Logic and Computer Design Fundamentals

Chapter 2 – Combinational Logic Circuits

Part 3 – Additional Gates and Circuits

Charles Kime & Thomas Kaminski

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Overview

- **Part 1 – Gate Circuits and Boolean Equations**
  - Binary Logic and Gates
  - Boolean Algebra
  - Standard Forms
- **Part 2 – Circuit Optimization**
  - Two-Level Optimization
  - Map Manipulation
  - Practical Optimization (Espresso)
  - Multi-Level Circuit Optimization
- **Part 3 – Additional Gates and Circuits**
  - Other Gate Types
  - Exclusive-OR Operator and Gates
  - High-Impedance Outputs

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Other Gate Types

- Why?
  - Implementation feasibility and low cost
  - Power in implementing Boolean functions
  - Convenient conceptual representation
- Gate classifications
  - Primitive gate - a gate that can be described using a single primitive operation type (AND or OR) plus an optional inversion(s).
  - Complex gate - a gate that requires more than one primitive operation type for its description
- Primitive gates will be covered first

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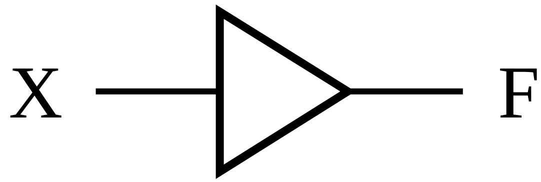
Buffer

- A buffer is a gate with the function F = X:



- In terms of Boolean function, a buffer is the same as a connection!
- So why use it?
  - A buffer is an electronic amplifier used to improve circuit voltage levels and increase the speed of circuit operation.

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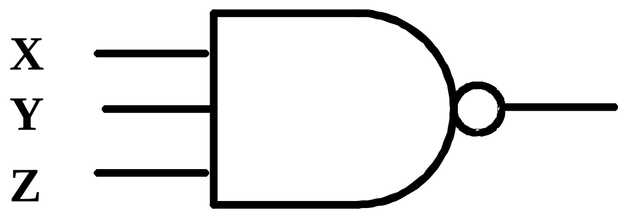
NAND Gate

- **The basic NAND gate has the following symbol, illustrated for three inputs:**
  - **AND-Invert (NAND)**



$$F(X, Y, Z) = \overline{X \cdot Y \cdot Z}$$

- **NAND represents <u>NOT</u> <u>AND</u>, i. e., the AND function with a NOT applied. The symbol shown is an AND-Invert. The small circle ("bubble") represents the invert function.**

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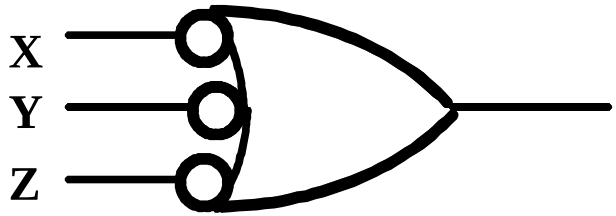
NAND Gates (continued)

- **Applying DeMorgan's Law gives Invert-OR (NAND)**



$$F(X, Y, Z) = \overline{X} + \overline{Y} + \overline{Z}$$

- **This NAND symbol is called Invert-OR, since inputs are inverted and then ORed together.**
- **AND-Invert and Invert-OR both represent the NAND gate. Having both makes visualization of circuit function easier.**
- **A NAND gate with one input degenerates to an inverter.**

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NAND Gates (continued)

- **The NAND gate is the natural implementation for CMOS technology in terms of chip area and speed.**
- ***Universal gate*** **- a gate type that can implement any Boolean function.**
- **The NAND gate is a universal gate as shown in Figure 2-24 of the text.**
- **NAND usually does not have a operation symbol defined since**
  - **the NAND operation is not associative, and**
  - **we have difficulty dealing with non-associative mathematics!**

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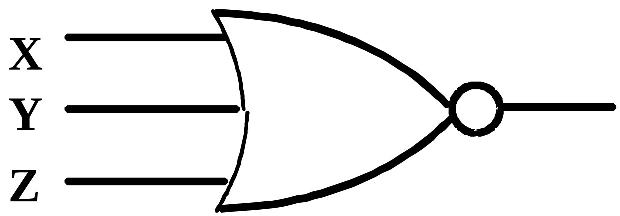
NOR Gate

- **The basic NOR gate has the following symbol, illustrated for three inputs:**
  - **OR-Invert (NOR)**



$$F(X, Y, Z) = \overline{X + Y + Z}$$

- **NOR represents <u>NOT - OR</u>, i. e., the OR function with a NOT applied. The symbol shown is an OR-Invert. The small circle ("bubble") represents the invert function.**

