Distributed System

THOAI NAM

Outline

- Communication modes
- MPI – Message Passing Interface Standard

TERMs (1)

- Blocking

  If return from the procedure indicates the user is allowed to reuse resources specified in the call

- Non-blocking

  If the procedure may return before the operation completes, and before the user is allowed to reuse resources specified in the call

- Collective

  If all processes in a process group need to invoke the procedure

- Message envelope

  Information used to distinguish messages and selectively receive them

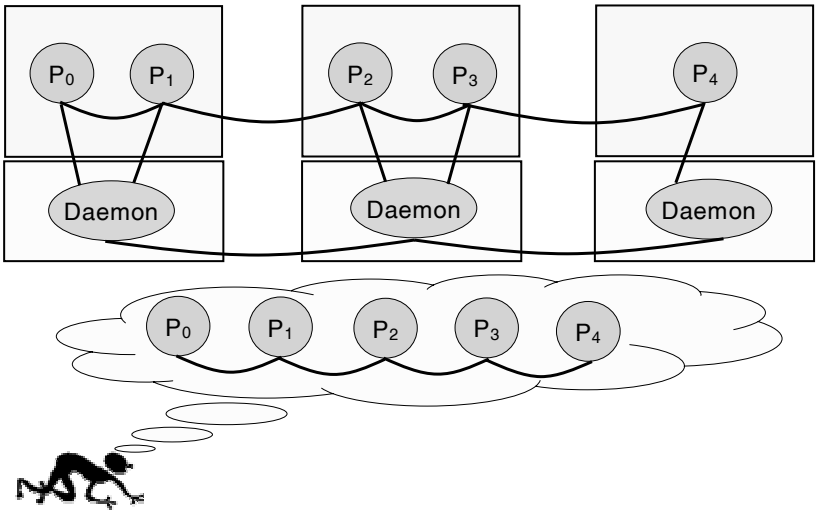
TERMs (2)

- Communicator
  - The communication context for a communication operation
  - Messages are always received within the context they were sent
  - Messages sent in different contexts do not interfere
  - MPI_COMM_WORLD
- Process group
  - The communicator specifies the set of processes that share this communication context.
  - This process group is ordered and processes are identified by their rank within this group

MPI

- Environment
- Point-to-point communication
- Collective communication
- Derived data type
- Group management

MPI



Environment

- MPI_INIT
- MPI_COMM_SIZE
- MPI_COMM_RANK
- MPI_FINALIZE
- MPI_ABORT

MPI_Init

- Usage
  - int MPI_Init(int* argc_ptr, /* in */
    char** argv_ptr[]); /* in */
- Description
  - Initialize MPI
  - All MPI programs must call this routines once and only once before any other MPI routines

MPI_Finalize

- Usage

  int MPI_Finalize (void);

- Description
  - Terminates all MPI processing
  - Make sure this routine is the last MPI call.
  - All pending communications involving a process have completed before the process calls MPI_FINALIZE

MPI_Comm_Size

- Usage

```
int MPI_Comm_size(
    MPI_Comm  comm, /*in */
    int* size );              /* out */
```

- Description
  - Return the number of processes in the group associated with a communicator

MPI_Comm_Rank

- Usage
  - int MPI_Comm_rank (
    MPI_Comm comm,/* in */
    int* rank); /* out */
- Description
  - Returns the rank of the local process in the group associated with a communicator
  - The rank of the process that calls it in the range from 0 … size - 1

MPI_Abort

- Usage
  - int MPI_Abort(MPI_Comm comm, /* in */
    int errorcode); /* in */
- Description
  - Forces all processes of an MPI job to terminate

Simple Program

```
#include "mpi.h"

int main( int argc, char* argv[] )
{
   int rank;
   int nproc;

   MPI_Init( &argc, &argv );
   MPI_Comm_size( MPI_COMM_WORLD, &nproc );
   MPI_Comm_rank( MPI_COMM_WORLD, &rank );
   /* write codes for you */
   MPI_Finalize();
}
```


Point-to-Point Communication

- MPI_SEND
- MPI_RECV
- MPI_ISEND
- MPI_IRECV
- MPI_WAIT
- MPI_GET_COUNT

Communication Modes in MPI (1)

