MPI

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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>

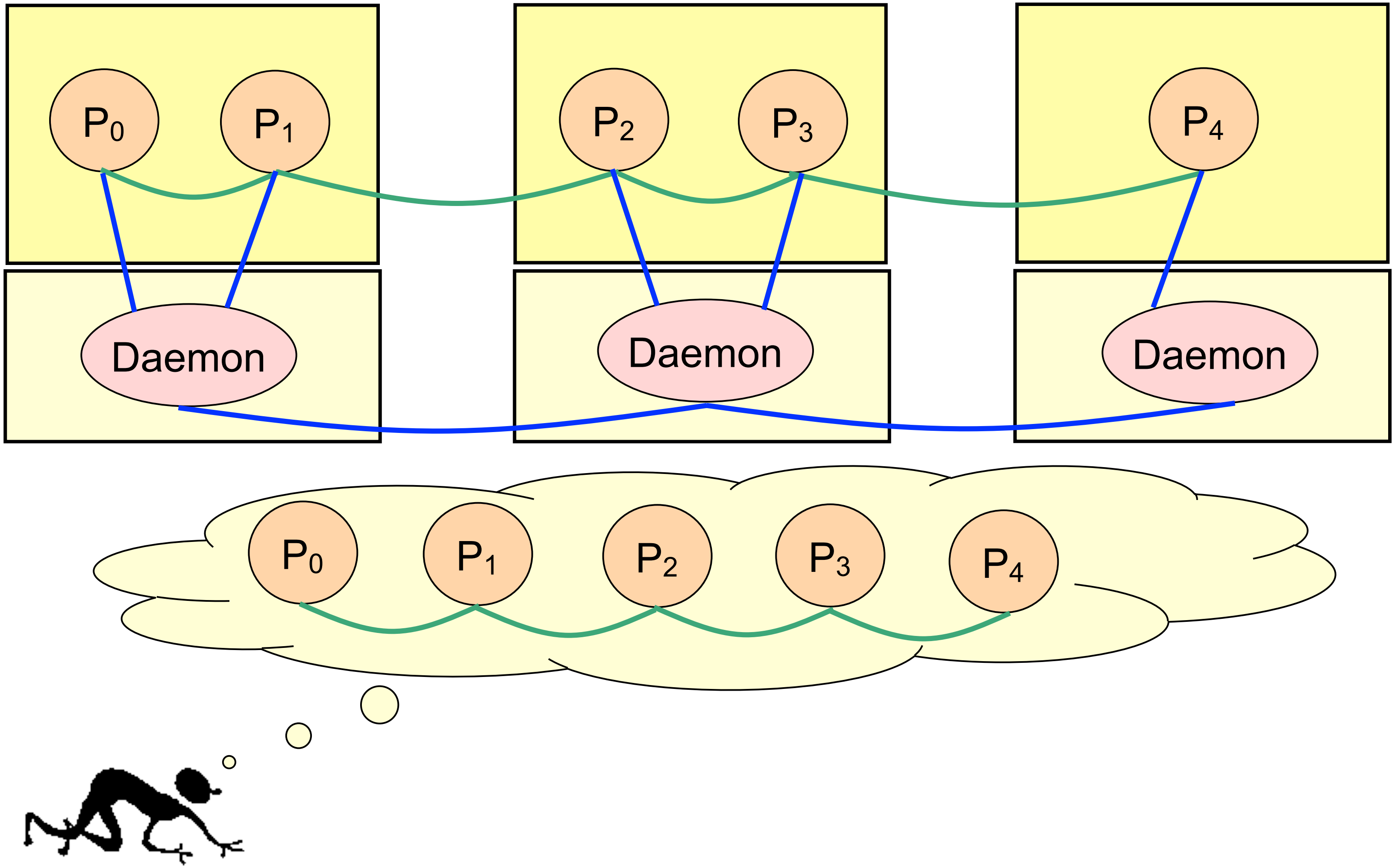
TERMs (2)

- ❑ 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



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 */
```

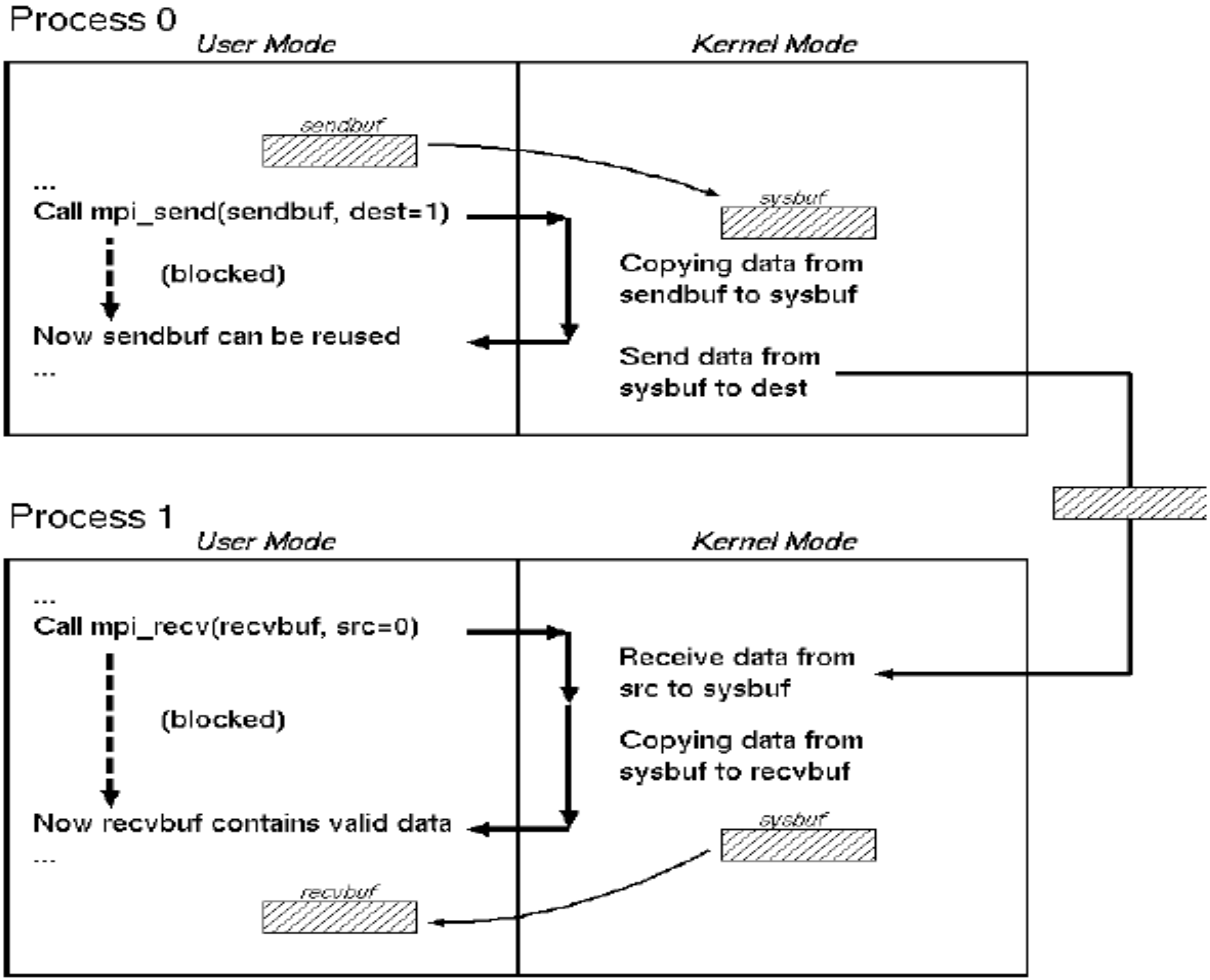
- Description
  - Performs a blocking standard mode send operation
  - The message can be received by either MPI_RECV or MPI_IRECV

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

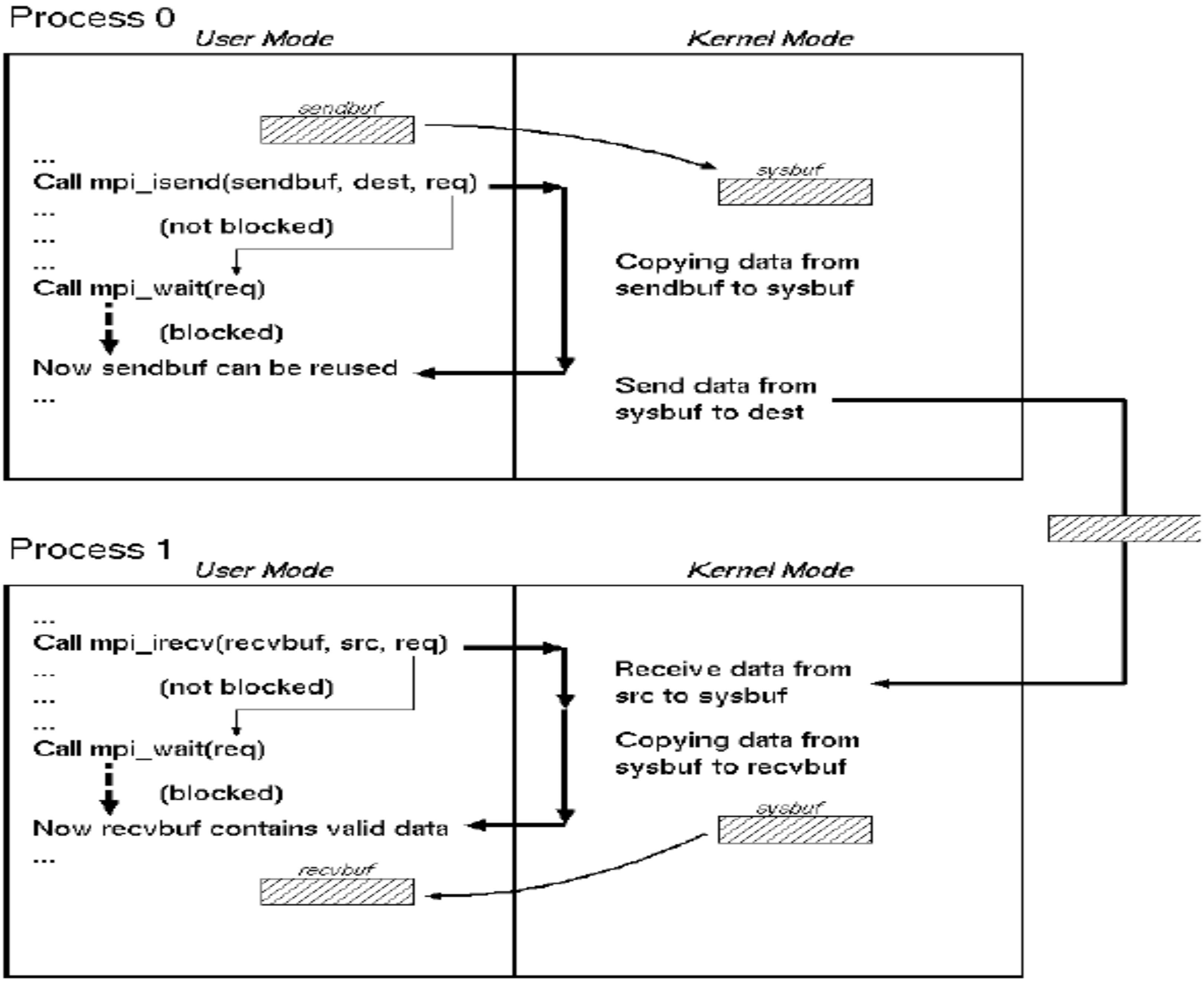
- Performs a nonblocking receive operation
- Do not access any part of the receive buffer until the receive is complete
- The message received must be less than or equal to the length of the receive buffer
- MPI_IRECV can receive a message sent by either MPI_SEND or MPI_ISEND

MPI_Wait

- Usage
  - int MPI_Wait(MPI_Request* request, /* inout */

