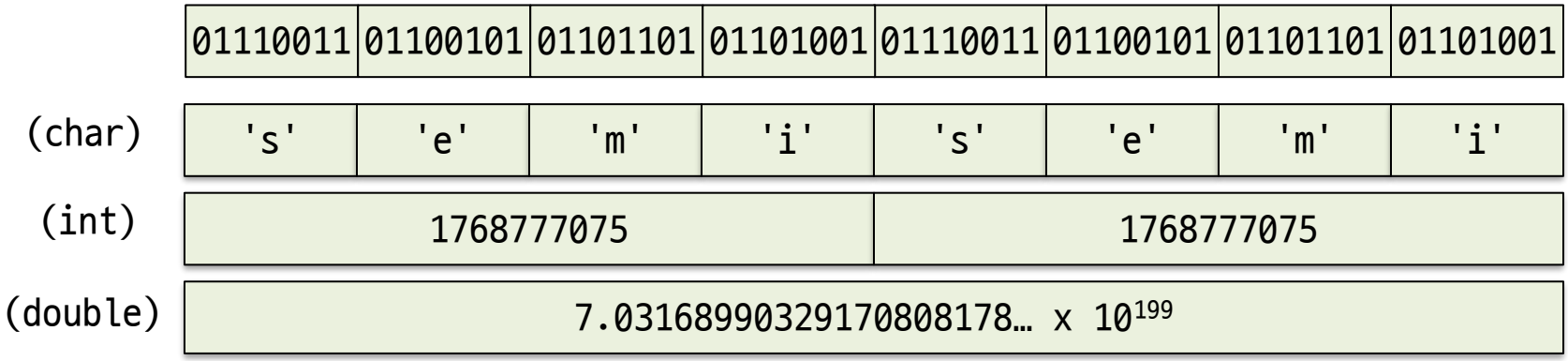
Computer Architecture Review

Jo, Heeseung

Representing Information

Information = Bits + Context

- Computers manipulate representations of things
- Things are represented as binary digits
- What can you represent with N bits?
  - 2^N things
  - Numbers, characters, pixels, positions, source code, executable files, machine instructions, …
  - Depends on what operations you do on them



What You Learned

How programs are translated into the machine language

- And how the hardware executes them

The hardware/software interface

What determines program performance

- And how it can be improved

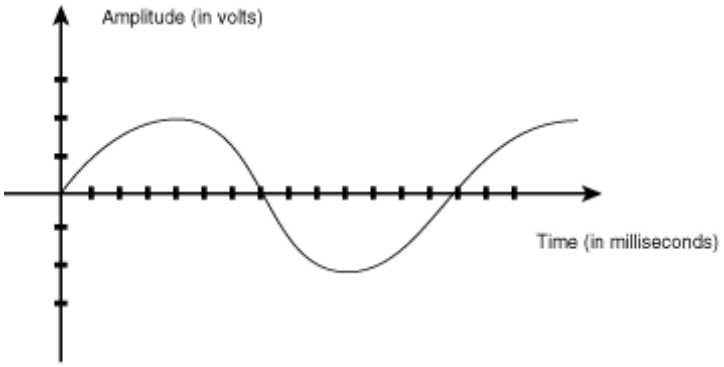
How hardware designers improve performance

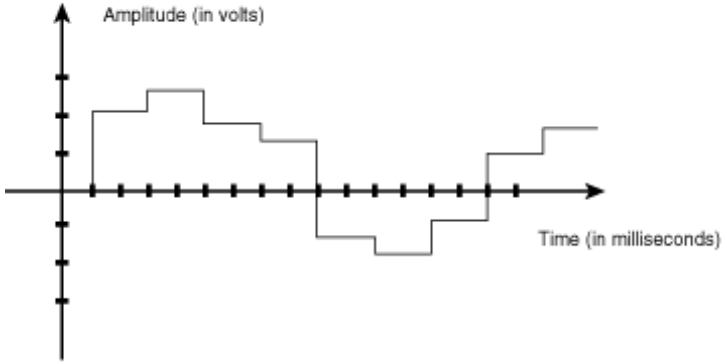
What is parallel processing

Introduction

The advent of the digital age

- Analog vs. digital?





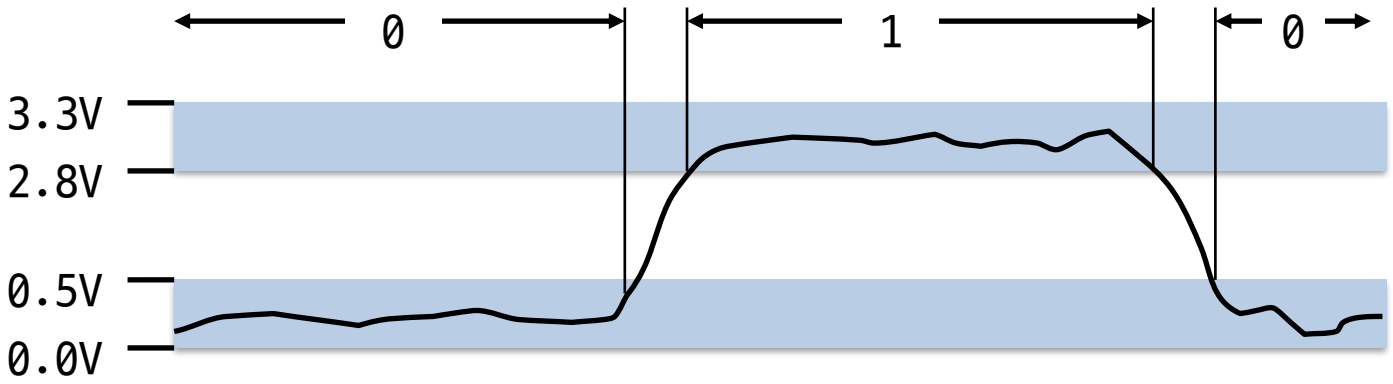
- Compact disc (CD)
  - 44.1 KHz, 16-bit, 2-channel
- MP3
  - A digital audio encoding with lossy data compression

Binary Representations

Why not base 10 representation?

