COMP 322: Fundamentals of Parallel Programming

Lecture 33: Introduction to the Message Passing Interface (MPI)

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Recap: Places in HJlib

`here()` = place at which current task is executing

`numPlaces()` = total number of places (runtime constant)

Specified by value of `p` in runtime option:

```
HjSystemProperty.numPlaces.set(p);
```

`place(i)` = place corresponding to index i

`<place-expr>.toString()` returns a string of the form "place(id=0)"

`<place-expr>.id()` returns the id of the place as an int

`asyncAt(P, () -> S)`

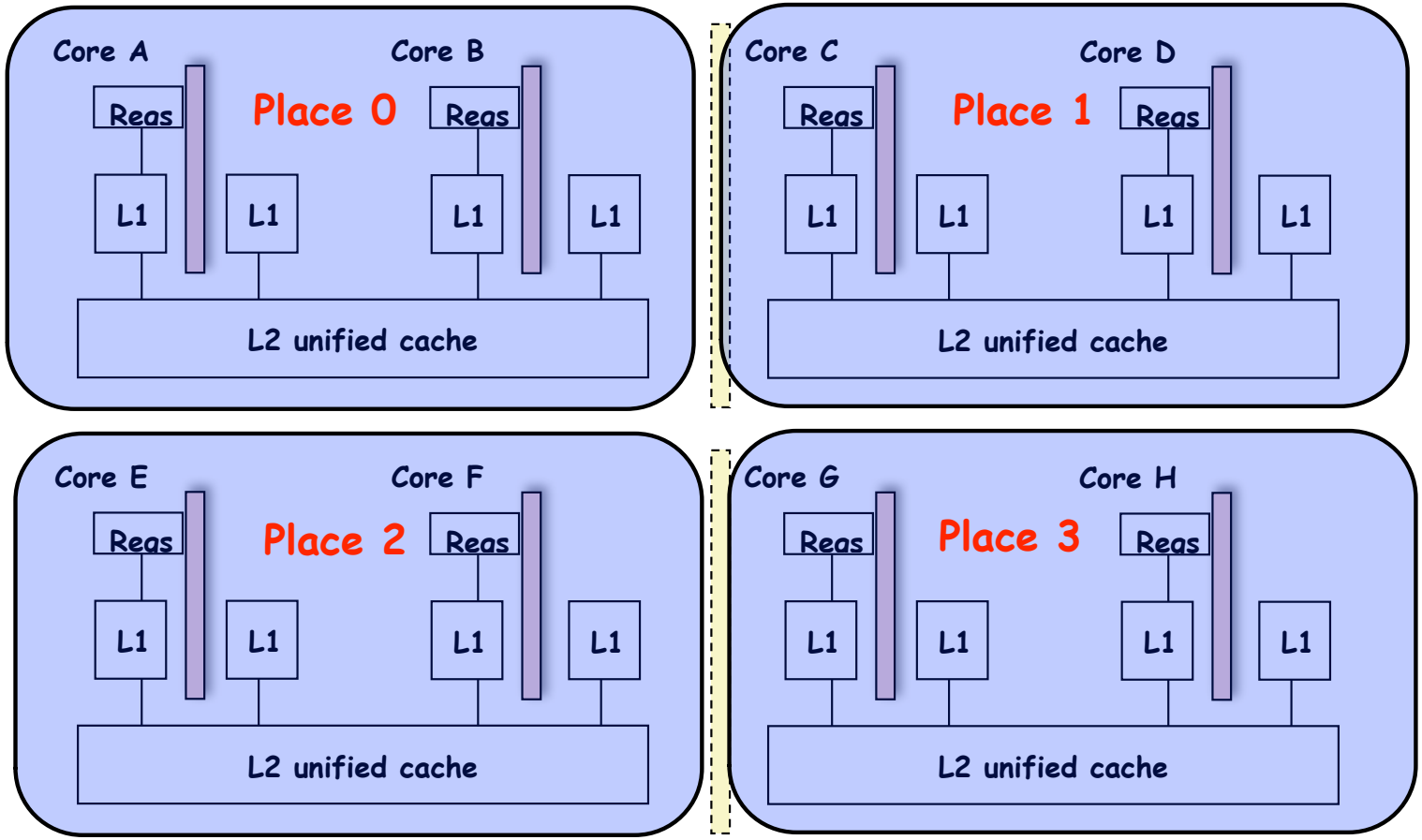
- Creates new task to execute statement S at place P
- `async(() -> S)` is equivalent to `asyncAt(here(), () -> S)`
- Main program task starts at `place(0)`

Note that `here()` in a child task refers to the place P at which the child task is executing, not the place where the parent task is executing

