# National Unified Operational Prediction Capability

# **NUOPC** Layer Reference

ESMF 8.5.0 beta snapshot

Content Standards Committee (CSC) Members

November 14, 2022

# **Contents**

1	Desc	ription	5
2	Desig	gn and Implementation Notes	5
	2.1	Generic Components	5
		2.1.1 Component Specialization	6
		2.1.2 Partial Specialization	8
	2.2		9
			9
		2.2.2 Preloaded Field Dictionary	
	2.3	Metadata	
	2.3	2.3.1 Driver Component Metadata	
		2.3.2 Model Component Metadata	
		2.3.3 Mediator Component Metadata	
		2.3.4 Connector Component Metadata	
		1	
	2.4	2.3.6 Field Metadata	
	2.4	Initialization	
		2.4.1 Phase Maps, Semantic Specialization Labels, and Component Labels	
		2.4.2 Field Pairing	
		2.4.3 Namespaces	
		2.4.4 Using Coupling Sets for Coupling Multiple Nests	
		2.4.5 Connection Options	6
		2.4.6 Data-Dependencies during Initialize	8
		2.4.7 Transfer of Grid/Mesh/LocStream Objects between Components	9
		2.4.8 Field and Grid/Mesh/LocStream Reference Sharing	0
		2.4.9 Field Mirroring	1
	2.5	Timekeeping	2
	2.6	Component Hierarchies	3
	2.7	Resource Control and Threaded Components	
	2.8	External NUOPC Interface	
	2.0	External (COT & Internate Cott )	_
3	API	4:	2
_	3.1	Generic Component: NUOPC_Driver	
	0.11	3.1.1 NUOPC_DriverAddComp	
		3.1.2 NUOPC_DriverAddComp	
		3.1.3 NUOPC_DriverAddComp	
		3.1.4 NUOPC DriverAddRunElement	
			_
		_	
		3.1.6 NUOPC_DriverAddRunElement	
		3.1.7 NUOPC_DriverEgestRunSequence	-
		3.1.8 NUOPC_DriverGet	
		3.1.9 NUOPC_DriverGetComp	
		3.1.10 NUOPC_DriverGetComp	
		3.1.11 NUOPC_DriverGetComp	
		3.1.12 NUOPC_DriverGetComp	
		3.1.13 NUOPC_DriverIngestRunSequence	1
		3.1.14 NUOPC_DriverNewRunSequence	4
		3.1.15 NUOPC_DriverPrint	4
		3.1.16 NUOPC DriverSetRunSequence	

3.2	_	55
3.3		57
	<del>-</del>	59
3.4		59
	<del>-</del>	61
3.5	<u> </u>	61
		62
	3.5.2 NUOPC_ConnectorSet	63
3.6	General Generic Component Methods	65
	3.6.1 NUOPC_CompAreServicesSet	65
	3.6.2 NUOPC_CompAreServicesSet	65
		66
		66
		66
		67
		67
	<del>-</del> 1	68
		69
	<del>-</del> 1	70
		70
		71
		72
		73
	= 1	74
	= 1 6	75
	= 1 &	76
	<del>-</del> 1	76
	<del>-</del> 1	77
	<b>–</b> 1	77
	<b>–</b> 1	78
	_ <u> </u>	78
	_ <u> </u>	
		78 70
		79 70
	<b>–</b> 1	79
	<del>-</del> 1	80
		80
	<del>-</del> 1	81
	<u> </u>	81
	_ <u> </u>	82
	<del>-</del> 1	82
	<del>-</del> 1 1	83
	<del>-</del> 1 1	83
	_ 1	84
	<u> </u>	84
	_ <u> </u>	85
	<b>=</b> 1 ₹	85
	<b>=</b> 1 ₹	86
	_ 1	87
	<u> </u>	87
	_ <u> </u>	88
	3.6.42 NUOPC CompSpecialize	88

		NUOPC_CompSpecialize
3.7	Field D	victionary Methods
	3.7.1	NUOPC_FieldDictionaryAddEntry
	3.7.2	NUOPC_FieldDictionaryEgest
	3.7.3	NUOPC_FieldDictionaryGetEntry
	3.7.4	NUOPC_FieldDictionaryHasEntry
	3.7.5	NUOPC_FieldDictionaryMatchSyno
	3.7.6	NUOPC_FieldDictionarySetSyno
	3.7.7	NUOPC_FieldDictionarySetup
	3.7.8	NUOPC FieldDictionarySetup
3.8		ormat Methods
	3.8.1	NUOPC_FreeFormatAdd
	3.8.2	NUOPC_FreeFormatCreate 93
	3.8.3	NUOPC_FreeFormatCreate
	3.8.4	NUOPC_FreeFormatDestroy
	3.8.5	NUOPC_FreeFormatGet
	3.8.6	NUOPC_FreeFormatGetLine
	3.8.7	NUOPC_FreeFormatLog
	3.8.8	= 6
2.0		<del>-</del>
3.9	•	Routines
	3.9.1	NUOPC_AddNamespace
	3.9.2	NUOPC_AddNestedState
	3.9.3	NUOPC_Advertise
	3.9.4	NUOPC_Advertise
	3.9.5	NUOPC_AdjustClock
	3.9.6	NUOPC_CheckSetClock
	3.9.7	NUOPC_GetAttribute
	3.9.8	NUOPC_GetAttribute
	3.9.9	NUOPC_GetAttribute
		NUOPC_GetStateMemberLists
		NUOPC_GetStateMemberCount
	3.9.12	NUOPC_GetTimestamp
	3.9.13	NUOPC_IngestPetList
	3.9.14	NUOPC_IsAtTime
	3.9.15	NUOPC_IsAtTime
	3.9.16	NUOPC_IsConnected
	3.9.17	NUOPC_IsConnected
	3.9.18	NUOPC_IsUpdated
		NUOPC_IsUpdated
		NUOPC_NoOp
		NUOPC_Realize
		NUOPC_Realize
		NUOPC Realize
		NUOPC_Realize
		NUOPC Realize
		NUOPC_SetAttribute
		NUOPC_SetAttribute
		NUOPC_SetTimestamp
		NUOPC_SetTimestamp
	1911	INCOPA. Sectionesiamb

		3.9.32 NUOPC_SetTimestamp	121
	3.10	Auxiliary Routines	122
		3.10.1 NUOPC_Write	122
		3.10.2 NUOPC_Write	122
		3.10.3 NUOPC_Write	123
		3.10.4 NUOPC_Write	124
		3.10.5 NUOPC_Write	125
4	Star	ndardized Component Dependencies	127
	4.1	Fortran components that are statically built into the executable	128
	4.2	Fortran components that are provided as shared libraries	131
	4.3	Components that are loaded during run-time as shared objects	132
	4.4	Components that depend on components	
	4.5	Components written in C/C++	135
5	NU	OPC Layer Compliance	138
	5.1	The Compliance Checker	138
	5.2	The Component Explorer	140
6	App	pendix A: Run Sequence Implementation	143
6 7		pendix A: Run Sequence Implementation pendix B: Initialize Phase Definition Versions	143 144
-			144
-	App	pendix B: Initialize Phase Definition Versions	<b>14</b> 4
-	<b>App</b> 7.1	pendix B: Initialize Phase Definition Versions  NUOPC_Driver IPD implementation	144 148 150
-	<b>App</b> 7.1 7.2	pendix B: Initialize Phase Definition Versions  NUOPC_Driver IPD implementation	144 148 150 151
-	<b>App</b> 7.1 7.2	pendix B: Initialize Phase Definition Versions  NUOPC_Driver IPD implementation	144 148 150 151 154 154
-	<b>App</b> 7.1 7.2	pendix B: Initialize Phase Definition Versions  NUOPC_Driver IPD implementation  NUOPC_ModelBase IPD implementation  NUOPC_Model IPD implementation  7.3.1 Initialize Phase Specialization - label_SetClock  7.3.2 Initialize Phase Specialization - label_DataInitialize  7.3.3 Run Phase Specialization - label_SetRunClock	144 148 150 151 154 154
-	<b>App</b> 7.1 7.2	pendix B: Initialize Phase Definition Versions  NUOPC_Driver IPD implementation  NUOPC_ModelBase IPD implementation  NUOPC_Model IPD implementation  7.3.1 Initialize Phase Specialization - label_SetClock  7.3.2 Initialize Phase Specialization - label_DataInitialize  7.3.3 Run Phase Specialization - label_SetRunClock  7.3.4 Run Phase Specialization - label_CheckImport	144 148 150 151 154 154 154
-	<b>App</b> 7.1 7.2	pendix B: Initialize Phase Definition Versions  NUOPC_Driver IPD implementation  NUOPC_ModelBase IPD implementation  NUOPC_Model IPD implementation  7.3.1 Initialize Phase Specialization - label_SetClock  7.3.2 Initialize Phase Specialization - label_DataInitialize  7.3.3 Run Phase Specialization - label_SetRunClock  7.3.4 Run Phase Specialization - label_CheckImport  7.3.5 Run Phase Specialization - label_Advance	144 148 150 151 154 154 154 154
-	<b>App</b> 7.1 7.2	pendix B: Initialize Phase Definition Versions  NUOPC_Driver IPD implementation  NUOPC_ModelBase IPD implementation  NUOPC_Model IPD implementation  7.3.1 Initialize Phase Specialization - label_SetClock  7.3.2 Initialize Phase Specialization - label_DataInitialize  7.3.3 Run Phase Specialization - label_SetRunClock  7.3.4 Run Phase Specialization - label_CheckImport  7.3.5 Run Phase Specialization - label_Advance  7.3.6 Run Phase Specialization - label_TimestampExport	144 148 150 151 154 154 154 154 155
-	<b>App</b> 7.1 7.2 7.3	pendix B: Initialize Phase Definition Versions  NUOPC_Driver IPD implementation  NUOPC_ModelBase IPD implementation  NUOPC_Model IPD implementation  7.3.1 Initialize Phase Specialization - label_SetClock  7.3.2 Initialize Phase Specialization - label_DataInitialize  7.3.3 Run Phase Specialization - label_SetRunClock  7.3.4 Run Phase Specialization - label_CheckImport  7.3.5 Run Phase Specialization - label_Advance  7.3.6 Run Phase Specialization - label_TimestampExport  7.3.7 Finalize Phase Specialization - label_Finalize	144 148 150 151 154 154 154 155 155
-	<b>App</b> 7.1 7.2	pendix B: Initialize Phase Definition Versions  NUOPC_Driver IPD implementation  NUOPC_ModelBase IPD implementation  NUOPC_Model IPD implementation  7.3.1 Initialize Phase Specialization - label_SetClock  7.3.2 Initialize Phase Specialization - label_DataInitialize  7.3.3 Run Phase Specialization - label_SetRunClock  7.3.4 Run Phase Specialization - label_CheckImport  7.3.5 Run Phase Specialization - label_Advance  7.3.6 Run Phase Specialization - label_TimestampExport	144 148 150 151 154 154 154 155 155 155

# 1 Description

The NUOPC Layer is an add-on to the standard ESMF library. It consists of generic code of two different kinds: *utility routines* and *generic components*. The NUOPC Layer further implements a dictionary for standard field metadata.

The utility routines are subroutines and functions that package frequently used calling sequences of ESMF methods into single calls. Unlike the pure ESMF API, which is very class centric, the utility routines of the NUOPC Layer often implement tasks that involve several ESMF classes.

The generic components are provided in form of Fortran modules that implement GridComp and CplComp specific methods. Generic components are useful when implementing NUOPC compliant driver, model, mediator, or connector components. The provided generic components form a hierarchy that allows the developer to pick and choose the appropriate level of specification for a certain application. Depending on how specific the chosen level, generic components require more or less specialization to result in fully implemented components.

# 2 Design and Implementation Notes

The NUOPC Layer is implemented in Fortran on top of the public ESMF Fortran API.

The NUOPC utility routines form a very straightforward Fortran API, accessible through the NUOPC Fortran module. The interfaces only use native Fortran types and public ESMF derived types. In order to access the utility API of the NUOPC Layer, user code must include the following two use lines:

```
use ESMF
use NUOPC
```

## 2.1 Generic Components

The NUOPC generic components are implemented as a *collection* of Fortran modules. Each module implements a single, well specified set of standard ESMF\_GridComp or ESMF\_CplComp methods. The nomenclature of the generic component modules starts with the NUOPC\_ prefix and continues with the kind: Driver, Model, Mediator, or Connector. The four kinds of generic components implemented by the NUOPC Layer are:

- NUOPC\_Driver A generic driver component. It implements a child component harness, made of State and Component objects, that follows the NUOPC Common Model Architecture. It is specialized by plugging Model, Mediator, and Connector components into the harness. Driver components can be plugged into the harness to construct component hierarchies. The generic Driver initializes its child components according to a standard Initialization Phase Definition, and drives their Run() methods according a customizable run sequence.
- NUOPC\_Model A generic model component that wraps a model code so it is suitable to be plugged into a generic Driver component.
- NUOPC\_Mediator A generic mediator component that wraps custom coupling code (flux calculations, averaging, etc.) so it is suitable to be plugged into a generic Driver component.
- NUOPC\_Connector A generic component that implements Field matching based on metadata and executes simple transforms (Regrid and Redist). It can be plugged into a generic Driver component.

The user code accesses the desired generic component(s) by including a use line for each one. Each generic component defines a small set of public names that are made available to the user code through the use statement. At a minimum the SetServices method is made public. Some of the generic components define additional public routines and labels as part of their user interface. It is recommended to rename entries of an imported generic component module, such as SetServices, in the local scope as part of the use association to prevent potential name clashes.

```
use NUOPC_<GenericComp>, &
     <GenericComp>SS => SetServices
```

A generic component is used by user code to implement a specialized version of the generic component. The user component derives from the generic component code by implementing its own public SetServices routine that calls into the generic SetServices routine via the NUOPC\_CompDerive() method. Typically this should be the first call made before doing anything else. It is through this mechanism that the deriving component *inherits* functionality that is implemented in the generic component. The example below shows how a specific *model* component is implemented, deriving from the generic NUOPC\_Model:

```
use NUOPC_Model, &
  modelSS => SetServices

subroutine SetServices(model, rc)
  type(ESMF_GridComp) :: model
  integer, intent(out) :: rc

! derive from NUOPC_Model
  call NUOPC_CompDerive(model, modelSS, rc=rc)
! specialize model
!... calls to NUOPC_CompSpecialize() here
end subroutine
```

#### 2.1.1 Component Specialization

After the call to NUOPC\_CompDerive() in a component's SetServices() method, the component is connected to all of the generic code provided by NUOPC for the respective component kind. In order to function properly, e.g. as an atmosphere model, ocean model, driver, etc., the component must be *specialized*.

The NUOPC\_CompSpecialize() method is used to link specific user provided routines to pre-defined NUOPC specialization points. The labels of the pre-defined specialization points are use associated named constants made available by the respective generic component module. The naming of all pre-defined specialization labels starts with the label\_prefix, and is followed by a short intent of the specialization. E.g. label\_Advertise refers to the specialization point responsible for advertising Fields in the import- and exportStates of the component.

There are pre-defined specialization labels for Initialize, Run, and Finalize phases. Section 2.4.1 discusses the semantic labeling of specializations in greater detail. Lists of *all* pre-defined specialization labels for Initialize, Run, and Finalize, for each of the generic NUOPC component kinds, are provided at the beginning of the respective API sections. (Driver: 3.1, Model: 3.3, Mediator: 3.4, Connector: 3.5)

The following code snippet shows a full specialization of NUOPC\_Model, using three specialization labels:

```
use NUOPC_Model, &
```

```
modelSS => SetServices
subroutine SetServices (model, rc)
  type (ESMF_GridComp) :: model
  integer, intent(out) :: rc
  rc = ESMF_SUCCESS
  ! derive from NUOPC_Model
  call NUOPC_CompDerive(model, modelSS, rc=rc)
  if (ESMF_LogFoundError(rcToCheck=rc, msg=ESMF_LOGERR_PASSTHRU, &
    line=__LINE__, &
   file=__FILE__)) &
    return ! bail out
  ! specialize model
  call NUOPC_CompSpecialize(model, specLabel=label_Advertise, &
    specRoutine=Advertise, rc=rc)
  if (ESMF_LogFoundError(rcToCheck=rc, msg=ESMF_LOGERR_PASSTHRU, &
   line=__LINE__, &
   file=__FILE__)) &
    return ! bail out
  call NUOPC_CompSpecialize(model, specLabel=label_RealizeProvided, &
    specRoutine=Realize, rc=rc)
  if (ESMF_LogFoundError(rcToCheck=rc, msg=ESMF_LOGERR_PASSTHRU, &
   line= LINE , &
    file=__FILE___)) &
    return ! bail out
  call NUOPC_CompSpecialize(model, specLabel=label_Advance, &
    specRoutine=Advance, rc=rc)
  if (ESMF_LogFoundError(rcToCheck=rc, msg=ESMF_LOGERR_PASSTHRU, &
    line=__LINE__, &
    file= FILE )) &
    return ! bail out
end subroutine
```

The user implemented specialization routines must follow the NUOPC interface definition.

```
subroutine SpecRoutine(comp, rc)
  type(ESMF_*Comp) :: comp
  integer, intent(out) :: rc
end subroutine
```

Here type (ESMF\_\*Comp) either corresponds to type (ESMF\_GridComp) for Models, Mediators, and Drivers, or type (ESMF\_CplComp) for Connectors.

### 2.1.2 Partial Specialization

Components that are derived from a generic component may choose to only specialize certain aspects, leaving other aspects unspecified. This allows a hierarchy of generic components to be implemented with a high degree of code re-use. The variable level of specialization supports the very differing user needs. Figure 1 depicts the inheritance structure of the standard generic components implemented by the NUOPC Layer. There are two trees, one is rooted in ESMF\_GridComp, while the other is rooted in ESMF\_CplComp.



Figure 1: The NUOPC Generic Component inheritance structure. The tree on the left is rooted in ESMF\_GridComp, while the tree on the right is rooted in ESMF\_CplComp. The ESMF data types are shown in green. The four main NUOPC Generic Component kinds are shown in dark blue boxes. The yellow box shows a partial specialization in the inheritance tree.

## 2.2 Field Dictionary

The NUOPC Layer uses standard metadata on Fields to guide the decision making process that is implemented in generic code. The generic NUOPC\_Connector component, for instance, uses the StandardName Attribute to construct a list of matching Fields between the import and export States. The NUOPC Field Dictionary provides a software implementation of a controlled vocabulary for the StandardName Field Attribute. It also associates each registered StandardName with CanonicalUnits. Currently the NUOPC Layer uses the CanonicalUnits entry to verify that Fields are provided in their canonical units. In the future, this entry may help support automatic unit conversion among exchanged fields.

The NUOPC Field Dictionary is set up by loading its content from a YAML 1.2 file. See section 2.2.1 for details.

Users can extend the dictionary by adding entries (field definitions or synonyms) to the YAML file, or by calling the NUOPC\_FieldDictionaryAddEntry() interface.

#### 2.2.1 Field Dictionary file

In a given NUOPC application, the NUOPC Field Dictionary can be set up by calling the NUOPC\_FieldDictionarySetup() method to read in a properly-formatted YAML file. This feature is intended to improve the interoperability of codes that use the NUOPC Layer, as it allows a broader scientific community to contribute to the growth and upkeep of a common NUOPC Field Dictionary file shared among different Earth System Models. At this time, an initial version of the NUOPC Field Dictionary file is available through the dedicated GitHub repository: https://github.com/ESCOMP/NUOPCFieldDictionary, hosted within the Earth System Community Modeling Portal (ESCOMP).

A NUOPC Field Dictionary YAML file is codified as a YAML map (an unordered association of unique keys to values) with only one key: field\_dictionary. The value associated with this key is itself a YAML map that should include the mandatory key entries (pointing to the complete set of dictionary entries), and may include the optional keys: version\_number, last\_modified, institution, contact, source, and description. These optional keys are intended to hold information about the file itself and are currently ignored by the NUOPC Layer.

Entries in the NUOPC Field dictionary are organized as YAML lists of maps. List items under the entries keyword must be indented and preceded with a hyphen (-).

A dictionary entry fully defines a Field if it includes both the standard\_name and canonical\_units keys and their associated values. This entry may also include a brief narrative describing the Field, stored as the value of the optional key description.

Synonyms can be defined by adding separate entries that include both the alias key, associated with either a single synonym (YAML scalar, e.g. alias: <name>) or a comma-separated list of synonyms within square brackets (YAML flow sequence, e.g. alias: [<name1>, <name2>, ...]), and the standard\_name key associated with the original Field name to be substituted. The original Field name must be fully defined in the dictionary file. While adding one alias keyword to a Field definition dictionary entry is allowed and will be parsed by the NUOPC Layer, it is recommended that all synonyms be included as separate entries.

A NUOPC Field dictionary sample file is included below.

```
field_dictionary:
    version_number: 0.0.1
    last_modified: 2018-03-14T11:01:19Z
    institution: National ESPC, CSC & MCL Working Groups
    contact: esmf_support@ucar.edu
```

```
https://github.com/ESCOMP/NUOPCFieldDictionary
source:
                Community-based dictionary for shared coupling fields
description:
entries:
  - standard_name: air_pressure
   canonical_units: Pa
   description: Air pressure
  - standard_name: air_temperature
    canonical units: K
    description:
      Bulk temperature of the air,
      not the surface (skin) temperature
  - alias: p
   standard name: air pressure
  - alias: [ t, temp ]
    standard_name: air_temperature
```

#### 2.2.2 Preloaded Field Dictionary

A version of the NUOPC Field Dictionary is preloaded by the NUOPC Layer at start-up, and, at this time, consists of the entries show in the table below. The value of the StandardName Attribute in each of these entries complies with the Climate and Forecast (CF) conventions guidelines.

StandardName	CanonicalUnits
air_pressure_at_sea_level	Pa
magnitude_of_surface_downward_stress	Pa
precipitation_flux	kg m-2 s-1
sea_surface_height_above_sea_level	m
sea_surface_salinity	1e-3
sea_surface_temperature	K
surface_downward_eastward_stress	Pa
surface_downward_heat_flux_in_air	W m-2
surface_downward_northward_stress	Pa
surface_downward_water_flux	kg m-2 s-1
surface_eastward_sea_water_velocity	m s-1
surface_net_downward_longwave_flux	W m-2
surface_net_downward_shortwave_flux	W m-2
surface_northward_sea_water_velocity	m s-1

### 2.3 Metadata

The NUOPC Layer makes extensive use of the ESMF Attribute class to implement metadata on Components, States, and Fields. ESMF Attribute Packages (or AttPacks for short) are used to build an Attribute hierarchy for each object.

In some cases the lowest level NUOPC AttPack contains a nested AttPack defined by ESMF. For all objects, the highest level of the NUOPC AttPack hierarchy is implemented with convention="NUOPC", purpose="Instance". The public NUOPC Layer API allows a user to add Attributes to the highest AttPack hierarchy level.

## 2.3.1 Driver Component Metadata

The Driver component metadata is implemented as an ESMF Attribute Package:

Convention: NUOPC Purpose: Instance

• Includes:

CIM Model Component Simulation Description (see for example the Component Attribute packages section in the ESMF v5.2.0rp2 documentation)

**Note** that some of the Attribute names in the following table are longer than the table column width. In these cases the Attribute name had to be broken into multiple lines. When that happens, a hyphen shows up to indicate the line break. The hyphen is *not* part of the Attribute name!

Attribute name	Definition	Controlled vocabulary
Kind	String value indicating component kind.	Driver
Verbosity	String value, converted into an integer, and interpreted as	0, 1, 2,
	a bit field. The lower 16 bits (0-15) are reserved to con-	"off" = $0$ (default),
	trol verbosity of the generic component implementation.	"low": some verbosity, bits: 0, 8, 9,
	Higher bits are available for user level verbosity control.	10, 13
	<b>bit 0</b> : Intro/Extro of methods with indentation.	"high": more verbosity, bits: 0, 4,
	<b>bit 1</b> : Intro/Extro with memory info.	8, 9, 10, 11, 12, 13, 14
	<b>bit 2</b> : Intro/Extro with garbage collection info.	"max": all lower 16 bits
	<b>bit 3</b> : Intro/Extro with local VM info.	
	<b>bit 4</b> : Log hierarchy protocol details.	
	<b>bit 8</b> : Log Initialize phase with >>>, <<<, and cur-	
	rTime.	
	<b>bit 9</b> : Log Run phase with >>>, <<<, and currTime.	
	<b>bit 10</b> : Log Finalize phase with >>>, <<<, and cur-	
	rTime.	
	bit 11: Log info about data dependency during initialize	
	resolution.	
	bit 12: Log run sequence execution.	
	bit 13: Log Component creation and destruction.	
	bit 14: Log State creation and destruction.	

Profiling	String value, converted into an integer, and interpreted as a bit field. The lower 16 bits (0-15) are reserved to control profiling of the generic component implementation. Higher	0, 1, 2,  "off" = 0 (default),  "low": Top level profiling.
	bits are available for user level profiling control.	"high": Top level, specialization
	<b>bit 0</b> : Top level profiling of <i>Initialize</i> phases.	point profiling, and additional pro-
	<b>bit 1</b> : Specialization point profiling of <i>Initialize</i> phases.	filing of internals.
	<b>bit 2</b> : Additional profiling of internals of <i>Initialize</i> phases.	"max": All lower 16 bits set.
	<b>bit 3</b> : Top level profiling of <i>Run</i> phases.	
	<b>bit 4</b> : Specialization point profiling of <i>Run</i> phases.	
	<b>bit 5</b> : Additional profiling of internals of <i>Run</i> phases.	
	<b>bit 6</b> : Top level profiling of <i>Finalize</i> phases.	
	bit 7: Specialization point profiling of <i>Finalize</i> phases.	
	<b>bit 8</b> : Additional profiling of internals of <i>Finalize</i> phases.	
	bit 9: Leading barrier for <i>Initialize</i> phases.	
	bit 10: Leading barrier for Run phases.	
	bit 11: Leading barrier for <i>Finalize</i> phases.	
	bit 12: Run sequence iteration events.	
CompLabel	String value holding the label under which the component	no restriction
	was added to its parent driver.	
InitializePhaseMap	List of string values, mapping the logical NUOPC initial-	IPDvXXpY=Z, where $XX = two-$
	ize phases, of a specific Initialize Phase Definition (IPD)	digit revision number, e.g. 01, Y
	version, to the actual ESMF initialize phase number under	= logical NUOPC phase number, Z
	which the entry point is registered.	= actual ESMF phase number, with
D D1 M	L'a faire la constitut la	Y, Z > 0 and $Y, Z < 10$
RunPhaseMap	List of string values, mapping the logical NUOPC run	label-string=Z, where label-string
	phases to the actual ESMF run phase number under which	can be chosen freely, and $Z = ac-$
EineligeDhageMan	the entry point is registered.  List of string values, mapping the logical NUOPC final-	tual ESMF phase number.  label-string=Z, where label-string
FinalizePhaseMap	ize phases to the actual ESMF finalize phase number under	can be chosen freely, and $Z = ac$
	which the entry point is registered.	tual ESMF phase number.
Internal-	List of string values, mapping the logical NUOPC initial-	IPDvXXpY=Z, where XX = two-
InitializePhaseMap	ize phases, of a specific Initialize Phase Definition (IPD)	digit revision number, e.g. 01, Y
	version, to the actual ESMF initialize phase number under	= logical NUOPC phase number, Z
	which the entry point is registered.	= actual ESMF phase number, with
	which the chary point is registered.	Y, Z > 0 and $Y, Z < 10$
NestingGeneration	Integer value enumerating nesting level.	0, 1, 2,
Nestling	Integer value enumerating siblings within the same gener-	0, 1, 2,
-	ation.	
Initialize-	String value indicating whether the resolution loop is dis-	false, true
DataResolution	abled or enabled.	
Initialize-	String value indicating whether all initialize data dependen-	false, true
DataComplete	cies have been satisfied.	
Initialize- DataProgress	String value indicating whether progress is being made resolving initialize data dependencies.	false, true

HierarchyProtocol	String value specifying the hierarchy protocol.	"PushUpAllExportsAndUnsatisfiedImport
		- activates field mirroring of all
		exports and unsatisfied imports.
		By default use reference shar-
		ing for the mirrored fields and
		geom objects. This is the de-
		fault behavior without having
		HierarchyProtocol set.
		"ConnectProvidedFields"- no field
		mirroring, only connect to exter-
		nally provided fields in the import-
		and exportStates. "Explorer" - like
		the default, but do not use reference
		sharing. All other values currently
		disable the hierarchy protocol.

## 2.3.2 Model Component Metadata

The Model component metadata is implemented as an ESMF Attribute Package:

• Convention: NUOPC

• Purpose: Instance

• Includes:

CIM Model Component Simulation Description (see for example the Component Attribute packages section in the ESMF v5.2.0rp2 documentation)

**Note** that some of the Attribute names in the following table are longer than the table column width. In these cases the Attribute name had to be broken into multiple lines. When that happens, a hyphen shows up to indicate the line break. The hyphen is *not* part of the Attribute name!

Attribute name	Definition	Controlled vocabulary
Kind	String value indicating component kind.	Model

Verbosity	String value, converted into an integer, and interpreted as	0, 1, 2,
	a bit field. The lower 16 bits (0-15) are reserved to con-	"off" = $0$ (default),
	trol verbosity of the generic component implementation.	"low": some verbosity,
	Higher bits are available for user level verbosity control.	"high": more verbosity,
	<b>bit 0</b> : Intro/Extro of methods with indentation.	"max": all lower 16 bits
	<b>bit 1</b> : Intro/Extro with memory info.	
	<b>bit 2</b> : Intro/Extro with garbage collection info.	
	<b>bit 3</b> : Intro/Extro with local VM info.	
	<b>bit 8</b> : Log Initialize phase with >>>, <<<, and cur-	
	rTime.	
	<b>bit 9</b> : Log Run phase with >>>, <<<, and currTime.	
	<b>bit 10</b> : Log Finalize phase with >>>, <<<, and cur-	
	rTime.	
	bit 11: Log info about data dependency during initialize	
	resolution.	
	bit 12: Log run sequence execution.	
	bit 13: Log Component creation.	
	bit 14: Log State creation.	
Profiling	String value, converted into an integer, and interpreted as a	0, 1, 2,
	bit field. The lower 16 bits (0-15) are reserved to control	"off" = $0$ (default),
	profiling of the generic component implementation. Higher	"low": Top level profiling.
	bits are available for user level profiling control.	"high": Top level, specialization
	<b>bit 0</b> : Top level profiling of <i>Initialize</i> phases.	point profiling, and additional pro-
	<b>bit 1</b> : Specialization point profiling of <i>Initialize</i> phases.	filing of internals.
	<b>bit 2</b> : Additional profiling of internals of <i>Initialize</i> phases.	"max": All lower 16 bits set.
	<b>bit 3</b> : Top level profiling of <i>Run</i> phases.	
	<b>bit 4</b> : Specialization point profiling of <i>Run</i> phases.	
	<b>bit 5</b> : Additional profiling of internals of <i>Run</i> phases.	
	<b>bit 6</b> : Top level profiling of <i>Finalize</i> phases.	
	<b>bit 7</b> : Specialization point profiling of <i>Finalize</i> phases.	
	<b>bit 8</b> : Additional profiling of internals of <i>Finalize</i> phases.	
	<b>bit 9</b> : Leading barrier for <i>Initialize</i> phases.	
	<b>bit 10</b> : Leading barrier for <i>Run</i> phases.	
	<b>bit 11</b> : Leading barrier for <i>Finalize</i> phases.	

Diagnostic	String value, converted into an integer, and interpreted as	0, 1, 2,
	a bit field. The lower 16 bits (0-15) are reserved to con-	"off" = $0$ (default),
	trol diagnostic of the generic component implementation.	"max": All lower 16 bits set.
	Higher bits are available for user level diagnostic control.	
	<b>bit 0</b> : Dump fields of the importState on entering <i>Initialize</i>	
	phases.	
	<b>bit 1</b> : Dump fields of the exportState on entering <i>Initialize</i>	
	phases.	
	<b>bit 2</b> : Dump fields of the importState on exiting <i>Initialize</i>	
	phases.	
	<b>bit 3</b> : Dump fields of the exportState on exiting <i>Initialize</i>	
	phases.	
	<b>bit 4</b> : Dump fields of the importState on entering <i>Run</i>	
	phases.	
	•	
	<b>bit 5</b> : Dump fields of the exportState on entering <i>Run</i>	
	phases.	
	<b>bit 6</b> : Dump fields of the importState on exiting <i>Run</i>	
	phases.	
	<b>bit 7</b> : Dump fields of the exportState on exiting <i>Run</i> phases.	
	<b>bit 8</b> : Dump fields of the importState on entering <i>Finalize</i>	
	phases.	
	<b>bit 9</b> : Dump fields of the exportState on entering <i>Finalize</i>	
	phases.	
	<b>bit 10</b> : Dump fields of the importState on exiting <i>Finalize</i>	
	phases.	
	<b>bit 11</b> : Dump fields of the exportState on exiting <i>Finalize</i>	
	phases.	
CompLabel	String value holding the label under which the component	no restriction
	was added to its parent driver.	
InitializePhaseMap		IPDvXXpY=Z, where $XX = two-$
	ize phases, of a specific Initialize Phase Definition (IPD)	digit revision number, e.g. 01, Y
	version, to the actual ESMF initialize phase number under	= logical NUOPC phase number, Z
	which the entry point is registered.	= actual ESMF phase number, with
		Y, Z > 0 and $Y, Z < 10$
RunPhaseMap	List of string values, mapping the logical NUOPC run	label-string=Z, where label-string
	phases to the actual ESMF run phase number under which	can be chosen freely, and $Z = ac$
	the entry point is registered.	tual ESMF phase number.
FinalizePhaseMap	List of string values, mapping the logical NUOPC final-	label-string=Z, where label-string
_	ize phases to the actual ESMF finalize phase number under	can be chosen freely, and $Z = ac$
	which the entry point is registered.	tual ESMF phase number.
Internal-	List of string values, mapping the logical NUOPC initial-	IPDvXXpY=Z, where $XX = two-$
InitializePhaseMap		digit revision number, e.g. 01, Y
	version, to the actual ESMF initialize phase number under	= logical NUOPC phase number, Z
	which the entry point is registered.	= actual ESMF phase number, with
	miner and entry point is registered.	Y, Z > 0 and $Y, Z < 10$
NestingGeneration	Integer value enumerating nesting level.	0, 1, 2,
Nestling	Integer value enumerating siblings within the same gener-	0, 1, 2,
INESCITIIA	integer value chumerating storings within the same gener-	U, 1, 4,
	ation	
Initialies	ation.	folsa truo
Initialize- DataComplete	ation.  String value indicating whether all initialize data dependencies have been satisfied.	false, true

Initialize-	String value indicating whether progress is being made re-	false, true
DataProgress	solving initialize data dependencies.	
HierarchyProtocol	String value specifying the hierarchy protocol.	"PushUpAllExportsAndUnsatisfiedIm for field mirroring and connecting, "ConnectProvidedFields" to only connect provided fields (no mirroring), All other values currently disable the hierarchy protocol.

## 2.3.3 Mediator Component Metadata

The Mediator component metadata is implemented as an ESMF Attribute Package:

• Convention: NUOPC

• Purpose: Instance

• Includes:

CIM Model Component Simulation Description (see for example the Component Attribute packages section in the ESMF v5.2.0rp2 documentation)

**Note** that some of the Attribute names in the following table are longer than the table column width. In these cases the Attribute name had to be broken into multiple lines. When that happens, a hyphen shows up to indicate the line break. The hyphen is *not* part of the Attribute name!

Attribute name	Definition	Controlled vocabulary
Kind	String value indicating component kind.	Mediator
Verbosity	String value, converted into an integer, and interpreted as	0, 1, 2,
	a bit field. The lower 16 bits (0-15) are reserved to con-	"off" = $0$ (default),
	trol verbosity of the generic component implementation.	"low": some verbosity,
	Higher bits are available for user level verbosity control.	"high": more verbosity,
	<b>bit 0</b> : Intro/Extro of methods with indentation.	"max": all lower 16 bits
	<b>bit 1</b> : Intro/Extro with memory info.	
	<b>bit 2</b> : Intro/Extro with garbage collection info.	
	<b>bit 3</b> : Intro/Extro with local VM info.	
	<b>bit 8</b> : Log Initialize phase with >>>, <<<, and cur-	
	rTime.	
	<b>bit 9</b> : Log Run phase with >>>, <<<, and currTime.	
	<b>bit 10</b> : Log Finalize phase with >>>, <<<, and cur-	
	rTime.	
	<b>bit 11</b> : Log info about data dependency during initialize	
	resolution.	
	bit 12: Log run sequence execution.	
	bit 13: Log Component creation.	
	bit 14: Log State creation.	

