COMP 322: Fundamentals of Parallel Programming

Lecture 31: Task Affinity with Places

(Start of Module 3 on Distribution & Locality)

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Worksheet #30: Characterizing Solutions to the Dining Philosophers Problem

For the five solutions studied in Lecture #29, indicate in the table below which of the following conditions are possible and why:

1. Deadlock: when all philosopher tasks are blocked
2. Livelock: when all philosopher tasks are executing (i.e., no philosopher is blocked) but ALL philosophers are starved (never get to eat)
3. Starvation: when one or more philosophers are starved (never get to eat)
4. Non-Concurrency: when more than one philosopher cannot eat at the same time, even when resources are available i.e., not being used

NOTES:

- Deadlock implies Starvation and Non-Concurrency
- Livelock implies Starvation and Non-Concurrency

	Deadlock	Livelock	Starvation	Non-concurrency
Solution 1: synchronized	Yes	No	Yes	Yes
Solution 2: tryLock/ unLock	No	Yes	Yes	Yes
Solution 3: isolated	No	No	Yes	Yes
Solution 4: object-based isolation	No	No	Yes	No
Solution 5: semaphores	No	No	No	No

Organization of a Distributed-Memory Multiprocessor

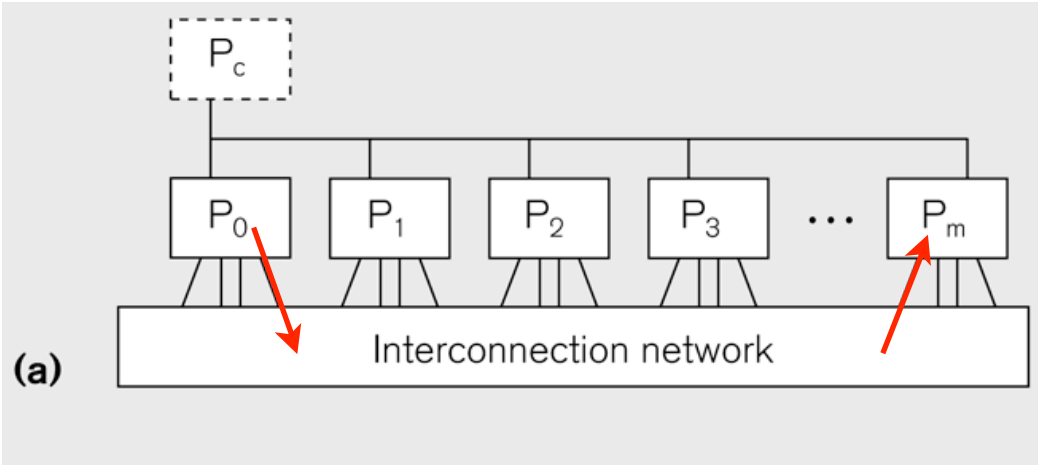
Figure (a)

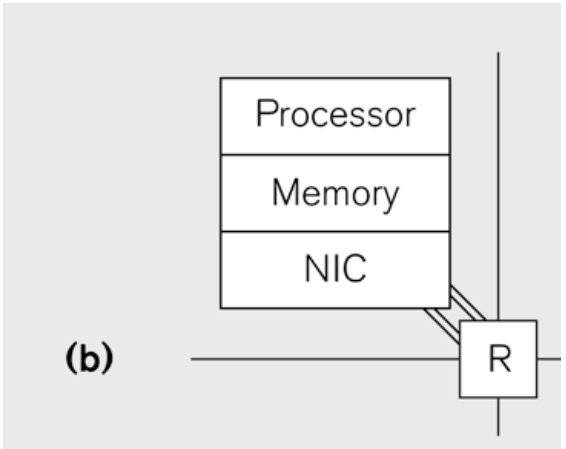
- Host node (Pc) connected to a cluster of processor nodes (P_0 … P_m)
- Processors P_0 … P_m communicate via an interconnection network which could be standard TCP/IP (e.g., for Map-Reduce) or specialized for high performance communication (e.g., for scientific computing)

Figure (b)