Recap: Example of 4:2 option on an 8-core node

```
// Main program starts at place 0
asyncAt(place(0), () -> S1);
asyncAt(place(0), () -> S2);
```

```
asyncAt(place(1), () -> S3);
asyncAt(place(1), () -> S4);
asyncAt(place(1), () -> S5);
```




```
asyncAt(place(2), () -> S6);
asyncAt(place(2), () -> S7);
asyncAt(place(2), () -> S8);
```

```
asyncAt(place(3), () -> S9);
asyncAt(place(3), () -> S10);
```


Worksheet #32 solution: impact of distribution on parallel completion time (rather than locality)

```
1.  public void sampleKernel(
2.      int iterations, int numChunks, Distribution dist) {
3.    for (int iter = 0; iter < iterations; iter++) {
4.      finish(() -> {
5.        forseq (0, numChunks - 1, (jj) -> {
6.          asyncAt(dist.get(jj), () -> {
7.            doWork(jj);
8.            // Assume that time to process chunk jj = jj units
9.          });
10.       });
11.     });
12.   } // for iter
13. } // sample kernel
```

- Assume an execution with n places, each place with one worker thread
- Will a block or cyclic distribution for `dist` have a smaller abstract completion time, assuming that all tasks on the same place are serialized with one worker per place?

Answer: Cyclic distribution because it leads to better load balance (locality was not a consideration in this problem)

Acknowledgments for Today's Lecture

- "Principles of Parallel Programming", Calvin Lin & Lawrence Snyder
  - Includes resources available at http://www.pearsonhighered.com/educator/academic/product/0,3110,0321487907,00.html
- "Parallel Architectures", Calvin Lin
  - Lectures 5 & 6, CS380P, Spring 2009, UT Austin
  - http://www.cs.utexas.edu/users/lin/cs380p/schedule.html
- Slides accompanying Chapter 6 of "Introduction to Parallel Computing", 2nd Edition, Ananth Grama, Anshul Gupta, George Karypis, and Vipin Kumar, Addison-Wesley, 2003
  - http://www-users.cs.umn.edu/~karypis/parbook/Lectures/AG/chap6_slides.pdf
- MPI slides from "High Performance Computing: Models, Methods and Means", Thomas Sterling, CSC 7600, Spring 2009, LSU
  - http://www.cct.lsu.edu/csc7600/coursemat/index.html
- mpiJava home page: http://www.hpjava.org/mpiJava.html
- MPI lectures given at Rice HPC Summer Institute 2009, Tim Warburton, May 2009

Organization of a Distributed-Memory Multiprocessor

Figure (a)

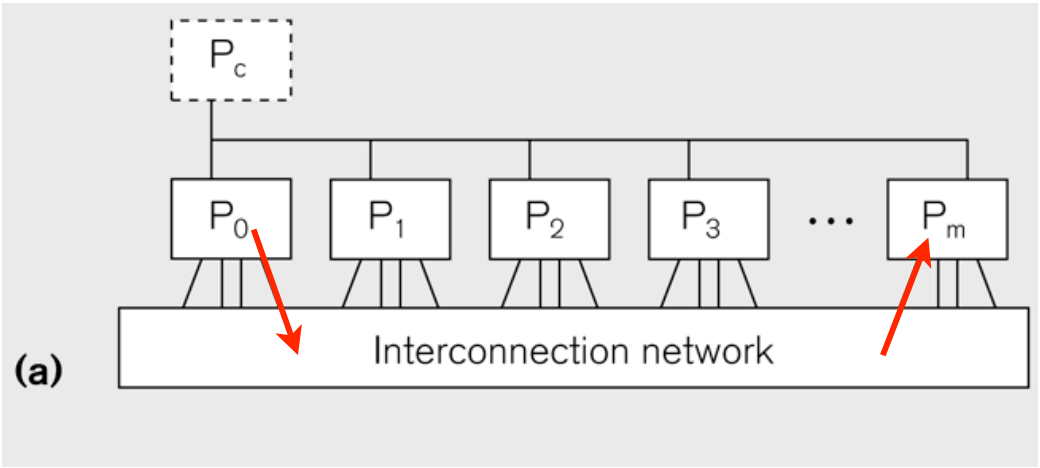
- Host node (Pc) connected to a cluster of processor nodes (P_0 … P_m)
- Processors P_0 … P_m communicate via an interconnection network which could be standard TCP/IP (e.g., for Map-Reduce) or specialized for high performance communication (e.g., for scientific computing)

