UPC
UNIVERSITAT POLITÈCNICA DE CATALUNYA
Departament d'Arquitectura de Computadors

Mini-tutorial on the message-passing interface (MPI)

Eduard Ayguadé and Daniel Jiménez
Computer Architecture Department (UPC)

BSC Barcelona Supercomputer Center
National Supercomputer Facility

Message Passing Interface (MPI)

- **Environment**
  - MPI_INIT
  - MPI_COMM_SIZE
  - MPI_COMM_RANK
  - MPI_FINALIZE
- **Point-to-point communication**
- **Collective communication**

Very Simple Program (VSP)

```
#include “mpi.h”

int rank;
int nproc;

int main( int argc, char* argv[] ) {
    MPI_Init( &argc, &argv );
    MPI_Comm_size( MPI_COMM_WORLD, &nproc );
    MPI_Comm_rank( MPI_COMM_WORLD, &rank );

    /* Nothing to do */
    printf("Process: %d out of %d:\\
            Hola mundo!\n",rank,nproc);

    MPI_Finalize();
}
```

MPI_INIT

Usage

```
int MPI_Init( int* argc_ptr,        /* in */
              char** argv_ptr[] );  /* in */
```

Description

- Initialize MPI
- All MPI programs must call this routine once and only once before any other MPI routines

MPI_COMM_SIZE

Usage

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

Description

- Return the number of processes (`size`) in the group associated with a communicator `comm`
- Communicator
  - ✓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
  - ✓Set of processes that share a communication context

MPI_COMM_RANK

Usage

```
int MPI_Comm_rank ( MPI_Comm comm,    /* in */
                    int* rank );  /* out */
```

Description

- Returns the identifier of the local process in the group associated with a communicator `comm`
- The identifier (`rank`) of the process is in the range from 0 … size - 1

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`

Message Passing Interface (MPI)

