DISTRIBUTED AND CLOUD COMPUTING

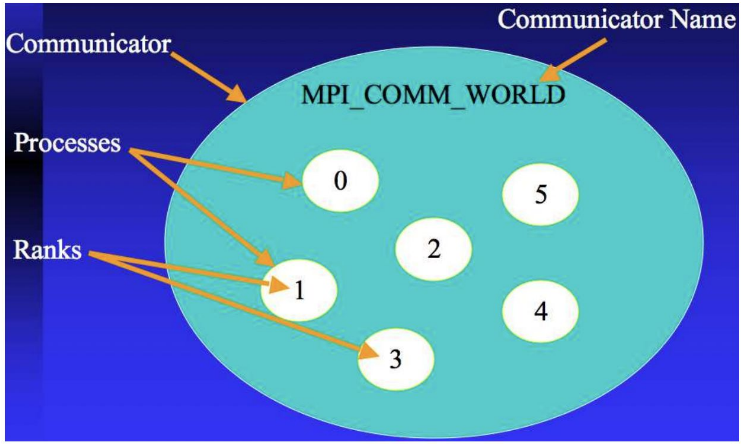
LAB 2: MPI COMMUNICATION MODELS

(Module: Message Passing)

RECAP: Message Passing Interface (MPI)

- **MPI:** a message passing **standard** to allow for distributed/parallel computation
- MPI implements an interface for ***parallel process communication***
  - Abstracts the low-level details of process communication
  - Allows the programmer to focus on the problem at hand (the parallel application)!
- **MPI processes:** managed by MPI and run concurrently (at the same time)
- **MPI communicators:** group processes and assign them ranks
  - "MPI_COMM_WORLD" is the default communicator

Communicators



Boilerplate code

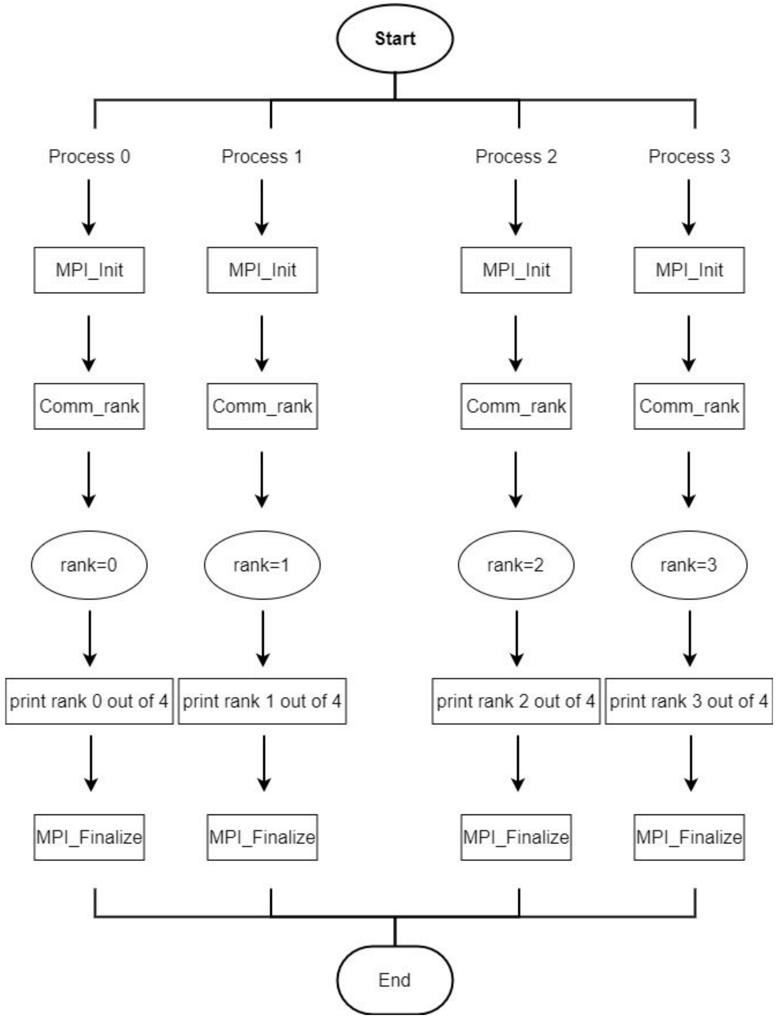
```
#include <mpi.h>

int main(int argc, char* argv[])
{
    // Initialization
    MPI_Init(NULL, NULL);

    // APPLICATION LOGIC.

    // Finalize MPI.
    MPI_Finalize();
}
```

