CS4100: 計算機結構

Introduction

國立清華大學資訊工程學系
九十三學年度第一學期

國立清華大學
National Tsing Hua University

電腦是什麼時候發展出來的?

大約一千三百多年前...

為什麼我們不稱它為「電腦」?

電動算盤

「電腦」倒底是什麼?

- **A device that computes, especially a programmable electronic machine that performs high-speed mathematical or logical operations or that assembles, stores, correlates, or otherwise processes information**
  -- *The American Heritage Dictionary of the English Language*, 4th Edition, 2000

其實歷史上已有許多計算裝置發展出來

- Special-purpose versus general-purpose
- Non-programmable versus programmable
- Scientific versus office data processing
- Mechanical, electromechanical, electronic, ...

Tabulating machine
(H. Hollerith, 1889)

Harvard Mark I
(IBM, H. Aiken, 1944)

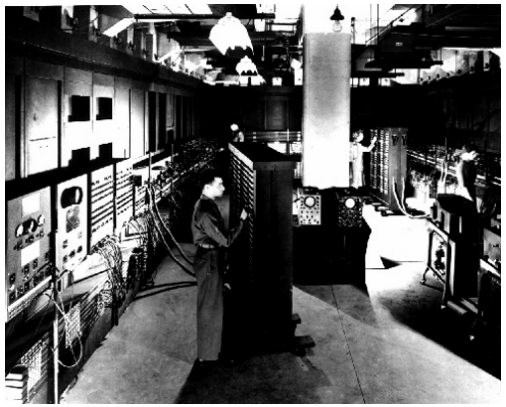
Difference Engine
(C. Babbage, 1822)

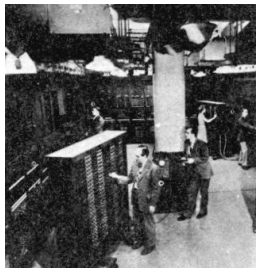
第一部
全電子式
可程式
一般用途
的電腦
是什麼時候發展出來的?

第一部「電」腦

- 一般認為：ENIAC (*Electronic Numerical Integrator and Calculator*)
- Work started in 1943 in Moore School of Electrical Engineering at the University of Pennsylvania, by John Mauchly and J. Presper Eckert
- Completed in 1946
- 約25公尺長、2.5公尺高
- 20 10-digit registers, each 2 feet
- 使用18,000個真空管 (electronic switches, 1906年發明)
- 每秒執行1900個加法
- Programming manually by plugging cables and setting switches

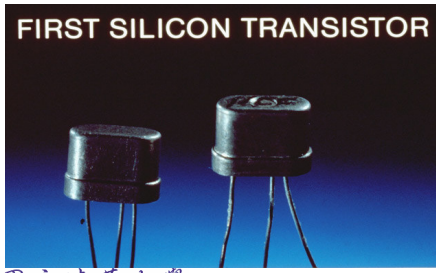
ENIAC

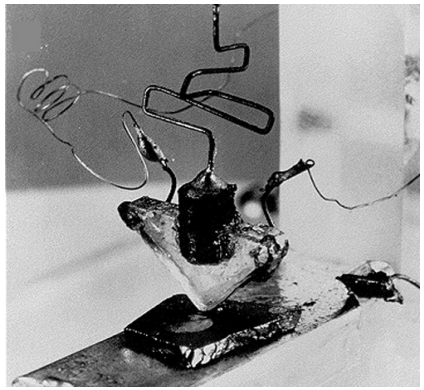




大約同一時期，人們發明了電晶體

- By W. Shockley, J. Bardeen, W. Brattain of Bell Lab. in 1947
  - Much more reliable than vacuum tubes
  - Electronic switches in "solids"





