CS2030 Lecture 11

Fork/Join Framework

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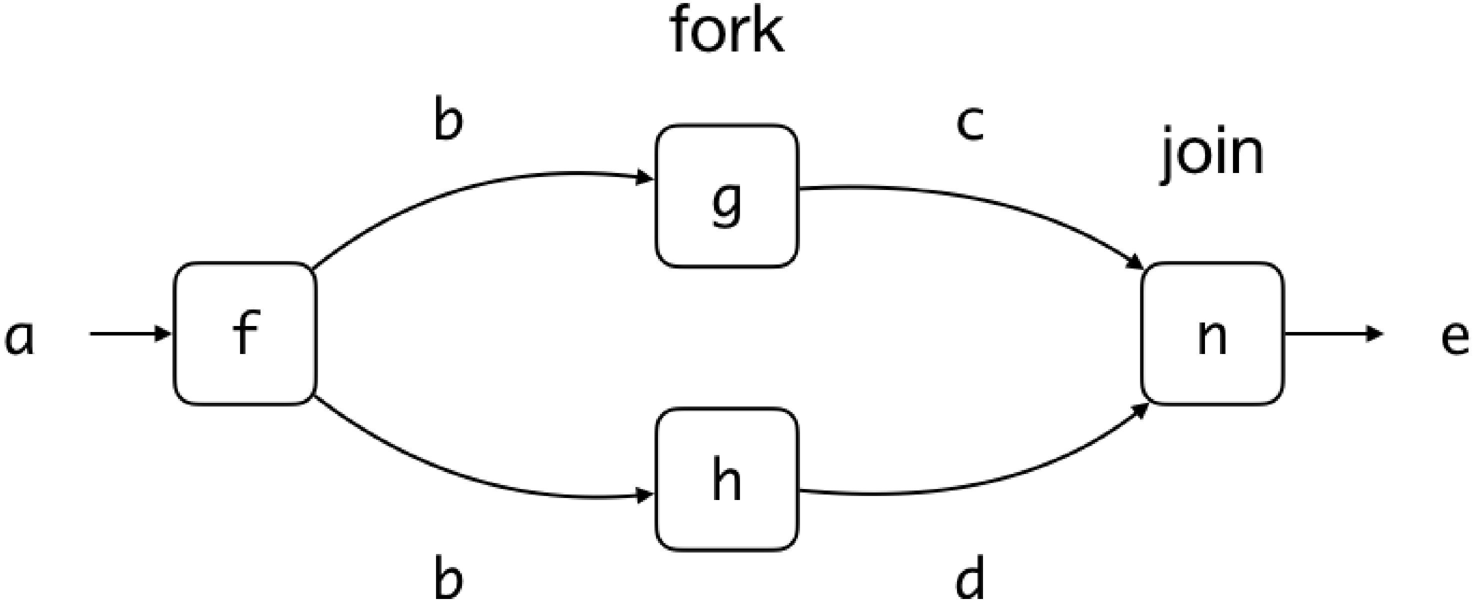
Lecture Outline

- □ Fork and join tasks
- □ Java's Fork/join framework
  - – Sub-classing a `RecursiveTask`
- □ Thread pools
  - – Global queue
  - – Local deque (double-ended queue)
- □ Work stealing
- □ Order of fork and join
- □ Overhead of fork and join

Fork and Join

- □ Given the following program fragment and *computation* graph

```
b = f(a);
c = g(b);
d = h(b);
e = n(c,d);
```



- □ `f(a)` invoked before `g(b)` and `h(b)`; `n(c,d)` invoked after
- □ How about the order of `g(b)` and `h(b)`?
  - If `g` and `h` does not produce side effects, then parallelize
  - **Fork** task `g` to execute at the same time as `h`, and **join** back task `g` later

Example: Summing an Array... *Recursively*

```java
class Summer {

    static int threshold;

    static int sumLeftRight(int[] array, int low, int high) {
        if (high - low < threshold) {
            int sum = 0;
            for (int i = low; i <= high; i++) {
                sum += array[i];
            }
            return sum;
        } else {
            int middle = (low + high) / 2;
            int leftSum = sumLeftRight(array, low, middle);
            int rightSum = sumLeftRight(array, middle + 1, high);
            return leftSum + rightSum;
        }
    }
}
        int[] array = IntStream.rangeClosed(1, 10).toArray();
        Summer.threshold = Integer.parseInt(args[0]);
        int sum = sumLeftRight(array, 0, array.length - 1);
```

