Lecture 1

信息科学与技术学院
School of Information Science and Technology

Introduction to Electronics and Switches

Haoyu Wang
ShanghaiTech University

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Outlines

- Administration
- Motivation
- Scope
- Switch Basis
- Switch Evolvement
- A CMOS NOT Gate
- Discussion

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Instructors

- Prof. Haoyu Wang
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- Prof. Junrui Liang
  - » Email: liangjr@shanghaitech.edu.cn
  - » Website: http://sist.shanghaitech.edu.cn/faculty/liangjr/
  - » Office: Research Bldg. Rm 212
  - » Office hours: Tuesday 9:15am-11:15am

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TAs

- Tianwei Wei weitw@shanghaitech.edu.cn
- Yang Li liyang@shanghaitech.edu.cn
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- TA Office Hours
  - » Weeks 13&15 (5/30/2015,6/13/2015)
    - – 19:00pm – 21:00pm
    - – 宿舍1号楼成长驿站
  - » Weeks 14&16 (6/6/2015,6/20/2015)
    - – 9:00am – 6:00pm
    - – Research center, Rm. 211 (Lab)

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Course Website

- http://shtech.org/course/ee100/

13	05-25	Introduction to Electronics and Switches	DDCA 1	Homework 0, Vocabulary, Administration
	05-28	Digital Logic		
14	06-01	Combinational Digital Circuits		
	06-04	Lab 1 Digital Circuits Lab		
15	06-08	Sequential Digital Circuits		
	06-11	Computing Units		
16	06-15	Electronics, Beyond the Logical Switches		
	06-18	Lab 2 Analog Circuits Lab		

Description

This course introduces fundamentals of information science and technology in four parts: programming, intelligent machines and robotics, signal and systems, and electronics.

References

- **[ICPY]** John V. Guttag, 2013. *Introduction to Computation and Programming Using Python*. MIT Press. (accessible only on campus)
- Python documentation
- LaValle, Mobile Robotics (draft)
- LaValle, Planning Algorithms
- **[DDCA]** David M. Harris and Sarah L. Harris, *Digital Design and Computer Architecture*

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Schedule

Week	Date	Topic	Location
13	5/25	Introduction to Electronics	Auditorium
	5/28	Digital logic	Auditorium
14	6/1	Combinational digital circuits	Auditorium
	6/4	Lab 1: digital circuits	Auditorium
	6/6	Lab session	Research Bldg. Rm. 211
15	6/8	Sequential digital circuits	Auditorium
	6/11	Digital building blocks	Auditorium
16	6/15	Beyond the logic switches	Auditorium
	6/18	Lab 2: analog circuits	Auditorium
	6/20	Lab session	Research Bldg. Rm. 211

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- Reference texts
  - David M. Harris and Sarah L. Harris, *Digital Design and Computer Architecture*
  - Ronald J. Tocci and Neal Widmer, *Digital Systems Principles and Applications*,11th edition
- Grading
  - Homework 50%
  - Quiz 20%
  - 2 Labs 30%

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Labs

Week	Date	Topic	Location
13	5/25	Introduction to Electronics	Auditorium
	5/28	Digital logic	Auditorium
14	6/1	Combinational digital circuits	Auditorium
	6/4	**Lab 1: digital circuits**	**Auditorium**
	6/6	**Lab session**	**Research Bldg. Rm. 211**
15	6/8	Sequential digital circuits	Auditorium
	6/11	Computing units	Auditorium
16	6/15	Beyond the logic switches	Auditorium
	6/18	**Lab 2: analog circuits**	**Auditorium**
	6/20	**Lab session**	**Research Bldg. Rm. 211**

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Labs

- Digital circuit lab (select 1 out of 2)
  - » 光控路障闪烁警示灯 (page 189)
  - » 停电自锁开关 (page 214)
- Analog circuit lab (select 1 out of 2)
  - » TBD
  - » TBD
- Reference book
  - » 王晓鹏, 《面包板电子制作68例》

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Teams and sessions

- 207 students
- 104 teams (self-formed)
- 5 sessions – (assigned; 6/6/2015,6/20/2015)
  - » Session 1: 9:00am – 10:30am
  - » Session 2: 10:30am – 12:00am
  - » Session 3: 1:00pm – 2:30pm
  - » Session 4: 2:30pm – 4:00pm
  - » Session 5: 4:00pm – 5:30pm
- Name lists of sessions will be posted on the course website

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- Scope
- Switch Basis
- Switch Evolvement
- A CMOS NOT Gate
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Impact of Electronics

- Electronics have revolutionized our world
  - » Cell phones, automobiles, medical devices, etc.