- Easy to store with bistable elements
- Straightforward implementation of arithmetic functions
- Reliably transmitted on noisy and inaccurate wires

Electronic implementation



Encoding Byte Values

Byte = 8 bits

- Binary: 00000000_2 to 11111111_2
- Octal: 000_8 to 377_8
  - An integer constant that begins with 0 is an octal number in C
- Decimal: 0_{10} to 255_{10}
  - First digit must not be 0 in C
- Hexadecimal: 00_{16} to FF_{16}
  - Base 16 number representation
  - Use characters '0' to '9' and 'A' to 'F'
  - Write $FA1D37B_{16}$ in C as **0xFA1D37B** or **0xfa1d37b**

Hex	Decimal	Binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
A	10	1010
B	11	1011
C	12	1100
D	13	1101
E	14	1110
F	15	1111

Boolean Algebra (1)

Developed by George Boole in 1849

- Algebraic representation of logic
  - Encode "True" as 1 and "False" as 0

And

- A&B = 1 when both A=1 and B=1

&	0	1
0	0	0
1	0	1

Or

- A¦B = 1 when either A=1 or B=1

|	0	1
0	0	1
1	1	1

Not

- ~A = 1 when A=0

~	
0	1
1	0

Exclusive-Or (Xor)

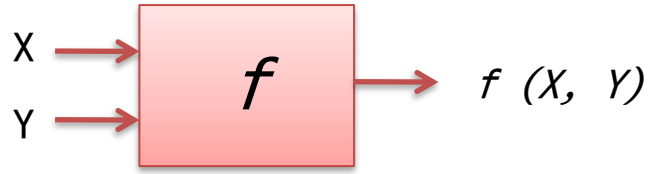
- A^B = 1 when either A=1 or B=1, but not both

^	0	1
0	0	1
1	1	0

Boolean Algebra (2)

0	0	1	1	X
0	1	0	1	Y

0	0	0	0	Constant 0
0	0	0	1	X & Y ; AND
0	0	1	0	~ (X → Y)
0	0	1	1	X
0	1	0	0	~ (Y → X)
0	1	0	1	Y
0	1	1	0	X ^ Y ; XOR
0	1	1	1	X ¦ Y ; OR
1	0	0	0	~ (X ¦ Y) ; NOR
1	0	0	1	~ (X ^ Y) ; X-NOR
1	0	1	0	~ Y
1	0	1	1	Y → X
1	1	0	0	~ X
1	1	0	1	X → Y ; Implication
1	1	1	0	~ (X & Y) ; NAND
1	1	1	1	Constant 1

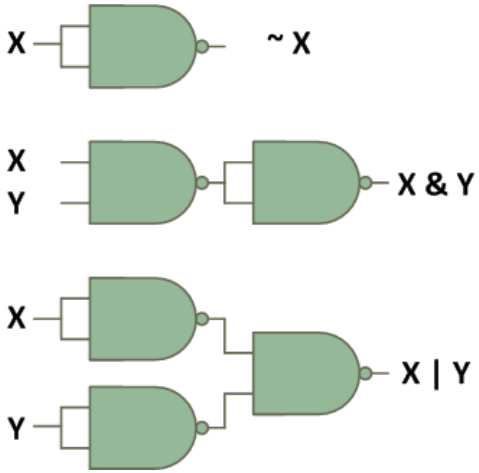


Basic operations: AND(&), OR(¦), NOT(~)

X ^ Y = (X & ~Y) ¦ (~X & Y)

X → Y = ~X ¦ Y

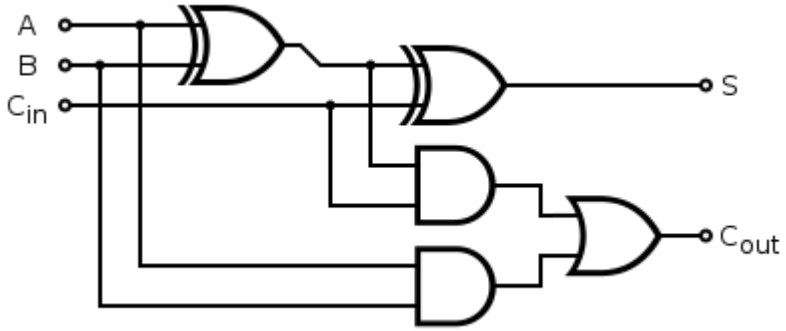
A complete set: NAND = ~ (X & Y)

