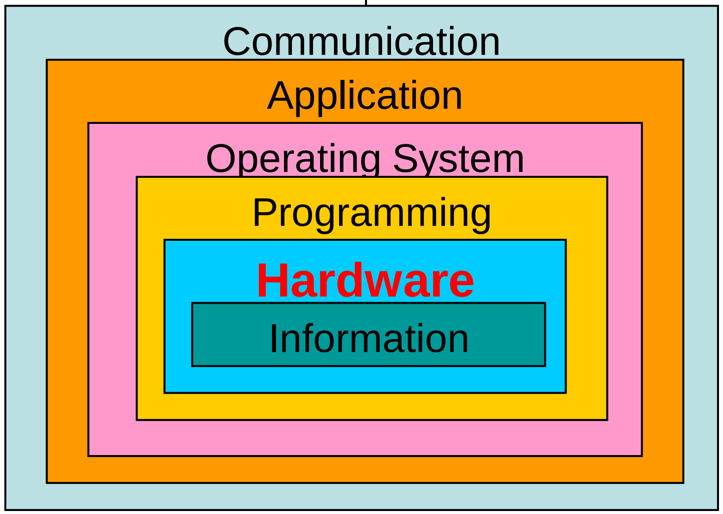
Introduction to Computing

Section 3 – Hardware

Gates & Circuits

Computing Components



Part 1

Gates & Circuits

Gates & Circuits

- Computers & Electricity
- Gates
- Constructing Gates
- Circuits
- Circuits as Memory
- Integrated Circuits
- CPU Chips

Computers and Electricity

Any given electronic signal has a level of voltage.

0-2V: low $\rightarrow$ bit 0.

2-5V/: high $\rightarrow$ bit 1.

Gate

A device that performs a basic operation on electrical signals

Circuits

Gates combined to perform more complicated tasks

Computers and Electricity

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How do we describe the behavior of gates and circuits?

Boolean expressions

Uses Boolean algebra, a mathematical notation for expressing two-valued logic

Logic diagrams

A graphical representation of a circuit; each gate has its own symbol

Truth tables

A table showing all possible input value and the associated output values

Gates

Six types of gates

- NOT
- AND
- OR
- XOR
- NAND
- NOR

Typically, logic diagrams are black and white with gates distinguished only by their shape

We use color for emphasis (and fun)

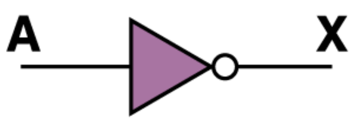
NOT Gate

A NOT gate accepts one input signal (0 or 1) and returns the opposite signal as output

Boolean Expression

$$X = A'$$

Logic Diagram Symbol



Truth Table

A	X
0	1
1	0

Figure 4.1 Various representations of a NOT gate

AND Gate

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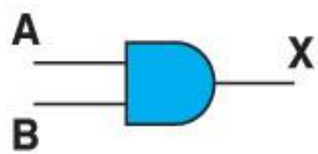
An AND gate accepts two input signals

If both are 1, the output is 1; otherwise, the output is 0

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

Figure 4.2 Various representations of an AND gate

OR Gate

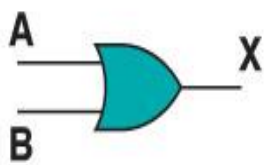
An OR gate accepts two input signals

If both are 0, the output is 0; otherwise, the output is 1

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

Figure 4.3 Various representations of a OR gate

XOR Gate

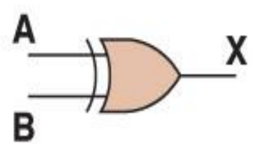
An XOR gate accepts two input signals

If both are the same, the output is 0; otherwise, the output is 1… same as binary addition except for the carry

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

Figure 4.4 Various representations of an XOR gate

XOR Gate

Note the difference between the XOR gate and the OR gate; they differ only in one input situation

