Lecture 5

Programming Using the Message-Passing Paradigm II

MPI: the Message Passing Interface; Unicast

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- However, often enough there were some *serious semantic differences* that required significant re-engineering to port a message-passing program from one library to another.
- The message-passing interface (MPI) was created to essentially solve this problem.

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- The MPI standard defines both the syntax as well as the semantics of a core set of library routines.
- The MPI library contains over 125 routines, but the number of key concepts is much smaller.
- In fact, it is possible to write fully-functional message-passing programs by using only six routines (see table 1).

Table: The minimal set of MPI routines.

MPI_Init	Initializes MPI
MPI_Finalize	Terminates MPI
MPI_Comm_size	Determines the number of processes
MPI_Comm_rank	Determines the label of the calling process
MPI_Send	Sends a message
MPI_Recv	Receives a message

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  - It performs various clean-up tasks to terminate the MPI environment.
  - No MPI calls may be performed after **MPI_Finalize** has been called, not even **MPI_Init.**
- Upon successful execution, **MPI_Init** and **MPI_Finalize** return *MPI_SUCCESS*; otherwise they return an implementation-defined error code.

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- Information about communication domains is stored in variables of type *MPI_Comm*, that are called <u>*communicators*</u>.
- These communicators are used as arguments to all message transfer MPI routines.
- They uniquely identify the processes participating in the message transfer operation.

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- For this reason, MPI defines a default communicator called *MPI_COMM_WORLD* which includes all the processes involved.
- However, in many cases we want to perform communication only within (possibly overlapping) groups of processes.
- By using a different communicator for each such group, we can ensure that no messages will ever interfere with messages destined to any other group.

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- Note that each process that calls either one of these functions must belong in the supplied communicator, otherwise an error will occur.
- The function MPI_Comm_size returns in the variable size the number of processes that belong to the communicator *comm*.
- So, when there is a single process per processor, the call

```
MPI_Comm_size(MPI_COMM_WORLD, &size)
```

will return in *size* the number of processors used by the program.

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- Up on return, the variable *rank* stores the rank of the process.

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Table: Correspondence between the datatypes supported by MPI and those supported by C.

MPI Datatype	C Datatype
MPI_CHAR	signed char
MPI_SHORT	signed short int
MPI_INT	signed int
MPI_LONG	signed long int
MPI_UNSIGNED_CHAR	unsigned char
MPI_UNSIGNED_SHORT	unsigned short int
MPI_UNSIGNED	unsigned int
MPI_UNSIGNED_LONG	unsigned long int
MPI_FLOAT	float
MPI_DOUBLE	double
MPI_LONG_DOUBLE	long double
MPI_BYTE	
MPI_PACKED	

Note that for all C datatypes, an equivalent MPI datatype is provided.

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- Specifying the length in terms of the number of entries has the advantage of making the MPI code *portable*,
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- The message-tag can take values ranging from zero up to the MPI defined constant *MPI_TAG_UB* (implementation specific, at least 32767).

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- MPI allows specification of wild card arguments for both source and tag.
  - If source is set to *MPI_ANY_SOURCE*, then any process of the communication domain can be the source of the message.
  - Similarly, if tag is set to *MPI_ANY_TAG*, then messages with any tag are accepted.

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- If the received message is larger than the supplied buffer, then an overflow error will occur, and the routine will return the error *MPI_ERR_TRUNCATE*.

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- *MPI_ERROR* stores the error-code of the received message.

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- **MPI_Get_count** takes as arguments the status returned by **MPI_Recv** and the type of the received data in *datatype*, and returns the number of entries that were actually received in the *count* variable.

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- That is, **MPI_Recv** is a **blocking** receive operation.

Sending and Receiving Messages IX

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Sending and Receiving Messages IX

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Sending and Receiving Messages IX

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2. **MPI_Send** first copies the message into a **buffer** and then returns, without waiting for the corresponding **MPI_Recv** to be executed.

- In either implementation, the buffer that is pointed by the *buf* argument of **MPI_Send** *can be safely reused and overwritten*.

Sending and Receiving Messages X

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- Such programs are called safe.
- In writing safe MPI programs, sometimes it is helpful to forget about the alternate implementation of **MPI_Send** and just think of it as being a blocking send operation.

