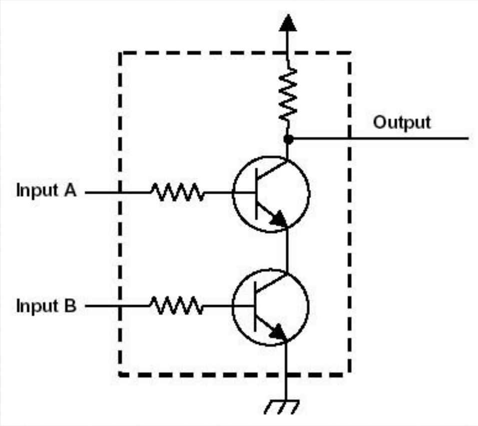
COMP1003 Computer Organization

Lecture 4 From Transistors to Gates



United International College

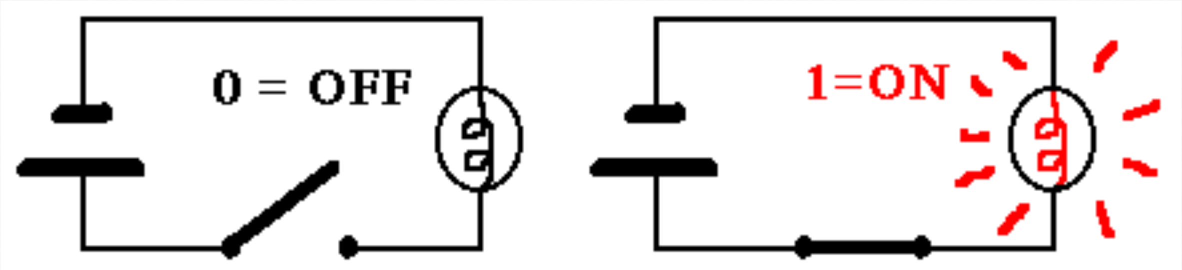
Claude Shannon

- His master's thesis in 1937, A Symbolic Analysis of Relay and Switching Circuits, is considered as "possibly the most important, and also the most famous, master's thesis of the century."
- He came up with the idea that electrical switches can be used to do Boolean logic

