Message-Passing Computing

More MPI routines:

Collective routines

Synchronous routines

Non-blocking routines

Collective message-passing routines

Have routines that send message(s) to a group of processes or receive message(s) from a group of processes

Higher efficiency than separate point-to-point routines although routines not absolutely necessary.

Collective Communication

Involves set of processes, defined by an intra-communicator. Message tags not present. Principal collective operations:

- **`MPI_Bcast()`** - Broadcast from root to all other processes
- **`MPI_Gather()`** - Gather values for group of processes
- **`MPI_Scatter()`** - Scatters buffer in parts to group of processes
- **`MPI_Alltoall()`** - Sends data from all processes to all processes
- **`MPI_Reduce()`** - Combine values on all processes to single value
- **`MPI_Reduce_scatter()`** - Combine values and scatter results
- **`MPI_Scan()`** - Compute prefix reductions of data on processes

- **MPI_Barrier()** - A means of synchronizing processes by stopping each one until they all have reached a specific “barrier” call.

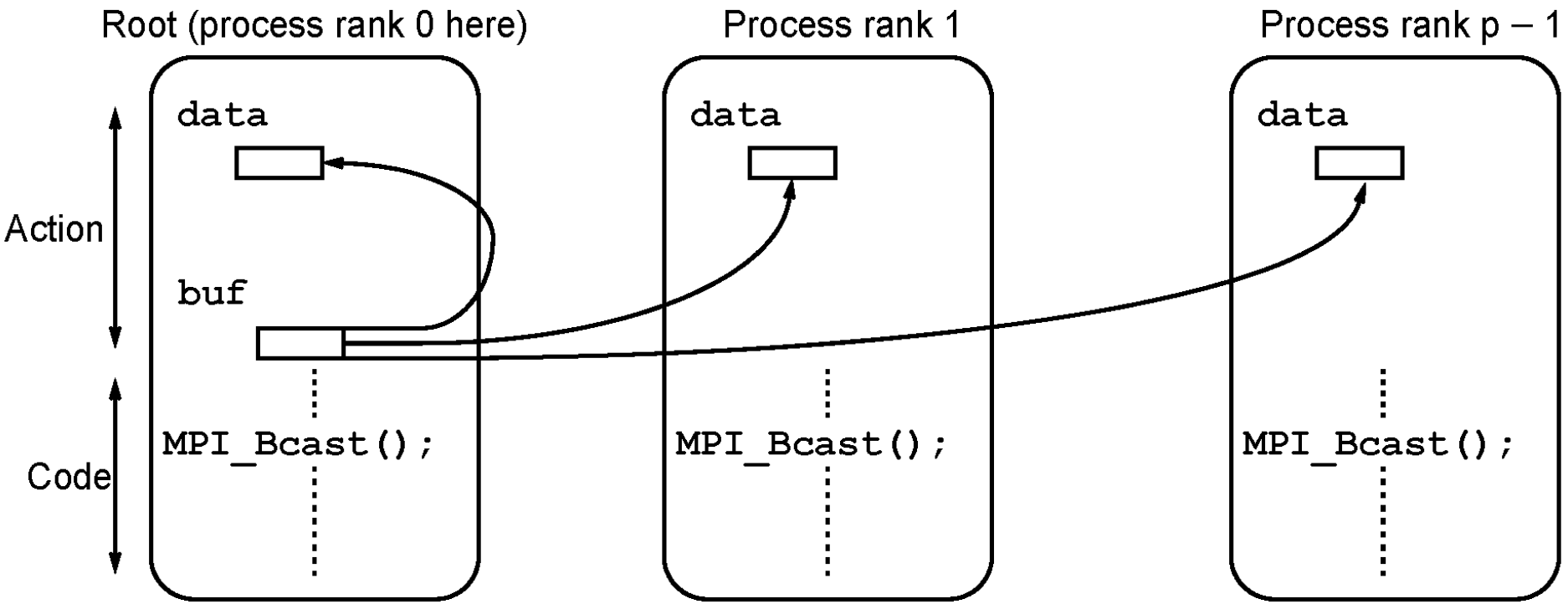
Collective routines
General features

- Performed on a group of processes, identified by a communicator
- Substitute for a sequence of point-to-point calls
- Communications are locally blocking
- Synchronization is *not* guaranteed (implementation dependent)
- Some routines use a *root* process to originate or receive all data
- Data amounts must exactly match
- Many variations to basic categories
- No message tags are needed

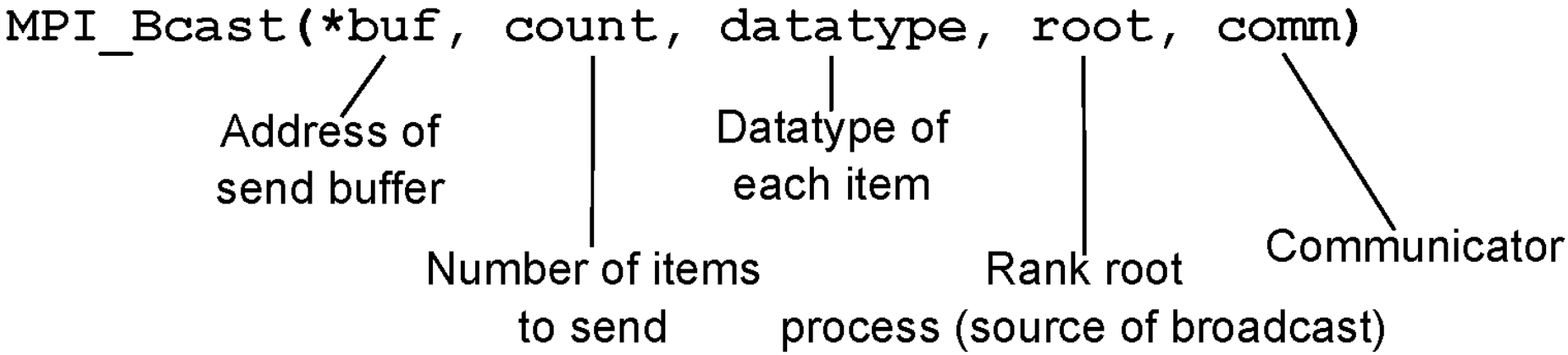
From http://www.pdc.kth.se/training/Talks/MPI/Collective.I/less.html#characteristics

MPI broadcast operation

Sending same message to all processes in communicator.
Multicast - sending same message to defined group of processes.

