Lecture 03: Boolean Algebra

Electronics, Devices and Circuits Part II

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Boolean Algebra

- How to do arithmetic in the decimal system? (Learned in School)
- The same arithmetic ideas can be carried out in binary system (Last Class)

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- The only freedom we have is to manipulate 0 and 1 and we need rules for this.

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- These rules are called Logic.
- Mathematical system of logical rules $\Rightarrow$ Boolean algebra

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- These rules are called Logic.
- Mathematical system of logical rules $\Rightarrow$ Boolean algebra

- But how to do this practically? $\Rightarrow$ Logic is implemented using Logic Gates

- Hardware implements Logic, Logic leads to bit manipulation and bit manipulation leads to computation

Arithmatic Computation $\rightarrow$ Bit Manipulation $\rightarrow$ Logic $\rightarrow$ Hardware

Boolean Algebra

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- Commutative: $s_1 * s_2 = s_2 * s_1$
- Identity: $s_1 * I = s_1$

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- Inverse: $s_1 * s_2 = I$, I is identity element.

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- Identity: $s_1 * I = s_1$
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- Distributive: $s_1 * (s_2 \odot s_3) = (s_1 * s_2) \odot (s_1 * s_3)$

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- Closure: $1 + 2 = 3 \in S$, $1 - 2 = -1 \notin S$
- Associative: $1 + (2 + 3) = (1 + 2) + 3$
- Associative: $1 - (2 - 3) \neq (1 - 2) - 3$

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- Identity: $5 + 0 = 5$, $5 \times 1 = 5$

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- Identity: $5 + 0 = 5$, $5 \times 1 = 5$
- Inverse: $5 + (-5) = 0$, $5 \times (1/5) = 1$
- Distributive: $2 \times (3 + 4) = (2 \times 3) + (2 * 4)$
- Distributive: $2 + (3 \times 4) \neq (2 + 3) \times (2 + 4)$

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- Distributive: $2 \times (3 + 4) = (2 \times 3) + (2 * 4)$
- Distributive: $2 + (3 \times 4) \neq (2 + 3) \times (2 + 4)$
- $+, \times$ operators follow all the properties of the number systems $\Rightarrow$ Elegant

Boolean Algebra

- $S \equiv \{0, 1\}$
- Operators: AND

Boolean Algebra

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- 0 AND 0 = 0
- 0 AND 1 = 0
- 1 AND 0 = 0
- 1 AND 1 = 1

Boolean Algebra

- $S \equiv \{0, 1\}$
- Operators: AND, OR

- 0 AND $0 = 0$
- 0 AND $1 = 0$
- 1 AND $0 = 0$
- 1 AND $1 = 1$

- 0 OR $0 = 0$
- 0 OR $1 = 1$
- 1 OR $0 = 1$
- 1 OR $1 = 1 \Rightarrow$ (Not Binary Addition)

Boolean Algebra

- $S \equiv \{0, 1\}$
- Operators: AND, OR, NOT

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- NOT $0 = 1$
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- NOT 0 = 1
- NOT 1 = 0

George Boole (1815-1864)

Why is Boolean Logic important?

Boolean Algebra

- $S \equiv \{0, 1\}$
- Operators: AND, OR, NOT

- 0 AND $0 = 0$
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- NOT $0 = 1$
- NOT $1 = 0$

George Boole (1815-1864)

$S \equiv \{0, 1\}$ with AND, OR, NOT

We can do all binary arithmatic

Boolean Algebra

- Since x, y, z are variables belonging to $\{0, 1\}$
- We can create a logic function $f(x, y, z)$ out of these three variables
- What does the logic do?
    - Truth Tables
    - Each one of them can take only 0 and 1.
    - What a logic function does for every possible input?
    - So we can write the outcome of logic explicitly using their values
    - Truth tables are complete and exact, brute force, grow exponentially
- Why does the logic work?
    - Boolean Algebra
    - All Possibilities $\rightarrow$ Cumbersome $\rightarrow$ Algebraic rules to reason about logic.
    - Boolean algebra $\Rightarrow$ simplify expressions symbolically
- How do we simplify the logic systematically?
    - Karnaugh Map (Later Classes)

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Boolean Algebra (Postulates)

1. Let x, y, z be variable that belongs to $\{0, 1\}$
2. $x + 0 = x$
3. $x \cdot 1 = x$
4. $x + \overline{x} = 1$
5. $x \cdot \overline{x} = 0$
6. $x + y = y + x$
7. $x \cdot y = y \cdot x$
8. $x \cdot (y + z) = x \cdot y + x \cdot z$
9. $x + (y \cdot z) = (x + y) \cdot (x + z)$

