CS2030 Lecture 11

Fork/Join Framework

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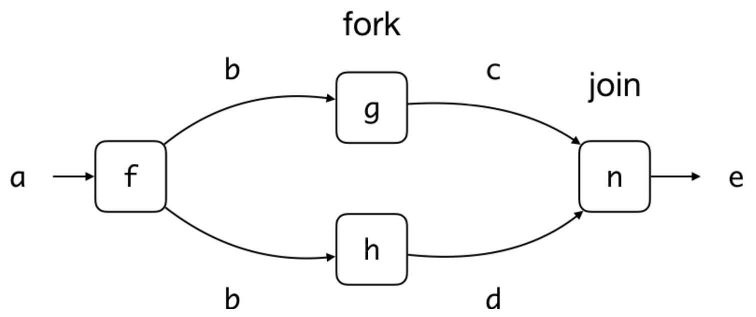
Lecture Outline

- 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/join in parallel streams

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*

```
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);
```

Transform to a Recursive Class

```java
class Summer {
    int[] array;
    int low;
    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();
        }
    }
}
```

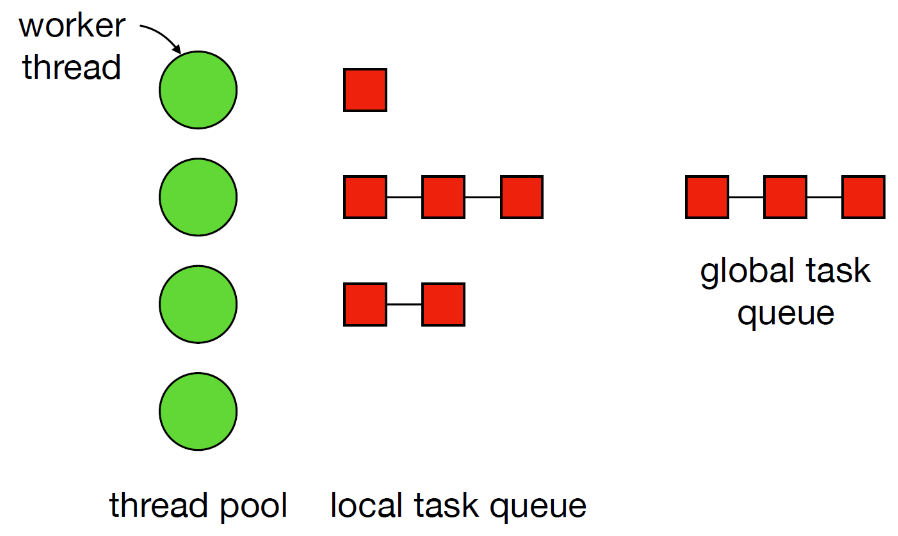

Subclassing `RecursiveTask<T>` for Fork/Join

```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

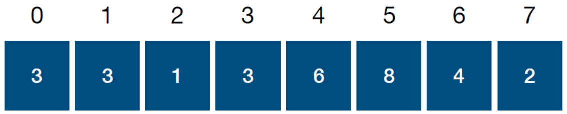


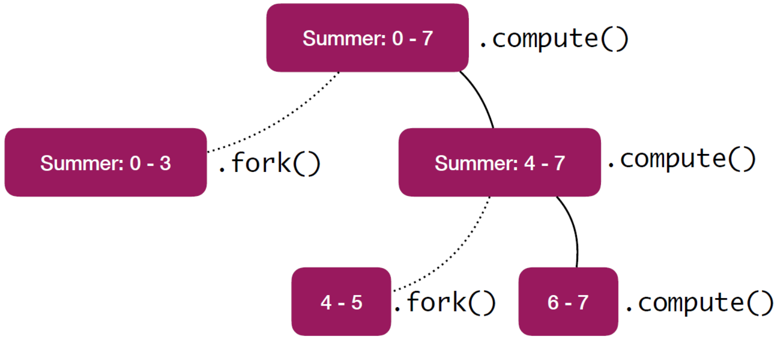
Thread Pools

- 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





Example: Summing an Array

