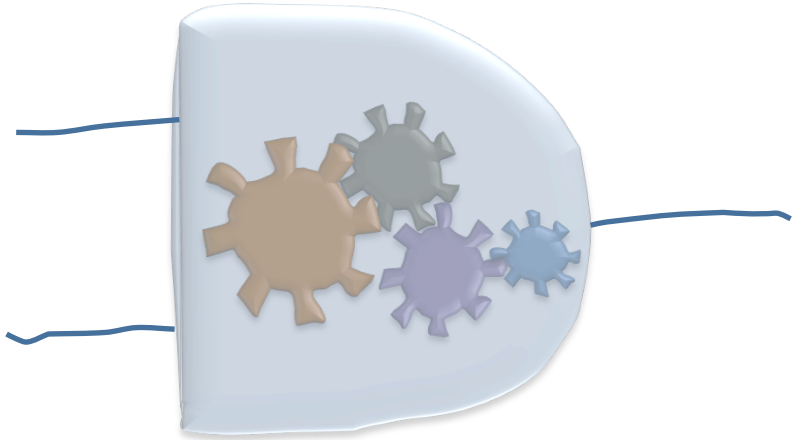
6.002x CIRCUITS AND ELECTRONICS

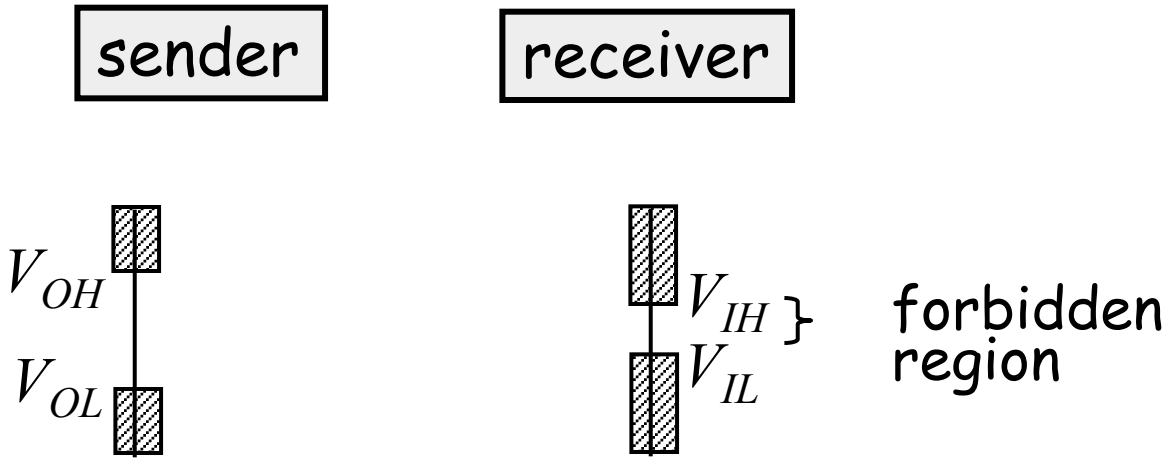
Inside the Digital Gate



Reading: Chapter 6 of A&L

Review The Digital Abstraction

- Discretize value: 0, 1
- Static discipline -- digital devices meet voltage thresholds

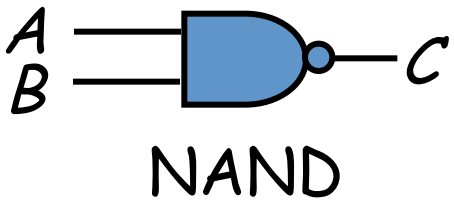


Specifies how gates must be designed

Review

Combinational gate abstraction

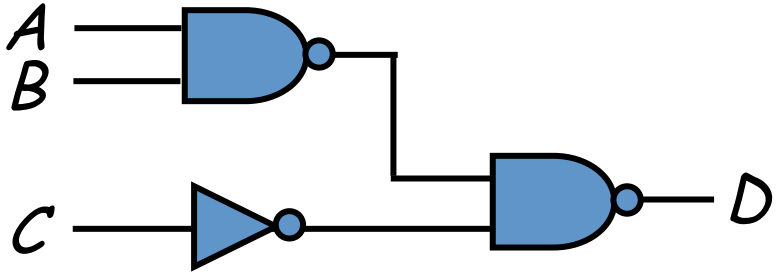
- ➡ outputs function of input alone
- ➡ satisfies static discipline



