CS3014 Concurrent Systems I

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Big Brother

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College Calendar, Part I, General Regulations

Objectives

The goal of this course is to learn the basics of practical parallel programming with the goal of achieving real speedups on multi-core systems. This is best done with a good understanding of the architecture.

Lab Work

- Linux server with four eight core processors
  - 32 cores
  - stoker.cs.tcd.ie

Why learn this stuff?

- You are computer scientists
  - So you should understand
- You will program parallel computers
  - Computers are now parallel
- You will have to make higher-level decisions about using parallel machines
  - Is parallelism the solution to my problem?
- You may have to design parallel architectures
  - I thought I would never have to, but I did
- The ideas are transferable to other domains

Why write a parallel program?

- For software engineering reasons
  - Many programs simulate the real world
  - The real world is parallel
    - E.g. Computer games
- Because your problem is distributed
  - May involve multiple sites
    - E.g. mobile phones, PDAs, sensors
  - No choice
    - there must be multiple computers

Why write a parallel program?

- To solve your problem more quickly
  - Divide work across parallel units
  - Main focus of this course
- But normally we say that you shouldn’t worry about running speed
  - At least until you discover it is a problem
  - But certain types of applications benefit a lot from speed optimizations

Why write a parallel program?

- Parallelizing a program is a speed optimization like any other
- Some parallelization is automatic
  - By compiler or processor itself
  - This is easy and good
  - But limitations on what can be done automatically

Why write a parallel program?

- Biggest speedups come from writing your own parallel program
  - This can be difficult and error prone
  - Programmer time is expensive
  - Errors may be even more expensive
    - Nuclear power stations explode
    - Wrong leg is amputated due to database bug
  - You shouldn’t rush to write a parallel program just because you are using a parallel compute

Why write a parallel program?

- Parallelizing a program is a speed optimization like any other
  - Consider it in the context of other speed optimizations
  - Use the best algorithm & data structure
  - Make sure to enable the compiler optimizations
  - Perhaps consider small code changes to key loops

Why write a parallel program?

- Many programs are wildly inefficient
  - No serious attempt to make them fast
    - And rightly so!
  - It’s usually pretty easy to get a factor of two speedup on most programs with simple optimizations
    - This is the very most we can expect from parallelizing on a dual-core processor
    - Even on 16 cores, a speedup of 5-6 might be good

Why write a parallel program?

- But sometimes you need more speed
  - Have a very efficient program
    - But still not fast enough
  - Parallel program will give more speed
- Some apps never fast enough
  - Games
  - Image processing
  - Scientific & engineering simulations
  - Code breaking

Why write a parallel program?

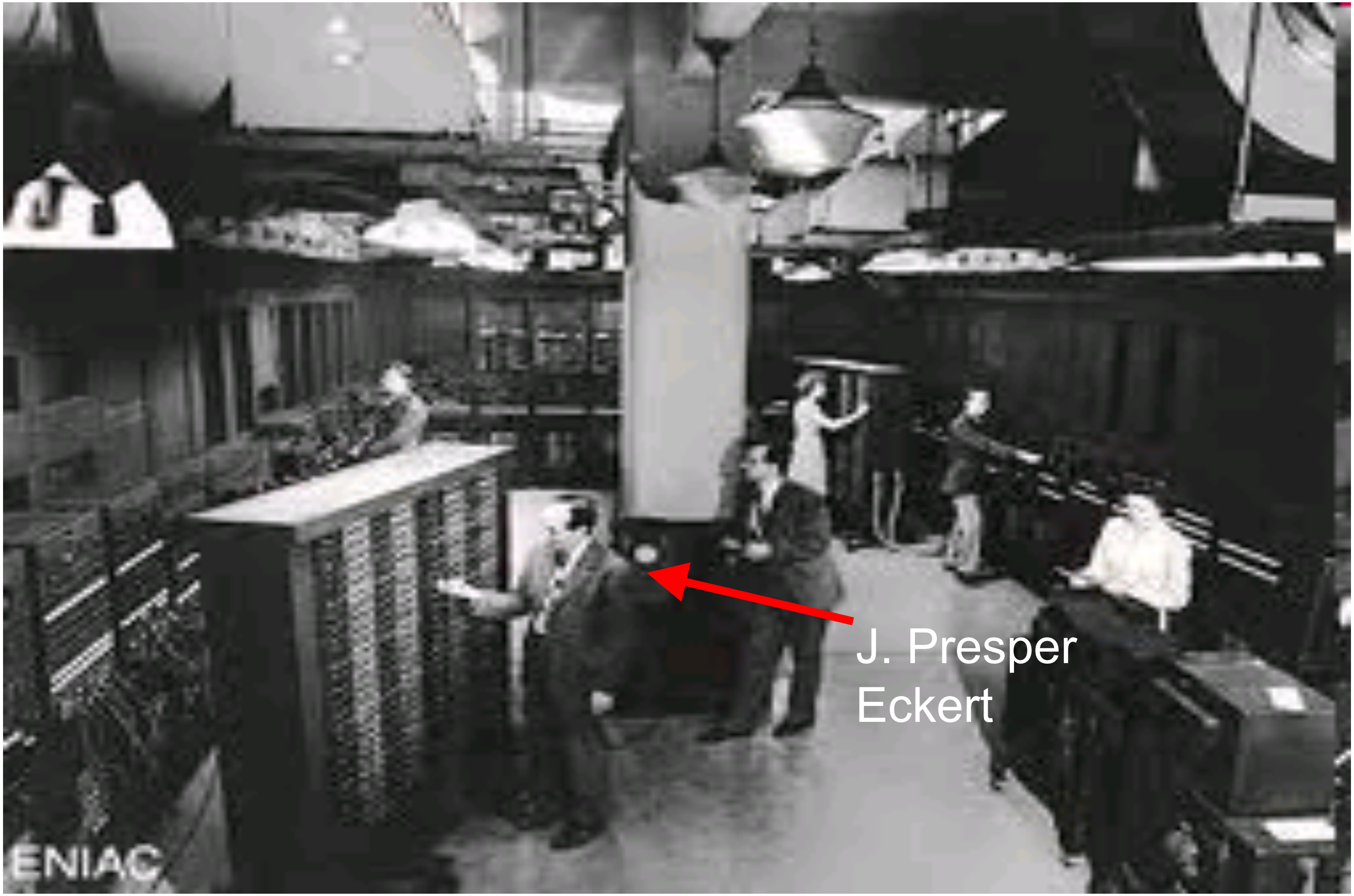
- Parallelism is also tied to energy
  - A parallel computer with several small processors may be more energy efficient than a similar machine with one super fast processor

