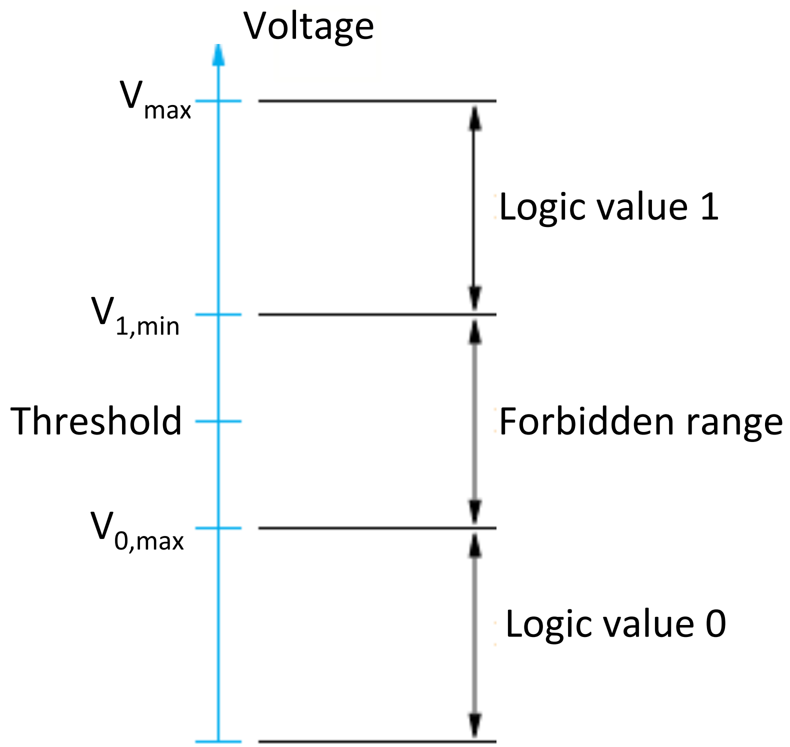
Gate Implementation

Logic variables have values of 1 and 0, or “high” and “low”

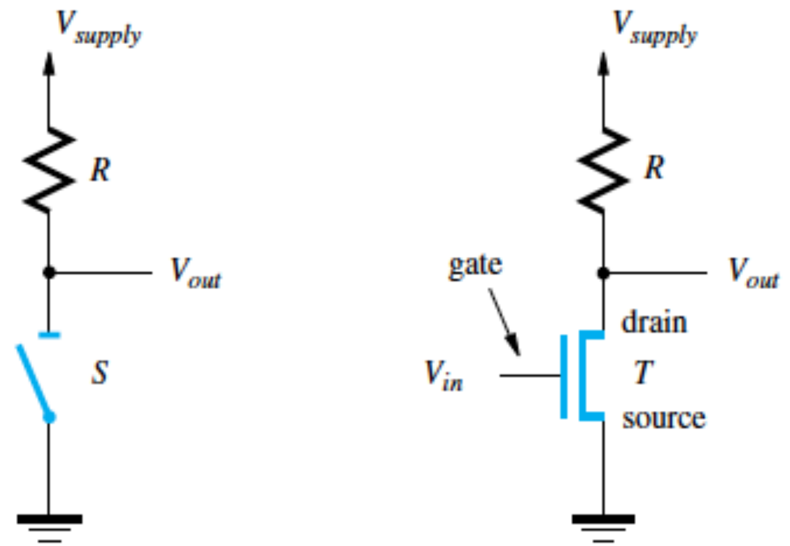
- Voltages or currents can represent logic variables
- Values above a given threshold represent one state (“on” or “off”)
- Values below the threshold represent the opposite state



Due to small random variations in the level (noise)