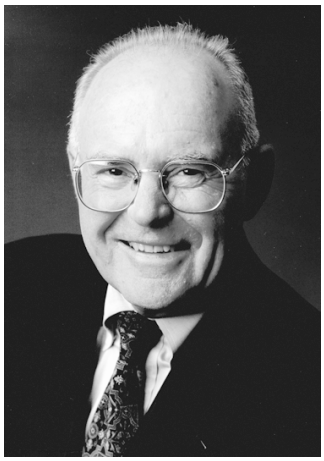
- The semiconductor industry has grown from $21 billion in 1985 to $305 billion in 2013.

Robert Noyce, 1927 - 1990

- Nicknamed "Mayor of Silicon Valley"
- Cofounded Fairchild Semiconductor in 1957
- Cofounded Intel in 1968
- Co-invented the integrated circuit (IC)

Gordon 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 1971, transistor counts have doubled every two years.



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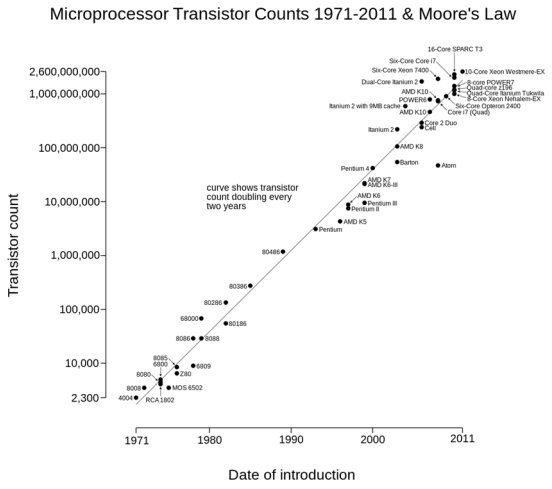
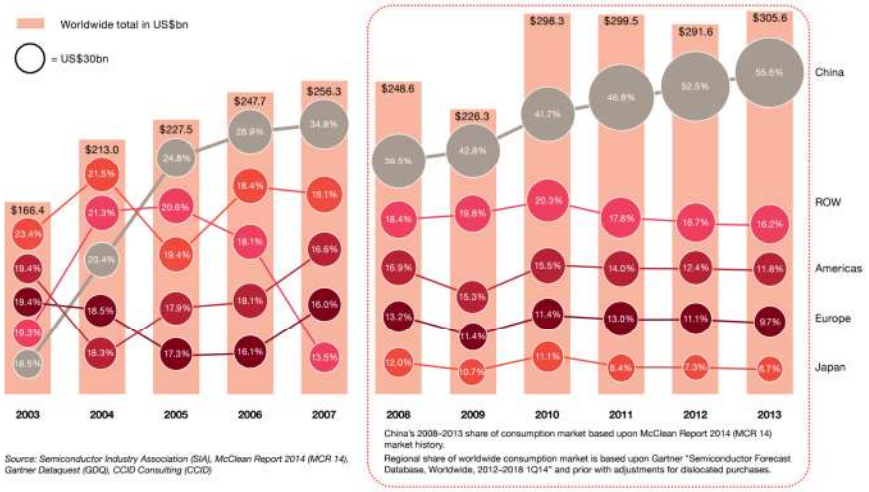
Since 1971: IC industry follows Moore's Law



