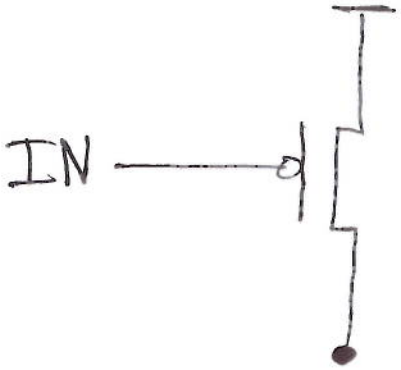
P-MOS



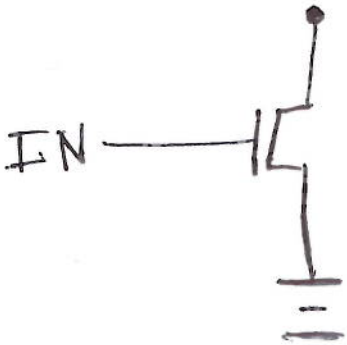
OFF
IN = 1

We don't know about voltage.

ON
IN = 0

Voltage is high.

N-MOS



ON
IN = 1

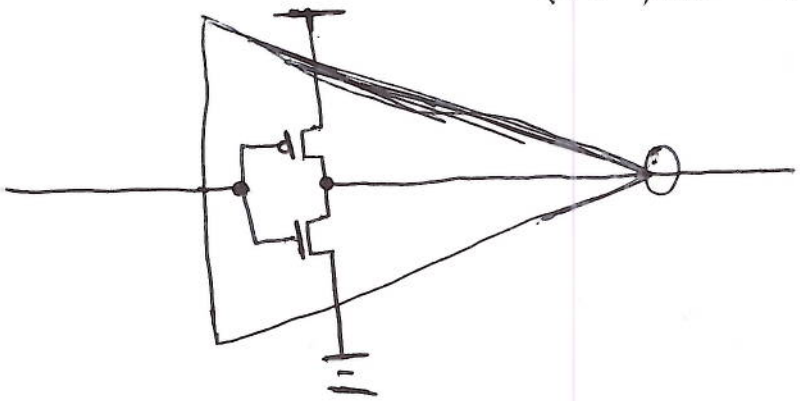
Voltage low.

