

Lecture 1

Course Overview and Why You Should Care

Prof. Aaron Franklin

ECE 230L, Duke University

Introduction to Microelectronic Devices and Circuits

FALL 2017

Outline

- Overview of course policies
- Piazza
- Socrative
- History of the transistor
- Moore's Law
- Computing from MOSFETs
- Why circuits matter

Syllabus

- Office hours
- Textbook
 - E-Book – Introduction to Microelectronic Devices and Circuits. ISBN – 9781121962194.
 - Students can purchase the e-book directly from McGraw-Hill using a credit card by logging into <https://create.mheducation.com/shop/> and searching by ISBN (note that the instructor name listed may not be accurate, but if the School is “Duke University” and the title is correct, then it is the right book).
- Grading criteria
 - Homework 20%
 - Quizzes 10%
 - Laboratory 10%
 - Midterms (2) 15% each
 - Final Exam 20%

Laboratory

- Lab section of course runs as a completely separate operation under direction of Kip Coonley
 - **Begins: THIS WEEK!**
 - **Location:** Hudson Hall 02H (basement)
 - **No lab notebook required**
 - **You MUST attend your specific lab section you are registered for**
- The lab is a key component of this course and will correlate with the material covered in lecture
- Questions about the lab should be directed to the lab TAs or tagged with the “lab” category in Piazza

Attendance, Homework and Quizzes

- **Attendance**

- Attending every lecture is crucial to your grade in this course

- **Homework**

- Exam questions will be very similar to the HW questions, so understanding the HW is critical
- HW will be due at the very beginning of lecture on the indicated due date. **NO LATE HW WILL BE ACCEPTED (see syllabus)**

- **Quizzes**

- Held ~once per week at the very beginning of lecture (see schedule)
- Will focus primarily on material from that day's scheduled reading assignment (see schedule)

TAs

- Lab TAs
 - Run the lab and are available for assistance with lab-related work
- Course TAs
 - Hold office hours for homework & course content help
 - Grade homework (discuss grading errors directly with them)

GTAs: Steven Noyce (steven.noyce@duke.edu) (Lecture, office hour: Fri. 10–11am, CIEMAS 3rd floor)
Jimmy Thostenson (james.thostenson@duke.edu) (Lecture, office hour: Tues. 9–10am, CIEMAS 3rd floor)

UGTAs: Sujay Garlanka (sujay.garlanka@duke.edu) (Lecture, office hour: Mon. 5–6pm, CIEMAS 3rd floor)
Gerry Chen (gdc9@duke.edu) (Lab 01L Tu 3:05–6:05PM)
Yao Yuan (yy123@duke.edu) (Lab 02L W 3:05–6:05PM)
Martin Li (ml328@duke.edu) (Lab 03L Th 3:05–6:05PM)
Michael Kuryshev (michael.kuryshev@duke.edu) (Lab 04L F 10:05AM–1:05PM)

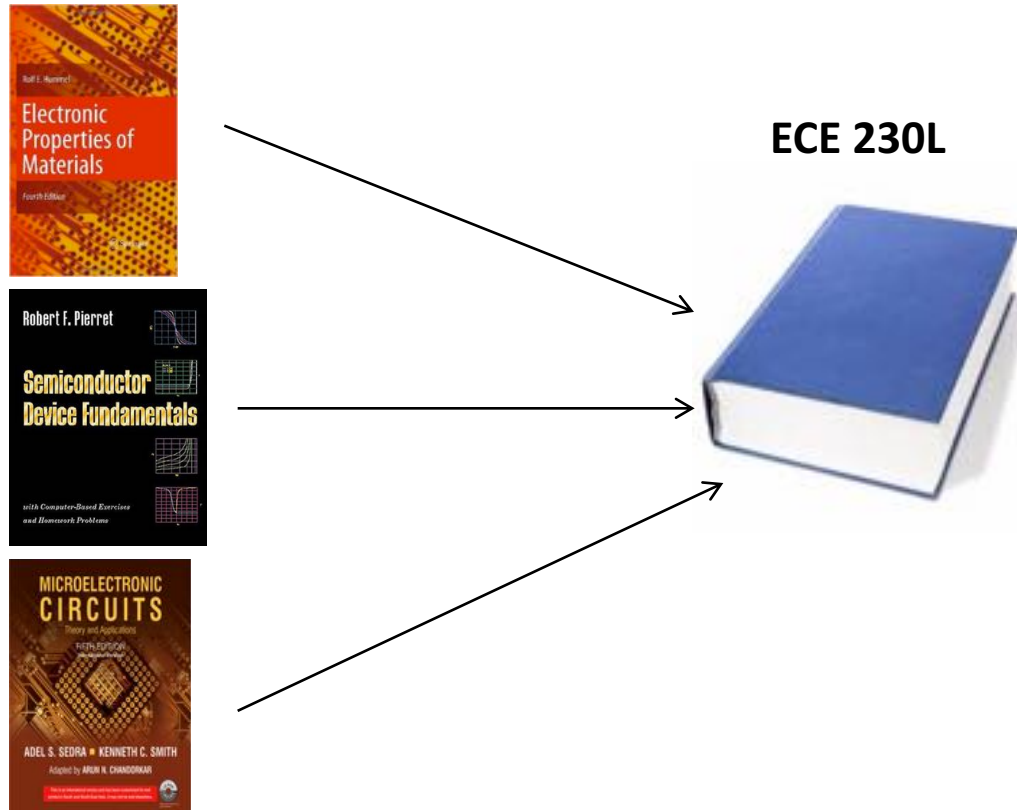
Schedule

Date	Lab		Lecture	Reading	HW/Quiz
T, 8/29	SMIF Intro	Semiconductor Materials	Course overview The Big Picture: Why Care About This Course?		
Th, 8/31			Crystal Structure of Solids	pg. 9-32	
T, 9/5	SMIF Tour		Quantum Theory of Solids (band structure)	pg. 34-48	Quiz #1
Th, 9/7			Quantum Theory of Solids (electrical transport)	pg. 48-81	HW #1 due
T, 9/12	Photolith I		Thermal Equilibrium	pg. 82-131	Quiz #2
Th, 9/14			Carrier Transport (drift)	pg. 132-147	HW #2 due
T, 9/19	Photolith II		Carrier Transport (diffusion)	pg. 148-155	Quiz #3
Th, 9/21		Devices	pn Junction Diodes (junction under zero-bias and reverse-bias)	pg. 169-190	HW #3 due
T, 9/26	pn Junction Diodes		pn Junction Diodes (junction under forward bias, ideal diode, deviations from ideal, light emitting diode)	pg. 204-232, 290-296	Quiz #4
Th, 9/28			EXAM 1 – Semiconductor Materials		
T, 10/3	P-Spice Circuit Simulatn		pn Junction Diodes (small-signal equivalent circuit, diode transients)	pg. 232-245, 425-430	HW #4 due
Th, 10/5			pn Junction Diodes (large-signal analysis, half-wave rectifier)	pg. 416-425, 449-453	Quiz #5
T, 10/10	NO LAB		FALL BREAK		
Th, 10/12			MOSFETs (MOS capacitors)	pg. 313-336	HW #5 due
T, 10/17	Project Intro		MOSFETs (capacitance-voltage characteristics)	pg. 336-345	Quiz #6
Th, 10/19			MOSFETs (basic MOSFET operation)	pg. 345-364	HW #6 due
T, 10/24	MOSFET		MOSFETs (small-signal equivalent circuit, CMOS technology, circuit symbols)	pg. 364-373, 519-523	Quiz #7
Th, 10/26		Circuits	Digital (NMOS inverters)	pg. 547-550, 836-850	HW #7 due
T, 10/31	MOSFET Model		Digital (CMOS inverters and logic gates)	pg. 861-885	Quiz #8
Th, 11/2			EXAM 2 – Devices		
T, 11/7	Basic Digital Circuits		Analog (DC Biasing of MOSFET circuits)	pg. 528-543	HW #8 due
Th, 11/9			Analog (common-source MOSFET amplifier)	pg. 550-551, 587-608	
T, 11/14	Multistage Amplifiers		Analog (common-drain, common-gate MOSFET amplifiers)	pg. 609-620	Quiz #9
Th, 11/16			Analog (single-stage MOSFET IC, multistage amplifiers)	pg. 620-626, 629-640	HW #9 due
T, 11/21	NO LAB		Analog (operational amplifier)	pg. 672-692	Quiz #10
Th, 11/23			THANKSGIVING BREAK		
T, 11/28	Op-Amp		Analog (operational amplifier applications)	pg. 692-708	HW #10 due
Th, 11/30			The Big Picture: Why does this matter? Future directions		Quiz #11
T, 12/5	Project Demos		"Create Final Exam" project		HW #11 due
Th, 12/7			Course Review for Final Exam		
Sa, 12/16			FINAL EXAM, 2pm – 5pm – Comprehensive		

Perspective on how much we have to cover

- We have a TON of material to get through!