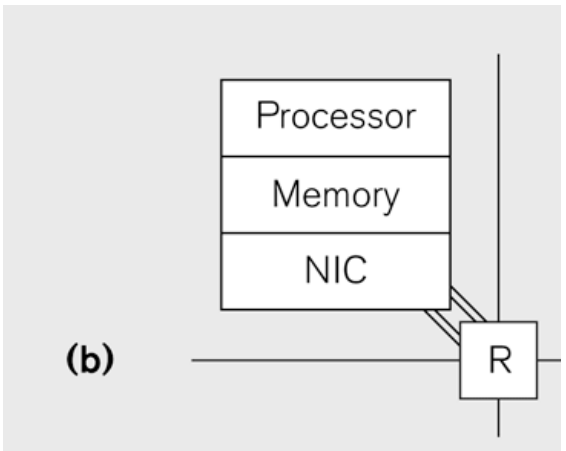
Figure (b)

- Each processor node consists of a processor, memory, and a Network Interface Card (NIC) connected to a router node (R) in the interconnect

Each node is like a "distributed place" with no sharing of memory

==> Processors communicate by sending messages via an interconnect





Message-Passing for Distributed-Memory Multiprocessors

- The logical view of a machine supporting the message-passing paradigm consists of *p processes*, each with its own exclusive address space, that are capable of executing on different nodes in a distributed-memory multiprocessor
  1. Each data element must belong to one of the partitions of the space; hence, data must be explicitly partitioned and placed.
  2. All interactions (read-only or read/write) require cooperation of two processes - the process that has the data and the process that wants to access the data.
- These two constraints, while onerous, make underlying costs very explicit to the programmer.
- In this loosely synchronous ("bulk synchronous") model, processes synchronize infrequently to perform interactions. Between these interactions, they execute completely asynchronously.

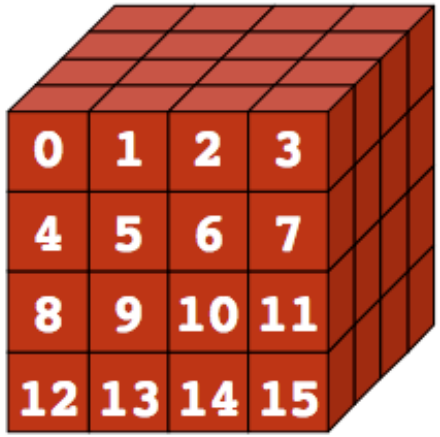
Data Distribution: Local View in Distributed-Memory Systems

Distributed memory

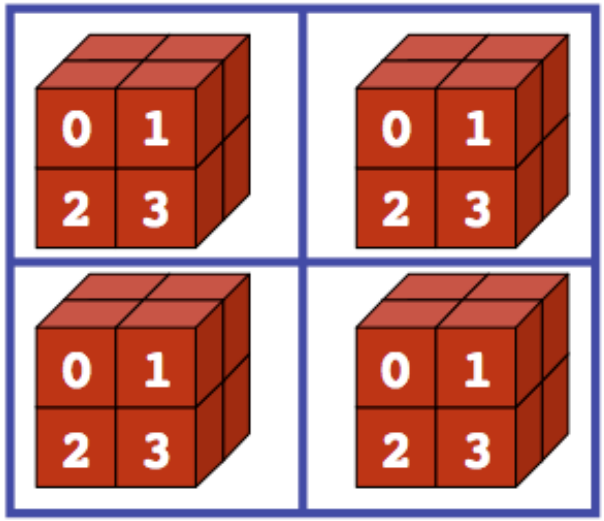
- Each process sees a local address space
- Processes send messages to communicate with other processes

Data structures

- Presents a Local View instead of Global View
- Programmer must make the mapping



Global View



Local View (4 processes)

MPI: The Message Passing Interface

- Sockets and Remote Method Invocation (RMI) are communication primitives used for distributed Java programs.
  - —Designed for standard TCP/IP networks rather than high-performance interconnects
- The Message Passing Interface (MPI) standard was designed to exploit high-performance interconnects
  - —MPI was standardized in the early 1990s by the MPI Forum—a substantial consortium of vendors and researchers
    - http://www-unix.mcs.anl.gov/mpi
  - —It is an API for communication between nodes of a distributed memory parallel computer
  - —The original standard defines bindings to C and Fortran (later C++)
    - Java support is available from a research project, mpiJava, developed at Indiana University 10+ years ago

      http://www.hpjava.org/mpiJava.html
- Most MPI programs are written using the single program multiple data (SPMD) model

