EE 330
Lecture 2

Basic Concepts

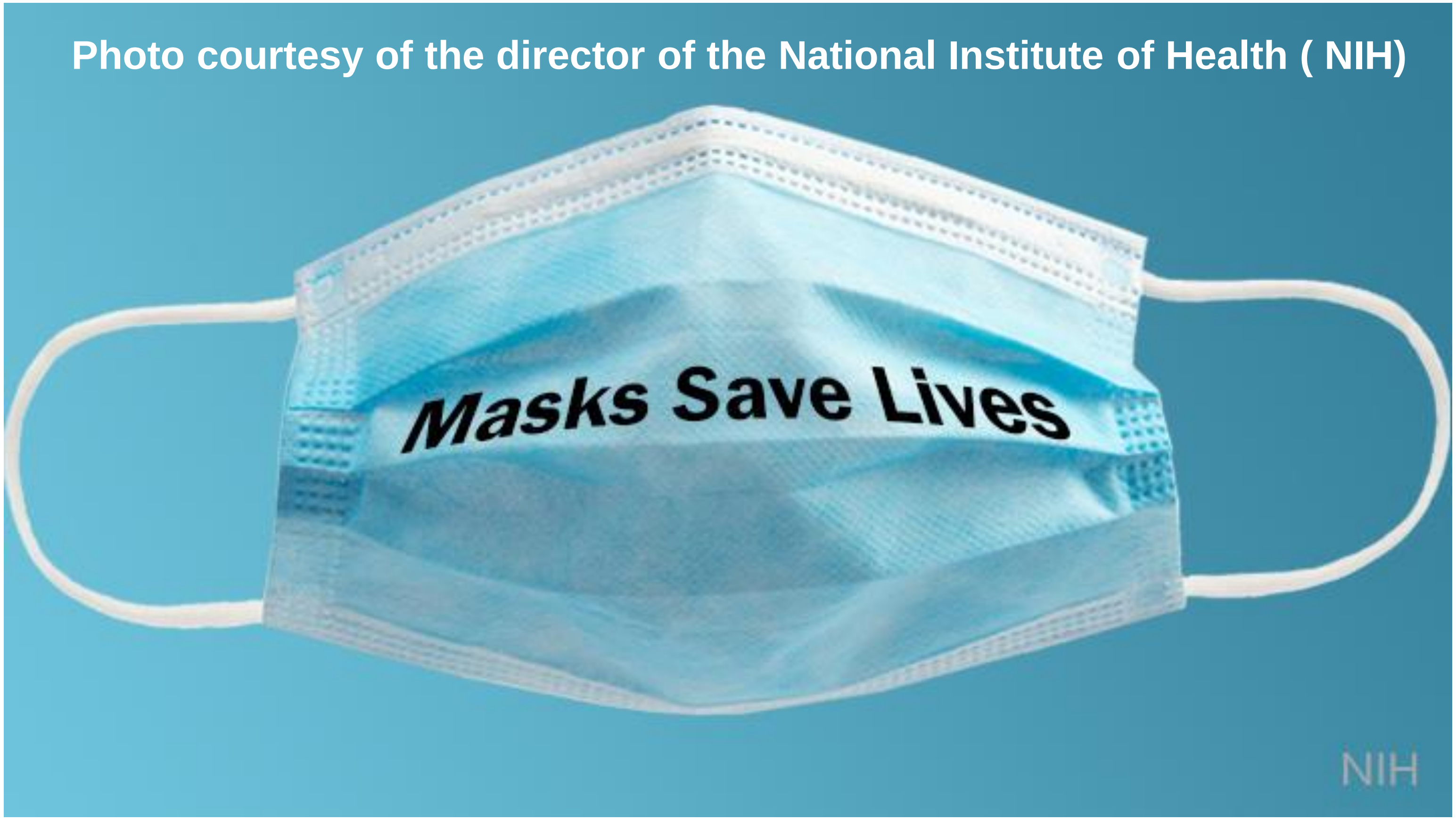


Photo courtesy of the director of the National Institute of Health (NIH)

As a courtesy to fellow classmates, TAs, and the instructor

Wearing of masks during lectures and in the laboratories for this course would be appreciated irrespective of vaccination status

Review from last lecture:

Grading Policy

3 Exams	100 pts each
1 Final	100 pts.
Homework	100 pts.total
Lab and Lab Reports	100 pts.total
Design Project	100 pts.

- A letter grade will be assigned based upon the total points accumulated
- Grade breaks will be determined based upon overall performance of the class

Review from last lecture:

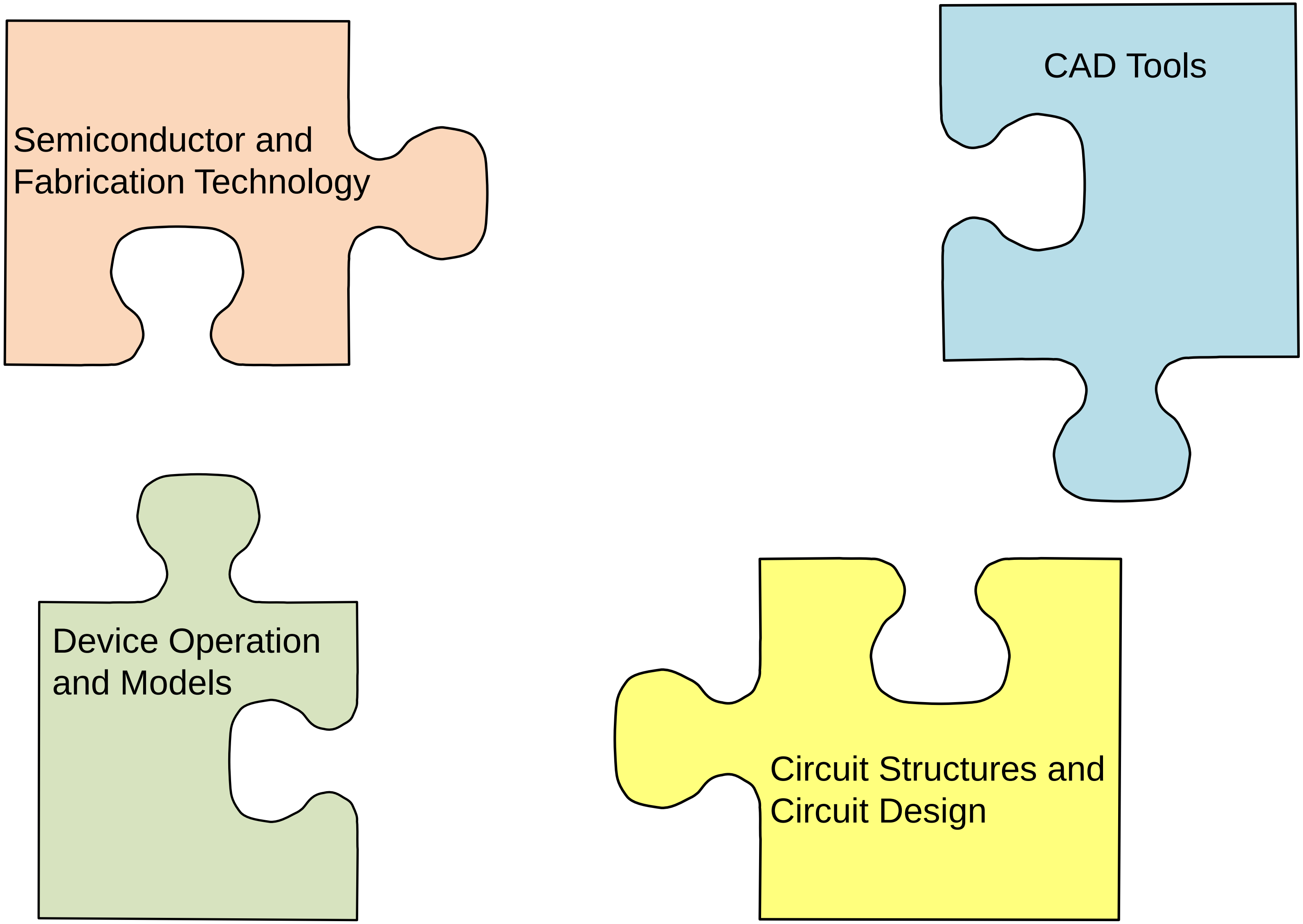
Equal Access Policy

Participation in all class functions and provisions for special circumstances including special needs will be in accord with ISU policy

Participation in any classes or laboratories, turning in of homework, or taking any exams is optional however grades will be assigned in accord with the described grading policy. No credit will be given for any components of the course without valid excuse if students choose to not contribute. Successful completion of ALL laboratory experiments and submission of complete laboratory reports for ALL laboratory experiments to TA by deadline established by laboratory instructor is, however, required to pass this course.

Review from last lecture:

How Integrated Electronics will be Approached



Semiconductor and Fabrication Technology

CAD Tools

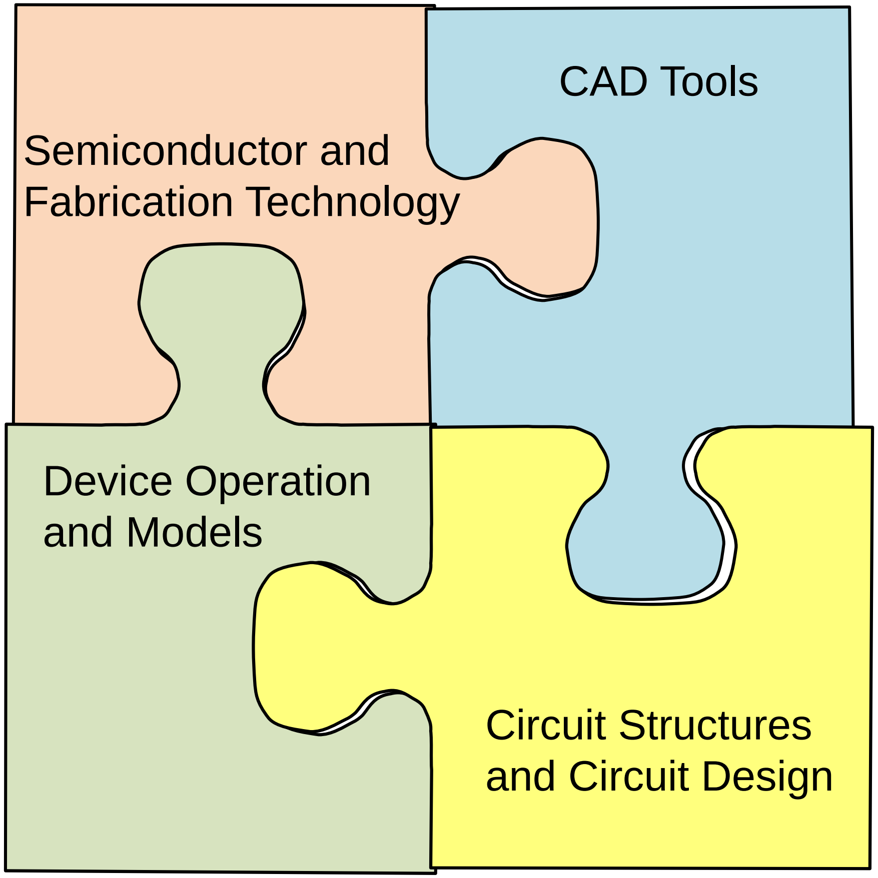
Device Operation and Models

Circuit Structures and Circuit Design

Review from last lecture:

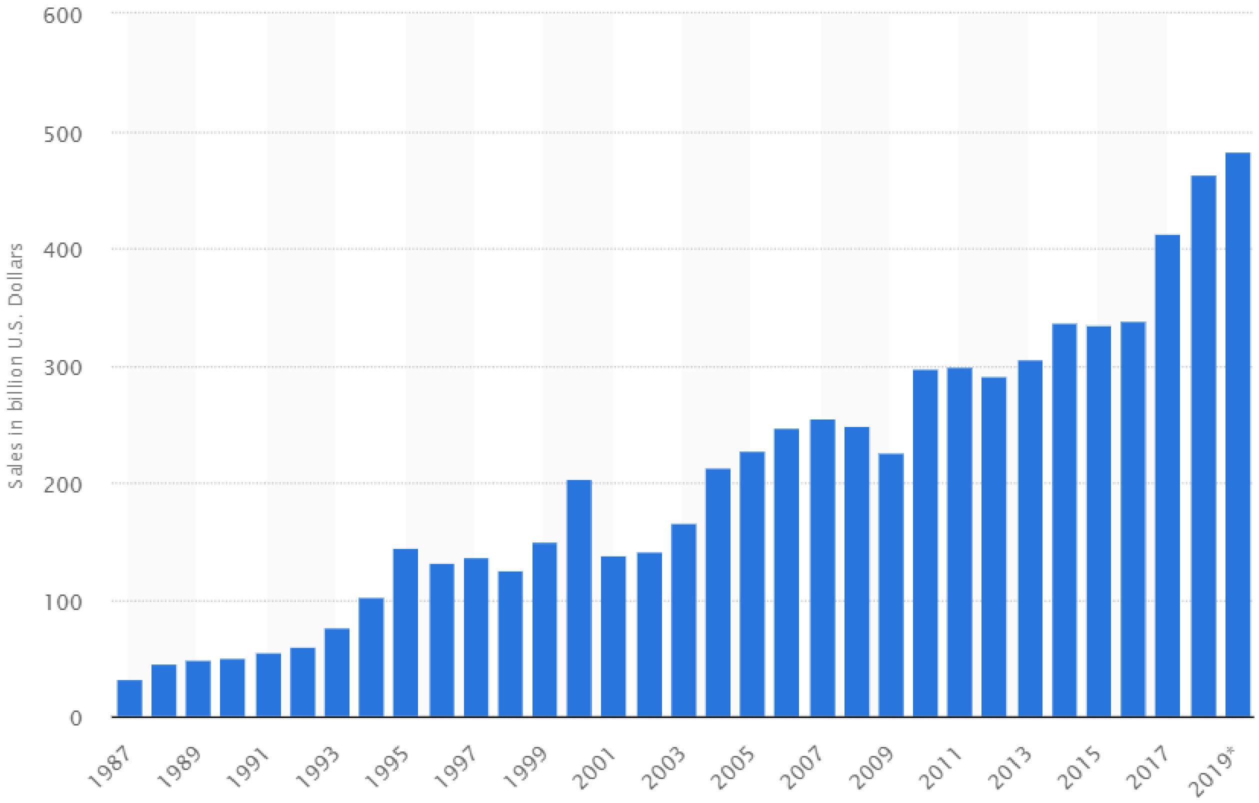
How Integrated Electronics will be Approached

After about four weeks, through laboratory experiments and lectures, the concepts should come together



Review from last lecture:

How big is the semiconductor industry?