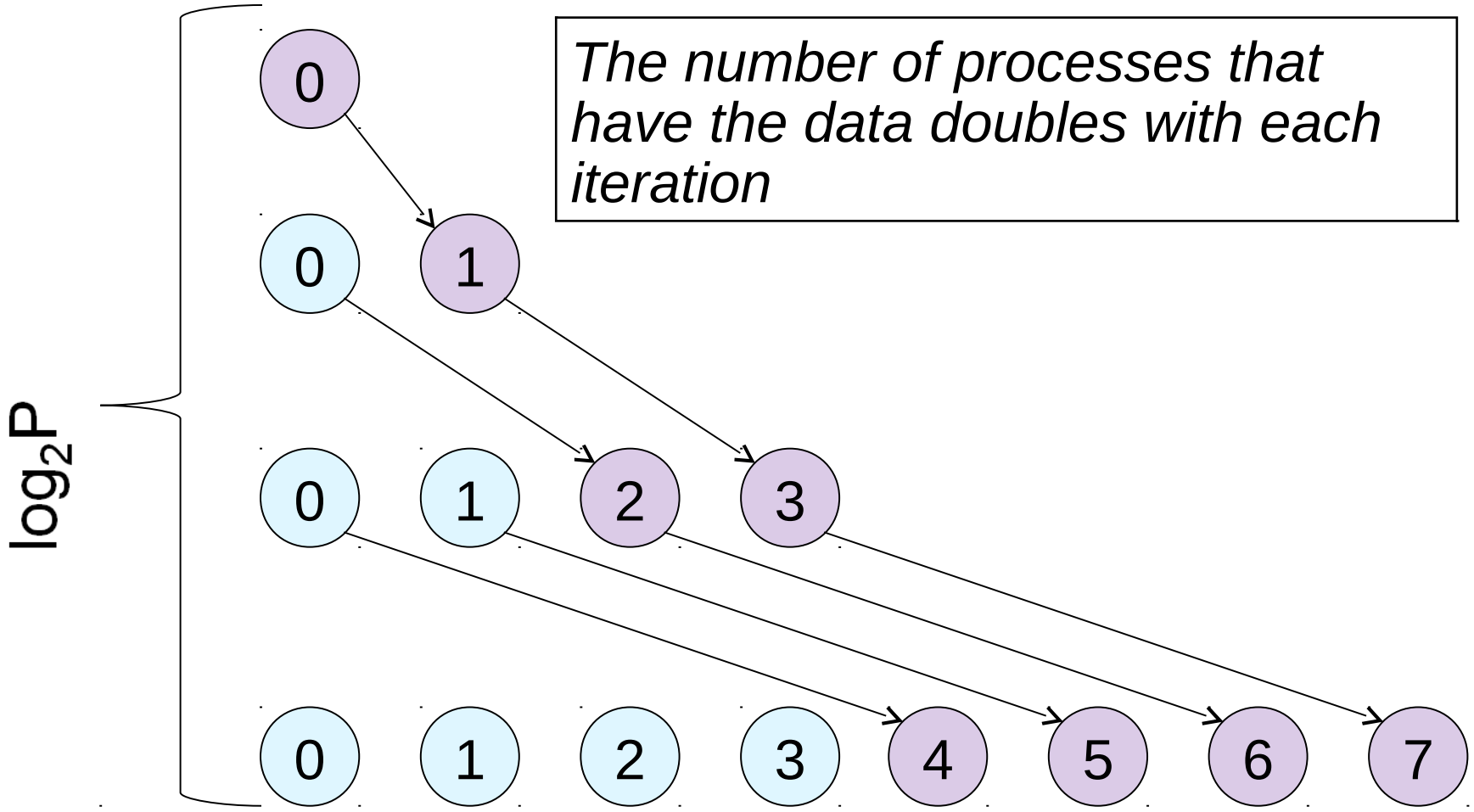


MPI_Bcast parameters



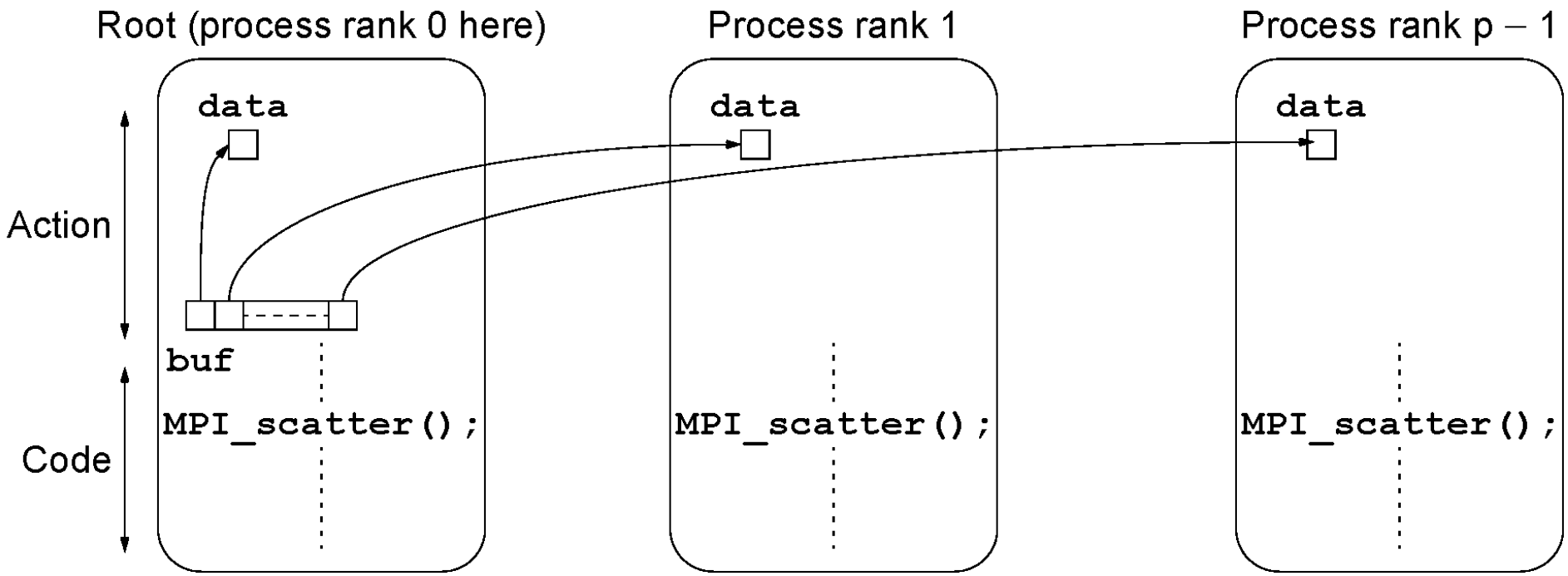
All processes in the Communicator must call the MPI_Bcast with the same parameters

Likely MPI_Bcast implementation

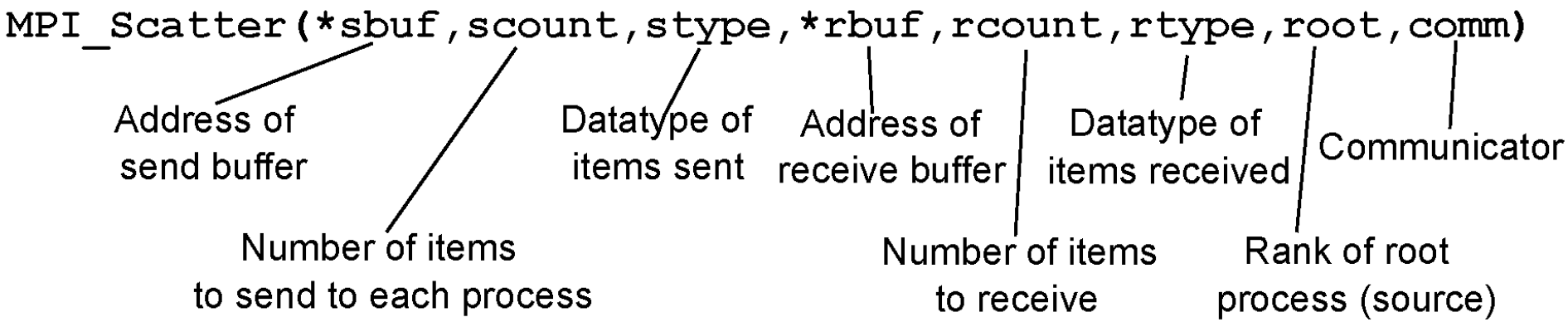


Basic MPI scatter operation

Sending each element of an array in root process to a separate process. Contents of *i*th location of array sent to *i*th process.