- Standard mode
  - It is up to MPI to decide whether outgoing messages will be buffered
  - Non-local operation
  - Buffered or synchronous?
- Buffered(asynchronous) mode
  - A send operation can be started whether or not a matching receive has been posted
  - It may complete before a matching receive is posted
  - Local operation

Communication Modes in MPI (2)

- Synchronous mode
  - A send operation can be started whether or not a matching receive was posted
  - The send will complete successfully only if a matching receive was posted and the receive operation has started to receive the message
  - The completion of a synchronous send not only indicates that the send buffer can be reused but also indicates that the receiver has reached a certain point in its execution
  - Non-local operation

Communication Modes in MPI (3)

- Ready mode
  - A send operation may be started only if the matching receive is already posted
  - The completion of the send operation does not depend on the status of a matching receive and merely indicates the send buffer can be reused
  - EAGER_LIMIT of SP system

MPI_Send

- Usage

```
int MPI_Send( void* buf,                  /* in */
              int count,                  /* in */
              MPI_Datatype datatype,/* in */
              int dest,                   /* in */
              int tag,                    /* in */
              MPI_Comm comm );    /* in */
```

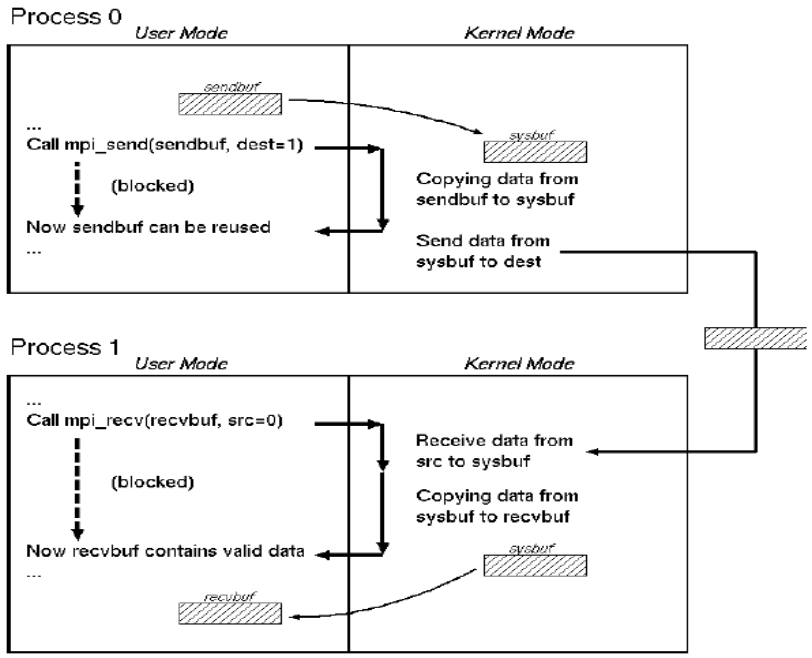
- Description
  - Performs a blocking standard mode send operation
  - The message can be received by either MPI_RECV or MPI_IRECV

MPI_Recv

- Usage

```
int MPI_Recv( void* buf,                /* out */
              int count,                /* in */
              MPI_Datatype datatype,    /* in */
              int source,               /* in */
              int tag,                  /* in */
              MPI_Comm comm,            /* in */
              MPI_Status* status );     /* out */
```

- Description
  - Performs a blocking receive operation
  - The message received must be less than or equal to the length of the receive buffer
  - MPI_RECV can receive a message sent by either MPI_SEND or MPI_ISEND



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Sample Program for Blocking Operations (1)

```
#include "mpi.h"

int main( int argc, char* argv[] )
{
   int rank, nproc;
   int isbuf, irbuf;

   MPI_Init( &argc, &argv );
   MPI_Comm_size( MPI_COMM_WORLD, &nproc );
   MPI_Comm_rank( MPI_COMM_WORLD, &rank );
```