Typical full courses



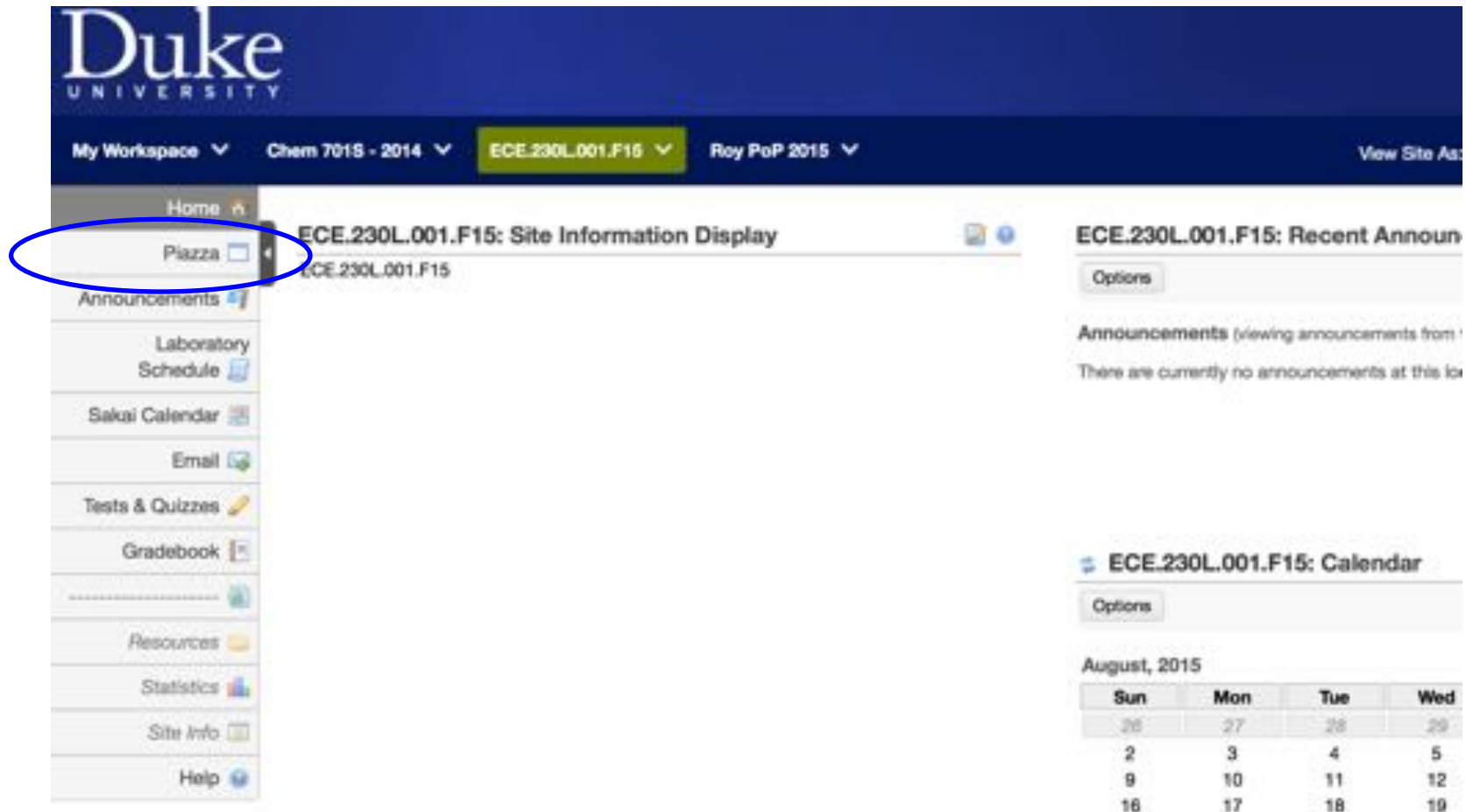
- Studying the textbook in addition to lecture will be essential!

Piazza

- All homework and lab questions should be posted on Piazza rather than emailed to professor/TAs
 - Only exception is for personal communications
 - **These posts can be made anonymous to the rest of the class!**
- Students are welcome to ‘discuss’ posted questions via Piazza, but **do not** simply give the answer to a HW problem!
- All course files will be posted under the “Resources” tab on the Piazza site

Accessing Piazza

- OPTION 1: Go straight to www.piazza.com
- OPTION 2: Use tab in Sakai:



The screenshot shows the Duke University Sakai LMS interface. The top navigation bar includes "My Workspace", "Chem 701S - 2014", "ECE.230L.001.F15" (highlighted), and "Roy PoP 2015". The left sidebar contains a list of tabs: Home, Piazza (circled in blue), Announcements, Laboratory Schedule, Sakai Calendar, Email, Tests & Quizzes, Gradebook, Resources, Statistics, Site Info, and Help. The main content area displays "ECE.230L.001.F15: Site Information Display" and "ECE.230L.001.F15: Recent Announcements". Below the announcements, there is a calendar for August 2015.

ECE.230L.001.F15: Calendar

Options

August, 2015

Sun	Mon	Tue	Wed
26	27	28	29
2	3	4	5
9	10	11	12
16	17	18	19

Accessing Piazza

The screenshot shows the Duke University Piazza interface. At the top, the Duke University logo is on the left, and navigation links for 'My Workspace', 'Chem 7015 - 2014', 'ECE.230L.001.F15', and 'Roy PoP 2015' are in the center. A 'View Site As' dropdown menu is on the right. On the left side, a vertical sidebar contains links: Home, Piazza (selected), Announcements, Laboratory Schedule, Sakai Calendar, Email, Tests & Quizzes, Gradebook, Resources, Statistics, Site info, and Help. The main content area is titled 'ECE.230L.001.F15: Piazza'. Below this, there's a sub-header with 'piazza', 'ECE 230L', 'Q & A', 'Resources', 'Statistics', and 'Manage Class'. A user profile picture and 'Prof.' are visible. Below the sub-header, there's a tabbed interface with 'Unread', 'Updated', 'Unresolved', 'Following', and a settings gear. A 'New Post' button and a search bar are present. The main content area features a section titled 'Enroll your students' with instructions to paste email addresses or share a Class Signup Link. Below this is a text input field containing 'john@email.com, smith@email.com' and an 'Enroll Students' button. At the bottom, a 'Student Enrollment' section shows a progress bar with '12 enrolled' and a total of '60 seats'.

Duke UNIVERSITY

My Workspace ▾ Chem 7015 - 2014 ▾ ECE.230L.001.F15 ▾ Roy PoP 2015 ▾ View Site As: - Select Role -

Home ▾ Piazza ▾ Announcements ▾ Laboratory Schedule ▾ Sakai Calendar ▾ Email ▾ Tests & Quizzes ▾ Gradebook ▾ Resources ▾ Statistics ▾ Site info ▾ Help ▾

ECE.230L.001.F15: Piazza

piazza ECE 230L Q & A Resources Statistics Manage Class Prof.

Unread Updated Unresolved Following

New Post Search or add a post...

Enroll your students

Paste email addresses below in any format. Or visit Manage Class page to upload your student list or share your Class Signup Link.

* Each will receive a welcome email.

john@email.com, smith@email.com

Enroll Students

Student Enrollment 12 enrolled out of 60 seats

Quick Piazza Overview

- Posting a question:

The screenshot shows the Piazza web interface for ECE 230L. The top navigation bar includes 'Q & A' (highlighted with a blue circle), 'Resources', 'Statistics', and 'Manage Class'. The left sidebar contains a 'New Post' button (highlighted with a blue circle) and a search bar. The main content area shows the 'Post Type' dropdown set to 'Question' (highlighted with a blue circle), with options for 'Question', 'Note', and 'Poll/In-Class Response'. The 'Post to' dropdown is set to 'Entire Class'. The 'Select Folder(s)' section shows a list of folders, with 'hw2' highlighted (circled in blue) and a blue arrow pointing to it. The 'Summary' field contains the text 'Problem 3' (circled in blue). The 'Details' section shows a rich text editor with the text 'I'm having a difficult time figuring out...'.

Quick Piazza Overview

- Accessing files:

The screenshot shows the Piazza website interface for the course ECE 230L at Duke University, Fall 2015. The top navigation bar includes the Piazza logo, the course name "ECE 230L", and links for "Q & A", "Resources" (circled in blue), "Statistics", and "Manage Class". A user profile icon for "Prof. A" is visible in the top right. Below the navigation bar, the course title "ECE 230L: Introduction to Microelectronic Devices & Circuits" is displayed. A sub-navigation bar contains "Course Information", "Staff", and "Resources" (circled in blue). The main content area features a "Homework" section with a message stating "Nothing has been added to the Homework section, yet. Click the 'Add Links' or 'Add Files' button to add resources." and buttons for "Add Links" and "Add Files". Below this is a "Homework Solutions" section with a similar message and buttons for "Add Links" and "Add Files". A blue button labeled "Edit Resource Sections" is located in the top right of the main content area.

Socrative for quizzes

- We will use Socrative (www.socrative.com) for all quizzes and occasionally for in-class exercises.
- Socrative can be readily accessed with any internet-connected device (smartphone, laptop, etc.):

The diagram illustrates the Socrative student login process and the required ID card. It consists of three main components: a 'Student Login' form, a second 'Student Login' form with a message, and a 'DukeCard'.

Student Login Form 1: The first form shows the 'socrative by MasteryConnect' logo at the top. Below it is a 'Student Login' section with a 'Room Name' input field containing 'ECE230L' and an orange 'JOIN' button.

Student Login Form 2: An arrow points from the first form to a second, identical form. This second form has a message box that says: 'This room requires a student ID. Please enter your student ID to continue.' Below this message is a 'Student ID' input field and an orange 'SUBMIT' button. A red circle highlights the 'Student ID' input field, with an arrow pointing to the 'DukeCard'.

DukeCard: The 'DukeCard' is a physical ID card from Duke University. It features the 'The DukeCard' logo, a barcode, and the text 'Issue Number'. Below the barcode, it displays 'UniqueID: 0000000' and 'DukeCard #: 771000000'. At the bottom, it has 'Unique ID Number' and 'DukeCard Number' in red. A red circle highlights the 'UniqueID' field, with an arrow pointing to the 'Student ID' input field in the second form.

