MPI

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

  <source, destination, tag, communicator>

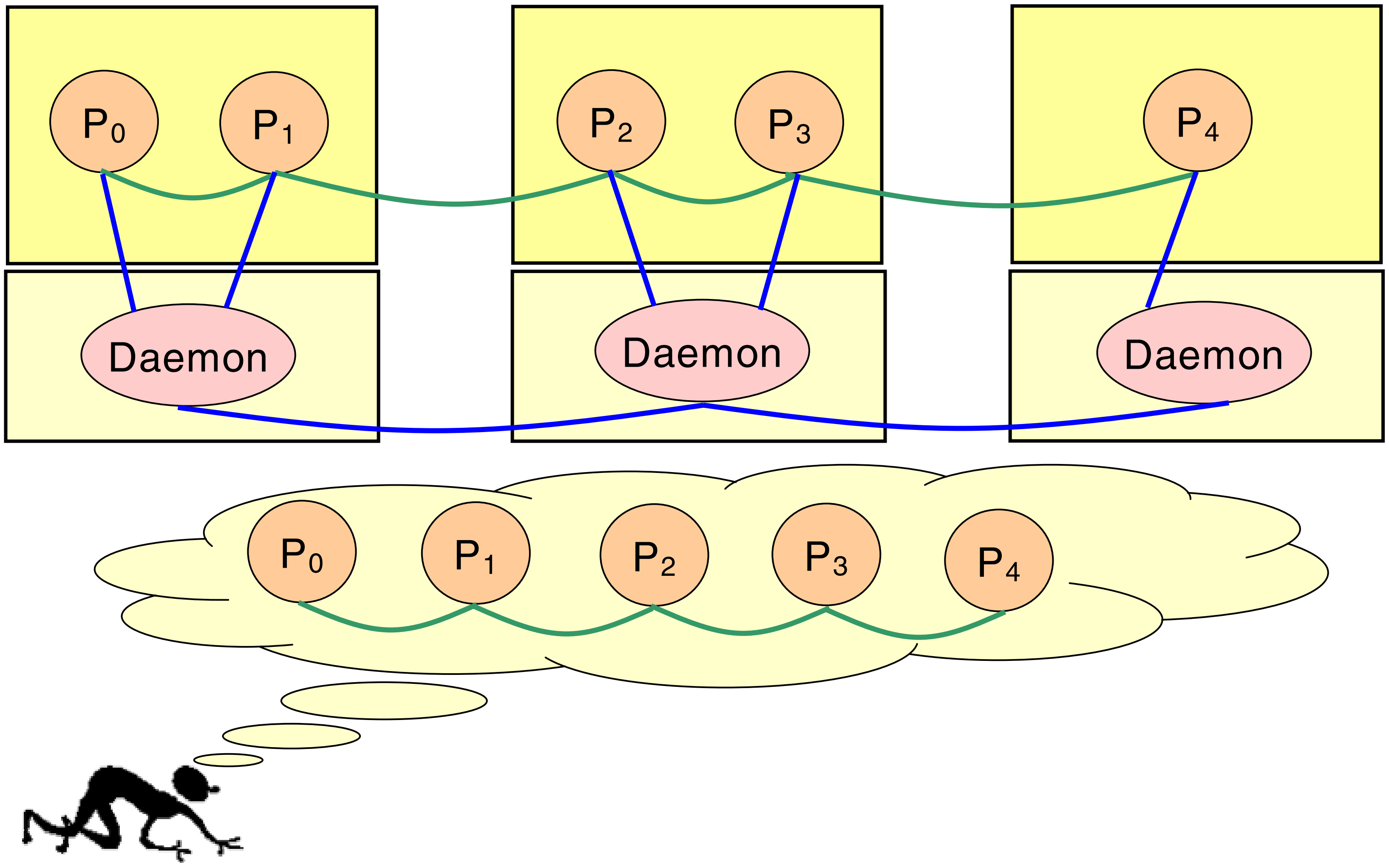
TERMs (2)

- 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



MPI Implementation

- LAM: http://www.lam-mpi.org/
- MPICH: http://www-unix.mcs.anl.gov/mpi/mpich/
- Others

- Documents:
  - http://www.mpi.org/
  - http://www.mpi-forum.org/

LAM

```
% cat lamhosts
# a 2-node LAM
node1.cluster.example.com
node2.cluster.example.com
```

The lamboot tool actually starts LAM on the specified cluster.

```
% lamboot -v lamhosts
```

```
LAM 7.0.4 - Indiana University
Executing hboot on n0 (node1.cluster.example.com - 1 CPU)...
Executing hboot on n1 (node2.cluster.example.com - 1 CPU)...
```

lamboot returns to the UNIX shell prompt. LAM does not force a canned environment or a "LAM shell". The tping command builds user confidence that the cluster and LAM are running.

Compiling MPI Programs

Refer to MPI: It's Easy to Get Started to see a simple MPI program. mpicc (and mpiCC and mpif77) is a wrapper for the C (C++, and F77) compiler that includes all the necessary command line switches to the underlying compiler to find the LAM include files, the relevant LAM libraries, etc.

```
shell$ mpicc -o foo foo.c
shell$ mpif77 -o foo foo.f
```

Executing MPI Programs

A MPI application is started by one invocation of the mpirun command. A SPMD application can be started on the mpirun command line.

```
shell$ mpirun -v -np 2 foo
2445 foo running on n0 (o) 361 foo running on n1
```

An application with multiple programs must be described in an application schema, a file that lists each program and its target node(s).

Terminating LAM

The lamhalt tool removes all traces of the LAM session on the network. This is only performed when LAM/MPI is no longer needed (i.e., no more mpirun/lamclean commands will be issued).

shell$ lamhalt

In the case of a catastrophic failure (e.g., one or more LAM nodes crash), the lamhalt utility will hang. In this case, the wipe tool is necessary. The same boot schema that was used with lamboot is necessary to list each node where the LAM run-time environment is running:

shell$ wipe -v lamhosts Executing tkill on n0 (node1.cluster.example.com)... Executing tkill on n1 (node2.cluster.example.com)...

