Introduction to MPI Part 1

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9-28-11

LSU

HPC HIGH PERFORMANCE COMPUTING

LONI Louisiana Optical Network Initiative

Overview

- Definition and rationale
- Important considerations
- Getting started
- Essential functions
- Exercises

What is Message Passing Interface (MPI)?

- A communication library for parallel computing over a *distributed* system.
- Distributed=loosely coupled computers—they do not share a clock or memory.
- Programmer writes one program in C or Fortran.
- The one program is loaded on one or more processors and called a *process.*

Major Parallel Computing Models

- Shared memory
  - Much like pthreads (multithreading library)
  - Processes (lightweight processes or threads) all share memory (i.e. globals)
  - Threads have some private memory (stack)
  - Locking is needed and handled through monitors and semaphores

Major Parallel Computing Models

- Message Passing
  - Each process has its own memory
  - Programmer handles any sharing of data by passing messages
  - MPI falls into this category

Parallel Programming Types

- Data Parallel: Single Instruction Multiple Data (SIMD) – instructions are same but work on different data
- Task Parallel: Multiple Instructions Multiple Data (MIMD) – instructions differ as does the data
- Single Program Multiple Data (SPMD): *program* (think source) is the same, but different parts of it execute depending on process rank (equiv. to MIMD)
- *Programming with MPI is typically SPMD.*

SPMD Diagram

Process 0

Code:

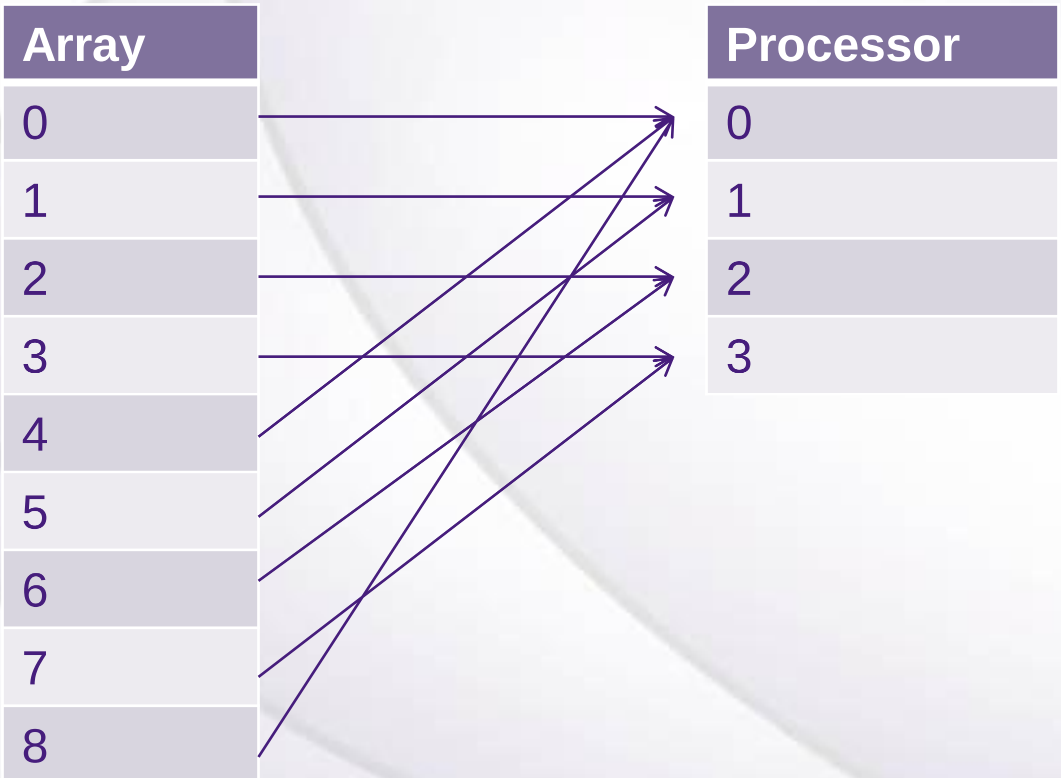
```
MPI_Init…
MPI_Comm_rank(MPI_C
OMM_WORLD, &rank);
if(rank==0) {
…
} else {
…
}
```

Process 1

Code:

```
MPI_Init…
MPI_Comm_rank(MPI_C
OMM_WORLD, &rank);
if(rank==0) {
…
} else {
…
}
```

Multiple Data



Why Use MPI?

