COMP 322: Fundamentals of Parallel Programming

Lecture 6: Finish Accumulators

Mack Joyner
mjoyner@rice.edu

http://comp322.rice.edu

Recursive Array Sum using Future Tasks (Two futures per method call)

Parallel divide-and-conquer pattern:

```
1.  int sum = computeSum(X, 0, X.length-1); // main
2.  static int computeSum(int[] X, int lo, int hi) {
3.    if ( lo > hi ) return 0;
4.    else if ( lo == hi ) return X[lo];
5.    else {
6.      int mid = (lo+hi)/2;
7.      future<int> sum1 = future {
8.                           computeSum(X, lo, mid); };
9.      future<int> sum2 = future {
10.                          computeSum(X, mid+1, hi); };
11.     // Parent now waits for the container values
12.     return sum1.get() + sum2.get();
13.   }
14. } // computeSum
```

Recursive Array Sum using Future Tasks (Two futures per method call)

Parallel divide-and-conquer pattern:

```
1.  int sum = computeSum(X, 0, X.length-1); // main
2.  static int computeSum(int[] X, int lo, int hi) {
3.    if ( lo > hi ) return 0;
4.    else if ( lo == hi ) return X[lo];
5.    else {
6.      int mid = (lo+hi)/2;
7.      future<int> sum1 = future {
8.                           computeSum(X, lo, mid); };
9.      future<int> sum2 = future {
10.                          computeSum(X, mid+1, hi); };
11.     a() // work is N
12.     // Parent now waits for the container values
13.     return sum1.get() + sum2.get();
14.   }
15. } // computeSum
```

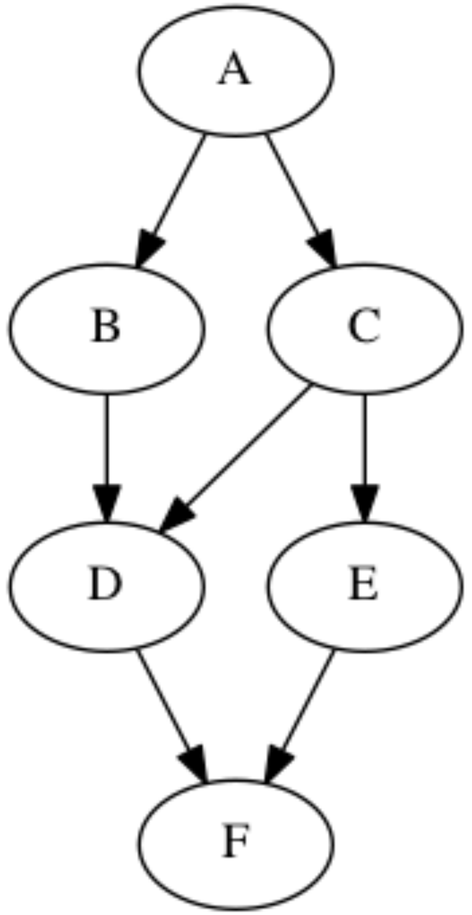
Worksheet #5: Computation Graphs for Async-Finish and Future Constructs

1) Can you write pseudocode with async-finish constructs that generates a Computation Graph with the same ordering constraints as the graph on the right? If so, provide a sketch of the program.

No. Finish cannot be used to ensure that D only waits for B and C, while E waits only for C.

