COMP 322: Fundamentals of Parallel Programming

Lecture 30: Task Affinity with Places

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Worksheet #29: Characterizing Solutions to the Dining Philosophers Problem

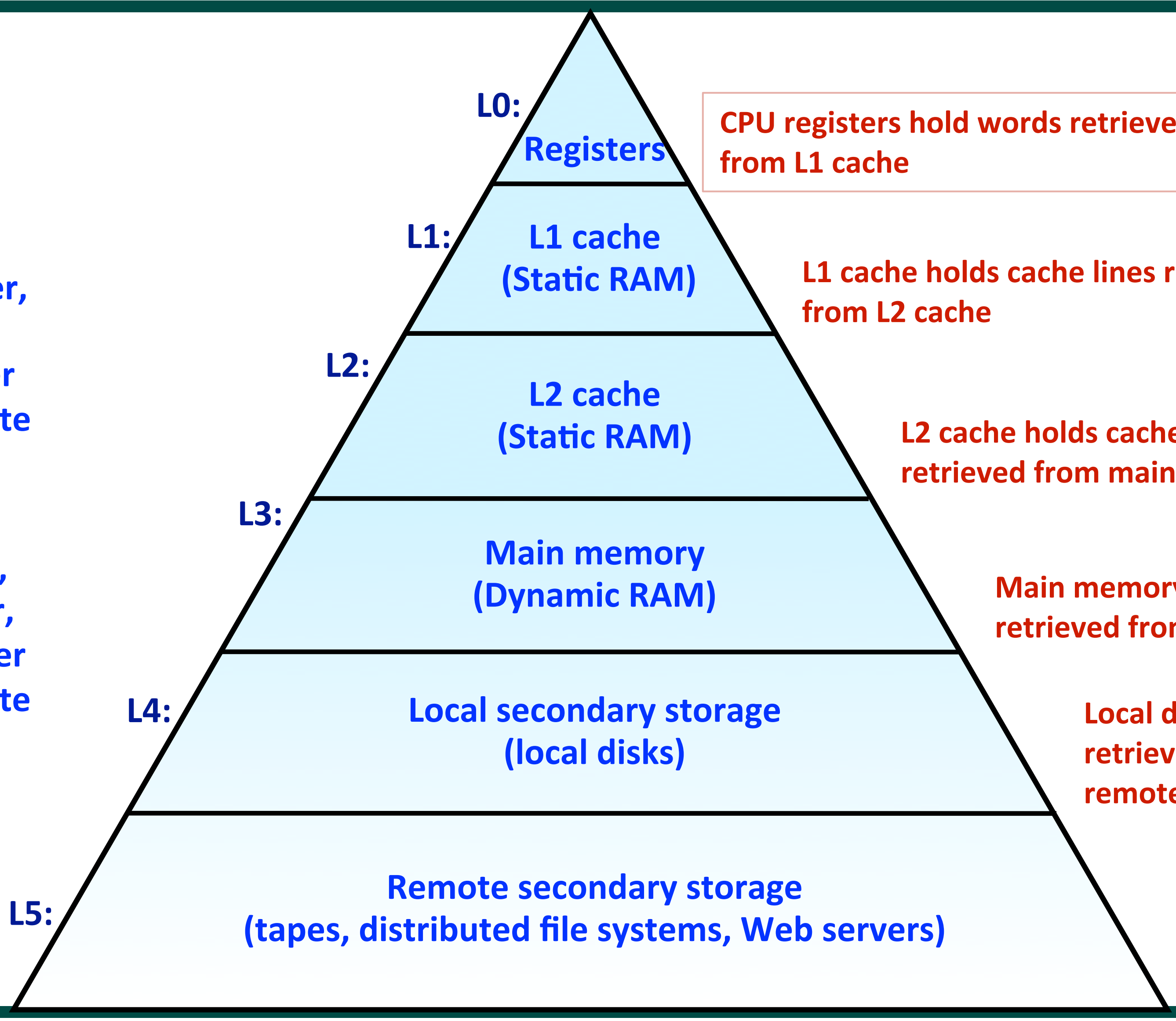
For the five solutions studied in Lecture #29, indicate in the table below which of the following conditions are possible and why:

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

NOTE: Deadlock implies Starvation, and Livelock implies Starvation

	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

An example Memory Hierarchy --- what is the cost of a Memory Access?