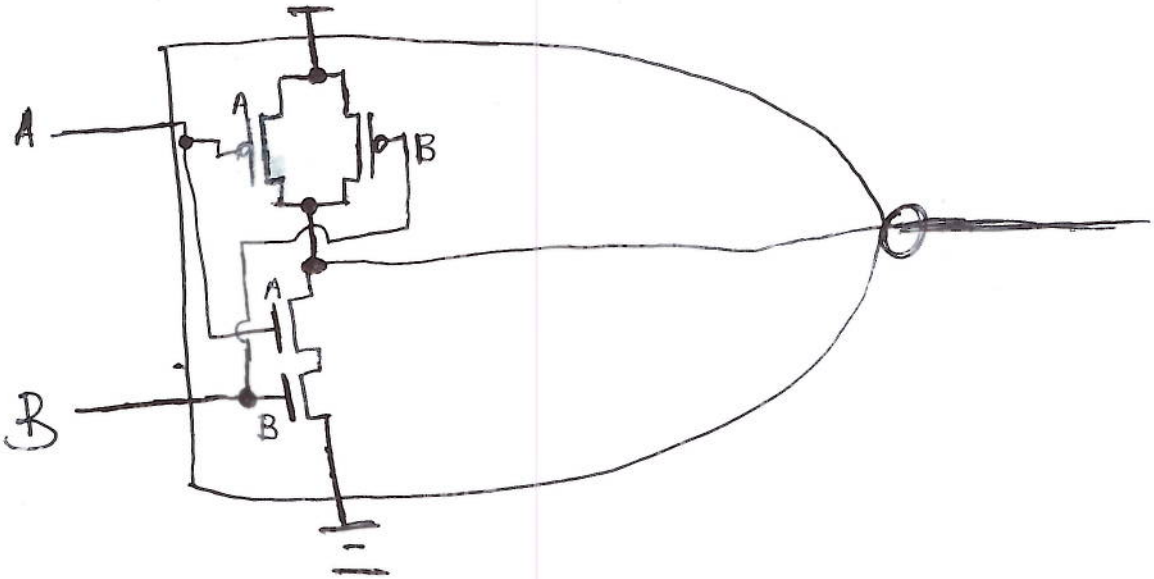
OFF
IN = 0

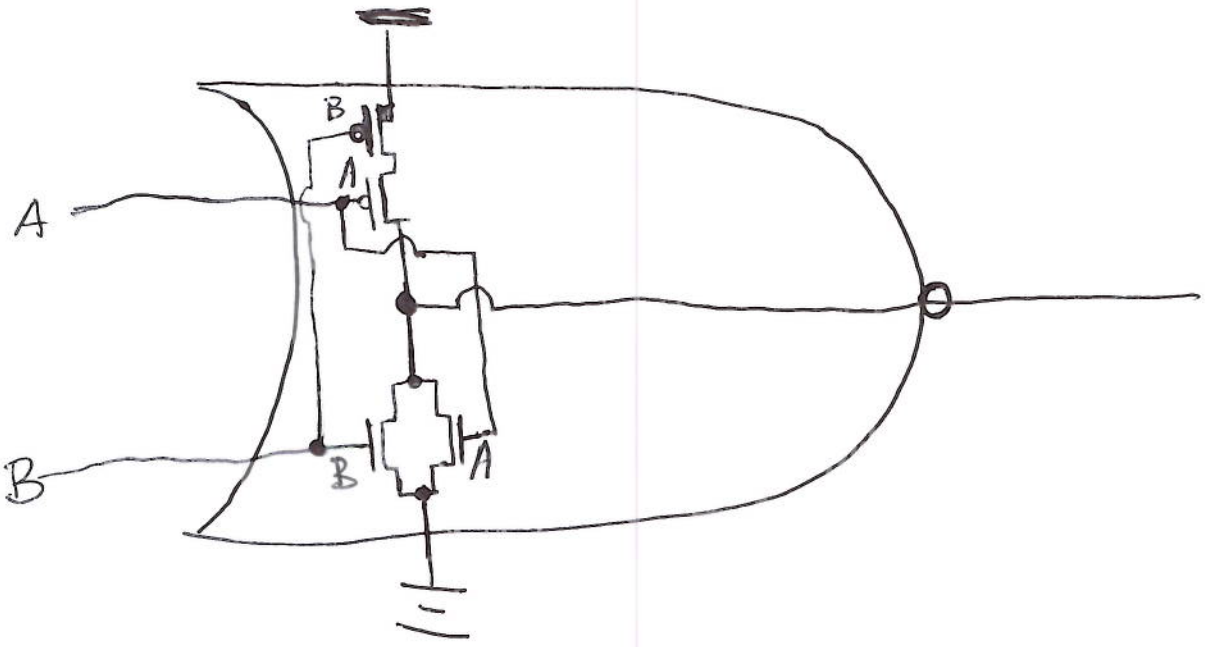
We can't determine voltage.

NATURAL GATES:

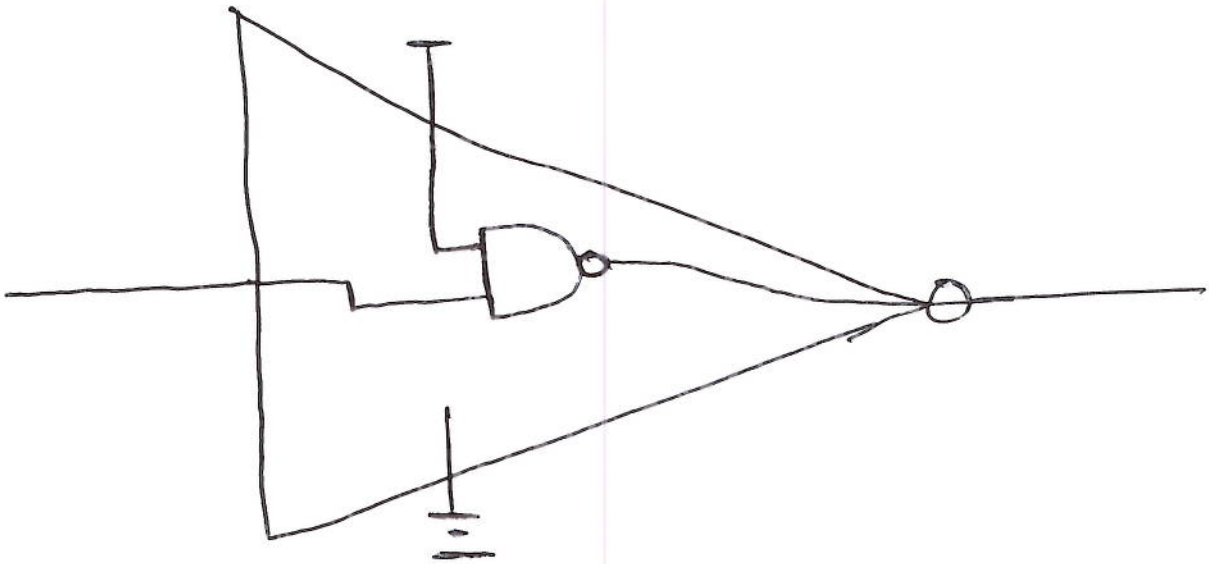
(NOT, NAND, NOR)

