Objects Analysis Threads Design 15-214

Principles of Software Construction: Objects, Design and Concurrency

The Perils of Concurrency

Can't live with it.
Can't live without it.

15-214

toad

Fall 2012

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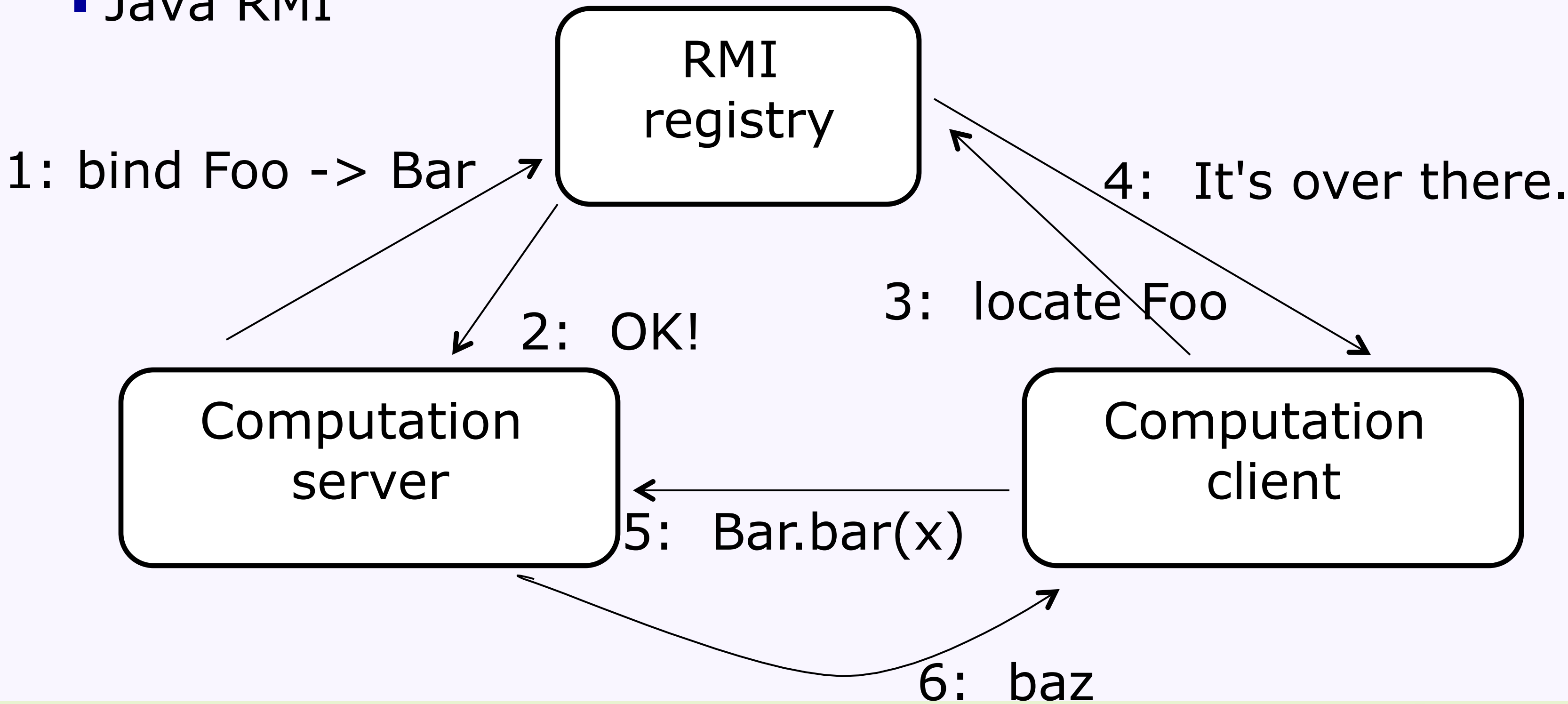
Administrivia

- Homework 6a design presentations tomorrow
  - See the Piazza note or Sign Up Genius for your presentation room