Sample Program for Blocking Operations (2)

```
if(rank == 0) {
      isbuf = 9;
      MPI_Send( &isbuf, 1, MPI_INTEGER, 1, TAG,
                  MPI_COMM_WORLD);
} else if(rank == 1) {
      MPI_Recv( &irbuf, 1, MPI_INTEGER, 0, TAG,
                  MPI_COMM_WORLD, &status);
      printf( "%d\n", irbuf );
   }
   MPI_Finalize();
}
```

MPI_Isend

- Usage

```
int MPI_Isend( void* buf,                /* in */
               int count,                /* in */
               MPI_Datatype datatype,    /* in */
               int dest,                 /* in */
               int tag,                  /* in */
               MPI_Comm comm,            /* in */
               MPI_Request* request );   /* out */
```

- Description
  - Performs a nonblocking standard mode send operation
  - The send buffer may not be modified until the request has been completed by MPI_WAIT or MPI_TEST
  - The message can be received by either MPI_RECV or MPI_IRECV

MPI_Irecv (1)

- Usage

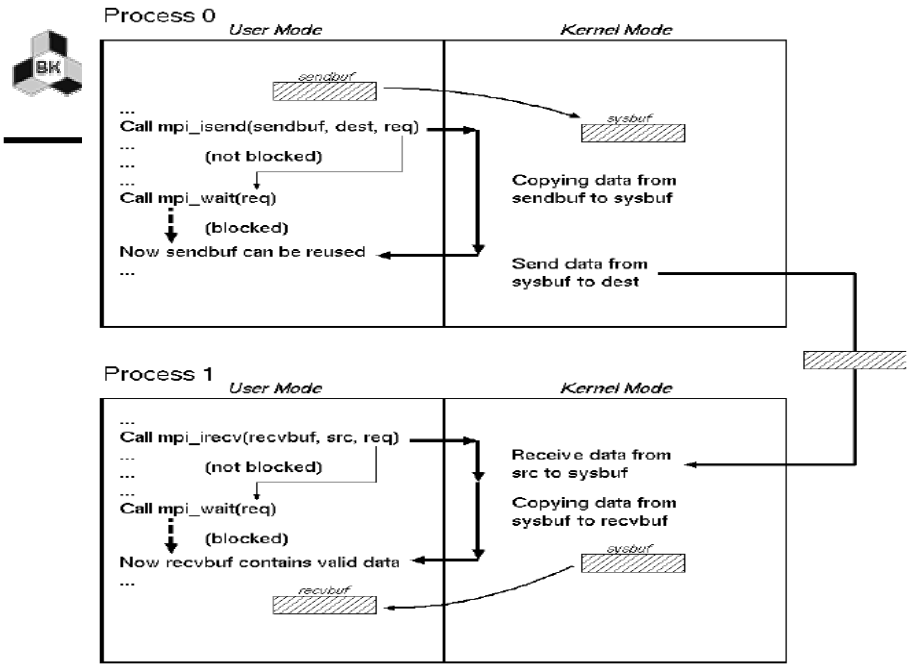
```
int MPI_Irecv( void* buf,                /* out */
               int count,                /* in */
               MPI_Datatype datatype,    /* in */
               int source,               /* in */
               int tag,                  /* in */
               MPI_Comm comm,            /* in */
               MPI_Request* request );   /* out */
```

MPI_Irecv (2)

- Description
  - Performs a nonblocking receive operation
  - Do not access any part of the receive buffer until the receive is complete
  - The message received must be less than or equal to the length of the receive buffer
  - MPI_IRECV can receive a message sent by either MPI_SEND or MPI_ISEND

MPI_Wait

- Usage
  - int MPI_Wait(MPI_Request* request, /* inout */
    MPI_Status* status); /* out */
- Description
  - Waits for a nonblocking operation to complete
  - Information on the completed operation is found in status.
  - If wildcards were used by the receive for either the source or tag, the actual source and tag can be retrieved by status->MPI_SOURCE and status->MPI_TAG



MPI_Get_count

- Usage
  - int MPI_Get_count(MPI_Status status, /* in */
    MPI_Datatype datatype,/* in */
    int* count); /* out */
- Description
  - Returns the number of elements in a message
  - The datatype argument and the argument provided by the call that set the status variable should match

