The Beauty and Joy of Computing

Lecture #10
Concurrency

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"KOOMEY'S LAW" – EFFICIENCY 2X EVERY 18 MO

Prof Jonathan Koomey looked at 6 decades of data and found that energy efficiency of computers doubles roughly every 18 months. This is even more relevant as battery-powered devices become more popular. Restated, it says that for a fixed computing load, the amount of battery you need drops by half every 18 months. This was true before transistors!

www.technologyreview.com/computing/38548/

Concurrency: A Definition

Concurrency: A property of computer systems in which several computations are executing simultaneously, and potentially interacting with each other.

Concurrency is Everywhere!

Examples:

- Mouse cursor movement while Snap*!* calculates.
- Screen clock advances while typing in a text.
- Busy cursor spins while browser connects to server, waiting for response
- Walking while chewing gum

Concurrency & Parallelism

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

- Future lecture
- Multiple computing "helpers" are different machines
- Aka "distributed computing"
  - Grid & cluster computing

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Anatomy: 5 components of any Computer

John von Neumann invented this architecture

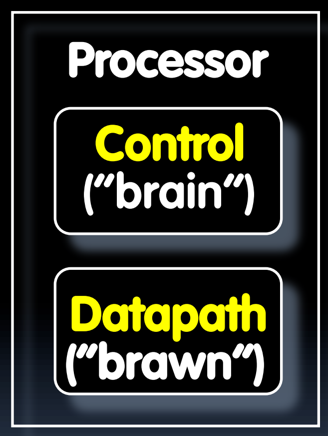
Computer

- **Processor**
  - Control ("brain")
  - Datapath ("brawn")
- **Memory**
- **Devices**
  - Input
  - Output

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

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

But what is INSIDE a Processor?



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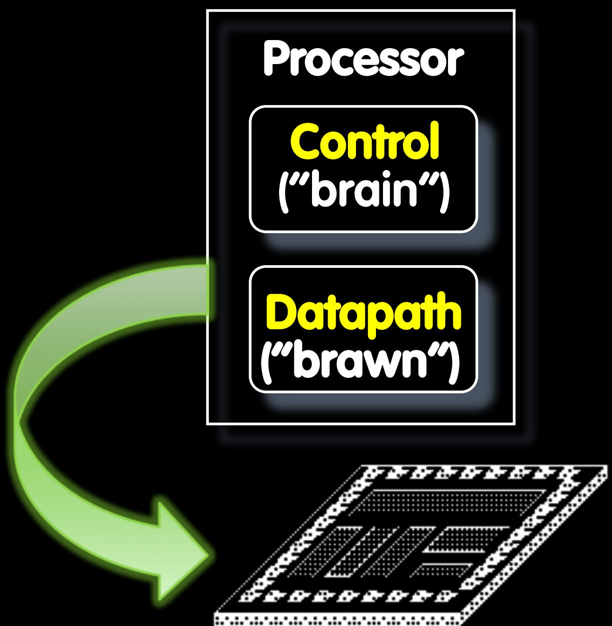
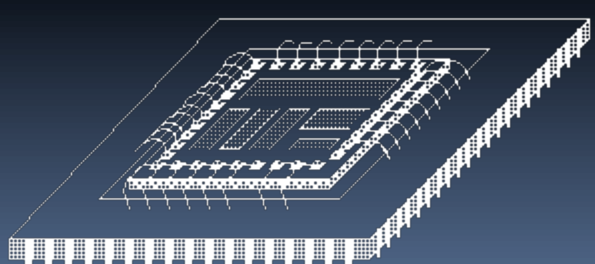


Bare Processor Die



Chip in Package

- Primarily Crystalline Silicon
- 1 mm – 25 mm on a side
- 2009 "feature size" (aka process) ~ 45 nm = 45 x 10^{-9} m (then 32, 22, and 16 [by yr 2013])
- 100 - 1000M transistors
- 3 - 10 conductive layers
- "CMOS" (complementary metal oxide semiconductor) - most common

- Package provides:
  - spreading of chip-level signal paths to board-level
  - heat dissipation.
- Ceramic or plastic with gold wires.