Socrative for quizzes

- Socrative test
- If you have any issues with accessing Socrative, please let me know!

My background . . . through logos and mascots

**B.S.E.
EE**



Ph.D. EE



Associate Professor



2004

2008

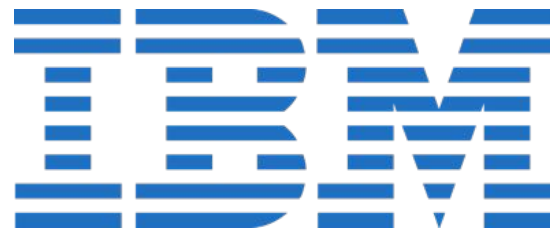
2014

2001

**Component
Design
Engineer**



Research Scientist



Adjunct Professor

Course overview

- What can you learn?
 - Why a semiconductor is a semiconductor based on the arrangement of its atoms.
 - How the conducting behavior of semiconductors can be modified by “doping.”
 - What happens when you connect two disparately doped semiconductor regions to form a p-n junction.
 - How charge carriers move through semiconductor material and junctions.
 - How junctions are put together to create transistors/MOSFETs.
 - How MOSFETs are connected to yield digital circuits.
 - How MOSFETs are used to yield basic analog circuits.
 - What basic applications there are for analog circuits.
 - How an operational amplifier works and can be used.

What enables electronics?

- Looking back ...

Advertisement from 1961 (General Electric)



NEW GENERAL ELECTRIC
All-Transistor
MINIATURE PORTABLE



**VEST-POCKET SIZE
FULL-ROOM POWER**
Complete with accessory kit and gift box!

An exciting new look in portable radios... the best-looking, best-performing radio for its size you've ever seen. Vest-pocket size... fits in the palm of your hand... weighs only 11½ ounces with battery. Features: 200,000 cycle oscillator, 4-transistor plus diode, variable tuning, built-in 100% full antenna. Complete with carrying case, earphone and battery, all in a rich leatherette jewelry box.



GENERAL ELECTRIC

What enables electronics?

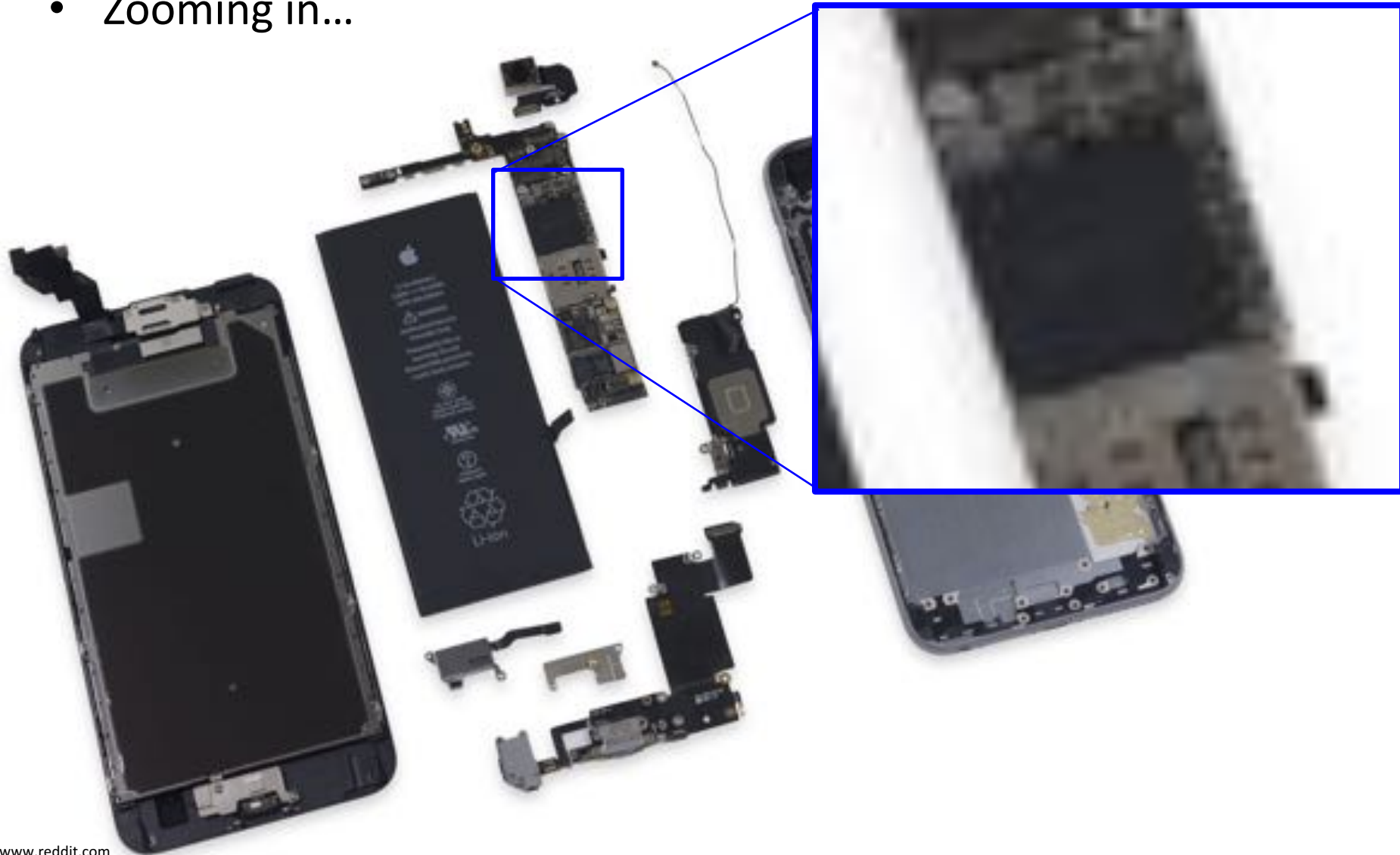
- Zooming in...



www.usatoday.com

What enables electronics?

- Zooming in...



www.reddit.com

What enables electronics?

- Zooming in...

BILLIONS of transistors!

strand
of hair

~100,000 nm

~100 nm (100×10^{-9} m)

one transistor

one transistor

www.intel.com

www.reddit.com

What enables electronics?

- Zooming in...

It's a switch . . .

OFF: electric current doesn't flow

ON: current flows



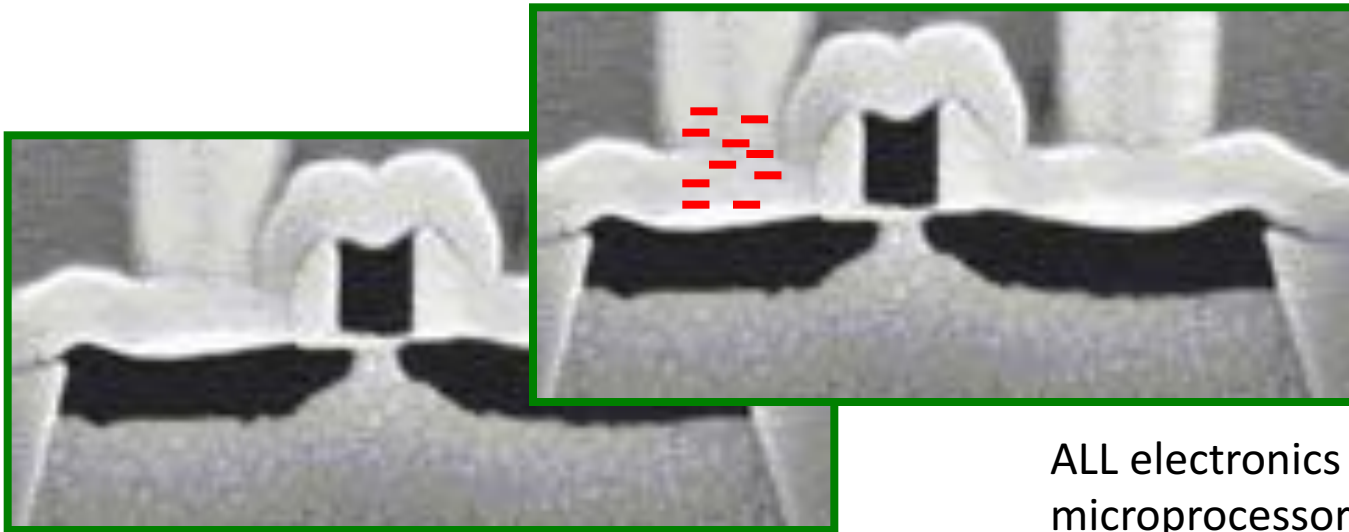
Properly combining these 0's (off) and 1's (on) switches together yields computation (*not just a math thing!*).



