Lecture 27: Parallelism II

CS 62

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Some slides based on those from Dan Grossman, U. of Washington

How to Create a Thread in Java

1. Define `class C extends Thread`
   - Override `public void run()`
   - `Thread` in `java.lang`
2. Create object of class `C`
3. Call that thread's `start` method
   - Creates new thread and starts executing `run` method.
   - Direct call of run won't work, similarly to the issue as paint-repaint.

```
class ExampleThread extends java.lang.Thread {
      int i;
      ExampleThread(int i) {
            this.i = i;
      }
      public void run() {
            System.out.println("Thread " + i + " says hi");
            System.out.println("Thread " + i + " says bye");
      }
}
class M {
      public static void main(String[] args) {
            for(int i=1; i <= 20; ++i) {
                  ExampleThread t = new ExampleThread(i);
                  t.start();
            }
      }
}
```

Pass any arguments for the new thread to constructor

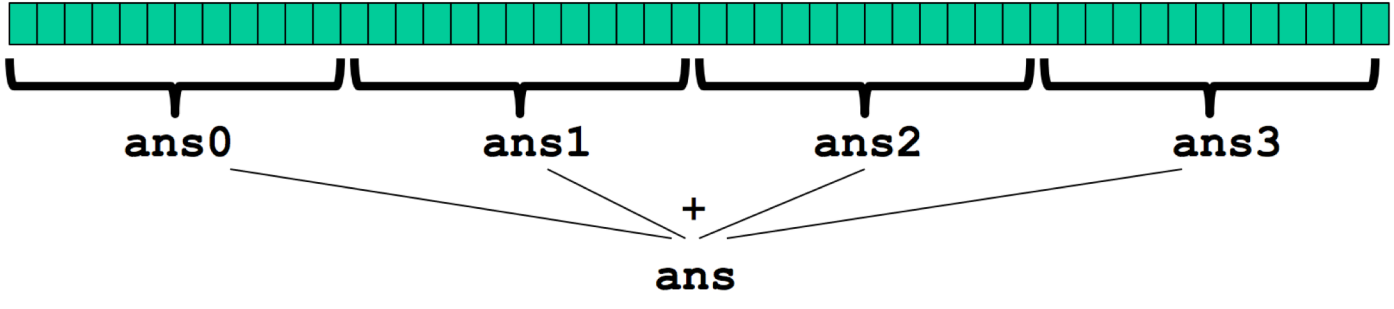
No guarantees in order of output

Thread 1 says hi
Thread 2 says hi
Thread 1 says bye
Thread 2 says bye
Thread 3 says hi
Thread 3 says bye
Thread 4 says hi
Thread 4 says bye
Thread 5 says hi
Thread 5 says bye
Thread 6 says hi
Thread 6 says bye
Thread 7 says hi
Thread 7 says bye
Thread 8 says hi
Thread 8 says bye
Thread 9 says hi
…

Thread 1 says hi
Thread 1 says bye
Thread 2 says hi
Thread 2 says bye
Thread 3 says hi
Thread 3 says bye
Thread 4 says hi
Thread 4 says bye
Thread 5 says hi
Thread 5 says bye
Thread 6 says hi
Thread 6 says bye
Thread 7 says hi
Thread 7 says bye
Thread 8 says hi
Thread 8 says bye
Thread 9 says hi
…

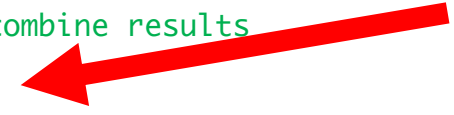
Another example of parallelism

- Method to calculate sum of elements of an array
  - Sequential algorithm takes $O(n)$
- Use 4 threads, which each sum 1/4 of the array
- Steps:
  - Create 4 thread objects, assigning each their portion of the work
  - Call `start()` on each thread object to actually run it
  - Wait for threads to finish
  - Add together their 4 answers for the final result



