Jump-starting the development of coupled climate models with minimal effort using a new communication library

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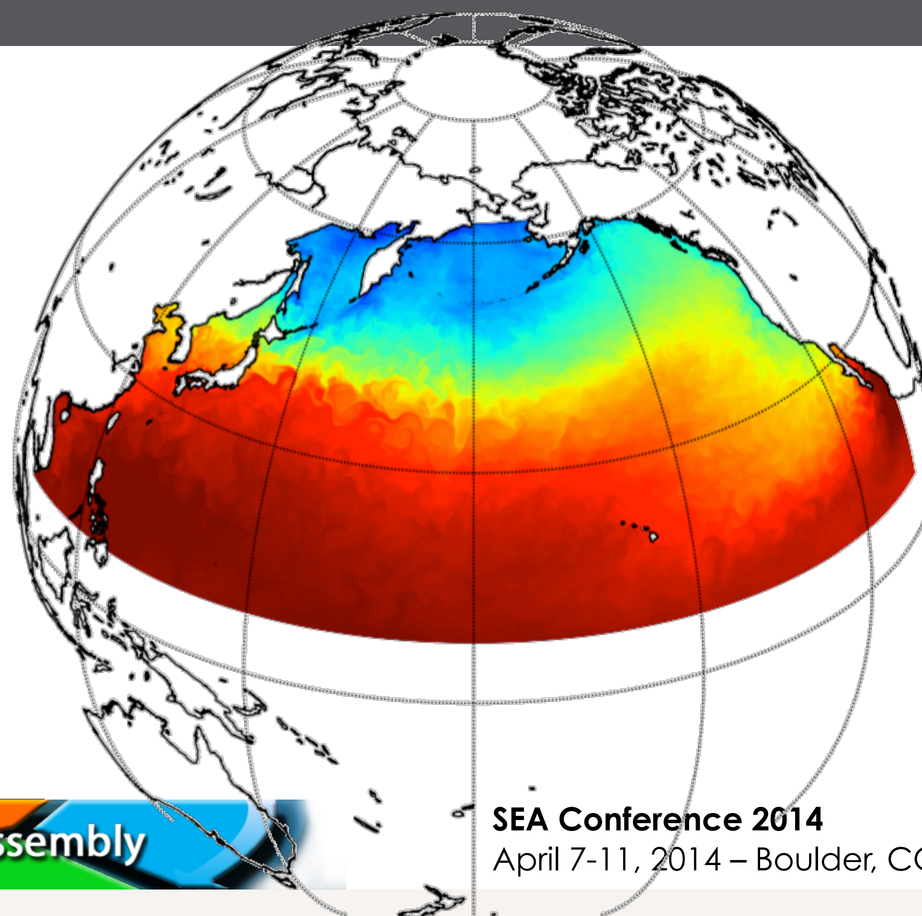