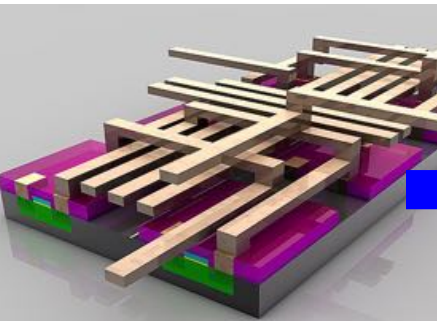
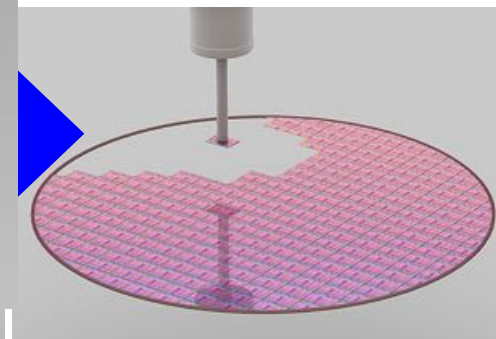
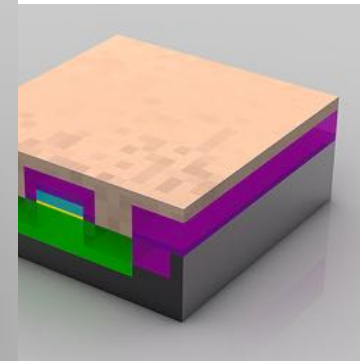
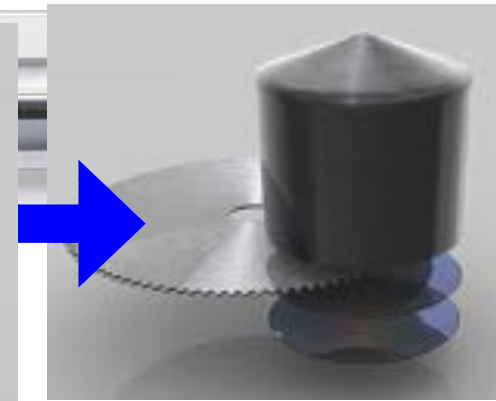
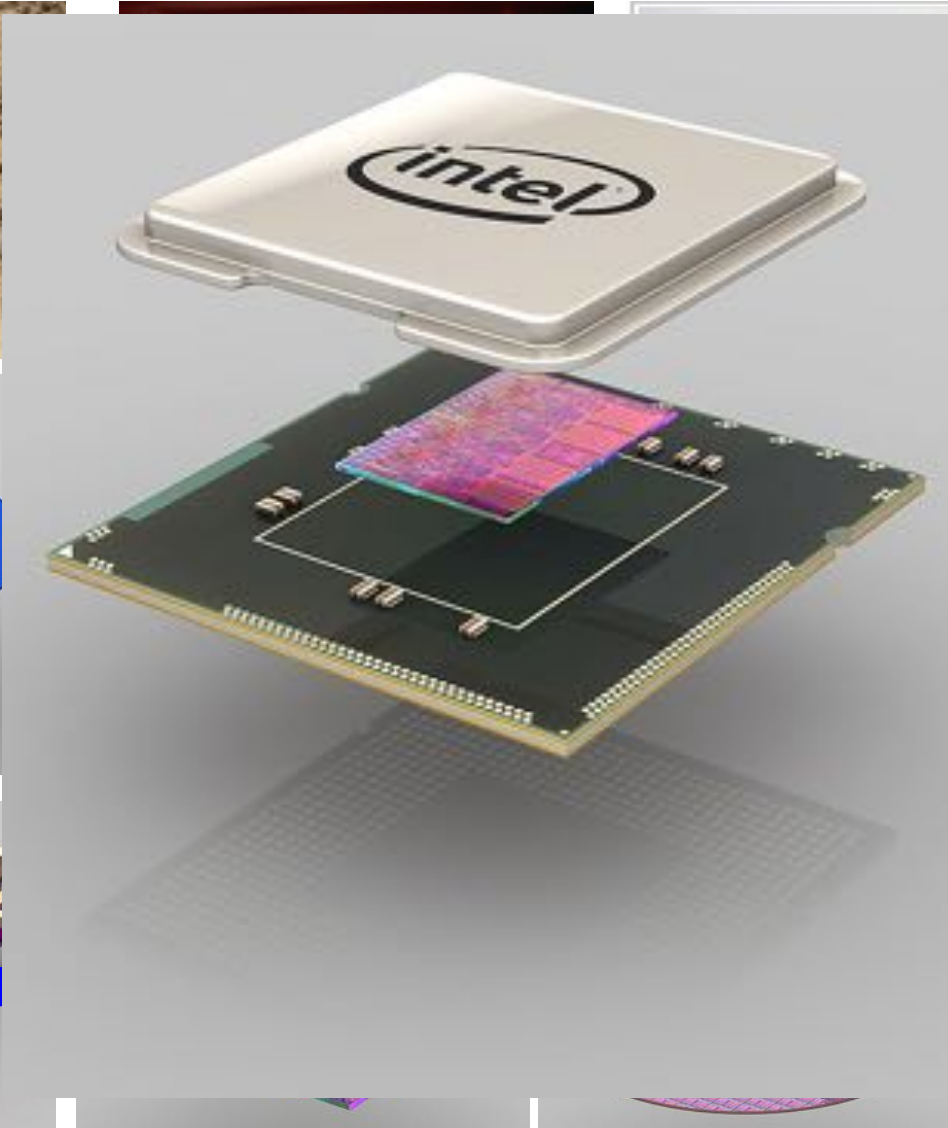
The more transistors you can put together (properly), the more you can do (faster electronics).



ALL electronics are enabled by a microprocessor brain that is a chip of BILLIONS of transistors!



Side note: How do you make silicon transistors?



<http://apcmag.com/picture-gallery-how-a-chip-is-made.htm/>

What enables electronics?

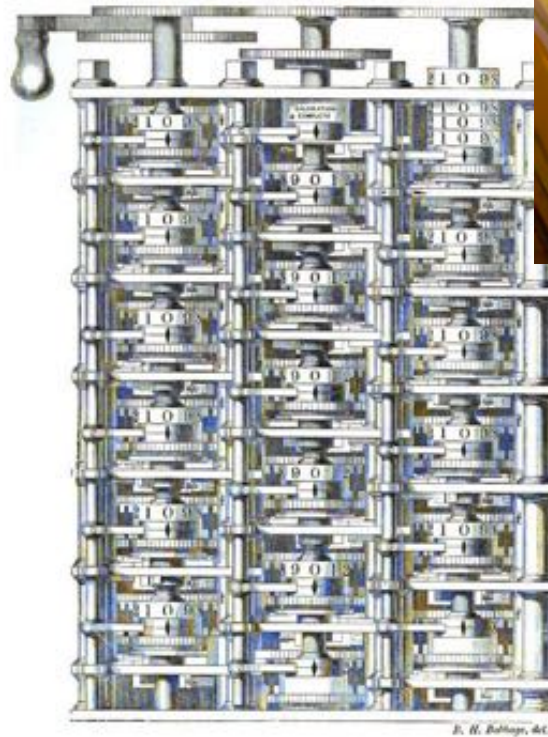
- Looking back ...

Ada Lovelace (1840's, England)



"First computer programmer"

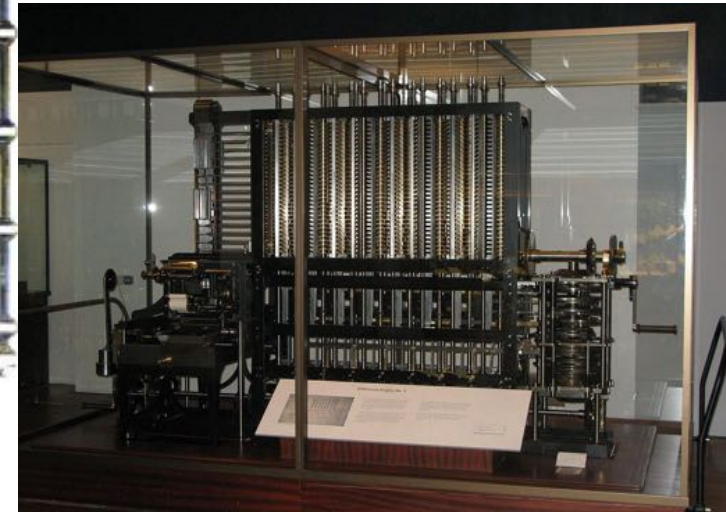
www.wikipedia.org



Charles Babbage's "difference engine"—first programmable computer



Late 1800's: Mechanical computers



History of the transistor

- First: The vacuum tube

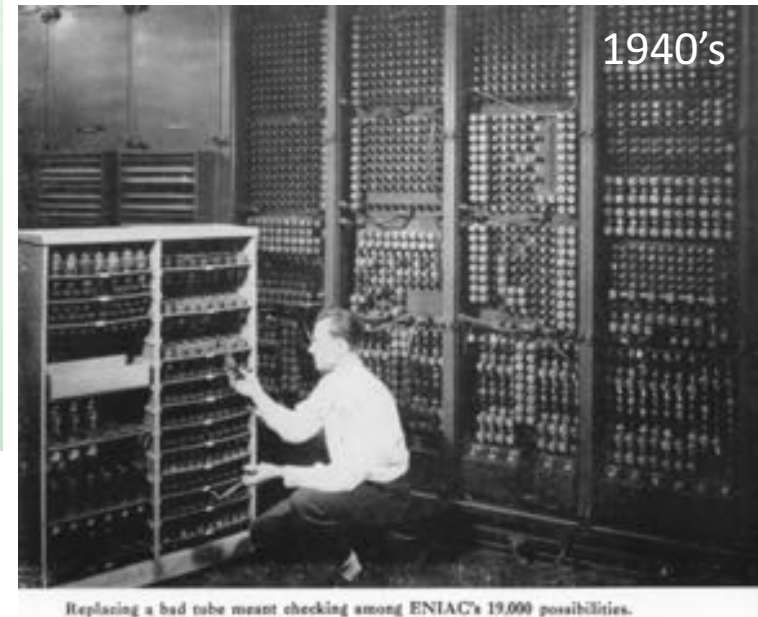


http://en.wikipedia.org/wiki/File:Triody_var.jpg

1918

1960's

- Applying voltage to a filament and plate allows for rectification, amplification, or switching of electrical signals.
- Crucial role in development of radio communications and early computing.



