Acknowledgements

The ESMF software is based on the contributions of a broad community. Below are the software packages that are included in ESMF or strongly influenced our design. We'd like to express our gratitude to the developers of these codes for access to their software as well as their ideas and advice.

• The Spherical Coordinate Remapping and Interpolation Package (SCRIP) from Los Alamos, on which we based our regridding functionality with the help of SCRIP author Phil Jones

• The Model Coupling Toolkit (MCT) from Argonne National Laboratory, on which we based our sparse matrix multiply approach to general regridding

• The Inpack configuration attributes package from NASA Goddard, which was adapted for use in ESMF by members of NASA Global Modeling and Assimilation group

• The Flexible Modeling System (FMS) package from GFDL and the Goddard Earth Modeling System (GEMS) from NASA Goddard, both of which provided inspiration for overall ESMF structure

• The Weather Research and Forecast (WRF) modeling system, on which we based our underlying I/O implementation

• The Common Component Architecture (CCA) effort within the DoE, from which we drew many ideas about how to design components

• The Vector Signal Image Processing Library (VSIPL) and its predecessors, which informed many aspects of our design, and the radar system software design group at Lincoln Laboratory

• The Portable, Extensible Toolkit for Scientific Computation (PETSc) package from Argonne National Laboratories, on which we based our initial makefile system
Contents

1 ESMF Overview 19

1 What is the Earth System Modeling Framework? 20

2 The ESMF Reference Manual for Fortran 20

3 How to Contact User Support and Find Additional Information 20

4 How to Submit New Requirements 20

5 Conventions 21

5.1 Document Conventions 21

5.2 Method Name and Argument Conventions 21

5.3 Locating Methods in this Manual 22

6 The ESMF Application Programming Interface 23

6.1 Standard Methods and Interface Rules 23

6.2 Deep and Shallow Classes 24

6.3 Special Methods 24

6.4 The ESMF Data Hierarchy 24

6.5 ESMF Spatial Classes 25

6.6 ESMF DataMap Classes 25

6.7 ESMF Specification Classes 26

6.8 ESMF Utility Classes 26

7 Overall Rules and Behavior 26

7.1 Allocation Rules 26

7.2 Equality and Copying Objects 26

7.3 Attributes 27

8 Integrating ESMF into Applications 27

8.1 Using the ESMF Superstructure 27

8.2 Using the ESMF Infrastructure 28

9 Global Options and Parameters 28

9.1 Flags 28

9.1.1 ESMF AllocFlag 28

9.1.2 ESMF BlockFlag 28

9.1.3 ESMF ContextFlag 28

9.1.4 ESMF CopyFlag 29

9.1.5 ESMF IndexFlag 29

9.1.6 ESMF InterleaveFlag 29

9.1.7 ESMF NeededFlag 29

9.1.8 ESMF ReadyFlag 30

9.1.9 ESMF ReduceFlag 30

9.1.10 ESMF ReqForRestartFlag 30

9.1.11 ESMF ValidFlag 30

9.2 Parameters 30

9.2.1 ESMF DataKind 30
13.6.1 ESMF_GridCompGetInternalState .................................................. 61
13.6.2 ESMF_GridCompSetEntryPoint ...................................................... 62
13.6.3 ESMF_GridCompSetInternalState ................................................... 63
13.6.4 ESMF_GridCompSetServices ......................................................... 63

14 CplComp Class ................................................................. 64

14.1 Description ................................................................................. 64
14.2 Use and Examples ...................................................................... 65
  14.2.1 Specifying a User-Code SetServices Routine ......................... 65
  14.2.2 Specifying a User-Code Initialize Routine ......................... 66
  14.2.3 Specifying a User-Code Run Routine ...................................... 66
  14.2.4 Specifying a User-Code Finalize Routine .......................... 67
14.3 Restrictions and Future Work ................................................. 69
14.4 Class API: Basic CplComp Methods ............................................. 69
  14.4.1 ESMF_CplCompCreate .............................................................. 69
  14.4.2 ESMF_CplCompDestroy .............................................................. 70
  14.4.3 ESMF_CplCompFinalize ............................................................. 70
  14.4.4 ESMF_CplCompGet ................................................................. 71
  14.4.5 ESMF_CplCompInitialize .......................................................... 72
  14.4.6 ESMF_CplCompPrint ............................................................... 73
  14.4.7 ESMF_CplCompRun ................................................................. 73
  14.4.8 ESMF_CplCompSet ................................................................. 74
  14.4.9 ESMF_CplCompValidate .......................................................... 75
  14.4.10 ESMF_CplCompWait ............................................................... 75
  14.4.11 ESMF_CplCompIsPetLocal ..................................................... 76
14.5 Class API: SetServices and Related Methods ............................. 76
  14.5.1 ESMF_CplCompGetInternalState ............................................. 76
  14.5.2 ESMF_CplCompSetEntryPoint ............................................... 77
  14.5.3 ESMF_CplCompSetInternalState ............................................. 77
  14.5.4 ESMF_CplCompSetServices ................................................... 78

15 State Class .............................................................. 78

15.1 Description ................................................................................. 78
15.2 State Options ............................................................................. 79
  15.2.1 ESMF_StateItemType .............................................................. 79
  15.2.2 ESMF_StateType ................................................................. 79
15.3 Use and Examples ........................................................................ 79
  15.3.1 Empty State Create ............................................................... 80
  15.3.2 Adding Items to a State .......................................................... 80
  15.3.3 Adding Placeholders to a State .............................................. 81
  15.3.4 Marking an Item Needed ......................................................... 81
  15.3.5 Creating a Needed Item .......................................................... 81
  15.3.6 Initialization and SetServices Routines ..................................... 82
  15.3.7 Creating Components on subsets of the current PET list ........... 83
  15.3.8 Invoking Components on a subset of the Parent PETs ............ 83
  15.3.9 Using State Reconcile ............................................................ 84
15.4 Restrictions and Future Work ................................................... 84
15.5 Design and Implementation Notes .............................................. 85
15.6 Object Model ............................................................................ 87
15.7 Class API: Basic State Methods .................................................. 87
  15.7.1 ESMF_StateAddInternArray ................................................. 87
17.4 Restrictions and Future Work ........................................... 113
17.5 Design and Implementation Notes ................................... 113
17.6 Class API: Basic Bundle Methods ................................... 114
  17.6.1 ESMF_BundleAddField ........................................... 114
  17.6.2 ESMF_BundleAddField ........................................... 114
  17.6.3 ESMF_BundleCreate ............................................. 115
  17.6.4 ESMF_BundleCreate ............................................. 115
  17.6.5 ESMF_BundleDestroy ............................................ 116
  17.6.6 ESMF_BundleGet ................................................ 116
  17.6.7 ESMF_BundleGetAttribute ..................................... 117
  17.6.8 ESMF_BundleGetAttributeCount ................................ 118
  17.6.9 ESMF_BundleGetAttributeInfo ................................ 118
  17.6.10 ESMF_BundleGetAttributeInfo ................................ 119
  17.6.11 ESMF_BundleGetField .......................................... 120
  17.6.12 ESMF_BundleGetField .......................................... 120
  17.6.13 ESMF_BundleGetFieldNames .................................. 121
  17.6.14 ESMF_BundlePrint ............................................. 121
  17.6.15 ESMF_BundleSetAttribute .................................... 122
  17.6.16 ESMF_BundleSetGrid .......................................... 122
  17.6.17 ESMF_BundleValidate ......................................... 123
17.7 Class API: Bundle Overloads for Fortran Arrays ................. 123
  17.7.1 ESMF_BundleGetDataPointer ................................... 123
17.8 Class API: Bundle Communications ................................ 124
  17.8.1 ESMF_BundleHalo .............................................. 124
  17.8.2 ESMF_BundleHaloRelease ...................................... 125
  17.8.3 ESMF_BundleHaloStore ......................................... 125
  17.8.4 ESMF_BundleRedist ............................................ 126
  17.8.5 ESMF_BundleRedist ............................................ 127
  17.8.6 ESMF_BundleRedistRelease ................................... 128
  17.8.7 ESMF_BundleRedistStore ...................................... 128
  17.8.8 ESMF_BundleRegrid ............................................ 129
18 BundleDataMap Class .................................................... 130
  18.1 Description ........................................................ 130
  18.2 BundleDataMap Options .......................................... 130
  18.3 Use and Examples ................................................. 130
    18.3.1 Setting BundleDataMap Defaults ............................. 130
    18.3.2 Setting BundleDataMap Values ............................... 131
    18.3.3 Getting BundleDataMap Values ............................... 131
  18.4 Restrictions and Future Work .................................... 131
  18.5 Class API .......................................................... 131
    18.5.1 ESMF_BundleDataMapGet .................................... 131
    18.5.2 ESMF_BundleDataMapPrint ................................. 132
    18.5.3 ESMF_BundleDataMapSet ..................................... 132
    18.5.4 ESMF_BundleDataMapSetDefault ............................ 133
    18.5.5 ESMF_BundleDataMapSetInvalid ............................ 133
    18.5.6 ESMF_BundleDataMapValidate .............................. 133
19 Field Class

19.1 Description ................................................................. 134
19.2 Use and Examples ....................................................... 134
   19.2.1 Field Creation ..................................................... 134
   19.2.2 Field Deletion ..................................................... 135
   19.2.3 Field Create with Grid and InternArray ......................... 135
   19.2.4 Field Create with Grid and ArraySpec .......................... 135
   19.2.5 Empty Field Create .............................................. 136
   19.2.6 Destroy a Field .................................................. 136
19.3 Restrictions and Future Work ......................................... 136
19.4 Design and Implementation Notes .................................... 136
19.5 Class API: Basic Field Methods ....................................... 137
   19.5.1 ESMF_FieldCreateNoData ...................................... 137
   19.5.2 ESMF_FieldCreateNoData ...................................... 138
   19.5.3 ESMF_FieldCreateNoData ...................................... 138
   19.5.4 ESMF_FieldDestroy ............................................. 139
   19.5.5 ESMF_FieldGet .................................................. 139
   19.5.6 ESMF_FieldGetLocalArray ..................................... 140
   19.5.7 ESMF_FieldGetInternArray .................................... 141
   19.5.8 ESMF_FieldGetAttribute ...................................... 141
   19.5.9 ESMF_FieldGetAttributeCount .................................. 142
   19.5.10 ESMF_FieldGetAttributeInfo ................................ 142
   19.5.11 ESMF_FieldGetAttributeInfo ................................ 143
   19.5.12 ESMF_FieldPrint ............................................... 144
   19.5.13 ESMF_FieldSetInternArray ................................... 144
   19.5.14 ESMF_FieldSetLocalArray ................................... 145
   19.5.15 ESMF_FieldSetAttribute .................................... 145
   19.5.16 ESMF_FieldSetGrid ........................................... 146
   19.5.17 ESMF_FieldSetDataMap ....................................... 147
   19.5.18 ESMF_FieldValidate .......................................... 147
   19.5.19 ESMF_FieldWrite ............................................. 148
19.6 Class API: Field Overloads for Fortran Arrays ..................... 148
   19.6.1 ESMF_FieldCreate ............................................. 148
   19.6.2 ESMF_FieldCreate ............................................. 149
   19.6.3 ESMF_FieldCreate ............................................. 150
   19.6.4 ESMF_FieldCreate ............................................. 151
   19.6.5 ESMF_FieldCreate ............................................. 152
   19.6.6 ESMF_FieldGetDataPointer ................................. 153
   19.6.7 ESMF_FieldSetDataPointer ................................. 153
19.7 Class API: Field Communications ................................... 154
   19.7.1 ESMF_FieldGather ............................................. 154
   19.7.2 ESMF_FieldHalo ................................................. 155
   19.7.3 ESMF_FieldHaloRelease ....................................... 156
   19.7.4 ESMF_FieldHaloStore ......................................... 156
   19.7.5 ESMF_FieldHaloValidate ..................................... 157
   19.7.6 ESMF_FieldRedist ............................................. 157
   19.7.7 ESMF_FieldRedist ............................................. 158
   19.7.8 ESMF_FieldRedistRelease .................................... 159
   19.7.9 ESMF_FieldRedistStore ...................................... 159
   19.7.10 ESMF_FieldRedistStore ..................................... 160
   19.7.11 ESMF_FieldRedistValidate ................................ 161
### 22.4 Restrictions and Future Work

### 22.5 Design and Implementation Notes
- 22.5.1 Grid Classes
- 22.5.2 InternDG Implementation Notes
- 22.5.3 PhysGrid Implementation Notes

### 22.6 Object Model

### 22.7 Class API: General Grid Methods
- 22.7.1 ESMF_GridAddVertHeight
- 22.7.2 ESMF_GridCreate
- 22.7.3 ESMF_GridDestroy
- 22.7.4 ESMF_GridDistribute
- 22.7.5 ESMF_GridDistribute
- 22.7.6 ESMF_GridGet
- 22.7.7 ESMF_GridGet
- 22.7.8 ESMF_GridGetAttribute
- 22.7.9 ESMF_GridGetAttributeCount
- 22.7.10 ESMF_GridGetAttributeInfo
- 22.7.11 ESMF_GridGetAttributeInfo
- 22.7.12 ESMF_GridGetCoord
- 22.7.13 ESMF_GridGetCoordByDim1D
- 22.7.14 ESMF_GridGetCoordByDim2D
- 22.7.15 ESMF_GridGetDELocalInfo
- 22.7.16 ESMF_GridGlobalToLocalIndex
- 22.7.17 ESMF_GridLocalToGlobalIndex
- 22.7.18 ESMF_GridPrint
- 22.7.19 ESMF_GridSet
- 22.7.20 ESMF_GridSetAttribute
- 22.7.21 ESMF_GridValidate

### 22.8 Class API: Logically Rectangular Grid Methods
- 22.8.1 ESMF_GridCreateHorzLatLon
- 22.8.2 ESMF_GridCreateHorzLatLon
- 22.8.3 ESMF_GridCreateHorzLatLonUni
- 22.8.4 ESMF_GridCreateHorzXY
- 22.8.5 ESMF_GridCreateHorzXY
- 22.8.6 ESMF_GridCreateHorzXYUni

### 23 DistGrid Class

#### 23.1 Description

#### 23.2 Use and Examples
- 23.2.1 2D DistGrid with simple LR domain and regular decomposition
- 23.2.2 DistGrid and DELayout
- 23.2.3 Single LR domain with decomposition by DE blocks
- 23.2.4 Periodic boundaries of a single LR domain
- 23.2.5 2D DistGrid with patchwork LR domain and regular decomposition

#### 23.3 Restrictions and Future Work

#### 23.4 Design and Implementation Notes

#### 23.5 Class API
- 23.5.1 ESMF_DistGridCreateRD
- 23.5.2 ESMF_DistGridCreateDB
- 23.5.3 ESMF_DistGridCreateRDP
- 23.5.4 ESMF_DistGridDestroy
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4.1</td>
<td>ESMF_IOSpecGet</td>
<td>271</td>
</tr>
<tr>
<td>25.4.2</td>
<td>ESMF_IOSpecGet</td>
<td>271</td>
</tr>
<tr>
<td>26</td>
<td>Overview of Distributed Data Methods</td>
<td>273</td>
</tr>
<tr>
<td>26.1</td>
<td>Higher Level Functions</td>
<td>273</td>
</tr>
<tr>
<td>26.2</td>
<td>Lower Level Functions</td>
<td>273</td>
</tr>
<tr>
<td>26.3</td>
<td>Common Options</td>
<td>273</td>
</tr>
<tr>
<td>26.3.1</td>
<td>ESMF_RouteOptions</td>
<td>274</td>
</tr>
<tr>
<td>26.4</td>
<td>Design and Implementation Notes</td>
<td>274</td>
</tr>
<tr>
<td>26.5</td>
<td>Object Model</td>
<td>283</td>
</tr>
<tr>
<td>27</td>
<td>Halo Method</td>
<td>285</td>
</tr>
<tr>
<td>27.1</td>
<td>Description</td>
<td>285</td>
</tr>
<tr>
<td>27.2</td>
<td>Halo Domains</td>
<td>285</td>
</tr>
<tr>
<td>28</td>
<td>Regrid Method</td>
<td>285</td>
</tr>
<tr>
<td>28.1</td>
<td>Description</td>
<td>285</td>
</tr>
<tr>
<td>28.2</td>
<td>Regrid Options</td>
<td>285</td>
</tr>
<tr>
<td>28.2.1</td>
<td>ESMF_RegridMethod</td>
<td>285</td>
</tr>
<tr>
<td>28.2.2</td>
<td>ESMF_RegridNormOpt</td>
<td>287</td>
</tr>
<tr>
<td>28.3</td>
<td>Use and Examples</td>
<td>287</td>
</tr>
<tr>
<td>28.3.1</td>
<td>Regrid and Grid Overlay</td>
<td>287</td>
</tr>
<tr>
<td>28.3.2</td>
<td>Regrid and Data Location</td>
<td>288</td>
</tr>
<tr>
<td>28.3.3</td>
<td>Regrid and Grid Refinement</td>
<td>288</td>
</tr>
<tr>
<td>28.3.4</td>
<td>Regrid and Periodicity</td>
<td>290</td>
</tr>
<tr>
<td>28.3.5</td>
<td>Regrid Examples: Precomputing and Executing a Regrid</td>
<td>290</td>
</tr>
<tr>
<td>28.4</td>
<td>Restrictions and Future Work</td>
<td>291</td>
</tr>
<tr>
<td>28.5</td>
<td>Design and Implementation Notes</td>
<td>292</td>
</tr>
<tr>
<td>28.5.1</td>
<td>Bilinear Regridding Algorithms</td>
<td>292</td>
</tr>
<tr>
<td>28.5.2</td>
<td>Bicubic Regridding Algorithms</td>
<td>295</td>
</tr>
<tr>
<td>28.5.3</td>
<td>Conservative Regridding Algorithms</td>
<td>296</td>
</tr>
<tr>
<td>28.5.4</td>
<td>Overview of Parallelization of Regrid</td>
<td>301</td>
</tr>
<tr>
<td>28.5.5</td>
<td>Parallelization of Regrid: Identification of Necessary Data</td>
<td>301</td>
</tr>
<tr>
<td>28.5.6</td>
<td>Parallelization of Regrid: Data Transfer</td>
<td>302</td>
</tr>
<tr>
<td>28.5.7</td>
<td>Parallelization of Regrid: Sweep Algorithms</td>
<td>304</td>
</tr>
<tr>
<td>28.5.8</td>
<td>Parallelization of Regrid: Calculation and Application of Interpolation Weights</td>
<td>305</td>
</tr>
<tr>
<td>28.5.9</td>
<td>Regrid Objects</td>
<td>305</td>
</tr>
<tr>
<td>29</td>
<td>Redist Method</td>
<td>305</td>
</tr>
<tr>
<td>29.1</td>
<td>Description</td>
<td>305</td>
</tr>
<tr>
<td>29.2</td>
<td>Use and Examples</td>
<td>306</td>
</tr>
<tr>
<td>29.2.1</td>
<td>Field Redistribution example</td>
<td>307</td>
</tr>
<tr>
<td>29.2.2</td>
<td>Field Redistribution example using a single call</td>
<td>308</td>
</tr>
<tr>
<td>29.3</td>
<td>Restrictions and Future Work</td>
<td>309</td>
</tr>
<tr>
<td>29.4</td>
<td>Design and Implementation Notes</td>
<td>309</td>
</tr>
<tr>
<td>29.4.1</td>
<td>Redist Objects</td>
<td>309</td>
</tr>
<tr>
<td>30</td>
<td>Overview of Infrastructure Utility Classes</td>
<td>310</td>
</tr>
<tr>
<td>IV</td>
<td>Infrastructure: Utilities</td>
<td>310</td>
</tr>
<tr>
<td>30.1</td>
<td>Overview of Infrastructure Utility Classes</td>
<td>311</td>
</tr>
</tbody>
</table>
31 Time Manager Utility

31.1 Time Manager Classes .................................................. 312
31.2 Calendar ........................................................................ 313
31.3 Time Instants and Time Intervals ........................................ 313
31.4 Clocks and Alarms .......................................................... 313
31.5 Design and Implementation Notes ...................................... 314
31.6 Object Model ................................................................. 316

32 Calendar Class

32.1 Description .................................................................... 317
32.2 Calendar Options ........................................................... 317
32.2.1 ESMF_CalendarType .................................................. 317
32.3 Use and Examples .......................................................... 317
32.3.1 Calendar Creation ....................................................... 318
32.3.2 Calendar Comparison .................................................. 318
32.3.3 Time Conversion Between Calendars ............................. 318
32.3.4 Calendar Destruction .................................................. 319
32.4 Restrictions and Future Work .......................................... 319
32.5 Class API ...................................................................... 319
32.5.1 ESMF_CalendarOperator(==) ...................................... 319
32.5.2 ESMF_CalendarOperator(==) ...................................... 320
32.5.3 ESMF_CalendarOperator(==) ...................................... 320
32.5.4 ESMF_CalendarOperator(==) ...................................... 321
32.5.5 ESMF_CalendarOperator(/=) ....................................... 321
32.5.6 ESMF_CalendarOperator(/=) ....................................... 322
32.5.7 ESMF_CalendarOperator(/=) ....................................... 322
32.5.8 ESMF_CalendarOperator(/=) ....................................... 323
32.5.9 ESMF_CalendarCreate ............................................... 323
32.5.10 ESMF_CalendarCreate ............................................. 324
32.5.11 ESMF_CalendarCreate ............................................. 324
32.5.12 ESMF_CalendarDestroy ............................................ 325
32.5.13 ESMF_CalendarGet ................................................. 325
32.5.14 ESMF_CalendarIsLeapYear ..................................... 326
32.5.15 ESMF_CalendarIsLeapYear ..................................... 327
32.5.16 ESMF_CalendarPrint .............................................. 328
32.5.17 ESMF_CalendarSet ................................................. 328
32.5.18 ESMF_CalendarSet .................................................. 329
32.5.19 ESMF_CalendarSetDefault ....................................... 330
32.5.20 ESMF_CalendarSetDefault ....................................... 330
32.5.21 ESMF_CalendarValidate .......................................... 331

33 Time Class

33.1 Description .................................................................... 332
33.2 Use and Examples ........................................................ 332
33.2.1 Time Initialization ....................................................... 332
33.2.2 Time Increment ........................................................ 333
33.2.3 Time Comparison ....................................................... 333
33.3 Restrictions and Future Work .......................................... 333
33.4 Class API ...................................................................... 334
33.4.1 ESMF_TimeOperator(+) ............................................. 334
33.4.2 ESMF_TimeOperator(-) ............................................. 334
33.4.3 ESMF_TimeOperator(-) .................................................. 335
33.4.4 ESMF_TimeOperator(==) ............................................. 335
33.4.5 ESMF_TimeOperator(/=) .............................................. 336
33.4.6 ESMF_TimeOperator(<) ................................................. 336
33.4.7 ESMF_TimeOperator(<=) .............................................. 337
33.4.8 ESMF_TimeOperator(>) ................................................. 337
33.4.9 ESMF_TimeOperator(>=) .............................................. 338
33.4.10 ESMF_TimeGet .......................................................... 338
33.4.11 ESMF_TimeIsLeapYear ............................................... 341
33.4.12 ESMF_TimeIsSameCalendar ......................................... 341
33.4.13 ESMF_TimePrint ....................................................... 342
33.4.14 ESMF_TimeSet .......................................................... 343
33.4.15 ESMF_TimeSyncToRealTime ....................................... 345
33.4.16 ESMF_TimeValidate .................................................. 345

34 TimeInterval Class ......................................................... 347
34.1 Description ............................................................... 347
34.2 Use and Examples ........................................................ 347
34.2.1 Time Interval Initialization ....................................... 348
34.2.2 Time Interval Conversion .......................................... 348
34.2.3 Time Interval Difference .......................................... 348
34.2.4 Time Interval Multiplication ..................................... 349
34.2.5 Time Interval Comparison ......................................... 349
34.3 Restrictions and Future Work ....................................... 349
34.4 Class API ................................................................. 349
34.4.1 ESMF_TimeIntervalOperator(+) .................................. 349
34.4.2 ESMF_TimeIntervalOperator(-) .................................. 350
34.4.3 ESMF_TimeIntervalOperator(/) .................................. 350
34.4.4 ESMF_TimeIntervalOperator(/) .................................. 351
34.4.5 ESMF_TimeIntervalFunction(MOD) ............................... 351
34.4.7 ESMF_TimeIntervalOperator(x) .................................. 352
34.4.8 ESMF_TimeIntervalOperator(x) .................................. 352
34.4.9 ESMF_TimeIntervalOperator(==) ................................ 353
34.4.10 ESMF_TimeIntervalOperator(/=) ............................... 353
34.4.11 ESMF_TimeIntervalOperator(<) ................................. 354
34.4.12 ESMF_TimeIntervalOperator(<=) ............................... 354
34.4.13 ESMF_TimeIntervalOperator(>) ................................. 355
34.4.14 ESMF_TimeIntervalOperator(>=) ............................... 355
34.4.15 ESMF_TimeIntervalAbsValue ................................... 356
34.4.16 ESMF_TimeIntervalGet ........................................... 356
34.4.17 ESMF_TimeIntervalGet ........................................... 359
34.4.18 ESMF_TimeIntervalGet ........................................... 361
34.4.19 ESMF_TimeIntervalGet ........................................... 363
34.4.20 ESMF_TimeIntervalNegAbsValue ............................... 366
34.4.21 ESMF_TimeIntervalPrint ........................................... 366
34.4.22 ESMF_TimeIntervalSet ........................................... 367
34.4.23 ESMF_TimeIntervalSet ........................................... 368
34.4.24 ESMF_TimeIntervalSet ........................................... 370
34.4.25 ESMF_TimeIntervalSet ........................................... 372
34.4.26 ESMF_TimeIntervalValidate ................................... 374
35 Clock Class

35.1 Description

35.2 Clock Options

35.2.1 ESMF_Direction

35.3 Use and Examples

35.3.1 Clock Creation

35.3.2 Clock Advance

35.3.3 Clock Examination

35.3.4 Clock Reversal

35.3.5 Clock Destruction

35.4 Restrictions and Future Work

35.5 Class API

35.5.1 ESMF_ClockOperator(==)

35.5.2 ESMF_ClockOperator(/=)

35.5.3 ESMF_ClockAdvance

35.5.4 ESMF_ClockCreate

35.5.5 ESMF_ClockCreate

35.5.6 ESMF_ClockDestroy

35.5.7 ESMF_ClockGet

35.5.8 ESMF_ClockGetAlarm

35.5.9 ESMF_ClockGetAlarmList

35.5.10 ESMF_ClockGetNextTime

35.5.11 ESMF_ClockIsDone

35.5.12 ESMF_ClockIsReverse

35.5.13 ESMF_ClockStopTime

35.5.14 ESMF_ClockStopTimeEnabled

35.5.15 ESMF_ClockPrint

35.5.16 ESMF_ClockSet

35.5.17 ESMF_ClockStopTimeDisable

35.5.18 ESMF_ClockStopTimeEnable

35.5.19 ESMF_ClockSyncToRealTime

35.5.20 ESMF_ClockValidate

36 Alarm Class

36.1 Description

36.2 Alarm Options

36.2.1 ESMF_AlarmListType

36.3 Use and Examples

36.3.1 Clock Initialization

36.3.2 Alarm Initialization

36.3.3 Clock Advance and Alarm Processing

36.3.4 Alarm and Clock Destruction

36.4 Restrictions and Future Work

36.5 Design and Implementation Notes

36.6 Class API

36.6.1 ESMF_AlarmOperator(==)

36.6.2 ESMF_AlarmOperator(/=)

36.6.3 ESMF_AlarmCreate

36.6.4 ESMF_AlarmCreate

36.6.5 ESMF_AlarmDestroy

36.6.6 ESMF_AlarmDisable
36.6.7 ESMF_AlarmEnable .................................................. 398
36.6.8 ESMF_AlarmGet ..................................................... 398
36.6.9 ESMF_AlarmIsEnabled ............................................... 399
36.6.10 ESMF_AlarmIsRinging ............................................. 400
36.6.11 ESMF_AlarmIsSticky ............................................... 400
36.6.12 ESMF_AlarmNotSticky ............................................. 401
36.6.13 ESMF_AlarmPrint .................................................. 401
36.6.14 ESMF_AlarmRingerOff ............................................. 402
36.6.15 ESMF_AlarmRingerOn .............................................. 402
36.6.16 ESMF_AlarmSet ..................................................... 403
36.6.17 ESMF_AlarmSticky .................................................. 404
36.6.18 ESMF_AlarmValidate .............................................. 405
36.6.19 ESMF_AlarmWasPrevRinging ..................................... 405
36.6.20 ESMF_AlarmWillRingNext ....................................... 406

37 Config Class ............................................................ 406

37.1 Description .......................................................... 406
  37.1.1 Package History .................................................. 406

37.2 Use and Examples .................................................... 406
  37.2.1 Resource Files .................................................... 406
  37.2.2 Package History .................................................. 407
  37.2.3 A Quick Overview ................................................ 407
  37.2.4 Common Code Arguments .......................................... 407
  37.2.5 Creation of a Config ............................................. 407
  37.2.6 Retrieval of constants ........................................... 408
  37.2.7 Retrieval of file names .......................................... 408
  37.2.8 Retrieval of tables ............................................... 408
  37.2.9 Destruction of a Config ......................................... 408

37.3 Class API .............................................................. 409
  37.3.1 ESMF_ConfigCreate ............................................... 409
  37.3.2 ESMF_ConfigDestroy .............................................. 409
  37.3.3 ESMF_ConfigFindLabel ............................................ 409
  37.3.4 ESMF_ConfigGetAttribute ........................................ 410
  37.3.5 ESMF_ConfigGetAttribute ........................................ 410
  37.3.6 ESMF_ConfigGetAttribute ........................................ 411
  37.3.7 ESMF_ConfigGetAttribute ........................................ 412
  37.3.8 ESMF_ConfigGetAttribute ........................................ 412
  37.3.9 ESMF_ConfigGetAttribute ........................................ 413
  37.3.10 ESMF_ConfigGetAttribute ....................................... 413
  37.3.11 ESMF_ConfigGetAttribute ....................................... 414
  37.3.12 ESMF_ConfigGetAttribute ....................................... 414
  37.3.13 ESMF_ConfigGetAttribute ....................................... 415
  37.3.14 ESMF_ConfigGetAttribute ....................................... 415
  37.3.15 ESMF_ConfigGetChar ............................................ 416
  37.3.16 ESMF_ConfigGetDim ............................................. 416
  37.3.17 ESMF_ConfigGetLen ............................................. 417
  37.3.18 ESMF_ConfigLoadFile .......................................... 418
  37.3.19 ESMF_ConfigNextLine .......................................... 419
  37.3.20 ESMF_ConfigValidate ........................................... 419
40 VM Class

40.1 Description

40.2 Use and Examples

40.2.1 VM Default Basics Example

40.2.2 VMGet MPI Communicator Example

40.2.3 ESMF inside user MPI application

40.2.4 ESMF inside user defined MPI communicator

40.2.5 VMSend/VMRecv Example

40.2.6 VMScatter/VMGather Example

40.2.7 VMAllFullReduce Example

40.2.8 VM Component Example

40.3 Restrictions and Future Work

40.4 Design and Implementation Notes

40.5 Class API

40.5.1 ESMF_VMAllFullReduce

40.5.2 ESMF_VMAllFullReduce

40.5.3 ESMF_VMAllFullReduce

40.5.4 ESMF_VMAllGather

40.5.5 ESMF_VMAllGather

40.5.6 ESMF_VMAllGather

40.5.7 ESMF_VMAllGather

40.5.8 ESMF_VMAllGatherV

40.5.9 ESMF_VMAllGatherV

40.5.10 ESMF_VMAllGatherV

40.5.11 ESMF_VMAllReduce

40.5.12 ESMF_VMAllReduce

40.5.13 ESMF_VMAllReduce

40.5.14 ESMF_VMAllToAllV

40.5.15 ESMF_VMAllToAllV

40.5.16 ESMF_VMAllToAllV

40.5.17 ESMF_VMBarrier

40.5.18 ESMF_VMBroadcast

40.5.19 ESMF_VMBroadcast

40.5.20 ESMF_VMBroadcast

40.5.21 ESMF_VMBroadcast

40.5.22 ESMF_VMGet

40.5.23 ESMF_VMGet

40.5.24 ESMF_VMGet

40.5.25 ESMF_VMGet

40.5.26 ESMF_VMGet

40.5.27 ESMF_VMGetGlobal

40.5.28 ESMF_VMGetCurrent

40.5.29 ESMF_VMGetPETLocalInfo

40.5.30 ESMF_VMPrint

40.5.31 ESMF_VMRrecv

40.5.32 ESMF_VMRrecv

40.5.33 ESMF_VMRrecv

40.5.34 ESMF_VMRrecv

40.5.35 ESMF_VMRrecv

40.5.36 ESMF_VMRreduce

40.5.37 ESMF_VMRreduce
40.5.38 ESMF_VMReduce .................................................. 482
40.5.39 ESMF_VMScatter .................................................. 483
40.5.40 ESMF_VMScatter .................................................. 484
40.5.41 ESMF_VMScatter .................................................. 485
40.5.42 ESMF_VMScatter .................................................. 486
40.5.43 ESMF_VMSend ..................................................... 486
40.5.44 ESMF_VMSend ..................................................... 487
40.5.45 ESMF_VMSend ..................................................... 488
40.5.46 ESMF_VMSend ..................................................... 489
40.5.47 ESMF_VMSend ..................................................... 490
40.5.48 ESMF_VMSendRecv ............................................... 490
40.5.49 ESMF_VMSendRecv ............................................... 491
40.5.50 ESMF_VMSendRecv ............................................... 492
40.5.51 ESMF_VMSendRecv ............................................... 493
40.5.52 ESMF_VMSendRecv ............................................... 494
40.5.53 ESMF_VMValidate ................................................ 495
40.5.54 ESMF_VMWait ..................................................... 496
40.5.55 ESMF_VMWaitQueue ............................................. 496
40.5.56 ESMF_VMWtime ................................................... 497
40.5.57 ESMF_VMWtimeDelay ........................................... 497
40.5.58 ESMF_VMWtimePrec ............................................. 497
40.5.59 ESMF_CommHandleValidate ................................... 498

41 Bibliography .......................................................... 499

Bibliography ............................................................. 499

V Appendices ............................................................. 500

42 Appendix A: A Brief Introduction to UML ........................................... 500

43 Appendix B: ESMF Error Return Codes ............................................. 501
Part I
ESMF Overview
1 What is the Earth System Modeling Framework?

The ESMF is a structured collection of software building blocks that can be used or customized to develop Earth system model components, and assemble them into applications. The simplest view of the ESMF is that it consists of an infrastructure of utilities and data structures for creating model components, and a superstructure for coupling them. User code sits between these two layers, making calls to the infrastructure libraries beneath it and being scheduled and synchronized by the superstructure above it. The configuration resembles a sandwich, as shown in Figure [1].

The ESMF architecture is scalable, flexible paradigm for building highly complex climate, weather, and related applications from components such as atmospheric models, land models, and data assimilation systems. The ESMF is not a single master application into which all components must fit; rather it is a way of developing components so that they can be used in many different user-written applications. Model components that adopt ESMF are designed to be usable in different contexts without code modification, and may be incorporated into other ESMF-based modeling systems within the Earth science community. In addition to high-level organization, ESMF provides a set of robust, portable, performance optimized libraries for regridding, data transfers, I/O, time management, and other common modeling functions. ESMF users may choose to extensively rewrite their codes to take advantage of the ESMF infrastructure, or they may decide to simply wrap user-written components in ESMF interfaces in order to adopt the ESMF architecture and utilize framework coupling services.

2 The ESMF Reference Manual for Fortran

The ESMF provides both Fortran and C++ versions of its interfaces for many methods. This ESMF Reference Manual is a listing of ESMF standard interfaces for Fortran. Interfaces are grouped by class. A class is an object-oriented software design construct that embodies a specific concept like a physical field. Superstructure classes are listed first in this Manual, followed by infrastructure classes.

The major classes in the ESMF superstructure are Components, which typically represent large pieces of functionality such as models, model couplers, and dynamics and physics packages; and States, which are the data structures used to store the fields and other data Components require or can make available. There are both data structures and utilities in the ESMF infrastructure; classes include Fields, collections of Fields on the same grid (called Bundles), Arrays, and utilities for communication, decomposition, time management, and application configuration.

For how to get started with ESMF, see the ESMF User's Guide. This document includes installation instructions, an overview of the whole framework, an extended example of a coupled code, and other useful information.

3 How to Contact User Support and Find Additional Information

The ESMF team can answer questions about the interfaces presented in this document. For user support, please contact esmf_support@ucar.edu. More information on the ESMF project as a whole is available on the ESMF website, http://www.esmf.ucar.edu. The website includes a description of ESMF testbed applications, related projects, the ESMF management structure, and more. The ESMF User's Guide contains installation instructions, an overview of the ESMF system and a description of how its classes interrelate. Other documents available on the ESMF site include an exhaustive ESMF Requirements Document and an ESMF Developer's Guide that details our project procedures and conventions.

4 How to Submit New Requirements

The Development link on the ESMF website includes on-line forms for the submission of new requirements, if it seems that the current API does not satisfy the needs of your application. We welcome input on any aspect of the

---

1 Since the audience for it is small, we have not yet prepared a comprehensive reference manual for C++.
Figure 1: Schematic of the ESMF “sandwich” architecture. In this design the framework consists of two parts, an upper level superstructure layer and a lower-level infrastructure layer. User code is sandwiched between these two layers.

ESMF project; general questions and comments should be sent to esmf@ucar.edu.

5 Conventions

5.1 Document Conventions

The following conventions for fonts and capitalization are used in this document.

<table>
<thead>
<tr>
<th>Style</th>
<th>Meaning</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>italics</td>
<td>documents</td>
<td>ESMF Reference Manual</td>
</tr>
<tr>
<td>courier</td>
<td>code fragments</td>
<td>ESMF_TRUE</td>
</tr>
<tr>
<td>courier()</td>
<td>ESMF method name</td>
<td>ESMF_FieldGet()</td>
</tr>
<tr>
<td>boldface</td>
<td>first definitions</td>
<td>An address space is ...</td>
</tr>
<tr>
<td>boldface</td>
<td>web links</td>
<td>Development webpage</td>
</tr>
<tr>
<td>Capitals</td>
<td>ESMF class name</td>
<td>DataMap</td>
</tr>
</tbody>
</table>

ESMF class names frequently coincide with words commonly used within the Earth system domain (field, grid, component, array, etc.) The convention we adopt in this manual is that if a word is used in the context of an ESMF class name it is capitalized, and if the word is used in a more general context it remains in lower case. We would write, for example, that an ESMF Field class represents a physical field.

Diagrams are drawn using the Unified Modeling Language (UML). UML is a visual tool that can illustrate the structure of classes, define relationships between classes, and describe sequences of actions. A reader interested in more detail can refer to a text such as The Unified Modeling Language Reference Manual.

5.2 Method Name and Argument Conventions

There are conventions for how class methods are presented throughout this document. Although Fortran interfaces are not case-sensitive, we use case to help parse multi-word names. We also use case to help make the presentation of Fortran interfaces consistent with the presentation of C++ interfaces.
Method names begin with `ESMF_` followed by the class name, followed by the name of the operation being performed. Each new word is capitalized.

For method arguments that are multi-word, the first word is lower case and subsequent words begin with upper case. ESMF class names (including typed flags) are an exception. When multi-word class names appear in argument lists, all letters after the first are lower case. The first letter is lower case if the class is the first word in the argument and upper case otherwise. For example, in an argument list the DELayout class name may appear as `delayout` or `srcDelayout`.

Most Fortran calls in the ESMF are subroutines, with any returned values passed through the interface. For the sake of convenience, some ESMF calls are written as functions.

A typical ESMF call thus looks like this:

```fortran
call ESMF_<ClassName><Operation>(classname, firstArgument,
    secondArgument, ..., rc)
```

where

- `<ClassName>` is the class name,
- `<method>` is the name of the action to be performed,
- `classname` is a variable of the derived type associated with the class,
- the `arg*` arguments are whatever other variables are required for the operation,
- and `rc` is a return code.

### 5.3 Locating Methods in this Manual

Methods for each class are located in the section devoted to that class in the Reference Manual. In some classes, methods are split into a number of different types. For example, there are separate listings for Basic Field Methods, Field Overloads for Fortran Arrays, and Field Communications. The methods in each listing are ordered alphabetically. The split into different listings is a side effect of the automated document generation system we use; it reflects which methods are located in the same source files. It is something we are working to eliminate!
6 The ESMF Application Programming Interface

The ESMF Application Programming Interface (API) is based on the object-oriented programming notion of a class. A class is a software construct that’s used for grouping a set of related variables together with the subroutines and functions that operate on them. We use classes in ESMF because they help to organize the code, and often make it easier to maintain and understand. A particular instance of a class is called an object. For example, Field is an ESMF class. An actual Field called temperature is an object. That is about as far as we will go into formal software engineering terminology.

The Fortran interface is implemented so that the variables associated with a class are stored in a derived type. For example, an ESMF_Field derived type stores the data array, grid information, and metadata associated with a physical field. The derived type for each class is stored in a Fortran module, and the operations associated with each class are defined as module procedures. We use the Fortran features of generic functions and optional arguments extensively to simplify our interfaces.

The modules for ESMF are bundled together and can be accessed with a single USE statement, USE ESMF_Mod.

6.1 Standard Methods and Interface Rules

ESMF defines a set of standard methods and interface rules that hold across the entire API. These are:

- **ESMF_<Class>Create()** and **ESMF_<Class>Delete()**, for creating and destroying classes. The ESMF_<Class>Create() method allocates memory for the class structure itself and for internal variables, and initializes variables as appropriate. It is always written as a Fortran function that returns a derived type instance of the class.

- **ESMF_<Class>Set()** and **ESMF_<Class>Get()**, for setting and retrieving a particular item or flag. In general, these methods are overloaded for all cases where the item can be manipulated as a name/value pair. If identifying the item requires more than a name, or if the class is of sufficient complexity that overloading in this way would result in an overwhelming number of options, we define specific ESMF_<Class>Set<Something>() and ESMF_<Class>Get<Something>() interfaces.

- **ESMF_<Class>Add()**, **ESMF_<Class>Get()**, and **ESMF_<Class>Remove()** for manipulating items that can be appended or inserted into a list of like items within a class. For example, the ESMF_StateAddField() method adds another Field to the list of Fields contained in the State class.

- **ESMF_<Class>Print()**, for printing the contents of a class to standard out. This method is mainly intended for debugging.

- **ESMF_<Class>ReadRestart()** and **ESMF_<Class>WriteRestart()**, for saving the contents of a class and restoring it exactly. Read and write restart methods have not yet been implemented for most ESMF classes, so where necessary the user needs to write restart values themselves.

- **ESMF_<Class>Validate()**, for determining whether a class is internally consistent. For example, ESMF_FieldValidate() checks whether the Array and Grid associated with a Field are consistent.

**EXAMPLE**

In this simple example, an ESMF Field is created with the name ‘temp’.

```
USE ESMF_Mod

type ESMF_Field :: field

field = ESMF_FieldCreate('temp')
```
6.2 Deep and Shallow Classes

The ESMF contains two types of classes. **Deep** classes require `ESMF_<Class>Create()` and `ESMF_<Class>Destroy()` calls. They take significant time to set up and should not be created in a time-critical portion of code. Deep objects persist even after the method in which they were created has returned. Most classes in the ESMF, including Fields, Bundles, Arrays, Grids and Clocks, fall into this category.

**Shallow** classes do not require `ESMF_<Class>Create()` and `ESMF_<Class>Destroy()` calls. They can simply be declared and their values set using an `ESMF_<Class>Set()` call. Shallow classes do not take long to set up and can be declared and set within a time-critical code segment. Shallow objects stop existing when the method in which they were declared has returned.

An exception to this is when a shallow object, such as an IOSpec, is used to carry values into a deep object, for example during an `ESMF_FieldCreate()` call during an application initialization phase. In this case an IOSpec is passed in through the `ESMF_FieldCreate()` argument list and the values of the IOSpec are copied into the new Field object. Although the IOSpec is destroyed when the initialization phase ends, the Field carries a copy of the IOSpec in persistent memory. This internal IOSpec is destroyed with the `ESMF_FieldDestroy()` call.

Other examples of shallow classes are Times, TimeIntervals, and ArraySpecs.

See Section 10, Overall Design and Implementation Notes, for a brief discussion of deep and shallow classes from an implementation perspective. For an in-depth look at the design and inter-language issues related to deep and shallow classes, please see the ESMF Implementation Report.

6.3 Special Methods

The following are special methods which, in one case, are required by any application using ESMF, and in the other case must be called by any application that is using ESMF Components.

- `ESMF_Initialize()` and `ESMF_Finalize()` are required methods that must bracket the use of ESMF within an application. They manage the resources required to run ESMF and shut it down gracefully.

- `ESMF_<Type>CompInitialize()`, `ESMF_<Type>CompRun()`, and `ESMF_<Type>CompFinalize()` are component methods that are used at the highest level within ESMF. `<Type>` may be `<Grid>`, for Gridded Components such as oceans or atmospheres, or `<Cpl>`, for Coupler Components that are used to connect them. The content of these methods is not part of the ESMF. Instead the methods call into associated Fortran subroutines within user code.

6.4 The ESMF Data Hierarchy

The ESMF API is organized around an hierarchy of five classes that contain model field data. The operations that are performed on model field data, such as regridding, redistribution, and halo updates, are accessed through these classes. The main data classes in ESMF, in order of increasing complexity, are:

- **Array** An ESMF Array is a distributed, multi-dimensional array that can carry information such as its type, kind, rank, and associated halo widths. It contains a reference to a native Fortran array.

- **Field** A Field represents a physical scalar or vector field. It contains a reference to an Array along with grid information and metadata.

- **Bundle** A Bundle is a collection of Fields discretized on the same grid. The staggering of data points may be different for different Fields within a Bundle.

- **State** A State represents the collection of data that a Component either requires to run (an Import State) or can make available to other Components (an Export State). States may contain references to Bundles, Fields, or Arrays.
Component

A Component is a substantial piece of software with a distinct function. ESMF currently recognizes two types of Components. Components that represent a physical domain or process, such as an atmospheric model, are called Gridded Components since they are usually discretized on an underlying grid. The Components responsible for regridding and transferring data between Gridded Components are called Coupler Components. Each Component is associated with an Import and an Export State. Components can be nested so that simpler components and applications can be used to compose more complex applications.

Underlying these data classes are native language arrays. ESMF allows you to reference an existing Fortran array to an ESMF Array, Field, or Bundle, so that ESMF data classes can be readily introduced into existing code. You can perform communication operations directly on Fortran arrays through the DELayout class, which serves as a unifying wrapper for distributed and shared memory communication libraries.

6.5 ESMF Spatial Classes

Like the hierarchy of model data classes, ranging from the simple to the complex, the ESMF is organized around an hierarchy of classes that represent different spaces associated with a computation. Each of these spaces can be indexed in some fashion, in order to give the user control over how a computation is executed. For Earth system applications, this hierarchy spans the environment associated with the computer to the physical region described by the application. The main spatial classes in ESMF, in order of those closest to the machine to those closest to the application, are:

- **Virtual Machine**, or VM
  The ESMF VM is an abstraction of a parallel computing environment that encompasses both shared and distributed memory. Its primary purpose is resource allocation. Each Component defines its own VM based on the resources it desires. The elements of a VM are **Persistent Execution Threads**, or PETs. A simple case is one in which every PET is associated with an MPI process running on a separate processor. If Components are nested, the parent component allocates a subset of its PETs to its children. The children have some flexibility, subject to the constraints of the computing environment, to decide how they want to use the PETs they’ve received.

- **DELayout**
  A DELayout represents a decomposition. Its basic elements are **Decomposition Elements**, or DEs. A DELayout associates a set of DEs and a topology - how the DEs are connected - with the PETs in a VM. The user can also define communication weights between DEs, for use in load balancing. DEs are not necessarily one-to-one with PETs. For cache blocking, or user-managed multi-threading, more DEs than PETs may be defined. Fewer DEs than PETs may be defined if an application requires, for example, a decomposition that is an integer multiple.

- **Grid**
  A Grid is an abstraction of a physical space. It associates a coordinate system, a set of coordinates, and a topology to a collection of grid cells.

- **Field**
  A Field may contain more dimensions than the Grid that it is discretized on. For example, for convenience during integration, a user may want to define a single Field object that holds snapshots of the data at multiple times. The Field must track what these additional dimensions mean. Fields also keep track of the location of a Field data point within its associated Grid cell.

Although it is not an ESMF class, the linear **address space** of the computer is another fundamental index space that must be mapped to data stored by the ESMF system.

6.6 ESMF DataMap Classes

In order to map the index spaces of the spatial classes, we require either implicit rules (in which case the relationship between index spaces is defined by default), or special classes that allow the user to specify the desired association. The following classes define how the data is laid out in memory.
- **ArrayDataMap** The ArrayDataMap class specifies how the address space of the computer relates to the array rank (e.g. row or column major order), and, optionally, how a list of array ranks corresponds to a list of Grid dimensions.

- **FieldDataMap** The FieldDataMap specifies the number of directional components in a vector Field, and how they are interleaved.

- **BundleDataMap** The BundleDataMap dictates how the Fields within a Bundle are interleaved.

### 6.7 ESMF Specification Classes

At various places in the ESMF, it is useful to make neat packets of descriptive parameters. Some of these are:

- **IOSpec**, for storing IO parameters.
- **ArraySpec**, for storing the specifics, such as type/kind/rank, of an array.

### 6.8 ESMF Utility Classes

There are a number of utilities in ESMF that can be used independently. These are:

- **TimeMgr**, for calendar, date, clock and alarm functions.
- **LogErr**, for logging and error handling.
- **Config**, for creating resource files that can replace namelists as a consistent way of setting configuration parameters.

### 7 Overall Rules and Behavior

#### 7.1 Allocation Rules

The basic rule of allocation and deallocation for the ESMF is: whoever allocates it is responsible for deallocating it. ESMF methods that allocate their own space for data will deallocate that space when the object is destroyed. Methods which accept a user-allocated buffer, for example `ESMF_FieldCreate()` with the `ESMF_DATA_REF` flag, will not deallocate that buffer at the time the object is destroyed. The user must arrange for the buffer to be deallocated when all use of it is complete.

Classes such as Fields, Bundles, and States may have Arrays, Fields, Grids and Bundles created externally and associated with them. These associated items are not destroyed along with the rest of the data object since it is possible for the items to be added to more than one data object at a time (e.g. the same Grid could be part of many Fields). It is the user’s responsibility to delete these items when the last use of them is done.

#### 7.2 Equality and Copying Objects

The equal sign operator in ESMF does not generate any special behavior on the part of the framework. If the user decides to set one object equal to another, the internal contents will simply be copied. That means that if there is a pointer within the object being copied, the pointer will be replicated and the data pointed to will be referenced by the object copy. As a matter of style and safety, users should try to avoid exploiting such implicit behavior. A preferable approach is to use a class creation or duplication method. Unfortunately, not all classes have duplication methods yet.
7.3 Attributes

Attributes are (name, value) pairs, where the name is a character string and the value can be either a single value or list of \texttt{int/I*4}, \texttt{double/R*8}, \texttt{logical (ESMF\_Logical)}, or \texttt{char */character} values. Attributes can be associated with Fields, Bundles, and States. Mixed types are not allowed in a single attribute, and all attribute names must be unique within a single object. Attributes are set by name, and can be retrieved either directly by name or by querying for a count of attributes and retrieving names and values by index number.

8 Integrating ESMF into Applications

Depending on the requirements of the application, the user may want to begin integrating ESMF in either a top-down or bottom-up manner. In the top-down approach, tools at the superstructure level are used to help reorganize and structure the interactions among large-scale components in the application. It is appropriate when interoperability is a primary concern; for example, when several different versions or implementations of components are going to be swapped in, or a particular component is going to be used in multiple contexts. Another reason for deciding on a top-down approach is that the application contains legacy code that for some reason (e.g., very large, difficult to work with, highly performance-tuned, resource limitations) there is little motivation to fully restructure. The superstructure can be incorporated into such applications in a way that is non-intrusive.

In the bottom-up approach, the user selects desired utilities (data communications, calendar management, performance profiling, logging and error handling, etc.) from the ESMF infrastructure and either writes new code using them, introduces them into existing code, or replaces the functionality in existing code with them. This makes sense when there is a specific need for some functionality, like robust data acommunications, or when the component writer is starting from scratch.

8.1 Using the ESMF Superstructure

The following is a typical set of steps involved in adopting the ESMF superstructure. The first two tasks, which occur before an ESMF call is ever made, have the potential to be the most difficult and time-consuming. They are the work of splitting an application into components and ensuring that each component has well-defined stages of execution.\footnote{ESMF aside, this sort of code structure helps to promote application clarity and maintainability, and the effort put into it is likely to be a good investment in any case.}

1. Decide how to organize the application as discrete Gridded and Coupler Components. The developer might need to reorganize code so that individual components are cleanly separated and their interactions consist of a minimal number of data exchanges.

2. Divide the code for each component into initialize, run, and finalize methods. These methods can be multi-phase, e.g., \texttt{init\_1, init\_2}.

3. Pack any data that will be transferred between components into ESMF Import and Export State data structures. The user must describe the distribution of grids over resources on a parallel computer via the VM and DELayout.

4. Pack time information into ESMF time management data structures.

5. Using code templates provided in the ESMF distribution, create ESMF Gridded and Coupler Components to represent each component in the user code.

6. Write a set services routine that sets ESMF entry points for each user component’s initialize, run, and finalize methods.

7. Run the application using an ESMF Application Driver.
8.2 Using the ESMF Infrastructure

Adoption of infrastructure utilities and data structures can follow many different paths. The calendar management utility is a popular place to start, since there is enough functionality in the ESMF time manager to merit the effort required to integrate it into codes and bundle it with an application.

9 Global Options and Parameters

9.1 Flags

9.1.1 ESMF_AllocFlag

DESCRIPTION:
Indicates whether to allocate data or not.
Valid values are:

ESMF_ALLOC  Allocate data.
ESMF_NO_ALLOC  Do not allocate data at this time.

9.1.2 ESMF_BlockingFlag

DESCRIPTION:
Indicates blocking behavior and PET synchronization.
Valid values are:

ESMF_BLOCKING  Communication calls: The called method will block until all (PET-)local operations are complete. After the return of a blocking communication method it is safe to modify or use all participating local data.
Component calls: The called method will block until all PETs in all virtual address spaces (VASs) have completed the operation.

ESMF_VASBLOCKING  Communication calls: Not available for communication calls.
Component calls: The called method will block until all PETs that operate in the PET-local VAS have completed the operation. For PETs that run as single threaded processes this means that the method does not synchronize PETs on return.

ESMF_NONBLOCKING  Communication calls: The called method will not block but returns immediately after initiating the requested operation. It is unsafe to modify or use participating local data before all local operations have completed.
Component calls: The called method will not block but returns immediately after initiating the requested operation. It is unsafe to modify or use participating local data before all local operations have completed.

9.1.3 ESMF_ContextFlag

DESCRIPTION:
Indicates the type of VM context in which a component is executing.
Valid values are:

ESMF_CHILD_IN_NEW_VM  The component is running in its own, separate VM context. Resources are inherited from the parent but can be arranged to fit the component’s requirements.
ESMF_CHILD_IN_PARENT_VM The component uses the parent’s VM for resource management. Compared to components that use their own VM context components that run in the parent’s VM context are more lightweight with respect to the overhead of calling into their Initialize, Run and Finalize methods. Furthermore, VM-specific properties remain unchanged when going from the parent component to the child component. These properties include the MPI communicator, the number of PETs, the PET labeling, communication attributes, threading-level.

9.1.4 ESMF_CopyFlag

DESCRIPTION:
Indicates whether to reference a data item or make a copy of it.

Valid values are:

ESMF_DATA_COPY Copy the data item to another buffer.

ESMF_DATA_REF Reference the data item.

9.1.5 ESMF_IndexFlag

DESCRIPTION:
Indicates whether index is local (per DE) or global (per object).

Valid values are:

ESMF_INDEX_DELOCAL Refers to indices on the local DE.

ESMF_INDEX_GLOBAL Refers to object-wide indices.

9.1.6 ESMF_InterleaveFlag

DESCRIPTION:
Interleave is used when there are multiple variables or if individual data items are vectors. Used in ESMF_FieldDataMap and ESMF_BundleDataMap. (The interleave option is not yet implemented.)

Valid values are:

ESMF_INTERLEAVE_BY_BLOCK Items are listed in blocks, all items of one type followed by all items of the next type.

ESMF_INTERLEAVE_BY_ITEM Items are interleaved item by item.

9.1.7 ESMF_NeededFlag

DESCRIPTION:
Specifies whether or not a data item is needed for a particular application configuration. Used in ESMF_State.

Valid values are:

ESMF_NEEDED Data is needed.

ESMF_NOTNEEDED Data is not needed.
9.1.8 ESMF_ReadyFlag

DESCRIPTION:
Specifies whether a data item is ready to read or write.
Valid values are:

ESMF_READYTOREAD Data is ready to read.
ESMFReadyTOWRITE Data is ready to write.
ESMF_NOTREADY Data is not ready.

9.1.9 ESMF_ReduceFlag

DESCRIPTION:
Indicates reduce operation to a Reduce() method.
Valid values are:

ESMF_SUM Use arithmetic sum to add all data elements.
ESMF_MIN Determine the minimum of all data elements.
ESMF_MAX Determine the maximum of all data elements.

9.1.10 ESMF_ReqForRestartFlag

DESCRIPTION:
Specifies whether a data item is necessary for restart.
Valid values are:

ESMF_REQUIRED_FOR_RESTART Data is required for restart.
ESMF_NOTREQUIRED_FOR_RESTART Data is not required for restart.

9.1.11 ESMF_ValidFlag

DESCRIPTION:
Specifies whether a data item contains valid data.
Valid values are:

ESMF_VALID Data is ready to read.
ESMF_INVALID Data is ready to write.
ESMF_NOTREADY Data is not ready.

9.2 Parameters

9.2.1 ESMF_DataKind

DESCRIPTION:
Supported ESMF data kinds. These are an ESMF derived type used for arguments to subroutines and functions which want to specify or query a data precision and type. They cannot be used when declaring variables; see the section below for more details.
Valid values are:

ESMF_I1 1 byte integer.
ESMF_I2  2 byte integer.
ESMF_I4  4 byte integer.
ESMF_I8  8 byte integer.
ESMF_R4  4 byte real.
ESMF_R8  8 byte real.
ESMF_C8  8 byte character.
ESMF_C16 16 byte character.

9.2.2 Fortran 90 Kinds

DESCRIPTION:
These are integer parameters of the proper type to be used when declaring variables with a specific precision in Fortran 90 syntax. For example:

```
integer(ESMF_KIND_I4) :: myintegervariable
real(ESMF_KIND_R4) :: myrealvariable
```

The Fortran 90 standard does not mandate what numeric values correspond to actual number of bytes allocated for the various kinds, so these are defined by ESMF to be correct across the different supported Fortran 90 compilers. Note that not all compilers support every kind listed below; in particular 1 and 2 byte integers can be problematic.

Valid values are:

ESMF_KIND_I1  1 byte integer.
ESMF_KIND_I2  2 byte integer.
ESMF_KIND_I4  4 byte integer.
ESMF_KIND_I8  8 byte integer.
ESMF_KIND_R4  4 byte real.
ESMF_KIND_R8  8 byte real.
ESMF_KIND_C8  8 byte character.
ESMF_KIND_C16 16 byte character.

9.2.3 ESMF_DataType

DESCRIPTION:
Supported ESMF data types. These are an ESMF derived type used for arguments to subroutines and functions which want to specify or query a data type.

Valid values are:

ESMF_DATA_INTEGER  Integer type.
ESMF_DATA_REAL    Real type.
ESMF_DATA_LOGICAL  Logical type.
ESMF_DATA_CHARACTER Character type.
10 Overall Design and Implementation Notes

1. **Deep and shallow classes.** The deep and shallow classes described in Section 6.2 differ in how and where they are allocated within a multi-language implementation environment. We distinguish between the implementation language, which is the language a method is written in, and the calling language, which is the language that the user application is written in. Deep classes are allocated off the process heap by the implementation language. Shallow classes are allocated off the stack by the calling language.

2. **Base class.** All ESMF classes are built upon a Base class. The Base is used to hold system-wide capabilities, such as Attributes. Attributes are implemented in the Base class so they can be attached to any object in the system which is built on the Base object. (This is true for all deep objects in the system.) Attributes are created by making a private copy of the information provided during the Set call. Lists of values are supported, but they are not intended for large data arrays. Attribute data is copied during a Get operation.
Part II
Superstructure
11 Overview of Superstructure

ESMF superstructure classes define an architecture for assembling Earth system applications from modeling components. A component may be defined in terms of the physical domain that it represents, such as an atmosphere or sea ice model. It may also be defined in terms of a computational function, such as a data assimilation system. Earth system research often requires that such components be coupled together to create an application. By coupling we mean the data transformations and, on parallel computing systems, data transfers, that are necessary to allow data from one component to be utilized by another. ESMF offers regridding methods and other tools to simplify the organization and execution of inter-component data exchanges.

In addition to components defined at the level of major physical domains and computational functions, components may be defined that represent smaller computational functions within larger components, such as the transformation of data between the physics and dynamics in a spectral atmosphere model, or the creation of nested higher resolution regions within a coarser grid. The objective is to couple components at varying scales both flexibly and efficiently. ESMF encourages a hierarchical application structure, in which large components branch into smaller sub-components (see Figure 2). ESMF also makes it easier for the same component to be used in multiple contexts without changes to its source code.

Key Features
Modular, component-based architecture.
Hierarchical assembly of components into applications.
Use of components in multiple contexts without modification.
Sequential or concurrent component execution.
Single program, multiple datastream (SPMD) applications for maximum portability and reconfigurability.

11.1 Superstructure Classes

There are a small number of classes in the ESMF superstructure:

- **Component** An ESMF component has two parts, one that is supplied by the ESMF and one that is supplied by the user. The part that is supplied by the framework is an ESMF derived type that is either a Gridded Component (GridComp) or a Coupler Component (CplComp). A Gridded Component typically represents a physical domain in which data is associated with one or more grids - for example, a sea ice model. A Coupler Component arranges and executes data transformations and transfers between one or more Gridded Components. Gridded Components and Coupler Components have standard methods, which include initialize, run, and finalize. These methods can be multi-phase.

The second part of an ESMF Component is user code, such as a model or data assimilation system. Users set entry points within their code so that it is callable by the framework. In practice, setting entry points means that within user code there are calls to ESMF methods that associate the name of a Fortran subroutine with a corresponding standard ESMF operation. For example, a user-written initialization routine called popOceanInit might be associated with the standard Initialize routine of an ESMF Gridded Component named “POP” that represents an ocean model.

- **State** ESMF components exchange information with other components only through States. A State is an ESMF derived type that can contain Fields, Bundles, Arrays, and other States. A Component is associated with two States, an Import State and an Export State. Its Import State holds the data that it receives from other Components. Its Export State contains data that it can make available to other Components.

- **Application Driver** The Application Driver (AppDriver) is a small, generic driver program that contains the “main” routine for an ESMF application.

An ESMF coupled application typically involves an AppDriver, a parent Gridded Component, two or more child Gridded Components that require an inter-component data exchange, and one or more Coupler Components.
Figure 2: ESMF enables applications such as the atmospheric general circulation model GEOS-5 to be structured hierarchically, and reconfigured and extended easily. Each box in this diagram is an ESMF Gridded Component.

The parent Gridded Component is responsible for creating the child Gridded Components that are exchanging data and creating the Coupler, for creating the necessary Import and Export States, and for setting up the desired sequencing. The AppDriver “main” routine calls the parent Gridded Component’s initialize, run, and finalize methods in order to execute the application. For each of these standard methods, the parent Gridded Component in turn calls the corresponding methods in the child Gridded Components and the Coupler Component. For example, consider a simple coupled ocean/atmosphere simulation. When the initialize method of the parent Gridded Component is called by the AppDriver, it in turn calls the initialize methods of its child atmosphere and ocean Gridded Components, and the initialize method of an ocean-to-atmosphere Coupler Component. Figure 3 shows this schematically for the atmospheric general circulation model GEOS-5, from Goddard Space Flight Center.

11.2 Hierarchical Creation of Components

Components are allocated computational resources in the form of Persistent Execution Threads, or PETs. A list of a Component’s PETs is contained in a structure called a Virtual Machine, or VM. The VM also contains information about the topology and characteristics of the underlying computer. Components are created hierarchically, with parent Components creating child Components and allocating some or all of its PETs to each one. By default ESMF creates a new VM for each child Component, which allows Components to tailor their VM resources to match their needs.

A Gridded Component may exist across all the PETs in an application. A Gridded Component may also reside on a subset of PETs in an application. These PETs may wholly coincide with, be wholly contained within, or wholly...
Figure 3: A call to a standard ESMF initialize (run, finalize) method by a parent component triggers calls to initialize (run, finalize) all of its child components.

11.3 Sequential and Concurrent Execution of Components

When a set of Gridded Components and a Coupler runs in sequence on the same set of PETs the application is executing in a **sequential** mode. When Gridded Components are created and run on mutually exclusive sets of PETs, and are coupled by a Coupler Component that extends over the union of these sets, the mode of execution is **concurrent**.

Figure 4 illustrates a typical configuration for a simple coupled sequential application, and Figure 5 shows a possible configuration for the same application running in a concurrent mode.

Parent Components can select if and when to wait for concurrently executing child Components, synchronizing only when required.

It is possible for ESMF applications to contain some component sets that are executing sequentially and others that are executing concurrently. We might have, for example, atmosphere and land components created on the same subset of PETs, ocean and sea ice components created on the remainder of PETs, and a Coupler created across all the PETs in the application.
Figure 4: Schematic of the run method of a coupled application, with an “Atmosphere” and an “Ocean” Gridded Component running sequentially with an “Atm-Ocean Coupler.” The top-level “Hurricane Model” Gridded Component contains the sequencing information and time advancement loop. The AppDriver, Coupler, and all Gridded Components are distributed over nine PETs.
Figure 5: Schematic of the run method of a coupled application, with an “Atmosphere” and an “Ocean” Gridded Component running concurrently with an “Atm-Ocean Coupler.” The top-level “Hurricane Model” Gridded Component contains the sequencing information and time advancement loop. The AppDriver, Coupler, and top-level “Hurricane Model” Gridded Component are distributed over nine PETs. The “Atmosphere” Gridded Component is distributed over three PETs and the “Ocean” Gridded Component is distributed over six PETs.
11.4 Intracompontent Communication

All data transfers within an ESMF application occur within a component. For example, a Gridded Component may contain halo updates. Another example is that a Coupler Component may contain a regridding and data redistribution between two Gridded Components. As a result, the architecture of ESMF does not depend on any particular data communication mechanism, and new communication schemes can be introduced without affecting the overall structure of the application.

Since all data communication happens within a component, a Coupler Component must be created on the union of the PETs of all the Gridded Components that it couples.

11.5 Data Distribution and Scoping in Components

ESMF utilizes a unison object creation strategy, where code on each PET calls the same object creation routines individually. Each PET can contain private local data, but all metadata about the object itself is common across all PETs. ESMF can compute metadata information about objects on remote PETs without making communication calls, which would incur additional overhead and add unnecessary synchronization points.

The scope of distributed objects is the VM of the currently executing Component. For this reason, all PETs in the current VM must make the same distributed object creation calls. When a Coupler Component running on a superset of a Gridded Component’s PETs needs to make communication calls involving objects created by the Gridded Component, an ESMF-supplied function called ESMF_StateReconcile() creates proxy objects in those PETs which had no previous information about the distributed objects. Proxy objects contain no local data but can be used in communication calls (such as regrid or redistribution) to describe the remote source for data being moved to the current PET, or as a remote destination for local data being moved from this PET. Figure is a simple schematic that shows the sequence of events in a reconcile call.

11.6 Performance

The ESMF design enables the user to configure ESMF applications so that data is transferred directly from one component to another, without requiring that it be copied or sent to a different data buffer as an interim step. This is likely to be the most efficient way of performing inter-component coupling. However, if desired, an application can also be configured so that data from a source component is sent to a distinct set of Coupler Component PETs for processing before being sent to its destination.

The ability to overlap computation with communication is essential for performance. When running with ESMF the user can initiate data sends during Gridded Component execution, as soon as the data is ready. Computations can then proceed simultaneously with the data transfer.
Figure 6: An ESMF\_StateReconcile() call creates proxy objects for use in subsequent communication calls. The reconcile call would normally be made during Coupler initialization.
11.7 Object Model

The following is a simplified UML diagram showing the relationships among ESMF superstructure classes. See Appendix A, *A Brief Introduction to UML*, for a translation table that lists the symbols in the diagram and their meaning.

![UML diagram](image)

12 Application Driver and Required ESMF Methods

12.1 Description

The ESMF Application Driver (*ESMF_AppDriver*), is a generic ESMF driver program that contains a “main.” Simpler applications may be able to use an Application Driver without modification; for more complex applications, an Application Driver can be used as an extendable template.

ESMF provides a number of different Application Drivers in the `$ESMF_DIR/src/Superstructure/AppDriver` directory. An appropriate one can be chosen depending on how the application is to be structured. Options when deciding how to structure an application include choices about:

**Sequential vs. Concurrent Execution** In a serial execution model every PET executes the same Gridded Component code until it has produced data needed by another Gridded Component, and then all PETs change to running the next Gridded Component or Coupler Component. This has the appeal of simplicity of data consumption and production: when a Gridded Component starts all required data is available for use, and when a Gridded Component finishes all data produced is ready for consumption by the next Gridded Component. This approach also has the possibility of less data movement if the gridding and data decomposition is done such that each processor’s memory contains the data needed by the next Component.

In a concurrent execution model subgroups of PETs run Gridded Components and all Gridded Components are active at the same time. Data exchange must be coordinated between Gridded Components so that data deadlock does not occur. This strategy has the advantage of allowing coupling to other Gridded Components at any time during the computational process, including not having to return to the calling level of code before making data available. ESMF supports the concurrent mode of execution but does not support asynchronous data transfer from within an executing Component at this time.

**Pairwise vs. Hub and Spoke** Coupler Components are responsible for taking data from one Gridded Component and putting it into the form expected by another Gridded Component. This might include regridding, change of units, averaging, or binning.

Coupler Components can be written for *pairwise* data exchange: the Coupler Component takes data from a single Component and transforms it for use by another single Gridded Component. This simplifies the structure of the Coupler Component code.
Couplers can also be written using a hub and spoke model where a single Coupler accepts data from all other Components, can do data merging or splitting, and formats data for all other Components. Multiple Couplers, using either of the above two models or some mixture of these approaches, are also possible.

**Implementation Language** The ESMF framework is implemented with a set of Fortran and C++ interfaces to all functions. The main executable program can be written in either Fortran or C++.

**Number of Executables** On a multiple processor machine a cooperating job can be run by starting the same executable on all nodes. All processors run the same code, but the computation proceeds in parallel by each processor working on a different subset of data. This is a SPMD model, Single Program Multiple Data.

The alternative is to start a different executable on different processors. This is a MPMD model, Multiple Program Multiple Data. There are complications with many job control systems on multiprocessor machines in getting the different executables started, and getting inter-process communications established. Currently ESMF does not support MPMD.

### 12.2 Application Driver and Required ESMF Methods Options

#### 12.2.1 ESMF_TerminationFlag

**DESCRIPTION:**
The ESMF_TerminationFlag determines how an ESMF application is shut down.

Valid values are:

- **ESMF_ABORT** Global abort of the ESMF application. There is no guarantee that all PETs will shut down cleanly during an abort. However, all attempts are made to prevent the application from hanging and the LogErr of at least one PET will be completely flushed during the abort. This option should only be used if a condition is detected that prevents normal continuation or termination of the application. Typical conditions that warrant the use of ESMF_ABORT are those that occur on a per PET basis where other PETs may be blocked in communication calls, unable to reach the normal termination point.

- **ESMF_FINALIZE** Normal termination of the ESMF application. Wait for all PETs of the global VM to reach ESMF_Finalize() before termination. This is the clean way of terminating an application. MPI_Finalize() will be called in case of MPI applications.

- **ESMF_KEEPMPI** Same as ESMF_FINALIZE but MPI_Finalize() will *not* be called. It is the user code’s responsibility to shut down MPI cleanly.

### 12.3 Use and Examples

ESMF encourages application organization in which there is a single top-level Gridded Component. This provides a simple, clear sequence of operations at the highest level, and also enables the entire application to be treated as a sub-Gridded Component of another, larger application if desired. When an application is organized in this fashion the standard AppDriver can probably be used without much modification.

Examples of program organization using the AppDriver can be found in the src/Superstructure/AppDriver directory. A set of subdirectories within the AppDriver directory follows the naming convention:

```
<seq|concur>_<pairwise|hub>_<f|c>driver_<spmd|mpmd>
```

The examples that are currently implemented are seq_pairwise_fdriver_spmd, which has sequential component execution, a pairwise coupler, a main program in Fortran, and all processors launching the same executable; and concur_pairwise_fdriver_spmd, which has concurrent component execution, a pairwise coupler, a main program in Fortran, and all processors launching the same executable.

The example seq_pairwise_fdriver_spmd is the simplest of the examples, and so it is also copied automatically into a top-level quick_start directory at compilation time.
The user can copy the AppDriver files into their own local directory. Some of the files can be used unchanged. Others are template files which have the rough outline of the code but need additional application-specific code added in order to perform a meaningful function. The README file in the AppDriver subdirectory or quick_start directory contains instructions about which files to change.

#----------------------------------------------------------
# The ChangeMe.F90 file contains a number of definitions
# that are used by the AppDriver, such as the name of the application’s
# main configuration file and the name of the application’s SetServices
# routine.
#----------------------------------------------------------

#include "ChangeMe.F90"

program ESMF_AppDriver

! ESMF module, defines all ESMF data types and procedures
use ESMF_Mod

! Gridded Component registration routines. Defined in "ChangeMe.F90"
use USER_APP_Mod, only : SetServices => USER_APP_SetServices

implicit none

! Local variables

! Components

! ESMF_GridComp) :: compGridded

type(ESMF_GridComp) :: compGridded

! States, Virtual Machines, and Layouts

type(ESMF_VDM) :: defaultvm

type(ESMF_DELayout) :: defaultlayout

type(ESMF_State) :: defaultstate

! Configuration information

type(ESMF_Config) :: config

! A common grid

type(ESMF_Grid) :: grid

! A clock, a calendar, and timesteps

type(ESMF_Clock) :: clock

type(ESMF_TimeInterval) :: timeStep

type(ESMF_Time) :: startTime

type(ESMF_Time) :: stopTime

! Variables related to grid and clock

integer :: i_max, j_max
real(ESMF_KIND_R4) :: x_min4, x_max4, y_min4, y_max4
real(ESMF_KIND_R8) :: x_min, x_max, y_min, y_max

! Return codes for error checks

integer :: rc

logical :: dummy
call ESMF_Initialize(defaultCalendar=ESMF_CAL_GREGORIAN, rc=rc)
if (rc .ne. ESMF_SUCCESS) stop 99

call ESMF_LogWrite("ESMF AppDriver start", ESMF_LOG_INFO)

! Read in Configuration information from a default config file

config = ESMF_ConfigCreate(rc)
call ESMF_ConfigLoadFile(config, USER_CONFIG_FILE, rc = rc)

! Get standard config parameters, for example:

! the default grid size and type
! the default start time, stop time, and running intervals
! for the main time loop.
!
! e.g. to get an integer parameter from the config file:
! call ESMF_ConfigGetAttribute( config, ndays, label = 'Number_of_Days:', &
!     default=30, rc = rc )
!
call ESMF_ConfigGetAttribute(config, i_max, 'I Counts:', default=20, rc=rc)
call ESMF_ConfigGetAttribute(config, j_max, 'J Counts:', default=80, rc=rc)
call ESMF_ConfigGetAttribute(config, x_min4, 'X Min:', default=0.0, rc=rc)
call ESMF_ConfigGetAttribute(config, y_min4, 'Y Min:', default=-180.0, rc=rc)
call ESMF_ConfigGetAttribute(config, x_max4, 'X Max:', default=90.0, rc=rc)
call ESMF_ConfigGetAttribute(config, y_max4, 'Y Max:', default=180.0, rc=rc)

! Get the default VM which contains all PEs this job was started on.
call ESMF_VMGetGlobal(defaultvm, rc)

call ESMF_LogWrite("Component Create finished", ESMF_LOG_INFO)

call ESMF_GridCompSetServices(compGridded, SetServices, rc)
if (ESMF_LogMsgFoundError(rc, "Registration failed", rc)) goto 10

!-------------------------------------------------- -----------------------------
! Create and initialize a clock, and a grid.
!-------------------------------------------------- -----------------------------

! Based on values from the Config file, create a default Grid
! and Clock. We assume we have read in the variables below from
! the config file.

call ESMF_TimeIntervalSet(timeStep, s=2, rc=rc)
call ESMF_TimeSet(startTime, yy=2004, mm=9, dd=25, rc=rc)
call ESMF_TimeSet(stopTime, yy=2004, mm=9, dd=26, rc=rc)
clock = ESMF_ClockCreate("Application Clock", timeStep, startTime, &
   stopTime, rc=rc)

! Same with the grid. Get a default layout based on the VM.
defaultlayout = ESMF_DELLayoutCreate(defaultvm, rc=rc)

x_min = x_min4
y_min = y_min4
x_max = x_max4
y_max = y_max4
grid = ESMF_GridCreateHorzXYUni(counts=(/i_max, j_max/), &
   minGlobalCoordPerDim=(/x_min, y_min/), &
   maxGlobalCoordPerDim=(/x_max, y_max/), &
   horzStagger=ESMF_GRID_HORZ_STAGGER_C_SE, &
   name="source grid", rc=rc)
call ESMF_GridDistribute(grid, delayout=defaultlayout, rc=rc)

! Attach the Grid to the Component
call ESMF_GridCompSet(compGridded, grid=grid, rc=rc)

!-------------------------------------------------- -----------------------------
! Create and initialize a State to use for both import and export.
!-------------------------------------------------- -----------------------------

defaultstate = ESMF_StateCreate("Default Gridded State", rc=rc)

!-------------------------------------------------- -----------------------------
! Init, Run, and Finalize section
!-------------------------------------------------- -----------------------------
call ESMF_GridCompInitialize(compGridded, defaultstate, defaultstate, &
clock, rc=rc)
if (ESMF_LogMsgFoundError(rc, "Initialize failed", rc)) goto 10

call ESMF_GridCompRun(compGridded, defaultstate, defaultstate, &
clock, rc=rc)
if (ESMF_LogMsgFoundError(rc, "Run failed", rc)) goto 10

call ESMF_GridCompFinalize(compGridded, defaultstate, defaultstate, &
clock, rc=rc)
if (ESMF_LogMsgFoundError(rc, "Finalize failed", rc)) goto 10

!-------------------------------------------------- ----------------------------
!-------------------------------------------------- ----------------------------
! Destroy section
!-------------------------------------------------- ----------------------------
!-------------------------------------------------- ----------------------------

! Clean up

call ESMF_ClockDestroy(clock, rc)
call ESMF_StateDestroy(defaultstate, rc)
call ESMF_GridCompDestroy(compGridded, rc)
call ESMF_DELayoutDestroy(defaultLayout, rc)

!-------------------------------------------------- ----------------------------
!-------------------------------------------------- ----------------------------
10 continue

call ESMF_Finalize(rc=rc)
end program ESMF_AppDriver

12.4 Restrictions and Future Work

1. **MPMD not supported.** Only single executable applications are supported at this time.

12.5 Required ESMF Methods
12.5.1 ESMF_Initialize - Initialize the ESMF

INTERFACE:

```fortran
subroutine ESMF_Initialize(defaultConfigFileName, defaultCalendar, &
                        defaultLogFileName, defaultLogType, mpiCommunicator, vm, rc)
```

ARGUMENTS:

- `character(len=*)`, intent(in), optional :: `defaultConfigFileName`
- `type(ESMF_CalendarType), intent(in), optional :: defaultCalendar`
- `character(len=*)`, intent(in), optional :: `defaultLogFileName`
- `type(ESMF_LogType), intent(in), optional :: defaultLogType`
- `integer, intent(in), optional :: mpiCommunicator`
- `type(ESMF_VM), intent(out), optional :: vm`
- `integer, intent(out), optional :: rc`

DESCRIPTION:

Initialize the ESMF. This method must be called before any other ESMF methods are used. The method contains a barrier before returning, ensuring that all processes made it successfully through initialization. Typically `ESMF_Initialize()` will call `MPI_Init()` internally unless MPI has been initialized by the user code before initializing the framework. If the MPI initialization is left to `ESMF_Initialize()` it inherits all of the MPI implementation dependent limitations of what may or may not be done before `MPI_Init()`. For instance, it is unsafe for some MPI implementations, such as MPICH, to do IO before the MPI environment is initialized. Please consult the documentation of your MPI implementation for details.

Before exiting the application the user must call `ESMF_Finalize()` to release resources and clean up the ESMF gracefully.

The arguments are:

- `[defaultConfigFilename]` Name of the default configuration file for the entire application.
- `[defaultCalendar]` Sets the default calendar to be used by ESMF Time Manager. See section 32.2.1 for a list of valid options. If not specified, defaults to `ESMF_CAL_NOCALENDAR`.
- `[defaultLogFileName]` Name of the default log file for warning and error messages. If not specified, defaults to `ESMF_ErrorLog`.
- `[defaultLogType]` Sets the default Log Type to be used by ESMF Log Manager. See section 38.2.3 for a list of valid options. If not specified, defaults to `ESMF_LOG_MULTI`.
- `[mpiCommunicator]` MPI communicator defining the group of processes on which the ESMF application is running. If not specified, defaults to `MPI_COMM_WORLD`.
- `[vm]` Returns the global `ESMF_VM` that was created during initialization.
- `[rc]` Return code; equals `ESMF_SUCCESS` if there are no errors.

12.5.2 ESMF_Finalize - Clean up and close the ESMF

INTERFACE:

```fortran
subroutine ESMF_Finalize(terminationflag, rc)
```

ARGUMENTS:
Finalize the ESMF. This must be called before the application exits to allow the ESMF to flush buffers, close open connections, and release internal resources cleanly. The optional argument terminationflag may be used to indicate the mode of termination.

The arguments are:

- **terminationflag** Specify mode of termination. The default is ESMF_FINAL which waits for all PETs of the global VM to reach ESMF_Finalize() before termination. See section [12.2.1](#) for a complete list and description of valid flags.

- **rc** Return code; equals ESMF_SUCCESS if there are no errors.

### 12.5.3 User-Code SetServices Method

Many programs call some library routines. The library documentation must explain what the routine name is, what arguments are required and what are optional, and what the code does.

In contrast, all ESMF components must be written to be called by another part of the program; in effect, an ESMF component takes the place of a library. The interface is prescribed by the framework, and the component writer must provide specific subroutines which have standard argument lists and perform specific operations.

One of the required interfaces a component must provide is the set services method. This subroutine must have an externally accessible name (be a public symbol), take a component as the first argument, and an integer return code as the second. Both arguments are required and must not be declared as optional. If an intent is specified in the interface it must be intent(inout) for the first and intent(out) for the second argument. The subroutine name is not predefined, it is set by the component writer, but must be provided as part of the component documentation.

The required function of the set services subroutine is to register the rest of the required functions in the component, currently initialize, run, and finalize methods. The ESMF method ESMF_<Grid/Cpl>CompSetEntryPoint() should be called for each of the required subroutines.

The names of the initialize, run, and finalize user-code subroutines do not need to be public; in fact it is far better for them to be private to lower the chances of public symbol clashes between different components.

Within the set services routine, the user can also register a private data block by calling the ESMF_<Grid|Cpl>CompSetInternalState method.

Note that a component does not call its own set services routine; the AppDriver or parent component code which is creating a component will first call ESMF_<Grid/Cpl>CompCreate() to create an ’empty’ component, and then must call the component-specific set services routine to associate ESMF-standard methods to user-code methods, and to create the VM in which this component will run. After set services has been called, the framework now will be able to call the component’s initialize, run, and finalize routines as required.

### 12.5.4 User-Code Initialize, Run, and Finalize Methods

User-code initialize, run, and finalize routines must be provided for each component. See Sections [13.6](#) and [14.5](#) for the prescribed interfaces and examples of how to set these up.

### 13 GridComp Class

#### 13.1 Description

In Earth system modeling, the most natural way to think about an ESMF Gridded Component, or ESMF_GridComp, is as a piece of code representing a particular physical domain; for example, an atmospheric model or an ocean model.

In many large modeling systems, each components is developed by its own group of domain experts. The ESMF Gridded Component construct provides domain experts with a structured, consistent set of component interfaces so
that it is straightforward, at least technically, to combine software from a number of groups, representing different physical domains, to form a complex application.

Earth system software components tend to share a number of basic features. Most contain a variety of physical fields; refer to a (possibly noncontiguous) spatial region and a grid that is partitioned across a set of computational resources; and require a clock, usually for stepping a governing set of PDEs forward in time. Most can also be divided into distinct initialize, run, and finalize computational phases. These common characteristics are used within ESMF to define a Gridded Component data structure that is both tailored for Earth system modeling and yet is still flexible enough to represent a variety of domains.

More broadly, an ESMF Gridded Component can be based on any software with a computational function that is associated with a grid. This might be a convection or radiation scheme, a dynamical core, or a data assimilation system. ESMF allows you to nest Gridded Components, so that the physics and dynamics within an atmospheric model can be considered Gridded Components, along with the atmospheric model itself.

A well-designed Gridded Component does not store information internally about how it couples to other Gridded Components. That allows it to be used in different contexts without changes to source code. Data is passed between Gridded Components using an intermediary Coupler Component, described in Section 14.1.

An ESMF Gridded Component has two parts, one which is user-written and another which is part of the framework. The user-written part is software representing a physical domain or performing some other computational function. It forms the body of the Gridded Component. It may be a piece of legacy code, or it may be developed expressly for use with the ESMF. It must contain routines with standard ESMF interfaces that can be called to initialize, run, and finalize the Gridded Component. These routines can have separate callable phases, such as distinct first and second initialization steps.

The part provided by ESMF is the Gridded Component derived type itself, ESMF_GridComp. An ESMF_GridComp must be created for every portion of the application that will be represented as a separate component; for example, in a climate model, there may be Gridded Components representing the land, ocean, sea ice, and atmosphere. If the application contains an ensemble of identical Gridded Components, every one has its own associated ESMF_GridComp.

Each Gridded Component has its own name and is allocated a set of computational resources, in the form of an ESMF Virtual Machine, or VM.

The user-written part of a Gridded Component is associated with an ESMF_GridComp derived type through a routine called SetServices. This is a routine that the user must write, and declare public. Inside the SetServices routine the user must call ESMF_SetEntryPoint methods that associate a standard ESMF operation with the name of the corresponding Fortran subroutine in their user code.

For example, a user-written initialization routine called popOceanInit might be associated with the standard initialize routine of an ESMF Gridded Component named “POP” that represents an ocean model.

### 13.2 GridComp Options

#### 13.2.1 ESMF_GridCompType

**DESCRIPTION:**

The ESMF_GridCompType flag identifies what sort of physical domain or computational function a particular ESMF_GridComp represents. The flag values are purely informational; they are not used anywhere within the framework. Use of this flag is optional.

Valid values are:

ESMF_ATM  Atmospheric model.

ESMF_LAND  Land model.

ESMF_OCEAN  Ocean model.

ESMF_SEAICE  Sea ice model.

ESMF_RIVER  River model.

ESMF_OTHER  Other type of model or system.

---

3 The idea here is to avoid situations in which slightly different versions of the same model source are maintained for use in different contexts - standalone vs. coupled versions, for example.
13.3 Use and Examples

A Gridded Component is a computational entity which consumes and produces data. It uses a State object to exchange data between itself and other Components. It uses a Clock object to manage time, and a VM to describe its own and its child components’ computational resources.

! !PROGRAM: ESMF_GCompEx.F90 - Gridded Component example
! !DESCRIPTION:
! The skeleton of one of many possible Gridded component models.
! !-------------------------------------------------- ---------------------------

13.3.1 Specifying a User-Code SetServices Routine

Every ESMF_GridComp is required to provide and document a set services routine. It can have any name, but must follow the declaration below: a subroutine which takes an ESMF_GridComp as the first argument, and an integer return code as the second. Both arguments are required and must not be declared as optional. If an intent is specified in the interface it must be intent(inout) for the first and intent(out) for the second argument.

The set services routine must call the ESMF method ESMF_GridCompSetEntryPoint() to register with the framework what user-code subroutines should be called to initialize, run, and finalize the component. There are additional routines which can be registered as well, for checkpoint and restart functions.

Note that the actual subroutines being registered do not have to be public to this module; only the set services routine itself must be available to be used by other code.

! Example Gridded Component
module ESMF_GriddedCompEx

! ESMF Framework module
use ESMF_Mod
implicit none
public GComp_SetServices
contains

subroutine GComp_SetServices(comp, rc)
type(ESMF_GridComp) :: comp
integer :: rc

! SetServices the callback routines.
call ESMF_GridCompSetEntryPoint(comp, ESMF_SETINIT, GComp_Init, 0, rc)
call ESMF_GridCompSetEntryPoint(comp, ESMF_SETRUN, GComp_Run, 0, rc)
call ESMF_GridCompSetEntryPoint(comp, ESMF_SETFINAL, GComp_Final, 0, rc)

! If desired, this routine can register a private data block
! to be passed in to the routines above:
! call ESMF_GridCompSetData(comp, mydatablock, rc)

rc = ESMF_SUCCESS
end subroutine
13.3.2 Specifying a User-Code Initialize Routine

When a higher level component is ready to begin using an ESMF_GridComp, it will call its initialize routine. The component writer must supply a subroutine with the exact calling sequence below; no arguments can be optional, and the types and order must match. At initialization time the component can allocate data space, open data files, set up initial conditions; anything it needs to do to prepare to run. The \textit{rc} return code should be set if an error occurs, otherwise the value \texttt{ESMF\_SUCCESS} should be returned.

\begin{verbatim}
subroutine GComp_Init(comp, importState, exportState, clock, rc)
  type(ESMF_GridComp) :: comp
  type(ESMF_State) :: importState, exportState
  type(ESMF_Clock) :: clock
  integer :: rc

  print *, "Gridded Comp Init starting"
  ! This is where the model specific setup code goes.
  ! If the initial Export state needs to be filled, do it here.
  ! call ESMF_StateAddField(exportState, field, rc)
  ! call ESMF_StateAddBundle(exportState, bundle, rc)
  print *, "Gridded Comp Init returning"
  rc = ESMF_SUCCESS

end subroutine GComp_Init
\end{verbatim}

13.3.3 Specifying a User-Code Run Routine

During the execution loop, the run routine may be called many times. Each time it should read data from the \texttt{importState}, use the \texttt{clock} to determine what the current time is in the calling component, compute new values or process the data, and produce any output and place it in the \texttt{exportState}. When a higher level component is ready to use the ESMF/GridComp it will call its run routine. The component writer must supply a subroutine with the exact calling sequence below; no arguments can be optional, and the types and order must match. It is expected that this is where the bulk of the model computation or data analysis will occur. The \textit{rc} return code should be set if an error occurs, otherwise the value \texttt{ESMF\_SUCCESS} should be returned.

\begin{verbatim}
subroutine GComp_Run(comp, importState, exportState, clock, rc)
  type(ESMF_GridComp) :: comp
  type(ESMF_State) :: importState, exportState
  type(ESMF_Clock) :: clock
  integer :: rc

  print *, "Gridded Comp Run starting"
  ! call ESMF_StateGetField(), etc to get fields, bundles, arrays
  ! from import state.
  ! This is where the model specific computation goes.

end subroutine GComp_Run
\end{verbatim}
! Fill export state here using ESMF_StateAddField(), etc

print *, "Gridded Comp Run returning"

rc = ESMF_SUCCESS

end subroutine GComp_Run

13.3.4 Specifying a User-Code Finalize Routine

At the end of application execution, each ESMF_GridComp should deallocate data space, close open files, and flush final results. These functions should be placed in a finalize routine. The rc return code should be set if an error occurs, otherwise the value ESMF_SUCCESS should be returned.

subroutine GComp_Final(comp, importState, exportState, clock, rc)
  type(ESMF_GridComp) :: comp
  type(ESMF_State) :: importState, exportState
  type(ESMF_Clock) :: clock
  integer :: rc

  print *, "Gridded Comp Final starting"
  ! Add whatever code here needed
  print *, "Gridded Comp Final returning"
  rc = ESMF_SUCCESS

end subroutine GComp_Final

end module ESMF_GriddedCompEx

! PROGRAM: ESMF_InternalStateEx - Example of using Set/Get Internal State
!
! DESCRIPTION:
! Example of using the Component level Internal State routines.
!
! These include:
! ESMF_GridCompGetInternalState
! ESMF_GridCompSetInternalState
! ESMF_CplCompGetInternalState
! ESMF_CplCompSetInternalState
!
! These routines save the address of an internal, private data block
! during the execution of a Component’s Initialize, Run, or Finalize
! code, and retrieve the address back during a different invocation
! of these routines.  See the code below for examples of use.
!
! ESMF Framework module
use ESMF_Mod
implicit none

type(ESMF_GridComp) :: comp1
integer :: rc, finalrc

! Internal State Variables
type testData
sequence
integer :: testValue
real :: testScaling
end type
type dataWrapper
sequence
    type(testData), pointer :: p
end type
type (dataWrapper) :: wrap1, wrap2
type(testData), target :: data1, data2

finalrc = ESMF_SUCCESS
!-------------------------------------------------- -----------------------
call ESMF_Initialize(rc=rc)
if (rc .ne. ESMF_SUCCESS) finalrc = ESMF_FAILURE
!-------------------------------------------------- -----------------------
! ! Creation of a Component
comp1 = ESMF_GridCompCreate(name="test", rc=rc)
if (rc .ne. ESMF_SUCCESS) finalrc = ESMF_FAILURE
!-------------------------------------------------- -----------------------
! ! This could be called, for example, during a routine’s initialize phase.
! ! Set Internal State
data1%testValue = 4567
data1%testScaling = 0.5
wrap1%p => data1

call ESMF_GridCompSetInternalState(comp1, wrap1, rc)
if (rc .ne. ESMF_SUCCESS) finalrc = ESMF_FAILURE
!-------------------------------------------------- -----------------------
! ! And this could be called, for example, during a routine’s run phase.
! ! Get Internal State
! ! note that we do not assign the pointer inside wrap2 - this call
! ! does that.
call ESMF_GridCompGetInternalState(comp1, wrap2, rc)
if (rc .ne. ESMF_SUCCESS) finalrc = ESMF_FAILURE
data2 = wrap2%p
if ((data2%testValue .ne. 4567) .or. (data2%testScaling .ne. 0.5)) then
    print *, "did not get same values back"
    finalrc = ESMF_FAILURE
else
    print *, "got same values back from GetInternalState as original"
endif

13.4 Restrictions and Future Work

1. **No Transforms.** Components must exchange data through ESMF_State objects. The input data are available at the time the user Component code is called, and data to be returned to another Component are available when that code returns.

2. **Data isolation.** Gridded Components must only communicate with other components via data in State objects. They must not make direct references to data in other States.

3. **Namespace isolation.** If possible, Gridded Components should attempt to make all data private, so public names do not interfere with data in other components.

4. **Single execution mode.** It is not expected that a single Gridded Component be able to function in both sequential and concurrent modes, although Gridded Components of different types can be nested. For example, a concurrently called Gridded Component can contain several nested sequential Gridded Components.

13.5 Class API: Basic GridComp Methods

13.5.1 ESMF_GridCompCreate - Create a Gridded Component

**INTERFACE:**

recursive function ESMF_GridCompCreate(name, gridcomptype, grid, config, configFile, clock, petList, contextflag, parentVm, rc)

**RETURN VALUE:**

type(ESMF_GridComp) :: ESMF_GridCompCreate

**ARGUMENTS:**

<table>
<thead>
<tr>
<th>!externa</th>
<th>services</th>
</tr>
</thead>
<tbody>
<tr>
<td>character(len=*)</td>
<td>intent(in), optional :: name</td>
</tr>
<tr>
<td>type(ESMF_GridCompType)</td>
<td>intent(in), optional :: gridcomptype</td>
</tr>
<tr>
<td>type(ESMF_Grid)</td>
<td>intent(inout), optional :: grid</td>
</tr>
<tr>
<td>type(ESMF_Config)</td>
<td>intent(inout), optional :: config</td>
</tr>
<tr>
<td>character(len=*)</td>
<td>intent(in), optional :: configFile</td>
</tr>
<tr>
<td>type(ESMF_Clock)</td>
<td>intent(inout), optional :: clock</td>
</tr>
<tr>
<td>integer</td>
<td>intent(in), optional :: petList</td>
</tr>
<tr>
<td>type(ESMF_ContextFlag)</td>
<td>intent(in), optional :: contextflag</td>
</tr>
<tr>
<td>type(ESMF_VM)</td>
<td>intent(inout), optional :: parentVm</td>
</tr>
<tr>
<td>integer</td>
<td>intent(out), optional :: rc</td>
</tr>
</tbody>
</table>

**DESCRIPTION:**

Create an ESMF_GridComp object.
The return value is the new ESMF_GridComp.
The arguments are:
**name**  Name of the newly-created ESMF_GridComp. This name can be altered from within the ESMF_GridComp code once the initialization routine is called.

**gridcomptype**  ESMF_GridComp model type, where model includes ESMF_ATM, ESMF_LAND, ESMF_OCEAN, ESMF SEAICE, ESMF_RIVER. Note that this has no meaning to the framework, it is an annotation for user code to query.

**grid**  Default ESMF_Grid associated with this gridcomp.

**config**  An already-created ESMF_Config configuration object from which the new component can read in namelist-type information to set parameters for this run. If both are specified, this object takes priority over configFile.

**configFile**  The filename of an ESMF_Config format file. If specified, this file is opened an ESMF_Config configuration object is created for the file, and attached to the new component. The user can call ESMF_GridCompGet() to get and use the object. If both are specified, the config object takes priority over this one.

**clock**  Component-specific ESMF_Clock. This clock is available to be queried and updated by the new ESMF_GridComp as it chooses. This should not be the parent component clock, which should be maintained and passed down to the initialize/run/finalize routines separately.

**petList**  List of parent PETs given to the created child component by the parent component. If petList is not specified all of the parent PETs will be given to the child component. The order of PETs in petList determines how the child local PETs refer back to the parent PETs.

**contextflag**  Specify the component’s VM context. The default context is ESMF_CHILD_IN_NEW_VM. See section 9.1.3 for a complete list of valid flags.

**parentVm**  ESMF_VM object for the current component. This will become the parent ESMF_VM for the newly created ESMF_GridComp object. By default the current VM is determined automatically.

**rc**  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 13.5.2 ESMF_GridCompDestroy - Release resources for a GridComp

**INTERFACE:**

```
subroutine ESMF_GridCompDestroy(gridcomp, rc)
```

**ARGUMENTS:**

```
type(ESMF_GridComp) :: gridcomp
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Releases all resources associated with this ESMF_GridComp.

The arguments are:

**gridcomp**  Release all resources associated with this ESMF_GridComp and mark the object as invalid. It is an error to pass this object into any other routines after being destroyed.

**rc**  Return code; equals ESMF_SUCCESS if there are no errors.
13.5.3  ESMF_GridCompFinalize - Call the GridComp’s finalize routine

INTERFACE:

recursive subroutine ESMF_GridCompFinalize(gridcomp, importState, &
   exportState, clock, phase, blockingflag, rc)

ARGUMENTS:

  type (ESMF_GridComp) :: gridcomp
  type (ESMF_State), intent(inout), optional :: importState
  type (ESMF_State), intent(inout), optional :: exportState
  type (ESMF_Clock), intent(inout), optional :: clock
  integer, intent(in), optional :: phase
  type (ESMF_BlockingFlag), intent(in), optional :: blockingflag
  integer, intent(out), optional :: rc

DESCRIPTION:

Call the associated user-supplied finalization code for an ESMF_GridComp.
The arguments are:

  gridcomp  The ESMF_GridComp to call finalize routine for.
  [importState]  ESMF_State containing import data. If not present, a dummy argument will be passed to the user-supplied routine. The importState argument in the user code cannot be optional.
  [exportState]  ESMF_State containing export data. If not present, a dummy argument will be passed to the user-supplied routine. The exportState argument in the user code cannot be optional.
  [clock]  External ESMF_Clock for passing in time information. This is generally the parent component’s clock, and will be treated as read-only by the child component. The child component can maintain a private clock for its own internal time computations. If not present, a dummy argument will be passed to the user-supplied routine. The clock argument in the user code cannot be optional.
  [phase]  Component providers must document whether their each of their routines are single-phase or multi-phase. Single-phase routines require only one invocation to complete their work. Multi-phase routines provide multiple subroutines to accomplish the work, accommodating components which must complete part of their work, return to the caller and allow other processing to occur, and then continue the original operation. For single-phase child components this argument is optional, but if specified it must be ESMF_SINGLEPHASE. For multiple-phase child components, this is the integer phase number to be invoked.
  [blockingflag]  Blocking behavior of this method call. See section 9.1.2 for a list of valid blocking options. Default option is ESMF_VASBLOCKING which blocks PETs and their spawned off threads across each VAS but does not synchronize PETs that run in different VASs.
  [rc]  Return code; equals ESMF_SUCCESS if there are no errors.

13.5.4  ESMF_GridCompGet - Query a GridComp for information

INTERFACE:

subroutine ESMF_GridCompGet(gridcomp, name, gridcomptype, &
   grid, config, configFile, clock, vm, contextflag, rc)

ARGUMENTS:
type (ESMF_GridComp), intent (inout) :: gridcomp
character(len=*), intent (out), optional :: name

DESCRIPTION:

Returns information about an ESMF_GridComp. For queries where the caller only wants a single value, specify the argument by name. All the arguments after the gridcomp argument are optional to facilitate this. The arguments are:

gridcomp ESMF_GridComp object to query.

[name] Return the name of the ESMF_GridComp.

[gridcomptype] Return the model type of this ESMF_GridComp.

[grid] Return the ESMF_Grid associated with this ESMF_GridComp.

[config] Return the ESMF_Config object for this ESMF_GridComp.

[configFile] Return the configuration filename for this ESMF_GridComp.

[clock] Return the private clock for this ESMF_GridComp.

[vm] Return the ESMF_VM for this ESMF_GridComp.

[contextflag] Return the ESMF_ContextFlag for this ESMF_GridComp. See section 9.1.3 for a complete list of valid flags.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

13.5.5 ESMF_GridCompInitialize - Call the GridComp’s initialize routine

INTERFACE:

recursive subroutine ESMF_GridCompInitialize(gridcomp, importState, &
    exportState, clock, phase, blockingflag, rc)

ARGUMENTS:

  type (ESMF_GridComp) :: gridcomp
  type (ESMF_State), intent (inout), optional :: importState
  type (ESMF_State), intent (inout), optional :: exportState
  type (ESMF_Clock), intent (inout), optional :: clock
  integer, intent (in), optional :: phase
  type (ESMF_BlockingFlag), intent (in), optional :: blockingflag
  integer, intent (out), optional :: rc
DESCRIPTION:

Call the associated user initialization code for a gridcomp. The arguments are:

**gridcomp** ESMF_GridComp to call initialize routine for.

**[importState]** ESMF_State containing import data for coupling. If not present, a dummy argument will be passed to the user-supplied routine. The importState argument in the user code cannot be optional.

**[exportState]** ESMF_State containing export data for coupling. If not present, a dummy argument will be passed to the user-supplied routine. The exportState argument in the user code cannot be optional.

**[clock]** External ESMF_Clock for passing in time information. This is generally the parent component’s clock, and will be treated as read-only by the child component. The child component can maintain a private clock for its own internal time computations. If not present, a dummy argument will be passed to the user-supplied routine. The clock argument in the user code cannot be optional.

**[phase]** Component providers must document whether their each of their routines are *single-phase* or *multi-phase*. Single-phase routines require only one invocation to complete their work. Multi-phase routines provide multiple subroutines to accomplish the work, accommodating components which must complete part of their work, return to the caller and allow other processing to occur, and then continue the original operation. For single-phase child components this argument is optional, but if specified it must be ESMF_SINGLEPHASE. For multiple-phase child components, this is the integer phase number to be invoked.

**[blockingflag]** Blocking behavior of this method call. See section 9.1.2 for a list of valid blocking options. Default option is ESMF_VASBLOCKING which blocks PETs and their spawned off threads across each VAS but does not synchronize PETs that run in different VASs.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

---

13.5.6 **ESMF_GridCompPrint - Print the contents of a GridComp**

INTERFACE:

```fortran
subroutine ESMF_GridCompPrint(gridcomp, options, rc)
ARGUMENTS:
  type(ESMF_GridComp) :: gridcomp
  character (len = *) , intent(in), optional :: options
  integer, intent(out), optional :: rc
```

DESCRIPTION:

Prints information about an ESMF_GridComp to stdout. The arguments are:

**gridcomp** ESMF_GridComp to print.

**[options]** Print options are not yet supported.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.
13.5.7 ESMF_GridCompRun - Call the GridComp’s run routine

INTERFACE:

recursive subroutine ESMF_GridCompRun(gridcomp, importState, exportState,& clock, phase, blockingflag, rc)

ARGUMENTS:

  type (ESMF_GridComp) :: gridcomp
  type (ESMF_State), intent(inout), optional :: importState
  type (ESMF_State), intent(inout), optional :: exportState
  type (ESMF_Clock), intent(inout), optional :: clock
  integer, intent(in), optional :: phase
  type (ESMF_BlockingFlag), intent(in), optional :: blockingflag
  integer, intent(out), optional :: rc

DESCRIPTION:

Call the associated user run code for an ESMF_GridComp. The arguments are:

gridcomp  ESMF_GridComp to call run routine for.

[importState] ESMF_State containing import data. If not present, a dummy argument will be passed to the user-supplied routine. The importState argument in the user code cannot be optional.

[exportState] ESMF_State containing export data. If not present, a dummy argument will be passed to the user-supplied routine. The exportState argument in the user code cannot be optional.

[clock] External ESMF_Clock for passing in time information. This is generally the parent component’s clock, and will be treated as read-only by the child component. The child component can maintain a private clock for its own internal time computations. If not present, a dummy argument will be passed to the user-supplied routine. The clock argument in the user code cannot be optional.

[phase] Component providers must document whether their each of their routines are single-phase or multi-phase. Single-phase routines require only one invocation to complete their work. Multi-phase routines provide multiple subroutines to accomplish the work, accommodating components which must complete part of their work, return to the caller and allow other processing to occur, and then continue the original operation. For single-phase child components this argument is optional, but if specified it must be ESMF_SINGLEPHASE. For multiple-phase child components, this is the integer phase number to be invoked. If multiple-phase restore, which phase number this is. Pass in 0 or ESMF_SINGLEPHASE for non-multiples.

[blockingflag] Blocking behavior of this method call. See section 9.1.2 for a list of valid blocking options. Default option is ESMF_VASBLOCKING which blocks PETs and their spawned off threads across each VAS but does not synchronize PETs that run in different VASs.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

13.5.8 ESMF_GridCompSet - Set or reset information about the GridComp

INTERFACE:

subroutine ESMF_GridCompSet(gridcomp, name, gridcomptype, grid, & config, configFile, clock, rc)
ARGUMENTS:

- `gridcomp`: ESMF_GridComp to change.
- `[name]` Set the name of the ESMF_GridComp.
- `[gridcomptype]` Set the model type for this ESMF_GridComp.
- `[grid]` Set the ESMF_Grid associated with the ESMF_GridComp.
- `[config]` Set the configuration information for the ESMF_GridComp from this already created ESMF_Config object. If specified, takes priority over `[configFile]`.
- `[configFile]` Set the configuration filename for this ESMF_GridComp. An ESMF_Config object will be created for this file and attached to the ESMF_GridComp. Superceded by `[config]` if both are specified.
- `[clock]` Set the private clock for this ESMF_GridComp.
- `[rc]` Return code; equals ESMF_SUCCESS if there are no errors.

DESCRIPTION:

Sets or resets information about an ESMF_GridComp. The caller can set individual values by specifying the arguments by name. All the arguments except `gridcomp` are optional to facilitate this.

13.5.9 ESMF_GridCompValidate - Check validity of a GridComp

INTERFACE:

```
subroutine ESMF_GridCompValidate(gridcomp, options, rc)
```

ARGUMENTS:

- `gridcomp`: ESMF_GridComp to validate.
- `[options]` Validation options are not yet supported.
- `[rc]` Return code; equals ESMF_SUCCESS if there are no errors.
13.5.10  ESMF_GridCompWait - Wait for a GridComp to return

INTERFACE:

    subroutine ESMF_GridCompWait(gridcomp, blockingFlag, rc)

ARGUMENTS:

    type(ESMF_GridComp), intent(inout) :: gridcomp
    type (ESMF_BlockingFlag), intent(in), optional :: blockingFlag
    integer, intent(out), optional :: rc

DESCRIPTION:

When executing asynchronously, wait for an ESMF_GridComp to return.

The arguments are:

gridcomp  ESMF_GridComp to wait for.

[blockingFlag] Blocking behavior of this method call. See section 9.1.2 for a list of valid blocking options. Default option is ESMF_VASBLOCKING which blocks PETs and their spawned off threads across each VAS but does not synchronize PETs that run in different VASs.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

13.5.11  ESMF_GridCompIsPetLocal - Inquire if this component is to execute on the calling PET.

INTERFACE:

    recursive function ESMF_GridCompIsPetLocal(gridcomp, rc)

RETURN VALUE:

    logical :: ESMF_GridCompIsPetLocal

ARGUMENTS:

    type(ESMF_GridComp), intent(inout) :: gridcomp
    integer, intent(out), optional :: rc

DESCRIPTION:

Inquire if this ESMF_GridComp object is to execute on the calling PET.

The return value is .true. if the component is to execute on the calling PET, .false. otherwise.

The arguments are:

gridcomp  ESMF_GridComp queried.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

13.6  Class API: SetServices and Related Methods

13.6.1  ESMF_GridCompGetInternalState - Get private data block pointer

INTERFACE:
subroutine ESMF_GridCompGetInternalState(gridcomp, dataPointer, rc)

ARGUMENTS:

type(ESMF_GridComp), intent(inout) :: gridcomp
type(any), pointer, intent(in) :: dataPointer
integer, intent(out) :: rc

DESCRIPTION:

Available to be called by an ESMF_GridComp at any time after ESMF_GridCompSetInternalState has been called. Since init, run, and finalize must be separate subroutines data that they need to share in common can either be module global data, or can be allocated in a private data block and the address of that block can be registered with the framework and retrieved by this call. When running multiple instantiations of an ESMF_GridComp, for example during ensemble runs, it may be simpler to maintain private data specific to each run with private data blocks. A corresponding ESMF_GridCompSetInternalState call sets the data pointer to this block, and this call retrieves the data pointer. Note that the dataPointer argument needs to be a derived type which contains only a pointer of the type of the data block defined by the user. When making this call the pointer needs to be unassociated. When the call returns the pointer will now reference the original data block which was set during the previous call to ESMF_GridCompSetInternalState.

The arguments are:

gridcomp An ESMF_GridComp object.

dataPointer A derived type, containing only an unassociated pointer to the private data block. The framework will fill in the pointer. When this call returns the pointer is set to the same address set during ESMF_GridCompSetInternalState. This level of indirection is needed to reliably set and retrieve the data block no matter which architecture or compiler is used.

rc Return code; equals ESMF_SUCCESS if there are no errors. Note: unlike most other ESMF routines, this argument is not optional because of implementation considerations.

13.6.2 ESMF_GridCompSetEntryPoint - Set name of GridComp subroutines

INTERFACE:

subroutine ESMF_GridCompSetEntryPoint(gridcomp, subroutineType, subroutineName, phase, rc)

ARGUMENTS:

type(ESMF_GridComp), intent(inout) :: gridcomp
character(len=*) intent(in) :: subroutineType
subroutine, intent(in) :: subroutineName
integer, intent(in) :: phase
integer, intent(out) :: rc

DESCRIPTION:

Intended to be called by an ESMF_GridComp during the registration process. An ESMF_GridComp calls ESMF_GridCompSetEntryPoint for each of the predefined init, run, and finalize routines, to associate the internal subroutine to be called for each function. If multiple phases for init, run, or finalize are needed, this can be called with phase numbers. After this subroutine returns, the framework now knows how to call the initialize, run, and finalize routines for this child ESMF_GridComp.

The arguments are:

gridcomp An ESMF_GridComp object.
subroutineType  One of a set of predefined subroutine types - e.g. ESMF_SETINIT, ESMF_SETRUN, ESMF_SETFINAL.

subroutineName  The name of the gridcomp subroutine to be associated with the subroutineType. This subroutine does not have to be public to the module.

phase  For ESMF_GridComps which need to initialize or run or finalize with multiple phases, the phase number which corresponds to this subroutine name. For single phase subroutines use the parameter ESMF_SINGLEPHASE. The ESMF_GridComp writer must document the requirements of the ESMF_GridComp for how and when the multiple phases are expected to be called.

rc  Return code; equals ESMF_SUCCESS if there are no errors. Note: unlike most other ESMF routines, this argument is not optional because of implementation considerations.

13.6.3 ESMF_GridCompSetInternalState - Set private data block pointer

INTERFACE:

    subroutine ESMF_GridCompSetInternalState(gridcomp, dataPointer, rc)

ARGUMENTS:

    type(ESMF_GridComp), intent(inout) :: gridcomp
    type(any), pointer, intent(in) :: dataPointer
    integer, intent(out) :: rc

DESCRIPTION:

Available to be called by an ESMF_GridComp at any time, but expected to be most useful when called during the registration process, or initialization. Since init, run, and finalize must be separate subroutines data that they need to share in common can either be module global data, or can be allocated in a private data block and the address of that block can be registered with the framework and retrieved by subsequent calls. When running multiple instantiations of an ESMF_GridComp, for example during ensemble runs, it may be simpler to maintain private data specific to each run with private data blocks. A corresponding ESMF_GridCompGetInternalState call retrieves the data pointer.

The arguments are:

gridcomp  An ESMF_GridComp object.

dataPointer  A pointer to the private data block, wrapped in a derived type which contains only a pointer to the block. This level of indirection is needed to reliably set and retrieve the data block no matter which architecture or compiler is used.

rc  Return code; equals ESMF_SUCCESS if there are no errors. Note: unlike most other ESMF routines, this argument is not optional because of implementation considerations.

13.6.4 ESMF_GridCompSetServices - Register GridComp interface routines

INTERFACE:

    subroutine ESMF_GridCompSetServices(gridcomp, subroutineName, rc)

ARGUMENTS:
type(ESMF_GridComp) :: gridcomp
subroutine :: subroutineName
integer, intent(out) :: rc

DESCRIPTION:

Call a gridded ESMF_GridComp's setservices registration routine. The parent component must first create an ESMF_GridComp, then call this routine. The arguments are the object returned from the create call, plus the public, well-known subroutine name that is the registration routine for this ESMF_GridComp. This name must be documented by the ESMF_GridComp provider.

After this subroutine returns, the framework now knows how to call the initialize, run, and finalize routines for the ESMF_GridComp.

The arguments are:

gridcomp An ESMF_GridComp object.

subroutineName The public name of the gridcomp's ESMF_GridCompSetServices call. An ESMF_GridComp writer must provide this information. Note that this is the actual subroutine, not a character string.

rc Return code; equals ESMF_SUCCESS if there are no errors. Note: unlike most other ESMF routines, this argument is not optional because of implementation considerations.

14 CplComp Class

14.1 Description

In a large, multi-component application such as a weather forecasting or climate prediction system running within ESMF, physical domains and major system functions are represented as Gridded Components (see Section ??). A Coupler Component, or ESMF_CplComp, arranges and executes the data transformations between the Gridded Components. Ideally, Coupler Components should contain all the information about inter-component communication for an application. This enables the Gridded Components in the application to be used in multiple contexts; that is, used in different coupled configurations without changes to their source code. For example, the same atmosphere might in one case be coupled to an ocean in a hurricane prediction model, and in another coupled to a data assimilation system for numerical weather prediction.

Like Gridded Components, Coupler Components have two parts, one that is provided by the user and another that is part of the framework. The user-written portion of the software is the coupling code necessary for a particular exchange between Gridded Components. The term “user-written” is somewhat misleading here, since within a Coupler Component the user can leverage ESMF infrastructure software for regridding, redistribution, lower-level communications, calendar management, and other functions. However, ESMF is unlikely to offer all the software necessary to customize a data transfer between Gridded Components. ESMF does not currently offer tools for unit transformations or time averaging operations, so users must manage those operations themselves.

The user-written Coupler Component code must be divided into separately callable initialize, run, and finalize methods. The interfaces for these methods are prescribed by ESMF.

The second part of a Coupler Component is the ESMF_CplComp derived type within ESMF. The user must create one of these types to represent a specific coupling function, such as the regular transfer of data between a data assimilation system and an atmospheric model.\footnote{It is not necessary to create a Coupler Component for each individual data transfer.}

The user-written part of a Coupler Component is associated with an ESMF_CplComp derived type through a routine called SetServices. This is a routine that the user must write, and declare public. Inside the SetServices routine the user must call ESMF_SetEntryPoint methods that associate a standard ESMF operation with the name of the corresponding Fortran subroutine in their user code. For example, a user routine called “couplerInit” might be associated with the standard initialize routine in a Coupler Component.

Coupler Components can be written to transform data between a pair of Gridded Components, or a single Coupler Component can couple more than two Gridded Components.

\footnote{It is not necessary to create a Coupler Component for each individual data transfer.}
14.2 Use and Examples

A Coupler Component manages the transformation of data between Components. It contains a list of State objects and the operations needed to make them compatible, including such things as regridding and unit conversion. Coupler Components are user-written, following prescribed ESMF interfaces and, wherever desired, using ESMF infrastructure tools.

! !PROGRAM: ESMF_CplEx.F90 - Coupler Component example
|
! !DESCRIPTION:
|
|    The skeleton of one of many possible Coupler component models.
|
!--------------------------------------------------------------------------------

14.2.1 Specifying a User-Code SetServices Routine

Every ESMF_CplComp is required to provide and document a set services routine. It can have any name, but must follow the declaration below: a subroutine which takes an ESMF_CplComp as the first argument, and an integer return code as the second. Both arguments are required and must not be declared as optional. If an intent is specified in the interface it must be intent(inout) for the first and intent(out) for the second argument.

The set services routine must call the ESMF method ESMF_CplCompSetEntryPoint() to register with the framework what user-code subroutines should be called to initialize, run, and finalize the component. There are additional routines which can be registered as well, for checkpoint and restart functions.

Note that the actual subroutines being registered do not have to be public to this module; only the set services routine itself must be available to be used by other code.

    ! Example Coupler Component
    module ESMF_CouplerEx
        ! ESMF Framework module
        use ESMF_Mod
        implicit none
        public CPL_SetServices
        contains

        subroutine CPL_SetServices(comp, rc)
            type(ESMF_CplComp) :: comp
            integer :: rc

            ! SetServices the callback routines.
            call ESMF_CplCompSetEntryPoint(comp, ESMF_SETINIT, CPL_Init, 0, rc)
            call ESMF_CplCompSetEntryPoint(comp, ESMF_SETRUN, CPL_Run, 0, rc)
            call ESMF_CplCompSetEntryPoint(comp, ESMF_SETFINAL, CPL_Final, 0, rc)

            ! If desired, this routine can register a private data block
            ! to be passed in to the routines above:
            ! call ESMF_CplCompSetInternalState(comp, mydatablock, rc)

            rc = ESMF_SUCCESS
        end subroutine

end module

65
14.2.2 Specifying a User-Code Initialize Routine

When a higher level component is ready to begin using an ESMF_CplComp, it will call its initialize routine. The component writer must supply a subroutine with the exact calling sequence below; no arguments can be optional, and the types and order must match. At initialization time the component can allocate data space, open data files, set up initial conditions; anything it needs to do to prepare to run.

The rc return code should be set if an error occurs, otherwise the value ESMF_SUCCESS should be returned.

