Computer Architecture Review

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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

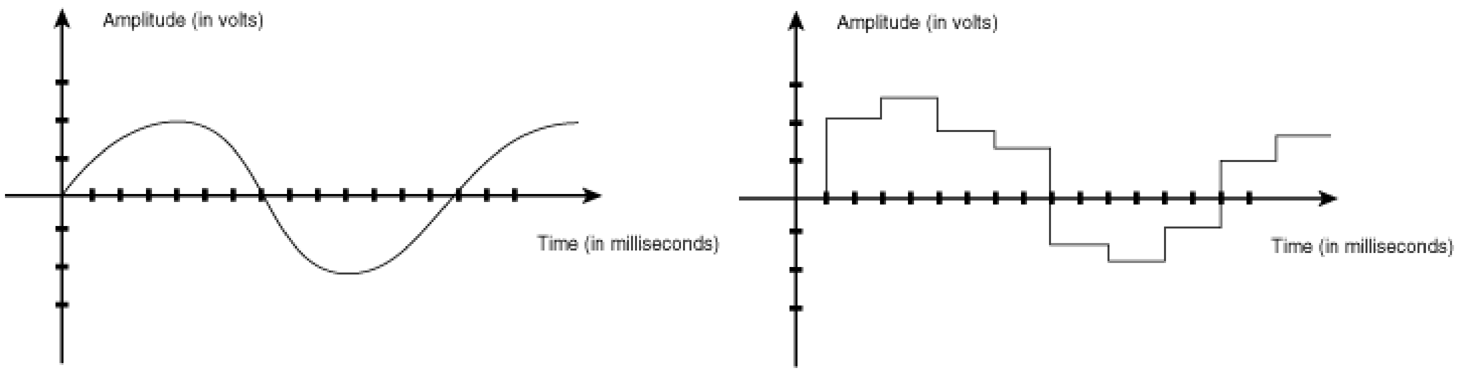
How hardware designers improve performance

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

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

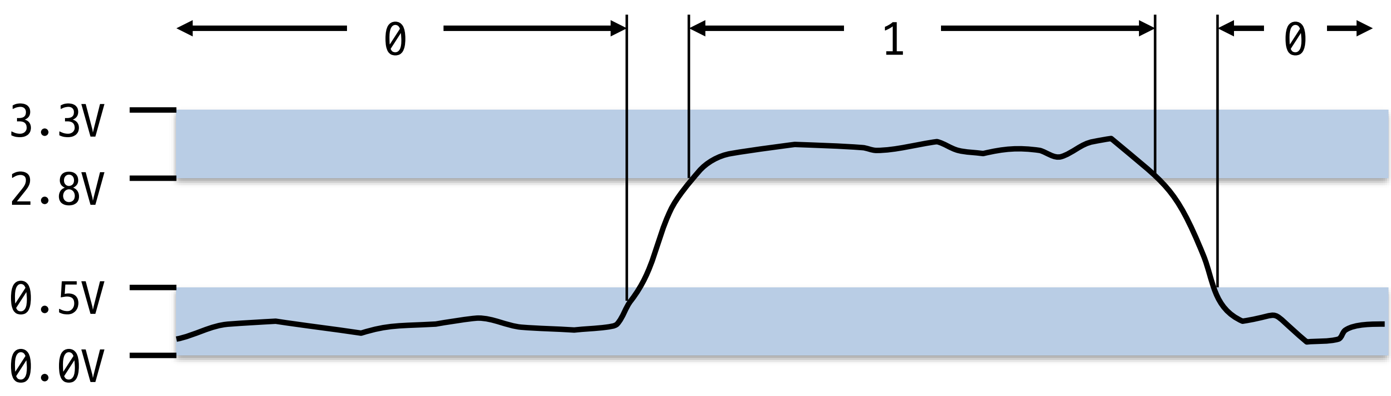
	01110011	01100101	01101101	01101001	01110011	01100101	01101101	01101001
(char)	's'	'e'	'm'	'i'	's'	'e'	'm'	'i'
(int)	1768777075				1768777075			
(double)	7.0316899032917080817 8… x 10^{199}							

