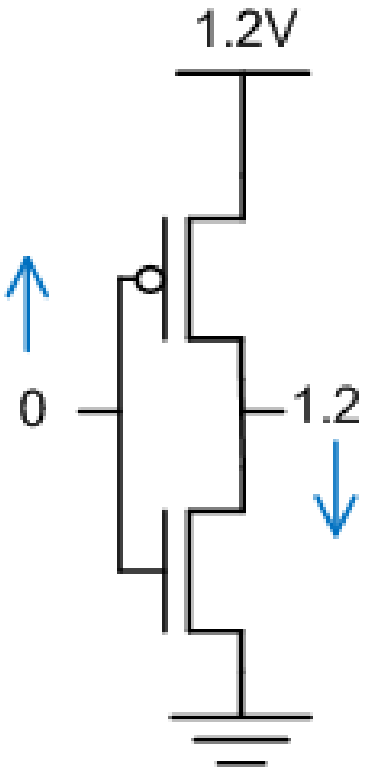
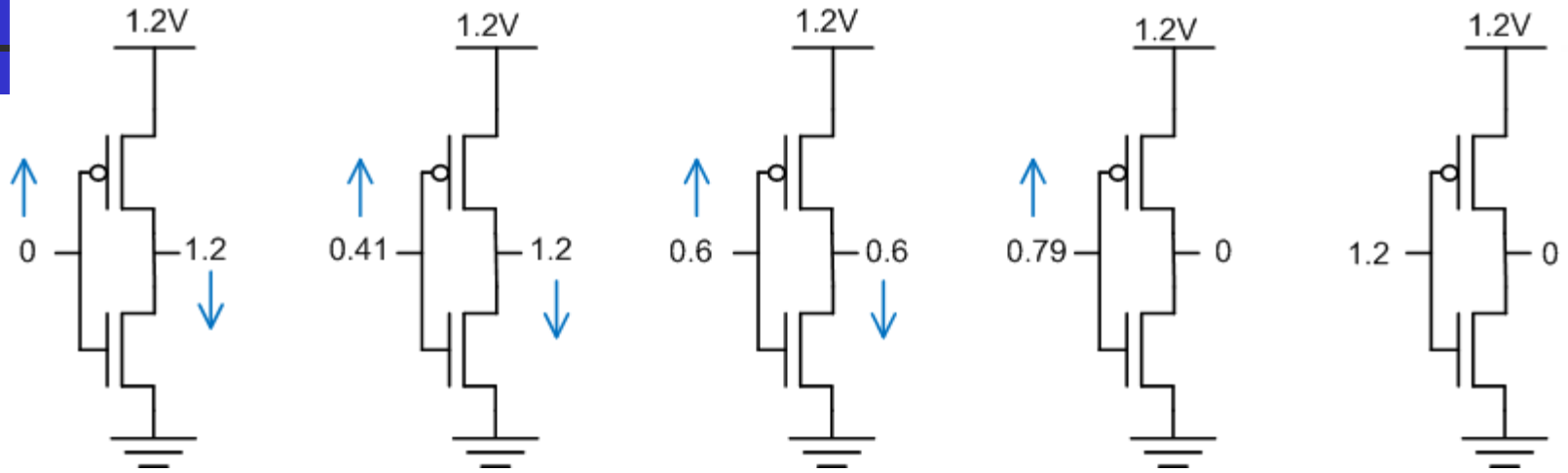
# Inverter




As the input voltage rises from 0 to 1.2, the PMOS and NMOS will transit from one operation region to another. We are going to use VIN rises from 0 to 1.2 for illustration.

So, what are the 5 operation region of invertor?

