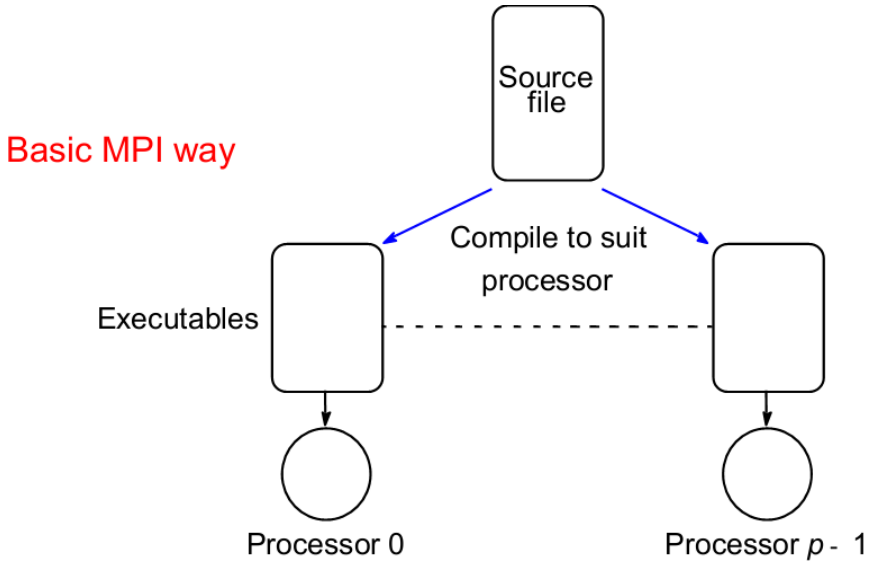
Message-Passing Computing and MPI

Message-Passing Programming using User-level Message-Passing Libraries

- Two primary mechanisms needed:
  1. A method of creating separate processes for execution on different computers
  2. A method of sending and receiving messages

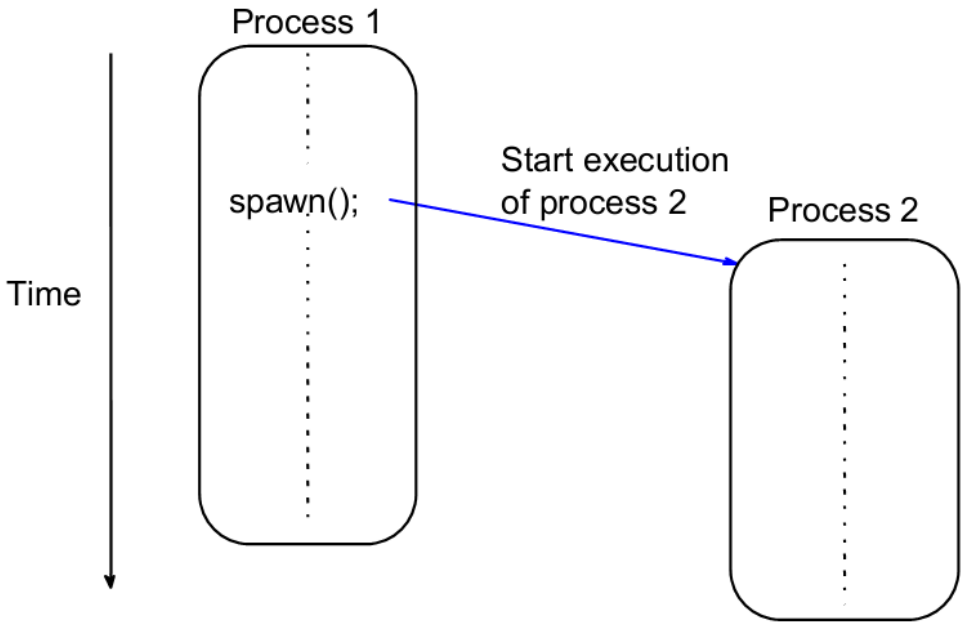
Single Program Multiple Data (SPMD) model

- Different processes merged into one program.
- Control statements select different parts for each processor to execute.
- All executables started together - **static process creation**