```java
@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();
    }
}
```

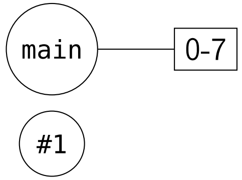
- Running with `ForkJoinPool.common.parallelism=2`

```
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
```

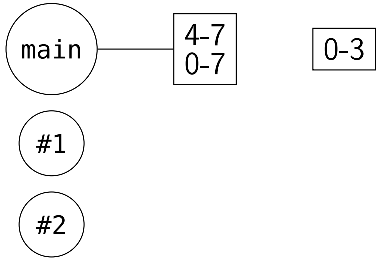
```
0,7:main
4,7:main
6,7:main
4,5:main
0,3:ForkJoinPool.commonPool-worker-2
0,1:ForkJoinPool.commonPool-worker-1
2,3:ForkJoinPool.commonPool-worker-2
```


Queuing of Forked Tasks

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

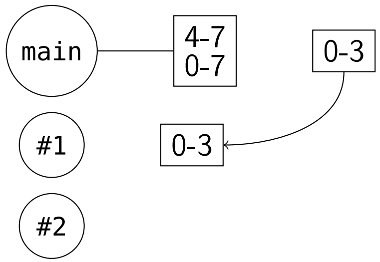


- `main` forks task `[0,3]` to local queue, then computes `[4,7]`

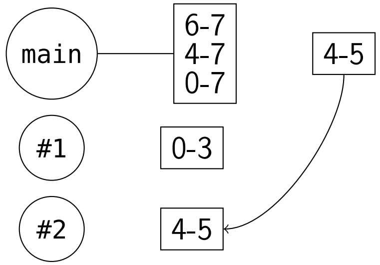


Work Stealing

- Worker **#1** steals task `[0-3]`

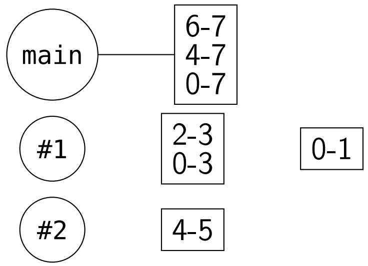


- `main` forks `[4-5]` (worker **#2** steals); `main` computes `[6-7]`

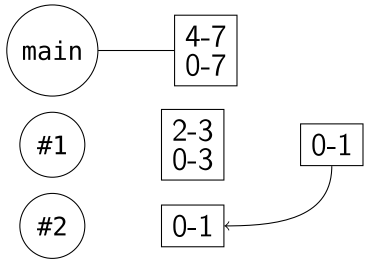


Work Stealing

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

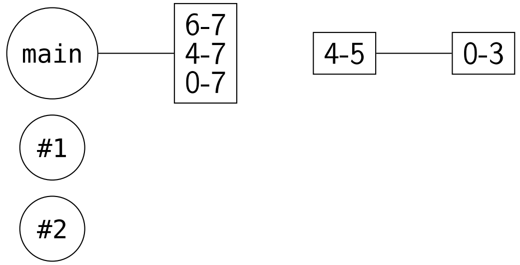


- Worker #2 completes [4-5] returns, and steals [0-1]



Local Deque (Double-Ended Queue)

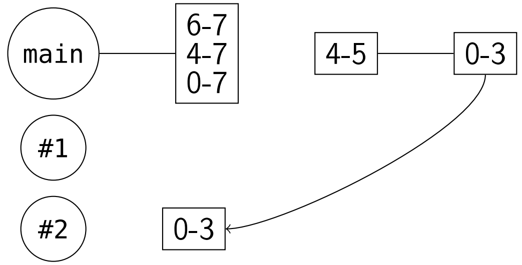
- `main` forks task [0-3] to local queue
- Before any work stealing, `main` computes [4-7] which forks [4-5] and computes [6-7]



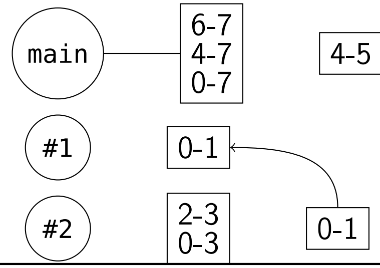
- Local task queue is a double ended queue
  - Forked tasks added to the **head** of the queue
  - Steal tasks from the **end of the queue**
  - Rational: bigger tasks are stolen; smaller ones self-served

Another Possible Scenario...

- Worker #2 steals task [0-3]

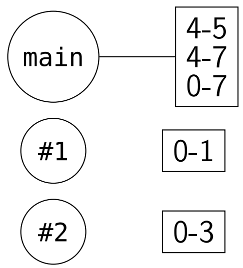


- Worker #2 forks [0-1] (worker #1 steals) and computes [2-3]



Another Possible Scenario...

- Suppose `main` completes [6-7], but worker #1 has not
- Worker #2 completes [2-3],but is now blocked waiting for worker #1 to return with a value
- `main` can service 4-5 from the head of its queue



- Indeed, if there are no workers, `main` completes everything on his own

Order of Fork/Join