Similar to the mergesort algorithm
=> Divide and Conquer Algo

Transform to a Recursive Class

```java
class Summer {
    private int[] array;
    private int low;
    private int high;
    static int threshold;

    Summer(int[] array, int low, int high) {
        this.array = array;
        this.low = low;
        this.high = high;
    }

    int compute() {
        if (high - low < threshold) {
            int sum = 0;
            for (int i = low; i <= high; i++) {
                sum += array[i];
            }
            return sum;
        } else {
            int middle = (low + high) / 2;
            Summer left = new Summer(array, low, middle);
            Summer right = new Summer(array, middle + 1, high);
            return left.compute() + right.compute();
        }
    }
}
```

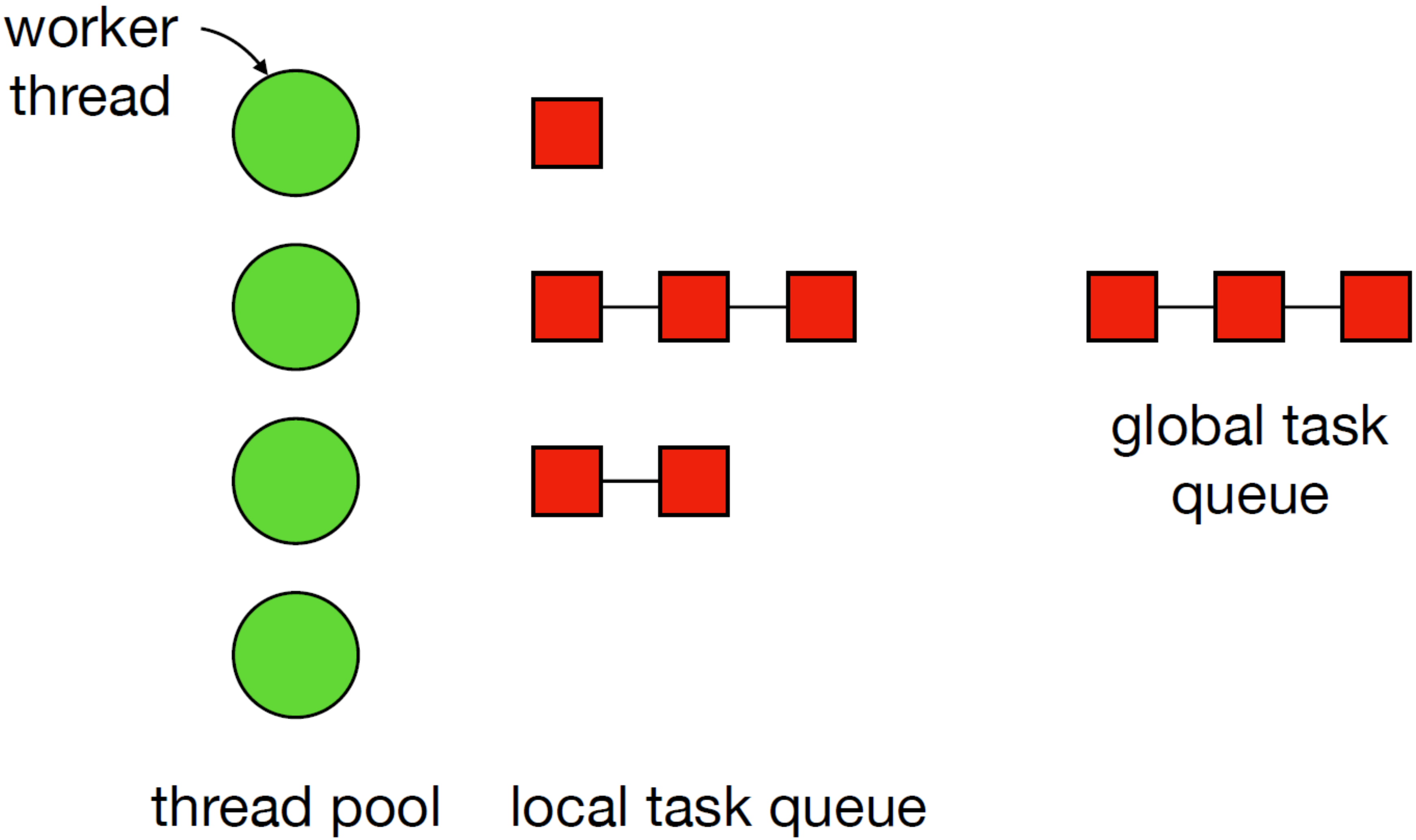
Subclassing RecursiveTask<T> for Fork/Join

```java
import java.util.concurrent.RecursiveTask;

class Summer extends RecursiveTask<Integer> {
    ...
    @Override
    protected Integer compute() {
        if (high - low < threshold) {
            int sum = 0;
            for (int i = low; i < high; i++) {
                sum += array[i];
            }
            return sum;
        } else {
            int middle = (low + high) / 2;
            Summer left = new Summer(low, middle, array);
            Summer right = new Summer(middle, high, array);

            left.fork();
            return right.compute() + left.join();
        }
    }
}
```