Never forget Amdahl

"For over a decade prophets have voiced the contention that the organization of a single computer has reached its limits and that truly significant advances can only be made by the interconnection of a multiplicity of computers in such a manner as to permit cooperative solution…. Demonstration is made of the continued validity of the single processor approach"

- Gene Myron Amdahl, 1967

Or J. Presper Eckert



J. Presper Eckert

- “Any steps that are programmed by the operator, who sets up the machine, should be set up only in a serial fashion. It has been shown over and over again that any departure from this procedure results in a system that is much too complicated to use.”

J. P. Eckert 1946

Long long ago in a distant time of single-core computer architecture

Notes borrowed from

David Patterson
Electrical Engineering and Computer Sciences
University of California, Berkeley

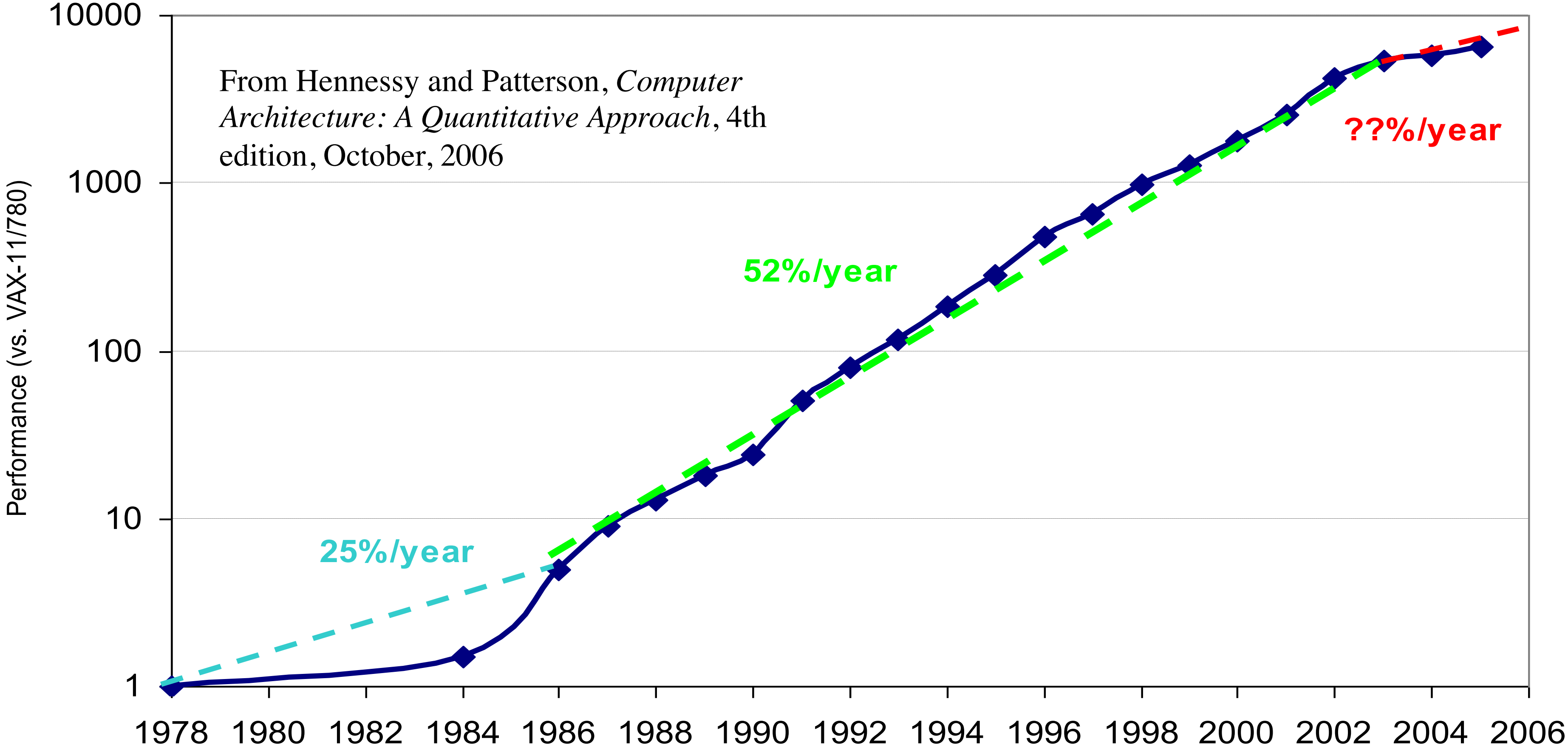
Crossroads 2005: Conventional Wisdom in Comp. Arch

