Giuseppe Iannaccone

Università di Pisa
Dip. Ingegneria dell'Informazione
www.iannaccone.org
@iannak1

Electronics and Communication Systems

- "Communication Systems" module – 4CFU
  - Prof. Marco Luise
- "Electronic Systems" module – 5 CFU
  - Prof. Giuseppe Iannaccone, Prof. Luca Fanucci,
- Lecture hours:
  - Tue 10:30-13:30 SI5 (Electronic Systems)
  - Wed 10:30-12:30 AD II1 (Communication Systems)
  - Wed 14:30-17:30 ADII2 (Electronic Systems)
  - Thu 11:30 – 13:30 A28 (Communication Systems)

Giuseppe Iannaccone

- Every information on www.iannaccone.org
- → "Teaching" tab
  - Office hours:
    - By appointment: call or send email
      - Tel. 050 2217677 – giuseppe.Iannaccone@unipi.it
    - Wed 10:30-12:30 or by appointment
  - Register to mailing list for students (through my website)

Syllabus (Electronic systems module)

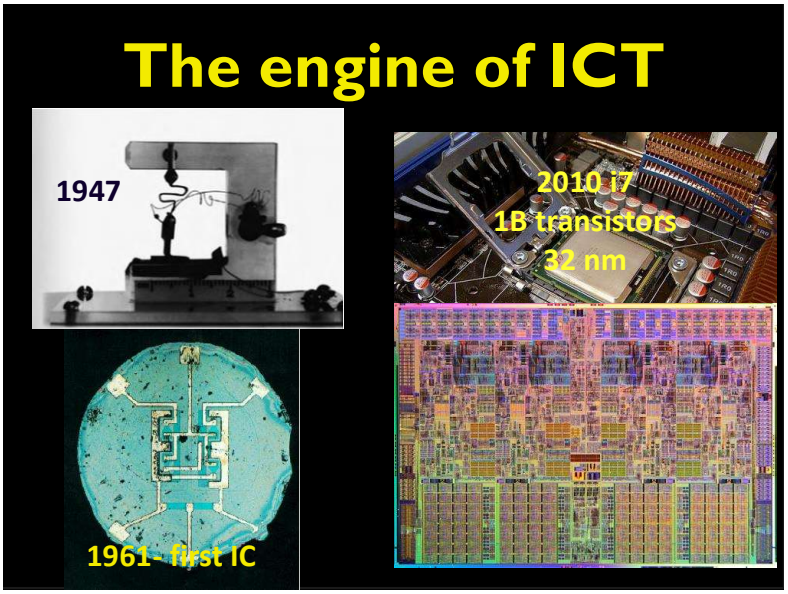
The smartphone: a top-down exploration of a reference electronic system

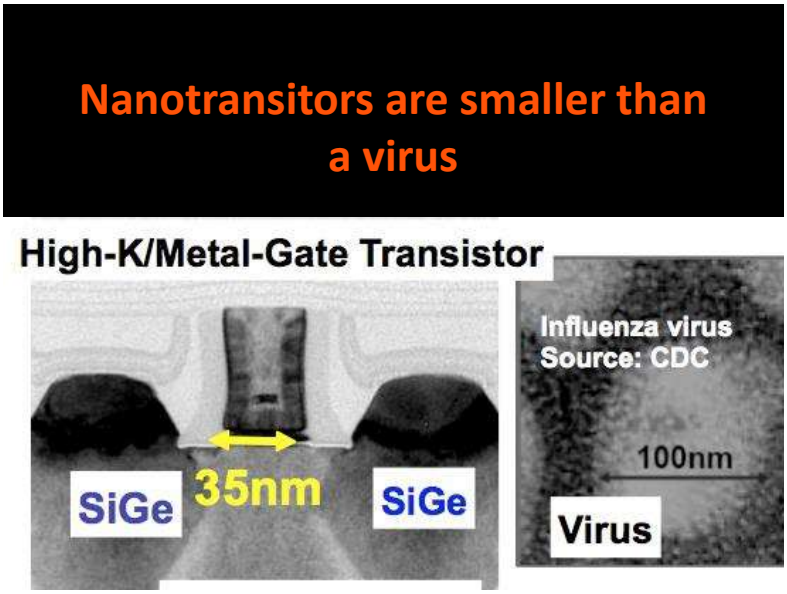
- Integrated Circuits: (CMOS technology, CMOS Systems design)
- Design methodology and EDA (Electronic Design Automation)
- Processor, Memory, Power Management
- Example of sensors

G. I. approx 30 h

Design of FPGA systems (Field-Programmable Gate Array)

Prof. Luca Fanucci – approx 20 h (more info from him)





Why do we need all these transistors?

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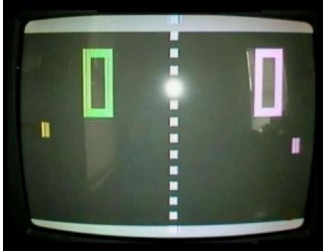
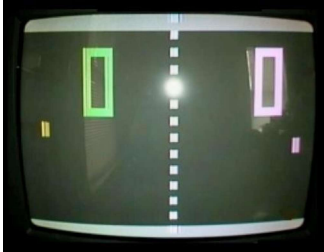


Atari PONG (1976)

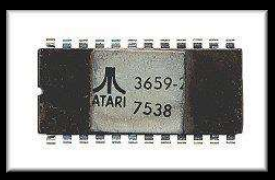
Why do we need all these transistors?

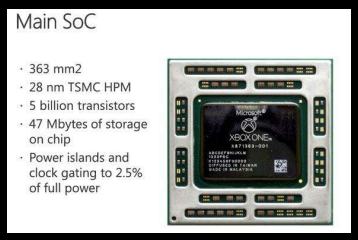


Atari PONG (1976)

FIFA 14 (2013)

Why do we need all these transistors?



