Collective Communications

Introduction to Collective Communications

- Thus far all communications we have looked at have been point-to-point
  - Single sending matched to a single receiving process
- Now we will look at collective communications
  - Multiple processes involved in a single communication event
- Same result could be achieved using multiple point to point communications
- …,but often less efficient
  - In collective communications information can be passed from processor to processor spreading the load
  - Can often achieve a speed scaling of close to log(p) rather than being linear in p as would be the case when using point to point communications

Broadcast using MPI_Bcast

```
int MPI_Bcast(
    void *buffer,
    int count,
    MPI_Datatype datatype,
    int root,
    MPI_Comm comm )
```

- Simplest, but one of the most useful collective operations
- Sends the same data from one process to all other processes
  - Needs to be called at the same time by all processes
- MPI_Bcast is blocking
- Function definition looks like an MPI_Send, but the source, rather than the destination, is specified by root
  - The destination is every other process
- On root process root buffer is a pointer to the data to be sent
- On other processes buffer is a pointer to where the sent data is to be stored
  - After the operation buffer will contain the same data on all processes

MPI_Bcast example

```
#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 num_send = 1;
	int *data = new int[num_send];

	if (id == 0)
		for (int i = 0; i < num_send; i++)
			data[i] = rand();


	MPI_Bcast(data, num_send , MPI_INT, 0, MPI_COMM_WORLD);

	if (id == 0) cout << "Process 0 sent this data: ";
	else cout << "Process " << id << " received this data: ";

	for (int i = 0; i < num_send; i++)
		cout << "\t" << data[i];
	cout << endl;
	cout.flush();

	delete[] data;

	MPI_Finalize();
}
```

Gather and Scatter Communications

- Broadcast sends the same data to all the processes from a single process
  - Note that, in the previous example, MPI_Bcast is called on all processes at the same time. This is true of all collective operations.
- Sometimes you wish to send different data to each of the processes, but originating at a single process
  - This is known as a Scatter operation
- The reverse of a Scatter operation is a Gather operation
  - Gather involves sending data from all the processes and collecting it on a single process

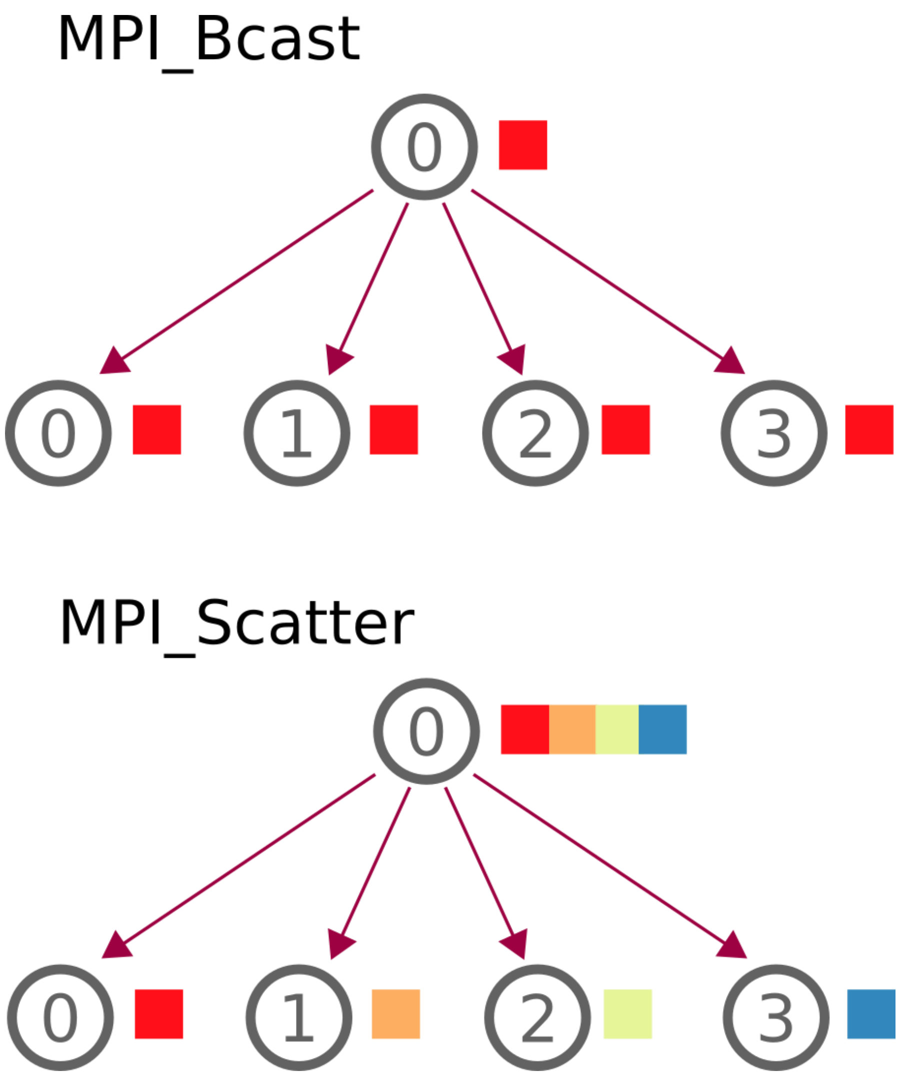
MPI_Scatter

```
int MPI_Scatter(
    void* send_data,
    int send_count,
    MPI_Datatype send_datatype,
    void* recv_data,
    int recv_count,
    MPI_Datatype recv_datatype,
    int root,
    MPI_Comm communicator)
```