```
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 */
  ```

- 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

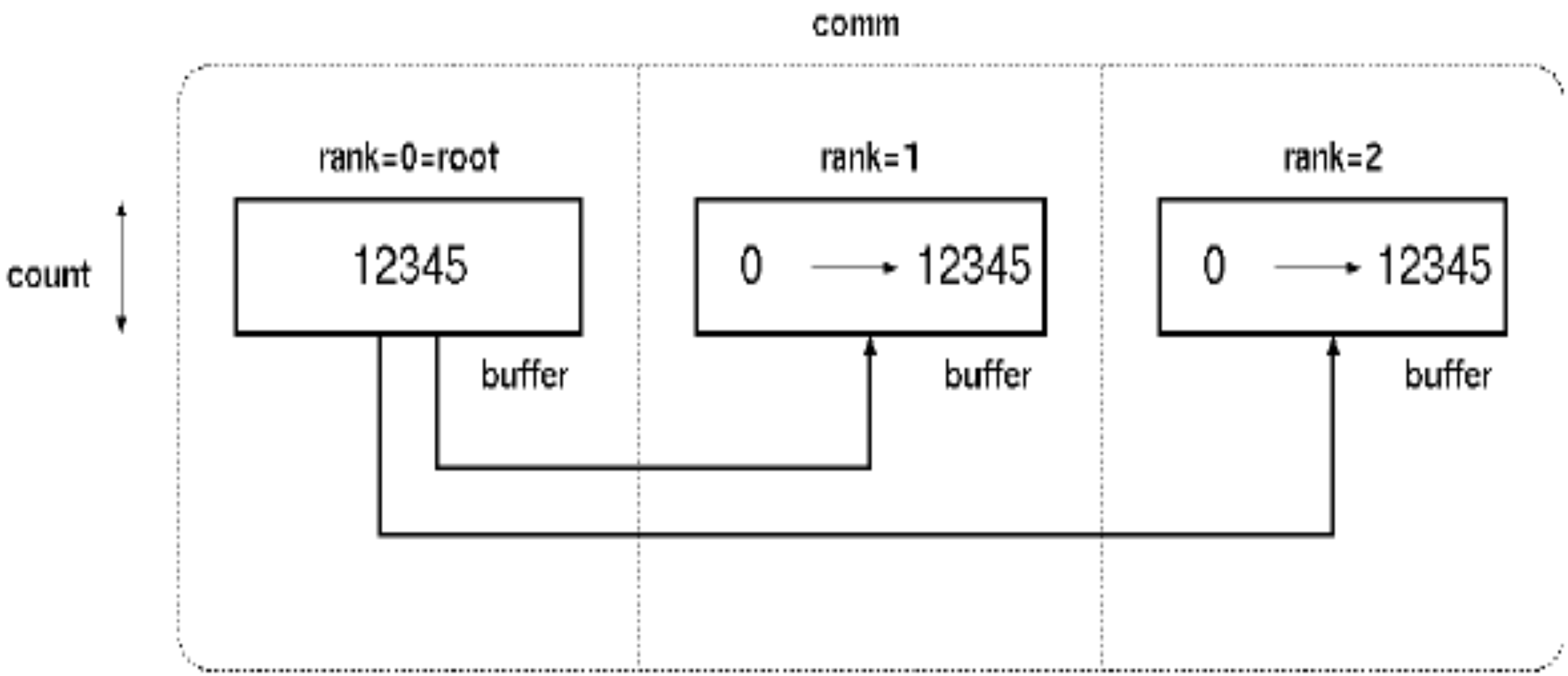
MPI_Bcast (1)

- Usage
  - int MPI_Bcast(void* buffer, /* inout */