Sample Program for Non-Blocking Operations (1)

```
#include "mpi.h"
int main( int argc, char* argv[] )
{
   int rank, nproc;
   int isbuf, irbuf, count;
   MPI_Request request;
   MPI_Status status;

   MPI_Init( &argc, &argv );
   MPI_Comm_size( MPI_COMM_WORLD, &nproc );
   MPI_Comm_rank( MPI_COMM_WORLD, &rank );

   if(rank == 0) {
      isbuf = 9;
      MPI_Isend( &isbuf, 1, MPI_INTEGER, 1, TAG, MPI_COMM_WORLD,
                 &request );
```


Sample Program for Non-Blocking Operations (2)

```
} else if (rank == 1) {
      MPI_Irecv( &irbuf, 1, MPI_INTEGER, 0, TAG,
                 MPI_COMM_WORLD, &request);
      MPI_Wait(&request, &status);
      MPI_Get_count(&status, MPI_INTEGER, &count);
      printf( "irbuf = %d source = %d tag = %d count = %d\n",
              irbuf, status.MPI_SOURCE, status.MPI_TAG, count);
   }
   MPI_Finalize();
}
```

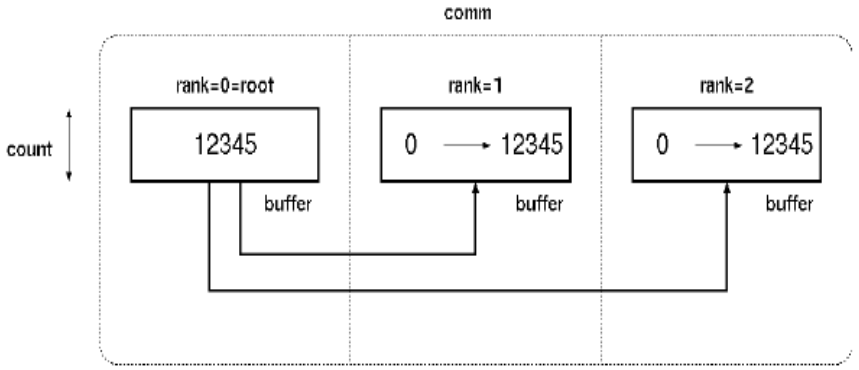
Collective Operations

- MPI_BCAST
- MPI_SCATTER
- MPI_SCATTERV
- MPI_GATHER
- MPI_GATHERV
- MPI_ALLGATHER
- MPI_ALLGATHERV
- MPI_ALLTOALL

MPI_Bcast (1)

- Usage
  - int MPI_Bcast(void* buffer, /* inout */
    int count, /* in */
    MPI_Datatype datatype, /* in */
    int root, /* in */
    MPI_Comm comm); /* in */
- Description
  - Broadcasts a message from root to all processes in communicator
  - The type signature of count, datatype on any process must be equal to the type signature of count, datatype at the root

MPI_Bcast (2)



MPI_Scatter

- Usage

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

- Description
  - Distribute individual messages from root to each process in communicator
  - Inverse operation to MPI_GATHER

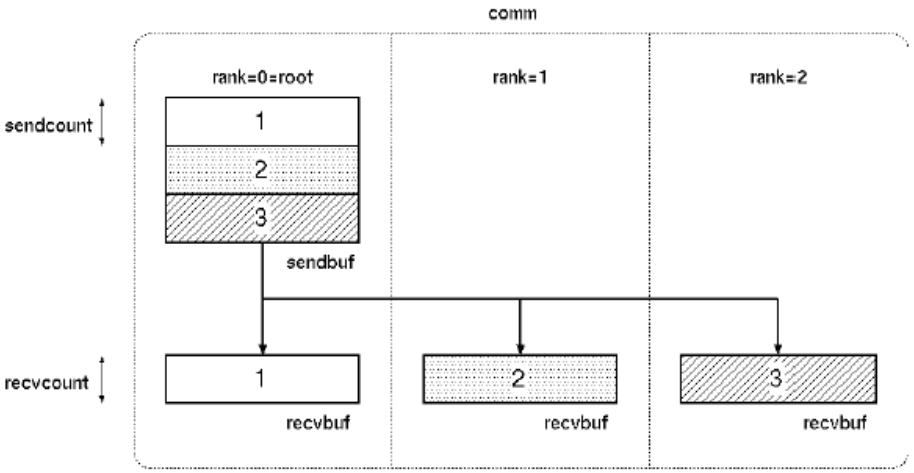
Example of MPI_Scatter (1)

```
#include "mpi.h"

int main( int argc, char* argv[] )
{
   int i;
   int rank, nproc;
   int isend[3], irecv;

   MPI_Init( &argc, &argv );
   MPI_Comm_size( MPI_COMM_WORLD, &nproc );
   MPI_Comm_rank( MPI_COMM_WORLD, &rank );
```