- Old Conventional Wisdom (CW): Power is free, Transistors expensive
- New Conventional Wisdom: "Power wall" Power expensive, transistors free (Can put more on chip than can afford to turn on)
- Old CW: Sufficiently increasing Instruction Level Parallelism via compilers, innovation (Out-of-order, speculation, VLIW, …)
- New CW: "ILP wall" law of diminishing returns on more HW for ILP
- Old CW: Multiplies are slow, Memory access is fast
- New CW: "Memory wall" Memory slow, multiplies fast (200 clock cycles to DRAM memory, 4 clocks for multiply)
- Old CW: Uniprocessor performance 2X / 1.5 yrs
- New CW: Power Wall + ILP Wall + Memory Wall = Brick Wall
  - Uniprocessor performance now 2X / 5(?) yrs

⇒ Sea change in chip design: multiple "cores"
(2X processors per chip / ~ 2 years)

- More simpler processors are more power efficient

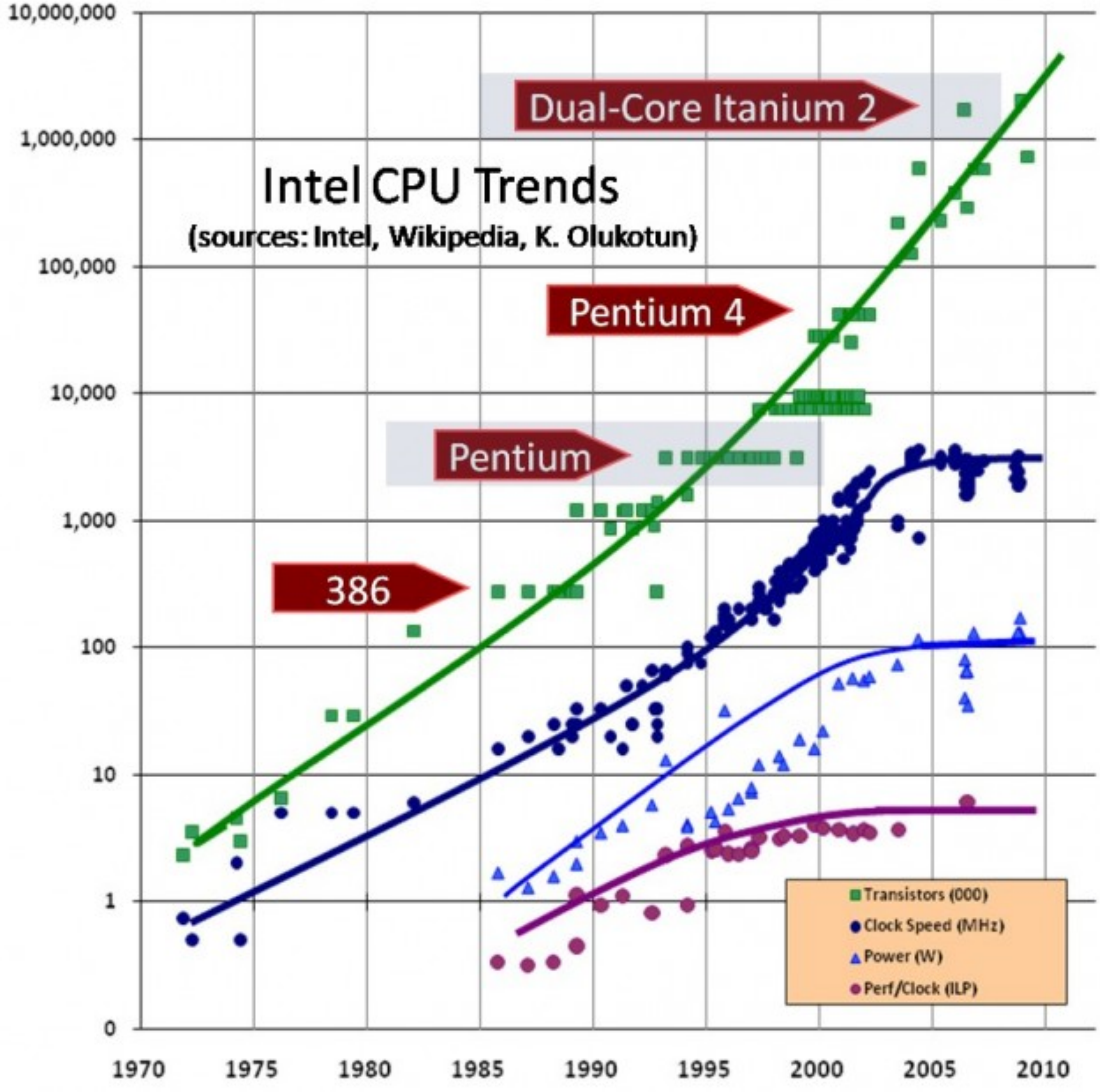
Crossroads: Uniprocessor Performance



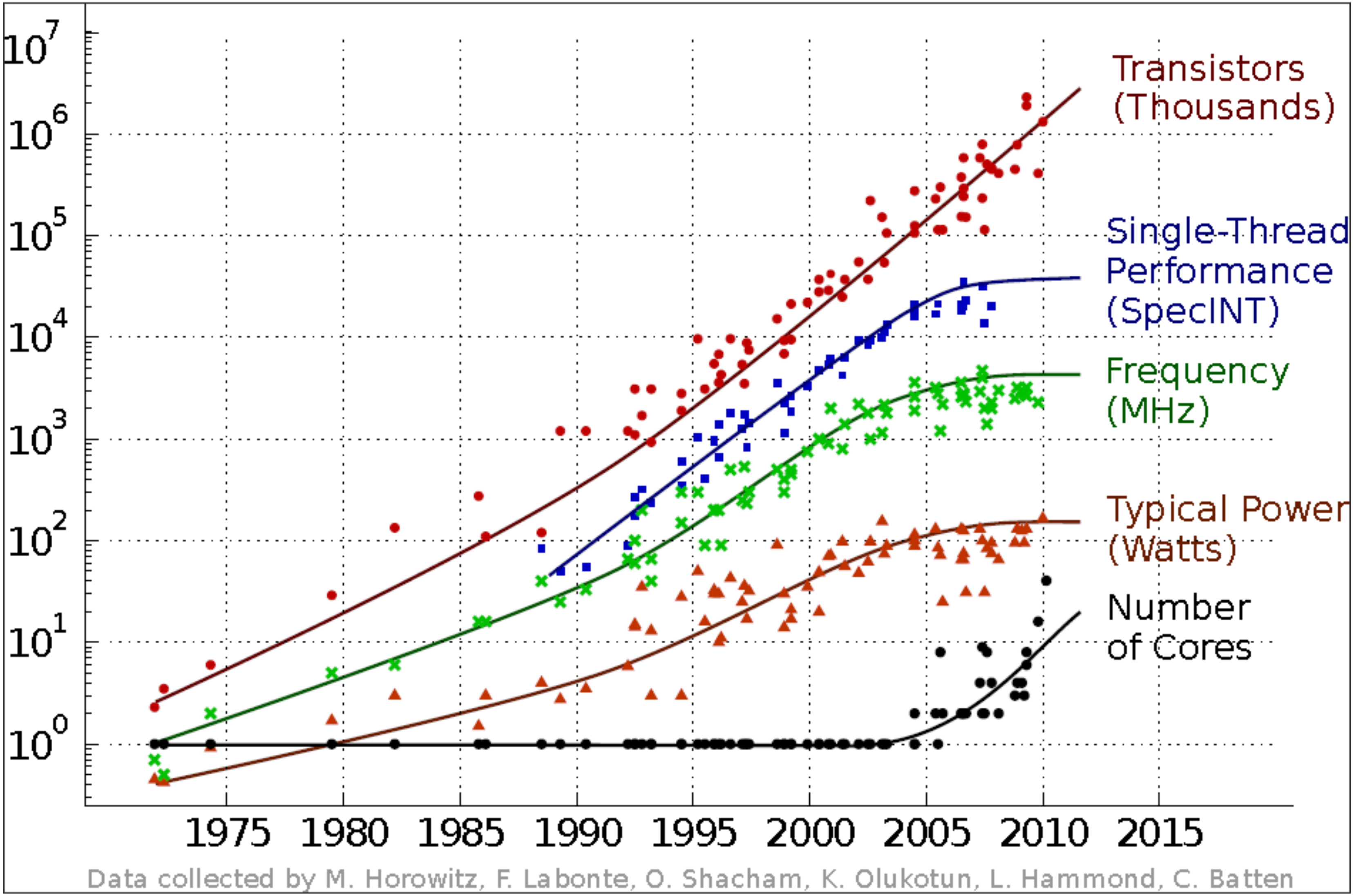
From Hennessy and Patterson, *Computer Architecture: A Quantitative Approach*, 4th edition, October, 2006

