MPI Intro
Lecture 3

CSCI 4974/6971

8 Sep 2016
Today’s Biz

1. Review OpenMP
2. Talk about project
3. Talk about homework
4. MPI slides
5. MPI tutorial
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OpenMP

- Basic data parallelism over for loops
  - #pragma omp parallel for
  - #pragma omp parallel { #pragma omp for { } }

- Avoiding race conditions
  - #pragma omp atomic
  - #pragma omp atomic capture
  - #pragma omp critical { }
  - #pragma omp single { }
  - #pragma omp master { }

- Reductions
  - #pragma omp parallel for reduction(op:variable)
  - op = +,-,min,max,etc. (see online resources for list)
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Project

- Small groups (1-2 students)
- Think of project ideas
  - Analysis-based: implement analytic and run on interesting dataset
  - Computation-based: implement known algorithm and optimize it or improve parallel scaling
  - Other: project based on your interests or research (talk to me)
  - Come discuss with me during office hours if you need ideas
- See website for due dates (proposal, update 1, update 2, final presentation and report)
Project Proposal

Proposal due September 22

- Group Members
- Project Title
- Short (< 1 page) summary
  - General project idea - problem being solved
  - Related work
  - Experiments - data and tests (how you’ll evaluate your success)
- Potential Outcomes
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Assignment 1

Due September 19th before class

- Introduction to iterative parallel graph algorithms
- Graph connectivity
- 6 functions to implement
  - 2 connectivity algorithms (push and pull)
  - Serial, OpenMP, MPI for each
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MPI Overview

Slides from Ahmed Louri, University of Arizona
MPI
Message Passing Interface
Outline

- Background
- Message Passing
- MPI
  - Group and Context
  - Communication Modes
  - Blocking/Non-blocking
  - Features
  - Programming / issues
- Tutorial
Distributed Computing Paradigms

- Communication Models:
  - Message Passing
  - Shared Memory

- Computation Models:
  - Functional Parallel
  - Data Parallel
Message Passing

- A process is a program counter and address space.
- Message passing is used for communication among processes.
- Inter-process communication:
  - Type:
    - Synchronous / Asynchronous
  - Movement of data from one process’s address space to another’s
Synchronous Vs. Asynchronous

○ A synchronous communication is not complete until the message has been received.

○ An asynchronous communication completes as soon as the message is on the way.
Synchronous Vs. Asynchronous (cont.)
What is message passing?

- Data transfer.
- Requires cooperation of sender and receiver.
- Cooperation not always apparent in code.
What is MPI?

- A message-passing library specifications:
  - Extended message-passing model
  - Not a language or compiler specification
  - Not a specific implementation or product

- For parallel computers, clusters, and heterogeneous networks.

- Communication modes: standard, synchronous, buffered, and ready.

- Designed to permit the development of parallel software libraries.

- Designed to provide access to advanced parallel hardware for
  - End users
  - Library writers
  - Tool developers
Group and Context

This image is captured from:
Writing Message Passing Parallel Programs with MPI
A Two Day Course on MPI Usage
Course Notes
Edinburgh Parallel Computing Centre
The University of Edinburgh
Group and Context (cont.)

- Are two important and indivisible concepts of MPI.
- Group: is the set of processes that communicate with one another.
- Context: it is somehow similar to the frequency in radio communications.
- Communicator: is the central object for communication in MPI. Each communicator is associated with a group and a context.
Communication Modes

Based on the type of send:

- Synchronous: Completes once the acknowledgement is received by the sender.
- Buffered send: completes immediately, unless if an error occurs.
- Standard send: completes once the message has been sent, which may or may not imply that the message has arrived at its destination.
- Ready send: completes immediately, if the receiver is ready for the message it will get it, otherwise the message is dropped silently.
Blocking vs. Non-Blocking

- Blocking, means the program will not continue until the communication is completed.

- Non-Blocking, means the program will continue, without waiting for the communication to be completed.
Features of MPI

- General
  - Communications combine context and group for message security.
  - Thread safety can’t be assumed for MPI programs.
Features that are NOT part of MPI

- Process Management
- Remote memory transfer
- Threads
- Virtual shared memory
Why to use MPI?

- MPI provides a powerful, efficient, and portable way to express parallel programs.

- MPI was explicitly designed to enable libraries which may eliminate the need for many users to learn (much of) MPI.

- Portable !!!!!!!!!!!!!!!!!!!!!!!!!!!!!

- Good way to learn about subtle issues in parallel computing
How big is the MPI library?