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 */

```
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 */
```

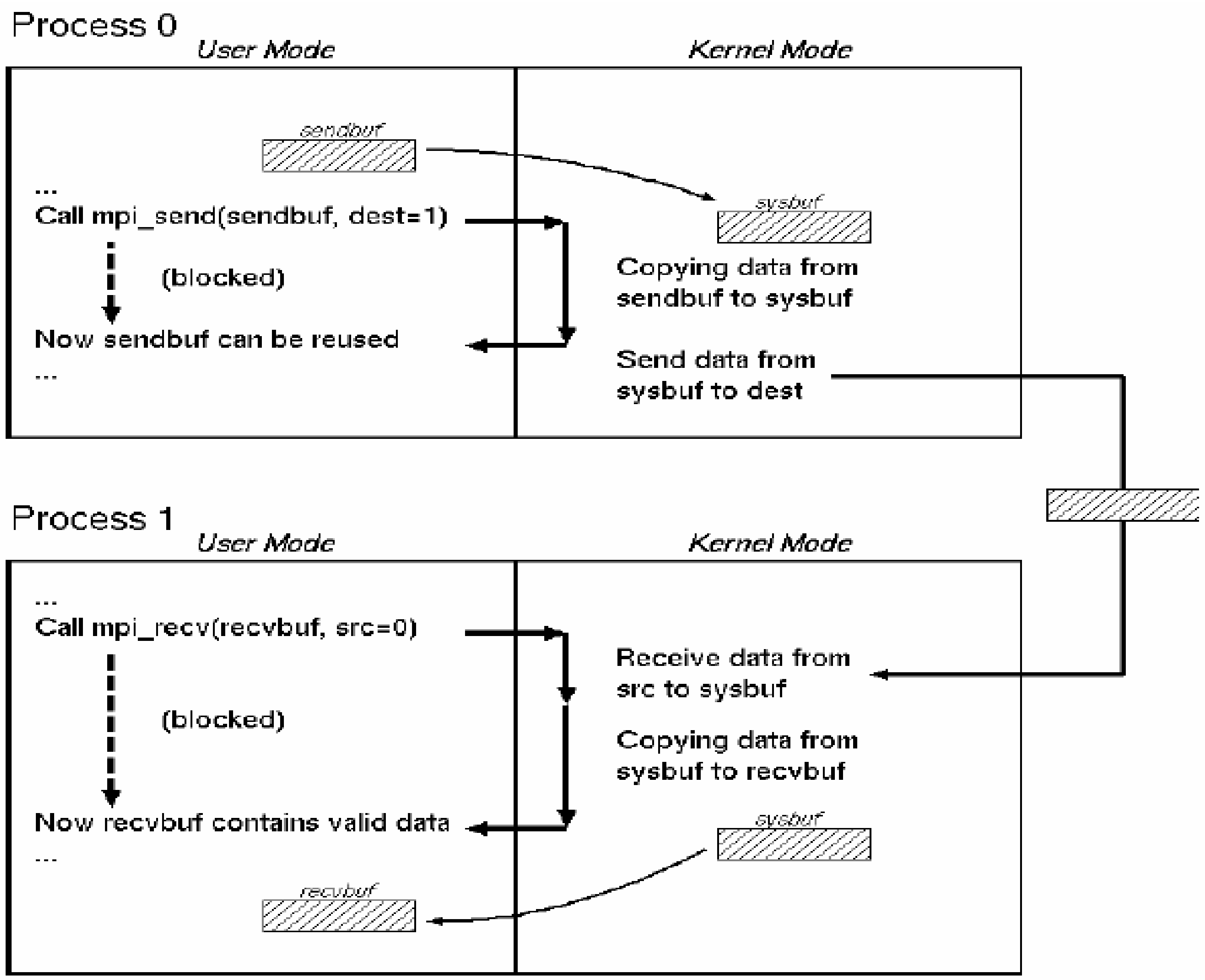
- Description
  - Performs a blocking standard mode send operation
  - The message can be received by either MPI_RECV or MPI_IRECV

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


Process 0
User Mode
Kernel Mode
sendbuf
...
Call mpi_send(sendbuf, dest=1)
(blocked)
Now sendbuf can be reused
...
sysbuf
Copying data from sendbuf to sysbuf
Send data from sysbuf to dest
Process 1
User Mode
Kernel Mode
...
Call mpi_recv(recvbuf, src=0)
(blocked)
Now recvbuf contains valid data
...
recvbuf
Receive data from src to sysbuf
Copying data from sysbuf to recvbuf
sysbuf

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)