Smaller, faster, costlier per byte

Larger, slower, cheaper per byte

L0: Registers

L1: L1 cache (Static RAM)

L2: L2 cache (Static RAM)

L3: Main memory (Dynamic RAM)

L4: Local secondary storage (local disks)

L5: Remote secondary storage (tapes, distributed file systems, Web servers)

CPU registers hold words retrieved from L1 cache

L1 cache holds cache lines retrieved from L2 cache

L2 cache holds cache lines retrieved from main memory

Main memory holds disk blocks retrieved from local disks

Local disks hold files retrieved from disks on remote network servers

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

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

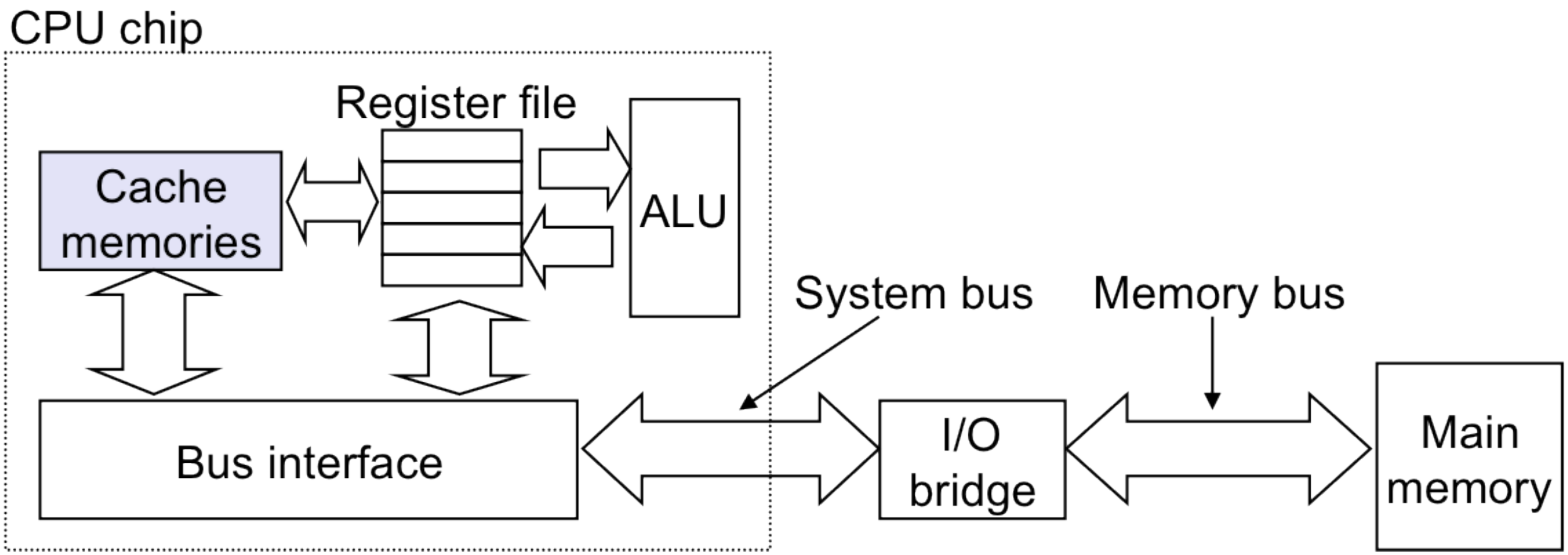
Disk

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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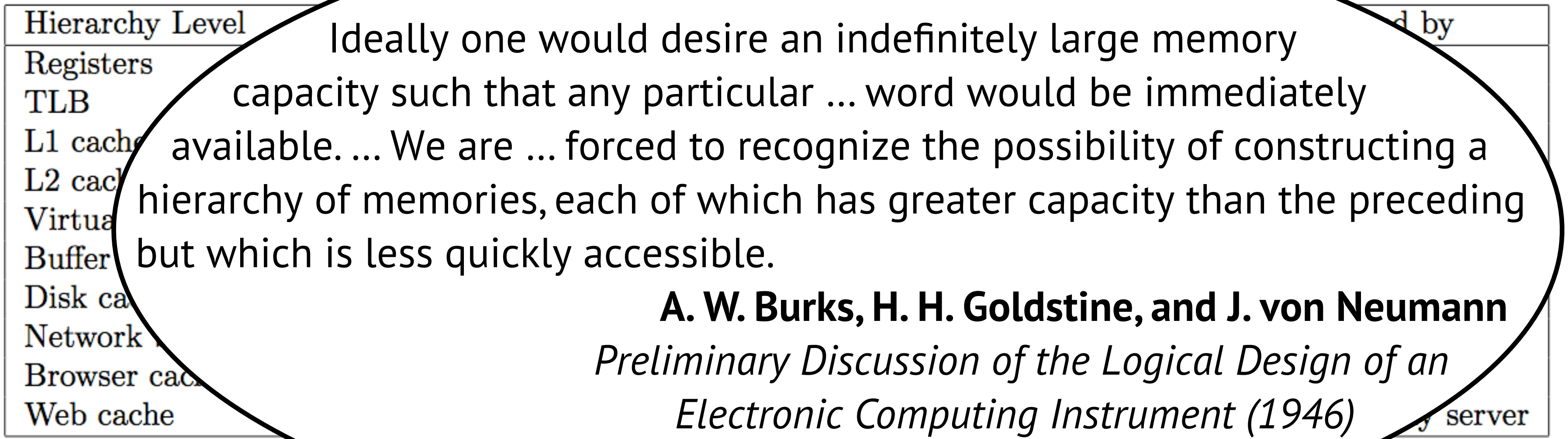
Examples of Caching in the Hierarchy



