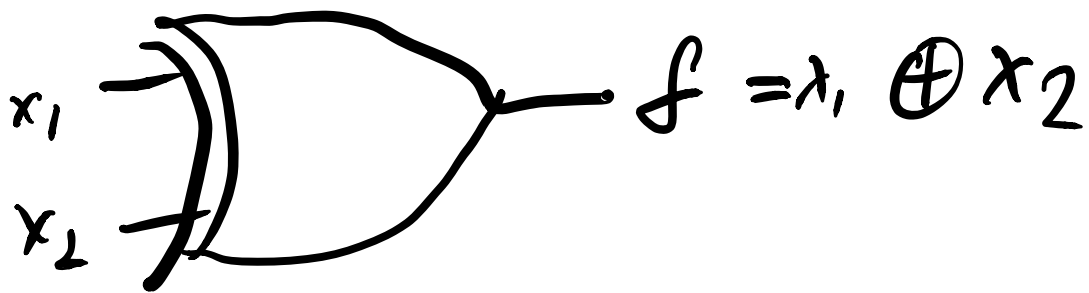
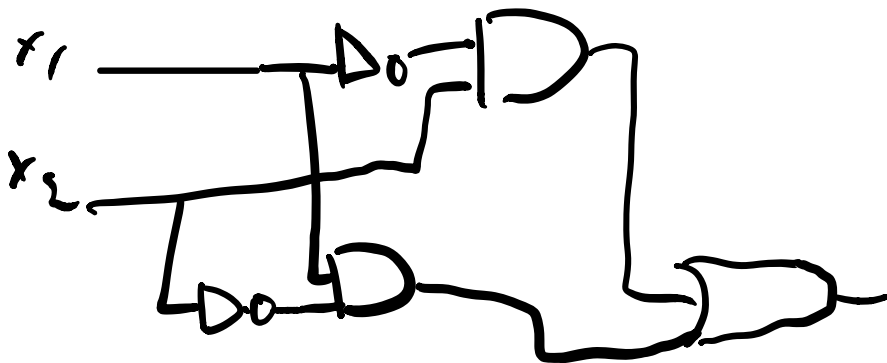


# XOR - exclusive or

| $x_1$ | $x_2$ | $f = x_1 \oplus x_2$ | $x_1 + x_2$ |
|-------|-------|----------------------|-------------|
| 0     | 0     | 0                    | 0           |
| 0     | 1     | 1                    | 1           |
| 1     | 0     | 1                    | 1           |
| 1     | 1     | 0                    | 0           |



$$x_1 \oplus x_2 = !x_1 x_2 + x_1 !x_2$$



Positive logic (NMOS and CMOS gates)

0 - Low voltage

1 - High voltage

Negative logic (7 segment display)

0 - High voltage

1 - Low voltage

MOSFET - most popular transistor for gates

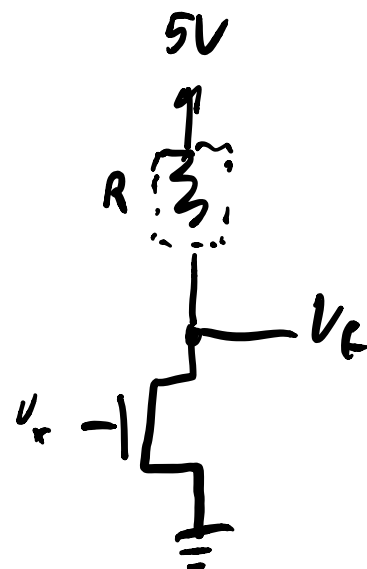
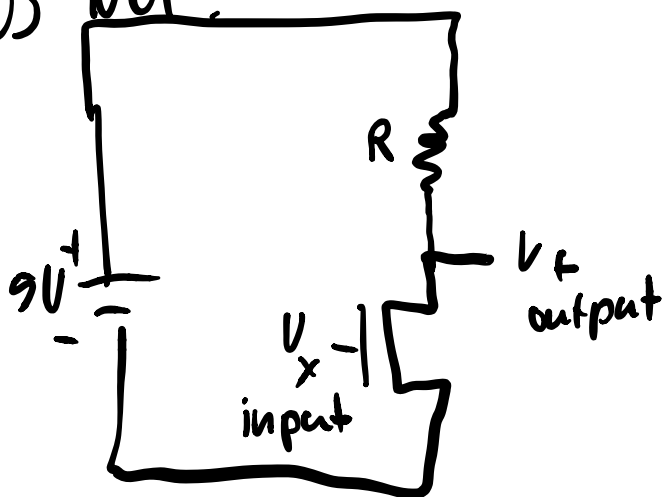
Types:

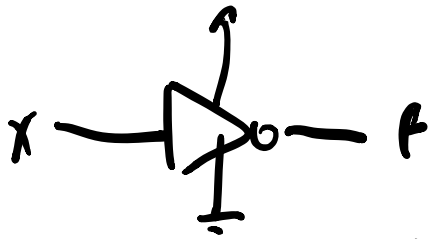
- N-channel (NMOS) } opposite

- P-channel (PMOS) }

- C-channel (CMOS) combination

NMOS Not:



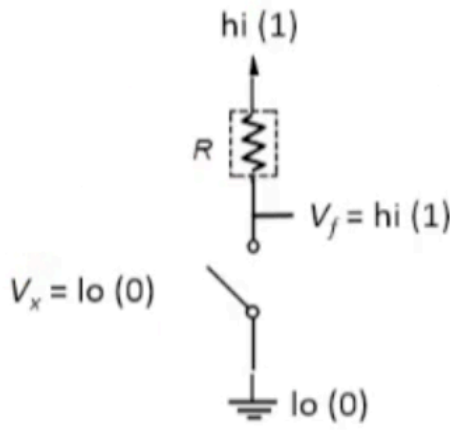
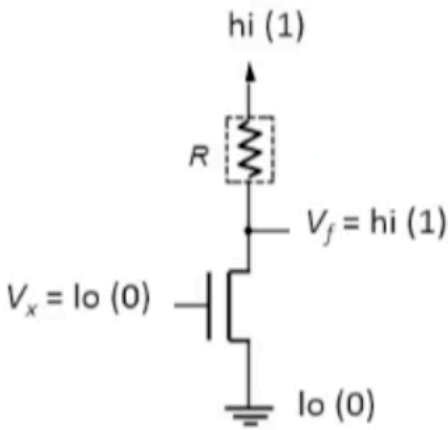


with power

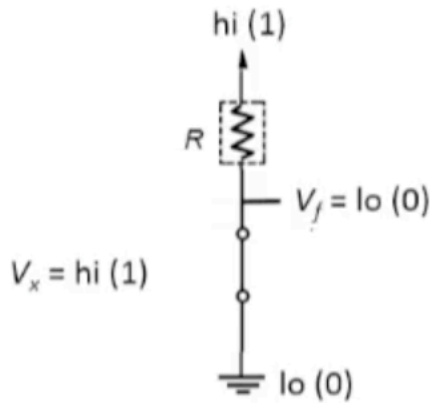
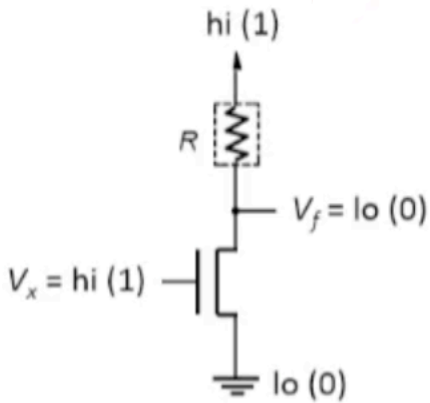


without power  
(simplified)

Graphical symbols

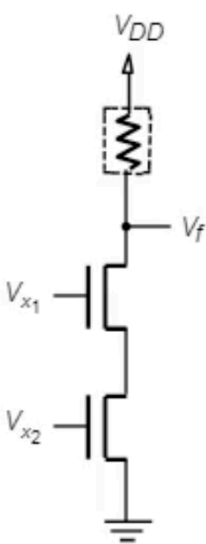


| $V_x$ | $V_f$ | $x$ | $f(x) = !x$ |
|-------|-------|-----|-------------|
| lo    | hi    | 0   | 1           |
| hi    | lo    | 1   | 0           |



NOT

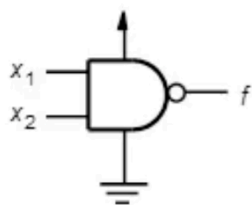
$$V_{DD} = 5\text{ V} = \text{hi (1)}$$



(a) Circuit

| $x_1$ | $x_2$ | $f$ |
|-------|-------|-----|
| 0     | 0     | 1   |
| 0     | 1     | 1   |
| 1     | 0     | 1   |
| 1     | 1     | 0   |

