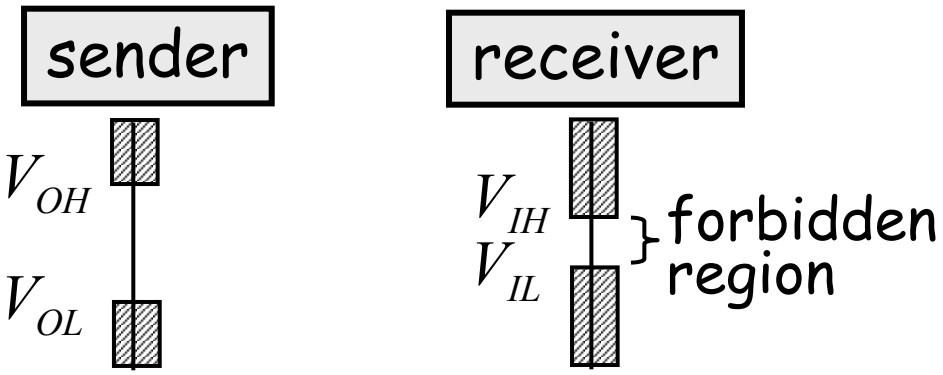
6.002 CIRCUITS AND ELECTRONICS

Inside the Digital Gate

Review

The Digital Abstraction

- Discretize value 0, 1
- Static discipline
  meet voltage thresholds

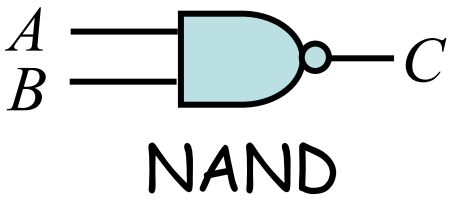


Specifies how gates must be designed

Review

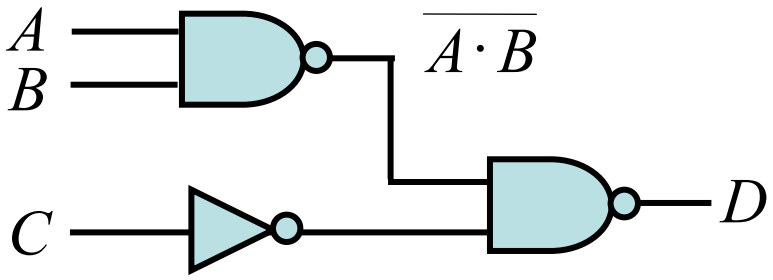
Combinational gate abstraction

- ➡ outputs function of input alone
- ➡ satisfies static discipline



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

For example: a digital circuit



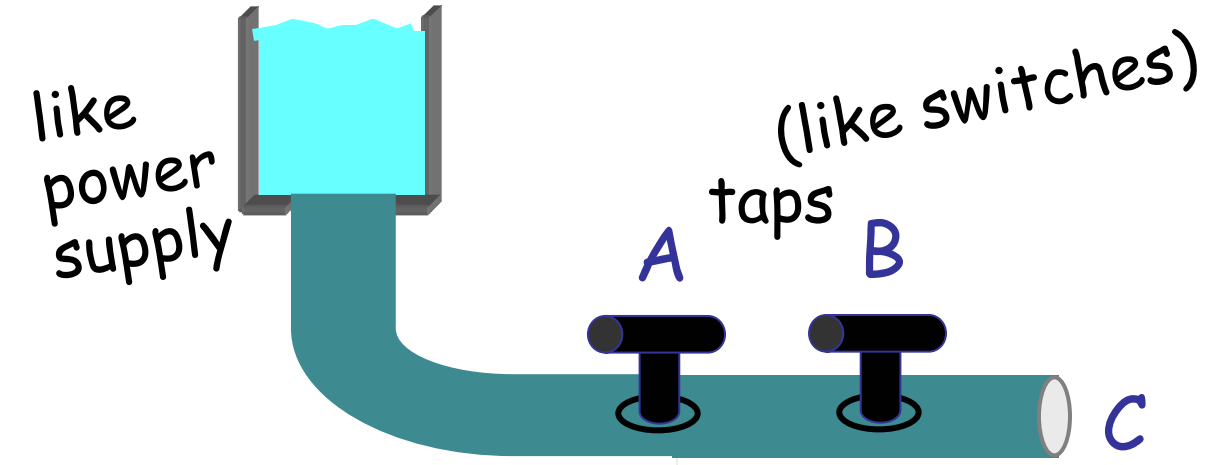
$$D = \overline{(\overline{C} \cdot (\overline{A \cdot B}))}$$

3 gates here

- A Pentium III class microprocessor is a circuit with over 4 million gates!!
- The RAW chip being built at the Lab for Computer Science at MIT has about 3 million gates.

