Lecture 3 Message-Passing Programming Using MPI (Part 2)

Non-blocking Communication

- Advantages:

  -- allows the separation between the initialization of the communication and the completion.

  -- can avoid deadlock

  -- can reduce latency by posting receive calls early

- Disadvantages:

  -- complex to develop, maintain and debug code

Non-block Send/Recv Syntax

- int MPI_Isend(void* message /* in */,
  int count /* in */,
  MPI_Datatype datatype /* in */,
  int dest /* in */,
  int tag /* in */,
  MPI_Comm comm /* in */,
  MPI_Request* request /* out */)

- int MPI_Irecv(void* message /* out */,
  int count /* in */,
  MPI_Datatype datatype /* in */,
  int source /* in */,
  int tag /* in */,
  MPI_Comm comm /* in */,
  MPI_Request* request /* out */)

Non-blocking Send/Recv Details

- Non-blocking operation requires a minimum of two function calls: a call to start the operation and a call to complete the operation.
- The "request" is used to query the status of the communicator or to wait for its completion.
- The user must NOT overwrite the send buffer until the send (data transfer) is complete.
- The user can not use the receiving buffer before the receive is complete.

Non-blocking Send/Recv Communication Completion

- Completion of a non-blocking send operation means that the sender is now free to update the send buffer "message".
- Completion of a non-blocking receive operation means that the receive buffer "message" contains the received data.

```
int MPI_Wait(MPI_Request*     request /* in-out */,
             MPI_Status*      status /* out */)
```

```
int MPI_Test(MPI_Request*    request /* out */,
             int*            flag /* out*/,
             MPI_Status*     status /* out */)
```

Details of Wait/Test

- "request" is used to identify a previously posted send/receive
- MPI_Wait() returns when the operation is complete, and the status is updated for a receive.
- MPI_Test() returns immediately, with "flag" = true if posted operation corresponding to the "request" handle is complete.

Non-blocking Send/Recv Example

```
#include <stdio.h>
#include "mpi.h"
int main(int argc, char** argv)
{

      int my_rank, nprocs, recv_count;
      MPI_Request  request;
      MPI_Status status;
      double s_buf[100], r_buf[100];

      MPI_Init(&argc, &argv);
      MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
      MPI_Comm_size(MPI_COMM_WORLD, &nprocs);

      if (my_rank==0){
           MPI_Irecv(r_buf, 1oo, MPI_DOUBLE, 1, 22, MPI_COMM_WORLD, &request);
           MPI_Send(s_buf, 100, MPI_DOUBLE, 1, 10, MPI_COMM_WORLD);
           MPI_Wait(&request, &status);
      }
      else if(my_rank == 1){
           MPI_Irecv(r_buf, 1oo, MPI_DOUBLE, 0, 10, MPI_COMM_WORLD, &request);
           MPI_Send(s_buf, 100, MPI_DOUBLE, 0, 22, MPI_COMM_WORLD);
           MPI_Wait(&request, &status);
      }
      MPI_Get_count((&status, MPI_DOUBLE, &recv_count);
      printf("proc %d, source %d, tag %d, count %d\n", my_rank,
            status.MPI_SOURCE, status.MPI_TAG, recv_count);
     MPI_Finalize();
}
```

Use MPI_Isend (not Safe to Change the Buffer)

```
#include <stdio.h>
#include "mpi.h"
int main(int argc, char** argv)
{

      int my_rank, nprocs, recv_count;
      MPI_Request  request;
      MPI_Status status;
      double s_buf[100], r_buf[100];

      MPI_Init(&argc, &argv);
      MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
      MPI_Comm_size(MPI_COMM_WORLD, &nprocs);

      if (my_rank==0){
           MPI_Isend(s_buf, 100, MPI_DOUBLE, 1, 10, MPI_COMM_WORLD, &request);
           MPI_Recv(r_buf, 1oo, MPI_DOUBLE, 1, 22, MPI_COMM_WORLD, &status);
           MPI_Wait(&request, &status);
      }
      else if(my_rank == 1){
           MPI_Isend(s_buf, 100, MPI_DOUBLE, 0, 22, MPI_COMM_WORLD, &request);
           MPI_Recv(r_buf, 1oo, MPI_DOUBLE, 0, 10, MPI_COMM_WORLD, &status);
           MPI_Wait(&request, &status);
      }
      MPI_Get_count((&status, MPI_DOUBLE, &recv_count);
      printf("proc %d, source %d, tag %d, count %d\n", my_rank,
            status.MPI_SOURCE, status.MPI_TAG, recv_count);
     MPI_Finalize();
}
```

