CC755: Distributed and Parallel Systems

Lecture 10: Programming Using the Message Passing Paradigm II

Slides by: Ananth Grama, Anshul Gupta, George Karypis, and Vipin Kumar

To accompany the text "Introduction to Parallel Computing", Addison Wesley, 2003.
With some edits from other sources

Dr. Manal Helal, Spring 2016

moodle.manalhelal.com

Topic Overview

- Topologies and Embedding
- Overlapping Communication with Computation
- Collective Communication and Computation Operations
- Groups and Communicators

Communicators

- A communicator defines a *communication domain* - a set of processes that are allowed to communicate with each other.
- Information about communication domains is stored in variables of type `MPI_Comm`.
- Communicators are used as arguments to all message transfer MPI routines.
- A process can belong to many different (possibly overlapping) communication domains.
- MPI defines a default communicator called `MPI_COMM_WORLD` which includes all the processes.

Avoiding Deadlocks

Consider:

```
int a[10], b[10], myrank;
MPI_Status status;
...
MPI_Comm_rank(MPI_COMM_WORLD, &myrank);
if (myrank == 0) {
    MPI_Send(a, 10, MPI_INT, 1, 1, MPI_COMM_WORLD);
    MPI_Send(b, 10, MPI_INT, 1, 2, MPI_COMM_WORLD);
}
else if (myrank == 1) {
    MPI_Recv(b, 10, MPI_INT, 0, 2, MPI_COMM_WORLD);
    MPI_Recv(a, 10, MPI_INT, 0, 1, MPI_COMM_WORLD);
}
...
```

If MPI_Send is blocking, there is a deadlock.

Avoiding Deadlocks

Consider the following piece of code, in which process i sends a message to process i + 1 (modulo the number of processes) and receives a message from process i - 1 (module the number of processes).

```
int a[10], b[10], npes, myrank;
MPI_Status status;
...
MPI_Comm_size(MPI_COMM_WORLD, &npes);
MPI_Comm_rank(MPI_COMM_WORLD, &myrank);
MPI_Send(a, 10, MPI_INT, (myrank+1)%npes, 1,
      MPI_COMM_WORLD);
MPI_Recv(b, 10, MPI_INT, (myrank-1+npes)%npes, 1,
MPI_COMM_WORLD);
...
```

Once again, we have a deadlock if MPI_Send is blocking.

Avoiding Deadlocks

We can break the circular wait to avoid deadlocks as follows:

```
int a[10], b[10], npes, myrank;
MPI_Status status;
...
MPI_Comm_size(MPI_COMM_WORLD, &npes);
MPI_Comm_rank(MPI_COMM_WORLD, &myrank);
if (myrank%2 == 1) {
        MPI_Send(a, 10, MPI_INT, (myrank+1)%npes, 1,
                MPI_COMM_WORLD);
        MPI_Recv(b, 10, MPI_INT, (myrank-1+npes)%npes, 1,
                MPI_COMM_WORLD);
}
else {
        MPI_Recv(b, 10, MPI_INT, (myrank-1+npes)%npes, 1,
                MPI_COMM_WORLD);
        MPI_Send(a, 10, MPI_INT, (myrank+1)%npes, 1,
                MPI_COMM_WORLD);
}
...
```

Sending and Receiving Messages Simultaneously

To exchange messages, MPI provides the following function:

```
int MPI_Sendrecv(void *sendbuf, int sendcount,
   MPI_Datatype senddatatype, int dest, int
   sendtag, void *recvbuf, int recvcount,
   MPI_Datatype recvdatatype, int source, int recvtag,
   MPI_Comm comm, MPI_Status *status)
```