# As VIN ↑, VOUT ↓



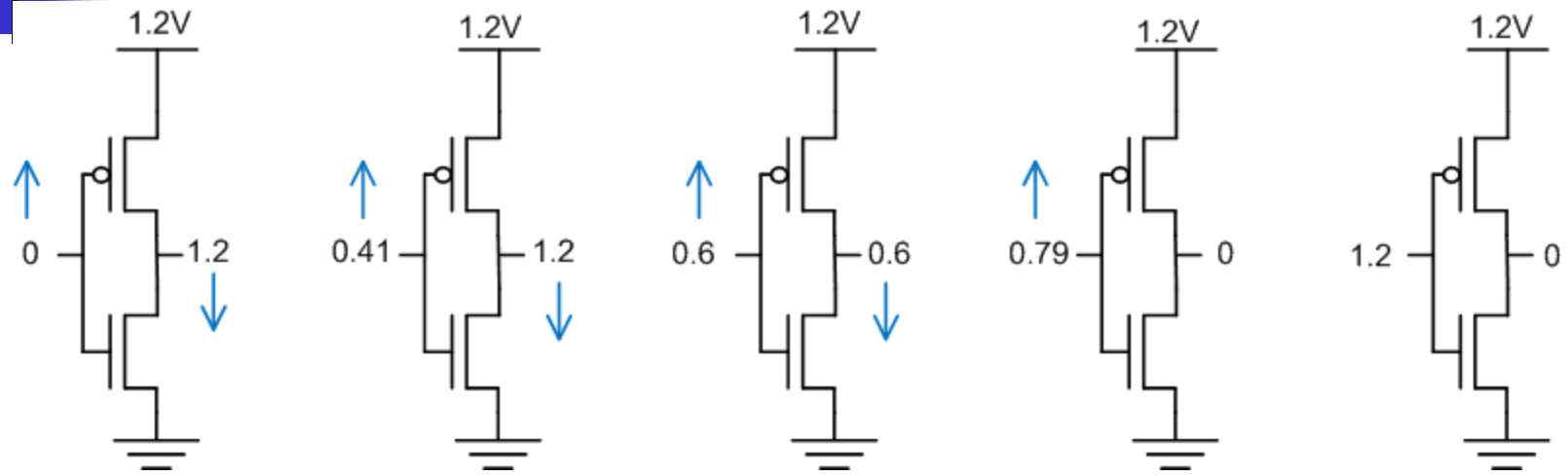

Assume VDD=1.2V, threshold voltage of PMOS and NMOS are 0.4V.

|Vthp|=0.4V & Vthn=0.4V. || means magnitude or absolute (don't care about the sign).

There are 5 regions of operation as VIN transits from 0V to 1.2V and VOUT transits from 1.2V to 0V.

We are not interested in the exact range of VIN and VOUT for each region. We just want to know that it does go through 5 regions of operation.

# 5 Regions?




| Operating Region | PMOS | NMOS |
|---|---|---|
| 1 | On, \|VgsP\|>0.4 | Off, VgsN<0.4 |
| 2 | On | On, VgsN>0.4 |
| 3 | On | On |
| 4 | On | On |
| 5 | Off, \|VgsP\|<0.4 | On |

# How many ‘on’?

There are actually 2 regions of operation for MOS when it is on: Linear (act as a small resistor) and Saturation (act as a current source). So, we still have more work…

Let’s go through each region one by one.

# 1st

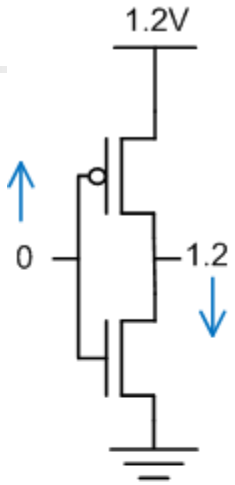
PMOS:

|Vgs|>|Vth| → | | means absolute. Forget about the sign.

1.2 > 0.4 [on]

|Vds|<|Vgs|-|Vth|

0 < 1.2-0.4 [Linear, Resistor]

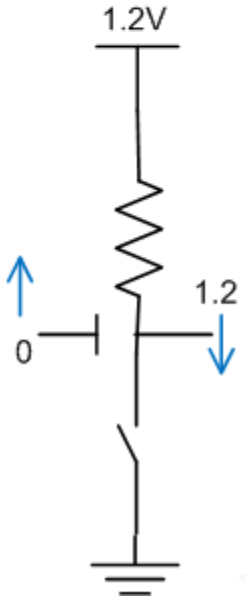



NMOS:

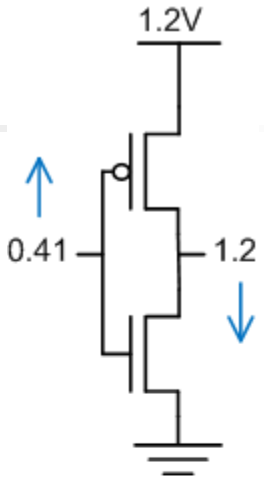
Vgs<Vth

0 <0.4 [off]

There is no current flow through the resistor since there is not voltage drop across it.