NOT Gate

Digital systems use transistors as switches



Acts as an inverter

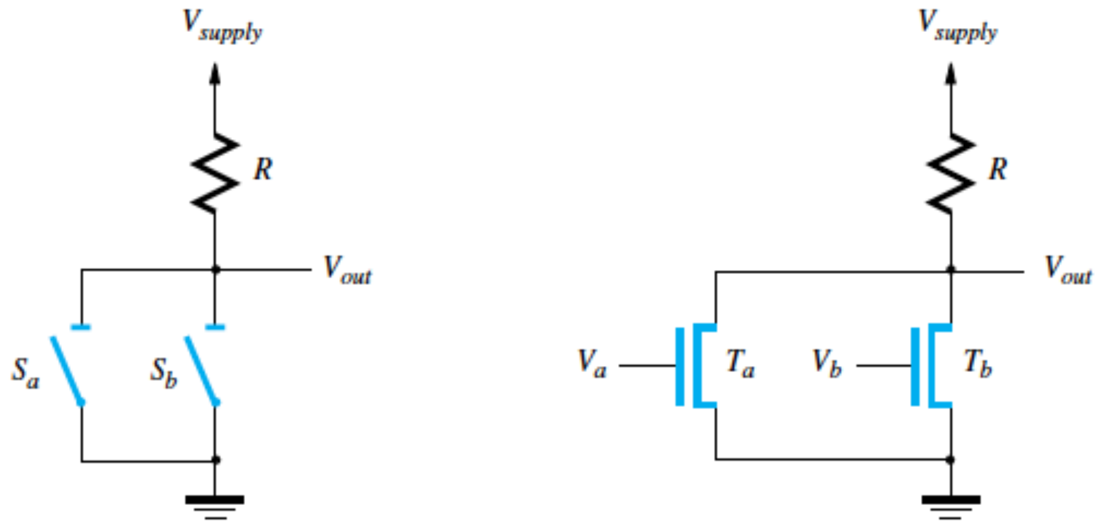
V_{out} = V_{supply} (1) when the switch is open

V_{out} = 0 when the switch is closed

Transistor act as an open switch when V_{in} = 0

Transistor act as a closed switch when V_{in} = 1

NOR Gate



Acts as NOR Gate

V_a	V_b	V_{out}
0	0	1
0	1	0
1	0	0
1	1	0

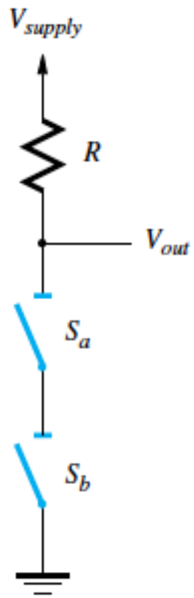
V_{out} = 0 when either switch is closed

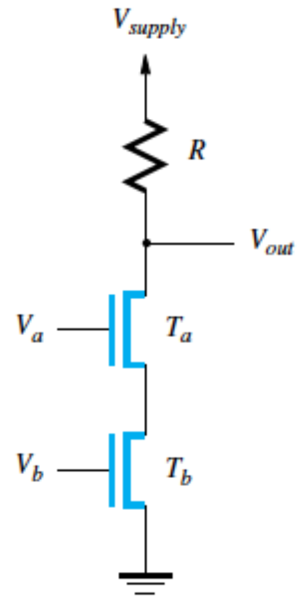
V_{out} = 1 when both switches are open

Transistor act as an open switch when V_{in} = 0

Transistor act as a closed switch when V_{in} = 1

NAND Gate





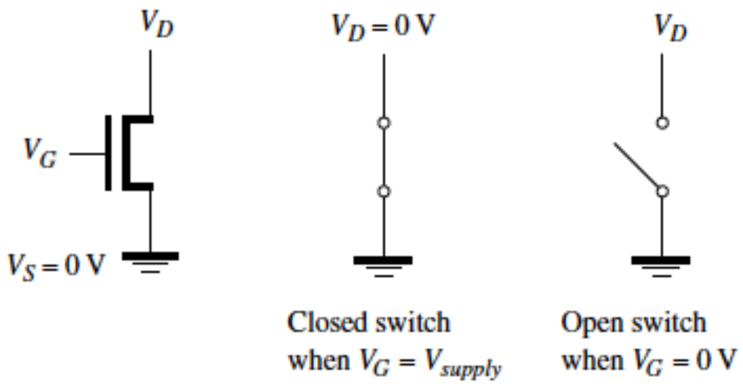
Acts as NAND Gate

V_a	V_b	V_{out}
0	0	1
0	1	1
1	0	1
1	1	0

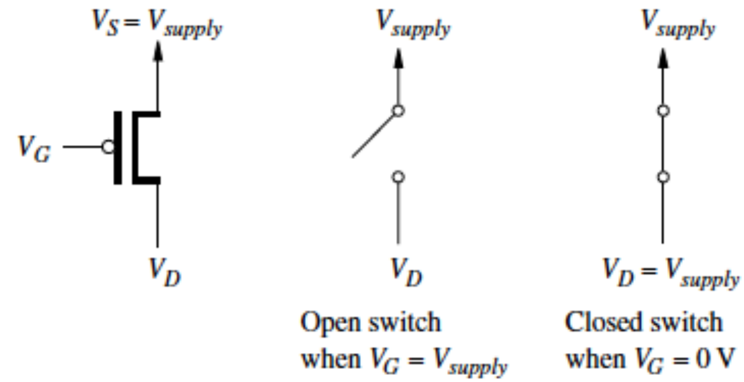
V_{out} = 1 when either switch is open
V_{out} = 0 when both switches are closed

