Processors and Performance

History of Computers

Generations in Computer Organization

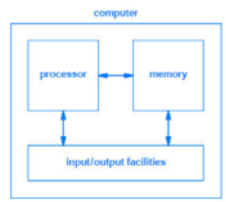
- Zeroth generation – mechanical computers (1642 – 1945)
- First generation – vacuum tubes (1945 – 1955)
- Second generation – transistors (1955 – 1965)
- Third generation – integrated circuits (1965 – 1980)
- Fourth generation – VLSI (Very Large Scale Integration) (1980 - ?)

Milestones in Computer Organization

- 1642, Blaise Pascal, mechanical machine with gears to add and subtract
- c. 1670, Baron Gottfried Wilhelm von Leibniz, mechanical machine with gears to add, subtract, multiply and divide
- 1834, Charles Babbage, Analytical Engine (Ada Lovelace wrote its “assembler”)
- 1936, Konrad Zuse, Z1, calculator made of electromagnetic relays
- 1940’s, John Atanasoff, George Stibbitz, Howard Aiken (Mark I and II); each worked independently on calculating machines with properties such as binary arithmetic and capacitors for memory

Milestones in Computer Organization

- 1943, Alan Turing and British govt., COLOSSUS, first electronic computer
- 1946, John Mauchley and J. Presper Eckert, ENIAC, vacuum tubes
- 1949, Maurice Wilkes, EDSAC, first stored-program computer
- 1952, John von Neumann, most current computers use his basic design



Milestones in Computer Organization

- 1950's, researchers at M.I.T (Massachusetts Institute of Technology), TX-0, first computer using transistors
- 1960, Kenneth Olsen founder of DEC (Digital Equipment Corp.), PDP-1, first mini-computer.
- 1961, IBM, 1401, very popular small business machine
- 1962, IBM, 7094, 709 with transistors. Dominated scientific computing.

Milestones in Computer Organization

- 1963, Burroughs, B500, first machine designed for high-level language (Algol)
- 1964, Seymour Cray of CDC (Control Data Corp.), 6600, nearly 10 times as fast as IBM's 7094 because CPU highly parallelized
- 1965, PDP-8, first mass-market mini-computer. Used a single bus.

Milestones in Computer Organization

- 1964, IBM, System/360, a family of machines (low end to high end), all compatible. First computer with multiprogramming (several programs in memory at once). Used integrated circuits (dozens of transistors on one chip)
- 1970, PDP-11, DEC, used integrated circuits.
- 1974, Intel, 8080, first general-purpose computer on a chip

Milestones in Computer Organization

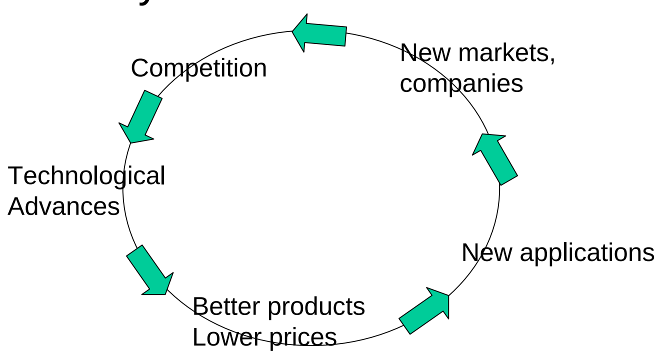
- 1974, Cray-1, first vector computer (single instructions on vectors of numbers)
- 1978, DEC, VAX, first 32-bit mini-computer
- Steve Jobs and Steve Wozniak, Apple, personal computer (PC)
- 1981, IBM, IBM PC, became most popular PC. Used MS-DOS by Microsoft as OS (operating system) and chip by Intel

Milestones in Computer Organization

- 1985, MIPS (company), MIPS, First commercial RISC machine
- 1987, Sun Microsystems, SPARC, RISC machine
- 1990, IBM, RS6000, first superscalar machine (CPU very parallelized)