```
int 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

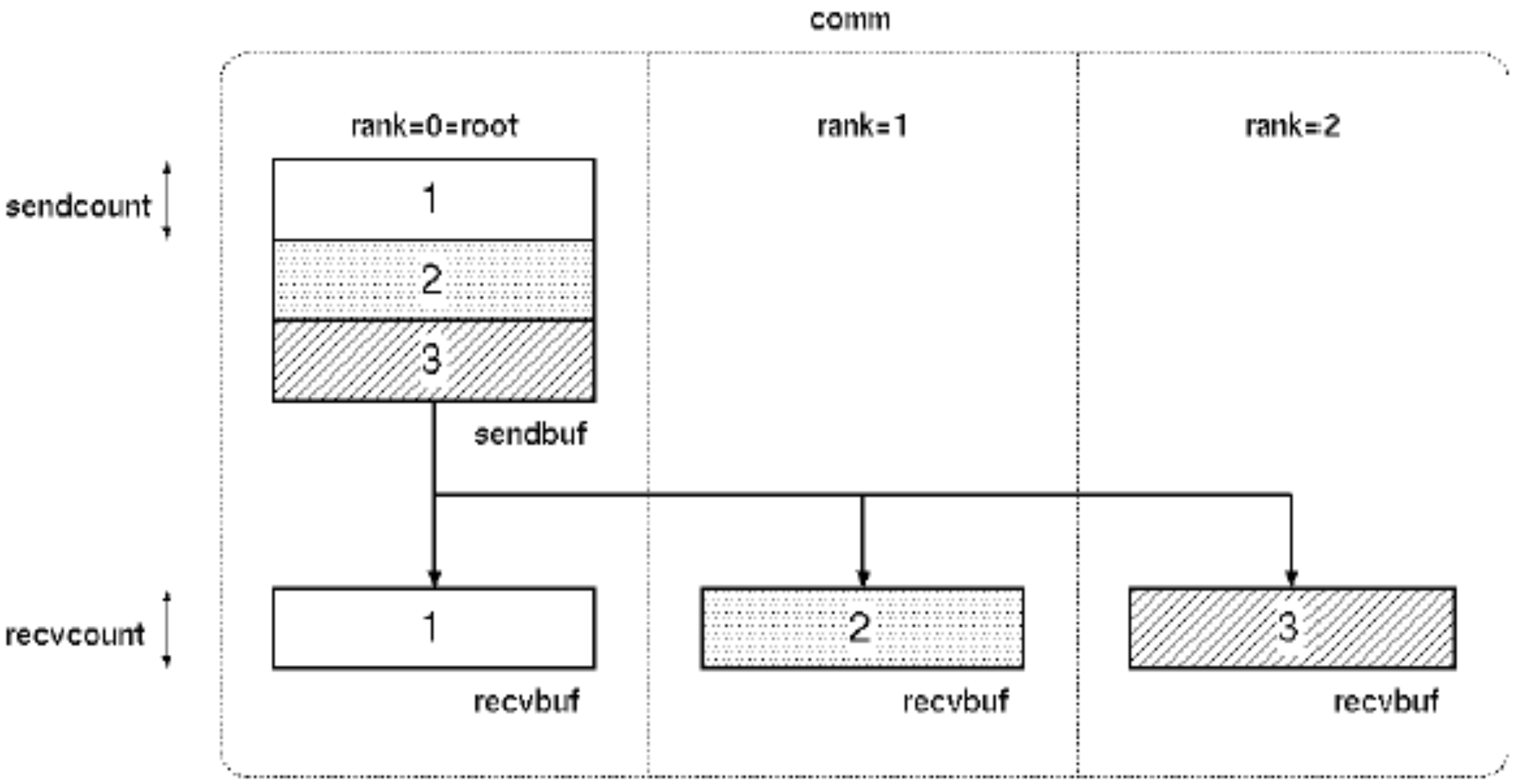
Example of MPI_Scatter (1)

```
#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 */
```

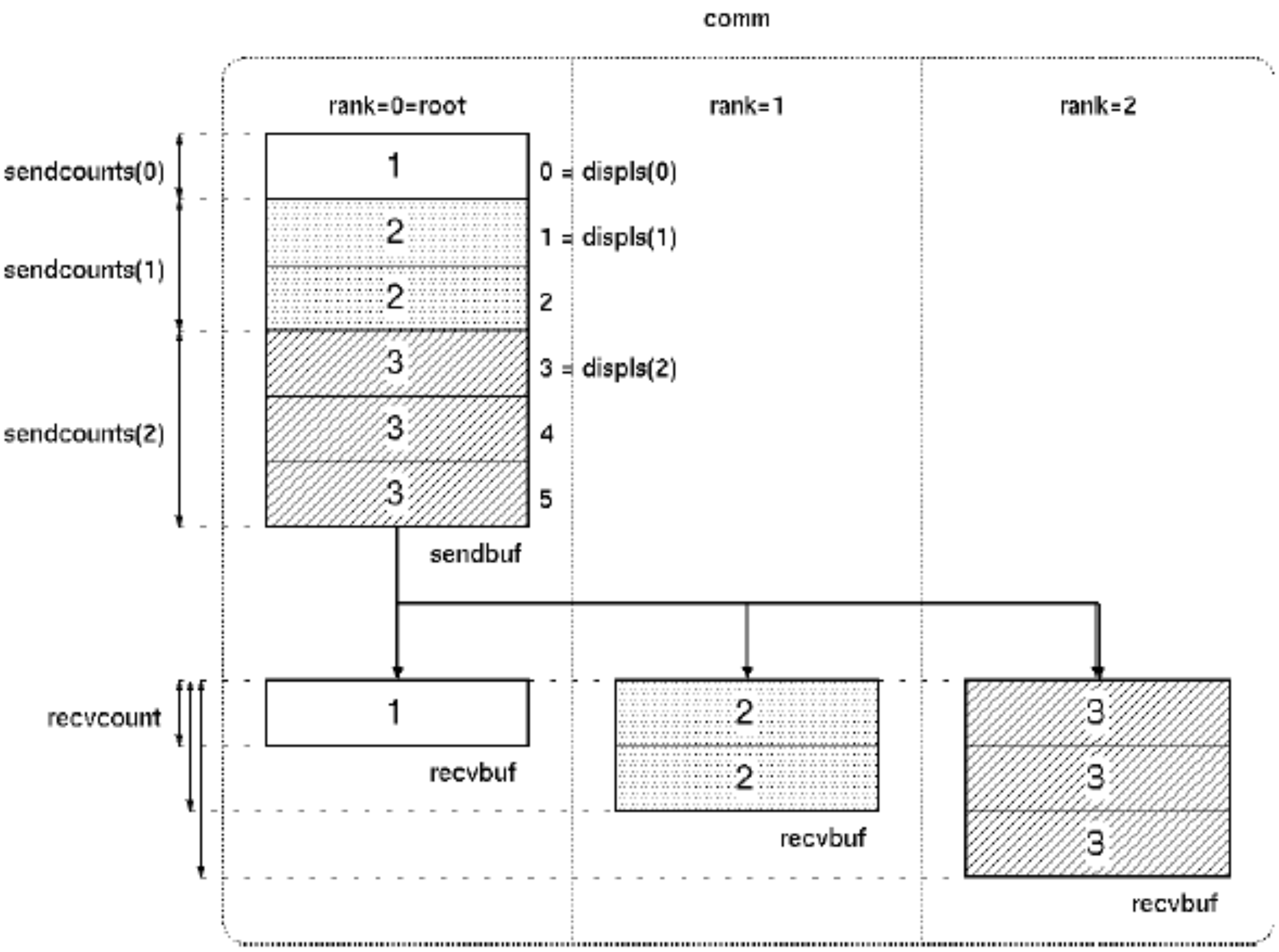
- Description
  - Distributes individual messages from root to each process in communicator
  - Messages can have different sizes and displacements