Profiling	String value, converted into an integer, and interpreted as a bit field. The lower 16 bits (0-15) are reserved to control profiling of the generic component implementation. Higher bits are available for user level profiling control.  bit 0: Top level profiling of <i>Initialize</i> phases.  bit 1: Specialization point profiling of <i>Initialize</i> phases.  bit 2: Additional profiling of internals of <i>Initialize</i> phases.  bit 3: Top level profiling of <i>Run</i> phases.  bit 4: Specialization point profiling of <i>Run</i> phases.  bit 5: Additional profiling of internals of <i>Run</i> phases.  bit 6: Top level profiling of <i>Finalize</i> phases.  bit 7: Specialization point profiling of <i>Finalize</i> phases.  bit 8: Additional profiling of internals of <i>Finalize</i> phases.  bit 9: Leading barrier for <i>Initialize</i> phases.  bit 10: Leading barrier for <i>Run</i> phases.  bit 11: Leading barrier for <i>Finalize</i> phases.	0, 1, 2,  "off" = 0 (default),  "low": Top level profiling.  "high": Top level, specialization point profiling, and additional profiling of internals.  "max": All lower 16 bits set.
Diagnostic	String value, converted into an integer, and interpreted as a bit field. The lower 16 bits (0-15) are reserved to control diagnostic of the generic component implementation. Higher bits are available for user level diagnostic control. bit 0: Dump fields of the importState on entering <i>Initialize</i> phases.  bit 1: Dump fields of the exportState on entering <i>Initialize</i> phases.  bit 2: Dump fields of the importState on exiting <i>Initialize</i> phases.  bit 3: Dump fields of the exportState on exiting <i>Initialize</i> phases.  bit 4: Dump fields of the importState on entering <i>Run</i> phases.  bit 5: Dump fields of the exportState on entering <i>Run</i> phases.  bit 6: Dump fields of the importState on exiting <i>Run</i> phases.  bit 7: Dump fields of the exportState on exiting <i>Run</i> phases.  bit 7: Dump fields of the exportState on entering <i>Finalize</i> phases.  bit 9: Dump fields of the exportState on entering <i>Finalize</i> phases.  bit 10: Dump fields of the importState on exiting <i>Finalize</i> phases.  bit 11: Dump fields of the exportState on exiting <i>Finalize</i> phases.  bit 11: Dump fields of the exportState on exiting <i>Finalize</i> phases.	0, 1, 2, "off" = 0 (default), "max": All lower 16 bits set.
CompLabel	String value holding the label under which the component was added to its parent driver.	no restriction

InitializePhaseMap	List of string values, mapping the logical NUOPC initial-	IPDvXXpY=Z, where $XX = two-$
	ize phases, of a specific Initialize Phase Definition (IPD)	digit revision number, e.g. 01, Y
	version, to the actual ESMF initialize phase number under	= logical NUOPC phase number, Z
	which the entry point is registered.	= actual ESMF phase number, with
		Y, Z > 0 and $Y, Z < 10$
RunPhaseMap	List of string values, mapping the logical NUOPC run	label-string=Z, where label-string
	phases to the actual ESMF run phase number under which	can be chosen freely, and $Z = ac$ -
!	the entry point is registered.	tual ESMF phase number.
FinalizePhaseMap	List of string values, mapping the logical NUOPC final-	label-string=Z, where label-string
	ize phases to the actual ESMF finalize phase number under	can be chosen freely, and $Z = ac$ -
	which the entry point is registered.	tual ESMF phase number.
Internal-	List of string values, mapping the logical NUOPC initial-	IPDvXXpY=Z, where $XX = two-$
InitializePhaseMap	ize phases, of a specific Initialize Phase Definition (IPD)	digit revision number, e.g. 01, Y
	version, to the actual ESMF initialize phase number under	= logical NUOPC phase number, Z
	which the entry point is registered.	= actual ESMF phase number, with
	1	Y, Z > 0  and  Y, Z < 10
NestingGeneration	Integer value enumerating nesting level.	0, 1, 2,
Nestling	Integer value enumerating siblings within the same gener-	0, 1, 2,
	ation.	
Initialize-	String value indicating whether all initialize data dependen-	false, true
DataComplete	cies have been satisfied.	
Initialize-	String value indicating whether progress is being made re-	false, true
DataProgress	solving initialize data dependencies.	
HierarchyProtocol	String value specifying the hierarchy protocol.	"PushUpAllExportsAndUnsatisfiedImport
	1	for field mirroring and connecting,
	1	"ConnectProvidedFields" to only
	1	connect provided fields (no mir-
	1	roring), All other values currently
1	I I	disable the hierarchy protocol.

## 2.3.4 Connector Component Metadata

The Connector Component metadata is implemented as an ESMF Attribute Package:

• Convention: NUOPC

• Purpose: General

• Includes:

ESG General (see for example the Component Attribute packages section in the ESMF v5.2.0rp2 documentation)

Attribute name	Definition	Controlled lary	vocabu-
Kind	String value indicating component kind.	Connector	

Verbosity	String value, converted into an integer, and interpreted as a bit field.	0, 1, 2,
verbosity	The lower 16 bits (0-15) are reserved to control verbosity of the generic component implementation. Higher bits are available for user level verbosity control.  bit 0: Intro/Extro of methods with indentation.	"off" = 0 (default), "low": Some verbosity. "high": More ver-
		bosity.
	bit 1: Intro/Extro with memory info.	"max": All lower 16
	bit 2: Intro/Extro with garbage collection info.	bits set.
	<b>bit 3</b> : Intro/Extro with local VM info.	
	bit 8: Log FieldTransferPolicy.	
	<b>bit 9</b> : Log bond level info.	
	bit 10: Log CplList construction.	
	bit 11: Log GeomObject Transfer.	
	<b>bit 12</b> : Log looping over all elements in CplList for RouteHandle com-	
	putation, FieldSharing, and Timestamp propagation.	
	<b>bit 13</b> : Log Run phase with >>>, <<<, and currTime.	
	bit 14: Log info about RouteHandle execution.	
	bit 15: Log info about RouteHandle release.	
Profiling	String value, converted into an integer, and interpreted as a bit field. The lower 16 bits (0-15) are reserved to control profiling of the generic component implementation. Higher bits are available for user level	0, 1, 2,  "off" = 0 (default),  "low": Top level profil-
	profiling control.	ing.
	<b>bit 0</b> : Top level profiling of <i>Initialize</i> phases.	"high": Top level, spe-
	<b>bit 1</b> : Specialization point profiling of <i>Initialize</i> phases.	cialization point profil-
	<b>bit 2</b> : Additional profiling of internals of <i>Initialize</i> phases.	ing, and additional pro-
	<b>bit 3</b> : Top level profiling of <i>Run</i> phases.	filing of internals.
	<b>bit 4</b> : Specialization point profiling of <i>Run</i> phases.	"max": All lower 16
	<b>bit 5</b> : Additional profiling of internals of <i>Run</i> phases.	bits set.
	<b>bit 6</b> : Top level profiling of <i>Finalize</i> phases.	
	<b>bit 7</b> : Specialization point profiling of <i>Finalize</i> phases.	
	<b>bit 8</b> : Additional profiling of internals of <i>Finalize</i> phases.	
	<b>bit 9</b> : Leading barrier for <i>Initialize</i> phases.	
	bit 10: Leading barrier for Run phases.	
	<b>bit 11</b> : Leading barrier for <i>Finalize</i> phases.	
Diagnostic	String value, converted into an integer, and interpreted as a bit field.	0, 1, 2,
	The lower 16 bits (0-15) are reserved to control diagnostic of the	"off" = $0$ (default),
	generic component implementation. Higher bits are available for user	"max": All lower 16
	level diagnostic control.	bits set.
	<b>bit 0</b> : Dump fields of the importState on entering <i>Initialize</i> phases.	
	<b>bit 1</b> : Dump fields of the exportState on entering <i>Initialize</i> phases.	
	<b>bit 2</b> : Dump fields of the importState on exiting <i>Initialize</i> phases.	
	<b>bit 3</b> : Dump fields of the exportState on exiting <i>Initialize</i> phases.	
	<b>bit 4</b> : Dump fields of the importState on entering <i>Run</i> phases.	
	<b>bit 5</b> : Dump fields of the exportState on entering <i>Run</i> phases.	
	<b>bit 6</b> : Dump fields of the importState on exiting <i>Run</i> phases.	
	hit 7. Dumm fields of the avmentState on eviting Dummhages	
	<b>bit 7</b> : Dump fields of the exportState on exiting <i>Run</i> phases.	
	bit 8: Dump fields of the exportState on extring <i>Kun</i> phases.  bit 8: Dump fields of the importState on entering <i>Finalize</i> phases.	
	1	
	<b>bit 8</b> : Dump fields of the importState on entering <i>Finalize</i> phases.	

CompLabel	String value holding the label under which the component was added to its parent driver.	no restriction
InitializePhaseMap	List of string values, mapping the logical NUOPC initialize phases, of a specific Initialize Phase Definition (IPD) version, to the actual ESMF initialize phase number under which the entry point is registered.	IPDvXXpY=Z, where XX = two-digit revision number, e.g. 01, Y = logical NUOPC phase number, Z = actual ESMF phase number, with Y, Z > 0 and Y, Z < 10
RunPhaseMap	List of string values, mapping the logical NUOPC run phases to the actual ESMF run phase number under which the entry point is registered.	label-string=Z, where label-string can be chosen freely, and Z = actual ESMF phase number.
FinalizePhaseMap	List of string values, mapping the logical NUOPC finalize phases to the actual ESMF finalize phase number under which the entry point is registered.	label-string=Z, where label-string can be chosen freely, and Z = actual ESMF phase number.
CplList	List of StandardNames of the connected Fields. Each StandardName entry may be followed by a colon separated list of connection options. The details are discussed in section 2.4.5	Standard names as per field dictionary, followed by connection options defined in section 2.4.5.
CplSetList	List of coupling sets. Each coupling set is identified by a string value.	no restriction
ConnectionOptions	String value specifying the connection options to be applied to all the fields in the CplList by default.	Connection options defined in section 2.4.5.
EpochThrottle	Integer specifying the maximum number of outstanding EPOCH messages between any two PETs. The ESMF level default is 10.	Any positive integer.

## 2.3.5 State Metadata

The State metadata is implemented as an ESMF Attribute Package:

Convention: NUOPC Purpose: Instance

• Includes:

- no other packages at the moment

• Description: Namespace implementation for import and export.

Attribute name	Definition	Controlled	vocabu-
		lary	

Namespace	String value holding the namespace of all the objects contained in the	no restriction
	State.	
FieldTransferPolic	Y String value indicating to Connector to transfer/mirror Fields.	transferNone,
		transferAll

## 2.3.6 Field Metadata

The Field metadata is implemented as an ESMF Attribute Package:

• Convention: NUOPC

• Purpose: Instance

• Includes:

- ESG General

• Description: Basic Field description with connection and time stamp metadata.

Attribute name Definition		Controlled vocabu-
		lary
Connected	Connected status.	false, true
ProducerConnection	String value indicating whether the Field has been connected with a	open, targeted,
	producer.	connected
ConsumerConnection	String value indicating whether the Field has been connected with a	open, targeted,
	consumer.	connected
Updated	String value indicating updated status during initialization.	false, true
ProducerTransferOf	f String value indicating a producer component's ability to transfer in-	will provide,
	formation about the advertised Field, including its GeomObject.	can provide,
		cannot provide
ProducerTransferAc	String value indicating the action a producer component is supposed to	provide, accept
	take with respect to transferring Field information, including its Geo-	
	mObject.	
ConsumerTransferOf	String value indicating a consumer component's ability to transfer in-	will provide,
	formation about the advertised Field, including its GeomObject.	can provide,
		cannot provide
ConsumerTransferAc	String value indicating the action a consumer component is supposed	provide, accept
	to take with respect to transferring Field information, including its Ge-	
	omObject.	
SharePolicyField	String value indicating a component's policy with respect to sharing	share,
	the Field data allocation.	not share
ShareStatusField	String value indicating the status with respect to sharing the underlying	shared,
	Field data allocation that was negotiated.	not shared
SharePolicyGeomObj	String value indicating a component's policy with respect to sharing	share,
	the Grid or Mesh on which the advertised Field object is defined.	not share
ShareStatusGeomObj	String value indicating the status with respect to sharing the underlying	shared,
	GeomObject that was negotiated.	not shared
UngriddedLBound	Integer value list. If present equals the ungriddedLBound of the	no restriction
	provider field during a GeomObject transfer.	

UngriddedUBound	Integer value list. If present equals the ungriddedUBound of the	no restriction
	provider field.during a GeomObject transfer.	
GridToFieldMap	Integer value list. If present equals the gridToFieldMap of the	no restriction
	provider field.during a GeomObject transfer.	
ArbDimCount	Integer value. If present equals the arbDimCount of the provider	no restriction
	field.during a GeomObject transfer.	
MinIndex	Integer value list. If present equals the minIndex (of tile 1) of the	no restriction
	provider field.during a GeomObject transfer.	
MaxIndex	Integer value list. If present equals the maxIndex (of tile 1) of the	no restriction
	provider field.during a GeomObject transfer.	
TypeKind	Integer value. If present equals the integer representation of	implementation depen-
	typekind of the provider field.during a GeomObject transfer.	dent range
GeomLoc	Integer value. If present equals the integer representation of	implementation depen-
	staggerloc (for Grid) or meshloc (for Mesh) of the provider	dent range
	field.during a GeomObject transfer.	

#### 2.4 Initialization

#### 2.4.1 Phase Maps, Semantic Specialization Labels, and Component Labels

The NUOPC layer adds an abstraction on top of the ESMF phase index. ESMF introduces the concept of standard component methods: Initialize, Run, and Finalize. ESMF further recognizes the need for being able to split each of the standard methods into multiple phases. On the ESMF level, phases are implemented by a simple integer phase index. With NUOPC, logical phase labels are introduced that are mapped to the ESMF phase indices.

The NUOPC Layer introducing three component level attributes: InitializePhaseMap, RunPhaseMap, and FinalizePhaseMap. These attributes map logical NUOPC phase labels to integer ESMF phase indices. A NUOPC compliant component fully documents its available phases through the phase maps.

The generic NUOPC\_Driver uses the InitializePhaseMap on each of its child component during the initialization stage to correctly interact with each component. The RunPhaseMap is used when setting up run sequences in the Driver. The NUOPC\_DriverAddRunElement () takes the phaseLabel argument, and uses the RunPhaseMap attribute internally to translates the label into the corresponding ESMF phase index. The FinalizePhaseMap is currently not used by the NUOPC Layer

Appendix B, section 7, lists the supported logical phase labels for reference. User code very rare needs to interact with the InitializePhaseMap or its entries directly. Instead, user code specializes the initialization behavior of a component through the semantic specialization labels discussed below.

NUOPC implements a very powerful initialization procedure. This procedure is, among other functions, capable of handling component hierarchies, transfer of geometries, reference sharing, and resolving data dependencies during initialization. The initialization features are discussed in detail in their respective sections of this document.

From the user level, specialization of the initialization is accessbile through the *semantic specialization labels*. These labels are predefined named constants that are passed into the NUOPC\_CompSpecialize() method, together with the user provided routine, implementing the required actions. On a technical level, the user routine must follow the standard interface defined by NUOPC. Semantically, the purpose of each specialization point is indicated by the name of the predefined specialization label. For a definition of the labels, and the ascribed purpose, see the SEMANTIC SPECIALIZATION LABELS section under each of the generic component kinds. (Driver: 3.1, Model: 3.3, Mediator: 3.4, Connector: 3.5)

Finally, under NUOPC, each component is associated with a label when it is added to a driver through the NUOPC\_DriverAddComp() call. Multiple instances of the same component can be added to a driver, provided each instance is given a unique label. Connectors between components are identified by providing the label of the source component and destination component.

#### 2.4.2 Field Pairing

The NUOPC Model and Mediator components are required to advertise their import and export Fields with a standard set of Field metadata. This set includes the StandardName attribute. The NUOPC Layer implements a strategy of pairing advertised Fields that is based primarily on the StandardName of the Fields, and in more complex situations further utilizes the Namespace attribute on States.

Field pairing is accomplished as part of the initialization procedure and is a collective effort of the Driver and its child components: Models, Mediator, Connectors. The Connectors are the most active players when it comes to Field pairing. The end result of the process is where each Connector has a list of Fields that it connects between its importState and its exportState. Each connector keeps this list in its component level metadata as CplList attribute.

During the first stage of Field pairing, each Connector matches all of the Fields in its importState to all of the Fields

in its exportState by looking at their StandardName attribute. For every match a *bondLevel* is calculated and stored in the Field on the export side, i.e. on the consumer side of the connection, in the Field's ConsumerConnection attribute. The larges found bondLevel is kept for each Field on the export side.

The bondLevel is a measure of how strong the pairing is considering the namespace rules explained in section 2.4.3. Without the use of namespaces the bondLevel for all Field pairs that match by their StandardName is equal to 1.

After the first stage, there may be umbiguous Field pairs present. Ambiguous Field pairs are those that map different producer Fields (i.e. Fields in the importState of a Connector) to the *same* consumer Field (i.e. a Field in the exportState of a Connector). While the NUOPC Layer support having multiple consumer Fields connected to a single producer Field, it does not support the opposite condition. The second stage of Field pairing is responsible for disambiguating Field pairs with the same consumer Field.

Field pair disambiguation is based on the *bondLevel* that was calculated and stored on the consumer side Field for each pair during the first stage. The disambiguation rule simply selects the connection with the highest bondLevel and discards all lesser connection to the same consumer side Field. However, if the highest bondLevel is not unique, i.e. there are multiple pairs with the same bondLevel, disambiguation is not possible and an error is returned to the Driver by the Connector that finds the ambiguity first.

Assuming that the disambiguation step was successful, each Connector holds a valid CplList attribute with entries that correspond to the Field pairs that it is responsible for. At this stage the Driver can still overwrite this attribute and implement custom pairs if that is desired.

#### 2.4.3 Namespaces

Namespaces are used to control and fine-tune the disambiguation of Field pairs during the initialization. The general procedure of Field pairing and disambiguation is outlined in section 2.4.2, here the use of namespaces is described.

The NUOPC Layer implements namespaces through the <code>Namespace</code> attribute on <code>ESMF\_State</code> objects. The value of this attribute is a simple character string. The NUOPC Layer automatically creates the import and export States of every Model and Mediator component that is added to a <code>Driver</code>. The <code>Namespace</code> attribute of these States is automatically set to the <code>compLabel</code> string that was provided during <code>NUOPC\_DriverAdd()</code>. Doing this places every Field that is advertised through these States inside the component's unique namespace.

A secondary namespace can be added to a State using the NUOPC\_StateNamespaceAdd() method. This creates a new State that is nested inside of an existing State, and sets the Namespace attribute of the new State. Fields that are advertised inside of such a nested State are in a namespace with two parts: NS1:NS2. Here NS1 is the preset namespace of the import or export State (equal to the compLabel), and NS2 is a freely chosen namespace string.

During Field pairing the namespace on each side of the connection is considered in the two part format NS1:NS2. The first part is equal to the compLabel of the corresponding component, and NS2 is either the namespace of a nested State, or empty if the Field is not inside a nested State. Using this format, the calculation of the *bondLevel* during Field pairing is governed by the following rules:

- Namespace matching is done in a cross wise fashion, meaning NS1 from one side is compared to NS2 of the other side, and vice versa.
- The bondLevel is incremented by one counter for each cross-wise match between namespaces. (Considering that the bondLevel starts out as 1 for any Field pair with matching standard names, the maximum bondLevel that can be reached is 3.)
- Finding one side of the cross-wise comparison being an empty string is neither counted as a match nor a mismatch. The bondLevel remains unchanged.

• A Field pair for which a mis-match in either of the two cross-wise namespace comparisons is detected is discarded from the possible pairs. It is not further considered.

In practice then, a component that targets a specific other component with its advertised Fields would add a secondary namespace to its import or export State, and set that namespace to the compLabel of the targeted component. This increases the bondLevel for each pair from 1 to 2. An even higher bondLevel of 3 is achieved when both sides target each other by specifying the other component's compLabel through a secondary namespace.

In conclusion, namespaces can affect the bondLevel calculation for each pair, but they do not affect how pairs are constructed and disambiguated. In particular, the requirement for unambiguous Field pairs for each consumer Field remains unchanged, and it is an error condition if the highest bondLevel for a consumer Field does not correspond to a unique Field pair.

#### 2.4.4 Using Coupling Sets for Coupling Multiple Nests

The NUOPC Layer can couple multiple data sets by adding nested states to the import and export states of a NUOPC\_Model. Each nested state is given a couple set identifier at the time it is added to the parent state. This identifier guarantees a NUOPC\_Connector will only pair fields within this nested state to fields in a connected state with an identifier.

During label\_Advertise, before calling NUOPC\_Advertise (using methods 3.9.3 or 3.9.4), add nested states to import and export states using NUOPC\_AddNestedState. Each nested state is given a couple set identifier using the CplSet argument, see 3.9.2. The nested states can then be used to advertise and realize fields. Each nested state may contain fields with identical standard names or unique standard names. Fields in each nested state will only connect to fields in another state if that state has an identical couple set identifier.

For a complete example of how to couple sets using the NUOPC API, see https://github.com/esmf-org/nuopc-app-prototypes/tree/develop/AtmOcnCplSetProto. The following code snippets demonstrates the critical pieces of code used to add a nested state with a couple set identifier.

```
subroutine Advertise (model, rc)
  type (ESMF_GridComp) :: model
  integer, intent(out) :: rc
  ! local variables
  type(ESMF_State) :: importState, exportState
  type(ESMF_State) :: NStateImp1, NStateImp2
  type (ESMF_State) :: NStateExp1, NStateExp2
  rc = ESMF SUCCESS
  ! query model for importState and exportState
  call NUOPC_ModelGet(model, importState=importState, &
    exportState=exportState, rc=rc)
  ! check rc
  ! add nested import states with couple set identifier
 call NUOPC_AddNestedState(importState, &
    CplSet="Nest1", nestedStateName="NestedStateImp_N1", &
   nestedState=NStateImp1, rc=rc)
  ! check rc
```

```
call NUOPC_AddNestedState(importState, &
   CplSet="Nest2", nestedStateName="NestedStateImp_N2", &
   nestedState=NStateImp2, rc=rc)
  ! check rc
  ! add nested export states with couple set identifier
 call NUOPC_AddNestedState(exportState, &
   CplSet="Nest1", nestedStateName="NestedStateExp_N1", &
   nestedState=NStateExp1, rc=rc)
  ! check rc
  call NUOPC_AddNestedState(exportState, &
    CplSet="Nest2", nestedStateName="NestedStateExp_N2", &
   nestedState=NStateExp2, rc=rc)
  ! check rc
  ! importable field: sea surface temperature
 call NUOPC_Advertise(NStateImp1, &
    StandardName="sea_surface_temperature", name="sst", rc=rc)
  ! check rc
  call NUOPC_Advertise(NStateImp2, &
   StandardName="sea_surface_temperature", name="sst", rc=rc)
  ! check rc
  ! exportable field: air_pressure_at_sea_level
  call NUOPC_Advertise(NStateExp1, &
   StandardName="air_pressure_at_sea_level", name="pmsl", rc=rc)
  ! check rc
  call NUOPC Advertise (NStateExp2, &
   StandardName="air_pressure_at_sea_level", name="pmsl", rc=rc)
  ! check rc
  ! exportable field: surface_net_downward_shortwave_flux
 call NUOPC Advertise (NStateExpl, &
   StandardName="surface_net_downward_shortwave_flux", name="rsns", rc=rc)
  ! check rc
 call NUOPC_Advertise(NStateExp2, &
    StandardName="surface_net_downward_shortwave_flux", name="rsns", rc=rc)
  ! check rc
end subroutine
```

#### 2.4.5 Connection Options

Once the field pairing discussed in the previous sections is completed, each Connector component holds an attribute by the name of CplList. The CplList is a list type attribute with as many entries as there are fields for which the Connector component is responsible for connecting. The first part of each of these entries is always the StandardName of the associated field. See section 2.2 for a discussion of the NUOPC field dictionary and standard names.

After the StandardName part, each CplList entry may optionally contain a string of *connection options*. Each Driver component has the chance as part of the label\_ModifyInitializePhaseMap specialization, to modify

the CplList attribute of all the Connectors that it drives.

The individual connection options are colon separated, leading to the following format for each CplList entry:

```
StandardName[:option1[:option2[: ...]]
```

The format of the options is:

```
OptionName=value1[=spec1][,value2[=spec2][, ...]]
```

OptionName and the value strings are case insensitive. There are single and multi-valued options as indicated in the table below. For single valued options only <code>value1</code> is relevant. If the same option is listed multiple times, only the first occurrence will be used. If an option has a default value, it is indicated in the table. If a value requires additional specification via <code>=spec</code> then the specifications are listed in the table.

OptionName	Definition	Type	Values
dstMaskValues	List of integer values that defines the mask values.	multi	List of integers.
dumpWeights	Enable or disable dumping of the interpolation weights into a file.	single	true, false(default)
extrapDistExponent	The exponent to raise the distance to when calculating weights for the nearest_idavg extrapolation method.	single	real(default 2.0)
extrapMethod	Fill in points not mapped by the regrid method.	single	none(default), nearest_idavg, nearest_stod, creep, creep_nrst_d
extrapNumLevels	The number of levels to output for the extrapolation methods that fill levels. When a method is used that requires this, then an error will be returned, if it is not specified.	single	integer
extrapNumSrcPnts	The number of source points to use for the extrapolation methods that use more than one source point.	single	integer(default 8)
ignoreDegenerate	Ignore degenerate cells when checking the input Grids or Meshes for errors.	single	true, false(default)
ignoreUnmatchedIndices	Ignore unmatched sequence indices when redistributing between source and destination index space.	single	true, false(default)
pipelineDepth	Maximum number of outstanding non-blocking communication calls during the parallel interpolation. Only relevant for cases where the automatic tuning procedure fails to find a setting that works well on a given hardware.	single	integer

poleMethod	Extrapolation method around the	single	none(default),
	pole(s).		allavg,
			npntavg="integer
			indicating number of
			points", teeth
remapMethod	Redistribution or interpolation to	single	redist,
	compute the regridding weights.		bilinear(default),
			patch,
			nearest_stod,
			nearest_dtos,
			conserve
srcMaskValues	List of integer values that defines	multi	List of integers.
	the mask values.		
srcTermProcessing	Number of terms in each partial	single	integer
	sum of the interpolation to process		
	on the source side. This setting im-		
	pacts the bit-for-bit reproducibility		
	of the parallel interpolation results		
	between runs. The strictest bit-for-		
	bit setting is achieved by setting the		
	value to 1.		
termOrder	Order of the terms in each par-	single	free(default),
	tial sum of the interpolation. This		srcseq, srcpet
	setting impacts the bit-for-bit re-		
	producibility of the parallel in-		
	terpolation results between runs.		
	The strictest bit-for-bit setting is		
	achieved by setting the value to		
	srcseq.		
unmappedAction	The action to take when unmapped	single	ignore(default),
	destination elements are encoun-		error
	tered.		
zeroRegion	The region of destination elements	single	total(default),
	set to zero before adding the result		select, empty
	of the sparse matrix multiplication.		
	The available options support total,		
	selective, or no zeroing of destina-		
	tion elements.		

### 2.4.6 Data-Dependencies during Initialize

For multi-model applications it is not uncommon that during start-up one or more components depends on data from one or more other components. These types of data-dependencies during initialize can become very complex very quickly. Finding the "correct" sequence to initialize all components for a complex dependency graph is not trivial. The NUOPC Layer deals with this issue by repeatedly looping over all components that indicate that their initialization has data dependencies on other components. The loop is finally exited when either all components have indicated completion of their initialization, or a dead-lock situation is being detected by the NUOPC Layer.

The data-dependency resolution loop considers all components that have specialized label\_DataInitialize.

Participating components communicate their current status to the NUOPC Layer via Field and Component metadata. Every time a component's label\_DataInitialize specialization routine is called, it is responsible for checking the Fields in the importState and for initializing any internal data structures and Fields in the exportState. Fields that are fully initialized in the exportState must be indicated by setting their Updated Attribute to "true". This is used by the NUOPC Layer to ensure that there is continued progress during the resolution loop iterations. Once the component is fully initialized it must further set its InitializeDataComplete Attribute to "true" before returning.

During the execution of the data-dependency resolution loop the NUOPC Layer calls all of the Connectors to a Model/Mediator component before calling the component's label\_DataInitialize. Doing so ensures that all the currently available Fields are passed to the component before it tries to access them. Once a component has set its InitializeDataComplete Attribute to "true", it, and the Connectors to it, will no longer be called during the remainder of the resolution loop.

When *all* of the components that participate in the data-dependency resolution loop have set their InitializeDataComplete Attribute to "true", the NUOPC Layer successfully exits the data-dependency resolution loop. The loop is also interrupted before all InitializeDataComplete Attributes are set to "true" if a full cycle completes without any indicated progress. The NUOPC Layer flags this situation as a potential dead-lock and returns with error.

#### 2.4.7 Transfer of Grid/Mesh/LocStream Objects between Components

There are modeling scenarios where the need arises to transfer physical grid information from one component to another. One common situation is that of modeling systems that utilize Mediator components to implement the interactions between Model components. In these cases the Mediator often carries out computations on a Model's native grid and performs regridding to the grid of other Model components. It is both cumbersome and error prone to recreate the Model grid in the Mediator. To solve this problem, NUOPC implements a transfer protocol for ESMF\_Grid, ESMF\_Mesh, and ESMF\_LocStream objects (generally referred to as GeomObjects) between Model and/or Mediator components during initialization.

The NUOPC Layer transfer protocol for GeomObjects is based on two Field attributes: TransferOfferGeomObject and TransferActionGeomObject. The TransferOfferGeomObject attribute is used by the Model and/or Mediator components to indicate for each Field their intent for the associated GeomObject. The predefined values of this attribute are: "will provide", "can provide", and "cannot provide". The TransferOfferGeomObject attribute must be set during label\_Advertise.

The generic Connector uses the intents from both sides and constructs a response according to the table below. The Connector's response is available during label\_RealizeProvided. It sets the value of the TransferActionGeomObject attribute to either "provide" or "accept" on each Field. Fields indicating TransferActionGeomObject equal to "provide" must be realized on a Grid, Mesh, or LocStream object in the Model/Mediator before returning from label\_RealizeProvided.

Fields that hold "accept" for the value of the TransferActionGeomObject attribute require two additional negotiation steps. During label\_AcceptTransfer the Model/Mediator component can access the transferred Grid/Mesh/LocStream on the Fields that have the "accept" value. However, only the DistGrid, i.e. the decomposition and distribution information of the Grid/Mesh/LocStream is available at this stage, not the full physical grid information such as the coordinates. At this stage the Model/Mediator may modify this information by replacing the DistGrid object in the Grid/Mesh/LocStream. The DistGrid that is set on the Grid/Mesh/LocStream objects when leaving the Model/Mediator phase label\_AcceptTransfer will consequently be used by the generic Connector to fully transfer the Grid/Mesh/LocStream object. The fully transferred objects are available on the Fields with "accept" during Model/Mediator phase label\_RealizeAccepted, where they are used to realize the respective Field objects. At this point all Field objects are fully realized and the initialization process can proceed as usual.

The following table shows how the generic Connector sets the TransferActionGeomObject attribute on the

Fields according to the incoming value of TransferOfferGeomObject.

TransferOfferGeomObject TransferOfferGeomObject Outgoing setting by generic Connector		
Incoming side A	Incoming side B	
"will provide"	"will provide"	A:TransferActionGeomObject="provide"
		B:TransferActionGeomObject="provide"
"will provide"	"can provide"	A:TransferActionGeomObject="provide"
		B:TransferActionGeomObject="accept"
"will provide"	"cannot provide"	A:TransferActionGeomObject="provide"
		B:TransferActionGeomObject="accept"
"can provide"	"will provide"	A:TransferActionGeomObject="accept"
		B:TransferActionGeomObject="provide"
"can provide"	"can provide"	if (A is import side) then
		A:TransferActionGeomObject="provide"
		B:TransferActionGeomObject="accept"
		if (B is import side) then
		A:TransferActionGeomObject="accept"
		B:TransferActionGeomObject="provide"
"can provide"	"cannot provide"	A:TransferActionGeomObject="provide"
		B:TransferActionGeomObject="accept"
"cannot provide"	"will provide"	A:TransferActionGeomObject="accept"
		B:TransferActionGeomObject="provide"
"cannot provide"	"can provide"	A:TransferActionGeomObject="accept"
		B:TransferActionGeomObject="provide"
"cannot provide"	"cannot provide"	Flagged as error!

### 2.4.8 Field and Grid/Mesh/LocStream Reference Sharing

For coupling scenarios with a very high coupling frequency, or for situations where large data volumes are exchanged (e.g. 3D volumetric fields), it can be necessary for fields and geom objects (Grid, Mesh, and LocStreams) to share their data via references. Reference sharing greatly reduces the coupling cost compared to local or remote copies.

In the current implementation, in order for NUOPC components to be coupled via reference sharing, they must only have data defined (i.e. have DEs) on PETs that are part of both components. Further, the distribution of data across the PETs must be identical for both components. If these conditions are met, and both sides of the connection indicate that they are willing to participate in reference sharing, the NUOPC Connector will handle technical details. The Connector will provide fields to the components that reference the exact same data allocations in memory. Notice however that once reference sharing is active, the NUOPC Layer cannot protect against components violating the data access conventions. Specifically fields in the importState are not to be modified by the component. Reference sharing requires a higher level of "trust" between the components. NUOPC therefore requires that both sides of a connection agree to reference sharing.

A component uses the SharePolicyField and SharePolicyGeomObject attributes on each field to indicate whether it is willing to reference share the data of a field, and/or the geom object on which the field is built. A setting of share indicates a component's willingness to share, while not share indicates the opposite. The share policy attributes are automatically set when a field is advertised via the NUOPC\_Advertise() method. By default this method sets both share policies to not share.

When a Connector negotiates the connections between two components, it first considers the transfer offer attributes (i.e. TransferOfferGeomObject) on both sides for each field to determine the TransferActionGeomObject attribute for both side. The details of this protocol are outline in section 2.4.7.

There are two cases to consider for each field that are relevant for reference sharing:

The simple case is where the Connector determines that for a specific field both sides must provide the field and geom object. This is indicated by TransferActionGeomObject being set to provide on both sides. For this case the ShareStatusField and ShareStatusGeomObject attributes are automatically set to not shared for all the fields, preventing any reference sharing.

The more interesting case is where one side of the connection receives the TransferActionGeomObject on a field set to provide, while the other side receives accept. In this case, the next step is for the Connector to take the SharePolicyField and SharePolicyGeomObject attributes on both sides into consideration. For each of the two attributes separately, if one side indicates not share, both sides will receive the associated ShareStatus set to not shared. However, if both sides of the connection indicate a SharePolicy of share, the Connector must further inspect the petLists to see if reference sharing is possible for the specific field. Under the current implementation a field is sharable with another component if all the PETs on which the field holds DEs are also in the other component's petList. If this condition is not met for the specific field, then the associated ShareStatus is set to not shared. Otherwise the ShareStatus is set to shared

During later phases of the Initialization protocol the Connector performs different operations, depending on how the TransferActionGeomObject, ShareStatusField, and ShareStatusGeomObject attributes were set as per the above protocol:

- For a field that has ShareStatusGeomObject equal to share, the geom object provided by the provider component will be made available to the acceptor component.
- For a field that has ShareStatusField equal to share, the Connector realizes the field for the acceptor component using the data allocation reference provided by the field of the provider component.

## 2.4.9 Field Mirroring

In some cases it is helpful for a NUOPC component to automatically mirror or match the set of fields advertised by another component. One purpose of this is to automatically resolve the import data dependencies of a component, by setting up a component that exactly provides all of the needed fields. This is currently used in the NUOPC Component Explorer: when driving a child NUOPC Model with required import fields, the Component Explorer uses the field mirroring capability to advertise in the driver-self export State the exact set of fields advertised in the child NUOPC Model. This ensures that the entire Initialize Phase Sequence will complete (because all dependencies are satisfied) and all phases can be exercised by the Component Explorer.

The field mirror capability is also useful with NUOPC Mediators since these components often exactly reflect, in separate States, the sets of fields of each of the connected components. The field mirroring capability, therefore, can be used to ensure that a Mediator is always capable of accepting fields from connected components, and removes the need to specify field lists in multiple places, i.e., both within a set of Model components connected to a Mediator and within the Mediator itself.

To access the field mirror capability, a component sets the FieldTransferPolicy attribute during label\_Advertise. The attribute is set on the Import- and/or Export- States to trigger field mirroring for each state, respectively. The default value of "TransferNone" indicates that no fields should be mirrored. The other option, "TransferAll", indicates that fields should be mirrored in the State of a connected component.