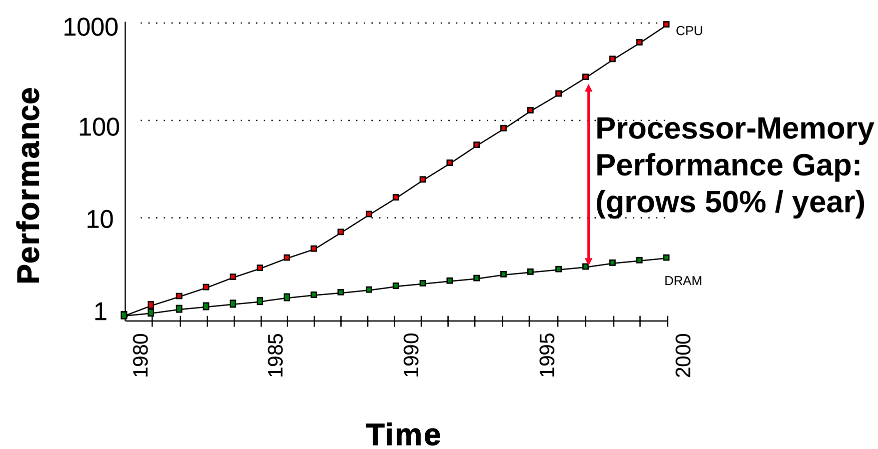
Milestones in Computer Organization

- Moore's Law: number of transistors on a chip doubles every 18 months. Virtuous cycle:



Memory Hierarchy Importance

1980: no cache in µproc; 1995: 2-level cache on chip
(1989 first Intel µproc with a cache on chip)



Processor Organization

Definition

The terms *processor* and *computational engine* refer broadly to any mechanism that drives computation.

Von Neumann Architecture

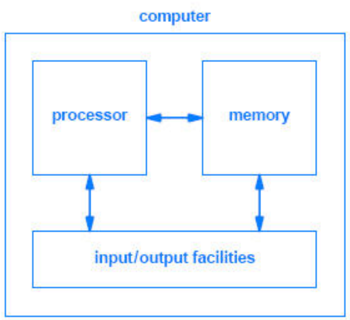
- Characteristic of most modern processors
- Reference to mathematician John Von Neumann who was one of the computer architecture pioneers
- Central idea is *stored program*

Three Basic Components of Von Neumann Architecture

- Processor
- Memory
- I/O facilities

All interact to form a complete computer

Illustration of Von Neumann Architecture



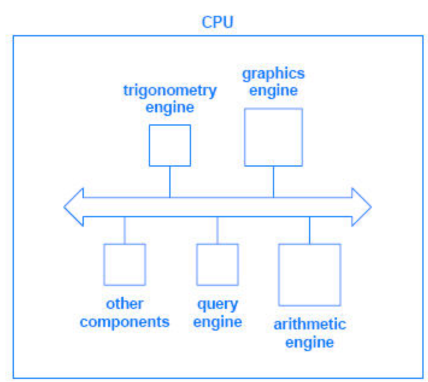
Processor

- Digital device
- Performs computation involving multiple steps
- Building blocks used to form computer system

Hierarchical Structure and Computational Engines

- Most computer architecture follows a hierarchical approach
- Subparts of a large, central processor are sophisticated enough to meet our definition of processor
- Some engineers use term *computational engine* for sub-piece that is less powerful than main processor

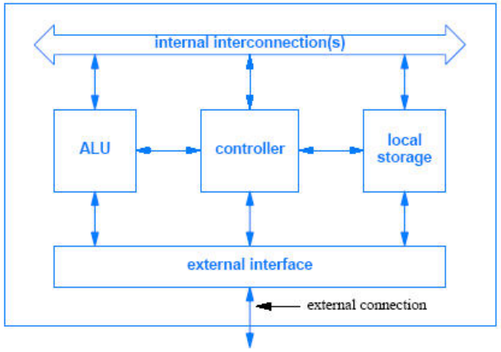
Illustration of Processor Hierarchy



Major Components of a Conventional Processor

- Controller
- Computational engine (ALU)
- Local data storage
- Internal interconnection(s)
- External interface

Illustration of a Conventional Processor



Parts of a Conventional Processor [1]

- Controller
  - Overall responsibility for execution
  - Moves through sequence of steps
  - Coordinates other units
- Computational engine
  - Operates as directed by controller
  - Typically provides arithmetic and Boolean operations (ALU)
  - Performs one operation at a time

