
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

```
1. // APPROACH 1  
2. forall (0, m - 1, (i) -> {  
3.     int sq = i*i;  
4.     System.out.println("Hello from task with square = " + sq);  
5. });  
6. forall (0, m - 1, (i) -> {  
7.     System.out.println("Goodbye from task with square = " + sq);  
8. });
```



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

1. // APPROACH 2

2. forallPhased (0, m - 1, (i) -> {

3. int sq = i*i;

4. System.out.println(“Hello from task with square = “ + sq);

5. next(); // Barrier

6. System.out.println(“Goodbye from task with square = “ + sq);

7. });

} Phase 0

} Phase 1

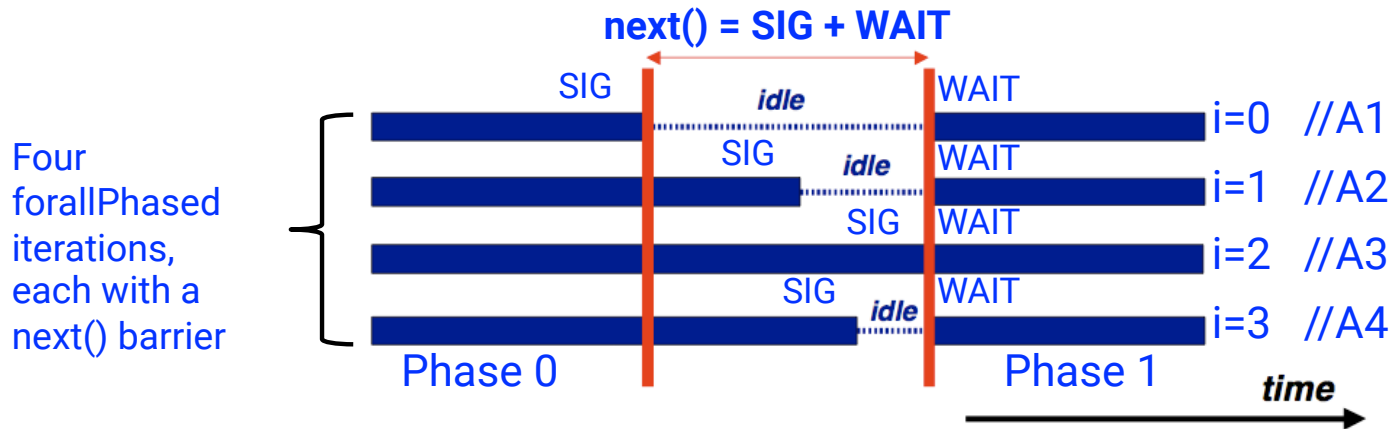
- **next** -> each forallPhased iteration waits at barrier until all iterations arrive (previous phase is completed), after which the next phase can start

– Scope of next is the closest enclosing forallPhased statement

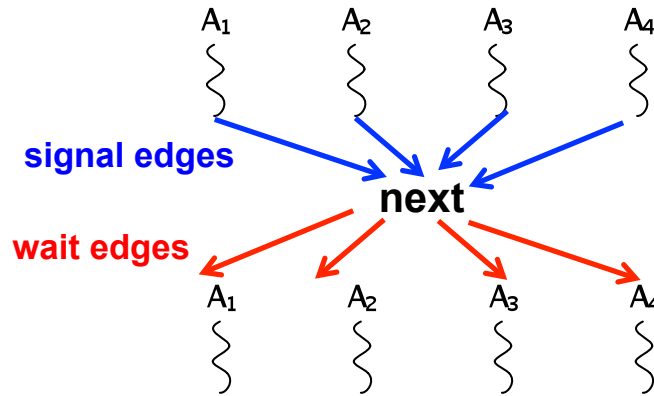
– If a forallPhased iteration terminates before executing “next”, then the other iterations don’t wait for it



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

```
1. forallPhased (0, m - 1, (i) -> {
2.   println("Starting forall iteration " + i);
3.   next(); // Acts as barrier for forallPhased-i
4.   forallPhased (0, n - 1, (j) -> {
5.     println("Hello from task (" + i + "," + j + ")");
6.     next(); // Acts as barrier for forallPhased-j
7.     println("Goodbye from task (" + i + "," + j + ")");
8.   } // forallPhased-j
9.   next(); // Acts as barrier for forallPhased-i
10.  println("Ending forallPhased iteration " + i);
11.}); // forallPhased-i
```



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

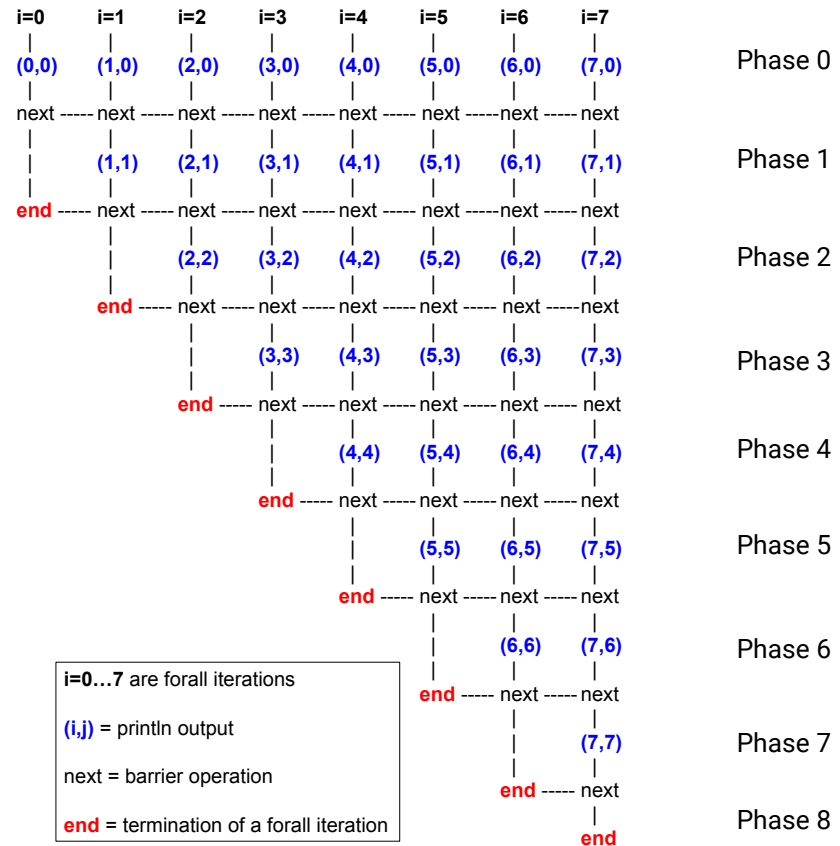
```
1. forallPhased (0, m - 1, (i) -> {
2.   forseq (0, i, (j) -> {
3.     // forall iteration i is executing phase j
4.     System.out.println("(" + i + "," + j + ")");
5.     next();
6.   }); //forseq-j
7. }); //forall-i
```

- 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



Announcements & Reminders

- HW2 is available and due by 11:59pm on Wednesday
- Quiz for Unit 2 (topics 2.1 - 2.6) is available on Canvas, and due by 11:59pm on Friday
- See course web site for all work assignments and due dates
- Use Piazza (public or private posts, as appropriate) for all communications re. COMP 322
- See [Office Hours](#) link on course web site for latest office hours schedule.