AND and OR can be implemented from NAND and NOR gates
- Just use NOT gate to invert output of NAND or NOR gates
- So more transistors are required for AND and OR gates

NMOS & PMOS Circuits



NMOS Transistor



PMOS Transistor

Two types of metal-oxide semiconductor (MOS) are available

- NMOS-type behave as closed switch when the gate voltage is high
- PMOS-type behave as closed switch when the gate voltage is low
- Inversion bubble on input denotes PMOS

Source for NMOS transistor is connected to ground (0)

Source for PMOS transistor is connected to V_{supply} (1)

CMOS Circuits

When the switches are closed, current flows

- Power is consumed by current flowing through the resistor
- More heat results when more power is dissipated

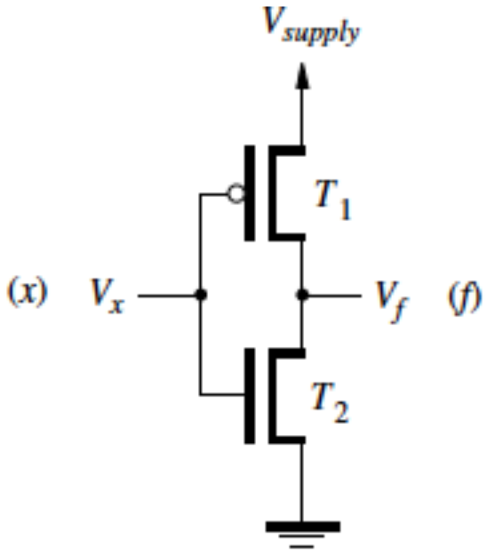
CMOS circuits combine NMOS and PMOS transistors

- CMOS means complementary metal-oxide semiconductor
- CMOS circuits consume less power

MOS transistors occupy a very small area on IC chips

- Billions can fit on a single integrated circuit (IC) chip
- Smaller transistors can switch at extremely high rates (GHz range)

CMOS NOT Gate



Circuit

(V_f = NOT V_x)

x	V_x	T_1 T_2	V_f	f
0	low	on off	high	1
1	high	off on	low	0

Truth table and transistor states

V_x=0 closes T_1 and opens T_2, pulling V_f up to V_{supply}

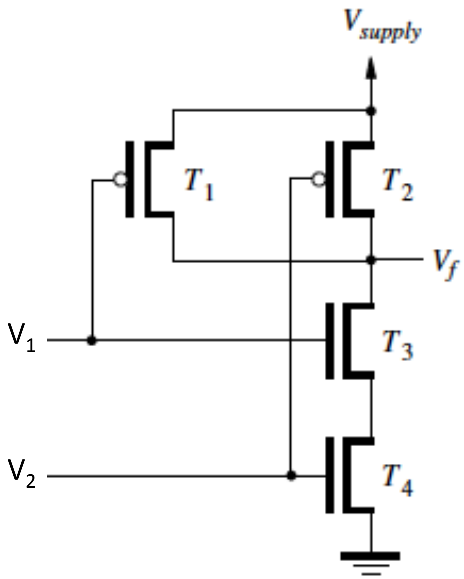
V_x=1 closes T_2 and opens T_1, pulling V_f down to 0

So V_f is the complement of V_x

T_1 and T_2 operate in a complementary fashion

CMOS NAND Gate

($V_f = V_1$ NAND V_2)



Circuit

V_1	V_2	T_1	T_2	T_3	T_4	f
0	0	on	on	off	off	1
0	1	on	off	off	on	1
1	0	off	on	on	off	1
1	1	off	off	on	on	0

Truth table and transistor states

- If T_1 or T_2 is closed V_f is pulled up to V_{supply}
  - $V_1 = 0$ closes T_1; $V_2 = 0$ closes T_2
- If T_3 and T_4 are closed V_f is pulled down to 0
  - $V_1 = 1$ closes T_1; $V_2 = 1$ closes T_2
- Dissipates power only when switching