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

Today's Biz

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

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)

Today's Biz

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

Project

- Small groups (1-2 students)
- Think of project ideas
  - Analysis-based: implement analytic and run on interesting dataset
  - Computation-based: implement know 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

Today's Biz

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

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

Today's Biz

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

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

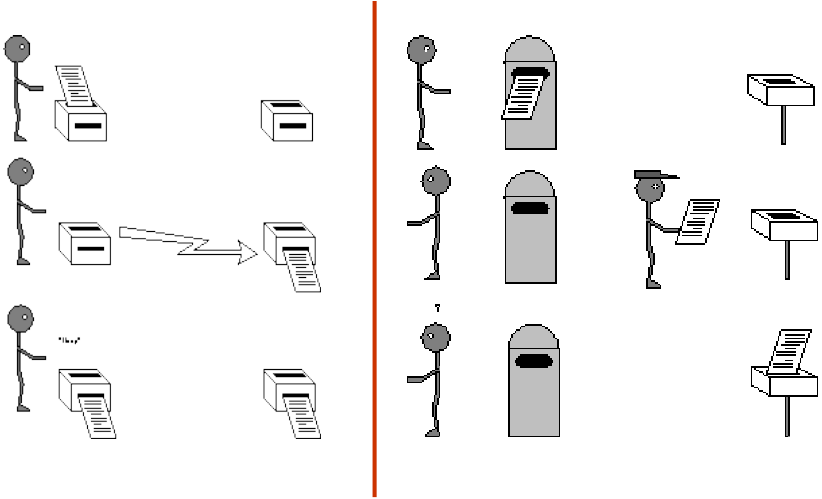
Message Passing

- 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.)



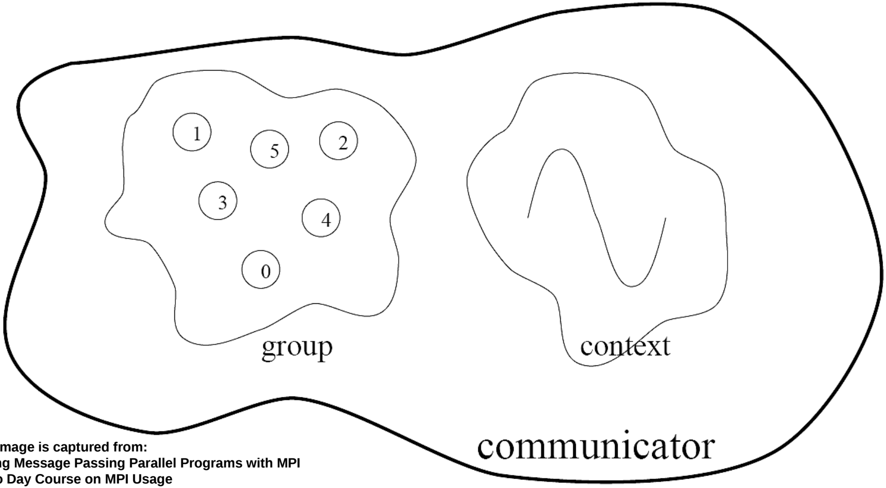
What is message passing?

- 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

```
#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

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

A minimal MPI program(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(c) (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.

Improved Hello (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

MPI datatype	C datatype
MPI_CHAR	signed char
MPI_SIGNED_CHAR	signed char
MPI_UNSIGNED_CHAR	unsigned char
MPI_SHORT	signed short
MPI_UNSIGNED_SHORT	unsigned short
MPI_INT	signed int
MPI_UNSIGNED	unsigned int
MPI_LONG	signed long
MPI_UNSIGNED_LONG	unsigned long
MPI_FLOAT	float
MPI_DOUBLE	double
MPI_LONG_DOUBLE	long double

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 souce (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 exrtra 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.

MPI_STATUS

- Status is a data structure
- In 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);
```

More info

- 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);
  }
```

Simple full example (Cont.)

```
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:

  ```
  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:

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

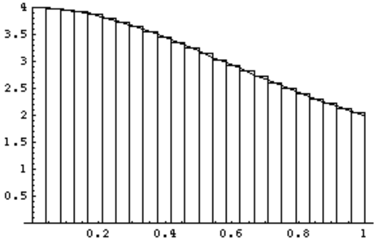
- In many numerical algorithm, send/receive can be replaced by Bcast/Reduce, improving both simplicity and efficiency.

Collective Operations

MPI_MAX, MPI_MIN, MPI_SUM, MPI_PROD, MPI_LAND, MPI_BAND, MPI_LOR, MPI_BOR, 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)

```
#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)
   }
```

Example: Compute PI (2)

```
        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

MPI on ECE Solaris Machines (2) ex2.c

```
#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)
  - http://www-unix.mcs.anl.gov/mpi/mpich/
- Open MPI (UNICES)
  - http://www.open-mpi.org/

Today's Biz

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

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