Worldwide semiconductor consumption



Worldwide IC company market share

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What are you going to learn

- What logic signals look like
- Model logic signals
- Boolean algebra for logic analysis
- Gates that process logic signals
- How to design basic logic circuits
- Flip-flops and memory elements that store logic signals
- What is beyond digital switches

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Topics covered

- Switch basis
- Boolean algebra
- Logic gates
- Logic circuits design
- Flip-flops and memory elements
- Computing units
- Beyond the logic switches

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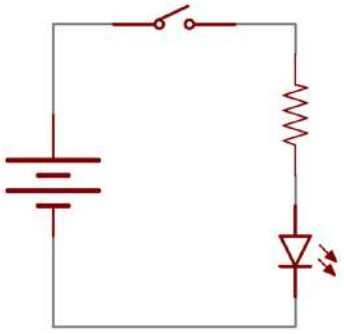
What is switch?

Switch

- A switch is a component which controls the open-ness or closed-ness of an electric circuit.



Key features of switch

- On/Off
  - » ON ⇔ Short circuit ⇔ a piece of conducting wire.
  - » OFF ⇔ Open circuit ⇔ an open gap in the circuit.
- Control
  - » On and off states of a switch is under control

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Poles and Throws

- Poles-count
  - » # of separate circuits the switch can control.
- Throws-count
  - » # of positions each of the switch's poles can be connected to.

Some examples

- Single pole single throw
  - » The switch will either be closed or completely disconnected

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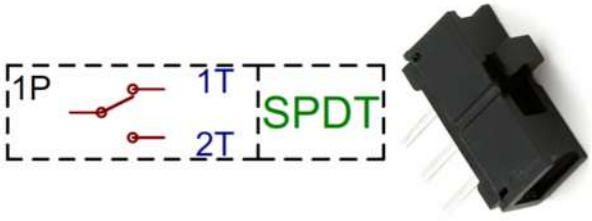
- Single pole double throw
  - » 3 terminals: 1 common pin and 2 pins which vie for connection to the common.



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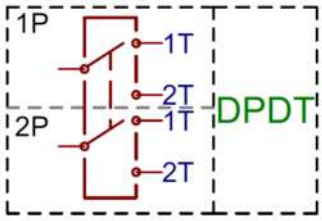
- Double pole double throw
  - » 6 terminals: 2 SPDT switches
  - » Control two separate circuits
  - » Switched together by a single actuator



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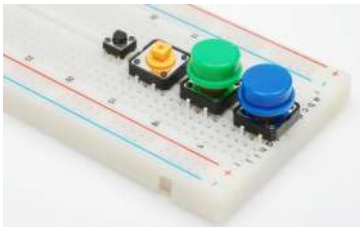
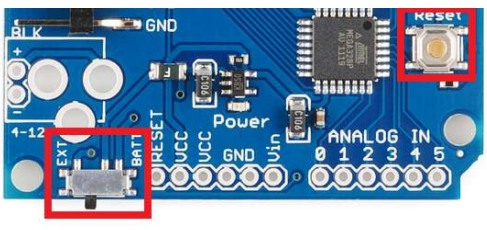
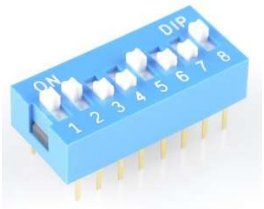
Mechanical Switch

- On/Off
  - » On-state: terminals mechanically attached
  - » Off-state: terminals mechanically detached
- Control
  - » mechanically actuated (push, pull, toggle, etc.)

Examples







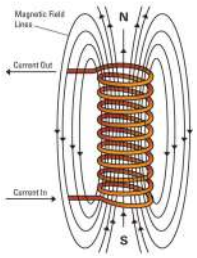
Mechanical Keyboard

Electric Switch

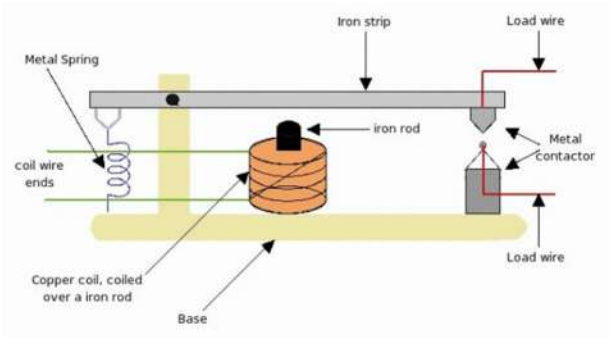
- Relay
  - » On/Off
    - – On-state: terminals mechanically attached
    - – Off-state: terminals mechanically detached
  - » Control
    - – Electromechanically actuated
    - – Weak signal control large current