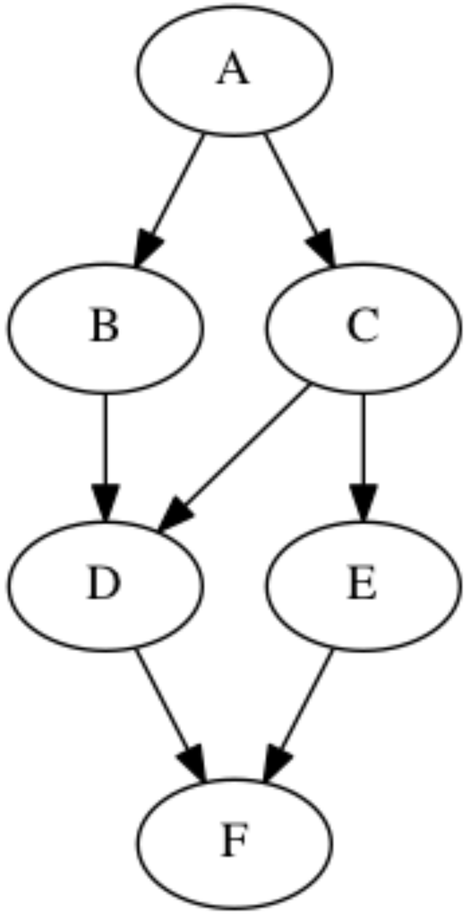
2) Can you write pseudocode with future async-get constructs that generates a Computation Graph with the same ordering constraints as the graph on the right? If so, provide a sketch of the program.

Yes, see program sketch with dummy return values.



Worksheet #5 solution (contd)

```
1.  HjFuture<String> A = future(() -> {
2.      return "A"; });
3.  HjFuture<String> B = future(() -> {
4.      A.get(); return "B"; });
5.  HjFuture<String> C = future(() -> {
6.      A.get(); return "C"; });
7.  HjFuture<String> D = future(() -> {
8.      // Order of B.get() & C.get() doesn't matter
9.      B.get(); C.get(); return "D"; });
10. HjFuture<String> E = future(() -> {
11.     C.get(); return "E"; });
12. HjFuture<String> F = future(() -> {
13.     D.get(); E.get(); return "F"; });
14. F.get();
```



Comparing Async-Finish with Future-Get

- Similarities:
  - Finish and Get can be used to synchronize and avoid data races
  - Finish waits for both async and future tasks
- Differences:
  - Futures have return values
  - Future gets can model a larger set of computation graphs than async-finish
  - Finish can wait for an unbounded set of tasks (determined at runtime)

Extending Finish Construct with "Finish Accumulators" (Pseudocode)

- Creation

```
accumulator ac = newFinishAccumulator(operator, type);
```

- *Operator must be associative and commutative (creating task "owns" accumulator)*
- Registration

```
finish (ac1, ac2, ...) { ... }
```

- *Accumulators ac1, ac2, ... are registered with the finish scope*
- Accumulation

```
ac.put(data);
```

- *Can be performed in parallel by any statement in finish scope that registers ac. Note that a put contributes to the accumulator, but does not overwrite it.*
- Retrieval

```
ac.get();
```

- *Returns initial value if called before end-finish, or final value after end-finish*
- `get()` *is nonblocking because no synchronization is needed (finish provides the necessary synchronization)*

Example: count occurrences of pattern in text (sequential version)

```
1. // Count all occurrences
2. int count = 0;
3. {
4.  for (int ii = 0; ii <= N - M; ii++) {
5.    int i = ii;
6.    // search for match at position i
7.    for (j = 0; j < M; j++)
8.      if (text[i+j] != pattern[j]) break;
9.    if (j == M) count++; // Increment count
10.  } // for-ii
11.  }
12. }
13. print count; // Output
```


Example: count occurrences of pattern in text (parallel version using finish accumulator)

```
1. // Count all occurrences
2. a = new Accumulator(SUM, int)
3. finish(a) {
4.  for (int ii = 0; ii <= N - M; ii++) {
5.   int i = ii;
6.   async { // search for match at position i
7.    for (j = 0; j < M; j++)
8.      if (text[i+j] != pattern[j]) break;
9.    if (j == M) a.put(1); // Increment count
10.  } // async
11.  }
12.} // finish
13.print a.get(); // Output
```


Error Conditions with Finish Accumulators

1. Non-owner task cannot access accumulator outside registered finish

```
// T1 allocates accumulator a
accumulator a = newFinishAccumulator(…);
a.put(1); // T1 can access a
async { // T2 cannot access a
  a.put(1); Number v1 = a.get( );
}
```