MPI scatter parameters

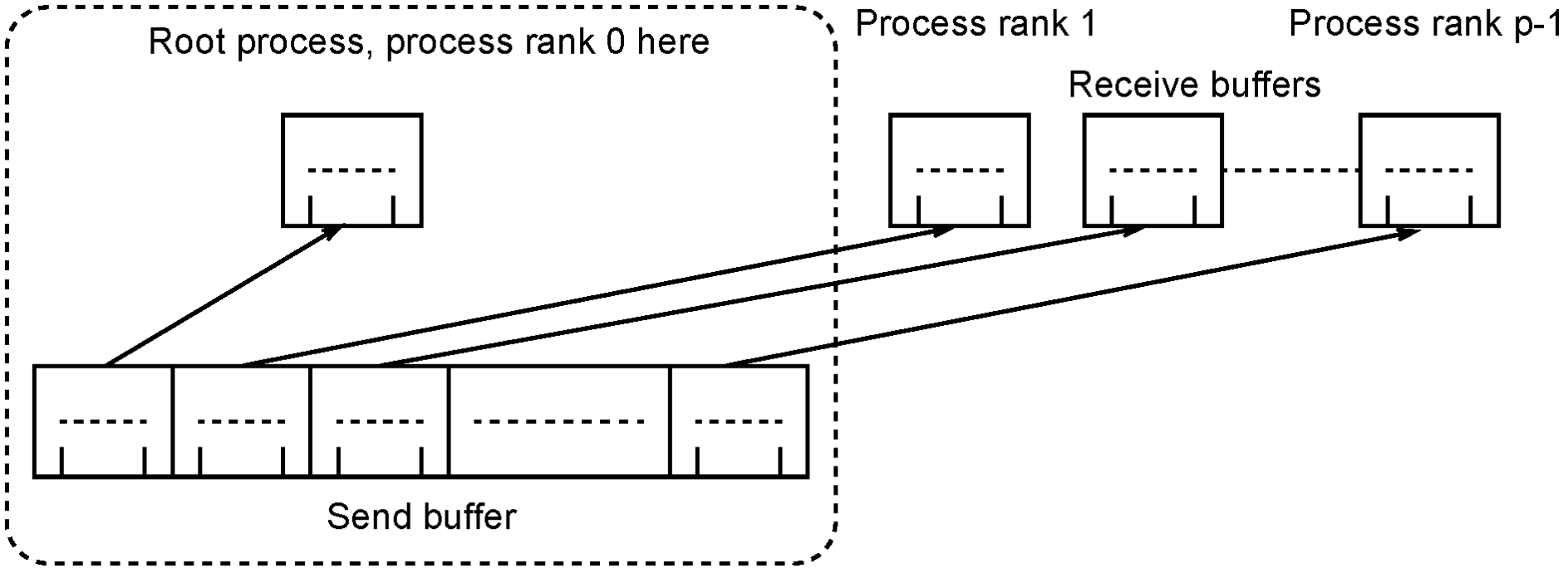


All processes in the Communicator must call the MPI_Scatter with the same parameters

- Simplest scatter would be as illustrated which one element of an array is sent to different processes.

- Extension provided in the MPI_Scatter() routine is to send a fixed number of **contiguous elements** to each process.

Scattering contiguous groups of elements to each process



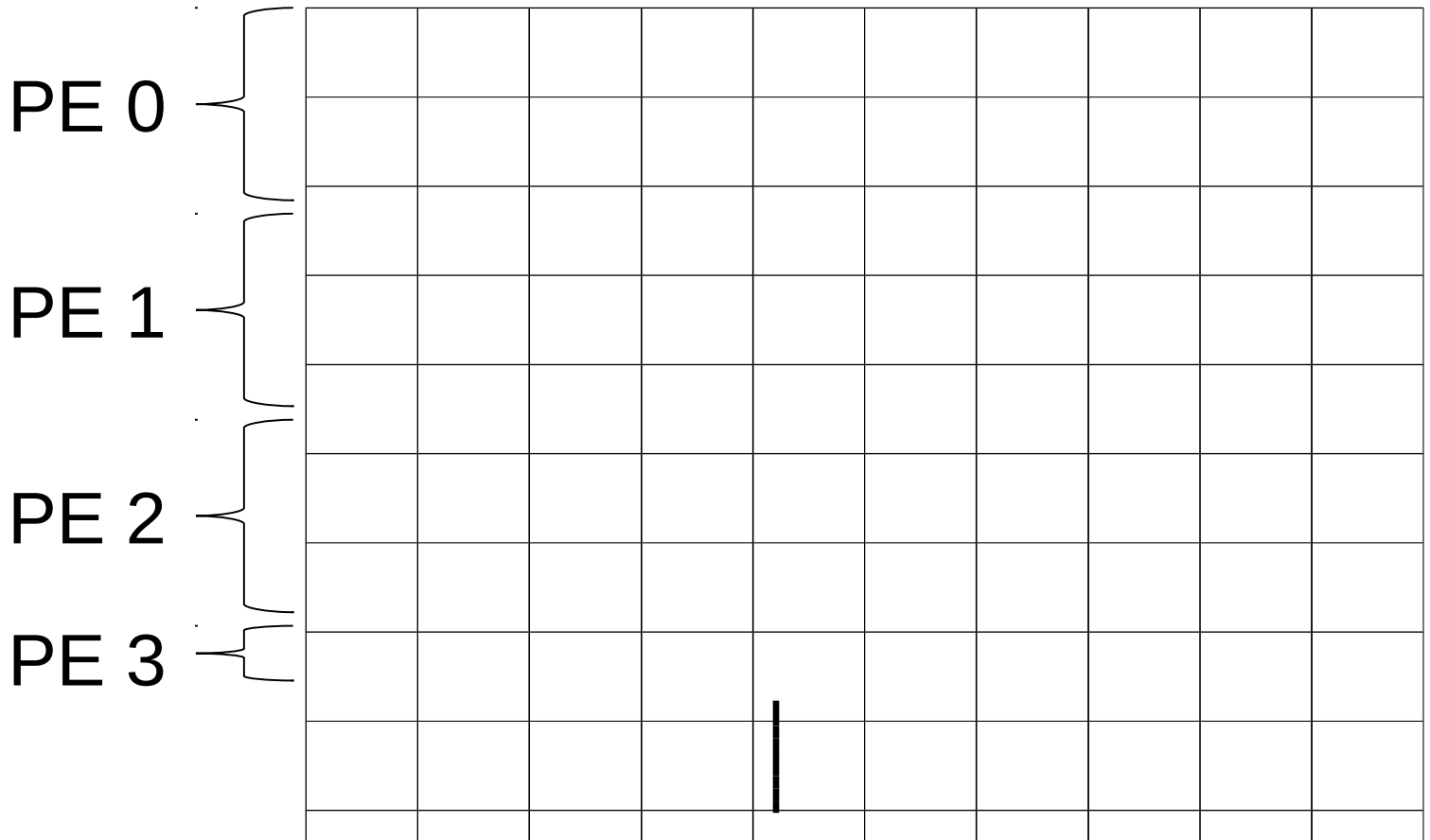
Example

In the following code, size of send buffer is given by 100 * <number of processes> and 100 contiguous elements are send to each process:

```
main (int argc, char *argv[]) {
int size, *sendbuf, recvbuf[100];                    /* for each process */
MPI_Init(&argc, &argv);        /* initialize MPI */
MPI_Comm_size(MPI_COMM_WORLD, &size);
sendbuf = (int *)malloc(size*100*sizeof(int));
.
MPI_Scatter(sendbuf,100,MPI_INT,recvbuf,100,MPI_INT,0,
MPI_COMM_WORLD);
.
MPI_Finalize();          /* terminate MPI */
}
```

