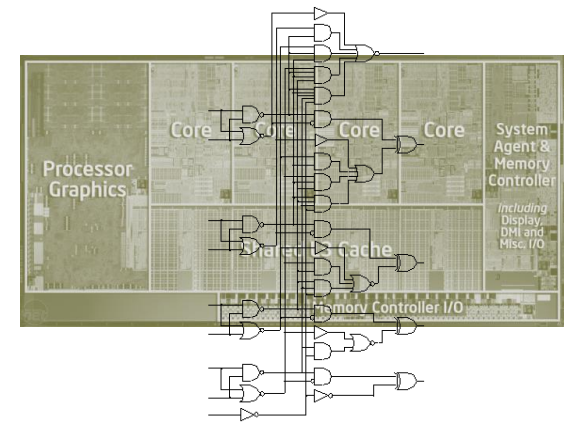




고려대학교
KOREA UNIVERSITY



COSE221, COMP211 Logic Design

Lecture 2. Logic Gates

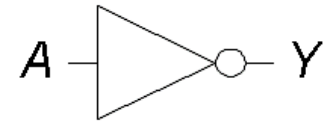
Prof. Taeweon Suh

Computer Science & Engineering

Korea University

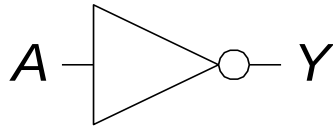
Logic Gates

- Logic gates are simple digital circuits that take one or more binary inputs and produce a binary output
 - Single-input logic gates
 - Inverter, Buffer
 - Two-input logic gates
 - AND, OR, XOR, NAND, NOR, XNOR etc
 - Multiple-input logic gates
 - AND, OR, XOR, NAND, NOR, XNOR etc
- Logic gates are prepared and given to you in the library of Computer-Aided Design (CAD) tools



Single-Input Logic Gates

NOT

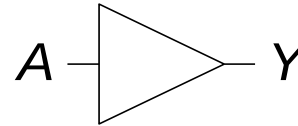


Boolean equation $Y = \overline{A}$

Truth table

A	Y
0	1
1	0

BUF

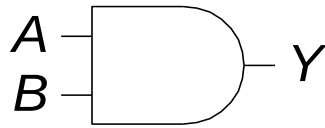


$Y = A$

A	Y
0	0
1	1

Two-Input Logic Gates

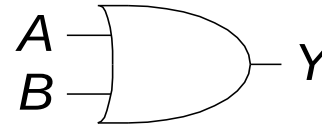
AND



$$Y = AB$$

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

OR

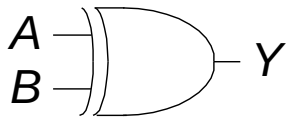


$$Y = A + B$$

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

More Two-Input Logic Gates

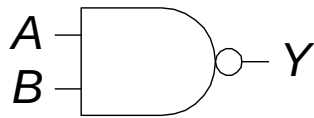
XOR



$$Y = A \oplus B$$

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

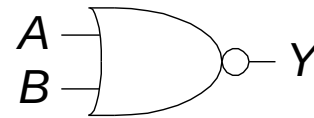
NAND



$$Y = \overline{AB}$$

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

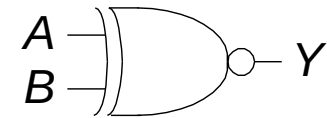
NOR



$$Y = \overline{A + B}$$

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

XNOR



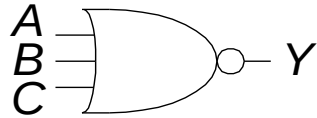
$$Y = \overline{A \oplus B}$$

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

- 2 input XOR (Exclusive OR) is “true” if either A or B (not both) is true

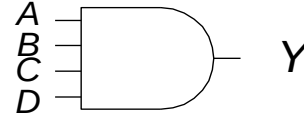
Multiple-Input Logic Gates

NOR3



$$Y = \overline{A+B+C}$$

AND4



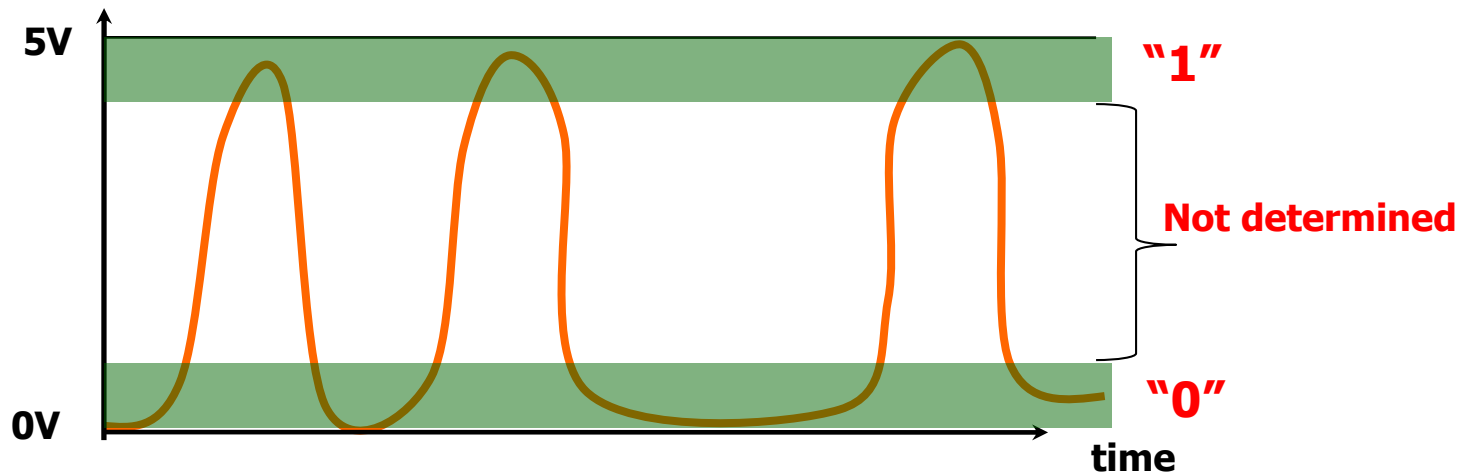
$$Y = ABCD$$

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

- Note that N-input XOR is “true” if an odd number of inputs is true

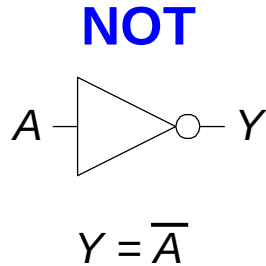
Logic Levels

- Logic levels define discrete voltages to represent 1 and 0
 - For example, we could define:
 - 0 to be 0 volts (ground)
 - 1 to be 5 volts (V_{DD})
 - But what if our gate produces, for example, 4.99 volts? Is that still a 1?
 - What about 3.2 volts?

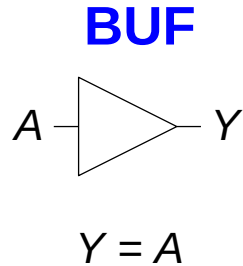


BTW, How Logic Gates are Built?

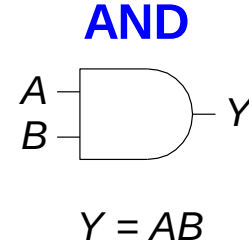
- What we saw so far are just symbols, right?
- What are those symbols built from in the real world?



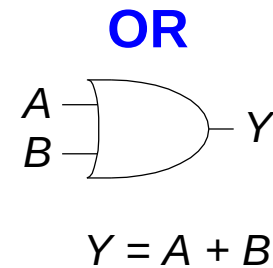
A	Y
0	1
1	0



A	Y
0	0
1	1



A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

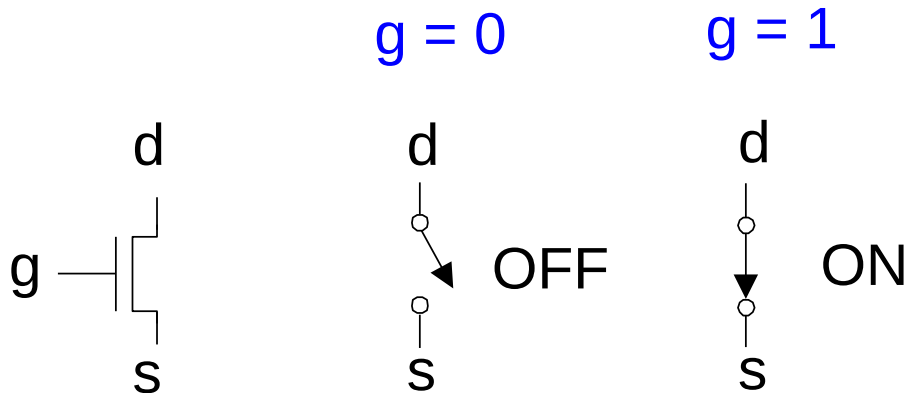


A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Transistors!