2. Non-owner task cannot register accumulator with a finish

```
// T1 allocates accumulator a
accumulator a = newFinishAccumulator(...);
async {
  // T2 cannot register a with finish
  finish (a) { async a.put(1);  }
}
```

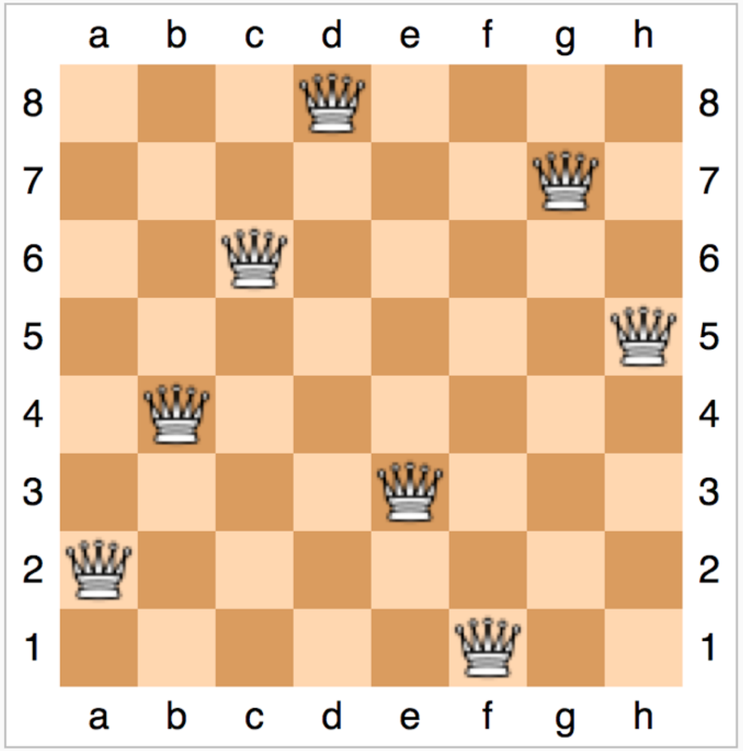

The N-Queens Problem

How can we place n queens on an n×n chessboard so that no two queens can capture each other?

A queen can move any number of squares horizontally, vertically, and diagonally.

Here, the possible target squares of the queen Q are marked with an x.

x			x			x	
	x		x		x		
		x	x	x			
x	x	x	Q	x	x	x	x
		x	x	x			
	x		x		x		
x			x			x	
			x				x