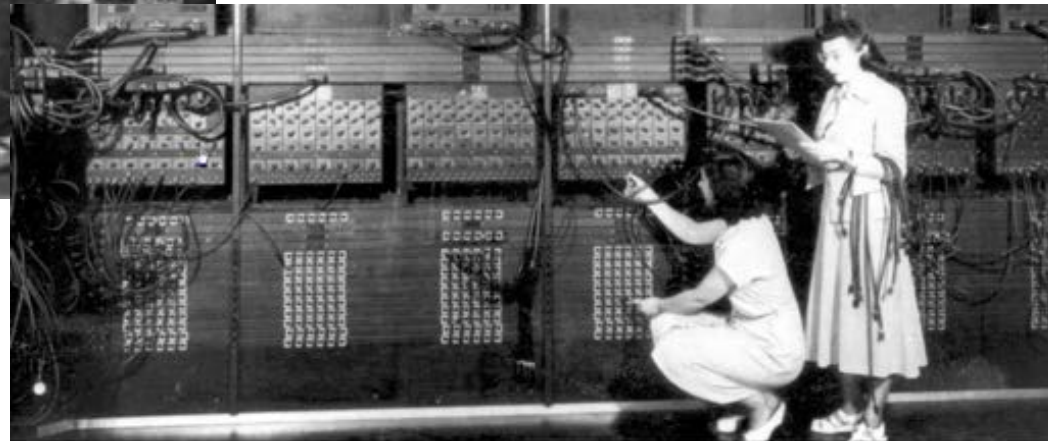
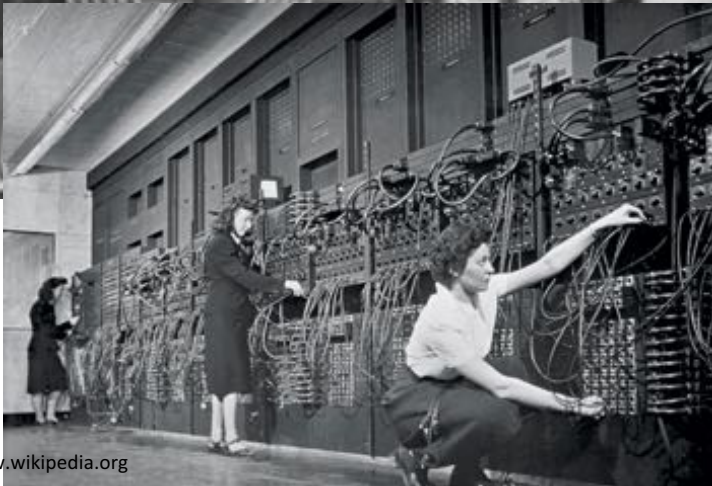
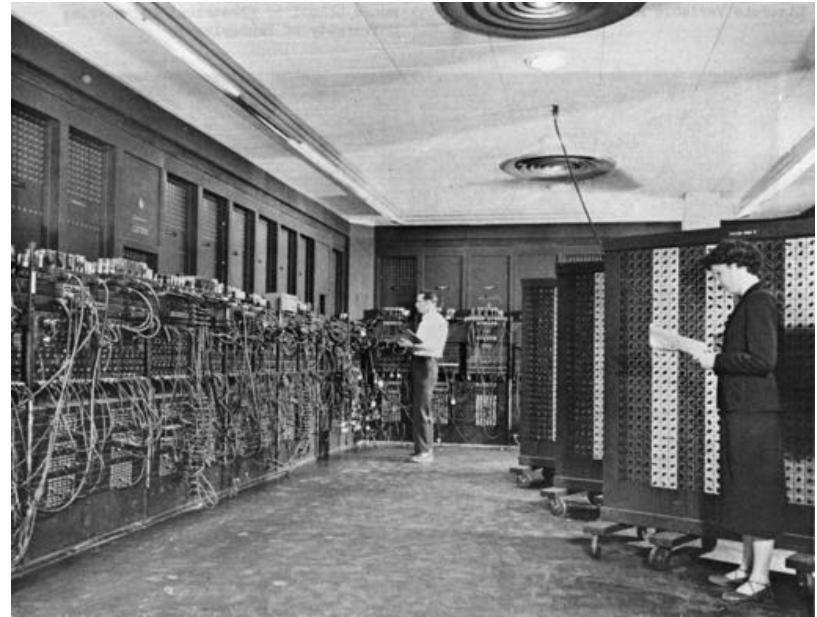
1940's

Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

What enables electronics?

- Looking back ...

once again, first programmers were women!



www.wikipedia.org

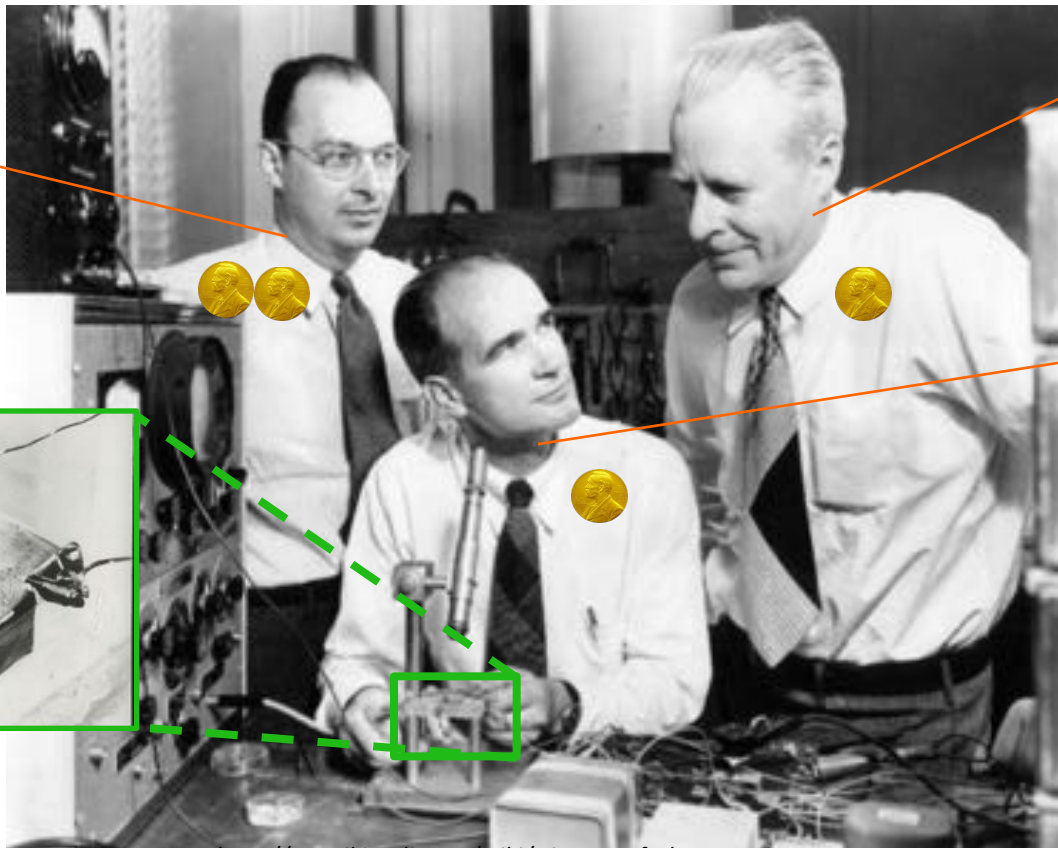
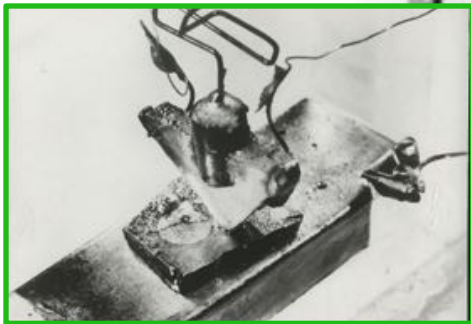
History of the transistor

- Bell labs pursues understanding of semiconductor physics and . . .
 - the transistor was born.