Last time: Stream I/O and Networking in Java

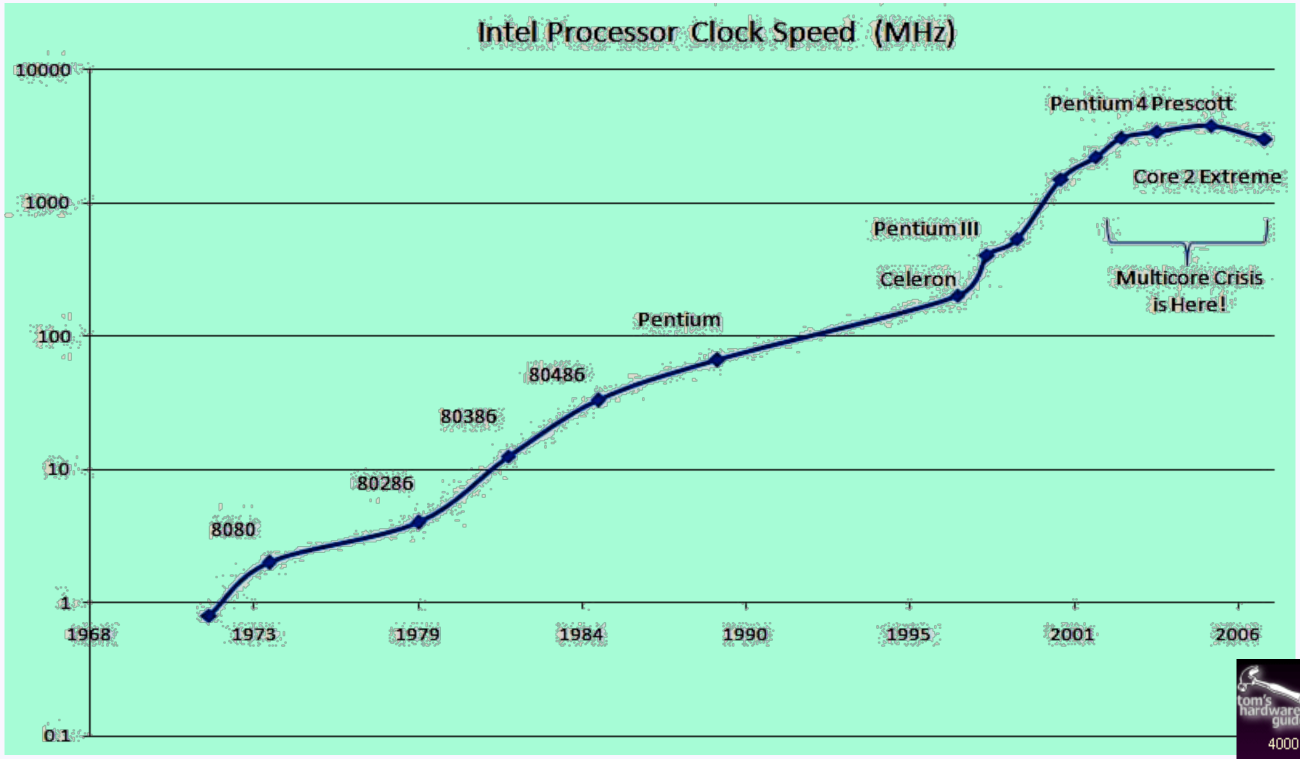
- Basic I/O Streams in Java
- Distributed systems
- Networking in Java
  - Communication via network sockets
  - Java RMI

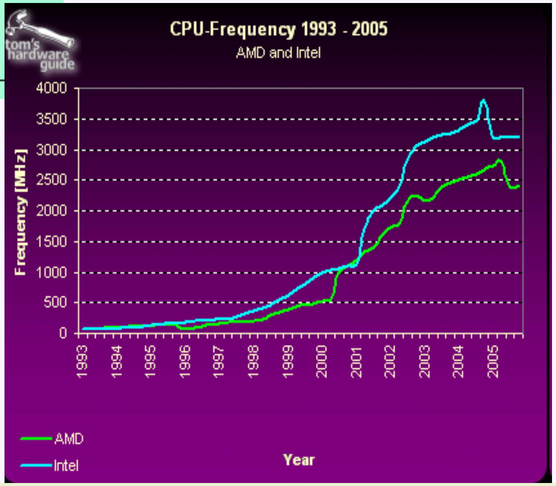


Today: Concurrency, part 1

- The concurrency backstory
  - Motivation, goals, problems, …
- Basic concurrency in Java
  - Synchronization
- Coming soon (but not today):
  - Higher-level abstractions for concurrency
    - Data structures
    - Computational frameworks