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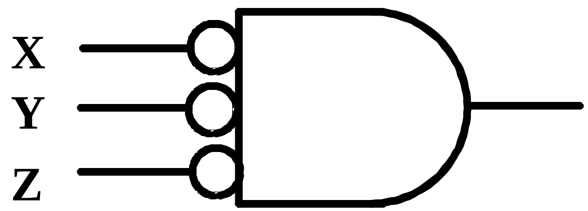
NOR Gate (continued)

- **Applying DeMorgan's Law gives Invert-AND (NOR)**



- **This NOR symbol is called Invert-AND, since inputs are inverted and then ANDed together.**
- **OR-Invert and Invert-AND both represent the NOR gate. Having both makes visualization of circuit function easier.**
- **A NOR gate with one input degenerates to an inverter.**

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NOR Gate (continued)

- **The NOR gate is a natural implementation for some technologies other than CMOS in terms of chip area and speed.**
- **The NOR gate is a universal gate**
- **NOR usually does not have a defined operation symbol since**
  - **the NOR operation is not associative, and**
  - **we have difficulty dealing with non-associative mathematics!**

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Exclusive OR/ Exclusive NOR

- **The *eXclusive OR* (*XOR*) function is an important Boolean function used extensively in logic circuits.**
- **The XOR function may be;**
  - **implemented directly as an electronic circuit (truly a gate) or**
  - **implemented by interconnecting other gate types (used as a convenient representation)**
- **The *eXclusive NOR* function is the complement of the XOR function**
- **By our definition, XOR and XNOR gates are complex gates.**

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Exclusive OR/ Exclusive NOR

- Uses for the XOR and XNORs gate include:
  - Adders/subtractors/multipliers
  - Counters/incrementers/decrementers
  - Parity generators/checkers
- Definitions
  - The XOR function is: $X \oplus Y = X\overline{Y} + \overline{X}Y$
  - The eXclusive NOR (XNOR) function, otherwise known as *equivalence* is: $\overline{X \oplus Y} = XY + \overline{X}\,\overline{Y}$
- Strictly speaking, XOR and XNOR gates do no exist for more that two inputs. Instead, they are replaced by odd and even functions.

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Truth Tables for XOR/XNOR

- **Operator Rules: XOR** **XNOR**

X	Y	$X \oplus Y$
0	0	0
0	1	1
1	0	1
1	1	0

X	Y	$\overline{(X \oplus Y)}$ or $X \equiv Y$
0	0	1
0	1	0
1	0	0
1	1	1

- **The XOR function means:**

  X OR Y, but NOT BOTH

- **Why is the XNOR function also known as the *equivalence* function, denoted by the operator ≡?**

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XOR/XNOR (Continued)

- The XOR function can be extended to 3 or more variables. For more than 2 variables, it is called an *odd function* or *modulo 2 sum* (*Mod 2 sum*), not an XOR:

$$X \oplus Y \oplus Z = \overline{X}\,\overline{Y}\,Z + \overline{X}\,Y\,\overline{Z} + X\,\overline{Y}\,\overline{Z} + X\,Y\,Z$$

- The complement of the odd function is the even function.
- The XOR identities:

$$X \oplus 0 = X \qquad X \oplus 1 = \overline{X}$$

$$X \oplus X = 0 \qquad X \oplus \overline{X} = 1$$

$$X \oplus Y = Y \oplus X$$

$$(X \oplus Y) \oplus Z = X \oplus (Y \oplus Z) = X \oplus Y \oplus Z$$

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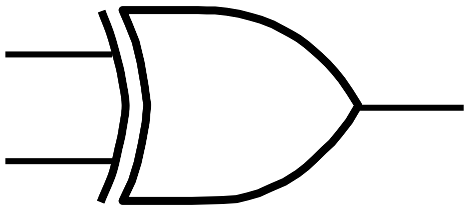
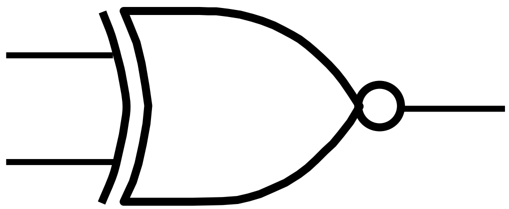
Symbols For XOR and XNOR

