COMP 322: Fundamentals of Parallel Programming

Lecture 33: Task Affinity with Places

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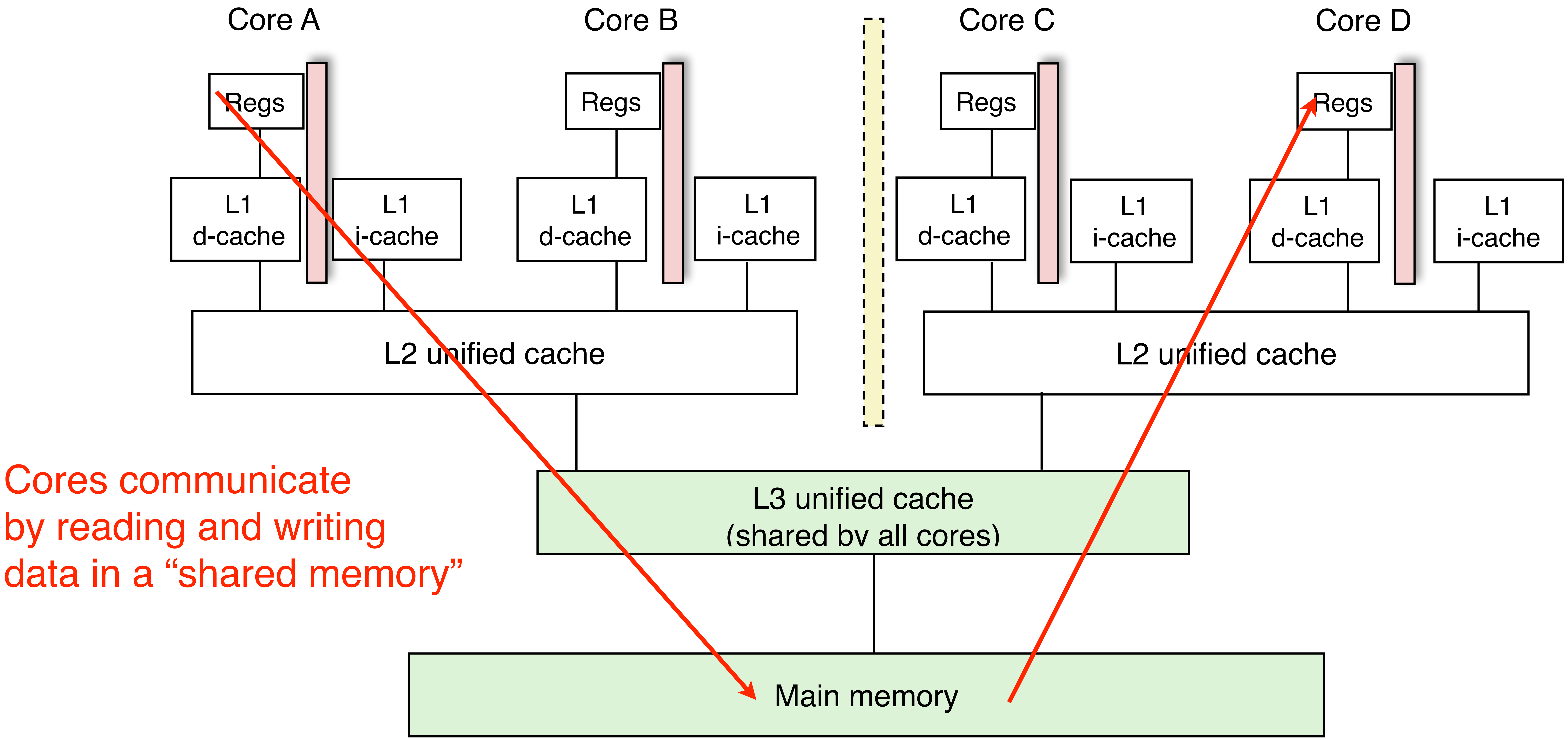
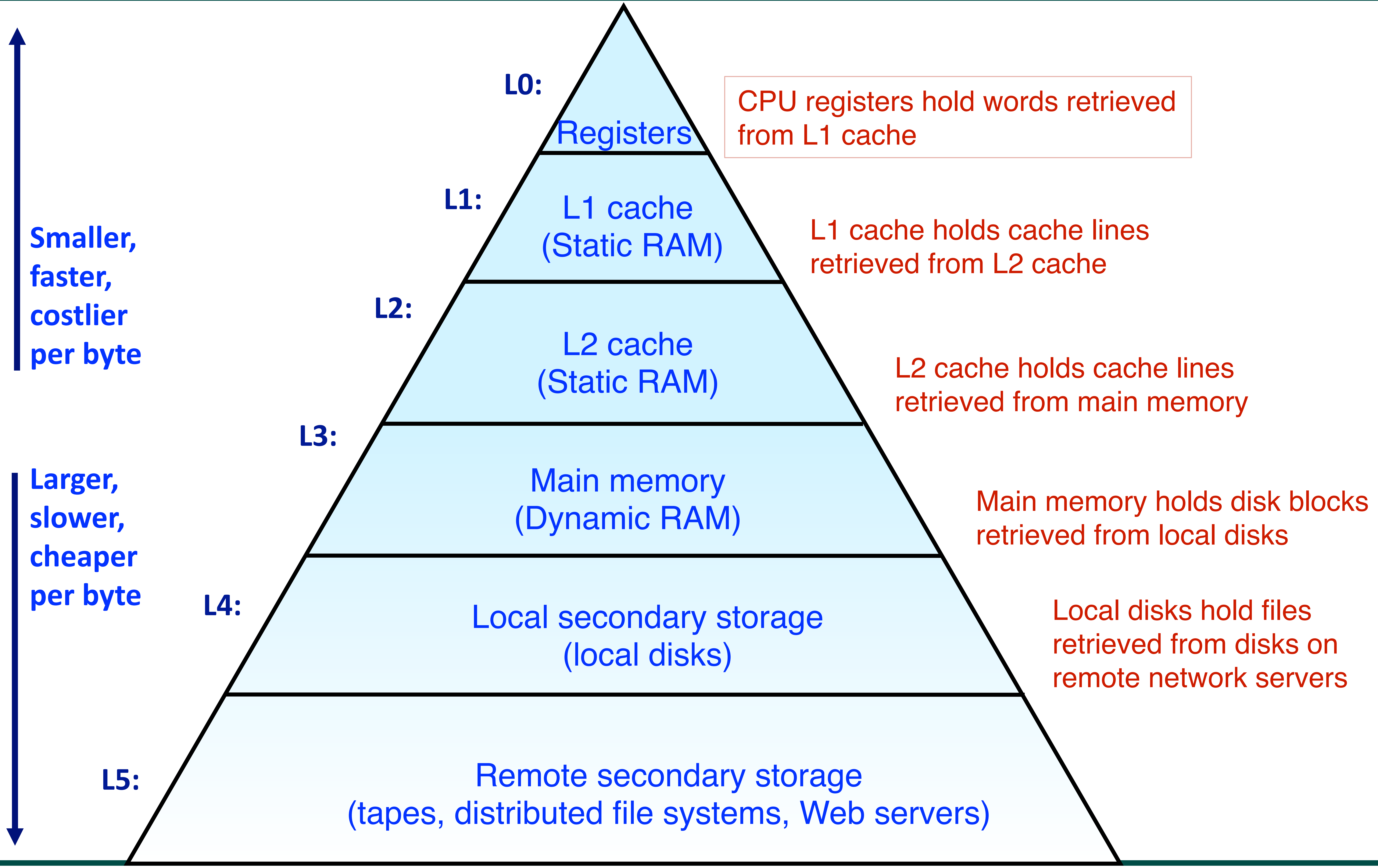
Organization of a Shared-Memory Multicore Symmetric Multiprocessor (SMP)