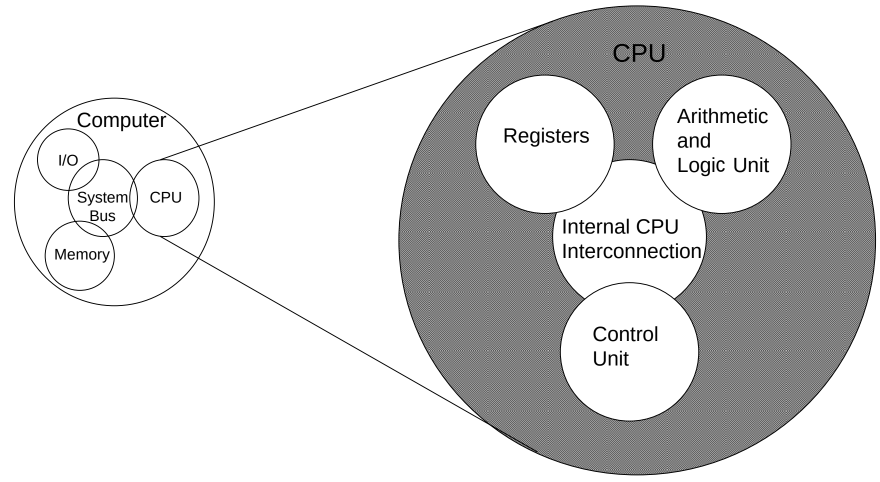
Parts of a Conventional Processor [2]

- Local data storage
  - Holds data values for operations
  - Must be loaded before operation can be performed
  - Typically implemented with registers
- Internal interconnections
  - Allow transfer of values among units of the processor
  - Sometimes called *data path*

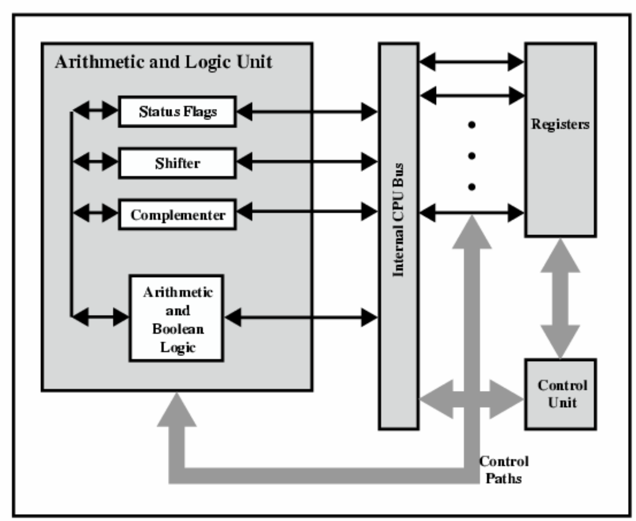
Parts of a Conventional Processor [3]

- External interface
  - Handles communication between processor and rest of computer system
  - Provides connections to external memory as well as external I/O devices

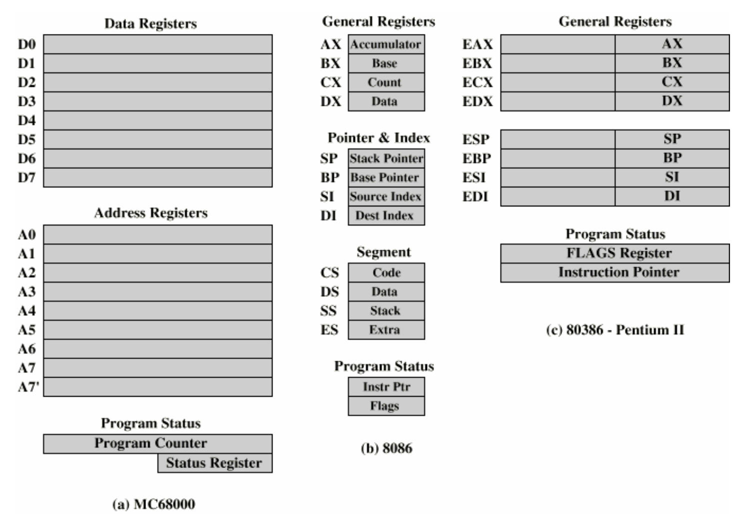
Another Illustration of Processor



Yet Another Illustration



Example Register Organizations



Arithmetic Logic Unit (ALU)