- **XOR symbol:**



- **XNOR symbol:**



- **Shaped symbols exist only for two inputs**

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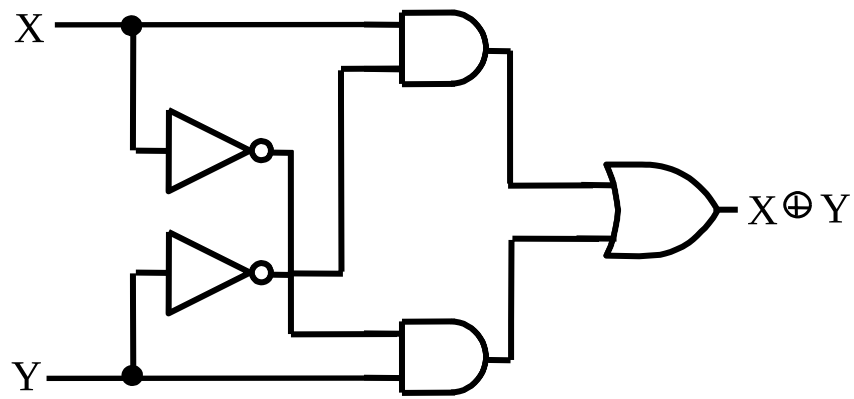
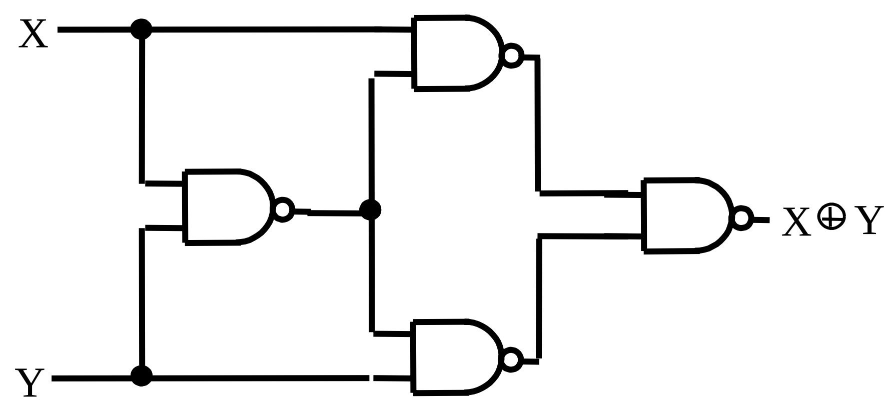
XOR Implementations

- **The simple SOP implementation uses the following structure:**



- **A NAND only implementation is:**



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Odd and Even Functions

- The odd and even functions on a K-map form "checkerboard" patterns.
- The 1s of an odd function correspond to minterms having an index with an odd number of 1s.
- The 1s of an even function correspond to minterms having an index with an even number of 1s.
- Implementation of odd and even functions for greater than four variables as a two-level circuit is difficult, so we use "trees" made up of :
  - 2-input XOR or XNORs
  - 3- or 4-input odd or even functions

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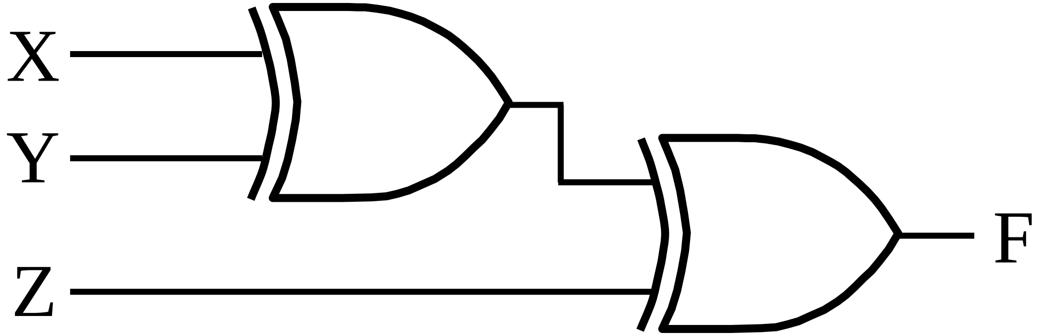
Example: Odd Function Implementation

- Design a 3-input odd function $F = X \oplus Y \oplus Z$ with 2-input XOR gates
- Factoring, $F = (X \oplus Y) \oplus Z$
- The circuit:



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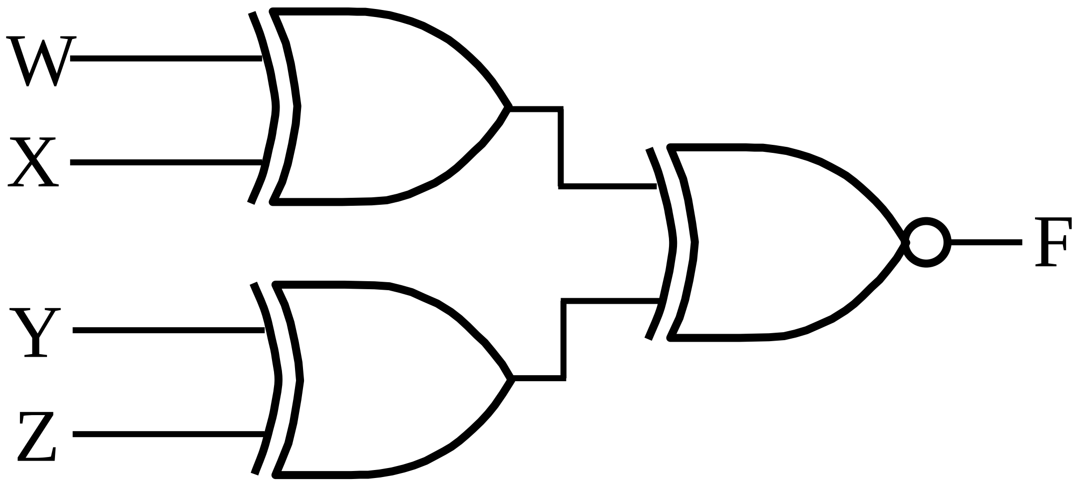
Example: Even Function Implementation

- **Design a 4-input odd function $F = W \oplus X \oplus Y \oplus Z$ with 2-input XOR and XNOR gates**
- **Factoring, $F = (W \oplus X) \oplus (Y \oplus Z)$**
- **The circuit:**



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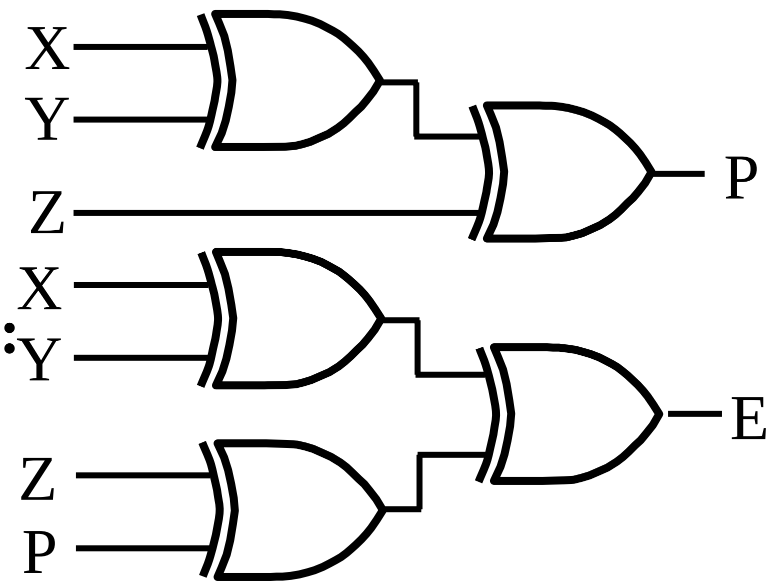
Parity Generators and Checkers

- **In Chapter 1, a parity bit added to n-bit code to produce an n + 1 bit code:**
  - **Add odd parity bit to generate code words with even parity**
  - **Add even parity bit to generate code words with odd parity**
  - **Use odd parity circuit to check code words with even parity**
  - **Use even parity circuit to check code words with odd parity**
- **Example: n = 3. Generate even parity code words of length four with odd parity generator:**
- **Check even parity code words of length four with odd parity checker:**
- **Operation: (X,Y,Z) = (0,0,1) gives (X,Y,Z,P) = (0,0,1,1) and E = 0. If Y changes from 0 to 1 between generator and checker, then E = 1 indicates an error.**



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Hi-Impedance Outputs

- **Logic gates introduced thus far**
  - **have 1 and 0 output values,**
  - **cannot have their outputs connected together, and**
  - **transmit signals on connections in only one direction.**
- **Three-state logic adds a third logic value, Hi-Impedance (Hi-Z), giving three states: 0, 1, and Hi-Z on the outputs.**
- **The presence of a Hi-Z state makes a gate output as described above behave quite differently:**
  - **"1 and 0" become "1, 0, and Hi-Z"**
  - **"cannot" becomes "can," and**
  - **"only one" becomes "two"**

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Hi-Impedance Outputs (continued)

- **What is a Hi-Z value?**
  - **The Hi-Z value behaves as an open circuit**
  - **This means that, looking back into the circuit, the output appears to be disconnected.**
  - **It is as if a switch between the internal circuitry and the output has been opened.**
- **Hi-Z may appear on the output of any gate, but we restrict gates to:**
  - **a 3-state buffer, or**
  - **Optional: a transmission gate (See Reading Supplement: More on CMOS Circuit-Level Design),**

each of which has one data input and one control input.

