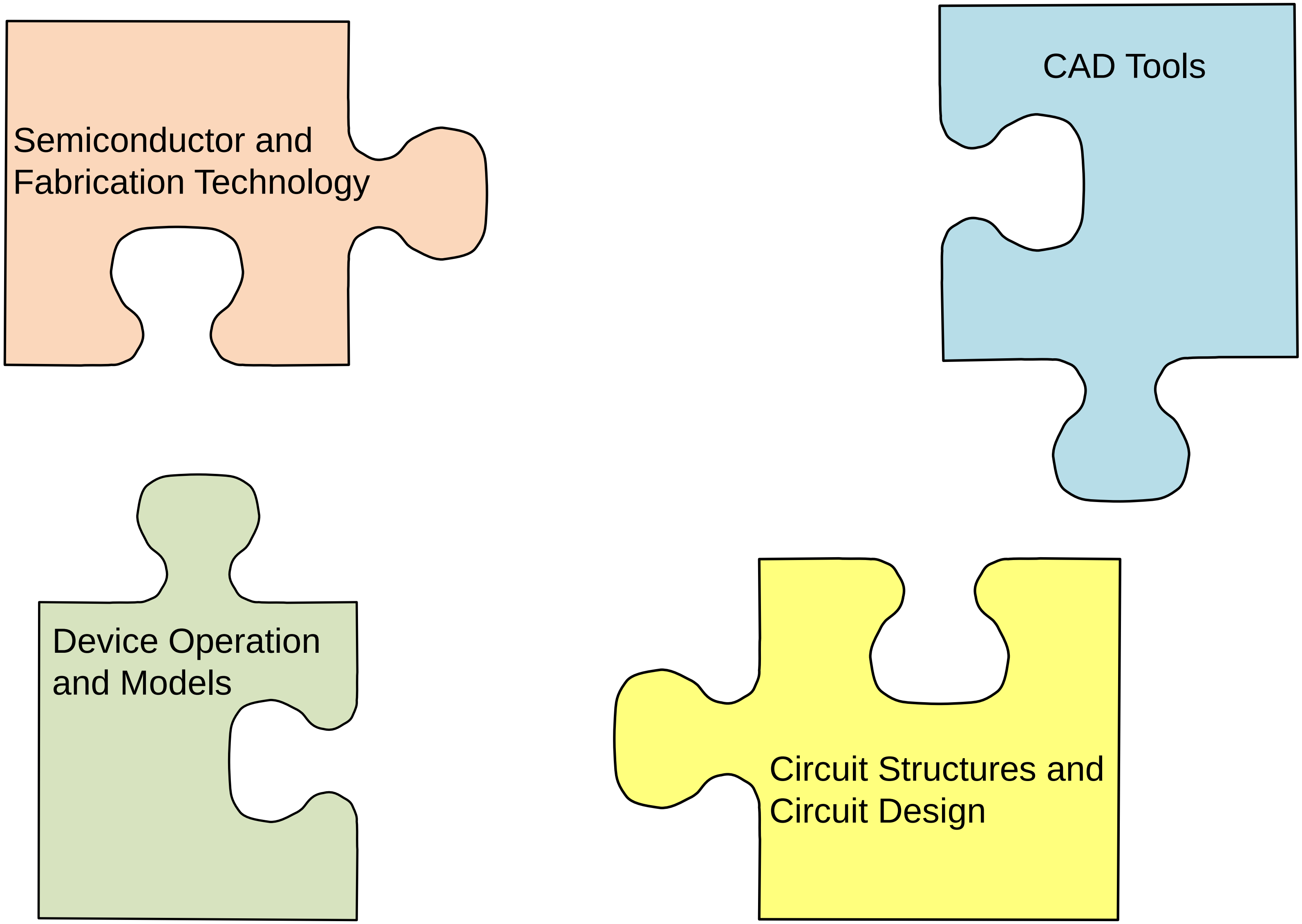
EE 330
Lecture 2

Basic Concepts

Review from last lecture:

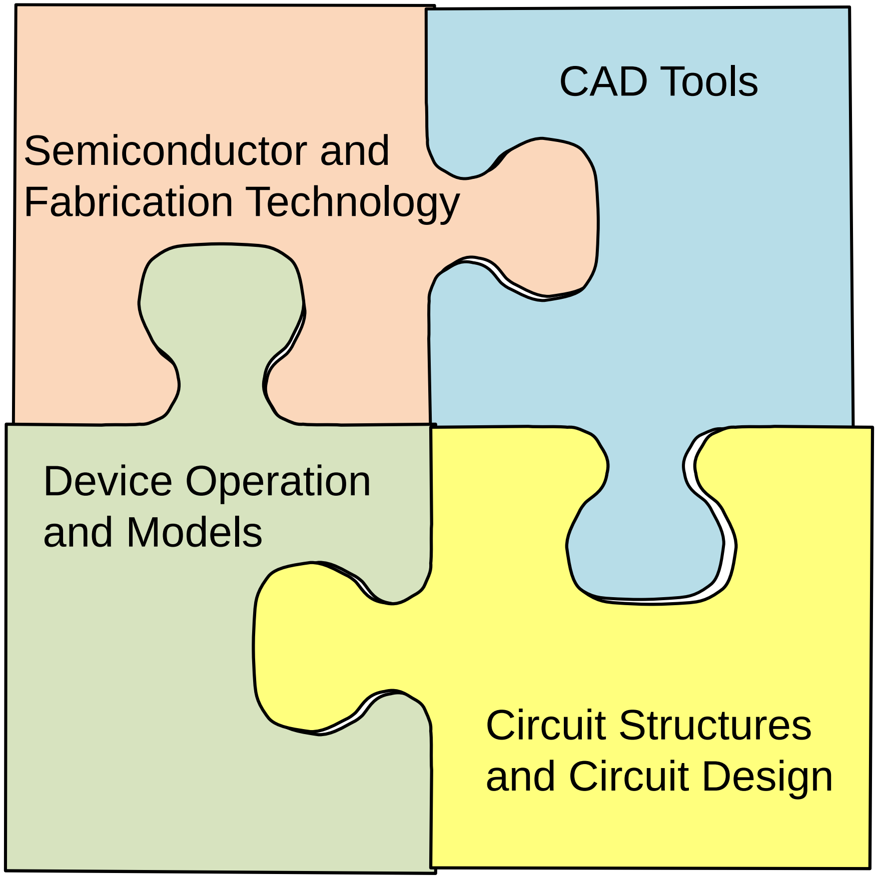
How Integrated Electronics will be Approached



Review from last lecture:

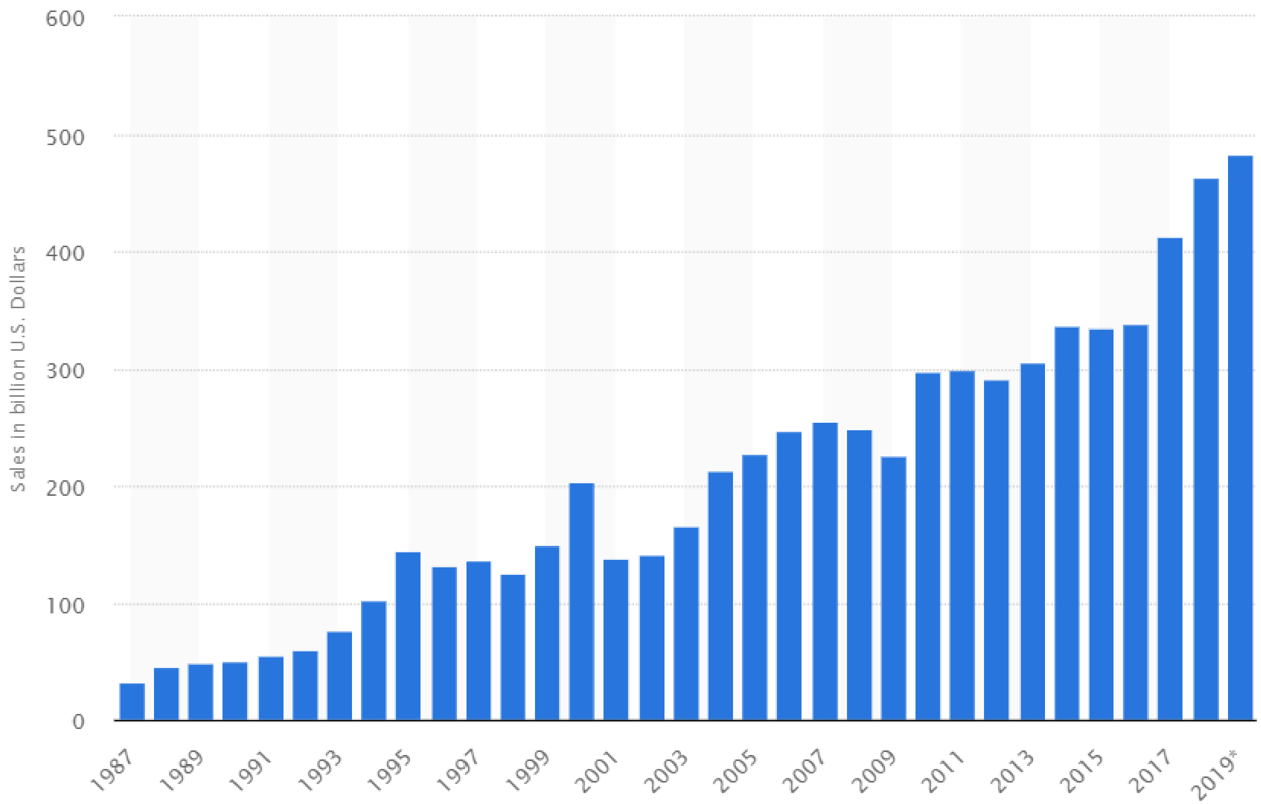
How Integrated Electronics will be Approached

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)

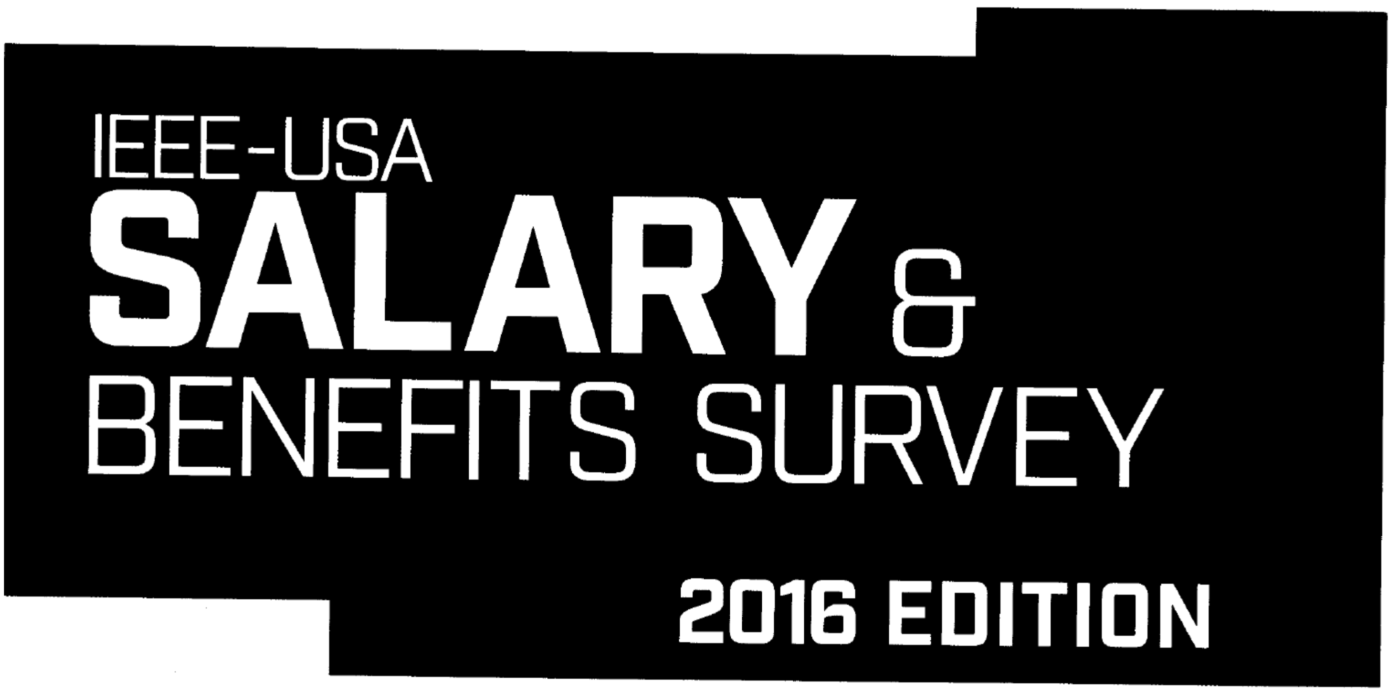
The semiconductor industry is one of the largest sectors in the world economy and continues to grow

Review from last lecture:

Is an automobile an electronics "gadget"?