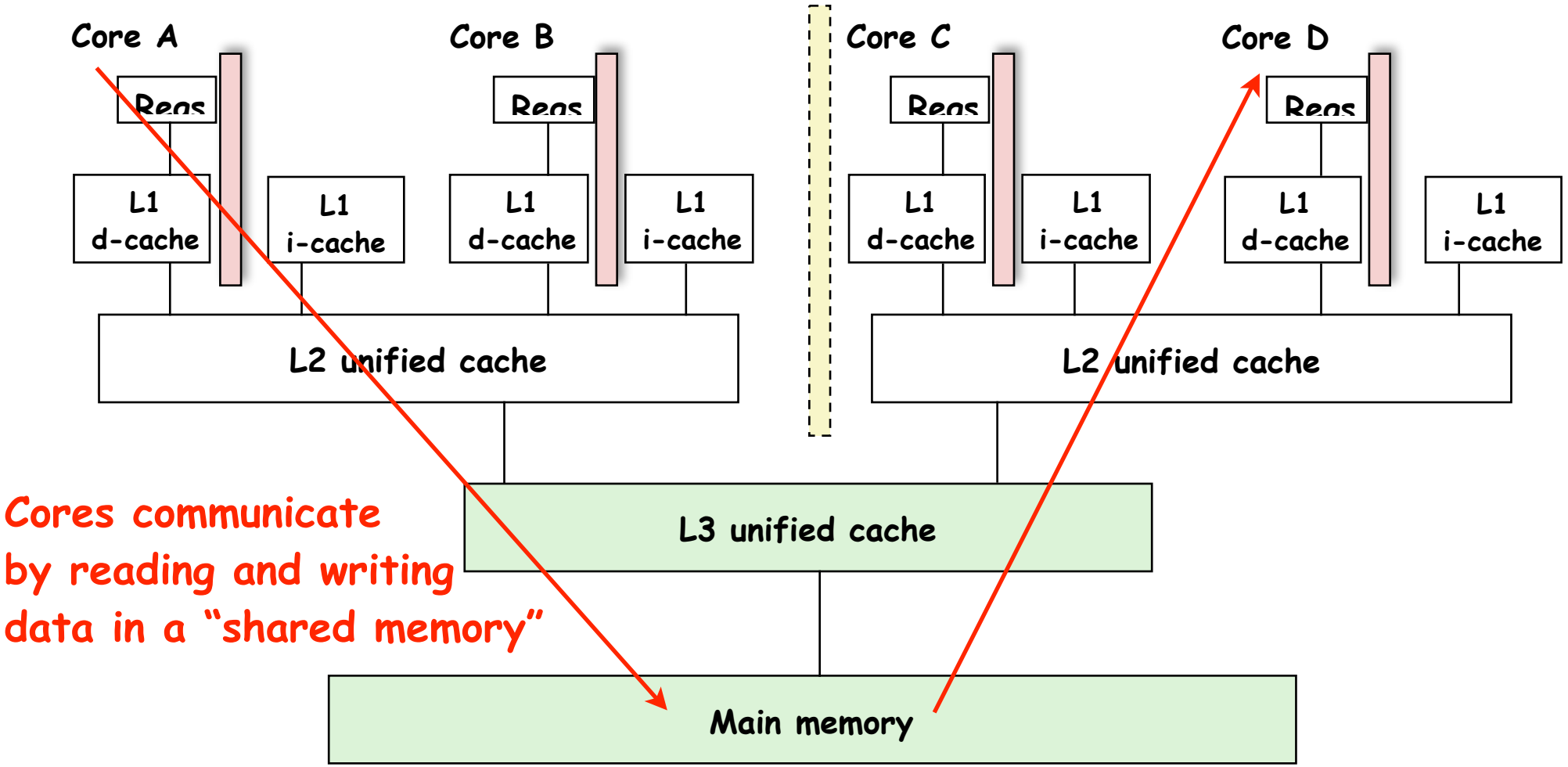
- Each processor node consists of a processor, memory, and a Network Interface Card (NIC) connected to a router node (R) in the interconnect