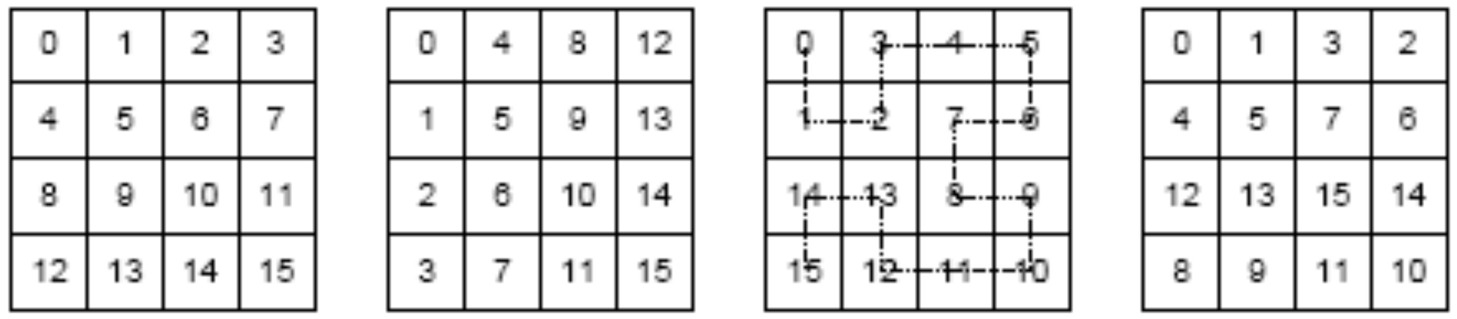
The arguments include arguments to the send and receive functions. If we wish to use the same buffer for both send and receive, we can use:

```
int MPI_Sendrecv_replace(void *buf, int count,
   MPI_Datatype datatype, int dest, int sendtag,
   int source, int recvtag, MPI_Comm comm,
   MPI_Status *status)
```

Topologies and Embeddings

- MPI allows a programmer to organise processors into logical k-d meshes.
- The processor ids in `MPI_COMM_WORLD` can be mapped to other communicators (corresponding to higher-dimensional meshes) in many ways.
- The goodness of any such mapping is determined by the interaction pattern of the underlying program and the topology of the machine.
- MPI does not provide the programmer any control over these mappings.

Topologies and Embeddings



(a) Row–major mapping

(b) Column–major mapping

(c) Space–filling curve mapping

(d) Hypercube mapping

Different ways to map a set of processes to a two-dimensional grid. (a) and (b) show a row- and column-wise mapping of these processes, (c) shows a mapping that follows a space-filling curve (dotted line), and (d) shows a mapping in which neighbouring processes are directly connected in a hypercube.

Creating and Using Cartesian Topologies

- We can create cartesian topologies using the function:

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

  This function takes the processes in the old communicator and creates a new communicator with dims dimensions.

- Each processor can now be identified in this new cartesian topology by a vector of dimension dims.

Creating and Using Cartesian Topologies

- Since sending and receiving messages still require (one-dimensional) ranks, MPI provides routines to convert ranks to cartesian coordinates and vice-versa.

```
int MPI_Cart_coord(MPI_Comm comm_cart, int rank, int maxdims,
                   int *coords)
int MPI_Cart_rank(MPI_Comm comm_cart, int *coords, int *rank)
```

- The most common operation on cartesian topologies is a shift. To determine the rank of source and destination of such shifts, MPI provides the following function:

```
int MPI_Cart_shift(MPI_Comm comm_cart, int dir, int s_step,
                   int *rank_source, int *rank_dest)
```

Overlapping Communication with Computation

- In order to overlap communication with computation, MPI provides a pair of functions for performing non-blocking send and receive operations.

```
int MPI_Isend(void *buf, int count, MPI_Datatype datatype,
                   int dest, int tag, MPI_Comm comm,
                   MPI_Request *request)
int MPI_Irecv(void *buf, int count, MPI_Datatype datatype,
                   int source, int tag, MPI_Comm comm,
                   MPI_Request *request)
```

- These operations return before the operations have been completed. Function `MPI_Test` tests whether or not the non-blocking send or receive operation identified by its request has finished.

```
int MPI_Test(MPI_Request *request, int *flag,
             MPI_Status *status)
```

- `MPI_Wait` waits for the operation to complete.

```
int MPI_Wait(MPI_Request *request, MPI_Status *status)
```