How to build a digital gate

Analogy

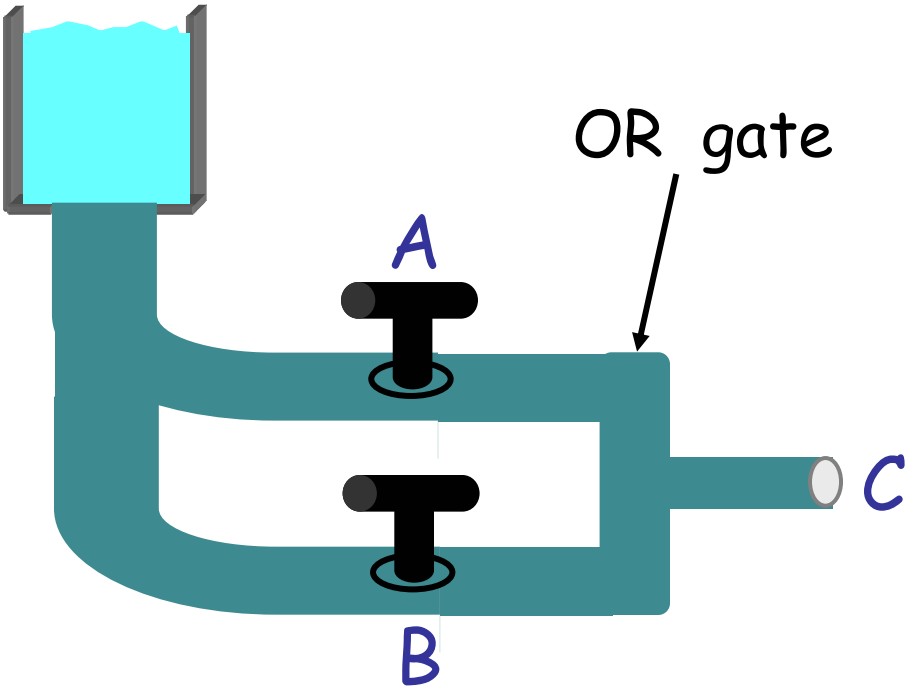


if A=ON AND B=ON
C has H_2O

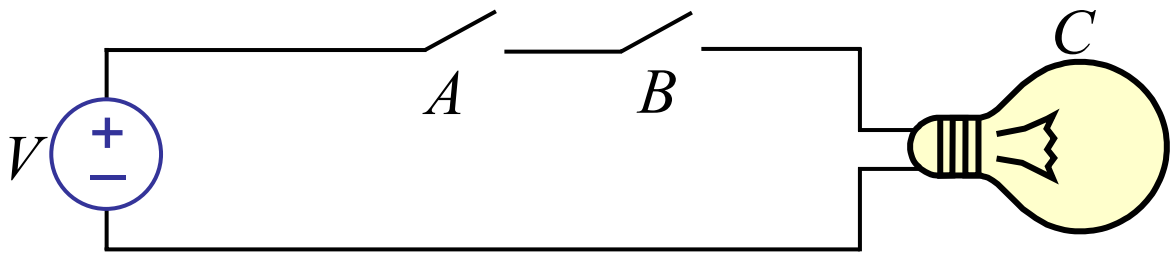
else
C has no H_2O

Use this insight to build an AND gate.

How to build a digital gate



Electrical Analogy



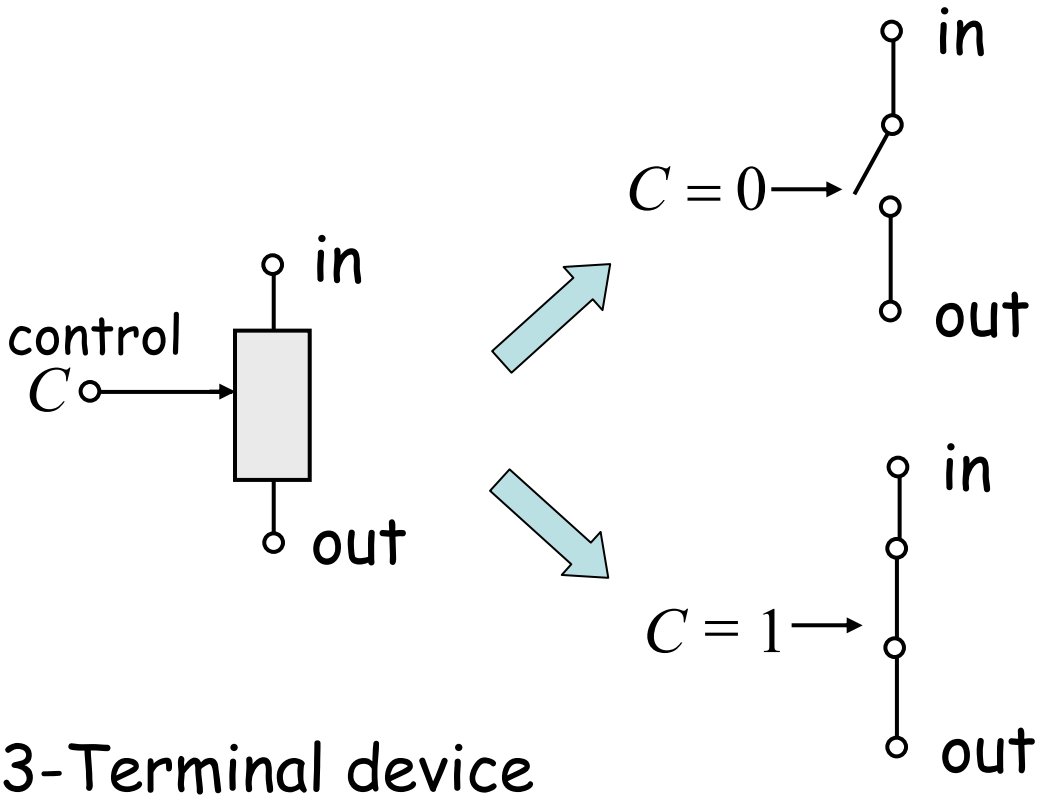
Bulb C is ON if A AND B are ON, else C is off