不久後電腦開始商品化

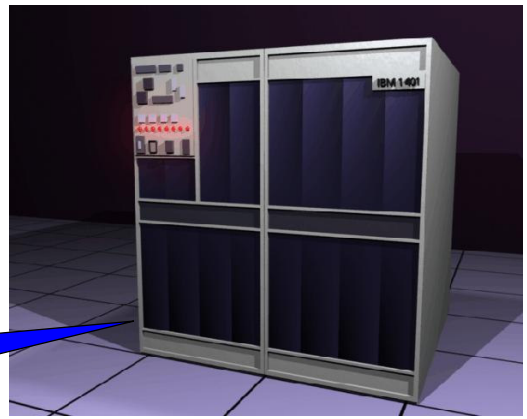
UNIVAC (Remington-Rand, 1951)

主要用途為商務、辦公室自動化
其次為科學計算

IBM 701 (IBM, 1952)

使用電晶體的電腦也跟著出現

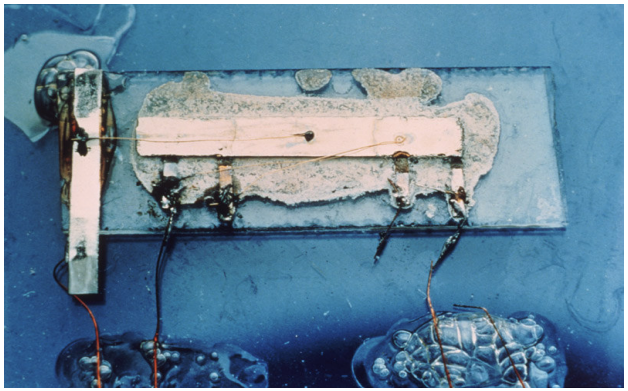
- Ex.: IBM 1401 (IBM, 1959)



This is how IBM is called "Big Blue"!

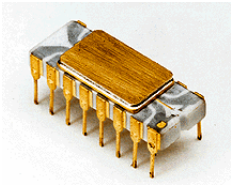
電腦元件的另一大突破是IC

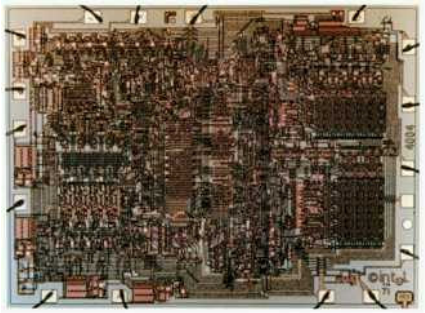
- 1958年德州儀器公司的Jack Kilby: integrated a transistor with resistors and capacitors on a single semiconductor chip, which is a monolithic IC



當更多的電晶體能放入IC後...

- 1971年第一個微處理器：Intel 4004
  - 108 KHz, 0.06 MIPS
  - 2300 transistors (10 microns)
  - Bus width: 4 bits
  - Memory addr.: 640 bytes
  - For Busicom calculator (original commission was 12 chips)





微處理器造就了...

- 1977年Apple II: Steve Jobs, Steve Wozniak Motorola 6502 CPU, 48Kb RAM

以及PC

- 1981年IBM PC: Intel 8088, 4.77MHz, 16Kb RAM, two 160Kb floppy disks

Microsoft Corporation, 1978

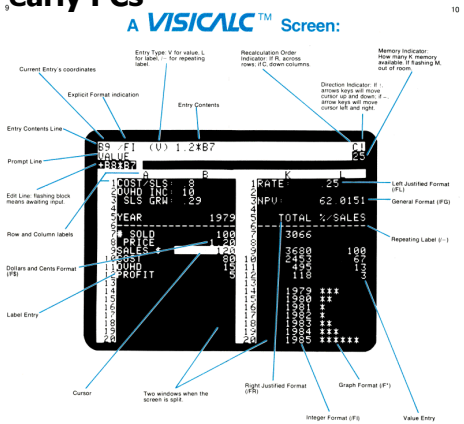
也造就了微軟

一些週邊設備也早已發展出來

- 1973: Researchers at Xerox PARC developed an experimental PC: Alto
  - Mouse, Ethernet, bit-mapped graphics, icons, menus, WYSIWG editing
- Hosted the invention of:
  - Local-area networking
  - Laser printing
  - All of modern client / server distributed computing

讓PC成為真正有用的東西--應用程式

- 1979: 1st electronic spreadsheet (VisiCalc for Apple II) by Don Bricklin and Bob Franston
  - "The killer application for early PCs"
  - Followed by dBASE II, ...