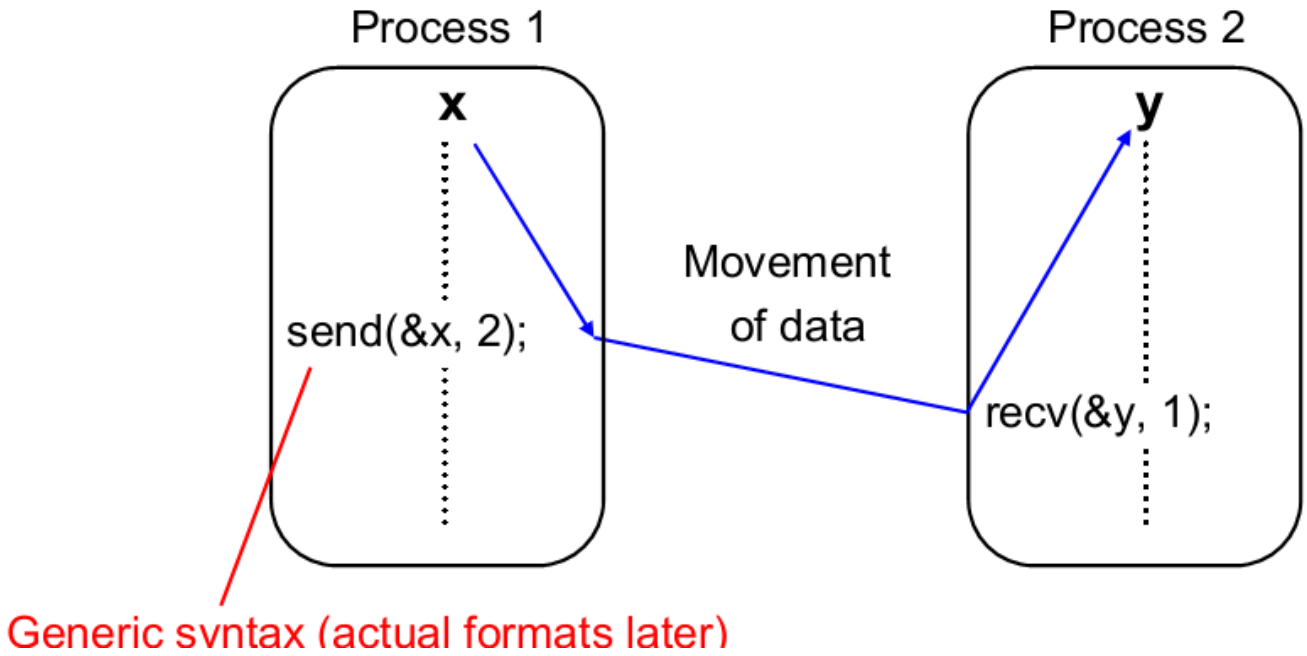
Multiple Program Multiple Data (MPMD) Model

- Separate programs for each processor.
- One processor executes master process.
- Other processes started from within master process - **dynamic process creation.**



Basic "point-to-point" Send and Receive Routines

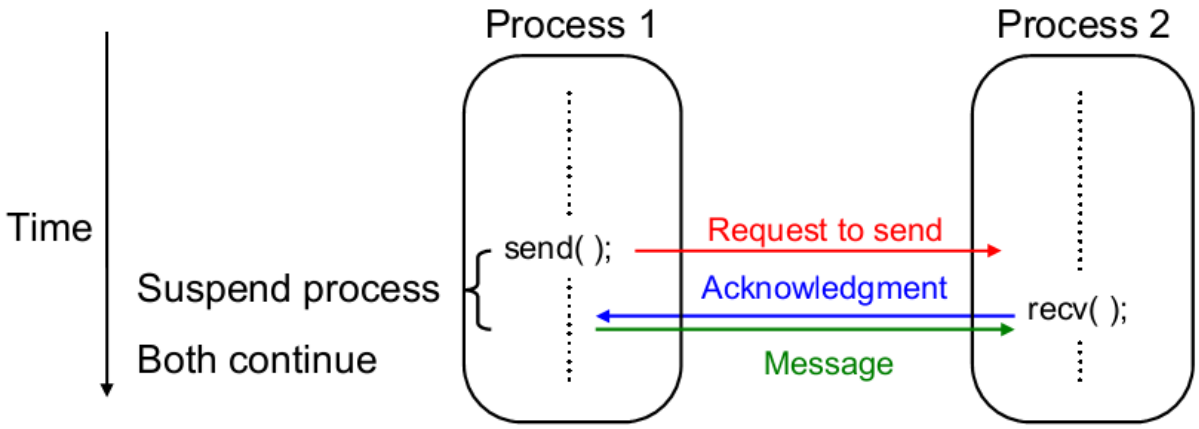
- Passing a message between processes using send() and recv() library calls:



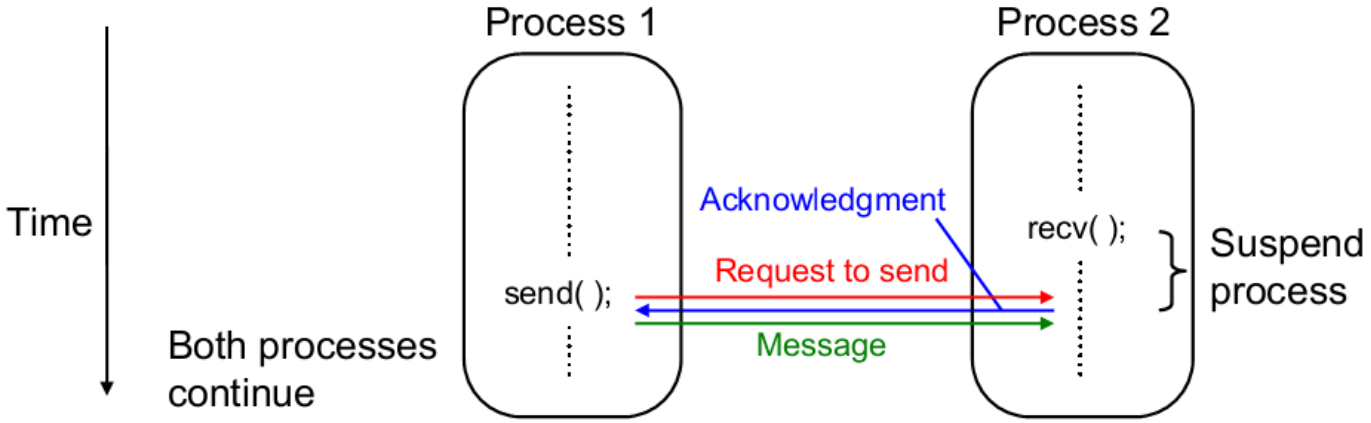
Synchronous Message Passing

- Routines that actually return when message transfer completed
  - Synchronous send routine
    - Waits until complete message can be accepted by the receiving process before sending the message
  - Synchronous receive routine
    - Waits until the message it is expecting arrives
- Synchronous routines intrinsically perform two actions:
  - transfer data and
  - synchronize processes

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



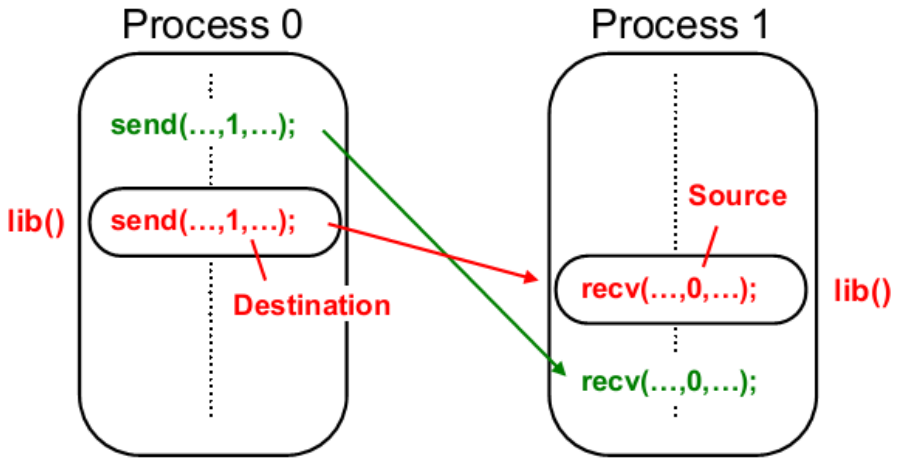
(a) When send() occurs before recv()



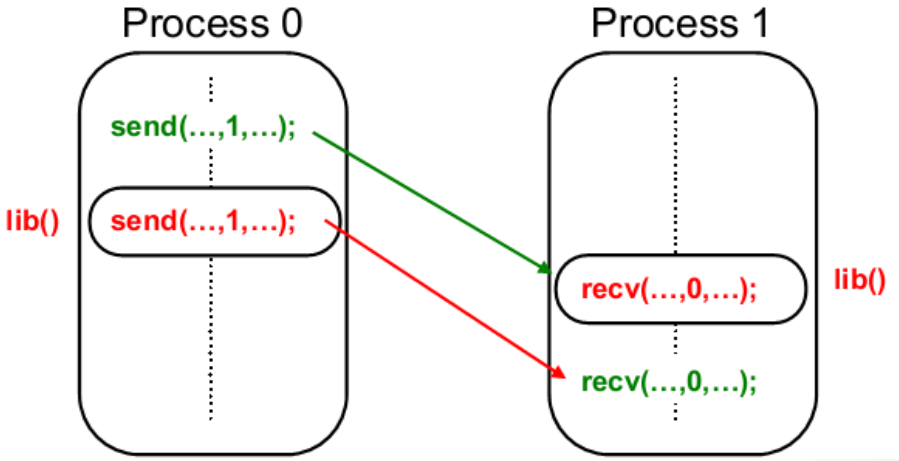
(b) When recv() occurs before send()