Switch

false

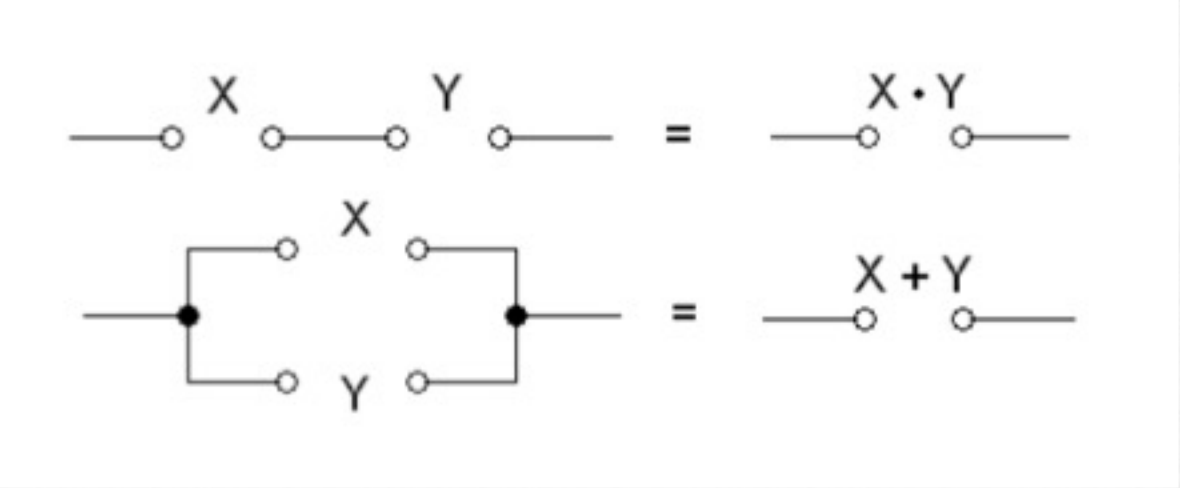
true



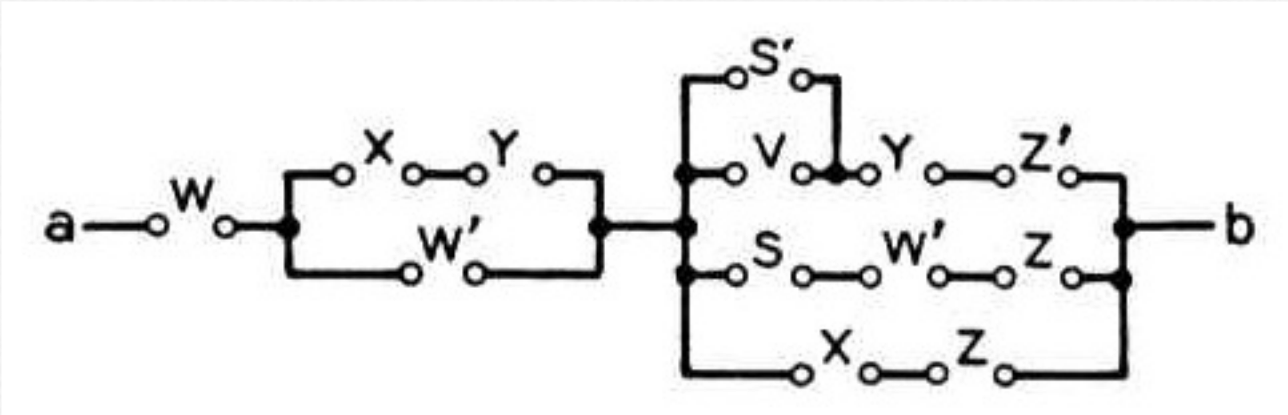
open

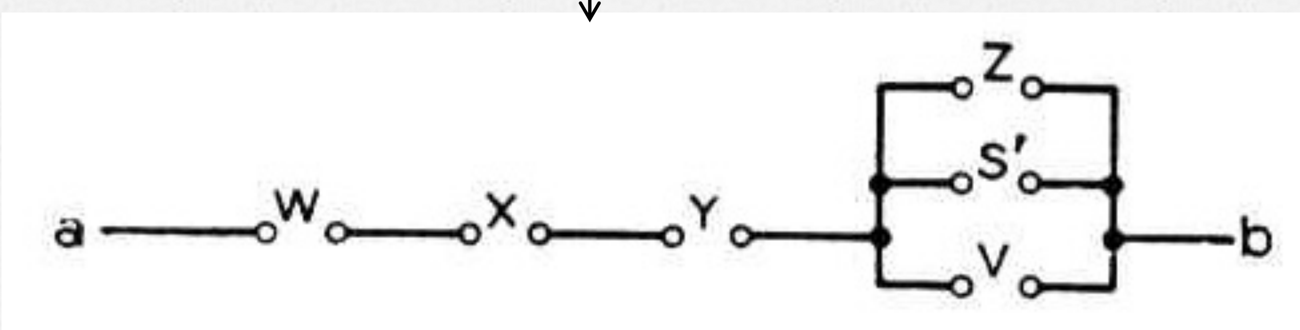
close

From Switches to Boolean Expression