Rewards in the Electronics Field

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



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

ENGINEERING AND HUMAN ENVIRONMENT	144	$73,868	$99,900	$132,667	$167,625	$220,728
Education	24	-	-	-	-	-
Engineering Management	87	$97,200	$116,000	$145,000	$180,000	$230,480
Professional Communication	0	-	-	-	-	-
Reliability	15	-	-	-	-	-
Social Implications of Technology	8	-	-	-	-	-
Other	14	-	-	-	-	-
INDUSTRIAL APPLICATIONS	340	$79,900	$100,000	$126,600	$160,000	$210,000
Dielectrics and Electrical Insulation	16	-	-	-	-	-
Industry Applications	149	$87,660	$108,400	$130,000	$166,220	$211,460
Instrumentation and Measurement	91	$68,000	$92,124	$118,000	$144,985	$180,000
Power Electronics	59	$81,835	$102,500	$130,000	$160,500	$208,400
Other	25	$99,780	$120,000	$143,000	$210,000	$235,145
SIGNALS AND APPLICATIONS	532	$94,100	$114,263	$142,792	$180,000	$223,000
Aerospace and Electronic Systems	162	$90,300	$113,010	$147,500	$179,250	$216,895
Geoscience and Remote Sensing	47	$96,600	$113,379	$153,200	$198,000	$220,531
Oceanic Engineering	13	-	-	-	-	-
Signal Processing	243	$95,046	$116,237	$141,200	$179,000	$230,649
Ultrasonics, Ferroelectrics and Frequency Control	36	$96,750	$117,197	$136,000	$167,657	$239,500
Other	30	$75,020	$106,250	$130,926	$178,277	$205,100
SYSTEMS AND CONTROL	689	$74,800	$98,000	$130,000	$165,000	$209,582
Control Systems	270	$72,000	$94,625	$122,183	$155,110	$197,000
Engineering in Medicine and Biology	124	$88,002	$113,847	$143,500	$182,000	$229,600
Industrial Electronics	62	$71,550	$89,250	$118,517	$154,113	$194,188
Information Theory	10	-	-	-	-	-
Robotics and Automation	129	$73,106	$92,842	$123,000	$154,609	$188,520
Systems, Man and Cybernetics	64	$75,000	$120,000	$146,946	$184,250	$222,800
Other	47	$97,600	$117,250	$154,000	$182,000	$224,960
OTHER	346	$79,000	$103,000	$131,424	$178,000	$235,000

Opportunities in the Electronics Field

- A lot has happened in the field in the past 4 decades
- Are there still opportunities?

But be realistic about the difference between what can be done and what can be done profitably

How many of you stream high definition video on smart phones?

If not, how many would like to?

An example of electronic opportunities

Consider High Definition Television (HDTV)

Video:

Frame size: 3840 x 2160 pixels (one UHD TV frame size)

Frame rate: 120 frames/second (one HDTV frame rate)

Pixel Resolution: 12 bits each RGB plus 12 bits alpha (48 bits/pixel) (no HDTV standard)

RAW (uncompressed) video data requirements: (3840*2160)*120*(48) = 48 G bits/sec
(some references show 36 G bits/sec)

8K UHD RAW (uncompressed) video data requirements: 144 G bits/sec

Audio:

Sample rate: 192 K SPS (44.1 more common)

Resolution: 24 bits (16 bits or less usually adequate)

Number of Channels: 2 (Stereo)

RAW (uncompressed) audio data requirements: 192K*24*2 = 9.2 Mbits/sec

- RAW video data rate approximately 5000X the RAW audio data rate
- Are RAW video data rates too large to be practical ??

How much would it cost to download a 2-hour UHD TV “movie” using RAW audio and video on a Verizon Smart Phone today?

Verizon Data Plan Jan 2016 (for over 12G per month) $3.5/GB

(to keep reasonable bandwidth without throttling)

RAW (uncompressed) video data requirements = 48 G bits/sec

RAW (uncompressed) audio data requirements: 192K*24*2 = 9.2 Mbits/sec

Total bits: 48x60x120 Gb = 346,000 Gb

Total bytes: 48x60x120/8 GB = 43,000 GB

Total cost: $150,000

- Moving audio and video data is still expensive and still challenging !
- Be careful about what you ask for because you can often get it!

What can be done to reduce these costs?

An example of electronic opportunities

Consider High Definition Television (UHDTV)

Video:

RAW (uncompressed) video data requirements: 48 G bits/sec

Audio:

RAW (uncompressed) audio data requirements: 192K*24*2 = 9.2 Mbits/sec

Compressive video coding widely used to reduce data speed and storage requirements

- UHDTV video streams used by the broadcast industry are typically between 14MB/sec and 19MB/sec (a compressive coding of about 14:1)
- But even with compression, the amount of data that must be processed and stored is very large
- Large electronic circuits required to gather, process, record, transmit, and receive data for HDTV

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

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 $15/1 GB
Verizon Up Rewards