- send_data is a pointer to the location of the source data
  - Note that this is only important on the root and can be a nullptr on other processes
- send_count is the number of items to be sent to each process, not the total amount data
  - E.g. if you are sending 10 integers to each process and there and 12 processes involved then send_data will need to contain 120 integers, but send_count will be 10
- recv_data is a pointer to the location where the data is to stored
  - Cannot be null on root as it will also receive its share of the data
- recv_count is the number of items expected
  - Generally this would be the same as the send_count, but could be different if, for instance, you sent the data as bytes and received then as integers

The structure of send_data

- With MPI_Scatter, the data in send_data is sent to processes in the order of the process id
- If send_count is greater than one then the first send_count items are sent to process zero, the second send_count items to process one etc.
- The size of send_data should therefore be send_count times the total number of processes
  - If you wish to scatter an amount of data not exactly divisible by the number of processes you may need to pad the data
- Note that the data for the root is also copied into recv_data on the root



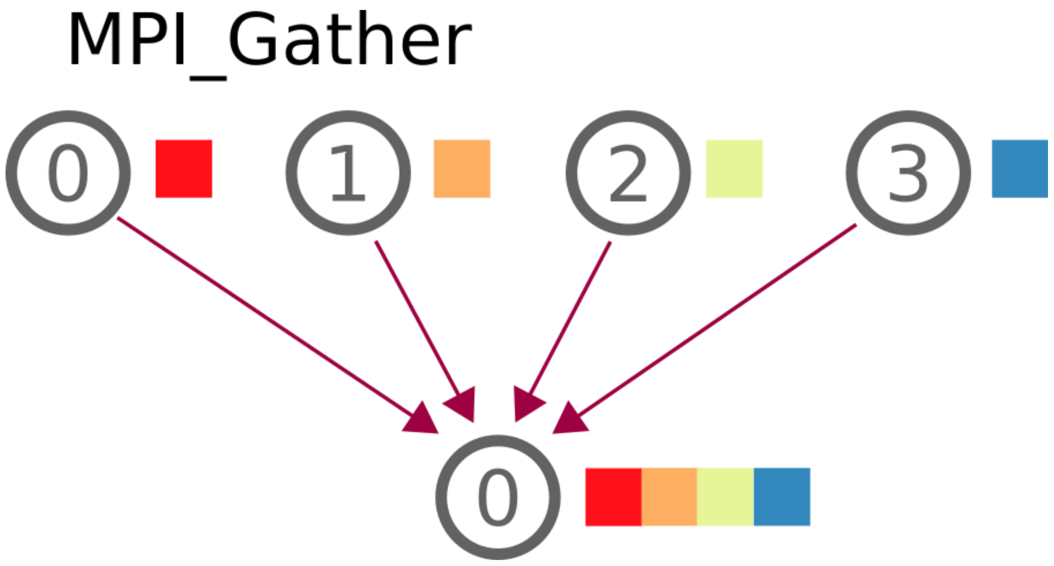
MPI_Gather

```
int MPI_Gather(
    void* send_data,
    int send_count,
    MPI_Datatype send_datatype,
    void* recv_data,
    int recv_count,
    MPI_Datatype recv_datatype,
    int root,
    MPI_Comm communicator)
```

- The parameters required for MPI_Gather are identical to that for MPI_Scatter
- The big difference is that now the send_data has only got send_count items, while recv_data will need space for recv_count times the number of processes of data
  - This time it is the recv_data that can be NULL (or nullptr) on processes other than the root

The structure of recv_data

- As MPI_Gather is essentially the reverse operation of MPI_Scatter, the structure of the data in recv_data will be similar to that in send_data from MPI_Scatter
  - recv_data will have the data sent from process zero stored in the first recv_count elements, the data for process one stored in the next recv_count elements etc.



