COMP 322: Fundamentals of Parallel Programming

Lecture 12: Barrier Synchronization

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Solution to Worksheet #11: One-dimensional Iterative Averaging Example

1) Assuming n=9 and the input array below, perform a "half-iteration" of the iterative averaging example by only filling in the blanks for odd values of j in the myNew[] array (different from the real algorithm). Recall that the computation is "myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;"

index, j	0	1	2	3	4	5	6	7	8	9	10
myVal	0	0	0.2	0	0.4	0	0.6	0	0.8	0	1
myNew	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

2) Will the contents of myVal[] and myNew[] change in further iterations?
No, this represents the converged value (equilibrium/fixpoint).

3) Write the formula for the final value of myNew[i] as a function of i and n. In general, this is the value that we will get if m (= #iterations in sequential for-iter loop) is large enough.
After a sufficiently large number of iterations, the iterated averaging code will converge with myNew[i] = myVal[i] = i / (n+1)

Hello-Goodbye Forall Example (Pseudocode)

```
forall (0, m - 1, (i) -> {
  int sq = i*i;  // NOTE: video used lookup(i) instead
  System.out.println("Hello from task with square = " + sq);
  System.out.println("Goodbye from task with square = " + sq);
});
```

Sample output for m = 4:

Hello from task with square = 0
Hello from task with square = 1
Goodbye from task with square = 0
Hello from task with square = 4
Goodbye from task with square = 4
Goodbye from task with square = 1
Hello from task with square = 9
Goodbye from task with square = 9

Hello-Goodbye Forall Example (contd)

```
forall (0, m - 1, (i) -> {
  int sq = i*i;
  System.out.println("Hello from task with square = " + sq);
  System.out.println("Goodbye from task with square = " + sq);
});
```

- **Question: how can we transform this code so as to ensure that all tasks say hello before *any* tasks say goodbye?**
- **Statements in red below will need to be moved to solve this problem**

Hello from task with square = 0
Hello from task with square = 1
Goodbye from task with square = 0
Hello from task with square = 4
Goodbye from task with square = 4
Goodbye from task with square = 1
Hello from task with square = 9
Goodbye from task with square = 9

Hello-Goodbye Forall Example (contd)

```
forall (0, m - 1, (i) -> {
  int sq = i*i;
  System.out.println("Hello from task with square = " + sq);
  System.out.println("Goodbye from task with square = " + sq);
});
```

- Question: how can we transform this code so as to ensure that all tasks say hello before any tasks say goodbye?
- *Approach 1: Replace the forall loop by two forall loops, one for the hello's and one for the goodbye's*
  - Problem: Need to communicate local sq values from first forall to the second

```
// APPROACH 1
forall (0, m - 1, (i) -> {
  int sq = i*i;
  System.out.println("Hello from task with square = " + sq);
});
forall (0, m - 1, (i) -> {
  System.out.println("Goodbye from task with square = " + sq);
});
```


Hello-Goodbye Forall Example (contd)

- Question: how can we transform this code so as to ensure that all tasks say hello before any tasks say goodbye, without having to change local ?
- Approach 2: insert a "barrier" ("next" statement) between the hello's and goodbye's

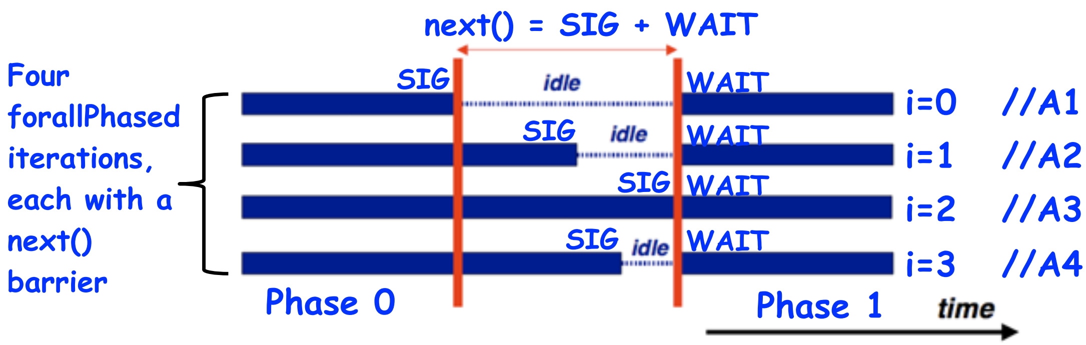
```
// APPROACH 2
forallPhased (0, m - 1, (i) -> {
  int sq = i*i;
  System.out.println("Hello from task with square = " + sq);
  next(); // Barrier
  System.out.println("Goodbye from task with square = " + sq);
});
```