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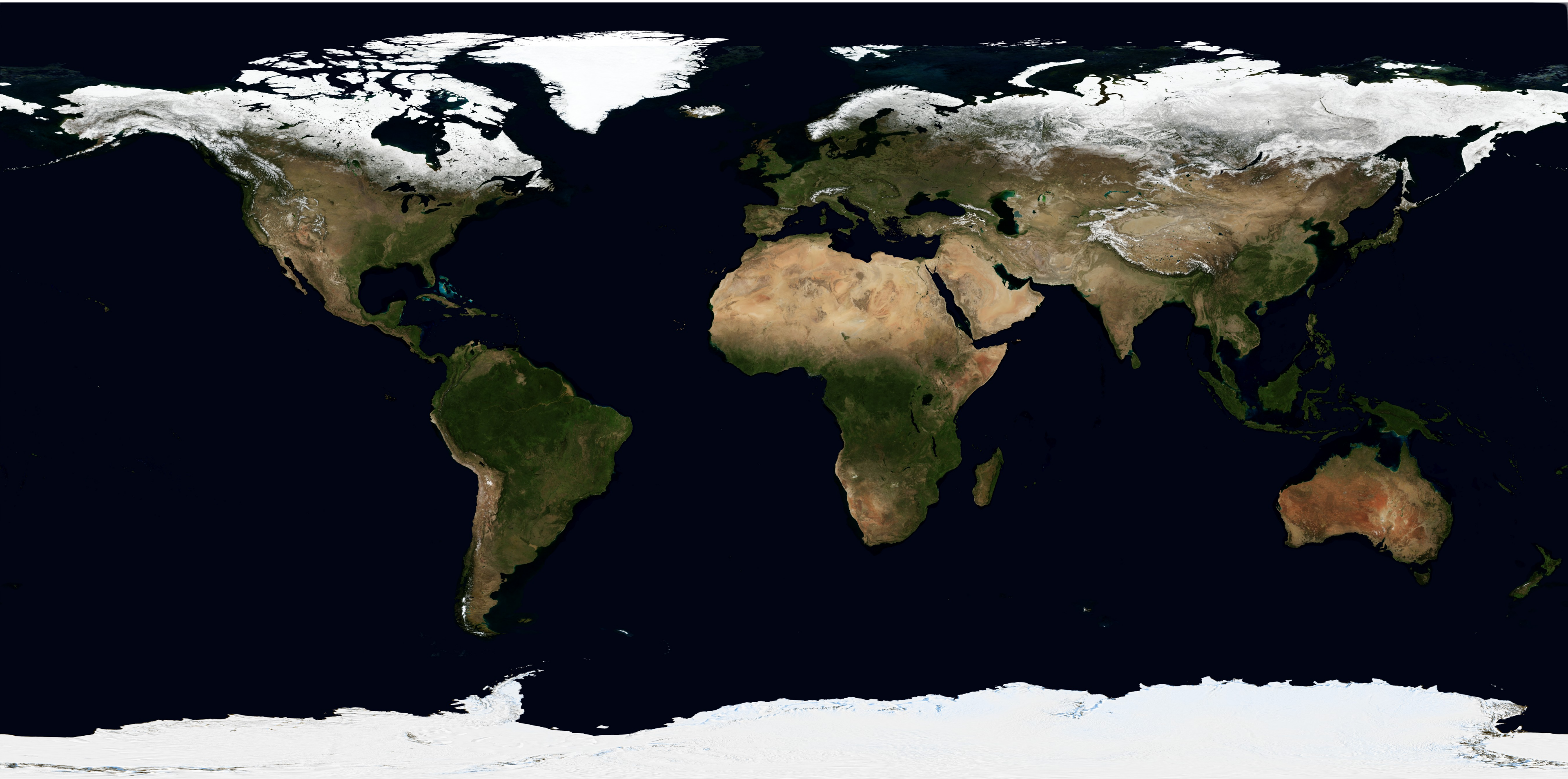
Outline

- Why a new library? Overview of available tools for building coupled models and practical challenges
- The Texas A&M Coupling Library (AMC):
  Foundations & Introduction to the API
- Hands-on exercise: let's build a coupled model!



Overview

Software tools available for building coupled models today

Available coupling software and tools

Major coupling frameworks:

CPL7 — NCAR model coupler, version 7 (Craig *et al.*, 2012)

Included in the Community Climate System Model (CCSM4) and in the Community Earth System Model (CESM1)

mct based on the **Model Coupling Toolkit**

OASIS — CERFACS/CNRS (France) coupler (Valcke *et al.*, 2006)

Originally based on the Prism System Model Interface (PSMILe)

mct **OASIS3-MCT** released on May 28, 2013

FMS — NOAA GFDL Flexible Modeling System (Balaji, 2004)

Communication kernels: ***MPP modules***, built on MPI/SHMEM/NUMA

ESMF — Earth System Model Framework (started in 2002)

Based on CCSM, FMS, mct, and more…

Available coupling software and tools

FOAM — custom coupler in Fast Ocean Atmosphere Model

ANL-UW, started 1994; development frozen in 2002 (version 1.5)

OpenPALM — robust coupler for multi-physics models (2011)