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: $\mathbf{00000000}_2$ to $\mathbf{11111111}_2$
- Octal: $\mathbf{000}_8$ to $\mathbf{377}_8$
  - An integer constant that begins with 0 is an octal number in C
- Decimal: $\mathbf{0}_{10}$ to $\mathbf{255}_{10}$
  - First digit must not be 0 in C
- Hexadecimal: $\mathbf{00}_{16}$ to $\mathbf{FF}_{16}$
  - Base 16 number representation
  - Use characters '0' to '9' and 'A' to 'F'
  - Write $\mathbf{FA1D37B}_{16}$ 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)

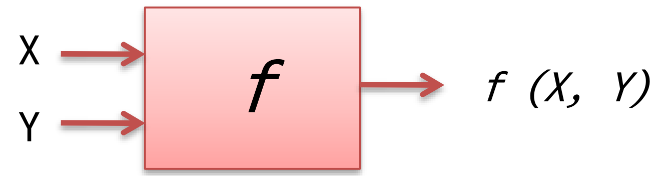
- A^B = 1 when either A=1 or B=1, but not both

^	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	

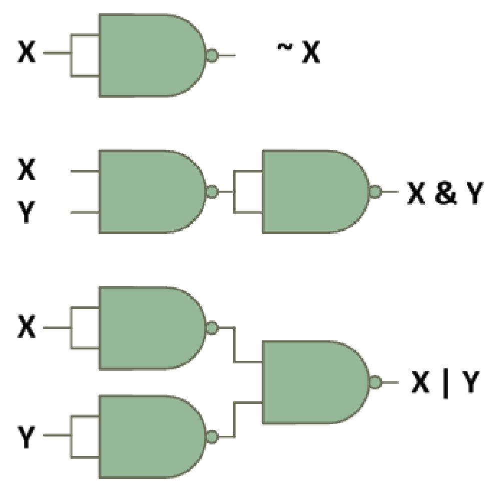


Basic operations: AND(&), OR(¦), NOT(~)

X ^ Y = (X & ~Y) ¦ (~X & Y)

X → Y = ~X ¦ Y

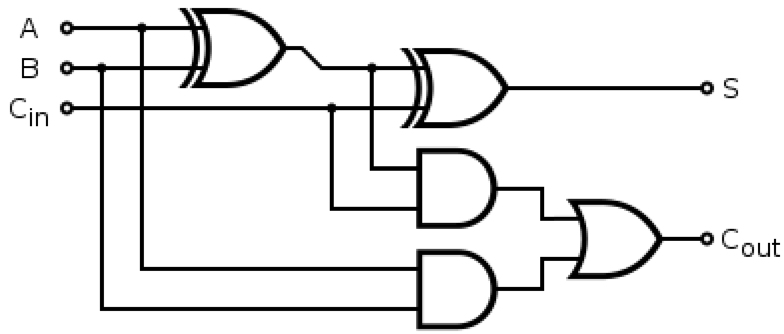
A complete set: NAND = ~ (X & Y)