More about Communication Modes

Send Modes	MPI function	Completion Condition
Synchronous send	MPI_Ssend() MPI_Issend()	A send will not complete until a matching receive has been posted and the matching receive has begun reception of the data.
Buffered send (It has additional associated functions. The send operation is **local**.)	MPI_Bsend() MPI_Ibsend()	Bsend() always completes (unless an error occurs) Completion is irrespective of the receiver.
****Standard send**	MPI_Send() MPI_Isend()	message sent (no guarantee that the receive has started). It is up to MPI to decide what to do.
Ready send	MPI_Rsend() MPI_Irsend()	may be used only when the a matching receive has already been posted

http://www.mpi-forum.org/docs/mpi-11-html/node40.html#Node40

http://www.mpi-forum.org/docs/mpi-11-html/node44.html#Node44

- MPI_Ssend()
  - -- synchronization of source and destination
  - -- the behavior is predictable and safe
  - -- recommend for debugging purpose
- MPI_Bsend()
  - -- only do copy message to buffer
  - -- completes immediately
  - -- predictable behavior and no synchronization
  - -- user must allocate extra buffer space by MPI_Buffer_attach()
- MPI_Rsend()
  - -- completes immediately
  - -- will succeed only if a matching receive is already posted
  - -- if receiving process is not ready, action is undefined.
  - -- may improve performance

“**Recommendations**: In general, use MPI_Send. If non-blocking routines are necessary, then try to use MPI_Isend or MPI_Irecv. Use MPI_Bsend only when it is too inconvenient to use MPI_Isend. The remaining routines, MPI_Rsend, MPI_Issend, etc., are rarely used but may be of value in writing system-dependent message-passing code entirely within MPI.” --- http://www.mcs.anl.gov/research/projects/mpi/sendmode.html

Buffered Mode

- Standard Mode – If buffer is provided, amount of buffering is not defined by MPI
- Buffered Mode - Send may start and return before a matching receive. Necessary to specify buffer space via routine MPI_Buffer_attach().

```
int MPI_Buffer_attach(void *buffer, int size)
int MPI_Buffer_detach(void *buffer, int *size)
```

- The buffer size given should be the sum of the sizes of all outstanding MPI_Bsends, plus MPI_BSEND_OVERHEAD for each MPI_Bsend that will be done.

- MPI_Buffer_detach() returns the buffer address and size so that nested libraries can replace and restore the buffer.

MPI collective Communications

- Routines that allow groups of processes to communicate.
- Classification by Operation:
  - One-To-All Mode
    - One process contributes to the results. All processes receive the result.
    - MPI_Bcast()
    - MPI_Scatter(), MPI_Scatterv()
  - All-To-One Mode
    - All processes contribute to the result. One process receive the result.
    - MPI_Gather(), MPI_Gatherv()
    - MPI_Reduce()
  - All-To-All Mode
    - All processes contribute to the result. All processes receive the result.
    - MPI_Alltoall(), MPI_Alltoallv()
    - MPI_Allgather(), MPI_Allgatherv()
    - MPI_Allreduce(), MPI_Reduce_scatter()
  - Other
    - Collective operations that do not fit into above categories
    - MPI_Scan()
    - MPI_Barrier()

Barrier Synchronization

MPI_Barrier(MPI_Comm comm)

- This routine provides the ability to block the calling process until all processes in the communicator have reached this routine.