Unsafe message passing - Example

(a) Intended Behavior



(b) Runtime Behavior might mix user with library messages



Asynchronous Message Passing

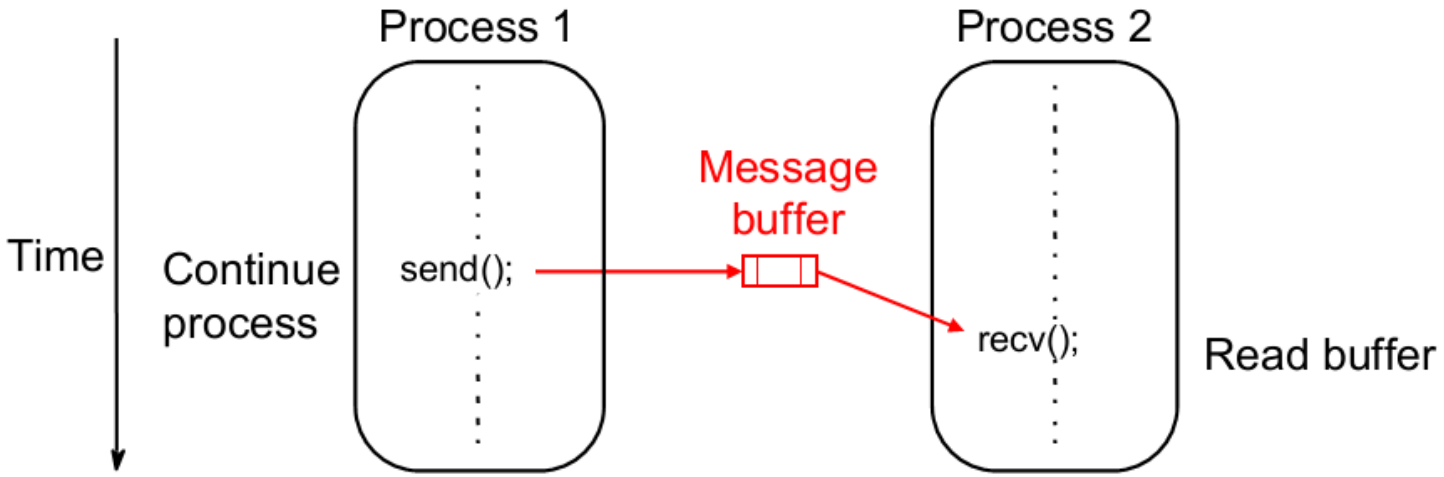
- Routines that do not wait for actions to complete before returning.
  - Usually require local storage for messages.
- More than one version depending upon the actual semantics for returning.
- In general, they do not synchronize processes but allow processes to move forward sooner.
- Must be used with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

MPI Definitions of Blocking and Non-Blocking

- **Blocking**- return after their local actions complete, though the message transfer may not have been completed.
- **Non-blocking**- return immediately.
  - 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.
- These terms may have different interpretations in other systems.

How message-passing routines return before message transfer completed

- Message buffer needed between source and destination to hold message:



Asynchronous routines changing to synchronous routines

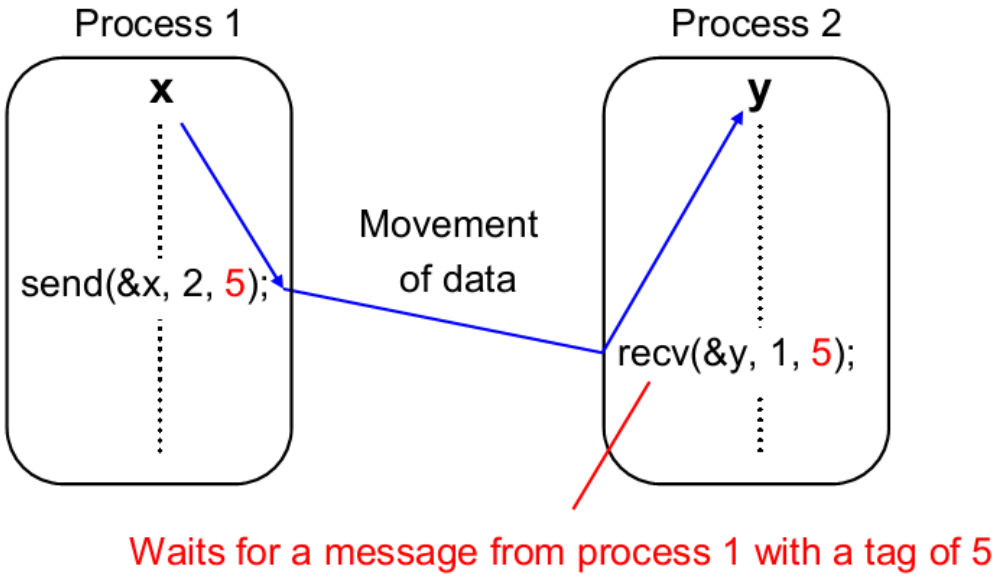
- Once local actions completed and message is safely on its way, sending process can continue with subsequent work.
- Buffers are only of finite length and a point could be reached when send routine held up because all available buffer space exhausted.
- Then, send routine will wait until storage becomes re-available - i.e then routine behaves as a synchronous routine.