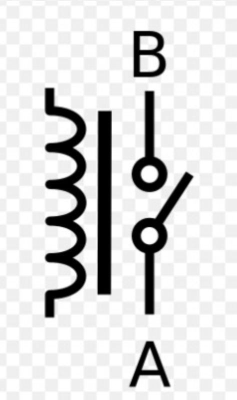


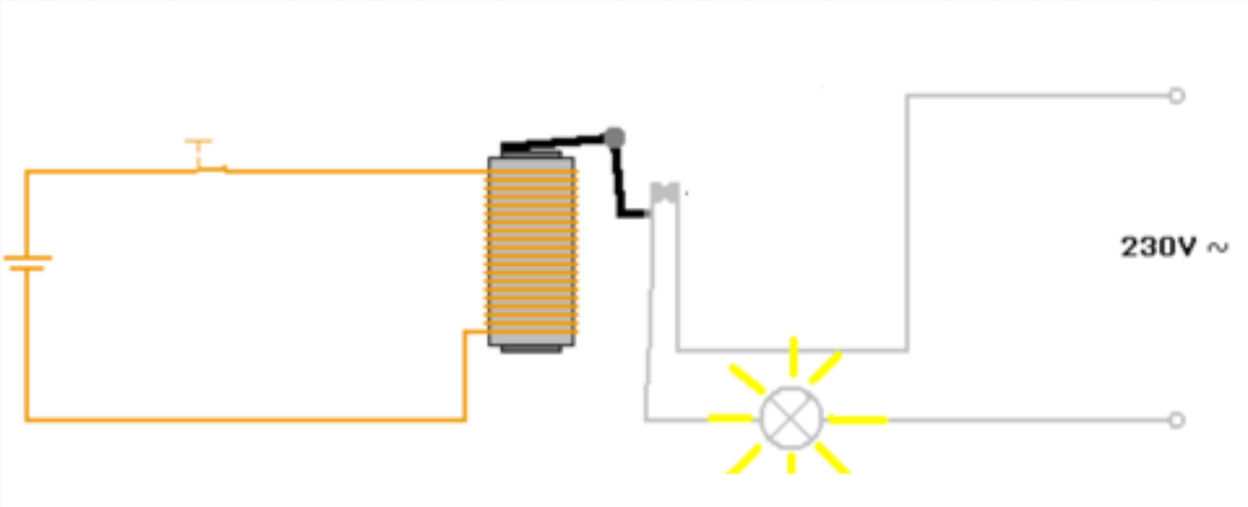
Simplifying Circuit by Boolean Logic



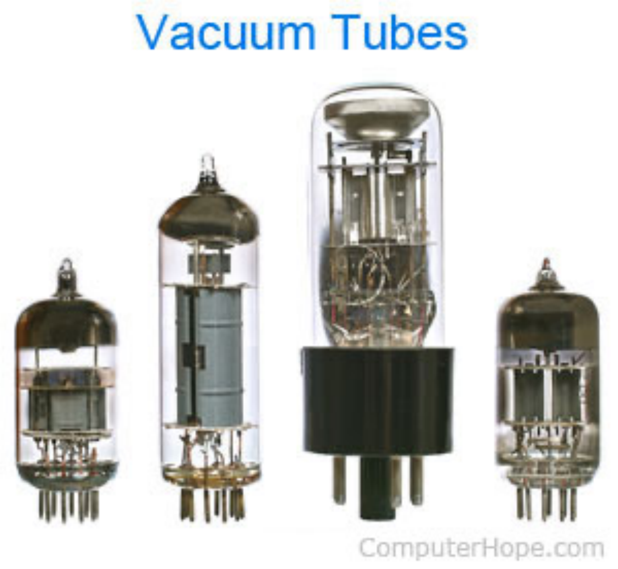


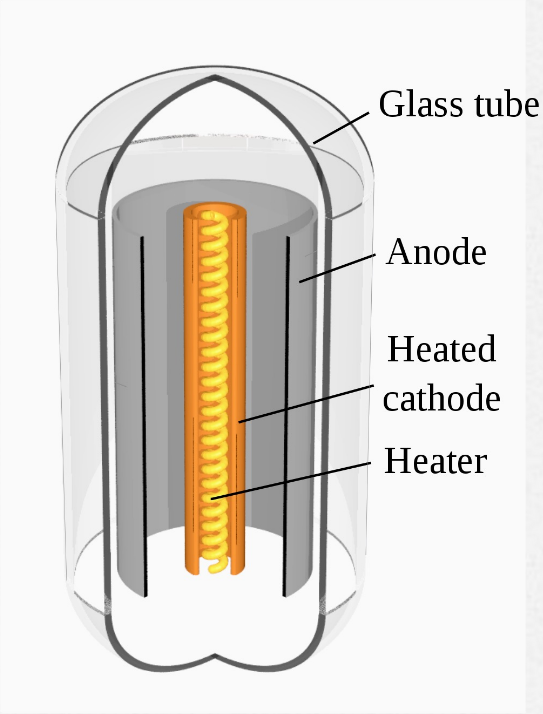
Relay(继电器)