Phase 0

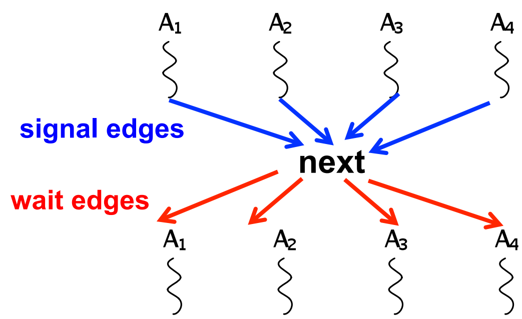
Phase 1

- **next → each forallPhased iteration waits at barrier until all iterations arrive (previous phase is completed), after which the next phase can start**
  - Scope of next is the closest enclosing forallPhased statement
  - If a forallPhased iteration terminates before executing "next", then the other iterations don't wait for it

Impact of barrier on scheduling forallPhased iterations



next() operation is modeled in the Computation Graph using *signal* and *wait* edges



forallPhased API's in HJlib
(http://www.cs.rice.edu/~vs3/hjlib/doc/edu/rice/hj/Module1.html)

- static void forallPhased(int s0, int e0, edu.rice.hj.api.HjProcedure<java.lang.Integer> body)
- static <T> void forallPhased(java.lang.Iterable<T> iterable, edu.rice.hj.api.HjProcedure<T> body)
- static void next()

- **NOTE:**
  - All forallPhased API's include an implicit finish at the end (just like a regular forall)
  - Calls to next() are only permitted in forallPhased(), not in forall()

Observation 1: Scope of synchronization for “next” barrier is its closest enclosing forallPhased statement

```
forallPhased (0, m - 1, (i) -> {
 println(“Starting forall iteration ” + i);
 next(); // Acts as barrier for forallPhased-i
 forallPhased (0, n - 1, (j) -> {
   println(“Hello from task (“ + i + “,” + j + “)”);
   next(); // Acts as barrier for forallPhased-j
   println(“Goodbye from task (“ + i + “,” + j + “)”);
 } // forallPhased-j
 next(); // Acts as barrier for forallPhased-i
 println(“Ending forallPhased iteration ” + i);
}); // forallPhased-i
```

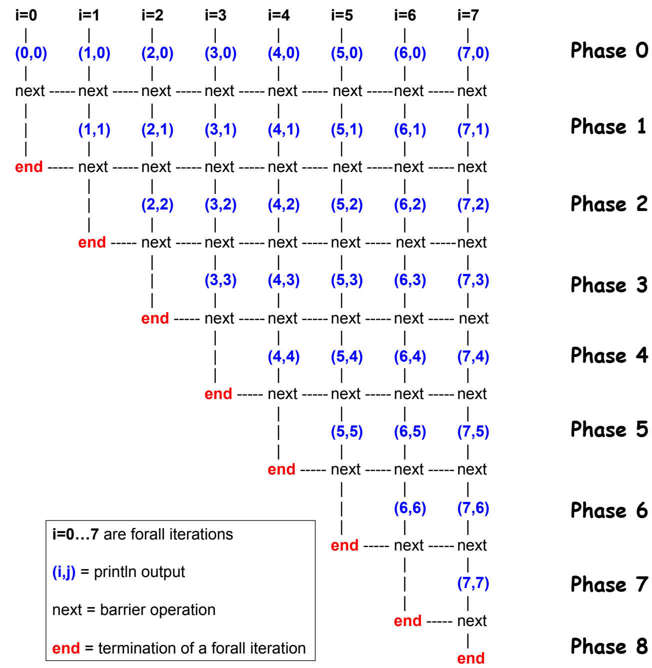

Observation 2: If a forall iteration terminates before “next”, then other iterations do not wait for it

```
1.  forallPhased (0, m - 1, (i) -> {
2.    forseq (0, i, (j) -> {
3.      // forall iteration i is executing phase j
4.      System.out.println("(" + i + "," + j + ")");
5.      next();
6.    });
7.  });
```

- Outer forall-i loop has m iterations, 0…m-1
- Inner sequential j loop has i+1 iterations, 0…i
- Line 4 prints (task,phase) = (i, j) before performing a next operation.
- Iteration i = 0 of the forall-i loop prints (0, 0), performs a next, and then terminates. Iteration i = 1 of the forall-i loop prints (1,0), performs a next, prints (1,1), performs a next, and then terminates. And so on.

Barrier Matching for previous example

- Iteration i=0 of the forallPhased-i loop prints (0, 0) in Phase 0, performs a next, and then ends Phase 1 by terminating.
- Iteration i=1 of the forallPhased-i loop prints (1,0) in Phase 0, performs a next, prints (1,1) in Phase 1, performs a next, and then ends Phase 2 by terminating.
- And so on until iteration i=8 ends an empty Phase 8 by terminating



Observation 3: Different forallPhased iterations may perform "next" at different program points

```
1.  forallPhased (0, m-1, (i) -> {
2.    if (i % 2 == 1) { // i is odd
3.      oddPhase0(i);
4.      next();
5.      oddPhase1(i);
6.    } else { // i is even
7.      evenPhase0(i);
8.      next();
9.      evenPhase1(i);
10.    } // if-else
11. }); // forall
```

Barriers are not statically scoped — matching barriers may come from different program points, and may even be in different methods!

- Barrier operation synchronizes odd-numbered iterations at line 4 with even-numbered iterations in line 8
- One reason why barriers are "less structured" than finish, async, future