OUTLINES

- Numbering and coding systems
- Digital primer
- Inside the computer

NUMBERING AND CODING SYSTEMS

Decimal and Binary Number Systems

- Human beings use base 10 (*decimal*) arithmetic
  - There are 10 distinct symbols, 0, 1, 2, …, 9
- Computers use base 2 (*binary*) system
  - There are only 0 and 1
  - These two binary digits are commonly referred to as *bits*

NUMBERING AND CODING SYSTEMS

Converting from Decimal to Binary

- Divide the decimal number by 2 repeatedly
- Keep track of the remainders
- Continue this process until the quotient becomes zero
- Write the remainders in reverse order to obtain the binary number

Ex. Convert 25_{10} to binary

		Quotient	Remainder	
25/2	=	12	1	LSB (least significant bit)
12/2	=	6	0	
6/2	=	3	0	
3/2	=	1	1	
1/2	=	0	1	MSB (most significant bit)

Therefore $25_{10} = 11001_2$

NUMBERING AND CODING SYSTEMS

Converting from Binary to Decimal

- Know the weight of each bit in a binary number
- Add them together to get its decimal equivalent

Ex. Convert 11001_2 to decimal

Weight:	2^4	2^3	2^2	2^1	2^0
Digits:	1	1	0	0	1
Sum:	16 +	8 +	0 +	0 +	1 = 25_{10}

- Use the concept of weight to convert a decimal number to a binary directly

Ex. Convert 39_{10} to binary

32 + 0 + 0 + 4 + 2 + 1 = 39

Therefore, $39_{10} = 100111_2$

NUMBERING AND CODING SYSTEMS

Hexadecimal System

- Base 16, the *hexadecimal* system, is used as a convenient representation of binary numbers
  - ex.

    It is much easier to represent a string of 0s and 1s such as 100010010110 as its hexadecimal equivalent of 896H

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

NUMBERING AND CODING SYSTEMS

Converting between Binary and Hex

- To represent a binary number as its equivalent hexadecimal number
  - Start from the right and group 4 bits at a time, replacing each 4-bit binary number with its hex equivalent

Ex. Represent binary 100111110101 in hex

	1001	1111	0101
=	9	F	5

- To convert from hex to binary
  - Each hex digit is replaced with its 4-bit binary equivalent

Ex. Convert hex 29B to binary

	2	9	B
=	0010	1001	1011

NUMBERING AND CODING SYSTEMS

Converting from Decimal to Hex

- Convert to binary first and then convert to hex
- Convert directly from decimal to hex by repeated division, keeping track of the remainders

Ex. Convert 45_{10} to hex

32	16	8	4	2	1	
1	0	1	1	0	1	32 + 8 + 4 + 1 = 45

$45_{10} = 0010\ 1101_2 = 2D_{16}$

Ex. Convert 629_{10} to hex

512	256	128	64	32	16	8	4	2	1
1	0	0	1	1	1	0	1	0	1

$629_{10} = 512+64+32+16+4+1 = 0010\ 0111\ 0101_2 = 275_{16}$

NUMBERING AND CODING SYSTEMS

Converting from Hex to Decimal

- Convert from hex to binary and then to decimal
- Convert directly from hex to decimal by summing the weight of all digits

Ex. $6B2_{16} = 0110\ 1011\ 0010_2$

1024	512	256	128	64	32	16	8	4	2	1
1	1	0	1	0	1	1	0	0	1	0

$1024 + 512 + 128 + 32 + 16 + 2 = 1714_{10}$

NUMBERING AND CODING SYSTEMS

Addition of Hex Numbers

- Adding the digits together from the least significant digits
  - If the result is less than 16, write that digit as the sum for that position
  - If it is greater than 16, subtract 16 from it to get the digit and carry 1 to the next digit

Ex. Perform hex addition: 23D9 + 94BE

23D9	LSD:	9 + 14 = 23	23 – 16 = 7 w/ carry
+ 94BE		1 + 13 + 11 = 25	25 – 16 = 9 w/ carry
B897		1 + 3 + 4 = 8	
	MSD:	2 + 9 = B	