Boolean Algebra (Postulates)

1. Let x, y, z be variable that belongs to $\{0, 1\}$
2. $x + 0 = x$ (Identity)
3. $x \cdot 1 = x$ (Identity)
4. $x + \overline{x} = 1$ (Inverse)
5. $x \cdot \overline{x} = 0$ (Inverse)
6. $x + y = y + x$ (Commutative)
7. $x \cdot y = y \cdot x$ (Commutative)
8. $x \cdot (y + z) = x \cdot y + x \cdot z$ (Distributive)
9. $x + (y \cdot z) = (x + y) \cdot (x + z)$ (Distributive)

Boolean Algebra (Theorem)

- Let us evaluate $x + 1$

Boolean Algebra (Theorem)

- Let us evaluate $x + 1$
- $x + 1 = 1 \cdot (x + 1)$ [Using Postulate 2]
- $x + 1 = (x + \overline{x}) \cdot (x + 1)$ [Using Postulate 3]
- $x + 1 = x + (\overline{x} \cdot 1)$ [Using Postulate 8]
- $x + 1 = x + \overline{x}$ [Using Postulate 2]
- $x + 1 = 1$ [Using Postulate 3]

Boolean Algebra (Theorem)

- Let us evaluate $x \cdot 0$

Boolean Algebra (Theorem)

- Let us evaluate $x \cdot 0$
- $x \cdot 0 = x \cdot 0 + 0$ [Using Postulate 1]
- $x \cdot 0 = (x \cdot 0) + (x \cdot \overline{x})$ [Using Postulate 4]
- $x \cdot 0 = x \cdot (0 + \overline{x})$ [Using Postulate 7]
- $x \cdot 0 = x \cdot \overline{x}$ [Using Postulate 1]
- $x \cdot 0 = 0$ [Using Postulate 4]

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- Let us evaluate $x + x$
- $x + x = 1 \cdot (x + x)$ [Using Postulate 2]
- $x + x = (x + \overline{x}) \cdot (x + x)$ [Using Postulate 3]
- $x + x = x + (\overline{x} \cdot x)$ [Using Postulate 8]
- $x + x = x + 0$ [Using Postulate 4]
- $x + x = x$ [Using Postulate 1]

Boolean Algebra (Theorem)

- Let us evaluate $x \cdot x$

Boolean Algebra (Theorem)

- Let us evaluate $x \cdot x$
- $x \cdot x = 0 + (x \cdot x)$ [Using Postulate 1]
- $x \cdot x = (x \cdot \overline{x}) + (x \cdot x)$ [Using Postulate 4]
- $x \cdot x = x \cdot (\overline{x} + x)$ [Using Postulate 7]
- $x \cdot x = x \cdot 1$ [Using Postulate 3]
- $x \cdot x = x$ [Using Postulate 2]

Boolean Algebra (Theorem)

- Let us evaluate $x \cdot (x + y)$

Boolean Algebra (Theorem)

- Let us evaluate $x \cdot (x + y)$
- $x \cdot (x + y) = (x + 0) \cdot (x + y)$ [Using Postulate 1]
- $x \cdot (x + y) = x + (0 \cdot y)$ [Using Postulate 8]
- $x \cdot (x + y) = x + 0$ [Using Theorem 2]
- $x \cdot (x + y) = x$ [Using Postulate 1]
- **Special Case :** If $y = 1$ above, $x \cdot (x + 1) = x \cdot x = x$

Boolean Algebra (Theorem)

- Let us evaluate $x + (x \cdot y)$

Boolean Algebra (Theorem)

- Let us evaluate $x + (x \cdot y)$
- $x + (x \cdot y) = (x \cdot 1) + (x \cdot y)$ [Using Postulate 2]
- $x + (x \cdot y) = x \cdot (1 + y)$ [Using Postulate 7]
- $x + (x \cdot y) = x \cdot 1$ [Using Theorem 1]
- $x + (x \cdot y) = x$ [Using Postulate 2]

Boolean Algebra (Theorem)

1. Let us assume x and y are two boolean variables (Show that $\overline{\overline{x}} = x$)

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1. Let us assume x and y are two boolean variables (Show that $\overline{\overline{x}} = x$)
2. $x + \overline{x} = 1, \quad x \cdot \overline{x} = 0$
3. $y + \overline{y} = 1, \quad y \cdot \overline{y} = 0$
4. Now let us substitute, $y = \overline{x}$?
5. Is this substitution allowed? Why?
6. Complement is a NOT operator operating on boolean variable x.
7. Closure property of Boolean set ensures result of NOT operator operated on a boolean variable also belongs to boolean set.
8. Hence substitution is perfectly valid under closure.
9. $\overline{x} + \overline{\overline{x}} = 1, \quad \overline{x} \cdot \overline{\overline{x}} = 0$
10. Compare 2 with 9,
11. $\overline{x} + \overline{\overline{x}} = x + \overline{x}, \quad \overline{x} \cdot \overline{\overline{x}} = x \cdot \overline{x}$
12. $\overline{x} + \overline{\overline{x}} = \overline{x} + x, \quad \overline{x} \cdot \overline{\overline{x}} = \overline{x} \cdot x$ [Using Postulate 5,6]
13. In order to satisfy above $\overline{\overline{x}} = x$