Message Tag

- Used to differentiate between different types of messages being sent.
- Message tag is carried within message.
- If special type matching is not required, a wild card message tag is used with recv(), so that it will match with any send().

Message Tag 2

- Example
  - To send a message, x, with message tag 5 from a source process, 1, to a destination process, 2, and assign to y:

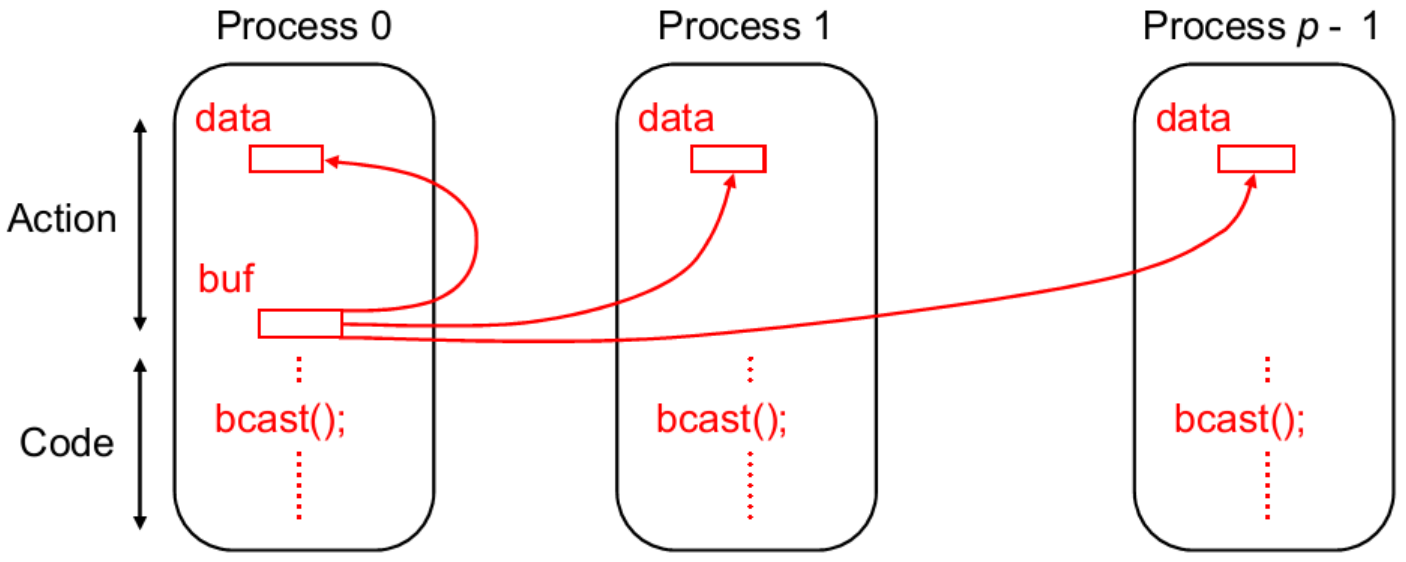


“Group” message passing routines

- 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 not absolutely necessary depending on implementation

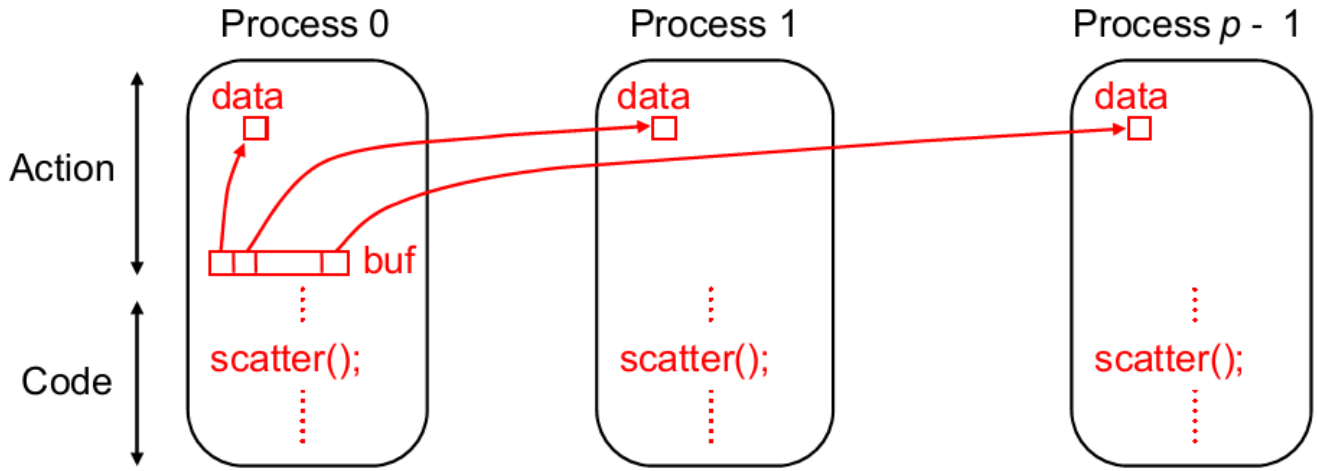
Broadcast

- Sending same message to all processes including the root (the sender) process
- Multicast - sending same message to a defined group of processes