SPMD Pattern

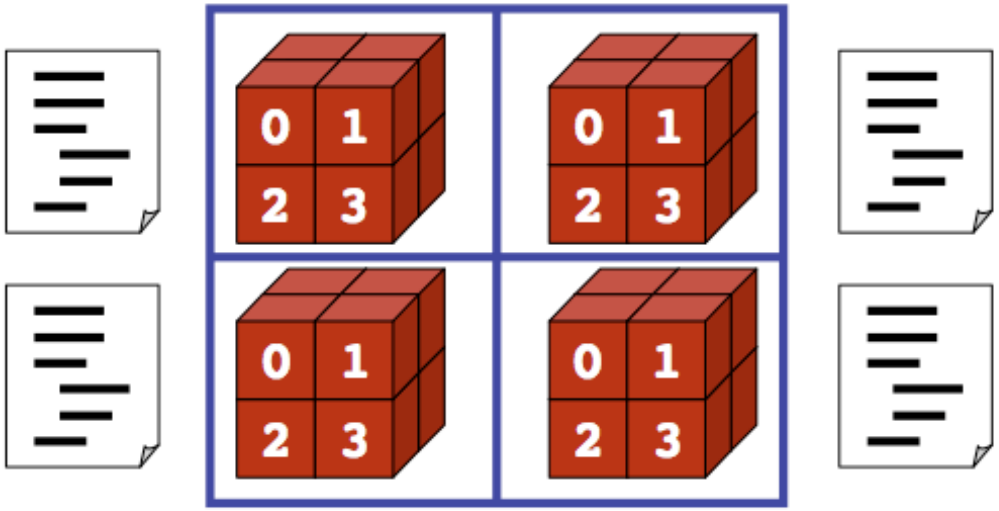
- SPMD: Single Program Multiple Data
- Run the same program on P processing elements (PEs)
- Use the "rank" … an ID ranging from 0 to (P-1) … to determine what computation is performed on what data by a given PE

  ⟹ you can think of the rank as the index of an implicit foralls across all PEs
- Different PEs can follow different paths through the same code
- Convenient pattern for hardware platforms that are not amenable to efficient forms of dynamic task parallelism
  - General-Purpose Graphics Processing Units (GPGPUs)
  - Distributed-memory parallel machines
- Key design decisions --- how should data and computation be distributed across PEs?

Using the Single Program Multiple Data (SPMD) model with a Local View

SPMD code

– Write one piece of code that executes on each processor



Local View (4 processes)

- **Processors must communicate via messages for non-local data accesses**
- **Similar to communication constraint for actors — except that we allow hybrid combinations of task parallelism and actor parallelism in HJlib, but there is no integration (as yet) of HJlib or Java ForkJoin with mpiJava**

The Minimal Set of MPI Routines (mpiJava)

- `MPI.Init(args)`
  - —initialize MPI in each process
- `MPI.Finalize()`
  - —terminate MPI
- `MPI.COMM_WORLD.Size()`
  - —number of processes in `COMM_WORLD` communicator
- `MPI.COMM_WORLD.Rank()`
  - —rank of this process in `COMM_WORLD` communicator
- Note:
  - COMM_WORLD is the default communicator that includes all N processes, and numbers them with ranks from 0 to N-1
  - The above are all static methods with names that don't follow current coding conventions!

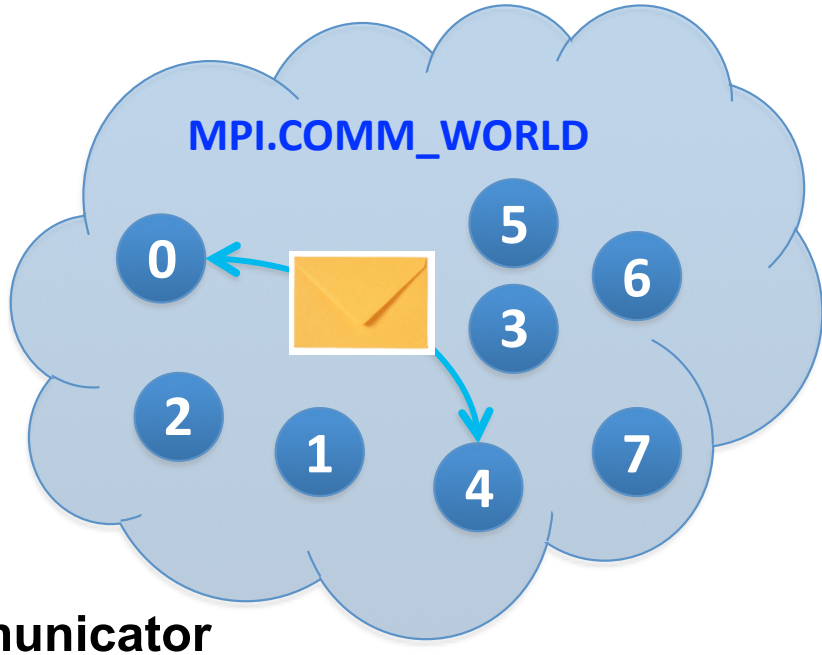
Our First MPI Program (mpiJava version)

