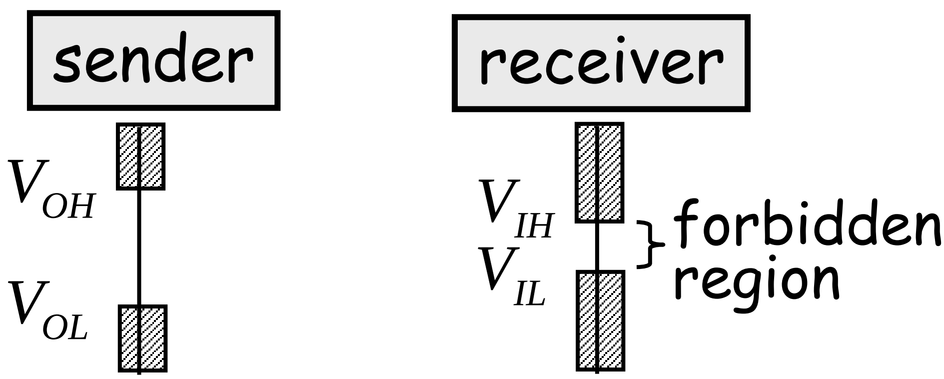
Inside the Digital Gate

Review

The Digital Abstraction

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

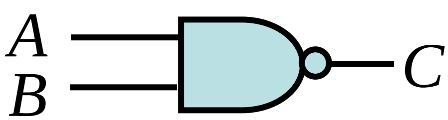


Specifies how gates must be designed

Review

Combinational gate abstraction

- outputs function of input alone
- satisfies static discipline

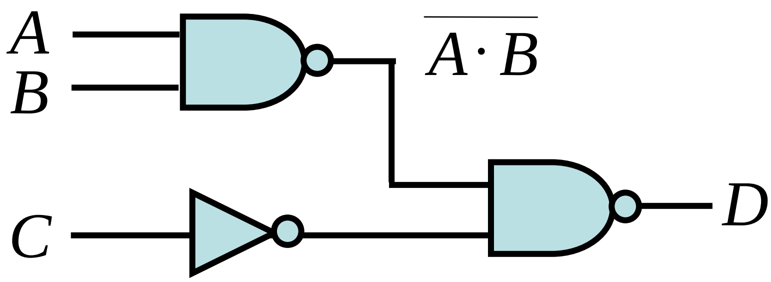


NAND

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

For example: a digital circuit

Demo



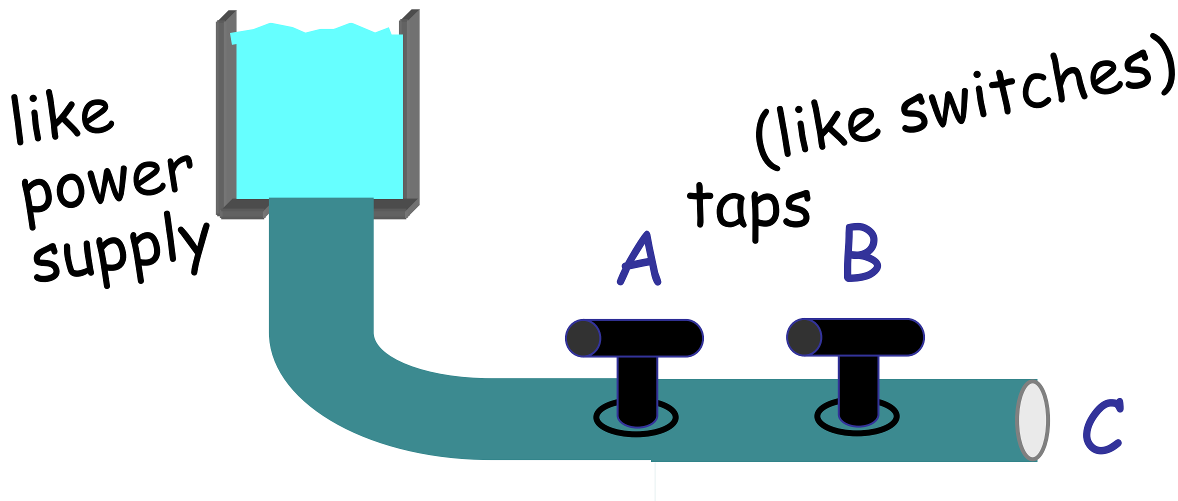
$$D = \overline{\left(\overline{C} \cdot \left(\overline{A \cdot B}\right)\right)}$$

3 gates here

- A Pentium III class microprocessor is a circuit with over 4 million gates!!
- The RAW chip (http://www.cag.lcs.mit.edu/raw) being built at the Lab for Computer Science at MIT has about 3 million gates.

