MPI - Part 2

- Basic message passing
- Semantics
- Simple IO

Introduction to MPI

- MPI is a standard for message passing interfaces
- MPI-1 covers point-to-point and collective communication
- MPI-2 covers connection based communication and I/O
- Typical implementations include MPICH (Used by Scyld), and LAMMPI

MPI Basics

Most used MPI commands

```
MPI_Init - start using MPI
MPI_Comm_size - get the number of tasks
MPI_Comm_rank - the unique index of this task
MPI_Send - send a message
MPI_Recv - receive a message
MPI_Finalize - stop using MPI
```

Initialize and Finalize

```
int MPI_Init(int *argc,char ***argv);
```

- Must be called before any other MPI calls

```
int MPI_Finalize();
```

- No MPI calls may be made after this
- Program MUST call this (or it won't terminate)

Initialize and Finalize

First MPI call must be to `MPI_Init`.
Last MPI call must be to `MPI_Finalize`.

```
#include <mpi.h>
main(int argc, int **argv)
{
     MPI_Init(&argc, &argv );
     // put program here
     MPI_Finalize();
}
```

Size and Rank

MPI_Comm_size returns the number of tasks in the job

```
int size;
MPI_Comm_size(MPI_COMM_WORLD, &size);
```

MPI_Comm_rank returns the number of the current task (0 .. size-1)

```
int rank;
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
```

A Simple Example

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

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

      int rank, size;

      MPI_Init( &argc,&argv);
      MPI_Comm_rank( MPI_COMM_WORLD, &rank);
      MPI_Comm_size( MPI_COMM_WORLD, &size);
      printf("Hello world from process %d of %d
\n",
         rank,size);
      MPI_Finalize();
      return 0;
}
```

Send and Recv

MPI_Send to send a message

```
char sbuf[COUNT];
MPI_Send(sbuf, COUNT, MPI_CHAR, 1, 99,
MPI_COMM_WORLD);
```

MPI_Recv to receive a message

```
char rbuf[COUNT];
MPI_Status status;
MPI_Recv(rbuf, COUNT, MPI_CHAR, 1, 99,
MPI_COMM_WORLD, &status);
```

Anatomy of MPI_Send

`MPI_Send(sbuf, COUNT, MPI_CHAR, 1, 99, MPI_COMM_WORLD);`

```
sbuf : pointer to send buffer
COUNT : items in send buffer
MPI_CHAR : MPI datatype
1 : destination task number (rank)
99 : message tag
MPI_COMM_WORLD : communicator
```

Anatomy of MPI_Recv

```
MPI_Recv(rbuf, COUNT, MPI_CHAR, 1, 99,
MPI_COMM_WORLD, &status);
rbuf : pointer to receive buffer
COUNT : items in receive buffer
MPI_CHAR : MPI datatype
1 : source task number (rank)
99 : message tag
MPI_COMM_WORLD : communicator
Status : pointer to status struct
```

MPI Datatypes

Encodes type of data sent and received

Built-in types

`MPI_CHAR, MPI_SHORT, MPI_INT, MPI_LONG`

`MPI_FLOAT, MPI_DOUBLE, MPI_LONG_DOUBLE`

`MPI_BYTE, MPI_PACKED`

User defined types (covered later)

`MPI_Type_contiguous, MPI_Type_vector,`

`MPI_Type_indexed, MPI_Type_struct MPI_Pack,`

`MPI_Unpack`

MPI Communicators

Abstract structure represents a group of MPI tasks that can communicate

`MPI_COMM_WORLD` represents all of the tasks in a given job

Programmer can create new communicators to subset `MPI_COMM_WORLD`

`RANK` or task number is relative to a given communicator

Messages from different communicators do not interfere

MPI Task Numbers

Each task in a job has a unique `rank` or task number

Numbers run from `0` to `size-1`, where `size` is the number of tasks

`MPI_Comm_size(MPI_COMM_WORLD, &size)`

`MPI_Comm_rank(MPI_COMM_WORLD, &rank)`

`Send` and `Recv` specify destination or source task by rank

`Recv` can specify source of `MPI_ANY_SOURCE` to receive from any task

Message Tags

All messages are sent with an integer message tag

`MPI_Recv` will only receive a message with the tag specified

`MPI_ANY_TAG` can be used to receive messages with any tag

MPI Status Struct

Allows user to query the return status of MPI call