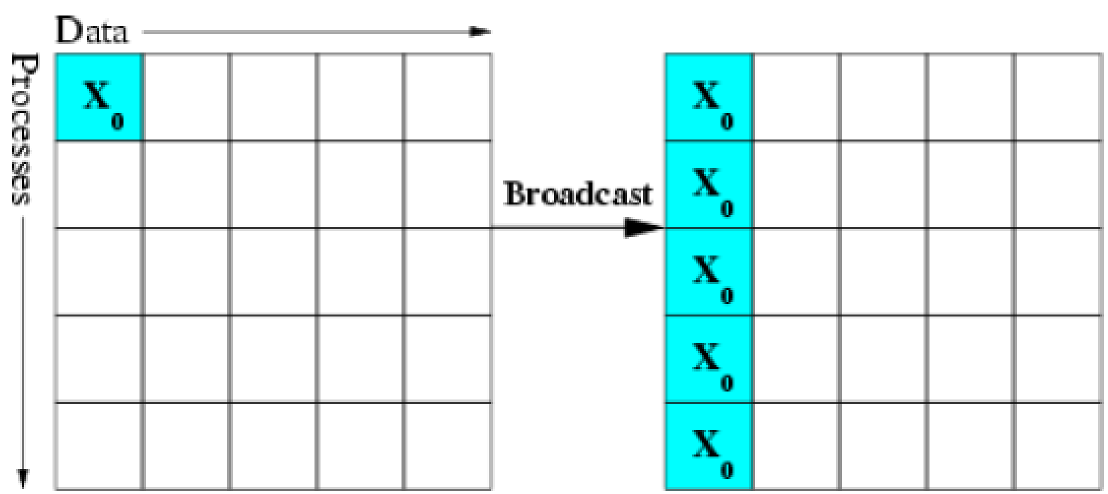
```
#include "mpi.h"
#include <stdio.h>
int main(int argc, char *argv[])
{
   int rank, nprocs;

   MPI_Init(&argc,&argv);
   MPI_Comm_size(MPI_COMM_WORLD,&nprocs);
   MPI_Comm_rank(MPI_COMM_WORLD,&rank);
   MPI_Barrier(MPI_COMM_WORLD);
   printf("Hello, world.  I am %d of %d\n", rank, procs);
   fflush(stdout);

   MPI_Finalize();
   return 0;
}
```

Broadcast (One-To-All)

MPI_Bcast(void *buffer /* in/out */, int count /* in */,

MPI_Datatype datatype /* in */, int root /* in */, MPI_Comm comm)

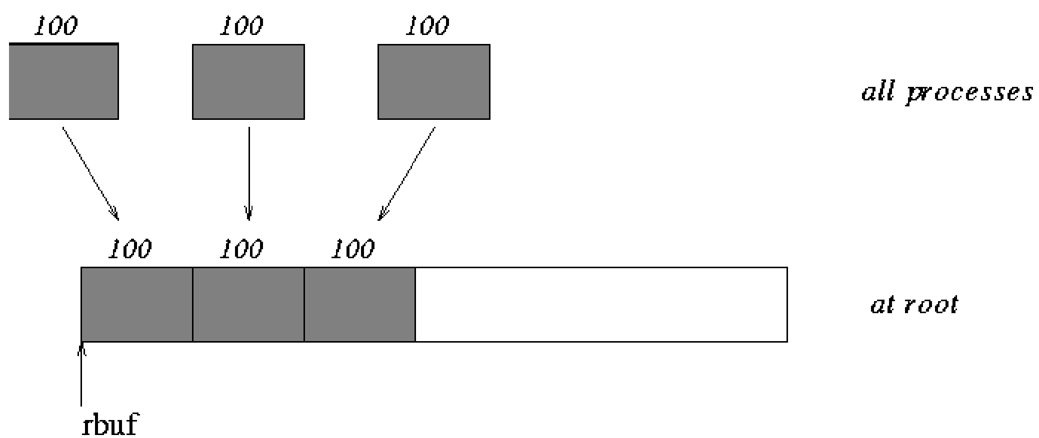
- Broadcasts a message from the process with rank "root" to all other processes of the communicator.
- All members of the communicator use the same argument for “comm”, “root”.
- On return, the content of root’s buffer has been copied to all processes.



Gather (All-To-One)

int MPI_Gather(void *sendbuf /* in */, int sendcnt /* in */, MPI_Datatype sendtype /* in */, void *recvbuf /* out */, int recvcnt /* in */, MPI_Datatype recvtype /* in */, int root /* in */, MPI_Comm comm /* in */)

