Lecture 34: Task Affinity with Places

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Worksheet #33: Combining Task and MPI parallelism

Compute the critical path length for the MPI program shown on the right in pseudocode, assuming that it is executed with 2 processes/ranks. (Assume that the send/recv calls in lines 5 & 10 match with each other.)

CPL = 2

Name: __________________________          Net ID: ___________________

Compute the critical path length for the MPI program shown on the right in pseudocode, assuming that it is executed with 2 processes/ranks. (Assume that the send/recv calls in lines 5 & 10 match with each other.)

CPL = 2

1. main() {
2.   if (my rank == 0) {
3.     finish { // F1
4.     async await(req) doWork(1);
5.     MPI_Irecv(rank 1, ..., req);
6.     doWork(1);
7.   }
8.   else {
9.     doWork(1);
10.    MPI_Send(rank 0, ...);
11.   }
12. } // main
Organization of a Distributed-Memory Multiprocessor

Figure (a)
- Host node ($P_c$) connected to a cluster of processor nodes ($P_0 \ldots P_m$)
- Processors $P_0 \ldots P_m$ 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

Processors communicate by sending messages via an interconnect
Organization of a Shared-Memory Multicore Symmetric Multiprocessor (SMP)

- Memory hierarchy for a single Intel Xeon (Nehalem) Quad-core processor chip
  - A NOTS node contains TWO 8-core or 12-core E5-2650 v2 Ivy Bridge chips, for a total of 16 or 24 cores

Cores communicate by reading and writing data in a "shared memory"
What is the cost of a Memory Access?  
An example Memory Hierarchy

Source: http://www.cs.cmu.edu/afs/cs/academic/class/15213-f10/www/lectures/09-memory-hierarchy.pptx
### Storage Trends

#### SRAM

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<td>$/MB</td>
<td>19,200</td>
<td>2,900</td>
<td>320</td>
<td>256</td>
<td>100</td>
<td>75</td>
<td>60</td>
<td>320</td>
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<tr>
<td>access (ns)</td>
<td>300</td>
<td>150</td>
<td>35</td>
<td>15</td>
<td>3</td>
<td>2</td>
<td>1.5</td>
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<tr>
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<td>0.256</td>
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<td>16</td>
<td>64</td>
<td>2,000</td>
<td>8,000</td>
<td>1,500,000</td>
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#### DRAM

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<td>$/MB</td>
<td>8,000</td>
<td>880</td>
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<td>1</td>
<td>0.1</td>
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<tr>
<td>access (ms)</td>
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<td>100</td>
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<td>50</td>
<td>40</td>
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<td>4</td>
<td>16</td>
<td>64</td>
<td>2,000</td>
<td>8,000</td>
<td>125,000</td>
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#### Disk

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<tr>
<td>$/MB</td>
<td>500</td>
<td>100</td>
<td>8</td>
<td>0.30</td>
<td>0.01</td>
<td>0.005</td>
<td>0.0003</td>
<td>1,600,000</td>
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<tr>
<td>access (ms)</td>
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<td>75</td>
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<tr>
<td>typical size (MB)</td>
<td>1</td>
<td>10</td>
<td>160</td>
<td>1,000</td>
<td>20,000</td>
<td>160,000</td>
<td>1,500,000</td>
<td>1,500,000</td>
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Examples of Caching in the Hierarchy

Ideally one would desire an indefinitely large memory capacity such that any particular word would be immediately available. We are forced to recognize the possibility of constructing a hierarchy of memories, each of which has greater capacity than the preceding but which is less quickly accessible.

A. W. Burks, H. H. Goldstine, and J. von Neumann

_Preliminary Discussion of the Logical Design of an Electronic Computing Instrument (1946)_

**Ultimate goal:** create a large pool of storage with average cost per byte that approaches that of the cheap storage near the bottom of the hierarchy, and average latency that approaches that of fast storage near the top of the hierarchy.

Cache Memories

- **Cache memories** are small, fast SRAM-based memories managed automatically in hardware.
  - Hold frequently accessed blocks of main memory
- CPU looks first for data in caches (e.g., L1, L2, and L3), then in main memory.
- Typical system structure:

  ![Diagram of computer architecture](http://www.cs.cmu.edu/afs/cs/academic/class/15213-f10/www/lectures/09-memory-hierarchy.pptx)
Cache Analogy

Hungry! must eat!

— Option 1: go to refrigerator
  • Found? -> eat!
  • Latency = 1 minute

— Option 2: go to store
  • Found? -> purchase, take home, eat!
  • Latency = 20-30 minutes

— Option 3: grow food!
  • Plant, wait ... wait ... wait ... , harvest, eat!
  • Latency = ~250,000 minutes (~ 6 months)
Locality

• Principle of Locality:
  — Empirical observation: Programs tend to use data and instructions with addresses near or equal to those they have used recently

• Temporal locality:
  — Recently referenced items are likely to be referenced again in the near future

• Spatial locality:
  — Items with nearby addresses tend to be referenced close together in time
  — A Java programmer can only influence spatial locality at the intra-object level or within arrays
    - The garbage collector and memory management system determines inter-object placement

Source: http://www.cs.cmu.edu/afs/cs/academic/class/15213-f10/www/lectures/09-memory-hierarchy.pptx
Locality Example

```c
sum = 0;
for (i = 0; i < n; i++)
    sum += a[i];
return sum;
```