A	B	C
0	0	1
0	1	1
1	0	1
1	10	

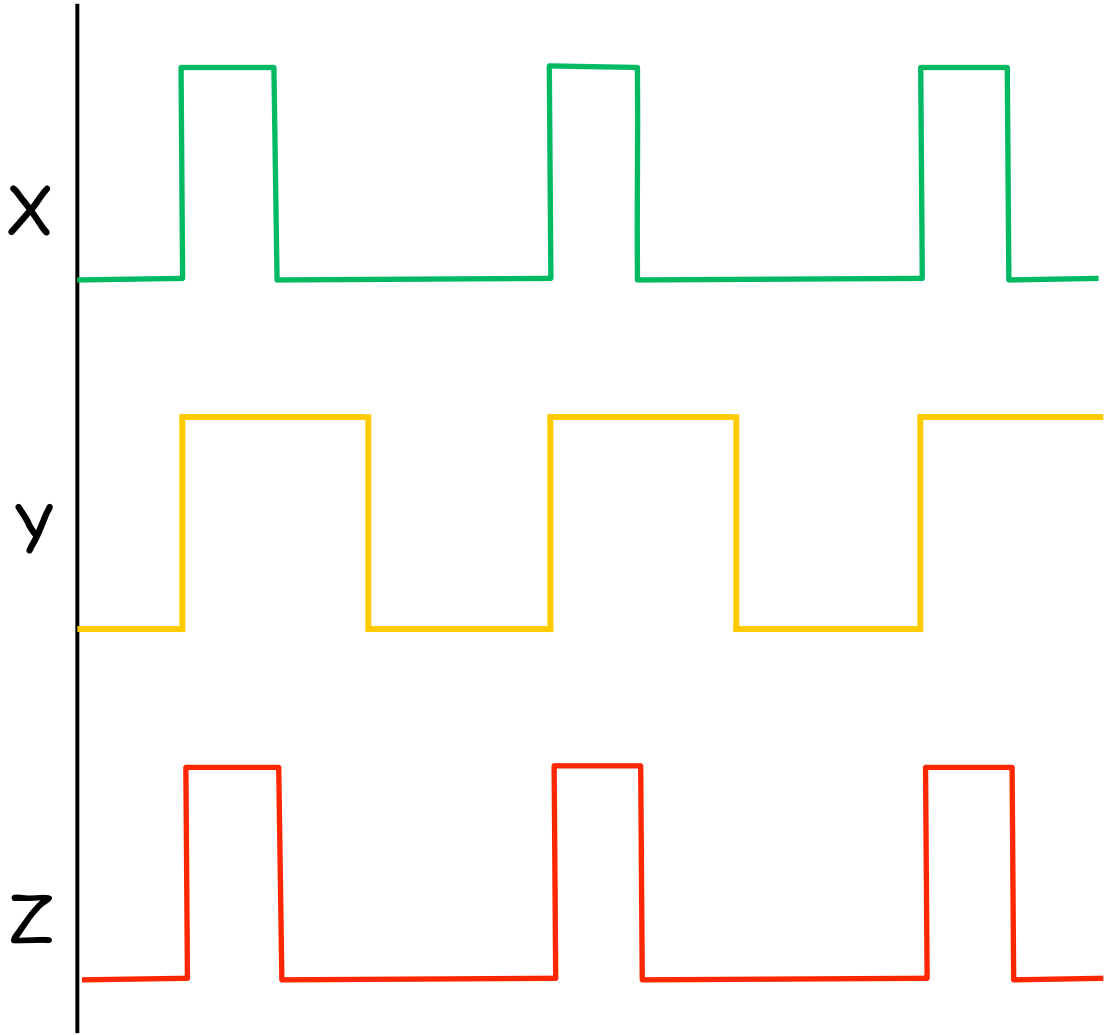
Review

A digital circuit



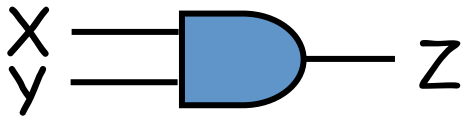
3 gates here

- A Nehalem class microprocessor from Intel has approx 1 billion gates
- The RAW multicore chip (http://groups.csail.mit.edu/cag/raw/) built by students at CSAIL, MIT, had about 3 million gates
- The 64-core Tile processor from Tilera has approx a half billion gates



Demo

$Z = X \cdot y$



How to build a digital gate

Analogy

Use this insight to build an AND gate.

How to build a digital gate

Electrical Analogy

Key: we need a “switch” device

New Switch Element

Consider abstract "switch" device

Equivalent ckt

For mechanical switch, control mechanical pressure

3-Terminal device
if C = 0: short circuit between in and out
else: open circuit between in and out

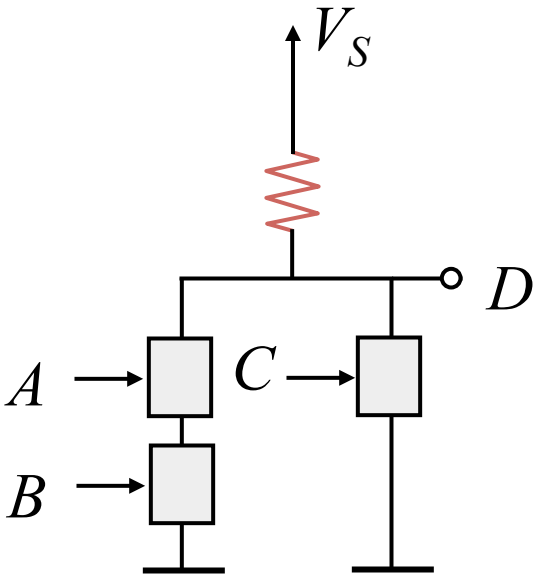
Now, consider this circuit

Behavior of this circuit

What about?