Useful functions

```
// Get the number of processes
int world_size;
MPI_Comm_size(MPI_COMM_WORLD,
&world_size);

// Get the rank of the process
int world_rank;
MPI_Comm_rank(MPI_COMM_WORLD,  &world_rank);
```

RECAP: Message Passing Interface (MPI)

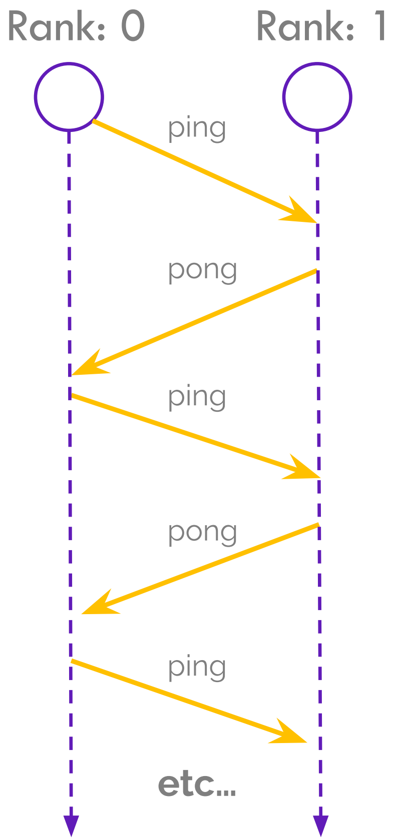
```c
#include <mpi.h>
#include <stdio.h>

int main(int argc, char* argv[]) {
    // Initialization
    MPI_Init(NULL, NULL);
    // Get the number of processes
    int world_size;
    MPI_Comm_size(MPI_COMM_WORLD, &world_size);
    // Get the rank of the process
    int world_rank;
    MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);
    // Get the name of the processor
    char processor_name[MPI_MAX_PROCESSOR_NAME];
    int name_len;
    MPI_Get_processor_name(processor_name, &name_len);
    // Print off a hello world message
    printf("Hello world from processor %s, rank %d out of %d
         processors\n", processor_name, world_rank, world_size);
    // Finalize the MPI environment.
    MPI_Finalize();
}
```



https://github.com/wesleykendall/mpitutorial/blob/gh-pages/tutorials/mpi-hello-world/code/mpi_hello_world.c

RECAP: PING-PONG

- The hello-world example does not involve communication between processes
- Here we consider an example that allows two MPI processes to play ping-pong
- MPI processes send messages to each other