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

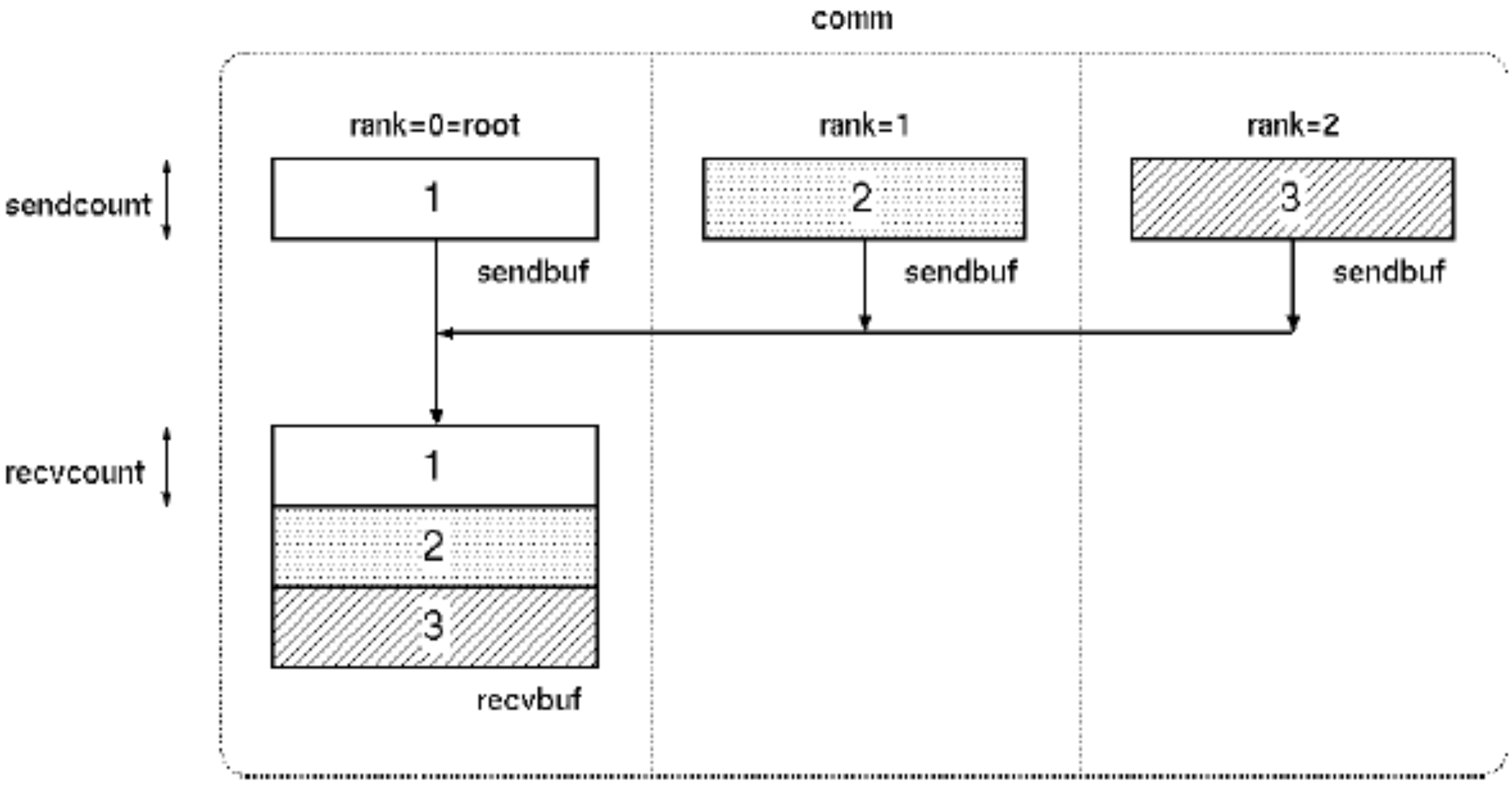
Example of MPI_Gather (1)

```
#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 */
```

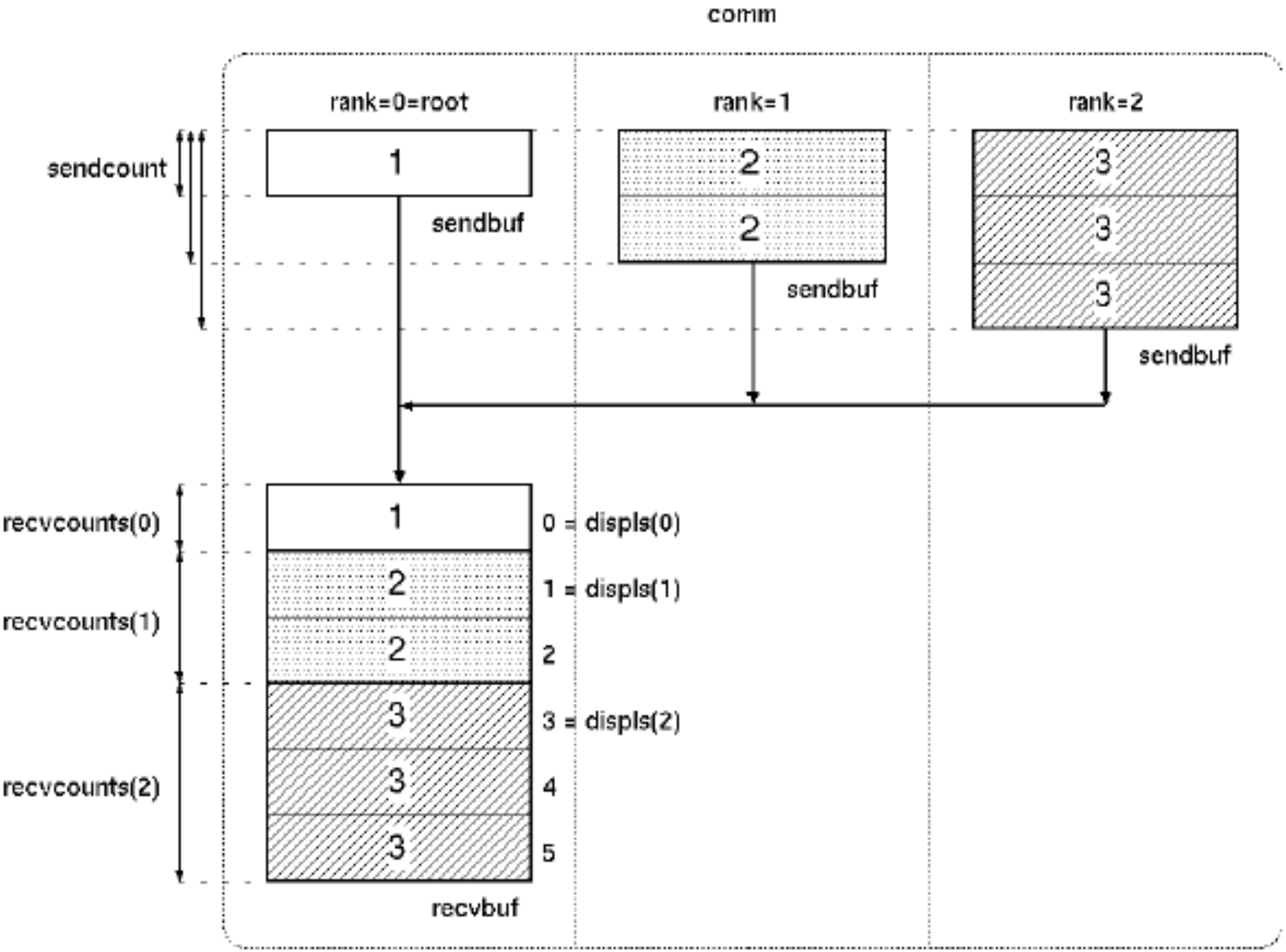
- Description
  - Collects individual messages from each process in communicator to the root process and store them in rank order