- Environment
- Point-to-point communication
- Collective communication

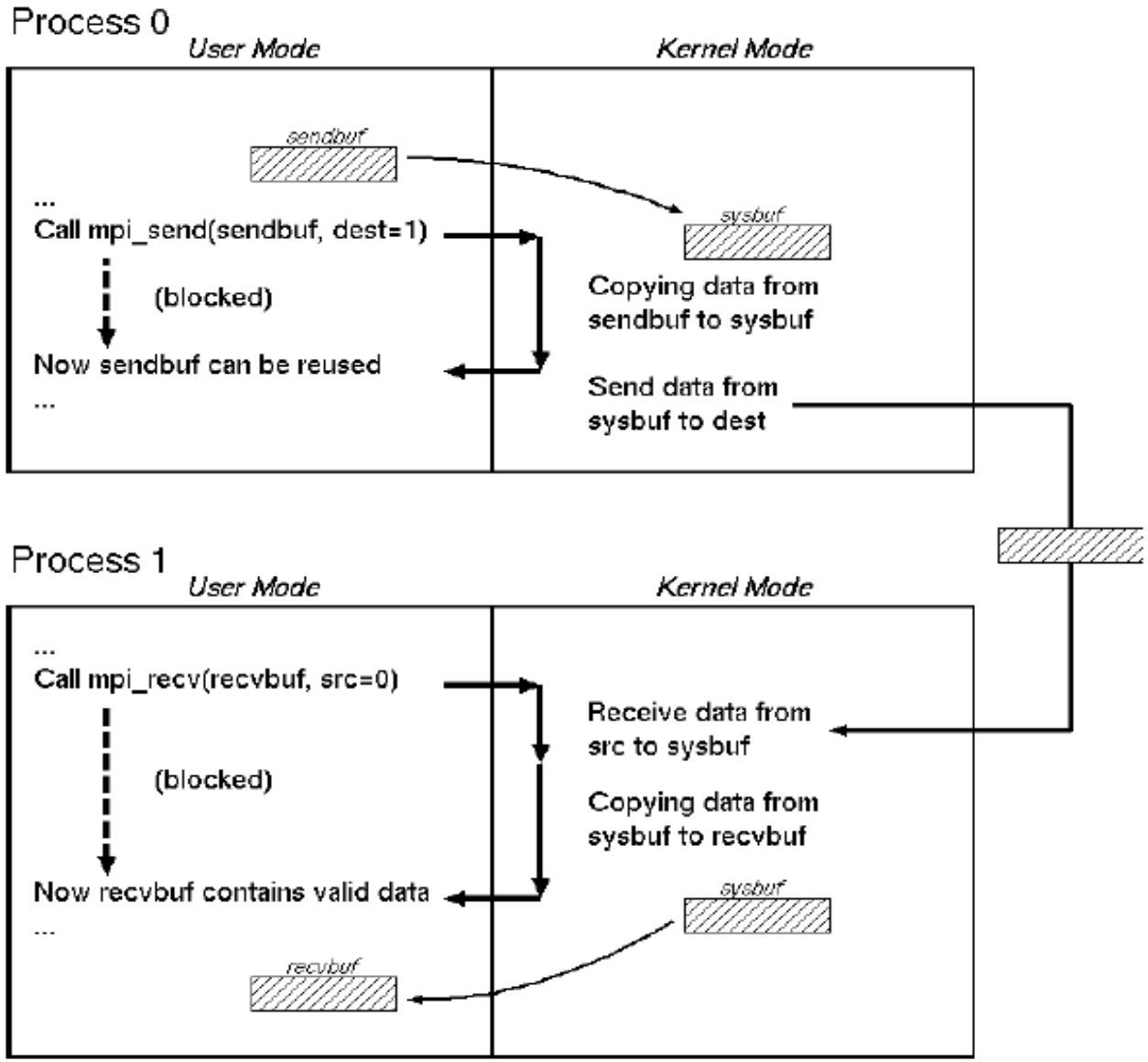
MPI: Point-to-point communication

- **Blocking**
  - Return from the procedure indicates the user is allowed to reuse resources specified in the call
- **Non-blocking**
  - The procedure may return before the operation completes, and before the user is allowed to reuse resources specified in the call
- **List of some basic routines:**
  - `MPI_SEND`
  - `MPI_RECV`
  - `MPI_ISEND`
  - `MPI_IRECV`
  - `MPI_WAIT`
  - `MPI_TEST`
  - `MPI_GET_COUNT`
  - `MPI_PROBE`

VSP: blocking operations

```
#include "mpi.h"

int rank, nproc;

int main( int argc, char* argv[] ) {
    int isbuf, irbuf;
    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_Send( &isbuf, 1, MPI_INTEGER, 1, 1, MPI_COMM_WORLD);
    } else if(rank == 1) {
        MPI_Recv( &irbuf, 1, MPI_INTEGER, 0, 1, MPI_COMM_WORLD,
                                &status);
        printf( "%d\n", irbuf );
    }
    MPI_Finalize();
}
```