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

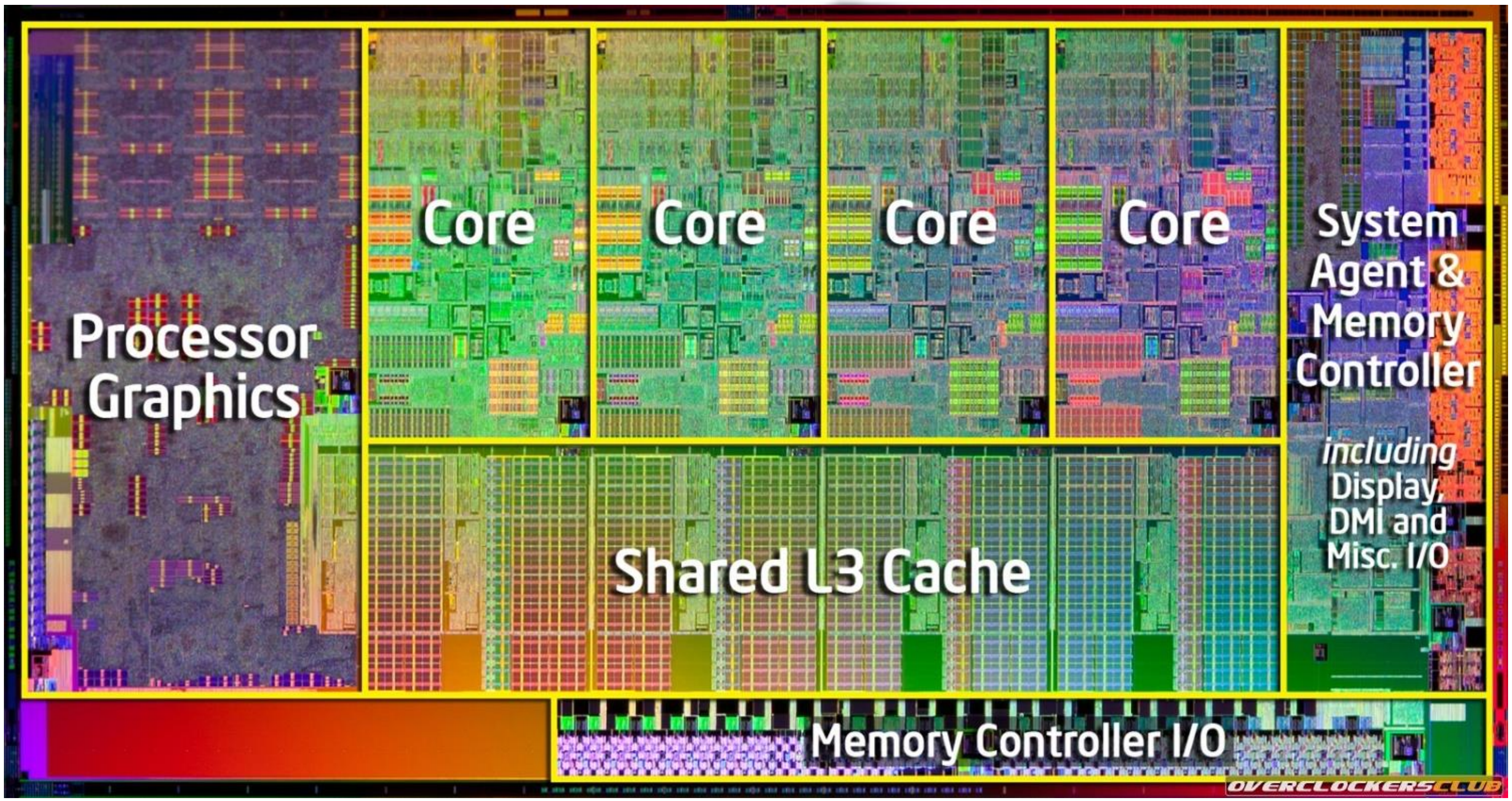
Challenge to Students

- 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

Recent Intel Processor

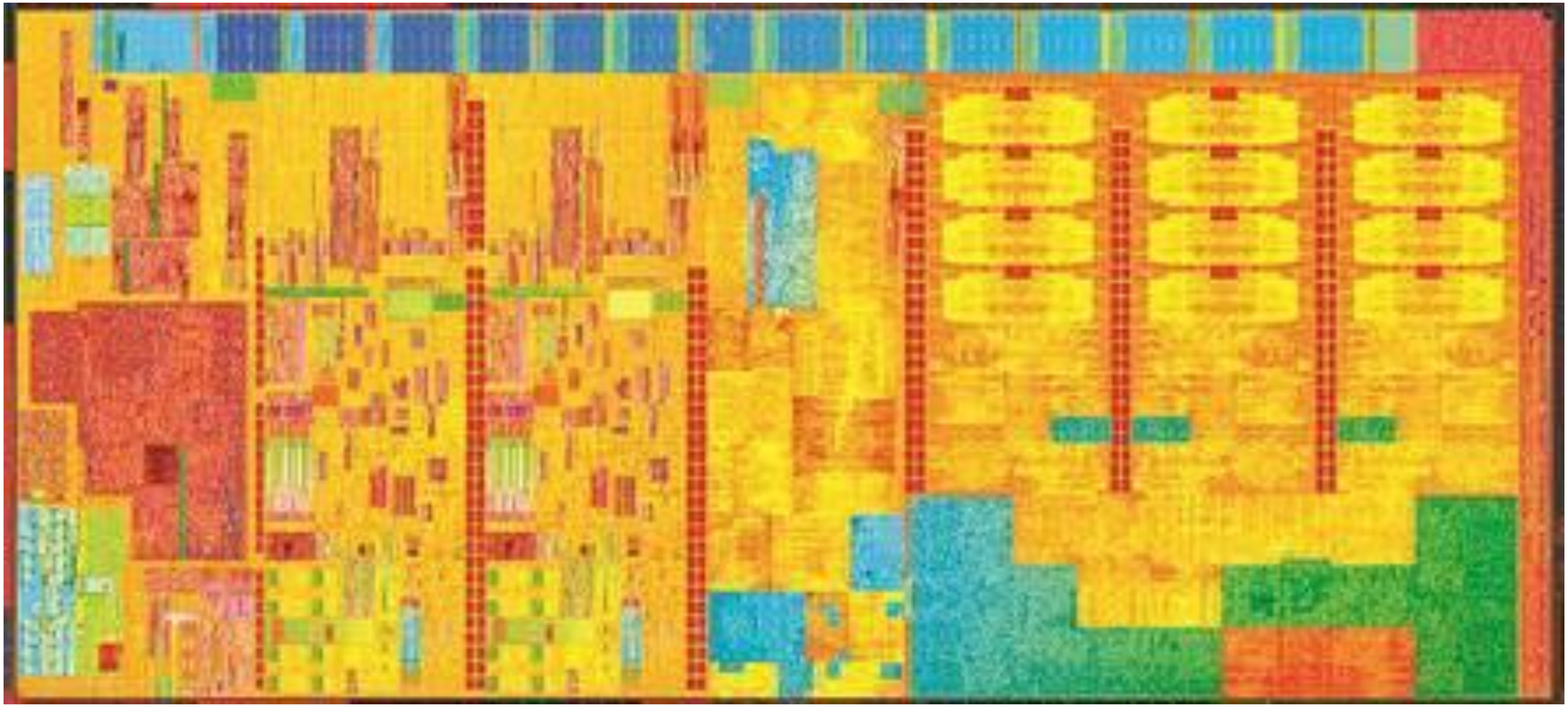


Processor

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

Power Dissipation: 95 watts

Today!