What about?

We can also build compound gates



Now let's get back to reality… we need a physical switch

The MOSFET Device

Metal-Oxide Semiconductor
Field-Effect Transistor

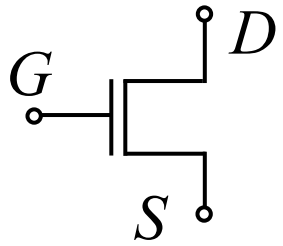
3 terminal lumped element
behaves like a switch

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

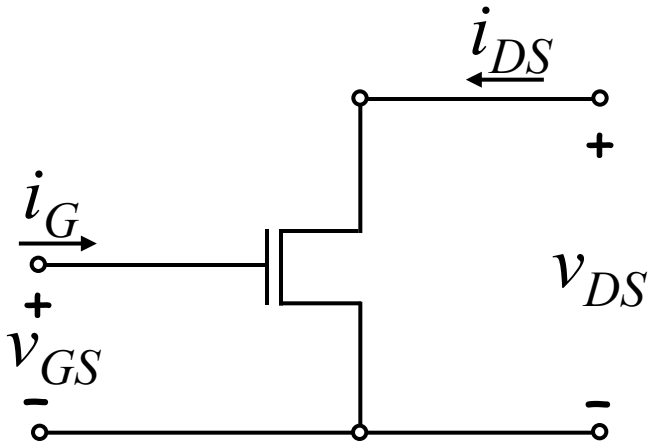


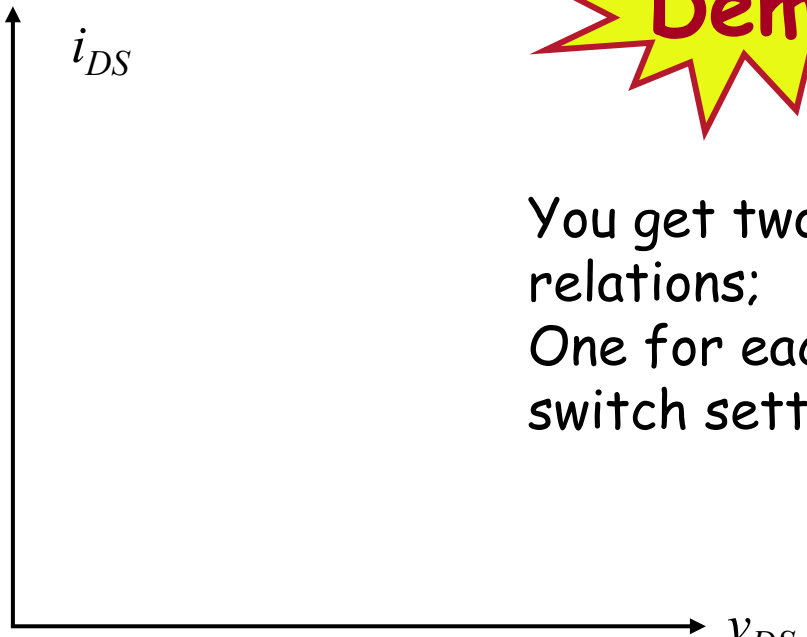
Check out the textbook for its internal Structure Sec 6.7