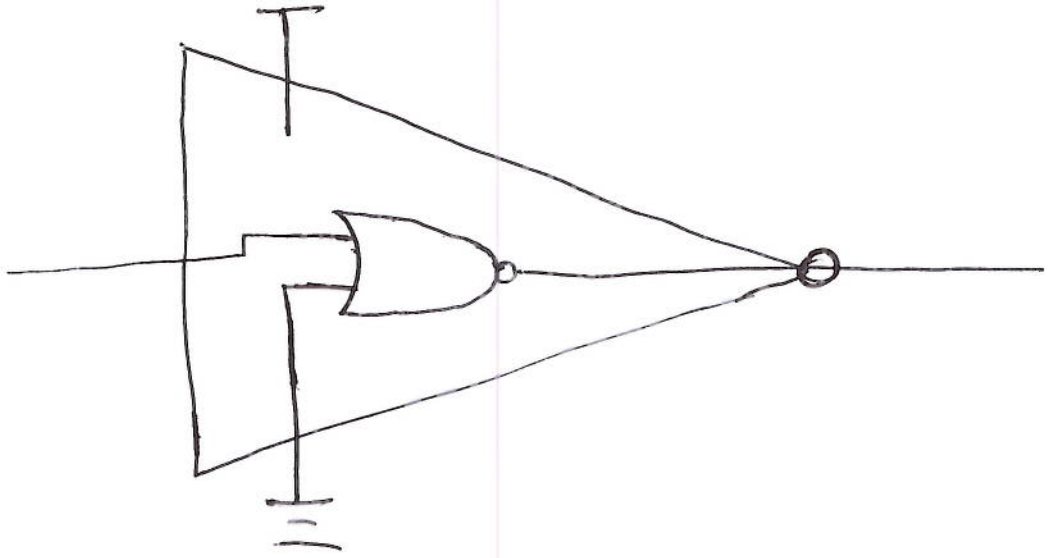




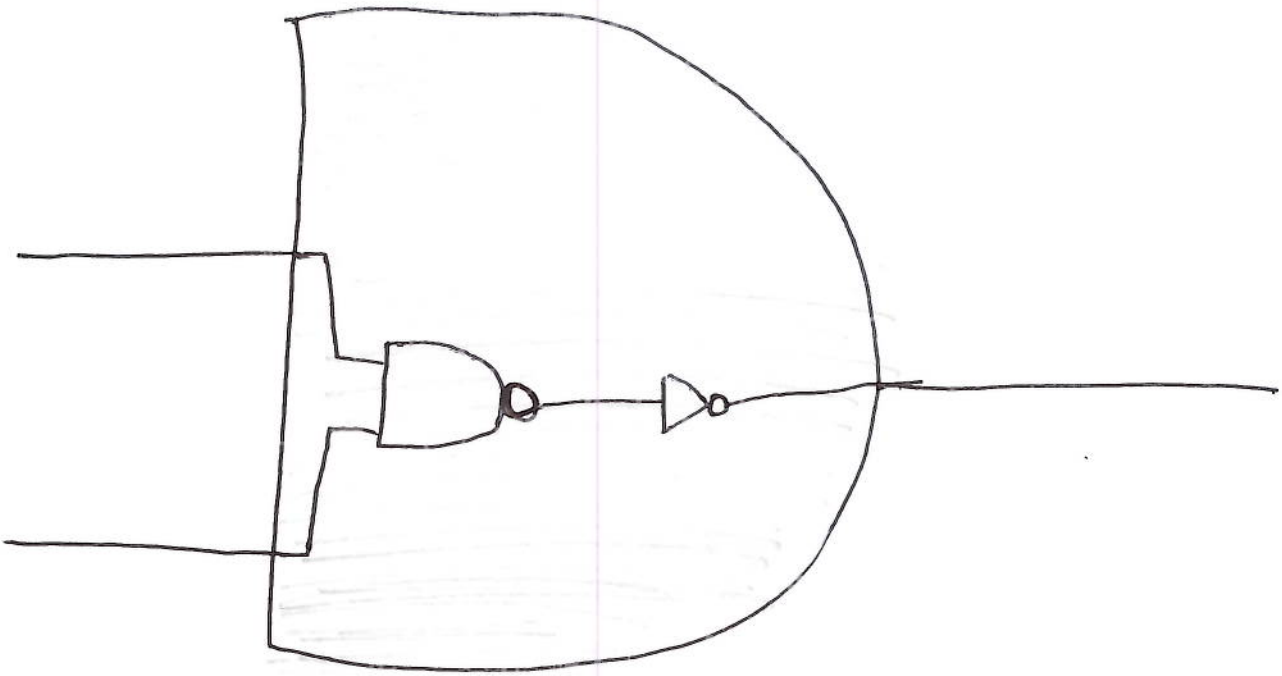


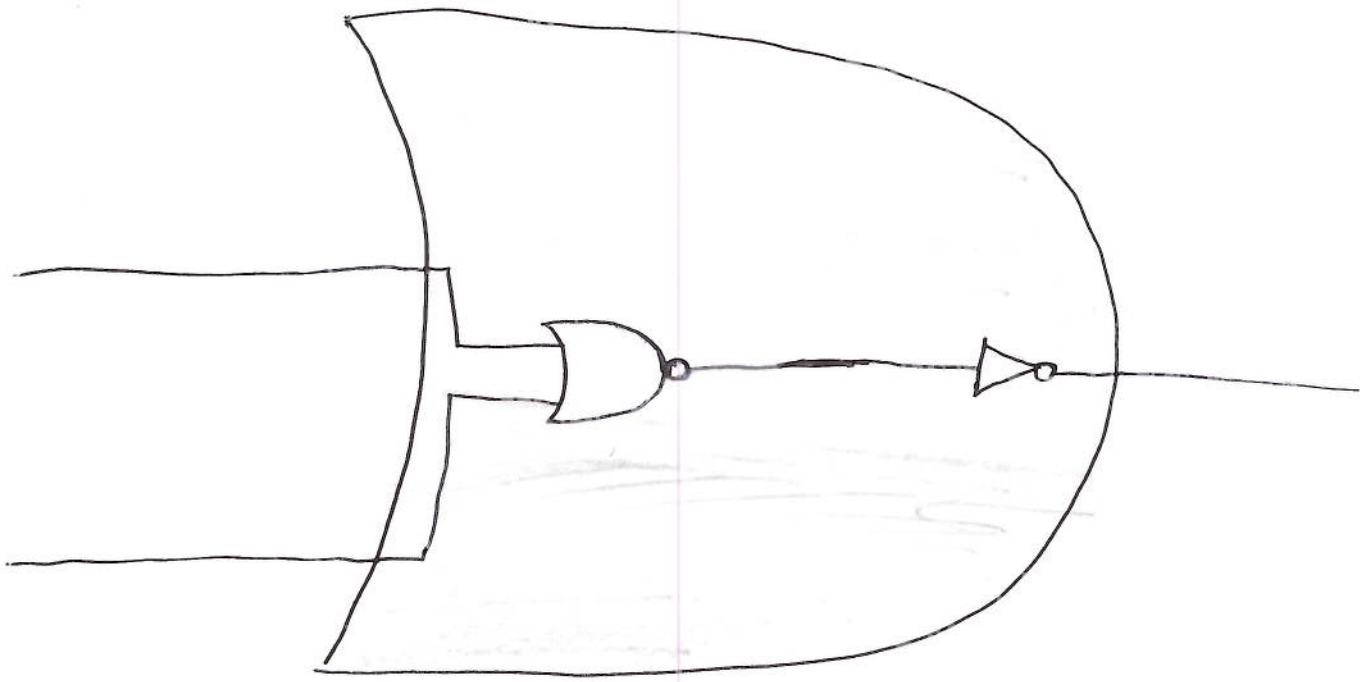