Processors communicate by sending messages via an interconnect



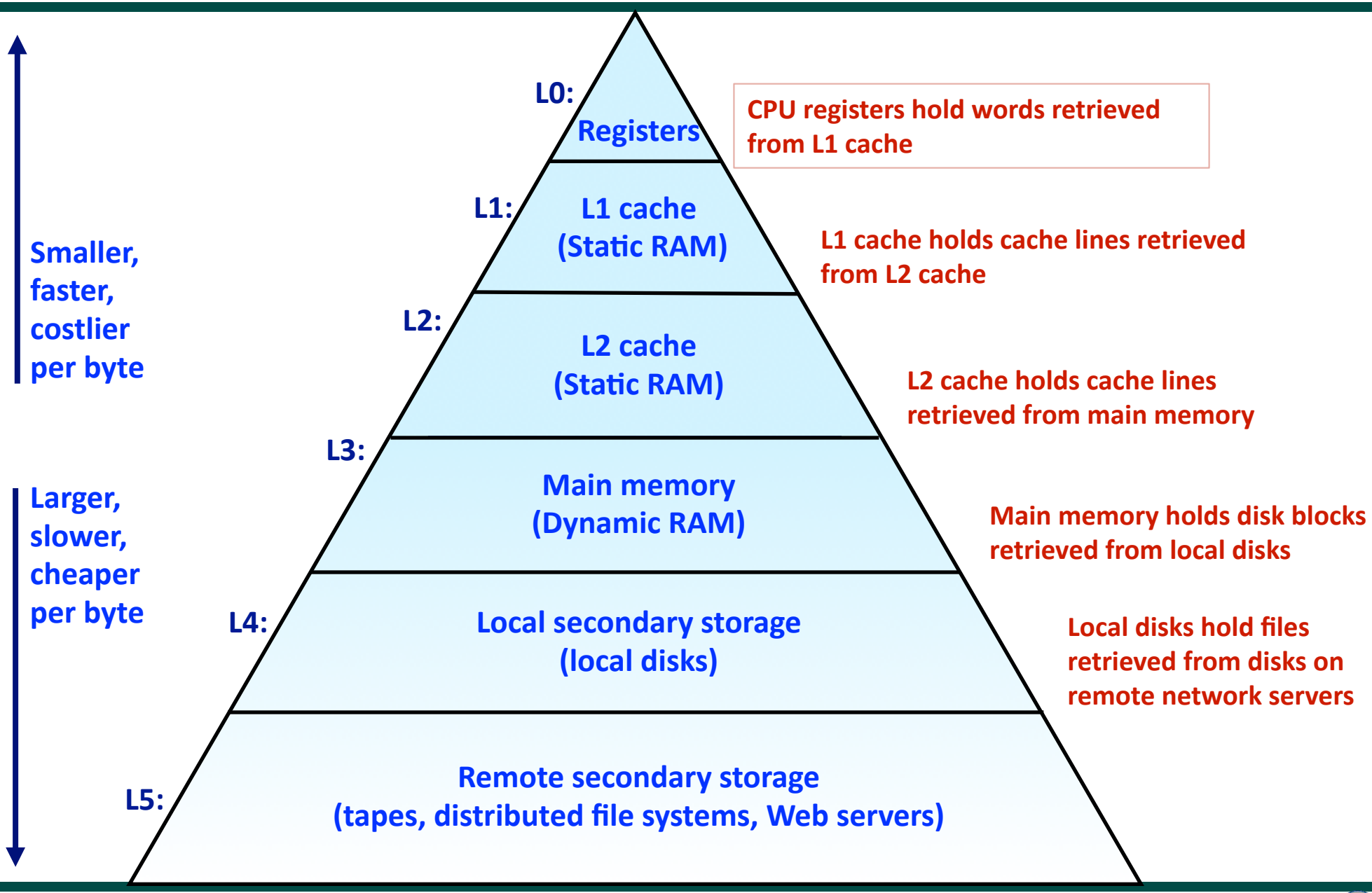


Organization of a Shared-Memory Multicore Symmetric Multiprocessor (SMP)



- Memory hierarchy for a single Intel Xeon (Nehalem) Quad-core processor chip
  - —A STIC node contains TWO such chips, for a total of 8 cores

What is the cost of a Memory Access? An example Memory Hierarchy



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Storage Trends

SRAM

Metric	1980	1985	1990	1995	2000	2005	2010	2010:1980
$/MB	19,200	2,900	320	256	100	75	60	320
access (ns)	300	150	35	15	3	2	1.5	200

DRAM

Metric	1980	1985	1990	1995	2000	2005	2010	2010:1980
$/MB	8,000	880	100	30	1	0.1	0.06	130,000
access (ns)	375	200	100	70	60	50	40	9
typical size (MB)	0.064	0.256	4	16	64	2,000	8,000	125,000

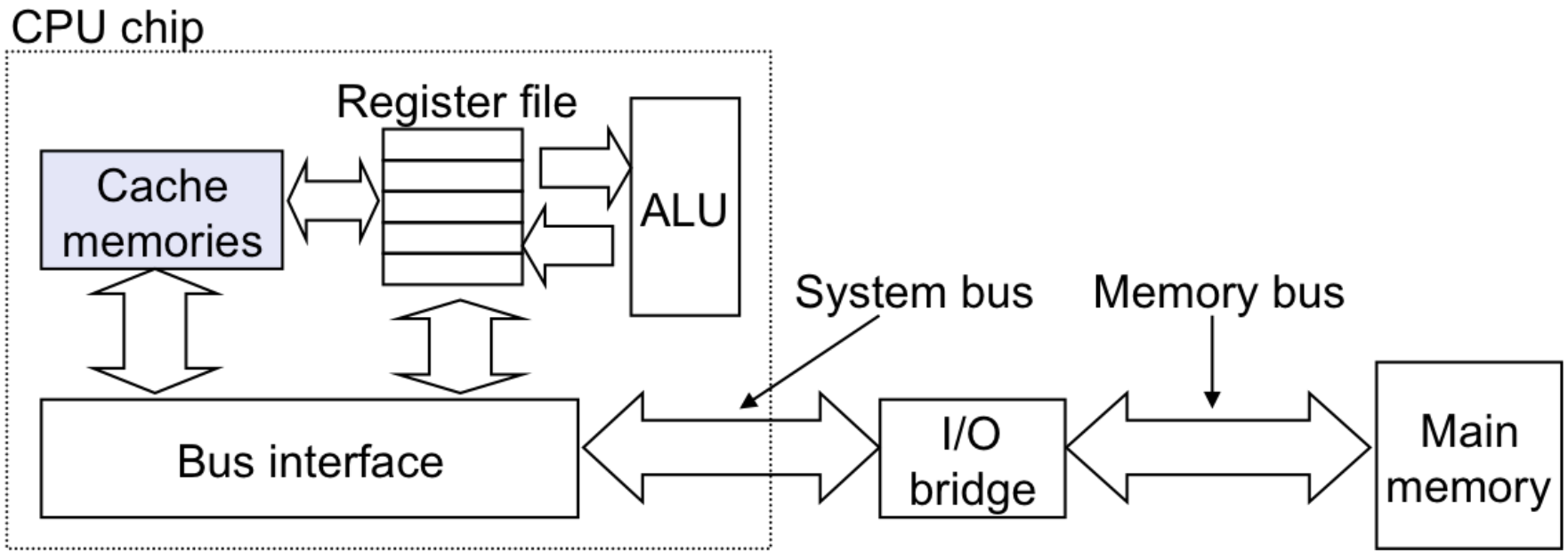
Disk

Metric	1980	1985	1990	1995	2000	2005	2010	2010:1980
$/MB	500	100	8	0.30	0.01	0.005	0.0003	1,600,000
access (ms)	87	75	28	10	8	4	3	29
typical size (MB)	1	10	160	1,000	20,000	160,000	1,500,000	1,500,000

