

CS 31007

Autumn 2021

COMPUTER ORGANIZATION AND ARCHITECTURE

Instructors

Rajat Subhra Chakraborty (*RSC*)
Bhargab B. Bhattacharya (*BBB*)

Lecture #1, #2:
Course Overview and Evolution of Computer Design
10 August 2021

Indian Institute of Technology Kharagpur
Computer Science and Engineering

CS 31007

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COMPUTER ORGANIZATION AND ARCHITECTURE

Class Schedule

Commencement: Tuesday, 10 August 2021

Closure: Thursday, 18 November 2021

Timing: 12:00-12:55 (Mon), 10:00-11:55 (Tue), and 8:00-8:55 (Thurs)

Online Classes will be held in real-time mode

or occasionally in pre-recorded mode

Tutorials and doubt-clearing sessions will be held
in real-time mode

Lab Course (39001): Computer Organization Laboratory

CS 31007

Autumn 2021

COMPUTER ORGANIZATION AND ARCHITECTURE

Course Page and TAs

Course Page: <https://moodlecse.iitkgp.ac.in/moodle/login/index.php>
Moodle Student Registration Key for the Course: STU31007

Teaching Assistants: Rijoy Mukherjee (rijoy.mukherjee@gmail.com)
Akashdeep Saha (akashdeepsaha95@gmail.com)
Rajat Sadhukhan (rajatssr835@gmail.com)
Sreekanth Balija Venkata
(balijavenkatasreekanth@gmail.com)

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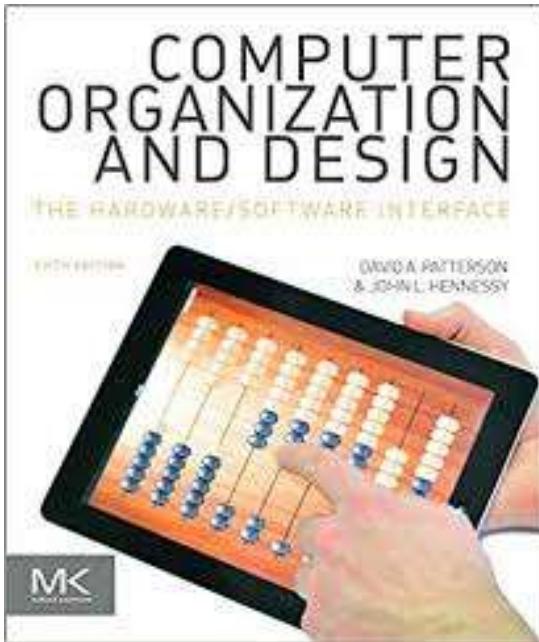
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Prerequisites

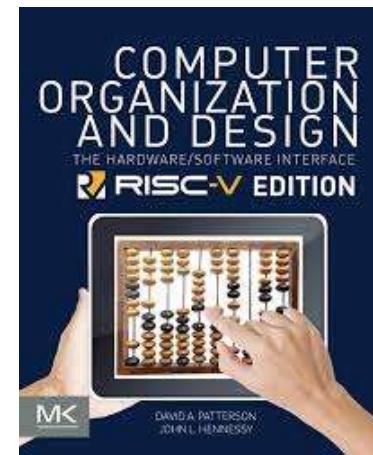
Basic logic design, combinational and sequential circuits,
knowledge of high-level programming language

Textbook

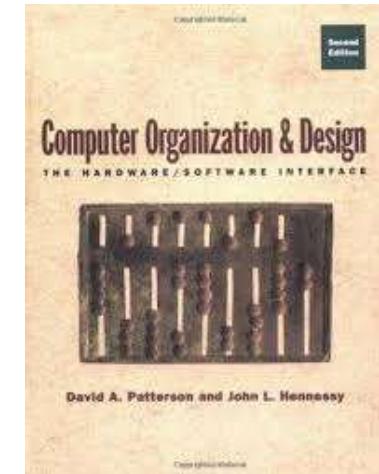


2017 ACM Turing Award

D. A. Patterson and J. L. Hennessy
Computer Organization and Design
- *The Hardware Software Interface*
5th Edition, Morgan Kaufmann, 2014
(MIPS Version)



RISC-V Edition 2018



Second Edition 1998

Further Reading

1. Smruti R. Sarangi, *Computer Organisation and Architecture*, McGraw Hill India, 2014
2. William Stallings, *Computer Organization and Architecture: Designing for Performance*, Eight Edition, Prentice Hall, 2010.
3. John P. Hayes, *Computer Architecture and Organization*, 3rd Edition, Tata McGraw Hill, 2012.

Grading Policy

- ❖ No Mid-Sem or End-Sem Examination
- ❖ Evaluation at regular intervals
- ❖ Homework for practicing
- ❖ Online exams/quizzes

The exams/quizzes would usually be scheduled in the regular class hours

Agenda

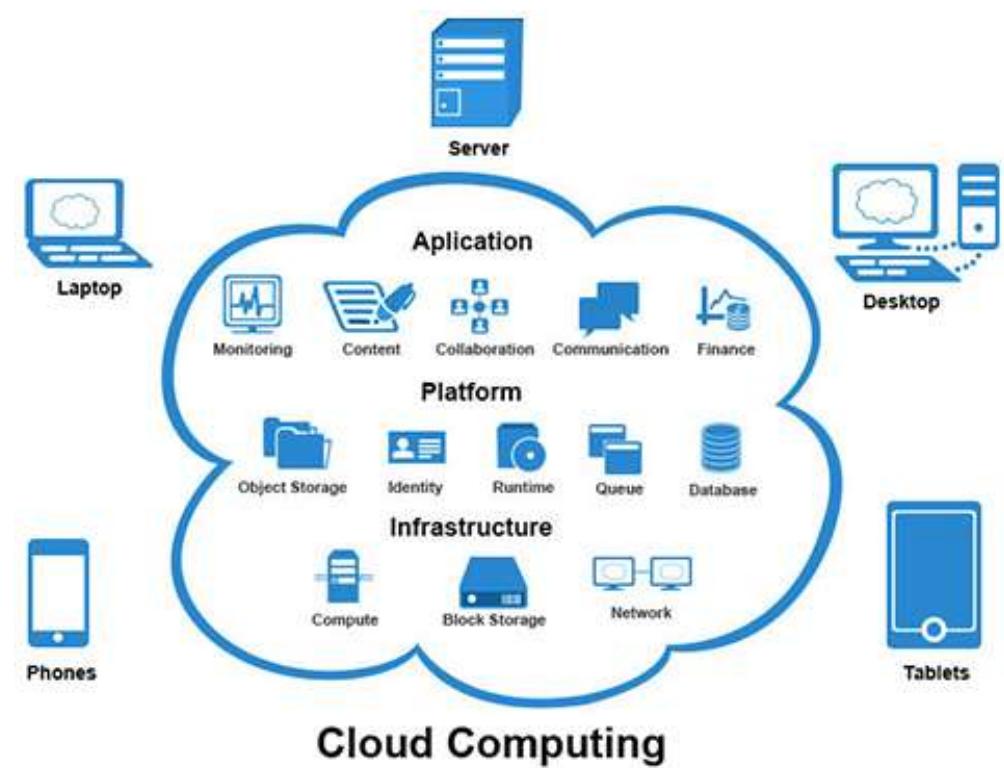
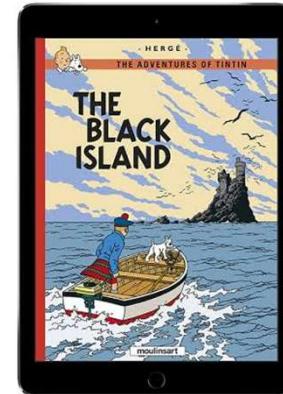
- ❖ Overview of the course
 - ❖ Evolution and history of computer design
 - ❖ Moore's law
 - ❖ Basic components of a computer
 - ❖ Instruction Set Architecture (ISA)
 - ❖ Computer organization and computer architecture: Bottom-up and Top-down view
-

Acknowledgement: Patterson and Hennessy; V. D. Agrawal; S. R. Sarangi

Goal is to understand

- What are the principles of computer design?
- What is the hardware-software interface?
- Computer organization *versus* computer architecture?
- How to design the instruction set of a machine?
- How instructions are executed in a machine?
- What are the techniques for performing fast computation?
- How to design a complete processor?

What is a Computer ?



Car or Computers?