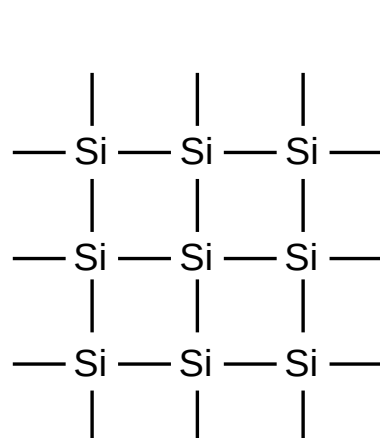
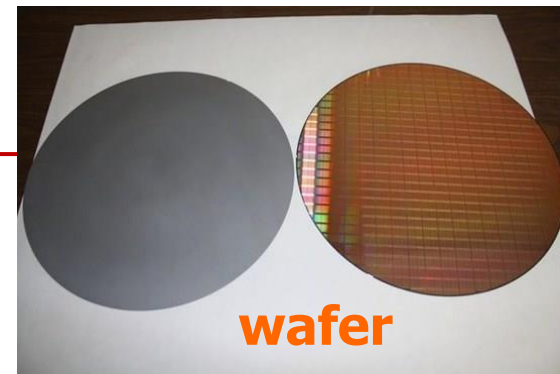
Transistor

- **Transistor is a three-ported voltage-controlled switch**
 - Two of the ports are connected depending on the voltage on the third port
 - For example, in the switch below the two terminals (d and s) are connected (ON) only when the third terminal (g) is 1
- Hmmmm, it is still a symbol! What is it really built from?

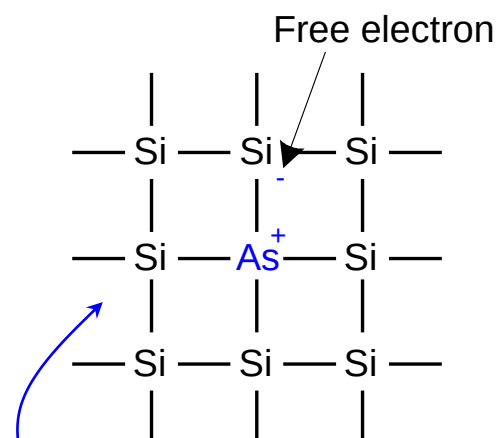


Silicon

- Transistors are built out of silicon, a semiconductor
- Silicon is not a conductor
- Doped silicon is a conductor
 - n-type (free **n**egative charges, electrons)
 - p-type (free **p**ositive charges, holes)



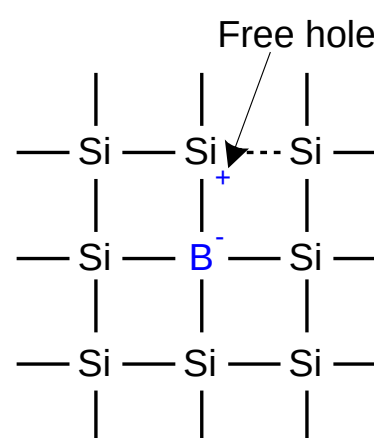
Silicon Lattice



n-Type

Majority: Electrons

Minority: Holes



p-Type

Majority: Holes

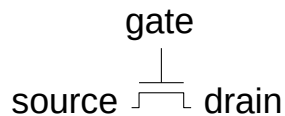
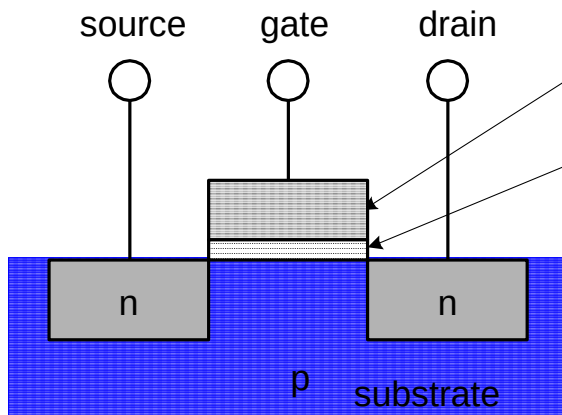
Minority: Electrons

Periodic Table of the Elements

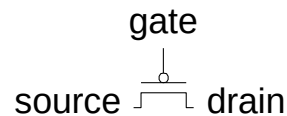
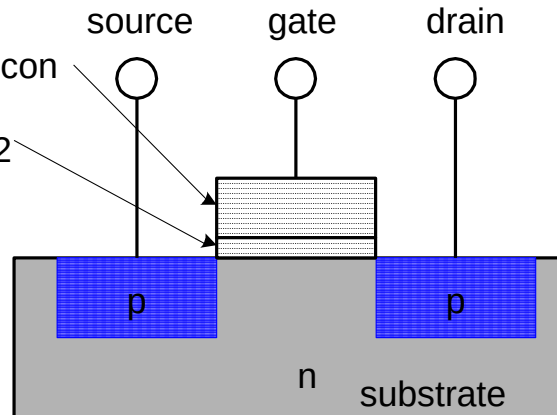
PERIODIC TABLE																	
Atomic Properties of the Elements																	
NIST																	
National Institute of Standards and Technology																	
Technology Administration, U.S. Department of Commerce																	
Physics Laboratory																	
Standard Reference Data Group																	
www.nist.gov/srd																	
Frequently used fundamental physical constants																	
For the most accurate values of these and other constants, visit physics.nist.gov/constants																	
1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs																	
□ Solids □ Liquids □ Gases □ Artificially Prepared □ Solids □ Liquids □ Gases □ Artificially Prepared																	
speed of light in vacuum c 299 792 458 m s⁻¹ (exact) Planck constant h 6.626 070 15 × 10⁻³⁴ J s elementary charge e 1.602 176 634 × 10⁻¹⁹ C electron mass m_e 9.109 383 56 × 10⁻³¹ kg proton mass m_p 1.672 621 9 × 10⁻²⁷ kg fine-structure constant α 1/137.035 999 084 Rydberg constant R_∞ 10 973 731.568 160 m⁻¹ Boltzmann constant k_B 1.380 658 × 10⁻²³ J K⁻¹																	
13 B 14 C 15 N 16 O 17 F 18 Ne																	
11 Na 12 Mg 13 Al 14 Si 15 P 16 S																	
19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr																	
25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn																	
31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr																	
37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo																	
43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd																	
49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe																	
55 Cs 56 Ba 57 La 58 Ce 59 Pr 60 Nd																	
61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy																	
67 Ho 68 Er 69 Tm 70 Yb 71 Lu 72 Hf																	
73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt																	
79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po																	
85 At 86 Rn 87 Fr 88 Ra 89 Ac 90 Th																	
91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm																	
97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No																	
103 Lr 104 Rf 105 Db 106 Sg 107 Bh 108 Hs																	
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MOS Transistors

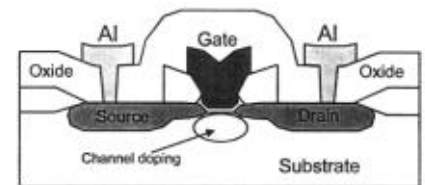
- Metal oxide silicon (MOS) transistors:
 - Polysilicon (used to be **Metal**) gate
 - **Oxide** (silicon dioxide) insulator
 - Doped **Silicon** substrate and wells