人們也先後發展出許多其他東西...

80年代，IC的集成進入VLSI

- New processor architecture was introduced: RISC (*Reduced Instruction Set Computer*)
  - IBM: John Cocke
  - UC Berkeley: David Patterson
  - Stanford: John Hennessy

- Commercial RISC processors around 1985
  - MIPS: MIPS
  - Sun: Sparc
  - IBM: Power RISC
  - HP: PA-RISC
  - DEC: Alpha
- They compete with CISC (complex instruction set computer) processors, mainly Intel x86 processors, for the next 15 years

後來的故事 ...

在計算機結構方面比較不精彩

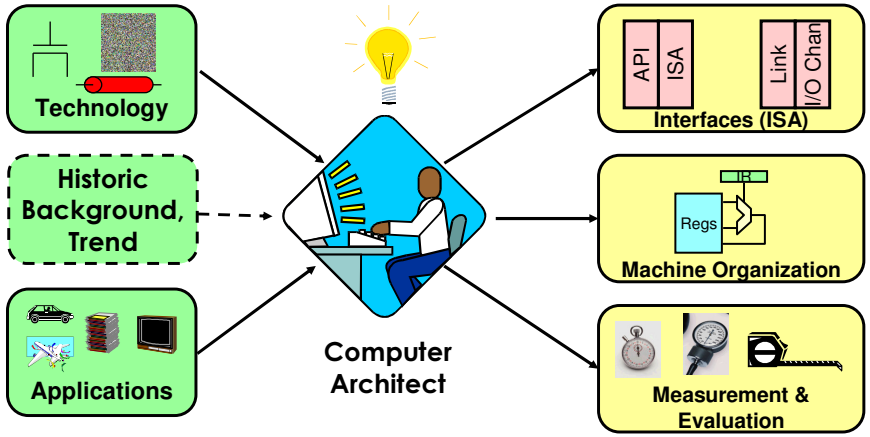
不過似乎後PC的時代已經來臨

Summary: Technology and Computers

- Computer generation according to technology:

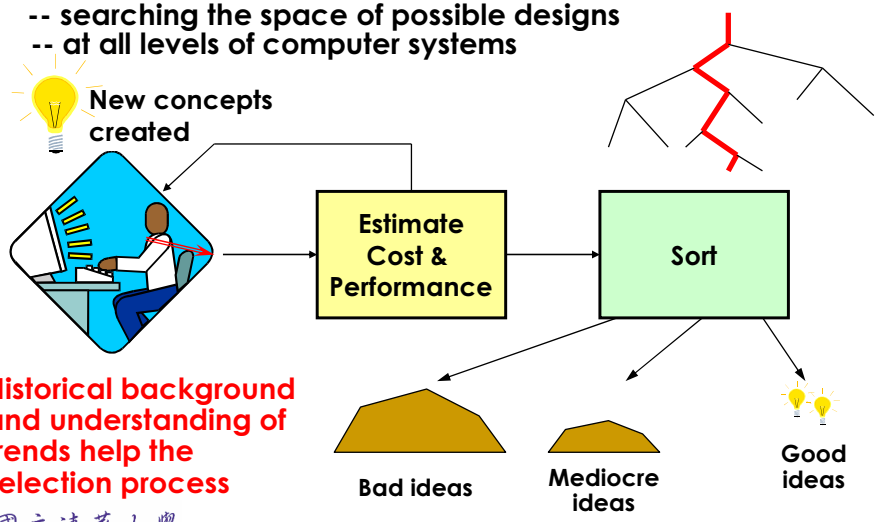
Generation	Date	Technology	Relative Performance per unit cost
1	1950-1959	Vacuum tubes	1
2	1960-1968	Transistors	35
3	1968-1977	IC	900
4	1978-?	LSI/VLSI	2,400,000

Why Do I Want to Know History?