BMW
345i



- 2,000,000 lines of code
- Fiftythree 8-bit microprocessors
- Eleven 32-bit microprocessors
- Seven 16-bit microprocessors

The Computer Revolution

- Makes novel applications feasible
 - Computers in automobiles
 - Cell phones
 - Human genome project
 - World Wide Web
 - Search Engines
- Computers are all pervasive

Classes of Computers

- Personal computers
 - General purpose, variety of software
 - Subject to cost/performance tradeoff
- Server computers
 - Network based
 - High capacity, performance, reliability
 - Range from small servers to building sized
 - Cloud



Classes of Computers

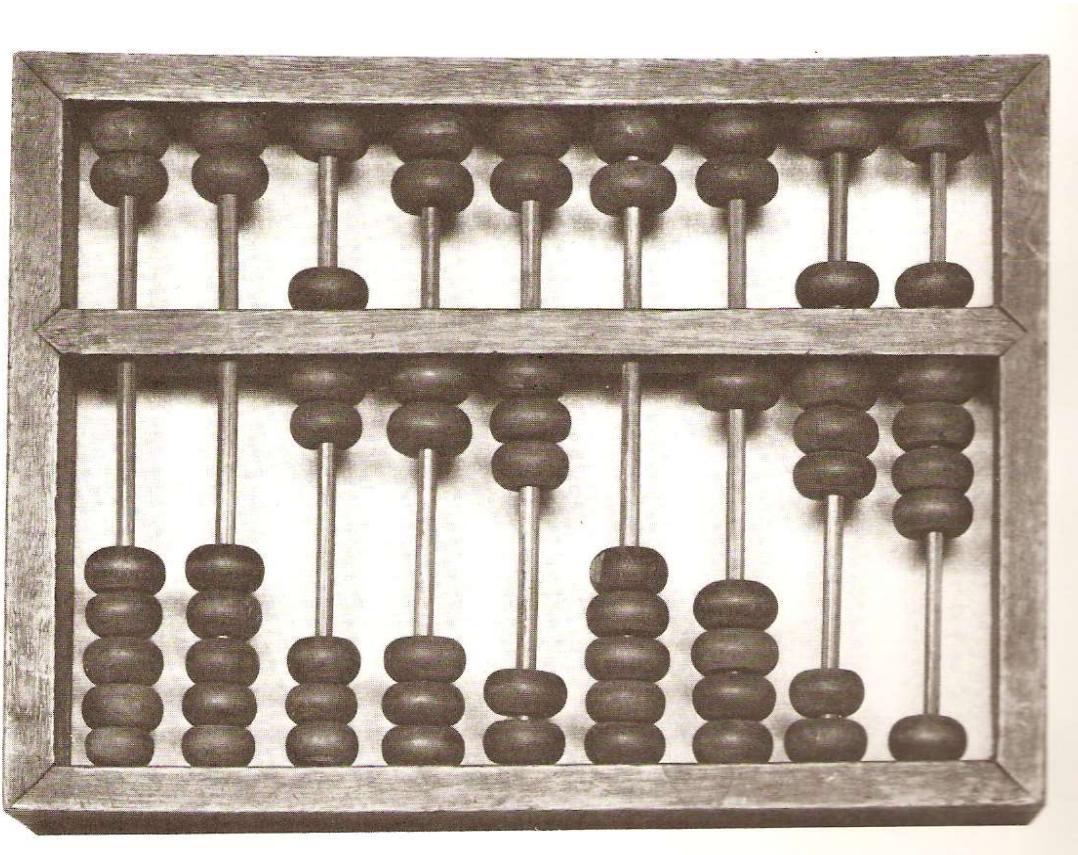
- Supercomputers
 - High-end scientific and engineering calculations
 - Highest capability but represent a small fraction of the overall computer market
- Embedded computers
 - Hidden as components of systems, IoT
 - Stringent power/performance/cost constraints
 - Autonomous vehicles, robotics



A computer is a general purpose
machine which can process
Information and yield results

However, centuries ago, by a
computer was meant ...

The First Mechanical Computing Device



The nineteenth century Chinese abacus, numbers are entered by sliding the beads towards the crossbar

First Steps in Computing



John Napier (1550-1617)

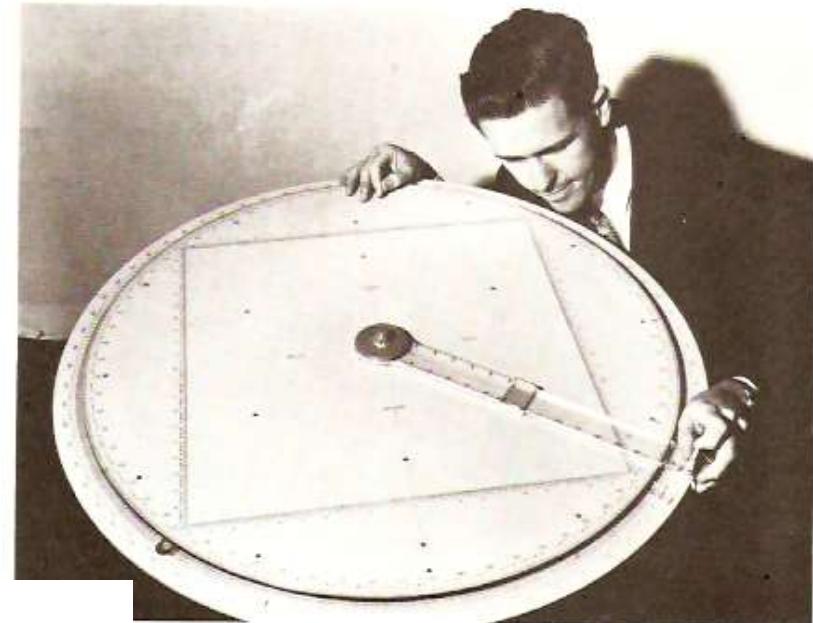
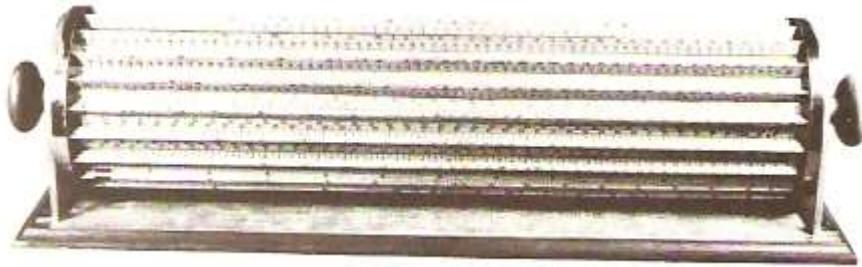
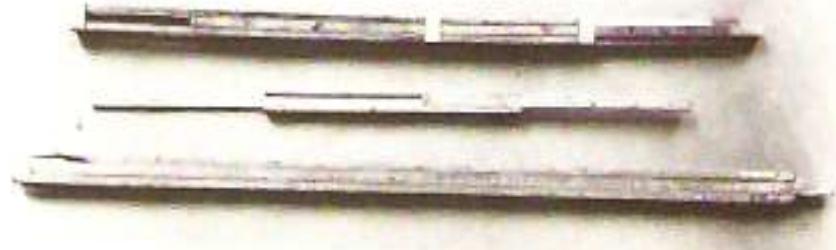


$$\log(a \times b) = \log a + \log b$$

$$\log(a / b) = \log a - \log b$$

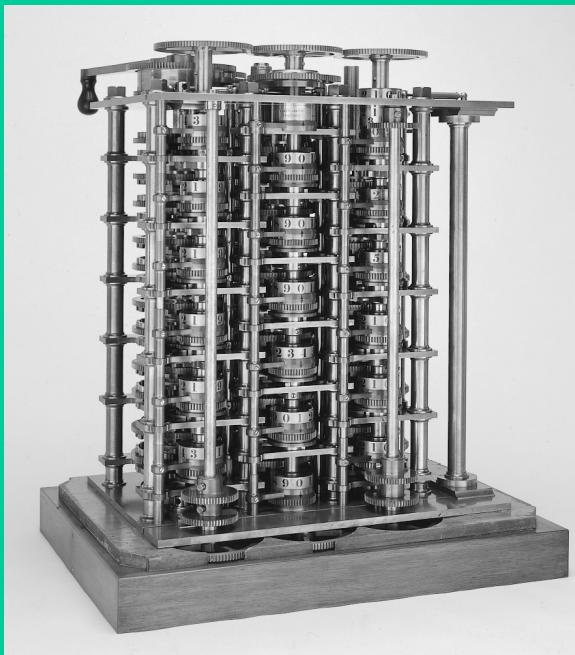
The front page of Napier's famous paper (1614) that introduced logarithm and contained ninety pages of tables.