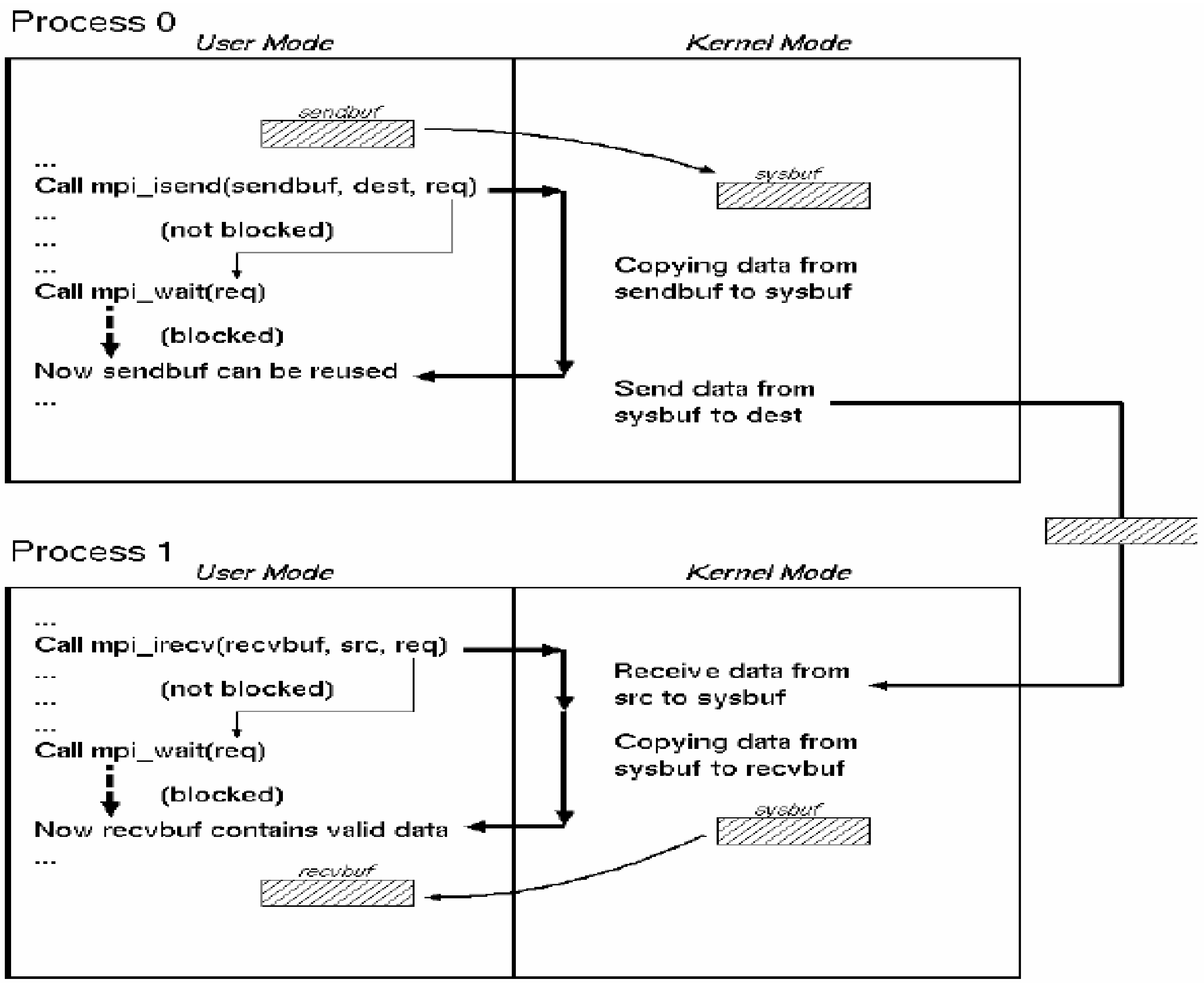
- Description
  - Performs a nonblocking receive operation
  - Do not access any part of the receive buffer until the receive is complete
  - The message received must be less than or equal to the length of the receive buffer
  - MPI_IRECV can receive a message sent by either MPI_SEND or MPI_ISEND

MPI_Wait

- Usage
  - int MPI_Wait(MPI_Request* request, /* inout */
    MPI_Status* status); /* out */

```
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


Process 0
User Mode
Kernel Mode
sendbuf
sysbuf
...
Call mpi_isend(sendbuf, dest, req)
...
(not blocked)
...
...
Call mpi_wait(req)
(blocked)
Now sendbuf can be reused
...
Copying data from sendbuf to sysbuf
Send data from sysbuf to dest
Process 1
User Mode
Kernel Mode
...
Call mpi_irecv(recvbuf, src, req)
...
(not blocked)
...
...
Call mpi_wait(req)
(blocked)
Now recvbuf contains valid data
...
recvbuf
Receive data from src to sysbuf
Copying data from sysbuf to recvbuf
sysbuf

MPI_Get_count

- Usage
  - int MPI_Get_count(MPI_Status status, /* in */
    MPI_Datatype datatype, /* in */
    int* count); /* out */

