Logic Design

S.Venkatesan
Network Security and Cryptography Lab
Department of Information Technology
Indian Institute of Information Technology, Allahabad
venkat@iiita.ac.in

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Introduction

- The electronics inside a modern computer are digital. Digital electronics operate with only two voltage levels of interest: a high voltage and a low voltage.
- All other voltage values are temporary and occur while transitioning between the values.
- In various logic families, the values and relationships between the two voltage values differ.
- Thus, rather than refer to the voltage levels, go for signals that are (logically) true, or 1, or are asserted; or signals that are (logically) false, or 0, or are de-asserted.
- The values 0 and 1 are called complements or inverses of one another.

Logic

- Logic blocks are categorized as one of two types, depending on whether they contain memory.
  - Combinational - A logic system whose blocks do not contain memory and hence compute the same output given the same input.
  - Sequential - A group of logic elements that contain memory and hence whose value depends on the inputs as well as the current contents of the memory

Truth Table

- Because a combinational logic block contains no memory, it can be completely specified by defining the values of the outputs for each possible set of input values.

- Such a description is normally given as a truth table.

- For a logic block with *n* inputs, there are *2^n* entries in the truth table, since there are that many possible combinations of input values.

TT - Example

Inputs			Outputs		
A	B	C	D	E	F
0	0	0	0	0	0
0	0	1	1	0	0
0	1	0	1	0	0
0	1	1	1	1	0
1	0	0	1	0	0
1	0	1	1	1	0
1	1	0	1	1	0
1	1	1	1	0	1

D is true if at least one input is true, E is true if exactly two inputs are true, and F is true only if all three inputs are true.

2^3 = 8 entries

Boolean Algebra

- OR (+)
- AND (.)
- NOT ($^{-}$)

- Example
  - D = A+B+C
  - F = A.B.C

$$E = ((A \cdot B) + (A \cdot C) + (B \cdot C)) \cdot (\overline{A \cdot B \cdot C})$$

Gates

- Logic blocks are built from gates that implement basic logic functions.
- For example, an AND gate implements the AND function, and an OR gate implements the OR function.
- Since both AND and OR are commutative and associative, an AND or an OR gate can have multiple inputs, with the output equal to the AND or OR of all the inputs.
- The logical function NOT is implemented with an inverter that always has a single input.
- *Any logical function can be constructed using AND gates, OR gates, and inversion*

Universal Gates

- All logic functions can be constructed with only a single gate type, if that gate is inverting.

- The two common inverting gates are called **NOR** and **NAND** and correspond to inverted OR and AND gates, respectively.

- NOR and NAND gates are called universal, since any logic function can be built using this one gate type.

Design

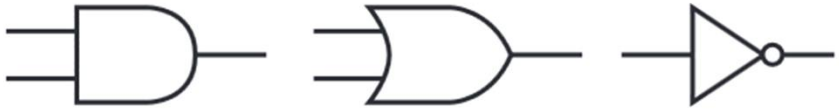


FIGURE B.2.1 Standard drawing for an AND gate, OR gate, and an inverter, shown from left to right. The signals to the left of each symbol are the inputs, while the output appears on the right. The AND and OR gates both have two inputs. Inverters have a single input.

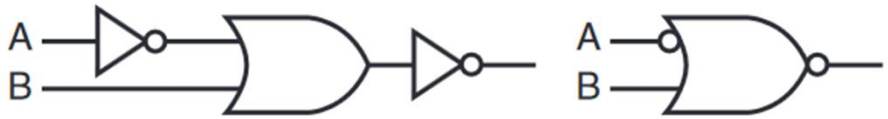
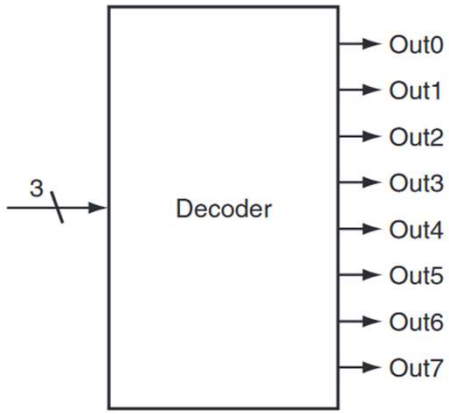


FIGURE B.2.2 Logic gate implementation of $\overline{\overline{A} + B}$ using explicit inverts on the left and bubbled inputs and outputs on the right. This logic function can be simplified to $A \cdot \overline{B}$ or in Verilog, A & ~ B.