When both input signals are 1, the OR gate produces a 1 and the XOR produces a 0

XOR is called the *exclusive OR*

NAND Gate

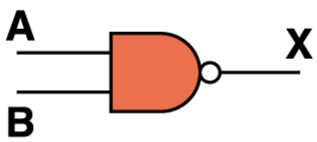
The NAND gate accepts two input signals

If both are 1, the output is 0; otherwise, the output is 1

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

Figure 4.5 Various representations of a NAND gate

NOR Gate

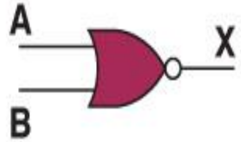
The NOR gate accepts two input signals

If both are 0, the output is 1; otherwise, the output is 0

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

Figure 4.6 Various representations of a NOR gate

Review of Gate Processing

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A NOT gate inverts its single input

An AND gate produces 1 if both input values are 1

An OR gate produces 0 if both input values are 0

An XOR gate produces 0 if input values are the same

A NAND gate produces 0 if both inputs are 1

A NOR gate produces a 1 if both inputs are 0

Gates with More Inputs

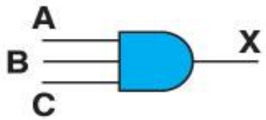
Gates can be designed to accept three or more input values

A three-input AND gate, for example, produces an output of 1 only if all input values are 1

Boolean Expression

$$X = A \cdot B \cdot C$$

Logic Diagram Symbol



Truth Table

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

Figure 4.7 Various representations of a three-input AND gate

Constructing Gates

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Transistor

A device that acts either as a wire that conducts electricity or as a resistor that blocks the flow of electricity, depending on the voltage level of an input signal

A transistor has no moving parts, yet acts like a switch

It is made of a semiconductor material, which is neither a particularly good conductor of electricity nor a particularly good insulator

Constructing Gates

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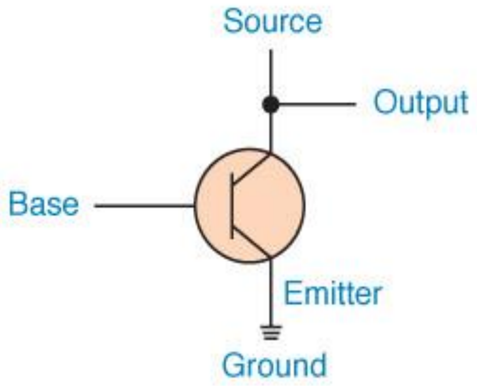

Figure 4.8 The connections of a transistor

A transistor has three terminals

- A source
- A base
- An emitter, typically connected to a ground wire

If the electrical signal is grounded, it is allowed to flow through an alternative route to the ground (literally) where it can do no harm