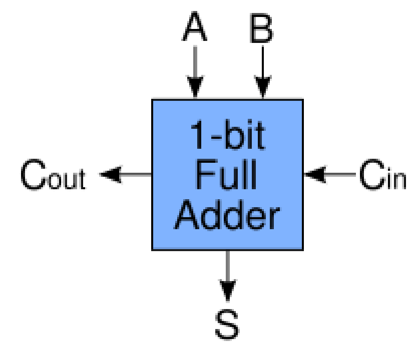


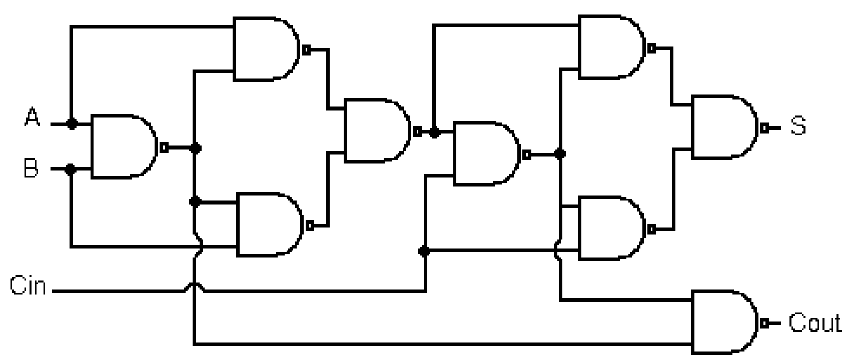
Combinational Logic

Adder

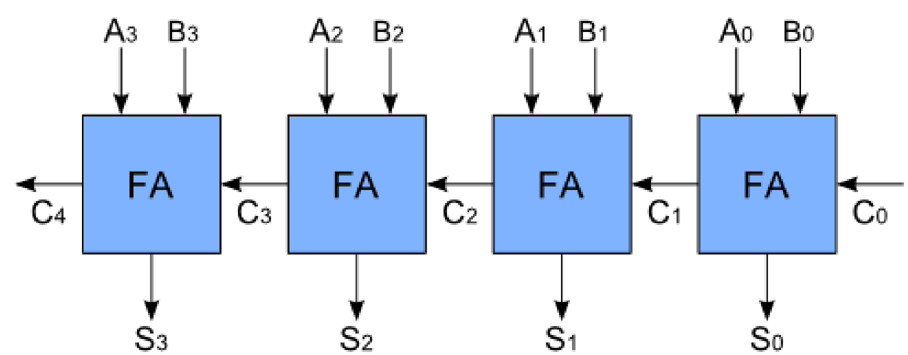
Full Adder







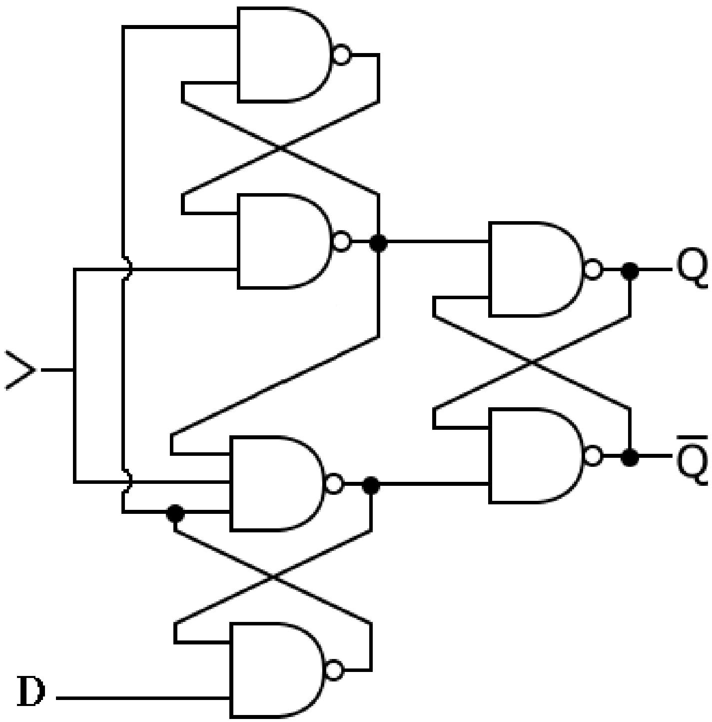
Full Adder (NAND version)