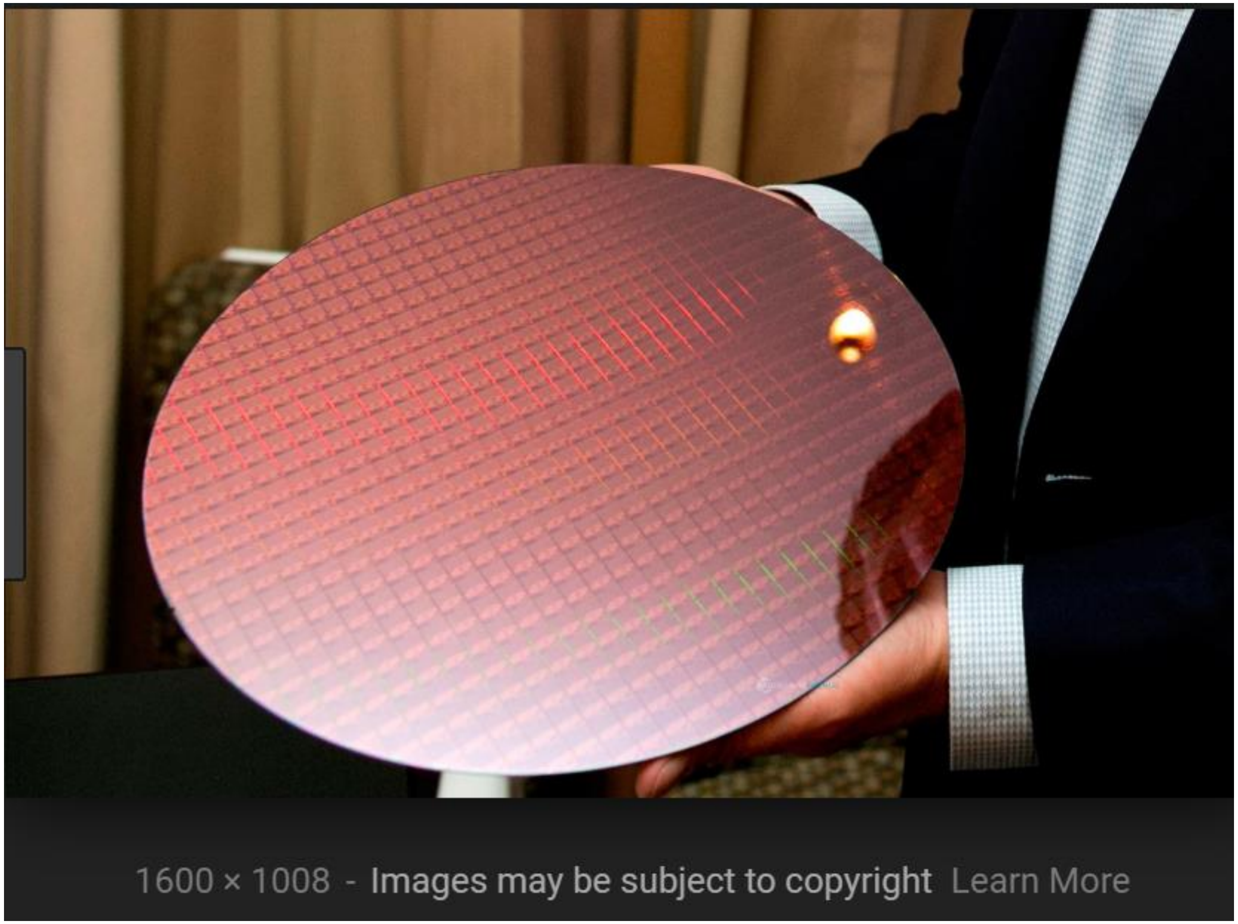
Processor

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

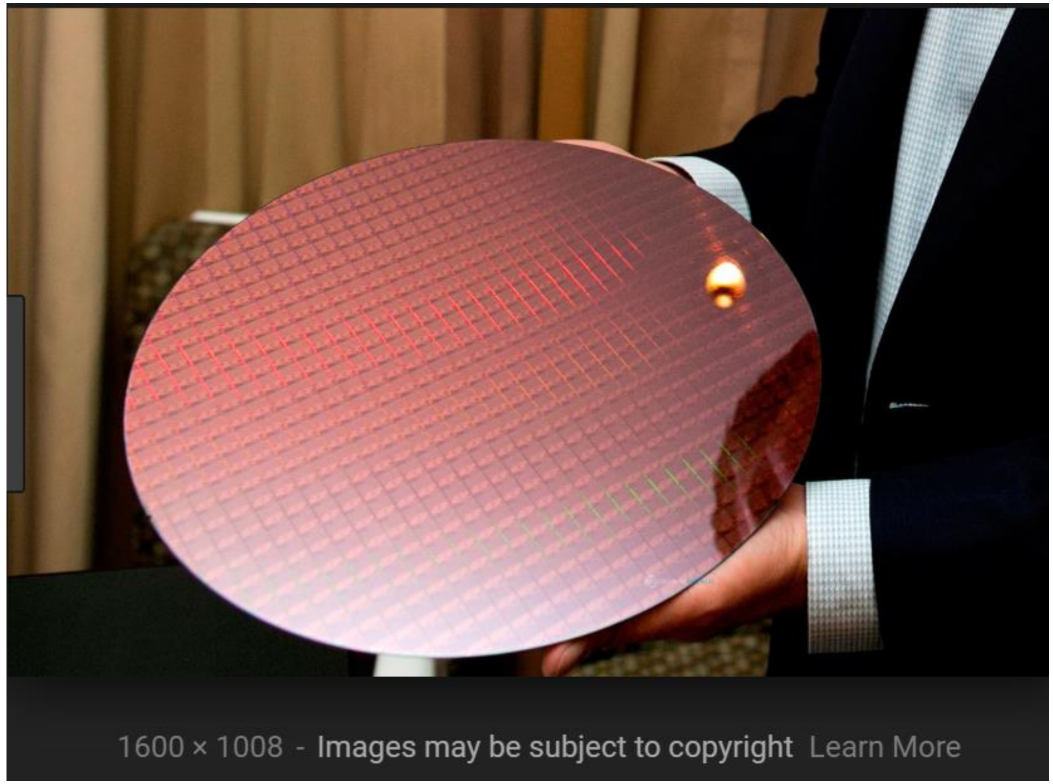
Today!



Cannon Lake Processor

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

Today!

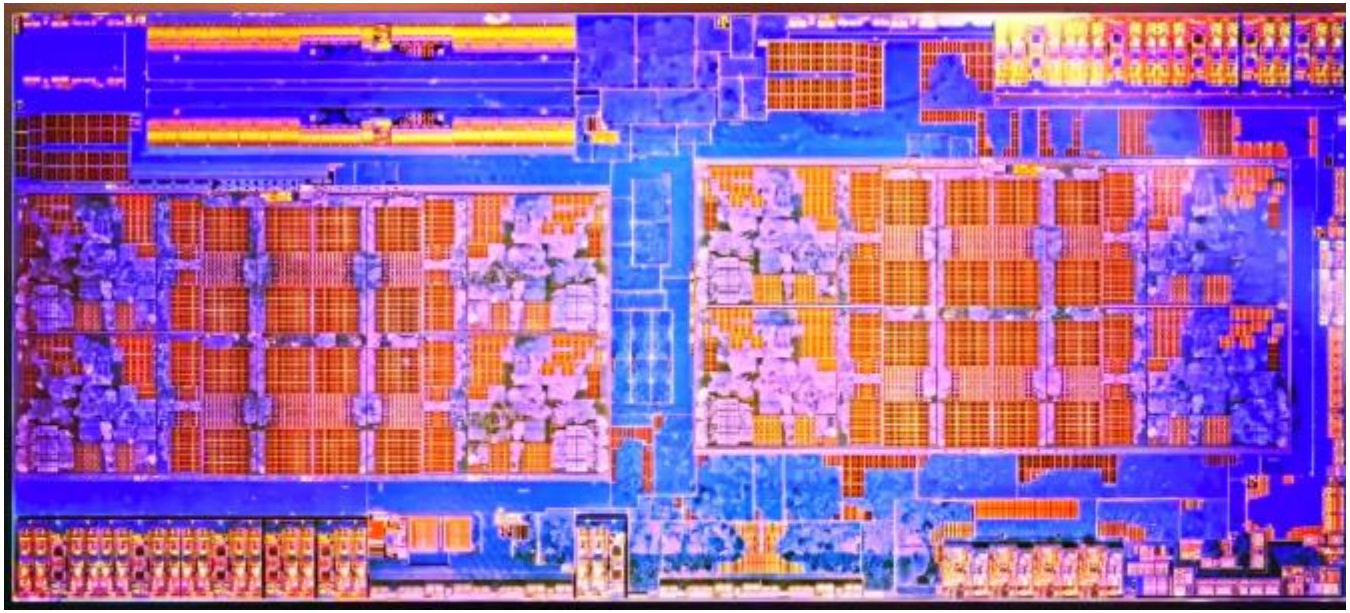


Cannon Lake Processor

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.

Today!



AMD Zen 2

7nm CMOS

Sampling July 2018 – Volume production 2019

Today!