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

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:**



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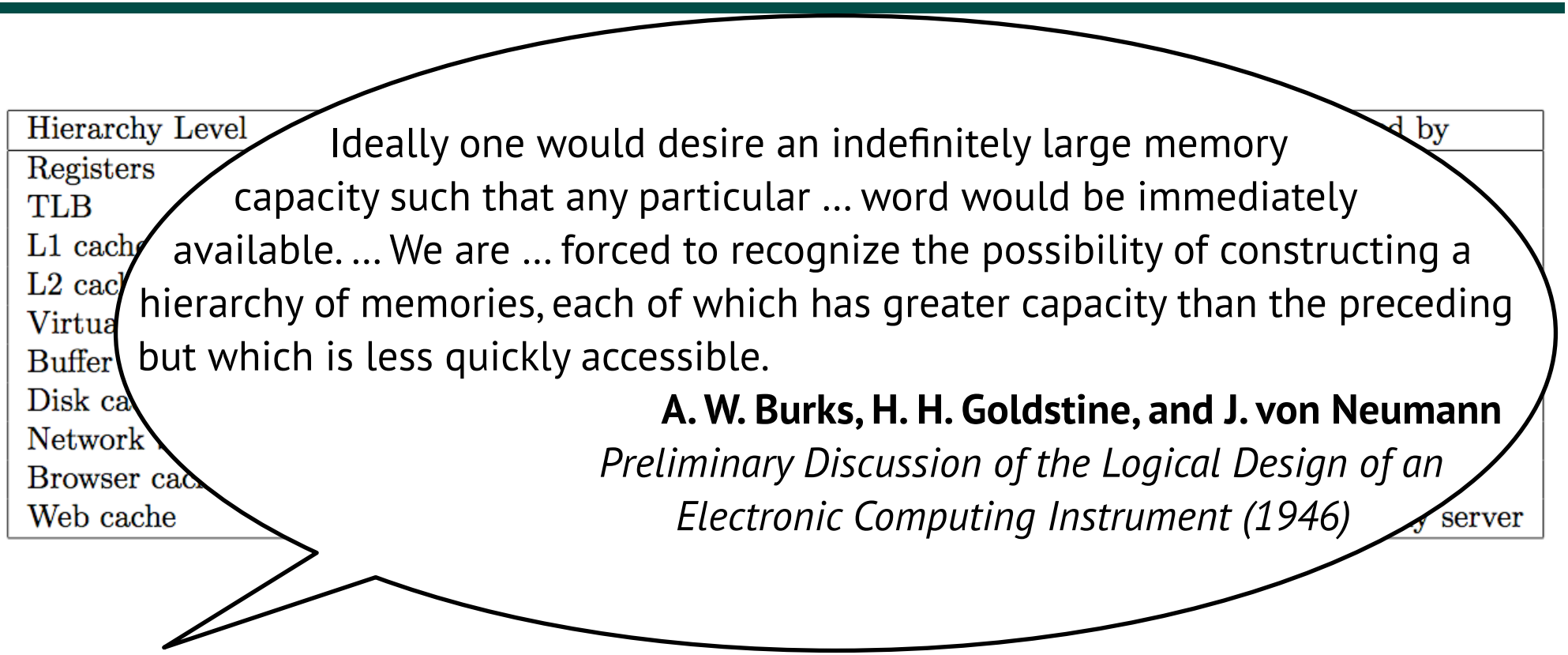
Examples of Caching in the Hierarchy



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)

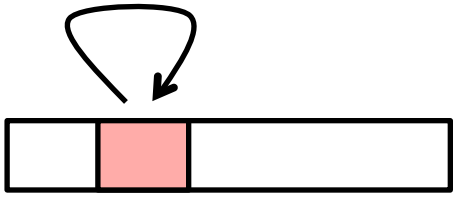
Ultimate goal: create a large pool of storage with average cost per byte that approaches that of the cheap storage near the bottom of the hierarchy, and average latency that approaches that of fast storage near the top of the hierarchy.

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

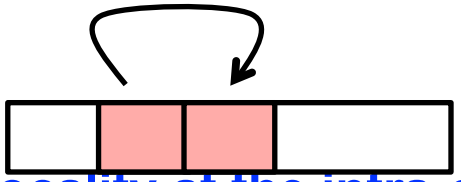
Locality

- **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
    - The garbage collector and memory management system determines inter-object placement