Key: "switch" device

Electrical Analogy

Key: "switch" device

equivalent ckt



3-Terminal device
if C = 0

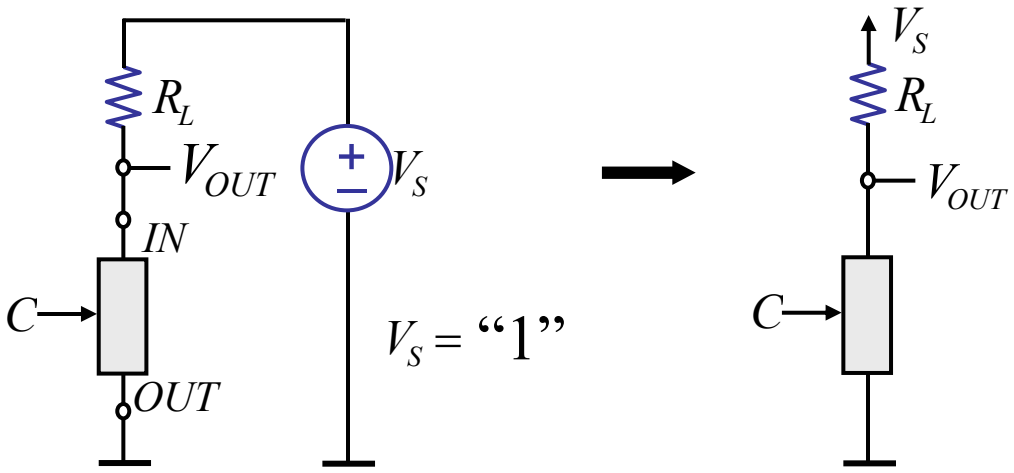
short circuit between in and out

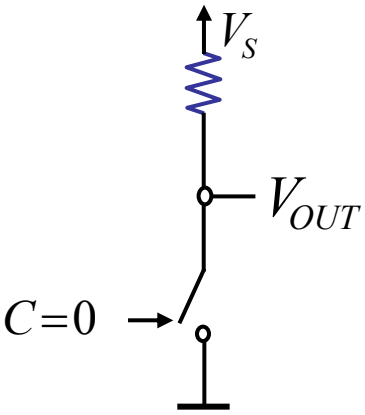
else

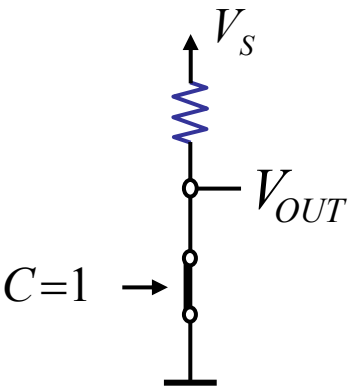
open circuit between in and out

For mechanical switch,
control ⟶ mechanical pressure

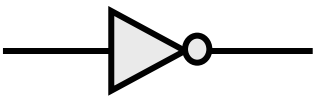
Consider





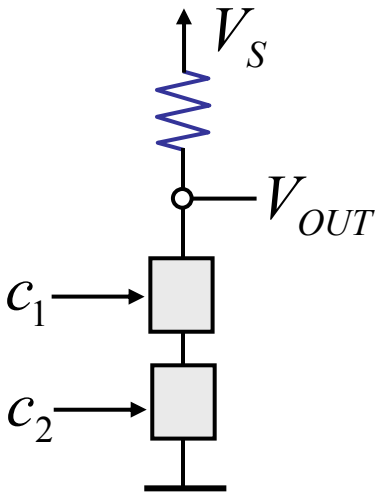


Truth table for

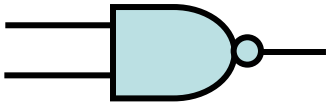


C	V_{OUT}
0	1
1	0

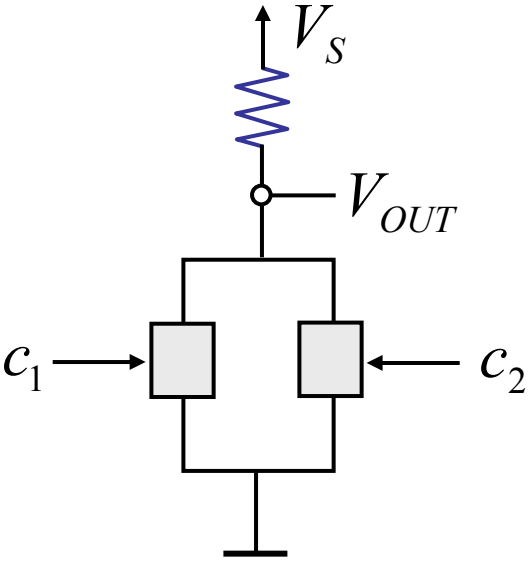
What about?