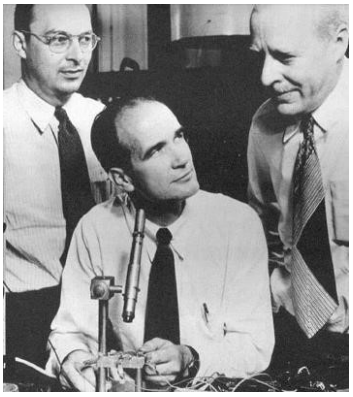


Atari PONG (1976)
Atari 3659-1C
3000 transistors

http://www.pong-story.com

FIFA 14 (2013)
XBox one – PSP 4
5 Billion transistors
8 Jaguar cores

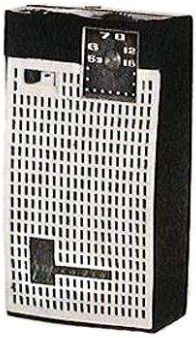
Point-contact Transistor –
Bardeen, Brattain, Schockley – 1948



http://history-computer.com/ModernComputer/Basis/transistor.html

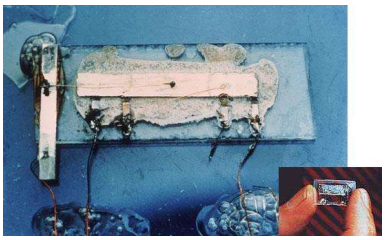
First transistor applications

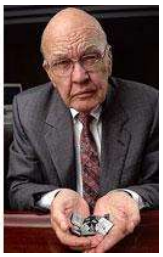
Hearing aid 1952



TR52 Transistor Radio, 1955

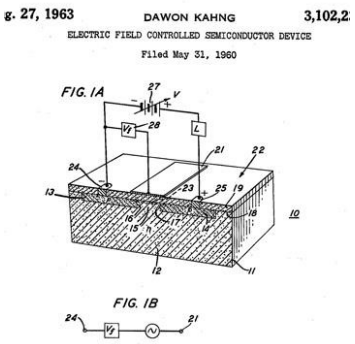
Integrated Circuit– 1958
J. Kilby (Nobel 2000), R. Noyce

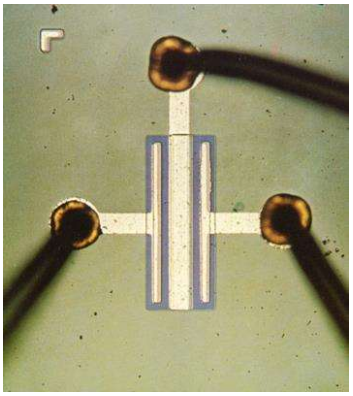




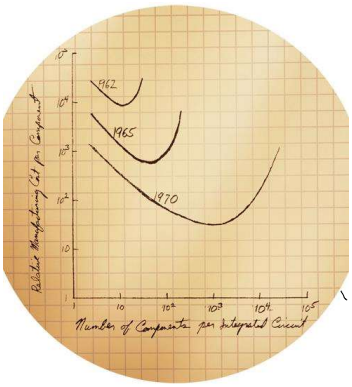
http://history-computer.com/ModernComputer/Basis/IC.html

MOSFET demonstrated 1960,
Atalla & Kahng





Moore's law, 1965



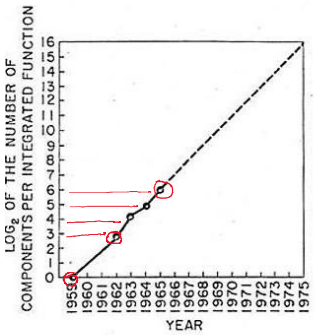
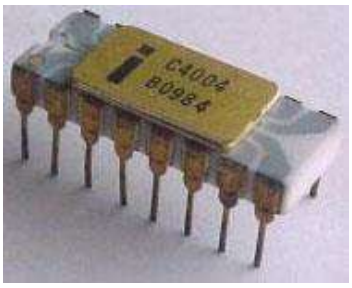


Fig. 2 Number of components per integrated function for minimum cost per component extrapolated vs time.

4004 Microprocessor – 1970 – Intel
(Hoff, Faggin, Mazor)



4004
2300 PMOS – 10 µm process
108 KHz
3 mm x 4 mm
http://history-computer.com/ModernComputer/Basis/microprocessor.html

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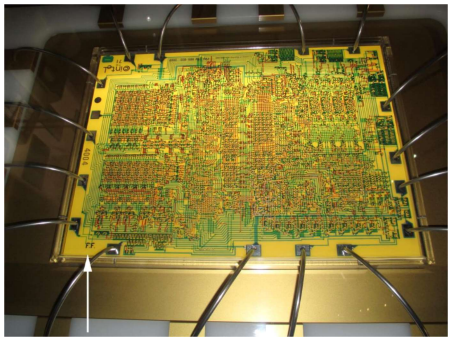
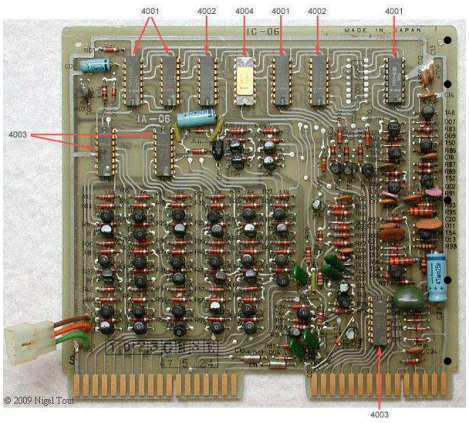


4004
2300 PMOS – 10 µm process
108 KHz
3 mm x 4 mm
http://www.intel4004.com/sign.htm

Busicom 141-PF calculator (NCR 18-36)

http://www.vintagecalculators.com/html/busicom_141-pf_and_intel_4004.html

Busicom 141-PF board

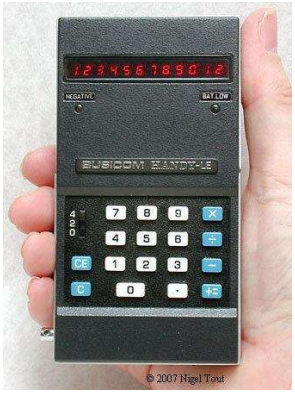


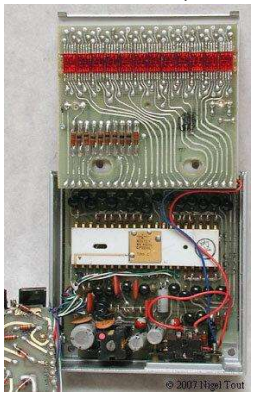
- 4 x 4001 (2048-bit ROM, mask programmable)
- 2 x 4002 (320-bit RAM).
- 3 x 4003, 10-bit shift register
- 4004, 4-bit CPU

http://www.vintagecalculators.com/html/busicom_141-pf_and_intel_4004.html

Busicom LE-120A "Handy" (1971)