```fortran
subroutine CPL_Init(comp, importState, exportState, clock, rc)
  type(ESMF_CplComp) :: comp
  type(ESMF_State) :: importState
  type(ESMF_State) :: exportState
  type(ESMF_Clock) :: clock
  integer :: rc

  print *, "Coupler Init starting"
  ! Add whatever code here needed
  ! Precompute any needed values, fill in any initial values
  ! needed in Import States
  rc = ESMF_SUCCESS
  print *, "Coupler Init returning"
end subroutine CPL_Init
```

14.2.3 Specifying a User-Code Run Routine

During the execution loop, the run routine may be called many times. Each time it should read data from the importState, use the clock to determine what the current time is in the calling component, compute new values or process the data, and produce any output and place it in the exportState.

When a higher level component is ready to use the ESMF_CplComp it will call its run routine. The component writer must supply a subroutine with the exact calling sequence below; no arguments can be optional, and the types and order must match.

It is expected that this is where the bulk of the model computation or data analysis will occur. The rc return code should be set if an error occurs, otherwise the value ESMF_SUCCESS should be returned.

```fortran
subroutine CPL_Run(comp, importState, exportState, clock, rc)
  type(ESMF_CplComp) :: comp
  type(ESMF_State) :: importState
  type(ESMF_State) :: exportState
  type(ESMF_Clock) :: clock
  integer :: rc

  print *, "Coupler Run starting"
  ! Add whatever code needed here to transform Export state data
  ! into Import states for the next timestep.
end subroutine CPL_Run
```
rc = ESMF_SUCCESS
print *, "Coupler Run returning"
end subroutine CPL_Run

14.2.4 Specifying a User-Code Finalize Routine

At the end of application execution, each ESMF_CplComp should deallocate data space, close open files, and flush final results. These functions should be placed in a finalize routine. The rc return code should be set if an error occurs, otherwise the value ESMF_SUCCESS should be returned.

subroutine CPL_Final(comp, importState, exportState, clock, rc)
  type(ESMF_CplComp) :: comp
  type(ESMF_State) :: importState
  type(ESMF_State) :: exportState
  type(ESMF_Clock) :: clock
  integer :: rc

  print *, "Coupler Final starting"
  ! Add whatever code needed here to compute final values and
  ! finish the computation.
  rc = ESMF_SUCCESS
  print *, "Coupler Final returning"
end subroutine CPL_Final

end module ESMF_CouplerEx

! PROGRAM: ESMF_InternalStateEx - Example of using Set/Get Internal State
!
! DESCRIPTION:
! Example of using the Component level Internal State routines.
!
! These include:
! ESMF_GridCompGetInternalState
! ESMF_GridCompSetInternalState
! ESMF_CplCompGetInternalState
! ESMF_CplCompSetInternalState
!
! These routines save the address of an internal, private data block
! during the execution of a Component’s Initialize, Run, or Finalize
! code, and retrieve the address back during a different invocation
! of these routines. See the code below for examples of use.
!-----------------------------------------------------------
! ESMF Framework module
use ESMF_Mod
implicit none

type(ESMF_GridComp) :: compl
integer :: rc, finalrc

! Internal State Variables
type testData
sequence
  integer :: testValue
  real :: testScaling
end type
type dataWrapper
sequence
  type(testData), pointer :: p
end type
type (dataWrapper) :: wrap1, wrap2
type(testData), target :: data1, data2

finalrc = ESMF_SUCCESS
!-------------------------------------------------- -----------------------
call ESMF_Initialize(rc=rc)
if (rc .ne. ESMF_SUCCESS) finalrc = ESMF_FAILURE
!-------------------------------------------------- -----------------------

! ! Creation of a Component
compl = ESMF_GridCompCreate(name="test", rc=rc)
if (rc .ne. ESMF_SUCCESS) finalrc = ESMF_FAILURE

! ! This could be called, for example, during a routine’s initialize phase.
! ! Set Internal State
data1%testValue = 4567
data1%testScaling = 0.5
wrap1%p => data1

call ESMF_GridCompSetInternalState(compl, wrap1, rc)
if (rc .ne. ESMF_SUCCESS) finalrc = ESMF_FAILURE

! ! And this could be called, for example, during a routine’s run phase.
!
! ! Get Internal State
! ! note that we do not assign the pointer inside wrap2 - this call
! ! does that.
call ESMF_GridCompGetInternalState(compl, wrap2, rc)
if (rc .ne. ESMF_SUCCESS) finalrc = ESMF_FAILURE
data2 = wrap2%p
if ((data2%testValue .ne. 4567) .or. (data2%testScaling .ne. 0.5)) then
  print *, "did not get same values back"
  finalrc = ESMF_FAILURE
else
  print *, "got same values back from GetInternalState as original"
endif

14.3 Restrictions and Future Work

1. No Transforms. Components must exchange data through ESMF_State objects. The input data are available at the time the component code is called, and data to be returned to another component are available when that code returns.

2. No automatic unit conversions. The ESMF framework does not currently contain tools for performing unit conversions, operations that are fairly standard within Coupler Components.

3. No accumulator. The ESMF does not have an accumulator tool, to perform time averaging of fields for coupling. This is likely to be developed in the near term.

14.4 Class API: Basic CplComp Methods

14.4.1 ESMF_CplCompCreate - Create a Coupler Component

INTERFACE:

   recursive function ESMF_CplCompCreate(name, config, configFile, &
                        clock, petList, contextflag, parentVm, rc)

RETURN VALUE:

   type(ESMF_CplComp) :: ESMF_CplCompCreate

ARGUMENTS:

   character(len=*) , intent(in), optional :: name
   type(ESMF_Config) , intent(inout), optional :: config
   character(len=*) , intent(in), optional :: configFile
   type(ESMF_Clock) , intent(inout), optional :: clock
   integer , intent(in), optional :: petList(:)
   type(ESMF_ContextFlag) , intent(in), optional :: contextflag
   type(ESMF_VM) , intent(inout), optional :: parentVm
   integer , intent(out), optional :: rc

DESCRIPTION:

Create an ESMF_CplComp object.
The return value is the new ESMF_CplComp.
The arguments are:

[name] Name of the newly-created ESMF_CplComp. This name can be altered from within the ESMF_CplComp code once the initialization routine is called.
[config] An already-created ESMF_Config configuration object from which the new component can read in namelist-type information to set parameters for this run. If both are specified, this object takes priority over configFile.

[configFile] The filename of an ESMF_Config format file. If specified, this file is opened, an ESMF_Config configuration object is created for the file, and attached to the new component. The user can call ESMF_CplCompGet() to get and use the object. If both are specified, the config object takes priority over this one.

[clock] Component-specific ESMF_Clock. This clock is available to be queried and updated by the new ESMF_CplComp as it chooses. This should not be the parent component clock, which should be maintained and passed down to the initialize/run/finalize routines separately.

[petList] List of parent PETs given to the created child component by the parent component. If petList is not specified all of the parent PETs will be given to the child component. The order of PETs in petList determines how the child local PETs refer back to the parent PETs.

[contextflag] Specify the component’s VM context. The default context is ESMF_CHILD_IN_NEW_VM. See section 9.1.3 for a complete list of valid flags.

[parentVm] ESMF_VM object for the current component. This will become the parent ESMF_VM for the newly created ESMF_CplComp object. By default the current VM is determined automatically.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

---

14.4.2 ESMF_CplCompDestroy - Release resources for a CplComp

INTERFACE:

    subroutine ESMF_CplCompDestroy(cplcomp, rc)

ARGUMENTS:

    type(ESMF_CplComp) :: cplcomp
    integer, intent(out), optional :: rc

DESCRIPTION:

Releases all resources associated with this ESMF_CplComp. The arguments are:

[cplcomp] Release all resources associated with this ESMF_CplComp and mark the object as invalid. It is an error to pass this object into any other routines after being destroyed.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

---

14.4.3 ESMF_CplCompFinalize - Call the CplComp’s finalize routine

INTERFACE:

    recursive subroutine ESMF_CplCompFinalize(cplcomp, importState, &
     exportState, clock, phase, blockingflag, rc)

ARGUMENTS:
Call the associated user-supplied finalization routine for an ESMF_CplComp.
The arguments are:

**cplcomp** The ESMF_CplComp to call finalize routine for.

**[importState]** ESMF_State containing import data for coupling. If not present, a dummy argument will be passed to the user-supplied routine. The importState argument in the user code cannot be optional.

**[exportState]** ESMF_State containing export data for coupling. If not present, a dummy argument will be passed to the user-supplied routine. The exportState argument in the user code cannot be optional.

**[clock]** External ESMF_Clock for passing in time information. This is generally the parent component’s clock, and will be treated as read-only by the child component. The child component can maintain a private clock for its own internal time computations. If not present, a dummy argument will be passed to the user-supplied routine. The clock argument in the user code cannot be optional.

**[phase]** Component providers must document whether their each of their routines are single-phase or multi-phase. Single-phase routines require only one invocation to complete their work. Multi-phase routines provide multiple subroutines to accomplish the work, accommodating components which must complete part of their work, return to the caller and allow other processing to occur, and then continue the original operation. For single-phase child components this argument is optional, but if specified it must be ESMF_SINGEPHASE. For multiple-phase child components, this is the integer phase number to be invoked.

**[blockingflag]** Blocking behavior of this method call. See section 9.1.2 for a list of valid blocking options. Default option is ESMF_VASBLOCKING which blocks PETs and their spawned off threads across each VAS but does not synchronize PETs that run in different VASs.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

### 14.4.4 ESMF_CplCompGet - Query a CplComp for information

**INTERFACE:**

```fortran
subroutine ESMF_CplCompGet(cplcomp, name, config, configFile, clock, &
                          vm, contextflag, rc)
```

**ARGUMENTS:**

```fortran
type (ESMF_CplComp), intent (inout) :: cplcomp
character(len=*) , intent (out), optional :: name
type (ESMF_Config) , intent (out), optional :: config
character(len=*) , intent (out), optional :: configFile
type (ESMF_Clock) , intent (out), optional :: clock
type (ESMF_VM) , intent (out), optional :: vm
type (ESMF_ContextFlag) , intent (out), optional :: contextflag
integer , intent (out), optional :: rc
```
DESCRIPTION:

Returns information about an ESMF_CplComp. For queries where the caller only wants a single value, specify the argument by name. All the arguments after cplcomp argument are optional to facilitate this. The arguments are:

**cplcomp** ESMF_CplComp to query.

- **[name]** Return the name of the ESMF_CplComp.
- **[config]** Return the ESMF_Config object for this ESMF_CplComp.
- **[configFile]** Return the configuration filename for this ESMF_CplComp.
- **[clock]** Return the private clock for this ESMF_CplComp.
- **[vm]** Return the ESMF_VM for this ESMF_CplComp.
- **[contextflag]** Return the ESMF_ContextFlag for this ESMF_CplComp. See section 9.1.3 for a complete list of valid flags.
- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

### 14.4.5 ESMF_CplCompInitialize - Call the CplComp’s initialize routine

**INTERFACE:**

```
recursive subroutine ESMF_CplCompInitialize(cplcomp, importState, &, exportState, clock, phase, blockingflag, rc)
```

**ARGUMENTS:**

- type (ESMF_CplComp) :: cplcomp
- type (ESMF_State), intent(inout), optional :: importState
- type (ESMF_State), intent(inout), optional :: exportState
- type (ESMF_Clock), intent(inout), optional :: clock
- integer, intent(in), optional :: phase
- type (ESMF_BlockingFlag), intent(in), optional :: blockingflag
- integer, intent(out), optional :: rc

**DESCRIPTION:**

Call the associated user initialization code for an ESMF_CplComp. The arguments are:

- **cplcomp** ESMF_CplComp to call initialize routine for.
- **[importState]** ESMF_State containing import data for coupling. If not present, a dummy argument will be passed to the user-supplied routine. The importState argument in the user code cannot be optional.
- **[exportState]** ESMF_State containing export data for coupling. If not present, a dummy argument will be passed to the user-supplied routine. The exportState argument in the user code cannot be optional.
- **[clock]** External ESMF_Clock for passing in time information. This is generally the parent component’s clock, and will be treated as read-only by the child component. The child component can maintain a private clock for its own internal time computations. If not present, a dummy argument will be passed to the user-supplied routine. The clock argument in the user code cannot be optional.
[phase] Component providers must document whether their each of their routines are single-phase or multi-phase. Single-phase routines require only one invocation to complete their work. Multi-phase routines provide multiple subroutines to accomplish the work, accommodating components which must complete part of their work, return to the caller and allow other processing to occur, and then continue the original operation. For single-phase child components this argument is optional, but if specified it must be ESMF_SINGLEPHASE. For multiple-phase child components, this is the integer phase number to be invoked.

[blockingflag] Blocking behavior of this method call. See section 9.1.2 for a list of valid blocking options. Default option is ESMF_VASBLOCKING which blocks PETs and their spawned off threads across each VAS but does not synchronize PETs that run in different VASs.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

14.4.6 ESMF_CplCompPrint - Print the contents of a CplComp

INTERFACE:

    subroutine ESMF_CplCompPrint(cplcomp, options, rc)

ARGUMENTS:

    type(ESMF_CplComp) :: cplcomp
    character (len = *), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Prints information about an ESMF_CplComp to stdout.
The arguments are:

cplcomp ESMF_CplComp to print.
[options] Print options are not yet supported.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

14.4.7 ESMF_CplCompRun - Call the CplComp’s run routine

INTERFACE:

    recursive subroutine ESMF_CplCompRun(cplcomp, importState, exportState, &
    clock, phase, blockingflag, rc)

ARGUMENTS:

    type (ESMF_CplComp) :: cplcomp
    type (ESMF_State), intent(inout), optional :: importState
    type (ESMF_State), intent(inout), optional :: exportState
    type (ESMF_Clock), intent(inout), optional :: clock
    integer, intent(in), optional :: phase
    type (ESMF_BlockingFlag), intent(in), optional :: blockingflag
    integer, intent(out), optional :: rc
DESCRIPTION:

Call the associated user run code for an ESMF_CplComp.
The arguments are:

- **cplcomp** ESMF_CplComp to call run routine for.
- **[importState]** ESMF_State containing import data for coupling. If not present, a dummy argument will be passed to the user-supplied routine. The importState argument in the user code cannot be optional.
- **[exportState]** ESMF_State containing export data for coupling. If not present, a dummy argument will be passed to the user-supplied routine. The exportState argument in the user code cannot be optional.
- **[clock]** ESMF_Clock for passing in time information. This is generally the parent component’s clock, and will be treated as read-only by the child component. The child component can maintain a private clock for its own internal time computations. If not present, a dummy argument will be passed to the user-supplied routine. The clock argument in the user code cannot be optional.
- **[phase]** Component providers must document whether their each of their routines are single-phase or multi-phase. Single-phase routines require only one invocation to complete their work. Multi-phase routines provide multiple subroutines to accomplish the work, accommodating components which must complete part of their work, return to the caller and allow other processing to occur, and then continue the original operation. For single-phase child components this argument is optional, but if specified it must be ESMF_SINGLEPHASE. For multiple-phase child components, this is the integer phase number to be invoked. If multiple-phase restore, which phase number this is. Pass in 0 or ESMF_SINGLEPHASE for non-multiples. External clock for passing in time information.
- **[blockingflag]** Blocking behavior of this method call. See section 9.1.2 for a list of valid blocking options. Default option is ESMF_VASBLOCKING which blocks PETs and their spawned off threads across each VAS but does not synchronize PETs that run in different VASs.
- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

14.4.8 ESMF_CplCompSet - Set or reset information about the CplComp

INTERFACE:

```fortran
subroutine ESMF_CplCompSet(cplcomp, name, config, configFile, clock, rc)
```

ARGUMENTS:

- type(ESMF_CplComp), intent(inout) :: cplcomp
- character(len=*) , intent(in), optional :: name
- type(ESMF_Config), intent(inout), optional :: config
- character(len=*) , intent(in), optional :: configFile
- type(ESMF_Clock), intent(inout), optional :: clock
- integer, intent(out), optional :: rc

DESCRIPTION:

Sets or resets information about an ESMF_CplComp. The caller can set individual values by specifying the arguments by name. All the arguments except cplcomp are optional to facilitate this. The arguments are:

- **cplcomp** ESMF_CplComp to change.
- **name** Set the name of the ESMF_CplComp.
Set the configuration information for the ESMF_CplComp from this already created ESMF_Config object. If specified, takes priority over configFile.

Set the configuration filename for this ESMF_CplComp. An ESMF_Config object will be created for this file and attached to the ESMF_CplComp. Superceeded by config if both are specified.

Set the private clock for this ESMF_CplComp.

Return code; equals ESMF_SUCCESS if there are no errors.

14.4.9 ESMF_CplCompValidate – Ensure the CplComp is internally consistent

INTERFACE:

    subroutine ESMF_CplCompValidate(cplcomp, options, rc)

ARGUMENTS:

    type(ESMF_CplComp) :: cplcomp
    character (len = *), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Currently all this method does is to check that the cplcomp exists. The arguments are:

cplcomp  ESMF_CplComp to validate.

[options] Validation options are not yet supported.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

14.4.10 ESMF_CplCompWait - Wait for a CplComp to return

INTERFACE:

    subroutine ESMF_CplCompWait(cplcomp, blockingFlag, rc)

ARGUMENTS:

    type(ESMF_CplComp), intent(inout) :: cplcomp
    type (ESMF_BlockingFlag), intent(in), optional :: blockingFlag
    integer, intent(out), optional :: rc

DESCRIPTION:

When executing asynchronously, wait for an ESMF_CplComp to return. The arguments are:

cplcomp  ESMF_CplComp to wait for.

[blockingFlag] Blocking behavior of this method call. See section 9.1.2 for a list of valid blocking options. Default option is ESMF_VASBLOCKING which blocks PETs and their spawned off threads across each VAS but does not synchronize PETs that run in different VASs.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
14.4.11  ESMF_CplCompIsPetLocal - Inquire if this component is to execute on the calling PET.

INTERFACE:
    recursive function ESMF_CplCompIsPetLocal(cplcomp, rc)

RETURN VALUE:
    logical :: ESMF_CplCompIsPetLocal

ARGUMENTS:
    type(ESMF_CplComp), intent(inout) :: cplcomp
    integer, intent(out), optional :: rc

DESCRIPTION:
Inquire if this ESMF_CplComp object is to execute on the calling PET. The return value is .true. if the component is to execute on the calling PET, .false. otherwise. The arguments are:

- cplcomp  ESMF_CplComp queried.
- [rc]  Return code; equals ESMF_SUCCESS if there are no errors.

14.5  Class API: SetServices and Related Methods

14.5.1  ESMF_CplCompGetInternalState - Get private data block pointer

INTERFACE:
    subroutine ESMF_CplCompGetInternalState(cplcomp, dataPointer, rc)

ARGUMENTS:
    type(ESMF_CplComp), intent(inout) :: cplcomp
    type(any), pointer, intent(in) :: dataPointer
    integer, intent(out) :: rc

DESCRIPTION:
Available to be called by an ESMF_CplComp at any time after ESMF_CplCompSetInternalState has been called. Since init, run, and finalize must be separate subroutines data that they need to share in common can either be module global data, or be allocated in a private data block and the address of that block can be registered with the framework and retrieved by this call. When running multiple instantiations of an ESMF_CplComp, for example during ensemble runs, it may be simpler to maintain private data specific to each run with private data blocks. A corresponding ESMF_CplCompSetInternalState call sets the data pointer to this block, and this call retrieves the data pointer. Note that the dataPointer argument needs to be a derived type which contains only a pointer of the type of the data block defined by the user. When making this call the pointer needs to be unassociated. When the call returns the pointer will now reference the original data block which was set during the previous call to ESMF_CplCompSetInternalState. The arguments are:

- cplcomp  An ESMF_CplComp object.
- dataPointer  A derived type, containing only an unassociated pointer to the private data block. The framework will fill in the pointer. When this call returns the pointer is set to the same address set during ESMF_CplCompSetInternalState. This level of indirection is needed to reliably set and retrieve the data block no matter which architecture or compiler is used.
- rc  Return code; equals ESMF_SUCCESS if there are no errors. Note: unlike most other ESMF routines, this argument is not optional because of implementation considerations.
14.5.2 ESMF_CplCompSetEntryPoint - Set name of CplComp subroutines

INTERFACE:

    subroutine ESMF_CplCompSetEntryPoint(cplcomp, subroutineType, subroutineName, phase, rc)

ARGUMENTS:

    type(ESMF_CplComp), intent(inout) :: cplcomp
    character(len=*), intent(in) :: subroutineType
    subroutine, intent(in) :: subroutineName
    integer, intent(in) :: phase
    integer, intent(out) :: rc

DESCRIPTION:

Intended to be called by an ESMF_CplComp during the registration process. An ESMF_CplComp calls ESMF_CplCompSetEntryPoint for each of the predefined init, run, and finalize routines, to associate the internal subroutine to be called for each function. If multiple phases for init, run, or finalize are needed, this can be called with phase numbers. After this subroutine returns, the framework now knows how to call the initialize, run, and finalize routines for this child ESMF_CplComp.

The arguments are:

- **cplcomp**  An ESMF_CplComp object.
- **subroutineType**  One of a set of predefined subroutine types - e.g. ESMF_SETINIT, ESMF_SETRUN, ESMF_SETFINAL.
- **subroutineName**  The name of the cplcomp subroutine to be associated with the subroutineType. This subroutine does not have to be public to the module.
- **[phase]**  For ESMF_CplComps which need to initialize, run, or finalize with multiple phases, the phase number which corresponds to this subroutine name. For single phase subroutines, either omit this argument, or use the parameter ESMF_SINGLEPHASE. The ESMF_CplComp writer must document the requirements of the ESMF_CplComp for how and when the multiple phases are expected to be called.
- **rc**  Return code; equals ESMF_SUCCESS if there are no errors. Note: unlike most other ESMF routines, this argument is not optional because of implementation considerations.

14.5.3 ESMF_CplCompSetInternalState - Set private data block pointer

INTERFACE:

    subroutine ESMF_CplCompSetInternalState(cplcomp, dataPointer, rc)

ARGUMENTS:

    type(ESMF_CplComp), intent(inout) :: cplcomp
    type(any), pointer, intent(in) :: dataPointer
    integer, intent(out) :: rc

DESCRIPTION:

Available to be called by an ESMF_CplComp at any time, but expected to be most useful when called during the registration process, or initialization. Since init, run, and finalize must be separate subroutines data that they need to share in common can either be module global data, or can be allocated in a private data block and the address of that block can be registered with the framework and retrieved by subsequent calls. When running multiple instantiations of an ESMF_CplComp, for example during ensemble runs, it may be simpler to maintain private data specific to each run with private data blocks. A corresponding ESMF_CplCompGetInternalState call retrieves the data pointer.

The arguments are:
AN ESMF_CplComp object.

dataPointer A pointer to the private data block, wrapped in a derived type which contains only a pointer to the block. This level of indirection is needed to reliably set and retrieve the data block no matter which architecture or compiler is used.

cplcomp An ESMF_CplComp object.

dataPointer A pointer to the private data block, wrapped in a derived type which contains only a pointer to the block. This level of indirection is needed to reliably set and retrieve the data block no matter which architecture or compiler is used.

rc Return code; equals ESMF_SUCCESS if there are no errors. Note: unlike most other ESMF routines, this argument is not optional because of implementation considerations.

14.5.4 ESMF_CplCompSetServices - Register CplComp interface routines

INTERFACE:

    subroutine ESMF_CplCompSetServices(cplcomp, subroutineName, rc)

ARGUMENTS:

    type(ESMF_CplComp), intent(inout) :: cplcomp
    subroutine, intent(in) :: subroutineName
    integer, intent(out) :: rc

DESCRIPTION:

Call an ESMF_CplComp’s setservices registration routine. The parent component must first create an ESMF_CplComp, then call this routine. The arguments are the object returned from the create call, plus the public, well-known, subroutine name that is the registration routine for this ESMF_CplComp. This name must be documented by the ESMF_CplComp provider.

After this subroutine returns the framework now knows how to call the initialize, run, and finalize routines for the ESMF_CplComp.

The arguments are:

    cplcomp An ESMF_CplComp object.

    subroutineName The public name of the cplcomp’s ESMF_CplCompSetServices call. An ESMF_CplComp writer must provide this information. Note this is the actual subroutine, not a character string.

    rc Return code; equals ESMF_SUCCESS if there are no errors. Note: unlike most other ESMF routines, this argument is not optional because of implementation considerations.

15 State Class

15.1 Description

A State contains the data and metadata to be transferred between ESMF components. It is an important class, because it defines a standard for how data is represented in Earth science components. The State construct is a rational compromise between a fully prescribed interface - one that would dictate what specific fields should be transferred between components - and an interface in which data structures are completely ad hoc.

There are two types of States, import and export. An import State contains data that is necessary for a Gridded Component or Coupler Component to execute, and an export State contains the data that a Gridded Component or Coupler Component can make available.

States can contain Bundles, Fields, Arrays, and other States. They cannot directly contain Fortran arrays. Objects in a State must span the VM on which they are running. For sequentially executing components which run on the same set of PETs this happens by calling the object create methods on each PET creating the object in unison. For concurrently executing components which are running on subsets of PETs, an additional method is provided by the ESMF to broadcast information about objects which were created in subcomponents.

State methods include creation and deletion, adding and retrieving data items, adding and retrieving attributes, and performing queries. An additional method, reconciliation, makes objects created on a subset of the current PETs available to all PETs in the current VM.
15.2 State Options

15.2.1 ESMF_StateItemType

DESCRIPTION:
Specifies the type of object being added to or retrieved from an ESMF_State.
Valid values are:

- **ESMF_STATEITEM_BUNDLE** Refers to an ESMF_Bundle within an ESMF_State.
- **ESMF_STATEITEM_FIELD** Refers to an ESMF_Field within an ESMF_State.
- **ESMF_STATEITEM_ARRAY** Refers to an ESMF_Array within an ESMF_State.
- **ESMF_STATEITEM_STATE** Refers to an ESMF_State within an ESMF_State.
- **ESMF_STATEITEM_NAME** Refers to a data name used as a placeholder within an ESMF_State.
- **ESMF_STATEITEM_NOTFOUND** Only valid as a return object type from a query routine. Indicates that no object with this name exists in the ESMF_State.
- **ESMF_STATEITEM_UNKNOWN** Object type within an ESMF_State is unknown.

15.2.2 ESMF_StateType

DESCRIPTION:
Specifies whether an ESMF_State contains data to be imported into a component or exported from a component.
Valid values are:

- **ESMF_STATE_IMPORT** Contains data to be imported into a component.
- **ESMF_STATE_EXPORT** Contains data to be exported out of a component.
- **ESMF_STATE_INVALID** Does not contain valid data.

15.3 Use and Examples

A Gridded Component generally has one associated import State and one export State. Generally the States associated with a Gridded Component will be created by the Gridded Component’s parent component. In many cases, the States will be created containing no data. Both the empty States and the newly created Gridded Component are passed by the parent component into the Gridded Component’s initialize method. This is where the States get prepared for use and the import State is first filled with data.

States can be created without the Fields, Arrays, Bundles, and other States they will eventually contain in a number of ways. They can be created with names as placeholders where these data items will eventually be. When the States are passed into the Gridded Component’s initialize method, Field, Bundle, and Array create calls can be made in that method to replace the name placeholders with real data objects.

States can also be filled with data items that do not yet have data allocated. Fields, Bundles, and Arrays each have methods that support their creation without actual data allocation - the grid and metadata are set up but no Fortran array of data values is allocated. In this approach, when a State is passed into its associated Gridded Component’s initialize method, the incomplete Arrays, Fields, and Bundles within the State can allocate or reference data inside the initialize method.

States are passed through the interfaces of the Gridded and Coupler Components’ run methods in order to carry data between the components. While we expect a Gridded Component’s import State to be filled with data during initialization, its export State will typically be filled over the course of its run method. At the end of a Gridded Component’s run method, the filled export State is passed out through the argument list into a Coupler Component’s run method. We recommend the convention that it enters the Coupler Component as the Coupler Component’s import State. Here is it transformed into a form that another Gridded Component requires, and passed out of the Coupler Component as its export State. It can then be passed into the run method of a recipient Gridded Component as that component’s import State.
While the above sounds complicated, the rule is simple: a State going into a component is an import State, and a State leaving a component is an export State.

Data items within a State can be marked needed or not needed, depending on whether they are required for a particular application configuration. If the item is marked not needed, the user can make the Gridded Component’s initialize method clever enough to not allocate the data for that item at all and not compute it within the Gridded Component code. For example, some diagnostics may not be desired for all runs.

Other flags will eventually be available for data items within a State, such as data ready for reading or writing, data valid or invalid, and data required for restart or not. These are not yet fully implemented, so only the default value for each value can be set at this time.

Objects inside States are normally created in unison where each PET executing a component makes the same object create call. If the object contains data, like a Field, each PET may have a different local chunk of the entire dataset but each Field has the same name and is logically one part of a single distributed object. As States are passed between components if any object in a State was not created in unison on all the current PETs then some PETs have no object to pass into a communication method (e.g. regrid or data redistribution). A State method called reconcile must be called to broadcast information about these objects to all PETs in a component; after which all PETs have a single uniform view of all objects.

If components are running in sequential mode on all available PETs and States are being passed between them there is no need to make the reconcile call since all PETs have a uniform view of the objects. However, if components are running on a subset of the PETs, as is usually the case when running in concurrent mode, then when States are passed into components which contain a superset of those PETs, for example, a Coupler Component, all PETs must call reconcile on the States before using them in any ESMF communication methods. The reconcile process broadcasts metadata information about objects which exist only on a subset of the PETs. On PETs missing those objects it creates a proxy object which contains any attributes of the original object plus enough information for it to be a data source or destination for a regrid or data redistribution operation.

```
! PROGRAM: ESMF_StateEx - State creation and operation

! DESCRIPTION:

! This program shows examples of State creation and manipulation
!-----------------------------------------------------------------------

! ESMF Framework module
use ESMF_Mod
implicit none

! Local variables
integer :: rc
character(ESMF_MAXSTR) :: statename, bundlename, dataname
!type(ESMF_Field) :: field1
!type(ESMF_Bundle) :: bundle1, bundle2
!type(ESMF_State) :: statel, state2, state3

15.3.1 Empty State Create

Creation of an empty ESMF_State, which will be added to later.

    statename = "Atmosphere"
    state1 = ESMF_StateCreate(statename, statetype=ESMF_STATE_IMPORT, rc=rc)

15.3.2 Adding Items to a State

Creation of an empty ESMF_State, and adding an ESMF_Bundle to it. Note that the ESMF_Bundle does not get destroyed when the ESMF_State is destroyed; the ESMF_State only contains a reference to the objects it contains.
```
It also does not make a copy; the original objects can be updated and code accessing them by using the ESMF_State will see the updated version.

```fortran
statename = "Ocean"
state2 = ESMF_StateCreate(statename, statetype=ESMF_STATE_EXPORT, rc=rc)

bundlename = "Temperature"
bundle1 = ESMF_BundleCreate(name=bundlename, rc=rc)
print *, "Bundle Create returned", rc

call ESMF_StateAddBundle(state2, bundle1, rc)
print *, "StateAddBundle returned", rc

call ESMF_StateDestroy(state2, rc)

call ESMF_BundleDestroy(bundle1, rc)
```

15.3.3 Adding Placeholders to a State

If a component could potentially produce a large number of optional items, one strategy is to add the names only of those objects to the ESMF_State. Other components can call framework routines to set the ESMF_NEEDED flag to indicate they require that data. The original component can query this flag and then produce only the data what is required by another component.

```fortran
statename = "Ocean"
state3 = ESMF_StateCreate(statename, statetype=ESMF_STATE_EXPORT, rc=rc)

dataname = "Downward wind"
call ESMF_StateAddNameOnly(state3, dataname, rc)

dataname = "Humidity"
call ESMF_StateAddNameOnly(state3, dataname, rc)
```

15.3.4 Marking an Item Needed

How to set the NEEDED state of an item.

```fortran
dataname = "Downward wind"
call ESMF_StateSetNeeded(state3, dataname, ESMF_NEEDED, rc)
```

15.3.5 Creating a Needed Item

Query an item for the NEEDED status, and creating an item on demand. Similar flags exist for "Ready", "Valid", and "Required for Restart", to mark each data item as ready, having been validated, or needed if the application is to be checkpointed and restarted. The flags are supported to help coordinate the data exchange between components.

```fortran
dataname = "Downward wind"
if (ESMF_StateIsNeeded(state3, dataname, rc)) then
```
bundle2 = ESMF_BundleCreate(name=bundlename, rc=rc)

call ESMF_StateAddBundle(state3, bundle2, rc)

else
    print *, "Data not marked as needed", trim(dataname)
endif

15.3.6 Initialization and SetServices Routines

These are the separate subroutines called by the code above.

! Initialize routine which creates "field1" on PETs 0 and 1
subroutine comp1_init(gcomp, istate, ostate, clock, rc)
    use ESMF_Mod
    type(ESMF_GridComp), intent(inout) :: gcomp
    type(ESMF_State), intent(inout) :: istate, ostate
    type(ESMF_Clock), intent(in) :: clock
    integer, intent(out) :: rc

type(ESMF_Field) :: field1
integer :: localrc

print *, "i am comp1_init"

field1 = ESMF_FieldCreateNoData(name="Comp1 Field", rc=localrc)
call ESMF_StateAddField(istate, field1, rc=localrc)
rc = localrc
end subroutine comp1_init

! Initialize routine which creates "field2" on PETs 2 and 3
subroutine comp2_init(gcomp, istate, ostate, clock, rc)
    use ESMF_Mod
    type(ESMF_GridComp), intent(inout) :: gcomp
    type(ESMF_State), intent(inout) :: istate, ostate
    type(ESMF_Clock), intent(in) :: clock
    integer, intent(out) :: rc

type(ESMF_Field) :: field2
integer :: localrc

print *, "i am comp2_init"

field2 = ESMF_FieldCreateNoData(name="Comp2 Field", rc=localrc)
call ESMF_StateAddField(istate, field2, rc=localrc)
rc = localrc
end subroutine comp2_init

subroutine comp_dummy(gcomp, rc)
  use ESMF_Mod
  type(ESMF_GridComp), intent(inout) :: gcomp
  integer, intent(out) :: rc
  rc = ESMF_SUCCESS
end subroutine comp_dummy

! !PROGRAM: ESMF_StateReconcileEx - State reconciliation
! !DESCRIPTION:
! ! This program shows examples of using the State Reconcile function
!--------------------------------------------------------------------------

! ESMF Framework module
use ESMF_Mod
use ESMF_StateReconcileEx_Mod
implicit none

! Local variables
  integer :: rc, petCount
  type(ESMF_State) :: state1
  type(ESMF_GridComp) :: comp1, comp2
  type(ESMF_VM) :: vm
  character(len=ESMF_MAXSTR) :: comp1name, comp2name, statename

15.3.7 Creating Components on subsets of the current PET list

A Component can be created which will run only on a subset of the current PET list.

! Get the global VM for this job.
call ESMF_VMGetGlobal(vm=vm, rc=rc)

comp1name = "Atmosphere"
comp1 = ESMF_GridCompCreate(name=comp1name, petList=(/ 0, 1 /), rc=rc)
print *, "GridComp Create returned, name = ", trim(comp1name)

comp2name = "Ocean"
comp2 = ESMF_GridCompCreate(name=comp2name, petList=(/ 2, 3 /), rc=rc)
print *, "GridComp Create returned, name = ", trim(comp2name)

statename = "Ocn2Atm"
state1 = ESMF_StateCreate(statename, rc=rc)

15.3.8 Invoking Components on a subset of the Parent PETs

Here we register the subroutines which should be called for initialization. Then we call ESMF_GridCompInitialize() on all PETs, but the code runs only on the PETs given in the petList when the Component was created.
Because this example is so short, we call the entry point code directly instead of the normal procedure of nesting it in a separate SetServices() subroutine.

! This is where the VM for each component is initialized.
! Normally you would call SetEntryPoint inside set services,
! but to make this example very short, they are called inline below.
! This is o.k. because the SetServices routine must execute from within
! the parent component VM.
call ESMF_GridCompSetServices(comp1, comp_dummy, rc)
call ESMF_GridCompSetServices(comp2, comp_dummy, rc)

print *, "ready to set entry point 1"
call ESMF_GridCompSetEntryPoint(comp1, ESMF_SETINIT, &
    comp1_init, ESMF_SINGLEPHASE, rc)

print *, "ready to set entry point 2"
call ESMF_GridCompSetEntryPoint(comp2, ESMF_SETINIT, &
    comp2_init, ESMF_SINGLEPHASE, rc)

print *, "ready to call init for comp 1"
call ESMF_GridCompInitialize(comp1, state1, rc=rc)
print *, "ready to call init for comp 2"
call ESMF_GridCompInitialize(comp2, state1, rc=rc)

15.3.9 Using State Reconcile

Now we have state1 containing field1 on PETs 0 and 1, and state1 containing field2 on PETs 2 and 3. For the code to have a rational view of the data, we call ESMF_StateReconcile which determines which objects are missing from any PET, and communicates information about the object. After the call to reconcile, all ESMF_State objects now have a consistent view of the data.

print *, "State before calling StateReconcile()"
call ESMF_StatePrint(state1, rc=rc)
call ESMF_StateReconcile(state1, vm, rc=rc)
print *, "State after calling StateReconcile()"
call ESMF_StatePrint(state1, rc=rc)

end program ESMF_StateReconcileEx

15.4 Restrictions and Future Work

1. Flags not fully implemented. The flags for indicating various qualities associated with data items in a State - validity, whether or not the item is required for restart, read/write status - are not fully implemented. Although their defaults can be set, the associated methods for setting and getting these flags have not been implemented. (The needed flag is fully supported.)

2. No synchronization at object create time. Object IDs are using during the reconcile process to identify objects which are unknown to some subset of the PETs in the currently running VM. Object IDs are assigned in sequential order at object create time. User input at design time requested there be no communication overhead during the create of an object, so there is no opportunity to synchronize IDs if one or more PETs create objects which are not in unison (not all PETs in the VM make the same calls).
Even if the user follows the unison rules, if components are running on a subset of the PETs, when they return to the parent (calling) component the next available ID will potentially not be the same across all PETs in the VM. Part of the reconcile process or part of the return to the parent will need to have a broadcast which sends the current ID number, and all PETs can reset the next available number to the highest number broadcast. This could be an async call to avoid as much as possible serialization and barrier issues.

Default object names are based on the object id (e.g. "Field1", "Field2") to create unique object names, so basing the detection of unique objects on the name instead of on the object id is no better solution.

15.5 Design and Implementation Notes

1. States contain the name of the associated Component, a flag for Import or Export, and a list of data objects, which can be a combination of Bundles, Fields, and/or Arrays. The objects must be named and have the proper attributes so they can be identified by the receiver of the data. For example, units and other detailed information may need to be associated with the data as an Attribute.

2. Data contained in States must be created in unison on each PET of the current VM. This allows the creation process to avoid doing communications since each PET can compute any information it needs to know about any remote PET (for example, the grid distribute method can compute the decomposition of the grid on not only the local PET but also the remote PETs since it knows each PET is making the identical call). For all PETs to have a consistent view of the data this means objects must be given unique names when created, or all objects must be created in the same order on all PETs so ESMF can generate consistent default names for the objects. When running components on subsets of the original VM all the PETs can create consistent objects but then when they are put into a State and passed to a component with a different VM and a different set of PETs, a communication call (reconcile) must be made to communicate the missing information to the PETs which were not involved in the original object creation. The reconcile call broadcasts object lists; those PETs which are missing any objects in the total list can receive enough information to reconstruct a proxy object which contains all necessary information about that object, with no local data, on that PET. These proxy objects can be queried by ESMF routines to determine the amount of data and what PETs contain data which is destined to be moved to the local PET (for receiving data) and conversely, can determine which other PETs are going to receive data and how much (for sending data).

For example, the FieldExcl system test creates 2 gridded components on separate subsets of PETs. They use the option of mapping particular, non-monotonic PETs to DEs. The following figures illustrate how the DEs are mapped in each of the gridded components in that test:
In the coupler code, all PETs must make the reconcile call before accessing data in the State. On PETs which already contain data, the objects are unchanged. On PETs which were not involved during the creation of the Bundles or Fields, the reconcile call adds an object to the State which contains all the same metadata associated with the object, but creates a slightly different Grid object, called a Proxy Grid. These PETs contain no local data, so the Array object is empty, and the DELayout for the Grid is like this:
Figure 10: The mapping of PETs (processors) to DEs (data) in the destination grid after the reconcile call in user_coupler.F90 in the FieldExcl system test.

15.6 Object Model

The following is a simplified UML diagram showing the structure of the State class. See Appendix A, *A Brief Introduction to UML*, for a translation table that lists the symbols in the diagram and their meaning.

15.7 Class API: Basic State Methods

15.7.1 ESMF_StateAddInternArray - Add an InternArray to a State

**INTERFACE:**

```fortran
! Private name; call using ESMF_StateAddInternArray()
subroutine ESMF_StateAddOneInternArray(state, array, rc)

ARGUMENTS:

type(ESMF_State), intent(inout) :: state
type(ESMF_InternArray), intent(in) :: array
integer, intent(out), optional :: rc
```
DESCRIPTION:

Add a single array reference to an existing state. The array name must be unique within the state. The arguments are:

state  An ESMF_State object.
array  The ESMF_InternArray to be added. This is a reference only; when the ESMF_State is destroyed the objects contained in it will not be destroyed. Also, the ESMF_InternArray cannot be safely destroyed before the ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user’s responsibility to manage the destruction of objects when they are no longer in use.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

15.7.2  ESMF_StateAddInternArray - Add a list of InternArrays to a State

INTERFACE:

! Private name; call using ESMF_StateAddInternArray()
subroutine ESMF_StateAddInternArrayList(state, arrayCount, arrayList, rc)

ARGUMENTS:

type(ESMF_State), intent(inout) :: state
integer, intent(in) :: arrayCount
type(ESMF_InternArray), dimension(:), intent(in) :: arrayList
integer, intent(out), optional :: rc

DESCRIPTION:

Add multiple ESMF_InternArrays to an ESMF_State. The arguments are:

state  An ESMF_State object.
arrayCount  The number of ESMF_InternArrays to be added.
arrayList  The list (Fortran array) of ESMF_InternArrays to be added. This is a reference only; when the ESMF_State is destroyed the objects contained in it will not be destroyed. Also, the ESMF_InternArrays cannot be safely destroyed before the ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user’s responsibility to manage the destruction of objects when they are no longer in use.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

15.7.3  ESMF_StateAddArray - Add an Array to a State

INTERFACE:

! Private name; call using ESMF_StateAddArray()
subroutine ESMF_StateAddOneArray(state, array, rc)

ARGUMENTS:
**15.7.4 ESMF_StateAddArray - Add a list of Arrays to a State**

**INTERFACE:**

```fortran
! Private name; call using ESMF_StateAddArray()
subroutine ESMF_StateAddArrayList(state, arrayCount, arrayList, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_State), intent(inout) :: state
type(ESMF_Array), dimension(:), intent(in) :: arrayList
type(ESMF_Array), intent(out), optional :: rc
```

**DESCRIPTION:**

Add multiple ESMF_Arrays to an ESMF_State.

The arguments are:

- `state` An ESMF_State object.
- `arrayCount` The number of ESMF_Arrays to be added.
- `arrayList` The list (Fortran array) of ESMF_Arrays to be added. This is a reference only; when the ESMF_State is destroyed the objects contained in it will not be destroyed. Also, the ESMF_Arrays cannot be safely destroyed before the ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user’s responsibility to manage the destruction of objects when they are no longer in use.

- `[rc]` Return code; equals ESMF_SUCCESS if there are no errors.

**15.7.5 ESMF_StateAddBundle - Add a Bundle to a State**

**INTERFACE:**

```fortran
! Private name; call using ESMF_StateAddBundle()
subroutine ESMF_StateAddOneBundle(state, bundle, rc)
```

**DESCRIPTION:**

Add a single array reference to an existing state. The array name must be unique within the state. The arguments are:

- `state` An ESMF_State object.
- `array` The ESMF_Array to be added. This is a reference only; when the ESMF_State is destroyed the objects contained in it will not be destroyed. Also, the ESMF_Array cannot be safely destroyed before the ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user’s responsibility to manage the destruction of objects when they are no longer in use.

- `[rc]` Return code; equals ESMF_SUCCESS if there are no errors.
ARGUMENTS:

```
type(ESMF_State), intent(inout) :: state
type(ESMF_Bundle), intent(in) :: bundle
integer, intent(out), optional :: rc
```

DESCRIPTION:

Add a single bundle reference to an existing state. The bundle name must be unique within the state. The arguments are:

- **state** The ESMF_State object.
- **bundle** The ESMF_Bundle to be added. This is a reference only; when the ESMF_State is destroyed the objects contained in it will not be destroyed. Also, the ESMF_Bundle cannot be safely destroyed before the ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user's responsibility to manage the destruction of objects when they are no longer in use.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

---

### 15.7.6 ESMF_StateAddBundle - Add a list of Bundles to a State

INTERFACE:

```
! Private name; call using ESMF_StateAddBundle()
subroutine ESMF_StateAddBundleList(state, bundleCount, bundleList, rc)
```

ARGUMENTS:

```
type(ESMF_State), intent(inout) :: state
integer, intent(in) :: bundleCount
type(ESMF_Bundle), dimension(:), intent(inout) :: bundleList
integer, intent(out), optional :: rc
```

DESCRIPTION:

Add multiple ESMF_Bundles to an ESMF_State. The arguments are:

- **state** An ESMF_State object.
- **bundleCount** The number of ESMF_Bundles to be added.
- **bundleList** The list (Fortran array) of ESMF_Bundles to be added. This is a reference only; when the ESMF_State is destroyed the objects contained in it will not be destroyed. Also, the ESMF_Bundles cannot be safely destroyed before the ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user's responsibility to manage the destruction of objects when they are no longer in use.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
15.7.7 ESMF_StateAddField - Add a Field to a State

INTERFACE:

    ! Private name; call using ESMF_StateAddField()
    subroutine ESMF_StateAddOneField(state, field, rc)

ARGUMENTS:

    type(ESMF_State), intent(inout) :: state
    type(ESMF_Field), intent(in) :: field
    integer, intent(out), optional :: rc

DESCRIPTION:

Add a single field reference to an existing state. The field name must be unique within the state. The arguments are:

state  An ESMF_State object.

field  The ESMF_Field to be added. This is a reference only; when the ESMF_State is destroyed the objects contained in it will not be destroyed. Also, the ESMF_Field cannot be safely destroyed before the ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user's responsibility to manage the destruction of objects when they are no longer in use.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

15.7.8 ESMF_StateAddField - Add a list of Fields to a State

INTERFACE:

    ! Private name; call using ESMF_StateAddField()
    subroutine ESMF_StateAddFieldList(state, fieldCount, fieldList, rc)

ARGUMENTS:

    type(ESMF_State), intent(inout) :: state
    integer, intent(in) :: fieldCount
    type(ESMF_Field), dimension(:), intent(inout) :: fieldList
    integer, intent(out), optional :: rc

DESCRIPTION:

Add multiple ESMF_Fields to an ESMF_State. The arguments are:

state  An ESMF_State object.

fieldCount  The number of ESMF_Fields to be added.

fieldList  The list (Fortran array) of ESMF_Fields to be added. This is a reference only; when the ESMF_State is destroyed the objects contained in it will not be destroyed. Also, the ESMF_Fields cannot be safely destroyed before the ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user's responsibility to manage the destruction of objects when they are no longer in use.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
15.7.9 ESMF_StateAddNameOnly - Add a name to a State as a placeholder

INTERFACE:

    ! Private name; call using ESMF_StateAddNameOnly()
    subroutine ESMF_StateAddOneName(state, name, rc)

ARGUMENTS:

    type(ESMF_State), intent(inout) :: state
    character (len=*) , intent(in) :: name
    integer, intent(out), optional :: rc

DESCRIPTION:

Add the character string name to an existing state. It can subsequently be replaced by an actual object with the same name. The name must be unique within the state. It is available to be marked needed by the consumer of the export ESMF_State. Then the data provider can replace the name with the actual ESMF_Bundle, ESMF_Field, or ESMF_Array which carries the needed data.

The arguments are:

state  An ESMF_State object.
name   The name to be added as a placeholder for a data object.
rc     Return code; equals ESMF_SUCCESS if there are no errors.

15.7.10 ESMF_StateAddNameList - Add a list of names to a State

INTERFACE:

    ! Private name; call using ESMF_StateAddNameList()
    subroutine ESMF_StateAddNameList(state, nameCount, nameList, rc)

ARGUMENTS:

    type(ESMF_State), intent(inout) :: state
    integer, intent(in) :: nameCount
    character (len=*) , intent(in) :: nameList(:)
    integer, intent(out), optional :: rc

DESCRIPTION:

Add a list of names to an existing state. They can subsequently be replaced by actual objects with the same name. Each name in the nameList must be unique within the state. It is available to be marked needed by the consumer of the export ESMF_State. Then the data provider can replace the name with the actual ESMF_Bundle, ESMF_Field, or ESMF_Array which carries the needed data. Unneeded data need not be generated.

The arguments are:

state  An ESMF_State object.
nameCount The count of names in the nameList.
nameList  A list (Fortran array) of character strings to be added as placeholders for data objects.
rc     Return code; equals ESMF_SUCCESS if there are no errors.
15.7.11  ESMF_StateAddState - Add a State to a State

INTERFACE:

    ! Private name; call using ESMF_StateAddState()
    subroutine ESMF_StateAddOneState(state, nestedState, rc)

ARGUMENTS:

    type(ESMF_State), intent(inout) :: state
    type(ESMF_State), intent(in) :: nestedState
    integer, intent(out), optional :: rc

DESCRIPTION:

Add a nestedState reference to an existing state. The nestedState name must be unique within the container state.

The arguments are:

state  An ESMF_State object. This is the container object.

nestedState  The ESMF_State to be added. This is the nested object. This is a reference only; when the ESMF_State is destroyed the objects contained in it will not be destroyed. Also, nested ESMF_States cannot be safely destroyed before the container ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user’s responsibility to manage the destruction of objects when they are no longer in use.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

---

15.7.12  ESMF_StateAddState - Add a list of States to a State

INTERFACE:

    ! Private name; call using ESMF_StateAddState()
    subroutine ESMF_StateAddStateList(state, nestedStateCount, nestedStateList, rc)

ARGUMENTS:

    type(ESMF_State), intent(inout) :: state
    integer, intent(in) :: nestedStateCount
    type(ESMF_State), dimension(:), intent(in) :: nestedStateList
    integer, intent(out), optional :: rc

DESCRIPTION:

Add multiple nested ESMF_States to a container ESMF_State. The nested ESMF_State names must be unique within the container ESMF_State.

The arguments are:

state  An ESMF_State object. This is the container object.

nestedStateCount  The number of ESMF_States to be added.

nestedStateList  The list (Fortran array) of ESMF_States to be added. This is a reference only; when the container state is destroyed the objects contained in it will not be destroyed. Also, the nestedStateList cannot be safely destroyed before the container state is destroyed. Since objects can be added to multiple containers, it remains the user’s responsibility to manage the destruction of objects when they are no longer in use.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
15.7.13 ESMF_StateCreate - Create a new State

INTERFACE:

    function ESMF_StateCreate(stateName, statetype, &
        bundleList, fieldList, arrayList, nestedStateList, &
        nameList, itemCount, &
        neededflag, readyflag, validflag, reqforrestartflag, rc)

RETURN VALUE:

    type(ESMF_State) :: ESMF_StateCreate

ARGUMENTS:

    character(len=*), intent(in), optional :: stateName
    type(ESMF_StateType), intent(in), optional :: statetype
    type(ESMF_Bundle), dimension(:), intent(inout), optional :: bundleList
    type(ESMF_Field), dimension(:), intent(inout), optional :: fieldList
    type(ESMF_InternArray), dimension(:), intent(in), optional :: arrayList
    type(ESMF_State), dimension(:), intent(in), optional :: nestedStateList
    character(len=*), dimension(:), intent(in), optional :: nameList
    integer, intent(in), optional :: itemCount
    type(ESMF_NeededFlag), optional :: neededflag
    type(ESMF_ReadyFlag), optional :: readyflag
    type(ESMF_ValidFlag), optional :: validflag
    type(ESMF_ReqForRestartFlag), optional :: reqforrestartflag
    integer, intent(out), optional :: rc

DESCRIPTION:

Create a new ESMF_State, set default characteristics for objects added to it, and optionally add initial objects to it. The arguments are:

[stateName] Name of this ESMF_State object. A default name will be generated if none is specified.

[statetype] Import or Export ESMF_State. Valid values are ESMF_STATE_IMPORT, ESMF_STATE_EXPORT, or ESMF_STATE_UNSPECIFIED. The default is ESMF_STATE_UNSPECIFIED.

[bundleList] A list (Fortran array) of ESMF_Bundles.

[fieldList] A list (Fortran array) of ESMF_Fields.

[arrayList] A list (Fortran array) of ESMF_Arrays.

[nestedStateList] A list (Fortran array) of ESMF_States to be nested inside the outer ESMF_State.

[nameList] A list (Fortran array) of character string name placeholders.

[itemCount] The total number of things – Bundles, Fields, Arrays, States, and Names – to be added. If itemCount is not specified, it will be computed internally based on the length of each object list. If itemCount is specified this routine will do an error check to verify the total number of items found in the argument lists matches this count of the expected number of items.

[neededflag] Set the default value for new items added to an ESMF_State. Possible values are listed in Section 9.1.7. If not specified, the default value is set to ESMF_NEEDED.

[readyflag] Set the default value for new items added to an ESMF_State. Possible values are listed in Section 9.1.8. If not specified, the default value is set to ESMF_READYTOREAD.
Set the default value for new items added to an ESMF_State. Possible values are listed in Section 9.1.11. If not specified, the default value is set to ESMF_VALID.

Set the default value for new items added to an ESMF_State. Possible values are listed in Section 9.1.10. If not specified, the default value is set to ESMF_REQUIRED_FOR_RESTART.

Return code; equals ESMF_SUCCESS if there are no errors.

15.7.14 ESMF_StateDestroy - Release resources for a State

INTERFACE:

subroutine ESMF_StateDestroy(state, rc)

ARGUMENTS:

type(ESMF_State) :: state
integer, intent(out), optional :: rc

DESCRIPTION:

Releases all resources associated with this ESMF_State. ESMF_States contain references only to other objects; when the ESMF_State is destroyed objects contained in it will not be destroyed. Objects inside a ESMF_State cannot be destroyed before the container ESMF_State is destroyed. Since objects can be added to multiple containers, it remains the user’s responsibility to manage the destruction of objects when they are no longer in use.

The arguments are:

state Destroy contents of this ESMF_State.

rc Return code; equals ESMF_SUCCESS if there are no errors.

15.7.15 ESMF_StateGet - Get information about a State

INTERFACE:

subroutine ESMF_StateGet(state, name, statetype, itemCount, &
itemNameList, stateitemtypeList, rc)

ARGUMENTS:

type(ESMF_State), intent(in) :: state
character (len=*) , intent(out), optional :: name
type(ESMF_StateType), intent(out), optional :: statetype
integer, intent(out), optional :: itemCount
character (len=*) , intent(out), optional :: itemNameList(:)
type(ESMF_StateItemType), intent(out), optional :: stateitemtypeList(:)
integer, intent(out), optional :: rc

DESCRIPTION:

Returns the requested information about this ESMF_State.

The arguments are:
state  An ESMF_State object to be queried.

[name]  Name of this ESMF_State.

[statetype]  Import or Export ESMF_State. Possible values are listed in Section 15.2.2.

[itemCount]  Count of items in state, including all objects as well as placeholder names.

[itemNameList]  Array of item names in state, including placeholder names. itemNameList must be at least itemCount long.

[stateitemtypeList]  Array of possible item object types in state, including placeholder names. Must be at least itemCount long. Options are listed in Section 15.2.1.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

---

15.7.16  ESMF_StateGetInternArray - Retrieve a data InternArray from a State

INTERFACE:

    subroutine ESMF_StateGetInternArray(state, arrayName, array, nestedStateName, rc)

ARGUMENTS:

    type(ESMF_State), intent(in) :: state
    character (len=*) , intent(in) :: arrayName
    type(ESMF_InternArray) , intent(out) :: array
    character (len=*) , intent(in), optional :: nestedStateName
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns an ESMF_InternArray from an ESMF_State by name. If the ESMF_State contains the object directly, only arrayName is required. If the state contains multiple nested ESMF_States and the object is one level down, this routine can return the object in a single call by specifying the proper nestedStateName. ESMF_States can be nested to any depth, but this routine only searches in immediate descendents. It is an error to specify a nestedStateName if the state contains no nested ESMF_States.

The arguments are:

state  State to query for an ESMF_InternArray named arrayName.

arrayName  Name of ESMF_InternArray to be returned.

array  Returned reference to the ESMF_InternArray.

[nestedStateName]  Optional. An error if specified when the state argument contains no nested ESMF_States.

Required if the state contains multiple nested ESMF_States and the object being requested is in one level down in one of the nested ESMF_State. ESMF_State must be selected by this nestedStateName.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
15.7.17  ESMF_StateGetArray - Retrieve an Array from a State

INTERFACE:

subroutine ESMF_StateGetArray(state, arrayName, array, nestedStateName, rc)

ARGUMENTS:

type(ESMF_State), intent(in) :: state
character (len=*), intent(in) :: arrayName
type(ESMF_Array), intent(out) :: array
character (len=*), intent(in), optional :: nestedStateName
integer, intent(out), optional :: rc

DESCRIPTION:

Returns an ESMF_Array from an ESMF_State by name. If the ESMF_State contains the object directly, only arrayName is required. If the state contains multiple nested ESMF_States and the object is one level down, this routine can return the object in a single call by specifying the proper nestedStateName. ESMF_States can be nested to any depth, but this routine only searches in immediate descendents. It is an error to specify a nestedStateName if the state contains no nested ESMF_States.

The arguments are:

state  State to query for an ESMF_Array named arrayName.
arrayName  Name of ESMF_Array to be returned.
array  Returned reference to the ESMF_Array.
[nestedStateName]  Optional. An error if specified when the state argument contains no nested ESMF_States. Required if the state contains multiple nested ESMF_States and the object being requested is in one level down in one of the nested ESMF_State. ESMF_State must be selected by this nestedStateName.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

15.7.18  ESMF_StateGetAttribute - Retrieve an attribute

INTERFACE:

subroutine ESMF_StateGetAttribute(state, name, <value argument>, rc)

ARGUMENTS:

type(ESMF_State), intent(in) :: state
character (len = *), intent(in) :: name
<value argument>, see below for supported values
integer, intent(out), optional :: rc

DESCRIPTION:

Returns an attribute from the state. Supported values for <value argument> are:

integer(ESMF_KIND_I4), intent(out) :: value
integer(ESMF_KIND_I4), dimension(:), intent(out) :: valueList
The arguments are:

**state**  An `ESMF_State` object.

**name**  The name of the attribute to retrieve.

**<value argument>**  The value of the named attribute.

**[rc]**  Return code; equals `ESMF_SUCCESS` if there are no errors.

---

### 15.7.19 ESMF_StateGetAttributeCount - Query the number of attributes

**INTERFACE:**

```fortran
subroutine ESMF_StateGetAttributeCount(state, count, rc)
```

**ARGUMENTS:**

- `type(ESMF_State), intent(in) :: state`
- `integer, intent(out) :: count`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Returns the number of attributes associated with the given `state` in the argument `count`.

The arguments are:

**state**  An `ESMF_State` object.

**count**  The number of attributes associated with this object.

**[rc]**  Return code; equals `ESMF_SUCCESS` if there are no errors.
15.7.20 ESMF_StateGetAttributeInfo - Query State attributes by name

INTERFACE:

! Private name; call using ESMF_StateGetAttributeInfo()
subroutine ESMF_StateGetAttrInfoByName(state, name, datatype, &
datakind, count, rc)

ARGUMENTS:

type(ESMF_State), intent(in) :: state
character(len=*), intent(in) :: name
type(ESMF_DataType), intent(out), optional :: datatype
type(ESMF_DataKind), intent(out), optional :: datakind
integer, intent(out), optional :: count
integer, intent(out), optional :: rc

DESCRIPTION:

Returns information associated with the named attribute, including datatype, datakind (if applicable), and item count.

The arguments are:

state An ESMF_State object.
name The name of the attribute to query.

[datatype] The data type of the attribute. One of the values ESMF_DATA_INTEGER, ESMF_DATA_REAL, ESMF_DATA_LOGICAL, or ESMF_DATA_CHARACTER.

[datakind] The datakind of the attribute, if attribute is type ESMF_DATA_INTEGER or ESMF_DATA_REAL. One of the values ESMF_I4, ESMF_I8, ESMF_R4, or ESMF_R8. For all other types the value ESMF_NOKIND is returned.

[count] The number of items in this attribute. For character types, the length of the character string.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

15.7.21 ESMF_StateGetAttributeInfo - Query State attributes by index number

INTERFACE:

! Private name; call using ESMF_StateGetAttributeInfo()
subroutine ESMF_StateGetAttrInfoByNum(state, attributeIndex, name, &
datatype, datakind, count, rc)

ARGUMENTS:

type(ESMF_State), intent(in) :: state
integer, intent(in) :: attributeIndex
character(len=*), intent(out), optional :: name
type(ESMF_DataType), intent(out), optional :: datatype
type(ESMF_DataKind), intent(out), optional :: datakind
integer, intent(out), optional :: count
integer, intent(out), optional :: rc
DESCRIPTION:

Returns information associated with the indexed attribute, including datatype, datakind (if applicable), and item count.

The arguments are:

state  An ESMF_State object.

attributeIndex  The index number of the attribute to query.

name  Returns the name of the attribute.

[datatype]  The data type of the attribute. One of the values ESMF_DATA_INTEGER, ESMF_DATA_REAL, ESMF_DATA_LOGICAL, or ESMF_DATA_CHARACTER.

[datakind]  The datakind of the attribute, if attribute is type ESMF_DATA_INTEGER or ESMF_DATA_REAL. One of the values ESMF_I4, ESMF_I8, ESMF_R4, or ESMF_R8. For all other types the value ESMF_NOKIND is returned.

[count]  Returns the number of items in this attribute. For character types, this is the length of the character string.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

15.7.22  ESMF_StateGetBundle - Retrieve a Bundle from a State

INTERFACE:

subroutine ESMF_StateGetBundle(state, bundleName, bundle, &
                               nestedStateName, rc)

ARGUMENTS:

type(ESMF_State), intent(in) :: state
character (len=*), intent(in) :: bundleName
type(ESMF_Bundle), intent(out) :: bundle
character (len=*), intent(in), optional :: nestedStateName
integer, intent(out), optional :: rc

DESCRIPTION:

Returns an ESMF_Bundle from an ESMF_State by name. If the ESMF_State contains the object directly, only bundleName is required. If the state contains multiple nested ESMF_States and the object is one level down, this routine can return the object in a single call by specifying the proper nestedStateName. ESMF_States can be nested to any depth, but this routine only searches in immediate descendents. It is an error to specify a nestedStateName if the state contains no nested ESMF_States.

The arguments are:

state  State to query for a ESMF_Bundle named bundleName.

bundleName  Name of ESMF_Bundle to be returned.

bundle  Returned reference to the ESMF_Bundle.

[nestedStateName]  Optional. An error if specified when the state argument contains no nested ESMF_States. Required if the state contains multiple nested ESMF_States and the object being requested is in one level down in one of the nested ESMF_State. ESMF_State must be selected by this nestedStateName.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
15.7.23  ESMF_StateGetField - Retrieve a Field from a State

INTERFACE:

    subroutine ESMF_StateGetField(state, fieldName, field, &
    nestedStateName, rc)

ARGUMENTS:

    type(ESMF_State), intent(in) :: state
    character (len=*) , intent(in) :: fieldName
    type(ESMF_Field), intent(out) :: field
    character (len=*) , intent(in), optional :: nestedStateName
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns an ESMF_Field from an ESMF_State by name. If the ESMF_State contains the object directly, only
fieldName is required. If the state contains multiple nested ESMF_States and the object is one level down,
this routine can return the object in a single call by specifying the proper nestedStateName. ESMF_States
can be nested to any depth, but this routine only searches in immediate descendents. It is an error to specify a
nestedStateName if the state contains no nested ESMF_States.
The arguments are:

state  State to query for an ESMF_Field named fieldName.

fieldName  Name of ESMF_Field to be returned.

field  Returned reference to the ESMF_Field.

[nestedStateName]  Optional. An error if specified when the state argument contains no nested ESMF_States.
Required if the state contains multiple nested ESMF_States and the object being requested is in one level
down in one of the nested ESMF_State. ESMF_State must be selected by this nestedStateName.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

15.7.24  ESMF_StateGetItemInfo - Get information about a State

INTERFACE:

    subroutine ESMF_StateGetItemInfo(state, name, stateitemtype, rc)

ARGUMENTS:

    type(ESMF_State), intent(in) :: state
    character (len=*) , intent(in) :: name
    type(ESMF_StateItemType), intent(out) :: stateitemtype
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns the type for the item named name in this ESMF_State. If no item with this name exists, the value
ESMF_STATEITEM_NOTFOUND will be returned and the error code will not be set to an error. Thus this routine
can be used to safely query for the existence of items by name whether or not they are expected to be there. The error
code will be set in case of other errors, for example if the ESMF_State itself is invalid.
The arguments are:
**state**  ESMF_State to be queried.

**name**  Name of the item to return information about.

**stateitemtype**  Returned item types for the item with the given name, including placeholder names. Options are listed in Section 15.2.1. If no item with the given name is found, ESMF_STATEITEM_NOTFOUND will be returned and rc will not be set to an error.

**[rc]**  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 15.7.25  ESMF_StateGetNeeded - Query whether a data item is needed

**INTERFACE:**

```fortran
subroutine ESMF_StateGetNeeded(state, itemName, neededflag, rc)
```

**ARGUMENTS:**

- `type(ESMF_State), intent(in) :: state`
- `character (len=*), intent(in) :: itemName`
- `type(ESMF_NeededFlag), intent(out) :: neededflag`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Returns the status of the neededflag for the data item named by itemName in the ESMF_State. The arguments are:

- **state**  The ESMF_State to query.
- **itemName**  Name of the data item to query.
- **neededflag**  Whether state item is needed or not for a particular application configuration. Possible values are listed in Section 9.1.7.

**[rc]**  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 15.7.26  ESMF_StateGetState - Retrieve a State nested in a State

**INTERFACE:**

```fortran
subroutine ESMF_StateGetState(state, nestedStateName, nestedState, rc)
```

**ARGUMENTS:**

- `type(ESMF_State), intent(in) :: state`
- `character (len=*), intent(in) :: nestedStateName`
- `type(ESMF_State), intent(out) :: nestedState`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Returns a nested ESMF_State from another ESMF_State by name. This does not allow the caller to retrieve an ESMF_State from two levels down. It returns immediate child objects only. The arguments are:
state  The ESMF_State to query for a nested ESMF_State named stateName.

nestedStateName  Name of nested ESMF_State to return.

nestedState  Returned ESMF_State.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

15.7.27  ESMF_StateIsNeeded – Return logical true if data item needed

INTERFACE:

    function ESMF_StateIsNeeded(state, itemName, rc)

RETURN VALUE:

    logical :: ESMF_StateIsNeeded

ARGUMENTS:

    type(ESMF_State), intent(in) :: state
    character (len=*), intent(in) :: itemName
    integer, intent(out), optional :: rc

DESCRIPTION:

    Returns true if the status of the needed flag for the data item named by itemName in the ESMF_State is ESMF_STATEITEM_NEEDED. Returns false for no item found with the specified name or item marked not needed. Also sets error code if dataname not found.

The arguments are:

state  ESMF_State to query.

itemName  Name of the data item to query.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

15.7.28  ESMF_StatePrint - Print the internal data for a State

INTERFACE:

    subroutine ESMF_StatePrint(state, options, rc)

ARGUMENTS:

    type(ESMF_State) :: state
    character (len = '*), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

    Prints information about the state to stdout.

The arguments are:

state  The ESMF_State to print.

[options]  Print options are not yet supported.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
15.7.29  ESMF_StateSetAttribute - Set an attribute

INTERFACE:

    subroutine ESMF_StateSetAttribute(state, name, <value argument>, rc)

ARGUMENTS:

    type(ESMF_State), intent(in) :: state
    character (len = *), intent(in) :: name
    <value argument>, see below for supported values
    integer, intent(out), optional :: rc

DESCRIPTION:

Attaches an attribute to the state. The attribute has a name and either a value or a valueList. Supported values for the <value argument> are:

- `integer(ESMF_KIND_I4), intent(in) :: value`
- `integer(ESMF_KIND_I4), dimension(:), intent(in) :: valueList`
- `integer(ESMF_KIND_I8), intent(in) :: value`
- `integer(ESMF_KIND_I8), dimension(:), intent(in) :: valueList`
- `real (ESMF_KIND_R4), intent(in) :: value`
- `real (ESMF_KIND_R4), dimension(:), intent(in) :: valueList`
- `real (ESMF_KIND_R8), intent(in) :: value`
- `real (ESMF_KIND_R8), dimension(:), intent(in) :: valueList`
- `type(ESMF_Logical), intent(in) :: value`
- `type(ESMF_Logical), dimension(:), intent(in) :: valueList`
- `character (len = *), intent(in), value`

The arguments are:

- `state` An ESMF_State object.
- `name` The name of the attribute to set.
- `<value argument>` The value of the attribute to set.
- `[rc]` Return code; equals ESMF_SUCCESS if there are no errors.

15.7.30  ESMF_StateSetNeeded - Set if a data item is needed

INTERFACE:

    subroutine ESMF_StateSetNeeded(state, itemName, neededFlag, rc)

ARGUMENTS:

Sets the status of the needed flag for the data item named by itemName in the ESMF_State. The arguments are:

state The ESMF_State to set.

itemName Name of the data item to set.

neededflag Set status of data item to this. See Section 9.1.7 for possible values.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

15.7.31 ESMF_StateValidate - Check validity of a State

INTERFACE:

subroutine ESMF_StateValidate(state, options, rc)

ARGUMENTS:

type(ESMF_State) :: state
class (len = *), intent(in), optional :: options
integer, intent(out), optional :: rc

DESCRIPTION:

Validates that the state is internally consistent. Currently this method determines if the state is uninitialized or already destroyed. The method returns an error code if problems are found.

The arguments are:

state The ESMF_State to validate.

[options] Validation options are not yet supported.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

15.8 Class API: State Overloads for Fortran Arrays

15.8.1 ESMF_StateGetDataPointer - Retrieve Fortran pointer directly from a State

INTERFACE:

! Private name; call using ESMF_StateGetDataPointer()
subroutine ESMF_StateGetDataPointer<rank><type><kind>(state, itemName, dataPointer, copyflag, nestedStateName, rc)

ARGUMENTS:
type(ESMF_State), intent(in) :: state
classer(len=*), intent(in) :: itemName
<type> (ESMF_KIND_<kind>), dimension(<rank>), pointer :: dataPointer
type(ESMF_CopyFlag), intent(in), optional :: copyflag
classer(len=*), intent(in), optional :: nestedStateName
integer, intent(out), optional :: rc

DESCRIPTION:

Retrieves data from a state, returning a direct Fortran pointer to the data array. Valid type/kind/rank combinations supported by the framework are: ranks 1 to 7, type real of kind *4 or *8, and type integer of kind *1, *2, *4, or *8. The arguments are:

**state** The ESMF_State to query.

**itemName** The name of the Bundle, Field, or Array to return data from.

**dataPointer** An unassociated Fortran pointer of the proper Type, Kind, and Rank as the data in the State. When this call returns successfully, the pointer will now reference the data in the State. This is either a reference or a copy, depending on the setting of the following argument. The default is to return a reference.

**[copyflag]** Defaults to ESMF_DATA_REF. If set to ESMF_DATA_COPY, a separate copy of the data will be made and the pointer will point at the copy.

**[nestedStateName]** Optional. If multiple states are present, a specific state name must be given.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

15.9 Class API: State Communications

15.9.1 ESMF_StateReconcile – Reconcile State data across all PETs in a VM

INTERFACE:

```fortran
subroutine ESMF_StateReconcile(state, vm, options, rc)
```

ARGUMENTS:

```fortran
type(ESMF_State), intent(inout) :: state
type(ESMF_VM), intent(in) :: vm
classer (len = *), intent(in), optional :: options
integer, intent(out), optional :: rc
```

DESCRIPTION:

Must be called for any ESMF_State which contains ESMF objects that have not been created on all the PETs of the currently running ESMF_Component. For example, if a coupler is operating on data which was created by another component that ran on only a subset of the coupler’s PETs, the coupler must make this call first before operating on any data inside that ESMF_State. After calling ESMF_StateReconcile all PETs will have a common view of all objects contained in this ESMF_State.

The arguments are:

**state** ESMF_State to reconcile.

**vm** ESMF_VM for this ESMF_Component.

**[options]** Currently unused. Here for possible future expansion in the options for the reconciliation process.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.
Part III
Infrastructure: Fields and Grids
16 Overview of Infrastructure Data Handling

The ESMF infrastructure data classes are part of the framework’s hierarchy of structures for handling Earth system model data and metadata on parallel platforms. The hierarchy is in complexity; the simplest data class in the infrastructure represents a distributed array and the most complex data class represents a bundle of physical fields that are discretized on the same grid. Data class methods are called both from user-written code and from other classes internal to the framework.

Data classes are distributed over DEs, or Decomposition Elements. A DE represents a piece of a decomposition. A DELayout is a collection of DEs with some associated connectivity that describes a specific distribution. For example, the distribution of a grid divided into four segments in the x-dimension would be expressed in ESMF as a DELayout with four DEs lying along an x-axis. This abstract concept enables a data decomposition to be defined in terms of threads, MPI processes, virtual decomposition elements, or combinations of these without changes to user code. This is a primary strategy for ensuring optimal performance and portability for codes using the ESMF for communications.

ESMF data classes are useful because they provide a standard, convenient way for developers to collect together information related to model or observational data. The information assembled in a data class includes a data pointer, a set of attributes (e.g. units, although attributes can also be user-defined), and a description of an associated grid. The same set of information within an ESMF data object can be used by the framework to arrange intercomponent data transfers, to perform I/O, for communications such as gathers and scatters, for simplification of interfaces within user code, for debugging, and for other functions. This unifies and organizes codes overall so that the user need not define different representations of metadata for the same field for I/O and for component coupling.

Since it is critical that users be able to introduce ESMF into their codes easily and incrementally, ESMF data classes can be created based on native Fortran pointers. Likewise, there are methods for retrieving native Fortran pointers from within ESMF data objects. This allows the user to perform allocations using ESMF, and to retrieve Fortran arrays later for optimized model calculations. The ESMF data classes do not have associated differential operators or other mathematical methods.

For flexibility, it is not necessary to build an ESMF data object all at once. For example, it’s possible to create a field but to defer allocation of the associated field data until a later time.

<table>
<thead>
<tr>
<th>Key Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hierarchy of data structures designed specifically for the Earth system domain and high performance, parallel computing.</td>
</tr>
<tr>
<td>Multi-use ESMF structures simplify user code overall.</td>
</tr>
<tr>
<td>Data objects support incremental construction and deferred allocation.</td>
</tr>
<tr>
<td>Native Fortran arrays can be associated with or retrieved from ESMF data objects, for ease of adoption, convenience, and performance.</td>
</tr>
</tbody>
</table>

16.1 Infrastructure Data Classes

The main classes that are used for model and observational data manipulation are as follows:

- **Array** An ESMF Array contains a data pointer, information about its associated datatype, precision, and dimension.
  
  Data elements in Arrays are partitioned into categories defined by the role the data element plays in distributed halo operations. Haloing - sometimes called ghosting - is the practice of copying portions of array data to multiple memory locations to ensure that data dependencies can be satisfied quickly when performing a calculation. ESMF Arrays contain an exclusive domain, which contains data elements updated exclusively and definitively by a given DE; a computational domain, which contains all data elements with values that are updated by the DE in computations; and a total domain, which includes both the computational domain and data elements from other DEs which may be read but are not updated in computations.

- **Field** A Field holds model and/or observational data together with its underlying grid or set of spatial locations. It provides methods for configuration, initialization, setting and retrieving data values, data I/O, data regridding, and manipulation of attributes.
**Bundle** Groups of Fields on the same underlying physical grid can be collected into a single object called a Bundle. A Bundle provides two major functions: it allows groups of Fields to be manipulated using a single identifier, for example during export or import of data between Components; and it allows data from multiple Fields to be packed together in memory for higher locality of reference and ease in subsetting operations. Packing a set of Fields into a single Bundle before performing a data communication allows the set to be transferred at once rather than as a Field at a time. This can improve performance on high-latency platforms.

Bundle objects contain methods for setting and retrieving constituent fields, regridding, data I/O, and reordering of data in memory.

### 16.2 Object Model

The following is a simplified UML diagram showing the relationships among ESMF Field, Grid and Bundle classes. See Appendix A, *A Brief Introduction to UML*, for a translation table that lists the symbols in the diagram and their meaning.

![UML Diagram](image)

### 16.3 Design and Implementation Notes

1. In communication methods such as Regrid, Redist, Scatter, etc. the Bundle and Field code cascades down through the Array code, so that the actual computations exist in only one place in the source.
17 Bundle Class

17.1 Description

The Bundle class represents “bundles” of Fields that are discretized on the same Grid and distributed in the same manner. Fields within a Bundle may be located at different locations relative to the vertices of their common Grid. The Fields in a Bundle may be of different dimensions, as long as the Grid dimensions that are distributed are the same. For example, a surface Field on a distributed lat/lon Grid and a 3D Field with an added vertical dimension on the same distributed lat/lon Grid can be included in the same Bundle.

Bundles currently function mainly as convenient containers for storing Fields. Bundles can be created and destroyed, can have attributes added or retrieved, and can have Fields added or retrieved. Methods include a variety of queries that return information about the attributes and the Fields that a Bundle contains. The Fortran data pointer of a Field within a Bundle can be obtained by passing the Bundle a Field name. Memory layout information is stored in a BundleDataMap object which is attached to the Bundle. It can be accessed by querying the Bundle. Although we have made the BundleDataMap public, many of the memory layout options have not been implemented.

Bundles are one of the data objects that can be added to States, which are used for sending to or receiving data from other components. In the future Bundles will serve as a mechanism for performance optimization. ESMF will take advantage of the similarities of the Fields within a Bundle in order to implement collective communication, IO, and regridding. See Section 17.4 for a description of features that are being planned.

17.2 Bundle Options

17.2.1 ESMF_PackFlag

DESCRIPTION:
Specifies whether a Bundle is packed or not. A packed Bundle contains an array in which all the data in its constituent Fields is packed contiguously. Bundles that are not packed are not guaranteed to carry a contiguous array of their data. This flag is not yet implemented; the value is always set to ESMF_NO_PACKED_DATA.

Valid values are:

ESMF_PACKED_DATA  Contains a packed array.
ESMF_NO_PACKED_DATA  Does not contain a packed array.

17.3 Use and Examples

Examples of creating, destroying and accessing Bundles and their constituent Fields are provided in this section, along with some notes on Bundle methods.

17.3.1 Bundle Creation

After creating multiple Fields, a Bundle can be created by passing a list of the Fields into the method ESMF_BundleCreate(). The Bundle will contain references to the Fields. An empty Bundle can also be created and Fields added singularly or in groups.

The feature which requests a packed Array be created from the combined Field data arrays is not implemented in this version of the framework.

17.3.2 Accessing Bundle Data

To access data in a Bundle the user can provide a Field name and retrieve the Field’s Fortran data pointer. Alternatively, the user can retrieve the data in the form of an ESMF Field and use the Field-level interfaces.

The packed Array feature of Bundles is not implemented in this version of the Framework.
17.3.3 Bundle Deletion

The user must call \texttt{ESMF\_BundleDestroy()} before deleting any of the Fields it contains. Because Fields can be shared by multiple Bundles and States, they are not deleted by this call. See the following code fragments for examples of how to create new Bundles.

```fortran
! Example program showing various ways to create a Bundle object.
program ESMF\_BundleCreateEx

! ESMF Framework module
use ESMF\_Mod

implicit none

! Local variables
integer :: i, rc, fieldcount
type(ESMF\_Grid) :: grid
type(ESMF\_ArraySpec) :: arrayspec
!type(ESMF\_FieldDataMap) :: datamap
!type(ESMF\_DELayout) :: delayout
type(ESMF\_VM) :: vm
character (len = ESMF\_MAXSTR) :: bname1, fname1, fname2
type(ESMF\_Field) :: field(10), returnedfield1, returnedfield2, simplefield
type(ESMF\_Bundle) :: bundle1, bundle2, bundle3
!real (selected\_real\_kind(6,45)), dimension(:,:), pointer :: f90ptr1, f90ptr2
integer :: counts(2)
real(ESMF\_KIND\_R8) :: min\_coord(2), max\_coord(2)

! Create several Fields and add them to a new Bundle.

counts = (/ 100, 200 /)
min\_coord = (/ 0.0, 0.0 /)
max\_coord = (/ 50.0, 60.0 /)
delayout = ESMF\_DELayoutCreate(vm, rc=rc)
grid = ESMF\_GridCreateHorzXYUni(counts, min\_coord, max\_coord, &
horzStagger=ESMF\_GRID\_HORIZ\_STAGGER\_A, rc=rc)
call ESMF\_GridDistribute(grid, delayout=delayout, rc=rc)

call ESMF\_ArraySpecSet(arrayspec, 2, ESMF\_DATA\_REAL, ESMF\_R8, rc)
field(1) = ESMF\_FieldCreate(grid, arrayspec, &
horzRelloc=ESMF\_CELL\_CENTER, &
name="pressure", rc=rc)

field(2) = ESMF\_FieldCreate(grid, arrayspec, &
horzRelloc=ESMF\_CELL\_CENTER, &
name="temperature", rc=rc)

field(3) = ESMF\_FieldCreate(grid, arrayspec, &
horzRelloc=ESMF\_CELL\_CENTER, &
name="temperature", rc=rc)
```

111
bundle1 = ESMF_BundleCreate(3, field, name="atmosphere data", rc=rc)
print *, "Bundle example 1 returned"

simplefield = ESMF_FieldCreate(grid, arrayspec, &
horzRelloc=ESMF_CELL_CENTER, name="rh", rc=rc)

bundle2 = ESMF_BundleCreate(name="time step 1", rc=rc)
call ESMF_BundleAddField(bundle2, simplefield, rc)
call ESMF_BundleGet(bundle2, fieldCount=fieldcount, rc=rc)
print *, "Bundle example 2 returned, fieldcount =", fieldcount

bundle3 = ESMF_BundleCreate(name="southern hemisphere", rc=rc)
call ESMF_BundleAddField(bundle3, 3, field, rc)
call ESMF_BundleGet(bundle3, fieldCount=fieldcount, rc=rc)
print *, "Bundle example 3 returned, fieldcount =", fieldcount

call ESMF_BundleGetField(bundle1, "pressure", returnedfield1, rc)
call ESMF_FieldGet(returnedfield1, name=fname1, rc=rc)
call ESMF_BundleGetField(bundle1, 2, returnedfield2, rc)
call ESMF_FieldGet(returnedfield2, name=fname2, rc=rc)
call ESMF_BundleGet(bundle1, name=bname1, rc=rc)

print *, "Bundle example 4 returned, field names = ", &
       trim(fname1), ", ", trim(fname2)
print *, "Bundle name = ", trim(bname1)

!-------------------------------------------------- -----------------------
call ESMF_BundleDestroy(bundle1, rc=rc)
call ESMF_BundleDestroy(bundle2, rc=rc)
call ESMF_BundleDestroy(bundle3, rc=rc)
do i=1, 3
call ESMF_FieldDestroy(field(i),rc=rc)
enddo
call ESMF_FieldDestroy(simplefield, rc=rc)
end program ESMF_BundleCreateEx

17.4 Restrictions and Future Work

1. No mathematical operators. The Bundle class does not support differential or other mathematical operators. We do not anticipate providing this functionality in the near future.

2. Limited validation and print options. We are planning to increase the number of validity checks available for Bundles as soon as possible. We also will be working on print options.

3. Limited communication support. Only a subset of the communication routines are currently supported for Bundles, and the Fields contained in the Bundles must currently have the same structure (e.g. same halo width, same dimensionality). Support for more variable data will be added in a later release. For those routines not implemented yet, or for those Bundles which contain Fields with differing data, the user can loop over the Fields in the Bundle and call the Field level communication routines instead.

4. Packed data not supported. One of the options that we are currently working on for Bundles is packing. Packing means that the data from all the Fields that comprise the Bundle are copied into a single Array and manipulated collectively. This operation can be done without destroying the original Field data. Packing is being designed to facilitate optimized regridding, data communication, and IO operations. It will be possible to collectively manipulate all the Fields within a Bundle at once, rather than operating on each Field separately. This will reduce the latency overhead of the communication.

5. Interleaving Fields within a Bundle. Data locality is important for performance on some computing platforms. An interleave option will allow the user to create a packed Bundle in which Fields are either concatenated in memory or in which Field elements are interleaved.

17.5 Design and Implementation Notes

1. Fields in a Bundle reference the same Grid. In order to reduce memory requirements and ensure consistency, the Fields within a Bundle all reference the same Grid object.
17.6 Class API: Basic Bundle Methods

17.6.1 ESMF_BundleAddField - Add a Field to a Bundle

INTERFACE:

! Private name; call using ESMF_BundleAddField()
subroutine ESMF_BundleAddOneField(bundle, field, rc)

ARGUMENTS:

type(ESMF_Bundle), intent(inout) :: bundle
type(ESMF_Field), intent(inout) :: field
integer, intent(out), optional :: rc

DESCRIPTION:

Adds a single field to an existing bundle. The field must be associated with the same ESMF_Grid as the other ESMF_Fields in the bundle. The field is referenced by the bundle, not copied.

The arguments are:

bundle The ESMF_Bundle to add the ESMF_Field to.
field The ESMF_Field to add.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

17.6.2 ESMF_BundleAddField - Add a list of Fields to a Bundle

INTERFACE:

! Private name; call using ESMF_BundleAddField()
subroutine ESMF_BundleAddFieldList(bundle, fieldCount, fieldList, rc)

ARGUMENTS:

type(ESMF_Bundle), intent(inout) :: bundle
integer, intent(in) :: fieldCount
type(ESMF_Field), dimension(:), intent(inout) :: fieldList
integer, intent(out), optional :: rc

DESCRIPTION:

Adds a fieldList to an existing ESMF_Bundle. The items added from the ESMF_fieldList must be associated with the same ESMF_Grid as the other ESMF_Fields in the bundle. The items in the fieldList are referenced by the bundle, not copied.

The arguments are:

bundle ESMF_Bundle to add ESMF_Fields to.
fieldCount Number of ESMF_Fields to be added to the ESMF_Bundle; must be equal to or less than the number of items in the fieldList.
fieldList Array of existing ESMF_Fields. The first fieldCount items will be added to the ESMF_Bundle.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.
17.6.3 ESMF_BundleCreate - Create a Bundle from existing Fields

INTERFACE:

! Private name; call using ESMF_BundleCreate()
function ESMF_BundleCreateNew(fieldCount, fieldList, &
   packflag, bundleinterleave, name, iospec, rc)

RETURN VALUE:

type(ESMF_Bundle) :: ESMF_BundleCreateNew

ARGUMENTS:

integer, intent(in) :: fieldCount

array of existing ESMF_Field s. The first fieldCount items will be added to the new ESMF_Bundle.

[packflag] The packing option is not yet implemented. See Section 17.2 for a description of packing, and Section [17.3] for anticipated values. The current implementation corresponds to the value ESMF_NO_PACKED_DATA, which means that every ESMF_Field is referenced separately rather than being copied into a single contiguous buffer. This is the case no matter what value, if any, is passed in for this argument.

[bundleinterleave] The interleave option is not yet implemented. See Section 17.2 for a brief description of interleaving, and Section 17.3 for anticipated values. The flag is not applicable to the current implementation, since it applies only to packed data (see the packflag argument).

[name] ESMF_Bundle name. A default name is generated if one is not specified.

[iospec] The ESMF_IOSpec is not yet used by ESMF_Bundles. Any values passed in will be ignored.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

17.6.4 ESMF_BundleCreate - Create a Bundle with no Fields

INTERFACE:

! Private name; call using ESMF_BundleCreate()
function ESMF_BundleCreateNoFields(grid, name, iospec, rc)

RETURN VALUE:
type(ESMF_Bundle) :: ESMF_BundleCreateNoFields

ARGUMENTS:

  type(ESMF_Grid), intent(in), optional :: grid
  character (len = *), intent(in), optional :: name
  type(ESMF_IOSpec), intent(in), optional :: iospec
  integer, intent(out), optional :: rc

DESCRIPTION:

Creates an ESMF_Bundle with no associated ESMF_Fields. The arguments are:

[grid] The ESMF_Grid which all ESMF_Fields added to this ESMF_Bundle must be associated with. If not specified now, the grid associated with the first ESMF_Field added will be used as the reference grid for the ESMF_Bundle.

[name] ESMF_Bundle name. A default name is generated if one is not specified.

[iospec] The ESMF_IOSpec is not yet used by ESMF_Bundles. Any values passed in will be ignored.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

17.6.5 ESMF_BundleDestroy - Free all resources associated with a Bundle

INTERFACE:

  subroutine ESMF_BundleDestroy(bundle, rc)

ARGUMENTS:

  type(ESMF_Bundle) :: bundle
  integer, intent(out), optional :: rc

DESCRIPTION:

Releases resources associated with the bundle. This method does not destroy the ESMF_Fields that the bundle contains. The bundle should be destroyed before the ESMF_Fields within it are.

[bundle] An ESMF_Bundle object.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

17.6.6 ESMF_BundleGet - Return information about a Bundle

INTERFACE:

  subroutine ESMF_BundleGet(bundle, grid, fieldCount, name, rc)

ARGUMENTS:
type(ESMF_Bundle), intent(inout) :: bundle
type(ESMF_Grid), intent(out), optional :: grid
integer, intent(out), optional :: fieldCount
character (len = *), intent(out), optional :: name
integer, intent(out), optional :: rc

DESCRIPTION:

Returns information about the bundle. If the ESMF_Bundle was originally created without specifying a name, a unique name will have been generated by the framework.

The arguments are:

bundle  The ESMF_Bundle object to query.

[grid]  The ESMF_Grid associated with the bundle.

[fieldCount]  Number of ESMF_Field in the bundle.

[name]  A character string where the bundle name is returned.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

17.6.7  ESMF_BundleGetAttribute - Retrieve an attribute

INTERFACE:

    subroutine ESMF_BundleGetAttribute(bundle, name, <value argument>, rc)

ARGUMENTS:

    type(ESMF_Bundle), intent(inout) :: bundle
    character (len = *), intent(in) :: name
    <value argument>, see below for supported values
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns an attribute from the bundle. Supported values for <value argument> are:

    integer(ESMF_KIND_I4), intent(out) :: value
    integer(ESMF_KIND_I4), dimension(:), intent(out) :: valueList
    integer(ESMF_KIND_I8), intent(out) :: value
    integer(ESMF_KIND_I8), dimension(:), intent(out) :: valueList
    real (ESMF_KIND_R4), intent(out) :: value
    real (ESMF_KIND_R4), dimension(:), intent(out) :: valueList
    real (ESMF_KIND_R8), intent(out) :: value
    real (ESMF_KIND_R8), dimension(:), intent(out) :: valueList
    type(ESMF_Logical), intent(out) :: value
    type(ESMF_Logical), dimension(:), intent(out) :: valueList
character (len = *), intent(out), value

The arguments are:

**bundle**  An ESMF_Bundle object.

**name**  The name of the attribute to retrieve.

<value argument>  The value of the named attribute.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 17.6.8 ESMF_BundleGetAttributeCount - Query the number of attributes

**INTERFACE:**

```fortran
subroutine ESMF_BundleGetAttributeCount(bundle, count, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_Bundle), intent(inout) :: bundle
integer, intent(out) :: count
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Returns the number of attributes associated with the given `bundle` in the argument `count`. The arguments are:

**bundle**  An ESMF_Bundle object.

**count**  The number of attributes associated with this object.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 17.6.9 ESMF_BundleGetAttributeInfo - Query Bundle attributes by name

**INTERFACE:**

```fortran
! Private name; call using ESMF_BundleGetAttributeInfo()
subroutine ESMF_BundleGetAttrInfoByName(bundle, name, datatype, &
   datakind, count, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_Bundle), intent(inout) :: bundle
character(len=*) , intent(in) :: name
type(ESMF_DataType), intent(out), optional :: datatype
type(ESMF_DataKind), intent(out), optional :: datakind
integer, intent(out), optional :: count
integer, intent(out), optional :: rc
```
DESCRIPTION:

Returns information associated with the named attribute, including `datatype`, `datakind` (if applicable), and item count. The arguments are:

- `bundle` An ESMF_Bundle object.
- `name` The name of the attribute to query.
- `[datatype]` The data type of the attribute. One of the values `ESMF_DATA_INTEGER`, `ESMF_DATA_REAL`, `ESMF_DATA_LOGICAL`, or `ESMF_DATA_CHARACTER`.
- `[datakind]` The data kind of the attribute, if attribute is type `ESMF_DATA_INTEGER` or `ESMF_DATA_REAL`. One of the values `ESMF_I4`, `ESMF_I8`, `ESMF_R4`, or `ESMF_R8`. For all other types the value `ESMF_NOKIND` is returned.
- `[count]` The number of items in this attribute. For character types, the length of the character string.
- `[rc]` Return code; equals `ESMF_SUCCESS` if there are no errors.

17.6.10 ESMF_BundleGetAttributeInfo - Query Bundle attributes by index number

INTERFACE:

```fortran
! Private name; call using ESMF_BundleGetAttributeInfo()
subroutine ESMF_BundleGetAttrInfoByNum(bundle, attributeIndex, name, &
    datatype, datakind, count, rc)
```

ARGUMENTS:

- `type(ESMF_Bundle), intent(inout) :: bundle`
- `integer, intent(in) :: attributeIndex`
- `character(len=*), intent(out), optional :: name`
- `type(ESMF_DataType), intent(out), optional :: datatype`
- `type(ESMF_DataKind), intent(out), optional :: datakind`
- `integer, intent(out), optional :: count`
- `integer, intent(out), optional :: rc`

DESCRIPTION:

Returns information associated with the indexed attribute, including `datatype`, `datakind` (if applicable), and item count. The arguments are:

- `bundle` An ESMF_Bundle object.
- `attributeIndex` The index number of the attribute to query.
- `name` Returns the name of the attribute.
- `[datatype]` The data type of the attribute. One of the values `ESMF_DATA_INTEGER`, `ESMF_DATA_REAL`, `ESMF_DATA_LOGICAL`, or `ESMF_DATA_CHARACTER`.
- `[datakind]` The data kind of the attribute, if attribute is type `ESMF_DATA_INTEGER` or `ESMF_DATA_REAL`. One of the values `ESMF_I4`, `ESMF_I8`, `ESMF_R4`, or `ESMF_R8`. For all other types the value `ESMF_NOKIND` is returned.
Returns the number of items in this attribute. For character types, the length of the character string.

Return code; equals ESMF_SUCCESS if there are no errors.

17.6.11 ESMF_BundleGetField - Retrieve a Field by name

INTERFACE:

! Private name; call using ESMF_BundleGetField()
subroutine ESMF_BundleGetFieldByName(bundle, name, field, rc)

ARGUMENTS:

type(ESMF_Bundle), intent(inout) :: bundle
class character (len = *), intent(in) :: name
type(ESMF_Field), intent(out) :: field
integer, intent(out), optional :: rc

DESCRIPTION:

Returns a field from a bundle using the field's name. The arguments are:

bundle ESMF_Bundle to query for ESMF_Field.
name ESMF_Field name.
field Returned ESMF_Field.
rc Return code; equals ESMF_SUCCESS if there are no errors.

17.6.12 ESMF_BundleGetField - Retrieve a Field by index number

INTERFACE:

! Private name; call using ESMF_BundleGetField()
subroutine ESMF_BundleGetFieldByNum(bundle, fieldIndex, field, rc)

ARGUMENTS:

type(ESMF_Bundle), intent(inout) :: bundle
integer, intent(in) :: fieldIndex
type(ESMF_Field), intent(out) :: field
integer, intent(out), optional :: rc

DESCRIPTION:

Returns a field from a bundle by index number. The arguments are:

bundle ESMF_Bundle to query for ESMF_Field.
fieldIndex ESMF_Field index number; first fieldIndex is 1.
field Returned ESMF_Field.
rc Return code; equals ESMF_SUCCESS if there are no errors.
17.6.13   ESMF_BundleGetFieldNames - Return all Field names in a Bundle

INTERFACE:

    subroutine ESMF_BundleGetFieldNames(bundle, nameList, nameCount, rc)

ARGUMENTS:

    type(ESMF_Bundle), intent(inout) :: bundle
    character (len = *), intent(out) :: nameList(:)
    integer, intent(out), optional :: nameCount
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns an array of ESMF_Field names in an ESMF_Bundle.  The arguments are:

bundle  An ESMF_Bundle object.

nameList  An array of character strings where each ESMF_Field name is returned. Must be at least as long as nameCount.

[nameCount] A count of how many ESMF_Field names were returned. Same as the number of ESMF_Fields in the ESMF_Bundle.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

17.6.14   ESMF_BundlePrint - Print information about a Bundle

INTERFACE:

    subroutine ESMF_BundlePrint(bundle, options, rc)

ARGUMENTS:

    type(ESMF_Bundle), intent(inout) :: bundle
    character (len=*) , intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Prints diagnostic information about the bundle to stdout. The arguments are:

bundle  An ESMF_Bundle object.

[options] Print options are not yet supported.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
17.6.15 ESMF_BundleSetAttribute - Set an attribute

INTERFACE:

    subroutine ESMF_BundleSetAttribute(bundle, name, <value argument>, rc)

ARGUMENTS:

    type(ESMF_Bundle), intent(inout) :: bundle
    character (len = *), intent(in) :: name
    <value argument>, see below for supported values
    integer, intent(out), optional :: rc

DESCRIPTION:

Attaches an attribute to the bundle. The attribute has a name and either a value or a valueList. Supported values for the <value argument> are:

    integer(ESMF_KIND_I4), intent(in) :: value
    integer(ESMF_KIND_I4), dimension(:), intent(in) :: valueList
    integer(ESMF_KIND_I8), intent(in) :: value
    integer(ESMF_KIND_I8), dimension(:), intent(in) :: valueList
    real (ESMF_KIND_R4), intent(in) :: value
    real (ESMF_KIND_R4), dimension(:), intent(in) :: valueList
    real (ESMF_KIND_R8), intent(in) :: value
    real (ESMF_KIND_R8), dimension(:), intent(in) :: valueList
    type(ESMF_Logical), intent(in) :: value
    type(ESMF_Logical), dimension(:), intent(in) :: valueList
    character (len = *), intent(in), value

The arguments are:

bundle An ESMF_Bundle object.

name The name of the attribute to set.

)value argument> The value of the attribute to set.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

17.6.16 ESMF_BundleSetGrid - Associate a Grid with an empty Bundle

INTERFACE:

    subroutine ESMF_BundleSetGrid(bundle, grid, rc)

ARGUMENTS:
DESCRIPTION:

Sets the grid for a bundle that contains no ESMF.Fields. All ESMF.Fields added to this bundle must be associated with the same ESMF_Grid. Returns an error if there is already an ESMF_Grid associated with the bundle.

The arguments are:

**bundle** An ESMF_Bundle object.

**grid** The ESMF_Grid which all ESMF.Fields added to this ESMF_Bundle must have.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

---

17.6.17 ESMF_BundleValidate - Check validity of a Bundle

INTERFACE:

```fortran
subroutine ESMF_BundleValidate(bundle, options, rc)
```

ARGUMENTS:

```fortran
type(ESMF_Bundle), intent(inout) :: bundle
character (len=*) , intent(in), optional :: options
integer, intent(out), optional :: rc
```

DESCRIPTION:

Validates that the bundle is internally consistent. Currently this method determines if the bundle is uninitialized or already destroyed. The method returns an error code if problems are found.

The arguments are:

**bundle** ESMF_Bundle to validate.

[options] Validation options are not yet supported.

[rc] Return code; equals ESMF_SUCCESS if the bundle is valid.

---

17.7 Class API: Bundle Overloads for Fortran Arrays

17.7.1 ESMF_BundleGetDataPointer - Retrieve Fortran pointer directly from a Bundle

INTERFACE:

```fortran
! Private name; call using ESMF_BundleGetDataPointer()
subroutine ESMF_BundleGetDataPointer<rank><type><kind>(bundle, fieldName, dataPointer, copyflag, rc)
```

ARGUMENTS:
type(ESMF_Bundle), intent(in) :: bundle
character(len=*), intent(in) :: fieldName
<type> (ESMF_KIND_<kind>), dimension(<rank>), pointer :: dataPointer
type(ESMF_CopyFlag), intent(in), optional :: copyflag
integer, intent(out), optional :: rc

DESCRIPTION:

Retrieves data from the bundle, returning a direct Fortran pointer to the data. Valid type/kind/rank combinations supported by the framework are: ranks 1 to 7, type real of kind *4 or *8, and type integer of kind *1, *2, *4, or *8. The arguments are:

**bundle**  The ESMF_Bundle to query.

**fieldName**  The name of the ESMF_Field inside the bundle to return. The bundle cannot have packed data.

**dataPointer**  An unassociated Fortran pointer of the proper Type, Kind, and Rank as the data in the Bundle. When this call returns successfully, the pointer will now point to the data in the Bundle. This is either a reference or a copy, depending on the setting of the following argument. The default is to return a reference.

**[copyflag]**  Defaults to ESMF_DATA_REF. If set to ESMF_DATA_COPY, a separate copy of the data will be made and the pointer will point at the copy.

**[rc]**  Return code; equals ESMF_SUCCESS if there are no errors.

### 17.8  Class API: Bundle Communications

#### 17.8.1  ESMF_BundleHalo - Execute a halo operation on each Field in a Bundle

**INTERFACE:**

```fortran
subroutine ESMF_BundleHalo(bundle, routehandle, blocking, &
commhandle, routeOptions, rc)
```

**ARGUMENTS:**

```fortran
    type(ESMF_Bundle), intent(inout) :: bundle
    type(ESMF_RouteHandle), intent(inout) :: routehandle
    type(ESMF_BlockingFlag), intent(in) , optional :: blocking
    type(ESMF_CommHandle), intent(inout), optional :: commhandle
    type(ESMF_RouteOptions), intent(in), optional :: routeOptions
    integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Perform a halo operation over each ESMF_Field in an ESMF_Bundle. This routine updates the data inside the ESMF_Bundle in place. The current version of the code does not support ESMF_Bundles with packed data. It simply operates on a ESMF_Field by ESMF_Field basis, updating each one at a time. The arguments are:

**bundle**  ESMF_Bundle containing data to be haloed.

**routehandle**  ESMF_RouteHandle which was returned by the corresponding ESMF_BundleHaloStore() call. It is associated with the precomputed data movement and communication needed to perform the halo operation.

**[blocking]**  Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, default is what was specified at Store time. (This feature is not yet supported. All operations are synchronous.)
If the blocking flag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.

Not normally specified. Specify which internal strategy to select when executing the communication needed to update the halo. See Section 26.3.1 for possible values.

Return code; equals ESMF_SUCCESS if there are no errors.

### 17.8.2 ESMF_BundleHaloRelease - Release resources associated w/ handle

**INTERFACE:**

```plaintext```
subroutine ESMF_BundleHaloRelease(routehandle, rc)
```

**ARGUMENTS:**

```plaintext```
type(ESMF_RouteHandle), intent(inout) :: routehandle
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Release all stored information about the halo operation associated with this ESMF_RouteHandle.

The arguments are:

- `routehandle` ESMF_RouteHandle associated with this halo operation.
- `rc` Return code; equals ESMF_SUCCESS if there are no errors.

### 17.8.3 ESMF_BundleHaloStore - Precompute a data halo operation on a Bundle

**INTERFACE:**

```plaintext```
subroutine ESMF_BundleHaloStore(bundle, routehandle, halodirection, & routeOptions, rc)
```

**ARGUMENTS:**

```plaintext```
type(ESMF_Bundle), intent(inout) :: bundle
type(ESMF_RouteHandle), intent(inout) :: routehandle
type(ESMF_HaloDirection), intent(in), optional :: halodirection
type(ESMF_RouteOptions), intent(in), optional :: routeOptions
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Precompute the data movement or communication operations needed to perform a halo operation over the data in an ESMF_Bundle. The list of operations will be associated internally to the framework with the ESMF_RouteHandle object. To perform the actual halo operation the ESMF_BundleHalo() routine must be called with the ESMF_Bundle containing the data to be updated and the ESMF_RouteHandle computed during this store call. Although probably less common with bundles than with fields, if more than one ESMF_Bundle has an identical ESMF_Grid and contains identical ESMF_Fields, then the same ESMF_RouteHandle can be computed once and used in multiple executions of the halo operation. In the current version of the code ESMF_Bundles with packed data are not supported.

The arguments are:
bundle  ESMF_Bundle containing data to be haloed.

routehandle  ESMF_RouteHandle which will be returned after being associated with the precomputed information for a halo operation on this ESMF_Bundle. This handle must be supplied at run time to execute the halo.

[halodirection] Optional argument to restrict halo direction to a subset of the possible halo directions. If not specified, the halo is executed along all boundaries. (This feature is not yet supported.)

[routeOptions] Not normally specified. Specify which internal strategy to select when executing the communication needed to update the halo. See Section 26.3.1 for possible values.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

17.8.4 ESMF_BundleRedist - Data redistribution operation on a Bundle

INTERFACE:

! Private name; call using ESMF_BundleRedist()
subroutine ESMF_BundleRedistAllinOne(srcBundle, dstBundle, parentVM, &
   blocking, commhandle, routeOptions, rc)

ARGUMENTS:

type(ESMF_Bundle), intent(inout) :: srcBundle
type(ESMF_Bundle), intent(inout) :: dstBundle
type(ESMF_VM), intent(in) :: parentVM
type(ESMF_BlockingFlag), intent(in), optional :: blocking
type(ESMF_CommHandle), intent(inout), optional :: commhandle
type(ESMF_RouteOptions), intent(in), optional :: routeOptions
integer, intent(out), optional :: rc

DESCRIPTION:

Perform a redistribution operation over the data in an ESMF_Bundle. This version does not take a routehandle and computes, runs, and releases the communication information in a single subroutine. It should be used when a redist operation will be done only a single time; otherwise computing and reusing a communication pattern will be more efficient. This routine reads the source bundle and leaves the data untouched. It reads the ESMF_Grid and ESMF_FieldDataMap from the destination bundle and updates the array data in the destination. The ESMF_Grids may have different decompositions (different ESMF_DELayouts) or different data maps, but the source and destination grids must describe the same set of coordinates. Unlike ESMF_BundleRegrid this routine does not do interpolation, only data movement. 

The arguments are:

srcBundle  ESMF_Bundle containing source data.

dstBundle  ESMF_Bundle containing destination grid.

parentVM  ESMF_VM which encompasses both ESMF_Bundles, most commonly the VM of the Coupler if the redistribution is inter-component, but could also be the individual VM for a component if the redistribution is intra-component.

[blocking] Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, default is to do synchronous communication. Valid values for this flag are ESMF_BLOCKING and ESMF_NONBLOCKING. (This feature is not yet supported. All operations are synchronous.)
If the blocking flag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.

Not normally specified. Specify which internal strategy to select when executing the communication needed to redistribute data. See Section 26.3.1 for possible values.

Return code; equals ESMF_SUCCESS if there are no errors.

17.8.5 ESMF_BundleRedist - Data redistribution operation on a Bundle

INTERFACE:

    ! Private name; call using ESMF_FieldRedist()
    subroutine ESMF_BundleRedistRun(srcBundle, dstBundle, routehandle, &
    blocking, commhandle, routeOptions, rc)

ARGUMENTS:

    type(ESMF_Bundle), intent(inout) :: srcBundle
    type(ESMF_Bundle), intent(inout) :: dstBundle
    type(ESMF_RouteHandle), intent(inout) :: routehandle
    type(ESMF_BlockingFlag), intent(in), optional :: blocking
    type(ESMF_CommHandle), intent(inout), optional :: commhandle
    type(ESMF_RouteOptions), intent(in), optional :: routeOptions
    integer, intent(out), optional :: rc

DESCRIPTION:

Perform a redistribution operation over the data in an ESMF_Bundle. This routine reads the source bundle and leaves the data untouched. It reads the ESMF_Grid and ESMF_FieldDataMap from the destination bundle and updates the array data in the destination. The ESMF_Grids may have different decompositions (different ESMF_DELayouts) or different data maps, but the source and destination grids must describe the same set of coordinates. Unlike ESMF_BundleRegrid this routine does not do interpolation, only data movement.

The arguments are:

srcbundle ESMF_Bundle containing source data.

dstbundle ESMF_Bundle containing destination grid.

routehandle ESMF_RouteHandle which was returned by the corresponding ESMF_BundleRedistStore() call. It is associated with the precomputed data movement and communication needed to perform the redistribution operation.

[blocking] Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, default is to do synchronous communication. Valid values for this flag are ESMF_BLOCKING and ESMF_NONBLOCKING. (This feature is not yet supported. All operations are synchronous.)

[commhandle] If the blocking flag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.

[routeOptions] Not normally specified. Specify which internal strategy to select when executing the communication needed to redistribute data. See Section 26.3.1 for possible values.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
17.8.6  ESMF_BundleRedistRelease - Release resources associated with handle

INTERFACE:

    subroutine ESMF_BundleRedistRelease(routehandle, rc)

ARGUMENTS:

    type(ESMF_RouteHandle), intent(inout) :: routehandle
    integer, intent(out), optional :: rc

DESCRIPTION:

Release all stored information about the redistribution operation associated with this ESMF_RouteHandle. The arguments are:

routehandle  ESMF_RouteHandle associated with this redistribution.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

17.8.7  ESMF_BundleRedistStore - Data redistribution operation on a Bundle

INTERFACE:

    subroutine ESMF_BundleRedistStore(srcBundle, dstBundle, parentVM, &
                                       routehandle, routeOptions, rc)

ARGUMENTS:

    type(ESMF_Bundle), intent(inout) :: srcBundle
    type(ESMF_Bundle), intent(inout) :: dstBundle
    type(ESMF_VM), intent(in) :: parentVM
    type(ESMF_RouteHandle), intent(out) :: routehandle
    type(ESMF_RouteOptions), intent(in), optional :: routeOptions
    integer, intent(out), optional :: rc

DESCRIPTION:

Precompute the data movement or communications operations needed to accomplish a data redistribution operation over the data in an ESMF_Bundle. Data redistribution differs from regridding in that redistribution does no interpolation, only a 1-for-1 movement of data from one location to another. Therefore, while the ESMF_Grids for the source and destination may have different decompositions (different ESMF_DELayouts) or different data maps, the source and destination grids must describe the same set of coordinates. The arguments are:

srcBundle  ESMF_Bundle containing source data.

dstBundle  ESMF_Bundle containing destination grid.

parentVM  ESMF_VM which encompasses both ESMF_Bundles, most commonly the VM of the Coupler if the redistribution is inter-component, but could also be the individual VM for a component if the redistribution is intra-component.

routehandle  ESMF_RouteHandle which will be used to execute the redistribution when ESMF_BundleRedist is called.

[routeOptions]  Not normally specified. Specify which internal strategy to select when executing the communication needed to update the halo. See Section 26.3.1 for possible values.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
17.8.8  ESMF_BundleRegrid - Execute a regrid operation on a Bundle

INTERFACE:

    ! Private name; call using ESMF_BundleRegrid()
    subroutine ESMF_BundleRegridAllinOne(srcBundle, dstBundle, parentVM, &
        regridMethod, regridNorm, &
        srcMask, dstMask, blocking, commhandle, &
        routeOptions, rc)

ARGUMENTS:

    type(ESMF_Bundle), intent(inout) :: srcBundle
    type(ESMF_Bundle), intent(inout) :: dstBundle
    type(ESMF_VM), intent(in) :: parentVM
    type(ESMF_RegridMethod), intent(in) :: regridMethod
    type(ESMF_RegridNormOpt), intent(in), optional :: regridNorm
    type(ESMF_Mask), intent(in), optional :: srcMask
    type(ESMF_Mask), intent(in), optional :: dstMask
    type(ESMF_BlockingFlag), intent(in), optional :: blocking
    type(ESMF_CommHandle), intent(inout), optional :: commhandle
    type(ESMF_RouteOptions), intent(in), optional :: routeOptions
    integer, intent(out), optional :: rc

DESCRIPTION:

Perform a regrid operation over the data in an ESMF_Bundle. This routine reads the source bundle and leaves the data untouched. It uses the ESMF_Grid and ESMF_FieldDataMap information in the destination bundle to control the transformation of data. The array data in the destination bundle is overwritten by this call. This version does not take a routehandle but computes, runs, and releases the communication information in a single subroutine. It should be used when a redist operation will be done only a single time; otherwise computing and reusing a communication pattern will be more efficient.

The arguments are:

srcBundle  ESMF_Bundle containing source data.
dstBundle  ESMF_Bundle containing destination grid.
parentVM   ESMF_VM which encompasses both ESMF_Bundles, most commonly the VM of the Coupler if the regridding is inter-component, but could also be the individual VM for a component if the regridding is intra-component.
regridMethod  Type of regridding to do. A set of predefined methods are supplied.
regridNorm  Normalization option, only for specific regrid types.
blocking  Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, default is to do synchronous communication. Valid values for this flag are ESMF_BLOCKING and ESMF_NONBLOCKING. (This feature is not yet supported. All operations are synchronous.)
commhandle  If the blocking flag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.
routeOptions  Not normally specified. Specify which internal strategy to select when executing the communication needed to redistribute data. See Section 26.3.1 for possible values.
rc  Return code; equals ESMF_SUCCESS if there are no errors.
18 BundleDataMap Class

18.1 Description

The BundleDataMap class specifies how the Fields within a packed Bundle are interleaved. In a packed Bundle, the data arrays of constituent Fields have been copied or transferred to a single combined data array. This is generally done for optimization - either to increase data locality for quick data retrieval from memory or to aggregate communications to reduce latency.

Packed Bundles are not fully implemented. Currently the Field data within Bundles are always stored as individual data references. At this point the BundleDataMap class is a placeholder; values for a Bundle interleave flag can be set and retrieved, but they are not used by the framework.

18.2 BundleDataMap Options

18.3 Use and Examples

A BundleDataMap is a shallow object. It can simply be declared as a local (stack) variable, and does not have to be created or destroyed. To initialize a BundleDataMap with default values a set default method is provided. To alter or query an existing object, use the set and get methods. A print method is provided for human-readable output or debugging.

! PROGRAM: ESMF_BundleDataMapEx - BundleDataMap manipulation examples
!
! DESCRIPTION:
!
! This program shows examples of BundleDataMap set and get usage
!-------------------------------------------------- ---------------------------

    ! ESMF Framework module
    use ESMF_Mod
    implicit none

    ! local variables
    type(ESMF_BundleDataMap) :: bundleDM
    type(ESMF_InterleaveFlag) :: il

    ! return code
    integer:: rc

    ! initialize ESMF framework
    call ESMF_Initialize(rc=rc)

18.3.1 Setting BundleDataMap Defaults

This example shows how to set the default values in an ESMF_BundleDataMap.

    call ESMF_BundleDataMapSetDefault(bundleDM, rc=rc)

    print *, "Default values for BundleDataMap = "
    call ESMF_BundleDataMapPrint(bundleDM, rc=rc)
18.3.2 Setting BundleDataMap Values

This example shows how to set values in an ESMF_BundleDataMap.