How to build a digital gate

Analogy



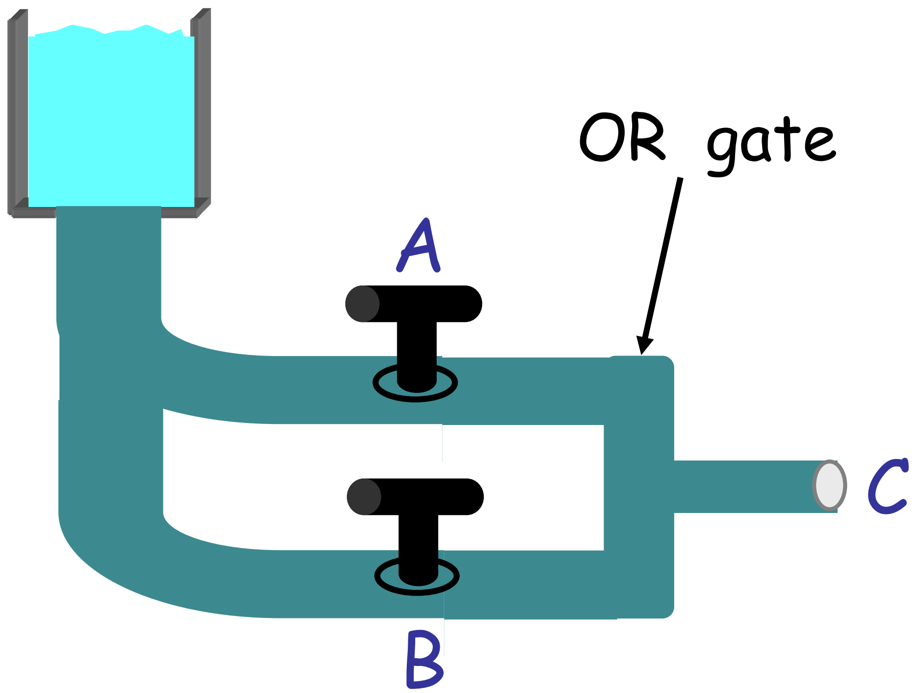
if A=ON AND B=ON

C has H_2O

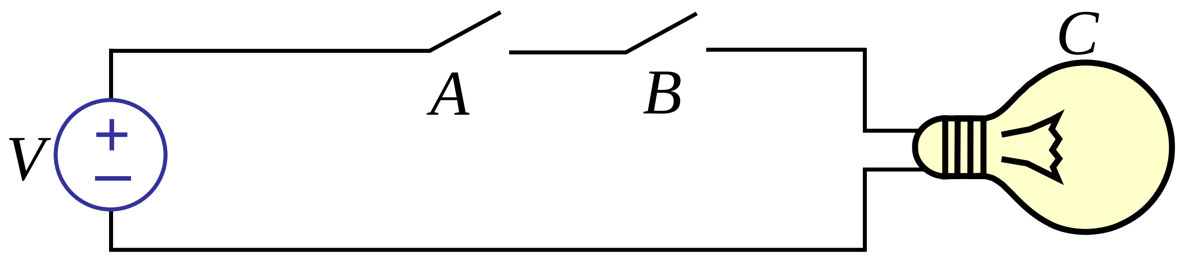
else C has no H_2O

Use this insight to build an AND gate.