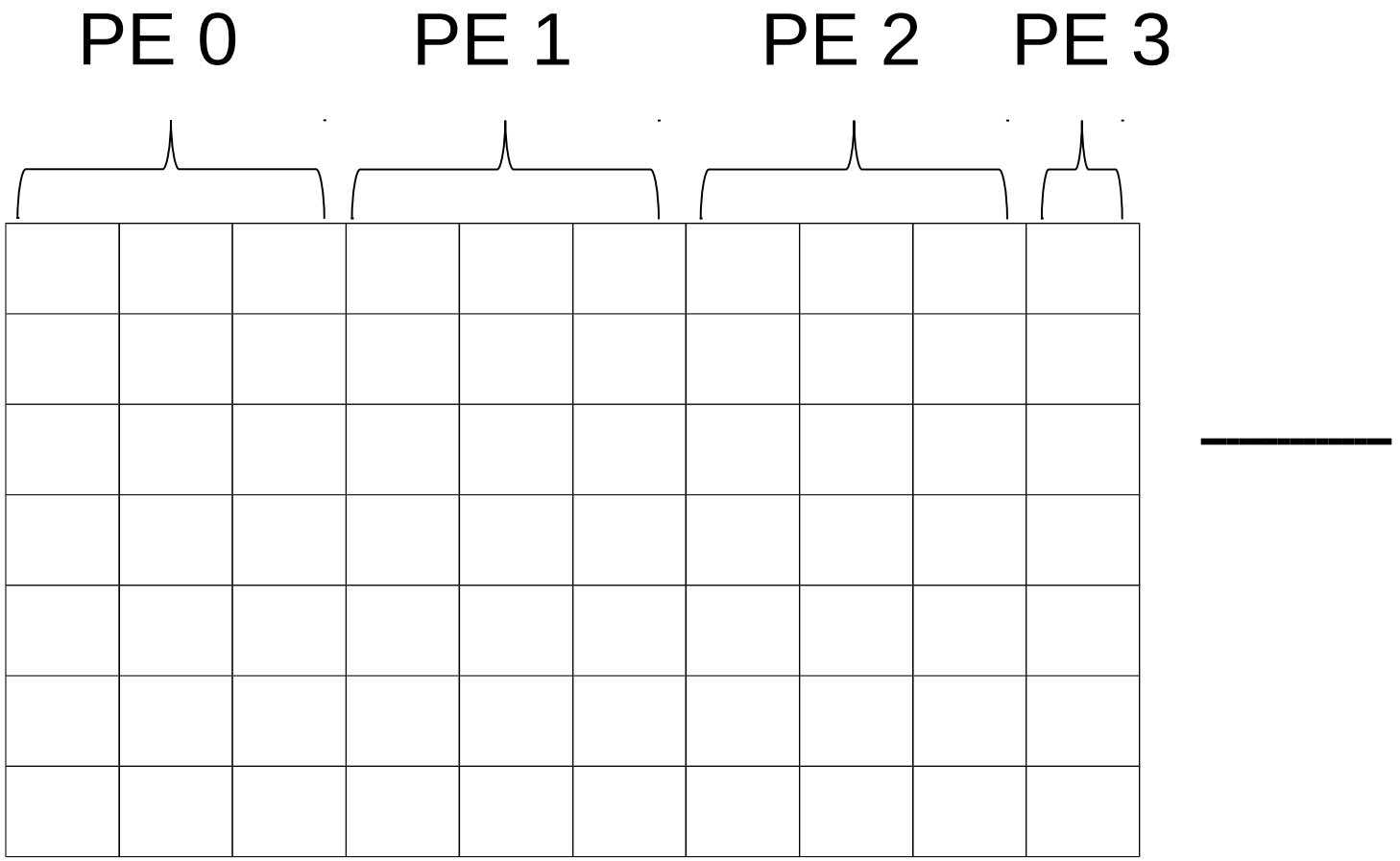
Scattering Columns of a Matrix

- Since C stores multi-dimensional arrays in row-major order, scattering rows of a matrix is easy



Scattering Columns of a Matrix

- What if we want to scatter columns?



Scattering Columns of a Matrix

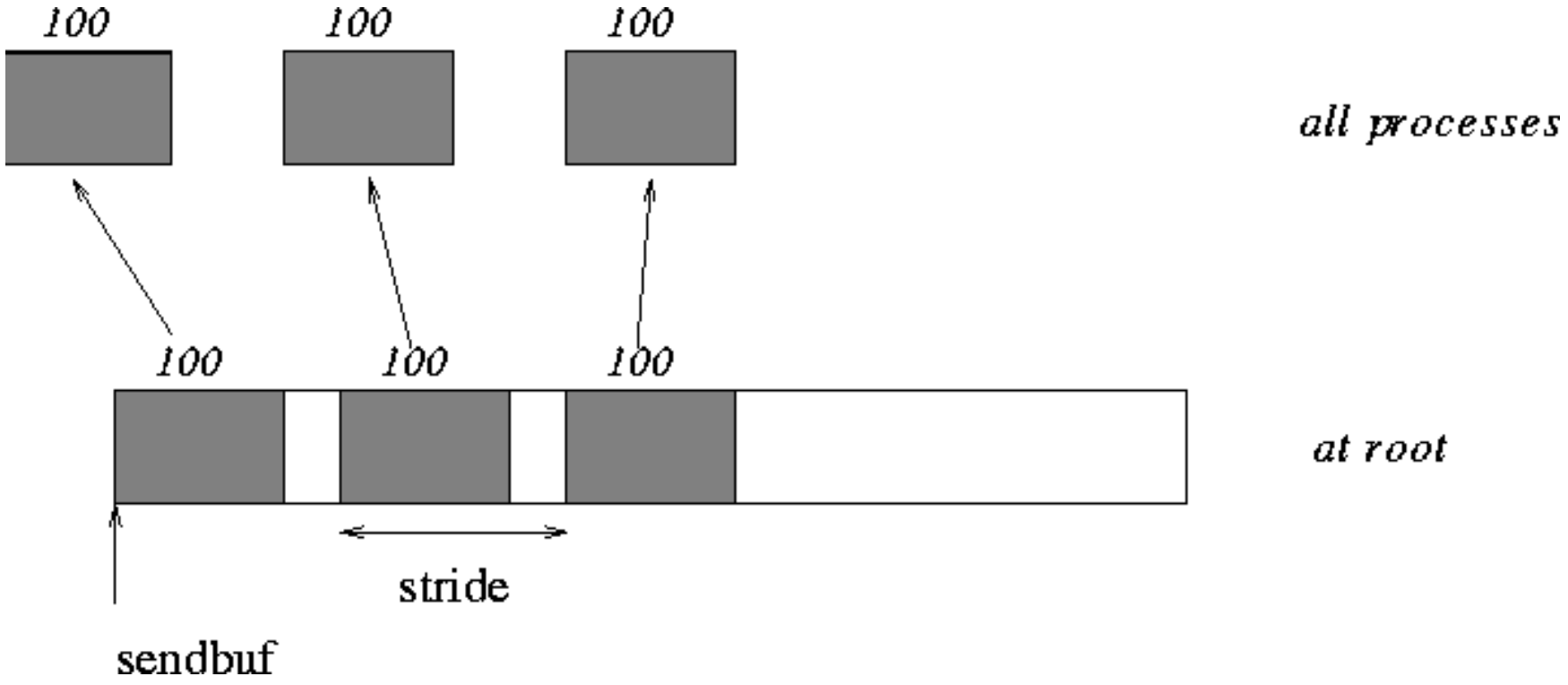
- Could use the MPI_Datatype and MPI_Type_vector features of MPI

OR

- An easier solution would be to transpose the matrix, then scatter the rows.

