

JOHN L. HENNESSY DAVID A. PATTERSON

COMPUTER ARCHITECTURE
A Quantitative Approach

MK

Technology Trends

Original slides from:
Computer Architecture
A Quantitative Approach
Hennessy, Patterson
Modified slides by YashwantMalaiya
Colorado State University

Exponential Growth

- Grows by a factor of $(1+x)$ per year.
- By a factor of $(1+x)^n$ for n years.
- Example: An investment of \$1000
 - 100% return in one year (i.e. doubles)
 - When will it become a million dollars?
 - Answer: $2^y=1000$, $y = ?$

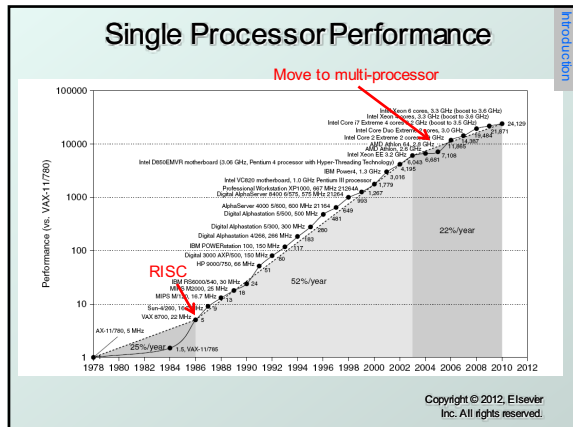
The computer industry has experienced exponential growth for decades: memory density, processor performance, circuit density, communications bandwidth, ...

Copyright © 2012, Elsevier Inc. All rights reserved.

Computer Technology

- Performance improvements:
 - Improvements in semiconductor technology
 - Reduced feature (circuit) size
 - Higher clock speeds
 - Improvements in computer architectures
 - Enabled by HLL compilers, UNIX
 - Lead to RISC architectures
 - Together have enabled:
 - Lightweight, portable, cheap, fast computers
 - Productivity-based programming languages
 - Advanced development environments and tools

Copyright © 2012, Elsevier Inc. All rights reserved.



Defining Computer Architecture

Defining Computer Architecture

- "Classical" computer architecture:
 - Instruction Set Architecture (ISA) design
 - i.e. decisions regarding:
 - registers, memory addressing, addressing modes, instruction operands, available operations, control flow instructions, instruction encoding
- "New" computer architecture:
 - Specific requirements of the target machine
 - Design to maximize performance within constraints:
 - **cost, power, and availability**
 - Includes ISA, microarchitecture, hardware

Copyright © 2012, Elsevier Inc. All rights reserved.

Trends in Technology

Trends in Technology

- Integrated circuit technology
 - Transistor density: 35%/year
 - Die size: 10-20%/year
 - Integration overall: 40-55%/year
- DRAM capacity: 25-40%/year (slowing)
- Flash capacity: 50-60%/year
 - 15-20X cheaper/bit than DRAM
- Magnetic disk technology: 40%/year
 - 15-25X cheaper/bit than Flash
 - 300-500X cheaper/bit than DRAM

Copyright © 2012, Elsevier Inc. All rights reserved.

