CMSC 714
Lecture 5
Message Passing with MPI

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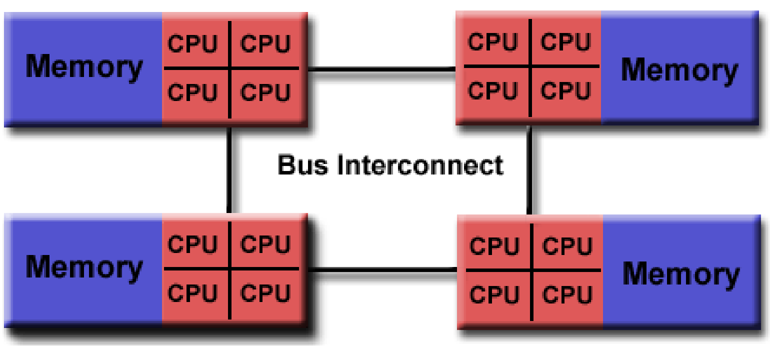
Notes

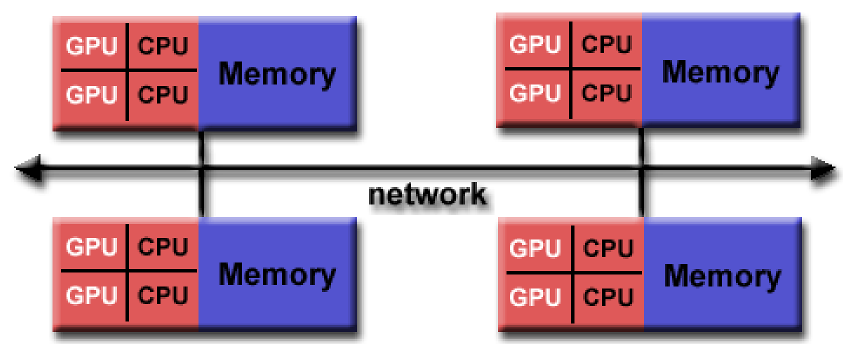
- Login info for zaratan cluster provided in zaratan primer, used for all assignments
- OpenMP assignment due next Thursday, Feb. 20
  - Questions?
- Check Readings page to see when you are assigned to send questions for a lecture

Distributed memory architecture

- Each processor/core on a node only has access to local memory on the node
- Writes in one node's memory have no effect on another node's memory



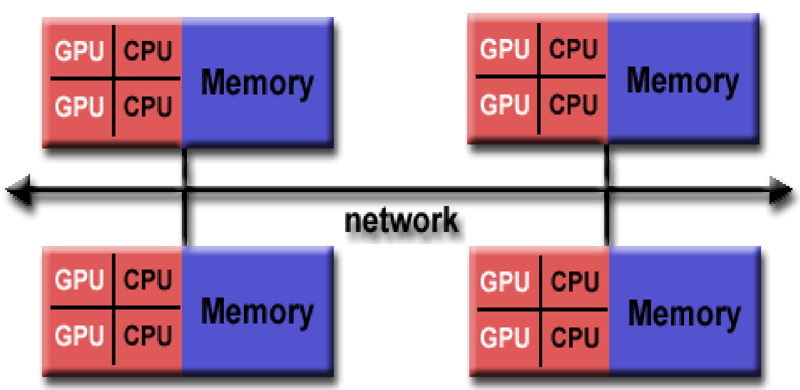
Non-uniform Memory Access (NUMA)

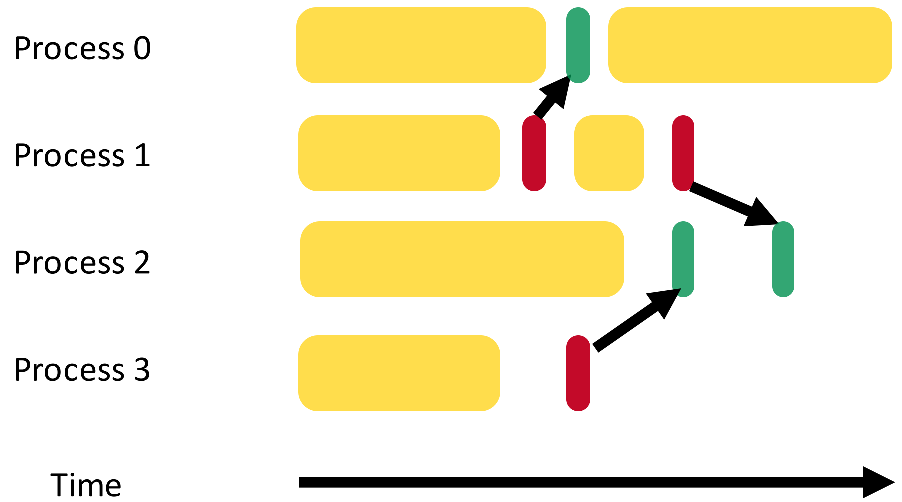


Distributed memory

Distributed memory programming models

- Each process only has access to its own local memory / address space
- When processes need data from remote processes, they have to send/receive messages