First Attempt – wrong!

```
class SumThread extends Thread{
        int lo, int hi, int[] arr;
        int ans = 0; // for communicating result
        SumThread(int[] a, int l, int h) {
                lo=l; hi=h; arr=a;}
        public void run(){
                for(int i=lo; i < hi; i++) ans += arr[i];}
}
//some other class
static int sum(int[] arr){
        int len = arr.length;
        int ans = 0;
        SumThread[] ts = new SumThread[4];
        for(int i=0; i < 4; i++){// do parallel computations
                ts[i] = new SumThread(arr,i*len/4,(i+1)*len/4);
                ts[i].start(); // use start not run
        }
        for(int i=0; i < 4; i++)// combine results
                ans += ts[i].ans;
        return ans;
}
```



Does not wait for helper threads to finish before it sums the ans fields

(Semi) Correct Version

```
class SumThread extends Thread {
        int lo, int hi, int[] arr
        int ans = 0;
        SumThread(int[] a, int l, int h) { … }
        public void run(){ … }
}
//some other class
static int sum(int[] arr){
        int len = arr.length;
        int ans = 0;
        SumThread[] ts = new SumThread[4];
        for(int i=0; i < 4; i++){
                ts[i] = new SumThread(arr,i*len/4,(i+1)*len/4);
                ts[i].start();}       }
         for(int i=0; i < 4; i++){
                ts[i].join(); // wait for helpers to finish!
                ans += ts[i].ans;
        }
        return ans;
}
```

Needs to be within a try/catch block for `java.lang.InterruptedException`

`Thread` class methods

- `void start()`, which calls `void run()`
- `void join()` which blocks until receiver thread is done
  - Style called fork/join parallelism
  - It needs a try-catch around `join` as it can throw `InterruptedException`
- Some memory sharing:
  - `lo, hi, arr` fields written by "main" thread, read by helper thread
  - `ans` field written by helper thread, read by "main" thread
- Later, we will learn how to protect data (race conditions) using `synchronized`

Great, right? Actually, no!

- If we time it, it's slower than sequential!!
- We want out code to be reusable and efficient as core count grows ("forward-portable").
  - At minimum, make #threads a parameter (e.g., in the `sum` method)
- Want to effectively use processors available *now*
  - Not being used by other programs or threads in your program
  - Can change while your threads running

Problem

- Suppose we have a computer with 3 processors and a problem of size n
  - If we create 3 threads and all 3 processors are available, overall t time.
  - If we create 4 threads, total time $1.5t$
    - Example: 12 units of work, 3 processors
    - 3 threads will take 4 units of time
    - 4 threads: After first 3 are finished (3 units), run 4th which takes another 3 units.
    - Total time ends up $3 + 3 = 6$
    - Runs 50% slower than with 3 threads!

More problems

- Subproblems can take significantly different amounts of time
  - Apply method f to every array element, but maybe f is much slower for some data items. e.g., is a large integer prime?
  - If unlucky, all slow operations may be assigned to the same thread
    - Certainly, won't see n speedup with n threads
    - May be much worse, due to *load imbalance*

Toward a solution

- To avoid having to wait too long for any one thread, instead create lots of threads, far more than #cores (counterintuitive)
- Schedule threads as processors become available.
- If a thread is very slow, many others will get scheduled on other processors while that one runs.
- Will work well if the slow thread is scheduled relatively early

Naive idea

Suppose we create 1 thread to process every 1000 elements

```
int sum(int[] arr){
      …
     int numThreads = arr.length / 1000;
     SumThread[] ts = new SumThread[numThreads];
     …
}
```

