Lecture 20: Parallelism & Concurrency

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

Splay Tree

- Idea behind splay tree.
  - Every time find, get, add: or remove an element x, move it to the root by a series of rotations.
  - Other elements rotate out of way while maintaining order.
- Splay means to spread outwards

How to Splay in Words

- if x is root, done.
- if x is left (or right) child of root,
  - rotate it to the root
- if x is left child of p, which is left child of g,
  - do right rotation about g and then about p to get x to grandparent position. Continue splaying until at root.
- if x is right child of p, which is left child of g,
  - rotate left about p and then right about g. Continue splaying until at root.

Results in moving node to root!

Splay Tree

- Modify tree operations:
  - When do add, contains, or get, splay the elt.
  - When remove an elt, splay its parent.
- Average depth of nodes on path to root cut in half on average!
- If repeatedly look for same elements, then rise to top -- and found faster!
- Splay code is ugly -- but follows ideas given

Example of modified operation

```
public boolean contains(E val)  {
  if (root.isEmpty()) return false;

  BinaryTree<E> possibleLocation = locate(root,val);
  if (val.equals(possibleLocation.value())) {
    root = possibleLocation;
    splay(root);
    return true;
  } else {
    return false;
}
```

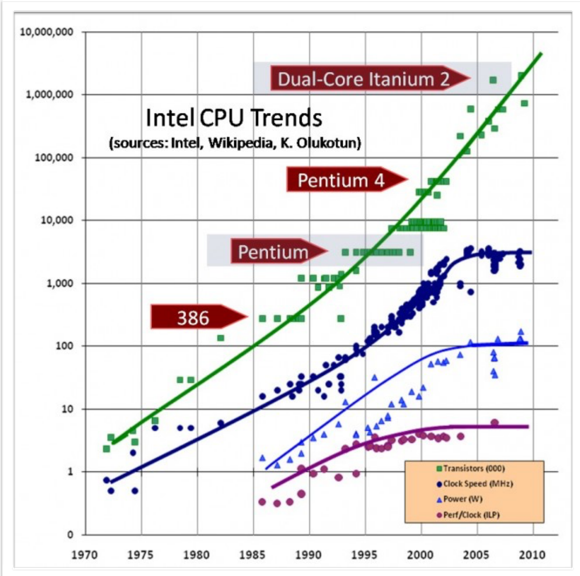
Parallelism & Concurrency

Parallelism & Concurrency

- Single-processor computers going away.
- Want to use separate processors to speed up computing by using them in parallel.
- Also have programs on single processor running in multiple threads. Want to control them so that program is responsive to user: Concurrency
- Often need concurrent access to data structures (e.g., event queue). Need to ensure don't interfere w/each other.

History

- Writing correct and efficient multithread code is more difficult than for single-threaded (sequential).
- From roughly 1980-2005, desktop computers got exponentially faster at running sequential programs
  - About twice as fast every 18 months to 2 years



More History

- Nobody knows how to continue this
- Increasing clock rate generates too much heat
- Relative cost of memory access is too high
- Can keep making "wires exponentially smaller" (Moore's "Law"), so put multiple processors on the same chip ("multicore")
- Now double number of cores every 2 years!

What can you do with multiple cores?

- Run multiple totally different programs at the same time
  - Already do that? Yes, but with time-slicing
- Do multiple things at once in one program
  - Our focus – more difficult
  - Requires rethinking everything from asymptotic complexity to how to implement data-structure operations

Parallelism vs. Concurrency

- Parallelism:
  - Use more resources for a faster answer
- Concurrency
  - Correctly and efficiently allow simultaneous access
- Connection:
  - Many programmers use threads for both
  - If parallel computations need access to shared resources, then something needs to manage the concurrency

Analogy

- Typical CS1 idea:
  - Writing a program is like writing a recipe for one cook who does one thing at a time!
- Parallelism:
  - Hire helpers, hand out potatoes and knives
  - But not too many chefs or you spend all your time coordinating (*or you'll get hurt!*)
- Concurrency:
  - Lots of cooks making different things, but only 4 stove burners
  - Want to allow simultaneous access to all 4 burners, but not cause spills or incorrect burner settings

Models Change

- Model: Shared memory w/explicit threads
- Program on single processor:
  - One call stack (w/ each stack frame holding local variables)
  - One program counter (current statement executing)
  - Static fields
  - Objects (created by new) in the heap (nothing to do with heap data structure)

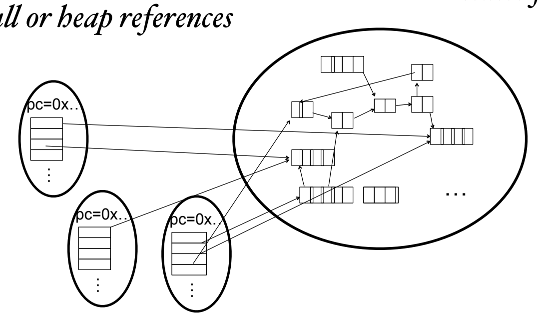
Multiple Theads/Processors

- New story:
  - A set of threads, each with its own call stack & program counter
  - No access to another thread's local variables
  - Threads can (implicitly) share static fields / objects
  - To communicate, write somewhere another thread reads

Shared Memory

Threads, each with own unshared call stack and current statement (pc for "program counter") local variables are numbers/null or heap references

Heap for all objects and static fields



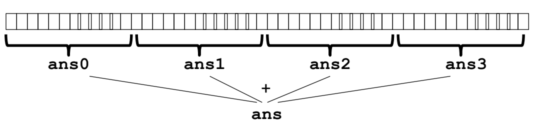
Other Models

- Message-passing:
  - Each thread has its own collection of objects. Communication is via explicit messages; language has primitives for sending and receiving them.
  - Cooks working in separate kitchens, with telephones
- Dataflow:
  - Programmers write programs in terms of a DAG and a node executes after all of its predecessors in the graph
  - Cooks wait to be handed results of previous steps
- Data parallelism:
  - Have primitives for things like “apply function to every element of an array in parallel”

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*

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

First Attempt

```
class SumThread extends Thread {
  int lo, int hi, int[] arr;//fields to know what to do
  int ans = 0; // for communicating result
  SumThread(int[] a, int l, int h) { … }
  public void run(){ … }
}

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;
}
```

What’s wrong?

Correct Version

```
class SumThread extends Thread {
  int lo, int hi, int[] arr;//fields to know what to do
  int ans = 0; // for communicating result
  SumThread(int[] a, int l, int h) { … }
  public void run(){ … }
}

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(); // start not run
  }
  for(int i=0; i < 4; i++) // combine results
    ts[i].join(); // wait for helper to finish!
    ans += ts[i].ans;
  return ans;
}
```

See program ParallelSum

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!!!