- 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

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



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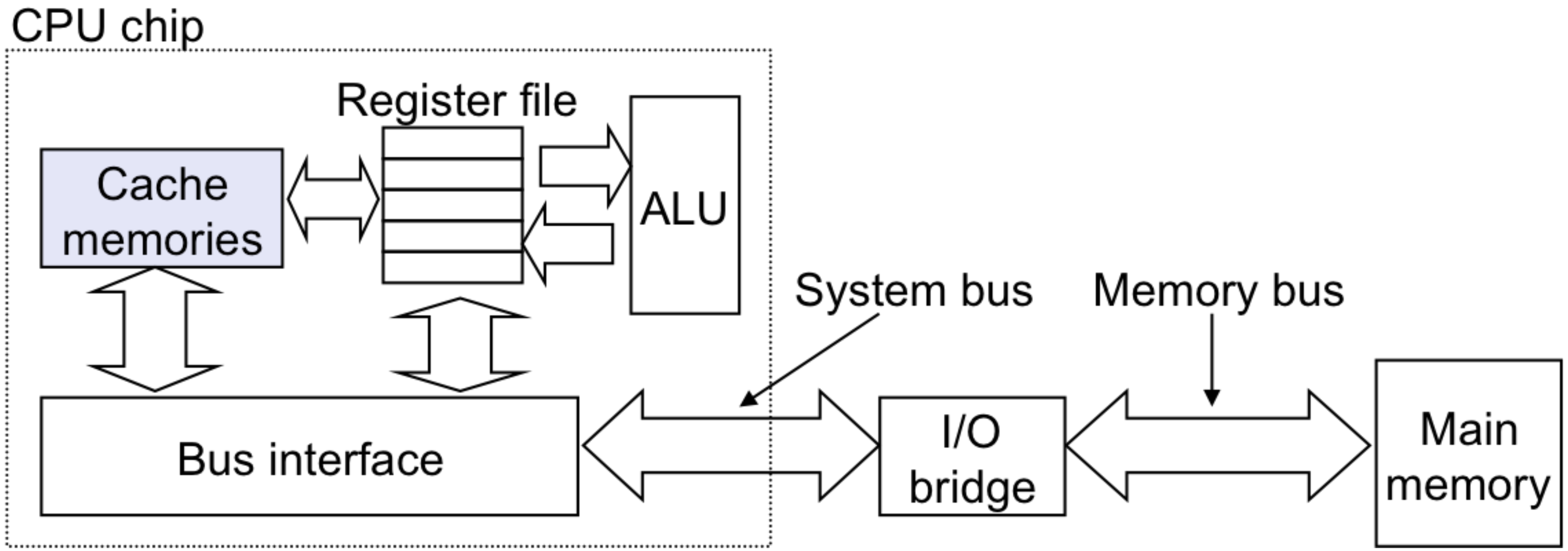
Cache Memories

