Virtual Topologies

- Virtual topologies
- Topology types
- Creating a cartesian virtual topology
- Cartesian example
- Cartesian mapping functions
  - `MPI_CART_RANK`*
  - `MPI_CART_COORDS`*
  - `MPI_CART_SHIFT`*
- Cartesian partitioning
- Exercise

* includes sample C and Fortran programs

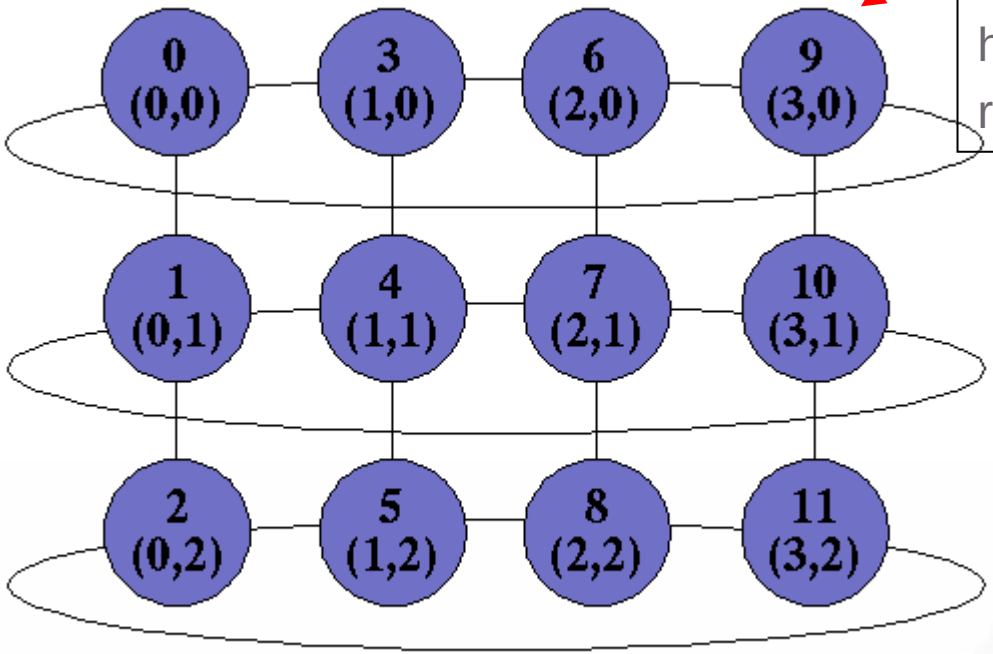
Virtual Topologies

- Convenient process naming
- Naming scheme to fit the communication pattern
- Simplifies writing of code
- Can allow MPI to optimize communications
- Rationale: access to useful topology routines

How to Use a Virtual Topology

- Creating a topology produces a new communicator
- MPI provides “mapping functions”
- Mapping functions compute processor ranks, based on the topology naming scheme

Example - 2D torus



Going “up” from here gives `MPI_PROC_NULL` (-1) and hence batch output is returned as error output

Topology Types

- Cartesian topologies
  - Each process is connected to its neighbors in a virtual grid
  - Boundaries can be cyclic
  - Processes can be identified by cartesian coordinates
- Graph topologies
  - General graphs
  - Will not be covered here

Creating a Cartesian Virtual Topology

C:

```
int MPI_Cart_create (MPI_Comm comm_old, int ndims,
        int *dims, int *periods, int reorder,
        MPI_Comm *comm_cart)
```

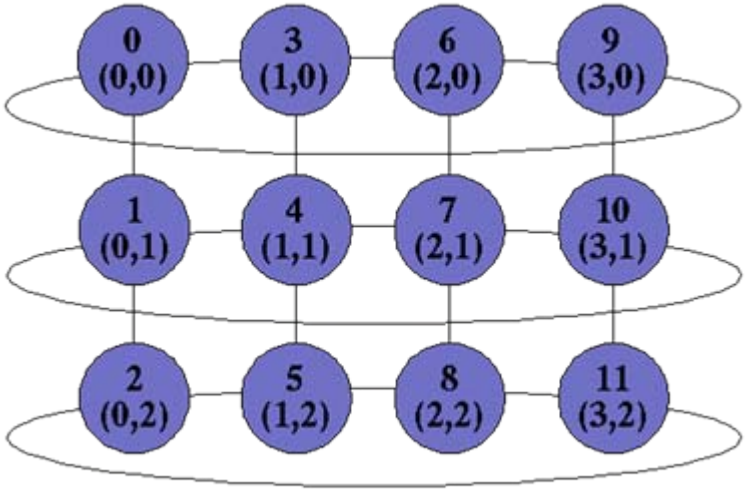
Fortran:

```
INTEGER COMM_OLD,NDIMS,DIMS(*),COMM_CART,IERROR
LOGICAL PERIODS(*),REORDER
CALL MPI_CART_CREATE(COMM_OLD,NDIMS,DIMS,PERIODS,REORDER,
            COMM_CART,IERROR)
```