Thread Pools



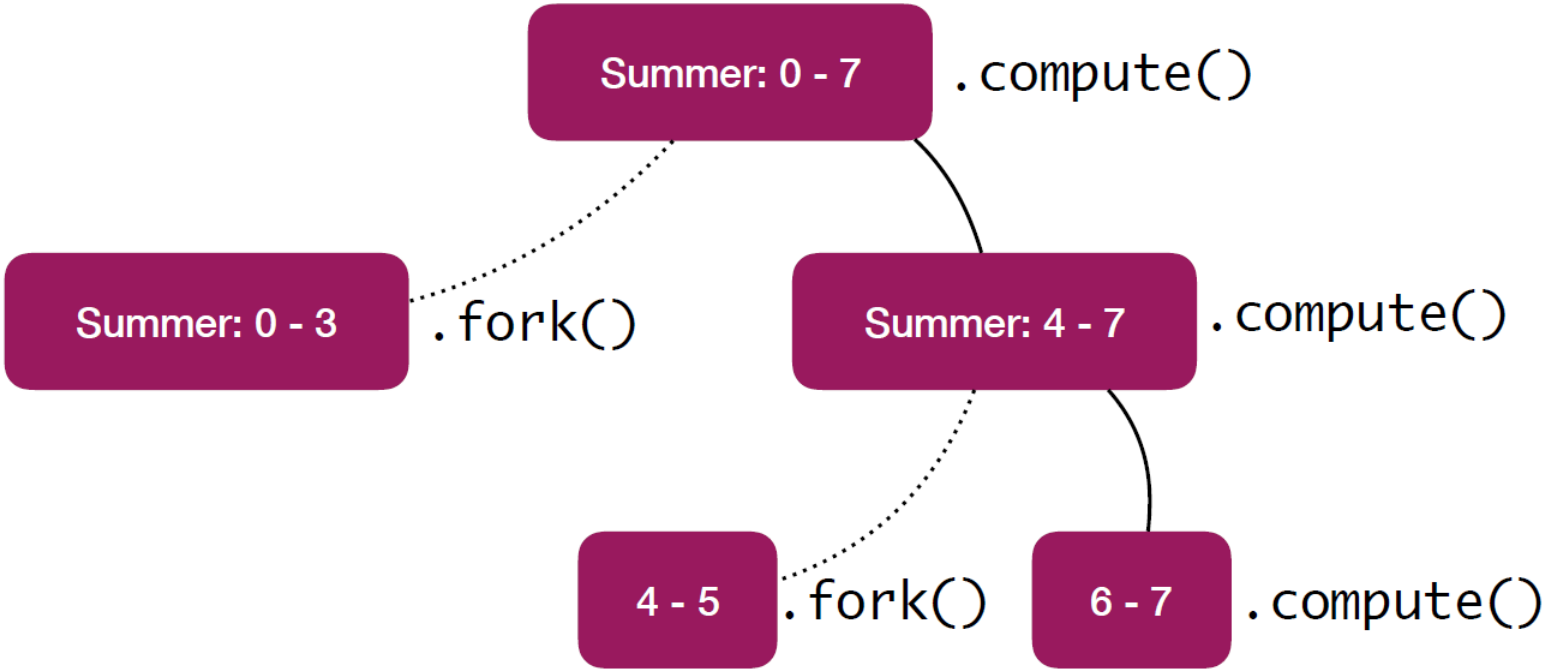
Thread Pools

- □ Java maintains a pool of *worker threads*
  - Each thread is an abstraction of a running task
  - Task submitted to the pool for execution, and joins the global queue or worker queue
  - Worker thread picks a task from the queue to execute
- □ `ForkJoinPool` is the class that implements the thread pool for `RecursiveTask` (a sub-class of `ForkJoinTask`)
- □ To submit `task` to the thread pool for execution, either
  - `task.compute()` that invokes task immediately; may result in stack overflow if too many recursive tasks
  - `invoke(task)` that gets the task to join the queue, waiting to be carried out by a worker (recommended)