Example of MPI_Scatter (2)

```
  if(rank == 0) {
      for(i=0; i<nproc; i++)
         isend(i) = i+1;
   }
  MPI_Scatter( isend, 1, MPI_INTEGER, irecv, 1,
                     MPI_INTEGER, 0,
  MPI_COMM_WORLD);
   printf("irecv = %d\n", irecv);

   MPI_Finalize();
}
```

Example of MPI_Scatter (3)



MPI_Scatterv

- Usage

```
int MPI_Scatterv( void* sendbuf,          /* in */
                  int* sendcounts,        /* in */
                  int* displs,            /* in */
                  MPI_Datatype sendtype,  /* in */
                  void* recvbuf,          /* in */
                  int recvcount,          /* in */
                  MPI_Datatype recvtype,  /* in */
                  int root,               /* in */
                  MPI_Comm comm);         /* in */
```

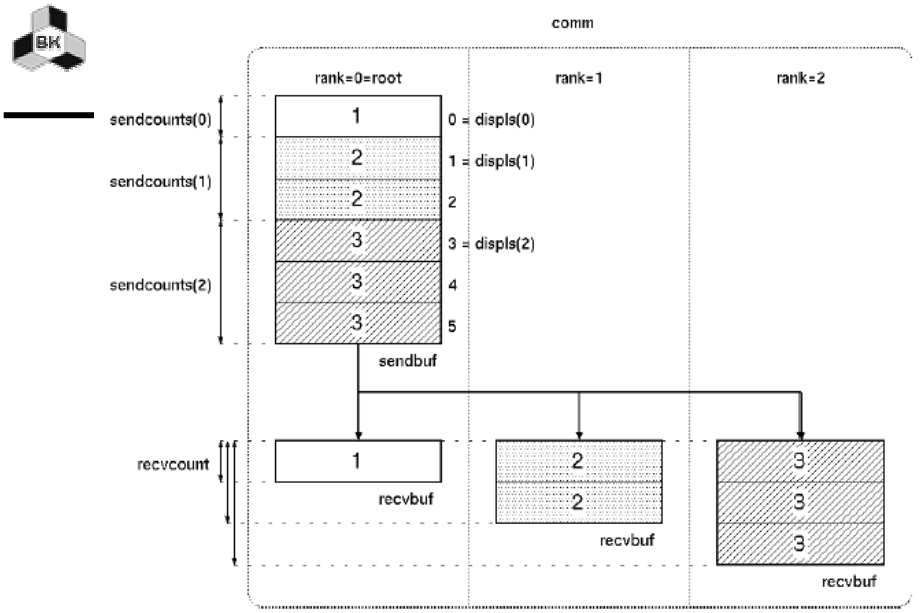
- Description
  - Distributes individual messages from root to each process in communicator
  - Messages can have different sizes and displacements

Example of MPI_Scatterv(1)

```
#include "mpi.h"
int main( int argc, char* argv[] )
{
   int i;
   int rank, nproc;
   int iscnt[3] = {1,2,3}, irdisp[3] = {0,1,3};
   int isend[6] = {1,2,2,3,3,3}, irecv[3];

   MPI_Init( &argc, &argv );
   MPI_Comm_size( MPI_COMM_WORLD, &nproc );
   MPI_Comm_rank( MPI_COMM_WORLD, &rank );
```