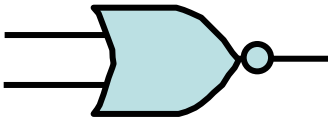
Truth table for



c_1	c_2	V_O
0	0	1
0	1	1
1	0	1
1	1	0



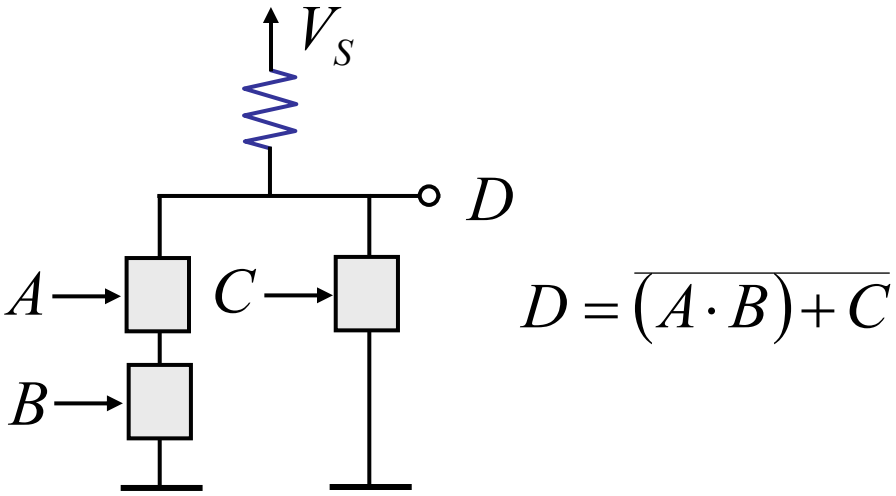
Truth table for



c_1	c_2	V_O
0	0	1
0	1	0
1	0	0
1	1	0

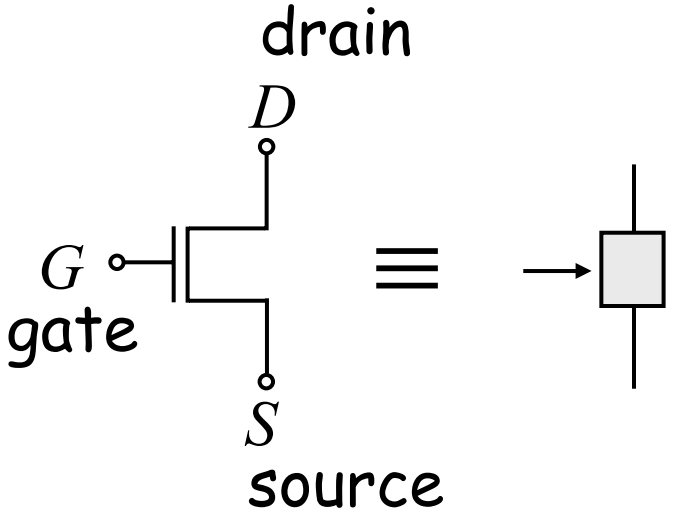
What about?

can also build compound gates



The MOSFET Device

Metal-Oxide Semiconductor Field-Effect Transistor



3 terminal lumped element behaves like a switch

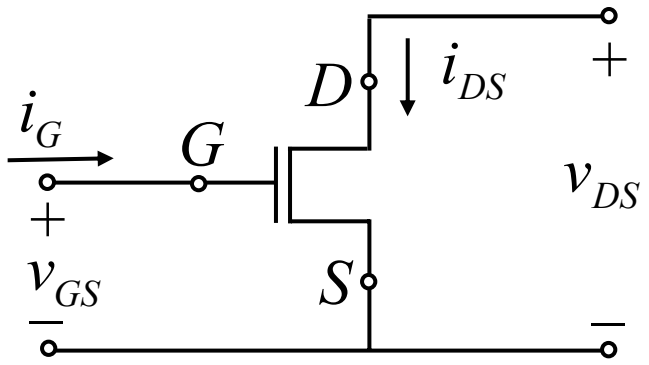
G : control terminal

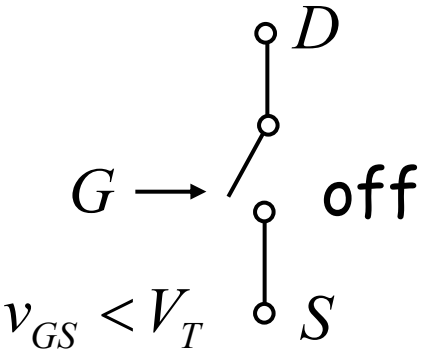
D, S : behave in a symmetric manner (for our needs)