main() is enclosed in an implicit "forall" --- each process runs a separate instance of main() with "index variable" = myrank

```
1.  import mpi.*;
2.  class Hello {
3.      static public void main(String[] args) {
4.          // Init() be called before other MPI calls
5.          MPI.Init(args);
6.          int npes = MPI.COMM_WORLD.Size()
7.          int myrank = MPI.COMM_WORLD.Rank() ;
8.          System.out.println("My process number is " + myrank);
9.          MPI.Finalize(); // Shutdown and clean-up
10.     }
11. }
```


MPI Communicators

- Communicator is an internal object
  - *Communicator registration is like phaser registration, except that MPI does not support dynamic creation of new processes in a communicator*
- MPI programs are made up of communicating processes
- Each process has its own address space containing its own attributes such as `rank`, `size` (and `argc`, `argv`, etc.)
- MPI provides functions to interact with it
- Default communicator is `MPI.COMM_WORLD`
  - All processes are its members
  - It has a size (the number of processes)
  - Each process has a rank within it
  - Can think of it as an ordered list of processes
- Additional communicator(s) can co-exist
- A process can belong to more than one communicator
- Within a communicator, each process has a unique rank



Adding Send() and Recv() to the

- `MPI.Init(args)`
  - initialize MPI in each process
- `MPI.Finalize()`
  - terminate MPI
- `MPI.COMM_WORLD.Size()`
  - number of processes in `COMM_WORLD` communicator
- `MPI.COMM_WORLD.Rank()`
  - rank of this process in `COMM_WORLD` communicator
- `MPI.COMM_WORLD.Send()`
  - send message using `COMM_WORLD` communicator
- `MPI.COMM_WORLD.Recv()`
  - receive message using `COMM_WORLD` communicator

Point-to-point commn

MPI Blocking Point to Point Communication: Basic Idea

- A very simple communication between two processes is:
  - —process zero sends ten doubles to process one
- In MPI this is a little more complicated than you might expect.
- Process zero has to tell MPI:
  - —to send a message to process one
  - —that the message contains ten entries
  - —the entries of the message are of type double
  - —the message has to be tagged with a label (integer number)
- Process one has to tell MPI:
  - —to receive a message from process zero
  - —that the message contains ten entries
  - —the entries of the message are of type double
  - —the label that process zero attached to the message

mpiJava send and receive

- Send and Recv methods in Comm object:

```
void Send(Object buf, int offset, int count,
          Datatype type, int dest, int tag);
Status Recv(Object buf, int offset, int count,
            Datatype type, int src, int tag);
```

- The arguments `buf`, `offset`, `count`, `type` describe the data buffer to be sent and received.
- Both `Send()` and `Recv()` are blocking operations ==> potential for deadlock!
  - Send() waits for a matching Recv() from its dest rank with matching type and tag
  - Recv() waits for a matching Send() from its src rank with matching type and tag
  - — Analogous to a phaser-specific `next` operation between two tasks registered in SIG_WAIT mode
  - The `Recv()` method also returns a `Status` value, discussed later.

Example of Send and Recv

```
1.  import mpi.*;
2.  class myProg {
3.    public static void main( String[] args ) {
4.      int tag0 = 0; int tag1 = 1;
5.      MPI.Init( args );                    // Start MPI computation
6.      if ( MPI.COMM_WORLD.rank() == 0 ) { // rank 0 = sender
7.        int loop[] = new int[1]; loop[0] = 3;
8.        MPI.COMM_WORLD.Send( "Hello World!", 0, 12, MPI.CHAR, 1, tag0 );
9.        MPI.COMM_WORLD.Send( loop, 0, 1, MPI.INT, 1, tag1 );
10.     } else {                             // rank 1 = receiver
11.       int loop[] = new int[1]; char msg[] = new char[12];
12.       MPI.COMM_WORLD.Recv( msg, 0, 12, MPI.CHAR, 0, tag0 );
13.       MPI.COMM_WORLD.Recv( loop, 0, 1, MPI.INT, 0, tag1 );
14.       for ( int i = 0; i < loop[0]; i++ )
15.         System.out.println( msg );
16.     }
17.     MPI.Finalize( );                     // Finish MPI computation
18.   }
19. }
```

Send() and Recv() calls are blocking operations