Introduction to MPI

http://people.sc.fsu.edu/∼jburkardt/presentations/ mpi_intro_2005.pdf

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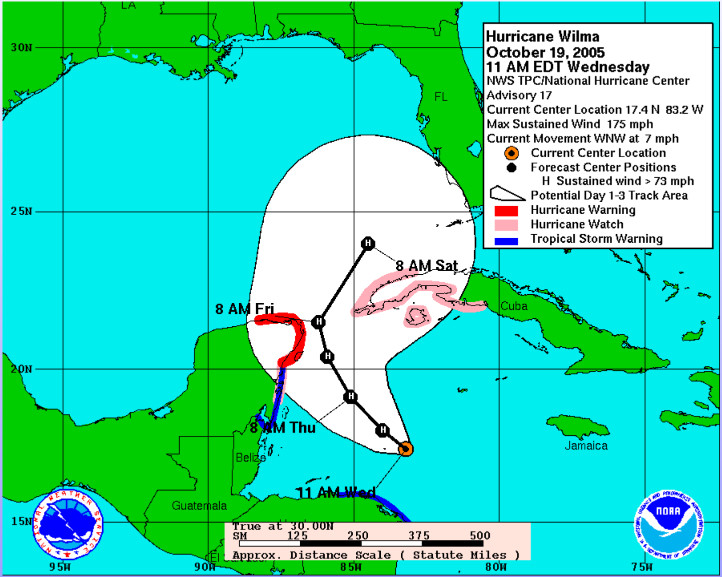
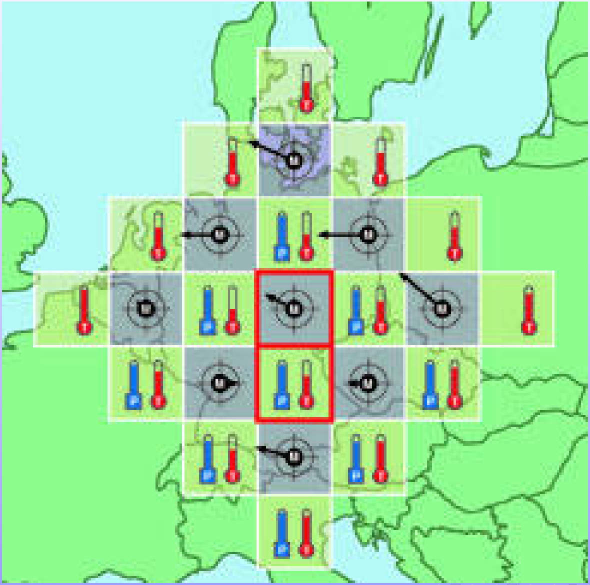
Introduction to MPI

- Why is MPI needed?
- What is an MPI computation doing?
- What does an MPI program look like?
- How (and where) do I compile and run an MPI program?

It Looks Easy Today



Richardson's Computation, 1917

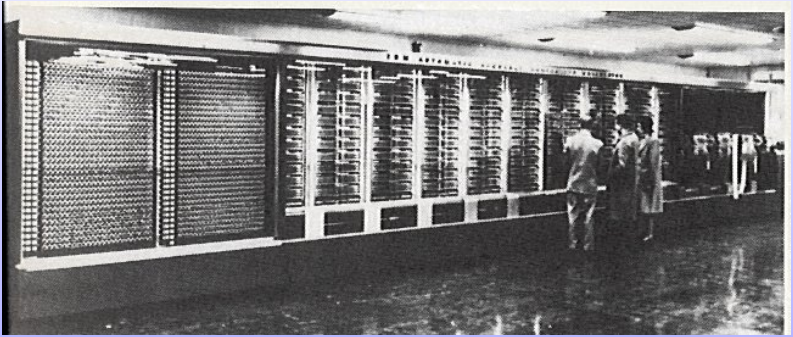


Richardson's Forecasting Factory

The First Computers

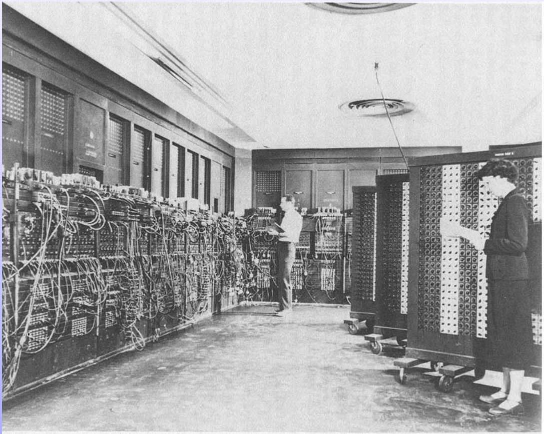
The Harvard College Observatory Computer Lab, 1890.

The Harvard Mark I: 1944



The first modern computers were awesome.