Constructing Gates

The easiest gates to create are the NOT, NAND, and NOR gates

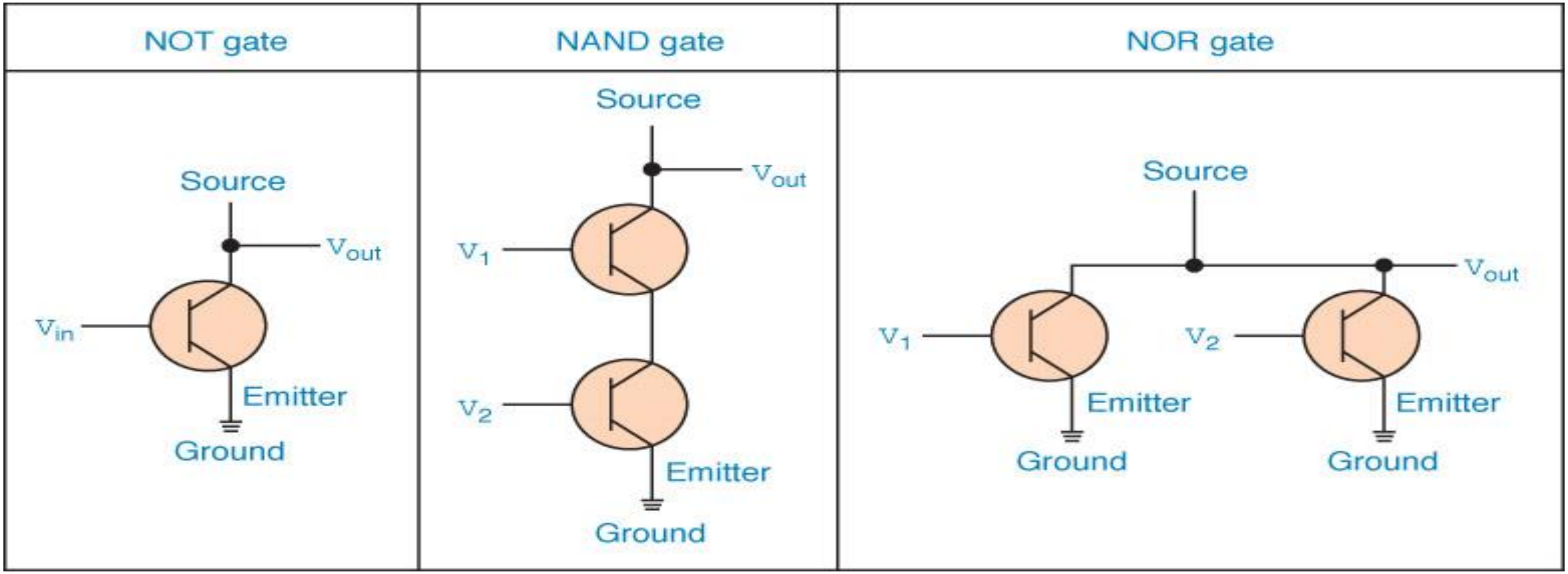

Figure 4.9 Constructing gates using transistors

Circuits

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Combinational circuit

The input values explicitly determine the output

Sequential circuit

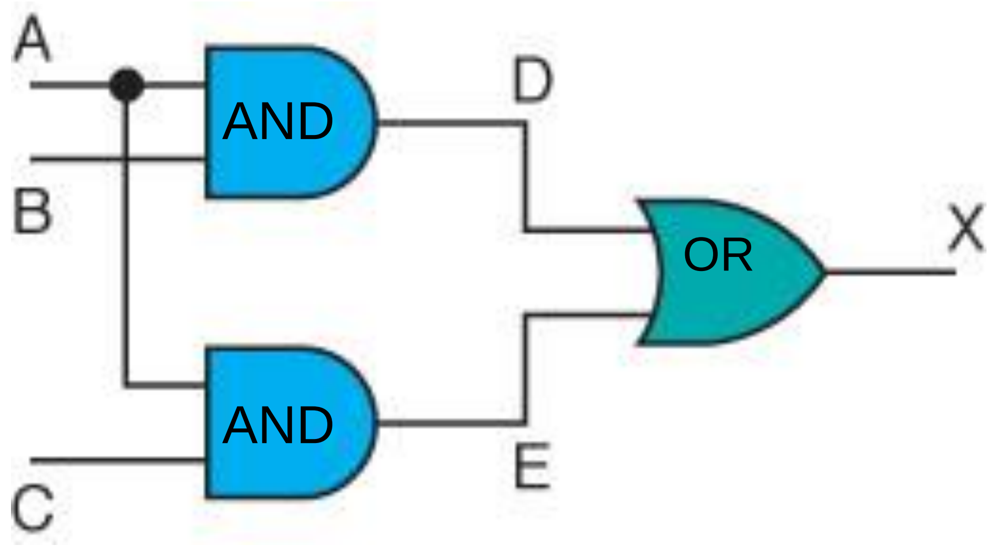
The output is a function of the input values and the existing state of the circuit

We describe the circuit operations using

- Boolean expressions
- Logic diagrams
- Truth tables

Combinational Circuits

Gates are combined into circuits by using the output of one gate as the input for another



