Lecture 22—Message Passing Interface (MPI) & Clusters; The Cloud

ECE 459: Programming for Performance

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Part I

MPI & Clusters

Continuing to Switch Gears

So far, we've seen how to make things fast on one computer:

- threads;
- compiler optimizations;
- GPUs.

To get a lot of bandwidth, though, you need lots of computers,
(if you're lucky and the problem allows!)

Today: programming for performance
with multiple computers via MPI.

Key Idea: Explicit Communication

Mostly we've seen shared-memory systems;
complication: must manage contention.

Recently, GPU programming: explicitly copy data.

Message-passing: yet another paradigm.

What is MPI?

Message Passing Interface:
A language-independent communation protocol
for parallel computers.

- Use it to run the same code on a number of nodes
  (different hardware threads; or servers in a cluster).
- Provides explicit message passing between nodes.
- Is the dominant model for high performance computing
  (de-facto standard).

High Level View of MPI

MPI is a type of SPMD (single process, multiple data).

Idea: have multiple instances of the same program,
all working on different data.

The program could be running on the same machine,
or a cluster of machines.

MPI facilitates communication of data between processes.

MPI Functions

```
// Initialize MPI
int MPI_Init(int *argc, char **argv)

// Determine number of processes within a communicator
int MPI_Comm_size(MPI_Comm comm, int *size)

// Determine processor rank within a communicator
int MPI_Comm_rank(MPI_Comm comm, int *rank)

// Exit MPI (must be called last by all processors)
int MPI_Finalize()

// Send a message
int MPI_Send (void *buf,int count, MPI_Datatype datatype,
              int dest, int tag, MPI_Comm comm)

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

MPI Function Notes

- `MPI_Comm`: a communicator,
  often `MPI_COMM_WORLD` for global channel.
- `MPI_Datatype`: just an enum, e.g. `MPI_FLOAT_INT`, etc.
- `dest`/`source`: "rank" of the process (in a communicator) to send a message to/receive a message from;
  you may use `MPI_ANY_SOURCE` in `MPI_Recv`.
- Both `MPI_Send` and `MPI_Recv` are blocking calls—
  see `man MPI_Send` or `man MPI_Recv` for more details.
- The `tag` allows you to organize your messages,
  so you can filter all but a specific tag.

Hello, World in MPI

As with OpenCL kernels:

first, figure out what “current” process is supposed to compute.

```
// http://www.dartmouth.edu/~rc/classes/intro_mpi/
#include <stdio.h>
#include <mpi.h>

int main (int argc, char * argv[])
{
  int rank, size;

  /* start MPI */
  MPI_Init (&argc, &argv);
  /* get current process id */
  MPI_Comm_rank (MPI_COMM_WORLD, &rank);
  /* get number of processes */
  MPI_Comm_size (MPI_COMM_WORLD, &size);
  printf("Hello world from process %d of %d\n", rank, size);
  MPI_Finalize();
  return 0;
}
```

Longer MPI Example (from Wikipedia)

Here's a common example:

- The "master" (rank 0) process creates some strings and sends them to the worker processes.
- The worker processes modify their string and send it back to the master.

Source:

`http://en.wikipedia.org/wiki/Message_Passing_Interface`.

Example Code (1)

```
/*
  "Hello World" MPI Test Program
 */
 #include <mpi.h>
 #include <stdio.h>
 #include <string.h>

 #define BUFSIZE 128
 #define TAG 0

 int main(int argc, char *argv[])
 {
   char idstr[32];
   char buff[BUFSIZE];
   int numprocs;
   int myid;
   int i;
   MPI_Status stat;
```

Example Code (2)

```
/* all MPI programs start with MPI_Init; all 'N'
 * processes exist thereafter
 */
MPI_Init(&argc,&argv);

/* find out how big the SPMD world is */
MPI_Comm_size(MPI_COMM_WORLD, &numprocs);

/* and this processes' rank is what? */
MPI_Comm_rank(MPI_COMM_WORLD, &myid);

/* At this point, all programs are running equivalently;
 * the rank distinguishes the roles of the programs in
 * the SPMD model, with rank 0 often used specially...
 */
```

Example Code (3)

```
    if(myid == 0)
    {
      printf("%d: We have %d processors\n", myid, numprocs);
      for(i=1; i<numprocs; i++)
      {
        sprintf(buff, "Hello %d! ", i);
        MPI_Send(buff, BUFSIZE, MPI_CHAR, i, TAG,
                 MPI_COMM_WORLD);
      }
      for(i=1; i<numprocs; i++)
      {
        MPI_Recv(buff, BUFSIZE, MPI_CHAR, i, TAG,
                 MPI_COMM_WORLD, &stat);
        printf("%d: %s\n", myid, buff);
      }
    }
```

Example Code (4)

```
  else
  {
    /* receive from rank 0: */
    MPI_Recv(buff, BUFSIZE, MPI_CHAR, 0, TAG,
             MPI_COMM_WORLD, &stat);
    sprintf(idstr, "Processor %d ", myid);
    strncat(buff, idstr, BUFSIZE-1);
    strncat(buff, "reporting for duty", BUFSIZE-1);
    /* send to rank 0: */
    MPI_Send(buff, BUFSIZE, MPI_CHAR, 0, TAG,
             MPI_COMM_WORLD);
  }

