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NEMS
(NOAA Environmental Modeling System)
and the ESMF and NUOPC layers it depends upon

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What is NEMS?

The **NOAA Environmental Modeling System (NEMS)** is a unified modeling system that supports multiple coupled modeling applications.

Each **coupled modeling application** is associated with a purpose, a set of model components, and a range of supported options including grids and resolutions. These are called **NEMS applications**.

A **unified infrastructure** means that many parts of NEMS are shared across modeling applications, including the build system, the coupling infrastructure, mediators, testing infrastructure, a common way of representing run configurations, and a common way to execute configurations.

Some Forces Affecting NEMS Design

- Increase in number of modeling component types
  - e.g., atmosphere, ocean, ice, land, hydrology, wave, surge, ionosphere, chemistry
- Multiple options for each modeling component type
  - e.g., MOM5, MOM6, HYCOM, “data” ocean component
- Community components developed external to EMC
- Multiple configurations needed for controlled experimentation
  - standalone model
  - coupled with “data” component
  - coupled with limited feedbacks
  - fully coupled
  - ensembles
  - alternative parameterizations
  - different resolutions

NEMS Nightly Regression Tests

Sample downloaded June 11, 2018 from http://www.emc.ncep.noaa.gov/projects/rt/
driven by https://vlab.ncep.noaa.gov/redmine/projects/nems-ext/repository/revisions/multi-app-test/entry/tests/apps.def

Test	Result	Age	Duration
xJet NEMSfv3gfs	PASS	23:29:39	01:28:05
sJet and vJet NEMSfv3gfs	PASS	23:29:33	01:28:11
Theia NEMSfv3gfs	PASS	20:07:24	00:39:42
Theia NEMSGSM	PASS	20:22:55	00:24:08
Theia HYCOM-GSM-CICE	PASS	20:22:51	00:24:10
Theia WW3-FV3	PASS	20:24:07	00:22:27
Theia WW3-ATM	PASS	20:03:21	00:43:08
Theia GSM-MOM5-CICE5	PASS	20:10:28	00:36:15
Theia FV3-MOM6-CICE5	PASS	20:17:34	00:29:22
WCOSS Phase 1 NEMSfv3gfs	PASS	18:03:35	01:10:05
WCOSS Phase 1 NEMSGSM	PASS	18:34:54	00:38:38
WCOSS Phase 2 NEMSfv3gfs	FAIL	17:38:15	01:35:13
WCOSS Phase 2 WW3-FV3	PASS	18:12:14	01:00:40
WCOSS Phase 2 WW3-ATM	PASS	18:25:49	00:47:02
WCOSS Phase 2 GSM-MOM5-CICE5	PASS	18:13:44	00:59:04
WCOSS Cray NEMSfv3gfs	PASS	17:03:34	02:10:15
WCOSS Cray WW3-FV3	PASS	18:27:13	00:46:16

Earth System Modeling Framework

The Earth System Modeling Framework (ESMF) was initiated in 2002 as a multi-agency response to calls for common modeling infrastructure.

ESMF provides:

- high performance utilities, including grid remapping, data communications, and model time management
- a component-based architecture for model construction

ESMF Metrics:
~7000 downloads

~100 components in use

~3000 individuals on info mailing list

~40 platform/compilers regression tested nightly

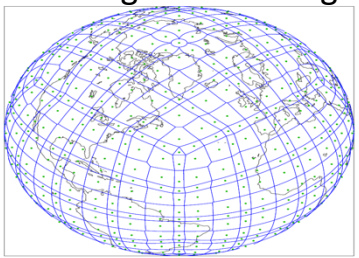
~6500 regression tests

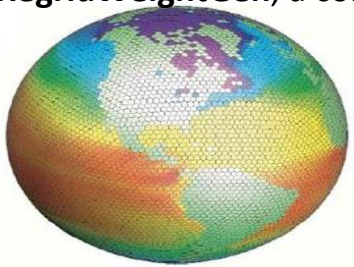
~1M SLOC

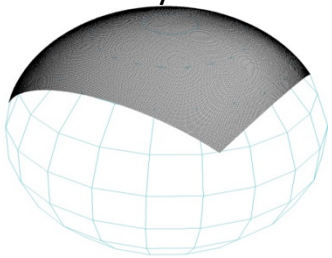
NUOPC is a software layer on top of ESMF 7+ that ensures interoperability of components. Most major U.S. modeling centers have adopted NUOPC conventions.