```
il = ESMF_INTERLEAVE_BY_ITEM
call ESMF_BundleDataMapSet(bundleDM, bundleInterleave = il, rc = rc)

print *, "BundleDataMap after setting interleave = "
call ESMF_BundleDataMapPrint(bundleDM, rc = rc)
```

18.3.3 Getting BundleDataMap Values

This example shows how to query an ESMF_BundleDataMap.

```
call ESMF_BundleDataMapGet(bundleDM, bundleInterleave = il, rc = rc)
if (il .eq. ESMF_INTERLEAVE_BY_ITEM) then
    print *, "Interleaved by individual data items"
else if (il .eq. ESMF_INTERLEAVE_BY_BLOCK) then
    print *, "Interleaved by fields"
endif

! finalize ESMF framework
call ESMF_Finalize(rc = rc)

end program ESMF_BundleDataMapEx
```

18.4 Restrictions and Future Work

1. **BundleDataMap is a placeholder until packed Bundles are implemented.** Packed Bundles have not been implemented in this version of ESMF.

18.5 Class API

18.5.1 ESMF_BundleDataMapGet - Get values from a BundleDataMap

**INTERFACE:**

```
subroutine ESMF_BundleDataMapGet(bundledatamap, bundleinterleave, rc)
```

**ARGUMENTS:**

```
type(ESMF_BundleDataMap), intent(in) :: bundledatamap
type(ESMF_InterleaveFlag), intent(out), optional :: bundleinterleave
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Return values from an ESMF_BundleDataMap.

The arguments are:
bundledatamap  An ESMF_BundleDataMap.

[bundleinterleave]  Type of interleave for ESMF_Bundle data if packed into a single array. Possible values are ESMF_INTERLEAVE_BY_ITEM and ESMF_INTERLEAVE_BY_FIELD.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

18.5.2  ESMF_BundleDataMapPrint - Print information about a BundleDataMap

INTERFACE:

    subroutine ESMF_BundleDataMapPrint(bundledatamap, options, rc)

ARGUMENTS:

    type(ESMF_BundleDataMap), intent(in) :: bundledatamap
    character (len = *), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Prints diagnostic information about the bundledatamap to stdout. The arguments are:

bundledatamap  ESMF_BundleDataMap to print.

[options]  Print options are not yet supported.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

18.5.3  ESMF_BundleDataMapSet - Set values in a BundleDataMap

INTERFACE:

    subroutine ESMF_BundleDataMapSet(bundledatamap, bundleinterleave, rc)

ARGUMENTS:

    type(ESMF_BundleDataMap), intent(inout) :: bundledatamap
    type(ESMF_InterleaveFlag), intent(in), optional :: bundleinterleave
    integer, intent(out), optional :: rc

DESCRIPTION:

Set values in an ESMF_BundleDataMap. The arguments are:

bundledatamap  An ESMF_BundleDataMap.

[bundleinterleave]  Type of interleave for ESMF_Bundle data if packed into a single array. Options are ESMF_INTERLEAVE_BY_ITEM and ESMF_INTERLEAVE_BY_FIELD.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
18.5.4 ESMF_BundleDataMapSetDefault - Set BundleDataMap default values

INTERFACE:

    subroutine ESMF_BundleDataMapSetDefault(bundledatamap, bundleinterleave, rc)

ARGUMENTS:

    type(ESMF_BundleDataMap) :: bundledatamap
    type(ESMF_InterleaveFlag), intent(in), optional :: bundleinterleave
    integer, intent(out), optional :: rc

DESCRIPTION:

Set default values of a ESMF_BundleDataMap type. The differences between this routine and ESMF_BundleDataMapSet() is that unspecified arguments are reset to their default values.

The arguments are:

bundledatamap An ESMF_BundleDataMap.

[bundleinterleave]  Type of interleave for ESMF_Bundle data if packed into a single array. Options are ESMF_INTERLEAVE_BY_ITEM and ESMF_INTERLEAVE_BY_FIELD. If not specified, the default is interleave by field.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

18.5.5 ESMF_BundleDataMapSetInvalid - Set BundleDataMap to invalid status

INTERFACE:

    subroutine ESMF_BundleDataMapSetInvalid(bundledatamap, rc)

ARGUMENTS:

    type(ESMF_BundleDataMap), intent(inout) :: bundledatamap
    integer, intent(out), optional :: rc

DESCRIPTION:

ESMF routine to set the contents of an ESMF_BundleDataMap to an invalid status.

The arguments are:

bundledatamap An ESMF_BundleDataMap.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

18.5.6 ESMF_BundleDataMapValidate - Check validity of a BundleDataMap

INTERFACE:

    subroutine ESMF_BundleDataMapValidate(bundledatamap, options, rc)

ARGUMENTS:

    type(ESMF_BundleDataMap), intent(in) :: bundledatamap
    character (len = *), intent(in), optional :: options
    integer, intent(out), optional :: rc
DESCRIPTION:

Validates that the bundledatamap is internally consistent. Currently this method determines if the bundledatamap is uninitialized or already destroyed. The method returns an error code if problems are found. The arguments are:

bundledatamap  ESMF_BundleDataMap to validate.

[options] Validation options are not yet supported.

[rc] Return code; equals ESMF_SUCCESS if the bundledatamap is valid.

19 Field Class

19.1 Description

An ESMF Field represents a physical field, such as temperature. The motivation for including Fields in ESMF is that bundles of Fields are the entities that are normally exchanged when coupling Components. The ESMF Field class contains discretized field data, a reference to its associated grid, and metadata. The Field class maintains the relationship of how a data array maps onto a grid (e.g. one item per cell located at the cell center, one item per cell located at the NW corner, one item per cell vertex). This means that different Fields which are on the same underlying ESMF Grid but have different staggerings can share the same Grid object without needing to replicate it multiple times.

ESMF does not currently support vector fields, so the components of a vector field must be stored as separate Field objects.

The Field class provides methods for initialization, setting and retrieving data values, general data redistribution and regridding, standard communication methods such as gather and scatter, and manipulation of attributes. Field methods are called from objects internal to the framework and can also be called from user code.

19.2 Use and Examples

A Field serves as an annotator of data, since it carries a description of the grid it is associated with and metadata such as name and units. Fields can be used in this capacity alone, as convenient, descriptive containers into which arrays can be placed and retrieved. However, for most codes the primary use of Fields is in the context of import and export States, which are the objects that carry coupling information between Components. Fields enable data to be self-describing, and a State holding ESMF Fields contains data in a standard format that is easy to query and manipulate.

The information that is necessary for describing a Field to another Component is similar to the information needed to write history files. Another use of Fields is as a mechanism for writing out data to files for history and restart. The sections below go into more detail about Field usage.

19.2.1 Field Creation

Fields can be created and destroyed at any time during application execution. However, these Field methods require some time to complete. We do not recommend that the user create or destroy Fields inside performance-critical computational loops.

All versions of the ESMF_FieldCreate() routines require a Grid object as input, or require a Grid be added before most operations involving Fields can be performed. The Grid contains the information needed to know which Decomposition Elements (DEs) are participating in the processing of this Field, and which subsets of the data are local to a particular DE.

The details of how the create process happens depends on which of the variants of the ESMF_FieldCreate() call is used. Some of the variants are discussed below.

There are versions of the ESMF_FieldCreate() interface which create the Field based on the input Grid. The ESMF can allocate the proper amount of space but not assign initial values. The user code can then get the pointer to the uninitialized buffer and set the initial data values.
Other versions of the ESMF_FieldCreate() interface allow user code to attach arrays that have already been allocated by the user. Empty Fields can also be created in which case the data can be added at some later time. For versions of Create which do not specify data values, user code can create an ArraySpec object, which contains information about the Type, Kind, and Rank of the data values in the array. Then at Field create time, the appropriate amount of memory is allocated to contain the data which is local to each DE.

19.2.2 Field Deletion

There is a ESMF_FieldDestroy() method which releases any data buffers which were allocated or copied by this Field, and deletes the Field object. Since a single Grid reference can be shared by multiple Fields, the Grid is not deleted by this call.

19.2.3 Field Create with Grid and InternArray

The user has already created an ESMF_Grid and an ESMF_InternArray with data. This create associates the two objects. An ESMF_FieldDataMap is created with all defaults.

    field1 = ESMF_FieldCreate(grid, iarray1, &
                           horzRelloc=ESMF_CELL_CENTER, name="pressure", rc=rc)

19.2.4 Field Create with Grid and ArraySpec

The user has already created an ESMF_Grid and an ESMF_ArraySpec which describes the data. This version of create will create an ESMF_Array based on the grid size and the ESMF_ArraySpec. An ESMF_FieldDataMap is created with all defaults.

    call ESMF_ArraySpecSet(arrayspec, 2, ESMF_DATA_REAL, ESMF_R4, rc)
field2 = ESMF_FieldCreate(grid, arrayspec, horzRelloc=ESMF_CELL_CENTER, &
name="rh", rc=rc)

19.2.5 Empty Field Create

The user creates an empty ESMF_Field object. The ESMF_Grid, ESMF_InternArray, and ESMF_FieldDataMap can be added later using the set methods.

field3 = ESMF_FieldCreateNoData("precip", rc=rc)

19.2.6 Destroy a Field

When finished with an ESMF_Field, the destroy method removes it. However, the objects inside the ESMF_Field should be deleted separately, since objects can be added to more than one ESMF_Field, for example the same ESMF_Grid can be used in multiple ESMF_Fields.

call ESMF_FieldDestroy(field1, rc=rc)

end program ESMF_FieldCreateEx

19.3 Restrictions and Future Work

1. **No mathematical operators.** The Fields class does not currently support advanced operations on fields, such as differential or other mathematical operators.

2. **No vector Fields.** ESMF does not currently support storage of multiple vector Field components in the same Field component, although that support is planned. At this time users need to create a separate Field object to represent each vector component.

19.4 Design and Implementation Notes

1. Some methods which have a Field interface are actually implemented at the underlying Grid or Array level; they are inherited by the Field class. This allows the user API (Application Programming Interface) to present functions at the level which is most consistent to the application without restricting where inside the ESMF the actual implementation is done.

2. The Field class is implemented in Fortran, and as such is defined inside the framework by a Field derived type and a set of subprograms (functions and subroutines) which operate on that derived type. The Field class itself is very thin; it is a container class which groups a Grid, an Array, and a FieldDataMap object together. As a programming convenience, the parts of the Field which refer to data which is local to a single DE are grouped in a LocalField sub-derived type, but it is not a true class in that there are no LocalField methods which operate on it. In general, any derived type members which are not in the LocalField subtype describe global information about the Field.

3. Fields follow the framework-wide convention of the unison creation and operation rule: All PETs which are part of the currently executing VM must create the same Fields at the same point in their execution. Since an early user request was that global object creation not impose the overhead of a barrier or synchronization point, Field creation does no inter-PET communication. For this to work, each PET must query the total number of PETs in this VM, and which local PET number it is. It can then compute which DE(s) are part of the local decomposition, and any global information can be computed in unison by all PETs independently of the others. In this way the overhead of communication is avoided, at the cost of more difficulty in diagnosing program bugs which result from not all PETs executing the same create calls.
4. Related to the item above, the user request to not impose inter-PET communication at object creation time means that requirement FLD 1.5.1, that all Fields will have unique names, and if not specified, the framework will generate a unique name for it, is difficult or impossible to support. A part of this requirement has been implemented; a unique object counter is maintained in the Base object class, and if a name is not given at create time a name such as "Field003" is generated which is guaranteed to not be repeated by the framework. However, it is impossible to error check that the user has not replicated a name, and it is possible under certain conditions that if not all PETs have created the same number of objects, that the counters on different PETs may not stay synchronized. This remains an open issue.

19.5 Class API: Basic Field Methods

19.5.1 ESMF_FieldCreateNoData - Create a Field with no associated data buffer

INTERFACE:

```fortran
! Private name; call using ESMF_FieldCreateNoData()
function ESMF_FieldCreateNoDataPtr(grid, arrayspec, horzRelloc, &
  vertRelloc, haloWidth, &
  datamap, name, iospec, rc)
```

RETURN VALUE:

```fortran
type(ESMF_Field) :: ESMF_FieldCreateNoDataPtr
```

ARGUMENTS:

```fortran
type(ESMF_Grid) :: grid

type(ESMF_ArraySpec), intent(inout) :: arrayspec

type(ESMF_RelLoc), intent(in), optional :: horzRelloc

type(ESMF_RelLoc), intent(in), optional :: vertRelloc

integer, intent(in), optional :: haloWidth

type(ESMF_FieldDataMap), intent(inout), optional :: datamap

character (len=*) , intent(in), optional :: name

type(ESMF_IOSpec), intent(in), optional :: iospec

integer, intent(out), optional :: rc
```

DESCRIPTION:

An interface function to ESMF_FieldCreateNoData(). Creates an ESMF_Field in its entirety except for the assignment or allocation of an associated raw data buffer. The arguments are:

- **grid** Pointer to an ESMF_Grid object.
- **arrayspec** Data specification.
- **[horzRelloc]** Relative location of data per grid cell/vertex in the horizontal grid. If a relative location is specified both as an argument here as well as set in the datamap, this takes priority.
- **[vertRelloc]** Relative location of data per grid cell/vertex in the vertical grid. If a relative location is specified both as an argument here as well as set in the datamap, this takes priority.
- **[haloWidth]** Halo region width when data is eventually created. Defaults to 0.
- **[datamap]** An ESMF_FieldDataMap which describes the mapping of data to the ESMF_Grid.
- **[name]** Field name.
- **[iospec]** I/O specification.
- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.
19.5.2 ESMF_FieldCreateNoData - Create a Field with no associated Array object

INTERFACE:

    ! Private name; call using ESMF_FieldCreateNoData()
    function ESMF_FieldCreateNoArray(grid, horzRelloc, vertRelloc, &
                                      datamap, name, iospec, rc)

RETURN VALUE:

    type(ESMF_Field) :: ESMF_FieldCreateNoArray

ARGUMENTS:

    type(ESMF_Grid) :: grid
    type(ESMF_RelLoc), intent(in), optional :: horzRelloc
    type(ESMF_RelLoc), intent(in), optional :: vertRelloc
    type(ESMF_FieldDataMap), intent(inout), optional :: datamap
    character (len=*) , intent(in), optional :: name
    type(ESMF_IOSpec), intent(in), optional :: iospec
    integer, intent(out), optional :: rc

DESCRIPTION:

An interface function to ESMF_FieldCreateNoData(). This version of ESMF_FieldCreate builds an ESMF_Field and depends on a later call to add an ESMF_Array to it. The arguments are:

[grid] Pointer to an ESMF_Grid object.

[horzRelloc] Relative location of data per grid cell/vertex in the horizontal grid. If a relative location is specified both as an argument here as well as set in the datamap, this takes priority.

[vertRelloc] Relative location of data per grid cell/vertex in the vertical grid. If a relative location is specified both as an argument here as well as set in the datamap, this takes priority.

[datamap] An ESMF_FieldDataMap which describes the mapping of data to the ESMF_Grid.

[name] Field name.

[iospec] I/O specification.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

19.5.3 ESMF_FieldCreateNoData - Create a Field with no Grid or Array

INTERFACE:

    ! Private name; call using ESMF_FieldCreateNoData()
    function ESMF_FieldCreateNoGridArray(name, iospec, rc)

RETURN VALUE:

    type(ESMF_Field) :: ESMF_FieldCreateNoGridArray

ARGUMENTS:
An interface function to `ESMF_FieldCreateNoData()`. This version of `ESMF_FieldCreate` builds an empty `ESMF_Field` and depends on later calls to add an `ESMF_Grid` and `ESMF_Array` to it.

The arguments are:

- **name** Field name.
- **iospec** I/O specification.
- **rc** Return code; equals `ESMF_SUCCESS` if there are no errors.

### 19.5.4 ESMF_FieldDestroy - Free all resources associated with a Field

**INTERFACE:**

```fortran
subroutine ESMF_FieldDestroy(field, rc)
```

**ARGUMENTS:**

- `type(ESMF_Field) :: field`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Releases all resources associated with the `ESMF_Field`. The arguments are:

- **field** Pointer to an `ESMF_Field` object.
- **rc** Return code; equals `ESMF_SUCCESS` if there are no errors.

### 19.5.5 ESMF_FieldGet - Return info associated with a Field

**INTERFACE:**

```fortran
subroutine ESMF_FieldGet(field, grid, array, datamap, horzRelloc, &
                         vertRelloc, haloWidth, iospec, type, kind, &
                         rank, lbounds, ubounds, name, rc)
```

**ARGUMENTS:**

- `type(ESMF_Field), intent(inout) :: field`
- `type(ESMF_Grid), intent(out), optional :: grid`
- `type(ESMF_InternArray), intent(out), optional :: array`
- `type(ESMF_FieldDataMap), intent(out), optional :: datamap`
- `type(ESMF_RelLoc), intent(out), optional :: horzRelloc`
- `type(ESMF_RelLoc), intent(out), optional :: vertRelloc`
- `integer, intent(out), optional :: haloWidth`
- `type(ESMF_IOSpec), intent(out), optional :: iospec`
type(ESMF_DataType), intent(out), optional :: type

type(ESMF_DataKind), intent(out), optional :: kind

type(ESMF_DataKind), intent(out), optional :: rank

type(ESMF_DataKind), intent(out), optional :: lbounds

type(ESMF_DataKind), intent(out), optional :: ubounds

character(len=*), intent(out), optional :: name

integer, intent(out), optional :: rc

DESCRIPTION:

Query an ESMF_Field for various things. All arguments after the Field are optional. To select individual items use the named_argument=value syntax.

The arguments are:

ftype  Pointer to an ESMF_Field object.

[grid]  ESMF_Grid.

[array]  ESMF_Array.

[datamap]  ESMF_FieldDataMap.

[horzRelloc]  Relative location of data per grid cell/vertex in the horizontal grid.

[vertRelloc]  Relative location of data per grid cell/vertex in the vertical grid.

[haloWidth]  Integer value for the width of the halo (ghost zone) region in the data array. This can also be queried directly from the ESMF_Array object.

[iospec]  ESMF_IOSpec object which contains settings for options

[type]  Type of Field.

[kind]  Kind specifier for type of Field.

[rank]  Rank of Field data.

[name]  Name of queried item.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.5.6  ESMF_FieldGetLocalArray - Get Local Array associated with the Field

INTERFACE:

subroutine ESMF_FieldGetLocalArray(field, array, rc)

ARGUMENTS:

type(ESMF_Field), intent(inout) :: field

type(ESMF_LocalArray), intent(out) :: array

integer, intent(out), optional :: rc

DESCRIPTION:

Get data in ESMF_LocalArray form.

The arguments are:
field  An ESMF_Field object.
[array] Field ESMF_LocalArray.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.5.7  ESMF_FieldGetInternArray - Get data Array associated with the Field

INTERFACE:

    subroutine ESMF_FieldGetInternArray(field, array, rc)

ARGUMENTS:

    type(ESMF_Field), intent(inout) :: field
    type(ESMF_InternArray), intent(out) :: array
    integer, intent(out), optional :: rc

DESCRIPTION:

Get data in ESMF_InternArray form.
The arguments are:

field  An ESMF_Field object.
[array] Field ESMF_InternArray.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.5.8  ESMF_FieldGetAttribute - Retrieve an attribute

INTERFACE:

    subroutine ESMF_FieldGetAttribute(field, name, <value argument>, rc)

ARGUMENTS:

    type(ESMF_Field), intent(inout) :: field
    character (len = *), intent(in) :: name
    <value argument>, see below for supported values
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns an attribute from the field. Supported values for <value argument> are:

    integer(ESMF_KIND_I4), intent(out) :: value
    integer(ESMF_KIND_I4), dimension(:), intent(out) :: valueList
    integer(ESMF_KIND_I8), intent(out) :: value
    integer(ESMF_KIND_I8), dimension(:), intent(out) :: valueList
The arguments are:

**field**  An ESMF_Field object.

**name**  The name of the attribute to retrieve.

**<value argument>**  The value of the named attribute.

**[rc]**  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 19.5.9 ESMF_FieldGetAttributeCount - Query the number of attributes

**INTERFACE:**

```fortran
subroutine ESMF_FieldGetAttributeCount(field, count, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_Field), intent(inout) :: field
type(ESMF_Field), intent(inout) :: field
integer, intent(out) :: count
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Returns the number of attributes associated with the given field in the argument count. The arguments are:

**field**  An ESMF_Field object.

**count**  The number of attributes associated with this object.

**[rc]**  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 19.5.10 ESMF_FieldGetAttributeInfo - Query Field attributes by name

**INTERFACE:**

```fortran
! Private name; call using ESMF_FieldGetAttributeInfo()
subroutine ESMF_FieldGetAttrInfoByName(field, name, datatype, &
  datakind, count, rc)
```

```
ARGUMENTS:

```fortran
    type(ESMF_Field), intent(inout) :: field
    character(len=*) , intent(in) :: name
    type(ESMF_DataType) , intent(out), optional :: datatype
    type(ESMF_DataKind) , intent(out), optional :: datakind
    integer , intent(out), optional :: count
    integer , intent(out), optional :: rc
```

DESCRIPTION:

Returns information associated with the named attribute, including `datatype` and `count`.

The arguments are:

- **field**: An ESMF_Field object.
- **name**: The name of the attribute to query.
- **[datatype]**: The data type of the attribute. One of the values `ESMF_DATA_INTEGER`, `ESMF_DATA_REAL`, `ESMF_DATA_LOGICAL`, or `ESMF_DATA_CHARACTER`.
- **[datakind]**: The datakind of the attribute, if attribute is type `ESMF_DATA_INTEGER` or `ESMF_DATA_REAL`. One of the values `ESMF_I4`, `ESMF_I8`, `ESMF_R4`, or `ESMF_R8`. For all other types the value `ESMF_NOKIND` is returned.
- **[count]**: The number of items in this attribute. For character types, the length of the character string.
- **[rc]**: Return code; equals `ESMF_SUCCESS` if there are no errors.

19.5.11 ESMF_FieldGetAttributeInfo - Query Field attributes by index number

INTERFACE:

```fortran
    ! Private name; call using ESMF_FieldGetAttributeInfo()
    subroutine ESMF_FieldGetAttrInfoByNum(field, attributeIndex, name, &
                                         datatype, datakind, count, rc)
```

ARGUMENTS:

```fortran
    type(ESMF_Field), intent(inout) :: field
    integer, intent(in) :: attributeIndex
    character(len=*) , intent(out), optional :: name
    type(ESMF_DataType) , intent(out), optional :: datatype
    type(ESMF_DataKind) , intent(out), optional :: datakind
    integer, intent(out), optional :: count
    integer, intent(out), optional :: rc
```

DESCRIPTION:

Returns information associated with the indexed attribute, including `name`, `datatype`, `datakind` (if applicable) and `count`.

The arguments are:

- **field**: An ESMF_Field object.
attributeIndex  The index number of the attribute to query.

name  Returns the name of the attribute.

[datatype]  The data type of the attribute. One of the values ESMF_DATA_INTEGER, ESMF_DATA_REAL, ESMF_DATA_LOGICAL, or ESMF_DATA_CHARACTER.

[datakind]  The data kind of the attribute, if attribute is type ESMF_DATA_INTEGER or ESMF_DATA_REAL. One of the values ESMF_I4, ESMF_I8, ESMF_R4, or ESMF_R8. For all other types the value ESMF_NOKIND is returned.

[count]  Returns the number of items in this attribute. For character types, this is the length of the character string.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.5.12  ESMF_FieldPrint - Print the contents of a Field

INTERFACE:

subroutine ESMF_FieldPrint(field, options, rc)

ARGUMENTS:

type(ESMF_Field), intent(inout) :: field
character (len = *), intent(in), optional :: options
integer, intent(out), optional :: rc

DESCRIPTION:

Prints information about the field to stdout.
The arguments are:

field  [options]  Print options are not yet supported.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.5.13  ESMF_FieldSetInternArray - Set data Array associated with the Field

INTERFACE:

subroutine ESMF_FieldSetInternArray(field, array, rc)

ARGUMENTS:

type(ESMF_Field), intent(inout) :: field
type(ESMF_InternArray), intent(in) :: array
integer, intent(out), optional :: rc

DESCRIPTION:

Set data in ESMF_Array form.
The arguments are:
field  An ESMF_Field object.
[array] ESMF_InternArray containing data.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

19.5.14  ESMF_FieldSetLocalArray - Set data Array associated with the Field

INTERFACE:

    subroutine ESMF_FieldSetLocalArray(field, array, rc)

ARGUMENTS:

    type(ESMF_Field), intent(inout) :: field
    type(ESMF_LocalArray), intent(in) :: array
    integer, intent(out), optional :: rc

DESCRIPTION:

Set data in ESMF_LocalArray form.
The arguments are:
field  An ESMF_Field object.
[array] ESMF_LocalArray containing data.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

19.5.15  ESMF_FieldSetAttribute - Set an attribute

INTERFACE:

    subroutine ESMF_FieldSetAttribute(field, name, <value argument>, rc)

ARGUMENTS:

    type(ESMF_Field), intent(inout) :: field
    character (len = *), intent(in) :: name
    <value argument>, see below for supported values
    integer, intent(out), optional :: rc

DESCRIPTION:

Attaches an attribute to the field. The attribute has a name and either a value or a valueList. Supported values for the <value argument> are:

    integer(ESMF_KIND_I4), intent(in) :: value
    integer(ESMF_KIND_I4), dimension(:), intent(in) :: valueList
    integer(ESMF_KIND_I8), intent(in) :: value
The arguments are:

**field**  An ESMF_Field object.

**name**  The name of the attribute to set.

**<value argument>**  The value of the attribute to set.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 19.5.16 ESMF_FieldSetGrid - Set Grid associated with the Field

**INTERFACE:**

```fortran
subroutine ESMF_FieldSetGrid(field, grid, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_Field), intent(inout) :: field
type(ESMF_Grid), intent(inout) :: grid
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Used only with the version of ESMF_FieldCreate which creates an empty ESMF_Field and allows the ESMF_Grid to be specified later. Otherwise it is an error to try to change the ESMF_Grid associated with an ESMF_Field. The arguments are:

**field**  An ESMF_Field object.

**grid**  ESMF_Grid to be added.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
19.5.17 ESMF_FieldSetDataMap - Set DataMap associated with a Field

INTERFACE:

    subroutine ESMF_FieldSetDataMap(field, datamap, rc)

ARGUMENTS:
    type(ESMF_Field), intent(inout) :: field
    type(ESMF_FieldDataMap), intent(inout) :: datamap
    integer, intent(out), optional :: rc

DESCRIPTION:

Used to set the ordering of an ESMF_Field. If an initialized ESMF_FieldDataMap and associated data are already in the ESMF_Field, the data will be reordered according to the new specification.

The arguments are:

- **field**: An ESMF_Field object.
- **datamap**: New memory order of data.
- **[rc]**: Return code; equals ESMF_SUCCESS if there are no errors.

19.5.18 ESMF_FieldValidate - Check validity of a Field

INTERFACE:

    subroutine ESMF_FieldValidate(field, options, rc)

ARGUMENTS:
    type(ESMF_Field), intent(in) :: field
    character (len=*), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Validates that the field is internally consistent. Currently this method determines if the field is uninitialized or already destroyed. The code also checks if the data and grid sizes agree. Currently we allow for 1 point mismatch to accommodate different staggerings. The method returns an error code if problems are found.

The arguments are:

- **field**: ESMF_Field to validate.
- **[options]**: Validation options are not yet supported.
- **[rc]**: Return code; equals ESMF_SUCCESS if the field is valid.
19.5.19  ESMF_FieldWrite - Write a Field to external storage

INTERFACE:

subroutine ESMF_FieldWrite(field, iospec, timestamp, rc)

ARGUMENTS:

type(ESMF_Field), intent(inout) :: field

type(ESMF_IOSpec), intent(in), optional :: iospec

type(ESMF_Time), intent(in), optional :: timestamp

integer, intent(out), optional :: rc ! return code

DESCRIPTION:

Used to write data to persistent storage in a variety of formats. (see WriteRestart/ReadRestart for quick data dumps.)
Details of I/O options specified in the IOSpec derived type.
The arguments are:

name  An ESMF_Field name.

[iospec]  I/O specification.

[timestamp]  A timestamp of type ESMF_Time for the data.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.6  Class API: Field Overloads for Fortran Arrays

19.6.1  ESMF_FieldCreate - Create a new Field

INTERFACE:

! Private name; call using ESMF_FieldCreate()
function ESMF_FieldCreateNew(grid, arrayspec, allocflag, horzRelloc, vertRelloc, haloWidth, datamap, name, &
iospec, rc)

RETURN VALUE:

type(ESMF_Field) :: ESMF_FieldCreateNew

ARGUMENTS:

type(ESMF_Grid) :: grid

type(ESMF_ArraySpec), intent(inout) :: arrayspec

type(ESMF_AllocFlag), intent(in), optional :: allocflag

type(ESMF_RelLoc), intent(in), optional :: horzRelloc

type(ESMF_RelLoc), intent(in), optional :: vertRelloc

integer, intent(in), optional :: haloWidth

type(ESMF_FieldDataMap), intent(inout), optional :: datamap

character (len=*) , intent(in), optional :: name

type(ESMF_IOSpec), intent(in), optional :: iospec

integer, intent(out), optional :: rc

DESCRIPTION:

An interface function to ESMF_FieldCreate(). Create an ESMF_Field and allocate space internally for a
gridded ESMF_Array. Return a new ESMF_Field.
The arguments are:
grid  Pointer to an ESMF_Grid object.

arrayspec  ESMF_Data specification.

[allocflag]  Whether to allocate space for the array. See Section 9.1.1 for possible values. Default is ESMF_ALLOC.

[horzRelloc]  Relative location of data per grid cell/vertex in the horizontal grid. If specified here, takes precedence
                    over the same setting in the datamap argument.

[vertRelloc]  Relative location of data per grid cell/vertex in the vertical grid. If specified here, takes precedence over
                    the same setting in the datamap argument.

[haloWidth]  Maximum halo depth along all edges. Default is 0.

[datamap]  An ESMF_FieldDataMap which describes the mapping of data to the ESMF_Grid.

[name]  Field name.

[iospec]  I/O specification.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.6.2 ESMF_FieldCreate - Create a Field from an existing ESMF Array

INTERFACE:

  ! Private name; call using ESMF_FieldCreate()
  function ESMF_FieldCreateFromArray(grid, array, copyflag, horzRelloc, &
          vertRelloc, haloWidth, datamap, name, &
          iospec, rc)

RETURN VALUE:

  type(ESMF_Field) :: ESMF_FieldCreateFromArray

ARGUMENTS:

  type(ESMF_Grid), intent(in) :: grid
  type(ESMF_InternArray), intent(in) :: array
  type(ESMF_CopyFlag), intent(in), optional :: copyflag
  type(ESMF_RelLoc), intent(in), optional :: horzRelloc
  type(ESMF_RelLoc), intent(in), optional :: vertRelloc
  integer, intent(in), optional :: haloWidth
  type(ESMF_FieldDataMap), intent(inout), optional :: datamap
  character (len = *), intent(in), optional :: name
  type(ESMF_IOSpec), intent(in), optional :: iospec
  integer, intent(out), optional :: rc

DESCRIPTION:

An interface function to ESMF_FieldCreate(). This version of creation assumes the data exists already and is
being passed in through an ESMF_Array.

The arguments are:

grid  Pointer to an ESMF_Grid object.

array  Includes data specification and allocated memory. It must already include space for the halo regions.
[copyflag] Indicates whether to reference the array or make a copy of it. Valid values are ESMF_DATA_COPY and ESMF_DATA_REF, respectively.

[horzRelloc] Relative location of data per grid cell/vertex in the horizontal grid. If specified here, takes precedence over the same setting in the datamap argument.

[vertRelloc] Relative location of data per grid cell/vertex in the vertical grid. If specified here, takes precedence over the same setting in the datamap argument.

[datamap] An ESMF_FieldDataMap which describes the mapping of data to the ESMF_Grid.

[name] Field name.

[iospec] I/O specification.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

19.6.3 ESMF_FieldCreate - Create a Field by remapping another Field

INTERFACE:

! Private name; call using ESMF_FieldCreate()
function ESMF_FieldCreateRemap(srcField, grid, horzRelloc, vertRelloc, 
haloWidth, datamap, name, iospec, rc)

RETURN VALUE:

type(ESMF_Field) :: ESMF_FieldCreateRemap

ARGUMENTS:

type(ESMF_Field), intent(in) :: srcField
type(ESMF_Grid), intent(in) :: grid
type(ESMF_RelLoc), intent(in), optional :: horzRelloc
type(ESMF_RelLoc), intent(in), optional :: vertRelloc
integer, intent(in), optional :: haloWidth
type(ESMF_FieldDataMap), intent(inout), optional :: datamap
character (len = *), intent(in), optional :: name
type(ESMF_IOSpec), intent(in), optional :: iospec
integer, intent(out), optional :: rc

DESCRIPTION:

An interface function to ESMF_FieldCreate(). Remaps data between an existing ESMF_Grid on a source ESMF_Field and a new ESMF_Grid. The ESMF_Grid is referenced by the new ESMF_Field. Data is copied.

The arguments are:

srcField Source ESMF_Field.

grid ESMF_Grid of source ESMF_Field.

horzRelLoc Relative location of data per grid cell/vertex in the horizontal grid.

vertRelLoc Relative location of data per grid cell/vertex in the vertical grid.

[haloWidth] Halo width.

[datamap] ESMF_FieldDataMap
19.6.4 **ESMF_FieldCreate** - Create a Field using an existing Fortran data pointer

**DESCRIPTION:**
Create an ESMF_Field and associate the data in the Fortran array with the ESMF_Field. Return a new ESMF_Field. Valid type/kind/rank combinations supported by the framework are: ranks 1 to 7, type real of kind *4 or *8, and type integer of kind *1, *2, *4, or *8.

The arguments are:

- `grid` Pointer to an ESMF_Grid object.
- `fptr` A Fortran array pointer which must be already allocated and the proper size for this portion of the grid.
- `copyflag` Whether to copy the existing data space or reference directly. Valid values are ESMF_DATA_COPY or ESMF_DATA_REF.
- `horzRelloc` Relative location of data per grid cell/vertex in the horizontal grid.
- `vertRelloc` Relative location of data per grid cell/vertex in the vertical grid.
- `haloWidth` Maximum halo depth along all edges. Default is 0.
- `datamap` Describes the mapping of data to the ESMF_Grid.
- `name` Field name.
- `iospec` I/O specification.
- `rc` Return code; equals ESMF_SUCCESS if there are no errors.
19.6.5 ESMF_FieldCreate - Create a Field using an unallocated Fortran data pointer

INTERFACE:

! Private name; call using ESMF_FieldCreate()
function ESMF_FieldCreateEPtr<rank><type><kind>(grid, fptr, allocflag, &
horzRelloc, vertRelloc, haloWidth, lbounds, ubounds, &
datamap, name, iospec, rc)

RETURN VALUE:

    type(ESMF_Field) :: ESMF_FieldCreateEPtr<rank><type><kind>

ARGUMENTS:

    type(ESMF_Grid), intent(in) :: grid
<type> (ESMF_KIND_<kind>), dimension(<rank>), pointer :: fptr
    type(ESMF_AllocFlag), intent(in), optional :: allocflag
ingar integer, intent(in), optional :: haloWidth
integer, dimension(:), intent(in), optional :: lbounds
integer, dimension(:), intent(in), optional :: ubounds
type(ESMF_FieldDataMap), intent(in), optional :: datamap
character (len=*) , intent(in), optional :: name
    type(ESMF_IOSpec), intent(in), optional :: iospec
        integer, intent(out), optional :: rc

DESCRIPTION:

Create an ESMF_Field, allocate necessary data space, and return with the Fortran array pointer initialized to point to the data space. Function return value is the new ESMF_Field. Valid type/kind/rank combinations supported by the framework are: ranks 1 to 7, type real of kind *4 or *8, and type integer of kind *1, *2, *4, or *8. The arguments are:

grid  Pointer to an ESMF_Grid object.
fptr  A Fortran array pointer which must be unallocated but of the proper rank, type, and kind for the data to be associated with this ESMF_Field.

[allocflag] Whether to allocate space for the array. See Section 9.1.1 for possible values. Default is ESMF_ALLOC.

[horzRelloc] Relative location of data per grid cell/vertex in the horizontal grid.

[vertRelloc] Relative location of data per grid cell/vertex in the vertical grid.

[haloWidth] Maximum halo depth along all edges. Default is 0.

[lbounds] An integer array of lower index values. Must be the same length as the rank.

[ubounds] An integer array of upper index values. Must be the same length as the rank.

[datamap] Describes the mapping of data to the ESMF_Grid.

[name] Field name.

[iospec] I/O specification.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
19.6.6 ESMF_FieldGetDataPointer - Retrieve Fortran pointer directly from a Field

INTERFACE:

! Private name; call using ESMF_FieldGetDataPointer()
subroutine ESMF_FieldGetDataPointer<rank><type><kind>(field, ptr, copyflag, rc)

ARGUMENTS:

type(ESMF_Field), intent(inout) :: field
<type> (ESMF_KIND_<kind>), dimension(<rank>), pointer :: ptr
type(ESMF_CopyFlag), intent(in), optional :: copyflag
integer, intent(out), optional :: rc

DESCRIPTION:

Returns a direct Fortran pointer to the data in an ESMF_Field. Valid type/kind/rank combinations supported by the framework are: ranks 1 to 7, type real of kind *4 or *8, and type integer of kind *1, *2, *4, or *8.
The arguments are:

field  The ESMF_Field to query.
ptr  An unassociated Fortran pointer of the proper Type, Kind, and Rank as the data in the Field. When this call returns successfully, the pointer will now point to the data in the Field. This is either a reference or a copy, depending on the setting of the following argument.

[copyflag]  Defaults to ESMF_DATA_REF. If set to ESMF_DATA_COPY, a separate copy of the data will be allocated and the pointer will point at the copy. If a new copy of the data is made, the caller is responsible for deallocating the space.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.6.7 ESMF_FieldSetDataPointer - Add data to a field directly by Fortran pointer

INTERFACE:

! Private name; call using ESMF_FieldSetDataPointer()
subroutine ESMF_FieldSetDataPointer<rank><type><kind>(field, &
dataPointer, copyflag, indexflag, rc)

ARGUMENTS:

type(ESMF_Field), intent(inout) :: field
<type> (ESMF_KIND_<kind>), dimension(<rank>), pointer :: dataPointer
integer, intent(in), optional :: haloWidth
type(ESMF_CopyFlag), intent(in), optional :: copyflag
type(ESMF_IndexFlag), intent(in), optional :: indexflag
integer, intent(out), optional :: rc

DESCRIPTION:

Set data in an ESMF_Field directly from a Fortran pointer. Valid type/kind/rank combinations supported by the framework are: ranks 1 to 7, type real of kind *4 or *8, and type integer of kind *1, *2, *4, or *8.
The arguments are:
field The ESMF_Field to query.

dataPointer An associated Fortran pointer of the proper Type, Kind, and Rank as the data in the Field. When this call returns successfully, the pointer will now point to the data in the Field. This is either a reference or a copy, depending on the setting of the following argument.

[copyflag] Defaults to ESMF_DATA_REF. If set to ESMF_DATA_COPY, a separate copy of the data will be allocated and the pointer will point at the copy. If a new copy of the data is made, the caller is responsible for deallocating the space.

[haloWidth] Defaults to 0. If specified, the halo width to add to all sides of the data array.

[indexflag] See Section 9.1.5 for possible values. Defaults to ESMF_INDEX_DELOCAL. If set to ESMF_INDEX_GLOBAL and the ESMF_Grid associated with the ESMF_Field is regular, then the lower bounds and upper bounds will be allocated with global index numbers corresponding to the grid.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

19.7 Class API: Field Communications

19.7.1 ESMF_FieldGather - Data gather operation on a Field

INTERFACE:

```fortran
subroutine ESMF_FieldGather(field, dstPET, array, blockingflag, &
   commhandle, rc)
```

ARGUMENTS:

```fortran
type(ESMF_Field), intent(inout) :: field
integer, intent(in) :: dstPET
type(ESMF_InternArray), intent(out) :: array
type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
```

DESCRIPTION:

Collect all local data associated with a distributed ESMF_Field into a new ESMF_Array which is created only on a single PET. This routine must be called collectively, that is, on all PETs in an ESMF_VM. The framework will create a new ESMF_Array to hold the resulting data only on the specified destination PET. After this call returns the array argument will be valid only on the dstPET and invalid on all other PETs. The input field will be unchanged; the routine creates a copy of the collected data.

The arguments are:

field ESMF_Field containing data to be gathered.

dstPET Destination PET number where the gathered data is to be returned.

array Newly created ESMF_Array containing the collected data on the specified PET. It is the size of the entire undecomposed grid. On all other PETs this argument returns an invalid object. Note that the user should not create an ESMF_Array before making this call; the ESMF_Array should be an uninitialized variable. When this routine returns, there will be a valid ESMF_Array only on the specified PET number, so code which will access the ESMF_Array should check the current PET number and only try to access it from a single PET.

[blockingflag] Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, the default is to do synchronous communications. Valid values for this flag are ESMF_BLOCKING and ESMF_NONBLOCKING. (This feature is not yet supported. All operations are synchronous.)
[commhandle] If the blockingflag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

19.7.2 ESMF_FieldHalo - Execute a halo operation on a Field

INTERFACE:

! Private name; call using ESMF_FieldHalo()
subroutine ESMF_FieldHaloRun(field, routehandle, blockingflag, &
   commhandle, halodirection, routeOptions, rc)

ARGUMENTS:

type(ESMF_Field), intent(inout) :: field

type(ESMF_RouteHandle), intent(inout) :: routehandle

type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

type(ESMF_CommHandle), intent(in), optional :: commhandle

type(ESMF_HaloDirection), intent(in), optional :: halodirection

type(ESMF_RouteOptions), intent(in), optional :: routeOptions

integer, intent(out), optional :: rc

DESCRIPTION:

Perform a halo operation over the data in an ESMF_Field. This routine updates the data inside the ESMF_Field in place.

The arguments are:

field ESMF_Field containing data to be haloed.

routehandle ESMF_RouteHandle which was returned by the corresponding ESMF_FieldHaloStore() call. It is associated with the precomputed data movement and communication needed to perform the halo operation.

[blockingflag] Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, default is what was specified at Store time. If both was specified at Store time, this defaults to blocking. Valid values for this flag are ESMF_BLOCKING and ESMF_NONBLOCKING. (This feature is not yet supported. All operations are synchronous.)

[commhandle] If the blockingflag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.

[halodirection] Optional argument to restrict halo direction to a subset of the possible halo directions. If not specified, the halo is executed along all boundaries. This option is used only in the situation where the halo must be precomputed at this time. (This feature is not yet supported.)

[routeOptions] Not normally specified. Specify which internal strategy to select when executing the communication needed to update the halo. See Section 26.3 for possible values.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
19.7.3  ESMF_FieldHaloRelease - Release resources associated w/ handle

INTERFACE:

    subroutine ESMF_FieldHaloRelease(routehandle, rc)

ARGUMENTS:

    type(ESMF_RouteHandle), intent(inout) :: routehandle
    integer, intent(out), optional :: rc

DESCRIPTION:

Release all stored information about the halo operation associated with this ESMF_RouteHandle.
The arguments are:

routehandle  ESMF_RouteHandle associated with this halo operation.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.7.4  ESMF_FieldHaloStore - Precompute a halo operation on a Field

INTERFACE:

    subroutine ESMF_FieldHaloStore(field, routehandle, halodirection, &
                                      routeOptions, rc)

ARGUMENTS:

    type(ESMF_Field), intent(inout) :: field
    type(ESMF_RouteHandle), intent(inout) :: routehandle
    type(ESMF_HaloDirection), intent(in), optional :: halodirection
    type(ESMF_RouteOptions), intent(in), optional :: routeOptions
    integer, intent(out), optional :: rc

DESCRIPTION:

Precompute the data movement or communication operations needed to perform a halo operation over the data in an ESMF_Field. The list of operations will be associated internally to the framework with the ESMF_RouteHandle object. To perform the actual halo operation the ESMF_FieldHalo() routine must be called with the ESMF_Field containing the data to be updated and the ESMF_RouteHandle computed during this store call. If more than one ESMF_Field has identical ESMF_Grids and ESMF_FieldDataMaps, then the same ESMF_RouteHandle can be computed once and used in multiple executions of the halo operation.
The arguments are:

field  ESMF_Field containing data to be haloed.

routehandle  ESMF_RouteHandle which will be returned after being associated with the precomputed information for a halo operation on this ESMF_Field. This handle must be supplied at run time to execute the halo.

halodirection  Optional argument to restrict halo direction to a subset of the possible halo directions. If not specified, the halo is executed along all boundaries. (This feature is not yet supported.)

routeOptions  Not normally specified. Specify which internal strategy to select when executing the communication needed to update the halo. See Section 26.3 for possible values.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
19.7.5  ESMF_FieldHaloValidate - Do extensive error checking on Halo

INTERFACE:

    subroutine ESMF_FieldHaloValidate(field, routehandle, halodirection, rc)

ARGUMENTS:

    type(ESMF_Field), intent(inout) :: field
    type(ESMF_RouteHandle), intent(in) :: routehandle
    type(ESMF_HaloDirection), intent(in), optional :: halodirection
    integer, intent(out), optional :: rc

DESCRIPTION:

Do extensive error checking on the incoming ESMF_Field and the precomputed ESMF_RouteHandle which was constructed to perform the communication necessary to execute the halo operation. If the inputs are not compatible with each other, for example if the handle was precomputed based on a different size ESMF_Field, an error message will be logged and an error returned from this routine.

The arguments are:

field  ESMF_Field containing data to be haloed.
routehandle  ESMF_RouteHandle which was returned by the corresponding ESMF_FieldHaloStore() call. It is associated with the precomputed data movement and communication needed to perform the halo operation.
halodirection  Optional argument to restrict halo direction to a subset of the possible halo directions. If not specified, the halo is executed along all boundaries. This option is used only in the situation where the halo must be precomputed at this time. (This feature is not yet supported.)
rc  Return code; equals ESMF_SUCCESS if there are no errors.

19.7.6  ESMF_FieldRedist - Data redistribution operation on a Field

INTERFACE:

    ! Private name; call using ESMF_FieldRedist()
    subroutine ESMF_FieldRedistAllinOne(srcField, dstField, parentVM, &
                                          blockingflag, commhandle, routeOptions, rc)

ARGUMENTS:

    type(ESMF_Field), intent(inout) :: srcField
    type(ESMF_Field), intent(inout) :: dstField
    type(ESMF_VM), intent(in) :: parentVM
    type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
    type(ESMF_CommHandle), intent(inout), optional :: commhandle
    type(ESMF_RouteOptions), intent(inout), optional :: routeOptions
    integer, intent(out), optional :: rc

DESCRIPTION:

Perform a redistribution operation over the data in an ESMF_Field. This version does not take a routehandle and computes, runs, and releases the communication information in a single subroutine. It should be used when a redist operation will be done only a single time; otherwise computing and reusing a communication pattern will be more efficient. This routine reads the source field and leaves the data untouched. It reads the ESMF_Grid and
ESMF_FieldDataMap from the destination field and updates the array data in the destination. The ESMF_Grids may have different decompositions (different ESMF_DELayouts) or different data maps, but the source and destination grids must describe the same set of coordinates. Unlike ESMF_FieldRegrid this routine does not do interpolation, only data movement.

The arguments are:

- **srcField** ESMF_Field containing source data.
- **dstField** ESMF_Field containing destination grid.
- **parentVM** ESMF_VM which encompasses both ESMF.Fields, most commonly the VM of the Coupler if the redistribution is inter-component, but could also be the individual VM for a component if the redistribution is intra-component.
- **blockingflag** Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, default is to do synchronous communication. Valid values for this flag are ESMF_BLOCKING and ESMF_NONBLOCKING. (This feature is not yet supported. All operations are synchronous.)
- **commhandle** If the blockingflag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.
- **routeOptions** Not normally specified. Specify which internal strategy to select when executing the communication needed to redistribute the data. See Section 26.3 for possible values.
- **rc** Return code; equals ESMF_SUCCESS if there are no errors.

### 19.7.7 ESMF_FieldRedist - Data redistribution operation on a Field

**INTERFACE:**

```fortran
! Private name; call using ESMF_FieldRedist()
subroutine ESMF_FieldRedistRun(srcField, dstField, routehandle, &
   blockingflag, commhandle, routeOptions, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_Field), intent(inout) :: srcField
type(ESMF_Field), intent(inout) :: dstField
type(ESMF_RouteHandle), intent(inout) :: routehandle
type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
type(ESMF_CommHandle), intent(inout), optional :: commhandle
type(ESMF_RouteOptions), intent(in), optional :: routeOptions
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Perform a redistribution operation over the data in an ESMF_Field. This routine reads the source field and leaves the data untouched. It reads the ESMF_Grid and ESMF_FieldDataMap from the destination field and updates the array data in the destination. The ESMF_Grids may have different decompositions (different ESMF_DELayouts) or different data maps, but the source and destination grids must describe the same set of coordinates. Unlike ESMF_FieldRegrid this routine does not do interpolation, only data movement.

The arguments are:

- **srcField** ESMF_Field containing source data.
- **dstField** ESMF_Field containing destination grid.
routehandle  ESMF_RouteHandle which was returned by the corresponding ESMF_FieldRedistStore() call. It is associated with the precomputed data movement and communication needed to perform the redistribution operation.

[blockingflag]  Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, default is to do synchronous communication. Valid values for this flag are ESMF_BLOCKING and ESMF_NONBLOCKING. (This feature is not yet supported. All operations are synchronous.)

[commhandle]  If the blockingflag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.

[routeOptions]  Not normally specified. Specify which internal strategy to select when executing the communication needed to redistribute the data. See Section 26.3 for possible values.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.7.8  ESMF_FieldRedistRelease - Release resources associated w/ handle

INTERFACE:

    subroutine ESMF_FieldRedistRelease(routehandle, rc)

ARGUMENTS:

    type(ESMF_RouteHandle), intent(inout) :: routehandle
    integer, intent(out), optional :: rc

DESCRIPTION:

Release all stored information about the redistribution associated with this ESMF_RouteHandle.

The arguments are:

routehandle  ESMF_RouteHandle associated with this redistribution.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.7.9  ESMF_FieldRedistStore - Data redistribution operation on a Field

INTERFACE:

    subroutine ESMF_FieldRedistStore(srcField, dstField, parentVM, &
    routeOptions, routehandle, rc)

ARGUMENTS:

    type(ESMF_Field), intent(inout) :: srcField
    type(ESMF_Field), intent(inout) :: dstField
    type(ESMF_VM), intent(in) :: parentVM
    type(ESMF_RouteHandle), intent(out) :: routehandle
    type(ESMF_RouteOptions), intent(in), optional :: routeOptions
    integer, intent(out), optional :: rc
DESCRIPTION:

Precompute the data movement or communications operations needed to accomplish a data redistribution operation over the data in an ESMF_Field. Data redistribution differs from regridding in that redistribution does no interpolation, only a 1-for-1 movement of data from one location to another. Therefore, while the ESMF_Grids for the source and destination may have different decompositions (different ESMF_DELayouts) or different data maps, the source and destination grids must describe the same set of coordinates.

The arguments are:

**srcField** ESMF_Field containing source data.

**dstField** ESMF_Field containing destination grid.

**parentVM** ESMF_VM which encompasses both ESMF_Fields, most commonly the VM of the Coupler if the redistribution is inter-component, but could also be the individual VM for a component if the redistribution is intra-component.

[routeOptions] Not normally specified. Specify which internal strategy to select when executing the communication needed to execute the See Section for possible values.

**routehandle** ESMF_RouteHandle which will be used to execute the redistribution when ESMF_FieldRedist is called.

**rc** Return code; equals ESMF_SUCCESS if there are no errors.

---

### 19.7.10 ESMF_FieldRedistStore - Data redistribution operation on a Field

**INTERFACE:**

```fortran
subroutine ESMF_FieldRedistStoreNew(srcField, decompIds, dstField, &
parentVM, routeOptions, &
routehandle, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_Field), intent(inout) :: srcField
integer, dimension(:,), intent(in) :: decompIds
type(ESMF_Field), intent(out) :: dstField
type(ESMF_VM), intent(in) :: parentVM
type(ESMF_RouteOptions), intent(in), optional :: routeOptions
type(ESMF_RouteHandle), intent(inout) :: routehandle
integer, intent(inout), optional :: rc
```

**DESCRIPTION:**

Precompute a redistribution operation over the data in a ESMF_Field. This routine reads the source field and leaves the data untouched. This version of RedistStore creates the destination ESMF_Field and its underlying ESMF_Grid and ESMF_FieldDataMap from the source grid and input decompIds. Unlike ESMF_FieldRegrid this routine does not do interpolation, only data movement.

The arguments are:

**srcField** ESMF_Field containing source data.

**decompIds** Array of decomposition identifiers.

**dstField** ESMF_Field containing destination grid.
parentVM  ESMF_VM which encompasses both ESMF_Fields, most commonly the VM of the Coupler if the redistribution is inter-component, but could also be the individual VM for a component if the redistribution is intra-component.

[routeOptions]  Not normally specified. Specify which internal strategy to select when executing the communication needed to execute the redistribution. See Section 26.3 for possible values.

routehandle  ESMF_RouteHandle which will be used to execute the redistribution when ESMF_FieldRedist is called.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.7.11  ESMF_FieldRedistValidate - Do extensive error checking on Redist

INTERFACE:

subroutine ESMF_FieldRedistValidate(srcField, dstField, routehandle, rc)

ARGUMENTS:

type(ESMF_Field), intent(inout) :: srcField
type(ESMF_Field), intent(inout) :: dstField
type(ESMF_RouteHandle), intent(inout) :: routehandle
integer, intent(out), optional :: rc

DESCRIPTION:

Do extensive error checking on the incoming ESMF_Field and the precomputed ESMF_RouteHandle which was constructed to perform the communication necessary to execute the redist operation. If the inputs are not compatible with each other, for example if the handle was precomputed based on different sized ESMF_Fields, an error message will be logged and an error returned from this routine.

The arguments are:

srcField  ESMF_Field containing source data.

dstField  ESMF_Field containing destination grid.

routehandle  ESMF_RouteHandle which was returned by the corresponding ESMF_FieldRedistStore() call. It is associated with the precomputed data movement and communication needed to perform the redistribution operation.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

19.7.12  ESMF_FieldRegrid - Data regrid operation on a Field

INTERFACE:

! Private name; call using ESMF_FieldRegrid()
subroutine ESMF_FieldRegridAllinOne(srcField, dstField, &
parentVM, regridmethod, regridnorm, &
srcMask, dstMask, blockingflag, &
commhandle, routeOptions, rc)

ARGUMENTS:
Perform a regrid operation over the data in an ESMF_Field. This version does not take a routehandle and computes, runs, and releases the communication information in a single subroutine. It should be used when a regrid operation will be done only a single time; otherwise computing and reusing a communication pattern will be more efficient. This routine reads the source field and leaves the data untouched. It uses the ESMF_Grid and ESMF_FieldDataMap information in the destination field to control the transformation of data. The array data in the destination field is overwritten by this call.

The arguments are:

**srcField** ESMF_Field containing source data.

**dstField** ESMF_Field containing destination grid and data map.

**parentVM** ESMF_VM which encompasses both ESMF_Field, most commonly the VM of the Coupler if the regridding is inter-component, but could also be the individual VM for a component if the regridding is intra-component.

**regridmethod** Type of regridding to do. A set of predefined methods are supplied.

**[regridnorm]** Normalization option, only for specific regrid types.

**[srcMask]** Optional ESMF_Mask identifying valid source data. (Not yet implemented.)

**[dstMask]** Optional ESMF_Mask identifying valid destination data. (Not yet implemented.)

**[blockingflag]** Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, default is to do synchronous communications. Valid values for this flag are ESMF_BLOCKING and ESMF_NONBLOCKING. (This feature is not yet supported. All operations are synchronous.)

**[commhandle]** If the blockingflag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.

**[routeOptions]** Not normally specified. Specify which internal strategy to select when executing the communication needed to execute the regrid. See Section 26.3 for possible values.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

---

19.7.13  **ESMF_FieldRegrid - Data regrid operation on a Field**

**INTERFACE:**
subroutine ESMF_FieldRegridRun(srcField, dstField, routehandle, &
srcMask, dstMask, blockingflag, &
commhandle, routeOptions, rc)

ARGUMENTS:

  type(ESMF_Field), intent(inout) :: srcField
  type(ESMF_Field), intent(inout) :: dstField
  type(ESMF_RouteHandle), intent(inout) :: routehandle
  type(ESMF_Mask), intent(in), optional :: srcMask
  type(ESMF_Mask), intent(in), optional :: dstMask
  type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
  type(ESMF_CommHandle), intent(inout), optional :: commhandle
  type(ESMF_RouteOptions), intent(in), optional :: routeOptions
  integer, intent(out), optional :: rc

DESCRIPTION:

Perform a regrid operation over the data in an ESMF_Field. This routine reads the source field and leaves the data untouched. It uses the ESMF_Grid and ESMF_FieldDataMap information in the destination field to control the transformation of data. The array data in the destination field is overwritten by this call.

The arguments are:

srcField ESMF_Field containing source data.
dstField ESMF_Field containing destination grid and data map.
routehandle ESMF_RouteHandle which was returned by the corresponding ESMF_FieldRegridStore() call. It is associated with the precomputed data movement and communication needed to perform the regrid operation.
[srcMask] Optional ESMF_Mask identifying valid source data. (Not yet implemented.)
[dstMask] Optional ESMF_Mask identifying valid destination data. (Not yet implemented.)
[blockingflag] Optional argument which specifies whether the operation should wait until complete before returning or return as soon as the communication between DEs has been scheduled. If not present, default is to do synchronous communications. Valid values for this flag are ESMF_BLOCKING and ESMF_NONBLOCKING. (This feature is not yet supported. All operations are synchronous.)
[commhandle] If the blockingflag is set to ESMF_NONBLOCKING this argument is required. Information about the pending operation will be stored in the ESMF_CommHandle and can be queried or waited for later.
[routeOptions] Not normally specified. Specify which internal strategy to select when executing the communication needed to execute the regrid. See Section 26.3 for possible values.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

19.7.14 ESMF_FieldRegridRelease - Release information for this handle

INTERFACE:

    subroutine ESMF_FieldRegridRelease(routehandle, rc)

ARGUMENTS:
type(ESMF_RouteHandle), intent(inout) :: routehandle
integer, intent(out), optional :: rc

DESCRIPTION:

Release all stored information about the regridding associated with this ESMF_RouteHandle. The arguments are:

routehandle ESMF_RouteHandle associated with this regrid operation.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

19.7.15 ESMF_FieldRegridStore - Data regrid operation on a Field

INTERFACE:

subroutine ESMF_FieldRegridStore(srcField, dstField, parentVM, &
    routehandle, regridmethod, regridnorm, &
    srcMask, dstMask, routeOptions, rc)

ARGUMENTS:

type(ESMF_Field), intent(inout) :: srcField
type(ESMF_Field), intent(inout) :: dstField
type(ESMF_VM), intent(in) :: parentVM
type(ESMF_RouteHandle), intent(inout) :: routehandle
type(ESMF_RegridMethod), intent(in) :: regridmethod
type(ESMF_RegridNormOpt), intent(in), optional :: regridnorm
type(ESMF_Mask), intent(in), optional :: srcMask
type(ESMF_Mask), intent(in), optional :: dstMask
type(ESMF_RouteOptions), intent(in), optional :: routeOptions
integer, intent(out), optional :: rc

DESCRIPTION:

Precompute the data movement or communications operations plus the interpolation information needed to execute a regrid operation which will move and transform data from the source field to the destination field. This information is associated with the ESMF_RouteHandle which must then be supplied during the actual execution of the regrid operation. The arguments are:

srcField ESMF_Field containing source data.

dstField ESMF_Field containing destination grid and data map.

parentVM ESMF_VM which encompasses both ESMF_Fields, most commonly the vm of the Coupler if the regridding is inter-component, but could also be the individual vm for a component if the regridding is intra-component.

routehandle Output from this call, identifies the precomputed work which will be executed when ESMF_FieldRegrid is called.

regridmethod Type of regridding to do. A set of predefined methods are supplied.

regridnorm Normalization option, only for specific regrid types.

srcMask Optional ESMF_Mask identifying valid source data.
[dstMask] Optional ESMF_Mask identifying valid destination data.

[routeOptions] Not normally specified. Specify which internal strategy to select when executing the communication needed to execute the regrid. See Section 19.7.3 for possible values.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

19.7.16 ESMF_FieldRegridValidate - Do extensive error checking on Regrid

INTERFACE:

    subroutine ESMF_FieldRegridValidate(srcField, dstField, routehandle, &
    srcMask, dstMask, rc)

ARGUMENTS:

    type(ESMF_Field), intent(inout) :: srcField
    type(ESMF_Field), intent(inout) :: dstField
    type(ESMF_RouteHandle), intent(inout) :: routehandle
    type(ESMF_Mask), intent(in), optional :: srcMask
    type(ESMF_Mask), intent(in), optional :: dstMask
    integer, intent(out), optional :: rc

DESCRIPTION:

Do extensive error checking on the incoming ESMF_Field and the precomputed ESMF_RouteHandle which was constructed to perform the communication necessary to execute the regrid operation. If the inputs are not compatible with each other, for example if the handle was precomputed based on different sized ESMF_Fields, an error message will be logged and an error returned from this routine.

The arguments are:

srcField ESMF_Field containing source data.

dstField ESMF_Field containing destination grid and data map.

routehandle ESMF_RouteHandle which was returned by the corresponding ESMF_FieldRegridStore() call. It is associated with the precomputed data movement and communication needed to perform the halo operation.

[srcMask] Optional ESMF_Mask identifying valid source data. (Not yet implemented.)

[dstMask] Optional ESMF_Mask identifying valid destination data. (Not yet implemented.)

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

20 FieldDataMap Class

20.1 Description

The FieldDataMap class describes how vector fields are interleaved. Since the ESMF Field class does not yet fully support vector fields, this class is simply a placeholder.
20.2 Use and Examples

FieldDataMaps are shallow objects. They can be declared as local (stack) variables in subroutines. They do not need a create or destroy method. There is a method to set the initial default values, to set and query individual values, and to print the contents in human-readable form for output or debugging.

! !PROGRAM: ESMF_FieldDataMapEx - Field DataMap manipulation examples
! !DESCRIPTION:
! ! This program shows examples of Field DataMap set and get usage
!---------------------------------------------------------------

! ESMF Framework module
use ESMF_Mod
implicit none

! local variables
type(ESMF_FieldDataMap) :: fieldDM
type(ESMF_RelLoc) :: relativeLocation
integer :: dataRank, dataIndexList(ESMF_MAXDIM)
! integer :: counts(ESMF_MAXDIM)
! type(ESMF_IndexOrder) :: indexOrder

! return code
integer:: rc

! initialize ESMF framework
call ESMF_Initialize(rc=rc)

20.2.1 Setting Field DataMap Defaults and Invalidation

This example shows how to set the default values in an ESMF_FieldDataMap, and how to intentionally mark an ESMF_FieldDataMap invalid.

! Set up a default data map for a Field with 2D data,
! and a 1-for-1 mapping with the Grid.
call ESMF_FieldDataMapSetDefault(fieldDM, 2, rc=rc)

print *, "Default values for FieldDataMap = "
call ESMF_FieldDataMapPrint(fieldDM, rc=rc)

relativeLocation = ESMF_CELL_NECORNER
call ESMF_FieldDataMapSetDefault(fieldDM, ESMF_INDEX_IJK, &
horzRelloc=relativeLocation, rc=rc)

print *, "FieldDataMap after set = "
call ESMF_FieldDataMapPrint(fieldDM, rc=rc)
20.2.2 Setting Field DataMap Values

This example shows how to set values in an ESMF_FieldDataMap.

```fortran
relativeLocation = ESMF_CELL_CENTER
call ESMF_FieldDataMapSet(fieldDM, dataRank=2, &
  horzRelloc=relativeLocation, rc=rc)
```

print *, "FieldDataMap after set = "
call ESMF_FieldDataMapPrint(fieldDM, rc=rc)

20.2.3 Getting Field DataMap Values

This example shows how to query an ESMF_FieldDataMap.

```fortran
call ESMF_FieldDataMapGet(fieldDM, dataRank, dataIndexList, &
  horzRelloc=relativeLocation, rc=rc)
```

print *, "Returned values from Field DataMap:",
print *, "data rank: ", dataRank
print *, "mapping of grid to data indices: ", dataIndexList

! finalize ESMF framework
call ESMF_Finalize(rc=rc)
```

end program ESMF_FieldDataMapEx

20.3 Restrictions and Future Work

1. **No support for vector Fields.** While vector interleave can be set and queried in a FieldDataMap, no support for it exists in other parts of this version of ESMF, since the Field class does not support vector Fields yet. The user can create a separate Field for each vector component.

20.4 Design and Implementation Notes

The FieldDataMap contains information needed by other objects in order to correctly handle data and grid operations. It is implemented as a simple Fortran derived type, and contains an ArrayDataMap object as well as additional information needed at the Field level.
20.5  Class API

20.5.1  ESMF_FieldDataMapGet - Get values from a FieldDataMap

INTERFACE:

```
subroutine ESMF_FieldDataMapGet(fielddatamap, dataRank, dataIndexList, counts, &
    horzRelloc, vertRelloc, rc)
```

ARGUMENTS:

- `type(ESMF_FieldDataMap), intent(inout) :: fielddatamap`
- `integer, intent(out), optional :: dataRank`
- `integer, dimension(:,), intent(out), optional :: dataIndexList`
- `integer, dimension(:,), intent(out), optional :: counts`
- `type(ESMF_RelLoc), intent(out), optional :: horzRelloc`
- `type(ESMF_RelLoc), intent(out), optional :: vertRelloc`
- `integer, intent(out), optional :: rc`

DESCRIPTION:

Return information about this ESMF_FieldDataMap.

The arguments are:

- `fielddatamap` An ESMF_FieldDataMap.
- `[datarank]` The number of dimensions in the data ESMF_Array.
- `[dataIndexList]` An integer array, datarank long, which specifies the mapping between rank numbers in the ESMF_Grid and the ESMF_Array. If there is no correspondence (because the ESMF_Array has a higher rank than the ESMF_Grid) the index value will be 0.
- `[counts]` An integer array, with length (datarank minus the grid rank). Each entry is the default item count which would be used for those ranks which do not correspond to grid ranks when creating an ESMF_Field using only an ESMF_ArraySpec and an ESMF_ArrayDataMap.
- `[horzRelloc]` Relative location of data per grid cell/vertex in the horizontal grid.
- `[vertRelloc]` Relative location of data per grid cell/vertex in the vertical grid.
- `[rc]` Return code; equals ESMF_SUCCESS if there are no errors.

20.5.2  ESMF_FieldDataMapPrint - Print a FieldDataMap

INTERFACE:

```
subroutine ESMF_FieldDataMapPrint(fielddatamap, options, rc)
```

ARGUMENTS:

- `type(ESMF_FieldDataMap), intent(inout) :: fielddatamap`
- `character (len = '*), intent(in), optional :: options`
- `integer, intent(out), optional :: rc`

DESCRIPTION:

Prints information about the fielddatamap to stdout.

The arguments are:
20.5.3 ESMF_FieldDataMapSet - Set values in a FieldDataMap

INTERFACE:

```fortran
subroutine ESMF_FieldDataMapSet(fielddatamap, dataRank, dataIndexList, counts, &
     horzRelloc, vertRelloc, rc)
```

ARGUMENTS:

```fortran
type(ESMF_FieldDataMap), intent(inout) :: fielddatamap
integer, intent(in), optional :: dataRank
integer, dimension(:), intent(in), optional :: dataIndexList
integer, dimension(:), intent(in), optional :: counts
     type(ESMF_RelLoc), intent(in), optional :: horzRelloc
     type(ESMF_RelLoc), intent(in), optional :: vertRelloc
integer, intent(out), optional :: rc
```

DESCRIPTION:

Set values in an ESMF_FieldDataMap.

The arguments are:

- **fielddatamap** An ESMF_FieldDataMap.
- **datarank** The number of dimensions in the data ESMF_Array.
- **dataIndexList** An integer array, dataRank long, which specifies the mapping between rank numbers in the ESMF_Grid and the ESMF_Array. If there is no correspondence (because the ESMF_Array has a higher rank than the ESMF_Grid) the index value must be 0.
- **counts** An integer array, with length (datarank minus the grid rank). If the ESMF_Array is a higher rank than the ESMF_Grid, the additional dimensions may optionally each have an item count defined here. This allows ESMF_FieldCreate() to take an ESMF_ArraySpec and an ESMF_ArrayDataMap and create the appropriately sized ESMF_Array for each DE. These values are unneeded if the ranks of the data and grid are the same, and ignored if ESMF_FieldCreate() is called with an already-created ESMF_Array.
- **horzRelloc** Relative location of data per grid cell/vertex in the horizontal grid.
- **vertRelloc** Relative location of data per grid cell/vertex in the vertical grid.
- **rc** Return code; equals ESMF_SUCCESS if there are no errors.

20.5.4 ESMF_FieldDataMapSetDefault - Set FieldDataMap default values

INTERFACE:

```fortran
! Private name; call using ESMF_FieldDataMapSetDefault()
subroutine ESMF_FieldDataMapSetDefExplicit(fielddatamap, dataRank, &
     dataIndexList, counts, &
     horzRelloc, vertRelloc, rc)
```
ARGUMENTS:

    type(ESMF_FieldDataMap) :: fielddatamap
    integer, intent(in) :: dataRank
    integer, dimension(:,), intent(in), optional :: dataIndexList
    integer, dimension(:,), intent(in), optional :: counts
    type(ESMF_RelLoc), intent(in), optional :: horzRelloc
    type(ESMF_RelLoc), intent(in), optional :: vertRelloc
    integer, intent(out), optional :: rc

DESCRIPTION:

Set default values of an ESMF_FieldDataMap. This differs from ESMF_FieldDataMapSet() in that all values which are not specified here will be overwritten with default values.

fielddatamap An ESMF_FieldDataMap.

datarank The number of dimensions in the data ESMF_Array.

[dataIndexList] An integer array, datarank long, which specifies the mapping between rank numbers in the ESMF_Grid and the ESMF_Array. If there is no correspondance (because the ESMF_Array has a higher rank than the ESMF_Grid) the index value must be 0. The default is a 1-to-1 mapping with the ESMF_Grid.

[counts] An integer array, with length (datarank minus the grid rank). If the ESMF_Array is a higher rank than the ESMF_Grid, the additional dimensions may optionally each have an item count defined here. This allows ESMF_FieldCreate() to take an ESMF_ArraySpec and an ESMF_ArrayDataMap and create the appropriately sized ESMF_Array for each DE. These values are unneeded if the ranks of the data and grid are the same, and ignored if ESMF_FieldCreate() is called called with an already-created ESMF_Array. If unspecified, the default lengths are 1.

[horzRelloc] Relative location of data per grid cell/vertex in the horizontal grid. The default is ESMF_CELL_CENTER.

[vertRelloc] Relative location of data per grid cell/vertex in the vertical grid. The default is ESMF_CELL_UNDEFINED.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

20.5.5 ESMF_FieldDataMapSetDefault - Set FieldDataMap default values

INTERFACE:

    ! Private name; call using ESMF_FieldDataMapSetDefault()
    subroutine ESMF_FieldDataMapSetDefIndex(fielddatamap, indexorder, counts, &
                                                 horzRelloc, vertRelloc, rc)

ARGUMENTS:

    type(ESMF_FieldDataMap) :: fielddatamap
    type(ESMF_IndexOrder), intent(in) :: indexorder
    integer, dimension(:,), intent(in), optional :: counts
    type(ESMF_RelLoc), intent(in), optional :: horzRelloc
    type(ESMF_RelLoc), intent(in), optional :: vertRelloc
    integer, intent(out), optional :: rc

DESCRIPTION:

Set default values of an ESMF_FieldDataMap. This differs from ESMF_FieldDataMapSet() in that all values which are not specified here will be overwritten with default values.
fielddatamap  An ESMF_FieldDataMap.

indexorder  An ESMF_DataIndexOrder which specifies one of several common predefined mappings between the grid and data ranks. This is simply a convenience for the common cases; there is a more general form of this call which allows the mapping to be specified as an integer array of index numbers directly.

[counts]  An integer array, with length (datarank minus the grid rank). If the ESMF_Array is a higher rank than the ESMF_Grid, the additional dimensions may optionally each have an item count defined here. This allows ESMF_FieldCreate() to take an ESMF_ArraySpec and an ESMF_ArrayDataMap and create the appropriately sized ESMF_Array for each DE. These values are unneeded if the ranks of the data and grid are the same, and ignored if ESMF_FieldCreate() is called with an already-created ESMF_Array. If unspecified, the default lengths are 1.

[horzRelloc]  Relative location of data per grid cell/vertex in the horizontal grid. The default is ESMF_CELL_CENTER.

[vertRelloc]  Relative location of data per grid cell/vertex in the vertical grid. The default is ESMF_CELL_UNDEFINED.

20.5.6  ESMF_FieldDataMapSetInvalid - Set FieldDataMap to an invalid status

INTERFACE:

    subroutine ESMF_FieldDataMapSetInvalid(fielddatamap, rc)

ARGUMENTS:

    type(ESMF_FieldDataMap), intent(inout) :: fielddatamap
    integer, intent(out), optional :: rc

DESCRIPTION:

Set the contents of an ESMF_FieldDataMap to an invalid status.
The arguments are:

fielddatamap  An ESMF_FieldDataMap.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

20.5.7  ESMF_FieldDataMapValidate - Check validity of a FieldDataMap

INTERFACE:

    subroutine ESMF_FieldDataMapValidate(fielddatamap, options, rc)

ARGUMENTS:

    type(ESMF_FieldDataMap), intent(inout) :: fielddatamap
    character (len = *) , intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Validates that the fielddatamap is internally consistent. Currently this method determines if the fielddatamap is uninitialized or already destroyed. The method returns an error code if problems are found.
The arguments are:

fielddatamap  ESMF_FieldDataMap to validate.

[options]  Validation options are not yet supported.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
21 ArraySpec Class

21.1 Description
An ArraySpec is a very simple class that contains type, kind, and rank information about an array. For those unfamiliar with Fortran:

- **Type** describes the data type of the elements in the array, such as integer, real, logical, etc.;
- **Kind** describes their precision; and
- **Rank** refers to their dimensionality.

The only methods that are associated with the ArraySpec class are those that allow you to set and retrieve this type, kind, and rank information.

21.2 Use and Examples
The ArraySpec is passed in as an argument at Field and Bundle creation in order to describe an Array that will be allocated or attached at a later time. There are any number of situations in which this approach is useful. One common example is a case in which the user wants to create a very flexible export State with many diagnostic variables predefined, but only a subset desired and consequently allocated for a particular run.

```fortran
! PROGRAM: ESMF_ArraySpecEx - ArraySpec manipulation examples
!
! DESCRIPTION:
!
! This program shows examples of ArraySpec set and get usage
!-------------------------------------------------------------

! ESMF Framework module
use ESMF_Mod
implicit none

! local variables
type(ESMF_ArraySpec) :: arrayDS
integer :: myrank
type(ESMF_DataType) :: mytype
type(ESMF_DataKind) :: mykind

! return code
integer:: rc

! initialize ESMF framework
call ESMF_Initialize(rc=rc)
```

21.2.1 Setting ArraySpec Values
This example shows how to set values in an ESMF_ArraySpec.

```fortran
call ESMF_ArraySpecSet(arrayDS, rank=2, type=ESMF_DATA_REAL, &
kind=ESMF_R8, rc=rc)
```
21.2.2 Getting ArraySpec Values

This example shows how to query an ESMF_ArraySpec.

```fortran
    call ESMF_ArraySpecGet(arrayDS, myrank, mytype, mykind, rc)
    print *, "Returned values from ArraySpec:"
    print *, "rank =", myrank

! finalize ESMF framework
    call ESMF_Finalize(rc=rc)

end program ESMF_ArraySpecEx
```

21.3 Restrictions and Future Work

1. Limit on rank. The values for type, kind and rank passed into the ArraySpec class are subject to the same limitations as Arrays. The maximum array rank is 7, which is the highest rank supported by Fortran.

21.4 Design and Implementation Notes

The information contained in an ESMF_ArraySpec is used to create ESMF_Array objects. ESMF_ArraySpec is a shallow class, and only set and get methods are needed. They do not need to be created or destroyed.

21.5 Class API

21.5.1 ESMF_ArraySpecGet - Get values from an ArraySpec

**INTERFACE:**

```fortran
subroutine ESMF_ArraySpecGet(arrayspec, rank, type, kind, rc)
ARGUMENTS:
    type(ESMF_ArraySpec), intent(inout) :: arrayspec
    integer, intent(out), optional :: rank
    type(ESMF_DataType), intent(out), optional :: type
    type(ESMF_DataKind), intent(out), optional :: kind
    integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Returns information about the contents of an ESMF_ArraySpec. The arguments are:

- `arrayspec` The ESMF_ArraySpec to query.
- `rank` ESMF_Array rank (dimensionality – 1D, 2D, etc). Maximum possible is 7D.
- `type` ESMF_Array type. Valid types include `ESMF_DATA_INTEGER, ESMF_DATA_REAL, ESMF_DATA_LOGICAL, ESMF_DATA_CHARACTER`.
- `kind` ESMF_Array kind. Valid kinds include `ESMF_I4, ESMF_I8, ESMF_R4, ESMF_R8, ESMF_C8, ESMF_C16`.
- `rc` Return code; equals ESMF_SUCCESS if there are no errors.
21.5.2 ESMF_ArraySpecSet - Set values for an ArraySpec using type,kind.rank

INTERFACE:

    ! Private name; call using ESMF_ArraySpecSet()
    subroutine ESMF_ArraySpecSetThree(arrayspec, rank, type, kind, rc)

ARGUMENTS:

    type(ESMF_ArraySpec), intent(inout) :: arrayspec
    integer, intent(in) :: rank
    type(ESMF_DataType), intent(in) :: type
    type(ESMF_DataKind), intent(in) :: kind
    integer, intent(out), optional :: rc

DESCRIPTION:

Creates a description of the data – the type, the dimensionality, etc. This specification can be used in an ESMF_ArrayCreate call with data to create a full ESMF_Array.
The arguments are:

arrayspec  The ESMF_ArraySpec to set.
rank      Array rank (dimensionality – 1D, 2D, etc). Maximum allowed is 7D.
type      ESMF_Array type. Valid types include ESMF_DATA_INTEGER, ESMF_DATA_REAL, ESMF_DATA_LOGICAL, ESMF_DATA_CHARACTER.
kind      ESMF_Array kind. Valid kinds include ESMF_I4, ESMF_I8, ESMF_R4, ESMF_R8, ESMF_C8, ESMF_C16.
[rc]      Return code; equals ESMF_SUCCESS if there are no errors.

21.5.3 ESMF_ArraySpecValidate - Validate ArraySpec internals

INTERFACE:

    subroutine ESMF_ArraySpecValidate(arrayspec, rc)

ARGUMENTS:

    type(ESMF_ArraySpec), intent(inout) :: arrayspec
    integer, intent(out), optional :: rc

DESCRIPTION:

Validates that the arrayspec is internally consistent. The method returns an error code if problems are found.
The arguments are:

arrayspec  Specified ESMF_ArraySpec object.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
22 Grid Class

22.1 Description

The ESMF Grid class represents all aspects of the computational domain and its decomposition in a parallel-processing environment, and must provide access to any necessary grid information to the rest of the ESMF. The ESMF Grid class is included in the Field class and the Gridded Component class and provides information needed in data communication methods like halo and redistribution. It has methods to internally generate a variety of simple grids or read in more complicated grids provided by a user (reading in grids is not yet implemented). The ESMF Grid class supports multi-component coupling by providing a common structure necessary for regridding.

ESMF Grids are currently assumed to be two-dimensional, logically-rectangular horizontal grids, with an optional vertical grid whose coordinates are independent of those of the horizontal grid. Each Grid is assigned a staggering in its create method call, which helps define the Grid according to typical Arakawa nomenclature. The staggering of the Grid sets the possible relative locations (ESMF_Rellocs) for the Fields associated with that Grid. This interaction between Grid and data placement is explained in detail in Section 22.1.1.

ESMF differentiates between global data, which describes a complete set of data, and DE-local data, which describes a distributed or decomposed chunk of data located on a single DE. The Grid class plays an integral role in this concept. A Grid is first instantiated, via a create call, on all DEs in its domain, but only in a global sense. By that we mean it stores only information about the global Grid, such as the number of grid cells and the coordinate extents, but has not generated all the information that will end up distributed, such as the cell coordinates. The Grid is then decomposed onto a given DELayout via an ESMF_Distribute() call. At that point, the DE-local data types are created and computed, so that on each DE there resides necessary global Grid information as well as its own DE-local Grid data. The DE-local data represented by an ESMF_Field is defined by the decomposition of the underlying ESMF_Grid.

22.1.1 Grids and Data Placement

An ESMF_Grid will support data placement only at specific cell relative locations, defined by its staggering and following typical Arakawa nomenclature. In ESMF, there are nine possible relative locations for data on a typical horizontal Grid cell, though each staggering will use a subset of them. These locations, with their corresponding ESMF_Rellocs, are illustrated in Figure 11.

ESMF_Grids are created with only those underlying structures, called subGrids, to support data at the specific cell locations defined by its given staggering. For example, an Arakawa C grid has some computational fields defined at the cell centers and other fields defined at specific cell face centers. An ESMF_Grid created with Arakawa C staggering will therefore make subGrids at the cell centers and specified cell faces (please see Section 22.2.4 for a complete list of implemented staggerings and their corresponding Rellocs). An example of the data locations for an Arakawa C_SE Grid is presented in Figure 12.

A vertical grid is also represented as one or more subGrids, each corresponding to a specific relative location along the defined vertical axis. The possible vertical relative locations are shown in Figure 13.

Note that the locations in the figure are represented by horizontal planes. The vertical relative location only defines the vertical coordinate of any point, and does not restrict the horizontal coordinates. This means that the horizontal and vertical Rellocs are independent of each other and can be combined in any way. For a complete list of implemented vertical staggerings and their corresponding Rellocs, please see Section 22.2.6. The staggering of the Grid limits the relative locations of any ESMF data class corresponding to it. When an ESMF_Field is created, it must be assigned to one (or more, in the case of a horizontal Grid with a vertical subGrid) of the appropriate subGrids present in the ESMF_Grid from which it is being created. Continuing the example above, an ESMF_Field created from a Grid with Arakawa C staggering would have to be defined at either the cell center or one of the prescribed cell faces.
Figure 11: Possible horizontal data locations for a representative computational cell.

Figure 12: Data locations for an Arakawa C_SE Grid.
22.1.2 Grid Distribution

The distribution (also referred to as decomposition) of the Grid on an ESMF_DisLayout determines the distribution as well for all related ESMF data classes. ESMF has currently implemented two different distribution strategies: block and arbitrary. In block distribution, logically rectangular chunks of the global Grid are represented as local decomposition elements (DEs), as shown in Figure 14.

In this distribution method, some of the geometry and connectivity of the global Grid are also true locally, in that most relative neighbor relationships are maintained. In arbitrary distribution, on the other hand, this is not necessarily so, since the user specifies lists of individual points to be grouped as DEs, as shown in Figure 15.

This method of distribution maintains local lists of cells without any sense of their relationship to one another beyond their global index. For that reason, some higher level communication methods (like halo) would be inefficient for arbitrarily distributed Grids and their corresponding data classes. ESMF has implemented this distribution primarily to support components with column physics, which typically do not require much communication. Currently for these objects ESMF only supports redistribution between itself and a block distribution of the same global Grid to allow users to move data from one representation to the other.

22.2 Grid Options

22.2.1 ESMF_CoordOrder

DESCRIPTION:

By default, ESMF assumes coordinates are ordered XYZ, which is also known as IJK ordering. This means that the first coordinate axis (for example, X in a cartesian system or latitude in a lat-lon system) is indexed first, the second coordinate axis is indexed second, and the third coordinate axis is indexed third in all internal arrays. The Grid class can be set to different ordering of coordinates, for example ZXY. This sets the default coordinate ordering

Figure 13: Possible vertical data locations for a representative computational cell.
Global Grid, decomposed into six logically rectangular pieces

Figure 14: Illustration of Block Distribution of a Grid.

Global Grid, decomposed into six vectors of arbitrary user-prescribed points

Distributed Elements (DEs) are local vectors of data from the global Grid

Figure 15: Illustration of Arbitrary Distribution of a Grid.
for all Fields created from the Grid as well (although there is also a way to override this default with a user-specified mapping between rank numbers in the Field and Grid during Field creation – please see the Field section for details). This feature is designed to provide the user with an simple mechanism to change the overall ordering of indices. The ESMF_CoordOrder parameter describes ordering options supported by ESMF. Valid values are:

- **ESMF_CoordOrder_UNKNOWN** Unknown or undefined coordinate ordering.
- **ESMF_CoordOrder_XYZ** The coordinates are ordered XYZ. For a 2D Grid, this defaults to XY mapping.
- **ESMF_CoordOrder_XZY** The coordinates are ordered XZY. For a 2D Grid, this defaults to XY mapping.
- **ESMF_CoordOrder_YXZ** The coordinates are ordered YXZ. For a 2D Grid, this defaults to YX mapping.
- **ESMF_CoordOrder_YZX** The coordinates are ordered YZX. For a 2D Grid, this defaults to YX mapping.
- **ESMF_CoordOrder_ZXY** The coordinates are ordered ZXY. For a 2D Grid, this defaults to XY mapping.
- **ESMF_CoordOrder_ZYX** The coordinates are ordered ZYX. For a 2D Grid, this defaults to YX mapping.

### 22.2.2 ESMF_CoordSystem

**DESCRIPTION:**
The Grid class supports a variety of coordinate systems, which are typically set by specific ESMF_GridCreate methods.

Valid values are:

- **ESMF_CoordSystem_CARTESIAN** Cartesian coordinates (x,y).
- **ESMF_CoordSystem_CYLINDRICAL** Cylindrical coordinates.
- **ESMF_CoordSystem_HEIGHT** Vertical z coordinate height (0 at bottom).
- **ESMF_CoordSystem_SPHERICAL** Spherical coordinates (longitude, latitude).
- **ESMF_CoordSystem_UNKNOWN** Unknown or undefined coordinate system.

### 22.2.3 ESMF_GridHorzStagger

**DESCRIPTION:**
The Grid class supports a variety of horizontal Grid staggerings. The ESMF_GridHorzStagger parameter describes the options, following typical Arakawa nomenclature.

Valid values are:

- **ESMF_GridHorzStagger_A** Arakawa A staggering, where all Fields, including velocities, are located at cell centers. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):
  - ESMF_CELLCENTER

- **ESMF_GridHorzStagger_B_NE** Arakawa B staggering, where both the U and V velocities are located at each cell’s NorthEast corner. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):
  - ESMF_CELLCENTER
  - ESMF_CELLNECORNER

- **ESMF_GridHorzStagger_B_NW** Arakawa B staggering, where both the U and V velocities are located at each cell’s NorthWest corner. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):
ESMF_CELL_CENTER
ESMF_CELL_NWCORNER

**ESMF_GRID_HORZ_STAGGER_B_SE** Arakawa B staggering, where both the U and V velocities are located at each cell’s SouthEast corner. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):

ESMF_CELL_CENTER
ESMF_CELL_SECORNER

**ESMF_GRID_HORZ_STAGGER_B_SW** Arakawa B staggering, where both the U and V velocities are located at each cell’s SouthWest corner. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):

ESMF_CELL_CENTER
ESMF_CELL_SWCORNER

**ESMF_GRID_HORZ_STAGGER_C_NE** Arakawa C staggering, where the U velocity is located at the East face and the V velocity is located at the North face. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):

ESMF_CELL_CENTER
ESMF_CELL_NFACE
ESMF_CELL_EFACE

**ESMF_GRID_HORZ_STAGGER_C_NW** Arakawa C staggering, where the U velocity is located at the West face and the V velocity is located at the North face. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):

ESMF_CELL_CENTER
ESMF_CELL_NFACE
ESMF_CELL_WFACE

**ESMF_GRID_HORZ_STAGGER_C_SE** Arakawa C staggering, where the U velocity is located at the East face and the V velocity is located at the South face. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):

ESMF_CELL_CENTER
ESMF_CELL_SFACE
ESMF_CELL_EFACE

**ESMF_GRID_HORZ_STAGGER_C_SW** Arakawa C staggering, where the U velocity is located at the West face and the V velocity is located at the South face. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):

ESMF_CELL_CENTER
ESMF_CELL_SFACE
ESMF_CELL_WFACE

**ESMF_GRID_HORZ_STAGGER_D_NE** Arakawa D staggering, where the U velocity is located at the North face and the V velocity is located at the East face. A Grid created with this staggering can only be used to create ESMF_Fields with the following horizontal ESMF_RelLocs (relative locations):

ESMF_CELL_CENTER
ESMF_CELL_NFACE
ESMF\_CELL\_EFACE

**ESMF\_GRID\_HORIZ\_STAGGER\_D\_NW** Arakawa D staggering, where the U velocity is located at the North face and the V velocity is located at the West face. A Grid created with this staggering can only be used to create ESMF\_Fields with the following horizontal ESMF\_RelLocs (relative locations):

- ESMF\_CELL\_CENTER
- ESMF\_CELL\_NFACE
- ESMF\_CELL\_WFACE

**ESMF\_GRID\_HORIZ\_STAGGER\_D\_SE** Arakawa D staggering, where the U velocity is located at the South face and the V velocity is located at the East face. A Grid created with this staggering can only be used to create ESMF\_Fields with the following horizontal ESMF\_RelLocs (relative locations):

- ESMF\_CELL\_CENTER
- ESMF\_CELL\_SFACE
- ESMF\_CELL\_EFACE

**ESMF\_GRID\_HORIZ\_STAGGER\_D\_SW** Arakawa D staggering, where the U velocity is located at the South face and the V velocity is located at the West face. A Grid created with this staggering can only be used to create ESMF\_Fields with the following horizontal ESMF\_RelLocs (relative locations):

- ESMF\_CELL\_CENTER
- ESMF\_CELL\_SFACE
- ESMF\_CELL\_WFACE

**ESMF\_GRID\_HORIZ\_STAGGER\_UNKNOWN** Unknown or undefined staggering.

### 22.2.4 ESMF\_GridStorage

**DESCRIPTION:**
Distributed Grid storage options supported by ESMF.

Valid values are:

- **ESMF\_GRID\_STORAGE\_BLOCK** Grid is distributed as single rectangular blocks on any, but not necessarily all, DEs. All high level communication methods are supported for this storage option.

- **ESMF\_GRID\_STORAGE\_UNKNOWN** Unknown or undefined Grid storage.

- **ESMF\_GRID\_STORAGE\_ARBITRARY** Grid is distributed as 1D arbitrary vectors on any, but not necessarily all, DEs. This storage option is intended for column based computations, so the only high level communication method that is supported is redistribution back and forth with its underlying Grid.

### 22.2.5 ESMF\_GridType

**DESCRIPTION:**
There are several Grid types supported by ESMF. In general, we expect each ESMF\_GridType to have its own explicit ESMF\_GridCreateHorz<GridType>() function.

Valid values are:

- **ESMF\_GRID\_TYPE\_LATLON** Latitude/longitude Grid with variable or unequal spacing.

- **ESMF\_GRID\_TYPE\_LATLON\_UNI** Latitude/longitude Grid with uniform spacing.

- **ESMF\_GRID\_TYPE\_UNKNOWN** Unknown or undefined Grid.

- **ESMF\_GRID\_TYPE\_XY** XY Cartesian Grid with variable or unequal spacing.

- **ESMF\_GRID\_TYPE\_XY\_UNI** XY Cartesian Grid with uniform spacing.
### 22.2.6 ESMF_GridVertStagger

**DESCRIPTION:**
The Grid class supports a variety of vertical subGrid staggerings. The ESMF_GridVertStagger parameter describes the options.
Valid values are:

- **ESMF_GRID_VERT_STAGGER_BOTTOM** Vertical velocity or pressure gradient is located at the bottom vertical face of the cell. A subGrid created with this staggering will only accept ESMF_Fields with the following vertical ESMF_RelLocs (relative locations):
  - ESMF_CELL_CELL
  - ESMF_CELL_BOTFACE

- **ESMF_GRID_VERT_STAGGER_CENTER** Vertical velocity or pressure gradient is located at vertical midpoints.
  A subGrid created with this staggering will only accept ESMF_Fields with the following vertical ESMF_RelLocs (relative locations):
  - ESMF_CELL_CELL

- **ESMF_GRID_VERT_STAGGER_TOP** Vertical velocity or pressure gradient is located at the top vertical face of the cell. A subGrid created with this staggering will only accept ESMF_Fields with the following vertical ESMF_RelLocs (relative locations):
  - ESMF_CELL_CELL
  - ESMF_CELL_TOPFACE

- **ESMF_GRID_VERT_STAGGER_UNKNOWN** Unknown or undefined staggering.

### 22.2.7 ESMF_GridVertType

**DESCRIPTION:**
Several vertical subGrid types are supported by ESMF. In general, we expect each ESMF_GridVertType to have its own explicit ESMF_GridAddVert<GridVertType>() subroutine.
Valid values are:

- **ESMF_GRID_TYPE_VERT_HEIGHT** Vertical subGrid with zero coordinate at bottom.

- **ESMF_GRID_TYPE_VERT_UNKNOWN** Unknown or undefined vertical subGrid.

### 22.3 Use and Examples

In typical applications, Grids are created either internally or read in from a file. The ESMF_Grid class will provide methods for both, though currently it only has routines for simple internal Grid generation. It also has a variety of methods to set and get Grid parameters such as the number of cells associated with a particular DE.

The creation of a distributed Grid requires multiple steps, as illustrated in the example code below. The ESMF_GridCreateHorz<GridType>() call, which has an explicit interface for each GridType, allocates space for the Grid class and sets parameters defining the horizontal grid. A vertical grid can then be attached to the Grid via an ESMF_GridAddVert<VertGridType>() call. Currently a Grid can have only a single vertical grid. The last call, ESMF_GridDistribute(), allocates some of the Grid subclasses and distributes the Grid in either a default or user-specified decomposition.

The default decomposition distributes the Grid cells as evenly as possible across the DEs in the attached DELayout. The user can define a specified distribution in the ESMF_GridDistribute() call through optional arguments. ESMF currently supports two different basic distribution patterns. In the first, logically-rectangular blocks of data are distributed, one per DE. Here, any two dimensions of a 3D Grid may be distributed. By default, the first Grid dimension is distributed by the first DELayout dimension and the second Grid dimension is distributed by the second DELayout dimension. Users can specify other distributions via another optional argument to the ESMF_GridDistribute() call. The second distribution pattern assigns arbitrary points to different DEs and is intended for vertical column...
calculations where horizontal communication is not necessary. Please see the ESMF_GridDistribute() interface
description for further details. Please note that ESMF_GridDistribute() must be called, even if mpiuni is used for communication. Currently,
these calls must be made in this order (i.e. it is not possible to add a vertical grid to an already distributed Grid), and
while an ESMF_GridAddVert<VertGridType>() call is optional, both an ESMF_GridCreate<GridType>()
and ESMF_GridDistribute() call are required.

! !PROGRAM: ESMF_GridCreateEx - Grid creation
! !DESCRIPTION:
! ! This program shows examples of different methods to create 2D and 3D grids
!---------------------------------------------------------------------

! ESMF Framework module
use ESMF_Mod
implicit none

! instantiate two grids
type(ESMF_Grid) :: grid1, grid2, grid3

! instantiate horizontal and vertical grid staggerings
type(ESMF_GridHorzStagger) :: horz_stagger
type(ESMF_GridVertStagger) :: vert_stagger

! local variables for Create routines
integer :: counts(2), countsPerDE1(2), countsPerDE2(2)
integer :: myCount
integer, dimension(:,,:), allocatable :: myIndices
character(len=ESMF_MAXSTR) :: name
real(ESMF_KIND_R8), dimension(2) :: min, max
real(ESMF_KIND_R8) :: delta1(40), delta2(50), delta3(10)
type(ESMF_ArraySpec):: arrayspec1
type(ESMF_Field):: humidity1

! return code
integer :: rc

! initialize ESMF framework
call ESMF_Initialize(rc=rc)

22.3.1 Uniform 2D Grid Creation
This example shows how to create a simple uniform horizontal ESMF_Grid.

! set the global number of computational cells in each direction
counts(1)    = 10
counts(2)    = 12

! set the global coordinate extrema
min(1)       = 0.0
max(1)       = 10.0
min(2)       = 0.0
max(2) = 12.0

! set the staggering for the horizontal grid
horz_stagger = ESMF_GRID_HORZ_STAGGER_A

! and add a name to the grid
name = "test grid 1"

! create a 2 x 2 layout for the Grid
layout = ESMF_DELayoutCreate(vm, (/ 2, 2 /), rc=rc)

! initialize a simple uniform horizontal grid with the above values
grid1 = ESMF_GridCreateHorzXYUni(counts=counts, &
    minGlobalCoordPerDim=min, &
    maxGlobalCoordPerDim=max, &
    horzstagger=horz_stagger, &
    name=name, rc=rc)

! distribute the grid
call ESMF_GridDistribute(grid1, delayout=layout, rc=rc)

print *, "Grid example 1 returned"
call ESMF_GridDestroy(grid1, rc)
print *, "Grid example 1 destroyed"

22.3.2 3D Grid Creation

This example shows how to create a 3D ESMF_Grid with specified, non-uniform spacing.

! set the global coordinate minima for the horizontal grid
! note: the vertical grid does not need a coordinate minimum
! because the specific call to GridAddVertHeight infers
! a minimum at 0.0.
min(1) = 0.0
min(2) = 0.0

! set up arrays of coordinate spacing for the horizontal grid
delta1 = (/ 1.0, 1.0, 1.0, 1.1, 1.1, 1.1, 1.2, 1.2, 1.3, 1.3, 1.4, &
    1.4, 1.5, 1.6, 1.6, 1.6, 1.8, 1.8, 1.7, 1.7, 1.6, &
    1.6, 1.6, 1.8, 1.8, 2.0, 2.0, 2.2, 2.2, 2.2, 2.2, &
    2.0, 1.7, 1.5, 1.3, 1.2, 1.1, 1.0, 1.0, 1.0, 0.9 /)
delta2 = (/ 0.8, 0.8, 0.8, 0.8, 0.8, 0.7, 0.7, 0.6, 0.7, 0.8, &
    0.9, 0.9, 0.9, 0.9, 1.0, 1.0, 1.0, 1.0, 0.9, 1.0, &
    1.0, 1.0, 1.0, 1.1, 1.2, 1.3, 1.3, 1.3, 1.4, 1.4, &
    1.4, 1.4, 1.4, 1.4, 1.3, 1.3, 1.3, 1.2, 1.2, &
    1.1, 1.0, 1.0, 0.9, 0.8, 0.7, 0.6, 0.6, 0.5, 0.5 /)

! set array of coordinate spacing for the vertical grid
delta3 = (/ 1.0, 1.0, 1.0, 0.5, 0.5, 0.6, 0.8, 1.0, 1.0, 1.0 /)
! set the staggerings for the horizontal and vertical grids
horz_stagger = ESMF_GRID_HORIZ_STAGGER_D_NE
vert_stagger = ESMF_GRID_VERT_STAGGER_CENTER

! and add a name to the grid
name = "test grid 2"

! set specified number of computational cells per DE for each ! decomposition direction
countsPerDE1 = (/ 26, 14 /)
countsPerDE2 = (/ 22, 28 /)

! initialize the grid with the above values
grid2 = ESMF_GridCreateHorzLatLon(minGlobalCoordPerDim=min, &
delta1=delta1, delta2=delta2, &
horzstagger=horz_stagger, &
name=name, rc=rc)

! add a vertical subgrid to the horizontal grid
! note: the vertical subgrid must be added before the grid is ! distributed
call ESMF_GridAddVertHeight(grid2, delta3, vertstagger=vert_stagger, &
rc=rc)

! distribute the grid using the same layout as from the first example ! but specifying the decomposition of computational cells
call ESMF_GridDistribute(grid2, delayout=layout, &
countsPerDEDim1=countsPerDE1, &
countsPerDEDim2=countsPerDE2, &
rc=rc)

22.3.3 3D Grid Creation with Arbitrary Distribution

This example shows how to create the same non-uniform 3D ESMF_Grid as from the previous example but distributed in an arbitrary fashion as one might for a column model. Different from a block distributed ESMF_Grid, the Field associated with an arbitrary Grid has to be one dimension less than the Grid itself. A Field associated with a 2D horizontal Grid is stored as a 1D array. In this example, the Field has to be a 2D Field for the 3D ESMF_Grid with the 2 horizontal dimensions collapsed into the first dimension of the Field and the vertical dimension stored in the second dimension of the Field.

! Use the same parameters to create the Grid as before
min(1) = 0.0
min(2) = 0.0

delta1 = (/ 1.0, 1.0, 1.0, 1.1, 1.1, 1.1, 1.2, 1.2, 1.3, 1.4, &
1.4, 1.5, 1.6, 1.6, 1.6, 1.8, 1.8, 1.7, 1.7, 1.6, &
1.6, 1.6, 1.8, 1.8, 2.0, 2.0, 2.2, 2.2, 2.2, 2.2, &
2.0, 1.7, 1.5, 1.3, 1.2, 1.1, 1.0, 1.0, 1.0, 0.9 /)
delta2 = (/ 0.8, 0.8, 0.8, 0.8, 0.8, 0.7, 0.7, 0.6, 0.7, 0.8, &
0.9, 0.9, 0.9, 0.9, 1.0, 1.0, 1.0, 1.0, 0.9, 1.0, &
1.0, 1.0, 1.0, 1.1, 1.2, 1.3, 1.3, 1.4, 1.4, 1.4 /)
1.4, 1.4, 1.4, 1.4, 1.4, 1.3, 1.3, 1.2, 1.2, &
1.1, 1.0, 1.0, 0.9, 0.8, 0.7, 0.6, 0.6, 0.5, 0.5 /)
delta3 = (/ 1.0, 1.0, 1.0, 0.5, 0.5, 0.6, 0.8, 1.0, 1.0, 1.0 /)

horz_stagger = ESMF_GRID_HORZ_STAGGER_D_NE
vert_stagger = ESMF_GRID_VERT_STAGGER_CENTER

name = "test grid 3"

! initialize the grid with the above values
grid3 = ESMF_GridCreateHorzLatLon(minGlobalCoordPerDim=min, &
delta1=delta1, delta2=delta2, &
horzstagger=horz_stagger, &
name=name, rc=rc)

! as before, add a vertical subgrid to the horizontal grid
call ESMF_GridAddVertHeight(grid3, delta3, vertstagger=vert_stagger, &
rc=rc)

! Calculate myIndices based on DE number.
! This is just a simple algorithm to create a semi-regular distribution
! of points to the pets. It starts at point (1,1+myDE) and go up in the
! j-direction first, and creates a 2D array of point indices that looks
! like: for n = 1, myCount
! myIndices(n,1) = global i-index of the nth local point
! myIndices(n,2) = global j-index of the nth local point
j1 = 1 + myDE
n = 0
do i = 1,counts(1)
do j = j1,counts(2),npets
  n = n + 1
  myIndices(n,1) = i
  myIndices(n,2) = j
enddo
j1 = j - counts(2)
enddo
myCount = n

! The distribute call is similar to the block distribute but with
! a couple of different arguments
call ESMF_GridDistribute(grid3, delayout=layout, myCount=myCount, &
myIndices=myIndices, rc=rc)

! The Field for an arbitrary Grid has to be one dimension less, i.e., 2D
! for a 3D Grid.
! Set up 2D Array for the Field
call ESMF_ArraySpecSet(arrayspec1, rank=2, type=ESMF_DATA_REAL,&
  kind=ESMF_R8)

! Create the Field
humidity1 = ESMF_FieldCreate(grid3, arrayspec1, &
horzRelloc=ESMF_CELL_CENTER, vertRelloc=ESMF_CELL_CENTER, &
22.4 Restrictions and Future Work

1. **Support is limited to 3D, logically rectangular Grids.** Currently the only interfaces supported are for two- or three-dimensional, logically rectangular Grids.

2. **Support is limited to 2D Grid distributions.** The decomposition of Grids is limited to any two dimensions of a two- or three-dimensional Grid.

3. **Future Grid Create methods.** Currently Grids can only be created by internal generation. In the future, the following create methods will be added:
   - ESMF_GridCreateCopy Create a new Grid by copying another Grid.
   - ESMF_GridCreateCutout Create a new Grid as a subset of an existing Grid.
   - ESMF_GridCreateDiffRes Create a new Grid by coarsening or refining an existing Grid.
   - ESMF_GridCreateExchange Create a new Grid from the intersection of two existing Grids.
   - ESMF_GridCreateRead Create a new Grid by reading in data from a file.

4. **Future Grid types.** The following Grids will be supported, although only some will have internal generation methods:
   - ESMF_GRID_TYPE_CART_SPECT Spectral space for cartesian coordinates.
   - ESMF_GRID_TYPE_CUBEDSPHERE Cubed sphere Grid.
   - ESMF_GRID_TYPE_DATASTREAM Data stream - set of locations.
   - ESMF_GRID_TYPE_DIPOLE Displaced-pole dipole Grid.
   - ESMF_GRID_TYPE_EXCHANGE Intersection of two Grids, which is itself a Grid.
   - ESMF_GRID_TYPE_GEODESIC Spherical geodesic Grid.
   - ESMF_GRID_TYPE_LATLON_GAUSS Latitude/Longitude Grid with gaussian-spaced latitudes.
   - ESMF_GRID_TYPE_LATLON_MERC Latitude/Longitude Grid with Mercator-spaced latitudes.
   - ESMF_GRID_TYPE_PHYSFOURIER Mixed Fourier Space/Physical Space Grid.
   - ESMF_GRID_TYPE_REduced Latitude/Longitude Grid where the number of longitudinal points is a function of the latitude.
   - ESMF_GRID_TYPE_SPHER_SPECT Spectral space for spherical harmonics.
   - ESMF_GRID_TYPE_TRIPOLE Tripolar Grids.

5. **Future coordinate system support.** Support for the following coordinate systems will be added:
   - ESMFCOORD_SYSTEM_DEPTH Vertical z coordinate depth (0 at top surface).
   - ESMFCOORD_SYSTEM_CYLINDRICAL Cylindrical coordinate.
   - ESMFCOORD_SYSTEM_ETA Vertical eta coordinate.
   - ESMFCOORD_SYSTEM_HYBRID Hybrid vertical coordinate.
   - ESMFCOORD_SYSTEM_ISOPYCNAL Vertical density coordinate.
   - ESMFCOORD_SYSTEM_LAGRANGIAN Lagrangian coordinate.
   - ESMFCOORD_SYSTEM_LATFOURIER Mixed latitude/Fourier spectral space.
   - ESMFCOORD_SYSTEM_PRESSURE Vertical pressure coordinate.
   - ESMFCOORD_SYSTEM_SIGMA Vertical sigma coordinate.
   - ESMFCOORD_SYSTEM_SPECTRAL Wavenumber space.
ESMF_COORD_SYSTEM_THETA  Vertical theta coordinate.
ESMF_COORD_SYSTEM_USER  User-defined coordinate system.

6. **Future horizontal Grid staggerings.** Support for the following horizontal staggerings will be added:
   - ESMF_GRID_HORZ_STAGGER_E  Arakawa E.
   - ESMF_GRID_HORZ_STAGGER_Z  C grid equivalent for geodesic Grid.

7. **Future vertical subGrid types.** Support for the following vertical subGrids will be added:
   - ESMF_COORD_SYSTEM_DEPTH  Vertical z coordinate depth (0 at top surface).
   - ESMF_COORD_SYSTEM_ETA  Vertical eta coordinate.
   - ESMF_COORD_SYSTEM_HYBRID  Hybrid vertical coordinates.
   - ESMF_COORD_SYSTEM_ISOPYCNAL  Vertical density coordinate.
   - ESMF_COORD_SYSTEM_LAGRANGIAN  Lagrangian coordinates.
   - ESMF_COORD_SYSTEM_PRESSURE  Vertical pressure coordinate.
   - ESMF_COORD_SYSTEM_SIGMA  Vertical sigma coordinate.
   - ESMF_COORD_SYSTEM_THETA  Vertical theta coordinate.

8. **Future Grid masks.** Grid masks will be implemented, including support for the following mask types:
   - ESMF_GRID_MASKTYPE_LOGICAL  Logical mask.
   - ESMF_GRID_MASKTYPE_MULTIPLICATIVE  Multiplicative mask.
   - ESMF_GRID_MASKTYPE_REGION_ID  Integer assigning unique ID to each point.

   Valid values are:

9. **Future Grid storage options.** Support for the following Grid distribution storage options will be added:
   - ESMF_GRID_STORAGE_MULTIBLOCK  Grid is distributed as multiple rectangular blocks on any, but not necessarily all, DEs. This is intended to be a method for assigning multiple DEs to single PETs. All high level communication methods should be supported for this storage option.

### 22.5  Design and Implementation Notes

#### 22.5.1  Grid Classes

The Grid class contains two internal private classes: the DistGrid (Distributed Grid) class and the PhysGrid (Physical Grid) class. The separation into two classes allows the code to differentiate between functions which define the DE-local decomposition of data and the DE-local representation of the grid. The Grid class itself maintains general information about the global grid (e.g. the grid type, staggering, and coordinate system). The Grid class is relatively thin and otherwise presents a unified interface for DistGrid and PhysGrid functions. Each Grid contains at least one subGrid, represented by a unique DistGrid and PhysGrid pair:

- **DistGrid** The DistGrid class maintains the relationship of how a DELayout maps onto a Grid representation and how that Grid is distributed. DistGrids can represent the same Grid but have different mappings (staggerings) and can be contained by the same Grid object. The DistGrid class represents the mapping between the global Grid and the DE-local data distribution; it has methods to aid in the collection and communication of global data.

- **PhysGrid** The PhysGrid class maintains the DE-local decomposed physical representation of a Grid, including all necessary coordinate data and masks. Separate PhysGrids are created for each relative location associated with the Grid’s staggering (e.g. a Grid with Arakawa D staggering will have PhysGrids representing the cell centers and specified cell faces), as well as for any vertical subGrids.