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Locality Example

```
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**

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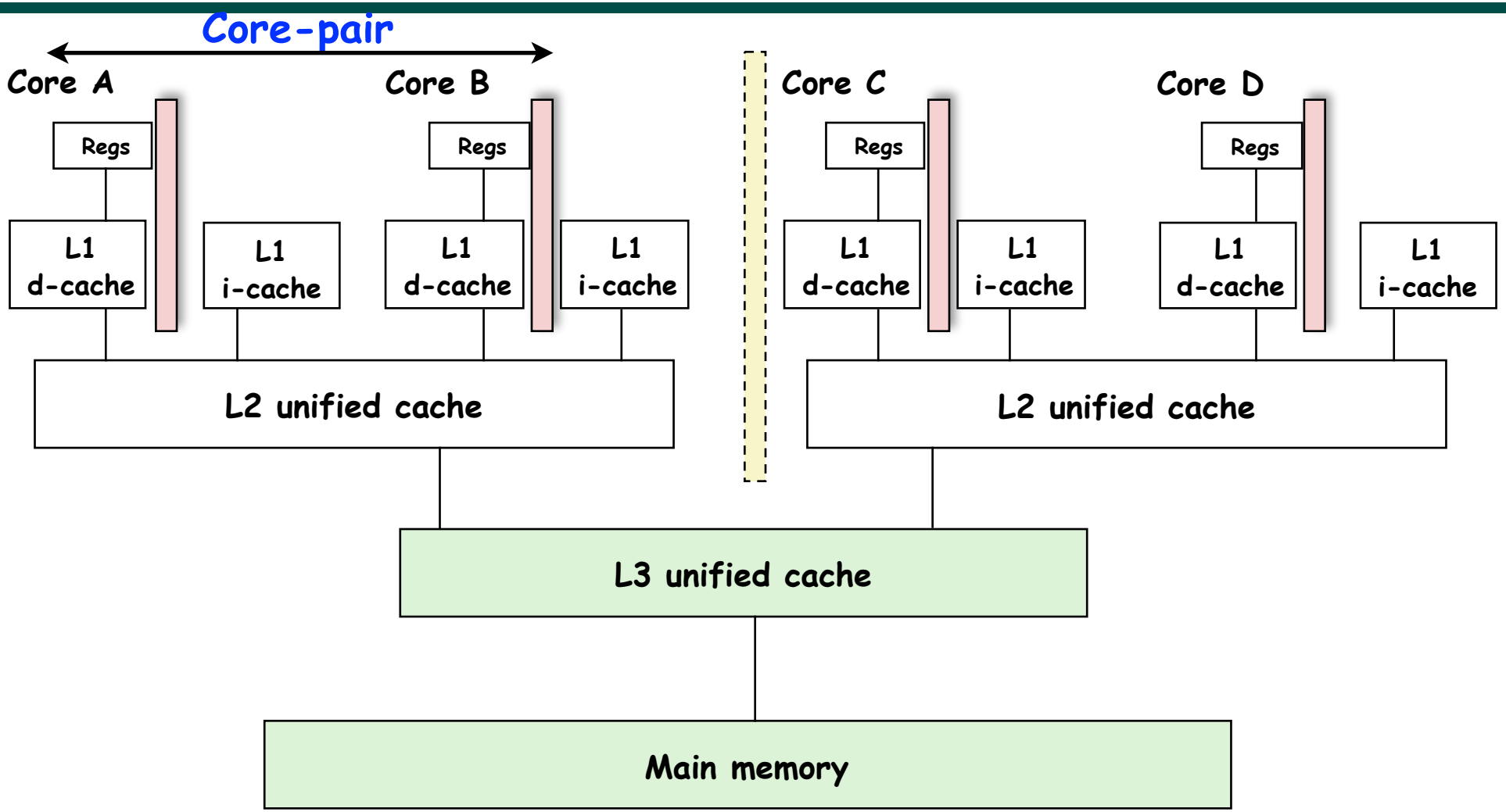
Memory Hierarchy in a Multicore Processor



- Memory hierarchy for a single Intel Xeon (Nehalem) Quad-core processor chip
  - —A STIC node contains TWO such chips, for a total of 8 cores

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
  - Current HJlib implementation supports one level of locality via places, but future HJlib versions will support hierarchical places

Places in HJlib

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