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 */
```

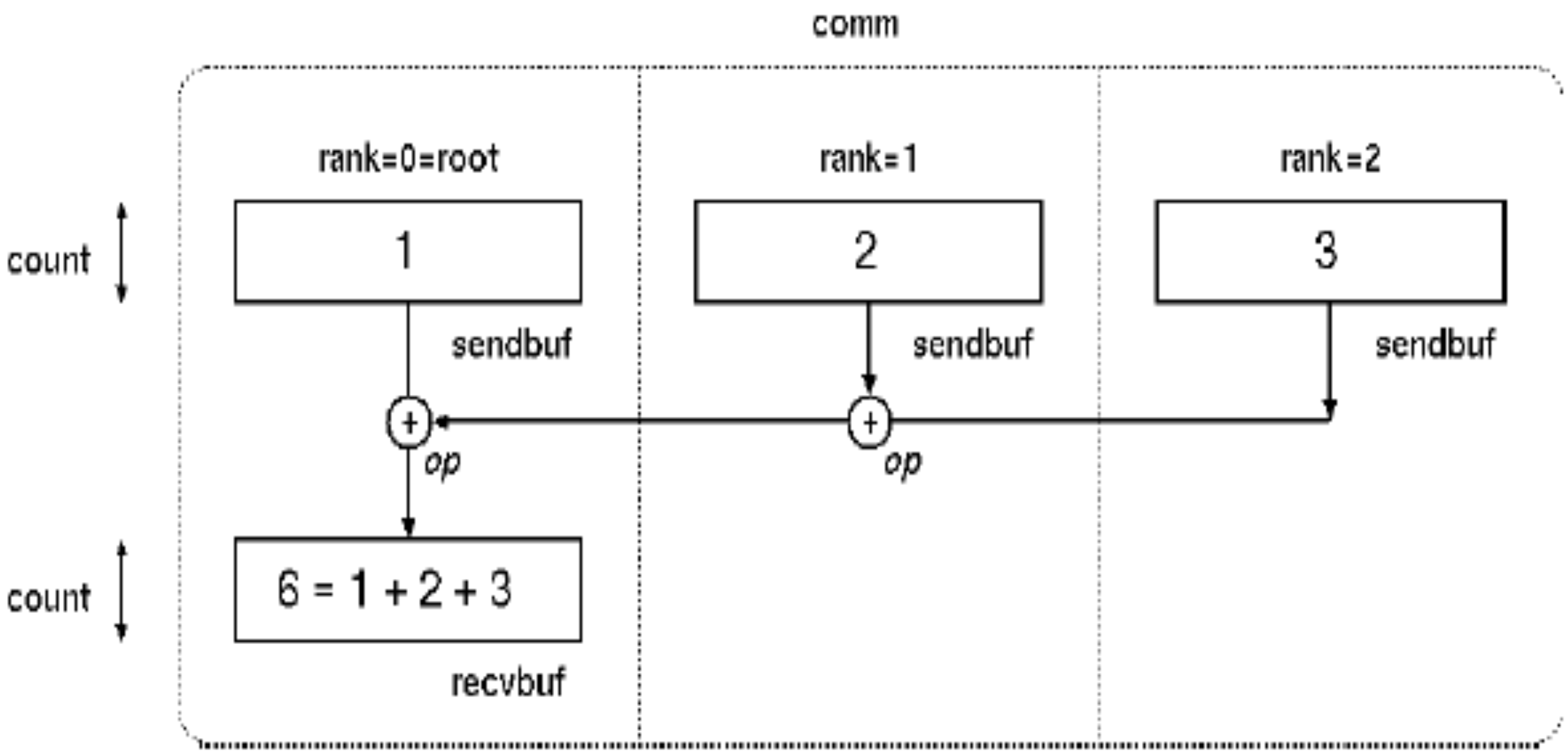
MPI_Reduce (2)

- 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

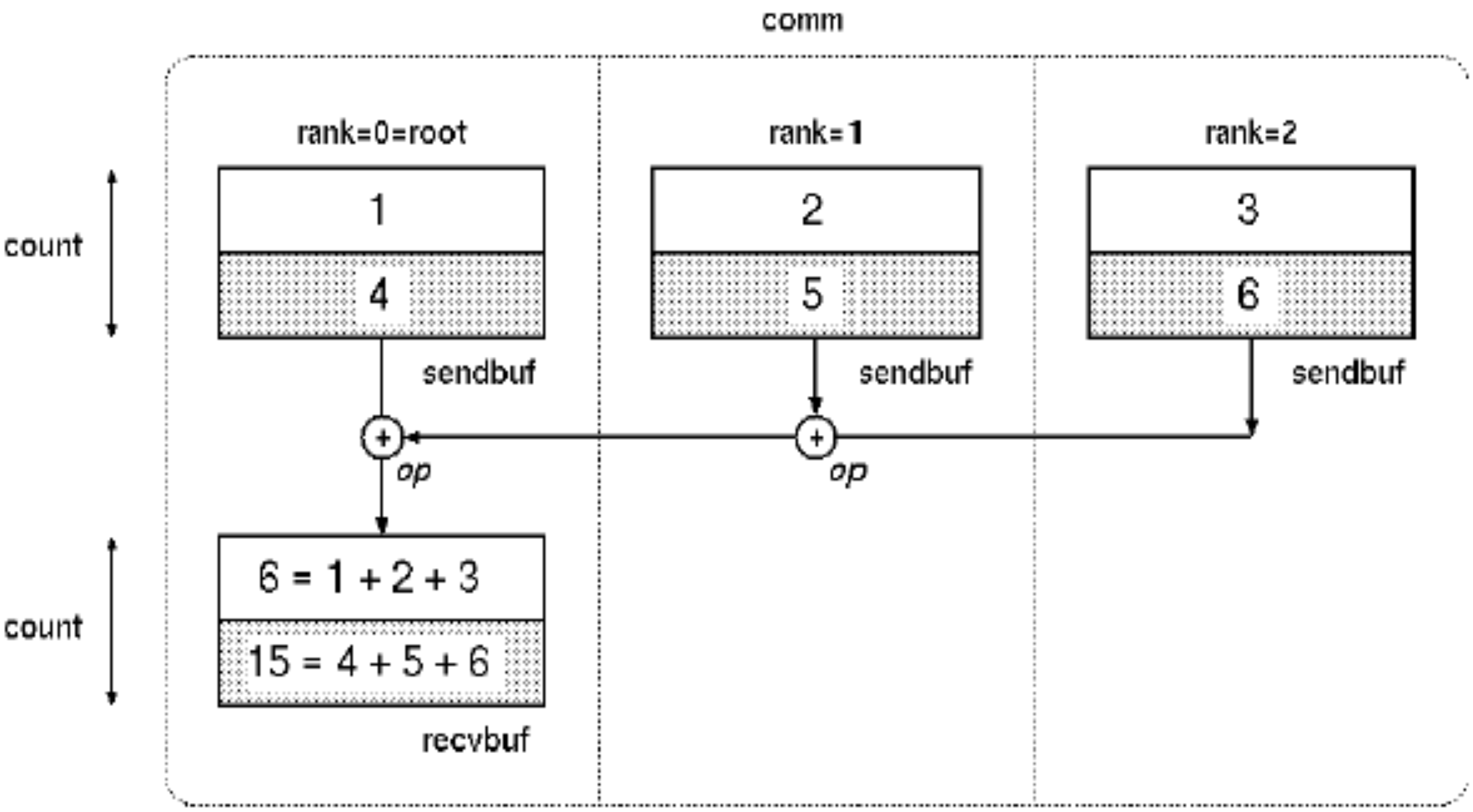
Example of MPI_Reduce