Projected at $483 Billion in 2019

Semiconductor sales do not include the sales of the electronic systems in which they are installed and this marked is much bigger !!

statista The Statistics Portal
Statistics and Studies from more than 22,500 Sources

Review from last lecture:

The Semiconductor Industry

How big is it ?

About $470B/Year and growing

How does it compare to Iowa-Centric Commodities?

Larger than major agricultural commodities (close to 3.5X)

The semiconductor industry is one of the largest sectors in the world economy and continues to grow

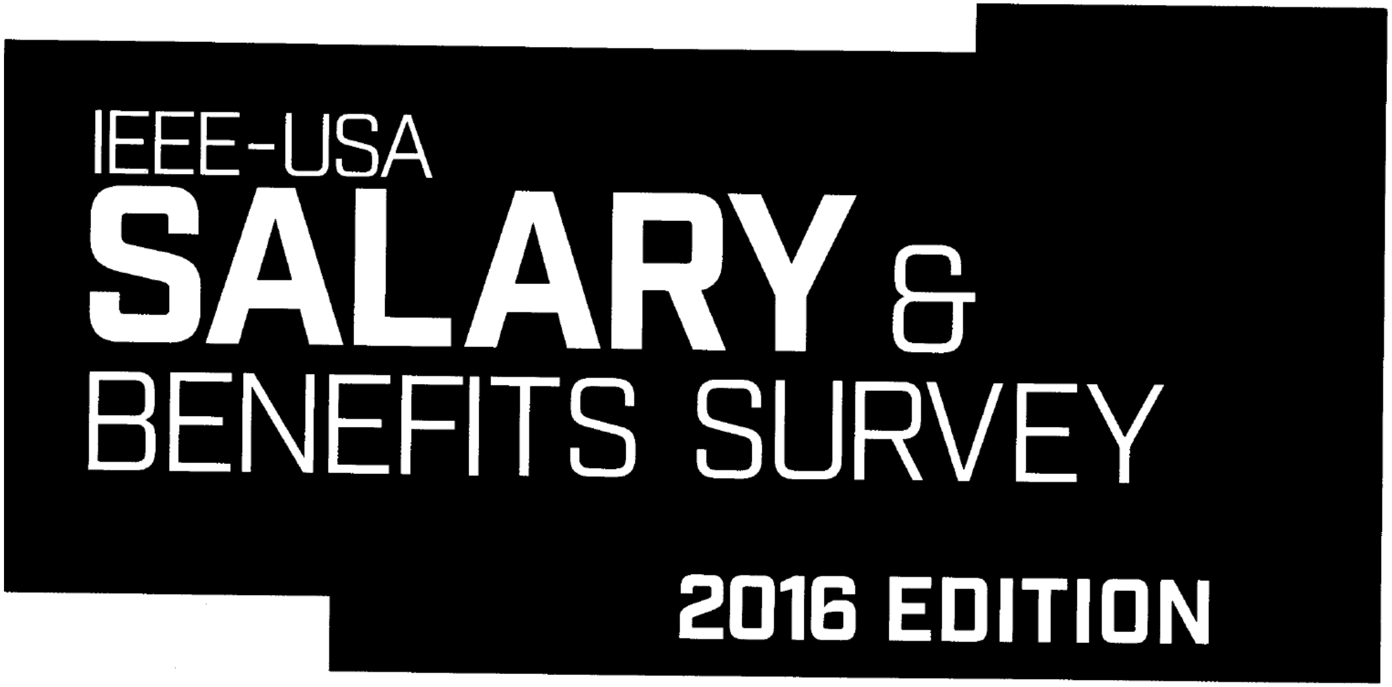
Review from last lecture:

Is an automobile an electronics "gadget"?

Review from last lecture:

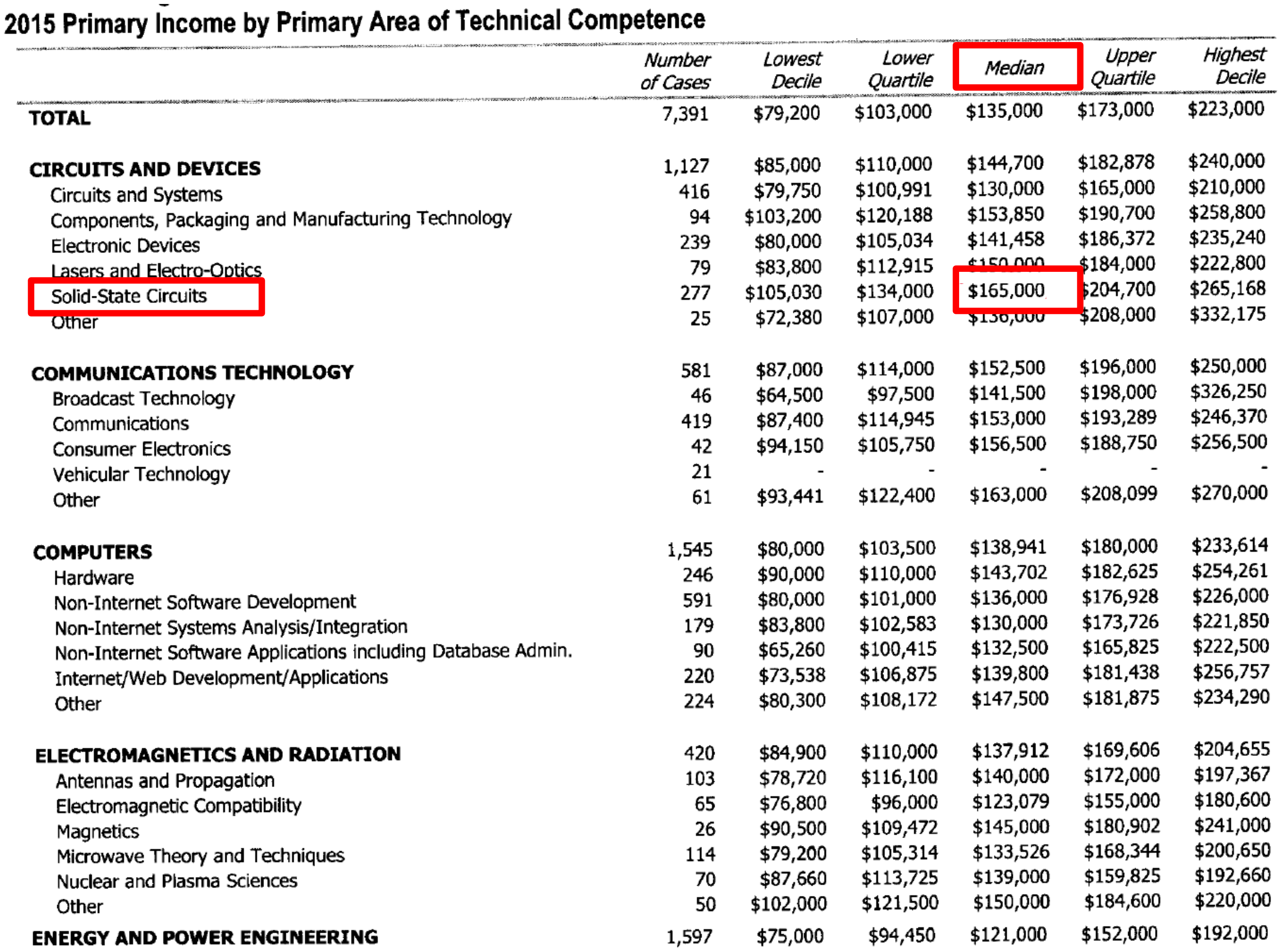
Rewards in the Electronics Field

Can engineers working in the semiconductor electronics field make a good living?



IEEE-USA
SALARY &
BENEFITS SURVEY
2016 EDITION

Review from last lecture:



2015 Primary Income by Primary Area of Technical Competence

	Number of Cases	Lowest Decile	Lower Quartile	Median	Upper Quartile	Highest Decile
TOTAL	7,391	$79,200	$103,000	$135,000	$173,000	$223,000
CIRCUITS AND DEVICES	1,127	$85,000	$110,000	$144,700	$182,878	$240,000
Circuits and Systems	416	$79,750	$100,991	$130,000	$165,000	$210,000
Components, Packaging and Manufacturing Technology	94	$103,200	$120,188	$153,850	$190,700	$258,800
Electronic Devices	239	$80,000	$105,034	$141,458	$186,372	$235,240
Lasers and Electro-Optics	79	$83,800	$112,915	$150,000	$184,000	$222,800
Solid-State Circuits	277	$105,030	$134,000	$165,000	$204,700	$265,168
Other	25	$72,380	$107,000	$136,000	$208,000	$332,175
COMMUNICATIONS TECHNOLOGY	581	$87,000	$114,000	$152,500	$196,000	$250,000
Broadcast Technology	46	$64,500	$97,500	$141,500	$198,000	$326,250
Communications	419	$87,400	$114,945	$153,000	$193,289	$246,370
Consumer Electronics	42	$94,150	$105,750	$156,500	$188,750	$256,500
Vehicular Technology	21	-	-	-	-	-
Other	61	$93,441	$122,400	$163,000	$208,099	$270,000
COMPUTERS	1,545	$80,000	$103,500	$138,941	$180,000	$233,614
Hardware	246	$90,000	$110,000	$143,702	$182,625	$254,261
Non-Internet Software Development	591	$80,000	$101,000	$136,000	$176,928	$226,000
Non-Internet Systems Analysis/Integration	179	$83,800	$102,583	$130,000	$173,726	$221,850
Non-Internet Software Applications including Database Admin.	90	$65,260	$100,415	$132,500	$165,825	$222,500
Internet/Web Development/Applications	220	$73,538	$106,875	$139,800	$181,438	$256,757
Other	224	$80,300	$108,172	$147,500	$181,875	$234,290
ELECTROMAGNETICS AND RADIATION	420	$84,900	$110,000	$137,912	$169,606	$204,655
Antennas and Propagation	103	$78,720	$116,100	$140,000	$172,000	$197,367
Electromagnetic Compatibility	65	$76,800	$96,000	$123,079	$155,000	$180,600
Magnetics	26	$90,500	$109,472	$145,000	$180,902	$241,000
Microwave Theory and Techniques	114	$79,200	$105,314	$133,526	$168,344	$200,650
Nuclear and Plasma Sciences	70	$87,660	$113,725	$139,000	$159,825	$192,660
Other	50	$102,000	$121,500	$150,000	$184,600	$220,000
ENERGY AND POWER ENGINEERING	1,597	$75,000	$94,450	$121,000	$152,000	$192,000

Review from last lecture:

How much would it cost to download a 2-hour HDTV “movie” using compressed audio and video on a Verizon Smart Phone today? Assume total signal compressed to 14MB/sec

Verizon Data Plan of Jan 2016 $3.50/GB

Total bytes: 43,000 GB/14 = 3070 GB = 3.1 TB

Total cost: $10,745

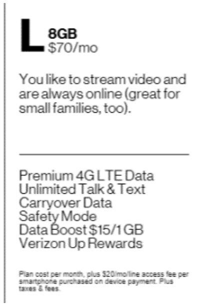
Moving audio and video data is still expensive and still challenging !

Data costs for cellular communications are dropping ?

(Verizon data plan of April 2014 is $15/GB from 1G to 3G increment)

(Verizon data plan of Aug 2015 is $7.50/GB from 1G to 3G increment)

(Verizon data plan of Aug 2018 is $15/GB over plan limit if not unlimited)



L **8GB**
$70/mo

You like to stream video and are always online (great for small families, too).

Premium 4G LTE Data
Unlimited Talk & Text
Carryover Data
Safety Mode
Data Boost $15/1GB
Verizon Up Rewards

Plan cost per month, plus $20/mo/line access fee per smartphone purchased on device payment. Plus taxes & fees.

