Introduction
A Brief History Of Computing

Some Basic Terms

Architecture: "The art or science of building habitable structures"

Our Structures: Computer Systems

Our Inhabitants: Computer programs

Computer Architecture: Art of describing and building computer systems which can execute computer programs; alternatively: structure & behavior of computer as seen by assembly level programmer

Computer Organization: Description of major logical & physical components of a computer and how they interact

Computer Implementation: Description of electrical components used to build a computer

Computer Execution Model: Description of how programs execute within a computer architecture

Instruction Set Architecture (ISA): Description of the instructions which can make up a computer program, and the semantics of what each does when executed

Feature Size (in microns): minimum width of a gate of a CMOS transistor possible in a particular technology generation

People & the Computer Design Process

Computer Architect: Architecture Level

- Develops ISA, computer system architecture
- Interplay between hardware (machine organization) and software (compilers, interpreters, runtime) needed to sustain the "inhabitants"

Computer Designer: Organization Level

- Develops detailed machine organization
  - Partitioning into major blocks
  - Specification of each block's interfaces & functionality
  - Selects technology to be used for each major block
- Develops overall timing, power, packaging specifications and budgets
- Develops test procedures to verify proper system operation

Logic Designer: Implementation Level

- Implementation of each block in specified technology
- Develop and test block implementation
- Integrate multiple blocks into higher levels

Physical Designer: positioning of transistors on chip & library of macros

History of Events Relevant to Computer Architecture

- xxx BC - Astronomical computers: Stonehenge, etc
- xxx BC - Pythagorous invents abacus
- 1400's - Arabic astrolabe for astronomical calculations
- 1600's - Chinese Slide rule
- 1642 - Blaise Pascal's mechanical calculator for addition & subtraction
- 1673 - Leibniz builds all metal calculator which can adds, subtract, multiply, and divide
- 1740s - Jacques de Vaucanson uses punch cards to store weaving patterns
- 1804 - Jacquard develops automated loom using punch cards to direct loom
- 1832 - Charles Babbage builds prototype of Difference Engine to mechanize computation of tables of functions using difference methods
- 1833 - Babbage designs Analytical Engine: use of punch cards for program store, intermediate data storage
  - Never finished - Babbage's son finishes partial prototype in 1910
- 1833 - Lady Ada Augusta Lovelace (daughter of Lord Byron) - world's first programmer (of Analytical Engine)

- 1876 - Kelvin's Tide Predicter - enter tide data via wheels, output on graph paper roll
- 1890 - Herman Hollerith develops use of punch cards for 1890 US Census
- 1896 - Hollerith founds Tabulating Machine Company
- 1924 - Tabulating Machine Company merges with others to form IBM
- 1930 - MIT Differential Analyzer:
  - Purpose: solve differential equations
  - Mechanical computation with first use of vacuum tubes for memory
  - Programmed by aligning gears on shafts
- 1936 - Konrad Zuse builds Z1 - first binary computer using Erector Set parts, keyoard and lights for output (relay memory)
- 1937 - Alan Turing, British Mathematician, develops theory of computability and the "Turing machine" model
- 1938 - Zuse builds Z2 - using punched tape and relays
- 1939 - Enigma - mechanical cipher/decipher machine (mechanical with keyboard)
- 1939 - John Atanasoff (Iowa State): designs ABC vacuum tube computer to solve simultaneous linear equations
  - Influenced John Mauchly's ENIAC
- 1941 - Z3: first operational general purpose stored-program computer

- 1941 - Von Neumann proposes EDVAC
  - Electronic Discrete Variable Computer
  - 4 address instructions (3 operand, 1 for next instruction)
  - Serial binary arithmetic
  - 1K words of mercury delay line main memory
  - 20K words magnetic wire secondary memory
  - Concept of "Stored Program" - program stored in memory like data
  - "Chaining:" one program loading another - beginnings of "operating system"
- 1943 - British Colossus - first all-electronic computer (2,400 vacuum tubes) used to crack German codes (contributions by Turing)
  - Decipher Enigma coded messages at 5,000 chars/seconds
  - At peak, 10 machines ran 24 hours a day
- 1943 - IBM/Harvard Mark I by Howard Aiken
  - electromechanical computer: recreation of Analytical Engine
  - 8 ft tall, 50 ft long, 1 million parts
  - Worlds fastest calculator: about 3 23 decimal-digit additions per second, 6 sec for multiple, 30 for divide; storage for 72 23-digit numbers
  - Made IBM household word