```
#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

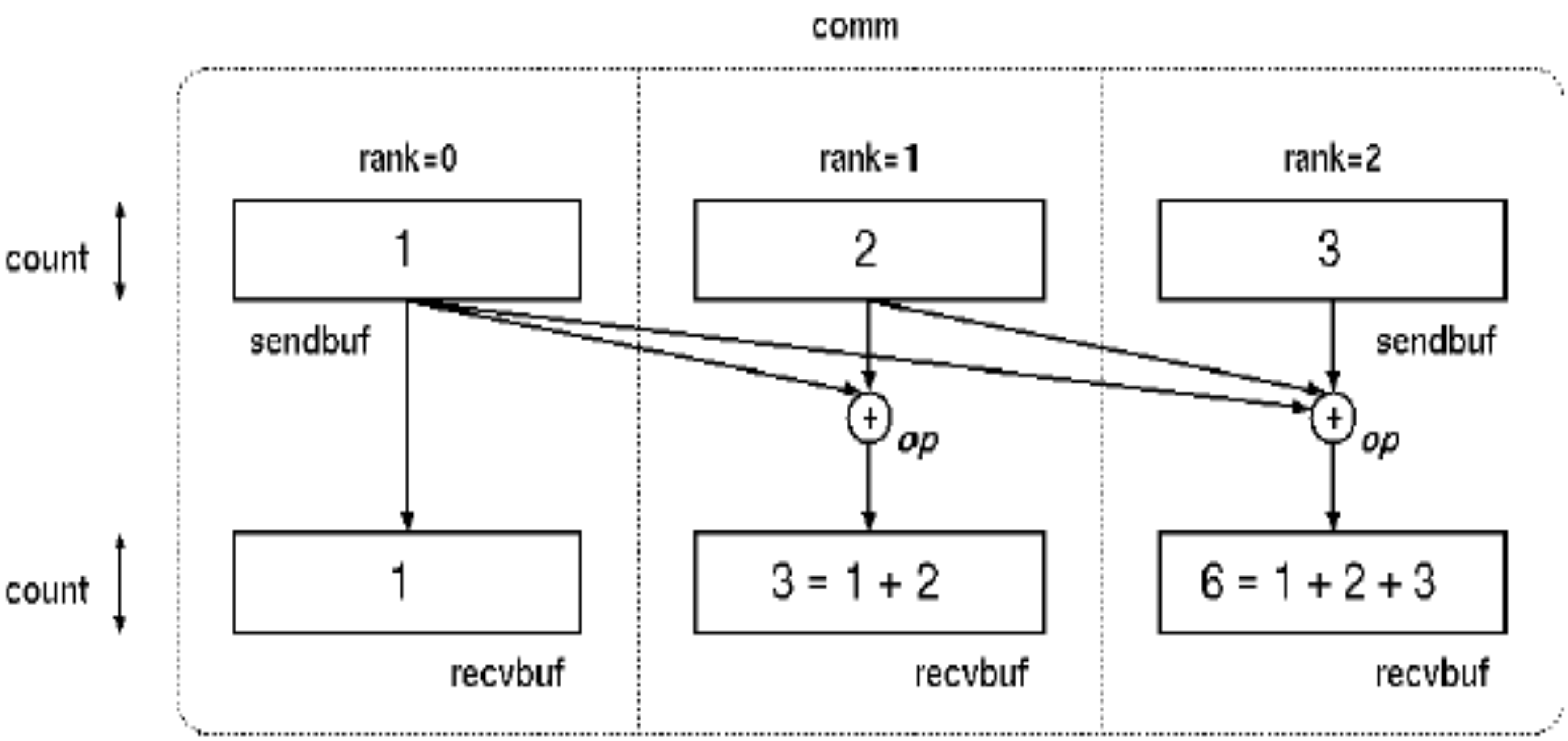
```
int MPI_Scan( void* sendbuf,                    /* in */
              void* recvbuf,                    /* out */
              int count,                        /* in */
              MPI_Datatype datatype,        /* in */
              MPI_Op op,                    /* in */
              MPI_Comm 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
1
2
3
sendbuf
sendbuf
op
op
count
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

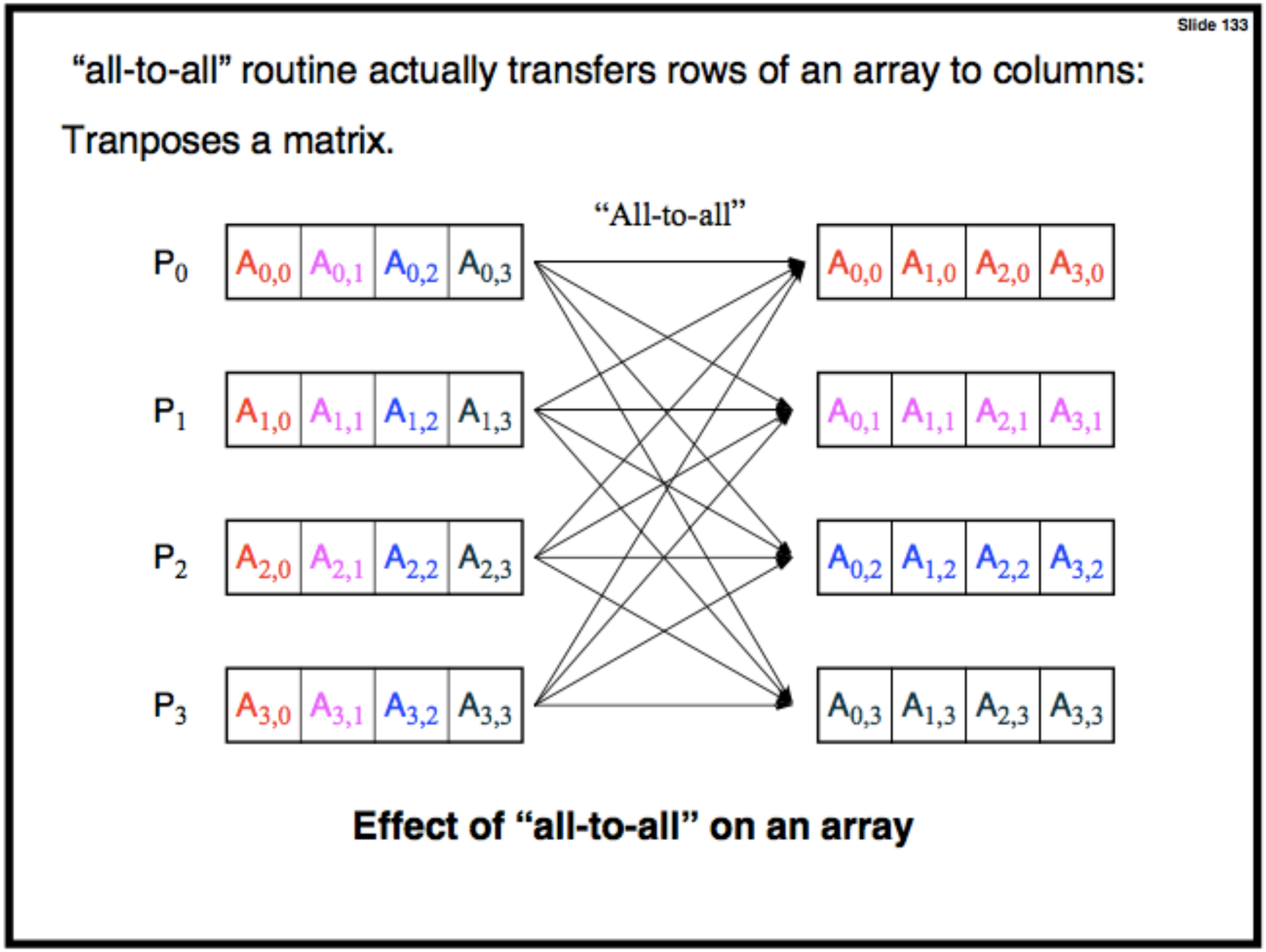
MPI_Alltoall

- Usage

```
int MPI_Alltoall(
    const void *sendbuf, int sendcount, MPI_Datatype sendtype,
    void *recvbuf, int recvcount, MPI_Datatype recvtype,
    MPI_Comm comm)
```

- Description
  - Thread-safe
  - All-to-all communication

All-to-all



Slide 133

"all-to-all" routine actually transfers rows of an array to columns:

Tranposes a matrix.

"All-to-all"

P_0	$A_{0,0}$	$A_{0,1}$	$A_{0,2}$	$A_{0,3}$	$A_{0,0}$	$A_{1,0}$	$A_{2,0}$	$A_{3,0}$
P_1	$A_{1,0}$	$A_{1,1}$	$A_{1,2}$	$A_{1,3}$	$A_{0,1}$	$A_{1,1}$	$A_{2,1}$	$A_{3,1}$
P_2	$A_{2,0}$	$A_{2,1}$	$A_{2,2}$	$A_{2,3}$	$A_{0,2}$	$A_{1,2}$	$A_{2,2}$	$A_{3,2}$
P_3	$A_{3,0}$	$A_{3,1}$	$A_{3,2}$	$A_{3,3}$	$A_{0,3}$	$A_{1,3}$	$A_{2,3}$	$A_{3,3}$

Effect of "all-to-all" on an array

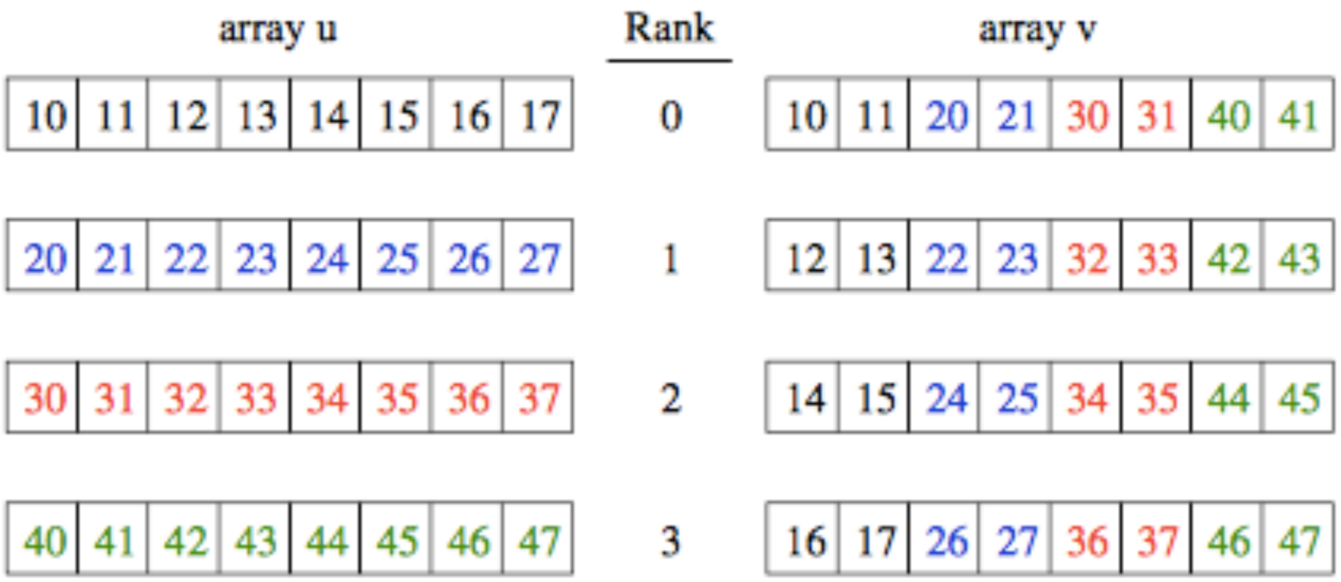
Slides for *Parallel Programming Techniques and Applications Using Networked Workstations and Parallel Computers* by Barry Wilkinson and Michael Allen, Prentice Hall, Upper Saddle River, New Jersey, USA, ISBN 0-13-671710-1. © 2002 by Prentice Hall Inc. All rights reserved.

All-to-all

Suppose there are four processes including the root, each with arrays as shown below on the left. After the all-to-all operation