Combinational Circuits

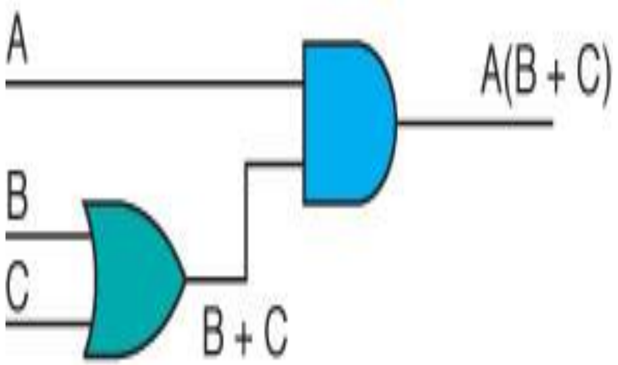
A	B	C	D	E	X
0	0	0	0	0	0
0	0	1	0	0	0
0	1	0	0	0	0
0	1	1	0	0	0
1	0	0	0	0	0
1	0	1	0	1	1
1	1	0	1	0	1
1	1	1	1	1	1

Three inputs require eight rows to describe all possible input combinations

This same circuit using a Boolean expression is $(AB + AC)$

Combinational Circuits

Consider the following Boolean expression $A(B + C)$



A	B	C	B + C	A(B + C)
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	1	0
1	0	0	0	0
1	0	1	1	1
1	1	0	1	1
1	1	1	1	1

Does this truth table look familiar?

Compare it with previous table

Combinational Circuits

Circuit equivalence

Two circuits that produce the same output for identical input

Boolean algebra allows us to apply provable mathematical principles to help design circuits

A(B + C) = AB + BC (distributive law) so circuits must be equivalent

Properties of Boolean Algebra

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Property	AND	OR
Commutative	AB = BA	A + B = B + A
Associative	(AB)C = A(BC)	(A + B) + C = A + (B + C)
Distributive	A(B + C) = (AB) + (AC)	A + (BC) = (A + B)(A + C)
Identity	A1 = A	A + 0 = A
Complement	A(A') = 0	A + (A') = 1
DeMorgan's law	(AB)' = A' OR B'	(A + B)' = A'B'

Adders

At the digital logic level, addition is performed in binary

Addition operations are carried out by special circuits called, appropriately, **adders**