Hierarchy Level	d by
Registers	
TLB	
L1 cach	
L2 cac	
Virtua	
Buffer	
Disk ca	
Network	
Browser cac	
Web cache	server

> 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)*

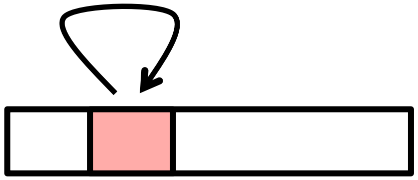
Ultimate goal: create a large pool of storage with average cost per byte that approaches that of the cheap storage near the bottom of the hierarchy, and average latency that approaches that of fast storage near the top of the hierarchy.

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

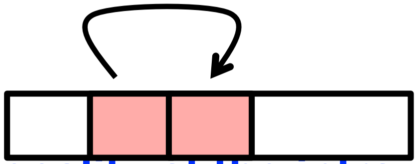
Locality

- **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

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

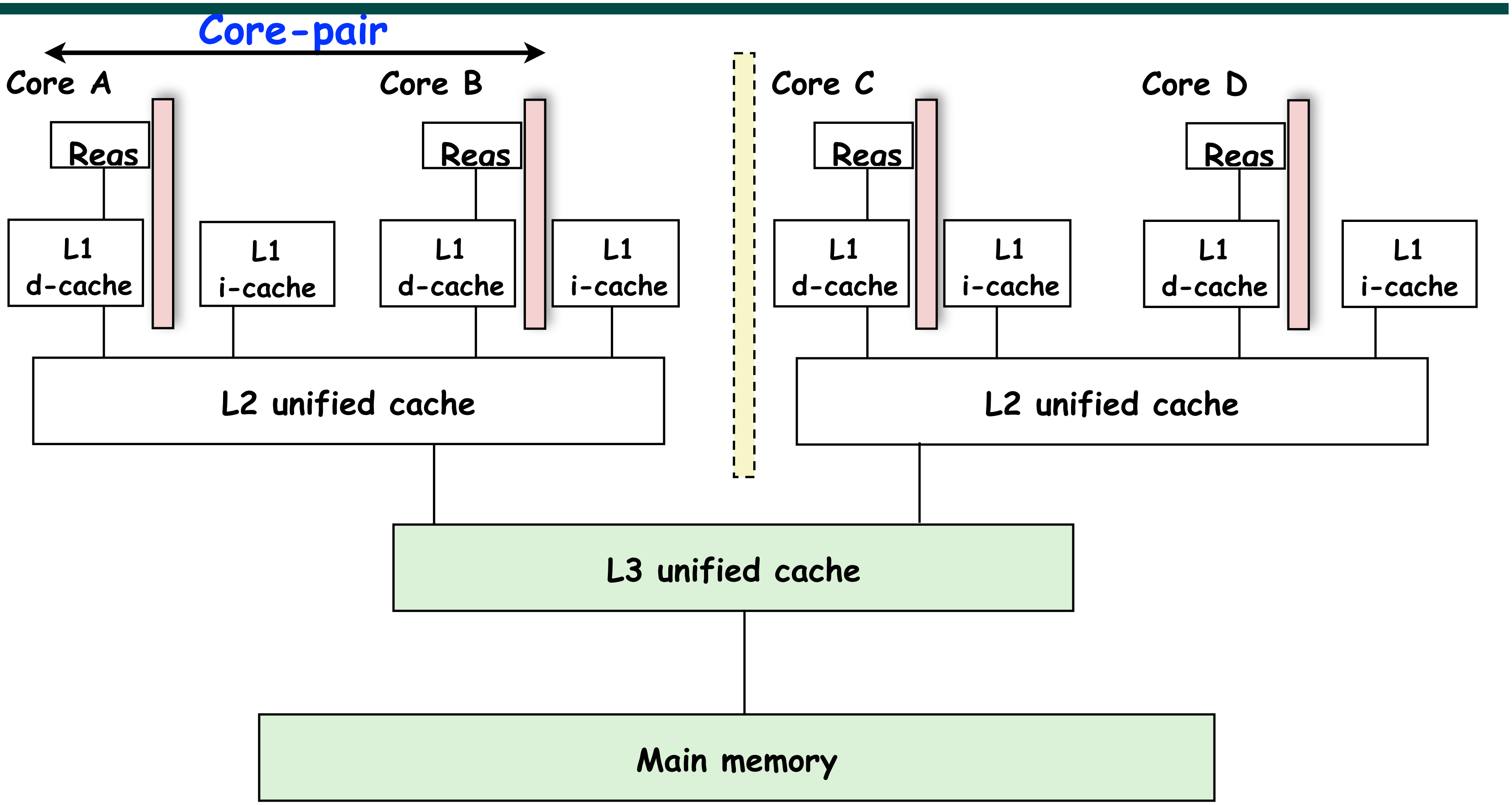
Locality Example

```
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**