Message passing

- Parallel programming model
  - Parallelism is achieved by making calls to a library and the execution model depends on the library used.
- Parallel runtime system:
  - Implements the parallel execution model
- A parallel message passing program consists of independent processes
  - Processes created by a launch/run script
- Each process typically runs the same executable, but potentially different parts of the program
- Often used for SPMD style of programming

MPI

- Goals:
  - Standardize prior message passing designs/implementations:
    - PVM, P4, NX (Intel), MPL (IBM), …
  - Support copy-free message passing
  - Portable to many platforms – *defines an API, not an implementation*
- Features:
  - point-to-point messaging
  - group/collective communications
  - profiling interface: every function has a name-shifted version
- Buffering (in standard mode)
  - no guarantee that there are buffers
  - possible that send will block until receive is called
- Delivery Order
  - two sends from same process to same dest. will arrive in order
  - no guarantee of fairness between processes on receive

Hello World in MPI

```
#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("Hello world! I'm %d of %d\n", rank, size);

  MPI_Finalize();
  return 0;
}
```

Compiling and running an MPI program

- Compiling:

```
mpicc -o hello hello.c
mpicxx –o hello hello.cpp
```

- Running:

```
mpirun -n 2 ./hello
```

Process creation / destruction

- `int MPI_Init(int argc, char **argv)`
  - Initialize the MPI execution environment
- `int MPI_Finalize(void)`
  - Terminates MPI execution environment

MPI Communicators

- Provide a named set of processes for communication
  - plus a *context* – system allocated unique tag
- All processes within a communicator can be named
  - a communicator is a group of processes and a context
  - numbered from 0…n-1
- Allows libraries to be constructed
  - application creates communicators
  - library uses it
  - prevents problems with posting wildcard receives
    - adds a communicator scope to each receive
- All programs start with MPI_COMM_WORLD
  - Functions for creating communicators from other communicators (split, duplicate, etc.)
  - Functions for finding out about processes within communicator (size, my_rank, …)

Process identification

- `int MPI_Comm_size(MPI_Comm comm, int *size)`
  - Determines the size of the group associated with a communicator
- `int MPI_Comm_rank(MPI_Comm comm, int *rank )`
  - Determines the rank (ID) of the calling process in the communicator

Send a message

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

```
buf: address of send buffer

count: number of elements in send buffer

datatype: datatype of each send buffer element

dest: rank of destination process

tag: message tag

comm: communicator
```

Receive a message

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

buf: address of receive buffer

status: status object

count: maximum number of elements in receive buffer

datatype: datatype of each receive buffer element

source: rank of source process

tag: message tag

comm: communicator

Simple send/receive in MPI

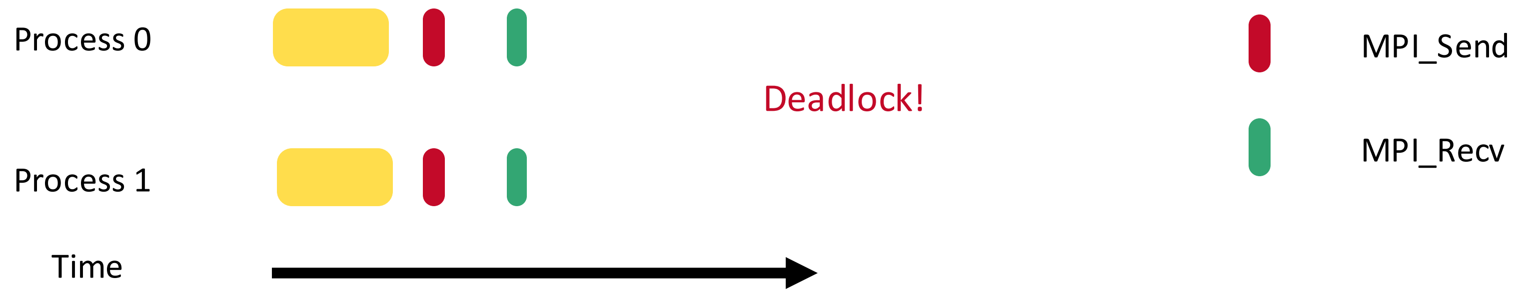
```
int main(int  argc, char *argv) {
  ...
  MPI_Comm_rank(MPI_COMM_WORLD, &rank);
  MPI_Comm_size(MPI_COMM_WORLD, &size);

  int data;
  if (rank == 0) {
    data = 7;
    MPI_Send(&data, 1, MPI_INT, 1, 0, MPI_COMM_WORLD);
  } else if (rank == 1) {
    MPI_Recv(&data, 1, MPI_INT, 0, 0, MPI_COMM_WORLD,
MPI_STATUS_IGNORE);
    printf("Process 1 received data %d from process 0\n",
data);
  }

  ...
}
```