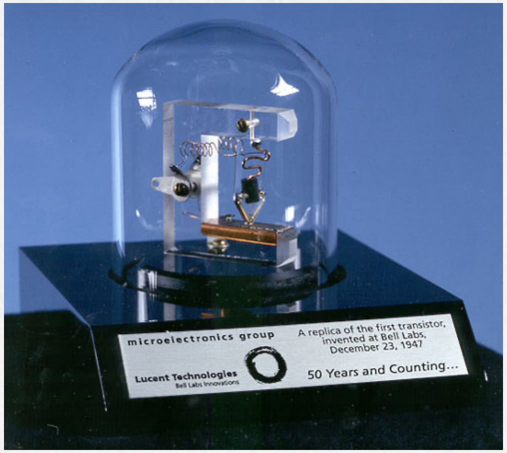


Vacuum Tube


Vacuum Tubes
ComputerHope.com

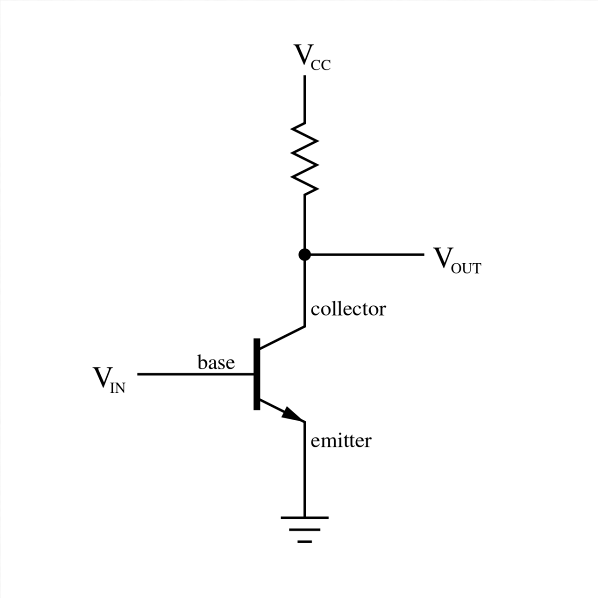

Glass tube
Anode
Heated cathode
Heater

Transistor



microelectronics group
A replica of the first transistor, invented at Bell Labs, December 23, 1947
Lucent Technologies
Bell Labs Innovations
50 Years and Counting...

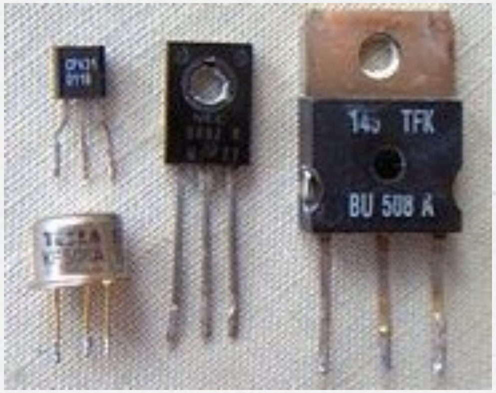
PHILCO
Production Model
Actual Size

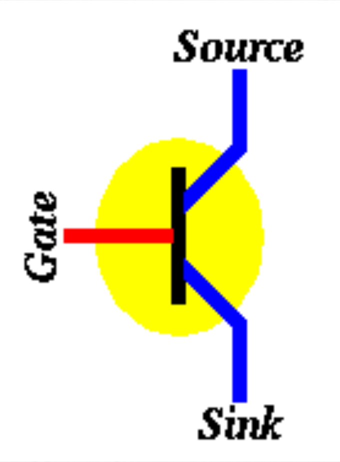


V_{CC}
V_{OUT}
collector
base
V_{IN}
emitter

Transistor

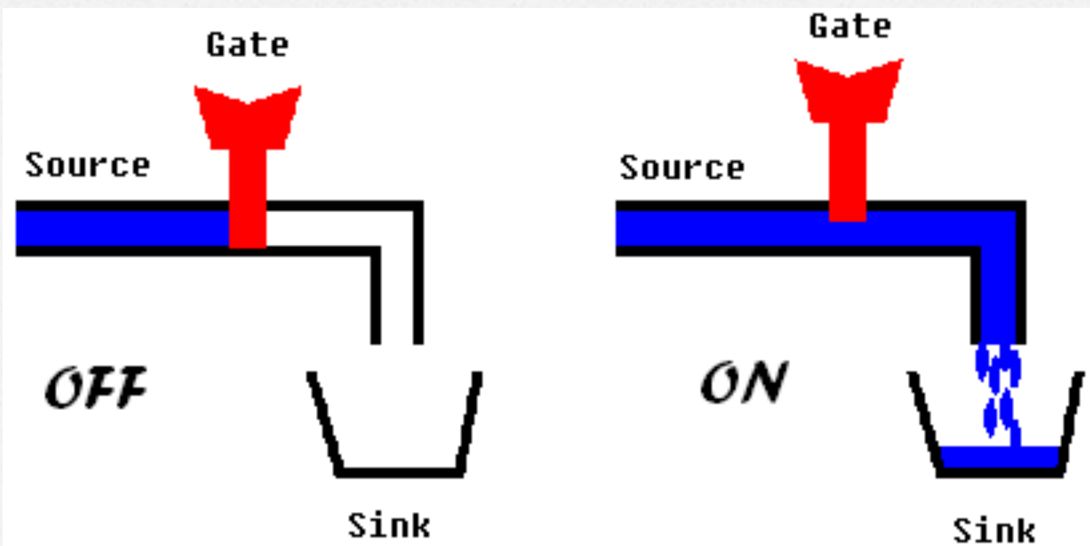
- A transistor is a discrete electronic component that can behave like a switch
- Tiny, cheap, flexible and reliable
- The greatest invention of the twentieth century