- **VAX : 25%/year 1978 to 1986**
- **RISC + x86: 52%/year 1986 to 2002**

The death of CPU scaling: From one core to many — and why we’re still stuck - Joel Hruska



DATA PROCESSING IN EXASCALE-CLASS COMPUTER SYSTEMS - Chuck Moore

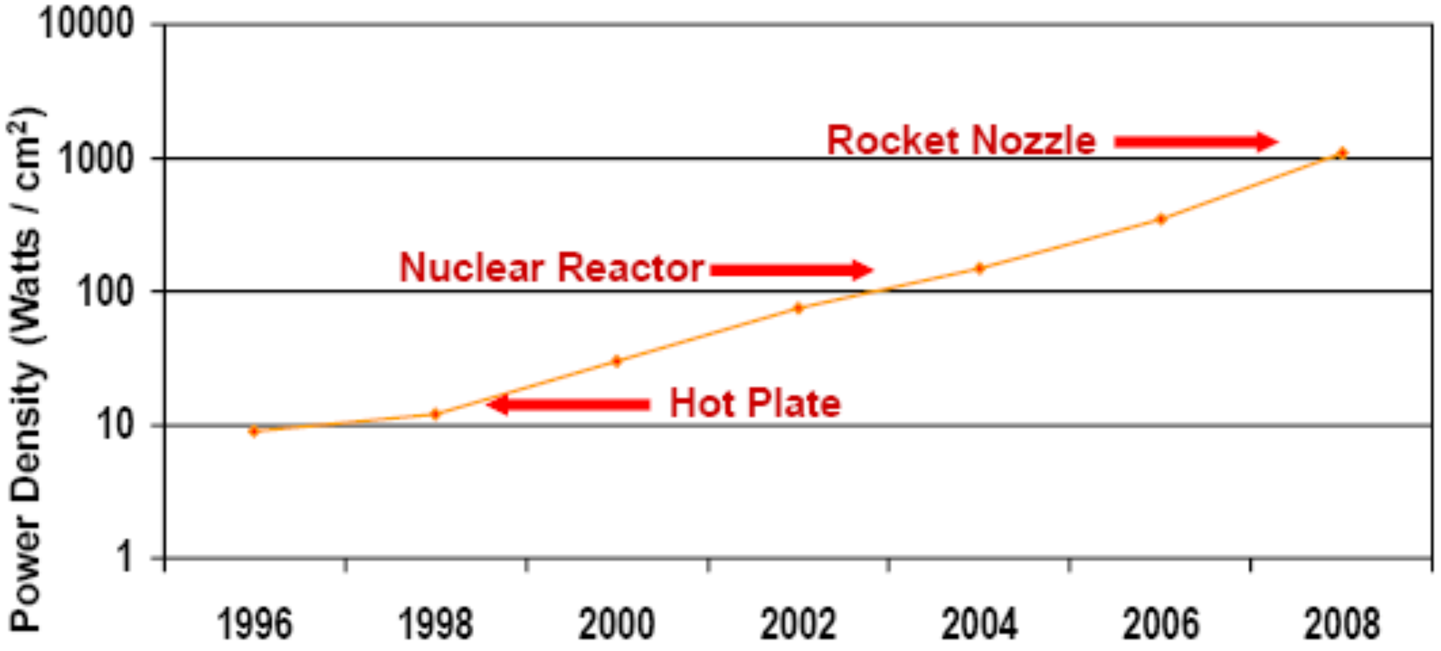


1. Original data collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond and C. Batten. Dotted line extrapolations by C. Moore

Limiting Force: Power Density

Moore's Law Extrapolation:

Power Density for Leading Edge Microprocessors



Power Density Becomes Too High to Cool Chips Inexpensively

Source: Shekhar Borkar, Intel Corp

Déjà vu all over again?

- Multiprocessors imminent in 1970s, ‘80s, ‘90s, ..
- “… today’s processors … are nearing an impasse as technologies approach the speed of light..”