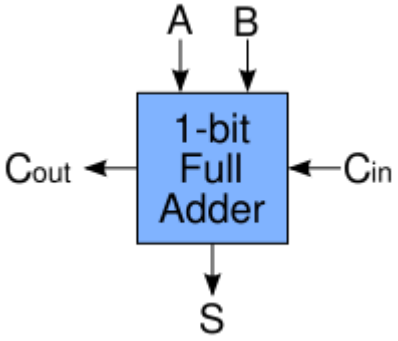


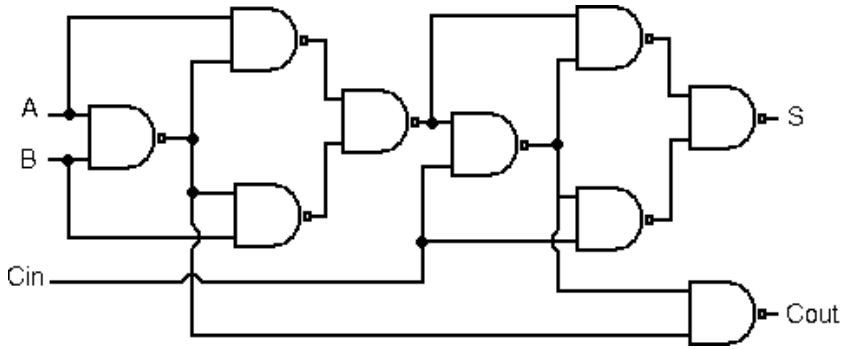
Combinational Logic

Adder

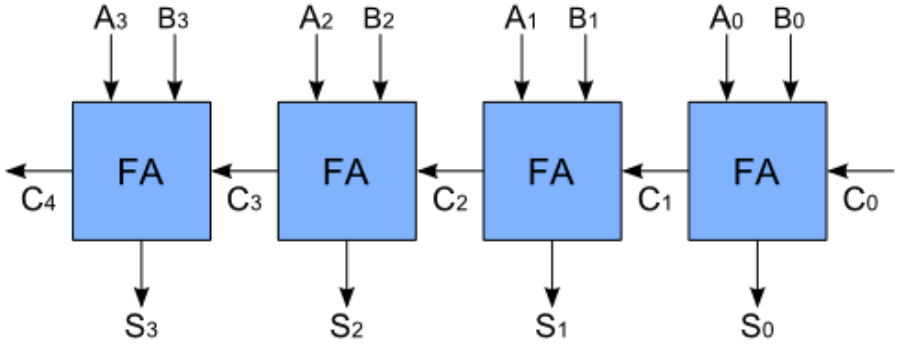
Full Adder







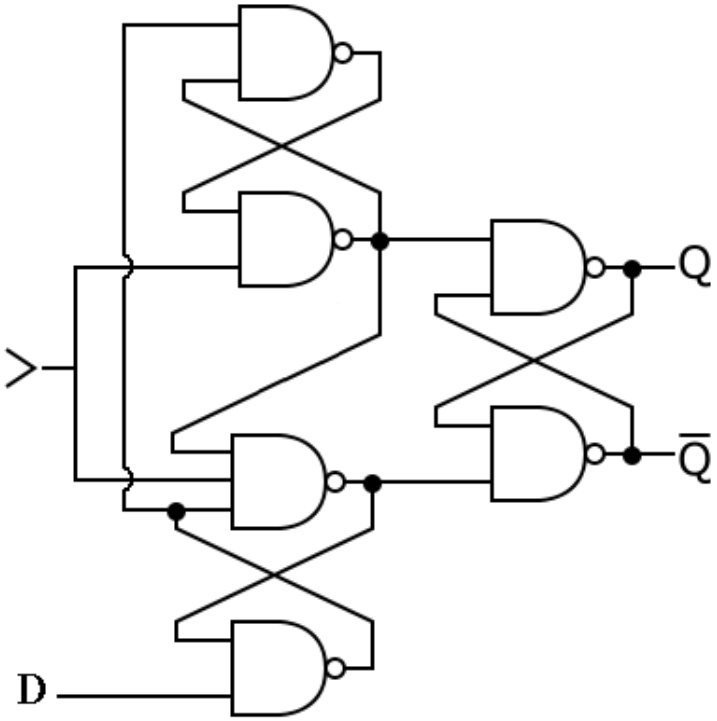
Full Adder (NAND version)