NOT from NAND and NOR



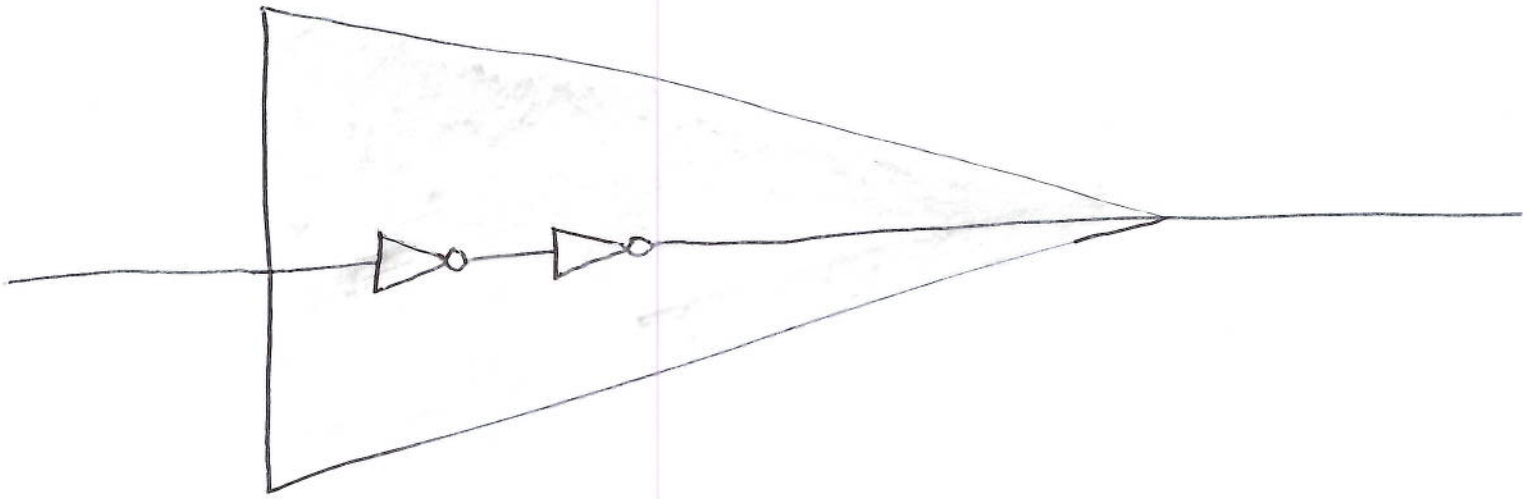


AND and OR are not fundamental.