NUMBERING AND CODING SYSTEMS

Subtraction of Hex Numbers

- If the second digit is greater than the first, borrow 16 from the preceding digit

Ex. Perform hex subtraction: 59F – 2B8

59F	LSD:	15 – 8 = 7
– 2B8		9 + 16 – 11 = 14 = E_{16}
2E7		5 – 1 – 2 = 2

NUMBERING AND CODING SYSTEMS

ASCII Code

- The ASCII (pronounced “ask-E”) code assigns binary patterns for
  - Numbers 0 to 9
  - All the letters of English alphabet, uppercase and lowercase
  - Many control codes and punctuation marks
- The ASCII system uses 7 bits to represent each code

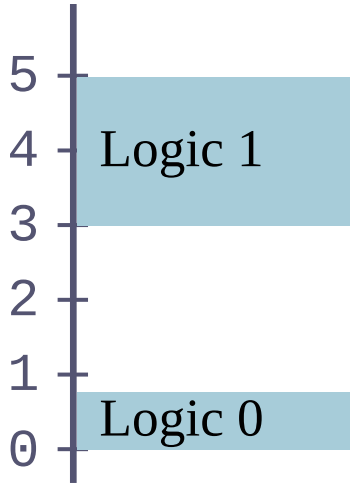
Selected ASCII codes

Hex	*Symbol*	*Hex*	*Symbol*
41	A	61	a
42	B	62	b
43	C	63	c
44	D	64	d
…	…	…	…
59	Y	79	y
5A	Z	7A	z

DIGITAL PRIMER

Binary Logic

- Two voltage levels can be represented as the two digits 0 and 1
- Signals in digital electronics have two distinct voltage levels with built-in tolerances for variations in the voltage
- A valid digital signal should be within either of the two shaded areas



DIGITAL PRIMER

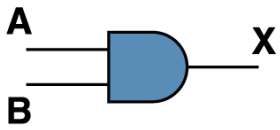
Logic Gates

- AND gate

Boolean Expression

$X = A \cdot B$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

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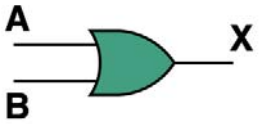
- OR gate

Boolean Expression

$X = A + B$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

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DIGITAL PRIMER

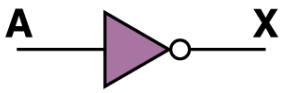
Logic Gates (cont')

- Tri-state buffer
- Inverter

Boolean Expression

$X = A'$

Logic Diagram Symbol



Truth Table

A	X
0	1
1	0

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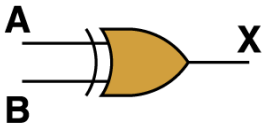
- XOR gate

Boolean Expression

$X = A \oplus B$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

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DIGITAL PRIMER

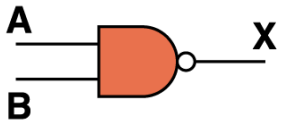
Logic Gates (cont')

NAND gate

Boolean Expression

$X = (A \cdot B)'$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

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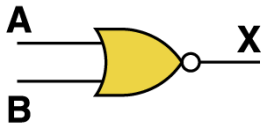
NOR gate

