# MPI – Communicators and Topologies

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# Communicators

- A communicator is a parameter in all MPI message passing routines
- A communicator is a collection of processors that can engage in communication
- A communicator consists of a *group* of processes and a *context*
- MPI_COMM_WORLD is the default communicator that consists of all processors
- MPI allows you to create subsets of communicators



# Why Communicators?

- Isolate communication to a small number of processors
- Useful for creating libraries
- Different processors can work on different parts of the problem
- Useful for communicating with "nearest neighbors"



# MPI_Comm_split

- Provides a short cut method to create a collection of communicators
- All processors with the "same color" will be in the same communicator
- Index gives rank in new communicator
- Fortran
  – call MPI_COMM_SPLIT(OLD_COMM, color, index, NEW_COMM, mpi_err)
- C
  – MPI_Comm_split(OLD_COMM, color, index, &NEW_COMM)

## MPI_Comm_split

- Split odd and even processors into 2 communicators

```
Program comm_split
include "mpif.h"
Integer color,zero_one
call MPI_INIT( mpi_err )
call MPI_COMM_SIZE( MPI_COMM_WORLD, numnodes, mpi_err )
call MPI_COMM_RANK( MPI_COMM_WORLD, myid, mpi_err )
color=mod(myid,2) !color is either 1 or 0
call MPI_COMM_SPLIT(MPI_COMM_WORLD,color,myid,NEW_COMM,mpi_err)
call MPI_COMM_RANK( NEW_COMM, new_id, mpi_err )
call MPI_COMM_SIZE( NEW_COMM, new_nodes, mpi_err )
Zero_one = -1
If(new_id==0)Zero_one = color
Call MPI_Bcast(Zero_one,1,MPI_INTEGER,0, NEW_COMM,mpi_err)
If(zero_one==0)write(*,*)"part of even processor communicator"
If(zero_one==1)write(*,*)"part of odd processor communicator"
Write(*,*)"old_id=", myid, "new_id=", new_id
Call MPI_FINALIZE(mpi_error)
End program
```



## MPI_Comm_split

- Split odd and even processors into 2 communicators

0: part of even processor communicator
0: old_id = 0 new_id = 0

2: part of even processor communicator
2: old_id = 2 new_id = 1

1: part of odd processor communicator
1: old_id = 1 new_id = 0

3: part of odd processor communicator
3: old_id = 3 new_id = 1



## Other Communicator Functions

- MPI_Comm_group gives the group of a communicator
  - MPI_COMM_GROUP(comm, group)
    [ IN comm] communicator (handle)
    [ OUT group] group corresponding to comm (handle)
- MPI_Group_incl defines a new group consisting of processes of specified rank from old group
  - MPI_GROUP_INCL(group, n, ranks, newgroup)
    [ IN group] group (handle)
    [ IN n] number of elements in array ranks (and size of newgroup) (integer)
    [ IN ranks] ranks of processes in group to appear in newgroup (array of integers)
    [ OUT newgroup] new group derived from above, in the order defined by ranks (handle)
- MPI_Comm_create creates a sub-communicator specified by a given group from a communicator
  - MPI_COMM_CREATE(comm, group, newcomm)
    [ IN comm] communicator (handle)
    [ IN group] Group, which is a subset of the group of comm (handle)
    [ OUT newcomm] new communicator (handle)



## Examples of Communicator Functions

- Comm_split
- Other communicator operations

```
#include "mpi.h"
#include <math.h>
int  main(argc,argv )
int  argc;
char *argv[];
{
   int myid,  numprocs;
   int color,Zero_one,new_id,new_nodes;
   MPI_Comm NEW_COMM;
   MPI_Init(&argc,&argv);
   MPI_Comm_size(MPI_COMM_WORLD,&numprocs);
   MPI_Comm_rank(MPI_COMM_WORLD,&myid);
      color= myid % 2;
      MPI_Comm_split(MPI_COMM_WORLD,color,myid,&NEW_COMM );
      MPI_Comm_rank ( NEW_COMM, &new_id);
      MPI_Comm_size( NEW_COMM, &new_nodes);
      Zero_one = -1;
      if(new_id==0)Zero_one = color;
      MPI_Bcast(&Zero_one,1,MPI_INT,0, NEW_COMM);
      if(Zero_one==0)printf("part of even processor communicator\n");
      if(Zero_one==1)printf("part of odd processor communicator \n");
      printf("old_id= %d new_id= %d\n", myid, new_id);
   MPI_Finalize();
}
```



# 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

*includes sample C and Fortran programs



# Virtual Topologies

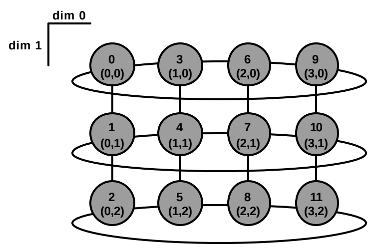
- Convenient process naming
- Naming scheme to fit the communication pattern
- Simplifies writing of code
- Can allow MPI to optimize communications
- Rationale: access to useful topology routines



# 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






# 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:

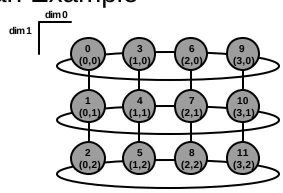
```
INTEGER    COMM_OLD,NDIMS,DIMS(*),COMM_CART,IERROR
LOGICAL    PERIODS(*),REORDER

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<br>(If TRUE, cyclic boundary conditions) |
| `reorder` | logical<br>(If FALSE, rank preserved)<br>(If 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 */
 void 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);
[redacted]
 }
```

## Sample Program #9 - Fortran

```
      PROGRAM Cartesian
C Run with 12 processes
       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,co[redacted]
         print*,'P:',rank,' proce[redacted]
         end if
       CALL MPI_FINALIZE(err)
       END
```



## 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,RANK_SOURCE,RANK_DEST,IERROR

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



## MPI_Cart_shift

- Does <u>not</u> actually shift data: returns the correct ranks for a shift which 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 shift off of the topology, `MPI_Proc_null` is returned



## Sample Program #10 - C

```
#include<mpi.h>
 #define TRUE 1
 #define FALSE 0
 void 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);
    }
[redacted]
 }
```

# 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
[redacted]
      CALL MPI_FINALIZE(err)
      END
```



# 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 back only the new communicator it is in



# Topology Example

- Topological functions
- Fox’s algorithm

# Problem Set

1) Write a program that will make a virtual topology using 8 processors. The topology should consist of 4 processor rows and 2 processors col umns with no wrap-around (cyclic) in either dimension. Each processor in the topology should have an integer variable with the same values used in Problem 4 (Day 3).

   After your program has created the topology, it should use virtual topology utility functions to have each processor calculate the average value of its integer and the integers contained in it's neighbors. Each proce ssor should then output its calculated average. (NOTE: do not use "diagonal" neighbors in the averaging. Only use "up", "down", "left", and "right" neighbors, if they exist).