  David Mitchell, *The Transputer: The Time Is Now* (1989)
- Transputer was premature

  ⇒ Custom multiprocessors strove to lead uniprocessors

  ⇒ Procrastination rewarded: 2X seq. perf. / 1.5 years
- “We are dedicating all of our future product development to multicore designs. … This is a sea change in computing”

  Paul Otellini, President, Intel (2004)
- Difference is all microprocessor companies switch to multiprocessors (AMD, Intel, IBM, Sun; all new Apples 2 CPUs)

Problems with Sea Change

- Algorithms, Programming Languages, Compilers, Operating Systems, Architectures, Libraries, … not ready to supply Thread Level Parallelism or Data Level Parallelism for 1000 CPUs / chip,
- Architectures not ready for 1000 CPUs / chip
    - Unlike Instruction Level Parallelism, cannot be solved by just by computer architects and compiler writers alone, but also cannot be solved *without* participation of computer architects

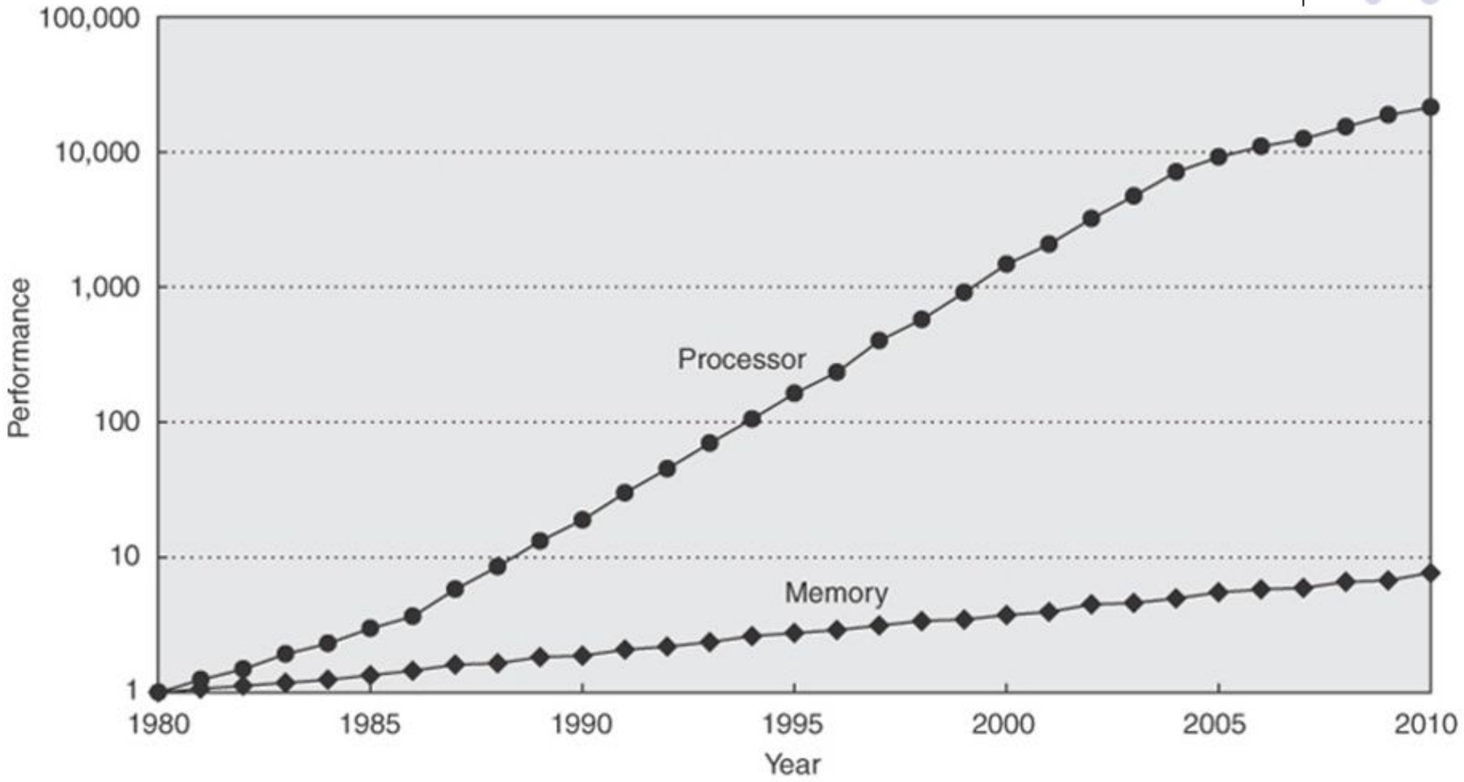
Some of the key performance issues

- Use an efficient algorithm
  - and data structures
  - with efficient implementation
- Locality
  - It is difficult to underestimate the importance of locality
  - But it is almost invisible to the programmer
- Parallelism
  - Multiple threads (everyone talks about this)
  - Vector parallelism (just as important)

The “memory wall”

Memory Speed:

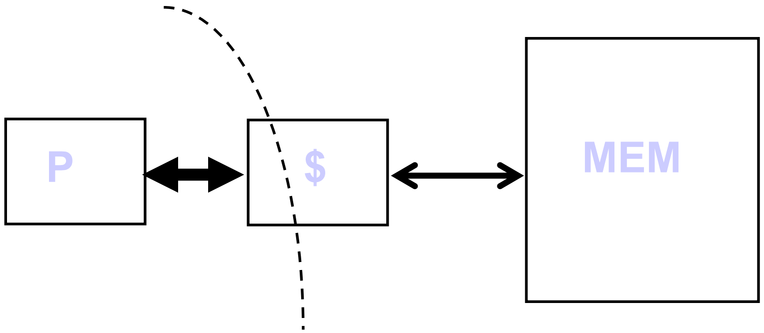
Widening of the Processor-DRAM Performance Gap



Courtesy of Elsevier, Computer Architecture, Hennessey and Patterson, fourth edition

The Principle of Locality

- The Principle of Locality:
  - Programs access a relatively small portion of the address space at any instant of time.
- Two Different Types of Locality:
  - Temporal Locality (Locality in Time): If an item is referenced, it will tend to be referenced again soon (e.g., loops, reuse)
  - Spatial Locality (Locality in Space): If an item is referenced, items whose addresses are close by tend to be referenced soon (e.g., straight-line code, array access)
- Last 30 years, HW relied on locality for memory perf.



Levels of the Memory Hierarchy

Capacity
Access Time
Cost

CPU Registers
100s Bytes
300 – 500 ps (0.3-0.5 ns)

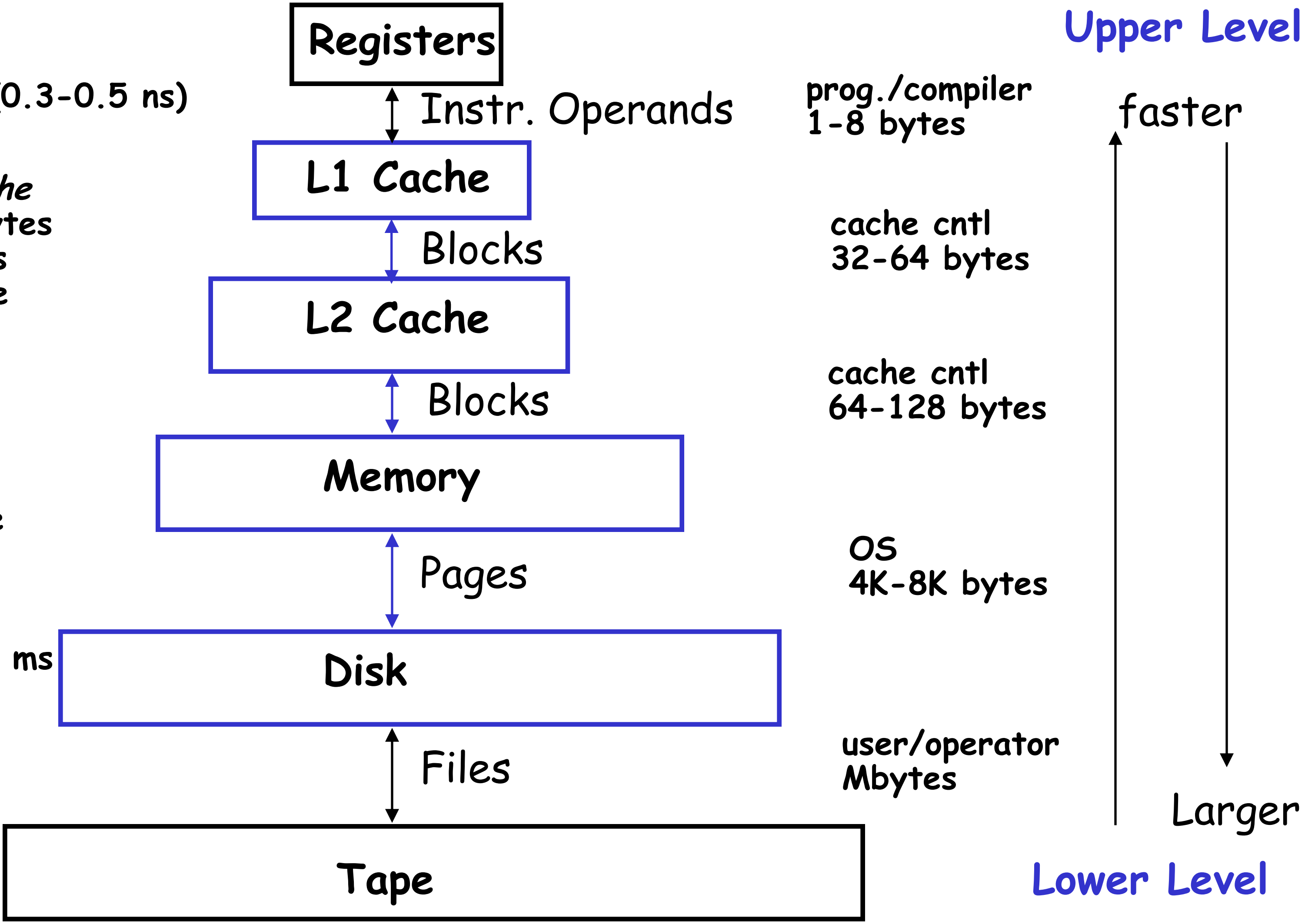
L1 and L2 Cache
10s-100s K Bytes
~1 ns - ~10 ns
$1000s/ GByte