  /* MPI Programs end with MPI Finalize; this is a weak
   * synchronization point.
   */
  MPI_Finalize();
  return 0;
}
```

Compiling with OpenMPI

```
// Wrappers for gcc (C/C++)
mpicc
mpicxx

// Compiler Flags
OMPI_MPICC_CFLAGS
OMPI_MPICXX_CXXFLAGS

// Linker Flags
OMPI_MPICC_LDFLAGS
OMPI_MPICXX_LDFLAGS
```

OpenMPI does not recommend that you set the flags yourself.
To see them, try:

```
# Show the flags necessary to compile MPI C applications
shell$ mpicc --showme:compile

# Show the flags necessary to link MPI C applications
shell$ mpicc --showme:link
```

Compiling and Running

```
mpirun -np <num_processors> <program>
mpiexec -np <num_processors> <program> # a synonym
```

Starts `num_processors` instances of the program using MPI.

```
jon@riker examples master % mpicc hello_mpi.c
jon@riker examples master % mpirun -np 8 a.out
0: We have 8 processors
0: Hello 1! Processor 1 reporting for duty
0: Hello 2! Processor 2 reporting for duty
0: Hello 3! Processor 3 reporting for duty
0: Hello 4! Processor 4 reporting for duty
0: Hello 5! Processor 5 reporting for duty
0: Hello 6! Processor 6 reporting for duty
0: Hello 7! Processor 7 reporting for duty
```

- By default, MPI uses the lowest-latency communication resource available; shared memory, in this case.

MPI Matrix Multiplication Example

Highlights of: `http://www.nccs.gov/wp-content/training/mpi-examples/C/matmul.c`.

To compute the matrix product AB:

1. Initialize MPI.
2. If the current process is the master task (task id 0):
    1. Initialize matrices.
    2. Send work to each worker task:
       row number (offset); number of rows; row contents from A; complete contents of matrix B.

       ```
       MPI_Send(&a[offset][0], rows*NCA, MPI_DOUBLE, dest,
                mtype, MPI_COMM_WORLD);
       ```
    3. Wait for results from all worker tasks (`MPI_Recv`).
    4. Print results.
3. For all other tasks:
    1. Receive offset, number of rows, partial matrix A, and complete matrix B, using `MPI_Recv`:

       ```
       MPI_Recv(&offset, 1, MPI_INT, MASTER,
                mtype, MPI_COMM_WORLD, &status);
       ```
    2. Do the computation.
    3. Send the results back to the sender.

Other Things MPI Can Do

We can use nodes on a network (by using a `hostfile`).

We can even use MPMD:

- *multiple processes, multiple data*

```
% mpirun -np 2 a.out : -np 2 b.out
```

This launches a single parallel application.

- All in the same `MPI_COMM_WORLD`; but
- Ranks 0 and 1 are instances of `a.out`, and
- Ranks 2 and 3 are instances of `b.out`.

You could also use the -app flag with an appfile instead of typing out everything.

Performance Considerations

Your bottleneck for performance here is message-passing.

Keep the communication to a minimum!

In general, the more machines/farther apart they are, the slower the communication.

Each step from multicore machines to GPU programming to MPI triggers an order-of-magnitude decrease in communication bandwidth and similar increase in latency.

Part II

Cloud Computing

Using a Cluster

Historically:

- find $$$;
- buy and maintain pile of expensive machines.

Not anymore!

We'll talk about Amazon's Elastic Compute Cloud (EC2) and principles behind it.

Evolution of servers

You want a server on the Internet.

- Once upon a time: had to get a physical machine hosted (e.g. in a rack).
  Or, live with inferior shared hosting.

- Virtualization: pay for part of a machine on that rack.
  A win: you're usually not maxing out a computer, and you'd be perfectly happy to share it with others, as long as there are good security guarantees. All users can get root access.

- Clouds enable you to add more machines on-demand.
  Instead of having just one virtual server, spin up dozens (or thousands) of server images when you need more compute capacity.
  Servers typically share persistent storage, also in the cloud.

Paying for Computes

Cloud computing:

- pay according to the number of machines, or instances, that you've started up.

Providers offer different instance sizes;
sizes vary according to the
number of cores, local storage, and memory.

Some instances even have GPUs!

Launching Instances

Need more computes? Launch an instance!

Input: Virtual Machine image.

Mechanics: use a command-line or web-based tool.

New instance gets an IP address and is network-accessible.
You have full root access to that instance.

What to Launch?

Amazon provides public images:

- different Linux distributions;
- Windows Server; and
- OpenSolaris (maybe not anymore?).

You can build an image which contains software you want, including Hadoop and OpenMPI.

Cleanup

Presumably you don't want to pay forever for your instances.

When you're done with an instance:

- shut it down, stop paying for it.

All data on instance goes away.

Data Storage

To keep persistent results:

- mount a storage device, also on the cloud (e.g. Amazon Elastic Block Storage); or,
- connect to a database on a persistent server (e.g. Amazon SimpleDB or Relational Database Service); or,
- you can store files on the Web (e.g. Amazon S3).

Summary

- MPI is a powerful tool for highly parallel computing across multiple machines.
- MPI Programming is similar to a more powerful version of `fork/join`; but you have to manage communication more explicitly.
- Saw cloud computing basics.