Combining Object-Oriented Techniques with Co-arrays in Fortran 2008

Robert W. Numrich

Minnesota Supercomputing Institute
Minneapolis, MN USA
rwn@msi.umn.edu

Fortran is a modern language

- Fortran 2003
  - Object-oriented
  - Portable C interface
  - Parametrized derived types
  - Strong typing through interfaces
- Fortran 2008
  - Co-arrays
  - First parallel addition to the language

Fortran 2003

- Object-oriented
  - Objects
    - User-defined derived types
    - Type-bound procedures
    - Type constructors
    - Type finalization
  - Abstract types
  - Inheritance
  - Deferred procedure bindings
  - Overloaded generic procedures
  - Polymorphism

Fortran 2008

- Co-arrays
  - Execution model
    - SPMD programming model (MPI rank <=> CAF image)
    - Explicit synchronization
  - Memory model
    - Explicit data decomposition
    - Explicit data movement
  - Co-array objects
    - `real    :: x[*]`
    - `type(Y) :: a[*]`

Using Co-arrays

```
real      :: x(n)[p,*]
type(Y) :: a[*]

real     :: y(n)
real     :: z

y(:)        = x(:)       ! local copy
y(:)        = x(:)[r,s]  ! remote copy
a[q]%x(k) = z
```

Memory Hierarchies

```
real,allocatable :: a[:,:,:]
p = coresPerChip()
q = chipsPerNode()
r = nodesPerSystem()
allocate(a[p,q,*])
x = a            local reference
x = a[:,q,r]     on-chip reference
x = a[p,:,r]     on-node reference
x = a[p,q,:]     off-node reference
```

Grid computing :-)

```
real :: balance
type(BankAccount) :: myAccount[*]
balance = myAccount[ftp://myBank.com]%balance
```

Assigning images to processors (cores?)

One-to-one

- one core to one image

Many-to-one

- many cores to one image (OpenMP)

One-to-many

- one core to many images (virtual processors)

Many-to-many

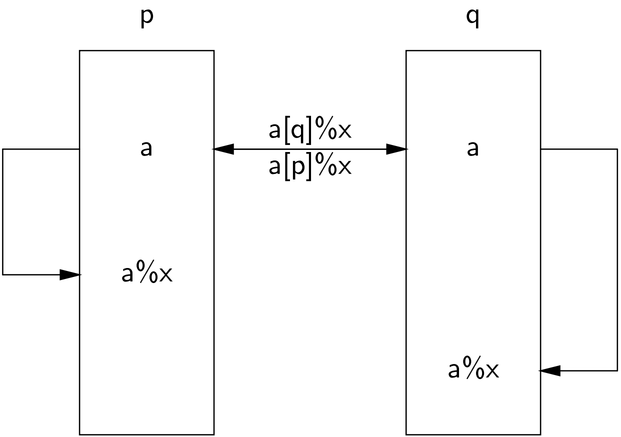
- many cores to many images (virtual processors with OpenMP)

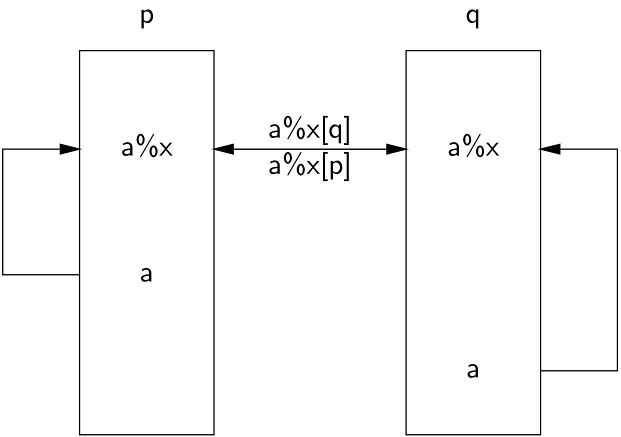
Co-array objects

```
type :: Y
   real,allocatable :: x(:)
end type

type(Y) :: a[*]
real,allocatable :: y(:)

y(:)=a[p]%x(:)
```

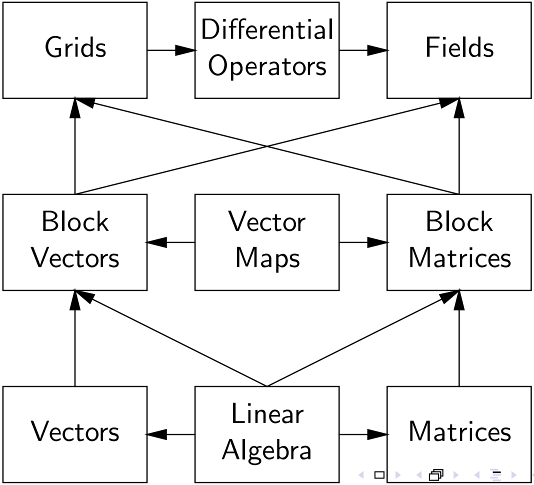
```
type :: Y
   real,allocatable :: x(:)[:]
end type

type(Y) :: a
real,allocatable :: y(:)

y(:)=a%x(:)[p]
```