Slide Rule



The first slide rule (top left) was made in 1654; the cylindrical slide rule (below left) and circular slide rules are useful modifications that were used for various computations; Slide rule (left-bottom) used by early generation of engineers.

Then:
The First Computer
(1832)



Babbage Difference
Engine (25000 parts)

Now:
The Zuchongzhi Quantum
Computer (July 2021)



China beats Google to claim the world's most powerful quantum computer. Solves a problem in around an hour that would take the world's most powerful supercomputers eight years to crack.

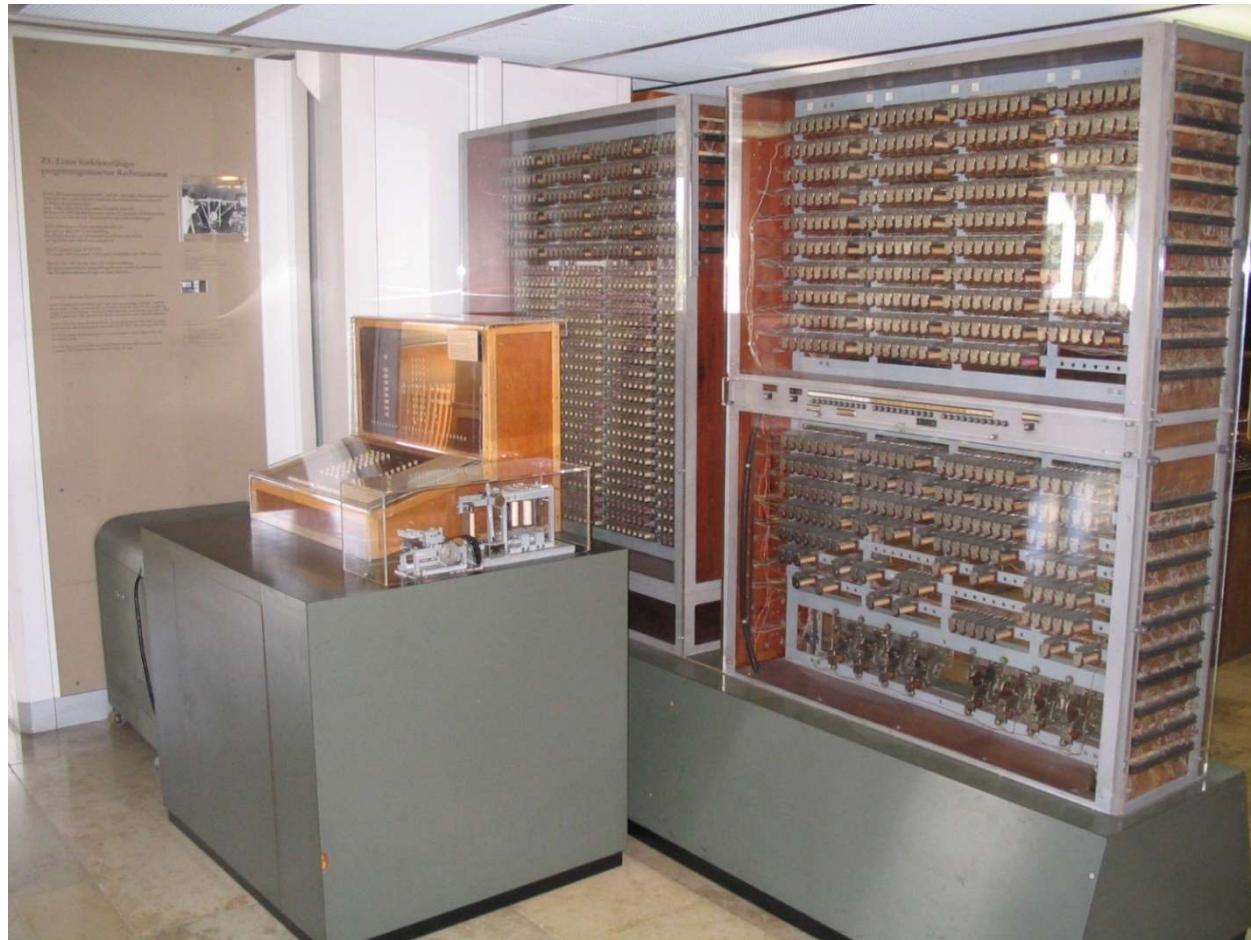
Read more:

<https://www.newscientist.com/article/2282961-china-beats-google-to-claim-the-worlds-most-powerful-quantum-computer/#ixzz733bp4964>

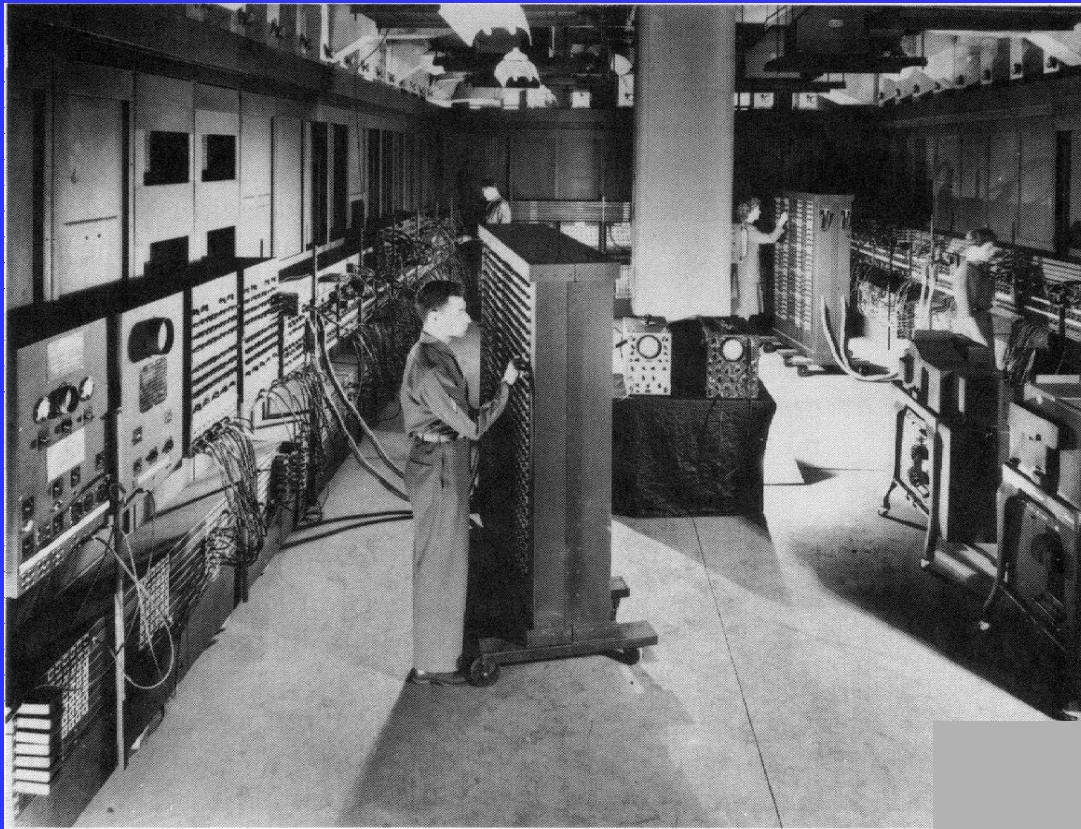
In 1941, Conrad Zuse built Z3, the first programmable computer in Germany.