Example: Summing an Array

□ Summing array of eight elements with threshold set to 2

0	1	2	3	4	5	6	7
3	3	1	3	6	8	4	2



Summer: 0 - 7 .compute()

Summer: 0 - 3 .fork()

Summer: 4 - 7 .compute()

4 - 5 .fork()

6 - 7 .compute()

Example: Summing an Array

```
@Override
protected Integer compute() {
    System.out.println(low + "," + high + ":" + Thread.currentThread().getName());
    if (high - low < threshold) {
        int sum = 0;
        for (int i = low; i < high; i++) {
            sum += array[i];
        }
        return sum;
    } else {
        int middle = (low + high) / 2;
        Summer left = new Summer(array, low, middle);
        Summer right = new Summer(array, middle + 1, high);
        left.fork();
        return right.compute()+ left.join();
    }
}
```

- □ Running with `ForkJoinPool.common.parallelism=2`

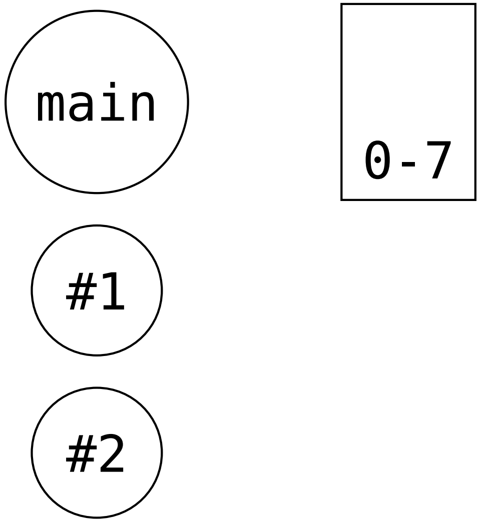
refer to the diagram next page

```
0,7:main
4,7:main
6,7:main
0,3:ForkJoinPool.commonPool-worker-1
4,5:ForkJoinPool.commonPool-worker-2
2,3:ForkJoinPool.commonPool-worker-1
0,1:ForkJoinPool.commonPool-worker-2
```

```
0,7:main
4,7:main
6,7:main
4,5:main
0,3:ForkJoinPool.commonPool-worker-2
0,1:ForkJoinPool.commonPool-worker-1
2,3:ForkJoinPool.commonPool-worker-2
```