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

Memory Hierarchy in a Multicore Processor



Core-pair

Core A

Regs

L1
d-cache

L1
i-cache

Core B

Regs

L1
d-cache

L1
i-cache

Core C

Regs

L1
d-cache

L1
i-cache

Core D

Regs

L1
d-cache

L1
i-cache

L2 unified cache

L2 unified cache

L3 unified cache

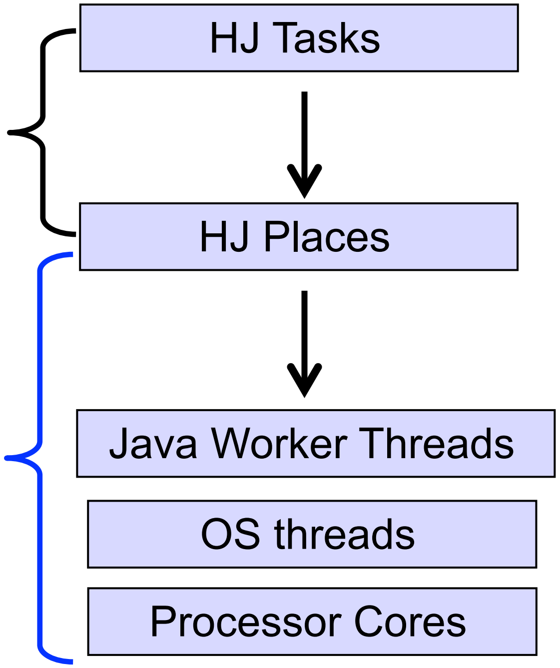
Main memory

- **Memory hierarchy for a single Intel Xeon Quad-core E5440 HarperTown processor chip**
  - —A SUG@R 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 map each task to a set of processors when the task is created

Places in HJ

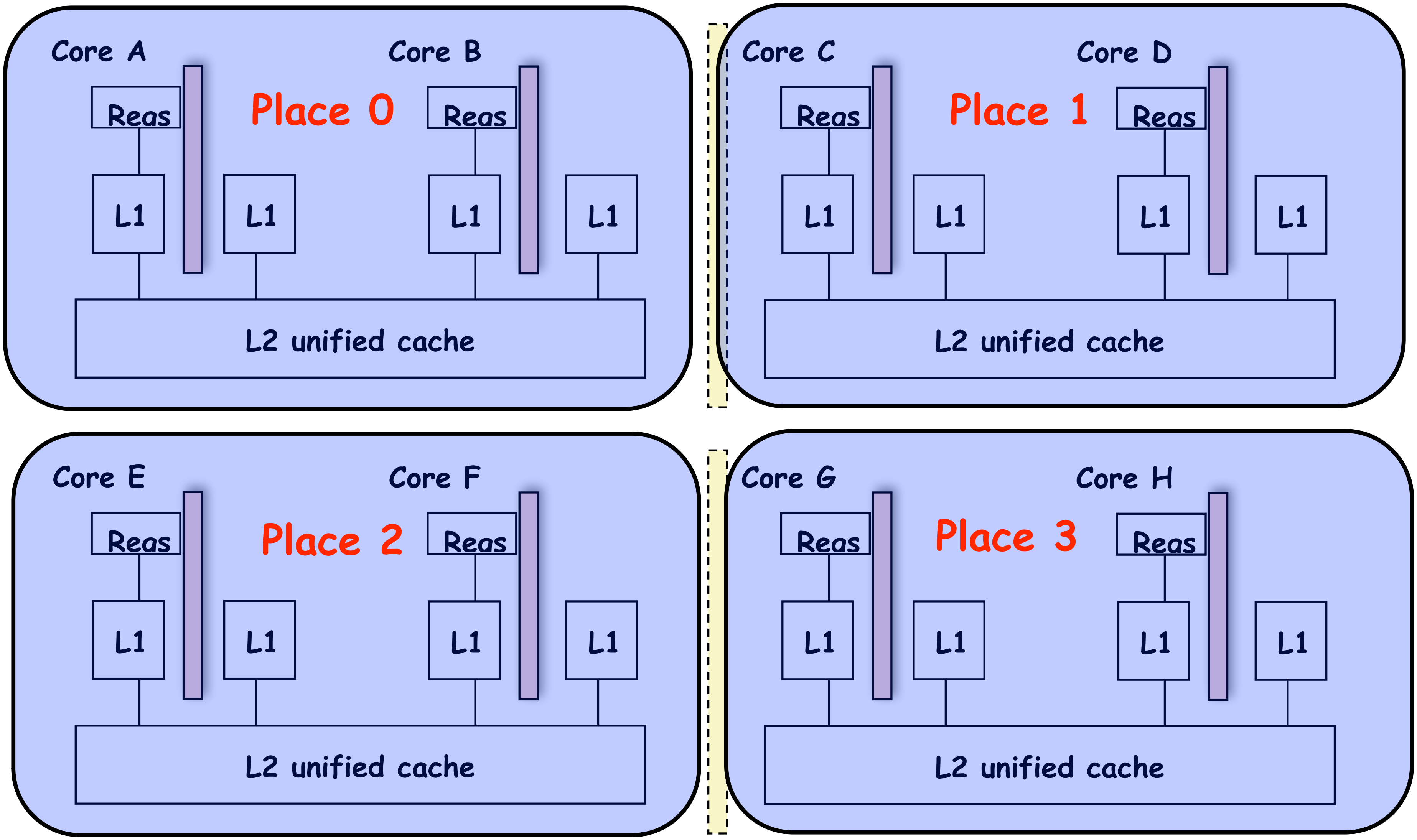


HJ programmer defines mapping from HJ tasks to set of places

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

The option "-places p:w" when executing an HJ program can be used to specify
