The Beauty and Joy of Computing

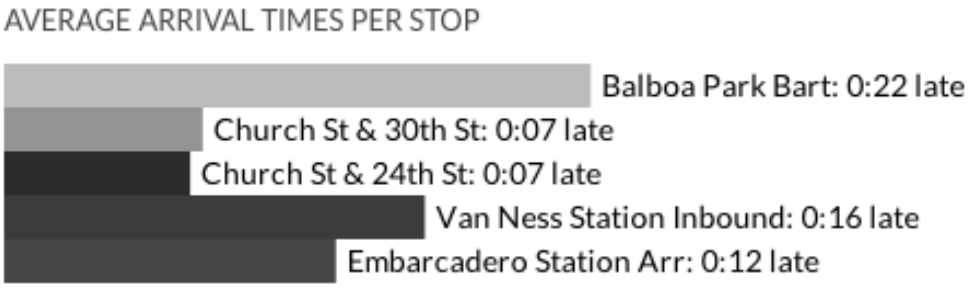
Lecture #7
Concurrency

Instructor :
Sean Morris

Quest (first exam) in **5 days!**
In this room!

Mozilla Ignite: Smarter Busses

The competition called for cutting-edge app ideas that would leverage ultra-fast, programmable networks to advance national priorities such as healthcare, energy, transportation and education in creative and innovative ways.



http://nsf.gov/news/news_summ.jsp?cntn_id=128315&org=NSF&from=news
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Concurrency & Parallelism, 10 mi up…

Intra-computer

- Today's lecture
- Multiple computing "helpers" are cores within one machine
- Aka "multi-core"
  - Although GPU parallism is also "intra-computer"

Inter-computer

- Week 6's lectures
- Multiple computing "helpers" are different machines
- Aka "distributed computing"
  - Grid & cluster computing

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Anatomy: 5 components of any Computer

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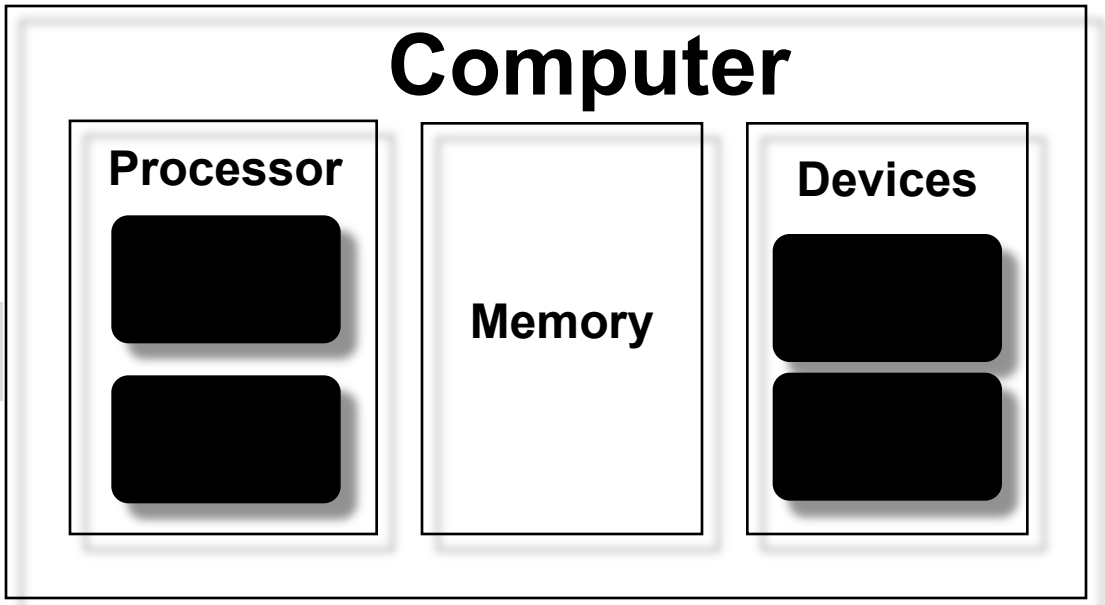
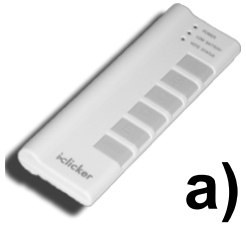
John von Neumann invented this architecture





a) Control
b) Datapath
c) Memory
d) Input
e) Output

What causes the most headaches for SW and HW designers with multi-core computing?