Conrad Zuse
(1910-1995)



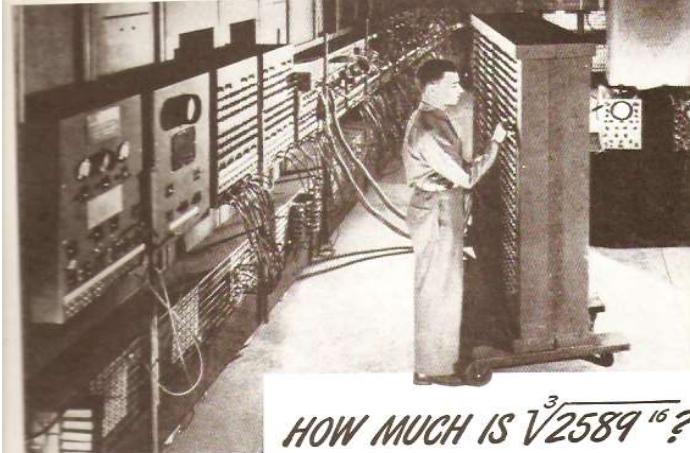
ENIAC - The First Electronic Computer (1943-1946)



Length = 80 ft
Height = 8.5 ft
Floor area = 1500 sq ft
Weight = 30 tons
18000 vacuum tubes
70,000 resistors
140 kw of power

John Mauchly (professor) and J. Presper Eckert (graduate student) built ENIAC at the University of Pennsylvania, Philadelphia

The Snapshots of ENIAC (1946)



HOW MUCH IS $\sqrt[3]{2589}^{16}$?

The Army's ENIAC can give you the answer in a fraction of a second!

Think that's a stumper? You should see some of the ENIAC's problems! Brain twisters that if put to paper would run off this page and feet beyond. . . addition, subtraction, multiplication, division—square root, cube root, any root. Solved by an incredibly complex system of circuits operating 18,000 electronic tubes and tipping the scales at 30 tons!

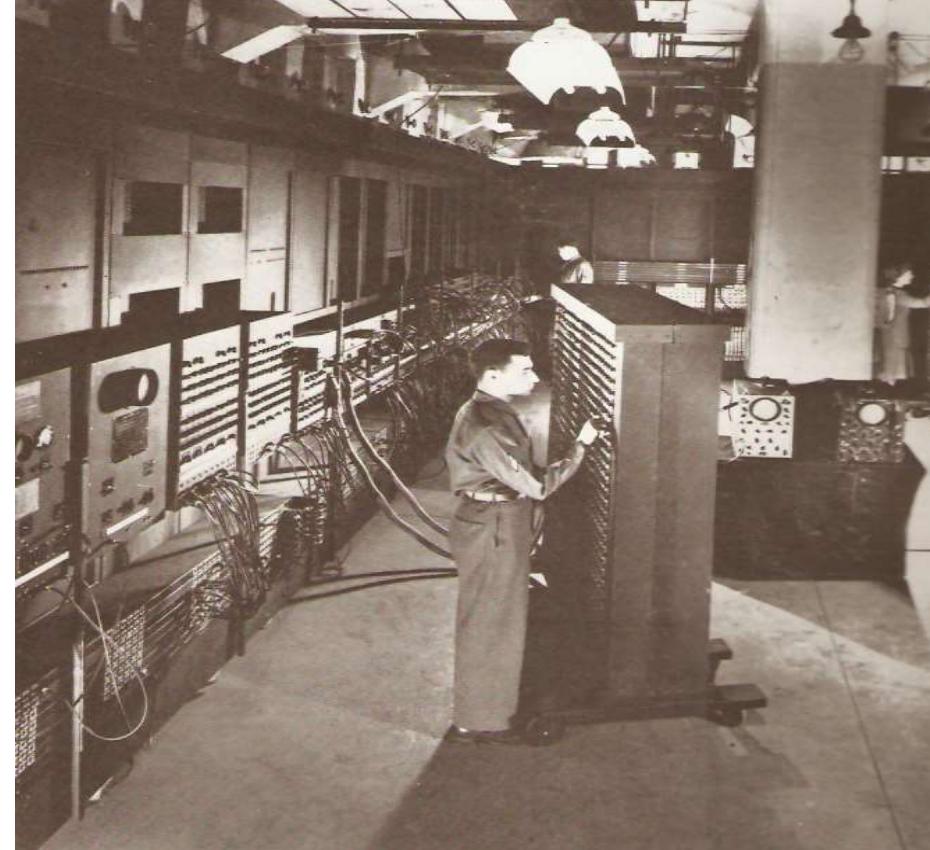
The ENIAC is symbolic of many amazing Army devices with a brilliant future for you! The new Regular Army needs men with aptitude for scientific work, and as one of the first trained in the post-war era, you stand to get on the ground floor of important jobs

YOUR REGULAR ARMY SERVES THE NATION AND MANKIND IN WAR AND PEACE

which have never before existed. You'll find that an Army career pays off.

The most attractive fields are filling quickly. Get into the swim while the getting's good! 1½, 2 and 3 year enlistments are open in the Regular Army to ambitious young men 18 to 34 (17 with parents' consent) who are otherwise qualified. If you enlist for 3 years, you may choose your own branch of the service, of those still open. Get full details at your nearest Army Recruiting Station.

A GOOD JOB FOR YOU
U. S. Army
CHOOSE THIS
FINE PROFESSION NOW!



This advertisement shows the amazing calculating powers of the ENIAC

A technician tracks down a misplaced cable in the ENIAC.

Courtesy: S. Augarten, Bit by Bit

First-Generation Computers

- Late 1940s and 1950s
- Stored-program computers
- Programmed in assembly language
- Used magnetic devices and earlier forms of memories
- Examples: IAS, ENIAC, EDVAC, UNIVAC, Mark I, IBM 701

Second Generation Computers

- 1955 to 1964
- Transistor replaced vacuum tubes
- Magnetic core memories
- Floating-point arithmetic
- High-level languages used: ALGOL, COBOL and FORTRAN
- System software: compilers, subroutine libraries, batch processing
- Example: IBM 7094

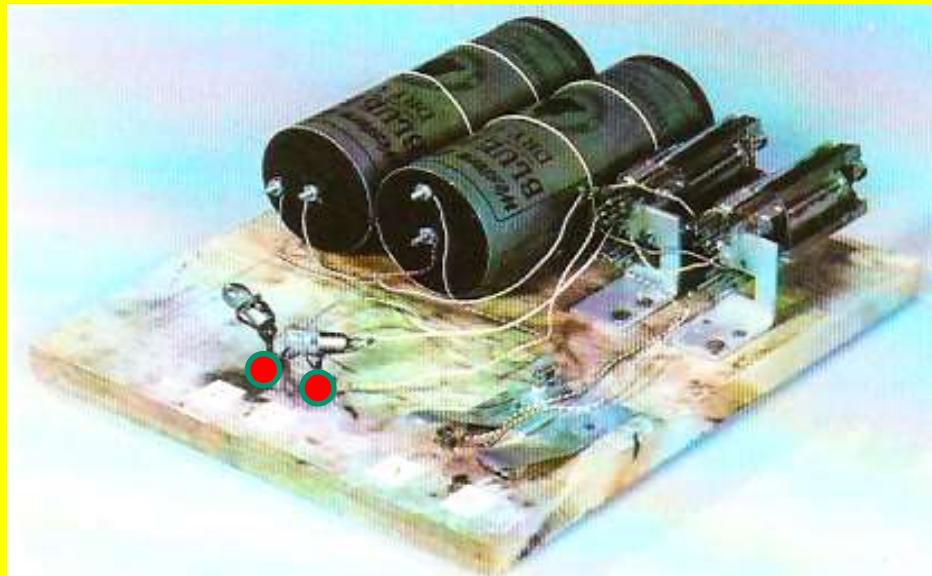
Third Generation Computers

- Beyond 1965
- Integrated circuit (IC) technology
- Semiconductor memories
- Memory hierarchy, virtual memories and caches
- Time-sharing
- Parallel processing and pipelining
- Microprogramming
- Examples: IBM 360 and 370, CYBER, ILLIAC IV, DEC PDP and VAX, Amdahl 470

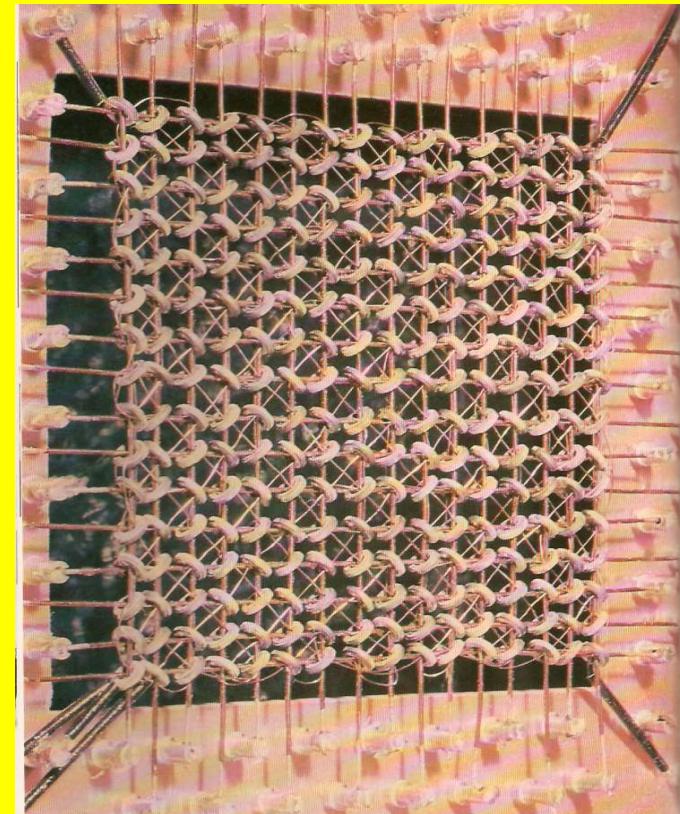
The Miracle of Electronic Evolution

What is this??

