A New Vision for Coarray Fortran

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Lessons from HPF

- Good parallelizations require proper partitionings
  - —inferior partitionings will fall short at scale
- Excess communication undermines scalability
  - —both frequency and volume must be right!
- Must exploit what smart users know
  - —allow the power user to relax consistency
- Single processor efficiency is critical
  - —node code must be competitive with serial versions
  - —must use caches effectively on microprocessors

Coarray Fortran (CAF)

- Explicitly-parallel extension of Fortran 95 (Numrich & Reid)
- Global address space SPMD parallel programming model
  - —one-sided communication
- Simple, two-level memory model for locality management
  - —local vs. remote memory
- Programmer has control over performance critical decisions
  - —data partitioning
  - —computation partitioning
  - —communication
  - —synchronization
- Suitable for mapping to a range of parallel architectures
  - —shared memory, clusters, hybrid

Classic CAF Programming Model

- SPMD process images
  - fixed number of images during execution: num_images()
  - images operate asynchronously: this_image()
- Both private and shared data
  - real x(20, 20) a private 20x20 array in each image
  - real y(20, 20) [*] a shared 20x20 array in each image
- Simple one-sided shared-memory communication
  - x(:,j:j+2) = y(:,p:p+2) [r] copy columns from p:p+2 into local columns
- Synchronization intrinsic functions
  - sync_all – a barrier and a memory fence
  - sync_mem – a memory fence
- Asymmetric dynamic allocation of shared data
- Weak memory consistency

Why a New Vision?

Fortran 2008 draft specification characteristics

- Coarrays must be allocated over all images
  - —no support for process subsets
- Coarrays must be declared as global variables
  - —no support for dynamic non-global coarrays
- No remote pointers
- No support for collective communication
- Synchronization is not expressive enough
- ... and so on ... (see our critique)
  - —www.j3-fortran.org/doc/meeting/183/08-126.pdf

Outline

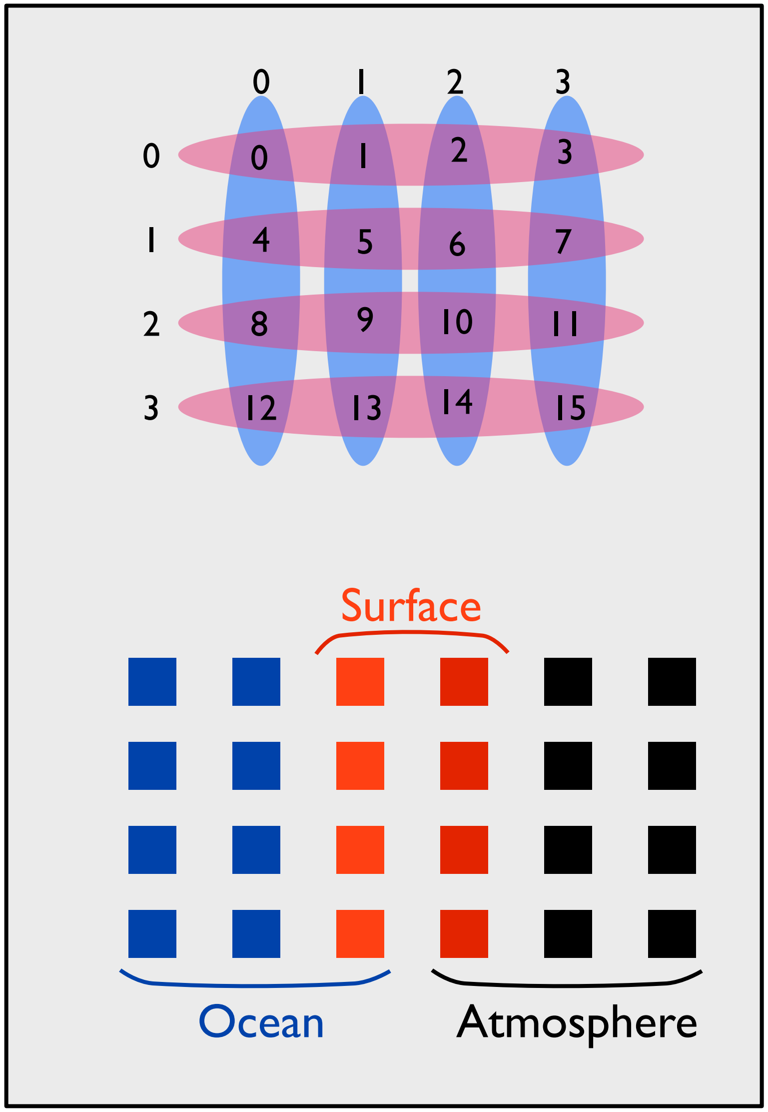
- Coarray Fortran 2.0
  - —Process subsets: teams
  - —Topologies
  - —Copointers
  - —Synchronization
  - —Collective communication
- Summary and ongoing work