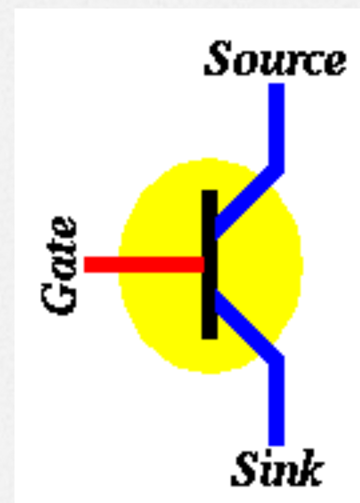




Water Flow Example

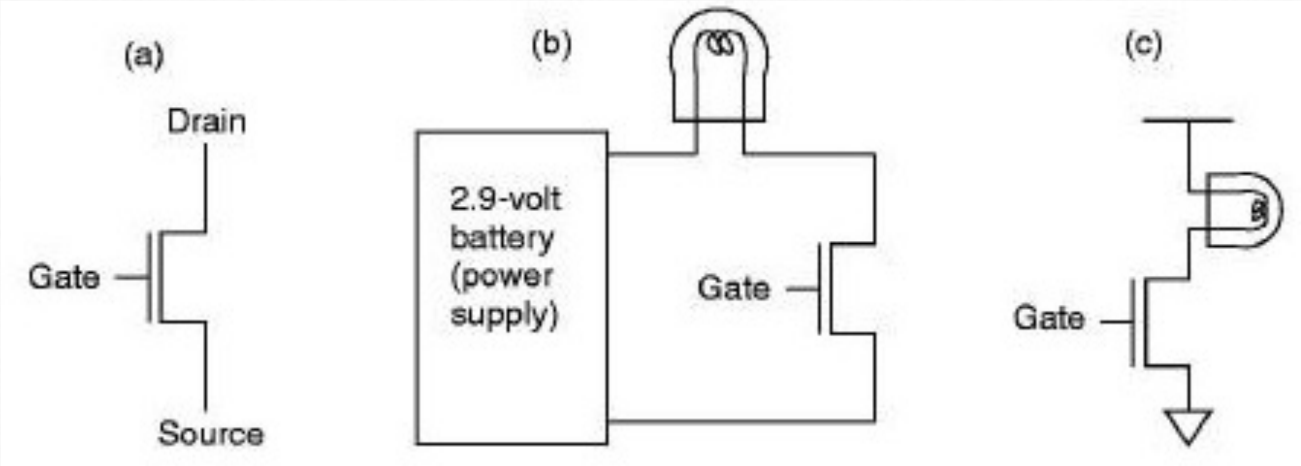
- Gate on, Water flow: 1 (close)
- Gate off, Water not flow: 0   (open)





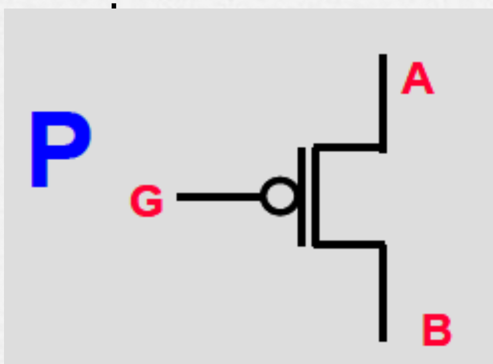
Transistor: Electricity Flow

- Conducts when V_{GS} is high (N Type transistor) (close)
- Blocks when V_{GS} is 0 (open)

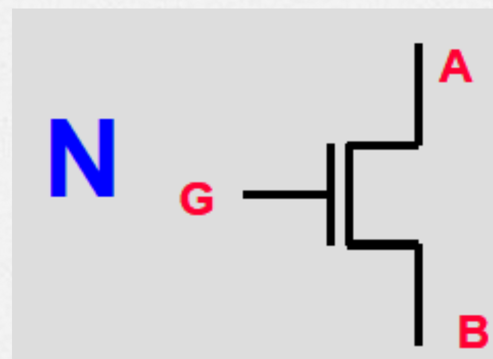


CMOS Transistors

- Complementary Metal-Oxide Semiconductor
  - Two types: P-type (positive) and N-type (negative)
  - P and N-type transistors operate in inverse



Open (insulating) if gate is "on" = 1
Closed (conducting) if gate is "off" = 0



Open if gate is "off" = 0
Closed if gate is "on" = 1

From Transistors to Logic Gates

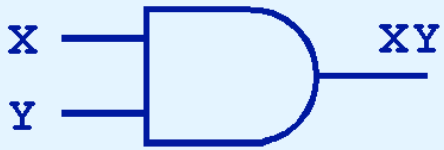
- We can use transistors as building blocks

- First let's look at how to build logic gates
  - NOT
  - OR/NOR
  - AND/NAND
  - XOR

Logic Gates

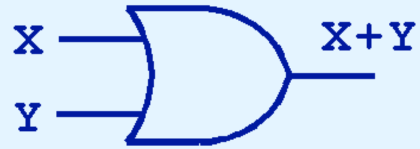
- Boolean functions are implemented in digital computer circuits called logic gates.
- A gate is an electronic device that produces a result based on two or more input values.
- In reality, gates consist of one to six transistors, but digital designers think of them as a single unit.
- Integrated circuits contain collections of gates suited to a particular purpose.

