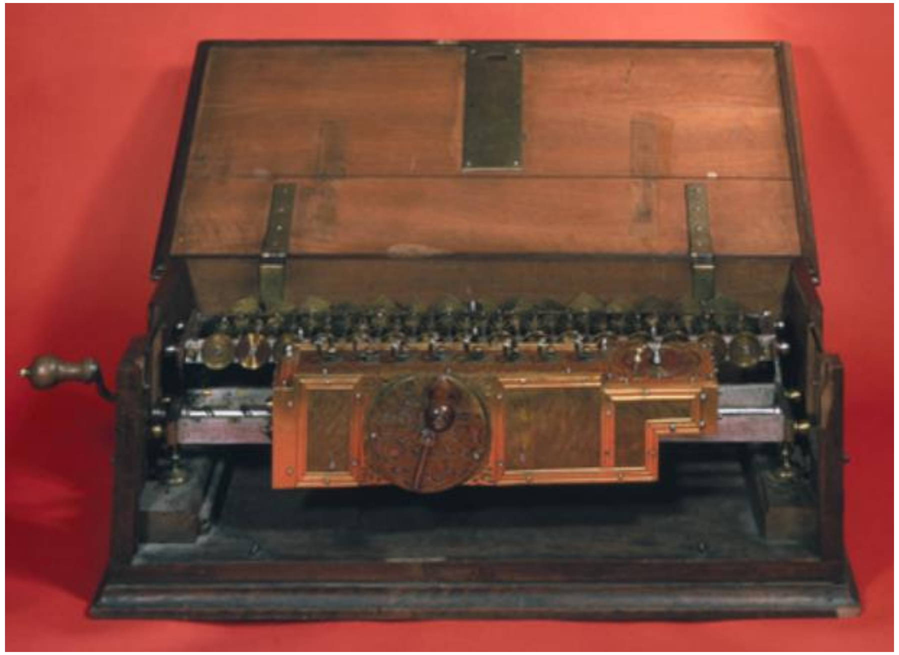
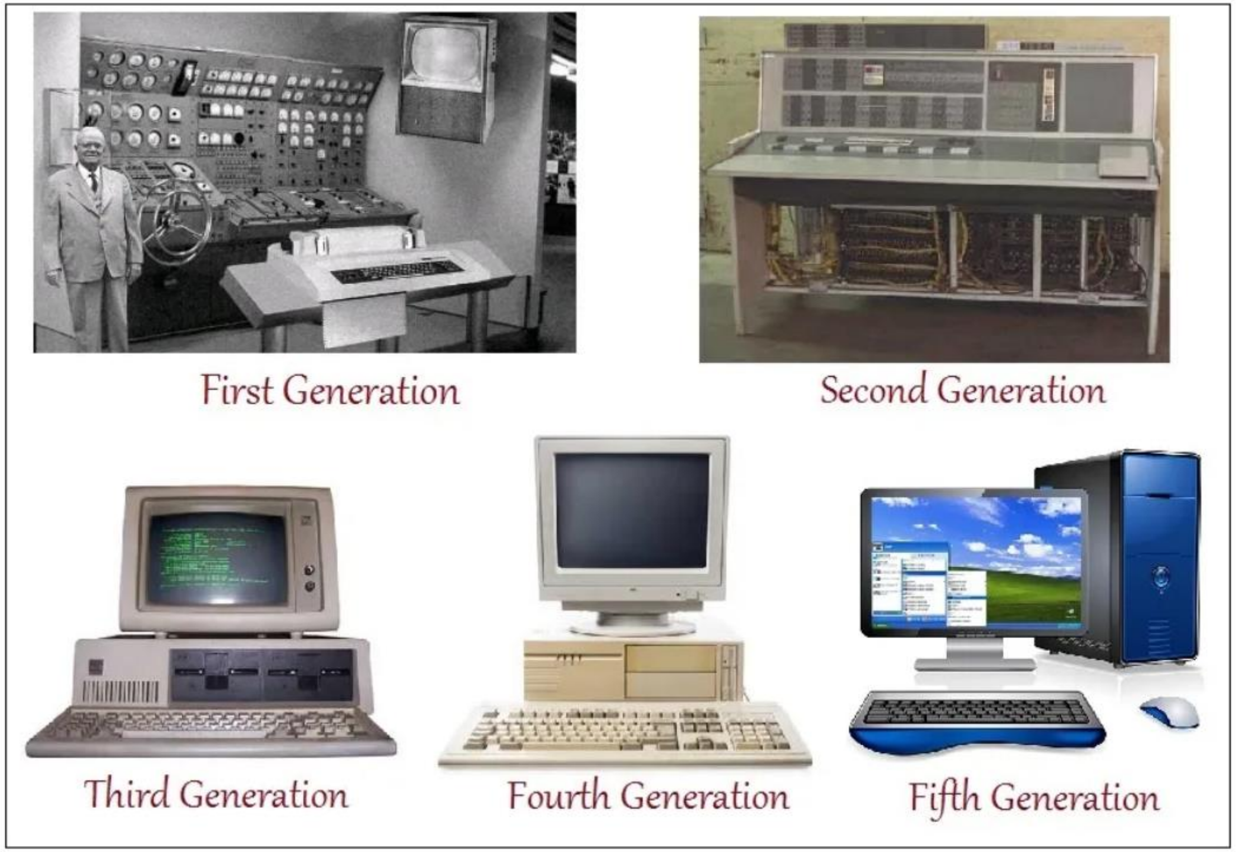
12. History and future of computer technology