```
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();
}
```

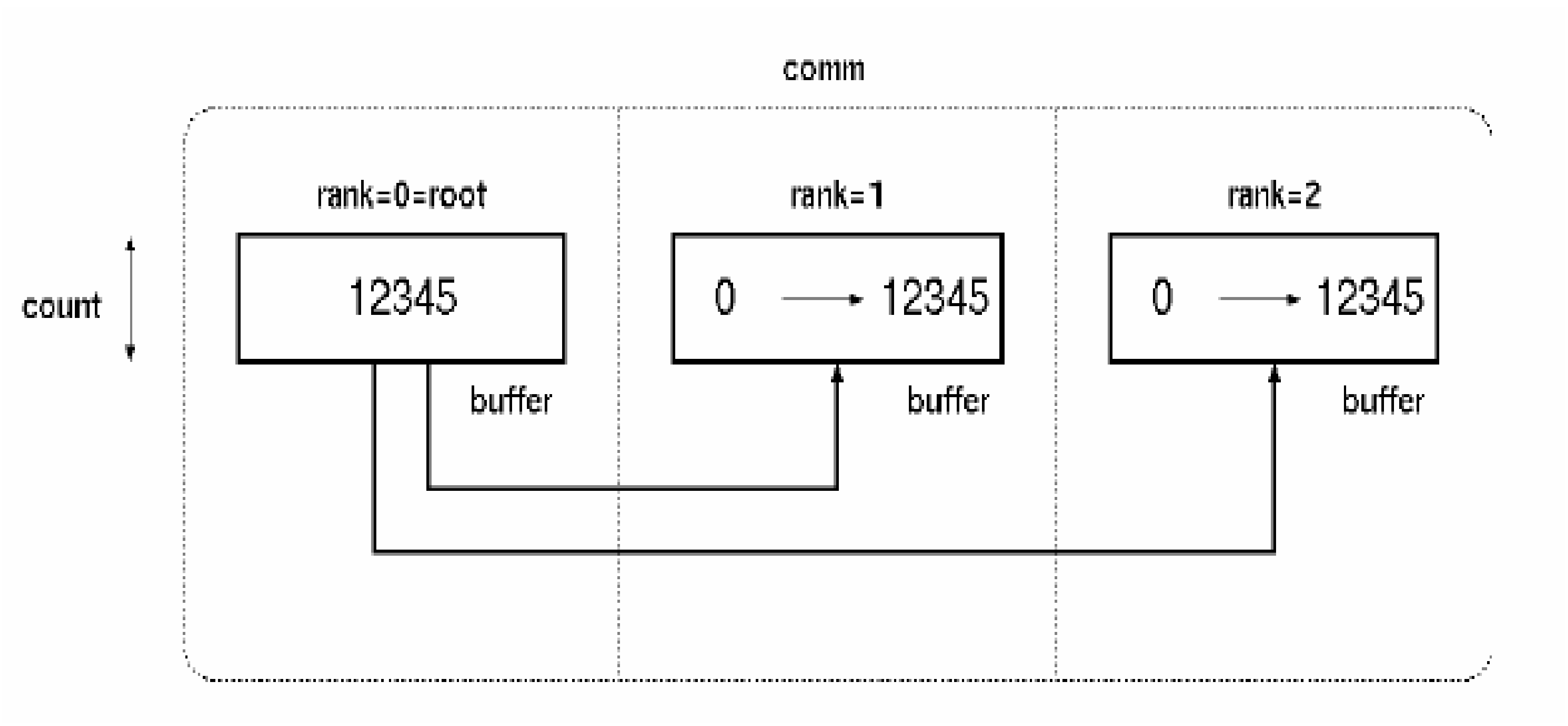
Collective Operations

- 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)


comm
rank=0=root
rank=1
rank=2
count
12345
0
12345
0
12345
buffer
buffer
buffer

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

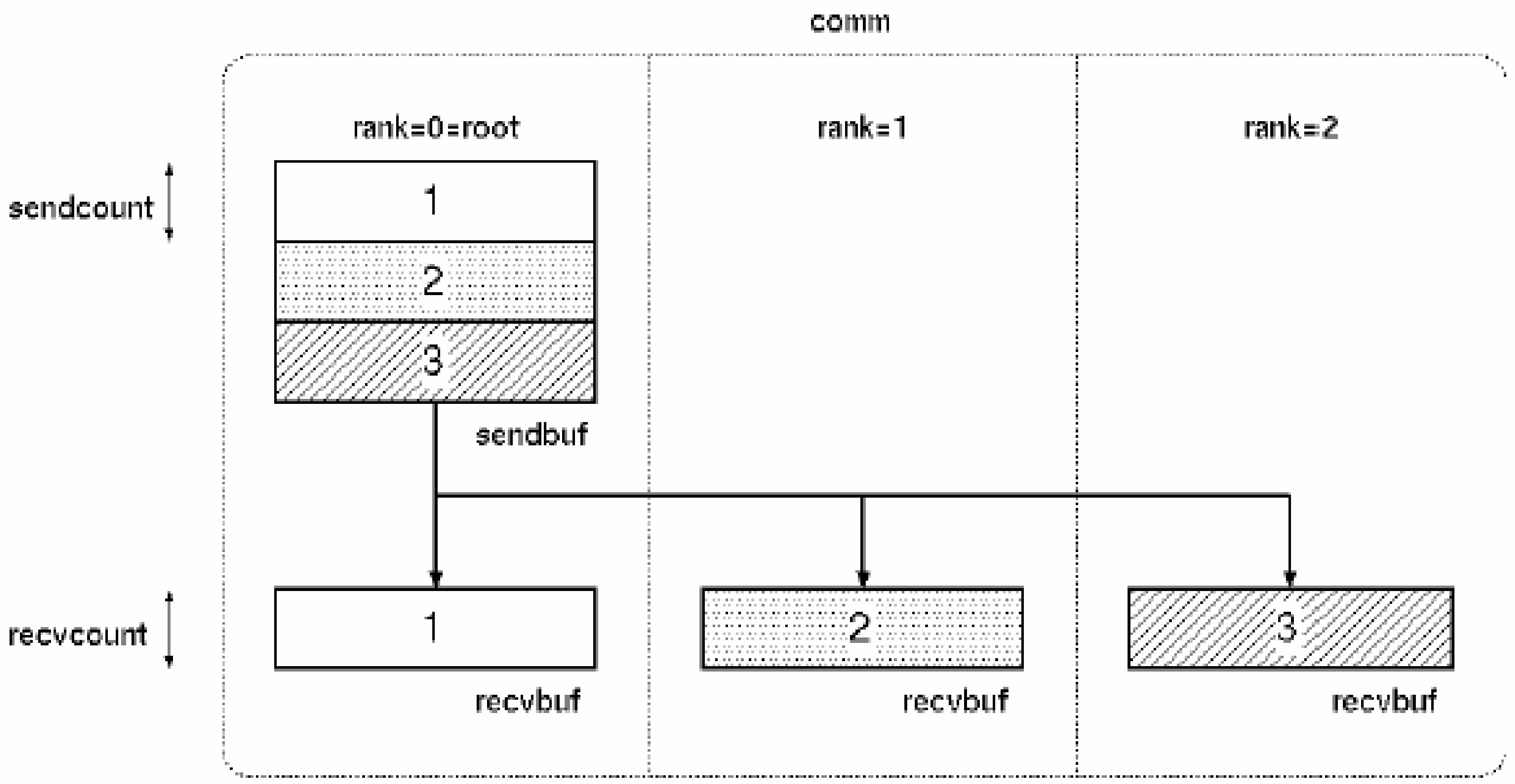
Example of MPI_Scatter (1)