Adders

The result of adding two binary digits could produce a *carry value*

Recall that 1 + 1 = 10 in base two

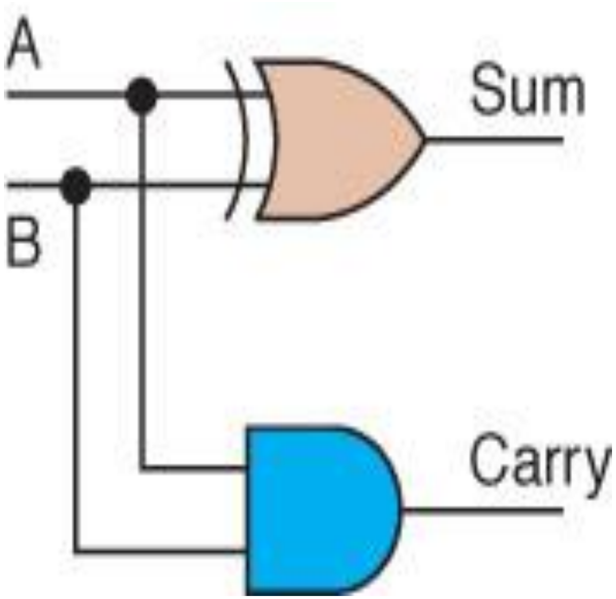
Half adder

A circuit that computes the sum of two bits and produces the correct carry bit

A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Truth table

Adders



Circuit diagram representing a half adder

Boolean expressions

$$sum = A \oplus B$$

$$carry = AB$$

Adders

Full adder

A circuit that takes the carry-in value into account

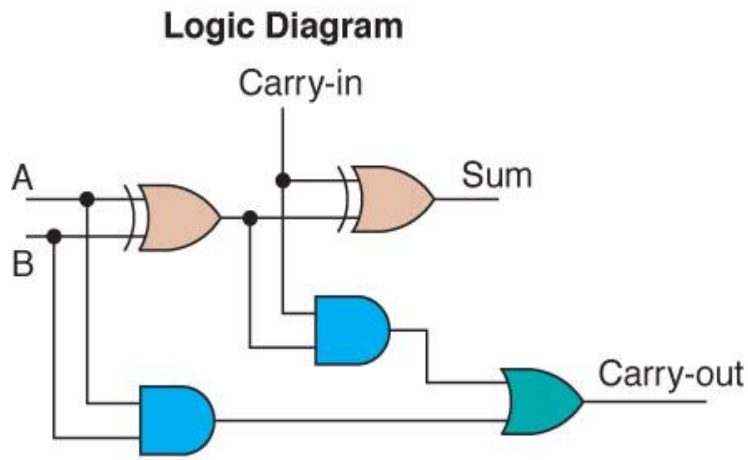


Figure 4.10 A full adder

Truth Table

A	B	Carry-in	Sum	Carry-out
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

Multiplexers

Multiplexer

A circuit that uses a few input control signals to determine which of several output data lines is routed to its output

Multiplexers

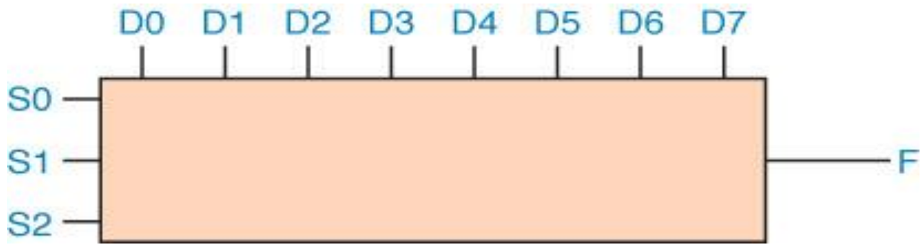


Figure 4.11 A block diagram of a multiplexer with three select control lines

S0	S1	S2	F
0	0	0	D0
0	0	1	D1
0	1	0	D2
0	1	1	D3
1	0	0	D4
1	0	1	D5
1	1	0	D6
1	1	1	D7

The control lines S0, S1, and S2 determine which of eight other input lines (D0 … D7) are routed to the output (F)

Circuits as Memory

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Digital circuits can be used to store information
These circuits form a sequential circuit, because the output of the circuit is also used as input to the circuit