MPI: blocking operations



MPI_SEND

- **Usage**
  - ```
    int MPI_Send( void* buf,                /* in */
                  int count,                /* in */
                  MPI_Datatype datatype,    /* in */
                  int destination,          /* in */
                  int tag,                  /* in */
                  MPI_Comm comm );          /* in */
    ```
- **Description**
  - Performs a blocking send operation
  - The message can be received by either `MPI_RECV` or `MPI_IRECV`
  - Message envelope
    - ✓ Information used to distinguish messages and selectively receive them
    - ✓ `<destination, tag, comm>`
    ```

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 `buf`
  - `MPI_RECV` can receive a message sent by either `MPI_SEND` or `MPI_ISEND`
  - Message envelope: `<source, tag, comm>`
    ```

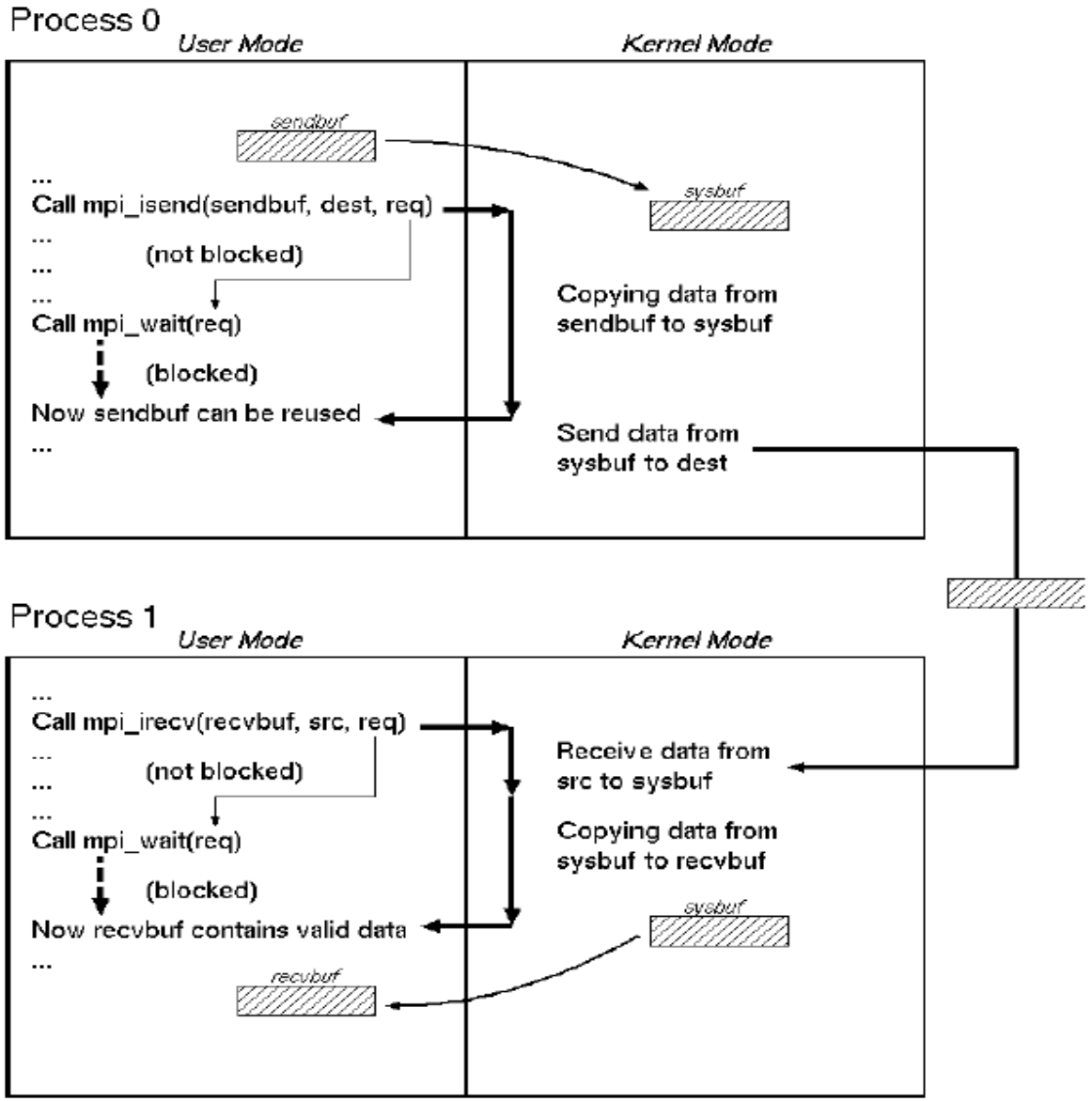
MPI_SENDRECV

- **Usage**
  - ```
    int MPI_Sendrecv(void *sendbuf,     /* in */
                     int sendcount,
                     MPI_Datatype sendtype,
                     int dest,
                     int sendtag,
                     void *recvbuf,     /* out */
                     int recvcount,
                     MPI_Datatype recvtype,
                     int source,
                     int recvtag,
                     MPI_Comm comm,
                     MPI_Status *status);
    ```