An example using MPI_Scatter and MPI_Gather

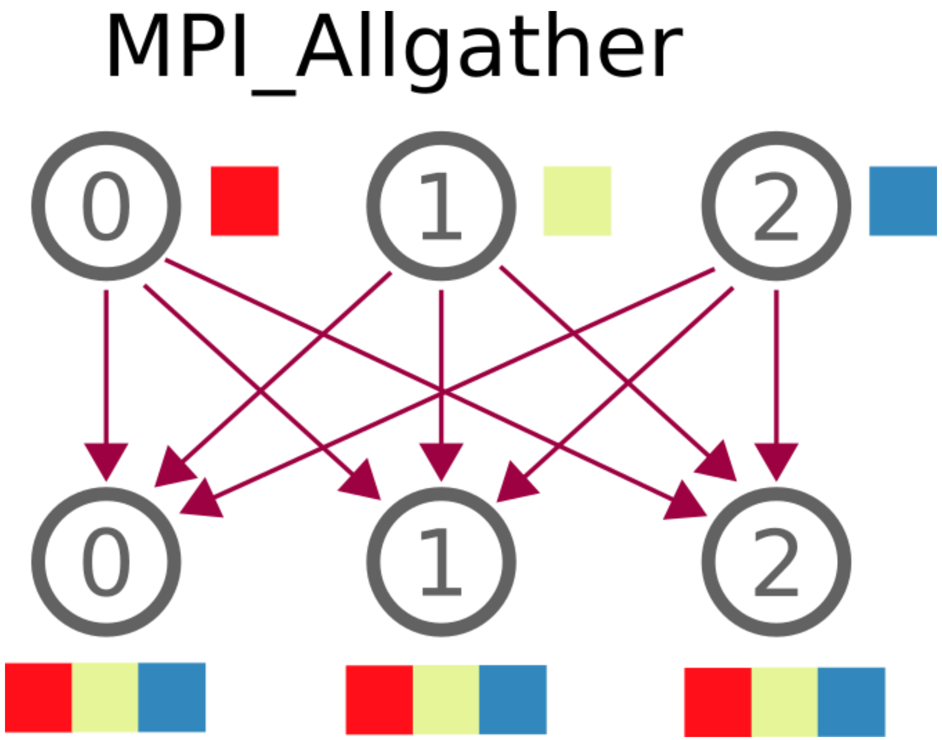
```
#include <mpi.h>
#include <iostream>
#include <cstdlib>
#include <time.h>

using namespace std;

int id, p;

double calc_ave(double *list, int num)
{
	double total = 0.0;
	for (int i = 0; i < num; i++)
		total += list[i];
	return total / num;
}

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);

	double *send_data1 = nullptr, send_data2;
	double *recv_data1 = nullptr, *recv_data2 = nullptr;
	int num_sendrecv = 20;

	if (id == 0)
	{
		send_data1 = new double[num_sendrecv*p];
		for (int i = 0; i < num_sendrecv*p; i++)
			send_data1[i] = ((double)rand() / (double)RAND_MAX)*100.0;
	}

	recv_data1 = new double[num_sendrecv];

	MPI_Scatter(send_data1, num_sendrecv, MPI_DOUBLE, recv_data1, num_sendrecv, MPI_DOUBLE, 0,
		MPI_COMM_WORLD);

	send_data2 = calc_ave(recv_data1, num_sendrecv);

	delete[] recv_data1;	//Can be called on all processes as it is NULL where not used
	delete[] send_data1;

	if (id == 0)
		recv_data2 = new double[p];

	MPI_Gather(&send_data2, 1, MPI_DOUBLE, recv_data2, 1, MPI_DOUBLE, 0, MPI_COMM_WORLD);

	if (id == 0)
	{
		cout << "The following averages were calculated for each set of data:" << endl;
		for (int i = 0; i < p; i++)
			cout << "\t" << i << " " << recv_data2[i] << endl;
	}
	delete[] recv_data2;
	MPI_Finalize();
}
```