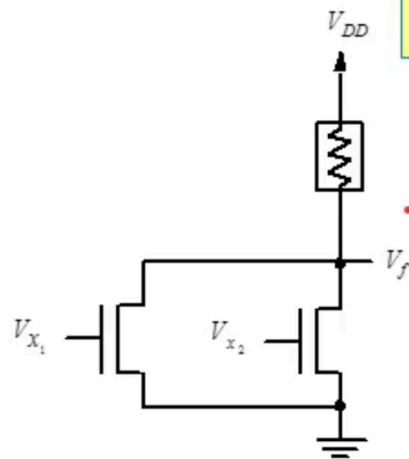
(b) Truth table



(c) Graphical symbols

NAND

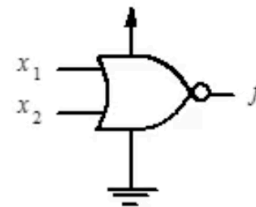
$$V_{DD} = 5\text{ V} = \text{hi (1)}$$



(a) Circuit

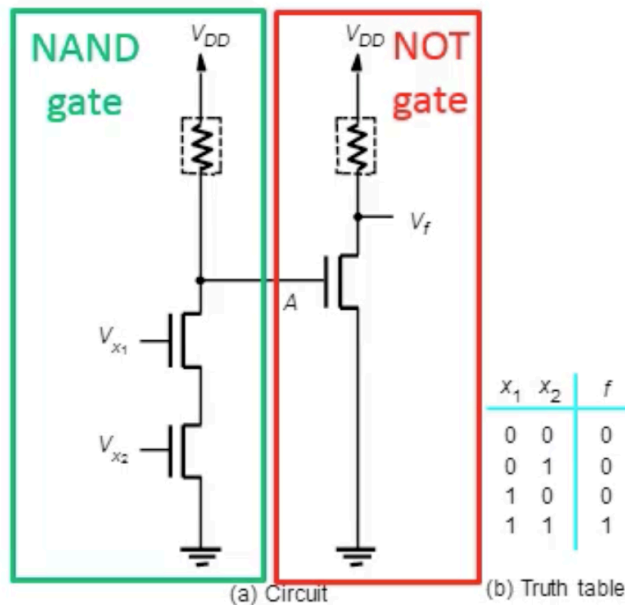
| $x_1$ | $x_2$ | $f$ |
|-------|-------|-----|
| 0     | 0     | 1   |
| 0     | 1     | 0   |
| 1     | 0     | 0   |
| 1     | 1     | 0   |

(b) Truth table



(c) Graphical symbols

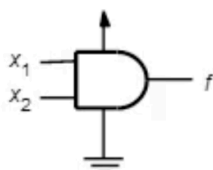
NOR



(a) Circuit

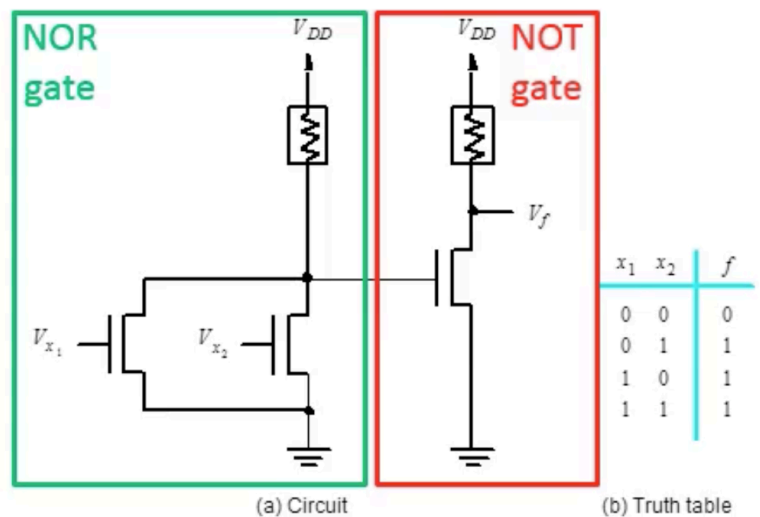
| $x_1$ | $x_2$ | $f$ |
|-------|-------|-----|
| 0     | 0     | 0   |
| 0     | 1     | 0   |
| 1     | 0     | 0   |
| 1     | 1     | 1   |