Chip: Mostek MK6010 (2100 transistors)





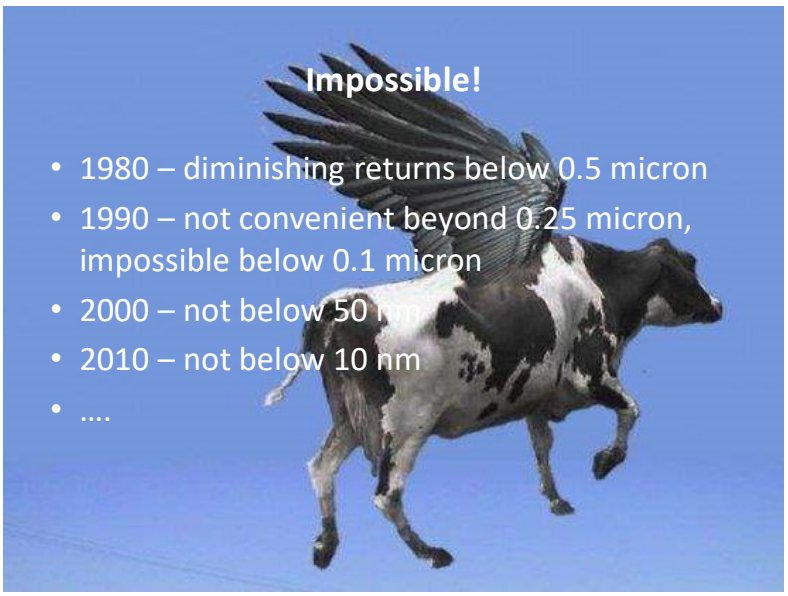
http://www.vintagecalculators.com/html/busicom_141-pf_and_intel_4004.html

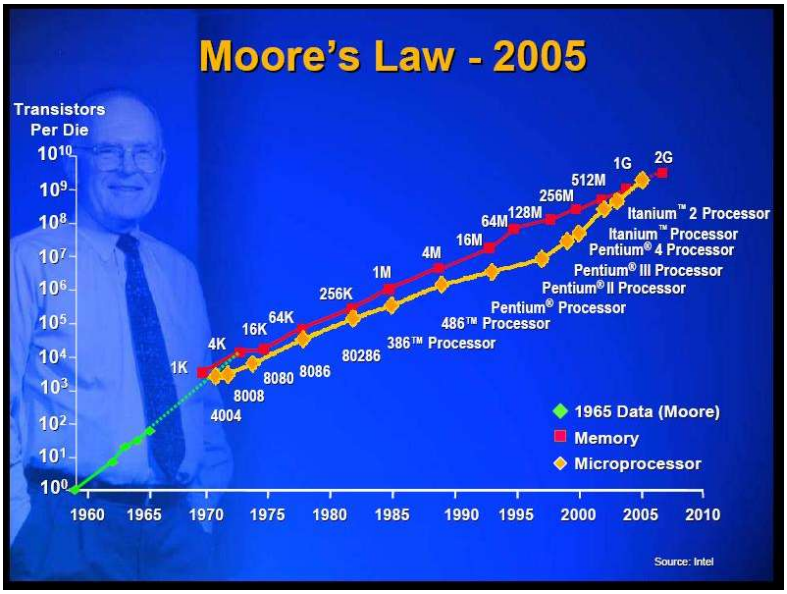
Scaling

- Larger chips and smaller transistors
- Why?
- Smaller transistor are faster
- Shorter time per operation (higher clock freq.)
- Better microarchitectures (more instructions per cycle)

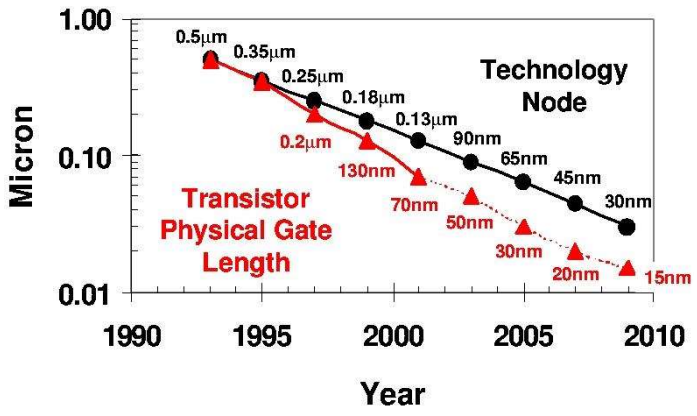
Dennard's scaling rules

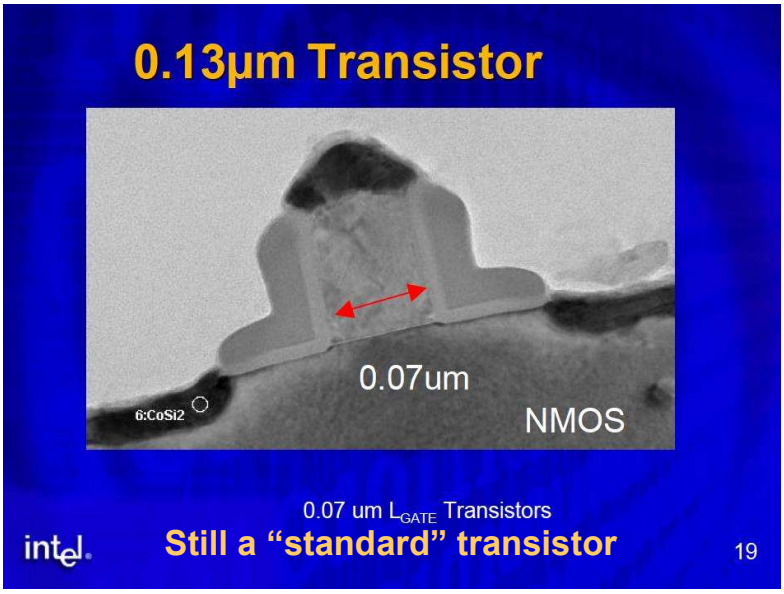
Parameter	Sensitivity	Dennard Scaling
L: Length		1/S
W: Width		1/S
t_{ox}: gate oxide thickness		1/S
V_{DD}: supply voltage		1/S
V_t: threshold voltage		1/S
NA: substrate doping		S
β	$W/(Lt_{ox})$	S
I_{on}: ON current	$\beta(V_{DD}-V_t)^2$	1/S
R: effective resistance	V_{DD}/I_{on}	1
C: gate capacitance	WL/t_{ox}	1/S
τ: gate delay	RC	1/S
f: clock frequency	$1/\tau$	S
E: switching energy / gate	CV_{DD}^2	$1/S^3$
P: switching power / gate	Ef	$1/S^2$
A: area per gate	WL	$1/S^2$
Switching power density	P/A	1
Switching current density	I_{on}/A	S



