COMP 322: Fundamentals of Parallel Programming

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Lecture 12: Barrier Synchronization

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Announcements

- Homework 4 assigned today, due by 5pm on Wednesday, Feb 16th
  - We will try and return graded homeworks by Feb 23rd
- Midterm will be a 2-hour take-home written exam
  - Closed-book, closed-notes, closed-computer
  - Will be given out at lecture on Wed, Feb 23rd
  - Must be handed in by 5pm on Friday, Feb 25th
- No lecture on Feb 25th since midterm is due that day

Acknowledgments for Today's Lecture

- "Principles of Parallel Programming", Calvin Lin & Lawrence Snyder, Addison-Wesley, 2009
  - Includes resources available at http://www.pearsonhighered.com/educator/academic/product/0,3110,0321487907,00.html
- Lecture 12 handout

Hello-Goodbye Forall Example

```
rank.count = 0; // rank object contains an int field, count
forall (point [i] : [0:m-1]) {
  int r;
  isolated {r = rank.count++;}
  System.out.println("Hello from task ranked " + r);
  System.out.println("Goodbye from task ranked " + r);
}
```

- Sample output for m = 4

```
Hello from task ranked 0
Hello from task ranked 1
Goodbye from task ranked 0
Hello from task ranked 2
Goodbye from task ranked 2
Goodbye from task ranked 1
Hello from task ranked 3
Goodbye from task ranked 3
```


Hello-Goodbye Forall Example (contd)

```
rank.count = 0; // rank object contains an int field, count
forall (point [i] : [0:m-1]) {
  int r;
  isolated {r = rank.count++;}
  System.out.println("Hello from task ranked " + r);
  System.out.println("Goodbye from task ranked " + r);
}
```

- Question: how can we transform this code so as to ensure that all tasks say hello before any tasks goodbye?
- Approach 1: Replace the forall loop by two forall loops, one for the hello's and one for the goodbye's
  - Need to communicate local r values from one forall to the next
- Approach 2: insert a "barrier" between the hello's and goodbye's
  - "next" statement in HJ

Barrier Synchronization: HJ's "next" statement

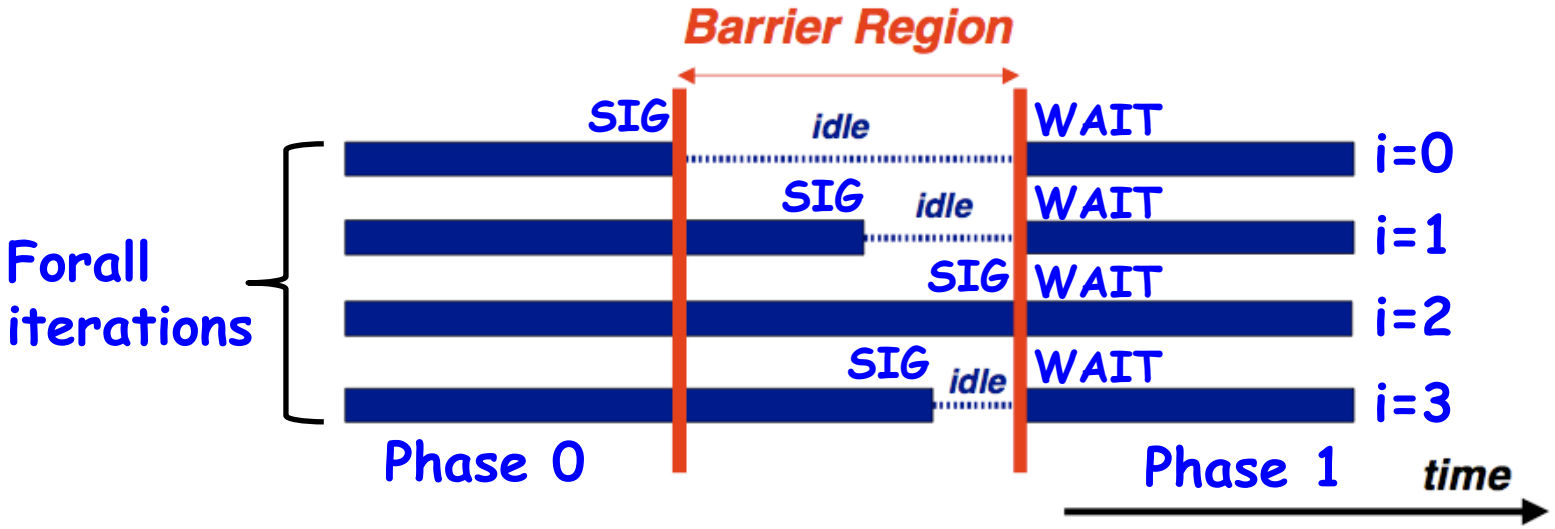
```
rank.count = 0; // rank object contains an int field, count
forall (point [i] : [0:m-1]) {
  int r;
  isolated {r = rank.count++;}
  System.out.println("Hello from task ranked " + r);
  next; // Acts as barrier between phases 0 and 1
  System.out.println("Goodbye from task ranked " + r);
}
```