- **p, the number of places**
- **w, the number of worker threads per place**

Example of –places 4:2 option on an 8-core node (4 places w/ 2 workers per place)



Places in HJ

here = place at which current task is executing

place.MAX_PLACES = total number of places (runtime constant)

Specified by value of **p** in runtime option, `-places p:w`

place.factory.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

async at(P) S

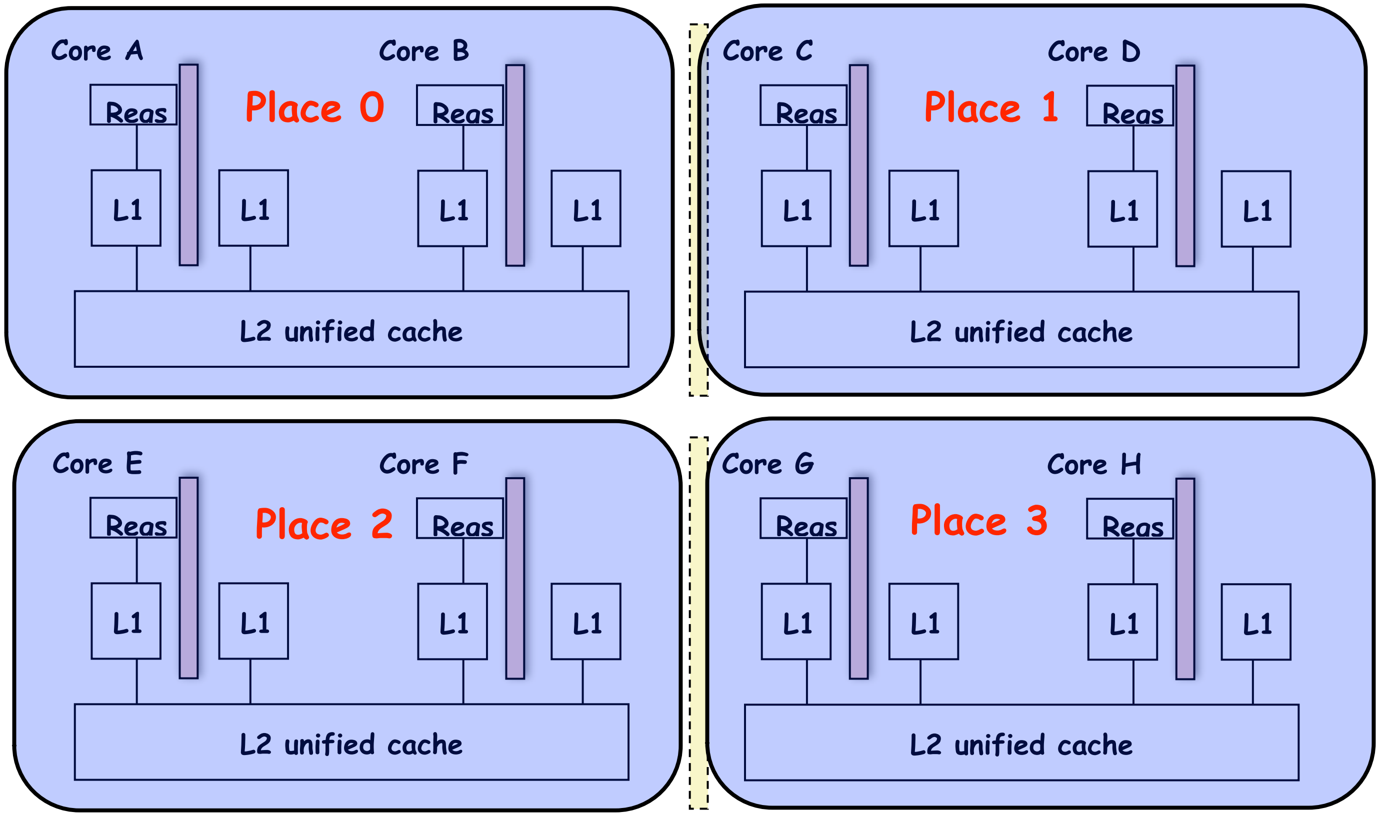
- Creates new task to execute statement S at place P
- **async S** is equivalent to **async at(here) S**
- Main program task starts at **place.factory.place(0)**

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 –places 4:2 option on an 8-core node (4 places w/ 2 workers per place)