Microprocessors [edit]

See also: Microprocessor chronology

A microprocessor incorporates the functions of a computer's central processing unit on a single integrated circuit. It is a multipurpose, programmable device that accepts digital

Processor	Transistor count	Date of introduction	Designer	Process	Area
TMS 1000	8,000	1974[3]	Texas Instruments	8,000 nm	11 mm²
Intel 4004	2,300	1971	Intel	10,000 nm	12 mm²
Intel 8008	3,500	1972	Intel	10,000 nm	14 mm²
MOS Technology 6502	3,510[4]	1975	MOS Technology	8,000 nm	21 mm²
Motorola 6800	4,100	1974	Motorola	6,000 nm	16 mm²
Intel 8080	4,500	1974	Intel	6,000 nm	20 mm²
RCA 1802	5,000	1974	RCA	5,000 nm	27 mm²
Intel 8085	6,500	1976	Intel	3,000 nm	20 mm²
Zilog Z80	8,500	1976	Zilog	4,000 nm	18 mm²
Motorola 6809	9,000	1978	Motorola	5,000 nm	21 mm²
Intel 8086	29,000	1978	Intel	3,000 nm	33 mm²
Intel 8088	29,000	1979	Intel	3,000 nm	33 mm²
Xbox One main SoC	5,000,000,000	2013	Microsoft/AMD	28 nm	363 mm²
18-core Xeon Haswell-E5	5,560,000,000[39]	2014	Intel	22 nm	661 mm²
IBM z14	6,100,000,000	2017	IBM	14 nm	696 mm²
Xbox One X (Project Scorpio) main SoC	7,000,000,000[40]	2017	Microsoft/AMD	16 nm	360 mm²[40]
IBM z13 Storage Controller	7,100,000,000	2015	IBM	22 nm	678 mm²
22-core Xeon Broadwell-E5	7,200,000,000[41]	2016	Intel	14 nm	456 mm²
POWER9	8,000,000,000	2017	IBM	14 nm	695 mm²
72-core Xeon Phi	8,000,000,000	2016	Intel	14 nm	683 mm²
IBM z14 Storage Controller	9,700,000,000	2017	IBM	14 nm	696 mm²
32-core SPARC M7	10,000,000,000[42]	2015	Oracle	20 nm	
Centriq 2400	18,000,000,000[43]	2017	Qualcomm	10 nm	398 mm²
32-core AMD Epyc	19,200,000,000	2017	AMD	14 nm	768 mm² (4 x 192 mm²)

Today!

GPUs [edit]

A graphics processing unit (GPU) is a specialized electronic circuit designed to rapidly manipulate and alter memory to accelerate

Processor	Transistor count	Date of introduction	Manufacturer	Process	Area
NV3	3,500,000	1997	NVIDIA	350 nm	90 mm²
Rage 128	8,000,000	1999	AMD	250 nm	70 mm²
NV5	15,000,000	1999	Nvidia	250 nm	
NV10	23,000,000	1999	Nvidia	220 nm	111 mm²
NV11	20,000,000	2000	Nvidia	180 nm	65 mm²
NV15	25,000,000	2000	Nvidia	180 nm	81 mm²
GP106 Pascal	4,400,000,000	2016	Nvidia	16 nm	200 mm²
Tonga	5,000,000,000	2014	AMD	28 nm	366 mm²
GM204 Maxwell	5,200,000,000	2014	Nvidia	28 nm	398 mm²
Polaris 10 "Ellesmere"	5,700,000,000[51]	2016	AMD	14 nm	232 mm²
Hawaii	6,300,000,000	2013	AMD	28 nm	438 mm²
GK110 Kepler	7,080,000,000[52]	2012[53]	Nvidia	28 nm	561 mm²
GP104 Pascal	7,200,000,000	2016	Nvidia	16 nm	314 mm²
GM200 Maxwell	8,000,000,000	2015	Nvidia	28 nm	601 mm²
Fiji	8,900,000,000	2015	AMD	28 nm	596 mm²
GP102 Pascal	11,800,000,000	2016	Nvidia	16 nm	471 mm²
Vega 10	12,500,000,000[54]	2017	AMD	14 nm	484 mm²
GP100 Pascal	15,300,000,000[55]	2016	Nvidia	16 nm	610 mm²
GV100 Volta	21,100,000,000[56]	2017	Nvidia	12 nm	815 mm²

Today!

FPGA	Transistor count	Date of introduction	Manufacturer	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	65 nm		[57]
Stratix IV	2,500,000,000	2008	Altera	40 nm		[58]
Stratix V	3,800,000,000	2011	Altera	28 nm		[59]
Arria 10	5,300,000,000	2014	Altera	20 nm		[60]
Virtex-7	6,800,000,000	2011	Xilinx	28 nm		[61]
Stratix 10 Family device, 10GX5500/10SX5500	17,000,000,000	2017	Intel (formally Altera)	14 nm	560 mm²	[62]
Virtex-Ultrascale XCVU440	20,000,000,000+	2014	Xilinx	20 nm		[63]
Everest	50,000,000,000	2018	Xilinx	7 nm		[64] [65]

Selected Semiconductor Trends

- Microprocessors
  - State of the art technology is now 10nm with over 20 Billion transistors on a chip
- DRAMS
  - State of the art is now 16G bits on a chip in a 10nm process which requires somewhere around 18 Billion transistors
- FPGA
  - FPGAs currently have over 50 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

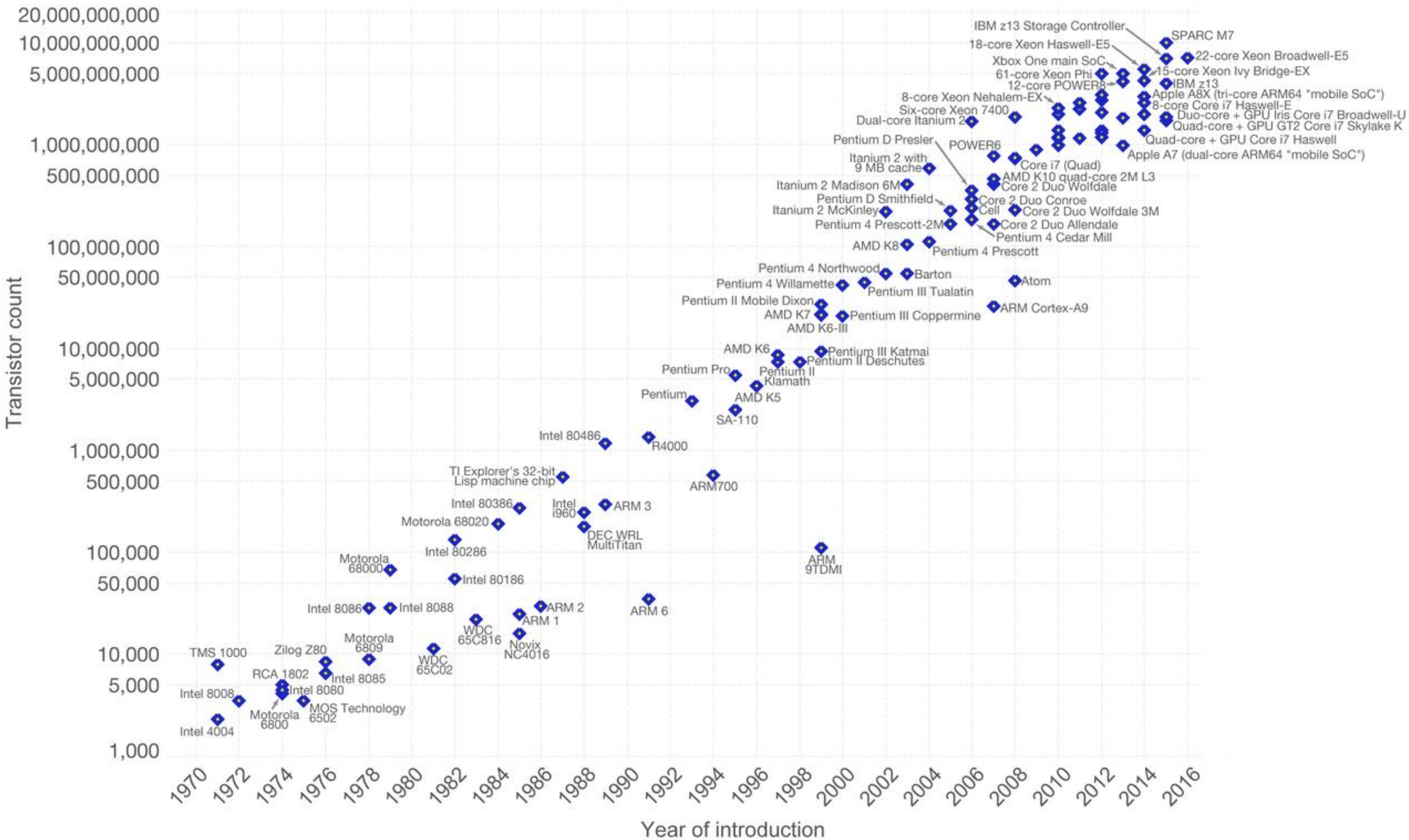
From Webopedia (Aug 2016)

