Operating Systems COT 4600 – Fall 2009

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Office hours: Tu, Th 3:00-4:00 PM

- Last time:
  - Systems and Complexity
  - Sources of Complexity
- Today
  - Knowledge and ethics.
  - Modularity, Abstractions, Layering, Hierarchy (slides from Lecture 1)
  - Computer Systems (slides by Kaashoek & Morris)
- Next time:
  - Computer Systems versus Other Systems
  - Coping with Computer System Complexity

Slides by Kaashoek & Morris

Composibility via static discipline

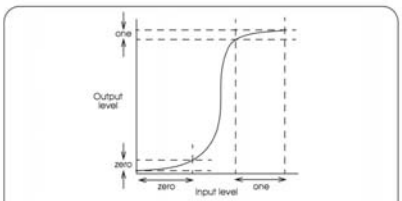


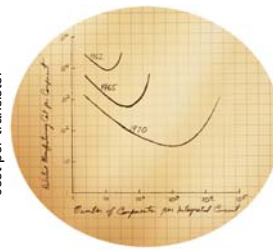
Figure 1-3: How gain and non-linearity of a digital component restore levels. The range of accepted inputs is much wider than the range of generated outputs.

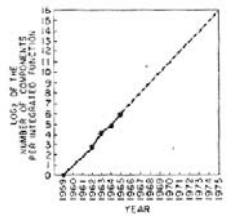
- Be tolerant of inputs and strict on outputs

Slides by Kaashoek & Morris

Moore's law

cost per transistor



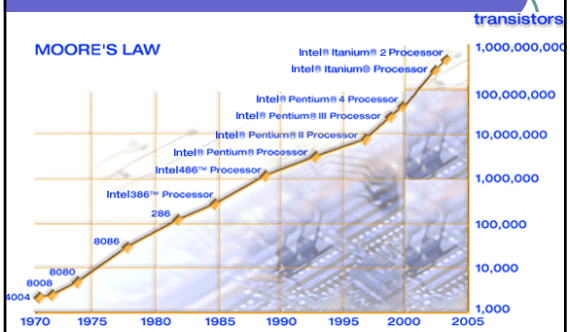


transistors per die

"Cramming More Components Onto Integrated Circuits", *Electronics*, April 1965

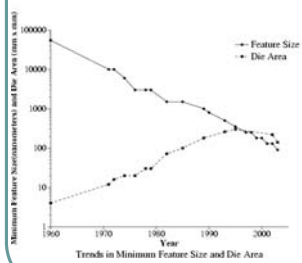
Slides by Kaashoek & Morris

Transistors/die doubles every ~18 months



Slides by Kaashoek & Morris

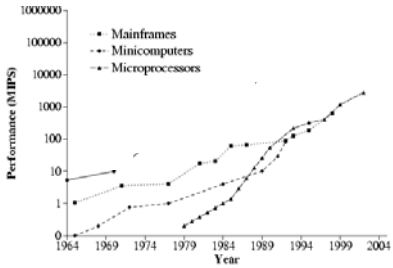
Lithography: the driver behind transistor count



- Components/area O(x^2) with feature size
- Total components O(a) with die area
- Switching rate O(x) with feature size

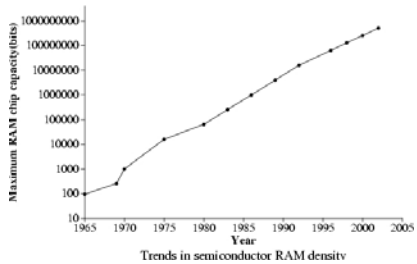
Slides by Kaashoek & Morris

CPU performance



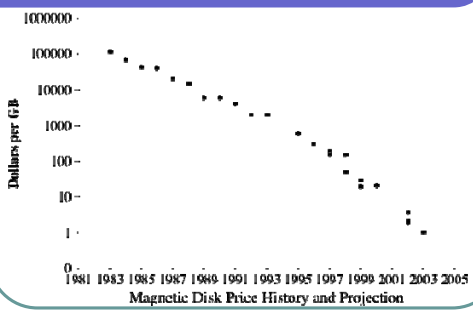
Trends in CPU performance growth, from microprocessors to supercomputers

DRAM density



Trends in semiconductor RAM density

Disk: Price per GByte drops at ~30-35% per year



Magnetic Disk Price History and Projection

ENIAC

- 1946
- Only one built
- 5000 adds/sec
- 20 10-digit registers
- 18,000 vacuum tubes
- 124,500 watts
- Not really stored program

UNIVAC (Universal Automatic Computer)

- 1951
- 46 sold
- 2000 ops/sec
- 1,000 12-digit words (mercury)
- 5000 tubes
- $1.5 million