One solution to the eight queens puzzle

Backtracking Solution

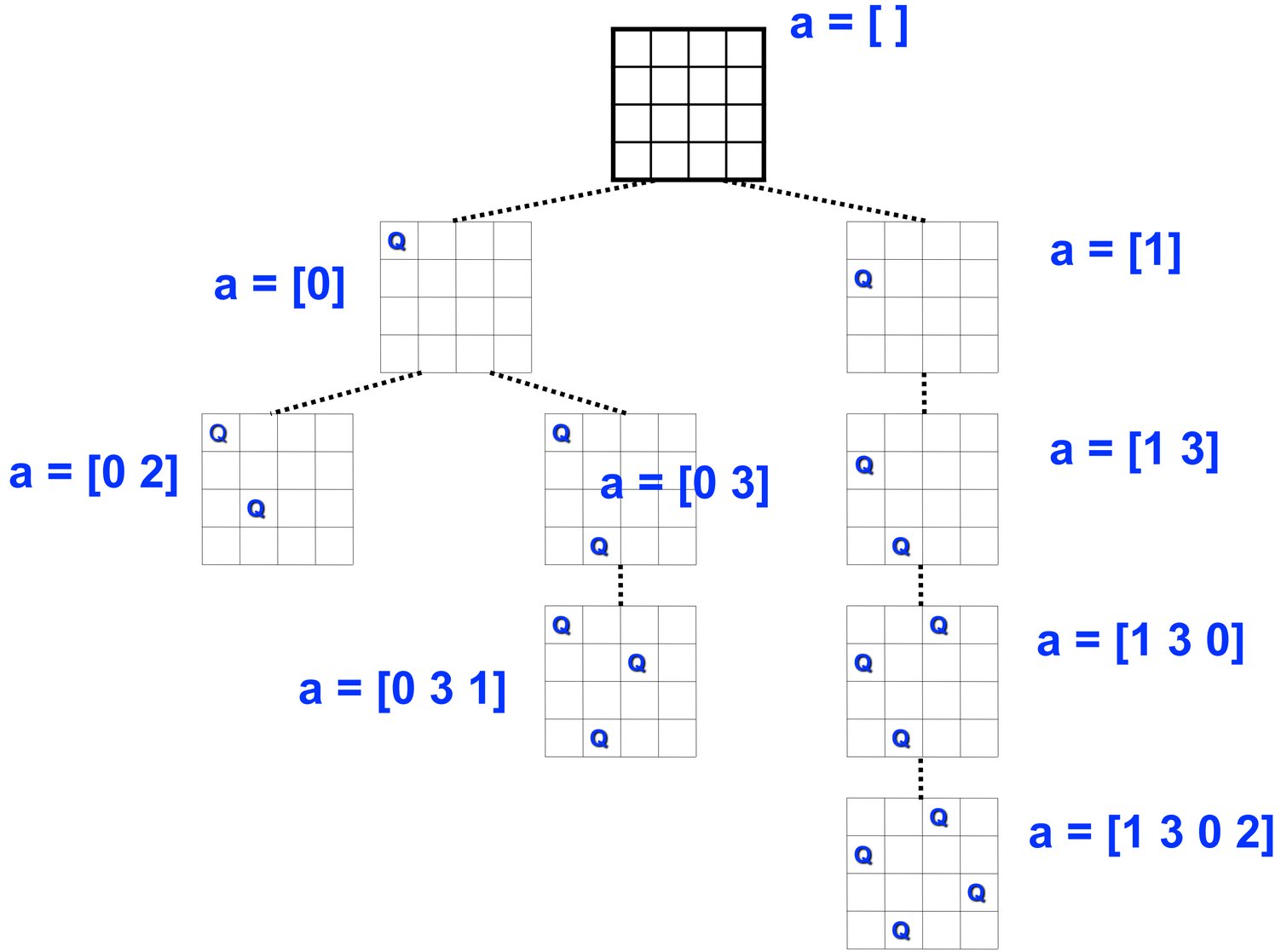
empty board

place 1st queen

place 2nd queen

place 3rd queen

place 4th queen



Sequential solution for NQueens (counting all solutions)

```
1.  count = 0;
2.  size = 8; nqueens_kernel_seq(new int[0], 0);
3.  System.out.println("No. of solutions = " + count);
4.  . . .
5.  void nqueens_kernel_seq(int [] a, int depth) {
6.    if (size == depth) count++;
7.    else
8.      /* try each possible position for queen at depth */
9.      for (int i =  0; i < size; i++) {
10.       /* allocate a temporary array and copy array a into it */
11.       int [] b = new int [depth+1];
12.       System.arraycopy(a, 0, b, 0, depth);
13.       b[depth] = i; // Try to place queen in row i of column depth
14.       if (ok(depth,b)) // check if placement is okay
15.          nqueens_kernel_seq(b, depth+1);
16.     } // for
17. } // nqueens_kernel_seq()
```