- **Description**
  - Sends and receives a message
  - Blocking exchange
    ```

MPI data types

- **MPI_Datatype can be one of the following:**
  - MPI_CHAR
  - MPI_SHORT
  - MPI_INT
  - MPI_LONG
  - MPI_UNSIGNED_CHAR
  - MPI_UNSIGNED_SHORT
  - MPI_UNSIGNED
  - MPI_UNSIGNED_LONG
  - MPI_FLOAT
  - MPI_DOUBLE
  - MPI_LONG_DOUBLE
  - MPI_BYTE
  - MPI_PACKED

VSP: non-blocking operations

```
#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, 1,
                   MPI_COMM_WORLD, &request );
```

VSP: non-blocking operations

```
MPI_Init(&argc, &argv);
MPI_Comm_rank(MPI_COMM_WORLD,&mpiRank);
MPI_Comm_size(MPI_COMM_WORLD,&P);
Float *Matriz_A;
Matriz_A=(float)malloc(sizeof(float)*(mpirank? NxN: NX(N/P+1)));
if(!mpiRank){
currentRow = (N/P)*N;
for(i=1;i<P;i++){
sizeToBeSent=(N/P+1)*N;
MPI_Send(Matriz_A+currentRow,sizeToBeSent,MPI_DOUBLE,i,TAG_INIT,
MPI_COMM_WORLD);
currentRow += (N/P)*N;
}
}
else { */
  MPI_Recv(Matriz_A, (N/P+1)*N, MPI_DOUBLE, 0, TAG_INIT,
MPI_COMM_WORLD, MPI_STATUS_IGNORE);
}
if(mpirank==(P---1)) endrow=N/P---1;
else endrow=N/P;
/* calcular shit
```

VSP: non-blocking operations

```
for(i=0;i<endrow; i++)
for(j=1; j<N; j++)
Matriz_A[i][j]=Matriz_A[i][j--1]+Matriz_A[i+1][j];
```

```
if (!mpiRank) {
currentRow = (N/P)*N;
sizeToBeSent = (N/P)*N
for (i=1; i<P; i++) {
  MPI_Recv(Matriz_A + currentRow, sizeToBeSent, MPI_DOUBLE, i,
TAG_RESULT, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
  currentRow += (N/P)*N;
}
}
else /* Send partial results to master */
MPI_Send(Matriz_A, (N/P)*N, MPI_DOUBLE, 0, TAG_RESULT,
MPI_COMM_WORLD); MPI_Finalize();
}
```

VSP: non-blocking operations

```
    } else if(rank == 1) {
        MPI_Irecv( &irbuf, 1, MPI_INTEGER, MPI_ANY_SOURCE,
                   MPI_ANY_TAG, MPI_COMM_WORLD, &request);
       /* OTHER WORK TO DO */
        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();
}
```

MPI: non-blocking operations



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 non-blocking send operation
  - `request` is an identifier for later enquiry with `MPI_WAIT` or `MPI_TEST`
  - The send buffer `buf` 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

- **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 */
    ```

- **Description**
  - Performs a non-blocking receive operation
  - Do not access any part of the receive buffer `buf` until the receive is completed by `MPI_WAIT` or `MPI_TEST`
  - The message received must be less than or equal to the length of the receive buffer `buf`
  - `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 non-blocking operation to complete, with identifier stored in `request`
  - Information on the completed operation is found in `status`
  - If wildcards (`MPI_ANY_SOURCE, MPI_ANY_TAG`) were used by the receive for either the `source` or `tag`, the actual source and tag can be retrieved from `status`→`MPI_SOURCE` and `status`→`MPI_TAG`