No, an early 1024-bit memory!

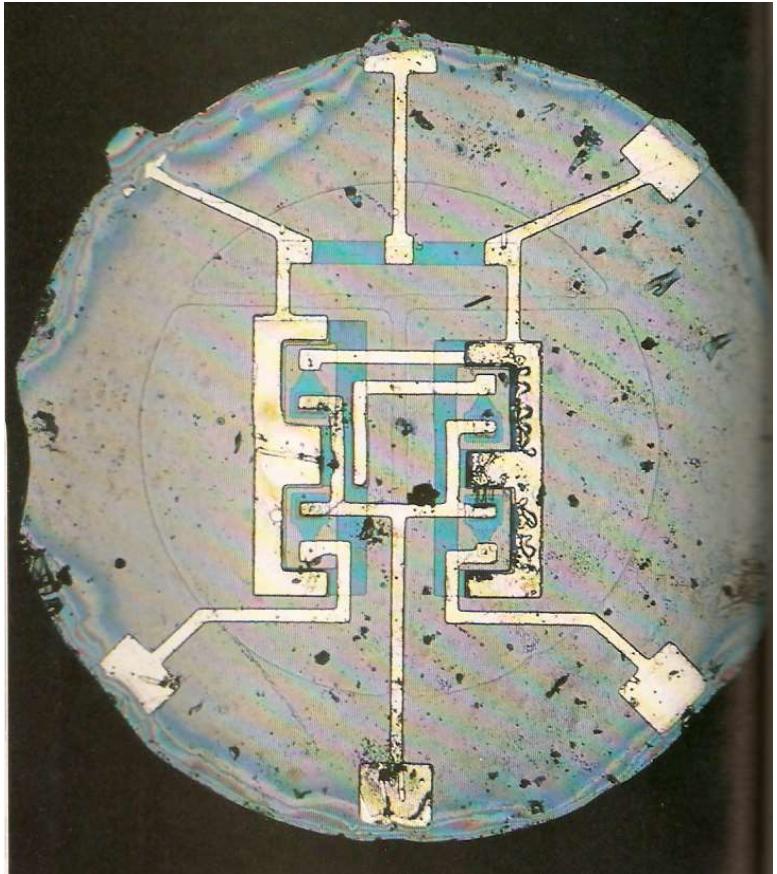


An early *one-bit* binary adder:
built on a kitchen table!



An electrical relay network??

The First Integrated Circuit

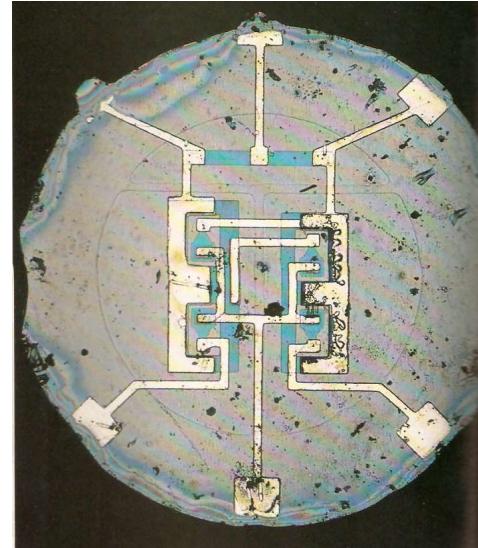


An early integrated circuit built by Fairchild Corporation in 1961. This is a logic IC with *two* flip flops, the *four* blue structures in the center are transistors, and the white lines are aluminum connectors.

“Scientists investigate that which already is; engineers create that which has never been.” - *Albert Einstein*

The Miracle of Integration

An early integrated circuit (1961)



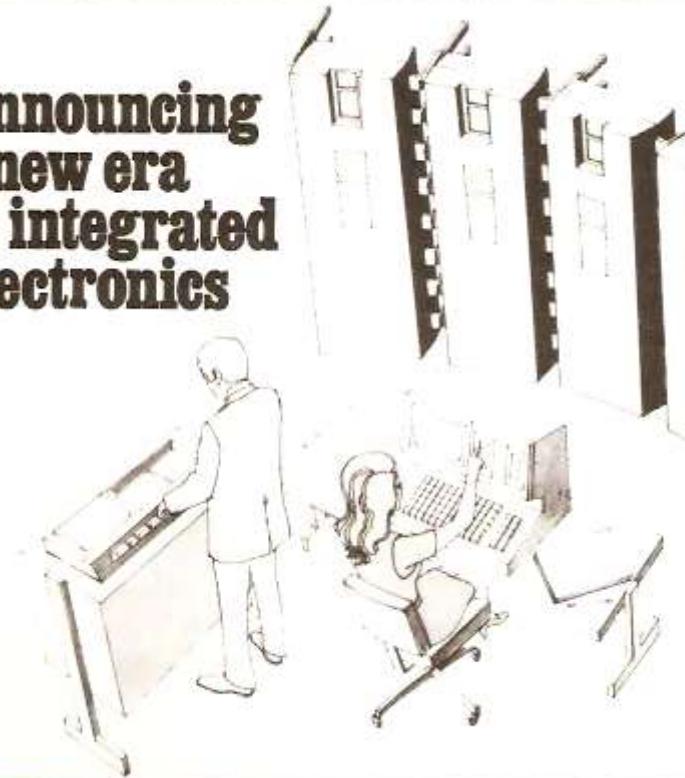
"Why can't we write the entire 24 volumes of the *Encyclopedia Britannica* on the head of a pin?" --
Richard Feynman (1959)

Hardware Design Creating History



Andy Grove, Robert Noyce, and Gordon Moore (1978)
Intel Founders

Entering the World of Microprocessors



**Announcing
a new era
of integrated
electronics**

A micro-programmable computer on a chip!

Intel's industry-leading integrated CPU, complete with a 4.77 MHz clock, is a state-of-the-art logic device. An accommodative and a cost-effective solution for one-offs. The core of a family of logic devices, it can be programmed to perform a variety of functions - from simple applications to those requiring the power and flexibility of a dedicated general-purpose computer. See us at the show in New York City this week.

MCY-4 is a programmable logic computing and control system for test systems, data acquisition, control, measurement systems, microprocessor systems and other applications.

The heart of MCY-4 is Intel's Type 4004 CPU, which includes a powerful set of 40 built-in宏instructions. Adding one or more Type 4007 ROMs to a complete storage and data system gives you a fully functional microcomputer system. MCY-4 has up to 16K of 16-bit 4000 RAMs (as well as 16K memory and Type 4003 registers) to expand the design space.

Using no external memory, MCY-4 can run the kinds of programs that require up to 16K of memory with only 4K of ROM storage and 32K of RAM storage. When you require rapid turn-around or need only a few specific宏instructions, add the programmable ROM, Type 4031, may be substituted for the Type 4007 mask-programmed ROM.

MCY-4 systems interface readily with switches, keypads, displays, telephones, printers, readers, A/D converters and other peripherals.

The MCY-4 family is now in volume at Intel's Santa Clara Headquarters and about marketing headquarters in Europe and Japan. In the U.S., contact your local Intel representative or write to Intel Corporation, Marketing Department, 3201 North 27th Street, Milwaukee, WI 53211. In Europe, contact Intel's Avenue Louise 218, B-1080 Brussels, Belgium. Phone 32/2/333. In Japan, contact Intel Japan, 1-12, Minami 2-chome, Nishi-ku, Kyoto 600-0836, Japan. Phone 07/541-1371. Phone 03/470-4247. Intel Corporation now produces microcomputers, memory devices and memory systems at 3005 Bowers Avenue, Santa Clara, Calif. 95051. Phone 408/248-7581.