Logic Gates



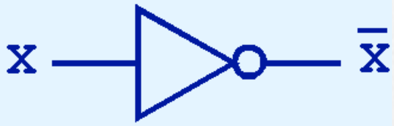
X AND Y

X	Y	XY
0	0	0
0	1	0
1	0	0
1	1	1



X OR Y

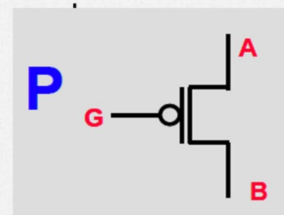
X	Y	X+Y
0	0	0
0	1	1
1	0	1
1	1	1



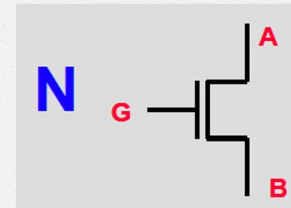
NOT X

X	$\overline{X}$
0	1
1	0

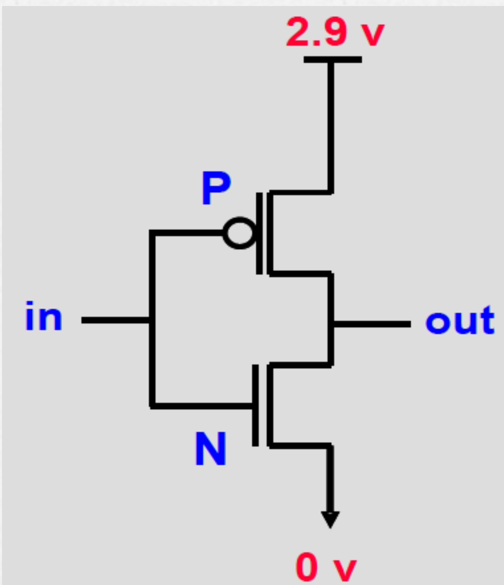
Inverter Gate (NOT)



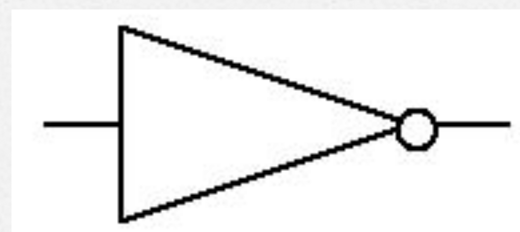
Open (insulating) if gate is "on" = 1
Closed (conducting) if gate is "off" = 0



Open if gate is "off" = 0
Closed if gate is "on" = 1

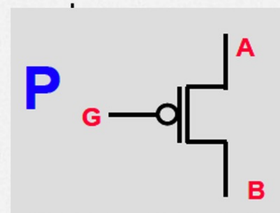


In	Out
0	1
1	0

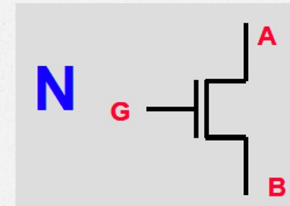


In = 0 (0 v) → N is open, P is closed → Out is 1 (2.9 v)