Coarray Fortran 2.0 Goals

- Facilitate construction of sophisticated parallel applications and parallel libraries
- Support irregular and adaptive applications
- Hide communication latency
- Colocate computation with remote data
- Scale to petascale architectures
- Exploit multicore processors
- Enable development of portable high-performance programs
- Interoperate with legacy models such as MPI

Process Subsets: Teams

- **Teams are first-class entities**
  - —ordered sequences of process images
  - —namespace for indexing images by rank r in team t
    - – r ∈ {0..team_size(t) - 1}
  - —domain for allocating coarrays
  - —substrate for collective communication
- **Teams need not be disjoint**
  - —an image may be in multiple teams



Creating New Teams

```
team_split (existing_team, color, key, new_team,
            [new_color=result_color,  err_msg=emsg_var])
```

- Images supplying the same **color** are assigned to the same team
- Each images's rank in the new team is determined by **key** order
- **result_color** ≠ **color** gets handle for another team
  - —used to arrange inter-team communication
  - —alternative to MPI's process groups
- **emsg_var** receives any error result message
- Predefined team: **TEAM_WORLD**

Accessing Coarrays on Teams

- **Accessing a coarray relative to a team**
  - x(i,j)[p@ocean] *! p names a rank in team ocean*

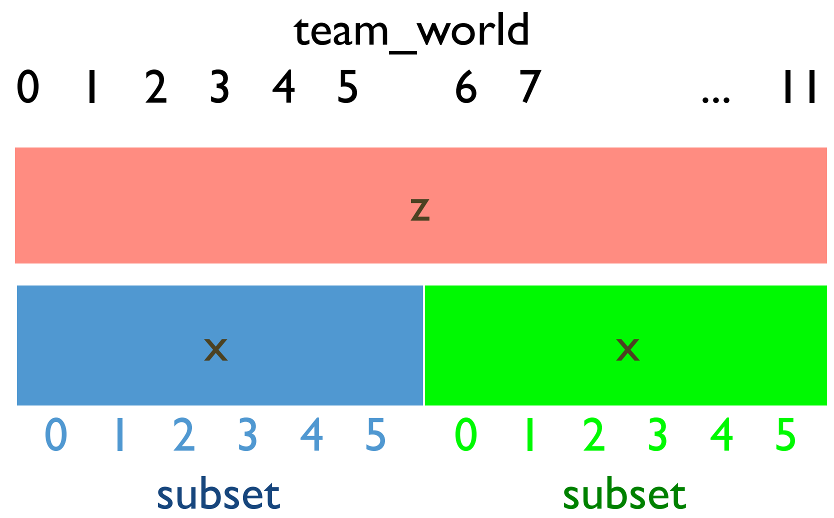
- **Accessing a coarray (default)**
  - x(i,j)[p] *! p names a rank in team_world (default)*