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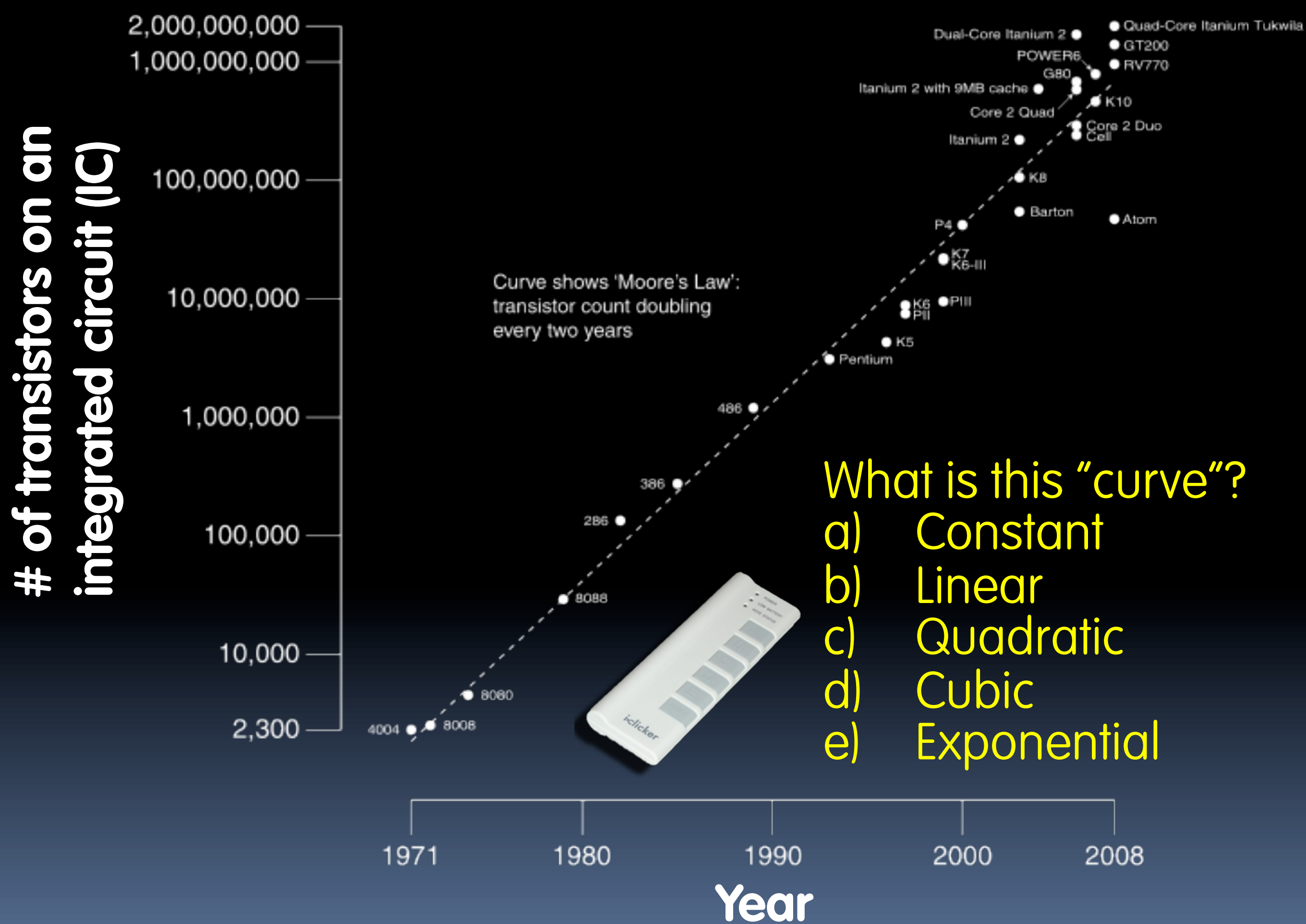
en.wikipedia.org/wiki/Moore's_law

