Blocking Point-to-Point Communications

Types of Communication

- In MPI there are two main types of communication

Point-to-point communication:

- A communication involving a pair of processes
- Good if a process only needs to communicate with a limited number of other processes

Collective communication:

- A communication involving all the processes
- May seem like point-to-point communication is all that is required as we could use a set of them to communicate with everyone
  - Very inefficient – Sending data from one process to every other process involves p-1 communications from the originating node
  - Collective communications can do things like relaying data – Original process sends to a subset of the nodes, which, in term, send the data on to other nodes that have not yet received it
  - Communication time scales as approximately $log(p)$

Blocking point-to-point communication

- We will initially do blocking point-to-point communication
  - Easier to code and shows the basic idea
  - Later on we will look at non-blocking communications

Two main functions involved:

- MPI_Send – Sends data to another process
- MPI_Recv – Receives data from another process

- Because these are blocking, you must be careful of the send and receive order
  - If a process tries to send data without all the previous receives being handled or vice versa there will be a block in communication and the code will hang or crash
  - We will later look at using probe as a way around this problem so that messages can be received from different processes in any order (amongst other uses)

Simple point-to-point communication

- This program sends data from process zero to all other processes (a different random number sent to each process):

```
#include <mpi.h>
#include <iostream>
#include <cstdlib>
#include <time.h>

using namespace std;

int id, p;

int main(int argc, char *argv[])
{
	MPI_Init(&argc, &argv);

	MPI_Comm_rank(MPI_COMM_WORLD, &id);
	MPI_Comm_size(MPI_COMM_WORLD, &p);
	srand(time(NULL)+id*10);

	int tag_num = 1;

	if (id == 0)
	{
		for (int i = 1; i < p; i++)
		{
			int send_data = rand();
			MPI_Send(&send_data, 1, MPI_INT, i, tag_num, MPI_COMM_WORLD);
			cout << send_data << " sent to processor " << i << endl;
			cout.flush();
		}
	}
	else
	{
		int recv_data;
		MPI_Recv(&recv_data, 1, MPI_INT, 0, tag_num, MPI_COMM_WORLD,
			MPI_STATUS_IGNORE);
		cout << recv_data << " received on processor " << id << endl;
		cout.flush();
	}

	MPI_Finalize();
}
```

Random Numbers

- In a lot of the examples I use random numbers to give me something to send
  - rand generates an integer random number between 0 and RAND_MAX
  - srand seeds the random number generator
  - Both of these functions are found in <cstdlib>
- To seed the random number I use srand(time(NULL)+id*10);
  - time(NULL) gives a time as the number of seconds since the beginning of 1970
  - As all the processes will start at the same time, I try and have them generate different random numbers by adding their id times 10
    - These are still only pseudo-random and so are likely to be related to one another
    - There are better random number generating libraries than the standard one and so these should be used if the “randomness” of the numbers is very important

MPI_Send

```
int MPI_Send(
    void* data,
    int count,
    MPI_Datatype datatype,
    int destination,
    int tag,
    MPI_Comm communicator)
```

- data is a pointer to the data to be sent
- count is the number of items to be sent
  - Note that this is the number of variables of type datatype to be sent, not the number of bytes
- datatype is the MPI data type to be sent
- destination is the id of the process that is to receive the data
- tag is an identifier for the communication
- For both MPI_Send and MPI_Recv the return value indicates error or success

MPI_Recv

```
int MPI_ Recv(
    void* data,
    int count,
    MPI_Datatype datatype,
    int source,
    int tag,
    MPI_Comm communicator,
    MPI_Status* status)
```

- data is a pointer to the data to be received
- count is the number of items to be received
  - Strictly speaking this is the maximum number
  - Send is allowed to send less than this amount
  - You can get the actual amount received from status
- datatype is the MPI data type to be received
- source is the id of process from which the data is to be received
- tag is an identifier for the communication
- status is a pointer to a structure that contains information about the communication
  - Stores information such as the processes involved and the size of the data being sent, as well as any communication error information
  - To ignore use MPI_STATUS_IGNORE

Do Worksheet 1 Exercise 1

MPI Types and their C/C++ equivalents

MPI_SHORT	short int
MPI_INT	int
MPI_LONG	long int
MPI_LONG_LONG	long 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	char
MPI_C_BOOL	bool (strictly MPI_CXX_BOOL for bool, though not all versions of MPI have this type) or _Bool

- These are some of the simple MPI_Datatypes available
  - Later we will look at creating our own MPI data types

More on MPI data types

- Note that MPI_BYTE can be used for sending generic data of a known size in bytes
    - E.g. if Object is a complex object of fixed size (watch out for objects, for instance, containing pointers!):

```
MPI_Send(&Object, sizeof(Object), MPI_BYTE, 0, 0, MPI_COMM_WORLD);
```