Trends in Technology

Bandwidth and Latency

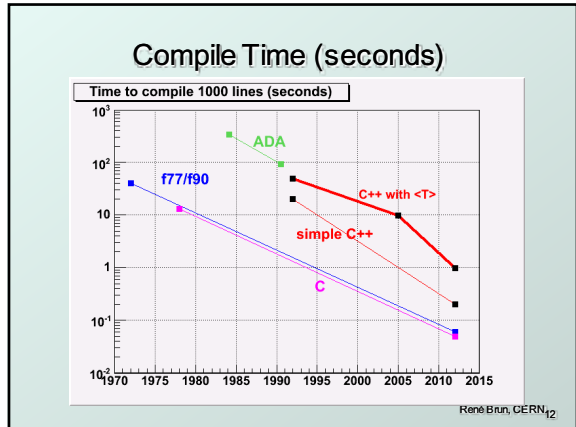
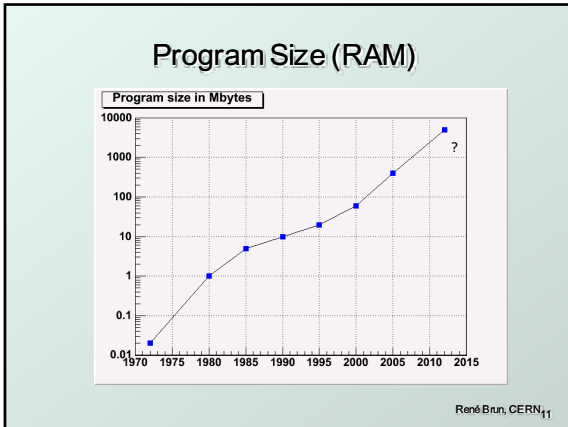
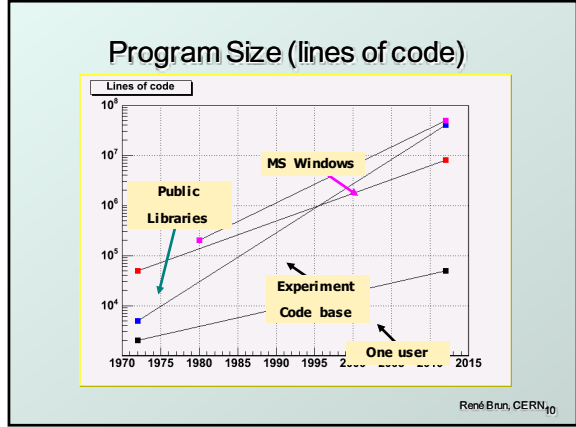
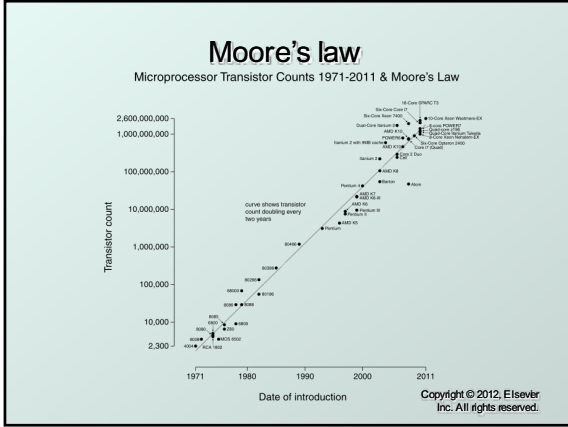
- Bandwidth or throughput
 - Total work done in a given time
 - 10,000-25,000X improvement for processors
 - 300-1200X improvement for memory and disks
- Latency or response time
 - Time between start and completion of an event
 - 30-80X improvement for processors
 - 6-8X improvement for memory and disks

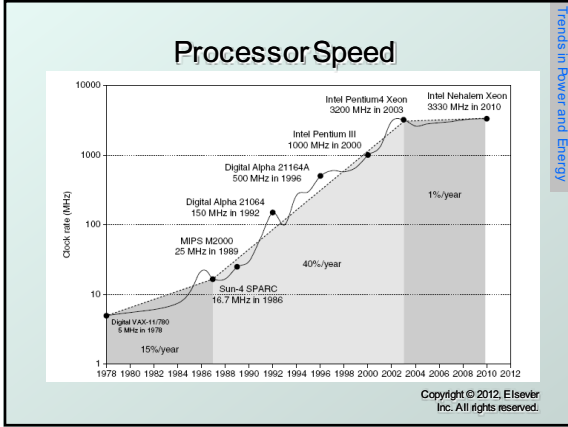
Copyright © 2012, Elsevier Inc. All rights reserved.

Technology Laws

- **Moore's Law:** formulated by Gordon Moore of Intel in the early 70's - **the number of transistors on a chip doubles every 18 months**; corollary, computers become faster and the price of a given level of computing power halves every 18 months.
- **Gilder's Law:** proposed by George Gilder, prolific author and prophet of the new technology age - **the total bandwidth of communication systems triples every twelve months**. New developments seem to confirm that bandwidth availability will continue to expand at a rate that supports Gilder's Law.
- **But no laws about Software (well, maybe Murphy's law!)**

8

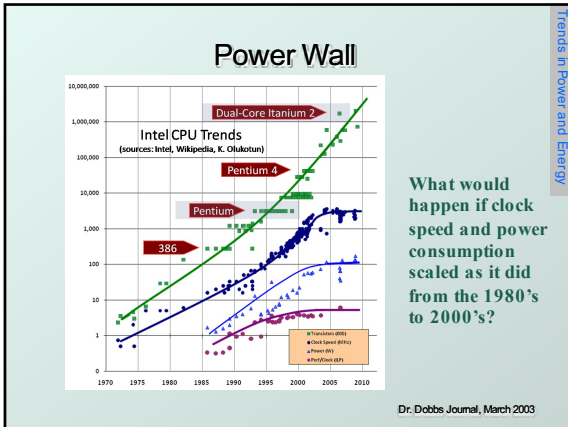




Trends in Power and Energy

- ### Power Scaling
- Intel 80386 running at 16 Mhz consumed around 2 Watts, less than a LED light bulb.
 - Intel Core i7 running at 3.3 GHz consumes 130 Watts, still less than a television.
 - However, heat must be dissipated from 1.5 x 1.5 cm chip in a closed case.
 - Even with aluminum cooling fins and a power fan, this is close the limit of what can be cooled.
 - Furthermore, the power consumption (based on CMOS technology) scales faster than clock speed.
 - So instead of increasing dock speed, CPU designers are adding multiple cores.
- Copyright © 2012, Elsevier Inc. All rights reserved.

Trends in Power and Energy



Trends in Power and Energy