$V_T \sim 1V$
for example

"Switch" model (S model) of the MOSFET

Check the MOS device on a scope





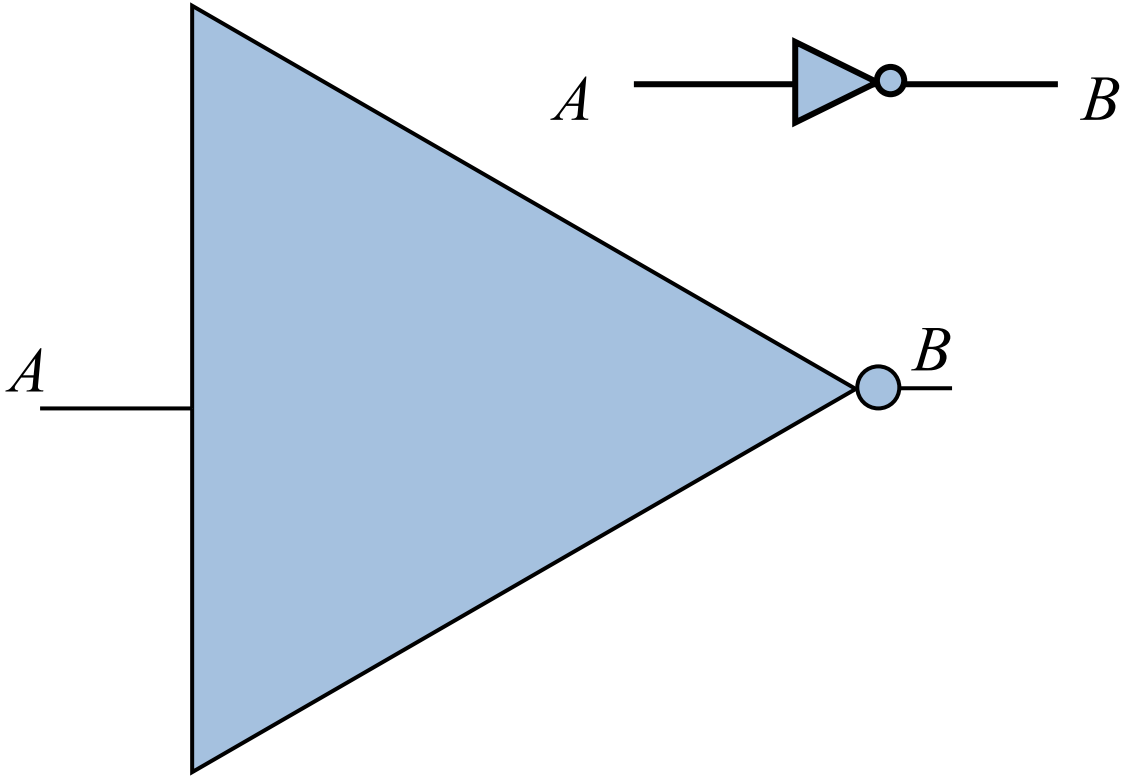
i_{DS} **vs** v_{DS}

Demo

You get two v-i relations;
One for each switch setting

(As we will see soon, note that the actual MOSFET behavior is quite a bit more complex. The above switch characterization is a gross simplification. If you cannot wait, check out Section 7.3 of the textbook for the actual MOSFET characteristics)

A MOSFET Inverter

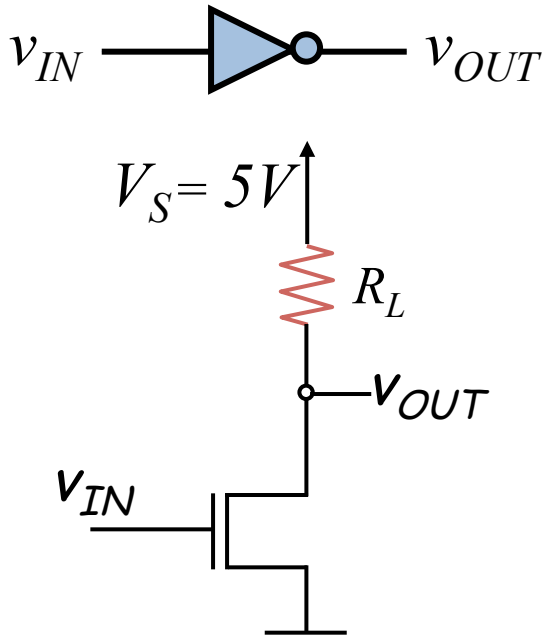


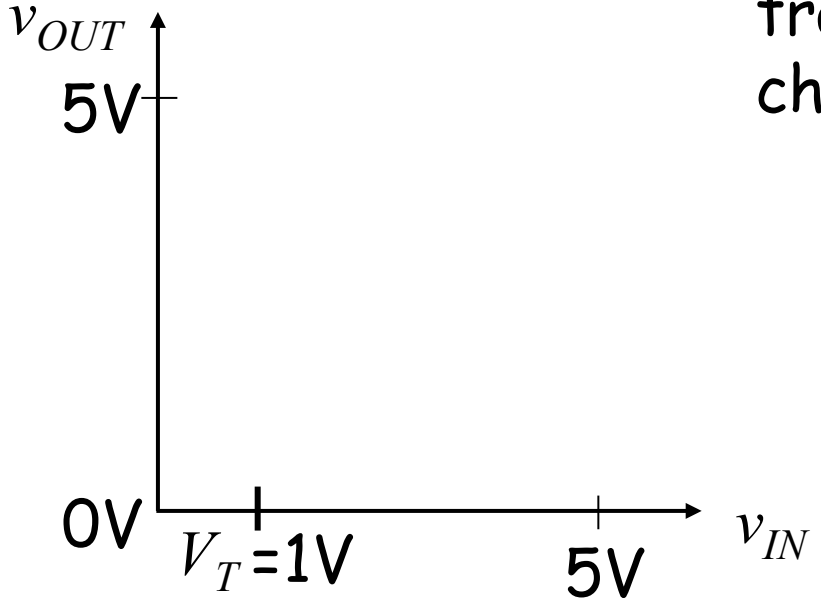
A, B: Logic value
v_{IN}: Voltage value

Note the power of abstraction:

The abstract inverter gate representation hides internal details such as power supply connections, R_L, GND, etc. When we build digital circuits, the ↑ and ⊥ are common across all gates!

