Lecture 28: Parallelism II

CS 62

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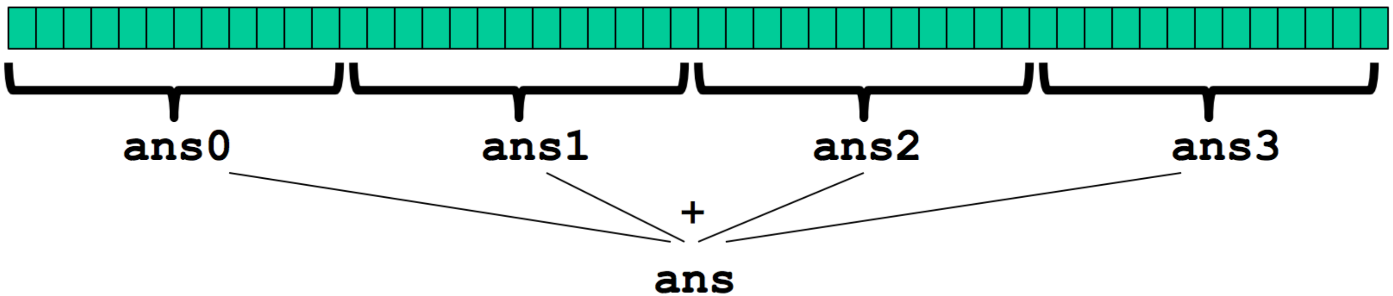
Some slides based on those fom Dan Grossman, U. of Washington

Example behind Parallelism Idea

- Method to calculate sum of elements of an array
- 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



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.

- Alternatively, define class implementing `Runnable`, create thread with it as parameter, and send start message
    - Allows class to extend a different one.

First Attempt

```
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

`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 4 processors and a problem of size n
  - We can solve the problem with 3 processors, each taking time t on $\frac{n}{3}$ elements.
- Suppose linear in size problem:
  - We want to use all 4 processors, but one is busy playing music
  - First 3 threads run, but 4th waits
    - First 3 threads scheduled and take time $\left(\frac{\frac{n}{4}}{\frac{n}{3}}\right) * t = ¾t$
    - After first 3 are finished, run 4th which takes another $¾t$
    - Total time ends up $¾t + ¾t = 1.5t$
    - 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*

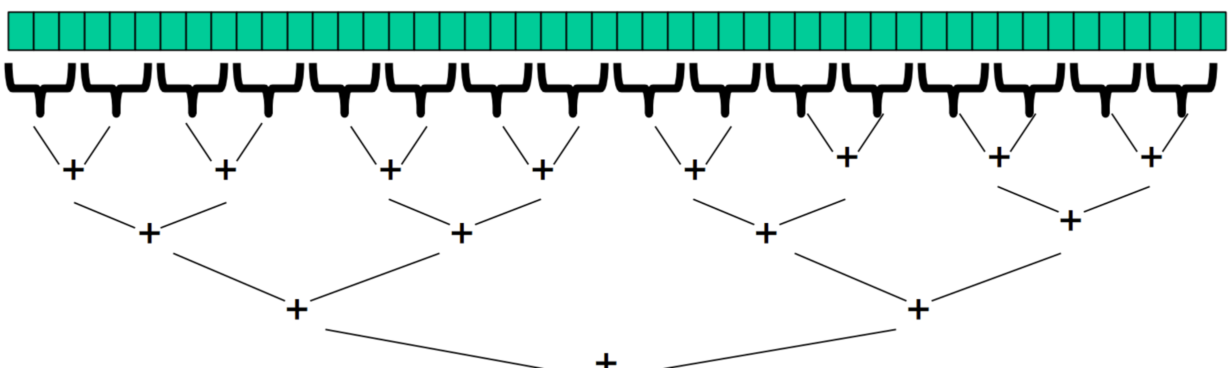
Toward a solution

- To avoid having to wait too long for any one thread, instead create lots of threads, far more than #cores
- 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

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 number of threads in half

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
- 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
- To optimize, call compute instead of fork (rather than run

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

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