```
status.MPI_SOURCE
status.MPI_TAG
status.MPI_ERROR
```

Allows user to query number of items received

```
int count;
MPI_Get_count(&status, MPI_CHAR, &count)
```

Send and Receive Example

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

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

    int numprocs, myrank, namelen, i;
    char processor_name[MPI_MAX_PROCESSOR_NAME];
    char greeting[MPI_MAX_PROCESSOR_NAME + 80];
    MPI_Status status;

    MPI_Init( &argc,&argv);
    MPI_Comm_rank( MPI_COMM_WORLD, &myrank);
    MPI_Comm_size( MPI_COMM_WORLD, &numprocs);
    MPI_Get_Processor_name( processor_name, &namelen);

    sprintf(greeting,"Hello world from process %d of %d on %s \n",
        myrank,numprocs, processor_name);
```

Send and Receive Example

```
if (myrank == 0) {
        printf("%s\n", greeting);
        for(i=1;i<numprocs;i++) {
             MPI_Recv(greeting,sizeof(greeting), MPI_CHAR,
                  i, 1, MPI_COMM_WORLD);
             printf("%s\n", greeting);
        }
}
else {
        MPI_Send(greeting, strlen(greeting) +1, MPI_CHAR,
             0,1,MPI_COMM_WORLD);
}

MPI_Finalize();
return( 0);
}
```

Receive Buffer Size

- Receive buffer must be big enough for the message being received
- If message is smaller, only part of buffer filled in
- If message is too big, overflow error
- MPI_Probe allows programmer to check the next message before receiving it

```
// src, tag, comm, stat
MPI_Probe(1, 99, MPI_COMM_WORLD,
&status);
```

Matching Send and Recv

- When `MPI_Send` called, send is "posted"
- When `MPI_Recv` called, receive is "posted"
- Posted `MPI_Recv` matches posted `MPI_Send` if
  - -Destination of `MPI_Send` matches receiving task
  - -Source of `MPI_Recv` matches sending task or source is `MPI_SOURCE_ANY`
  - -Tag of `MPI_Send` matches tag of `MPI_Recv` or tag of `MPI_Recv` is `MPI_TAG_ANY`
  - -Communicator or `MPI_Send` matches communicator of `MPI_Recv`

Semantics

Covered on next pages ...

-Messages are non-overtaking

-Progress is guaranteed

-Fairness is not guaranteed

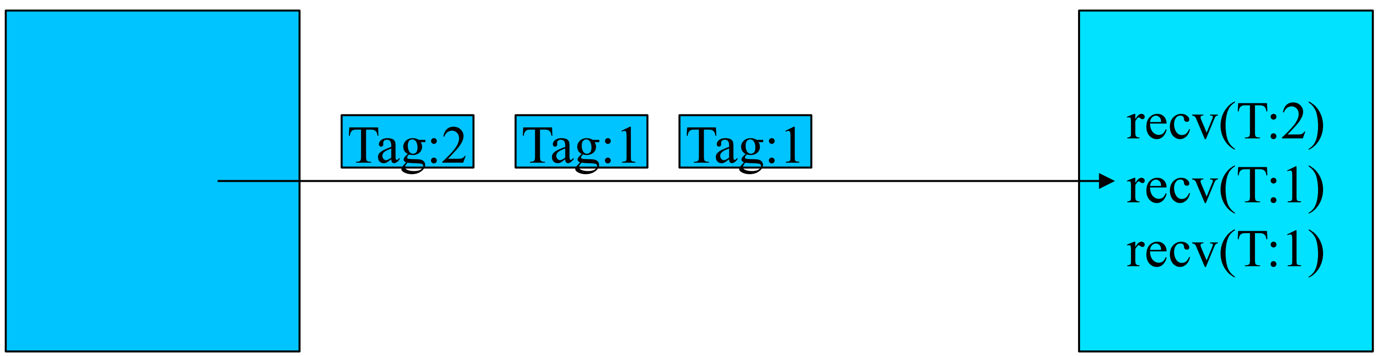
-System resources may be limited

Non-Overtaking Messages

- If a sender sends two messages in succession to the same destination, and both match the same receive, then this operation cannot receive the second message if the first one is still pending.
- If a receiver posts two receives in succession, and both match the same message, then the second receive operation cannot be satisfied by this message, if the first one is still pending.