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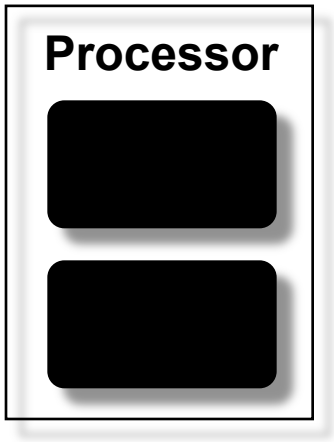
But what is INSIDE a Processor?



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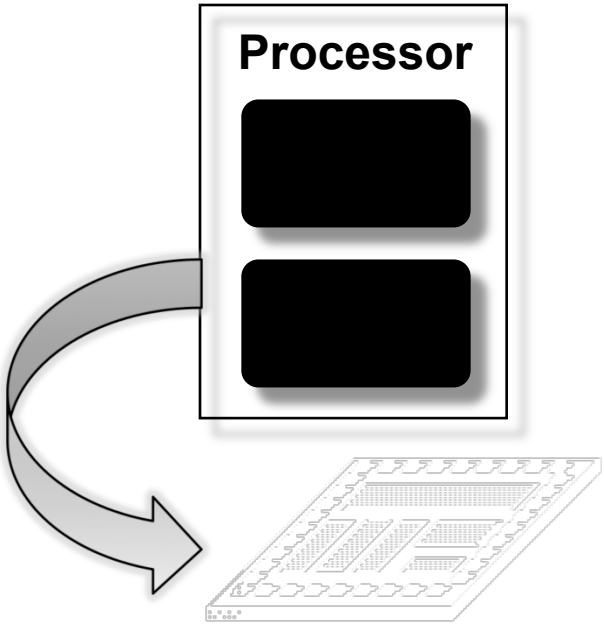
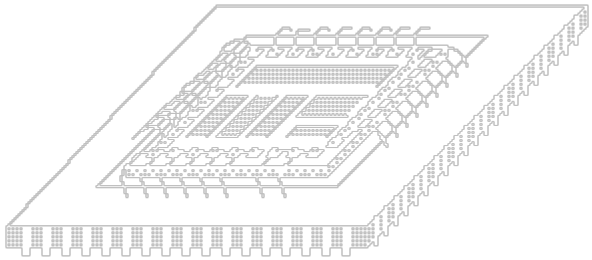


Bare Processor Die



Chip in Package

- Primarily Crystalline Silicon
- 1 mm – 25 mm on a side
- 2012 “feature size” (aka process)
  ~ 22 nm = 22 x 10^{-9} m
  (16 maybe [by yr 2014]) – the limit(!?))
- 100 - 2000M transistors
- 3 - 10 conductive layers
- “CMOS” (complementary metal oxide semiconductor) - most common

- **Package provides:**
  - **board-level**
  - **heat dissipation.**
- **Ceramic or plastic with gold wires.**