**intel[®]
delivers.**

Intel's first advertisement for the 4004 microprocessor that appeared in November 1971.

Evolution of Electronic Technology

“Student: Dr. Einstein, Aren’t these the same question as last year’s [physics] final exam?

Dr. Einstein: Yes; but this year, the answers are different.” --

-- *Albert Einstein*

Evolution of Microprocessors

1970: 4004 μ P



#T = 2300
Auditorium

1982: 286 μ P



#T = 1,34,000
Stadium

1999: Pent III



#T = 32 million
Population of
Tokyo

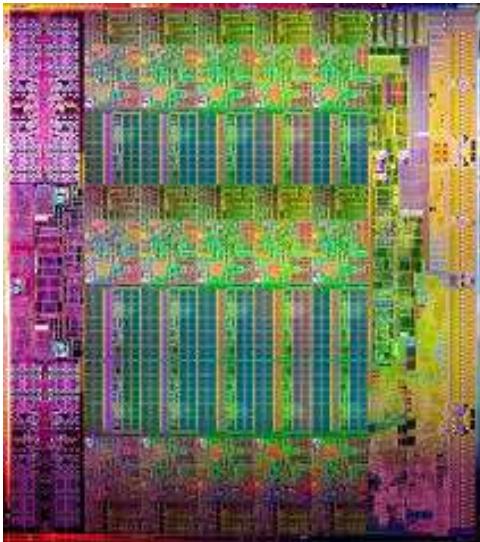
2008: Core i7



#T = 1.3 billion
Population of India

Number of transistors (#T)

Modern Processors



Intel 15-Core Xeon Ivy Bridge-Ex (2014)

22 *nm* technology

4.3 billion transistors

Die size ~600 *mm*²



AMD Ryzen 9 5900X processor (2021); ~ 4 billion Transistors

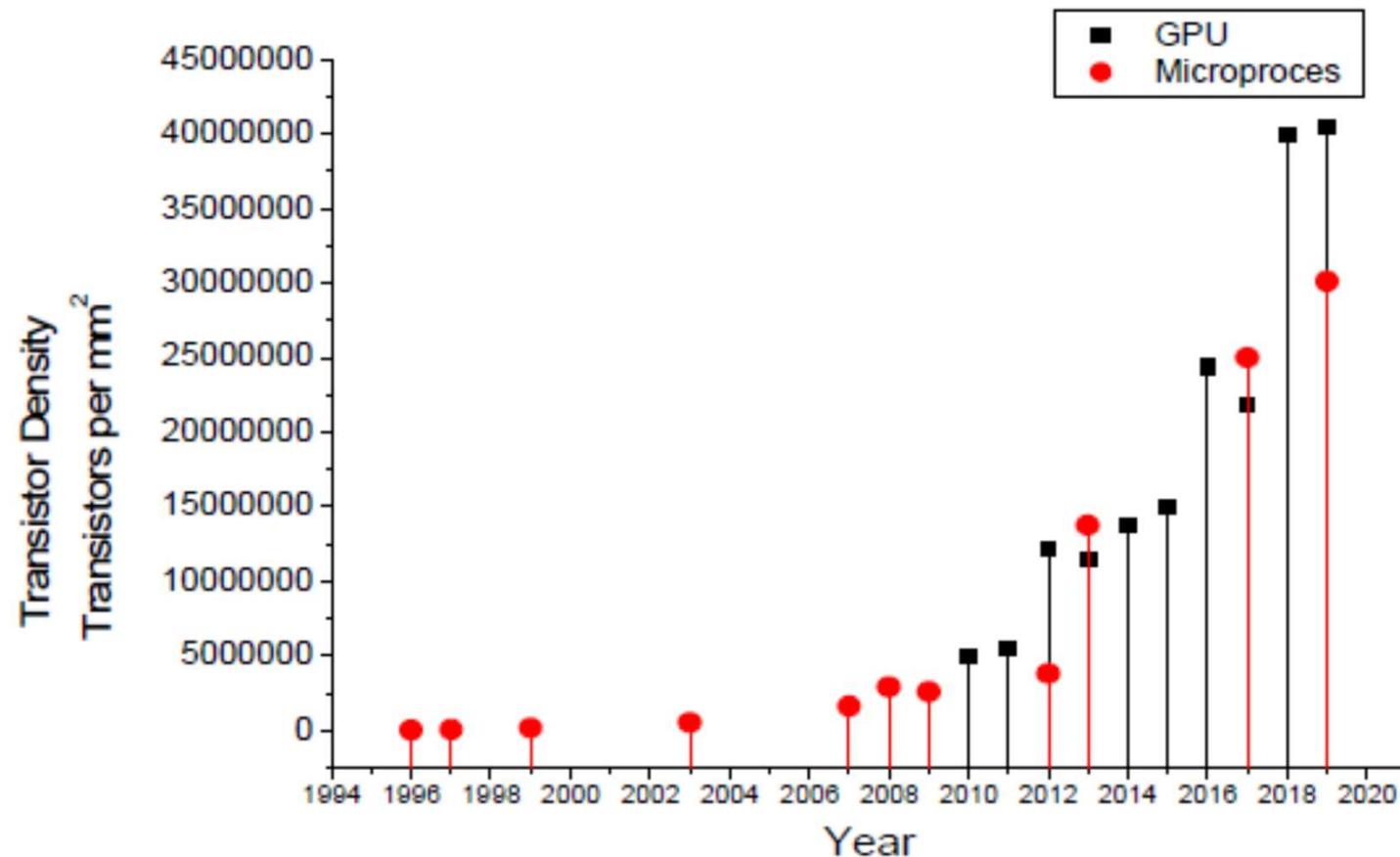
Intel Broadwell EP Xeon SoC (2016) – 7.2 billion T; 14 *nm*

IBM Deep Blue defeated Grand Master Garry Kasparov in May 1997

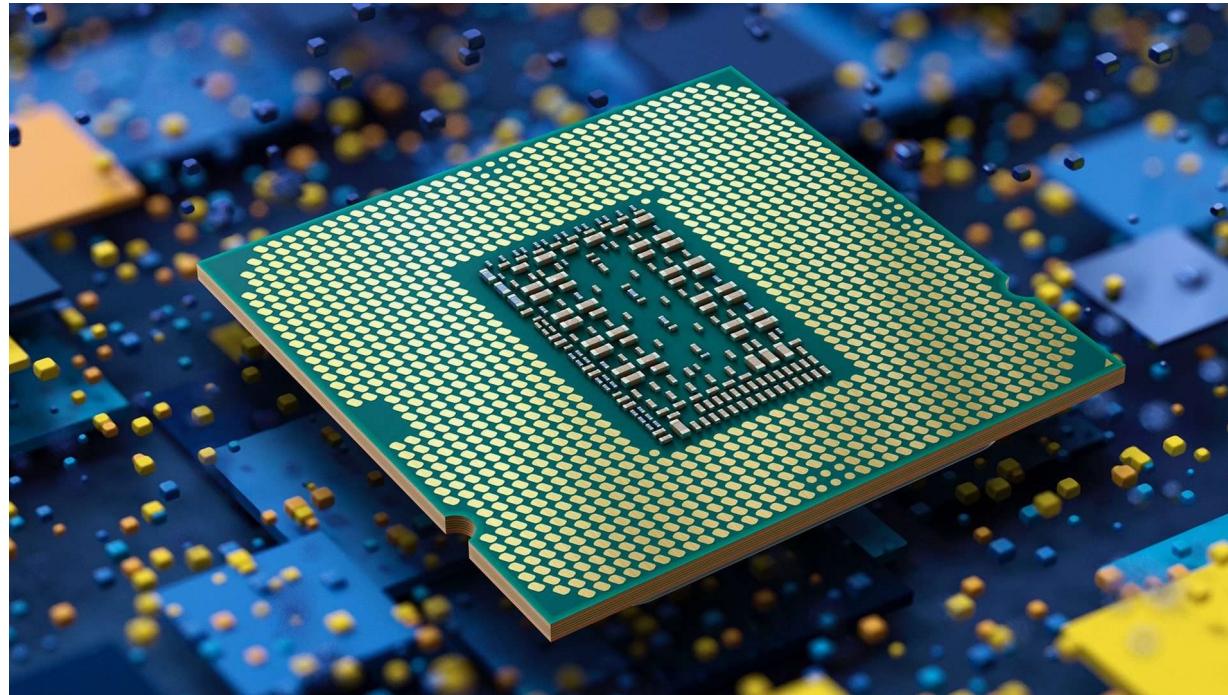


“Any sufficiently developed technology is indistinguishable from magic”
– Arthur C. Clarke (1962)