Electromagnets

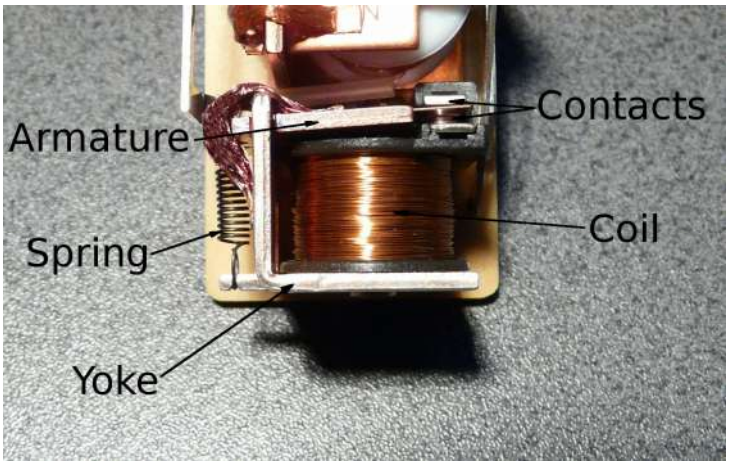
- With an electric current passing through, the coils behave like a magnet
- When the electricity stops flowing, the coils don't act like a magnet anymore



Animation



The structure of a relay



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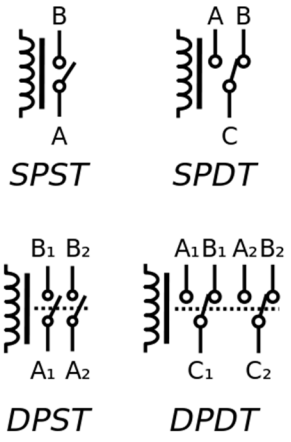

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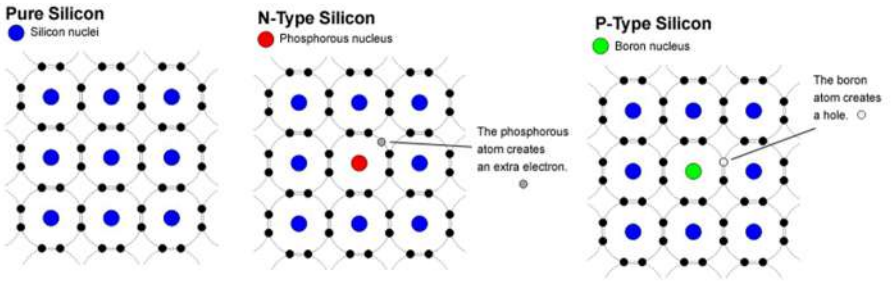
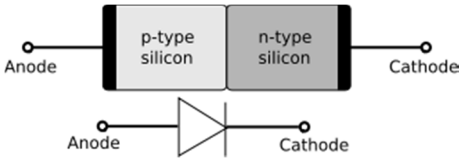
Electronic Switch

- Diode
  - » Passive switch
- MOSFET
  - » Actively controlled switch

Silicon



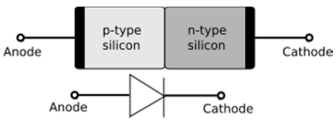
Diode



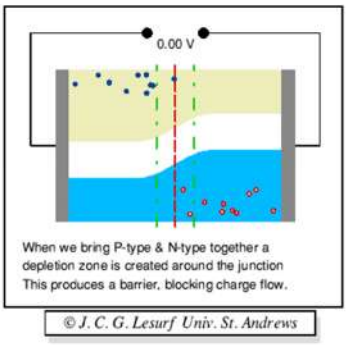
- Two terminal device
- P-N junction
- P-type region: anode
- N-type region: cathode

Diode (ctd.)