More on tags

- Data can potentially be received out of the expected order
  - Especially true in non-blocking communications
  - Need a method to ensure that the correct communication is being dealt with
  - A “race condition” refers to the situation where communications are undesirably handled in the wrong order
- Each communication is given a tag
- The tag should identify the specific type and/or order of communication
  - Either increment the tag for each communication (what I usually do)
  - …or have a different tag for each type of communication (though this might run the risk of being out by a whole cycle of communications)
  - …or do a combination by, for instance, having a unique identifier for each communication with a value between 0 and 100 and then add 100 times the number of communication cycles to this value to produce the tag
- Note that I don’t change the tags in most of the examples because I am showing a single communication
- Tags can be any non-negative value below MPI_TAG_UB

MPI return codes

- Most MPI communications give a return value that indicates either success or what went wrong. These are some those codes:

MPI_SUCCESS

- Communication completed successfully

MPI_ERR_COMM

- Invalid communicator

MPI_ERR_COUNT

- Invalid count argument (usually a negative count – a zero, indicating an empty communication, is usually valid)

MPI_ERR_TYPE

- Invalid datatype argument (Either not a valid MPI type or, for types you created yourself, an type that has not been committed – more on this in a later lecture)

MPI_ERR_TAG

- Invalid tag argument

MPI_ERR_RANK

- Invalid source or destination rank. Ranks must be between zero and the size of the communicator minus one

Using a Probe

- A probe allows information about a communication to be read before the communication is completed
  - i.e. before MPI_Recv is called in the context of blocking communications
- Two very useful pieces of information can be obtained by doing this
  - Which process has sent the data
  - …and how much data is being sent
    - You need to be able to assign enough memory to the data pointer that is receiving the data
      - You could assign more than the maximum that that will ever be sent, but this can be inefficient and you need to know what the maximum that could be send is
    - If you wish to assign the correct amount of memory for the amount of data being sent you can either send a separate communication saying how much data to expect or you can use a probe to find out

MPI_Probe

- MPI_Probe is the function that probes the communication:

```
int MPI_Probe(
    int source,
    int tag,
    MPI_Comm comm,
    MPI_Status *status)
```

- source is the source process
- tag for the communication
- comm is the communicator
- status is a pointer to the structure containing the status information

- Having to specify the source and the tag does seem to remove some of the utility of the function, but MPI_ANY_SOURCE and/or MPI_ANY_TAG can be set
  - Note that these can also be set for MPI_Recv as well

Using the information from MPI_Status

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

- count is the number of received entries
  - Use MPI_Get_count in conjunction with the status rather than using this variable directly – avoids potential issues with mismatches in variable type or size
- cancelled is true or false depending on whether the corresponding communication was cancelled
- MPI_SOURCE is the source process for the communication
- MPI_TAG is the tag associated with the communication
- MPI_ERROR is an error code (there are a lot of potential errors and you can look them up if you want)
  - Has a value of MPI_SUCCESS if there is no error

MPI_Get_count

- MPI_Get_count is used in conjunction with the status to get the number of items (not bytes) sent:

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

- status is a pointer to the status structure
- datatype of the data being sent
- count is a pointer to an integer that will store the number of items being sent

- Note that the return value is again an error code and not the number of items (which is stored in the variable pointed to by count)

Using MPI_Probe to get the size of the data

- Similar to the previous example, with processor zero sending data to each of the other processes – Difference is that it randomly sends between 1 and 5 items

```
#include <mpi.h>
#include <iostream>
#include <cstdlib>
#include <time.h>

using namespace std;

int id, p;

int main(int argc, char *argv[])
{
	MPI_Init(&argc, &argv);
	MPI_Comm_rank(MPI_COMM_WORLD, &id);
	MPI_Comm_size(MPI_COMM_WORLD, &p);
	srand(time(NULL)+id*10);

	int tag_num = 1;

	if (id == 0)
	{
		for (int i = 1; i < p; i++)
		{
			int num_send = 1 + rand() % 5;
			int *send_data = new int[num_send];
			for (int j = 0; j < num_send; j++) send_data[j] = rand();

			MPI_Send(send_data, num_send, MPI_INT, i, tag_num, MPI_COMM_WORLD);
			for (int j = 0; j < num_send; j++) cout << send_data[j] << "\t";
			cout << " sent to processor " << i << endl;
			cout.flush();

			delete[] send_data;
		}
	}
	else
	{
		int *recv_data;
		int num_recv;
		MPI_Status status;
		MPI_Probe(0, tag_num, MPI_COMM_WORLD, &status);
		MPI_Get_count(&status, MPI_INT, &num_recv);
		recv_data = new int[num_recv];
		MPI_Recv(recv_data, num_recv, MPI_INT, 0, tag_num, MPI_COMM_WORLD,
			MPI_STATUS_IGNORE);
		for (int j = 0; j < num_recv; j++) cout << recv_data[j] << "\t";
		cout << " received on processor " << id << endl;
		cout.flush();
		delete[] recv_data;
	}
	MPI_Finalize();
}
```