Combinational Logic: Decoder

- A logic block that has an n-bit input and 2^n outputs, where only one output is asserted for each input combination.



a. A 3-bit decoder

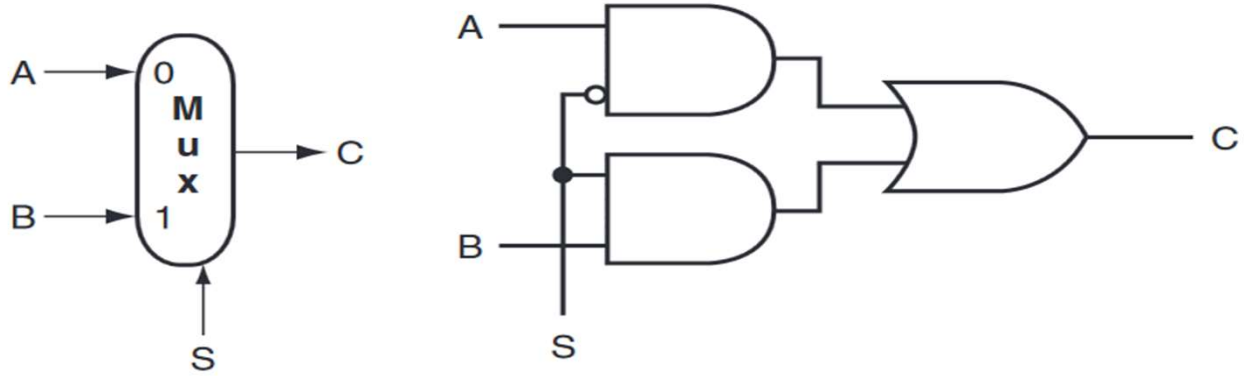
Inputs			Outputs							
12	11	10	Out7	Out6	Out5	Out4	Out3	Out2	Out1	Out0
0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	0	0	1	0
0	1	0	0	0	0	0	0	1	0	0
0	1	1	0	0	0	0	1	0	0	0
1	0	0	0	0	0	1	0	0	0	0
1	0	1	0	0	1	0	0	0	0	0
1	1	0	0	1	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0	0

b. The truth table for a 3-bit decoder

There is also a logic element called an encoder that performs the inverse function of a decoder, taking 2^n inputs and producing an n-bit output.

Multiplexor

- A multiplexor might more properly be called a selector, since its output is one of the inputs that is selected by a control.



- The left side shows this multiplexor has three inputs: two data values and a selector (or control) value.

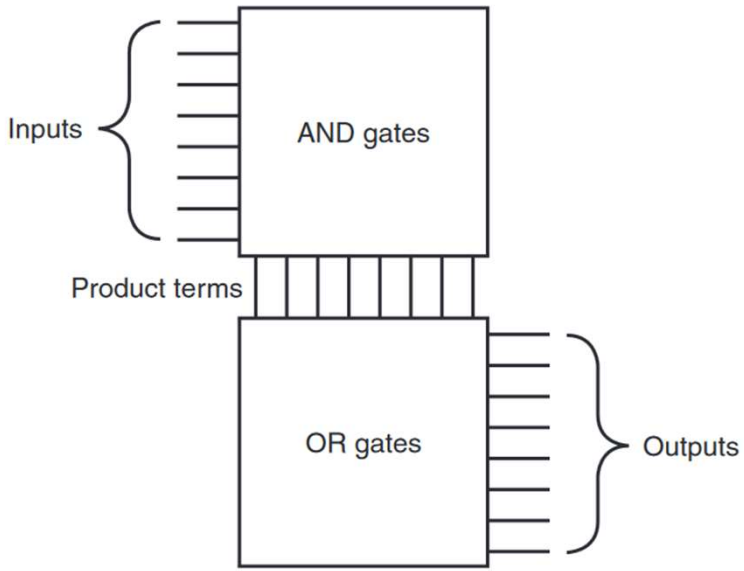
- The selector value determines which of the inputs becomes the output. We can represent the logic function computed by a two-input multiplexor, shown in gate form on the right side as C = (A.S) + (B.S) .

Two Level Logic

- Sum of products
- Product of sums.

Programmable Logic Array

- The sum-of-products representation corresponds to a common structured-logic implementation called a programmable logic array (PLA).



Constructing ALU

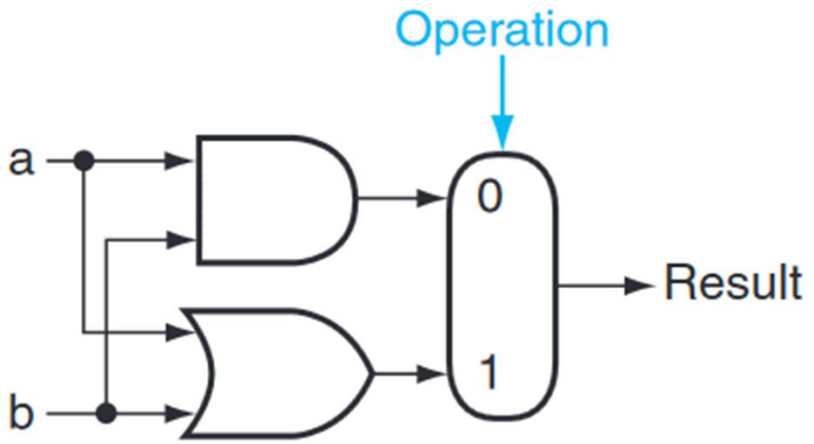


FIGURE B.5.1 The 1-bit logical unit for AND and OR.