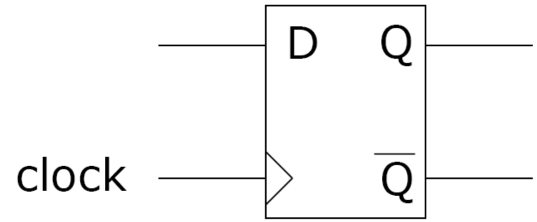
4-bit Ripple Carry Adder

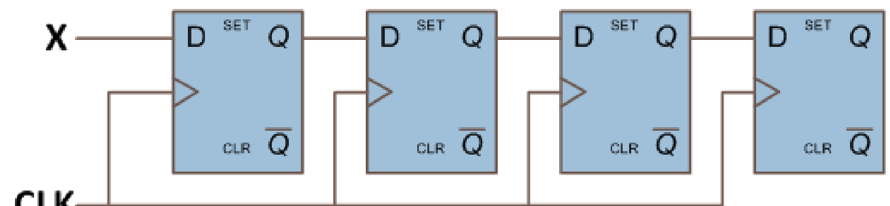
Sequential Logic

Flip-flops

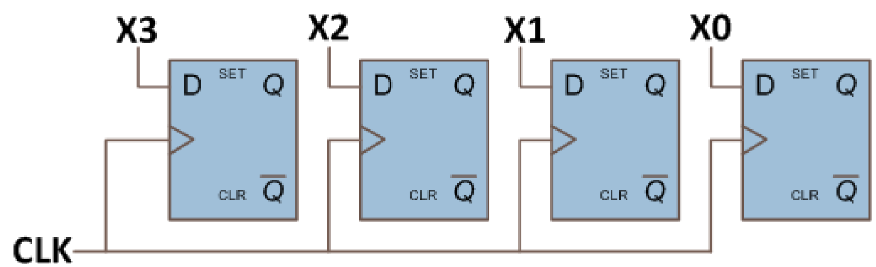


Edge triggered D flip-flop





Shifter

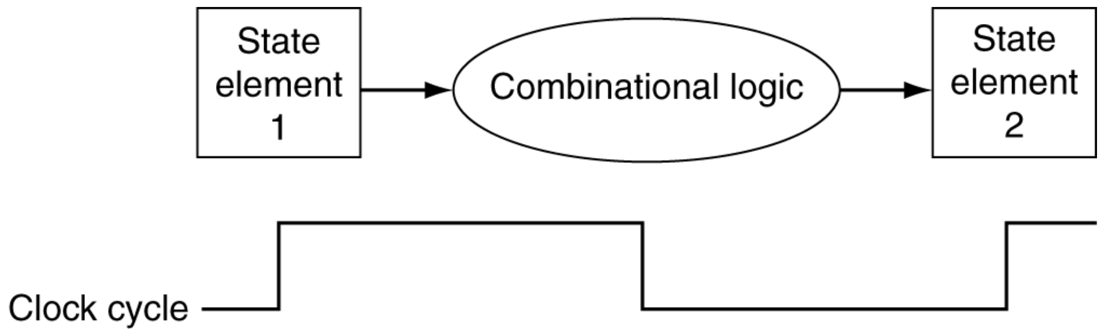


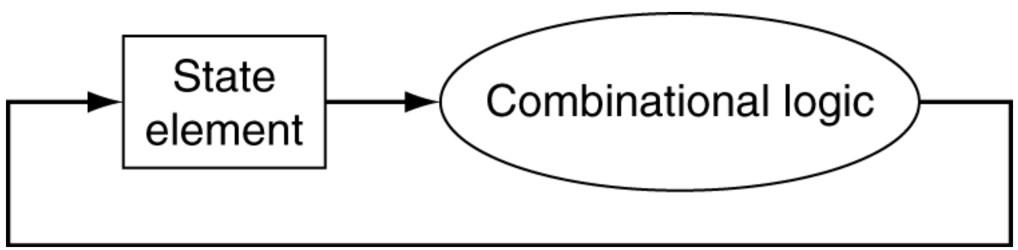
4-bit register

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



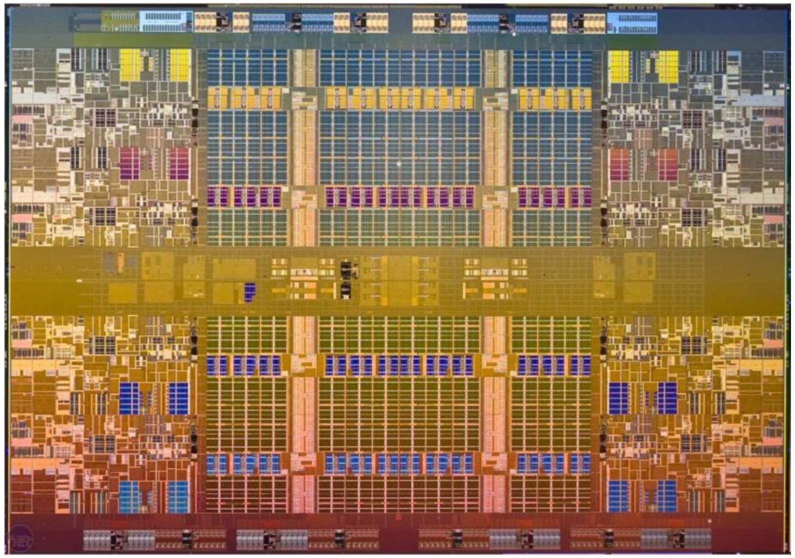