Avoiding Deadlocks

Using non-blocking operations remove most deadlocks. Consider:

```
int a[10], b[10], myrank;
MPI_Status status;
...
MPI_Comm_rank(MPI_COMM_WORLD, &myrank);
if (myrank == 0) {
   MPI_Send(a, 10, MPI_INT, 1, 1, MPI_COMM_WORLD);
   MPI_Send(b, 10, MPI_INT, 1, 2, MPI_COMM_WORLD);
}
else if (myrank == 1) {
   MPI_Recv(b, 10, MPI_INT, 0, 2, &status, MPI_COMM_WORLD);
   MPI_Recv(a, 10, MPI_INT, 0, 1, &status, MPI_COMM_WORLD);
}
...
```

Replacing either the send or the receive operations with non-blocking counterparts fixes this deadlock.

Collective Communication and Computation Operations

- MPI provides an extensive set of functions for performing common collective communication operations.
- Each of these operations is defined over a group corresponding to the communicator.
- All processors in a communicator must call these operations.

Collective Communication Operations

- The barrier synchronisation operation is performed in MPI using:

  ```
  int MPI_Barrier(MPI_Comm comm)
  ```

  The one-to-all broadcast operation is:

  ```
  int MPI_Bcast(void *buf, int count, MPI_Datatype datatype,
         int source, MPI_Comm comm)
  ```

- The all-to-one reduction operation is:

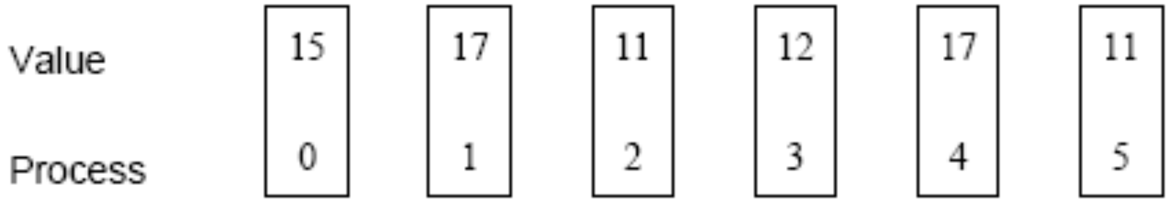
  ```
  int MPI_Reduce(void *sendbuf, void *recvbuf, int count,
         MPI_Datatype datatype, MPI_Op op, int target,
         MPI_Comm comm)
  ```

Predefined Reduction Operations

Operation	Meaning	Datatypes
`MPI_MAX`	Maximum	C integers and floating point
`MPI_MIN`	Minimum	C integers and floating point
`MPI_SUM`	Sum	C integers and floating point
`MPI_PROD`	Product	C integers and floating point
`MPI_LAND`	Logical AND	C integers
`MPI_BAND`	Bit-wise AND	C integers and byte
`MPI_LOR`	Logical OR	C integers
`MPI_BOR`	Bit-wise OR	C integers and byte
`MPI_LXOR`	Logical XOR	C integers
`MPI_BXOR`	Bit-wise XOR	C integers and byte
`MPI_MAXLOC`	max-min value-location	Data-pairs
`MPI_MINLOC`	min-min value-location	Data-pairs

Collective Communication Operations

- The operation MPI_MAXLOC combines pairs of values (v_i, l_i) and returns the pair (v, l) such that v is the maximum among all v_i 's and l is the corresponding l_i (if there are more than one, it is the smallest among all these l_i 's).
- MPI_MINLOC does the same, except for minimum value of v_i.



```
MinLoc(Value, Process) = (11, 2)
MaxLoc(Value, Process) = (17, 1)
```

An example use of the MPI_MINLOC and MPI_MAXLOC operators.

Collective Communication Operations

MPI datatypes for data-pairs used with the `MPI_MAXLOC` and `MPI_MINLOC` reduction operations.