- 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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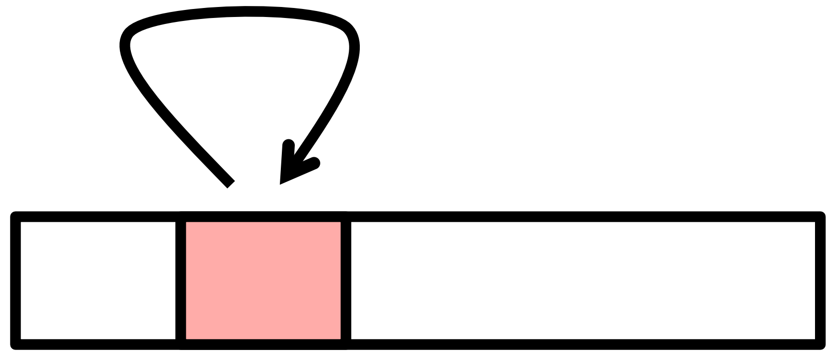
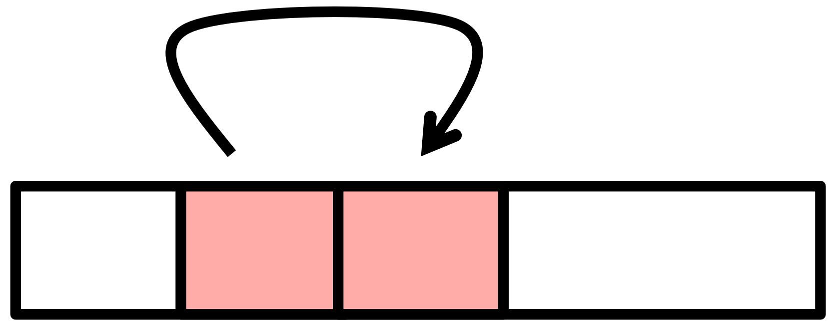
Locality

- 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).
  - Reference variable sum each iteration.
- Instruction references
  - Cycle through loop repeatedly.
  - Reference instructions in sequence.