Basic MPI_Send and MPI_Recv

- MPI_Send and MPI_Recv routines are blocking
  - Only return when the buffer specified in the call can be used
  - Send: Returns once sender can reuse the buffer
  - Recv: Returns once data from Recv is available in the buffer



Non-Blocking Point-to-point Functions

- Two Parts
  - post the operation
  - wait for results
- Also includes a poll/test option
  - checks if the operation has finished
- Semantics
  - must not alter buffer while operation is pending (wait returns or test returns true)
  - and data not valid for a receive until operation completes

Collective Communication

- Communicator specifies process group to participate
- Various operations, that may be optimized in an MPI implementation
  - Barrier synchronization
  - Broadcast
  - Gather/scatter (with one destination, or all in group)
  - Reduction operations – predefined and user-defined
    - Also with one destination or all in group
  - Scan – prefix reductions
- Collective operations may or may not synchronize
  - Up to the implementation, so application can't make assumptions

MPI Calls

- Include <mpi.h> in your C/C++ program

- First call MPI_Init(&argc, &argv)
- MPI_Wtime()
  - Returns wall time
- At the end, call MPI_Finalize()
  - No MPI calls allowed after this

MPI Communication

- Parameters of various calls (in later example)
  - var – a variable (pointer to memory)
  - num – number of elements in the variable to use
  - type {MPI_INT, MPI_REAL, MPI_BYTE, ...}
  - root – rank of process at root of collective operation
  - src/dest – rank of source/destination process
  - status - variable of type MPI_Status;
- Calls (all return a code – check for MPI_Success)
  - MPI_Send(var, num, type, dest, tag, MPI_COMM_WORLD)
  - MPI_Recv(var, num, type, src, MPI_ANY_TAG, MPI_COMM_WORLD, &status)

  - MPI_Bcast(var, num, type, root, MPI_COMM_WORLD)
  - MPI_Barrier(MPI_COMM_WORLD)

MPI datatypes

- All messages are typed
  - base/primitive types are pre-defined:
    - int, double, real, {unsigned}{short, char, long}
    - MPI_INT, MPI_DOUBLE, MPI_CHAR, …
- Derived or user-defined datatypes:
  - Array of elements of another datatype
  - struct data type to accommodate sending multiple datatypes

MPI Misc.

- Processor Topologies
  - Allows construction of Cartesian & arbitrary graphs
  - May make it easier to map processes to processors/nodes for some communication patterns
  - May allow some systems to run faster
- Language bindings for C, Fortran, C++, …
- What else is in current versions of MPI
  - Dynamic process creation
  - Parallel I/O – MPI-IO
  - One-sided communication
  - And much more – current version of standard is MPI 4, committee is working on MPI 5
    - See https://www.mpi-forum.org/

Sample MPI Program

```
#include "mpi.h"
int main(int argc, char **argv) {
    int myrank, friendRank;
    char message[MESSAGESIZE];
    int i, tag=MSG_TAG;
    MPI_Status status;

    /* Initialize, no spawning necessary */
    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD,&myrank);
    if (myrank==0)  { /* I am the first process */
        friendRank = 1;
    }
    else { /*I am the second process */
        friendRank=0;
    }
    MPI_Barrier(MPI_COMM_WORLD);
  if (myrank==0) {
        /* Initialize the message */
        for (i=0 ; i<MESSAGESIZE ; i++) {
            message[i]='1';
        }
  }
/* Now start passing the message back and forth */
    for (i=0 ; i<ITERATIONS ; i++) {
        if (myrank==0) {
            MPI_Send(message, MESSAGESIZE,
            MPI_CHAR, friendRank, tag,
            MPI_COMM_WORLD);
            MPI_Recv(message, MESSAGESIZE,
            MPI_CHAR, friendRank, tag,
            MPI_COMM_WORLD, &status);
        }
        else {
            MPI_Recv(message, MESSAGESIZE,
            MPI_CHAR, friendRank, tag,
            MPI_COMM_WORLD, &status);
            MPI_Send(message, MESSAGESIZE,
            MPI_CHAR, friendRank, tag,
            MPI_COMM_WORLD);
        }
    }
    MPI_Finalize();
    exit(0);
}
```

For more details

- https://www.mpi-forum.org
  - includes 4.1 documentation (API), but goes all the way back to 1.0
    - 5.0 under development
- books from MIT Press include *Using MPI* and *MPI: The Complete Reference*
- multiple public domain implementations available
    - mpich2 – Argonne National Lab and open source team – https://www.mpich.org/
    - OpenMPI – large open source team – https://www.open-mpi.org
    - MVAPICH – high performance implementation from OSU - https://mvapich.cse.ohio-state.edu/
  - vendor implementations available too (Intel, IBM, HPE/Cray, …)
- for zaratan cluster info, see https://hpcc.umd.edu/hpcc/help/usage.html