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 integrated circuit chips (1971-2016)

Our World in Data

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are strongly linked to Moore's law.



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

Licensed under CC-BY-SA by the author Max Roser.

https://en.wikipedia.org/wiki/Moore%27s_law#/media/File:Moore%27s_Law_Transistor_Count_1971-2016.png

Aug 21, 2018

More on Moore's Law

MIT Technology Review

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redhat. SEE HOW WITH open technologies. START EXPLORING

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

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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 ...

IEEE SPECTRUM

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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)

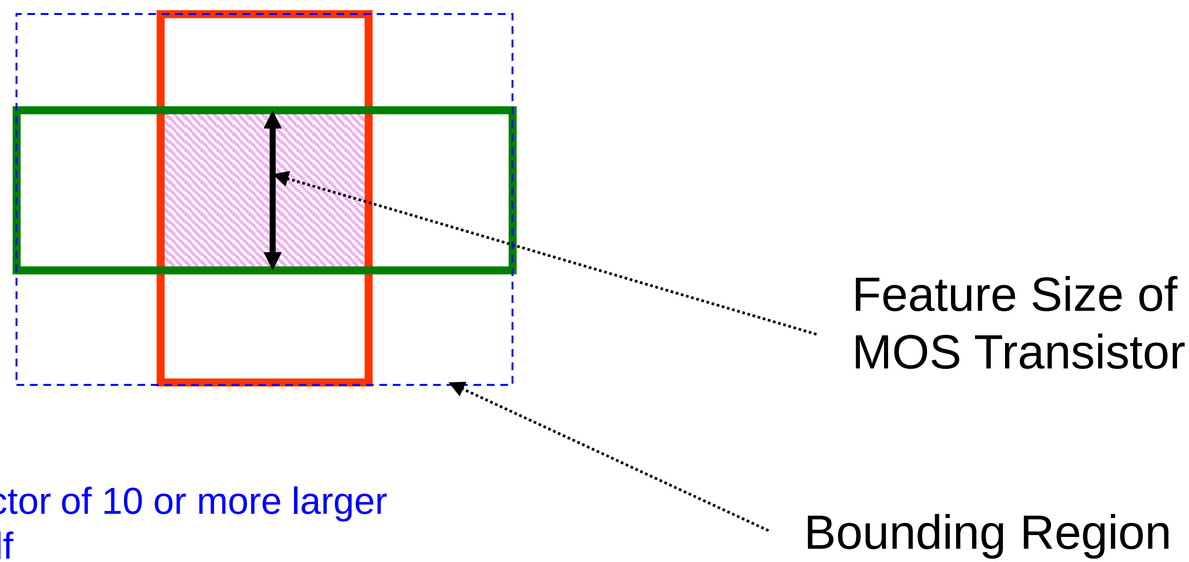
….However, in April 2016, Intel CEO Brian Krzanich stated that "In my 34 years in the semiconductor industry, I have witnessed the advertised death of Moore’s Law no less than four times. As we progress from 14 nanometer technology to 10 nanometer and plan for 7 nanometer and 5 nanometer and even beyond, 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.

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)



- 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

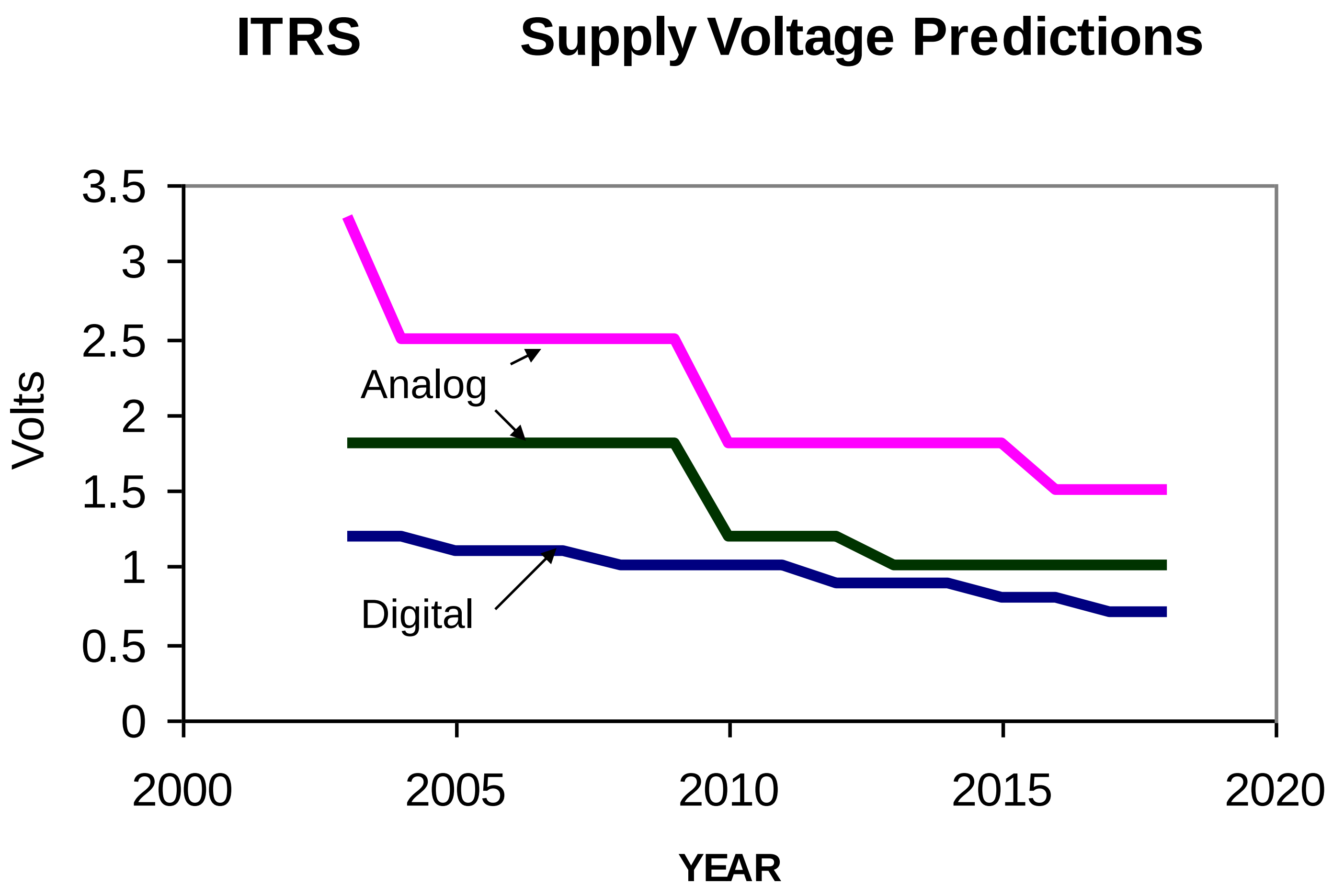
(from Wikipedia)

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.

