Computer Systems are Different!

6.033 Spring 2007

Static discipline

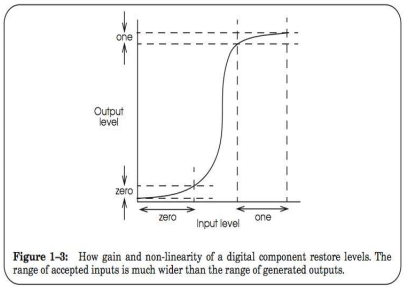
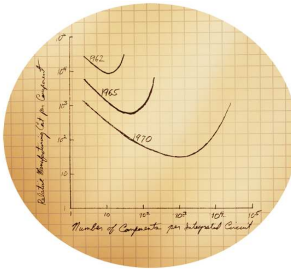


Figure 1–3: How gain and non-linearity of a digital component restore levels. The range of accepted inputs is much wider than the range of generated outputs.

- Be tolerant of inputs and strict on outputs

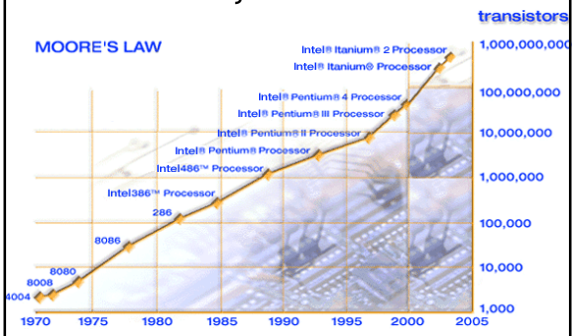
Moore's law



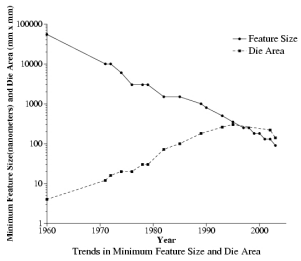
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

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

Moore's Law: # transistors/die doubles every ~18 months

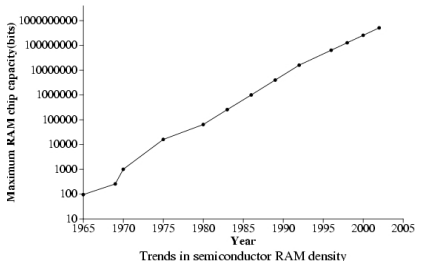


Lithography: the driver behind transistor count

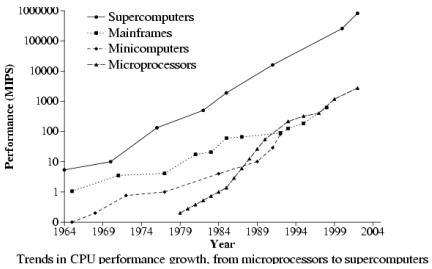


- Number of components scales $O(n^2)$ with feature size
- Switching time scales $O(n)$ with features size
- Number of components scale $O(n^2)$ with die area

RAM density

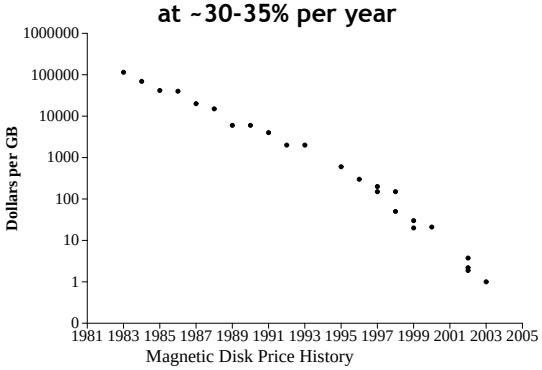


CPU performance



Trends in CPU performance growth, from microprocessors to supercomputers

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



Magnetic Disk Price History

ENIAC

- 1st built in 1946
- 80 feet
- 20 10-digit registers
- 18,000 vacuum tubes
- 124,500 watts

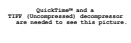
UNIVAC (Universal Automatic Computer)

- Introduced in 1951
- 46 delivered in all, until 1958
- Predicted '52 election results based on early results (1%)
- 1,905 ops/sec, at 2.25 Mhz clock
- 1,000 words of 12 characters
- No monitor, only typewriter

IBM Systems/360

- 1960s
- Model 40
  - 1.6 Mhz
  - 32-64 Kilobyte
  - $225,000

DEC PDP



- PDP-8, 1964
- 330,000 adds/s
- $16-20K
- UNIX introduced on PDP-10

Cray 1: supercomputer

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

- 1976
- Most expensive, fastest, best price/performance ratio
- $5-8 Million
- 166 Million adds/s
- 32 Mbyte