Quoted from: MPI: A Message-Passing Interface Standard

Non-overtaking Messages

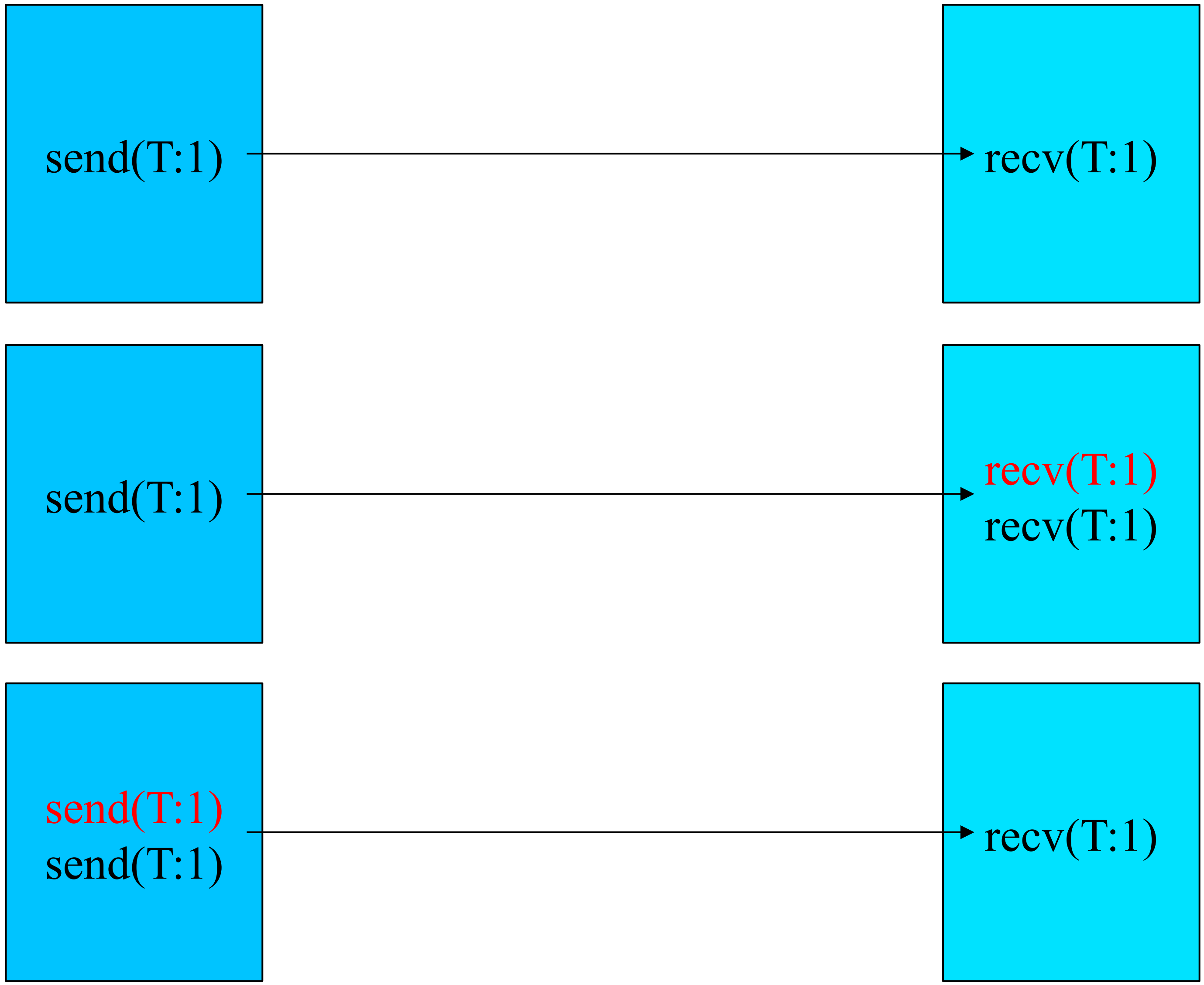


Progress

- If a pair of matching send and receives have been initiated on two processes, then at least one of these two operations will complete, independently of other actions in the system: the send operation will complete, unless the receive is satisfied by another message, and completes; the receive operation will complete, unless the message sent is consumed by another matching receive that was posted at the same destination process.

