Computer Architecture
(Hardware Engineering)

- Dr. BEN CHOI
- Ph.D. in EE (Computer Engineering), The Ohio State University
- System Performance Engineer, Lucent Technologies - Bell Labs Innovations
- Pilot, FAA certified pilot for airplanes and helicopters

Computer Evolution

- ENIAC - background
  - Electronic Numerical Integrator And Computer
  - Eckert and Mauchly
  - University of Pennsylvania
  - Trajectory tables for weapons
  - Started 1943
  - Finished 1946
  - Too late for war effort
  - Used until 1955

- ENIAC - details
  - Decimal (not binary)
  - 20 accumulators of 10 digits
  - Programmed manually by switches
  - 18,000 vacuum tubes
  - 30 tons
  - 15,000 square feet
  - 140 kW power consumption
  - 5,000 additions per second

CH02 Computer Evolution and Performance

- A Brief History of Computers
- Designing for Performance
- Pentium and PowerPC Evolution

von Neumann/Turing

- Stored Program concept
- Main memory storing programs and data
- ALU operating on binary data
- Control unit interpreting instructions from memory and executing
- Input and output equipment operated by control unit
- Princeton Institute for Advanced Studies
  - IAS
- Completed 1952
Structure of von Nuemann machine

IAS - details

- 1000 x 40 bit words
- Binary number
- 2 x 20 bit instructions
- Set of registers (storage in CPU)
  - Memory Buffer Register
  - Memory Address Register
  - Instruction Register
  - Instruction Buffer Register
  - Program Counter
  - Accumulator
  - Multiplier Quotient

Structure of IAS - detail

Commercial Computers

- 1947 - Eckert-Mauchly Computer Corporation
- UNIVAC I (Universal Automatic Computer)
- US Bureau of Census 1950 calculations
- Became part of Sperry-Rand Corporation
- Late 1950s - UNIVAC II
  - Faster
  - More memory

IBM

- Punched-card processing equipment
- 1953 - the 701
  - IBM's first stored program computer
  - Scientific calculations
- 1955 - the 702
  - Business applications
- Lead to 700/7000 series

Transistors

- Replaced vacuum tubes
- Smaller
- Cheaper
- Less heat dissipation
- Solid State device
- Made from Silicon (Sand)
- Invented 1947 at Bell Labs
- William Shockley et al.
### Transistor Based Computers
- Second generation machines
- NCR & RCA produced small transistor machines
- IBM 7000
- DEC - 1957
  - Produced PDP-1

### Microelectronics
- Literally - “small electronics”
- A computer is made up of gates, memory cells and interconnections
- These can be manufactured on a semiconductor
  - e.g. silicon wafer

### Generations of Computer
- Vacuum tube - 1946-1957
- Transistor - 1958-1964
- Small scale integration - 1965 on
  - Up to 100 devices on a chip
- Medium scale integration - to 1971
  - 100-3,000 devices on a chip
- Large scale integration - 1971-1977
  - 3,000 - 100,000 devices on a chip
- Very large scale integration - 1978 to date
  - 100,000 - 100,000,000 devices on a chip
- Ultra large scale integration
  - Over 100,000,000 devices on a chip

### Moore’s Law
- Increased density of components on chip
- Gordon Moore - cofounder of Intel
- Number of transistors on a chip will double every year
  - Since 1970’s development has slowed a little
  - Number of transistors doubles every 18 months
- Cost of a chip has remained almost unchanged
- Higher packing density means shorter electrical paths, giving higher performance
- Smaller size gives increased flexibility
- Reduced power and cooling requirements
- Fewer interconnections increases reliability

### IBM 360 series
- 1964
- Replaced (& not compatible with) 7000 series
- First planned “family” of computers
  - Similar or identical instruction sets
  - Similar or identical O/S
  - Increasing speed
  - Increasing number of I/O ports (i.e. more terminals)
  - Increased memory size
  - Increased cost
**DEC PDP-8**
- 1964
- First minicomputer (after miniskirt!)
- Did not need air conditioned room
- Small enough to sit on a lab bench
- $16,000 → $100k+ for IBM 360
- Embedded applications & OEM
- BUS STRUCTURE

**DEC - PDP-8 Bus Structure**

![DEC - PDP-8 Bus Structure Diagram]

**Semiconductor Memory**
- 1970
- Fairchild
- A chip about size of a single core → i.e. 1 bit of magnetic core storage
- Holds 256 bits
- Non-destructive read
- Much faster than core
- Capacity approximately doubles each year

**Intel**
- 1971 - 4004
  → First microprocessor
  → All CPU components on a single chip
  → 4 bit
- Followed in 1972 by 8008
  → 8 bit
  → Both designed for specific applications
- 1974 - 8080
  → Intel’s first general purpose microprocessor

**Speeding it up**
- Pipelining
- On board cache
- On board L1 & L2 cache
- Branch prediction
- Data flow analysis
- Speculative execution

**Performance Mismatch**
- Processor speed increased
- Memory capacity increased
- Memory speed lags behind processor speed
Design for Performance: DRAM and Processor Characteristics

Trends in DRAM use

Performance Balance: Solutions
- Increase number of bits retrieved at one time
  - Make DRAM “wider” rather than “deeper”
- Change DRAM interface
  - Cache
- Reduce frequency of memory access
  - More complex cache and cache on chip
- Increase interconnection bandwidth
  - High speed buses
  - Hierarchy of buses

Internet Resources
- http://www.intel.com/
  - Search for the Intel Museum
- http://www.ibm.com
- http://www.dec.com
- Charles Babbage Institute
- PowerPC
- Intel Developer Home