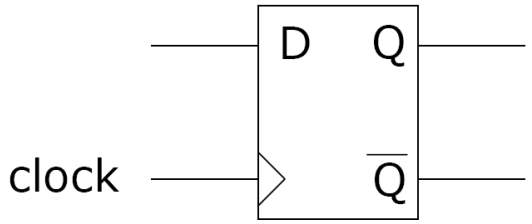
4-bit Ripple Carry Adder

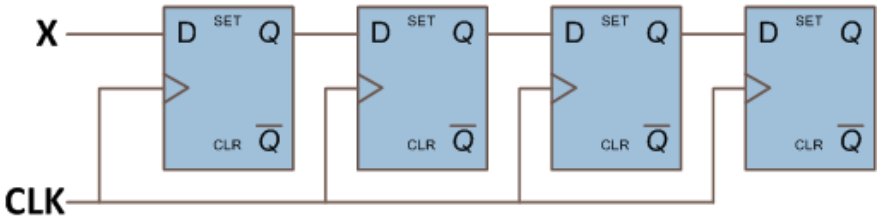
Sequential Logic

Flip-flops

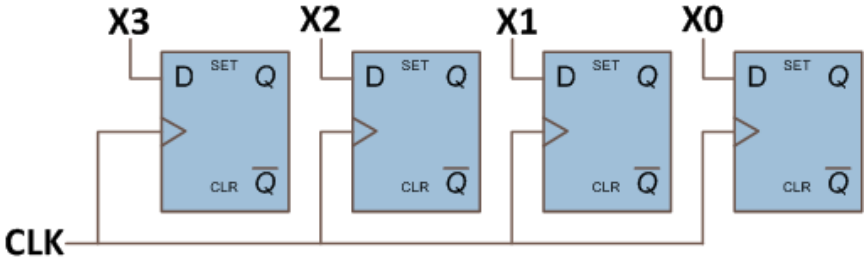


Edge triggered D flip-flop





Shifter

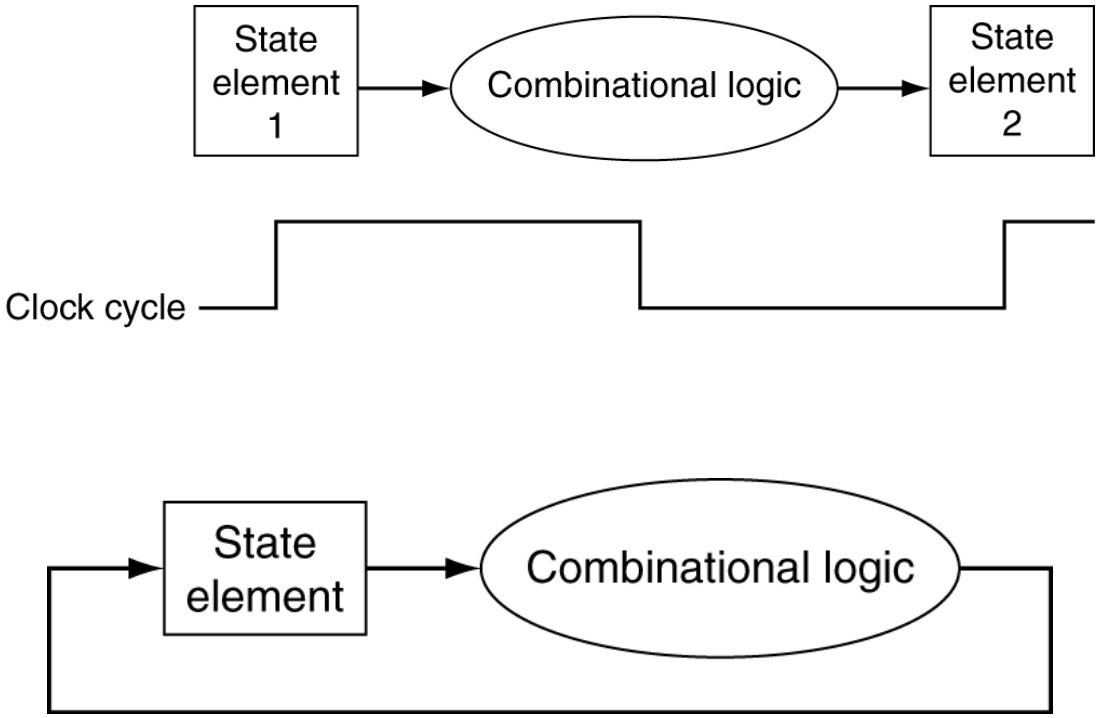


4-bit register

Clocking Methodology

Combinational logic transforms data during clock cycles

- Between clock edges
- Input from state elements, output to state element
- Longest delay determines clock period

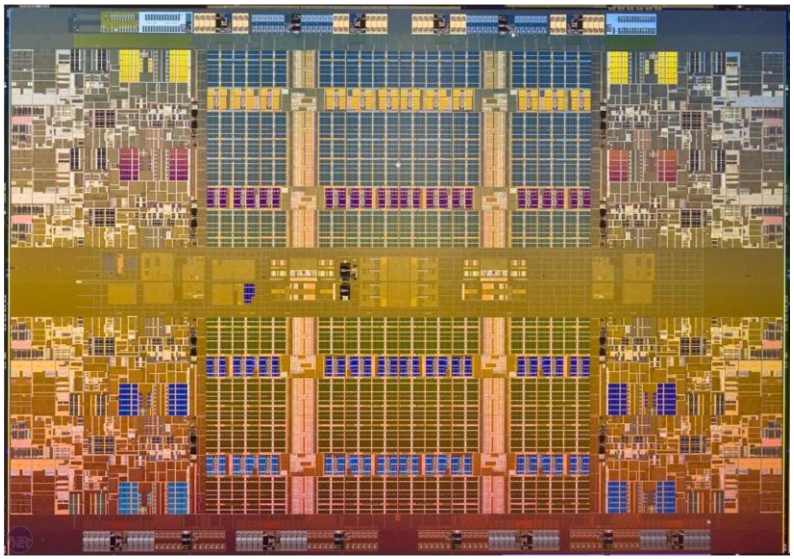


Digital Systems

Summary

- Boolean algebra is a mathematical foundation for modern digital systems
- Boolean algebra provides an effective means of describing circuits built with switches
  - Claude Shannon in the late 1930's
- You can build any digital systems with NAND gates
- A NAND gate can be easily built with CMOS transistors
- The transistor is the basic building block for digital systems

Intel Xeon 7560 (8-core): 2.3B transistors



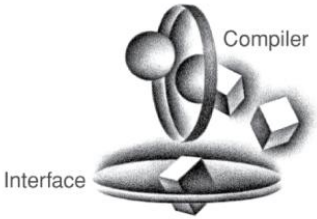
Components of a Computer

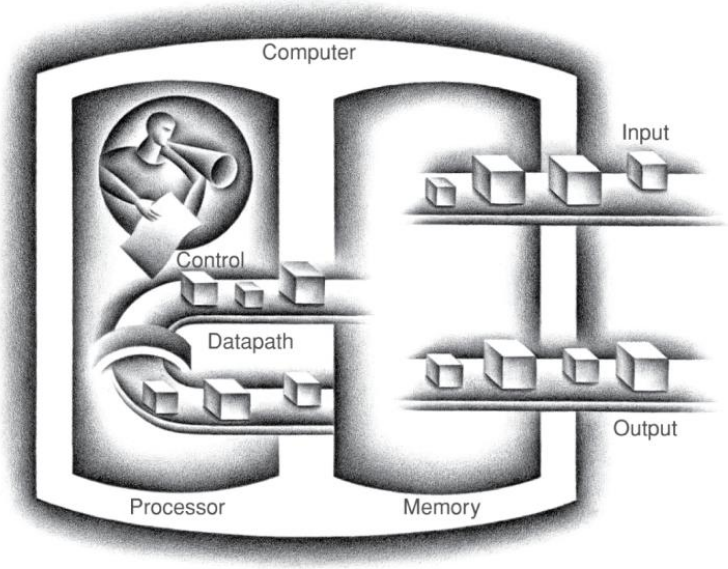
Same components for all kinds of computer