Supports industrial codes *via* TCP/IP connections

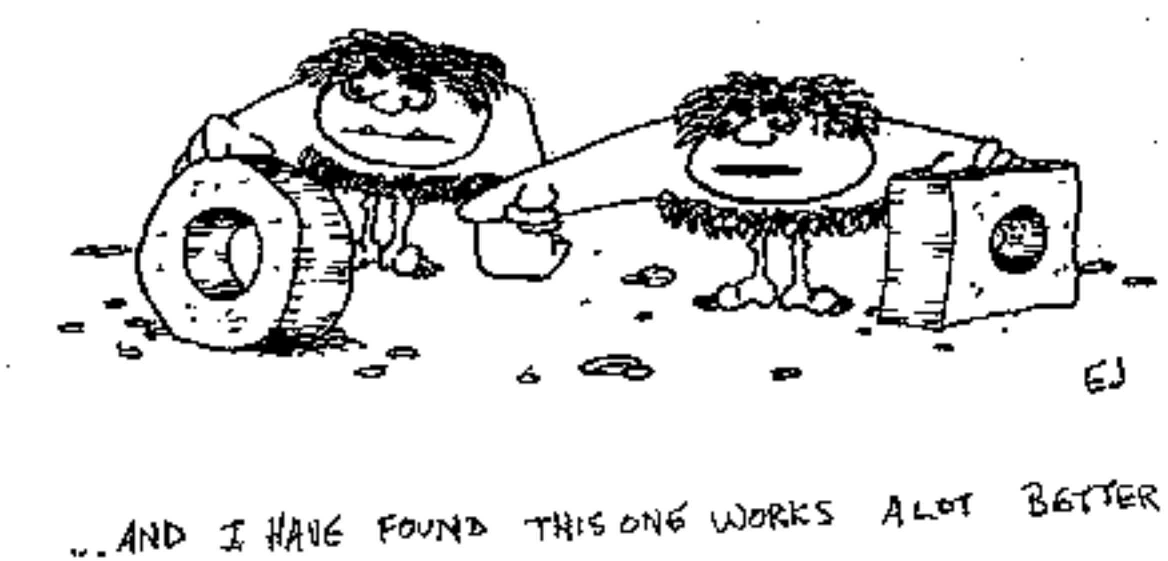
FLUME — FLexible Unified Model Environment (Ford & Riley,2002)

Built specifically for the UK Met Office Unified Model System

—Is a new coupling framework necessary?

Why a new coupling library?