Example of MPI_Scatterv(2)

```
  ircnt = rank + 1;

  MPI_Scatterv( isend, iscnt, idisp, MPI_INTEGER, irecv,
              ircnt, MPI_INTEGER, 0,
  MPI_COMM_WORLD);
   printf("irecv = %d\n", irecv);

   MPI_Finalize();
}
```



MPI_Gather

- Usage

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

- Description
  - Collects individual messages from each process in communicator to the root process and store them in rank order

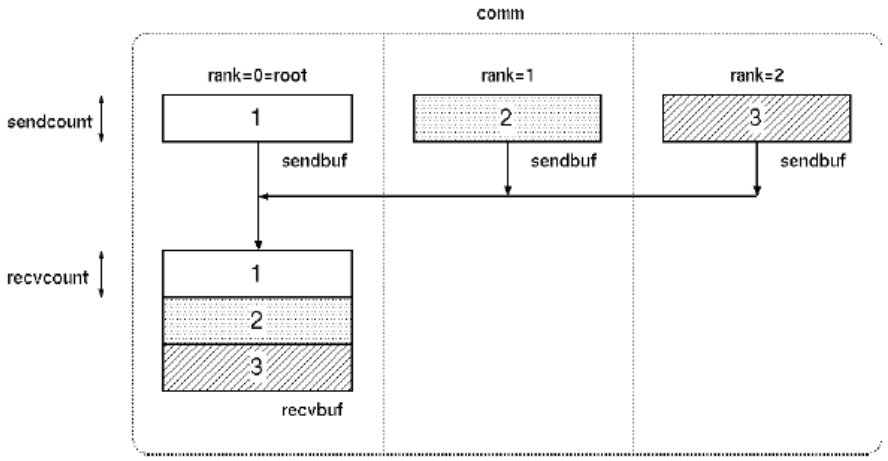
Example of MPI_Gather (1)

```
#include "mpi.h"

int main( int argc, char* argv[] )
{
    int i;
    int rank, nproc;
    int isend, irecv[3];

    MPI_Init( &argc, &argv );
    MPI_Comm_size( MPI_COMM_WORLD, &nproc );
    MPI_Comm_rank( MPI_COMM_WORLD, &rank );
```


Example of MPI_Gather (2)

```
   isend = rank + 1;
    MPI_Gather( &isend, 1, MPI_INTEGER, irecv, 1,
                    MPI_INTEGER, 0, MPI_COMM_WORLD);

   if(rank == 0) {
       for(i=0; i<3; i++)
          printf("irecv = %d\n", irecv[i]);

    MPI_Finalize();
}
```

MPI_Gather



MPI_Gatherv

- Usage

```
int MPI_Gatherv( void* sendbuf,                 /* in */
                 int sendcount,                 /* in */
                 MPI_Datatype sendtype, /* in */
                 void* recvbuf,                /* out */
                 int* recvcount,                /* in */
                 int* displs,                   /* in */
                 MPI_Datatype recvtype,   /* in */
                 int root,                      /* in */
                 MPI_Comm comm );       /* in */
```

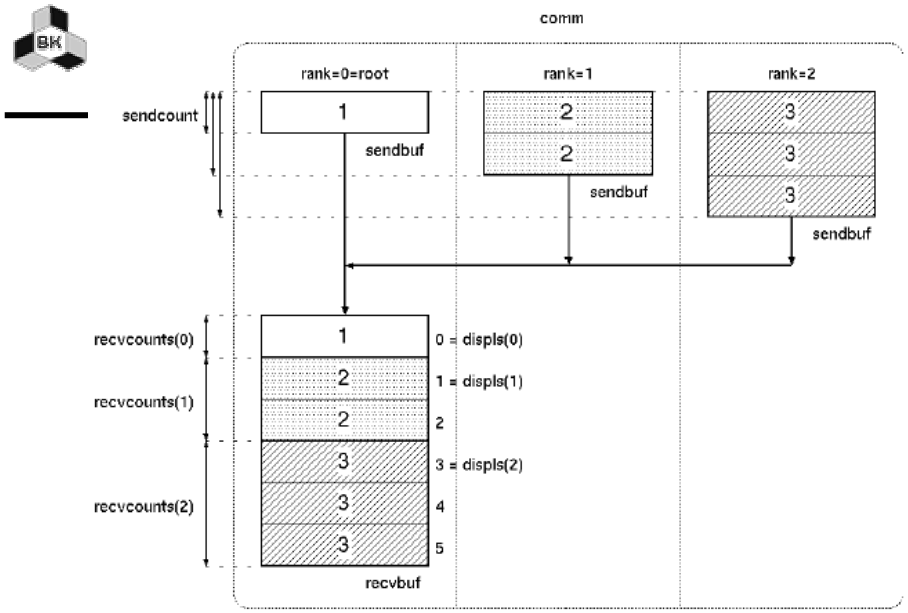
- Description
  - Collects individual messages from each process in communicator to the root process and store them in rank order