- Huge (125 Functions).
- Basic (6 Functions).
Basic Commands

Standard with blocking
Skeleton MPI Program

```c
#include <mpi.h>
main( int argc, char** argv )
{
    MPI_Init( &argc, &argv );
    /* main part of the program */
    /*
     * Use MPI function call depend on your data partitioning and the parallelization architecture
     */
    MPI_Finalize();
}
```
Initializing MPI

- The initialization routine MPI_INIT is the first MPI routine called.

- MPI_INIT is called once

```c
int mpi_Init( int *argc, char **argv );
```
A minimal MPI program(c)

```c
#include "mpi.h"
#include <stdio.h>
int main(int argc, char *argv[])
{
    MPI_Init(&argc, &argv);
    printf("Hello, world!\n");
    MPI_Finalize();
    Return 0;
}
```
A minimal MPI program (cont.)

- `#include “mpi.h”` provides basic MPI definitions and types.
- `MPI_Init` starts MPI
- `MPI_Finalize` exits MPI
- Note that all non-MPI routines are local; thus “printf” run on each process
- Note: MPI functions return error codes or `MPI_SUCCESS`
Error handling

- By default, an error causes all processes to abort.
- The user can have his/her own error handling routines.
- Some custom error handlers are available for downloading from the net.
```c
#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("I am %d of %d\n", rank, size);
    MPI_Finalize();
    return 0;
}
```
Some concepts

- The default communicator is the `MPI_COMM_WORLD`

- A process is identified by its rank in the group associated with a communicator.
Data Types

- The data message which is sent or received is described by a triple (address, count, datatype).
- The following data types are supported by MPI:
  - Predefined data types that are corresponding to data types from the programming language.
  - Arrays.
  - Sub blocks of a matrix
  - User defined data structure.
  - A set of predefined data types
### Basic MPI types

<table>
<thead>
<tr>
<th>MPI datatype</th>
<th>C datatype</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPI_CHAR</td>
<td>signed char</td>
</tr>
<tr>
<td>MPI_SIGNED_CHAR</td>
<td>signed char</td>
</tr>
<tr>
<td>MPI_UNSIGNED_CHAR</td>
<td>unsigned char</td>
</tr>
<tr>
<td>MPI_SHORT</td>
<td>signed short</td>
</tr>
<tr>
<td>MPI_UNSIGNED_SHORT</td>
<td>unsigned short</td>
</tr>
<tr>
<td>MPI_INT</td>
<td>signed int</td>
</tr>
<tr>
<td>MPI_UNSIGNED</td>
<td>unsigned int</td>
</tr>
<tr>
<td>MPI_LONG</td>
<td>signed long</td>
</tr>
<tr>
<td>MPI_UNSIGNED_LONG</td>
<td>unsigned long</td>
</tr>
<tr>
<td>MPI_FLOAT</td>
<td>float</td>
</tr>
<tr>
<td>MPI_DOUBLE</td>
<td>double</td>
</tr>
<tr>
<td>MPI_LONG_DOUBLE</td>
<td>long double</td>
</tr>
</tbody>
</table>
Why defining the data types during the send of a message?

Because communications take place between heterogeneous machines. Which may have different data representation and length in the memory.
MPI blocking send

MPI_SEND(void *start, int count, MPI_DATATYPE datatype, int dest, int tag, MPI_COMM comm)

- The message buffer is described by \((start, count, datatype)\).
- \(dest\) is the rank of the target process in the defined communicator.
- \(tag\) is the message identification number.
MPI blocking receive

MPI_RECV(void *start, int count, MPI_DATATYPE datatype, int source, int tag, MPI_COMM comm, MPI_STATUS *status)

- **Source** is the rank of the sender in the communicator.

- The receiver can specify a wildcard value for source (MPI_ANY_SOURCE) and/or a wildcard value for tag (MPI_ANY_TAG), indicating that any source and/or tag are acceptable.

- **Status** is used for extra information about the received message if a wildcard receive mode is used.

- If the count of the message received is less than or equal to that described by the MPI receive command, then the message is successfully received. Else it is considered as a buffer overflow error.
Status is a data structure

In C:

```c
int recvd_tag, recvd_from, recvd_count;
MPI_Status status;
MPI_Recv(..., MPI_ANY_SOURCE, MPI_ANY_TAG, ...
    ..., &status)
recvd_tag = status.MPI_TAG;
recvd_from = status.MPI_SOURCE;
MPI_Get_count(&status, datatype,
&recvd_count);
```
A receive operation may accept messages from an arbitrary sender, but a send operation must specify a unique receiver.

Source equals destination is allowed, that is, a process can send a message to itself.
Why MPI is simple?