Processor speeds over time



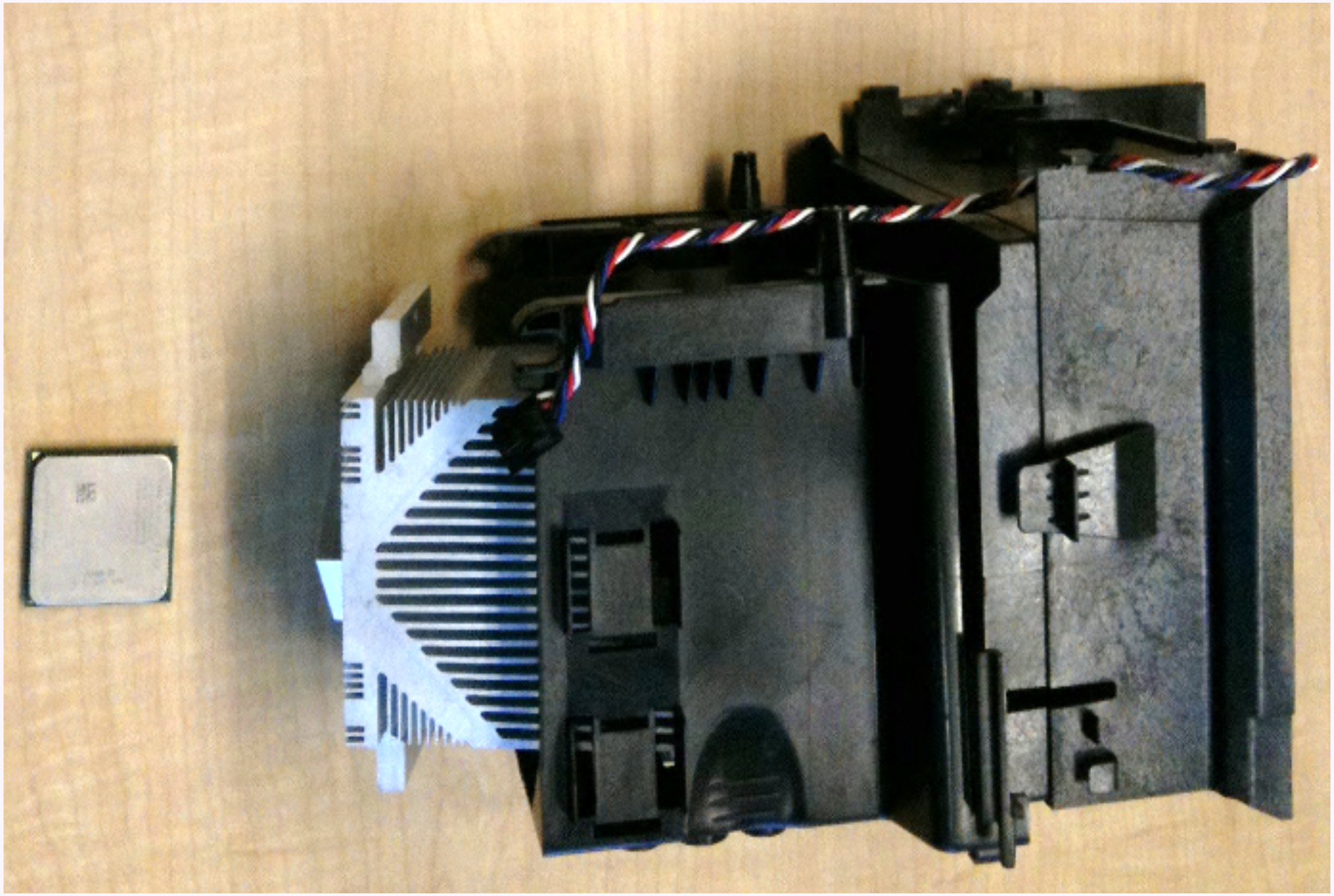


Power requirements of a CPU

- Approx.: **C**apacitance * **V**oltage^2 * **F**requency
- To increase performance:
  - More transistors, thinner wires: more **C**
    - More power leakage: increase **V**
  - Increase clock frequency **F**
- Problem: Power requirements are super-linear to performance
  - Heat output is proportional to power input

One option: fix the symptom

- Dissipate the heat



One option: fix the symptom

- Better: Dissipate the heat with liquid nitrogen
  - Overclocking by Tom's Hardware's 5 GHz project

http://www.tomshardware.com/reviews/5-ghz-project,731-8.html

Another option: fix the underlying problem

- Reduce heat by limiting power input
  - Adding processors increases power requirements linearly with performance
    - Reduce power requirement by reducing the frequency and voltage
    - Problem: requires concurrent processing

