COMP 322: Fundamentals of Parallel Programming

Lecture 13: Iterative Averaging Revisited, Single-Program Multiple-Data (SPMD) pattern

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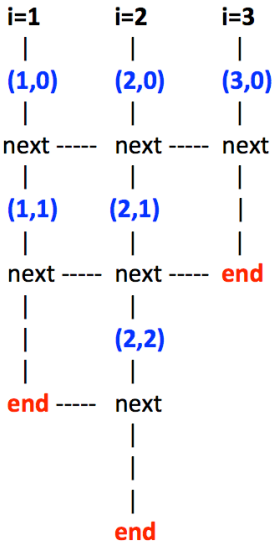
Worksheet #12: Forall Loops and Barriers

Draw a "barrier matching" figure similar to lecture 12 slide 13 for the code fragment below.

```
1. String[] a = { "ab", "cde", "f" };
2. . . . int m = a.length; . . .
3. forallPhased (0, m-1, (i) -> {
4.   for (int j = 0; j < a[i].length(); j++) {
5.     // forall iteration i is executing phase j
6.     System.out.println("(" + i + "," + j + ")");
7.     next();
8.   }
9. });
```

Solution



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] = (myVal[i-1]+myVal[i+1])/2, for all i in 1..n

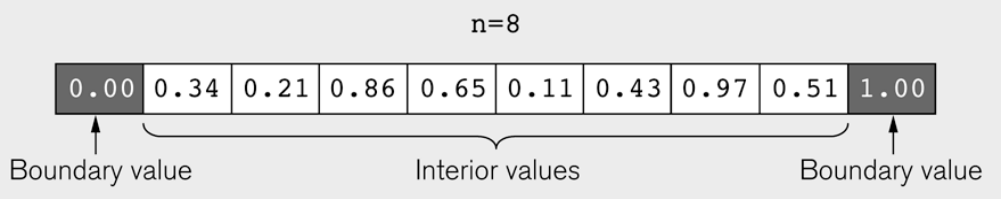


Illustration of an intermediate step for n = 8 (source: Figure 6.19 in Lin-Snyder book)

Iterative Averaging is similar to a Finite Difference solution to the One-Dimensional Heat Equation

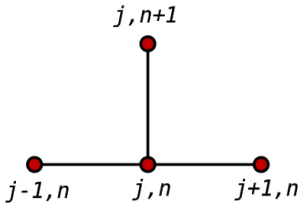
- Using a forward difference at time and a second-order central difference for the space derivative at position (FTCS) we get the recurrence equation:

$$\frac{u_j^{n+1} - u_j^n}{k} = \frac{u_{j+1}^n - 2u_j^n + u_{j-1}^n}{h^2}.$$

- This is an explicit method for solving the one-dimensional heat equation.
- We can obtain from the other values this way:

$$u_j^{n+1} = (1-2r)u_j^n + ru_{j-1}^n + ru_{j+1}^n$$

- where $r = k/h^2$



- So, with this recurrence relation, and knowing the values at time n, one can obtain the corresponding values at time n+1.
- Source: http://en.wikipedia.org/wiki/Finite_difference_method

HJ code for One-Dimensional Iterative Averaging using nested `forseq-forall` structure (Lecture 11)

```
1.  double[] myVal=new double[n+2]; myVal[n+1] = 1;
2.  double[] myNew=new double[n+2]; myNew[n+1] = myVal[n+1];
3.  forseq(0, m-1, (iter) -> {
4.    // Compute MyNew as function of input array MyVal
5.    forall(1, n, (j) -> { // Create n tasks
6.       myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
7.    }); // forall
8.    // Swap myVal & myNew;
9.     temp=myVal; myVal=myNew; myNew=temp;
10.    // myNew becomes input array for next iteration
11. }); // for
```


General Approach for Iteration Grouping (Loop Chunking)

Parallel fork-join solution with grouped forall:

```
for (iter : [0:iterations-1]) {
  forall (g : [0:ng-1])
    for(j : myGroup(g,[1:n],ng)
      myNew[j] = (myVal[j-1] + myVal[j+1])/2;
  Swap myNew and myVal
}
```


Example: HJ code for One-Dimensional Iterative Averaging with forseq-forall structure w/ chunking (Lecture 11)

```
1.  double[] myVal=new double[n+2]; myVal[n+1] = 1;
2.  double[] myNew=new double[n+2]; myNew[n+1] = myVal[n+1];
3.  int nc = numWorkerThreads();
4.   forseq(0, m-1, (iter) -> {
5.     // Compute MyNew as function of input array MyVal
6.     forallChunked(1, n, n/nc, (j) -> { // Create nc tasks
7.         myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
8.     }); // forallChunked
9.     temp=myVal; myVal=myNew; myNew=temp;// Swap myVal & myNew;
10.    // myNew becomes input array for next iteration
11.  }); // for
```