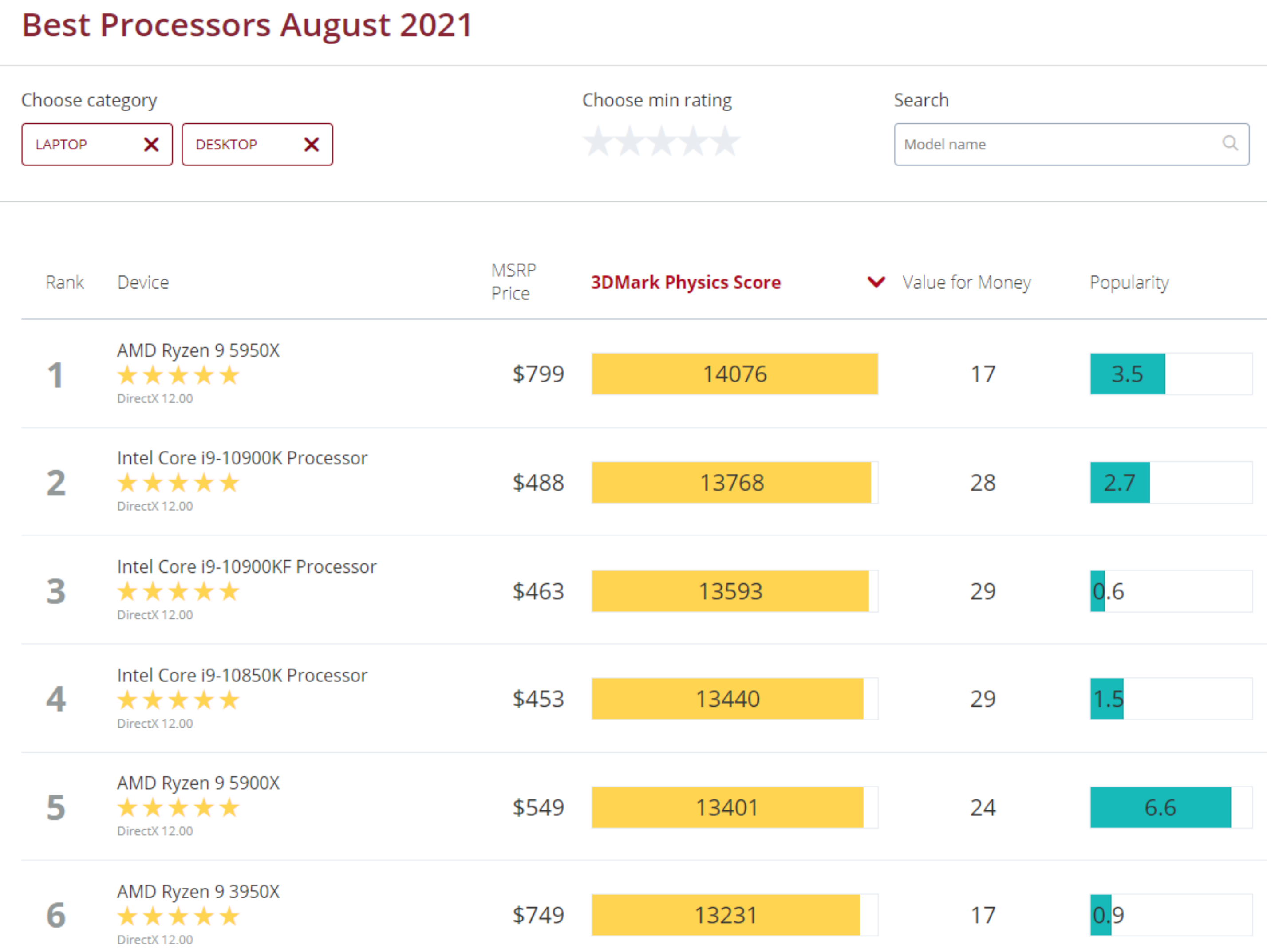
Review from last lecture:

Challenge to Students

- Become aware of how technology operates
- Identify opportunities where electronics technology can be applied
- Ask questions about how things operate and why

Selected Semiconductor Trends

- Microprocessors
- DRAMS
- FPGA



Best Processors August 2021

Choose category

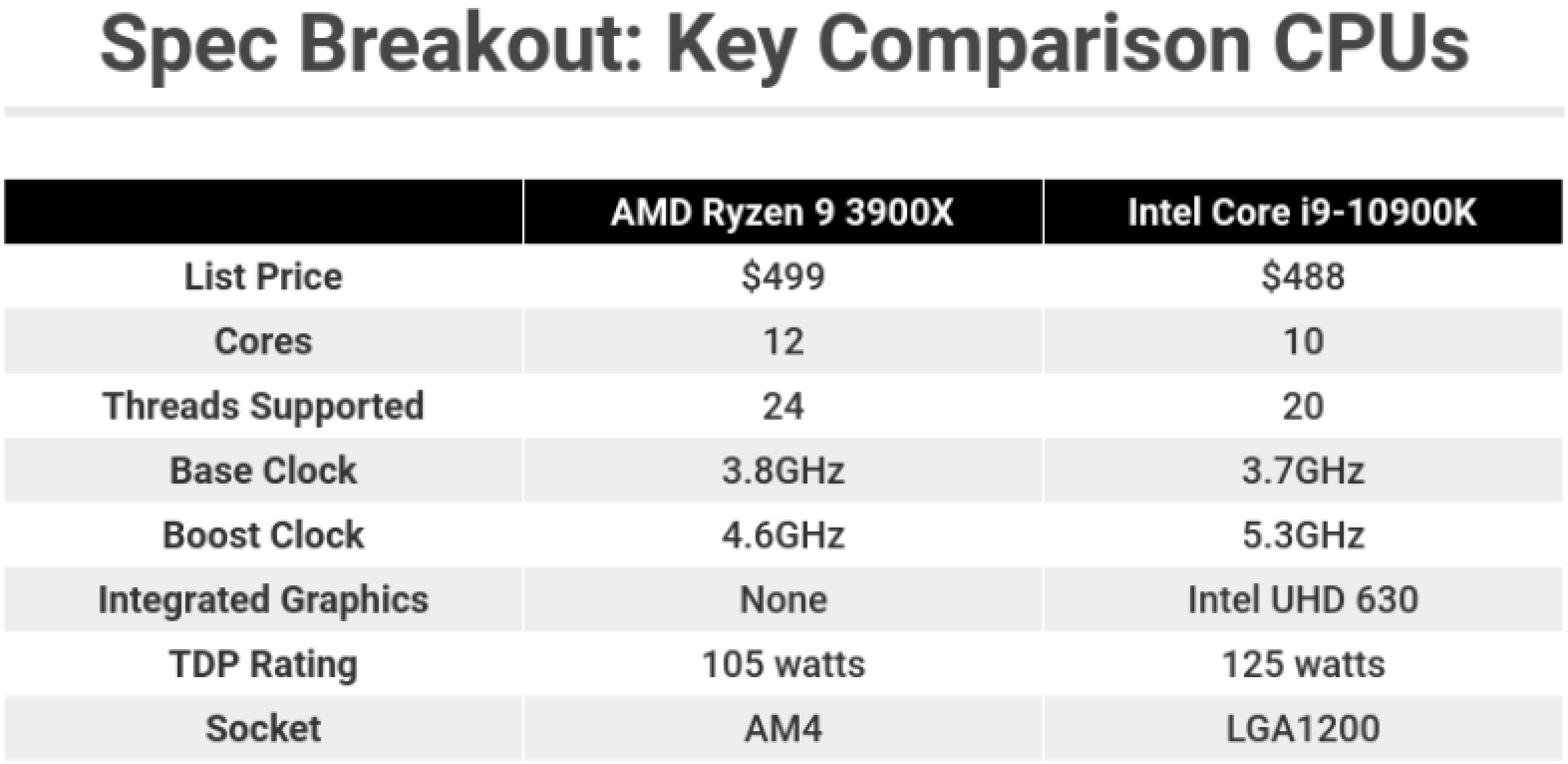
Choose min rating

☆☆☆☆☆

Search

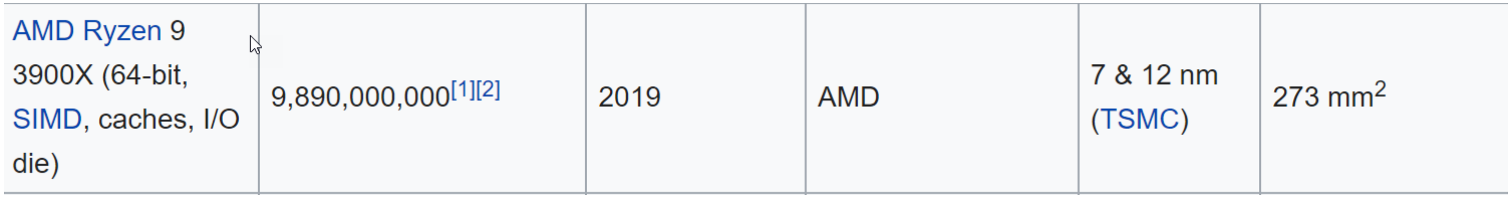
Rank	Device	MSRP Price	3DMark Physics Score	Value for Money	Popularity
1	AMD Ryzen 9 5950X ★★★★★ DirectX 12.00	$799	14076	17	3.5
2	Intel Core i9-10900K Processor ★★★★★ DirectX 12.00	$488	13768	28	2.7
3	Intel Core i9-10900KF Processor ★★★★★ DirectX 12.00	$463	13593	29	0.6
4	Intel Core i9-10850K Processor ★★★★★ DirectX 12.00	$453	13440	29	1.5
5	AMD Ryzen 9 5900X ★★★★★ DirectX 12.00	$549	13401	24	6.6
6	AMD Ryzen 9 3950X ★★★★★ DirectX 12.00	$749	13231	17	0.9

7	Intel Core i9-9960X Processor ★★★★★ DirectX 12.00	n/a	13076	n/a	0.0
8	Intel Core i9-11900K Processor ★★★★★ DirectX 12.00	$539	12762	23	0.3
9	Intel Core i9-7980XE Processor ★★★★★ DirectX 12.00	$1979	12376	6	0.1
10	Intel Core i9-10900 Processor ★★★★★ DirectX 12.00	$440	12278	27	0.1
11	AMD Ryzen Threadripper 3960X ★★★★★ DirectX 12.00	$1399	12248	8	0.1
12	AMD Ryzen 9 3900XT ★★★★★ DirectX 12.00	$499	12124	24	0.4
13	AMD Ryzen 9 3900X ★★★★★ DirectX 12.00	$499	12120	24	3.2



Spec Breakout: Key Comparison CPUs

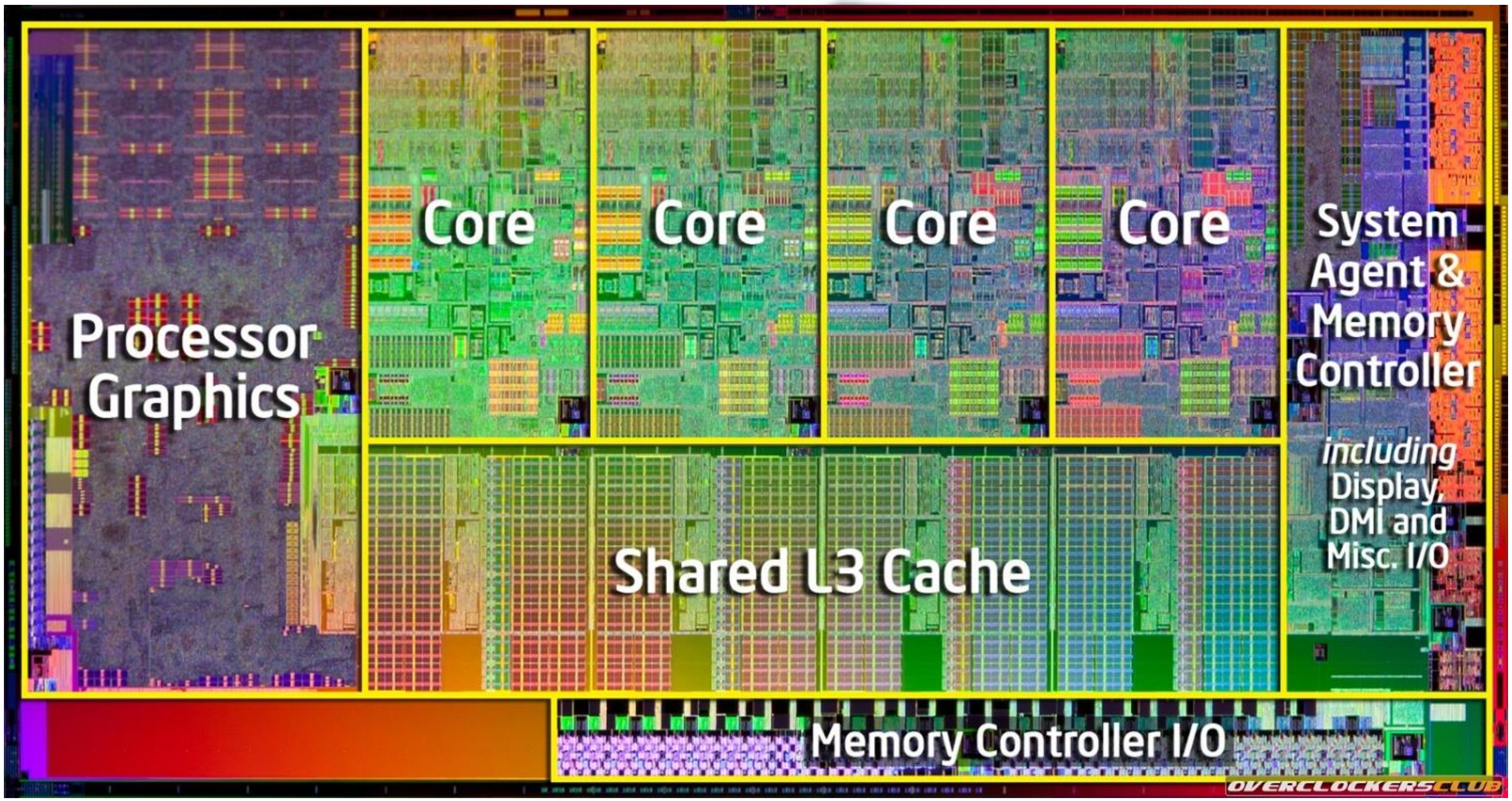
	AMD Ryzen 9 3900X	Intel Core i9-10900K
List Price	$499	$488
Cores	12	10
Threads Supported	24	20
Base Clock	3.8GHz	3.7GHz
Boost Clock	4.6GHz	5.3GHz
Integrated Graphics	None	Intel UHD 630
TDP Rating	105 watts	125 watts
Socket	AM4	LGA1200