Aside: Three sources of disruptive innovation

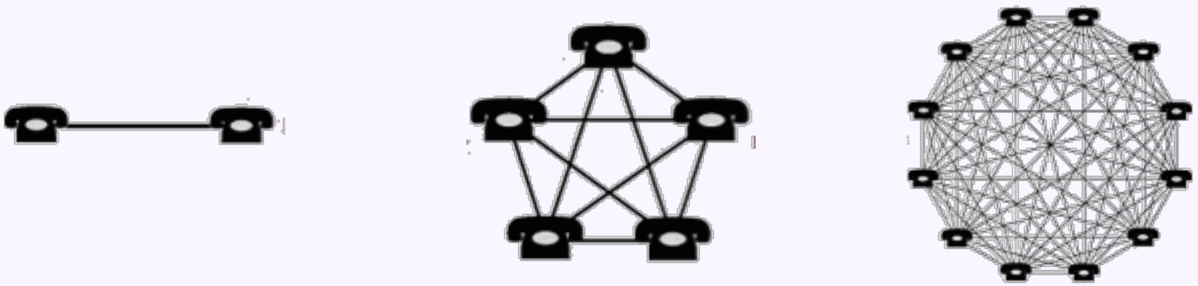
- Growth crosses some threshold
  - e.g., Concurrency: ability to add transistors exceeded ability to dissipate heat
- Colliding growth curves
  - Rapid design change forced by jump from one curve onto another
- Network effects
  - Amplification of small triggers leads to rapid change

Aside: The threshold for distributed computing

- Too big for a single computer?
  - Forces use of distributed architecture
    - Shifts responsibility for reliability from hardware to software
      - Allows you to buy cheap flaky machines instead of expensive somewhat-flaky machines
        - Revolutionizes data center design

Aside: Network effects

- Metcalfe's rule: network value grows quadratically in the number of nodes
  - a.k.a. Why my mom has a Facebook account
  - `n(n-1)/2` potential connections for `n` nodes



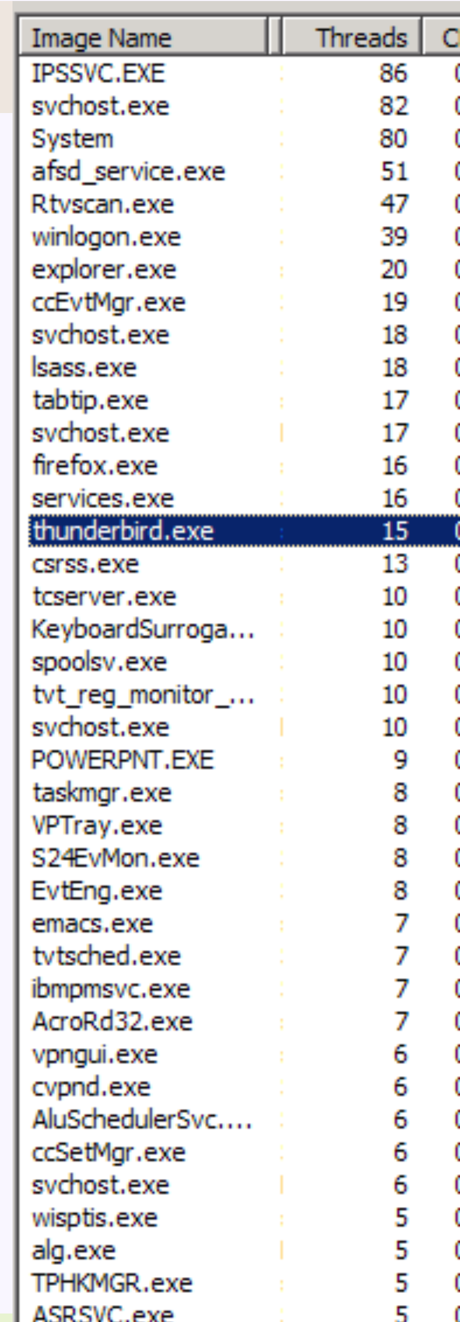
  - Creates a strong imperative to merge networks
    - Communication standards, USB, media formats, ...