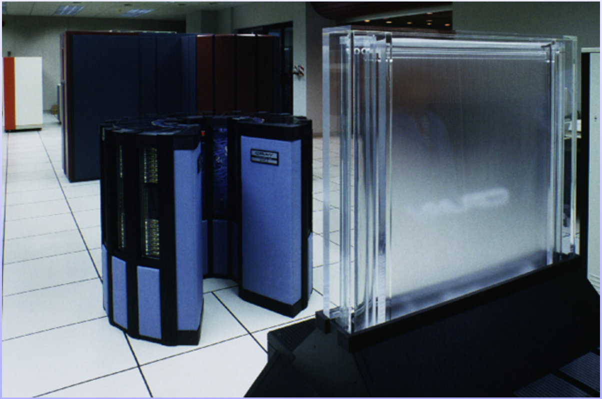
The ENIAC: 1942



The ENIAC.
Smithsonian Institution Photo No. 53192.

John von Neumann wanted ENIAC for weather prediction.

The Cray YMP: 1990



As problems got bigger, supercomputers got **smaller** and **hotter**.

Grace Hopper with a Nanosecond

1 gigahertz clock cycle implies one "nanosecond" radius.

Parallel Processing to the Rescue

A single processor is exponentially expensive to upgrade. but a *cluster* of processors is trivial to upgrade; just buy some more!

The rate of communication is an problem, so controlling the *amount* of communication is important.

MPI enables the cluster of processors to work together, and communicate.

Philosophy: MPI is just a library

- User program written in C, C++, F77 or F90;
- MPI operations invoked as calls to functions;
- MPI symbols are special constants.

Philosophy: One Program Does it All

- A single program embodies the entire task;
- This program runs on multiple processors;
- Each processor knows its ID number.

HELLO HELLO HELLO HELLO in C

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

int main ( int argc, char *argv[] )
{
  int ierr;
  int num_procs;
  int my_id;

  ierr = MPI_Init ( &argc, &argv );
  ierr = MPI_Comm_rank ( MPI_COMM_WORLD, &my_id );
  if ( my_id == 0 )
  {
    ierr = MPI_Comm_size ( MPI_COMM_WORLD, &num_procs );
    printf ( "\n" );
    printf ( "HELLO_WORLD - Master process:\n" );
    printf ( "  A simple C program using MPI.\n" );
    printf ( "\n" );
    printf ( "  The number of processes is %d.\n", num_procs );
    printf ( "\n" );
  }
  else
  {
    printf ( "  Process %d says 'Hello, world!'\n", my_id );
  }
  ierr = MPI_Finalize ( );
  return 0;
}
```

HELLO HELLO HELLO HELLO in FORTRAN77

```
program main

include 'mpif.h'

integer error
integer my_id
integer num_procs

call MPI_Init ( error )

call MPI_Comm_rank ( MPI_COMM_WORLD, my_id, error )

if ( my_id == 0 ) then
  call MPI_Comm_size ( MPI_COMM_WORLD, num_procs, error )
  print , ' '
  print , 'HELLO_WORLD - Master process:'
  print , '  A FORTRAN77 program using MPI.'
  print , ' '
  print , '  The number of processes is ', num_procs
  print , ' '
else
  print , ' '
  print , '  Process ', my_id, ' says "Hello, world!"'
end if

call MPI_Finalize ( error )

stop
end
```

HELLO HELLO HELLO HELLO in C++

```
# include <cstdlib>
# include <iostream>
# include "mpi.h"
using namespace std;


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

  MPI::Init ( argc, argv );
  my_id = MPI::COMM_WORLD.Get_rank ( );

  if ( my_id == 0 )
  {
    num_procs = MPI::COMM_WORLD.Get_size ( );
    cout << "\n";
    cout << "HELLO_WORLD - Master process:\n";
    cout << "  A simple C++ program using MPI.\n";
    cout << "  The number of processes is " << num_procs << "\n";
  }
  else
  {
    cout << "  Process " << my_id << " says 'Hello, world!'\n";
  }

  MPI::Finalize ( );

  return 0;
}
```

The output from *HELLO*^{4}

```
Process 2 says ”Hello, world!”

HELLO WORLD - Master Process:
A simple FORTRAN90 program using MPI.
The number of processes is 4

Process 3 says ”Hello, world!”

Process 1 says ”Hello, world!’
```

Philosophy: Each Process(or) Has Its Own Data

MPI data is not shared, but can be *communicated*.

- Each process has its own data;
- To communicate, one process may send some data to another;
- Basic routines **MPI_Send** and **MPI_Recv**.

Communication: MPI_Send

MPI_Send (data, count, type, to, tag, channel)

- **data**, the address of the data;
- **count**, number of data items;
- **type**, the data type (use an MPI symbolic value);
- **to**, the processor ID to which data is sent;
- **tag**, a message identifier;
- **channel**, the channel to be used.

Communication: MPI_Recv

MPI_Recv (data, count, type, from, tag, channel, status)

- **data**, the address of the data;
- **count**, number of data items;
- **type**, the data type (use an MPI symbolic value);
- **from**, the processor ID from which data is received;
- **tag**, a message identifier;
- **channel**, the channel to be used;
- **status**, warnings, errors, etc.

Communication: An example algorithm

Compute $A * x = b$.

- a "task" is to multiply one row of A times x;
- we can assign one task to each processor. Whenever a processor is done, give it another task.
- each processor needs a copy of x at all times; for each task, it needs a copy of the corresponding row of A.
- processor 0 will do no tasks; instead, it will pass out tasks and accept results.

Matrix * Vector in FORTRAN77 (Page 1)