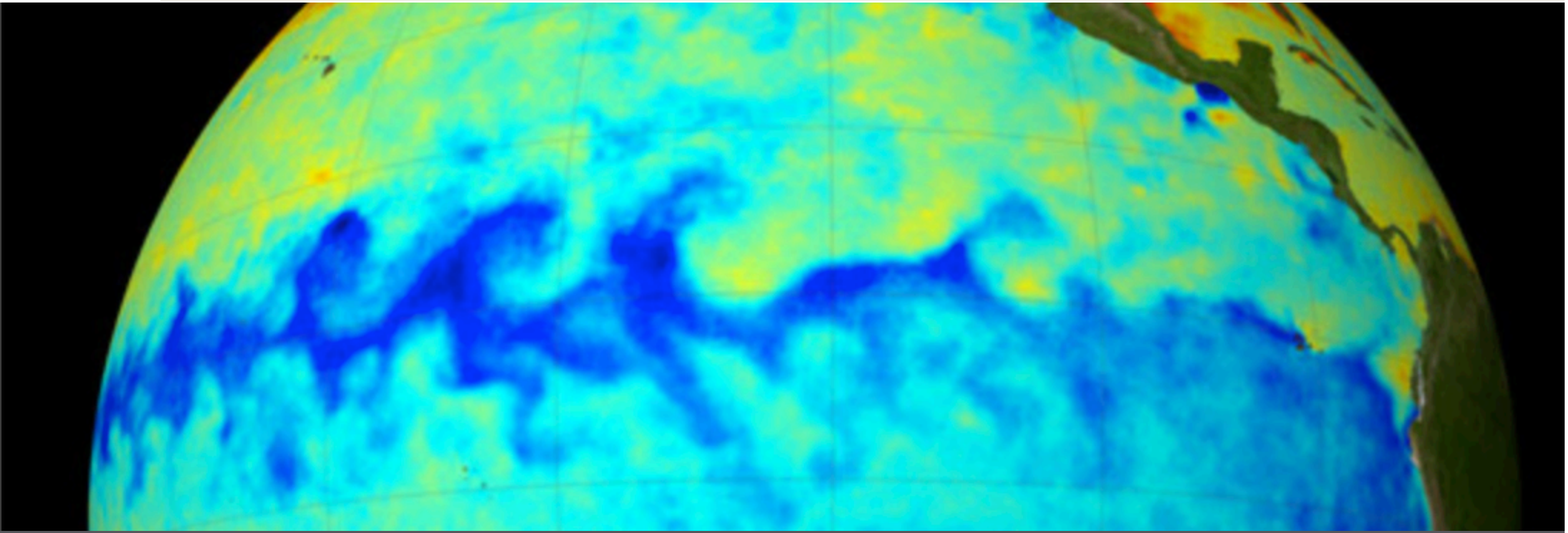
— *Are we going to reinvent the wheel?*



http://tradingeducationblogs.com/day-trading-mistakes/

Motivation

- Available coupling tools are highly complex—their manipulation requires expert software engineers
- Advances in science often require testing unconventional hypotheses
- Academic research usually doesn't involve teams of expert software engineers
- Is it possible to create a model-coupling tool of minimal complexity that can be quickly learned by researchers with diverse backgrounds and interests?



The Texas A&M Coupling Library (AMC)

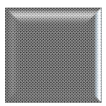
Foundations and API

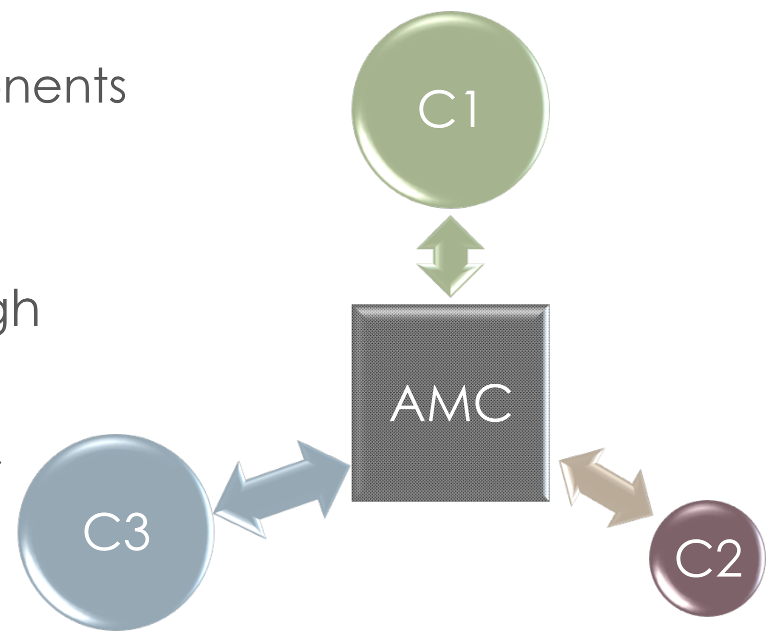
AMC: Foundations

AMC is a parallel coupling library conceived to enable data exchange between individual programs (components) with minimal coding

- AMC's design is based on a distributed-memory model:
  each parallel task is assumed to have access only to its individual memory space
- Given its design, AMC's implementation using the Message Passing Interface (MPI) is straightforward
- AMC is written in standard Fortran 90
- *Disclaimer*: AMC is work in progress