Concurrency

- Simply: doing more than one thing at a time
  - In software: more than one point of control
    - Threads, processes
- Resources simultaneously accessed by more than one thread or process

Concurrency then and now

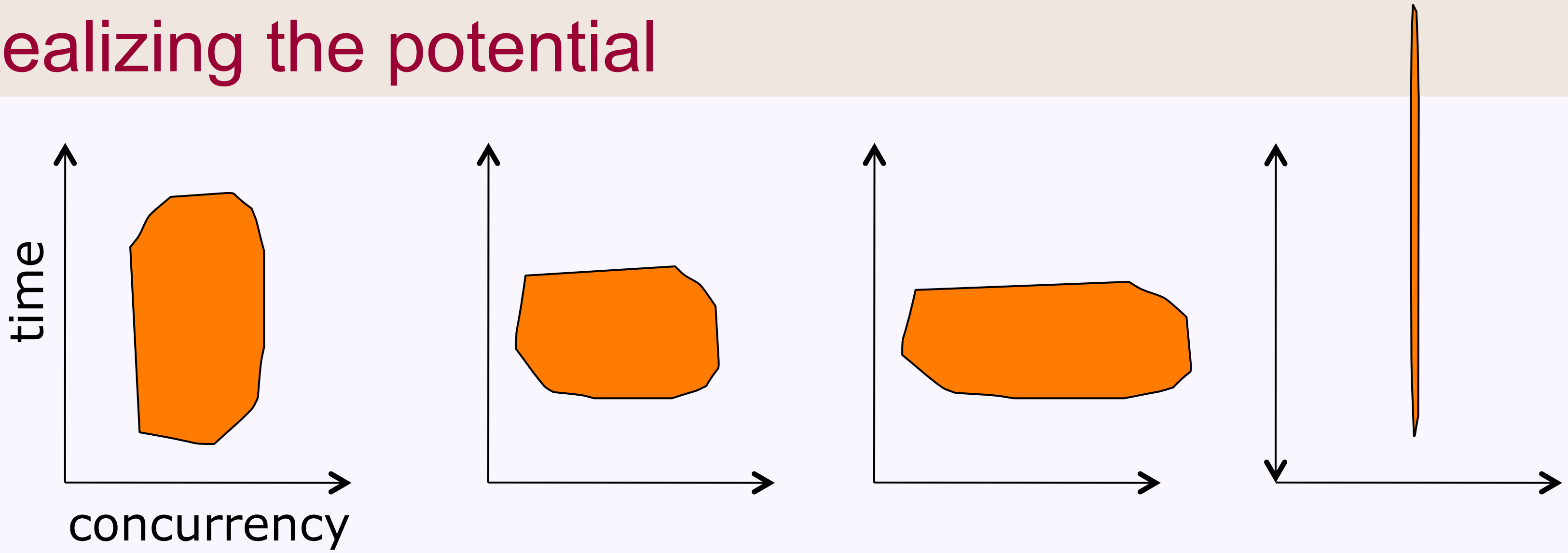
- In the past multi-threading was just a convenient abstraction
  - GUI design: event threads
  - Server design: isolate each client's work
  - Workflow design: producers and consumers
- Now: must use concurrency for scalability and performance