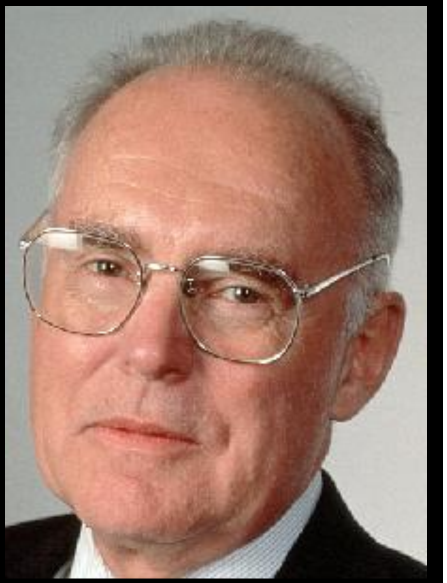
Moore's Law

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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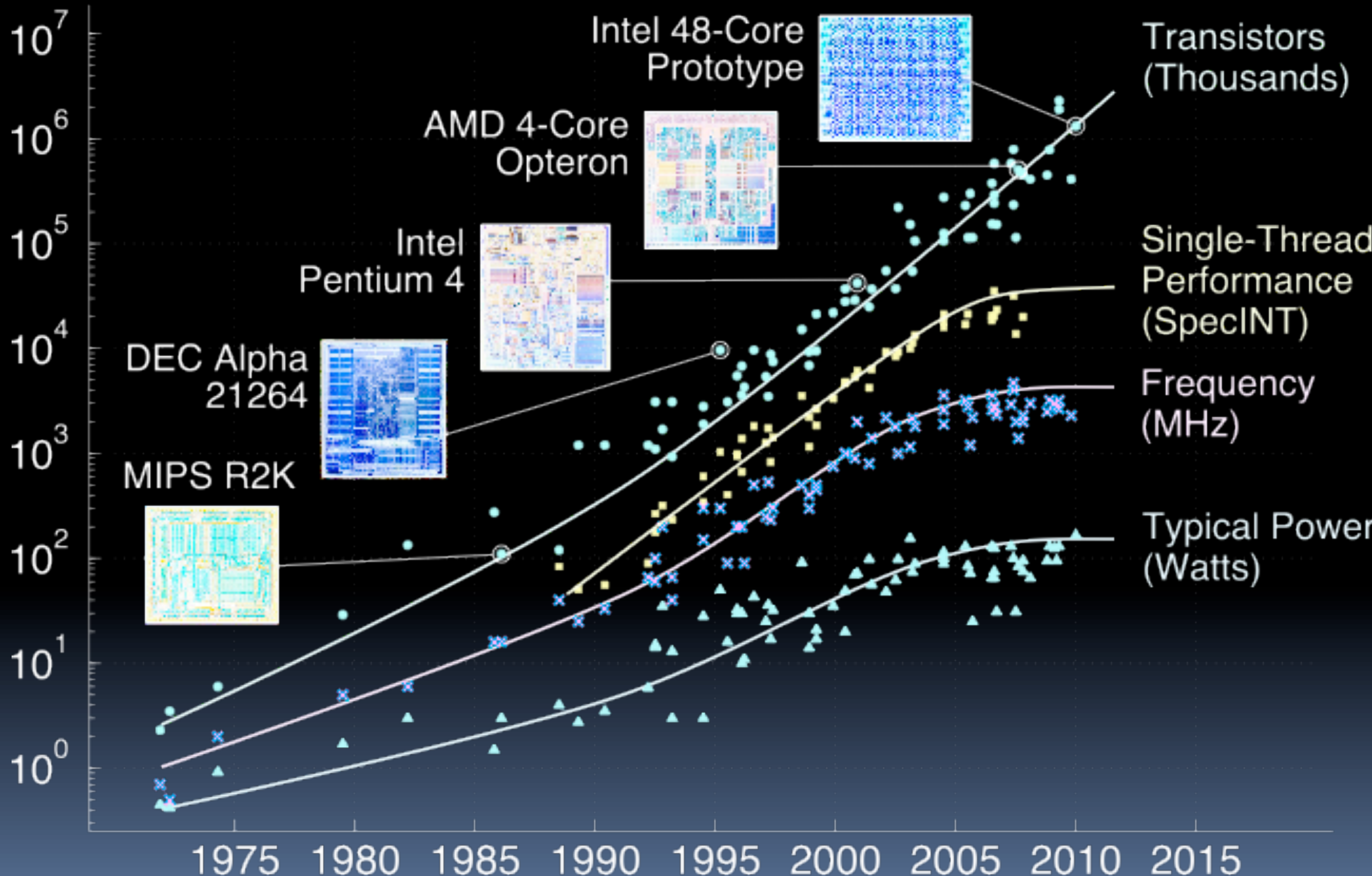
Moore's Law and related curves



Data partially collected by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond

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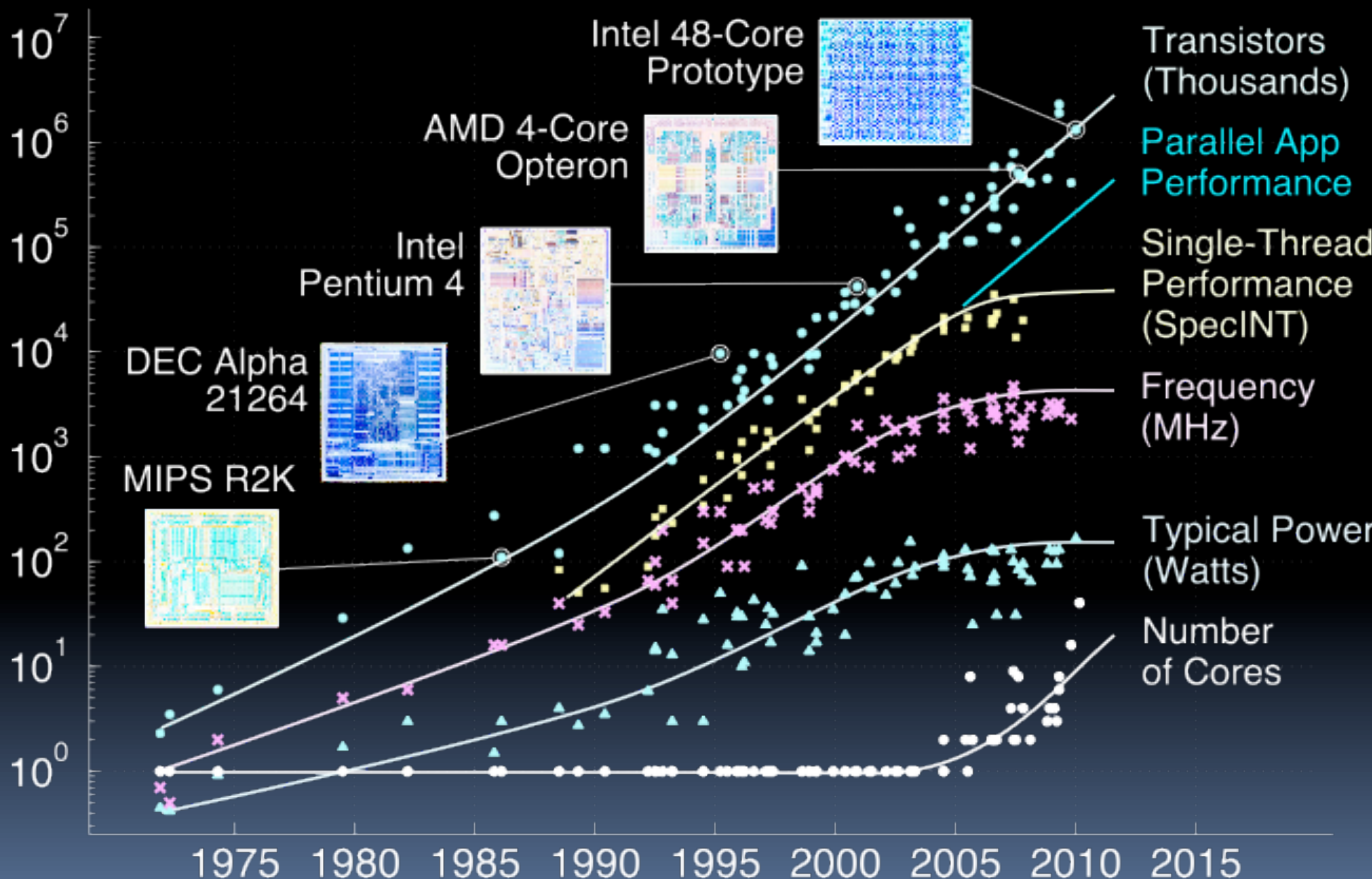
Moore's Law and related curves