Each Connector consider the FieldTransferPolicy Attribute on both its import and export States. If both States have a FieldTransferPolicy of "TransferAll", then fields are transferred between the States in both directions (i.e., import to export and export to import). The transfer process works as follows: First, the TransferOfferGoemObject attribute is reversed between the providing side and accepting side. Intuitively, if a field from the providing component is to be mirrored and it can provide its own geometric object, then the mir-

rored field on the accepting side should be set to accept a geometric object. Then, the field to be mirrored is advertised in the accepting State using a call to NUOPC\_Advertise() such that the mirrored field shares the same Standard Name.

Components have the opportunity, using specialiozation point label\_ModifyAdvertised, to modify any of the mirrored Fields in their Import/ExportState. After this the initialization sequence continues as usual. Since fields to be mirrored have been advertised with matching Standard Names, the field pairing algorithm will now match them in the usual way thereby establishing a connection between the original and mirrored fields.

## 2.5 Timekeeping

The NUOPC Layer associates an internal clock with three of its four generic component kinds: NUOPC\_Driver, NUOPC\_Model, and NUOPC\_Mediator. The NUOPC\_Connector is the only NUOPC component kind that does not have an internal clock object that is managed by NUOPC.

The component internal clocks are implemented as ESMF\_Clock objects. The interaction between these clock objects between a parent component (driver) and its child components (models, mediators, and drivers) is defined by the NUOPC timekeeping behavior described below.

For a simple run sequence with only a single coupling time-step, the driver clock sets the startTime, stopTime, and timeStep to be the beginning, the end, and the coupling period of the run, respectively. At the beginning of executing the run sequence, the driver clock currTime is set to its startTime. As the driver component executes the run sequence, it passes its clock to each child component that it executes. At the end of each full sweep through the run sequence the driver currTime is incremented by timeStep (i.e. the coupling period). This continues until the driver clock stopTime has been reached, and the run is complete.

When a child component is being called during the execution of the driver run sequence, it receives the driver/parent clock. This access is read-only, and the child component is only allowed to inspect but not modify the parent clock. The child component is expected to run forward a single coupling period, i.e. one timeStep on the parent clock. Specifically this means that the currTime on the child clock must match the currTime on the parent clock. It then must take a single timeStep of the parent clock forward, using its own clock to do so. The child component can implement this forward step by taking multiple smaller advances on its own clock.

The generic NUOPC component implementation provides the following assistance to implement the above described behavior:

- During initialization of a component, its clock is set as a copy of its parent clock. Specifically the settings for startTime, stopTime, timeStep, and currTime are propagated. Alarms are not propagated.
- A component can customize aspects of its clock during initialization by using the label\_SetClock specialization point.
- During run time, the default label\_SetRunClock specialization checks that the currTime matches between child and parent clock. It further checks that the child clock can reach the parent's currTime+timeStep, i.e. the next coupling time, by an integral number of it's own time steps. If so, the stopTime on the child clock is set to the parent's currTime+timeStep.
  - It can be useful to customize label\_SetRunClock, e.g. if the parent uses dynamic coupling periods, or in case of a run sequence with multiple coupling periods. In these cases the component must react to the parent timeStep provided during execution of the run sequence. In general the currTime match should be implemented, followed by setting the child's timeStep according to the information provided on the parent clock. Finally the the stopTime on the child clock should be set as to return at the next coupling time determined by the parent clock.

- Once past the label\_SetRunClock specialization, the component checks the timestamps on the fields in the import state. This is done by calling into the label\_CheckImport specialization point. The default implementation simply checks that all import fields are at currTime of the child clock.
  - In more complex situations, where the interaction between different components happens with different coupling periods, it can be necessary to specialialize the label\_CheckImport of a component. For example, a component might receive fields in its import state that carry different timestamps. Consequentely, label\_CheckImport must implement a more complex relationship between the component's currTime, and the timestamps on each import field.
- Finally the component clock is stepped forward from currTime to stopTime, using the timeStep interval set in the child clock. During this loop, the label\_Advance specialization is called for each time step. The label Advance specialization is responsible for any accumulating and averaging that may be necessary.
  - In practice often the timeStep on the child clock is chosen to be identical to that of the parent clock. This way the label\_Advance specialization is only called once for every coupling period. In this approach the details about potentially smaller model time steps, and associated accumulation and averaging is handled below the NUOPC cap layer of a model.
- After the stopTime has been reached on the child clock, the label\_TimestampExport specialization point is called before the component returns to the parent. The default implementation simply timestamps all the fields in the export state with the currTime of of the child clock.

### 2.6 Component Hierarchies

The NUOPC Layer supports component hierarchies. The key function to support this capability is the ability for a generic NUOPC\_Driver to add another NUOPC\_Driver component as a child, and to drive it much like a NUOPC\_Model component. The interactions upward and downward the hierarchy tree are governed by the standard NUOPC component interaction protocols.

In the current implementation, data-dependencies during initialization can be resolved throughout the entire component hierarchy. The implementation is based on a sweep algorithm that continues up and down the hierarchy until either all data-dependencies have been resolved, or a dead-lock situation has been detected and flagged.

Along the downward direction, the interaction of a driver with its children allows the driver to mirror its child components' fields, and to transfer or share geom objects and fields up the component hierarchy. All of the interactions of a driver with its child components are handled by explicit NUOPC\_Connector instances. These instances are automatically added by the driver when needed.

The detailed behavior of a NUOPC\_Driver component within a component hierarchy depends on the setting of the HierarchyProtocol attribute on the driver component itself. Section 2.3.1 lists all of the driver attributes defined by NUOPC. By default the HierarchyProtocol attribute is unset. For unset HierarchyProtocol or when set to PushUpAllExportsAndUnsatisfiedImports, the driver component pushes all the fields from its children exportStates into its own exportState, and all unsatisfied fields in its children importStates into its own importState. This is done using the standard Field Mirroring protocol discussed under 2.4.9. Further the driver sets the SharePolicyGeomObject, and SharePolicyField to share for all the fields it mirrors. This triggers the reference share protocol as described in section 2.4.8.

When the HierarchyProtocol is set to Explorer, the driver component still mirrors the fields from its child components' import- and exportStates, as was done for the default, however, the share policies will not be set. This protocol option is used by the NUOPC ComponentExplorer to connect to user provided components.

Finally, for a setting of HierarchyProtocol to ConnectProvidedFields, the driver does not modify its own import- and exportState. Instead connections are made only between fields that have been added to the driver

states externally. This is useful for the situation where a NUOPC\_Driver component is called directly via ESMF component method from a level that is outside of NUOPC. In this situation, field and/or geom object sharing must be activated explicitly if desired.

## 2.7 Resource Control and Threaded Components

Each instance of a NUOPC component within an application is defined on a fixed set of compute resources. The association of resources occurs when the component is added to its parent component via the NUOPC\_DriverAddComp() call. Subsequently when any of the component's Initialize, Run, or Finalize phases is called, the component code executes on the associated resources.

The primary control of resource management under NUOPC is implemented through the petList argument that is accepted by NUOPC\_DriverAddComp(). This argument holds a list of Persistent Execution Thread (PET) ids of the parent component on which the child component is to execute. By default, i.e. when petList is *not* specified, *all* of the parent PETs are associated with the added child component. Using custom petList constructions, a driver has control of exactly how its child components are sharing the available PET resources.

Notice that the *order* of PETs listed in a petList is significant. The local PET labeling inside a child component always goes from 0 to size (petList) -1. The order in which the child PETs correspond to the parent PETs is that specified by the petList. It is erroneous to list the same parent PET multiple times in the *same* petList argument.

For the following discussion it is convenient to think of PETs as simple MPI processes. While this is not strictly correct on a technically ESMF level, there are currently no features available to NUOPC where this interpretation would lead to inconsistencies. One of the key consequences of equating each PET to a simple MPI process is that each PET can only execute a single component's code at any given time. Therefore, in order to allow components to execute concurrently, a necessary condition is to define them on exclusive petLists. Of course the data dependencies between components must also support concurrent execution. Often this requires careful placement of Connectors in the run sequence and the introduction of time lags. However, this is more of a scientific than the resource control question covered in this section.

Many model components today implement the hybrid MPI+OpenMP paradigm to support scalability to larger core counts than would be possible in a purely MPI or OpenMP approach. NUOPC supports hybrid MPI+OpenMP components in two ways: NUOPC aware and NUOPC unaware. In the NUOPC unaware approach, the application is launched only on those MPI ranks that are going to participate in the hybrid execution with OpenMP. Usually this means that the MPI launch system (mpirun, mpiexec, aprun, srun, etc.), and a set of environment variables get involved in correctly associating the desired number of hardware cores with each MPI process, and to assure correct affinities. In this approach NUOPC is not at all involved in the resource management, and OpenMP threading happens purely on the user level.

The NUOPC *unaware* hybrid MPI+OpenMP approach provides a quick way to run hybrid applications that consist of a single model component, or where all of the model components use the same hybrid approach with the same ratio of OpenMP threads per MPI rank. In this case, shell-based user level resource control is often sufficient. However, for more complex coupling scenarios the NUOPC *aware* hybrid approach provides additional levels of control that are often needed to achieve optimal utilization of the available resources

Under the NUOPC *aware* resource control, some components might be purely MPI based, while others use the hybrid approach. Different hybrid components can be configured to run with different threading levels. This is possible independent on whether the components use the same or exclusive sets of resources.

Besides the already discussed petList argument, there are two additional optional arguments to NUOPC\_DriverAddComp(). It is through those arguments that the advanced resource control features under NUOPC are implemented. One of these arguments is compSetVMRoutine. This argument allows the user to point to a specific public method of the child component. The signature of this method is the same as for

the compSetServicesRoutine argument. If compSetVMRoutine is provided, it will be called before compSetServicesRoutine. The purpose of compSetVMRoutine is to allow the child component to set specific aspects of its own ESMF virtual machine (VM) before instantiating it. The ESMF reference manual discusses the details of this procedure under the "User-code SetVM method" section. Based on the information provided there, a user could implement a custom compSetVMRoutine method for a component. However, for convenience, NUOPC provides a generic implementation that can be passed into compSetVMRoutine. For most common situation, the generic implementation provided by NUOPC is sufficient, and there is no need for the user to provide a custom implementation of compSetVMRoutine.

Utilizing the generic SetVM method provided by NUOPC involves a few steps. First, the component implementation must make the generic SetVM *public* inside its own *cap* module:

module MODEL

contains

end module

```
!-----
! MODEL Component.
!------
use ESMF
use NUOPC
use NUOPC_Model, &
  modelSS => SetServices

implicit none
private

public SetVM, SetServices ! Here making SetVM and SetServices public.
```

Second, the driver component that adds MODEL via NUOPC\_DriverAddComp() as a child component, must make a USE association to the SetVM:

```
!-----
! Code that specializes generic NUOPC_Driver
!-----
use MPI
use ESMF
use NUOPC
use NUOPC
use NUOPC_Driver, &
    driverSS => SetServices
```

```
modelSS => SetServices, &
  modelSVM => SetVM ! Here making USE association to SetVM.

implicit none

private

public SetServices
!------
contains
!-------
end module
```

Third, the driver can now pass the modelSVM into NUOPC\_DriverAddComp() via the compSetVMRoutine argument, essentially providing the generic SetVM method.

Finally, the generic SetVM implementation needs to be informed about the specific resource control request. This is handled through *the other* optional argument to NUOPC\_DriverAddComp() alluded to earlier. This is the info argument.

The info argument is of type (ESMF\_Info), which implements a structured key/value pair class. An info object must first be created via ESMF\_InfoCreate() before any key/value pairs can be set.

```
type(ESMF_Info) :: info
...
info = ESMF_InfoCreate(rc=rc)
! check rc
```

NUOPC resource control is implemented under the /NUOPC/Hint/PePerPet *structure*. The following table documents the available *keys* under this structure, the supported *values*, and their meaning. Notice that *structure* and *keys* are case sensitive, while *values* are case insensitive.

key	value	Meaning

MaxCount	Positive integer	The maximum number of Processing Elements (PEs), i.e. cores or hardware threads, associated with each child PET. The procedure is this: the PEs associated with the incoming parent PETs (e.g. via petList), are grouped by single system image (SSI), i.e. shared memory domain or hardware node. Within each SSI the PEs are divided by the MaxCount to determine how many child PETs are needed for each SSI. The PEs on each SSI are then associated with the child PETs.  Note that this procedure only then results in every child PET holding exactly MaxCount PEs when the number of PEs per SSI brought in by the parent PETs is a multiple of MaxCount.  Parent PETs that for the child VM gave up their PEs, and are not executing as child PETs, are paused for the duration of the child component execution. They resume execution under the parent VM once the child component returns control to the parent.
OpenMpHandling	String: none, set, init, or pin (the default)	For "none", OpenMP handling is completely left to the user. In this case the user child component code will typically want to query the child VM for the local number of PEs under each child PET. This number then would be used in an explicit call to omp_set_num_threads() in order to set the OpenMP thread number according to the available PEs under each child PET.  For "set", the NUOPC/ESMF layer make the call to omp_set_num_threads() under each child PET with the appropriate number of PEs.  For "init", the NUOPC/ESMF layers sets the number of OpenMP threads in each team, and triggers the instantiation of all the threads in the team.  For "pin", the NUOPC/ESMF layers sets the number of OpenMP threads in each team, triggers the instantiation of the team, and pins each OpenMP thread to the corresponding PE.
OpenMpNumThreads	Positive integer	By default the "set", "init", or "pin" option under OpenMpHandling sets the number of OpenMP threads in each team equal to the number of PEs under each PET. Setting OpenMpNumThreads, this default can be overwritten. The option allows the user to under- or oversubscribe the PEs held by each PET.
ForceChildPthreads	Logical: .true., or .false. (the default)	By default (.false.) each PET executes under the same thread as its parent PET. Typically this means that PETs execute directly as the MPI process under which they were created. In some cases it is beneficial to create a separate Pthread for each child PET. This can be accomplished by setting the value to .true

PthreadMinStackSize	Positive integer	The minimum stack size in <i>byte</i> of each child PET that
		is executing as Pthread. By default child PETs do not
		execute as Pthreads. Therefore the stack size by de-
		fault is equal to that of the parent PET. However, if
		ForceChildPthreads is set to true, all child PETs
		are instantiated as Pthreads. This means that the stack
		size cannot be unlimited. ESMF implements a default
		minimum stack size for child PETs of 20MiB. This min-
		imum default can be changed (up or down) via the
		PthreadMinStackSize key.
		The system limit or ulimit commands can be
		used to further <i>increase</i> the stack size of child PETs.
		Any limit set lower than the PthreadMinStackSize,
		or set to unlimited, will result in usage of the
		PthreadMinStackSize if set, or the 20MiB default.
		Note further that when OpenMP is used inside the
		child component, each child PET becomes the root
		thread of each of the OpenMP thread teams. It is
		therefore the root thread stack size that is affected by
		PthreadMinStackSize. The stack size of all the other
		OpenMP threads in each team is set via environment vari-
		able OMP_STACKSIZE as usual.

The following code snippet demonstrates a typical resource control request using the generic SetVM routine and an info object. This request is suitable for a hybrid MPI+OpenMP component where every child PET is expected to run 4-way OpenMP threaded.

```
call ESMF_InfoSet(info, key="/NUOPC/Hint/PePerPet/MaxCount", value=4, rc=rc)
! check rc
call NUOPC_DriverAddComp(driver, "MODEL1", modelSS, modelSVM, info=info, rc=rc)
! check rc
```

A second child component can be created that uses the same parent resources as the first, but sets up 8-way OpenMP threading under each child PET.

```
call ESMF_InfoSet(info, key="/NUOPC/Hint/PePerPet/MaxCount", value=8, rc=rc)
! check rc
call NUOPC_DriverAddComp(driver, "MODEL2", modelSS, modelSVM, info=info, rc=rc)
! check rc
```

If the default settings for some of the keys are not appropriate, they can be set explicitly. Here for instance a child component with the same number of PETs as the previous 4-way OpenMP threaded case is created, but is instructed to not handle any of the OpenMP aspects.

```
call ESMF_InfoSet(info, key="/NUOPC/Hint/PePerPet/MaxCount", value=4, rc=rc)
! check rc
call ESMF_InfoSet(info, key="/NUOPC/Hint/PePerPet/OpenMpHandling", &
   value="none", rc=rc)
```

```
! check rc
call NUOPC_DriverAddComp(driver, "MODEL3", modelSS, modelSVM, info=info, rc=rc)
! check rc
```

In this example, all three child components "MODEL1", "MODEL2", and "MODEL3" use the exact same parent resources. Due to this fact all three components can only execute sequentially. However, each child component manages the resources provided by the parent differently, and independently. Through this tailored approach, NUOPC allows optimal use of the available resources by each component. NUOPC\_Connector components defined between components work as usual, taking care of all the required data movements automatically and completely transparent to the user.

In order to obtain best performance when using NUOPC *aware* resource control for hybrid parallelism, it is *strongly recommended* to set OMP\_WAIT\_POLICY=PASSIVE in the environment. This is one of the standard OpenMP environment variables. The PASSIVE setting ensures that OpenMP threads relinquish the hardware threads (i.e. cores) as soon as they have completed their work. Without that setting ESMF resource control threads can be delayed, and context switching between components becomes more expensive.

### 2.8 External NUOPC Interface

Complete applications can easily be built by assembling NUOPC compliant components. Many such NUOPC applications are in productive use across several institutions. The top level of such applications is typically implemented via a very thin application layer holding the main program that calls into the top level driver component that derives from NUOPC\_Driver. Model components sit under the top level driver, interacting with one another and the driver through the NUOPC protocols. Complex systems have one or more component hierarchy levels under the top level driver as discussed in the previous section.

There are situation, however, where a NUOPC application needs to be controlled by an outside component. Such an outside component does not derive from any of the generic NUOPC components, and cannot be expected to implement the complete NUOPC protocol. Typically such an external component implements its own control structure outside of NUOPC and ESMF. One example of such a situation are data assimilation systems that want to drive a NUOPC forecast application.

In order to facilitate the external access into a NUOPC application, the NUOPC\_Driver provides an *external interface*. This interface is implemented through the standard ESMF component methods: Initialize, Run, and Finalize. This interface with the top level NUOPC driver allows an external component to control and interact with the entire NUOPC application.

The standard ESMF component interfaces hold importState, exportState, and a clock argument. These arguments are used to pass data in and out of the NUOPC application, and control the time stepping of the NUOPC model, respectively. The top level driver of a NUOPC application has access to any field that is advertised by any of the components and therefore serves as a single point of access for the entire application.

The external NUOPC interface is currently defined by the Initialize, Run, and Finalize phases documented in the following table.

methodFlag	phaseLabel	Meaning
ESMF_METHOD_INITIALIZE	label_ExternalAdvertise	Called after the external component has set up the import-
		and exportStates with fields (advertised) that it plans to in-
		teract with. On the NUOPC application side this call will
		got through the complete advertise cylce.

ESMF_METHOD_INITIALIZE	label_ExternalRealize	Called after the external component has been informed
		about the connected status of the fields in the import- and
		exportState. On the NUOPC application side this call will
		finish setting up RouteHandles between all components in-
		volved.
ESMF_METHOD_INITIALIZE	label_ExternalDataInit	Trigger a complete data initialize throughout the NUOPC
		application. The expectation is that all components reset
		their data consistent with the clock argument.
ESMF_METHOD_RUN		The default Run() method steps the NUOPC application
		forward in time according to the clock argument.
ESMF_METHOD_FINALIZE	label_ExternalReset	Inform the NUOPC application about a clock reset.
ESMF_METHOD_FINALIZE		Completely finalize and shut down the NUOPC applica-
		tion.

Here <code>methodFlag</code> and <code>phaseLabel</code> correspond to the respective arguments of method <code>NUOPC\_CompSearchPhaseMap()</code>. This method is used to determine the actual ESMF phase index needed when calling into <code>ESMF\_GridCompInitialize()</code>, <code>ESMF\_GridCompRun()</code>, or <code>ESMF\_GridCompFinalize()</code>. In cases where no <code>phaseLabel</code> is indicated, the default phase is used for the implementation, accessible by not specifying the argument.

For a complete example of how the *External NUOPC API* is used in practice, see https://github.com/esmf-org/nuopc-app-prototypes/tree/develop/ExternalDriverAPIProto. The following code snippets demonstrates the critical pieces of code from the external layer interacting with NUOPC/ESMF.

```
! Create the external level import/export States
! NOTE: The "stateintent" must be specified, and it must be set from the
! perspective of the external level:
! -> state holding fields exported by the external level to the ESM component
externalExportState = ESMF_StateCreate(stateintent=ESMF_STATEINTENT_EXPORT, rc=rc)
  ! check rc
! -> state holding fields imported by the external level from the ESM component
externalImportState = ESMF_StateCreate(stateintent=ESMF_STATEINTENT_IMPORT, rc=rc)
  ! check rc
! Advertise field(s) in external import state to receive from the NUOPC layer
call NUOPC_Advertise(externalImportState, &
  StandardNames=(/"sea surface temperature"/), &
  TransferOfferGeomObject="cannot provide", SharePolicyField="share", rc=rc)
  ! check rc
! Call "ExternalAdvertise" Initialize for the earth system Component
call NUOPC_CompSearchPhaseMap(nuopcApp, methodflag=ESMF_METHOD_INITIALIZE, &
 phaseLabel=label ExternalAdvertise, phaseIndex=phase, rc=rc)
  ! check rc
call ESMF_GridCompInitialize(nuopcApp, phase=phase, clock=clock, &
  importState=externalExportState, exportState=externalImportState, userRc=urc, rc=rc)
  ! check rc and urc
! Call "ExternalRealize" Initialize for the earth system Component
```

```
call NUOPC_CompSearchPhaseMap(nuopcApp, methodflag=ESMF_METHOD_INITIALIZE, &
 phaseLabel=label_ExternalRealize, phaseIndex=phase, rc=rc)
  ! check rc
call ESMF_GridCompInitialize(nuopcApp, phase=phase, clock=clock, &
  importState=externalExportState, exportState=externalImportState, userRc=urc, rc=rc)
  ! check rc and urc
! Call "ExternalDataInit" Initialize for the earth system Component
call NUOPC_CompSearchPhaseMap(nuopcApp, methodflag=ESMF_METHOD_INITIALIZE, &
 phaseLabel=label_ExternalDataInit, phaseIndex=phase, rc=rc)
  ! check rc
call ESMF_GridCompInitialize(nuopcApp, phase=phase, clock=clock, &
  importState=externalExportState, exportState=externalImportState, userRc=urc, rc=rc)
  ! check rc and urc
! Explicit time stepping loop on the external level, here based on ESMF_Clock
do while (.not.ESMF_ClockIsStopTime(clock, rc=rc))
  ! Run the earth system Component: i.e. step ESM forward by timestep
 call ESMF_GridCompRun(nuopcApp, clock=clock, &
    importState=externalExportState, exportState=externalImportState, userRc=urc, rc=rc
  ! check rc and urc
  ! Advance the clock
 call ESMF_ClockAdvance(clock, rc=rc)
  ! check rc
end do
! Finalize the earth system Component
call ESMF_GridCompFinalize(nuopcApp, clock=clock, &
  importState=externalExportState, exportState=externalImportState, userRc=urc, rc=rc)
  ! check rc and urc
```

# 3 API

# 3.1 Generic Component: NUOPC\_Driver

### MODULE:

```
module NUOPC_Driver
```

# **DESCRIPTION:**

Component that drives and coordinates initialization of its child components: Model, Mediator, and Connector components. For every Driver time step the same run sequence, i.e. sequence of Model, Mediator, and Connector Run methods is called. The run sequence is fully customizable. The default run sequence implements explicit time stepping.

### SUPER:

```
ESMF_GridComp
```

### USE DEPENDENCIES:

use ESMF

# SETSERVICES:

```
subroutine SetServices(driver, rc)
type(ESMF_GridComp) :: driver
integer, intent(out) :: rc
```

# SEMANTIC SPECIALIZATION LABELS:

• Initialize:

#### - label SetModelServices

- \* Optional. By default driver has no child components.
- \* Use NUOPC\_DriverAddComp () repeatedly to add child components to the driver.
- $\ast$  Use NUOPC\_CompAttributeSet() or NUOPC\_CompAttributeIngest() to set attributes on child components.
- \* Create and set driver clock with startTime, stopTime, and timeStep, if not done by the driver's parent.

#### - label SetRunSequence

- \* Optional. By default drive child components in the sequence they were added.
- \* Define and set a RunSequence either by calling NUOPC\_DriverIngestRunSequence(), or by using the NUOPC\_DriverNewRunSequence() and NUOPC\_DriverAddRunElement() API.

# label\_ModifyInitializePhaseMap

- \* Optional. By default InitializePhaseMap attributes are not modified.
- \* Modify the InitializePhaseMap attribute on the child components as desired. This is very rarely needed.

# label\_ModifyCplLists

\* Optional. By default CplList attributes are not modified.

\* Modify the CplList attribute on the child components as desired. This can be useful to set custom Connection Options for specific Field pairs.

#### - label PreChildrenAdvertise

- \* Optional.
- \* Allow driver to execute specific code before calling the Advertise phase of its children.

#### - label PostChildrenAdvertise

- \* Optional.
- \* Allow driver to execute specific code after calling the Advertise phase of its children.

#### - label PreChildrenRealize

- \* Optional.
- \* Allow driver to execute specific code before calling the Realize phase of its children.

### - label PostChildrenRealize

- \* Optional.
- \* Allow driver to execute specific code after calling the Realize phase of its children.

## - label PreChildrenDataInitialize

- \* Optional.
- \* Allow driver to execute specific code before calling the DataInitialize phase of its children.

### label\_PostChildrenDataInitialize

- \* Optional.
- \* Allow driver to execute specific code after calling the DataInitialize phase of its children.

## • Run:

### - label SetRunClock

- \* Optional. By default driver clock is not modified each time its Run is entered.
- \* Modify the driver clock before executing RunSequence. This is very rarely needed.

# - label\_ExecuteRunSequence

- \* Optional. By default use NUOPC generic RunSequence execution.
- \* Implement a custom RunSequence execution. This is very rarely needed.

### • Finalize:

# label\_Finalize

- \* Optional. By default do nothing.
- \* Destroy any objects created during Initalize.

# 3.1.1 NUOPC\_DriverAddComp - Add a GridComp child to a Driver

### INTERFACE:

```
! Private name; call using NUOPC_DriverAddComp()
recursive subroutine NUOPC_DriverAddGridComp(driver, compLabel, &
   compSetServicesRoutine, compSetVMRoutine, petList, info, config, comp, rc)
```

```
type(ESMF_GridComp)
                                        :: driver
character(len=*), intent(in)
                                        :: compLabel
interface
  recursive subroutine compSetServicesRoutine(gridcomp, rc)
   use ESMF
   implicit none
   end subroutine
end interface
interface
  recursive subroutine compSetVMRoutine(gridcomp, rc)
   use ESMF
    implicit none
   end subroutine
end interface
optional
                                         :: compSetVMRoutine
integer, intent(in), optional :: petList(:)
type(ESMF_Info), intent(in), optional :: info
type(ESMF_Config), intent(in), optional :: config
type(ESMF_GridComp), intent(out), optional :: comp
integer,
                   intent(out), optional :: rc
```

Create and add a GridComp (i.e. Model, Mediator, or Driver) as a child component to a Driver. The component is created on the provided petList, or by default across all of the Driver PETs.

The specified <code>compSetServicesRoutine()</code> is called back immediately after the new child component has been created internally. Very little around the component is set up at that time (e.g. NUOPC component attributes will not be available). The routine should therefore be very light weight, with the sole purpose of setting the entry points of the component – typically by deriving from a generic component followed by the appropriate specilizations.

If provided, the <code>compSetVMRoutine()</code> is called back before the <code>compSetServicesRoutine()</code>. This allows the child component to set aspects of its own VM, such as threading or the PE distribution among PETs.

The info argument can be used to pass custom attributes to the child component. These attributes are available on the component when <code>compSetVMRoutine()</code> and <code>compSetServicesRoutine()</code> are called. The attributes provided in <code>info</code> are <code>copied</code> onto the child component. This allows the same <code>info</code> object to be used for multiple child components without conflict.

The compLabel must uniquely identify the child component within the context of the Driver component.

If the comp argument is specified, it will reference the newly created component on return.

### 3.1.2 NUOPC\_DriverAddComp - Add a GridComp child from shared object to a Driver

#### INTERFACE:

```
! Private name; call using NUOPC_DriverAddComp()
recursive subroutine NUOPC_DriverAddGridCompSO(driver, compLabel, &
```

```
sharedObj, petList, info, config, comp, rc)
```

#### **ARGUMENTS:**

#### **DESCRIPTION:**

Create and add a GridComp (i.e. Model, Mediator, or Driver) as a child component to a Driver. The component is created on the provided petList, or by default across all of the Driver PETs.

The SetServices () routine in the sharedObj is called back immediately after the new child component has been created internally. Very little around the component is set up at that time (e.g. NUOPC component attributes will not be available). The routine should therefore be very light weight, with the sole purpose of setting the entry points of the component – typically by deriving from a generic component followed by the appropriate specilizations.

The info argument can be used to pass custom attributes to the child component. These attributes are available on the component when <code>compSetVMRoutine()</code> and <code>compSetServicesRoutine()</code> are called. The attributes provided in <code>info</code> are <code>copied</code> onto the child component. This allows the same <code>info</code> object to be used for multiple child components without conflict.

The compLabel must uniquely identify the child component within the context of the Driver component.

If the comp argument is specified, it will reference the newly created component on return.

### 3.1.3 NUOPC\_DriverAddComp - Add a CplComp child to a Driver

## INTERFACE:

```
! Private name; call using NUOPC_DriverAddComp()
recursive subroutine NUOPC_DriverAddCplComp(driver, srcCompLabel, &
  dstCompLabel, compSetServicesRoutine, compSetVMRoutine, petList, info, &
  config, comp, rc)
```

```
integer, intent(out) :: rc ! must not be optional
  end subroutine
end interface
interface
  recursive subroutine compSetVMRoutine(cplcomp, rc)
    use ESMF
    implicit none
    type (ESMF CplComp)
                                 :: cplcomp ! must not be optional
    integer, intent(out)
                                 :: rc ! must not be optional
  end subroutine
end interface
optional
                                                 :: compSetVMRoutine
integer, target, intent(in), optional :: petList(:)
type(ESMF_Info), intent(in), optional :: info
type(ESMF_Config), intent(in), optional :: config
type(ESMF_CplComp), intent(out), optional :: comp
integer,
                       intent(out), optional :: rc
```

Create and add a CplComp (i.e. Connector) as a child component to a Driver. The component is created on the provided petList, or by default across the union of PETs of the components indicated by srcCompLabel and dstCompLabel.

The specified SetServices () routine is called back immediately after the new child component has been created internally. Very little around the component is set up at that time (e.g. NUOPC component attributes will not be available). The routine should therefore be very light weight, with the sole purpose of setting the entry points of the component – typically by deriving from a generic component followed by the appropriate specilizations.

The info argument can be used to pass custom attributes to the child component. These attributes are available on the component when <code>compSetVMRoutine()</code> and <code>compSetServicesRoutine()</code> are called. The attributes provided in <code>info</code> are <code>copied</code> onto the child component. This allows the same <code>info</code> object to be used for multiple child components without conflict.

The compLabel must uniquely identify the child component within the context of the Driver component.

If the comp argument is specified, it will reference the newly created component on return.

### 3.1.4 NUOPC\_DriverAddRunElement - Add RunElement for Model, Mediator, or Driver

#### **INTERFACE:**

```
! Private name; call using NUOPC_DriverAddRunElement()
recursive subroutine NUOPC_DriverAddRunElementMPL(driver, slot, compLabel, &
    phaseLabel, relaxedflag, rc)
```

```
type(ESMF_GridComp) :: driver
integer, intent(in) :: slot
  character(len=*), intent(in) :: compLabel
-- The following arguments require argument keyword syntax (e.g. rc=rc). --
```

Add an element associated with a Model, Mediator, or Driver component to the run sequence of the Driver. The component must have been added to the Driver, and associated with complabel prior to this call.

If phaseLabel was not specified, the first entry in the RunPhaseMap attribute of the referenced component will be used to determine the run phase of the added element.

By default an error is returned if no component is associated with the specified <code>compLabel</code>. This error can be suppressed by setting <code>relaxedflag=.true.</code>, and no entry will be added to the run sequence.

The slot number identifies the run sequence time slot in case multiple sequences are available. Slots start counting from 1.

#### 3.1.5 NUOPC DriverAddRunElement - Add RunElement for Connector

#### INTERFACE:

```
! Private name; call using NUOPC_DriverAddRunElement()
recursive subroutine NUOPC_DriverAddRunElementCPL(driver, slot, srcCompLabel,&
dstCompLabel, phaseLabel, relaxedflag, rc)
```

### ARGUMENTS:

```
:: driver
    type(ESMF_GridComp)
    integer,
                           intent(in)
                                                   :: slot
    character(len=*),
                          intent(in)
                                                   :: srcCompLabel
    character(len=*), intent(in)
                                                   :: dstCompLabel
-- The following arguments require argument keyword syntax (e.g. rc=rc). --
    \texttt{character(len=*),} \qquad \texttt{intent(in),} \quad \texttt{optional :: phaseLabel}
    logical,
                           intent(in), optional :: relaxedflag
    integer,
                          intent(out), optional :: rc
```

# **DESCRIPTION:**

Add an element associated with a Connector component to the run sequence of the Driver. The component must have been added to the Driver, and associated with srcCompLabel and dstCompLabel prior to this call.

If phaseLabel was not specified, the first entry in the RunPhaseMap attribute of the referenced component will be used to determine the run phase of the added element.

By default an error is returned if no component is associated with the specified <code>compLabel</code>. This error can be suppressed by setting <code>relaxedflag=.true.</code>, and no entry will be added to the run sequence.

The slot number identifies the run sequence time slot in case multiple sequences are available. Slots start counting from 1.

# 3.1.6 NUOPC\_DriverAddRunElement - Add RunElement that links to another slot

# INTERFACE:

```
! Private name; call using NUOPC_DriverAddRunElement() recursive subroutine NUOPC_DriverAddRunElementL(driver, slot, linkSlot, rc)
```

#### **ARGUMENTS**:

### DESCRIPTION:

Add an element to the run sequence of the Driver that links to the time slot indicated by linkSlot.

## 3.1.7 NUOPC\_DriverEgestRunSequence - Egest the run sequence as FreeFormat

# INTERFACE:

```
recursive subroutine NUOPC_DriverEgestRunSequence(driver, freeFormat, rc)
```

### **ARGUMENTS:**

#### **DESCRIPTION:**

Egest the run sequence stored in the driver as a FreeFormat object. It is the caller's responsibility to destroy the created freeFormat object.

# 3.1.8 NUOPC\_DriverGet - Get info from a Driver

### **INTERFACE:**

```
! Private name; call using NUOPC_DriverGet()
recursive subroutine NUOPC_DriverGet(driver, slotCount, parentClock, &
  importState, exportState, rc)
```

#### **ARGUMENTS:**

```
type(ESMF_GridComp)
integer,
intent(out), optional :: slotCount
type(ESMF_Clock), intent(out), optional :: parentClock
type(ESMF_State), intent(out), optional :: importState
type(ESMF_State), intent(out), optional :: exportState
integer, intent(out), optional :: rc
```

### **DESCRIPTION:**

Access Driver information.

### 3.1.9 NUOPC\_DriverGetComp - Get a GridComp child from a Driver

#### INTERFACE:

```
! Private name; call using NUOPC_DriverGetComp()
recursive subroutine NUOPC_DriverGetGridComp(driver, compLabel, comp, petList, &
  importState, exportState, relaxedflag, rc)
```

## **ARGUMENTS:**

# **DESCRIPTION:**

Query the Driver for a GridComp (i.e. Model, Mediator, or Driver) child component that was added under compLabel.

If provided, the petList argument will be associated with the petList that was used to create the referenced component. This pointer must not be deallocated by the user!

By default an error is returned if no component is associated with the specified <code>compLabel</code>. This error can be suppressed by setting <code>relaxedflag=.true.</code>, and unassociated arguments will be returned.

# 3.1.10 NUOPC\_DriverGetComp - Get a CplComp child from a Driver

#### INTERFACE:

```
! Private name; call using NUOPC_DriverGetComp()
recursive subroutine NUOPC_DriverGetCplComp(driver, srcCompLabel, &
  dstCompLabel, comp, petList, relaxedflag, rc)
```

#### **ARGUMENTS**:

#### **DESCRIPTION:**

Query the Driver for a CplComp (i.e. Connector) child component that was added under compLabel.

If provided, the petList argument will be associated with the petList that was used to create the referenced component. This pointer must not be deallocated by the user!

By default an error is returned if no component is associated with the specified <code>compLabel</code>. This error can be suppressed by setting <code>relaxedflag=.true.</code>, and unassociated arguments will be returned.

