COMP 322: Fundamentals of Parallel Programming

Lecture 14: Finish Accumulators

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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)

Two-way Parallel Array Sum using async & finish constructs

Algorithm 2: Two-way Parallel ArraySum

Input: Array of numbers, X.
Output: sum = sum of elements in array X.

```
// Start of Task T1 (main program)
```
$sum1 \leftarrow 0$; $sum2 \leftarrow 0$;
```
// Compute sum1 (lower half) and sum2 (upper half) in parallel.
```
finish{
  async{
    `// Task T2`
    for $i \leftarrow 0$ **to** $X.length/2 - 1$ **do**
      $sum1 \leftarrow sum1 + X[i]$;
  };
  async{
    `// Task T3`
    for $i \leftarrow X.length/2$ **to** $X.length - 1$ **do**
      $sum2 \leftarrow sum2 + X[i]$;
  };
};
```
// Task T1 waits for Tasks T2 and T3 to complete
// Continuation of Task T1
```
$sum \leftarrow sum1 + sum2$;
return sum;

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);  }
```

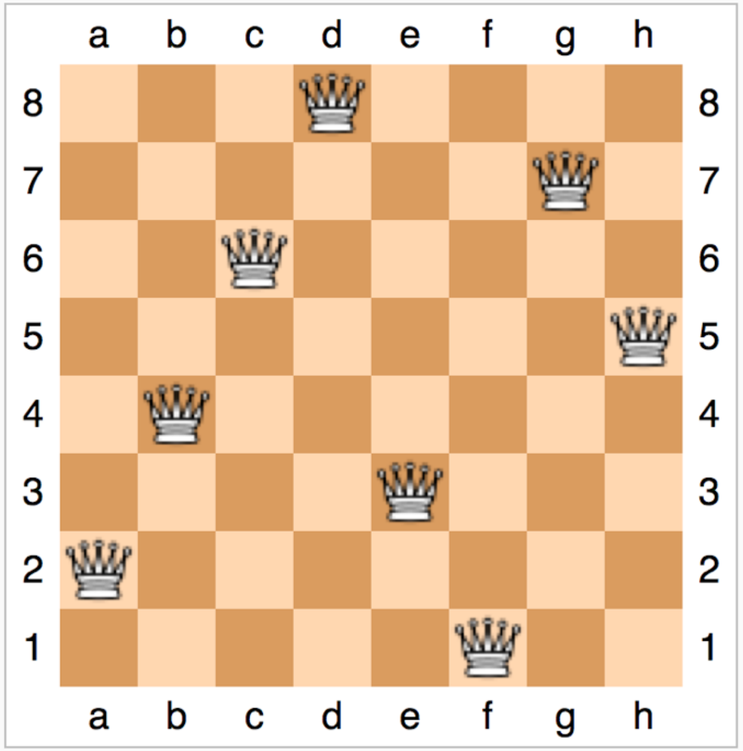

The N-Queens Problem

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

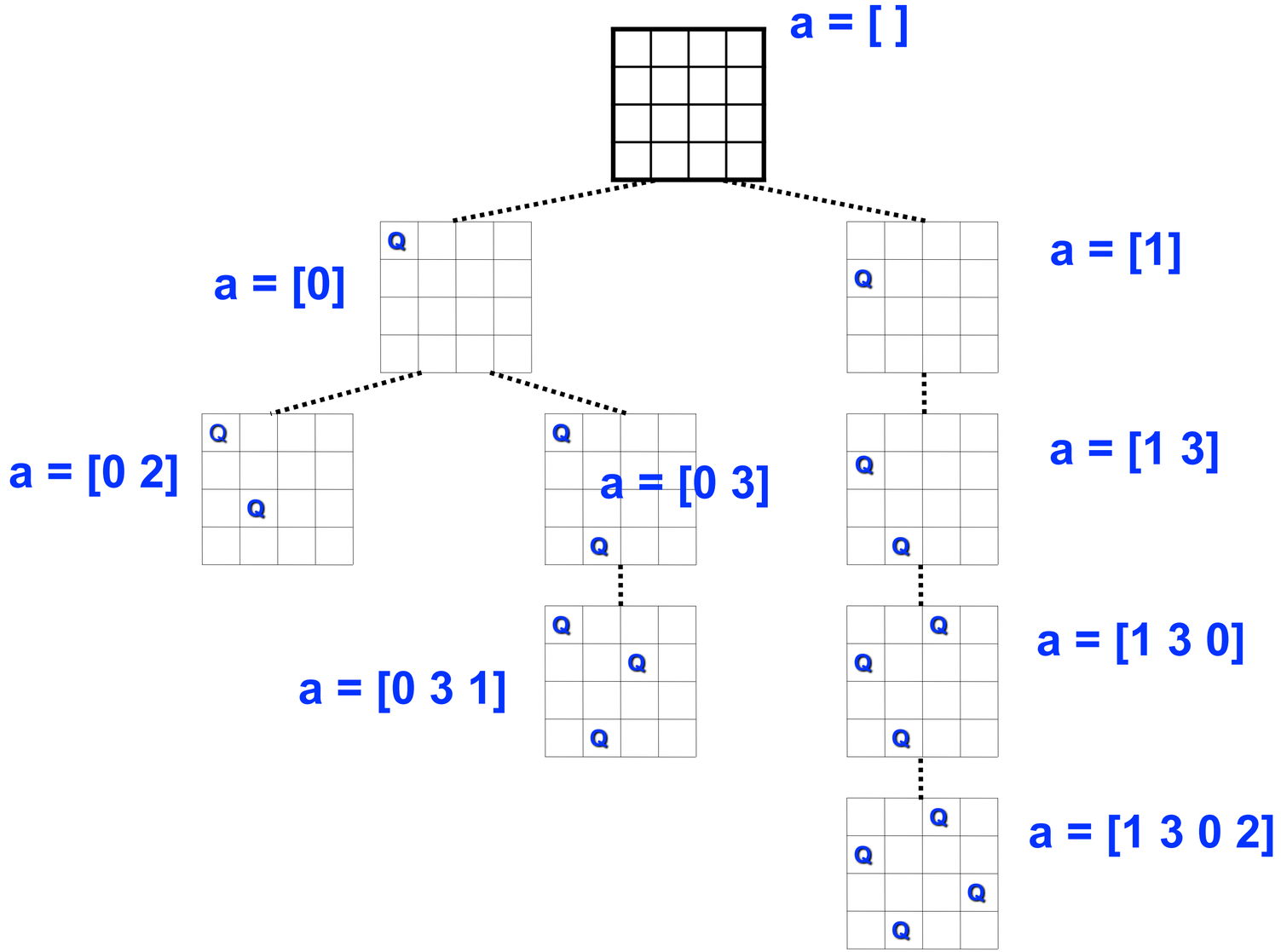
empty board

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()
```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1.  count = 0;
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8.      /* try each possible position for queen at depth */
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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()
```


Announcements & Reminders

- Quiz #3 is due Tuesday, Feb. 15th at 11:59pm
- Midterm exam is Thursday, Feb. 24th from 7pm - 10pm (Canvas)