- **Data references**
  - Reference array elements in succession (stride-1 reference pattern).  
    - Spatial locality
  - Reference variable sum each iteration.  
    - Temporal locality

- **Instruction references**
  - Reference instructions in sequence.  
    - Spatial locality
  - Cycle through loop repeatedly.  
    - Temporal locality

• Memory hierarchy for a single Intel Xeon (Nehalem) Quad-core processor chip
Programmer Control of Task Assignment to Processors

- The parallel programming constructs that we've studied thus far result in tasks that are assigned to processors dynamically by the HJ runtime system
  - Programmer does not worry about task assignment details
- Sometimes, programmer control of task assignment can lead to significant performance advantages due to improved locality
- Motivation for HJ “places”
  - Provide the programmer a mechanism to restrict task execution to a subset of processors for improved locality
  - HJlib implementation used in COMP322 supports one level of locality via places, there are more general HJlib versions that support hierarchical places
HJ programmer defines mapping from HJ tasks to set of places

HJ runtime defines mapping from places to one or more worker Java threads per place

The API calls
HjSystemProperty.numPlaces.set(p);
HjSystemProperty.numWorkers.set(w);

when executing an HJ program can be used to specify
   p, the number of places
   w, the number of worker threads per place
we will abbreviate this as p:w
Example of 4:2 option on an 8-core node (4 places w/ 2 workers per place)
Places in HJlib

\( \text{here() = place at which current task is executing} \)

\( \text{numPlaces() = total number of places (runtime constant)} \)

\( \text{Specified by value of p in runtime option:} \)
\( \text{HjSystemProperty.numPlaces.set(p);} \)

\( \text{place(i) = place corresponding to index i} \)

\( <\text{place-exp}>.\text{toString()} \) \text{returns a string of the form “place(id=0)”}\\
\( <\text{place-exp}>.\text{id()} \) \text{returns the id of the place as an int}\\

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

Note that \text{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
Example of 4:2 option on an 8-core node
(4 places w/ 2 workers per place)

// 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);
Example 1:8 option (1 place w/ 8 workers per place)

All async’s run at place 0 when there’s only one place!
HJ program with places

1. private static class T1 {
2.     final HjPlace affinity;
4.     public T1(HjPlace affinity) {
5.         // set affinity of instance to place where it is created
6.         this.affinity = here();
7.         ...
8.     }
9.     public void foo() { ... }
10. }
11.
12. finish(() -> {
13.     println("Parent place: " + here());
14.     for (T1 a : t1Objects) {
15.         // Execute async at place with affinity to a
16.         asyncAt(a.affinity, () -> {
17.             println("Child place: " + here()); // Child task's place
18.             a.foo();
19.         });
20.     }
21. });
Chunked Fork-Join Iterative Averaging Example with Places

1. public void runDistChunkedForkJoin(
2.     int iterations, int numChunks, Dist dist) {
3.     // dist is a user-defined map from int to HjPlace
4.     for (int iter = 0; iter < iterations; iter++) {
5.         finish(() -> {
6.             forseq (0, numChunks - 1, (jj) -> {
7.                 asyncAt(dist.get(jj), () -> {
8.                     forseq (getChunk(1, n, numChunks, jj), (j) -> {
9.                         myNew[j] = (myVal[j-1] + myVal[j+1]) / 2.0;
10.                     }
11.                 });
12.             });
13.         });
14.         double[] temp = myNew; myNew = myVal; myVal = temp;
15.     } // for iter
16. }

• Chunk jj is always executed in the same place for each iter
• Method runDistChunkedForkJoin can be called with different values of distribution parameter dist
Analyzing Locality of Fork-Join Iterative Averaging Example with Places

Locality benefits will be realized if all instances of chunk 0 execute on the same core and reuse data from the same cache.
Block Distribution

• A block distribution splits the index region into contiguous subregions, one per place, while trying to keep the subregions as close to equal in size as possible.
• Block distributions can improve the performance of parallel loops that exhibit spatial locality across contiguous iterations.
• Example: dist.get(index) for a block distribution on 4 places, when index is in the range, 0...15

<table>
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<tr>
<th>Index</th>
<th>0</th>
<th>1</th>
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<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
<tr>
<td>Place id</td>
<td>0</td>
<td>1</td>
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Distributed Parallel Loops

- The pseudocode below shows the typical pattern used to iterate over an input region \( r \), while creating one async task for each iteration \( p \) at the place dictated by distribution \( d \) i.e., at place \( d \text{.get}(p) \).

- This pattern works correctly regardless of the rank and contents of input region \( r \) and input distribution \( d \) i.e., it is not constrained to block distributions.

```
finish {
    region r = ... ; // e.g., [0:15] or [0:7,0:1]
    dist d = dist.factory.block(r);
    for (point p:r)
        async at(d.get(p)) {
            // Execute iteration \( p \) at place specified by distribution \( d \)
        }
} // finish
```
Cyclic Distribution

- A cyclic distribution “cycles” through places 0 … place.MAX PLACES – 1 when spanning the input region.
- Cyclic distributions can improve the performance of parallel loops that exhibit load imbalance.
- Example: `dist.get(index)` for a cyclic distribution on 4 places, when index is in the range, 0…15.

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