In Fact, Architecture Design Is an Iterative Process

-- searching the space of possible designs
-- at all levels of computer systems

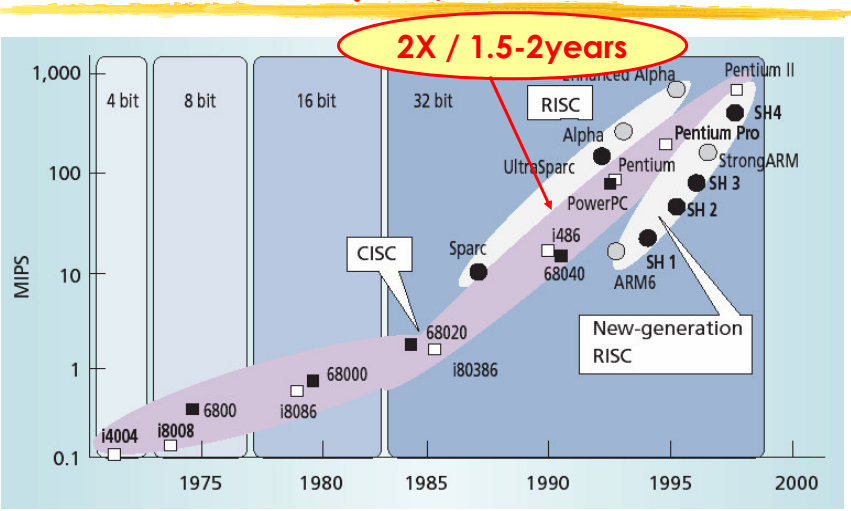


Historical background and understanding of trends help the selection process

Outline

- Computer: A historical perspective
- Forces behind computer evolution and design
  - Supply: technology, architecture
  - Demand: applications
- Implementation technology and its trends
- Applications of processors

Let's Start with Processor Performance



("The Cooler the Better: New Directions in the Nomadic Ages," *Computer*, April 2001.)

Why Such Changes?

Several factors:

- **IC technology:**
  clock rate, power, transistors per chip
  ⇩ enable
- **Computer architecture:**
  pipeline, cache, MMX, instructions per cycle
  ⇩ supported by
- **Mass market:**
  market share, revenue, applications

Let's examine IC technology first ...