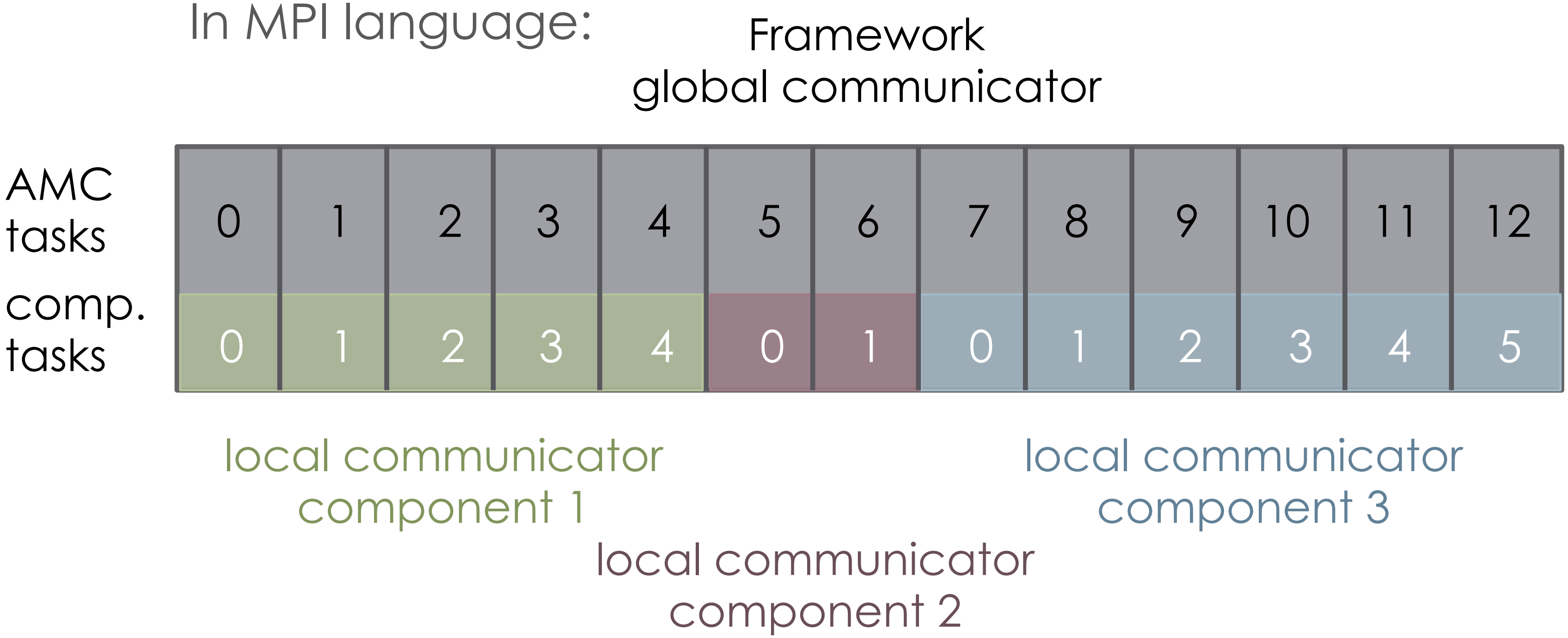
AMC: Foundations

- AMC's architecture relies on:
  -  A communication framework (driver/dispatcher)
  -  Coupled components
- All communications between components are routed through a **hub** (framework)
- The hub is *solely* responsible for handling all communications (dispatch)



AMC: Foundations

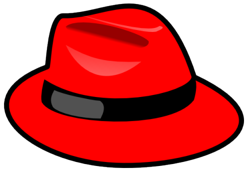
In MPI language:



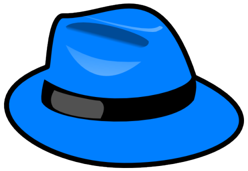
- Components do not overlap
- The order of components and components tasks can be chosen
- Identity of *root* task can be assigned in each component

AMC: Foundations

- Each AMC parallel task has a **dual identity**:



It belongs to the *framework*



It belongs to the *component*

- Task identities are fully handled internally
  - e.g.: local vs. remote memory access
- Public variables are provided to identify tasks:
  - *Framework IDs* may be accessed by all components
  - *Component IDs* are defined only inside the component

AMC: Initialization

The AMC library provides the following variables to identify each parallel task:

Framework

```
integer ::   &
 amc_comm,   & ! global comm
 amc_root,   & ! root task
 amc_rank,   & ! rank id
 amc_size,   & ! total # tasks
 amc_io_rank   ! id of I/O task

logical ::   &
 amc_is_io,  & ! is the I/O task?
 amc_is_root   ! is root task?
```

component

```
integer ::          &
 amc_cmp_comm,      & ! Local comm
 amc_cmp_root,      & ! root task
 amc_cmp_rank,      & ! rank id
 amc_cmp_size,      & ! # cmp tasks
 amc_cmp_io_rank    ! id of I/O task

logical ::         &
 amc_cmp_is_io,   & ! is I/O task?
 amc_cmp_is_root    ! is root task?
```

AMC: Syntax

Basic syntax rules:

`amc_` symbols are used in framework

`amc_cmp_` symbols are used in components

Names of functions and subroutines follow the rule:

Framework:

`amc_<object>_<method>`

Component:

`amc_cmp_<object>_<method>`

AMC: Initialization

A **minimal** set of calls is required to connect/disconnect a model component to/from the framework

Reminder: All connections and communications are handled by the framework (dispatcher)