1. Recap of last week & MPI Datatypes

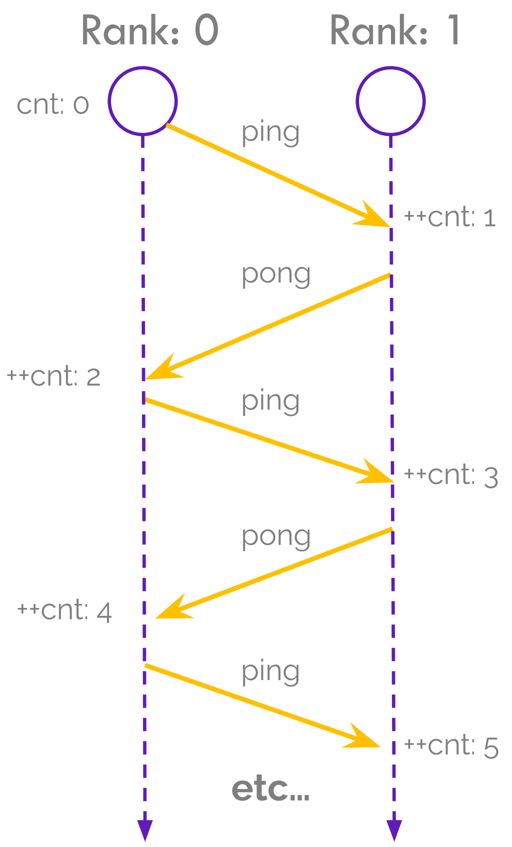
Example program: ping-pong
It implements message passing between two MPI processes

```
const int PING_PONG_LIMIT = 10;
// Some code is not shown here!!!

int ping_pong_count = 0; Local rank
int partner_rank = (world_rank + 1) % 2;
while (ping_pong_count < PING_PONG_LIMIT) {
    if (world_rank == ping_pong_count % 2) {
        // Increment the ping pong count before you send it
        ping_pong_count++;

                Send Buffer          SizeOf Buff  Data type   Rank of dest   Tag  Communicator
SEND    MPI_Send(&ping_pong_count, 1, MPI_INT, partner_rank, 0, MPI_COMM_WORLD);
        printf("%d sent and incremented ping_pong_count %d to %d\n",
               world_rank, ping_pong_count, partner_rank);
    } else {
        MPI_Recv(&ping_pong_count, 1, MPI_INT, partner_rank, 0,
RECEIVE          MPI_COMM_WORLD, MPI_STATUS_IGNORE);
        printf("%d received ping_pong_count %d from %d\n",
               world_rank, ping_pong_count, partner_rank);
    }
}
```

world_rank	partner_rank
1	0
0	1

https://github.com/wesleykendall/mpitutorial/tree/gh-pages/tutorials/mpi-send-and-receive/code/ping_pong.c

1. Recap of last week & MPI Datatypes




```
~ mpirun -np 2 ./mpi-ping-pong
0 sent and incremented ping_pong_count 1 to 1
1 received ping_pong_count 1 from 0
1 sent and incremented ping_pong_count 2 to 0
0 received ping_pong_count 2 from 1
0 sent and incremented ping_pong_count 3 to 1
0 received ping_pong_count 4 from 1
0 sent and incremented ping_pong_count 5 to 1
0 received ping_pong_count 6 from 1
0 sent and incremented ping_pong_count 7 to 1
0 received ping_pong_count 8 from 1
0 sent and incremented ping_pong_count 9 to 1
0 received ping_pong_count 10 from 1
1 received ping_pong_count 3 from 0
1 sent and incremented ping_pong_count 4 to 0
1 received ping_pong_count 5 from 0
1 sent and incremented ping_pong_count 6 to 0
1 received ping_pong_count 7 from 0
1 sent and incremented ping_pong_count 8 to 0
1 received ping_pong_count 9 from 0
1 sent and incremented ping_pong_count 10 to 0
```

2. MPI Communication Modes

MPI Communication Modes

- **Standard Mode, Buffered Mode, Synchronous Mode, Ready Mode**
- They have the same set of parameters
- **Differences:** The **method of sending** message and the **state of receiver**
- **Locality of mode:** whether the mode requires communicating with other processes.
    - **Local:** Completion of procedure depends only on local process.
    - **Non-local:** Completion of procedure needs to interact with other processes.