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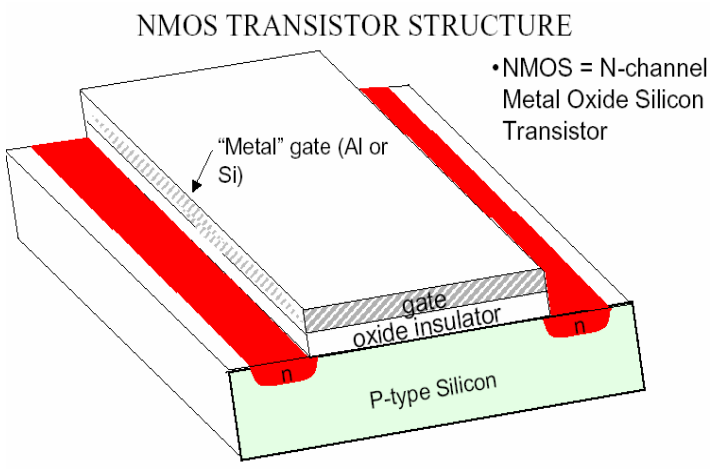
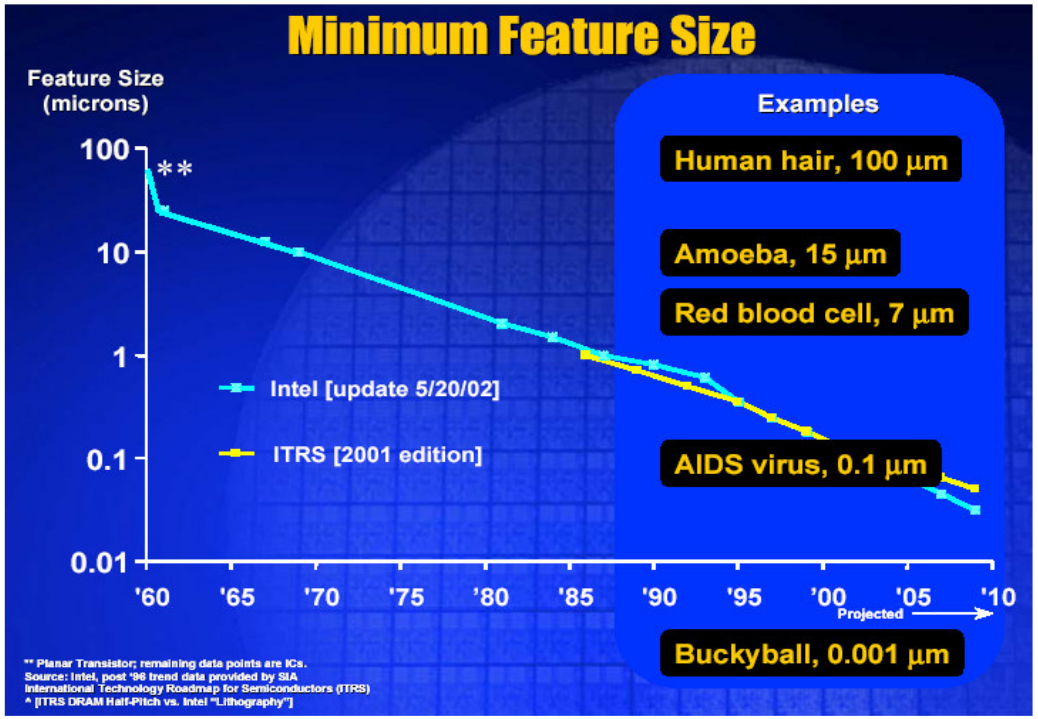
VLSI IC Technology

	2001	2005	2010	2016
Line width (nm)	130	80	45	22
Clock (GHz)	1.7	5.2	11.5	28.8
DRAM cost (microcents/bit)	7.7	1.9	0.34	0.042
MPU cost (microcent/trans)	97	24	4.31	0.54
Supply voltage(V)	1.2	1.0	0.8	0.6
Wiring levels	7	9	10	10

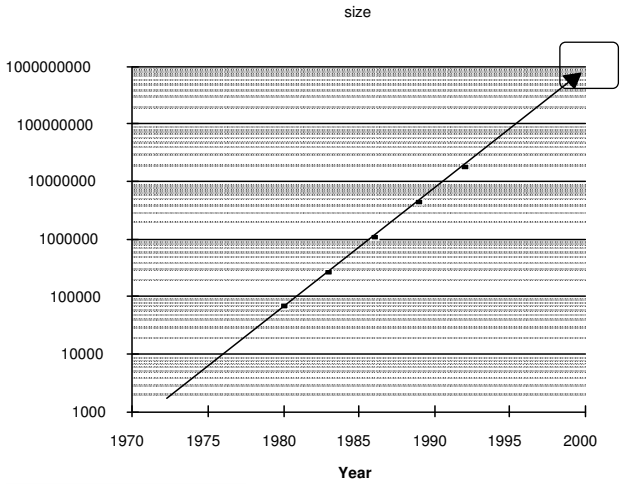
cost per transistor↓ chip density↑

Line Width/Feature Size





Technology Trends: Memory Capacity (1 Chip DRAM)



