COMP311-08B
Computer Systems Architecture

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## Overview

- 200
  - Introduction to how a computer operates
  - Only small emphasis on issues that affect performance
- 311
  - how to analyse their performance (or how not to!)
  - issues affecting modern processor design (caches, pipelines)

## COMP311 – 2008

- Moodle
- Lectures
  - Lecture 1 Tue 16:00 - 18:00 K.G.06
  - Lecture 2 Thu 12:00 - 13:00 G.B.13
  - Lecture 3 Fri 09:00 - 10:00 K.G.01
- Textbook
  - *Computer Organization and Design: The Hardware/Software Interface*, THIRD Edition, Patterson and Hennessy
    - Excellent and essential part of the course

## COMP311 – 2008

- Assignments (30%)
  - Assignment 1: Due Fri 1st August (5%)
  - Assignment 2: Due Fri 22nd August (5%)
  - Assignment 3: Due Fri 19th September 5pm (5%)
  - Assignment 4: Due Fri 3rd October (5%)
  - Assignment 5: Due Fri 17th October (10%)
- Test (20%)
  - 90 Minutes (Tuesday 19th August) during lecture time
- Exam (50%)
  - 3hrs closed book – date and time to be set

## COMP311 – 2008

- No tutor assigned
- Class Representatives
  - Ben Stasiewicz
    ben@staz.net.nz
  - Shane Howearth
    sah54@students.waikato.ac.nz

## Computer Architectures

- This class will study MIPS, for the most part
  - RISC architecture
  - Excellent real-world architecture to teach

## Why not study i386?

- i386 (IA-32) is known as a CISC architecture
  - Complex Instruction Set Computer
- Practically all CPU architectures designed since the mid 1980s are RISC architectures
  - Reduced instruction set computer
  - In terms of units shipped, IA-32 is only important in the personal computer industry

## Common Architectures

- IA-32
- x86-64

CISC

- MIPS
- ARM
- Sparc
- Power
- ~~DEC Alpha~~

RISC

## Sales of Microprocessors

- 1998 to 2002
  - 125 million IA-32 units per year
- ARM
  - 1998: 45 million units
  - 2002: 500 million units
  - Any guesses as to cause?
- Source: Figure 1.2 P&H

## Windows NT 3.5, 4.0

- NT 4.0 supported
  - i386
  - PowerPC
  - MIPS
  - Alpha
- All capable of addressing at least 4GB of memory
- Only i386 supported today
  - Guesses as to why?

## What is so great about MIPS?

- MIPS architecture designed to lend itself to optimised implementations, from the outset
  - Pipelining
  - Multiple instruction issue
- Low power, low heat, relatively high performance

## What is so great about MIPS?

- Licensable architecture
  - QED, Texas Instruments, Broadcom, + others
- System on a chip designs
- Common in embedded systems
  - Linksys WRT54G
  - Many DSL routers
- CPU in Sony Playstation, Playstation 2.
- High-end Juniper routers use MIPS processors as their CPU
  - Their low-end is x86

## RISC CPUs

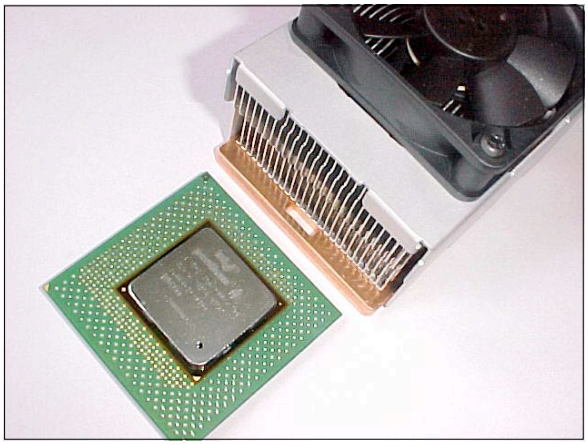
- ARM architecture
  - Cell phones
  - embedded designs : system on a chip
  - Hardware accelerated Java (Jazelle)
  - 75% of embedded RISC market
- Power architecture
  - Supercomputers
  - PlayStation 3
    - Cell broadband engine architecture: 3.2Ghz
  - Xbox 360, Nintendo Wii
    - PowerPC architecture
  - Earlier Apple computers
    - PowerPC architecture too

## Topics

- Introduction and Performance
- The Future of Computer Architecture
- Hardware Description Language Intro
  - VHDL
- Design
  - Components
  - Single cycle per instruction CPU
  - Multi-cycle implementation
  - Pipelined Implementation
- Memory
  - caching
- I/O
- PC Architectures

