Lecture 6

Programming Using the Message-Passing Paradigm II

MPI: the Message Passing Interface; Unicast

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Dr. Cem Özdoğan
Engineering Sciences Department
İzmir Kâtip Çelebi University

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MPI: the Message Passing Interface I

- Many early generation commercial parallel computers were based on the message-passing architecture due to its lower cost relative to shared-address-space architectures.
- Message-passing became the modern-age form of assembly language, in which every hardware vendor provided its own library.
- Performed very well on its own hardware, but was incompatible with the parallel computers offered by other vendors.
- Many of the differences between the various vendor-specific message-passing libraries were only syntactic.
- 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.**

MPI: the Message Passing Interface II

- MPI defines
  - a standard library for message-passing,
  - can be used to develop **portable** message-passing programs.
- The MPI standard defines both the syntax as well as the semantics of a core set of library routines.
- The MPI library contains many 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).

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

Starting and Terminating the MPI Library

MPI_Init is called prior to any calls to other MPI routines.

- Its purpose is to initialize the mpi environment.
- Calling **MPI_Init** more than once during the execution of a program will lead to an error.

MPI_Finalize is called at the end of the computation.

- 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.

Communicators I

- A key concept used throughout MPI is that of the communication domain.
- A communication domain is a set of processes that are allowed to communicate with each other.
- Information about communication domains is stored in variables of type *MPI_Comm*, that are called *communicators*.
- These communicators are used as arguments to all message transfer MPI routines.
- They uniquely identify the processes participating in the message transfer operation.
- **In general, all the processes may need to communicate with each other.**
- For this reason, MPI defines a **default communicator** called *MPI_COMM_WORLD* which includes all the processes involved.

Getting Information I

- **MPI_Comm_size** function ⟹ number of processes
- **MPI_Comm_rank** function ⟹ label of the calling process
- The calling sequences of these routines are as follows:

```
int MPI_Comm_size(MPI_Comm comm, int *size)
int MPI_Comm_rank(MPI_Comm comm, int *rank)
```

- The function MPI_Comm_size returns in the variable size the number of processes that belong to the communicator *comm*.
- Every process that belongs to a communicator is uniquely identified by its *rank*.
- The rank of a process is an integer that ranges from zero up to the size of the communicator minus one.
- Up on return, the variable *rank* stores the rank of the process.

Sending and Receiving Messages I

- The basic functions for sending and receiving messages in MPI are the **MPI_Send** and **MPI_Recv**, respectively.
- The calling sequences of these routines are as follows:

```
int MPI_Send(void *buf, int count,
             MPI_Datatype datatype,
             int dest, int tag,
             MPI_Comm comm)
int MPI_Recv(void *buf, int count,
             MPI_Datatype datatype,
             int source, int tag,
             MPI_Comm comm,
             MPI_Status *status)
```

1. **MPI_Send** sends the data stored in the buffer pointed by *buf*.

- This buffer consists of consecutive entries of the type specified by the parameter datatype.
- The number of entries in the buffer is given by the parameter *count*.

Sending and Receiving Messages II

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.

Sending and Receiving Messages III

- MPI allows two additional datatypes that are not part of the C language.
- These are *MPI_BYTE* and *MPI_PACKED*.
  - *MPI_BYTE* corresponds to a byte (8 bits)
  - *MPI_PACKED* corresponds to a collection of data items that has been created by packing non-contiguous data.
- Note that the length of the message in **MPI_Send**, as well as in other MPI routines, is specified *in terms of the number of entries* being sent and *not in terms of the number of bytes*.
- The destination of the message sent by **MPI_Send** is uniquely specified by
  - *dest* argument. This argument is the *rank* of the destination process in the communication domain specified by the communicator *comm*.
  - *comm* argument.
- Each message has an integer-valued *tag* associated with it.
- This is used to **distinguish** different types of messages.

Sending and Receiving Messages IV

2 **MPI_Recv** receives a message sent by a process whose *rank* is given by the *source* in the communication domain specified by the *comm* argument.

- The *tag* of the sent message must be that specified by the tag argument.
- If there are many messages with identical tag from the same process, then **any one of** these messages is received.
- 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.
- The received message is stored in continuous locations in the buffer pointed to by *buf*.
- The *count* and *datatype* arguments of **MPI_Recv** are used to specify the length of the supplied buffer.

Sending and Receiving Messages V

- The received message should be of length equal to or less than this length.
- 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*.
- After a message has been received, the status variable can be used to get information about the **MPI_Recv** operation.
- In C, status is stored using the *MPI_Status* data-structure.
- This is implemented as a structure with three fields, as follows:

```
typedef struct MPI_Status {
  int MPI_SOURCE;
  int MPI_TAG;
  int MPI_ERROR;
};
```

- *MPI_SOURCE* and *MPI_TAG* store the source and the tag of the received message.

Sending and Receiving Messages VI

- They are particularly useful when *MPI_ANY_SOURCE* and *MPI_ANY_TAG* are used for the source and tag arguments.
- *MPI_ERROR* stores the error-code of the received message.
- The status argument also returns information about the length of the received message.
- This information is not directly accessible from the status variable, but it can be retrieved by calling the **MPI_Get_count** function.
- The calling sequence:

```
int MPI_Get_count(MPI_Status *status,
                  MPI_Datatype datatype,
                  int *count)
```

- **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.

Sending and Receiving Messages VII

- The **MPI_Recv** returns **only after** the requested message has been **received** and **copied** into the buffer.
- That is, **MPI_Recv** is a **blocking** receive operation.
- However, MPI allows two different implementations for **MPI_Send**.

1. **MPI_Send** returns only after the corresponding **MPI_Recv** have been issued and the message has been sent to the receiver.
2. **MPI_Send** first copies the message into a **buffer** and then returns, without waiting for the corresponding **MPI_Recv** to be executed.

- MPI programs must be able to run correctly regardless of which of the two methods is used for implementing **MPI_Send**. 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

- The semantics of **MPI_Send** and **MPI_Recv** place some restrictions on how we can mix and match send and receive operations.
- 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);
}
...
```

- If **MPI_Send** is implemented using buffering, then this code will run correctly (if sufficient buffer space is available).

Avoiding Deadlocks II

- However, if **MPI_Send** is implemented by blocking until the matching receive has been issued, then neither of the two processes will be able to proceed.
- This code fragment is not safe, as its behavior is implementation dependent.
- 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.
- 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.

Avoiding Deadlocks III

- 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);
...
```

- 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.
- However, if **MPI_Send** blocks until the matching receive has been issued,
  - all processes will enter an infinite wait state, waiting for the neighbouring process to issue a **MPI_Recv** operation.

Avoiding Deadlocks IV

- 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.
- The above example can be made safe, by rewriting:

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

- This version 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

- The above communication pattern appears frequently in many message-passing programs,
- For this reason MPI provides the **MPI_Sendrecv** function that both sends and receives a message.
- **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)
```

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

Sending and Receiving Messages Simultaneously II

- 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);
...
```