Quoted from: MPI: A Message-Passing Interface Standard

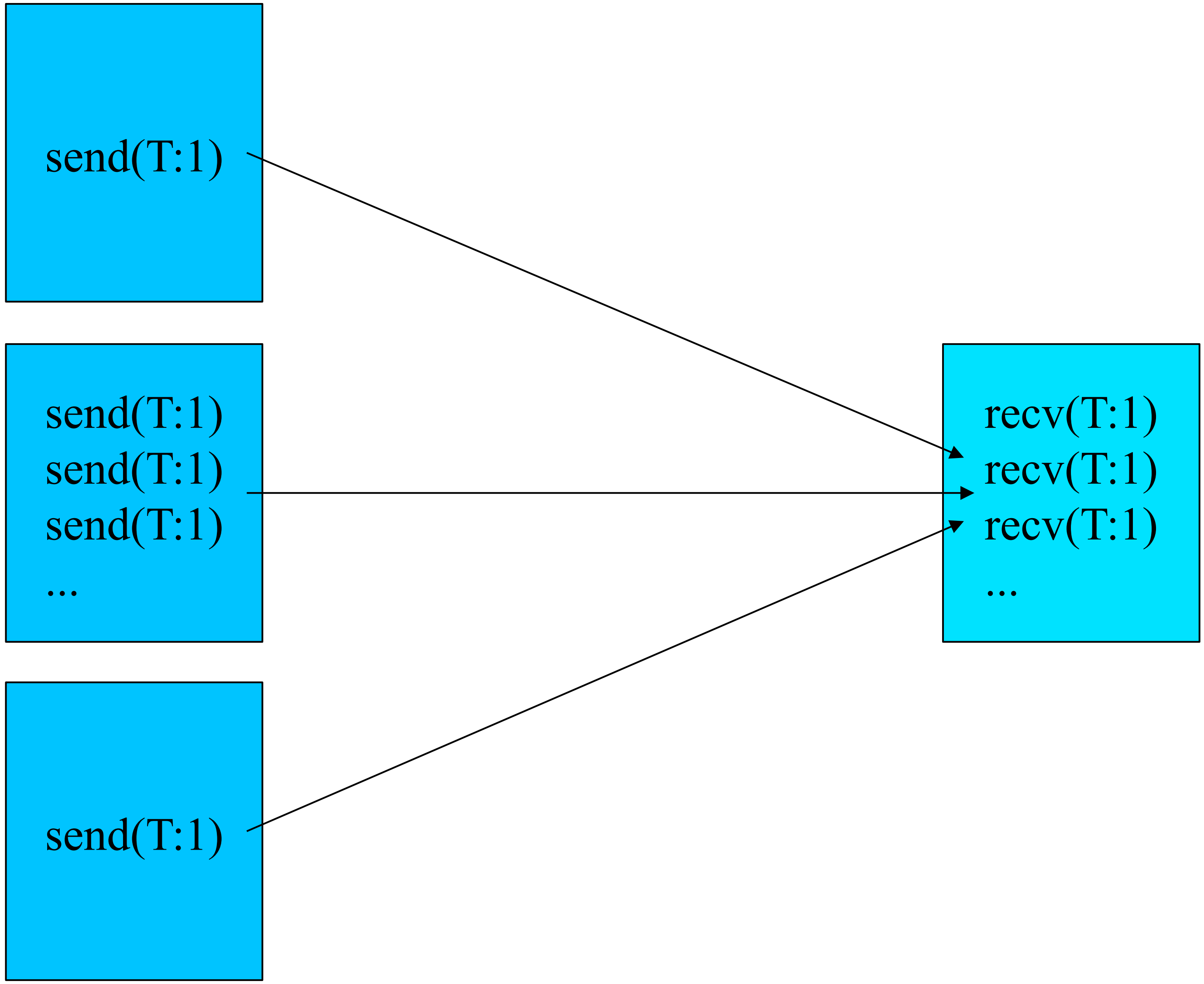
Progress Guaranteed



Fairness

- MPI does not guarantee fairness in matching messages
- Messages from different sources may overtake one another
- Programmer's responsibility to prevent starvation

