Computer Organisation and Architecture

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COA

Term 1:
Weeks 1-10 Tuesday 13:05 -> 13:55 ACCR
Weeks 1-5 Wednesday 11:05 -> 11:55 L3
Weeks 6-9 Lab. either 9-12 Thursdays
or 10-1 Fridays
Week 10 Lab. (CBS Only)

Term 2:
Weeks 11-20 Wednesday 11:05 -> 11:55 L3
Thursday 13:05 -> 13:55 L3
Lab. either 9-12 Thursdays
or 10-1 Fridays

COA Term 1 Overview

1) Introduction
   Historical Background
   Future Trends
2) System Overview
3) Information
4) Logic
5) Microprocessors
6)68008
6) Input / Output 1 (Digital)
7) Input / Output 2 (Analogue)

Note Taking

COA Lecture Slides will be available on-line:
http://www.dcs.warwick.ac.uk/~djke

No printed versions available from lecturer or CS department

Use lectures wisely!!

Take notes on main points during lecture
Summarise lectures in your own words

COA Term 2 Overview

8) Term 2 Intro
9) Memory Systems
10) Peripherals
   Display Technologies & Techniques
11) System Design
12) System & Real-Time Software
13) Multiple Interrupts
14) Memory Management and Cache
15) Processor Architectures
16) Parallel Computing

COA Books

1 "Structured Computer Organization”,
   A. Tannenbaum,
   Prentice Hall, 1998

2 "The Principles of Computer Hardware”
   A. Clements

3 "Computer Organization and Design”
   D.A. Paterson and J.L. Hennessy
   Morgan Kaufmann, 1996
**Historical Background**

- ~3000 BC Abacus
- 1642 Blaise PASCAL First Mechanical Adding Machine
- 1673 Gottfried LEIBNITZ Better Calculator
- 1780 Joseph JACQUARD Punched Cards
- 1821 Charles BABBAGE “Difference Engine”
- 1822 Charles BABBAGE Demonstration of Model to Royal Astronomical Society
- 1842 Charles BABBAGE Abandoned

**Babbage’s Analytical Engine**

1833 Work Began on Analytical Engine:
- First Programmable Computer
- Model in London Science Museum
- Input on Punched Cards
- Arithmetic Unit ("The Mill")
- Control Unit
- Store (memory) of 1000 50 digit numbers
- Augusta ADA, Countess of Lovelace (Daughter of Lord Byron) wrote “Observations on Mr. Babbage’s Analytical Engine”

**View of Babbage’s ‘Mill’**

**1890 12th American Census**

1890 Results processed by Hollerith cards
- Fast (Electromechanical)
- Processing took 6 weeks
- (11th Census took over 7 years to process by hand)

Hermann HOLLERITH set up the
- “TABULATING MACHINE COMPANY”
- “COMPUTING TABULATING & RECORDING COMPANY”
- “INTERNATIONAL BUSINESS MACHINE CORPORATION”
- IBM

**1935/36 Konrad ZUSE (Germany)**

Engineering Student at University of Berlin
Built the Z1 Computer
- Z1 Computer
  - Programmable Calculator
  - Relays
  - Binary
  - 35 mm film with punched holes to carry instructions
  - Output on light bulbs

**1938 Helmut SCHREYER (Germany)**

- Close friend of Zuse
- Replaced relays with valves (Electronic)
- Binary
- Project suspended during World War II
1936 Howard Aitken (USA)
- General Purpose Calculator at Harvard University
- Thomas J. Watson of IBM invested $1 000 000
- IBM AUTOMATIC SEQUENCE CONTROLLED CALCULATOR (aka THE MARK I)
- Data from switches or cards
- Relays
- Binary
- Control: 24 column paper tape
- 55 feet long and 8 feet high
- used by US Military during WW II

1940-45 "The Bletchley Machines" (UK)
- Cryptography
  - Cracking German "ENIGMA" cipher machine
- Electromechanical Machines
  - "HEATH ROBINSON" Built by Wynn-Williams of TRE with Alan Turing
  - "PETER ROBINSON"
  - "ROBINSON & CLEAVER"
  - "SUPER ROBINSON"
- Electronic Machines
  - COLOSSUS I 2000 valves, paper tape, 5000 chars/sec
  - COLOSSUS II 25 000 chars / sec