# 2nd



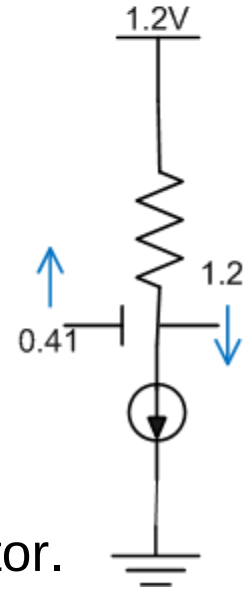

PMOS:

|Vgs|>|Vth|

0.79 > 0.4 [on]

|Vds|<|Vgs|-|Vth|

0 < 0.79-0.4 [Linear, Resistor]




NMOS:

Vgs >Vth

0.41 >0.4 [on]

Vds > Vgs-Vth

1.2 > 0.41-0.4 [Saturation, Current Source]

VOUT will start to drop since current flow through resistor.

# 3rd

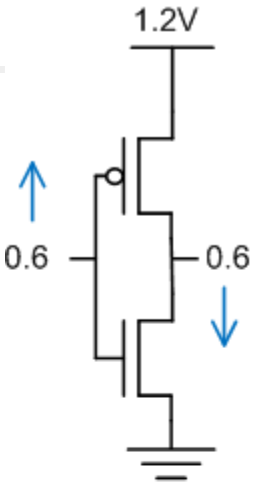
PMOS:

|Vgs|>|Vth|

0.6 > 0.4 [on]

|Vds|>|Vgs|-|Vth|

0.6 > 0.6-0.4 [Saturation, Current Source]



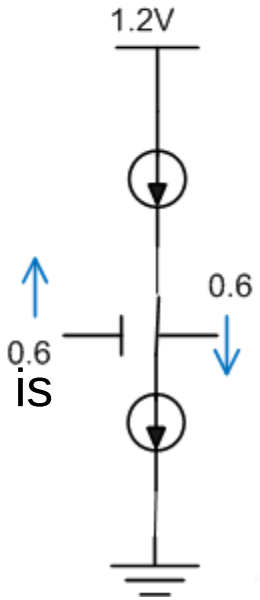

NMOS:

Vgs >Vth

0.6 >0.4 [on]

Vds > Vgs-Vth

0.6 > 0.6-0.4 [Saturation, Current Source]




Current flow directly from supply to ground. This interval is very short, or else power is wasted. VOUT continues to drop.

# 4th

PMOS:

|Vgs|>|Vth|

0.41 > 0.4 [on]

|Vds|>|Vgs|-|Vth|

1.2 > 0.41-0.4 [Saturation, Current Source]

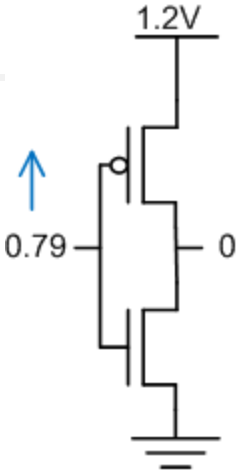
NMOS:

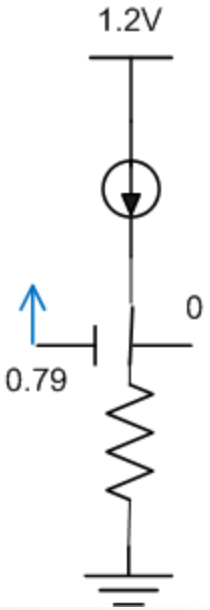
Vgs >Vth

0.79 >0.4 [on]

Vds < Vgs-Vth

0 > 0.79-0.4 [Linear, Resistor]



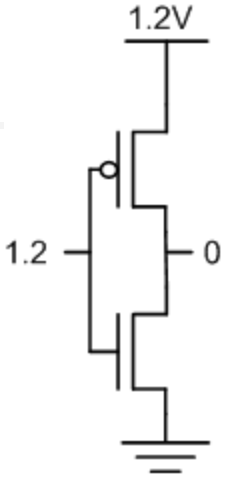

The resistor will short VOUT to ground. Will the current flowing into resistor rises VOUT? No, current is small because PMOS size is not too large.

