

ECE 2020 Lecture 2:

Switches, Transistors, and Logic Levels

Instructor: Samuel Talkington

August 30, 2024

Logistics

- Office hours happened today! Any additional questions?
- Adjustment to office hours schedule this week: **Friday** office hours *virtual*.
- Extra in-person office hours: Tues. Sep. 3rd, 11:30am-1pm.
- First homework assignment due date extended to September 4th, 2024, 11:59pm.
- Updated course schedule coming tonight after course survey deadline.

Exam schedule

- 1 Exam 1: September 15th
- 2 Exam 2: October 6th
- 3 Exam 3: November 3rd
- 4 Exam 4: TBD

Agenda

- Recap of digital signals and boolean algebra
- Switching logic signals and truth tables
- Transistors
- Manipulating digital signals with Boolean logic
- DeMorgan's Theorem
- Understanding switching operations

Recap

Boolean variables

A **Boolean variable**, also known as a **binary variable**, is a variable that can take the values **one** or **zero** depending on whether some other thing is **true** or **false**, i.e.:

$$X = \begin{cases} 1 & \text{if some thing is true} \\ 0 & \text{if some thing is false.} \end{cases} \quad (1)$$

A digital signal, also known as a **binary function**, **Boolean function**, or **logic function**, is a function F that receives a **collection of binary/boolean variables** X, Y, \dots as input:

$$Z = F(X, Y, \dots), \quad (2)$$

then performs a sequence of **logical operations**, and returns another binary Z .

Logic gates: Making logic pretty and practical

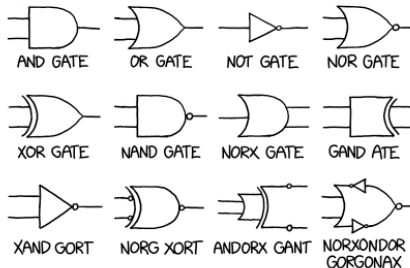
Logic gates

Are the fundamental building blocks of digital circuits.

The key idea

Gates = Operators
Circuits = Functions

COMMON LOGIC GATE SYMBOLS



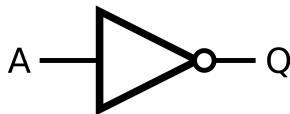
Source: xkcd

The NOT operator

Truth table

A	$Q = \bar{A}$
0	1
1	0

Logic gate



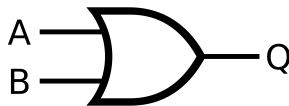
The NOT gate

The OR operator

Truth table

A	B	$Q = A + B$
0	0	0
0	1	1
1	0	1
1	1	1

Logic gate



The OR gate

The AND operator

Truth table

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

Logic gate



The AND gate

The XOR operator

Truth table

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

Logic gate



The XOR gate

DeMorgan's Theorem

What is a Theorem?

What is a theorem?

What is a theorem?

A *theorem* is a *non-obvious* mathematical relationship that works as long as some other assumptions are true.

DeMorgan's Theorem

Assumption: Suppose that you are given *any* two digital signals

$$X, Y = \begin{cases} 1 & \text{if something is true} \\ 0 & \text{if something is false} \end{cases}$$

Then, the following two logical relationships are *always* true:

$$\overline{X + Y} = \overline{X} \cdot \overline{Y} \quad (3a)$$

$$\overline{X \cdot Y} = \overline{X} + \overline{Y} \quad (3b)$$

Proof of DeMorgan's first Theorem by Truth Table

Hold on...

This is **amazing**.

We just figured out something that is not obvious *at all*, but it's **always** true for **any** two digital signals...

Challenge question

Challenge question

Can you prove DeMorgan's Theorem using the inverse identities?

$$A + \bar{A} = 1 \quad (4a)$$

$$A \cdot \bar{A} = 0 \quad (4b)$$

To appear as bonus on the second homework.

Participation puzzle!

Solve the following puzzle on a piece of paper.

After class, fill out the short survey on Canvas.

Remember, any submission receives full credit.

Participation puzzle

Let X and Y be two digital signals. We just reviewed the first one of DeMorgan's laws: $\overline{X + Y} = \overline{X} \cdot \overline{Y}$. Now, you try DeMorgan's other law:

$$\overline{X \cdot Y} = \overline{X} + \overline{Y}. \quad (5)$$

- 1 Use a truth table to prove that this law is true.
- 2 Do you know what gate this represents? If so, draw it and name it.

Please write your name somewhere so I can give you credit :)

Remember, any submission receives full credit.

Switching

A very simple, but powerful idea

A **switch** is a simple but powerful idea:

Either electricity flows through a circuit or it does not

So, we can represent logic via switches too!

Logic gates are actually... switches?

I've spent years of my life studying it, but **electricity** can be confusing.

Logic gates are a little less confusing.

Thankfully, if you know a *little bit* of logic gates, it turns out you know a *lot* about circuits.

Rapid review of electricity fundamentals

Transistors

We're all sort of familiar with switches. But these days, there's a better device—a *transistor*

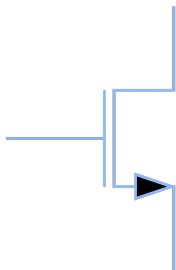
What is CMOS?

CMOS

A **complimentary metal oxide semiconductor field effect transistor** (CMOS) is a 3-terminal device that acts like a voltage-controlled resistance. It is a **powered switch** that can be controlled with a voltage.

In digital logic, a MOS transistor is operated so its resistance is always either very high (and the transistor is “off”) or very low (and the transistor is “on”).

NMOS diagram

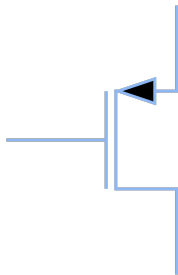


NMOS facts

Logic

$$R_{ds} = \begin{cases} \text{large } \Omega & v_{gs} \leq 0 \\ \text{small } \Omega & v_{gs} > 0 \end{cases}$$

PMOS diagram



PMOS Facts

Logic

$$R_{ds} = \begin{cases} \text{small } \Omega & v_{gs} < 0 \\ \text{large } \Omega & v_{gs} \geq 0 \end{cases}$$

Transistors

Transistors: They are just cool-looking switches.

We can use NMOS and PMOS transistors (switches) to design logical operations in real life!

Inverter design example

Example

Suppose you want to implement, with CMOS switches, the NOT gate (aka, inverter):

$$V_{\text{out}} = \overline{V_{\text{in}}}$$

How would this be done?

Inverter design example

Foreshadowing

Think about it for a second:

There's an infinite number of real numbers and integers. But we can **count** the integers.

Wait... how do we even store real numbers in computers?

Think about it... **number systems are coming soon**