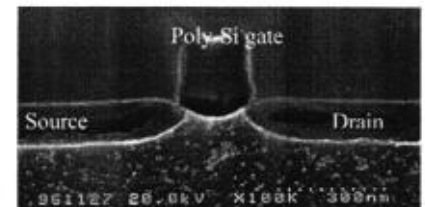
nMOS



pMOS



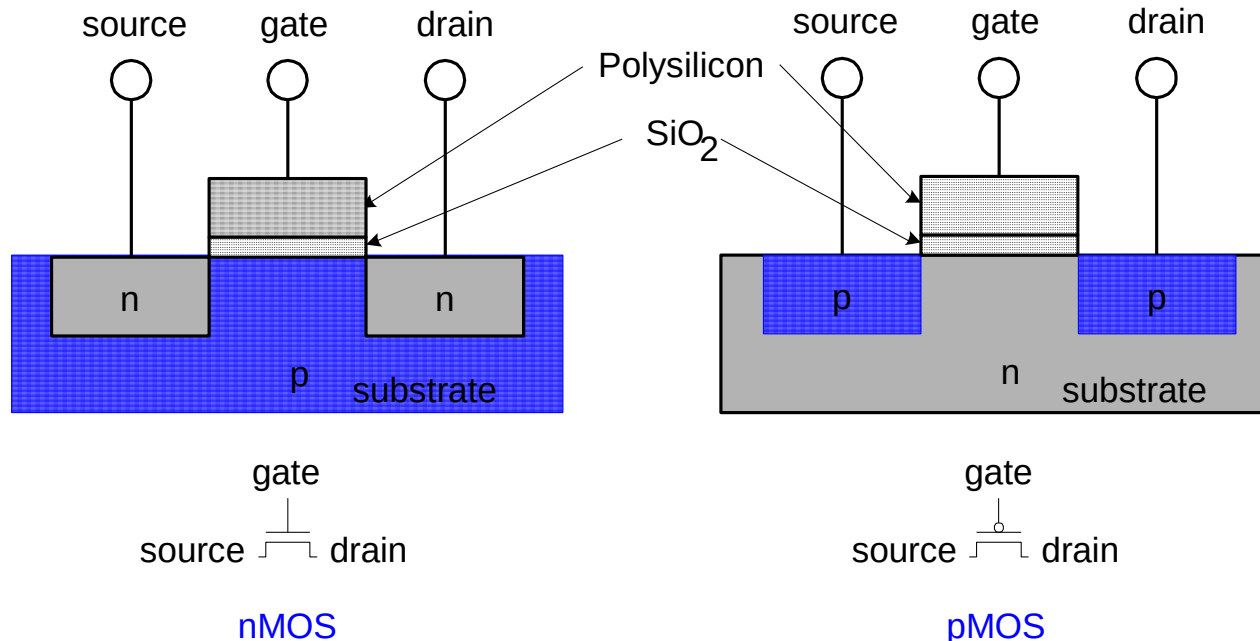
(a)



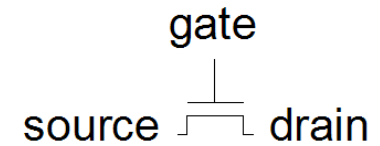
(b)

MOS Transistors

- The MOS sandwich acts as a capacitor (two conductors with insulator between them)
- When voltage is applied to the gate, the opposite charge is attracted to the semiconductor on the other side of the insulator, which could form **a channel** of charge

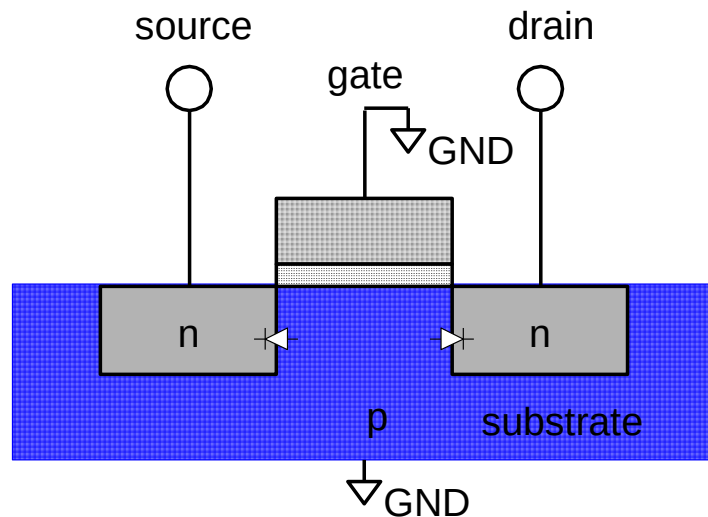


nMOS Transistor



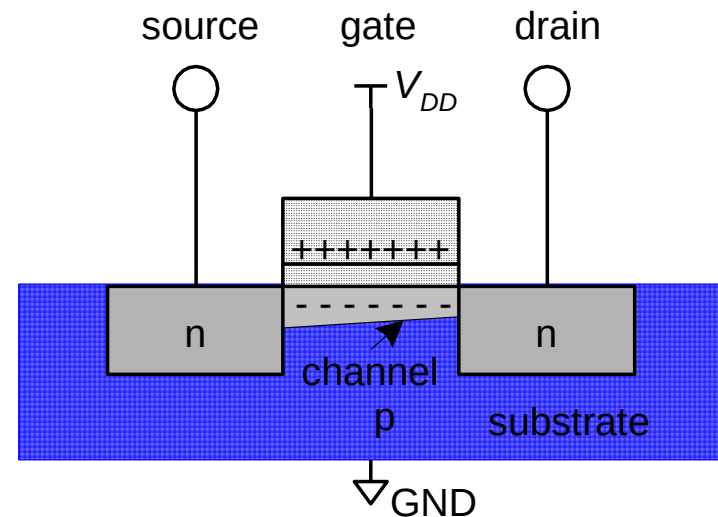
Gate = 0 (OFF)

(**no connection** between source and drain)

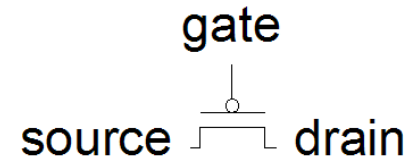


Gate = 1 (ON)

(**connection** between source and drain)



pMOS Transistor

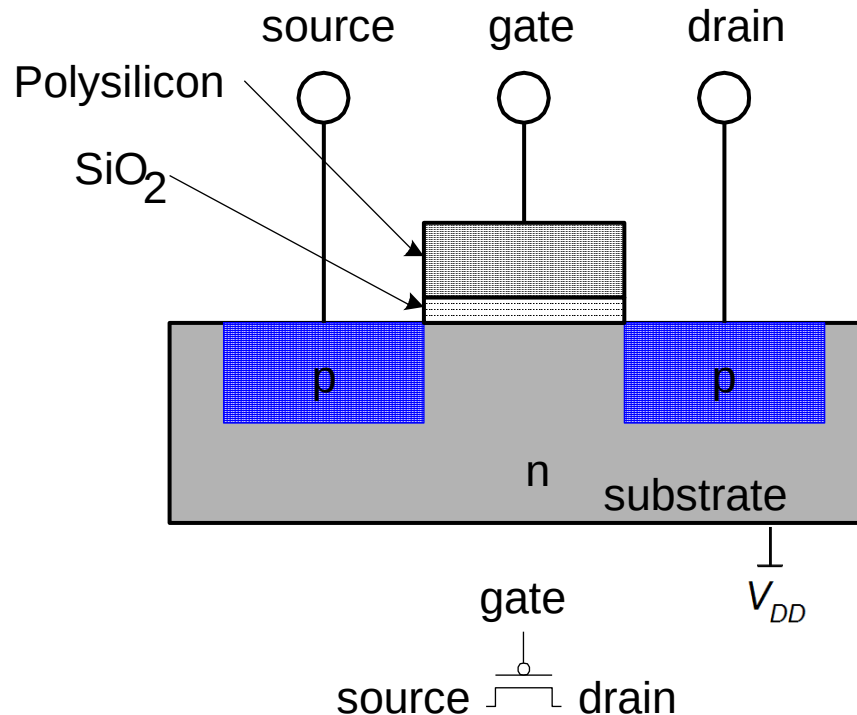


Gate = 0 (ON)