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5. $x + y + \overline{x} \cdot \overline{y} = y + x + \overline{x}$ [Using Postulate 5]
6. $x + y + \overline{x} \cdot \overline{y} = y + 1$ [Using Postulate 3]
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Boolean Algebra (Theorem)

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5. $x + y + \overline{x} \cdot \overline{y} = y + x + \overline{x}$ [Using Postulate 5]
6. $x + y + \overline{x} \cdot \overline{y} = y + 1$ [Using Postulate 3]
7. $x + y + \overline{x} \cdot \overline{y} = 1$ [Using Theorem 1]
8. But we also know for any boolean variable A
9. $\overline{A} + A = 1$,
10. If we set $A = \overline{x + y}$ [using closure property]
11. Then $\overline{\overline{x + y}} + \overline{x + y} = 1$ [using closure property]
12. It follows that $x + y + \overline{x + y} = 1$ [using Theorem 7]
13. By comparing 7 and 12 we can deduce $\overline{x + y} = \overline{x} \cdot \overline{y}$
14. **This is DeMorgan's first theorem**

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2. $\overline{x} + \overline{y} + x \cdot y = \overline{x} + (\overline{y} + x) \cdot (\overline{y} + y)$ [Using Postulate 8]
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4. $\overline{x} + \overline{y} + x \cdot y = \overline{x} + \overline{y} + x$ [Using Postulate 2]
5. $\overline{x} + \overline{y} + x \cdot y = \overline{y} + x + \overline{x}$ [Using Postulate 5]
6. $\overline{x} + \overline{y} + x \cdot y = \overline{y} + 1$ [Using Postulate 3]
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Boolean Algebra (Theorem)

1. Let us evaluate $\overline{x} + \overline{y} + x \cdot y$
2. $\overline{x} + \overline{y} + x \cdot y = \overline{x} + (\overline{y} + x) \cdot (\overline{y} + y)$ [Using Postulate 8]
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6. $\overline{x} + \overline{y} + x \cdot y = \overline{y} + 1$ [Using Postulate 3]
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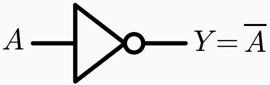
11. Then $\overline{\overline{x \cdot y}} + \overline{x \cdot y} = 1$ [using closure property]
12. It follows that $x \cdot y + \overline{x \cdot y} = 1$ [using Theorem 7]
13. By comparing 7 and 12 we can deduce $\overline{x \cdot y} = \overline{x} + \overline{y}$
14. **This is DeMorgan's second theorem**

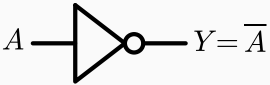
Boolean Algebra (Theorem)

1. $xy + x\overline{y}$
2. $(x + y)(x + \overline{y})$
3. $xyz + \overline{x}y + xy\overline{z}$
4. $(\overline{x + y})\,\overline{(\overline{x} + \overline{y})}$
5. $xy\overline{z} + \overline{x}yz + xyz + \overline{x}y\overline{z}$
6. $(x + y + \overline{z})(\overline{x} + \overline{y} + z)$
7. $xyz + \overline{x}y + xy\overline{z}$
8. $\overline{x}yz + xz$
9. $(\overline{x + y})(\overline{x} + \overline{y})$
10. $xy + x(wz + w\overline{z})$
11. $(B\overline{C} + \overline{A}D)(A\overline{B} + C\overline{D})$
12. $(x + \overline{y} + \overline{z})(\overline{x} + \overline{z})$
13. $\overline{AC} + ABC + A\overline{C}$
14. $\overline{(\overline{xy} + z)} + z + xy + wz$
15. $\overline{A}B(\overline{D} + \overline{C}D) + B(A + \overline{A}CD)$
16. $(\overline{A} + C)(\overline{A} + \overline{C})(A + B + \overline{C}D)$