Do Worksheet 3 Exercise 1

MPI_Allgather

```
int MPI_Allgather(
    void* send_data,
    int send_count,
    MPI_Datatype send_datatype,
    void* recv_data,
    int recv_count,
    MPI_Datatype recv_datatype,
    MPI_Comm communicator)
```

- MPI_Allgather is very closely related to MPI_Gather
  - The difference is that the recv_data ends up on all processes
  - A root is therefore not required



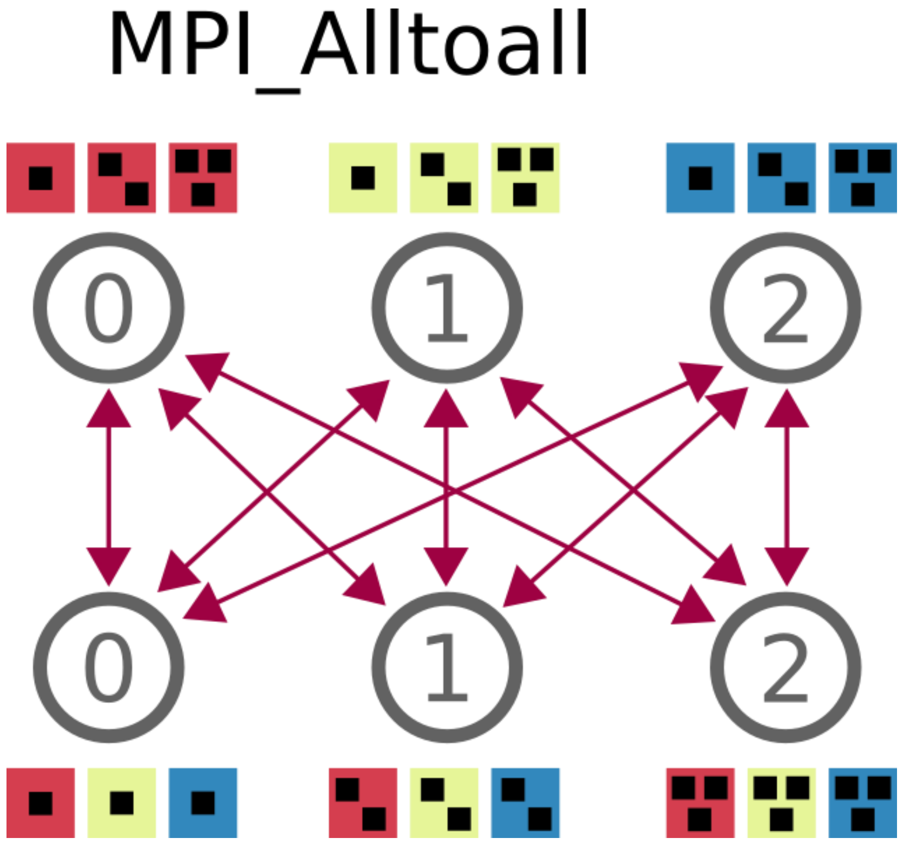
MPI_Alltoall

```
int MPI_Alltoall(
    void* send_data,
    int send_count,
    MPI_Datatype send_datatype,
    void* recv_data,
    int recv_count,
    MPI_Datatype recv_datatype,
    MPI_Comm communicator)
```

- The parameters in MPI_Alltoall are the same as those for MPI_Allgather, but what it does is somewhat different

MPI_Alltoall

- Unlike in MPI_Allgather, where each process receives the same data, in MPI_Alltoall each process sends a different piece of data to each other process
  - The total size of both send_data and recv_data must be equal to the count times the number of processes
  - Achieves the same thing as the previous lecture's everyone communicating with everyone example, but is more efficient



Transferring data from everyone to everyone

- MPI_Alltoall

```
double *send_data = new double[p*num_send];
double *recv_data = new double[p *num_send];

//Set values of send_data

MPI_Alltoall(send_data , num_send, MPI_DOUBLE, recv_data, num_send,
        MPI_DOUBLE, MPI_COMM_WORLD);
```