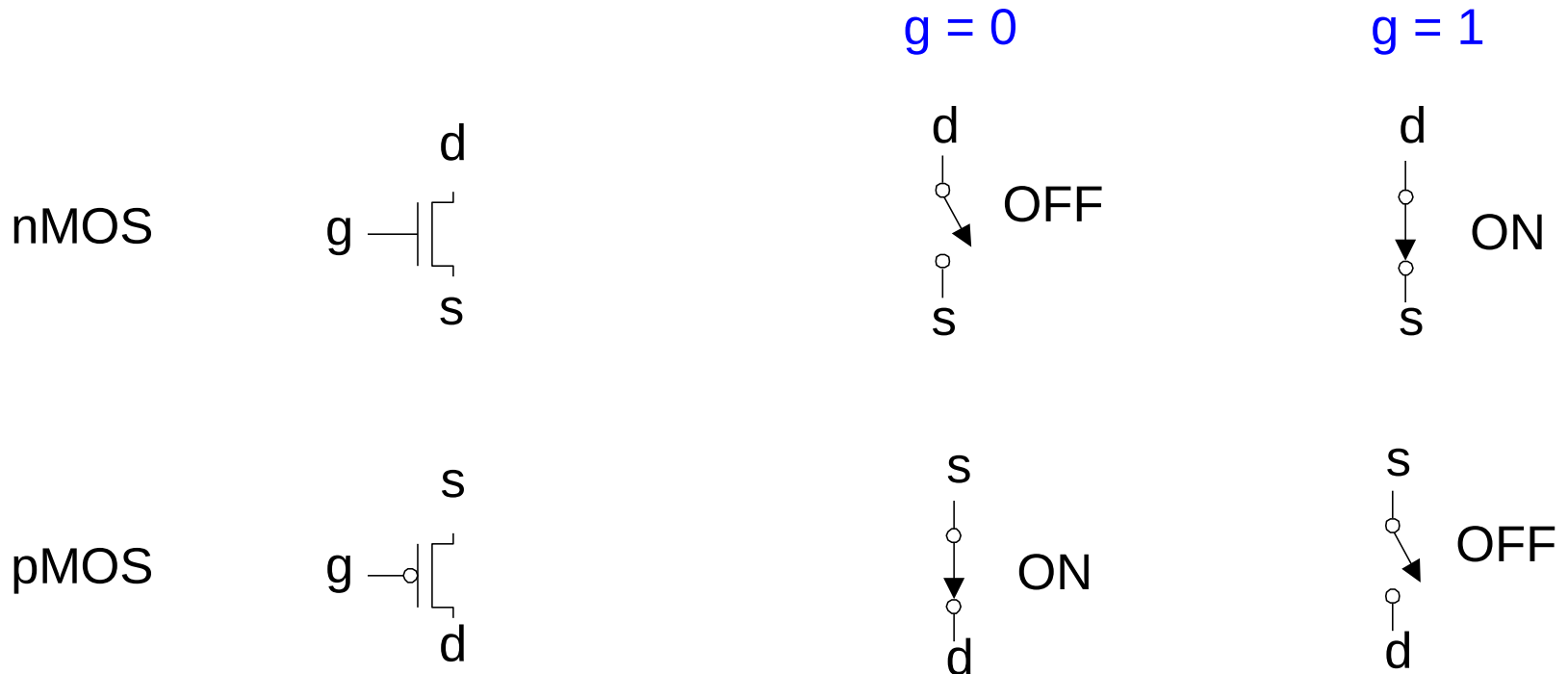
(**connection** between source and drain)

Gate = 1 (OFF)

(no **connection** between source and drain)

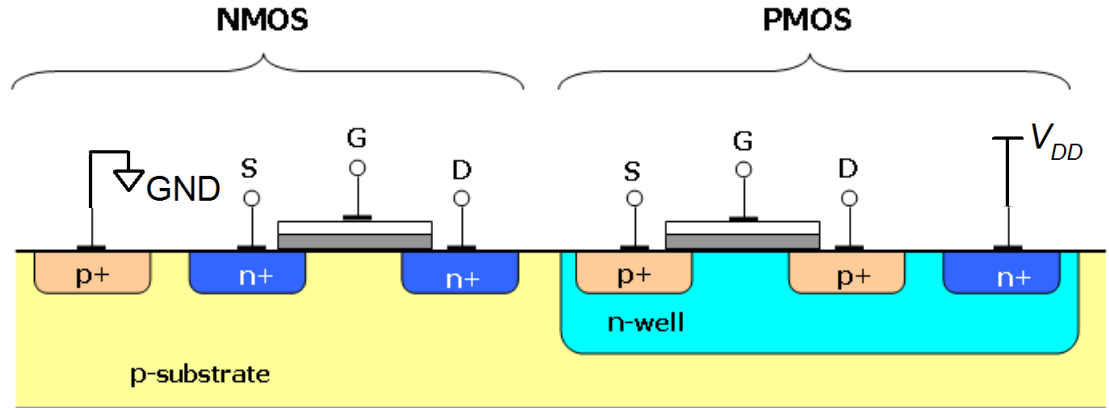
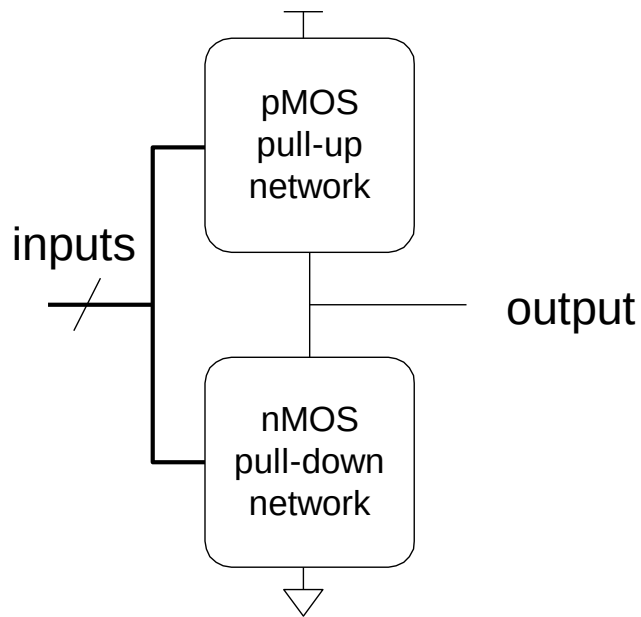


Transistor Function



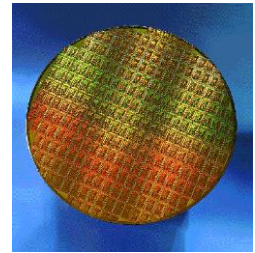
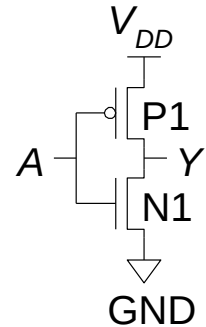
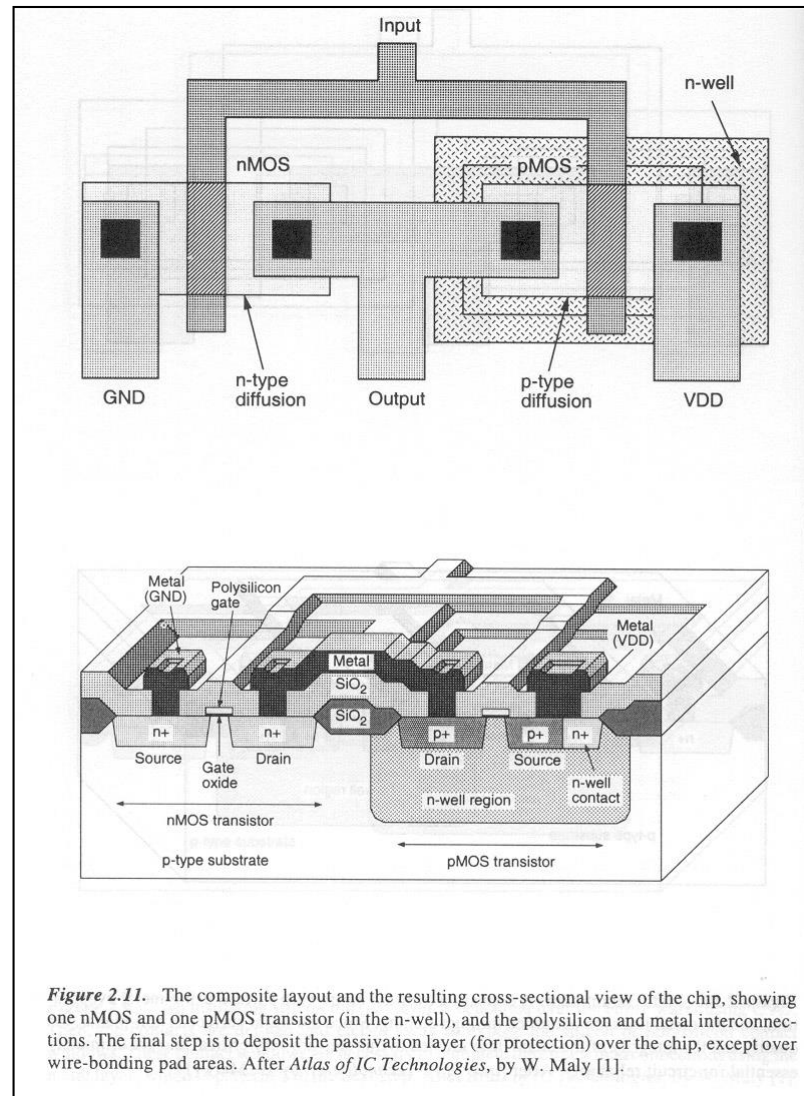
CMOS (Complementary MOS)