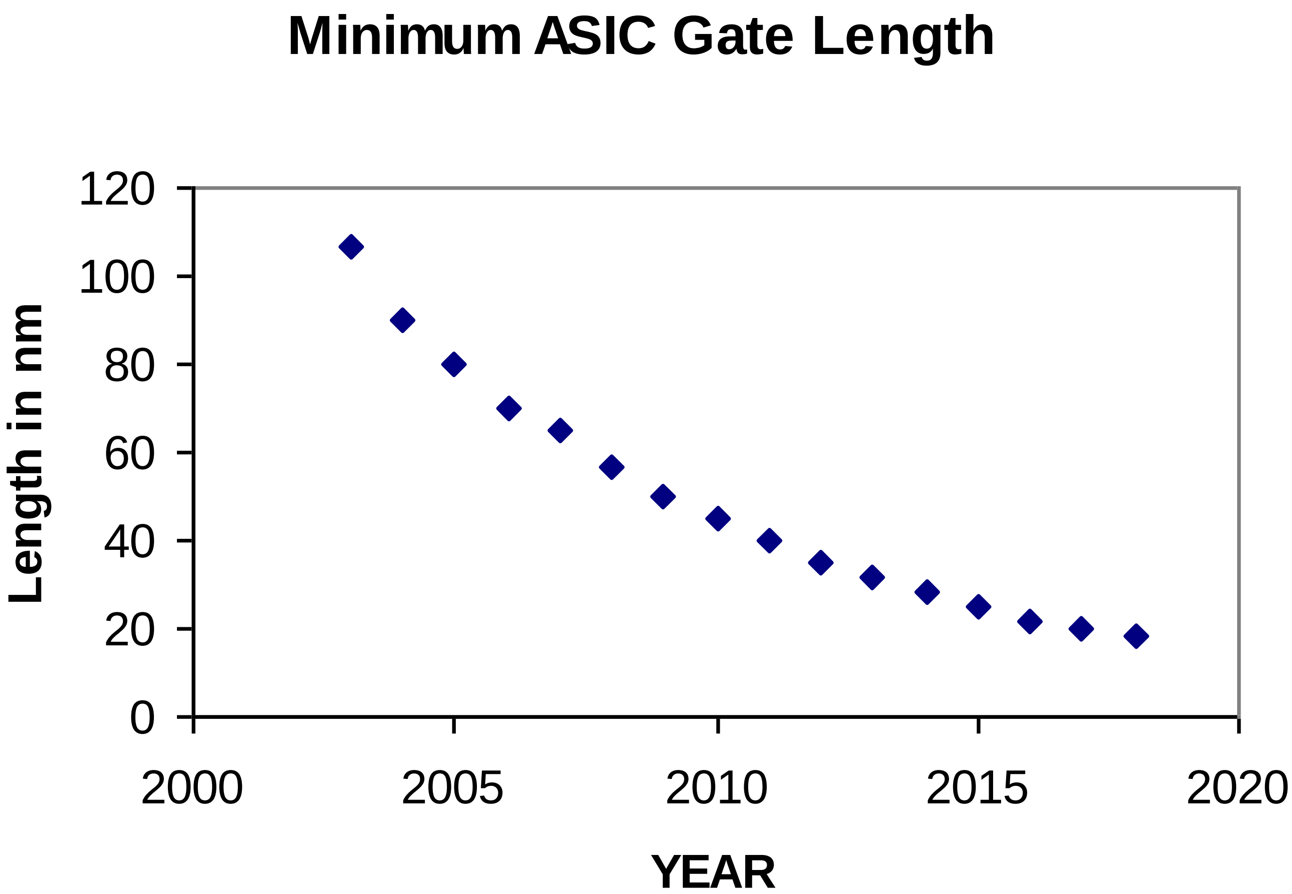
- Observation, not a physical law
- Often misinterpreted or generalized
- Many say it has been dead for several years
- Many say it will continue for a long while
- Not intended to be a long-term prophecy about trends in the semiconductor field
- Something a reporter can always comment about when they 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 !!

ITRS Technology Predictions



ITRS Technology Predictions



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 and 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

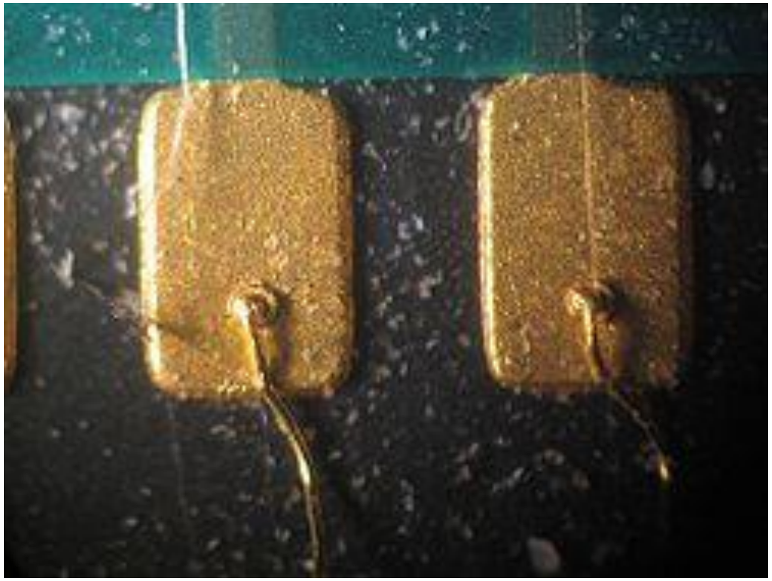
Most integrated circuits are comprised of transistors along with a small number of passive components and maybe a few diodes

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

Leading Analog IC Suppliers ($M)

2014 Rank	Company	2013	2014	% Change	% Marketshare
1	Texas Instruments	7,194	8,104	13%	18%
2	ST	2,775	2,836	2%	6%
3	Infineon	2,550	2,770	9%	6%
4	Analog Devices	2,409	2,615	9%	6%
5	Skyworks Solutions	1,807	2,570	42%	6%
6	Maxim	2,055	2,035	-1%	4%
7	NXP	1,430	1,730	21%	4%
8	Linear Technology	1,317	1,437	9%	3%
9	ON Semi	1,239	1,291	4%	3%
10	Renesas	975	910	-7%	2%

Source: IC Insights, company reports

End of Lecture 2