There is a version scatter called MPI_Scatterv, that can jump over parts of the array:

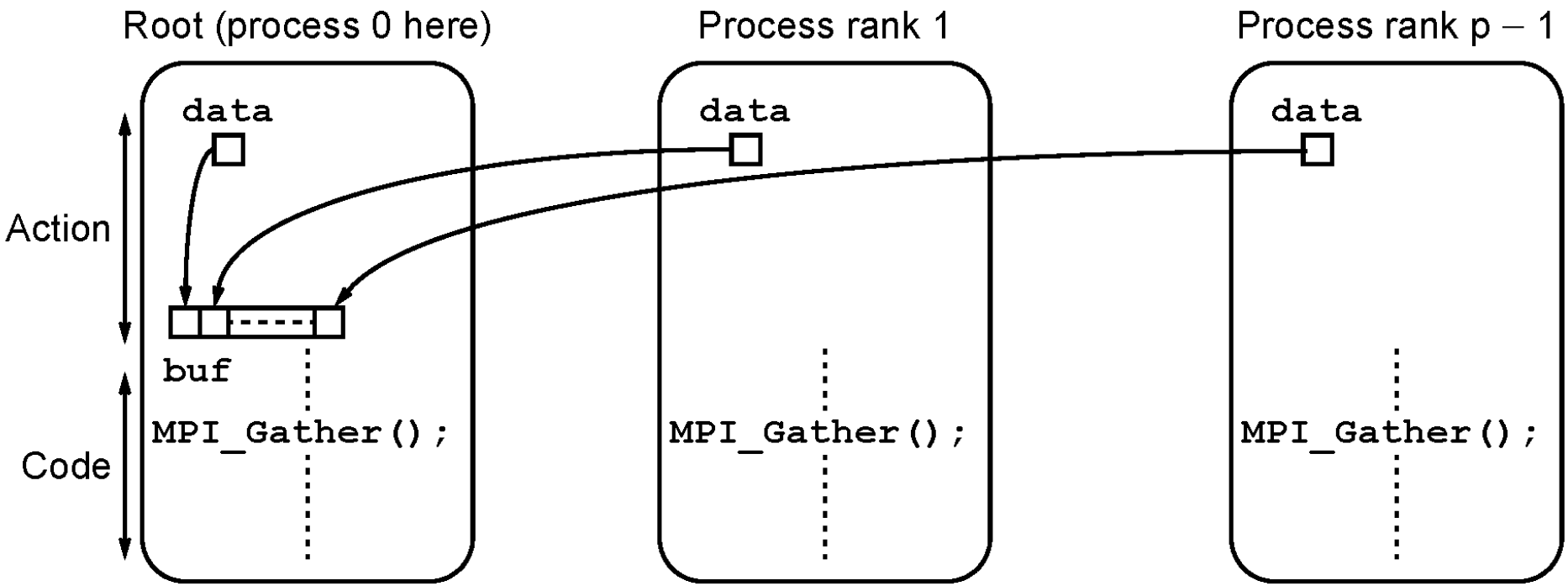
MPI_Scatterv Example



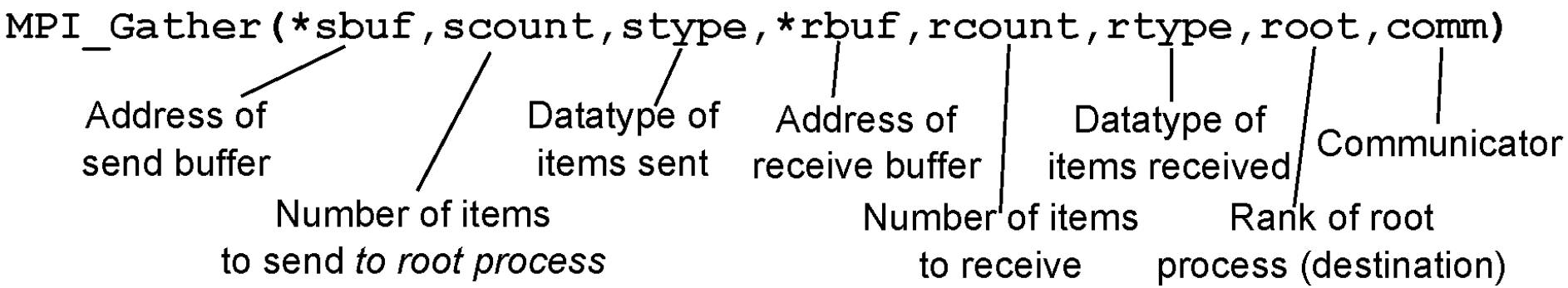
(source: http://www.mpi-forum.org)

Gather

Having one process collect individual values from set of processes.



Gather parameters



All processes in the Communicator must call the MPI_Gather with the same parameters

Gather Example

To gather items from group of processes into process 0, using dynamically allocated memory in root process:

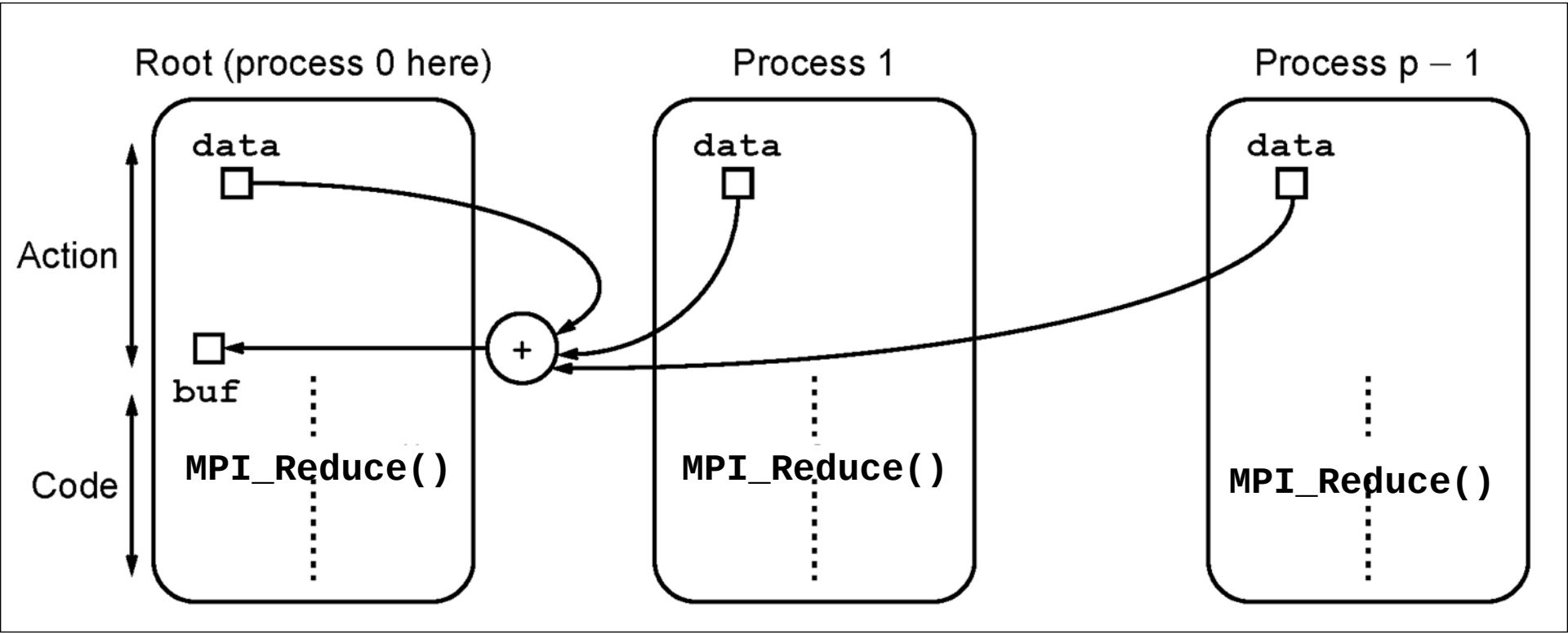
```
int data[10];                /*data to be gathered from processes*/
MPI_Comm_rank(MPI_COMM_WORLD, &myrank); /* find rank */
if (myrank == 0) {
       MPI_Comm_size(MPI_COMM_WORLD, &grp_size); /*find group
size*/
       buf = (int *)malloc(grp_size*10*sizeof (int)); /*alloc.
mem*/
}
MPI_Gather(data,10,MPI_INT,buf,grp_size*10,MPI_INT,0,MPI_COMM_WOR
LD) ;
…
```