- CMOS is used to build the vast majority of all transistors fabricated today, to build **low-power** logic gates
 - nMOS transistors pass good 0's, so connect source to GND
 - pMOS transistors pass good 1's, so connect source to V_{DD}



CMOS Layout

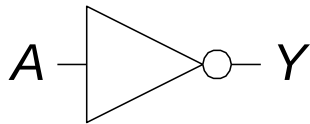
- Top view



- Cross-section

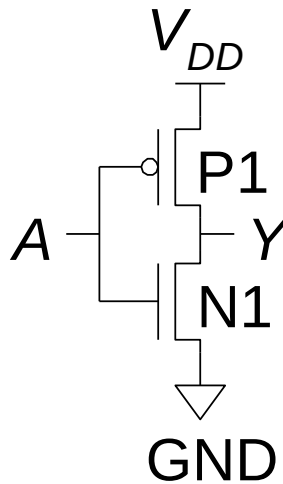
NOT Gate

NOT

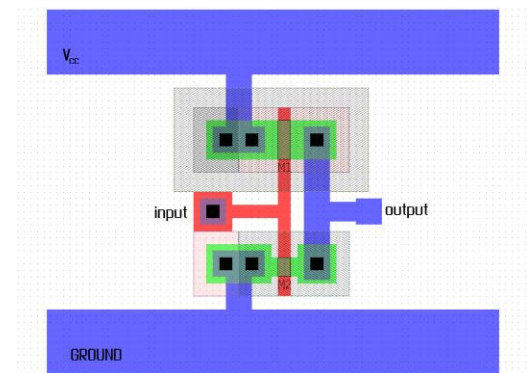


$$Y = \overline{A}$$

A	Y
0	1
1	0



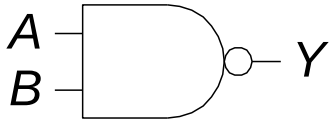
Layout (top view)



A	P1	N1	Y
0	ON	OFF	1
1	OFF	ON	0

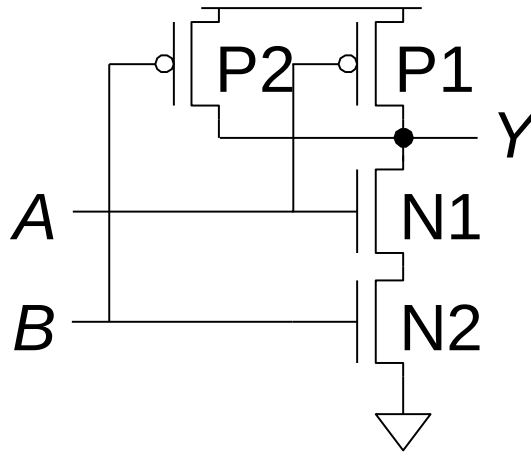
NAND Gate

NAND

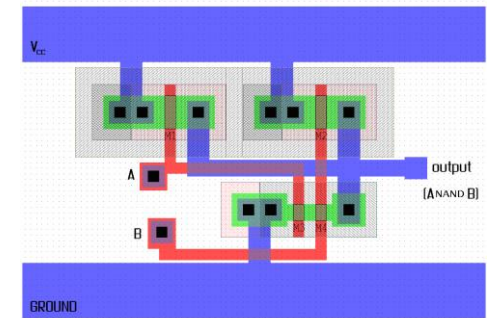


$$Y = \overline{AB}$$

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0



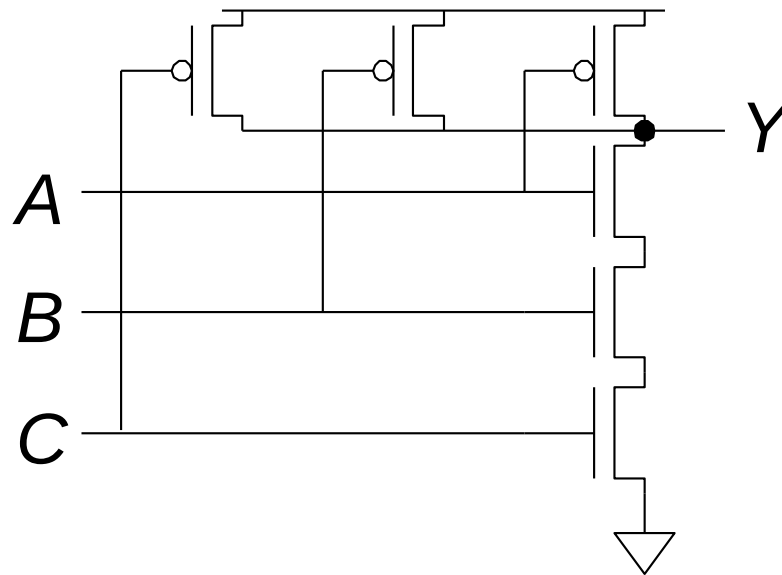
Layout



A	B	P1	P2	N1	N2	Y
0	0	ON	ON	OFF	OFF	1
0	1	ON	OFF	OFF	ON	1
1	0	OFF	ON	ON	OFF	1
1	1	OFF	OFF	ON	ON	0

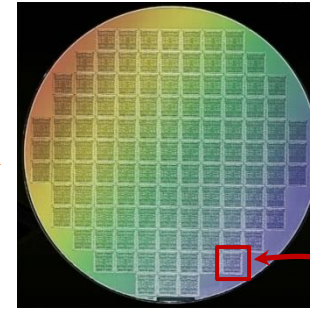
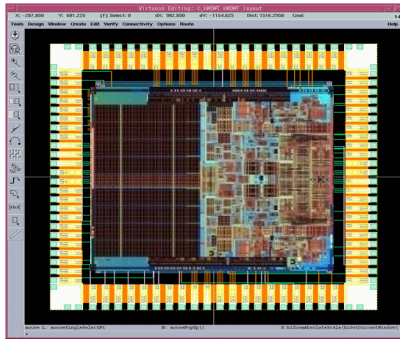
3-Input NAND Gate

- How do you build a three-input NAND gate?

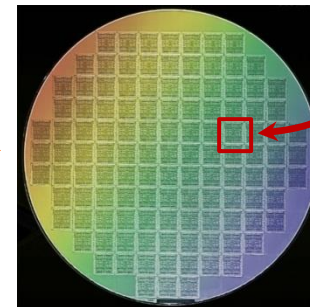
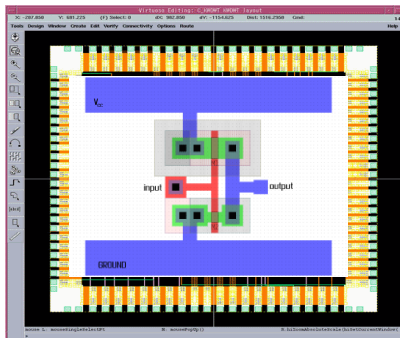


Now, Let's Make an Inverter Chip

Core 2 Duo



Your Inverter chip



die

- **Yield** means how many dies are working correctly after fabrication

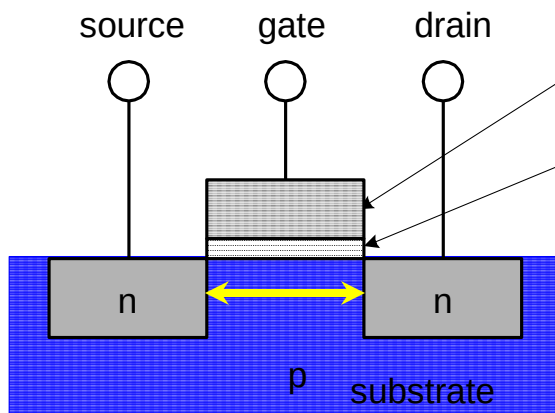
Semiconductor Fab. at TSMC



http://www.youtube.com/watch?v=4Q_n4vdyZzc

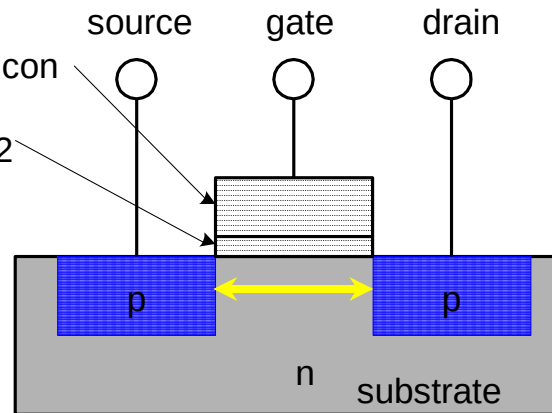
(Semiconductor) Technology

- **IC (Integrated Circuit)** combined dozens to hundreds of transistors into a single chip
- **VLSI (Very Large Scale Integration)** is used to describe the tremendous increase in the number of transistors in a chip
- **(Semiconductor) Technology**: How small can you make a transistor
 - **0.1 μm (100nm), 90nm, 65nm, 45nm, 32nm, 22nm, 14nm technologies**