Boolean Expression

$X = (A + B)'$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

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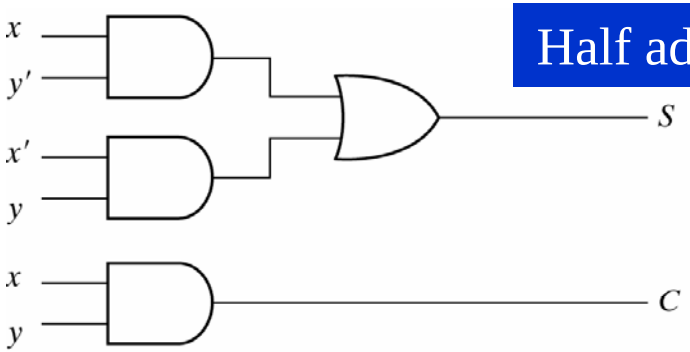
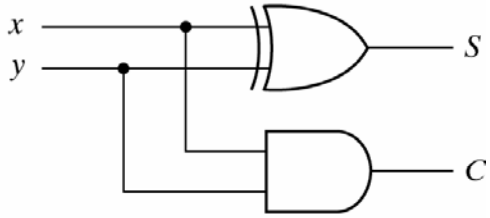
DIGITAL PRIMER

Logic Design Using Gates

Half adder

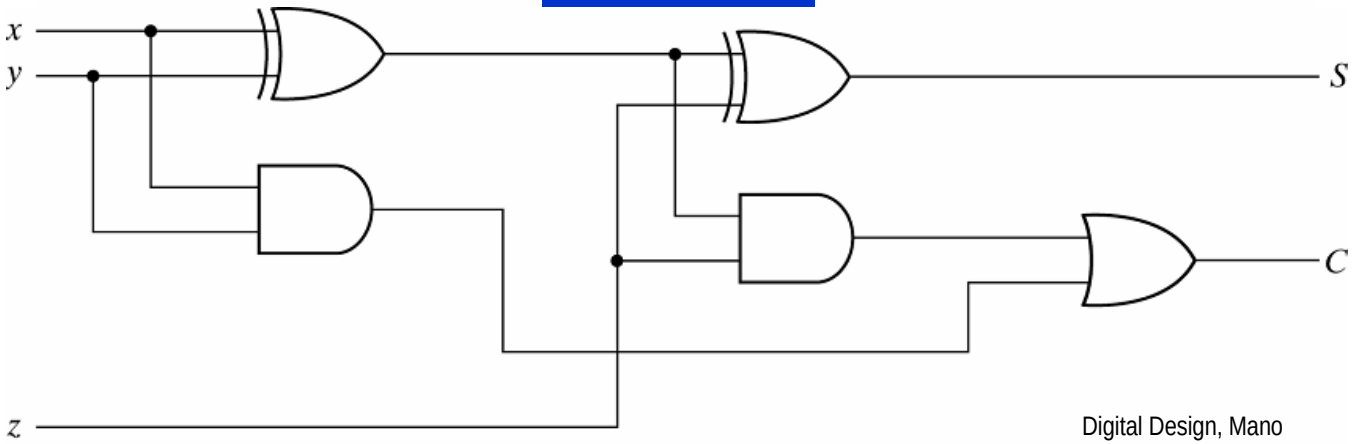


(a) $S = xy' + x'y$
$C = xy$



(b) $S = x \oplus y$
$C = xy$

Full adder



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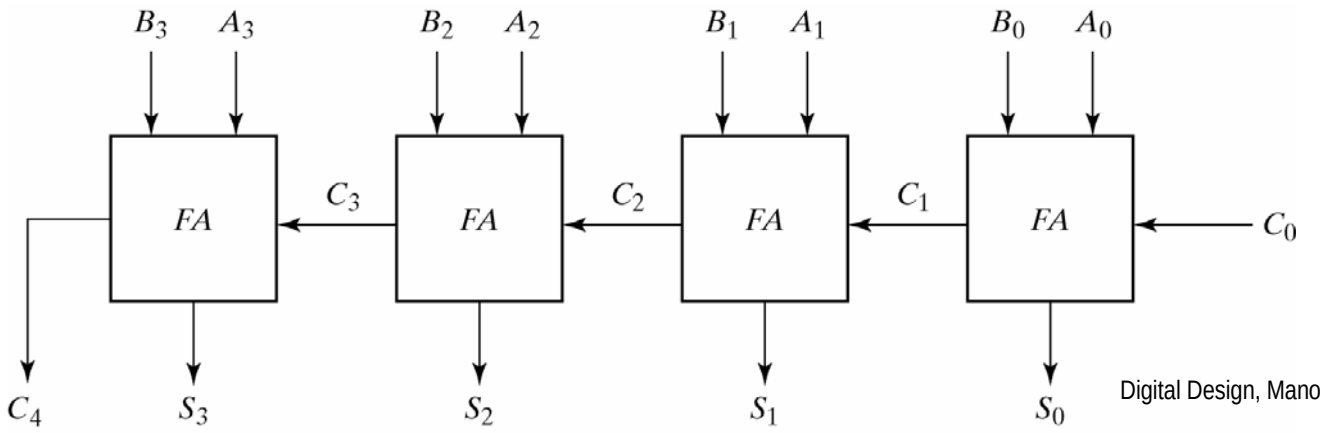
DIGITAL PRIMER