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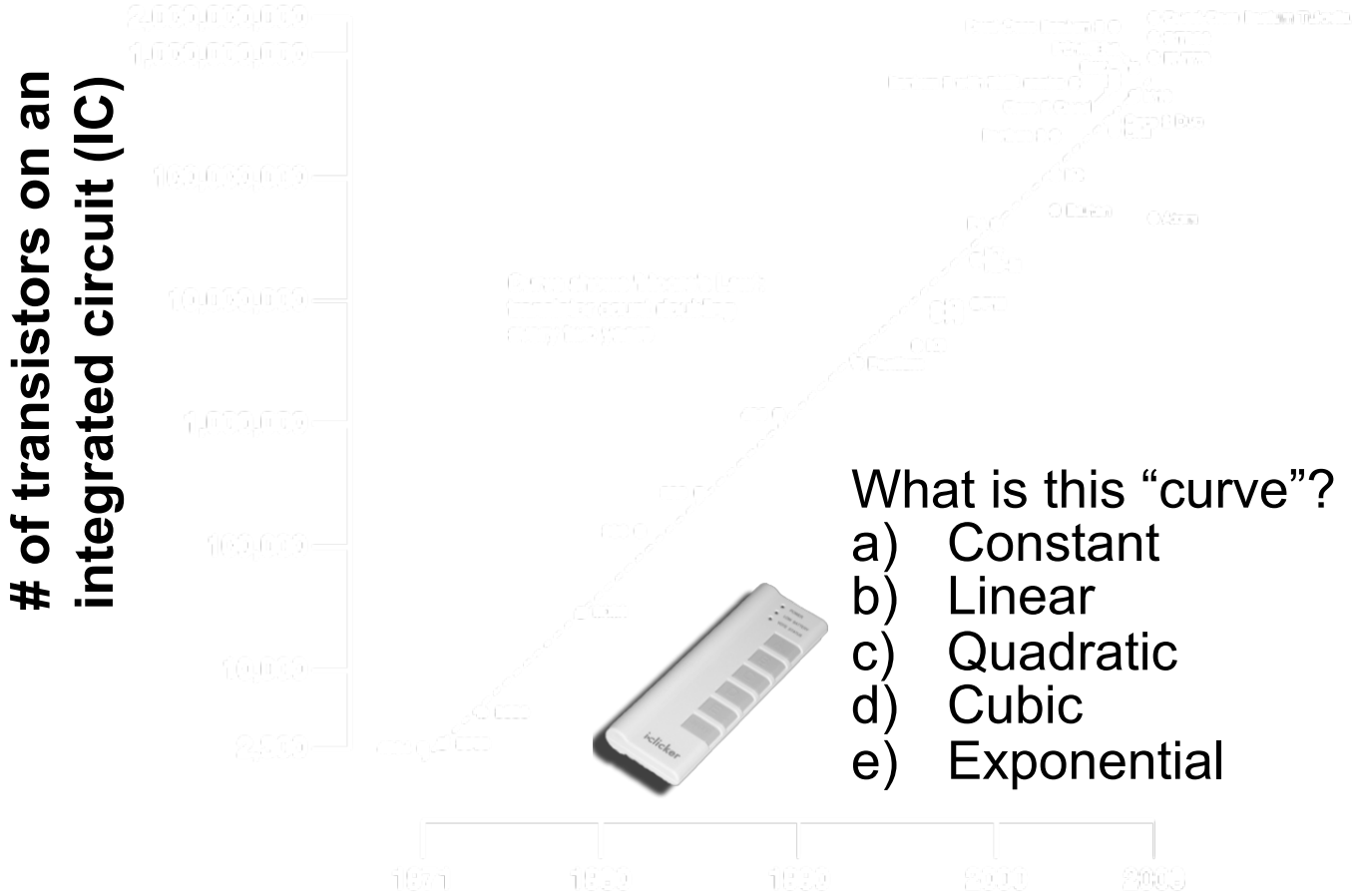
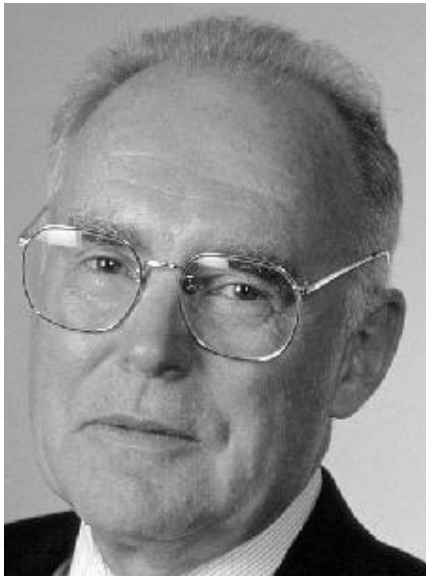
Moore's Law

Predicts: 2X Transistors / chip every 2 years



What is this "curve"?

a) Constant
b) Linear
c) Quadratic
d) Cubic
e) Exponential



Gordon Moore
Intel Cofounder
B.S. Cal 1950!