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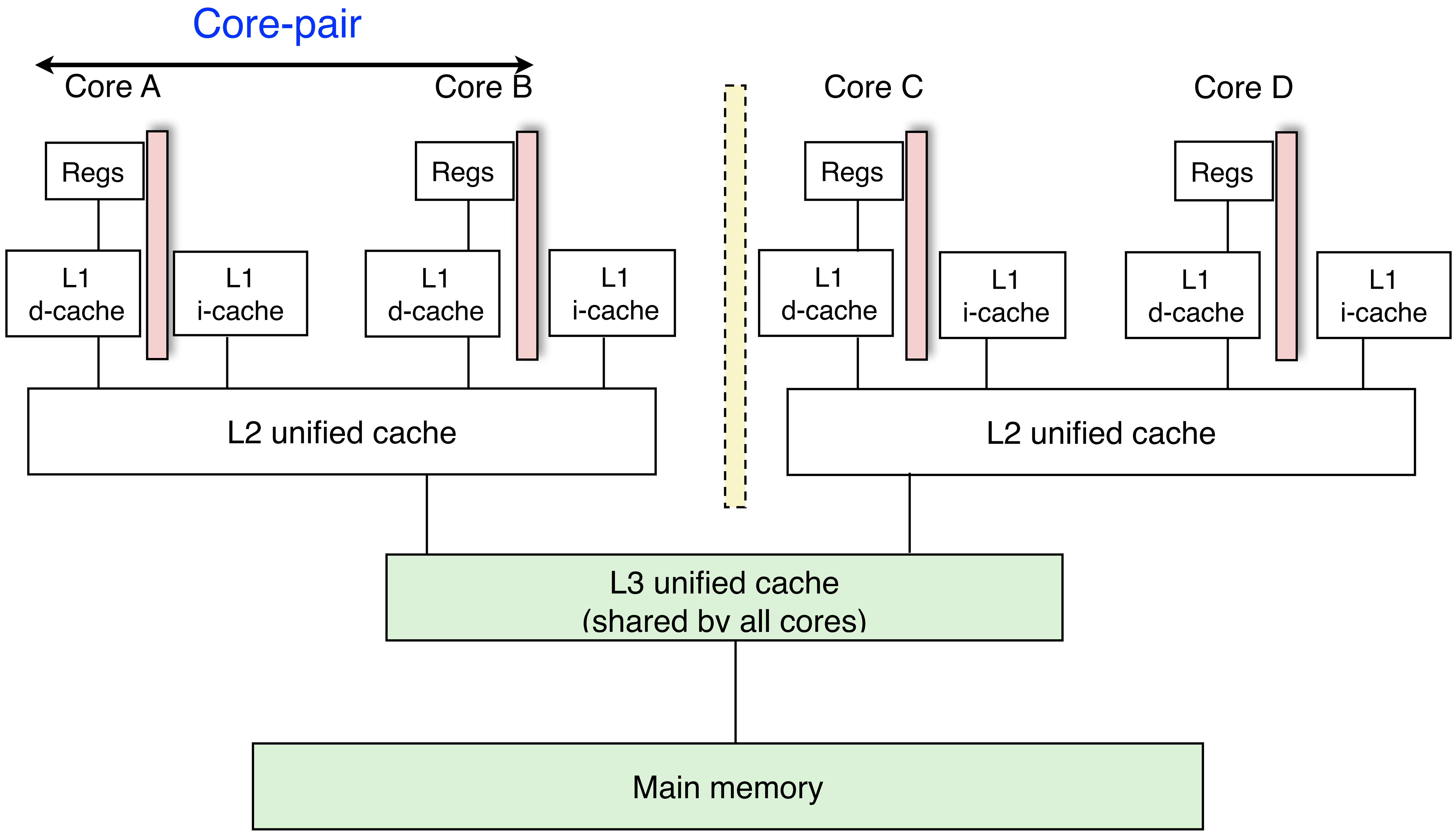
Memory Hierarchy in a Multicore Processor



- 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

Places in HJlib

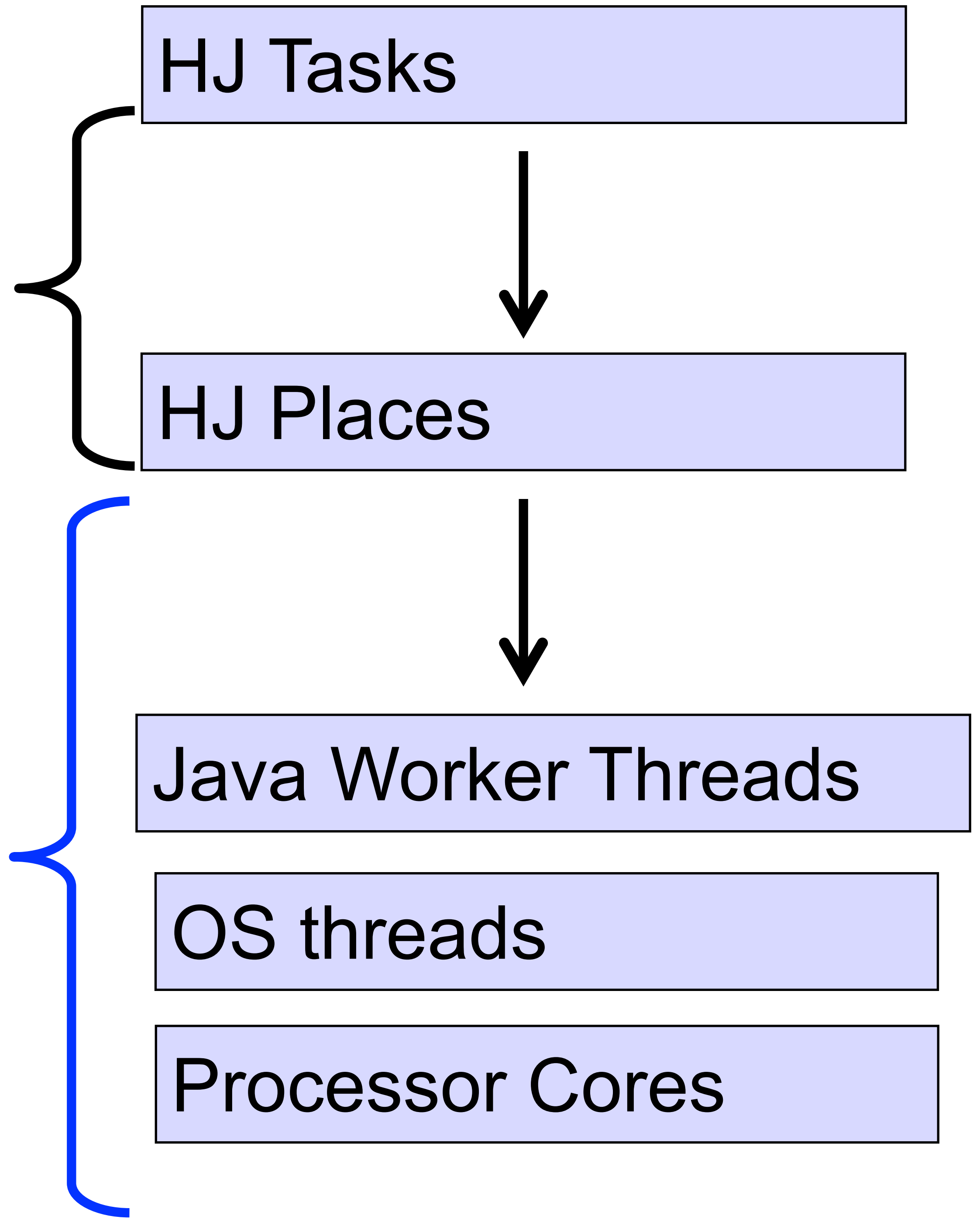
HJ programmer defines mapping from HJ tasks to set of places