MPI_TEST

- **Usage**
  - ```
    int MPI_Test (MPI_Request* request,   /* inout */
                  int *flag,              /* out */
                  MPI_Status* status );   /* out */
    ```
- **Description**
  - Test for the completion of a send or receive
  - `flag` equals `MPI_SUCCESS` if MPI routine completed successfully
    ```

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 (indicated by `status`)
  - The `datatype` argument and the argument provided by the call that set the `status` variable should match
    ```

MPI_PROBE

- **Usage**
  - ```
    int MPI_Probe(int source,              /* input */
                  int tag,                  /* input */
                  MPI_Comm comm,            /* input */
                  MPI_Status *status);      /* out */
    ```
- **Description**
  - Blocking call that returns only after a matching message is found
  - Wildcards can be used to wait for messages coming from any source (`MPI_ANY_SOURCE`) or with any tag (`MPI_ANY_TAG`)
  - There is a non-blocking MPI_Iprobe
    ```

Message Passing Interface (MPI)

- Environment
- Point-to-point communication
- Collective communication

MPI: collective communication

- **Collective**
  - If all processes in a process group need to invoke the procedure
- **List of some routines:**
  - **MPI_BCAST**
  - **MPI_REDUCE**
  - MPI_SCATTER
  - MPI_SCATTERV
  - MPI_GATHER
  - MPI_GATHERV
  - MPI_ALLGATHER
  - MPI_ALLTOALL
  - MPI_ALLTOALLV

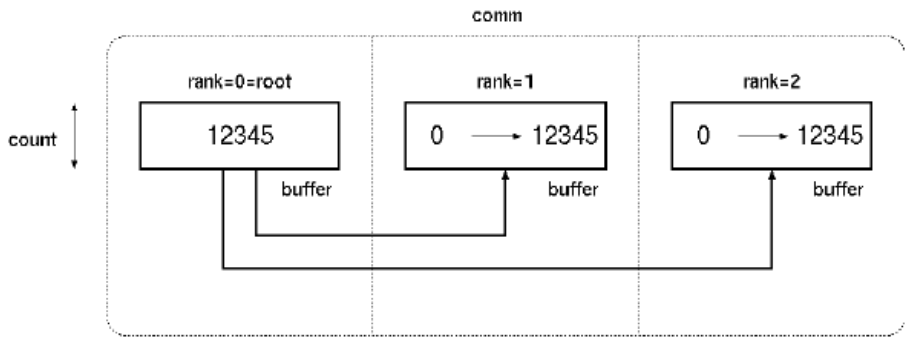
PI: broadcast and reduce

```
#include <mpi.h>
void main (int argc, char *argv[])
{
    int i, my_id, numprocs, num_steps;
    double x, pi, step, sum = 0.0 ;

    MPI_Init(&argc, &argv) ;
    MPI_Comm_Rank(MPI_COMM_WORLD, &my_id);
    MPI_Comm_Size(MPI_COMM_WORLD, &numprocs) ;
    if (my_id==0) scanf("%d",&num_steps);
    MPI_Bcast(&num_steps, 1, MPI_INT, 0, MPI_COMM_WORLD)
    step = 1.0/(double) num_steps ;
    my_steps = num_steps/numprocs ;

    for (i=my_id*my_steps; i<(my_id+1)*my_steps; i++){
        x = (i+0.5)*step;
        sum += 4.0/(1.0+x*x);
        }
    sum *= step ;
    MPI_Reduce(&sum, &pi, 1, MPI_DOUBLE,
            MPI_SUM, 0, MPI_COMM_WORLD) ;
    MPI_Finalize() ;
}
```

MPI_BCAST

- **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 `comm`
  - The type signature of `count` and `datatype` on any process must be equal to the type signature of `count` and `datatype` at the `root`