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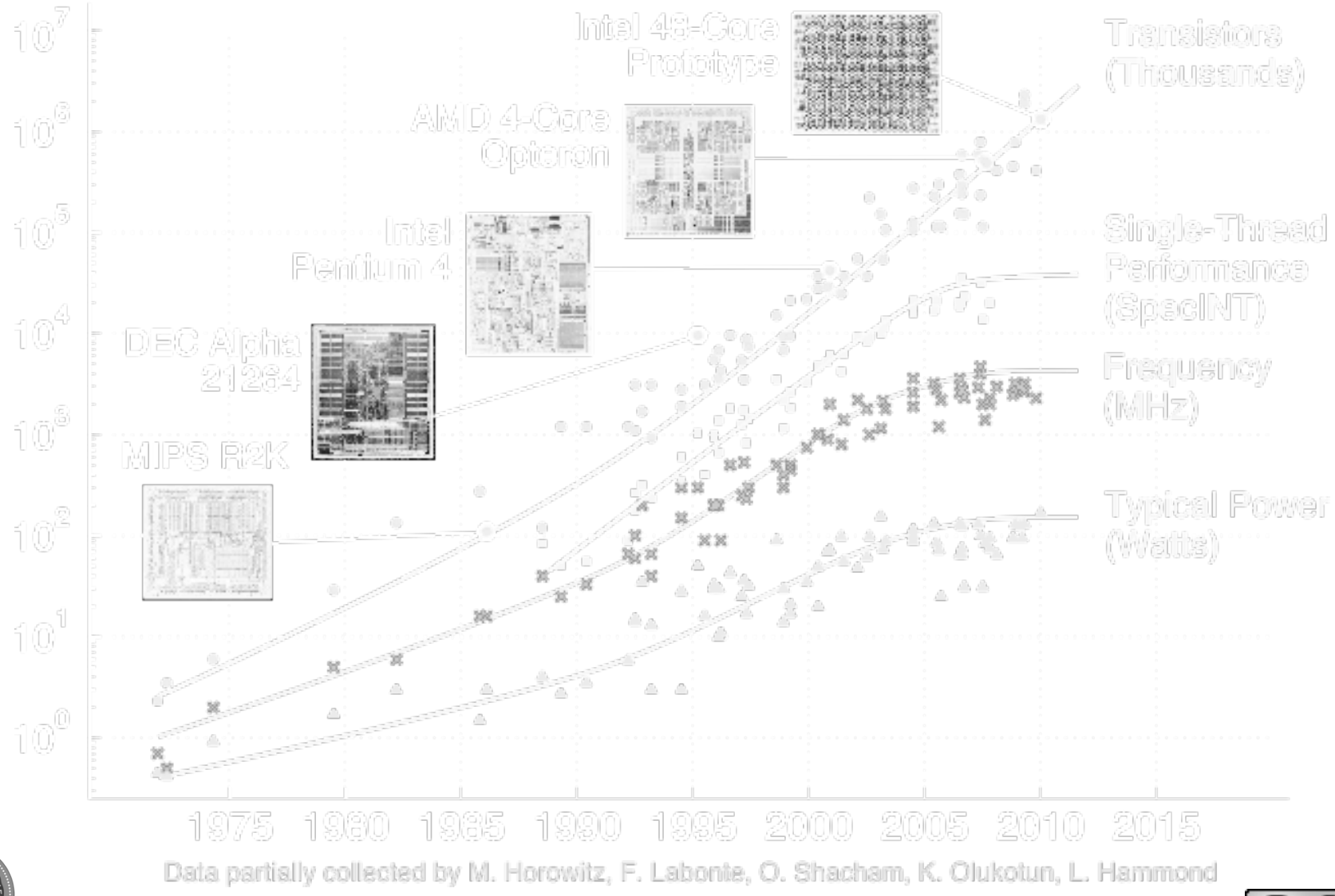
Moore's Law and related curves