- Desktop, server, embedded

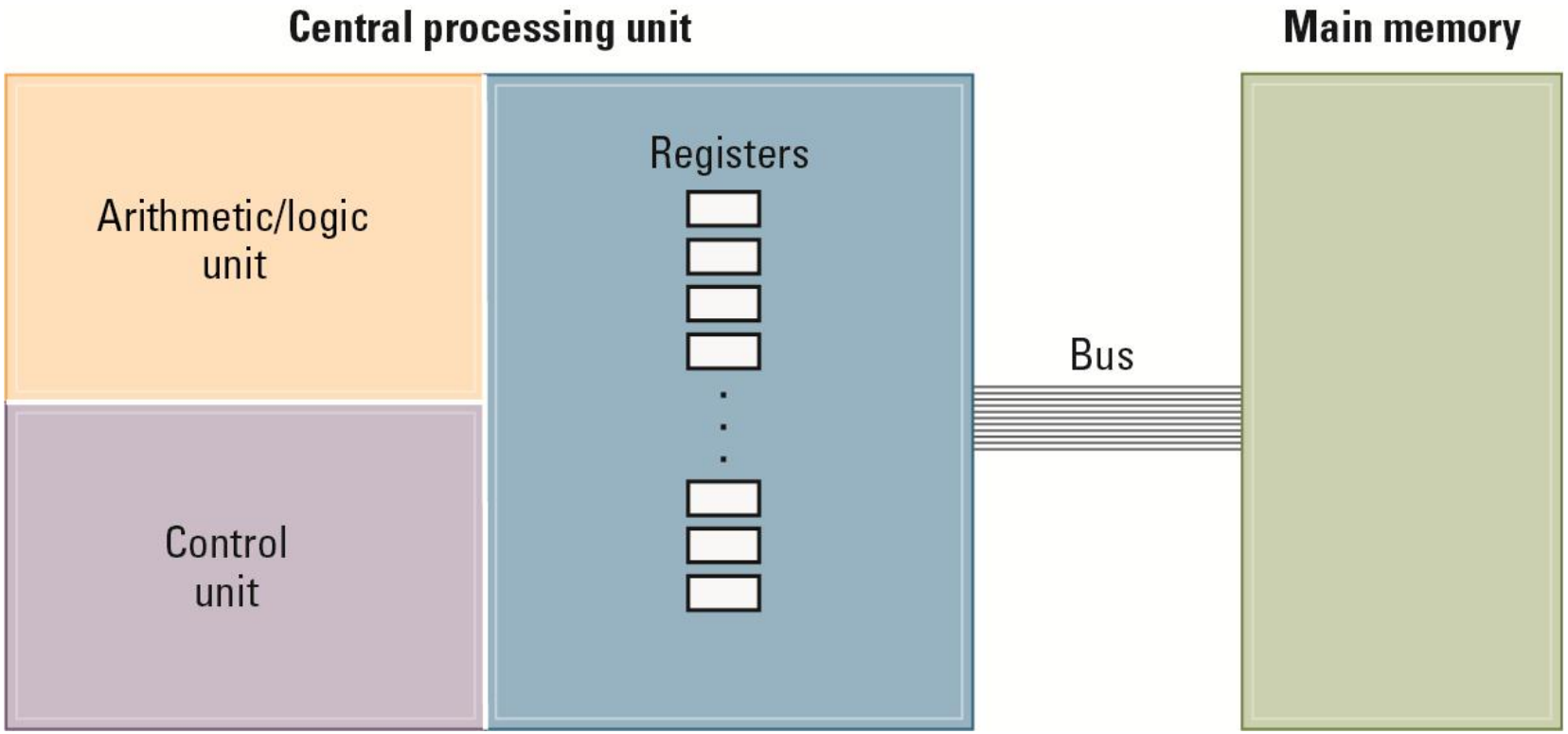
Input/output includes

- User-interface devices
  - Display, keyboard, mouse
- Storage devices
  - Hard disk, CD/DVD, flash
- Network adapters
  - For communicating with other computers





컴퓨터의 구성요소


Central processing unit
Main memory
Arithmetic/logic unit
Control unit
Registers
Bus