## Introduction

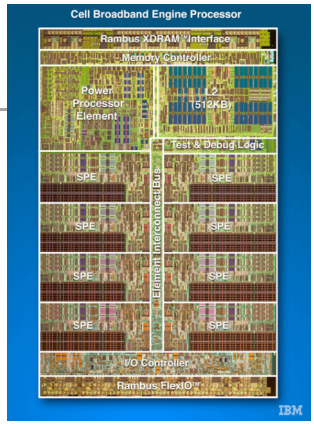
- Rapid Advances in Computer technology
  - first stored program computer ran 1st program 50 years ago
- Looks like the first phase has ended
  - CPU clock speeds have tended to double every two years
  - Heat becoming a bigger issue
  - New techniques will be required to extract performance gains



## Multi-core

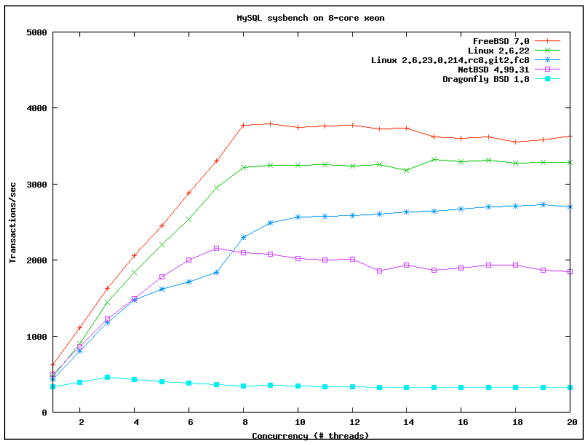
- Current trend is to place multiple processors on a single CPU
- Two approaches
  - Full-featured multiple cores per CPU
    - Intel/AMD
    - UltraSPARC
    - Octeon MIPS64
    - ARMv7
  - Simplified processor engines
    - Cell processor

## Cell

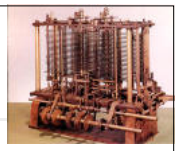



## Multi-core challenges

- Parallel programming
  - Requires software writer to think about how they will exploit available parallelism
  - Particularly, locking constructs
    - This is really a topic for COMP301
    - Though I do plan to talk about required CPU architecture support for locking
- Compiler support
  - gcc 4.2 and later support OpenMP
  - Incremental parallelism
- Topology awareness
  - Cores may be physically separated



## History



- Babbage (The Father/Great Uncle of Computing) 1791 – 1871
  - 1822: Difference Engine
  - Designed a computer to calculate polynomial functions
  - He did not successfully build the machine
  - Using his plans, 1989 – 1991 it was built, London Science Museum
  - A ‘computer’ was someone who produced mathematical tables by hand

## History

- Babbage (The Father/Great Uncle of Computing) 1791 - 1871
  - Designed a General purpose Computer (Analytical Engine)
    - Machine controlled by punched cards strung together like punched paper tape
    - Location in Data store numbered
    - For control he devised a system rotating barrels with projecting studs (barrels could step forward or backwards an arbitrary number of steps
  - Never built, but programmed by Ada Lovelace
- Next significant step not till 1945

## History

- Eckert + Mauchly at the Moore School of the University of Pennsylvania
  - Funded by the US army to build a machine to calculate artillery firing tables
  - Electronic Numerical Integrator and Calculator (ENIAC)

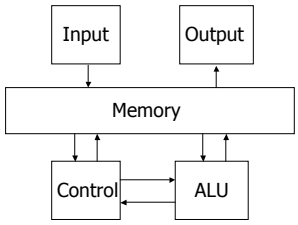
## History

- In 1944 John von Neumann and others joined the team
- Ideas they came up with can be summarized as:
  - Electronic Operation
  - Binary
  - Instruction set as user interface
  - Serial execution of instructions
  - Single Memory
  - Modification and construction of instructions
- Paper published only had Von Neumann’s name on

## History

- ENIAC (Electronic Numerical Integrator and Calculator) was operating in 1945
  - Designed and built by Eckert and Mauchly
  - 18,000 Valves
  - 30 Tons
  - Was programmable and had conditional Jumps
  - Programmed using a set of plugs and switches