AMD Ryzen 9 3900X (64-bit, SIMD, caches, I/O die)	9,890,000,000[1][2]	2019	AMD	7 & 12 nm (TSMC)	273 mm^2

Intel Core i9 10900K 14nm CMOS

Recent Intel Processor

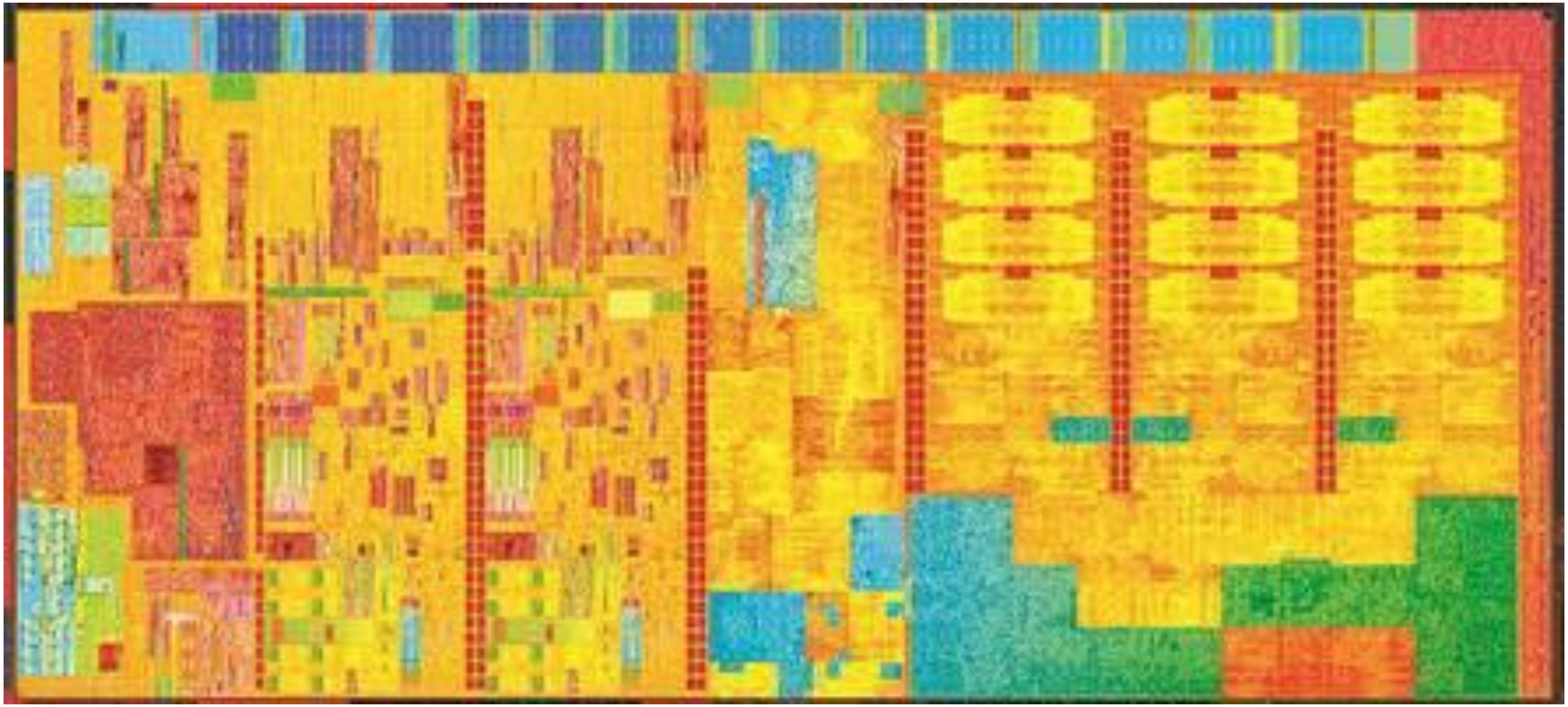


Processor

Quad-Core Intel® Core i7 Processor Up to 3.4GHz in 32nm CMOS

Power Dissipation: 95 watts

Today!



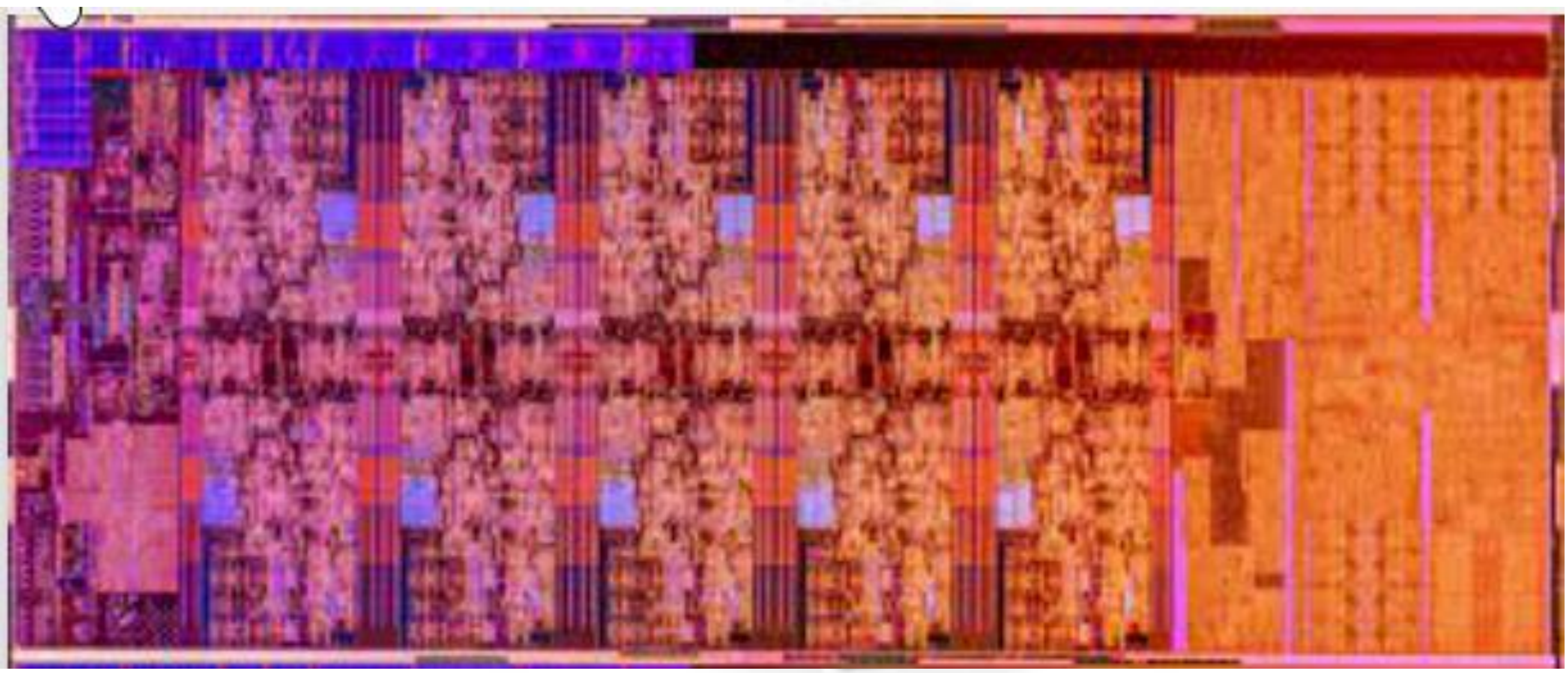
Processor

8-core (2.6B) or 18-core Broadwell Intel® Core M Processor in 14nm CMOS

Intel Tic-Toc product (“Toc” from 22nm Haswell processor)

Power Dissipation: 4.9 watts

Today!

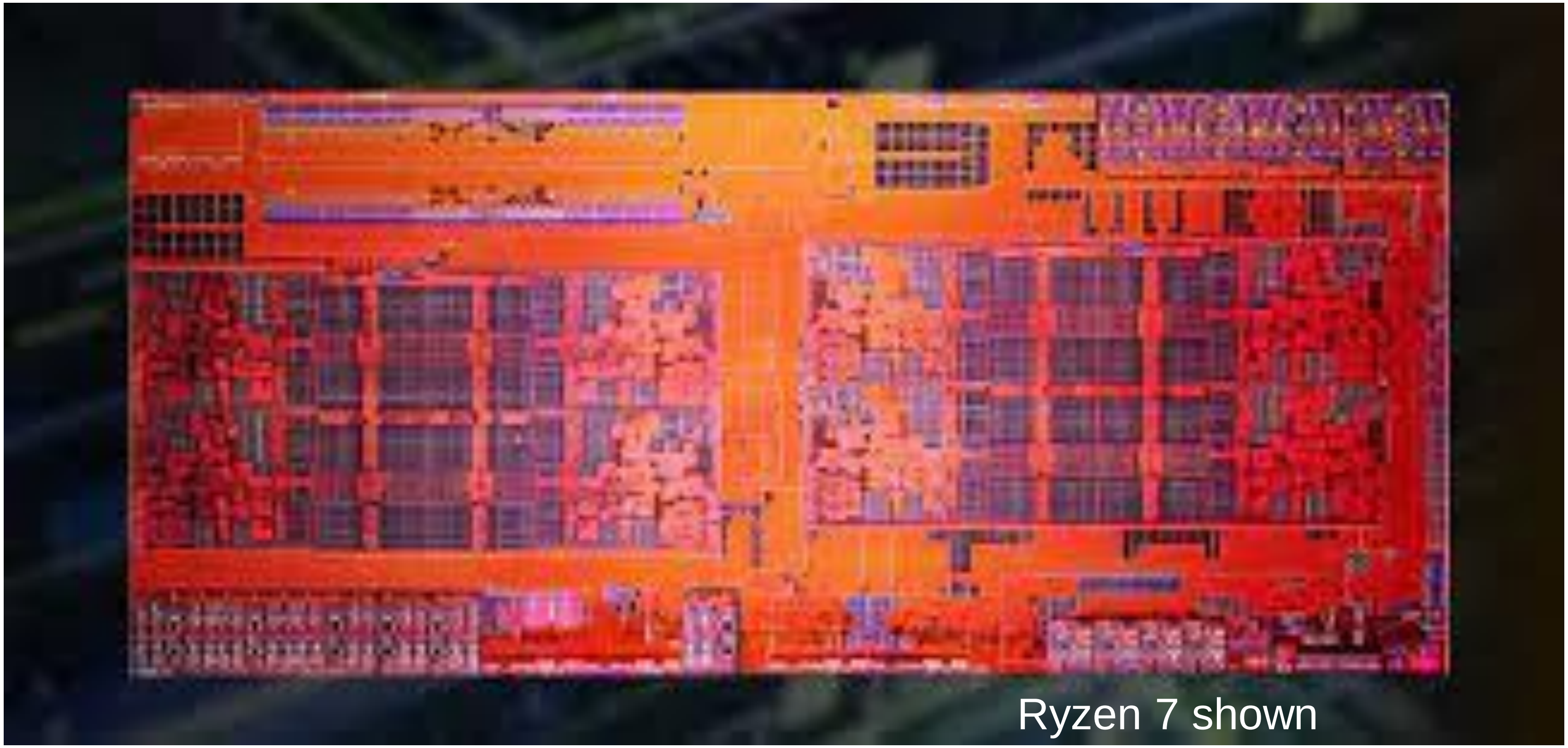


Processor   Intel Core i9 10900K

10-core Processor in 14nm CMOS, 3.7GHz

Power Dissipation: 125 watts

Today!