Arguments

`comm_old`	existing communicator
`ndims`	number of dimensions
`periods`	logical array indicating whether a dimension is cyclic (TRUE=>cyclic boundary conditions)
`reorder`	logical (FALSE=>rank preserved) (TRUE=>possible rank reordering)
`comm_cart`	new cartesian communicator

Cartesian Example




```
MPI_Comm vu;
int dim[2], period[2], reorder;

dim[0]=4; dim[1]=3;
period[0]=TRUE; period[1]=FALSE;
reorder=TRUE;

MPI_Cart_create(MPI_COMM_WORLD,2,dim,period,reorder,&vu);
```

Cartesian Mapping Functions

Mapping process grid coordinates to ranks

C:

```
int MPI_Cart_rank (MPI_Comm comm, init *coords, int *rank)
```

Fortran:

```
INTEGER COMM,COORDS(*),RANK,IERROR
CALL MPI_CART_RANK(COMM,COORDS,RANK,IERROR)
```

Cartesian Mapping Functions

Mapping ranks to process grid coordinates

C:

```
int MPI_Cart_coords (MPI_Comm comm, int rank, int maxdims,
                     int *coords)
```

Fortran:

```
INTEGER COMM, RANK, MAXDIMS, COORDS(*), IERROR
CALL MPI_CART_COORDS(COMM, RANK, MAXDIMS, COORDS, IERROR)
```

Sample Program #9 - C

```
#include<mpi.h>
/* Run with 12 processes */
 int main(int argc, char *argv[]) {
    int rank;
    MPI_Comm vu;
    int dim[2],period[2],reorder;
    int coord[2],id;
    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD,&rank);
    dim[0]=4; dim[1]=3;
    period[0]=TRUE; period[1]=FALSE;
    reorder=TRUE;
    MPI_Cart_create(MPI_COMM_WORLD,2,dim,period,reorder,&vu);
    if(rank==5){
      MPI_Cart_coords(vu,rank,2,coord);
      printf("P:%d My coordinates are %d %d\n",rank,coord[0],coord[1]);
    }
    if(rank==0) {
      coord[0]=3; coord[1]=1;
      MPI_Cart_rank(vu,coord,&id);
      printf("The processor at position (%d, %d) has rank %d\n",coord[0],coord[1],id);
    }
    MPI_Finalize();
 }
```

Program output

```
The processor at position (3,1) has rank 10
P:5 My coordinates are 1 2
```

Sample Program #9 - Fortran

```
      PROGRAM Cartesian
C
C Run with 12 processes
C
      INCLUDE 'mpif.h'
      INTEGER err, rank, size
      integer vu,dim(2),coord(2),id
      logical period(2),reorder
      CALL MPI_INIT(err)
      CALL MPI_COMM_RANK(MPI_COMM_WORLD,rank,err)
      CALL MPI_COMM_SIZE(MPI_COMM_WORLD,size,err)
      dim(1)=4
      dim(2)=3
      period(1)=.true.
      period(2)=.false.
      reorder=.true.
      call MPI_CART_CREATE(MPI_COMM_WORLD,2,dim,period,reorder,vu,err)
      if(rank.eq.5) then
        call MPI_CART_COORDS(vu,rank,2,coord,err)
        print*,'P:',rank,' my coordinates are',coord
      end if
      if(rank.eq.0) then
        coord(1)=3
        coord(2)=1
        call MPI_CART_RANK(vu,coord,id,err)
        print*,'P:',rank,' processor at position',coord,' is',id
        end if
      CALL MPI_FINALIZE(err)
      END
```

```
            Program Output
P:5 my coordinates are 1, 2
P:0 processor at position 3, 1 is 10
```

