• 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`.

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

- MPI_Comm_rank returns the number of the current task (0 .. size-1)
  
  ```c
  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 \( \text{size}-1 \), where \( \text{size} \) 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

```c
#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);

  printf(greeting,"Hello world from process %d of %d on %s \n",
      myrank,numprocs, processor_name);
```
Send and Receive Example

```c
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.

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

- 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

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Non-overtaking Messages

Tag:2  Tag:1  Tag:1

recv(T:2)
recv(T:1)
recv(T:1)
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.

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Progress Guaranteed

send(T:1) → recv(T:1)

send(T:1) → recv(T:1)  recv(T:1)

send(T:1)  send(T:1) → recv(T:1)
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

```c
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

```c
#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

```c
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);
    }
}
Exchange Using Sendrecv

```c
exchangeBorders(int n; int SIZE, int RANK, int input[][]) {
    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);
    }
}
```
Working Exchange

```c
exchangeBorders(int n; int SIZE, int RANK, int input[][n])
{
    MPI_Status status;
    if (RANK == 0)
        MPI_Send(&input[n/SIZE][0], n, MPI_INT, 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);
}
```
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, SIZE, 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 its 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);
}

ppart(int total, int *first, int *count, int *max)
{
    *max = *count = total / SIZE;
    *first = RANK * *count;
    *max += total - (*count * SIZE);
    if (RANK == SIZE-1)
        *count = *max;
}
**Partitioning Items**

```c
ppart(int total, int *first, int *count, int *max)
{
    int tcount = total / SIZE;
    int leftover = total -
        (tcount * SIZE);
    if (max && leftover > 0)
        *max = tcount + 1;
    if (RANK < leftover)
        tcount++;
    if (first)
        if (RANK < leftover)
            *first = RANK * tcount;
        else
            *first = RANK * tcount + leftover
    if (count)
        *count = tcount;
}
```
parallel_read_from (int fd, int offset, char *buffer, int tcount, int size)
{
    int first, count;
    ppart(tcount, &first, &count, NULL);
    start = first * size + offset;
    lseek (fd, start, SEEK_SET);
    read(fd, count * 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)
    {
        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, mode);
    }
    return fd;
}
Barrier

- Barrier synchronizes all tasks of a communicator
  
  \[ \text{MPI\_Barrier}(	ext{MPI\_COMM\_WORLD}); \]

- 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 `mpiccc`
  - 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 `mpirun`
Mpirun

• Runs one or more tasks on nodes:

  mpirun [options] prog-name arg1 arg2 ...
  -np <int> run <int> tasks
  --all_cpus run a task on each cpu
  --all_local run all tasks on master node
  --no_local run no tasks on master node
  --exclude <int>[::<int>]
      run on any nodes not listed
  --map <int>[::<int>]
      run nodes listed