Queuing of Forked Tasks

□ `main` thread performs `compute` on task `[0,7]`



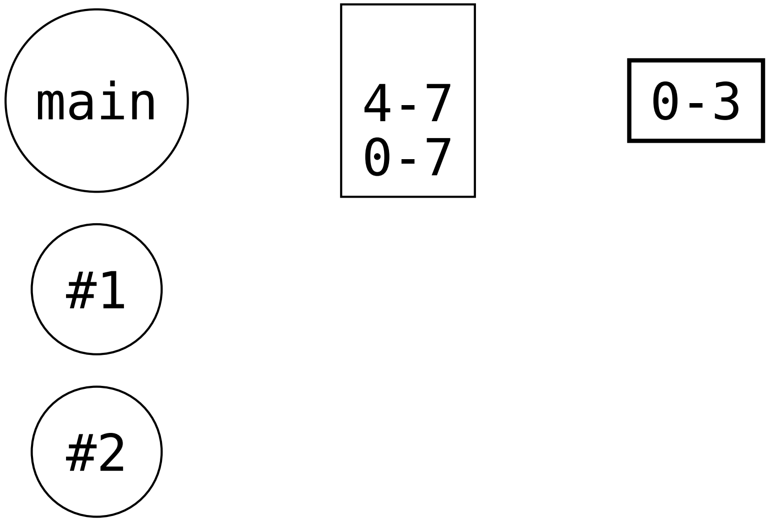
main

0-7

#1

#2

□ `main` forks task `[0,3]` to global queue, then computes `[4,7]`



main

4-7
0-7

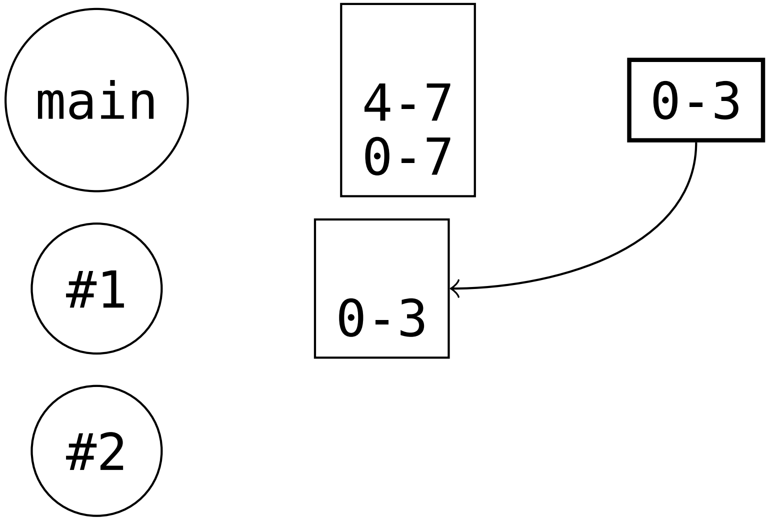
0-3

#1

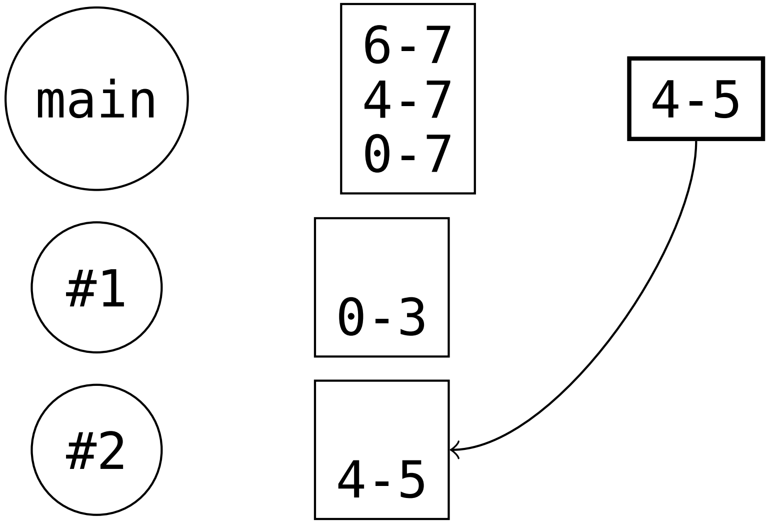
#2

Work Fetching from Global Queue

- □ Worker #1 fetches task `[0-3]` from global queue

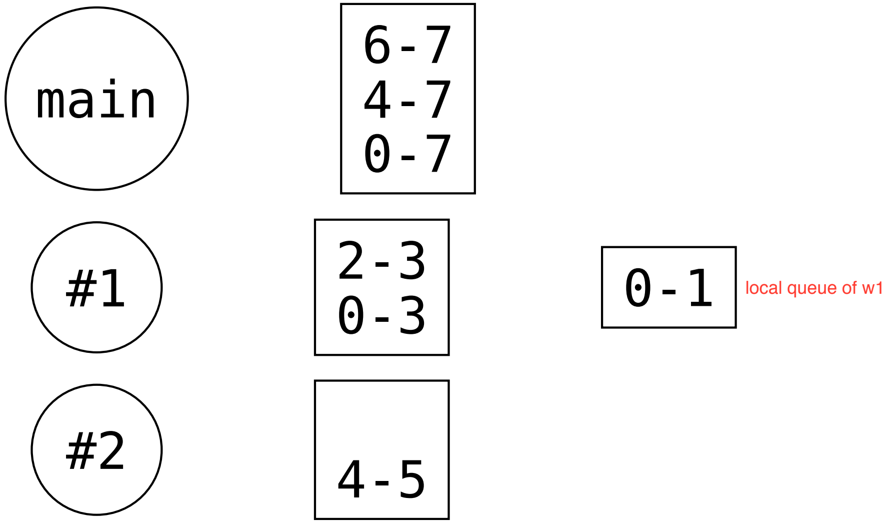


- □ `main` forks `[4-5]` & computes `[6-7]`; worker #2 fetches `[4-5]`

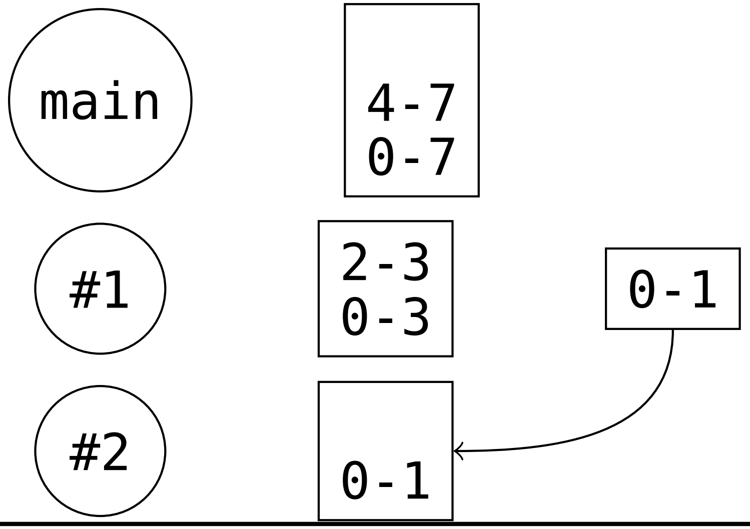


Work Stealing

- □ Worker #1 forks `[0-1]` and computes `[2-3]`

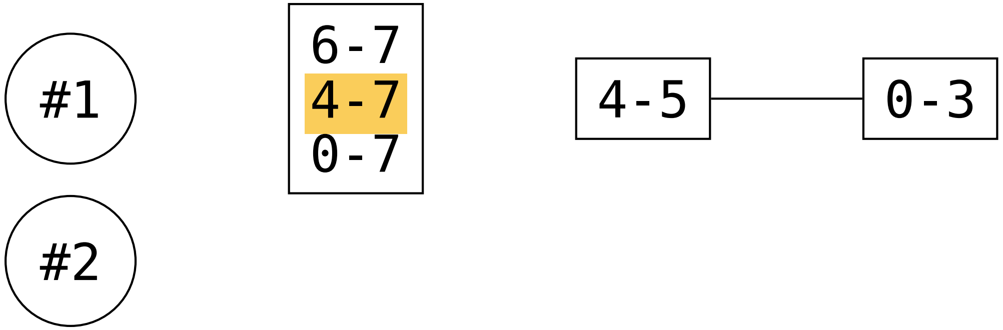