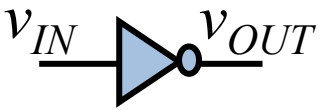
We can plot the relationship between the input and output voltages





Called voltage transfer characteristic

Question: The T1000 model laptop needs gates that satisfy a static discipline with voltage thresholds given below. Does our inverter qualify?



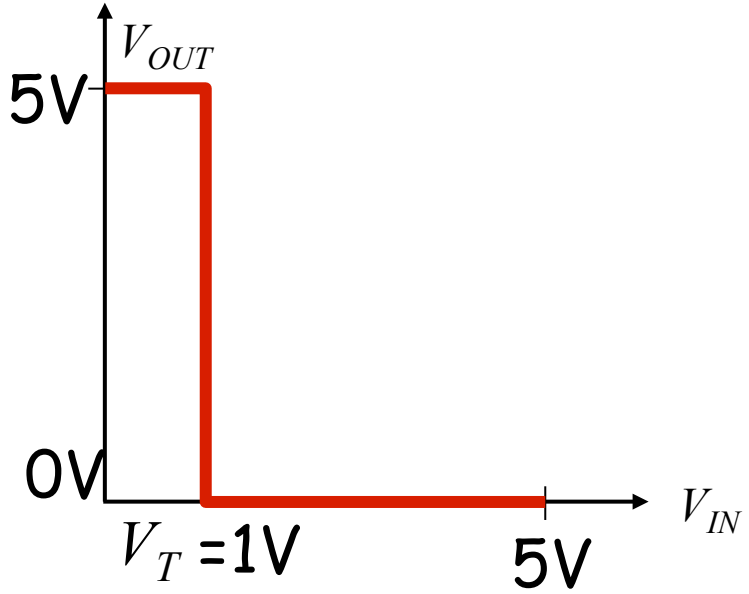
V_{OL} = 0.5V V_{IL} = 0.9V

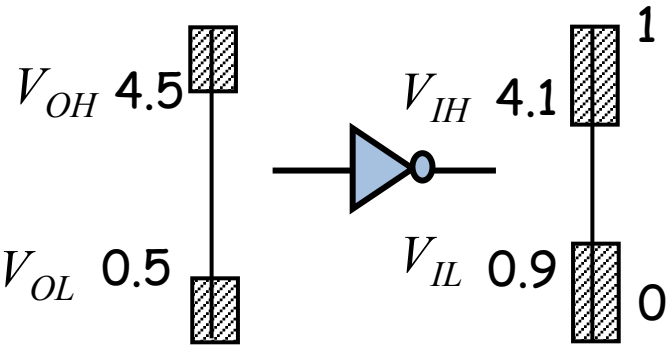
V_{OH} = 4.5V V_{IH} = 4.1V

Does our inverter satisfy the voltage thresholds for this static discipline?

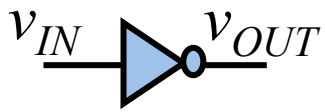
V_{OL} = 0.5V V_{IL} = 0.9V

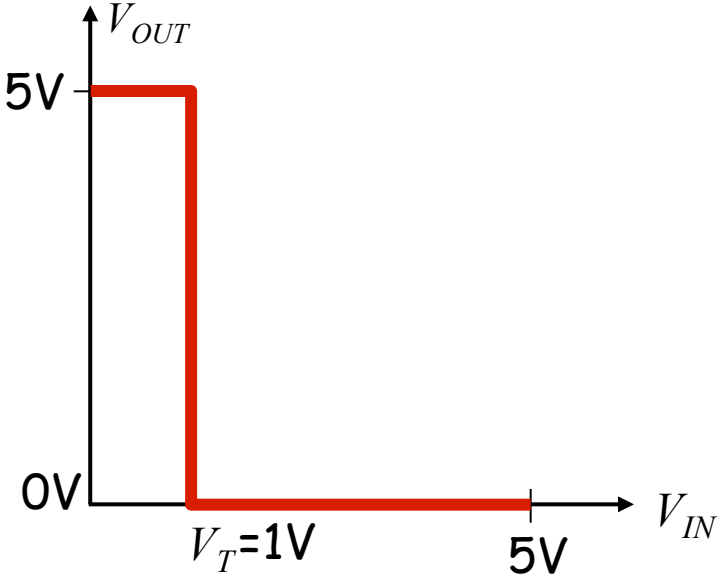
V_{OH} = 4.5V V_{IH} = 4.1V





Does our inverter satisfy the static discipline for these different thresholds?