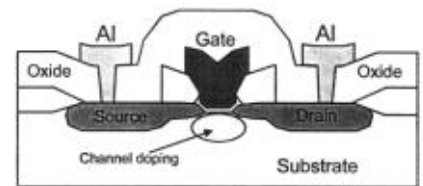
gate
source — drain

nMOS

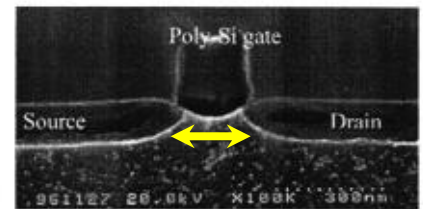


gate
source — drain

pMOS

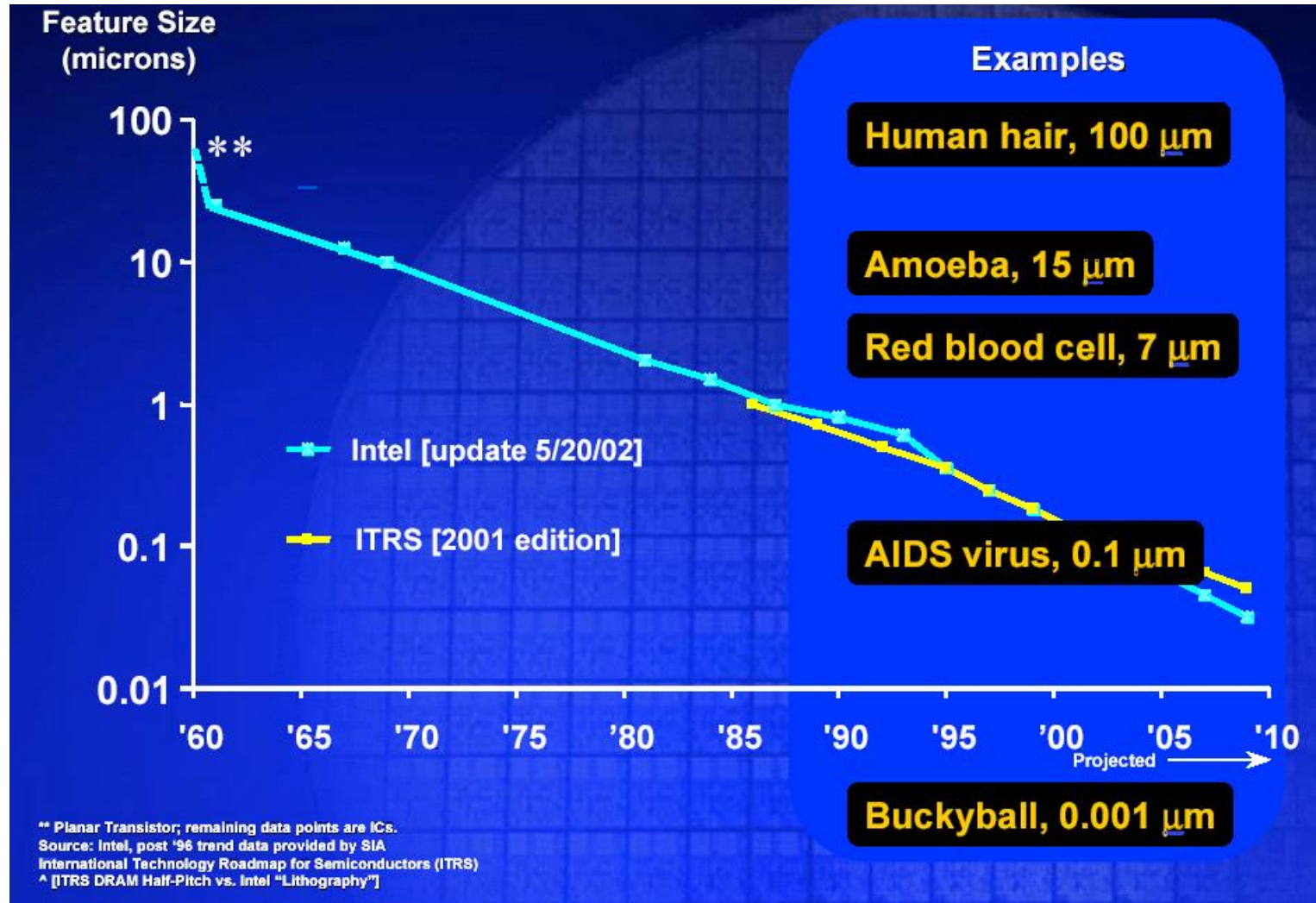


(a)



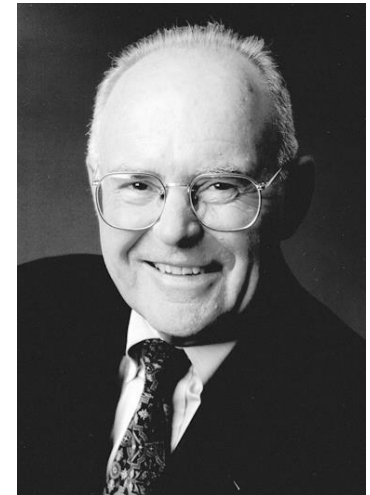
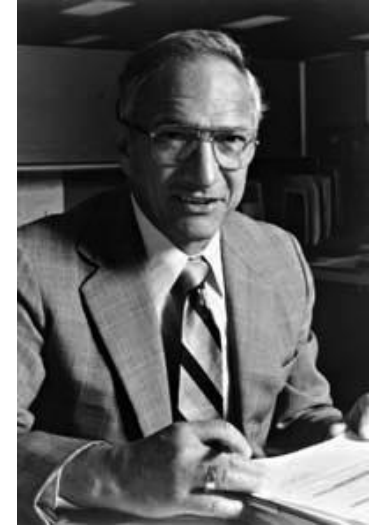
(b)

Feature Size (Technology) Trend



Intel Founders

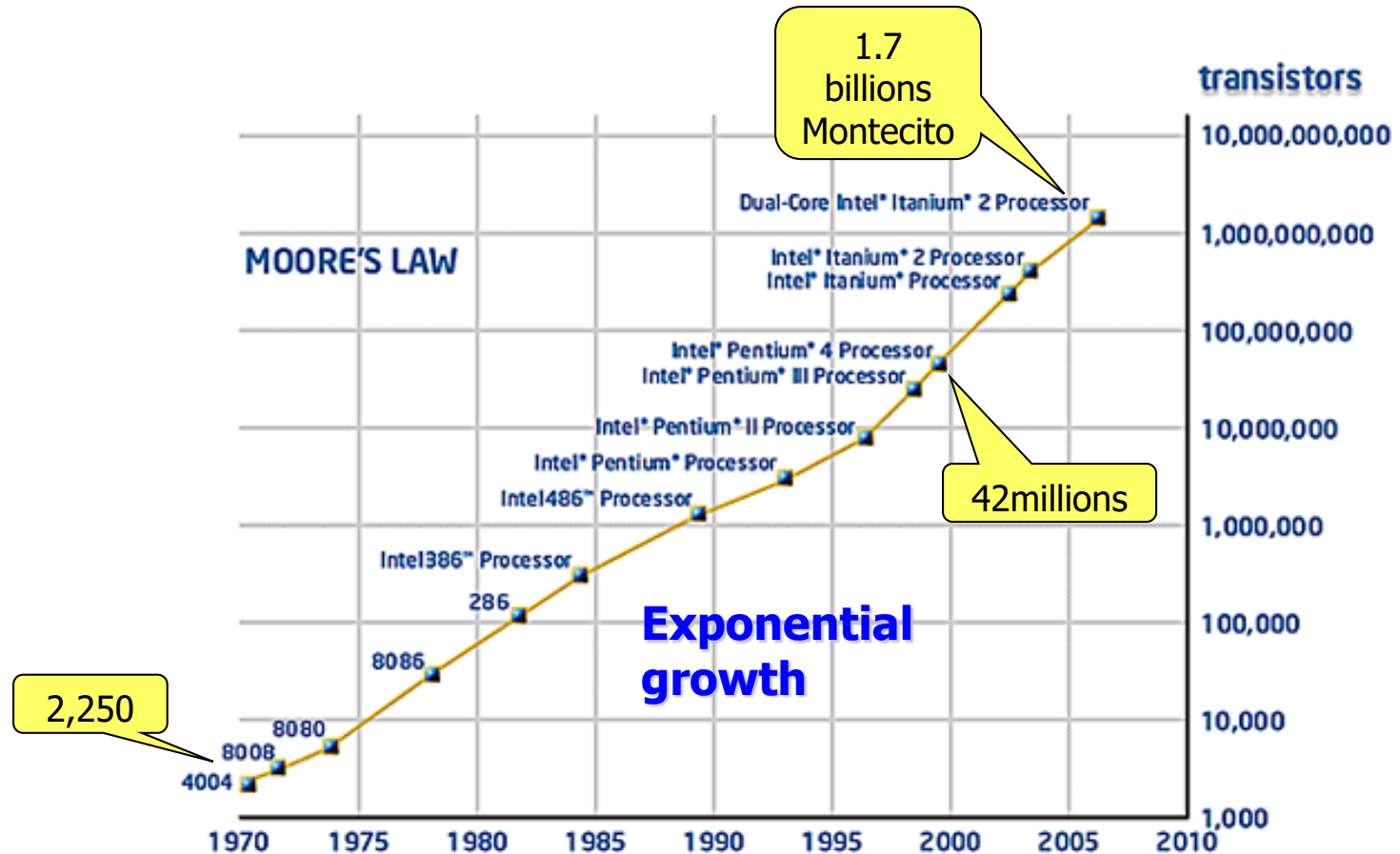
- **Robert Noyce** (1927~1990)
 - Nicknamed “Mayor of Silicon Valley”
 - Cofounded Fairchild Semiconductor in 1957
 - Cofounded Intel in 1968
 - Co-invented the **integrated circuit (IC)**
- **Gorden Moore** (1929~)
 - Cofounded Intel in 1968 with Robert Noyce.
 - **Moore’s Law**: the number of transistors on a computer chip doubles every year (observed in 1965)
 - Since 1975, transistor counts have doubled every two years