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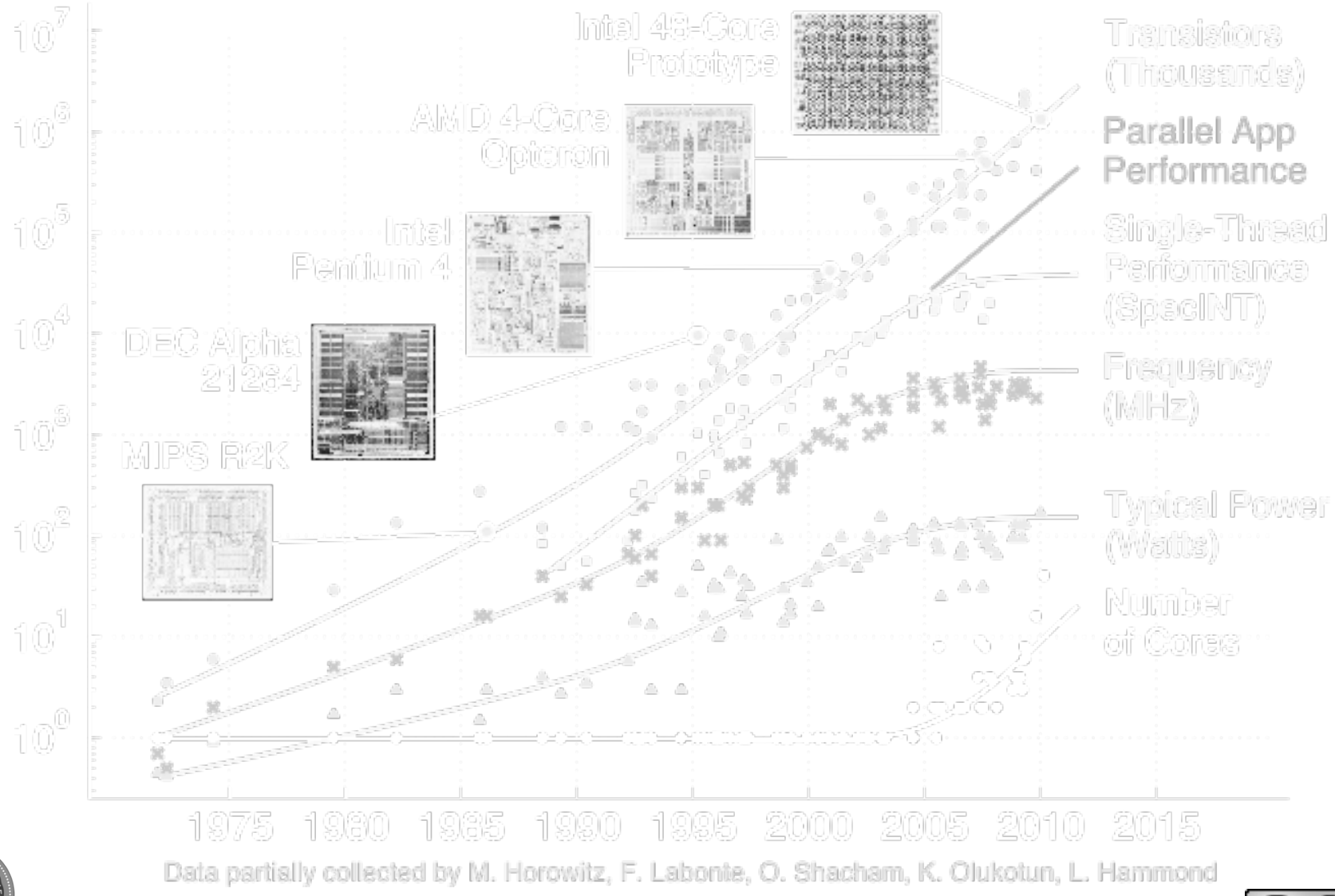
Moore's Law and related curves



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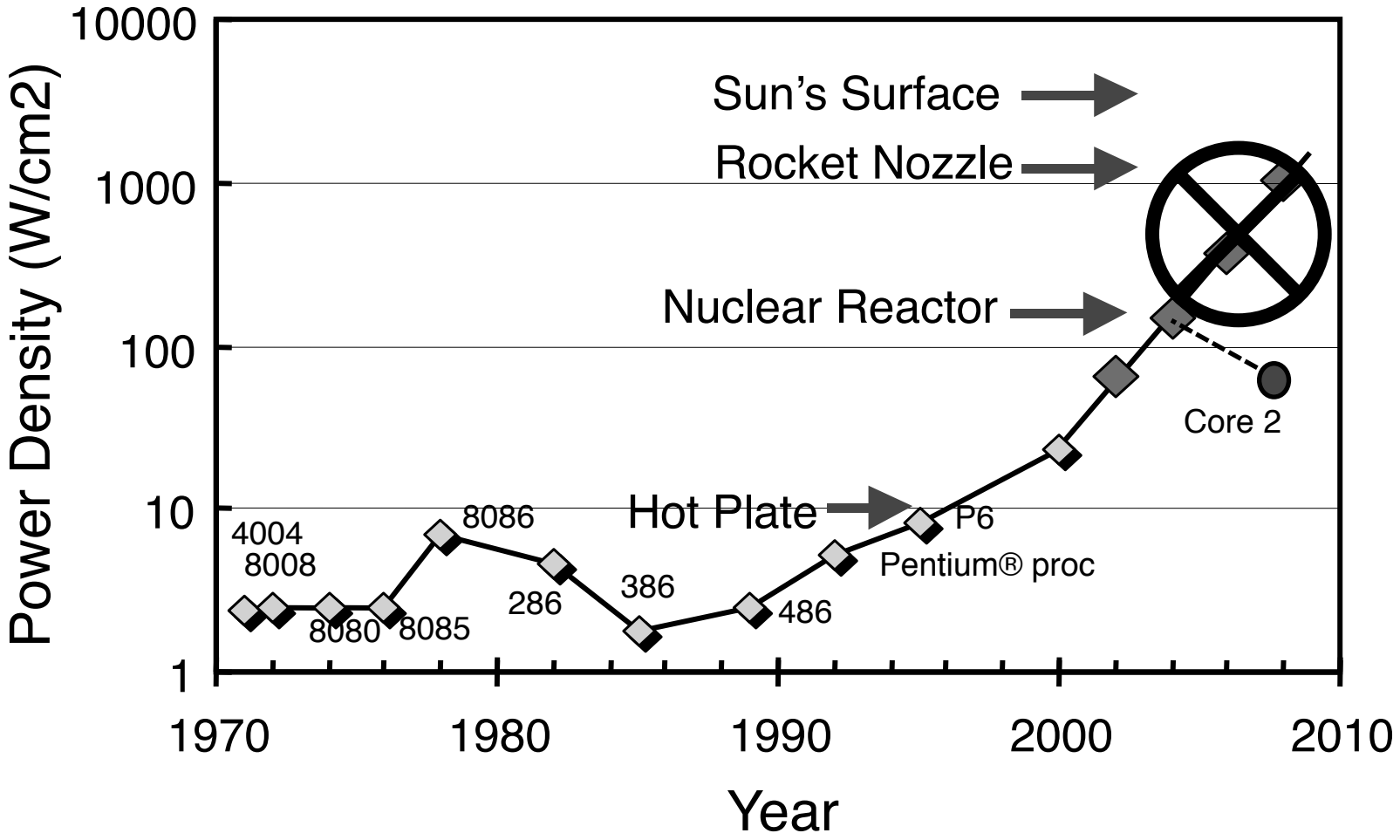
Power Density Prediction circa 2000