How to extend sequential solution to obtain a parallel solution?

```
1.  count = 0;
2.  size = 8; finish nqueens_kernel_par(new int[0], 0);
3.  System.out.println("No. of solutions = " + count);
4.  . . .
5.  void nqueens_kernel_par(int [] a, int depth) {
6.    if (size == depth) count++;
7.    else
8.      /* try each possible position for queen at depth */
9.      for (int i =  0; i < size; i++) async {
10.       /* allocate a temporary array and copy array a into it */
11.       int [] b = new int [depth+1];
12.       System.arraycopy(a, 0, b, 0, depth);
13.       b[depth] = i; // Try to place queen in row i of column depth
14.       if (ok(depth,b)) // check if placement is okay
15.          nqueens_kernel_par(b, depth+1);
16.     } // for
17. } // nqueens_kernel_par()
```


How to extend sequential solution to obtain a parallel solution?

```
1.  count = 0;
2.  size = 8; finish nqueens_kernel_par(new int[0], 0);
3.  System.out.println("No. of solutions = " + count);
4.  . . .
5.  void nqueens_kernel_par(int [] a, int depth) {
6.    if (size == depth) count++;
7.    else
8.      /* try each possible position for queen at depth */
9.      for (int i =  0; i < size; i++) async {
10.       /* allocate a temporary array and copy array a into it */
11.       int [] b = new int [depth+1];
12.       System.arraycopy(a, 0, b, 0, depth);
13.       b[depth] = i; // Try to place queen in row i of column depth
14.       if (ok(depth,b)) // check if placement is okay
15.          nqueens_kernel_par(b, depth+1);
16.     } // for
17. } // nqueens_kernel_par()
```

DATA RACE!

How to extend sequential solution to obtain a parallel solution?

```
1.  FinishAccumulator ac = newFinishAccumulator(Operator.SUM, int.class);
2.  size = 8; finish(ac) nqueens_kernel_par(new int[0], 0);
3.  System.out.println("No. of solutions = " + ac.get().intValue());
4.  . . .
5.  void nqueens_kernel_par(int [] a, int depth) {
6.    if (size == depth) ac.put(1);
7.    else
8.      /* try each possible position for queen at depth */
9.      for (int i =  0; i < size; i++) async {
10.       /* allocate a temporary array and copy array a into it */
11.       int [] b = new int [depth+1];
12.       System.arraycopy(a, 0, b, 0, depth);
13.       b[depth] = i; // Try to place queen in row i of column depth
14.       if (ok(depth,b)) // check if placement is okay
15.          nqueens_kernel_par(b, depth+1);
16.     } // for-async
17. } // nqueens_kernel_par()
```


Efficient Parallelism

```
1.  FinishAccumulator ac = newFinishAccumulator(Operator.SUM, int.class);
2.  size = 8; finish(ac) nqueens_kernel_par(new int[0], 0);
3.  System.out.println("No. of solutions = " + ac.get().intValue());
4.  . . .
5.  void nqueens_kernel_par(int [] a, int depth) {
6.    if (size == depth) ac.put(1);
7.    else
8.      /* try each possible position for queen at depth */
9.      for (int i =  0; i < size; i++) async {
10.       /* allocate a temporary array and copy array a into it */
11.       int [] b = new int [depth+1];
12.       System.arraycopy(a, 0, b, 0, depth);
13.       b[depth] = i; // Try to place queen in row i of column depth
14.       if (ok(depth,b)) // check if placement is okay
15.          nqueens_kernel_par(b, depth+1);
16.     } // for-async
17. } // nqueens_kernel_par()
```

When depth is close to size, the async tasks get too small

Efficient Parallelism

```
1.  FinishAccumulator ac = newFinishAccumulator(Operator.SUM, int.class);
2.  size = 8; finish(ac) nqueens_kernel(new int[0], 0);
3.  System.out.println("No. of solutions = " + ac.get().intValue());
4.  . . .
5.  void nqueens_kernel(int [] a, int depth) {
6.    if (depth > size - threshold) {
7.       nqueens_kernel_seq(a, depth)
8.    } else {
9.       nqueens_kernel_par(a, depth)
10.   }
11. } // nqueens_kernel()
```