- Many parallel programs can be written using just these six functions, only two of which are non-trivial:
  - MPI_INIT
  - MPI_FINALIZE
  - MPI_COMM_SIZE
  - MPI_COMM_RANK
  - MPI_SEND
  - MPI_RECV
Simple full example

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

int main(int argc, char *argv[]) {
  const int tag = 42;   /* Message tag */
  int id, ntasks, source_id, dest_id, err, i;
  MPI_Status status;
  int msg[2];   /* Message array */

  err = MPI_Init(&argc, &argv);   /* Initialize MPI */
  if (err != MPI_SUCCESS) {
    printf("MPI initialization failed!\n");
    exit(1);
  }

  err = MPI_Comm_size(MPI_COMM_WORLD, &ntasks);   /* Get nr of tasks */
  err = MPI_Comm_rank(MPI_COMM_WORLD, &id);   /* Get id of this process */
  if (ntasks < 2) {
    printf("You have to use at least 2 processors to run this program\n");
    MPI_Finalize();   /* Quit if there is only one processor */
    exit(0);
  }
}
if (id == 0) {  /* Process 0 (the receiver) does this */
    for (i=1; i<ntasks; i++) {
        err = MPI_Recv(msg, 2, MPI_INT, MPI_ANY_SOURCE, tag, MPI_COMM_WORLD, 
                        &status);                        /* Receive a message */
        source_id = status.MPI_SOURCE; /* Get id of sender */
        printf("Received message %d %d from process %d\n", msg[0], msg[1], 
                source_id);
    }
}
else {       /* Processes 1 to N-1 (the senders) do this */
    msg[0] = id; /* Put own identifier in the message */
    msg[1] = ntasks; /* and total number of processes */
    dest_id = 0; /* Destination address */
    err = MPI_Send(msg, 2, MPI_INT, dest_id, tag, MPI_COMM_WORLD);
}

err = MPI_Finalize(); /* Terminate MPI */
if (id==0) printf("Ready\n");
exit(0);
return 0;
Collective Operations
Introduction to collective operations in MPI

- Collective operations are called by all processes in a communicator.
- MPI_Bcast distributes data from one process (the root) to all others in a communicator.
  Syntax:
  ```c
  MPI_Bcast(void *message, int count, MPI_Datatype datatype, int root, MPI_Comm comm)
  ```
- MPI_Reduce combines data from all processes in communicator or and returns it to one process
  Syntax:
  ```c
  MPI_Reduce(void *message, void *recvbuf, int count, MPI_Datatype datatype, MPI_Op op, int root, MPI_Comm comm)
  ```
- In many numerical algorithm, send/receive can be replaced by Bcast/Reduce, improving both simplicity and efficiency.
Collective Operations

MPI_MAX, MPI_MIN, MPI_SUM, MPI_PROD, MPI_BAND, MPI_LAND, MPI_BOR, MPI_LOR, MPI_LXOR, MPI_BXOR, MPI_MAXLOC, MPI_MINLOC
Example: Compute $\pi$ (0)

$$\pi = \int_{0}^{1} \frac{4}{1 + x^2} \, dx$$
Example: Compute PI (1)

```c
#include "mpi.h"
#include <math.h>

int main(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;
        }
    }
    MPI_Finalize();
}
```
Example: Compute PI (2)

```c
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();
return 0;
```
When to use MPI

- Portability and Performance
- Irregular data structure
- Building tools for others
- Need to manage memory on a per processor basis
Programming with MPI
Compile and run the code

- Compile using:
  - mpicc –o pi pi.c
  - Or
  - mpic++ –o pi pi.cpp
- mpirun –np # of procs –machinefile XXX pi
  - -machinefile tells MPI to run the program on the machines of XXX.
MPI on ECE Solaris Machines (1)

- Log in to *draco.ece.arizona.edu*
- From outside the UofA first log in to *shell.ece.arizona.edu*
- Create a Text file and name it. For example ML, and have the following lines:

```
150.135.221.71
150.135.221.72
150.135.221.73
150.135.221.74
150.135.221.75
150.135.221.76
150.135.221.77
150.135.221.78
```
#include "mpi.h"
#include <math.h>
#include <stdio.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 on ECE Solaris Machines (3)

- How to compile:
  mpicc ex2.c -o ex2 -lm

- How to run:
  mpirun -np 4 -machinefile ml ex2
Where to get MPI library?

- MPICH (WINDOWS / UNICES)

- Open MPI (UNICES)
  - http://www.open-mpi.org/
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5. **MPI tutorial**
1. Basic compilation
2. Environment
3. Send/Recv
4. Collective operations
5. Implementing BFS
C++ Demonstration – Blank code and data available on website
www.cs.rpi.edu/~slotag/classes/FA16/index.html