https://www.mpi-forum.org/docs/mpi-2.2/mpi22-report/node53.htm

MPI Communication Modes

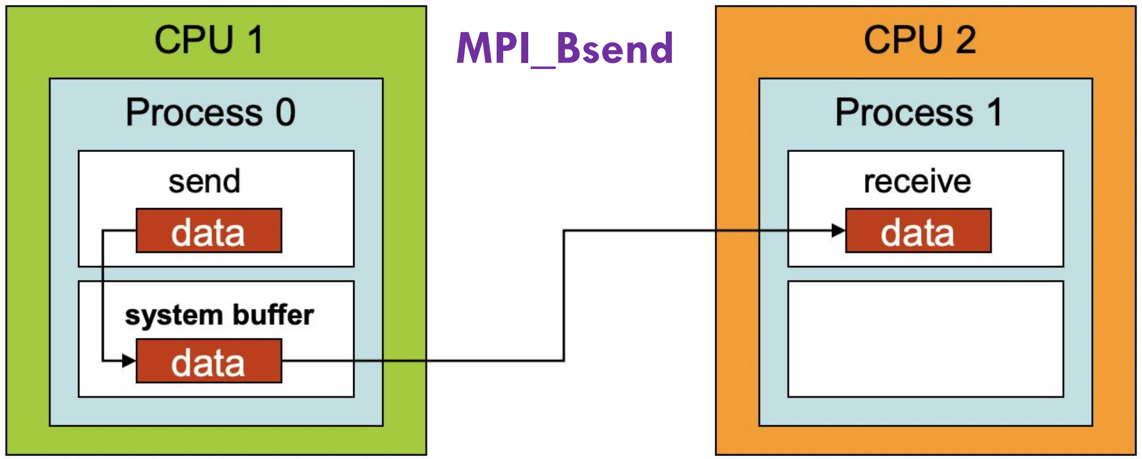
Standard mode:

- In standard mode, MPI determines if the data will be **buffered**
- **Buffered:** Copy the data into a buffer and return immediately
  - The sending will be done by MPI later
- **Non-buffered:** Return when the data has completed sending
- Standard mode is **non-local**
  - **Non-buffered case** required processes to communicate

MPI Communication Modes

Buffered mode:

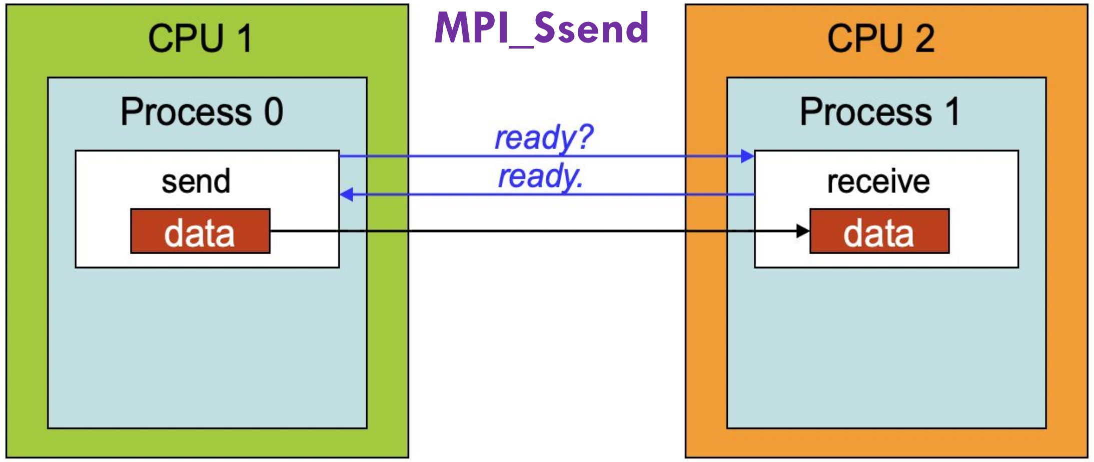
- MPI **ALWAYS** copies the data to a provided buffer and returns immediately
- The sending is done by MPI in the background
- Buffered mode is **local**



MPI Communication Modes

Synchronous mode:

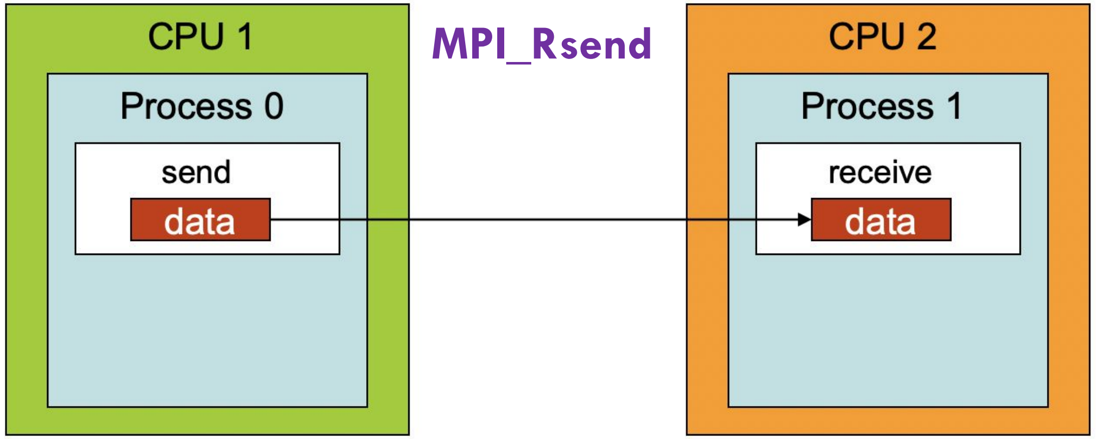
- Synchronous mode only returns when the recipient has started receiving message.
- Sending and receiving tasks must “handshake”
- Handshake procedure ensures both processes are ready
- Synchronous mode is **non-local.**



MPI Communication Modes

Ready mode:

- Ready mode **assumes the recipient is at ready state**
- Recipient **unable** to receive → **Erroneous**
- Ready mode is **non-local**



MPI Communication Modes

- This is mostly **encyclopedic** knowledge to provide intuition on MPI communication types
- In practise, we will **mostly use the standard type** communication

Blocking & Non-blocking Communication

Blocking communication:

- The function waits until operation is completed to return
- Suspends execution until the message buffer being sent/received is safe to use
  - **Example:** MPI_Send, MPI_Recv

Non-blocking communication:

- Function call returns immediately
- The actual operation is completed by MPI in background.
- User must ensure operation is completed before using received data
  - **Example:** MPI_Isend, MPI_Irecv

MPI: Available Send & Receive Functions

SEND	Blocking	Nonblocking
Standard	mpi_send	mpi_isend
Ready	mpi_rsend	mpi_irsend
Synchronous	mpi_ssend	mpi_issend
Buffered	mpi_bsend	mpi_ibsend

RECEIVE	Blocking	Nonblocking
Standard	mpi_recv	mpi_irecv

MPI Data Types

- MPI supports various data types to be send among processes
- Complex MPI applications typically use **MPI_BYTE** to communicate with custom protocols
  - The bytes are then encoded back into their original structure based on the protocol

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_INT	unsigned int
MPI_UNSIGNED_LONG	unsigned long int
MPI_FLOAT	float
MPI_DOUBLE	double
MPI_LONG_DOUBLE	long double
MPI_BYTE	
MPI_PACKED	

3. Collective Communication

Collective Communication

- Collective communication refers to the communication among multiple processes.
- **One to many (1-N) | many to one (N-1) | many to many(N-N)**
  - In 1-N and N-1 modes: the “1” process is often called **‘root’**

Collective communication is the “bread and butter” communication of distributed systems!