```
// Main program starts at place 0
async at(place.factory.place(0)) S1;
async at(place.factory.place(0)) S2;
```

```
async at(place.factory.place(1)) S3;
async at(place.factory.place(1)) S4;
async at(place.factory.place(1)) S5;
```

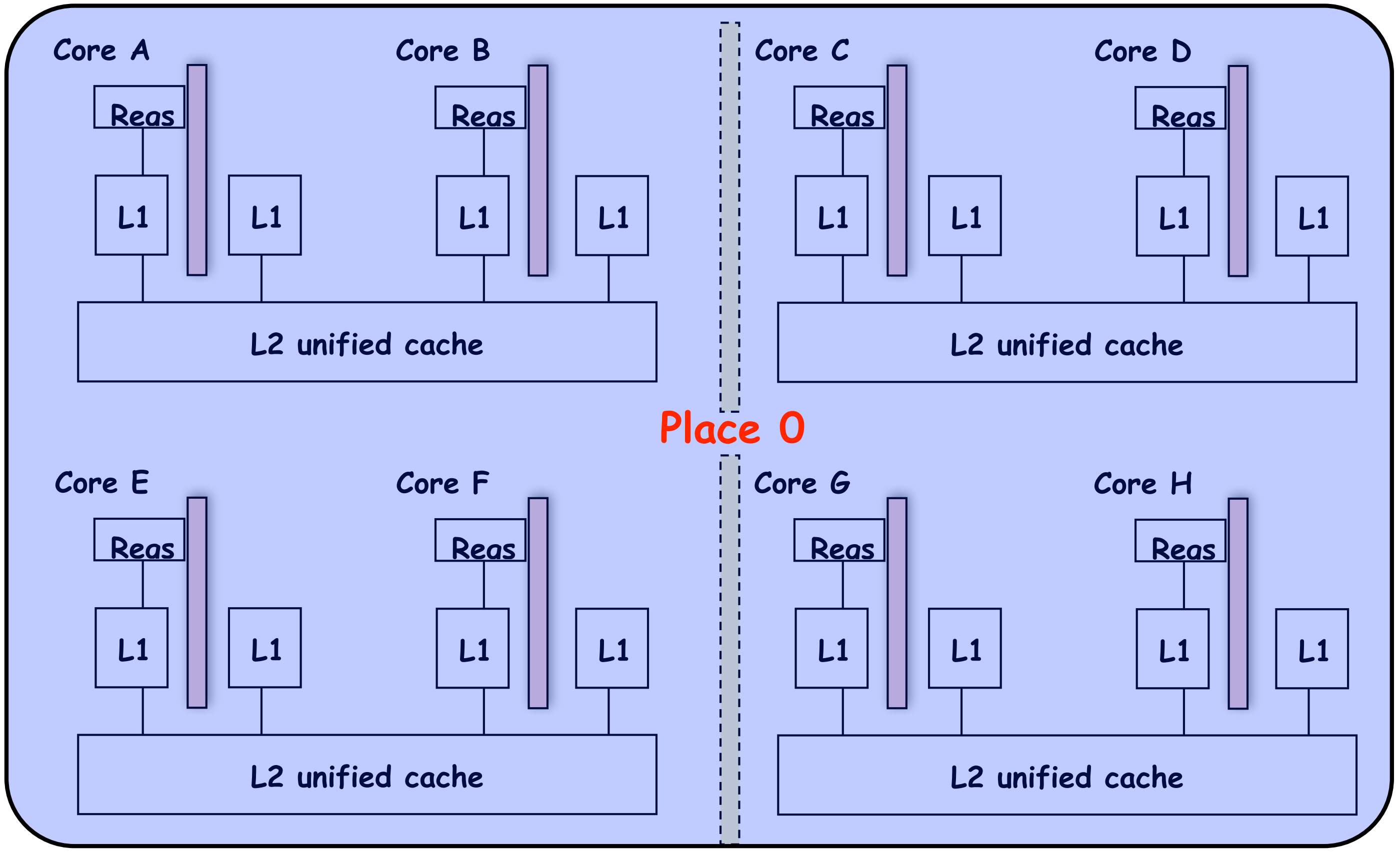