`MPI_Gather()` gathers from all processes, including root.

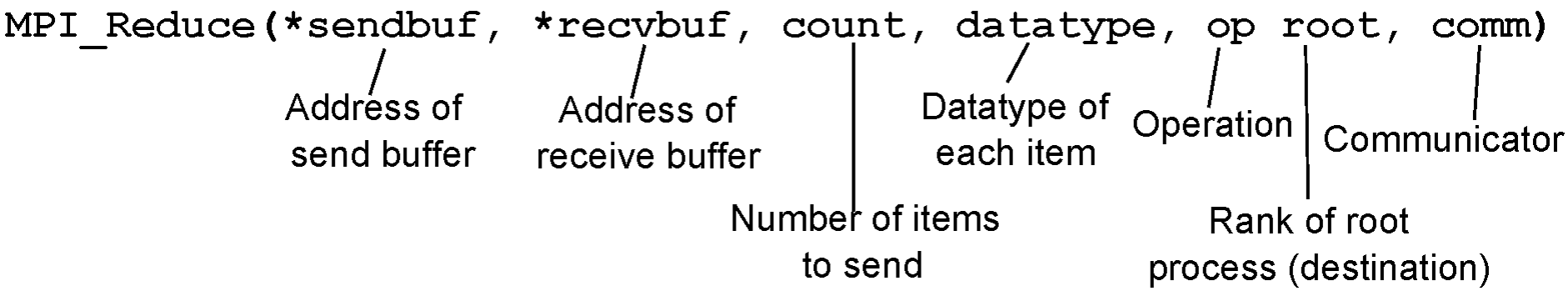
Reduce

Gather operation combined with specified arithmetic/logical operation.

Example: Values could be gathered and then added together by root:



Reduce parameters



All processes in the Communicator must call the MPI_Reduce with the same parameters

Reduce - operations

```
MPI_Reduce(*sendbuf,*recvbuf,count,datatype,op,root,comm)
```

Parameters:

`*sendbuf`	send buffer address
`*recvbuf`	receive buffer address
`count`	number of send buffer elements
`datatype`	data type of send elements
`op`	reduce operation. Several operations, including

`MPI_MAX`	Maximum
`MPI_MIN`	Minimum
`MPI_SUM`	Sum
`MPI_PROD`	Product

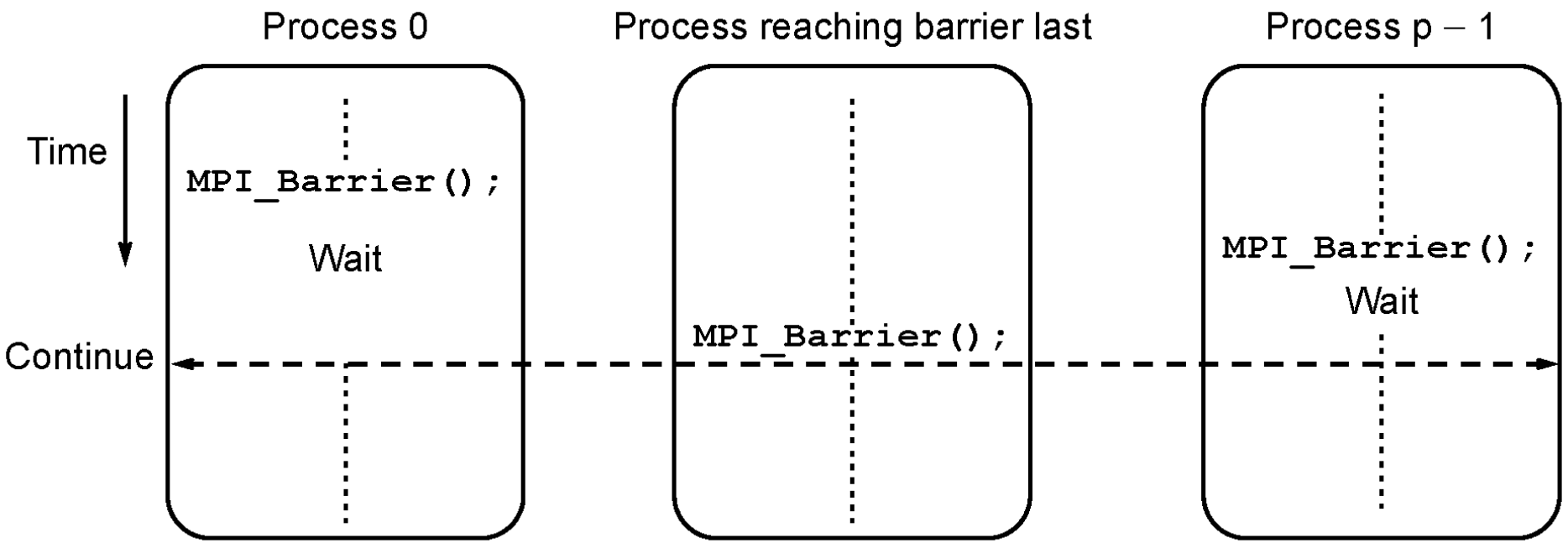
`root`	root process rank for result
`comm`	communicator

Barrier

Block process until all processes have called it.
Synchronous operation.

```
MPI_Barrier(comm)
```

Communicator



MPI_Barrier use with time stamps

A common example of using a barrier is to synchronize the processors before taking a time stamp.