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

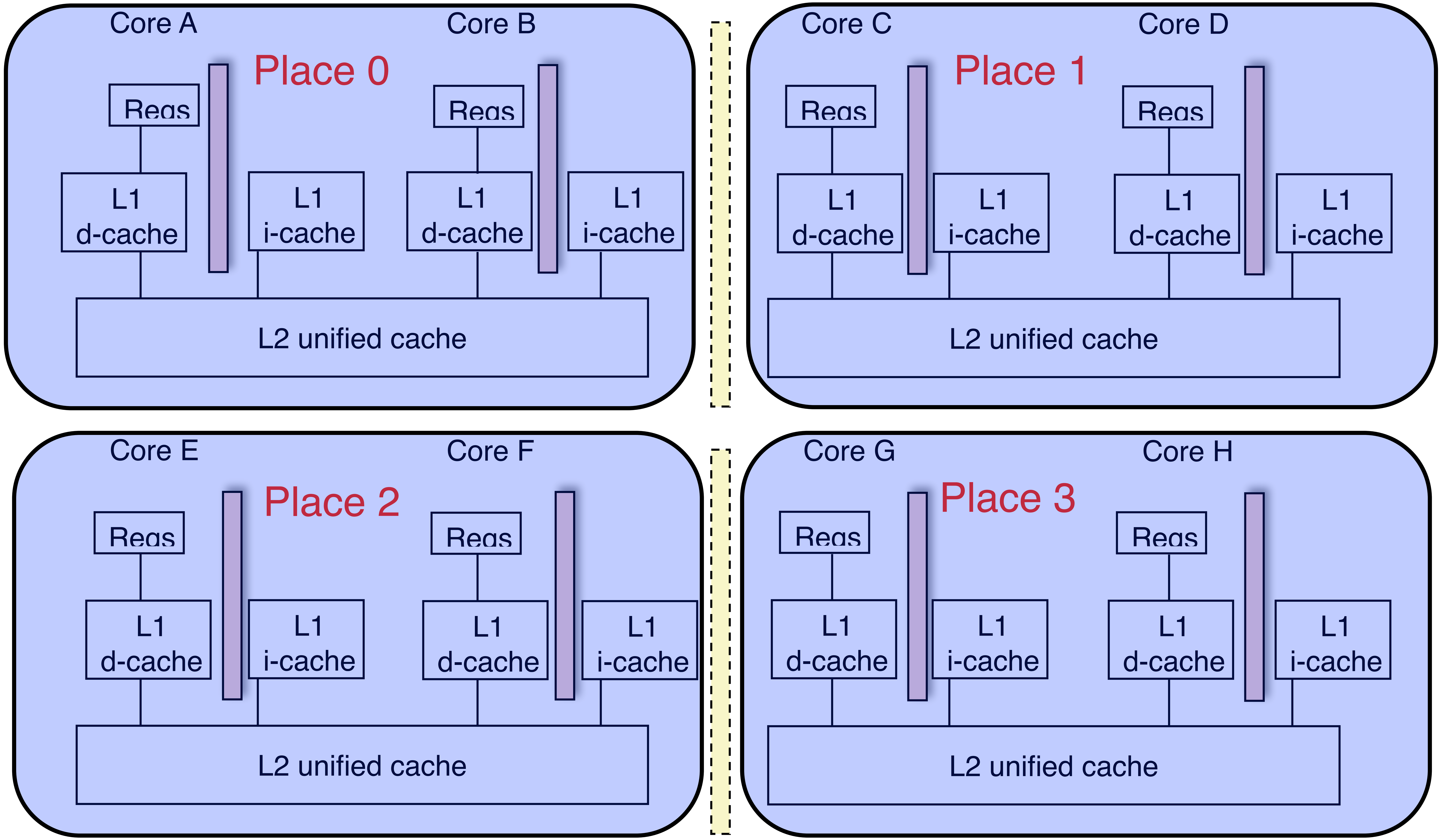
The API calls
HjSystemProperty.numPlaces.set(p);
HjSystemProperty.numWorkers.set(w);