Adder

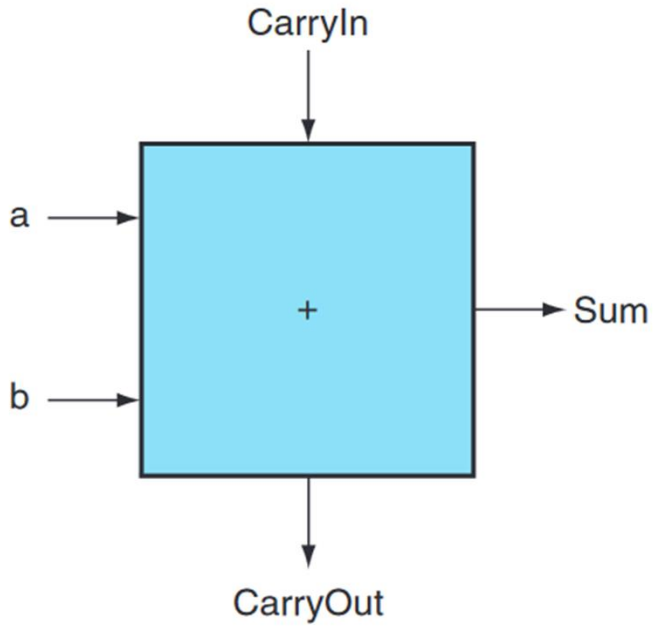
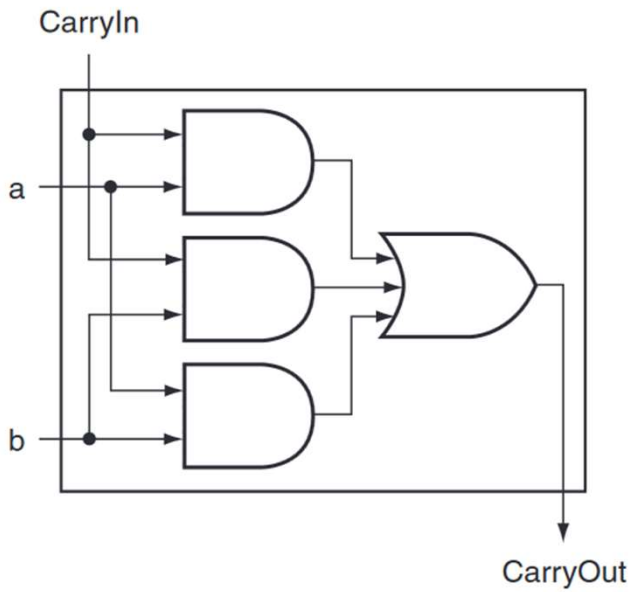
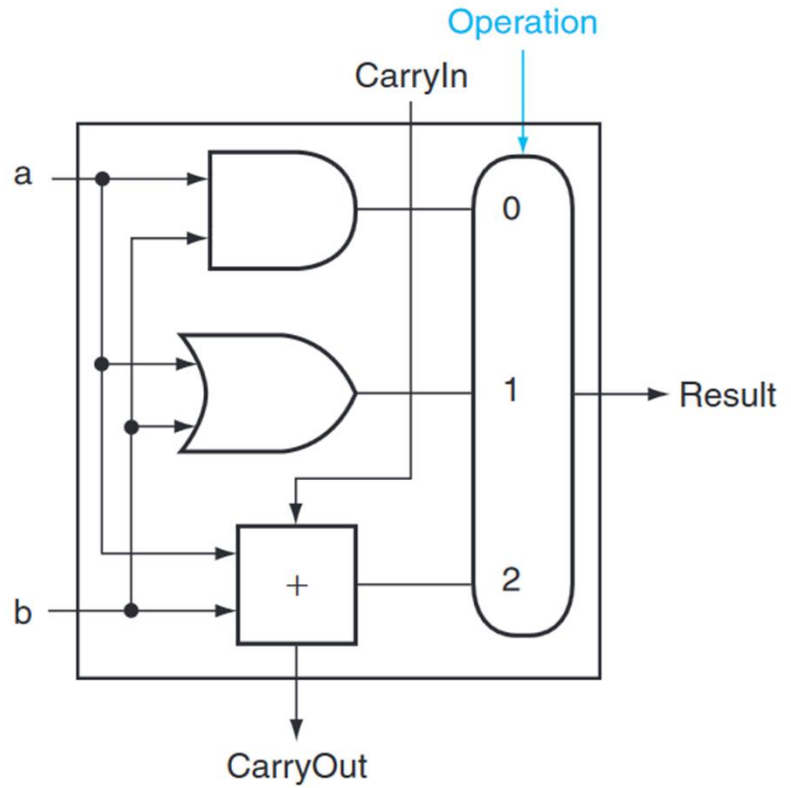


FIGURE B.5.2 A 1-bit adder. This adder is called a full adder; it is also called a (3,2) adder because it has 3 inputs and 2 outputs. An adder with only the a and b inputs is called a (2,2) adder or half-adder.

1- Bit ALU





A 1-bit ALU that performs AND, OR, and addition (see

What about 32 Bit ALU?

Reference

- Computer Organization and Design (ARM edition) - The Hardware and Software Interface by David A. Patterson and John L. Hennessy