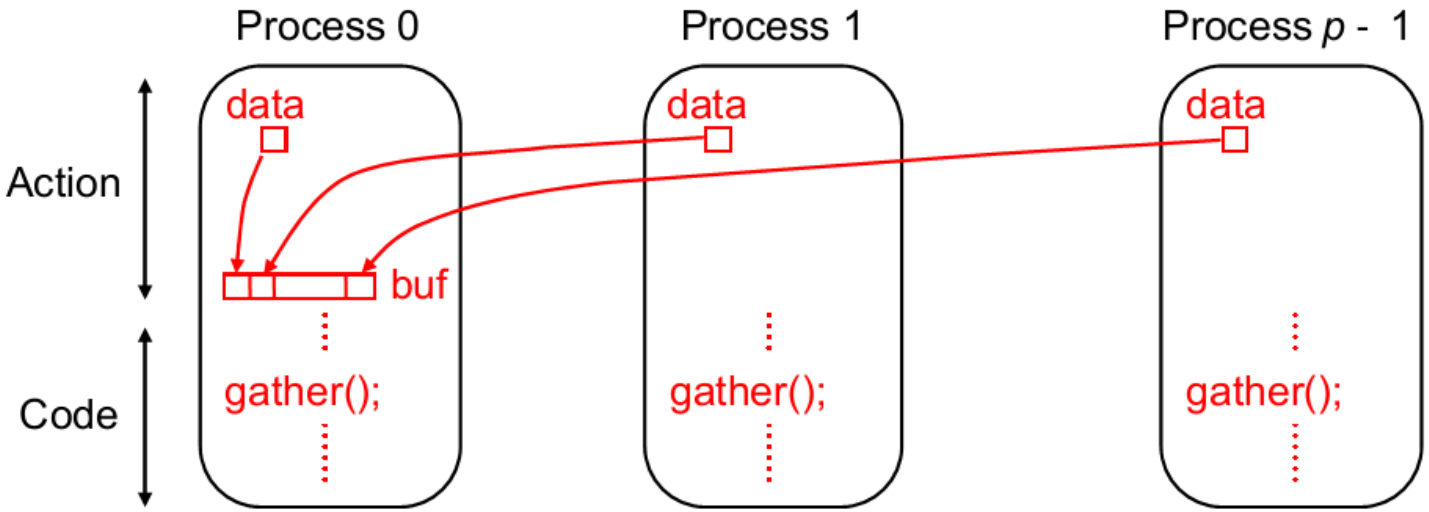
Scatter

- 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.



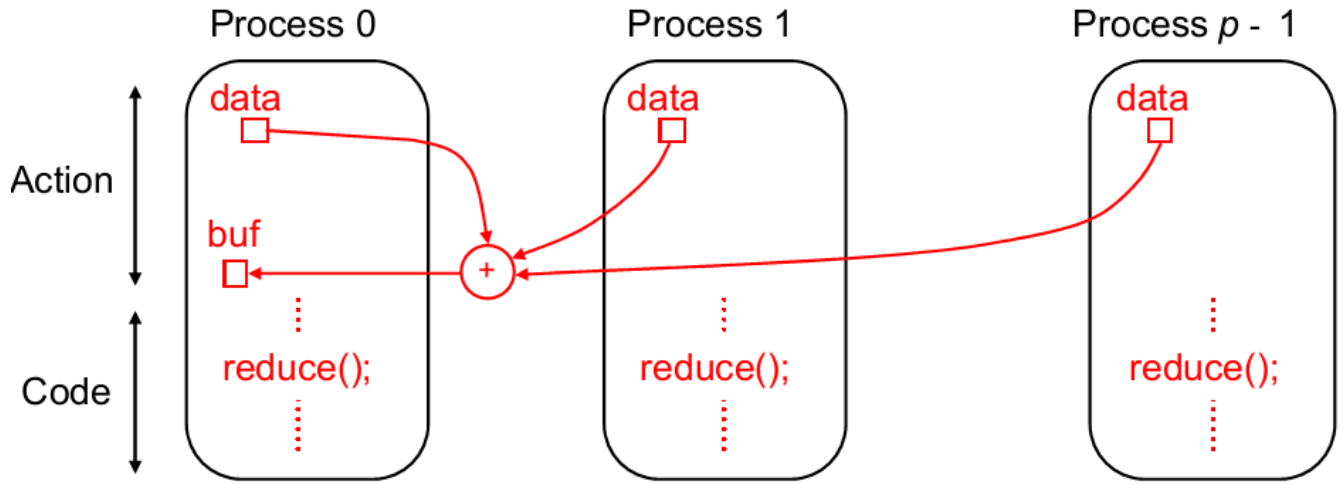
Gather

- Having one process collect individual values from a set of processes.