Transistor density in AMD Processors



Intel's 7nm PC Chip Will Arrive in 2023 Using TSMC's Technology



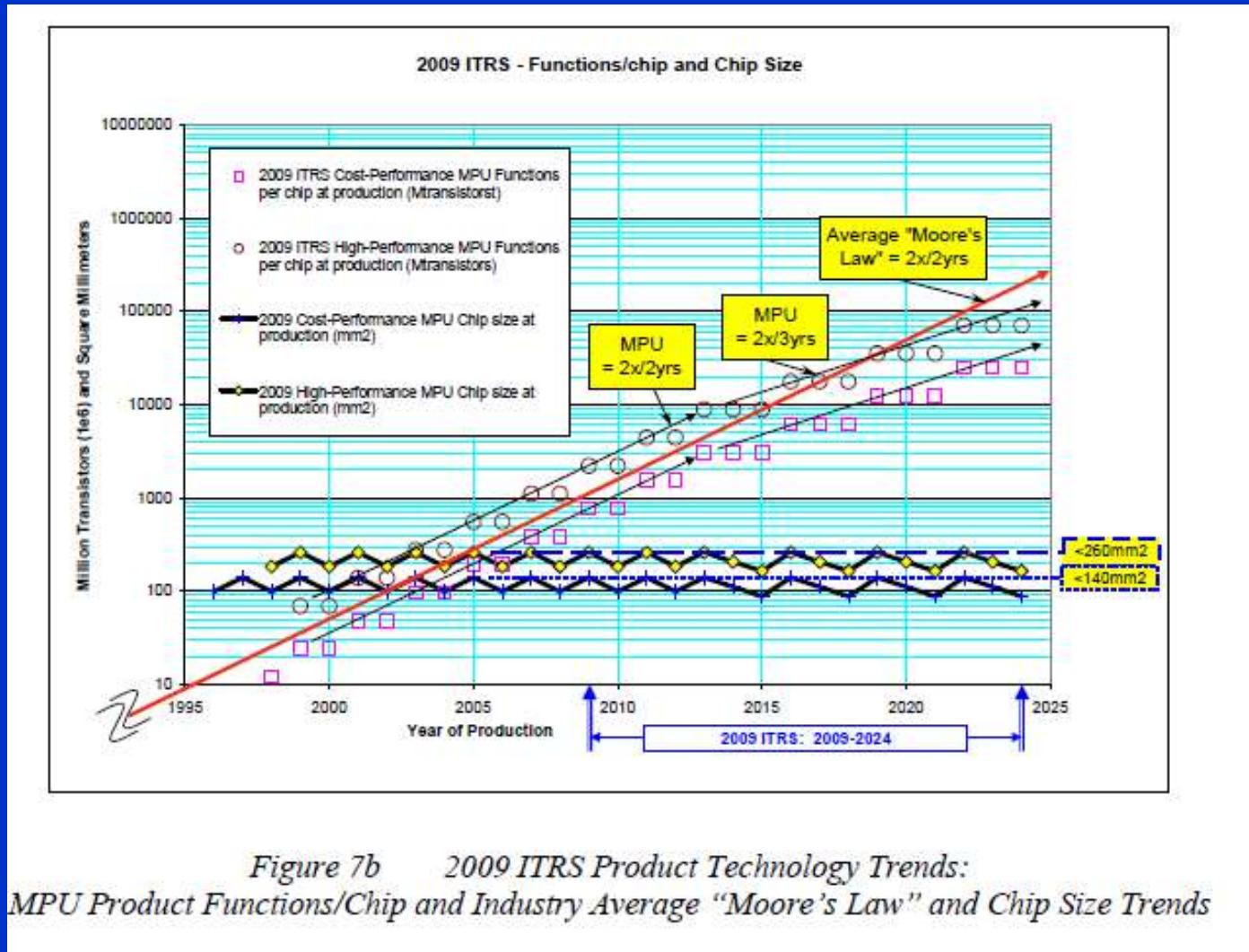
Meteor Lake (for PC) and Granite Rapids (for Data Centers)
Technology: 7 nm; Stacking *compute tiles* one over another
that include the CPU, graphics, and AI-focused processors
~ 200 million transistors per square mm of the chip!

Gordon Moore: 1965

Progress in computer technology underpinned by
Moore's Law

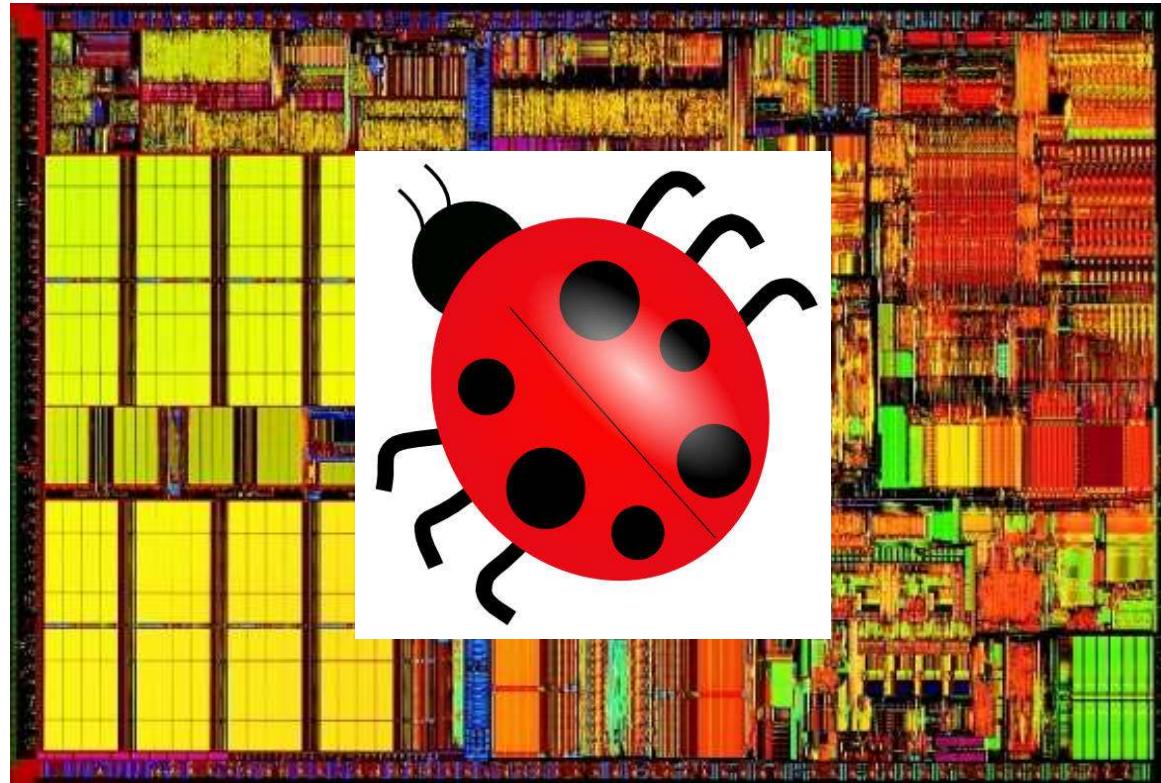
- Predicted that the number of transistors integrated on a die would grow exponentially (doubling every 12 to 18 months)
- Million transistors/chip barrier crossed in the 1980s
- Today:
Around several billion transistors per chip

Transistor Count in a Chip



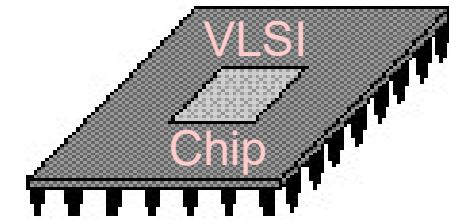
Courtesy: ITRS 2010

Today's processors encapsulate billions of transistors



Design bugs/manufacturing defects/
field malfunctioning/aging

Reliability of Hardware Design (managing defects/hazards/errors)



US Airways jet crash landed in the Hudson river on January 16, 2009

Example: Intel Pentium Bug (1994)



66 MHz Intel
Pentium

- The FDIV-bug (in floating-point division unit) was discovered in 1994 by Prof. Thomas R. Nicely at Lynchburg College, USA
- 4 to 5 million Pentium chips produced with bug
- Scientists suspected errors and posted on the Internet in September 1994
- On Nov. 22, 1994, Intel made Press release:
“Can make errors in 9th digit”

Courtesy: D. A. Patterson and J. L. Hennessy, Computer Organization and Design, Morgan Kaufmann

Pentium Conclusion: Dec. 21, 1994

\$ 500M write-off

“To owners of Pentium processor-based computers and the PC community:

We at Intel wish to sincerely apologize for our handling of the recently publicized Pentium processor flaw.