Co-array objects

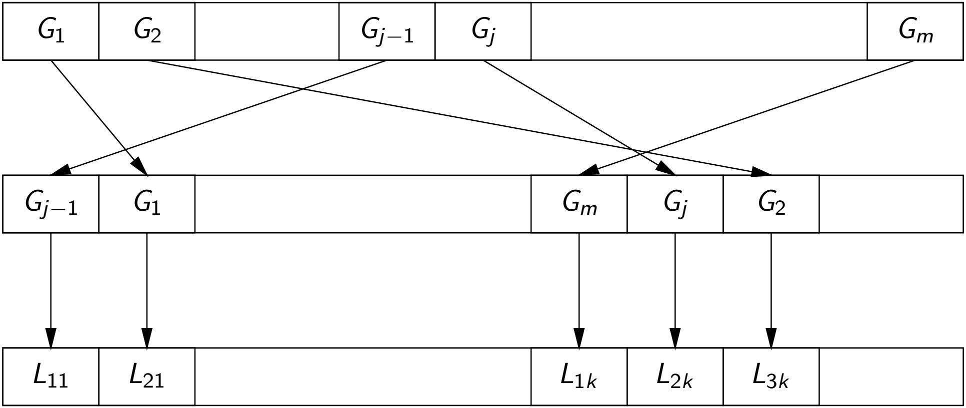



p
q
a%x[q]
a%x
a%x[p]
a%x
a
a

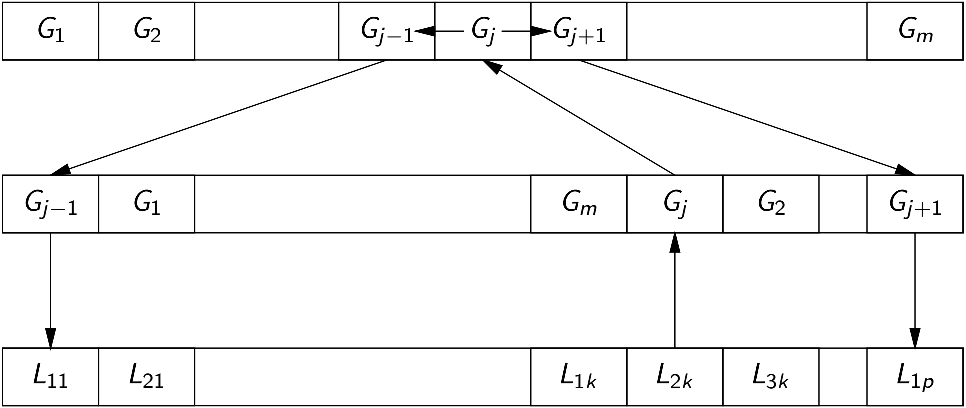
A Parallel Numerical Library (Fortran 95)



Object Maps (Composite Pattern)



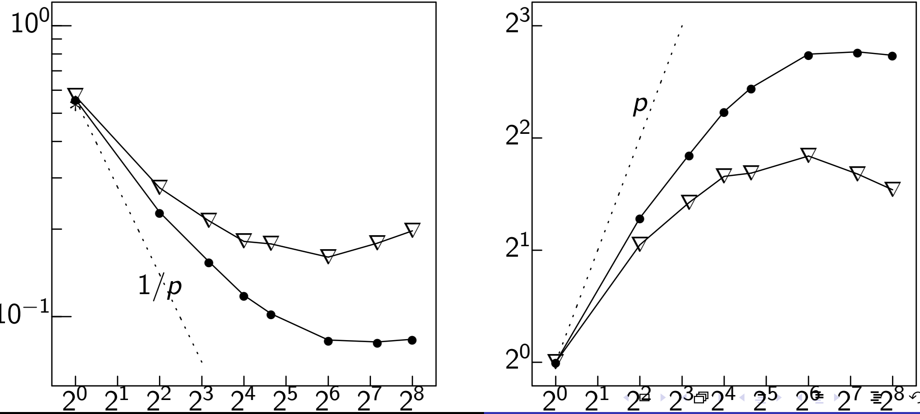
Inverse object maps (neighbors)