Source: S. Borkar (Intel)

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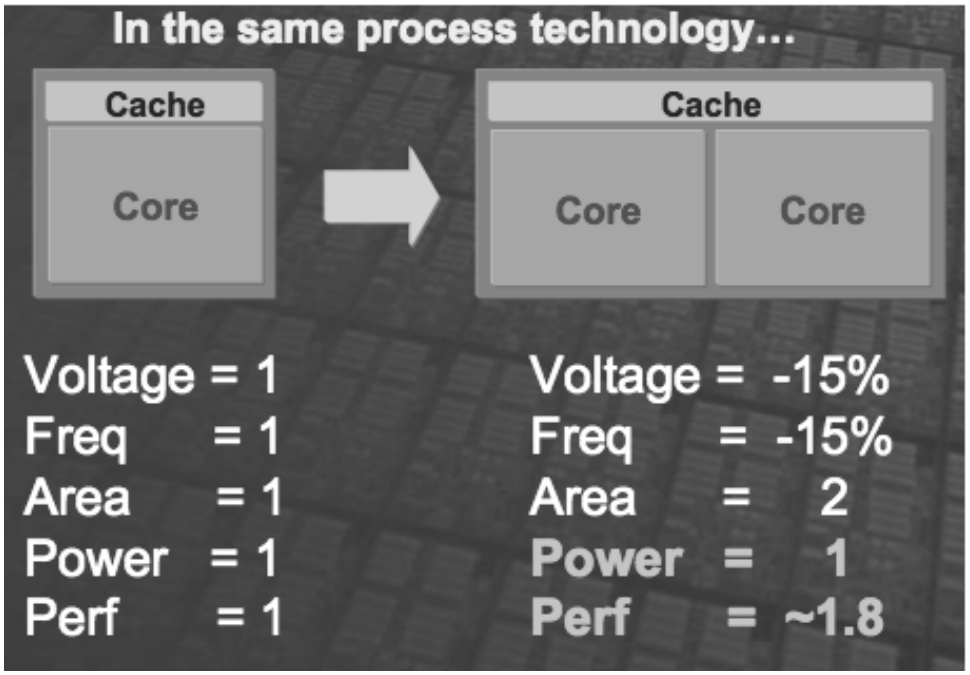
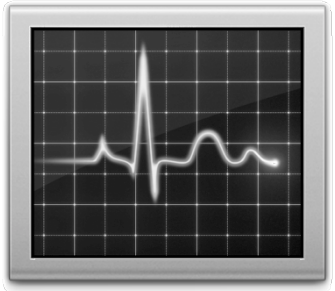
Going Multi-core Helps Energy Efficiency

- Power of typical integrated circuit ~ C V^2 *f*
  - C = Capacitance, how well it "stores" a charge
  - V = Voltage
  - *f* = frequency. I.e., how fast clock is (e.g., 3 GHz)