Intel will exchange the current version of the Pentium processor for an updated version, in which this floating-point divide flaw is corrected, for any owner who requests it, free of charge anytime during the life of their computer. Just call 1-800-628-8686.”

Sincerely,

Andrew S. Grove Craig R. Barrett Gordon E. Moore

Computers of the Future ...

Computers – Present and Future

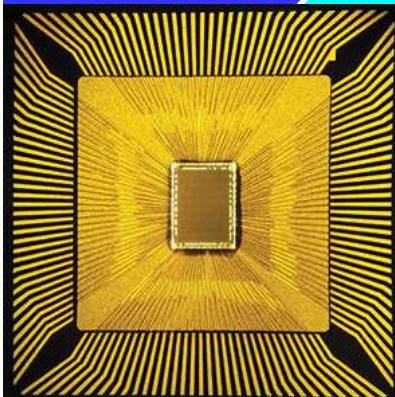
- Personal computers
- Laptops and Palmtops
- Networking, wireless, IoT
- SOC and MEMS technology
- Future generations
 - Biological computing
 - Neuromorphic computing
 - Molecular computing
 - Nanotechnology – Carbon Nano-tube (CNT) based CPU
 - Optical computing
 - Quantum computing

Neuromorphic Chips

Bridging the gap between artificial and natural computation

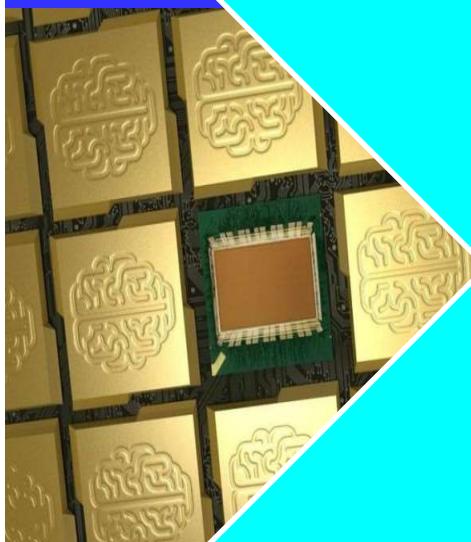


Advances in neuroscience and chip technology now enable to process data in a similar way like brain. These “neuromorphic” chips will play chess, drive cars reliably in all conditions, and empower smartphones to act as personal assistants.



Neuromorphic Chips

Bridging the gap between artificial and natural computation



IBM TrueNorth cores, which have 256 million neurons and 2 billion synapses, two orders of magnitude smaller than the biological building blocks that make up the human brain.

This IBM chip can recognize patterns of pulsing activity and map them to one of the 16 categories neuroscientists have identified and stores in memory.

SyNAPSE (Systems of Neurons and Scalable Electronics) project

Recognizes people, cyclists, cars, buses, and trucks with about 80 percent accuracy.



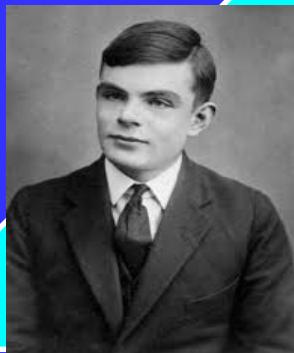
Do not separate processor & memory

Burns only 63 mW of power to process streaming video with 30 frames per sec.

Google, IBM Announce Quantum Computers (2015 - 2019)

These processors will work on sub-atomic levels based on the principles of quantum mechanics making them much faster

Technology could one day lead to intelligent machines that are capable of thinking



Alan Turing
(1912-1954)

Can machines think?

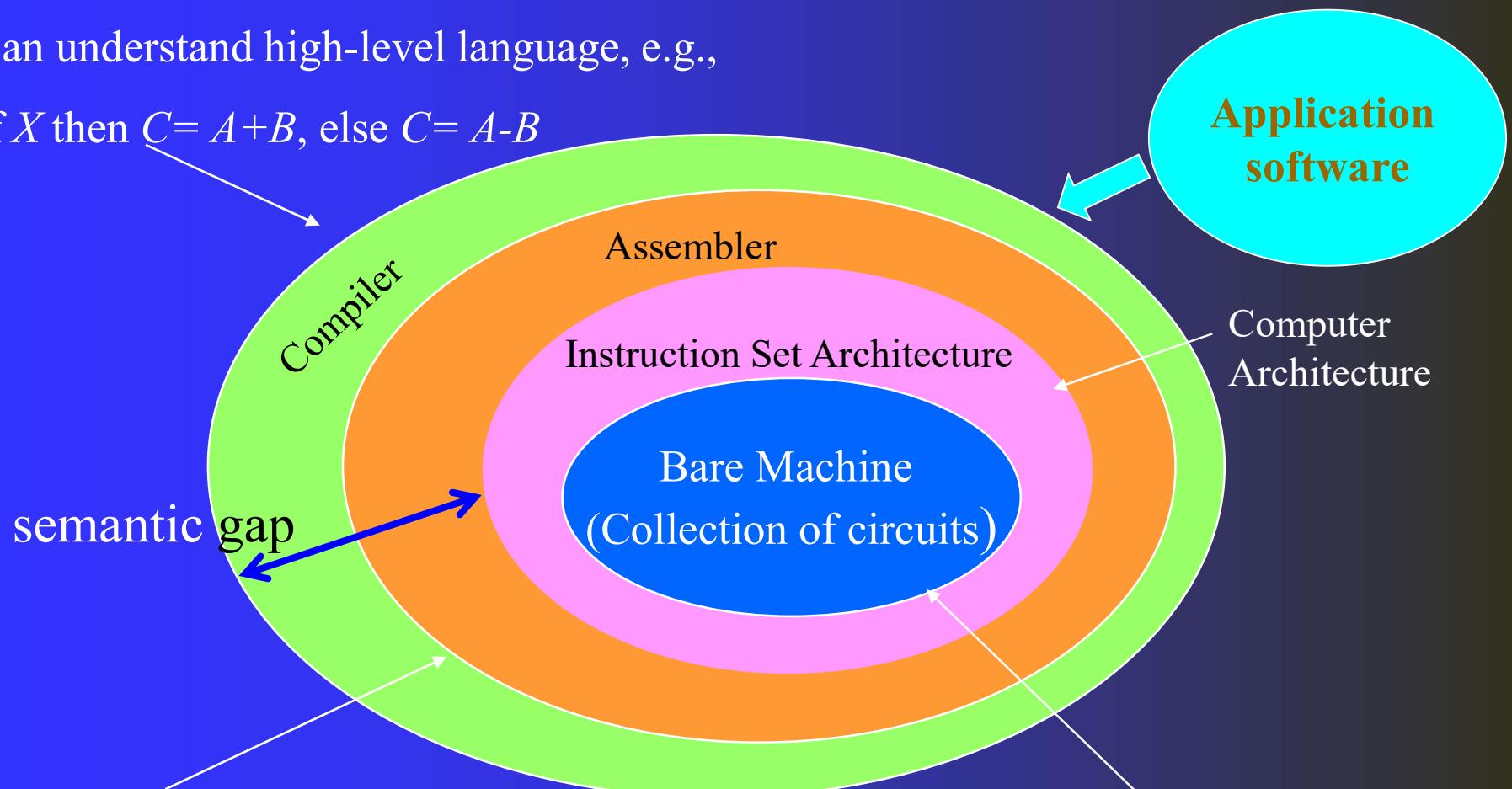


China announces a very powerful QC in 2021

Computing System Hierarchy

Can understand high-level language, e.g.,

If X then $C = A + B$, else $C = A - B$



Can understand symbolic assembly language, e.g., add C, A, B

can understand only machine language – binary strings of 0's and 1's, (0101001100..) i.e., electrical *off* and *on* signals (Computer Organization)