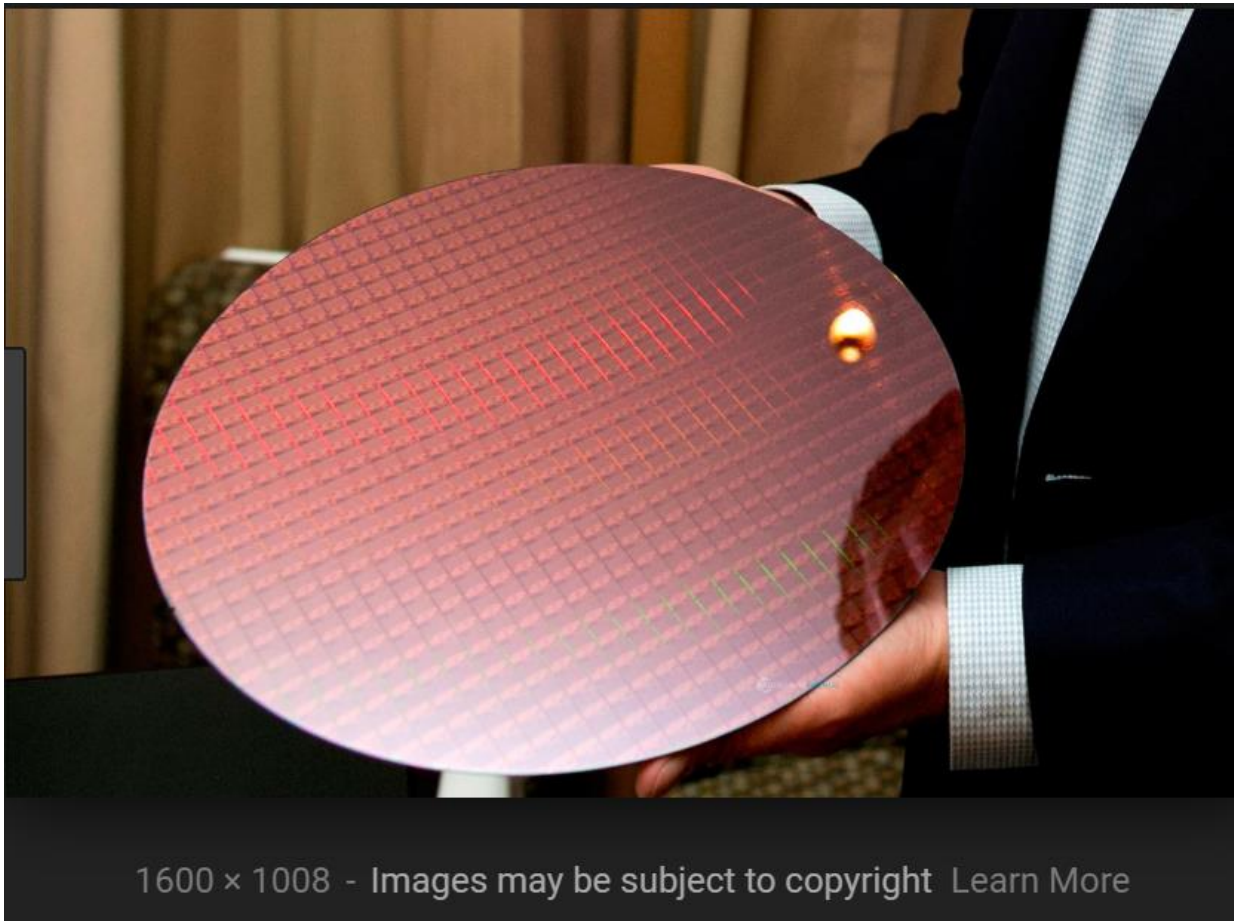

Ryzen 7 shown

Processor AMD Ryzen 5950X

16-core Processor in 7nm CMOS, 3.4-4.9 GHz

Power Dissipation: 105 watts

A bit ago!



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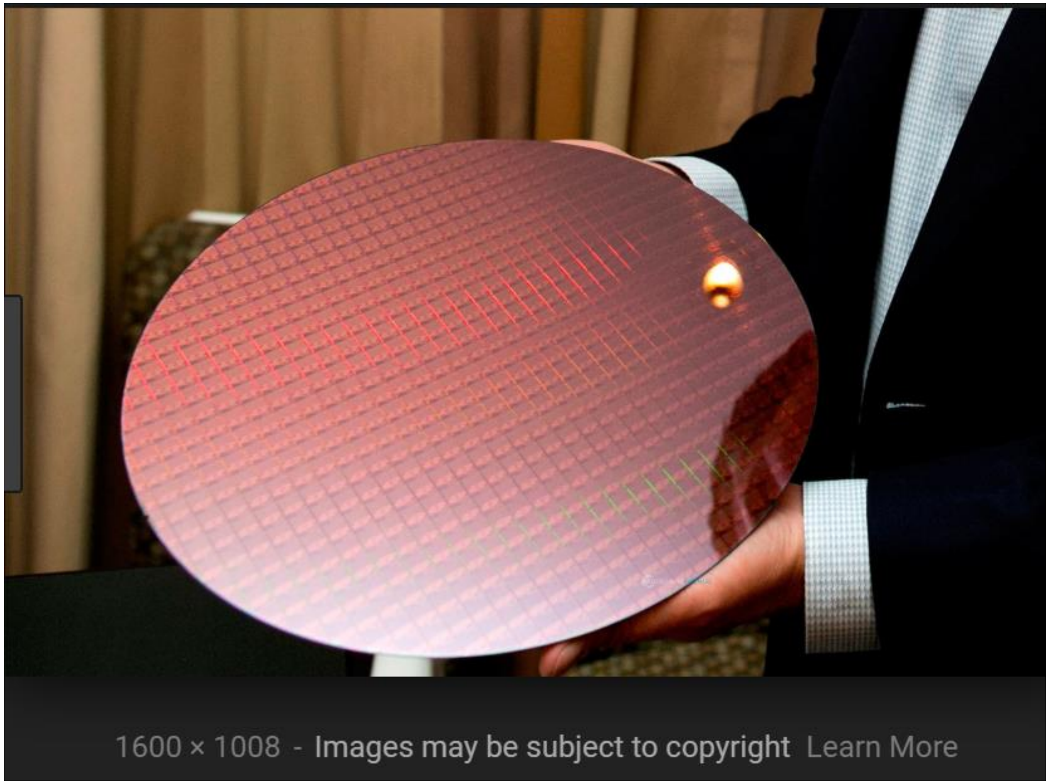
Cannon Lake Processor

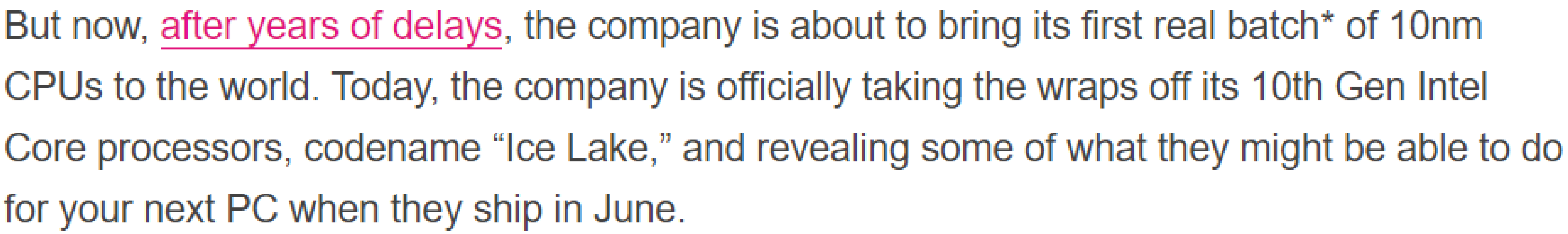
10nm CMOS
i3-8121U
Delayed production schedule – expected to ramp up in 2019

A bit ago!



Cannon Lake Processor

Press release from Intel – May 28, 2019

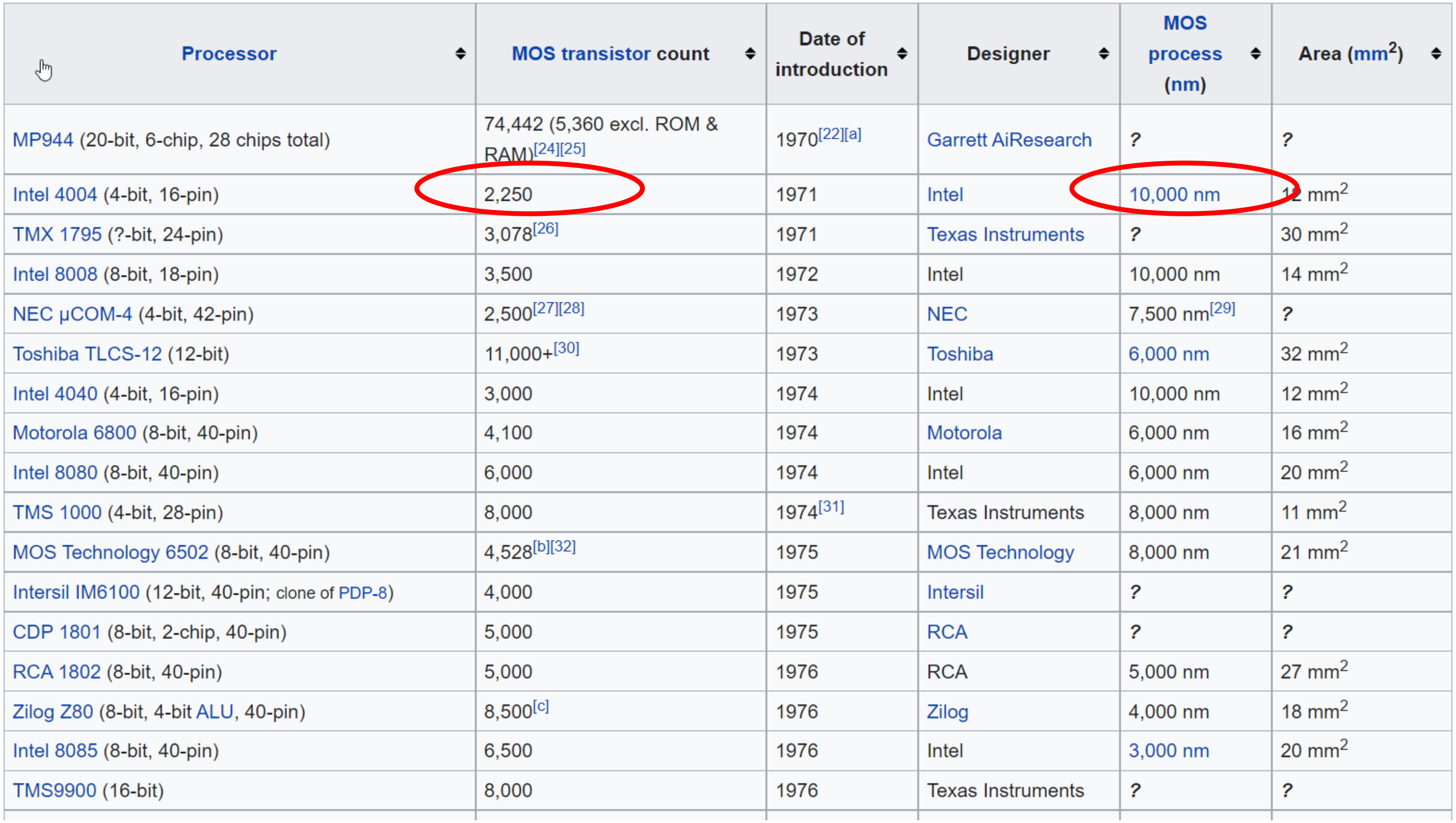


But now, after years of delays, the company is about to bring its first real batch* of 10nm CPUs to the world. Today, the company is officially taking the wraps off its 10th Gen Intel Core processors, codename “Ice Lake,” and revealing some of what they might be able to do for your next PC when they ship in June.

Update: Intel discontinued the Cannon Lake Processor on Feb 28, 2020

Yesterday!