William Holt, HOT Chips 2005



Activity Monitor (on the lab Macs) shows how active your cores are

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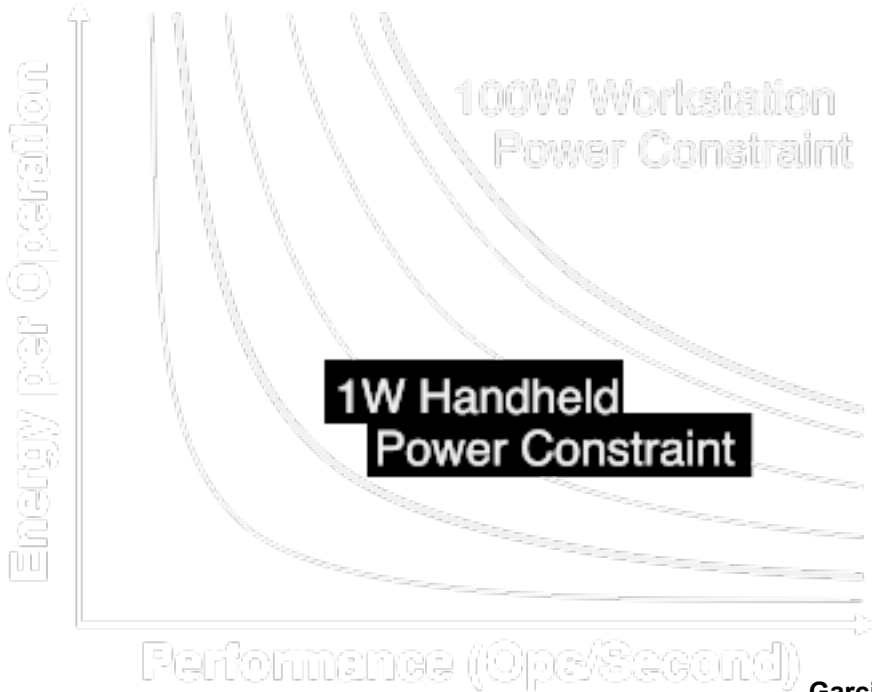
Energy & Power Considerations

$$\text{Power} = \frac{\text{Energy}}{\text{Second}} = \frac{\text{Energy}}{\text{Op}} \times \frac{\text{Ops}}{\text{Second}}$$

Power	Energy
Chip Packaging	Battery Life
Chip Cooling	Electricity Bill
System Noise	Mobile Device Weight
Case Temperature	
Data-Center Air Conditioning	



Courtesy: Chris Batten

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Parallelism again? What's different this time?

triumphant stride forward based on breakthroughs in novel software and architectures for parallelism; instead, this plunge into parallelism is actually a retreat from even greater challenges that thwart efficient silicon implementation of traditional uniprocessor architectures."

– Berkeley View, December 2006

- HW/SW Industry bet its future that breakthroughs will appear before it's too late

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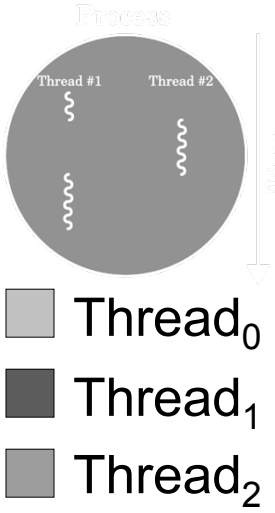
Background: Threads

- A *Thread* stands for "thread of execution", is a single stream of instructions
  - A program / process can split, or fork itself into separate threads, which can (in theory) execute simultaneously.
  - An easy way to describe/think about parallelism
- A single CPU can execute many threads by *Time Division Multiplexing*



- *Multithreading* is running multiple threads through the same hardware

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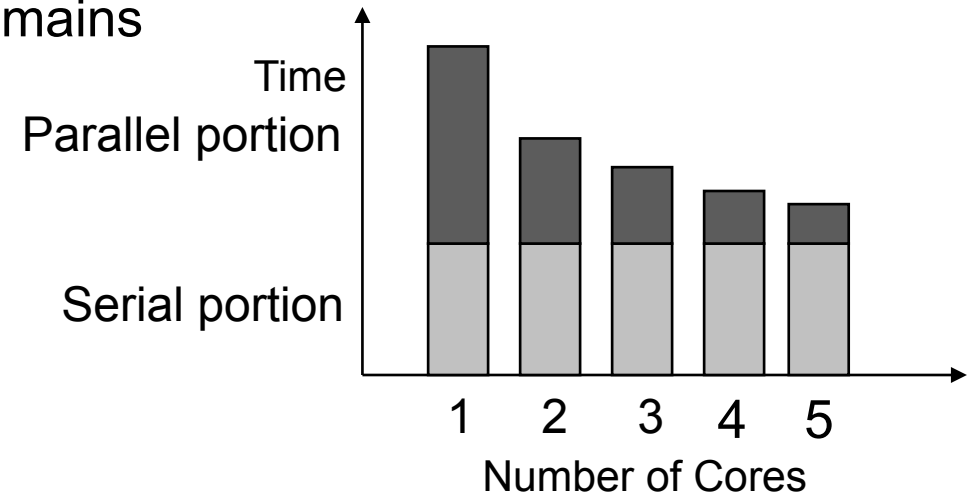
Speedup Issues : Amdahl's Law