How to build a digital gate



Electrical Analogy

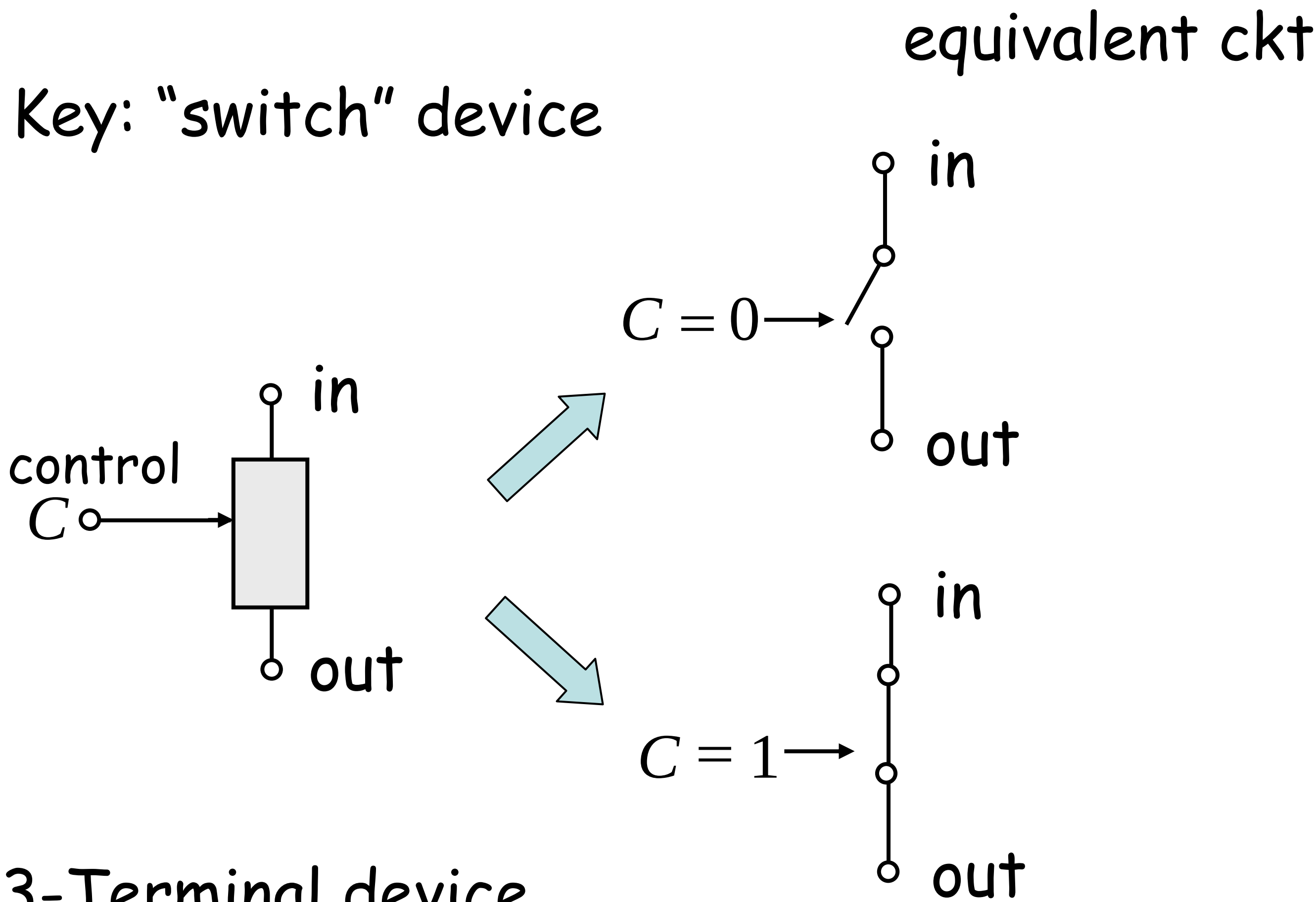


Bulb C is ON if A AND B are ON,
else C is off

Key: “switch” device

Electrical Analogy

Key: "switch" device



3-Terminal device
if $C = 0$

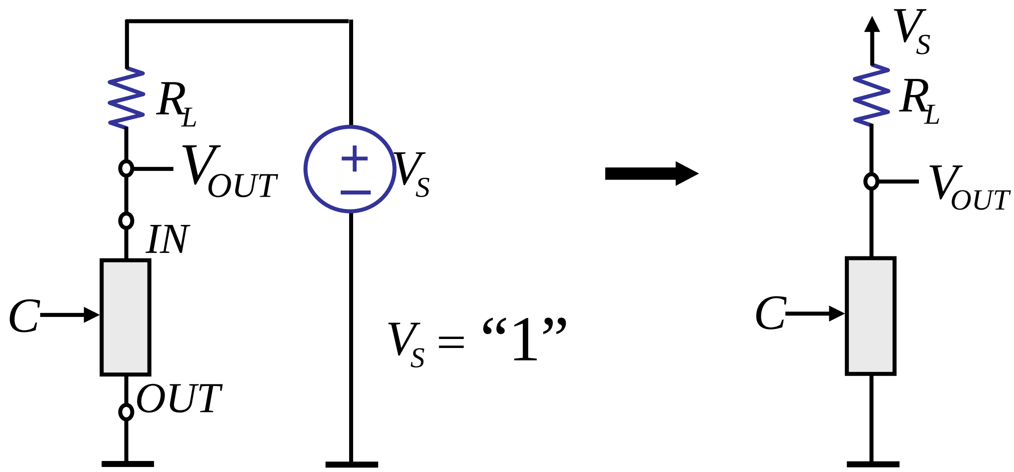
short circuit between in and out

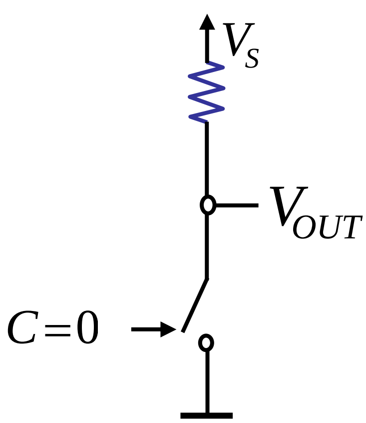
else

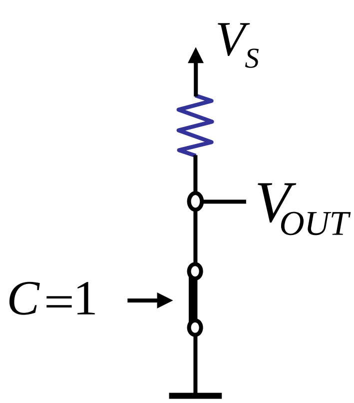
open circuit between in and out

For mechanical switch,
control ➡ mechanical pressure

