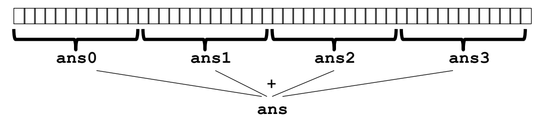
Lecture 22: Parallelism & Concurrency

CS 62
Fall 2016
Kim Bruce & Peter Mawhorter

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

Parallelism Idea



- Example: Sum 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

Parallel Programming in Java

- Creating a thread:
  1. Define a class C extending Thread
     - Override `public void run()` method
  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, as just be a normal method call
  - *Alternatively, define class implementing Runnable, create thread w/it as parameter, and send start message*

    Allows class to extend a different one.

Thread Class Methods

- void start( ), which calls void run( )
- void join( ) -- blocks until receiver thread done
- Style called fork/join parallelism
  - Need try-catch around join as it can throw exception InterruptedException
- Some memory sharing: lo, hi, arr, ans fields
- Later learn how to protect using synchronized.

Actually not so great.

- If do timing, it's slower than sequential!!
- Want code to be reusable and efficient as core count grows.
  - At minimum, make #threads a parameter.
- Want to effectively use processors available *now*
  - Not being used by other programs
  - Can change while your threads running

Problem

- Suppose 4 processors on computer
- Suppose have problem of size n
  - can solve w/3 processors each taking time t on n/3 elts.
- Suppose linear in size of problem.
  - Try to use 4 threads, but one processor busy playing music.
  - First 3 threads run, but 4th waits.
    - First 3 threads scheduled & take time ((n/4)/(n/3))*t = 3/4 t
    - After 1st 3 finish, run 4th & takes another 3/4 t
    - Total time 1.5 * t , runs 50% slower than with 3 threads!!!

Other Possible Problems

- On some problems, different threads may take significantly different times to complete
- Imagine applying f to all members of an array, where f applied to some elts takes a long time
- If unlucky, all the slow elts may get assigned to same thread.
  - Certainly won't see n time speedup w/ n threads.
  - May be much worse! Load imbalance problem!

Other Possible Problems

- May not have as many processors available as threads
- On some problems, different threads may take significantly different times to complete

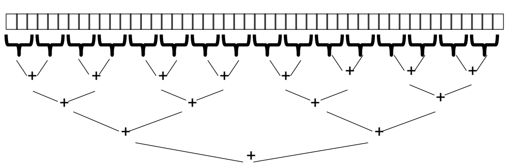
Toward a Solution

- To avoid having to wait too long for any one thread, instead create lots of threads
- Schedule threads as processors become available.
- If 1 thread very slow, many others will get scheduled on other processors while that one runs.
- Will work well if slow thread scheduled relatively early.

Naive Algorithm Not Work

- Suppose divide up work into threads which each handle 100 elts.
- Then will be n/100 threads.
  - Adding them up linear in size of array
  - If each thread handles only 1 sum then back to sequential algorithm.

Divide & Conquer



- Divide in half, w/ one thread per half.
  - Each half further subdivided w/ new threads, etc.
  - Depth is O(log n), which is optimal
  - If have numProc processors then total time O(n/numProc + log n)

straight-line code cost in step 1

each layer is O(1) in parallel

In practice

- Creating all threads and communication swamps savings so
  - use sequential cutoff of about 500
  - Don't create two recursive threads
    - one new and reuse old.
    - Cuts number of threads in half.

EfficentDivideConquerParallelSum

Even Better

- Java threads too heavyweight -- space and time overhead.
- ForkJoin Framework solves problems
- Standard as of Java 7.
  - We'll use additions as of Java 8

To Use Library

- Create a ForkJoinPool via
  - fjPool =ForkJoinPool.commonPool()
- Instead of subclass Thread, subclass RecursiveTask<V>
- Override compute, rather than run
- Return answer from compute rather than instance vble
- Call fork instead of start
- Call join that returns answer
- Start by writing fjPool.invoke(t) where t is initial thread
- To optimize, call compute instead of fork (*rather than run*)
- See *ForkJoinFrameworkDivideConquerPSum*

Considerations

- Entire program should have one ForkJoinPool.
  - Might as well make it static — use commonPool() method
- Start up everything with fjPool.invoke(new ...)
  - Once you are inside, use fork or compute.
- Use:
  - RecursiveTask<T> when return a value of type T
  - RecursiveAction when there is nothing to return

Getting Good Results

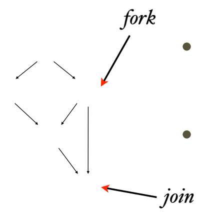
- Documentation recommends 100-50000 basic ops in each piece of program
- Library needs to warm up, like rest of java, to see good results
- Works best with more processors (> 4)

Similar Problems

- Speed up to $O(\log n)$ if divide and conquer and merge results in time $O(1)$.
- Other examples:
  - Find max, min
  - Find (leftmost) elt satisfying some property
  - Count elts satisfying some property
  - Histogram of test results
  - Called *reductions*
- Won't work if answer to 1 subproblem depends on another (e.g. one to left)

Program Graph

- Program using fork and join can be seen as directed acyclic graph (DAG).
  - Nodes: pieces of work
  - Edges: dependencies - source must finish before start destination



- Fork command finishes node and makes two edges out:
  - New thread & continuation of old
- Join ends node & makes new node w/ 2 edges coming in

Performance

- Let T_P be running time if there are P processors
- Work = T_1 = sum of run-time of all nodes in DAG
- Span = T_∞ = sum of run-time of all nodes on most expensive path in DAG
- Speed-up on P processors = T_1/T_P

What does it mean?

- Guarantee: $T_P = O((T_1 / P) + T_\infty)$
  - No implementation can beat $O(T_\infty)$ by more than constant factor.
  - No implementation on P processors can beat $O((T_1 / P)$
  - So framework on average gives best can do, assuming user did best possible.
- Bottom line:
  - Focus on your algos, data structures, & cut-offs rather than # processors and scheduling.
  - Just need T_1, T_∞, and P to analyze running time