Problems of concurrency

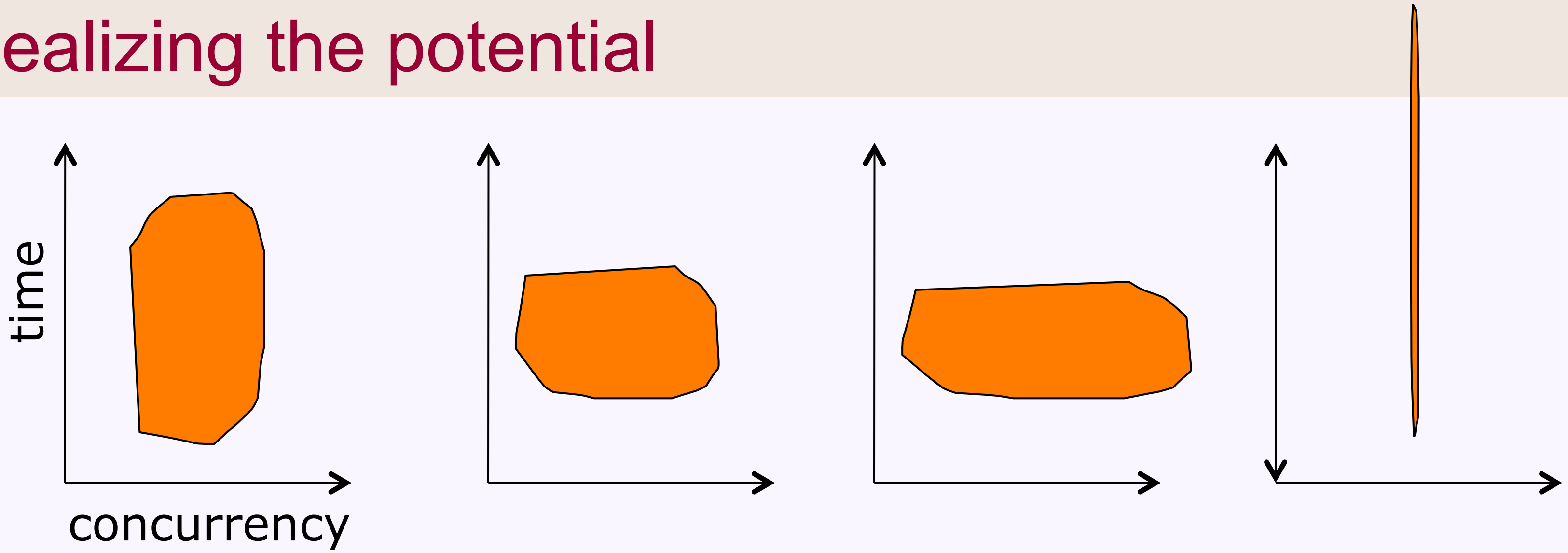
- Realizing the potential
  - Keeping all threads busy doing useful work
- Delivering the right language abstractions
  - How do programmers think about concurrency?
  - Aside: parallelism vs. concurrency
- Non-determinism
  - Repeating the same input can yield different results

Realizing the potential



- Possible metrics of success
  - Breadth: extent of simultaneous activity
    - width of the shape
  - Depth (or span): length of longest computation
    - height of the shape
  - Work: total effort required
    - area of the shape
- Typical goals in parallel algorithm design?

Realizing the potential



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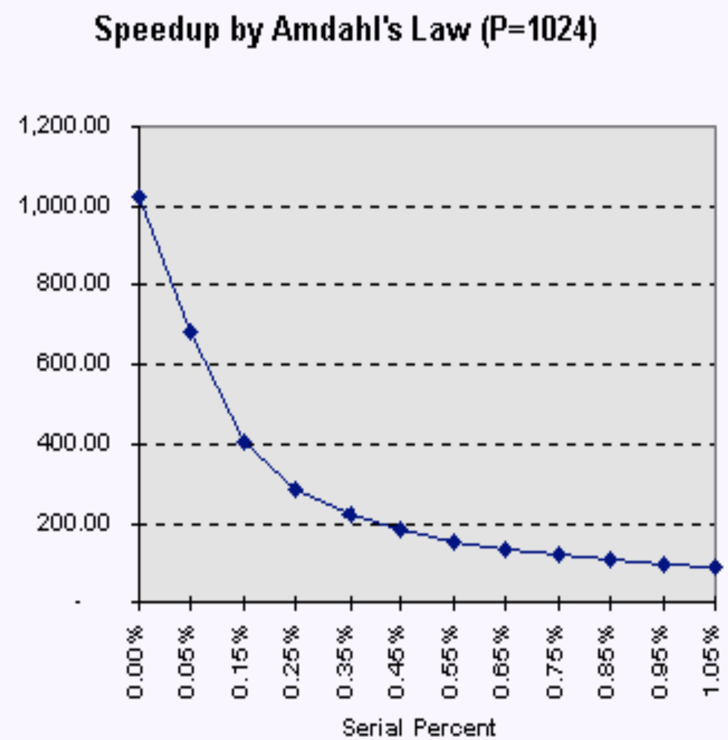
    - area of the shape
- Typical goals in parallel algorithm design?
  - First minimize depth (total time we wait), then minimize work

Amdahl's law: How good can the depth get?