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)

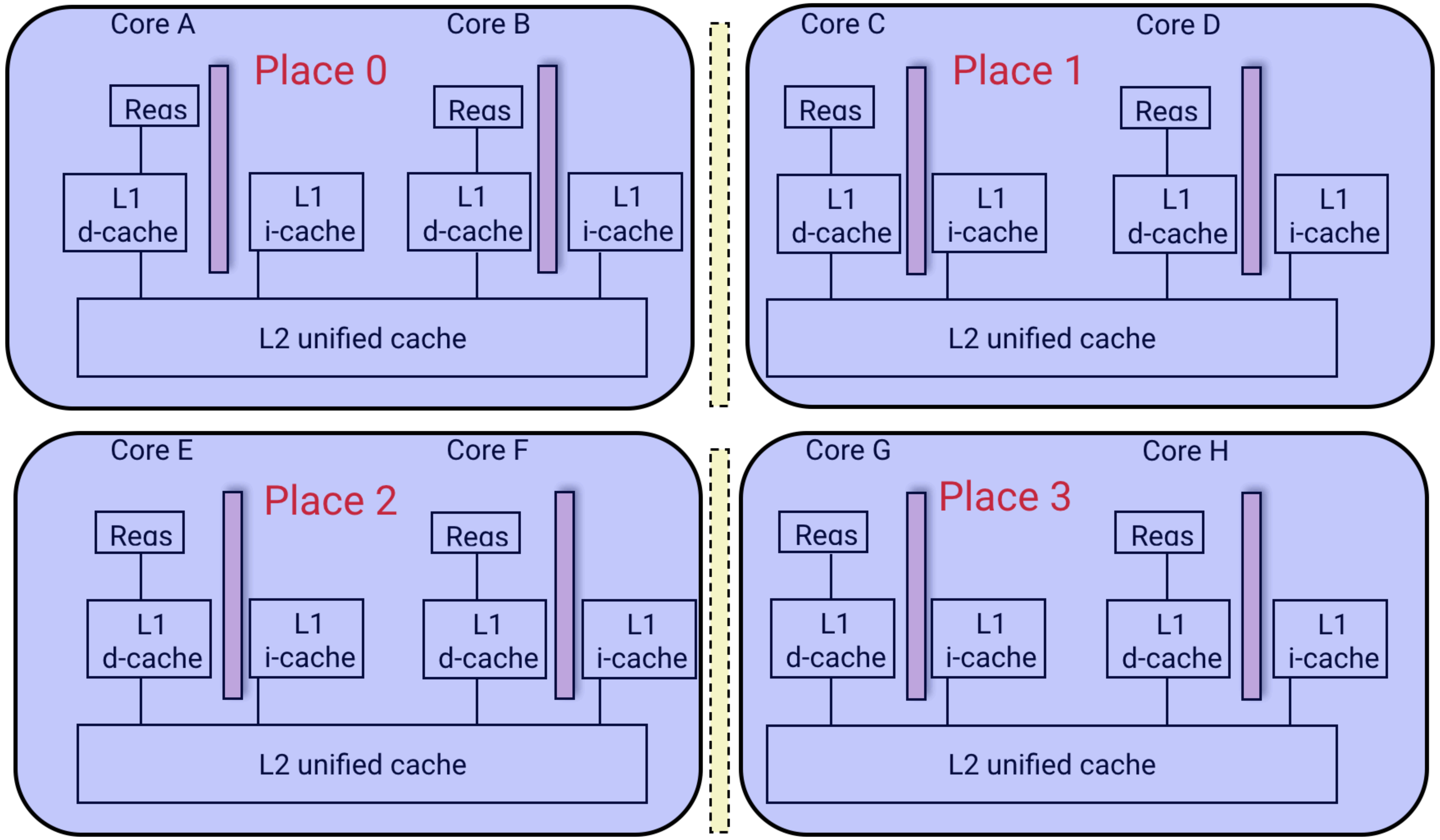
- Creates new task to execute statement S at place P
- async(() -> S) is equivalent to asyncAt(here(), () -> S)
- Main program task starts at place(0)