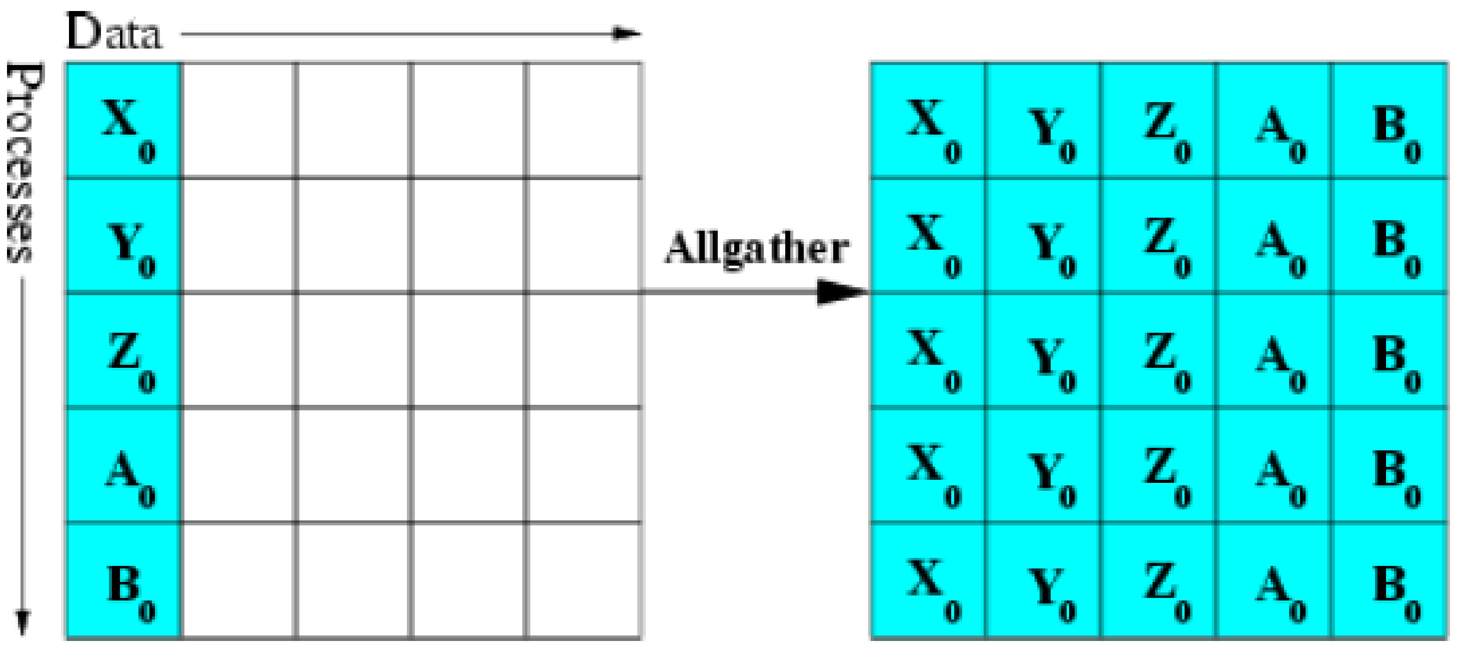
- Each process sends contents in “sendbuf” to “root”.
- Root stores received contents in rank order
- “recvbuf” is the address of receive buffer, which is significant only at “root”.
- “recvcnt” is the number of elements for any single receive, which is significant only at “root”.



AllGather (All-To-All)

int MPI_Allgather(void *sendbuf /* in */, int sendcount /* in */, MPI_Datatype sendtype /* in */, void *recvbuf /* out */, int recvcount /* in */, MPI_Datatype recvtype /* in */, MPI_Comm comm /* in */)

