

COMP 322: Fundamentals of Parallel Programming

Lecture 13: 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); }
}
```

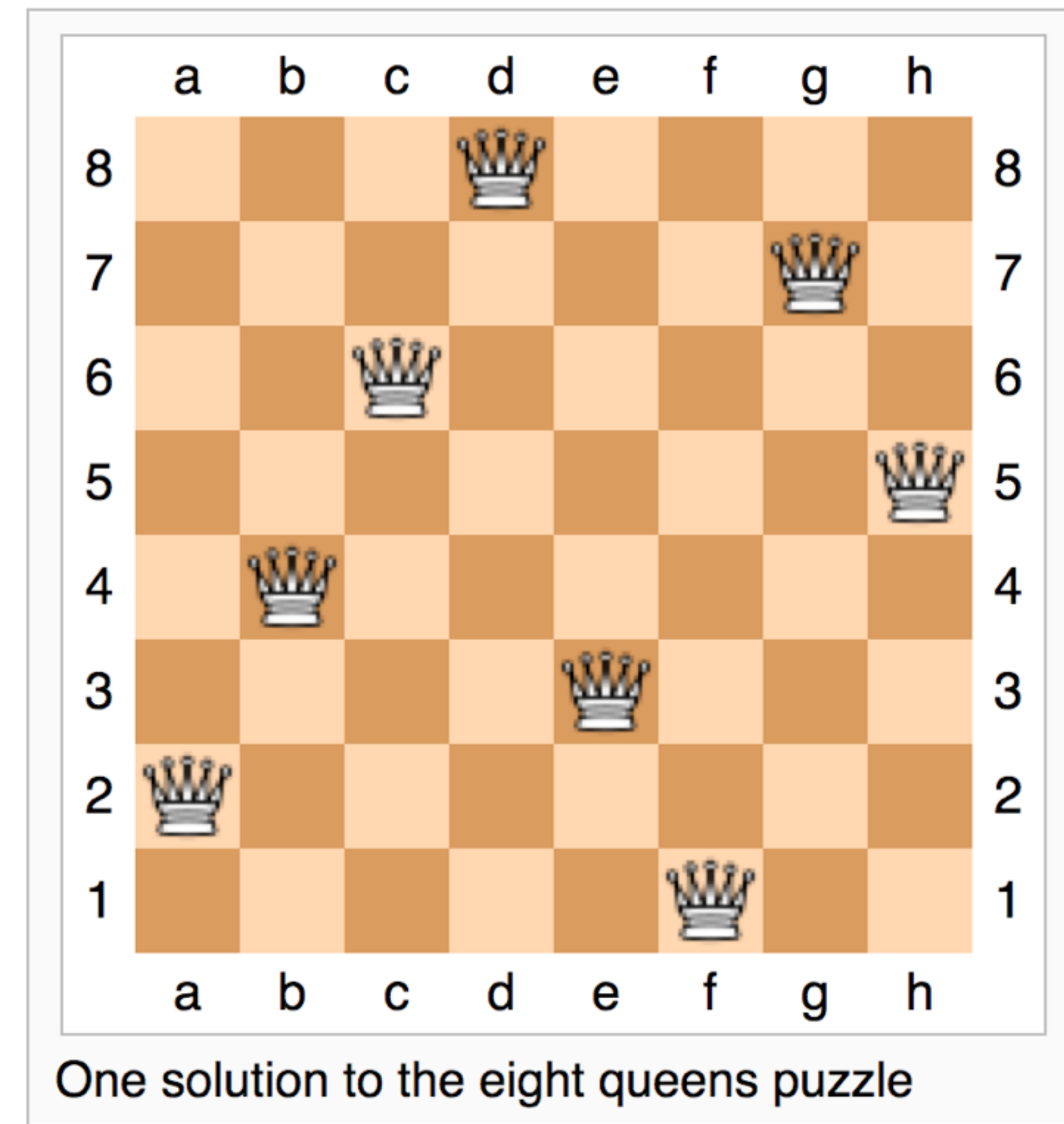