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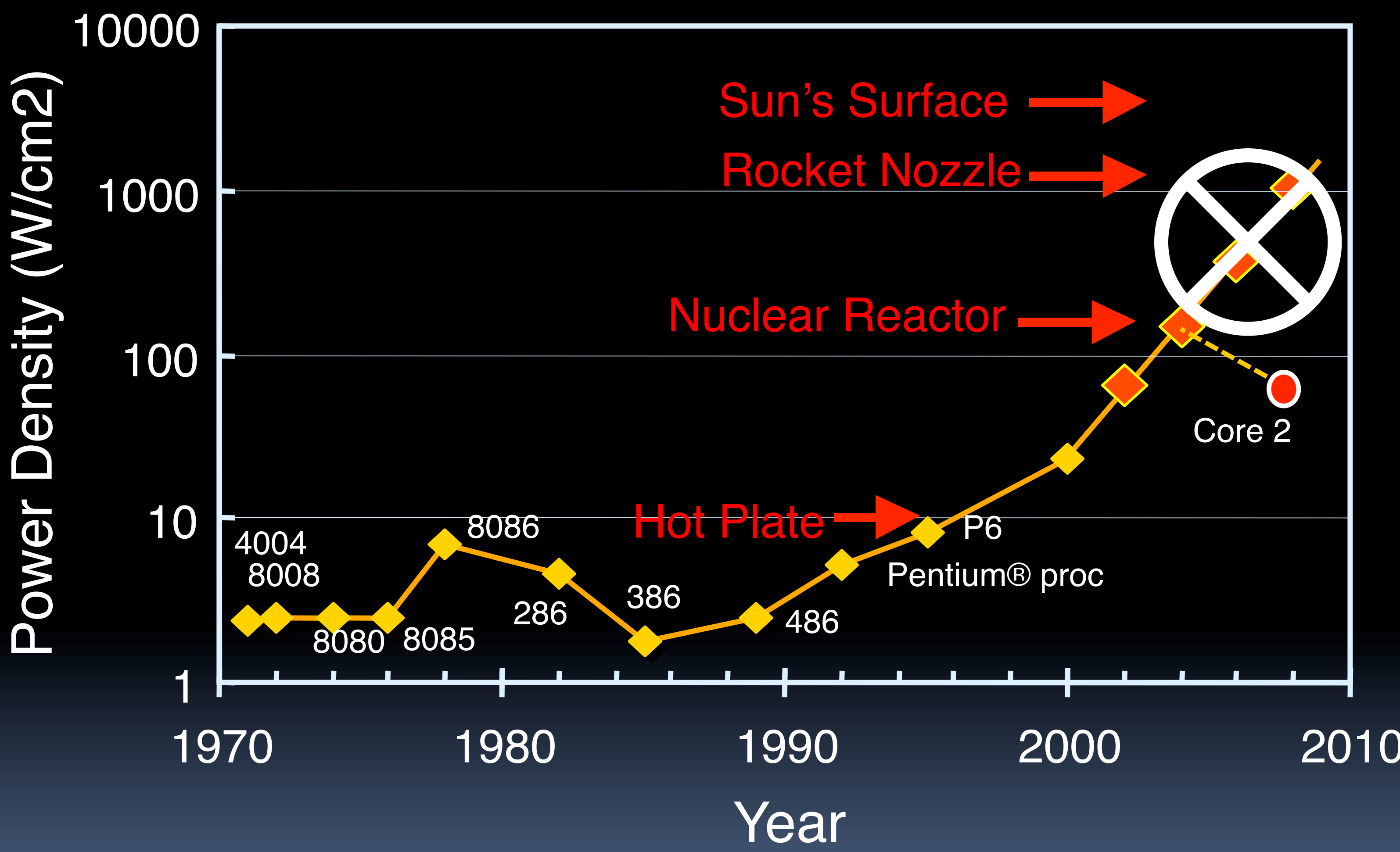
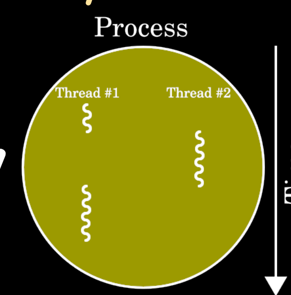
Power Density Prediction circa 2000