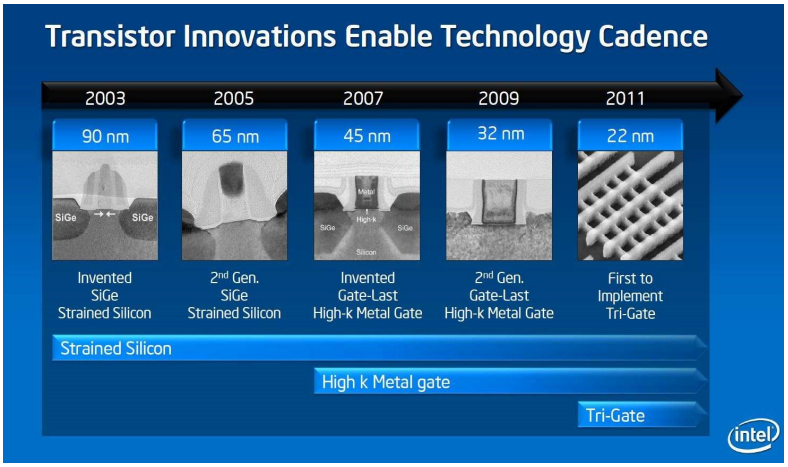


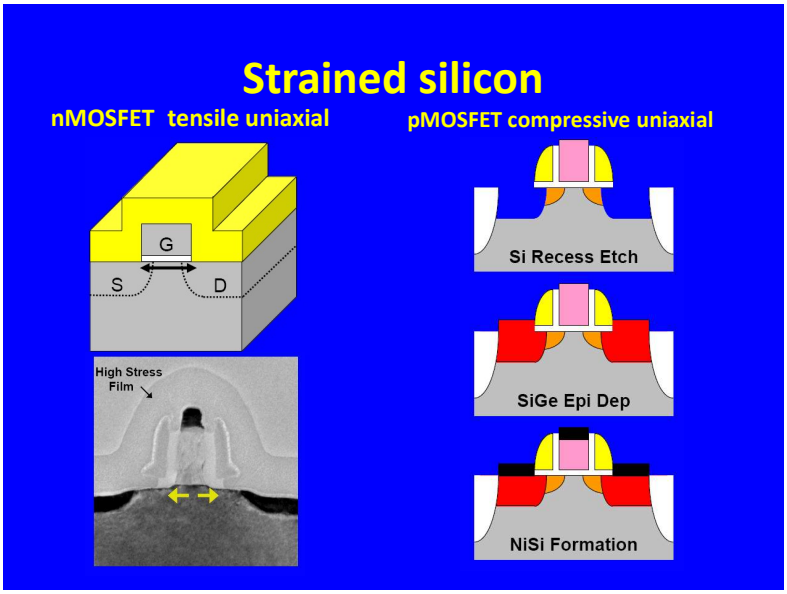
Intel, presentation from 2001
The incredible shrinking transistor