Some methods which have a Grid interface are actually implemented at the underlying DistGrid or PhysGrid level; they will be inherited by the Grid class. This allows the API to present functions at the level which is most consistent to the application without restricting the actual implementation.
22.5.2 InternDG Implementation Notes

The DistGrid class contains the mapping between the DE-local grid decompositions and the global logical Grid. It contains methods to synchronize data values between the boundaries of subsets, and to collect and communicate global data values. It interacts closely with the PhysGrid object.

1. DistGrid Internal Classes

   The DistGrid class contains the DELayout class as well as two private subclasses, the DistGridGlobal and DistGridLocal classes. The separation between DistGridGlobal and DistGridLocal allows the code to clearly differentiate between functions which operate internal to a single DE on a local decomposition of data, and those which must be aware of the global state of the distribution.

   - **DELayout** The DELayout class is described in detail in the Utilities section of this document.
   - **DistGridGlobal** The DistGridGlobal class contains general information about each of the partitions that the entire Grid has been decomposed into. This includes information about how each part relates to the whole, how many points/cells there are per decomposition, etc. This information allows DistGrid to compute information about DEs on other PETs without having to do communication first.
   - **DistGridLocal** The DistGridLocal class contains detailed subGrid information for the data located on this DE, such as the DE-local cell count and the number of cells along each axis and their position in the global Grid. When we implement multiple DEs per PET, then we will have a list of these instead of a single one in the DistGrid class.

2. DE-Local verses Global Data

   The primary purpose of DistGrid is to encapsulate information about the local decomposition(s) (DE) of the Grid on this PET. This includes such information as the total number of this DE’s local (or DE-local) cells, if logically rectangular the numbers of cells along each dimension, and the location of this DE-local data in the global ESMF_Grid. The minimum information required would be to compute and store data only for the local DE.

   However, at create time DistGrid computes information not only about the local decomposition, but also less detailed information about the other decompositions for the entire Grid. While this duplicates some data, it avoids communication when a DE on one PET requires information that would otherwise require sending data to or receiving data from DEs on other PETs.

3. Boundary Cells

   As part of the create-time computation DistGrid computes sizes and lengths for the DE-local grid cells, and also does a secondary computation of sizes and lengths taking into account a layer of boundary cells around each DE. These boundary cells are distinct from the halo cells which are specified on a per-Field basis and are visible to the user code.

   The boundary cells inside DistGrid are only used internally to the Framework, for example during regridding, to avoid unnecessary inter-PET communication and to handle exterior boundaries in a consistent manner.

Some methods which have a DistGrid interface will actually be implemented at the underlying DELayout or Array level; they will be inherited by the DistGrid class. This allows the user API to present functions at the level which is most consistent to the application without restricting the actual implementation.

The DistGrid class has two instances of both DistGridLocal and DistGridGlobal classes. One represents the computational domain, which is the part of the Grid this DE is responsible for computing on, and one represents the total domain, which includes halo and ghost cells as well as computational cells.

22.5.3 PhysGrid Implementation Notes

The PhysGrid class is itself private and is part of the Grid class. It is designed to contain all information describing physical properties of the Grid, as well as methods to initialize them and to calculate user-requested metrics.

The PhysGrid class contains the following private classes:
- **ESMF_GridMask** Data type describing masks for a PhysGrid. GridMasks are named and can be of different types, including logical masks, multiplicative masks, and integer region identifiers. This private class will be replaced by the ESMF_Mask class once it has been implemented.

- **ESMF_PhysCoord** Data type describing a coordinate axis in the physical domain, including attributes like names and flags for special properties of an axis. This information is used by PhysGrid and Grid to help describe the complete physical properties of a Grid.

- **ESMF_PhysLocation** Data type containing coordinate values for the location of the center of each grid cell.

- **ESMF_PhysRegion** Data type containing coordinate values for a set of points defining regions of the Grid (e.g. cell vertices or domains of influence). These typically describe each grid cell, though they can also be used to define bounding boxes of larger regions. Regions can be either polygons or circles/spheres/ellipses.

There is a correspondence between the DistGrid class and the PhysGrid class. The PhysGrid class maintains all the local data necessary to represent the Grid, while the DistGrid class describes the local extents of that data and its relationship to the global decomposition. Together, a PhysGrid and related DistGrid define a representation of a Grid. There is a correspondence between the PhysGrid class and the Field class as well: the PhysGrid data on a DE describes the physical location of the corresponding Field data.

The PhysGrid class maintains a DE-local physical representation of a Grid, including all necessary data and masks. PhysGrids can represent subGrids of a single Grid and be contained by the same Grid object. The PhysGrid class must have methods that can internally generate a variety of computational Grids in a distributed environment from relatively simple input. The PhysGrid data has to be accessible to the ESMF user in a variety of specified ways or metrics, and it must have the capability to attach a number of masks or identifiers. Please note that the PhysGrid class is designed to be an private class; all access to its contents are via Grid methods.

**22.6 Object Model**

The following is a simplified UML diagram showing the structure of the Grid class. See Appendix A, *A Brief Introduction to UML*, for a translation table that lists the symbols in the diagram and their meaning.

```
+-----------------+        +-----------------+        +-----------------+        +-----------------+
| Grid            |        | DistGrid        |        | PhysGrid        |        | GridMask        |
|                 |        | DistGridLocal   |        | PhysLocation    |        |                |
| 1..n             |        | 2               |        | 1               |        | 1..n            |
| DistGridGlobal  |        | DistGridGlobal  |        | PhysRegion      |        |                |
| 2               |        |                 |        | 1               |        |                |
| PhysCoord       |        | PhysLocation    |        | 1               |        |                |
| 1..n            |        | PhysRegion      |        | 1               |        |                |
| GridMask        |        | GridMask        |        | 1..n            |        |                |
```

Each Grid contains at least one Distributed Grid and a related Physical Grid. The Physical Grid maintains information about the global coordinates. In general the coordinates are described implicitly by specifying the grid type and the
corresponding parameters. However it is possible that the Physical Grid must be completely enumerated, perhaps in
the case of assimilated data or unstructured data. The Distributed Grid defines an index space that corresponds to cells
in the Physical Grid and is decomposed among DEs in a DELayout. Please see Sections 22.5.2 and 22.5.3 for more
information about the private DistGrid and PhysGrid classes.

22.7 Class API: General Grid Methods

22.7.1 ESMF_GridAddVertHeight - Add a vertical subGrid to an existing Grid

INTERFACE:

subroutine ESMF_GridAddVertHeight(grid, delta, coord, vertstagger, &
dimName, dimUnit, name, rc)

ARGUMENTS:

type(ESMF_Grid) :: grid
real(ESMF_KIND_R8), dimension(:), intent(in), optional :: delta
real(ESMF_KIND_R8), dimension(:), intent(in), optional :: coord
type(ESMF_GridVertStagger), intent(in), optional :: vertstagger
character(len=*) , intent(in), optional :: dimName
character(len=*) , intent(in), optional :: dimUnit
character(len=*) , intent(in), optional :: name
integer, intent(out), optional :: rc

DESCRIPTION:

This routine adds a vertical subGrid (or subGrids) to an already allocated Grid. The ESMF_GridAddVertHeight
interface only creates vertical subGrids with coordinate systems where the zero point is defined at the bottom. An
ESMF_GridAddVert<GridVertType>() can only be called for any ESMF_Grid once; if a vertical subGrid
already exists for the ESMF_Grid that is passed in, an error is returned. Please note that this subroutine may create
more than one subGrid because some vertical staggerings infer more than one vertical relative location (for example,
ESMF_GRID_VERT_STAGGER_BOTTOM
staggering indicates that some Fields are represented at the vertical cell
centers and some at the cell bottom faces). This routine generates ESMF_Grid coordinates from either of two optional
sets of arguments:

1. given array of coordinate increments or spacings, assuming 0 is the minimum or starting coordinate (optional
argument delta);

2. given array of coordinates (optional argument coord).

If neither of these sets of arguments is present and valid, an error message is issued and an error code returned.
The arguments are:

grid Existing ESMF_Grid the vertical subGrid(s) is being added to.
[delta] Array of physical increments in the vertical direction.
[coord] Array of physical coordinates in the vertical direction.
[vertstagger] ESMF_GridVertStagger specifier denoting vertical subGrid stagger. The default value is ESMF_GRID_VERT_STAGGER_BOTTOM.
[dimName] Dimension name.
[dimUnit] Dimension unit.
[name] Name for the vertical subGrid(s).
[rc] Return code; equals ESMF_SUCCESS if there are no errors.
22.7.2  ESMF_GridCreate - Create a new Grid with no contents

INTERFACE:

    ! Private name; call using ESMF_GridCreate()
    function ESMF_GridCreateEmpty(name, rc)

RETURN VALUE:

    type(ESMF_Grid) :: ESMF_GridCreateEmpty

ARGUMENTS:

    character (len=*) intent(in), optional :: name
    integer, intent(out), optional :: rc

DESCRIPTION:

Allocates memory for a new ESMF_Grid object and constructs its internal derived types, but does not fill in any contents. Returns a pointer to the new ESMF_Grid. The arguments are:

[name] ESMF_Grid name.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.3  ESMF_GridDestroy - Free all resources associated with a Grid

INTERFACE:

    subroutine ESMF_GridDestroy(grid, rc)

ARGUMENTS:

    type(ESMF_Grid) :: grid
    integer, intent(out), optional :: rc

DESCRIPTION:

Destroys an ESMF_Grid object and all related internal structures previously allocated via an ESMF_GridCreate routine. The arguments are:

[grid] ESMF_Grid to be destroyed.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.4  ESMF_GridDistribute - Distribute a Grid with block storage

INTERFACE:

    ! Private name; call using ESMF_GridDistribute()
    subroutine ESMF_GridDistributeBlock(grid, delayout, countsPerDEDim1, &
        countsPerDEDim2, decompIds, rc)
**ARGUMENTS:**

```plaintext
type(ESMF_Grid) :: grid
type(ESMF_DELayout), intent(in) :: delayout
integer, dimension(:,), intent(in), optional :: countsPerDEDim1
integer, dimension(:,), intent(in), optional :: countsPerDEDim2
integer, dimension(:,), intent(in), optional :: decompIds
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Sets the decomposition of an ESMF_Grid.

The arguments are:

- **grid**: ESMF_Grid to be distributed.
- **delayout**: ESMF_DELayout on which grid is to be decomposed.
- **countsPerDEDim1**: Array denoting the number of grid cells per DE in the first decomposition axis. By default, the number of grid cells per DE in a decomposition is calculated internally by an algorithm designed to distribute the cells as evenly as possible. This optional argument is available to allow users to instead specify the decomposition of a Grid axis by a related DELayout axis. The number of elements in this array must be greater than or equal to the number of DE's along the first axis of the attached DELayout. The sum of this array must equal exactly the number of grid cells along a related Grid axis, which is the first axis by default but can also be set by the decompIds argument in this call.
- **countsPerDEDim2**: Array denoting the number of grid cells per DE in the second decomposition axis. Please see the description of countsPerDEDim1 above for more details.
- **decompIds**: Integer array identifying which Grid axes are decomposed. This array describes the relationship between the Grid and the DELayout. The elements of this array contain decomposition information for the corresponding Grid axis. The following is a list of valid values and the meaning of each:
  - 0: the Grid axis is not distributed;
  - 1: the Grid axis is distributed by the first decomposition axis in the DELayout;
  - 2: the Grid axis is distributed by the second decomposition axis in the DELayout.

The number of array elements should be greater or equal to the number of Grid dimensions. The default is that the first Grid axis is distributed by the first decomposition axis, the second Grid axis is distributed by the second decomposition axis, and the third Grid axis (if applicable) is not distributed. The relationship between data axes (from an ESMF_Field or ESMF_Array) and Grid axes are defined elsewhere in ESMF_FieldDataMap and ESMF_ArrayDataMap interfaces.

- **rc**: Return code; equals ESMF_SUCCESS if there are no errors.

------

### 22.7.5 ESMF_GridDistribute - Distribute a Grid as an arbitrary vector of points

**INTERFACE:**

```plaintext
! Private name; call using ESMF_GridDistribute()
subroutine ESMF_GridDistributeArbitrary(grid, delayout, myCount, &
     myIndices, decompIds, rc)
```

**ARGUMENTS:**
type(ESMF_Grid) :: grid
type(ESMF_DELayout), intent(in) :: delayout
integer, intent(in) :: myCount
integer, dimension(:,,:), intent(in) :: myIndices
integer, dimension(:,), intent(in), optional :: decompIds
integer, intent(out), optional :: rc

DESCRIPTION:

Sets the decomposition of an ESMF_Grid.

The arguments are:

grid    ESMF_Grid to be distributed.
delayout ESMF_DELayout on which grid is to be decomposed.
myCount Number of grid cells to be distributed to this DE.
myIndices Array of Grid indices to be distributed to this DE, as (i,j) pairs. The size of this array must be at least myCount in the first dimension and 2 in the second.
[decompIds] Integer array identifying which Grid axes are decomposed. This array describes the relationship between the Grid and the DELayout. The elements of this array contains decomposition information for the corresponding Grid axis. The following is a list of valid values and the meaning of each:

0  the Grid axis is not distributed;
1  the Grid axis is distributed by the first decomposition axis in the DELayout;
2  the Grid axis is distributed by the second decomposition axis in the DELayout.

The number of array elements should be greater or equal to the number of Grid dimensions. The default is that the first Grid axis is distributed by the first decomposition axis, the second Grid axis is distributed by the second decomposition axis, and the third Grid axis (if applicable) is not distributed. The relationship between data axes (from an ESMF_Field or ESMF_Array) and Grid axes are defined elsewhere in ESMF_FieldDataMap and ESMF_ArrayDataMap interfaces.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.6  ESMF_GridGet - Get a variety of general information about a Grid

INTERFACE:

! Private name; call using ESMF_GridGet()
subroutine ESMF_GridGetGeneral(grid, &
  horzgridtype, vertgridtype, &
  horzstagger, vertstagger, &
  horzcoordsystem, vertcoordsystem, &
  coordorder, &
  dimCount, distDimCount, gridstorage, &
  minGlobalCoordPerDim, maxGlobalCoordPerDim, &
  periodic, delayout, name, rc)

ARGUMENTS:
DESCRIPTION:

Gets general information about an ESMF_Grid, depending on a list of optional arguments.
The arguments are:

- **grid** [ESMF_Grid] to be queried.
- **horzgridtype** [ESMF_GridType] specifier denoting horizontal Grid type.
- **vertgridtype** [ESMF_GridVertType] specifier denoting vertical subGrid type.
- **horzstagger** [ESMF_GridHorzStagger] specifier denoting horizontal Grid stagger.
- **vertstagger** [ESMF_GridVertStagger] specifier denoting vertical subGrid stagger.
- **horzcoordsystem** [ESMF_CoordSystem] which identifies an ESMF standard coordinate system (e.g. spherical, cartesian, pressure, etc.) for the horizontal Grid.
- **vertcoordsystem** [ESMF_CoordSystem] which identifies an ESMF standard coordinate system (e.g. spherical, cartesian, pressure, etc.) for the vertical subGrid.
- **coordorder** [ESMF_CoordOrder] specifier denoting the default coordinate ordering for the Grid and all related Fields (i.e. ZXY).
- **dimCount** Number of dimensions represented by this Grid.
- **distDimCount** Number of dimensions represented by the distribution of this Grid. For Grids distributed arbitrarily, this could be different than the rank of the underlying Grid.
- **gridstorage** [ESMF_GridStorage] specifier denoting Grid storage.
- **minGlobalCoordPerDim** Array of minimum global physical coordinates in each direction.
- **maxGlobalCoordPerDim** Array of maximum global physical coordinates in each direction.
- **periodic** Logical array that returns the periodicity of the coordinate axes.
- **delayout** delayout that this Grid was distributed over.
- **name** [ESMF_Grid] name.
- **rc** Return code; equals ESMF_SUCCESS if there are no errors.
22.7.7 ESMF_GridGet - Get a variety of relloc-specified information about a Grid

INTERFACE:

! Private name; call using ESMF_GridGet()
subroutine ESMF_GridGetWithRelloc(grid, horzrelloc, vertrelloc, &
horzgridtype, vertgridtype, &
horzstagger, vertstagger, &
horzcoordsystem, vertcoordsystem, &
coordorder, &
dimCount, distDimCount, gridstorage, &
minGlobalCoordPerDim, &
maxGlobalCoordPerDim, &
globalCellCountPerDim, &
globalStartPerDEPerDim, &
maxLocalCellCountPerDim, &
cellCountPerDEPerDim, periodic, &
delayout, name, rc)

ARGUMENTS:

 type(ESMF_Grid), intent(inout) :: grid
 type(ESMF_RelLoc), intent(in) :: horzrelloc
 type(ESMF_RelLoc), intent(in), optional :: vertrelloc
 type(ESMF_GridType), intent(out), optional :: horzgridtype
 type(ESMF_GridVertType), intent(out), optional :: vertgridtype
 type(ESMF_GridHorzStagger), intent(out), optional :: horzstagger
 type(ESMF_GridVertStagger), intent(out), optional :: vertstagger
 type(ESMF_CoordSystem), intent(out), optional :: horzcoordsystem
 type(ESMF_CoordSystem), intent(out), optional :: vertcoordsystem
 type(ESMF_CoordOrder), intent(out), optional :: coordorder
 integer, intent(out), optional :: dimCount
 integer, intent(out), optional :: distDimCount
 type(ESMF_GridStorage), intent(out), optional :: gridstorage
 real(ESMF_KIND_R8), intent(out), dimension((),), optional :: &
 minGlobalCoordPerDim
 real(ESMF_KIND_R8), intent(out), dimension((),), optional :: &
 maxGlobalCoordPerDim
 integer, intent(out), dimension((),), optional :: globalCellCountPerDim
 integer, intent(out), dimension((),), optional :: globalStartPerDEPerDim
 integer, intent(out), dimension((),), optional :: maxLocalCellCountPerDim
 integer, intent(out), dimension((),), optional :: cellCountPerDEPerDim
 type(ESMF_Logical), intent(out), dimension((),), optional :: periodic
 type(ESMF_DELayout), intent(out), optional :: delayout
 character(len = *), intent(out), optional :: name
 integer, intent(out), optional :: rc

DESCRIPTION:

Gets information about an ESMF_Grid or specified subGrid, depending on user-supplied relative locations, and a list of optional arguments.

The arguments are:

 grid  ESMF_Grid to be queried.

horzrelloc  Horizontal relative location of the subGrid to be queried.

[vertrelloc]  Vertical relative location of the subGrid to be queried.
[horzgridtype] ESMF_GridType specifier denoting horizontal Grid type.

[vertgridtype] ESMF_GridVertType specifier denoting vertical subGrid type.


[vertstagger] ESMF_GridHorzStagger specifier denoting vertical subGrid stagger.

[horzcoordsystem] ESMF_CoordSystem which identifies an ESMF standard coordinate system (e.g. spherical, cartesian, pressure, etc.) for the horizontal grid.

[vertcoordsystem] ESMF_CoordSystem which identifies an ESMF standard coordinate system (e.g. spherical, cartesian, pressure, etc.) for the vertical subGrid.

[coordorder] ESMF_CoordOrder specifier denoting the default coordinate ordering for the Grid and all related Fields (i.e. ZXY).

[dimCount] Number of dimensions represented by this Grid.

[distDimCount] Number of dimensions represented by the distribution of this Grid.


[minGlobalCoordPerDim] Array of minimum global physical coordinates in each direction.

[maxGlobalCoordPerDim] Array of maximum global physical coordinates in each direction.

[globalCellCountPerDim] Array of numbers of global Grid increments in each direction.

[globalStartPerDEPerDim] Array of global starting locations for each DE and in each direction.

[maxLocalCellCountPerDim] Array of maximum number of Grid cells on any DE in each direction.

[cellCountPerDEPerDim] 2-D array of number of Grid cells on each DE and in each direction.

[periodic] Logical array that returns the periodicity of the coordinate axes.

[delayout] delayout that this Grid was distributed over.

[name] ESMF_Grid name.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.8 ESMF_GridGetAttribute - Retrieve an attribute

INTERFACE:

    subroutine ESMF_GridGetAttribute(grid, name, <value argument>, rc)

ARGUMENTS:

    type(ESMF_Grid), intent(in) :: grid
    character (len = *), intent(in) :: name
    <value argument>, see below for supported values
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns an attribute from the grid. Supported values for <value argument> are:
integer(ESMF_KIND_I4), intent(out) :: value
integer(ESMF_KIND_I4), dimension(:,), intent(out) :: valueList
integer(ESMF_KIND_I8), intent(out) :: value
integer(ESMF_KIND_I8), dimension(:,), intent(out) :: valueList
real (ESMF_KIND_R4), intent(out) :: value
real (ESMF_KIND_R4), dimension(:,), intent(out) :: valueList
real (ESMF_KIND_R8), intent(out) :: value
real (ESMF_KIND_R8), dimension(:,), intent(out) :: valueList
type(ESMF_Logical), intent(out) :: value
type(ESMF_Logical), dimension(:,), intent(out) :: valueList
character (len = *), intent(out), value

The arguments are:

grid  An ESMF_Grid object.
name  The name of the attribute to retrieve.
<value argument>  The value of the named attribute.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 22.7.9 ESMF_GridGetAttributeCount - Query the number of attributes

#### INTERFACE:

```fortran
subroutine ESMF_GridGetAttributeCount(grid, count, rc)
```

#### ARGUMENTS:

```fortran
type(ESMF_Grid), intent(in) :: grid
integer, intent(out) :: count
integer, intent(out), optional :: rc
```

#### DESCRIPTION:

Returns the number of attributes associated with the given Grid in the argument `count`. The arguments are:

grid  An ESMF_Grid object.

count  The number of attributes associated with this object.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
22.7.10  ESMF_GridGetAttributeInfo - Query Grid attributes by name

INTERFACE:

! Private name; call using ESMF_GridGetAttributeInfo()
subroutine ESMF_GridGetAttrInfoByName(grid, name, datatype, &
datakind, count, rc)

ARGUMENTS:

type(ESMF_Grid), intent(in) :: grid
character(len=*_), intent(in) :: name

type(ESMF_DataType), intent(out), optional :: datatype

type(ESMF_DataKind), intent(out), optional :: datakind

integer, intent(out), optional :: count

integer, intent(out), optional :: rc

DESCRIPTION:

Returns information associated with the named attribute, including
datatype, datakind (if applicable), and count.
The arguments are:

grid  An ESMF_Grid object.

name  The name of the attribute to query.

[datatype] The data type of the attribute. One of the values ESMF_DATA_INTEGER, ESMF_DATA_REAL, ESMF_DATA_LOGICAL, or ESMF_DATA_CHARACTER.

[datakind] The datakind of the attribute, if attribute is type ESMF_DATA_INTEGER or ESMF_DATA_REAL. One of the values ESMF_I4, ESMF_I8, ESMF_R4, or ESMF_R8. For all other types the value ESMF_NOKIND is returned.

count The number of items in this attribute. For character types, the length of the character string.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.11  ESMF_GridGetAttributeInfo - Query Grid attributes by index number

INTERFACE:

! Private name; call using ESMF_GridGetAttributeInfo()
subroutine ESMF_GridGetAttrInfoByNum(grid, attributeIndex, name, &
datatype, datakind, count, rc)

ARGUMENTS:

type(ESMF_Grid), intent(in) :: grid

integer, intent(in) :: attributeIndex

character(len=*_), intent(in) :: name


type(ESMF_DataType), intent(out), optional :: datatype

type(ESMF_DataKind), intent(out), optional :: datakind

integer, intent(out), optional :: count

integer, intent(out), optional :: rc
DESCRIPTION:

Returns information associated with the indexed attribute, including datatype, datakind (if applicable), and item count. The arguments are:

- **grid**: An ESMF_Grid object.
- **attributeIndex**: The index number of the attribute to query.
- **name**: Returns the name of the attribute.
- **[datatype]**: The data type of the attribute. One of the values ESMF_DATA_INTEGER, ESMF_DATA_REAL, ESMF_DATA_LOGICAL, or ESMF_DATA_CHARACTER.
- **[datakind]**: The datakind of the attribute, if attribute is type ESMF_DATA_INTEGER or ESMF_DATA_REAL. One of the values ESMF_I4, ESMF_I8, ESMF_R4, or ESMF_R8. For all other types the value ESMF_NOKIND is returned.
- **count**: Returns the number of items in this attribute. For character types, this is the length of the character string.
- **[rc]**: Return code; equals ESMF_SUCCESS if there are no errors.

22.7.12 ESMF_GridGetCoord - Get the horizontal and/or vertical coordinates of a Grid

INTERFACE:

```fortran
subroutine ESMF_GridGetCoord(grid, horzrelloc, vertrelloc, centerCoord, &
cornerCoord, faceCoord, reorder, total, rc)
```

ARGUMENTS:

- `type(ESMF_Grid), intent(inout) :: grid`
- `type(ESMF_RelLoc), intent(in), optional :: horzrelloc`
- `type(ESMF_RelLoc), intent(in), optional :: vertrelloc`
- `type(ESMF_InternArray), intent(out), dimension(:), optional :: centerCoord`
- `type(ESMF_InternArray), intent(out), dimension(:), optional :: cornerCoord`
- `type(ESMF_InternArray), intent(out), dimension(:), optional :: faceCoord`
- `logical, intent(in), optional :: reorder`
- `logical, intent(in), optional :: total`
- `integer, intent(in), optional :: rc`

DESCRIPTION:

Returns coordinate information for the grid. The arguments are:

- **grid**: ESMF_Grid to be queried.
- **[horzrelloc]**: Horizontal relative location of the subGrid to be queried.
- **[vertrelloc]**: Vertical relative location of the subGrid to be queried.
- **[centerCoord]**: Coordinates of each cell center. The dimension index should be defined first (e.g. x = coord(1,i,j), y=coord(2,i,j)).
[cornerCoord] Coordinates of corners of each cell. The dimension index should be defined first, followed by the corner index. Corners can be numbered in either clockwise or counter-clockwise direction, but must be numbered consistently throughout the Grid.

[faceCoord] Coordinates of face centers of each cell. The dimension index should be defined first, followed by the face index. Faces should be numbered consistently with corners. For example, face 1 should correspond to the face between corners 1,2.

[reorder] If TRUE, reorder any results using a previously set CoordOrder before returning. If FALSE, do not reorder. The default value is TRUE and users should not need to reset this for most applications. This optional argument is available mostly for internal use.

[total] If TRUE, return the total coordinates including internally generated boundary cells. If FALSE, return the computational cells (which is what the user will be expecting). The default value is FALSE.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.13 ESMF_GridGetCoordByDim1D - Get the horizontal and/or vertical coordinates of a Grid

INTERFACE:

subroutine ESMF_GridGetCoordByDim1D(grid, dim, horzrelloc, vertrelloc, &
    centerCoord, cornerCoord, faceCoord, reorder, total, localCounts, &
    docopy, rc)

ARGUMENTS:

type(ESMF_Grid), intent(inout) :: grid
integer, intent(in) :: dim
 type(ESMF_RelLoc), intent(in), optional :: horzrelloc
 type(ESMF_RelLoc), intent(in), optional :: vertrelloc
 real(ESMF_KIND_R8), pointer, dimension(:) :: centerCoord
 real(ESMF_KIND_R8), pointer, dimension(:), optional :: cornerCoord
 real(ESMF_KIND_R8), pointer, dimension(:), optional :: faceCoord
 logical, intent(in), optional :: reorder
 logical, intent(in), optional :: total
 integer, intent(out), optional :: localCounts(1)
 type(ESMF_CopyFlag), intent(in), optional :: docopy
 integer, intent(out), optional :: rc

DESCRIPTION:

Returns coordinate information for the grid. The arguments are:

grid ESMF_Grid to be queried.

dim dimension to be queried.

[horzrelloc] Horizontal relative location of the subGrid to be queried.

[vertrelloc] Vertical relative location of the subGrid to be queried.

[centerCoord] Coordinates of each cell center. The dimension index should be defined first (e.g. x = coord(1,i,j), y=coord(2,i,j)).
[cornerCoord] Coordinates of corners of each cell. The dimension index should be defined first, followed by the corner index. Corners can be numbered in either clockwise or counter-clockwise direction, but must be numbered consistently throughout the Grid.

[faceCoord] Coordinates of face centers of each cell. The dimension index should be defined first, followed by the face index. Faces should be numbered consistently with corners. For example, face 1 should correspond to the face between corners 1,2.

[reorder] If TRUE, reorder any results using a previously set CoordOrder before returning. If FALSE, do not reorder. The default value is TRUE and users should not need to reset this for most applications. This optional argument is available mostly for internal use.

[total] If TRUE, return the total coordinates including internally generated boundary cells. If FALSE, return the computational cells (which is what the user will be expecting). The default value is FALSE.

[localCounts] Counts per dimension of the local piece of decomposition.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.14 ESMF_GridGetCoordByDim2D - Get the horizontal and/or vertical coordinates of a Grid

INTERFACE:

    subroutine ESMF_GridGetCoordByDim2D(grid, dim, horzrelloc, vertrelloc, &
        centerCoord, cornerCoord, faceCoord, reorder, total, localCounts, &
        docopy, rc)

ARGUMENTS:

    type(ESMF_Grid), intent(inout) :: grid
    integer, intent(in) :: dim
    type(ESMF_RelLoc), intent(in), optional :: horzrelloc
    type(ESMF_RelLoc), intent(in), optional :: vertrelloc
    real(ESMF_KIND_R8), pointer, dimension(:,,:), optional :: centerCoord
    real(ESMF_KIND_R8), pointer, dimension(:,,:), optional :: cornerCoord
    real(ESMF_KIND_R8), pointer, dimension(:,,:), optional :: faceCoord
    logical, intent(in), optional :: reorder
    logical, intent(in), optional :: total
    integer, intent(out), optional :: localCounts(2)
    type(ESMF_CopyFlag), intent(in), optional :: docopy
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns coordinate information for the grid. The arguments are:

grid  ESMF_Grid to be queried.
dim  dimension to be queried.

[horzrelloc] Horizontal relative location of the subGrid to be queried.
[vertrelloc] Vertical relative location of the subGrid to be queried.

[centerCoord] Coordinates of each cell center. The dimension index should be defined first (e.g. x = coord(1,i,j), y=coord(2,i,j)).
[cornerCoord] Coordinates of corners of each cell. The dimension index should be defined first, followed by the corner index. Corners can be numbered in either clockwise or counter-clockwise direction, but must be numbered consistently throughout the Grid.

[faceCoord] Coordinates of face centers of each cell. The dimension index should be defined first, followed by the face index. Faces should be numbered consistently with corners. For example, face 1 should correspond to the face between corners 1,2.

[reorder] If TRUE, reorder any results using a previously set CoordOrder before returning. If FALSE, do not reorder. The default value is TRUE and users should not need to reset this for most applications. This optional argument is available mostly for internal use.

[total] If TRUE, return the total coordinates including internally generated boundary cells. If FALSE, return the computational cells (which is what the user will be expecting). The default value is FALSE.

[localCounts] Counts per dimension of the local piece of decomposition.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

### 22.7.15 ESMF_GridGetDELocalInfo - Get DE-local information for a Grid

**INTERFACE:**

```fortran
subroutine ESMF_GridGetDELocalInfo(grid, horzrelloc, vertrelloc, &
   myDE, localCellCount, localCellCountPerDim, &
   minLocalCoordPerDim, maxLocalCoordPerDim, &
   globalStartPerDim, reorder, total, rc)
```

**ARGUMENTS:**

- `type(ESMF_Grid) :: grid`
- `type(ESMF_RelLoc), intent(in) :: horzrelloc`
- `type(ESMF_RelLoc), intent(in), optional :: vertrelloc`
- `integer, intent(out), optional :: myDE`
- `integer, intent(out), optional :: localCellCount`
- `integer, dimension(:), intent(out), optional :: localCellCountPerDim`
- `real(ESMF_KIND_R8), intent(out), dimension(:), optional :: minLocalCoordPerDim`
- `real(ESMF_KIND_R8), intent(out), dimension(:), optional :: maxLocalCoordPerDim`
- `integer, dimension(:), intent(out), optional :: globalStartPerDim`
- `logical, intent(in), optional :: reorder`
- `logical, intent(in), optional :: total`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Gets Grid or subGrid information for a particular Decomposition Element (DE) assigned to this PET. This routine cannot retrieve information about a DE on a different PET.

The arguments are:

- `grid` ESMF_Grid to be queried.
- `horzrelloc` Horizontal relative location of the subGrid to be queried.
- `vertrelloc` Vertical relative location of the subGrid to be queried.
[myDE] Identifier for this ESMF_DE, zero-based. Note that this is a returned value, not an input one.

[localCellCount] Local (on this ESMF_DE) number of cells.

[localCellCountPerDim] Local (on this ESMF_DE) number of cells per dimension.

[minLocalCoordPerDim] Array of minimum local coordinate values on this DE in each dimension. The number of array elements should be greater or equal to the number of Grid dimensions.

[maxLocalCoordPerDim] Array of maximum local coordinate values on this DE in each dimension. The number of array elements should be greater or equal to the number of Grid dimensions.

[globalStartPerDim] Global index of starting counts for each dimension. The number of array elements should be greater or equal to the number of Grid dimensions.

[reorder] If TRUE, reorder any results using a previously set CoordOrder before returning. If FALSE, do not reorder. The default value is TRUE and users should not need to reset this for most applications. This optional argument is available primarily for internal use.

[total] If TRUE, return queries based on the total coordinates including internally generated boundary cells. If FALSE, return queries based on the computational cells (which is what the user will be expecting). The default value is FALSE.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

---

**22.7.16 ESMF_GridGlobalToDELocalIndex - Translate global indexing to DE-local**

**INTERFACE:**

```fortran
subroutine ESMF_GridGlobalToDELocalIndex(grid, horzrelloc, vertrelloc, &
global1D, local1D, &
global2D, local2D, &
dimOrder, rc)
```

**ARGUMENTS:**

- `type(ESMF_Grid) :: grid`
- `type(ESMF_RelLoc), intent(in) :: horzrelloc`
- `type(ESMF_RelLoc), intent(in), optional :: vertrelloc`
- `integer(ESMF_KIND_I4), dimension(:), optional, intent(in) :: global1D`
- `integer(ESMF_KIND_I4), dimension(:), optional, intent(out) :: local1D`
- `integer(ESMF_KIND_I4), dimension(:,:), optional, intent(in) :: global2D`
- `integer(ESMF_KIND_I4), dimension(:,:), optional, intent(out) :: local2D`
- `integer, dimension(:), optional, intent(in) :: dimOrder`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Translates an array of integer cell identifiers from global indexing to DE-local indexing. This routine is intended to identify equivalent positions of grid elements in distributed (DE-local) arrays and gathered (global) arrays, either by memory location or index pairs. **WARNING:** This routine is meant for very limited user access. It works with Grid indices and will give erroneous results if applied to Field or Array indices. In the future, this should be a Field method, but in the meantime it will be left available here.

The arguments are:

- `grid` ESMF_Grid to be used.
[horzrelloc] Horizontal relative location of the subGrid to be used for the translation.

[vertrelloc] Vertical relative location of the subGrid to be used for the translation.

[global1D] One-dimensional array of global identifiers to be translated. Usage of this optional argument infers translating between positions in memory from a global array to a DE-local (or distributed) one. This array is dimensioned (N), where N is the number of memory locations to be translated.

[local1D] One-dimensional array of DE-local identifiers for the return of the translation. This array must be the same size as global1D, and must be present if global1D is present. If either of these conditions is not met, an error is issued.

[global2D] Two-dimensional array of global identifiers to be translated. Usage of this optional argument infers translating between indices in IJ space. This array is assumed to be dimensioned (N,2), where N is the number of index locations to be translated and the second dimension corresponds to the two Grid indices that are distributed (currently any two dimensions of a three-dimensional Grid can be distributed). So to translate three sets of global indices to DE-local indexing:

\[
\begin{align*}
global2D(1,1) &= \text{index1(1)} \\
global2D(1,2) &= \text{index1(2)} \\
global2D(2,1) &= \text{index2(1)} \\
global2D(2,2) &= \text{index2(2)} \\
global2D(3,1) &= \text{index3(1)} \\
global2D(3,2) &= \text{index3(2)}
\end{align*}
\]

[local2D] Two-dimensional array of DE-local identifiers for the return of the translation. This array must be the same size as global2D, and must be present if global2D is present. If either of these conditions is not met, an error is issued.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.17 ESMF_GridDELocalToGlobalIndex - Translate DE-local indexing to global

INTERFACE:

\[
\begin{align*}
\text{subroutine ESMF_GridDELocalToGlobalIndex(grid, horzrelloc, vertrelloc,} \\
\text{local1D, global1D,} \\
\text{local2D, global2D, rc)}
\end{align*}
\]

ARGUMENTS:

\[
\begin{align*}
type(ESMF\_Grid) &:: \text{grid} \\
type(ESMF\_RelLoc), \text{intent(in)} &:: \text{horzrelloc} \\
type(ESMF\_RelLoc), \text{intent(in)}, \text{optional} &:: \text{vertrelloc} \\
integer(ESMF\_KIND\_I4), \text{dimension(():), optional, intent(in)} &:: \text{local1D} \\
integer(ESMF\_KIND\_I4), \text{dimension(():), optional, intent(out)} &:: \text{global1D} \\
integer(ESMF\_KIND\_I4), \text{dimension(():), optional, intent(in)} &:: \text{local2D} \\
integer(ESMF\_KIND\_I4), \text{dimension(():), optional, intent(out)} &:: \text{global2D} \\
integer, \text{intent(out)}, \text{optional} &:: \text{rc}
\end{align*}
\]
DESCRIPTION:

Translates an array of integer cell identifiers from DE-local indexing to global indexing. This routine is intended to identify equivalent positions of grid elements in distributed (DE-local) arrays and gathered (global) arrays, either by memory location or index pairs. WARNING: This routine is meant for very limited user access. It works with Grid indices and will give erroneous results if applied to Field or Array indices. In the future, this should be a Field method, but in the meantime it will be left available here.

The arguments are:

grid  ESMF_Grid to be used.

[horzrelloc] Horizontal relative location of the subGrid to be used for the translation.

[vertrelloc] Vertical relative location of the subGrid to be used for the translation.

[local1D] One-dimensional array of DE-local identifiers to be translated. Usage of this optional argument infers translating between positions in memory from a DE-local (or distributed) Grid array to a global one. This array is dimensioned (N), where N is the number of memory locations to be translated.

[global1D] One-dimensional array of global identifiers for the return of the translation. This array must be the same size as local1D, and must be present if local1D is present. If either of these conditions is not met, an error is issued.

[local2D] Two-dimensional array of DE-local identifiers to be translated. Usage of this optional argument infers translating between indices in IJ space. This array is assumed to be dimensioned (N,2), where N is the number of index locations to be translated and the second dimension corresponds to the two Grid indices that are distributed (currently any two dimensions of a three-dimensional Grid can be distributed). So to translate three sets of DE-local indices to global indexing,

\[
\begin{align*}
\text{local2D}(1,1) &= \text{index1}(1) \\
\text{local2D}(1,2) &= \text{index1}(2) \\
\text{local2D}(2,1) &= \text{index2}(1) \\
\text{local2D}(2,2) &= \text{index2}(2) \\
\text{local2D}(3,1) &= \text{index3}(1) \\
\text{local2D}(3,2) &= \text{index3}(2)
\end{align*}
\]

[global2D] Two-dimensional array of global identifiers for the return of the translation. This array must be the same size as local2D, and must be present if local2D is present. If either of these conditions is not met, an error is issued.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.18  ESMF_GridPrint - Print the contents of a Grid

INTERFACE:

    subroutine ESMF_GridPrint(grid, options, rc)

ARGUMENTS:

    type(ESMF_Grid),  intent(in) :: grid
    character (len=*), intent(in), optional :: options
    integer, intent(out), optional :: rc
DESCRIPTION:

Prints information about the grid to stdout. The arguments are:

grid ESMF_Grid to print.

[options] Print options are not yet supported.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.7.19 ESMF_GridSet - Set a variety of information about a Grid

INTERFACE:

subroutine ESMF_GridSet(grid, horzgridtype, vertgridtype, &
  horzstagger, vertstagger, &
  horzcoordsystem, vertcoordsystem, &
  coordorder, minGlobalCoordPerDim, &
  maxGlobalCoordPerDim, periodic, name, rc)

ARGUMENTS:

type(ESMF_Grid) :: grid
  type(ESMF_GridType), intent(in), optional :: horzgridtype
  type(ESMF_GridVertType), intent(in), optional :: vertgridtype
  type(ESMF_GridHorzStagger), intent(in), optional :: horzstagger
  type(ESMF_GridVertStagger), intent(in), optional :: vertstagger
  type(ESMF_CoordSystem), intent(in), optional :: horzcoordsystem
  type(ESMF_CoordSystem), intent(in), optional :: vertcoordsystem
  type(ESMF_CoordOrder), intent(in), optional :: coordorder
  real(ESMF_KIND_R8), dimension(:), intent(in), optional :: minGlobalCoordPerDim
  real(ESMF_KIND_R8), dimension(:), intent(in), optional :: maxGlobalCoordPerDim
  type(ESMF_Logical), intent(in), optional :: periodic(:)
  character(len=*) , intent(in), optional :: name
  integer, intent(out), optional :: rc

DESCRIPTION:

Sets information for the Grid that may not have been included at Grid creation. WARNING: This routine does not automatically regenerate the Grid when used to reset its values, some of which may significantly alter the existing Grid. Therefore this routine may only be used prior to the ESMF_GridDistribute() call. The arguments are:

grid ESMF_Grid to be modified.

[horzgridType] ESMF_GridType specifier denoting horizontal Grid type.

[vertgridType] ESMF_GridVertType specifier denoting vertical subGrid type.


[horzcoordsystem] ESMF_CoordSystem which identifies an ESMF standard coordinate system (e.g. spherical, cartesian, pressure, etc.) for the horizontal Grid.
ESMF_CoordSystem which identifies an ESMF standard coordinate system (e.g. spherical, cartesian, pressure, etc.) for the vertical subGrid.

ESMF_CoordOrder specifier denoting the default coordinate ordering for the Grid and all related Fields (i.e. ZXY).

Array of minimum global physical coordinates in each direction.

Array of maximum global physical coordinates in each direction.

Logical array that returns the periodicity of the coordinate axes.

Character string name of ESMF_Grid.

Return code; equals ESMF_SUCCESS if there are no errors.

22.7.20 ESMF_GridSetAttribute - Set an attribute

INTERFACE:

    subroutine ESMF_GridSetAttribute(grid, name, <value argument>, rc)

ARGUMENTS:

    type(ESMF_Grid), intent(inout) :: grid
    character (len = *), intent(in) :: name
    <value argument>, see below for supported values
    integer, intent(out), optional :: rc

DESCRIPTION:

Attaches an attribute to the grid. The attribute has a name and either a value or a valueList. Supported values for the <value argument> are:

    integer(ESMF_KIND_I4), intent(in) :: value
    integer(ESMF_KIND_I4), dimension(:), intent(in) :: valueList
    integer(ESMF_KIND_I8), intent(in) :: value
    integer(ESMF_KIND_I8), dimension(:), intent(in) :: valueList
    real (ESMF_KIND_R4), intent(in) :: value
    real (ESMF_KIND_R4), dimension(:), intent(in) :: valueList
    real (ESMF_KIND_R8), intent(in) :: value
    real (ESMF_KIND_R8), dimension(:), intent(in) :: valueList
    type(ESMF_Logical), intent(in) :: value
    type(ESMF_Logical), dimension(:), intent(in) :: valueList
    character (len = *), intent(in), value

The arguments are:

    grid    An ESMF_Grid object.
    name    The name of the attribute to set.
    <value argument>    The value of the attribute to set.
    [rc]    Return code; equals ESMF_SUCCESS if there are no errors.
22.7.21 ESMF_GridValidate - Check validity of a Grid

INTERFACE:

    subroutine ESMF_GridValidate(grid, options, rc)

ARGUMENTS:

    type(ESMF_Grid), intent(in) :: grid
    character (len=*), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Validates that an ESMF_Grid is internally consistent. Currently checks to ensure:

1. the pointer to the Grid is associated; and
2. the Grid status indicates the Grid is ready to use.

The arguments are:

grid ESMF_Grid to be validated.

[options] Validation options are not yet supported.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.8 Class API: Logically Rectangular Grid Methods

22.8.1 ESMF_GridCreateHorzLatLon - Create a new horizontal LatLon Grid

INTERFACE:

    ! Private name; call using ESMF_GridCreateHorzlatLon()
    function ESMF_GridCreateHorzLatLonCoord(coord1, coord2, &
                                          horzstagger, dimNames, dimUnits, &
                                          coordorder, periodic, name, rc)

RETURN VALUE:

    type(ESMF_Grid) :: ESMF_GridCreateHorzLatLonCoord

ARGUMENTS:

    real(ESMF_KIND_R8), dimension(:), intent(in) :: coord1
    real(ESMF_KIND_R8), dimension(:), intent(in) :: coord2
    type(ESMF_GridHorzStagger), intent(in), optional :: horzstagger
    character(len=*), dimension(:), intent(in), optional :: dimNames
    character(len=*), dimension(:), intent(in), optional :: dimUnits
    type(ESMF_CoordOrder), intent(in), optional :: coordorder
    type(ESMF_Logical), dimension(:), intent(in), optional :: periodic
    character(len=*), intent(in), optional :: name
    integer, intent(out), optional :: rc

DESCRIPTION:

Allocates memory for a new ESMF_Grid object, constructs its internal derived types, and internally generates the ESMF_Grid. Returns a pointer to the new ESMF_Grid. This routine creates an ESMF_Grid with the following parameters:
logically rectangular;
user-specified spacing;
horizontal spherical coordinate system.

This routine generates ESMF_Grid coordinates from the following set of arguments:
given arrays of coordinates (arguments coord1 and coord2).

The arguments are:

**coord1** Array of physical vertex coordinates in the first direction. Note that there must be 1 more vertex coordinate in each dimension than the number of cells.

**coord2** Array of physical vertex coordinates in the second direction. Note that there must be 1 more vertex coordinate in each dimension than the number of cells.

**horzstagger** ESMF_GridHorzStagger specifier denoting horizontal Grid stagger. If none is specified, the default is ESMF_GRID_HORZ_STAGGER_A.

**dimNames** Array of dimension names.

**dimUnits** Array of dimension units.

**coordorder** ESMF_CoordOrder specifier denoting the default coordinate ordering for the Grid and all related Fields (i.e. ZXY). If none is specified, the default is ESMF_COORD_ORDER_XYZ.

**periodic** Logical array denoting the periodicity of the coordinate axes. The default is FALSE for all axes.

**name** ESMF_Grid name.

**rc** Return code; equals ESMF_SUCCESS if there are no errors.

### 22.8.2 ESMF_GridCreateHorzLatLon - Create a new horizontal LatLon Grid

**INTERFACE:**

```
! Private name; call using ESMF_GridCreateHorzlatLon()
function ESMF_GridCreateHorzLatLonDelta(minGlobalCoordPerDim, &
delta1, delta2, horzstagger, &
dimNames, dimUnits, &
coordorder, periodic, name, rc)
```

**RETURN VALUE:**

```
type(ESMF_Grid) :: ESMF_GridCreateHorzLatLonDelta
```

**ARGUMENTS:**

```
real(ESMF_KIND_R8), dimension(:), intent(in) :: minGlobalCoordPerDim
real(ESMF_KIND_R8), dimension(:), intent(in) :: delta1
real(ESMF_KIND_R8), dimension(:), intent(in) :: delta2
type(ESMF_GridHorzStagger), intent(in), optional :: horzstagger
character(len=*), dimension(:), intent(in), optional :: dimNames
type(ESMF_CoordOrder), intent(in), optional :: coordorder
type(ESMF_Logical), dimension(:), intent(in), optional :: periodic
classic_monotype character(len=*)], intent(in), optional :: name
integer, intent(out), optional :: rc
```
DESCRIPTION:

Allocates memory for a new ESMF_Grid object, constructs its internal derived types, and internally generates the ESMF_Grid. Returns a pointer to the new ESMF_Grid. This routine creates an ESMF_Grid with the following parameters:

- logically rectangular;
- user-specified spacing;
- horizontal spherical coordinate system.

This specific routine generates ESMF_Grid coordinates from the following set of arguments:

given array of minimum coordinates and arrays of deltas (arguments minGlobalCoordPerDim, delta1 and delta2).

The arguments are:

- `minGlobalCoordsPerDim` Array of minimum physical coordinate in each direction. Note this is the vertex coordinate and not the cell center.
- `delta1` Array of physical increments between nodes in the first direction. These are cell widths, and there should be as many as there are cells in the grid.
- `delta2` Array of physical increments between nodes in the second direction. These are cell widths, and there should be as many as there are cells in the grid.
- `[horzstagger]` ESMF_GridHorzStagger specifier denoting horizontal Grid stagger. If none is specified, the default is ESMF_GRID_HORZ_STAGGER_A.
- `[dimNames]` Array of dimension names.
- `[dimUnits]` Array of dimension units.
- `[coordorder]` ESMF_CoordOrder specifier denoting the default coordinate ordering for the Grid and all related Fields (i.e. ZXY). If none is specified, the default is ESMF_COORD_ORDER_XYZ.
- `[periodic]` Logical array denoting the periodicity of the coordinate axes. The default is FALSE for all axes.
- `[name]` ESMF_Grid name.
- `[rc]` Return code; equals ESMF_SUCCESS if there are no errors.

### 22.8.3 ESMF_GridCreateHorzLatLonUni - Create a new uniform horizontal LatLon Grid

**INTERFACE:**

```fortran
function ESMF_GridCreateHorzLatLonUni(counts, minGlobalCoordPerDim, &
    maxGlobalCoordPerDim, &
    deltaPerDim, horzstagger, &
    dimNames, dimUnits, &
    coordorder, periodic, name, rc)
```

**RETURN VALUE:**

```fortran
type(ESMF_Grid) :: ESMF_GridCreateHorzLatLonUni
```
ARGUMENTS:

integer, dimension(:,), intent(in) :: counts
real(ESMF_KIND_R8), dimension(:,), intent(in) :: minGlobalCoordPerDim
real(ESMF_KIND_R8), dimension(:,), intent(in), optional :: &
                    maxGlobalCoordPerDim
real(ESMF_KIND_R8), dimension(:,), intent(in), optional :: &
                    deltaPerDim
type(ESMF_GridHorzStagger), intent(in), optional :: horzstagger
class(len=*), dimension(:,), intent(in), optional :: dimNames
class(len=*), dimension(:,), intent(in), optional :: dimUnits
type(ESMF_CoordOrder), intent(in), optional :: coordorder
type(ESMF_Logical), dimension(:,), intent(in), optional :: periodic
class(len=*), intent(in), optional :: name
integer, intent(out), optional :: rc

DESCRIPTION:

Allocates memory for a new ESMF_Grid object, constructs its internal derived types, and internally generates the ESMF_Grid. Returns a pointer to the new ESMF_Grid. This routine creates an ESMF_Grid with the following parameters:

- logically rectangular;
- uniformly spaced coordinates (the distance between any two consecutive grid points is equal);
- horizontal spherical coordinate system.

This routine generates ESMF_Grid coordinates from either of two optional sets of arguments:
1. given min, max, and count (arguments minGlobalCoordPerDim, maxGlobalCoordPerDim, and counts);
2. given min, delta, and count (arguments minGlobalCoordPerDim, deltaPerDim, and counts).

If neither of these sets of arguments is present and valid, an error message is issued and the program is terminated.

The arguments are:

- **counts** Array of number of grid increments in each dimension. This array must have at least a length of two and have valid values in the first two array locations or a fatal error occurs.
- **minGlobalCoordPerDim** Array of minimum physical coordinates in each dimension. Note these are the vertex coordinates and not the cell centers.
- **maxGlobalCoordPerDim** Array of maximum physical coordinates in each direction. Note these are the vertex coordinates and not the cell centers.
- **deltaPerDim** Array of constant physical increments in each direction.
- **horzstagger** ESMF_GridHorzStagger specifier denoting horizontal Grid stagger. If none is specified, the default is ESMF_GRID_HORZ_STAGGER_A.
- **dimNames** Array of dimension names.
- **dimUnits** Array of dimension units.
- **coordorder** ESMF_CoordOrder specifier denoting the default coordinate ordering for the Grid and all related Fields (i.e. ZXY). If none is specified, the default is ESMF_COORD_ORDER_XYZ.
- **periodic** Logical array denoting the periodicity of the coordinate axes. The default is FALSE for all axes.
- **name** ESMF_Grid name.
- **rc** Return code; equals ESMF_SUCCESS if there are no errors.
22.8.4 ESMF_GridCreateHorzXY - Create a new horizontal XY Grid

INTERFACE:

! Private name; call using ESMF_GridCreateHorzXY()
function ESMF_GridCreateHorzXYCoord(coord1, coord2, &
    horzstagger, dimNames, dimUnits, &
    coordorder, periodic, name, rc)

RETURN VALUE:

type(ESMF_Grid) :: ESMF_GridCreateHorzXYCoord

ARGUMENTS:

real(ESMF_KIND_R8), dimension(:), intent(in) :: coord1
real(ESMF_KIND_R8), dimension(:), intent(in) :: coord2
type(ESMF_GridHorzStagger), intent(in), optional :: horzstagger
class(len=*), dimension(:), intent(in), optional :: dimNames
class(len=*), dimension(:), intent(in), optional :: dimUnits
type(ESMF_CoordOrder), intent(in), optional :: coordorder
type(ESMF_Logical), dimension(:), intent(in), optional :: periodic
class(len=*), intent(in), optional :: name
integer, intent(out), optional :: rc

DESCRIPTION:

Allocates memory for a new ESMF_Grid object, constructs its internal derived types, and internally generates the ESMF_Grid. Returns a pointer to the new ESMF_Grid. This routine creates an ESMF_Grid with the following parameters:

- logically rectangular;
- user-specified spacing;
- horizontal cartesian coordinate system.

This routine generates ESMF_Grid coordinates from the following set of arguments:

- given arrays of coordinates (arguments coord1 and coord2).

The arguments are:

coord1 Array of physical vertex coordinates in the first direction. Note that there must be 1 more vertex coordinate in each dimension than the number of cells.

coord2 Array of physical vertex coordinates in the second direction. Note that there must be 1 more vertex coordinate in each dimension than the number of cells.

[horzstagger] ESMF_GridHorzStagger specifier denoting horizontal Grid stagger. If none is specified, the default is ESMF_GRID_HORZ_STAGGER_A.

[dimNames] Array of dimension names.

[dimUnits] Array of dimension units.

[coordorder] ESMF_CoordOrder specifier denoting the default coordinate ordering for the Grid and all related Fields (i.e. ZXY). If none is specified, the default is ESMF_COORD_ORDER_XYZ.

[periodic] Logical array denoting the periodicity of the coordinate axes. The default is FALSE for all axes.

[name] ESMF_Grid name.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
22.8.5 ESMF_GridCreateHorzXY - Create a new horizontal XY Grid

INTERFACE:

! Private name; call using ESMF_GridCreateHorzXY()
function ESMF_GridCreateHorzXYDelta(minGlobalCoordPerDim, &
delta1, delta2, &
horzstagger, dimNames, dimUnits, &
coordorder, periodic, name, rc)

RETURN VALUE:

type(ESMF_Grid) :: ESMF_GridCreateHorzXYDelta

ARGUMENTS:

real(ESMF_KIND_R8), dimension(:,), intent(in) :: minGlobalCoordPerDim
real(ESMF_KIND_R8), dimension(:,), intent(in) :: delta1
real(ESMF_KIND_R8), dimension(:,), intent(in) :: delta2
type(ESMF_GridHorzStagger), intent(in), optional :: horzstagger
character(len=*), dimension(:,), intent(in), optional :: dimNames
character(len=*), dimension(:,), intent(in), optional :: dimUnits
type(ESMF_CoordOrder), intent(in), optional :: coordorder
type(ESMF_Logical), dimension(:,), intent(in), optional :: periodic
character(len=*), intent(in), optional :: name
integer, intent(out), optional :: rc

DESCRIPTION:

Allocates memory for a new ESMF_Grid object, constructs its internal derived types, and internally generates the ESMF_Grid. Returns a pointer to the new ESMF_Grid. This routine creates an ESMF_Grid with the following parameters:

logically rectangular;

user-specified spacing;

horizontal cartesian coordinate system.

This routine generates ESMF_Grid coordinates from the following set of arguments:

given array of minimum coordinates and arrays of deltas (arguments minGlobalCoordPerDim, delta1 and delta2).

The arguments are:

minGlobalCoordsPerDim Array of minimum physical coordinates in each direction. Note this is the vertex coordinate and not the cell center.

delta1 Array of physical increments between nodes in the first direction. These are cell widths, and there should be as many as there are cells in the grid.

delta2 Array of physical increments between nodes in the second direction. These are cell widths, and there should be as many as there are cells in the grid.

[horzstagger] ESMF_GridHorzStagger specifier denoting horizontal Grid stagger. If none is specified, the default is ESMF_GRID_HORZ_STAGGER_A.

[dimNames] Array of dimension names.
[dimUnits] Array of dimension units.
[coordorder] ESMF_CoordOrder specifier denoting the default coordinate ordering for the Grid and all related Fields (i.e. ZXY). If none is specified, the default is ESMF_COORD_ORDER_XYZ.
[periodic] Logical array denoting the periodicity of the coordinate axes. The default is FALSE for all axes.
[name] ESMF_Grid name.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

22.8.6 ESMF_GridCreateHorzXYUni - Create a new uniform horizontal XY Grid

INTERFACE:

    function ESMF_GridCreateHorzXYUni(counts, minGlobalCoordPerDim, & maxGlobalCoordPerDim, &
    deltaPerDim, horzstagger, &
    dimNames, dimUnits, &
    coordorder, periodic, name, rc)

RETURN VALUE:

    type(ESMF_Grid) :: ESMF_GridCreateHorzXYUni

ARGUMENTS:

    integer, dimension(:,), intent(in) :: counts
    real(ESMF_KIND_R8), dimension(:,), intent(in) :: minGlobalCoordPerDim
    real(ESMF_KIND_R8), dimension(:,), intent(in), optional :: &
        maxGlobalCoordPerDim
    real(ESMF_KIND_R8), dimension(:,), intent(in), optional :: &
        deltaPerDim
    type(ESMF_GridHorzStagger), intent(in), optional :: horzstagger
    character(len=*), dimension(:,), intent(in), optional :: dimNames
    character(len=*), dimension(:,), intent(in), optional :: dimUnits
    type(ESMF_CoordOrder), intent(in), optional :: coordorder
    type(ESMF_Logical), dimension(:,), intent(in), optional :: periodic
    character(len=*), intent(in), optional :: name
    integer, intent(out), optional :: rc

DESCRIPTION:

Allocates memory for a new ESMF_Grid object, constructs its internal derived types, and internally generates the ESMF_Grid. Returns a pointer to the new ESMF_Grid. This routine creates an ESMF_Grid with the following parameters:

- logically rectangular;
- uniformly spaced coordinates (the distance between any two consecutive grid points is equal);
- horizontal cartesian coordinate system.

This routine generates ESMF_Grid coordinates from either of two optional sets of arguments:

1. given min, max, and count (arguments minGlobalCoordPerDim, maxGlobalCoordPerDim, and counts);
2. Given min, delta, and count (arguments minGlobalCoordPerDim, deltaPerDim, and counts).

If neither of these sets of arguments is present and valid, an error message is issued and the program is terminated.

The arguments are:

- **counts** Array of number of grid increments in each dimension. This array must have at least a length of two and have valid values in the first two array locations or a fatal error occurs.

- **minGlobalCoordPerDim** Array of minimum physical coordinates in each dimension. Note this is the vertex coordinate and not the cell center.

- **[maxGlobalCoordPerDim]** Array of maximum physical coordinates in each direction. Note this is the vertex coordinate and not the cell center.

- **[deltaPerDim]** Array of constant physical increments in each direction.

- **[horzstagger]** ESMF_GridHorzStagger specifier denoting horizontal Grid stagger. If none is specified, the default is ESMF_GRID_HORZ_STAGGER_A.

- **[dimNames]** Array of dimension names.

- **[dimUnits]** Array of dimension units.

- **[coordorder]** ESMF_CoordOrder specifier denoting the default coordinate ordering for the Grid and all related Fields (i.e. ZXY). If none is specified, the default is ESMF_COORD_ORDER_XYZ.

- **[periodic]** Logical array denoting the periodicity of the coordinate axes. The default is FALSE for all axes.

- **[name]** ESMF_Grid name.

- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

## 23 DistGrid Class

### 23.1 Description

The ESMF_DistGrid class sits on top of the DELayout class and holds domain information in index space. A DistGrid object captures the index space topology and describes its decomposition in terms of DEs. Combined with DELayout and VM the DistGrid defines the data distribution of a domain decomposition across the computational resources of an ESMF component.

The global domain is defined as the union or “patchwork” of logically rectangular (LR) sub-domains or patches. The DistGrid create methods allow the specification of such a patchwork global domain, which may be decomposed into exclusive, DE-local LR regions according to various degrees of user specified constraints. Complex index space topologies can be constructed by specifying contact relationships between LR patches during creation.

The DistGrid class holds domain information for all DEs. Each DE is associated with a local LR region. No overlap of the regions is allowed. The DistGrid offers query methods that allow DE-local topology information to be extracted, e.g. for the construction of halos by higher classes.

The DistGrid only contains decomposable dimensions. The rank of a DELayout contained in a DistGrid is equal to the DistGrid rank. Higher classes that use DistGrid may be of higher rank, keeping track of which dimensions map to DistGrid dimensions.

### 23.2 Use and Examples

The following examples demonstrate how to create, use and destroy DistGrid objects. All of the currently proposed ESMF_DistGridCreate() calls require to be called on all PETs with a complete set of valid arguments.
23.2.1 2D DistGrid with simple LR domain and regular decomposition

The minimum information required to create an ESMF_DistGrid object for a simple LR domain with regular decomposition are the corners of the domain and the decomposition descriptor \( \text{regDecomp} \). The following line creates a DistGrid for a 5x5 global LR domain that is to be decomposed into \( 2 \times 3 = 6 \) DEs.

\[
\text{distgrid} = \text{ESMF_DistGridCreate} (\text{minCorner}=\langle 1,1 \rangle, \text{maxCorner}=\langle 5,5 \rangle, \& \\text{regDecomp}=\langle 2,3 \rangle, \text{rc}=\text{rc})
\]

The default DE labeling sequence follows column major order for the \( \text{regDecomp} \) argument:

```
-----------> 2nd dimension
    0  2  4
    1  3  5

v
```

1st dimension

By default grid points along all dimensions are homogeneously divided between the DEs. The maximum cell count difference between DEs along any dimension is 1. The (min) ~ (max) corners of the DE-local LR domains of the above example are as follows:

- DE 0 - (1,1) ~ (3,2)
- DE 1 - (4,1) ~ (5,2)
- DE 2 - (1,3) ~ (3,4)
- DE 3 - (4,3) ~ (5,4)
- DE 4 - (1,5) ~ (3,5)
- DE 5 - (4,5) ~ (5,5)

The decomposition of the global LR domain into DE-local LR domains can be modified by the optional \( \text{decompflag} \) argument. The following line shows how this argument is used to keep ESMF's default decomposition in the first dimension but move extra grid points of the second dimension to the last DEs in that direction. Extra cells occur if the number of DEs for a certain dimension does not evenly divide its extent. In this example there are 2 extra grid points for the second dimension.

\[
\text{distgrid} = \text{ESMF_DistGridCreate} (\text{minCorner}=\langle 1,1 \rangle, \text{maxCorner}=\langle 5,5 \rangle, \& \\text{regDecomp}=\langle 2,3 \rangle, \text{decompflag}=\langle \text{ESMF_DECOMP_DEFAULT, ESMF_DECOMP_RESTLAST} \rangle, \& \text{rc}=\text{rc})
\]

This will result in a modified decomposition:

- DE 0 - (1,1) ~ (3,1)
- DE 1 - (4,1) ~ (5,1)
- DE 2 - (1,2) ~ (3,2)
- DE 3 - (4,2) ~ (5,2)
- DE 4 - (1,3) ~ (3,5)
- DE 5 - (4,3) ~ (5,5)

An alternative way of indicating the DE-local LR boxes is to list the global indices for each dimension. For this 2D example there are two lists (dim 1) / (dim 2) for each DE:

- DE 0 - (1,2,3) / (1)
- DE 1 - (4,5) / (1)
- DE 2 - (1,2,3) / (2)
- DE 3 - (4,5) / (2)
- DE 4 - (1,2,3) / (3,4,5)
- DE 5 - (4,5) / (3,4,5)
Information about DE-local LR domains in the latter format can be obtained from a DistGrid object by use of ESMF_DistGridGet() methods:

```fortran
allocate(dimExtent(2, 6)) ! (dimCount, deCount)
call ESMF_DistGridGet(distgrid, dimExtent=dimExtent, rc=rc) ! get dimExtent
if (rc /= ESMF_SUCCESS) call ESMF_Finalize(terminationflag=ESMF_ABORT)
do de=1, 6
  do dim=1, 2
    allocate(indexList(dimExtent(dim, de))) ! allocate list to hold indices
    call ESMF_DistGridGet(distgrid, de=de-1, dim=dim, &
      indexList=indexList, rc=rc)
    if (localPet==0) then
      print *, "indexList for de=",de-1,"along dim=",dim," :: ", indexList
    endif
    deallocate(indexList)
  enddo
enddo
deallocate(dimExtent)
```

The advantage of the indexList format is that it can be used directly as a look-up table for DE-local to patch index dereferencing. Furthermore it allows to express very general decompositions such as the cyclic decompositions in the first dimension generated by the following create call:

```fortran
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
  regDecomp=(/2,3/), decompflag=(/ESMF_DECOMP_CYCLIC,ESMF_DECOMP_RESTLAST/),&
  rc=rc)
```

with decomposition:

- **DE 0** - (1,3,5) / (1)
- **DE 1** - (2,4) / (1)
- **DE 2** - (1,3,5) / (2)
- **DE 3** - (2,4) / (2)
- **DE 4** - (1,3,5) / (3,4,5)
- **DE 5** - (2,4) / (3,4,5)

Finally, a DistGrid object can be destroyed by calling

```fortran
call ESMF_DistGridDestroy(distgrid, rc=rc)
```

### 23.2.2 DistGrid and DELayout

The examples of this section use the 2D DistGrid of the previous section to show the interplay between DistGrid and DELayout. By default, i.e. without specifying the delayout argument, a DELayout will be created during DistGrid creation that provides as many DEs as the DistGrid object requires. The implicit call to ESMF_DELayoutCreate() is issued with a fixed number of DEs and default settings in all other aspects. The resulting DE to PET mapping depends on the number of PETs of the current VM context. Assuming 6 PETs in the VM

```fortran
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
  regDecomp=(/2,3/), rc=rc)
```

will result in the following domain decomposition in terms of DEs
and their layout or distribution over the available PETs:

```
DE 0 -> PET 0
DE 1 -> PET 1
DE 2 -> PET 2
DE 3 -> PET 3
DE 4 -> PET 4
DE 5 -> PET 5
```

Running the same example on a 4 PET VM will not change the domain decomposition into 6 DEs as specified by

```
0 2 4
1 3 5
```

but the layout across PETs will now contain multiple DE-to-PET mapping with default cyclic distribution:

```
DE 0 -> PET 0
DE 1 -> PET 1
DE 2 -> PET 2
DE 3 -> PET 3
DE 4 -> PET 0
DE 5 -> PET 1
```

Sometimes it may be desirable for performance tuning to construct a DELayout with specific characteristics. For instance, if the 6 PETs of the above example are running on 3 nodes of a dual-SMP node cluster and there is a higher communication load along the first dimension of the model than along the second dimension it would be sensible to place DEs according to this knowledge. There are two ways to accomplish this in ESMF. First the `fastAxis` argument can be used when creating the DistGrid object to indicate which axis should have faster communication characteristics:

```
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
    regDecomp=(/2,3/), fastAxis=1, rc=rc)
```

A second way to achieve the same distribution is to explicitly create a suitable DELayout object. The following example first creates a DELayout with 6 DEs where groups of 2 DEs are to be in fast connection. This DELayout is then used to create a DistGrid.

```
delayout = ESMF_DELayoutCreate(deCount=6, deGrouping=(/(i/2,i=0,5)/), rc=rc)
```

```
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
    regDecomp=(/2,3/), delayout=delayout, rc=rc)
```

Either case (`fastAxis` or `DELayout`) will ensure a distribution of DEs across the cluster resource in the following way:

```
0 2 4
1 3 5
```
The interplay between DistGrid and DELayout may at first seem complicated. The simple but important rule to understand is that DistGrid describes a domain decomposition and each domain is labeled with a DE number. The DELayout describes how these DEs are laid out over the compute resources of the VM. The DEs are purely logical elements of decomposition and may be relabeled to fit the algorithm or legacy code better. The following example demonstrates this by describing the exact same distribution of the domain data across the fictitious cluster of SMP-nodes with a different choice of DE labeling:

```
delayout = ESMF_DELayoutCreate(deCount=6, deGrouping=\{(mod(i,3),i=0,5)/\}, &
     rc=rc)

distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
     regDecomp=(/2,3/), deLabelList=(/0,3,1,4,2,5/), delayout=delayout, rc=rc)
```

Here the \textit{deLabelList} argument changes the default DE label sequence from column major to row major. The DELayout compensates for this change in DE labeling by changing the \textit{deGrouping} argument to map the first dimension to SMP nodes as before. The decomposition and layout now looks as follows:

\begin{center}
\begin{tabular}{ccc}
0 & 1 & 2 \\
3 & 4 & 5 \\
SMP & SMP & SMP \\
\end{tabular}
\end{center}

Finally, in order to achieve a completely user-defined distribution of the domain data across the PETs of the VM a DELayout may be created from a \textit{petMap} before using it in the creation of a DistGrid. If for instance the desired distribution of a 2 x 3 decomposition puts the DEs of the first row onto 3 separate PETs (PET 0, 1, 2) and groups the DEs of the second row onto PET 3 a \textit{petMap} must first be setup that takes the DE labeling of the DistGrid into account. The following lines of code result in the desired distribution using column major DE labeling by first create a DELayout and then using it in the DistGrid creation.

```
delayout = ESMF_DELayoutCreate(petMap=(/0,3,1,3,2,3/), rc=rc)

distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
     regDecomp=(/2,3/), delayout=delayout, rc=rc)
```

This decomposes the global domain into

\begin{center}
\begin{tabular}{c}
0 & 2 & 4 \\
1 & 3 & 5 \\
\end{tabular}
\end{center}

and associates the DEs to the following PETs:

\begin{center}
DE 0 \rightarrow PET 0 \\
DE 1 \rightarrow PET 3 \\
DE 2 \rightarrow PET 1 \\
DE 3 \rightarrow PET 3 \\
DE 4 \rightarrow PET 2 \\
DE 5 \rightarrow PET 3 \\
\end{center}

\subsection{23.2.3 Single LR domain with decomposition by DE blocks}

The examples of the previous sections showed how DistGrid objects with regular decompositions are created. However, in some cases a regular decomposition may not be specific enough. The following example shows how the \textit{deBlockList} argument is used to create a DistGrid object with completely user-defined decomposition.
A single 5x5 LR domain is to be decomposed into 6 DEs. To this end a list is constructed that holds the min and max corners of all six DE LR blocks. The DE-local LR blocks are arranged as to cover the whole patch domain without overlap.

```plaintext
allocate(deBlockList(2, 2, 6)) ! (dimCount, 3, deCount)
deBlockList(:,1,1) = (/1,1/) ! minCorner
deBlockList(:,2,1) = (/3,2/) ! maxCorner
deBlockList(:,1,2) = (/4,1/) ! minCorner
deBlockList(:,2,2) = (/5,2/) ! maxCorner
deBlockList(:,1,3) = (/1,3/)  
deBlockList(:,2,3) = (/2,4/)  
deBlockList(:,1,4) = (/3,3/)  
deBlockList(:,2,4) = (/5,4/)  
deBlockList(:,1,5) = (/1,5/)  
deBlockList(:,2,5) = (/3,5/)  
deBlockList(:,1,6) = (/4,5/)  
deBlockList(:,2,6) = (/5,5/)  

distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
deBlockList=deBlockList, rc=rc)
```

### 23.2.4 Periodic boundaries of a single LR domain

By default the edges of all LR patches have solid wall boundary conditions. Periodic boundary conditions can be imposed by specifying connections between patches. For the single LR domain of the last section periodic boundaries along the first dimension are imposed by adding a `connectionList` argument with only one element to the create call.

Each `connectionList` element is a vector of \((2 \times \text{dimCount} + 2)\) integer numbers:

```plaintext
allocate(connectionList(2*2+2, 1)) ! (2*dimCount+2, number of connections)
```

and has the following format:

`(/\text{patchIndex}_A, \text{patchIndex}_B, \text{positionVector}, \text{orientationVector}/)`

The following constructor call can be used to construct a suitable `connectionList` element.

```plaintext
call ESMF_Connection(connection=connectionList(:,1), &
patchIndexA=1, patchIndexB=1, &
positionVector=(/5, 0/), &
orientationVector=(/1, 2/), rc=rc)
```

The `patchIndexA` and `patchIndexB` arguments specify that this is a connection within patch 1. The `positionVector` indicates that there is no offset between patch B and patch A along the second dimension, but there is an offset of 5 along the first dimension (which in this case is the length of dimension 1). Finally, the `orientationVector` fixes the orientation of the patch B index space to be the same as the orientation of patch A (it maps index 1 of patch A to index 1 of patch B and the same for index 2). Note that the `orientationVector` could have been omitted in this case which corresponds to the default orientation.

The `connectionList` can now be used to create a `DistGrid` object with the desired boundary conditions.

```plaintext
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
deBlockList=deBlockList, connectionList=connectionList, rc=rc)

deallocate(connectionList)
```

This closes the LR patch along the first dimension on itself, thus imposing periodic boundaries along this direction.
23.2.5 2D DistGrid with patchwork LR domain and regular decomposition

Creating a DistGrid from a list of LR domains is a straightforward extension of the case with a single LR domain. The first four arguments of `ESMF_DistGridCreate()` are promoted to rank 2, the second dimension being the patch count index.

The following 2D patchwork domain consisting of 3 LR patches will be used in the examples of this section:

```plaintext
----------------------------------------> 2nd dim
|                                           |
| (1,11)-----(1,20)                         |
| (10,11)---(10,20)                         |
| (11,1)----(11,10)                         |
| (11,11)---(11,20)                         |
|                                           |
|                                           |
| (20,1)----(20,10)                         |
| (20,11)---(20,20)                         |
|                                           |
| v                                          |
1st dim
```

The first step in creating a patchwork global domain is to construct the `minCorner` and `maxCorner` arrays.

```plaintext
allocate(minCorner(2,3))  ! (dimCount, number of patches)
allocate(maxCorner(2,3))   ! (dimCount, number of patches)
minCorner(:,1) = (/11,1/)  ! (1,11)
maxCorner(:,1) = (/20,10/) ! (10,11)
minCorner(:,2) = (/11,11/) ! (1,11)
maxCorner(:,2) = (/20,20/) ! (10,20)
minCorner(:,3) = (/1,11/)  ! (11,1)
maxCorner(:,3) = (/10,20/) ! (11,11)
```

Next the regular decomposition for each patch is set up in the `regDecomp` array. In this example each patch is associated with a single DE.

```plaintext
allocate(regDecomp(2,3))  ! (dimCount, number of patches)
regDecomp(:,1) = (/1,1/)  ! one DE
regDecomp(:,2) = (/1,1/)  ! one DE
regDecomp(:,3) = (/1,1/)  ! one DE
```

Finally the DistGrid can be created by calling

```plaintext
distgrid = ESMF_DistGridCreate(minCorner=minCorner, maxCorner=maxCorner, &
regDecomp=regDecomp, rc=rc)
```

The default DE labeling sequence is identical to the patch labeling sequence and follows the sequence in which the patches are defined during the create call. However, DE labels start at 0 whereas patch labels start at 1. In this case the DE labels look as:
Each patch can be decomposed differently into DEs. The default DE labeling follows the column major order for each patch. This is demonstrated in the following case where the patchwork global domain is decomposed into 9 DEs,

\[
\begin{align*}
\text{regDecomp}(:,1) &= (/2,2/) \quad ! 4 \text{ DEs} \\
\text{regDecomp}(:,2) &= (/1,3/) \quad ! 3 \text{ DEs} \\
\text{regDecomp}(:,3) &= (/2,1/) \quad ! 2 \text{ DEs}
\end{align*}
\]

\[
distgrid = \text{ESMF\_DistGridCreate}(\text{minCorner}=\text{minCorner}, \text{maxCorner}=\text{maxCorner}, & \\
\text{regDecomp}=\text{regDecomp, rc}=\text{rc})
\]

resulting in the following decomposition:

```
+-------+       +-------+
| 7     |       | 8     |
+-------+       +-------+
| 0 2 |       | 4 5 6 |
| 1 3 |       |       |
+-------+       +-------+
  DE 0 - (11,1) ~ (15,5)
  DE 1 - (16,1) ~ (20,5)
  DE 2 - (11,6) ~ (15,10)
  DE 3 - (16,6) ~ (20,10)
  DE 4 - (11,11) ~ (20,14)
  DE 5 - (11,15) ~ (20,17)
  DE 6 - (11,18) ~ (20,20)
  DE 7 - (1,11) ~ (5,20)
  DE 8 - (6,11) ~ (10,20)
```

The \text{decompflag} and \text{deLabelList} arguments can be used much like in the single LR domain case to overwrite the default grid decomposition (per patch) and to change the overall DE labeling sequence, respectively.

23.3 Restrictions and Future Work

- Topologies that require Connections and ConnectionTransforms are not supported yet.
- DEs that participate in cyclic decompositions are excluded from GetDeLinks queries.

23.4 Design and Implementation Notes

This section will be updated as the implementation of the DistGrid class nears completion.

23.5 Class API

23.5.1 ESMF\_DistGridCreateRD - Create DistGrid with regular decomposition

INTERFACE:
function ESMF_DistGridCreateRD(minCorner, maxCorner, regDecomp, &
decompflag, deLabelList, indexflag, connectionList, connectionTransformList, &
delayout, vm, rc)

ARGUMENTS:

integer, intent(in) :: minCorner(:)
integer, intent(in) :: maxCorner(:)
integer, target, intent(in), optional :: regDecomp(:)
type(ESMF_DecompFlag), target,intent(in), optional :: decompflag(:)
integer, target, intent(in), optional :: deLabelList(:)
type(ESMF_IndexFlag), intent(in), optional :: indexflag
integer, target, intent(in), optional :: connectionList(:,:)
type(ESMF_DELayout), intent(in), optional :: delayout
integer, target, intent(in), optional :: connectionTransformList(:,:)
type(ESMF_VM), intent(in), optional :: vm
integer, intent(out),optional :: rc

RETURN VALUE:

type(ESMF_DistGrid) :: ESMF_DistGridCreateRD

DESCRIPTION:

Create an ESMF_DistGrid from a single logically rectangular (LR) domain with regular decomposition. A regular decomposition is of the same rank as the domain and decomposes each dimension into a fixed number of DEs. A regular decomposition of a single LR domain is expressed by a single regDecomp list of DE counts in each dimension. The arguments are:

minCorner Global coordinate tuple of the lower corner of the global domain.

maxCorner Global coordinate tuple of the upper corner of the global domain.

[regDecomp] List of DE counts for each dimension. The default decomposition will be deCount x 1 x ... x 1. The value of deCount for a default DELayout equals petCount, i.e. the default decomposition will be into as many DEs as there are PETs and the distribution will be 1 DE per PET.

[decompflag] List of decomposition flags indicating how each dimension of the global domain is to be divided between the DEs. The default setting is ESMF_DECOMP_HOMOGEN in all dimensions. See section ?? for a list of valid decomposition flag options.

[deLabelList] List assigning DE labels to the default sequence of DEs. The default sequence is ESMF_DECOMP_HOMOGEN in all dimensions. See section ?? for a list of valid decomposition flag options.

[indexflag] Indicates whether the indices provided by the minCorner and maxCorner arguments are to be interpreted to form a flat pseudo global index space (ESMF_INDEX_GLOBAL) or are to be taken as patch local (ESMF_INDEX_DELOCAL), which is the default.

[connectionList] List of connections between patches in index space. The second dimension of connectionList steps through the connection interface elements, defined by the first index. The first index must be of size 2 x dimCount + 2, where dimCount is the rank of the decomposed index space. Each connectionList element specifies the connection interface in the format

(/patchIndex_A, patchIndex_B, positionVector, orientationVector/) where:

• patchIndex_A and patchIndex_B are the patch index of the two connected patches respectively,
• positionVector is the vector that points from patch A’s minCorner to patch B’s minCorner.
• orientationVector associates each dimension of patch A with a dimension in patch B’s index space. Negative index values may be used to indicate a reversal in index orientation.

[connectionTransformList] List of transforms associated with patch connections defined in connectionList. The second dimension of connectionTransformList steps through the connection transforms, defined by the first index. The first index must be of size 5 + dimCount, where dimCount is the rank of the decomposed index space. Each connectionTransformList element specifies a connection transform by a list of integer values in the format (/connectionIndex, direction, staggerSrc, staggerDst, offsetDst, signVector/), where

• connectionIndex corresponds to the index of the connection in connectionList,
• direction can be +1 to specify forward direction, i.e. source patch of the transform is patch_A and destination patch is patch_B of the corresponding connection, or −1 to indicate reverse direction through the connection. The only other valid direction value is 0 which indicates a bidirectional connection with source and destination definitions as in the forward case.
• staggerSrc and staggerDst indicate staggering location in the source and destination patch interface, respectively,
• offsetDst is a vector of size dimCount that specifies the index offset on the destination side of this connection,
• signVector is of size dimCount with elements either +1 or −1 to indicate optional sign change of vector components along the respective directions.

[delayout] Optional ESMF_DELayout object to be used. By default a new DELayout object will be created with the correct number of DEs. If a DELayout object is specified its number of DEs must match the number indicated by regDecomp.

[vm] Optional ESMF_VM object of the current context. Providing the VM of the current context will lower the method’s overhead.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

23.5.2 ESMF_DistGridCreateDB - Create DistGrid with DE blocks

INTERFACE:

! Private name; call using ESMF_DistGridCreate()

function ESMF_DistGridCreateDB(minCorner, maxCorner, deBlockList, &
delabelList, indexflag, connectionList, connectionTransformList, delayout, &
vm, rc)

ARGUMENTS:

integer, intent(in) :: minCorner(:)
integer, intent(in) :: maxCorner(:)
integer, intent(in) :: deBlockList(:,:,:)
integer, intent(in), optional :: delabelList(:)
type(ESMF_IndexFlag), intent(in), optional :: indexflag
integer, intent(in), optional :: connectionList(:,):
type(ESMF_DELayout), intent(in), optional :: delayout
type(ESMF_VM), intent(in), optional :: vm
integer, intent(out),optional :: rc
RETURN VALUE:

type(ESMF_DistGrid) :: ESMF_DistGridCreateDB

DESCRIPTION:

Create an ESMF_DistGrid from a single logically rectangular (LR) domain with decomposition specified by deBlockList. The arguments are:

**minCorner** Global coordinate tuple of the lower corner of the global domain.

**maxCorner** Global coordinate tuple of the upper corner of the global domain.

**deBlockList** List of DE-local LR blocks. The third index of deBlockList steps through the deBlock elements, which are defined by the first two indices. The first index must be of size dimCount and the second index must be of size 2. Each 2D element of deBlockList defined by the first two indices hold the following information.

<table>
<thead>
<tr>
<th>1st index</th>
<th>2nd index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 minCorner(1)</td>
<td>maxCorner(1)</td>
</tr>
<tr>
<td>2 minCorner(2)</td>
<td>maxCorner(2)</td>
</tr>
<tr>
<td>. minCorner(.)</td>
<td>maxCorner(.)</td>
</tr>
</tbody>
</table>

It is required that there be no overlap between the LR segments defined by deBlockList.

**[deLabelList]** List assigning DE labels to the default sequence of DEs. The default sequence is given by the column major order of the regDecomp argument.

**[indexflag]** Indicates whether the indices provided by the minCorner and maxCorner arguments are to be interpreted to form a flat pseudo global index space (ESMF_INDEX_GLOBAL) or are to be taken as patch local (ESMF_INDEX_DELOCAL), which is the default.

**[connectionList]** List of connections between patches in index space. The second dimension of connectionList steps through the connection interface elements, defined by the first index. The first index must be of size 2 x dimCount + 2, where dimCount is the rank of the decomposed index space. Each connectionList element specifies the connection interface in the format

```
(patchIndex_A, patchIndex_B, positionVector, orientationVector)
```

- patchIndex_A and patchIndex_B are the patch index of the two connected patches respectively.
- positionVector is the vector that points from patch A’s minCorner to patch B’s minCorner.
- orientationVector associates each dimension of patch A with a dimension in patch B’s index space. Negative index values may be used to indicate a reversal in index orientation.

**[connectionTransformList]** List of transforms associated with patch connections defined in connectionList. The second dimension of connectionTransformList steps through the connection transforms, defined by the first index. The first index must be of size 5 + dimCount, where dimCount is the rank of the decomposed index space. Each connectionTransformList element specifies a connection transform by a list of integer values in the format

```
(connectionIndex, direction, staggerSrc, staggerDst, offsetDst, signVector)
```

- connectionIndex corresponds to the index of the connection in connectionList.
direction can be +1 to specify forward direction, i.e. source patch of the transform is patch_A and destination patch is patch_B of the corresponding connection, or -1 to indicate reverse direction through the connection. The only other valid direction value is 0 which indicates a bidirectional connection with source and destination definitions as in the forward case.

staggerSrc and staggerDst indicate staggering location in the source and destination patch interface, respectively.

offsetDst is a vector of size dimCount that specifies the index offset on the destination side of this connection.

signVector is of size dimCount with elements either +1 or -1 to indicate optional sign change of vector components along the respective directions.

[delayout] Optional ESMF_DELayout object to be used. By default a new DELayout object will be created with the correct number of DEs. If a DELayout object is specified its number of DEs must match the number indicated by regDecomp.

[vm] Optional ESMF_VM object of the current context. Providing the VM of the current context will lower the method’s overhead.

/rc] Return code; equals ESMF_SUCCESS if there are no errors.

23.5.3  ESMF_DistGridCreateRDP - Create DistGrid from patch work with regular decomposition

INTERFACE:

! Private name; call using ESMF_DistGridCreate()

function ESMF_DistGridCreateRDP(minCorner, maxCorner, regDecomp,&
   decompflag, deLabelList, indexflag, connectionList, connectionTransformList,&
   delayout, vm, rc)

ARGUMENTS:

integer, intent(in) :: minCorner(:,:)
integer, intent(in) :: maxCorner(:,:)
integer, intent(in), optional :: regDecomp(:,:)
type(ESMF_DecompFlag), target, intent(in), optional :: decompflag(:,:)
integer, intent(in), optional :: deLabelList(:)
type(ESMF_IndexFlag), intent(in), optional :: indexflag
integer, intent(in), optional :: connectionList(:,:)
integer, intent(in), optional :: connectionTransformList(:,:)
type(ESMF_DELayout), intent(in), optional :: delayout
type(ESMF_VM), intent(in), optional :: vm
integer, intent(out),optional :: rc

RETURN VALUE:

type(ESMF_DistGrid) :: ESMF_DistGridCreateRDP

DESCRIPTION:

Create an ESMF_DistGrid from a patch work of logically rectangular (LR) domains with regular decomposition. A regular decomposition is of the same rank as the global domain and decomposes each dimension into a fixed number of DEs. A regular decomposition of a patch work of LR domains is expressed by a list of DE count vectors, one vector for each patch domain. Each vector contained in the regDecomp argument ascribes DE counts for each dimension. It is erroneous to provide more domain patches than there are DEs.

The arguments are:
**minCorner** The first index provides the global coordinate tuple of the lower corner of a global domain patch. The second index indicates the patch number.

**maxCorner** The first index provides the global coordinate tuple of the upper corner of a global domain patch. The second index indicates the patch number.

**[regDecomp]** List of DE counts for each dimension. The second index indicates the patch number. The default decomposition will be deCount $\times 1 \times \ldots \times 1$. The value of deCount for a default DELayout equals petCount, i.e. the default decomposition will be into as many DEs as there are PETs and the distribution will be 1 DE per PET.

**[decompflag]** List of decomposition flags indicating how each dimension of each patch domain is to be divided between the DEs. The default setting is ESMF_DECOMP_HOMOGEN in all dimensions for all patches. See section ?? for a list of valid decomposition flag options. The second index indicates the patch number.

**[deLabelList]** List assigning DE labels to the default sequence of DEs. The default sequence is given by the column major order of the regDecomp elements in the sequence as they appear following the patch index.

**[indexflag]** Indicates whether the indices provided by the minCorner and maxCorner arguments are to be interpreted to form a flat pseudo global index space (ESMF_INDEX_GLOBAL) or are to be taken as patch local (ESMF_INDEX_DELOCAL), which is the default.

**[connectionList]** List of connections between patches in index space. The second dimension of connectionList steps through the connection interface elements, defined by the first index. The first index must be of size $2 \times \dimCount + 2$, where dimCount is the rank of the decomposed index space. Each connectionList element specifies the connection interface in the format

```
(patchIndex_A, patchIndex_B, positionVector, orientationVector)
```

- patchIndex_A and patchIndex_B are the patch index of the two connected patches respectively,
- positionVector is the vector that points from patch A’s minCorner to patch B’s minCorner.
- orientationVector associates each dimension of patch A with a dimension in patch B’s index space. Negative index values may be used to indicate a reversal in index orientation.

**[connectionTransformList]** List of transforms associated with patch connections defined in connectionList. The second dimension of connectionTransformList steps through the connection transforms, defined by the first index. The first index must be of size $5 + \dimCount$, where dimCount is the rank of the decomposed index space. Each connectionTransformList element specifies a connection transform by a list of integer values in the format

```
(connectionIndex, direction, staggerSrc, staggerDst, offsetDst, signVector)
```

- connectionIndex corresponds to the index of the connection in connectionList,
- direction can be +1 to specify forward direction, i.e. source patch of the transform is patch_A and destination patch is patch_B of the corresponding connection, or -1 to indicate reverse direction through the connection. The only other valid direction value is 0 which indicates a bidirectional connection with source and destination definitions as in the forward case.
- staggerSrc and staggerDst indicate staggering location in the source and destination patch interface, respectively,
- offsetDst is a vector of size dimCount that specifies the index offset on the destination side of this connection,
- signVector is of size dimCount with elements either +1 or -1 to indicate optional sign change of vector components along the respective directions.

**[delayout]** Optional ESMF_DELayout object to be used. By default a new DELayout object will be created with the correct number of DEs. If a DELayout object is specified its number of DEs must match the number indicated by regDecomp.
Optional ESMF_VM object of the current context. Providing the VM of the current context will lower the method’s overhead.

Return code; equals ESMF_SUCCESS if there are no errors.

#### 23.5.4 ESMF_DistGridDestroy - Destroy DistGrid object

**INTERFACE:**

```fortran
subroutine ESMF_DistGridDestroy(distgrid, rc)
```

**ARGUMENTS:**

- `type(ESMF_DistGrid), intent(inout) :: distgrid`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Destroy an ESMF_DistGrid object.

The arguments are:

- **distgrid** ESMF_DistGrid object to be destroyed.
- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

#### 23.5.5 ESMF_DistGridGet - Get information about DistGrid object

**INTERFACE:**

```fortran
subroutine ESMF_DistGridGet(distgrid, delayout, patchCount, patchList, &
   dimCount, dimExtent, regDecompFlag, rc)
```

**ARGUMENTS:**

- `type(ESMF_DistGrid), intent(in) :: distgrid`
- `type(ESMF_DELayout), intent(out), optional :: delayout`
- `integer, intent(out), optional :: patchCount`
- `integer, intent(out), optional :: patchList(:)`
- `integer, intent(out), optional :: dimCount`
- `integer, intent(out), optional :: dimExtent(:, :)`
- `type(ESMF_Logical), intent(out), optional :: regDecompFlag`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Get internal DistGrid information.

The arguments are:

- **distgrid** Queried ESMF_DistGrid object.
- **[delayout]** Upon return this holds the ESMF_DELayout object associated with this DistGrid object.
- **[patchCount]** Upon return this holds the number of patches the DistGrid object is composed of.
Upon return this holds a list of patch id numbers, one for each DE.

Upon return this holds the number dimensions (or rank) of the DistGrid object.

Upon return this array holds the extents for all dimensions of the DE-local LR boxes for all DEs. The supplied variable must be at least of size (/dimCount, deCount/).

Upon return this flag indicates regular decompositions by ESMF_TRUE and other decompositions by ESMF_FALSE.

Return code; equals ESMF_SUCCESS if there are no errors.

---

23.5.6 ESMF_DistGridGetPDePDim - Get DE local information for dimension about DistGrid

INTERFACE:

subroutine ESMF_DistGridGetPDePDim(distgrid, de, dim, indexList, rc)

ARGUMENTS:

type(ESMF_DistGrid), intent(in) :: distgrid
integer, intent(in) :: de
integer, intent(in) :: dim
integer, intent(out), optional :: indexList(:)
integer, intent(out), optional :: rc

DESCRIPTION:

Get internal DistGrid information.

The arguments are:

distgrid  Queried ESMF_DistGrid object.
de  Queried DE.
dim  Queried dimension.

Upon return this array holds the indices that lie in de’s DE-local LR domain along dimension dim. The supplied variable must be at least of size dimExtent(dim, de).

Return code; equals ESMF_SUCCESS if there are no errors.

---

23.5.7 ESMF_DistGridPrint - Print DistGrid internals

INTERFACE:

subroutine ESMF_DistGridPrint(distgrid, options, rc)

ARGUMENTS:

type(ESMF_DistGrid), intent(in) :: distgrid
ccharacter(len=*)), intent(in), optional :: options
integer, intent(out), optional :: rc
DESCRIPTION:

Prints internal information about the specified ESMF_DistGrid object to stdout. The arguments are:

distgrid  Specified ESMF_DistGrid object.

[options]  Print options are not yet supported.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

23.5.8 ESMF_DistGridValidate - Validate DistGrid internals

INTERFACE:

    subroutine ESMF_DistGridValidate(distgrid, rc)

ARGUMENTS:

    type(ESMF_DistGrid), intent(in) :: distgrid
    integer, intent(out), optional :: rc

DESCRIPTION:

Validates that the distgrid is internally consistent. The method returns an error code if problems are found. The arguments are:

distgrid  Specified ESMF_DistGrid object.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

23.5.9 ESMF_Connection - Construct a connection element

INTERFACE:

    subroutine ESMF_Connection(connection, patchIndexA, patchIndexB, &
       positionVector, orientationVector, rc)

ARGUMENTS:

    integer, intent(out) :: connection(:)
    integer, intent(in) :: patchIndexA
    integer, intent(in) :: patchIndexB
    integer, intent(in) :: positionVector(:)
    integer, intent(in), optional :: orientationVector(:)
    integer, intent(out), optional :: rc

DESCRIPTION:

This call helps to construct a connection, which is a simple vector of integers, out of its components. The arguments are:
**24 Array Class**

### 24.1 Description

The **ESMF_Array** class is an index space based, distributed data storage class. It provides DE-local memory allocations within DE-centric index regions and defines the relationship to the index space described by DistGrid. The Array class offers common communication patterns within the index space formalism. As part of the ESMF index space layer Array has close relationship to the DistGrid and DELayout classes.

### 24.2 Use and Examples

An **ESMF_Array** is a distributed object that must exist on all PETs of the current context. Each PET-local instance of an Array object contains memory allocations for all PET-local DEs. There may be 0, 1, or more DEs per PET and the number of DEs per PET can differ between PETs for the same Array object. Memory allocations may be provided for each PET by the user during Array creation or can be allocated as part of the Array create call. Many of the concepts of the proposed **ESMF_Array** class are illustrated by the following examples.

#### 24.2.1 Array from native Fortran90 array with 1 DE per PET

The create call of the **ESMF_Array** class has been overloaded extensively to facilitate the need for generality while keeping simple cases simple. The following program demonstrates one of the simpler cases, where existing local Fortran90 arrays are to be used to provide the PET-local memory allocations for the Array object.

```fortran
program ESMF_ArrayFarrayEx
  use ESMF_Mod
  implicit none

  ! The Fortran90 language provides a variety of ways to define and allocate an array. Actual Fortran90 array objects must either be explicit-shape or deferred-shape. In the first case the memory allocation and deallocation is automatic from the user's perspective and the details of the allocation (static or dynamic, heap or stack) are left to the compiler. (Compiler flags may be used to control some of the details). In the second case, i.e. for deferred-shape actual objects, the array definition must include the pointer or allocatable attribute and it is the user's responsibility to allocate memory. While it is also the user's responsibility to deallocate memory for arrays with pointer attribute the compiler will automatically deallocate allocatable arrays under certain circumstances defined by the standard.

  ! The **ESMF_ArrayCreate()** interface has been written to accept native Fortran90 arrays of any flavor as a means to allow user-controlled memory management. The Array create call will check on each PET if sufficient memory has been provided by the specified Fortran90 arrays and will indicate an error if a problem is detected. However, the
```

connection Element to be constructed. The provided connection must be dimensioned to hold exactly the number of integers that result from the input information.

patchIndexA Index of one of the two patches that are to be connected.

patchIndexB Index of one of the two patches that are to be connected.

positionVector Position of patch B’s minCorner with respect to patch A’s minCorner.

[orientationVector] Associates each dimension of patch A with a dimension in patch B’s index space. Negative index values may be used to indicate a reversal in index orientation. It is erroneous to associate multiple dimensions of patch A with the same index in patch B.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
Array create call cannot validate the lifetime of the provided memory allocations. If, for instance, an Array object was created in a subroutine from an automatic explicit-shape array or an allocatable array, the memory allocations referenced by the Array object will be automatically deallocated on return from the subroutine unless provisions are made by the application writer to prevent such behavior. The Array object cannot control when memory that has been provided by the user during Array creation becomes deallocated, however, the Array will indicate an error if it’s memory references have been invalidated.

The easiest, portable way to provide safe native Fortran90 memory allocations to Array create is to use arrays with the pointer attribute. Memory allocated for an array pointer will not be deallocated automatically. However, in this case the possibility of memory leaks becomes an issue of concern. The deallocation of memory provided to an Array in form of a native Fortran90 allocation will remain the user’s responsibility.

None of the concerns discussed above are an issue in this example where the native Fortran90 array \texttt{farray} is defined in the main program. All different types of array memory allocation are demonstrated in this example. First \texttt{farrayE} is defined as a 2D explicit-shape array on each PET which will automatically provide memory for $10 \times 10$ elements.

\begin{verbatim}
! local variables
real(ESMF_KIND_R8) :: farrayE(10,10) ! explicit shape F90 array
\end{verbatim}

Then an allocatable array \texttt{farrayA} is declared which will be used to show user-controlled dynamic memory allocation.

\begin{verbatim}
real(ESMF_KIND_R8), allocatable :: farrayA(:, :) ! allocatable F90 array
\end{verbatim}

Finally an array with pointer attribute \texttt{farrayP} is declared, also used for user-controlled dynamic memory allocation.

\begin{verbatim}
real(ESMF_KIND_R8), pointer :: farrayP(:, :) ! F90 array pointer
\end{verbatim}

A matching array pointer must also be available to gain access to the arrays held by an Array object.

\begin{verbatim}
real(ESMF_KIND_R8), pointer :: farrayPtr(:, :) ! matching F90 array pointer
type(ESMF_DistGrid) :: distgrid ! DistGrid object
type(ESMF_Array) :: array ! Array object
integer :: rc
\end{verbatim}

\begin{verbatim}
call ESMF_Initialize(rc=rc)
if (rc /= ESMF_SUCCESS) call ESMF_Finalize(terminationflag=ESMF_ABORT)
\end{verbatim}

On each PET \texttt{farrayE} can be accessed directly to initialize the entire PET-local array.

\begin{verbatim}
 farrayE = 12.45d0 ! initialize to some value
\end{verbatim}

In order to create an Array object a DistGrid must first be created that describes the total index space and how it is decomposed and distributed. In the simplest case only the \texttt{minCorner} and \texttt{maxCorner} of the total space must be provided.

\begin{verbatim}
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/40,10/), rc=rc)
\end{verbatim}

This example is assumed to run on 4 PETs. The default 2D decomposition will then be into 4 x 1 DEs as to ensure 1 DE per PET.

Now the Array object can be created using the \texttt{farrayE} and the DistGrid just created.
array = ESMF_ArrayCreate(farray=farrayE, distgrid=distgrid, rc=rc)

The 40 x 10 index space defined by the minCorner and maxCorner arguments paired with the default decomposition will result in the following distributed Array.

Providing farrayE during Array creation does not change anything about the actual farrayE object. This means that each PET can use its local farrayE directly to access the memory referenced by the Array object.

print *, farrayE

Another way of accessing the memory associated with an Array object is to use ArrayGet() to obtain an Fortran90 pointer that references the PET-local array.

call ESMF_ArrayGet(array, farrayPtr=farrayPtr, rc=rc)

print *, farrayPtr

Finally the Array object must be destroyed. The PET-local memory of the farrayEs will remain in user control and will not be altered by ArrayDestroy().

call ESMF_ArrayDestroy(array, rc=rc)

Since the memory allocation for each farrayE is automatic there is nothing more to do. The interaction between farrayE and the Array class is representative also for the two other cases farrayA and farrayP. The only difference is in the handling of memory allocations.
allocate(farrayA(10,10)) ! user controlled allocation
farrayA = 23.67d0 ! initialize to some value
array = ESMF_ArrayCreate(farray=farrayA, distgrid=distgrid, rc=rc)

print *, farrayA ! print PET-local farrayA directly
call ESMF_ArrayGet(array, farrayPtr=farrayPtr, rc=rc) ! obtain array pointer
print *, farrayPtr ! print PET-local piece of Array through pointer
call ESMF_ArrayDestroy(array, rc=rc) ! destroy the Array
deallocate(farrayA) ! user controlled de-allocation

The farrayP case is identical.

allocate(farrayP(10,10)) ! user controlled allocation
farrayP = 56.81d0 ! initialize to some value
array = ESMF_ArrayCreate(farray=farrayP, distgrid=distgrid, rc=rc)

print *, farrayP ! print PET-local farrayA directly
call ESMF_ArrayGet(array, farrayPtr=farrayPtr, rc=rc) ! obtain array pointer
print *, farrayPtr ! print PET-local piece of Array through pointer
call ESMF_ArrayDestroy(array, rc=rc) ! destroy the Array
deallocate(farrayP) ! user controlled de-allocation

To wrap things up the DistGrid object is destroyed and ESMF can be finalized.

call ESMF_DistGridDestroy(distgrid, rc=rc) ! destroy the DistGrid

call ESMF_Finalize(rc=rc)

end program

### 24.2.2 Array from native Fortran90 array with cells for halo

The example of the previous section showed how easy it is to create an Array object from existing PET-local Fortran90 arrays. The example did, however, not define any halos around the DE-local regions. The following code demonstrates how an Array object with space for a halo can be set up.

program ESMF_ArrayFarrayHaloEx

use ESMF_Mod

implicit none

The allocatable array farrayA will be used to provide the PET-local Fortran90 array for this example.
The Array is to cover the exact same index space as in the previous example. Furthermore decomposition and distribution are also kept the same. Hence the same DistGrid object will be created and it is expected to execute this example with 4 PETs.

```
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/40,10/), rc=rc)
```

This DistGrid describes a 40 x 10 index space that will be decomposed into 4 DEs when executed on 4 PETs, associating 1 DE per PET. Each DE-local exclusive region contains 10 x 10 cells. The DistGrid also stores and provides information about the relationship between DEs in index space, however, DistGrid does not contain information about halos. Arrays contain halo information and it is possible to create multiple Arrays covering the same index space with identical decomposition and distribution using the same DistGrid object, while defining different, Array-specific halo regions.

The extra memory required to cover the halo in the Array object must be taken into account when allocating the PET-local `farrayA` arrays. For a halo of 2 cells in each direction the following allocation will suffice.

```
allocate(farrayA(14,14)) ! Fortran90 array with halo: 14 = 10 + 2 * 2
```

The `farrayA` can now be used to create an Array object with enough space for a two cell halo in each direction. The Array creation method checks for each PET that the local Fortran90 array can accommodate the requested regions. The default behavior of ArrayCreate() is to center the exclusive region within the total region. Consequently the following call will provide the 2 extra cells on each side of the exclusive 10 x 10 region without having to specify any additional arguments.

```
array = ESMF_ArrayCreate(farray=farrayA, distgrid=distgrid, rc=rc)
```

The exclusive Array region on each PET can be accessed through a suitable Fortran90 array pointer. See section 24.2.6 for more details on Array regions.

```
call ESMF_ArrayGet(array, farrayPtr=farrayPtr, rc=rc)
```

Following Array bounds convention, which by default puts the beginning of the exclusive region at (1, 1, ...), the following loop will add up the values of the local exclusive region for each DE, regardless of how the bounds were chosen for the original PET-local `farrayA` arrays.

```
localSum = 0.
do j=1, 10
    do i=1, 10
        localSum = localSum + farrayPtr(i, j)
    enddo
enddo
```
Cells with $i$ or $j$ in the $[-1,0]$ or $[11,12]$ ranges are located outside the exclusive region and may be used to define extra computational points or halo operations.

Cleanup and shut down ESMF.

```fortran
  call ESMF_ArrayDestroy(array, rc=rc)
deallocate(farrayA)
call ESMF_DistGridDestroy(distgrid, rc=rc)

call ESMF_Finalize(rc=rc)
end program
```

### 24.2.3 Array from ESMF_LocalArray

Alternative to the direct usage of Fortran90 arrays during Array creation it is also possible to first create an `ESMF_LocalArray` and create the Array from it. While this may seem more burdensome for the 1 DE per PET cases discussed in the previous sections it allows a straightforward generalization to the multiple DE per PET case. The following example first recaptures the previous example using an `ESMF_LocalArray` and then expands to the multiple DE per PET case.

```fortran
program ESMF_ArrayLarrayEx
  use ESMF_Mod
  implicit none

  ! local variables
  real(ESMF_KIND_R8), pointer :: farrayP(:, :) ! F90 array pointer
  real(ESMF_KIND_R8), pointer :: farrayPtr(:, :) ! matching F90 array pointer
  type(ESMF_LocalArray) :: larray ! ESMF_LocalArray object
  type(ESMF_LocalArray) :: larrayRef ! ESMF_LocalArray object
  type(ESMF_DistGrid) :: distgrid ! DistGrid object
  type(ESMF_Array) :: array ! Array object
  integer :: rc, i, j, de
  real :: localSum
  type(ESMF_LocalArray), allocatable :: larrayList(:) ! ESMF_LocalArray object list
  type(ESMF_LocalArray), allocatable :: larrayRefList(:) ! ESMF_LocalArray object list
  type(ESMF_VM):: vm
  integer:: localPet, petCount

  call ESMF_Initialize(vm=vm, rc=rc)
  if (rc /= ESMF_SUCCESS) call ESMF_Finalize(terminationflag=ESMF_ABORT)
call ESMF_VMGet(vm, localPet=localPet, petCount=petCount, rc=rc)
  if (rc /= ESMF_SUCCESS) call ESMF_Finalize(terminationflag=ESMF_ABORT)
  if (petCount /= 4) goto 10 ! TODO: use EXAMPLES_MULTI_ONLY once available
```

The current `ESMF_LocalArray` interface requires Fortran90 arrays to be defined with pointer attribute.
DistGrid and array allocation remains unchanged.

```fortran
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/40,10/), rc=rc)
allocate(farrayP(14,14)) ! allocate Fortran90 array on each PET with halo
```

Now instead of directly creating an Array object using the PET-local `farrayP`s an `ESMF_LocalArray` object will be created on each PET.

```fortran
larray = ESMF_LocalArrayCreate(farrayP, ESMF_DATA_REF, rc=rc)
```

The Array object can now be created from `larray`. The Array creation method checks for each PET that the LocalArray can accomodate the requested regions.

```fortran
array = ESMF_ArrayCreate(larrayList=(/larray/), distgrid=distgrid, rc=rc)
```

Once created there is no difference in how the Array object can be used. The exclusive Array region on each PET can be accessed through a suitable Fortran90 array pointer as before.

```fortran
call ESMF_ArrayGet(array, farrayPtr=farrayPtr, rc=rc)
```

Alternatively it is also possible (independent of how the Array object was created) to obtain the reference to the array allocation held by Array in form of an `ESMF_LocalArray` object. The `farrayPtr` can then be extracted using LocalArray methods.

```fortran
call ESMF_ArrayGet(array, larray=larrayRef, rc=rc)
call ESMF_LocalArrayGetData(larrayRef, farrayPtr, rc=rc)
```

Either way the `farrayPtr` reference can be used now to add up the values of the local exclusive region for each DE. The following loop works regardless of how the bounds were chosen for the original PET-local `farrayP` arrays and consequently the PET-local `larray` objects.

```fortran
localSum = 0.
do j=1, 10
   do i=1, 10
      localSum = localSum + farrayPtr(i, j)
   enddo
print *, "localSum=", localSum
enddo
```

Cleanup.

```fortran
call ESMF_ArrayDestroy(array, rc=rc)
call ESMF_LocalArrayDestroy(larray, rc=rc)
deallocate(farrayP) ! use the pointer that was used in allocate statement
call ESMF_DistGridDestroy(distgrid, rc=rc)
```
While the usage of LocalArrays is unnecessarily cumbersome for 1 DE per PET Arrays, it provides a straightforward path for extending the interfaces to multiple DEs per PET.

In the following example a 8 x 8 index space will be decomposed into 2 x 4 = 8 DEs. The situation is captured by the following DistGrid object.

```
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/8,8/), &
  regDecomp=(/2,4/), rc=rc)
```

The `distgrid` object created in this manner will contain 8 DEs no matter how many PETs are available during execution. Assuming an execution on 4 PETs will result in the following distribution of the decomposition.

```
+---------------------------------------> 2nd dimension
| (1,1)
| +-----------+-----------+-----------+-----------+
| | DE0, PET0 | DE2, PET1 | DE4, PET2 | DE6, PET3 |
| | * * | * * | * * | * * |
| | * * | * * | * * | * * |
| | * * | * * | * * | * * |
| | * * | * * | * * | * * |
| | DE1, PET0 | DE3, PET1 | DE5, PET2 | DE7, PET3 |
| | * * | * * | * * | * * |
| | * * | * * | * * | * * |
| | * * | * * | * * | * * |
| | * * | * * | * * | * * |
| +-----------+-----------+-----------+-----------+
| (8,8)      |
```

Obviously each PET is associated with 2 DEs. Each PET must allocate enough space for all its DEs. This is done by allocating as many DE-local arrays as there are DEs on the PET. The reference to these array allocations is passed into ArrayCreate via a LocalArray list argument that holds as many elements as there are DEs on the PET. Here each PET must allocate for two DEs.

```
allocate(larrayList(2)) ! 2 DEs per PET
allocate(farrayP(4, 2)) ! without halo each DE is of size 4 x 2
farrayP = 123.456d0
larrayList(1) = ESMF_LocalArrayCreate(farrayP, ESMF_DATA_REF, rc=rc) ! 1st DE
allocate(farrayP(4, 2)) ! without halo each DE is of size 4 x 2
farrayP = 456.789d0
larrayList(2) = ESMF_LocalArrayCreate(farrayP, ESMF_DATA_REF, rc=rc) ! 2nd DE
```

Notice that it is perfectly fine to re-use `farrayP` for all allocations of DE-local Fortran90 arrays. The allocated memory can be deallocated at the end using the array pointer contained in the `larrayList`.

With this information an Array object can be created. The `distgrid` object indicates 2 DEs for each PET and ArrayCreate() expects to find two LocalArray elements in `larrayList`.
array = ESMF_ArrayCreate(larrayList=larrayList, distgrid=distgrid, rc=rc)

Usage of a LocalArray list is the only way to provide a list of variable length of Fortran90 array allocations to ArrayCreate() for each PET. The array object created by the above call is an ESMF distributed object. As such it must follow the ESMF convention that requires that the call to ESMF_ArrayCreate() must be issued in unison by all PETs of the current context. Each PET only calls ArrayCreate() once, even if there are multiple DEs per PET. The ArrayGet() method provides access to the list of LocalArrays on each PET.

allocate(larrayRefList(2))
call ESMF_ArrayGet(array, larrayList=larrayRefList, rc=rc)

Finally, access to the actual Fortran90 pointers is done on a per DE basis. Generally each PET will loop over its DEs.

do de=1, 2
   call ESMF_LocalArrayGetData(larrayRefList(de), farrayPtr, rc=rc)
   localSum = 0.
   do j=1, 2
      do i=1, 4
         localSum = localSum + farrayPtr(i, j)
      enddo
   enddo
   print *, "localSum=", localSum
endo

Note: If the VM associates multiple PEs with a PET the application writer may for decide to use OpenMP loop parallelization on the de loop. Cleanup requires that the PET-local deallocations are done before the pointers to the actual Fortran90 arrays get lost. Notice that larrayList is used to obtain the pointers used in the deallocate statement. Pointers obtained from the larrayRefList, while pointing to the same data, cannot be used to deallocated the array allocations!

do de=1, 2
   call ESMF_LocalArrayGetData(larrayList(de), farrayPtr, rc=rc)
   deallocate(farrayPtr)
   call ESMF_LocalArrayDestroy(larrayList(de), rc=rc)
endo
dealallocate(larrayList)
deallocate(larrayRefList)
call ESMF_ArrayDestroy(array, rc=rc)
call ESMF_DistGridDestroy(distgrid, rc=rc)

With that ESMF can be shut down cleanly.

call ESMF_Finalize(rc=rc)

end program
24.2.4 Array creation with automatic memory allocation

The examples of the previous sections made the user responsible for providing memory allocations for the PET-local regions of the Array object. The user was able to use any of the Fortran90 methods to obtain allocated arrays and pass them into ArrayCreate(). Alternatively, users may wish for ESMF to control memory management of an Array object. The following example shows the interfaces that are available to the user to do just this.

To create an ESMF_Array object without providing an existing Fortran90 array at least two pieces of information are required. First the type, kind and rank (tkr) of the array must be specified in form of an ESMF_ArraySpec argument. Here a 2D Array of double precision real numbers is to be created:

```fortran
call ESMF_ArraySpecSet(arrayspec, type=ESMF_DATA_REAL, kind=ESMF_R8, rank=2, &
rc=rc)
```

Further an ESMF_DistGrid argument must be constructed that holds information about the entire domain (patchwork) and the decomposition into DE-local exclusive regions. The following line creates a DistGrid for a 5x5 global LR domain that is decomposed into 2 x 3 = 6 DEs.

```fortran
distgrid = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
regDecomp=(/2,3/), rc=rc)
```

This is enough information to create a Array object with default settings.

```fortran
array = ESMF_ArrayCreate(arrayspec=arrayspec, distgrid=distgrid, rc=rc)
```

The array object created by the above call is an ESMF distributed object. As such it must follow the ESMF convention that requires that the call to ESMF_ArrayCreate() must be issued in unison by all PETs of the current context.

The index space covered by the Array object and the decomposition into DE-local exclusive cell regions, as it is described by the DistGrid object, is illustrated in the following diagram. Each asterix (*) represents a single cell.

![Diagram of Array object and DistGrid](image)

24.2.5 Native language memory access – the most general way

The exact decomposition of the index space covered by the array object into DEs is contained in the distgrid object. Further, the layout of the DEs across the PETs of the component is stored in the delayout contained within the
distgrid object. In the above example a default DELayout was created during the ESMF_DistGridCreate() call (see the refDoc/proposal for ESMF_DELayout and ESMF_DistGrid for details).
In order to use the array object it is necessary to know how many DEs are located on each calling PET. To this end the corresponding DELayout object needs to be extracted from distgrid first and then can be queried for the PET-local deCount.