Avoiding Deadlocks I

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Avoiding Deadlocks I

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- Consider the following not complete code in which process 0 sends two messages with different tags to process 1, and process 1 receives them in the reverse order.

```
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);
}
...
```

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- It is up to the programmer to ensure that his or her program will run correctly on any MPI implementation.
- The problem in this program can be corrected by matching the order in which the send and receive operations are issued.
- Similar deadlock situations can also occur when a process sends a message to itself.

Avoiding Deadlocks III

- Improper use of **MPI_Send** and **MPI_Recv** can also lead to deadlocks in situations when each processor needs to send and receive a message in a circular fashion.

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- Improper use of **MPI_Send** and **MPI_Recv** can also lead to deadlocks in situations when each processor needs to send and receive a message in a circular fashion.
- Consider the following not complete code, in which

```
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);
 ...
```

Avoiding Deadlocks III

- Improper use of **MPI_Send** and **MPI_Recv** can also lead to deadlocks in situations when each processor needs to send and receive a message in a circular fashion.
- Consider the following not complete code, in which
  - process i sends a message to process $i + 1$ (modulo 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,
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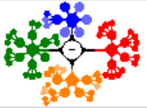
Avoiding Deadlocks III

- Improper use of **MPI_Send** and **MPI_Recv** can also lead to deadlocks in situations when each processor needs to send and receive a message in a circular fashion.
- Consider the following not complete code, in which
  - process *i* sends a message to process $i + 1$ (modulo the number of processes),
  - process *i* 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);
 ...
```

Avoiding Deadlocks IV

- When **MPI_Send** is implemented using buffering, the program will work correctly,



Avoiding Deadlocks IV

- When **MPI_Send** is implemented using buffering, the program will work correctly,
  - since every call to **MPI_Send** will get buffered, allowing the call of the **MPI_Recv** to be performed, which will transfer the required data.

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  - all processes will enter an infinite wait state, waiting for the neighbouring process to issue a **MPI_Recv** operation.
- Note that the deadlock still remains even when we have only two processes.
- Thus, when pairs of processes need to exchange data, the above method leads to an unsafe program.

Avoiding Deadlocks V

- The above example can be made <u>safe</u>, by rewriting it 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);
}
...
```

Avoiding Deadlocks V

- The above example can be made safe, by rewriting it 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);
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                                   MPI_COMM_WORLD);
}
else {
  MPI_Recv(b, 10, MPI_INT, (myrank-1+npes)%npes, 1,
                                   MPI_COMM_WORLD);
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```

- This new implementation partitions the processes into two groups.

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else {
  MPI_Recv(b, 10, MPI_INT, (myrank-1+npes)%npes, 1,
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                                MPI_COMM_WORLD);
}
...
```

- This new implementation partitions the processes into two groups.
- One consists of the odd-numbered processes and the other of the even-numbered processes.

Sending and Receiving Messages Simultaneously I

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- **MPI_Sendrecv** does not suffer from the circular deadlock problems of **MPI_Send** and **MPI_Recv**.
- You can think of **MPI_Sendrecv** as allowing data to travel for both send and receive simultaneously.
- The calling sequence of **MPI_Sendrecv** is as the following:

```
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)
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        MPI_Status *status)
```

- The arguments of **MPI_Sendrecv** are essentially the combination of the arguments of **MPI_Send** and **MPI_Recv**.

Sending and Receiving Messages Simultaneously II

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Sending and Receiving Messages Simultaneously II

- The send and receive buffers must be disjoint, and the source and destination of the messages can be the same or different.
- The safe version of our previous example using **MPI_Sendrecv** is as the following;

```
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_SendRecv(a, 10, MPI_INT, (myrank+1)%npes, 1,
             b, 10, MPI_INT, (myrank-1+npes)%npes, 1,
             MPI_COMM_WORLD, &status);
...
```

Sending and Receiving Messages Simultaneously III

- In many programs, the requirement for the send and receive buffers of **MPI_Sendrecv** be disjoint may force us to use a temporary buffer.

Sending and Receiving Messages Simultaneously III

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- This function performs a blocking send and receive, but it uses a single buffer for both the send and receive operation.

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- This increases the amount of memory required by the program and also increases the overall run time due to the extra copy.
- This problem can be solved by using that **MPI_Sendrecv_replace** MPI function.
- This function performs a blocking send and receive, but it uses a single buffer for both the send and receive operation.
- That is, the received data replaces the data that was sent out of the buffer.