Moore's Law

- Transistor count will be doubled every 18 months



x86?

- What is x86?
 - Generic term referring to processors from Intel, AMD and VIA
 - Derived from the model numbers of the first few generations of processors:
 - 80**86**, 802**86**, 803**86**, 804**86** → **x86**
 - Now it generally refers to processors from Intel, AMD, and VIA
 - x86-16: 16-bit processor
 - x86-32 (aka IA32): 32-bit processor * IA: Intel Architecture
 - x86-64: 64-bit processor
- Intel takes about 80% of the PC market and AMD takes about 20%
 - Apple also have been introducing Intel-based Mac from Nov. 2006



Power under the hood.

Inside the MacBook is a powerful 2.13GHz Intel Core 2 Duo processor based on advanced Core microarchitecture. MacBook provides a fast 1066MHz frontside bus and 3MB of shared L2 cache, so you'll have more than enough horsepower to get the job done.



x86 History (as of 2008)

40 years of changing the world

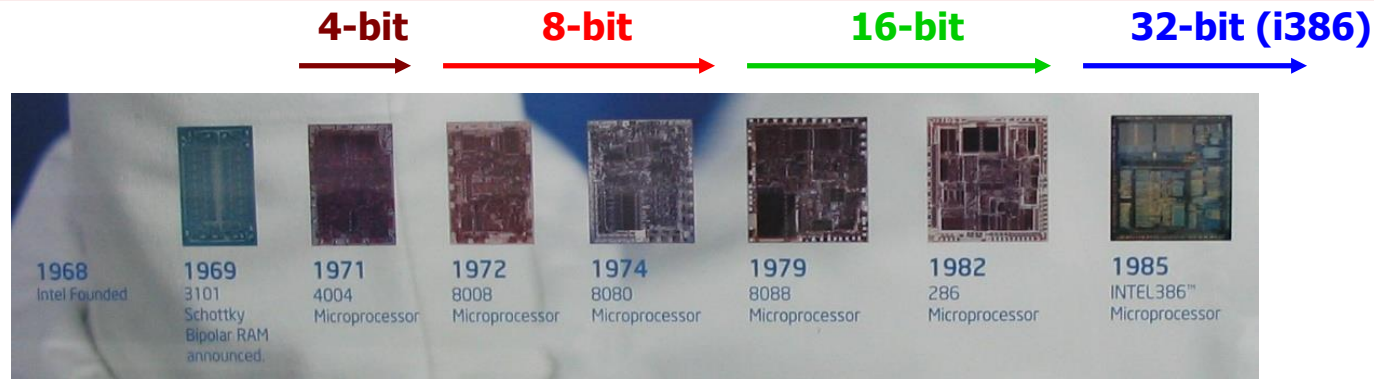
Since Intel's earliest days, we've harnessed the power of the transistor to transform what's possible for people around the world. In our first 40 years we've redefined how people live, work and play. Imagine what we can do together in the next 40.

Learn more at next40.intel.com

intel Leap ahead™

Year	Processor
1968	Intel 4004
1969	Intel 8008
1971	Intel 8080
1972	Intel 8085
1974	Intel 8088
1979	Intel 8086
1982	Intel 286
1985	Intel 386
1989	Intel 486
1993	Intel Pentium
1997	Intel Pentium Pro
1999	Intel Pentium 4
2000	Intel Pentium 4
2006	Intel Core 2 Duo
2008	Intel Core 2 Duo

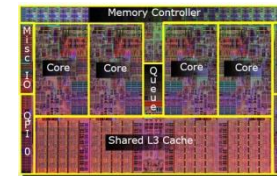
x86 History (Cont.)



32-bit (i586)

32-bit (i686)

64-bit (x86_64)

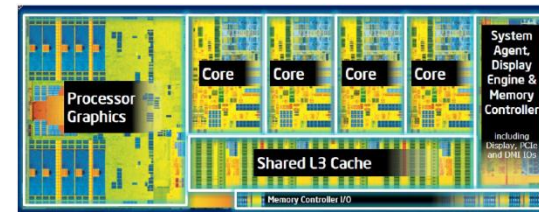
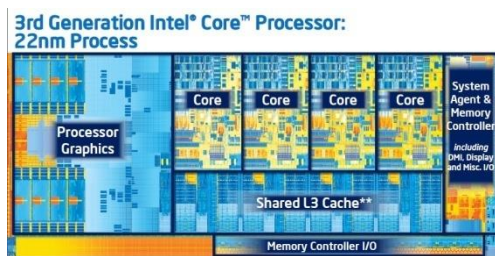


2009
1st Gen. Core i7 (Nehalem)



2011
2nd Gen. Core i7 (Sandy Bridge)

2012
3rd Gen. Core i7 (Ivy Bridge)

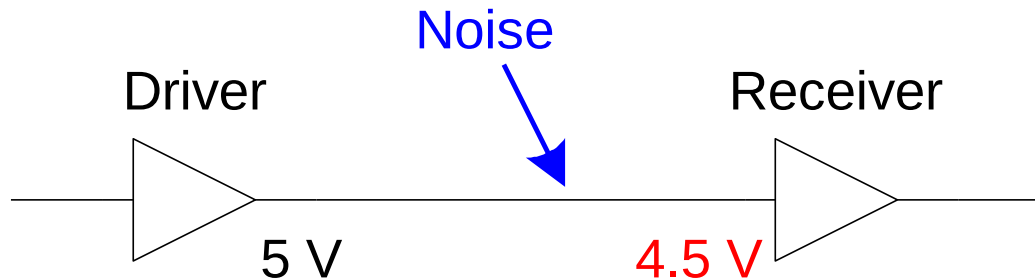


2013
4th Gen. Core i7 (Haswell)