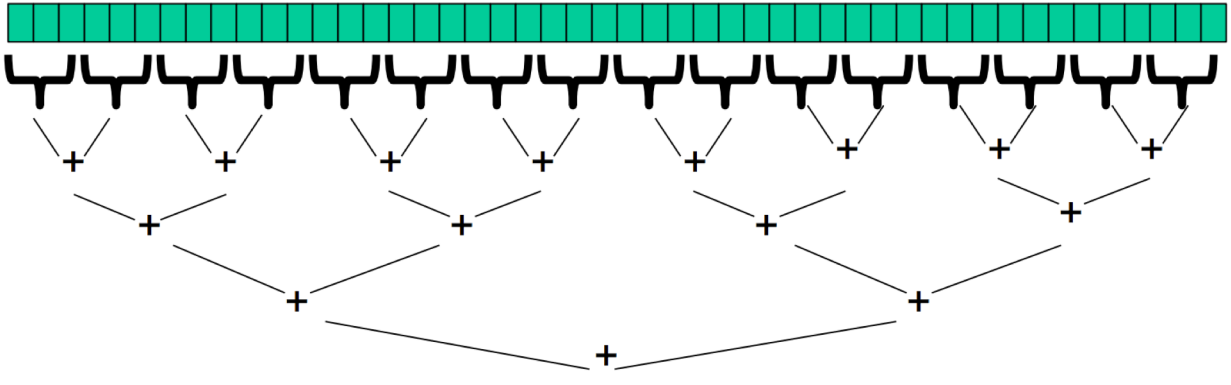
- Combining results will be linear in size of array (1/1000 constant)
- Extreme case: 1 thread per element, like original sequential algorithm

Divide and Conquer

1. Divide problem into pieces recursively:
   - Start with full problem at root – Halve and make new thread until size is at some cutoff
2. Combine answers in pairs as we return from recursion

- If have $numProc$ processors then total time

$$O(\frac{n}{numProc} + \log n)$$



In practice

- Creating so many threads and synchronizing their communication swamps savings
- Instead, use sequential cutoff about 500-1000
  - Eliminates almost all the recursive thread creation (bottom levels of tree)
  - Exactly like quicksort switching to insertion sort for small subproblems, but more important here
- Don't create two recursive threads: create one thread and do the other piece of work "yourself". Cuts #threads in half
- Instead of:
- `left.start(); right.start(); left.join();right.join();`
- do:
  `left.start(); right.run(); left.join();`

ForkJoin Framework to the rescue

- Java's threads are too heavyweight
- ForkJoin Framework addresses the need for divide-and-conquer fork-join parallel programming
- Part of Java 7

Java Threads VS ForkJoin

- Create a ForkJoinPool
  `ForkJoinPool.commonPool().invoke`
- Don't subclass `Thread` → Subclass `RecursiveTask<V>`
- Don't override `run` → Do override `compute`
- Do not use an `ans` field → Do return a `V` from `compute`
- Don't call `start` → Do call `fork`
- Call `join` that returns answer

Getting good results in practice

- Sequential threshold
  - Library documentation recommends doing approximately 100-5000 basic operations in each "piece" of your algorithm
- Library needs to "warm up" – May see slow results before the Java virtual machine reoptimizes the library internals
- Wait until your computer has more processors
  - Seriously, overhead may dominate at 4 processors, but parallel programming is likely to become much more important

```
class SumArray extends RecursiveTask<Integer> {
   int lo; int hi; int[] arr; // arguments
   SumArray(int[] a, int l, int h) { … }
   protected Integer compute(){// return answer
   if(hi – lo < SEQUENTIAL_CUTOFF) {
      int ans = 0;
      for(int i=lo; i < hi; i++)
      ans += arr[i];
      return ans;
   } else {
      SumArray left = new SumArray(arr,lo,(hi+lo)/2);
      SumArray right= new SumArray(arr,(hi+lo)/2,hi);
      left.fork();
      int rightAns = right.compute();
      int leftAns = left.join();
      return leftAns + rightAns;
   }}}
   static final ForkJoinPool fjPool = new ForkJoinPool();
   int sum(int[] arr){
      return ForkJoinPool.commonPool().invoke(new
                  SumArray(arr,0,arr.length));
}
```

Examples

- Maximum or minimum element
- Is there an element satisfying some property (e.g., is there a 47)?
- Left-most element satisfying some property (e.g., first 47)
- Smallest rectangle encompassing a number of points
- Counts; for example, number of strings that start with a vowel
- Are these elements in sorted order?
- Create a Histogram of test results from a much larger array of actual test results

CPU vs GPU

From Mythbusters:

https://www.youtube.com/watch?v=-P28LKWTzrI&feature=youtu.be

In a bit more detail:

https://www.youtube.com/watch?v=1kypaBjJ-pg