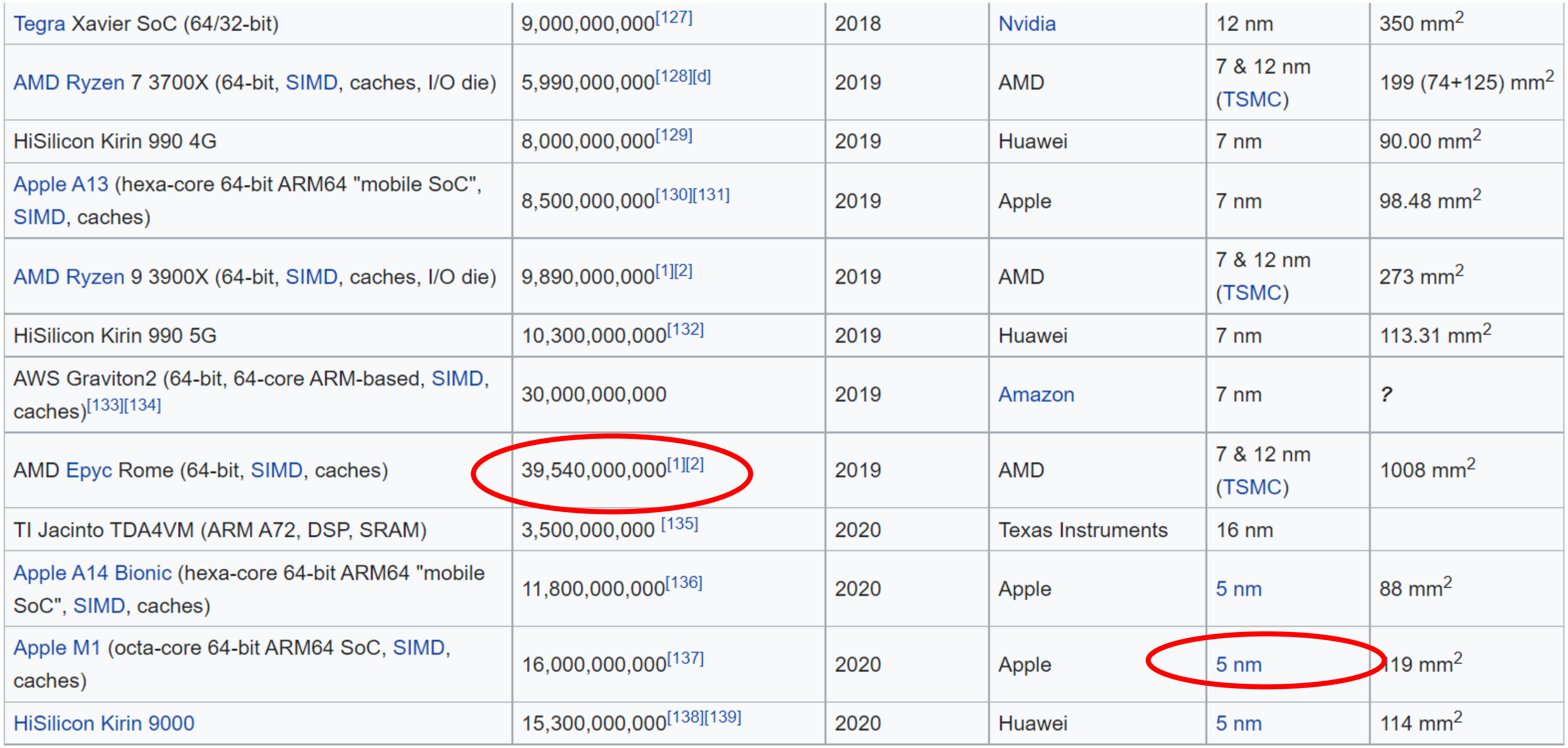
Processors



Processor	MOS transistor count	Date of introduction	Designer	MOS process (nm)	Area (mm^2)
MP944 (20-bit, 6-chip, 28 chips total)	74,442 (5,360 excl. ROM & RAM)[24][25]	1970[22][a]	Garrett AiResearch	?	?
Intel 4004 (4-bit, 16-pin)	2,250	1971	Intel	10,000 nm	12 mm^2
TMX 1795 (?-bit, 24-pin)	3,078[26]	1971	Texas Instruments	?	30 mm^2
Intel 8008 (8-bit, 18-pin)	3,500	1972	Intel	10,000 nm	14 mm^2
NEC μCOM-4 (4-bit, 42-pin)	2,500[27][28]	1973	NEC	7,500 nm[29]	?
Toshiba TLCS-12 (12-bit)	11,000+[30]	1973	Toshiba	6,000 nm	32 mm^2
Intel 4040 (4-bit, 16-pin)	3,000	1974	Intel	10,000 nm	12 mm^2
Motorola 6800 (8-bit, 40-pin)	4,100	1974	Motorola	6,000 nm	16 mm^2
Intel 8080 (8-bit, 40-pin)	6,000	1974	Intel	6,000 nm	20 mm^2
TMS 1000 (4-bit, 28-pin)	8,000	1974[31]	Texas Instruments	8,000 nm	11 mm^2
MOS Technology 6502 (8-bit, 40-pin)	4,528[b][32]	1975	MOS Technology	8,000 nm	21 mm^2
Intersil IM6100 (12-bit, 40-pin; clone of PDP-8)	4,000	1975	Intersil	?	?
CDP 1801 (8-bit, 2-chip, 40-pin)	5,000	1975	RCA	?	?
RCA 1802 (8-bit, 40-pin)	5,000	1976	RCA	5,000 nm	27 mm^2
Zilog Z80 (8-bit, 4-bit ALU, 40-pin)	8,500[c]	1976	Zilog	4,000 nm	18 mm^2
Intel 8085 (8-bit, 40-pin)	6,500	1976	Intel	3,000 nm	20 mm^2
TMS9900 (16-bit)	8,000	1976	Texas Instruments	?	?

Today!

Processors

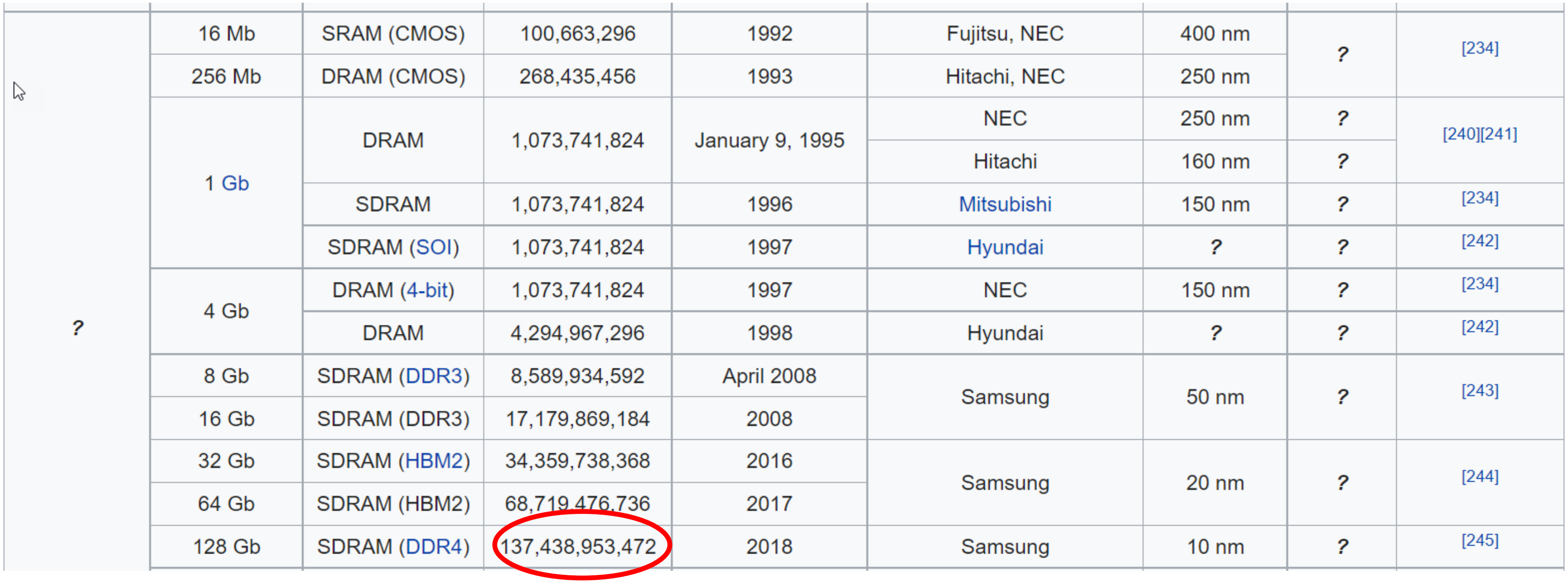


Tegra Xavier SoC (64/32-bit)	9,000,000,000[127]	2018	Nvidia	12 nm	350 mm^2
AMD Ryzen 7 3700X (64-bit, SIMD, caches, I/O die)	5,990,000,000[128][d]	2019	AMD	7 & 12 nm (TSMC)	199 (74+125) mm^2
HiSilicon Kirin 990 4G	8,000,000,000[129]	2019	Huawei	7 nm	90.00 mm^2
Apple A13 (hexa-core 64-bit ARM64 "mobile SoC", SIMD, caches)	8,500,000,000[130][131]	2019	Apple	7 nm	98.48 mm^2
AMD Ryzen 9 3900X (64-bit, SIMD, caches, I/O die)	9,890,000,000[1][2]	2019	AMD	7 & 12 nm (TSMC)	273 mm^2
HiSilicon Kirin 990 5G	10,300,000,000[132]	2019	Huawei	7 nm	113.31 mm^2
AWS Graviton2 (64-bit, 64-core ARM-based, SIMD, caches)[133][134]	30,000,000,000	2019	Amazon	7 nm	?
AMD Epyc Rome (64-bit, SIMD, caches)	39,540,000,000[1][2]	2019	AMD	7 & 12 nm (TSMC)	1008 mm^2
TI Jacinto TDA4VM (ARM A72, DSP, SRAM)	3,500,000,000 [135]	2020	Texas Instruments	16 nm	
Apple A14 Bionic (hexa-core 64-bit ARM64 "mobile SoC", SIMD, caches)	11,800,000,000[136]	2020	Apple	5 nm	88 mm^2
Apple M1 (octa-core 64-bit ARM64 SoC, SIMD, caches)	16,000,000,000[137]	2020	Apple	5 nm	119 mm^2
HiSilicon Kirin 9000	15,300,000,000[138][139]	2020	Huawei	5 nm	114 mm^2

Today!

FPGA	MOS transistor count	Date of introduction	Designer	Manufacturer	MOS process	Area	Ref
Virtex	70,000,000	1997	Xilinx				
Virtex-E	200,000,000	1998	Xilinx				
Virtex-II	350,000,000	2000	Xilinx		130 nm		
Virtex-II PRO	430,000,000	2002	Xilinx				
Virtex-4	1,000,000,000	2004	Xilinx		90 nm		
Virtex-5	1,100,000,000	2006	Xilinx	TSMC	65 nm		[195]
Stratix IV	2,500,000,000	2008	Altera	TSMC	40 nm		[196]
Stratix V	3,800,000,000	2011	Altera	TSMC	28 nm		[197]
Arria 10	5,300,000,000	2014	Altera	TSMC	20 nm		[198]
Virtex-7 2000T	6,800,000,000	2011	Xilinx	TSMC	28 nm		[199]
Stratix 10 SX 2800	17,000,000,000	TBD	Intel	Intel	14 nm	560 mm^2	[200][201]
Virtex-Ultrascale VU440	20,000,000,000	Q1 2015	Xilinx	TSMC	20 nm		[202][203]
Virtex-Ultrascale+ VU19P	35,000,000,000	2020	Xilinx	TSMC	16 nm	900 mm^2 [e]	[204][205][206]
Versal VC1902	37,000,000,000	2H 2019	Xilinx	TSMC	7 nm		[207][208][209]
Stratix 10 GX 10M	43,300,000,000	Q4 2019	Intel	Intel	14 nm	1400 mm^2 [e]	[210][211]
Versal VP1802	92,000,000,000	2021 ?[f]	Xilinx	TSMC	7 nm	?	[212][213]

Memory Trends



?	16 Mb	SRAM (CMOS)	100,663,296	1992	Fujitsu, NEC	400 nm	?	[234]
	256 Mb	DRAM (CMOS)	268,435,456	1993	Hitachi, NEC	250 nm		
	1 Gb	DRAM	1,073,741,824	January 9, 1995	NEC	250 nm	?	[240][241]
					Hitachi	160 nm	?	
		SDRAM	1,073,741,824	1996	Mitsubishi	150 nm	?	[234]
		SDRAM (SOI)	1,073,741,824	1997	Hyundai	?	?	[242]
	4 Gb	DRAM (4-bit)	1,073,741,824	1997	NEC	150 nm	?	[234]
		DRAM	4,294,967,296	1998	Hyundai	?	?	[242]
	8 Gb	SDRAM (DDR3)	8,589,934,592	April 2008	Samsung	50 nm	?	[243]
	16 Gb	SDRAM (DDR3)	17,179,869,184	2008				
	32 Gb	SDRAM (HBM2)	34,359,738,368	2016	Samsung	20 nm	?	[244]
	64 Gb	SDRAM (HBM2)	68,719,476,736	2017				
	128 Gb	SDRAM (DDR4)	137,438,953,472	2018	Samsung	10 nm	?	[245]