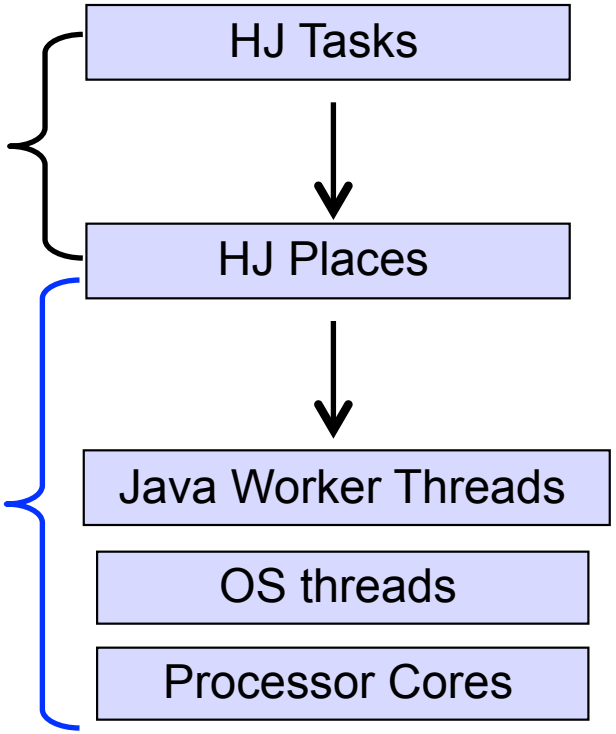
The API calls

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

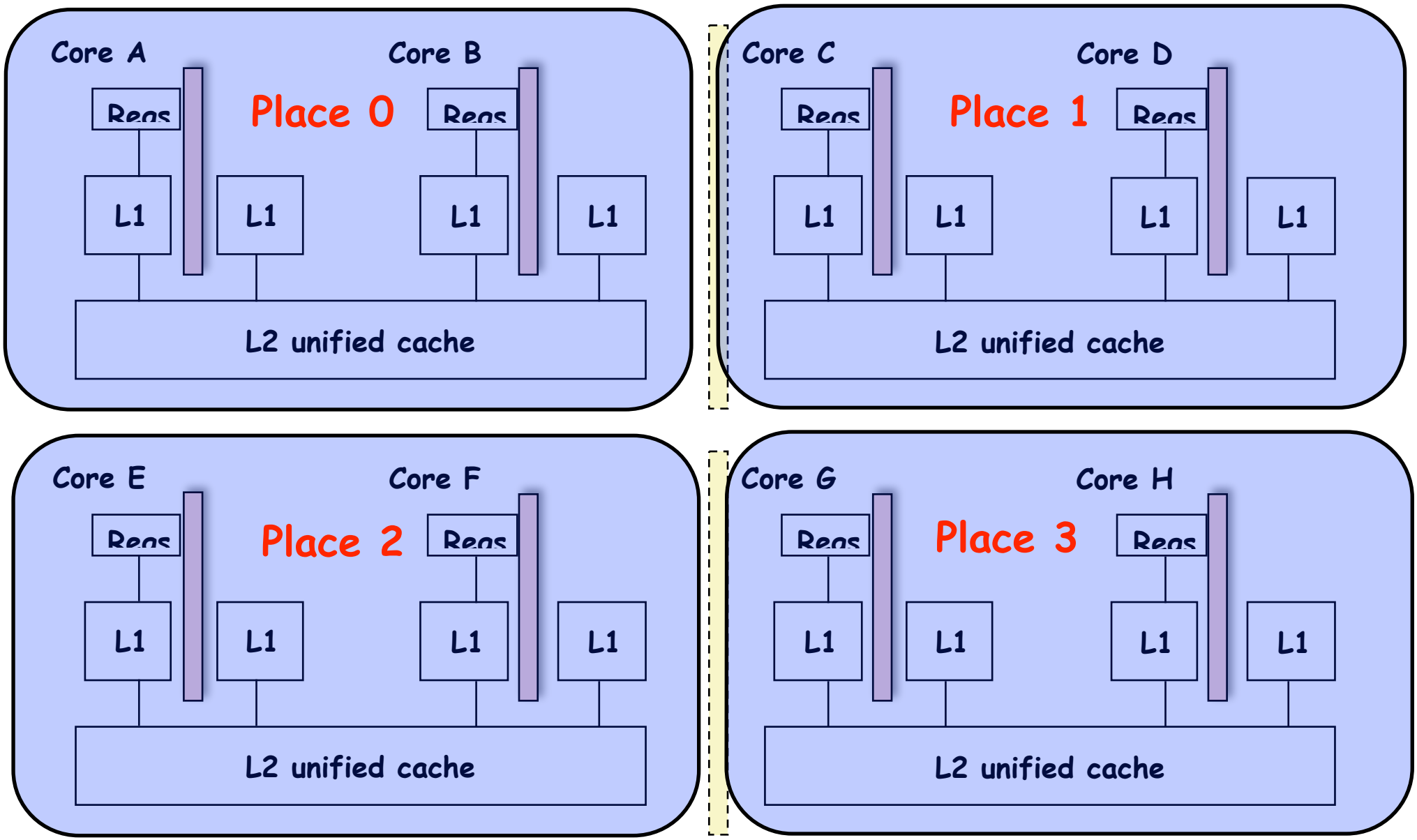
when executing an HJ program can be used to specify

- 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

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)

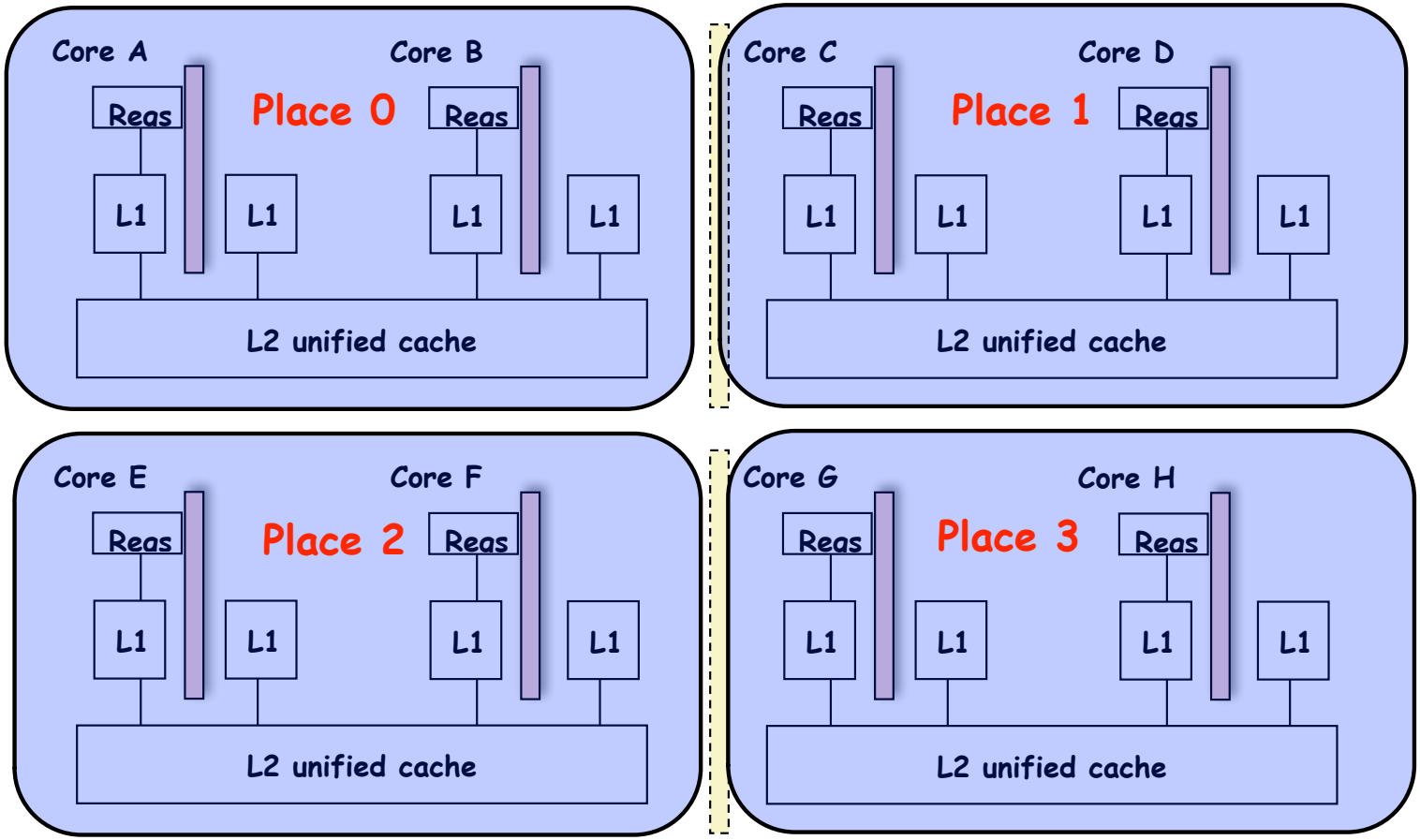
- Creates new task to execute statement S at place P
- async(() -> S) is equivalent to asyncAt(here(), () -> S)
- Main program task starts at place(0)

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

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);
```