Logic Design Using Gates (cont')

4-bit adder



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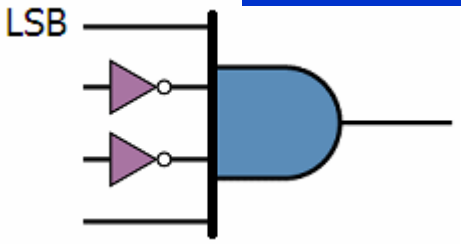
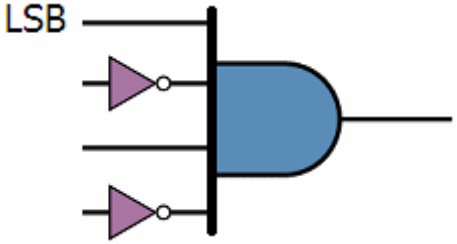
Logic Design Using Gates (cont')

- Decoders
  - Decoders are widely used for address decoding in computer design

Address Decoders





Address decoder for 9 (1001_2)

The output will be 1 if and only if the input is 1001_2

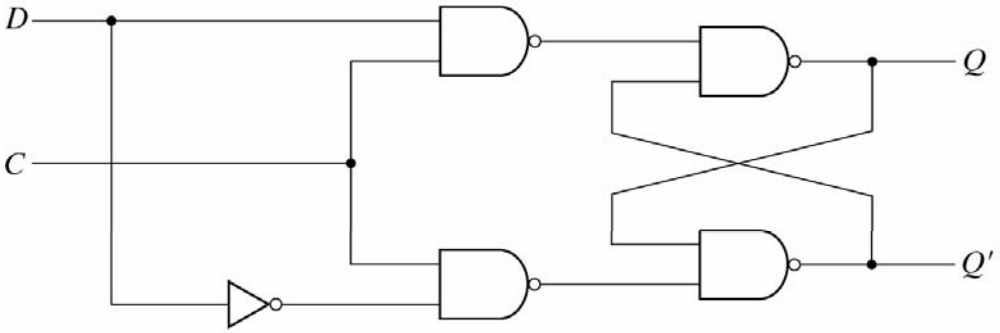
Address decoder for 5 (0101_2)

The output will be 1 if and only if the input is 0101_2

DIGITAL PRIMER

Logic Design Using Gates (cont')

- Flip-flops
  - Flip-flops are frequently used to store data



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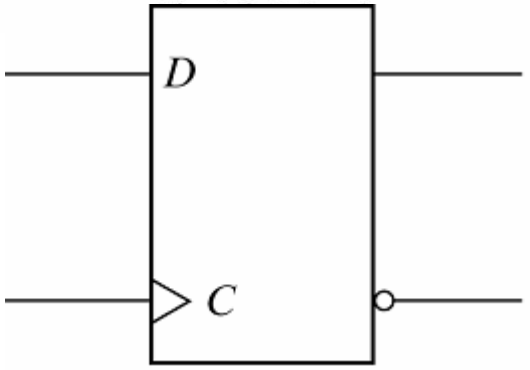
(a) Logic diagram