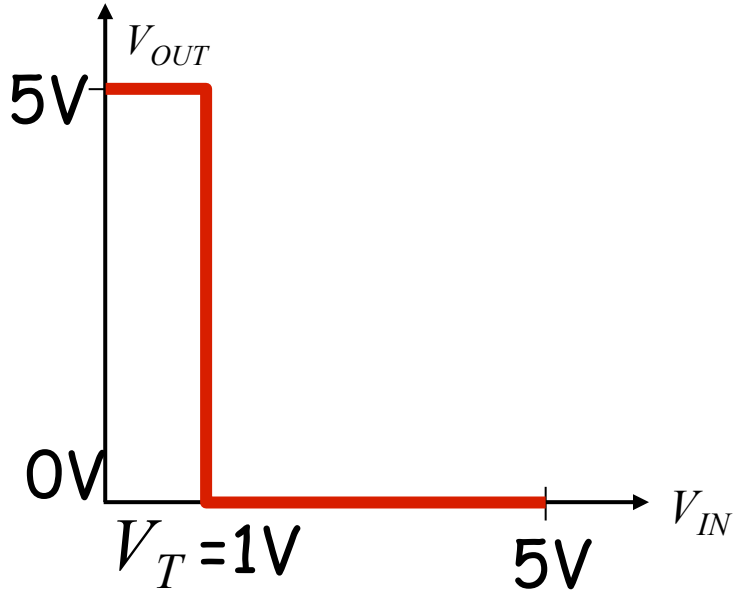
V_{OL} = 0.2V V_{IL} = 0.5V

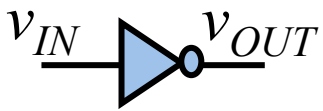
V_{OH} = 5.1V V_{IH} = 4.5V

V_{OL} = 0.2V V_{IL} = 0.5V

V_{OH} = 5.1V V_{IH} = 4.5V

How about these thresholds?