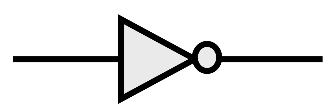
Consider





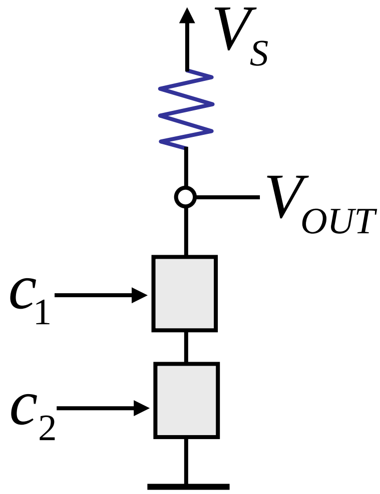


Truth table for

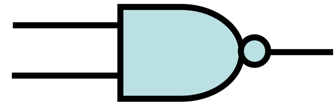


C	V_{OUT}
0	1
1	0

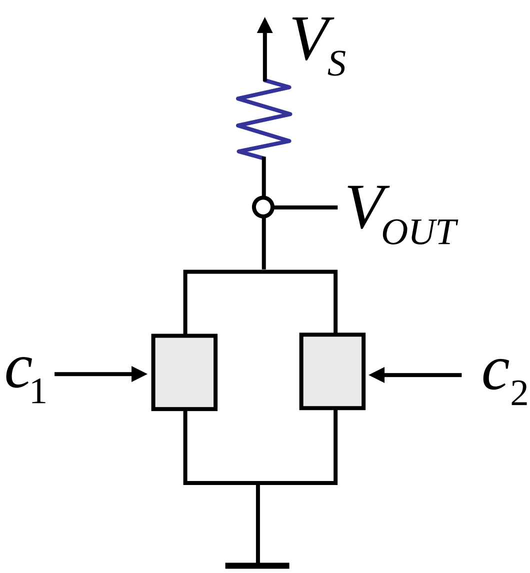
What about?



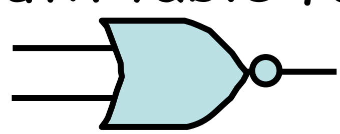
Truth table for



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



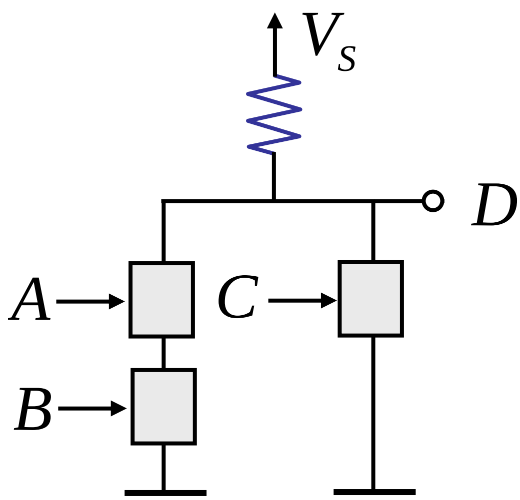
Truth table for



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

What about?