Fairness NOT Guaranteed



Limited System Resources

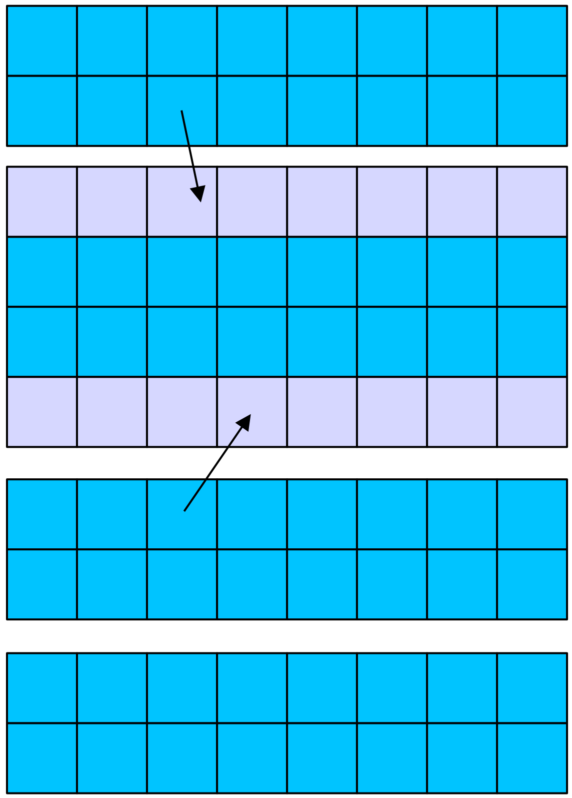
- MPI does not guarantee system resources exist for buffering messages
- Programs that assume system resources available can deadlock if resources become busy
- Properly coded programs usually exist that will complete regardless of available buffer space
- Buffered mode allows programmer to provide adequate buffer space

Combined Send/Recv

- Single call both sends and receives a message
- Can send and receive to same task, or different tasks
- Guarantees that buffering and blocking semantics will not result in deadlock

```
MPI_Sendrecv(sbuf, scount, stype, dest,
stag, rbuf, rcount, rtype, source, rtag,
comm, &status);
MPI_Sendrecv_replace(buf, count, type,
dest, stag, source, rtag, comm,
&status);
```

Smoothing Example



Back to our example

```
#include <mpi.h>
#define n 1000;
main(int argc, char **argv)
{
    int n, SIZE, RANK;
    int *input, *output;

    MPI_Init(&argc, &argv);
    MPI_Comm_size(MPI_COMM_WORLD, &SIZE);
    MPI_Comm_rank(MPI_COMM_WORLD, &RANK);

    input = (int *)malloc((n/SIZE+2) * n * sizeof(int));
    output = (int *)malloc(n/SIZE * n * sizeof(int));

    read_image(n, SIZE, RANK, input);
    parallel_smooth(n, SIZE, RANK, input, output);
    write_image(n, SIZE, RANK, output);

    MPI_Finalize();
}
```

Smoothing Function

```
parallel_smooth(int n, int SIZE, int RANK,
        int input[][n], int output[][n])
{
    int r, c, rm, cm, sum, cnt;
    exchange_borders(n, SIZE, RANK, input);
    for (r = 1; r < (n/SIZE)+1; r++)
        for (c = 0; c < n; c++)
        {
            cnt = 0;
            sum = 0;
            for (rm = -1; rm < 2; rm++)
            {
                if (RANK == 0 && r+rm < 1 ||
                        RANK == SIZE-1 && r+rm > n/SIZE)
                    continue;
                for (cm = -1; cm < 2; cm++)
                {
                    if (c+cm < 0 || c+cm >= n)
                            continue;
                    sum += input[r+rm][c+cm];
                    cnt++;
                }
            }
            output[r][c] = sum / cnt;
        }
}
```