Phase 0

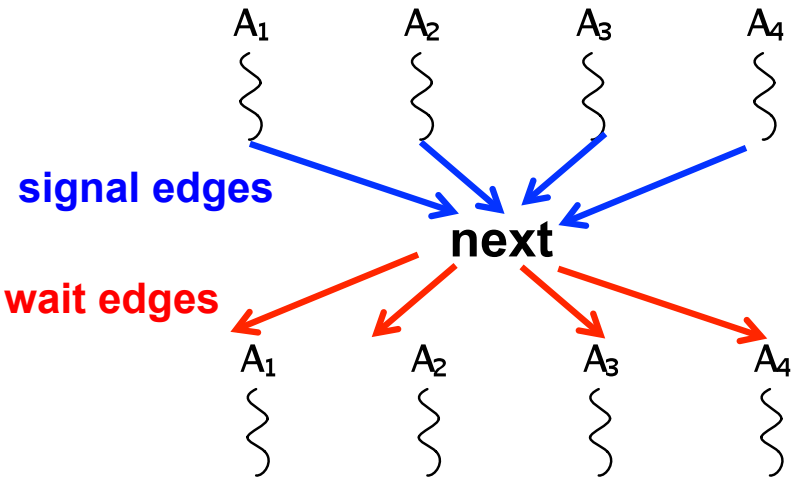
Phase 1

- next ➔ each forall iteration suspends at next until all iterations arrive (complete previous phase), after which the phase can be advanced
  - If a forall iteration terminates before executing "next", then the other iterations do not wait for it
  - Scope of synchronization is the closest enclosing forall statement
  - Special case of "phaser" construct (will be covered in following lectures)

Impact of barrier on scheduling forall iterations



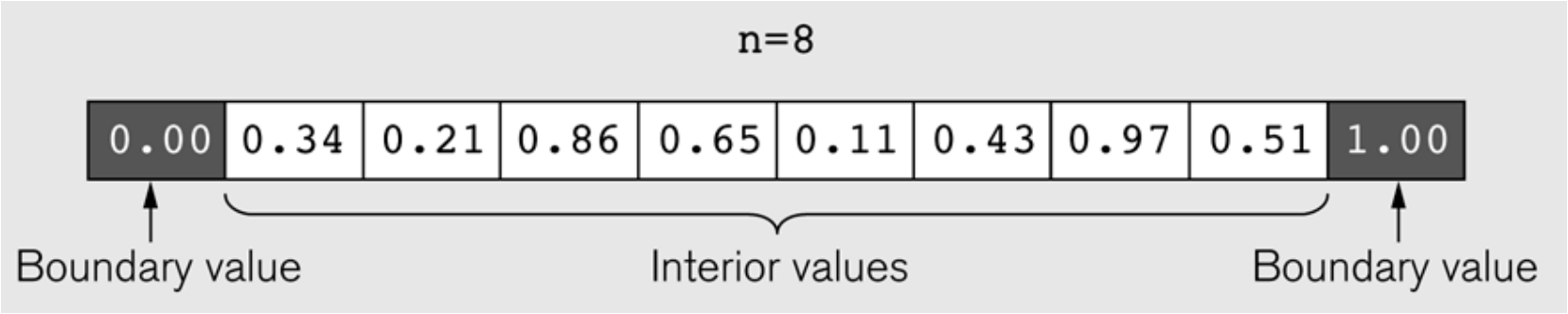
Modeling a next operation in the computation graph



One-Dimensional Iterative Averaging Example

- Initialize a one-dimensional array of (n+2) double's with boundary conditions, myVal[0] = 0 and myVal[n+1] = 1.
- In each iteration, each interior element myVal[i] in 1..n is replaced by the average of its left and right neighbors.
  - Two separate arrays are used in each iteration, one for old values and the other for the new values
- After a sufficient number of iterations, we expect each element of the array to converge to myVal[i] = i/(n+1)
  - In this case, myVal[i] = (myVal[i-1]+myVal[i+1])/2, for all i in 1..n

Illustration of an intermediate step for n = 8 (source: Figure 6.19 in Lin-Snyder book)



HJ code for One-Dimensional Iterative Averaging using nested for-forall structure (Listing 3)

```
1. double[] myVal = new double[n]; myVal[0] = 0; myVal[n+1] = 1;
2. double[] myNew = new double[n]; double[] temp = null;
3. int batchSize = CeilDiv(n,t); // Number of elements per task
4. for (point [iter] : [0:iterations-1]) {
5.   forall (point [i] : [0:t-1]) { // Create t tasks
6.     int start = i*batchSize + 1;
7.     for (point[j] : [start:Math.min(start+batchSize-1,n)])
8.       myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
9.   } // forall
10.  temp = myNew; myNew = myVal; myVal = temp; // swap(myNew, myVal)
11.} // for
```

How many tasks does this version create?