1942 (USA)
- John MAUCHLY & J. Presper ECKERT
  - Proposed computing machine based on valves
  - "ELECTRONIC NUMERICAL INTEGRATOR & CALCULATOR" (ENIAC)
- 1946 ENIAC Completed
  - Decimal Machine
  - 18 000 Valves
  - 5 000 Additions per second
  - 20 X 10 decimal digit store
  - 6 000 multi-position switches for program
  - Conditional jumps

1945 (USA)
- Herman GOLDSTINE (working on ENIAC) met Johnny von NEUMANN at Aberdeen (Maryland) train station, had a chat (or so the story goes):
  - von Neumann saw that a program could be stored in memory just like data
  - STORED PROGRAM CONTROL
  - EDVAC Proposed (Electronic Discrete VAriable Automatic Computer)

Further Developments
- 1949 (UK) Maurice WILKES at Cambridge University
  - EDSAC (Electronic Delay Storage Automatic Computer)
- 1951 (USA) UNIVAC
  - Remington Rand Corporation
  - FIRST COMMERCIAL MACHINE
Commercial Machines 1

- First Era 1945 - 1958
  - Vacuum tubes (valves)
  - High Cost
  - Poor reliability
  - High power dissipation
  - 100 to 1000 words of memory
  - Clock cycle time 100µs to 10ms

Commercial Machines 2

- Second Era 1958 - 1964
  - Transistor invented in 1947, in use by mid 1950's
  - Reliable
  - Faster
  - Cheaper
  - Low power
  - Core memory
  - Cycle time ~10 µs

Commercial Machines 3

- Third Era: Integrated Circuits
- 1964 - 1970
  - Small Scale Integration (SSI)
  - Several logic gates per chip
  - Appearance of MiniComputers
- 1971
  - Medium Scale Integration (MSI)
  - ~ 100 gates per chip
  - Core memory
  - Cycle time ~10 µs

Microprocessors

- 1972
  - First Microprocessor (INTEL 4004)
- 1975
  - Large Scale Integration (LSI)
    - ~ 10^4 gates per chip
- >1975
  - Very Large Scale Integration (VLSI)
    - ~ 10^5 gates per chip in 1978
    - ~ 10^6 gates per chip in 1991
    - ~ 10^7 gates per chip in 2000

Computer Generations

<table>
<thead>
<tr>
<th>Generation</th>
<th>Dates</th>
<th>Technology</th>
<th>Principle Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1945-58</td>
<td>Vacuum Tubes</td>
<td>Commercial, Electronic Computer</td>
</tr>
<tr>
<td>2</td>
<td>1958-64</td>
<td>Transistors</td>
<td>Cheaper Computers</td>
</tr>
<tr>
<td>3</td>
<td>1964-75</td>
<td>MSI and LSI</td>
<td>Minicomputer</td>
</tr>
<tr>
<td>4</td>
<td>1976-97</td>
<td>LSI and VLSI</td>
<td>Personal computers, workstations</td>
</tr>
<tr>
<td>5</td>
<td>1993-??</td>
<td>Microprocessors</td>
<td>Portable computing, Network computing, parallel processing</td>
</tr>
</tbody>
</table>
### Key Commercial Computers

<table>
<thead>
<tr>
<th>Year</th>
<th>Name</th>
<th>Size (Cu ft)</th>
<th>Memory (Kb)</th>
<th>Performance (adds/sec)</th>
<th>Price (1996 $)</th>
<th>Price / Performance vs UNIVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>UNIVAC</td>
<td>1000</td>
<td>48</td>
<td>1,900</td>
<td>5,000,000</td>
<td>1</td>
</tr>
<tr>
<td>1964</td>
<td>IBM S360</td>
<td>60</td>
<td>64</td>
<td>500,000</td>
<td>4,100,000</td>
<td>320</td>
</tr>
<tr>
<td>1965</td>
<td>PDP-8</td>
<td>4</td>
<td>4</td>
<td>550,000</td>
<td>60,000</td>
<td>13,000</td>
</tr>
<tr>
<td>1976</td>
<td>Cray-1</td>
<td>58</td>
<td>32,000</td>
<td>166,000,000</td>
<td>8,500,000</td>
<td>51,000</td>
</tr>
<tr>
<td>1981</td>
<td>IBM PC</td>
<td>1</td>
<td>256</td>
<td>240,000</td>
<td>4,000</td>
<td>154,000</td>
</tr>
<tr>
<td>1991</td>
<td>HP 9000</td>
<td>2</td>
<td>16,000</td>
<td>50,000,000</td>
<td>8,000</td>
<td>16,100,000</td>
</tr>
<tr>
<td>1996</td>
<td>Intel P-Pro</td>
<td>2</td>
<td>16,000</td>
<td>400,000,000</td>
<td>4,400</td>
<td>240,000,000</td>
</tr>
</tbody>
</table>