- **Simplifying processor indexing using "with team"**

```
with team atmosphere ! make atmosphere the default team
   ! p is wrt team atmosphere, q is wrt team ocean
   x(:,0)[p] = y(:)[q@ocean]
end with team
```

Teams and Coarrays

```
real, allocatable :: x(:,:)[*] ! 2D array
real, allocatable :: z(:,:)[*]
team :: subset
integer :: color, rank

! each image allocates a singleton for z
allocate( z(200,200) [@team_world] )

color = floor((2*team_rank(team_world)) /
                    team_size(team_world))

! split into two subsets:
!    top and bottom half of team_world
team_split(team_world, color,  &
                   team_rank(team_world), subset)

! members of the two subset teams
! independently allocate their own coarray x
allocate( x(100,n)[@ subset])
```



team_rank(team):
returns the relative rank of the current image within a team
team_size(team):
returns the number of images of a given team

Topology

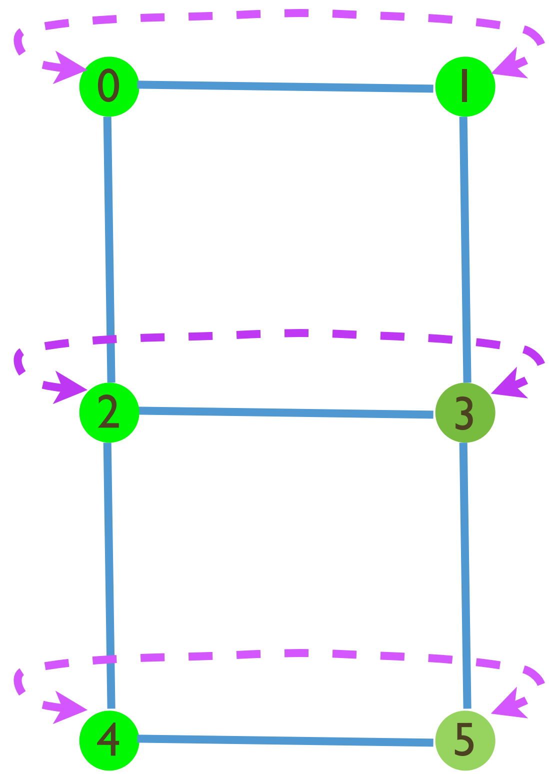
- **Motivation**
  - —a vector of images may not adequately reflect their logical communication structure
  - —multiple codimensions only support grid-like logical structures
  - —want a single mechanism for expressing more general structures
- **Topology**
  - —augments a team with a logical structure for communication
  - —more expressive than multiple codimensions

Using Topologies

- Creation
  - —Graph: topology_graph(n,e)
  - —Cartesian: topology_cartesian(/e1,e2,.../)
- Modification
  - —graph_neighbor_add(g,e,n,nv)
  - —graph_neighbor_delete(g,e,n,nv)
- Binding: topology_bind(team,topology)
- Accessing coarrays using a topology
  - —Cartesian
    - array(:) [(i1, i2, ..., in)@ocean] ! absolute index wrt team ocean
    - array(:) [+(i1, i2, ..., in)@ocean] ! relative index wrt self in team ocean
    - array(:) [i1, i2, ..., ik] ! wrt enclosing default team
  - —Graph: access k^{th} neighbor of image i in edge class e
    - array(:) [(e,i,k)@g] ! wrt team g
    - array(:) [e,i,k] ! wrt enclosing default team