Collective Communication

Synchronization:

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

Broadcast message to all processes

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

Split data amongst all processes

```
int MPI_Scatter(void * sendbuf, int sendcount, MPI_Datatype sendtype, void * recvbuf, int
recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)
```

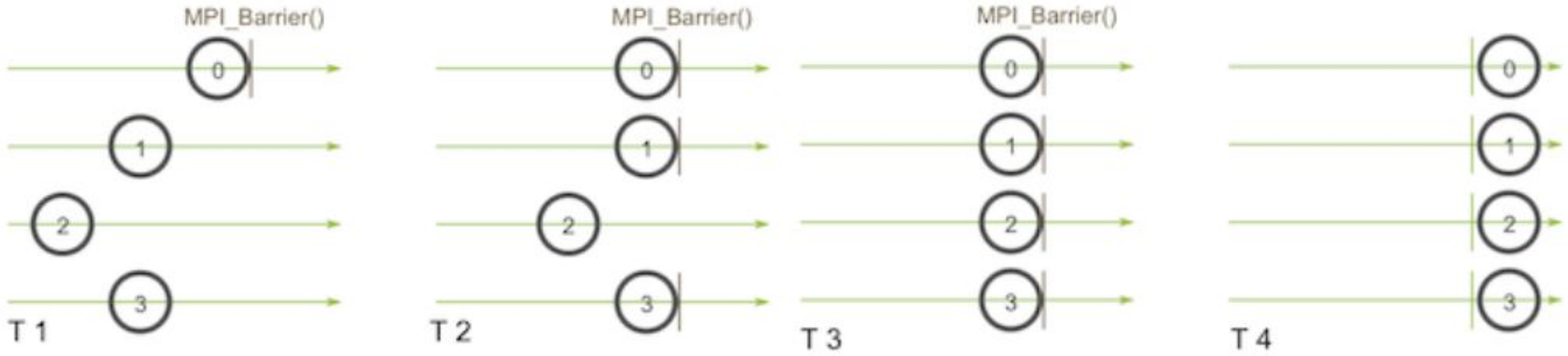
Receive messages from all processes:

```
int MPI_Gather(void * sendbuf, int sendcount, MPI_Datatype sendtype, void * recvbuf, int
recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)
```

Collective Communication

Barrier | int MPI_Barrier(MPI_Comm comm)

- **Blocks execution** of process in the given communicator **until all processes** (in that that communicator) **have reached their barrier**

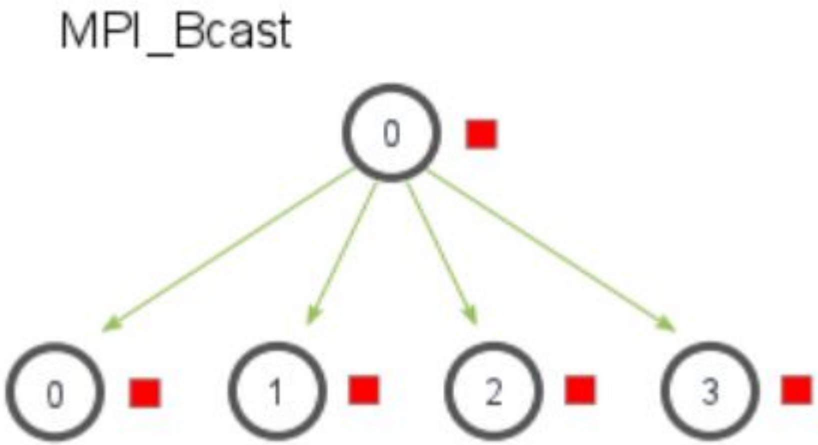


https://mpitutorial.com/tutorials/mpi-broadcast-and-collective-communication/

Collective Communication (1-N)

Broadcast | `int MPI_Bcast(void* buf, int count, MPI_Datatype datatype, int root, MPI_Comm comm)`