중앙처리장치의 주요 구성요소

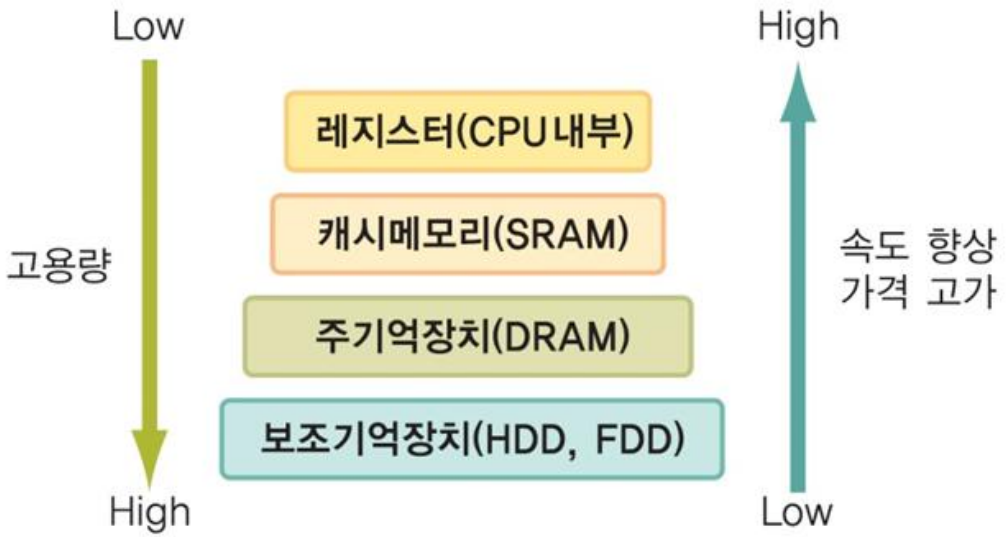
레지스터 장치(register unit)

- 레지스터(Register)
  - CPU내에서 정보를 임시로 저장하기 위해 사용
  - 여러 개의 레지스터를 가짐 (register file)
  - 성능에 매우 중요한 요소이므로 가격과 성능을 고려하여 결정
- 레지스터 종류
  - 범용 레지스터 : CPU에서 처리되는 데이터를 위한 임시 저장공간
    - 연산장치 회로의 입력들을 저장하고 있거나, 연산장치에서 계산된 결과를 저장하기 위한 공간으로 이용
  - 용도 지정 레지스터 : 임의 사용 불가능
    - 명령 레지스터, 프로그램 카운터 등

컴퓨터 내의 기억장치의 계층

기억장치 계층의 필요

- 기억장치의 속도와 용량, 가격과 그 쓰임새를 고려
- 기억장치의 속도가 빠르면 가격이 비쌈
- 동일한 비용으로 속도를 유지하려면 용량은 작아져야 함



컴퓨터 내의 기억장치의 계층

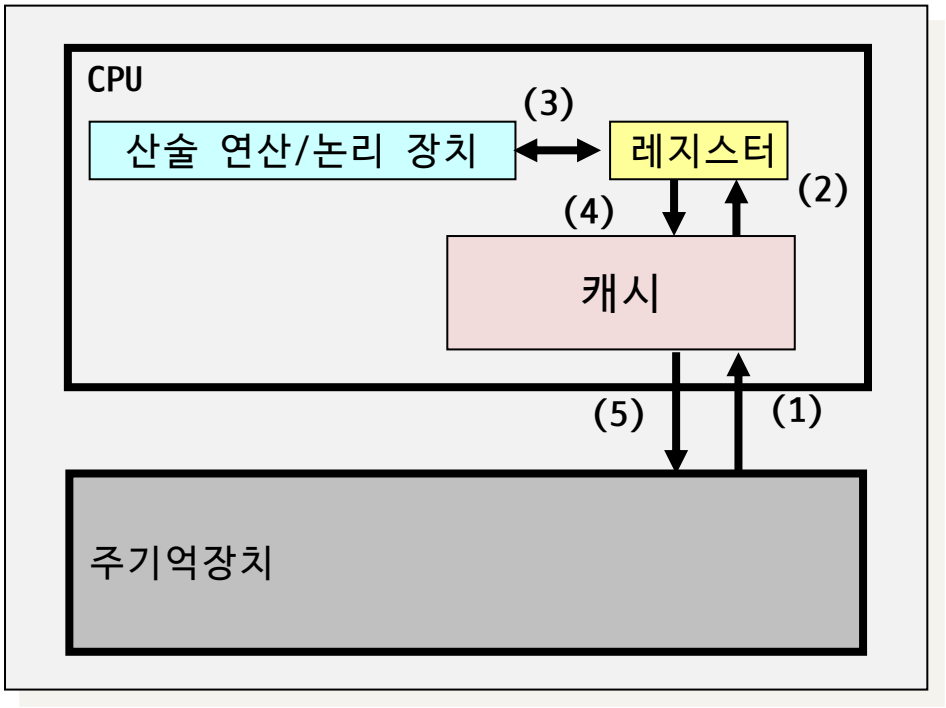
다양한 기억장치의 이용

- 레지스터 : 곧바로 사용될 데이터 보관
- 캐시 메모리
  - CPU 내부에 위치한 고속 메모리
  - 현재 자주 사용하는 주기억장치 부분의 복사본 유지
  - 캐시 메모리에 일어나는 변경들은 모아서 적절한 시점에 한꺼번에 주기억장치로 전달
  - 레지스터보다 느리지만 메인메모리보다 빠른 속도
  - 왜 쓰나? -> 주기억장치가 느리기 때문
- 주기억장치 : 가까운 시간 안에 사용될 데이터 보관
- 보조기억장치 : 당장 필요하지는 않은 데이터 보관

데이터 연산 처리 과정

주기억장치에 저장된 데이터에 대한 연산을 수행하려면..