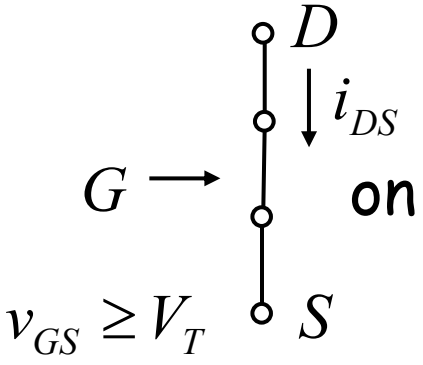
The MOSFET Device

Understand its operation by viewing it as a two-port element —

Check out the textbook for its internal structure.



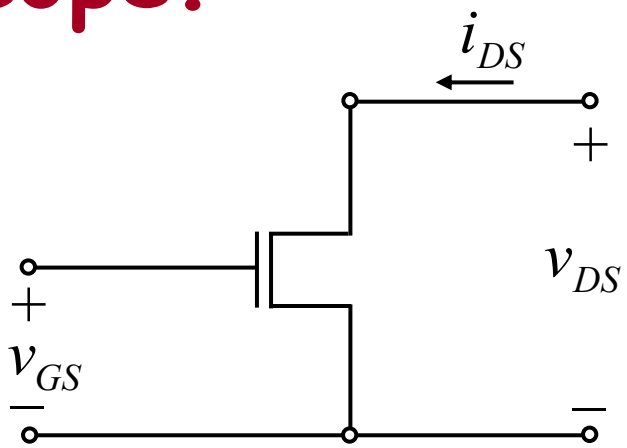


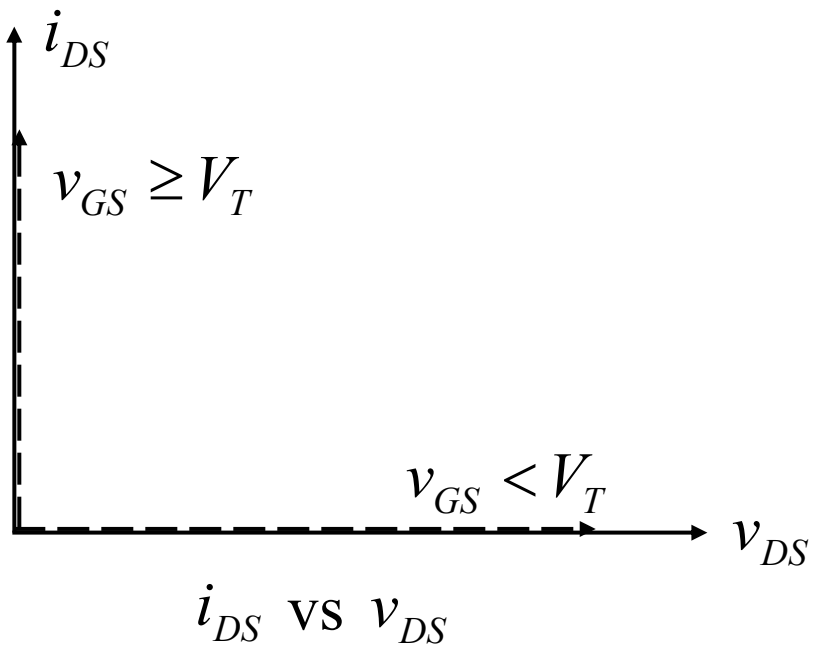


$V_T \approx 1V$ typically

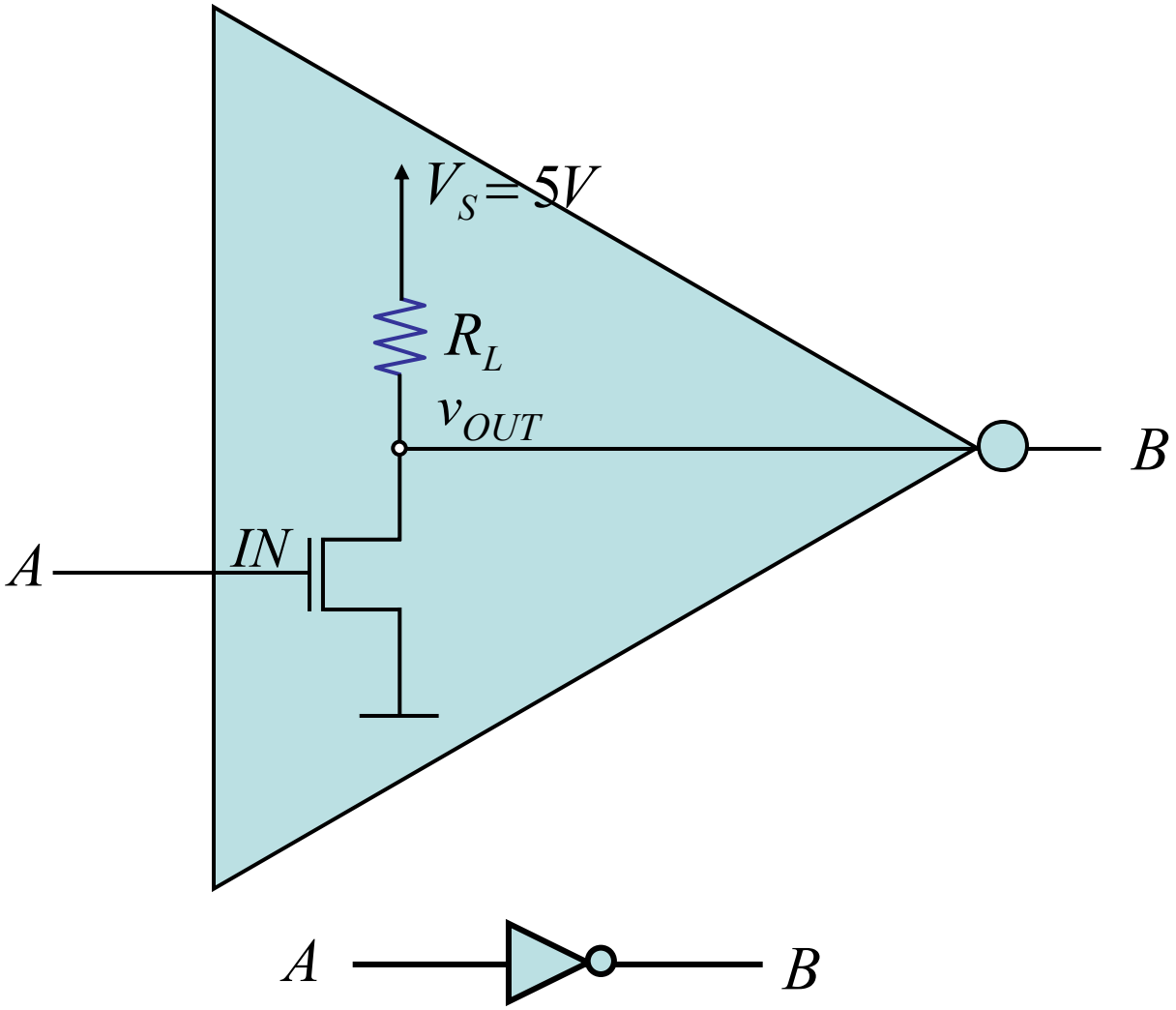
"Switch" model (S model) of the MOSFET