Exchange Function

```
exchange_borders(int n; int SIZE, int RANK, int input[][n])
{
   MPI_Status status;
   if (RANK < SIZE-1)
   {
      MPI_Send(&input[1][0], n, MPI_INT, RANK+1, 1,
            MPI_COMM_WORLD);
      MPI_Recv(&input[0][0], n, MPI_INT, RANK+1, 1,
            MPI_COMM_WORLD, &status);
   }
   if (RANK > 0)
   {
      MPI_Send(&input[n/SIZE][0], n, MPI_INT, RANK-1, 1,
            MPI_COMM_WORLD);
      MPI_Recv(&input[n/SIZE+1][0], n, MPI_INT, RANK-1, 1,
            MPI_COMM_WORLD, &status);
   }
}
/* THIS COULD DEADLOCK */
```

Exchange Using Sendrecv

```
exchange_borders(int n; int SIZE, int RANK, int input[][n])
{
   MPI_Status status;
   if (RANK < SIZE-1)
   {
      MPI_Sendrecv(&input[1][0], n, MPI_INT, RANK+1, 1,
            &input[0][0], n, MPI_INT, RANK+1, 1,
            MPI_COMM_WORLD, &status);
   }
   if (RANK > 0)
   {
      MPI_Sendrecv(&input[n/SIZE][0], n, MPI_INT, RANK-1, 1,
            &input[n/SIZE+1][0], n, MPI_INT, RANK-1, 1,
            MPI_COMM_WORLD, &status);
   }
}
/* THIS WILL DEADLOCK */
```

Working Exchange

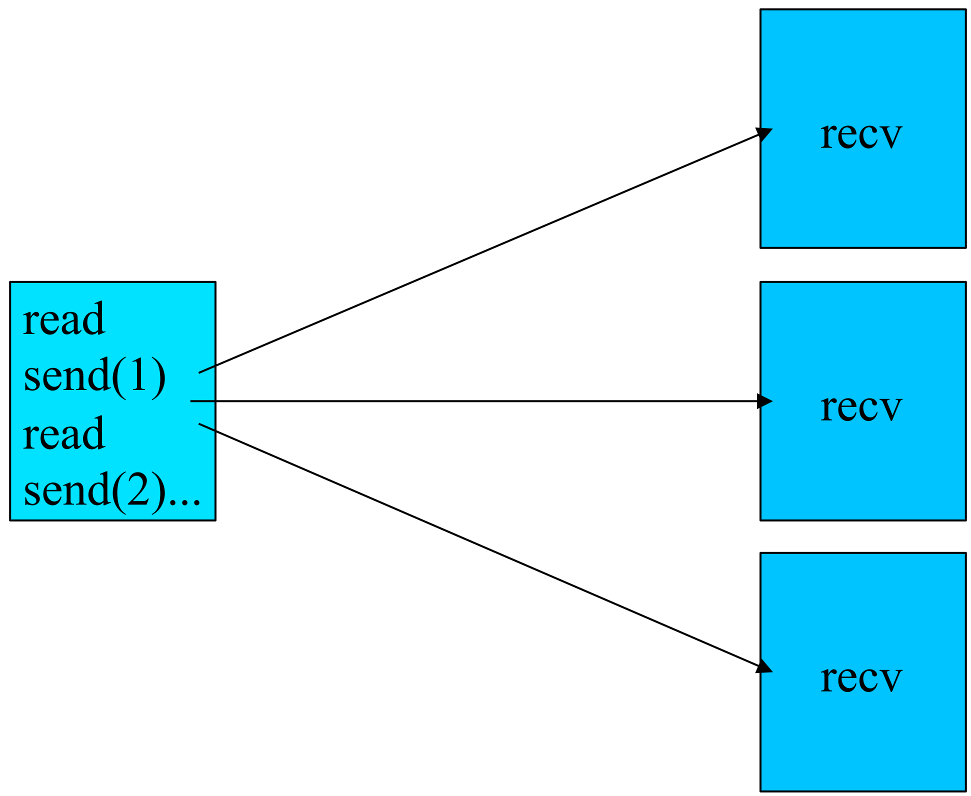
```
exchange_borders(int n; int SIZE, int RANK, int input[][n])
{
   MPI_Status status;
   if (RANK == 0)
      MPI_Send(&input[n/SIZE][0], n, MPI_INT, RANK+1, 1,
            MPI_COMM_WORLD);
   else if (RANK < SIZE-1)
      MPI_Sendrecv(&input[n/SIZE][0], n, MPI_INT, RANK+1, 1,
            &input[0][0], n, MPI_INT, RANK-1, 1,
            MPI_COMM_WORLD, &status);
   else
      MPI_Recv(&input[0][0], n, MPI_INT, RANK-1, 1,
            MPI_COMM_WORLD, &status);
   if (RANK == 0)
      MPI_Recv(&input[n/SIZE+1][0], n, MPI_INT, 1, 1,
            MPI_COMM_WORLD);
   else if (RANK < SIZE-1)
      MPI_Sendrecv(&input[1][0], n, MPI_INT, RANK-1, 1,
            &input[n/SIZE+1][0], n, MPI_INT, RANK+1, 1,
            MPI_COMM_WORLD, &status);
   else
      MPI_Send(&input[1][0], n, MPI_INT, RANK-1, 1,
            MPI_COMM_WORLD, &status);
} /* THIS WORKS */
```