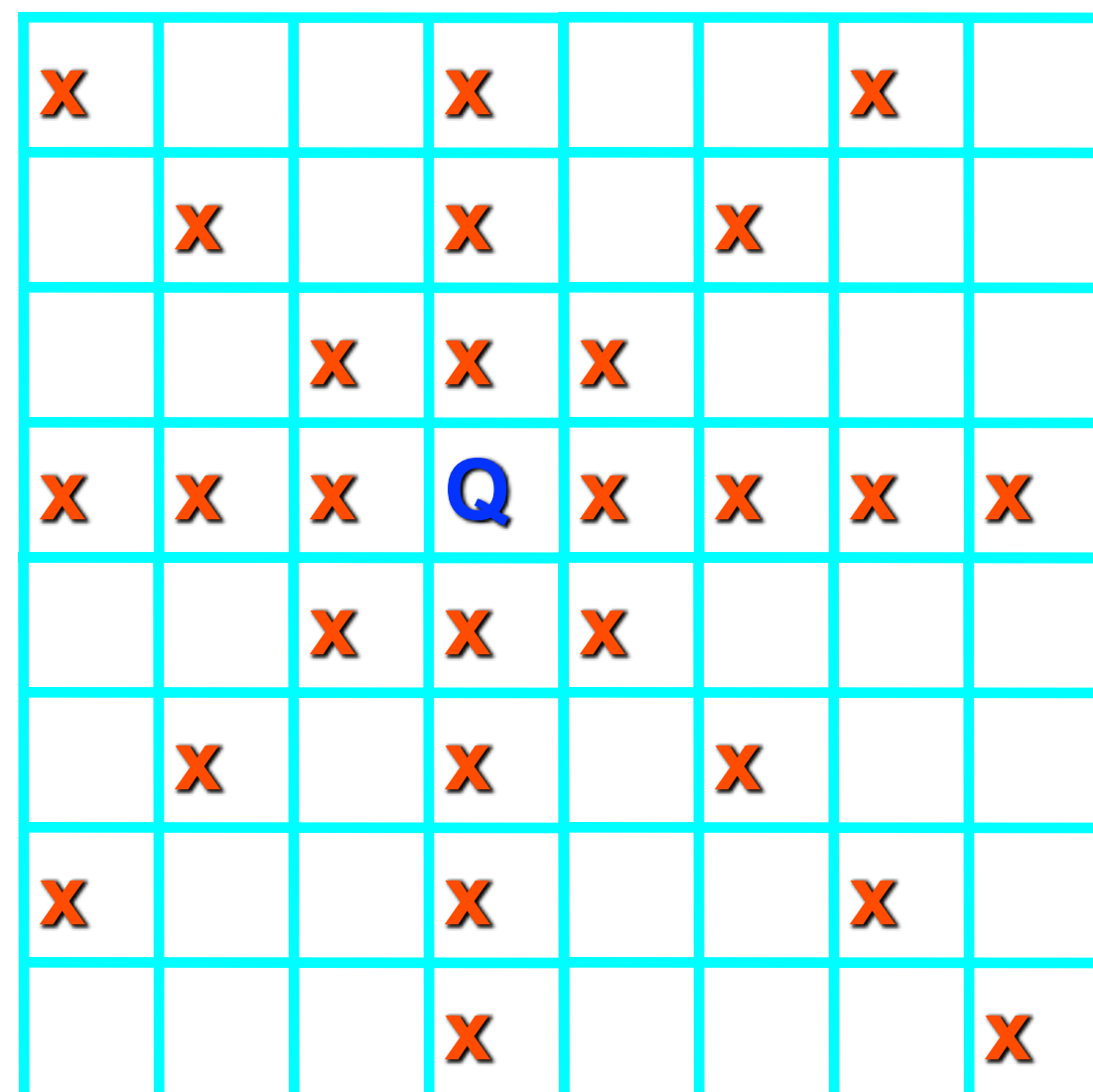


The N-Queens Problem

How can we place n queens on an $n \times n$ 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 .