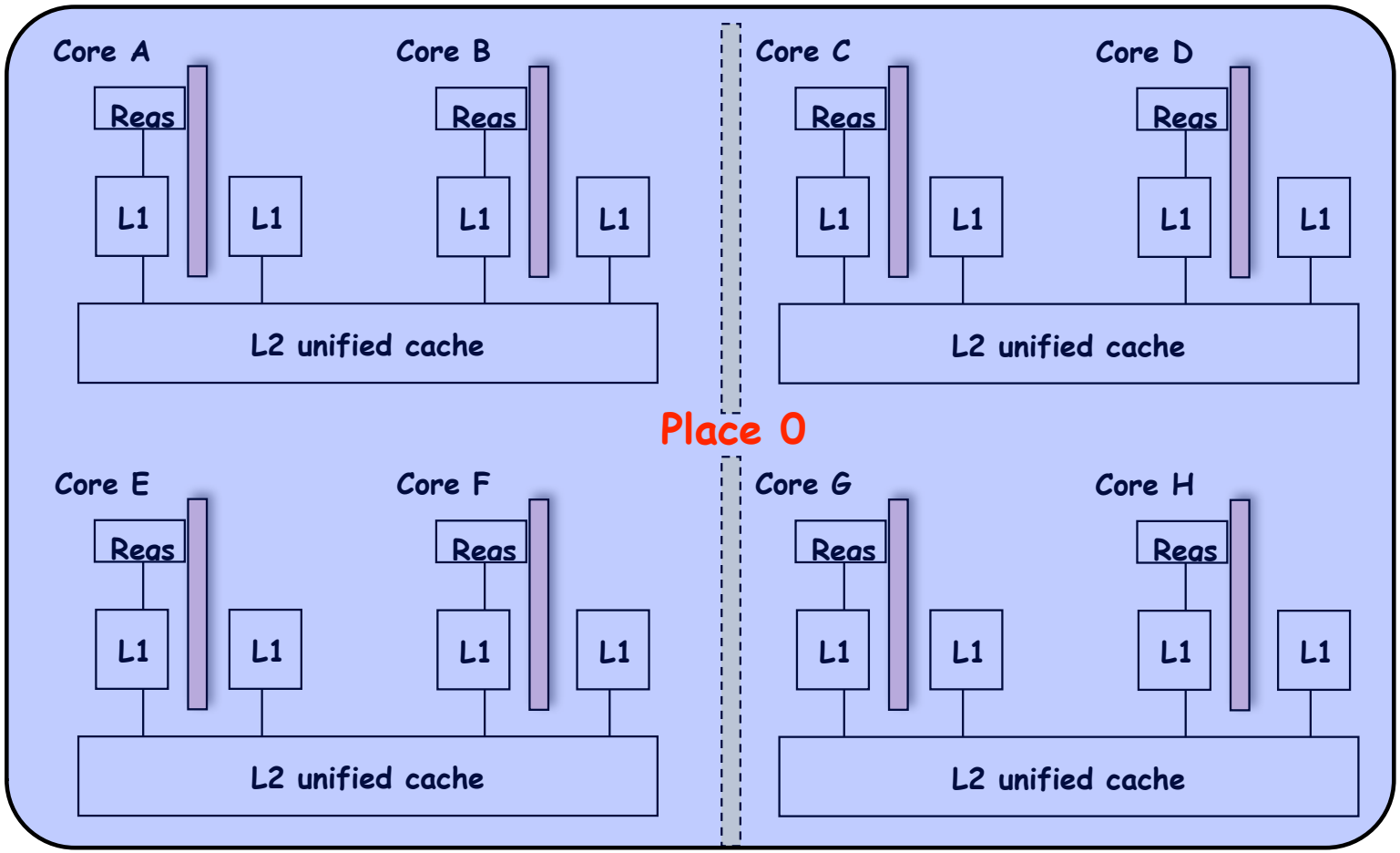



```
asyncAt(place(2), () -> S6);
asyncAt(place(2), () -> S7);
asyncAt(place(2), () -> S8);
```