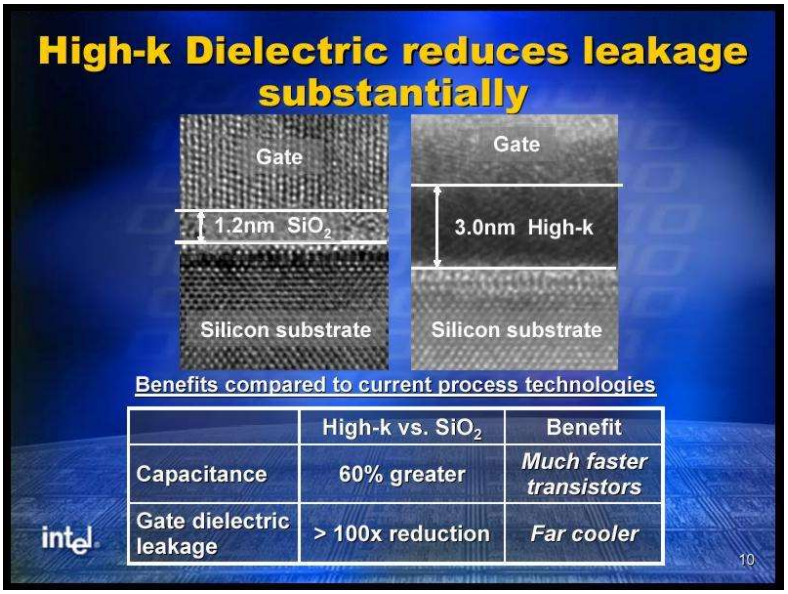


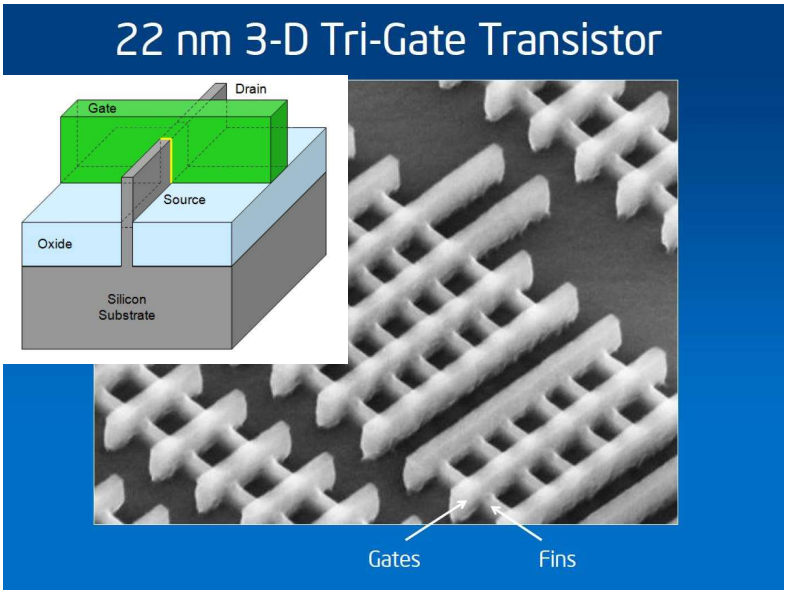


"New" scaling
Not your dad's transistor

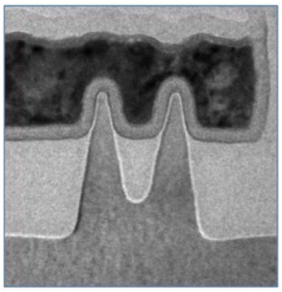






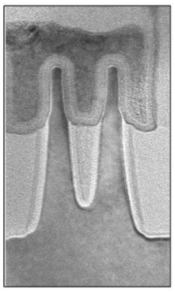


Transistor Fin Optimization



22 nm Process

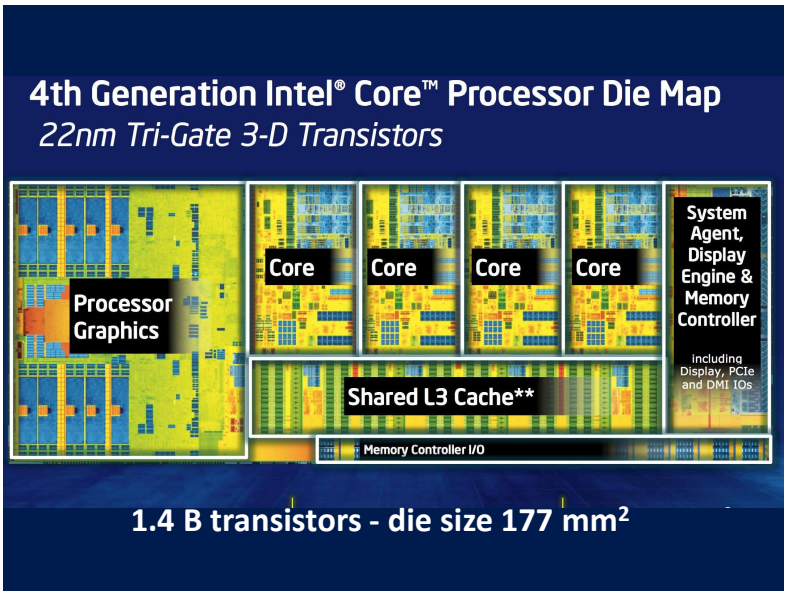
1st generation Tri-gate



14 nm Process

2nd generation Tri-gate

From Mark Bohr, IDF 2014



Industry Lithography Roadmap, HVM Start
Data announced by companies during conference calls, press briefings and in press releases

	2017		2018		2019		2020		2021	2022	22+
	1H	2H	1H	2H	1H	2H	1H	2H			
GF	14LPP	12HP	12LP	7nm DUV	7nm EUV 1st Gen*		7nm EUV 2nd Gen*			?	?
Intel	14nm+		14nm++		10 nm*		10 nm+*			?	?
Samsung	10LPE		10LPP	7LPP** 8LPP 10LPU*	7LPP	5LPE**	5LPE	4LPE*		4LPP*	3GAAE* 3GAAP*
SMIC	14 nm in development									?	?
TSMC	N10FF N16FFC		N7FF N12FFC		N12FFC N12ULP	N7FF+		N5FF		?	?
UMC	-	14nm	no data								

*Exact timing not announced
**May be available only to Samsung LSI

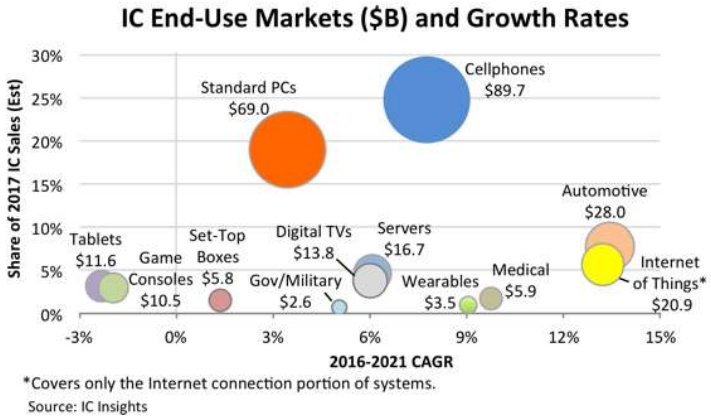
May 2018, Anandtech

Market data (2014 unless otherwise indicated)

Global Gross Domestic Product:	**76.5 $T**
Global Production electronic systems:	**1.49 $T**
Global Semiconductor Market:	**353 $B**
Semiconductor Capital Spending:	**65 $B**
Semiconductor Materials Spending:	**44.8 $B**
Fab cost (22 nm):	**~10 B$**
Intel revenue 2013 (2016):	**53.3 B$ (55,3 B$)**

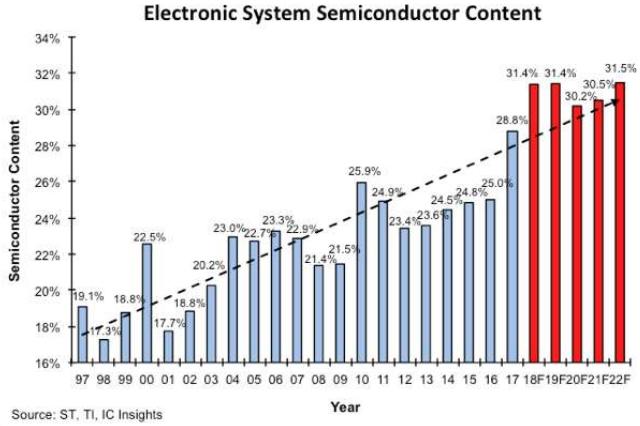
Source: IC Insights, Intel

Global Integrated Circuits market: 297B$ (2017)