- Main computational engine in conventional processor
- Complex unit that can perform variety of tasks
- Typical ALU operations
  - Integer arithmetic (add, subtract, multiply, divide)
  - Shift (left, right, circular)
  - Boolean (*and, or, not, exclusive or*)

Processor Categories and Roles

- Many possible roles for individual processors in
  - Coprocessors
  - Microcontrollers
  - Microsequencers
  - Embedded system processors
  - General-purpose processors

Coprocessor

- Operates in conjunction with and under the control of another processor
- Usually
  - Special-purpose processor
  - Performs a single task
  - Operates at high speed
- Example: floating point accelerator

Microcontroller

- Programmable device
- Dedicated to control of a physical system
- Example: run automobile engine or grocery store door

Example Steps a Microcontroller Performs (Automatic Door)

```
do forever {
    wait for the sensor to be tripped;
    turn on power to the door motor;
    wait for a signal that indicates the
        door is open;
    wait for the sensor to reset;
    delay ten seconds;
    turn off power to the door motor;
}
```


Microsequencer

- Similar to microcontroller
- Controls coprocessors and other engines within a large processor
- Example: move operands to floating point unit; invoke an operation; move result back to memory

Embedded System Processor

- Runs sophisticated electronic device
- Usually more powerful than microcontroller
- Example: control DVD player, including commands from a remote control

General-Purpose Processor

- Most powerful type of processor
- Completely programmable
- Full functionality
- Example: CPU in a personal computer

Processor Performance

Clock and Instruction Rate

- Clock cycle
  - Time interval in which all basic circuits (steps) inside a processor must complete
  - Time at which gates are clocked
- Clock rate
  - 1 / clock cycle (GHz – billion cycles per second)
- Instruction rate
  - Measure of time required to *execute* instructions (MIPS – million instructions per second)
  - Varies because some instructions take more time (require more cycles) than others
  - Can typically estimate average cycles per instruction for normal job mix

Basic Performance Equation

Define: N = actual number of instructions executed in program

S = average number of cycles for instructions in program

R = clock rate

T = program execution time

$$T = \frac{N * S}{R}$$

Improve Performance

- To improve performance, must decrease N or S or increase R
- Parameters are not independent (e.g., increasing R may increase S)
- N primarily controlled by compiler
- Processors with largest R may not have the best performance (due to different S)
- Making logic circuits faster is a clear win, increases R while S and N remain unchanged

Benchmarks

- SPEC rating
  - Based upon a suite of applications

$$SPEC_i = \frac{\text{run time on reference computer}}{\text{run time on test computer}}$$

$$SPEC\ rating = \left(\prod_{i=1}^{n} SPEC_i \right)^{1/n}$$

  - http://www.spec.org
- LINPACK (Scientific Computing)
  - Speed in solving linear system of equation
  - http://www.top500.org/lists/2005/11/basic

TOP500 26th List: The TOP10

	Manufacturer	Computer	Rmax [TF/s]	Installation Site	Country	Year	#Proc
1	IBM	BlueGene/L eServer Blue Gene	280.6	DOE/NNSA/LLNL	USA	2005	131072
2	IBM	BGW eServer Blue Gene	91.29	IBM Thomas Watson	USA	2005	40960
3	IBM	ASC Purple eServer pSeries p575	63.39	DOE/NNSA/LLNL	USA	2005	10240
4 (3)	SGI	Columbia Altix, Infiniband	51.87	NASA Ames	USA	2004	10160
5	Dell	Thunderbird	38.27	Sandia	USA	2005	8000
6 (10)	Cray	Red Storm Cray XT3	36.19	Sandia	USA	2005	10880
7 (1)	NEC	Earth-Simulator	35.86	Earth Simulator Center	Japan	2002	5120
8 (5)	IBM	MareNostrum BladeCenter JS20, Myrinet	27.91	Barcelona Supercomputer Center	Spain	2005	4800
9 (6)	IBM	eServer Blue Gene	27.45	ASTRON University Groningen	Netherlands	2005	12288
10	Cray	Jaguar Cray XT3	20.53	Oak Ridge National Lab	USA	2005	5200

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