Apple II

- 1977
- 6502 microprocessor
- 4 to 48 Kilobyte

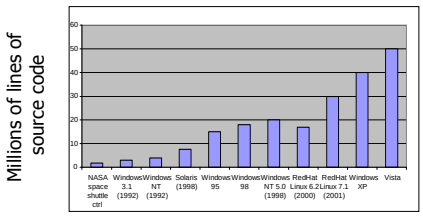
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

IBM's wrist watch

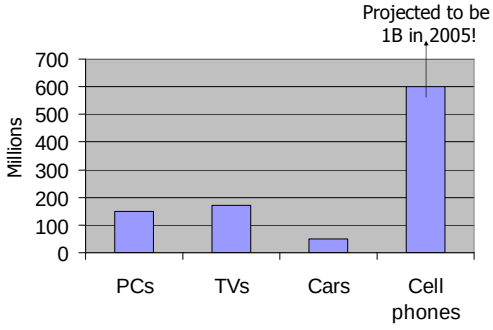
- 2001
- Linux and X11
- 19Mhz ARM
- 8 Megabyte flash
- 8 Megabyte DRAM

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

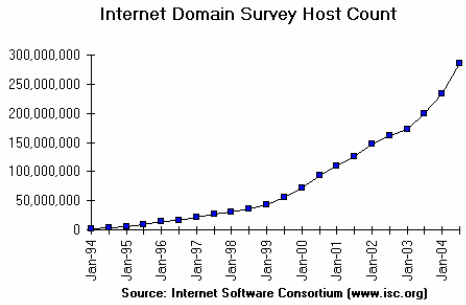
Software system complexity



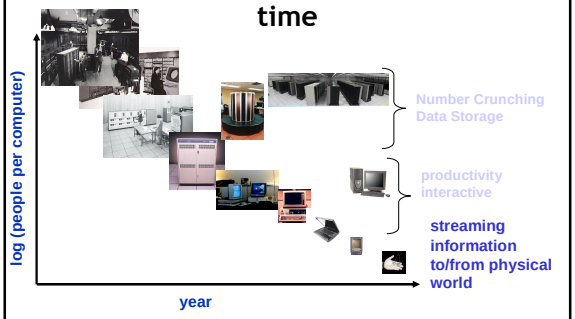
Computing is everywhere!



Internet hosts (names) with time: ~40% per year

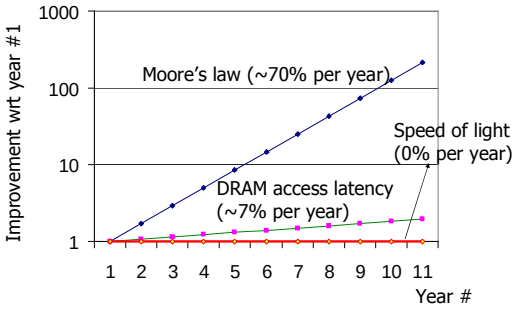


People-to-computer ratio with time

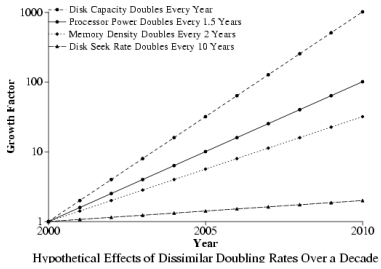


Slide from David Culler, UC Berkeley

Latency improves slowly

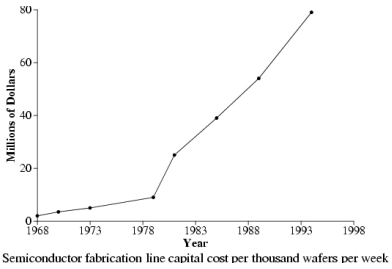


Incommensurate doubling



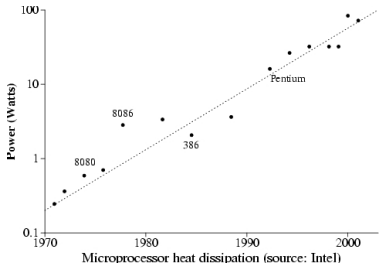
Hypothetical Effects of Dissimilar Doubling Rates Over a Decade

Fabrication is expensive



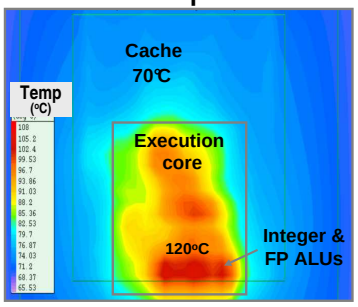
Semiconductor fabrication line capital cost per thousand wafers per week

Heat is a problem



Microprocessor heat dissipation (source: Intel)

Itanium Temperature Plot



[Source: Intel]

Principles

Adopt sweeping simplifications

Avoid excessive generality

- Be explicit
- Decouple modules with indirection

Design for iteration

- End-to-end argument

Incommensurate scaling rule

Law of diminishing returns

- Open design principle
- Principle of least surprise

Robustness principle

Unyielding foundations rule