- 1944 - John Von Neumann teams with Mauchly & Eckert
  - Start work on first programmable computer - EDVAC
- 1946 - Bipolar transistor developed at AT&T Bell Labs
- 1946 - ENIAC - first US all-electronic computer - trajectory calculations
  - John Mauchly & Presper Eckert
  - 18,000 tubes, 60,000 lbs, 1,500 sq. ft, staff of 5 to replace tubes
  - Programmed by wire plugs into panels
  - 5,000 decimal additions (or 300 multiplies) per second
  - 20 10-decimal digit “accumulators”; each digit = 10 vacuum tubes
- 1947 - Eckert & Mauchly start Eckert-Mauchly Company (bought by Sperry-Rand)
- 1948 - IBM 604 Electronic Tabulating Punch sells as widespread business machine
- Late 1940's - Manchester Univ. & Ferranti ATLAS invents
  - one-level store - predecessor to virtual memory
  - 32 "Page" main memory of 512 words & 200 page drum
- 1950 - UNIVAC-I - first non-military programmable computer
  - Memory was sound waves in mercury delay line
  - GE first non military customer

- 1951 - Maurice Wilkes invents microprogramming as alternative to hardwired control logic
- 1950s - assembly language programming
- 1952 - Completion of Von Neumann’s ideas in Princeton IAS computer
  - 40 bit memory words , each holding 40 bit 2’s complement #
  - 20 bit instructions, 2 to a word
- 1952 - Sperry-Rand UNIVAC-I predicts presidential race on TV
- 1952 - first magnetic core memory demonstrated
- 1953 - IBM 701 - first machine designed to be mass produced
  - 1,024 bits of RAM using electrostatic CRT tubes
  - Magnetic Tape units
- 1953 - IBM 650 - smaller low cost machine for business
  - Magnetic drum used for main memory
  - 1,800 sold vs forcast by marketing of “0”
- 1953 - MIT TX-0 is 1st transistorized computer
- 1953 - IBM builds first magnetic disk drive
- 1955 - IBM 704
  - Vacuum tube
  - ISA included index registers & binary floating point

- rudimentary operating system
- Separate Input/Output Processors

- 1955 - Beginning of use of magnetic cores for main memory
- 1957 - Digital Equipment Corp. (DEC) formed & delivers PDP-1
- 1957 - John Backus at IBM invents FORTRAN
  - FORmula TRANslation
- 1958 - Robert Noyce (Fairchild) & Jack Kilby (Texas Instruments) independently invent Integrated Circuit
- 1959 - IBM 7090: first solid state computers delivered to US Air Force for Early Warning System
- 1959 - Standardization of COBOL (COmmon Business OrientedLanguage) - Grace Hopper
- 1960 - Lisp language developed
- 1961 - IBM STRETCH
  - high speed transistorized core memory scientific computers
  - Overlapped instruction fetch & execute
  - Multiprocessing
- 1961 - Start of MIT Apollo Guidance Computer
  - 256 words total of 16 bit eraseable memory
  - 4,000 words of non eraseable memory (core ropes)

- later uprated to 2K eraseable, 36K nonerasable
- 1962 - IBM computer for GEMINI spacecraft
  - 4,096 39-bit words of core memory
  - 13 bit instructions, 26 bit data
  - Programmed in octal by hand
- 1963 MIT LINC - predecessor of low cost minicomputer
- 1963 - English Electric KDF-9, Burroughs B5000
  - Accumulator replaced by hardware managed stack“Accumulator” instruction set architecture
- 1963 MIT LINC - predecessor of low cost minicomputer
- 1963 - DEC PDP-5 first minicomputer
- 1963 - English Electric KDF-9, Burroughs B5000
  - Accumulator replaces by hardware managed stack
- 1963 MIT develops CTSS : Compatible Time-Sharing System
- 1963 - SECD abstract machine defined for Lisp
- 1964 - UNIVAC 1107 is ND's central computer
- 1964 - CDC 6600: large scale scientific computer
  - 60 bit 1's complement, multiple floating point function units
  - ISA including multiple index and accumulator registers