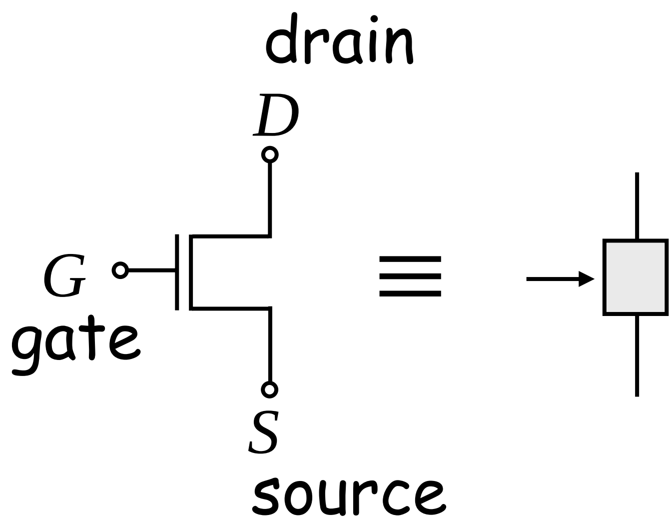
can also build compound gates



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

The MOSFET Device

Metal-Oxide
Semiconductor
Field-Effect
Transistor



3 terminal lumped element
behaves like a switch

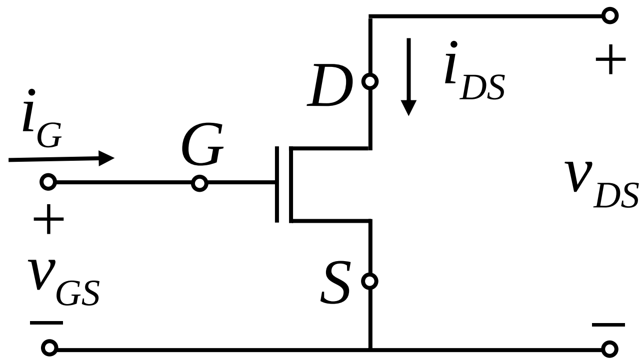
G : control terminal

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.