#### 3.1.11 NUOPC\_DriverGetComp - Get all the GridComp child components from a Driver

### INTERFACE:

```
! Private name; call using NUOPC_DriverGetComp()
recursive subroutine NUOPC_DriverGetAllGridComp(driver, compList, petLists, &
   rc)
```

#### **ARGUMENTS**:

```
type(ESMF_GridComp)
type(ESMF_GridComp), pointer, optional
type(ESMF_PtrInt1D), pointer, optional
integer,
intent(out), optional :: rc
:: driver
:: compList(:)
:: petLists(:)
```

### **DESCRIPTION:**

Get all the GridComp (i.e. Model, Mediator, or Driver) child components from a Driver. The incoming compList and petLists arguments must be unassociated. This means that the user code must explicitly call nullify() or use the => null() syntax on the variables passed in as the actual arguments. On return it becomes the responsibility of the caller to deallocate any associated compList and petLists arguments.

### 3.1.12 NUOPC\_DriverGetComp - Get all the CplComp child components from a Driver

#### INTERFACE:

```
! Private name; call using NUOPC_DriverGetComp()
recursive subroutine NUOPC DriverGetAllCplComp(driver, compList, petLists, rc)
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Get all the CplComp (i.e. Connector) child components from a Driver. The incoming compList and petLists arguments must be unassociated. This means that the user code must explicitly call nullify() or use the => null() syntax on the variables passed in as the actual arguments. On return it becomes the responsibility of the caller to deallocate any associated compList and petLists arguments.

#### 3.1.13 NUOPC\_DriverIngestRunSequence - Ingest the run sequence from FreeFormat

### INTERFACE:

```
recursive subroutine NUOPC_DriverIngestRunSequence(driver, freeFormat, &
   autoAddConnectors, rc)
```

## ARGUMENTS:

### **DESCRIPTION:**

Ingest the run sequence from a FreeFormat object and replace the run sequence currently held by the driver. Every line in freeFormat corresponds to either a component run sequence element, or is part of a time loop or alarm block defintion.

**Component run sequence elements** define the run method of a single component. The lines are interpreted sequentially, however, components will execute concurrently as long as this is not prevented by data-dependencies or overlapping petLists.

Each line specifies the precise run method phase for a single component instance. For model, mediator, and driver components the format is this:

```
compLabel [phaseLabel]
```

Here complabel is the label by which the component instance is known to the driver. It is optionally followed a phaseLabel identifying a specific run phase. An example of calling the run phase of the ATM instance that contains the "fast" processes, and is labeled fast:

```
ATM fast
```

By default, i.e. without phaseLabel, the first registered run method of the component is used.

The format for connector components is different. It looks like this:

```
srcCompLabel -> dstCompLabel [connectionOptions]
```

A connector instance is uniquely known by the two components it connects, i.e. by srcCompLabel and dstCompLabel. The syntax requires that the token -> be specified between source and destination. Optionally connectionOptions can be supplied using the format discussed under section 2.4.5. The connection options are set as attribute ConnectionOptions on the respective connector component.

An example of executing the connector instance that transfers fields from the ATM component to the OCN component, using redistribution for remapping:

```
ATM -> OCN :remapMethod=redist
```

By default autoAddConnectors is .false., which means that all components referenced in the freeFormat run sequence, including connectors, must already be available as child components of the driver component. An error will be returned if this is not the case. However, when autoAddConnectors is set to .true., connector components encountered in the run sequence that are no already present in the driver will be added automatically. The default NUOPC\_Connector implementation is used for all automatically added connector instances.

Lines that contain a **time loop** definition have the general format:

```
@{timeStep|*}[:runDuration]
...
...
```

Both timeStep and runDuration are numbers in units of seconds. Time loops can be nested and concatenated.

A wildcard "\*" character can be specified in place of an actual timeStep number. In this case the timeStep of the associated run clock object is set to be equal to the timeStep of the time loop one level up in the loop nesting hierarchy. If a wildcard time step is used for a single outer time loop in the run sequence, then the associated run clock is identical to the driver clock and must be set explicitly by the driver code, or its parent component.

The runDuration specification is optional. If omitted, the duration of the associated run clock is set to the timeStep of the time loop one level up in the loop nesting hierarchy. This ensures that for a single nested time loop, the loop returns to the parent loop level at the appropriate time.

A simple example of a single time loop with one hour timestep:

```
@3600
...
```

Each time loop has its own associated clock object. NUOPC manages these clock objects, i.e. their creation and destruction, as well as startTime, endTime, timeStep adjustments during the execution. The outer most time loop of the run sequence is a special case. It uses the driver clock itself. If a single outer most loop is defined in the run sequence provided by freeFormat, this loop becomes the driver loop level directly. Therefore, setting the timeStep or runDuration for the outer most time loop results modifying the driver clock itself. However, for cases with concatenated loops on the upper level of the run sequence in freeFormat, a single outer loop is added automatically during ingestion, and the driver clock is used for this loop instead.

A more complex run sequence example, that shows component run sequence elements outside of time loops, a nested time loop, time step wildcards, explicit duration specifications, and concatenated time loops:

```
@100:800
  ATM -> OCN
  OCN -> ATM
  ATM
  OCN
    OCN -> EXTOCN
    EXTOCN
  @
(a
ATM -> EXTATM
EXTATM
@100:1000
  ATM -> OCN
  OCN -> ATM
  ATM
  OCN
@
```

Here the timeStep of the first time loop is explicitly chosen at 100s. The runDuration is explicitly set to 800s. The first time loop steps the current time forward for 800s, for each iteration executing ATM-OCN coupling, followed by the nested loop that calls the OCN  $\rightarrow$  EXTOCN and EXTOCN components. The nested loop uses a wildcard timeStep and therefore is identical to the parent loop level timeStep of 100s. The nested runDuration is not specified and therefore also defaults to the parent time step of 100s. In other words, the nested loop is executed exactly once for every parent loop iteration.

After 800s the first time loop is exited, and followed by explicit calls to ATM  $\rightarrow$  EXTAMT and EXTATM components. Finally the second time loop is entered for another 1000s runDuration. The timeStep is again explicitly set to 100s. The second time loop only implements ATM-OCN coupling, and no coupling to EXTOCN is implemented. Finally, after 1800s the sequence returns to the driver level loop.

Lines that contain an **alarm block** definition have the general format:

```
@@{alarmTime|*}
    ...
@@
```

The alarmTime is a number in units of seconds, and indicates at which interval the alarm will ring. The first ring time of an alarm is the current time of the parent clock.

Specification of the wildcard character \* sets the alarmTime equal to the timeStep of the parentClock.

When an alarm rings, the entire alarm block is executed once.

Nesting of time loops and alarm blocks is supported.

# 3.1.14 NUOPC\_DriverNewRunSequence - Replace the run sequence in a Driver

#### INTERFACE:

```
recursive subroutine NUOPC_DriverNewRunSequence(driver, slotCount, rc)
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Replace the current run sequence of the Driver with a new one that has slotCount slots. Each slot uses its own clock for time keeping.

# 3.1.15 NUOPC\_DriverPrint - Print internal Driver information

### **INTERFACE:**

```
recursive subroutine NUOPC_DriverPrint(driver, orderflag, rc)
```

#### **ARGUMENTS:**

```
type(ESMF_GridComp)
logical, intent(in), optional :: orderflag
integer, intent(out), optional :: rc
```

# **DESCRIPTION:**

Print internal Driver information. If orderflag is provided and set to .true., the output is ordered from lowest to highest PET. Setting this flag makes the method collective.

## 3.1.16 NUOPC\_DriverSetRunSequence - Set internals of RunSequence slot

#### INTERFACE:

```
! Private name; call using NUOPC_DriverSetRunSequence() recursive subroutine NUOPC_DriverSetRunSequence(driver, slot, clock, alarm, rc)
```

#### **ARGUMENTS:**

```
type(ESMF_GridComp)
integer, intent(in) :: slot
type(ESMF_Clock), intent(in) :: clock
type(ESMF_Alarm), intent(in), optional :: alarm
integer, intent(out), optional :: rc
```

### **DESCRIPTION:**

Set the clock in the run sequence under slot of the Driver.

# 3.2 Generic Component: NUOPC\_ModelBase

#### MODULE:

```
module NUOPC_ModelBase
```

### **DESCRIPTION:**

Partial specialization of a component with a default *explicit* time dependency. Each time the Run method is called the component steps one timeStep forward on the passed in parent clock. The component flags incompatibility during Run if the current time of the incoming clock does not match the current time of the internal clock.

### SUPER:

```
ESMF_GridComp
```

# **USE DEPENDENCIES:**

use ESMF

### SETSERVICES:

```
subroutine SetServices(modelBase, rc)
type(ESMF_GridComp) :: modelBase
integer, intent(out) :: rc
```

#### SEMANTIC SPECIALIZATION LABELS:

- Initialize:
  - label\_Advertise
    - \* Required in order to advertise fields.

- \* Use NUOPC\_Advertise() to advertise specific fields in the Import- and ExportState of the component.
- \* Alternatively set the FieldTransferPolicy attribute on the Import- and ExportState of the component to request field mirroring.

# - label\_ModifyAdvertised

- \* Optional. By default do not modify the advertised fields.
- \* Mostly used when field mirroring was requested during Advertise.
- \* Remove undesired advertised fields in the Import- and ExportState of the component.
- \* Adjust attributes e.g. for TransferOffer on advertised fields.

#### - label RealizeProvided

- \* Required in order to realize fields.
- \* Use NUOPC\_Realize() to realize fields previously advertised, and for which this component is responsible for providing the Field allocation and/or the GeomObject.

#### label AcceptTransfer

- \* Optional. By default accept the Distribution of the transferred GeomObjects.
- \* Change the distribution of any of the transferred GeomObjects.

### - label\_RealizeAccepted

- \* Optional. Needed for any fields for which component is accepting the GeomObject.
- \* Use NUOPC\_Realize() to realize fields previously advertised, and for which this component is accepting the GeomObject.

#### - label SetClock

- \* Optional. By default create clock according to time information provided by driver.
- \* Adjust and set the component clock.

#### - label DataInitialize

- \* Optional. Needed to initialize data, and to participate in resolution of data dependencies between components during initialize.
- \* Initialize data in fields.
- \* Set NUOPC attributes used for data dependency resolution.

#### • Run:

### - label Advance

- \* Called every timeStep on the component internal clock.
- \* Implement the forward integration of the model.
- \* Ensure data in the export fields is updated before returning.

#### - label AdvanceClock

\* Optional. By default the component internal clock is advanced by one internal timeStep at the end of the Advance step.

### - label CheckImport

\* Optional. By default check the timestamp of all import fields against the current time of the internal clock.

## label\_SetRunClock

\* Optional. By default do not adjust the internal clock when entering Run.

#### label TimestampExport

\* Optinal. By default timestamp all export fields according to the current time of the component internal clock before returning.

### • Finalize:

#### - label Finalize

- \* Optional. By default do nothing.
- \* Destroy any objects created during Initalize.

# 3.3 Generic Component: NUOPC\_Model

#### MODULE:

module NUOPC\_Model

# **DESCRIPTION:**

Model component with a default *explicit* time dependency. Each time the Run method is called the model integrates one timeStep forward on the passed in parent clock. The internal clock is advanced at the end of each Run call. The component flags incompatibility during Run if the current time of the incoming clock does not match the current time of the internal clock.

# SUPER:

NUOPC ModelBase

## **USE DEPENDENCIES:**

use ESMF

# SETSERVICES:

```
subroutine SetServices(model, rc)
type(ESMF_GridComp) :: model
integer, intent(out) :: rc
```

#### SEMANTIC SPECIALIZATION LABELS:

### • Initialize:

## - label\_Advertise

- \* Required in order to advertise fields.
- \* Use NUOPC\_Advertise() to advertise specific fields in the Import- and ExportState of the component.
- \* Alternatively set the FieldTransferPolicy attribute on the Import- and ExportState of the component to request field mirroring.

## label\_ModifyAdvertised

- \* Optional. By default do not modify the advertised fields.
- \* Mostly used when field mirroring was requested during Advertise.
- \* Remove undesired advertised fields in the Import- and ExportState of the component.
- \* Adjust attributes e.g. for TransferOffer on advertised fields.

## - label\_RealizeProvided

\* Required in order to realize fields.

\* Use NUOPC\_Realize() to realize fields previously advertised, and for which this component is responsible for providing the Field allocation and/or the GeomObject.

## label\_AcceptTransfer

- \* Optional. By default accept the Distribution of the transferred GeomObjects.
- \* Change the distribution of any of the transferred GeomObjects.

#### - label RealizeAccepted

- \* Optional. Needed for any fields for which component is accepting the GeomObject.
- $\ast$  Use NUOPC\_Realize() to realize fields previously advertised, and for which this component is accepting the GeomObject.

#### - label SetClock

- \* Optional. By default create clock according to time information provided by driver.
- \* Adjust and set the component clock.

### - label\_DataInitialize

- \* Optional. Needed to initialize data, and to participate in resolution of data dependencies between components during initialize.
- \* Initialize data in fields.
- \* Set NUOPC attributes used for data dependency resolution.

#### • Run:

### - label Advance

- \* Called every timeStep on the component internal clock.
- \* Implement the forward integration of the model.
- \* Ensure data in the export fields is updated before returning.

#### label\_AdvanceClock

\* Optional. By default the component internal clock is advanced by one internal timeStep at the end of the Advance step.

### - label\_CheckImport

\* Optional. By default check the timestamp of all import fields against the current time of the internal clock.

#### - label SetRunClock

\* Optional. By default do not adjust the internal clock when entering Run.

#### - label TimestampExport

\* Optinal. By default timestamp all export fields according to the current time of the component internal clock before returning.

# • Finalize:

#### label Finalize

- \* Optional. By default do nothing.
- \* Destroy any objects created during Initalize.

### 3.3.1 NUOPC\_ModelGet - Get info from a Model

### INTERFACE:

```
subroutine NUOPC_ModelGet(model, driverClock, modelClock, &
  importState, exportState, rc)
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Access Model information.

# 3.4 Generic Component: NUOPC\_Mediator

# MODULE:

```
module NUOPC_Mediator
```

# **DESCRIPTION:**

Mediator component with a default *explicit* time dependency. Each time the Run method is called, the time stamp on the imported Fields must match the current time (on both the incoming and internal clock). Before returning, the Mediator time stamps the exported Fields with the same current time, before advancing the internal clock one timeStep forward.

# SUPER:

```
NUOPC_ModelBase
```

#### **USE DEPENDENCIES:**

use ESMF

# SETSERVICES:

```
subroutine SetServices(mediator, rc)
type(ESMF_GridComp) :: mediator
integer, intent(out) :: rc
```

# SEMANTIC SPECIALIZATION LABELS:

• Initialize:

### - label\_Advertise

- \* Required in order to advertise fields.
- \* Use NUOPC\_Advertise() to advertise specific fields in the Import- and ExportState of the component.
- \* Alternatively set the FieldTransferPolicy attribute on the Import- and ExportState of the component to request field mirroring.

### label\_ModifyAdvertised

- \* Optional. By default do not modify the advertised fields.
- \* Mostly used when field mirroring was requested during Advertise.
- \* Remove undesired advertised fields in the Import- and ExportState of the component.
- \* Adjust attributes e.g. for TransferOffer on advertised fields.

#### - label RealizeProvided

- \* Required in order to realize fields.
- \* Use NUOPC\_Realize() to realize fields previously advertised, and for which this component is responsible for providing the Field allocation and/or the GeomObject.

# - label\_AcceptTransfer

- \* Optional. By default accept the Distribution of the transferred GeomObjects.
- \* Change the distribution of any of the transferred GeomObjects.

#### - label RealizeAccepted

- \* Optional. Needed for any fields for which component is accepting the GeomObject.
- \* Use NUOPC\_Realize() to realize fields previously advertised, and for which this component is accepting the GeomObject.

### label\_SetClock

- \* Optional. By default create clock according to time information provided by driver.
- \* Adjust and set the component clock.

#### - label DataInitialize

- \* Optional. Needed to initialize data, and to participate in resolution of data dependencies between components during initialize.
- \* Initialize data in fields.
- \* Set NUOPC attributes used for data dependency resolution.

#### • Run:

### - label Advance

- \* Called every timeStep on the component internal clock.
- \* Implement the forward integration of the model.
- \* Ensure data in the export fields is updated before returning.

### label\_AdvanceClock

\* Optional. By default the component internal clock is advanced by one internal timeStep at the end of the Advance step.

### - label CheckImport

\* Optional. By default check the timestamp of all import fields against the current time of the internal clock.

# - label\_SetRunClock

\* Optional. By default do not adjust the internal clock when entering Run.

#### label TimestampExport

- \* Optinal. By default timestamp all export fields according to the current time of the component internal clock before returning.
- Finalize:
  - label Finalize
    - \* Optional. By default do nothing.
    - \* Destroy any objects created during Initalize.

# 3.4.1 NUOPC\_MediatorGet - Get info from a Mediator

#### INTERFACE:

```
subroutine NUOPC_MediatorGet(mediator, driverClock, mediatorClock, &
  importState, exportState, rc)
```

# ARGUMENTS:

```
type(ESMF_GridComp)
type(ESMF_Clock), intent(out), optional :: driverClock
type(ESMF_Clock), intent(out), optional :: mediatorClock
type(ESMF_State), intent(out), optional :: importState
type(ESMF_State), intent(out), optional :: exportState
integer, intent(out), optional :: rc
```

# **DESCRIPTION:**

Access Mediator information.

# 3.5 Generic Component: NUOPC\_Connector

## MODULE:

```
module NUOPC_Connector
```

#### **DESCRIPTION:**

Component that makes a unidirectional connection between model, mediator, and or driver components. During initialization field pairing is performed between the import and export side according to section 2.4.2, and paired fields are connected. By default the bilinear regrid method is used during Run to transfer data from the connected import Fields to the connected export Fields.

### SUPER:

```
ESMF_CplComp
```

## **USE DEPENDENCIES:**

```
use ESMF
```

### SETSERVICES:

```
subroutine SetServices(connector, rc)
type(ESMF_CplComp) :: connector
integer, intent(out) :: rc
```

### SEMANTIC SPECIALIZATION LABELS:

- Initialize:
  - label\_ComputeRouteHandle
    - \* Optional. By default compute routehandles according to CplList attribute.
- Run:
  - label ExecuteRouteHandle
    - \* Optional. By default execute routehandles stored in the Connector.
- Finalize:
  - label ReleaseRouteHandle
    - \* Optional. By default release routehandles stored in the Connector.
  - label Finalize
    - \* Optional. By default do nothing.
    - \* Destroy any objects created during Initalize.

# 3.5.1 NUOPC\_ConnectorGet - Get parameters from a Connector

### **INTERFACE:**

```
subroutine NUOPC_ConnectorGet(connector, srcFields, dstFields, rh, state, &
   CplSet, cplSetList, srcVM, dstVM, driverClock, rc)
```

Get parameters from the connector internal state.

The Connector keeps information about the connection that it implements in its internal state. When customizing a Connector, it is often necessary to access and sometimes modify these data objects.

The arguments are:

**connector** The Connector component.

[srcFields] The FieldBundle under which the Connector keeps track of all connected source side fields. The order in which the fields are stored in srcFields is significant, as it corresponds to the order of fields in dstFields. Consequently, when accessing and modifying the fields inside of srcFields, it is important to use the itemorderflag=ESMF\_ITEMORDER\_ADDORDER option to ESMF\_FieldBundleGet().

[dstFields] The FieldBundle under which the Connector keeps track of all connected destination side fields. The order in which the fields are stored in dstFields is significant, as it corresponds to the order of fields in srcFields. Consequently, when accessing and modifying the fields inside of dstFields, it is important to use the itemorderflag=ESMF\_ITEMORDER\_ADDORDER option to ESMF\_FieldBundleGet().

[rh] The RouteHandle that the Connector uses to move data from srcFields to dstFields.

[state] A State object that the Connector keeps to make customization of the Connector more convenient. The generic Connector code handles creation and destruction of state, but does *not* access it directly for information.

[CplSet] If present, all of the returned information is specific to the specified coupling set.

[cplSetList] The list of coupling sets currently known to the Connector. This argument must enter the call *unassociated* or an error is returned. This means that the user code must explicitly call nullify() or use the => null() syntax on the variable passed in as cplSetList argument. On return, the cplSetList argument will be associated, potentially of size zero. The responsibility for deallocation transfers to the caller.

[srcVM] The VM of the source side component.

[dstVM] The VM of the destination side component.

[driverClock] The Clock object used by the current RunSequence level to drive this component.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.5.2 NUOPC\_ConnectorSet - Set parameters in a Connector

#### INTERFACE:

```
subroutine NUOPC_ConnectorSet(connector, srcFields, dstFields, rh, state, &
   CplSet, srcVM, dstVM, rc)
```

Set parameters in the connector internal state.

The Connector keeps information about the connection that it implements in its internal state. When customizing a Connector, it is often necessary to access and sometimes modify these data objects.

The arguments are:

**connector** The Connector component.

[srcFields] The FieldBundle under which the Connector keeps track of all connected source side fields. The order in which the fields are stored in srcFields is significant, as it corresponds to the order of fields in dstFields. Consequently, when setting srcFields, it is important to add them in the same order as for dstFields.

[dstFields] The FieldBundle under which the Connector keeps track of all connected destination side fields. The order in which the fields are stored in dstFields is significant, as it corresponds to the order of fields in srcFields. Consequently, when setting dstFields, it is important to add them in the same order as for srcFields.

[rh] The RouteHandle that the Connector uses to move data from srcFields to dstFields.

[state] A State object that the Connector keeps to make customization of the Connector more convenient. Only in very rare cases would the user want to replace the state that is managed by the generic Connector implementation. If state is set by this call, the user essentially claims ownership of the previous state object, and becomes responsible for its destruction. Ownership of the new state is transferred to the Connector and must not be explicitly destroyed by the user code.

[CplSet] If present, all of the passed in information is set under the specified coupling set.

[srcVM] The VM of the source side component.

[dstVM] The VM of the destination side component.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

# 3.6 General Generic Component Methods

# 3.6.1 NUOPC\_CompAreServicesSet - Check if SetServices was called

### INTERFACE:

```
! Private name; call using NUOPC_CompAreServicesSet()
function NUOPC_GridCompAreServicesSet(comp, rc)
```

### RETURN VALUE:

```
logical :: NUOPC_GridCompAreServicesSet
```

#### **ARGUMENTS:**

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

# **DESCRIPTION:**

Return .true. if SetServices has been called for comp. Otherwise return .false..

### 3.6.2 NUOPC\_CompAreServicesSet - Check if SetServices was called

# **INTERFACE**:

```
! Private name; call using NUOPC_CompAreServicesSet()
function NUOPC_CplCompAreServicesSet(comp, rc)
```

## RETURN VALUE:

```
logical :: NUOPC_CplCompAreServicesSet
```

# ARGUMENTS:

```
type(ESMF_CplComp), intent(in) :: comp
integer, intent(out), optional :: rc
```

### **DESCRIPTION:**

Return .true. if SetServices has been called for comp. Otherwise return .false..

# 3.6.3 NUOPC\_CompAttributeAdd - Add NUOPC GridComp Attributes

### INTERFACE:

```
! Private name; call using NUOPC_CompAttributeAdd()
subroutine NUOPC_GridCompAttributeAdd(comp, attrList, rc)
```

#### **ARGUMENTS**:

```
type(ESMF_GridComp)
character(len=*), intent(in) :: attrList(:)
integer, intent(out), optional :: rc
```

# **DESCRIPTION:**

Add Attributes to the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

# 3.6.4 NUOPC\_CompAttributeAdd - Add NUOPC CplComp Attributes

# **INTERFACE**:

```
! Private name; call using NUOPC_CompAttributeAdd()
subroutine NUOPC_CplCompAttributeAdd(comp, attrList, rc)
```

#### **ARGUMENTS:**

## **DESCRIPTION:**

Add Attributes to the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

# 3.6.5 NUOPC\_CompAttributeEgest - Egest NUOPC GridComp Attributes in FreeFormat

# INTERFACE:

```
! Private name; call using NUOPC_CompAttributeEgest()
subroutine NUOPC_GridCompAttributeEge(comp, freeFormat, rc)
```

#### **ARGUMENTS:**

```
type(ESMF_GridComp), intent(in) :: comp
type(NUOPC_FreeFormat), intent(out) :: freeFormat
integer, intent(out), optional :: rc
```

### **DESCRIPTION:**

Egest the Attributes of the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance") as a FreeFormat object. It is the caller's responsibility to destroy the created freeFormat object.

### 3.6.6 NUOPC\_CompAttributeEgest - Egest NUOPC CplComp Attributes in FreeFormat

# **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeEgest()
subroutine NUOPC_CplCompAttributeEge(comp, freeFormat, rc)
```

#### **ARGUMENTS:**

```
type(ESMF_CplComp), intent(in) :: comp
type(NUOPC_FreeFormat), intent(out) :: freeFormat
integer, intent(out), optional :: rc
```

#### **DESCRIPTION:**

Egest the Attributes of the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance") as a FreeFormat object. It is the caller's responsibility to destroy the created freeFormat object.

# 3.6.7 NUOPC\_CompAttributeGet - Get a NUOPC GridComp Attribute

#### **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeGet()
subroutine NUOPC_GridCompAttributeGet(comp, name, value, isPresent, isSet, rc)
```

Access the attribute name inside of comp using the convention NUOPC and purpose Instance.

Unless isPresent and isSet are provided, return with error if the attribute is not present or not set, respectively.

Note that attributes ingested by NUOPC\_CompAttributeIngest() are stored and returned as type character string. See 3.6.15 for details.

The arguments are:

```
comp The ESMF_GridComp object to be queried.
```

**name** The name of the queried attribute.

value The value of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

#### 3.6.8 NUOPC CompAttributeGet - Get a NUOPC CplComp Attribute

### **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeGet() subroutine NUOPC_CplCompAttributeGet(comp, name, value, isPresent, isSet, rc)
```

#### **ARGUMENTS:**

```
type(ESMF_CplComp), intent(in) :: comp
character(*), intent(in) :: name
character(*), intent(out) :: value
logical, intent(out), optional :: isPresent
logical, intent(out), optional :: isSet
integer, intent(out), optional :: rc
```

#### DESCRIPTION:

Access the attribute name inside of comp using the convention NUOPC and purpose Instance.

Unless isPresent and isSet are provided, return with error if the attribute is not present or not set, respectively.

Note that attributes ingested by NUOPC\_CompAttributeIngest() are stored and returned as type character string. See 3.6.16 for details.

The arguments are:

comp The ESMF\_CplComp object to be queried.

name The name of the queried attribute.

**value** The value of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.6.9 NUOPC\_CompAttributeGet - Get a NUOPC GridComp Attribute

### **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeGet()
subroutine NUOPC_GridCompAttributeGetI(comp, name, value, isPresent, isSet, rc)
```

#### **ARGUMENTS:**

#### **DESCRIPTION:**

Access the attribute name inside of comp using the convention NUOPC and purpose Instance.

Unless isPresent and isSet are provided, return with error if the attribute is not present or not set, respectively.

Note that attributes ingested by NUOPC\_CompAttributeIngest() are stored and returned as type character string. See 3.6.15 for details.

The arguments are:

comp The ESMF\_GridComp object to be queried.

**name** The name of the queried attribute.

value The value of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.6.10 NUOPC\_CompAttributeGet - Get a NUOPC CplComp Attribute

#### INTERFACE:

```
! Private name; call using NUOPC_CompAttributeGet() subroutine NUOPC_CplCompAttributeGetI(comp, name, value, isPresent, isSet, rc)
```

#### **ARGUMENTS:**

```
type(ESMF_CplComp), intent(in) :: comp
character(*), intent(in) :: name
integer, intent(out) :: value
logical, intent(out), optional :: isPresent
logical, intent(out), optional :: isSet
integer, intent(out), optional :: rc
```

#### DESCRIPTION:

Access the attribute name inside of comp using the convention NUOPC and purpose Instance.

Unless isPresent and isSet are provided, return with error if the attribute is not present or not set, respectively.

Note that attributes ingested by NUOPC\_CompAttributeIngest() are stored and returned as type character string. See 3.6.16 for details.

The arguments are:

comp The ESMF\_CplComp object to be queried.

**name** The name of the queried attribute.

value The value of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

# 3.6.11 NUOPC\_CompAttributeGet - Get a NUOPC GridComp Attribute

#### **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeGet()
subroutine NUOPC_GridCompAttributeGetSL(comp, name, valueList, isPresent, &
  isSet, itemCount, typekind, rc)
```

Access the attribute name inside of comp using the convention NUOPC and purpose Instance. Returns with error if the attribute is not present or not set.

Unless isPresent and isSet are provided, return with error if the attribute is not present or not set, respectively.

Note that attributes ingested by NUOPC\_CompAttributeIngest() are stored and returned as type character string. See 3.6.15 for details.

The arguments are:

comp The ESMF\_GridComp object to be queried.

name The name of the queried attribute.

[valueList] The list of values of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

[itemCount] Number of items in the attribute. Return 0 if not present or not set.

**[typekind]** The typekind of the queried attribute.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

# 3.6.12 NUOPC\_CompAttributeGet - Get a NUOPC CplComp Attribute

### **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeGet()
subroutine NUOPC_CplCompAttributeGetSL(comp, name, valueList, isPresent, &
   isSet, itemCount, typekind, rc)
```

Access the attribute name inside of comp using the convention NUOPC and purpose Instance. Returns with error if the attribute is not present or not set.

Unless isPresent and isSet are provided, return with error if the attribute is not present or not set, respectively.

Note that attributes ingested by NUOPC\_CompAttributeIngest() are stored and returned as type character string. See 3.6.16 for details.

The arguments are:

**comp** The ESMF\_CplComp object to be queried.

name The name of the queried attribute.

[valueList] The list of values of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

[itemCount] Number of items in the attribute. Return 0 if not present or not set.

**[typekind]** The typekind of the queried attribute.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.6.13 NUOPC CompAttributeGet - Get a NUOPC GridComp Attribute

# INTERFACE:

```
! Private name; call using NUOPC_CompAttributeGet()
subroutine NUOPC_GridCompAttributeGetIL(comp, name, valueList, isPresent, &
  isSet, itemCount, typekind, rc)
```

### ARGUMENTS:

### **DESCRIPTION:**

Access the attribute name inside of comp using the convention NUOPC and purpose Instance. Returns with error if the attribute is not present or not set.

Unless isPresent and isSet are provided, return with error if the attribute is not present or not set, respectively.

Note that attributes ingested by NUOPC\_CompAttributeIngest() are stored and returned as type character string. See 3.6.15 for details.

The arguments are:

comp The ESMF\_GridComp object to be queried.

**name** The name of the queried attribute.

valueList The list of values of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

[itemCount] Number of items in the attribute. Return 0 if not present or not set.

**[typekind]** The typekind of the queried attribute.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

#### 3.6.14 NUOPC CompAttributeGet - Get a NUOPC CplComp Attribute

### INTERFACE:

```
! Private name; call using NUOPC_CompAttributeGet()
subroutine NUOPC_CplCompAttributeGetIL(comp, name, valueList, isPresent, &
  isSet, itemCount, typekind, rc)
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Access the attribute name inside of comp using the convention NUOPC and purpose Instance. Returns with error if the attribute is not present or not set.

Unless isPresent and isSet are provided, return with error if the attribute is not present or not set, respectively.

Note that attributes ingested by NUOPC\_CompAttributeIngest() are stored and returned as type character string. See 3.6.16 for details.

The arguments are:

```
comp The ESMF_CplComp object to be queried.
```

**name** The name of the queried attribute.

valueList The list of values of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

**[itemCount]** Number of items in the attribute. Return 0 if not present or not set.

**[typekind]** The typekind of the queried attribute.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.6.15 NUOPC CompAttributeIngest - Ingest free format NUOPC GridComp Attributes

#### INTERFACE:

```
! Private name; call using NUOPC_CompAttributeIngest()
subroutine NUOPC_GridCompAttributeIng(comp, freeFormat, addFlag, rc)
```

# ARGUMENTS:

```
type(ESMF_GridComp), intent(in) :: comp
type(NUOPC_FreeFormat), intent(in) :: freeFormat
logical, intent(in), optional :: addFlag
integer, intent(out), optional :: rc
```

### **DESCRIPTION:**

Ingest the Attributes from a FreeFormat object onto the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

Important: Attributes ingested by this method are stored as type character strings, and must be accessed accordingly. Conversion from string into a different data type, e.g. integer or real, is the user's responsibility.

If addFlag is .false. (default), an error will be returned if an attribute is to be ingested that was not previously added to the comp object. If addFlag is .true., all missing attributes will be added by this method automatically as needed.

Each line in freeFormat is of this format:

```
attributeName = attributeValue
```

### For example:

```
Verbosity = 0
Profiling = 0
Diagnostic = 0
```

could directly be ingested as Attributes for any instance of the four standard NUOPC component kinds. This is because Verbosity, Profiling, and Diagnostic are pre-defined Attributes of the NUOPC component kinds according to sections 2.3.1, 2.3.2, 2.3.3, and 2.3.4.

When Attributes are specified in freeFormat that are not pre-defined for a specific component kind, they can still be ingested by a component instance using the addFlag=.true. option. For instance:

```
ModelOutputChoice = 2
```

specifies a user-level Attribute, which is not part of the pre-defined Attributes of any of the standard NUOPC component kinds.

### 3.6.16 NUOPC\_CompAttributeIngest - Ingest free format NUOPC CplComp Attributes

#### INTERFACE:

```
! Private name; call using NUOPC_CompAttributeIngest() subroutine NUOPC_CplCompAttributeIng(comp, freeFormat, addFlag, rc)
```

### **ARGUMENTS:**

```
type(ESMF_CplComp), intent(in) :: comp
type(NUOPC_FreeFormat), intent(in) :: freeFormat
logical, intent(in), optional :: addFlag
integer, intent(out), optional :: rc
```

# **DESCRIPTION:**

Ingest the Attributes from a FreeFormat object onto the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

Important: Attributes ingested by this method are stored as type character strings, and must be accessed accordingly. Conversion from string into a different data type, e.g. integer or real, is the user's responsibility.

If addFlag is .false. (default), an error will be returned if an attribute is to be ingested that was not previously added to the comp object. If addFlag is .true., all missing attributes will be added by this method automatically as needed.

Each line in freeFormat is of this format:

```
attributeName = attributeValue
```

# For example:

```
Verbosity = 0
Profiling = 0
Diagnostic = 0
```

could directly be ingested as Attributes for any instance of the four standard NUOPC component kinds. This is because Verbosity, Profiling, and Diagnostic are pre-defined Attributes of the NUOPC component kinds according to sections 2.3.1, 2.3.2, 2.3.3, and 2.3.4.

When Attributes are specified in freeFormat that are not pre-defined for a specific component kind, they can still be ingested by a component instance using the addFlag=.true. option. For instance:

```
ModelOutputChoice = 2
```

specifies a user-level Attribute, which is not part of the pre-defined Attributes of any of the standard NUOPC component kinds.