```
#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 */
```

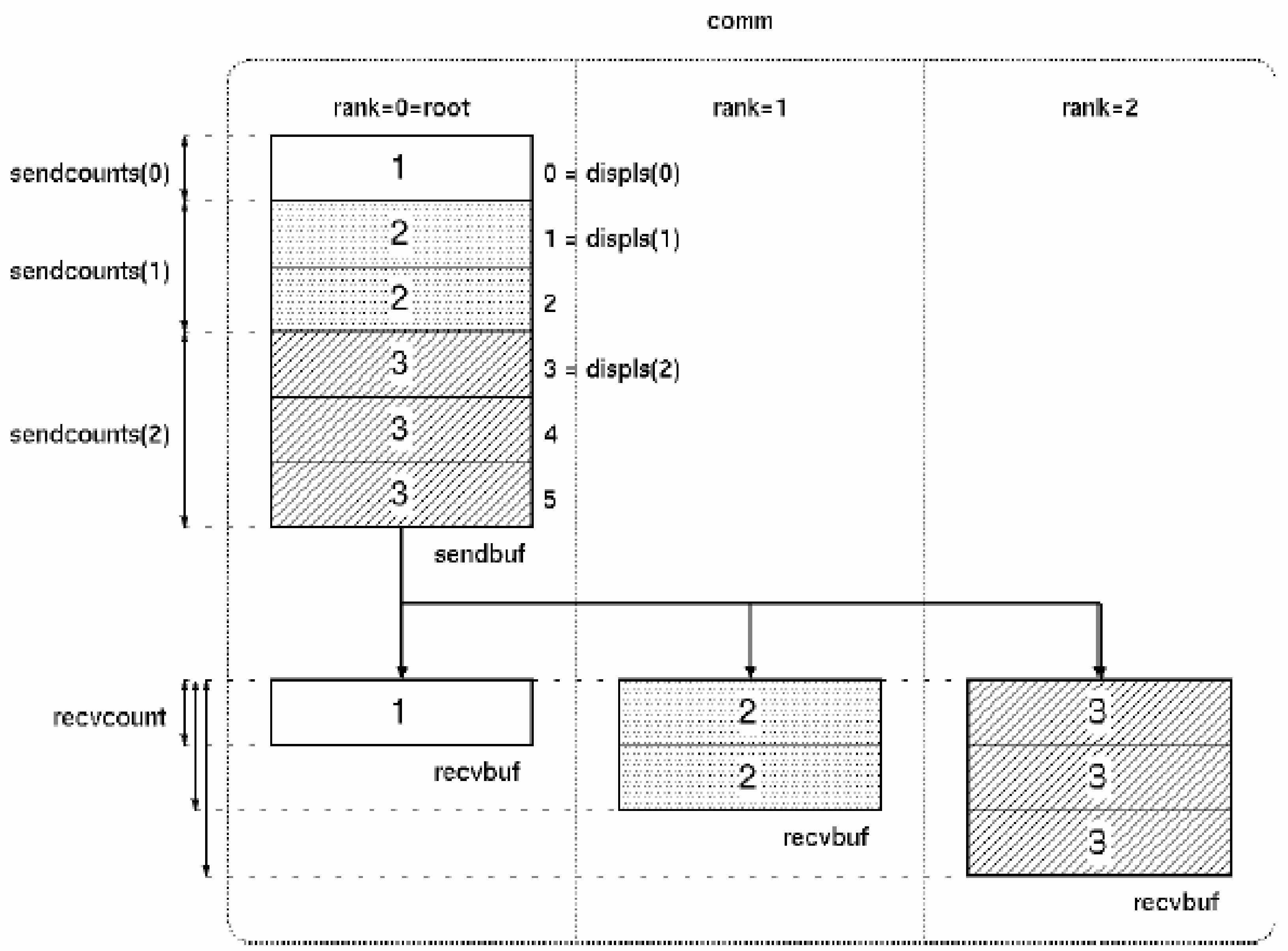
- Description
  - Distributes individual messages from root to each process in communicator
  - Messages can have different sizes and displacements

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();
}
```


comm
rank=0=root
rank=1
rank=2
sendcounts(0)
sendcounts(1)
sendcounts(2)
1
2
2
3
3
3
0 = displs(0)
1 = displs(1)
2
3 = displs(2)
4
5
sendbuf
recvcount
1
recvbuf
2
2
recvbuf
3
3
3
recvbuf

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

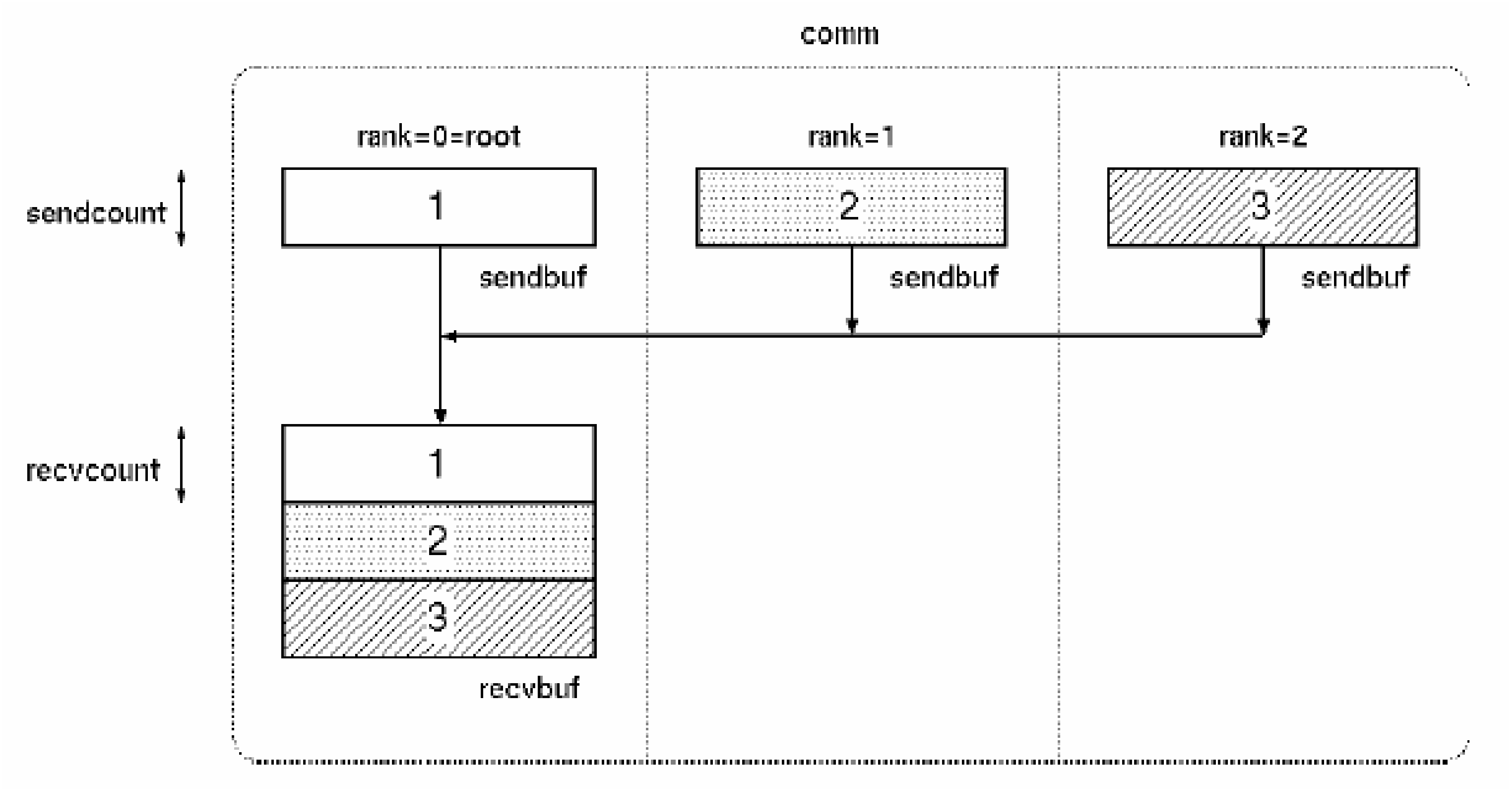
Example of MPI_Gather (1)

```
#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


comm
rank=0=root
rank=1
rank=2
sendcount
1
2
3
sendbuf
sendbuf
sendbuf
recvcount
1
2
3
recvbuf

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 */
```