```
async at(place.factory.place(2)) S6;
async at(place.factory.place(2)) S7;
async at(place.factory.place(2)) S8;
```

```
async at(place.factory.place(3)) S9;
async at(place.factory.place(3)) S10;
```

Example of –places 1:8 option (1 place w/ 8 workers per place)

All async's run at place 0 when there's only one place!



Example HJ program with places

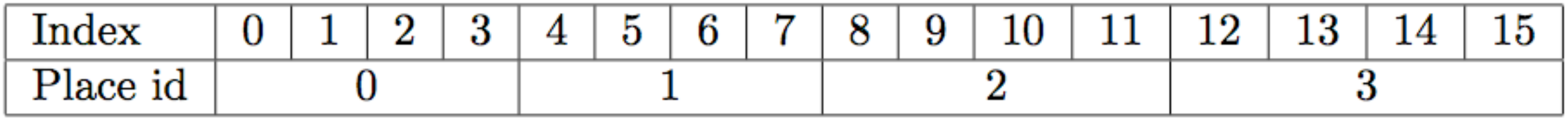
```
class T1 {
  final place affinity;
  . . .
  // T1's constructor sets affinity to place where instance was created
  T1() { affinity = here; ... }
  . . .
}
. . .
finish { // Inter-place parallelism
  System.out.println(”Parent␣place␣=␣”, here); // Parent task s place
  for (T1 a = . . .) {
    async at (a.affinity) { // Execute async at place with affinity to a
      a.foo();
      System.out.println(”Child␣place␣=␣”, here); // Child task's place
    } // async
  } // for
} // finish
. . .
```

Distributions --- hj.lang.dist

- A distribution maps points in a rectangular index space (region) to places e.g.,
    - i → place.factory.place(i % place.MAX_PLACES)
- Programmers are free to create any data structure they choose to store and compute these mappings
- For convenience, the HJ language provides a predefined type, hj.lang.dist, to simplify working with distributions
- Some public members available in an instance d of hj.lang.dist are:
    - d.rank = number of dimensions in the input region for distribution d
    - d.get(p) = place for point p mapped by distribution d. It is an error to call d.get(p) if p.rank != d.rank.
    - d.places() = set of places in the range of distribution d
    - d.restrictToRegion(pl) = region of points mapped to place pl by distribution d

Block Distribution

- **dist.factory.block([lo:hi]) creates a block distribution over the one-dimensional region, lo:hi.**
- **A block distribution splits the 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 in Table 1: dist.factory.block([0:15]) for 4 places**



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

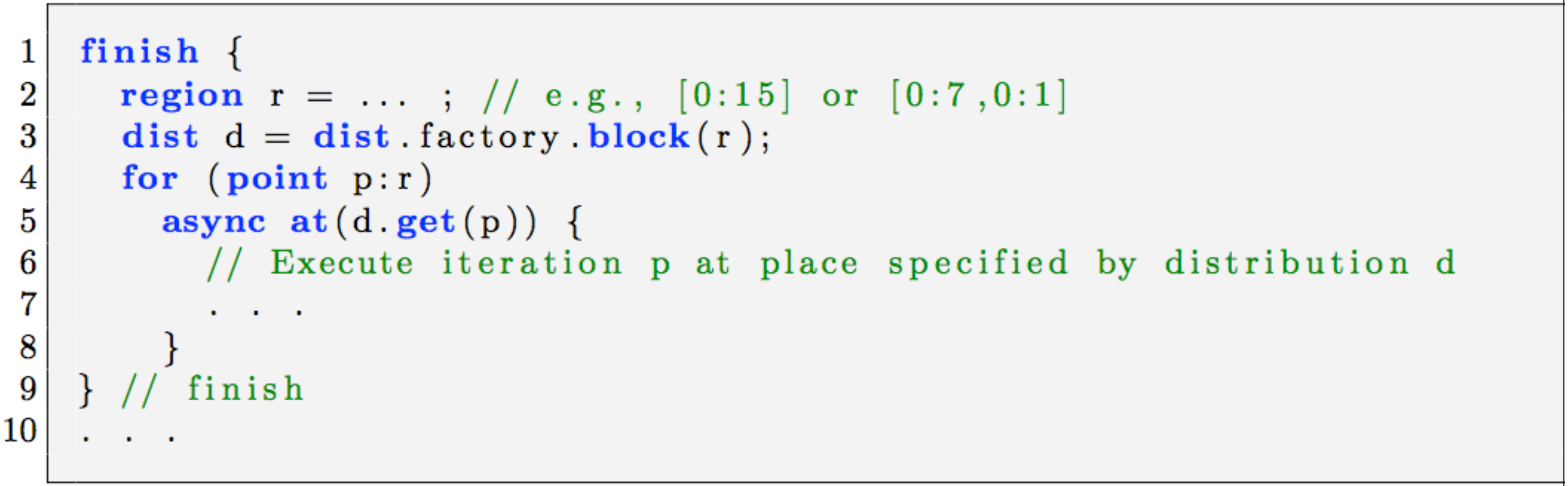
Block Distribution (contd)

- **If the input region is multidimensional, then a block distribution is computed over the linearized one-dimensional version of the multidimensional region**
- **Example in Table 2: dist.factory.block([0:7,0:1]) for 4 places**

Index	[0,0]	[0,1]	[1,0]	[1,1]	[2,0]	[2,1]	[3,0]	[3,1]	[4,0]	[4,1]	[5,0]	[5,1]	[6,0]	[6,1]	[7,0]	[7,1]
Place id	0				1				2				3			

Distributed Parallel Loops

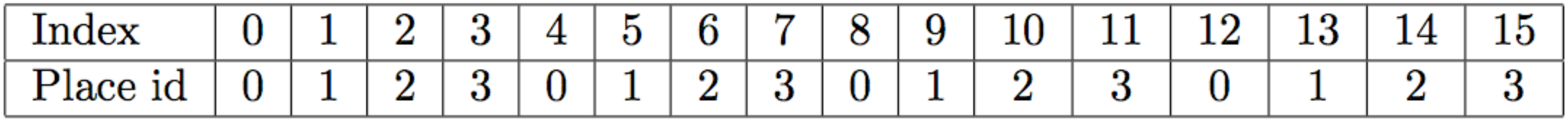
- **Listing 2 shows the typical pattern used to iterate over an input region r, while creating one async task for each iteration p at the place dictated by distribution d i.e., at place d.get(p).**
- **This pattern works correctly regardless of the rank and contents of input region r and input distribution d i.e., it is not constrained to block distributions**



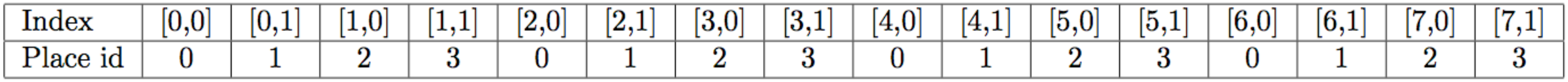
```
finish {
  region r = ... ; // e.g., [0:15] or [0:7,0:1]
  dist d = dist.factory.block(r);
  for (point p:r)
    async at(d.get(p)) {
      // Execute iteration p at place specified by distribution d
      . . .
    }
} // finish
. . .
```

Cyclic Distribution

- **dist.factory.cyclic([lo:hi]) creates a cyclic distribution over the one-dimensional region, lo:hi.**
- **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 in Table 3: dist.factory.cyclic([0:15]) for 4 places**



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



Index	[0,0]	[0,1]	[1,0]	[1,1]	[2,0]	[2,1]	[3,0]	[3,1]	[4,0]	[4,1]	[5,0]	[5,1]	[6,0]	[6,1]	[7,0]	[7,1]
Place id	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3

Chunked Fork-Join Iterative Averaging Example with Places