ESMF Grid Remapping

- Uniquely fast, reliable, and general – interpolation weights computed in parallel in 3D space
- Supported grids:
  - Logically rectangular and unstructured grids in 2D and 3D, point clouds/observations
  - Global and regional grids
- Supported interpolation methods:
  - Nearest neighbor, bilinear, higher order patch recovery, and 1st order conservative methods
  - Options for straight or great circle lines, masking, and a variety of pole treatments
- Multiple ways to call ESMF grid remapping:
  - Generate and apply weights using the **ESMF API**, within a model
  - Generate and apply weights using **ESMPy**, through a Python interface
  - Generate weights from grid files using **ESMF_RegridWeightGen**, a command-line utility







Standard Component Interfaces

ESMF/NUOPC components have three kinds of methods with standard interfaces:

- Initialize, Run, and Finalize

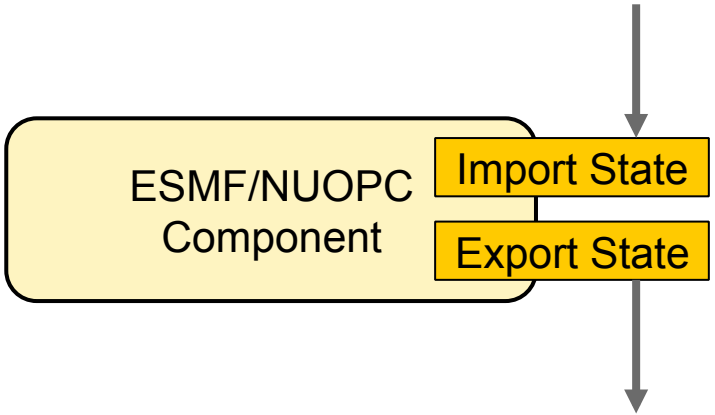
```
subroutine InitP1(comp, importState, exportState, clock, rc)
  type(ESMF_GridComp)   :: comp
  type(ESMF_State)      :: importState
  type(ESMF_State)      :: exportState
  type(ESMF_Clock)      :: clock
  integer, intent(out)  :: rc

  ! This is where the model specific setup code goes.
  rc = ESMF_SUCCESS

end subroutine InitP1
```

Interfaces are wrappers and can often be introduced in a non-intrusive and high-performance way. ESMF is designed to coexist with native model infrastructure.

Components Share Data via Import and Export States



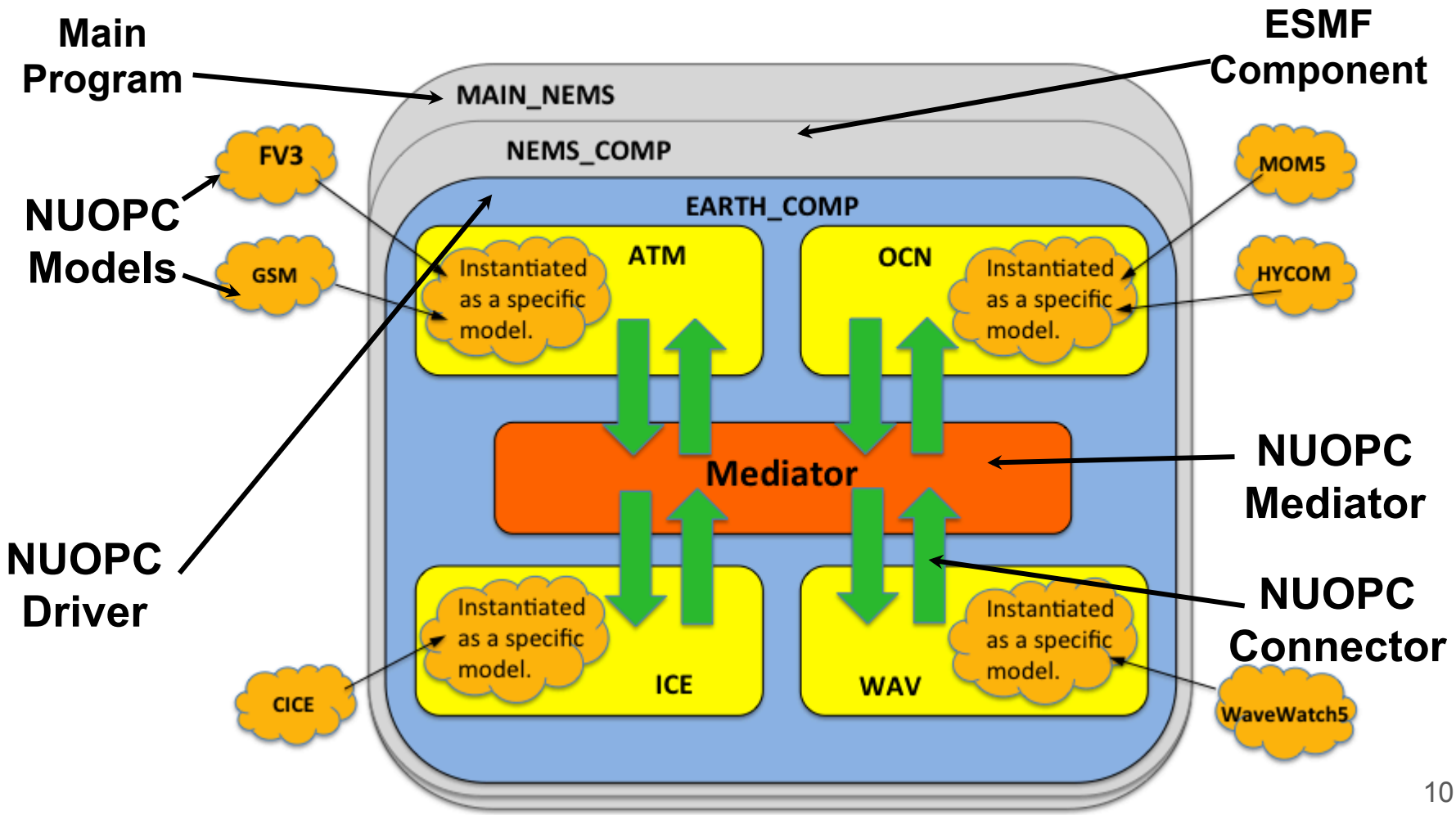
- **Components do not directly access each other's data**.
- The only way data moves in or out of a Component is via instances of the ESMF **State** class (`ESMF_State`).
- A State is a **container** for ESMF data types that wrap native model data.
- Model data can be **referenced**, avoiding duplicates and copies.
- **Metadata** (e.g., name, coordinates, decomposition) travels with data objects.