John Bardeen
theorist

Walter Brattain
experimentalist

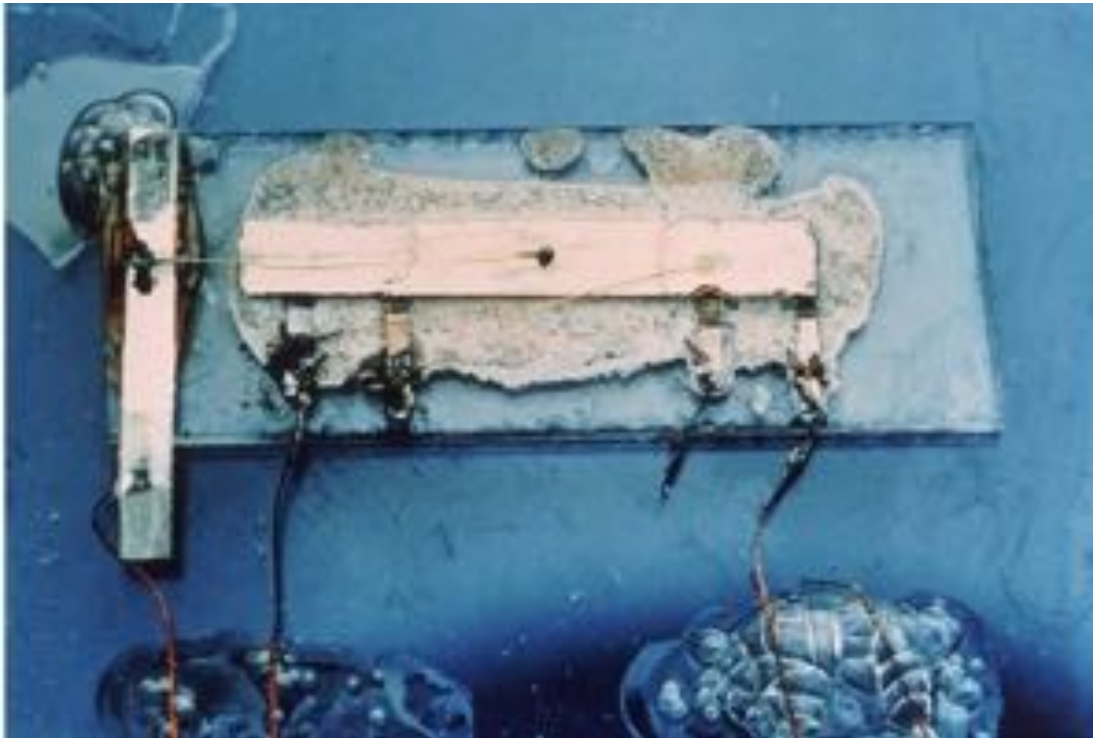
William Shockley
*management /
ideas*



http://en.wikipedia.org/wiki/History_of_the_transistor

History of the transistor

Integrated circuit (IC) made the transistor *revolutionary*



http://en.wikipedia.org/wiki/Integrated_circuit



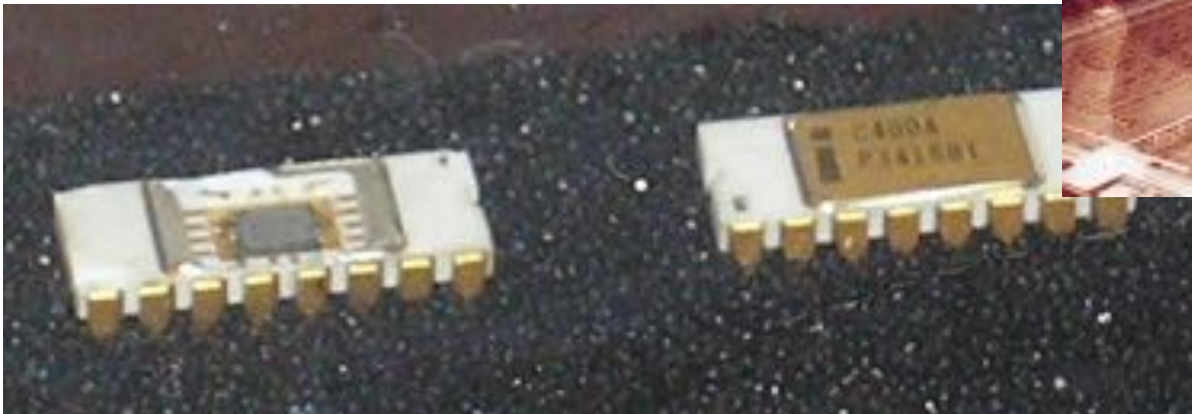
Jack Kilby (TI) → germanium
and first patent (1959)

Robert Noyce (Fairchild) →
silicon and first full technology
(1960's)



History of the transistor

- Looking back ...
 - IC's used mostly by government for first few years
 - First consumer IC, microprocessor (Intel 4004)
 - 1971
 - 2,300 transistors

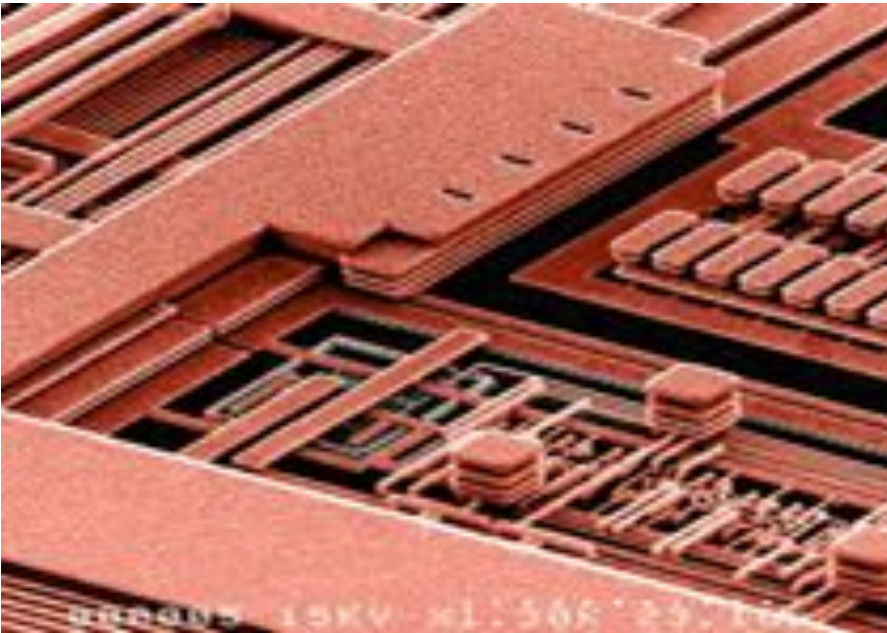


http://en.wikipedia.org/wiki/Intel_4004

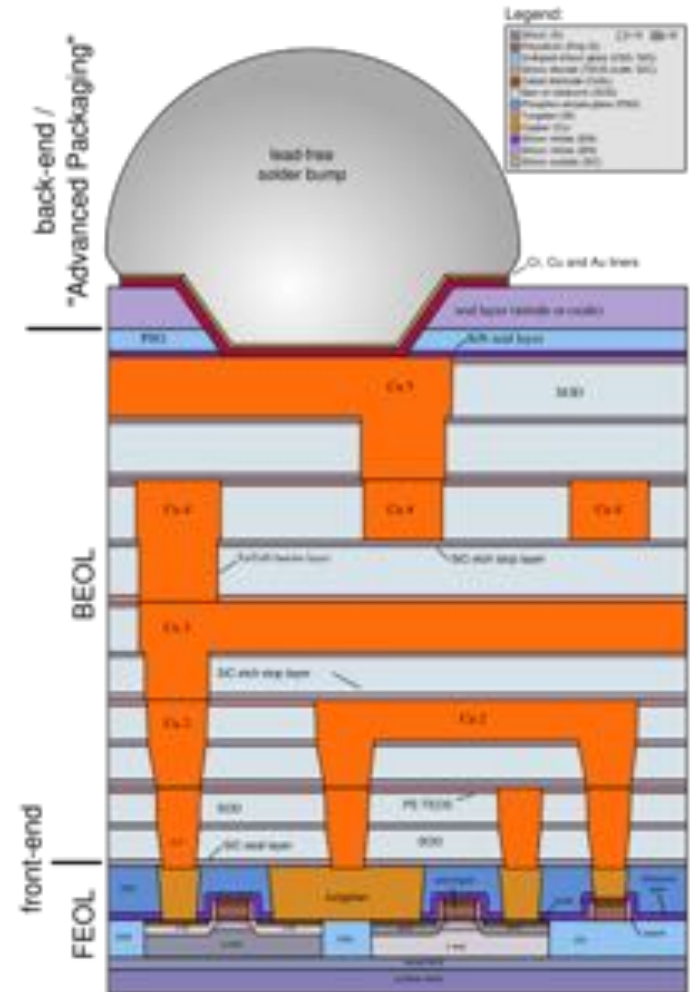


History of the transistor

- SSI → MSI → LSI → VLSI → ULSI



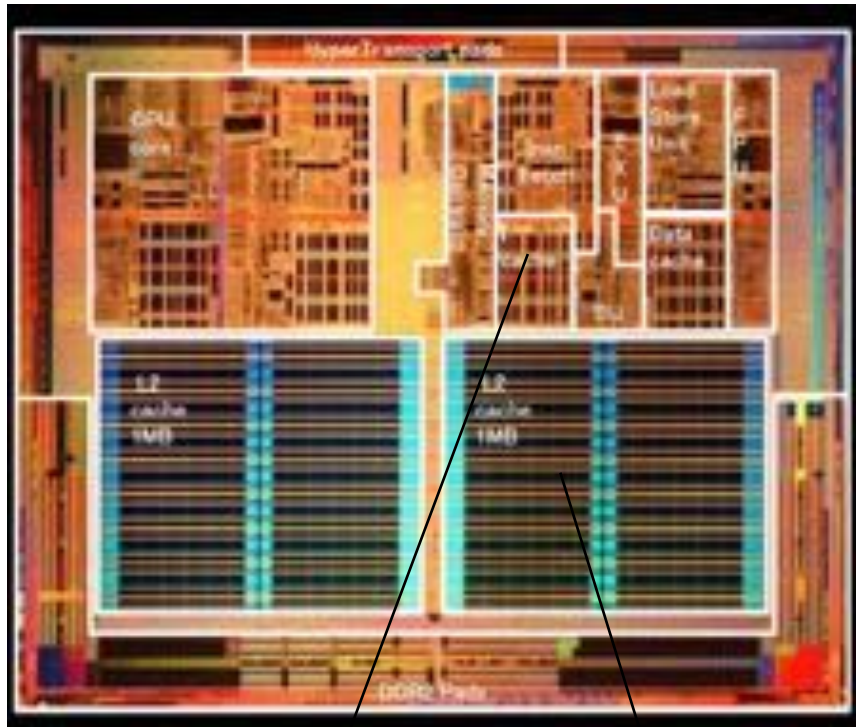
http://www.copper.org/publications/newsletters/innovations/2006/01/copper_nanotechnology.html



Importance of memory devices

- Allocation of chip real estate—how much is memory (cache)?