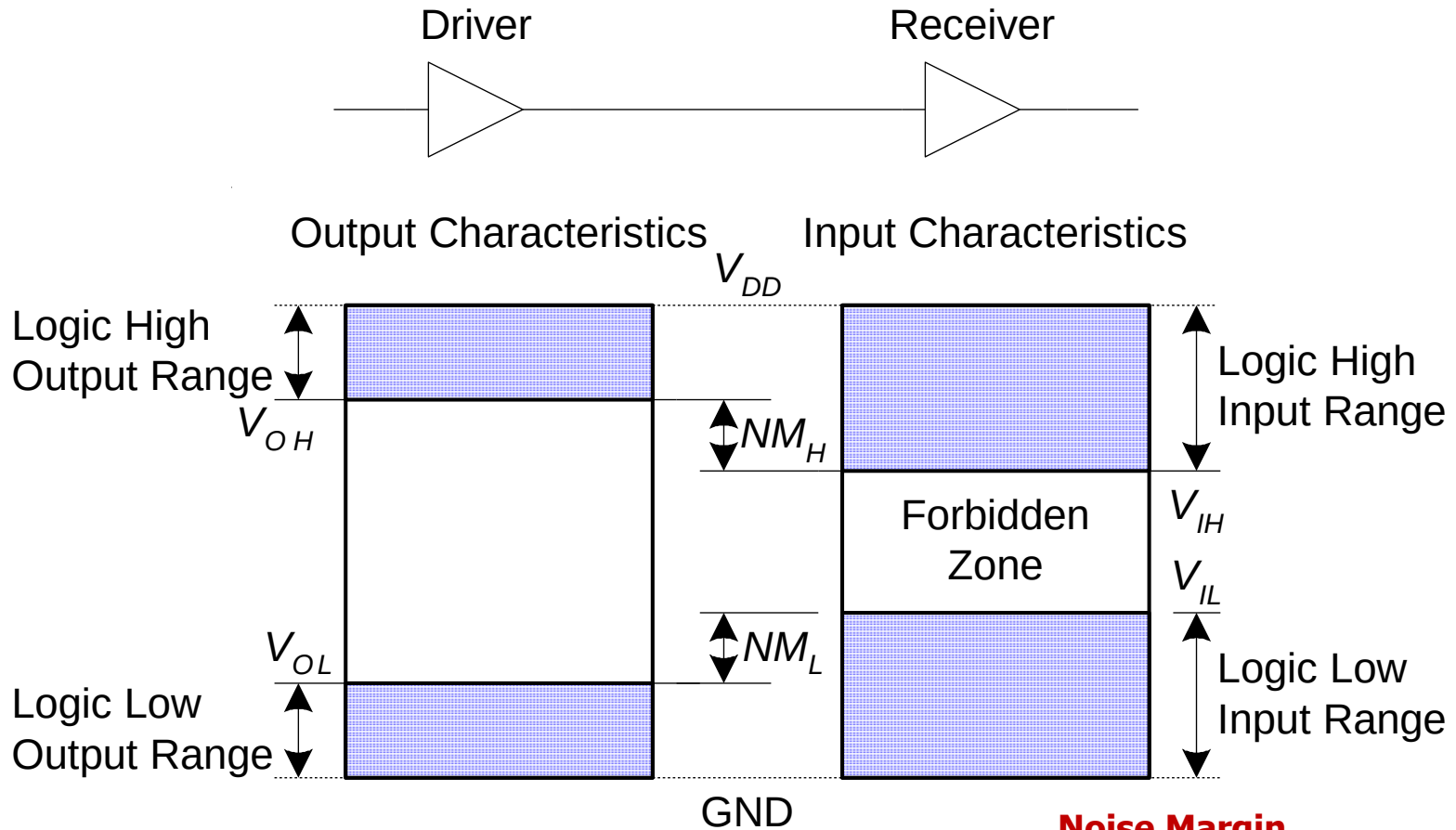
Backup Slides

Logic Levels

- Define **a range** of voltages to represent 1 and 0
- Define **different ranges for outputs and inputs** to allow for **noise** in the system
 - Noise is anything that degrades the signal
 - For example, a gate (driver) could output a 5 volt signal but, because of losses in the wire and other noise, the signal could arrive at the receiver with a degraded value, for example, 4.5 volts



Logic Levels



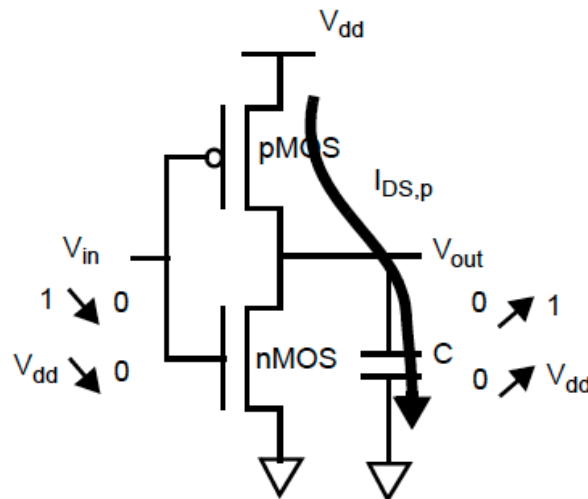
Noise Margin

$$NM_H = V_{OH} - V_{IH}$$

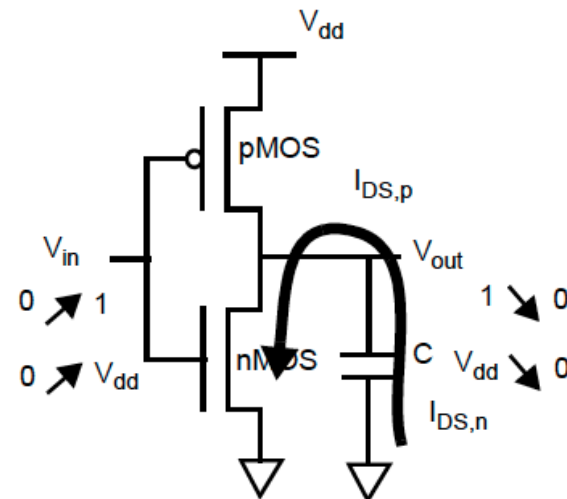
$$NM_L = V_{IL} - V_{OL}$$

CMOS Inverter

- Dynamic power is consumed when device changes ON $\rightarrow$ OFF or OFF $\rightarrow$ ON
 - Input change 1 $\rightarrow$ 0: current flows to move charges to capacitance
 - Input change 0 $\rightarrow$ 1: current flows from capacitance to ground
- **Charging and discharging of capacitance causes the power dissipation**
- But, no steady state current flow! $\rightarrow$ Low power design



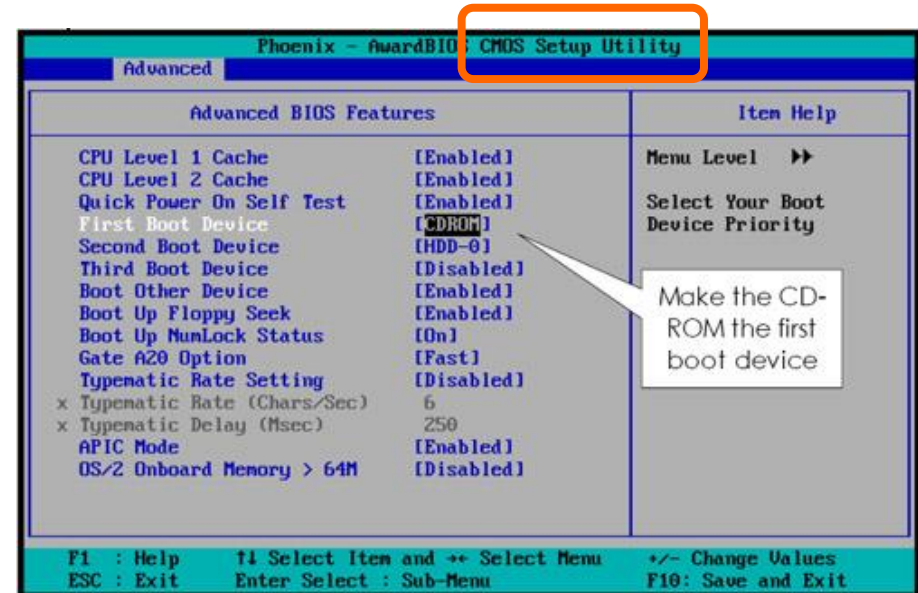
(a) Input switches from 1 to 0



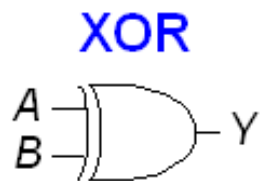
(b) Input switches from 0 to 1

Is this CMOS that CMOS in Computer?

- Non-volatile BIOS memory (NVRAM) refers to a small memory on PC motherboards that is used to store BIOS settings
 - The NVRAM has a typical capacity of 512 Bytes, which is enough for all BIOS-settings
 - It was traditionally called **CMOS RAM** because it used a low-power CMOS SRAM powered by a small battery
 - The term remains in wide use, but it has grown into a misnomer
 - Non-volatile storage in contemporary computers is often in EEPROM or flash memory



XOR Gate



$$Y = A \oplus B$$

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