MPI Datatype	C Datatype
`MPI_2INT`	pair of ints
`MPI_SHORT_INT`	short and int
`MPI_LONG_INT`	long and int
`MPI_LONG_DOUBLE_INT`	long double and int
`MPI_FLOAT_INT`	float and int
`MPI_DOUBLE_INT`	double and int

Collective Communication Operations

- If the result of the reduction operation is needed by all processes, MPI provides:

```
int MPI_Allreduce(void *sendbuf, void *recvbuf,
                  int count, MPI_Datatype datatype,
                  MPI_Op op, MPI_Comm comm)
```

- To compute prefix-sums, MPI provides:

```
int MPI_Scan(void *sendbuf, void *recvbuf, int
             count,MPI_Datatype datatype, MPI_Op op,
             MPI_Comm comm)
```

Collective Communication Operations

- The gather operation is performed in MPI using:

```
int MPI_Gather(void *sendbuf, int sendcount,
               MPI_Datatype senddatatype, void *recvbuf,
               int recvcount, MPI_Datatype recvdatatype,
               int target, MPI_Comm comm)
```

- MPI also provides the MPI_Allgather function in which the data are gathered at all the processes.

```
int MPI_Allgather(void *sendbuf, int sendcount,
        MPI_Datatype senddatatype, void *recvbuf,
               int recvcount, MPI_Datatype recvdatatype,
               MPI_Comm comm)
```

- The corresponding scatter operation is:

```
int MPI_Scatter(void *sendbuf, int sendcount,
               MPI_Datatype senddatatype, void *recvbuf,
               int recvcount, MPI_Datatype recvdatatype,
               int source, MPI_Comm comm)
```

Collective Communication Operations

- The all-to-all personalized communication operation is performed by:

```
int MPI_Alltoall(void *sendbuf, int sendcount,
        MPI_Datatype senddatatype, void *recvbuf, int
        recvcount, MPI_Datatype recvdatatype,
        MPI_Comm comm)
```

- Using this core set of collective operations, a number of programs can be greatly simplified.

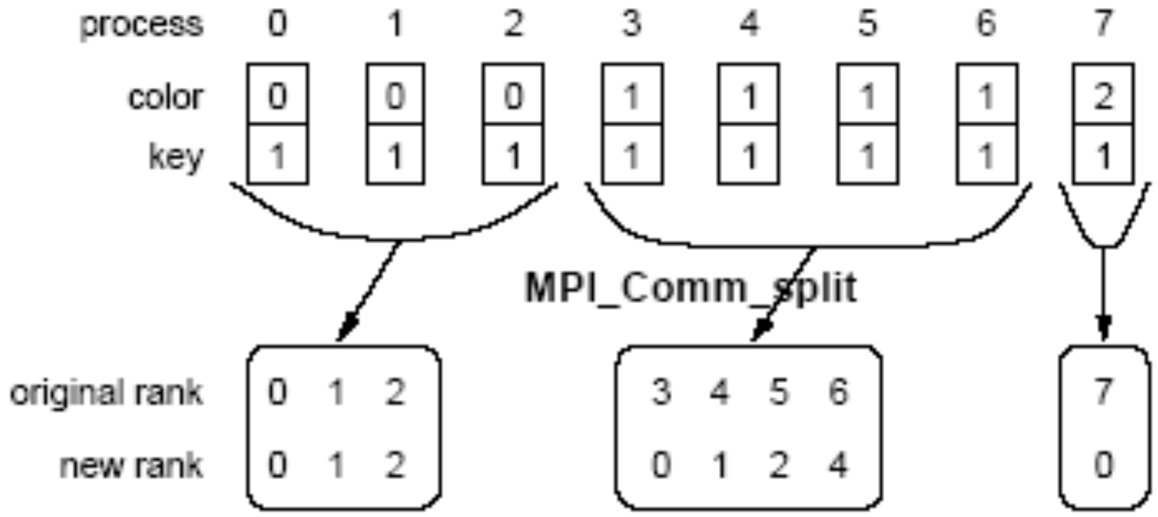
Groups and Communicators

- In many parallel algorithms, communication operations need to be restricted to certain subsets of processes.
- MPI provides mechanisms for partitioning the group of processes that belong to a communicator into subgroups each corresponding to a different communicator.
- The simplest such mechanism is:

```
int MPI_Comm_split(MPI_Comm comm, int color, int
                   key, MPI_Comm *newcomm)
```

- This operation groups processors by color and sorts resulting groups on the key.