(b) Truth table



(c) Graphical symbols

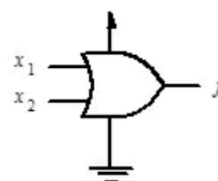
AND



(a) Circuit

| $x_1$ | $x_2$ | $f$ |
|-------|-------|-----|
| 0     | 0     | 0   |
| 0     | 1     | 1   |
| 1     | 0     | 1   |
| 1     | 1     | 1   |

(b) Truth table



(c) Graphical symbols

OR

# CMOS

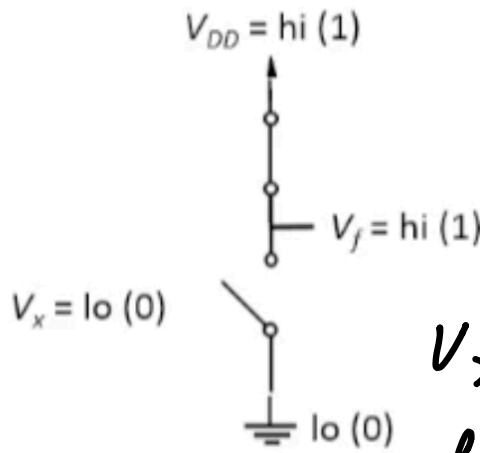
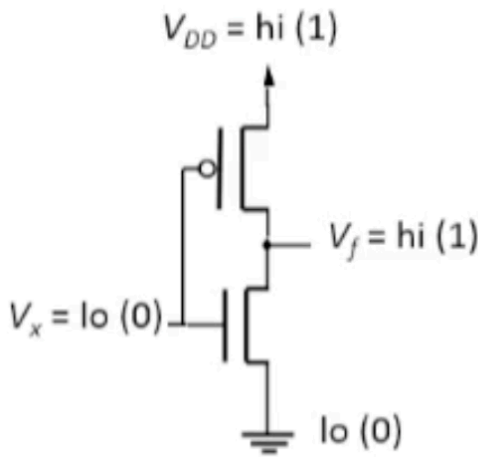
circle means PMOS

PMOS:

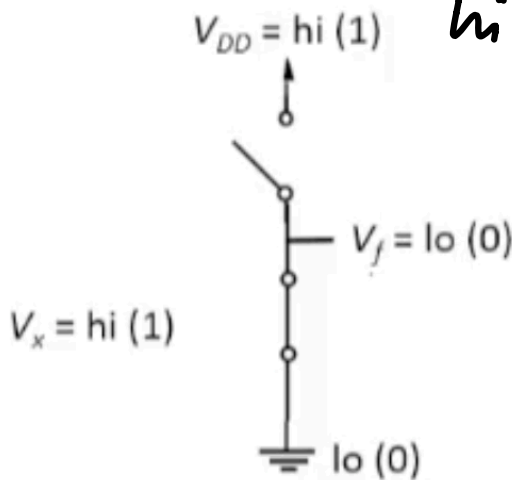
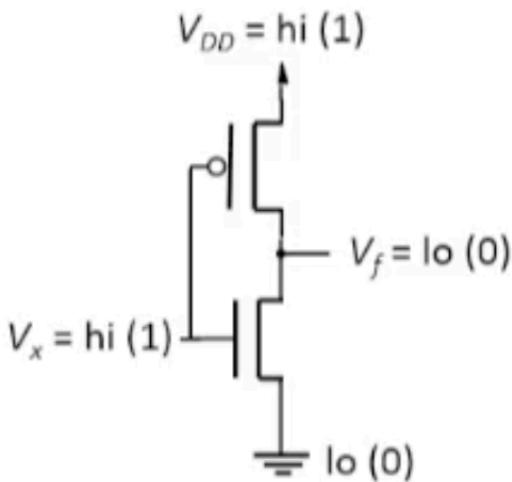