Check the MOS device on a scope.





A MOSFET Inverter

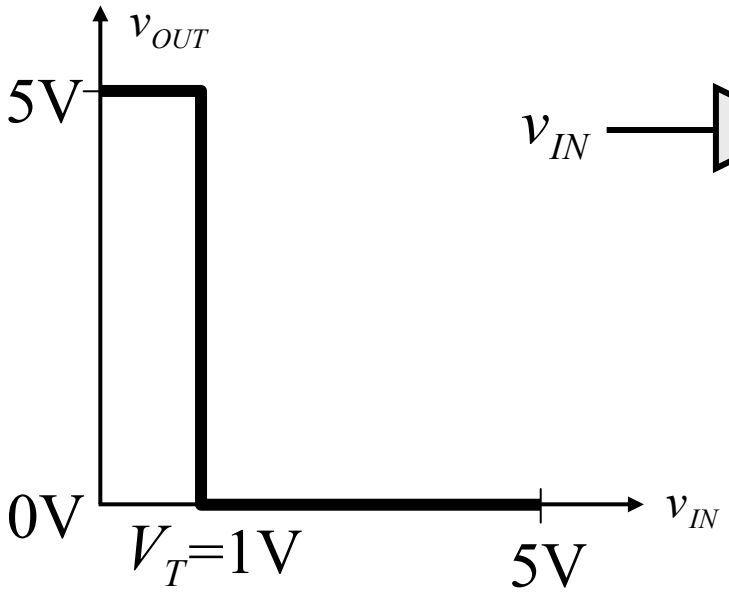


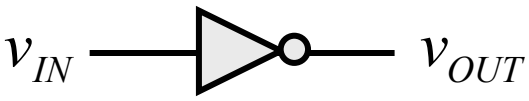
Note the power of abstraction.

The abstract inverter gate representation hides the internal details such as power supply connections, R_L, GND, etc.

(When we build digital circuits, the ↑ and ⊥ are common across all gates!)