year	size(Mbit)
1980	0.0625
1983	0.25
1986	1
1989	4
1992	16
1996	64
2000	256

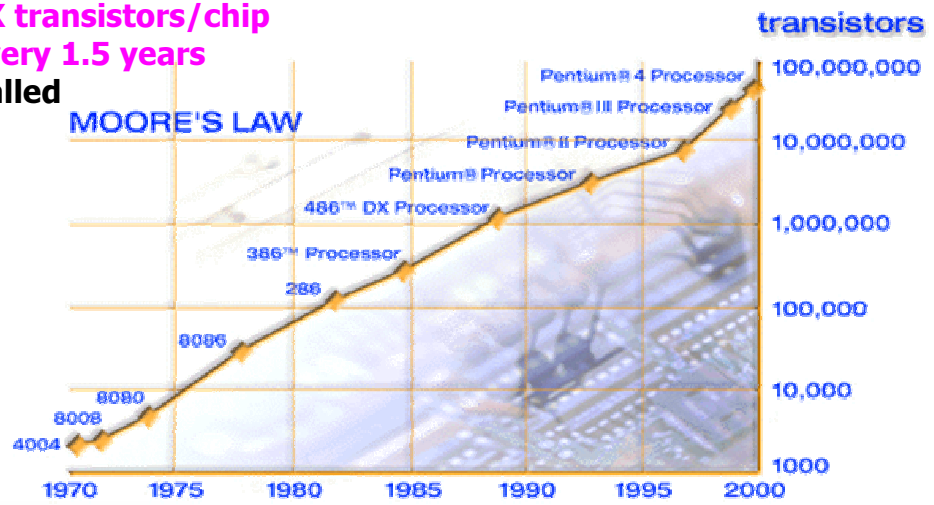
1.4X/yr, or doubling every 2 years

4000X since 1980

Technology Trends: Microprocessor Capacity

2X transistors/chip every 1.5 years

Called MOORE'S LAW



Technology => Dramatic Change

- Processor
  - 2X in speed every 1.5 years; 100X in last decade
- Memory
  - DRAM capacity: 2x / 2 years; 64X size in last decade
  - Cost per bit: improves about 25% per year
- Disk
  - Capacity: > 2X every year; 120X in last decade
  - Cost per bit: improves about 100% per year
- State-of-the-art PC when you graduate:
  - Processor clock: 4.0 GHz
  - Memory capacity: 1.0 GBytes
  - Disk capacity: 1.0 TeraBytes
  - New units! Mega => Giga, Giga => Tera

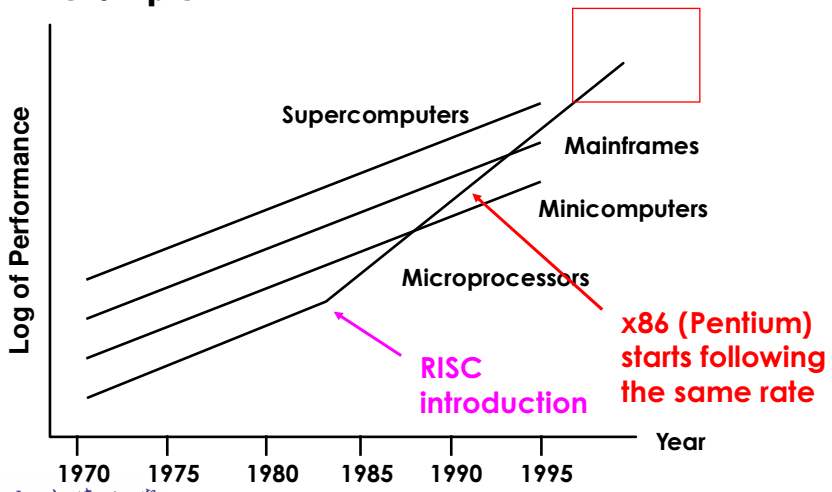
Technology Progress: Implication

- Minimum feature size: halve every 7 years
  - $O(n^2)$ with respect to transistor count and O(n) with respect to switching time
    - ➢ $O(n^3)$ improve in computing with lithography
  - Power dissipation
- Die size: X2 every 3 years
  - $O(n^2)$ with respect to transistor count
- Others: provide one-time improvement
- Price: lower costs due to
  - Simpler development and higher volumes with CMOS

➢ ***Highly integrated chips with improved speed, reliability, cost, functionality***

Technology Enables Architectural Innovation

- An example:



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Computer Progress Supported/Driven by Market and Usage

- Applications drive machine "balance"
  - Numerical simulations: floating-point, memory BW
  - Transaction processing: I/O, INT performance
  - Media processing: low-precision 'pixel' arithmetic
- Applications drive machine performance
  - What if my computer runs all my software very fast?
  - Programs use increasing amount of memory:
    - 1.5-2 per year, or 0.5-1 addressing bit per year
  - High-level programming languages replace assembly languages => compilers important
    - Compiler and architecture work together
- Effects of compatibility and ease of use
- Effects of market demands and market share
  - Can investment in R&D, production be paid off?