Example Program

```
program LU
  type(BlockR8Matrix) :: A[*]
  type(PivotVector)   :: Pivot[*]
  integer,parameter   :: n=1000
  integer,parameter   :: block=100
  integer,parameter   :: p=4,q=4
  A     = BlockMatrix(n,block,n,block,p,q)
  Pivot = PivotVector(A)
  call A%readBlockMatrix()
  call A%LU(Pivot)
  call A%writeBlockMatrix()
end program LU
```

LU Decomposition



Communication in LU Decomposition

Row interchange

```
temp(:) = a(k,:)
a(k,:) = a(j,:) [p,myQ]
a(j,:) [p,myQ] = temp(:)
```

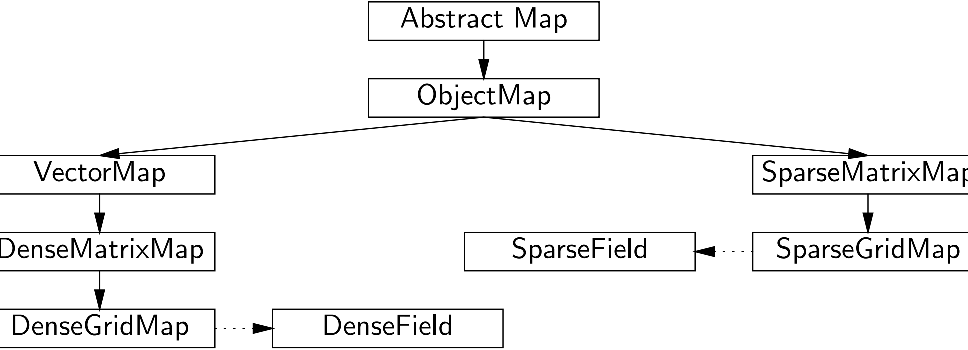
"Row Broadcast"

```
L0(i:n,i) = a(i:,n,i) [p,p] i=1,n
```

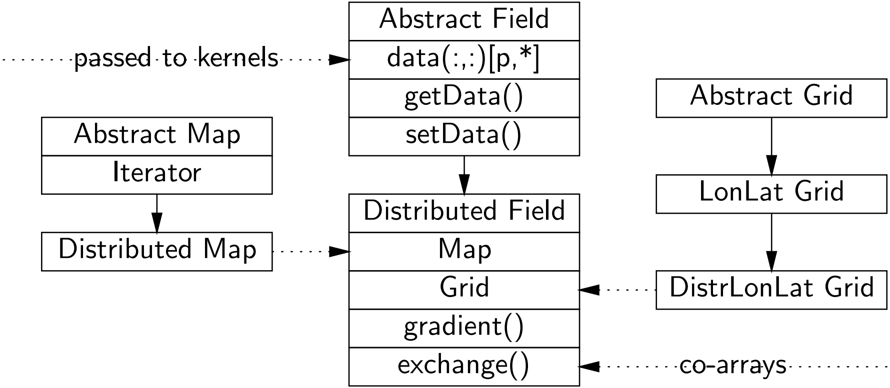
"Row/Column Broadcast "

```
L1 (:,:) = a(:,:) [myP,p]
U1(:,:) = a(:,:) [p,myQ]
```

Data Decomposition and Distribution via Maps



Distributed fields



Constructor for Distributed Field objects

```
type(DistributedField) :: a
a = DistributedField(map)
  function DistributedField(map) result(a)
    type(DistributedField) :: a
    type(DistributedMap) :: map
    a%map => map
    nx = map%getX()
    ny = map%getY()
    p = map%getP()
    allocate(a%data(nx,ny)[p,*])
  end function
```

Load balancing work queue

```
type(PhysicalField) :: a
type(Iterator) :: iterator
real,contiguous,pointer :: ptrA(:,:)
  iterator => a%getGlobalIterator()
  do while(iterator%hasNext())
    ptrA => iterator%requireField()
    call kernel(ptrA)
    ptrA => iterator%releaseField()
  end do
```

Compilers that support co-arrays

- Cray has supported co-arrays for over ten years
- g95 has a preliminary implementation
- IBM under development
- gfortan in discussion phase
- Ask Intel for a multi-core implementation

Summary

- The co-array model is simpler and easier to use than the MPI model.
- Co-arrays should be as good as MPI on any architecture.
- Co-arrays work best on hardware with a true global address space.
- How important are the object-oriented features of Fortran 2008?

References

- J. Reid and R.W. Numrich, Co-arrays in the next Fortran Standard, *Scientific Programming*, 15(1), pp. 9-26, 2007.
- R.W. Numrich, A Parallel Numerical Library for Co-Array Fortran, *Proceedings PPAM05*, pp. 960-969, 2005.
- R.W. Numrich, Parallel numerical algorithms based on tensor notation and Co-Array Fortran syntax, *Paralle Computing*, 31, pp. 588-607, 2005.
- R.W. Numrich, CafLib Users' Manual: Release 1.2, technical report.