- ISA: simple load/store memory access (predecessor of RISC)
- "Scoreboarding" for instruction scheduling
- Multiple I/O Processors for overlapped I/O
- IOPs designed with precursor of multithreading

- 1964 - Bell No. 1 ESS: first computer controlled telephone exchange with high fault tolerance
- 1964 - IBM System/360 - first family of ISA-compatible computers
  - Largest privately financed research program in the world
- 1966 - PDP-8: first high volume minicomputer
- 1967 - BASIC developed at Dartmouth College
  - Beginner's All-purpose Symbolic Instruction Code
- 1967 - Tomasulo algorithm used in IBM 360 Model 91 for first instruction level parallelism
- Late 1960s: AT&T Bell Labs invents UNIX Operating System
- 1967 - *ND student* writes FORTRAN interpreter
- 1968 - Edison de Castro (designer of PDP-8) leaves DEC and starts Data General
  - First machine: DG NOVA designed around 74181 ALU slice
- 1968 - IBM 360/85: first computer with cache
- 1968 - ND EE Dept. gets PDP-8i for *student* projects: parallel I/O port

- 1968 - Noyce starts Intel Corp.
- Late 1960s - Saturn V first stage controlled by 10,000 operations per second computer designed in early 1960s
- 1969 - Mariner Mars spacecraft computer: 128 22-bit words
- 1970 - DEC PDP-11: first 16 bit minicomputer
  - Unibus allows user-constructed peripherials
- 1970 - IBM invents floppy disk & uses it for microprogram load
- 1970 - Alain Colmerauer invents PROLOG (Programming in LOGic)
- 1970 - Ed Codd at IBM invents relational algebra, leading to relational database systems
- 1970 - Apollo astronauts carry portable programmable calculators as backup to navigation computer
- 1971 - Mariner Mars spacecraft computer - upgraded to 512 words
- 1971 - Intel 4004 - first microprocessor (4 bits; 2,300 transistors)
  - 60,000 operations/second matched ENIAC
  - Computer used on board 1972 Pioneer 10 - still functioning!
- 1972 - Intel 8008 - 8 bit microprocessor - needed 20 support chips
- 1972 - ILLIAC IV by Dan Slotnick = first SIMD parallel processor:
  - 64 separate memories and floating point dataflows
  - interconnected in a wrapped 2D mesh (torus)

- all executing same instructions from single control unit
- 1972 - Virtual Memory support added to IBM S/360 OS/VS, VM/370 announced as matching operating systems
- 1972 - Texas Instruments Advanced Scientific Computer (ASC)
  - Pipelined vector processor with reconfigurable functional units
- 1972 - CDC-STAR 100 (STring ARray computer):
  - Vector instruction set
  - Memory to memory vectors
  - APL-like hardware
- 1972 - Burroughs B1700 microprogrammable machine designed to emulate other ISAs
- 1972 - First CS dept. at ND folds
- 1974 - Intel 8080 - Enhanced 8 bit microprocessor - needed only 6 support chips
- Jan. 1974 - MITS ALTAIR computer kit offered for $397
- Late 1974 - Bill Gates & Paul Allen write BASIC for ALTAIR
- 1974 - Sperry Rand loses legal fight with Honeywell over basic computer patents from ENIAC
  - Court's decision: Atanasoff was there first, but never patented idea

- 1974 - Space Shuttle IOP designed by former ND student as 24 way 6600-like parallel processor - first spacebore parallel processor
- 1975 - Goodyear STARAN: first parallel SIMD processor using 1 bit dataflow nodes
- 1975 - Seymour Cray announces CRAY-I - world's first supercomputer
  - Vector registers
  - Multiple functional units
  - High bandwidth memory paths
  - Hierarchy of programmer visible register sets
  - Architecture designed around fast packaging
- 1976 - Bill Mensch at MOSTEK designs 6502 microprocessor
  - 1990's Mensch's daughters attend ND
  - 1990s Mensch on ND College of Engineering Advisory Board
- 1976 - Steve Jobs and Steve Wozniak build Apple I in garage using 6502
- 1976 - IBM 3838 (designed by former ND student) is fastest IBM single precision floating point accelerator computer for IBM mainframes and seismic application
- 1977 - Apple Corp. starts with Apple II
- 1977 - Radio Shack introduces TRS-80 including Gates' BASIC and OS
- 1977 - Warren Abstract Machine (WAM) developed for Prolog