- □ Worker #2 completes `[4-5]` returns, and steals `[0-1]`



Local Deque (Double-Ended Queue)

- □ E.g., invoking `ForkJoinPool.commonPool().invoke(task)`
- □ Worker #1 processes `0-7`: forks `[0-3]` and computes `[4-7]`
- □ Worker #1 processes `4-7`: forks `[4-5]` and computes `[6-7]`

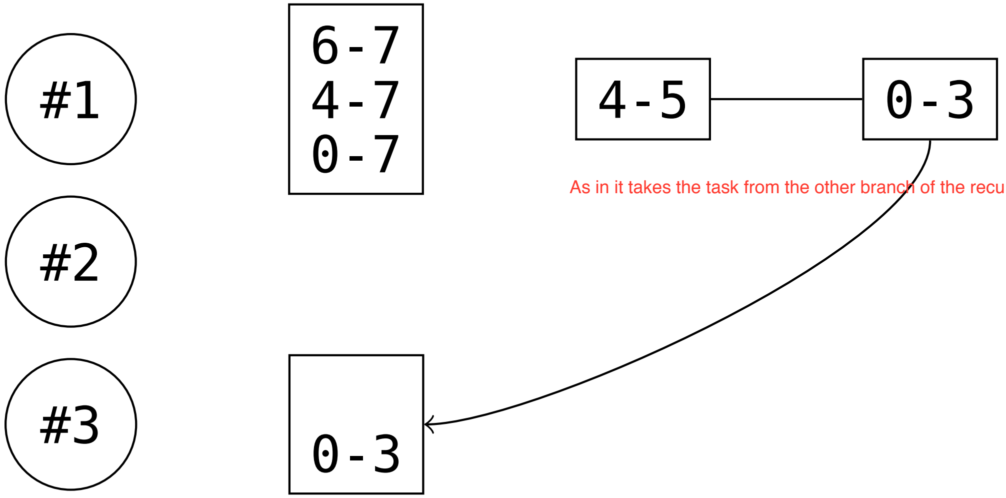


- □ When worker #1 completes `[6-7]`, it makes more sense for him to work on `[4-5]`, so as to complete `[4-7]` So that 4-7 is completed and the size of the stack is decreased
- □ Local task queue is a double ended queue
  - – Forked tasks added to the **head** of the queue
  - – Steal tasks from the **end of the queue**
  - – Rational: bigger tasks are stolen; smaller ones self-served