- Ideal parallelism with N processors:
  - Speedup = N
- In reality, some work is always inherently sequential
  - Let F be the portion of the total task time that is inherently sequential
  - Speedup = $$\frac{1}{F + (1 - F)/N}$$
  - Suppose F = 10%. What is the max speedup? (you choose N)



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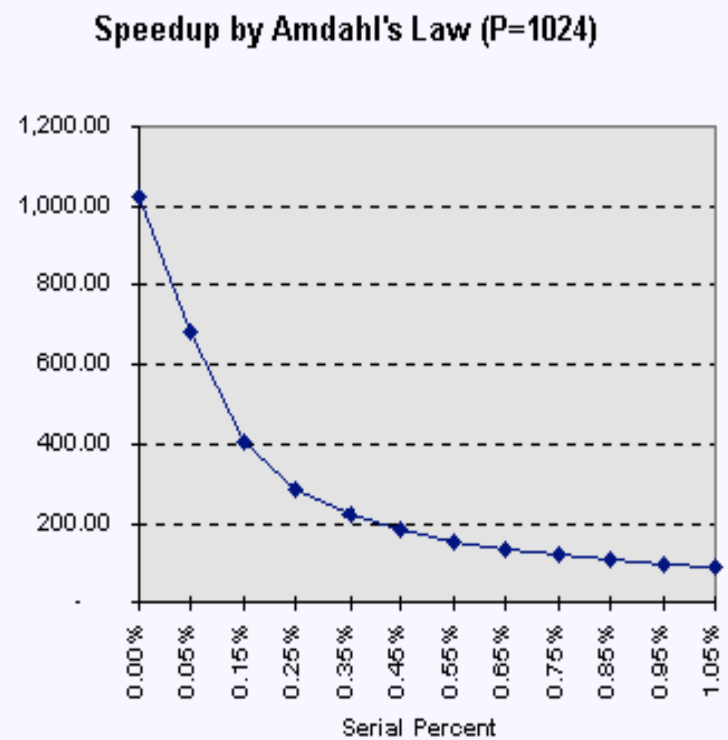
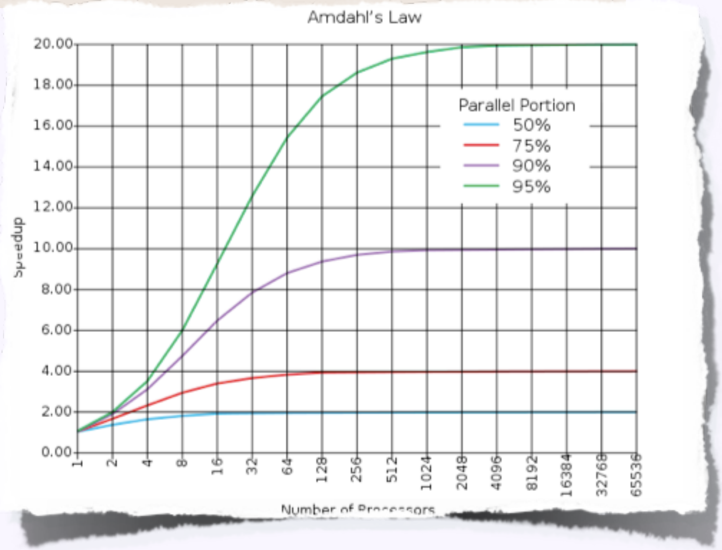


  - Suppose F = 10%. What is the max speedup? (you choose N)
    - As N approaches ∞, 1/(0.1 + 0.9/N) approaches 10.