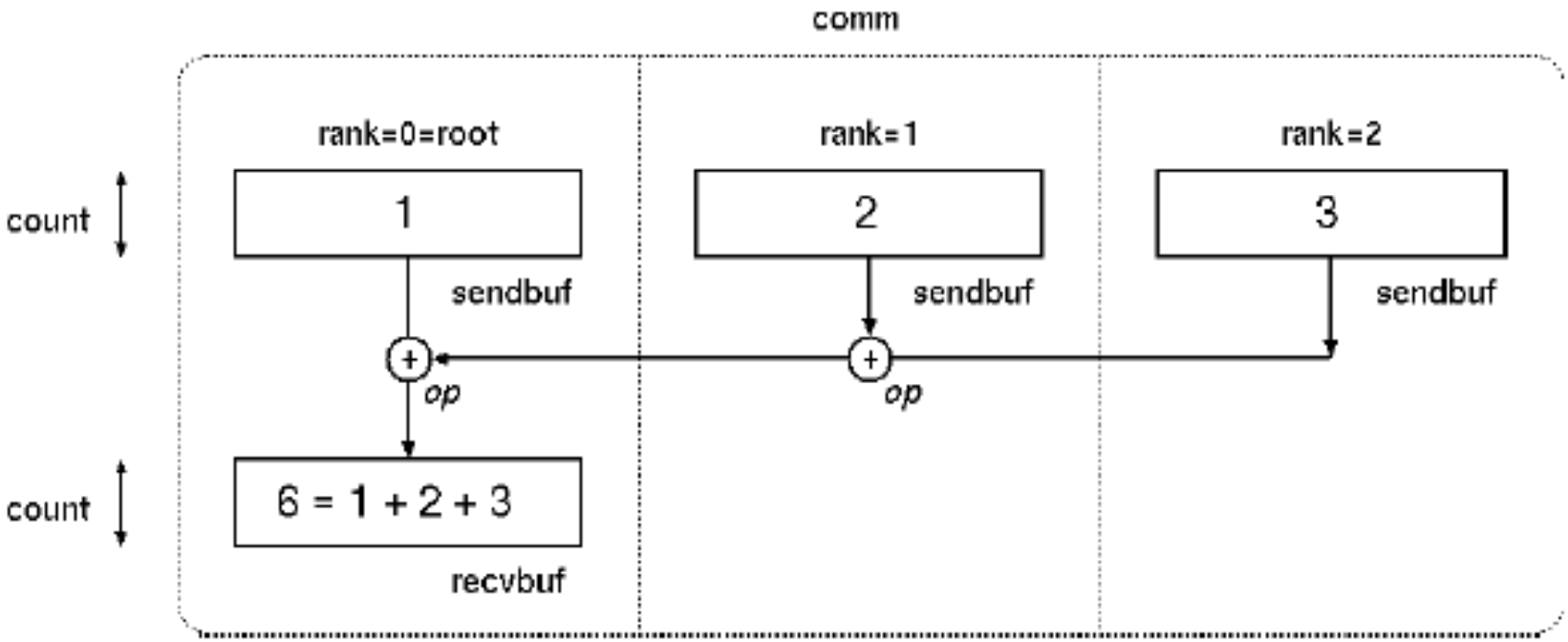

    ```

MPI_REDUCE

- **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 */
    ```

- **Description**
  - Applies a reduction operation to the vector `sendbuf` over the set of processes specified by communicator `comm` and places the result in `recvbuf` on `root`
    ```

MPI_REDUCE (cont'd)

- **Description (Cont'd)**
  - 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