Logic Gates

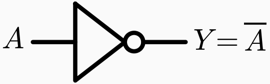


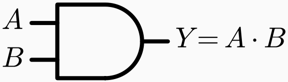
Logic Gates

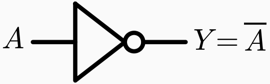


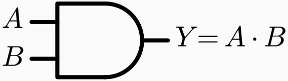
A	$Y = \overline{A}$
0	1
1	0

Logic Gates



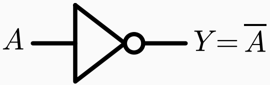


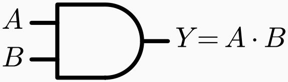


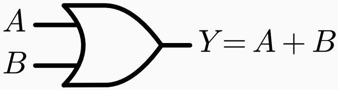


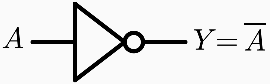
A	B	$Y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

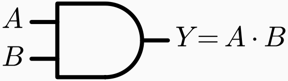
Logic Gates

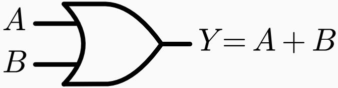






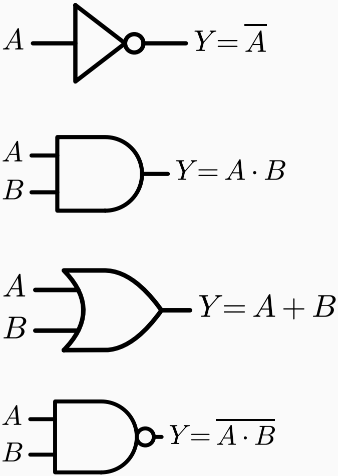




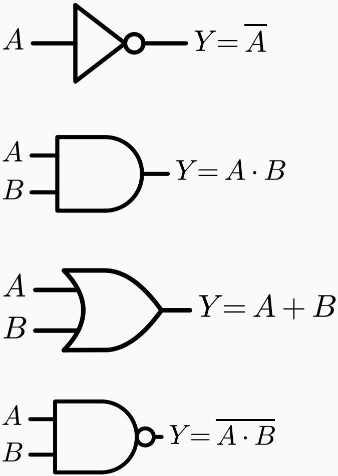


A	B	$Y = A + B$
0	0	0
0	1	1
1	0	1
1	1	1

Logic Gates

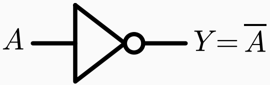


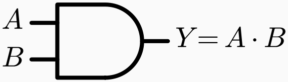
Logic Gates

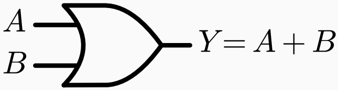


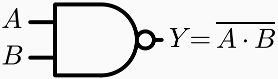
A	B	$Y = \overline{A \cdot B}$
0	0	1
0	1	1
1	0	1
1	1	0

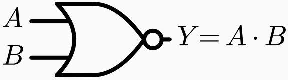
Logic Gates


A
$Y = \overline{A}$

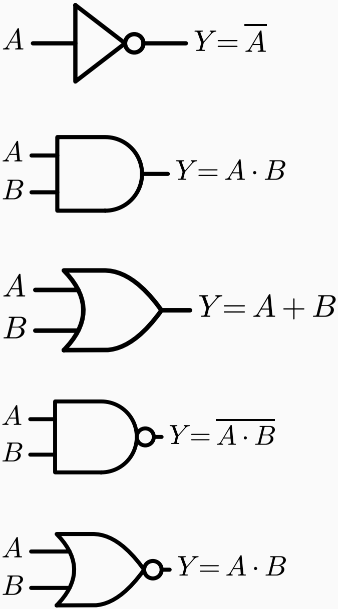

A
B
$Y = A \cdot B$


A
B
$Y = A + B$


A
B
$Y = \overline{A \cdot B}$

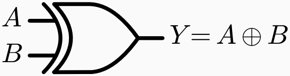

A
B
$Y = A \cdot B$

Logic Gates

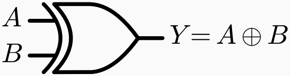


A	B	$Y = \overline{A + B}$
0	0	1
0	1	0
1	0	0
1	1	0

Logic Gates

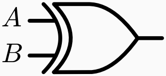


Logic Gates

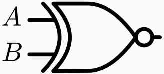


A	B	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

Logic Gates

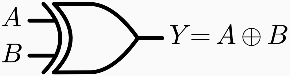


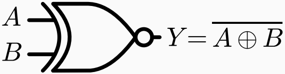
$Y = A \oplus B$



$Y = \overline{A \oplus B}$

Logic Gates





A	B	$Y = \overline{A \oplus B}$
0	0	1
0	1	0
1	0	0
1	1	1