AMD Dual Core

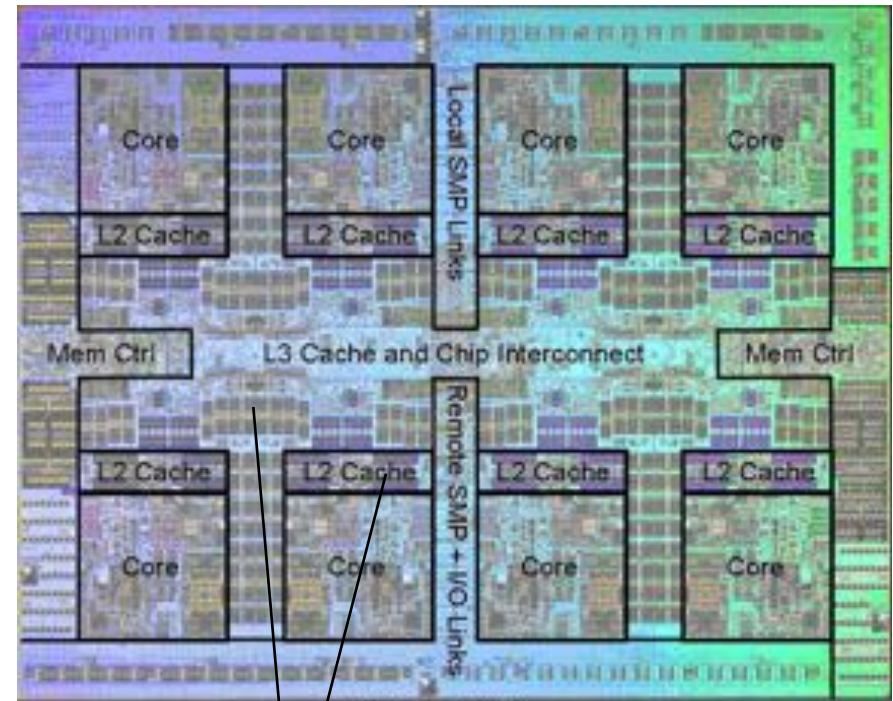


<http://www.cyberindian.net/2006/06/02/amd-athlon-64-fx-62-dual-core-processor-for-amd-socket-am2-now-available/>

DRAM or SRAM

DRAM

IBM Multi Core



<http://www.edn.com/electronics-news/4314117/IBM-Power7-architecture-illustrates-some-issues-for-the-rest-of-us>

DRAM or SRAM (but not as likely)

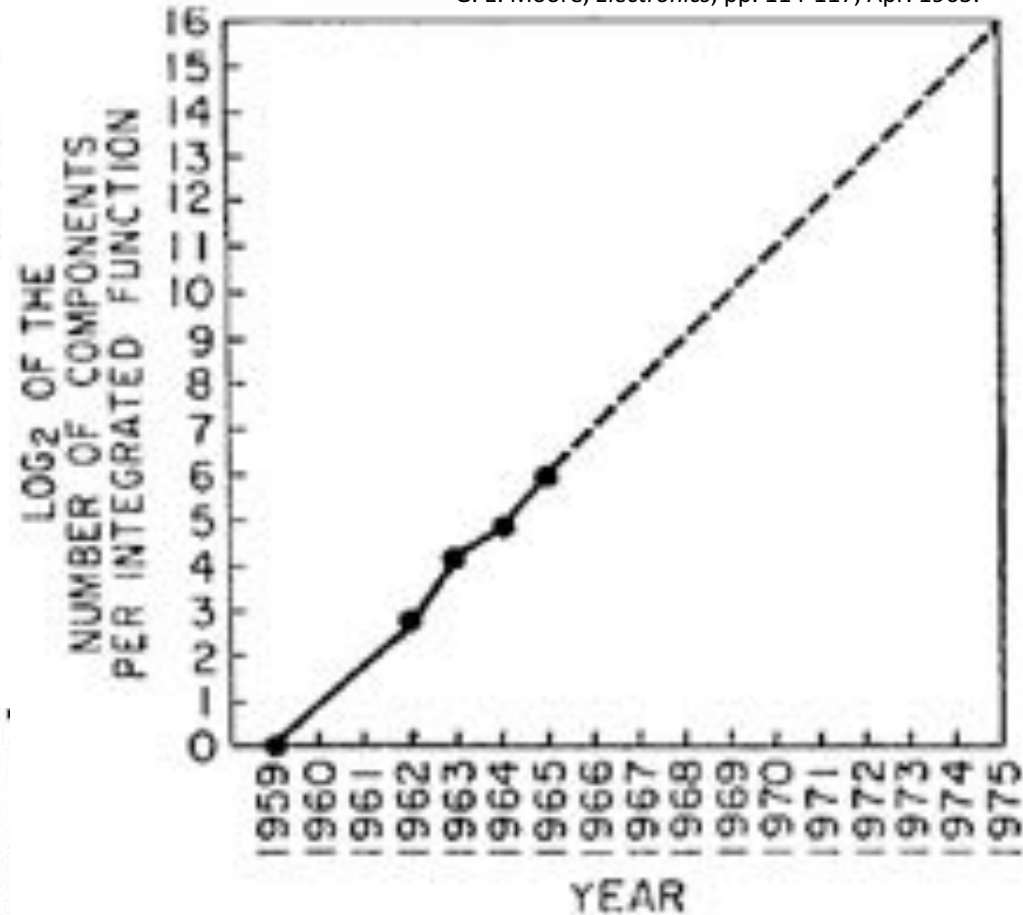
Moore's Law

- Gordon Moore working at Fairchild Semiconductor made an observation in 1965:



G. E. Moore is one of the new breed of electronic engineers, schooled in the physical sciences rather than in electronics. He earned a B.S. degree in chemistry from the University of California and a Ph.D. degree in physical chemistry from the California Institute of Technology. He was one of the founders of Fairchild Semiconductor and has been Director of the research and development laboratories since 1959.

G. E. Moore, *Electronics*, pp. 114-117, Apr. 1965.



VII. HEAT PROBLEM

Will it be possible to remove the heat generated by tens of thousands of components in a single silicon chip?

If we could shrink the volume of a standard high-speed digital computer to that required for the components themselves, we would expect it to glow brightly with present power dissipation. But it won't happen with integrated circuits. Since integrated electronic structures are



What enables electronics?

- Looking back ... Moore's law – 70s – 90s

40 years of the microprocessor

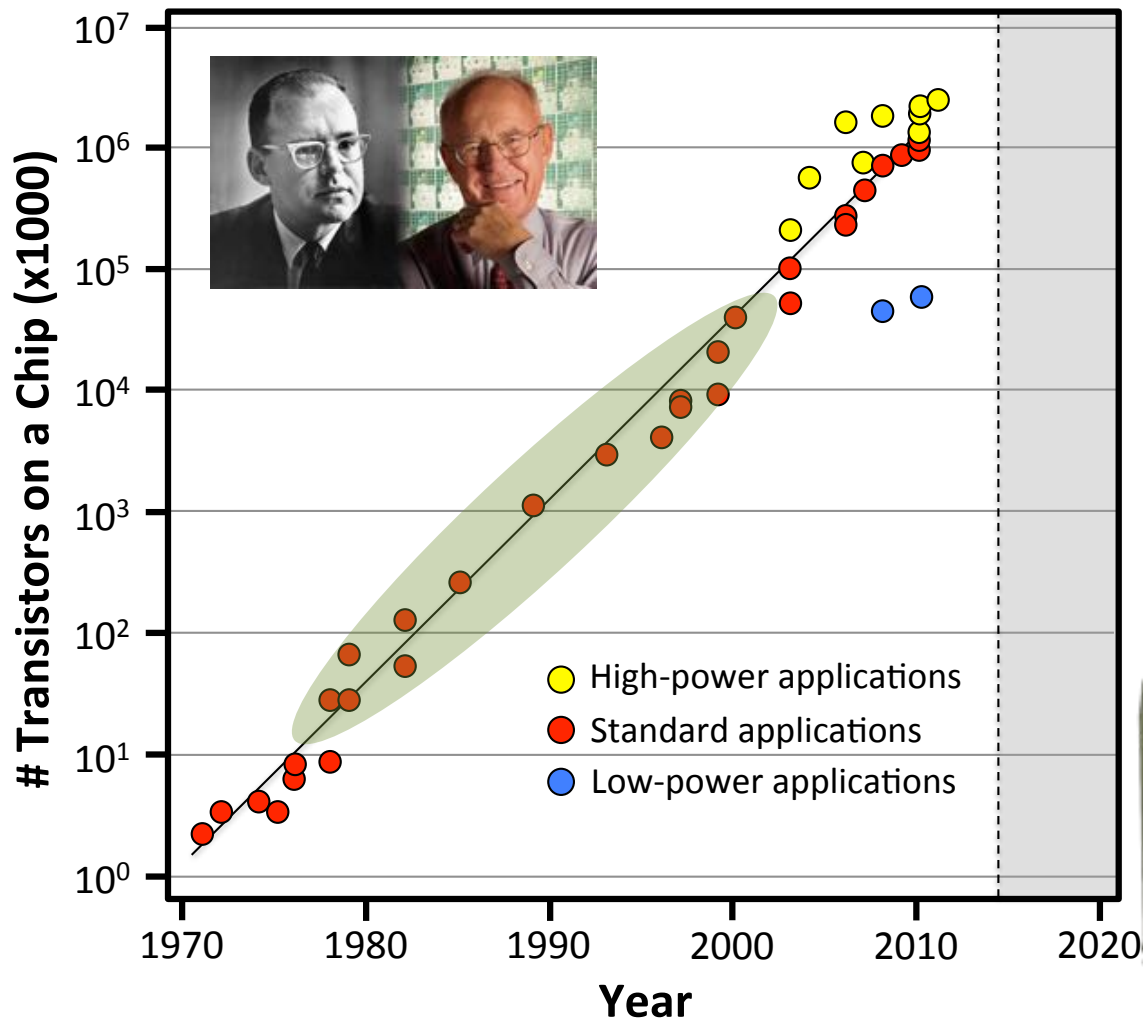
The frequent looky back at the most significant microprocessor developments that have shaped the IT industry