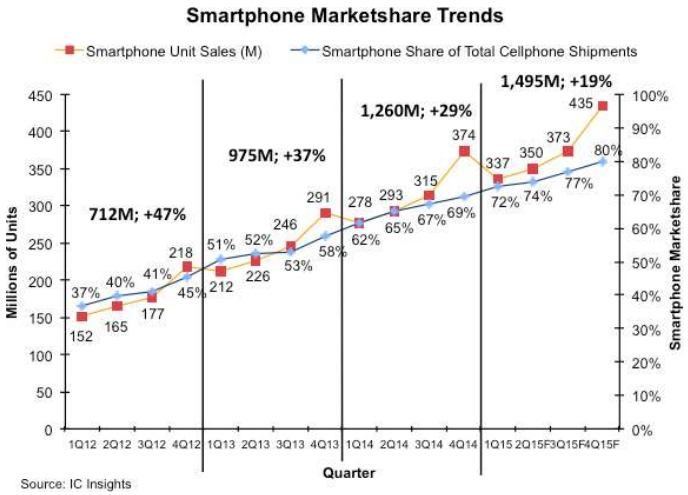


Compound annual growth rate

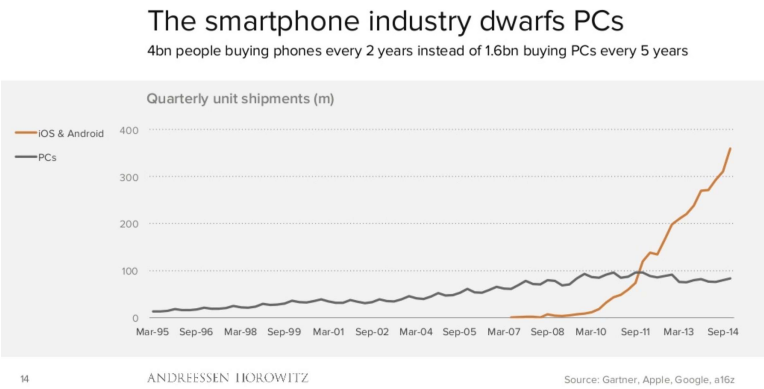
Integrated circuit cost as a fraction of total Electronic Systems cost



1.5 B smartphone sold in 2015

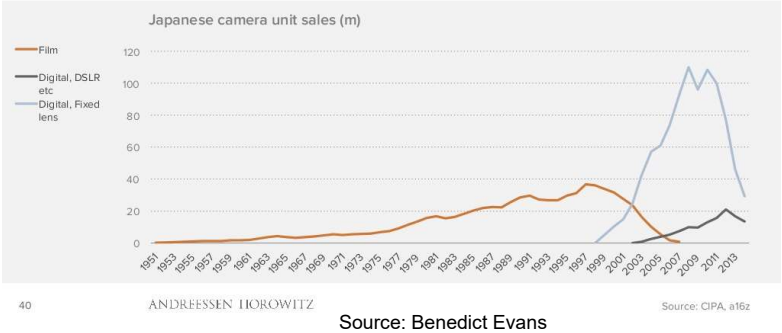


The smartphone is the reference electronic system



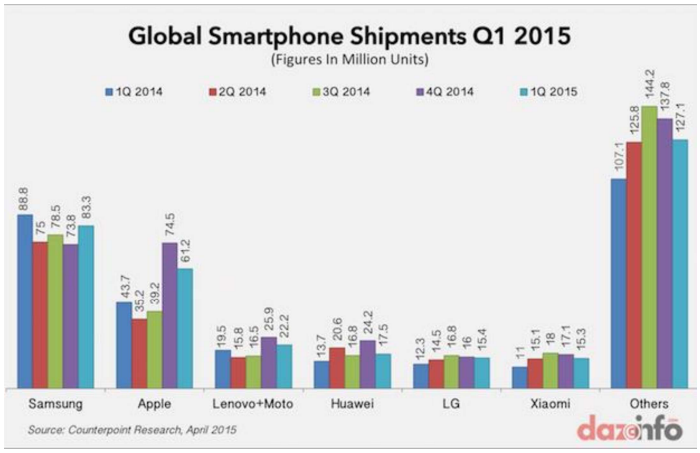
Source: Benedict Evans

Smartphones are eroding the camera market

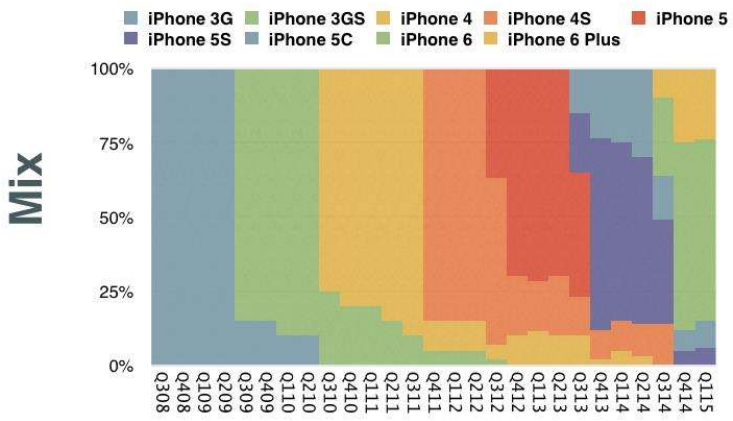


Source: Benedict Evans

the iPhone 6 is the most sold smartphone

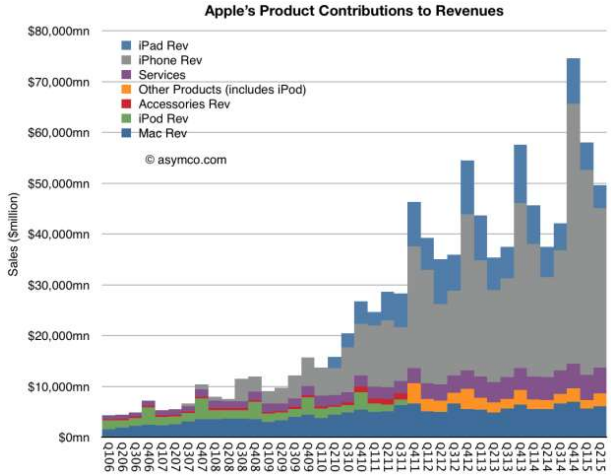


Mix of iPhone models (estimate)