### 3.6.17 NUOPC\_CompAttributeReset - Reset NUOPC GridComp Attributes

### **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeReset() subroutine NUOPC_GridCompAttributeReset(comp, attrList, rc)
```

### ARGUMENTS:

```
type(ESMF_GridComp)
character(len=*), intent(in) :: attrList(:)
integer, intent(out), optional :: rc
```

### **DESCRIPTION:**

Reset Attributes on the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

### 3.6.18 NUOPC\_CompAttributeReset - Reset NUOPC CplComp Attributes

#### INTERFACE:

```
! Private name; call using NUOPC_CompAttributeReset()
subroutine NUOPC_CplCompAttributeReset(comp, attrList, rc)
```

Reset Attributes on the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

### 3.6.19 NUOPC\_CompAttributeSet - Set a NUOPC GridComp Attribute

### **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeSet()
subroutine NUOPC_GridCompAttributeSetS(comp, name, value, rc)
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Set the Attribute name inside of comp on the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

# 3.6.20 NUOPC\_CompAttributeSet - Set a NUOPC CplComp Attribute

#### INTERFACE:

```
! Private name; call using NUOPC_CompAttributeSet() subroutine NUOPC_CplCompAttributeSetS(comp, name, value, rc)
```

### **ARGUMENTS:**

### DESCRIPTION:

Set the Attribute name inside of comp on the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

### 3.6.21 NUOPC\_CompAttributeSet - Set a NUOPC GridComp Attribute

### **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeSet()
subroutine NUOPC_GridCompAttributeSetI(comp, name, value, rc)
```

### **ARGUMENTS:**

#### DESCRIPTION:

Set the Attribute name inside of comp on the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

# 3.6.22 NUOPC\_CompAttributeSet - Set a NUOPC CplComp Attribute

### INTERFACE:

```
! Private name; call using NUOPC_CompAttributeSet() subroutine NUOPC_CplCompAttributeSetI(comp, name, value, rc)
```

### **ARGUMENTS:**

### **DESCRIPTION:**

Set the Attribute name inside of comp on the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

### 3.6.23 NUOPC\_CompAttributeSet - Set a NUOPC GridComp List Attribute

# INTERFACE:

```
! Private name; call using NUOPC_CompAttributeSet()
subroutine NUOPC_GridCompAttributeSetSL(comp, name, valueList, rc)
```

#### DESCRIPTION:

Set the Attribute name inside of comp on the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

### 3.6.24 NUOPC\_CompAttributeSet - Set a NUOPC CplComp List Attribute

### **INTERFACE:**

```
! Private name; call using NUOPC_CompAttributeSet()
subroutine NUOPC_CplCompAttributeSetSL(comp, name, valueList, rc)
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Set the Attribute name inside of comp on the highest level of the standard NUOPC AttPack hierarchy (convention="NUOPC", purpose="Instance").

### 3.6.25 NUOPC\_CompCheckSetClock - Check Clock compatibility and set stopTime

### INTERFACE:

```
! Private name; call using NUOPC_CompCheckSetClock()
subroutine NUOPC_GridCompCheckSetClock(comp, externalClock, checkTimeStep, &
forceTimeStep, rc)
```

Compare externalClock to the internal clock of comp to make sure they match in their current time. Also ensure that the time step of the external clock is a multiple of the time step of the internal clock. If both conditions are satisfied then set the stop time of the internal clock so it is reached in one time step of the external clock. Otherwise leave the internal clock unchanged and return with error. The direction of the involved clocks is taking into account. Setting the forceTimeStep argument to .true. forces the timeStep of the externalClock to be used to reset the timeStep of the internal clock.

### 3.6.26 NUOPC\_CompDerive - Derive a GridComp from a generic component

### **INTERFACE:**

```
! Private name; call using NUOPC_CompDerive()
recursive subroutine NUOPC_GridCompDerive(comp, genericSetServicesRoutine, rc)
```

#### **ARGUMENTS:**

#### **DESCRIPTION:**

Derive a GridComp (i.e. Model, Mediator, or Driver) from a generic component by calling into the specified SetServices() routine of the generic component. This is typically the first call in the SetServices() routine of the specializing component, and is followed by NUOPC\_CompSpecialize() calls.

# 3.6.27 NUOPC\_CompDerive - Derive a CplComp from a generic component

### INTERFACE:

```
! Private name; call using NUOPC_CompDerive() recursive subroutine NUOPC_CplCompDerive(comp, genericSetServicesRoutine, rc)
```

```
type(ESMF_CplComp), intent(in) :: comp
interface
  subroutine genericSetServicesRoutine(cplcomp, rc)
    use ESMF
    implicit none
    type(ESMF_CplComp) :: cplcomp ! must not be optional
    integer, intent(out) :: rc ! must not be optional
    end subroutine
end interface
integer, intent(out), optional :: rc
```

Derive a CplComp (i.e. Connector) from a generic component by calling into the specified SetServices() routine of the generic component. This is typically the first call in the SetServices() routine of the specializing component, and is followed by NUOPC\_CompSpecialize() calls.

### 3.6.28 NUOPC\_CompFilterPhaseMap - Filter the Phase Map of a GridComp

### **INTERFACE:**

```
! Private name; call using NUOPC_CompFilterPhaseMap()
subroutine NUOPC_GridCompFilterPhaseMap(comp, methodflag, acceptStringList, &
    rc)
```

### **ARGUMENTS:**

### **DESCRIPTION:**

Filter all PhaseMap entries in a GridComp (i.e. Model, Mediator, or Driver) that do *not* match any entry in the acceptStringList.

### 3.6.29 NUOPC\_CompFilterPhaseMap - Filter the Phase Map of a CplComp

### INTERFACE:

```
! Private name; call using NUOPC_CompFilterPhaseMap()
subroutine NUOPC_CplCompFilterPhaseMap(comp, methodflag, acceptStringList, &
    rc)
```

#### **DESCRIPTION:**

Filter all PhaseMap entries in a CplComp (i.e. Connector) that do *not* match any entry in the acceptStringList.

## 3.6.30 NUOPC\_CompGet - Access info from GridComp

### INTERFACE:

```
! Private name; call using NUOPC_CompGet() subroutine NUOPC_GridCompGet(comp, name, verbosity, profiling, diagnostic, rc)
```

#### **ARGUMENTS:**

### DESCRIPTION:

Access information from a GridComp.

### 3.6.31 NUOPC\_CompGet - Access info from CplComp

### INTERFACE:

```
! Private name; call using NUOPC_CompGet() subroutine NUOPC_CplCompGet(comp, name, verbosity, profiling, diagnostic, rc)
```

Access information from a CplComp.

### 3.6.32 NUOPC\_CompSearchPhaseMap - Search the Phase Map of a GridComp

#### INTERFACE:

```
! Private name; call using NUOPC_CompSearchPhaseMap()
subroutine NUOPC_GridCompSearchPhaseMap(comp, methodflag, internalflag, &
    phaseLabel, phaseIndex, rc)
```

#### **ARGUMENTS:**

# **DESCRIPTION:**

Search all PhaseMap entries in a GridComp (i.e. Model, Mediator, or Driver) to see if phaseLabel is found. Return the associated ESMF phaseIndex, or -1 if not found. If phaseLabel is not specified, set phaseIndex to the first entry in the PhaseMap, or -1 if there are no entries. The internalflag argument allows to search the internal phase maps of driver components. The default is internalflag=.false..

# 3.6.33 NUOPC\_CompSearchPhaseMap - Search the Phase Map of a CplComp

### **INTERFACE:**

```
! Private name; call using NUOPC_CompSearchPhaseMap()
subroutine NUOPC_CplCompSearchPhaseMap(comp, methodflag, phaseLabel, &
    phaseIndex, rc)
```

Search all PhaseMap entries in a CplComp (i.e. Connector) to see if phaseLabel is found. Return the associated ESMF phaseIndex, or -1 if not found. If phaseLabel is not specified, set phaseIndex to the first entry in the PhaseMap, or -1 if there are no entries.

### 3.6.34 NUOPC\_CompSearchRevPhaseMap - Reverse Search the Phase Map of a GridComp

#### INTERFACE:

```
! Private name; call using NUOPC_CompSearchRevPhaseMap()
subroutine NUOPC_GridCompSearchRevPhaseMap(comp, methodflag, internalflag, &
    phaseIndex, phaseLabel, rc)
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Search all PhaseMap entries in a GridComp (i.e. Model, Mediator, or Driver) to see if the ESMF phaseIndex is found. Return the associated phaseLabel, or an empty string if not found. If phaseIndex is not specified, set phaseLabel to the first entry in the PhaseMap, or an empty string if there are no entries. The internal flag argument allows to search the internal phase maps of driver components. The default is internal flag...

### 3.6.35 NUOPC\_CompSearchRevPhaseMap - Reverse Search the Phase Map of a CplComp

### INTERFACE:

```
! Private name; call using NUOPC_CompSearchRevPhaseMap()
subroutine NUOPC_CplCompSearchRevPhaseMap(comp, methodflag, phaseIndex, &
    phaseLabel, rc)
```

Search all PhaseMap entries in a CplComp (i.e. Connector) to see if the ESMF phaseIndex is found. Return the associated phaseLabel, or an empty string if not found. If phaseIndex is not specified, set phaseLabel to the first entry in the PhaseMap, or an empty string if there are no entries.

### 3.6.36 NUOPC\_CompSetClock - Initialize and set the internal Clock of a GridComp

#### INTERFACE:

```
! Private name; call using NUOPC_CompSetClock()
subroutine NUOPC_GridCompSetClock(comp, externalClock, stabilityTimeStep, rc)
```

### **ARGUMENTS:**

#### **DESCRIPTION:**

Set the component internal clock as a copy of externalClock, but with a timeStep that is less than or equal to the stabilityTimeStep. At the same time ensure that the timeStep of the external clock is a multiple of the timeStep of the internal clock. If the stabilityTimeStep argument is not provided then the internal clock will simply be set as a copy of the external clock.

### 3.6.37 NUOPC\_CompSetEntryPoint - Set entry point for a GridComp (DEPRECATED!)

#### INTERFACE:

```
! Private name; call using NUOPC_CompSetEntryPoint()
subroutine NUOPC_GridCompSetEntryPoint(comp, methodflag, phaseLabelList, &
    userRoutine, rc)
```

```
use ESMF_ClockMod
implicit none
type(ESMF_GridComp) :: gridcomp ! must not be optional
type(ESMF_State) :: importState ! must not be optional
type(ESMF_State) :: exportState ! must not be optional
type(ESMF_Clock) :: clock ! must not be optional
integer, intent(out) :: rc ! must not be optional
end subroutine
end interface
integer, intent(out), optional :: rc
```

Set an entry point for a GridComp (i.e. Model, Mediator, or Driver). Publish the new entry point in the correct PhaseMap component attribute.

Starting with version 8.1.0, the use of this method is deprecated. Components should instead specialize exclusively using the NUOPC\_CompSpecialize() method.

### 3.6.38 NUOPC\_CompSetEntryPoint - Set entry point for a CplComp (DEPRECATED!)

### **INTERFACE:**

```
! Private name; call using NUOPC_CompSetEntryPoint()
subroutine NUOPC_CplCompSetEntryPoint(comp, methodflag, phaseLabelList, &
  userRoutine, rc)
```

### ARGUMENTS:

```
type (ESMF_CplComp)
                                                  :: comp
type(ESMF_Method_Flag), intent(in)
                                                 :: methodflag
character(len=*), intent(in)
                                                  :: phaseLabelList(:)
interface
  subroutine userRoutine(cplcomp, importState, exportState, clock, rc)
     use ESMF_CompMod
     use ESMF_StateMod
    use ESMF_ClockMod
     implicit none
                                 :: cplcomp ! must not be optional
:: importState ! must not be optional
:: exportState ! must not be optional
:: clock ! must not be optional
:: rc ! must not be optional
    type(ESMF_CplComp)
    type(ESMF_State)
    type(ESMF_State)
type(ESMF_Clock)
    integer, intent(out)
  end subroutine
end interface
integer,
                      intent(out), optional :: rc
```

### **DESCRIPTION:**

Set an entry point for a CplComp (i.e. Connector). Publish the new entry point in the correct PhaseMap component attribute.

Starting with version 8.1.0, the use of this method is deprecated. Components should instead specialize exclusively using the NUOPC\_CompSpecialize() method.

### 3.6.39 NUOPC\_CompSetInternalEntryPoint - Set internal entry point for a GridComp

#### INTERFACE:

```
! Private name; call using NUOPC_CompSetInternalEntryPoint()
subroutine NUOPC_GridCompSetIntEntryPoint(comp, methodflag, phaseLabelList, &
    userRoutine, rc)
```

#### **ARGUMENTS:**

```
type(ESMF_GridComp)
                                                         :: comp
type(ESMF_Method_Flag), intent(in)
                                                        :: methodflag
character(len=*), intent(in)
                                                        :: phaseLabelList(:)
interface
  subroutine userRoutine(gridcomp, importState, exportState, clock, rc)
     use ESMF_CompMod
     use ESMF_StateMod
     use ESMF_ClockMod
     implicit none
     type(ESMF_GridComp) :: gridcomp ! must not be optional type(ESMF_State) :: importState ! must not be optional type(ESMF_State) :: exportState ! must not be optional type(ESMF_Clock) :: clock ! must not be optional integer, intent(out) :: rc ! must not be optional
  end subroutine
end interface
                        intent(out), optional :: rc
integer,
```

### **DESCRIPTION:**

Set an *internal* entry point for a GridComp (i.e. Driver). Only Drivers currently utilize internal entry points. Internal entry points allow user specialization on the driver level during initialization and run sequencing.

### 3.6.40 NUOPC\_CompSetServices - Try to find and call SetServices in a shared object

### **INTERFACE:**

```
! Private name; call using NUOPC_CompSetServices() recursive subroutine NUOPC_GridCompSetServices(comp, sharedObj, userRc, rc)
```

Try to find a routine called "SetServices" in the sharedObj file and execute the routine. An attempt is made to find a routine that is close in name to "SetServices", allowing for compiler name mangling, i.e. upper and lower case, as well as trailing underscores.

### 3.6.41 NUOPC\_CompSetVM - Try to find and call SetVM in a shared object

#### INTERFACE:

```
! Private name; call using NUOPC_CompSetVM()
recursive subroutine NUOPC_GridCompSetVM(comp, sharedObj, userRc, rc)
```

### **ARGUMENTS:**

### **DESCRIPTION:**

Try to find a routine called "SetVM" in the sharedObj file and execute the routine. An attempt is made to find a routine that is close in name to "SetVM", allowing for compiler name mangling, i.e. upper and lower case, as well as trailing underscores.

### 3.6.42 NUOPC\_CompSpecialize - Specialize a derived GridComp

### INTERFACE:

```
! Private name; call using NUOPC_CompSpecialize()
subroutine NUOPC_GridCompSpecialize(comp, specLabel, specPhaseLabel, &
    specRoutine, rc)
```

Specialize a derived GridComp (i.e. Model, Mediator, or Driver). If specPhaseLabel is specified, the specialization only applies to the associated phase. Otherwise the specialization applies to all phases.

### 3.6.43 NUOPC\_CompSpecialize - Specialize a derived CplComp

#### INTERFACE:

```
! Private name; call using NUOPC_CompSpecialize()
subroutine NUOPC_CplCompSpecialize(comp, specLabel, specPhaseLabel, &
    specRoutine, rc)
```

#### **ARGUMENTS:**

```
type (ESMF_CplComp)
                                     :: comp
character(len=*), intent(in)
                                   :: specLabel
character(len=*), intent(in), optional :: specPhaseLabel
interface
 subroutine specRoutine(cplcomp, rc)
   use ESMF
   implicit none
   type(ESMF_CplComp)
                         :: cplcomp ! must not be optional
   integer, intent(out)
                            :: rc ! must not be optional
 end subroutine
end interface
                intent(out), optional :: rc
integer,
```

### **DESCRIPTION:**

Specialize a derived CplComp (i.e. Connector). If specPhaseLabel is specified, the specialization only applies to the associated phase. Otherwise the specialization applies to all phases.

### 3.7 Field Dictionary Methods

### 3.7.1 NUOPC\_FieldDictionaryAddEntry - Add an entry to the NUOPC Field dictionary

#### INTERFACE:

```
subroutine NUOPC_FieldDictionaryAddEntry(standardName, canonicalUnits, rc)
```

### **DESCRIPTION:**

Add an entry to the NUOPC Field dictionary. If necessary the dictionary is first set up.

### 3.7.2 NUOPC\_FieldDictionaryEgest - Egest NUOPC Field dictionary into FreeFormat

#### INTERFACE:

```
subroutine NUOPC_FieldDictionaryEgest(freeFormat, iofmt, rc)
```

### **ARGUMENTS:**

```
type(NUOPC_FreeFormat), intent(out) :: freeFormat
type(ESMF_IOFmt_Flag), intent(in), optional :: iofmt
integer, intent(out), optional :: rc
```

### **DESCRIPTION:**

Egest the contents of the NUOPC Field dictionary into a FreeFormat object. If I/O format option iofmt is provided and equal to ESMF\_IOFMT\_YAML, the FreeFormat object will contain the NUOPC Field dictionary expressed in YAML format. Other values for iofmt are ignored and this method behaves as if the optional iofmt argument were missing. In such a case, freeFormat will contain NUOPC Field dictionary entries in the traditional format. It is the caller's responsibility to destroy the created freeFormat object.

### 3.7.3 NUOPC\_FieldDictionaryGetEntry - Get information about a NUOPC Field dictionary entry

### INTERFACE:

```
subroutine NUOPC_FieldDictionaryGetEntry(standardName, canonicalUnits, rc)
```

Return the canonical units that the NUOPC Field dictionary associates with the standardName.

### 3.7.4 NUOPC\_FieldDictionaryHasEntry - Check whether the NUOPC Field dictionary has a specific entry

### **INTERFACE**:

function NUOPC\_FieldDictionaryHasEntry(standardName, rc)

#### RETURN VALUE:

```
logical :: NUOPC_FieldDictionaryHasEntry
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Return .true. if the NUOPC Field dictionary has an entry with the specified standardName, .false. otherwise.

# 3.7.5 NUOPC\_FieldDictionaryMatchSyno - Check whether the NUOPC Field dictionary considers the standard names synonyms

# INTERFACE:

```
function NUOPC_FieldDictionaryMatchSyno(standardName1, standardName2, rc)
```

### RETURN VALUE:

```
logical :: NUOPC_FieldDictionaryMatchSyno
```

```
character(*),
character(*),
intent(in)
intent(in)
intent(in)
intent(out), optional
:: rc
```

Return .true. if the NUOPC Field dictionary considers standardName1 and standardName2 synonyms, .false. otherwise. Also, if standardName1 and/or standardName2 do not correspond to an existing dictionary entry, .false. will be returned.

# 3.7.6 NUOPC\_FieldDictionarySetSyno - Set synonyms in the NUOPC Field dictionary

#### INTERFACE:

```
subroutine NUOPC_FieldDictionarySetSyno(standardNames, rc)
```

### **ARGUMENTS:**

```
character(*),
integer,
intent(in)
intent(out), optional :: rc
```

#### **DESCRIPTION:**

Set all of the elements of the standardNames argument to be considered synonyms by the field dictionary. Every element in standardNames must correspond to the standard name of already existing entries in the field dictionary, or else an error will be returned.

### 3.7.7 NUOPC\_FieldDictionarySetup - Setup the default NUOPC Field dictionary

### INTERFACE:

```
! Private name; call using NUOPC_FieldDictionarySetup()
subroutine NUOPC_FieldDictionarySetupDefault(rc)
```

### **ARGUMENTS:**

```
integer, intent(out), optional :: rc
```

### **DESCRIPTION:**

Setup the default NUOPC Field dictionary.

### 3.7.8 NUOPC\_FieldDictionarySetup - Setup the NUOPC Field dictionary from file

### **INTERFACE:**

```
! Private name; call using NUOPC_FieldDictionarySetup() subroutine NUOPC_FieldDictionarySetupFile(fileName, rc)
```

#### **DESCRIPTION:**

Setup the NUOPC Field dictionary by reading its content from YAML file. If the NUOPC Field dictionary already exists, remove it and create a new one. This feature requires ESMF built with YAML support. Please see the ESMF User's Guide for details.

#### 3.8 Free Format Methods

### 3.8.1 NUOPC FreeFormatAdd - Add lines to a FreeFormat object

#### INTERFACE:

```
subroutine NUOPC FreeFormatAdd(freeFormat, stringList, line, rc)
```

### **ARGUMENTS:**

### **DESCRIPTION:**

Add lines to a FreeFormat object. The capacity of freeFormat may increase during this operation. The new lines provided in stringList are added starting at position line. If line is greater than the current lineCount of freeFormat, blank lines are inserted to fill the gap. By default, i.e. without specifying the line argument, the elements in stringList are added to the *end* of the freeFormat object.

### 3.8.2 NUOPC FreeFormatCreate - Create a FreeFormat object

### **INTERFACE:**

```
! Private name; call using NUOPC_FreeFormatCreate() function NUOPC FreeFormatCreateDefault(freeFormat, stringList, capacity, rc)
```

### RETURN VALUE:

```
type(NUOPC_FreeFormat) :: NUOPC_FreeFormatCreateDefault
```

#### **DESCRIPTION:**

Create a new FreeFormat object, which by default is empty. If freeFormat is provided, then the newly created object starts as a copy of freeFormat. If stringList is provided, then it is added to the end of the newly created object. If capacity is provided, it is used for the *initial* creation of the newly created FreeFormat object. However, if the freeFormat or stringList arguments are present, the final capacity may be larger than specified by capacity.

### 3.8.3 NUOPC\_FreeFormatCreate - Create a FreeFormat object from Config

### **INTERFACE:**

```
! Private name; call using NUOPC_FreeFormatCreate()
function NUOPC_FreeFormatCreateRead(config, label, relaxedflag, rc)
```

### RETURN VALUE:

```
type(NUOPC_FreeFormat) :: NUOPC_FreeFormatCreateRead
```

### **ARGUMENTS:**

### **DESCRIPTION:**

Create a new FreeFormat object from ESMF\_Config object. The config object must exist, and label must reference either a single line or a table attribute within config. The content of the attribute is read and returned in the newly created FreeFormat object.

By default an error is returned if label is not found in config. This error can be suppressed by setting relaxedflag=.true., in which case an empty FreeFormat object is returned.

### 3.8.4 NUOPC\_FreeFormatDestroy - Destroy a FreeFormat object

#### **INTERFACE:**

```
subroutine NUOPC_FreeFormatDestroy(freeFormat, rc)
```

#### **DESCRIPTION:**

Destroy a FreeFormat object. All internal memory is deallocated.

# 3.8.5 NUOPC\_FreeFormatGet - Get information from a FreeFormat object

#### INTERFACE:

```
subroutine NUOPC_FreeFormatGet(freeFormat, lineCount, capacity, stringList, rc)
```

#### **ARGUMENTS:**

```
type(NUOPC_FreeFormat),
integer,
integer,
character(len=NUOPC_FreeFormatLen),
integer,
integer,
character(len=NUOPC_FreeFormatLen),
integer,
integer,
integer,
intent(in) :: freeFormat
intent(out) :: lineCount
intent(out) :: capacity
integer,
integer,
integer,
intent(in) :: freeFormat
intent(out) :: rc
```

### **DESCRIPTION:**

Get information from a FreeFormat object.

### 3.8.6 NUOPC\_FreeFormatGetLine - Get line info from a FreeFormat object

#### INTERFACE:

```
subroutine NUOPC_FreeFormatGetLine(freeFormat, line, lineString, tokenCount, &
   tokenList, rc)
```

Get information about a specific line in a FreeFormat object.

### 3.8.7 NUOPC\_FreeFormatLog - Write a FreeFormat object to the default Log

#### **INTERFACE:**

```
subroutine NUOPC_FreeFormatLog(freeFormat, rc)
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Write a FreeFormat object to the default Log.

### 3.8.8 NUOPC\_FreeFormatPrint - Print a FreeFormat object

### **INTERFACE:**

```
subroutine NUOPC_FreeFormatPrint(freeFormat, rc)
```

### **ARGUMENTS:**

# DESCRIPTION:

Print a FreeFormat object.

# 3.9 Utility Routines

### 3.9.1 NUOPC\_AddNamespace - Add a nested state with Namespace to a State

### INTERFACE:

```
subroutine NUOPC_AddNamespace(state, Namespace, nestedStateName, &
   nestedState, rc)
```

#### **DESCRIPTION:**

Add a Namespace to state. Namespaces are implemented via nested states. This creates a nested state inside of state. The nested state is returned as nestedState. If provided, nestedStateName will be used to name the newly created nested state. The default name of the nested state is equal to Namespace.

The arguments are:

**state** The ESMF State object to which the Namespace is added.

Namespace The Namespace string.

[nestedStateName] Name of the nested state. Defaults to Namespace.

[nestedState] Optional return of the newly created nested state.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

#### 3.9.2 NUOPC AddNestedState - Add a nested state to a state with NUOPC attributes

#### INTERFACE:

```
subroutine NUOPC_AddNestedState(state, Namespace, CplSet, nestedStateName, &
    vm, nestedState, rc)
```

# ARGUMENTS:

### DESCRIPTION:

Create a nested state inside of state. The arguments Namespace and tt CplSet are used to set NUOPC attributes on the newly created state. The nested state is returned as nestedState. If provided, nestedStateName will be used to name the newly created nested state. The default name of the nested state is equal to Namespace\_CplSet, Namespace, or CplSet if the arguments are provided.

The arguments are:

state The ESMF\_State object to which the namespace is added.

[Namespace] Optional The Namespace string. Defaults to "UNSPECIFIED".

[CplSet] Optional The CplSet string. Defaults to "\_\_UNSPECIFIED\_\_".

[nestedStateName] Name of the nested state. Defaults to Namespace\_CplSet, Namespace, or CplSet if arguments are provided.

[vm] If present, the nested state object is created on the specified ESMF\_VM object. The default is to create the nested state object on the VM of the current component context.

[nestedState] Optional return of the newly created nested state.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.9.3 NUOPC\_Advertise - Advertise a single Field in a State

#### INTERFACE:

```
! Private name; call using NUOPC_Advertise()
subroutine NUOPC_AdvertiseField(state, StandardName, Units, &
   LongName, ShortName, name, TransferOfferGeomObject, SharePolicyField, &
   SharePolicyGeomObject, vm, field, rc)
```

#### **ARGUMENTS:**

### **DESCRIPTION:**

Advertise a field in a state. This creates an empty field and adds it to state. The "StandardName", "Units", "Long-Name", "ShortName", and "TransferOfferGeomObject" attributes of the field are set according to the provided input...

The call checks the provided information against the NUOPC Field Dictionary to ensure correctness. Defaults are set according to the NUOPC Field Dictionary.

The arguments are:

**state** The ESMF\_State object through which the field is advertised.

- **StandardName** The "StandardName" attribute of the advertised field. Must be a StandardName found in the NUOPC Field Dictionary.
  - NOTE that if by below default rules, StandardName is also used as the input for name, then it must not contain the slash ("/") character.
- [Units] The "Units" attribute of the advertised field. Must be convertible to the canonical units specified in the NUOPC Field Dictionary for the specified StandardName. (Currently this is restricted to be identical to the canonical units specified in the NUOPC Field Dictionary.) If omitted, the default is to use the canonical units associated with the StandardName in the NUOPC Field Dictionary.
- [LongName] The "LongName" attribute of the advertised field. NUOPC does not restrict the value of this attribute. If omitted, the default is to use the StandardName.
- [ShortName] The "ShortName" attribute of the advertised field. NUOPC does not restrict the value of this attribute. If omitted, the default is to use the StandardName.
  - NOTE that if by below default rules, ShortName is also used as the input for name, then it must not contain the slash ("/") character.
- [name] The actual name of the advertised field by which it is accessed in the state object. The string provided for name must not contain the slash ("/") character. If omitted, the default is to use the value of the ShortName.
- [TransferOfferGeomObject] If the state intent of state is ESMF\_STATEINTENT\_EXPORT, the "ProducerTransferOffer" attribute of the advertised field is set. If the state intent of state is ESMF\_STATEINTENT\_IMPORT, the "ConsumerTransferOffer" attribute of the advertised field is set. NUOPC controls the vocabulary of this attribute. Valid options are "will provide", "can provide", "cannot provide". If omitted, the default is "will provide".
- [SharePolicyField] The "SharePolicyField" attribute of the advertised field. NUOPC controls the vocabulary of this attribute. Valid options are "share", and "not share". If omitted, the default is "not share".
- [SharePolicyGeomObject] The "SharePolicyGeomObject" attribute of the advertised field. NUOPC controls the vocabulary of this attribute. Valid options are "share", and "not share". If omitted, the default is equal to SharePolicyField.
- [vm] If present, the Field object used during advertising is created on the specified ESMF\_VM object. The default is to create the Field object on the VM of the current component context.
- [field] Returns the empty field object that was used to advertise.
- [rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.9.4 NUOPC\_Advertise - Advertise a list of Fields in a State

### INTERFACE:

```
! Private name; call using NUOPC_Advertise()
subroutine NUOPC_AdvertiseFields(state, StandardNames, &
   TransferOfferGeomObject, SharePolicyField, SharePolicyGeomObject, rc)
```

Advertise a list of fields in a state. This creates a list of empty fields and adds it to the state. The "StandardName", "TransferOfferGeomObject", "SharePolicyField", and "SharePolicyGeomObject" attributes of all the fields are set according to the provided input. The "Units", "LongName", and "ShortName" attributes for each field are set according to the defaults documented under method 3.9.3

The call checks the provided information against the NUOPC Field Dictionary to ensure correctness.

The arguments are:

**state** The ESMF\_State object through which the fields are advertised.

**StandardNames** A list of "StandardName" attributes of the advertised fields. Must be StandardNames found in the NUOPC Field Dictionary.

[TransferOfferGeomObject] The "TransferOfferGeomObject" attribute of the advertised fields. This setting applies to all the fields advertised in this call. NUOPC controls the vocabulary of this attribute. Valid options are "will provide", "can provide", "cannot provide". If omitted, the default is "will provide".

[SharePolicyField] The "SharePolicyField" attribute of the advertised fields. This setting applies to all the fields advertised in this call. NUOPC controls the vocabulary of this attribute. Valid options are "share", and "not share". If omitted, the default is "not share".

[SharePolicyGeomObject] The "SharePolicyGeomObject" attribute of the advertised fields. This setting applies to all the fields advertised in this call. NUOPC controls the vocabulary of this attribute. Valid options are "share", and "not share". If omitted, the default is equal to SharePolicyField.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.9.5 NUOPC AdjustClock - Adjust the timestep in a clock

### INTERFACE:

```
subroutine NUOPC_AdjustClock(clock, maxTimestep, rc)
```

### **ARGUMENTS:**

# **DESCRIPTION:**

Adjust the clock to have a potentially smaller timestep. The timestep on the incoming clock object is compared to the maxTimestep, and reset to the smaller of the two.

The arguments are:

**clock** The clock to be adjusted.

[maxTimestep] Upper bound of the timestep allowed in clock.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.9.6 NUOPC\_CheckSetClock - Check a Clock for compatibility and set its values

### **INTERFACE:**

```
subroutine NUOPC_CheckSetClock(setClock, checkClock, setStartTimeToCurrent, &
    currTime, forceCurrTime, checkTimeStep, forceTimeStep, rc)
```

#### **ARGUMENTS:**

```
intent(inout)
                                             :: setClock
type(ESMF_Clock),
                                             :: checkClock
type(ESMF_Clock),
                       intent(in)
logical,
                       intent(in), optional :: setStartTimeToCurrent
type(ESMF_Time),
                      intent(in), optional :: currTime
logical,
                       intent(in), optional :: forceCurrTime
                       intent(in), optional :: checkTimeStep
logical,
                       intent(in), optional :: forceTimeStep
logical,
integer,
                       intent(out), optional :: rc
```

### **DESCRIPTION:**

By default compare setClock to checkClock to ensure they match in their current time. Further ensure that the timeStep of checkClock is a multiple of the timeStep of setClock. If both conditions are satisfied then the stopTime of the setClock is set one checkClock timeStep, or setClock runDuration, ahead of the current time, which ever is shorter. The direction of checkClock is considered when setting the stopTime.

By default the startTime of the setClock is not modified. However, if setStartTimeToCurrent == .true. the startTime of setClock is set to the currentTime of checkClock.

The arguments are:

setClock The ESMF\_Clock object to be checked and set.

**checkClock** The reference clock object.

[setStartTimeToCurrent] If .true. then also set the startTime in setClock according to the startTime in checkClock. The default is .false..

[currTime] If provided, use currTime instead of checkClock when checking or setting the current time of setClock.

- [forceCurrTime] If .true. then do not check the current time of the setClock, but instead force it to align with the checkClock, or currTime, if it was provided. The default is .false..
- [checkTimeStep] If .true. then check that timeStep of the setClock can reach the next increment on the checkClock by an integer number of steps. For .false. do not check this condition. The default is .true..
- [forceTimeStep] If .true. then do *not* use the timeStep of the setClock to check if the next increment on the checkClock can be reached in an integer number of steps. Instead set the timeStep of the setClock to the timeStep of the checkClock. The default is .false..
- [rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.9.7 NUOPC\_GetAttribute - Get the value of a NUOPC Field Attribute

#### INTERFACE:

```
! Private name; call using NUOPC_GetAttribute() subroutine NUOPC_GetAttributeFieldVal(field, name, value, isPresent, isSet, rc)
```

### **ARGUMENTS:**

### DESCRIPTION:

Access the attribute name inside of field using the convention NUOPC and purpose Instance.

Unless isPresent and isSet are provided, return with error if the Attribute is not present or not set, respectively.

The arguments are:

**field** The ESMF\_Field object to be queried.

name The name of the queried attribute.

**value** The value of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.9.8 NUOPC\_GetAttribute - Get the typekind of a NUOPC Field Attribute

#### INTERFACE:

```
! Private name; call using NUOPC_GetAttribute()
subroutine NUOPC_GetAttributeFieldTK(field, name, isPresent, isSet, &
  itemCount, typekind, rc)
```

#### **ARGUMENTS**:

### **DESCRIPTION:**

Query the typekind of the attribute name inside of field using the convention NUOPC and purpose Instance. Unless isPresent and isSet are provided, return with error if the Attribute is not present or not set, respectively. The arguments are:

field The ESMF\_Field object to be queried.

name The name of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

**[itemCount]** Number of items in the attribute. Return 0 if not present or not set.

**[typekind]** The typekind of the queried attribute.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.9.9 NUOPC GetAttribute - Get the value of a NUOPC State Attribute

### INTERFACE:

```
! Private name; call using NUOPC_GetAttribute()
subroutine NUOPC_GetAttributeState(state, name, value, isPresent, isSet, &
  itemCount, typekind, rc)
```

Access the attribute name inside of state using the convention NUOPC and purpose Instance. Returns with error if the attribute is not present or not set.

Unless isPresent and isSet are provided, return with error if the Attribute is not present or not set, respectively.

The arguments are:

```
state The ESMF_State object to be queried.
```

**name** The name of the queried attribute.

[value] The value of the queried attribute.

[isPresent] Set to .true. if the queried attribute is present, .false. otherwise.

[isSet] Set to .true. if the queried attribute is set, .false. otherwise.

**[itemCount]** Number of items in the attribute. Return 0 if not present or not set.

**[typekind]** The typekind of the queried attribute.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.9.10 NUOPC GetStateMemberLists - Build lists of information of State members

### INTERFACE:

```
subroutine NUOPC_GetStateMemberLists(state, StandardNameList, &
   ConnectedList, NamespaceList, CplSetList, itemNameList, fieldList, &
   stateList, nestedFlag, rc)
```

Construct lists containing the StandardNames, field names, and connected status of the fields in state. Return this information in the list arguments. Recursively parse through nested States.

All pointer arguments present must enter this method unassociated. This means that the user code must explicitly call nullify() or use the => null() syntax on the variables passed in as any of the pointer arguments. On return, the pointer arguments may either be unassociated or associated. Consequently the user code must first check the status of any of the returned pointer arguments via the associated() intrinsic before accessing the argument. The responsibility for deallocation of associated pointer arguments transfers to the caller.

The arguments are:

**state** The ESMF\_State object to be queried.

- [StandardNameList] If present, return a list of the "StandardName" attribute of each member. See the note about pointer arguments in the description section above for correct usage.
- [ConnectedList] If present, return a list of the "Connected" attribute of each member. See the note about pointer arguments in the description section above for correct usage.
- [NamespaceList] If present, return a list of the "Namespace" attribute of each member. See the note about pointer arguments in the description section above for correct usage.
- [CplSetList] If present, return a list of the "CplSet" attribute of each member. See the note about pointer arguments in the description section above for correct usage.
- [itemNameList] If present, return a list of each member name. See the note about pointer arguments in the description section above for correct usage.
- [fieldList] If present, return a list of the member fields. See the note about pointer arguments in the description section above for correct usage.
- [stateList] If present, return a list of the states corresonding to the owner of the fields returned under fieldList. See the note about pointer arguments in the description section above for correct usage.
- [nestedFlag] When set to .true., returns information from nested States (default). When set to .false., returns information at the current State level only.
- [rc] Return code; equals ESMF\_SUCCESS if there are no errors.

# 3.9.11 NUOPC\_GetStateMemberCount - Determing number of State members

#### INTERFACE:

```
subroutine NUOPC_GetStateMemberCount(state, fieldCount, nestedFlag, rc)
```

Determine the number of fields in state. By default recursively parse through nested States.

The arguments are:

**state** The ESMF\_State object to be queried.

[fieldCount] Number of fields.

[nestedFlag] When set to .true., returns information from nested States (default). When set to .false., returns information at the current State level only.

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

# 3.9.12 NUOPC\_GetTimestamp - Get the timestamp of a Field

### INTERFACE:

```
subroutine NUOPC_GetTimestamp(field, isValid, time, rc)
```

### **ARGUMENTS:**

### DESCRIPTION:

Access the timestamp on field in form of an ESMF\_Time object.

The arguments are:

**field** The ESMF\_Field object to be checked.

[isValid] Set to .true. if the timestamp is valid, .false. otherwise.

[time] The timestamp as ESMF\_Time object.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

### 3.9.13 NUOPC\_IngestPetList - Ingest a petList from FreeFormat

# INTERFACE:

```
subroutine NUOPC_IngestPetList(petList, freeFormat, rc)
```

```
integer, allocatable, intent(out) :: petList(:)
type(NUOPC_FreeFormat), intent(in), target :: freeFormat
integer, intent(out), optional :: rc
```

#### DESCRIPTION:

Construct a petList from a FreeFormat object.

