COMP 322: Fundamentals of Parallel Programming

Lecture 12: Iterative Averaging Revisited, Single-Program Multiple-Data (SPMD) pattern

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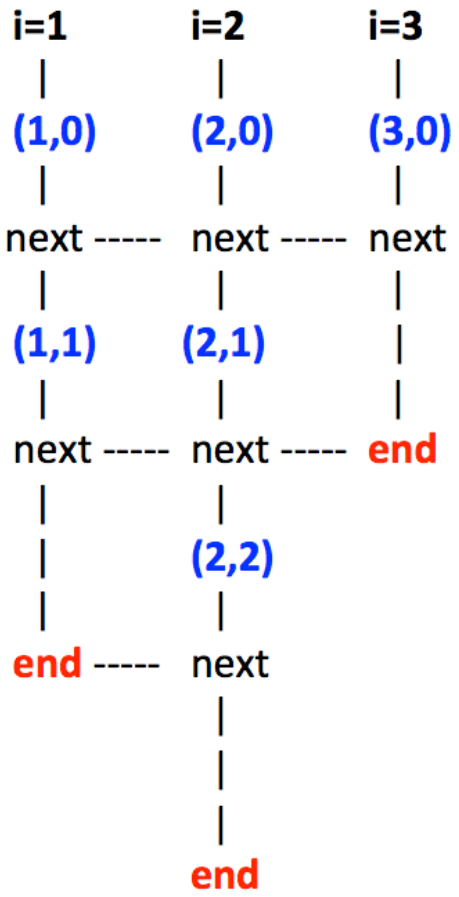
https://wiki.rice.edu/confluence/display/PARPROG/COMP322

Worksheet #11: Forall Loops and Barriers

Draw a "barrier matching" figure similar to 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

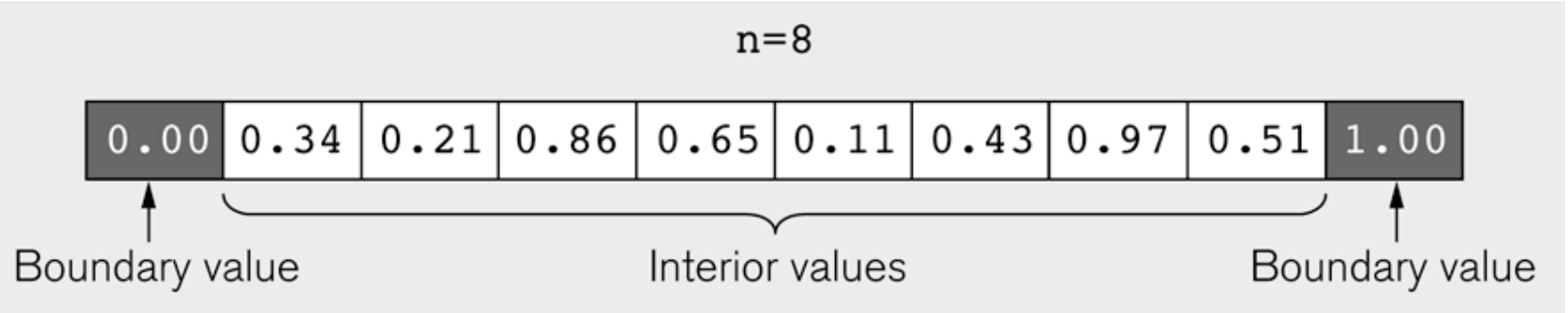


Illustration of an intermediate step for n = 8 (source: Figure 6.19 in Lin-Snyder book)

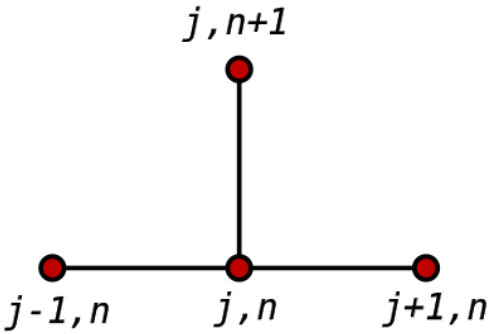
Iterative Averaging is similar to a Finite Difference solution to the One-Dimensional Heat Equation

- 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

Orignal HJ code for One-Dimensional Iterative Averaging with forseq-forall structure

```
1.  double[] myVal=new double[n+2]; myVal[n+1] = 1;
2.  double[] myNew=new double[n+2];
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.    temp=myVal; myVal=myNew; myNew=temp;// Swap myVal &
    myNew;
9.    // myNew becomes input array for next iteration
10. }); // 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
}
```


HJ code for One-Dimensional Iterative Averaging with forseq-forallChunked structure

```
1.  double[] myVal=new double[n+2]; myVal[n+1] = 1;
2.  double[] myNew=new double[n+2];
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
```


HJ code for One-Dimensional Iterative Averaging with forall-forseq structure and 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

HJ code for One-Dimensional Iterative Averaging with grouped forall-forseq structure and barriers

```
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
```


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

```
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.

Announcements

- Reminder: Homework 2 is due by 5pm on Wednesday, February 11, 2015
- Worksheets can be submitted at the start of the next lecture, if needed
- Lecture handouts for Topic 3 should be coming soon!
- My office hours today will be during 3pm - 3:30pm in Duncan Hall room 3131

  —Or meet me here after class