Computer Usage: General Purpose

- Uses: commercial (int.), scientific (FP, graphics), home (int., audio, video, graphics)
  - Software compatibility is the most important factor
  - Short product life; higher price and profit margin
  - OS issue: OS serves another interface above arch.
    - Effects of OS developments on architecture
    - RISC-based Unix workstation vs x86-based PC: (1) units sold is only 1% of PC's, (2) emphasize more on performance than on price
      - survive only if performance is high enough?
      - effects of Linux-based PCs?
- Future:
  - Use increased transistors for performance, human interface (multimedia), bandwidth, monitoring

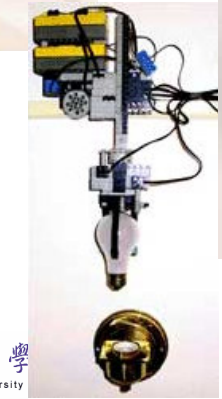
Computer Usage: Embedded

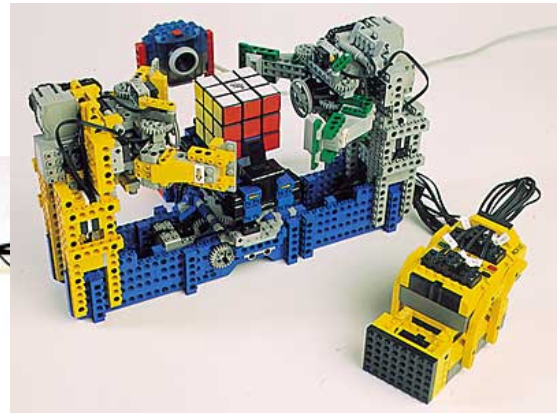
- Uses: control (traffic, printer, disk); consumer electronics (video game, CD player, PDA)

Lego Mindstorms

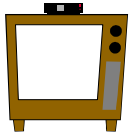
Robotic command explorer:
A "Programmable Brick",
Hitachi H8 CPU (8-bit), 32KB RAM,
LCD, batteries,
infrared transmitter/receiver,
4 control buttons, 6 connectors

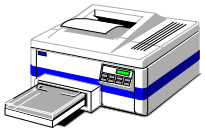
它可以做什麼?

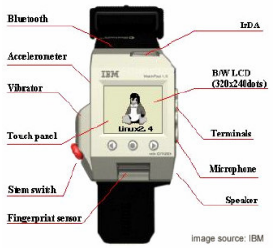




生活裡的應用比比皆是







Embedded Computers

- Typically w/o FP or MMU, but integrating various peripheral functions, e.g., DSP
  - Large variety in ISA, performance, on-chip peripherals
  - Compatibility is non-issue, new ISA easy to enter, low power become important
- More architecture and survive longer:
  4- or 8-bit microprocessor still in use
  (8-bit for cost-sensitive, 32-bit for performance)
- Large volume sale (billions) at low price ($40-$5)
  - 1995 #1: x86; #2: 6800; #3: Hitachi SuperH (Sega)
  - Others: MIPS, StrongARM, PA-RISC
- Trend: lower cost, more functionality
  - system-on-chip, μP core on ASIC

Summary

- Computer architecture studies instruction set architecture and computer organization
- Instruction set architecture is about interface
- All computers consist of five components:
  - Processor: (1) datapath and (2) control
  - (3) Memory
  - (4) Input devices and (5) output devices
- Architecture design is an iterative process; must consider:
  - Device technology
  - Application and market
  - Performance evaluation