The arguments are:

**petList** The constructed petList. The size and content is set by this method.

freeFormat The incoming petList information in free format. The format supports two types of elements:

- Single PET elements consist of a single number referring to the PET.
- Block elements consist of two PET numbers, separated by a "-" character. No white spaces are accepted between the dash and the PET numbers. A block element includes all of the PETs between the lower bound (left PET number), and the upper bound (right PET number), bounds inclusive. The upper bound must *not* be less than the lower bound.

Any number of elements may be listed in the free format. The idividual elements are separated by white spaces. For an example, the free format petList definition

```
"2-5 12 0 15-23"
```

would translate into a petList output of

```
(/2, 3, 4, 5, 12, 0, 15, 16, 17, 18, 19, 20, 21, 22, 23/)
```

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.14 NUOPC\_IsAtTime - Check if a Field is at the given Time

#### **INTERFACE:**

```
! Private name; call using NUOPC_IsAtTime()
function NUOPC_IsAtTimeField(field, time, rc)
```

### RETURN VALUE:

```
logical :: NUOPC_IsAtTimeField
```

## DESCRIPTION:

Returns .true. if field has a timestamp that matches time. Otherwise returns .false.. On PETs with only a proxy instance of the field, .true. is returned regardless of the actual timestamp.

The arguments are:

field The ESMF Field object to be checked.

**time** The time to compare against.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.15 NUOPC\_IsAtTime - Check if Field(s) in a State are at the given Time

## INTERFACE:

```
! Private name; call using NUOPC_IsAtTime()
function NUOPC_IsAtTimeState(state, time, fieldName, count, fieldList, rc)
```

## RETURN VALUE:

```
logical :: NUOPC_IsAtTimeState
```

#### **ARGUMENTS:**

#### **DESCRIPTION:**

Return .true. if the field(s) in state have a timestamp that matches time. Otherwise return .false..

The arguments are:

state The ESMF\_State object to be checked.

**time** The time to compare against.

[fieldName] The name of the field in state to be checked. If provided, and the state does not contain a field with fieldName, return an error in rc. If not provided, check *all* the fields contained in state and return .true. if all the fields are at the correct time.

[count] If provided, the number of fields that are at time are returned. If fieldName is present then count cannot be greater than 1.

[fieldList] If provided, the fields that are *not* at time are returned. If fieldName is present then fieldList can contain a maximum of 1 field.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.16 NUOPC IsConnected - Check if a Field is connected

## **INTERFACE:**

```
! Private name; call using NUOPC_IsConnected()
function NUOPC_IsConnectedField(field, rc)
```

## RETURN VALUE:

```
logical :: NUOPC_IsConnectedField
```

## ARGUMENTS:

```
type(ESMF_Field), intent(in) :: field
integer, intent(out), optional :: rc
```

## **DESCRIPTION:**

Return .true. if the field is connected. Otherwise return .false..

The arguments are:

field The ESMF\_Field object to be checked.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.17 NUOPC\_IsConnected - Check if Field(s) in a State are connected

## **INTERFACE**:

```
! Private name; call using NUOPC_IsConnected() function NUOPC_IsConnectedState(state, fieldName, count, rc)
```

## RETURN VALUE:

```
logical :: NUOPC_IsConnectedState
```

#### **ARGUMENTS:**

#### DESCRIPTION:

Return .true. if the field(s) in state are connected. Otherwise return .false..

The arguments are:

state The ESMF\_State object to be checked.

[fieldName] The name of the field in state to be checked. If provided, and the state does not contain a field with fieldName, return an error in rc. If not provided, check *all* the fields contained in state and return .true. if all the fields are connected.

[count] If provided, the number of fields that are connected are returned. If fieldName is present then count cannot be greater than 1.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.18 NUOPC\_IsUpdated - Check if a Field is marked as updated

## INTERFACE:

```
! Private name; call using NUOPC_IsUpdated()
function NUOPC_IsUpdatedField(field, rc)
```

## RETURN VALUE:

```
logical :: NUOPC_IsUpdatedField
```

#### **ARGUMENTS:**

```
type(ESMF_Field), intent(in) :: field
integer, intent(out), optional :: rc
```

## DESCRIPTION:

Return .true. if the field has its "Updated" attribute set to "true". Otherwise return .false..

The arguments are:

field The ESMF\_Field object to be checked.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.19 NUOPC\_IsUpdated - Check if Field(s) in a State are marked as updated

## INTERFACE:

```
! Private name; call using NUOPC_IsUpdated()
function NUOPC_IsUpdatedState(state, fieldName, count, rc)
```

#### RETURN VALUE:

```
logical :: NUOPC_IsUpdatedState
```

## **ARGUMENTS:**

## **DESCRIPTION:**

Return .true. if the field(s) in state have the "Updated" attribute set to "true". Otherwise return .false..

The arguments are:

state The ESMF\_State object to be checked.

[fieldName] The name of the field in state to be checked. If provided, and the state does not contain a field with fieldName, return an error in rc. If not provided, check *all* the fields contained in state and return .true. if all the fields are updated.

[count] If provided, the number of fields that are updated are returned. If fieldName is present then count cannot be greater than 1.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.20 NUOPC\_NoOp - No-Operation attachable method for GridComp

## INTERFACE:

```
subroutine NUOPC_NoOp(gcomp, rc)
```

## ARGUMENTS:

```
type(ESMF_GridComp) :: gcomp
integer, intent(out) :: rc
```

## **DESCRIPTION:**

No-Op method with an interface that matches the requirements for a attachable method for ESMF\_GridComp objects. The arguments are:

**gcomp** The ESMF\_GridComp object to which this method is attached.

rc Return code; equals ESMF\_SUCCESS if there are no errors.

# 3.9.21 NUOPC\_Realize - Realize previously advertised Fields inside a State on a single Grid with internal allocation

#### INTERFACE:

```
! Private name; call using NUOPC_Realize()
subroutine NUOPC_RealizeCompleteG(state, grid, fieldName, typekind, &
    staggerloc, selection, dataFillScheme, field, rc)
```

#### **ARGUMENTS:**

#### **DESCRIPTION:**

Realize or remove fields inside of state according to selection. All of the fields that are realized are created internally on the same grid object, allocating memory for as many field dimensions as there are grid dimensions.

The type and kind of the created fields is according to argument typekind.

Realized fields are filled with data according to the dataFillScheme argument.

The arguments are:

state The ESMF\_State object in which the fields are realized.

**grid** The ESMF\_Grid object on which to realize the fields.

[fieldName] The name of the field in state to be realized, or removed, according to selection. If provided, and the state does not contain a field with name fieldName, return an error in rc. If not provided, realize *all* the fields contained in state according to selection.

[typekind] The typekind of the internally created field(s). The valid options are ESMF\_TYPEKIND\_I4, ESMF\_TYPEKIND\_I8, ESMF\_TYPEKIND\_R4, and ESMF\_TYPEKIND\_R8. By default use the typekind of the partially created field used during advertise, or ESMF\_TYPEKIND\_R8, if the advertised field did not have a typekind defined.

[staggerloc] Stagger location of data in grid cells. By default use the same stagger location as the advertising field, or ESMF STAGGERLOC CENTER if the advertising field was created empty.

**[selection]** Selection of mode of operation:

- "realize\_all" (default)
- "realize\_connected\_remove\_others"
- "realize\_connected+provide\_remove\_others"

[dataFillScheme] Realized fields will be filled according to the selected fill scheme. See ESMF\_FieldFill() for fill schemes. Default is to leave the data in realized fields uninitialized.

[field] Returns the completed field that was realized by this method. This option is only supported if also argument fieldName was specified.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

# 3.9.22 NUOPC\_Realize - Realize previously advertised Fields inside a State on a single LocStream with internal allocation

#### **INTERFACE:**

```
! Private name; call using NUOPC_Realize()
subroutine NUOPC_RealizeCompleteLS(state, locstream, fieldName, typekind, selection,&
   dataFillScheme, field, rc)
```

#### **ARGUMENTS:**

#### **DESCRIPTION:**

Realize or remove fields inside of state according to selection. All of the fields that are realized are created internally on the same locstream object, allocating memory accordingly.

The type and kind of the created fields is according to argument typekind.

Realized fields are filled with data according to the dataFillScheme argument.

The arguments are:

state The ESMF\_State object in which the fields are realized.

locstream The ESMF LocStream object on which to realize the fields.

[fieldName] The name of the field in state to be realized, or removed, according to selection. If provided, and the state does not contain a field with name fieldName, return an error in rc. If not provided, realize *all* the fields contained in state according to selection.

[typekind] The typekind of the internally created field(s). The valid options are ESMF\_TYPEKIND\_I4, ESMF\_TYPEKIND\_I8, ESMF\_TYPEKIND\_R4, and ESMF\_TYPEKIND\_R8. By default use the typekind of the partially created field used during advertise, or ESMF\_TYPEKIND\_R8, if the advertised field did not have a typekind defined.

[selection] Selection of mode of operation:

```
• "realize_all" (default)
```

• "realize connected remove others"

[dataFillScheme] Realized fields will be filled according to the selected fill scheme. See ESMF\_FieldFill() for fill schemes. Default is to leave the data in realized fields uninitialized.

[field] Returns the completed field that was realized by this method. This option is only supported if also argument fieldName was specified.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

# 3.9.23 NUOPC\_Realize - Realize previously advertised Fields inside a State on a single Mesh with internal allocation

#### INTERFACE:

```
! Private name; call using NUOPC_Realize()
subroutine NUOPC_RealizeCompleteM(state, mesh, fieldName, typekind, &
  meshloc, selection, dataFillScheme, field, rc)
```

#### ARGUMENTS:

```
type(ESMF_State)
type(ESMF_Mesh),
character(*),
type(ESMF_TypeKind_Flag),
intent(in),
type(ESMF_MeshLoc),
character(len=*),
character(len=*),
type(ESMF_Field),
intent(out),
type(ESMF_Field)
intent(out)
int
```

#### **DESCRIPTION:**

Realize or remove fields inside of state according to selection. All of the fields that are realized are created internally on the same mesh object, allocating memory accordingly.

The type and kind of the created fields is according to argument typekind.

Realized fields are filled with data according to the dataFillScheme argument.

The arguments are:

state The ESMF\_State object in which the fields are realized.

mesh The ESMF\_Mesh object on which to realize the fields.

[fieldName] The name of the field in state to be realized, or removed, according to selection. If provided, and the state does not contain a field with name fieldName, return an error in rc. If not provided, realize *all* the fields contained in state according to selection.

[typekind] The typekind of the internally created field(s). The valid options are ESMF\_TYPEKIND\_I4, ESMF\_TYPEKIND\_I8, ESMF\_TYPEKIND\_R4, and ESMF\_TYPEKIND\_R8. By default use the typekind of the partially created field used during advertise, or ESMF\_TYPEKIND\_R8, if the advertised field did not have a typekind defined.

[meshloc] Location of data in the mesh cell. By default use the same mesh location as the advertising field, or ESMF\_STAGGERLOC\_NODE if the advertising field was created empty.

[selection] Selection of mode of operation:

- "realize\_all" (default)
- "realize\_connected\_remove\_others"

[dataFillScheme] Realized fields will be filled according to the selected fill scheme. See ESMF\_FieldFill() for fill schemes. Default is to leave the data in realized fields uninitialized.

[field] Returns the completed field that was realized by this method. This option is only supported if also argument fieldName was specified.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.24 NUOPC\_Realize - Realize a previously advertised Field in a State

#### INTERFACE:

```
! Private name; call using NUOPC_Realize()
subroutine NUOPC RealizeField(state, field, rc)
```

## **ARGUMENTS:**

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

## **DESCRIPTION:**

Realize a previously advertised field in state by replacing the advertised field with field of the same name.

The arguments are:

state The ESMF\_State object in which the fields are realized.

**field** The new field to put in place of the previously advertised (empty) field.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.25 NUOPC\_Realize - Realize a previously advertised Field in a State after Transfer of GeomObject

#### INTERFACE:

```
! Private name; call using NUOPC_Realize()
subroutine NUOPC_RealizeTransfer(state, fieldName, typekind, gridToFieldMap, &
  ungriddedLBound, ungriddedUBound, totalLWidth, totalUWidth, &
  realizeOnlyConnected, removeNotConnected, realizeOnlyNotShared, &
  realizeOnlyNotComplete, field, rc)
```

#### ARGUMENTS:

```
type (ESMF_State)
                                                                          :: state
character(*),
                                       intent(in)
                                                                          :: fieldName
type(ESMF_TypeKind_Flag), intent(in), optional :: typekind
integer, target,
intent(in), optional :: ungriddedLBound(:)
integer,
intent(in), optional :: totalLWidth(:)
                                      intent(in), optional :: totalUWidth(:)
integer,
                                      intent(in), optional :: realizeOnlyConnected
logical,
                                      intent(in), optional :: removeNotConnected
logical,
                                 intent(in), optional :: realizeOnlyNotShared
intent(in), optional :: realizeOnlyNotComplete
intent(out), optional :: field
intent(out) optional :: realizeOnlyNotComplete
logical,
logical,
type(ESMF_Field),
integer,
                                       intent(out), optional :: rc
```

## **DESCRIPTION:**

Realize a field where GeomObject has been set by the NUOPC GeomObject transfer protocol.

The data of the realized field is left uninitialized by this method.

The arguments are:

**state** The ESMF\_State object in which the field is realized.

fieldName The name of the field in state to be realized. If state does not contain a field with name fieldName, return an error in rc.

[typekind] The typekind of the internally created field(s). The valid options are ESMF\_TYPEKIND\_I4, ESMF\_TYPEKIND\_I8, ESMF\_TYPEKIND\_R4, and ESMF\_TYPEKIND\_R8. By default use the typekind of the connected provider field.

- [gridToFieldMap] The mapping of grid/mesh dimensions against field dimensions. The argument is of rank 1 and with a size of dimCount. The elements correspond to the grid/mesh elements in order, and associates it with the indicated field dimension. Only entries between 1 and the field rank are allowed. There must be no duplicate entries in gridToFieldMap. By default use the gridToFieldMap of the connected provider field.
- [ungriddedLBound] Lower bounds of the ungridded dimensions of the field. The number of elements defines the number of ungridded dimensions of the field and must be consistent with ungriddedUBound. By default use the ungriddedLBound of the connected provider field.
- [ungriddedUBound] Upper bounds of the ungridded dimensions of the field. The number of elements defines the number of ungridded dimensions of the field and must be consistent with ungriddedLBound. By default use the ungriddedLBound of the connected provider field.
- **[totalLWidth]** This argument is only supported for fields defined on ESMF\_Grid. The number elements outside the lower bound of the exclusive region. The argument is of rank 1 and with a size of dimCount, the number of gridded dimensions of the field. The ordering of the dimensions is that of the field (considering gridToFieldMap). By default a zero vector is used, resulting in no elements outside the exclusive region.
- **[totalUWidth]** This argument is only supported for fields defined on ESMF\_Grid. The number elements outside the upper bound of the exclusive region. The argument is of rank 1 and with a size of dimCount, the number of gridded dimensions of the field. The ordering of the dimensions is that of the field (considering gridToFieldMap). By default a zero vector is used, resulting in no elements outside the exclusive region.
- [realizeOnlyConnected] If set to .false., realize the specified field irregardless of the connected status. If set to .true., only a connected field will be realized. The default is .true..
- [removeNotConnected] If set to .false., do not remove a field from the state due to its connected status. If set to .true., remove the field if it is not connected. This requires realizeOnlyConnected to be .true., and a runtime error will be returned otherwise. The default is .true..
- [realizeOnlyNotShared] If set to .false., realize the specified field irregardless of its shared status. If set to .true., only a field that has "ShareStatusField" set to "not shared" will be realized. The default is .true..
- [realizeOnlyNotComplete] If set to .false., realize the specified field irregardless of its complete status. If set to .true., only a field that has not yet been completed will be realized. The default is .true..
- [field] Returns the completed field that was realized by this method. An invalid field object will be returned if the conditions were such that the field was not realized.
- [rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.26 NUOPC\_SetAttribute - Set the value of a NUOPC Field Attribute

## **INTERFACE:**

```
! Private name; call using NUOPC_SetAttribute() subroutine NUOPC_SetAttributeField(field, name, value, rc)
```

#### **ARGUMENTS:**

## **DESCRIPTION:**

Set the attribute name inside of field using the convention NUOPC and purpose Instance.

The arguments are:

**field** The ESMF\_Field object on which to set the attribute.

**name** The name of the set attribute.

value The value of the set attribute.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.27 NUOPC SetAttribute - Set the value of a NUOPC State Attribute

## **INTERFACE:**

```
! Private name; call using NUOPC_SetAttribute()
subroutine NUOPC_SetAttributeState(state, name, value, rc)
```

## **ARGUMENTS:**

## **DESCRIPTION:**

Set the attribute name inside of state using the convention NUOPC and purpose Instance.

The arguments are:

**state** The ESMF\_State object on which to set the attribute.

**name** The name of the set attribute.

value The value of the set attribute.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.28 NUOPC\_SetTimestamp - Set the TimeStamp on a Field

## INTERFACE:

```
! Private name; call using NUOPC_SetTimestamp()
subroutine NUOPC_SetTimestampField(field, time, rc)
```

#### **ARGUMENTS:**

## **DESCRIPTION:**

Set the TimeStamp according to time on field.

This call should rarely be needed in user written code.

The arguments are:

**field** The ESMF\_Field object to be time stampped.

time The ESMF\_Time object defining the TimeStamp.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.29 NUOPC\_SetTimestamp - Set the TimeStamp on Fields in a list

#### INTERFACE:

```
! Private name; call using NUOPC_SetTimestamp() subroutine NUOPC_SetTimestampFieldList(fieldList, time, selective, rc)
```

## ARGUMENTS:

### **DESCRIPTION:**

Set the TimeStamp according to time on field.

This call should rarely be needed in user written code.

The arguments are:

**fieldList** The list of ESMF\_Field objects to be time stampped.

time The ESMF\_Time object defining the TimeStamp.

[selective] If .true., then only set the TimeStamp on those fields for which the "Updated" attribute is equal to "true". Otherwise set the TimeStamp on all the fields. Default is .false..

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.30 NUOPC\_SetTimestamp - Set the TimeStamp on Fields in a list from Clock

#### INTERFACE:

```
! Private name; call using NUOPC_SetTimestamp() subroutine NUOPC_SetTimestampFieldListClk(fieldList, clock, selective, rc)
```

#### **ARGUMENTS:**

#### DESCRIPTION:

Set the TimeStamp according to time on field.

This call should rarely be needed in user written code.

The arguments are:

fieldList The list of ESMF\_Field objects to be time stampped.

**clock** The ESMF\_Clock object defining the TimeStamp by its current time.

[selective] If .true., then only set the TimeStamp on those fields for which the "Updated" attribute is equal to "true". Otherwise set the TimeStamp on all the fields. Default is .false..

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.31 NUOPC\_SetTimestamp - Set the TimeStamp on all the Fields in a State

## **INTERFACE:**

```
! Private name; call using NUOPC_SetTimestamp() subroutine NUOPC_SetTimestampState(state, time, selective, rc)
```

## **ARGUMENTS:**

## **DESCRIPTION:**

Set the TimeStamp according to clock on all the fields in state. Depending on selective, all or only some fields may be updated.

This call should rarely be needed in user written code. It is used by the generic Connector.

The arguments are:

**state** The ESMF\_State object holding the fields to be time stampped.

time The ESMF\_Time object defining the TimeStamp.

[selective] If .true., then only set the TimeStamp on those fields for which the "Updated" attribute is equal to "true". Otherwise set the TimeStamp on all the fields. Default is .false..

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.9.32 NUOPC\_SetTimestamp - Set the TimeStamp on all the Fields in a State from Clock

## **INTERFACE:**

```
! Private name; call using NUOPC_SetTimestamp() subroutine NUOPC_SetTimestampStateClk(state, clock, selective, rc)
```

## ARGUMENTS:

#### **DESCRIPTION:**

Set the TimeStamp according to clock on all the fields in state. Depending on selective, all or only some fields may be updated.

This call should rarely be needed in user written code. It is used by the generic Connector.

The arguments are:

**state** The ESMF\_State object holding the fields to be time stampped.

**clock** The ESMF\_Clock object defining the TimeStamp by its current time.

[selective] If .true., then only set the TimeStamp on those fields for which the "Updated" attribute is equal to "true". Otherwise set the TimeStamp on all the fields. Default is .false..

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.10 Auxiliary Routines

Auxiliary routines are provided with the NUOPC Layer as a convenience to the user. Typically more work is needed on these methods before considering them NUOPC core functionality.

## 3.10.1 NUOPC Write - Write a distributed interpolation matrix to file in SCRIP format

#### **INTERFACE:**

```
! Private name; call using NUOPC_Write()
subroutine NUOPC_SCRIPWrite(factorList, factorIndexList, fileName, &
  relaxedflag, rc)
```

## **ARGUMENTS:**

## **DESCRIPTION:**

Write the destributed interpolaton matrix provided by factorList and factorIndexList to a SCRIP formatted NetCDF file. Each PET calls with its local list of factors and indices. The call then writes the distributed factors into a single file. If the file already exists, the contents is replaced by this call.

The arguments are:

factorList The distributed factor list.

factorIndexList The distributed list of source and destination indices.

**fileName** The name of the file to be written to.

[relaxedflag] If .true., then no error is returned even if the call cannot write the file due to library limitations. Default is .false..

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.10.2 NUOPC Write - Write a distributed factorList to file

## INTERFACE:

```
! Private name; call using NUOPC_Write()
subroutine NUOPC_FactorsWrite(factorList, fileName, rc)
```

#### **ARGUMENTS:**

#### DESCRIPTION:

#### THIS METHOD IS DEPRECATED. Use 3.10.1 instead.

Write the destributed factorList to file. Each PET calls with its local list of factors. The call then writes the distributed factors into a single file. The order of the factors in the file is first by PET, and within each PET the PET-local order is preserved. Changing the number of PETs for the same regrid operation will likely change the order of factors across PETs, and therefore files written will differ.

The arguments are:

factorList The distributed factor list.

**fileName** The name of the file to be written to.

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 3.10.3 NUOPC\_Write - Write Field data to file

## INTERFACE:

```
! Private name; call using NUOPC_Write()
subroutine NUOPC_FieldWrite(field, fileName, overwrite, status, timeslice, &
  iofmt, relaxedflag, rc)
```

#### **ARGUMENTS:**

## **DESCRIPTION:**

Write the data in field to file under the field's "StandardName" attribute if supported by the iofmt.

The arguments are:

field The ESMF\_Field object whose data is to be written.

fileName The name of the file to write to.

[overwrite] A logical flag, the default is .false., i.e., existing Field data may *not* be overwritten. If .true., the data corresponding to each field's name will be be overwritten. If the timeslice option is given, only data for the given timeslice may be overwritten. Note that it is always an error to attempt to overwrite a NetCDF variable with data which has a different shape.

[status] The file status. Valid options are ESMF\_FILESTATUS\_NEW, ESMF\_FILESTATUS\_OLD, ESMF\_FILESTATUS\_REPLACE, and ESMF\_FILESTATUS\_UNKNOWN (default).

**[timeslice]** Time slice counter. Must be positive. The behavior of this option may depend on the setting of the overwrite flag:

```
overwrite = .false.: If the timeslice value is less than the maximum time already in the file, the write will fail.
```

```
overwrite = .true.: Any positive timeslice value is valid.
```

By default, i.e. by omitting the timeslice argument, no provisions for time slicing are made in the output file, however, if the file already contains a time axis for the variable, a timeslice one greater than the maximum will be written.

[iofmt] The I/O format. Supported options are ESMF\_IOFMT\_NETCDF, ESMF\_IOFMT\_NETCDF4P, and ESMF\_IOFMT\_NETCDF4C. If not present, defaults to ESMF\_IOFMT\_NETCDF.

[relaxedflag] If .true., then no error is returned even if the call cannot write the file due to library limitations, or because field does not contain any data. Default is .false..

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

#### 3.10.4 NUOPC Write - Write the Fields within a State to NetCDF files

#### **INTERFACE:**

```
! Private name; call using NUOPC_Write()
subroutine NUOPC_StateWrite(state, fieldNameList, fileNamePrefix, overwrite, &
    status, timeslice, iofmt, relaxedflag, rc)
```

#### **ARGUMENTS:**

```
intent(in)
                                                :: state
type(ESMF_State),
character(len=*),
                          intent(in), optional :: fieldNameList(:)
character(len=*),
                          intent(in), optional :: fileNamePrefix
logical,
                          intent(in), optional :: overwrite
type(ESMF_FileStatus_Flag), intent(in), optional :: status
                          intent(in), optional :: timeslice
integer,
type(ESMF_IOFmt_Flag),
                         intent(in), optional :: iofmt
logical,
                          intent(in), optional :: relaxedflag
                           intent(out), optional :: rc
integer,
```

## **DESCRIPTION:**

Write the data of the fields within a state to NetCDF files. Each field is written to an individual file using the "StandardName" attribute as NetCDF attribute.

The arguments are:

**state** The ESMF\_State object containing the fields.

[fieldNameList] List of names of the fields to be written. By default write all the fields in state.

[fileNamePrefix] File name prefix, common to all the files written.

[overwrite] A logical flag, the default is .false., i.e., existing Field data may *not* be overwritten. If .true., the data corresponding to each field's name will be be overwritten. If the timeslice option is given, only data for the given timeslice may be overwritten. Note that it is always an error to attempt to overwrite a NetCDF variable with data which has a different shape.

[status] The file status. Valid options are ESMF\_FILESTATUS\_NEW, ESMF\_FILESTATUS\_OLD, ESMF\_FILESTATUS\_REPLACE, and ESMF\_FILESTATUS\_UNKNOWN (default).

**[timeslice]** Time slice counter. Must be positive. The behavior of this option may depend on the setting of the overwrite flag:

overwrite = .false.: If the timeslice value is less than the maximum time already in the file, the write will fail.

overwrite = .true.: Any positive timeslice value is valid.

By default, i.e. by omitting the timeslice argument, no provisions for time slicing are made in the output file, however, if the file already contains a time axis for the variable, a timeslice one greater than the maximum will be written.

[iofmt] The I/O format. Supported options are ESMF\_IOFMT\_NETCDF, ESMF\_IOFMT\_NETCDF4P, and ESMF\_IOFMT\_NETCDF4C. If not present, defaults to ESMF\_IOFMT\_NETCDF.

[relaxedflag] If .true., then no error is returned even if the call cannot write the file due to library limitations. Default is .false..

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

#### 3.10.5 NUOPC\_Write - Write the Fields within a FieldBundle to NetCDF files

## INTERFACE:

```
! Private name; call using NUOPC_Write() subroutine NUOPC_FieldBundleWrite(fieldbundle, fieldNameList, fileNamePrefix, overwrit status, timeslice, iofmt, relaxedflag, rc)
```

#### **ARGUMENTS:**

```
:: fieldbundle
type (ESMF_FieldBundle),
                           intent(in)
                           intent(in), optional :: fieldNameList(:)
character(len=*),
character(len=*),
                           intent(in), optional :: fileNamePrefix
logical,
                           intent(in), optional :: overwrite
type(ESMF_FileStatus_Flag), intent(in), optional :: status
                           intent(in), optional :: timeslice
integer,
type(ESMF_IOFmt_Flag),
                            intent(in), optional :: iofmt
                            intent(in), optional :: relaxedflag
logical,
                            intent(out), optional :: rc
integer,
```

## **DESCRIPTION:**

Write the data of the fields within a fieldbundle to NetCDF files. Each field is written to an individual file using the "StandardName" attribute as NetCDF attribute.

The arguments are:

fieldbundle The ESMF\_FieldBundle object containing the fields.

[fieldNameList] List of names of the fields to be written. By default write all the fields in fieldbundle.

[fileNamePrefix] File name prefix, common to all the files written.

[overwrite] A logical flag, the default is .false., i.e., existing Field data may *not* be overwritten. If .true., the data corresponding to each field's name will be be overwritten. If the timeslice option is given, only data for the given timeslice may be overwritten. Note that it is always an error to attempt to overwrite a NetCDF variable with data which has a different shape.

[status] The file status. Valid options are ESMF\_FILESTATUS\_NEW, ESMF\_FILESTATUS\_OLD, ESMF\_FILESTATUS\_REPLACE, and ESMF\_FILESTATUS\_UNKNOWN (default).

**[timeslice]** Time slice counter. Must be positive. The behavior of this option may depend on the setting of the overwrite flag:

overwrite = .false.: If the timeslice value is less than the maximum time already in the file, the write will fail.

overwrite = .true.: Any positive timeslice value is valid.

By default, i.e. by omitting the timeslice argument, no provisions for time slicing are made in the output file, however, if the file already contains a time axis for the variable, a timeslice one greater than the maximum will be written.

[iofmt] The I/O format. Supported options are ESMF\_IOFMT\_NETCDF, ESMF\_IOFMT\_NETCDF4P, and ESMF\_IOFMT\_NETCDF4C. If not present, defaults to ESMF\_IOFMT\_NETCDF.

[relaxedflag] If .true., then no error is returned even if the call cannot write the file due to library limitations. Default is .false..

[rc] Return code; equals ESMF\_SUCCESS if there are no errors.

## 4 Standardized Component Dependencies

Most of the NUOPC Layer deals with specifying the interaction between ESMF components within a running ESMF application. ESMF provides several mechanisms of how an application can be made up of individual Components. This chapter deals with reigning in the many options supported by ESMF and setting up a standard way for assembling NUOPC compliant components into a working application.

ESMF supports single executable as well as some forms of multiple executable applications. Currently the NUOPC Layer only addresses the case of single executable applications. While it is generally true that executing single executable applications is easier and more widely supported than executing multiple executable applications, building a single executable from multiple components can be challenging. This is especially true when the individual components are supplied by different groups, and the assembly of the final application happens apart from the component development. The purpose of standardizing component dependencies as part of the NUOPC Layer is to provide a solution to the technical aspect of assembling applications built from NUOPC compliant components.

As with the other parts of the NUOPC Layer, the standardized component dependencies specify aspects that ESMF purposefully leaves unspecified. Having a standard way to deal with component dependencies has several advantages. It makes reading and understand NUOPC compliant applications more easily. It also provides a means to promote best practices across a wide range of application systems. Ultimately the goal of standardizing the component dependencies is to support "plug & build" between NUOPC compliant components and applications, where everything needed to use a component by a upper level software layer is supplied in a standard way, ready to be used by the software.

There is one aspect of the standardized component dependency that affects the component code itself: **The name of the public set services entry point into a NUOPC compliant component must be called "SetServices"**. The only exception to this rule are components that are written in C/C++ and made available for static linking. In this case, because of lack of namespace protection, the SetServices part must be followed by a component specific suffix. This will be discussed later in this chapter. For all other cases, unique namespaces exist that allow the entry point to be called SetServices across all components.

Having standardized the name of the single public entry point into a component solves the issue of having to communicate its name to the software layer that intends to use the component. At the same time, limiting the public entry point to a single accepted name does not remove any flexibility that is generally leveraged by ESMF applications. Within the context of the NUOPC Layer, there is great flexibility designed into the initialize steps. Removing the need to have to deal with alternative set services routines focuses and clarifies the NUOPC approach.

The remaining aspects of component dependency standardization all deal with build specific issues, i.e. how does the software layer that uses a component compile and link against the component code. For now the NUOPC Layer does not deal with the question on how the component itself is being built. Instead the focus is on the information that a component must provide about itself, and the format of this information, in order to be usable by another piece of software. This clear separation allows components to provide their own independent build system, which often is critical to ensure bit-for-bit reproducibility. At the same time it does not prevent build systems to be connected top-down if that is desirable.

Technically the problem of passing component specific build information up the build hierarchy is solved by using GNU makefile fragments that allow every component to provide information in form of variables to the upper level build system. The NUOPC Layer standardization requires that: **Every component must provide a makefile fragment that defines 6 variables:** 

```
ESMF_DEP_FRONT
ESMF_DEP_INCPATH
ESMF_DEP_CMPL_OBJS
ESMF_DEP_LINK_OBJS
ESMF_DEP_SHRD_PATH
ESMF_DEP_SHRD_LIBS
```

The convention for makefile fragments is to provide them in files with a suffix of .mk. The NUOPC Layer currently adds no further restriction to the name of the makefile fragment file of a component. There seems little gain in

standardizing the name of the NUOPC compliant makefile fragment of a component since the location must be made available anyway, and adding the specific file name at the end of the supplied path does not appear inappropriate.

The meaning of the 6 makefile variables is defined in a manner that supports many different situations, ranging from simple statically linked components to situations where components are made available in shared objects, not loaded by the application until needed during runtime. The design idea of the NUOPC Layer component makefile fragment is to have each component provide a simple makefile fragment that is self-describing. Usage of advanced options requires a more sophisticated build system on the software layer that *uses* the component, while at the same time the same standard format is able to keep simple situations simple.

An indepth understanding of the capabilities of the NUOPC Layer build dependency standard requires looking at various common cases in detail. The remainder of this chapter is dedicated to this effort. Here a general definition of each variable is provided.

- ESMF\_DEP\_FRONT The name of the Fortran module to be used in a USE statement, or (if it ends in ".h") the name of the header file to be used in an #include statement, or (if it ends in ".so") the name of the shared object to be loaded at run-time.
- ESMF\_DEP\_INCPATH The include path to find module or header files during compilation. Must be specified as absolute path.
- ESMF\_DEP\_CMPL\_OBJS Object files that need to be considered as compile dependencies. Must be specified with absolute path.
- ESMF\_DEP\_LINK\_OBJS Object files that need to be considered as link dependencies. Must be specified with absolute path.
- ESMF\_DEP\_SHRD\_PATH The path or list of paths to find shared libraries during link-time (and during runtime unless overridden by LD\_LIBRARY\_PATH). Must be specified as absolute paths.
- ESMF\_DEP\_SHRD\_LIBS Shared libraries that need to be specified during link-time, and must be available during run-time. Must be specified with absolute path.

The following sections discuss how the standard makefile fragment is utilized in common use cases. It shows how the .mk file would need to look like in these cases. Each section further contains hints of how a compliant .mk file can be auto-generated by the component build system (provider side), as well as hints on how it can be used by an upper level software layer (consumer side). Makefile segments provided in these hint sections are *not* part of the NUOPC Layer component dependency standard. They are only provided here as a convenience to the user, showing best practices of how the standard .mk files can be used in practice. Any specific compiler and linker flags shown in the hint sections are those compliant with the GNU Compiler Collection.

The NUOPC Layer standard only covers the contents of the .mk file itself.

## 4.1 Fortran components that are statically built into the executable

Statically building a component into the executable requires that the associated files (object files, and for Fortran the associated module files) are available when the application is being built. It makes the component code part of the executable. A change in the component code requires re-compilation and re-linking of the executable.

A NUOPC compliant Fortran component that defines its public entry point in a module called "ABC", where all component code is contained in a single object file called "abc.o", makes itself available by providing the following .mk file:

```
ESMF_DEP_LINK_OBJS = <absolute path>/abc.o
ESMF_DEP_SHRD_PATH =
ESMF_DEP_SHRD_LIBS =
```

If, however, the component implementation is spread across several object files (e.g. abc.o and xyz.o), they must all be listed in the ESMF\_DEP\_LINK\_OBJS variable:

In cases that require a large number of object files to be linked into the executable it is often more convenient to provide them in an archive file, e.g. "libABC.a". Archive files are also specified in ESMF\_DEP\_LINK\_OBJS:

**Hints for the provider side:** A build rule for creating a compliant self-describing .mk file can be added to the component's makefile. For the case that component "ABC" is implemented in object files listed in variable "OBJS", a build rule that produces "abc.mk" could look like this:

```
.PRECIOUS: %.o
%.mk : %.o
        @echo "# ESMF self-describing build dependency makefile fragment" > $@
        @echo >> $@
        @echo "ESMF DEP FRONT
                                  = ABC"
                                                                    >> $@
        @echo "ESMF_DEP_INCPATH = 'pwd'"
                                                                    >> $@
        @echo "ESMF_DEP_CMPL_OBJS = 'pwd'/"$<</pre>
                                                                    >> $@
        @echo "ESMF_DEP_LINK_OBJS = "$(addprefix 'pwd'/, $(OBJS)) >> $@
        @echo "ESMF DEP SHRD PATH = "
                                                                    >> $@
        @echo "ESMF_DEP_SHRD_LIBS = "
                                                                    >> $@
abc.mk: $(OBJS)
```

**Hints for the consumer side:** The format of the NUOPC compliant .mk files allows the consumer side to collect the information provided by multiple components into one set of internal variables. Notice that in the makefile code below it is critical to use the := style assignment instead of a simple = in order to have the assignment be based on the *current* value of the right hand variables.

```
include abc.mk

DEP_FRONTS := $(DEP_FRONTS) -DFRONT_ABC=$(ESMF_DEP_FRONT)

DEP_INCS := $(DEP_INCS) $(addprefix -I, $(ESMF_DEP_INCPATH))

DEP_CMPL_OBJS := $(DEP_CMPL_OBJS) $(ESMF_DEP_CMPL_OBJS)

DEP_LINK_OBJS := $(DEP_LINK_OBJS) $(ESMF_DEP_LINK_OBJS)

DEP_SHRD_PATH := $(DEP_SHRD_PATH) $(addprefix -L, $(ESMF_DEP_SHRD_PATH))
```

```
DEP_SHRD_LIBS := $(DEP_SHRD_LIBS) $(addprefix -1, $(ESMF_DEP_SHRD_LIBS))
include xyz.mk
DEP_FRONTS := $(DEP_FRONTS) -DFRONT_XYZ=$(ESMF_DEP_FRONT)
DEP_INCS := $(DEP_INCS) $(addprefix -I, $(ESMF_DEP_INCPATH))
DEP_CMPL_OBJS := $(DEP_CMPL_OBJS) $(ESMF_DEP_CMPL_OBJS)
DEP_LINK_OBJS := $(DEP_LINK_OBJS) $(ESMF_DEP_LINK_OBJS)
DEP_SHRD_PATH := $(DEP_SHRD_PATH) $(addprefix -L, $(ESMF_DEP_SHRD_PATH))
DEP_SHRD_LIBS := $(DEP_SHRD_LIBS) $(addprefix -1, $(ESMF_DEP_SHRD_LIBS))
```

Besides the accumulation of information into the internal variables, there is a small amount of processing going on. The module name provided by the ESMF\_DEP\_FRONT variable is assigned to a pre-processor macro. The intention of this macro is to be used in a Fortran USE statement to access the Fortran module that contains the public access point of the component.