- ON
  - » Forward biased
  - » Anode voltage > cathode voltage
- OFF
  - » Reverse biased
  - » Anode voltage < cathode voltage
- Control
  - » Passively controlled by the biased voltage



Animation



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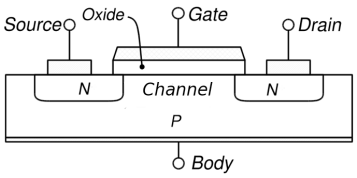
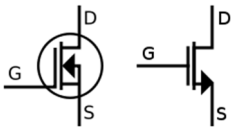
MOSFET

- Metal-Oxide-Semiconductor Field-Effect Transistor
- On/Off
  - » On-state: carrier channel formed, where the current can flow
  - » Off-state: carrier channel does not exist, no path for current to pass
- Control
  - » Actively controlled by electric field

MOSFET (n channel)

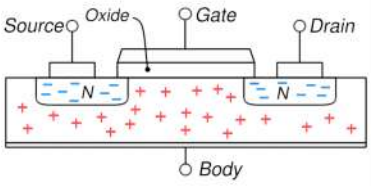
- Gate
- Source
- Drain
- Substrate (Body)





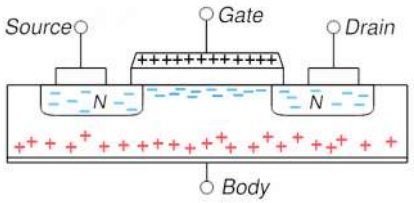
Vgs = 0

- Source & Drain
  - » N-type
- Substrate
  - » P-type
- No channel exists for the carriers to pass from source to the drain
  - » OFF!



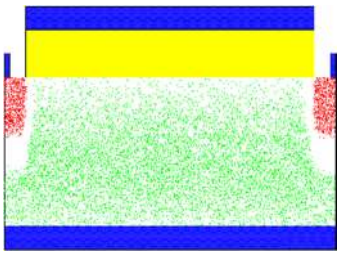
Vgs ≥ Vth

- Vth: Threshold voltage
- Vgs repels all holes and attracts electrons into the channel
- The p-type region in the channel has been inverted in doping
- Carrier channel is formed
  - » ON!



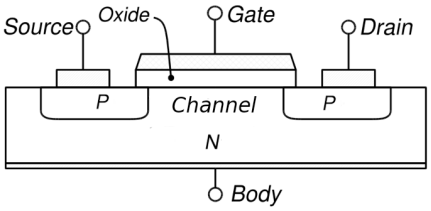
Animation

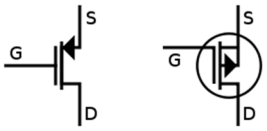
- With the increase of Vgs



MOSFET (p channel)

- Source & Drain
  - » P-type
- Substrate
  - » N-type
- Vgs = 0
  - » No channel => OFF!
- Vgs ≤ -|Vth|
  - » P channel is formed!
  - » ON!





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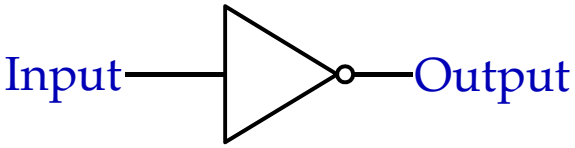
Inverter/Not gate



Input	Output
1	0
0	1

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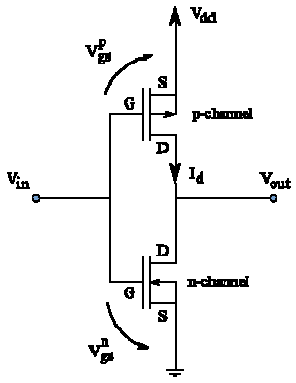
Question

- How to implement an inverter using electronics switches (MOSFETs)?