Digital Systems

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



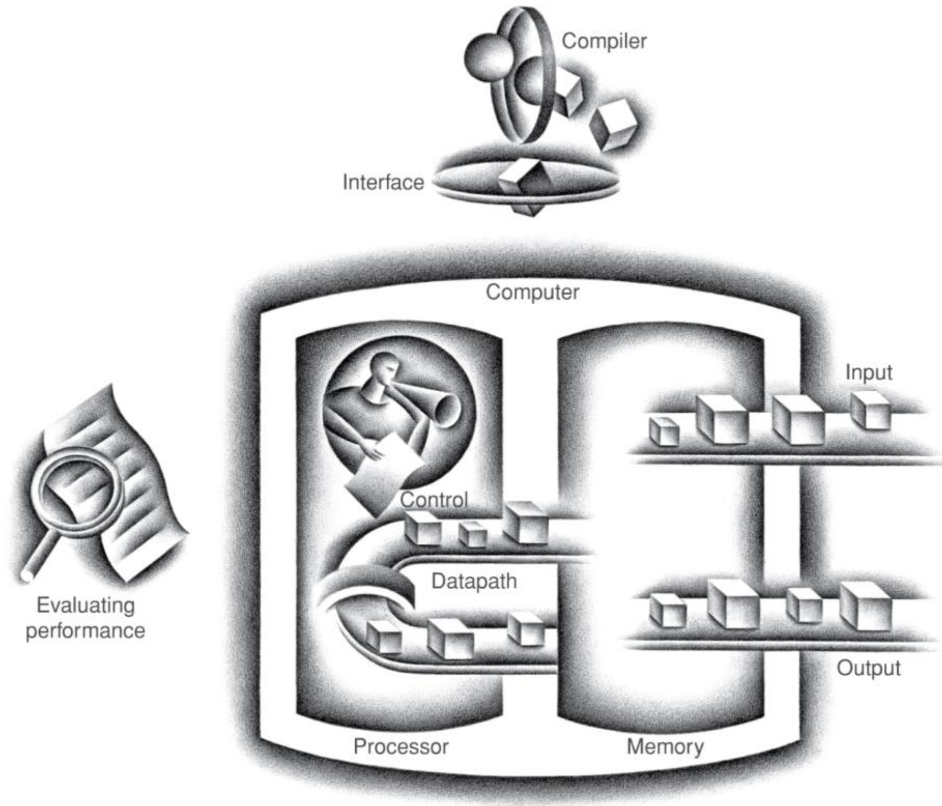
Components of a Computer

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



Understanding Performance

Algorithm

- Determines number of operations executed

Programming language, compiler, architecture

- Determine number of machine instructions executed per operation