- 제어장치가 데이터를 주기억장치로부터 범용 레지스터로 전송
- 어느 레지스터가 데이터를 갖고 있는지 연산장치에 알려주고,
- 연산장치 안의 적절한 회로를 작동시키고,
- 연산장치에게 결과를 받을 레지스터가 어느 것인지 알려줌



Understanding Performance

Algorithm

- Determines number of operations executed

Programming language, compiler, architecture

- Determine number of machine instructions executed per operation

Processor and memory system

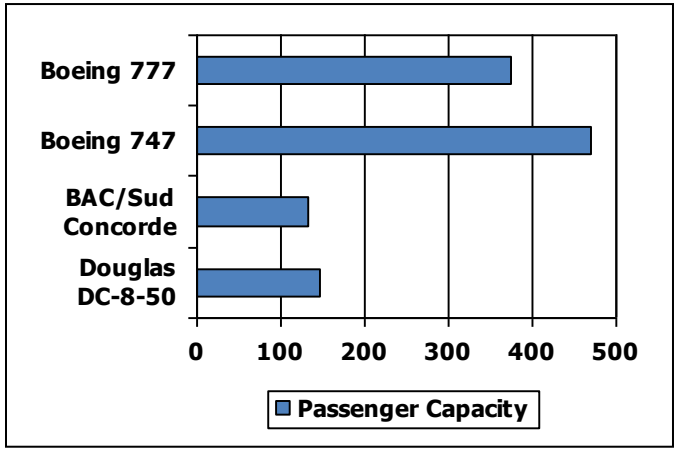
- Determine how fast instructions are executed

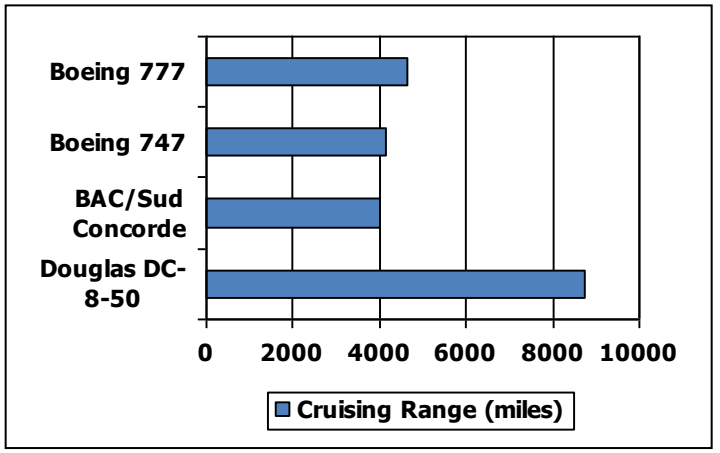
I/O system (including OS)

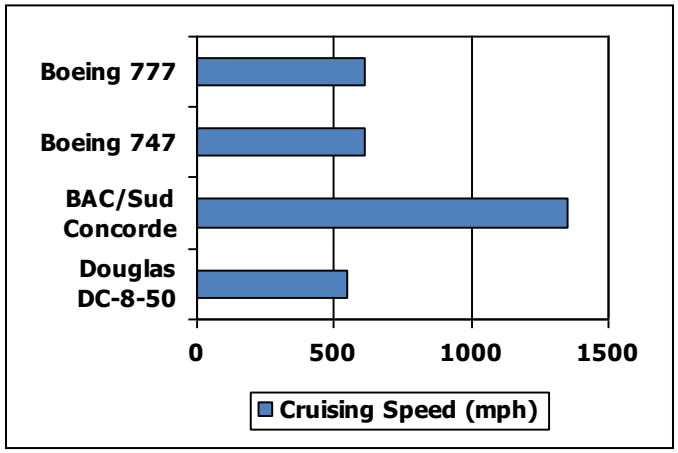
- Determines how fast I/O operations are executed

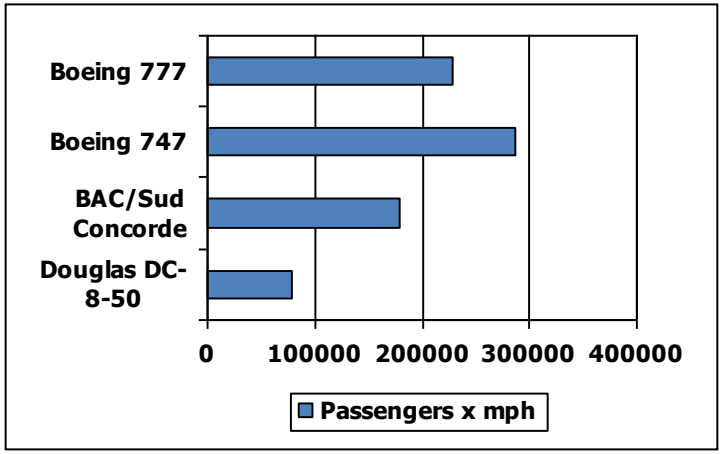
Defining Performance

Which airplane has the best performance?









Response Time and Throughput

Response time

- How long it takes to do a task

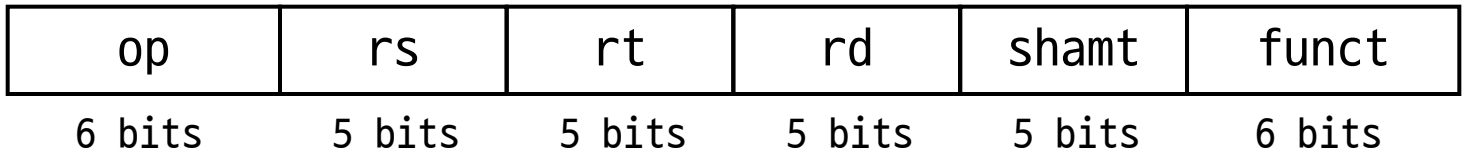
Throughput

- Total work done per unit time
  - e.g., tasks/transactions/… per hour

How are response time and throughput affected by

- Replacing the processor with a faster version?
- Adding more processors?