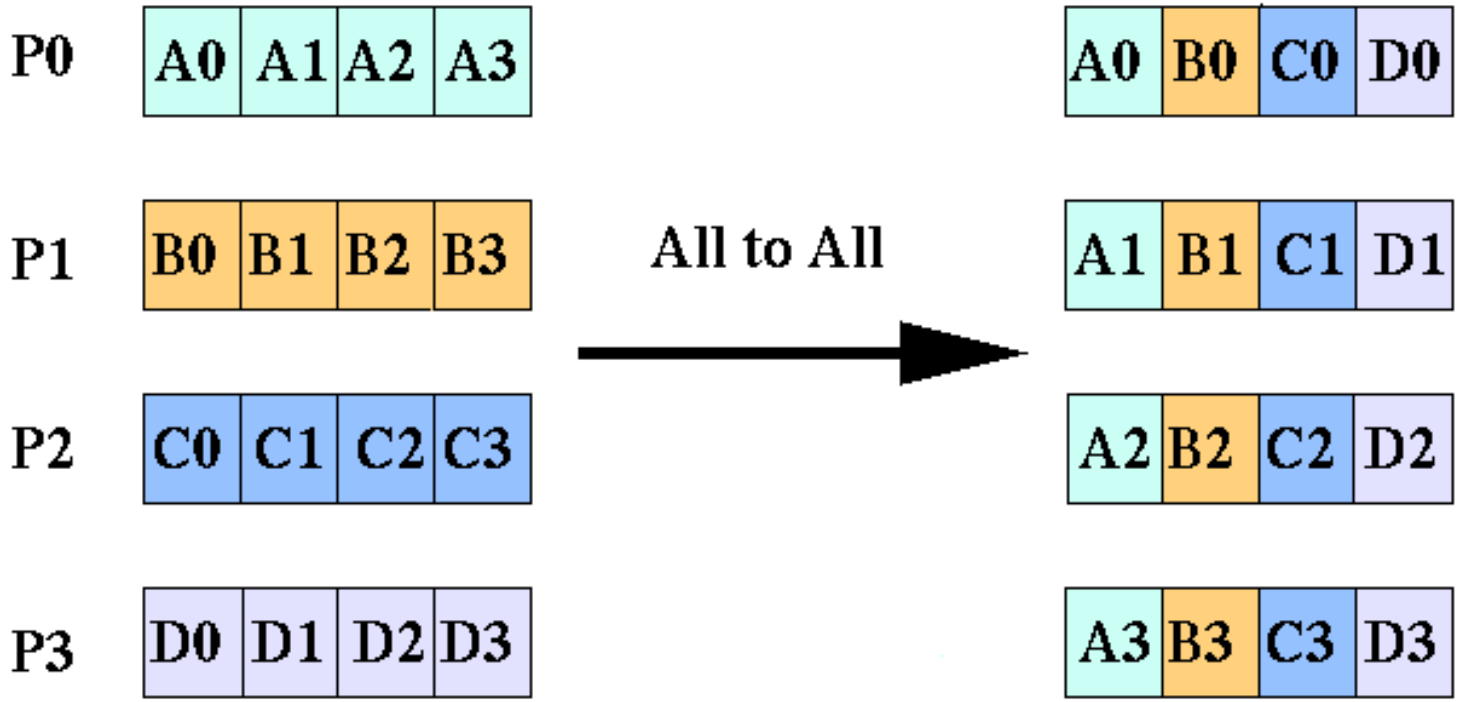
```
MPI_Barrier(MPI_COMM_WORLD);
start_time = MPI_Wtime();
…  \\ Do work
MPI_Barrier(MPI_COMM_WORLD);
end_time = MPI_Wtime();
```

2nd barrier not always needed if there is a gather

Once the root has the correct data, who cares what the other processes are doing. We have the answer.

MPI_AlltoAll

Combines multiple scatters:



This is essentially matrix transposition

MPI_AlltoAll parameters

int MPI_Alltoall (

void **sendbuf,*

int *sendcount*,

MPI_Datatype *sendtype*,

void **recvbuf*,

int *recvcount*,

MPI_Datatype *recvtype*,

MPI_Comm *comm* **);**

Synchronous Message Passing

Routines that return when message transfer completed.

Synchronous send routine

- Waits until complete message can be accepted by the receiving process before sending the message.

  In MPI, MPI_SSend() routine.

Synchronous receive routine

- Waits until the message it is expecting arrives.

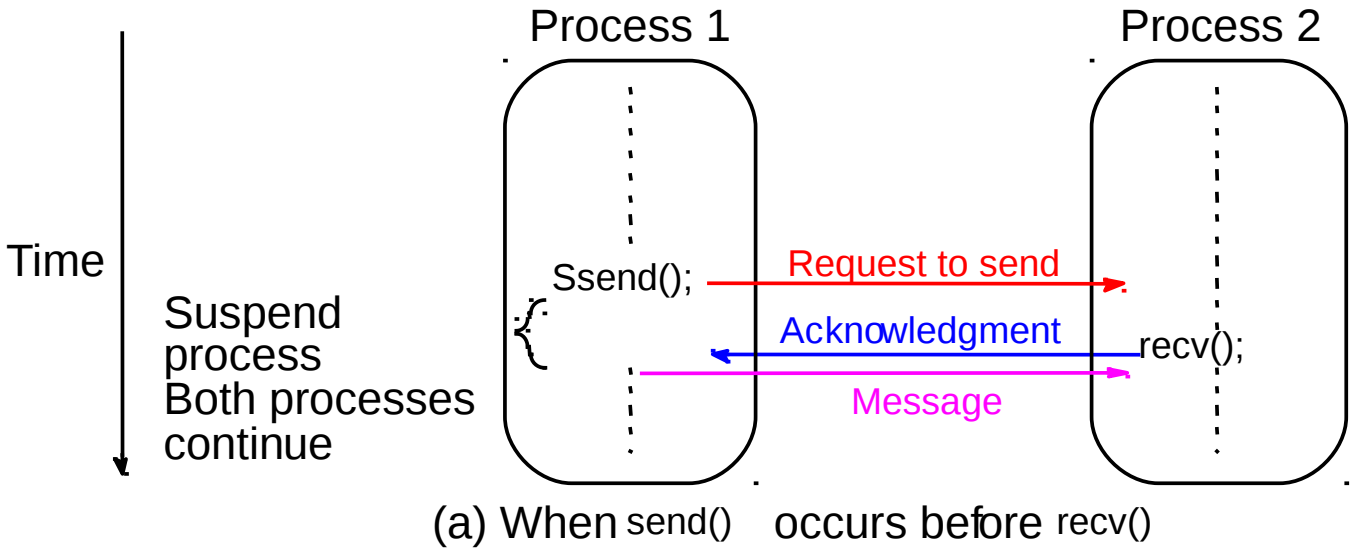
  In MPI, actually the regular MPI_recv() routine.

Synchronous Message Passing

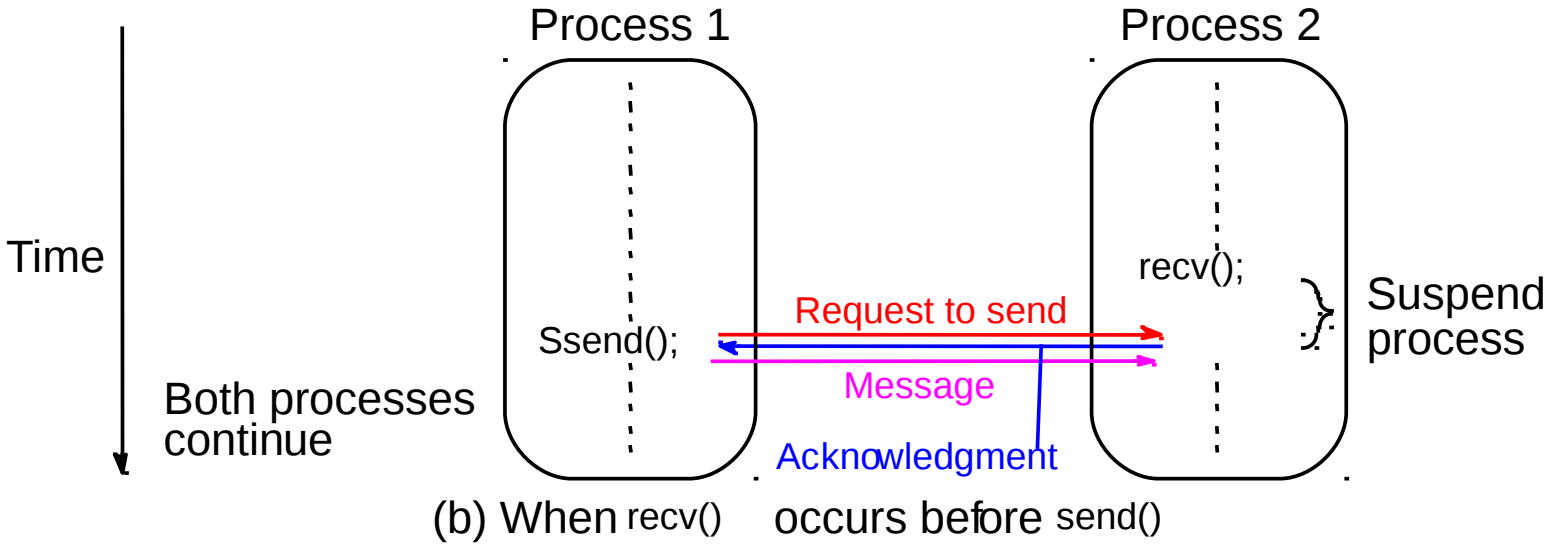
Synchronous message-passing routines intrinsically perform two actions:

- They transfer data and
- They synchronize processes.