# 5th

PMOS:

|Vgs|<|Vth|

0 <0.4 [off]



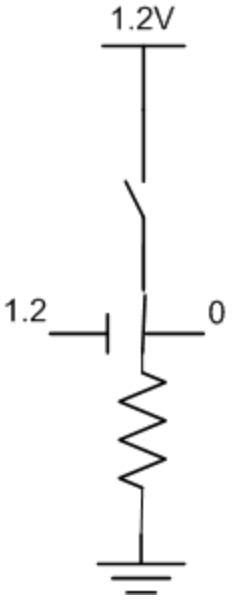

NMOS:

Vgs >Vth

1.2 >0.4 [on]

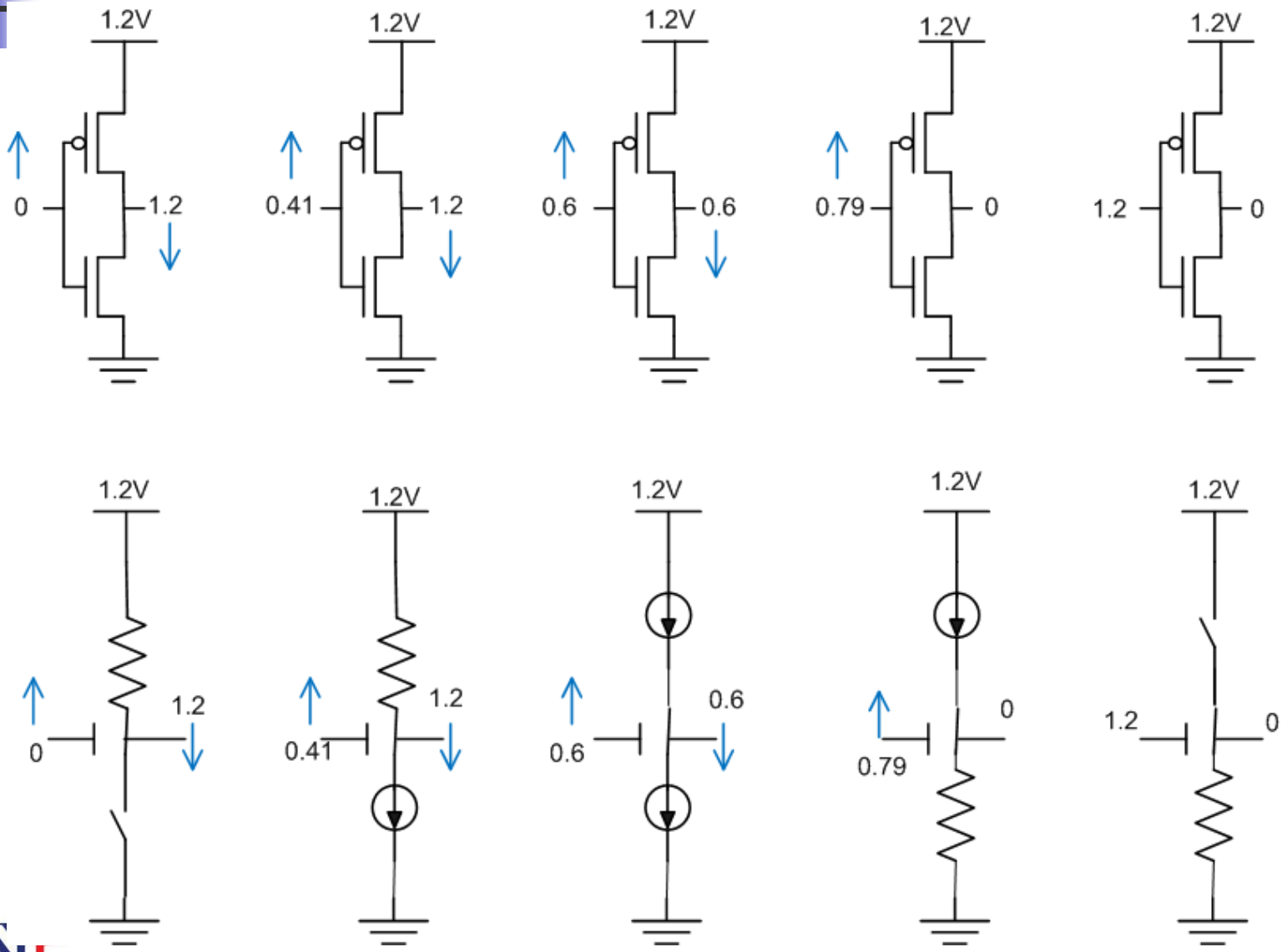
Vds < Vgs-Vth

0 < 1.2-0.4 [Linear, Resistor]




No current flow through resistor since there is no voltage drop across it. VOUT is always pull down to 0V.

# Finally…


1.2V
0
1.2
1.2V
0.41
1.2
1.2V
0.6
0.6
1.2V
0.79
0
1.2V
1.2
0
1.2V
0
1.2
1.2V
0.41
1.2
1.2V
0.6
0.6
1.2V
0.79
0
1.2V
1.2
0