Recursive task-> to hit the base case and then ping back

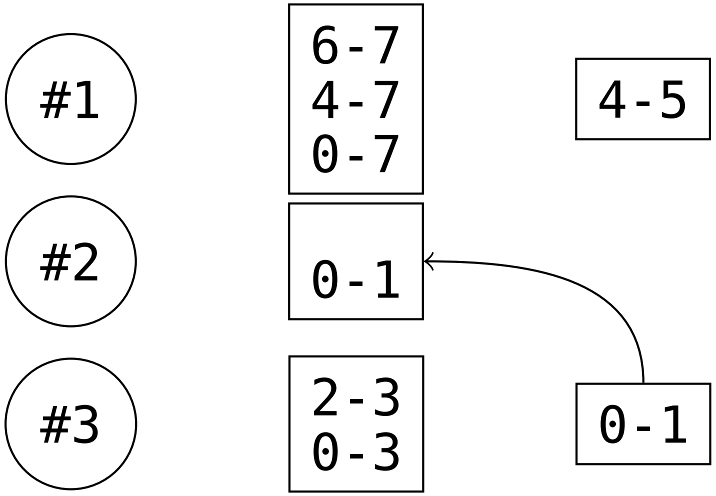
Work Stealing from Back of Dequeue

- □ Worker #3 steals task `[0-3]`



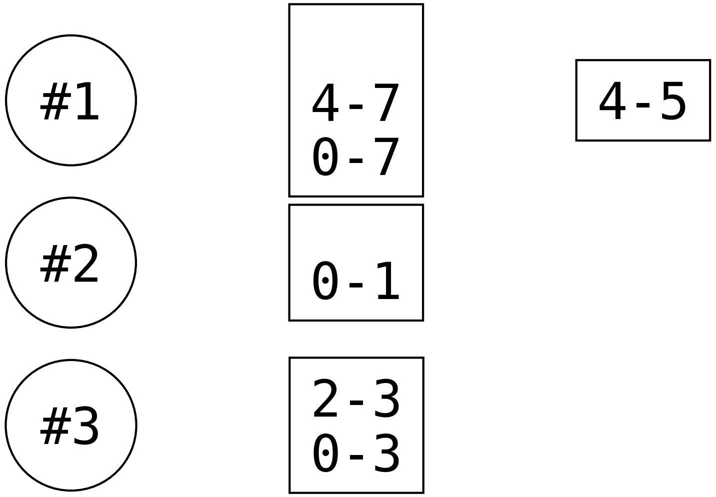
As in it takes the task from the other branch of the recursion to reduce the stack, rather than redistributing unevenly.

- □ Worker #3 forks `[0-1]` (worker #2 steals) and computes `[2-3]`



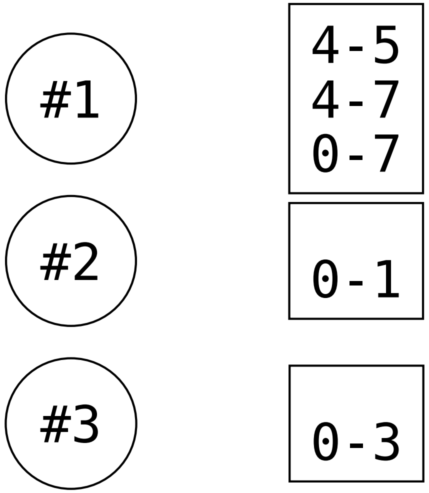
Another Possible Scenario...