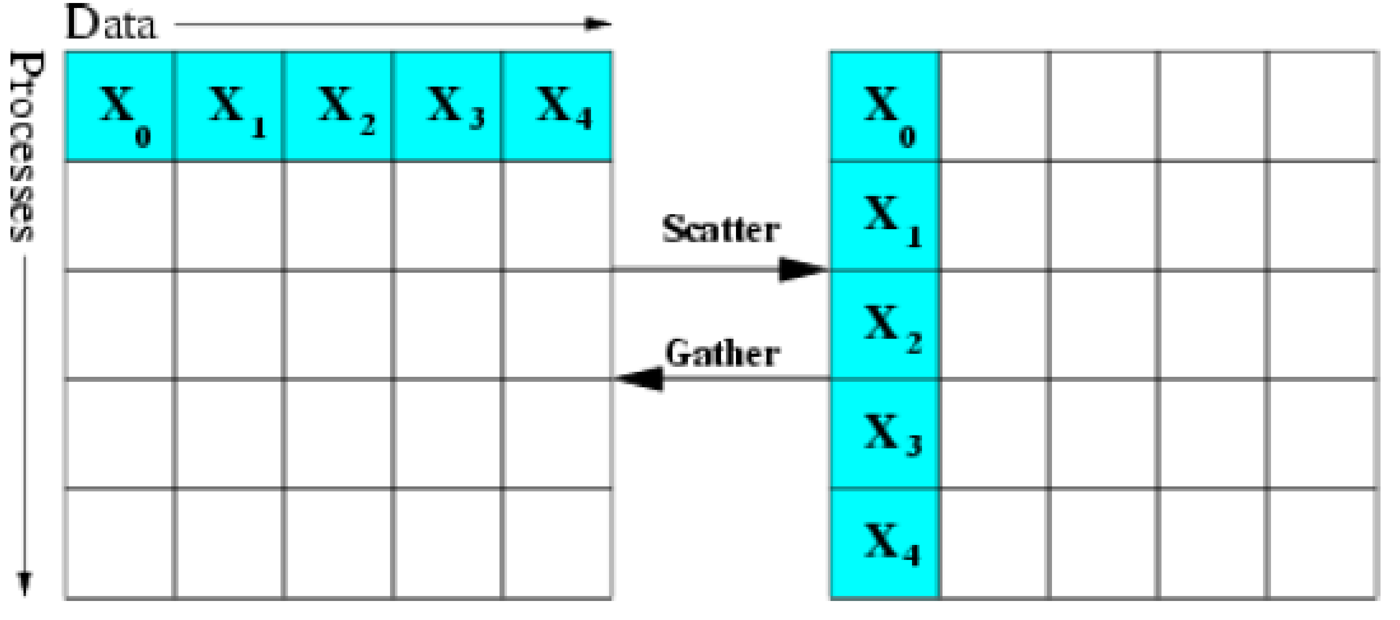
- Gather data from all tasks and distribute the combined data to all tasks
- Similar to Gather + Bcast



Scatter (One-To-All)

int MPI_Scatter(void *sendbuf /* in */, int sendcnt /* in */, MPI_Datatype sendtype /* in */, void *recvbuf /* out */, int recvcnt /* in */, MPI_Datatype recvtype /* in */, int root /* in */, MPI_Comm comm /* in */);

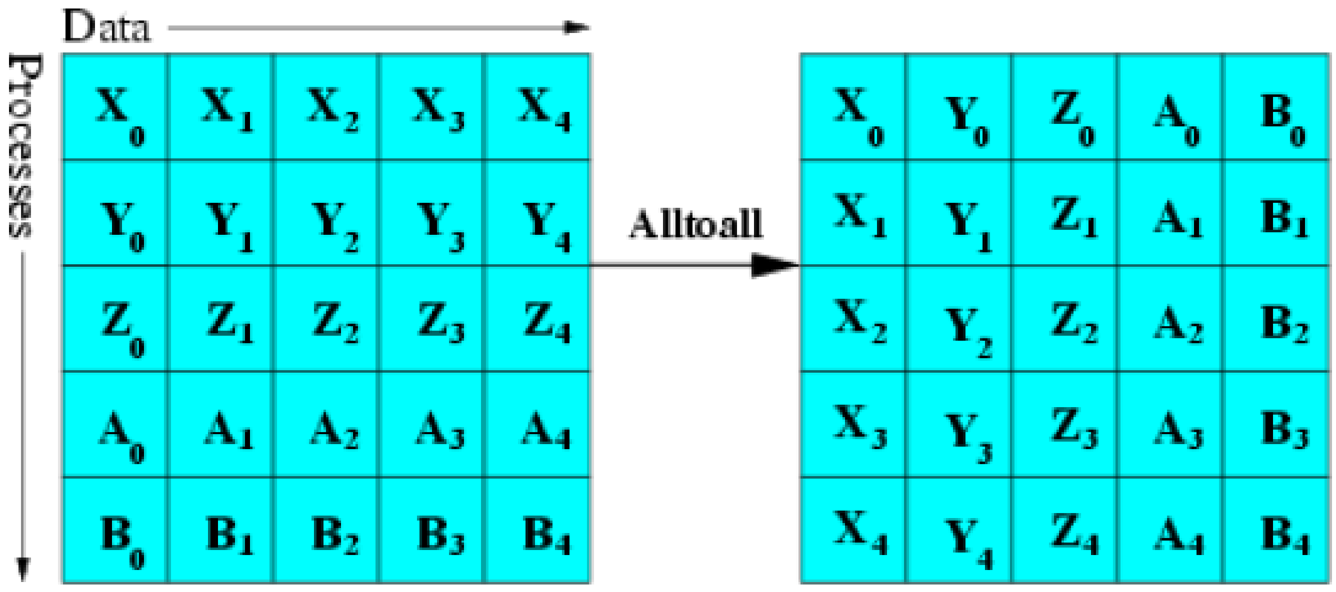
- Send data from one process “root” to all other processes in “comm”.
- It is the reverse operation of MPI_Gather
- It is a One-To-All operation which each recipient get a different chunk.
- “sendbuf”, “sendcnt” and “sendtype” are significant only at “root”.