The include paths in ESMF\_DEP\_INCPATH are prepended with the appropriate compiler flag (here "-I"). The ESMF\_DEP\_SHRD\_PATH and ESMF\_DEP\_SHRD\_LIBS variables are also prepended by the respective compiler and linker flags in case a component brings in a shared library dependencies.

Once the .mk files of all component dependencies have been included and processed in this manner, the internal variables can be used in the build system of the application layer, as shown in the following example:

```
.SUFFIXES: .f90 .F90 .c .C
%.o: %.f90
        $(ESMF F90COMPILER) -c $(DEP FRONTS) $(DEP INCS) \
$(ESMF F90COMPILEOPTS) $(ESMF F90COMPILEPATHS) $(ESMF F90COMPILEFREENOCPP) $<
%.o: %.F90
       $(ESMF_F90COMPILER) -c $(DEP_FRONTS) $(DEP_INCS) \
$(ESMF F90COMPILEOPTS) $(ESMF F90COMPILEPATHS) $(ESMF F90COMPILEFREECPP) \
$(ESMF_F90COMPILECPPFLAGS) $<
%.0 : %.C
        $(ESMF_CXXCOMPILER) -c $(DEP_FRONTS) $(DEP_INCS) \
$(ESMF CXXCOMPILEOPTS) $(ESMF CXXCOMPILEPATHSLOCAL) $(ESMF CXXCOMPILEPATHS) \
$(ESMF_CXXCOMPILECPPFLAGS) $<
%.o: %.C
        $(ESMF_CXXCOMPILER) -c $(DEP_FRONTS) $(DEP_INCS) \
$(ESMF CXXCOMPILEOPTS) $(ESMF CXXCOMPILEPATHSLOCAL) $(ESMF CXXCOMPILEPATHS) \
$(ESMF CXXCOMPILECPPFLAGS) $<
app: app.o appSub.o $(DEP_LINK_OBJS)
        $(ESMF_F90LINKER) $(ESMF_F90LINKOPTS) $(ESMF_F90LINKPATHS) \
$(ESMF_F90LINKRPATHS) -o $@ $^ $(DEP_SHRD_PATH) $(DEP_SHRD_LIBS) \
$(ESMF F90ESMFLINKLIBS)
app.o: appSub.o
appSub.o: $(DEP_CMPL_OBJS)
```

## 4.2 Fortran components that are provided as shared libraries

Providing a component in form of a shared library requires that the associated files (object files, and for Fortran the associated module files) are available when the application is being built. However, different from the statically linked case, the component code does *not* become part of the executable, instead it will be loaded separately each time the executable is loaded during start-up. This requires that the executable finds the component shared libraries, on which it depends, during start-up. A change in the component code typically does not require re-compilation and re-linking of the executable, instead a new version of the component shared library will be loaded automatically when it is available at execution start-up.

A NUOPC compliant Fortran component that defines its public entry point in a module called "ABC", where all component code is contained in a single shared library called "libABC.so", makes itself available by providing the following .mk file:

**Hints for the provider side:** The following build rule will create a compliant self-describing .mk file ("abc.mk") for a component that is made available as a shared library. The case assumes that component "ABC" is implemented in object files listed in variable "OBJS".

```
.PRECIOUS: %.so
%.mk : %.so
       @echo "# ESMF self-describing build dependency makefile fragment" > $@
        @echo >> $@
        @echo "ESMF_DEP_FRONT
                                  = ABC"
                                                                   >> $@
        @echo "ESMF_DEP_INCPATH = 'pwd'"
                                                                   >> $@
        @echo "ESMF_DEP_CMPL_OBJS = "
                                                                   >> $@
        @echo "ESMF_DEP_LINK_OBJS = "
                                                                   >> $@
        @echo "ESMF DEP SHRD PATH = 'pwd'"
                                                                   >> $@
        @echo "ESMF DEP SHRD LIBS = "$*
                                                                   >> $@
abc.mk:
abc.so: $(OBJS)
        $(ESMF_CXXLINKER) -shared -o $@ $<
       mv $@ lib$@
       rm -f $<
```

**Hints for the consumer side:** The format of the NUOPC compliant .mk files allows the consumer side to collect the information provided by multiple components into one set of internal variables. This is independent on whether some or all of the components are provided as shared libraries.

The path specified in ESMF\_DEP\_SHRD\_PATH is required when building the executable in order for the linker to find the shared library. Depending on the situation, it may be desirable to also encode this search path into the executable through the RPATH mechanism as shown below. However, in some cases, e.g. when the actual shared library to be used during execution is *not* available from the same location as during build-time, it may not be useful to encode the RPATH. In either case, having set the LD\_LIBRARY\_PATH environment variable to the desired location of the shared library at run-time will ensure that the correct library file is found.

Notice that in the makefile code below it is critical to use the := style assignment instead of a simple = in order to have the assignment be based on the *current* value of the right hand variables.

```
include abc.mk

DEP_FRONTS := $(DEP_FRONTS) -DFRONT_ABC=$(ESMF_DEP_FRONT)

DEP_INCS := $(DEP_INCS) $(addprefix -I, $(ESMF_DEP_INCPATH))

DEP_CMPL_OBJS := $(DEP_CMPL_OBJS) $(ESMF_DEP_CMPL_OBJS)

DEP_LINK_OBJS := $(DEP_LINK_OBJS) $(ESMF_DEP_LINK_OBJS)

DEP_SHRD_PATH := $(DEP_SHRD_PATH) $(addprefix -L, $(ESMF_DEP_SHRD_PATH)) \
    $(addprefix -Wl$(COMMA) -rpath$(COMMA), $(ESMF_DEP_SHRD_PATH))

DEP_SHRD_LIBS := $(DEP_SHRD_LIBS) $(addprefix -1, $(ESMF_DEP_SHRD_LIBS))
```

(Here COMMA is a variable that contains a single comma which would cause syntax issues if it was written into the "addprefix" command directly.)

The internal variables set by the above makefile code can then be used by exactly the same makefile rules shown for the statically linked case. In fact, component "ABC" that comes in through "abc.mk" could either be a statically linked component or a shared library component. The makefile code shown here for the consumer side handles both cases alike.

## 4.3 Components that are loaded during run-time as shared objects

Making components available in the form of shared objects allows the executable to be built in the complete absence of any information that depends on the component code. The only information required when building the executable is the name of the shared object file that will supply the component code during run-time. The shared object file of the component can be replaced at will, and it is not until run-time, when the executable actually tries to access the component, that the shared object must be available to be loaded.

A NUOPC compliant component where all component code, including its public access point, is contained in a single shared object called "abc.so", makes itself available by providing the following .mk file:

```
ESMF_DEP_FRONT = abc.so
ESMF_DEP_INCPATH =
ESMF_DEP_CMPL_OBJS =
ESMF_DEP_LINK_OBJS =
ESMF_DEP_SHRD_PATH =
ESMF_DEP_SHRD_LIBS =
```

The other parts of the .mk file may be utilized in special cases, but typically the shared object should be self-contained.

It is interesting to note that at this level of abstraction, there is no more difference between a component written in Fortran, and a component written in in C/C++. In both cases the public entry point available in the shared object must be SetServices as required by the NUOPC Layer component dependency standard. (NUOPC does allow for customary name mangling by the Fortran compiler.)

**Hints for the provider side:** The following build rule will create a compliant self-describing .mk file ("abc.mk") for a component that is made available as a shared object. The case assumes that component "ABC" is implemented in object files listed in variable "OBJS".

**Hints for the consumer side:** The format of the NUOPC compliant .mk files still allows the consumer side to collect the information provided by multiple components into one set of internal variables. This still holds when some or all of the components are provided as shared objects. In fact it is very simple to make all of the component sections in the consumer makefile handle both cases.

Notice that in the makefile code below it is critical to use the := style assignment instead of a simple = in order to have the assignment be based on the *current* value of the right hand variables.

```
include abc.mk
ifneq (,$(findstring .so,$(ESMF_DEP_FRONT)))
           := $(DEP_FRONTS) -DFRONT_SO_ABC=\"$(ESMF_DEP_FRONT)\"
DEP_FRONTS
else
DEP FRONTS
             := $ (DEP_FRONTS) -DFRONT_ABC=$ (ESMF_DEP_FRONT)
endif
DEP_FRONTS
             := $ (DEP_FRONTS) -DFRONT_ABC=$ (ESMF_DEP_FRONT)
DEP_INCS
             := $(DEP_INCS) $(addprefix -I, $(ESMF_DEP_INCPATH))
DEP_CMPL_OBJS := $(DEP_CMPL_OBJS) $(ESMF_DEP_CMPL_OBJS)
DEP_LINK_OBJS := $(DEP_LINK_OBJS) $(ESMF_DEP_LINK_OBJS)
DEP_SHRD_PATH := $(DEP_SHRD_PATH) $(addprefix -L, $(ESMF_DEP_SHRD_PATH)) \
  $(addprefix -Wl$(COMMA)-rpath$(COMMA), $(ESMF_DEP_SHRD_PATH))
DEP_SHRD_LIBS := $(DEP_SHRD_LIBS) $(addprefix -1, $(ESMF_DEP_SHRD_LIBS))
```

The above makefile segment supports component "ABC" that is described in "abc.mk" to be made available as a Fortran static component, a Fortran shared library, or a shared object. The conditional around assigning variable DEP\_FRONTS either leads to having set the macro FRONT\_ABC as before, or setting a different macro FRONT\_SO\_ABC. The former indicates that a Fortran module is available for the component and requires a USE statement in the code. The latter macro indicates that the component is made available through a shared object, and the macro can be used to specify the name of the shared object in the associated call.

Again the internal variables set by the above makefile code can be used by the same makefile rules shown for the statically linked case.

## 4.4 Components that depend on components

The NUOPC Layer supports component hierarchies where a component can be a child of another component. This hierarchy of components translates into component build dependencies that must be dealt with in the NUOPC Layer standardization of component dependencies.

A component that sits in an intermediate level of the component hierarchy depends on the components "below" while at the same time it introduces a dependency by itself for the parent further "up" in the hierarchy. Within the NUOPC Layer component dependency standard this means that the intermediate component functions as a consumer of its child components' .mk files, and as a provider of its own .mk file that is then consumed by its parent. In practice this double role translates into passing link dependencies and shared library dependencies through to the parent, while the front and compile dependency is simply defined my the intermediate component itself.

Consider a NUOPC compliant component that defines its public entry point in a module called "ABC", and where all component code is contained in a single object file called "abc.o". Further assume that component "ABC" depends on two components "XXX" and "YYY", where "XXX" provides the .mk file:

and "YYY" provides the following:

Then the .mk file provided by "ABC" needs to contain the following information:

**Hints for an intermediate component that is consumer and provider:** For the consumer side it is convenient to collect the information provided by multiple component dependencies into one set of internal variables. However, the details on how some of the imported information is processed into the internal variables depends on whether the intermediate component is going to make itself available for static or dynamic access.

In the static case all link and shared library dependencies must be passed to the next higher level, and these dependencies should simply be collected and passed on to the next level:

```
include xxx.mk
DEP FRONTS := $(DEP FRONTS) -DFRONT XXX=$(ESMF DEP FRONT)
DEP INCS
             := $(DEP_INCS) $(addprefix -I, $(ESMF_DEP_INCPATH))
DEP CMPL_OBJS := $(DEP_CMPL_OBJS) $(ESMF_DEP_CMPL_OBJS)
DEP_LINK_OBJS := $(DEP_LINK_OBJS) $(ESMF_DEP_LINK_OBJS)
DEP_SHRD_PATH := $(DEP_SHRD_PATH) $(ESMF_DEP_SHRD_PATH)
DEP_SHRD_LIBS := $(DEP_SHRD_LIBS) $(ESMF_DEP_SHRD_LIBS)
include yyy.mk
DEP FRONTS
            := $(DEP FRONTS) -DFRONT YYY=$(ESMF DEP FRONT)
             := $(DEP_INCS) $(addprefix -I, $(ESMF_DEP_INCPATH))
DEP INCS
DEP_CMPL_OBJS := $(DEP_CMPL_OBJS) $(ESMF_DEP_CMPL_OBJS)
DEP_LINK_OBJS := $(DEP_LINK_OBJS) $(ESMF_DEP_LINK_OBJS)
DEP_SHRD_PATH := $(DEP_SHRD_PATH) $(ESMF_DEP_SHRD_PATH)
DEP SHRD LIBS := $(DEP SHRD LIBS) $(ESMF DEP SHRD LIBS)
.PRECIOUS: %.o
```

```
@echo "# ESMF self-describing build dependency makefile fragment" > $@
@echo >> $@
@echo "ESMF_DEP_FRONT
                           = ABC"
                                                           >> $@
                                                           >> $@
@echo "ESMF_DEP_INCPATH
                           = 'pwd'"
@echo "ESMF_DEP_CMPL_OBJS = 'pwd'/"$<</pre>
                                                           >> $@
@echo "ESMF_DEP_LINK_OBJS = 'pwd'/"$< $(DEP_LINK_OBJS)</pre>
                                                           >> $@
@echo "ESMF DEP SHRD PATH = " $(DEP SHRD PATH)
                                                           >> $@
@echo "ESMF_DEP_SHRD_LIBS = " $ (DEP_SHRD_LIBS)
                                                           >> $@
```

In the case where the intermediate component is linked into a dynamic library, or a dynamic object, all of its object and shared library dependencies can be linked in. In this case it is more useful to do some processing on the shared library dependencies, and not to include them in the produced .mk file.

```
include xxx.mk
DEP_FRONTS := $(DEP_FRONTS) -DFRONT_XXX=$(ESMF_DEP_FRONT)
             := $(DEP_INCS) $(addprefix -I, $(ESMF_DEP_INCPATH))
DEP_INCS
DEP_CMPL_OBJS := $(DEP_CMPL_OBJS) $(ESMF_DEP_CMPL_OBJS)
DEP_LINK_OBJS := $(DEP_LINK_OBJS) $(ESMF_DEP_LINK_OBJS)
DEP_SHRD_PATH := $(DEP_SHRD_PATH) $(addprefix -L, $(ESMF_DEP_SHRD_PATH)) \
 $(addprefix -W1$(COMMA)-rpath$(COMMA), $(ESMF_DEP_SHRD_PATH))
DEP_SHRD_LIBS := $(DEP_SHRD_LIBS) $(addprefix -1, $(ESMF_DEP_SHRD_LIBS))
include yyy.mk
DEP_FRONTS := $(DEP_FRONTS) -DFRONT_YYY=$(ESMF_DEP_FRONT)
DEP_INCS
         := $(DEP_INCS) $(addprefix -I, $(ESMF_DEP_INCPATH))
DEP_CMPL_OBJS := $(DEP_CMPL_OBJS) $(ESMF_DEP_CMPL_OBJS)
DEP_LINK_OBJS := $(DEP_LINK_OBJS) $(ESMF_DEP_LINK_OBJS)
DEP SHRD PATH := $(DEP SHRD PATH) $(addprefix -L, $(ESMF DEP SHRD PATH)) \
  $(addprefix -Wl$(COMMA)-rpath$(COMMA), $(ESMF_DEP_SHRD_PATH))
DEP SHRD LIBS := $(DEP SHRD LIBS) $(addprefix -1, $(ESMF DEP SHRD LIBS))
.PRECIOUS: %.o
%.mk : %.o
@echo "# ESMF self-describing build dependency makefile fragment" > $@
@echo >> $@
                                                        >> $@
@echo "ESMF DEP FRONT
                         = ABC"
@echo "ESMF DEP INCPATH = 'pwd'"
                                                        >> $@
@echo "ESMF_DEP_CMPL_OBJS = 'pwd'/"$<</pre>
                                                        >> $@
@echo "ESMF_DEP_LINK_OBJS = 'pwd'/"$<</pre>
                                                        >> $@
@echo "ESMF DEP SHRD PATH = "
                                                        >> $@
@echo "ESMF DEP SHRD LIBS = "
                                                        >> $@
```

## 4.5 Components written in C/C++

ESMF provides a basic C API that supports writing components in C or C++. There is currently no C version of the NUOPC Layer API available, making it harder, but not impossible to write NUOPC Layer compliant ESMF components in C/C++. For the sake of completeness, the NUOPC component dependency standardization does cover the case of components being written in C/C++.

The issue of whether a component is written in Fortran or C/C++ only matters when the dependent software layer has a compile dependency on the component. In other words, components that are accessed through a shared object have no compile dependency, and the language is of no effect (see 4.3). However, components that are statically linked or made available through shared libraries do introduce compile dependencies. These compile dependencies become language

dependent: a Fortran component must be accessed via the USE statement, while a component with a C interface must be accessed via #include.

The decision between the three cases: compile dependency on a Fortran component, compile dependency on a C/C++ component, or no compile dependency can be made on the ESMF\_DEP\_FRONT variable. By default it is assumed to contain the name of the Fortran module that provides the public entry point into a component written in Fortran. However, if the contents of the ESMF\_DEP\_FRONT variable ends in .h, it is interpreted as the header file of a component with a C interface. Finally, if it ends in .so, there is no compile dependency, and the component is accessible through a shared object.

A NUOPC compliant component written in C/C++ that defines its public access point in "abc.h", where all component code is contained in a single object file called "abc.o", makes itself available by providing the following .mk file:

## **Hints for the implementor:**

There are a few subtle complications to cover for the case where a component with C interface comes in as a compile dependency. First there is Fortran name mangling of symbols which includes underscores, but also changes to lower or upper case letters. The ESMF C interface provides a macro (FTN\_X) that deals with the underscore issue on the C component side, but it cannot address the lower/upper case issue. The ESMF convention for using C in Fortran assumes all external symbols lower case. The NUOPC Layer follows this convention in accessing components with C interface from Fortran.

Secondly, there is no namespace protection of the public entry points. For this reason, the public entry point cannot just be setservices for all components written in C. Instead, for components with C interface, the public entry point must be setservices\_name, where "name" is the same as the root name of the header file specified in ESMF\_DEP\_FRONT. (The absence of namespace protection is still an issue where multiple C components with the same name are specified. This case requires that components are renamed to something more unique.)

Finally there is the issue of providing an explicit Fortran interface for the public entry point. One way of handling this is to provide the explicit Fortran interface as part of the components header file. This is essentially a few lines of Fortran code that can be used by the upper software layer to implement the explicit interface. As such it must be protected from being processed by the C/C++ compiler:

```
type(ESMF_GridComp) :: gcomp
  integer, intent(out) :: rc
  end subroutine
end interface
#endif
```

An upper level software layer that intends to use a component that comes with such a header file can then use it directly on the Fortran side to make the component available with an explicit interface. For example, assuming the macro FRONT\_H\_ATMF holds the name of the associated header file:

```
#ifdef FRONT_H_ATMF
module ABC
#include FRONT_H_ATMF
end module
#endif
```

This puts the explicit interface of the setservices\_abc entry point into a module named "ABC". Except for this small block of code, the C/C++ component becomes indistinguishable from a component implemented in Fortran.

**Hints for the provider side:** Adding a build rule for creating a compliant self-describing .mk file into the component's makefile is straightforward. For the case that the component in "abc.h" is implemented in object files listed in variable "OBJS", a build rule that produces "abc.mk" could look like this:

```
.PRECIOUS: %.o
%.mk : %.o
@echo "# ESMF self-describing build dependency makefile fragment" > $@
@echo >> $@
@echo "ESMF_DEP_FRONT
                          = abc.h"
                                        >> $@
@echo "ESMF DEP INCPATH = 'pwd'"
                                         >> $@
@echo "ESMF_DEP_CMPL_OBJS = 'pwd'/"$<</pre>
                                         >> $@
@echo "ESMF_DEP_LINK_OBJS = 'pwd'/"$<</pre>
                                        >> $@
@echo "ESMF_DEP_SHRD_PATH = "
                                         >> $@
@echo "ESMF_DEP_SHRD_LIBS = "
                                         >> $@
abc.mk:
abc.o: abc.h
```

**Hints for the consumer side:** The format of the NUOPC compliant .mk files still allows the consumer side to collect the information provided by multiple components into one set of internal variables. This still holds even when any of the provided components could come in as a Fortran component for static linking, as a C/C++ component for static linking, or as a shared object. All of the component sections in the consumer makefile can be made capable of handling all three cases. However, if it is clear that a certain component is for sure supplied as one of these flavors, it may be clearer to hard-code support for only one mechanism for this component.

Notice that in the makefile code below it is critical to use the := style assignment instead of a simple = in order to have the assignment be based on the *current* value of the right hand variables.

This example shows how the section for a specific component can be made compatible with all component dependency modes:

```
include abc.mk
```

```
ifneq (,$(findstring .h,$(ESMF_DEP_FRONT)))
             := $(DEP FRONTS) -DFRONT H ABC=\"$(ESMF DEP FRONT)\"
DEP FRONTS
else ifneq (,$(findstring .so,$(ESMF_DEP_FRONT)))
DEP_FRONTS
             := $(DEP_FRONTS) -DFRONT_SO_ABC=\"$(ESMF_DEP_FRONT)\"
else
DEP_FRONTS
              := $ (DEP_FRONTS) -DFRONT_ABC=$ (ESMF_DEP_FRONT)
endif
DEP FRONTS
             := $(DEP FRONTS) -DFRONT ABC=$(ESMF DEP FRONT)
              := $(DEP_INCS) $(addprefix -I, $(ESMF_DEP_INCPATH))
DEP INCS
DEP_CMPL_OBJS := $(DEP_CMPL_OBJS) $(ESMF_DEP_CMPL_OBJS)
DEP_LINK_OBJS := $(DEP_LINK_OBJS) $(ESMF_DEP_LINK_OBJS)
DEP_SHRD_PATH := $(DEP_SHRD_PATH) $(addprefix -L, $(ESMF_DEP_SHRD_PATH)) \
  $(addprefix -Wl$(COMMA)-rpath$(COMMA), $(ESMF_DEP_SHRD_PATH))
DEP_SHRD_LIBS := $(DEP_SHRD_LIBS) $(addprefix -1, $(ESMF_DEP_SHRD_LIBS))
```

The above makefile segment will end up setting macro FRONT\_H\_ABC to the header file name, if the component described in "abc.mk" is a C/C++ component. It will instead set macro FRONT\_SO\_ABC to the shared object if this is how the component is made available, or set macro FRONT\_ABC to the Fortran module name if that is the mechanism for gaining access to the component code. The calling code can use these macros to activate the corresponding code, as well as has access to the required name string in each case

The internal variables set by the above makefile code can be used by the same makefile rules shown for the statically linked case. This usage implements the correct dependency rules, and passes the macros through the compiler flags.

## 5 NUOPC Layer Compliance

The NUOPC Layer introduces a modeling system architecture based on Models, Mediators, Connectors, and Drivers. The Layer defines the rules of engagement between these components. Many of these rules are formulated on the basis of metadata. This metadata can be expected for compliance.

One of the challenges when inspecting a component for NUOPC Layer compliance is that many of the rules of engagement are run-time rules. This means that they address the dynamical behavior of a component during run-time. For this reason, comprehensive compliance testing cannot be done statically but requires the execution of code.

Currently there are two sets of tools available to address the issue of NUOPC Layer compliance testing. The *Compliance Checker* is a runtime analysis tool that can be enabled by setting an ESMF environment variable at runtime. When active, the Compliance Checker intercepts all interactions between components that go throught the ESMF component interface, and analyzes them with respect to the NUOPC Layer rules of engagement. Warnings are printed to the log files when issues or non-compliances are detected.

The *Component Explorer* is another compliance testing tool. It focuses on interacting with a single component, and analyzing it during the early initialization phases. The Component Explorer and Compliance Checker are compatible with each other and it is often useful to use them both at the same time.

## 5.1 The Compliance Checker

The NUOPC Compliance Checker is a run-time analysis tool that can be turned on for any ESMF application. The Compliance Checker is turned off by default, as to not negatively affect performance critical runs. The Compliance Checker is enabled by setting the following ESMF runtime environment variable:

```
ESMF_RUNTIME_COMPLIANCECHECK=ON
```

As a run-time variable, setting it does not require recompilation of the ESMF library or the user application. The same

executable and library will start to generate Compliance Checker output when the above variable is found set during execution.

The function of the Compliance Checker is to intercept all interactions between the components of an ESMF application, and to analyze them according to the NUOPC Layer rules of engagement. The following aspects are currently reported on:

- Presence of the standard ESMF Initialize, Run, and Finalize methods and the number of phases in each.
- Timekeeping and whether it conforms with the NUOPC Layer rules.
- Fields or FieldBundles (not Arrays/ArrayBundles) being passed between Components.
- Details about the Fields being passed through import and export States.
- Component and Field metadata.

Besides the above aspects, the output of the Compliance Checker also provides a means to easily get an idea of the exact dynamical control flow between the components of an application.

The Compliance Checker uses the ESMF Log facility to produce the compliance report during the execution of an ESMF application. The output is located in the default ESMF Log files. There are advantages of using the existing Log facility to generate the compliance report. First, the ESMF Log facility offers time stamping of messages, and deals with all of the file access and multi-PET issues. Second, going through the ESMF Log guarantees that all the output appears in the correct chronological order. This applies to all of the output, including entries from other ESMF system levels or from the user level.

A sample output of the Compliance Checker output in action:

```
PETO COMPLIANCECHECKER: | -> | -> | ->: ATM:>START register compliance check
                                                                                                 PETO COMPLIANCECHECKER:|->|->|->:ATM: phase Zero for Initialize registered.

PETO COMPLIANCECHECKER:|->|->|->:ATM: phase Zero for Initialize registered.

PETO COMPLIANCECHECKER:|->|->:ATM: 5 phase(s) of Initialize registered.

PETO COMPLIANCECHECKER:|->|->:ATM: 1 phase(s) of Run registered.
20131108 172844.458 INFO
                                                                                              PETO COMPLIANCECHECKER: |->|->|->:ATM: 1 phase(s) of Run registered.

PETO COMPLIANCECHECKER: |->|->|->:ATM: 1 phase(s) of Finalize registered.

PETO COMPLIANCECHECKER: |->|->|->:ATM:>STOP register compliance check.

PETO COMPLIANCECHECKER: |->|->|->:ATM2MED: >START register compliance check.

PETO COMPLIANCECHECKER: |->|->|->:ATM2MED: phase Zero for Initialize registered.

PETO COMPLIANCECHECKER: |->|->|->:ATM2MED: 1 phase(s) of Run registered.

PETO COMPLIANCECHECKER: |->|->|->:ATM2MED: 1 phase(s) of Run registered.

PETO COMPLIANCECHECKER: |->|->|->:ATM2MED: 1 phase(s) of Finalize registered.

PETO COMPLIANCECHECKER: |->|->|->:ATM2MED: 1 phase(s) of Finalize registered.
20131108 172844.458 INFO
                                                                                              PETO COMPLIANCECHECKER: |->|->|->:ATMZMHED:

1 phase(s) of rindize registered.

PETO COMPLIANCECHECKER: |->|->|->:ATMZMHED:>STOP register compliance check.

PETO COMPLIANCECHECKER: |->|->|->:MEDZATM:>START register compliance check.

PETO COMPLIANCECHECKER: |->|->|->:MEDZATM: phase Zero for Initialize registered.

PETO COMPLIANCECHECKER: |->|->|->:MEDZATM: 3 phase(s) of Initialize registered.

PETO COMPLIANCECHECKER: |->|->|->:MEDZATM: 1 phase(s) of Run registered.
20131108 172844.458 INFO
20131108 172844.458 INFC
20131108 172844.458 INFC
                                                                                                PETO COMPLIANCECHECKER: |->|->|->:MED2ATM: 1 phase(s) of Finalize registered.
PETO COMPLIANCECHECKER: |->|->|->:MED2ATM:>STOP register compliance check.
                                                                                               PETO COMPLIANCECHECKER:|->|->|->:ATM: >START InitializePrologue for phase=
0 PETO COMPLIANCECHECKER:|->|->|->:ATM: importState name: modelComp 1 Import State
PETO COMPLIANCECHECKER:|->|->|->:ATM: importState stateintent: ESMF_STATEINTENT_IMPORT
PETO COMPLIANCECHECKER:|->|->|->:ATM: importState itemCount:
20131108 172844.459 INFO
20131108 172844.459 INFO
20131108 172844.459 INFO
20131108 172844.459 INFO
                                                                                            PETO COMPLIANCECHECKER: |-|> |-> : ATM: importState itemCount:

PETO COMPLIANCECHECKER: |-|> |-> : ATM: importState itemCount:

PETO COMPLIANCECHECKER: |-> |-> : ATM: exportState name: modelComp 1 Export State

PETO COMPLIANCECHECKER: |-> |-> : ATM: exportState stateintent: ESMF_STATEINTENT_EXPORT

PETO COMPLIANCECHECKER: |-> |-> |-> : ATM: exportState stateintent: ESMF_STATEINTENT_EXPORT

PETO COMPLIANCECHECKER: |-> |-> |-> : ATM: exportState itemCount:

PETO COMPLIANCECHECKER: |-> |-> |-> : ATM: ESMF Stats: the virtual memory used by this PET (in KB): 974868

PETO COMPLIANCECHECKER: |-> |-> |-> : ATM: ESMF Stats: the physical memory used by this PET (in KB): 49440

PETO COMPLIANCECHECKER: |-> |-> : ATM: ESMF Stats: ESMF objects (F & C++) referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-> |-> : ATM: ESMF Stats: ESMF objects (F & C++) referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-> |-> : ATM: ESMF Stats: ESMF objects (F & C++) referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-< |-< : ATM: ESMF Stats: ESMF objects (F & C++) referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-< |-< : ATM: ESMF Stats: ESMF objects (F & C++) referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-< |-< : ATM: ESMF Stats: ESMF Fortran objects referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-< |-< : ATM: ESMF Stats: ESMF Fortran objects referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-< |-< : ATM: ESMF Stats: ESMF objects (F & C++) referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-< |-< : ATM: ESMF Stats: ESMF objects (F & C++) referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-< |-< : ATM: ESMF Stats: ESMF objects (F & C++) referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-< |-< : ATM: ESMF Stats: ESMF objects (F & C++) referenced by the ESMF garbage collection: 0

PETO COMPLIANCECHECKER: |-< |-< : ATM: ESMF Stats: ESM
20131108 172844.459 INFO
20131108 172844.459 INFO
20131108 172844.459 INFC
20131108 172844.459 INFO
20131108 172844.459 TNFO
20131108 172844.459 WARNING
20131108 172844.459 WARNING
20131108 172844.459 WARNING
                                                                                             20131108 172844.459 WARNING
20131108 172844.459 WARNING
20131108 172844.459 WARNING
20131108 172844.459 WARNING
20131108 172844.459 WARNING
20131108 172844 459 WARNING
20131108 172844.459 INFO
20131108 172844.459 INFO
20131108 172844.459 INFO
20131108 172844.460 INFO
```

All of the output generated by the Compliance Checker contains the string COMPLIANCECHECK, which can be used to grep on. The checker currently generates two types of messages, INFO for general analysis output, and WARNING for when issues with respect to the NUOPC Layer rules are detected.

In practice, when dealing with applications that have been componentized down to a very low level of the model, the output generated by the Compliance Checker can become overwhelming. For this reason a depth parameter is available that can be specified for the Compliance Checker environment variable:

```
ESMF RUNTIME COMPLIANCECHECK=ON:depth=4
```

This will limit the number of component levels that the Compliance Checker parses (here 4 levels), starting from the top level application.

## **5.2** The Component Explorer

The NUOPC Component Explorer is a run-time tool that can be used to gain insight into a NUOPC Layer compliant component, or to test a component's compliance. The Component Explorer is currently available as a separate download from the prototype repository:

```
https://sourceforge.net/p/esmfcontrib/svn/HEAD/tree/NUOPC/trunk/ComponentExplorer/
```

There are two parts to the Component Explorer. First the script nuopcExplorerScript is used to compile and link the explorer application specifically against a specified component. This part of the explorer leverages and tests the standardized component dependencies discussed in section 4. This step is initiated by calling the explorer script with the component's mk-file as an argument:

```
./nuopcExplorerScript <component-mk-file>
```

Any issues found during this step are reported. The successful completion of this step will produce an executable called nuopcExplorerApp. Success is indicated by

```
SUCCESS: nuopcExplorerApp successfully built ...exiting nuopcExplorerScript.
```

and failure by

```
FAILURE: nuopcExplorerApp failed to build ...exiting nuopcExplorerScript.
```

The second part of the Component Explorer is the explorer application itself. It can either be built using the explorer script as outlined above (recommended when a makefile fragment for the component is available) or by using the makefile directly:

```
make nuopcExplorerApp
```

In the second case the resulting nuopcExplorerApp is not tied to a specific component, instead the executable expects a component in form of a shared object to be specified as a command line argument when executing nuopcExplorerApp. In either case the explorer application needs to be started according to the execution requirements of the component it attempts to explore. This may mean that input files must be present, and that the executable be launched on a sufficient number of processes. In terms of the common mpirun tool, launching of nuopcExplorerApp may look like this

```
mpirun -np X ./nuopcExplorerApp
```

for an executable that was built against a specific component. Or like this

```
mpirun -np X ./nuopcExplorerApp <component-shared-object-file>
```

for an executable that expects a the component in form of a shared object.

The nuopcExplorerApp expects to find a configuration file by the name of explorer.config in the run directory. The configuration file contains several basic model parameter used to explore the component. An example configuration file is shown here:

```
### NUOPC Component Explorer configuration file ###
                           2009
start_year:
start_month:
                           12
start_day:
                           01
start hour:
                           00
start_minute:
                           0
start_second:
                           2009
stop_year:
                           12
stop_month:
                           03
stop_day:
stop hour:
                           00
                           0
stop_minute:
                           0
stop_second:
                           21600
step_seconds:
filter_initialize_phases: no
enable run:
                           yes
enable_finalize:
                           yes
```

The nuopcExplorerApp starts to interact with the specified component, using the information read in from the configuration file. During the interaction the finding are reported to stdout, with output that will look similar to this:

```
NUOPC Component Explorer App
------
Exploring a component with a Fortran module front...
Model component # 1 InitializePhaseMap:
IPDv00p1=1
IPDv00p2=2
```

```
IPDv00p3=3
  IPDv00p4=4
Model component # 1 // name = ocnA
  ocnA: <LongName> : Attribute is present but NOT set! ocnA: <ShortName> : Attribute is present but NOT set!
  ocnA: <Description> : Attribute is present but NOT set!
  ocnA: importState // itemCount = 2
  ocnA: importState // item # 001 // [FIELD] name = pmsl
                <StandardName> = air_pressure_at_sea_level
                       \langle Units \rangle = Pa
                    <LongName> = Air Pressure at Sea Level
                   <ShortName> = pmsl
  ocnA: importState // item # 002 // [FIELD] name = rsns
                <StandardName> = surface_net_downward_shortwave_flux
                       <Units> = W m-2
                    <LongName> = Surface Net Downward Shortwave Flux
                   <ShortName> = rsns
  ocnA: exportState // itemCount = 1
  ocnA: exportState // item # 001 // [FIELD] name = sst
                <StandardName> = sea_surface_temperature
                       \langle Units \rangle = K
                    <LongName> = Sea Surface Temperature
                   <ShortName> = sst
```

Turning on the Compliance Checker (see section 5.1) will result in additional information in the log files.