```
MPI_Alltoall(u, 2, MPI_INT, v, 2, MPI_INT, MPI_COMM_WORLD);
```

the data will be distributed as shown below on the right:



array u								Rank	array v							
10	11	12	13	14	15	16	17	0	10	11	20	21	30	31	40	41
20	21	22	23	24	25	26	27	1	12	13	22	23	32	33	42	43
30	31	32	33	34	35	36	37	2	14	15	24	25	34	35	44	45
40	41	42	43	44	45	46	47	3	16	17	26	27	36	37	46	47

MPI_Sendrecv

- Usage

```
int MPI_Sendrecv(const void *sendbuf, int sendcount,
          MPI_Datatype sendtype, int dest, int sendtag,
     void *recvbuf, int recvcount, MPI_Datatype recvtype,
          int source, int recvtag,
    MPI_Comm comm, MPI_Status *status)
```

- Description
  - Thread-safe
  - Send & Recv proceed in parallel

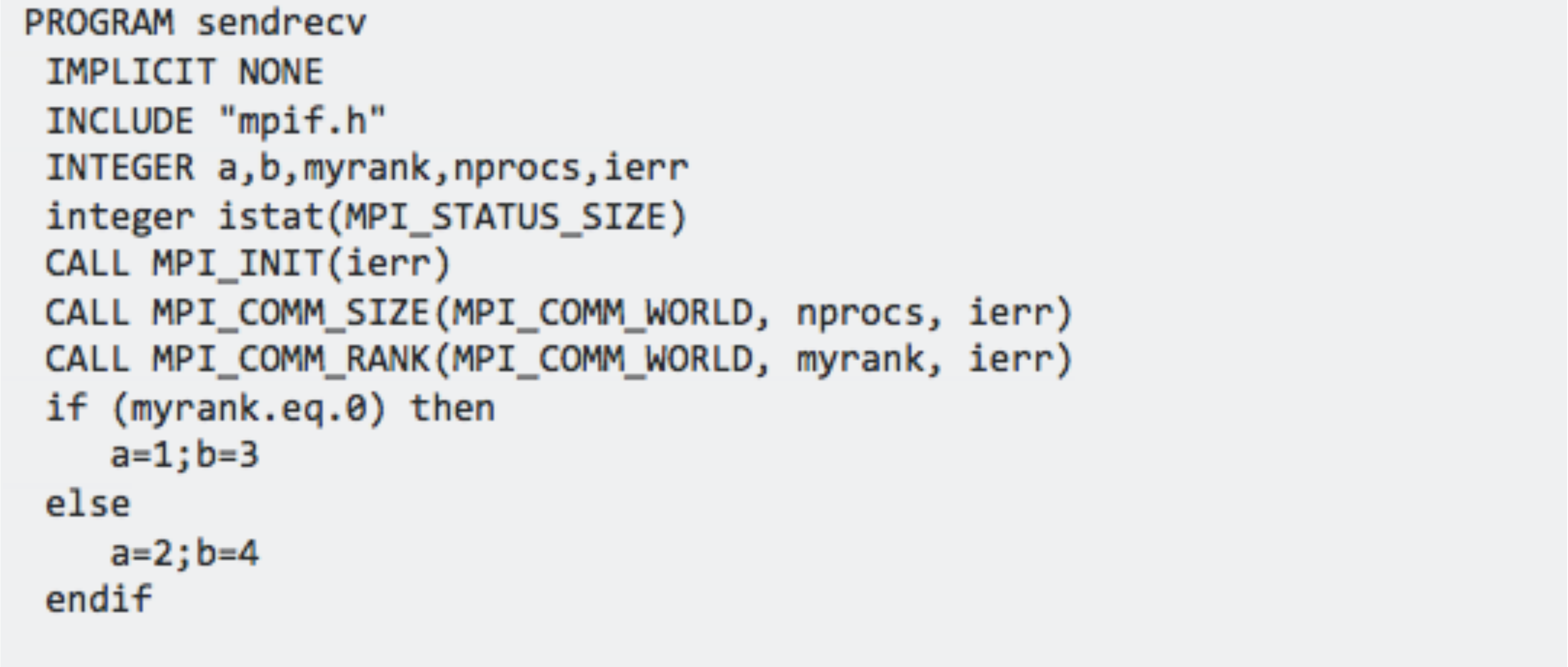
MPI_Sendrecv_replace

- Usage