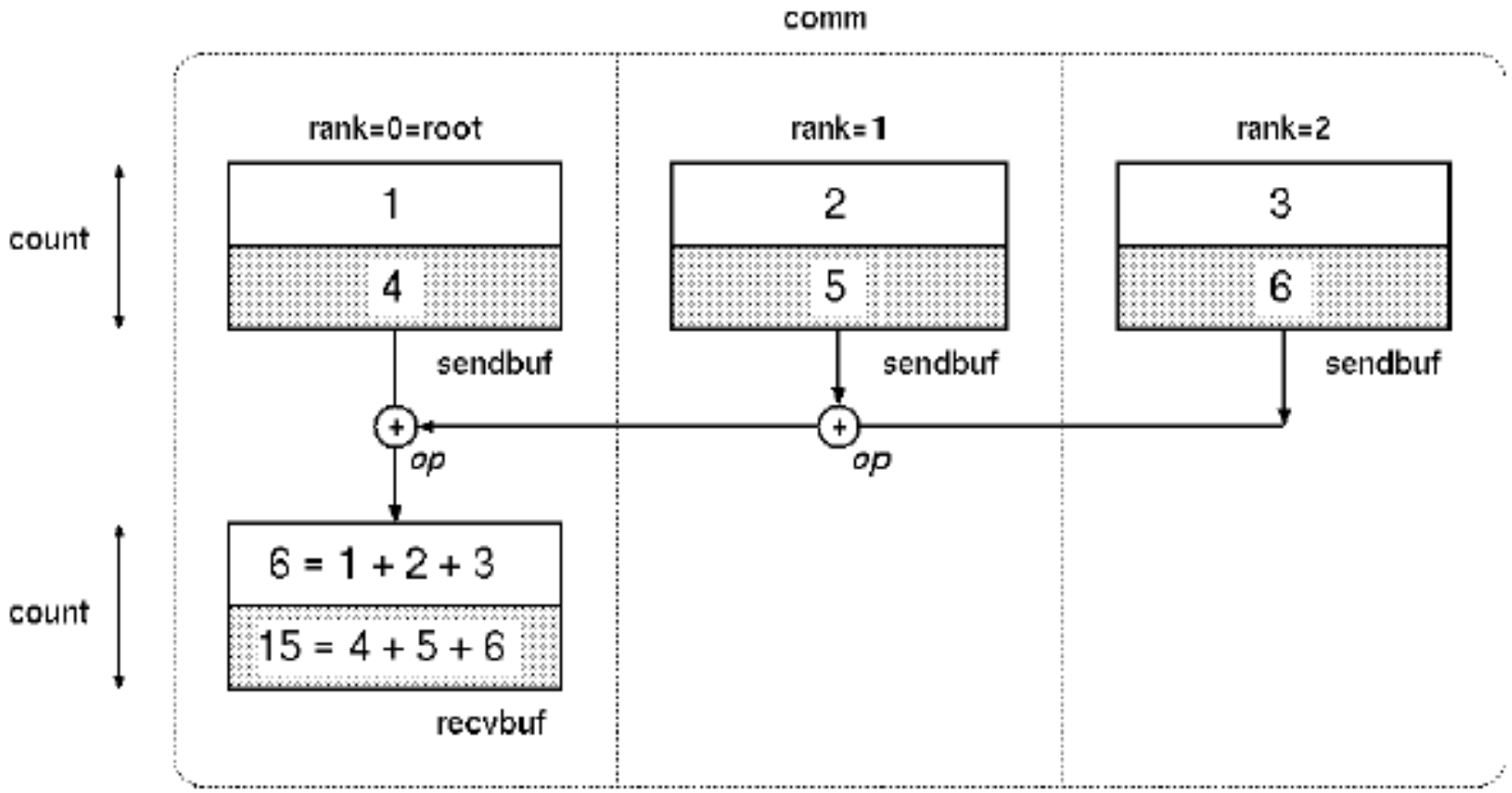
- **Predefined operations**
  - `MPI_SUM, MPI_PROD`
  - `MPI_MAX, MPI_MIN`
  - `MPI_MAXLOC, MPI_MINLOC`
  - `MPI_LAND, MPI_LOR, MPI_LXOR`
  - `MPI_BAND, MPI_BOR, MPI_BXOR`

MPI_REDUCE (cont'd)



`MPI_REDUCE` for scalars

MPI_REDUCE (cont'd)



`MPI_REDUCE` for arrays