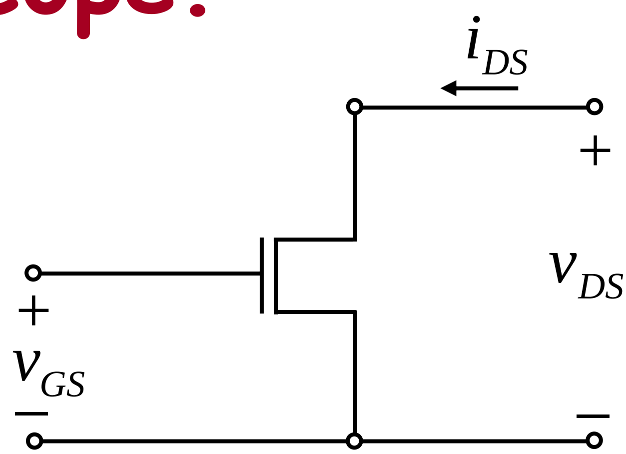


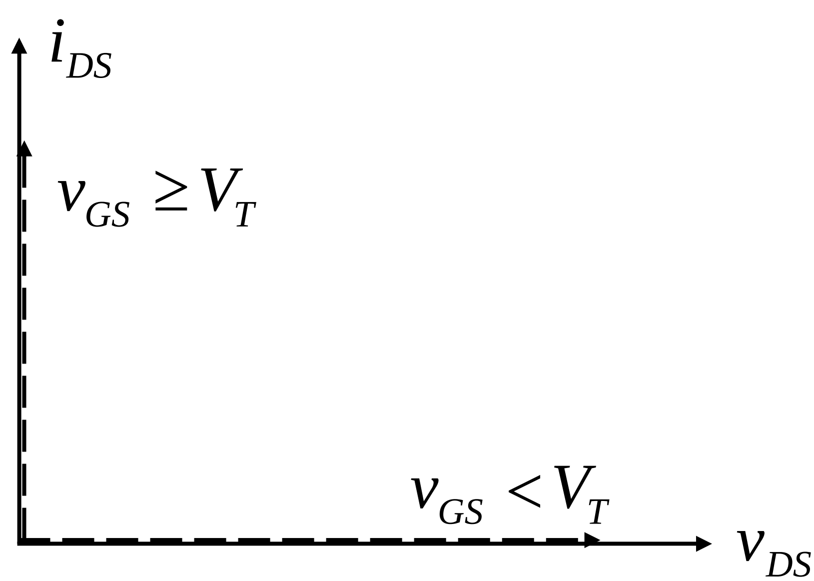
$V_T \approx 1V$ typically

"Switch" model (S model) of the MOSFET

Demo

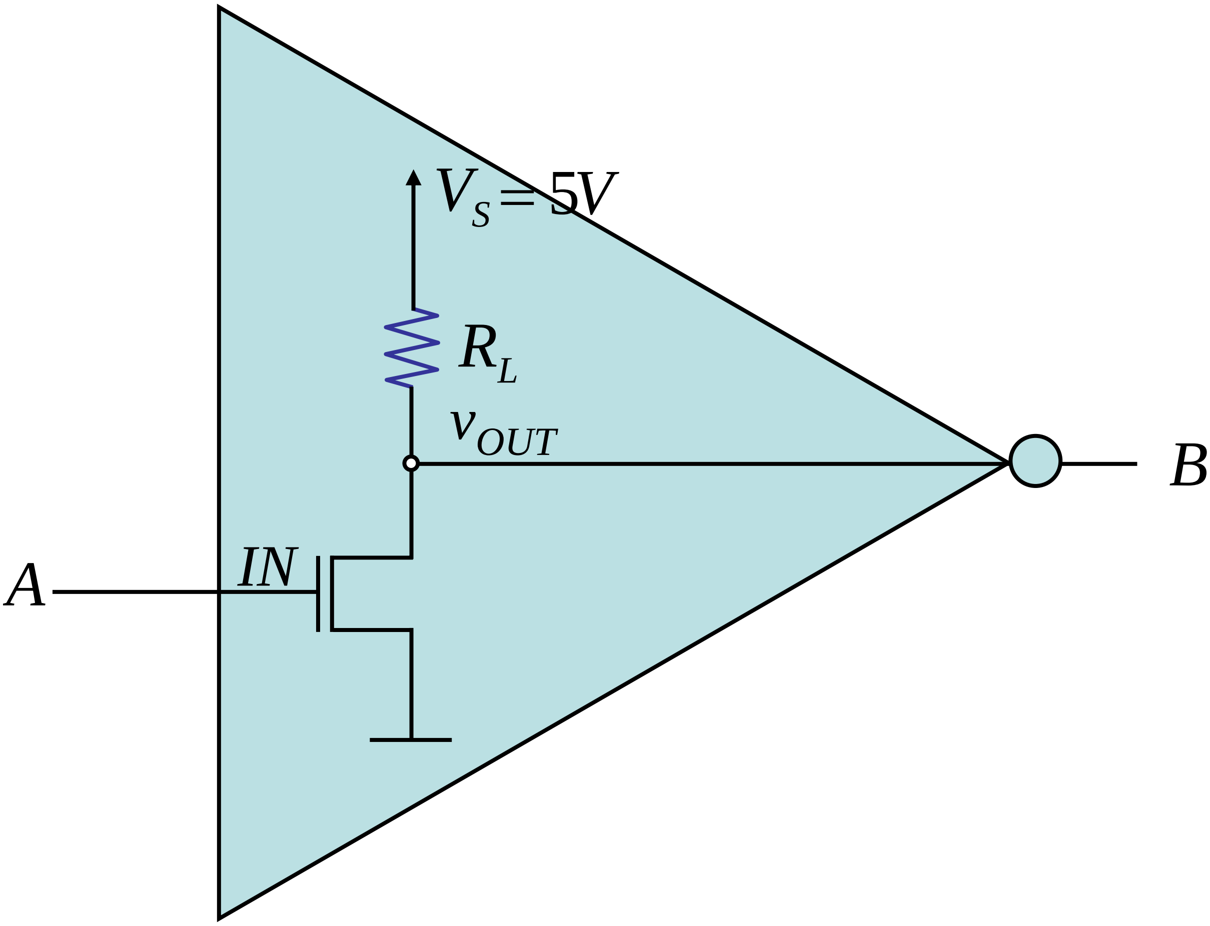
Check the MOS device on a scope.

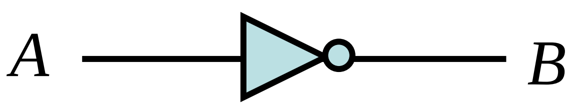




i_{DS} vs v_{DS}

A MOSFET Inverter



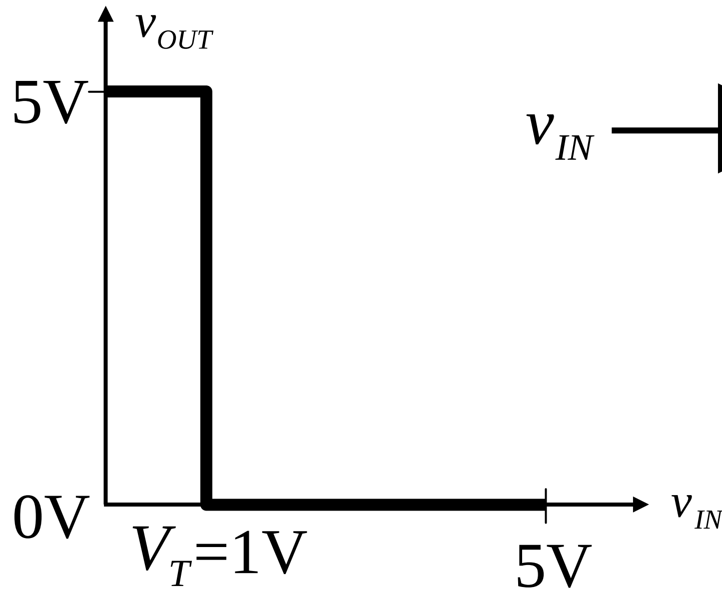


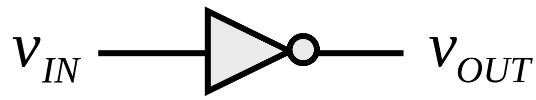
Note the power of abstraction.