```fortran
call ESMF_DistGridGet(distgrid, delayout=delayout, rc=rc)
call ESMF_DELayoutGet(delayout, localDeCount=localDeCount, rc=rc)
allocate(localDeList(localDeCount))
call ESMF_DELayoutGet(delayout, localDeList=localDeList, rc=rc)
```

In general it must be assumed that there may be multiple DEs associated with the calling PET, i.e. localDeCount >= 1. The situation where there is exactly one DE for each PET, i.e. localDeCount = 1 on every PET, is merely a special case of the more general formulation.
Consequently, in order to gain access to the DE-local memory segments that have been allocated on each PET by the ArrayCreate() call the Array must be queried for a list of LocalArray objects, each element corresponding to one PET-local DE.

```fortran
allocate(larrayList(localDeCount))
call ESMF_ArrayGet(array, larrayList=larrayList, rc=rc)
```

Now each PET can loop through its local list of DEs and access the associated memory through a suitable Fortran90 pointer. In the current example the native pointer myF90Array must be declared as
```fortran
real(ESMF_KIND_R8), pointer:: myF90Array(:,:)
```
in order to match the arrayspec that was used to create the array object. The following loop uses the native language access to initialize the entire memory chunks of all PET-local DEs to 0 using Fortran90 array syntax.

```fortran
do de=1, localDeCount
    call ESMF_LocalArrayGetData(larrayList(de), myF90Array, ESMF_DATA_REF, rc=rc)
    myF90Array = 0.
enddo
```

### 24.2.6 Regions and default bounds

Each Array object is decomposed into DEs as specified by the associated DistGrid object. Each piece of this decomposition, i.e. each DE, holds a chunk of the array data in its own private piece of memory. The details of the Array decomposition are described in the following paragraphs.
At the center of the Array decomposition is the ESMF_DistGrid class. The DistGrid object specified during Array creation contains three essential pieces of information:

- The extent and topology of the global domain covered by the Array object in terms of indexed cells. The total extent may be a composition or patchwork of smaller logically rectangular (LR) domain pieces or patches.
- The decomposition of the entire domain into "cell exclusive" DE-local LR chunks. Cell exclusive means that there is no cell overlap between DE-local chunks. This, however, does not exclude degeneracies between staggering locations for certain topologies (e.g. bipolar).
- The layout of DEs over the available PETs and thus the distribution of the Array data.

Each cell of an Array is associated with a single DE. The union of cells associated with a DE, as defined by the DistGrid above, will correspond to a LR chunk of index space, called the exclusive region of the DE.
There is a hierarchy of four regions that can be identified for each DE in an Array object. Their definition and relationship to each other is as follows:

---

242
• **Interior Region**: Region that only contains local cells that are *not* mapped into the halo of any other DE. The shape and size of this region for a particular DE depends non-locally on the halos defined by other DEs and may change during computations. Knowledge of the interior cells may be used to improve performance by overlapping communications with ongoing computation for a DE.

• **Exclusive Region**: Cells for which this DE claims exclusive ownership. Practically this means that the DE will be the source for these cells in halo and reduce operations. There are exceptions to this for certain staggering locations in some topologies. These cases remain well-defined with the information available through DistGrid. This region includes all cells of the interior region.

• **Computational Region**: Region of all cells that are kept locally and are updated during computation by the local DE. The additional computational cells, beyond the exclusive cells of the DE, are either overlapping with the exclusive region of another DE or lie outside the global domain as defined by the DistGrid. Extra computational points may be chosen differently for different stagger locations.

• **Total (Memory) Region**: Total of all DE-locally allocated cells. The size and shape of the total memory region must accommodate the computational region but may contain additional cells to be used in halos and/or as memory padding.

With the following definitions:

\[
\text{totalLWidth}(:, :) = \text{exclusiveLBound}(:, :) - \text{totalLBound}(:, :)
\]

\[
\text{totalUWidth}(:, :) = \text{totalUBound}(:, :) - \text{exclusiveLBound}(:, :)
\]
and

\[
\text{computationalLWidth}(:, \) = \text{exclusiveLBound}(:) - \text{computationalLBound}(:) \\
\text{computationalUWidth}(:, \) = \text{computationalUBound}(:) - \text{exclusiveLBound}(:)
\]

The **exclusive region** is determined during Array creation by the DistGrid argument. Optional arguments may be used to specify the **computational region** when the Array is created, by default it will be set equal to the exclusive region. The **total region**, i.e. the actual memory allocation for each DE, is also determined during Array creation. When creating the Array object from existing Fortran90 arrays the total region is set equal to the memory provided by the Fortran90 arrays. Otherwise the default is to allocate as much memory as is needed to accommodate the computational region. Finally it is also possible to use optional arguments to the ArrayCreate() call to specify the total region of the object.

Once an Array object has been created its total region cannot be changed. The computational region, however, may be adjusted within the limits of the total region using the ArraySet() call.

The **interior region** is very different from the other regions in that it cannot be specified. The **interior region** for each DE is a consequence of the choices made for the other regions collectively across all DEs into which an Array object is decomposed. An Array object can be queried for its DE-local **interior regions** as to offer additional information to the user necessary to write more efficient code. See section ?? for more details.

By default the bounds of each DE-local **total region** are defined as to put the start of the DE-local **exclusive region** at the "origin" of the local index space, i.e. at \((1, 1, ..., 1)\). With that the following loop will access each element of the DE-local memory segment for each PET-local DE of the Array object created in the previous sections and print its content.

```fortran
24.2.7 Array bounds
```

The loop over Array elements at the end of the last section only works correctly because of the default definition of the **computational and total regions** used in the example. In general, without such specific knowledge about an Array object, it is necessary to use a more formal approach to access its regions with DE-local indices.

The DE-local **exclusive region** takes a central role in the definition of Array bounds. Even as the **computational region** may adjust during the course of execution the **exclusive region** remains unchanged. Furthermore the **exclusive region** is identical for all stagger locations (discussed in a later section) and as such provides a unique reference frame for the index space of all Arrays associated with the same DistGrid.

There is a choice between two indexing options that needs to be made during Array creation. By default each DE-local exclusive region starts at \((1, 1, ..., 1)\). However, for some computational kernels it may be more convenient to choose the index bounds of the DE-local exclusive regions to match the index space coordinates as they are defined in the corresponding DistGrid object. The second option is only available if the DistGrid object does not contain any non-contiguous decompositions (such as cyclically decomposed dimensions).

The following example code demonstrates the safe way of dereferencing the DE-local exclusive regions of the previously created array object.

```fortran
allocate(exclusiveUBound(2, localDeCount)) \! dimCount=2
allocate(exclusiveLBound(2, localDeCount)) \! dimCount=2
call ESMF_ArrayGet(array, indexflag=indexflag, &
 exclusiveLBound=exclusiveLBound, exclusiveUBound=exclusiveUBound, rc=rc)
```
if (indexflag == ESMF_INDEX_DELOCAL) then
    ! print *, "DE-local exclusive regions start at (1,1)"
    do de=1, localDeCount
        call ESMF_LocalArrayGetData(larrayList(de), myF90Array, ESMF_DATA_REF, rc=rc)
        ! print *, "DE-local exclusive region for PET-local DE=", de, 
        ! ": array(" , i , ",", , j , ")=" , myF90Array(i,j)
    enddo
enddo
else
    ! print *, "DE-local exclusive regions of this Array have global bounds"
    do de=1, localDeCount
        call ESMF_LocalArrayGetData(larrayList(de), myF90Array, ESMF_DATA_REF, rc=rc)
        ! print *, "DE-local exclusive region for PET-local DE=", de, 
        ! ": array(" , i , ",", , j , ")=" , myF90Array(i,j)
    enddo
enddo
endif

Obviously the second branch of this simple code will work for either case, however, if a complex computational kernel was written assuming ESMF_INDEX_DELOCAL type bounds the second branch would simply be used to indicate the problem and bail out.

If the Array uses ESMF_INDEX_DELOCAL type bounds and the code accessing the Array data requires knowledge of global index space information then the corresponding DistGrid object can be queried for this kind of information. Please see the DistGrid proposal for more details.

24.2.8 Computational region and extra cells for halo or padding

In the previous examples the computational region of array was chosen by default to be identical to the exclusive region defined by the DistGrid argument during Array creation. In the following the same arrayspec and distgrid objects as before will be used to create an Array but now a larger computational region shall be defined around each DE-local exclusive region. Furthermore, extra space will be defined around the computational region of each DE to accommodate a halo and/or serve as memory padding.

In this example the indexflag argument is set to ESMF_INDEX_GLOBAL indicating that the bounds of the exclusive region correspond to the index space coordinates as they are defined by the DistGrid object.

    call ESMF_ArrayDestroy(array, rc=rc) ! first destroy the old array object

The same arrayspec and distgrid objects as before are used which also allows the reuse of the already allocated larrayList variable.

    array = ESMF_ArrayCreate(arrayspec=arrayspec, distgrid=distgrid, &
                        computationalLWidth=(/0,3/), computationalUWidth=(/1,1/), &
                        totalLWidth=(/1,4/), totalUWidth=(/3,1/), &
                        indexflag=ESMF_INDEX_GLOBAL, rc=rc)

    call ESMF_ArrayGet(array, larrayList=larrayList, rc=rc)
The bounds of DE 1 for array are shown in the following diagram to illustrate the situation. Notice that the `totalLWidth` and `totalUWidth` arguments in the `ArrayCreate()` call define the total region with respect to the exclusive region given for each DE by the `distgrid` argument.

When working with this array it is possible for the computational kernel to overstep the exclusive region for both read/write access (computational region) and potentially read-only access into the total region outside of the computational region, if a halo operation provides valid entries for these cells.

The Array object can be queried for absolute bounds:

```fortran
allocate(computationalLBound(2, localDeCount)) ! dimCount=2
allocate(computationalUBound(2, localDeCount)) ! dimCount=2
allocate(totalLBound(2, localDeCount)) ! dimCount=2
allocate(totalUBound(2, localDeCount)) ! dimCount=2
call ESMF_ArrayGet(array, exclusiveLBound=exclusiveLBound, &
    exclusiveUBound=exclusiveUBound, computationalLBound=computationalLBound, &
    computationalUBound=computationalUBound, totalLBound=totalLBound, &
    totalUBound=totalUBound, rc=rc)
```

or for the relative widths:

```fortran
allocate(computationalLWidth(2, localDeCount)) ! dimCount=2
allocate(computationalUWidth(2, localDeCount)) ! dimCount=2
allocate(totalLWidth(2, localDeCount)) ! dimCount=2
allocate(totalUWidth(2, localDeCount)) ! dimCount=2
call ESMF_ArrayGet(array, computationalLWidth=computationalLWidth, &
    computationalUWidth=computationalUWidth, totalLWidth=totalLWidth, &
    totalUWidth=totalUWidth, rc=rc)
```

Either way the dereferencing of Array data is centered around the DE-local exclusive region:

```fortran
do de=1, localDeCount
    call ESMF_LocalArrayGetData(larrayList(de), myF90Array, ESMF_DATA_REF, rc=rc) ! initialize the DE-local array
    myF90Array = 0.1d0 * localDeList(de)
    ! first time through the total region of array
    ! print *, "myF90Array bounds for DE=", localDeList(de), lbound(myF90Array), &
    !    ubound(myF90Array)
    ! do j=exclusiveLBound(2, de), exclusiveUBound(2, de)
```

246
do i=exclusiveLBound(1, de), exclusiveUBound(1, de)
print *, "Excl region DE=" localDeList(de), ": array(" ,i," ,",j," )=" , &
myF90Array(i,j)
enddo
enddo
!
do j=computationalLBound(2, de), computationalUBound(2, de)
!
do i=computationalLBound(1, de), computationalUBound(1, de)
!
print *, "Excl region DE=" localDeList(de), ": array(" ,i," ,",j," )=" , &
myF90Array(i,j)
!
enddo
enddo
!
do j=totalLBound(2, de), totalUBound(2, de)
!
do i=totalLBound(1, de), totalUBound(1, de)
!
print *, "Total region DE=" localDeList(de), ": array(" ,i," ,",j," )=" , &
myF90Array(i,j)
!
enddo
enddo
!
second time through the total region of array
!
do j=exclusiveLBound(2, de)-totalLWidth(2, de), &
exclusiveUBound(2, de)+totalUWidth(2, de)
!
do i=exclusiveLBound(1, de)-totalLWidth(1, de), &
exclusiveUBound(1, de)+totalUWidth(1, de)
!
print *, "Excl region DE=" localDeList(de), ": array(" ,i," ,",j," )=" , &
myF90Array(i,j)
!
enddo
enddo

24.2.9 SparseMatMul communication

Sparse matrix multiplication is a fundamental Array communication method. One frequently used application of this method is the interpolation between pairs of Arrays. The principle is this: the value of each cell in the exclusive region of the destination Array is expressed as a linear combination of all the exclusive cells of the source Array. Naturally most of the coefficients of these linear combinations will be zero and it is more efficient to store explicit information about the non-zero elements than to keep track of all the coefficients.

There is a choice to be made with respect to the format in which to store the information about the non-zero elements. One option is to store the value of each coefficient together with the corresponding destination cell index and source cell index. Destination and source indices could be expressed in terms of the corresponding DistGrid patch index together with the coordinate tuple within the patch. While this format may be the most natural way to express cells in the source and destination Array, it has a major drawback, it is extremely bulky. For two 2D Arrays it requires 6 integers to store the source and destination cell information for each non-zero interpolation weight.

An alternative format exists that only requires two integers to be stored with each non-zero interpolation coefficient, regardless of the rank of source and destination Arrays. For this format a unique cell order must be defined which allows to uniquely address each exclusive cell in an Array object by a single integer number. In other words the cells defined by the DistGrid associated with the Array must be sequentialized. The cell sequence suggested in this proposal first moves fastest through the DistGrid dimensions in their order and then moves through the patches of the DistGrid.

In the following example array1 will be the source Array that will be interpolated onto array2, the destination Array. Both Arrays are 2D Arrays of double precision real numbers. array1 uses the 5 x 5 DistGrid decomposed over 2 x 3 = 6 DEs as was used in previous examples. array2 is defined on a [-4,...,2] x [1,...,3] DistGrid that is decomposed over as many DEs as there are PETs in the context at runtime. Notice also that array1 only allocates space for the exclusive DE-local regions whereas array2 allocates a 1 cell wide rim around each exclusive region to define a larger total region for each of its DE.

distgrid1 = ESMF_DistGridCreate(minCorner=(/1,1/), maxCorner=(/5,5/), &
regDecomp=(/2,3/, rc=rc)
array1 = ESMF_ArrayCreate(arrayspec=arrayspec, distgrid=distgrid1, rc=rc)
distgrid2 = ESMF_DistGridCreate(minCorner=([-4,1/], maxCorner=(/2,3/), rc=rc)
array2 = ESMF_ArrayCreate(arrayspec=arrayspec, distgrid=distgrid2, &
  totalLWidth=(/1,1/), totalUWidth=(/1,1/), rc=rc)

The sequentialization of both Arrays is straight forward.
array1:

<table>
<thead>
<tr>
<th>Array/DistGrid coordinate</th>
<th>sequential index</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, 1)</td>
<td>1</td>
</tr>
<tr>
<td>(2, 1)</td>
<td>2</td>
</tr>
<tr>
<td>(3, 1)</td>
<td>3</td>
</tr>
<tr>
<td>(4, 1)</td>
<td>4</td>
</tr>
<tr>
<td>(5, 1)</td>
<td>5</td>
</tr>
<tr>
<td>(1, 2)</td>
<td>6</td>
</tr>
<tr>
<td>(2, 2)</td>
<td>7</td>
</tr>
<tr>
<td>(3, 2)</td>
<td>8</td>
</tr>
<tr>
<td>(4, 2)</td>
<td>9</td>
</tr>
<tr>
<td>(5, 2)</td>
<td>10</td>
</tr>
<tr>
<td>(1, 3)</td>
<td>11</td>
</tr>
<tr>
<td>(2, 3)</td>
<td>12</td>
</tr>
<tr>
<td>(3, 3)</td>
<td>13</td>
</tr>
<tr>
<td>(4, 3)</td>
<td>14</td>
</tr>
<tr>
<td>(5, 3)</td>
<td>15</td>
</tr>
<tr>
<td>(1, 4)</td>
<td>16</td>
</tr>
<tr>
<td>(2, 4)</td>
<td>17</td>
</tr>
<tr>
<td>(3, 4)</td>
<td>18</td>
</tr>
<tr>
<td>(4, 4)</td>
<td>19</td>
</tr>
<tr>
<td>(5, 4)</td>
<td>20</td>
</tr>
<tr>
<td>(1, 5)</td>
<td>21</td>
</tr>
<tr>
<td>(2, 5)</td>
<td>22</td>
</tr>
<tr>
<td>(3, 5)</td>
<td>23</td>
</tr>
<tr>
<td>(4, 5)</td>
<td>24</td>
</tr>
<tr>
<td>(5, 5)</td>
<td>25</td>
</tr>
</tbody>
</table>

array2:

<table>
<thead>
<tr>
<th>Array/DistGrid coordinate</th>
<th>sequential index</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-4, 1)</td>
<td>1</td>
</tr>
<tr>
<td>(-3, 1)</td>
<td>2</td>
</tr>
<tr>
<td>(-2, 1)</td>
<td>3</td>
</tr>
<tr>
<td>(-1, 1)</td>
<td>4</td>
</tr>
<tr>
<td>( 0, 1)</td>
<td>5</td>
</tr>
<tr>
<td>( 1, 1)</td>
<td>6</td>
</tr>
<tr>
<td>( 2, 1)</td>
<td>7</td>
</tr>
<tr>
<td>(-4, 2)</td>
<td>8</td>
</tr>
<tr>
<td>(-3, 2)</td>
<td>9</td>
</tr>
<tr>
<td>(-2, 2)</td>
<td>10</td>
</tr>
<tr>
<td>(-1, 2)</td>
<td>11</td>
</tr>
<tr>
<td>( 0, 2)</td>
<td>12</td>
</tr>
<tr>
<td>( 1, 2)</td>
<td>13</td>
</tr>
<tr>
<td>( 2, 2)</td>
<td>14</td>
</tr>
</tbody>
</table>
Notice that the number of cells in source and destination Arrays need not match. Also, the only meaning the sequential indices carry is to provide a unique order for the source and destination cells for the sparse matrix multiplication.

In order to carry out a sparse matrix multiplication of the data stored in array1 and to store the result in array2 the non-zero values of the sparse matrix need to be provided. In case of an Array to Array interpolation the matrix values correspond to the interpolation weights for the specific case. A number of different schemes exist to generate the coefficients from the physical grid information associated with the Arrays. In ESMF the physical information stored in the Grids is not accessible on the index space level on which the Array class is defined. For the Array an interpolation or regridding is simply a sparse matrix multiplication.

It is very common to compute the interpolation weights between two physical grids with an external tool, and then read these values in from file before the multiplication is to be performed. The ArraySparseMatMulStore() method requires this information in two arguments on the rootPET. The factorList argument provides the non-zero coefficients as a list of real numbers. The factorIndexList is a two dimensional array that has as many elements in the second dimension as there are non-zero factors. The first dimension is of size 2 and provides the sequentialized index of the source and destination cell, respectively.

The ArraySparseMatMul() operation performs the following update on the destination array:

\[
\text{do } n=1, \text{ size(factorList)} \\
\quad \text{dstArray(factorIndexList(2, n)) += factorList(n) * srcArray(factorIndexList(1, n))} \\
\text{enddo}
\]

In principle, a full linear combination of all cells of array1 to all cells of array2 would require a total of 21 x 25 = 525 coefficients. However, most of the coefficients will be zero. For this example assume that only the following 4 factors are non-zero.

\[
\text{factorList(:)} = \text{factorIndexList(1,:)} / \text{factorIndexList(2,:)} \\
0.5 - 8 / 4 \\
0.5 - 9 / 4 \\
0.8 - 11 / 20 \\
0.2 - 15 / 20
\]

allocate(factorList(4), factorIndexList(2,4))

factorList = (/0.5, 0.5, 0.8, 0.2/) ! weights
factorIndexList(1,:) = (/8, 9, 11, 15/) ! source cell indices
factorIndexList(2,:) = (/4, 4, 20, 20/) ! destination cell indices

With this information available on rootPET the Array SparseMatMul can be precomputed and stored.

\[
\text{call ESMF_ArraySparseMatMulStore(srcArray=array1, dstArray=array2, &} \\
\quad \text{factorList=factorList, factorIndexList=factorIndexList, rootPET=0, &} \\
\quad \text{routehandle=sparseMatMulHandle, rc=rc)}
\]

The call to ESMF_ArraySparseMatMulStore() will have distributed the sparse matrix coefficients according to the distribution pattern of array1 and array2. Furthermore the exchange patterns of the Array data has been precomputed and is stored in a Route object referenced by the returned RouteHandle object. The sparseMatMulHandle can now be used to execute the sparse matrix multiplication.
This parallel sparse matrix multiplication call will have updated two cells of destination array (array2):

\[
\text{array2}(-1,1) = \text{array2}(-1,1) + 0.5 \times \text{array1}(3,2) + 0.5 \times \text{array1}(4,2)
\]

and

\[
\text{array2}(1,3) = \text{array2}(1,3) + 0.8 \times \text{array1}(1,3) + 0.2 \times \text{array1}(5,3)
\]

All other values in array2 will be left unchanged.

Finally the RouteHandle can be used to release all memory allocation associated with the precomputed ArrayMatMul operation.

call ESMF_RouteHandleRelease(routehandle=sparseMatMulHandle, rc=rc)

24.2.10 1D and 3D Arrays

All previous examples were written for the 2D case. There is, however, no restriction within the Array or DistGrid class that limits the dimensionality of Array objects beyond the language specific limitations.

In order to create an n-dimensional Array the rank indicated by both the arrayspec and the distgrid arguments specified during Array create must be equal to n. A 1D Array of double precision real data hence requires the following arrayspec.

call ESMF_ArraySpecSet(arrayspec, type=ESMF_DATA_REAL, kind=ESMF_R8, rank=1, &
rc=rc)

The index space covered by the Array and the decomposition description is provided to the Array create method by the distgrid argument. The index space in this example has 16 cells and covers the interval $[-10, 5]$. It is decomposed into as many DEs as there are PETs in the current context.

distgrid1D = ESMF_DistGridCreate(minCorner=(/-10/), maxCorner=(/5/), &
regDecomp=(/petCount/), rc=rc)

A 1D Array object with default regions can now be created.

array1D = ESMF_ArrayCreate(arrayspec=arrayspec, distgrid=distgrid1D, rc=rc)

The creation of a 3D Array proceeds analogous to the 1D case. The rank of the arrayspec must be changed to 3

call ESMF_ArraySpecSet(arrayspec, type=ESMF_DATA_REAL, kind=ESMF_R8, rank=3, &
rc=rc)

and an appropriate 3D DistGrid object must be created

distgrid3D = ESMF_DistGridCreate(minCorner=(/1,1,1/), maxCorner=(/16,16,16/), &
regDecomp=(/4,4,4/), rc=rc)
before an Array object can be created.

\[
\text{array3D} = \text{ESMF}\_\text{ArrayCreate}(\text{arrayspec}=\text{arrayspec}, \text{distgrid}=\text{distgrid3D}, \text{rc}=\text{rc})
\]

The distgrid3D object decomposes the 3-dimensional index space into \(4 \times 4 \times 4 = 64\) DEs. These DEs are laid out across the computational resources (PETs) of the current component according to a default DELayout that is created during the DistGrid create call. Notice that in the index space proposal a DELayout does not have a sense of dimensionality. The DELayout function is simply to map DEs to PETs. The DistGrid maps chunks of index space against DEs and thus its rank is equal to the number of index space dimensions.

The previously defined DistGrid and the derived Array object decompose the index space along all three dimensions. It is, however, not a requirement that the decomposition be along all dimensions. An Array with the same 3D index space could as well be decomposed along just one or along two of the dimensions. The following example shows how for the same index space only the last two dimensions are decomposed while the first Array dimension has full extent on all DEs.

\[
\begin{align*}
\text{call ESMF\_ArrayDestroy(array3D, rc=rc)} & \\
\text{call ESMF\_DistGridDestroy(distgrid3D, rc=rc)} & \\
\text{distgrid3D} = \text{ESMF\_DistGridCreate(minCorner}= (/1,1,1/), \text{maxCorner}= (/16,16,16/), \&
\text{regDecomp}= (/1,4,4/), \text{rc}=\text{rc}) & \\
\text{array3D} = \text{ESMF\_ArrayCreate(arrayspec}=\text{arrayspec}, \text{distgrid}=\text{distgrid3D}, \text{rc}=\text{rc})
\end{align*}
\]

Finally, the definition and usage of the stagger location index as it was described in sections ?? and ?? for the 2D case applies without change to 1D, 3D or any other dimensionality. Connections defined in the DistGrid object may utilize the stagger location index in order to express characteristics of the index space topology. The concept is completely rank independent.

### 24.2.11 Working with Arrays of different rank

Assume a computational kernel that involves the array3D object as it was created at the end of the previous section. Assume further that the kernel also involves a 2D Array on a 16x16 index space where each point (j,k) was interacting with each (i,j,k) column of the 3D Array. An efficient formulation would require that the decomposition of the 2D Array must match that of the 3D Array and further the DELayout be identical. The following code shows how this can be accomplished.

\[
\begin{align*}
\text{call ESMF\_DistGridGet(distgrid3D, delayout}=\text{delayout}, \text{rc}=\text{rc} ) & ! \text{ get DELayout} \\
\text{distgrid2D} = \text{ESMF\_DistGridCreate(minCorner}= (/1,1/), \text{maxCorner}= (/16,16/), \&
\text{regDecomp}= (/4,4/), \text{delayout}=\text{delayout}, \text{rc}=\text{rc}) & \\
\text{call ESMF\_ArraySpecSet(arrayspec, type}=\text{ESMF\_DATA\_REAL}, \text{kind}=\text{ESMF\_R8}, \text{rank}=2, \&
\text{rc}=\text{rc}) & \\
\text{array2D} = \text{ESMF\_ArrayCreate(arrayspec}=\text{arrayspec}, \text{distgrid}=\text{distgrid2D}, \text{rc}=\text{rc})
\end{align*}
\]

Now the following kernel is sure to work with array3D and array2D.

\[
\begin{align*}
\text{call ESMF\_DELLayoutGet(delayout, localDeCount}=\text{localDeCount}, \text{rc}=\text{rc} ) & \\
\text{allocate(larrayList1(localDeCount))} & \\
\text{call ESMF\_ArrayGet(array3D, larrayList}=\text{larrayList1}, \text{rc}=\text{rc} ) & \\
\text{allocate(larrayList2(localDeCount))} & \\
\text{call ESMF\_ArrayGet(array2D, larrayList}=\text{larrayList2}, \text{rc}=\text{rc} ) & \\
\text{do de}=1, \text{localDeCount} & \\
\text{call ESMF\_LocalArrayGetData(larrayList1(de), myF90Array3D, ESMF\_DATA\_REF, \&}
\text{rc}=\text{rc}) & \\
\text{myF90Array3D} = 0.1d0 * \text{de} ! \text{initialize} & \\
\text{call ESMF\_LocalArrayGetData(larrayList2(de), myF90Array2D, ESMF\_DATA\_REF, \&}
\text{rc}=\text{rc}) &
\end{align*}
\]
myF90Array2D = 0.5d0 * de ! initialize
do k=1, 4
  do j=1, 4
    dummySum = 0.d0
    do i=1, 16
      dummySum = dummySum + myF90Array3D(i,j,k) ! sum up the (j,k) column
    enddo
    dummySum = dummySum * myF90Array2D(j,k) ! multiply with local 2D element
    ! print *, "dummySum(",j,k,")="",dummySum
  enddo
enddo
enddo

24.2.12 Array and DistGrid rank – 2D+1 Arrays

All of the Array create interfaces require the specification of at least the arrayspec and the distgrid arguments. Both arguments contain a sense of dimensionality. The interaction between these two arguments deserves extra attention.

The arrayspec argument is of type ESMF_ArraySpec and determines, among other things, the rank of the Array (data storage). This means, for example, that the rank of a native language array extracted from an Array object is equal to that specified in the arrayspec argument, which is also what is returned as rank by the ESMF_ArrayGet() call. The arrayspec argument does not determine, however, how the Array dimensions are decomposed and distributed.

The rank specification contained in the distgrid argument, which is of type ESMF_DistGrid, on the other hand has no affect on the dimensionality of the Array. The DistGrid rank specifies the dimensionality of the decomposition, i.e. the number of Array dimensions that are decomposed. Consequently, the DistGrid rank must be smaller or equal to the Array rank.

The DistGrid rank, furthermore, determines the dimensionality of the index space of the Array. Array dimensions that do not correspond to DistGrid dimensions are considered extra or tensor dimensions of the Array. They are not part of the index space. Tensor dimensions are used to address multiple data storage arrays in the same Array object. It is, for example, possible to store array1 and array2 of section ?? in a single Array object using one additional tensor dimension of size 2. The same distgrid object as before can be used to create the Array. The rank in the arrayspec argument, however, must be changed from 2 to 3 in order to provide for the extra Array dimension.

call ESMF_ArraySpecSet(arrayspec, type=ESMF_DATA_REAL, kind=ESMF_R8, rank=3, &
rc=rc)

during Array creation with extra dimension(s) it is necessary to specify the bounds of these tensor dimension(s). This requires two additional arguments, lbounds and ubounds, which are vectors in order to accommodate multiple tensor dimensions. The other arguments remain unchanged and apply across all tensor components. The optional arguments used in the following call are identical to those used to create array1 of section ?? This will set the total region and the stagger location of both tensor components to be those of array1.

array = ESMF_ArrayCreate(arrayspec=arrayspec, distgrid=distgrid, &
totalLWidth=(/0,1/), totalUWidth=(/0,1/), staggerLoc=1, &
lbounds=(/1/), ubounds=(/2/), rc=rc)

call ESMF_ArrayPrint(array, rc=rc)
if (rc /= ESMF_SUCCESS) call ESMF_Finalize(terminationflag=ESMF_ABORT)

This will create array with 2+1 dimensions, i.e. a 2D DistGrid is used to describe the index space and decomposition into DEs and an extra Array dimension captures the fact that multiple 2D user data arrays are kept in a single data storage object (Array). By default the distgrid dimensions are associated with the first Array dimensions in
sequence. For the example above this means that the first 2 Array dimensions are decomposed according to the
provided 2D DistGrid. The 3rd Array dimension does not have an associated DistGrid dimension, rendering it a tensor
dimension.
The optional arguments that were used to create array ensure that the total region is large enough to accommodate
the halo for tensor component 1 and the computational region for tensor component 2. However, the regions for tensor
component 2 must still be adjusted to correctly reflect the array2 settings as in section ?? . The stagger location,
too, must be changed from "1" to "2" to match correctly. The Array class provides a special method that allows to
individually address tensor elements in an Array and set stagger location, computational and halo widths.

    call ESMF_ArraySet(array, tensorIndex=(/2/), computationalLWidth=(/0,1/), &
                        staggerLoc=2, rc=rc)

The array object is now completely self-contained with respect to the connection transformation stored in the Dist-
Grid which mixes stagger location "1" and "2" when crossing the interface. Consequently, array can be haloed
without the need to specify a list of Array objects.

    call ESMF_ArrayHalo(array, rc=rc)

Native loop access to an Array with tensor dimensions is in principle the same as without extra dimensions. The
following loop shows how a Fortran90 pointer to the DE-local data chunks can be obtained and used to set data values
in the exclusive regions. The myF90Array3 variable must be of rank 3 to match the Array rank of array. However,
variables such as exclusiveUBound that store the information about the decomposition, remain to be allocated for
a 2D decomposition.

    call ESMF_ArrayGet(array, exclusiveLBound=exclusiveLBound, &
                       exclusiveUBound=exclusiveUBound, rc=rc)
    do de=1, localDeCount
        call ESMF_LocalArrayGetData(larrayList(de), myF90Array3, ESMF_DATA_REF, rc=rc)
        myF90Array3(exclusiveLBound(de,1):exclusiveUBound(de,1), &
                    exclusiveLBound(de,2):exclusiveUBound(de,2), 1) = 1
        myF90Array3(exclusiveLBound(de,1):exclusiveUBound(de,1), &
                    exclusiveLBound(de,2):exclusiveUBound(de,2), 2) = 2
    enddo

For some applications the default association rules between DistGrid and Array dimensions may not satisfy the user’s
needs. The optional dimmap argument may be used during Array creation to explicitly specify the mapping between
Array and DistGrid dimensions. To demonstrate this the following lines of code reproduce the above example but
with rearranged dimensions. Here the dimmap argument is a list with two elements corresponding to the DistGrid
rank of 2. The first element indicates against which Array dimension the 1st DistGrid dimension is mapped. Here
the 1st DistGrid dimension maps against the 3rd Array and the 2nd DistGrid dimension maps against the 1st Array
dimension. This leaves the 2nd Array dimension to be the extra or tensor dimension of the created Array object.

    call ESMF_ArrayDestroy(array, rc=rc)
    array = ESMF_ArrayCreate(arrayspec=arrayspec, distgrid=distgrid, &
                            dimmap=(/3, 1/), totalLWidth=(/0,1/), totalUWidth=(/0,1/), &
                            lbounds=(/1/), ubounds=(/2/), rc=rc)
    call ESMF_ArraySet(array, tensorIndex=(/1/), staggerLoc=1, rc=rc)
    call ESMF_ArraySet(array, tensorIndex=(/2/), computationalLWidth=(/0,1/), &
                        staggerLoc=2, rc=rc)

Operations on the Array object as a whole are unchanged by the different mapping of dimensions.

    call ESMF_ArrayHalo(array, rc=rc)
When working with Arrays that contain explicitly mapped Array and DistGrid dimensions it is critical to understand that width and bound arguments are always defined in terms of the DistGrid dimension order. The Array dimensions indicate how the data is actually stored in the Array object, and that can be different for each Array, even if the same DistGrid is used. The index space defined in DistGrid, however, does not change and is the same for each Array that uses it, regardless of the dimension order in the Array. The DistGrid dimension order thus becomes a common reference order for all Arrays that use the same DistGrid.

The dimmap argument optionally provided during Array create indicates the DistGrid to Array dimension mapping. Depending on the formulation of the computational kernel, the inverse mapping, i.e. Array to DistGrid dimension mapping, is just as important. The ESMF_ArrayGet() call offers both mappings as dimmap and inverseDimmap, respectively. The number of elements in inverseDimmap is equal to the rank of the Array. Each element corresponds to an Array dimension and indicates the associated DistGrid dimension by an integer number. An entry of "0" indicates an extra Array dimension.

The association between Array and DistGrid dimensions becomes critical for correct native language access to the Array. In the following example the inverse mapping information is used to determine the correct bounds or the Array dimensions and to verify that the kernel’s assumption about which Array dimension is of tensor character is correct.

```fortran
allocate(inverseDimmap(3))  ! arrayRank = 3
call ESMF_ArrayGet(array, inverseDimmap=inverseDimmap, &
   exclusiveLBound=exclusiveLBound, exclusiveUBound=exclusiveUBound, rc=rc)
if (inverseDimmap(2) /= 0) then  ! check if extra dimension at expected index
   ! indicate problem and bail out
endif
! prepare inverse dimmap variables for kernel loop
idm1=inverseDimmap(1)
idm3=inverseDimmap(3)
do de=1, localDeCount
   call ESMF_LocalArrayGetData(larrayList(de), myF90Array3, ESMF_DATA_REF, rc=rc)
   myF90Array3(exclusiveLBound(de, idm1):exclusiveUBound(de, idm1), &
      1, exclusiveLBound(de, idm3):exclusiveUBound(de, idm3)) = 10.5 ! dummy assignment
   myF90Array3(exclusiveLBound(de, idm1):exclusiveUBound(de, idm1), &
      2, exclusiveLBound(de, idm3):exclusiveUBound(de, idm3)) = 23.3 ! dummy assignment
enddo
```

### 24.3 Restrictions and Future Work

- Currently all native Fortran90 entry points to the Array API are severely limited with respect to type/kind/rank: only 2D and 3D real(ESMF_KIND_R8) interfaces are implemented.
- Non-blocking communication, PET-based and DE-based, has not been formulated or implemented.

### 24.4 Design and Implementation Notes

This section will be updated as the implementation of the Array class nears completion.

### 24.5 Class API

#### 24.5.1 ESMF_ArrayCreateAssumedShape - Create Array from Fortran90 array

**INTERFACE:**

```fortran
! Private name; call using ESMF_ArrayCreate()
function ESMF_ArrayCreateAssumedShape(farray, distgrid, dimmap, &
    computationalLWidth, computationalUWidth, totalLWidth, totalUWidth, &
    indexflag, staggerLoc, vectorDim, lbounds, ubounds, rc)
```
ARGUMENTS:

- real(ESMF_KIND_R8), intent(in), target :: farray(:, :)
- type(ESMF_DistGrid), intent(in) :: distgrid
- integer, intent(in), optional :: dimmap(:)
- integer, intent(in), optional :: computationalLWidth(:)
- integer, intent(in), optional :: computationalUWidth(:)
- integer, intent(in), optional :: totalLWidth(:)
- integer, intent(in), optional :: totalUWidth(:)
- type(ESMF_IndexFlag), intent(in), optional :: indexflag
- integer, intent(in), optional :: staggerLoc
- integer, intent(in), optional :: vectorDim
- integer, intent(in), optional :: lbounds(:)
- integer, intent(in), optional :: ubounds(:)
- integer, intent(out), optional :: rc

RETURN VALUE:

- type(ESMF_Array) :: ESMF_ArrayCreateAssumedShape

DESCRIPTION:

Create an ESMF_Array object from an existing local native Fortran90 array according to distgrid. Besides farray each PET must issue this call with identical arguments in order to create a consistent Array object. The local arrays provided must be dimensioned according to the DE-local total region. Bounds of the exclusive regions are set as specified in the distgrid argument. Bounds for array dimensions that are not distributed can be chosen freely. This interface requires a 1 DE per PET decomposition. The Array object will not be created and an error will be returned if this condition is not met.

The not distributed array dimensions form a tensor of rank = array.rank - distgrid.dimCount. By default all tensor elements are associated with stagger location 0. The widths of the computational region are set to the provided value, or zero by default, for all tensor elements. Use ESMF_ArraySetTensor() to change these default settings after the Array object has been created.

The return value is the new ESMF_Array.

The arguments are:

- **farray** Valid native Fortran90 array, i.e. memory must be associated with the actual argument. The type/kind/rank information of farray will be used to set Array's properties accordingly. The shape of farray will be checked against the information contained in the distgrid.

- **distgrid** ESMF_DistGrid object that describes how the array is decomposed and distributed over DEs. The dimCount of distgrid must be smaller or equal to the rank of farray.

- **[dimmap]** List that contains as many elements as is indicated by distgrid’s dimCount. The elements map each dimension of distgrid to a dimension in farray. The default is to map all of distgrid’s dimensions against the lower dimension of farray in sequence. Unmapped farray dimensions are considered to be not distributed dimensions and form a tensor of rank = farray.rank - distgrid.dimCount or farray.rank - distgrid.dimCount - 1 if farray contains an additional DE dimension.

- **[computationalLWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the lower corner of the computational region with respect to the lower corner of the exclusive region. The default is a zero vector.

- **[computationalUWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the upper corner of the computational region with respect to the upper corner of the exclusive region. The default is a zero vector.

- **[totalLWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the lower corner of the total memory region with respect to the lower corner of the exclusive region. The default is a zero vector.
This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the upper corner of the total memory region with respect to the upper corner of the exclusive region. The default is a vector that contains the remaining number of cells in each direction as to fit the computational region into the memory region provided by the farray argument.

Flag that indicates how the DE-local indices are to be defined.

Stagger location is an arbitrary integer index.

If the data stored in this Array object is a component of a vector field then the vectorDim argument may be used to identify the dimension along which the vector component is aligned. This information is used to correctly apply the signChangeVector defined in the connection transformations of the corresponding DistGrid.

Lower bounds for the array dimensions that are not distributed.

Upper bounds for the array dimensions that are not distributed.

Return code; equals ESMF_SUCCESS if there are no errors.

24.5.2 ESMF_ArrayCreateLocalArray - Create from a list of LocalArray elements

INTERFACE:

! Private name; call using ESMF_ArrayCreate()
function ESMF_ArrayCreateLocalArray(larrayList, distgrid, dimmap, &
  computationalLWidth, computationalUWidth, totalLWidth, totalUWidth, &
  indexflag, staggerLoc, vectorDim, lbounds, ubounds, rc)

ARGUMENTS:

  type(ESMF_LocalArray), intent(in) :: larrayList(:)
  type(ESMF_DistGrid), intent(in) :: distgrid
  integer, intent(in), optional :: dimmap(:)
  integer, intent(in), optional :: computationalLWidth(:)
  integer, intent(in), optional :: computationalUWidth(:)
  integer, intent(in), optional :: totalLWidth(:)
  integer, intent(in), optional :: totalUWidth(:)
  type(ESMF_IndexFlag), intent(in), optional :: indexflag
  integer, intent(in), optional :: staggerLoc
  integer, intent(in), optional :: vectorDim
  integer, intent(in), optional :: lbounds(:)
  integer, intent(in), optional :: ubounds(:)
  integer, intent(out), optional :: rc

RETURN VALUE:

  type(ESMF_Array) :: ESMF_ArrayCreateLocalArray

DESCRIPTION:

Create an ESMF_Array object from existing ESMF_LocalArray objects according to distgrid. Besides larrayList each PET must issue this call with identical arguments in order to create a consistent Array object. The local arrays provided must be dimensioned according to the DE-local total region. Bounds of the exclusive regions are set as specified in the distgrid argument. Bounds for array dimensions that are not distributed can be chosen freely. This interface is able to handle multiple DEs per PET.
The not distributed array dimensions form a tensor of rank = array.rank - distgrid.dimCount. By default all tensor elements are associated with stagger location 0. The widths of the computational region are set to the provided value, or zero by default, for all tensor elements. Use ESMF_ArraySetTensor() to change these default settings after the Array object has been created.

The return value is the new ESMF_Array.

The arguments are:

- **larrayList** List of valid ESMF_LocalArray objects, i.e. memory must be associated with the actual arguments. The type/kind/rank information of all larrayList elements must be identical and will be used to set Array’s properties accordingly. The shape of each larrayList element will be checked against the information contained in the distgrid.

- **distgrid** ESMF_DistGrid object that describes how the array is decomposed and distributed over DEs. The dimCount of distgrid must be smaller or equal to the rank specified in arrayspec, otherwise a runtime ESMF error will be raised.

- **[dimmap]** List that has as many elements as is indicated by distgrid’s dimCount value. The elements map each dimension of distgrid to a dimension in arrayspec. The default is to map all of distgrid’s dimensions against the lower dimension of arrayspec in sequence.

- **[computationalLWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the lower corner of the computational region with respect to the lower corner of the exclusive region.

- **[computationalUWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the upper corner of the computational region with respect to the upper corner of the exclusive region.

- **[totalMemoryLWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the lower corner of the total memory region with respect to the lower corner of the exclusive region.

- **[totalMemoryUWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the upper corner of the total memory region with respect to the upper corner of the exclusive region.

- **[indexflag]** Flag that indicates how the DE-local indices are to be defined.

- **[staggerLoc]** Stagger location is an arbitrary integer index.

- **[vectorDim]** If the data stored in this Array object is a component of a vector field then the vectorDim argument may be used to identify the dimension along which the vector component is aligned. This information is used to correctly apply the signChangeVector defined in the connection transformations of the corresponding DistGrid.

- **[lbounds]** Lower bounds for tensor array dimensions.

- **[ubounds]** Upper bounds for tensor array dimensions.

- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

---

### 24.5.3 ESMF_ArrayCreateAllocate - Create Array and allocate memory

**INTERFACE:**

```fortran
! Private name; call using ESMF_ArrayCreate()
function ESMF_ArrayCreateAllocate(arrayspec, distgrid, dimmap, &
  computationalLWidth, computationalUWidth, totalLWidth, totalUWidth, &
  indexflag, staggerLoc, vectorDim, lbounds, ubounds, rc)
```
ARGUMENTS:

```
type(ESMF_ArraySpec), intent(inout) :: arrayspec
type(ESMF_DistGrid), intent(in) :: distgrid
integer, intent(in), optional :: dimmap(:)
integer, intent(in), optional :: computationalLWidth(:)
integer, intent(in), optional :: computationalUWidth(:)
integer, intent(in), optional :: totalLWidth(:)
integer, intent(in), optional :: totalUWidth(:)
type(ESMF_IndexFlag), intent(in), optional :: indexflag
integer, intent(in), optional :: staggerLoc
integer, intent(in), optional :: vectorDim
integer, intent(in), optional :: lbounds(:)
integer, intent(in), optional :: ubounds(:)
integer, intent(out), optional :: rc
```

RETURN VALUE:

```
type(ESMF_Array) :: ESMF_ArrayCreateAllocate
```

DESCRIPTION:

Create an ESMF_Array object and allocate uninitialized data space according to arrayspec and distgrid. Each PET must issue this call with identical arguments in order to create a consistent Array object. DE-local allocations are made according to the total region defined by the arguments to this call: distgrid and the optional Width arguments. The return value is the new ESMF_Array.

The arguments are:

- **arrayspec** ESMF_ArraySpec object containing the type/kind/rank information.
- **distgrid** ESMF_DistGrid object that describes how the array is decomposed and distributed over DEs. The dimCount of distgrid must be smaller or equal to the rank specified in arrayspec, otherwise a runtime ESMF error will be raised.
- **[dimmap]** List that has as many elements as is indicated by distgrid's dimCount value. The elements map each dimension of distgrid to a dimension in arrayspec. The default is to map all of distgrid's dimensions against the lower dimension of arrayspec in sequence.
- **[computationalLWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the lower corner of the computational region with respect to the lower corner of the exclusive region.
- **[computationalUWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the upper corner of the computational region with respect to the upper corner of the exclusive region.
- **[totalMemoryLWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the lower corner of the total memory region with respect to the lower corner of the exclusive region.
- **[totalMemoryUWidth]** This vector argument must have dimCount elements, where dimCount is specified in distgrid. It specifies the upper corner of the total memory region with respect to the upper corner of the exclusive region.
- **[indexflag]** Flag that indicates how the DE-local indices are to be defined.
- **[staggerLoc]** Stagger location is an arbitrary integer index.
- **[vectorDim]** If the data stored in this Array object is a component of a vector field then the vectorDim argument may be used to identify the dimension along which the vector component is aligned. This information is used to correctly apply the signChangeVector defined in the connection transformations of the corresponding DistGrid.
[lbounds] Lower bounds for tensor array dimensions.
[ubounds] Upper bounds for tensor array dimensions.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

24.5.4 ESMF_ArrayDestroy - Destroy Array object

INTERFACE:

    subroutine ESMF_ArrayDestroy(array, rc)

ARGUMENTS:

    type(ESMF_Array), intent(inout) :: array
    integer, intent(out), optional :: rc

DESCRIPTION:

Destroy an ESMF_Array object.
The arguments are:

array ESMF_Array object to be destroyed.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

24.5.5 ESMF_ArrayGet - Get Array internals

INTERFACE:

    subroutine ESMF_ArrayGet(array, type, kind, rank, larrayList, distgrid, &
       delayout, indexflag, dimmap, inverseDimmap, exclusiveLBound, exclusiveUBound,&
       computationalLBound, computationalUBound, totalLBound, totalUBound, &
       computationalLWidth, computationalUWidth, totalLWidth, totalUWidth, &
       name, rc)

ARGUMENTS:

    type(ESMF_Array), intent(in) :: array
    type(ESMF_DataType), intent(out), optional :: type
    type(ESMF_DataKind), intent(out), optional :: kind
    integer, intent(out), optional :: rank
    type(ESMF_LocalArray), target, intent(out), optional :: larrayList(:)
    type(ESMF_DistGrid), intent(out), optional :: distgrid
    type(ESMF_DELayout), intent(out), optional :: delayout
    type(ESMF_IndexFlag), intent(out), optional :: indexflag
    integer, intent(out), optional :: dimmap(:)
    integer, intent(out), optional :: inverseDimmap(:)
    integer, intent(out), optional :: exclusiveLBound(:,:)
    integer, intent(out), optional :: exclusiveUBound(:,:)
    integer, intent(out), optional :: computationalLBound(:,:),
    integer, intent(out), optional :: computationalUBound(:,),
    integer, intent(out), optional :: totalLBound(:,:),
    integer, intent(out), optional :: totalUBound(:,:)

259
DESCRIPTION:

Get internal information.
This interface works for any number of DEs per PET.
The arguments are:

array Queried ESMF_Array object.
[type] Type of the Array object.
[kind] Kind of the Array object.
[rank] Rank of the Array object.
[larrayList] Upon return this holds a list of the associated ESMC_LocalArray objects. larrayList must be allocated to be at least of size localDeCount, i.e. the number of DEs associated with the calling PET.
[distgrid] Upon return this holds the associated ESMF_DistGrid object.
[delayout] Upon return this holds the associated ESMF_DELayout object.
[indexflag] Upon return this flag indicates how the DE-local indices are defined.
[exclusiveLBound] Upon return this holds the lower bounds of the exclusive regions for all PET-local DEs. exclusiveLBound must be allocated to be of size (dimCount, localDeCount).
[exclusiveUBound] Upon return this holds the upper bounds of the exclusive regions for all PET-local DEs. exclusiveUBound must be allocated to be of size (dimCount, localDeCount).
[computationalLBound] Upon return this holds the lower bounds of the computational regions for all PET-local DEs. computationalLBound must be allocated to be of size (dimCount, localDeCount).
[computationalUBound] Upon return this holds the upper bounds of the computational regions for all PET-local DEs. computationalUBound must be allocated to be of size (dimCount, localDeCount).
[totalLBound] Upon return this holds the lower bounds of the total regions for all PET-local DEs. totalLBound must be allocated to be of size (dimCount, localDeCount).
[totalUBound] Upon return this holds the upper bounds of the total regions for all PET-local DEs. totalUBound must be allocated to be of size (dimCount, localDeCount).
[computationalLWidth] Upon return this holds the lower width of the computational regions for all PET-local DEs. computationalLWidth must be allocated to be of size (dimCount, localDeCount).
[computationalUWidth] Upon return this holds the upper width of the computational regions for all PET-local DEs. computationalUWidth must be allocated to be of size (dimCount, localDeCount).
[totalLWidth] Upon return this holds the lower width of the total memory regions for all PET-local DEs. totalLWidth must be allocated to be of size (dimCount, localDeCount).
[totalUWidth] Upon return this holds the upper width of the total memory regions for all PET-local DEs. totalUWidth must be allocated to be of size (dimCount, localDeCount).
[name] Name of the Array object.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

24.5.6 ESMF_ArrayGetFarray - Get Fortran90 pointer to memory region

INTERFACE:

! Private name; call using ESMF_Get()
[subroutine ESMF_ArrayGetFarray2R8(array, farrayPtr, rc)]

ARGUMENTS:

type(ESMF_Array), intent(in) :: array
type(ESMF_KIND_R8), pointer :: farrayPtr(:,:)
integer, intent(out), optional :: rc

DESCRIPTION:

Get Fortran90 pointer to DE-local memory regions in Array object.
This interface requires that exactly 1 DE is associated with the calling PET. An error will be returned if this condition
is not met.
The arguments are:
array Queried ESMF_Array object.
[farrayPtr] Upon return farrayPtr points to the DE-local data allocation of array.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

24.5.7 ESMF_ArrayGetFarray - Get Fortran90 pointer to memory region

INTERFACE:

! Private name; call using ESMF_Get()
[subroutine ESMF_ArrayGetFarray3R8(array, farrayPtr, rc)]

ARGUMENTS:

type(ESMF_Array), intent(in) :: array
type(ESMF_KIND_R8), pointer :: farrayPtr(:,:,)
integer, intent(out), optional :: rc

DESCRIPTION:

Get Fortran90 pointer to DE-local memory regions in Array object.
This interface requires that exactly 1 DE is associated with the calling PET. An error will be returned if this condition
is not met.
The arguments are:
array Queried ESMF_Array object.
[farrayPtr] Upon return farrayPtr points to the DE-local data allocation of array.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.
24.5.8 ESMF_ArrayGetLArray - Get Array internals

INTERFACE:

! Private name; call using ESMF_Get()
subroutine ESMF_ArrayGetLArray(array, larray, rc)

ARGUMENTS:

type(ESMF_Array),           intent(in)       :: array

type(ESMF_LocalArray),      intent(inout)     :: larray

integer,                   intent(out),     optional :: rc

DESCRIPTION:
Get internal information.
This interface requires that exactly 1 DE is associated with the calling PET. An error will be returned if this condition
is not met.
The arguments are:
array Queried ESMF_Array object.
larray Upon return larray refers to the DE-local data allocation of array.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

24.5.9 ESMF_ArrayPrint - Print Array internals

INTERFACE:

subroutine ESMF_ArrayPrint(array, options, rc)

ARGUMENTS:

type(ESMF_Array),           intent(in)       :: array

character(len=*),           intent(in),     optional :: options

integer,                   intent(out),     optional :: rc

DESCRIPTION:
Prints internal information about the specified ESMF_DELayout object to stdout.
The arguments are:
array Specified ESMF_Array object.
[options] Print options are not yet supported.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.
24.5.10 ESMF_ArraySparseMatMulStore - Store an Array sparse matrix multiplication operation

INTERFACE:

    subroutine ESMF_ArraySparseMatMulStore(srcArray, dstArray, &
        factorList, factorIndexList, rootPET, routehandle, rc)

ARGUMENTS:

    type(ESMF_Array), intent(in) :: srcArray
    type(ESMF_Array), intent(inout) :: dstArray
    real(ESMF_KIND_R8), target, intent(in), optional :: factorList(:)
    integer, intent(in), optional :: factorIndexList(:, :)
    integer, intent(in) :: rootPET
    type(ESMF_RouteHandle), intent(inout) :: routehandle
    integer, intent(out), optional :: rc

DESCRIPTION:

Store an Array sparse matrix multiplication operation from srcArray to dstArray with the non-zero matrix coefficients stored in factorList. Both Arrays are interpreted as sequentialized vectors. The sequence is defined by the order of DistGrid dimensions and the order of patches within the DistGrid. Source and destination Arrays may have different shape and different number of cells.

The sparse matrix is constructed from the factorList and factorIndexList arguments which must be provided on rootPET.

A routehandle is returned and can be used on any pairs of Arrays that are DistGrid-conform with the Array pair for which the Route was precomputed.

This version of the interface implements the PET-based blocking paradigm: Each PET of the VM must issue this call exactly once for all of its DEs. The call will block until all PET-local data objects are accessible.

srcArray ESMF_Array containing source data.

dstArray ESMF_Array holding destination data.

[factorList] List of non-zero coefficients. Only rootPET must provide a valid factorList.

[factorIndexList] List of indices for the factors stored in factorList. The second dimension steps through the list elements which are defined by the first dimension. Each list element contains two integers: factorIndexList(1,:) indicates the index in the source Array and factorIndexList(2,:) indicates the index in the destination Array. Only rootPET must provide a valid factorIndexList.

rootPet PET on which weights are provided.

routehandle Handle to the Route that stores the precomputed operation.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

24.5.11 ESMF_ArraySparseMatMul - Execute an Array sparse matrix multiplication operation

INTERFACE:

    subroutine ESMF_ArraySparseMatMul(srcArray, dstArray, routehandle, rc)

ARGUMENTS:
**24.5.12 ESMF_ArrayScatter - Scatter a Fortran90 array across Array**

**INTERFACE:**

```fortran
subroutine ESMF_ArrayScatter2R8(array, farray, patch, rootPET, vm, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_Array), intent(inout) :: array
real(ESMF_KIND_R8), target, intent(in) :: farray(:,:)
integer, intent(in), optional :: patch
integer, intent(in) :: rootPET
integer, intent(in), optional :: vm
integer, intent(inout, optional) :: rc
```

**DESCRIPTION:**

Scatter the data of `farray` located on `rootPET` across an `ESMF_Array` object. A single `farray` must be scattered across a single DistGrid patch in Array. The optional `patch` argument allows selection of the patch. For Arrays defined on a single patch DistGrid the default selection (patch 1) will be correct. The shape of `farray` must match the shape of the patch in Array. This version of the interface implements the PET-based blocking paradigm: Each PET of the VM must issue this call exactly once for all of its DEs. The call will block until all PET-local data objects are accessible. The arguments are:

- **array** The `ESMF_Array` object across which data will be scattered.
- **farray** The Fortran90 array that is to be scattered. Only root must provide a valid `farray`.
- **patch** The DistGrid patch in `array` into which to scatter `farray`. By default `farray` will be scattered into patch 1.
- **rootPET** PET that holds the valid data in `farray`.
- **vm** Optional `ESMF_VM` object of the current context. Providing the VM of the current context will lower the method’s overhead.
- **rc** Return code; equals `ESMF_SUCCESS` if there are no errors.
24.5.13 ESMF_ArrayScatter - Scatter a Fortran90 array across Array

INTERFACE:

```fortran
subroutine ESMF_ArrayScatter3R8(array, farray, patch, rootPet, vm, rc)
```

ARGUMENTS:

```fortran
type(ESMF_Array), intent(inout) :: array
real(ESMF_KIND_R8), target, intent(in) :: farray(:,:,:)
integer, intent(in), optional :: patch
integer, intent(in) :: rootPet
integer, intent(in), optional :: vm
integer, intent(out), optional :: rc
```

DESCRIPTION:

Scatter the data of `farray` located on `rootPET` across an ESMF_Array object. A single `farray` must be scattered across a single DistGrid patch in Array. The optional `patch` argument allows selection of the patch. For Arrays defined on a single patch DistGrid the default selection (patch 1) will be correct. The shape of `farray` must match the shape of the patch in Array.

This version of the interface implements the PET-based blocking paradigm: Each PET of the VM must issue this call exactly once for all of its DEs. The call will block until all PET-local data objects are accessible.

The arguments are:

- **array**: The ESMF_Array object across which data will be scattered.
- **farray**: The Fortran90 array that is to be scattered. Only root must provide a valid `farray`.
- **patch**: The DistGrid patch in `array` into which to scatter `farray`. By default `farray` will be scattered into patch 1.
- **rootPet**: PET that holds the valid data in `farray`.
- **vm**: Optional ESMF_VM object of the current context. Providing the VM of the current context will lower the method’s overhead.
- **rc**: Return code; equals ESMF_SUCCESS if there are no errors.

24.5.14 ESMF_ArraySet - Set Array properties

INTERFACE:

```fortran
subroutine ESMF_ArraySet(array, name, rc)
```

ARGUMENTS:

```fortran
type(ESMF_Array), intent(inout) :: array
character (len = *) , intent(in) :: name
integer, intent(out), optional :: rc
```

DESCRIPTION:

Sets the name of the ESMF_Array object. Note: Unlike most other ESMF objects there are very few items which can be changed once an ESMF_Array object has been created.

The arguments are:

- **array** : The ESMF_Array object.
- **name** : The name to assign to the ESMF_Array object.
- **rc** : Return code; equals ESMF_SUCCESS if there are no errors.
array  An ESMF_Array.
name  The Array name.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

24.5.15  ESMF_ArrayValidate - Validate Array internals

INTERFACE:

    subroutine ESMF_ArrayValidate(array, rc)

ARGUMENTS:

    type(ESMF_Array), intent(in) :: array
    integer, intent(out), optional :: rc

DESCRIPTION:

Validates that the Array is internally consistent. The method returns an error code if problems are found.

The arguments are:

array  Specified ESMF_Array object.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

24.5.16  ESMF_ArrayBundleValidate - Validate ArrayBundle internals

INTERFACE:

    subroutine ESMF_ArrayBundleValidate(arraybundle, rc)

ARGUMENTS:

    type(ESMF_ArrayBundle), intent(in) :: arraybundle
    integer, intent(out), optional :: rc

DESCRIPTION:

Validates that the ArrayBundle is internally consistent. The method returns an error code if problems are found.

The arguments are:

arraybundle  Specified ESMF_ArrayBundle object.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
ESMF_LocalArrayCreate – Generic interface to create an LocalArray

INTERFACE:

    interface ESMF_LocalArrayCreate

PRIVATE MEMBER FUNCTIONS:

    module procedure ESMF_LocalArrayCreateByList ! specify TKR
    module procedure ESMF_LocalArrayCreateByLst1D ! allow integer counts
    module procedure ESMF_LocalArrayCreateBySpec ! specify ArraySpec

! Plus interfaces for each T/K/R expanded by macro.

This interface provides a single (heavily overloaded) entry point for the various types of ESMF_LocalArrayCreate functions. There are 3 options for setting the contents of the ESMF_LocalArray at creation time:

Allocate Space Only  Data space is allocated but not initialized. The caller can query for a pointer to the start of the space to address it directly. The caller must not deallocate the space; the ESMF_LocalArray will release the space when it is destroyed.

Data Copy  An existing Fortran array is specified and the data contents are copied into new space allocated by the ESMF_LocalArray. The caller must not deallocate the space; the ESMF_LocalArray will release the space when it is destroyed.

Data Reference  An existing Fortran array is specified and the data contents reference it directly. The caller is responsible for deallocating the space; when the ESMF_LocalArray is destroyed it will not release the space.

There are 3 options for specifying the type/kind/rank of the ESMF_LocalArray data:

List  The characteristics of the ESMF_LocalArray are given explicitly by individual arguments to the create function.

ArraySpec  A previously created ESMF_ArraySpec object is given which describes the characteristics.

Fortran 90 Pointer  An associated or unassociated Fortran 90 array pointer is used to describe the array. (Only available from the Fortran interface.)

The concept of an “empty” ESMF_LocalArray does not exist. To make an ESMF object which stores the Type/Kind/Rank information create an ESMF_ArraySpec object which can then be used repeatedly in subsequent ESMF_LocalArray Create calls.

end interface

ESMF_LocalArrayCreate – Create an LocalArray specifying all options.

INTERFACE:

    ! Private name; call using ESMF_LocalArrayCreate()
    function ESMF_LocalArrayCreateByList(rank, type, kind, counts, lbounds, &
    ubounds, rc)

RETURN VALUE:

    type(ESMF_LocalArray) :: ESMF_LocalArrayCreateByList

267
ARGUMENTS:

- `integer, intent(in) :: rank`
- `type(ESMF_DataType), intent(in) :: type`
- `type(ESMF_DataKind), intent(in) :: kind`
- `integer, dimension(:,), intent(in) :: counts`
- `integer, dimension(:,), intent(in), optional :: lbounds`
- `integer, dimension(:,), intent(in), optional :: ubounds`
- `integer, intent(out), optional :: rc`

DESCRIPTION:

Create a new `ESMF_LocalArray` and allocate data space, which remains uninitialized. The return value is a new `LocalArray`.

The arguments are:

- **rank**  Array rank (dimensionality, 1D, 2D, etc). Maximum allowed is 5D.
- **type** Array type. Valid types include `ESMF_DATA_INTEGER`, `ESMF_DATA_REAL`, `ESMF_DATA_LOGICAL`, `ESMF_DATA_CHARACTER`.
- **kind** Array kind. Valid kinds include `ESMF_I4`, `ESMF_I8`, `ESMF_R4`, `ESMF_R8`.
- **counts** The number of items in each dimension of the array. This is a 1D integer array the same length as the rank.
- **lbounds** An integer array of length rank, with the lower index for each dimension.
- **ubounds** An integer array of length rank, with the upper index for each dimension.
- **rc** Return code; equals `ESMF_SUCCESS` if there are no errors.

24.5.19 `ESMF_LocalArrayCreate` – Create a new LocalArray from an ArraySpec

INTERFACE:

```fortran
! Private name; call using ESMF_LocalArrayCreate()
function ESMF_LocalArrayCreateBySpec(arrayspec, counts, lbounds, ubounds, rc)
RETURN VALUE:

type(ESMF_LocalArray) :: ESMF_LocalArrayCreateBySpec

ARGUMENTS:

- `type(ESMF_ArraySpec), intent(inout) :: arrayspec`
- `integer, intent(in), dimension(:,), intent(in) :: counts`
- `integer, dimension(:,), intent(in), optional :: lbounds`
- `integer, dimension(:,), intent(in), optional :: ubounds`
- `integer, intent(out), optional :: rc`

DESCRIPTION:

Create a new `ESMF_LocalArray` and allocate data space, which remains uninitialized. The return value is a new `LocalArray`.

The arguments are:

- **arrayspec** ArraySpec object.
- **counts** The number of items in each dimension of the array. This is a 1D integer array the same length as the rank.
An integer array of length rank, with the lower index for each dimension.

[ubounds] An integer array of length rank, with the upper index for each dimension.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

24.5.20 ESMF_LocalArrayDestroy - Remove a LocalArray

INTERFACE:

subroutine ESMF_LocalArrayDestroy(array, rc)

ARGUMENTS:

type(ESMF_LocalArray), intent(inout) :: array
integer, intent(out), optional :: rc

DESCRIPTION:

Releases all resources associated with this ESMF_LocalArray. The arguments are:

array Destroy contents of this ESMF_LocalArray.

[rc ] Return code; equals ESMF_SUCCESS if there are no errors.

To reduce the depth of crossings of the F90/C++ boundary we first query to see if we are responsible for deleting the data space. If so, first deallocate the space and then call the C++ code to release the object space. When it returns we are done and can return to the user. Otherwise we would need to make a nested call back into F90 from C++ to do the deallocate() during the object delete.

24.5.21 ESMF_LocalArrayGetData – Get an F90 pointer to the data contents

INTERFACE:

interface ESMF_LocalArrayGetData

PRIVATE MEMBER FUNCTIONS:

! < declarations of interfaces for each T/K/R >

<This section created by macro - do not edit directly>

#ifdef ESMF_NO_INTEGER_1_BYTE
module procedure ESMF_LocalArrayGetData1DI1
module procedure ESMF_LocalArrayGetData2DI1
module procedure ESMF_LocalArrayGetData3DI1
module procedure ESMF_LocalArrayGetData4DI1
#endif

#ifdef ESMF_NO_GREATER_THAN_4D
module procedure ESMF_LocalArrayGetData5DI1
module procedure ESMF_LocalArrayGetData6DI1
module procedure ESMF_LocalArrayGetData7DI1
#endif

#ifdef ESMF_NO_INTEGER_2_BYTE
module procedure ESMF_LocalArrayGetData1DI2
#endif

269
DESCRIPTION:

This interface provides a single entry point for the various types of ESMF_LocalArrayGetData functions.

25 IOSpec Class

25.1 Description

The IOSpec in a simple class that specifies the options for an IO activity. An important choice is the IO format. Currently only netCDF is supported. Other options include whether IO should be written to a single file or multiple files, the Fortran unit number, and the filename. The IO activity can be identified as being a restart write
ESMF_IO_RESTART or a history write ESMF_IO_HISTORY, if desired.

### 25.2 Use and Examples

The IOSpec can be used in two ways. The first way an IOSpec can be used is by passing it into the creation method of a data class such as a Field or Bundle. This sets a default IOSpec for the data object. Any IO method that involves the data object will use the settings in the default IOSpec, as long as there is no other IO specification that overrides it. This brings us to the second way to use an IOSpec. This is not implemented for all data classes throughout ESMF yet; only Fields can write out data.

The second mode of usage is to pass an IOSpec into a particular IO method, such as an ESMF_FieldWrite() call. The IOSpec passed into a write or read call overrides any default settings that were set up at data object creation.

### 25.3 Restrictions and Future Work

1. **Limited support for archival formats.** The IOSpec does not support archival formats besides binary and netCDF. We anticipate adding support for HDF variants, GRIB, and BUFR in the future.

### 25.4 Class API

#### 25.4.1 ESMF_IOSpecGet - Get values in an IOSpec

**INTERFACE:**

```fortran
subroutine ESMF_IOSpecGet(iospec, filename, iofileformat, &
                          iorwtype, asyncIO, rc)
```

**PARAMETERS:**

- `type (ESMF_IOSpec), intent(in) :: iospec`
- `character(len=*), intent(out), optional :: filename`
- `type (ESMF_IOFileFormat), intent(out), optional :: iofileformat`
- `type (ESMF_IORWType), intent(out), optional :: iorwtype`
- `logical, intent(out), optional :: asyncIO`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

(insert documentation here.)

**REQUIREMENTS:**

#### 25.4.2 ESMF_IOSpecSet - Set values in an IOSpec

**INTERFACE:**

```fortran
subroutine ESMF_IOSpecSet(iospec, filename, iofileformat, &
                         iorwtype, asyncIO, rc)
```

**PARAMETERS:**

- `type (ESMF_IOSpec), intent(inout) :: iospec`
- `character(len=*), intent(in), optional :: filename`
- `type (ESMF_IOFileFormat), intent(in), optional :: iofileformat`
- `type (ESMF_IORWType), intent(in), optional :: iorwtype`
- `logical, intent(in), optional :: asyncIO`
- `integer, intent(out), optional :: rc`

---

271
DESCRIPTION:

(insert documentation here.)

!REQUIREMENTS:
26 Overview of Distributed Data Methods

Bundles, Fields, and Arrays all have versions of the following data communication methods. In these objects, data is communicated between DEs. Depending on the underlying communication mechanism, this may translate within the framework to a data copy, an MPI call, or something else. The ESMF goal of providing performance portability means the framework will in the future attempt to select the fastest communication strategy on each hardware platform transparently to the user code. (The current implementation uses MPI for communication.) Communication patterns, meaning exactly which bytes need to be copied or sent from one PET to another to perform the requested operation, can be precomputed during an initialization phase and then later executed repeatedly. There is a common object handle, an `ESMF_RouteHandle`, which identifies these stored communication patterns. Only the `ESMF_RouteHandle` and the source and destination data pointers must be supplied at runtime to minimize execution overhead.

26.1 Higher Level Functions

The following three methods are intended to map closely to needs of applications programs. They represent higher level communications and are described in more detail in the following sections. They are:

- **Halo** Update ghost-cell or halo regions at the boundaries of a local data decomposition.
- **Regrid** Transform data from one Grid to another, performing any necessary data interpolation.
- **Redist** Copy data associated with a single Grid from one decomposition to another. No data interpolation is necessary.

26.2 Lower Level Functions

The following methods correspond closely to the lower level MPI communications primitives. They are:

- **Gather** Reassembling data which is decomposed over a set of DEs into a single block of data on one DE.
- **AllGather** Reassembling data which is decomposed over a set of DEs into multiple copies of a single block of data, one copy per original DE.
- **Scatter** Spreading an undecomposed block of data on one DE over a set of DEs, decomposing that single block into smaller subsets of data, one data decomposition per DE.
- **AlltoAll** Spreading an undecomposed block of data from multiple DEs onto each of the other DEs in the set, resulting in a set of multiple decomposed data blocks per DE, one from each of the original source DEs.
- **Broadcast** Spreading an undecomposed block of data from one DE onto all other DEs, where the resulting data is still undecomposed and simply copied to all other DEs.
- **Reduction** Computing a single data value, e.g. the data maximum, minimum, sum, etc from a group of decomposed data blocks across a set of DEs, where the result is delivered to a single DE.
- **AllReduce** Computing a single data value, e.g. the data maximum, minimum, sum, etc from a group of decomposed data blocks across a set of DEs, where the result is delivered to all DEs in the set.

26.3 Common Options

ESMF will select an appropriate default for the internal communication strategy for executing the communications. However, additional control is available to the user by specifying the following route options. (For more details on exactly what changes with the various options, see Section 26.4)
26.3.1 ESMF_RouteOptions

DESCRIPTION:
Specifies control options when executing the communication represented by a Route object. Normally these do not need to be set by the user, but can be specified if the best communication strategy is known in advance. The synchronous and asynchronous options are mutually exclusive; and the other packing options are also mutually exclusive. Setting the Route options is "sticky"; it maintains the last value set until explicitly changed. Note that these options control the internal execution of a single set of communications represented by a Route object and do not affect the user level behavior at all. For example, the asynchronous option does not cause the user level entry point to return sooner; it means the route will queue all communication requests first and then go back and check for completion in an internal loop.

Valid values are:

ESMF_ROUTE_OPTION_ASYNC Use an internal asynchronous strategy to execute the Route.
ESMF_ROUTE_OPTION_SYNC Use an internal synchronous strategy to execute the Route.
ESMF_ROUTE_OPTION_PACK_PET Pack all data from or to another PET into a single buffer when sending or receiving.
ESMF_ROUTE_OPTION_PACK_XP Pack all data from each non-contiguous exchange packet into a single buffer when sending or receiving.
ESMF_ROUTE_OPTION_PACK_NOPACK Do no buffering; send each contiguous run of data as a distinct communications operation.
ESMF_ROUTE_OPTION_PACK VECTOR Use the MPI type vector interfaces to send non-contiguous data which has regular strides when sending or receiving.
ESMF_ROUTE_OPTION_PACK BUFFER When multiple data addresses are sent to the Route routines (for example, identical ESMF_Fields from an ESMF_Bundle), this flag controls whether to pack the buffers together or send them separately.
ESMF_ROUTE_OPTION_DEFAULT Use the system default for communication, which is the combination of ESMF_ROUTE_OPTION_PACK_BUFFER, ESMF_ROUTE_OPTION_PACK_PET, and ESMF_ROUTE_OPTION_SYNC.

26.4 Design and Implementation Notes

1. There is an internal ESMC_Route class which supports the distributed communication methods. There are 4 additional internal-only classes which support ESMC_Route: ESMC_AxisIndex, ESMC_XPacket, ESMC_CommTable, and ESMC_RTable; and a public ESMF_RouteHandle class which is what the user sets and gets. The implementation is in C++, with interfaces in Fortran 90.

The general communication strategy is that each DE computes its own communication information independently, in parallel, and adds entries to a per-PET route table which contains all needed sends and receives (or gets and puts) stored in terms relative to itself. (Implementation note: this code will need to be made thread-safe if multiple threads are trying to add information to the same route table.)

AxisIndex is a small helper class which contains an index minimum and maximum for each dimension and is used to describe an n-dimensional hypercube of information in index space. These are associated with logically rectangular grids and local data arrays. There are usually multiple instances of them, for example the local data chunk, and the overall global index-space grid this data is a subset of. Within each of the local or global categories, there are also multiple instances to describe the allocated space, the total area, the computational area, and the exclusive area. See Figure 22 for the definitions of each of these regions. (Implementation note: the allocated space is only partially implemented internally and has no external user API yet.)

An Exchange Packet (XPacket) describes groups of memory addresses which constitute an n-dimensional hypercube of data. Each XPacket has an offset from a base address, a contiguous run length, a stride (or number of items to skip) per dimension, and a repeat count per dimension. See Figure 16 for a diagram of how the XPacket describes memory. The actual unit size stored in an XPacket is an item count, so before using an XPacket to
address bytes of memory the item size must be known and the counts multiplied by the number of bytes per item. This allows the same XPacket to describe different data types which have the same memory layout, for example 4 byte integers and 8 byte reals/doubles. The XPacket methods include basic set/get, how to turn a list of AxisIndex objects into an XPacket, compute a local XPacket from one in global (undecomposed grid) space, and a method to compute the intersection of 2 XPackets and produce a 3rd XPacket describing that region.

The Communication Table (CommTable) class encapsulates which other PETs this PET needs to talk to, and in what order. There are create and destroy methods, methods to set that a PET has data either to send or receive, and query routines that return an answer to the question ‘which PET should I exchange data with next’.

The Route Table (RTable) class contains a list of XPackets to be sent and received from other PETs. It has create/destroy methods, methods to add XPackets to the list for each PET, and methods to retrieve the XPackets from any list.

The top level class is a Route. A Route object contains a send RTable, a recv RTable, a CommTable, and a pointer to a Virtual Machine. The VM must include all PETs which are participating in this communication. The Route methods include create/destroy, setting a send or recv XPacket for a particular PET, and some higher level functions specific to each type of communication, for example RoutePrecomputeHalo or RoutePrecomputeRedist. These latter functions are where the XPackets are actually computed and added to the Route table. Each DE computes its own set of intersections, either source or destination, and fills its own corresponding PET.
The Route methods also include a RouteRun method which executes the code which actually traverses the table and sends the information between PETs.

A RouteHandle class is a small helper class which is returned through the public API to the user when a Route is created, and passed back in through the API to select which precomputed Route is to be executed. A RouteHandle contains a handle type and a pointer to a Route object. In addition, for use only by the Regrid code, there is an additional Route pointer and a TransformValues pointer. (TransformValues is an internal class only used by the Regridding code.) If the RouteHandle describes the Route for a Bundle, then the RouteHandle can contain a list of Routes, one for each Field in the Bundle, and for Regrid use, a list of additional Routes instead of a single Route. There is also a flag to indicate whether a single Route is applicable to all Fields in a Bundle or whether there are multiple Routes. The RouteHandle methods are fairly basic; mostly accessor methods for getting and setting values.

2. While intended for any distributed data communication method, the current implementation only builds a Route object for the halo, redist, and regrid methods. Scatter, Gather, AllGather, and AlltoAll should have the option of building a Route for operations which are executed repeatedly. This should only require writing a Precompute method for each one; the existing RouteRun can be invoked for these operations. (This is a lack-of-implementation-time issue, not a design or architecture issue.)

3. The original design included automatic detection of different Routes and internal caching, so the user API did not have to include a RouteHandle object to identify which Route was being invoked. However, users requested that the framework not cache and that explicit RouteHandle arguments be created and required to invoke the distributed data methods. Nothing prevents this code from being revived from the CVS repository and reinstated in the system, should automatic caching be desired by future users.

4. The current distributed methods have 2 related but distinct interfaces which differ in what information they require and whether they use RouteHandles:

Precompute/Run/Release This is the most frequently used interface set. It contains 3 distinct phases: precomputing which bytes must be moved, actually executing the communications operation, and releasing the stored information. This is intended for any communication pattern which will be executed more than once.

All-in-One For a communication which will only be executed once, or in any situation in which the user does not want to save a RouteHandle, there are interfaces which do not have RouteHandles as part of the argument list. Internally the code computes a Route, executes it, and releases the resources before returning.

5. The current CommTable code executes one very specific communication strategy based on input from a user who did extensive timing measurements on several different hardware platforms. Rather than broadcasting all data at once asynchronously, it selects combinations of pairs of processors and has them execute a SendRecv operation, which does both a data send and a data receive in a single call. At each step in the execution, different pairs of processors exchange data until all pair combinations have been selected.

The table itself must be a power of 2 in size; the number of PETs is rounded up to the next power of 2 and then all entries for PETs larger than the actual number are marked as no-ops.

There are many alternative execution strategies, including a completely asynchronous execution, in numeric PET order, without computing processor pairs. Also single-direction communications are possible (only the Send XPackets are processed, or only the Receive XPackets) in either a synchronous or asynchronous mode. This would not require any changes to the XPacket or RTable classes, but would require writing a set of alternative RouteRun methods.

6. The current RouteRun routine has many possible performance options for how to make the tradeoff between time spent packing disjoint memory blocks into a single buffer to minimize the number of sends, verses simply sending the contiguous blocks without the pack overhead. The tradeoffs are not expected to be the same on all systems; hardware latency verses bandwidth characteristics will differ, plus the underlying communication software (MPI, shared memory, etc) will change the performance. Also the size of the data blocks to be sent, the amount of contiguity, and limits on the number of outstanding communication buffers all affect what options are best.
The ESMF_RouteOptions are listed in 26.3; the following description contains more implementation detail about what each of the options controls inside the execution of a Route. Note that the options do not affect the creation of a Route, nor any of the Precompute code, and can optionally be changed each time the Route is run.

Packing options:

By Buffer  If multiple memory addresses are provided to RouteRun (from bundle-level communications, for example), then this option packs data across all buffers/blocks as specified by the other packing flags before sending or receiving. Note: unlike the other packing flags, this is handled in the code at a higher level by either passing down multiple addresses into the route run routine or not. If multiple addresses are passed into the run routine, they will be packed. The “no-packing” option at this level would be identical to looping at the outermost level in the RouteRun code and therefore there is no disadvantage to calling this routine once per address (and the advantage is not adding yet another coding loop inside the already complex RouteRun code). The higher level list-of-address code can be disabled by clearing this flag (which is on by default).

By PET  All data from a single block intended for a remote PET is packed into a single send buffer, and sent in a single VM communications call. A buffer large enough to receive all data coming from that remote PET is allocated, the data is received, and then the data is copied into the final location. See 21.

By XP  All data described by a single XPacket (which is an n-dimensional hyperslab of memory) is packed into a single buffer for sending, and a single buffer large enough to receive an XPacket is allocated for receiving the data. See 20.

No Packing  A VM communication call is made for each single contiguous strip of memory, regardless of how long or short.

MPI Vector  MPI implements a set of interfaces for sending and receiving which allows certain strided memory patterns to be sent in a single call. The actual implementation is up to the MPI library itself. But no user-level data copy is needed in this case. (Not implemented yet.)

Note that in all packing options, if the XPacket describes a chunk of memory which is completely contiguous, then the code does not allocate a packing or unpacking buffer but supplies the actual data address to the communications call so the data is read or written in place.

The following options refer to the internal strategy for executing the route and not to whether the user-level API call returns before the route has finished executing. The current system only implements user-synchronous calls; asynchronous calls are on the to-be-written list.

Sync  Each pair of processors exchanges data with the VM equivalent of an MPI_SendRecv() call, which does not return until both the send and receive have completed.

Async  Each processor executes both an asynchronous send and asynchronous receive to the other processor and does not wait for completion before moving on to the next communication in the CommTable. Then in a separate loop through the RTables, each call is waited for in turn and when all outstanding communication calls have completed, then the API call returns to the user.

(Note that in the Async case it makes much more sense to iterate throught the Route table in PET order instead of the complication of computing communication pairs and iterating in a non-sequential order. The code is as it is now for reasons of implementation speed and not for any other design reason. This would require a slightly simpler, but separate, version of the RouteRun() subroutine.)
Figure 17: A common XPacket pattern which generally benefits from packing; the overlap region between 2 DEs during a halo update are often short in the contiguous dimension and have a high repeat count.
Figure 18: When there are multiple XPackets destined for the same remote PET there are more options for how to order the contiguous pieces into a packed buffer.
Figure 19: When the XPacket describes memory which is physically a single contiguous region, there is no need to copy the data into another buffer; it can be communicated in place. There is a flag in the XPacket which marks how many of the dimensions are contiguous.
Figure 20: Often the overhead of making multiple communication calls outweighs the cost of copying non-contiguous data into a contiguous buffer, sending it in a single operation, and then copying it to the final memory locations on the receiving side.
Figure 21: Once there is more than a single XPacket to pack, there are many more interleave options. For example, packing in the order: 1, 4, 2, 5, 3, 6 would also be possible here. However the code becomes more complicated when the X_packets have different repeat counts, and has no real performance advantage over the straightforward packing of each XPacket in sequence. Note that this packing is the same whether it refers to multiple X_packets from the same memory buffer or from multiple buffers.
7. Bundle-level communication calls have additional packing options under certain circumstances. Bundles are groups of Fields which share the same Grid, but they are not required to share the same data types, data ranks, nor relative data locations. Bundles in which these things are the same in all Fields are marked inside the bundle code as being congruent. At communication store time Bundles which have congruent data in all the Fields have the option of packing all Field data together into fewer communication calls which generally is expected to give better performance. Fields where the data is not of the same type or perhaps not the same number of items (e.g. different rank, vertex-centered data vs. cell centered data) can in theory also be packed but in fact the code becomes more complicated, and in the case of differing data types may cause system errors because of accessing data on non-standard byte offsets or putting mixing integer data with floating data and causing NaN (not a number) exceptions. In this case, the conservative implementation strategy is to construct a separate Route object for each Field, all enclosed in the same RouteHandle. Inside the Bundle communication code the execution for both types of Bundles is identical for the caller, but inside the congruent Bundle code calls the ESMF_RouteRun() code once and all communication for all Fields in the Bundle is done when it returns. The non-congruent Bundles execute a separate ESMF_RouteRun() call for each Field and return to the user when all Field data have been sent/received.

There are comments in the code for an intermediate level of optimization in which the Bundle code determines the smallest number of unique types of Fields in the Bundle, and all same types share the same Route object, but this has not been implemented at this time. Once the existing code has been in use for a while, whether this is useful or needed may become more clear.

8. The precompute code for all operations must have enough information to compute which parts of the data arrays are expected to be sent to remote PETs and also what remote data is expected to be received by this PET.

These computations depend heavily on what type of distributed method is being executed. The regridding methods are described in detail separately in the Regrid Design and Implementation Notes section. The halo and redistribution operations are described here.

**Halo** The total array area, which includes any halo regions, are intersected with the computational area of other DEs. The overlap regions are converted from index space into memory space and stored as XPackets in the RTables. This code must be aware of: whether the grid was defined as periodic in any or all of the dimensions since that affects which halo regions overlap at the grid edges; if the data is only decomposed into a single block in any dimension (which means it halos with itself); and if the halo region is large enough that a halo operation may require intersection with the N+1 neighbor in any dimension.

**Redistribute** Each DE computes the overlap between its own computational region and all DEs in the remote Grid, again only working in computational area. The overlap regions are converted from index space into memory space and stored as XPackets in the RTables. After execution a redistribution, a halo operation may be required to populate any halo regions with consistent data.

(Note: the Redistribution code has been reimplemented to intersect the DEs in index space and then convert the overlap region to an XPacket representation. Halo still converts the regions from AxisIndex to XPackets and then intersects the XPackets, but this code needs to be changed to intersect in AxisIndex space and once the overlap is computed then convert to XPackets. Intersecting AxisIndex objects is very much simpler, both to understand and to execute, and more easily extensible to multiple dimensions than intersecting XPackets.)

### 26.5 Object Model

The following is a simplified UML diagram showing the structure of the public RouteHandle class. See Appendix A, *A Brief Introduction to UML*, for a translation table that lists the symbols in the diagram and their meaning.
27 Halo Method

27.1 Description

Halo operations update ghost cell or halo regions at the boundaries of a local data decomposition. Halo regions are to be considered read-only by the local process; their data values can be used to compute the new values for cells which are local to this process, but they cannot be updated except by a halo operation. Haloing is supported at the Array and Field level. The description of halo regions that follows is phrased in terms of Arrays, but also holds for Fields (which contain Arrays).

27.2 Halo Domains

Array objects can have an optional \textit{halo width} which defines what part of the Array is the \textit{exclusive domain}, the \textit{computational domain}, and the \textit{total domain}. With no halo region, all these are the same and equal to the total size of the Array. The domains are defined as follows.

- \textbf{Exclusive} The exclusive domain is the subset of the Array which is never read by any other DE.
- \textbf{Computational} The computational domain is the subset of the Array which is read and written by the current DE.
- \textbf{Total} The total domain includes the region where data is updated from another DE during a halo operation and read but not updated by the current DE.

Figure 22 illustrates these concepts.

Halo domain information must be stored at the Array level to support operations such as the gather, which collects decomposed parts of a logically contiguous object onto a single DE. Only the computational domain is copied since the halo regions are duplicated data. The exclusive domain is guaranteed to never be the source of data for a halo operation, so no synchronization of updates to those data items needs to be done. The total domain is the actual memory size allocated for the Array, and is used when computing offsets for subdomains within the Array.

28 Regrid Method

28.1 Description

Bundle, Field, and Array classes all have regrid methods that transform their data from one ESMF\_Grid to another. Regrid operations compute addresses and interpolation weights for remapping between different grids. All the information necessary to perform a regridding, including ESMF\_Routes to collect non-local data and the addresses and weights, are contained in the ESMF\_RouteHandle which is returned to the user. Since interpolation weights are based solely on the grids’ geometries and addresses are stored as offsets, regrids can be shared by data classes providing they have the same ESMF\_Rellocs. Some of the algorithms and implementation in ESMF’s regridding routines are adapted from a software package called SCRIP that was developed at the Los Alamos National Laboratory by Phil Jones. However, SCRIP is a serial code and the ESMF regridding routines have been parallelized.

28.2 Regrid Options

28.2.1 ESMF\_RegridMethod

DESCRIPTION:
General Regrid methods supported by ESMF.

Valid values are:

- \textbf{ESMF\_REGRID\_METHOD\_BILINEAR} Bilinear regridding using a local bilinear approximation to interpolate to a point in a quadrilateral grid. For more details, please see Section 28.5.1

NOTE: This is applicable only for logically-rectangular or block-structured logically-rectangular grids.
This example shows a grid with a length of 12 cells along the x-axis and a length of 12 cells along the y-axis. The grid is decomposed over a DELayout that has a length of 3 DEs along the x-axis and 3 DEs along the y-axis. We will look at how halo domains are defined for the data assigned to the central DE. The indices shown in red are global grid indices in the form (x,y).

We will assume that the data on each DE depends on a nearest neighbor in each direction (N,S,E,W). In order to perform computations efficiently, we would like this data on the local DE. To do this we specify a halo width of 1 cell in all directions for the data on each DE at Array or Field creation. Extra memory is allocated to hold the replicated grid cells.

The diagram directly left shows index values for the data on the central DE. The global grid indices are shown in red. Axis indices, which correspond to the memory allocated on the DE, are shown in blue. The exclusive domain is the inner black square; it contains grid cells that are not replicated on any other DEs. The black square outlined darkly in black is the computational domain; it contains all of the grid cells that have unique global grid indices and are updated by the local DE. The total domain is the entire extent of the memory allocated on the local DE.
ESMF_REGRID_METHOD_CONSERV1  First-order conservative remapping. For algorithm details, please see Section 28.5.3.

ESMF_REGRID_METHOD_LINEAR  This is a standard linear regridding algorithm for 1-d grids only. In ESMF, it is used to regrid between vertical grids.

ESMF_REGRID_METHOD_NONE  No regridding or undefined regrid.

28.2.2 ESMF_RegridNormOpt

DESCRIPTION:
Regrid normalization options supported by ESMF, for conservative regridding only.
Valid values are:

ESMF_REGRID_NORM_DSTAREA  The Regrid weights are normalized by the destination area of each cell.

ESMF_REGRID_NORM_FRACAREA  The Regrid weights are normalized by the area of the source grid overlapped by each cell (default).

ESMF_REGRID_NORM_NONE  No normalization applied to Regrid weights.

ESMF_REGRID_NORM_UNKNOWN  Unknown or undefined normalization.

28.3 Use and Examples

Regrid is designed to be called with Field or Bundle arguments in order to utilize information embedded in these objects. For example, Regrid requires knowledge of underlying grid information (both PhysGrid and DistGrid) and of the relative location (staggering) of Fields on the Grid. In addition, Regrid uses any mask information that may be associated with a Field. However, ESMF also provides an Array interface for users who have gathered all necessary information.

Regrid is separated into RegridStore functions, a Regrid function, and a RegridRelease function. The Store functions compute interpolation weights and initialize communication requirements for performing a regridding of a Field from one Grid to another, returning an object called an ESMF_RouteHandle. The Regrid function uses the created RouteHandle object to perform the actual regridding of Fields or Bundles. The Release function deletes the RouteHandle object and frees all memory associated with a Regrid. The reason for the separation is that in many cases, the initial creation is expensive and re-used often throughout an application. The Regrid and RegridRelease functions are also common to all the Regrid methods.

Because many methods are supported for regridding, the main Store function branches to a specific creation function based on the regrid method requested (e.g. bilinear, conservative, spectral). Each of these regrid methods are in a separate module to prevent the main Regrid module from becoming too large. The user is unaware of this hierarchy as the top-level module provides a unified API.

In general, Regrid interfaces are relatively simple and require little information directly from users. Besides prescribing the actual Regrid method, they offer users few options, as shown in the example in Section 28.5.5. However, the simplicity of the interfaces belies the complicated nature of the underlying code. ESMF endeavors to hide as much of this complication from its users as possible. However, Regrid does have current limitations that require user awareness to successfully use its routines. These issues are discussed below.

28.3.1 Regrid and Grid Overlap

Regrid assumes both the source and destination Grids share the same coordinate system and units. Although 3D regridding is not yet available, this rule is also expected to be valid for vertical grids as well. At this point, the ESMF definition of a common coordinate system includes the extents used to define a domain. For example, Regrid routines do not understand that latitudes from -180 to +180 degrees and latitudes from 0 to 360 degrees are describing the same domain with a different range. Currently, users are responsible for any necessary conversion or translation.

There are five possible physical overlap situations between the source and destination Grids, illustrated in Figure 23.
Regrid can provide complete interpolation weights for the destination Field only for those situations where there is source data covering the entire physical domain of the destination Grid (cases (b) and (e) above). In all the other cases, there are parts of the destination Grid for which there is no source. When source data is not available, Regrid routines will not extrapolate data values and the destination Field may contain data points that have not been calculated or filled. Currently, regrid routines initialize the destination Field to a value of zero prior to regridding, so unfilled destination data points will have that value. In the future, regrid routines will have an optional argument allowing users to specify a fill value besides zero.

28.3.2 Regrid and Data Location

There is no restriction in Regrid that the source and destination Fields define their data in the same relative location (RelLoc). However, regridding between Fields with different RelLocs can have unintended consequences if the related Grids cover exactly the same physical domain. The RelLocs represent different subGrids, which can shift the represented physical domain by plus or minus one-half of a cell width. This is illustrated below in Figure 24 which shows the physical areas described by two sample RelLocs and the effect on the overlap of the global Grids. In this situation, there may be some unfilled or less accurate Field data at some of the Grid boundaries.

28.3.3 Regrid and Grid Refinement

Different refinement or cell sizes (also called resolution) between the source and destination Grids may have a similar effect on regridding as does different data locations. This can be true even if the source and destination Fields have the same RelLoc, as illustrated in Figure 24. In this diagram, the areas of the two grids represented by the corresponding Fields do not overlap exactly despite sharing identical physical extents and relative data locations. Again, this situation may cause some inaccuracy in the regridded Field data at the Grid boundaries.
Figure 24: Illustration of Grid areas represented by differing RelLocs.

Note that even though the two Grids have exactly the same physical extent and relative location, the represented areas are different and may lead to Regrid inconsistencies along the Grid boundaries.

Figure 25: Illustration of areas represented by the same RelLoc on Grids with different refinement.
28.3.4 Regrid and Periodicity

Some of the Regrid issues raised in the previous sections concerning the effect of data locations and Grid refinement are negated by the integration of periodic boundary conditions into Regrid routines. As illustrated in Figure 26, areas represented by Field data that would otherwise extend beyond the nominal Grid boundaries are mapped or "wrapped" back onto the Grid at the corresponding periodic boundary. This effectively ensures complete overlap for Grids that share identical physical extents.

Unfortunately, the Regrid routines in ESMF do not currently include periodic boundary effects, so users must be aware of possible problems.

28.3.5 Regrid Examples: Precomputing and Executing a Regrid

The following code fragments show an example of the steps involved in computing and applying a Regrid.

```fortran
! !PROGRAM: ESMF_RegridEx - Using the Regridding methods
! !DESCRIPTION:
! ! This program shows examples of using Regrid on Field data
!------------------------------------------------------------------------------
! ESMF Framework module
```

Figure 26: Illustration of Regrid Overlap issues solved by the implementation of periodic boundary conditions.
use ESMF_Mod

implicit none

! Local variables to be used in the Regrid method calls.
! The code creating and filling these variables is not included in the
! example documentation because those interfaces are not specific to
! Regrid.
type(ESMF_Field) :: field1, field2
type(ESMF_Grid) :: srcgrid, dstgrid
type(ESMF_RouteHandle) :: regrid_rh
type(ESMF_DELayout) :: layout1, layout2
integer :: rc

The user has already created an ESMF_Grid, an ESMF_Array with data, and put them together in an ESMF_Field. An ESMF_RouteHandle is created by the regrid store call and the data movement needed to execute the regrid is stored with that handle by the store method. To actually execute the operation, the source and destination data objects must be supplied, along with the same ESMF_RouteHandle.

call ESMF_FieldRegridStore(field1, field2, vm, &
   routehandle=regrid_rh, &
   regridmethod=ESMF_REGRID_METHOD_BILINEAR, rc=rc)

call ESMF_FieldRegrid(field1, field2, regrid_rh, rc=rc)

call ESMF_FieldRegridRelease(regrid_rh, rc=rc)

28.4 Restrictions and Future Work
1. Support is limited to 1D and 2D regridding. Regridding support is limited to two dimensions.

2. Masks are not implemented. Regridding methods take masks in their argument lists, but they currently are not used or applied.

3. Regridding only fills computational domains. Currently, regridded values are not automatically applied to halo or ghost domains. Users must manually call Halo after regridding in order to do so. This also means that Grid periodicity will not affect regridding results without manual Halo calls.

4. Special pole treatment is not implemented. Conservative regridding methods do not yet have the special pole treatment completed. Please see the conservative regrid algorithm description (Section 28.5.3) for further details.

5. Interpolation weights are not available to users. Currently, there is no method to allow users access to the interpolation weights for any desired manipulations.

6. Spherical coordinates are not shifted. Regrid methods do not yet shift longitude coordinates (or their equivalent) from the source Grid to place them on the same 360 degree (or 2*pi) range as the destination Grid. For Grids that cover the entire sphere and assume a periodic longitude boundary, this may produce errors along the Grid edges even though they share the same 360 degree range.

7. Future regrid methods. The following methods will be added:

   ESMF_REGRID_METHOD_ADJOINT Create adjoint of existing regrid
Regrid has been designed to be as efficient as possible during its Run routine. Although the initial calculation during the Store routines can be computationally intensive, the ESMF_RouteHandle object it creates is designed to be reused by similar Fields on the same Grids. And, as long as the Grids are static, RegridStore can be called once and reused throughout a simulation. It leverages internal structures and methods used throughout ESMF for communication so that algorithmic and programming improvements can be focused on a single location. Because many methods are supported for regridding, the main Store function branches to a specific creation function based on the regrid method requested (e.g. bilinear, conservative, spectral). Each of these regrid methods are in a separate module to prevent the main Regrid module from becoming too large. The user is unaware of this hierarchy as the top-level module provides a unified API.

The RouteHandle object created by the RegridStore function contains a set of "links" which identify how a Field at a point on the destination Grid is related to a Field at a point on the source Grid. As such, a "link" consists of a source address, a destination address and a weight. The addresses are stored as indices to allow reuse by different Fields on the same Grids. Because the Grids are generally distributed very differently, the Regrid object also contains communication information for data motion required for the regridding.

Our early application codes use static computational meshes, so initial optimization efforts have been focused on making the Regrid run routines fast, at the expense of the Store routines if necessary. Therefore, Regrid has been designed to move as much work as possible to the calculation of weights that takes place inside Store. In initial timings, typical RegridStore calls take on the order of seconds while the application routines themselves require more on the order of milliseconds. Scaling on parallel architectures is reasonably good up until communication overhead dominates timings (see Figure 27 for scaling curves from an example application).

### Bilinear Regridding Algorithm

The bilinear regridding method uses a local bilinear approximation to interpolate to a point in a quadrilateral grid. This is applicable only for logically-rectangular or block-structured logically-rectangular grids. Standard bilinear interpolation schemes can be found in many textbooks. Here we present a more general scheme which uses a local bilinear approximation to interpolate to a point in a quadrilateral grid. Consider the grid points shown in Figure 28 labelled with logically-rectangular indices (e.g. \((i, j)\)).

Let the latitude-longitude coordinates of point 1 be \((\theta(i, j), \phi(i, j))\), the coordinates of point 2 be \((\theta(i + 1, j), \phi(i + 1, j))\), etc. Now let \(\alpha\) and \(\beta\) be continuous local coordinates such that the coordinates \((\alpha, \beta)\) of point 1 are \((0, 0)\), point 2 are \((1, 0)\), point 3 are \((1, 1)\) and point 4 are \((0, 1)\). If point \(P\) lies inside the cell formed by the four points above, the function \(f\) at point \(P\) can be approximated by

\[
 f_P = (1 - \alpha)(1 - \beta)f(i, j) + \alpha(1 - \beta)f(i + 1, j) + \\
 \alpha\beta f(i + 1, j + 1) + (1 - \alpha)\beta f(i, j + 1)
\]

The remapping weights must therefore be computed by finding \(\alpha\) and \(\beta\) at point \(P\).
These sample results are for regridding from a 720x360 source grid to a 1080x540 destination grid using bilinear interpolation. The different decomposition descriptions refer first to the source grid decomposition and second to the destination grid.

Timings by Peggy Li on NCAR’s IBM system bluesky, December 2004.

Figure 27: Sample scaling graphs for Regrid Run and Store routines.
The latitude-longitude coordinates \((\theta, \phi)\) of point \(P\) are known and can also be approximated by

\[
\begin{align*}
\theta & = (1 - \alpha)(1 - \beta)\theta_1 + \alpha(1 - \beta)\theta_2 + \alpha\beta\theta_3 + (1 - \alpha)\beta\theta_4 \\
\phi & = (1 - \alpha)(1 - \beta)\phi_1 + \alpha(1 - \beta)\phi_2 + \alpha\beta\phi_3 + (1 - \alpha)\beta\phi_4. 
\end{align*}
\]

(2)

Because (2) is nonlinear in \(\alpha\) and \(\beta\), we must linearize and iterate toward a solution. Differentiating (2) results in

\[
\begin{bmatrix}
\delta \theta \\
\delta \phi
\end{bmatrix} = A
\begin{bmatrix}
\delta \alpha \\
\delta \beta
\end{bmatrix},
\]

(3)

where

\[
A = \begin{bmatrix}
(\theta_2 - \theta_1) + (\theta_1 - \theta_4 + \theta_3 - \theta_2)\beta & (\theta_4 - \theta_1) + (\theta_1 - \theta_4 + \theta_3 - \theta_2)\alpha \\
(\phi_2 - \phi_1) + (\phi_1 - \phi_4 + \phi_3 - \phi_2)\beta & (\phi_4 - \phi_1) + (\phi_1 - \phi_4 + \phi_3 - \phi_2)\alpha
\end{bmatrix}.
\]

(4)

Inverting this system,

\[
\delta \alpha = \begin{bmatrix}
\delta \theta \\
\delta \phi
\end{bmatrix} \begin{bmatrix}
(\theta_4 - \theta_1) + (\theta_1 - \theta_4 + \theta_3 - \theta_2)\alpha \\
(\phi_4 - \phi_1) + (\phi_1 - \phi_4 + \phi_3 - \phi_2)\alpha
\end{bmatrix} \div \det(A),
\]

(5)

and

\[
\delta \beta = \begin{bmatrix}
\delta \theta \\
\delta \phi
\end{bmatrix} \begin{bmatrix}
(\theta_2 - \theta_1) + (\theta_1 - \theta_4 + \theta_3 - \theta_2)\beta \\
(\phi_2 - \phi_1) + (\phi_1 - \phi_4 + \phi_3 - \phi_2)\beta
\end{bmatrix} \div \det(A).
\]

(6)

Starting with an initial guess for \(\alpha\) and \(\beta\) (say \(\alpha = \beta = 0\)), equations (5) and (6) can be iterated until \(\delta \alpha\) and \(\delta \beta\) are suitably small. The weights can then be computed from (1). Note that for simple latitude-longitude grids, this iteration will converge in the first iteration.
In order to compute the weights using this general bilinear iteration, it must be determined in which box the point \( P \) resides. Because this method is valid only for logically-rectangular grids, the sweep algorithm can be optimized to take advantage of this restriction. The sweep method currently in ESMF steps through each data point \( P \) on the destination grid. For each destination point, it then loops through the cells on the source grid, comparing the coordinates of point \( P \) with the bounding box formed by each cell’s minimum and maximum coordinates. Most source cells can be efficiently eliminated from the sweep via this simple test. This loop is further optimized by tracking the index of the source cell containing the previous point and using that as the initial starting index for the next point’s sweep, since both grids are logically ordered. Please see Figure 29 for an illustration of the sweep algorithm.

28.5.2 Bicubic Regridding Algorithm
Not yet implemented!
Like the bilinear remapping, bicubic remapping is applicable only for logically-rectangular or block-structured logically-rectangular grids. The bicubic remapping exactly follows the bilinear remapping except that four weights for each
corner point are required. Thus, num_wts is set to four for this option. The bicubic remapping is

\[
f_P = (1 - \beta^2(3 - 2\alpha))f(i, j) + \\
(1 - \beta^2(3 - 2\alpha))\alpha^2(3 - 2\alpha)f(i + 1, j) + \\
\beta^2(3 - 2\beta)\alpha^2(3 - 2\alpha)f(i + 1, j + 1) + \\
\beta^2(3 - 2\beta)(1 - \alpha^2(3 - 2\alpha))f(i, j + 1) + \\
(1 - \beta^2(3 - 2\beta))\alpha(\alpha - 1)^2\frac{\partial f}{\partial i}(i, j) + \\
(1 - \beta^2(3 - 2\beta))\alpha^2(\alpha - 1)\frac{\partial f}{\partial i}(i + 1, j) + \\
\beta^2(3 - 2\beta)\alpha^2(\alpha - 1)\frac{\partial f}{\partial i}(i + 1, j + 1) + \\
\beta^2(3 - 2\beta)\alpha(\alpha - 1)^2\frac{\partial f}{\partial j}(i, j) + \\
\beta(\beta - 1)^2(1 - \alpha^2(3 - 2\alpha))\frac{\partial f}{\partial j}(i, j) + \\
\beta(\beta - 1)^2\alpha^2(3 - 2\alpha)\frac{\partial f}{\partial j}(i + 1, j) + \\
\beta^2(\beta - 1)\alpha^2(3 - 2\alpha)\frac{\partial f}{\partial j}(i + 1, j + 1) + \\
\beta^2(\beta - 1)(1 - \alpha^2(3 - 2\alpha))\frac{\partial f}{\partial j}(i, j + 1) + \\
\alpha(\alpha - 1)^2\beta(\beta - 1)^2\frac{\partial^2 f}{\partial i \partial j}(i, j) + \\
\alpha^2(\alpha - 1)\beta(\beta - 1)^2\frac{\partial^2 f}{\partial i \partial j}(i + 1, j) + \\
\alpha^2(\alpha - 1)\beta^2(\beta - 1)\frac{\partial^2 f}{\partial i \partial j}(i + 1, j + 1) + \\
\alpha(\alpha - 1)^2\beta^2(\beta - 1)\frac{\partial^2 f}{\partial i \partial j}(i, j + 1)
\]

where \(\alpha\) and \(\beta\) are identical to those found in the bilinear case and are found using an identical algorithm. Note that unlike the conservative remappings, the gradients here are gradients with respect to the logical variable and not latitude or longitude. Lastly, the four weights corresponding to each address pair correspond to the weight multiplying the field value at the point, the weight multiplying the gradient with respect to \(i\), the weight multiplying the gradient with respect to \(j\), and the weight multiplying the cross gradient in that order.

28.5.3 Conservative Regridding Algorithms

First-order and second-order conservative remapping share a common algorithm, though currently only first-order has been implemented. ESMF implements a conservative remapping scheme described in detail elsewhere \[6\]. A brief outline will be given here to aid the user in understanding this regridding algorithm.

To compute a flux on a new (destination) grid which results in the same energy or water exchange as a flux \(f\) on an old (source) grid, the destination flux \(F\) at a destination grid cell \(k\) must satisfy

\[
F_k = \frac{1}{A_k} \int \int_{A_k} f dA,
\]

where \(F\) is the area-averaged flux and \(A_k\) is the area of cell \(k\). Because the integral in \(8\) is over the area of the destination grid cell, only those cells on the source grid that are covered at least partly by the destination grid cell
contribute to the value of the flux on the destination grid. If cell \( k \) overlaps \( N \) cells on the source grid, the remapping can be written as

\[
F_k = \frac{1}{A_k} \sum_{n=1}^{N} \int \int_{A_n} f_n dA,
\]

(9)

where \( A_{nk} \) is the area of the source grid cell \( n \) covered by the destination grid cell \( k \), and \( f_n \) is the local value of the flux in the source grid cell (see Figure 30). Note that (9) is normalized by the destination area \( A_k \) corresponding to the \( \text{ESMF}_\text{RegridNormOpt} \) value of \( \text{ESMF}_\text{REGRID}_\text{NORM}_\text{DSTAREA} \). The sum of the weights for a destination cell \( k \) in this case would be between 0 and 1 and would be the area fraction if \( f_n \) were identically 1 everywhere on the source grid. The normalization option \( \text{ESMF}_\text{REGRID}_\text{NORM}_\text{FRACAREA} \) would actually divide by the area of the source grid overlapped by cell \( k \):

\[
\sum_{n=1}^{N} \int \int_{A_n} dA.
\]

(10)

For this normalization option, remapping a function \( f \) which is 1 everywhere on the source grid would result in a function \( F \) that is exactly one wherever the destination grid overlaps a non-masked source grid cell and zero otherwise. A normalization option of \( \text{ESMF}_\text{REGRID}_\text{NORM}_\text{NONE} \) would result in the actual angular area participating in the remapping.

Assuming \( f_n \) is constant across a source grid cell, (9) would lead to the first-order area-weighted schemes used in current coupled models. A more accurate form of the remapping is obtained by using

\[
f_n = \bar{f}_n + \nabla_n f \cdot (\vec{r} - \vec{r}_n),
\]

(11)

where \( \nabla_n f \) is the gradient of the flux in cell \( n \) and \( \vec{r}_n \) is the centroid of cell \( n \) defined by

\[
\vec{r}_n = \frac{1}{A_n} \int \int_{A_n} \vec{r} dA.
\]

(12)

Such a distribution satisfies the conservation constraint and is equivalent to the first terms of a Taylor series expansion of \( f \) around \( \vec{r}_n \). The remapping is thus second-order accurate if \( \nabla_n f \) is at least a first-order approximation to the gradient.

The remapping can now be expanded in spherical coordinates as

\[
F_k = \sum_{n=1}^{N} \left[ \bar{f}_n w_{1nk} + \left( \frac{\partial f}{\partial \theta} \right)_n w_{2nk} + \left( \frac{1}{\cos \theta} \frac{\partial f}{\partial \phi} \right)_n w_{3nk} \right],
\]

(13)

where \( \theta \) is latitude, \( \phi \) is longitude and the three remapping weights are

\[
w_{1nk} = \frac{1}{A_k} \int \int_{A_n} dA,
\]

(14)

\[
w_{2nk} = \frac{1}{A_k} \int \int_{A_n} (\theta - \theta_n) dA = \frac{1}{A_k} \int \int_{A_n} \theta dA - \frac{w_{1nk}}{A_n} \int \int_{A_n} \theta dA,
\]

(15)

and

\[
w_{3nk} = \frac{1}{A_k} \int \int_{A_n} \cos \theta (\phi - \phi_n) dA = \frac{1}{A_k} \int \int_{A_n} \phi \cos \theta dA - \frac{w_{1nk}}{A_n} \int \int_{A_n} \phi \cos \theta dA.
\]

(16)
Figure 30: An example of a triangular destination grid cell $k$ overlapping a quadrilateral source grid. The region $A_{kn}$ is where cell $k$ overlaps the quadrilateral cell $n$. Vectors used by search and intersection routines are also labelled.

Again, if the gradient is zero, (13) reduces to a first-order area-weighted remapping.

The area integrals in equations (14)–(16) are computed by converting the area integrals into line integrals using the divergence theorem. Computing line integrals around the overlap regions is much simpler; one simply integrates first around every grid cell on the source grid, keeping track of intersections with destination grid lines, and then one integrates around every grid cell on the destination grid in a similar manner. After the sweep of each grid, all overlap regions have been integrated.

Choosing appropriate functions for the divergence, the integrals in equations (14)–(16) become

$$\int \int_{A_{nk}} \theta dA = \oint_{C_{nk}} [-\cos \theta - \theta \sin \theta] d\phi, \quad (17)$$

$$\int \int_{A_{nk}} \phi \cos \theta dA = \oint_{C_{nk}} -\frac{\phi}{2} [\sin \theta \cos \theta + \theta] d\phi, \quad (18)$$

where $C_{nk}$ is the counterclockwise path around the region $A_{nk}$. Computing these three line integrals during the sweeps of each grid provides all the information necessary for computing the remapping weights.

As described above, the algorithm for computing the remapping weights is relatively simple. The process amounts to finding the location of the endpoint of a segment and then finding the next intersection with the other grid. The line integrals are then computed and summed according to which grid cells are associated with that particular subsegment. The most time-consuming portion of the algorithm is finding which cell on one grid contains an endpoint from the other grid. This process consists of sweeping through lists of cells from the other grid, hunting for intersections with an identified subsegment. Much of the potential for optimization of regridding algorithms comes from limiting the range of cells to sweep. Optimal methods can be more easily written when the grid is well structured and regular. However,
For each bin, the corresponding minimum and maximum Grid indices are determined and stored along with the minimum and maximum physical coordinates. The sweep looking for intersections with this line segment would use the minimum and maximum Grid indices of the corresponding bin.

Figure 31: Illustration of the Conservative Sweep Algorithm.

for a general grid, a hierarchy of methods appears to work best. In the ESMF implementation, two algorithms are used to restrict the range of cells that are swept. First, prior to looping through the cells on either grid, coordinate bins are created from the other grid. In this process, the local physical domain of the grid being swept is divided into logical blocks, each one represented by a bin. The cells of the grid being swept are looped through to determine the minimum and maximum grid indices corresponding to each bin’s range of physical coordinates. Each bin therefore identifies an index range corresponding to a physical coordinate range. Then when the sweep begins, only those cells in the index range belonging to the same coordinate bin as the identified subsegment are used. Please reference Figure 31 for an illustration of binning and the sweep algorithm.

Note that currently ESMF creates bins based only on coordinates in the second grid direction (typically "y" or "latitude"). The second stage checks the bounding box of each grid cell in the determined bin. The bounding box is formed by the cell’s minimum and maximum coordinates. This process further restricts the actual sweep to a small number of cells.

Once the sweep has been restricted, a robust algorithm that works for most cases is a cross-product test. In this test, a cross product is computed between the vector corresponding to a cell side ($\vec{r}_{12}$ in Figure 30) and a vector extending from the beginning of the cell side to the search point ($\vec{r}_{1b}$). If

$$\vec{r}_{12} \times \vec{r}_{1b} > 0,$$  \hspace{1cm} (20)

the point lies to the left of the cell side. If (20) holds for every cell side, the point is enclosed by the cell. This test is not completely robust and will fail for grid cells that are non-convex.
Once the location of an initial endpoint is found, it is necessary to check to see if the segment intersects with the cell side. If the segment is parametrized as
\[ \theta = \theta_b + s_1(\theta_e - \theta_b) \]
\[ \phi = \phi_b + s_1(\phi_e - \phi_b) \]
and the cell side as
\[ \theta = \theta_1 + s_2(\theta_2 - \theta_1) \]
\[ \phi = \phi_1 + s_2(\phi_2 - \phi_1) \]
where \( \theta_1, \phi_1, \theta_2, \phi_2, \theta_e, \) and \( \theta_e \) are endpoints as shown in Figure 30. the intersection of the two lines occurs when \( \theta \) and \( \phi \) are equal. The linear system
\[
\begin{bmatrix}
(\theta_e - \theta_b) & (\theta_1 - \theta_2) \\
(\phi_e - \phi_b) & (\phi_1 - \phi_2)
\end{bmatrix}
\begin{bmatrix}
s_1 \\
s_2
\end{bmatrix}
= \begin{bmatrix}
(\theta_1 - \theta_b) \\
(\phi_1 - \phi_b)
\end{bmatrix}
\]
is then solved to determine \( s_1 \) and \( s_2 \) at the intersection point. If \( s_1 \) and \( s_2 \) are between zero and one, an intersection occurs with that cell side.