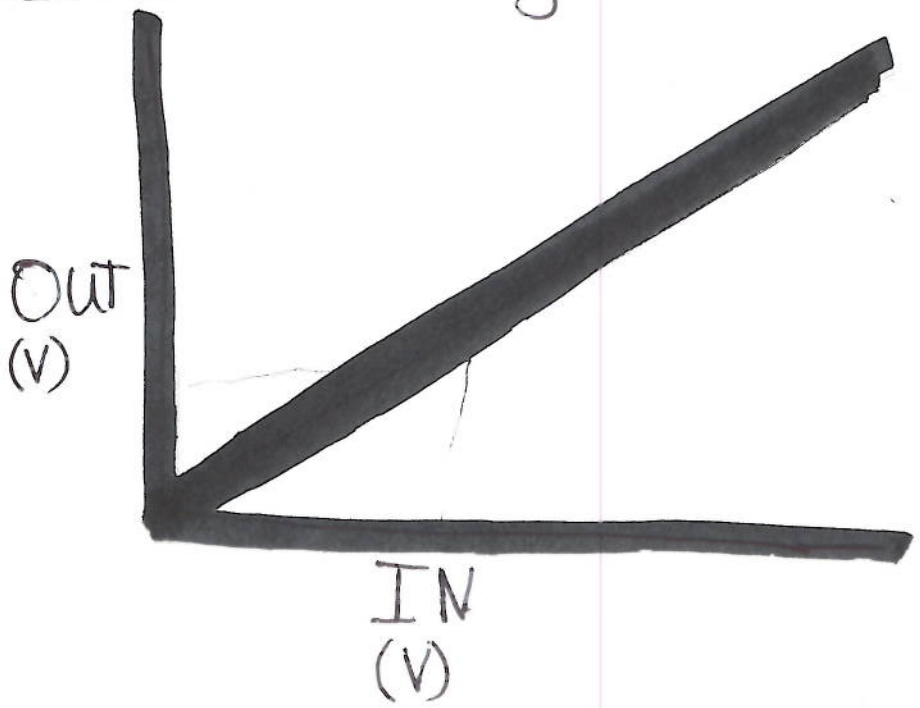




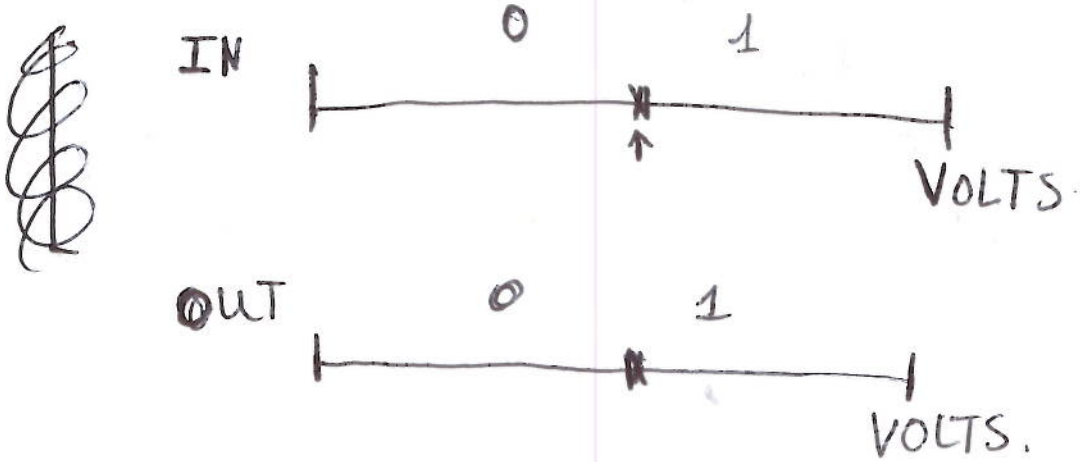
Buffers are not fundamental.