Program IO

- Master task IO model
  - -One task (task 0?) does all IO
  - -Sends/recvs from other tasks
  - -A must if data not available on all nodes
- Independent IO model
  - -Each task does its own IO
  - -Each node must have data available
- Hybrid models
  - -Subset of nodes have access to data
- Parallel IO model
  - -System software supports IO by parallel tasks

Master Task IO

- One task reads data, then sends to other tasks
- Other tasks receive data from IO task

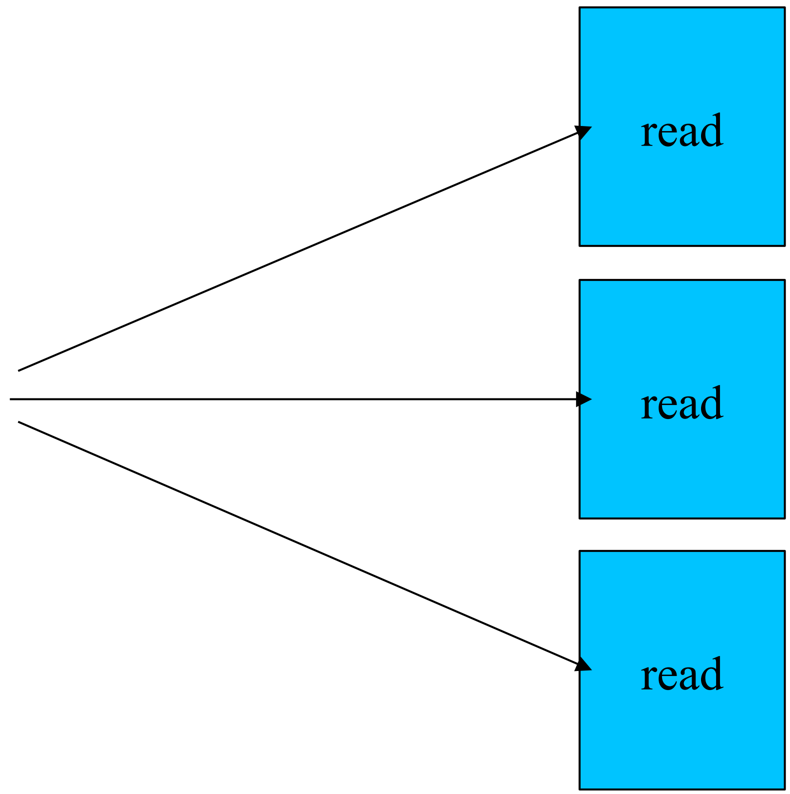


Master task IO

```
parallel_read_buffer (int fd, char *buffer, int count)
{
    if (RANK == 0)
    {
        int t;
        lseek (fd, count, SEEK_SET); /* skip task 0's data */
        for (t = 1; t < SIZE; t++)
        {
            read(fd, count, buffer); /* assume task data is sequential */
            MPI_Send(buffer, count, MPI_BYTE, t, 1, MPI_COMM_WORLD);
        }
        lseek (fd, 0, SEEK_SET); /* now read task 0's data */
        read(fd, count, buffer);
    }
    else
    {
        MPI_Status status;
        MPI_Recv(buffer, count, MPI_BYTE, 0, 1,
                MPI_COMM_WORLD, &status);
    }
}
```