- It allows one to parallelize his/her own programs.
- It is a solid communication library for distributed computing.

Process

- Each *process* is really just the one program, but usually executes differently on each *processor (core)*.
- Each process has a *rank* from 0 .. #CPUs, which is accessible from the running process.
- The programmer generally writes conditional blocks depending on this *rank.*

Rank

- Depending on the rank, the process may:
  - work on a different part of the problem space *(slave),*
  - split up a problem space and distribute the work (*master*),
  - combine results and save/display them (*master*), or
  - anything else the programmer wishes to do.

Writing a Program

- MPI has many functions in its library.
  - Point-to-point
  - Collective
- With only syntactic differences, the functions are the same in C and Fortran.

Compiling a Program

- Compiling code only involves:
  - Including a C or Fortran header file
  - Compiling using included special compiler wrapper
- Running code is as easy as using mpirun or placing in a batch script for use with qsub.

Basic MPI Program Structure

```
Call to Initialize MPI library.
If rank ≠ 0: //Here, the master is 0.
  Read input data (from master or a file).
  Do necessary operations.
  Send result to process 0.
Else:
  Send all/part of input data to slave processes
    if necessary.
  For each process i:
    Receive result from process i.
    Combine result with final result.
  Output final result.
Call to Finalize MPI library.
```

Basic MPI Program in C

```
#include <stdio.h>
#include <mpi.h>
main(int argc, char **argv) {
   int np, rank;
   MPI_Init(&argc, &argv);
   MPI_Comm_rank(MPI_COMM_WORLD, &rank);
   MPI_Comm_size(MPI_COMM_WORLD, &np);
   printf(“Hello World on process %d of %d.\n", rank,
   np);
   MPI_Finalize();
}
```

Compiling & Running Program

```
$ mpicc –o 00basic 00basic.c
$ qsub -I -l nodes=1:ppn=4 -l walltime=00:01:00 -q workq
…
$ mpirun -np 4 00basic
```

script:

```
#!/bin/bash
#PBS -q workq
#PBS -A loni_ccavatrain
#PBS -l nodes=1:ppn=4
#PBS -l walltime=00:00:01
#PBS -o 00basic.out
#PBS -j oe
#PBS -N basic
export WORK_DIR=/work/ccava/mpi
cd $WORK_DIR
export NPROCS=`wc -l $PBS_NODEFILE |gawk '//{print $1}'`
mpirun -machinefile $PBS_NODEFILE -np $NPROCS
/home/ccava/mpi/00basic
```

```
$ qsub script
```

Using Rank to Affect Flow

```
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &np);
if( rank == 0 ) { /* process 0 */ }
else if( rank == 1 ) { /* process 1 */ }
else if( rank == 2 ) { /* process 2 */ }
else { /* other process */ }
```

Sending Messages: MPI_Send

```
int MPI_Send( void *buf, int count, MPI_Datatype
datatype, int dest, int tag, MPI_Comm comm )
```

buf - initial address of send buffer (choice)

count - number of elements in send buffer (nonnegative integer)

datatype - datatype of each send buffer element (handle)

dest - rank of destination (integer)

tag - message tag (integer)

comm - communicator (handle)

Receiving Messages: MPI_Recv

```
int MPI_Recv( void *buf, int count, MPI_Datatype
datatype, int source, int tag, MPI_Comm comm,
MPI_Status *status )
```

buf - initial address of receive buffer (choice)

status - status object (Status)

count - maximum number of elements in receive buffer (integer)

datatype - datatype of each receive buffer element (handle)

source - rank of source (integer)

tag - message tag (integer)

comm - communicator (handle)