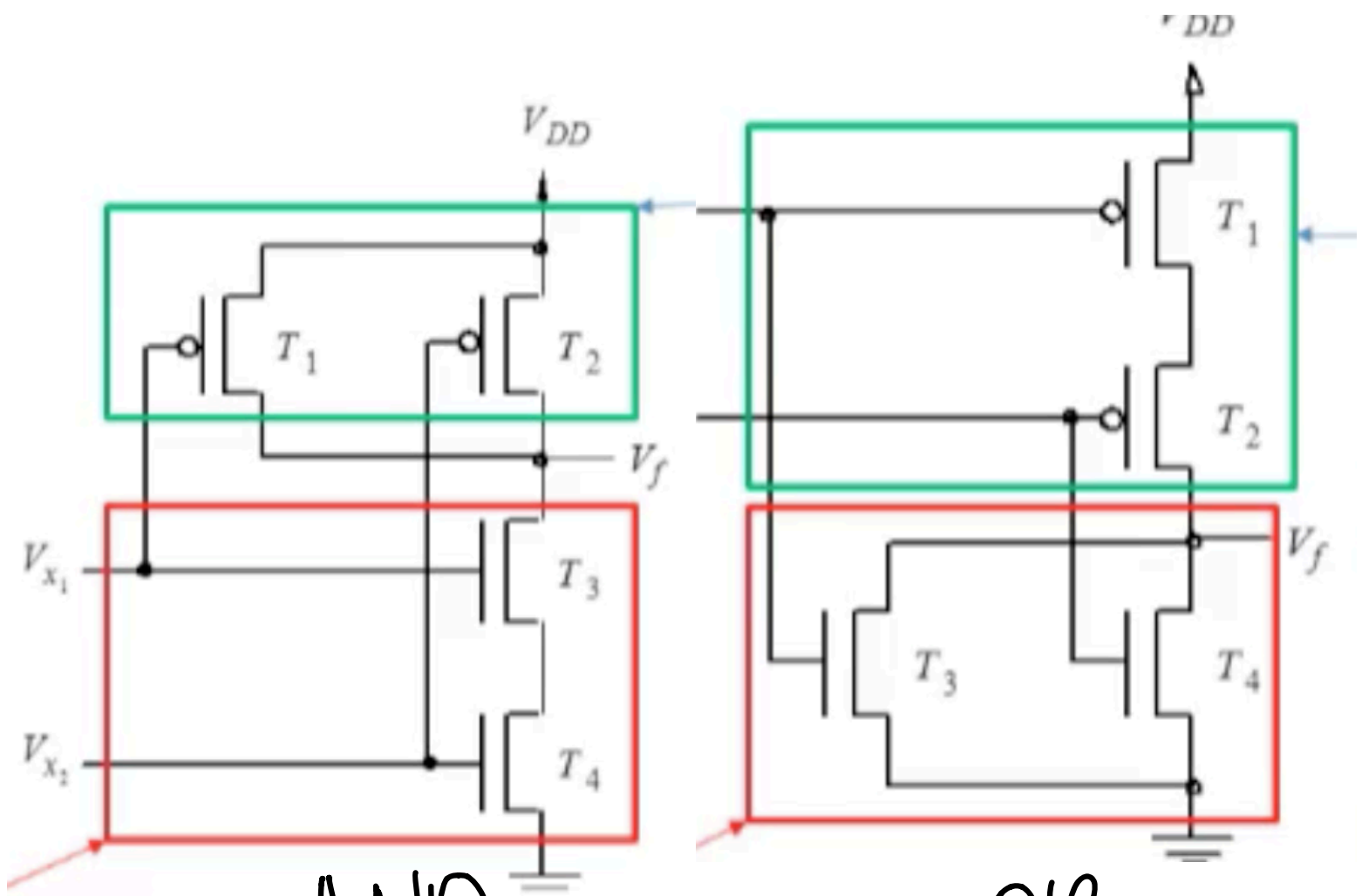
$V_g = \text{high}$

$V_g = \text{low}$



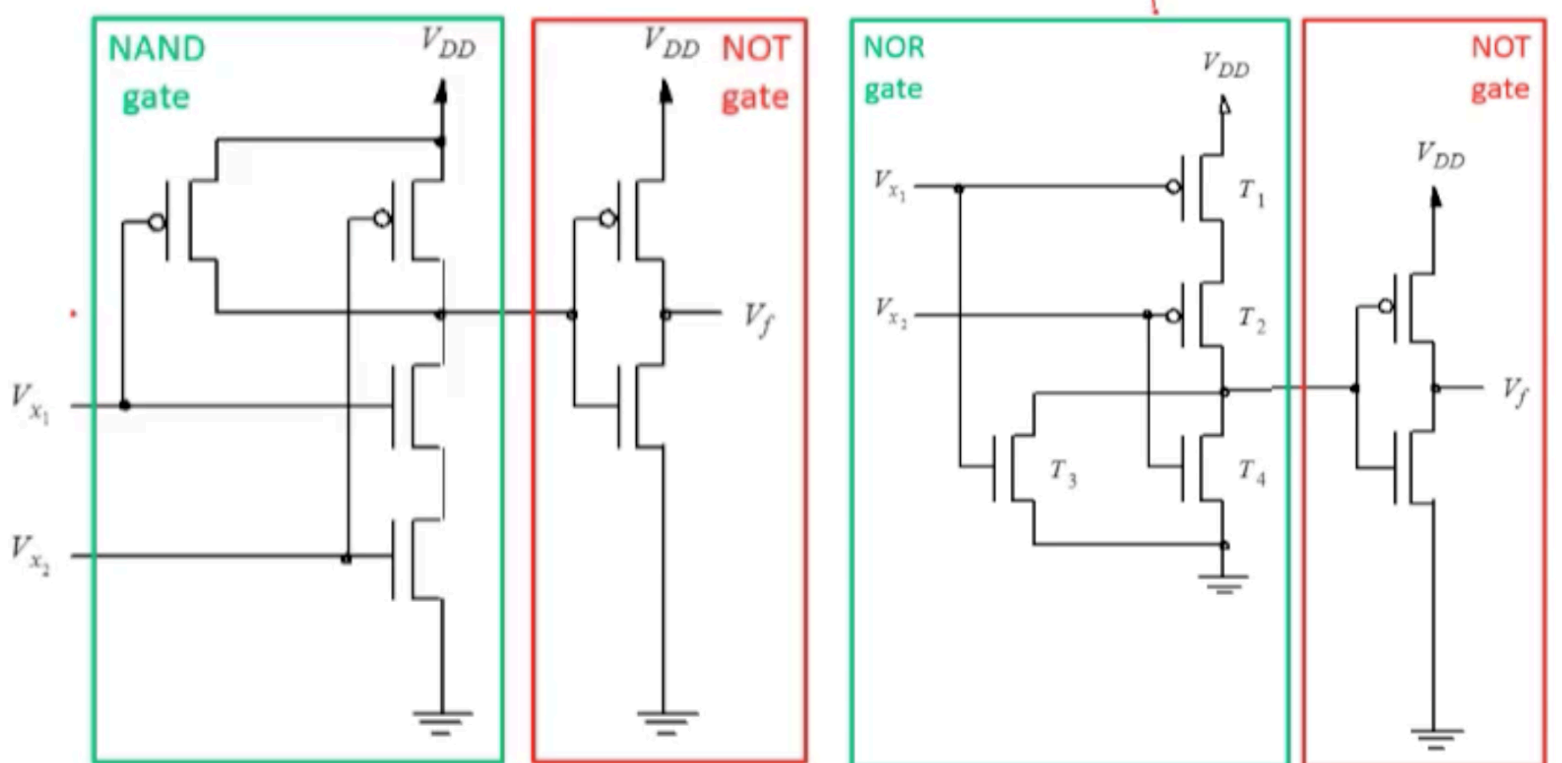
| $V_x$ | $V_f$ | $r$ | $f(x) = 'r$ |
|-------|-------|-----|-------------|
| lo    | hi    | 0   | 1           |
| hi    | lo    | 1   | 0           |





NAND

NOR



AND

PDN

OR

PUN

| Logic Gate | pull down                    |  | pull up                      |  |
|------------|------------------------------|--|------------------------------|--|
|            | Number of Transistors (NMOS) |  | Number of Transistors (CMOS) |  |
| NOT        | 1                            |  | 2                            |  |
| NAND       | 1 per input                  |  | 2 per input                  |  |
| NOR        | 1 per input                  |  | 2 per input                  |  |
| AND        | 1 + 1 per input              |  | 2 + 2 per input              |  |
| OR         | 1 + 1 per input              |  | 2 + 2 per input              |  |

PUN series  $\Leftrightarrow$  PDN parallel

PDN series  $\Leftrightarrow$  PUN parallel

(compliment the function)