Independent IO

- Each task reads it own data
- Each task must determine which data to read



Independent IO

```
parallel_read_buffer (int fd, char *buffer, int count)
{
    int start;
    start = RANK * count;
    lseek (fd, start, SEEK_SET);
    read(fd, count, buffer);
}
```

Block Decomposition Macros

```
#define BLOCK_LOW(id,p,n)  ((id)*(n)/(p))

#define BLOCK_HIGH(id,p,n) \
        (BLOCK_LOW((id)+1,p,n)-1)

#define BLOCK_SIZE(id,p,n) \
        (BLOCK_LOW((id)+1)-BLOCK_LOW(id))

#define BLOCK_OWNER(index,p,n) \
        (((p)*((index)+1)-1)/(n))
```

Independent IO - Redux

```
parallel_read_from (int fd, int offset, char *buffer,
        int total_count, int element_size)
{
    int start;
    start = BLOCK_LOW(RANK, SIZE, total_count) * element_size
        + offset;
    lseek (fd, start, SEEK_SET);
    read(fd, BLOCK_SIZE(RANK, SIZE, total_count) * element_size,
        buffer);
}
```

Independent Writes

- Work just like reads except ...
  - -Local cache may cause unexpected behavior
  - -File creation can be tricky
  - -Extending a file can cause data loss
- When using NFS, usually best to ...
  - -Have one task create file
  - -Have one task pre-allocate file to final length
- Use of MPI-IO (covered later)
  - -Should fix task creation/extending problems
  - -May fix cache related issues
  - -Depends on file system used for implementation

Parallel Open

```
int parallel_open (char *fname, int flags,
        int mode, int size)
{
    int fd;
    char data = 0;
    if (RANK == 0 && (flags&O_WRONLY || flags&O_RDWR))
    {
        fd = open(fname, flags, mode);
        lseek(fd, size-1, SEEK_SET);
        write(fd, &data, 1);
        lseek (fd, 0, SEEK_SET);
        MPI_Barrier(MPI_COMM_WORLD);
    }
    else
    {
        MPI_Barrier(MPI_COMM_WORLD);
        fd = open (fname, flags&(^(O_CREAT|O_TRUNC)), mode);
    }
    return fd;
}
```

Barrier

Barrier synchronizes all tasks of a communicator

`MPI_Barrier(MPI_COMM_WORLD);`

Each task calling `MPI_Barrier` will stop until all tasks in the communicator have called `MPI_Barrier`

Running MPI programs with LAM

- LAMMPI already installed on ullab machines
- Compile your programs with `mpicc`
  - Automatically handles includes and libraries
  - Otherwise just like `cc` or `gcc`
- Run `lamboot` to start local area machine
  - All tasks run on local machine
  - `bhost` file specifies additional machines
  - Shut down machine with `wipe`
- Run programs with `mpiexec` or `mpirun`

Mpiexec

Runs one or more tasts on nodes:

```
mpiexec [options] prog-name arg1 arg2 ...
-np <int>      run <int> tasks
-localonly     run all tasks on master node
-host <hname> run task on a specific host
-hosts <int> <hname1> <hname2> …
               Run tasks on given hosts
```

Alternative (older) form:

```
mpirun [options] prog-name arg1 arg2 ...
```

Using PBS or Torque

- Batch scheduler on many clusters
  - -Launch job by submitting a script
  - -Variables control the job

```
#!/bin/bash

### Set the job name
#PBS -N hello
### Time out in 5 minutes
#PBS -l walltime 00:05:00
### Set the number of nodes that will be used.
#PBS -l select=1:ncpus=4:mpiprocs=4:mem=1gb:interconnect=1g
### Tell PBS to keep both stdout and stderr
#PBS -k oe

mpiexec -np 4 hello
```

PBS Commands

- Submit a job
  qsub <PBS script>
- See status of the queue
  qstat
- Kill a job in the queue
  qdel <job number>

PBS assumptions

- PBS runs your script …
  - In your home directory
  - With your standard path
  - You can cd in your script or change env vars
- PBS drops your stdout and stderr
  - You can keep it with a directive
  - Ends up in your home dir with the job number as a tag
- PBS can change working dir for you …
  - But it doesn't always work as expected