Circuits as Memory

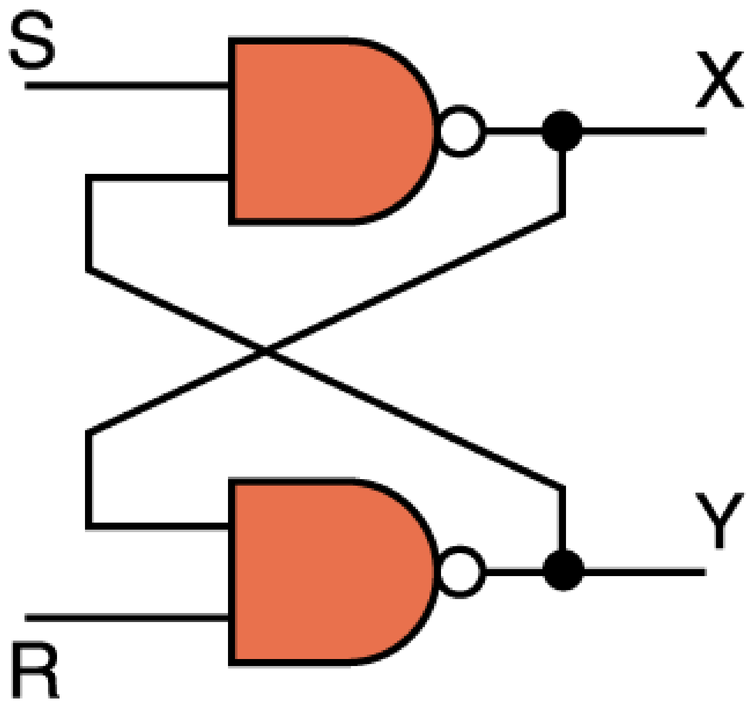


Figure 4.12 An S-R latch

- An S-R latch stores a single binary digit (1 or 0)
- There are several ways an S-R latch circuit can be designed using various kinds of gates

Integrated Circuits

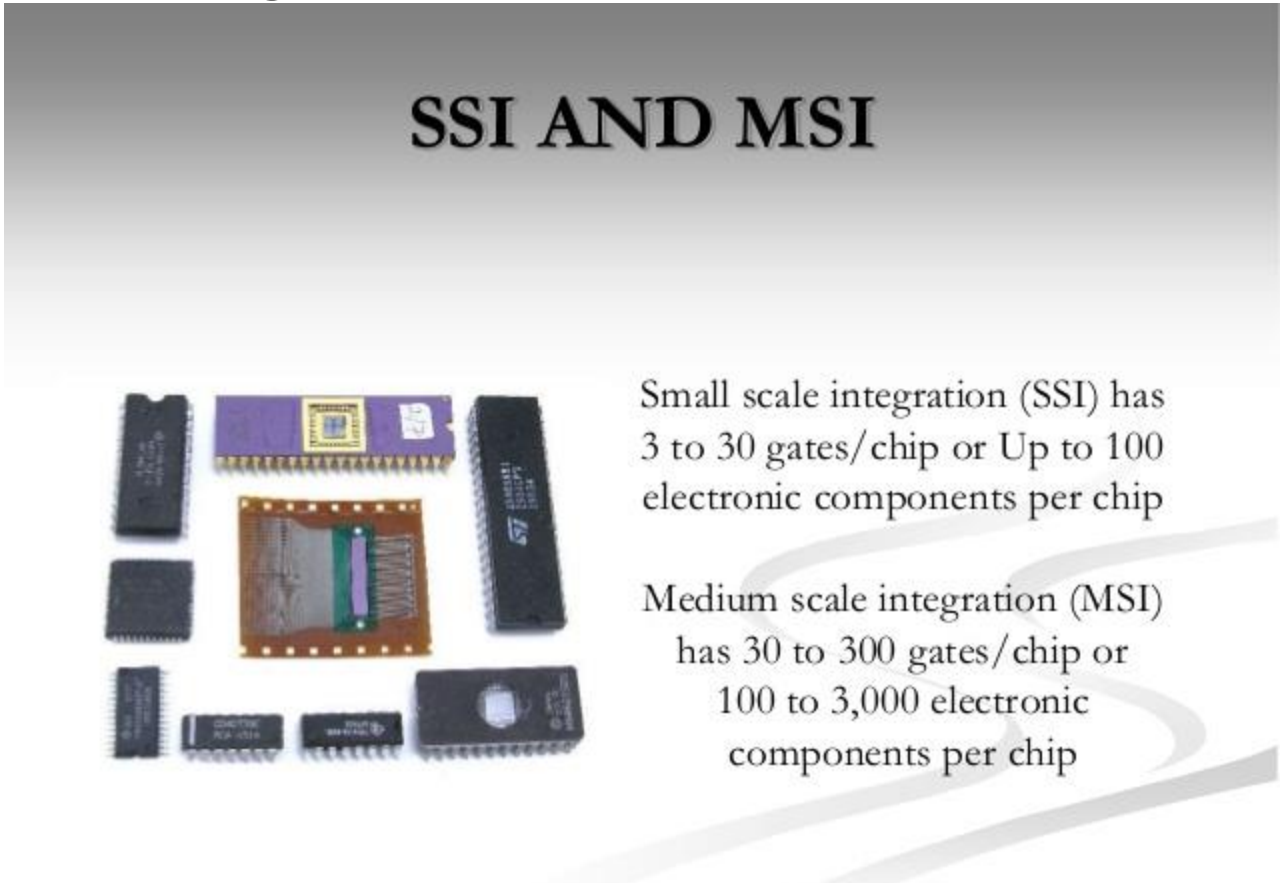
Integrated circuit (also called a *chip*)