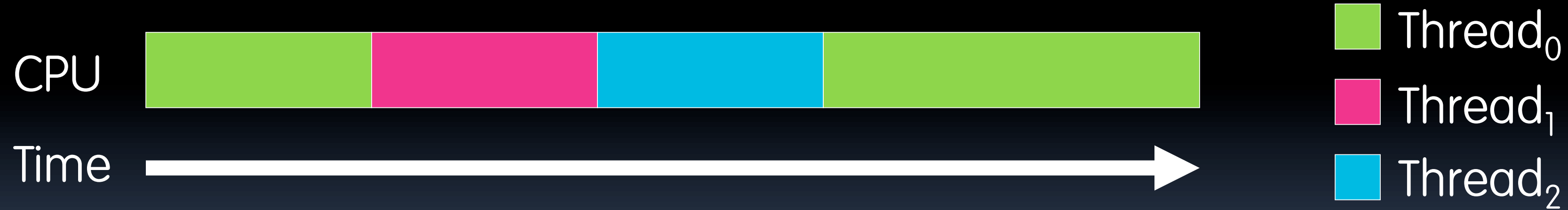
Source: S. Borkar (Intel)

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



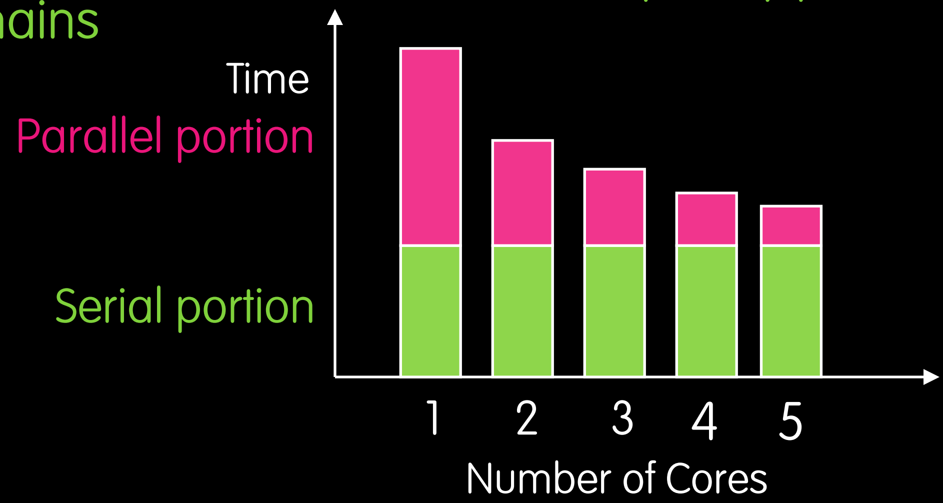
- A single CPU can execute many threads by ***Time Division Multipexing***



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

Speedup Issues : Amdahl's Law

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



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

Speedup(P) = Time(1) / Time(P)

$\leq 1 / (s + [(1-s) / P)]$, and as $P \rightarrow \infty$

$\leq 1 / s$

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

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

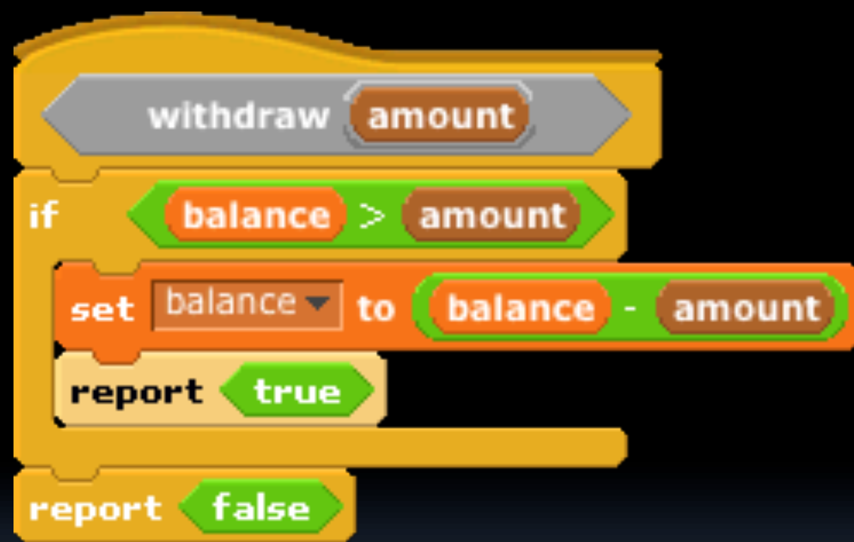
Life in a multi-core world…

- 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

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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en.wikipedia.org/wiki/Deadlock

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

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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