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);
```

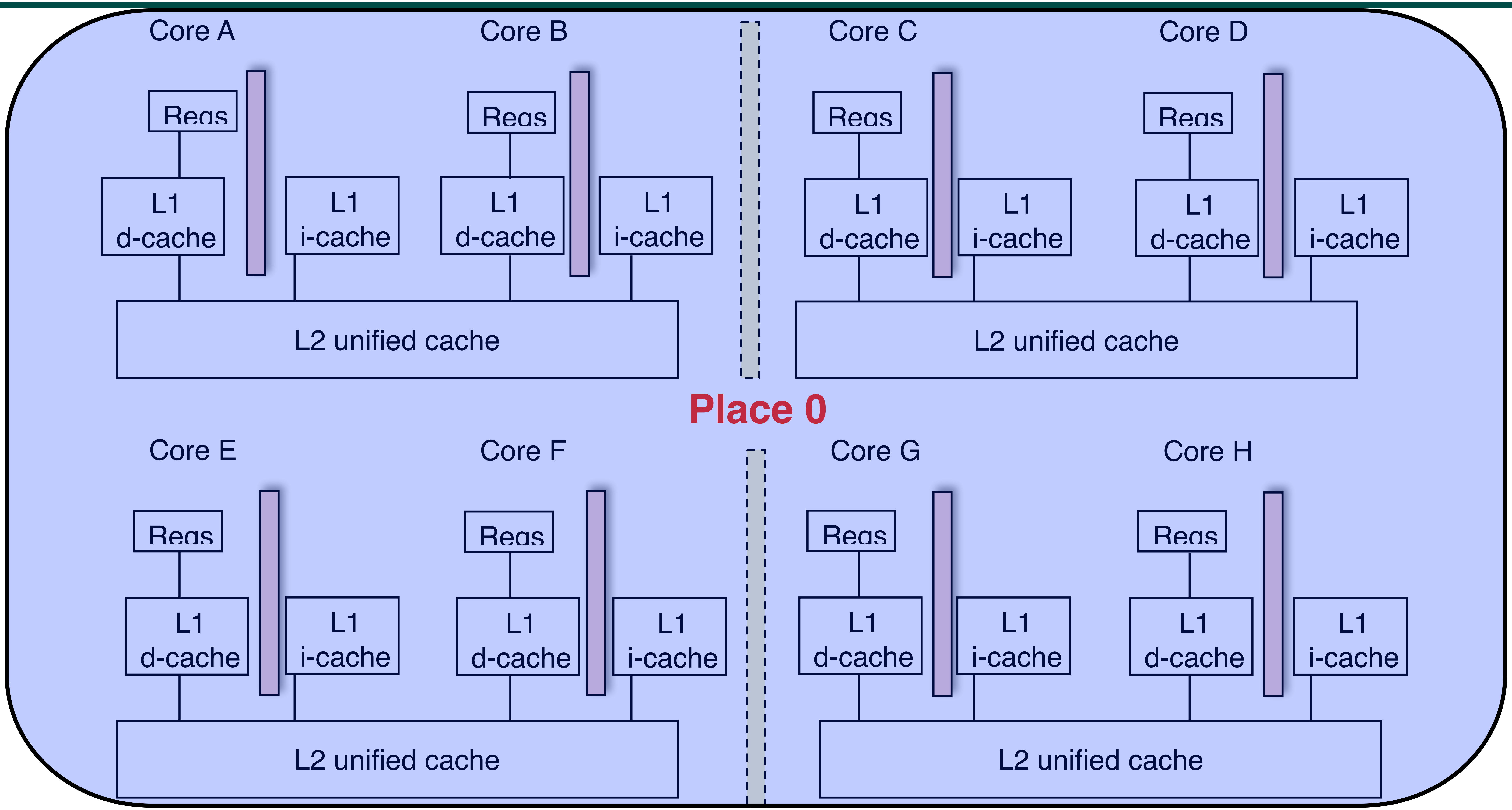
```
asyncAt(place(1), () -> S3);
asyncAt(place(1), () -> S4);
asyncAt(place(1), () -> S5);
```




```
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

```
private static class T1 {
  final HjPlace affinity;

  public T1(HjPlace affinity) {
    // set affinity of instance to place where it is created
    this.affinity = here();
    ...
  }
  public void foo() { ... }
}

finish(() -> {
  println("Parent place: " + here());
  for (T1 a : t1Objects) {
    // Execute async at place with affinity to a
    asyncAt(a.affinity, () -> {
      println("Child place: " + here()); // Child task's place
      a.foo();
    });
  }
});
```