IBM System/360-40

- 1964
- 1.6 MHz
- 16-256 KB core
- $225,000
- Family of six
- 32-bit
- Time-sharing

Cray 1: supercomputer

- 1976
- 80 sold
- 80 MHz
- 8 Mbyte SRAM
- 230,000 gates
- $5 million

DEC PDP-8 (1964)

- 60,000 sold
- 330,000 adds/sec
- 4096 12-bit words
- $18,000

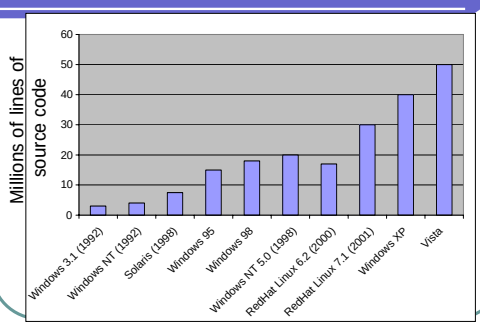
Apple II

- 1977
- 1 MHz
- 6502 microprocessor
- 4 to 48 Kilobytes RAM
- $1300
- Basic, Visicalc

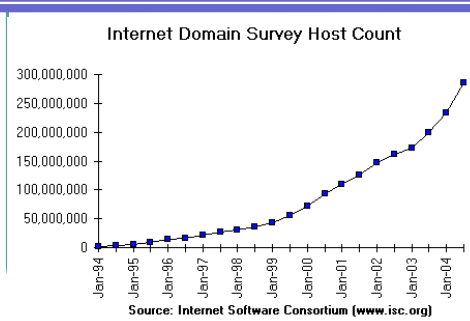
IBM's wrist watch

- 2001
- Linux and X11
- 74 Mhz CPU
- 8 Megabyte flash
- 8 Megabyte DRAM
- Wireless

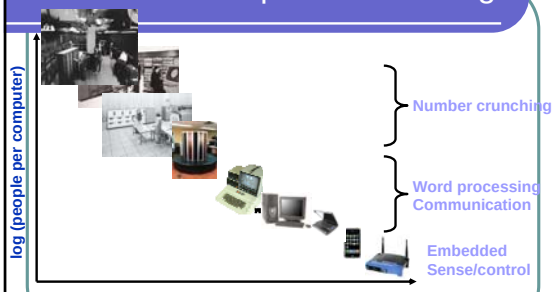
Software follows hardware



Cheap → Pervasive



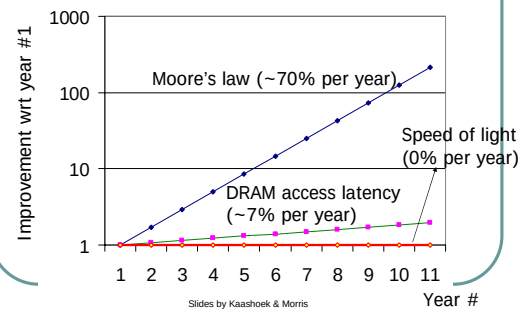
Pervasive → qualitative change



Slides by Kaashoek & Morris

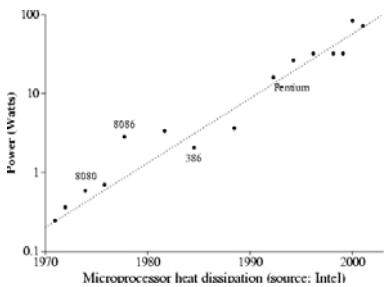
Slide from David Culler, UC Berkeley

Latency improves slowly



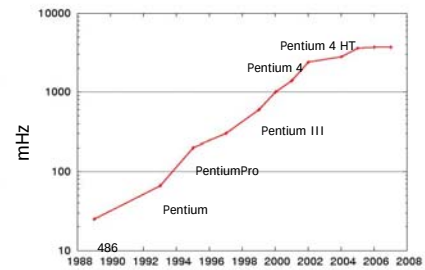
Slides by Kaashoek & Morris

Heat is a problem

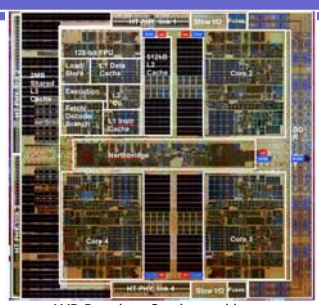


Slides by Kaashoek & Morris

Recent Intel CPU Clock Rates



The Future: will it be painful?



AMD Barcelona Quad-core chip

Slides by Kaashoek & Morris

What went right?

- Unbounded composibility
- General-purpose computers
  - Only need to make one thing fast
- Separate architecture from implementation
  - S/W can exploit new H/W
- Cumulative R&D investment over years

Slides by Kaashoek & Morris