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

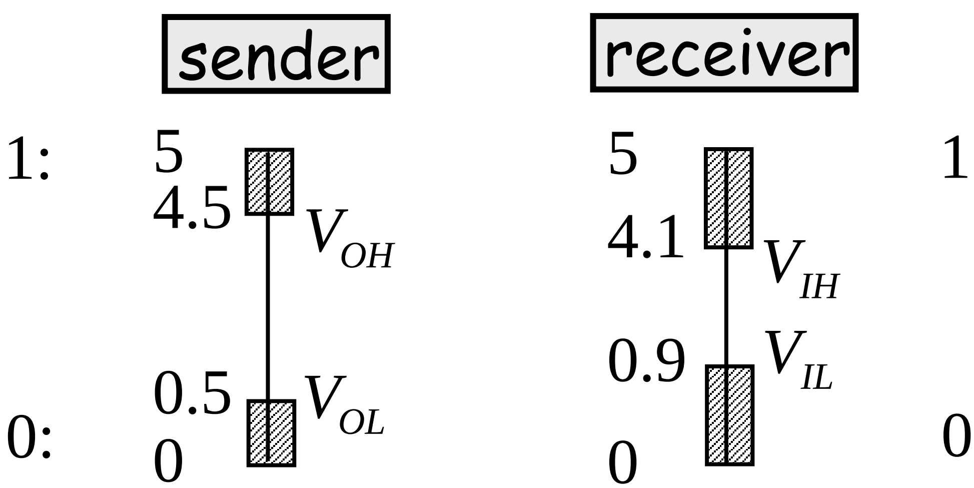




The T1000 model laptop desires gates that satisfy the static discipline with voltage thresholds. Does out inverter qualify?

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

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



Our inverter satisfies this.

E.g.:

Does our inverter satisfy the static discipline for these thresholds:

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

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

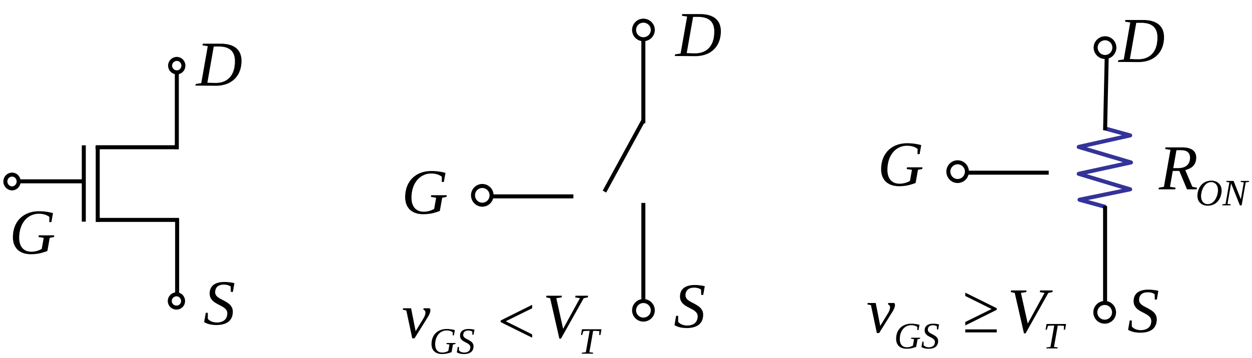
✗

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

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

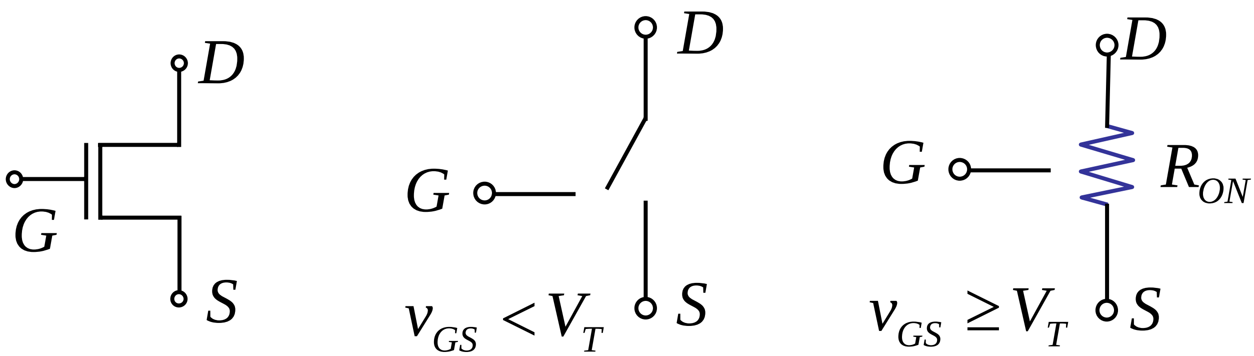
Switch resistor (SR) model of MOSFET

…more accurate MOS model

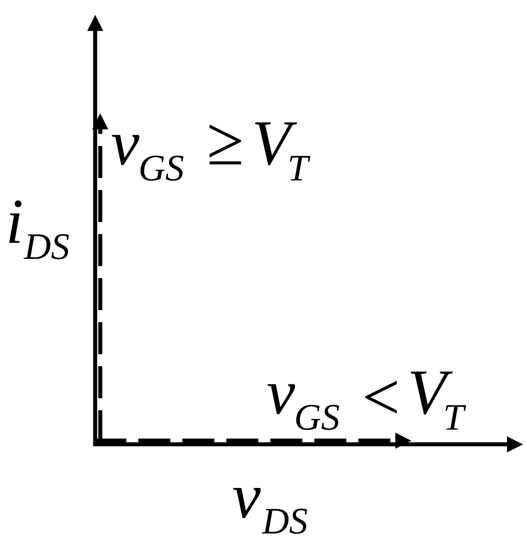


e.g. $R_{ON} = 5K\Omega$

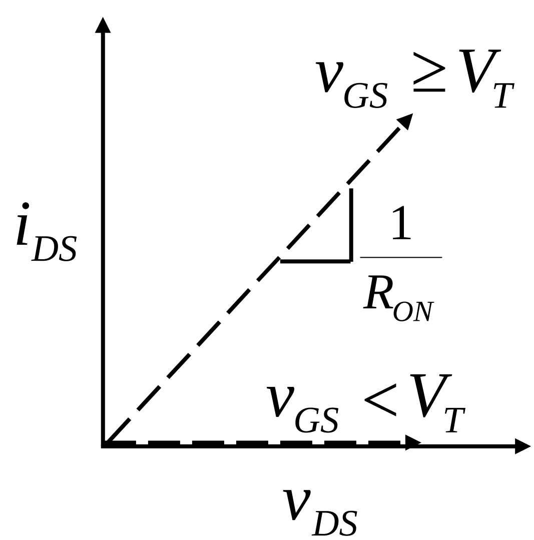
SR Model of MOSFET



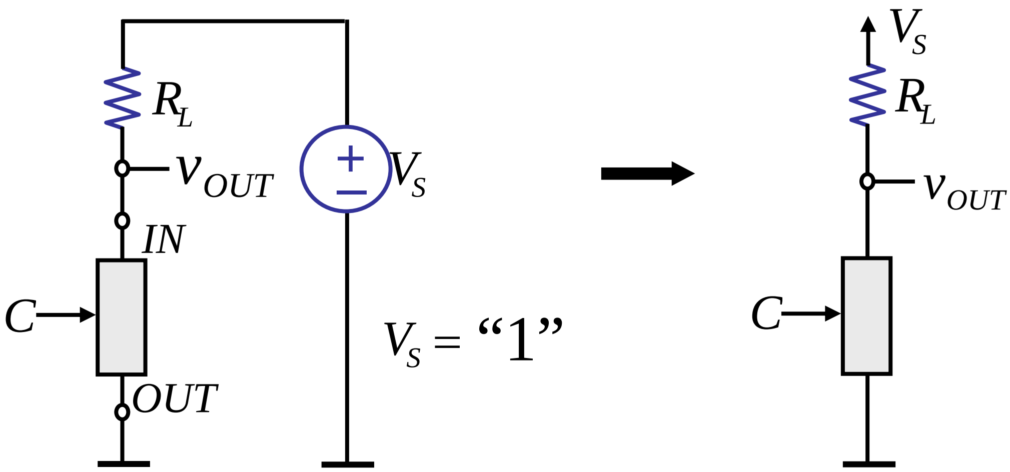
MOSFET
S model

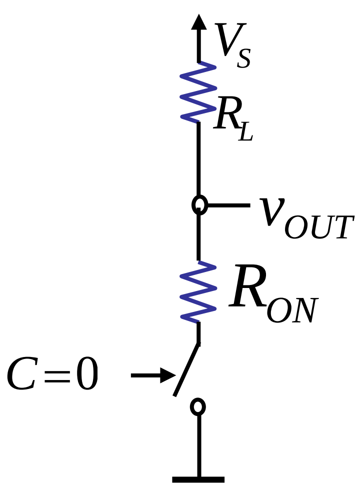


MOSFET
SR model

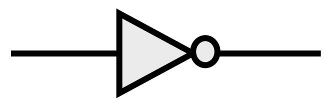


Using the SR model

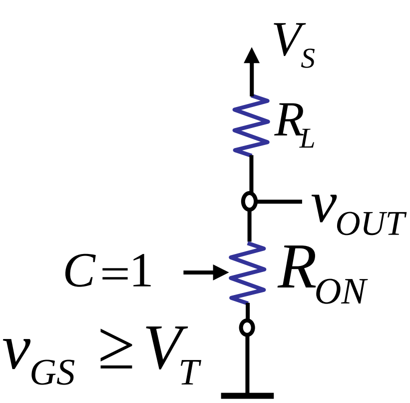




Truth table for



C	V_{OUT}
0	1
1	0



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

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