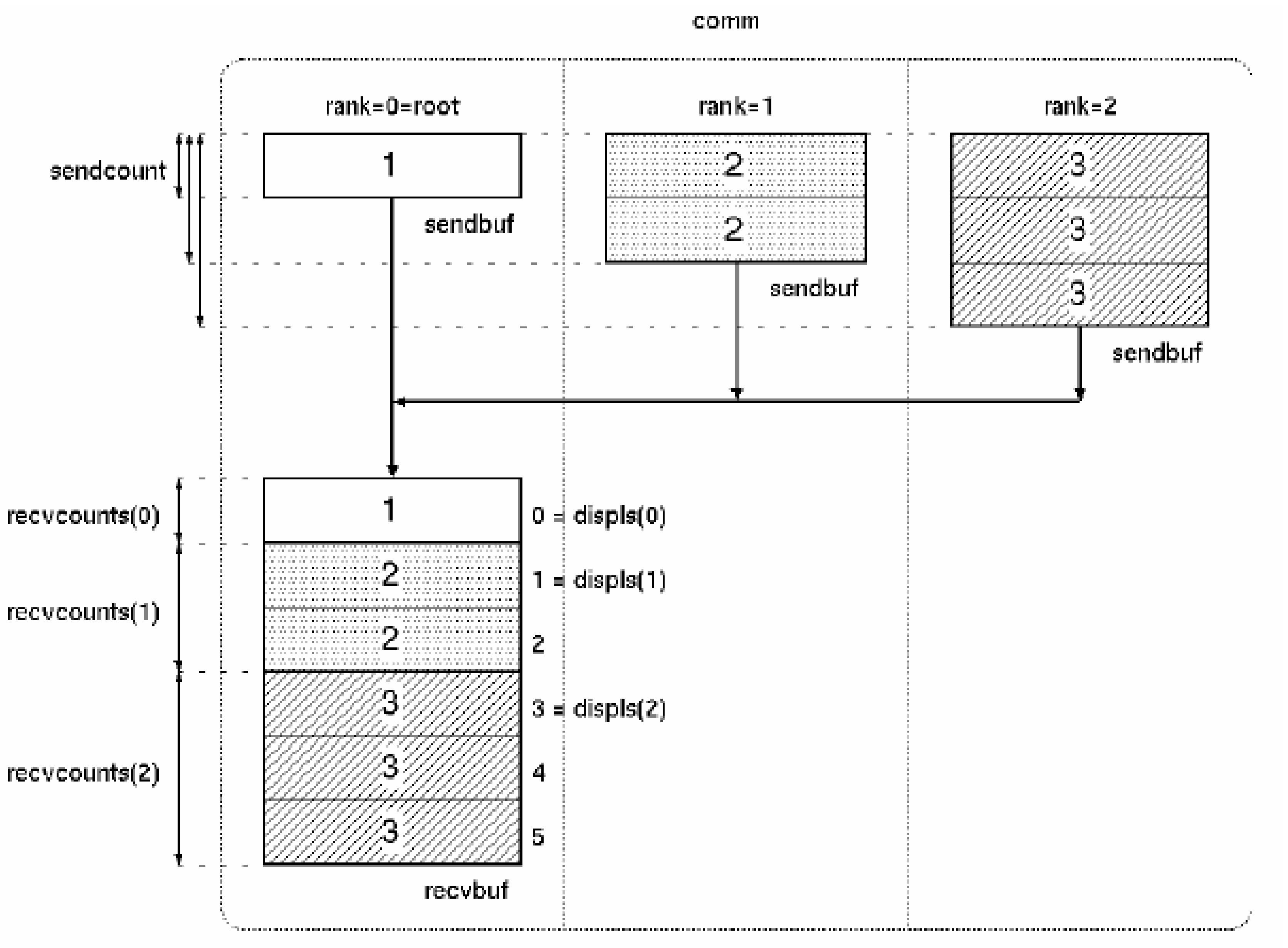
- Description
  - Collects individual messages from each process in communicator to the root process and store them in rank order

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();
}
```


comm
rank=0=root
rank=1
rank=2
sendcount
1
sendbuf
2
2
sendbuf
3
3
3
sendbuf
recvcounts(0)
recvcounts(1)
recvcounts(2)
1
2
2
3
3
3
0 = displs(0)
1 = displs(1)
2
3 = displs(2)
4
5
recvbuf

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 */
```