NUOPC Layer Components

The NUOPC Layer's four **generic components** represent the major structural pieces needed to build coupled models.

NUOPC Generic Components	
Driver	Harness that initializes components according to an *Initialization Phase Definition*, and drives their Run() methods according to a customizable run sequence.
Connector	Implements field matching based on standard metadata and executes simple transforms (e.g. grid remapping, redistribution). It can be plugged into a generic Driver component to connect Models and/or Mediators.
Model	Wraps model code so it is suitable to be plugged into a generic Driver component.
Mediator	Wraps custom coupling code (flux calculations, averaging, etc.) so it is suitable to be plugged into a generic Driver component.

From Theurich et al. 2016


Main Program
ESMF Component
MAIN_NEMS
NEMS_COMP
EARTH_COMP
FV3
GSM
NUOPC Models
MOM5
HYCOM
ATM
OCN
Instantiated as a specific model.
Instantiated as a specific model.
Mediator
NUOPC Mediator
NUOPC Driver
NUOPC Connector
Instantiated as a specific model.
Instantiated as a specific model.
ICE
WAV
CICE
WaveWatch5

NEMS Schematic

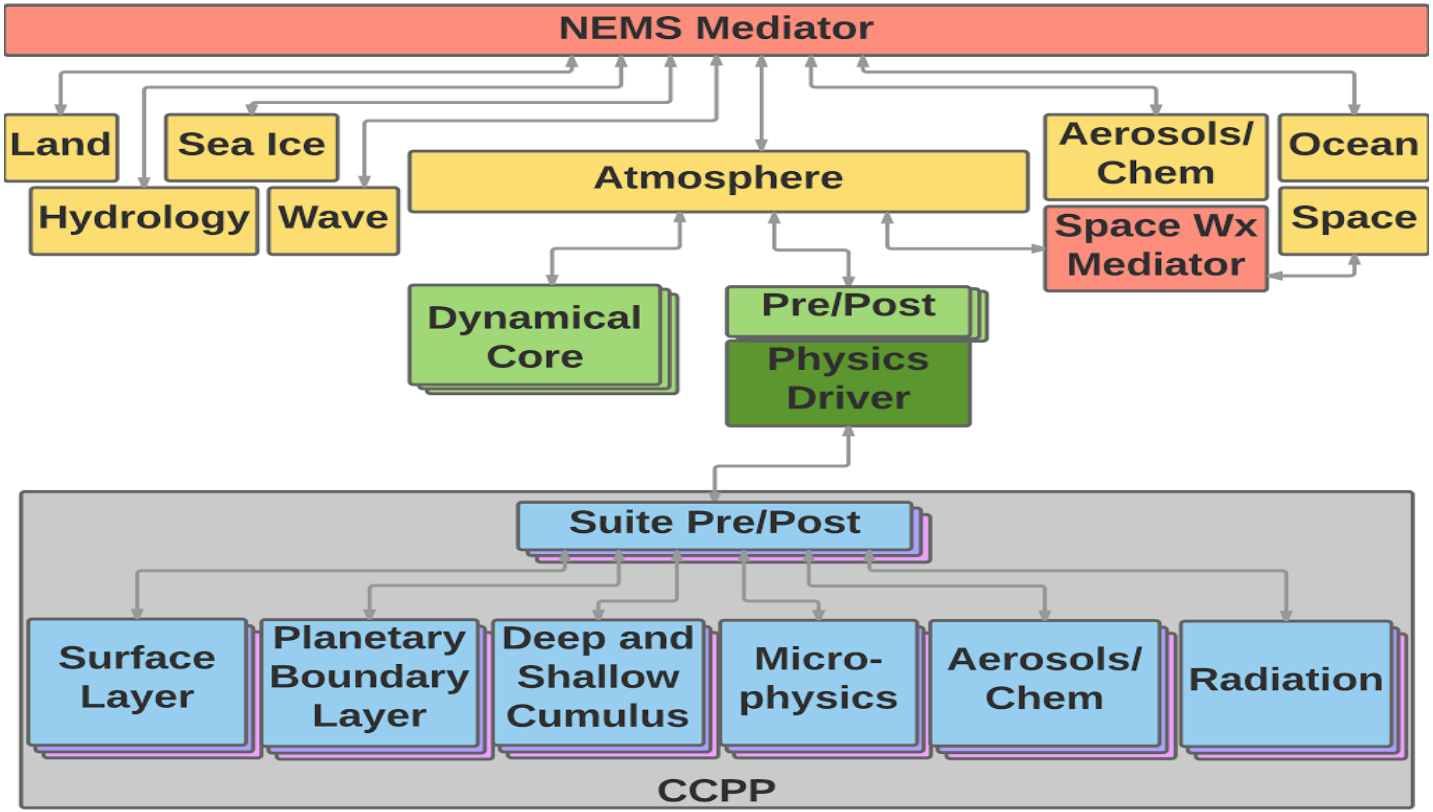


Image courtesy of the Developmental Testbed Center

Sample NEMS Configure File (nems.configure)

```
################################
# NEMS Run Time Configuration File  #
################################
# EARTH #
EARTH_component_list: MED ATM OCN ICE

# MED #
med_model:                      nems
med_petlist_bounds:             60 65

#ATM#
atm_model:              gsm
atm_petlist_bounds:             0 31