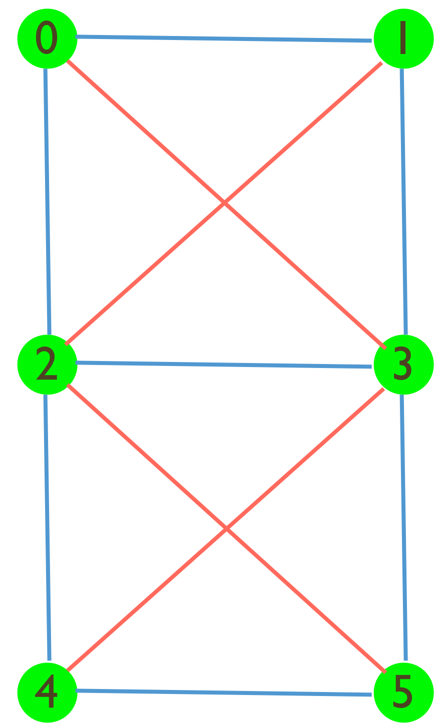
Cartesian Topology Example

```
Topology :: Cart
Integer, Allocatable :: X(:)[*], Y(:)[*]
Team :: Ocean, SeaSurface

! create a cartesian topology 2 (cyclic) by 3
Cart = Topology_cartesian( /-2, 3/ )

! bind Cart to teams Ocean and SeaSurface
Call Topology_bind( Ocean, Cart )
Call Topology_bind( SeaSurface, Cart )

  allocate( X(100)[@SeaSurface])
 allocate( Y(100)[@Ocean])

! Ocean is the default team in this scope
With Team Ocean
   Y(:) [1, 1] = X(:)[ (-1, 2)@SeaSurface ]
End With Team
```



Graph Topology Example

```
Topology :: graph
graph = topology_graph( 6, 2 )
integer :: red, blue, myrank

myrank = team_rank(team_world)

read *, blue_neighbors, red_neighbors
! blue edges
call graph_neighbor_add( graph, blue, myrank, blue_neighbors )

! red edges
call graph_neighbor_add( graph, red, myrank, red_neighbors )

! bind team with the topology
call topology_bind( ocean, graph )

allocate( x(100)@ocean )
y(:) = x(20:80) [ (myrank, blue, 2)@ocean ]
```



Copointers

- Motivation: support linked data structures
- **copointer** attribute enables association with remote shared data
- **imageof(x)**returns the image number for **x**
  - useful to determine whether copointer x is local

```
integer, allocatable :: a(:,:)[*]
integer, copointer :: x(:,:)[*]

allocate(a(1:20, 1:30)[@ team_world]

! associate copointer x with a
! remote section of a coarray
x => a(4:20, 2:25)[p]

! imageof intrinsic returns the target
! image for x
prank = imageof(x)

x(7,9) = 4      ! assumes target of x is local
x(7,9)[ ] = 4  ! target of x may be remote
```

Synchronization

- **Lockset: ordered sets of locks**
  - —convenient to avoid deadlock when locking/unlocking multiple locks -- uses a canonical ordering
- **Point-to-point synchronization via event variables**
  - —like counting semaphores
  - —each variable provides a synchronization context
  - —a program can use as many events as it needs
    - – user program events are distinct from library events
  - —event_notify() / event_wait()

Collective Communication

- Collective operations:
  - —usual suspects: broadcast, all/gather, permute, all/reduce, scan, scatter, segmented_scan, shift
- Flavors
  - —traditional: two-sided synchronous
  - —new modalities
    - two-sided asynchronous: all start it and later finish it
    - one-sided synchronous: one starts it and blocks until done
    - one-sided asynchronous: one starts it and later finishes it
- A new twist: all/select for min, max, max_copy, min_copy
- User-defined reduction and selection operators
- Split-phase barriers

Summary and Ongoing Work

- CAF 2.0 supports many new features
  - —process subsets (teams), coarrays allocated on teams, dynamic allocation of coarrays, collectives on teams
  - —topologies
  - —copointers
  - —events for safe pair-wise synchronization
  - —locksets
- Provides expressiveness, simplicity and orthogonality
- Source-to-source translator is a work in progress
  - —requires no vendor buy-in
  - —will deliver node performance of mature vendor compilers
- Coming attractions:
  - —cofunctions: remote procedure calls for latency avoidance
  - —coarray binding interface for inter-team communication