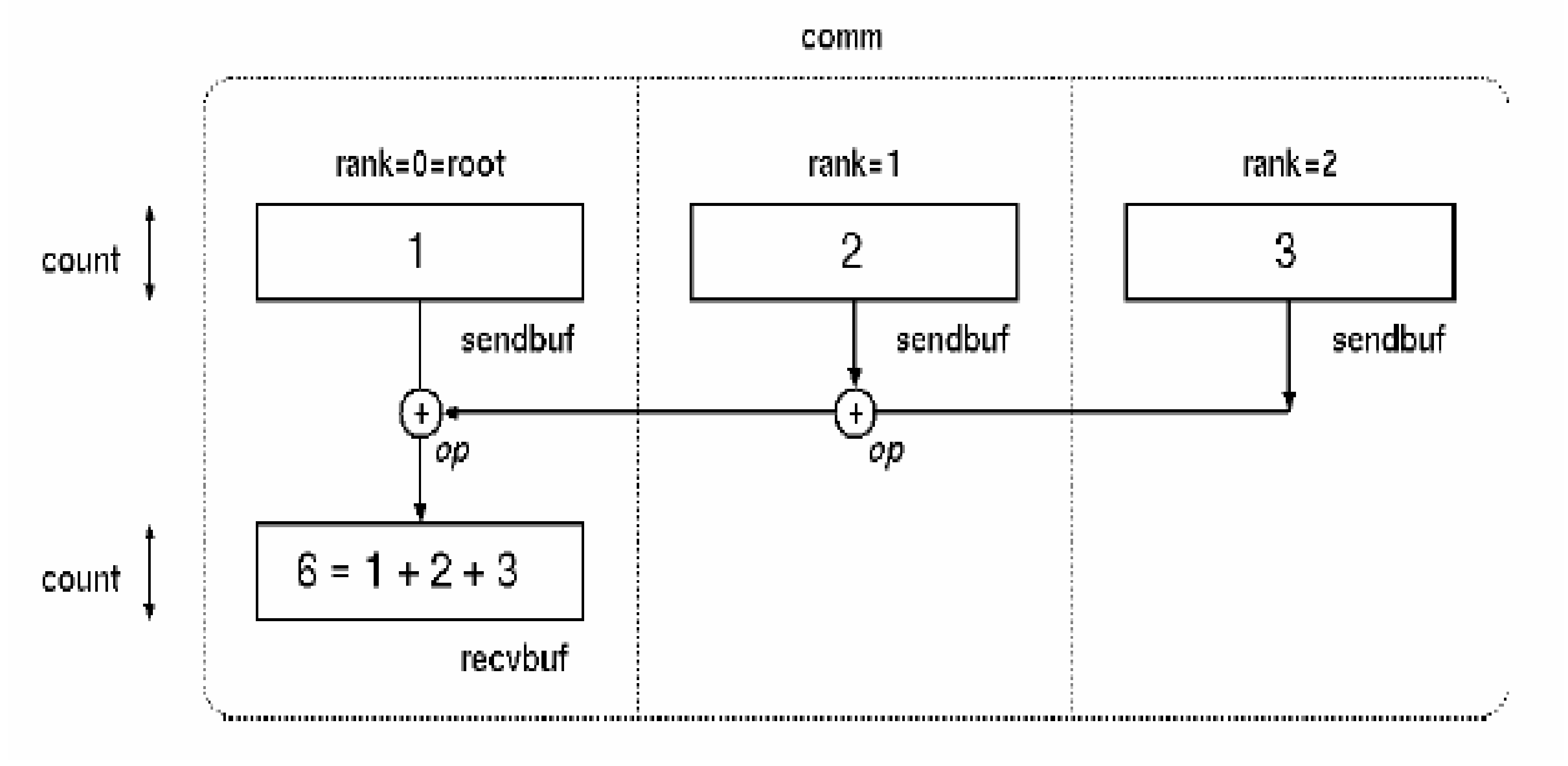
MPI_Reduce (2)