# OCN #
ocn_model:
ocn_petlist_bounds:

# ICE #
ice_model:                              cice
ice_petlist_bounds:             56 59
```

Run sequence ingested into Driver

```
 # Run Sequence #
runSeq::
  @1800.0
    MED MedPhase_prep_ocn
    MED -> OCN :remapMethod=redist
    OCN
    @600.0
      MED MedPhase_prep_ice
      MED MedPhase_prep_atm
      MED -> ATM :remapMethod=redist
      MED -> ICE :remapMethod=redist
      ATM
      ICE
      ATM -> MED :remapMethod=redist
      ICE -> MED :remapMethod=redist
      MED MedPhase_atm_ocn_flux
      MED MedPhase_accum_fast
    @
    OCN -> MED :remapMethod=redist
  @
::
```

Colors show actions performed by:

- Connectors (->)
- Mediator (MED)
- Models

(@) indicates coupling interval

Role of the NEMS Mediator

- The Mediator is set up with ATM, OCN, ICE, LND, and HYD components.
- Slow (ocean) and fast (atmosphere and ice) coupling phases
- The mediator includes the following functions:
  - Connects fields whose standard names match
  - Accumulates and averages atmosphere and ice fields between calls to the ocean
  - Merges fields with a generic merge method that allows for weighting
  - Performs custom coupling operations, along with unit transformations
  - Performs interpolation (fluxes are mapped conservatively, states bilinearly, high

More information about the mediator:
http://cog-esgf.esrl.noaa.gov/projects/couplednems/mediator_design

Worksheet of planned coupling fields across all modeling applications:
https://docs.google.com/spreadsheets/d/11t0TqbYfEqH7lmTZ7dYe1DSCh6vOUFgX-3qvXgce-q0/edit#gid=0

Thanks