Framework

```fortran
use amc

integer :: n1  ! N. tasks comp. 1
integer :: n2  ! N. tasks comp. 2
integer :: rc  ! Return code

call amc_init(rc)

call amc_frame_setup((/n1,n2/),rc)
```

```fortran
call amc_frame_connect(req,rc)
! connections are asynchronous
call amc_req_complete(req)
```

component

```fortran
use amc

integer :: root ! Rank of root
integer :: comm ! communicator
integer :: rc   ! Return code

comm = amc_cmp_comm

! Init component and connect
! to framework (blocking)
call amc_cmp_init(root,comm,rc)
```

handshake

AMC: Communications

Communications (data exchanges) are carried out as:

`_info_` *unstructured* communications

informational data exchanges, not necessarily related to each other

`_stream_` *structured* communications

data exchanges follow known patterns

Example: surface fluxes between ocean and atmosphere

AMC: Routing

Communications are **always** routed through the framework (dispatcher) :

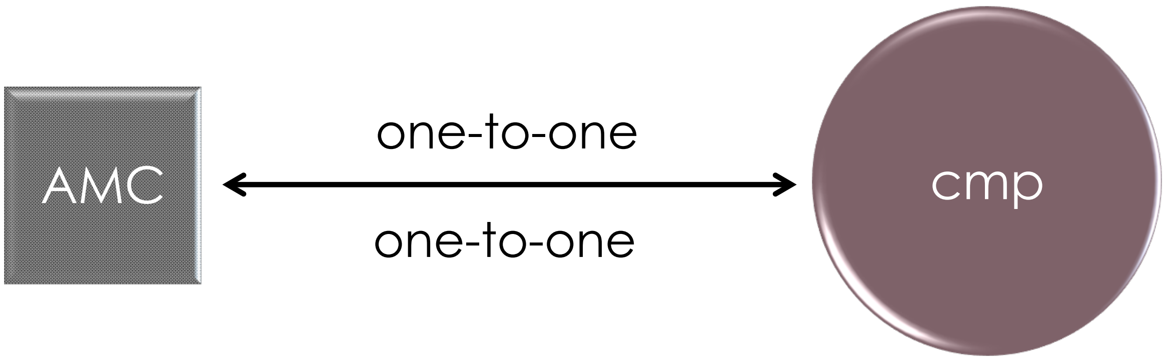
`_info_` unstructured communications may occur only between a single framework task (*root*) and a single component task (*root*)

`_stream_` structured communications occur between a single framework task (*root*) and all the tasks of a given component via the component's *root* task

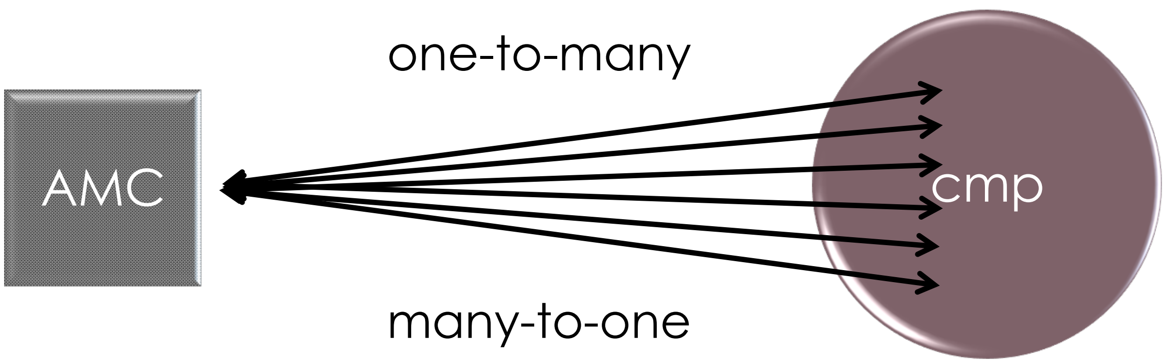
AMC: Routing

To summarize:

info unstructured communications



stream structured communications



AMC: Streams

- **Multiple** streams can be opened for each component
- Each stream can be configured with its unique data packing/unpacking method
- Each stream includes a regridding procedure based on the SCRIP package (Jones, 1998). The regridder can be configured, then turned on or off if needed.
- Multiple streams per component may be used to couple multiple domains in nested models