C	D	Next state of Q
0	X	No change
1	0	Q = 0; Reset state
1	1	Q = 1; Set state

(b) Function table



INSIDE THE COMPUTER

Important Terminology

- The unit of data size
  - *Bit* : a binary digit that can have the value 0 or 1
  - *Byte* : 8 bits
  - *Nibble* : half of a bye, or 4 bits
  - *Word* : two bytes, or 16 bits
- The terms used to describe amounts of memory in IBM PCs and compatibles
  - *Kilobyte* (K): 2^{10} bytes
  - *Megabyte* (M) : 2^{20} bytes, over 1 million
  - *Gigabyte* (G) : 2^{30} bytes, over 1 billion
  - *Terabyte* (T) : 2^{40} bytes, over 1 trillion

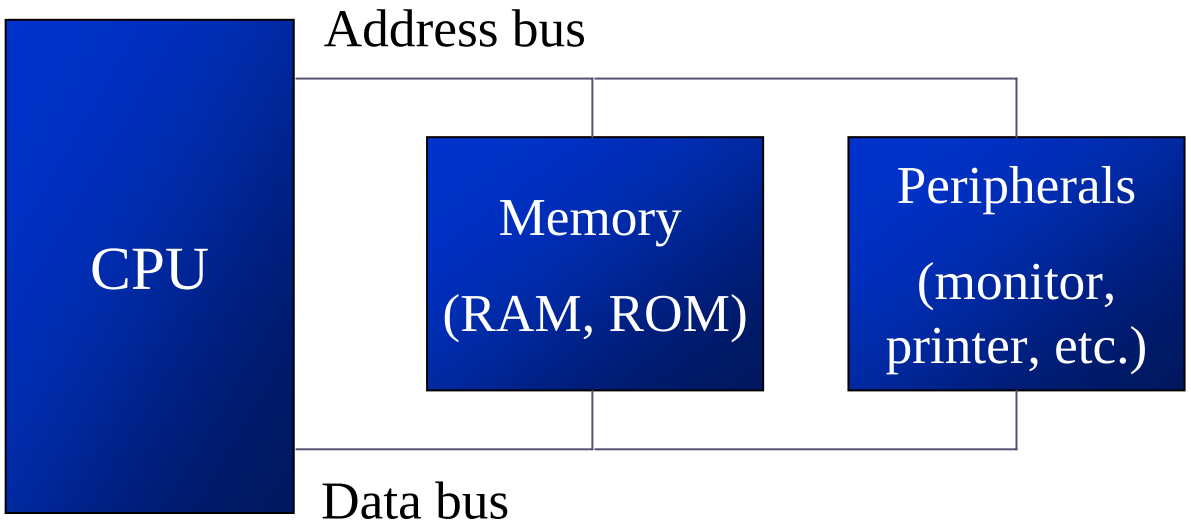
INSIDE THE COMPUTER

Internal Organization of Computers

- CPU (Central Processing Unit)
  - Execute information stored in memory
- I/O (Input/output) devices
  - Provide a means of communicating with CPU
- Memory
  - RAM (Random Access Memory) – temporary storage of programs that computer is running
    - The data is lost when computer is off
  - ROM (Read Only Memory) – contains programs and information essential to operation of the computer
    - The information cannot be changed by use, and is not lost when power is off
      - It is called *nonvolatile memory*