Example

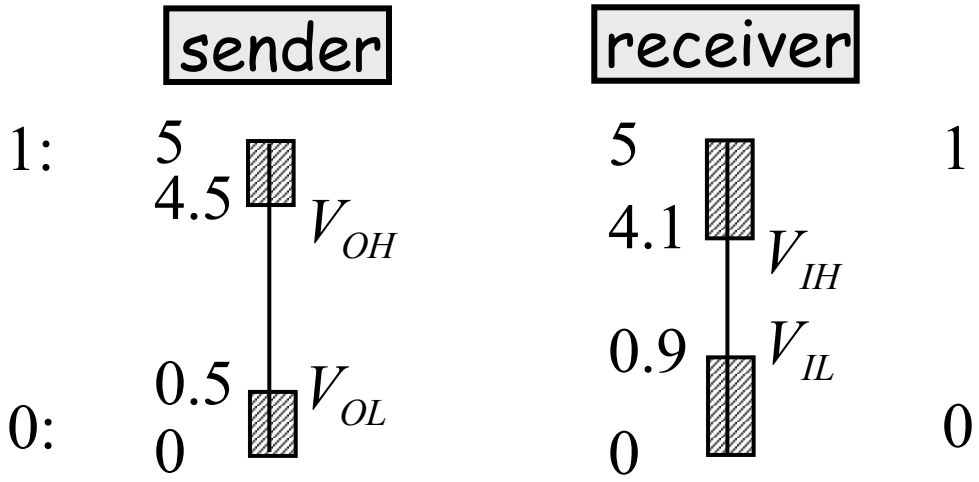




The T1000 model laptop desires gates that satisfy the static discipline with voltage thresholds. Does out inverter qualify?

$$V_{OL} = 0.5\text{V} \qquad V_{IL} = 0.9\text{V}$$

$$V_{OH} = 4.5\text{V} \qquad V_{IH} = 4.1\text{V}$$



Our inverter satisfies this.

E.g.:

Does our inverter satisfy the static discipline for these thresholds:

$V_{OL} = 0.2\text{V}$ $V_{IL} = 0.5\text{V}$

$V_{OH} = 4.8\text{V}$ $V_{IH} = 4.5\text{V}$ } yes

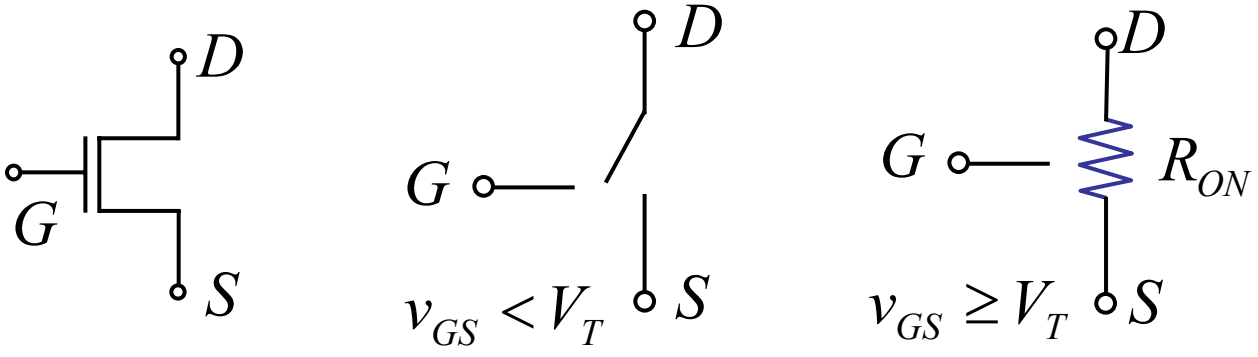
X

$V_{OL} = 0.5\text{V}$ $V_{IL} = 1.5\text{V}$

$V_{OH} = 4.5\text{V}$ $V_{IH} = 3.5\text{V}$ } no

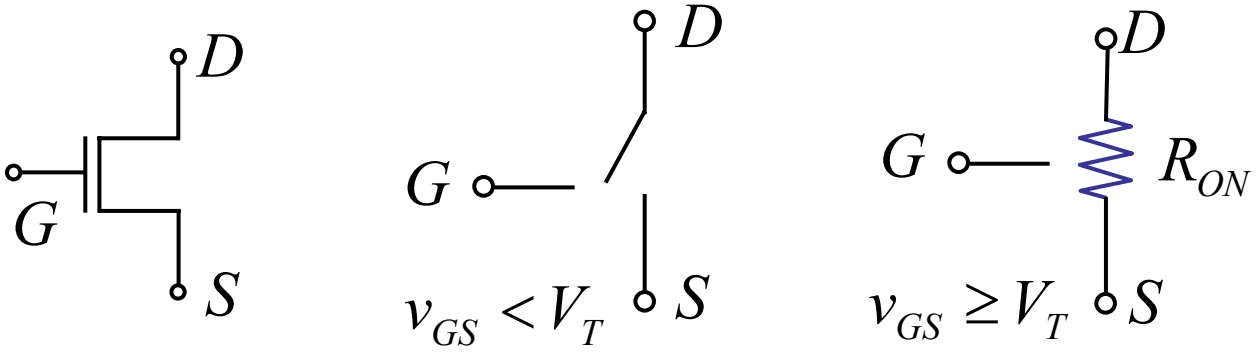
Switch resistor (SR) model of MOSFET

...more accurate MOS model

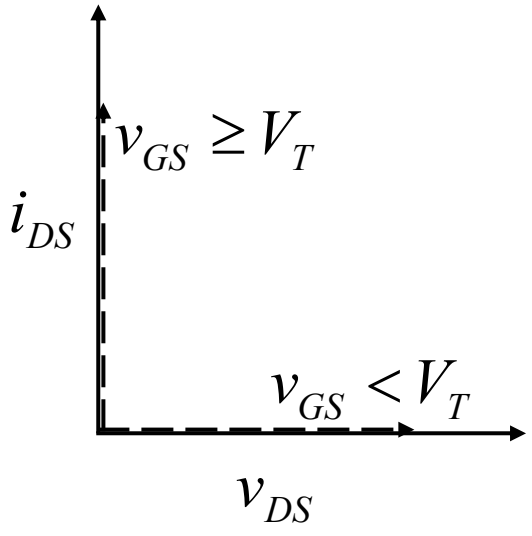


e.g. $R_{ON} = 5K\Omega$

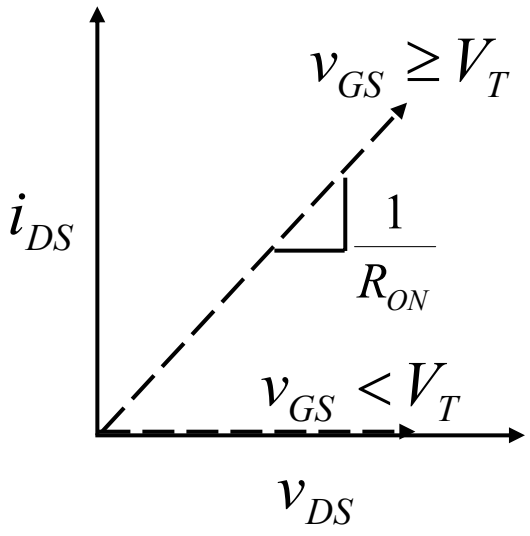
SR Model of MOSFET



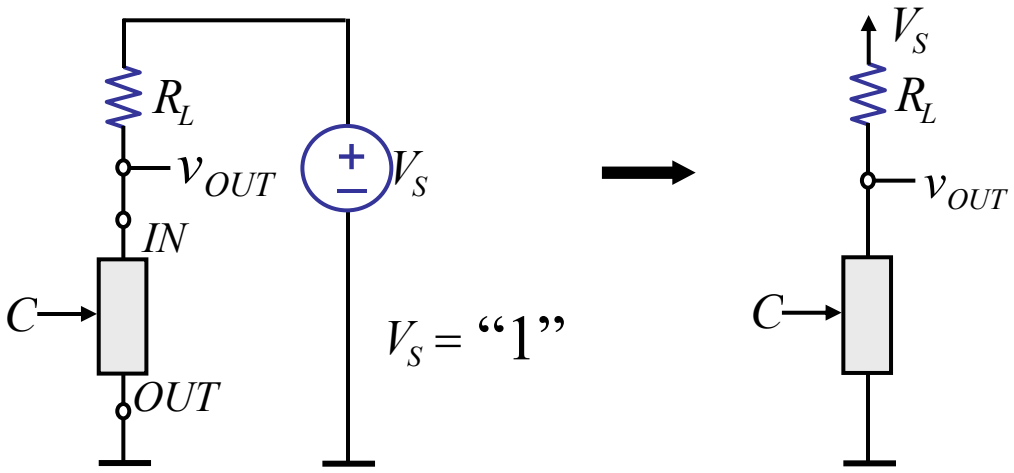
MOSFET
S model

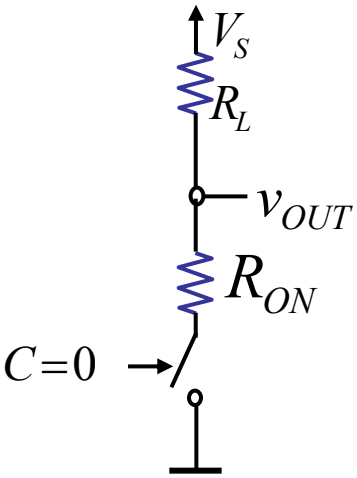


MOSFET
SR model

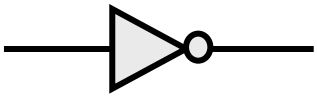


Using the SR model

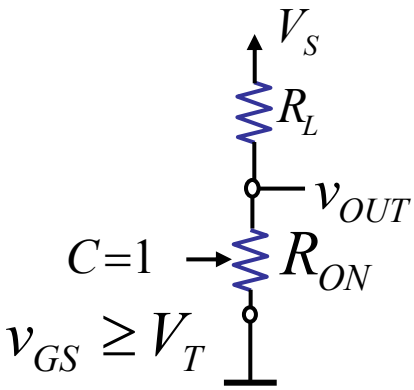




Truth table for



C	V_{OUT}
0	1
1	0



Choose R_L, R_{ON}, V_S such that:

$$v_{OUT} = \frac{V_S R_{ON}}{R_{ON} + R_L} \leq V_{OL}$$