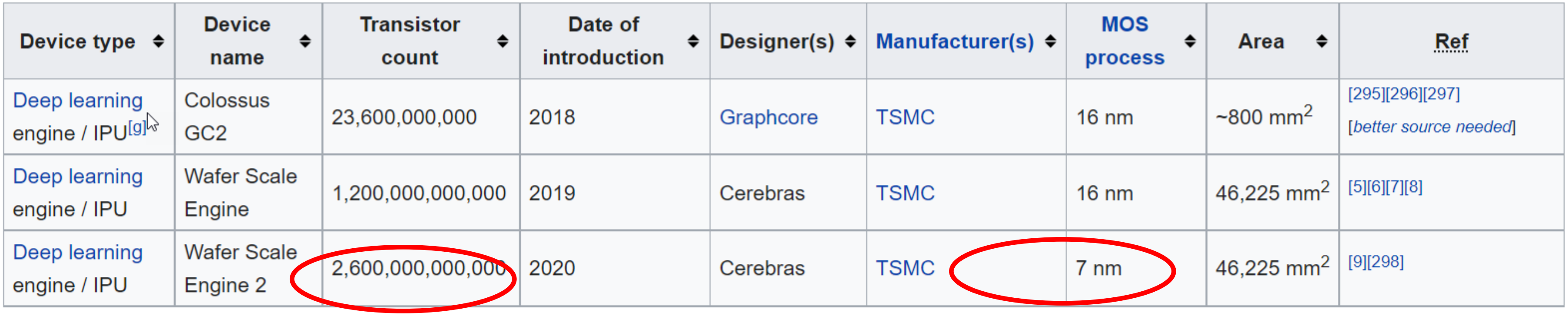
Memory Trends

?	1 Gb	2-bit NAND	536,870,912	2001	Samsung	?	?	[234]
					Toshiba, SanDisk	160 nm	?	[251]
	2 Gb	NAND	2,147,483,648	2002	Samsung, Toshiba	?	?	[252][253]
	8 Gb	NAND	8,589,934,592	2004	Samsung	60 nm	?	[252]
	16 Gb	NAND	17,179,869,184	2005	Samsung	50 nm	?	[254]
	32 Gb	NAND	34,359,738,368	2006	Samsung	40 nm		
THGAM	128 Gb	Stacked NAND	128,000,000,000	April 2007	Toshiba	56 nm	252 mm^2	[255]
THGBM	256 Gb	Stacked NAND	256,000,000,000	2008	Toshiba	43 nm	353 mm^2	[256]
THGBM2	1 Tb	Stacked 4-bit NAND	256,000,000,000	2010	Toshiba	32 nm	374 mm^2	[257]
KLMCG8GE4A	512 Gb	Stacked 2-bit NAND	256,000,000,000	2011	Samsung	?	192 mm^2	[258]
KLUFG8R1EM	4 Tb	Stacked 3-bit V-NAND	1,365,333,333,504	2017	Samsung	?	150 mm^2	[259]
eUFS (1 TB)	8 Tb	Stacked 4-bit V-NAND	2,048,000,000,000	2019	Samsung	?	150 mm^2	[4][260]

FPGA Trends

FPGA	MOS transistor count	Date of introduction	Designer	Manufacturer	MOS process	Area	Ref
Virtex	70,000,000	1997	Xilinx				
Virtex-E	200,000,000	1998	Xilinx				
Virtex-II	350,000,000	2000	Xilinx		130 nm		
Virtex-II PRO	430,000,000	2002	Xilinx				
Virtex-4	1,000,000,000	2004	Xilinx		90 nm		
Virtex-5	1,100,000,000	2006	Xilinx	TSMC	65 nm		[195]
Stratix IV	2,500,000,000	2008	Altera	TSMC	40 nm		[196]
Stratix V	3,800,000,000	2011	Altera	TSMC	28 nm		[197]
Arria 10	5,300,000,000	2014	Altera	TSMC	20 nm		[198]
Virtex-7 2000T	6,800,000,000	2011	Xilinx	TSMC	28 nm		[199]
Stratix 10 SX 2800	17,000,000,000	TBD	Intel	Intel	14 nm	560 mm^2	[200][201]
Virtex-Ultrascale VU440	20,000,000,000	Q1 2015	Xilinx	TSMC	20 nm		[202][203]
Virtex-Ultrascale+ VU19P	35,000,000,000	2020	Xilinx	TSMC	16 nm	900 mm^2 [e]	[204][205]
Versal VC1902	37,000,000,000	2H 2019	Xilinx	TSMC	7 nm		[207][208]
Stratix 10 GX 10M	43,300,000,000	Q4 2019	Intel	Intel	14 nm	1400 mm^2 [e]	[210][211]
Versal VP1802	92,000,000,000	2021 ?[f]	Xilinx	TSMC	7 nm	?	[212][213]

Special Purpose Systems



Device type	Device name	Transistor count	Date of introduction	Designer(s)	Manufacturer(s)	MOS process	Area	Ref
Deep learning engine / IPU[g]	Colossus GC2	23,600,000,000	2018	Graphcore	TSMC	16 nm	~800 mm^2	[295][296][297] [*better source needed*]
Deep learning engine / IPU	Wafer Scale Engine	1,200,000,000,000	2019	Cerebras	TSMC	16 nm	46,225 mm^2	[5][6][7][8]
Deep learning engine / IPU	Wafer Scale Engine 2	2,600,000,000,000	2020	Cerebras	TSMC	7 nm	46,225 mm^2	[9][298]

Selected Semiconductor Trends

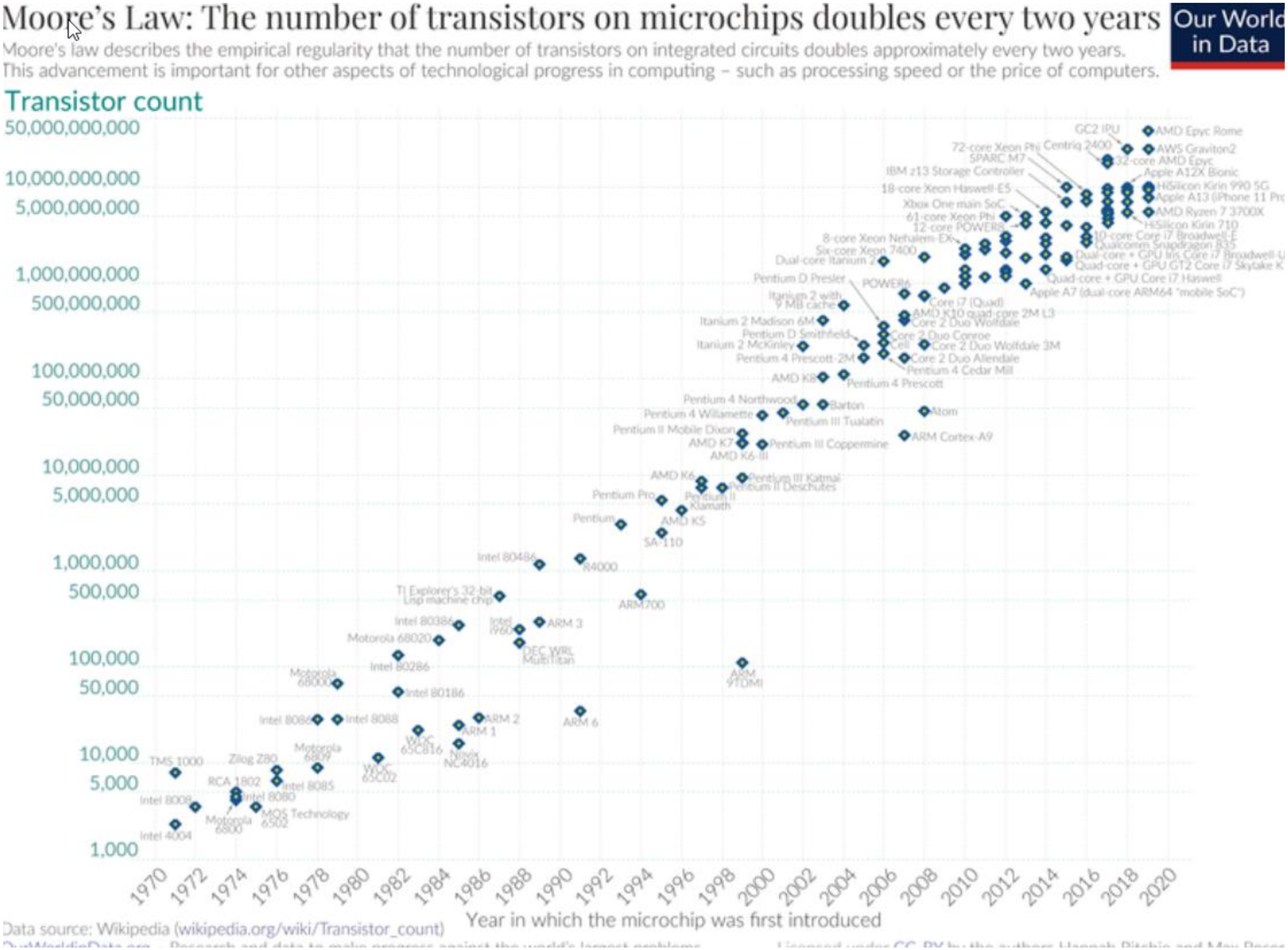
- Microprocessors
  - State of the art technology is now 5 nm with over 40 Billion transistors on a chip
- DRAMS
  - State of the art is now 128G bits on a chip in a 10nm process which requires somewhere around 140 Billion transistors
- FPGA
  - FPGAs currently have over 90 Billion transistors with 7nm technology and are growing larger

Device count on a chip has been increasing rapidly with time, device size has been decreasing rapidly with time and speed/performance has been rapidly increasing

Moore’s Law

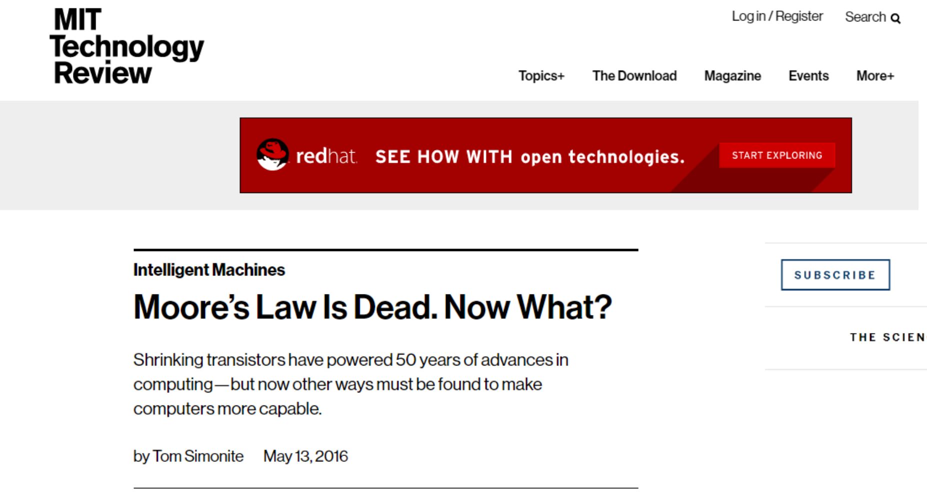
From Webopedia (Aug 2016)

The observation made in 1965 by Gordon Moore, co-founder of Intel, that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented. Moore predicted that this trend would continue for the foreseeable future. In subsequent years, the pace slowed down a bit, but data **density has doubled approximately every 18 months, and this is the current definition of Moore's Law, which Moore himself has blessed. Most experts, including Moore himself, expect Moore's Law to hold for at least another two decades.**

Moore's Law: The number of transistors on microchips doubles every two years
Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years.
This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.
Our World in Data
Transistor count
50,000,000,000
10,000,000,000
5,000,000,000
1,000,000,000
500,000,000
100,000,000
50,000,000
10,000,000
5,000,000
1,000,000
500,000
100,000
50,000
10,000
5,000
1,000
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year in which the microchip was first introduced
TMS 1000
Intel 8008
Intel 4004
RCA 1802
Zilog Z80
Intel 8080
Motorola 6800
MOS Technology 6502
Intel 8085
Motorola 6809
Intel 8086
Intel 8088
Motorola 68000
WDC 65C02
Intel 80286
Intel 80186
WDC 65C816
Novix NC4016
ARM 1
ARM 2
Motorola 68020
Intel 80386
TI Explorer's 32-bit Lisp machine chip
Intel i960
DEC WRL MultiTitan
ARM 3
Intel 80486
R4000
ARM 6
ARM700
Pentium
Pentium Pro
SA-110
AMD K5
AMD K6
Pentium II Klamath
Pentium II Deschutes
Pentium III Katmai
ARM 9TDMI
AMD K6-III
AMD K7
Pentium II Mobile Dixon
Pentium III Coppermine
Pentium 4 Willamette
Pentium III Tualatin
Pentium 4 Northwood
Barton
AMD K8
Pentium 4 Prescott
Pentium 4 Prescott-2M
Itanium 2 McKinley
Pentium D Smithfield
Itanium 2 Madison 6M
Itanium 2 with 9 MB cache
Pentium D Presler
POWER6
Cell
Core 2 Duo Conroe
Core 2 Duo Allendale
Pentium 4 Cedar Mill
Core 2 Duo Wolfdale 3M
AMD K10 quad-core 2M L3
Core 2 Duo Wolfdale
Core i7 (Quad)
Atom
ARM Cortex-A9
Dual-core Itanium 2
Six-core Xeon 7400
8-core Xeon Nehalem-EX
12-core POWER8
61-core Xeon Phi
Xbox One main SoC
18-core Xeon Haswell-E5
IBM z13 Storage Controller
SPARC M7
72-core Xeon Phi
Centriq 2400
GC2 IPU
AMD Epyc Rome
AWS Graviton2
32-core AMD Epyc
Apple A12X Bionic
HiSilicon Kirin 990 5G
Apple A13 (iPhone 11 Pro)
AMD Ryzen 7 3700X
HiSilicon Kirin 710
10-core Core i7 Broadwell-E
Qualcomm Snapdragon 835
Dual-core + GPU Iris Core i7 Broadwell-U
Quad-core + GPU GT2 Core i7 Skylake K
Quad-core + GPU Core i7 Haswell
Apple A7 (dual-core ARM64 "mobile SoC")
Data source: Wikipedia (wikipedia.org/wiki/Transistor_count)

Aug 25, 2021

More on Moore’s Law

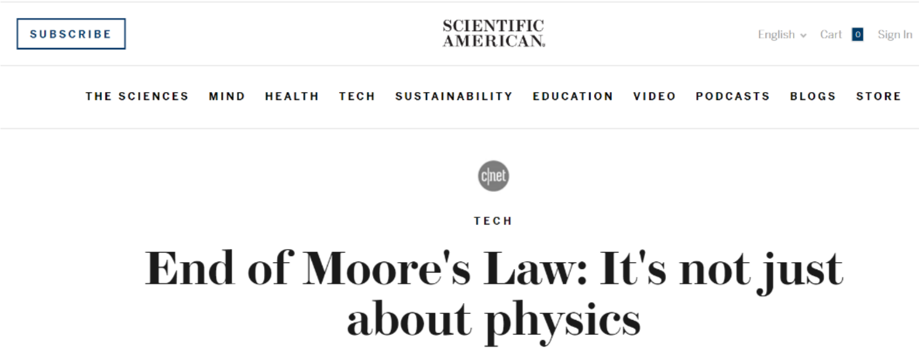


Intelligent Machines

Moore’s Law Is Dead. Now What?