```
public void runDistChunkedForkJoin(int iterations,
                                   int numChunks, dist d) {
  for (int iter = 0; iter < iterations; iter++) {
    finish for (point [jj] : [0:numChunks-1])
      async at(d.get(jj)) {
        for (point [j] : getChunk([1:n],numChunks,jj))
          myNew[j] = (myVal[j-1] + myVal[j+1]) / 2.0;
    } // finish-for-async
    double[] temp = myNew; myNew = myVal; myVal = temp;
  } // for iter
} // runDistChunkedForkJoin
```

- Chunk jj is always executed in the same place for each iter
- Method runDistChunkedForkJoin can be called with different values of distribution parameter d

Let's try another example of a distributed parallel loop in Worksheet 30!

Worksheet #30: impact of distribution on parallel completion time

Name 1: ______________________

Name 2: ______________________

```
public void sampleKernel(int iterations,
                         int numChunks, dist d) {
  for (int iter = 0; iter < iterations; iter++) {
    finish for (point [jj] : [0:numChunks-1])
      async at(d.get(jj)) {
        perf.doWork(jj);
        // Assume that time to process chunk jj = jj units
    } // finish-for-async
    double[] temp = myNew; myNew = myVal; myVal = temp;
  } // for iter
} // sample kernel
```

- *Assume an execution with n places using the option, -places n:1*
- *Will a block or cyclic distribution for d have a smaller abstract completion time, assuming that all tasks on the same place are serialized?*

BACKUP SLIDES START HERE