1970s	1980s	1990s
 <p>1971 Intel 4004 Marked the start of the microprocessor era. The 4004 was a 4-bit chip with 2,300 transistors and clocked at 1MHz.</p>	 <p>1978 Intel 8086 The 8086 was a high-performance upgrade of the 8080, and marked the start of the PC era. It was clocked at 5MHz and had 290,000 transistors.</p>	 <p>1985 Intel 386 introduced PowerPC chip The 386 was a significant upgrade from the 286, and marked the start of the 32-bit era. It was clocked at 10MHz and had 2.75 million transistors.</p>
 <p>1982 Intel 8088 The 8088 was a 16-bit chip with 290,000 transistors and clocked at 5MHz. It was the first 8080-compatible chip to be manufactured in a 1.5µm process.</p>	 <p>1982 Intel 286 The 286 was a significant upgrade from the 8086, and marked the start of the 286 era. It was clocked at 6MHz and had 1.2 million transistors.</p>	 <p>1989 Intel 486 introduced Pentium chip The 486 was a significant upgrade from the 386, and marked the start of the 486 era. It was clocked at 10MHz and had 1.2 million transistors.</p>
 <p>1974 Intel 8080 The 8080 was a significant upgrade from the 4004, and marked the start of the 8080 era. It was clocked at 2MHz and had 6,000 transistors.</p>	 <p>1985 Intel 386 The 386 was a significant upgrade from the 286, and marked the start of the 386 era. It was clocked at 10MHz and had 2.75 million transistors.</p>	 <p>1989 Intel 486 The 486 was a significant upgrade from the 386, and marked the start of the 486 era. It was clocked at 10MHz and had 1.2 million transistors.</p>
 <p>1976 Intel 8085 The 8085 was a significant upgrade from the 8080, and marked the start of the 8085 era. It was clocked at 5MHz and had 6,000 transistors.</p>	 <p>1989 Intel 486 The 486 was a significant upgrade from the 386, and marked the start of the 486 era. It was clocked at 10MHz and had 1.2 million transistors.</p>	 <p>1992 Intel 586 The 586 was a significant upgrade from the 486, and marked the start of the 586 era. It was clocked at 33MHz and had 3.1 million transistors.</p>
 <p>1982 Intel 8088 The 8088 was a significant upgrade from the 8080, and marked the start of the 8088 era. It was clocked at 5MHz and had 290,000 transistors.</p>	 <p>1992 Intel 586 The 586 was a significant upgrade from the 486, and marked the start of the 586 era. It was clocked at 33MHz and had 3.1 million transistors.</p>	 <p>1995 Intel 686 The 686 was a significant upgrade from the 586, and marked the start of the 686 era. It was clocked at 60MHz and had 2.75 million transistors.</p>
 <p>1974 Intel 8080 The 8080 was a significant upgrade from the 4004, and marked the start of the 8080 era. It was clocked at 2MHz and had 6,000 transistors.</p>	 <p>1995 Intel 686 The 686 was a significant upgrade from the 586, and marked the start of the 686 era. It was clocked at 60MHz and had 2.75 million transistors.</p>	 <p>1995 Intel 7445 The 7445 was a significant upgrade from the 686, and marked the start of the 7445 era. It was clocked at 100MHz and had 3.1 million transistors.</p>
 <p>1976 Intel 8085 The 8085 was a significant upgrade from the 8080, and marked the start of the 8085 era. It was clocked at 5MHz and had 6,000 transistors.</p>	 <p>1995 Intel 7445 The 7445 was a significant upgrade from the 686, and marked the start of the 7445 era. It was clocked at 100MHz and had 3.1 million transistors.</p>	 <p>1989 Intel 80486 The 80486 was a significant upgrade from the 486, and marked the start of the 80486 era. It was clocked at 33MHz and had 1.2 million transistors.</p>
 <p>1982 Intel 8088 The 8088 was a significant upgrade from the 8080, and marked the start of the 8088 era. It was clocked at 5MHz and had 290,000 transistors.</p>	 <p>1989 Intel 80486 The 80486 was a significant upgrade from the 486, and marked the start of the 80486 era. It was clocked at 33MHz and had 1.2 million transistors.</p>	 <p>1993 Intel Pentium The Pentium was a significant upgrade from the 80486, and marked the start of the Pentium era. It was clocked at 60MHz and had 3.1 million transistors.</p>
 <p>1974 Intel 8080 The 8080 was a significant upgrade from the 4004, and marked the start of the 8080 era. It was clocked at 2MHz and had 6,000 transistors.</p>	 <p>1993 Intel Pentium The Pentium was a significant upgrade from the 80486, and marked the start of the Pentium era. It was clocked at 60MHz and had 3.1 million transistors.</p>	 <p>1993 Intel Pentium The Pentium was a significant upgrade from the 80486, and marked the start of the Pentium era. It was clocked at 60MHz and had 3.1 million transistors.</p>
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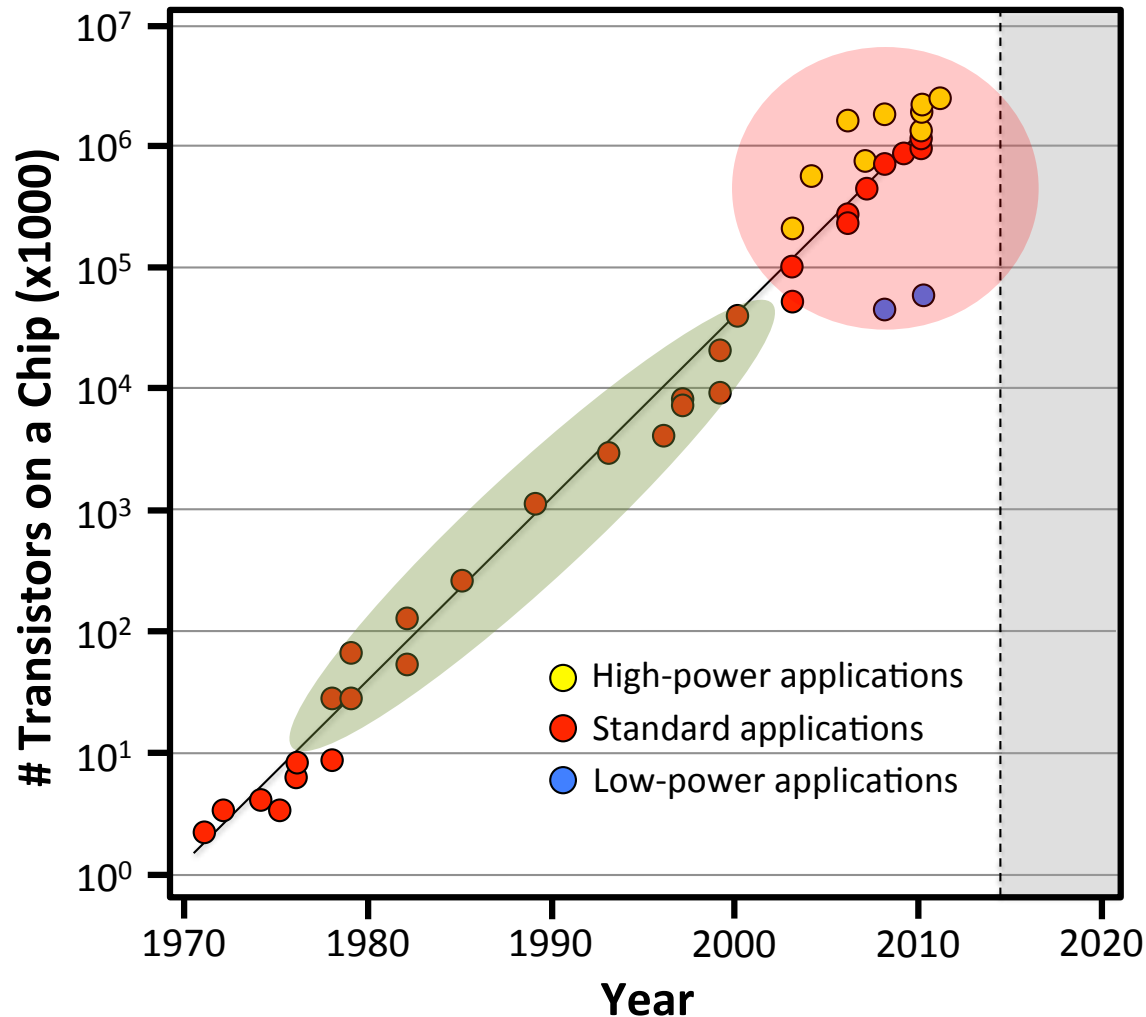
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