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>
<tr><td>Index</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td></tr>
<tr><td>Place id</td><td colspan="4">0</td><td colspan="4">1</td><td colspan="4">2</td><td colspan="4">3</td></tr>
</table>

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

```
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
. . .
```

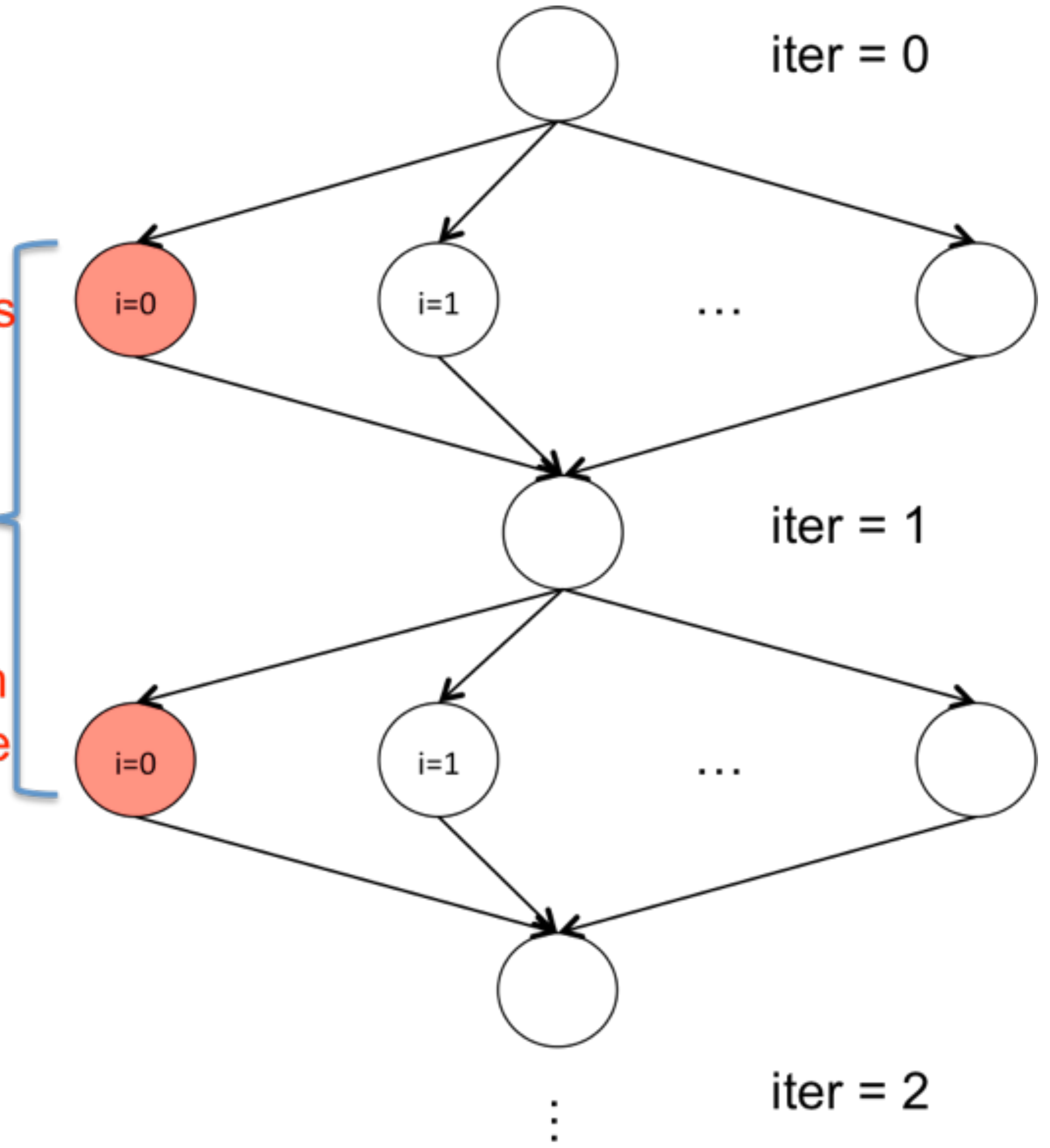
Chunked Fork-Join Iterative Averaging Example with Places

```
public void runDistChunkedForkJoin(
  int iterations, int numChunks, Dist dist) {
  // dist is a user-defined map from int to HjPlace
  for (int iter = 0; iter < iterations; iter++) {
    finish(() -> {
      for (0, numChunks - 1, (jj) -> {
        asyncAt(dist.get(jj), () -> {
          for (getChunk(1, n, numChunks, jj), (j) -> {
            myNew[j] = (myVal[j-1] + myVal[j+1]) / 2.0;
          }
        });
      });
    });
    double[] temp = myNew; myNew = myVal; myVal = temp;
  } // for iter
}
```

- 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

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



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