Alltoall (All-To-All)

int MPI_Alltoall(void *sendbuf /* in */, int sendcount /* in */, MPI_Datatype sendtype /* in */, void *recvbuf /* out */, int recvcount /* in */, MPI_Datatype recvtype /* in */, MPI_Comm comm /* in */)

- an extension of MPI_ALLGATHER to case where each process sends distinct data to each of the receivers.
- the *j*th block from process *i* is received by process *j* and is placed in the *i*th block of recvbuf.
- The type signature associated with sendcount, sendtype at a process must be equal to the type structure associated with recvcount, recvtype at any other process.



Reduction (All-To-One)

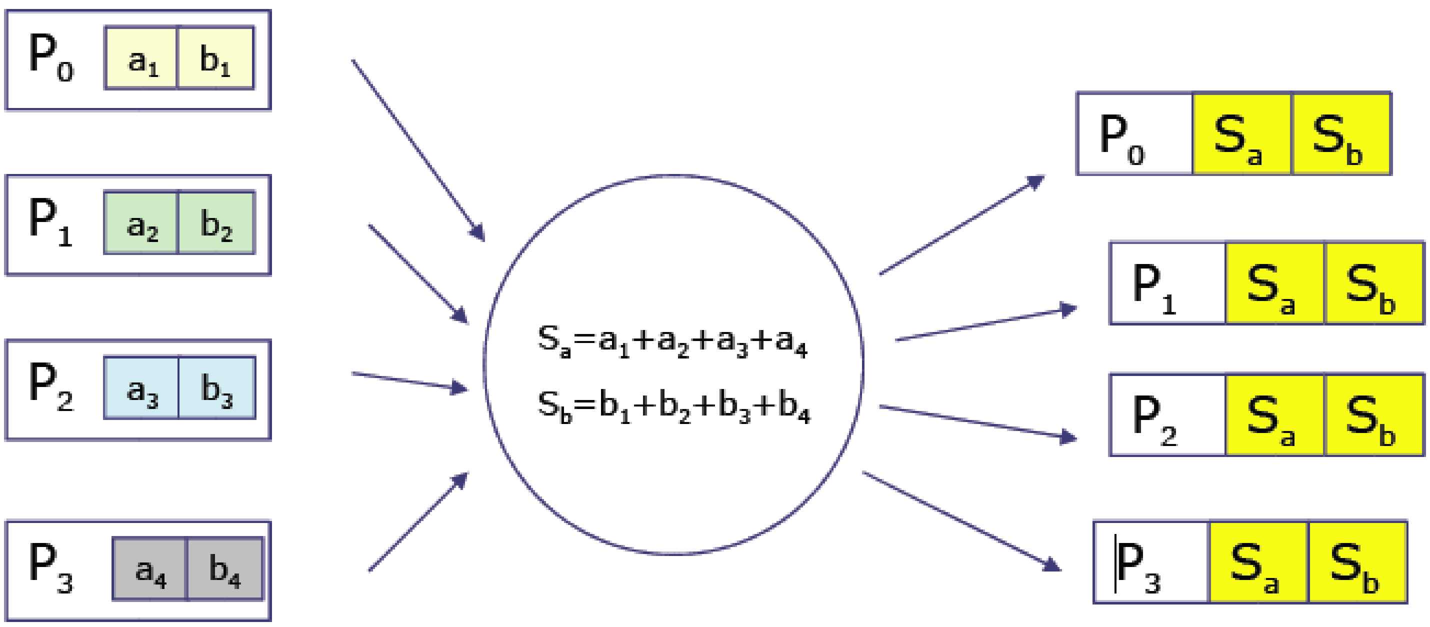
int MPI_Reduce(void *sendbuf /* in */, void *recvbuf /* out */, int count /* in */, MPI_Datatype datatype /* in */, MPI_Op op /* in */, int root /* in */, MPI_Comm comm /* in */)

- This routine combines values in “sendbuf” on all processes to a single value using the specified operation “op”.
- The combined value is put in “recvbuf” of the process with rank “root”.
- The routine is called by all group members using the same arguments for count, datatype, op, root and comm.