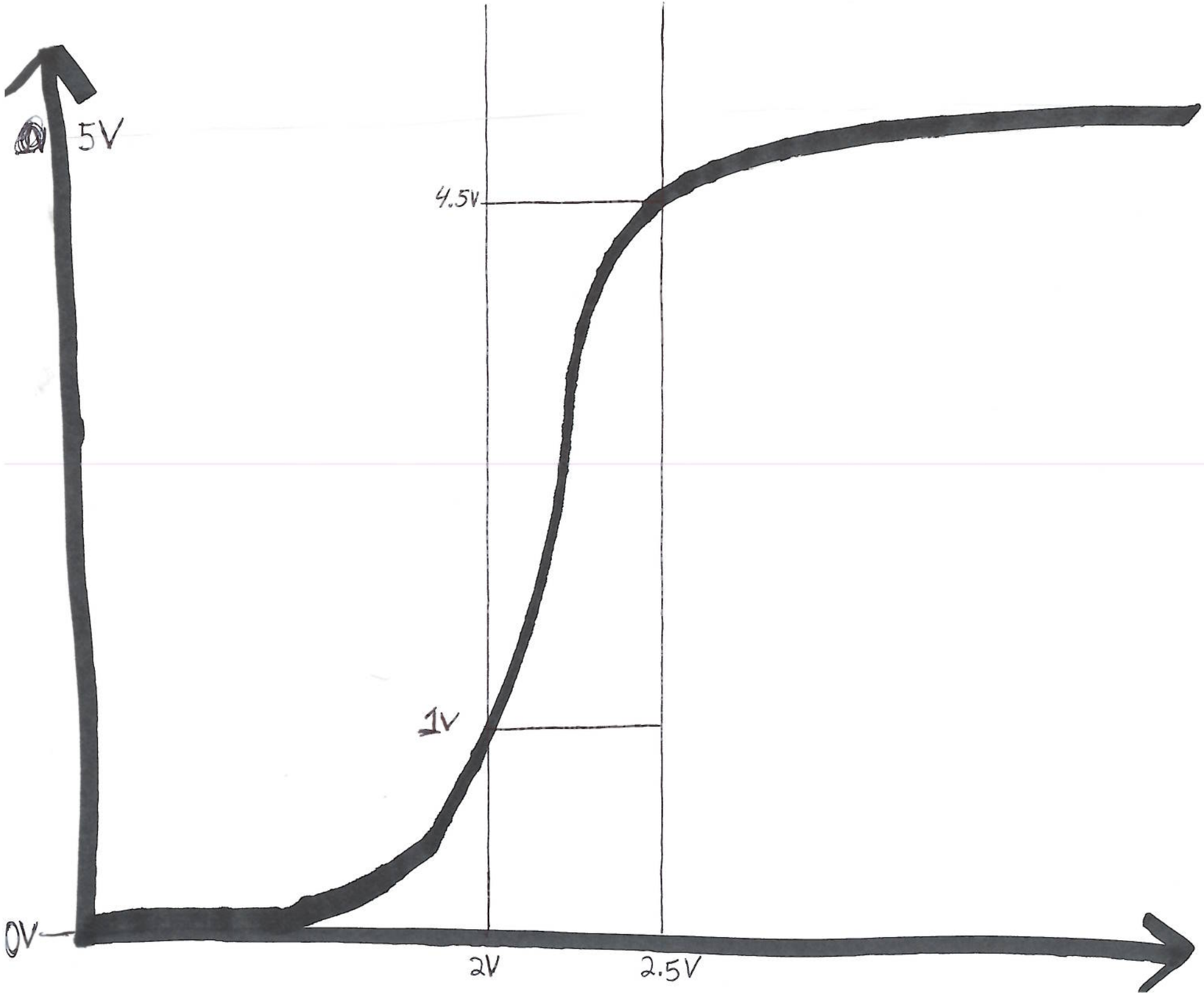
What makes a good buffer?



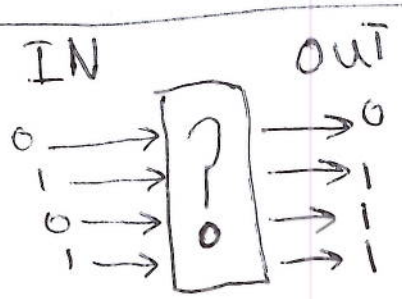
Broad tip pen because this isn't perfect!
There will be error!