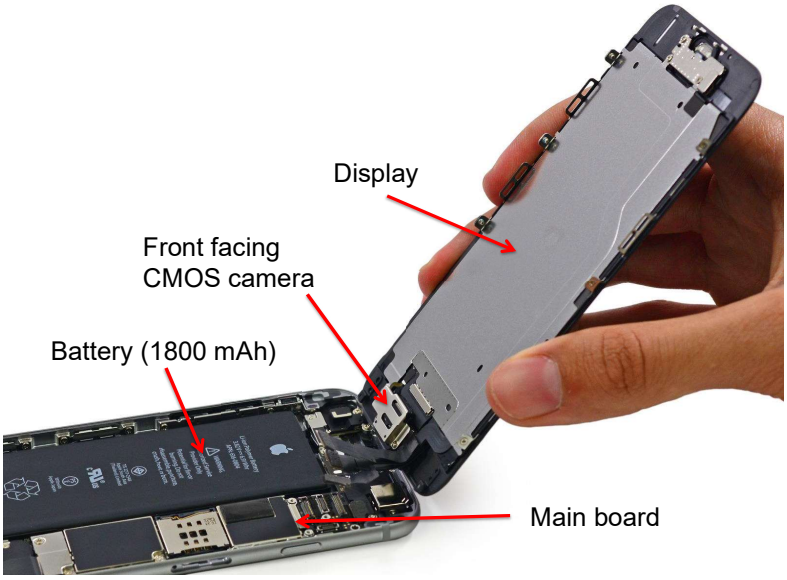
Source: Asymco.com

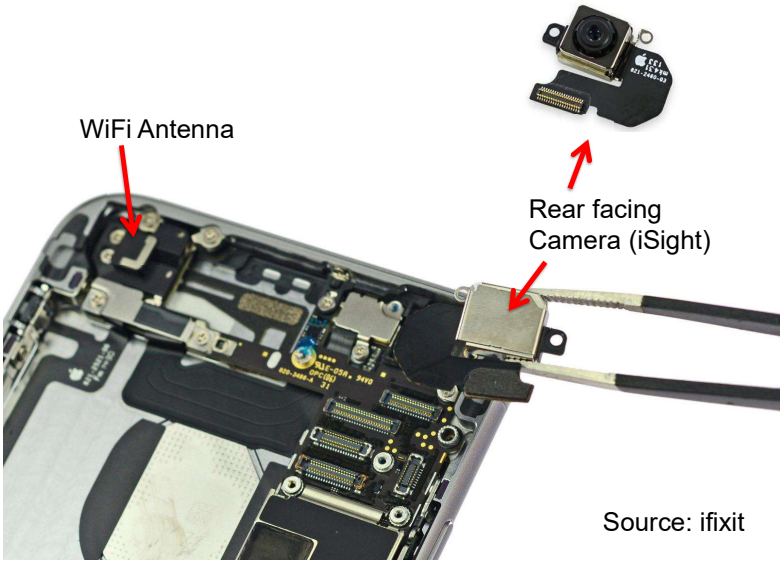
iPhone is most of Apple's revenues



iPhone 6 tear down

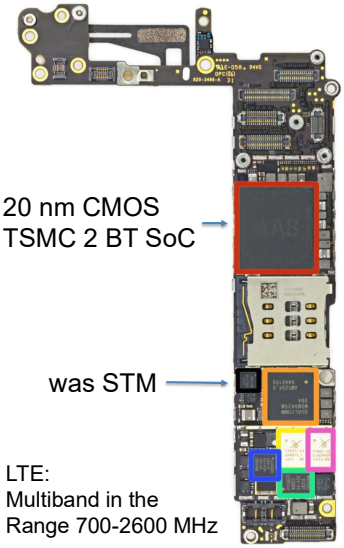
Source: ifixit





Source: ifixit

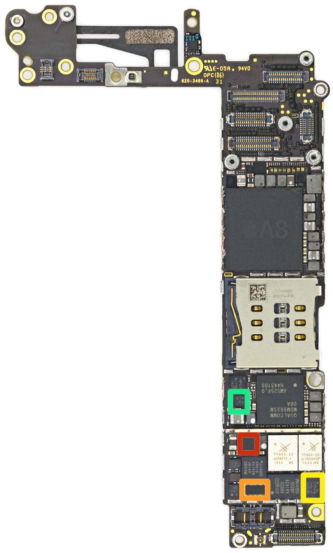
Board: front side 1/2



- Apple A8 APL1011 SoC + SK Hynix RAM as denoted by the markings H9CKNNN8KTMRWR-NTH (we presume it is 1 GB LPDDR3 RAM, the same as in the iPhone 6 Plus)
- Qualcomm MDM9625M LTE Modem
- Skyworks 77802-23 Low Band LTE PAD
- Avago A8020 High Band PAD
- Avago A8010 Ultra High Band PA + FBARs
- SkyWorks 77803-20 Mid Band LTE PAD
- InvenSense MP67B 6-axis Gyroscope and Accelerometer Combo

Source: ifixit

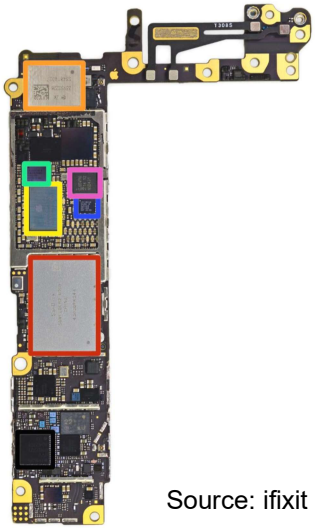
Board: front side 2/2



- Qualcomm QFE1000 Envelope Tracking IC
- RF Micro Devices RF5159 Antenna Switch Module
- SkyWorks 77356-8 Mid Band PAD
- Bosch Sensortec BMA280

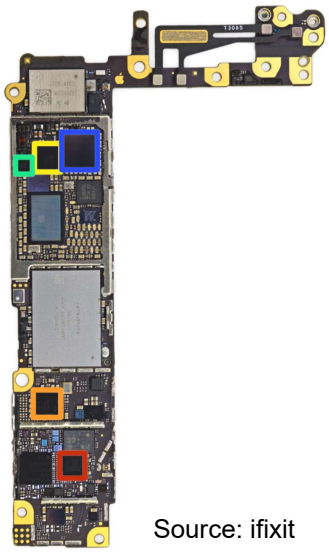
Source: ifixit

Board: back side 1/2



Source: ifixit

- SanDisk SDMFLBCB2 128 Gb (16 GB) NAND Flash
- Murata 339S0228 Wi-Fi Module
- Apple/Dialog 338S1251-AZ Power Management IC
- Broadcom BCM5976 Touchscreen Controller
- NXP LPC18B1UK ARM Cortex-M3 Microcontroller (also known as the M8 motion coprocessor)
- NXP 65V10 NFC module + Secure Element (likely contains an NXP PN544 NFC controller inside)
- Qualcomm WTR1625L RF Transceiver