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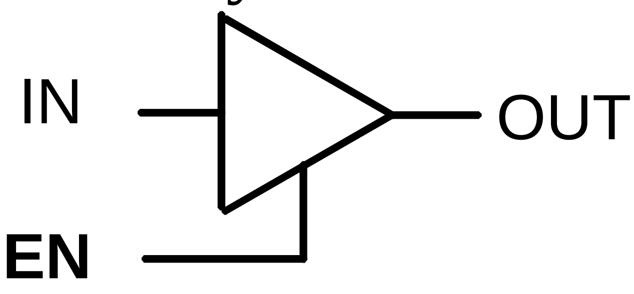
The 3-State Buffer

- **For the symbol and truth table, IN is the <u>data input,</u> and EN, the <u>control input</u>.**
- **For EN = 0, regardless of the value on IN (denoted by X), the output value is Hi-Z.**
- **For EN = 1, the output value follows the input value.**
- **Variations:**
  - **Data input, IN, can be inverted**
  - **Control input, EN, can be inverted**

  by addition of "bubbles" to signals.

Symbol



Truth Table

EN	IN	OUT
0	X	Hi-Z
1	0	0
1	1	1

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Resolving 3-State Values on a Connection

- **Connection of two 3-state buffer outputs, B1 and B0, to a wire, OUT**
- **Assumption: Buffer data inputs can take on any combination of values 0 and 1**
- **Resulting Rule: At least one buffer output value must be Hi-Z. Why?**
- **How many valid buffer output combinations exist?**
- **What is the rule for *n* 3-state buffers connected to wire, OUT?**
- **How many valid buffer output combinations exist?**

Resolution Table		
B1	**B0**	**OUT**
0	Hi-Z	0
1	Hi-Z	1
Hi-Z	0	0
Hi-Z	1	1
Hi-Z	Hi-Z	Hi-Z

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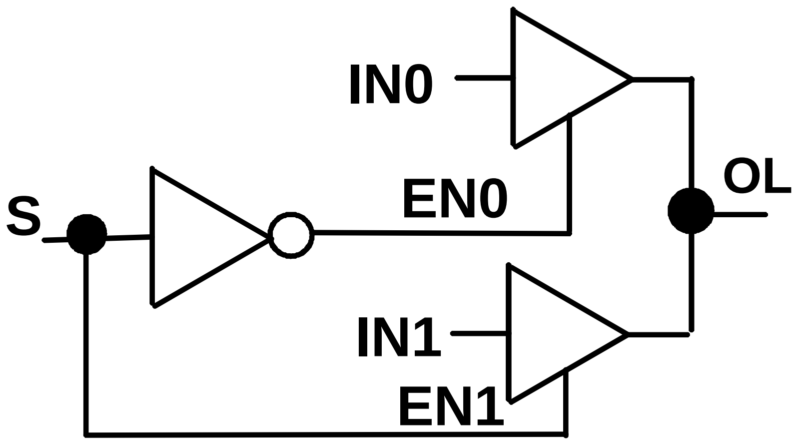
3-State Logic Circuit

- **Data Selection Function: If s = 0, OL = IN0, else OL = IN1**
- **Performing data selection with 3-state buffers:**

EN0	IN0	EN1	IN1	OL
0	X	1	0	0
0	X	1	1	1
1	0	0	X	0
1	1	0	X	1
0	X	0	X	X



- **Since EN0 = $\overline{S}$ and EN1 = S, one of the two buffer outputs is always Hi-Z plus the last row of the table never occurs.**

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More Complex Gates

- The remaining complex gates are SOP or POS structures with and without an output inverter.
- The names are derived using:
  - A - AND
  - O - OR
  - I - Inverter
  - Numbers of inputs on first-level "gates" or directly to second-level "gates"

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More Complex Gates (continued)

- Example: AOI - AND-OR-Invert consists of a single gate with AND functions driving an OR function which is inverted.
- Example: 2-2-1 AO has two 2-input ANDS driving an OR with one additional OR input
- These gate types are used because:
  - the number of transistors needed is fewer than required by connecting together primitive gates
  - potentially, the circuit delay is smaller, increasing the circuit operating speed

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