```java
@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.compute()+ left.compute();
    }
}
```

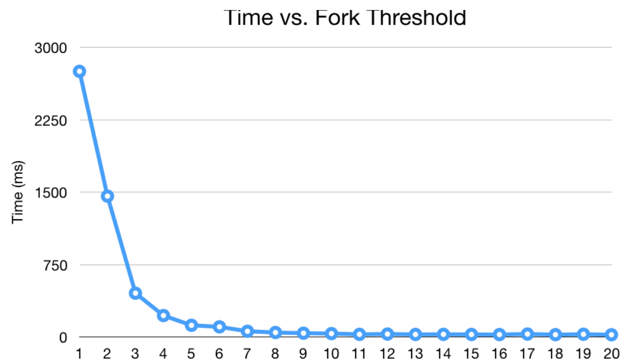
- How about using only `forks` and `joins`
- Does the ordering matter?

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
  - `a.fork(); b.fork(); b.join(); a.join();` is likely to be substantially more efficient than joining `a` before `b`.
- Work-stealing threadpools have a fixed number of threads
  - Any blocking operation in one of these threads will reduce overall performance
- Will all threads be blocked?
  - Synchronization primitive classes recognize when a thread is about to be blocked and create a *compensation thread* before the current thread blocks

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



Fork/Join in Parallel Streams

- `parallel()` runs `fork` to create sub-tasks running the same chain of operations on sub-streams
- `combiner` in `reduce` runs `join` to combine the results
- Parallelizing a trivial task actually creates more work in terms of parallelizing overhead

```java
IntStream.range(2, (int) Math.sqrt(n) + 1)
    .parallel()
    .noneMatch(x -> n % x == 0);
```

- Parallelization is worthwhile if the task is complex enough that the benefit of parallelization outweighs the overhead
- In the following example, what happens when we parallelize `isPrime`?

Fork/Join in Parallel Streams

```java
    public static boolean isPrime(int n) {
        return IntStream.range(2, (int) Math.sqrt(n) + 1)
            .noneMatch(x -> n % x == 0);
    }

    public static void main(String[] args) {

        System.out.println("Number of worker threads: " +
                ForkJoinPool.commonPool().getParallelism());

        Instant start = Instant.now();
        long howMany = IntStream.range(2_000_000, 3_000_000)
            .parallel()
            .filter(x -> isPrime(x))
            .count();
        Instant stop = Instant.now();

        System.out.println(howMany + " : " +
                Duration.between(start, stop).toMillis() + "ms");
    }
}
```


Lecture Summary

- Appreciate the use of fork and join in parallel/concurrent programming
- Understand how tasks are forked in a local dequeu, 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