## 6 Appendix A: Run Sequence Implementation

The NUOPC Driver utilizes an internal class to parametrize the run sequence. The NUOPC\_RunSequence provides a unified data structure that allows simple as well as complex time loops to be encoded and executed. There are entry points that allow different run phases to be mapped against distinctly different time loops. Figure 2 depicts the data structures surrounding the NUOPC\_RunSequence, starting with the InternalState of the NUOPC\_Driver generic component.



Figure 2: NUOPC\_RunSequence class as it relates to the surrounding data structures.

# 7 Appendix B: Initialize Phase Definition Versions

IMPORTANT: Use of explicit Initialize Phase Definition versions and phase labels is deprecated - this section is provided only for reference for NUOPC caps that still use the IPD syntax. See the section on Semantic Specialization Labels for the preferred method of specializing NUOPC caps.

The interaction between NUOPC compliant components during the initialization process is regulated by the **Initialize Phase Definition** or **IPD**. The IPDs are versioned, with a higher version number indicating backward compatibility with all previous versions.

There are two perspectives of looking at the IPD. From the driver perspective the IPD regulates the sequence in which it must call the different phases of the Initialize() routines of its child components. To this end the generic NUOPC\_Driver component implements support for IPDs up to a version specified in the API documentation.

The other angle of looking at the IPD is from the driver's child components. From this perspective the IPD assigns specific meaning to each initialize phase. The child components of a driver can be divided into two groups with respect to the meaning the IPD assigns to each initialize phase. In one group are the model, mediator, and driver components, and in the other group are the connector components. Child components publish their available initialize phases through the InitializePhaseMap attribute.

The driver also calls into its own internal initialize methods. This allows the driver to participate in the initialization of its children in a structured fashion. The internal initialization phases of a driver are published via the InternalInitializePhaseMap attribute.

The following tables document the meaning of each initialization phase of the available IPD versions for the child components and for the driver component itself. The phases are listed in the sequence in which the driver calls them.

IPDv00 label	Component	Meaning
IPDv00p1	driver-internal	unspecified by NUOPC
IPDv00p1	models, mediators, drivers	Advertise their import and export Fields.
IPDv00p1	connectors	Construct their CplList Attribute.
IPDv00p2	driver-internal	unspecified by NUOPC
IPDv00p2	models, mediators, drivers	Realize their import and export Fields.
IPDv00p2a	connectors	Set the Connected Attribute on each import and export Field accord-
		ing to the CplList Attribute. Reconcile the import and export States.
IPDv00p2b	connectors	Precompute the RouteHandle.
IPDv00p3	driver-internal	unspecified by NUOPC
IPDv00p3	models, mediators, drivers	Check for compatibility of their Fields' Connected status.
IPDv00p4	driver-internal	unspecified by NUOPC
IPDv00p4	models, mediators, drivers	Handle Field data initialization. Timestamp their export Fields.

IPDv01 label	Component	Meaning
IPDv01p1	driver-internal	unspecified by NUOPC
IPDv01p1	models, mediators, drivers	Advertise their import and export Fields.
IPDv01p1	connectors	Construct their CplList Attribute.
IPDv01p2	driver-internal	Modify the CplList Attributes on the Connectors.
IPDv01p2	models, mediators, drivers	unspecified/unused by NUOPC
IPDv01p2	connectors	Set the Connected Attribute on each import and export Field accord-
		ing to the CplList Attribute.

IPDv01p3	driver-internal	unspecified by NUOPC
IPDv01p3	models, mediators, drivers	Realize their "connected" import and export Fields.
IPDv01p3a	connectors	Reconcile the import and export States.
IPDv01p3b	connectors	Precompute the RouteHandle according to the CplList Attribute.
IPDv01p4	driver-internal	unspecified by NUOPC
IPDv01p4	models, mediators, drivers	Check for compatibility of their Fields' Connected status.
IPDv01p5	driver-internal	unspecified by NUOPC
IPDv01p5	models, mediators, drivers	Handle Field data initialization. Timestamp their export Fields.

IPDv02 label	Component	Meaning
IPDv02p1	driver-internal	unspecified by NUOPC
IPDv02p1	models, mediators, drivers	Advertise their import and export Fields.
IPDv02p1	connectors	Construct their CplList Attribute.
IPDv02p2	driver-internal	Modify the CplList Attributes on the Connectors.
IPDv02p2	models, mediators, drivers	unspecified/unused by NUOPC
IPDv02p2	connectors	Set the Connected Attribute on each import and export Field accord-
		ing to the CplList Attribute.
IPDv02p3	driver-internal	unspecified by NUOPC
IPDv02p3	models, mediators, drivers	Realize their "connected" import and export Fields.
IPDv02p3a	connectors	Reconcile the import and export States.
IPDv02p3b	connectors	Precompute the RouteHandle according to the CplList Attribute.
IPDv02p4	driver-internal	unspecified by NUOPC
IPDv02p4	models, mediators, drivers	Check for compatibility of their Fields' Connected status.
IPDv02p5	driver-internal	unspecified by NUOPC
IPDv02p5	models, mediators, drivers	Handle Field data initialization. Timestamp their export Fields.
A loop is entered o	ver all those model, mediator, d	river Components that use IPDv02 and have
unsatisfied data de	pendencies, repeating the follow	ing two steps:
Run()	connectors	Loop over all Connectors that connect to the Component that is cur-
		rently indexed by the outer loop.
IPDv02p5	models, mediators, drivers	Handle Field data initialization. Timestamp their export Fields and set
		the Updated and InitializeDataComplete Attributes accord-
		ingly.
Repeat these two steps until all data dependencies have been statisfied, or a dead-lock situation		
is detected.		

IPDv03 label	Component	Meaning
IPDv03p1	driver-internal	unspecified by NUOPC
IPDv03p1	models, mediators, drivers	Advertise their import and export Fields and set the
		TransferOfferGeomObject Attribute.
IPDv03p1	connectors	Construct their CplList Attribute.
IPDv03p2	driver-internal	Modify the CplList Attributes on the Connectors.
IPDv03p2	models, mediators, drivers	unspecified/unused by NUOPC

IPDv03p2	connectors	Set the Connected Attribute on each import and export Field according to the CplList Attribute. Set the TransferActionGeomObject Attribute.
IPDv03p3	driver-internal	unspecified by NUOPC
IPDv03p3	models, mediators, drivers	Realize their "connected" import and export Fields that have TransferActionGeomObject equal to "provide".
IPDv03p3	connectors	Transfer the Grid/Mesh/LocStream objects (only DistGrid) for Field pairs that have a provider and an acceptor side.
IPDv03p4	driver-internal	unspecified by NUOPC
IPDv03p4	models, mediators, drivers	Optionally modify the decomposition and distribution information of the accepted Grid/Mesh/LocStream by replacing the DistGrid.
IPDv03p4	connectors	Transfer the full Grid/Mesh/LocStream objects (with coordinates) for Field pairs that have a provider and an acceptor side.
IPDv03p5	driver-internal	unspecified by NUOPC
IPDv03p5	models, mediators, drivers	Realize all Fields that have TransferActionGeomObject equal to "accept" on the transferred Grid/Mesh/LocStream objects.
IPDv03p5a	connectors	Reconcile the import and export States.
IPDv03p5b	connectors	Precompute the RouteHandle according to the CplList Attribute.
IPDv03p6	driver-internal	unspecified by NUOPC
IPDv03p6	models, mediators, drivers	Check compatibility of their Fields' Connected status.
IPDv03p7	driver-internal	unspecified by NUOPC
IPDv03p7	models, mediators, drivers	Handle Field data initialization. Timestamp the export Fields.
A loop is entered	d over all those model, mediator, a	river Components that use IPDv02 and have
unsatisfied data d	dependencies, repeating the follow	ving two steps:
Run()	connectors	Loop over all Connectors that connect to the Component that is cur-
		rently indexed by the outer loop.
IPDv03p7	models, mediators, drivers	Handle Field data initialization. Time stamp the export Fields and set
		the Updated and InitializeDataComplete Attributes accord-
		ingly.
Repeat these two is detected.	steps until all data dependencies	have been statisfied, or a dead-lock situation

IPDv04 label	Component	Meaning
IPDv04p1	driver-internal	unspecified by NUOPC
IPDv04p1	models, mediators, drivers	Advertise their import and export Fields and set the
		TransferOfferGeomObject Attribute.
IPDv04p1a	connectors	Consider all connection possibilities for their CplList Attribute.
IPDv04p1b	connectors	Unambiguous construction of their CplList Attribute.
IPDv04p2	driver-internal	Modify the CplList Attributes on the Connectors.
IPDv04p2	models, mediators, drivers	unspecified/unused by NUOPC
IPDv04p2	connectors	Set the Connected Attribute on each import and ex-
		port Field according to the CplList Attribute. Set the
		TransferActionGeomObject Attribute.
IPDv04p3	driver-internal	unspecified by NUOPC
IPDv04p3	models, mediators, drivers	Realize their "connected" import and export Fields that have
		TransferActionGeomObject equal to "provide".

IPDv04p3	connectors	Transfer the Grid/Mesh/LocStream objects (only DistGrid) for Field
		pairs that have a provider and an acceptor side.
IPDv04p4	driver-internal	unspecified by NUOPC
IPDv04p4	models, mediators, drivers	Optionally modify the decomposition and distribution information of
		the accepted Grid/Mesh/LocStream by replacing the DistGrid.
IPDv04p4	connectors	Transfer the full Grid/Mesh/LocStream objects (with coordinates) for
		Field pairs that have a provider and an acceptor side.
IPDv04p5	driver-internal	unspecified by NUOPC
IPDv04p5	models, mediators, drivers	Realize all Fields that have TransferActionGeomObject equal
		to "accept" on the transferred Grid/Mesh/LocStream objects.
IPDv04p5a	connectors	Reconcile the import and export States.
IPDv04p5b	connectors	Precompute the RouteHandle according to the CplList Attribute.
IPDv04p6	driver-internal	unspecified by NUOPC
IPDv04p6	models, mediators, drivers	Check compatibility of their Fields' Connected status.
IPDv04p7	driver-internal	unspecified by NUOPC
IPDv04p7	models, mediators, drivers	Handle Field data initialization. Timestamp the export Fields.
A loop is entered	l over all those model, mediator, a	lriver Components that use IPDv02 and have
unsatisfied data d	dependencies, repeating the follow	ving two steps:
Run()	connectors	Loop over all Connectors that connect to the Component that is cur-
		rently indexed by the outer loop.
IPDv04p7	models, mediators, drivers	Handle Field data initialization. Time stamp the export Fields and set
		the Updated and InitializeDataComplete Attributes accord-
		ingly.
Repeat these two	steps until all data dependencies	have been statisfied, or a dead-lock situation
is detected.		

IPDv05 label	Component	Meaning
IPDv05p1	driver-internal	Advertise import and export Fields and set the
		TransferOfferGeomObject Attribute. Optionally set
		FieldTransferPolicy Attribute on States.
IPDv05p1	models, mediators, drivers	Advertise their import and export Fields and set the
		TransferOfferGeomObject Attribute. Optionally set
		FieldTransferPolicy Attribute on States.
IPDv05p1	connectors	Consider FieldTransferPolicy Attribute on import and export
		States. Advertise Fields to be transferred.
IPDv05p2	driver-internal	Optionally modify import and export States before connectors con-
		struct CplList Attribute.
IPDv05p2	models, mediators, drivers	Optionally modify import and export States before connectors con-
		struct CplList Attribute.
IPDv05p2a	connectors	Consider all connection possibilities for their CplList Attribute.
IPDv05p2b	connectors	Unambiguous construction of their CplList Attribute.
IPDv05p3	driver-internal	Modify the CplList Attributes on the Connectors.
IPDv05p3	models, mediators, drivers	unspecified/unused by NUOPC
IPDv05p3	connectors	Set the Connected Attribute on each import and ex-
		port Field according to the CplList Attribute. Set the
		TransferActionGeomObject Attribute.

IPDv05p4	driver-internal	Realize "connected" import and export Fields that have
		TransferActionGeomObject equal to "provide".
IPDv05p4	models, mediators, drivers	Realize their "connected" import and export Fields that have TransferActionGeomObject equal to "provide".
IPDv05p4	connectors	Transfer the Grid/Mesh/LocStream objects (only DistGrid) for Field
-		pairs that have a provider and an acceptor side.
IPDv05p5	driver-internal	Optionally modify the decomposition and distribution information of
		the accepted Grid/Mesh/LocStream by replacing the DistGrid.
IPDv05p5	models, mediators, drivers	Optionally modify the decomposition and distribution information of
		the accepted Grid/Mesh/LocStream by replacing the DistGrid.
IPDv05p5	connectors	Transfer the full Grid/Mesh/LocStream objects (with coordinates) for
		Field pairs that have a provider and an acceptor side.
IPDv05p6	driver-internal	Realize all Fields that have TransferActionGeomObject equal
		to "accept" on the transferred Grid/Mesh/LocStream objects.
IPDv05p6	models, mediators, drivers	Realize all Fields that have TransferActionGeomObject equal
		to "accept" on the transferred Grid/Mesh/LocStream objects.
IPDv05p6a	connectors	Reconcile the import and export States.
IPDv05p6b	connectors	Precompute the RouteHandle according to the CplList Attribute.
IPDv05p7	driver-internal	unspecified by NUOPC
IPDv05p7	models, mediators, drivers	Check compatibility of their Fields' Connected status.
IPDv05p8	driver-internal	unspecified by NUOPC
IPDv05p8	models, mediators, drivers	Handle Field data initialization. Timestamp the export Fields.
A loop is entered	d over all those model, mediator, a	driver Components that use IPDv02 and have
unsatisfied data	dependencies, repeating the follow	
Run()	connectors	Loop over all Connectors that connect to the Component that is cur-
		rently indexed by the outer loop.
IPDv05p8	models, mediators, drivers	Handle Field data initialization. Time stamp the export Fields and set
		the Updated and InitializeDataComplete Attributes accord-
		ingly.
•	o steps until all data dependencies	have been statisfied, or a dead-lock situation
is detected.		

# 7.1 NUOPC\_Driver IPD implementation

# **INITIALIZE**:

- phase 0: (REQUIRED, NUOPC PROVIDED)
  - Ensure that the InitializePhaseMap and InternalInitializePhaseMap attributes are set consistent with the available NUOPC Initialize Phase Definition (IPD) versions (see section 7 for a precise definition). The default implementation uses IPDv02 for InitializePhaseMap, and sets
    - \* IPDv02p1 (NUOPC PROVIDED)
    - \* IPDv02p3 (NUOPC PROVIDED)
    - \* IPDv02p5 (NUOPC PROVIDED).

The default implementation uses IPDv05 for InternalInitializePhaseMap, and sets

- \* IPDv05p1 (NUOPC PROVIDED)
- \* IPDv05p2 (NUOPC PROVIDED)

- \* IPDv05p3 (NUOPC PROVIDED)
- \* IPDv05p4 (NUOPC PROVIDED)
- \* IPDv05p6 (NUOPC PROVIDED)
- \* IPDv05p8 (NUOPC PROVIDED).
- phase 1: (REQUIRED, NUOPC PROVIDED)
  - A default Initialize entry point for the higher level (e.g. application level) to initialize the Driver with a single call.
  - Internally calls into the InitializePhaseMap: IPDv02p1, IPDv02p3, IPDv02p5 phases in sequence.
- InitializePhaseMap: IPDv02p1 (NUOPC PROVIDED)
  - Allocate and initialize internal data structures.
  - If the internal clock is not yet set, set the default internal clock to be a copy of the incoming clock, but only
    if the incoming clock is valid.
  - Required specialization to set component services: label\_SetModelServices.
    - \* Call NUOPC\_DriverAddComp () for all Model, Mediator, and Connector components to be added.
    - \* Optionally replace the default clock.
  - Create States for all of the child GridComps.
  - Create Connectors to/from Driver component itself.
  - Set default run sequence.
  - Execute Initialize phase=0 for all Model, Mediator, and Connector components. This is the method where each component is required to initialize its InitializePhaseMap Attribute.
  - Optional specialization to analyze and modify the InitializePhaseMap Attribute of the child components before the Driver uses it: label\_ModifyInitializePhaseMap.
  - Optional specialization to set run sequence: label\_SetRunSequence.
  - Drive the initialize sequence for the child components, compatible with up to IPDv05, as documented in section 7, through IPDv05p3.
- InitializePhaseMap: IPDv02p3 (NUOPC PROVIDED)
  - Continue to drive the initialize sequence for the child components, compatible with up to IPDv05, as documented in section 7, through IPDv05p7.
- InitializePhaseMap: IPDv02p5 (NUOPC Provided)
  - Continue to drive the initialize sequence for the child components, compatible with up to IPDv05, as documented in section 7, through IPDv05p8.
- $\bullet \ \, \texttt{InternalInitializePhaseMap: IPDv05p1} \ (NUOPC \ Provided)$ 
  - Request that fields in export and import State of child components are mirrored onto the driver's own import and export States.
  - This includes transferring the associated Grid, Mesh, or LocStream objects.
- InternalInitializePhaseMap: IPDv05p2 (NUOPC PROVIDED)
  - Reset the request of field mirroring.
- InternalInitializePhaseMap: IPDv05p3 (NUOPC Provided)
  - Add the REMAPMETHOD=redist option to all entries in CplList attribute on all Connectors to/from the driver itself.

- Optional specialization to modify the CplList attribute on all of the Connectors: label\_ModifyCplLists.
- InternalInitializePhaseMap: IPDv05p4 (NUOPC PROVIDED)
  - Check that all connected fields in the driver's own import and export State have a producer connection.
- InternalInitializePhaseMap: IPDv05p6 (NUOPC PROVIDED)
  - Complete the allocation of all the fields in the driver's own import and export State.
- InternalInitializePhaseMap: IPDv05p8 (NUOPC PROVIDED)
  - Set the InitializeDataComplete consistent with the data-dependency protocol.

- phase 1: (REQUIRED, NUOPC PROVIDED)
  - If the incoming clock is valid, set the internal stop time to one time step interval on the incoming clock.
  - Drive the time stepping loop, from current time to stop time, incrementing by time step.
    - \* For each time step iteration the Model and Connector components Run() methods are being called according to the run sequence.

#### FINALIZE:

- phase 1: (REQUIRED, NUOPC PROVIDED)
  - Execute the Finalize() methods of all Connector components in order.
  - Execute the Finalize() methods of all Model components in order.
  - Optional specialization to finalize custom parts of the component: label\_Finalize.
  - Destroy all Model components and their import and export states.
  - Destroy all Connector components.
  - Internal clean-up.

# 7.2 NUOPC\_ModelBase IPD implementation

- phase 0: (REQUIRED, NUOPC PROVIDED)
  - Initialize the InitializePhaseMap Attribute according to the NUOPC Initialize Phase Definition (IPD) version 00 (see section 7 for a precise definition). The default implementation sets the following mapping:
    - \* IPDv00p1 = 1: (REQUIRED, IMPLEMENTOR PROVIDED)
    - \* IPDv00p2 = 2: (REQUIRED, IMPLEMENTOR PROVIDED)
    - \* IPDv00p3 = 3: (REQUIRED, IMPLEMENTOR PROVIDED)
    - \* IPDv00p4 = 4: (REQUIRED, IMPLEMENTOR PROVIDED)

- phase 1: (NUOPC PROVIDED)
  - SPECIALIZATION REQUIRED/PROVIDED: label\_SetRunClock to check and set the internal Clock against the incoming Clock.
    - \* IF (Phase specific specialization present): Execute the phase specific specialization.
    - \* ELSE: Execute the phase independent specialization. PROVIDED: By default check that internal Clock and incoming Clock agree on current time and that the time step of the incoming Clock is a multiple of the internal Clock time step. Under these conditions set the internal stop time to one time step interval of the incoming Clock. Otherwise exit with error, flagging an incompatibility.
  - SPECIALIZATION REQUIRED/PROVIDED: label\_CheckImport to check Fields in the import State.
    - \* IF (Phase specific specialization is present): Execute the phase specific specialization.
    - \* ELSE: Execute the phase independent specialization. PROVIDED: By default check that all import Fields are at the current time of the internal Clock.
  - Time stepping loop: starting at current time, running to stop time of the internal Clock.
    - \* Timestamp the Fields in the export State according to the current time of the internal Clock.
    - \* SPECIALIZATION REQUIRED: label\_Advance to execute model or mediation code.
    - \* SPECIALIZATION OPTIONAL: label\_AdvanceClock to advance the current time of the internal Clock. By default (without specialization) advance the current time of the internal Clock according to the time step of the internal Clock.
  - SPECIALIZATION OPTIONAL: label\_TimestampExport to timestamp Fields in the export State.

#### FINALIZE:

- phase 1: (REQUIRED, NUOPC PROVIDED)
  - Optional specialization to finalize custom parts of the component: label\_Finalize.

# 7.3 NUOPC\_Model IPD implementation

- phase 0: Set Initialize Phase Definition Version (REQUIRED, NUOPC PROVIDED)
  - Initialize the InitializePhaseMap Attribute according to the NUOPC Initialize Phase Definition (IPD) version 00 (see section 7 for a precise definition). The default implementation sets the following mapping:
    - \* IPDv00p1 = 1: (REQUIRED, IMPLEMENTOR PROVIDED)
      - · Advertise Fields in import and export States.
    - \* IPDv00p2 = 2: (REQUIRED, IMPLEMENTOR PROVIDED)
      - · Realize the advertised Fields in import and export States.
    - \* IPDv00p3 = 3: (REQUIRED, NUOPC PROVIDED)
      - · Check compatibility of the Fields' Connected status.
    - \* IPDv00p4 = 4: (REQUIRED, NUOPC PROVIDED)
      - · Handle Field data initialization. Time stamp the export Fields.

- IPDv00p1, IPDv01p1, IPDv02p1, IPDv03p1, IPDv04p1, IPDv05p1: Advertise fields in import and export States (Required, IMPLEMENTOR PROVIDED)
  - Advertise fields in import/export states using one of the two NUOPC\_Advertise methods (3.9.3, 3.9.4). The methods require Standard Names for each field, and the Standard Names must appear in the NUOPC Field Dictionary or a runtime error is generated. NUOPC\_Advertise accepts a TransferOfferGeomObject argument which may be one of:
    - \* "will provide" (default) The field will provide its own geometric object (i.e., Grid, Mesh, or Loc-Stream)
    - \* "can provide"- The field can provide its own geometric object, but only if the connected field in the other component will not provide it
    - \* "cannot provide" The field cannot provide its own geometric object. It must accept a geometric object from a connected field.

See section 2.4.7 for more details about transferring geometric objects between NUOPC components. Memory is not allocated for advertised fields, but attributes are set on the field which can be used in later phases, especially for determining if another component can provide and/or consume the advertised field.

- IPDv00p2, IPDv01p3, IPDv02p3, IPDv03p3, IPDv04p3, IPDv05p4: Realize field *providing* a geometric object (REQUIRED\*, IMPLEMENTOR PROVIDED)
  - Realize connected import and export fields that have their TransferActionGeomObject attribute set to "provide", i.e., that will provide their own geometric object (i.e., Grid, Mesh, or LocStream). "provide" is the default value of TransferActionGeomObject. Realize means an ESMF\_Field object is created on a geometric object and memory for the field is allocated or referenced.

The NUOPC\_Realize methods (3.9.21, 3.9.22, 3.9.23, 3.9.24, 3.9.25) are used to realize fields. Only previously advertised fields can be realized and the field's name is used to search the state for the previously advertised field.

- \*Note: This phase is not required if all fields are accepting a geometric object.
- IPDv03p4, IPDv04p4, IPDv05p5: Modify decomposition of accepted geometric object (OPTIONAL, IMPLE-MENTOR PROVIDED)
  - Optionally modify the decomposition information of any accepted geometric object by replacing the Dist-Grid. In the case of the Grid geometric object, this can be accomplished by retrieving the Grid (and its DistGrid) from the Field, creating a new DistGrid with modified decomposition, creating a new Grid on the new (modified) DistGrid, and then using ESMF\_FieldEmptySet to replace the existing Grid with the new one.
    - This phase is useful when accepting a Grid from another component, but when the PET counts differ between components. In this case, a new decomposition needs to be set based on the current processor count.
- IPDv03p5, IPDv04p5, IPDv05p6: Realize fields *accepting* a geometric object (REQUIRED\*, IMPLEMENTOR PROVIDED)
  - Realize connected import and export fields that have their TransferActionGeomObject attribute set to "accept", i.e., that will accept a geometric object from a connected field in another component. If the generic NUOPC\_Connector is used, at this point the full geometric object has already been set in the field and only a call to ESMF\_FieldEmptyComplete is required to allocate memory for the field.
    - The NUOPC\_Realize methods (3.9.21, 3.9.22, 3.9.23, 3.9.24, 3.9.25) are used to realize fields. Only previously advertised fields can be realized and the field's name is used to search the state for the previously advertised field.
    - \*Note: This phase is not required if all fields are providing a geometric object.
- IPDv00p3, IPDv01p4, IPDv02p4, IPDv03p6, IPDv04p6, IPDv05p7: Verify import fields connected and set clock (NUOPC PROVIDED)

- If the model internal clock is found to be not set, then set the model internal clock as a copy of the incoming clock.
- Optional specialization to set the internal clock and/or alarms: label\_SetClock.
- Check compatibility, ensuring all advertised import Fields are connected.
- IPDv00p4, IPDv01p5: Initialize export fields (NUOPC PROVIDED)
  - Optional specialization to initialize export Fields: label DataInitialize
  - Time stamp Fields in export State for compatibility checking.
- IPDv02p5, IPDv03p7, IPDv04p7, IPDv05p8: Initialize export fields (NUOPC PROVIDED)
  - Optional specialization to initialize export Fields: label\_DataInitialize
  - Timestamp Fields in export State for compatibility checking.
  - Set Component metadata used to resolve initialize data dependencies.

- phase 1: (REQUIRED, NUOPC PROVIDED)
  - SPECIALIZATION REQUIRED/PROVIDED: label\_SetRunClock to check and set the internal Clock against the incoming Clock.
    - \* IF (Phase specific specialization present): Execute the phase specific specialization.
    - \* ELSE: Execute the phase independent specialization. PROVIDED: By default check that internal Clock and incoming Clock agree on current time and that the time step of the incoming Clock is a multiple of the internal Clock time step. Under these conditions set the internal stop time to one time step interval of the incoming Clock. Otherwise exit with error, flagging an incompatibility.
  - SPECIALIZATION REQUIRED/PROVIDED: label\_CheckImport to check Fields in the import State.
    - \* IF (Phase specific specialization is present): Execute the phase specific specialization.
    - \* ELSE: Execute the phase independent specialization. PROVIDED: By default check that all import Fields are at the current time of the internal Clock.
  - Time stepping loop: starting at current time, running to stop time of the internal Clock.
    - \* Timestamp the Fields in the export State according to the current time of the internal Clock.
    - \* SPECIALIZATION REQUIRED: label\_Advance to execute model code.
    - \* SPECIALIZATION OPTIONAL: label\_AdvanceClock to advance the current time of the internal Clock. By default (without specialization) advance the current time of the internal Clock according to the time step of the internal Clock.
  - SPECIALIZATION OPTIONAL/PROVIDED: label\_TimestampExport to timestamp Fields in the export State.
    - \* IF (Phase specific specialization present): Execute the phase specific specialization.
    - \* ELSE: Execute the phase independent specialization. PROVIDED: Timestamp all Fields in the export State according to the current time of the internal Clock, which now is identical to the stop time of the internal Clock.

### FINALIZE:

- phase 1: (REQUIRED, NUOPC PROVIDED)
  - Optional specialization to finalize custom parts of the component: label Finalize.

### 7.3.1 Initialize Phase Specialization - label\_SetClock

OPTIONAL, IMPLEMENTOR PROVIDED

Called from: IPDv00p3, IPDv01p4, IPDv02p4, IPDv03p6, IPDv04p6, IPDv05p7

The specialization method can change aspects of the internal clock, which defaults to a copy of the incoming parent clock. For example, the timeStep size may be changed and/or Alarms may be set on the clock.

The method NUOPC\_CompSetClock (comp, externalClock, stabilityTimeStep) (3.6.36) can be used to set the internal clock as a copy of externalClock, but with a timeStep that is less than or equal to the stabilityTimeStep. At the same time it ensures that the timeStep of the external clock is a multiple of the timeStep of the internal clock. If the stabilityTimeStep argument is not provided then the internal clock will simply be set as a copy of the external clock.

## 7.3.2 Initialize Phase Specialization - label\_DataInitialize

OPTIONAL, IMPLEMENTOR PROVIDED

Called from: IPDv00p4, IPDv01p5, IPDv02p5, IPDv03p7, IPDv04p7, IPDv05p8

The specialization method should initialize field data in the export state. Fields in the export state will be timestamped automatically by the calling phase for all fields that have the "Updated" attribute set to "true".

#### 7.3.3 Run Phase Specialization - label\_SetRunClock

REQUIRED, NUOPC PROVIDED Called from: default run phase

A specialization method to check and set the internal clock against the incoming clock. This method is called by the default run phase.

If not overridden, the default method will check that the internal clock and incoming clock agree on the current time and that the time step of the incoming clock is a multiple of the internal clock time step. Under these conditions set the internal stop time to one time step interval of the incoming clock. Otherwise exit with error, flagging an incompatibility.

### 7.3.4 Run Phase Specialization - label\_CheckImport

REQUIRED, NUOPC PROVIDED Called from: default run phase

A specialization method to verify import fields before advancing in time. If not overridden, the default method verifies that all import fields are at the current time of the internal clock.

# 7.3.5 Run Phase Specialization - label\_Advance

REQUIRED, IMPLEMENTOR PROVIDED

Called from: default run phase

A specialization method that advances the model forward in time by one timestep of the internal clock. This method will be called iteratively by the default run phase until reaching the stop time on the internal clock.

# 7.3.6 Run Phase Specialization - label\_TimestampExport

REQUIRED, NUOPC PROVIDED Called from: default run phase

A specialization method to set the timestamp on export fields after the model has advanced. If not overridden, the default method sets the timestamp on all export fields to the stop time on the internal clock (which is also now the current model time).

# 7.3.7 Finalize Phase Specialization - label\_Finalize

OPTIONAL, IMPLEMENTOR PROVIDED Called from: default finalize phase

An optional specialization method for custom finalization code and deallocations of user data structures.

# 7.4 NUOPC\_Mediator IPD implementation

- phase 0: (REQUIRED, NUOPC PROVIDED)
  - Initialize the InitializePhaseMap Attribute according to the NUOPC Initialize Phase Definition (IPD) version 00 (see section 7 for a precise definition). The default implementation sets the following mapping:
    - \* IPDv00p1 = 1: (REQUIRED, IMPLEMENTOR PROVIDED)
      - · Advertise Fields in import and export States.
    - \* IPDv00p2 = 2: (REQUIRED, IMPLEMENTOR PROVIDED)
      - · Realize the advertised Fields in import and export States.
    - \* IPDv00p3 = 3: (REQUIRED, NUOPC PROVIDED)
      - $\cdot$  Check compatibility of the Fields' Connected status.
    - \* IPDv00p4 = 4: (REQUIRED, NUOPC PROVIDED)
      - · Handle Field data initialization. Time stamp the export Fields.
- IPDv00p3, IPDv01p4, IPDv02p4: (NUOPC PROVIDED)
  - Set the Mediator internal clock as a copy of the incoming clock.
  - Check compatibility, ensuring all advertised import Fields are connected.
- IPDv00p4, IPDv01p5: (NUOPC PROVIDED)
  - Optional specialization to initialize export Fields: label\_DataInitialize
  - Time stamp Fields in import and export States for compatibility checking.

- IPDv02p5: (NUOPC PROVIDED)
  - Optional specialization to initialize export Fields: label\_DataInitialize
  - Time stamp Fields in export State for compatibility checking.
  - Set Component metadata used to resolve initialize data dependencies.

- phase 1: (REQUIRED, NUOPC PROVIDED)
  - SPECIALIZATION REQUIRED/PROVIDED: label\_SetRunClock to check and set the internal Clock against the incoming Clock.
    - \* IF (Phase specific specialization present): Execute the phase specific specialization.
    - \* ELSE: Execute the phase independent specialization. PROVIDED: By default check that internal Clock and incoming Clock agree on current time and that the time step of the incoming Clock is a multiple of the internal Clock time step. Under these conditions set the internal stop time to one time step interval of the incoming Clock. Otherwise exit with error, flagging an incompatibility.
  - Specialization Required/Provided: label\_CheckImport to check Fields in the import State.
    - \* IF (Phase specific specialization is present): Execute the phase specific specialization.
    - \* ELSE: Execute the phase independent specialization. PROVIDED: By default check that all import Fields are at the current time of the internal Clock.
  - Time stepping loop: starting at current time, running to stop time of the internal Clock.
    - \* Timestamp the Fields in the export State according to the current time of the internal Clock.
    - \* SPECIALIZATION REQUIRED: label Advance to execute mediation code.
    - \* SPECIALIZATION OPTIONAL: label\_AdvanceClock to advance the current time of the internal Clock. By default (without specialization) advance the current time of the internal Clock according to the time step of the internal Clock.
  - SPECIALIZATION OPTIONAL/PROVIDED: label\_TimestampExport to timestamp Fields in the export State.
    - \* IF (Phase specific specialization present): Execute the phase specific specialization.
    - \* ELSE: Execute the phase independent specialization. PROVIDED: Timestamp all Fields in the export State according to the current time of the internal Clock when *entering* the RUN method.

#### FINALIZE:

- phase 1: (REQUIRED, NUOPC PROVIDED)
  - Optional specialization to finalize custom parts of the component: label\_Finalize.

# 7.5 NUOPC\_Connector IPD implementation

- phase 0: (REQUIRED, NUOPC PROVIDED)
  - Initialize the InitializePhaseMap Attribute according to the NUOPC Initialize Phase Definition (IPD) version 04 (see section 7 for a precise definition). The default implementation sets the following mapping:

- \* IPDv04p1a = phase : (REQUIRED, NUOPC PROVIDED)
- \* IPDv04p1b = phase : (REQUIRED, NUOPC PROVIDED)
- \* IPDv04p2 = phase : (REQUIRED, NUOPC PROVIDED)
- \* IPDv04p3 = phase : (REQUIRED, NUOPC PROVIDED)
- \* IPDv04p4 = phase : (REQUIRED, NUOPC PROVIDED)
- \* IPDv04p5a = phase : (REQUIRED, NUOPC PROVIDED)
- \* IPDv04p5b = phase : (REQUIRED, NUOPC PROVIDED)
- IPDv01p1, IPDv02p1: (NUOPC PROVIDED)
  - Construct a list of matching Field pairs between import and export State based on the StandardName Field metadata.
  - Store this list of StandardName entries in the CplList attribute of the Connector Component metadata.
- IPDv01p2, IPDv02p2: (NUOPC PROVIDED)
  - Allocate and initialize the internal state.
  - Use the CplList attribute to construct srcFields and dstFields FieldBundles in the internal state that hold matched Field pairs.
  - Set the Connected attribute to true in the Field metadata for each Field that is added to the srcFields and dstFields FieldBundles.
- IPDv01p3, IPDv02p3: (NUOPC PROVIDED)
  - Use the CplList attribute to construct srcFields and dstFields FieldBundles in the internal state
    that hold matched Field pairs.
  - Set the Connected attribute to true in the Field metadata for each Field that is added to the srcFields and dstFields FieldBundles.
  - Optional specialization to precompute a Connector operation: label\_ComputeRouteHandle. Simple custom implementations store the precomputed communication RouteHandle in the rh member of the internal state. More complex implementations use the state member in the internal state to store auxiliary Fields, FieldBundles, and RouteHandles.
  - By default (if label\_ComputeRouteHandle was not provided) precompute the Connector Route-Handle as a bilinear Regrid operation between srcFields and dstFields, with unmappedaction set to ESMF\_UNMAPPEDACTION\_IGNORE. The resulting RouteHandle is stored in the rh member of the internal state.

- phase 1: (REQUIRED, NUOPC PROVIDED)
  - Optional specialization to execute a Connector operation: label\_ExecuteRouteHandle. Simple custom implementations access the srcFields, dstFields, and rh members of the internal state to implement the required data transfers. More complex implementations access the state member in the internal state, which holds the auxiliary Fields, FieldBundles, and RouteHandles that potentially were added during the optional label\_ComputeRouteHandle method during initialize.
  - By default (if label\_ExecuteRouteHandle was not provided) execute the precomputed Connector RouteHandle between srcFields and dstFields.
  - Update the time stamp on the Fields in dstFields to match the time stamp on the Fields in srcFields.

#### FINALIZE:

- phase 1: (REQUIRED, NUOPC PROVIDED)
  - Optional specialization to release the custom Connector operation: label\_ReleaseRouteHandle; or by default, if label\_ReleaseRouteHandle was not provided, release the default Connector RouteHandle.
  - Optional specialization to finalize custom parts of the component: label\_Finalize.
  - Internal clean-up.