Using Amdahl's law as a design guide

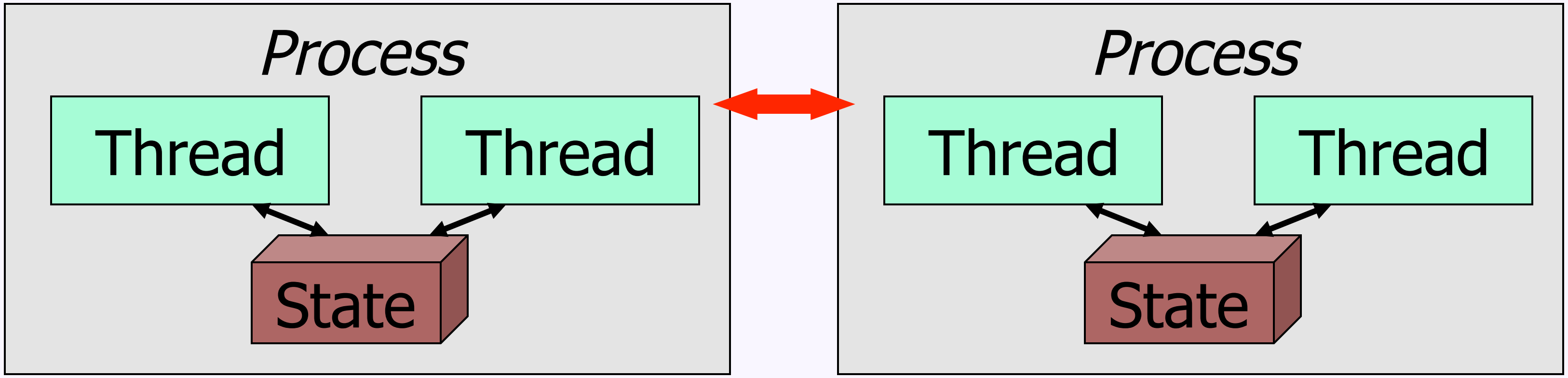


- For a given algorithm, suppose
  - `N` processors
  - Problem size `M`
  - Sequential portion `F`
- An obvious question:
  - What happens to speedup as `N` scales?
- Another important question:
  - What happens to `F` as problem size `M` scales?

"For the past 30 years, computer performance has been driven by Moore's Law; from now on, it will be driven by Amdahl's Law."
— Doron Rajwan, Intel Corp

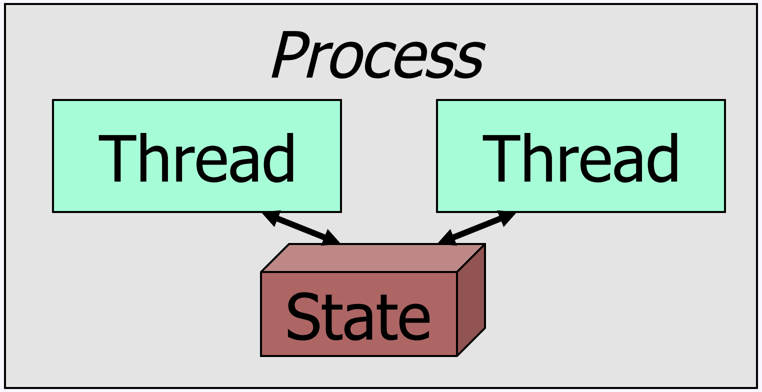
Abstractions of concurrency

- Processes
  - Execution environment is isolated
    - Processor, in-memory state, files, …
  - Inter-process communication typically slow, via message passing
    - Sockets, pipes, …
- Threads
  - Execution environment is shared
  - Inter-thread communication typically past, via shared state

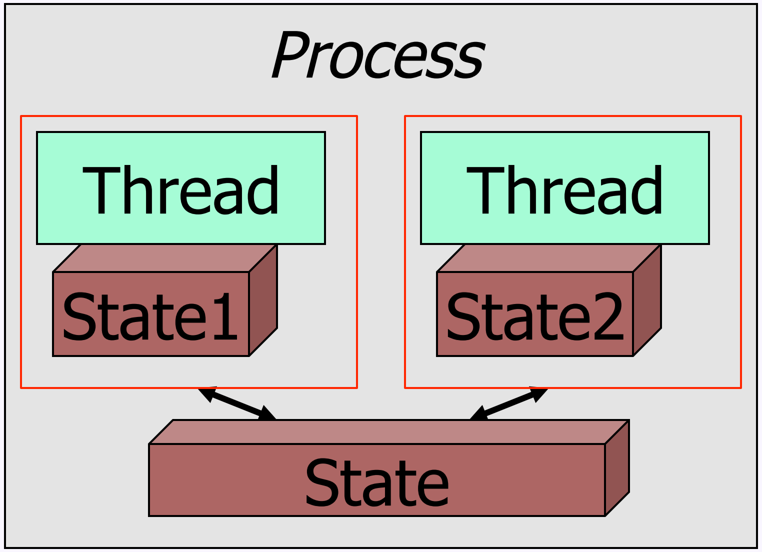


Aside: Abstractions of concurrency

- What you see:
  - State is all shared



- A (slightly) more accurate view of the hardware:
  - Separate state stored in registers and caches
  - Shared state stored in caches and memory



Basic concurrency in Java

- The `java.lang.Runnable` interface

```
void           run();
```

- The `java.lang.Thread` class

```
Thread(Runnable r);
void           start();
static void    sleep(long millis);
void           join();
boolean        isAlive();
static Thread currentThread();
```

- See IncrementTest.java

Thursday:

- More concurrency