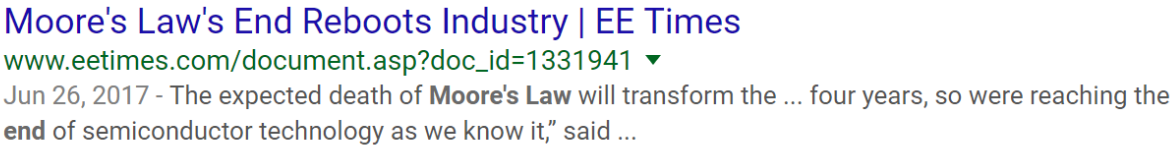
Shrinking transistors have powered 50 years of advances in computing—but now other ways must be found to make computers more capable.

by Tom Simonite May 13, 2016



TECH

End of Moore's Law: It's not just about physics



Moore's Law's End Reboots Industry | EE Times

www.eetimes.com/document.asp?doc_id=1331941

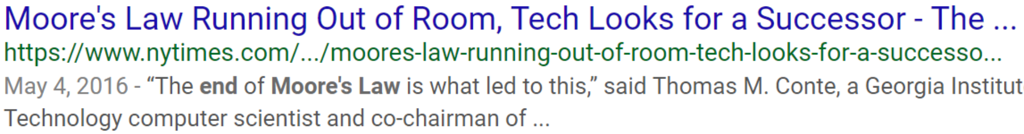
Jun 26, 2017 - The expected death of **Moore's Law** will transform the ... four years, so were reaching the **end** of semiconductor technology as we know it,” said ...

Transistors Could Stop Shrinking in 2021

A key industry report forecasts an end to traditional scaling of transistors

Posted 22 Jul 2016 | 13:04 GMT

By RACHEL COURTLAND



Moore's Law Running Out of Room, Tech Looks for a Successor - The ...

https://www.nytimes.com/.../moores-law-running-out-of-room-tech-looks-for-a-successo...

May 4, 2016 - “The **end** of **Moore's Law** is what led to this,” said Thomas M. Conte, a Georgia Institute of Technology computer scientist and co-chairman of ...

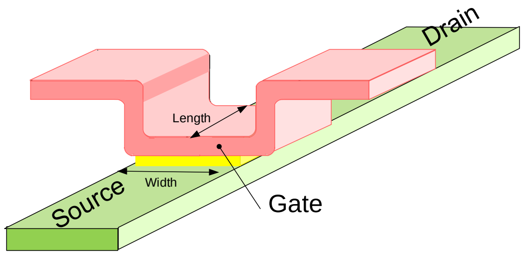
Moore’s Law

From Wikopedia (Aug 2017)

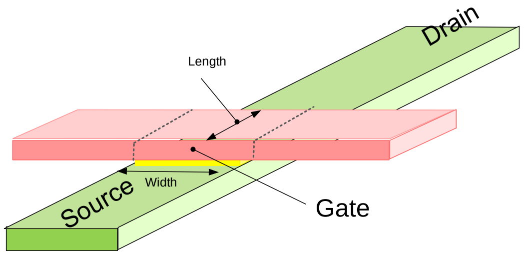
….However, in April 2016, Intel CEO Brian Krzanich stated that "In my 34 years in the semiconductor industry, I have witnessed the advertised death of Moore’s Law no less than four times. As we progress from 14 nanometer technology to 10 nanometer and plan for 7 nanometer and 5 nanometer and even beyond, our plans are proof that Moore’s Law is alive and well".[25] In January 2017, he declared that "I've heard the death of Moore's law more times than anything else in my career ... And I'm here today to really show you and tell you that Moore's Law is alive and well and flourishing."[26]

Today hardware has to be designed in a multi-core manner to keep up with Moore's law. In turn, this also means that software has to be written in a multi-threaded manner to take full advantage of the hardware.

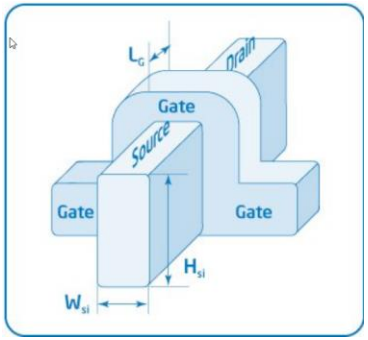
Field Effect Transistors



Planar
MOSFET
(LOCOS)



Planar
MOSFET
(STI)



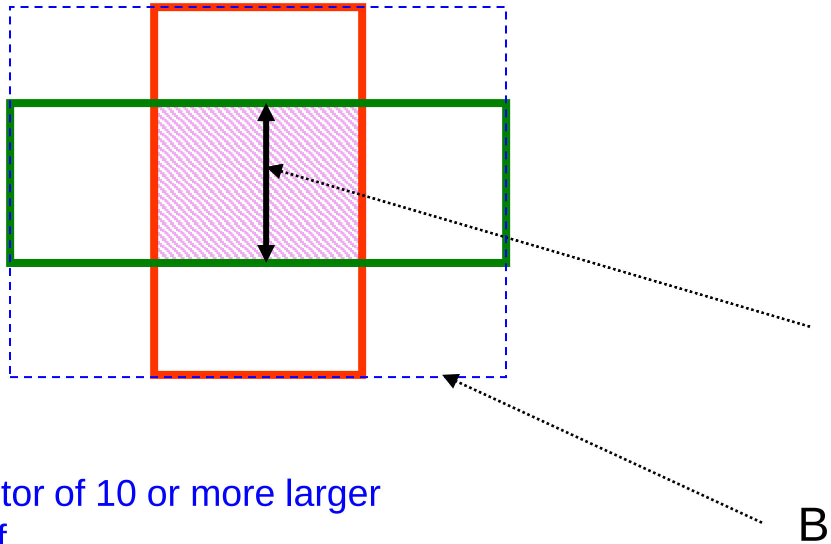
FinFET
Tri-Gate

Dielectric not shown

Feature Size

The feature size of a process generally corresponds to the minimum lateral dimensions of the transistors that can be fabricated in the process

(Top Surface View)



Feature Size of MOS Transistor

Bounding Region

- Bounding region often a factor of 10 or more larger than area of transistor itself
- This along with interconnect requirements and sizing requirements throughout the circuit create an area overhead factor of 10x to 100x

Moore’s Law

(from Wikipedia)

Moore's law is the empirical observation that the complexity of integrated circuits, with respect to minimum component cost, doubles every 24 months[1]. It is attributed to Gordon E. Moore[2], a co-founder of Intel.

- Observation, not a physical law
- Often misinterpreted or generalized
- Many say it has been dead for several years
- Many say it will continue for a long while
- Not intended to be a long-term prophecy about trends in the semiconductor field
- Something a reporter can always comment about when they have nothing to say!

Device scaling, device count, circuit complexity, device cost, … in leading-edge processes will continue to dramatically improve (probably nearly geometrically with a time constant of around 2 years) for the foreseeable future !!

Challenges

- Managing increasing device count
- Short lead time from conception to marketplace
- Process technology advances
- Device performance degradation
- Increasing variability
- Increasing pressure for cost reduction
- Power dissipation

Future Trends and Opportunities

- Is there an end in sight?

No ! But the direction the industry will follow is not yet known but the role semiconductor technology plays on society will increase dramatically!

- Will engineers trained in this field become obsolete at mid-career ?

No ! Engineers trained in this field will naturally evolve to support the microelectronics technology of the future. Integrated Circuit designers are now being trained to efficiently manage enormous levels of complexity and any evolutionary technology will result in even larger and more complexity systems with similar and expanded skills being required by the engineering community with the major changes occurring only in the details.

Future Trends and Opportunities

- Will engineers trained in this field be doing things the same way as they are now at mid-career?

No ! There have been substantive changes in approaches every few years since 1965 and those changes will continue. Continuing education to track evolutionary and revolutionary changes in the field will be essential to remain productive in the field.

- What changes can we expect to see beyond the continued geometric growth in complexity (capability) ?

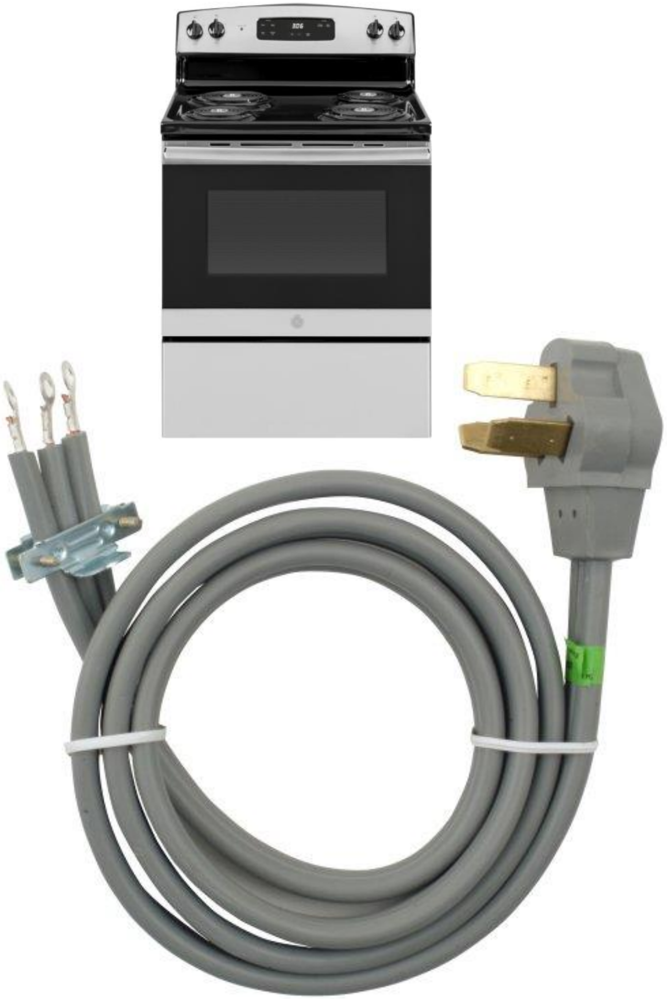
That will be determined by the creativity and marketing skills of those who become immersed in the technology. New "Gordon Moores", "Bill Gates" and "Jim Dells" will evolve.

Creation of Integrated Circuits

Most integrated circuits are comprised of transistors along with a small number of passive components and maybe a few diodes

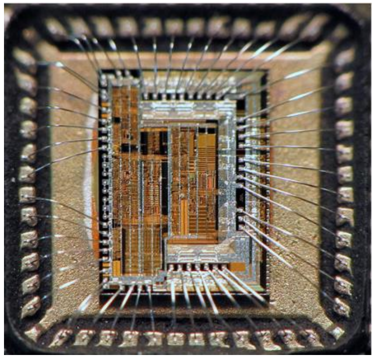
This course will focus on understanding how transistors operate and on how they can be interconnected and possibly combined with a small number of passive components to form useful integrated circuits

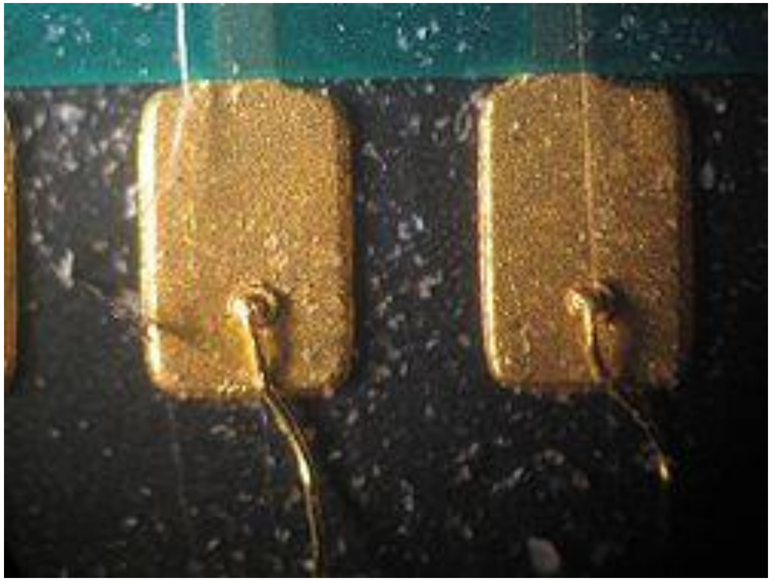
Wire Sizes for Electrical Interconnects



50 A Range Cord

6 ga Wiring 0.162 in diameter





25um Gold Bonding Wire

Stay Safe and Stay Healthy !

End of Lecture 2