A piece of silicon on which multiple gates have been embedded

Silicon pieces are mounted on a plastic or ceramic package with pins along the edges that can be soldered onto circuit boards or inserted into appropriate sockets

Integrated Circuits

Integrated circuits (IC) are classified by the number of gates contained in them



LSI AND VLSI

Large scale integration (LSI)-300 to 3,000 gates/chip or 3,000 to 100,000 electronic components per chip.

Very large scale integration (VLSI)-more than 3,000 gates/chip or 100,000 to 1,000,000 electronic components per chip

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ULSI

Ultra Large-Scale Integration (ULSI)- More than 1 million electronic components per chip

The Intel 486 and Pentium microprocessors, for example, use ULSI technology. The line between VLSI and ULSI is vague.

Medium Scale Integration DEMUX

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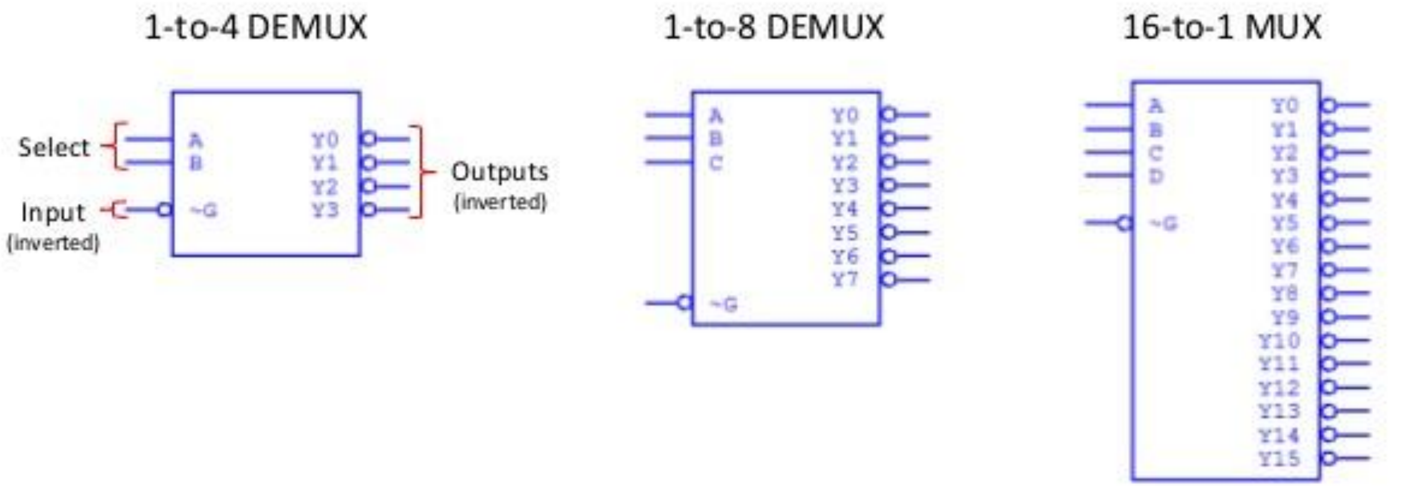

Note : Most Medium Scale Integrated (MSI) DEMUXs , like the three shown, have outputs that are inverted. This is done because it requires few logic gates to implement DEMUXs with inverted outputs rather than no-inverted outputs.

4

CPU Chips

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The most important integrated circuit in any computer is the Central Processing Unit, or CPU

Each CPU chip has a large number of pins through which essentially all communication in a computer system occurs