Cartesian mapping functions

Computing ranks of neighboring processes

C:

```
int MPI_Cart_shift (MPI_Comm comm, int direction,
                    int disp, int *rank_source,
                    int *rank_dest)
```

Fortran:

```
INTEGER COMM, DIRECTION, DISP
INTEGER RANK_SOURCE, RANK_DEST, IERROR
CALL MPI_CART_SHIFT(COMM, DIRECTION, DISP,
                    RANK_SOURCE, RANK_DEST, IERROR)
```

MPI_Cart_shift

- Does not actually shift data: returns the correct ranks for a shift that can be used in subsequent communication calls
- Arguments:
  - `direction` (dimension in which the shift should be made)
  - `disp` (length of the shift in processor coordinates [+ or -])
  - `rank_source` (where calling process should receive a message **from** during the shift)
  - `rank_dest` (where calling process should send a message **to** during the shift)
- If we shift off of the topology, `MPI_Proc_null` (`-1`) is returned

Sample Program #10 - C

```
#include<mpi.h>
#define TRUE 1
#define FALSE 0
int main(int argc, char *argv[]) {
   int rank;
   MPI_Comm vu;
   int dim[2],period[2],reorder;
   int up,down,right,left;
   MPI_Init(&argc, &argv);
   MPI_Comm_rank(MPI_COMM_WORLD,&rank);
   dim[0]=4; dim[1]=3;
   period[0]=TRUE; period[1]=FALSE;
   reorder=TRUE;
   MPI_Cart_create(MPI_COMM_WORLD,2,dim,period,reorder,&vu);
   if(rank==9){
     MPI_Cart_shift(vu,0,1,&left,&right);
     MPI_Cart_shift(vu,1,1,&up,&down);
     printf("P:%d My neighbors are r: %d d:%d 1:%d u:%d\n",rank,right,down,left,up);
   }
   MPI_Finalize();
}
```

```
                Program Output
P:9 my neighbors are r:0 d:10 1:6 u:-1
```

Sample Program #10- Fortran

```
      PROGRAM neighbors
C
C Run with 12 processes
C
      INCLUDE 'mpif.h'
      INTEGER err, rank, size
      integer vu
      integer dim(2)
      logical period(2),reorder
      integer up,down,right,left
      CALL MPI_INIT(err)
      CALL MPI_COMM_RANK(MPI_COMM_WORLD,rank,err)
      CALL MPI_COMM_SIZE(MPI_COMM_WORLD,size,err)
      dim(1)=4
      dim(2)=3
      period(1)=.true.
      period(2)=.false.
      reorder=.true.
      call MPI_CART_CREATE(MPI_COMM_WORLD,2,dim,period,reorder,vu,err)
      if(rank.eq.9) then
        call MPI_CART_SHIFT(vu,0,1,left,right,err)
        call MPI_CART_SHIFT(vu,1,1,up,down,err)
        print*,'P:',rank,' neighbors (rdlu)are',right,down,left,up
      end if
      CALL MPI_FINALIZE(err)
      END
```

```
Program Output
P:9 neighbors (rdlu) are 0, 10, 6, -1
```

Cartesian partitioning

- Often we want to do an operation on only part of an existing cartesian topology
- Cut a grid up into ‘slices’
- A new communicator is produced for each slice
- Each slice can then perform its own collective communications
- `MPI_Cart_sub` and `MPI_CART_SUB` generate new communicators for the slice

MPI_Cart_sub

C:

```
int MPI_Cart_sub (MPI_Comm comm, int *remain_dims,
            MPI_Comm *newcomm)
```

Fortran:

```
INTEGER COMM, NEWCOMM, IERROR
LOGICAL REMAIN_DIMS(*)
CALL MPI_CART_SUB(COMM, REMAIN_DIMS, NEWCOMM, IERROR)
```

- If comm is a 2x3x4 grid and `remain_dims={TRUE,FALSE,TRUE}`, then three new communicators are created, each being a 2x4 grid
- Calling processor receives its new communicator only

Class Exercise: Ring Topology

- Rewrite the “Calculating Ring” exercise using a Cartesian Topology
- Extra credit: Extend the problem to two dimensions. Each row of the grid should compute its own separate sum