Predefined Reduction Operations

MPI_MAX	maximum
MPI_MIN	minimum
MPI_SUM	sum
MPI_PROD	product
MPI_LAND	logical and
MPI_BAND	bit-wise and
MPI_LOR	logical or
MPI_BOR	bit-wise or
MPI_LXOR	logical xor
MPI_BXOR	bit-wise xor
MPI_MINLOC	min value and location
MPI_MAXLOC	max value and location

- Each process can provide one element, or a sequence of elements, in which case the combine operation is executed element-by-element on each entry of the sequence.



Benchmarking Parallel Performance

double MPI_Wtime(void)

- Return an elapsed time in seconds on the calling processor
- There is no requirement that different nodes return "the same time".

```
#include "mpi.h"
#include <windows.h>
#include <stdio.h>

int main( int argc, char *argv[] )
{
   double t1, t2;

   MPI_Init( 0, 0 );
   t1 = MPI_Wtime();
   Sleep(1000);
   t2 = MPI_Wtime();
   printf("MPI_Wtime measured a 1 second sleep to be: %1.2f\n", t2-t1);
   fflush(stdout);
   MPI_Finalize( );
   return 0;
}
```

Numerical Integration

- Composite Trapezoidal Rule

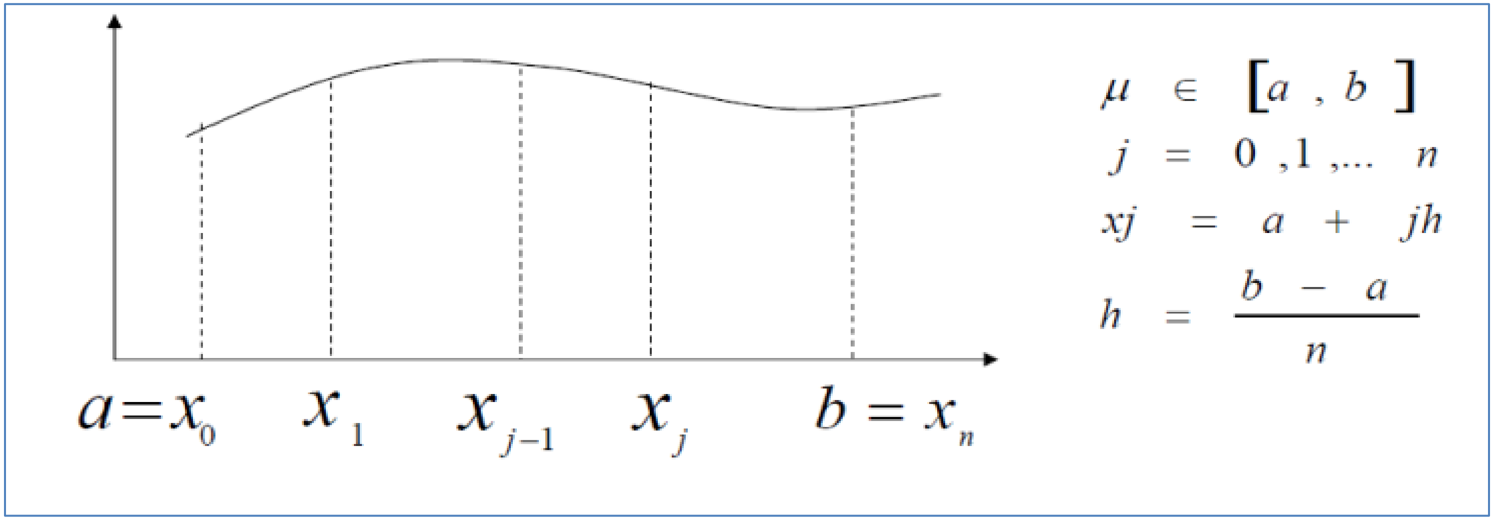


Figure 1 Composite Trapezoidal Rule

$$\int_a^b f(x)dx = \frac{h}{2}\left[f(a) + 2\sum_{j=1}^{n-1} f(x_j) + f(b)\right]$$

- Parallel Trapezoidal Rule

Input: number of processes *p*, entire interval of integration [*a*, *b*], number of subintervals *n*, *f(x)*

Assume *n/p is* integer