MPI_Send & MPI_Recv Example

```
#include "mpi.h"
#include <stdio.h>
int main(argc,argv) int argc; char *argv[]; {
     int numtasks, rank, dest, source, rc, count, tag=1;
     char inmsg, outmsg='x';
     MPI_Status Stat;
     MPI_Init(&argc,&argv);
     MPI_Comm_size(MPI_COMM_WORLD, &numtasks);
     MPI_Comm_rank(MPI_COMM_WORLD, &rank);
     if (rank == 0) {
          dest = 1;
          source = 1;
          rc = MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag, MPI_COMM_WORLD);
          rc = MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag, MPI_COMM_WORLD, &Stat);
     } else if (rank == 1) {
          dest = 0;
          source = 0;
          rc = MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag, MPI_COMM_WORLD, &Stat);
          rc = MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag, MPI_COMM_WORLD);
     }
     rc = MPI_Get_count(&Stat, MPI_CHAR, &count);
     printf("Task %d: Received %d char(s) from task %d with tag %d \n", rank, count,
     Stat.MPI_SOURCE, Stat.MPI_TAG);
     MPI_Finalize();
}
```

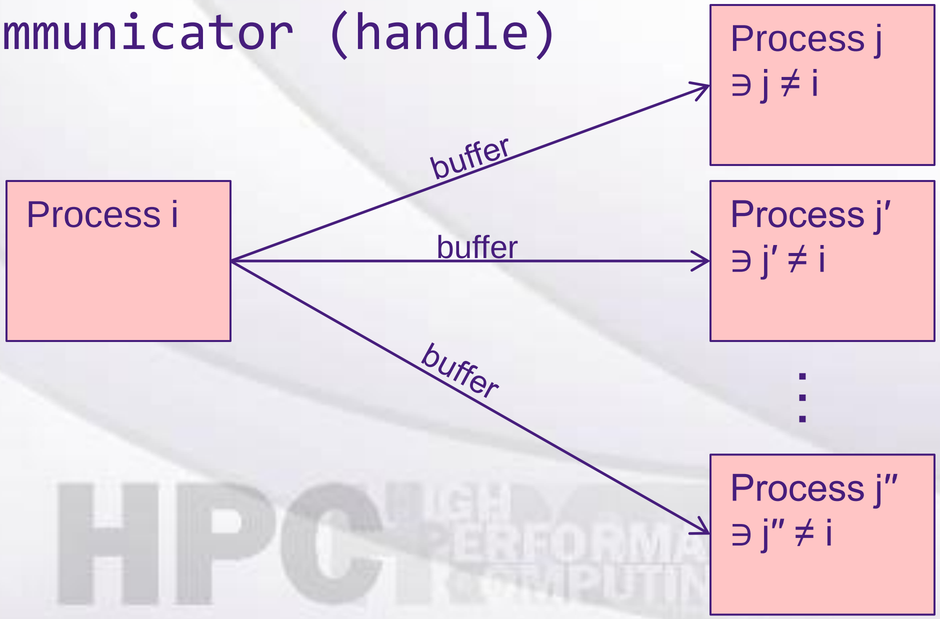
Data Types

MPI_CHAR
MPI_SHORT
MPI_INT
MPI_LONG
MPI_UNSIGNED_CHAR
MPI_UNSIGNED_SHORT
MPI_UNSIGNED_LONG
MPI_UNSIGNED
MPI_FLOAT
MPI_DOUBLE
MPI_LONG_DOUBLE
MPI_BYTE
MPI_PACKED

Distributing Data: MPI_Bcast

```
int MPI_Bcast ( void *buffer, int count, MPI_Datatype datatype, int root, MPI_Comm comm )
```

```
buffer - starting address of buffer (choice)
count - number of entries in buffer (integer)
datatype - data type of buffer (handle)
root - rank of broadcast root (integer)
comm - communicator (handle)
```



Collecting & Calculating with Data: MPI_Reduce

```
int MPI_Reduce ( void *sendbuf, void *recvbuf, int count,
MPI_Datatype datatype, MPI_Op op, int root, MPI_Comm comm )
```

sendbuf - address of send buffer (choice)

count - number of elements in send buffer (integer)