AMC: Streams

- Streams need to be created in each component
- Streams must be connected to the frameworks to allow communication with the component
- Stream connections are handled *exclusively* by the framework
- All streams in a component are connected at once
- Each component's stream is identified by a *unique* integer *id* assigned at creation time

AMC: Streams

Example:

component

```
integer :: id, idx(:), n, rc

n = 0
do i = ibeg, iend  ! tile bounds (tiled domain)
   n = n + 1
   idx(n) = i      ! build address array
end do

id = 2      ! set the new stream id to 2
call amc_cmp_stream_create(id, idx, n, rc)
```

Framework

```
integer :: cmp_id, rc, req(:) ! N. tasks comp. 1

cmp_id = 1 ! connect all streams from component 1

call amc_stream_connect(cmp_id, req, rc)
! connections are asynchronous
call amc_req_complete(req)
```

AMC: Communicate

- Generic send/receive methods provided:

`_get()` retrieve method (remote to local)

`_set()` send method (local to remote)

- Call syntax may be "*fully transparent*"
  —Symbols names are identical on both ends when buffers declaration statements are included in a common module
  —Buffers at end side are automatically allocated, if needed
- `_info_` communications are *asynchronous*
  They can be aggregated to improve performance

AMC: Receive info

shared module

```
module buffers
  integer :: rbuflen   ! Length of message buffer
  real, dimension(:), pointer :: rbuf ! frame<-cmp
end module buffers
```

component

```
use buffers

allocate rbuf(rbuflen)

rbuf(:) = localdata(:)     ! pack data into buffer
```

Framework

```
use buffers
integer :: cmp_id, rc, req(:)

cmp_id = 1 ! receive data from component 1
call amc_info_get(rbuflen, cmp_id, req, rc)
call amc_req_complete(req) ! connections are asynchronous

call amc_info_get(rbuf, rbuflen, cmp_id, req, rc)
call amc_req_complete(req)
```

AMC: Send info

shared module

```
module buffers
  integer :: sbuflen   ! Length of message buffer
  real, dimension(:), pointer :: sbuf ! frame->cmp
end module buffers
```

Framework

```
use buffers
integer :: cmp_id, rc, req(:)

allocate sbuf(sbuflen)
sbuf(:) = ...

cmp_id = 2 ! send data to component 2
call amc_info_set(sbuf, buflen, cmp_id, req, rc)
call amc_req_complete(req) ! connections are asynchronous
```

component

```
use buffers

localdata(:) = sbuf(:)     ! Use received data
```

AMC: Receive data stream

shared module

```
module buffers
  ! global & local receive buffers: cmp->frame
  real, dimension(:), pointer :: rbuf_glob, rbuf_loc
end module buffers
```

component

```
use buffers
integer :: i, n

n = 0
do i = ibeg, iend  ! tile bounds (tiled domain)
   n = n + 1
   rbuf_loc(n) = localdata(i)
end do
```

Framework

```
use buffers
integer :: id, cmp_id, rc

cmp_id = 1 ! receive data from component 1
id = 2     ! receive data from stream 2 of component 1

call amc_stream_get(id, rbuf_glob, rbuf_loc, cmp_id, rc)
```

AMC: Send data stream

shared module

```
module buffers
 ! global & local receive buffers
  real, dimension(:), pointer :: sbuf_glob, sbuf_loc
end module buffers
```

Framework

```
use buffers
integer :: id, cmp_id, rc

cmp_id = 3  ! send data to component 3
id = 1       ! send data to stream 1 of component 3
sbuf_glob(:) = globaldata(:)

call amc_stream_set(id, sbuf_glob, sbuf_loc, cmp_id, rc)
```

component

```
use buffers

allocate rbuf_loc(iend-ibeg+1) ! allocate buffer on local tile

rbuf_loc(:) = localdata(:)     ! load tiled data chunk
```

AMC: Communications

NOTE: Since all communications are initiated by the framework (dispatcher), **strict synchronization is required** between components and framework

Framework

```
call amc_sync(rc)
! exchange data (get/set)
call amc_sync(rc)
```

AMC: Regridding capabilities

- A regridding procedure based on SCRIP (Jones, 1998) is embedded in each `_stream_`
- It can be referenced using the object name: `_stream_map_`
- Regridding of a data stream can be setup and activated/deactivated using the following methods:

`_load()`	Loads regridding parameters (weights, grid data)
`_switch()`	Turns regridding on/off

NOTE: `_stream_map_` can only be used by *root* task in framework

AMC: Regridding capability

Regrid data *from* framework *to* component

Framework

```
! load regridding data (SCRIP) to stream id in
! component cmp_id for frame->cmp regridding

call amc_stream_map_load(id, wts, num_wts, num_lnk, &
                         dst_add, dst_grd_size,     &
                         src_add, src_grd_size, to = cmp_id)

! activate regridding
call amc_stream_map_switch(id, cmp_id, .true.)
```

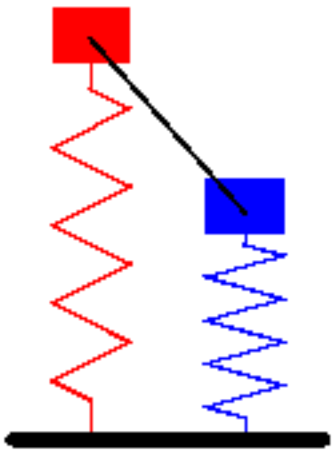
Regrid data *from* component *to* framework

Framework

```
! load regridding data (SCRIP) to stream id in
! component cmp_id for frame->cmp regridding

call amc_stream_map_load(id, wts, num_wts, num_lnk, &
                         dst_add, dst_grd_size,     &
                         src_add, src_grd_size, from = cmp_id)

! activate regridding
call amc_stream_map_switch(id, cmp_id, .true.)
```



Hands-on exercise: Let's build a coupled model!

How to build a basic coupled model using AMC

Building a basic coupled model

Three parts:

1. Model driver
2. Component 1 (*e.g.* atmosphere)
3. Component 2 (*e.g.* ocean)

Building a basic coupled model

Model driver

```
program drv
 integer :: rc

 call drv_init(rc)
 if (rc.eq.0) call drv_run(rc)
 call drv_finalize(rc)

end program drv
```

```
subroutine drv_finalize
 use amc

 call amc_finalize

end subroutine drv_finalize
```

```
subroutine drv_init(rc)
 use amc
 use buffers
 integer :: n1, n2, rc, req(:)

 call amc_init(rc)
 call amc_frame_setup((/n1,n2/), rc)

 call amc_frame_connect(req,rc)
 select case (amc_cmp_id)
  case (1)
   call atm_init(rc)
  case (2)
   call ocn_init(rc)
 end select
 call amc_req_complete(req)

 call amc_stream_connect(1, req, rc)
 call amc_stream_connect(2, req, rc)
 call amc_req_complete(req)
end subroutine drv_init
```

Building a basic coupled model

Model driver

```
subroutine drv_run(rc)
 use amc
 use buffers

 do     ! main time loop
  select case (amc_cmp_id)
   case (1)
    call atm_import(rc)
    call atm_run(rc)
    call atm_export(rc)
   case (2)
    call ocn_import(rc)
    call ocn_run(rc)
    call ocn_export(rc)
  end select
  call amc_sync(rc)
  call amc_stream_get(1, atm_buf_g, atm_buf, 1, rc)
  call amc_stream_set(1, ocn_buf_g, ocn_buf, 2, rc)
  call amc_sync(rc)
 end do
end subroutine drv_run
```

Building a basic coupled model

- Layout of a model component (atmosphere)

```
subroutine atm_init(rc)
 use amc
 use buffers
 integer :: comm, root, rc, req(:)

 comm = amc_cmp_comm
 call amc_cmp_init(root, comm, rc)

 n = 0
 do i = ibeg, iend
   n = n + 1
   idx(n) = i
 end do

 call amc_cmp_stream_create(1,idx,n,rc)
end subroutine atm_init
```

```
subroutine atm_run(rc)
 ! run model
end subroutine atm_run
```

```
subroutine atm_import(rc)
 use buffers
 localdata(:) = recvbuf(:)
end subroutine atm_import
```

```
subroutine atm_export(rc)
 use buffers
 sendbuf(:) = localdata(:)
end subroutine atm_export
```

Future work

- Finalize first public release of AMC
- Parallelize regridding in streams
- Implement collective communications
- Build a state-of-the-art coupled regional climate model for research

Questions?

Thank you!

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