It is important also to compute identical intersections during the sweeps of each grid. To ensure that this will occur, the entire line segment is used to compute intersections rather than using a previous or next intersection as an endpoint. Often, pairs of grids will share common lines (e.g. the Equator). When this is the case, the method described above will double-count the contribution of these line segments. Coincidences can be detected when computing cross products for the search algorithm described above. If the cross product is zero in this case, the endpoint lies on the cell side. A second cross product between the line segment and the cell side can then be computed. If the second cross product is also zero, the lines are coincident. Once a coincidence has been detected, the contribution of the coincident segment can be computed during the first sweep and ignored during the second sweep.

Some aspects of the spherical coordinate system introduce additional problems for the method described above. Longitude is multiple valued on one line on the sphere, and this branch cut may be chosen differently by different grids. Care must be taken when calculating intersections and line integrals to ensure that the proper longitude values are used. A simple method is to always check to make sure the longitude is in the same interval as the source grid cell center.

Another problem with computing weights in spherical coordinates is the treatment of the pole. First, note that although the pole is physically a point, it is a line in latitude-longitude space and has a nonzero contribution to the weight integrals. If a grid does not contain the pole explicitly as a grid vertex, the pole contribution must be added to the appropriate cells. The pole contribution can be computed analytically. The pole also creates problems for the search and intersection algorithms described above. For example, a grid cell that overlaps the pole can result in a nonconvex cell in latitude-longitude coordinates. The cross-product test described above will fail in this case. In addition, segments near the pole typically exhibit large changes in longitude even for very short segments. In such a case, the linear parametrizations used above result in inaccuracies for determining the correct intersections.

To avoid these problems, a coordinate transformation can be used poleward of a given threshold latitude (typically within one degree of the pole). A possible transformation is the Lambert equivalent azimuthal projection
\[
X = 2 \sin \left( \frac{\pi}{4} - \frac{\theta}{2} \right) \cos \phi \\
Y = 2 \sin \left( \frac{\pi}{4} - \frac{\theta}{2} \right) \sin \phi
\]
for the North Pole. The transformation for the South Pole is similar. This transformation is only used to compute intersections; line integrals are still computed in latitude-longitude coordinates. Because intersections computed in the transformed coordinates can be different from those computed in latitude-longitude coordinates, line segments which cross the latitude threshold must be treated carefully. To compute the intersections consistently for such a segment, intersections with the threshold latitude are detected and used as a normal grid intersection to provide a clean break between the two coordinate systems.
28.5.4 Overview of Parallelization of Regrid

On parallel processing platforms, the physical domains of the source and destination Grids are decomposed into logical Decomposition Elements (DEs), as illustrated in Figure 32. In order to calculate interpolation weights, each destination DE will require coordinate data from any of the source Grid that overlaps it in physical space, which may span several DEs from the source Grid. Corresponding source Field data is necessary later for regridding calculations using the regridding weights. The DEs for each Grid are mapped to sets of PETs, which can be either shared or unique. However, RegridStore and RegridRun must be called with a VM encompassing the union of the sets of PETs, typically from a CouplerComponent. In any case, most situations will require data transfer between PETs for regridding. Once source data is available locally, the regridding algorithms discussed earlier can be applied.

There are four major sections of regridding that are impacted by the parallelization process: identifying necessary data, transferring that data, the sweep algorithms, and then calculating and applying the interpolation weights to calculate regridded Fields. Each will be discussed below.

28.5.5 Parallelization of Regrid: Identification of Necessary Data

The calculation of interpolation weights requires coordinate information from both source and destination Grids, and the application of those weights to determine regridded values needs corresponding source data. In a serial implementation of regridding, the complete source and destination Grids, with all their related data, are stored on a single processor. In a parallel implementation, the Grids and their corresponding data have been decomposed as DEs on a number of PETs. In this situation, none of the PETs responsible for part of the destination Grid, represented as a DE, necessarily has all the source data needed for the calculation or application of interpolation weights. The easiest approach to making the necessary source information available is to simply transfer or maintain copies of all of the source Grid coordinate and Field data on each of those PETs. However, this tends to be inefficient in terms of either communication or memory usage, and computational time spent in search algorithms. It requires only a slight bit more work to identify which source DEs intersect the local destination DE in physical space and then transfer all the data from those DEs. In some cases, this will save communication and memory overhead. But in other cases, like between one Grid decomposed in rows and another decomposed by columns as illustrated in Figure 33, that still ultimately means copying all of the source Grid to each destination PET. It often makes more sense to identify and transfer only the data from the source Grid that is required by the destination DE. In a parallel environment, this means determining which source DEs intersect the local destination DE in physical space, determining the extent of the data
Source Grid, decomposed in rows across 6 DEs

Destination Grid, decomposed in columns on 4 DEs

Note that this regrid means each source DE intersects each destination DE. For simple data identification algorithms, this would mean the transfer of all the source Grid data to each PET with a destination DE.

Figure 33: Example of parallel regridding requiring transfer of all data, when transferring all data between intersecting DEs.

on that source DE that must be transferred, and then gathering it to the local PET. Both of these approaches, either identifying the exact extent of the data that must be communicated or communicating data as entire DEs, are currently implemented in the framework. By default the framework will transfer only the necessary data, and the option is currently not readily available to users but is set internally in the Grid code using a parameter called "domainOption."

This intersection of DEs is calculated in physical space, using a private Grid method. In complicated Grids, these intersections could be non-rectangular, but for the current logically rectangular Grids each intersection is defined as the block of the source DE that encompasses any physical overlap with the destination DE’s domain. Future Grid types would need appropriate methods to identify intersections, based on their topologies as well as communication issues. As shown in Figure 34 the intersection is often a subset of both the source and destination DEs’ domains, which means that each destination DE must receive and process data from multiple source DEs. Each PET involved in a regridding process must calculate which other PETs it must send data to and how much (if it has a source DE) and which it must receive data from and how much (if it has a destination DE). The current Grid structures contain enough global information to individually determine the sending data, but the calculation of the data to be received takes some global communication.

Regridding algorithms that are point-based (as opposed to cell-based), like bilinear or bicubic interpolation, require an extra layer of cells around the identified region, because those algorithms need the location of all surrounding data points (see Figure 35).

Points in this extra layer are assigned internal mask values and are used in the calculation of interpolation weights for data locations inside the identified region, but are not assigned weights themselves. However, these points could be used in the future as a mechanism for regridding of periodic grids or to avoid extrapolation issues near the edges of computational grids.

28.5.6 Parallelization of Regrid: Data Transfer

Once a block of data to send or receive has been identified, it is stored as an internal structure called a domain and added to a domainList. There are separate send and receive domainLists for each DE. From the domainLists, all
Figure 34: Intersection of DE Domains in Parallel Regridding.

Figure 35: Illustration of the extra layer of points required by point-based Regrid algorithms.
the sending and receiving information between PETs is stored internally as a Route, so that it can leverage other ESMF code for efficient communication. Internal to the Regrid Store routines, this Route is used to gather necessary Grid coordinate information. However, since Routes apply offsets in memory from a base address rather than addresses themselves, these Routes are reusable by structures that are distributed in the same way. The Route to transfer Field data is similar to that to move Grid coordinates but must be modified for any Field ranks that do not correspond to a Grid axis and the Field’s halo width and lower bounds. The modified Route is added to the RouteHandle that is returned to users and applied later during the routine that actually regrids data from one Field to another. Each PET has its own unique Route. The data it gathers, either Grid coordinates or Field values, are stored locally as single 1D Arrays.

28.5.7 Parallelization of Regrid: Sweep Algorithms

The conservative regrid schemes create coordinate bins to decrease the number of cells that must be swept, as described earlier. SCRIP had an input parameter to set the number of bins to be created, but for a parallel implementation that number needs to be dynamic. Dynamic binning balances the cost, in terms of computational efficiency and storage, of setting up bins with the savings of having fewer points in each bin to sweep through. Rather than specify a number of bins, ESMF added a parameter to set a targeted number of cells per bin, called targetBinSize. The number of bins on any PET is set by the local number of cells divided by the targetBinSize. Currently this parameter is hard-coded in Regrid, but could be made available to users. It has been set to 250, based on some preliminary timings on its effect on Regrid Store (see Figure 36).

Because the conservative regrid algorithm is based on cells and assumes data values at the vertices, it can operate on the entire set of 1D Arrays of Grid coordinate information at once.
The bilinear algorithm, on the other hand, is point-based and must assume the data is logically rectangular. For that reason, its sweep routine operates on a single domain at a time, which typically represents just a part of the 1D gathered Arrays. It is otherwise unaffected by parallelization.

28.5.8 Parallelization of Regrid: Calculation and Application of Interpolation Weights

Once the necessary data has been identified and gathered, the calculation and application of interpolation weights are entirely local operations, requiring no inter-processor communication. Once an interpolation weight has been determined using one of the algorithms described earlier, the weight is stored as part of a local list of links (described previously) in an object called an ESMF_TransformValues. This object is itself part of the ESMF_RouteHandle object, and contains:

```
numlist  The number of links included in the object. It also represents the size of the corresponding arrays.
srcindex An array of indices into the local array of source data. This array is of size [numlist] and kind ESMF_KIND_I4.
          Only a single integer is required to identify the source index because the source data has been gathered as a vector.
dstindex An array of indices into the local array of destination data. This array is of size [2*numlist] and kind
          ESMF_KIND_I4. Each destination index address requires two integers, one for each rank of the data array that
          corresponds to a Grid axis. However, rather than being an array of rank 2, the index pairs are stored sequentially
          in the [dstindex] array.
weights  An array of interpolation weights. This array is of size [numlist] and kind ESMF_KIND_R8.
```

Each link is represented by an entry in this set of arrays. Also note that there is a single link for each unique combination of source and destination indices.

The application of the interpolation weights occurs during the Regrid run routines. The only necessary communication is that to gather the required source data locally into a one-dimensional array, using a precomputed Route. Fundamentally, the application of the weights is a vector multiply of a sparse matrix, with indirect addressing of the indices. The main calculation is a loop over the number of links that effectively sums the product of the source data and the interpolation weights and loads the result into the corresponding destination address. A sample code fragment below illustrates the simplest case, where both the source and destination data are two-dimensional arrays whose data axes correspond to the grids’ exactly, with no reordering:

```
do n = 1,numlinks
   d1 = dstIndex((n-1)*2 + 1)
   d2 = dstIndex((n-1)*2 + 2)
   s1 = srcIndex(n)
   dstData2D(d1,d2) = dstData2D(d1,d2) &
                        + (gatheredData(s1) * weights(n))
endo  ! numlinks
```

The coding becomes increasingly more complicated for data arrays of higher rank, but is inherently similar.

28.5.9 Regrid Objects

There is no ESMF_Regrid object per se. Users are returned an ESMF_RouteHandle object, which contains one or more ESMF_Routes used to gather source data, an ESMF_TransformValues object with the list of links, and an identifier for the type of RouteHandle. All of these objects are private and users are not expected to access or modify them.

29 Redist Method

29.1 Description

As the name implies, Redistribution operations move data from one distribution, or decomposition, to another. The distribution of the data may differ in several ways:
Redistribution can look like regridding, but the underlying global grids must be the same. The only allowable difference in the grids is their decomposition.

Figure 37: Illustration of redistribution of data.

The data could be decomposed across multiple DEs differently. In this case, the source data might be decomposed by a 3 by 2 DELayout and be redistributed onto a 1 by 6 DELayout.

The data could have different index orderings. For example, the data might be reordered from IJK to KIJ, where the source data is dimensioned srcData(ni,nj,nk) and is redistributed to dstData(nk,ni,nj).

Different indices of the data could be decomposed. Source data decomposed only in the first index could be redistributed to being only in the second or third index. For example, if both the source and destination data are decomposed by a 4 by 1 DELayout but the source applies the decomposition to the first index and the destination applies it to the second, then the source data will be locally dimensioned srcData(ni/4,nj,nk) and redistributed to dstData(ni,nj/4,nk).

In all of these situations, the source and destination data structures are required to have identical global sizes but not DE-local sizes. Although illustrations of Redistribution may look very similar to Regridding (please see Figure 29.1), Redistribution methods involve only data movement; no interpolation, data binning, or averaging is performed. For data associated with physical locations on a Grid, this means the source and destination Grids must have identical global coordinates. Like Haloing and other high level communication routines, Redistribution is supported at the Array, Field, and Bundle levels.

29.2 Use and Examples

Redist is designed to be called with Field or Bundle arguments in order to utilize information embedded in these objects. For example, Redist requires knowledge of the distribution contained in the underlying Grid and of the relative location (staggering) of Fields on the Grid. In addition, Redist uses any mask information that may be associated with a Field. However, ESMF also provides an Array interface for users who have gathered all necessary information. In general, Redist interfaces are relatively simple and require little information directly from users. The only option currently available to users via Redist interfaces sets communication strategy through an optional argument, routeOptions, and is not normally specified. For more information on this option, please see Section 26.3.1.

Like other high-level ESMF communication methods, Redist has separate functions for RedistStore, Redist, and RedistRelease. The Store functions initialize and precompute the communication patterns required for performing the data redistribution, returning an object called an ESMF_RouteHandle. This object is reusable by other co-located ESMF data objects. The Redist functions use the communication patterns contained in the RouteHandle object to
perform the actual redistribution of the ESMF data objects. The Release function deletes the RouteHandle object and frees all memory associated with a Redist. ESMF assumes users will call each of these functions sequentially, but the Redist also has Field and Bundle interfaces that allow for a single call to the Redist function instead, without requiring Store and Release calls. In this case, the Redist interfaces have been overloaded and for this version a parent VM must be included in the calling argument list. Also, no RouteHandle is returned to the user for possible reuse. Please see the examples below for representative FieldRedist usage.

### 29.2.1 Field Redistribution example

This example illustrates the use of Field interfaces for redistribution of data. Basically redistribution works on two Fields that are on the same Grid except that the Grid is distributed differently. In this example, two Grids are created from the same underlying 2D horizontal Grid, but one is distributed as logical blocks and the other is distributed as arbitrary vectors.

! First create two layouts, one for a 2D block distribution and a 1D layout for vector distribution:

```fortran
! First create two layouts, one for a 2D block distribution and a 1D layout
! for vector distribution:

delayout1 = ESMF_DELayoutCreate(vm, (/ 2, npets/2 /), rc=rc)
delayout2 = ESMF_DELayoutCreate(vm, (/ npets, 1 /), rc=rc)

! Next create the Grids with exactly the same underlying parameters:

counts(1) = 60
counts(2) = 40
min(1)  = 0.0
max(1)  = 60.0
min(2)  = 0.0
max(2)  = 50.0
horz_stagger = ESMF_GRID_HORZ_STAGGER_A  

grid1 = ESMF_GridCreateHorzXYUni(counts=counts, &
  minGlobalCoordPerDim=min, &
  maxGlobalCoordPerDim=max, &
  horzStagger=horz_stagger, &
  name="source grid", rc=rc)  

grid2 = ESMF_GridCreateHorzXYUni(counts=counts, &
  minGlobalCoordPerDim=min, &
  maxGlobalCoordPerDim=max, &
  horzStagger=horz_stagger, &
  name="source grid", rc=rc)  

! With two identical Grids, distribute one in the normal block style:

call ESMF_GridDistribute(grid1, delayout=delayout1, rc=rc)

! The second Grid is distributed in arbitrary vectors. The following code
! fragment calculates the vectors of index pairs in myIndices, based
! on the local DE number. This is just a simple algorithm to create a
! semi-regular distribution of points to the PETs.

i = int((counts(1)*counts(2) + npets -1)/npets)
```
allocate (myIndices(i,2))

j1 = 1 + myDE
add = 0

do i = 1, counts(1)
    do j = j1, counts(2), npets
        add = add + 1
        myIndices(add,1) = i
        myIndices(add,2) = j
    enddo
    j1 = j - counts(2)
enddo

call ESMF_GridDistribute(grid2, delayout=delayout2, myCount=add, &
    myIndices=myIndices, rc=rc)

! Create Fields for each of the Grids:
field1 = ESMF_FieldCreate(grid1, arrayspec2D, &
    horzRealloc=ESMF_CELL_CENTER, &
    haloWidth=0, name="humidity1", rc=rc)

field2 = ESMF_FieldCreate(grid2, arrayspec1D, &
    horzRealloc=ESMF_CELL_CENTER, &
    haloWidth=0, name="humidity2", rc=rc)

! Then precompute the communication pattern to
! move data from the regularly distributed Field1
! to the arbitrarily stored Field2:
call ESMF_FieldRedistStore(field1, field2, vm, routehandle=rh12, rc=rc)

! After the data in Field1 has been filled, simply call the
! redistribution method here to move the data to Field2:
call ESMF_FieldRedist(field1, field2, rh12, rc=rc)

! Once the Route is no longer needed, it is up to the user to release
! it, since the user created it:
call ESMF_FieldRedistRelease(rh12, rc)

29.2.2 Field Redistribution example using a single call

This example illustrates the use of Field interfaces for redistribution of data with a single call. Using the data structures from the previous example, this example illustrates the capability to perform a redistribution in a single call to FieldRedist rather than the three separate calls to FieldRedistStore, FieldRedist, and FieldRedistRelease. Please note that in this case the calling argument list does not include a RouteHandle and one is not returned to the user for reuse. However, this interface can be useful for some applications where there is no future use of the communication patterns.

! Note that this call looks similar to the previous one applying the
! precomputed RouteHandle with the exception of requiring the VM in
! the calling list.

call ESMF_FieldRedist(field1, field2, parentVM=vm, rc=rc)
29.3 Restrictions and Future Work

1. **Redistribution only fills computational domains.** Currently, redistributed values are not automatically applied to halo or ghost domains. Users must manually call Halo after redistribution in order to do so. This also means that Grid periodicity will not affect results without manual Halo calls.

2. **Masks are not implemented.** Redist methods should apply any Masks attached to the data objects, but they currently do not. Redist interfaces should also include Masks as arguments.

29.4 Design and Implementation Notes

Like Regrid, Redist has been designed to be as efficient as possible during its Run routine. The calculation of redistribution mostly involves determining intersections in index space between DEs from the source and destination data structures. Although this initial calculation during the Store routines can be computationally intensive, the ESMF_RouteHandle object it creates is designed to be reused by similar Fields on the same Grids. And, as long as the Grids are static, RegridStore can be called once and reused throughout a simulation. It leverages internal structures and methods used throughout ESMF to precompute communication patterns and store them for application.

29.4.1 Redist Objects

There is no ESMF_Redist object per se. Users are returned an ESMF_RouteHandle object, which contains one or more ESMF_Routes used to gather source data, and an identifier for the type of RouteHandle. These objects are private and users are not expected to access or modify them.
Part IV
Infrastructure: Utilities
30 Overview of Infrastructure Utility Classes

The ESMF utilities are a set of tools for quickly assembling modeling applications. The Time Management Library provides utilities for time and date representation and calculation, and higher-level utilities that control model time stepping and alarming.

The Array class offers an efficient, language-neutral way of storing and manipulating data arrays. The Communications/Memory/Kernel library provides utilities for isolating system-dependent functions to ease platform portability. It provides services to represent a particular machine’s characteristics and to organize these into processor lists and layouts to allow for optimal allocation of resources to an ESMF component. Also provided is a unified interface for system-dependent communication services such as MPI or pthreads.

ESMF Configuration Management is based on NASA DAO’s Inpak package, a collection of routines for accessing files containing input parameters stored in an ASCII format.
31 Time Manager Utility

The ESMF Time Manager utility includes software for time and date representation and calculations, model time advancement, and the identification of unique and periodic events. Since multi-component geophysical applications often require synchronization across the time management schemes of the individual components, the Time Manager’s standard calendars and consistent time representation promote component interoperability.

**Key Features**

- Drift-free timekeeping through an integer-based internal time representation.
- The ability to represent time as a rational fraction, to support exact timekeeping in applications that involve grid refinement.
- Support for many calendar types, including user-customized calendars.
- Support for both concurrent and sequential modes of component execution.
- Support for varying and negative time steps.

31.1 Time Manager Classes

There are five ESMF classes that represent time concepts:

- **Calendar** A Calendar can be used to keep track of the date as an ESMF Gridded Component advances in time. Standard calendars (such as Gregorian and 360-day) and user-specified calendars are supported. Calendars can be queried for quantities such as seconds per day, days per month, and days per year.

- **Time** A Time represents a time instant in a particular calendar, such as November 28, 1964, at 7:31pm EST in the Gregorian calendar. The Time class can be used to represent the start and stop time of a time integration.

- **TimeInterval** TimeIntervals represent a period of time, such as 300 milliseconds. Time steps can be represented using TimeIntervals.

- **Clock** Clocks collect the parameters and methods used for model time advancement into a convenient package. A Clock can be queried for quantities such as start time, stop time, current time, and time step. Clock methods include incrementing the current time, and determining if it is time to stop.

- **Alarm** Alarms identify unique or periodic events by “ringing” - returning a true value - at specified times. For example, an Alarm might be set to ring on the day of the year when leaves start falling from the trees in a climate model.

The ESMF Time Manager utility includes software to manage model calendars, advance model time, and perform time and date calculations. The software classes that handle these functions are **Times**, **TimeIntervals**, **Clocks**, **Alarms**, and **Calendars**.
In the remainder of this section, we briefly summarize the functionality that the Time Manager classes provide. Detailed descriptions and usage examples precede the API listing for each class.

### 31.2 Calendar

An ESMF Calendar can be queried for seconds per day, days per month and days per year. The flexible definition of Calendars allows them to be defined for planetary bodies other than Earth. The set of supported calendars includes:

- **Gregorian** The standard Gregorian calendar.
- **no-leap** The Gregorian calendar with no leap years.
- **Julian** The standard Julian date calendar.
- **Julian Day** The standard Julian days calendar.
- **360-day** A 30-day-per-month, 12-month-per-year calendar.
- **no calendar** Tracks only elapsed model time in hours, minutes, seconds.

See Section 32.1 for more details on supported standard calendars, and how to create a customized ESMF Calendar.

### 31.3 Time Instants and Time Intervals

TimeIntervals and Time instants (simply called Times) are the computational building blocks of the Time Manager utility. TimeIntervals support operations such as add, subtract, compare size, reset value, copy value, and subdivide by a scalar. Times, which are moments in time associated with specific Calendars, can be incremented or decremented by TimeIntervals, compared to determine which of two Times is later, differenced to obtain the TimeInterval between two Times, copied, reset, and manipulated in other useful ways. Times support a host of different queries, both for values of individual Time components such as year, month, day, and second, and for derived values such as day of year, middle of current month and Julian day. It is also possible to retrieve the value of the hardware realtime clock in the form of a Time. See Sections 33.1 and 34.1 respectively, for use and examples of Times and TimeIntervals. Since climate modeling, numerical weather prediction and other Earth and space applications have widely varying time scales and require different sorts of calendars, Times and TimeIntervals must support a wide range of time specifiers, spanning nanoseconds to years. The interfaces to these time classes are defined so that the user can specify a time using a combination of units selected from the list shown in Table 1.

### 31.4 Clocks and Alarms

Although it is possible to repeatedly step a Time forward by a TimeInterval using arithmetic on these basic types, it is useful to identify a higher-level concept to represent this function. We refer to this capability as a Clock, and include in its required features the ability to store the start and stop times of a model run, to check when time advancement should cease, and to query the value of quantities such as the current time and the time at the previous time step. The Time Manager includes a class with methods that return a true value when a periodic or unique event has taken place; we refer to these as Alarms. Applications may contain temporary or multiple Clocks and Alarms. Sections 35.1 and 36.1 describe the use of Clocks and Alarms in detail.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;yy</td>
<td>yy_i8&gt;</td>
</tr>
<tr>
<td>mm</td>
<td>Month of the year.</td>
</tr>
<tr>
<td>dd</td>
<td>Day of the month.</td>
</tr>
<tr>
<td>&lt;d</td>
<td>d_i8</td>
</tr>
<tr>
<td>&lt;h</td>
<td>h_r8&gt;</td>
</tr>
<tr>
<td>&lt;m</td>
<td>m_r8&gt;</td>
</tr>
<tr>
<td>&lt;s</td>
<td>s_i8</td>
</tr>
<tr>
<td>&lt;ms</td>
<td>ms_r8&gt;</td>
</tr>
<tr>
<td>&lt;us</td>
<td>us_r8&gt;</td>
</tr>
<tr>
<td>&lt;ns</td>
<td>ns_r8&gt;</td>
</tr>
<tr>
<td>O</td>
<td>Time zone offset in integer number of hours and minutes.</td>
</tr>
<tr>
<td>sN</td>
<td>Numerator for times of the form $s + \frac{sN}{sD}$, where s is seconds and s, sN, and sD are integers. This format provides a mechanism for supporting exact behavior.</td>
</tr>
<tr>
<td>sD</td>
<td>Denominator for times of the form $s + \frac{sN}{sD}$, where s is seconds and s, sN, and sD are integers.</td>
</tr>
</tbody>
</table>

### 31.5 Design and Implementation Notes

1. **Base TimeIntervals and Times on the same integer representation.** It is useful to allow both TimeIntervals and Times to inherit from a single class, BaseTime. In C++, this can be implemented by using inheritance. In Fortran, it can be implemented by having the derived types TimeIntervals and Times contain a derived type BaseTime. In both cases, the BaseTime class can be made private and invisible to the user.

   The result of this strategy is that Time Intervals and Times gain a consistent core representation of time as well a set of basic methods.

   The BaseTime class can be designed with a minimum number of elements to represent any required time. The design is based on the idea used in the real-time POSIX 1003.1b-1993 standard. That is, to represent time simply as a pair of integers: one for seconds (whole) and one for nanoseconds (fractional). These can then be converted at the interface level to any desired format.

   For ESMF, this idea can be modified and extended, in order to handle the requirements for a large time range (> 200,000 years) and to exactly represent any rational fraction, not just nanoseconds. To handle the large time range, a 64-bit or greater integer is used for whole seconds. Any rational fractional second is expressed using two additional integers: a numerator and a denominator. Both the whole seconds and fractional numerator are signed to handle negative time intervals and instants. For arithmetic consistency both must carry the same sign (both positive or both negative), except, of course, for zero values. The fractional seconds element (numerator) is bounded with respect to whole seconds. If the absolute value of the numerator becomes greater than or equal to the denominator, whole seconds are incremented or decremented accordingly and the numerator is reset to the remainder. Conversions are performed upon demand by interface methods within the TimeInterval and Time classes. This is done because different applications require different representations of time intervals and time instances.

   The BaseTime class defines increment and decrement methods for basic TimeInterval calculations between Time instants. It is done here rather than in the Calendar class because it can be done with simple second-based arithmetic that is calendar independent.

   Comparison methods can also be defined in the BaseTime class. These perform equality/inequality, less than, and greater than comparisons between any two TimeIntervals or Times. These methods capture the common comparison logic between TimeIntervals and Times and hence are defined here for sharing.
2. **The Time class depends on a calendar.** The Time class contains an internal Calendar class. Upon demand by a user, the results of an increment or decrement operation are converted to user units, which may be calendar-dependent, via methods obtained from their internal Calendar.
31.6 Object Model

The following is a simplified UML diagram showing the structure of the Time Manager utility. See Appendix A, A Brief Introduction to UML, for a translation table that lists the symbols in the diagram and their meaning.
32 Calendar Class

32.1 Description
The Calendar class represents the standard calendars used in geophysical modeling: Gregorian, Julian, Julian Day, no-leap, 360-day, and no-calendar. It also supports a user-customized calendar. Brief descriptions are provided for each calendar below. For more information on standard calendars, see [10] and [7].

32.2 Calendar Options

32.2.1 ESMF_CalendarType
DESCRIPTION: Supported calendar types.
Valid values are:

ESMF_CAL_360DAY Valid range: machine limits
In the 360-day calendar, there are 12 months, each of which has 30 days. Like the no-leap calendar, this is a simple approximation to the Gregorian calendar sometimes used by modelers.

ESMF_CAL_CUSTOM Valid range: machine limits
The user can set calendar parameters in the generic calendar.

ESMF_CAL_GREGORIAN Valid range: 3/1/4801 BC to 10/29/292,277,019,914
The Gregorian calendar is the calendar currently in use throughout Western countries. Named after Pope Gregory XIII, it is a minor correction to the older Julian calendar. In the Gregorian calendar every fourth year is a leap year in which February has 29 and not 28 days; however, years divisible by 100 are not leap years unless they are also divisible by 400. As in the Julian calendar, days begin at midnight.

ESMF_CAL_JULIAN Valid range: 3/1/4713 BC to 4/24/292,271,018,333
The Julian calendar was introduced by Julius Caesar in 46 B.C., and reached its final form in 4 A.D. The Julian calendar differs from the Gregorian only in the determination of leap years, lacking the correction for years divisible by 100 and 400 in the Gregorian calendar. In the Julian calendar, any year is a leap year if divisible by 4. Days are considered to begin at midnight.

ESMF_CAL_JULIANDAY Valid range: +/- 1x10^{14}
Julian days simply enumerate the days and fraction of a day which have elapsed since the start of the Julian era, defined as beginning at noon on Monday, 1st January of year 4713 B.C. in the Julian calendar. Julian days, unlike the dates in the Julian and Gregorian calendars, begin at noon.

ESMF_CAL_NOCALENDAR Valid range: machine limits
The no-calendar option simply tracks the elapsed model time in seconds.

ESMF_CAL_NOLEAP Valid range: machine limits
The no-leap calendar is the Gregorian calendar with no leap years - February is always assumed to have 28 days. Modelers sometimes use this calendar as a simple, close approximation to the Gregorian calendar.

32.3 Use and Examples
In most multi-component Earth system applications, the timekeeping in each component must refer to the same standard calendar in order for the components to properly synchronize. It therefore makes sense to create as few ESMF Calendars as possible, preferably one per application. A typical strategy would be to create a single Calendar at the start of an application, and use that Calendar in all subsequent calls that accept a Calendar, such as ESMF_TimeSet.

The following example shows how to set up an ESMF Calendar.

! !PROGRAM: ESMF_CalendarEx - Calendar creation examples
!!!
This program shows examples of how to create different calendar types

! ESDF Framework module
use ESMF_Mod
implicit none

! instantiate calendars
type(ESMF_Calendar) :: gregorianCalendar
type(ESMF_Calendar) :: julianDayCalendar

! local variables for Get methods
integer(ESMF_KIND_I8) :: dl
type(ESMF_Time) :: time

! return code
integer:: rc

call ESMF_Initialize(rc=rc)

32.3.1 Calendar Creation
This example shows how to create two ESMF_Calendars.

! create a Gregorian calendar
gregorianCalendar = ESMF_CalendarCreate("Gregorian", &
ESMF_CAL_GREGORIAN, rc)

! create a Julian Day calendar
julianDayCalendar = ESMF_CalendarCreate("JulianDay", &
ESMF_CAL_JULIANDAY, rc)

32.3.2 Calendar Comparison
This example shows how to compare an ESMF_Calendar with a known calendar type.

! compare calendar type against a known type
if (gregorianCalendar == ESMF_CAL_GREGORIAN) then
    print *, "gregorianCalendar is of type ESMF_CAL_GREGORIAN."
else
    print *, "gregorianCalendar is not of type ESMF_CAL_GREGORIAN."
end if

32.3.3 Time Conversion Between Calendars
This example shows how to convert a time from one ESMF_Calendar to another.

call ESMF_TimeSet(time, yy=2004, mm=4, dd=17, &
calendar=gregorianCalendar, rc=rc)
call ESMF_TimeSet(time, calendar=julianDayCalendar, rc=rc)
call ESMF_TimeGet(time, d_i8=dl, rc=rc)
print *, "Gregorian date 2004/4/17 is ", dl, &
" days in the Julian Day calendar."

32.3.4 Calendar Destruction
This example shows how to destroy two ESMF_Calendars.
call ESMF_CalendarDestroy(julianDayCalendar, rc)
call ESMF_CalendarDestroy(gregorianCalendar, rc)

! finalize ESMF framework
call ESMF_Finalize(rc=rc)

end program ESMF_CalendarEx

32.4 Restrictions and Future Work
1. Months per year set to 12. Due to the requirement of only Earth modeling, the number of months per year is hard-coded at 12. However, for easy modification, this is implemented via a Fortran parameter and a C preprocessor #define.

32.5 Class API
32.5.1 ESMF_CalendarOperator(==) - Test if Calendar 1 is equal to Calendar 2

INTERFACE:
interface operator(==)
if (calendar1 == calendar2) then ... endif
OR
result = (calendar1 == calendar2)

RETURN VALUE:
logical :: result

ARGUMENTS:
type(ESMF_Calendar), intent(in) :: calendar1
type(ESMF_Calendar), intent(in) :: calendar2

DESCRIPTION:
Overloads the (==) operator for the ESMF_Calendar class. Compare two calendar objects for equality; return true if equal, false otherwise. Comparison is based on the calendar type. The arguments are:
calendar1 The first ESMF_Calendar in comparison.
calendar2 The second ESMF_Calendar in comparison.
32.5.2 ESMF_CalendarOperator(==) - Test if Calendar Type 1 is equal to Calendar Type 2

INTERFACE:

```fortran
interface operator(==)
   if (calendartype1 == calendartype2) then ... endif
   OR
   result = (calendartype1 == calendartype2)
end interface
```

RETURN VALUE:

```fortran
logical :: result
```

ARGUMENTS:

```fortran
  type(ESMF_CalendarType), intent(in) :: calendartype1
  type(ESMF_CalendarType), intent(in) :: calendartype2
```

DESCRIPTION:

Overloads the (==) operator for the ESMF_Calendar class. Compare two calendar types for equality; return true if equal, false otherwise.

The arguments are:

- `calendartype1` The first ESMF_CalendarType in comparison.
- `calendartype2` The second ESMF_CalendarType in comparison.

---

32.5.3 ESMF_CalendarOperator(==) - Test if Calendar is equal to Calendar Type

INTERFACE:

```fortran
interface operator(==)
   if (calendar == calendartype) then ... endif
   OR
   result = (calendar == calendartype)
end interface
```

RETURN VALUE:

```fortran
logical :: result
```

ARGUMENTS:

```fortran
  type(ESMF_Calendar), intent(in) :: calendar
  type(ESMF_CalendarType), intent(in) :: calendartype
```

DESCRIPTION:

Overloads the (==) operator for the ESMF_Calendar class. Compare a calendar object’s type with a given calendar type for equality; return true if equal, false otherwise.

The arguments are:

- `calendar` The ESMF_Calendar in comparison.
- `calendartype` The ESMF_CalendarType in comparison.
32.5.4 ESMF_CalendarOperator(==) - Test if Calendar Type is equal to Calendar

INTERFACE:

    interface operator(==)
    if (calendartype == calendar) then ... endif
    OR
    result = (calendartype == calendar)

RETURN VALUE:

    logical :: result

ARGUMENTS:

    type(ESMF_CalendarType), intent(in) :: calendartype
    type(ESMF_Calendar), intent(in) :: calendar

DESCRIPTION:

Overloads the (==) operator for the ESMF_Calendar class. Compare a calendar type with a given calendar object’s type for equality; return true if equal, false otherwise.

The arguments are:

calendartype The ESMF(CalendarType in comparison.

calendar The ESMF_Calendar in comparison.

---

32.5.5 ESMF_CalendarOperator(/=) - Test if Calendar 1 is not equal to Calendar 2

INTERFACE:

    interface operator(/=)
    if (calendar1 /= calendar2) then ... endif
    OR
    result = (calendar1 /= calendar2)

RETURN VALUE:

    logical :: result

ARGUMENTS:

    type(ESMF_Calendar), intent(in) :: calendar1
    type(ESMF_Calendar), intent(in) :: calendar2

DESCRIPTION:

Overloads the (/=) operator for the ESMF_Calendar class. Compare two calendar objects for inequality; return true if not equal, false otherwise. Comparison is based on the calendar type.

The arguments are:

calendar1 The first ESMF_Calendar in comparison.

calendar2 The second ESMF_Calendar in comparison.
32.5.6 ESMF_CalendarOperator(/=) - Test if Calendar Type 1 is not equal to Calendar Type 2

INTERFACE:

```
interface operator(/=)
  if (calendartype1 /= calendartype2) then ... endif
OR
  result = (calendartype1 /= calendartype2)
```

RETURN VALUE:

```
logical :: result
```

ARGUMENTS:

```
type(ESMF_CalendarType), intent(in) :: calendartype1
type(ESMF_CalendarType), intent(in) :: calendartype2
```

DESCRIPTION:

Overloads the (/=) operator for the ESMF_Calendar class. Compare two calendar types for inequality; return true if not equal, false otherwise.
The arguments are:

- **calendartype1** The first ESMF_CalendarType in comparison.
- **calendartype2** The second ESMF_CalendarType in comparison.

---

32.5.7 ESMF_CalendarOperator(/=) - Test if Calendar is not equal to Calendar Type

INTERFACE:

```
interface operator(/=)
  if (calendar /= calendartype) then ... endif
OR
  result = (calendar /= calendartype)
```

RETURN VALUE:

```
logical :: result
```

ARGUMENTS:

```
type(ESMF_Calendar), intent(in) :: calendar
type(ESMF_CalendarType), intent(in) :: calendartype
```

DESCRIPTION:

Overloads the (/=) operator for the ESMF_Calendar class. Compare a calendar object’s type with a given calendar type for inequality; return true if equal, false otherwise.
The arguments are:

- **calendar** The ESMF_Calendar in comparison.
- **calendartype** The ESMF_CalendarType in comparison.
32.5.8 ESMF_CalendarOperator(/=) - Test if Calendar Type is not equal to Calendar

INTERFACE:

interface operator(/=)
  if (calendartype /= calendar) then ... endif
  result = (calendartype /= calendar)
end interface

RETURN VALUE:

logical :: result

ARGUMENTS:

type(ESMF_CalendarType), intent(in) :: calendartype
type(ESMF_Calendar), intent(in) :: calendar

DESCRIPTION:

Overloads the (/=) operator for the ESMF_Calendar class. Compare a calendar type with a given calendar object’s type for inequality; return true if equal, false otherwise.

The arguments are:

calendartype    The ESMF_CalendarType in comparison.
calendar        The ESMF_Calendar in comparison.

32.5.9 ESMF_CalendarCreate - Create a new ESMF Calendar of built-in type

INTERFACE:

! Private name; call using ESMF_CalendarCreate()
function ESMF_CalendarCreateBuiltIn(name, calendartype, rc)

RETURN VALUE:

type(ESMF_Calendar) :: ESMF_CalendarCreateBuiltIn

ARGUMENTS:

character (len=*), intent(in), optional :: name
type(ESMF_CalendarType), intent(in) :: calendartype
integer, intent(out), optional :: rc

DESCRIPTION:

Creates and sets a calendar to the given built-in ESMF_CalendarType. This is a private method; invoke via the public overloaded entry point ESMF_CalendarCreate().

The arguments are:

[name]    The name for the newly created calendar. If not specified, a default unique name will be generated: "CalendarNNN" where NNN is a unique sequence number from 001 to 999.
calendartype    The built-in ESMF_CalendarType. Valid values are: ESMF_CAL_360DAY, ESMF_CAL_GREGORIAN, ESMF_CAL_JULIAN, ESMF_CAL_JULIANDAY, ESMF_CAL_NOCALENDAR, and ESMF_CAL_NOLEAP. See Section 32.2 for a description of each calendar type.
[rc]    Return code; equals ESMF_SUCCESS if there are no errors.
32.5.10  ESMF_CalendarCreate - Create a copy of an ESMF Calendar

INTERFACE:

! Private name; call using ESMF_CalendarCreate()
function ESMF_CalendarCreateCopy(calendar, rc)

RETURN VALUE:

type(ESMF_Calendar) :: ESMF_CalendarCreateCopy

ARGUMENTS:

type(ESMF_Calendar), intent(in) :: calendar
integer, intent(out), optional :: rc

DESCRIPTION:

Creates a copy of a given ESMF_Calendar.
This is a private method; invoke via the public overloaded entry point ESMF_CalendarCreate().
The arguments are:

calendar  The ESMF_Calendar to copy.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

32.5.11  ESMF_CalendarCreate - Create a new custom ESMF Calendar

INTERFACE:

! Private name; call using ESMF_CalendarCreate()
function ESMF_CalendarCreateCustom(name, daysPerMonth, secondsPerDay, &
daysPerYear, daysPerYearDn, &
daysPerYearDd, rc)

RETURN VALUE:

type(ESMF_Calendar) :: ESMF_CalendarCreateCustom

ARGUMENTS:

character (len=*),  intent(in), optional :: name
integer, dimension(:), intent(in), optional :: daysPerMonth
integer(ESMF_KIND_I4), intent(in), optional :: secondsPerDay
integer(ESMF_KIND_I4), intent(in), optional :: daysPerYear  ! not implemented
integer(ESMF_KIND_I4), intent(in), optional :: daysPerYearDn ! not implemented
integer(ESMF_KIND_I4), intent(in), optional :: daysPerYearDd ! not implemented
integer, intent(out), optional :: rc

DESCRIPTION:

Creates a custom ESMF_Calendar and sets its properties.
This is a private method; invoke via the public overloaded entry point ESMF_CalendarCreate().
The arguments are:
[name] The name for the newly created calendar. If not specified, a default unique name will be generated: "CalendarNNN" where NNN is a unique sequence number from 001 to 999.

[daysPerMonth] Integer array of days per month, for each month of the year. The number of months per year is variable and taken from the size of the array. If unspecified, months per year = 0, with the days array undefined.

[secondsPerDay] Integer number of seconds per day. Defaults to 86400 if not specified.

[daysPerYear] Integer number of days per year. Use with daysPerYearDn and daysPerYearDd (see below) to specify a days-per-year calendar for any planetary body. Default = 0. (Not implemented yet).

[daysPerYearDn] Integer numerator portion of fractional number of days per year (daysPerYearDn/daysPerYearDd). Use with daysPerYear (see above) and daysPerYearDd (see below) to specify a days-per-year calendar for any planetary body. Default = 0. (Not implemented yet).

[daysPerYearDd] Integer denominator portion of fractional number of days per year (daysPerYearDn/daysPerYearDd). Use with daysPerYear and daysPerYearDn (see above) to specify a days-per-year calendar for any planetary body. Default = 1. (Not implemented yet).

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

32.5.12 ESMF_CalendarDestroy - Free resources associated with a Calendar

INTERFACE:

    subroutine ESMF_CalendarDestroy(calendar, rc)

ARGUMENTS:

    type(ESMF_Calendar) :: calendar
    integer, intent(out), optional :: rc

DESCRIPTION:

Releases all resources associated with this ESMF_Calendar. The arguments are:

calendar Destroy contents of this ESMF_Calendar.

[rc ] Return code; equals ESMF_SUCCESS if there are no errors.

32.5.13 ESMF_CalendarGet - Get Calendar properties

INTERFACE:

    subroutine ESMF_CalendarGet(calendar, name, calendartype, &
    daysPerMonth, monthsPerYear, &
    secondsPerDay, secondsPerYear, &
    daysPerYear, &
    daysPerYearDn, daysPerYearDd, rc)

ARGUMENTS:
type(ESMF_Calendar), intent(inout) :: calendar
character (len=*)    , intent(out), optional :: name
type(ESMF_CalendarType), intent(out), optional :: calendartype
integer, dimension(:), intent(out), optional :: daysPerMonth
integer, intent(out), optional :: monthsPerYear
integer(ESMF_KIND_I4), intent(out), optional :: secondsPerDay
integer(ESMF_KIND_I4), intent(out), optional :: secondsPerYear
integer(ESMF_KIND_I4), intent(out), optional :: daysPerYear ! not implemented
integer(ESMF_KIND_I4), intent(out), optional :: daysPerYearDn ! not implemented
integer(ESMF_KIND_I4), intent(out), optional :: daysPerYearDd ! not implemented
integer, intent(out), optional :: rc

DESCRIPTION:

Gets one or more of an ESMF_Calendar’s properties.
The arguments are:

calendar  The object instance to query.
[name]    The name of this calendar.
[calendartype]  The CalendarType ESMF_CAL_GREGORIAN, ESMF_CAL_JULIAN, etc.
[daysPerMonth] Integer array of days per month, for each month of the year.
[monthsPerYear] Integer number of months per year; the size of the daysPerMonth array.
[secondsPerDay] Integer number of seconds per day.
[secondsPerYear] Integer number of seconds per year.
[daysPerYear] Integer number of days per year. For calendars with intercalations, daysPerYear is the number of days
    for years without an intercalation. For other calendars, it is the number of days in every year. (Not implemented
    yet).
[daysPerYearDn] Integer fractional number of days per year (numerator). For calendars with intercalations, daysPerYearDn/daysPerYearDd
    is the average fractional number of days per year (e.g. 25/100 for Julian 4-year intercalation). For other calen-
    dars, it is zero. (Not implemented yet).
[daysPerYearDd] Integer fractional number of days per year (denominator). See daysPerYearDn above. (Not imple-
    mented yet).
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

32.5.14  ESMF_CalendarIsLeapYear - Determine if given year is a leap year

INTERFACE:

    ! Private name; call using ESMF_CalendarIsLeapYear()
    function ESMF_CalendarIsLeapYearI4(calendar, yy, rc)

RETURN VALUE:

    logical :: ESMF_CalendarIsLeapYearI4
ARGUMENTS:

    type(ESMF_Calendar), intent(inout) :: calendar
    integer(ESMF_KIND_I4), intent(in) :: yy
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns true if the given year is a leap year within the given calendar, and false otherwise. See also ESMF_TimeIsLeapYear(). This is a private method; invoke via the public overloaded entry point ESMF_CalendarIsLeapYear().

The arguments are:

calendar  ESMF_Calendar to determine leap year within.

yy       Year to check for leap year.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

32.5.15   ESMF_CalendarIsLeapYear - Determine if given year is a leap year

INTERFACE:

    ! Private name; call using ESMF_CalendarIsLeapYear()
    function ESMF_CalendarIsLeapYearI8(calendar, yy_i8, rc)

RETURN VALUE:

    logical :: ESMF_CalendarIsLeapYearI8

ARGUMENTS:

    type(ESMF_Calendar), intent(inout) :: calendar
    integer(ESMF_KIND_I8), intent(in) :: yy_i8
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns true if the given year is a leap year within the given calendar, and false otherwise. See also ESMF_TimeIsLeapYear(). This is a private method; invoke via the public overloaded entry point ESMF_CalendarIsLeapYear().

The arguments are:

calendar  ESMF_Calendar to determine leap year within.

yy_i8     Year to check for leap year.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
32.5.16 ESMF_CalendarPrint - Print the contents of a Calendar

INTERFACE:

    subroutine ESMF_CalendarPrint(calendar, options, rc)

ARGUMENTS:

    type(ESMF_Calendar), intent(inout) :: calendar
    character (len=*), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Prints out an ESMF_Calendar's properties to stdio, in support of testing and debugging. The options control the type of information and level of detail.

The arguments are:

calendar ESMF_Calendar to be printed out.

[options] Print options. If none specified, prints all calendar property values.
    "calendartype" - print the calendar's type (e.g. ESMF_CAL_GREGORIAN).
    "daysPerMonth" - print the array of number of days for each month.
    "daysPerYear" - print the number of days per year (integer and fractional parts).
    "monthsPerYear" - print the number of months per year.
    "name" - print the calendar's name.
    "secondsPerDay" - print the number of seconds in a day.
    "secondsPerYear" - print the number of seconds in a year.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

32.5.17 ESMF_CalendarSet - Set a Calendar to a built-in type

INTERFACE:

    ! Private name; call using ESMF_CalendarSet()
    subroutine ESMF_CalendarSetBuiltIn(calendar, name, calendartype, rc)

ARGUMENTS:

    type(ESMF_Calendar), intent(inout) :: calendar
    character (len=*), intent(in), optional :: name
    type(ESMF_CalendarType), intent(in) :: calendartype
    integer, intent(out), optional :: rc

DESCRIPTION:

Sets calendar to the given built-in ESMF_CalendarType.
This is a private method; invoke via the public overloaded entry point ESMF_CalendarSet().

The arguments are:
calendar  The object instance to initialize.

[name]  The new name for this calendar.

calendarType  The built-in CalendarType. Valid values are: ESMF_CAL_360DAY, ESMF_CAL_GREGORIAN, ESMF_CAL_JULIAN, ESMF_CAL_JULIANDAY, ESMF_CAL_NOCALENDAR, and ESMF_CAL_NOLEAP. See Section 32.2 for a description of each calendar type.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

32.5.18  ESMF_CalendarSet - Set properties of a custom Calendar

INTERFACE:

    ! Private name; call using ESMF_CalendarSet()
    subroutine ESMF_CalendarSetCustom(calendar, name, daysPerMonth, &
    secondsPerDay, &
    daysPerYear, daysPerYearDn, &
    daysPerYearDd, rc)

ARGUMENTS:

type(ESMF_Calendar), intent(inout) :: calendar
character (len=*), intent(in), optional :: name
integer, dimension(:), intent(in), optional :: daysPerMonth
integer(ESMF_KIND_I4), intent(in), optional :: secondsPerDay
integer(ESMF_KIND_I4), intent(in), optional :: daysPerYear  ! not implemented
integer(ESMF_KIND_I4), intent(in), optional :: daysPerYearDn ! not implemented
integer(ESMF_KIND_I4), intent(in), optional :: daysPerYearDd ! not implemented
integer, intent(out), optional :: rc

DESCRIPTION:

Sets properties in a custom ESMF_Calendar.
This is a private method; invoke via the public overloaded entry point ESMF_CalendarSet().
The arguments are:

calendar  The object instance to initialize.

[name]  The new name for this calendar.

daysPerMonth] Integer array of days per month, for each month of the year. The number of months per year is variable and taken from the size of the array. If unspecified, months per year = 0, with the days array undefined.

secondsPerDay] Integer number of seconds per day. Defaults to 86400 if not specified.

daysPerYear] Integer number of days per year. Use with daysPerYearDn and daysPerYearDd (see below) to specify a days-per-year calendar for any planetary body. Default = 0. (Not implemented yet).

daysPerYearDn] Integer numerator portion of fractional number of days per year (daysPerYearDn/daysPerYearDd) Use with daysPerYear (see above) and daysPerYearDd (see below) to specify a days-per-year calendar for any planetary body. Default = 0. (Not implemented yet).

daysPerYearDd] Integer denominator portion of fractional number of days per year (daysPerYearDn/daysPerYearDd). Use with daysPerYear and daysPerYearDn (see above) to specify a days-per-year calendar for any planetary body. Default = 1. (Not implemented yet).

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
32.5.19 ESMF_CalendarSetDefault - Set the default Calendar type

INTERFACE:

! Private name; call using ESMF_CalendarSetDefault()
subroutine ESMF_CalendarSetDefaultType(calendartype, rc)

ARGUMENTS:

type(ESMF_CalendarType), intent(in) :: calendartype
integer, intent(out), optional :: rc

DESCRIPTION:

Sets the default calendar to the given type. Subsequent Time Manager operations requiring a calendar where one isn’t specified will use the internal calendar of this type.
This is a private method; invoke via the public overloaded entry point ESMF_CalendarSetDefault().
The arguments are:

**calendartype** The calendar type to be the default.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

32.5.20 ESMF_CalendarSetDefault - Set the default Calendar

INTERFACE:

! Private name; call using ESMF_CalendarSetDefault()
subroutine ESMF_CalendarSetDefaultCal(calendar, rc)

ARGUMENTS:

type(ESMF_Calendar), intent(inout) :: calendar
integer, intent(out), optional :: rc

DESCRIPTION:

Sets the default calendar to the one given. Subsequent Time Manager operations requiring a calendar where one isn’t specified will use this calendar.
This is a private method; invoke via the public overloaded entry point ESMF_CalendarSetDefault().
The arguments are:

**calendar** The object instance to be the default.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.
32.5.21 ESMF_CalendarValidate - Validate a Calendar’s properties

INTERFACE:

    subroutine ESMF_CalendarValidate(calendar, options, rc)

ARGUMENTS:

    type(ESMF_Calendar), intent(inout) :: calendar
    character (len=*) , intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Checks whether a calendar is valid. Must be one of the defined calendar types. daysPerMonth, daysPerYear, secondsPerDay must all be greater than or equal to zero.

The arguments are:

calendar  ESMF_Calendar to be validated.

[options] Validation options are not yet supported.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
33 Time Class

33.1 Description

A Time represents a specific point in time. In order to accommodate the range of time scales in Earth system applications, Times in the ESMF can be specified in many different ways, from years to nanoseconds. The Time interface is designed so that you select one or more options from a list of time units in order to specify a Time. The options for specifying a Time are shown in Table 1.

There are Time methods defined for setting and getting a Time, incrementing and decrementing a Time by a TimeInterval, taking the difference between two Times, and comparing Times. Special quantities such as the middle of the month and the day of the year associated with a particular Time can be retrieved. There is a method for returning the Time value as a string in the ISO 8601 format YYYY-MM-DDThh:mm:ss.

A Time that is specified in hours, minutes, seconds, or subsecond intervals does not need to be associated with a standard calendar; a Time whose specification includes time units of a day and greater must be. The ESMF representation of a calendar, the Calendar class, is described in Section 32.1. The ESMF_TimeSet method is used to initialize a Time as well as associate it with a Calendar. If a Time method is invoked in which a Calendar is necessary and one has not been set, the ESMF method will return an error condition.

In the ESMF the TimeInterval class is used to represent time periods. This class is frequently used in combination with the Time class. The Clock class, for example, advances model time by incrementing a Time with a TimeInterval.

33.2 Use and Examples

Times are most frequently used to represent start, stop, and current model times. The following examples show how to create, initialize, and manipulate Time.

! PROGRAM: ESMF_TimeEx - Time initialization and manipulation examples
! !DESCRIPTION:
! This program shows examples of Time initialization and manipulation
!----------------------------------------------------------------------------

! ESMF Framework module
call ESMF_Initialize(defaultCalendar=ESMF_CAL_GREGORIAN, rc=rc)

33.2.1 Time Initialization

This example shows how to initialize an ESMF_Time.
initialize time1 to 2/28/2000 2:24:45
! initialize time1 to 2/28/2000 2:24:45
call ESMF_TimeSet(time1, yy=2000, mm=2, dd=28, h=2, m=24, s=45, rc=rc)

print *, "Time1 = "
call ESMF_TimePrint(time1, "string", rc)

33.2.2 Time Increment
This example shows how to increment an ESMF_Time by an ESMF_TimeInterval.

! initialize a time interval to 2 days, 8 hours, 36 minutes, 15 seconds
! initialize a time interval to 2 days, 8 hours, 36 minutes, 15 seconds
call ESMF_TimeIntervalSet(timeinterval1, d=2, h=8, m=36, s=15, rc=rc)

print *, "Timeinterval1 = "
call ESMF_TimeIntervalPrint(timeinterval1, "string", rc)

! increment time1 with timeinterval1
! increment time1 with timeinterval1
time2 = time1 + timeinterval1
time2 = time1 + timeinterval1
call ESMF_TimeGet(time2, yy=YY, mm=MM, dd=DD, h=H, m=M, s=S, rc=rc)
print *, "time2 = time1 + timeinterval1 = ", YY, "/", MM, "/", DD, ":", &
H, ":", M, ":", ":", S

33.2.3 Time Comparison
This example shows how to compare two ESMF_Times.

if (time2 > time1) then
  print *, "time2 is larger than time1"
else
  print *, "time1 is smaller than or equal to time2"
endif

! finalize ESMF framework
! finalize ESMF framework
call ESMF_Finalize(rc=rc)

end program ESMF_TimeEx

33.3 Restrictions and Future Work

1. Limits on size and resolution of Time. The limits on the size and resolution of the time representation are based on the 64-bit and 32-bit integer types used. For seconds, a signed 64-bit integer will have a range of +/- \(2^{63}-1\), or +/- 9223372036854775807. This corresponds to a maximum size of +/- \((2^{63}-1)/(86400 \times 365.25)\) or +/- 292,271,023,045 years.

For fractional seconds, a signed 32-bit integer will handle a resolution of +/- \(2^{31}-1\), or +/- 2,147,483,647 parts of a second.
33.4 Class API

33.4.1 ESMF_TimeOperator(+) - Increment a Time by a TimeInterval

INTERFACE:

    interface operator(+)
    time2 = time1 + timeinterval
    end interface

RETURN VALUE:

type(ESMF_Time) :: time2

ARGUMENTS:

    type(ESMF_Time), intent(in) :: time1
    type(ESMF_TimeInterval), intent(in) :: timeinterval

DESCRIPTION:

Overloads the (+) operator for the ESMF_Time class to increment time1 with timeinterval and return the result as an ESMF_Time.

The arguments are:

time1  The ESMF_Time to increment.

timeinterval  The ESMF_TimeInterval to add to the given ESMF_Time.

33.4.2 ESMF_TimeOperator(-) - Decrement a Time by a TimeInterval

INTERFACE:

    interface operator(-)
    time2 = time1 - timeinterval
    end interface

RETURN VALUE:

    type(ESMF_Time) :: time2

ARGUMENTS:

    type(ESMF_Time), intent(in) :: time1
    type(ESMF_TimeInterval), intent(in) :: timeinterval

DESCRIPTION:

Overloads the (-) operator for the ESMF_Time class to decrement time1 with timeinterval, and return the result as an ESMF_Time.

The arguments are:

time1  The ESMF_Time to decrement.

timeinterval  The ESMF_TimeInterval to subtract from the given ESMF_Time.
33.4.3 ESMF_TimeOperator(-) - Return the difference between two Times

INTERFACE:

    interface operator(-)
    time3 = time1 - time2
    end interface

RETURN VALUE:

type(ESMF_Time) :: time3

ARGUMENTS:

    type(ESMF_Time), intent(in) :: time1
    type(ESMF_Time), intent(in) :: time2

DESCRIPTION:

Overloads the (-) operator for the ESMF_Time class to return the difference between time1 and time2 as an ESMF_TimeInterval. It is assumed that time1 is later than time2; if not, the resulting ESMF_TimeInterval will have a negative value.

The arguments are:

    time1 The first ESMF_Time in comparison.
    time2 The second ESMF_Time in comparison.

33.4.4 ESMF_TimeOperator(==) - Test if Time 1 is equal to Time 2

INTERFACE:

    interface operator(==)
    if (time1 == time2) then ... endif
    OR
    result = (time1 == time2)
    end interface

RETURN VALUE:

    logical :: result

ARGUMENTS:

    type(ESMF_Time), intent(in) :: time1
    type(ESMF_Time), intent(in) :: time2

DESCRIPTION:

Overloads the (==) operator for the ESMF_Time class to return true if time1 and time2 are equal, and false otherwise.

The arguments are:

    time1 First ESMF_Time in comparison.
    time2 Second ESMF_Time in comparison.
33.4.5  ESMF_TimeOperator(=/=) - Test if Time 1 is not equal to Time 2

INTERFACE:

    interface operator(/=)
    if (time1 /= time2) then ... endif
    OR
    result = (time1 /= time2)

RETURN VALUE:

    logical :: result

ARGUMENTS:

    type(ESMF_Time), intent(in) :: time1
    type(ESMF_Time), intent(in) :: time2

DESCRIPTION:

Overloads the (/=) operator for the ESMF_Time class to return true if time1 and time2 are not equal, and false otherwise. The arguments are:

time1  First ESMF_Time in comparison.
time2  Second ESMF_Time in comparison.

33.4.6  ESMF_TimeOperator(<) - Test if Time 1 is less than Time 2

INTERFACE:

    interface operator(<)
    if (time1 < time2) then ... endif
    OR
    result = (time1 < time2)

RETURN VALUE:

    logical :: result

ARGUMENTS:

    type(ESMF_Time), intent(in) :: time1
    type(ESMF_Time), intent(in) :: time2

DESCRIPTION:

Overloads the (<) operator for the ESMF_Time class to return true if time1 is less than time2, and false otherwise. The arguments are:

time1  First ESMF_Time in comparison.
time2  Second ESMF_Time in comparison.
33.4.7 ESMF_TimeOperator(<=) - Test if Time 1 is less than or equal to Time 2

INTERFACE:

```fortran
interface operator(<=)
  if (time1 <= time2) then ... endif
  OR
  result = (time1 <= time2)
end interface
```

RETURN VALUE:

```
logical :: result
```

ARGUMENTS:

```
type(ESMF_Time), intent(in) :: time1
type(ESMF_Time), intent(in) :: time2
```

DESCRIPTION:

Overloads the (<=) operator for the ESMF_Time class to return true if time1 is less than or equal to time2, and false otherwise.

The arguments are:

- **time1** First ESMF_Time in comparison.
- **time2** Second ESMF_Time in comparison.

33.4.8 ESMF_TimeOperator(>) - Test if Time 1 is greater than Time 2

INTERFACE:

```fortran
interface operator(>)
  if (time1 > time2) then ... endif
  OR
  result = (time1 > time2)
end interface
```

RETURN VALUE:

```
logical :: result
```

ARGUMENTS:

```
type(ESMF_Time), intent(in) :: time1
type(ESMF_Time), intent(in) :: time2
```

DESCRIPTION:

Overloads the (>) operator for the ESMF_Time class to return true if time1 is greater than time2, and false otherwise.

The arguments are:

- **time1** First ESMF_Time in comparison.
- **time2** Second ESMF_Time in comparison.
33.4.9 ESMF_TimeOperator(>=) - Test if Time 1 is greater than or equal to Time 2

INTERFACE:

    interface operator(>=)
    if (time1 >= time2) then ... endif
    OR
    result = (time1 >= time2)

RETURN VALUE:

    logical :: result

ARGUMENTS:

    type(ESMF_Time), intent(in) :: time1
    type(ESMF_Time), intent(in) :: time2

DESCRIPTION:

Overloads the (>=) operator for the ESMF_Time class to return true if time1 is greater than or equal to time2, and false otherwise.

The arguments are:

**time1** First ESMF_Time in comparison.

**time2** Second ESMF_Time in comparison.

33.4.10 ESMF_TimeGet - Get a Time value

INTERFACE:

    subroutine ESMF_TimeGet(time, yy, yy_i8, &
                            mm, dd, &
                            d, d_i8, &
                            h, m, &
                            s, s_i8, &
                            ms, us, ns, &
                            d_r8, h_r8, m_r8, s_r8, &
                            ms_r8, us_r8, ns_r8, &
                            sN, sD, &
                            calendar, calendarType, timeZone, &
                            timeString, timeStringISOFrac, &
                            dayOfWeek, midMonth, &
                            dayOfYear, dayOfYear_r8, &
                            dayOfYear_intvl, rc)

ARGUMENTS:

    type(ESMF_Time), intent(inout) :: time
    integer(ESMF_KIND_I4), intent(out), optional :: yy
    integer(ESMF_KIND_I8), intent(out), optional :: yy_i8
    integer, intent(out), optional :: mm
    integer, intent(out), optional :: d
    integer(ESMF_KIND_I4), intent(out), optional :: d_i8

DESCRIPTION:

Gets the value of time in units specified by the user via Fortran optional arguments. See ESMF_TimeSet() above for a description of time units and calendars.

The ESMF Time Manager represents and manipulates time internally with integers to maintain precision. Hence, user-specified floating point values are converted internally from integers. For example, if a time value is 5 and 3/8 seconds (s=5, sN=3, sD=8), and you want to get it as floating point seconds, you would get 5.375 (s_r8=5.375). (Reals not implemented yet).

Units are bound (normalized) by the next larger unit specified. For example, if a time is defined to be 2:00 am on February 2, 2004, then ESMF_TimeGet(dd=day, h=hours, s=seconds) would return day = 2, hours = 2, seconds = 0, whereas ESMF_TimeGet(dd = day, s=seconds) would return day = 2, seconds = 7200. Note that hours and seconds are bound by a day. If bound by a month, ESMF_TimeGet(mm=month, h=hours, s=seconds) would return month = 2, hours = 26, seconds = 0, and ESMF_TimeGet(mm = month, s=seconds) would return month = 2, seconds = 93600 (26 * 3600). Similarly, if bound to a year, ESMF_TimeGet(yy=year, h=hours, s=seconds) would return year = 2004, hours = 770 (32*24+2), seconds = 0, and ESMF_TimeGet(yy = year, s=seconds) would return year = 2004, seconds = 2772000 (770 * 3600).

For timeString, timeStringISO8601, dayOfWeek, midMonth, dayOfYear, dayOfYear_r8, and dayOfYear_intvl described below, valid calendars are Gregorian, Julian, No Leap, 360 Day and Custom calendars. Not valid for Julian Day or No Calendar.

For timeString and timeStringISO8601, YYYY format returns at least 4 digits; years <= 999 are padded on the left with zeroes and years >= 10000 return the number of digits required.

For timeString, convert ESMF_Time’s value into partial ISO 8601 format YYYY-MM-DDThh:mm:ss[:n/d]. See [5] and [2]. See also method ESMF_TimePrint().

For timeStringISO8601, convert ESMF_Time’s value into full ISO 8601 format YYYY-MM-DDThh:mm:ss[.f]. See [5] and [2]. See also method ESMF_TimePrint().
For dayOfWeek, gets the day of the week the given ESMF_Time instant falls on. ISO 8601 standard: Monday = 1 through Sunday = 7. See [5] and [2].
For midMonth, gets the middle time instant of the month that the given ESMF_Time instant falls on.
For dayOfYear, gets the day of the year that the given ESMF_Time instant falls on. See range discussion in argument list below. Return as an integer value.
For dayOfYear_r8, gets the day of the year the given ESMF_Time instant falls on. See range discussion in argument list below. Return as floating point value; fractional part represents the time of day. (Reals not implemented yet).
For dayOfYear_intvl, gets the day of the year the given ESMF_Time instant falls on. Return as an ESMF_TimeInterval. The arguments are:

**time**  The object instance to query.

[yy] Integer year (>= 32-bit).
[yy_i8] Integer year (large, >= 64-bit).
[mm] Integer month.
[dd] Integer day of the month.
[d] Integer Julian days (>= 32-bit).
[d_i8] Integer Julian days (large, >= 64-bit).
[h] Integer hours.
[m] Integer minutes.
[s] Integer seconds (>= 32-bit).
[s_i8] Integer seconds (large, >= 64-bit).
[ms] Integer milliseconds.
[us] Integer microseconds.
[ns] Integer nanoseconds.
[d_r8] Double precision days. (Not implemented yet).
[h_r8] Double precision hours. (Not implemented yet).
[m_r8] Double precision minutes. (Not implemented yet).
[s_r8] Double precision seconds. (Not implemented yet).
[ms_r8] Double precision milliseconds. (Not implemented yet).
[us_r8] Double precision microseconds. (Not implemented yet).
[ns_r8] Double precision nanoseconds. (Not implemented yet).
[sN] Integer numerator portion of fractional seconds (sN/sD).
[sD] Integer denominator portion of fractional seconds (sN/sD).
[calendar] Associated Calendar.
[calendarType] Associated CalendarType.
[timeZone] Associated timezone (hours offset from UCT, e.g. EST = -5). (Not implemented yet).
Convert time value to format string YYYY-MM-DDThh:mm:ss[: n/d], where n/d is numerator/denominator of any fractional seconds and all other units are in ISO 8601 format. See [5] and [2]. See also method ESMF_TimePrint().

Convert time value to strict ISO 8601 format string YYYY-MM-DDThh:mm:ss[.f], where f is decimal form of any fractional seconds. See [5] and [2]. See also method ESMF_TimePrint().

dayOfWeek] The time instant’s day of the week [1-7].

MidMonth] The given time instant’s middle-of-the-month time instant.


dayOfYear_intvl] The ESMF_Time instant’s day of the year as an ESMF_TimeInterval.

rc] Return code; equals ESMF_SUCCESS if there are no errors.

33.4.11 ESMF_TimeIsLeapYear - Determine if a Time is in a leap year

INTERFACE:

    function ESMF_TimeIsLeapYear(time, rc)

RETURN VALUE:

    logical :: ESMF_TimeIsLeapYear

ARGUMENTS:

    type(ESMF_Time), intent(inout) :: time
    integer,       intent(out), optional :: rc

DESCRIPTION:

Returns true if given time is in a leap year, and false otherwise. See also ESMF_CalendarIsLeapYear(). The arguments are:

time The ESMF_Time to check for leap year.

rc] Return code; equals ESMF_SUCCESS if there are no errors.

33.4.12 ESMF_TimeIsSameCalendar - Compare Calendars of two Times

INTERFACE:

    function ESMF_TimeIsSameCalendar(time1, time2, rc)
RETURN VALUE:

    logical :: ESMF_TimeIsSameCalendar

ARGUMENTS:

    type(ESMF_Time), intent(inout) :: time1
    type(ESMF_Time), intent(inout) :: time2
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns true if the Calendars in these Times are the same, false otherwise.
The arguments are:

    time1  The first ESMF_Time in comparison.
    time2  The second ESMF_Time in comparison.
    [rc]  Return code; equals ESMF_SUCCESS if there are no errors.

33.4.13 ESMF_TimePrint - Print the contents of a Time

INTERFACE:

    subroutine ESMF_TimePrint(time, options, rc)

ARGUMENTS:

    type(ESMF_Time), intent(inout) :: time
    character (len=*), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Prints out the contents of an ESMF_Time to stdout, in support of testing and debugging. The options control the
   type of information and level of detail. For options "string" and "string isofrac", YYYY format returns at least 4 digits;
years <= 999 are padded on the left with zeroes and years >= 10000 return the number of digits required.
The arguments are:

    time  The ESMF_Time to be printed out.
    [options]  Print options. If none specified, prints all Time property values.
        "string" - prints time’s value in ISO 8601 format for all units through seconds. For any non-zero fractional
seconds, prints in integer rational fraction form n/d. Format is YYYY-MM-DDThh:mm:ss[.f], where [n/d] is the integer
numerator and denominator of the fractional seconds value, if present. See 5 and 2. See also method ESMF_TimeGet(..., timeString= , ...)
        "string isofrac" - prints time’s value in strict ISO 8601 format for all units, including any fractional
seconds part. Format is YYYY-MM-DDThh:mm:ss[.f] where [f] represents fractional seconds in decimal form, if
present. See 5 and 2. See also method ESMF_TimeGet(..., timeStringISOFrac= , ...)
    [rc]  Return code; equals ESMF_SUCCESS if there are no errors.
33.4.14 ESMF_TimeSet - Initialize or set a Time

INTERFACE:

subroutine ESMF_TimeSet(time, yy, yy_i8, &
  mm, dd, &
  d, d_i8, &
  h, m, &
  s, s_i8, &
  ms, us, ns, &
  d_r8, h_r8, m_r8, s_r8, &
  ms_r8, us_r8, ns_r8, &
  sN, sD, calendar, calendarType, &
  timeZone, rc)

ARGUMENTS:

type(ESMF_Time), intent(inout) :: time
integer(ESMF_KIND_I4), intent(in), optional :: yy
integer(ESMF_KIND_I8), intent(in), optional :: yy_i8
integer, intent(in), optional :: mm
integer, intent(in), optional :: dd
integer(ESMF_KIND_I4), intent(in), optional :: d
integer(ESMF_KIND_I8), intent(in), optional :: d_i8
integer(ESMF_KIND_I4), intent(in), optional :: h
integer(ESMF_KIND_I4), intent(in), optional :: m
integer(ESMF_KIND_I4), intent(in), optional :: s
integer(ESMF_KIND_I4), intent(in), optional :: s_i8
integer(ESMF_KIND_I4), intent(in), optional :: ms
integer(ESMF_KIND_I4), intent(in), optional :: us
integer(ESMF_KIND_I4), intent(in), optional :: ns
real(ESMF_KIND_R8), intent(in), optional :: d_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: h_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: m_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: s_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: ms_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: us_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: ns_r8 ! not implemented
integer(ESMF_KIND_I4), intent(in), optional :: sN
integer(ESMF_KIND_I4), intent(in), optional :: sD
type(ESMF_Calendar), intent(in), optional :: calendar
type(ESMF_CalendarType), intent(in), optional :: calendarType
integer, intent(out), optional :: timeZone ! not implemented
integer, intent(out), optional :: rc

DESCRIPTION:

Initializes an ESMF_Time with a set of user-specified units via Fortran optional arguments. The range of valid values for mm and dd depend on the calendar used. For Gregorian, Julian, and No-Leap calendars, mm is [1-12] and dd is [1-28,29,30, or 31], depending on the value of mm and whether yy or yy_i8 is a leap year. For the 360-day calendar, mm is [1-12] and dd is [1-30]. For the Julian-day and No-calendar, yy, yy_i8, mm, and dd are invalid inputs, since these calendars do not define them. When valid, the yy and yy_i8 arguments should be fully specified, e.g. 2003 instead of 03. yy and yy_i8 ranges are only limited by machine word size, except for the Gregorian and Julian calendars, where the lowest date limits are 3/1/-4800 and 3/1/-4712, respectively. This is a limitation of the
Gregorian date-to-Julian day and Julian date-to-Julian day conversion algorithms used to convert Gregorian and Julian dates to the internal representation of seconds. See [3] for a description of the Gregorian date-to-Julian day algorithm and [4] for a description of the Julian date-to-Julian day algorithm. The Custom calendar will have user-defined values for yy, yy_i8, mm, and dd.

The Julian day specifier, d or d_i8, can only be used with the Julian-day calendar, and has a valid range depending on the word size. For a signed 32-bit d, the range is [+- 248855]. For a signed 64-bit d or d_i8, the valid range is [+- 106,751,991,167,300]. The Julian day number system adheres to the conventional standard where the reference day of d=0 corresponds to 11/24/-4713 in the Gregorian calendar and 1/1/-4712 in the Julian calendar. See [8] and [1].

Note that d and d_i8 are not valid for the No-Calendar. To remain consistent with non-Earth calendars added to ESMF in the future, ESMF requires a calendar to be planet-specific. Hence the No-Calendar does not know what a day is; it cannot assume an Earth day of 86400 seconds.

Hours, minutes, seconds, and sub-seconds can be used with any calendar, since they are standardized units that are the same for any planet.

Time manager represents and manipulates time internally with integers to maintain precision. Hence, user-specified floating point values are converted internally to integers. Sub-second values are represented internally with an integer numerator and denominator fraction (sN/sD). The smallest resolution is nanoseconds (denominator), as per Time Manager requirement TMG3.1. Anything smaller will be truncated. For example, pi would be represented as s=3, sN=141592654, sD=1000000000. (Reals not implemented yet).

The arguments are:

- **time** The object instance to initialize.
- **[yy]** Integer year (>= 32-bit). Default = 0
- **[yy_i8]** Integer year (large, >= 64-bit). Default = 0
- **[mm]** Integer month. Default = 1
- **[dd]** Integer day of the month. Default = 1
- **[d]** Integer Julian days (>= 32-bit). Default = 0
- **[d_i8]** Integer Julian days (large, >= 64-bit). Default = 0
- **[h]** Integer hours. Default = 0
- **[m]** Integer minutes. Default = 0
- **[s]** Integer seconds (>= 32-bit). Default = 0
- **[s_i8]** Integer seconds (large, >= 64-bit). Default = 0
- **[ms]** Integer milliseconds. Default = 0.
- **[us]** Integer microseconds. Default = 0.
- **[ns]** Integer nanoseconds. Default = 0.
- **[d_r8]** Double precision days. Default = 0.0. (Not implemented yet).
- **[h_r8]** Double precision hours. Default = 0.0. (Not implemented yet).
- **[m_r8]** Double precision minutes. Default = 0.0. (Not implemented yet).
- **[s_r8]** Double precision seconds. Default = 0.0. (Not implemented yet).
- **[ms_r8]** Double precision milliseconds. Default = 0.0. (Not implemented yet).
- **[us_r8]** Double precision microseconds. Default = 0.0. (Not implemented yet).
- **[ns_r8]** Double precision nanoseconds. Default = 0.0. (Not implemented yet).
[sN] Integer numerator portion of fractional seconds (sN/sD). Default = 0.

[sD] Integer denominator portion of fractional seconds (sN/sD). Default = 1.

calendar Associated Calendar. Defaults to calendar ESMF_CAL_NOCALENDAR or default specified in ESMF_Initialize() or ESMF_CalendarSetDefault(). Alternate to, and mutually exclusive with, calendarType below. Primarily for specifying a custom calendar type.

calendarType Alternate to, and mutually exclusive with, calendar above. More convenient way of specifying a built-in calendar type.

timeZone Associated timezone (hours offset from UTC, e.g. EST = -5). Default = 0 (UTC). (Not implemented yet).

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

33.4.15 ESMF_TimeSyncToRealTime - Get system real time (wall clock time)

INTERFACE:

    subroutine ESMF_TimeSyncToRealTime(time, rc)

ARGUMENTS:

    type(ESMF_Time), intent(inout) :: time
    integer, intent(out), optional :: rc

DESCRIPTION:

Gets the system real time (wall clock time), and returns it as an ESMF_Time. Accurate to the nearest second. The arguments are:

time The object instance to receive the real time.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

33.4.16 ESMF_TimeValidate - Validate a Time

INTERFACE:

    subroutine ESMF_TimeValidate(time, options, rc)

ARGUMENTS:

    type(ESMF_Time), intent(inout) :: time
    character (len=*), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Checks whether an ESMF_Time is valid. Must be a valid date/time on a valid calendar. The options control the type of validation. The arguments are:
**time**  ESMF\_Time instant to be validated.

**[options]** Validation options. If none specified, validates all \time\ property values.
- "calendar" - validate only the \time\’s calendar.
- "timezone" - validate only the \time\’s timezone.

**[rc]** Return code; equals ESMF\_SUCCESS if there are no errors.
34 TimeInterval Class

34.1 Description

A TimeInterval represents a period between time instants. It can be either positive or negative. Like the Time interface, the TimeInterval interface is designed so that you can choose one or more options from a list of time units in order to specify a TimeInterval. See Section 33.1 Table 1 for the available options.

There are TimeInterval methods defined for setting and getting a TimeInterval, for incrementing and decrementing a TimeInterval by another TimeInterval, and for multiplying and dividing TimeIntervals by integers, reals, fractions and other TimeIntervals. Methods are also defined to take the absolute value and negative absolute value of a TimeInterval, and for comparing the length of two TimeIntervals.

The class used to represent time instants in ESMF is Time, and this class is frequently used in operations along with TimeIntervals. For example, the difference between two Times is a TimeInterval.

When a TimeInterval is used in calculations that involve an absolute reference time, such as incrementing a Time with a TimeInterval, calendar dependencies may be introduced. The length of the time period that the TimeInterval represents will depend on the reference Time and the standard calendar that is associated with it. The calendar dependency becomes apparent when, for example, adding a TimeInterval of 1 day to the Time of February 28, 1996, at 4:00pm EST. In a 360 day calendar, the resulting date would be February 29, 1996, at 4:00pm EST. In a no-leap calendar, the result would be March 1, 1996, at 4:00pm EST.

TimeIntervals are used by other parts of the ESMF timekeeping system, such as Clocks (Section 35.1) and Alarms (Section 36.1).

34.2 Use and Examples

A typical use for a TimeInterval in a geophysical model is representation of the time step by which the model is advanced. Some models change the size of their time step as the model run progresses; this could be done by incrementing or decrementing the original time step by another TimeInterval, or by dividing or multiplying the time step by an integer value. An example of advancing model time using a TimeInterval representation of a time step is shown in Section 35.1.

The following brief example shows how to create, initialize and manipulate TimeInterval.

```fortran
! PROGRAM: ESMF_TimeIntervalEx - Time Interval initialization and manipulation examples
!
! DESCRIPTION:
!
! This program shows examples of Time Interval initialization and manipulation
!-----------------------------------------------------------------------------------

! ESMF Framework module
use ESMF_Mod
implicit none

! instantiate some time intervals
type(ESMF_TimeInterval) :: timeinterval1, timeinterval2, timeinterval3

! local variables
integer :: d, h, m, s

! return code
integer:: rc

! initialize ESMF framework
call ESMF_Initialize(defaultCalendar=ESMF_CAL_GREGORIAN, rc=rc)
```

347
34.2.1 Time Interval Initialization

This example shows how to initialize two ESMF_TimeIntervals.

! initialize time interval1 to 1 day
call ESMF_TimeIntervalSet(timeinterval1, d=1, rc=rc)

call ESMF_TimeIntervalPrint(timeinterval1, "string", rc)

! initialize time interval2 to 4 days, 1 hour, 30 minutes, 10 seconds
call ESMF_TimeIntervalSet(timeinterval2, d=4, h=1, m=30, s=10, rc=rc)

call ESMF_TimeIntervalPrint(timeinterval2, "string", rc)

34.2.2 Time Interval Conversion

This example shows how to convert ESMF_TimeIntervals into different units.

call ESMF_TimeIntervalGet(timeinterval1, s=s, rc=rc)
print *, "Time Interval1 = ", s, " seconds."

call ESMF_TimeIntervalGet(timeinterval2, h=h, m=m, s=s, rc=rc)
print *, "Time Interval2 = ", h, " hours, ", m, " minutes, ", 
&
s, " seconds."

34.2.3 Time Interval Difference

This example shows how to calculate the difference between two ESMF_TimeIntervals.

! difference between two time intervals
timeinterval3 = timeinterval2 - timeinterval1
call ESMF_TimeIntervalGet(timeinterval3, d=d, h=h, m=m, s=s, rc=rc)
print *, "Difference between TimeInterval2 and TimeInterval1 = ", 
&
d, " days, ", h, " hours, ", m, " minutes, ", s, " seconds."

34.2.4 Time Interval Multiplication

This example shows how to multiply an ESMF_TimeInterval.

! multiply time interval by an integer
timeinterval3 = timeinterval2 * 3
call ESMF_TimeIntervalGet(timeinterval3, d=d, h=h, m=m, s=s, rc=rc)
print *, "TimeInterval2 multiplied by 3 = ", d, " days, ", h, &
" hours, ", m, " minutes, ", s, " seconds."
34.2.5 Time Interval Comparison

This example shows how to compare two ESMF_TimeIntervals.

! comparison
if (timeinterval1 < timeinterval2) then
  print *, "TimeInterval1 is smaller than TimeInterval2"
else
  print *, "TimeInterval1 is larger than or equal to TimeInterval2"
end if

! finalize ESMF framework
call ESMF_Finalize(rc=rc)

end program ESMF_TimeIntervalEx

34.3 Restrictions and Future Work

1. Limits on time span. The limits on the time span that can be represented are based on the 64-bit and 32-bit integer types used. For seconds, a signed 64-bit integer will have a range of +/- 2^{63}-1, or +/- 9223372036854775807. This corresponds to a range of +/- (2^{63}-1)/(86400 * 365.25) or +/- 292,271,023,045 years.

34.4 Class API

34.4.1 ESMF_TimeIntervalOperator(+) - Add two TimeIntervals

INTERFACE:

    interface operator(+)
    sum = timeinterval1 + timeinterval2
    end interface

RETURN VALUE:

    type(ESMF_TimeInterval) :: sum

ARGUMENTS:

    type(ESMF_TimeInterval), intent(in) :: timeinterval1
    type(ESMF_TimeInterval), intent(in) :: timeinterval2

DESCRIPTION:

Overloads the (+) operator for the ESMF_TimeInterval class to add timeinterval1 to timeinterval2 and return the sum as an ESMF_TimeInterval.

The arguments are:

    timeinterval1 The augend.
    timeinterval2 The addend.
34.4.2 ESMF_TimeIntervalOperator(-) - Subtract one TimeInterval from another

INTERFACE:

    interface operator(-)
    difference = timeinterval1 - timeinterval2
    end interface

RETURN VALUE:

    type(ESMF_TimeInterval) :: difference

ARGUMENTS:

    type(ESMF_TimeInterval), intent(in) :: timeinterval1
    type(ESMF_TimeInterval), intent(in) :: timeinterval2

DESCRIPTION:

Overloads the (-) operator for the ESMF_TimeInterval class to subtract timeinterval2 from timeinterval1 and return the difference as an ESMF_TimeInterval.

The arguments are:

    timeinterval1  The minuend.
    timeinterval2  The subtrahend.

34.4.3 ESMF_TimeIntervalOperator(-) - Perform unary negation on a TimeInterval

INTERFACE:

    interface operator(-)
    timeinterval = -timeinterval
    end interface

RETURN VALUE:

    type(ESMF_TimeInterval) :: -timeInterval

ARGUMENTS:

    type(ESMF_TimeInterval), intent(in) :: timeinterval

DESCRIPTION:

Overloads the (-) operator for the ESMF_TimeInterval class to perform unary negation on timeinterval and return the result.

The arguments are:

    timeinterval  The time interval to be negated.

34.4.4 ESMF_TimeIntervalOperator(/) - Divide two TimeIntervals, return double precision quotient

INTERFACE:

    interface operator(/)
    quotient = timeinterval1 / timeinterval2
    end interface
RETURN VALUE:

    real(ESMF_KIND_R8) :: quotient

ARGUMENTS:

    type(ESMF_TimeInterval), intent(in) :: timeinterval1
    type(ESMF_TimeInterval), intent(in) :: timeinterval2

DESCRIPTION:

Overloads the (/) operator for the ESMF_TimeInterval class to return timeinterval1 divided by timeinterval2 as a double precision quotient.

The arguments are:

    timeinterval1  The dividend.
    timeinterval2  The divisor.

34.4.5  ESMF_TimeIntervalOperator(/) - Divide a TimeInterval by an integer, return TimeInterval quotient

INTERFACE:

    interface operator(/)
    quotient = timeinterval / divisor
    end interface

RETURN VALUE:

    type(ESMF_TimeInterval) :: quotient

ARGUMENTS:

    type(ESMF_TimeInterval), intent(in) :: timeinterval
    integer(ESMF_KIND_I4), intent(in) :: divisor

DESCRIPTION:

Overloads the (/) operator for the ESMF_TimeInterval class to divide a timeinterval by an integer divisor, and return the quotient as an ESMF_TimeInterval.

The arguments are:

    timeinterval  The dividend.
    divisor      Integer divisor.

34.4.6  ESMF_TimeIntervalFunction(MOD) - Divide two TimeIntervals, return TimeInterval remainder

INTERFACE:

    interface MOD
    remainder = MOD(timeinterval1, timeinterval2)
    end interface

RETURN VALUE:

    type(ESMF_TimeInterval) :: remainder
ARGUMENTS:

- type(ESMF_TimeInterval), intent(in) :: timeinterval1
- type(ESMF_TimeInterval), intent(in) :: timeinterval2

DESCRIPTION:

Overloads the pre-defined MOD() function for the ESMF_TimeInterval class to return the remainder of timeinterval1 divided by timeinterval2 as an ESMF_TimeInterval.

The arguments are:

- **timeinterval1** The dividend.
- **timeinterval2** The divisor.

---

### 34.4.7 ESMF_TimeIntervalOperator(x) - Multiply a TimeInterval by an integer

**INTERFACE:**

```fortran
interface operator(*)
    product = timeinterval * multiplier
end interface
```

**RETURN VALUE:**

- type(ESMF_TimeInterval) :: product

**ARGUMENTS:**

- type(ESMF_TimeInterval), intent(in) :: timeinterval
- integer(ESMF_KIND_I4), intent(in) :: multiplier

**DESCRIPTION:**

Overloads the (*) operator for the ESMF_TimeInterval class to multiply a timeinterval by an integer multiplier, and return the product as an ESMF_TimeInterval. Commutative complement to overloaded operator (*) below.

The arguments are:

- **timeinterval** The multiplicand.
- **multiplier** The integer multiplier.

---

### 34.4.8 ESMF_TimeIntervalOperator(x) - Multiply a TimeInterval by an integer

**INTERFACE:**

```fortran
interface operator(*)
    product = multiplier * timeinterval
end interface
```

**RETURN VALUE:**

- type(ESMF_TimeInterval) :: product

**ARGUMENTS:**
Overloads the (*) operator for the ESMF_TimeInterval class to multiply a timeinterval by an integer multiplier, and return the product as an ESMF_TimeInterval.
Commutative complement to overloaded operator (*) above.
The arguments are:

multiplier The integer multiplier.
timeinterval The multiplicand.

34.4.9  ESMF_TimeIntervalOperator(==) - Test if TimeInterval 1 is equal to TimeInterval 2

INTERFACE:

interface operator(==)
   if (timeinterval1 == timeinterval2) then ... endif
   OR
   result = (timeinterval1 == timeinterval2)
end interface

RETURN VALUE:

   logical :: result

ARGUMENTS:

   type(ESMF_TimeInterval), intent(in) :: timeinterval1
   type(ESMF_TimeInterval), intent(in) :: timeinterval2

DESCRIPTION:

Overloads the (==) operator for the ESMF_TimeInterval class to return true if timeinterval1 and timeinterval2 are equal, and false otherwise.
The arguments are:
timeinterval1 First ESMF_TimeInterval in comparison.
timeinterval2 Second ESMF_TimeInterval in comparison.

34.4.10  ESMF_TimeIntervalOperator(=/=) - Test if TimeInterval 1 is not equal to TimeInterval 2

INTERFACE:

interface operator(=/=)
   if (timeinterval1 /= timeinterval2) then ... endif
   OR
   result = (timeinterval1 /= timeinterval2)
end interface

RETURN VALUE:

   logical :: result
ARGUMENTS:

type(ESMF_TimeInterval), intent(in) :: timeinterval1
type(ESMF_TimeInterval), intent(in) :: timeinterval2

DESCRIPTION:

Overloads the (=) operator for the ESMF_TimeInterval class to return true if timeinterval1 and timeinterval2 are not equal, and false otherwise.

The arguments are:

timeinterval1  First ESMF_TimeInterval in comparison.
timeinterval2  Second ESMF_TimeInterval in comparison.

34.4.11  ESMF_TimeIntervalOperator(<) - Test if TimeInterval 1 is less than TimeInterval 2

INTERFACE:

interface operator(<)
  if (timeinterval1 < timeinterval2) then ... endif
  result = (timeinterval1 < timeinterval2)
end

RETURN VALUE:

logical :: result

ARGUMENTS:

type(ESMF_TimeInterval), intent(in) :: timeinterval1
type(ESMF_TimeInterval), intent(in) :: timeinterval2

DESCRIPTION:

Overloads the (<) operator for the ESMF_TimeInterval class to return true if timeinterval1 is less than timeinterval2, and false otherwise.

The arguments are:

timeinterval1  First ESMF_TimeInterval in comparison.
timeinterval2  Second ESMF_TimeInterval in comparison.

34.4.12  ESMF_TimeIntervalOperator(<=) - Test if TimeInterval 1 is less than or equal to TimeInterval 2

INTERFACE:

interface operator(<=)
  if (timeinterval1 <= timeinterval2) then ... endif
  result = (timeinterval1 <= timeinterval2)
end

RETURN VALUE:

logical :: result
ARGUMENTS:

\[
\begin{align*}
type(\text{ESMF\_TimeInterval}), \text{intent(in)} &: \text{timeinterval1} \\
type(\text{ESMF\_TimeInterval}), \text{intent(in)} &: \text{timeinterval2}
\end{align*}
\]

DESCRIPTION:
Overloads the (\(\leq\)) operator for the ESMF\_TimeInterval class to return true if \text{timeinterval1} is less than or equal to \text{timeinterval2}, and false otherwise.
The arguments are:
\text{timeinterval1} First ESMF\_TimeInterval in comparison.
\text{timeinterval2} Second ESMF\_TimeInterval in comparison.

34.4.13 ESMF\_TimeIntervalOperator(\(>\)) - Test if TimeInterval 1 is greater than TimeInterval 2

INTERFACE:

\[
\begin{align*}
&\text{interface operator(\(>\))} \\
&\text{if (timeinterval1 > timeinterval2) then ... endif} \\
&\text{OR} \\
&\text{result = (timeinterval1 > timeinterval2)}
\end{align*}
\]

RETURN VALUE:

\[
\text{logical :: result}
\]

ARGUMENTS:

\[
\begin{align*}
type(\text{ESMF\_TimeInterval}), \text{intent(in)} &: \text{timeinterval1} \\
type(\text{ESMF\_TimeInterval}), \text{intent(in)} &: \text{timeinterval2}
\end{align*}
\]

DESCRIPTION:
Overloads the (\(<\)) operator for the ESMF\_TimeInterval class to return true if \text{timeinterval1} is greater than \text{timeinterval2}, and false otherwise.
The arguments are:
\text{timeinterval1} First ESMF\_TimeInterval in comparison.
\text{timeinterval2} Second ESMF\_TimeInterval in comparison.

34.4.14 ESMF\_TimeIntervalOperator(\(\geq\)) - Test if TimeInterval 1 is greater than or equal to TimeInterval 2

INTERFACE:

\[
\begin{align*}
&\text{interface operator(\(\geq\))} \\
&\text{if (timeinterval1 \(\geq\) timeinterval2) then ... endif} \\
&\text{OR} \\
&\text{result = (timeinterval1 \(\geq\) timeinterval2)}
\end{align*}
\]

RETURN VALUE:

\[
\text{logical :: result}
\]
ARGUMENTS:

    type(ESMF_TimeInterval), intent(in) :: timeinterval1
    type(ESMF_TimeInterval), intent(in) :: timeinterval2

DESCRIPTION:

Overloads the (<=) operator for the ESMF_TimeInterval class to return true if timeinterval1 is greater than or equal to timeinterval2, and false otherwise.

The arguments are:

    timeinterval1  First ESMF_TimeInterval in comparison.
    timeinterval2  Second ESMF_TimeInterval in comparison.

34.4.15 ESMF_TimeIntervalAbsValue - Get the absolute value of a TimeInterval

INTERFACE:

    function ESMF_TimeIntervalAbsValue(timeinterval)

RETURN VALUE:

    type(ESMF_TimeInterval) :: ESMF_TimeIntervalAbsValue

ARGUMENTS:

    type(ESMF_TimeInterval), intent(in) :: timeinterval

DESCRIPTION:

Returns the absolute value of timeinterval.

The argument is:

    timeinterval  The object instance to take the absolute value of. Absolute value is returned as the value of the function.

34.4.16 ESMF_TimeIntervalGet - Get a TimeInterval value

INTERFACE:

    ! Private name; call using ESMF_TimeIntervalGet()
    subroutine ESMF_TimeIntervalGetDur(timeinterval, &
        yy, yy_i8, &
        mm, mm_i8, &
        d, d_i8, &
        h, m, &
        s, s_i8, &
        ms, us, ns, &
        d_r8, h_r8, m_r8, s_r8, &
        ms_r8, us_r8, ns_r8, &
        sN, sD, &
        startTime, calendar, calendarType, &
        timeString, timeStringISOFrac, rc)
ARGUMENTS:

type(ESMF_TimeInterval), intent(inout) :: timeinterval
integer(ESMF_KIND_I4), intent(out), optional :: yy
integer(ESMF_KIND_I8), intent(out), optional :: yy_i8
integer(ESMF_KIND_I4), intent(out), optional :: mm
integer(ESMF_KIND_I8), intent(out), optional :: mm_i8
integer(ESMF_KIND_I4), intent(out), optional :: d
integer(ESMF_KIND_I8), intent(out), optional :: d_i8
integer(ESMF_KIND_I4), intent(out), optional :: h
integer(ESMF_KIND_I8), intent(out), optional :: m
integer(ESMF_KIND_I4), intent(out), optional :: s
integer(ESMF_KIND_I8), intent(out), optional :: s_i8
integer(ESMF_KIND_I4), intent(out), optional :: sN
integer(ESMF_KIND_I4), intent(out), optional :: sD
real(ESMF_KIND_R8), intent(out), optional :: h_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: m_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: s_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: ms_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: us_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: ns_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: d_r8
real(ESMF_KIND_R8), intent(out), optional :: m_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: s_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: ms_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: us_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: ns_r8 ! not implemented
integer(ESMF_KIND_I4), intent(out), optional :: startTime
integer(ESMF_KIND_I4), intent(out), optional :: calendar
integer(ESMF_KIND_I4), intent(out), optional :: calendarType
character (len=*) , intent(out), optional :: timeString
character (len=*) , intent(out), optional :: timeStringISOFrac
integer, intent(out), optional :: rc

DESCRIPTION:

Gets the value of timeinterval in units specified by the user via Fortran optional arguments. The ESMF Time Manager represents and manipulates time internally with integers to maintain precision. Hence, user-specified floating point values are converted internally from integers. (Reals not implemented yet). Units are bound (normalized) to the next larger unit specified. For example, if a time interval is defined to be one day, then ESMF_TimeIntervalGet(d = days, s = seconds) would return days = 1, seconds = 0, whereas ESMF_TimeIntervalGet(s = seconds) would return seconds = 86400. See ../include/ESMC_BaseTime.h and ../include/ESMC_TimeInterval.h for complete description.

For timeString, converts ESMF_TimeInterval's value into partial ISO 8601 format PyYmMdDThHmMs[n/d]S. See §5 and §6. See also method ESMF_TimeIntervalPrint().

For timeStringISOFrac, converts ESMF_TimeInterval's value into full ISO 8601 format PyYmMdDThHmMs[f]S. See §5 and §6. See also method ESMF_TimeIntervalPrint().

The arguments are:

timeinterval The object instance to query.

[yy] Integer years (>= 32-bit).

[yy_i8] Integer years (large, >= 64-bit).

[mm] Integer months (>= 32-bit).

[mm_i8] Integer months (large, >= 64-bit).
[**d**] Integer Julian days (\(\geq 32\)-bit).

[**d_i8**] Integer Julian days (large, \(\geq 64\)-bit).

[**h**] Integer hours.

[**m**] Integer minutes.

[**s**] Integer seconds (\(\geq 32\)-bit).

[**s_i8**] Integer seconds (large, \(\geq 64\)-bit).

[**ms**] Integer milliseconds.

[**us**] Integer microseconds.

[**ns**] Integer nanoseconds.

[**d_r8**] Double precision days. (Not implemented yet).

[**h_r8**] Double precision hours. (Not implemented yet).

[**m_r8**] Double precision minutes. (Not implemented yet).

[**s_r8**] Double precision seconds. (Not implemented yet).

[**ms_r8**] Double precision milliseconds. (Not implemented yet).

[**us_r8**] Double precision microseconds. (Not implemented yet).

[**ns_r8**] Double precision nanoseconds. (Not implemented yet).

[**sN**] Integer numerator portion of fractional seconds (sN/sD).

[**sD**] Integer denominator portion of fractional seconds (sN/sD).

[**startTime**] Starting time, if set, of an absolute calendar interval (yy, mm, and/or d).

[**calendar**] Associated Calendar, if any.

[**calendarType**] Associated CalendarType, if any.

[**timeString**] Convert time interval value to format string PyYmMdDTmHmMs:[n/d]S, where n/d is numerator/denominator of any fractional seconds and all other units are in ISO 8601 format. See [5] and [2]. See also method ESMF_TimeIntervalPrint().

[**timeStringISOFrac**] Convert time interval value to strict ISO 8601 format string PyYmMdDTmHmMs[,]f, where f is decimal form of any fractional seconds. See [5] and [2]. See also method ESMF_TimeIntervalPrint().

[**rc**] Return code; equals ESMF_SUCCESS if there are no errors.
34.4.17  ESMF_TimeIntervalGet - Get a TimeInterval value

INTERFACE:

! Private name; call using ESMF_TimeIntervalGet()
subroutine ESMF_TimeIntervalGetDurStart(timeinterval, &
yy, yy_i8, &
mm, mm_i8, &
d, d_i8, &
h, m, &
s, s_i8, &
ms, us, ns, &
d_r8, h_r8, m_r8, s_r8, &
ms_r8, us_r8, ns_r8, &
sN, sD, &
startTime, &
calendar, calendarType, &
startTimeIn, &
timeString, timeStringISOFrac, rc)

ARGUMENTS:

  type(ESMF_TimeInterval), intent(inout) :: timeinterval
  integer(ESMF_KIND_I4), intent(out), optional :: yy
  integer(ESMF_KIND_I8), intent(out), optional :: mm
  integer(ESMF_KIND_I4), intent(out), optional :: d
  integer(ESMF_KIND_I4), intent(out), optional :: h
  integer(ESMF_KIND_I4), intent(out), optional :: s
  integer(ESMF_KIND_I4), intent(out), optional :: ms
  integer(ESMF_KIND_I4), intent(out), optional :: d_r8
  integer(ESMF_KIND_I4), intent(out), optional :: h_r8
  integer(ESMF_KIND_I4), intent(out), optional :: m
  integer(ESMF_KIND_I4), intent(out), optional :: s_r8
  integer(ESMF_KIND_I4), intent(out), optional :: ms_r8
  integer(ESMF_KIND_I4), intent(out), optional :: us
  integer(ESMF_KIND_I4), intent(out), optional :: ns
  integer(ESMF_KIND_I4), intent(out), optional :: sN
  integer(ESMF_KIND_I4), intent(out), optional :: sD
  type(ESMF_Time), intent(out), optional :: startTime
  type(ESMF_Calendar), intent(out), optional :: calendar
  type(ESMF_CalendarType), intent(out), optional :: calendarType
  type(ESMF_Time), intent(inout) :: startTimeIn  ! Input
  character (len=*) , intent(out), optional :: timeString
  character (len=*) , intent(out), optional :: timeStringISOFrac
  integer, intent(out), optional :: rc

DESCRIPTION:
Gets the value of `timeinterval` in units specified by the user via Fortran optional arguments. The ESMF Time Manager represents and manipulates time internally with integers to maintain precision. Hence, user-specified floating point values are converted internally from integers. (Reals not implemented yet). Units are bound (normalized) to the next larger unit specified. For example, if a time interval is defined to be one day, then `ESMF_TimeIntervalGet(d = days, s = seconds)` would return `days = 1, seconds = 0`, whereas `ESMF_TimeIntervalGet(s = seconds)` would return `seconds = 86400`. See `../include/ESMC_BaseTime.h` and `../include/ESMC_TimeInterval.h` for complete description.

For `timeString`, converts ESMF_TimeInterval’s value into partial ISO 8601 format `PyYmMdDTmHmMsn:[n/d]S`. See [3] and [2]. See also method `ESMF_TimeIntervalPrint()`.

For `timeStringISOFra`, converts ESMF_TimeInterval’s value into full ISO 8601 format `PyYmMdDTmHmMsn.fS`. See [3] and [2]. See also method `ESMF_TimeIntervalPrint()`.

The arguments are:

- `timeinterval` The object instance to query.
  - `[yy]` Integer years (>= 32-bit).
  - `[yy_i8]` Integer years (large, >= 64-bit).
  - `[mm]` Integer months (>= 32-bit).
  - `[mm_i8]` Integer months (large, >= 64-bit).
  - `[d]` Integer Julian days (>= 32-bit).
  - `[d_i8]` Integer Julian days (large, >= 64-bit).
  - `[h]` Integer hours.
  - `[m]` Integer minutes.
  - `[s]` Integer seconds (>= 32-bit).
  - `[s_i8]` Integer seconds (large, >= 64-bit).
  - `[ms]` Integer milliseconds.
  - `[us]` Integer microseconds.
  - `[ns]` Integer nanoseconds.
  - `[d_r8]` Double precision days. (Not implemented yet).
  - `[h_r8]` Double precision hours. (Not implemented yet).
  - `[m_r8]` Double precision minutes. (Not implemented yet).
  - `[s_r8]` Double precision seconds. (Not implemented yet).
  - `[ms_r8]` Double precision milliseconds. (Not implemented yet).
  - `[us_r8]` Double precision microseconds. (Not implemented yet).
  - `[ns_r8]` Double precision nanoseconds. (Not implemented yet).
  - `[sN]` Integer numerator portion of fractional seconds (sN/sD).
  - `[sD]` Integer denominator portion of fractional seconds (sN/sD).
  - `[startTime]` Starting time, if set, of an absolute calendar interval (yy, mm, and/or d).
  - `[calendar]` Associated Calendar, if any.
[calendarType]  Associated CalendarType, if any.

startTimeIn  INPUT argument: pins a calendar interval to a specific point in time to allow conversion between relative units (yy, mm, d) and absolute units (d, h, m, s). Overrides any startTime and/or endTime previously set. Mutually exclusive with endTimeIn and calendarIn.

timeString  Convert time interval value to format string PyYMdDTmHmMs[n/d]S, where n/d is numerator/denominator of any fractional seconds and all other units are in ISO 8601 format. See [5] and [2]. See also method ESMF_TimeIntervalPrint().

timeStringISOfrac  Convert time interval value to strict ISO 8601 format string PyYMdDTmHmMs[f], where f is decimal form of any fractional seconds. See [5] and [2]. See also method ESMF_TimeIntervalPrint().

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

34.4.18  ESMF_TimeIntervalGet - Get a TimeInterval value

INTERFACE:

! Private name; call using ESMF_TimeIntervalGet()
subroutine ESMF_TimeIntervalGetDurCal(timeinterval, &
  yy, yy_i8, &
  mm, mm_i8, &
  d, d_i8, &
  h, m, &
  s, s_i8, &
  ms, us, ns, &
  d_r8, h_r8, m_r8, s_r8, &
  ms_r8, us_r8, ns_r8, &
  sN, sD, &
  startTime, &
  calendar, calendarType, &
  calendarIn, &
  timeString, timeStringISOfrac, rc)

ARGUMENTS:

type(ESMF_TimeInterval), intent(inout) :: timeinterval
integer(ESMF_KIND_I4), intent(out), optional :: yy
integer(ESMF_KIND_I8), intent(out), optional :: yy_i8
integer(ESMF_KIND_I4), intent(out), optional :: mm
integer(ESMF_KIND_I8), intent(out), optional :: mm_i8
integer(ESMF_KIND_I4), intent(out), optional :: d
integer(ESMF_KIND_I8), intent(out), optional :: d_i8
integer(ESMF_KIND_I4), intent(out), optional :: h
integer(ESMF_KIND_I4), intent(out), optional :: m
integer(ESMF_KIND_I4), intent(out), optional :: s
integer(ESMF_KIND_I8), intent(out), optional :: s_i8
integer(ESMF_KIND_I4), intent(out), optional :: ms
integer(ESMF_KIND_I4), intent(out), optional :: us
integer(ESMF_KIND_I4), intent(out), optional :: ns
real(ESMF_KIND_R8), intent(out), optional :: d_r8
real(ESMF_KIND_R8), intent(out), optional :: h_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: m_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: s_r8  ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: ms_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: us_r8 ! not implemented
real(ESMF_KIND_R8), intent(out), optional :: ns_r8 ! not implemented
integer(ESMF_KIND_I4), intent(out), optional :: sN
integer(ESMF_KIND_I4), intent(out), optional :: sD
type(ESMF_Time), intent(inout), optional :: startTime
type(ESMF_Calendar), intent(out), optional :: calendar
type(ESMF_CalendarType), intent(out), optional :: calendarType
type(ESMF_Calendar), intent(in) :: calendarIn  ! Input
classer (len=*), intent(out), optional :: timeString
character (len=*), intent(out), optional :: timeStringISOFrac
integer, intent(out), optional :: rc

DESCRIPTION:

Gets the value of timeinterval in units specified by the user via Fortran optional arguments. The ESMF Time Manager represents and manipulates time internally with integers to maintain precision. Hence, user-specified floating point values are converted internally from integers. (Reals not implemented yet).

Units are bound (normalized) to the next larger unit specified. For example, if a time interval is defined to be one day, then ESMF_TimeIntervalGet(d = days, s = seconds) would return days = 1, seconds = 0, whereas ESMF_TimeIntervalGet(s = seconds) would return seconds = 86400.

See ../include/ESMC_BaseTime.h and ../include/ESMC_TimeInterval.h for complete description.

For timeString, converts ESMF_TimeInterval’s value into partial ISO 8601 format PyYmMdDThHmMs[:n/d]S. See [5] and [2]. See also method ESMF_TimeIntervalPrint().

For timeStringISOFrac, converts ESMF_TimeInterval’s value into full ISO 8601 format PyYmMdDThHmMs[f]S. See [5] and [2]. See also method ESMF_TimeIntervalPrint().

The arguments are:

timeinterval  The object instance to query.

[yy] Integer years (>= 32-bit).
[yy_i8] Integer years (large, >= 64-bit).
[mm] Integer months (>= 32-bit).
[mm_i8] Integer months (large, >= 64-bit).
[d] Integer Julian days (>= 32-bit).
[d_i8] Integer Julian days (large, >= 64-bit).
[h] Integer hours.
[m] Integer minutes.
[s] Integer seconds (>= 32-bit).
[s_i8] Integer seconds (large, >= 64-bit).
[ms] Integer milliseconds.
[us] Integer microseconds.
[ns] Integer nanoseconds.
[d_r8] Double precision days. (Not implemented yet).
[h_r8] Double precision hours. (Not implemented yet).
[m_r8] Double precision minutes. (Not implemented yet).
[s_r8] Double precision seconds. (Not implemented yet).
[ms_r8] Double precision milliseconds. (Not implemented yet).
[us_r8] Double precision microseconds. (Not implemented yet).
[ns_r8] Double precision nanoseconds. (Not implemented yet).
[sN] Integer numerator portion of fractional seconds (sN/sD).
[sD] Integer denominator portion of fractional seconds (sN/sD).
[startTime] Starting time, if set, of an absolute calendar interval (yy, mm, and/or d).
[calendar] Associated Calendar, if any.
[calendarType] Associated CalendarType, if any.
[calendarIn] INPUT argument: pins a calendar interval to a specific calendar to allow conversion between relative units (yy, mm, d) and absolute units (d, h, m, s). Mutually exclusive with startTimeIn and endTimeIn since they contain a calendar. Alternate to, and mutually exclusive with, calendarTypeIn below. Primarily for specifying a custom calendar type.
[timeString] Convert time interval value to format string PyYmMdDThHmMs[:n/d]S, where n/d is numerator/denominator of any fractional seconds and all other units are in ISO 8601 format. See [5] and [2]. See also method ESMF_TimeIntervalPrint().
[timeStringISOFrac] Convert time interval value to strict ISO 8601 format string PyYmMdDThHmMs[,f], where f is decimal form of any fractional seconds. See [5] and [2]. See also method ESMF_TimeIntervalPrint().
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

34.4.19 ESMF_TimeIntervalGet - Get a TimeInterval value

INTERFACE:

! Private name; call using ESMF_TimeIntervalGet()
subroutine ESMF_TimeIntervalGetDurCalTyp(timeinterval, &
  yy, yy_i8, &
  mm, mm_i8, &
  d, d_i8, &
  h, m, &
  s, s_i8, &
  ms, us, ns, &
  d_r8, h_r8, m_r8, s_r8, &
  ms_r8, us_r8, ns_r8, &
  sN, sD, &
  startTime, &
  calendar, calendarType, &
  calendarTypeIn, &
  timeString, &
  timeStringISOFrac, rc)
ARGUMENTS:

```fortran
  type(ESMF_TimeInterval), intent(inout) :: timeinterval
  integer(ESMF_KIND_I4), intent(out), optional :: yy
  integer(ESMF_KIND_I8), intent(out), optional :: yy_i8
  integer(ESMF_KIND_I4), intent(out), optional :: mm
  integer(ESMF_KIND_I8), intent(out), optional :: mm_i8
  integer(ESMF_KIND_I4), intent(out), optional :: d
  integer(ESMF_KIND_I8), intent(out), optional :: d_i8
  integer(ESMF_KIND_I4), intent(out), optional :: h
  integer(ESMF_KIND_I4), intent(out), optional :: m
  integer(ESMF_KIND_I8), intent(out), optional :: s
  integer(ESMF_KIND_I8), intent(out), optional :: s_i8
  integer(ESMF_KIND_I4), intent(out), optional :: ms
  integer(ESMF_KIND_I4), intent(out), optional :: us
  integer(ESMF_KIND_I4), intent(out), optional :: ns
  real(ESMF_KIND_R8), intent(out), optional :: d_r8
  real(ESMF_KIND_R8), intent(out), optional :: h_r8 ! not implemented
  real(ESMF_KIND_R8), intent(out), optional :: m_r8 ! not implemented
  real(ESMF_KIND_R8), intent(out), optional :: s_r8 ! not implemented
  real(ESMF_KIND_R8), intent(out), optional :: ms_r8 ! not implemented
  real(ESMF_KIND_R8), intent(out), optional :: us_r8 ! not implemented
  real(ESMF_KIND_R8), intent(out), optional :: ns_r8 ! not implemented
  integer(ESMF_KIND_I4), intent(out), optional :: sN
  integer(ESMF_KIND_I4), intent(out), optional :: sD
  type(ESMF_Time), intent(out), optional :: startTime
  type(ESMF_Calendar), intent(out), optional :: calendar
  type(ESMF_CalendarType), intent(out), optional :: calendarType
  type(ESMF_CalendarType), intent(in) :: calendarTypeIn ! Input
  character (len=*), intent(out), optional :: timeString
  character (len=*), intent(out), optional :: timeStringISOFrac
  integer, intent(out), optional :: rc
```

DESCRIPTION:

Gets the value of `timeinterval` in units specified by the user via Fortran optional arguments. The ESMF Time Manager represents and manipulates time internally with integers to maintain precision. Hence, user-specified floating point values are converted internally from integers. (Reals not implemented yet).

Units are bound (normalized) to the next larger unit specified. For example, if a time interval is defined to be one day, then `ESMF_TimeIntervalGet(d = days, s = seconds)` would return `days = 1, seconds = 0`, whereas `ESMF_TimeIntervalGet(s = seconds)` would return `seconds = 86400`.

See `../include/ESMC_BaseTime.h` and `../include/ESMC_TimeInterval.h` for complete description.

For `timeString`, converts `ESMF_TimeInterval`'s value into partial ISO 8601 format `PyYmMdDThHmMs[:n/d]S`.

See [5] and [2]. See also method `ESMF_TimeIntervalPrint()`.

For `timeStringISOFrac`, converts `ESMF_TimeInterval`'s value into full ISO 8601 format `PyYmMdDThHmMs[.f]S`.

See [5] and [2]. See also method `ESMF_TimeIntervalPrint()`.

The arguments are:

- `timeinterval` The object instance to query.
- `[yy]` Integer years (>= 32-bit).
- `[yy_i8]` Integer years (large, >= 64-bit).
- `[mm]` Integer months (>= 32-bit).
[mm_i8] Integer months (large, >= 64-bit).
[d] Integer Julian days (>= 32-bit).
[d_i8] Integer Julian days (large, >= 64-bit).
[h] Integer hours.
[m] Integer minutes.
[s] Integer seconds (>= 32-bit).
[s_i8] Integer seconds (large, >= 64-bit).
[ms] Integer milliseconds.
[us] Integer microseconds.
[ns] Integer nanoseconds.
[d_r8] Double precision days. (Not implemented yet).
[h_r8] Double precision hours. (Not implemented yet).
[m_r8] Double precision minutes. (Not implemented yet).
[s_r8] Double precision seconds. (Not implemented yet).
[ms_r8] Double precision milliseconds. (Not implemented yet).
[us_r8] Double precision microseconds. (Not implemented yet).
[ns_r8] Double precision nanoseconds. (Not implemented yet).
[sN] Integer numerator portion of fractional seconds (sN/sD).
[sD] Integer denominator portion of fractional seconds (sN/sD).
[startTime] Starting time, if set, of an absolute calendar interval (yy, mm, and/or d).
[calendar] Associated Calendar, if any.
[calendarType] Associated CalendarType, if any.
[calendarTypeIn] INPUT argument: Alternate to, and mutually exclusive with, calendarIn above. More convenient way of specifying a built-in calendar type.
[timeString] Convert time interval value to format string PyYmMdDThHmMs[:n/d]S, where n/d is numerator/denominator of any fractional seconds and all other units are in ISO 8601 format. See [5] and [2]. See also method ESMF_TimeIntervalPrint().
[timeStringISOFrac] Convert time interval value to strict ISO 8601 format string PyYmMdDThHmMs[.f], where f is decimal form of any fractional seconds. See [5] and [2]. See also method ESMF_TimeIntervalPrint().
[rc] Return code; equals ESMF_SUCCESS if there are no errors.
34.4.20  ESMF_TimeIntervalNegAbsValue - Get the negative absolute value of a TimeInterval

INTERFACE:

    function ESMF_TimeIntervalNegAbsValue(timeinterval)

RETURN VALUE:

    type(ESMF_TimeInterval) :: ESMF_TimeIntervalNegAbsValue

ARGUMENTS:

    type(ESMF_TimeInterval), intent(inout) :: timeinterval

DESCRIPTION:

Returns the negative absolute value of timeinterval.
The argument is:

    timeinterval The object instance to take the negative absolute value of. Negative absolute value is returned as the
                 value of the function.