Example of MPI_Gatherv (1)

```
#include "mpi.h"

int main( int argc, char* argv[] )
{
   int i;
   int rank, nproc;
   int isend[3], irecv[6];
   int ircnt[3] = {1,2,3}, idisp[3] = {0,1,3};

   MPI_Init( &argc, &argv );
   MPI_Comm_size( MPI_COMM_WORLD, &nproc );
   MPI_Comm_rank( MPI_COMM_WORLD, &rank );
```


Example of MPI_Gatherv (2)

```
   for(i=0; i<rank; i++)
      isend[i] = rank + 1;
   iscnt = rank + 1;
   MPI_Gatherv( isend, iscnt, MPI_INTEGER, irecv,
   ircnt,                idisp, MPI_INTEGER, 0,
   MPI_COMM_WORLD);
   if(rank == 0) {
      for(i=0; i<6; i++)
         printf("irecv = %d\n", irecv[i]);
   }
   MPI_Finalize();
}
```



MPI_Reduce (1)

- Usage

```
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 */
```

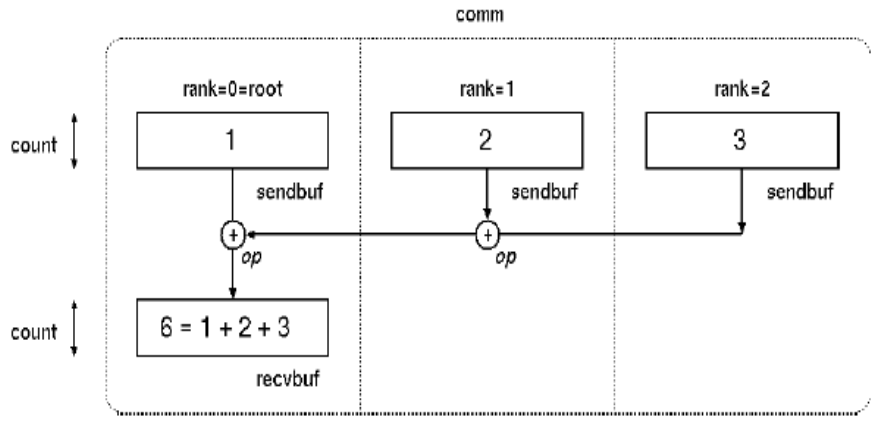
MPI_Reduce (2)

- Description
  - Applies a reduction operation to the vector sendbuf over the set of processes specified by communicator and places the result in recvbuf on root
  - Both the input and output buffers have the same number of elements with the same type
  - Users may define their own operations or use the predefined operations provided by MPI
- Predefined operations
  - MPI_SUM, MPI_PROD
  - MPI_MAX, MPI_MIN
  - MPI_MAXLOC, MPI_MINLOC
  - MPI_LAND, MPI_LOR, MPI_LXOR
  - MPI_BAND, MPI_BOR, MPI_BXOR