HJ code for One-Dimensional Iterative Averaging using nested forall-for-next structure (Listing 4)

```
1. double[] val1 = new double[n]; val[0] = 0; val[n+1] = 1;
2. double[] val2 = new double[n];
3. int batchSize = CeilDiv(n,t); // Number of elements per task
4. forall (point [i] : [0:t-1]) { // Create t tasks
5.   double[] myVal = val1; double myNew = val2; double[] temp = null;
6.   int start = i*batchSize + 1; int end = Math.min(start+batchSize-1,n);
7.   for (point [iter] : [0:iterations-1]) {
8.     for (point[j] : [start:end])
9.       myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
10.    next; // barrier
11.    temp = myNew; myNew = myVal; myVal = temp; // swap(myNew,
   myVal)
12.  } // for
13.} // forall
```

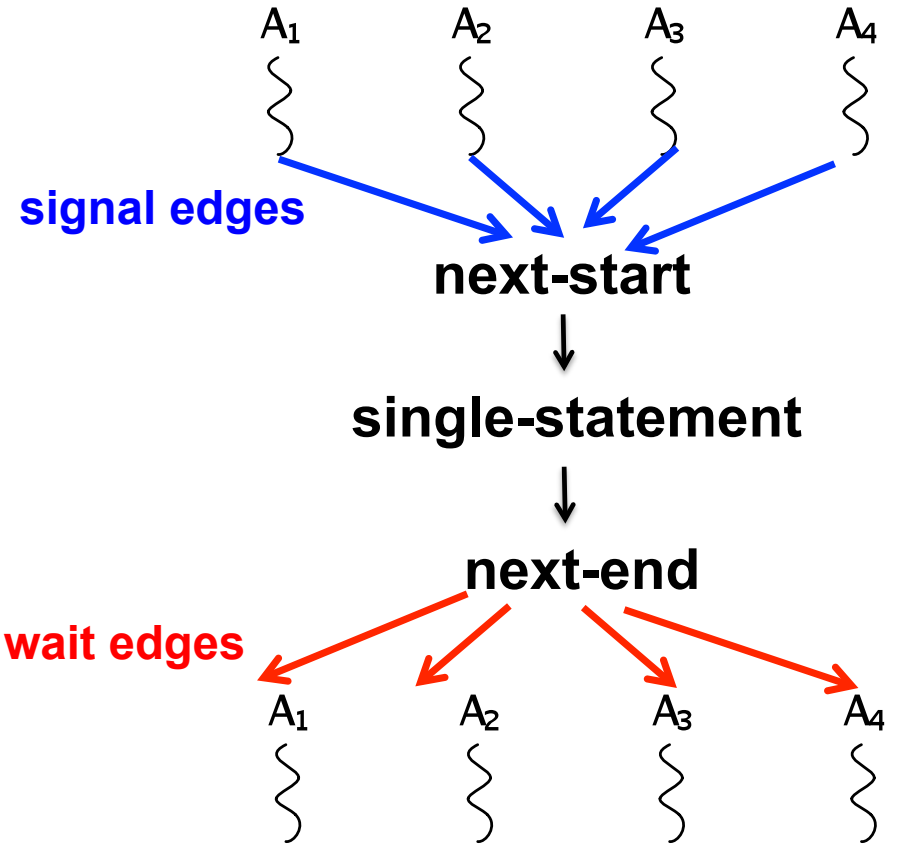

Extension: adding a print statement between phases with Two Barriers (Listing 5)

```
forall (point [i] : [0:t-1]) { // Create t tasks
  . . .
  for (point [iter] : [0:iterations-1]) {
    double sum = 0;
    for (point[j] : [start:end]) {
      myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
      sum += Math.abs(myNew[j] - myVal[i]);  }
    tSum[i] = sum;
    next; // first barrier
    if (i == 0) {
      double sum = 0; for(point[k]:[0:t-1]) sum += tSum[k];
      System.out.println("Sum = " + sum + " for iteration " + iter);
    }
    next; // second barrier
    . . .
} // forall
```


Next-with-Single Statement

next <single-stmt> is a barrier in which single-stmt is performed exactly once after all tasks have completed the previous phase and before any task begins its next phase.

Modeling next-with-single in the Computation Graph



Use of next-with-single to add a print statement between phases (Listing 6)

```
forall (point [i] : [0:t-1]) { // Create t tasks
  . . .
  for (point [iter] : [0:iterations-1]) {
    double sum = 0;
    for (point [j] : [start:end]) {
      myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
      sum += Math.abs(myNew[j] - myVal[i]);
    }
    tSum[i] = sum;
    next { // next-with-single statement replaces two barriers
      double sum = 0; for(point[k]:[0:t-1]) sum += tSum[k];
      System.out.println("Sum = " + sum + " for iteration " + iter);
     }
    . . .
} // forall
```