Backtracking Solution

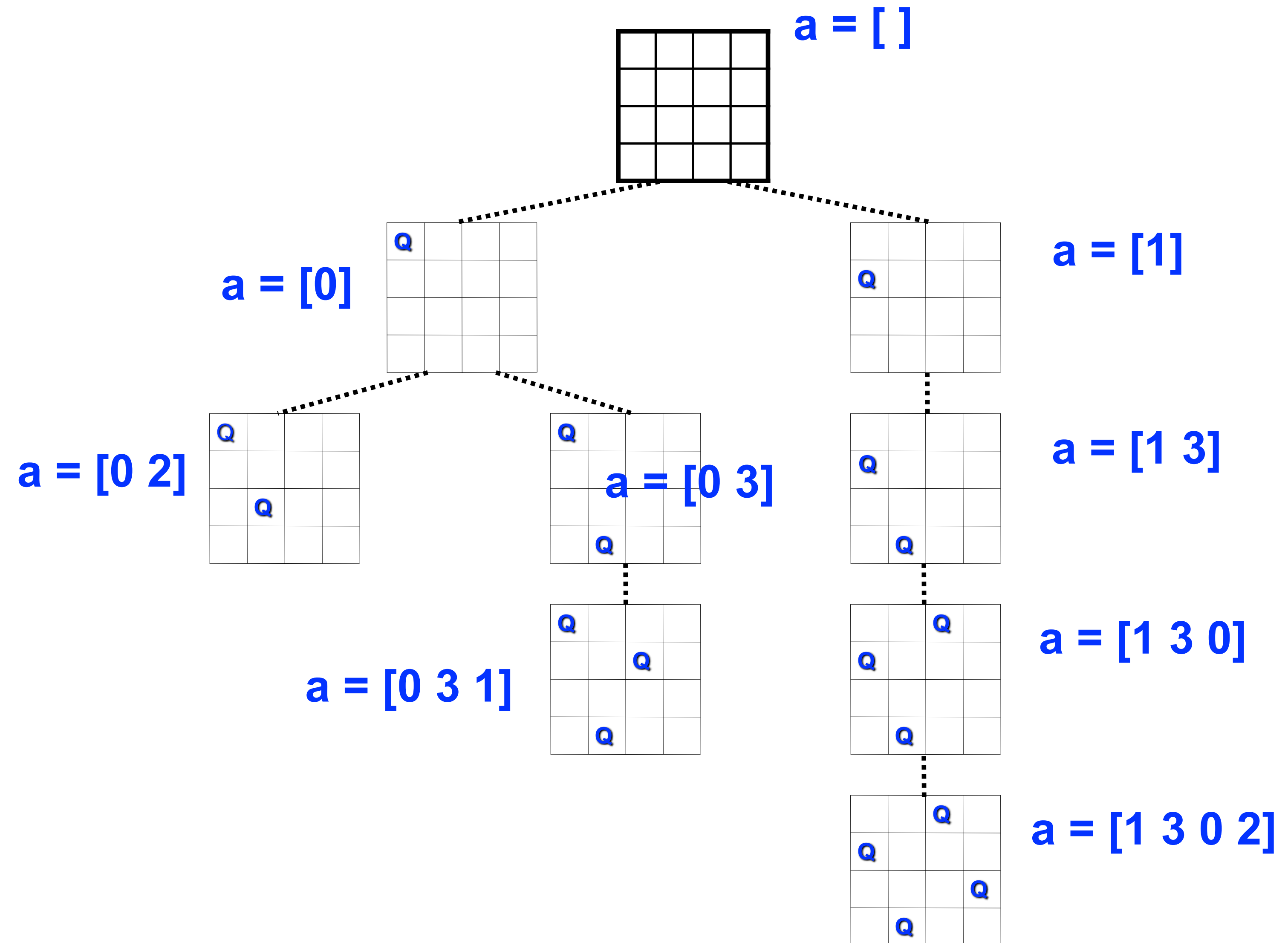
empty board

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++;
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8.     /* try each possible position for queen at depth */
9.     for (int i = 0; i < size; i++) async {
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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()
```



Announcements & Reminders

- Homework #2 is due Wednesday, Feb. 15th at 11:59pm
- Quiz #3 is due Monday, Feb. 20th at 11:59pm
- Midterm exam is Thursday, Feb. 23rd from 7pm - 10pm (Canvas)