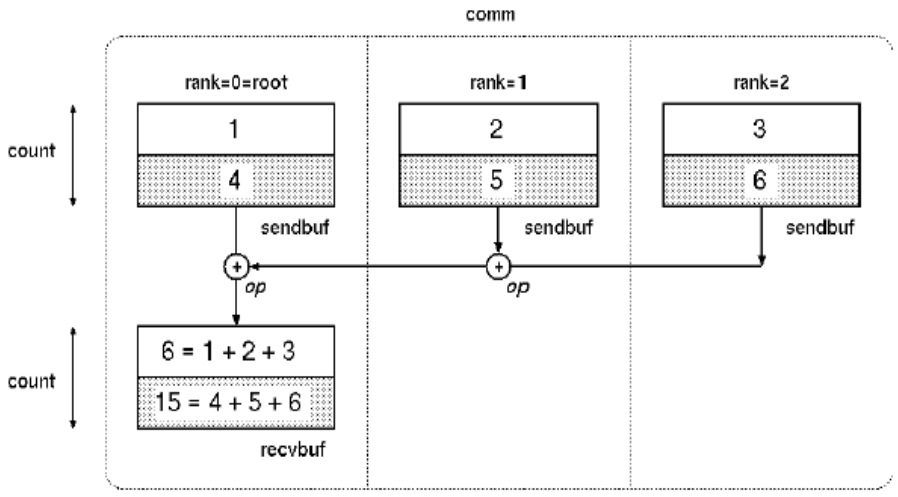
Example of MPI_Reduce

```
#include "mpi.h"
int main( int argc, char* argv[] )
{
   int rank, nproc;
   int isend, irecv;

   MPI_Init( &argc, &argv );
   MPI_Comm_size( MPI_COMM_WORLD, &nproc );
   MPI_Comm_rank( MPI_COMM_WORLD, &rank );

   isend = rank + 1;
   MPI_Reduce(&isend, &irecv, 1, MPI_INTEGER, MPI_SUM, 0,
                  MPI_COMM_WORLD);
   if(rank == 0) printf("irecv = %d\n", irecv);
   MPI_Finalize();
}
```

MPI_Reduce



MPI_Reduce



MPI_Scan

- Usage

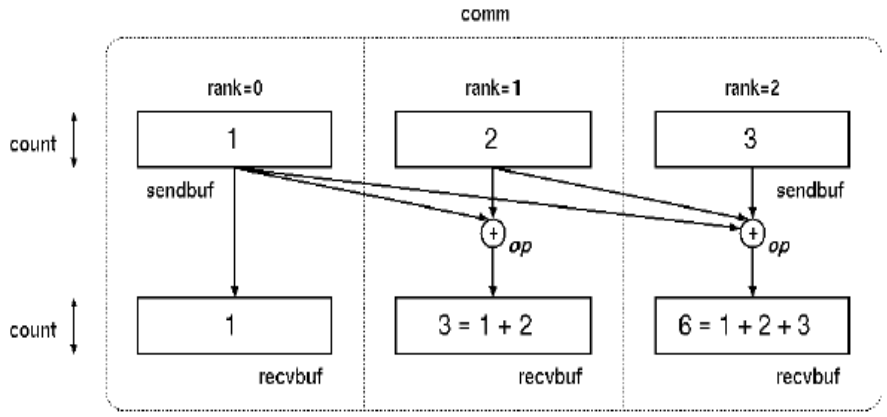
```
int MPI_Scan( void* sendbuf, /* in */
              void* recvbuf, /* out */
              int count, /* in */
              MPI_Datatype datatype, /* in */
              MPI_Op op,             /* in */
              MPI_Comm comm); /* in */
```

- Description
  - Performs a parallel prefix reduction on data distributed across a group
  - The operation returns, in the receive buffer of the process with rank i, the reduction of the values in the send buffers of processes with ranks 0…i

Example of MPI_Scan

```
#include "mpi.h"
int main( int argc, char* argv[] )
{
   int rank, nproc;
   int isend, irecv;

   MPI_Init( &argc, &argv );
   MPI_Comm_size( MPI_COMM_WORLD, &nproc );
   MPI_Comm_rank( MPI_COMM_WORLD, &rank );

   isend = rank + 1;
   MPI_Scan(&isend, &irecv, 1, MPI_INTEGER, MPI_SUM,
            MPI_COMM_WORLD);
   printf("irecv = %d\n", irecv);
   MPI_Finalize();
}
```

MPI_Scan



MPI_Barrier

- Usage

```
int MPI_Barrier(MPI_Comm comm); /*
  in */
```

- Description
  - Blocks each process in communicator until all processes have called it