INSIDE THE COMPUTER

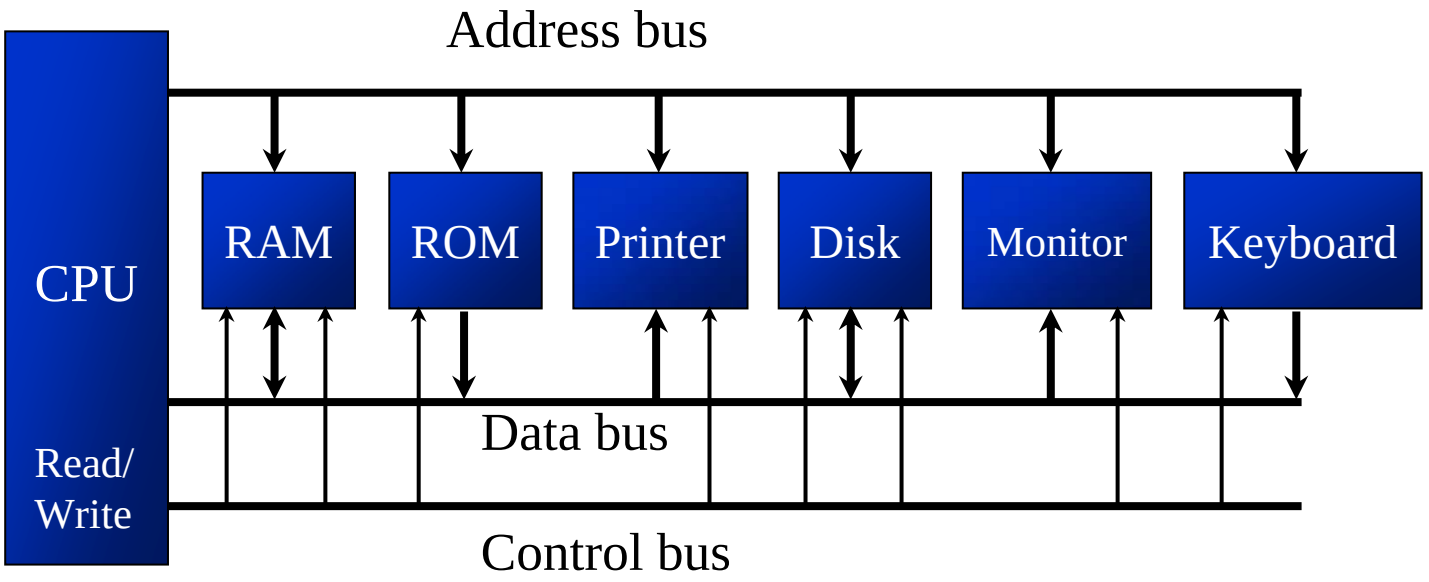
Internal Organization of Computers (cont')



INSIDE THE COMPUTER

Internal Organization of Computers (cont')

- The CPU is connected to memory and I/O through strips of wire called a *bus*
  - Carries information from place to place
    - Address bus
    - Data bus
    - Control bus



INSIDE THE COMPUTER

Internal Organization of Computers (cont')

- Address bus
  - For a device (memory or I/O) to be recognized by the CPU, it must be assigned an address
    - The address assigned to a given device must be unique
    - The CPU puts the address on the address bus, and the decoding circuitry finds the device
- Data bus
  - The CPU either gets data from the device or sends data to it
- Control bus
  - Provides read or write signals to the device to indicate if the CPU is asking for information or sending it information

INSIDE THE COMPUTER

More about Data Bus

- The more data buses available, the better the CPU
  - Think of data buses as highway lanes
- More data buses mean a more expensive CPU and computer
  - The average size of data buses in CPUs varies between 8 and 64
- Data buses are bidirectional
  - To receive or send data
- The processing power of a computer is related to the size of its buses

INSIDE THE COMPUTER

More about Address Bus

- The more address buses available, the larger the number of devices that can be addressed
- The number of locations with which a CPU can communicate is always equal to 2^x, where x is the address lines, regardless of the size of the data bus
  - ex. a CPU with 24 address lines and 16 data lines can provide a total of 2^{24} or 16M bytes of addressable memory
  - Each location can have a maximum of 1 byte of data, since all general-purpose CPUs are *byte addressable*
- The address bus is unidirectional