Main Memory
G Bytes
80ns- 200ns
~ $100/ GByte

Disk
10s T Bytes, 10 ms
(10,000,000 ns)
~ $1 / GByte

Tape
infinite
sec-min
~$1 / GByte

Staging
Xfer Unit



Registers

Instr. Operands

prog./compiler
1-8 bytes

L1 Cache

Blocks

cache cntl
32-64 bytes

L2 Cache

Blocks

cache cntl
64-128 bytes

Memory

Pages

OS
4K-8K bytes

Disk

Files

user/operator
Mbytes

Tape

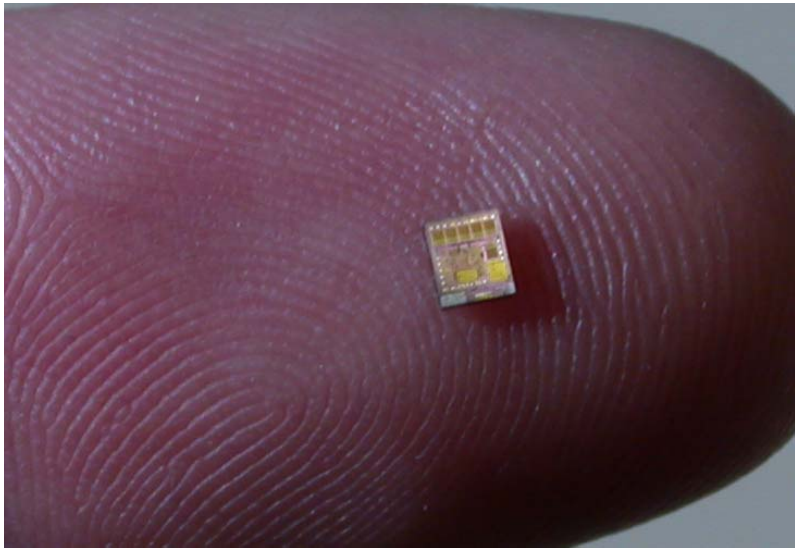
Upper Level

faster

Larger

Lower Level

It’s not just about bigger and faster!



- The world changed in 2005 with multicore processors
  - “I for one welcome our new multicore overlords”
- But that’s not the end of the story…

The Teeny Years

- Since 2010 computer architecture has been changing
- Are these changes really fundamental?
  - Or does it just seem that way because we're living through it?
  - It's difficult to say

- Changes are being driven by a mix of…
  - Computer hardware technology
  - Applications

- Applications are really important
  - We design computers to run particular types of applications well
  - There is no such thing as a fast computer
  - The question is always, what type of applications can it run fast?
  - If the type of important applications change, we design new computers

Some recent changes

- <u>Computing has moved off the desktop</u>
- Part of computing has moved to the cloud
  - Computing in big centralized facilities
  - It sometimes seems almost like a trip back to the 1960s
- Part of computing has moved to mobile devices
  - Since the 1970s there has been lots of embedded computing
    - In cars, TVs, washing machines, factories
  - But now people are carrying their computer with them
  - Is it like the microcomputer revolution all over again?

- <u>Computing continues to become smaller and cheaper</u>
  - Doubling of transistors on a chip every 18-24 months
  - Relentless falling in the cost of computing capacity
  - Falling costs allow better and more powerful computers in more devices
  - Which has helped to move computing from the desktop to mobile devices

Some recent changes

- Changes in types of applications
- We live in a time of self surveilance
  - People upload huge amounts of data about themselves
  - Huge amounts of data available unlike at any time before
    - E.g. Compared to Staatssicherheitsdienst in East Germany
  - Falling computing costs make it feasible to process that data
  - Makes new types of applications possible
- Computers are untethered from the desktop
  - Computers move around
  - They can collect data from cameras, microphones, GPS
  - New data available to be processed
  - Falling computing costs make it feasible to process that data
  - Makes new types of applications possible

Some recent changes

- Developments in AI
- Deep neural networks are really good at some tasks
  - Especially image processing
  - Train a neural network rather than writing a program
  - Enables much more sophisticated analysis of non-text data
    - E.g. The pictures of that night out that you upload
  - Also enables mobile autonomous computing
    - Especially drones, cars
  - Neural networks require HUGE amounts of processing capacity