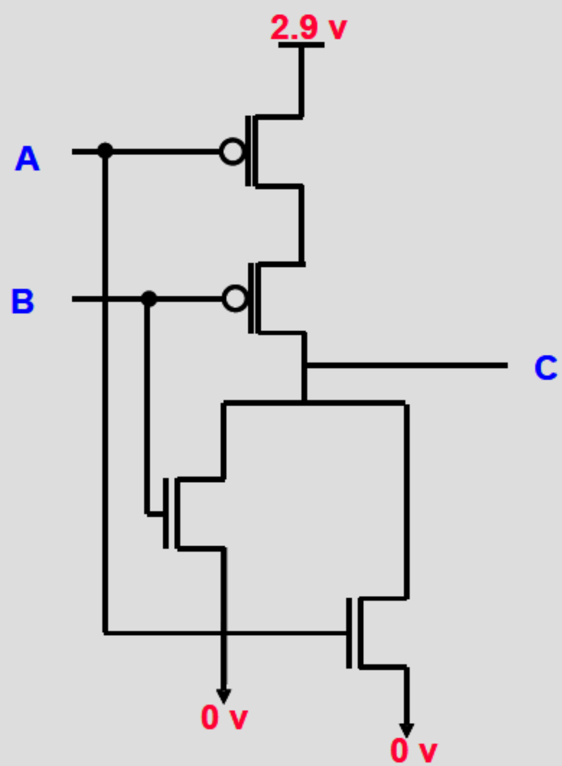
NOR Gate



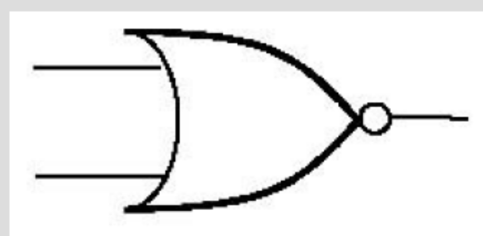
Open (insulating) if gate is “on” = 1
Closed (conducting) if gate is “off” = 0



Open if gate is “off” = 0
Closed if gate is “on” = 1

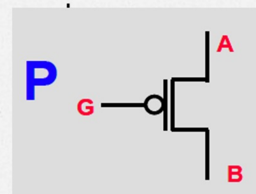


A	B	C
0	0	*1*
0	1	*0*
1	0	*0*
1	1	*0*

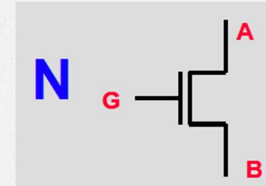


NOR

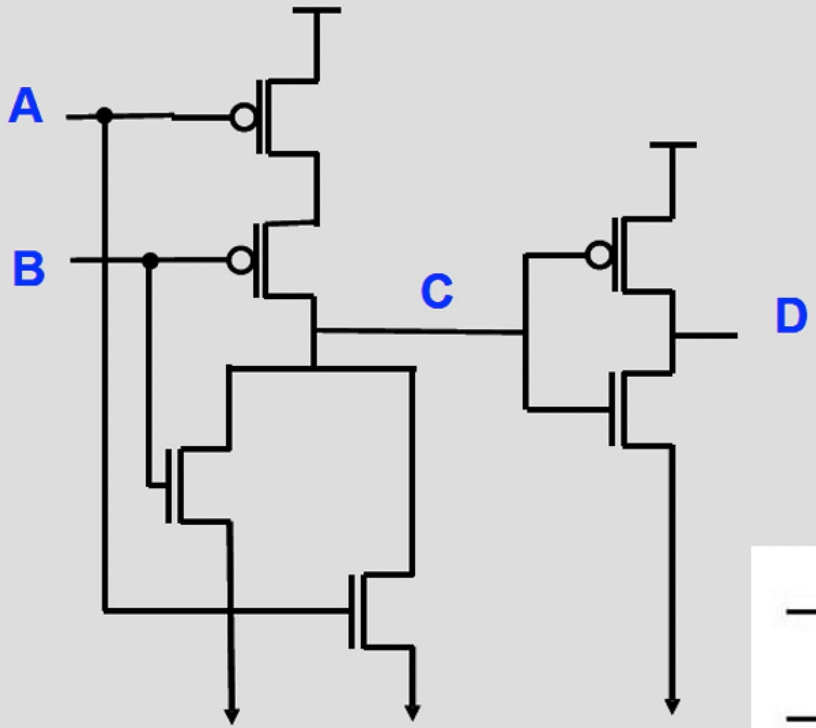
OR Gate



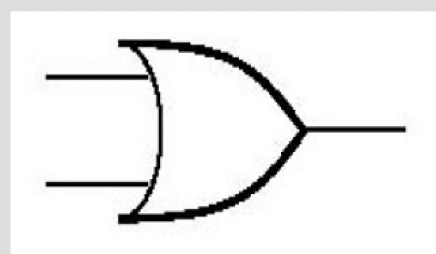
Open (insulating) if gate is "on" = 1
Closed (conducting) if gate is "off" = 0