BAD


5V
4.5V
1V
0V
2V
2.5V

Combinational devices



- How to use:
  1) Apply input voltages on input pins.
  2) Wait a while.
  3) Observe output voltages on output pins.

- Properties
  1) Once you've waited long enough for the 'right' answer, the answer will not change.
  2) Applying the same inputs (1's an 0's) will give you the same output every time.

THEREFORE:

- The output of a given combinational device is a pure function of its inputs.
- There exists a (possibly large) table mapping inputs to outputs!! This table defines the combinational device!

Binary counting

- Computers are good at counting and working in BINARY!
- (Computers use true and false equivalent to 0 and 1)
- How to count in binary?

0
1
10
11
100
101
110
111
1000
1001
1010
1011
1100
1101
1110
1111
10000
10001
10010
10011
⋮

- Terminology:

index 9. index 0

1 0 0 1 0 0 1 1 0 1

High bit low bit.

~~index 9~~ ~~index 0~~

Binary to decimal

Binary : Base 2
Decimal: Base 10

Binary	Decimal
1	1
10	2
100	4
1000	8
10000	16
100000	32
1000000	64
10000000	128
100000000	256
1000000000	512
10000000000	1024
100000000000	2048

Binary gets long faster!

1001101

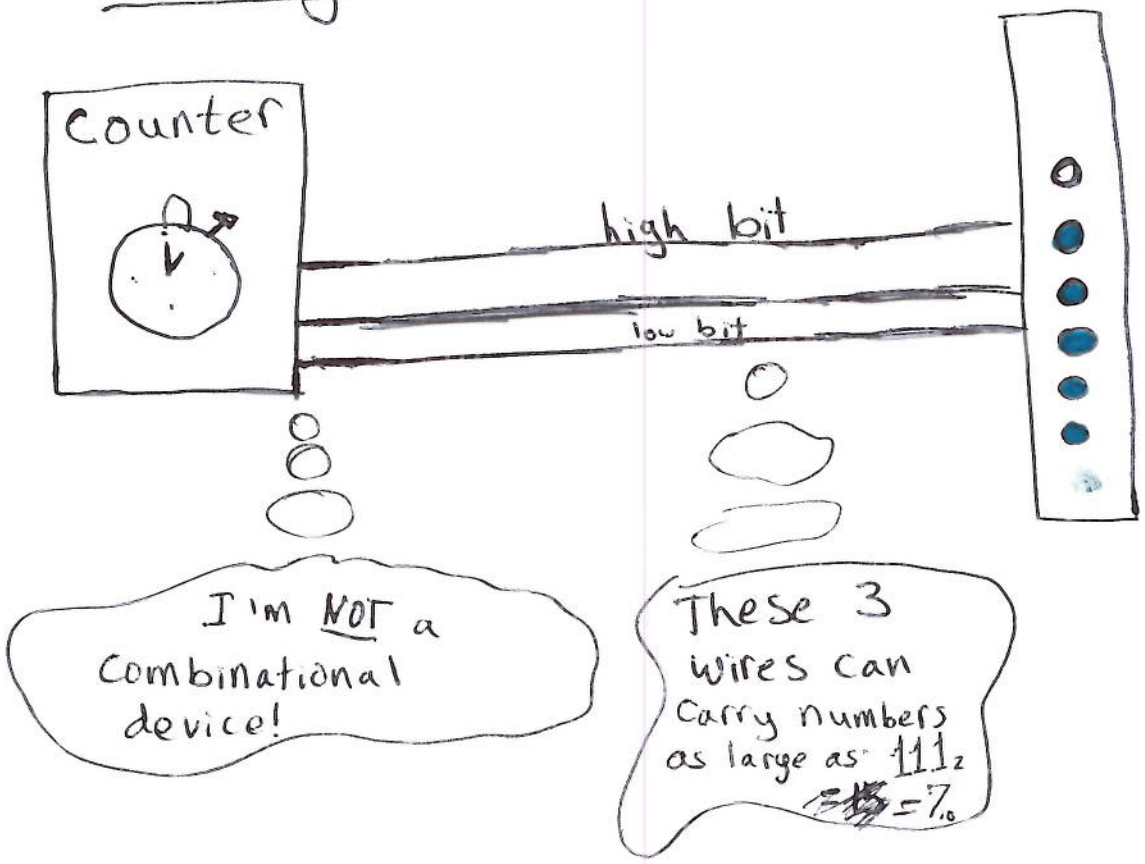
64 32 16 8 4 2 1

64 + 8 + 4 + 1

77

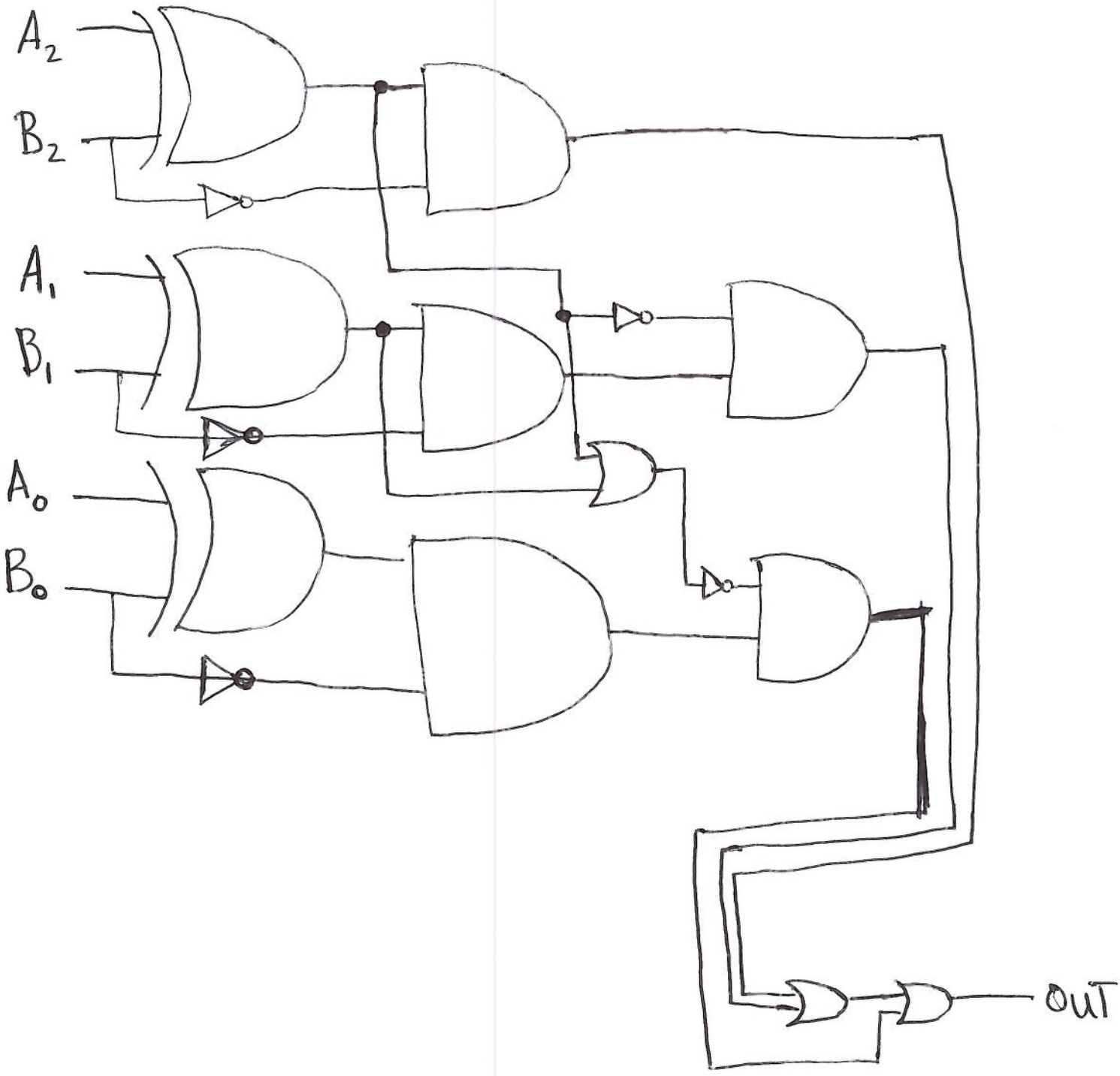
Challenge

Design a set of simple comparators.



- The counter on the left cycles through the outputs 000 through 111.
- The device on the right lights up more lights as the counter counts up. When the counter outputs 0, the lights are off.
  - When it outputs 1, 1 light comes on (the bottom one).
  - When outputs 2, the bottom 2 lights come on
- Your job: build a combinational device that controls each light.

FIRST: What is the rule for the nth light being ON?


A_2
B_2
A_1
B_1
A_0
B_0
OUT

$\geq$ is enough!

$A \geq B$ iff $A \geq B$

$A < B$ iff NOT$(A \geq B)$

$A = B$ iff $(A \geq B$ AND $B \geq A)$

$A \leq B$ iff $(A < B$ OR $A = B)$

$A > B$ iff NOT$(A \leq B)$