- Applications can almost never be completely parallelized; some serial code remains



- s is serial fraction of program, C is # of cores (was processors)
- **Amdahl's law:**

$$Speedup(C) = \frac{Time(1)}{Time(C)} \leq \frac{1}{[s + \frac{(1-s)}{C}]}$$ (and C → ∞) so, $\leq \frac{1}{s}$

- Even if the parallel portion of your application speeds up perfectly, your performance may be limited by the sequential portion

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Speedup Issues : Amdahl's Law

- Try this out …

$$Speedup(C) = \frac{Time(1)}{Time(C)} \leq \frac{1}{[s + \frac{(1-s)}{C}]} \text{ (and C → ∞) so, } \leq \frac{1}{s}$$

Ex. 1: 100% serialized

Ex. 2: 80% parallelized, 4 cores

Ex. 3: 80% parallelized -> What is the best we can expect?

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Speedup Issues : Overhead

- Even assuming no sequential portion, there's…
  - Time to think how to divide the problem up
  - Time to hand out small "work units" to workers
  - All workers may not work equally fast

  - Some workers may fail
  - There may be contention for shared resources
  - Workers could overwriting each others' answers
  - You may have to wait until the last worker returns to proceed (the slowest / weakest link problem)
  - There's time to put the data back together in a way that looks as if it were done by one

Garcia

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Life in a multi-core world…

- This "sea change" to multi-core parallelism means that the computing community has to rethink:
  a) Languages
  b) Architectures
  c) Algorithms
  d) Data Structures
  e) All of the above

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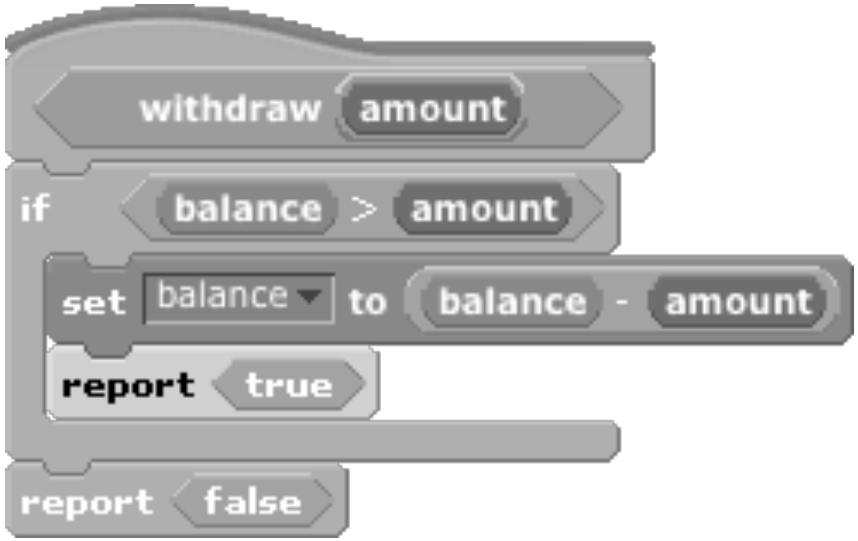
en.wikipedia.org/wiki/Concurrent_computing

But parallel programming is hard!

- What if two people were calling withdraw at the same time?
  - E.g., balance=100 and two withdraw 75 each
  - Can anyone see what the problem *could* be?
  - This is a race condition
- In most languages, this is a problem.
  - In Scratch, the system doesn't let two of these run at once.



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Another concurrency problem … deadlock!

- Two people need to draw a graph but there is only one pencil and one ruler.
  - One grabs the pencil
  - One grabs the ruler
  - Neither release what they hold, waiting for the other to release
- Livelock also possible
  - Movement, no progress
  - 2 people in a hallway

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Summary

- "Sea change" of computing because of inability to cool CPUs means we're now in multi-core world
- This brave new world offers lots of potential for innovation by computing professionals, but challenges persist

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