Open if gate is "off" = 0
Closed if gate is "on" = 1

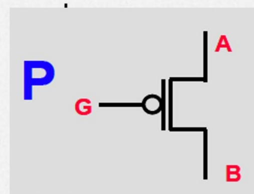


A	B	*C*	*D*
0	0	*1*	*0*
0	1	*0*	*1*
1	0	*0*	*1*
1	1	*0*	*1*

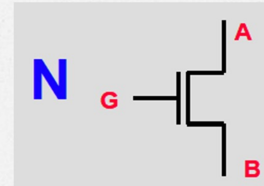


OR

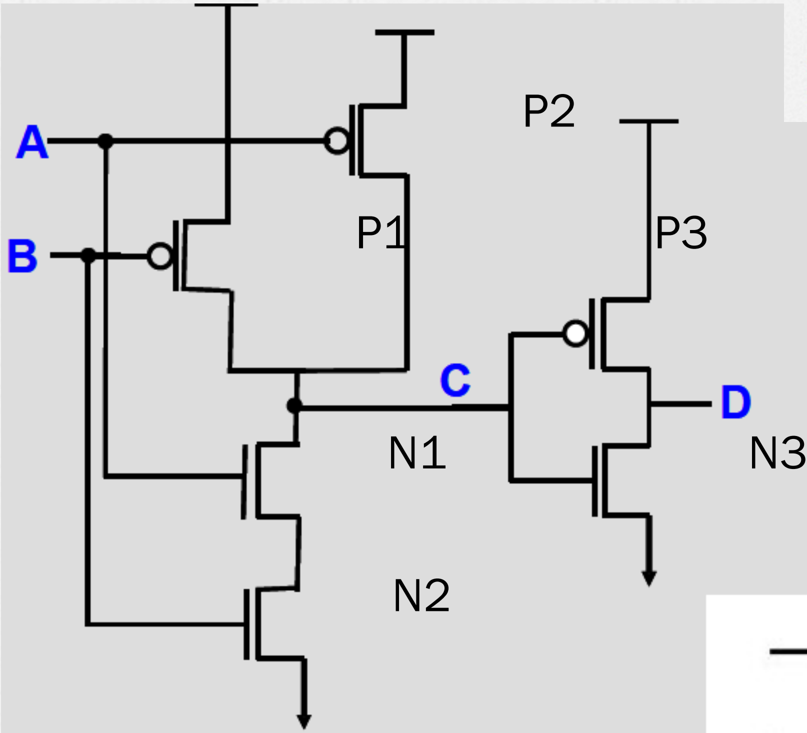
AND/NAND



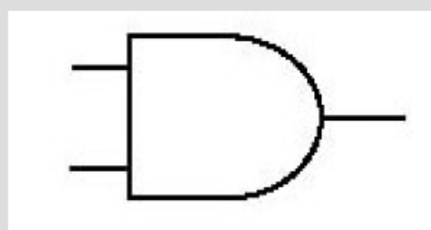
Open (insulating) if gate is “on” = 1
Closed (conducting) if gate is “off” = 0



Open if gate is “off” = 0
Closed if gate is “on” = 1



A	B	C	D
0	0	*1*	*0*
0	1	*1*	*0*
1	0	*1*	*0*
1	1	*0*	*1*



AND

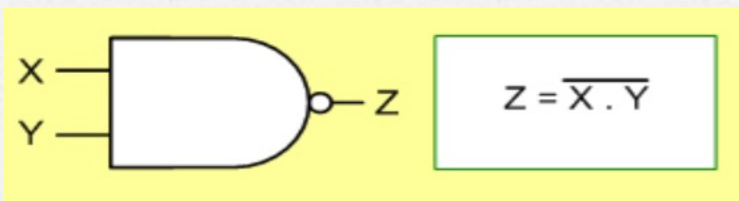
A = 0, B = 0 → N1, N2 open, P1, P2 close
→ C = 1→ P3 open, N3 close → D = 0

Universal Logical Gate

- A universal gate is a gate which can implement any Boolean function without need to use any other gate type.
- The NAND and NOR gates are universal gates.
- In practice, this is advantageous since NAND and NOR gates are economical and easier to fabricate and are the basic gates used in all IC digital logic families.

NAND

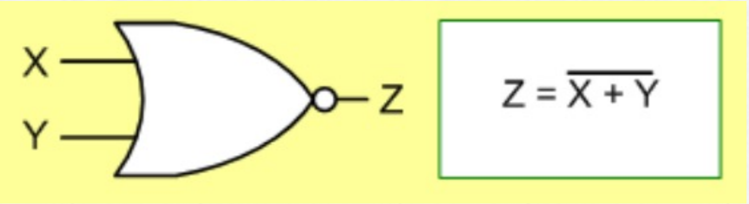
- Prove that NAND is a universal gate



X	Y	NAND
0	0	1
0	1	1
1	0	1
1	1	0

NOR

- Prove that NOR is a universal gate



X	Y	NOR
0	0	1
0	1	0
1	0	0
1	1	0

Summary

- Information can be represented by bits
- Binary arithmetic/operations can be done by Boolean algebra
- Electronic signals can represent bits
- Shannon found that Boolean logic can be implemented using electrical switches
- Transistors can switch electronic signals
- NAND and NOR are universal logical gates

What's Next

- How to use logic gates to build more complex and more powerful circuits