V_{OL} = 0.5V V_{IL} = 1.5V

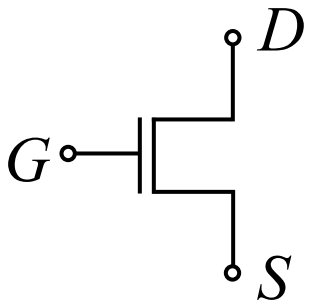
V_{OH} = 4.5V V_{IH} = 3.5V

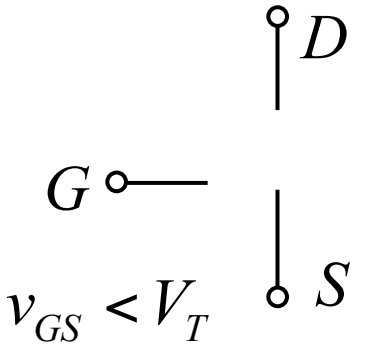
V_{OL} = 0.5V V_{IL} = 1.5V

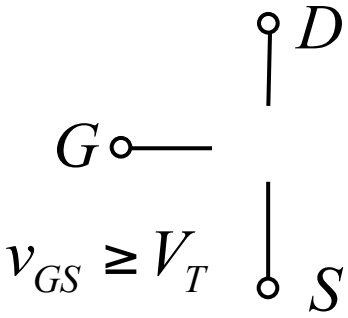
V_{OH} = 4.5V V_{IH} = 3.5V

Switch Resistor (SR) Model of MOSFET

…a more accurate MOSFET model



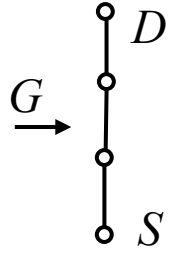




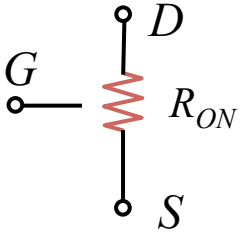
SR Model of MOSFET

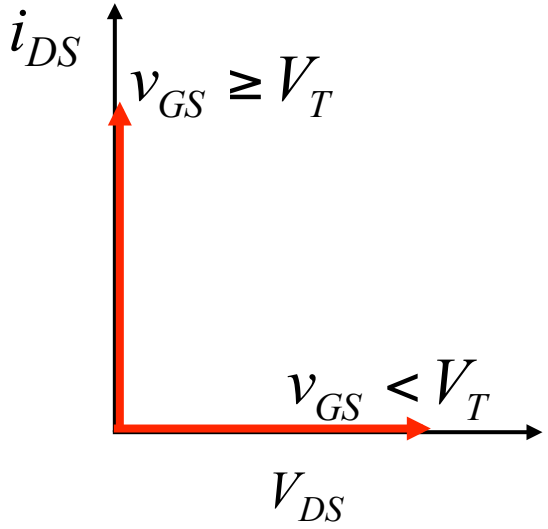
Demo

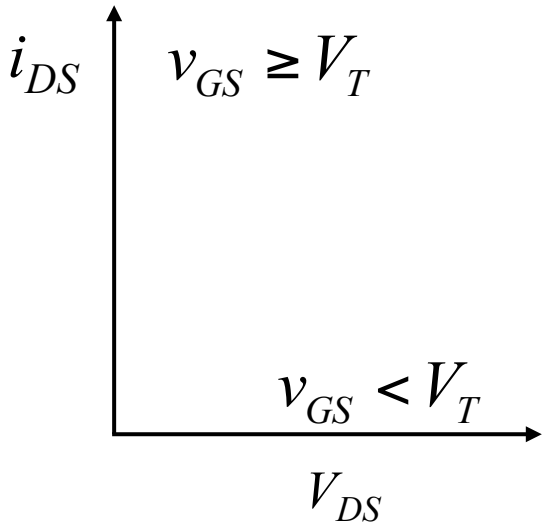
MOSFET
S model



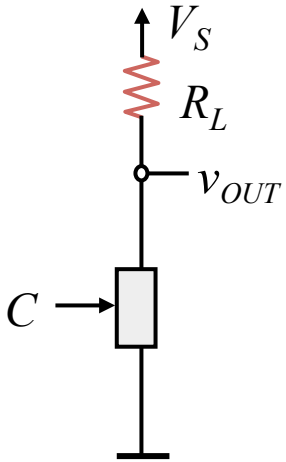
MOSFET
SR model



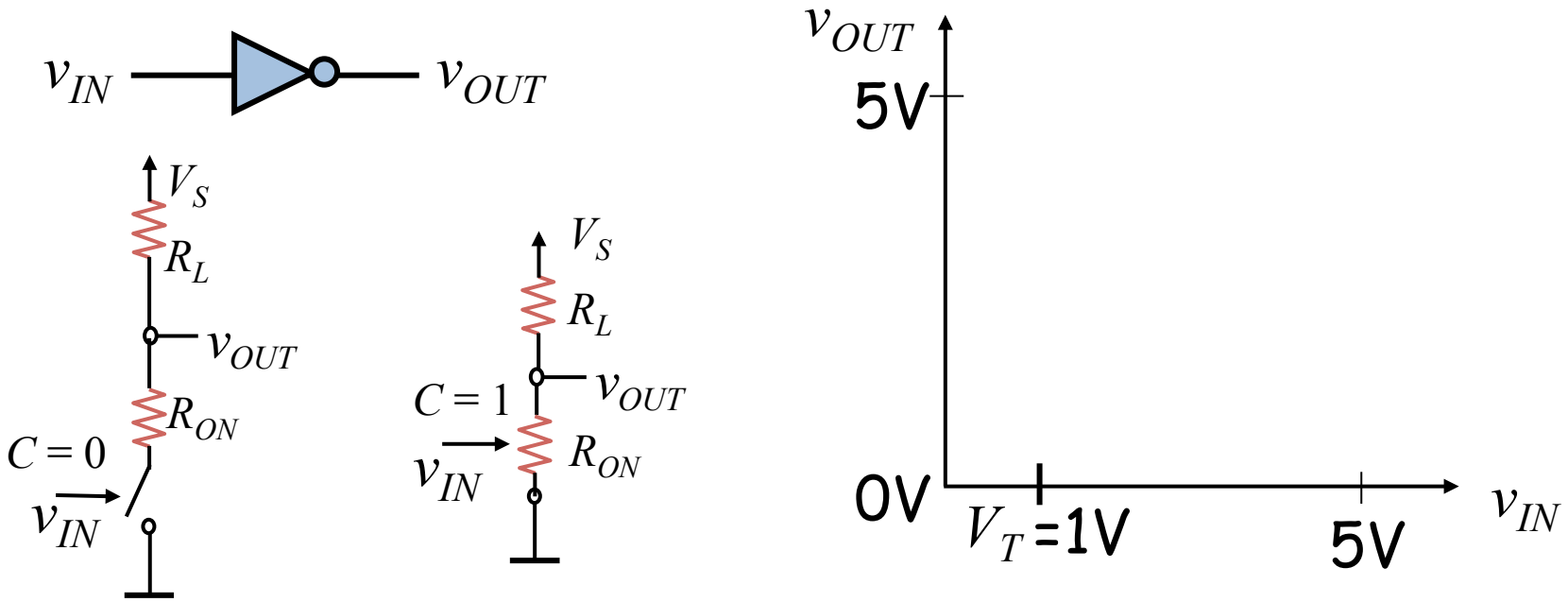




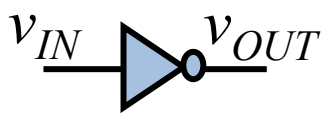
Using the SR model



Transfer Function for Inverter using the SR MOSFET Model



Does our inverter satisfy the voltage thresholds for this static discipline?