INSIDE THE COMPUTER

CPU's Relation to RAM and ROM

- For the CPU to process information, the data must be stored in RAM or ROM, which are referred to as *primary memory*
- ROM provides information that is fixed and permanent
  - Tables or initialization program
- RAM stores information that is not permanent and can change with time
  - Various versions of OS and application packages
  - CPU gets information to be processed
    - first form RAM (or ROM)
    - if it is not there, then seeks it from a mass storage device, called *secondary memory*, and transfers the information to RAM

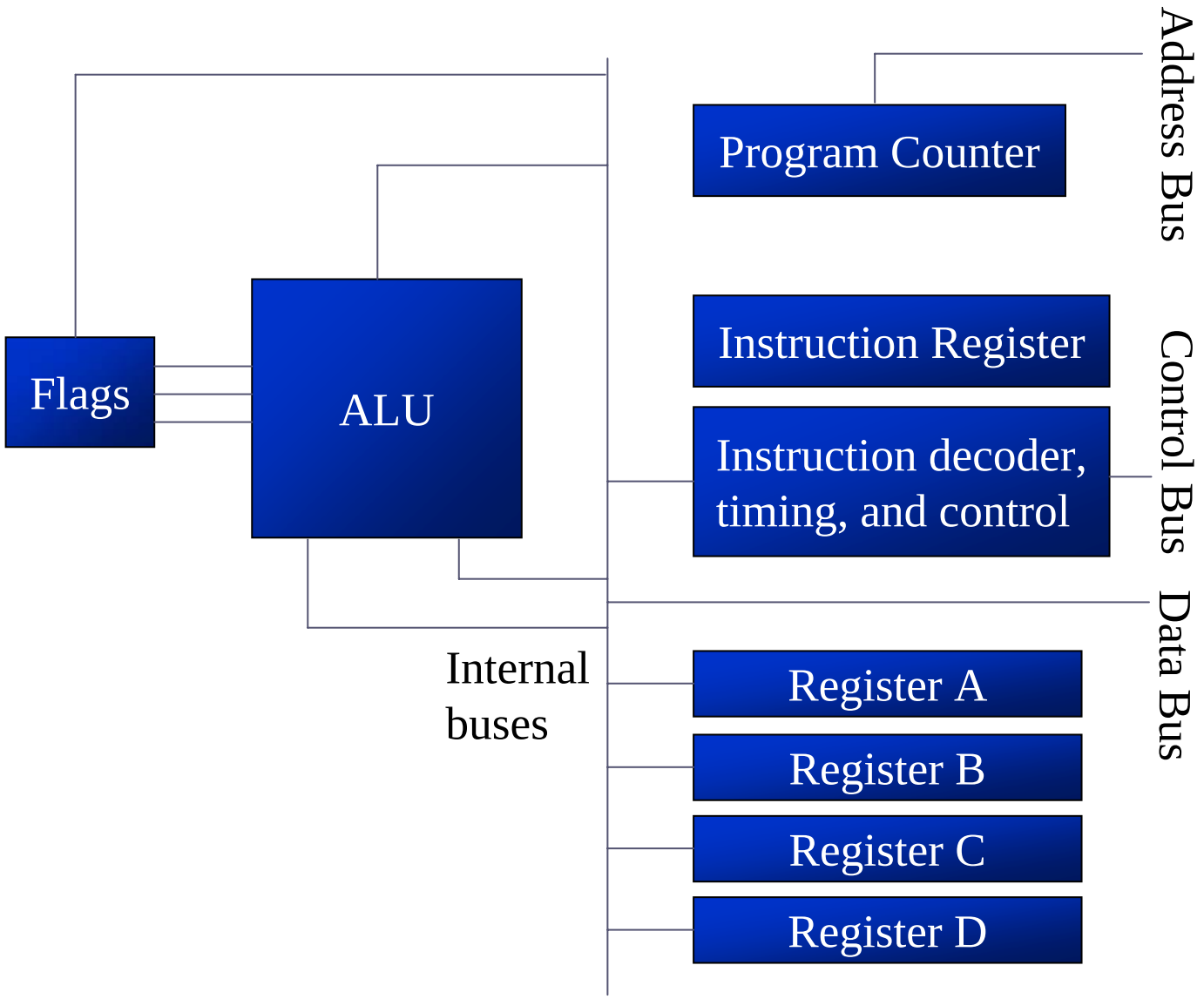
INSIDE THE COMPUTER

Inside CPUs

- Registers
  - The CPU uses registers to store information temporarily
    - Values to be processed
    - Address of value to be fetched from memory
  - In general, the more and bigger the registers, the better the CPU
    - Registers can be 8-, 16-, 32-, or 64-bit
    - The disadvantage of more and bigger registers is the increased cost of such a CPU

INSIDE THE COMPUTER

Inside CPUs (cont')



INSIDE THE COMPUTER

Inside CPUs (cont')

- ALU (arithmetic/logic unit)
  - Performs arithmetic functions such as add, subtract, multiply, and divide, and logic functions such as AND, OR, and NOT
- Program counter
  - Points to the address of the next instruction to be executed
    - As each instruction is executed, the program counter is incremented to point to the address of the next instruction to be executed
- Instruction decoder
  - Interprets the instruction fetched into the CPU
    - A CPU capable of understanding more instructions requires more transistors to design

INSIDE THE COMPUTER

Internal Working of Computers

Ex. A CPU has registers A, B, C, and D and it has an 8-bit data bus and a 16-bit address bus. The CPU can access memory from addresses 0000 to FFFFH

Assume that the code for the CPU to move a value to register A is B0H and the code for adding a value to register A is 04H

The action to be performed by the CPU is to put 21H into register A, and then add to register A values 42H and 12H

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INSIDE THE COMPUTER

Internal Working of Computers (cont')

Ex. (cont')

Action	*Code*	*Data*
Move value 21H into reg. A	B0H	21H
Add value 42H to reg. A	04H	42H
Add value 12H to reg. A	04H	12H

Mem. addr.	*Contents of memory address*
1400	(B0) code for moving a value to register A