### Technology Trends

- **Three Key areas in Information Technology:**
  - Processing
  - Storage
  - Transmission

  - Machine performance increasing by ~60% per year (doubling every 1.5 years)

### Workstation Relative Performance

![Graph showing workstation relative performance from 1987 to 1997.](image)

- **Integrated Circuits**
  - Number of transistors increases by ~25% per year (doubles in 3 years).
  - Speed increases by ~40% per year (doubles in 2 years)

- **Semiconductor DRAM memory**
  - Density (bits per square cm) increases by ~60% per year (quadruples in 3 years)
  - Cycle time decreases by 9% per year

- **Disk Technology**
  - Density doubles per year
  - Access time decreases by 30% in ten years

### Transistor Trends

![Graph showing transistor trends from 1970 to 2010.](image)

### DRAM Capacity

![Graph showing DRAM memory chip capacity from 1970 to 2020.](image)
Relative Improvement in Speed

Typical "Desktop" Machine

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>μP Transistors</td>
<td>10 000 000</td>
<td>40 000 000</td>
</tr>
<tr>
<td>Clock (MHz)</td>
<td>800</td>
<td>6 400</td>
</tr>
<tr>
<td>Memory (Mbytes)</td>
<td>128</td>
<td>2048</td>
</tr>
<tr>
<td>access time (ns)</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Disk (Mbytes)</td>
<td>20 000</td>
<td>1 280 000</td>
</tr>
<tr>
<td>access time (ms)</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

Silicon Manufacture

Silicon Ingot

Blank Wafers

Patterned Wafers

Dies

Dicer

Bond

Packaged Dies

Silicon Manufacture

Importance of Chip Size

- CHIP is called a DIE
- DIEs are made in batches on a WAFER

\[
\text{COST OF DIE} = \frac{\text{COST OF WAFER}}{\text{DIES PER WAFER} \times \text{DIE YIELD}}
\]

- DIE YIELD is the proportion of DIEs that work [0, 1]

Die Yield

\[
\text{DIEYIELD} = \frac{\text{WAFFRARYIELD}}{1 + (D \times \text{DIEAREA} / 2)^2}
\]

where:
- \( D \) is Defects per unit area

\[ \therefore \text{COST OF DIE} = (\text{DIE AREA})^2 \]

Doubling DIE area raises cost by a factor of \( \sim 4 \)

Wafers and Dies (1)

E.g. Small Die

E.g. Large Die
Clock Rate

- Processor clock rate determines the number of instructions executed per second
- Speed of light determines maximum speed of electrical signals (~3x10^8 m/s)
  
  E.g. Max distance that can be travelled at a clock rate of 1 Giga-Hertz (1x10^9 Hz) is:
  
  3x10^8 / 1x10^9 = 30cm
  
  (NB electrical signals also delayed in transistors)

The Future of Computing

Depends on developments in a wide range of active research and development fields including:

- Theoretical Techniques (algorithms)
- Software Engineering
- Languages
- System Software
- Processor Architectures
- Distributed and Parallel processors
- Device and Materials Technologies
- Networking

Opto-electronics

Mass Data Storage
17Gbytes "floppy" disks
  -> Digital Versatile Disks (DVD)

Processors?

Communications
Integrated speech, data, and video
Offices/houses on high bandwidth lines
  -> Very large heterogeneous computer networks

Grand Challenges

- Climate Modelling
- Fluid Turbulence
- Pollution Dispersion
- Human Genome Project
- Ocean Circulation
- Quantum Chromodynamics
- Semiconductor Modelling
- Superconductor Modelling
- Combustion Systems
- Vision and Cognition
Summary

Progress in Computer Systems is Driven by progress in Technology and Theory/understanding.

Processor architecture is a key factor to understanding increased performance (eg CISC v. RISC)

There are expected limits to performance (eg clock rate), but alternative approaches possible (eg parallelism).

Application domains exist where performance increases of many orders of magnitude are required.

Information Technology is central to our cultures and economies.