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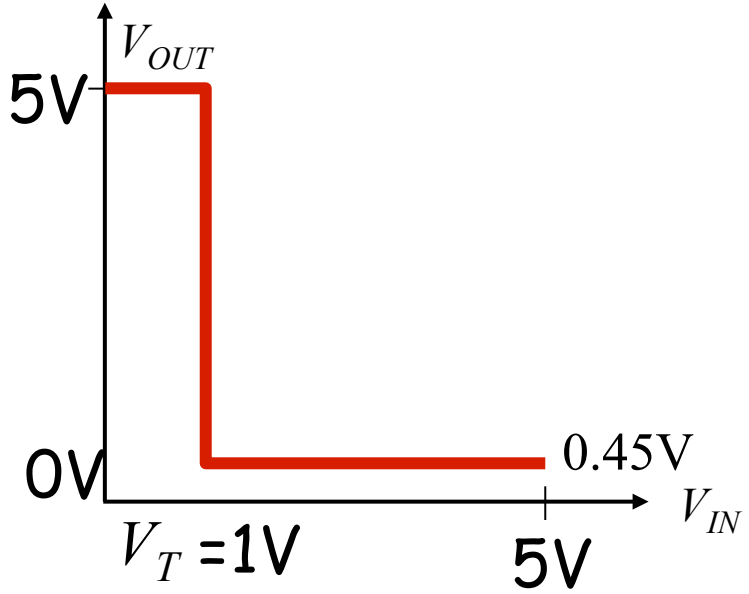
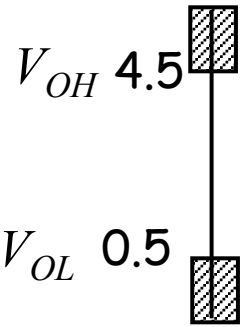
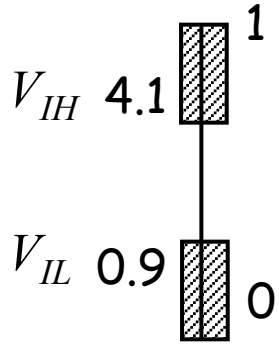
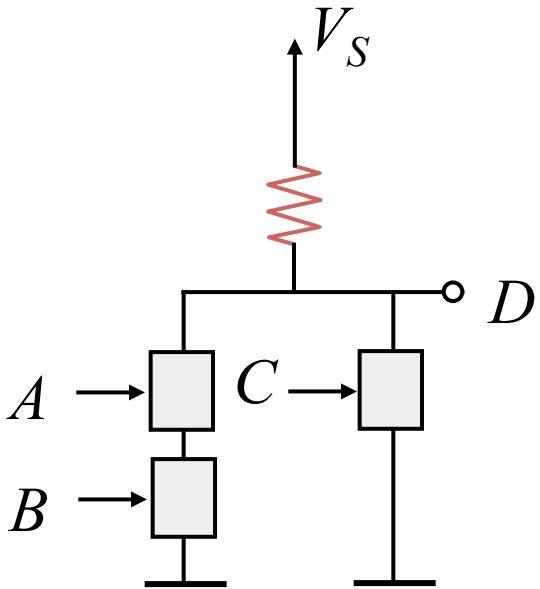


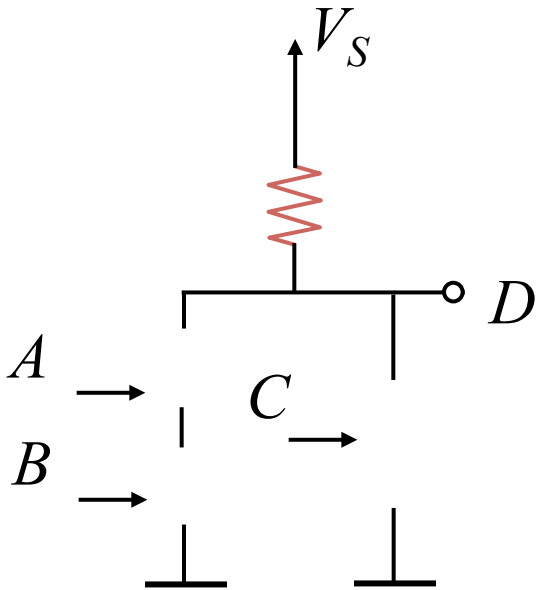




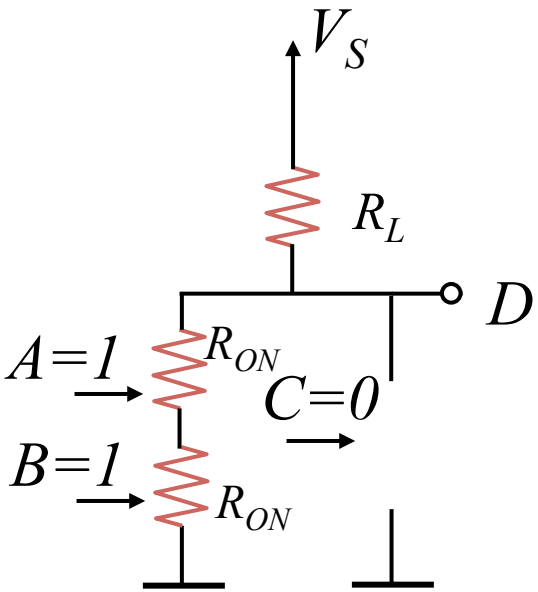
So, our inverter satisfies this static discipline

Some Interesting Insights…
Our Digital Subcircuits are Linear





Static Power in Digital Circuits



Analog and Digital (or Mixed Signals) are Everywhere