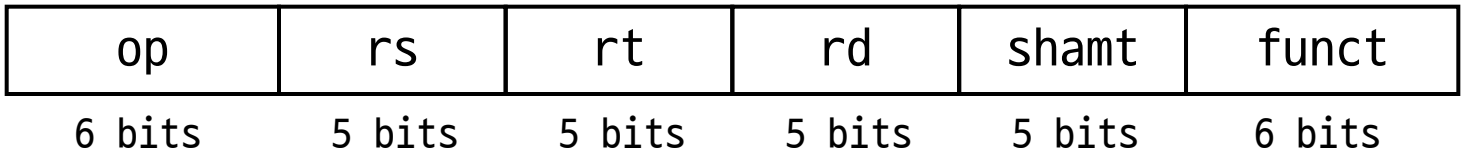
MIPS R-format Instructions



Instruction fields

- op: operation code (opcode)
- rs: first source register number
- rt: second source register number
- rd: destination register number
- shamt: shift amount (00000 for now)
- funct: function code (extends opcode)

R-format Example




```
add $t0, $s1, $s2
```

special	$s1	$s2	$t0	0	add
0	17	18	8	0	32
000000	10001	10010	01000	00000	100000

$00000100011001001000000000100000_2 = 02324020_{16}$

프로그램 내장(stored program) 개념

초기의 컴퓨터 : hard-wired programming

- CPU의 회로를 변경하도록 설계됨
- 스위치 조작으로 프로그래밍
- 데이터는 주기억장치에 저장, 프로그램 CPU의 일부로 생각

프로그램 내장 개념

- 프로그램도 비트 패턴으로 인코딩되어 주기억장치에 저장
- CPU는 주기억장치에서 명령들을 읽어와서 실행
- 또한 실행될 프로그램을 주기억장치 안에서 쉽게 변경

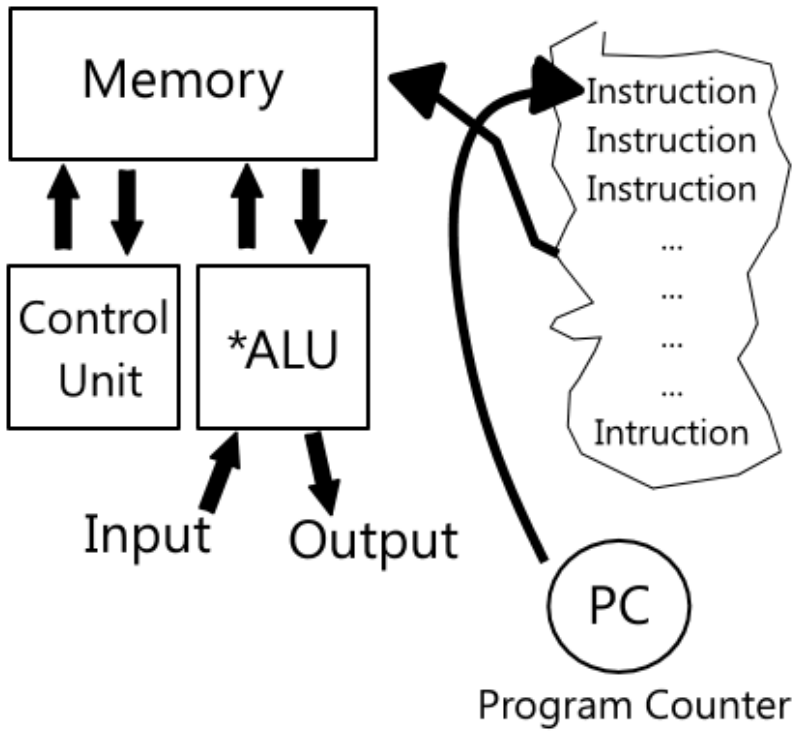
프로그램 내장형 컴퓨터(폰 노이만 기계)

- 컴퓨터 프로그램을 데이터와 동일하게 주기억장치 안에 저장
- 제어장치가 메모리에서 프로그램을 가져와서 명령을 해석하고 실행하도록 설계
- 제어장치 회로를 변경하는 대신, 컴퓨터의 메모리 내용을 변경하는 것만으로도 컴퓨터가 수행할 프로그램 변경가능

프로그램의 실행

CPU가 프로그램을 실행시키려면?

- 프로그램들이 메모리에 위치
  - 프로그램이 실행되려면 먼저 프로그램이 실행 가능한 상태로 준비되어 있어야 함
- 컴퓨터는 필요한 대로 명령들을 메모리에서 CPU로 복사
- 일단 CPU로 옮겨진 명령은 해석되고 실행됨



**ALU(Arithmetic Logic Unit)*

Levels of Program Code

High-level language

- Level of abstraction closer to problem domain
- Provides for productivity and portability

Assembly language

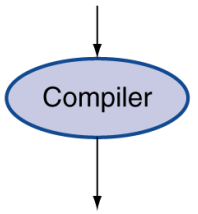
- Textual representation of instructions

Hardware representation

- Binary digits (bits)
- Encoded instructions and data

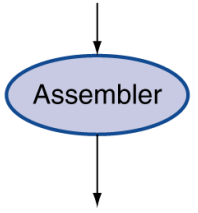
High-level language program (in C)

```
swap(int v[], int k)
{int temp;
   temp = v[k];
   v[k] = v[k+1];
   v[k+1] = temp;
}
```



Assembly language program (for MIPS)

```
swap:
      muli $2, $5,4
      add  $2, $4,$2
      lw   $15, 0($2)
      lw   $16, 4($2)
      sw   $16, 0($2)
      sw   $15, 4($2)
      jr   $31
```



Binary machine language program (for MIPS)

```
00000000101000010000000000011000
00000000000110000001100000100001
10001100011000100000000000000000
10001100111100100000000000000100
10101100111100100000000000000000
10101100011000100000000000000100
00000011111000000000000000001000
```

Translation and Startup