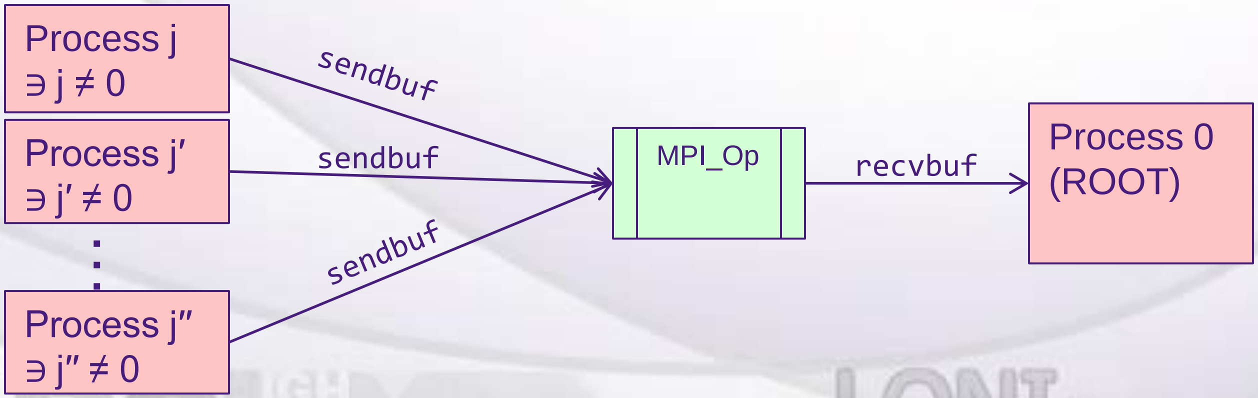
datatype - data type of elements of send buffer (handle)

op - reduce operation (handle)

root - rank of root process (integer)

comm - communicator (handle)

recvbuf - address of receive buffer (choice, significant only at root)



MPI_Op Values

MPI_MAX maximum
MPI_MIN minimum
MPI_SUM sum
MPI_PROD product
MPI_LAND logical and
MPI_BAND bit-wise and
MPI_LOR logical or
MPI_BOR bit-wise or
MPI_LXOR logical xor
MPI_BXOR bit-wise xor
MPI_MAXLOC max value and location
MPI_MINLOC min value and location

Programmer may define own operation (using MPI_Op_create)

MPI_Bcast & MPI_Reduce Example

```
#include "mpi.h"
#include <math.h>
int main(argc,argv) int argc; char *argv[]; {
  int done = 0, n, myid, numprocs, i, rc;
  double PI25DT = 3.141592653589793238462643;
  double mypi, pi, h, sum, x, a;
  MPI_Init(&argc,&argv);
  MPI_Comm_size(MPI_COMM_WORLD,&numprocs);
  MPI_Comm_rank(MPI_COMM_WORLD,&myid);
  while (!done){
    if (myid == 0) {
      printf("Enter the number of intervals: (0 quits) ");
      scanf("%d",&n); }
    MPI_Bcast(&n, 1, MPI_INT, 0, MPI_COMM_WORLD);
    if (n == 0) break;
    h = 1.0 / (double) n;
    sum = 0.0;
    for (i = myid + 1; i <= n; i += numprocs) {
      x = h * ((double)i - 0.5);
      sum += 4.0 / (1.0 + x*x); }
    mypi = h * sum;
    MPI_Reduce(&mypi, &pi, 1, MPI_DOUBLE, MPI_SUM, 0, MPI_COMM_WORLD);
    if (myid == 0)
      printf("pi is approximately %.16f, Error is %.16f\n", pi, fabs(pi - PI25DT)); }
  MPI_Finalize(); }
```

MPI_Barrier

Synchronizes all processes by blocking until all reach this function.

int MPI_Barrier (MPI_Comm comm)

comm - communicator (handle)

Using MPI_Barrier to Compute Time

```
double start,end;
…
MPI_Barrier(MPI_COMM_World);
if(rank==0) start = MPI_Wtime(); //seconds
…
MPI_Barrier(MPI_COMM_World);
if(rank==0) end = MPI_Wtime();
…
```

Exercises