Reduce

- Gather operation combined with specified arithmetic/logical operation.
- Alternative Action: values could be gathered and then added together by root



MPI (Message Passing Interface)

- Message passing library standard developed by group of academics and industrial partners to foster more widespread use and portability
- Defines routines, not implementation
  - MPI 1 defined 120+ functions (MPI 2 added more)
  - Only need few (about 20)to write programs
  - All MPI routines start with the prefix **MPI_** (C version)
- Several free implementations exist
  - MPICH Argonne National Laboratory
  - LAM/MPI Ohio Supercomputing Center

MPI Process Creation and Execution

- Purposely not defined - Will depend upon implementation.
- Only static process creation supported in MPI version 1.
- All processes must be defined prior to execution and started together.
- Originally SPMD model of computation.
- MPMD also possible with static creation - each program to be started together specified.

MPI Solution: Communicators

- Defines a communication domain - a set of processes that are allowed to communicate between themselves.
- Communication domains of libraries can be separated from that of a user program.
- Used in all point-to-point and collective MPI message-passing communications.

Communicators

- Defines scope of a communication operation.
- Processes have ranks associated with communicator.
- Initially, all processes enrolled in a “universe” called MPI_COMM_WORLD, and each process is given a unique rank number from 0 to p- 1, with *p* processes.
- Other communicators can be established for groups of processes.

Using SPMD Computational Model

```
main (int argc, char *argv[]) {

        MPI_Init(&argc, &argv);
                .
                .
        MPI_Comm_rank(MPI_COMM_WORLD, &myrank); /*find process rank */

        if (myrank == 0)
                master();
        else
                slave();
                .
                .
        MPI_Finalize();
}
```

where master() and slave() are to be executed by master process and slave processes, respectively.

Initializing and Ending MPI

- Initialize MPI Environment

  MPI_Init(&argc, &argv)

  Before calling any MPI function

  argc is the argument count (main function)

  argv is the argument vector (main function)

- Terminate MPI execution environment

  MPI_Finalize( )

MPI Point-to-Point Communication

- Uses send and receive routines with message tags as well as communicator
- Wild card message tags available
- MPI Blocking Routines
  - Return when “locally complete” - when location used to hold message can be used again or altered without affecting message being sent.
  - Blocking send will send message and return -does not mean that message has been received, just that process free to move on without adversely affecting message.

Blocking send and receive

- Send

  MPI_Send(buf, count, datatype, dest, tag, comm)

void*	buf	Address of send buffer
Int	count	Number of items to send
MPI_Datatype	datatype	Datatype of each item
int	dest	Rank of destination process
int	tag	Message tag
MPI_Comm	comm	Communicator

- Receive

  MPI_Recv(buf, count, datatype, src, tag, comm, status)

void*	buf	Address of receive buffer (loaded)
Int	count	Max number of items to receive
MPI_Datatype	datatype	Datatype of each item
Int	src	Rank of source process
Int	tag	Message tag
MPI_Comm	comm	Communicator
MPI_Status*	status	Status after operation (returned)

Wildcards and Status in MPI_Recv

- MPI_ANY_SOURCE matches any source
- MPI_ANY_TAG matches any tag
- Status is a return value
  - status -> MPI_SOURCE rank of source
  - status -> MPI_TAG tag of message
  - status -> MPI_ERROR potential errors

Wildcards and Status in MPI_Recv

- Example
  - To send an integer x from process 0 to process 1

```
int myrank;
int tag = 0;
int x;
MPI_Comm_rank(MPI_COMM_WORLD, &myrank); /* find rank */

if (myrank == 0) {
   /* input some value for x */
   MPI_Send(&x, 1, MPI_INT, 1, tag, MPI_COMM_WORLD);
}
else if (myrank == 1) {
   MPI_Recv(&x, 1, MPI_INT, 0, tag, MPI_COMM_WORLD, status);
   . . .
}
```

Some Predefined MPI Datatypes

MPI datatype	C datatype
MPI_CHAR	signed char
MPI_SHORT	signed short int
MPI_INT	signed int
MPI_UNSIGNED_CHAR	unsigned char
MPI_UNSIGNED_SHORT	unsigned short int
MPI_UNSIGNED	unsigned int
MPI_FLOAT	float
MPI_DOUBLE	double