- 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

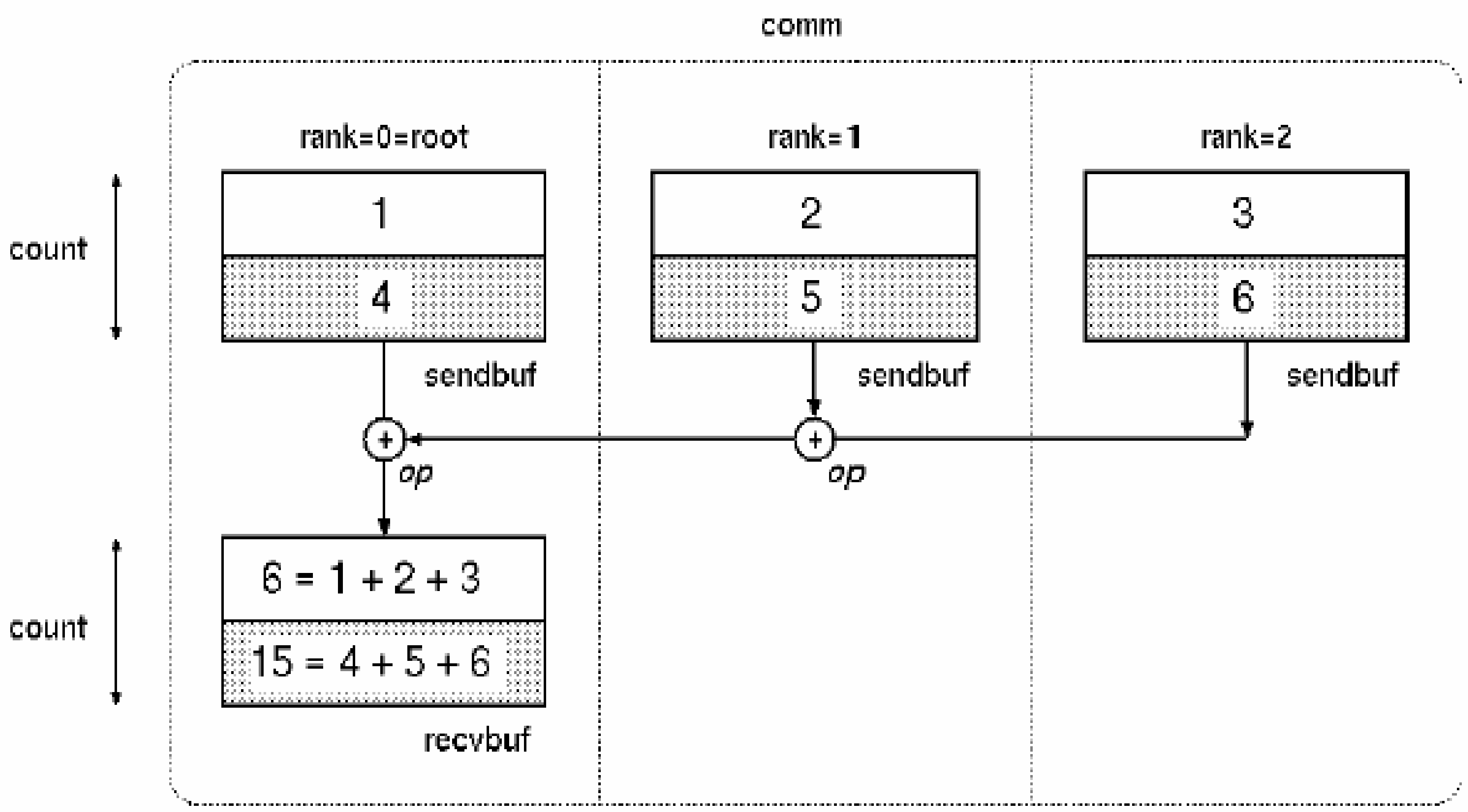
Example of MPI_Reduce

```
#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


comm
rank=0=root
rank=1
rank=2
count
1
2
3
sendbuf
sendbuf
sendbuf
op
op
count
6 = 1 + 2 + 3
recvbuf

MPI_Reduce


comm
rank=0=root
rank=1
rank=2
count
1
4
2
5
3
6
sendbuf
sendbuf
sendbuf
op
op
count
6 = 1 + 2 + 3
15 = 4 + 5 + 6
recvbuf

MPI_Scan

- Usage

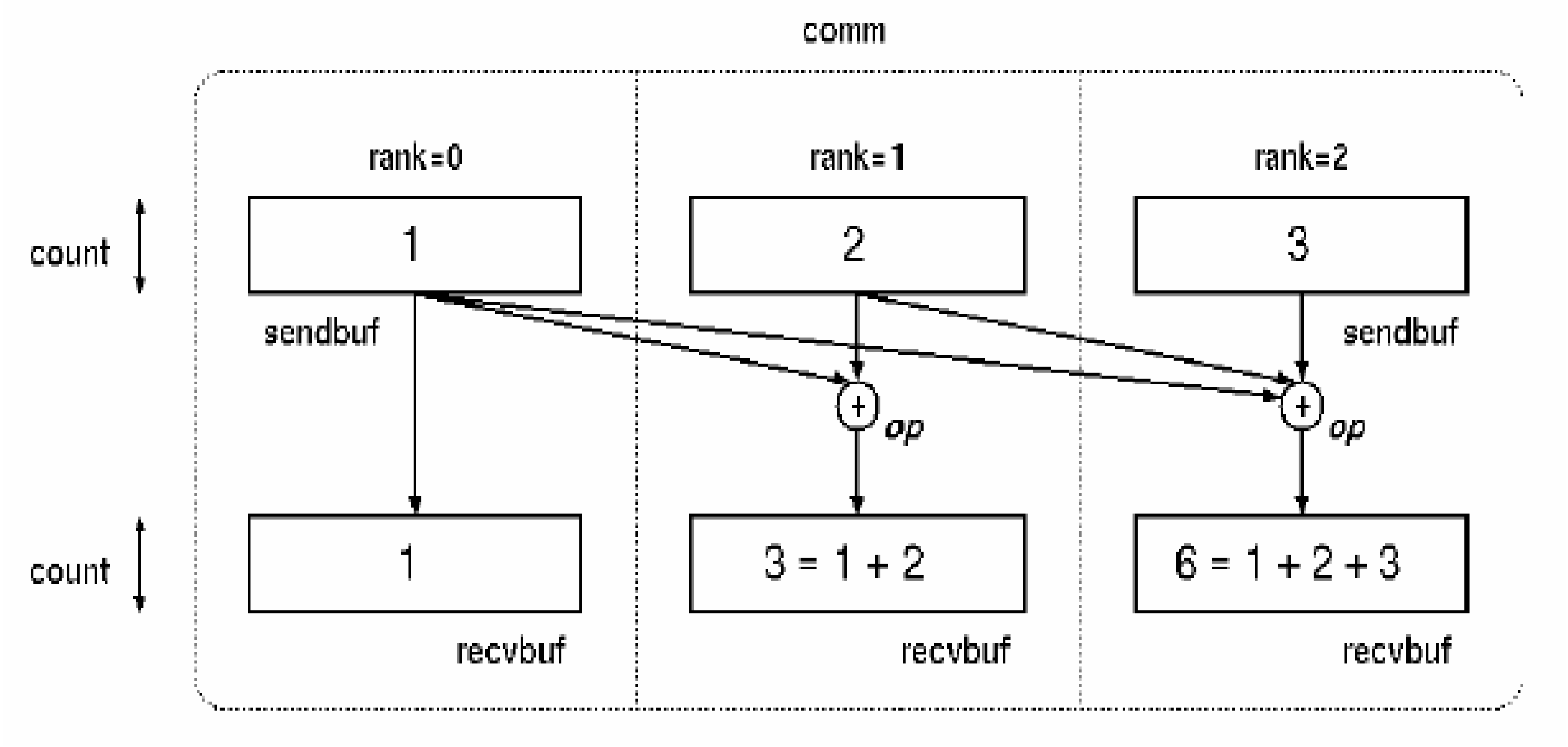
```
int MPI_Scan( void* sendbuf,            /* in */
              void* recvbuf,            /* out */
              int count,                /* in */
              MPI_Datatype datatype,    /* in */
              MPI_Op op,                /* in */
              MPI_Comm comm);           /* in */
```

- 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


comm
rank=0
rank=1
rank=2
count
count
1
2
3
sendbuf
sendbuf
op
op
1
3 = 1 + 2
6 = 1 + 2 + 3
recvbuf
recvbuf
recvbuf

MPI_Barrier

- Usage

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

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