- **Root** sends message **to all processes** in the communicator

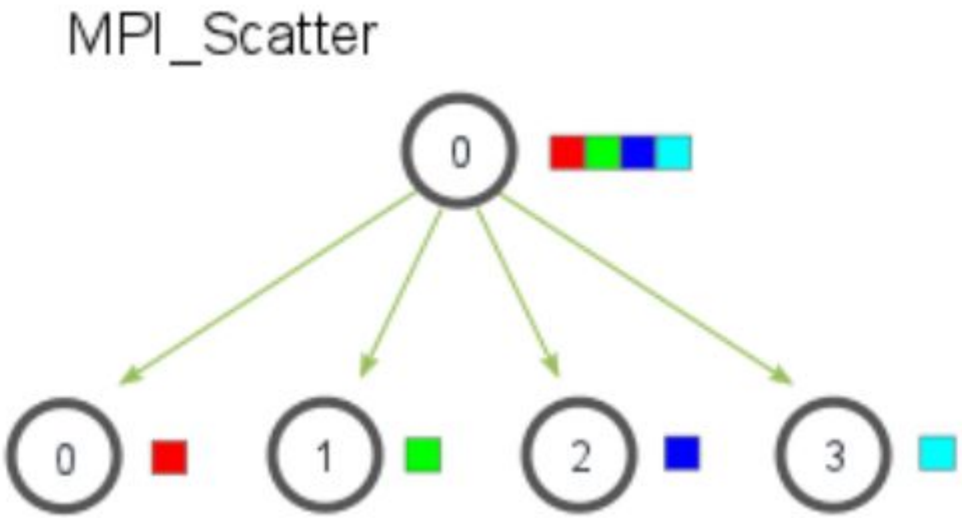


https://mpitutorial.com/tutorials/mpi-broadcast-and-collective-communication/

Collective Communication (1-N)

Scatter| int MPI_Scatter(void * sendbuf, int sendcount, MPI_Datatype sendtype, void * recvbuf, int recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)

- **Root splits a message into sub-messages to all processes**

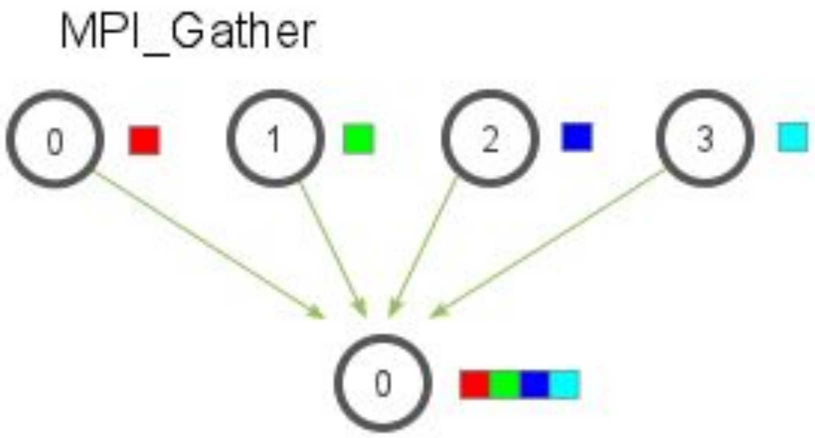


https://mpitutorial.com/tutorials/mpi-scatter-gather-and-allgather/

Collective Communication (N-1)

Gather | int MPI_Gather(void * sendbuf, int sendcount, MPI_Datatype sendtype, void * recvbuf, int recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)

- **Root receives a** message **from all processes** in the communicator **(including root!)**



https://mpitutorial.com/tutorials/mpi-scatter-gather-and-allgather/

Collective Communication (N-1)

Execute the Synchronize, Broadcast and Scatter_Gather examples available on blackboard and observe their behaviour!

```
mpicc source.c -o executable_name
mpirun –np <num_processes>  ./executable_name
```

TASK: DISTRIBUTED CALCULATOR

Using the examples we've seen today write a distributed calculator program!

- The root process (0) will broadcast 2 numbers to 4 worker processes (including the root).
- Each worker will have a designated operation (0: addition, 1:subtraction, 2:multiplication, 3: division)
- After receiving the data from the root each worker will perform that operation
- Finally, the root processes will gather and print all results

```
mpicc source.c -o executable_name
mpirun –np <num_processes>  ./executable_name
```