Converting forseq-forall version (Slide 5) into a forall-forseq version with barriers

```
1.  double[] gVal=new double[n+2]; gVal[n+1] = 1;
2.  double[] gNew=new double[n+2];
3.  forallPhased(1, n, (j) -> { // Create n tasks
4.    // Initialize myVal and myNew as local pointers
5.    double[] myVal = gVal; double[] myNew = gNew;
6.    forseq(0, m-1, (iter) -> {
7.      // Compute MyNew as function of input array MyVal
8.      myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
9.      next(); // Barrier before executing next iteration of iter loop
10.     // Swap local pointers, myVal and myNew
11.     double[] temp=myVal; myVal=myNew; myNew=temp;
12.     // myNew becomes input array for next iteration
13.   }); // forseq
14. }); // forall
```


General Approach for Iteration Grouping with Barriers

Barrier-based solution:

```
// Note that iter-loop is inserted between forall-g and for-j loops
forall (g : [0:ng-1])
  for (iter : [0:iterations-1]) {
    for(j : myGroup(g,[1:n],ng)
      myNew[j] = (myVal[j-1] + myVal[j+1])/2;
    next; // Barrier
    Swap myNew and myVal
  } // for iter
```

Also referred to as a "single program multiple data" (SPMD) pattern

Converting forall-forseq-next version (Slide 8) into a forall-forseq-forseq-next version with grouping

```
1.  double[] gVal=new double[n+2]; gVal[n+1] = 1;
2.  double[] gNew=new double[n+2];
3.  HjRegion1D iterSpace = newRectangularRegion1D(1,n);
4.  int nc = numWorkerThreads();
5.  forallPhased(0, nc-1, (jj) -> { // Create nc tasks
6.    // Initialize myVal and myNew as local pointers
7.    double[] myVal = gVal; double[] myNew = gNew;
8.    forseq(0, m-1, (iter) -> {
9.      forseq(myGroup(jj,iterSpace,nc), (j) -> {
10.       // Compute MyNew as function of input array MyVal
11.       myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
12.     }); // forseq
13.     next(); // Barrier before executing next iteration of iter loop
14.     // Swap local pointers, myVal and myNew
15.     double[] temp=myVal; myVal=myNew; myNew=temp;
16.     // myNew becomes input array for next iter
17.   }); // forseq
18. }); // forall
```


Single Program Multiple Data (SPMD) Parallel Programming Model

Basic idea

- **Run the same code (program) on P workers**
- **Use the "rank" --- an ID ranging from 0 to (P-1) --- to determine what data is processed by which worker**
  - **—Hence, "single-program" and "multiple-data"**
  - **—Rank is equivalent to index in a top-level "forall (point[i] : [0:P-1])" loop**
- **Lower-level programming model than dynamic async/finish parallelism**
  - **—Programmer's code is essentially at the worker level (each forall iteration is like a worker), and work distribution is managed by programmer by using barriers and other synchronization constructs**
  - **—Harder to program but can be more efficient for restricted classes of applications (e.g. for OneDimAveraging, but not for NQueens)**
- **Convenient for hardware platforms that are not amenable to efficient dynamic task parallelism**
  - **—General-Purpose Graphics Processing Unit (GPGPU) accelerators**
  - **—Distributed-memory parallel machines**

HJ code for One-Dimensional Iterative Averaging with grouped forall-forseq structure and barriers (Slide 10)

```
1.  double[] gVal=new double[n+2]; gVal[n+1] = 1;
2.  double[] gNew=new double[n+2];
3.  HjRegion1D iterSpace = newRectangularRegion1D(1,m);
4.  int nc = numWorkerThreads();
5.  forallPhased(1, nc, (jj) -> { // Create nc tasks
6.    // Initialize myVal and myNew as local pointers
7.    double[] myVal = gVal; double[] myNew = gNew;
8.    forseq(0, m-1, (iter) -> {
9.      forseq(myGroup(jj,iterSpace,nc), (j) -> {
10.       // Compute MyNew as function of input array MyVal
11.       myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
12.     }); // forseq
13.     next(); // Barrier before executing next iteration of iter loop
14.     // Swap local pointers, myVal and myNew
15.     double[] temp=myVal; myVal=myNew; myNew=temp;
16.     // myNew becomes input array for next iter
17.   }); // forseq
18. }); // forall
```


Instead of async-finish, this SPMD version creates one task per worker, uses myGroup() to distribute work, and use barriers to synchronize workers.

Worksheet #13: Iterative Averaging Revisited

Name: _____ Net ID: _____

Answer the questions in the table below for the versions of the Iterative Averaging code shown in slides 5, 7, 8, 10. Write in your answers as functions of m, n, and nc.

	Slide 5	Slide 7	Slide 8	Slide 10
How many tasks are created (excluding the main program task)?				
How many barrier operations (calls to next per task) are performed?				

BACKUP SLIDES START HERE

Announcements

- Reminder: Homework 2 is due by 12 noon on Friday, February 12, 2016
- Worksheets can be submitted at the start of the next lecture, if needed
- My office hours today will be during 2pm - 3pm in Duncan Hall room 3092
  - —Or meet me here after class