```
      if ( my_id == master )

        numsent = 0
c
c  BROADCAST X to all the workers.
c
        call MPI_BCAST ( x, cols, MPI_DOUBLE_PRECISION, master,
     &    MPI_COMM_WORLD, ierr )

c
c  SEND row I to worker process I; tag the message with the row number.
c
        do i = 1, min ( num_procs-1, rows )

          do j = 1, cols
            buffer(j) = a(i,j)
          end do

          call MPI_SEND ( buffer, cols, MPI_DOUBLE_PRECISION, i,
     &      i, MPI_COMM_WORLD, ierr )

          numsent = numsent + 1

        end do
```

Matrix * Vector in FORTRAN77 (Page 2)

```
c
c  Wait to receive a result back from any processor;
c  If more rows to do, send the next one back to that processor.
c
        do i = 1, rows

          call MPI_RECV ( ans, 1, MPI_DOUBLE_PRECISION,
     &       MPI_ANY_SOURCE, MPI_ANY_TAG,
     &       MPI_COMM_WORLD, status, ierr )

          sender = status(MPI_SOURCE)
          anstype = status(MPI_TAG)
          b(anstype) = ans

          if ( numsent .lt. rows ) then

            numsent = numsent + 1

            do j = 1, cols
              buffer(j) = a(numsent,j)
            end do

            call MPI_SEND ( buffer, cols, MPI_DOUBLE_PRECISION,
     &         sender, numsent, MPI_COMM_WORLD, ierr )

          else

            call MPI_SEND ( MPI_BOTTOM, 0, MPI_DOUBLE_PRECISION,
     &        sender, 0, MPI_COMM_WORLD, ierr )

          end if

        end do
```

Matrix * Vector in FORTRAN77 (Page 3)

```
c
c  Workers receive X, then compute dot products until
c  done message received
c
        else

          call MPI_BCAST ( x, cols, MPI_DOUBLE_PRECISION, master,
     &      MPI_COMM_WORLD, ierr )

   90     continue

          call MPI_RECV ( buffer, cols, MPI_DOUBLE_PRECISION, master,
     &      MPI_ANY_TAG, MPI_COMM_WORLD, status, ierr )

          if ( status(MPI_TAG) .eq. 0 ) then
            go to 200
          end if

          row = status(MPI_TAG)

          ans = 0.0
          do i = 1, cols
            ans = ans + buffer(i) * x(i)
          end do

          call MPI_SEND ( ans, 1, MPI_DOUBLE_PRECISION, master,
     &        row, MPI_COMM_WORLD, ierr )

          go to 90

  200     continue

        end if
```

Running MPI: on Phoenix

At SCS, there is a public cluster called Phoenix.

Any SCS user can log in to **phoenix.csit.fsu.edu**.

Compile your MPI program with **mpicc**, **mpiCC**, **mpif77**.
(**mpif90** is not working yet!)

Run your job by writing a condor script:
condor_submit job.condor

Running MPI: on Phoenix

A sample Condor script:

```
universe = MPI
initialdir = /home/u8/users/burkardt
executable = matvec
log = matvec.log
output = output$(NODE).txt
machine_count = 4
queue
```

Running MPI: on Teragold

Two IBM clusters, Teragold and Eclipse.

To get an account requires an application process.

Log in to **teragold.fsu.edu**.

Run your job by writing a LoadLeveler script:
llsubmit job.ll

Running MPI: on Teragold

A sample LoadLeveler script:

```
# job_name = matvec
# class = short
# wall_clock_limit = 100
# job_type = parallel
# node = 1
# tasks_per_node = 4
# node_usage = shared
# network.mpi = css0,shared,US
# queue
mpcc_r matvec.c
mv a.out matvec
matvec > matvec.out
```

References: Books

- Peter Pacheco, **Parallel Programming with MPI** ;
- Stan Openshaw+, **High Performance Computing+**;
- Scott Vetter+, **RS/600 SP: Practical MPI Programming**;
- William Gropp+, **Using MPI**;
- Marc Snir, **MPI: The Complete Reference**.

References: Web Pages

With prefix **http://www.csit.fsu.edu/**

- **this talk:** ∼burkardt/pdf/mpi_intro.pdf
- **MPI + C:** ∼burkardt/c_src/mpi/mpi.html
  (or cpp_src, f77_src, f_src)
- **Condor:** ∼burkardt/f_src/condor/condor.html
  or
  twiki/bin/view/TechHelp/UsingCondor
- **LoadLeveler:** supercomputer/sp3_batch.html

Message Passing Inyerface

As today's master process...

I BROADCAST the following MESSAGE:

Happy Parallel Trails to You!

MPI_Finalize( )!