Groups and Communicators



Using `MPI_Comm_split` to split a group of processes in a communicator into subgroups.

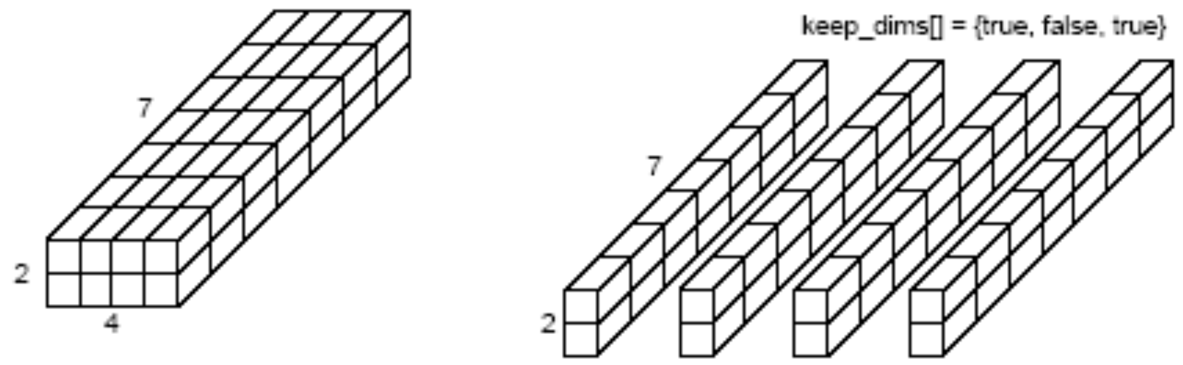
Groups and Communicators

- In many parallel algorithms, processes are arranged in a virtual grid, and in different steps of the algorithm, communication needs to be restricted to a different subset of the grid.
- MPI provides a convenient way to partition a Cartesian topology to form lower-dimensional grids:

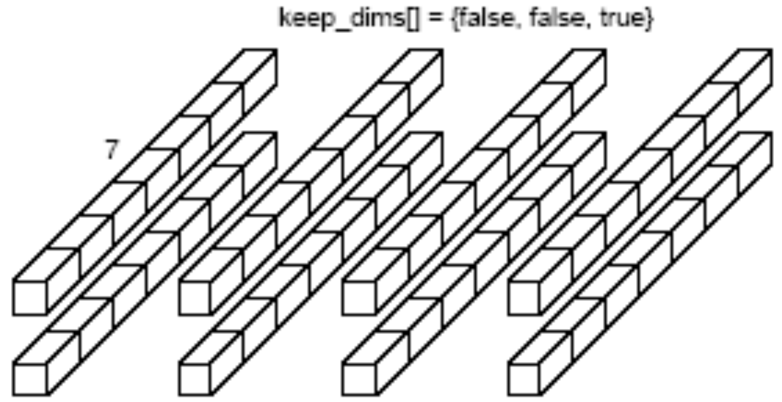
```
int MPI_Cart_sub(MPI_Comm comm_cart, int *keep_dims,
                 MPI_Comm *comm_subcart)
```

- If `keep_dims[i]` is true (non-zero value in C) then the `i`th dimension is retained in the new sub-topology.
- The coordinate of a process in a sub-topology created by `MPI_Cart_sub` can be obtained from its coordinate in the original topology by disregarding the coordinates that correspond to the dimensions that were not retained.

Groups and Communicators



(a)



(b)

Splitting a Cartesian topology of size 2 x 4 x 7 into (a) four subgroups of size 2 x 1 x 7, and (b) eight subgroups of size 1 x 1 x 7.