Do Worksheet 1 Exercise 2

Using MPI_Probe to get the source of the data

- MPI_Probe can be used to both wait for data to be sent and to find out where it has come from
  - Note that in some implementations MPI_Probe can time out (you can check for this as it will give an error) and, if you wish to, probe again to continue waiting
  - Note that MPI_Recv could directly wait for a message from any process, but it is often useful to prepare to receive data from a specific process
- The following example plays multi-processor ping-pong, with a processor receiving a communication and then passing it on to another random process
- I exit when one process has received 10 messages
  - I send -1 to all other processes to indicate that the multi-player ping-pong is over
- Processor zero starts the ping-pong
- You will notice that some of the outputs will be out of the logical order
  - A process sends its cout back to originating process and so may arrive back in a different order to which the processes generated them – Watch out for this problem when trying to debug parallel code

```
#include <mpi.h>
#include <iostream>
#include <cstdlib>
#include <time.h>

using namespace std;

int id, p;
int tag_num = 1;

void Send_Random_Data(void)
{
	int to_proc;
	while ((to_proc = rand() % p) == id);	//Stop code sending to itself
	int send_data = id;

	MPI_Send(&send_data, 1, MPI_INT, to_proc, tag_num, MPI_COMM_WORLD);

	cout << "Processor " << id << " sent data to processor " << to_proc << endl;
	cout.flush();
}
```

MPI_Probe example continued

```
//Function probes to receive data from any process. Function will return -1 if a negative number is received
bool Recv_Data(void)
{
	int from_proc;
	int recv_data;
	MPI_Status status;

	while (MPI_Probe(MPI_ANY_SOURCE, tag_num, MPI_COMM_WORLD, &status) != MPI_SUCCESS)
		cout << "Communication timed out or failed! " << id << endl;

	from_proc = status.MPI_SOURCE;

	MPI_Recv(&recv_data, 1, MPI_INT, from_proc, tag_num, MPI_COMM_WORLD, &status);

	//if a negative number is received the code needs to exit
	if (recv_data == -1)
		return false;

	cout << "Processor " << id << " received data from processor " << from_proc << endl;
	cout.flush();

	return true;
}
```

```
int main(int argc, char *argv[])
{
	int recv_cnt = 0;
	bool status = true;
	MPI_Init(&argc, &argv);

	MPI_Comm_rank(MPI_COMM_WORLD, &id);
	MPI_Comm_size(MPI_COMM_WORLD, &p);
	srand(time(NULL) + id * 10);

	if (id == 0) Send_Random_Data();			//Starts the ping-pong

	while (status)
	{
		status = Recv_Data();				//Waits for and receives data
		recv_cnt++;
		if (recv_cnt<10 && status)
			Send_Random_Data();			//Sends it on to a new processor
		else break;			//Exits if 10 communications are received or a negative number is received
	}

	if (status)				//process has left by breaking after 10 communications
	{
		cout << endl << "Process " << id << " has received 10 communications and is exiting" << endl;
		cout.flush();
		for (int i = 0; i < p; i++)
			if (i!=id)
			{
				int send_data = -1;
				//send a negative numbers to each of the other processors to tell them to exit
				MPI_Send(&send_data, 1, MPI_INT, i, tag_num, MPI_COMM_WORLD);
			}
	}

	MPI_Finalize();
	return 0;
}
```

What is wrong with blocking communications?

- The main problem with blocking communications is that it is hard to do them efficiently if a lot of communications are required
  - Either you can let each process communicate in turn
    - Lots of idle time waiting for other processes to finish their communications
  - …or you can try and do clever ordering of the communications so that all processes get to do communications at the same time
    - Easy to get wrong – Will block and crash if, for instance, two process are trying to send data to one another or receive data from one another at the same time
    - Still likely to be inefficient as even efficient ordering will rely on, for instance, an assumption that all communications take about the same time
- Things can be much more efficient if communications don't block one another
  - MPI provides the tools to do this
  - More complex to implement, but potentially much more efficient code
- Note that some MPI implementations of blocking communications don't block when you might think that they should
  - Some implementations of MPI implement some blocking communications using an underlying non-blocking framework
  - Don't rely on this as it is very implementation specific
  - You also might get away with it when sending small amounts of data, but end up blocking with large amounts of data

Do Worksheet 1 Exercise 3