Processor and memory system

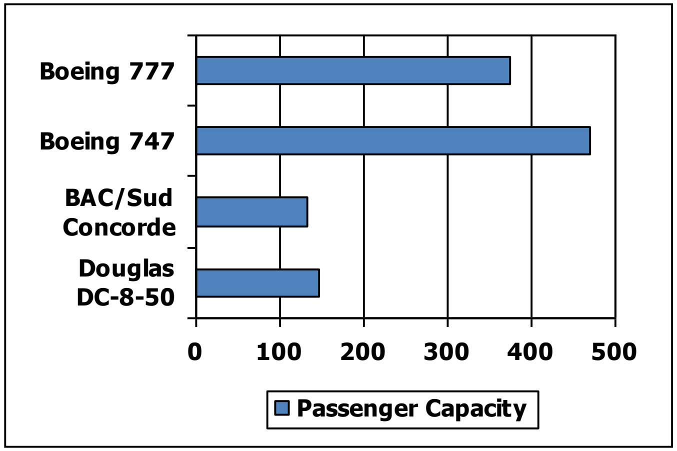
- Determine how fast instructions are executed

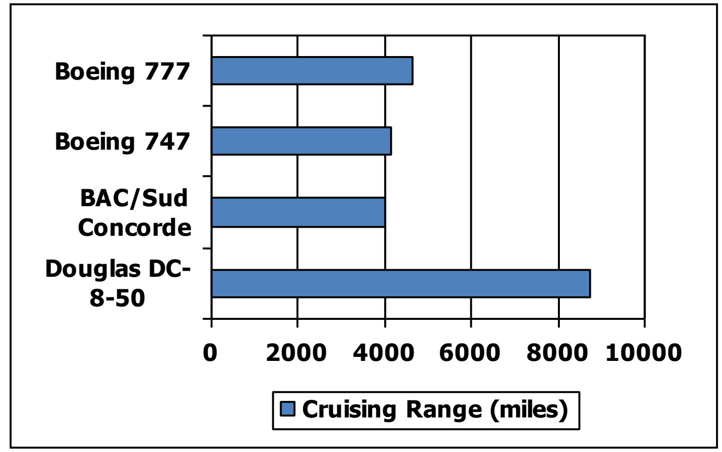
I/O system (including OS)

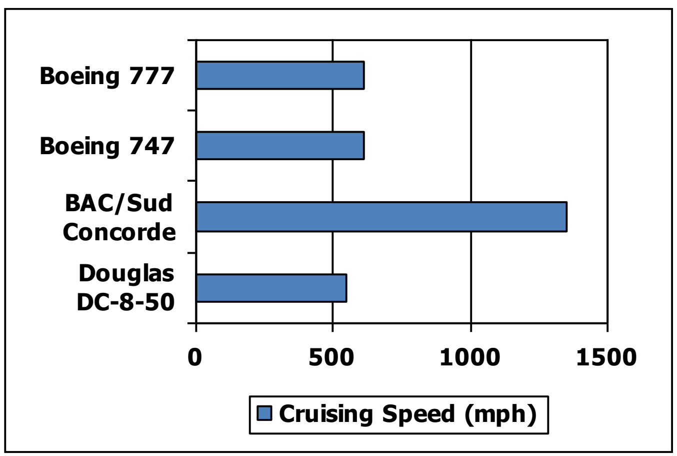
- Determines how fast I/O operations are executed

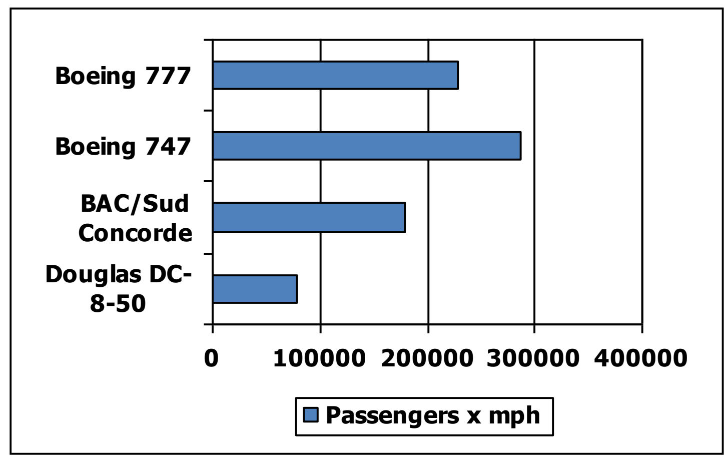
Defining Performance

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?