- MPI_Isend and MPI_Irecv

```
double *send_data = new double[p*num_send];
double *recv_data = new double[p *num_send];

//Set values of send_data

for (int i=0;i<p;i++)
        if (i != id)
        {
                MPI_Irecv(&recv_data[i* num_send], num_send, MPI_DOUBLE, i,
                        tag_num, MPI_COMM_WORLD, &request[cnt]);
                cnt++;
        }
        else for (int j=0;j< num_send;j++)
                recv_data[i*numsend+j] = send_data[i*numsend+j] ;

for (int i = 0; i<p; i++)
        if (i != id)
        {
                MPI_Isend(&send_data[i* num_send], num_send, MPI_DOUBLE, i,
                        tag_num, MPI_COMM_WORLD, &request[cnt]);
                cnt++;
        }

//Potentially do work here while waiting

MPI_Waitall(cnt, request, MPI_STATUS_IGNORE);
```

MPI_Reduce

- MPI_Reduce is a very useful collective operation which shares some similarity to MPI_Gather in that data is sent from all the processes and collated on root
- Its big difference is that the data is not stored separately, but combined using an operation op
  - This is also why there is a single count and datatype as the operation must involve a single type
  - The operation is applied separately to each of the items in the data
- MPI_Allreduce is similar to MPI_Reduce except that the data is received on all processes
  - A root is therefore not required

```
int MPI_Reduce(
    void* send_data,
    void* recv_data,
    int count,
    MPI_Datatype datatype,
    MPI_Op op,
    int root,
    MPI_Comm communicator)
```

Reduce operations in MPI (MPI_Op op)

- There are a large number of different reduce operations that are available:

MPI_MAX: Stores the maximum value

MPI_MIN: Stores the minimum value

MPI_SUM: Stores the sum of the values

MPI_PROD: Stores the product of the values

MPI_LAND: Carries out a logical “and” on all the values

MPI_BAND: Carries out a bit-wise “and” on all the values

MPI_LOR: Carries out a logical “or” on all the values

MPI_BOR: Carries out a bit-wise “or” on all the values

MPI_LXOR: Carries out a logical “xor” on all the values

MPI_BXOR: Carries out a bit-wise “xor” on all the values

MPI_MAXLOC: Gives a maximum value and its location (i.e. it returns a pair of values)

MPI_MINLOC: Same as MPI_MAXLOC, but based on a minimum value

Modifying the previous example: MPI_Reduce

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

using namespace std;

int id, p;

double calc_ave(double *list, int num)
{
	double total = 0.0;
	for (int i = 0; i < num; i++)
		total += list[i];
	return total / num;
}

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);

	double *send_data1 = nullptr, send_data2;
	double *recv_data1 = nullptr, recv_data2;
	int num_sendrecv = 20;

	if (id == 0)
	{
		send_data1 = new double[num_sendrecv*p];
		for (int i = 0; i < num_sendrecv*p; i++)
			send_data1[i] = ((double)rand() / (double)RAND_MAX)*100.0;
	}

	recv_data1 = new double[num_sendrecv];

	MPI_Scatter(send_data1, num_sendrecv, MPI_DOUBLE, recv_data1, num_sendrecv, MPI_DOUBLE, 0,
		MPI_COMM_WORLD);

	send_data2 = calc_ave(recv_data1, num_sendrecv);

	delete[] recv_data1;		//Can be called on all processes as it is NULL where not used
	delete[] send_data1;

	MPI_Reduce(&send_data2, &recv_data2, 1, MPI_DOUBLE, MPI_SUM, 0, MPI_COMM_WORLD);

	if (id == 0)
		cout << "The average of all the data is " << recv_data2 / p << endl;

	MPI_Finalize();
}
```

Do Worksheet 3 Exercise 2 and 3

Non-blocking collectives

- You could use the non-blocking version of the collective operation, which allows you to do things like continuing working while waiting for them to complete
  - We will not specifically look at non-blocking collectives here, but their difference to the blocking version is similar to the difference between, for instance, MPI_Send and MPI_Isend
  - They also require a request variable and are guaranteed to have completed once MPI_Wait has been called
  - They can also be checked for completion using MPI_Test
- The non-blocking equivalents all have an I in their name. E.g.
  - Non-blocking MPI_Bcast is MPI_Ibcast
  - Non-blocking MPI_Gather is MPI_Igather etc.
- The parameters they take in and their usage are identical to their non-blocking equivalents except for the extra MPI_Request* variable

Do Worksheet 3 Exercise 4

In the next lecture we will look at some other things that may be required for writing MPI programs