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


Example of 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 (pseudocode)

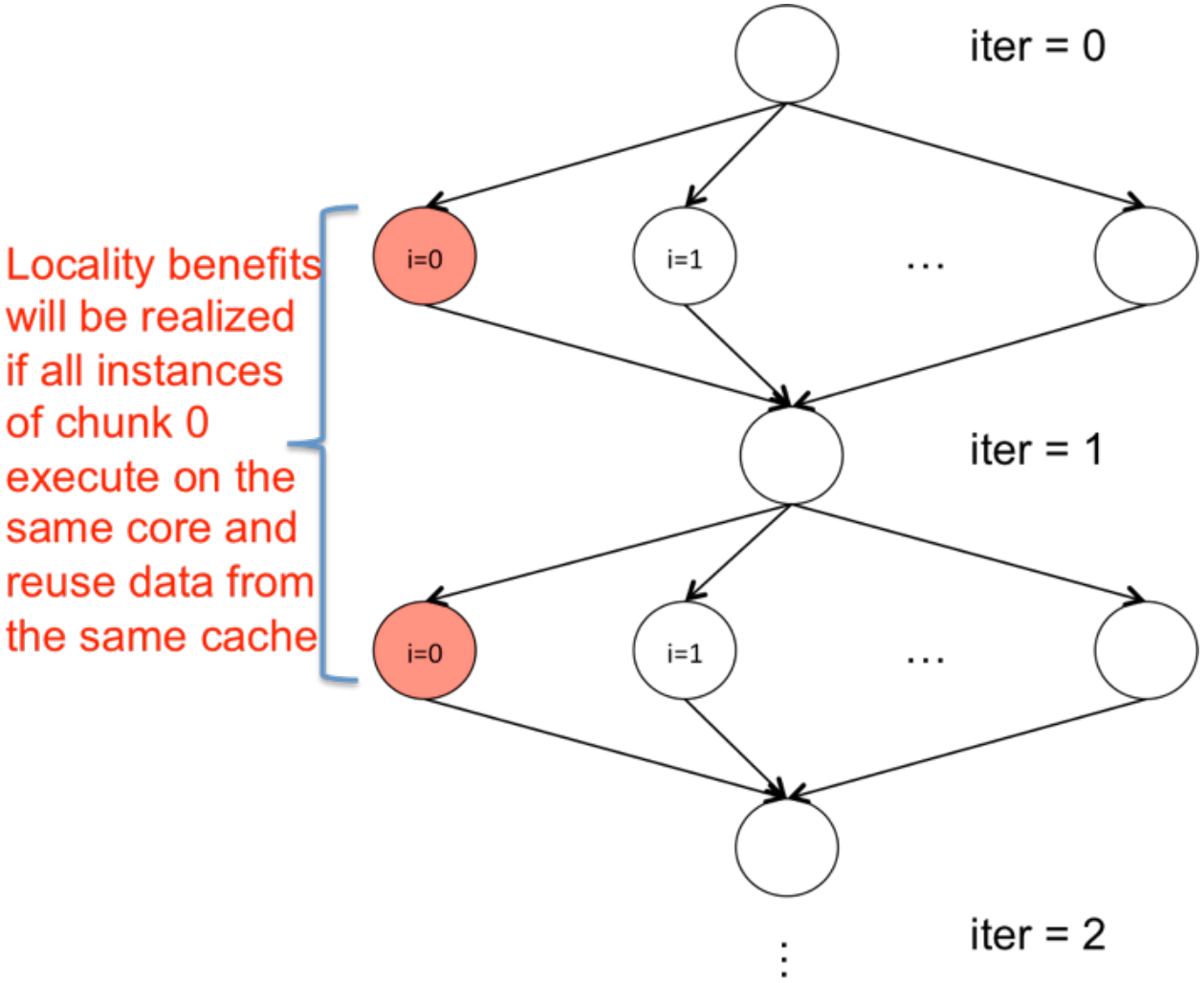
```
1  class T1 {
2    final place affinity;
3    . . .
4    // T1's constructor sets affinity to place where instance was created
5    T1() { affinity = here; ... }
6    . . .
7  }
8  . . .
9  finish { // Inter-place parallelism
10   System.out.println("Parent place = ", here); // Parent task s place
11   for (T1 a = . . .) {
12     async at (a.affinity) { // Execute async at place with affinity to a
13       a.foo();
14       System.out.println("Child place = ", here); // Child task's place
15     } // async
16   } // for
17 } // finish
18 . . .
```


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 d

Analyzing Locality of Fork-Join Iterative Averaging Example with Places



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

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Place id	0				1				2				3			

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.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

```
1  finish {
2    region r = ... ; // e.g., [0:15] or [0:7,0:1]
3    dist d = dist.factory.block(r);
4    for (point p:r)
5      async at(d.get(p)) {
6        // Execute iteration p at place specified by distribution d
7        . . .
8      }
9  } // finish
0  . . .
```


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

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Place id	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3