Process Rank and Group Size

- MPI_Comm_rank(comm, rank)
  - returns rank of calling process
- MPI_Comm_size(comm, size)
  - returns size of group within comm

MPI_Comm	comm	communicator
int*	rank	process rank (returned)
int*	size	size of group (returned)

MPI Non-Blocking 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.
- The 'I' in 'Isend' and 'Irecv' means Immediate

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

MPI_Irecv(buf, count, datatype,src, tag, comm, request)

void*	buf	Address of buffer
Int	count	number of items to send/receive
MPI_Datatype	datatype	Datatype of each item
Int	dest/src	Rank of destination/source process
Int	tag	Message tag
MPI_Comm	comm	Communicator
MPI_Request*	request	Request handle (returned)

Completion Detection

- Completion detected by MPI_Wait()and MPI_Test()

MPI_Wait(request, status)

Wait until operation completes and then return

MPI_Test(request, flag, status)

Test for completion of a non-blocking operation

MPI_Request *	request	request handle
MPI_Status *	status	same as return status of MPI_Recv()
int * (returned)	flag	true if operation completed

Example

- Send an integer x from process 0 to process 1 and allow process 0 to continue

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

Send Communication Modes

- **Standard Mode Send** - Not assumed that corresponding receive routine has started. Amount of buffering not defined by MPI. Ifbuffering provided, send could complete before receive reached.
- **Buffered Mode**- Send may start and return before a matching receive. Necessary to specify buffer space via routine MPI_Buffer_attach().
- **Synchronous Mode**- Send and receive can start before each other but can only complete together.
- **Ready Mode**- Send can only start if matching receive already reached, otherwise error. Use with care.

Send Communication Modes – cont'd

- Each of the four modes can be applied to both blocking and non-blocking send routines.

MPI_Send()	MPI_Isend()	Standard send
MPI_Bsend()	MPI_Ibsend()	Buffered send
MPI_Ssend()	MPI_Issend()	ynchronous send
MPI_Rsend()	MPI_Irsend()	Ready send

- Only the standard mode is available for the blocking and non-blocking receive routines.
- Any type of send routine can be used with any type of receive routine.

Collective Communication

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

MPI_Bcast (buf, count, datatype, root, comm)

- Broadcast message from root to all processes in comm and to itself

MPI_Scatter (sendbuf, sendcount, sendtype, recvbuf, recvcount, recvtype, root, comm)

- Scatter a buffer from root in parts to group of processes

MPI_Gather (sendbuf, sendcount, sendtype,recvbuf, recvcount, recvtype, root, comm)

- Gather values for group of processes including root

Collective Communication – Cont'd

MPI_Alltoall (sendbuf, sendcount, sendtype, recvbuf, recvcount, recvtype, comm)

- Send data from all processes to all processes

MPI_Reduce(sendbuf, recvbuf, count, datatype, operation, root, comm)

- Combines values on all processes to a single value at root

MPI_Scan (sendbuf, recvbuf, count, datatype, operation, comm)

- Computes the partial reductions ofdata on a collection of processes

MPI_Barrier(comm)

- Block process until all processes have called it

Sample MPI program

```
#include <mpi.h>
#include <stdio.h>
#include <math.h>
#define MAXSIZE 100000
void main(int argc, char *argv)
{
    int myid, numprocs;
    int data[MAXSIZE], i, x, low, high, myresult, result;
    char fn[255];
    char *fp;
    MPI_Init(&argc, &argv);
    MPI_Comm_size(MPI_COMM_WORLD,&numprocs);
    MPI_Comm_rank(MPI_COMM_WORLD,&myid);
    if (myid == 0) {  /* Open input file and initialize data */
          strcpy(fn, getenv("HOME"));
          strcat(fn, "/MPI/rand_data.txt");
          if ((fp = fopen(fn, "r")) == NULL) {
                printf("Can't open the input file: %s\n\n", fn);
                exit(1);
          }
          for(i = 0; i < MAXSIZE; i++) fscanf(fp,"%d", &data[i]);
    }
```

Sample MPI program – cont'd

Can you guess what this program is doing?

```
  /* broadcast data */
  MPI_Bcast(data, MAXSIZE, MPI_INT, 0, MPI_COMM_WORLD);
  /* Add my portion of data */
  x = n/nproc;
  low = myid * x;
  high = low + x;
  for(i = low; i < high; i++)
       myresult += data[i];
  printf("I got %d from %d\n", myresult, myid);
  /* Compute global sum */
  MPI_Reduce(&myresult, &result, 1, MPI_INT, MPI_SUM, 0,
             MPI_COMM_WORLD);
  if (myid == 0) printf("The sum is %d.\n", result);
  MPI_Finalize();
}
```