## History



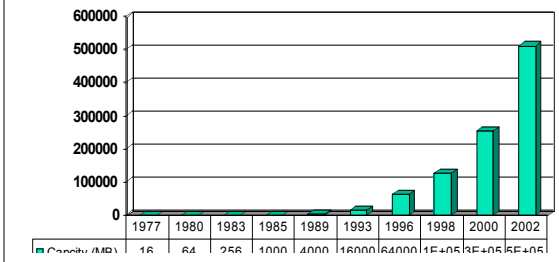

## History

- This led to a whole series of machines being developed:
  - Mark-I built at the University of Manchester
  - EDSAC by Maurice Wilkes of Cambridge University (1949)
  - 1949 BINAC (Eckert and Mauchly Corp.)
  - 1951 UNIVAC I (Remington-Rand Corp.)
  - 1964 System/360 (IBM)
  - 1976 Cray-1
  - …

## Technology Improvements

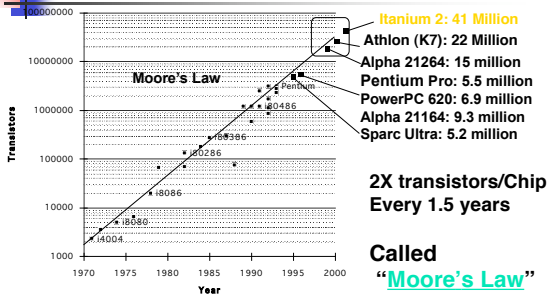
- Technologies used in Computers over time
  - 1951 – Vacuum Tube
    - Tube with electrodes in a vacuum, held in glass
  - 1965 – Transistor
    - On/off switch controlled by electricity
  - 1975 – Integrated Circuit
    - Dozens of transistors in a die
  - 1995 – Very Large Scale Circuit
    - Hundreds of millions of transistors in a die
- Rate of increasing integration has been very constant over time

## DRAM Capacity






## Performance Increases




Itanium 2: 41 Million
Athlon (K7): 22 Million
Alpha 21264: 15 million
Pentium Pro: 5.5 million
PowerPC 620: 6.9 million
Alpha 21164: 9.3 million
Sparc Ultra: 5.2 million

**2X transistors/Chip Every 1.5 years**

**Called "Moore's Law"**

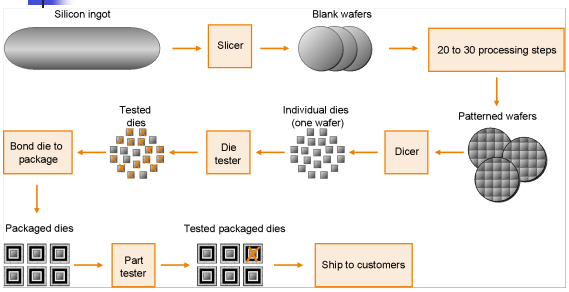
## Technology => dramatic change

- Processor
  - logic capacity: about 30% per year
  - clock rate: about 20% per year
- Memory
  - DRAM capacity: about 60% per year (4x every 3 years)
  - Memory speed: about 10% per year
  - Cost per bit: improves about 25% per year
- Disk
  - capacity: about 60% per year
  - Total use of data: 100% per 9 months!
- Network Bandwidth
  - Bandwidth increasing more than 100% per year!

## Characteristics over Time

| Year | Name | Size (cu. Ft.) | Power (watts) | Performance (adds/sec) | Memory (KB) | Adjusted price (1996$) | Adjusted price/perfomance |
|---|---|---|---|---|---|---|---|
| 1951 | UNIVAC1 | 1000 | 124,500 | 1,900 | 48 | 4,996,749 | 1 |
| 1964 | IBM S/360 model 50 | 60 | 10,000 | 500,000 | 64 | 4,140,257 | 318 |
| 1965 | PDP-8 | 8 | 500 | 330,00 | 4 | 66,071 | 13,135 |
| 1976 | Cray-1 | 58 | 60,000 | 166,000,000 | 32,768 | 8,459,712 | 51,604 |
| 1981 | IBM PC | 1 | 150 | 240,000 | 256 | 4,081 | 154,673 |
| 1991 | HP9000 /model 750 | 2 | 500 | 50,000,000 | 16,384 | 8,156 | 16,122,356 |
| 1996 | Intel Ppro PC | 2 | 500 | 400,000,000 | 16,384 | 4,400 | 239,078,908 |

## Chip Manufacture




## Software Technology

- Designers must also be aware of software technologies
  - Mixes of instructions generated by compilers
  - Locality of reference (memory hierarchy)

## Price/Performance

- Other areas designers must be aware of:
  - Target markets
  - Price
  - Performance
  - Price/performance

## Parting Thought

- Compare with transport industry
  - If similar advances made the travel coast to coast in US in 5 seconds for 50 cents

## Further reading

- P & H Chapter 1
- http://people.freebsd.org/~kris/scaling/smp.html