34.4.21  ESMF_TimeIntervalPrint - Print the contents of a TimeInterval

INTERFACE:

    subroutine ESMF_TimeIntervalPrint(timeinterval, options, rc)

ARGUMENTS:

    type(ESMF_TimeInterval), intent(inout) :: timeinterval
    character (len=*) , intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Prints out the contents of an ESMF_TimeInterval to stdout, in support of testing and debugging. The options
control the type of information and level of detail.
The arguments are:

    timeinterval Time interval to be printed out.

[options] Print options. If none specified, prints all timeinterval property values.
        "string" - prints timeinterval's value in ISO 8601 format for all units through seconds. For any non-zero
        fractional seconds, prints in integer rational fraction form n/d. Format is PyYmMdDThHmMs[:n/d]S, where
        [:n/d] is the integer numerator and denominator of the fractional seconds value, if present. See [5] and [2]. See
        also method ESMF_TimeIntervalGet(..., timeString= , ...)
        "string isofrac" - prints timeinterval's value in strict ISO 8601 format for all units, including any fractional
        seconds part. Format is PyYmMdDThHmMs[.f]S, where [.f] represents fractional seconds in decimal form, if
        present. See [5] and [2]. See also method ESMF_TimeIntervalGet(..., timeStringISOFrac= , ...)

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
### 34.4.22 ESMF_TimeIntervalSet - Initialize or set a TimeInterval

**INTERFACE:**

```fortran
! Private name; call using ESMF_TimeIntervalSet()
subroutine ESMF_TimeIntervalSetDur(timeinterval, &
   yy, yy_i8, &
   mm, mm_i8, &
   d, d_i8, &
   h, m, &
   s, s_i8, &
   ms, us, ns, &
   d_r8, h_r8, m_r8, s_r8, &
   ms_r8, us_r8, ns_r8, &
   sN, sD, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_TimeInterval), intent(inout) :: timeinterval
integer(ESMF_KIND_I4), intent(in), optional :: yy
integer(ESMF_KIND_I8), intent(in), optional :: yy_i8
integer(ESMF_KIND_I4), intent(in), optional :: mm
integer(ESMF_KIND_I8), intent(in), optional :: mm_i8
d, d_i8, &
h, m, &
s, s_i8, &
ms, us, ns, &
d_r8, h_r8, m_r8, s_r8, &
ms_r8, us_r8, ns_r8, &
sN, sD, rc)
```

**DESCRIPTION:**

Sets the value of the `ESMF_TimeInterval` in units specified by the user via Fortran optional arguments. The ESMF Time Manager represents and manipulates time internally with integers to maintain precision. Hence, user-specified floating point values are converted internally to integers. (Reals not implemented yet). Ranges are limited only by machine word size. Numeric defaults are 0, except for sD, which is 1.

The arguments are:

- `timeinterval` The object instance to initialize.
- `[yy]` Integer years (>= 32-bit). Default = 0
- `[yy_i8]` Integer years (large, >= 64-bit). Default = 0
Integer months (>= 32-bit). Default = 0

Integer months (large, >= 64-bit). Default = 0

Integer Julian days (>= 32-bit). Default = 0

Integer Julian days (large, >= 64-bit). Default = 0

Integer hours. Default = 0

Integer minutes. Default = 0

Integer seconds (>= 32-bit). Default = 0

Integer seconds (large, >= 64-bit). Default = 0

Integer milliseconds. Default = 0.

Integer microseconds. Default = 0.

Integer nanoseconds. Default = 0.

Double precision days. Default = 0.0. (Not implemented yet).

Double precision hours. Default = 0.0. (Not implemented yet).

Double precision minutes. Default = 0.0. (Not implemented yet).

Double precision seconds. Default = 0.0. (Not implemented yet).

Double precision milliseconds. Default = 0.0. (Not implemented yet).

Double precision microseconds. Default = 0.0. (Not implemented yet).

Double precision nanoseconds. Default = 0.0. (Not implemented yet).

Integer numerator portion of fractional seconds (sN/sD). Default = 0.

Integer denominator portion of fractional seconds (sN/sD). Default = 1.

Return code; equals ESMF_SUCCESS if there are no errors.

34.4.23 ESMF_TimeIntervalSet - Initialize or set a TimeInterval

INTERFACE:

! Private name; call using ESMF_TimeIntervalSet()
subroutine ESMF_TimeIntervalSetDurStart(timeinterval, &
  yy, yy_i8, &
  mm, mm_i8, &
  d, d_i8, &
  h, m, &
  s, s_i8, &
  ms, us, ns, &
  d_r8, h_r8, m_r8, s_r8, &
  ms_r8, us_r8, ns_r8, &
  sN, sD, startTime, rc)
ARGUMENTS:

- `type(ESMF_TimeInterval), intent(inout) :: timeinterval`
- `integer(ESMF_KIND_I4), intent(in), optional :: yy`
- `integer(ESMF_KIND_I8), intent(in), optional :: yy_i8`
- `integer(ESMF_KIND_I4), intent(in), optional :: mm`
- `integer(ESMF_KIND_I8), intent(in), optional :: mm_i8`
- `integer(ESMF_KIND_I4), intent(in), optional :: d`
- `integer(ESMF_KIND_I8), intent(in), optional :: d_i8`
- `integer(ESMF_KIND_I4), intent(in), optional :: h`
- `integer(ESMF_KIND_I4), intent(in), optional :: m`
- `integer(ESMF_KIND_I4), intent(in), optional :: s`
- `integer(ESMF_KIND_I8), intent(in), optional :: s_i8`
- `integer(ESMF_KIND_I4), intent(in), optional :: ms`
- `integer(ESMF_KIND_I4), intent(in), optional :: us`
- `real(ESMF_KIND_R8), intent(in), optional :: d_r8` ! not implemented
- `real(ESMF_KIND_R8), intent(in), optional :: h_r8` ! not implemented
- `real(ESMF_KIND_R8), intent(in), optional :: m_r8` ! not implemented
- `real(ESMF_KIND_R8), intent(in), optional :: s_r8` ! not implemented
- `real(ESMF_KIND_R8), intent(in), optional :: ms_r8` ! not implemented
- `real(ESMF_KIND_R8), intent(in), optional :: us_r8` ! not implemented
- `integer(ESMF_KIND_I4), intent(in), optional :: sN`
- `integer(ESMF_KIND_I4), intent(in), optional :: sD`  
- `type(ESMF_Time), intent(inout) :: startTime`
- `integer, intent(out), optional :: rc`

DESCRIPTION:

Sets the value of the ESMF_TimeInterval in units specified by the user via Fortran optional arguments.

The ESMF Time Manager represents and manipulates time internally with integers to maintain precision. Hence, user-specified floating point values are converted internally to integers. (Reals not implemented yet).

Ranges are limited only by machine word size. Numeric defaults are 0, except for sD, which is 1.

The arguments are:

- **timeinterval**: The object instance to initialize.
- **[yy]** Integer years (≥ 32-bit). Default = 0
- **[yy_i8]** Integer years (large, ≥ 64-bit). Default = 0
- **[mm]** Integer months (≥ 32-bit). Default = 0
- **[mm_i8]** Integer months (large, ≥ 64-bit). Default = 0
- **[d]** Integer Julian days (≥ 32-bit). Default = 0
- **[d_i8]** Integer Julian days (large, ≥ 64-bit). Default = 0
- **[h]** Integer hours. Default = 0
- **[m]** Integer minutes. Default = 0
- **[s]** Integer seconds (≥ 32-bit). Default = 0
- **[s_i8]** Integer seconds (large, ≥ 64-bit). Default = 0
- **[ms]** Integer milliseconds. Default = 0
[us]  Integer microseconds. Default = 0.
[ns]  Integer nanoseconds. Default = 0.
[d_r8]  Double precision days. Default = 0.0. (Not implemented yet).
[h_r8]  Double precision hours. Default = 0.0. (Not implemented yet).
[m_r8]  Double precision minutes. Default = 0.0. (Not implemented yet).
[s_r8]  Double precision seconds. Default = 0.0. (Not implemented yet).
[ms_r8]  Double precision milliseconds. Default = 0.0. (Not implemented yet).
[us_r8]  Double precision microseconds. Default = 0.0. (Not implemented yet).
[ns_r8]  Double precision nanoseconds. Default = 0.0. (Not implemented yet).
[sN]  Integer numerator portion of fractional seconds (sN/sD). Default = 0.
[sD]  Integer denominator portion of fractional seconds (sN/sD). Default = 1.

startTime  Starting time of an absolute calendar interval (yy, mm, and/or d); pins a calendar interval to a specific point in time. If not set, and calendar also not set, calendar interval "floats" across all calendars and times.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

34.4.24  ESMF_TimeIntervalSet - Initialize or set a TimeInterval

INTERFACE:

  ! Private name; call using ESMF_TimeIntervalSet()
  subroutine ESMF_TimeIntervalSetDurCal(timeinterval, &
     yy, yy_i8, &
     mm, mm_i8, &
     d, d_i8, &
     h, m, &
     s, s_i8, &
     ms, us, ns, &
     d_r8, h_r8, m_r8, s_r8, &
     ms_r8, us_r8, ns_r8, &
     sN, sD, calendar, rc)

ARGUMENTS:

  type(ESMF_TimeInterval), intent(inout) :: timeinterval
  integer(ESMF_KIND_I4), intent(in), optional :: yy
  integer(ESMF_KIND_I8), intent(in), optional :: yy_i8
  integer(ESMF_KIND_I4), intent(in), optional :: mm
  integer(ESMF_KIND_I8), intent(in), optional :: mm_i8
  integer(ESMF_KIND_I4), intent(in), optional :: d
  integer(ESMF_KIND_I4), intent(in), optional :: h
  integer(ESMF_KIND_I4), intent(in), optional :: m
  integer(ESMF_KIND_I4), intent(in), optional :: s
  integer(ESMF_KIND_I8), intent(in), optional :: s_i8
  integer(ESMF_KIND_I8), intent(in), optional :: sN
  integer(ESMF_KIND_I8), intent(in), optional :: sD
  integer(ESMF_KIND_I4), intent(in), optional :: calendar
  integer(ESMF_KIND_I4), intent(inout) :: rc

370
DESCRIPTION:

Sets the value of the ESMF_TimeInterval in units specified by the user via Fortran optional arguments.
The ESMF Time Manager represents and manipulates time internally with integers to maintain precision. Hence,
user-specified floating point values are converted internally to integers. (Reals not implemented yet).
Ranges are limited only by machine word size. Numeric defaults are 0, except for sD, which is 1.
The arguments are:

timeinterval The object instance to initialize.

[yy] Integer years (>= 32-bit). Default = 0
[yy_i8] Integer years (large, >= 64-bit). Default = 0
[mm] Integer months (>= 32-bit). Default = 0
[mm_i8] Integer months (large, >= 64-bit). Default = 0
[d] Integer Julian days (>= 32-bit). Default = 0
[d_i8] Integer Julian days (large, >= 64-bit). Default = 0
[h] Integer hours. Default = 0
[m] Integer minutes. Default = 0
[s] Integer seconds (>= 32-bit). Default = 0
[s_i8] Integer seconds (large, >= 64-bit). Default = 0
[ms] Integer milliseconds. Default = 0.
[us] Integer microseconds. Default = 0.
[ns] Integer nanoseconds. Default = 0.
[d_r8] Double precision days. Default = 0.0. (Not implemented yet).
[h_r8] Double precision hours. Default = 0.0. (Not implemented yet).
[m_r8] Double precision minutes. Default = 0.0. (Not implemented yet).
[s_r8] Double precision seconds. Default = 0.0. (Not implemented yet).
[ms_r8] Double precision milliseconds. Default = 0.0. (Not implemented yet).
Double precision microseconds. Default = 0.0. (Not implemented yet).

Double precision nanoseconds. Default = 0.0. (Not implemented yet).

Integer numerator portion of fractional seconds (sN/sD). Default = 0.

Integer denominator portion of fractional seconds (sN/sD). Default = 1.

Calendar used to give better definition to calendar interval (yy, mm, and/or d) for arithmetic, comparison, and conversion operations. Allows calendar interval to "float" across all times on a specific calendar. Default = NULL; if startTime also not specified, calendar interval "floats" across all calendars and times. Mutually exclusive with startTime since it contains a calendar. Alternate to, and mutually exclusive with, calendarType below. Primarily for specifying a custom calendar type.

Return code; equals ESMF_SUCCESS if there are no errors.

34.4.25 ESMF_TimeIntervalSet - Initialize or set a TimeInterval

INTERFACE:

! Private name; call using ESMF_TimeIntervalSet()
! subroutin ESMF_TimeIntervalSetDurtCalTyp(timeinterval, 
&
   yy, yy_i8, 
   mm, mm_i8, 
   d, d_i8, 
   h, m, 
   s, s_i8, 
   ms, us, ns, 
   d_r8, h_r8, m_r8, s_r8, 
   ms_r8, us_r8, ns_r8, &
   sN, sD, calendarType, rc)

ARGUMENTS:

type(ESMF_TimeInterval), intent(inout) :: timeinterval
integer(ESMF_KIND_I4), intent(in), optional :: yy
integer(ESMF_KIND_I8), intent(in), optional :: yy_i8
integer(ESMF_KIND_I4), intent(in), optional :: mm
integer(ESMF_KIND_I8), intent(in), optional :: mm_i8
integer(ESMF_KIND_I4), intent(in), optional :: d
integer(ESMF_KIND_I8), intent(in), optional :: d_i8
integer(ESMF_KIND_I4), intent(in), optional :: h
integer(ESMF_KIND_I4), intent(in), optional :: m
integer(ESMF_KIND_I4), intent(in), optional :: s
integer(ESMF_KIND_I4), intent(in), optional :: s_i8
integer(ESMF_KIND_I4), intent(in), optional :: ms
integer(ESMF_KIND_I4), intent(in), optional :: us
integer(ESMF_KIND_I4), intent(in), optional :: ns
real(ESMF_KIND_R8), intent(in), optional :: d_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: h_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: m_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: s_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: ms_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: us_r8 ! not implemented
real(ESMF_KIND_R8), intent(in), optional :: ns_r8 ! not implemented
integer(ESMF_KIND_I4), intent(in), optional :: sN
integer(ESMF_KIND_I4), intent(in), optional :: sD
type(ESMF_CalendarType), intent(in) :: calendarType
integer, intent(out), optional :: rc

DESCRIPTION:

Sets the value of the ESMF_TimeInterval in units specified by the user via Fortran optional arguments. The ESMF Time Manager represents and manipulates time internally with integers to maintain precision. Hence, user-specified floating point values are converted internally to integers. (Reals not implemented yet). Ranges are limited only by machine word size. Numeric defaults are 0, except for sD, which is 1.

The arguments are:

- **timeinterval** The object instance to initialize.
- [yy] Integer years (>= 32-bit). Default = 0
- [yy_i8] Integer years (large, >= 64-bit). Default = 0
- [mm] Integer months (>= 32-bit). Default = 0
- [mm_i8] Integer months (large, >= 64-bit). Default = 0
- [d] Integer Julian days (>= 32-bit). Default = 0
- [d_i8] Integer Julian days (large, >= 64-bit). Default = 0
- [h] Integer hours. Default = 0
- [m] Integer minutes. Default = 0
- [s] Integer seconds (>= 32-bit). Default = 0
- [s_i8] Integer seconds (large, >= 64-bit). Default = 0
- [ms] Integer milliseconds. Default = 0.
- [us] Integer microseconds. Default = 0.
- [ns] Integer nanoseconds. Default = 0.
- [d_r8] Double precision days. Default = 0.0. (Not implemented yet).
- [h_r8] Double precision hours. Default = 0.0. (Not implemented yet).
- [m_r8] Double precision minutes. Default = 0.0. (Not implemented yet).
- [s_r8] Double precision seconds. Default = 0.0. (Not implemented yet).
- [ms_r8] Double precision milliseconds. Default = 0.0. (Not implemented yet).
- [us_r8] Double precision microseconds. Default = 0.0. (Not implemented yet).
- [ns_r8] Double precision nanoseconds. Default = 0.0. (Not implemented yet).
- [sN] Integer numerator portion of fractional seconds (sN/sD). Default = 0.
- [sD] Integer denominator portion of fractional seconds (sN/sD). Default = 1.
- **calendarType** Alternate to, and mutually exclusive with, calendar above. More convenient way of specifying a built-in calendar type.
- **rc** Return code; equals ESMF_SUCCESS if there are no errors.
34.4.26  ESMF_TimeIntervalValidate - Validate a TimeInterval

INTERFACE:

    subroutine ESMF_TimeIntervalValidate(timeinterval, options, rc)

ARGUMENTS:

    type(ESMF_TimeInterval), intent(inout) :: timeinterval
    character (len=*), intent(in), optional :: options
    integer, intent(out), optional :: rc

DESCRIPTION:

Checks whether a timeinterval is valid. If fractional value, denominator must be non-zero. The options control
the type of validation.
The arguments are:

    timeinterval  ESMF_TimeInterval to be validated.

    [options]  Validation options are not yet supported.

    [rc]  Return code; equals ESMF_SUCCESS if there are no errors.
35 Clock Class

35.1 Description
The Clock class advances model time and tracks its associated date on a specified Calendar. It stores start time, stop time, current time, previous time, and a time step. It can also store a reference time, typically the time instant at which a simulation originally began. For a restart run, the reference time can be different than the start time, when the application execution resumes.

A user can call the ESMF_ClockSet method and reset the time step as desired.

A Clock also stores a list of Alarms, which can be set to flag events that occur at a specified time instant or at a specified time interval. See Section 36.1 for details on how to use Alarms.

There are methods for setting and getting the Times and Alarms associated with a Clock. Methods are defined for advancing the Clock’s current time, checking if the stop time has been reached, reversing direction, and synchronizing with a real clock.

35.2 Clock Options
35.2.1 ESMF_Direction
DESCRIPTION:
Specifies the time-stepping direction of a clock. Use with "direction" argument to methods ESMF_ClockSet() and ESMF_ClockGet(). Cannot be used with method ESMF_ClockCreate(), since it only initializes a clock in the default forward mode; a clock must be advanced (timestepped) at least once before reversing direction via ESMF_ClockSet(). This also holds true for negative timestep clocks which are initialized (created) with stopTime < startTime, since "forward" means timestepping from startTime towards stopTime (see ESMF_MODE_FORWARD below).

"Forward" and "reverse" directions are distinct from positive and negative timesteps. "Forward" means timestepping in the direction established at ESMF_ClockCreate(), from startTime towards stopTime, regardless of the timestep sign. "Reverse" means timestepping in the opposite direction, back towards the clock’s startTime, regardless of the timestep sign.

Clocks and alarms run in reverse in such a way that the state of a clock and its alarms after each time step is precisely replicated as it was in forward time-stepping mode. All methods which query clock and alarm state will return the same result for a given timeStep, regardless of the direction of arrival.

Valid values are:

ESMF_MODE_FORWARD Upon calling ESMF_ClockAdvance(), the clock will timestep from its startTime toward its stopTime. This is the default direction. A user can use either ESMF_ClockIsStopTime() or ESMF_ClockIsDone() methods to determine when stopTime is reached. This forward behavior also holds for negative timestep clocks which are initialized (created) with stopTime < startTime.

ESMF_MODE_REVERSE Upon calling ESMF_ClockAdvance(), the clock will timestep backwards toward its startTime. Use method ESMF_ClockIsDone() to determine when startTime is reached. This reverse behavior also holds for negative timestep clocks which are initialized (created) with stopTime < startTime.

35.3 Use and Examples
The following is a typical sequence for using a Clock in a geophysical model.
At initialize:

- Set a Calendar.
- Set start time, stop time and time step as Times and Time Intervals.
- Create and Initialize a Clock using the start time, stop time and time step.
- Define Times and Time Intervals associated with special events, and use these to set Alarms.

At run:
• Advance the Clock, checking for ringing alarms as needed.
• Check if it is time to stop.

At finalize:
• Since Clocks and Alarms are deep classes, they need to be explicitly destroyed at finalization. Times and TimeIntervals are lightweight classes, so they don’t need explicit destruction.

The following code example illustrates Clock usage.

```fortran
! PROGRAM: ESMF_ClockEx - Clock initialization and time-stepping
! !DESCRIPTION:
! This program shows an example of how to create, initialize, advance, and
! examine a basic clock
!-------------------------------------------------- ---------------------------
use ESMF_Mod
implicit none

! instantiate a clock
type(ESMF_Clock) :: clock

! instantiate time_step, start and stop times
type(ESMF_TimeInterval) :: timeStep
type(ESMF_Time) :: startTime
type(ESMF_Time) :: stopTime

! local variables for Get methods
type(ESMF_Time) :: currTime
integer(ESMF_KIND_I8) :: advanceCount
integer :: YY, MM, DD, H, M, S

! return code
integer :: rc

! initialize ESMF framework
call ESMF_Initialize(defaultCalendar=ESMF_CAL_GREGORIAN, rc=rc)

35.3.1 Clock Creation
This example shows how to create and initialize an ESMF_Clock.

! initialize time interval to 2 days, 4 hours (6 timesteps in 13 days)
call ESMF_TimeIntervalSet(timeStep, d=2, h=4, rc=rc)

! initialize start time to 4/1/2003 2:24:00 ( 1/10 of a day )
call ESMF_TimeSet(startTime, yy=2003, mm=4, dd=1, h=2, m=24, rc=rc)

! initialize stop time to 4/14/2003 2:24:00 ( 1/10 of a day )
call ESMF_TimeSet(stopTime, yy=2003, mm=4, dd=14, h=2, m=24, rc=rc)
```
! initialize the clock with the above values
clock = ESMF_ClockCreate("Clock 1", timeStep, startTime, stopTime, rc=rc)

35.3.2 Clock Advance
This example shows how to time-step an ESMF_Clock.

! time step clock from start time to stop time
do while (.not.ESMF_ClockIsStopTime(clock, rc))
    call ESMF_ClockPrint(clock, "currTime string", rc)
    call ESMF_ClockAdvance(clock, rc=rc)
end do

35.3.3 Clock Examination
This example shows how to examine an ESMF_Clock.

! get the clock’s final current time
call ESMF_ClockGet(clock, currTime=currTime, rc=rc)

call ESMF_TimeGet(currTime, yy=YY, mm=MM, dd=DD, h=H, m=M, s=S, rc=rc)
print *, "The clock’s final current time is ", YY, "/", MM, "/", DD, &
" ", H, ":", M, ":", S

! get the number of times the clock was advanced
call ESMF_ClockGet(clock, advanceCount=advanceCount, rc=rc)
print *, "The clock was advanced ", advanceCount, " times."

35.3.4 Clock Reversal
This example shows how to time-step an ESMF_Clock in reverse mode.
call ESMF_ClockSet(clock, direction=ESMF_MODE_REVERSE, rc=rc)

! time step clock in reverse from stop time back to start time;
! note use of ESMF_ClockIsDone() rather than ESMF_ClockIsStopTime()
do while (.not.ESMF_ClockIsDone(clock, rc))
    call ESMF_ClockPrint(clock, "currTime string", rc)
    call ESMF_ClockAdvance(clock, rc=rc)
end do
35.3.5 Clock Destruction

This example shows how to destroy an ESMF_Clock.

```fortran
! destroy clock
call ESMF_ClockDestroy(clock, rc)

! finalize ESMF framework
call ESMF_Finalize(rc=rc)

end program ESMF_ClockEx
```

35.4 Restrictions and Future Work

1. **Alarm list allocation factor** The alarm list within a clock is dynamically allocated automatically, 200 alarm references at a time. This constant is defined in both Fortran and C++ with a #define for ease of modification.

2. **Clock variable timesteps in reverse** In order for a clock with variable timesteps to be run in ESMF_MODE_REVERSE, the user must supply those timesteps to ESMF_ClockAdvance(). Essentially, the user must save the timesteps while in forward mode. In a future release, the Time Manager will assume this responsibility by saving the clock state (including the timeStep) at every timestep while in forward mode.

35.5 Class API

35.5.1 ESMF_ClockOperator(==) - Test if Clock 1 is equal to Clock 2

**INTERFACE:**

```fortran
interface operator(==)
  if (clock1 == clock2) then ... endif
  OR
  result = (clock1 == clock2)
end interface
```

**RETURN VALUE:**

```fortran
logical :: result
```

**ARGUMENTS:**

```fortran
type(ESMF_Clock), intent(in) :: clock1
type(ESMF_Clock), intent(in) :: clock2
```

**DESCRIPTION:**

Overloads the (==) operator for the ESMF_Clock class. Compare two clocks for equality; return true if equal, false otherwise. Comparison is based on IDs, which are distinct for newly created clocks and identical for clocks created as copies.

The arguments are:

- **clock1** The first ESMF_Clock in comparison.
- **clock2** The second ESMF_Clock in comparison.
35.5.2 ESMF_ClockOperator(/=) - Test if Clock 1 is not equal to Clock 2

INTERFACE:

interface operator(/=)
  if (clock1 /= clock2) then ... endif
OR
  result = (clock1 /= clock2)
end interface

RETURN VALUE:

logical :: result

ARGUMENTS:

type(ESMF_Clock), intent(in) :: clock1

type(ESMF_Clock), intent(in) :: clock2

DESCRIPTION:

Overloads the (=) operator for the ESMF_Clock class. Compare two clocks for inequality; return true if not equal, false otherwise. Comparison is based on IDs, which are distinct for newly created clocks and identical for clocks created as copies.

The arguments are:

clock1 The first ESMF_Clock in comparison.

clock2 The second ESMF_Clock in comparison.

35.5.3 ESMF_ClockAdvance - Advance a Clock's current time by one time step

INTERFACE:

subroutine ESMF_ClockAdvance(clock, timeStep, ringingAlarmList, &
  ringingAlarmCount, rc)

ARGUMENTS:

type(ESMF_Clock), intent(inout) :: clock

type(ESMF_TimeInterval), intent(inout), optional :: timeStep

type(ESMF_Alarm), dimension(:), intent(out), optional :: ringingAlarmList

integer, intent(out), optional :: ringingAlarmCount

integer, intent(out), optional :: rc

DESCRIPTION:

Advances the clock's current time by one time step: either the clock's, or the passed-in timeStep (see below). When the clock is in ESMF_MODE_FORWARD (default), this method adds the timeStep to the clock's current time. In ESMF_MODE_REVERSE, timeStep is subtracted from the current time. In either case, timeStep can be positive or negative. See the "direction" argument in method ESMF_ClockSet(). ESMF_ClockAdvance() optionally returns a list and number of ringing ESMF_Alarms. See also method ESMF_ClockGetRingingAlarms().

The arguments are:

clock The object instance to advance.
[timeStep] Time step is performed with given timeStep, instead of the ESMF_Clock's. Does not replace the ESMF_Clock's timeStep; use ESMF_ClockSet(clock, timeStep, ...) for this purpose. Supports applications with variable time steps. timeStep can be positive or negative.

[ringingAlarmList] Returns the array of alarms that are ringing after the time step.

[ringingAlarmCount] The number of alarms ringing after the time step.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

35.5.4 ESMF_ClockCreate - Create a new ESMF Clock

INTERFACE:

! Private name; call using ESMF_ClockCreate()
function ESMF_ClockCreateNew(name, timeStep, startTime, stopTime, &
    runDuration, runTimeStepCount, refTime, rc)

RETURN VALUE:

type(ESMF_Clock) :: ESMF_ClockCreateNew

ARGUMENTS:

character (len=*)          , intent(in), optional :: name
type(ESMF_TimeInterval)    , intent(in)      :: timeStep
type(ESMF_Time)            , intent(in)      :: startTime
type(ESMF_Time)            , intent(in), optional :: stopTime
type(ESMF_TimeInterval)    , intent(in), optional :: runDuration
integer                   , intent(in), optional :: runTimeStepCount
integer                   , intent(in), optional :: refTime
integer                   , intent(out), optional :: rc

DESCRIPTION:

Creates and sets the initial values in a new ESMF_Clock.
This is a private method; invoke via the public overloaded entry point ESMF_ClockCreate().
The arguments are:

[name] The name for the newly created clock. If not specified, a default unique name will be generated: "ClockNNN" where NNN is a unique sequence number from 001 to 999.

timeStep The ESMF_Clock's time step interval, which can be positive or negative.

startTime The ESMF_Clock’s starting time. Can be less than or or greater than stopTime, depending on a positive or negative timeStep, respectively, and whether a stopTime is specified; see below.

[stopTime] The ESMF_Clock's stopping time. Can be greater than or less than the startTime, depending on a positive or negative timeStep, respectively. If neither stopTime, runDuration, nor runTimeStepCount is specified, clock runs "forever"; user must use other means to know when to stop (e.g. ESMF_Alarm or ESMF_ClockGet(clock, currTime)). Mutually exclusive with runDuration and runTimeStepCount.

[runDuration] Alternative way to specify ESMF_Clock's stopping time; stopTime = startTime + runDuration. Can be positive or negative, consistent with the timeStep's sign. Mutually exclusive with stopTime and runTimeStep-
Alternative way to specify ESMF_Clock’s stopping time; stopTime = startTime + (runTimeStepCount * timeStep). stopTime can be before startTime if timeStep is negative. Mutually exclusive with stopTime and runDuration.

The ESMF_Clock’s reference time. Provides reference point for simulation time (see currSimTime in ESMF_ClockGet() below).

Return code; equals ESMF_SUCCESS if there are no errors.

35.5.5 ESMF_ClockCreate - Create a copy of an existing ESMF Clock

INTERFACE:

! Private name; call using ESMF_ClockCreate()
function ESMF_ClockCreateCopy(clock, rc)

RETURN VALUE:

type(ESMF_Clock) :: ESMF_ClockCreateCopy

ARGUMENTS:

type(ESMF_Clock), intent(in) :: clock
integer, intent(out), optional :: rc

DESCRIPTION:

Creates a copy of a given ESMF_Clock. This is a private method; invoke via the public overloaded entry point ESMF_ClockCreate(). The arguments are:

clock The ESMF_Clock to copy.

Return code; equals ESMF_SUCCESS if there are no errors.

35.5.6 ESMF_ClockDestroy - Free all resources associated with a Clock

INTERFACE:

subroutine ESMF_ClockDestroy(clock, rc)

ARGUMENTS:

type(ESMF_Clock) :: clock
integer, intent(out), optional :: rc

DESCRIPTION:

Releases all resources associated with this ESMF_Clock. The arguments are:

clock Destroy contents of this ESMF_Clock.

Return code; equals ESMF_SUCCESS if there are no errors.
35.5.7 ESMF_ClockGet - Get a Clock’s properties

INTERFACE:

subroutine ESMF_ClockGet(clock, name, timeStep, startTime, stopTime, &
runDuration, runTimeStepCount, refTime, &
currTime, prevTime, currSimTime, prevSimTime, &
calendar, calendarType, timeZone, advanceCount, &
alarmCount, direction, rc)

ARGUMENTS:

type(ESMF_Clock), intent(in) :: clock
character (len=*), intent(out), optional :: name
type(ESMF_TimeInterval), intent(out), optional :: timeStep
type(ESMF_Time), intent(out), optional :: startTime
type(ESMF_Time), intent(out), optional :: stopTime
type(ESMF_TimeInterval), intent(out), optional :: runDuration
real(ESMF_KIND_R8), intent(out), optional :: runTimeStepCount
type(ESMF_Time), intent(out), optional :: refTime
type(ESMF_Time), intent(out), optional :: currTime
type(ESMF_Time), intent(out), optional :: prevTime
type(ESMF_TimeInterval), intent(out), optional :: currSimTime
type(ESMF_TimeInterval), intent(out), optional :: prevSimTime
type(ESMF_Calendar), intent(out), optional :: calendar
type(ESMF_CalendarType), intent(out), optional :: calendarType
integer, intent(out), optional :: timeZone
integer(ESMF_KIND_I8), intent(out), optional :: advanceCount
integer, intent(out), optional :: alarmCount
type(ESMF_Direction), intent(out), optional :: direction
integer, intent(out), optional :: rc

DESCRIPTION:

Gets one or more of the properties of an ESMF_Clock.
The arguments are:

clock  The object instance to query.
[name] The name of this clock.
[timeStep] The ESMF_Clock’s time step interval.
[startTime] The ESMF_Clock’s starting time.
[stopTime] The ESMF_Clock’s stopping time.
[runDuration] Alternative way to get ESMF_Clock’s stopping time; runDuration = stopTime - startTime.
[runTimeStepCount] Alternative way to get ESMF_Clock’s stopping time; runTimeStepCount = (stopTime - startTime) / timeStep.
[refTime] The ESMF_Clock’s reference time.
[currTime] The ESMF_Clock’s current time.
[prevTime] The ESMF_Clock’s previous time. Equals currTime at the previous time step.
[currSimTime] The current simulation time (currTime - refTime).
[prevSimTime] The previous simulation time. Equals currSimTime at the previous time step.
[calendar] The Calendar on which all the Clock’s times are defined.
[calendarType] The CalendarType on which all the Clock’s times are defined.
[timeZone] The timezone within which all the Clock’s times are defined.
[advanceCount] The number of times the ESMF_CLOCK has been advanced. Increments in ESMF_MODE_FORWARD and decrements in ESMF_MODE_REVERSE; see "direction" argument below and in ESMF_CLOCKSet().
[alarmCount] The number of ESMF_Alarms in the ESMF_CLOCK’s ESMF_Alarm list.
[direction] The ESMF_CLOCK’s time stepping direction. See also ESMF_CLOCKIsReverse(), an alternative for convenient use in "if" and "do while" constructs.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

35.5.8 ESMF_CLOCKGetAlarm - Get an Alarm in a Clock’s Alarm list

INTERFACE:

    subroutine ESMF_CLOCKGetAlarm(clock, name, alarm, rc)

ARGUMENTS:

    type(ESMF_CLOCK), intent(inout) :: clock
    character (len=*), intent(in) :: name
    type(ESMF_Alarm), intent(out) :: alarm
    integer, intent(out), optional :: rc

DESCRIPTION:

Gets the alarm whose name is the value of name in the clock’s ESMF_Alarm list. The arguments are:

clock The object instance to get the ESMF_Alarm from.
name The name of the desired ESMF_Alarm.
alarm The desired alarm.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

35.5.9 ESMF_CLOCKGetAlarmList - Get a list of Alarms from a Clock

INTERFACE:

    subroutine ESMF_CLOCKGetAlarmList(clock, alarmListType, &
                                        alarmList, alarmCount, timeStep, rc)
ARGUMENTS:

- **clock**: The object instance from which to get an `ESMF_Alarm` list.
- **alarmListType**: The type of list to get:
  - `ESMF_ALARMLIST_ALL`: Returns the `ESMF_Clock`'s entire list of alarms.
  - `ESMF_ALARMLIST_NEXTRINGING`: Return only those alarms that will ring upon the next `clock` time step. Can optionally specify argument `timeStep` (see below) to use instead of the `clock`'s. See also method `ESMF_AlarmWillRingNext()` for checking a single alarm.
  - `ESMF_ALARMLIST_PREVRINGING`: Return only those alarms that were ringing on the previous `ESMF_Clock` time step. See also method `ESMF_AlarmWasPrevRinging()` for checking a single alarm.
  - `ESMF_ALARMLIST_RINGING`: Returns only those `clock` alarms that are currently ringing. See also method `ESMF_ClockAdvance()` for getting the list of ringing alarms subsequent to a time step. See also method `ESMF_AlarmIsRinging()` for checking a single alarm.
- **alarmList**: The array of returned alarms.
- **alarmCount**: The number of `ESMF_Alarm` s in the returned list.
- **[timeStep]** Optional time step to be used instead of the `clock`'s. Only used with `ESMF_ALARMLIST_NEXTRINGING` `alarmListType` (see above); ignored if specified with other `alarmListTypes`.
- **[rc]** Return code; equals `ESMF_SUCCESS` if there are no errors.

35.5.10  ESMF_ClockGetNextTime - Calculate a Clock's next time

INTERFACE:

```fortran
subroutine ESMF_ClockGetNextTime(clock, nextTime, timeStep, rc)
```

ARGUMENTS:

- **clock**: The object instance from which to get an `ESMF_Alarm` list.
- **nextTime**: The next time of the `clock`.
- **timeStep**: Optional time step to be used instead of the `clock`'s. Only used with `ESMF_ALARMLIST_NEXTRINGING` `alarmListType` (see above); ignored if specified with other `alarmListTypes`.
- **rc**: Return code; equals `ESMF_SUCCESS` if there are no errors.

DESCRIPTION:

Calculates what the next time of the `clock` will be, based on the `clock`'s current time step or an optionally passed-in `timeStep`.

The arguments are:
clock  The object instance for which to get the next time.

nextTime  The resulting ESMF_Clock's next time.

[timeStep]  The time step interval to use instead of the clock's.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

35.5.11  ESMF_ClockIsDone - Based on its direction, test if the Clock has reached or exceeded its stop time or start time

INTERFACE:

    function ESMF_ClockIsDone(clock, rc)

RETURN VALUE:

    logical :: ESMF_ClockIsDone

ARGUMENTS:

    type(ESMF_Clock), intent(in) :: clock
    integer, intent(out), optional :: rc

DESCRIPTION:

Returns true if currentTime is greater than or equal to stopTime in ESMF_MODE_FORWARD, or if currentTime is less than or equal to startTime in ESMF_MODE_REVERSE. It returns false otherwise.

The arguments are:

clock  The object instance to check.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

35.5.12  ESMF_ClockIsReverse - Test if the Clock is in reverse mode

INTERFACE:

    function ESMF_ClockIsReverse(clock, rc)

RETURN VALUE:

    logical :: ESMF_ClockIsReverse

ARGUMENTS:

    type(ESMF_Clock), intent(in) :: clock
    integer, intent(out), optional :: rc
DESCRIPTION:

Returns true if clock is in ESMF_MODE_REVERSE, and false if in ESMF_MODE_FORWARD. Allows convenient use in "if" and "do while" constructs. Alternative to ESMF_ClockGet(...direction=...).

The arguments are:

- **clock** The object instance to check.
- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

35.5.13 ESMF_ClockIsStopTime - Test if the Clock has reached or exceeded its stop time

INTERFACE:

```
function ESMF_ClockIsStopTime(clock, rc)
RETURN VALUE:
  logical :: ESMF_ClockIsStopTime
ARGUMENTS:
  type(ESMF_Clock), intent(in) :: clock
  integer,                  intent(out), optional :: rc
```

DESCRIPTION:

Returns true if the clock has reached or exceeded its stop time, and false otherwise. The arguments are:

- **clock** The object instance to check.
- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

35.5.14 ESMF_ClockIsStopTimeEnabled - Test if the Clock’s stop time is enabled

INTERFACE:

```
function ESMF_ClockIsStopTimeEnabled(clock, rc)
RETURN VALUE:
  logical :: ESMF_ClockIsStopTimeEnabled
ARGUMENTS:
  type(ESMF_Clock), intent(in) :: clock
  integer,                  intent(out), optional :: rc
```

DESCRIPTION:

Returns true if the clock’s stop time is set and enabled, and false otherwise. The arguments are:

- **clock** The object instance to check.
- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.
35.5.15  ESMF_ClockPrint - Print the contents of a Clock

INTERFACE:

    subroutine ESMF_ClockPrint(clock, options, rc)

ARGUMENTS:

    type(ESMF_Clock),  intent(in)  :: clock
    character (len=*),  intent(in),  optional :: options
    integer,  intent(out),  optional :: rc

DESCRIPTION:

Prints out an ESMF_Clock’s properties to stdout, in support of testing and debugging. The options control the type of information and level of detail. The arguments are:

**clock**  ESMF_Clock to be printed out.

**[options]**  Print options. If none specified, prints all clock property values.
   - “advanceCount” - print the number of times the clock has been advanced.
   - “alarmCount” - print the number of alarms in the clock’s list.
   - “alarmList” - print the clock’s alarm list.
   - “currTime” - print the current clock time.
   - “direction” - print the clock’s timestep direction.
   - “name” - print the clock’s name.
   - “prevTime” - print the previous clock time.
   - “refTime” - print the clock’s reference time.
   - “startTime” - print the clock’s start time.
   - “stopTime” - print the clock’s stop time.
   - “timeStep” - print the clock’s time step.

**[rc]**  Return code; equals ESMF_SUCCESS if there are no errors.

35.5.16  ESMF_ClockSet - Set one or more properties of a Clock

INTERFACE:

    subroutine ESMF_ClockSet(clock, name, timeStep, startTime, stopTime, runDuration, runtimeStepCount, refTime, currTime, advanceCount, direction, rc)

ARGUMENTS:

    type(ESMF_Clock),  intent(inout)  :: clock
    character (len=*),  intent(in),  optional :: name
    type(ESMF_TimeInterval),  intent(inout),  optional :: timeStep
    type(ESMF_Time),  intent(inout),  optional :: startTime
    type(ESMF_Time),  intent(inout),  optional :: stopTime
    type(ESMF_TimeInterval),  intent(inout),  optional :: runDuration


DESCRIPTION:

Sets/resets one or more of the properties of an ESMF_Clock that was previously initialized via ESMF_ClockCreate(). The arguments are:

clock  The object instance to set.

[name] The new name for this clock.

[timeStep] The ESMF_Clock's time step interval, which can be positive or negative. This is used to change a clock’s
timestep property for those applications that need variable timesteps. See ESMF_ClockAdvance() below
for specifying variable timesteps that are NOT saved as the clock’s internal time step property. See "direction"
argument below for behavior with

t ESMF_MODE_REVERSE direction.

[startTime] The ESMF_Clock's starting time. Can be less than or greater than stopTime, depending on a positive
or negative timeStep, respectively, and whether a stopTime is specified; see below.

[stopTime] The ESMF_Clock's stopping time. Can be greater than or less than the startTime, depending on
a positive or negative timeStep, respectively. If neither stopTime, runDuration, nor runTimeStepCount is
specified, clock runs “forever”; user must use other means to know when to stop (e.g. ESMF_Alarm or
ESMF_ClockGet(clock, currTime)). Mutually exclusive with runDuration and runTimeStepCount.

[runDuration] Alternative way to specify ESMF_Clock's stopping time; stopTime = startTime + runDuration. Can
be positive or negative, consistent with the timeStep's sign. Mutually exclusive with stopTime and runTimeStepCount.

[runTimeStepCount] Alternative way to specify ESMF_Clock's stopping time; stopTime = startTime + (run-
TimeStepCount * timeStep). stopTime can be before startTime if timeStep is negative. Mutually exclusive
with stopTime and runDuration.

[refTime] The ESMF_Clock's reference time. See description in ESMF_ClockCreate() above.

[currTime] The current time.

[advanceCount] The number of times the clock has been timesteped.

[direction] Sets the clock's time-stepping direction. If called with ESMF_MODE_REVERSE, sets the clock in "re-
verse" mode, causing it to timestep back towards its startTime. If called with ESMF_MODE_FORWARD, sets the
clock in normal, "forward" mode, causing it to timestep in the direction of its startTime to stopTime. This holds
true for negative timestep clocks as well, which are initialized (created) with stopTime < startTime. The default
mode is ESMF_MODE_FORWARD, established at ESMF_ClockCreate(). timeStep can also be specified as
an argument at the same time, which allows for a change in magnitude and/or sign of the clock’s timeStep. If
not specified with ESMF_MODE_REVERSE, the clock’s current timeStep is effectively negated. If timeStep is
specified, its sign is used as specified; it is not negated internally. E.g., if the specified timeStep is negative and
the clock is placed in ESMF_MODE_REVERSE, subsequent calls to ESMF_ClockAdvance() will cause the
clock’s current time to be decremented by the new timeStep’s magnitude.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
### 35.5.17 ESMF_ClockStopTimeDisable - Disable a Clock’s stop time

**INTERFACE:**

```fortran
subroutine ESMF_ClockStopTimeDisable(clock, rc)
```

**ARGUMENTS:**

- `type(ESMF_Clock), intent(inout) :: clock`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Disables a `ESMF_Clock`’s stop time; `ESMF_ClockIsStopTime()` will always return false, allowing a clock to run past its stopTime.

The arguments are:
- `clock` The object instance whose stop time to disable.
- `[rc]` Return code; equals `ESMF_SUCCESS` if there are no errors.

---

### 35.5.18 ESMF_ClockStopTimeEnable - Enable an Clock’s stop time

**INTERFACE:**

```fortran
subroutine ESMF_ClockStopTimeEnable(clock, stopTime, rc)
```

**ARGUMENTS:**

- `type(ESMF_Clock), intent(inout) :: clock`
- `type(ESMF_Time), intent(in), optional :: stopTime`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Enables a `ESMF_Clock`’s stop time, allowing `ESMF_ClockIsStopTime()` to respect the stopTime.

The arguments are:
- `clock` The object instance whose stop time to enable.
- `[stopTime]` The stop time to set or reset.
- `[rc]` Return code; equals `ESMF_SUCCESS` if there are no errors.

---

### 35.5.19 ESMF_ClockSyncToRealTime - Set Clock’s current time to wall clock time

**INTERFACE:**

```fortran
subroutine ESMF_ClockSyncToRealTime(clock, rc)
```
ARGUMENTS:

- `type(ESMF_Clock), intent(inout) :: clock`
- `integer, intent(out), optional :: rc`

DESCRIPTION:

Sets a clock’s current time to the wall clock time. It is accurate to the nearest second.

The arguments are:

- **clock** The object instance to be synchronized with wall clock time.
- **rc** Return code; equals ESMF_SUCCESS if there are no errors.

35.5.20 ESMF_ClockValidate - Validate a Clock’s properties

INTERFACE:

```fortran
subroutine ESMF_ClockValidate(clock, options, rc)
```

ARGUMENTS:

- `type(ESMF_Clock), intent(inout) :: clock`
- `character (len=*), intent(in), optional :: options`
- `integer, intent(out), optional :: rc`

DESCRIPTION:

Checks whether a clock is valid. Must have a valid startTime and timeStep. If clock has a stopTime, its currTime must be within startTime to stopTime, inclusive; also startTime’s and stopTime’s calendars must be the same.

The arguments are:

- **clock** ESMF_Clock to be validated.
- **options** Validation options are not yet supported.
- **rc** Return code; equals ESMF_SUCCESS if there are no errors.
36 Alarm Class

36.1 Description
The Alarm class identifies events that occur at specific Times or specific TimeIntervals by returning a true value at those times or subsequent times, and a false value otherwise.

36.2 Alarm Options
36.2.1 ESMF_AlarmListType
DESCRIPTION:
Specifies the characteristics of Alarms that populate a retrieved Alarm list.
Valid values are:

ESMF_ALARMLIST_ALL All alarms.
ESMF_ALARMLIST_NEXTRINGING Alarms that will ring before or at the next timestep.
ESMF_ALARMLIST_PREVRINGING Alarms that rang at or since the last timestep.
ESMF_ALARMLIST_RINGING Only ringing alarms.

36.3 Use and Examples
Alarms are used in conjunction with Clocks (see Section 35.1). Multiple Alarms can be associated with a Clock. During the ESMF_ClockAdvance() method, a Clock iterates over its internal Alarms to determine if any are ringing. Alarms ring when a specified Alarm time is reached or exceeded, taking into account whether the time step is positive or negative. In ESMF_MODE.Reverse (see Section 35.1), alarms ring in reverse, i.e., they begin ringing when they originally ended, and end ringing when they originally began. On completion of the time advance call, the Clock optionally returns a list of ringing alarms. Each ringing Alarm can then be processed using Alarm methods for identifying, turning off, disabling or resetting the Alarm. Alarm methods are defined for obtaining the ringing state, turning the ringer on/off, enabling/disabling the Alarm, and getting/setting associated times.

The following example shows how to set and process Alarms.

```fortran
! PROGRAM: ESMF_AlarmEx - Alarm examples
!
! DESCRIPTION:
!
! This program shows an example of how to create, initialize, and process!
! alarms associated with a clock.
!-----------------------------------------------

! ESMF Framework module
use ESMF_Mod
implicit none

! instantiate time_step, start, stop, and alarm times
type(ESMF_TimeInterval) :: timeStep, alarmInterval
type(ESMF_Time) :: alarmTime, startTime, stopTime

! instantiate a clock
type(ESMF_Clock) :: clock

! instantiate Alarm lists
```

391
integer, parameter :: NUMALARMS = 2
type(ESMF_Alarm) :: alarm(NUMALARMS)

! local variables for Get methods
integer :: ringingAlarmCount ! at any time step (0 to NUMALARMS)

! name, loop counter, result code
character (len=ESMF_MAXSTR) :: name
integer :: i, rc

! initialize ESMF framework
call ESMF_Initialize(defaultCalendar=ESMF_CAL_GREGORIAN, rc=rc)

36.3.1 Clock Initialization
This example shows how to create and initialize an ESMF_Clock.

! initialize time interval to 1 day
call ESMF_TimeIntervalSet(timeStep, d=1, rc=rc)

! initialize start time to 9/1/2003
call ESMF_TimeSet(startTime, yy=2003, mm=9, dd=1, rc=rc)

! initialize stop time to 9/30/2003
call ESMF_TimeSet(stopTime, yy=2003, mm=9, dd=30, rc=rc)

! create & initialize the clock with the above values
clock = ESMF_ClockCreate("The Clock", timeStep, startTime, stopTime, &
rc=rc)

36.3.2 Alarm Initialization
This example shows how to create and initialize two ESMF_Alarms and associate them with the clock.

! Initialize first alarm to be a one-shot on 9/15/2003 and associate
! it with the clock
call ESMF_TimeSet(alarmTime, yy=2003, mm=9, dd=15, rc=rc)

alarm(1) = ESMF_AlarmCreate("Example alarm 1", clock, &
ringTime=alarmTime, rc=rc)

! Initialize second alarm to ring on a 1 week interval starting 9/1/2003
! and associate it with the clock
call ESMF_TimeSet(alarmTime, yy=2003, mm=9, dd=1, rc=rc)

call ESMF_TimeIntervalSet(alarmInterval, d=7, rc=rc)

! Alarm gets default name "Alarm002"
alarm(2) = ESMF_AlarmCreate(clock=clock, ringTime=alarmTime, &
ringInterval=alarmInterval, rc=rc)
36.3.3 Clock Advance and Alarm Processing

This example shows how to advance an ESMF_Clock and process any resulting ringing alarms.

```fortran
! time step clock from start time to stop time
do while (.not.ESMF_ClockIsStopTime(clock, rc))

! perform time step and get the number of any ringing alarms
call ESMF_ClockAdvance(clock, ringingAlarmCount=ringingAlarmCount, &
rc=rc)
call ESMF_ClockPrint(clock, "currTime string", rc)

! check if alarms are ringing
if (ringingAlarmCount > 0) then
  print *, "number of ringing alarms = ", ringingAlarmCount
  do i = 1, NUMALARMS
    if (ESMF_AlarmIsRinging(alarm(i), rc)) then
      call ESMF_AlarmGet(alarm(i), name=name, rc=rc)
      print *, trim(name), " is ringing!"

      ! after processing alarm, turn it off
      call ESMF_AlarmRingerOff(alarm(i), rc)
    end if ! this alarm is ringing
  end do ! each ringing alarm
endif ! ringing alarms
end do ! timestep clock
```

36.3.4 Alarm and Clock Destruction

This example shows how to destroy ESMF_Alarms and ESMF_Clocks.

```fortran
call ESMF_AlarmDestroy(alarm(1), rc=rc)
call ESMF_AlarmDestroy(alarm(2), rc=rc)
call ESMF_ClockDestroy(clock, rc=rc)

! finalize ESMF framework
call ESMF_Finalize(rc=rc)
end program ESMF_AlarmEx```
36.4 Restrictions and Future Work

1. **Alarm list allocation factor** The alarm list within a clock is dynamically allocated automatically, 200 alarm references at a time. This constant is defined in both Fortran and C++ with a #define for ease of modification.

2. **Sticky alarm end times in reverse** For sticky alarms, there is an implicit limitation that in order to properly reverse timestep through a ring end time, that time must have already been traversed in the forward direction. This is due to the fact that the Time Manager cannot predict when user code will call ESMF_AlarmRingerOff(). An error message will be logged when this limitation is not satisfied.

3. **Sticky alarm ring interval in reverse** For repeating sticky alarms, it is currently assumed that the ringInterval is constant, so that only the time of the last call to ESMF_AlarmRingerOff() is saved. In ESMF_MODE_REVERSE, this information is used to turn sticky alarms back on. In a future release, ringIntervals will be allowed to be variable, by saving alarm state at every timestep.

36.5 Design and Implementation Notes

The Alarm class is designed as a deep, dynamically allocatable class, based on a pointer type. This allows for both indirect and direct manipulation of alarms. Indirect alarm manipulation is where ESMF_Alarm API methods, such as ESMF_AlarmRingerOff(), are invoked on alarm references (pointers) returned from ESMF_Clock queries such as "return ringing alarms." Since the method is performed on an alarm reference, the actual alarm held by the clock is affected, not just a user’s local copy. Direct alarm manipulation is the more common case where alarm API methods are invoked on the original alarm objects created by the user.

For consistency, the ESMF_Clock class is also designed as a deep, dynamically allocatable class. An additional benefit from this approach is that Clocks and Alarms can be created and used from anywhere in a user’s code without regard to the scope in which they were created. In contrast, statically created Alarms and Clocks would disappear if created within a user’s routine that returns, whereas dynamically allocated Alarms and Clocks will persist until explicitly destroyed by the user.

36.6 Class API

36.6.1 ESMF_AlarmOperator(==) - Test if Alarm 1 is equal to Alarm 2

INTERFACE:

```plaintext
interface operator(==)
if (alarm1 == alarm2) then ... endif
OR
result = (alarm1 == alarm2)
```

RETURN VALUE:

```plaintext
logical :: result
```

ARGUMENTS:

```plaintext
type(ESMF_Alarm), intent(in) :: alarm1
type(ESMF_Alarm), intent(in) :: alarm2
```

DESCRIPTION:

Overloads the (==) operator for the ESMF_Alarm class. Compare two alarms for equality; return true if equal, false otherwise. Comparison is based on IDs, which are distinct for newly created alarms and identical for alarms created as copies.

The arguments are:

- **alarm1** The first ESMF_Alarm in comparison.
- **alarm2** The second ESMF_Alarm in comparison.
36.6.2 ESMF_AlarmOperator(/=) - Test if Alarm 1 is not equal to Alarm 2

INTERFACE:

    interface operator(/=)
      if (alarm1 /= alarm2) then ... endif
      OR
      result = (alarm1 /= alarm2)
    endif

RETURN VALUE:

    logical :: result

ARGUMENTS:

    type(ESMF_Alarm), intent(in) :: alarm1
    type(ESMF_Alarm), intent(in) :: alarm2

DESCRIPTION:

Overloads the (/=) operator for the ESMF_Alarm class. Compare two alarms for inequality; return true if not equal, false otherwise. Comparison is based on IDs, which are distinct for newly created alarms and identical for alarms created as copies.

The arguments are:

alarm1 The first ESMF_Alarm in comparison.
alarm2 The second ESMF_Alarm in comparison.

36.6.3 ESMF_AlarmCreate - Create a new ESMF Alarm

INTERFACE:

    ! Private name; call using ESMF_AlarmCreate()
    function ESMF_AlarmCreateNew(name, clock, ringTime, ringInterval, &
      stopTime, ringDuration, &
      ringTimeStepCount, &
      refTime, enabled, sticky, rc)
    !
    RETURN VALUE:

    type(ESMF_Alarm) :: ESMF_AlarmCreateNew

ARGUMENTS:

    character (len=*) , intent(in), optional :: name
    type(ESMF_Clock), intent(in) :: clock
    type(ESMF_Time), intent(in), optional :: ringTime
    type(ESMF_TimeInterval), intent(in), optional :: ringInterval
    type(ESMF_Time), intent(in), optional :: stopTime
    type(ESMF_TimeInterval), intent(in), optional :: ringDuration
    integer, intent(in), optional :: ringTimeStepCount
    type(ESMF_Time), intent(in), optional :: refTime
    logical, intent(in), optional :: enabled
    logical, intent(in), optional :: sticky
    integer, intent(out), optional :: rc
DESCRIPTION:

Creates and sets the initial values in a new ESMF_Alarm.
In ESMF_MODE_REVERSE (see Section 35.1), alarms ring in reverse, i.e., they begin ringing when they originally ended, and end ringing when they originally began.
This is a private method; invoke via the public overloaded entry point ESMF_AlarmCreate().
The arguments are:

[name] The name for the newly created alarm. If not specified, a default unique name will be generated: "AlarmNNN" where NNN is a unique sequence number from 001 to 999.
clock The clock with which to associate this newly created alarm.
[ringTime] The ring time for a one-shot alarm or the first ring time for a repeating (interval) alarm. Must specify at least one of ringTime or ringInterval.
[ringInterval] The ring interval for repeating (interval) alarms. If ringTime is not also specified (first ring time), it will be calculated as the clock's current time plus ringInterval. Must specify at least one of ringTime or ringInterval.
[stopTime] The stop time for repeating (interval) alarms. If not specified, an interval alarm will repeat forever.
[ringDuration] The absolute ring duration. If not sticky (see argument below), alarms rings for ringDuration, then turns itself off. Mutually exclusive with ringTimeStepCount (below); used only if ringTimeStepCount is zero. See also ESMF_AlarmSticky(), ESMF_AlarmNotSticky().
[ringTimeStepCount] The relative ring duration. If not sticky (see argument below), alarms rings for ringTimeStepCount, then turns itself off. Mutually exclusive with ringDuration (above); used if non-zero, otherwise ringDuration is used. See also ESMF_AlarmSticky(), ESMF_AlarmNotSticky().
[refTime] The reference (i.e. base) time for an interval alarm.
[enabled] Sets the enabled state; default is on (true). If disabled, an alarm will not function at all. See also ESMF_AlarmEnable(), ESMF_AlarmDisable().
[sticky] Sets the sticky state; default is on (true). If sticky, once an alarm is ringing, it will remain ringing until turned off manually via a user call to ESMF_AlarmRingerOff(). If not sticky, an alarm will turn itself off after a certain ring duration specified by either ringDuration or ringTimeStepCount (see above). There is an implicit limitation that in order to properly reverse timestep through a ring end time in ESMF_MODE_REVERSE, that time must have already been traversed in the forward direction. This is due to the fact that the Time Manager cannot predict when user code will call ESMF_AlarmRingerOff(). An error message will be logged when this limitation is not satisfied. See also ESMF_AlarmSticky(), ESMF_AlarmNotSticky().
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

36.6.4 ESMF_AlarmCreate - Create a copy of an existing ESMF Alarm

INTERFACE:

        ! Private name; call using ESMF_AlarmCreate()
        function ESMF_AlarmCreateCopy(alarm, rc)

RETURN VALUE:

        type(ESMF_Alarm) :: ESMF_AlarmCreateCopy

396
ARGUMENTS:

    type(ESMF_Alarm), intent(inout) :: alarm
    integer, intent(out), optional :: rc

DESCRIPTION:

Creates a copy of a given ESMF_Alarm.
This is a private method; invoke via the public overloaded entry point ESMF_AlarmCreate().
The arguments are:

alarm  The ESMF_Alarm to copy.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

36.6.5  ESMF_AlarmDestroy - Free all resources associated with an Alarm

INTERFACE:

    subroutine ESMF_AlarmDestroy(alarm, rc)

ARGUMENTS:

    type(ESMF_Alarm) :: alarm
    integer, intent(out), optional :: rc

DESCRIPTION:

Releases all resources associated with this ESMF_Alarm.
The arguments are:

alarm  Destroy contents of this ESMF_Alarm.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

36.6.6  ESMF_AlarmDisable - Disable an Alarm

INTERFACE:

    subroutine ESMF_AlarmDisable(alarm, rc)

ARGUMENTS:

    type(ESMF_Alarm), intent(inout) :: alarm
    integer, intent(out), optional :: rc

DESCRIPTION:

Disables an ESMF_Alarm.
The arguments are:

alarm  The object instance to disable.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
36.6.7 ESMF_AlarmEnable - Enable an Alarm

INTERFACE:

subroutine ESMF_AlarmEnable(alarm, rc)

ARGUMENTS:

type(ESMF_Alarm), intent(inout) :: alarm
integer, intent(out), optional :: rc

DESCRIPTION:

Enables an ESMF_Alarm to function.
The arguments are:
alarm  The object instance to enable.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

36.6.8 ESMF_AlarmGet - Get Alarm properties

INTERFACE:

subroutine ESMF_AlarmGet(alarm, name, clock, ringTime, prevRingTime, &
ringInterval, stopTime, ringDuration, &
ringTimeStepCount, timeStepRingingCount, &
ringBegin, ringEnd, refTime, ringing, &
ringingOnPrevTimeStep, enabled, sticky, rc)

ARGUMENTS:

type(ESMF_Alarm), intent(inout) :: alarm
character (len=*), intent(out), optional :: name
type(ESMF_Clock), intent(out), optional :: clock
type(ESMF_Time), intent(out), optional :: ringTime
type(ESMF_Time), intent(out), optional :: prevRingTime
type(ESMF_TimeInterval), intent(out), optional :: ringInterval
type(ESMF_Time), intent(out), optional :: stopTime
type(ESMF_TimeInterval), intent(out), optional :: ringDuration
integer, intent(out), optional :: ringTimeStepCount
integer, intent(out), optional :: timeStepRingingCount
type(ESMF_Time), intent(out), optional :: ringBegin
type(ESMF_Time), intent(out), optional :: ringEnd
type(ESMF_Time), intent(out), optional :: refTime
logical, intent(out), optional :: ringing
logical, intent(out), optional :: ringingOnPrevTimeStep
logical, intent(out), optional :: enabled
logical, intent(out), optional :: sticky
integer, intent(out), optional :: rc
DESCRIPTION:

Gets one or more of an ESMF_Alarm’s properties.

The arguments are:

alarm  The object instance to query.

[name]  The name of this alarm.

clock]  The associated clock.

[ringTime]  The ring time for a one-shot alarm or the next repeating alarm.

[prevRingTime]  The previous ring time.

[ringInterval]  The ring interval for repeating (interval) alarms.

[stopTime]  The stop time for repeating (interval) alarms.

[ringDuration]  The ring duration. Mutually exclusive with ringTimeStepCount (see below).

[ringTimeStepCount]  The number of time steps comprising the ring duration. Mutually exclusive with ringDuration (see above).

[timeStepRingingCount]  The number of time steps for which the alarm has been ringing thus far. Used internally for tracking ringTimeStepCount ring durations (see above). Mutually exclusive with ringBegin (see below). Increments in ESMF_MODE_FORWARD and decrements in ESMF_MODE_REVERSE; see Section 35.1.

[ringBegin]  The time when the alarm began ringing. Used internally for tracking ringDuration (see above). Mutually exclusive with timeStepRingingCount (see above).

[ringEnd]  The time when the alarm ended ringing. Used internally for re-ringing alarm in ESMF_MODE_REVERSE.

[refTime]  The reference (i.e. base) time for an interval alarm.

[ringing]  The current ringing state. See also ESMF_AlarmRingerOn(), ESMF_AlarmRingerOff().

[ringingOnPrevTimeStep]  The ringing state upon the previous time step. Same as ESMF_AlarmWasPrevRinging().

[enabled]  The enabled state. See also ESMF_AlarmEnable(), ESMF_AlarmDisable().

[sticky]  The sticky state. See also ESMF_AlarmSticky(), ESMF_AlarmNotSticky().

36.6.9 ESMF_AlarmIsEnabled - Check if Alarm is enabled

INTERFACE:

function ESMF_AlarmIsEnabled(alarm, rc)

RETURN VALUE:

logical :: ESMF_AlarmIsEnabled

ARGUMENTS:

type(ESMF_Alarm), intent(inout) :: alarm
integer, intent(out), optional :: rc
DESCRIPTION:

Check if ESMF_Alarm is enabled.
The arguments are:

alarm  The object instance to check for enabled state.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

36.6.10  ESMF_AlarmIsRinging - Check if Alarm is ringing

INTERFACE:

    function ESMF_AlarmIsRinging(alarm, rc)

RETURN VALUE:

    logical :: ESMF_AlarmIsRinging

ARGUMENTS:

    type(ESMF_Alarm), intent(inout) :: alarm
    integer, intent(out), optional :: rc

DESCRIPTION:

Check if ESMF_Alarm is ringing.
See also method ESMF_ClockGetAlarmList(clock, ESMF_ALARMLIST_RINGING, ...) to get a list
of all ringing alarms belonging to an ESMF_Clock.
The arguments are:

alarm  The alarm to check for ringing state.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

36.6.11  ESMF_AlarmIsSticky - Check if Alarm is sticky

INTERFACE:

    function ESMF_AlarmIsSticky(alarm, rc)

RETURN VALUE:

    logical :: ESMF_AlarmIsSticky

ARGUMENTS:

    type(ESMF_Alarm), intent(inout) :: alarm
    integer, intent(out), optional :: rc
DESCRIPTION:

Check if alarm is sticky.

The arguments are:

alarm The object instance to check for sticky state.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

36.6.12 ESMF_AlarmNotSticky - Unset an Alarm’s sticky flag

INTERFACE:

```fortran
subroutine ESMF_AlarmNotSticky(alarm, ringDuration, &
                             ringTimeStepCount, rc)
```

ARGUMENTS:

```fortran
type(ESMF_Alarm), intent(inout) :: alarm

! Optional arguments:
type(ESMF_TimeInterval), intent(in), optional :: ringDuration
integer, intent(in), optional :: ringTimeStepCount
integer, intent(out), optional :: rc
```

DESCRIPTION:

Unset an ESMF_Alarm’s sticky flag; once alarm is ringing, it turns itself off after ringDuration.

The arguments are:

alarm The object instance to unset sticky.

[ringDuration] If not sticky, alarms rings for ringDuration, then turns itself off.

[ringTimeStepCount] If not sticky, alarms rings for ringTimeStepCount, then turns itself off.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

36.6.13 ESMF_AlarmPrint - Print out an Alarm’s properties

INTERFACE:

```fortran
subroutine ESMF_AlarmPrint(alarm, options, rc)
```

ARGUMENTS:

```fortran
type(ESMF_Alarm), intent(inout) :: alarm

character (len=*) , intent(in), optional :: options
integer, intent(out), optional :: rc
```

DESCRIPTION:

Prints out an ESMF_Alarm’s properties to stdout, in support of testing and debugging. The options control the type of information and level of detail.

The arguments are:
alarm ESMF_Alarm to be printed out.

[options] Print options. If none specified, prints all alarm property values.
  "clock" - print the associated clock’s name.
  "enabled" - print the alarm’s ability to ring.
  "name" - print the alarm’s name.
  "prevRingTime" - print the alarm’s previous ring time.
  "ringBegin" - print time when the alarm actually begins to ring.
  "ringDuration" - print how long this alarm is to remain ringing.
  "ringEnd" - print time when the alarm actually ends ringing.
  "ringing" - print the alarm’s current ringing state.
  "ringingOnPrevTimeStep" - print whether the alarm was ringing immediately after the previous clock time step.
  "ringInterval" - print the alarm’s periodic ring interval.
  "ringTime" - print the alarm’s next time to ring.
  "ringTimeStepCount" - print how long this alarm is to remain ringing, in terms of a number of clock time steps.
  "refTime" - print the alarm’s interval reference (base) time.
  "sticky" - print whether the alarm must be turned off manually.
  "stopTime" - print when alarm intervals end.
  "timeStepRingingCount" - print the number of time steps the alarm has been ringing thus far.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

36.6.14 ESMF_AlarmRingerOff - Turn off an Alarm

INTERFACE:

    subroutine ESMF_AlarmRingerOff(alarm, rc)

ARGUMENTS:

    type(ESMF_Alarm), intent(inout) :: alarm
    integer, intent(out), optional :: rc

DESCRIPTION:

Turn off an ESMF_Alarm; unsets ringing state. For a sticky alarm, this method must be called to turn off its ringing state. This is true for either ESMF_MODE_FORWARD (default) or ESMF_MODE_REVERSE. See Section 35.1

The arguments are:

alarm The object instance to turn off.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

36.6.15 ESMF_AlarmRingerOn - Turn on an Alarm

INTERFACE:

    subroutine ESMF_AlarmRingerOn(alarm, rc)
ARGUMENTS:

```
type(ESMF_Alarm), intent(inout) :: alarm
integer, intent(out), optional :: rc
```

DESCRIPTION:

Turn on an ESMF_Alarm; sets ringing state.
The arguments are:

- **alarm** The object instance to turn on.
- [rc] Return code; equals ESMF_SUCCESS if there are no errors.

---

### 36.6.16 ESMF_AlarmSet - Set Alarm properties

**INTERFACE:**

```
subroutine ESMF_AlarmSet(alarm, name, clock, ringTime, ringInterval, &
                     stopTime, ringDuration, ringTimeStepCount, &
                     refTime, ringing, enabled, sticky, rc)
```

**ARGUMENTS:**

```
type(ESMF_Alarm), intent(inout) :: alarm
character (len=*) , intent(in), optional :: name
type(ESMF_Clock), intent(in), optional :: clock
type(ESMF_Time), intent(in), optional :: ringTime
type(ESMF_Time), intent(in), optional :: ringInterval
type(ESMF_Time), intent(in), optional :: stopTime
type(ESMF_Time), intent(in), optional :: ringDuration
integer, intent(in), optional :: ringTimeStepCount
integer, intent(in), optional :: refTime
logical, intent(in), optional :: ringing
logical, intent(in), optional :: enabled
logical, intent(in), optional :: sticky
integer, intent(out), optional :: rc
```

**DESCRIPTION:**

Sets/resets one or more of the properties of an ESMF_Alarm that was previously initialized via ESMF_AlarmCreate().
The arguments are:

- **alarm** The object instance to set.
- [name] The new name for this alarm.
- [clock] Re-associates this alarm with a different clock.
- [ringTime] The next ring time for a one-shot alarm or a repeating (interval) alarm.
- [ringInterval] The ring interval for repeating (interval) alarms.
- [stopTime] The stop time for repeating (interval) alarms.
[ringDuration] The absolute ring duration. If not sticky (see argument below), alarms rings for ringDuration, then turns itself off. Mutually exclusive with ringTimeStepCount (below); used only if ringTimeStepCount is zero. See also ESMF_AlarmSticky(), ESMF_AlarmNotSticky().

[ringTimeStepCount] The relative ring duration. If not sticky (see argument below), alarms rings for ringTimeStep-Count, then turns itself off. Mutually exclusive with ringDuration (above); used if non-zero, otherwise ringDu-

[refTime] The reference (i.e. base) time for an interval alarm.

[ringing] Sets the ringing state. See also ESMF_AlarmRingerOn(), ESMF_AlarmRingerOff().

[enabled] Sets the enabled state. If disabled, an alarm will not function at all. See also ESMF_AlarmEnable(), ESMF_AlarmDisable().

[sticky] Sets the sticky state. If sticky, once an alarm is ringing, it will remain ringing until turned off manually via a user call to ESMF_AlarmRingerOff(). If not sticky, an alarm will turn itself off after a certain ring duration specified by either ringDuration or ringTimeStepCount (see above). There is an implicit limitation that in order to properly reverse timestep through a ring end time in ESMF_MODE_REVERSE, that time must have already been traversed in the forward direction. This is due to the fact that the Time Manager cannot predict when user code will call ESMF_AlarmRingerOff(). An error message will be logged when this limitation is not satisfied. See also ESMF_AlarmSticky(), ESMF_AlarmNotSticky().

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

36.6.17 ESMF_AlarmSticky - Set an Alarm’s sticky flag

INTERFACE:

    subroutine ESMF_AlarmSticky(alarm, rc)
    !- ARGUMENTS:
    !   type(ESMF_Alarm), intent(inout) :: alarm
    !   integer, intent(out), optional :: rc

DESCRIPTION:

Set an ESMF_Alarm’s sticky flag; once alarm is ringing, it remains ringing until ESMF_AlarmRingerOff() is called. There is an implicit limitation that in order to properly reverse timestep through a ring end time in ESMF_MODE_REVERSE, that time must have already been traversed in the forward direction. This is due to the fact that the Time Manager cannot predict when user code will call ESMF_AlarmRingerOff(). An error message will be logged when this limitation is not satisfied.

The arguments are:

alarm The object instance to be set sticky.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
36.6.18 ESMF_AlarmValidate - Validate an Alarm’s properties

INTERFACE:

subroutine ESMF_AlarmValidate(alarm, options, rc)

ARGUMENTS:

type(ESMF_Alarm), intent(inout) :: alarm
character (len=*), intent(in), optional :: options
integer, intent(out), optional :: rc

DESCRIPTION:

Performs a validation check on an ESMF_Alarm’s properties. Must have a valid ringTime, set either directly or indirectly via ringInterval. See ESMF_AlarmCreate(). The arguments are:

alarm ESMF_Alarm to be validated.

[options] Validation options are not yet supported.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

36.6.19 ESMF_AlarmWasPrevRinging - Check if Alarm was ringing on the previous Clock timestep

INTERFACE:

function ESMF_AlarmWasPrevRinging(alarm, rc)

RETURN VALUE:

logical :: ESMF_AlarmWasPrevRinging

ARGUMENTS:

type(ESMF_Alarm), intent(inout) :: alarm
integer, intent(out), optional :: rc

DESCRIPTION:

Check if ESMF_Alarm was ringing on the previous clock timestep. See also method ESMF_ClockGetAlarmList(clock, ESMF_ALARMLIST_PREVRINGING, ... ) get a list of all alarms belonging to an ESMF_Clock that were ringing on the previous time step. The arguments are:

alarm The object instance to check for previous ringing state.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
36.6.20  ESMF_AlarmWillRingNext - Check if Alarm will ring upon the next Clock timestep

INTERFACE:

    function ESMF_AlarmWillRingNext(alarm, timeStep, rc)

RETURN VALUE:

    logical :: ESMF_AlarmWillRingNext

ARGUMENTS:

    type(ESMF_Alarm), intent(inout) :: alarm
    type(ESMF_TimeInterval), intent(in), optional :: timeStep
    integer, intent(out), optional :: rc

DESCRIPTION:

Check if ESMF_Alarm will ring on the next clock timestep, either the current clock timestep or a passed-in timestep. See also method ESMF_ClockGetAlarmList(clock, ESMF_ALARMLIST_NEXTRINGING, ...) to get a list of all alarms belonging to a ESMF_Clock that will ring on the next time step. The arguments are:

alarm  The alarm to check for next ringing state.

[timeStep]  Optional timestep to use instead of the clock’s.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

37  Config Class

37.1  Description

ESMF Configuration Management is based on NASA DAO’s Inpak 90 package, a Fortran 90 collection of routines/functions for accessing Resource Files in ASCII format. The package is optimized for minimizing formatted I/O, performing all of its string operations in memory using Fortran intrinsic functions.

Module ESMF_ConfigMod is implemented in Fortran.

37.1.1  Package History

The ESMF Configuration Management Package was evolved by Leonid Zaslavsky and Arlindo da Silva from Ipack90 package created by Arlindo da Silva at NASA DAO. Back in the 70’s Eli Isaacson wrote IOPACK in Fortran 66. In June of 1987 Arlindo da Silva wrote Inpak77 using Fortran 77 string functions; Inpak 77 is a vastly simplified IOPACK, but has its own goodies not found in IOPACK. Inpak 90 removes some obsolete functionality in Inpak77, and parses the whole resource file in memory for performance.

37.2  Use and Examples

37.2.1  Resource Files

A Resource File is a text file consisting of variable length lines (records), each possibly starting with a label (or key), followed by some data. A simple resource file looks like this:
In this example, `my_file_names:` and `constants:` are labels, while `jan87.dat`, `jan88.dat` and `jan89.dat` are data associated with label `my_file_names:`. Resource files can also contain simple tables of the form:

```
my_table_name::
1000  3000  263.0
925   3000  263.0
850   3000  263.0
700   3000  269.0
500   3000  287.0
400   3000  295.8
300   3000  295.8
::
```

Resource files are intended for random access (except between `::`'s in a table definition). Normally, the order of records should not be important. However, the order of records may be important if the same label appears multiple times.

### 37.2.2 Package History

The ESMF Configuration Management Package was evolved by Leonid Zaslavsky and Arlindo da Silva from Ipack90 package created by Arlindo da Silva at NASA DAO.

Back in the 70's Eli Isaacson wrote IOPACK in Fortran 66. In June of 1987 Arlindo da Silva wrote Inpak77 using Fortran 77 string functions; Inpak 77 is a vastly simplified IOPACK, but has its own goodies not found in IOPACK. Inpak 90 removes some obsolete functionality in Inpak77, and parses the whole resource file in memory for performance.

### 37.2.3 A Quick Overview

### 37.2.4 Common Code Arguments

Common Arguments used in the following code fragments:

```
character(ESMF_MAXSTR) :: fname ! file name
character*20 :: fn1, fn2, fn3
integer :: rc               ! error return code (0 is OK)
integer :: n
real :: r
real :: table(7,3)

type(ESMF_Config) :: cf
```

### 37.2.5 Creation of a Config

The first step is to create the `ESMF_Config` and load the ASCII resource (rc) file into memory:

```
    cf = ESMF_ConfigCreate(rc)
```

---

3 See next section for a complete description of parameters for each routine/function
fname = "myResourceFile.rc"
call ESMF_ConfigLoadFile(cf, fname, rc=rc)

37.2.6 Retrieval of constants

The next step is to select the label (record) of interest, say

    call ESMF_ConfigFindLabel(cf, 'constants:', rc=rc)

Two constants, r and n, can be retrieved with the following code fragment:

    call ESMF_ConfigGetAttribute(cf, r, rc=rc) ! results in r = 3.1415
    call ESMF_ConfigGetAttribute(cf, n, rc=rc) ! results in n = 25

37.2.7 Retrieval of file names

File names can be retrieved with the following code fragment:

    call ESMF_ConfigFindLabel(cf, 'my_file_names:', rc=rc)
    call ESMF_ConfigGetAttribute(cf, fn1, rc=rc) ! results in fn1 = 'jan87.dat'
    call ESMF_ConfigGetAttribute(cf, fn2, rc=rc) ! results in fn2 = 'jan88.dat'
    call ESMF_ConfigGetAttribute(cf, fn3, rc=rc) ! results in fn3 = 'jan89.dat'

37.2.8 Retrieval of tables

To access tabular data, the user first must use ESMF_ConfigFindLabel() to locate the beginning of the table, e.g.,

    call ESMF_ConfigFindLabel(cf, 'my_table_name::', rc=rc)

Subsequently, call ESMF_ConfigNextLine() can be used to gain access to each row of the table. Here is a code fragment to read the above table (7 rows, 3 columns):

    do i = 1, 7
       call ESMF_ConfigNextLine(cf, rc=rc)
       do j = 1, 3
          call ESMF_ConfigGetAttribute(cf, table(i,j), rc=rc)
       enddo
    enddo

37.2.9 Destruction of a Config

The work with the configuration file cf is finalized by call to ESMF_ConfigDestroy():

    call ESMF_ConfigDestroy(cf, rc)
37.3 Class API

37.3.1 ESMF_ConfigCreate - Create a Config object

INTERFACE:

    type(ESMF_Config) function ESMF_ConfigCreate( rc )

ARGUMENTS:

    integer,intent(out), optional :: rc

DESCRIPTION:

Creates an ESMF_Config for use in subsequent calls.
The arguments are:

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

37.3.2 ESMF_ConfigDestroy - Destroy a Config object

INTERFACE:

    subroutine ESMF_ConfigDestroy( config, rc )

ARGUMENTS:

    type(ESMF_Config) :: config
    integer,intent(out), optional :: rc

DESCRIPTION:

Destroys the config object.
The arguments are:

config Already created ESMF_Config object.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

37.3.3 ESMF_ConfigFindLabel - Find a label

INTERFACE:

    subroutine ESMF_ConfigFindLabel( config, label, rc )

ARGUMENTS:

    type(ESMF_Config), intent(inout) :: config
    character(len=*)            , intent(in) :: label
    integer, intent(out), optional :: rc
DESCRIPTION:

Finds the label (key) in the config file. Since the search is done by looking for a word in the whole resource file, it is important to use special conventions to distinguish labels from other words in the resource files. The DAO convention is to finish line labels by : and table labels by ::.

The arguments are:

config  Already created ESMF_Config object.

label  Identifying label.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors. Equals -1 if buffer could not be loaded, -2 if label not found, and -3 if invalid operation with index.

37.3.4 ESMF_ConfigGetAttribute - Get a character string

INTERFACE:

! Private name; call using ESMF_ConfigGetAttribute()
subroutine ESMF_ConfigGetString( config, value, label, default, rc )

ARGUMENTS:

type(ESMF_Config), intent(inout) :: config
character(len=*), intent(out) :: value
character(len=*), intent(in), optional :: label
character(len=*), intent(in), optional :: default
integer, intent(out), optional :: rc

DESCRIPTION:

Gets a sequence of characters. It will be terminated by the first white space.

The arguments are:

config  Already created ESMF_Config object.

value  Returned value.

[label]  Identifying label.

[default]  Default value if label is not found in config object.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

37.3.5 ESMF_ConfigGetAttribute - Get a 4-byte real number

INTERFACE:

! Private name; call using ESMF_ConfigGetAttribute()
subroutine ESMF_ConfigGetFloatR4( config, value, label, default, rc )

ARGUMENTS:
type(ESMF_Config), intent(inout) :: config
real(ESMF_KIND_R4), intent(out) :: value
character(len=*), intent(in), optional :: label
real(ESMF_KIND_R4), intent(in), optional :: default
integer, intent(out), optional :: rc

DESCRIPTION:

Gets a 4-byte real value from the config object.
The arguments are:

config Already created ESMF_Config object.
value Returned value.
[label] Identifying label.
[default] Default value if label is not found in config object.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

37.3.6 ESMF_ConfigGetAttribute - Get an 8-byte real number

INTERFACE:

! Private name; call using ESMF_ConfigGetAttribute()
subroutine ESMF_ConfigGetFloatR8( config, value, label, default, rc )

ARGUMENTS:

type(ESMF_Config), intent(inout) :: config
real(ESMF_KIND_R8), intent(out) :: value
character(len=*), intent(in), optional :: label
real(ESMF_KIND_R8), intent(in), optional :: default
integer, intent(out), optional :: rc

DESCRIPTION:

Gets an 8-byte real value from the config object.
The arguments are:

config Already created ESMF_Config object.
value Returned real value.
[label] Identifying label.
[default] Default value if label is not found in config object.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.
37.3.7  ESMF_ConfigGetAttribute - Get a list of 4-byte real numbers

INTERFACE:

    ! Private name; call using ESMF_ConfigGetAttribute()
    subroutine ESMF_ConfigGetFloatsR4( config, valueList, count, label, &
                                         default, rc )

ARGUMENTS:

    type(ESMF_Config), intent(inout) :: config
    real(ESMF_KIND_R4), intent(inout) :: valueList(:)
    integer, intent(in) :: count
    character(len=*) , intent(in), optional :: label
    real(ESMF_KIND_R4), intent(in), optional :: default
    integer, intent(out), optional :: rc

DESCRIPTION:

Gets a 4-byte real valueList of a given count from the config object.
The arguments are:

config     Already created ESMF_Config object.
valueList  Returned real values.
count      Number of returned values expected.
[label]    Identifying label.
[default]  Default value if label is not found in configuration object.
[rc]       Return code; equals ESMF_SUCCESS if there are no errors.

37.3.8  ESMF_ConfigGetAttribute - Get a list of 8-byte real numbers

INTERFACE:

    ! Private name; call using ESMF_ConfigGetAttribute()
    subroutine ESMF_ConfigGetFloatsR8( config, valueList, count, label, &
                                         default, rc )

ARGUMENTS:

    type(ESMF_Config), intent(inout) :: config
    real(ESMF_KIND_R8), intent(inout) :: valueList(:)
    integer, intent(in) :: count
    character(len=*) , intent(in), optional :: label
    real(ESMF_KIND_R8), intent(in), optional :: default
    integer, intent(out), optional :: rc

DESCRIPTION:

Gets an 8-byte real valueList of a given count from the config object.
The arguments are:
config Already created ESMF_Config object.
valueList Returned values.
count Number of returned values expected.
[label] Identifying label.
[default] Default value if label is not found in configuration object.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

37.3.9 ESMF_ConfigGetAttribute - Get a 4-byte integer number

INTERFACE:

! Private name; call using ESMF_ConfigGetAttribute()
subroutine ESMF_ConfigGetIntI4( config, value, label, default, rc )

ARGUMENTS:

type(ESMF_Config), intent(inout) :: config
ingeteger(ESMF_KIND_I4), intent(out) :: value
character(len=*), intent(in), optional :: label
integer(ESMF_KIND_I4), intent(in), optional :: default
integer, intent(out), optional :: rc

DESCRIPTION:

Gets an integer value from the config object.
The arguments are:
config Already created ESMF_Config object.
value Returned integer value.
[label] Identifying label.
[default] Default value if label is not found in configuration object.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.

37.3.10 ESMF_ConfigGetAttribute - Get an 8-byte integer number

INTERFACE:

! Private name; call using ESMF_ConfigGetAttribute()
subroutine ESMF_ConfigGetIntI8( config, value, label, default, rc )

ARGUMENTS:
DESCRIPTION:

Gets an 8-byte integer value from the config object. The arguments are:

config Already created ESMF_Config object.

value Returned integer value.

[label] Identifying label.

[default] Default value if label is not found in configuration object.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

37.3.11 ESMF_ConfigGetAttribute - Get a list of 4-byte integers

INTERFACE:

! Private name; call using ESMF_ConfigGetAttribute()
subroutine ESMF_ConfigGetIntsI4( config, valueList, count, label, &
        default, rc )

ARGUMENTS:

DESCRIPTION:

Gets a 4-byte integer valueList of given count from the config object. The arguments are:

config Already created ESMF_Config object.

valueList Returned values.

count Number of returned values expected.

[label] Identifying label.

[default] Default value if label is not found in configuration object.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
37.3.12  ESMF_ConfigGetAttribute - Get a list of 8-byte integers

INTERFACE:

    ! Private name; call using ESMF_ConfigGetAttribute()
    subroutine ESMF_ConfigGetIntsI8( config, valueList, count, label, &
    default, rc )

ARGUMENTS:

    type(ESMF_Config), intent(inout) :: config
    integer(ESMF_KIND_I8), intent(inout) :: valueList(:)
    integer, intent(in) :: count
    character(len=*), intent(in), optional :: label
    integer(ESMF_KIND_I8), intent(in), optional :: default
    integer, intent(out), optional :: rc

DESCRIPTION:

Gets an 8-byte integer valueList of given count from the config object.
The arguments are:

config  Already created ESMF_Config object.
valueList  Returned values.
count  Number of returned values expected.
[label]  Identifying label.
[default]  Default value if label is not found in configuration object.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

37.3.13  ESMF_ConfigGetAttribute - Get a logical value

INTERFACE:

    ! Private name; call using ESMF_ConfigGetAttribute()
    subroutine ESMF_ConfigGetLogical( config, value, label, default, rc )

ARGUMENTS:

    type(ESMF_Config), intent(inout) :: config
    logical, intent(out) :: value
    character(len=*), intent(in), optional :: label
    logical, intent(in), optional :: default
    integer, intent(out), optional :: rc

DESCRIPTION:

Gets a logical value from the config object.
Recognizes any upper/lowercase composition of the following keywords as logical true/false values:
true t .true. .t. yes y on
false f .false. .f. no n off

The arguments are:


**config**  Already created ESMF_Config object.

**value**  Returned logical value.

[label]  Identifying label.

[default]  Default value if label is not found in configuration object. If not specified, the default value is .false.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 37.3.14 ESMF_ConfigGetAttribute - Get a list of logical values

**INTERFACE:**

```plaintext
! Private name; call using ESMF_ConfigGetAttribute()
subroutine ESMF_ConfigGetLogicals( config, valueList, count, label, &
   default, rc )
```

**ARGUMENTS:**

<table>
<thead>
<tr>
<th>Argument</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>config</td>
<td>type(ESMF_Config), intent(inout)</td>
<td></td>
</tr>
<tr>
<td>valueList</td>
<td>logical, intent(inout)</td>
<td>Returned values.</td>
</tr>
<tr>
<td>count</td>
<td>integer, intent(in)</td>
<td>Number of returned values expected.</td>
</tr>
<tr>
<td>label</td>
<td>character(len=*), intent(in), optional</td>
<td>Identifying label.</td>
</tr>
<tr>
<td>default</td>
<td>logical, intent(in), optional</td>
<td>Default value if label is not found in configuration object.</td>
</tr>
<tr>
<td>rc</td>
<td>integer, intent(out), optional</td>
<td>Return code; equals ESMF_SUCCESS if there are no errors.</td>
</tr>
</tbody>
</table>

**DESCRIPTION:**

Gets a logical valueList of given count from the config object.

The arguments are:

**config**  Already created ESMF_Config object.

**valueList**  Returned values.

**count**  Number of returned values expected.

[label]  Identifying label.

[default]  Default value if label is not found in configuration object.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

---

### 37.3.15 ESMF_ConfigGetChar - Get a character

**INTERFACE:**

```plaintext
subroutine ESMF_ConfigGetChar( config, value, label, default, rc )
```

**ARGUMENTS:**

<table>
<thead>
<tr>
<th>Argument</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>config</td>
<td></td>
<td>Already created ESMF_Config object.</td>
</tr>
<tr>
<td>value</td>
<td></td>
<td>Returned logical value.</td>
</tr>
<tr>
<td>label</td>
<td></td>
<td>Identifying label.</td>
</tr>
<tr>
<td>default</td>
<td></td>
<td>Default value if label is not found in configuration object.</td>
</tr>
<tr>
<td>rc</td>
<td></td>
<td>Return code; equals ESMF_SUCCESS if there are no errors.</td>
</tr>
</tbody>
</table>

---
**37.3.16 ESMF_ConfigGetDim - Get table sizes**

**INTERFACE:**

```fortran
subroutine ESMF_ConfigGetDim( config, label, lineCount, columnCount, rc )

    implicit none

    type(ESMF_Config), intent(inout) :: config ! ESMF Configuration
    integer, intent(out) :: lineCount
    integer, intent(out) :: columnCount

    character(len=*) , intent(in), optional :: label ! label (if present)
    character(len=*) , intent(in), optional :: default ! otherwise, current line

    integer, intent(out), optional :: rc ! Error code
```

**DESCRIPTION:**

Returns the number of lines in the table in `lineCount` and the maximum number of words in a table line in `columnCount`.

The arguments are:

- **config** Already created ESMF_Config object.
- **lineCount** Returned number of lines in the table.
- **columnCount** Returned maximum number of words in a table line.
- **label** Identifying label.
- **rc** Return code; equals ESMF_SUCCESS if there are no errors.
37.3.17  ESMF_ConfigGetLen - Get the length of the line in words

INTERFACE:

    integer function ESMF_ConfigGetLen( config, label, rc )

ARGUMENTS:

    type(ESMF_Config), intent(inout) :: config
    character(len=*), intent(in), optional :: label
    integer, intent(out), optional :: rc

DESCRIPTION:

Gets the length of the line in words by counting words disregarding types. Returns the word count as an integer. The arguments are:

config  Already created ESMF_Config object.
[label] Identifying label. If not specified, use the current line.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

37.3.18  ESMF_ConfigLoadFile - Load resource file into memory

INTERFACE:

    subroutine ESMF_ConfigLoadFile( config, filename, delayout, unique, rc )

ARGUMENTS:

    type(ESMF_Config), intent(inout) :: config
    character(len=*), intent(in) :: filename
    type(ESMF_DELayout), intent(in), optional :: delayout
    logical, intent(in), optional :: unique
    integer, intent(out), optional :: rc

DESCRIPTION:

Resource file with filename is loaded into memory. The arguments are:

config  Already created ESMF_Config object.
filename  Configuration file name.
[delayout] ESMF_DELayout associated with this config object.
[unique] If specified as true, uniqueness of labels are checked and error code set if duplicates found.
[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
37.3.19  ESMF_ConfigNextLine - Find next line

INTERFACE:

    subroutine ESMF_ConfigNextLine( config, tableEnd, rc)

ARGUMENTS:

    type(ESMF_Config), intent(inout) :: config
    logical, intent(out), optional :: tableEnd
    integer, intent(out), optional:: rc

DESCRIPTION:

Selects the next line (for tables).
The arguments are:

config  Already created ESMF_Config object.

[tableEnd] If specified as TRUE, end of table mark (:) is checked.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

37.3.20  ESMF_ConfigValidate - Validate a Config object

INTERFACE:

    subroutine ESMF_ConfigValidate(config, options, rc)

ARGUMENTS:

    type(ESMF_Config), intent(inout) :: config
    character (len=*) , intent(in), optional :: options
    integer, intent(out) , optional :: rc

DESCRIPTION:

Checks whether a config object is valid.
The arguments are:

config  ESMF_Config object to be validated.

[options] If none specified: simply check that the buffer is not full and the pointers are within range. "unusedAttributes" - Report to the default logfile all attributes not retrieved via a call to ESMF_ConfigGetAttribute() or ESMF_ConfigGetChar(). The attribute name (label) will be logged via ESMF_LogErr with the WARNING log message type. For an array-valued attribute, retrieving at least one value via ESMF_ConfigGetAttribute() or ESMF_ConfigGetChar() constitutes being "used."

[rc] Return code; equals ESMF_SUCCESS if there are no errors. Equals ESMF_RC_ATTR_UNUSED if any unused attributes are found with option "unusedAttributes" above.
38 LogErr Class

38.1 Description

The Log class consists of a variety of methods for writing error, warning, and informational messages to files. A default Log is created at ESMF initialization. Other Logs can be created later in the code by the user. Most LogErr methods take a Log as an optional argument and apply to the default Log when another Log is not specified. A set of standard return codes and associated messages are provided for error handling.

LogErr provides capabilities to store message entries in a buffer, which is flushed to a file, either when the buffer is full, or when the user calls an ESMF_LogFlush() method. Currently, the default is for the Log to flush after every ten entries. This can easily be changed by using the ESMF_LogSet() method and setting the maxElements property to another value. The ESMF_LogFlush() method is automatically called when the program exits by any means (program completion, halt on error, or when the Log is closed).

The user has the capability to halt the program on an error or on a warning by using the ESMF_LogSet() method with the halt property. When the halt property is set to ESMF_LOG_HALTWARN, the program will stop on any and all warning or errors. When the halt property is set to ESMF_LOG_HALTERROR, the program will only halt on errors. Lastly, the user can choose to never halt by setting the halt property to ESMF_LOG_HALTNEVER; this is the default.

LogErr will automatically put the PET number into the Log. Also, the user can either specify ESMF_LOG_SINGLE which writes all the entries to a single Log or ESMF_LOG_MULTI which writes entries to multiple Logs according to the PET number. To distinguish Logs from each other when using ESMF_LOG_MULTI, the PET number (in the format PETx.) will be prepended to the file name where x is the PET number.

Opening multiple log files and writing log messages from all the processors may affect the application performance while running on a large number of processors. For that reason, ESMF_LOG_NONE is provided to switch off the LogErr capability. All the LogErr methods have no effect in the ESMF_LOG_NONE mode.

Other options that are planned for LogErr are to adjust the verbosity of output, and to optionally write to stdout instead of file(s).

38.2 LogErr Options

38.2.1 ESMF_HaltType

DESCRIPTION:
Specifies when to halt - e.g., never, warning, error.
Valid values are:
ESMF_LOG_HALTNEVER  Never halt.
ESMF_LOG_HALTWARNING Halt on a warning.
ESMF_LOG_HALTERROR  Halt on an error.

38.2.2 ESMF_MsgType

DESCRIPTION:
Specifies what sort of message - e.g., info, warning, error - will be written to an ESMF_Log file.
Valid values are:
ESMF_LOG_INFO  Message is informational.
ESMF_LOG_WARNING Message is a warning.
ESMF_LOG_ERROR  Message indicates an error.

38.2.3 ESMF_LogType

DESCRIPTION:
Specifies single, multi or no Log.
Valid values are:
**ESMF_LOG_SINGLE**  Log is single Log.

**ESMF_LOG_MULTI**  Log is multi Log.

**ESMF_LOG_NONE**  There is no Log.

### 38.3 Use and Examples

By default `ESMF_Initialize()` opens a default Log in `ESMF_LOG_MULTI` mode. ESMF handles the initialization and finalization of the default Log so the user can immediately start using it. If additional Log objects are desired, they must be explicitly created or opened using `ESMF_LogOpen()`.

`ESMF_LogOpen()` requires a Log object and filename argument. Additionally, the user can specify single or multi Logs by setting the `logtype` property to `ESMF_LOG_SINGLE` or `ESMF_LOG_MULTI`. This is useful as the PET numbers are automatically added to the Log entries. A single Log will put all entries, regardless of PET number, into a single log while a multi Log will create multiple Logs with the PET number prepended to the filename and all entries will be written to their corresponding Log by their PET number.

By default, the Log file is not truncated at the start of a new run; it just gets appended each time. Future functionality would include an option to either truncate or append to the Log file.

In all cases where a Log is opened, a unit number is assigned to a specific Log. A Log is assigned the lowest available unit number starting with 11. If a unit number is occupied, the next higher unit number is checked using the Fortran “inquire” method. The process repeats until a free unit number is found or when the unit number reaches `ESMF_LOG_UPPER` in which case an error is returned. As a result, the user should always check for free numbers using Fortran’s “inquire” to prevent potential unit number conflicts. In the future we anticipate supporting an option in which a desired unit number can be passed in.

The user can then set or get options on how the Log should be used with the `ESMF_LogSet()` and `ESMF_LogGet()` methods. These are partially implemented at this time.

Depending on how the options are set, `ESMF_LogWrite()` either writes user messages directly to a Log file or writes to a buffer that can be flushed when full or by using the `ESMF_LogFlush()` method. The default is to flush after every ten entries because `maxElements` is initialized to ten (which means the buffer reaches its full state after every ten writes and then flushes).

For every `ESMF_LogWrite()`, a time and date stamp is prepended to the Log entry. The time is given in microsecond precision. The next item shown is the type of message (INFO in this case). Next, the PET number is added. Lastly, the content is written.

When calling `ESMF_LogWrite()`, the user can supply an optional line, file and method. These arguments can be passed in explicitly or with the help of cpp macros. In the latter case, a define for an `ESMF_FILENAME` must be placed at the beginning of a file and a define for `ESMF_METHOD` must be placed at the beginning of each method. The user can then use the `ESMF_CONTEXT` cpp macro in place of line, file and method to insert the parameters into the method. The user does not have to specify line number as it is a value supplied by cpp.

An example of Log output is given below running with `logtype` property set to `ESMF_LOG_MULTI` (default) using the default Log:

(Log file PET0.ESMF_LogFile)

```
20041105 163418.472210 INFO PET0 Running with ESMF Version 2.2.1
```

(Log file PET1.ESMF_LogFile)

```
20041105 163419.186153 ERROR PET1 ESMF_Field.F90 812
ESMF_FieldGet No Grid or Bad Grid attached to Field
```

The first entry shows date and time stamp. The time is given in microsecond precision. The next item shown is the type of message (INFO in this case). Next, the PET number is added. Lastly, the content is written.

The second entry shows something slightly different. In this case, we have an ERROR. The method name (`ESMF_Field.F90`) is automatically provided from the cpp macros as well as the line number (812). Then the content of the message is written.

When done writing messages, the default Log is closed by calling `ESMF_LogFinalize()` or `ESMF_LogClose()` for user created Logs. Both methods will release the assigned unit number.
! PROGRAM: ESMF_LogErrEx - Log Error examples
!
! DESCRIPTION:
!
! This program shows examples of Log Error writing

Macros for cpp usage
File define
#define ESMF_FILENAME "ESMF_LogErrEx.F90"
! Method define
#define ESMF_METHOD "program ESMF_LogErrEx"
#include "ESMF_LogMacros.inc"

 ! ESMP Framework module
use ESMF_Mod
implicit none

! return variables
integer :: rc1, rc2, rc3, rcToTest, allocRcToTest
type(ESMF_LOG) :: alog ! a log object that is not the default log
type(ESMF_LogType) :: defaultLogtype
type(ESMF_Time) :: time
integer, pointer :: intptr(:)

38.3.1 Default Log
This example shows how to use the default Log. This example does not use cpp macros but does use multi Logs. A separate Log will be created for each PET.

! Initialize ESMF to initialize the default Log
call ESMF_Initialize(rc=rc1, defaultLogtype=ESMF_LOG_MULTI)

! LogWrite
call ESMF_LogWrite("Log Write 2", ESMF_LOG_INFO, rc=rc2)

! LogMsgSetError
call ESMF_LogMsgSetError(ESMF_FAILURE, "Convergence failure", &
rcToReturn=rc2)
! LogMsgFoundError
call ESMF_TimeSet(time, calendarType=ESMF_CAL_NOCALENDAR)
call ESMF_TimeSyncToRealTime(time, rcToTest)
if (ESMF_LogMsgFoundError(rcToTest, "getting wall clock time", &
rcToReturn=rc2)) then
! Error getting time. The previous call will have printed the error
! already into the log file. Add any additional error handling here.
! (This call is expected to provoke an error from the Time Manager.)
endif

! LogMsgFoundAllocError
allocate(intptr(10), stat=allocRcToTest)
if (ESMF_LogMsgFoundAllocError(allocRcToTest, "integer array", &
rcToReturn=rc2)) then
! Error during allocation. The previous call will have logged already
! an error message into the log.
endif
deallocate(intptr)

38.3.2 User Created Log

This example shows how to use a user created Log. This example uses cpp macros.

! Open a Log named "Testlog.txt" associated with alog.
call ESMF_LogOpen(alog, "TestLog.txt", rc=rc1)

! LogWrite; ESMF_CONTEXT expands into __LINE__,ESMF_FILENAME,ESMF_METHOD
call ESMF_LogWrite("Log Write 2", ESMF_LOG_INFO, ESMF_CONTEXT, &
log=alog, rc=rc2)

! LogMsgSetError; ESMF_CONTEXT expands into
! __LINE__,ESMF_FILENAME,ESMF_METHOD
call ESMF_LogMsgSetError(ESMF_FAILURE, "Interpolation Failure", &
ESMF_CONTEXT, rcToReturn=rc2, log=alog)

38.3.3 Get and Set

This example shows how to use Get and Set routines, on both the default Log and the user created Log from the
previous examples.

! This is an example showing a query of the default Log. Please note that
! no Log is passed in the argument list, so the default Log will be used.
call ESMF_LogGet(logtype=defaultLogtype, rc=rc3)

! This is an example setting a property of a Log that is not the default.
! It was opened in a previous example, and the handle for it must be
! passed in the argument list.
call ESMF_LogSet(log=alog, halt=ESMF_LOG_HALTERROR, rc=rc2)

! Close the user log.
call ESMF_LogClose(alog, rc3)

! Finalize ESMF to close the default log
call ESMF_Finalize(rc=rc1)

38.4 Restrictions and Future Work

1. Line, file and method are only available when using the C preprocess
   Message writing methods are expanded using the ESMF macro ESMF_CONTEXT that adds the predefined symbolic constants __LINE__
   and __FILE__ (or the ESMF constant ESMF_FILENAME if defined) and the ESMF constant ESMF_METHOD
to the argument list. Using these constants, we can associate a file name, line number and method name with
the message. If the CPP preprocessor is not used, this expansion will not be done and hence the ESMF macro
ESMF_CONTEXT can not be used, leaving the file name, line number and method out of the Log text.
2. Get and set methods are partially implemented. Currently, the ESMF_LogGet() and ESMF_LogSet() methods are partially implemented.

3. Log only appends entries. All writing to the Log is appended rather than overwriting the Log. Future enhancements include the option to either append to an existing Log or overwrite the existing Log.

4. Avoiding conflicts with the default Log. The private methods ESMF_LogInitialize() and ESMF_LogFinalize() are called during ESMF_Initialize() and ESMF_Finalize() respectively, so they do not need to be called if the default Log is used. If a new Log is required, ESMF_LogOpen() is used with a new Log object passed in so that there are no conflicts with the default Log.

5. ESMF_LOG_SINGLE does not work properly. When the ESMF_LogType is set to ESMF_LOG_SINGLE, different system may behave differently. The log messages from some processors may be lost or overwritten by other processors. Users are advised not to use this mode. The MPI-based I/O will be implemented to fix the problem in the future release.

38.5 Design and Implementation Notes

1. The Log class was implemented in Fortran and uses the Fortran I/O libraries when the class methods are called from Fortran. The C/C++ Log methods use the Fortran I/O library by calling utility functions that are written in Fortran. These utility functions call the standard Fortran write, open and close functions. At initialization an ESMF_LOG is created. The ESMF_LOG stores information for a specific Log file. When working with more than one Log file, multiple ESMF_LOG’s are required (one ESMF_LOG for each Log file). For each Log, a handle is returned through the ESMF_LogInitialize method for the default log or ESMF_LogOpen for a user created log. The user can specify single or multi logs by setting the logtype property in the ESMF_LogInitialize or ESMF_Open method to ESMF_LOG_SINGLE or ESMF_LOG_MULTI. Similarly, the user can set the defaultLogtype property for the default Log with the ESMF_Initialize method call. The logtype is useful as the PET numbers are automatically added to the log entries. A single log will put all entries, regardless of PET number, into a single log while a multi log will create multiple logs with the PET number prepended to the filename and all entries will be written to their corresponding log by their PET number.

The properties for a Log are set with the ESMF_LogSet() method and retrieved with the ESMF_LogGet() method.

Additionally, buffering is enabled. Buffering allows ESMF to manage output data streams in a desired way. Writing to the buffer is transparent to the user because all the Log entries are handled automatically by the ESMF_LogWrite() method. All the user has to do is specify the buffer size (the default is ten) by setting the maxElements property. Every time the ESMF_LogWrite() method is called, a LogEntry element is populated with the ESMF_LogWrite() information. When the buffer is full (i.e., when all the LogEntry elements are populated), the buffer will be flushed and all the contents will be written to file. If buffering is not needed, that is maxElements=1 or flushImmediately=ESMF_TRUE, the ESMF_LogWrite() method will immediately write to the Log file(s).

38.6 Object Model

The following is a simplified UML diagram showing the structure of the Log class. See Appendix A, A Brief Introduction to UML, for a translation table that lists the symbols in the diagram and their meaning.
38.7  Class API

38.7.1  ESMF_LogClose - Close Log file(s)

INTERFACE:

subroutine ESMF_LogClose(log, rc)

ARGUMENTS:

  type(ESMF_Log) :: log
  integer, intent(out),optional :: rc

DESCRIPTION:

This routine closes the file(s) associated with the log. The arguments are:

log   An ESMF_Log object.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

38.7.2  ESMF_LogFlush - Flushes the Log file(s)

INTERFACE:

subroutine ESMF_LogFlush(log,rc)

ARGUMENTS:

  type(ESMF_LOG), target,optional :: log
  integer, intent(out),optional :: rc
DESCRIPTION:
This subroutine flushes the ESMF_Log buffer to its associated file.
The arguments are:

[log] An optional ESMF_Log object that can be used instead of the default Log.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

38.7.3 ESMF_LogFoundAllocError - Check Fortran status for allocation error

INTERFACE:

function ESMF_LogFoundAllocError(statusToCheck, line, file, &
   method, rcToReturn,log)

RETURN VALUE:

   logical ::ESMF_LogFoundAllocError

ARGUMENTS:

   integer, intent(in) :: statusToCheck
   integer, intent(in), optional :: line
   character(len=__), intent(in), optional :: file
   character(len=__), intent(in), optional :: method
   integer, intent(out),optional :: rcToReturn
   type(ESMF_LOG),intent(inout),optional :: log

DESCRIPTION:

This function returns a logical true when a Fortran status code returned from a memory allocation indicates an allocation error. An ESMF predefined memory allocation error message will be added to the ESMF_Log along with line, file and method. Additionally, the statusToCheck will be converted to a rcToReturn. The arguments are:

statusToCheck  Fortran allocation status to check.

[line] Integer source line number. Expected to be set by using the preprocessor macro __LINE__ macro.

[file] User-provided source file name.

[method] User-provided method string.

[rcToReturn] If specified, set the rcToReturn value to ESMF_RC_MEM which is the error code for a memory allocation error.

[log] An optional ESMF_Log object that can be used instead of the default Log.
38.7.4 ESMF_LogFoundError - Check ESMF return code for error

INTERFACE:

    function ESMF_LogFoundError(rcToCheck, line, file, method,&
       rcToReturn, log)

RETURN VALUE:

    logical :: ESMF_LogFoundError

ARGUMENTS:

    integer, intent(in) :: rcToCheck
    integer, intent(in), optional :: line
    character(len=*) , intent(in), optional :: file
    character(len=*) , intent(in), optional :: method
    integer, intent(out), optional :: rcToReturn
    type(ESMF_LOG),intent(inout), target, optional :: log

DESCRIPTION:

This function returns a logical true for ESMF return codes that indicate an error. A predefined error message will added to the ESMF_Log along with line, file and method. Additionally, rcToReturn will be set to rcToCheck. The arguments are:

rcToCheck  Return code to check.
[line]  Integer source line number. Expected to be set by using the preprocessor macro __LINE__ macro.
[file]  User-provided source file name.
[method]  User-provided method string.
[rcToReturn]  If specified, copy the rcToCheck value to rc. This is not the return code for this function; it allows the calling code to do an assignment of the error code at the same time it is testing the value.
[log]  An optional ESMF_Log object that can be used instead of the default Log.

38.7.5 ESMF_LogMsgFoundAllocError - Check Fortran status for allocation error and write message

INTERFACE:

    function ESMF_LogMsgFoundAllocError(statusToCheck, msg, line, file, &
       method, rcToReturn, log)

RETURN VALUE:

    logical :: ESMF_LogMsgFoundAllocError

ARGUMENTS:
integer, intent(in) :: statusToCheck
character(len=*), intent(in) :: msg
integer, intent(in), optional :: line
character(len=*), intent(in), optional :: file
character(len=*), intent(in), optional :: method
integer, intent(out),optional :: rcToReturn
type(ESMF_LOG), intent(inout), optional :: log

DESCRIPTION:

This function returns a logical true when a Fortran status code returned from a memory allocation indicates an allocation error. An ESMF predefined memory allocation error message will be added to the ESMF_Log along with a user added msg, line, file and method. Additionally, statusToCheck will be converted to rcToReturn.

The arguments are:

statusToCheck  Fortran allocation status to check.
msg  User-provided message string.
[line]  Integer source line number. Expected to be set by using the preprocessor macro __LINE__ macro.
[file]  User-provided source file name.
[method]  User-provided method string.
[rcToReturn] If specified, set the rcToReturn value to ESMF_RC_MEM which is the error code for a memory allocation error.
[log]  An optional ESMF_Log object that can be used instead of the default Log.

38.7.6 ESMF_LogMsgFoundError - Check ESMF return code for error and write message

INTERFACE:

function ESMF_LogMsgFoundError(rcToCheck, msg, line, file, method, &
rcToReturn, log)

RETURN VALUE:

logical ::ESMF_LogMsgFoundError

ARGUMENTS:

integer, intent(in) :: rcToCheck
character(len=*), intent(in) :: msg
integer, intent(in), optional :: line
character(len=*), intent(in), optional :: file
character(len=*), intent(in), optional :: method
integer, intent(out),optional :: rcToReturn
type(ESMF_LOG), intent(inout), target, optional :: log

DESCRIPTION:

This function returns a logical true for ESMF return codes that indicate an error. A predefined error message will added to the ESMF_Log along with a user added msg, line, file and method. Additionally, rcToReturn will be set to rcToCheck.

The arguments are:
rcToCheck  Return code to check.

msg  User-provided message string.

[line]  Integer source line number. Expected to be set by using the preprocessor macro __LINE__ macro.

[file]  User-provided source file name.

[method]  User-provided method string.

[rcToReturn]  If specified, copy the rcToCheck value to rc. This is not the return code for this function; it allows the calling code to do an assignment of the error code at the same time it is testing the value.

[log]  An optional ESMF_Log object that can be used instead of the default Log.

38.7.7  ESMF_LogMsgSetError - Set ESMF return code for error and write msg

INTERFACE:

subroutine ESMF_LogMsgSetError(rcValue, msg, line, file, method, &
rcToReturn, log)

ARGUMENTS:

integer, intent(in) :: rcValue
character(len=*), intent(in) :: msg
integer, intent(in), optional :: line
character(len=*), intent(in), optional :: file
character(len=*), intent(in), optional :: method
integer, intent(out),optional :: rcToReturn
type(ESMF_LOG), intent(inout), target, optional :: log

DESCRIPTION:

This subroutine sets the rcToReturn value to rcValue if rcToReturn is present and writes this error code to the ESMF_Log if an error is generated. A predefined error message will added to the ESMF_Log along with a user added msg, line, file and method.

The arguments are:

rcValue  rc value for set

msg  User-provided message string.

[line]  Integer source line number. Expected to be set by using the preprocessor macro __LINE__ macro.

[file]  User-provided source file name.

[method]  User-provided method string.

[rcToReturn]  If specified, copy the rcValue value to rcToReturn. This is not the return code for this function; it allows the calling code to do an assignment of the error code at the same time it is testing the value.

[log]  An optional ESMF_Log object that can be used instead of the default Log.
38.7.8 ESMF_LogOpen - Open Log file(s)

INTERFACE:

    subroutine ESMF_LogOpen(log, filename, logtype, rc)

ARGUMENTS:

    type(ESMF_Log)              :: log
    character(len=*)             :: filename
    type(ESMF_LogType), intent(in),optional :: logtype
    integer, intent(out),optional :: rc

DESCRIPTION:

This routine opens a file with filename and associates it with the ESMF_Log. This is only used when the user does not want to use the default Log. The arguments are:

log An ESMF_Log object.
filename Name of file. Maximum length 26 characters to allow for the PET number to be added and keep the total file name length under 32 characters.
logtype Set the logtype. See section 38.2.3 for a list of valid options. If not specified, defaults to ESMF_LOG_MULTI.
rc Return code; equals ESMF_SUCCESS if there are no errors.

38.7.9 ESMF_LogSet - Set Log parameters

INTERFACE:

    subroutine ESMF_LogSet(log,verbose,flush,rootOnly,halt, &
                            stream,maxElements,errorMask,rc)

ARGUMENTS:

    type(ESMF_LOG), target,optional :: log
    type(ESMF_Logical), intent(in),optional :: verbose
    type(ESMF_Logical), intent(in),optional :: flush
    type(ESMF_Logical), intent(in),optional :: rootOnly
    type(ESMF_HaltType), intent(in),optional :: halt
    integer, intent(in),optional      :: stream
    integer, intent(in),optional      :: maxElements
    integer, intent(in),optional      :: errorMask(:)
    integer, intent(out),optional     :: rc

DESCRIPTION:

This subroutine sets the properties for the Log object. The arguments are:

log An optional ESMF_Log object that can be used instead of the default Log.
verbose Verbose flag.
[rootOnly] Root only flag.

[halt] Halt definition, with the following valid values:

    ESMF_LOG_HALTWARNING;
    ESMF_LOG_HALTERROR;
    ESMF_LOG_HALTNEVER.

[stream] The type of stream, with the following valid values and meanings:

    0 free;
    1 preordered.

[maxElements] Maximum number of elements in the Log.

[errorMask] List of error codes that will not be logged as errors.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

38.7.10 ESMF_LogWrite - Write to Log file(s)

INTERFACE:

    recursive subroutine ESMF_LogWrite(msg,MsgType,line,file,method,log,rc)

ARGUMENTS:

    character(len=*) , intent(in)     :: msg
    type(ESMF_MsgType) , intent(in)   :: msgtype
    integer , intent(in) , optional   :: line
    character(len=*) , intent(in) , optional :: file
    character(len=*) , intent(in) , optional :: method
    type(ESMF_LOG) , target,optional   :: log
    integer , intent(out) , optional   :: rc

DESCRIPTION:

This subroutine writes to the file associated with an ESMF_Log. A message is passed in along with the msgtype, line, file and method. If the write to the ESMF_Log is successful, the function will return a logical true. This function is the base function used by all the other ESMF_Log writing methods.

The arguments are:

    msg  User-provided message string.

    msgtype The type of message. See Section 38.2.2 for possible values.

    [line] Integer source line number. Expected to be set by using the preprocessor macro __LINE__ macro.

    [file] User-provided source file name.

    [method] User-provided method string.

    [log] An optional ESMF_Log object that can be used instead of the default Log.

    [rc] Return code; equals ESMF_SUCCESS if there are no errors.
39 DELayout Class

39.1 Description

The DELayout class provides an additional layer of abstraction on top of the Virtual Machine (VM) layer. DELayout does this by introducing DEs (Decomposition Elements) as logical resource units. The DELayout object keeps track of the relationship between its DEs and the resources of the associated VM object.

The relationship between DEs and VM resources (PETs (Persistent Execution Threads) and VASs (Virtual Address Spaces)) contained in a DELayout object is defined during its creation and cannot be changed thereafter. There are, however, a number of hint and specification arguments that can be used to shape the DELayout during its creation.

Contrary to the number of PETs and VASs contained in a VM object which are fixed by the available resources the number of DEs contained in a DELayout can be chosen freely to best match the computational problem or other design criteria. Creating a DELayout with less DEs than there are PETs in the associated VM object can be used to share resources between decomposed objects within an ESMF component. Creating a DELayout with more DEs than there are PETs in the associated VM object can be used to evenly partition the computation over the available resources.

The simplest case, however, is where the DELayout contains the same number of DEs as there are PETs in the associated VM context. In this case the DELayout may be used to re-label the hardware and operating system resources held by the VM. For instance, it is possible to order the resources so that specific DEs have best available communication paths. The DELayout will map the DEs to the PETs of the VM according to the resource details provided by the VM instance.

Furthermore, general DE to PET mapping can be used to offer computational resources with finer granularity than the VM does. The DELayout can be queried for computational and communication capacities of DEs and DE pairs, respectively. This information can be used to best utilize the DE resources when partitioning the computational problem. In combination with other ESMF classes general DE to PET mapping can be used to realize cache blocking, communication hiding and dynamic load balancing.

Finally, the DELayout layer offers primitives that allow a work queue style dynamic load balancing between DEs.

39.2 Use and Examples

The following examples demonstrate how to create, use and destroy DELayout objects.

39.2.1 Default DELayout

Without specifying any of the optional parameters the created ESMF_DELayout defaults into having as many DEs as there are PETs in the associated VM object. Consequently the resulting DELayout describes a simple 1-to-1 DE to PET mapping.