Synchronous Ssend() and recv() using 3-way protocol

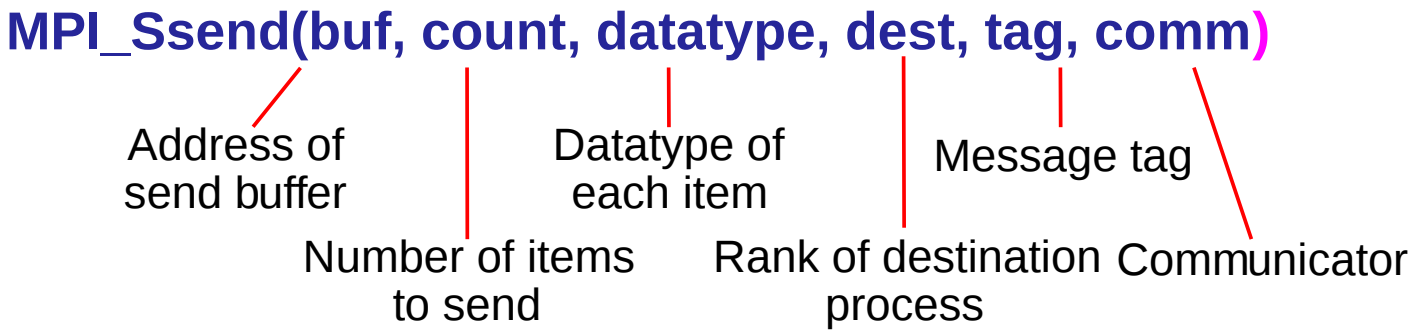


(a) When send() occurs before recv()



(b) When recv() occurs before send()

Parameters of synchronous send (same as blocking send)



Asynchronous Message Passing

- Routines that do not wait for actions to complete before returning. Usually require local storage for messages.
- More than one version depending upon the actual semantics for returning.
- In general, they do not synchronize processes but allow processes to move forward sooner.
- Must be used with care.

MPI Definitions of Blocking and Non-Blocking

- Blocking - return after their local actions complete, though the message transfer may not have been completed. Sometimes called locally blocking.

- Non-blocking - return immediately (*asynchronous*)

  Non-blocking assumes that data storage used for transfer not modified by subsequent statements prior to being used for transfer, and it is left to the programmer to ensure this.

  Blocking/non-blocking terms may have different interpretations in other systems.

MPI blocking routines
Block until local actions complete

- Blocking send - MPI_send() - blocks only until message is on its way. User can modify buffer after it returns.

- Blocking receive - MPI_recv() - blocks until message arrives

MPI Nonblocking Routines

- Non-blocking send - MPI_Isend() - will return "immediately" even before source location is safe to be altered.

- Non-blocking receive - MPI_Irecv() - will return even if no message to accept.

Nonblocking Routine Formats

```
MPI_Isend(buf,count,datatype,dest,tag,comm,request)
```

```
MPI_Irecv(buf,count,datatype,source,tag,comm, request)
```

Completion detected by **`MPI_Wait()`** and **`MPI_Test()`**.

`MPI_Wait()` waits until operation completed and returns then.

`MPI_Test()` returns with flag set indicating whether operation completed at that time.

Need to know whether particular operation completed.

Determined by accessing **`request`** parameter.

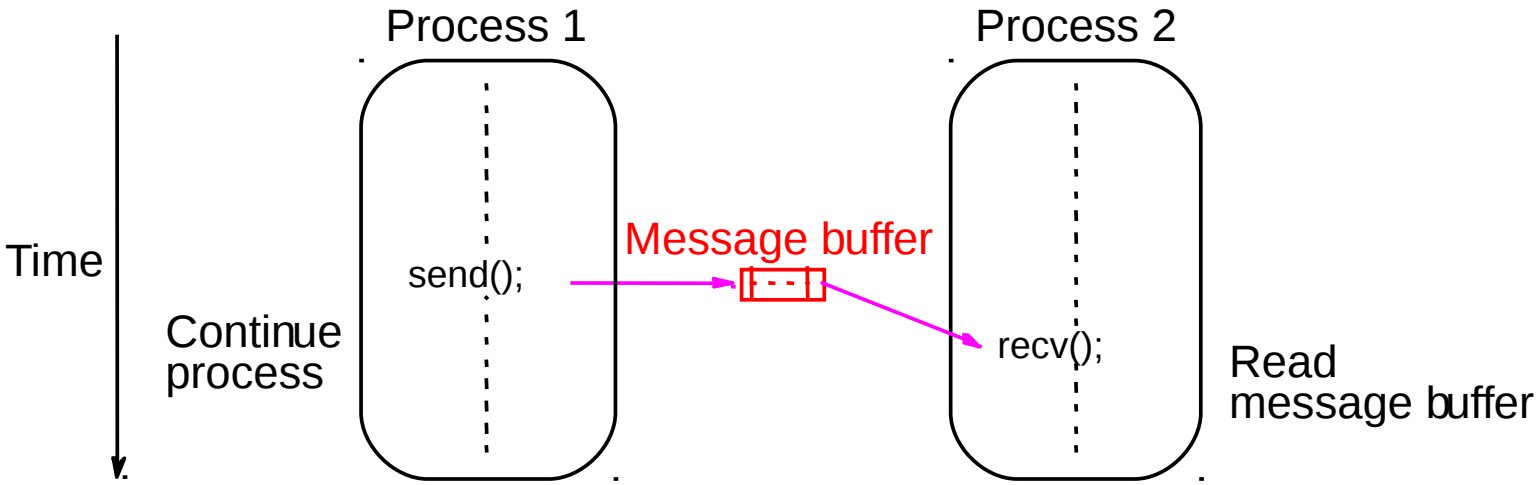
Example

To send an integer x from process 0 to process 1 and allow process 0 to continue:

```
MPI_Comm_rank(MPI_COMM_WORLD, &myrank); /* find rank */
if (myrank == 0) {
   int x;
   MPI_Isend(&x,1,MPI_INT, 1, msgtag, MPI_COMM_WORLD, req1);
   compute();
   MPI_Wait(req1, status);
} else if (myrank == 1) {
   int x;
   MPI_Recv(&x,1,MPI_INT,0,msgtag, MPI_COMM_WORLD, status);
}
```

How message-passing routines return before message transfer completed

Message buffer needed between source and destination to hold message:



Asynchronous (blocking) routines *changing to* synchronous routines

- Message buffers only of finite length
- A point could be reached when send routine held up because all available buffer space exhausted.
- Then, send routine will wait until storage becomes re-available - i.e. routine will behave as a synchronous routine.

That's it!