- 1978 - MIT CADR machine implements SECD variant as ISA
- 1978 - SCHEME developed as clean Lisp
- 1978 - Intel announces 8086 - 16bit microprocessor
- 1978 - IBM 801 Project - John Cocke invents RISC
- 1978 - IBM 3033 supports cache invalidation for shared memory multiprocessors
- 1978 - Carnegie Mellon Cm* one of first hierarchical shared memory parallel processors
- 1979 - MIT graduate class develops SCHEME-79 chip and all chip CAD tools
- 1979 - VISICALC is world's first spreadsheet - legitimizes Apples for business use
- 1979 - Motorola 68000 one of first 32 bit microprocessors
- 1980 - Digital Research President on vacation when IBM calls - Bill Gates buys rights to DOS for $10K and answer phone from IBM
- 1980 - Goodyear/NASA MPP: 16,384 1 bit processors
- 1980 - Data General designs ECLIPSE - 32 bit supermini
- 1980 - DEC VAX: ultimate regularized CISC ISA
- 1981 - Tracy Kidder wins Pulitzer Prize for "Soul of a New Machine" book on ECLIPSE
- 1981 - ALICE dataflow computer built in England

- 1981 - "The Architecture of Pipelined Computers" by former *ND student*
- 1981 - John Hennessey & David Patterson popularize RISC
- 1981 - Space Shuttle uses closely coupled computers for digital flight, & multithreaded parallel computer (designed by former *ND student*) for I/O
- August 1981 - IBM announces PC
  - Used 8088 instead of 68000 because of cheap part
- 1982 - Combining network used in NYU Ultracomputer
- 1982 - CRAY X-MP multiprocessor version of CRAY-1
- 1982 - Tandem/16 loosely-coupled fault tolerant multiprocessor
- 1982 - Intel 286 adds memory management to x86 ISA
- 1983 - CalTech COSMIC CUBE: 64 node binary hypercube distributed
- memory parallel processor
- 1983 - IBM extends S/370 ISA to 31 bit addressing1984 - IBM ROMP is first RISC microprocessor but held from market until 1986
- 1984 - Teradata builds massively parallel database machine
- 1985 - Japanese build machines with Prolog WAM-like ISAs
- 1985 - IEEE 754 Standard for floating point issued
- 1985 - Symbolics 3600 becomes most popular Lisp machine
- 1985 - Intel announces 80386 - first x86 to include memory management
- 1986 - IBM adds vector registers & instructions to S/370 ISA

- 1987 - WAM implemented in microcode for DEC 8600
- 1987 - MIPS Computer Systems introduces R2000 RISC microprocessor Based on Hennessey's Stanford MIPS chip
- 1987 - Connection Machine & CM-2
  - 64,000 i bit processors
  - Both 2D mesh and packet switched router network
  - Serious data parallel algorithm & language work
- 1988 - SUN announced SPARC RISC microprocessor
  - Based on Patterson's Berkeley RISC-II chip
  - Includes register window stack for procedure arguments
- 1989 - Intel 486 includes on chip cache
- 1989 - Intel i860 2 way superscalar microprocessor Includes graphics generation support
- 1989 - Galileo spacecraft launched to Jupiter:
  - Utilized very low power RCA 1802 8 bit microprocessor
- 1990 - IBM RISC System/6000 RISC microprocessor
- 1990 - “The Architecture of Symbolic Computers” by former *ND student*
- 1991 - IBM/Motorola/Apple team to develop POWERPC RISC chip family
- 1992 - CSE Dept. splits off of ND EE Dept.