```
int MPI_Sendrecv_replace(
    void *buf, int count, MPI_Datatype datatype,
    int dest, int sendtag,
    int source, int recvtag,
    MPI_Comm comm, MPI_Status *status)
```

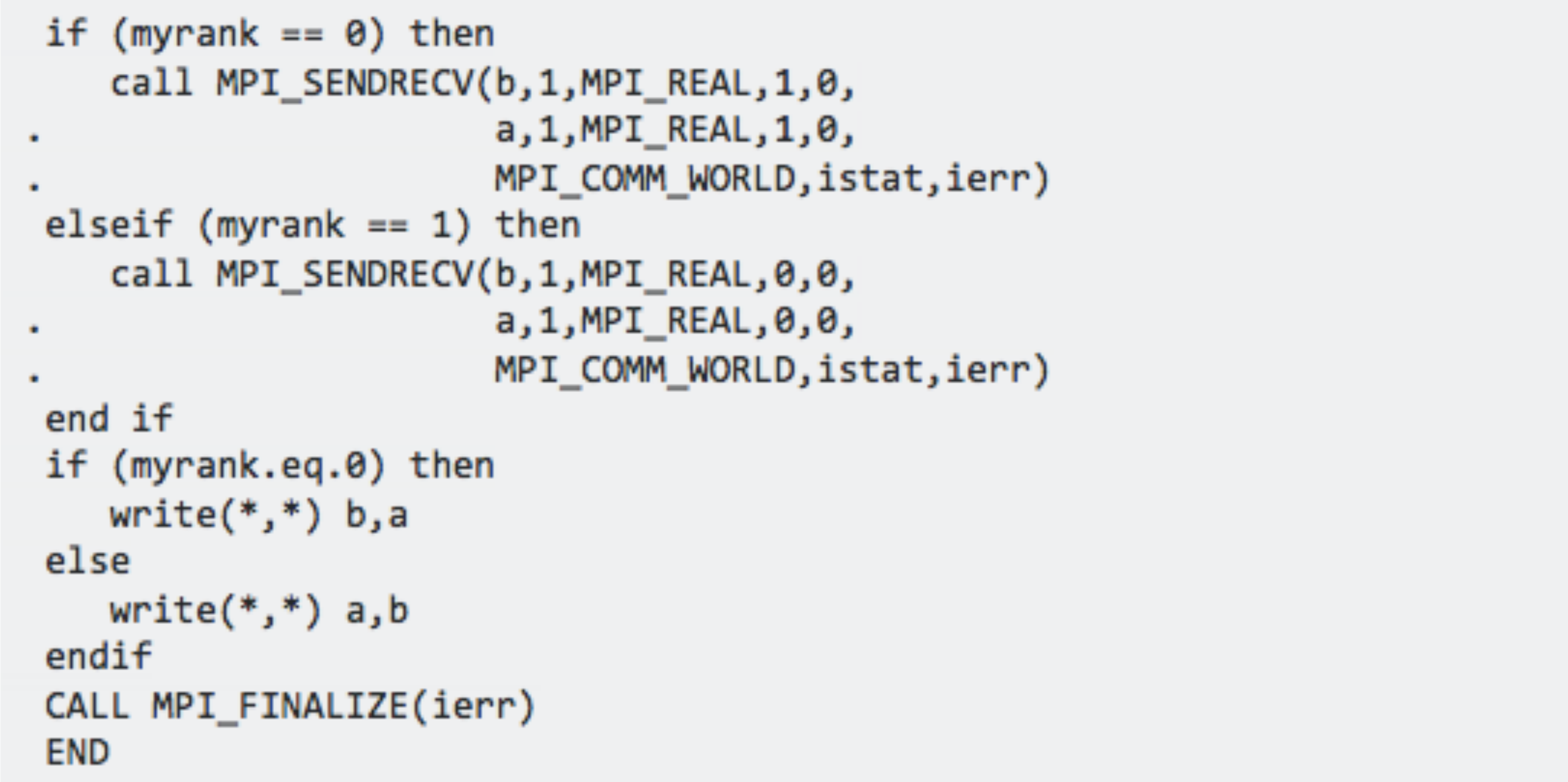
- Description
  - Thread-safe
  - Send & Recv proceed in parallel

MPI_Sendrecv example (1)



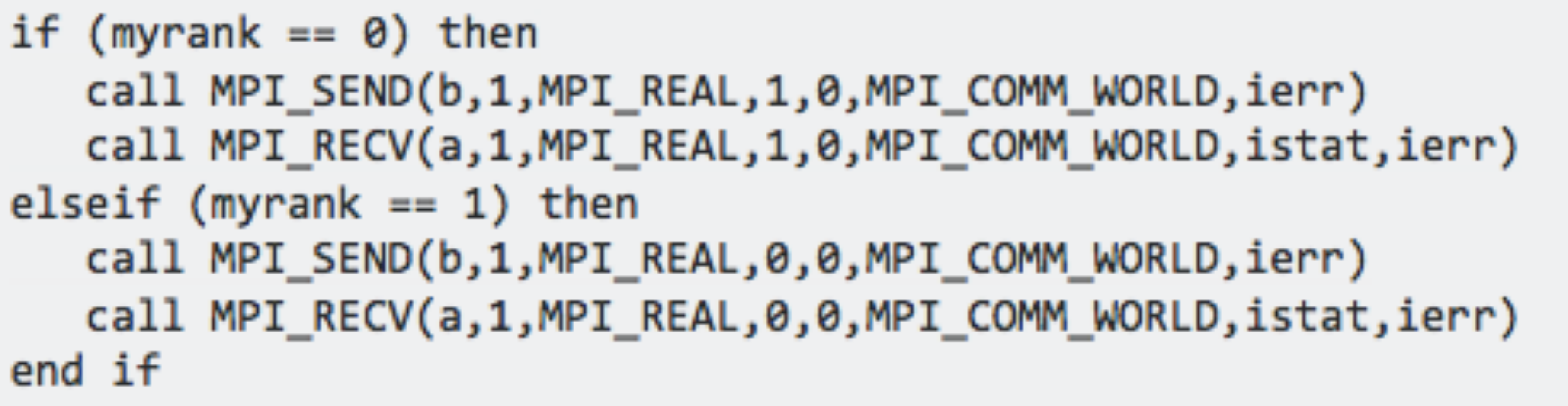
```
PROGRAM sendrecv
 IMPLICIT NONE
 INCLUDE "mpif.h"
 INTEGER a,b,myrank,nprocs,ierr
 integer istat(MPI_STATUS_SIZE)
 CALL MPI_INIT(ierr)
 CALL MPI_COMM_SIZE(MPI_COMM_WORLD, nprocs, ierr)
 CALL MPI_COMM_RANK(MPI_COMM_WORLD, myrank, ierr)
 if (myrank.eq.0) then
    a=1;b=3
 else
    a=2;b=4
 endif
```

MPI_Sendrecv example (2)



```
 if (myrank == 0) then
    call MPI_SENDRECV(b,1,MPI_REAL,1,0,
.                     a,1,MPI_REAL,1,0,
.                     MPI_COMM_WORLD,istat,ierr)
 elseif (myrank == 1) then
    call MPI_SENDRECV(b,1,MPI_REAL,0,0,
.                     a,1,MPI_REAL,0,0,
.                     MPI_COMM_WORLD,istat,ierr)
 end if
 if (myrank.eq.0) then
    write(*,*) b,a
 else
    write(*,*) a,b
 endif
 CALL MPI_FINALIZE(ierr)
 END
```

MPI_Sendrecv example (3)



```
if (myrank == 0) then
   call MPI_SEND(b,1,MPI_REAL,1,0,MPI_COMM_WORLD,ierr)
   call MPI_RECV(a,1,MPI_REAL,1,0,MPI_COMM_WORLD,istat,ierr)
elseif (myrank == 1) then
   call MPI_SEND(b,1,MPI_REAL,0,0,MPI_COMM_WORLD,ierr)
   call MPI_RECV(a,1,MPI_REAL,0,0,MPI_COMM_WORLD,istat,ierr)
end if
```

MPI_Allgather

- Usage

```
int MPI_Allgather(
    const void *sendbuf, int sendcount, MPI_Datatype sendtype,
    void *recvbuf, int recvcount, MPI_Datatype recvtype,
    MPI_Comm comm)
```

- Description
  - Thread-safe
  - All-to-gather comm

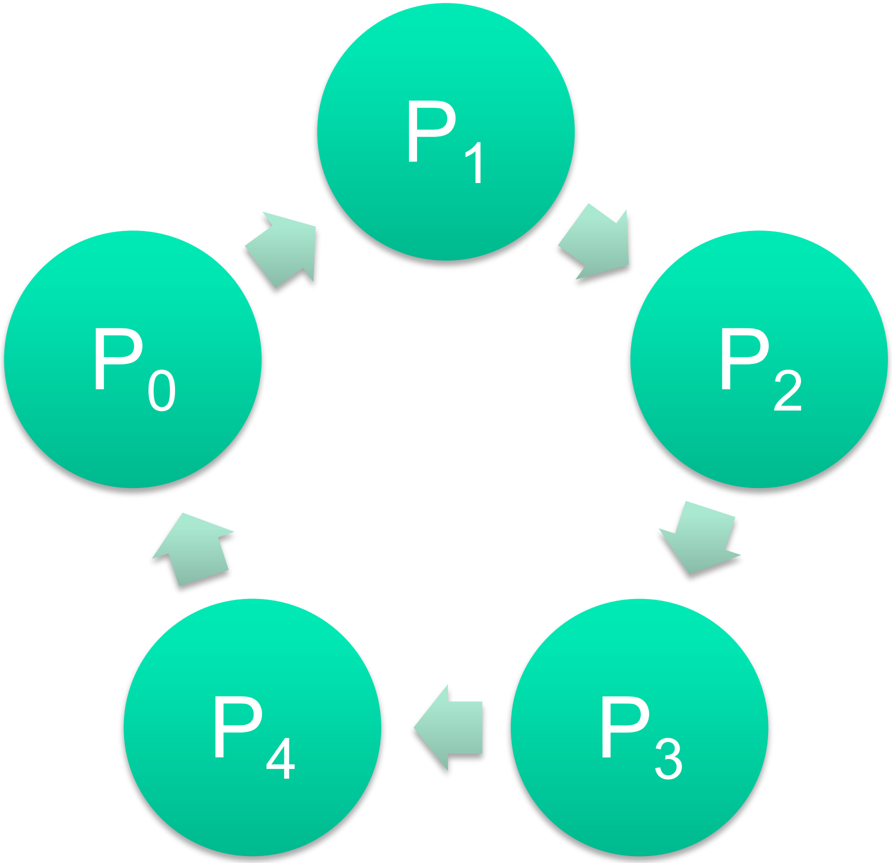
MPI_Allgatherv

- ❑ Usage

```
int MPI_Allgatherv(
        const void *sendbuf, int sendcount, MPI_Datatype sendtype,
        void *recvbuf, const int *recvcounts, const int *displs,
        MPI_Datatype recvtype, MPI_Comm comm)
```

- ❑ Description
  - – Thread-safe
  - – All-to-gather vector comm

Chain communication


P_1
P_2
P_3
P_4
P_0