CMOS inverter



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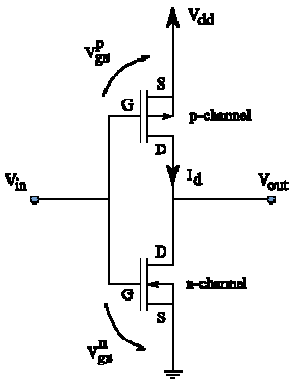
Define logic 1 and 0

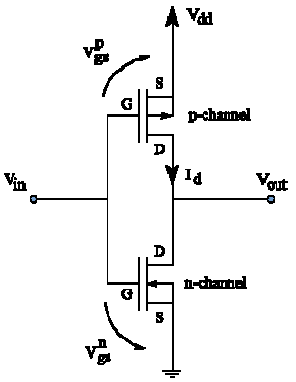
- Vdd ⇔ Logic 1
- 0 V ⇔ Logic 0



If Vin = 0 V

- Vgsp = -Vdd ≤ -|Vthp|
  - » PMOS is ON!
  - » Vout = Vdd
- Logic 0 => Logic 1

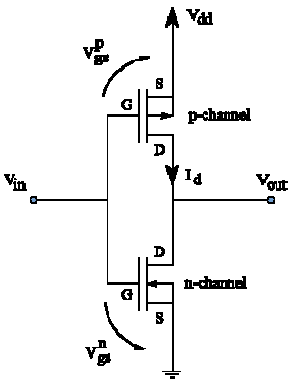
Input	Output
1	0
0	**1**



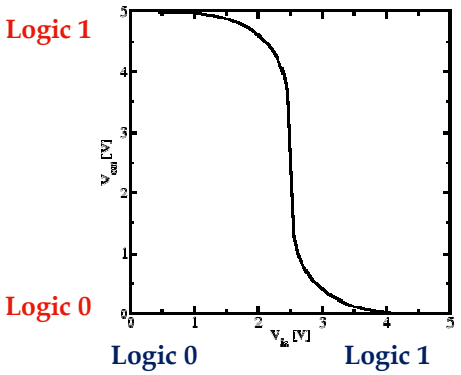
If Vin = Vdd

- Vgsn = Vdd ≥ Vthn
  - » NMOS is ON!
  - » Vout = 0
- Logic 1 => Logic 0

Input	Output
1	**0**
0	1



Voltage transfer characteristics



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What is CMOS

- Complementary Metal–Oxide–Semiconductor
- Application of CMOS
  - » Digital circuits: Microprocessors, microcontrollers, static RAM, and other digital logic circuits.
  - » Analog circuits: image sensors (CMOS sensor), data converters,
  - » Radio frequency circuits: transceivers

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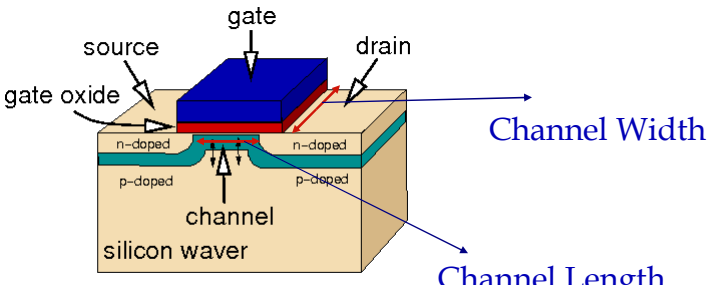
MOSFET scaling



Metal–Oxide Field–Effect Transistor (MOSFET)

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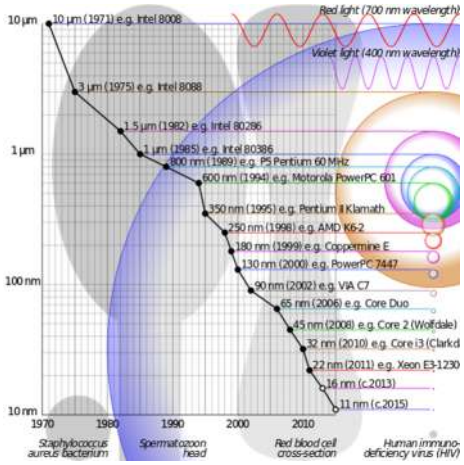
Semiconductor device fabrication