Levels of Program Code

High-level language

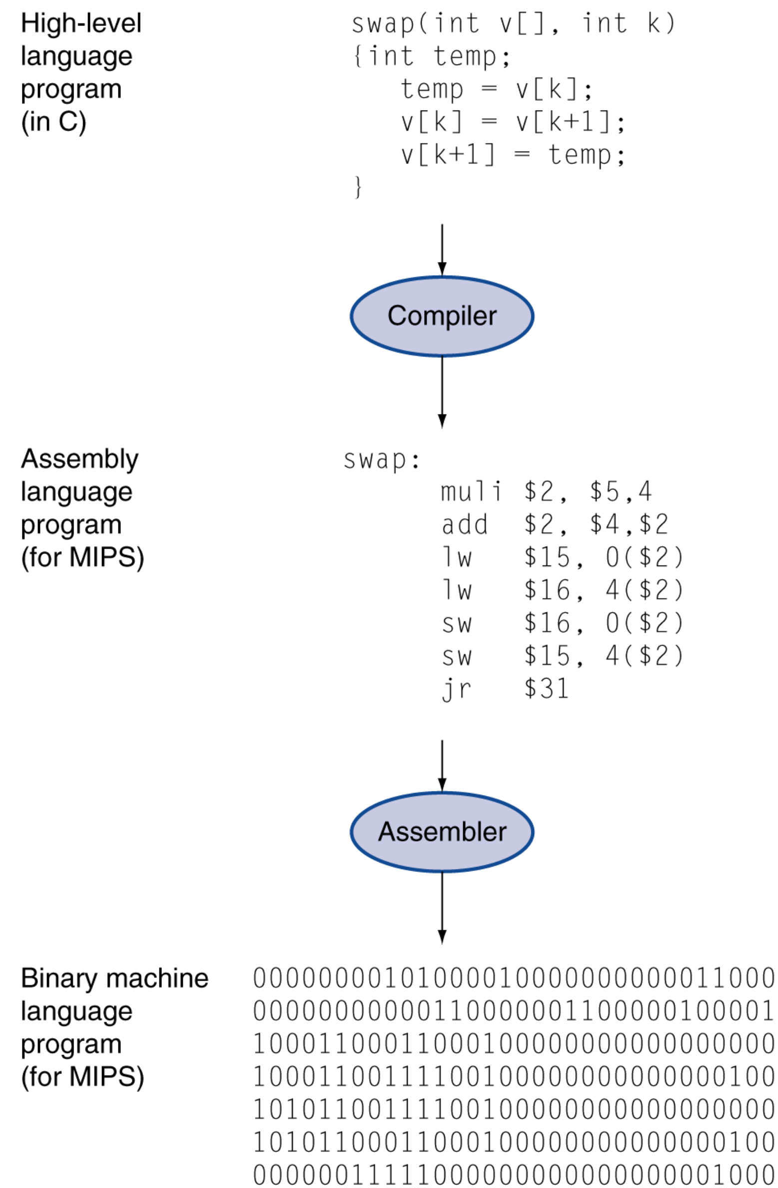
- Level of abstraction closer to problem domain
- Provides for productivity and portability

Assembly language

- Textual representation of instructions

Hardware representation

- Binary digits (bits)
- Encoded instructions and data



MIPS R-format Instructions

op	rs	rt	rd	shamt	funct
6 bits	5 bits	5 bits	5 bits	5 bits	6 bits

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

op	rs	rt	rd	shamt	funct
6 bits	5 bits	5 bits	5 bits	5 bits	6 bits

add $t0, $s1, $s2

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

$00000010001100100100000000100000_2 = 02324020_{16}$

Translation and Startup