```python
delayout = ESMF_DELayoutCreate(rc=rc)
```

The default DE to PET mapping is simply:

```
DE 0 -> PET 0
DE 1 -> PET 1
...
```

DELayout objects that are not used any longer should be destroyed.

```python
call ESMF_DELayoutDestroy(delayout, rc=rc)
```

The optional vm argument can be provided to DELayoutCreate() to lower the method’s overhead by the amount it takes to determine the current VM.

```python
delayout = ESMF_DELayoutCreate(vm=vm, rc=rc)
```
By default all PETs of the associated VM will be considered. However, if the optional argument petList is present
DEs will only be mapped against the PETs contained in the list. When the following example is executed on four
PETs it creates a DELayout with four DEs by default that are mapped to the provided PETs in their given order. It is
erroneous to specify PETs that are not part of the VM context on which the DELayout is defined.

delayout = ESMF_DELayoutCreate(petList=/(i,i=petCount-1,1,-1)/), rc=rc)

Once the end of the petList has been reached the DE to PET mapping continues from the beginning of the list. For a 4
PET VM the above created DELayout will end up with the following DE to PET mapping:

DE 0 -> PET 3
DE 1 -> PET 2
DE 2 -> PET 1
DE 2 -> PET 3

39.2.2 DELayout with specified number of DEs

The deCount argument can be used to specify the number of DEs. In this example a DELayout is created that
contains four times as many DEs as there are PETs in the VM.

delayout = ESMF_DELayoutCreate(deCount=4*petCount, rc=rc)

Cyclic DE to PET mapping is the default. For 4 PETs this means:

DE 0, 4, 8, 12 -> PET 0
DE 1, 5, 9, 13 -> PET 1
DE 2, 6, 10, 14 -> PET 2
DE 3, 7, 11, 15 -> PET 3

The default DE to PET mapping can be overridden by providing the deGrouping argument. This argument provides
a positive integer group number for each DE in the DELayout. All of the DEs of a group will be mapped against the
same PET. The actual group index is arbitrary (but must be positive) and its value is of no consequence.

delayout = ESMF_DELayoutCreate(deCount=4*petCount, &
    deGrouping=/(i/4,i=0,4*petCount-1)/), rc=rc)

This will achieve blocked DE to PET mapping. For 4 PETs this means:

DE 0, 1, 2, 3 -> PET 0
DE 4, 5, 6, 7 -> PET 1
DE 8, 9, 10, 11 -> PET 2
DE 12, 13, 14, 15 -> PET 3

39.2.3 DELayout with computational and communication weights

The quality of the partitioning expressed by the DE to PET mapping depends on the amount and quality of information
provided during DELayout creation. In the following example the compWeights argument is used to specify relative
computational weights for all DEs and communication weights for DE pairs are provided by the commWeights
argument. The example assumes four DEs.
allocate(compWeights(4))
allocate(commWeights(4, 4))

! setup compWeights and commWeights according to computational problem
delayout = ESMF_DELayoutCreate(deCount=4, compWeights=compWeights, &
commWeights=commWeights, rc=rc)
ddeallocate(compWeights, commWeights)

The resulting DE to PET mapping depends on the specifics of the VM object and the provided compWeights and commWeights arrays.

### 39.2.4 DELayout from petMap

Full control over the DE to PET mapping is provided via the petMap argument. This example maps the DEs to PETs in reverse order. In the 4 PET case this will result in the following mapping:

- DE 0 -> PET 3
- DE 1 -> PET 1
- DE 2 -> PET 2
- DE 3 -> PET 0

\[
\text{delayout} = \text{ESMF\_DELayoutCreate}(/(i, i=i=\text{petCount-1, 0, -1})/, \text{rc}=\text{rc})
\]

### 39.2.5 DELayout from petMap with multiple DEs per PET

The petMap argument gives full control over DE to PET mapping. The following example runs on 4 or more PETs maps DEs to PETs according to the following table:

- DE 0 -> PET 3
- DE 1 -> PET 3
- DE 2 -> PET 1
- DE 3 -> PET 0
- DE 4 -> PET 2
- DE 5 -> PET 1
- DE 6 -> PET 3
- DE 7 -> PET 1

\[
\text{delayout} = \text{ESMF\_DELayoutCreate}(/3, 3, 1, 0, 2, 1, 3, 1/, \text{rc}=\text{rc})
\]

### 39.2.6 Working with a DELayout - simple 1-to-1 DE to PET mapping

The simplest case is a DELayout with as many DEs as PETs where each DE is against a separate PET. This of course implies that the number of DEs equals the number of PETs. This special 1-to-1 DE to PET mapping is very common and many codes assume this mapping. The following example code shows how a DELayout can be queried about its mapping.

\[
\text{delayout} = \text{ESMF\_DELayoutCreate}(\text{rc}=\text{rc})
\]

call ESMF\_DELayoutGet(delayout, oneToOneFlag=oneToOneFlag, rc=rc)
if (rc /= ESMF\_SUCCESS) finalrc=rc
if (oneToOneFlag == ESMF\_FALSE) then
    ! handle the unexpected case of general DE to PET mapping
endif
allocate(localDeList(1))
call ESMF_DELayoutGet(delayout, localDeList=localDeList, rc=rc)
if (rc /= ESMF_SUCCESS) finalrc=rc
myDe = localDeList(1)
deallocate(localDeList)

39.2.7 Working with a DELayout - general DE to PET mapping

In general a DELayout may describe a DE to PET mapping that is not 1-to-1. The following example shows how code can be written in a general form that will work on all PETs for DELayouts with general or 1-to-1 DE to PET mapping.

delayout = ESMF(DELayoutCreate(deCount=petCount+2, rc=rc)
call ESMF_DELayoutGet(delayout, localDeCount=localDeCount, rc=rc)
allocate(localDeList(localDeCount))
call ESMF_DELayoutGet(delayout, localDeList=localDeList, rc=rc)
if (rc /= ESMF_SUCCESS) finalrc=rc
do i=1, localDeCount
   workDe = localDeList(i)
! print *, "I am PET", localPET, " and I am working on DE ", workDe
enddo
deallocate(localDeList)

39.2.8 Work queue dynamic load balancing

The DELayout API includes two calls that can be used to easily implement work queue dynamic load balancing. The work load is broken up into DEs (more than there are PETs) and processed by the PETs. Load balancing is only possible for ESMF multi-threaded VMs and requires that DEs are pinned to VASs instead of the PETs (default). The following example will run for any VM and DELayout, however, load balancing will only occur under the mentioned conditions.

delayout = ESMF_DELayoutCreate(deCount=petCount+2, dePinFlag=ESMF_DE_PIN_VAS, &
rc=rc)
call ESMF_DELayoutGet(delayout, vasLocalDeCount=localDeCount, rc=rc)
allocate(localDeList(localDeCount))
call ESMF_DELayoutGet(delayout, vasLocalDeList=localDeList, rc=rc)
if (rc /= ESMF_SUCCESS) finalrc=rc
do i=1, localDeCount
   workDe = localDeList(i)
   print *, "I am PET", localPET, " and I am offering service for DE ", workDe
   reply = ESMF_DELayoutServiceOffer(delayout, de=workDe, rc=rc)
   if (rc /= ESMF_SUCCESS) finalrc=rc
   if (reply == ESMF_DELAYOUT_SERVICE_ACCEPT) then
      ! process work associated with workDe
      print *, "I am PET", localPET, ", service offer for DE ", workDe, 
      " was accepted."
      call ESMF_DELayoutServiceComplete(delayout, de=workDe, rc=rc)
   end if
if (rc /= ESMF_SUCCESS) finalrc=rc

435
39.3 Restrictions and Future Work

39.4 Design and Implementation Notes

The DELayout class is a light weight object. It stores the DE to PET and VAS mapping for all DEs within all PET instances and a list of local DEs for each PET instance. The DELayout does not store the computational and communication weights optionally provided as arguments to the create method. These hints are only used during create while they are available in user owned arrays.

39.5 Class API

39.5.1 ESMF_DELayoutCreateDefault - Create DELayout (default)

INTERFACE:

function ESMF_DELayoutCreateDefault(deCount, deGrouping, dePinFlag, petList, & vm, rc)

ARGUMENTS:

<table>
<thead>
<tr>
<th>Argument</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>deCount</td>
<td>integer, optional</td>
<td>Number of DEs to be provided by the created DELayout. By default the number of DEs equals the number of PETs in the associated VM context. Specifying a deCount smaller than the number of PETs will result in unassociated PETs. This may be used to share VM resources between DELayouts within the same ESMF component. Specifying a deCount greater than the number of PETs will result in multiple DE to PET mapping.</td>
</tr>
<tr>
<td>deGrouping</td>
<td>integer, target, optional</td>
<td>DE group index to each DE of the DELayout. A group index of -1 indicates that the associated DE isn’t member of any particular group. The significance of DE groups is that all the DEs belonging to a certain group will be mapped against the same PET. This does not, however, mean that DEs belonging to different DE groups must be mapped to different PETs.</td>
</tr>
<tr>
<td>dePinFlag</td>
<td>type(ESMF_DePinFlag), optional</td>
<td>This flag specifies which type of resource DEs are pinned to. The default is to pin DEs to PETs. Alternatively it is also possible to pin DEs to VASs. See section ?? for a list of valid pinning options.</td>
</tr>
<tr>
<td>petList</td>
<td>integer, target, optional</td>
<td>This is a list of PET instances. The number of PETs in the associated VM context. Specifying a deCount smaller than the number of PETs will result in unassociated PETs. This may be used to share VM resources between DELayouts within the same ESMF component. Specifying a deCount greater than the number of PETs will result in multiple DE to PET mapping.</td>
</tr>
<tr>
<td>vm</td>
<td>type(ESMF_VM), optional</td>
<td>This is a list of VM contexts.</td>
</tr>
<tr>
<td>rc</td>
<td>integer, out, optional</td>
<td>Return value indicating success or failure.</td>
</tr>
</tbody>
</table>

RETURN VALUE:

type (ESMF_DELayout) :: ESMF_DELayoutCreateDefault

DESCRIPTION:

Create an ESMF_DELayout object on the basis of optionally provided restrictions. By default a DELayout with deCount equal to petCount will be created, each DE mapped to a single PET. However, the number of DEs as well grouping of DEs and PETs to map to can be specified via the optional arguments.

The arguments are:

- [deCount] Number of DEs to be provided by the created DELayout. By default the number of DEs equals the number of PETs in the associated VM context. Specifying a deCount smaller than the number of PETs will result in unassociated PETs. This may be used to share VM resources between DELayouts within the same ESMF component. Specifying a deCount greater than the number of PETs will result in multiple DE to PET mapping.

- [deGrouping] This optional argument must be of size deCount. Its content assigns a DE group index to each DE of the DELayout. A group index of -1 indicates that the associated DE isn’t member of any particular group. The significance of DE groups is that all the DEs belonging to a certain group will be mapped against the same PET. This does not, however, mean that DEs belonging to different DE groups must be mapped to different PETs.

- [dePinFlag] This flag specifies which type of resource DEs are pinned to. The default is to pin DEs to PETs. Alternatively it is also possible to pin DEs to VASs. See section ?? for a list of valid pinning options.
**petList** List specifying PETs to be used by this DELayout. This can be used to control the PET overlap between DELayouts within the same ESMF component. It is erroneous to specify PETs that are not within the provided VM context. The default is to include all the PETs of the VM.

**vm** Optional ESMF_VM object of the current context. Providing the VM of the current context will lower the method's overhead.

**rc** Return code; equals ESMF_SUCCESS if there are no errors.

### 39.5.2 ESMF_DELayoutCreateFromPetMap - Create DELayout from petMap

**INTERFACE:**

```fortran
! Private name; call using ESMF_DELayoutCreate()
function ESMF_DELayoutCreateFromPetMap(petMap, dePinFlag, vm, rc)
ARGUMENTS:
integer, intent(in) :: petMap(:)
type(ESMF_DePinFlag), intent(in), optional :: dePinFlag
type(ESMF_VM), intent(in), optional :: vm
integer, intent(out),optional :: rc
RETURN VALUE:
type(ESMF_DELayout) :: ESMF_DELayoutCreateFromPetMap
```

**DESCRIPTION:**

Create an ESMF_DELayout with exactly specified DE to PET mapping. This ESMF method must be called in unison by all PETs of the VM. Calling this method from a PET not part of the VM or not calling it from a PET that is part of the VM will result in undefined behavior. ESMF does not guard against violation of the unison requirement. The call is not collective, there is no communication between PETs.

The arguments are:

- **petMap** List specifying the DE-to-PET mapping. The list elements correspond to DE 0, 1, 2, ... and map against the specified PET of the VM context. The size of the petMap argument determines the number of DEs in the created DELayout. It is erroneous to specify a PET identifier that lies outside the VM context.

- **dePinFlag** This flag specifies which type of resource DEs are pinned to. The default is to pin DEs to PETs. Alternatively it is also possible to pin DEs to VASs. See section ?? for a list of valid pinning options.

- **vm** Optional ESMF_VM object. The VM of the current context is the typical and default value.

- **rc** Return code; equals ESMF_SUCCESS if there are no errors.

### 39.5.3 ESMF_DELayoutCreateHintWeights - Create DELayout with weight hints

**INTERFACE:**

```fortran
! Private name; call using ESMF_DELayoutCreate()
function ESMF_DELayoutCreateHintWeights(deCount, compWeights, commWeights, &
   deGrouping, dePinFlag, petList, vm, rc)
```
ARGUMENTS:

integer, intent(in), optional :: deCount
integer, intent(in) :: compWeights(:)
integer, intent(in) :: commWeights(:,:)
integer, target, intent(in), optional :: deGrouping(:)
type(ESMF_DePinFlag), intent(in), optional :: dePinFlag
integer, target, intent(in), optional :: petList(:)
type(ESMF_VM), intent(in), optional :: vm
integer, intent(out), optional :: rc

RETURN VALUE:

type(ESMF_DELayout) :: ESMF_DELayoutCreateHintWeights

DESCRIPTION:

Create an ESMF_DELayout on the basis of computational and communication weights. In addition this call provides control over the number of DEs, DE domains, DE pinning and the PETs to map against.

The arguments are:

[deCount] Number of DEs to be provided by the created DELayout. By default the number of DEs equals the number of PETs in the associated VM context. Specifying a deCount smaller than the number of PETs will result in unassociated PETs. This may be used to share VM resources between DELayouts within the same ESMF component. Specifying a deCount greater than the number of PETs will result in multiple DE to PET mapping.

compWeights This argument provides the computational weight hint. The compWeights list must contain at least deCount elements and specifies a relative measure of the computational weight for each DE in form of an integer number. The weights are a relative measure and only meaningful when compared to weights of the same DELayout.

commWeights This argument provides the communication weight hint. commWeights is a 2D array and must contain at least deCount elements in each dimension. The element indices correspond to the DEs of the DELayout and each element specifies a relative communication weight for a DE pair. The commWeight matrix must be symmetric and diagonal elements are ignored. The weights are a relative measure and only meaningful when compared to weights of the same DELayout.

[deStride] This optional argument can be used to specify DE domains. The argument holds two elements: (/interStride, intraStride/) which are used to form DE subsets from the full set { 0, 1, ..., deCount-1 } of DEs. The elements of the kth subset are { k * interStride + i * intraStride } where i and k start at 0. DEs within each subset are mapped against the same PET, causing multiple DE to PET mapping. The default is to generate homogeneously sized, blocked DE domains. If the number of DEs is a multiple of the number of PETs the default can be expressed as deStride = (/deCount/petCount, 1/).

[dePinFlag] This flag specifies which type of resource DEs are pinned to. The default is to pin DEs to PETs. Alternatively it is also possible to pin DEs to VASs. See section ?? for a list of valid pinning options.

[petList] List specifying PETs to be used by this DELayout. This can be used to control the PET overlap between DELayouts within the same ESMF component. It is erroneous to specify PETs that are not within the provided VM context. The default is to include all the PETs of the VM.

[vm] Optional ESMF_VM object of the current context. Providing the VM of the current context will lower the method’s overhead.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
39.5.4 ESMF_DELayoutDestroy - Destroy DELayout object

INTERFACE:

    subroutine ESMF_DELayoutDestroy(delayout, rc)

ARGUMENTS:

    type(ESMF_DELayout), intent(inout) :: delayout
    integer, intent(out), optional :: rc

DESCRIPTION:

Destroy an ESMF_DELayout object.
The arguments are:

delayout  ESMF_DELayout object to be destroyed.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

39.5.5 ESMF_DELayoutGet - Get DELayout internals

INTERFACE:

    subroutine ESMF_DELayoutGet(delayout, vm, deCount, petMap, vasMap, &
                                compCapacity, commCapacity, oneToOneFlag, dePinFlag, &
                                localDeCount, localDeList, vasLocalDeCount, vasLocalDeList, rc)

ARGUMENTS:

    type(ESMF_DELayout), intent(in) :: delayout
    type(ESMF_VM), intent(out), optional :: vm
    integer, intent(out), optional :: deCount
    integer, target, intent(out), optional :: petMap(:)
    integer, target, intent(out), optional :: vasMap(:)
    integer, target, intent(out), optional :: compCapacity(:)
    integer, target, intent(out), optional :: commCapacity(:,:)
    integer, target, intent(out), optional :: oneToOneFlag
    integer, target, intent(out), optional :: dePinFlag
    integer, target, intent(out), optional :: localDeCount
    integer, target, intent(out), optional :: localDeList(:)
    integer, target, intent(out), optional :: vasLocalDeCount
    integer, target, intent(out), optional :: vasLocalDeList(:)
    integer, intent(out), optional :: rc

DESCRIPTION:

Access to DELayout information.
The arguments are:

delayout  Queried ESMF_DELayout object.

[vm]  Upon return this holds the ESMF_VM object on which the delayout is defined.
Upon return this holds the total number of DEs.

Upon return this holds the list of PETs against which the DEs are mapped. The petMap argument must at least be of size deCount.

Upon return this holds the list of VASs against which the DEs are mapped. The vasMap argument must at least be of size deCount.

Upon return this holds a relative measure of the computational capacity for each DE. The compCapacity argument must at least be of size deCount.

Upon return this holds a relative measure of the communication capacity for each pair of DEs. The commCapacity argument is a 2D array where each dimension must at least be of size deCount.

Upon return this holds ESMF_TRUE if the specified ESMF_DELayout describes a 1-to-1 mapping between DEs and PETs, ESMF_FALSE otherwise.

Upon return this flag will indicate the type of DE pinning. See section ?? for a list of valid pinning options.

Upon return this holds the number of DEs associated with the local PET.

Upon return this holds the list of DEs associated with the local PET. The provided argument must at least be of size localDeCount.

Upon return this holds the number of DEs associated with the local VAS.

Upon return this holds the list of DEs associated with the local VAS. The provided argument must at least be of size vasLocalDeCount.

Return code; equals ESMF_SUCCESS if there are no errors.

39.5.6 ESMF_DELayoutPrint - Print DELayout internals

INTERFACE:

    subroutine ESMF_DELayoutPrint(delayout, options, rc)

ARGUMENTS:

    type (ESMF_DELayout), intent (in) :: delayout
    character (len=*), intent (in), optional :: options
    integer, intent (out), optional :: rc

DESCRIPTION:

Prints internal information about the specified ESMF_DELayout object to stdout. The arguments are:

delayout  Specified ESMF_DELayout object.

options  Print options are not yet supported.

rc  Return code; equals ESMF_SUCCESS if there are no errors.
39.5.7  ESMF_DELayoutServiceComplete - Close service window

INTERFACE:

recursive subroutine ESMF_DELayoutServiceComplete(delayout, de, rc)

ARGUMENTS:

  type(ESMF_DELayout), intent(in) :: delayout
  integer, intent(in) :: de
  integer, intent(out), optional :: rc

DESCRIPTION:

The PET who’s service offer was accepted for de must use ESMF_DELayoutServiceComplete to close the service window.

The arguments are:

delayout  Specified ESMF_DELayout object.

de  DE for which to close service window.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

39.5.8  ESMF_DELayoutServiceOffer - Offer service for a DE in DELayout

INTERFACE:

recursive function ESMF_DELayoutServiceOffer(delayout, de, rc)

ARGUMENTS:

  type(ESMF_DELayout), intent(in) :: delayout
  integer, intent(in) :: de
  integer, intent(out), optional :: rc

RETURN VALUE:

  type(ESMF_DELayoutServiceReply) :: ESMF_DELayoutServiceOffer

DESCRIPTION:

Offer service for a DE in the ESMF_DELayout object. This call together with ESMF_DELayoutServiceComplete() provides the synchronization primitives between the PETs of an ESMF multi-threaded VM necessary for dynamic load balancing via a work queue approach. The calling PET will either receive ESMF_DE LazayOUT_SERVICE_ACCEPT if the service offer has been accepted by DLayout or ESMF_DE LazayOUT_SERVICE_DENY if the service offer was denied. The service offer paradigm is different from a simple mutex approach in that DLayout keeps track of the number of service offers issued for each DE by each PET and accepts only one PET’s offer for each offer increment. This requires that all PETs use ESMF_DELayoutServiceOffer() in unison.

The arguments are:

delayout  Specified ESMF_DELayout object.

de  DE for which service is offered by the calling PET.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
39.5.9 ESMF_DELLayoutValidate - Validate DELayout internals

INTERFACE:

    subroutine ESMF_DELLayoutValidate(delayout, rc)

ARGUMENTS:

    type(ESMF_DELLayout), intent(in) :: delayout
    integer, intent(out), optional :: rc

DESCRIPTION:

Validates that the delayout is internally consistent. The method returns an error code if problems are found.

The arguments are:

delayout Specified ESMF_DELLayout object.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40 VM Class

40.1 Description

The ESMF_VM (Virtual Machine) class is a generic representation of hardware and system software resources. There is exactly one VM object per ESMF component, providing the execution environment for the component code. The VM object handles all resource management tasks of a component and provides a topological description of the underlying configuration of the compute resources used by the component. The basic elements of a VM are called PETs, which stands for Persistent Execution Threads. These are equivalent to OS threads with a lifetime of at least that of the associated component. All VM functionality is expressed in terms of PETs. In the current version of ESMF a PET is equivalent to an MPI process. Future ESMF releases, however, will provide more flexibility on the PET level.

The resource management functions of the VM class come into play when a component creates sub-components. There are two parts to resource management, the parent and the child. When the parent component creates a child component its own VM object is provided to the ESMF_GridCompCreate() or ESMF_CplCompCreate() method. Optionally a petList can be specified to limit the resources the parent gives to the child. The child on the other hand may specify - during its SetServices method - how it wants the inherited resources to be arranged in its own VM. All registered methods of the component will henceforth execute in the thus defined child VM. Notice that the SetServices routine, although part of the child component, executes before the child VM has been started up. Hence it runs within the parent VM context.

In addition to resource management and topological description the VM class offers the lowest level of ESMF communication methods. Data references in VM communication calls must be provided as raw, language specific, one-dimensional, contiguous data arrays, much like in MPI. In fact, the similarity between VM and MPI communication calls is striking and there are many equivalent point-to-point and collective communication calls. However, unlike MPI, future versions of ESMF will allow PETs to be POSIX threads within multi-threaded POSIX processes. The VM communications API is completely transparent with respect to the different natures of the PETs and provides a common interface to shared memory and message passing communications.

40.2 Use and Examples

The concept of the ESMF Virtual Machine (VM) is so fundamental to the framework that every ESMF application uses it. Even in the simplest case, that of an ESMF main program without any components, a global default VM is being created during the ESMF_Initialize() call and removed during ESMF_Finalize().

By its very nature the VM class is quite different from other ESMF classes. One reflection of this fact is that VM objects appear in the API of infrastructure and superstructure ESMF classes. The first place to encounter a VM object is at the ESMF_Initialize() call. If the optional vm= argument is specified the global default VM will
be returned to the user code. The default VM can also be obtained anywhere throughout the application by calling ESMF_VMGetGlobal().

The default VM is an MPI-only VM that spans all processes in MPI_COMM_WORLD and it is the context in which the main program is executing. After the initialization the default VM may be used within the main program in query or communication calls, just like any other VM.

One of the main tasks of the VM class is resource management. Thus the VM plays a major part when a new ESMF component is created. On the parent side of this process the parent VM serves as a contributor of resources. When the parent component creates a child component it provides its own VM object and further may specify a list of resources (in terms of PETs) that it wants to give to the child component. This allows a parent to divide its resources among several children without oversubscribing the computational resources it holds.

On the child side of the creation process each child may set key properties of its VM, i.e. it is up to the child component to decide on how to use the resources it receives from the parent component. This is done in the child’s SetServices routine.

Notice that the SetServices routine, although part of the child component, executes within the parent VM context. The child’s VM has not been started up when the SetServices routine is being called. It is during the return of the SetServices call that all required information about the child component’s VM is available and the child’s VM can be started up.

After a child component has been created by the parent, and its SetServices has been called, it may be entered via one of the registered initialize / run / finalize entry points. Each time a component is entered through these registered methods the associated component routine will start running within the context of the child’s own VM. On return of a registered component method the VM is placed on hold, waiting for the next invocation. It is not until the component is destroyed that the associated VM is shut down.

The user component code may gain access to the VM of its context by querying the active component object via the respective CompGet call. Alternatively, a simpler way to obtain the current VM context is to use the ESMF_VMGetCurrent() call which does not require any input information and returns the VM of the current context. Either way, once a ESMF_VM object has been obtained it may be used in query and communication calls, and - creating a hierarchy of components - to create child components.

### 40.2.1 VM Default Basics Example

This complete example program demonstrates the simplest ESMF application, consisting of only a main program without any components. The global default VM, which is automatically created during the ESMF_Initialize() call, is obtained and then used in its print method and several VM query calls.

```fortran
program ESMF_VMDefaultBasicsEx
    use ESMF_Mod
    implicit none

    ! local variables
    integer:: rc
    type(ESMF_VM):: vm
    integer:: localPet, petCount, peCount, ssiId, vas

    call ESMF_Initialize(vm=vm, rc=rc)

    call ESMF_VMPrint(vm, rc=rc)

    call ESMF_VMGet(vm, localPet=localPet, petCount=petCount, peCount=peCount, &
                    rc=rc)

end program ESMF_VMDefaultBasicsEx
```

443
This PET is localPet: ", localPet
of a total of ",petCount," PETs in this VM."
There are ", peCount," PEs referenced by this VM"

This PET is executing in virtual address space (VAS) ", vas
located on single system image (SSI) ", ssiId
and is associated with ", peCount," PEs."
40.2.4 ESMF inside user defined MPI communicator

The following example code demonstrates how ESMF can run inside of a user defined MPI communicator.

```fortran
  call MPI_Init(ierr)
  call MPI_Comm_rank(MPI_COMM_WORLD, rank, ierr)
  if (rank < 2) then
    call ESMF_Initialize(mpiCommunicator=esmfComm, rc=rc)
    call ESMF_Finalize(terminationflag=ESMF_KEEPMPI, rc=rc)
  endif
  call MPI_Finalize(ierr)
```

40.2.5 VMSend/VMRecv Example

The VM layer provides MPI-like point-to-point communication. Use VMSend and VMRecv to communicate between two PETs. The following SPMD code sends data from PET `src` and receives it on PET `dst` of the VM. The sendData and recvData arguments must be 1-dimensional arrays.

```fortran
  if (localPet==src) &
    call ESMF_VMSend(vm, sendData=localData, count=count, dst=dst, rc=rc)
  if (localPet==dst) &
    call ESMF_VMRecv(vm, recvData=localData, count=count, src=src, rc=rc)
```

40.2.6 VMScatter/VMGather Example

The VM layer provides MPI-like collective communication. This example demonstrates the use of VM-wide VMScatter and VMGather.

```fortran
  call ESMF_VMScatter(vm, sendData=array1, recvData=array2, count=nsize, &
                      root=scatterRoot, rc=rc)
  call ESMF_VMGather(vm, sendData=array2, recvData=array1, count=nsize, &
                      root=gatherRoot, rc=rc)
```

40.2.7 VMAllFullReduce Example

The VMAllFullReduce method can be used to find the VM-wide global sum of a data set.

```fortran
  call ESMF_VMAllFullReduce(vm, sendData=array1, recvData=result, count=nsize, &
                            reduceflag=ESMF_SUM, rc=rc)
```
40.2.8 VM Component Example

The following example shows the role that VMs play in connection with ESMF components. Here a single component is created in the main program and the default VM gives all its resources to the child component. When the child component code is entered through the registered methods (Initialize, Run or Finalize) the user code will be executed in the child’s VM.

```fortran
module ESMF_VMComponentEx_gcomp_mod

  public mygcomp_register

  contains !---------------------------------------------------------------

  subroutine mygcomp_register(gcomp, rc)

    ! register INIT method
    call ESMF_GridCompSetEntryPoint(gcomp, ESMF_SETINIT, mygcomp_init, &
      ESMF_SINGLEPHASE, rc)
    ! register RUN method
    call ESMF_GridCompSetEntryPoint(gcomp, ESMF_SETRUN, mygcomp_run, &
      ESMF_SINGLEPHASE, rc)
    ! register FINAL method
    call ESMF_GridCompSetEntryPoint(gcomp, ESMF_SETFINAL, mygcomp_final, &
      ESMF_SINGLEPHASE, rc)
  end subroutine !---------------------------------------------------------------

  recursive subroutine mygcomp_init(gcomp, istate, estate, clock, rc)

    ! get this component’s vm
    call ESMF_GridCompGet(gcomp, vm=vm)
    call ESMF_VMPrint(vm, rc)
  end subroutine !---------------------------------------------------------------

  recursive subroutine mygcomp_run(gcomp, istate, estate, clock, rc)

    ! get this component’s vm
    call ESMF_GridCompGet(gcomp, vm=vm)
    call ESMF_VMPrint(vm, rc)
  end subroutine !---------------------------------------------------------------

  recursive subroutine mygcomp_final(gcomp, istate, estate, clock, rc)

    ! get this component’s vm
    call ESMF_GridCompGet(gcomp, vm=vm)
    call ESMF_VMPrint(vm, rc)
```

446
end subroutine

end module

program ESMF_VMComponentEx

use ESMF_VMComponentEx_gcomp_mod

gcomp = ESMF_GridCompCreate(name='My gridded component', rc=rc)

call ESMF_GridCompSetServices(gcomp, mygcomp_register, rc)

call ESMF_GridCompInitialize(gcomp, rc=rc)

call ESMF_GridCompRun(gcomp, rc=rc)

call ESMF_GridCompFinalize(gcomp, rc=rc)

call ESMF_GridCompDestroy(gcomp, rc=rc)

call ESMF_Finalize(rc=rc)

end program

40.3 Restrictions and Future Work

1. Non-blocking Reduce() operations not implemented. None of the reduce communication calls have an implementation for the non-blocking feature. This affects:
   • ESMF_VMAAllFullReduce().
   • ESMF_VMAAllReduce().
   • ESMF_VMReduce().

2. Limitations when using mpiuni mode. In mpiuni mode non-blocking communications are limited to one outstanding message per source-destination PET pair. Furthermore, in mpiuni mode the message length must be smaller than the internal ESMF buffer size.

3. ESMF-Threading not supported. The ESMF multi-threading features of the VM are enabled but not currently supported. By default VMs run without threads. The entry points to threaded VMs are not currently advertised.

4. Alternative communication paths not accessible. All user accessible VM communication calls are currently implemented using MPI-1.2. VM’s implementation of alternative communication techniques, such as shared memory between threaded PETs and POSIX IPC between PETs located on the same single system image, are currently inaccessible to the user. (One exception to this is the mpiuni case for which the VM automatically utilizes a shared memory path.)

5. Data arrays in VM comm calls are assumed shape with rank=1. Currently all dummy arrays in VM comm calls are defined as assumed shape arrays of rank=1. While this guards against the Fortran copy in/out problem it may not be as flexible as desired. Alternatively all dummy arrays could be defined as assumed size arrays, as it is done in most MPI implementations, thus allowing arrays of various rank to be passed into the comm methods.

6. None of the topology features have been implemented.
40.4 Design and Implementation Notes

The VM class provides an additional layer of abstraction on top of the POSIX machine model, making it suitable for HPC applications. There are four key aspects the VM class deals with.

1. Encapsulation of hardware and operating system details within the concept of Persistent Execution Threads (PETs).
2. Resource management in terms of PETs with a guard against over-subscription.
3. Topological description of the underlying configuration of the compute resources in terms of PETs.
4. Transparent communication API for point-to-point and collective PET-based primitives, hiding the many different communication channels and offering best possible performance.

Definition of terms used in the diagram

- **PE**: A processing element (PE) is an alias for the smallest physical processing unit available on a particular hardware platform. In the language of today’s microprocessor architecture technology a PE is identical to a core, however, if future microprocessor designs change the smallest physical processing unit the mapping of the PE to actual hardware will change accordingly. Thus the PE layer separates the hardware specific part of the VM from the hardware-independent part. Each PE is labeled with an id number which identifies it uniquely within all of the VM instances of an ESMF application.

- **Core**: A Core is the smallest physical processing unit which typically comprises a register set, an integer arithmetic unit, a floating-point unit and various control units. Traditionally there was one core per CPU, however,
today some dual-core CPUs are available and multi-core CPU designs are on most manufacturers’ road-maps. Each Core is labeled with an id number which identifies it uniquely within all of the VM instances of an ESMF application.

- **CPU**: The central processing unit (CPU) houses single or multiple cores, providing them with the interface to system memory, interconnects and IO. Typically the CPU provides some level of caching for the instruction and data streams in and out of the Cores. Cores in a multi-core CPU typically share some caches. Each CPU is labeled with an id number which identifies it uniquely within all of the VM instances of an ESMF application.

- **SSI**: A single system image (SSI) spans all the CPUs controlled by a single running instance of the operating system. SMP and NUMA are typical multi-CPU SSI architectures. Each SSI is labeled with an id number which identifies it uniquely within all of the VM instances of an ESMF application.

- **TOE**: A thread of execution (TOE) executes an instruction sequence. TOE’s come in two flavors: PET and TET.

- **PET**: A persistent execution thread (PET) executes an instruction sequence on an associated set of data. The PET has a lifetime at least as long as the associated data set. In ESMF the PET is the central concept of abstraction provided by the VM class. The PETs of an VM object are labeled from 0 to N-1 where N is the total number of PETs in the VM object.

- **TET**: A transient execution thread (TET) executes an instruction sequence on an associated set of data. A TET’s lifetime might be shorter than that of the associated data set.

- **OS-Instance**: The OS-Instance of a TOE describes how a particular TOE is instantiated on the OS level. Using POSIX terminology a TOE will run as a single thread within a single- or multi-threaded process.

- **Pthreads**: Communication via the POSIX Thread interface.

- **MPI-1, MPI-2**: Communication via MPI standards 1 and 2.

- **armci**: Communication via the aggregate remote memory copy interface.

- **SHMEM**: Communication via the SHMEM interface.

- **OS-IPC**: Communication via the operating system’s inter process communication interface. Either POSIX IPC or System V IPC.

- **InterCon-lib**: Communication via the interconnect’s library native interface. An example is the Elan library for Quadrics.

The POSIX machine abstraction, while a very powerful concept, needs augmentation when applied to HPC applications. Key elements of the POSIX abstraction are processes, which provide virtually unlimited resources (memory, I/O, sockets, ...) to possibly multiple threads of execution. Similarly POSIX threads create the illusion that there is virtually unlimited processing power available to each POSIX process. While the POSIX abstraction is very suitable for many multi-user/multi-tasking applications that need to share limited physical resources, it does not directly fit the HPC workload where over-subscription of resources is one of the most expensive modes of operation.

ESMF’s virtual machine abstraction is based on the POSIX machine model but holds additional information about the available physical processing units in terms of Processing Elements (PEs). A PE is the smallest physical processing unit and encapsulates the hardware details (Cores, CPUs and SSIs).

There is exactly one physical machine layout for each application, and all VM instances have access to this information. The PE is the smallest processing unit which, in today’s microprocessor technology, corresponds to a single Core. Cores are arranged in CPUs which in turn are arranged in SSIs. The setup of the physical machine layout is part of the ESMF initialization process.

On top of the PE concept the key abstraction provided by the VM is the PET. All user code is executed by PETs while OS and hardware details are hidden. The VM class contains a number of methods which allow the user to prescribe how the PETs of a desired virtual machine should be instantiated on the OS level and how they should map onto the hardware. This prescription is kept in a private virtual machine plan object which is created at the same time the associated component is being created. Each time component code is entered through one of the component’s registered top-level methods (Initialize/Run/Finalize), the virtual machine plan along with a pointer to the respective
user function is used to instantiate the user code on the PETs of the associated VM in form of single- or multi-threaded POSIX processes. The process of starting, entering, exiting and shutting down a VM is very transparent, all spawning and joining of threads is handled by VM methods “behind the scenes”. Furthermore, fundamental synchronization and communication primitives are provided on the PET level through a uniform API, hiding details related to the actual instantiation of the participating PETs.

Within a VM each PE of the physical machine maps to 0 or 1 PETs. Allowing unassigned PEs provides a means to prevent over-subscription between multiple concurrently running virtual machines. Similarly a maximum of one PET per PE prevents over-subscription within a single VM instance. However, over-subscription is possible by subscribing PETs from different virtual machines to the same PE. This type of over-subscription can be desirable for PETs associated with IO workloads expected to be used infrequently and to block often on IO requests.

On the OS level each PET of a VM object is represented by a POSIX thread (Pthread) either belonging to a single- or multi-threaded process and maps to at least 1 PE of the physical machine, ensuring its execution. Mapping a single PET to multiple PEs provides resources for user-level multi-threading, in which case the user code inquires how many PETs are associated with its PET and if there are multiple PETs available the user code can spawn an equal number of threads (e.g. OpenMP) without risking over-subscription. Typically these user spawned threads are short-lived and used for fine-grained parallelization in form of TETs. All PETs mapped against a single PET must be part of a unique SSI in order to allow user-level multi-threading!

In addition to discovering the physical machine the ESMF initialization process sets up the default global virtual machine. This VM object, which is the ultimate parent of all VMs created during the course of execution, contains as many PETs as there are PEs in the physical machine. All of its PETs are instantiated in form of single-threaded MPI processes and a 1:1 mapping of PETs to PEs is used for the default global VM.

The VM design and implementation is based on the POSIX process and thread model as well as the MPI-1.2 standard. As a consequence of the latter standard the number of processes is static during the course of execution and is determined at start-up. The VM implementation further requires that the user starts up the ESMF application with as many MPI processes as there are PEs in the available physical machine using the platform dependent mechanism to ensure proper process placement.

All MPI processes participating in a VM are grouped together by means of an MPI_Group object and their context is defined via an MPI_Comm object (MPI intra-communicator). The PET local process id within each virtual machine is equal to the MPI_Comm_rank in the local MPI_Comm context whereas the PET process id is equal to the MPI_Comm_rank in MPI_COMM_WORLD. The PET process id is used within the VM methods to determine the virtual memory space a PET is operating in.

In order to provide a migration path for legacy MPI-applications the VM offers accessor functions to its MPI_Comm object. Once obtained this object may be used in explicit user-code MPI calls within the same context.

40.5 Class API

40.5.1 ESMF_VMAllFullReduce - AllFullReduce 4-byte integers

INTERFACE:

! Private name; call using ESMF_VMAllFullReduce()
subroutine ESMF_VMAllFullReduceI4(vm, sendData, recvData, count, &
       reduceflag, blockingflag, commhandle, rc)

ARGUMENTS:

type (ESMF_VM), intent (in) :: vm
integer (ESMF_KIND_I4), target, intent (in) :: sendData(:)
integer (ESMF_KIND_I4), intent (out) :: recvData
integer, intent (in) :: count
type (ESMF_ReduceFlag), intent (in) :: reduceflag
type (ESMF_BlockingFlag), intent (in), optional :: blockingflag
type (ESMF_CommHandle), intent (out), optional :: commhandle
integer, intent (out), optional :: rc
DESCRIPTION:

Collective ESMF_VM communication call that reduces a contiguous data array of kind ESMF_KIND_I4 across the ESMF_VM object into a single value of the same type. The result is returned on all PETs. Different reduction operations can be specified.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.

recvData Single data variable to be received. All PETs must specify a valid result variable.

count Number of elements in sendData. Must be the same on all PETs.

reduceflag Reduction operation. See section 2.1.9 for a list of valid reduce operations.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.2 ESMF_VMAllFullReduce - AllFullReduce 4-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllFullReduce()
subroutine ESMF_VMAllFullReduceR4(vm, sendData, recvData, count, & reduceflag, blockingflag, commhandle, rc)

ARGUMENTS:

type (ESMF_VM), intent (in) :: vm
real (ESMF_KIND_R4), target, intent (in) :: sendData(:)
real (ESMF_KIND_R4), intent (out) :: recvData
integer, intent (in) :: count

type (ESMF_ReduceFlag), intent (in) :: reduceflag

type (ESMF_BlockingFlag), intent (in), optional :: blockingflag

type (ESMF_CommHandle), intent (out), optional :: commhandle

integer, intent (out), optional :: rc

451
DESCRIPTION:

Collective ESMF_VM communication call that reduces a contiguous data array of kind ESMF_KIND_R4 across the ESMF_VM object into a single value of the same type. The result is returned on all PETs. Different reduction operations can be specified.

Todo: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.

recvData Single data variable to be received. All PETs must specify a valid result variable.

count Number of elements in sendData. Must be the same on all PETs.

reduceflag Reduction operation. See section 9.1.9 for a list of valid reduce operations.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.

ESMF_NONBLOCKING Return immediately without blocking.

[commanhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.3 ESMF_VMAllFullReduce - AllFullReduce 8-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllFullReduce()
 subroutine ESMF_VMAllFullReduceR8(vm, sendData, recvData, count, &
 reduceflag, blockingflag, commhandle, rc)
ARGUMENTS:

type (ESMF_VM), intent (in) :: vm
real(ESMF_KIND_R8), target, intent (in) :: sendData(:)
real(ESMF_KIND_R8), intent (out) :: recvData
integer, intent (in) :: count

type (ESMF_ReduceFlag), intent (in) :: reduceflag

type (ESMF_BlockingFlag), intent (in), optional :: blockingflag

type (ESMF_CommHandle), intent (out), optional :: commhandle

integer, intent (out), optional :: rc

452
DESCRIPTION:

Collective ESMF_VM communication call that reduces a contiguous data array of kind ESMF_KIND_R8 across the ESMF_VM object into a single value of the same type. The result is returned on all PETs. Different reduction operations can be specified.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with `blockingflag = ESMF_NONBLOCKING` error code `ESMF_RC_NOT_IMPL` will be returned and an error will be logged.

The arguments are:

- **vm** ESMF_VM object.
- **sendData** Contiguous data array holding data to be send. All PETs must specify a valid source array.
- **recvData** Single data variable to be received. All PETs must specify a valid result variable.
- **count** Number of elements in sendData. Must be the same on all PETs.
- **reduceflag** Reduction operation. See section 9.1.9 for a list of valid reduce operations.
- **[blockingflag]** Flag indicating whether this call behaves blocking or non-blocking:
  - `ESMF_BLOCKING` (default) Block until local operation has completed.
  - `ESMF_NONBLOCKING` Return immediately without blocking.
- **[commhandle]** If present, a communication handle will be returned in case of a non-blocking request (see argument `blockingflag`). The `commhandle` can be used in `ESMF_VMWait()` to block the calling PET until the communication call has finished PET-locally. If no `commhandle` was supplied to a non-blocking call the VM method `ESMF_VMWaitQueue()` may be used to block on all currently queued communication calls of the VM context.
- **[rc]** Return code; equals `ESMF_SUCCESS` if there are no errors.

40.5.4 ESMF_VMAllGather - AllGather 4-byte integers

INTERFACE:

```
! Private name; call using ESMF_VMAllGather()
subroutine ESMF_VMAllGatherI4(vm, sendData, recvData, count, &
    blockingflag, commhandle, rc)
```

ARGUMENTS:

```
type (ESMF_VM),       intent (in)                :: vm
integer (ESMF_KIND_I4), target,  intent (in)    :: sendData(:)
integer (ESMF_KIND_I4), target,  intent (out)   :: recvData(:)
integer,              intent (in)                :: count
integer (ESMF_BlockingFlag),  intent (in),   optional :: blockingflag
integer (ESMF_CommHandle),  intent (out),   optional :: commhandle
integer,              intent (out),   optional :: rc
```
DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_KIND_I4 from all PETs of an ESMF_VM object into an array on all PETs.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.

recvData Contiguous data array for data to be received. All PETs must specify a valid recvData argument.

count Number of elements to be gathered from each PET. Must be the same on all PETs.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.5 ESMF_VMAllGather - AllGather 4-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllGather()
subroutine ESMF_VMAllGatherR4(vm, sendData, recvData, count, &
   blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R4), target, intent(in) :: sendData(:)
real(ESMF_KIND_R4), target, intent(out) :: recvData(:)
integer, intent(in) :: count

[blockingflag] type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
[commhandle] type(ESMF_CommHandle), intent(out), optional :: commhandle

DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_KIND_R4 from all PETs of an ESMF_VM object into an array on all PETs.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.
recvData  Contiguous data array for data to be received. All PETs must specify a valid recvData argument.

count  Number of elements to be gathered from each PET. Must be the same on all PETs.

[blockingflag]  Flag indicating whether this call behaves blocking or non-blocking:

  ESMF_BLOCKING  (default) Block until local operation has completed.
  ESMF_NONBLOCKING  Return immediately without blocking.

[commhandle]  If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.6  ESMF_VMAllGather - AllGather 8-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllGather()
subroutine ESMF_VMAllGatherR8(vm, sendData, recvData, count, &
  blockingflag, commhandle, rc)

ARGUMENTS:

  type(ESMF_VM), intent(in)  :: vm
  real(ESMF_KIND_R8), target, intent(in)  :: sendData(:)
  real(ESMF_KIND_R8), target, intent(out)  :: recvData(:)
  integer, intent(in)  :: count
  type(ESMF_BlockingFlag), intent(in), optional  :: blockingflag
  type(ESMF_CommHandle), intent(out), optional  :: commhandle
  integer, intent(out), optional  :: rc

DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_KIND_R8 from all PETs of an ESMF_VM object into an array on all PETs.

The arguments are:

  vm  ESMF_VM object.

  sendData  Contiguous data array holding data to be send. All PETs must specify a valid source array.

  recvData  Contiguous data array for data to be received. All PETs must specify a valid recvData argument.

  count  Number of elements to be gathered from each PET. Must be the same on all PETs.

  [blockingflag]  Flag indicating whether this call behaves blocking or non-blocking:

    ESMF_BLOCKING  (default) Block until local operation has completed.
    ESMF_NONBLOCKING  Return immediately without blocking.
If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in `ESMF_VMWait()` to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method `ESMF_VMWaitQueue()` may be used to block on all currently queued communication calls of the VM context.

Return code; equals `ESMF_SUCCESS` if there are no errors.

---

### 40.5.7 ESMF_VMAllGather - AllGather ESMF_Logical

**Interface:**

```fortran
subroutine ESMF_VMAllGatherLogical(vm, sendData, recvData, count, &
   blockingflag, commhandle, rc)
```

**Arguments:**

<table>
<thead>
<tr>
<th>Type</th>
<th>Intent</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>type(ESMF_VM), intent(in)</code></td>
<td></td>
<td><code>vm</code> - ESMF_VM object.</td>
</tr>
<tr>
<td><code>type(ESMF_Logical), target, intent(in)</code></td>
<td></td>
<td><code>sendData</code> - Contiguous data array holding data to be send. All PETs must specify a valid source array.</td>
</tr>
<tr>
<td><code>type(ESMF_Logical), target, intent(out)</code></td>
<td></td>
<td><code>recvData</code> - Contiguous data array for data to be received. All PETs must specify a valid <code>recvData</code> argument.</td>
</tr>
<tr>
<td><code>integer, intent(in)</code></td>
<td></td>
<td><code>count</code> - Number of elements to be gathered from each PET. Must be the same on all PETs.</td>
</tr>
<tr>
<td><code>type(ESMF_BlockingFlag), intent(in), optional</code></td>
<td></td>
<td><code>blockingflag</code> - Flag indicating whether this call behaves blocking or non-blocking:</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>ESMF_BLOCKING</code> (default) Block until local operation has completed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>ESMF_NONBLOCKING</code> Return immediately without blocking.</td>
</tr>
<tr>
<td><code>type(ESMF_CommHandle), intent(out), optional</code></td>
<td></td>
<td><code>commhandle</code> - If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in <code>ESMF_VMWait()</code> to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method <code>ESMF_VMWaitQueue()</code> may be used to block on all currently queued communication calls of the VM context.</td>
</tr>
<tr>
<td><code>integer, intent(out), optional</code></td>
<td></td>
<td><code>rc</code> - Return code; equals <code>ESMF_SUCCESS</code> if there are no errors.</td>
</tr>
</tbody>
</table>

**Description:**

Collective `ESMF_VM` communication call that gathers contiguous data of kind `ESMF_Logical` from all PETs of an `ESMF_VM` object into an array on all PETs.

The arguments are:

- `vm` - ESMF_VM object.
- `sendData` - Contiguous data array holding data to be send. All PETs must specify a valid source array.
- `recvData` - Contiguous data array for data to be received. All PETs must specify a valid `recvData` argument.
- `count` - Number of elements to be gathered from each PET. Must be the same on all PETs.
- `blockingflag` - Flag indicating whether this call behaves blocking or non-blocking:
  - `ESMF_BLOCKING` (default) Block until local operation has completed.
  - `ESMF_NONBLOCKING` Return immediately without blocking.
- `commhandle` - If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in `ESMF_VMWait()` to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method `ESMF_VMWaitQueue()` may be used to block on all currently queued communication calls of the VM context.
- `rc` - Return code; equals `ESMF_SUCCESS` if there are no errors.
40.5.8 ESMF_VMAllGatherV - AllGatherV 4-byte integers

INTERFACE:

! Private name; call using ESMF_VMAllGatherV()
subroutine ESMF_VMAllGatherVI4(vm, sendData, sendCount, recvData, &
recvCounts, recvOffsets, blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
integer(ESMF_KIND_I4), target, intent(in) :: sendData(:)
integer, intent(in) :: sendCount
integer(ESMF_KIND_I4), target, intent(out) :: recvData(:)
integer, intent(in) :: recvCounts(:)
integer, intent(in) :: recvOffsets(:)
type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

type(ESMF_CommHandle), intent(out), optional :: commhandle
integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_Logical from all PETs of an
ESMF_VM object into an array on all PETs.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When
calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be re-
turned and an error will be logged.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.

sendCount Number of sendData elements to send from local PET to all other PETs.

recvData Single data variable to be received. All PETs must specify a valid result variable.

recvCounts Number of recvData elements to be received from corresponding source PET.

recvOffsets Offsets in units of elements in recvData marking the start of element sequence to be received from
source PET.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument
blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the
communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM
method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the
VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
40.5.9  ESMF_VMAllGatherV - AllGatherV 4-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllGatherV()
subroutine ESMF_VMAllGatherVR4(vm, sendData, sendCount, recvData, &
  recvCounts, recvOffsets, blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R4), target, intent(in) :: sendData(:)
integer, intent(in) :: sendCount
real(ESMF_KIND_R4), target, intent(out) :: recvData(:)
integer, intent(in) :: recvCounts(:)
integer, intent(in) :: recvOffsets(:)
type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

type(ESMF_CommHandle), intent(out), optional :: commhandle
integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_Logical from all PETs of an
ESMF_VM object into an array on all PETs.

Todo: The current version of this method does not provide an implementation of the non-blocking feature. When
calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be re-
turned and an error will be logged.

The arguments are:

vm  ESMF_VM object.

sendData  Contiguous data array holding data to be send. All PETs must specify a valid source array.

sendCount  Number of sendData elements to send from local PET to all other PETs.

recvData  Single data variable to be received. All PETs must specify a valid result variable.

recvCounts  Number of recvData elements to be received from corresponding source PET.

recvOffsets  Offsets in units of elements in recvData marking the start of element sequence to be received from
  source PET.

[blockingflag]  Flag indicating whether this call behaves blocking or non-blocking:

  ESMF_BLOCKING  (default) Block until local operation has completed.
  ESMF_NONBLOCKING  Return immediately without blocking.

[commhandle]  If present, a communication handle will be returned in case of a non-blocking request (see argument
  blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the
  communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM
  method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the
  VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
40.5.10  ESMF_VMAllGatherV - AllGatherV 8-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllGatherV()
subroutine ESMF_VMAllGatherVR8(vm, sendData, sendCount, recvData, &
recvCounts, recvOffsets, blockingflag, commhandle, rc)

ARGUMENTS:

    type(ESMF_VM), intent(in) :: vm
    real(ESMF_KIND_R8), target, intent(in) :: sendData(:)
    integer, intent(in) :: sendCount
    real(ESMF_KIND_R8), target, intent(out) :: recvData(:)
    integer, intent(in) :: recvCounts(:)
    integer, intent(in) :: recvOffsets(:)
    type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
    type(ESMF_CommHandle), intent(out), optional :: commhandle
    integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_Logical from all PETs of an ESMF_VM object into an array on all PETs.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

vm  ESMF_VM object.

sendData  Contiguous data array holding data to be send. All PETs must specify a valid source array.

sendCount  Number of sendData elements to send from local PET to all other PETs.

recvData  Single data variable to be received. All PETs must specify a valid result variable.

recvCounts  Number of recvData elements to be received from corresponding source PET.

recvOffsets  Offsets in units of elements in recvData marking the start of element sequence to be received from source PET.

[blockingflag]  Flag indicating whether this call behaves blocking or non-blocking:

          ESMF_BLOCKING  (default) Block until local operation has completed.
          ESMF_NONBLOCKING  Return immediately without blocking.

[commanhandle]  If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
40.5.11 ESMF_VMAllReduce - AllReduce 4-byte integers

INTERFACE:

! Private name; call using ESMF_VMAllReduce()
subroutine ESMF_VMAllReduceI4(vm, sendData, recvData, count, reduceflag, &
       blockingflag, commhandle, rc)

ARGUMENTS:

    type(ESMF_VM), intent(in) :: vm
    integer(ESMF_KIND_I4), target, intent(in) :: sendData(:)
    integer(ESMF_KIND_I4), target, intent(out) :: recvData(:)
    integer, intent(in) :: count
    type(ESMF_ReduceFlag), intent(in) :: reduceflag
    type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
    type(ESMF_CommHandle), intent(out), optional :: commhandle
    integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that reduces a contiguous data array of kind ESMF_KIND_I4 across the
ESMF_VM object into a contiguous data array of the same type. The result array is returned on all PETs. Different
reduction operations can be specified.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When
calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be re-
turned and an error will be logged.

The arguments are:

vm ESMF_VM object.
sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.
recvData Single data variable to be received. All PETs must specify a valid result variable.
count Number of elements in sendData and recvData. Must be the same on all PETs.
reduceflag Reduction operation. See section 9.1.9 for a list of valid reduce operations.
[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:
    ESMF_BLOCKING (default) Block until local operation has completed.
    ESMF_NONBLOCKING Return immediately without blocking.
[comchandle] If present, a communication handle will be returned in case of a non-blocking request (see argument
    blockingflag). The comchandle can be used in ESMF_VMWait() to block the calling PET until the
    communication call has finished PET-locally. If no comchandle was supplied to a non-blocking call the VM
    method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the
    VM context.
[rc] Return code; equals ESMF_SUCCESS if there are no errors.
40.5.12 ESMF_VMAllReduce - AllReduce 4-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllReduce()
subroutine ESMF_VMAllReduceR4(vm, sendData, recvData, count, reduceflag, &
  blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R4), target, intent(in) :: sendData(:)
real(ESMF_KIND_R4), target, intent(out) :: recvData(:)
integer, intent(in) :: count
  type(ESMF_ReduceFlag), intent(in) :: reduceflag
  type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
  type(ESMF_CommHandle), intent(out), optional :: commhandle
  integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that reduces a contiguous data array of kind ESMF_KIND_R4 across the
ESMF_VM object into a contiguous data array of the same type. The result array is returned on all PETs. Different
reduction operations can be specified.

Todo: The current version of this method does not provide an implementation of the non-blocking feature. When
calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be re-
turned and an error will be logged.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.

recvData Contiguous data array for data to be received. All PETs must specify a valid destination array.

count Number of elements in sendData and recvData. Must be the same on all PETs.

reduceflag Reduction operation. See section 9.1.9 for a list of valid reduce operations.

blockingflag Flag indicating whether this call behaves blocking or non-blocking:

  ESMF_BLOCKING (default) Block until local operation has completed.
  ESMF_NONBLOCKING Return immediately without blocking.

commhandle If present, a communication handle will be returned in case of a non-blocking request (see argument
blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the
communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM
method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the
VM context.

rc Return code; equals ESMF_SUCCESS if there are no errors.
40.5.13 ESMF_VMAllReduce - AllReduce 8-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllReduce()
subroutine ESMF_VMAllReduceR8(vm, sendData, recvData, count, reduceflag, &
   blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R8), target, intent(in) :: sendData(:)
real(ESMF_KIND_R8), target, intent(out) :: recvData(:)
integer, intent(in) :: count

type(ESMF_ReduceFlag), intent(in) :: reduceflag

type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

type(ESMF_CommHandle), intent(out), optional :: commhandle

integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that reduces a contiguous data array of kind ESMF_KIND_R8 across the ESMF_VM object into a contiguous data array of the same type. The result array is returned on all PETs. Different reduction operations can be specified.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.

recvData Contiguous data array for data to be received. All PETs must specify a valid destination array.

count Number of elements in sendData and recvData. Must be the same on all PETs.

reduceflag Reduction operation. See section 9.1.9 for a list of valid reduce operations.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
40.5.14  ESMF_VMAllToAllV - AllToAllV 4-byte integers

INTERFACE:

! Private name; call using ESMF_VMAllToAllV()
subroutine ESMF_VMAllToAllVI4(vm, sendData, sendCounts, sendOffsets, & recvData, recvCounts, recvOffsets, blockingflag, commhandle, rc)

ARGUMENTS:

  type(ESMF_VM), intent(in) :: vm
  integer(ESMF_KIND_I4), target, intent(in) :: sendData(:)
  integer, intent(in) :: sendCounts(:)
  integer, intent(in) :: sendOffsets(:)
  integer(ESMF_KIND_I4), target, intent(out) :: recvData(:)
  integer, intent(in) :: recvCounts(:)
  integer, intent(in) :: recvOffsets(:)
  type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
  type(ESMF_CommHandle), intent(out), optional :: commhandle
  integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that performs a total exchange operation, sending pieces of the contiguous data buffer sendData to all other PETs while receiving data into the contiguous data buffer recvData from all other PETs.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

vm  ESMF_VM object.

sendData  Contiguous data array holding data to be send. All PETs must specify a valid source array.

sendCounts  Number of sendData elements to send from local PET to destination PET.

sendOffsets  Offsets in units of elements in sendData marking to start of element sequence to be send from local PET to destination PET.

recvData  Single data variable to be received. All PETs must specify a valid result variable.

recvCounts  Number of recvData elements to be received by local PET from source PET.

recvOffsets  Offsets in units of elements in recvData marking to start of element sequence to be received by local PET from source PET.

[blockingflag]  Flag indicating whether this call behaves blocking or non-blocking:

  ESMF_BLOCKING  (default)  Block until local operation has completed.
  ESMF_NONBLOCKING  Return immediately without blocking.

[commhandle]  If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.
40.5.15 ESMF_VMAllToAllV - AllToAllV 4-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllToAllV()
subroutine ESMF_VMAllToAllVR4(vm, sendData, sendCounts, sendOffsets, &
recvData, recvCounts, recvOffsets, blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R4), target, intent(in) :: sendData(:)
integer, intent(in) :: sendCounts(:)
integer, intent(in) :: sendOffsets(:)
real(ESMF_KIND_R4), target, intent(out) :: recvData(:)
integer, intent(in) :: recvCounts(:)
integer, intent(in) :: recvOffsets(:)
type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

DESCRIPTION:

Collective ESMF_VM communication call that performs a total exchange operation, sending pieces of the contiguous data buffer sendData to all other PETs while receiving data into the contiguous data buffer recvData from all other PETs.

Todo: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.

sendCounts Number of sendData elements to send from local PET to destination PET.

sendOffsets Offsets in units of elements in sendData marking to start of element sequence to be send from local PET to destination PET.

recvData Single data variable to be received. All PETs must specify a valid result variable.

recvCounts Number of recvData elements to be received by local PET from source PET.

recvOffsets Offsets in units of elements in recvData marking to start of element sequence to be received by local PET from source PET.

blockingflag Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.
[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.16 ESMF_VMAllToAllV - AllToAllV 4-byte reals

INTERFACE:

! Private name; call using ESMF_VMAllToAllV()
 subroutine ESMF_VMAllToAllVR8(vm, sendData, sendCounts, sendOffsets, &
 recvData, recvCounts, recvOffsets, blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R8), target, intent(in) :: sendData(:)
integer, intent(in) :: sendCounts(:)
integer, intent(in) :: sendOffsets(:)
real(ESMF_KIND_R8), target, intent(out) :: recvData(:)
integer, intent(in) :: recvCounts(:)
integer, intent(in) :: recvOffsets(:)
type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

type(ESMF_CommHandle), intent(out), optional :: commhandle
integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that performs a total exchange operation, sending pieces of the contiguous data buffer sendData to all other PETs while receiving data into the contiguous data buffer recvData from all other PETs.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.

sendCounts Number of sendData elements to send from local PET to destination PET.

sendOffsets Offsets in units of elements in sendData marking to start of element sequence to be send from local PET to destination PET.

recvData Single data variable to be received. All PETs must specify a valid result variable.

recvCounts Number of recvData elements to be received by local PET from source PET.

recvOffsets Offsets in units of elements in recvData marking to start of element sequence to be received by local PET from source PET.
[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.17 ESMF_VMBarrier - VM wide barrier

INTERFACE:

subroutine ESMF_VMBarrier(vm, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
integer, intent(out), optional :: rc

DESCRIPTION:
Collective ESMF_VM communication call that blocks calling PET until all PETs of the VM context have issued the call.

The arguments are:

vm ESMF_VM object.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.18 ESMF_VMBroadcast - Broadcast 4-byte integers

INTERFACE:

! Private name; call using ESMF_VMBroadcast()
subroutine ESMF_VMBroadcastI4(vm, bcstData, count, root, &
   blockingflag, commhandle, rc)

ARGUMENTS:

    type(ESMF_VM), intent(in) :: vm
    integer(ESMF_KIND_I4), target, intent(inout) :: bcstData(:)
    integer, intent(in) :: count
    integer, intent(in) :: root
    type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
    type(ESMF_CommHandle), intent(out), optional :: commhandle
    integer, intent(out), optional :: rc
DESCRIPTION:

Collective ESMF_VM communication call that broadcasts a contiguous data array of kind ESMF_KIND_I4 from PET root to all other PETs of the ESMF_VM object.

The arguments are:

**vm** ESMF_VM object.

**bcstData** Contiguous data array. On root PET bcstData holds data that is to be broadcasted to all other PETs. On all other PETs bcstData is used to receive the broadcasted data.

**count** Number of elements in sendData and recvData. Must be the same on all PETs.

**root** Id of the root PET within the ESMF_VM object.

**[blockingflag]** Flag indicating whether this call behaves blocking or non-blocking:

- ESMF_BLOCKING (default) Block until local operation has completed.
- ESMF_NONBLOCKING Return immediately without blocking.

**[commhandle]** If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

### 40.5.19 ESMF_VMBroadcast - Broadcast 4-byte reals

INTERFACE:

```fortran
! Private name; call using ESMF_VMBroadcast()
subroutine ESMF_VMBroadcastR4(vm, bcstData, count, root, &
    blockingflag, commhandle, rc)
ARGUMENTS:
    type(ESMF_VM), intent(in) :: vm
    real(ESMF_KIND_R4), target, intent(inout) :: bcstData(:)
    integer, intent(in) :: count
    integer, intent(in) :: root
    type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
    type(ESMF_CommHandle), intent(out), optional :: commhandle
    integer, intent(out), optional :: rc
```

DESCRIPTION:

Collective ESMF_VM communication call that broadcasts a contiguous data array of kind ESMF_KIND_R4 from PET root to all other PETs of the ESMF_VM object.

The arguments are:

**vm** ESMF_VM object.
bcstData Contiguous data array. On root PET bcstData holds data that is to be broadcasted to all other PETs. On all other PETs bcstData is used to receive the broadcasted data.

count Number of elements in sendData and recvData. Must be the same on all PETs.

root Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.20 ESMF_VMBroadcast - Broadcast 8-byte reals

INTERFACE:

! Private name; call using ESMF_VMBroadcast()
subroutine ESMF_VMBroadcastR8(vm, bcstData, count, root, &
   blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R8), target, intent(inout) :: bcstData(:)
integer, intent(in) :: count
integer, intent(in) :: root

! for blockingflag
! type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

! for commhandle
! type(ESMF_CommHandle), intent(out), optional :: commhandle

integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that broadcasts a contiguous data array of kind ESMF_KIND_R8 from PET root to all other PETs of the ESMF_VM object.

The arguments are:

vm ESMF_VM object.

bcstData Contiguous data array. On root PET bcstData holds data that is to be broadcasted to all other PETs. On all other PETs bcstData is used to receive the broadcasted data.

count Number of elements in sendData and recvData. Must be the same on all PETs.

root Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:
ESMF_BLOCKING  (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.21   ESMF_VMBroadcast - Broadcast ESMF_Logical

INTERFACE:

! Private name; call using ESMF_VMBroadcast()
subroutine ESMF_VMBroadcastLogical(vm, bcstData, count, root, &
blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm

type(ESMF_Logical), target, intent(inout) :: bcstData(:)

integer, intent(in) :: count

integer, intent(in) :: root

type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

type(ESMF_CommHandle), intent(out), optional :: commhandle

integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that broadcasts a contiguous data array of kind ESMF_Logical from PET root to all other PETs of the ESMF_VM object.

The arguments are:

vm ESMF_VM object.

bcstData  Contiguous data array. On root PET bcstData holds data that is to be broadcasted to all other PETs. On all other PETs bcstData is used to receive the broadcasted data.

count  Number of elements in sendData and recvData. Must be the same on all PETs.

root  Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING  (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
40.5.22  ESMF_VMGather - Gather 4-byte integers

INTERFACE:

! Private name; call using ESMF_VMGather()
subroutine ESMF_VMGatherI4(vm, sendData, recvData, count, root, &
   blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
integer(ESMF_KIND_I4), target, intent(in) :: sendData(:)
integer(ESMF_KIND_I4), target, intent(out) :: recvData(:)
integer, intent(in) :: count
integer, intent(in) :: root
integer, intent(in), optional :: blockingflag
integer, intent(in), optional :: commhandle
integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_KIND_I4 from all PETs of an
ESMF_VM object (including root) into an array on the root PET.

The arguments are:

vm  ESMF_VM object.

sendData  Contiguous data array holding data to be send. All PETs must specify a valid source array.

recvData  Contiguous data array for data to be received. Only the recvData array specified by the root PET will
   be used by this method.

count  Number of elements to be send from each PET to root. Must be the same on all PETs.

root  Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING  (default) Block until local operation has completed.
ESMF_NONBLOCKING  Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument
blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the
communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM
method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the
VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.23  ESMF_VMGather - Gather 4-byte reals

INTERFACE:
subroutine ESMF_VMGatherR4(vm, sendData, recvData, count, root, & blockingflag, commhandle, rc)

ARGUMENTS:

ARGUMENTS:

ARGUMENTS:

ARGUMENTS:

DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_KIND_R4 from all PETs of an ESMF_VM object (including root) into an array on the root PET.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.

recvData Contiguous data array for data to be received. Only the recvData array specified by the root PET will be used by this method.

count Number of elements to be send from each PET to root. Must be the same on all PETs.

root Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.

ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.24 ESMF_VMGather - Gather 8-byte reals

INTERFACE:

INTERFACE:

INTERFACE:

ARGUMENTS:
DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_KIND_R8 from all PETs of an ESMF_VM object (including root) into an array on the root PET.

The arguments are:

- **vm** ESMF_VM object.
- **sendData** Contiguous data array holding data to be send. All PETs must specify a valid source array.
- **recvData** Contiguous data array for data to be received. Only the recvData array specified by the root PET will be used by this method.
- **count** Number of elements to be send from each PET to root. Must be the same on all PETs.
- **root** Id of the root PET within the ESMF_VM object.
- [**blockingflag**] Flag indicating whether this call behaves blocking or non-blocking:
  - ESMF_BLOCKING (default) Block until local operation has completed.
  - ESMF_NONBLOCKING Return immediately without blocking.
- [**commhandle**] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.
- [**rc**] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.25 ESMF_VMGather - Gather ESMF_Logical

INTERFACE:

```fortran
! Private name; call using ESMF_VMGather()
subroutine ESMF_VMGatherLogical(vm, sendData, recvData, count, root, &
  blockingflag, commhandle, rc)
```

ARGUMENTS:

```fortran
type (ESMF_VM), intent(in) :: vm
real (ESMF_KIND_R8), target, intent(in) :: sendData(:)
real (ESMF_KIND_R8), target, intent(out) :: recvData(:)
integer, intent(in) :: count
integer, intent(in) :: root
```

```fortran
type (ESMF_Logical), target, intent(in) :: sendData(:)
```

```fortran
type (ESMF_Logical), target, intent(out) :: recvData(:)
```

```fortran
integer, intent(out), optional :: commhandle
integer, intent(out), optional :: rc
```

```fortran
type (ESMF_BlockingFlag), intent(in), optional :: blockingflag
```
DESCRIPTION:

Collective ESMF_VM communication call that gathers contiguous data of kind ESMF_Logical from all PETs of an ESMF_VM object (including root) into an array on the root PET.

The arguments are:

vm  ESMF_VM object.

sendData  Contiguous data array holding data to be send. All PETs must specify a valid source array.

recvData  Contiguous data array for data to be received. Only the recvData array specified by the root PET will be used by this method.

count  Number of elements to be send from each PET to root. Must be the same on all PETs.

root  Id of the root PET within the ESMF_VM object.

[blockingflag]  Flag indicating whether this call behaves blocking or non-blocking:

  ESMF_BLOCKING (default) Block until local operation has completed.
  ESMF_NONBLOCKING Return immediately without blocking.

[commhandle]  If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.26  ESMF_VMGet - Get VM internals

INTERFACE:

subroutine ESMF_VMGet(vm, localPet, petCount, peCount, mpiCommunicator, & okOpenMpFlag, rc)

ARGUMENTS:

type (ESMF_VM), intent (in), optional :: vm
integer, intent (out), optional :: localPet
integer, intent (out), optional :: petCount
integer, intent (out), optional :: peCount
integer, intent (out), optional :: mpiCommunicator
type (ESMF_Logical), intent (out), optional :: okOpenMpFlag
integer, intent (out), optional :: rc

DESCRIPTION:

Get internal information about the specified ESMF_VM object.

The arguments are:
vm Queried ESMF_VM object.

[localPet] Upon return this holds the id of the PET that issued this call.

[petCount] Upon return this holds the number of PETs in the specified ESMF_VM object.

[peCount] Upon return this holds the number of PEs referenced by the specified ESMF_VM object.

[mpiCommunicator] Upon return this holds the MPI intra-communicator used by the specified ESMF_VM object. This communicator may be used for user-level MPI communications. It is recommended that the user duplicates the communicator via MPI_Comm_Dup() in order to prevent any interference with ESMF communications.

[okOpenMpFlag] Upon return this holds a flag indicating whether user-level OpenMP threading is supported by the specified ESMF_VM object.

ESMF_TRUE User-level OpenMP threading is supported.

ESMF_FALSE User-level OpenMP threading is not supported.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.27 ESMF_VMGetGlobal - Get Global VM

INTERFACE:

subroutine ESMF_VMGetGlobal(vm, rc)

ARGUMENTS:

type(ESMF_VM), intent(out) :: vm
integer, intent(out), optional :: rc

DESCRIPTION:

Get the global default ESMF_VM object. This is the ESMF_VM object that is created during ESMF_Initialize() and is the ultimate parent of all ESMF_VM objects in an ESMF application.

The arguments are:

vm Upon return this holds the global default ESMF_VM object.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.28 ESMF_VMGetCurrent - Get Current VM

INTERFACE:

subroutine ESMF_VMGetCurrent(vm, rc)

ARGUMENTS:

type(ESMF_VM), intent(out) :: vm
integer, intent(out), optional :: rc
DESCRIPTION:

Get the ESMF_VM object of the current execution context.

The arguments are:

vm  Upon return this holds the ESMF_VM object of the current context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.29 ESMF_VMGetPETLocalInfo - Get VM PET local internals

INTERFACE:

subroutine ESMF_VMGetPETLocalInfo(vm, pet, peCount, ssiId, threadCount, &
threadId, vas, rc)

ARGUMENTS:

type (ESMF_VM), intent(in) :: vm
integer, intent(in) :: pet
integer, intent(out), optional :: peCount
integer, intent(out), optional :: ssiId
integer, intent(out), optional :: threadCount
integer, intent(out), optional :: threadId
integer, intent(out), optional :: vas
integer, intent(out), optional :: rc

DESCRIPTION:

Get internal information about a specific PET within an ESMF_VM object.

The arguments are:

vm  Queried ESMF_VM object.

pet  Queried PET id within the specified ESMF_VM object.

[peCount] Upon return this holds the number of PEs associated with the specified PET in the ESMF_VM object.

[ssiId] Upon return this holds the id of the single-system image (SSI) the specified PET is running on.

[threadCount] Upon return this holds the number of PETs in the specified PET”s thread group.

[threadId] Upon return this holds the thread id of the specified PET within the PET”s thread group.

[vas] Virtual address space in which this PET operates.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
40.5.30  ESMF_VMPrint - Print VM internals

INTERFACE:

    subroutine ESMF_VMPrint (vm, rc)

ARGUMENTS:

    type(ESMF_VM), intent(in) :: vm
    integer, intent(out), optional :: rc

DESCRIPTION:

Print internal information about the specified ESMF_VM to stdout.

The arguments are:

    vm  Specified ESMF_VM object.
    [rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.31  ESMF_VMRecv - Receive 4-byte integers

INTERFACE:

    ! Private name; call using ESMF_VMRecv()
    subroutine ESMF_VMRecvI4 (vm, recvData, count, src, blockingflag, &
    commhandle, rc)

ARGUMENTS:

    type(ESMF_VM),       intent(in)        :: vm
    integer(ESMF_KIND_I4), target, intent(out) :: recvData(:)
    integer,             intent(in)        :: count
    integer,             intent(in)        :: src
    type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
    type(ESMF_CommHandle), intent(out), optional :: commhandle
    integer,             intent(out), optional :: rc

DESCRIPTION:

Receive contiguous data of kind ESMF_KIND_I4 from a PET within the same ESMF_VM object.

The arguments are:

    vm  ESMF_VM object.
    recvData  Contiguous data array for data to be received.
    count  Number of elements to be received.
    src  Id of the source PET within the same ESMF_VM object.
    [blockingflag]  Flag indicating whether this call behaves blocking or non-blocking:
        ESMF_BLOCKING  (default)  Block until local operation has completed.
        ESMF_NONBLOCKING  Return immediately without blocking.
If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

Return code; equals ESMF_SUCCESS if there are no errors.

40.5.32  ESMF_VMRecv - Receive 4-byte reals

INTERFACE:

    ! Private name; call using ESMF_VMRecv()
    subroutine ESMF_VMRecvR4(vm, recvData, count, src, blockingflag, &
    commhandle, rc)

ARGUMENTS:

    type(ESMF_VM), intent(in) :: vm
    real(ESMF_KIND_R4), target, intent(out) :: recvData(:)
    integer, intent(in) :: count
    integer, intent(in) :: src
    type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
    type(ESMF_CommHandle), intent(out), optional :: commhandle
    integer, intent(out), optional :: rc

DESCRIPTION:

Receive contiguous data of kind ESMF_KIND_R4 from a PET within the same ESMF_VM object.

The arguments are:

vm ESMF_VM object.

recvData Contiguous data array for data to be received.

count Number of elements to be received.

src Id of the source PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

    ESMF_BLOCKING (default) Block until local operation has completed.
    ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

rc Return code; equals ESMF_SUCCESS if there are no errors.
40.5.33  ESMF_VMRecv - Receive 8-byte reals

INTERFACE:

! Private name; call using ESMF_VMRecv()
subroutine ESMF_VMRecvR8(vm, recvData, count, src, blockingflag, &
                         commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R8), target, intent(out) :: recvData(:)
integer, intent(in) :: count
integer, intent(in) :: src

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

  ESMF_BLOCKING (default) Block until local operation has completed.
  ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.34  ESMF_VMRecv - Receive ESMF_Logical

INTERFACE:

! Private name; call using ESMF_VMRecv()
subroutine ESMF_VMRecvLogical(vm, recvData, count, src, blockingflag, &
                               commhandle, rc)

ARGUMENTS:
type (ESMF_VM), intent(in) :: vm

type (ESMF_Logical), target, intent(out) :: recvData(:)

integer, intent(in) :: count

integer, intent(in) :: src

type (ESMF_BlockingFlag), intent(in), optional :: blockingflag

type (ESMF_CommHandle), intent(out), optional :: commhandle

integer, intent(out), optional :: rc

DESCRIPTION:

Receive contiguous data of type ESMF_Logical from a PET within the same ESMF_VM object.

The arguments are:

vm ESMF_VM object.

recvData Contiguous data array for data to be received.

count Number of elements to be received.

src Id of the source PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.

ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.35 ESMF_VMRecv - Receive Character

INTERFACE:

! Private name; call using ESMF_VMRecv()
 subroutine ESMF_VMRecvCharacter(vm, recvData, count, src, blockingflag, &
 commhandle, rc)

ARGUMENTS:

 type (ESMF_VM), intent(in) :: vm
character(*) intent(out) :: recvData

integer, intent(in) :: count

integer, intent(in) :: src

type (ESMF_BlockingFlag), intent(in), optional :: blockingflag

type (ESMF_CommHandle), intent(out), optional :: commhandle

integer, intent(out), optional :: rc

DESCRIPTION:

Receive contiguous data of type character from a PET within the same ESMF_VM object.

The arguments are:
**vm**  ESMF_VM object.

**recvData**  Contiguous data array for data to be received.

**count**  Number of elements to be received.

**src**  Id of the source PET within the ESMF_VM object.

**[blockingflag]**  Flag indicating whether this call behaves blocking or non-blocking:

- **ESMF_BLOCKING**  (default) Block until local operation has completed.
- **ESMF_NONBLOCKING**  Return immediately without blocking.

**[commhandle]**  If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

**[rc]**  Return code; equals ESMF_SUCCESS if there are no errors.

### 40.5.36  ESMF_VMReduce - Reduce 4-byte integers

**INTERFACE:**

```fortran
! Private name; call using ESMF_VMReduce()
subroutine ESMF_VMReduceI4(vm, sendData, recvData, count, reduceflag, &
  root, blockingflag, commhandle, rc)
```

**ARGUMENTS:**

- `type(ESMF_VM), intent(in) :: vm`
- `integer(ESMF_KIND_I4), target, intent(in) :: sendData(:)`
- `integer(ESMF_KIND_I4), target, intent(out) :: recvData(:)`
- `integer, intent(in) :: count`
- `type(ESMF_ReduceFlag), intent(in) :: reduceflag`
- `integer, intent(in) :: root`
- `type(ESMF_BlockingFlag), intent(in), optional :: blockingflag`
- `type(ESMF_CommHandle), intent(out), optional :: commhandle`
- `integer, intent(out), optional :: rc`

**DESCRIPTION:**

Collective ESMF_VM communication call that reduces a contiguous data array of kind ESMF_KIND_I4 across the ESMF_VM object into a contiguous data array of the same type. The result array is returned on root PET. Different reduction operations can be specified.

**TODO:** The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

- **vm**  ESMF_VM object.
- **sendData**  Contiguous data array holding data to be send. All PETs must specify a valid source array.
recvData  Single data variable to be received. All PETs must specify a valid result variable.

count  Number of elements in sendData and recvData. Must be the same on all PETs.

reduceflag  Reduction operation. See section 9.1.9 for a list of valid reduce operations.

root  Id of the root PET within the ESMF_VM object.

[blockingflag]  Flag indicating whether this call behaves blocking or non-blocking:

  ESMF_BLOCKING (default) Block until local operation has completed.
  ESMF_NONBLOCKING  Return immediately without blocking.

[commhandle]  If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.37 ESMF_VMReduce - Reduce 4-byte reals

INTERFACE:

! Private name; call using ESMF_VMReduce()
subroutine ESMF_VMReduceR4(vm, sendData, recvData, count, reduceflag, &
  root, blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM),       intent(in) :: vm
real(ESMF_KIND_R4), target, intent(in) :: sendData();
real(ESMF_KIND_R4), target, intent(out) :: recvData();
integer,       intent(in) :: count

  type(ESMF_ReduceFlag), intent(in) :: reduceflag
integer,       intent(in) :: root

  type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
  type(ESMF_CommHandle), intent(out), optional :: commhandle
integer,       intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that reduces a contiguous data array of kind ESMF_KIND_R4 across the ESMF_VM object into a contiguous data array of the same type. The result array is returned on root PET. Different reduction operations can be specified.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

  vm  ESMF_VM object.

  sendData  Contiguous data array holding data to be send. All PETs must specify a valid source array.
recvData Contiguous data array for data to be received. All PETs must specify a valid destination array.

count Number of elements in sendData and recvData. Must be the same on all PETs.

reduceflag Reduction operation. See section 9.1.9 for a list of valid reduce operations.

root Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.38 ESMF_VMReduce - Reduce 8-byte reals

INTERFACE:

! Private name; call using ESMF_VMReduce()
subroutine ESMF_VMReduceR8(vm, sendData, recvData, count, reduceflag, &
root, blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R8), target, intent(in) :: sendData(:)
real(ESMF_KIND_R8), target, intent(out) :: recvData(:)
integer, intent(in) :: count

various types

DESCRIPTION:

Collective ESMF_VM communication call that reduces a contiguous data array of kind ESMF_KIND_R8 across the ESMF_VM object into a contiguous data array of the same type. The result array is returned on root PET. Different reduction operations can be specified.

TODO: The current version of this method does not provide an implementation of the non-blocking feature. When calling this method with blockingflag = ESMF_NONBLOCKING error code ESMF_RC_NOT_IMPL will be returned and an error will be logged.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. All PETs must specify a valid source array.
recvData Contiguous data array for data to be received. All PETs must specify a valid destination array.

count Number of elements in sendData and recvData. Must be the same on all PETs.

reduceflag Reduction operation. See section 9.1.9 for a list of valid reduce operations.

root Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.39 ESMF_VMScatter - Scatter 4-byte integers

INTERFACE:

! Private name; call using ESMF_VMScatter()
subroutine ESMF_VMScatterI4(vm, sendData, recvData, count, root, &
   blockingflag, commhandle, rc)

ARGUMENTS:

type (ESMF_VM), intent (in) :: vm
integer (ESMF_KIND_I4), target, intent (in) :: sendData(:)
integer (ESMF_KIND_I4), target, intent (out) :: recvData(:)
integer, intent (in) :: count
integer, intent (in) :: root

|type (ESMF_BlockingFlag), intent (in), optional :: blockingflag
|type (ESMF_CommHandle), intent (out), optional :: commhandle
integer, intent (out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that scatters contiguous data of kind ESMF_KIND_I4 from the root PET to all PETs of an ESMF_VM object (including root).

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. Only the sendData array specified by the root PET will be used by this method.

recvData Contiguous data array for data to be received. All PETs must specify a valid destination array.

count Number of elements to be send from root to each of the PETs. Must be the same on all PETs.
root  Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.40 ESMF_VMScatter - Scatter 4-byte reals

INTERFACE:

! Private name; call using ESMF_VMScatter()
subroutine ESMF_VMScatterR4(vm, sendData, recvData, count, root, &
    blockingflag, commhandle, rc)

ARGUMENTS:

  type(ESMF_VM), intent(in) :: vm
  real(ESMF_KIND_R4), target, intent(in) :: sendData(:)
  real(ESMF_KIND_R4), target, intent(out) :: recvData(:)
  integer, intent(in) :: count
  integer, intent(in) :: root
  type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
  type(ESMF_CommHandle), intent(out), optional :: commhandle
  integer, intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that scatters contiguous data of kind ESMF_KIND_R4 from the root PET to all PETs of an ESMF_VM object (including root).

The arguments are:

vm  ESMF_VM object.

sendData  Contiguous data array holding data to be send. Only the sendData array specified by the root PET will be used by this method.

recvData  Contiguous data array for data to be received. All PETs must specify a valid destination array.

count  Number of elements to be send from root to each of the PETs. Must be the same on all PETs.

root  Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.
[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.41 ESMF_VMScatter - Scatter 8-byte reals

INTERFACE:

! Private name; call using ESMF_VMScatter()
subroutine ESMF_VMScatterR8(vm, sendData, recvData, count, root, &
  blockingflag, commhandle, rc)
ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R8), target, intent(in) :: sendData(:)
real(ESMF_KIND_R8), target, intent(out) :: recvData(:)
integer, intent(in) :: count
integer, intent(in) :: root

type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

type(ESMF_CommHandle), intent(out), optional :: commhandle

type(ESMF_CommHandle), intent(out), optional :: rc

DESCRIPTION:

Collective ESMF_VM communication call that scatters contiguous data of kind ESMF_KIND_R8 from the root PET to all PETs of an ESMF_VM object (including root).

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send. Only the sendData array specified by the root PET will be used by this method.

recvData Contiguous data array for data to be received. All PETs must specify a valid destination array.

count Number of elements to be send from root to each of the PETs. Must be the same on all PETs.

root Id of the root PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.

ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
40.5.42  ESMF_VMScatter - Scatter ESMF_Logical

INTERFACE:

! Private name; call using ESMF_VMScatter()
subroutine ESMF_VMScatterLogical(vm, sendData, recvData, count, root, &
  blockingflag, commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm

type(ESMF_Logical), target, intent(in) :: sendData(:)

type(ESMF_Logical), target, intent(out) :: recvData(:)

integer, intent(in) :: count

integer, intent(in) :: root

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:
    ESMF_BLOCKING (default) Block until local operation has completed.
    ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.43  ESMF_VMSend - Send 4-byte integers

INTERFACE:
! Private name; call using ESMF_VMSend()

subroutine ESMF_VMSendI4(vm, sendData, count, dst, blockingflag, &
commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
integer(ESMF_KIND_I4), target, intent(in) :: sendData(:)
integer, intent(in) :: count
integer, intent(in) :: dst

type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

type(ESMF_CommHandle), intent(out), optional :: commhandle

type(ESMF_CommHandle), intent(out), optional :: rc

DESCRIPTION:

Send contiguous data of kind ESMF_KIND_I4 to a PET within the same ESMF_VM object.

The arguments are:

vm ESMF_VM object.

sendData Contiguous data array holding data to be send.

count Number of elements to be send.

dst Id of the destination PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.44 ESMF_VMSend - Send 4-byte reals

INTERFACE:

! Private name; call using ESMF_VMSend()

subroutine ESMF_VMSendR4(vm, sendData, count, dst, blockingflag, &
commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in) :: vm
real(ESMF_KIND_R4), target, intent(in) :: sendData(:)
integer, intent(in) :: count
integer, intent(in) :: dst


type(ESMF_BlockingFlag), intent(in), optional :: blockingflag

type(ESMF_CommHandle), intent(out), optional :: commhandle

type(ESMF_CommHandle), intent(out), optional :: rc

487
DESCRIPTION:

Send contiguous data of kind ESMF_KIND_R4 to a PET within the same ESMF_VM object.

The arguments are:

- **vm** ESMF_VM object.
- **sendData** Contiguous data array holding data to be send.
- **count** Number of elements to be send.
- **dst** Id of the destination PET within the ESMF_VM object.
- **blockingflag** Flag indicating whether this call behaves blocking or non-blocking:
  - ESMF_BLOCKING (default) Block until local operation has completed.
  - ESMF_NONBLOCKING Return immediately without blocking.
- **commhandle** If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.
- **rc** Return code; equals ESMF_SUCCESS if there are no errors.

40.5.45 ESMF_VMSend - Send 8-byte reals

INTERFACE:

```fortran
! Private name; call using ESMF_VMSend()
subroutine ESMF_VMSendR8(vm, sendData, count, dst, blockingflag, &
commhandle, rc)
ARGUMENTS:
  type(ESMF_VM), intent(in) :: vm
  real(ESMF_KIND_R8), target, intent(in) :: sendData(:)
  integer, intent(in) :: count
  integer, intent(in) :: dst
  type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
  type(ESMF_CommHandle), intent(out), optional :: commhandle
  integer, intent(out), optional :: rc
```

DESCRIPTION:

Send contiguous data of kind ESMF_KIND_R8 to a PET within the same ESMF_VM object.

The arguments are:

- **vm** ESMF_VM object.
- **sendData** Contiguous data array holding data to be send.
- **count** Number of elements to be send.
dst  Id of the destination PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING  (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.46  ESMF_VMSend - Send ESMF_Logical

INTERFACE:

! Private name; call using ESMF_VMSend()
subroutine ESMF_VMSendLogical(vm, sendData, count, dst, blockingflag, &
  commhandle, rc)

ARGUMENTS:

type(ESMF_VM), intent(in)          :: vm

  type(ESMF_Logical), target,       intent(in) :: sendData(:)

  integer,                         intent(in) :: count

  integer,                         intent(in) :: dst

  type(ESMF_BlockingFlag),         intent(in), optional :: blockingflag

  type(ESMF_CommHandle),           intent(out), optional :: commhandle

  integer,                         intent(out), optional :: rc

DESCRIPTION:

Send contiguous data of type ESMF_Logical to a PET within the same ESMF_VM object.

The arguments are:

vm  ESMF_VM object.

sendData  Contiguous data array holding data to be send.

count  Number of elements to be send.

dst  Id of the destination PET within the ESMF_VM object.

[blockingflag] Flag indicating whether this call behaves blocking or non-blocking:

ESMF_BLOCKING  (default) Block until local operation has completed.
ESMF_NONBLOCKING Return immediately without blocking.

[commhandle] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
### 40.5.47 ESMF_VMSend - Send Character

#### INTERFACE:

```plaintext
! Private name; call using ESMF_VMSend()
subroutine ESMF_VMSendCharacter(vm, sendData, count, dst, blockingflag, &
    commhandle, rc)
```

#### ARGUMENTS:

- `type(ESMF_VM), intent(in) :: vm` : ESMF_VM object.
- `character(*), intent(in) :: sendData` : Contiguous data array holding data to be send.
- `integer, intent(in) :: count` : Number of elements to be send.
- `integer, intent(in) :: dst` : Id of the destination PET within the ESMF_VM object.
- `type(ESMF_BlockingFlag), intent(in), optional :: blockingflag` : Flag indicating whether this call behaves blocking or non-blocking:
  - `ESMF_BLOCKING` (default) Block until local operation has completed.
  - `ESMF_NONBLOCKING` Return immediately without blocking.
- `type(ESMF_CommHandle), intent(out), optional :: commhandle` : If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.
- `integer, intent(out), optional :: rc` : Return code; equals ESMF_SUCCESS if there are no errors.

#### DESCRIPTION:

Send contiguous data of type character to a PET within the same ESMF_VM object.

The arguments are:

- **vm** ESMF_VM object.
- **sendData** Contiguous data array holding data to be send.
- **count** Number of elements to be send.
- **dst** Id of the destination PET within the ESMF_VM object.

[**blockingflag**] Flag indicating whether this call behaves blocking or non-blocking:

- `ESMF_BLOCKING` (default) Block until local operation has completed.
- `ESMF_NONBLOCKING` Return immediately without blocking.

[**commhandle**] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

[**rc**] Return code; equals ESMF_SUCCESS if there are no errors.

### 40.5.48 ESMF_VMSendRecv - SendRecv 4-byte integers

#### INTERFACE:

```plaintext
! Private name; call using ESMF_VMSendRecv()
subroutine ESMF_VMSendRecvI4(vm, sendData, sendCount, dst, &
    recvData, recvCount, src, blockingflag, commhandle, rc)
```

#### ARGUMENTS:

### 490
Send contiguous data of kind ESMF_KIND_I4 to a PET within the same ESMF_VM object while receiving contiguous data of kind ESMF_KIND_I4 from a PET within the same ESMF_VM object. The sendData and recvData arrays must be disjoint!

The arguments are:

- **vm** ESMF_VM object.
- **sendData** Contiguous data array holding data to be send.
- **sendCount** Number of elements to be send.
- **dst** Id of the destination PET within the ESMF_VM object.
- **recvData** Contiguous data array for data to be received.
- **recvCount** Number of elements to be received.
- **src** Id of the source PET within the ESMF_VM object.
- [**blockingflag**] Flag indicating whether this call behaves blocking or non-blocking:
  - ESMF_BLOCKING (default) Block until local operation has completed.
  - ESMF_NONBLOCKING Return immediately without blocking.
- [**commhandle**] If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.
- [**rc**] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.49 ESMF_VMSendRecv - SendRecv 4-byte real

INTERFACE:

```fortran
! Private name; call using ESMF_VMSendRecv()
subroutine ESMF_VMSendRecvR4(vm, sendData, sendCount, dst, &
  recvData, recvCount, src, blockingflag, commhandle, rc)
```

ARGUMENTS:
Send contiguous data of kind `ESMF_KIND_R4` to a PET within the same `ESMF_VM` object while receiving contiguous data of kind `ESMF_KIND_R4` from a PET within the same `ESMF_VM` object. The `sendData` and `recvData` arrays must be disjoint!

The arguments are:

`vm` `ESMF_VM` object.

`sendData` Contiguous data array holding data to be send.

`sendCount` Number of elements to be send.

`dst` Id of the destination PET within the `ESMF_VM` object.

`recvData` Contiguous data array for data to be received.

`recvCount` Number of elements to be received.

`src` Id of the source PET within the `ESMF_VM` object.

`[blockingflag]` Flag indicating whether this call behaves blocking or non-blocking:

- `ESMF_BLOCKING` (default) Block until local operation has completed.
- `ESMF_NONBLOCKING` Return immediately without blocking.

`[commhandle]` If present, a communication handle will be returned in case of a non-blocking request (see argument `blockingflag`). The `commhandle` can be used in `ESMF_VMWait()` to block the calling PET until the communication call has finished PET-locally. If no `commhandle` was supplied to a non-blocking call the VM method `ESMF_VMWaitQueue()` may be used to block on all currently queued communication calls of the VM context.

`[rc]` Return code; equals `ESMF_SUCCESS` if there are no errors.

40.5.50 ESMF_VMSendRecv - SendRecv 8-byte real

INTERFACE:

```fortran
! Private name; call using ESMF_VMSendRecv()
subroutine ESMF_VMSendRecvR8(vm, sendData, sendCount, dst, &
recvData, recvCount, src, blockingflag, commhandle, rc)
```

ARGUMENTS:
Send contiguous data of kind ESMF_KIND_R8 to a PET within the same ESMF_VM object while receiving contiguous data of kind ESMF_KIND_R8 from a PET within the same ESMF_VM object. The sendData and recvData arrays must be disjoint!

The arguments are:

- **vm** ESMF_VM object.
- **sendData** Contiguous data array holding data to be send.
- **sendCount** Number of elements to be send.
- **dst** Id of the destination PET within the ESMF_VM object.
- **recvData** Contiguous data array for data to be received.
- **recvCount** Number of elements to be received.
- **src** Id of the source PET within the ESMF_VM object.
- **[blockingflag]** Flag indicating whether this call behaves blocking or non-blocking:
  - ESMF_BLOCKING (default) Block until local operation has completed.
  - ESMF_NONBLOCKING Return immediately without blocking.
- **[commhandle]** If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.
- **[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

---

40.5.51 ESMF_VMSendRecv - SendRecv ESMF_Logical

INTERFACE:

! Private name; call using ESMF_VMSendRecv()
subroutine ESMF_VMSendRecvLogical(vm, sendData, sendCount, dst, &
  recvData, recvCount, src, blockingflag, commhandle, rc)

ARGUMENTS:
Send contiguous data of type `ESMF_Logical` to a PET within the same `ESMF_VM` object while receiving contiguous data of kind `ESMF_Logical` from a PET within the same `ESMF_VM` object. The `sendData` and `recvData` arrays must be disjoint!

The arguments are:

- `vm` `ESMF_VM` object.
- `sendData` Contiguous data array holding data to be send.
- `sendCount` Number of elements to be send.
- `dst` Id of the destination PET within the `ESMF_VM` object.
- `recvData` Contiguous data array for data to be received.
- `recvCount` Number of elements to be received.
- `src` Id of the source PET within the `ESMF_VM` object.
- `[blockingflag]` Flag indicating whether this call behaves blocking or non-blocking:
  - `ESMF_BLOCKING` (default) Block until local operation has completed.
  - `ESMF_NONBLOCKING` Return immediately without blocking.
- `[commhandle]` If present, a communication handle will be returned in case of a non-blocking request (see argument `blockingflag`). The `commhandle` can be used in `ESMF_VMWait()` to block the calling PET until the communication call has finished PET-locally. If no `commhandle` was supplied to a non-blocking call the VM method `ESMF_VMWaitQueue()` may be used to block on all currently queued communication calls of the VM context.
- `[rc]` Return code; equals `ESMF_SUCCESS` if there are no errors.

**INTERFACE:**

```fortran
! Private name; call using ESMF_VMSendRecv()
subroutine ESMF_VMSendRecvCharacter(vm, sendData, sendCount, dst, &
  recvData, recvCount, src, blockingflag, commhandle, rc)
```

**ARGUMENTS:**

```fortran
type(ESMF_VM), intent(in) :: vm

type(ESMF_Logical), target, intent(in) :: sendData(:)

integer, intent(in) :: sendCount

integer, intent(in) :: dst

type(ESMF_Logical), target, intent(out) :: recvData(:)

integer, intent(in) :: recvCount

integer, intent(in) :: src

```

```fortran
type(ESMF_BlockingFlag), intent(in), optional :: blockingflag
```

```fortran
type(ESMF_CommHandle), intent(out), optional :: commhandle
```

```fortran
integer, intent(out), optional :: rc
```
DESCRIPTION:

Send contiguous data of type character to a PET within the same ESMF_VM object while receiving contiguous data of kind ESMF_Logical from a PET within the same ESMF_VM object. The sendData and recvData arrays must be disjoint!

The arguments are:

**vm** ESMF_VM object.

**sendData** Contiguous data array holding data to be send.

**sendCount** Number of elements to be send.

**dst** Id of the destination PET within the ESMF_VM object.

**recvData** Contiguous data array for data to be received.

**recvCount** Number of elements to be received.

**src** Id of the source PET within the ESMF_VM object.

**[blockingflag]** Flag indicating whether this call behaves blocking or non-blocking:

- **ESMF_BLOCKING** (default) Block until local operation has completed.
- **ESMF_NONBLOCKING** Return immediately without blocking.

**[commhandle]** If present, a communication handle will be returned in case of a non-blocking request (see argument blockingflag). The commhandle can be used in ESMF_VMWait() to block the calling PET until the communication call has finished PET-locally. If no commhandle was supplied to a non-blocking call the VM method ESMF_VMWaitQueue() may be used to block on all currently queued communication calls of the VM context.

**[rc]** Return code; equals ESMF_SUCCESS if there are no errors.

40.5.53 ESMF_VMValidate - Validate VM internals

INTERFACE:

```fortran
subroutine ESMF_VMValidate(vm, rc)
```

ARGUMENTS:

```fortran
type(ESMF_VM), intent(in) :: vm
integer, intent(out), optional :: rc
```
DESCRIPTION:

Validates that the vm is internally consistent. The method returns an error code if problems are found. The arguments are:

vm  Specified ESMF_VM object.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.54 ESMF_VMWait - Wait for non-blocking VM communication to complete

INTERFACE:

    subroutine ESMF_VMWait(vm, commhandle, rc)

ARGUMENTS:

    type(ESMF_VM),          intent(in)    :: vm
    type(ESMF_CommHandle),  intent(in)    :: commhandle
    integer,                intent(out),  optional :: rc

DESCRIPTION:

Wait for non-blocking VM communication specified by the commhandle to complete.

The arguments are:

vm  ESMF_VM object.

commhandle  Handle specifying a previously issued non-blocking communication request.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.55 ESMF_VMWaitQueue - Wait for all non-blocking VM comms to complete

INTERFACE:

    subroutine ESMF_VMWaitQueue(vm, rc)

ARGUMENTS:

    type(ESMF_VM),          intent(in)    :: vm
    integer,                intent(out),  optional :: rc

DESCRIPTION:

Wait for all pending non-blocking VM communication within the specified VM context to complete.

The arguments are:

vm  ESMF_VM object.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.
40.5.56  ESMF_VMWtime - Get floating-point number of seconds

INTERFACE:

    subroutine ESMF_VMWtime(time, rc)

ARGUMENTS:

    real(ESMF_KIND_R8), intent(out) :: time
    integer, intent(out), optional :: rc

DESCRIPTION:

Get floating-point number of seconds of elapsed wall-clock time since some time in the past.

The arguments are:

time  Time in seconds.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.57  ESMF_VMWtimeDelay - Delay execution

INTERFACE:

    subroutine ESMF_VMWtimeDelay(delay, rc)

ARGUMENTS:

    real(ESMF_KIND_R8), intent(in) :: delay
    integer, intent(out), optional :: rc

DESCRIPTION:

Delay execution for amount of seconds.

The arguments are:

delay  Delay time in seconds.

[rc]  Return code; equals ESMF_SUCCESS if there are no errors.

40.5.58  ESMF_VMWtimePrec - Timer precision as floating-point number of seconds

INTERFACE:

    subroutine ESMF_VMWtimePrec(prec, rc)

ARGUMENTS:

    real(ESMF_KIND_R8), intent(out) :: prec
    integer, intent(out), optional :: rc
DESCRIPTION:

Get a run-time estimate of the timer precision as floating-point number of seconds. This is a relatively expensive call since the timer precision is measured several times before the maximum is returned as the estimate. The returned value is PET-specific and may differ across the VM context.

The arguments are:

prec Timer precision in seconds.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.

40.5.59   ESMF_CommHandleValidate - Validate CommHandle internals

INTERFACE:

    subroutine ESMF_CommHandleValidate(commhandle, rc)

ARGUMENTS:

    type(ESMF_CommHandle), intent(in) :: commhandle
    integer, intent(out), optional :: rc

DESCRIPTION:

Validates that the commhandle is internally consistent. The method returns an error code if problems are found. The arguments are:

commhandle  Specified ESMF_CommHandle object.

[rc] Return code; equals ESMF_SUCCESS if there are no errors.
41 Bibliography

References


Part V
Appendices

42 Appendix A: A Brief Introduction to UML

The schematic below shows the Unified Modeling Language (UML) notation for the class diagrams presented in this Reference Manual. For more on UML, see references such as The Unified Modeling Language Reference Manual, Rumbaugh et al. [9].

- **Public class.** This is a class whose methods can be called by the user. In Fortran a public class is usually associated with a derived type and a corresponding module that contains class methods and flags.

- **Private class.** This type of class does not have methods that should be called by the user. Like a public class it is usually associated with a derived type and a corresponding module.

- **A line indicates some sort of association among classes.**

  - **A hollow diamond at one end of a line drawn between classes represents an association called aggregation.** Aggregation is a part-whole relationship that can be read as “the class at the end of the line without the diamond is part of the class at the end of the line with the diamond.” The class that is the “part” can be created and destroyed separately, and it is usually implemented as a reference contained with the structure of the class that is the “whole.”

  - **A filled diamond at one end of a line drawn between classes represents an association called composition.** Composition is a part-whole relationship that is similar to aggregation, but stronger. It implies that that class that is the “part” is created and destroyed by the class that is the “whole.” It is often implemented as a structure within part of the contiguous memory of a larger structure.

- **Multiplicities** at association line ends show how many classes on the one end are associated with how many classes on the other end.

- **The triangle indicates an inheritance relationship.** Inheritance means that a child class shares a set of characteristics (such as the same attributes or methods) with a parent class. The child can specialize and extend the behavior of the parent. This diagram shows a GridComp class that inherits from a more general Comp class.

- **This simple diagram shows that a public class called Field is associated with another public class, called Grid.** The aggregation relationship indicated by the unfilled diamond means that a Field contains a Grid, but that a Grid can be created and destroyed outside of a Field. The diagram multiplicities show that a Field can be associated with no Grid or with one Grid, but that a single Grid can be associated with any number of Fields.
### Appendix B: ESMF Error Return Codes

The tables below show the possible error return codes for Fortran and C++ methods.

#### Success/Failure Return codes for both Fortran and C++

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESMF_SUCCESS</td>
<td>0</td>
</tr>
<tr>
<td>ESMF_FAILURE</td>
<td>-1</td>
</tr>
</tbody>
</table>

#### Fortran Return codes 1-500

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESMF_RC_OBJ_BAD</td>
<td>1</td>
</tr>
<tr>
<td>ESMF_RC_OBJ_INIT</td>
<td>2</td>
</tr>
<tr>
<td>ESMF_RC_OBJ_CREATE</td>
<td>3</td>
</tr>
<tr>
<td>ESMF_RC_OBJ_COR</td>
<td>4</td>
</tr>
<tr>
<td>ESMF_RC_OBJ_WRONGSTATE</td>
<td>5</td>
</tr>
<tr>
<td>ESMF_RC_ARG_BAD</td>
<td>6</td>
</tr>
<tr>
<td>ESMF_RC_ARG_RANK</td>
<td>7</td>
</tr>
<tr>
<td>ESMF_RC_ARG_SIZE</td>
<td>8</td>
</tr>
<tr>
<td>ESMF_RC_ARG_VALUE</td>
<td>9</td>
</tr>
<tr>
<td>ESMF_RC_ARG_DUP</td>
<td>10</td>
</tr>
<tr>
<td>ESMF_RC_ARG_SAMEETYPE</td>
<td>11</td>
</tr>
<tr>
<td>ESMF_RC_ARG_SAMECOMM</td>
<td>12</td>
</tr>
<tr>
<td>ESMF_RC_ARG_INCOMP</td>
<td>13</td>
</tr>
<tr>
<td>ESMF_RC_ARG_CORRUPT</td>
<td>14</td>
</tr>
<tr>
<td>ESMF_RC_ARG_WRONG</td>
<td>15</td>
</tr>
<tr>
<td>ESMF_RC_ARG_OUTOF RANGE</td>
<td>16</td>
</tr>
<tr>
<td>ESMF_RC_ARG_OPT</td>
<td>17</td>
</tr>
<tr>
<td>ESMF_RC_NOT_IMPL</td>
<td>18</td>
</tr>
<tr>
<td>ESMF_RC_FILE_OPEN</td>
<td>19</td>
</tr>
<tr>
<td>ESMF_RC_FILE_CREATE</td>
<td>20</td>
</tr>
<tr>
<td>ESMF_RC_FILE_READ</td>
<td>21</td>
</tr>
<tr>
<td>ESMF_RC_FILE_WRITE</td>
<td>22</td>
</tr>
<tr>
<td>ESMF_RC_FILE_UNEXPECTED</td>
<td>23</td>
</tr>
<tr>
<td>ESMF_RC_FILE_CLOSE</td>
<td>24</td>
</tr>
<tr>
<td>ESMF_RC_FILE_ACTIVE</td>
<td>25</td>
</tr>
<tr>
<td>ESMF_RC_PTR_NULL</td>
<td>26</td>
</tr>
<tr>
<td>ESMF_RC_PTR_BAD</td>
<td>27</td>
</tr>
<tr>
<td>ESMF_RC_PTR_NOTALLOC</td>
<td>28</td>
</tr>
<tr>
<td>ESMF_RC_PTR_ISALLOC</td>
<td>29</td>
</tr>
<tr>
<td>ESMF_RC_MEM</td>
<td>30</td>
</tr>
<tr>
<td>ESMF_RC_MEMC</td>
<td>31</td>
</tr>
<tr>
<td>ESMF_RC_DUP_NAME</td>
<td>32</td>
</tr>
<tr>
<td>ESMF_RC_LONG_NAME</td>
<td>33</td>
</tr>
<tr>
<td>ESMF_RC_LONG_STR</td>
<td>34</td>
</tr>
<tr>
<td>ESMF_RC_COPY_FAIL</td>
<td>35</td>
</tr>
<tr>
<td>ESMF_RC_DIV_ZERO</td>
<td>36</td>
</tr>
<tr>
<td>ESMF_RC_CANNOT_GET</td>
<td>37</td>
</tr>
<tr>
<td>ESMF_RC_CANNOT_SET</td>
<td>38</td>
</tr>
<tr>
<td>ESMF_RC_NOT_FOUND</td>
<td>39</td>
</tr>
<tr>
<td>ESMF_RC_NOT_VALID</td>
<td>40</td>
</tr>
<tr>
<td>ESMF_RC_INTNRL_LIST</td>
<td>41</td>
</tr>
</tbody>
</table>
ESMF_RC_INTNRL_INCONS 42
ESMF_RC_INTNRL_BAD 43
ESMF_RC_SYS 44
ESMF_RC_BUSY 45
ESMF_RC_LIB 46
ESMF_RC_ATTR_UNUSED 47
ESMF_RC_OBJ_NOT_CREATED 48
ESMF_RC_OBJ_DELETED 49

50-500 reserved for future Fortran return code definitions

=========================
C++ Return codes 501-1000
=========================

ESMC_RC_OBJ_BAD 501
ESMC_RC_OBJ_INIT 502
ESMC_RC_OBJ_CREATE 503
ESMC_RC_OBJ_COR 504
ESMC_RC_OBJ_WRONGSTATE 505
ESMC_RC_ARG_BAD 506
ESMC_RC_ARG_RANK 507
ESMC_RC_ARG_SIZE 508
ESMC_RC_ARG_VALUE 509
ESMC_RC_ARG_DUP 510
ESMC_RC_ARG_SAMEETYPE 511
ESMC_RC_ARG_SAMECOMM 512
ESMC_RC_ARG_INCORRECT 513
ESMC_RC_ARG_CORRUPT 514
ESMC_RC_ARG_WRONG 515
ESMC_RC_ARG_OUTOFRANGE 516
ESMC_RC_ARG_OPT 517
ESMC_RC_NOT_IMPL 518
ESMC_RC_FILE_OPEN 519
ESMC_RC_FILE_CREATE 520
ESMC_RC_FILE_READ 521
ESMC_RC_FILE_WRITE 522
ESMC_RC_FILE_UNEXPECTED 523
ESMC_RC_FILE_CLOSE 524
ESMC_RC_FILE_ACTIVE 525
ESMC_RC_PTR_NULL 526
ESMC_RC_PTR_BAD 527
ESMC_RC_PTR_NOTALLOC 528
ESMC_RC_PTR_ISALLOC 529
ESMC_RC_MEM 530
ESMC_RC_MEMC 531
ESMC_RC_DUP_NAME 532
ESMC_RC_LONG_NAME 533
ESMC_RC_LONG_STR 534
ESMC_RC_COPY_FAIL 535
ESMC_RC_DIV_ZERO 536
ESMC_RC_CANNOT_GET 537
ESMC_RC_CANNOT_SET 538
ESMC_RC_NOT_FOUND 539
ESMC_RC_NOT_VALID 540
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESMC_RC_INTNRL_LIST</td>
<td>541</td>
</tr>
<tr>
<td>ESMC_RC_INTNRL_INCONS</td>
<td>542</td>
</tr>
<tr>
<td>ESMC_RC_INTNRL_BAD</td>
<td>543</td>
</tr>
<tr>
<td>ESMC_RC_SYS</td>
<td>544</td>
</tr>
<tr>
<td>ESMC_RC_BUSY</td>
<td>545</td>
</tr>
<tr>
<td>ESMC_RC_LIB</td>
<td>546</td>
</tr>
<tr>
<td>ESMC_RC_ATTR_UNUSED</td>
<td>547</td>
</tr>
<tr>
<td>ESMC_RC_OBJ_NOT_CREATED</td>
<td>548</td>
</tr>
<tr>
<td>ESMC_RC_OBJ_DELETED</td>
<td>549</td>
</tr>
</tbody>
</table>

550–1000 reserved for future C++ return code definitions