□ Worker #1 completes `[6-7]`, but worker #2 has not



□ Worker #3 completes `[2-3]`,but is now blocked waiting for worker #2 to return with a value

□ Worker #1 can then service `[4-5]` from the head of its queue



Order of Fork/Join

```
@Override
protected Integer compute() {
    System.out.println(low + "," + high + ":" + Thread.currentThread().getName());
    if (high - low < threshold) {
        int sum = 0;
        for (int i = low; i < high; i++) {
            sum += array[i];
        }
        return sum;
    } else {
        int middle = (low + high) / 2;
        Summer left = new Summer(array, low, middle);
        Summer right = new Summer(array, middle + 1, high);

        left.fork();
        right.fork();

        return right.join()+ left.join();
    }
}
```

Main does 0,7
fork left(4,7) fork right (0,3)
now the queue: (4,7) (0,3)
self service from the front can only pick up from the front but task (4,7) is blocking task (0,3)

- □ How about using only `forks` and `joins`
- □ Does the ordering matter?

Order of Fork/Join

□ Fork-join pair acts like a call (fork) and return (join) from a parallel recursive function.

- Returns (joins) should be performed innermost-first
- Performing

```
a.fork(); b.fork();
b.join(); a.join();
```

FIFO
First In First Out
The first Task added must be computed first

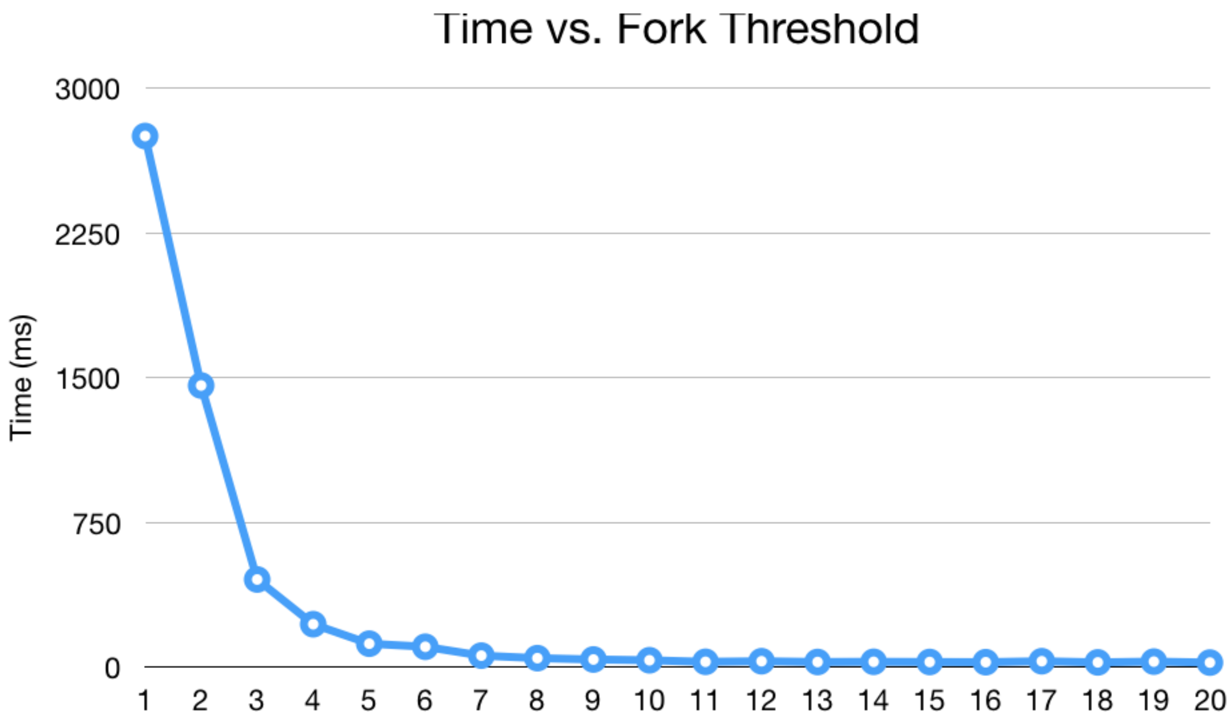
is likely to be substantially more efficient than joining task `a` before task `b`

□ Work-stealing threadpools have a fixed number of threads

- Any blocking operation in one of these threads will reduce overall performance

Overhead of Fork/Join

- Forking and joining creates additional overhead
  - wrap the computation in an object
  - submit object to a queue of tasks
  - workers go though the queue to execute tasks



Lecture Summary

□ Appreciate the use of fork and join in parallel/concurrent programming

□ Understand how tasks are forked in a local deque, and why the ordering of forks and joins matter

□ Understand how work stealing distributes tasks among worker threads

□ Appreciate the overhead involved in parallelizing using fork and join