- 1993 - EXECUBE chip architected by former ND student: 3D binary hypercube parallel processor on a chip
  - Wins Slotnick award in 1994
  - First high density *Processor-In-Memory* (PIM) chip
- 1993 - POWERPC 601 supports out-of-order execution
- 1993 - Pentium introduced
- 1993 - IBM SP-1: closely coupled network of workstation microprocessors to form parallel compute engine
- 1994 - Initial workshop on approaches to 1 Petaflop computers
- 1994 - Pentium includes dynamic branch prediction logic
- 1995 - DEC Alpha 21164 include 4 instruction superscalar issue
- 1995 - Installation of SP-2 at ND
- 1996 - ND begins using PIM concepts for Petaflop machines & deep space autonomous probes
- 1996 - Intel ASCI Red machine achieves sustained 1 Teraflop
- 1996 - DEC Alpha 21164 running at 500 MHz
- October, 1996 - Seymour Cray dies after car accident
- Dec. 1996 - MARS Pathfinder spacecraft launched
  - Lander section includes radiation hardened RS/6000 microprocessor
  - Rover has low power 80C51 microcontroller

- 1997 - Intel Pentium MMX - MultiMedia Extension to x86 ISA
- Jan. 1997 - Supposed birthday of HAL-9000 from 2001: A Space Odyssy
- 1997 - 0.25 micron CMOS technology allows 8 MB memory chips
- 1997 - Joint CalTech/ND/Princeton/SUNY Stoneybrook starts petaflops machine design (World's fasted computer by a factor of ***1,000***)
  - RSFQ superconduction x00 GHz CPU parts
  - PIM "smart memory" (ND Portion)
  - All optical interconnection network at petabyte/sec cross section bandwidth
  - 3D Holographic storage in crystals
- 1997 - ND EE Dept. demonstrates first quantum dot devices called ***Quantum Cellular Arrays*** (**QCA**)
- 1997 - ND seniors design real SIMPLE12 in 2 micron CMOS
- 1998 - ND CSE Dept. starts work on 64 Mbit PIM chip
- 1998 - ND EE Dept. demonstrates quantum dot XOR gate
- 1999 - 0.18 micron CMOS technology allows 32 MB memory chips
- 1999 - AMD announces Athelon: x86 chip; Intel & AMD leapfrog each other in clock rate to reach 750-800 MHz clock rates
- 1999 - ND CSE seniors build real SIMPLE12's using 4 micron SORIN chip on 2nd floor of Fitz as part of *Bits to Chips Program*

- 1999 - IBM announces plans to build petaflops computer to do protein folding calculations using PIM technology
- 1999 - IBM announces POWER4 chip - four 1+ GHz microprocessors on a single chip
- 2000 - ND grad student receives MS for design of world's first QCA microprocessor - a SIMPLE12
- May 2000 - CSE322 class achieves 100% successful JAM8 designs
- Fall 2000 - ND CSE'01 students build real silicon JAM8 on ND line
- 2001 - 0.15 micron CMOS technology allows 128 MB memory chips
- 2001 - ND CSE class of '01 enter hi tech firms
- 2001 - Gigaflop gameboys become popular
- 2002 - Complete PC integrated to single chip - PIM becomes commonplace
- 2003 - 0.13 micron CMOS technology allows 512 MB memory chips
- 2003 - ND demonstrates first quantum dot computer - a multithreaded SIMPLE12 running MaxFinder
- 2004 - ND-designed PIM chip powers Mars rover
- 2005 - 1997 ND work results in world's first general purpose petaflops machine
- 2006 - 0.10 micron CMOS technology allows 2 GB memory chips
- 2009 - 0.07 micron CMOS technology allows 8 GB memory chips

- **2010 - ND CSE'01 grads enter middle management of hi tech companies**
- **2010 - High temperature quantum dot technology developed**
- **2012 - Silicon based logic runs out of steam around 0.05 micron feature size (32 GB memory part) & QCA technology takes over with first commercial holographic petaflop gameboys**
- **2013 - ND CSE "old guard" begins retirement**
- **2014 - 3 dimensional arrays of "Bionically Implanted Organically Grown (BORG)" QCA PIM chips enable ND football team to be declared National Champs after 3 games ("resistance is futile")**
- **2015 - first autonomous, semi-intelligent, interstellar probe launched with exaflop QCA-based PIM computer with 10 billion internal processing nodes**
- **2028 - Former ND '01 student returns to be Dean of Engineering**
- **2046 - CSE class of '01 enters retirement**