1401	(21) value to be moved
1402	(04) code for adding a value to register A
1403	(42) value to be added
1404	(04) code for adding a value to register A
1405	(12) value to be added
1406	(F4) code for halt

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INSIDE THE COMPUTER

Internal Working of Computers (cont')

Ex. (cont')

The actions performed by CPU are as follows:

1. The program counter is set to the value 1400H, indicating the address of the first instruction code to be executed
2.
   - The CPU puts 1400H on address bus and sends it out
     - The memory circuitry finds the location
   - The CPU activates the READ signal, indicating to memory that it wants the byte at location 1400H
     - This causes the contents of memory location 1400H, which is B0, to be put on the data bus and brought into the CPU

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INSIDE THE COMPUTER

Internal Working of Computers (cont')

Ex. (cont')

3.

- The CPU decodes the instruction B0
- The CPU commands its controller circuitry to bring into register A of the CPU the byte in the next memory location
  - The value 21H goes into register A
- The program counter points to the address of the next instruction to be executed, which is 1402H
  - Address 1402 is sent out on the address bus to fetch the next instruction

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INSIDE THE COMPUTER

Internal Working of Computers (cont')

Ex. (cont')

4.

- From memory location 1402H it fetches code 04H
- After decoding, the CPU knows that it must add to the contents of register A the byte sitting at the next address (1403)
- After the CPU brings the value (42H), it provides the contents of register A along with this value to the ALU to perform the addition
  - It then takes the result of the addition from the ALU's output and puts it in register A
  - The program counter becomes 1404, the address of the next instruction

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INSIDE THE COMPUTER

Internal Working of Computers (cont')

Ex. (cont')

5.

- Address 1404H is put on the address bus and the code is fetched into the CPU, decoded, and executed
  - This code is again adding a value to register A
  - The program counter is updated to 1406H

6.

- The contents of address 1406 are fetched in and executed
- This HALT instruction tells the CPU to stop incrementing the program counter and asking for the next instruction