- 10 µm – 1971
- 6 µm – 1974
- 3 µm – 1977
- 1.5 µm – 1982
- 1 µm – 1985
- 800 nm – 1989
- 600 nm – 1994
- 350 nm – 1995
- 250 nm – 1997
- 180 nm – 1999
- 130 nm – 2001
- 90 nm – 2004
- 65 nm – 2006
- 45 nm – 2008
- 32 nm – 2010
- 22 nm – 2012
- 14 nm – 2014
- 10 nm – 2016
- 7 nm – *2018*
- 5 nm – *2020*



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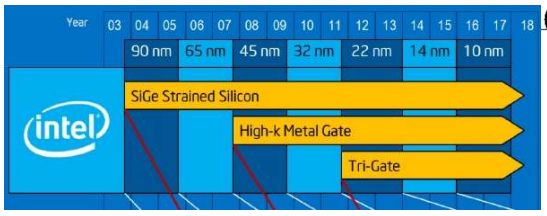
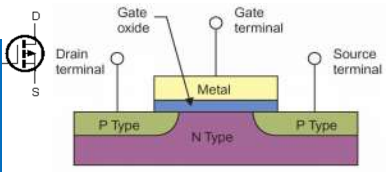
Moore's law is 50 years old!

http://shtech.org/course/ee100/video/Gordon_Moore.mp4

Question

Challenges

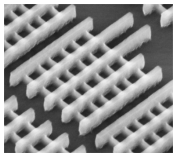




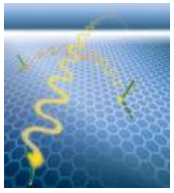
Quantum Limit

- Tunneling between Source/Drain
- Sub-threshold Leakage
- Turn-on Voltage Scaling Issue

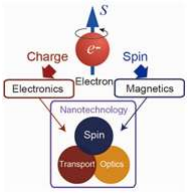
- What's the technology after 5nm?
  - » 3D FinFET
  - » Graphene
  - » Spintronics



3D FinFET
Intel 22nm
(2011)



graphene channel



Spintronics

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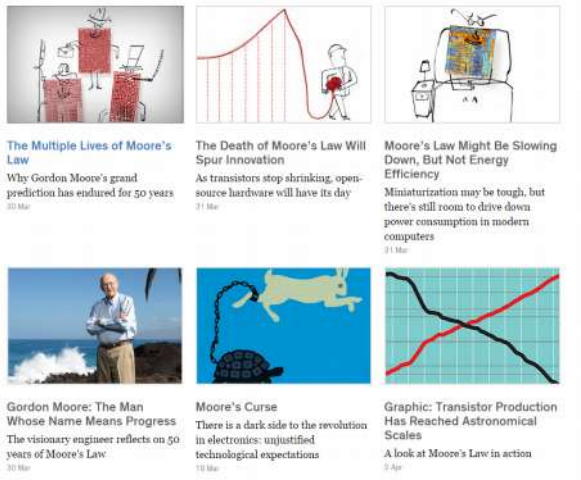
SPECIAL REPORT: 50 YEARS OF MOORE'S LAW



http://spectrum.ieee.org/static/special-report-50-years-of-moores-law

Foundry & Fabless

- What is Foundry?
- What is Fabless?

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Foundry & Fabless

- Foundry:
  - » A factory where ICs are manufactured

- Fabless:
  - » Design and sell ICs
  - » Device fabrication outsourced to foundries

Introduction to Information Science and Technology (Electronics) ShanghaiTech University

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Foundry & Fabless in mainland China

- Foundry
  - » SMIC, 5th worldwide
    - – 40nm; 28nm will be released in 2015
- Fabless
  - » Huawei Hisilicon, 12th worldwide
    - – 6% of Qualcomm
  - » Spreadtrum, 14th worldwide

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Semiconductor giants worldwide