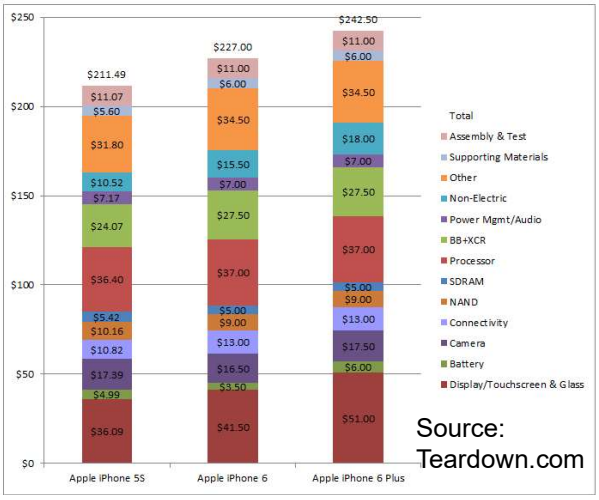


Source: ifixit

Board: back side 2/2

- Qualcomm WFR1620 receive-only companion chip. Qualcomm states that the WFR1620 is "required for implementation of carrier aggregation with WTR1625L."
- Qualcomm PM8019 Power Management IC
- Texas Instruments 343S0694 Touch Transmitter
- AMS AS3923 NFC Booster IC designed to "improve performance of existing NFC controllers for challenging environments such as mobile and wearables" and also delivers "less restrictive antenna design requirements".
  - We believe this chip is an NFC frontend to improve performance in noisy environments using 'active peer to peer bit rates [up to] 212kb/s.'
- Cirrus Logic 338S1201 Audio Codec

Component cost



Source: Teardown.com

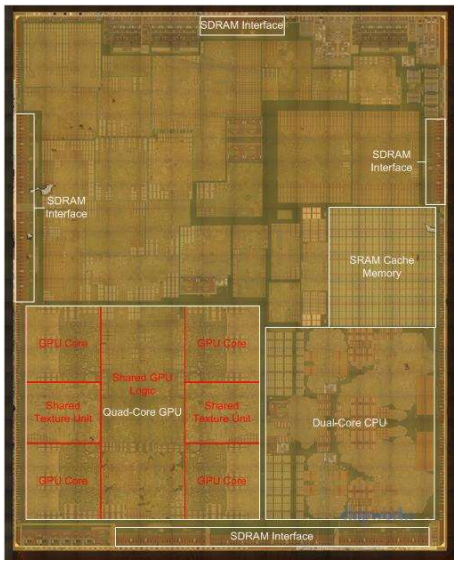
A8 package on package

Top: 1GB DRAM

Bottom: processor

20 nm CMOS process by TMSC

A8 die



89 mm^2

(8.5 mm x 10.5 mm)

TSMC 20 nm CMOS

2 Billion transistors

10 level metal

Dual-core CPU

(Cyclone **ARMv8** - 64 bit)

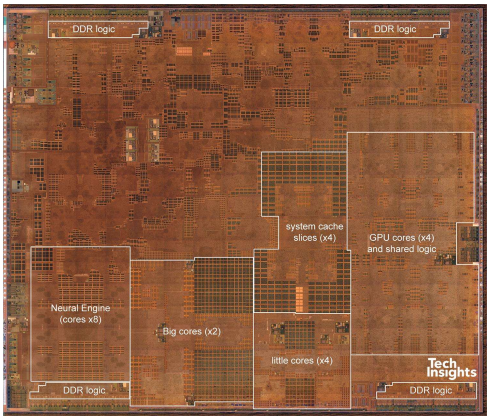
Quad-core GPU

(**PowerVR 6xT** GX6450)

Common Level 3 Cache

Cost Analysis (X and XS)

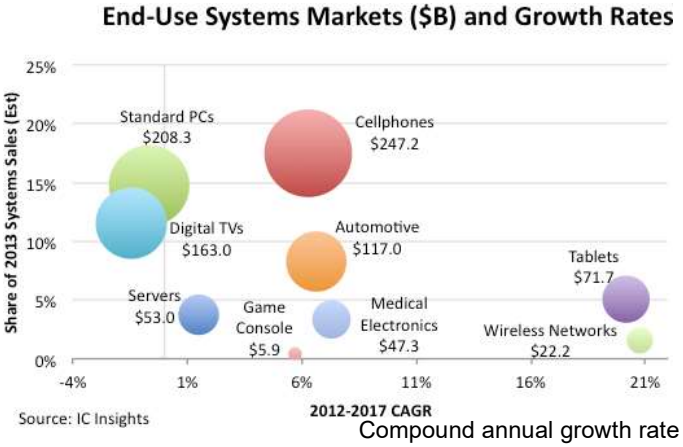
A12 preview (X, XS, XR)



Package on Package

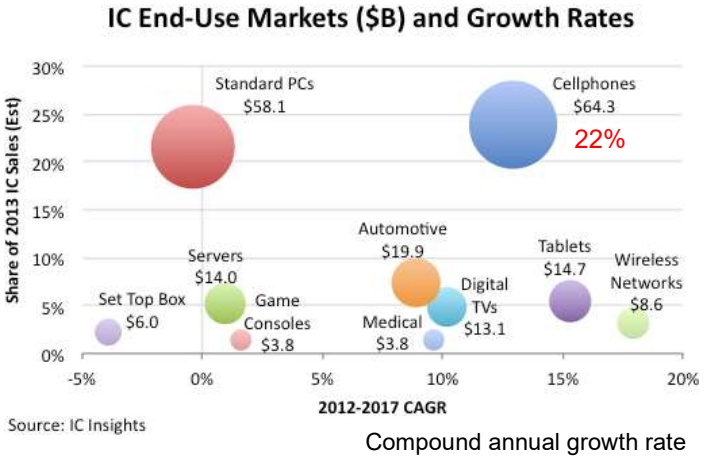
- Top: 4 GB DRAM
- Bottom: Processor
  - 6 CPUs (2 HP + 4 LP cores)
  - 4 GPUs
  - 8-core Neural Engine
- TSMC 7 nm FINFET CMOS technology
  - Die size 83.27 mm^2
  - 6.9 B Transistors

Global Electronics Systems market: 1.3 $T (year 2012)



Compound annual growth rate

Global Integrated Circuits market: 292 $B (year 2012)



Compound annual growth rate