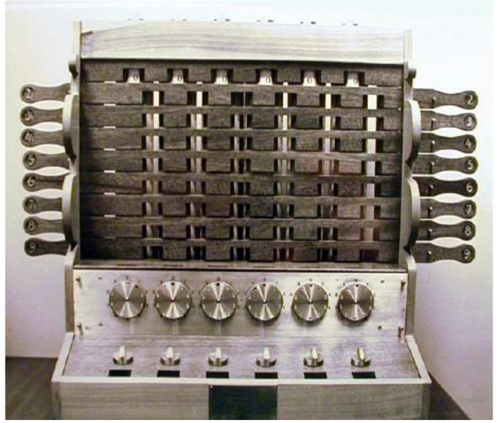
Generations of computers

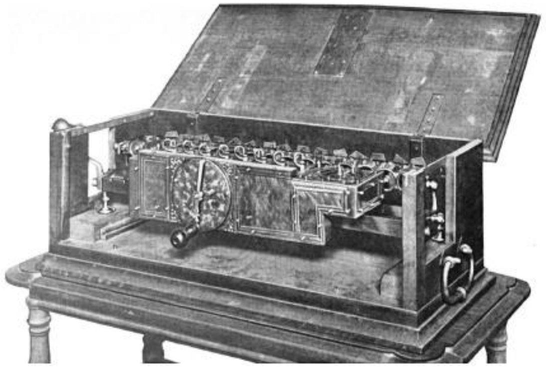
- The origin of computers can be traced to calculating devices
- Computing technology has not developed steadily; biggest advances have been made due to novel inventions of some new technology
- History of computers can be divided to generations according to these technological breakthroughs

	Time Period	Defining Technology
Generation 0	1642–1945	Mechanical devices (e.g., gears, relays)
Generation 1	1945–1954	Vacuum tubes
Generation 2	1954–1963	Transistors
Generation 3	1963–1973	Integrated circuits
Generation 4	1973–1985	Very large scale integration (VLSI)
Generation 5	1985–????	Parallel processing and networking

Mechanical calculators

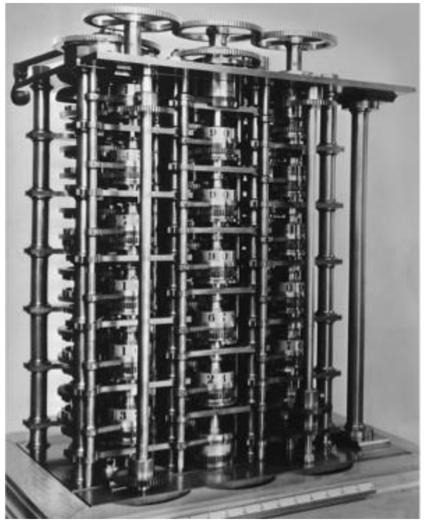
- “Gen 0” refers to mechanical devices
- The first calculator in the world was developed by Wilhelm Schickard in 1623 (“calculating clock”)
  - Napier’s bones for multiplication, gears for addition/subtraction
  - Destroyed in a fire, replica built in 1960s
- Pascal’s mechanical calculator, 1642
  - Mechanical gears, turned by hand
  - Could handle 8-digit numbers, but only addition & subtraction
- Leibnitz’s stepped reckoner, 1694
  - Stepped drum (teeth differ in length) and gears
  - All four basic arithmetic operations + square root
  - Same idea was later used in Curta Calculator (popular after WW2)



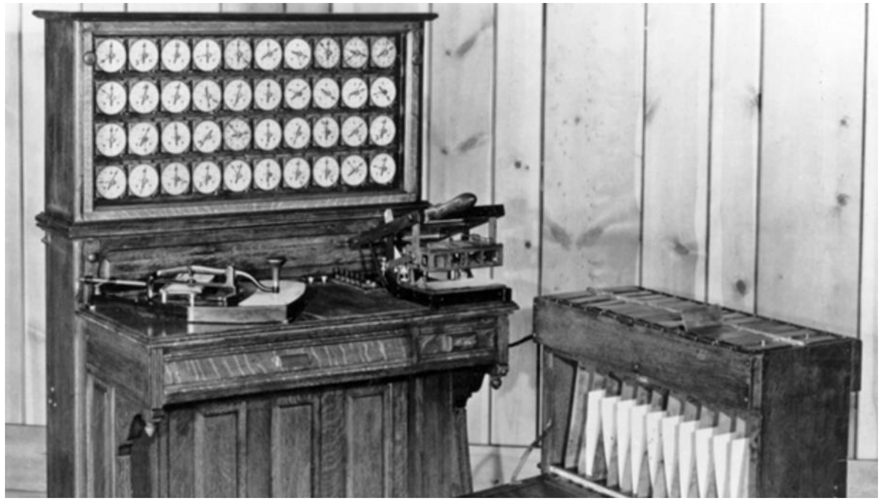


Programmable mechanical machines

- First machine ever that could be programmed was, surprisingly, not a calculator, but a weaving machine: Jacquard's loom in 1801
  - Weaving patterns were specified by cards with punched holes; hooks passed through the holes to raise specific threads, creating the desired pattern
  - Enabled mass-production of tapestries and other fabrics
- Charles Babbage's Difference Engine, 1821
  - Engine for calculating table values for logarithms and trigonometric functions
  - Only addition and subtraction; performed iterations
  - Steam-powered; not fully constructed due to 19th century limitations in manufacturing technology (only a limited prototype built)
  - "Difference Engine 2" was built by Science Museum of London in 1991 according to Babbage's original drawings; works like a charm!
- Babbage's Analytical Engine, 1837
  - Programmable (with punch cards), arithmetic operations AND comparison, square root, loops, conditional jump statements…
  - Never finished due to high ambitions; not even a prototype



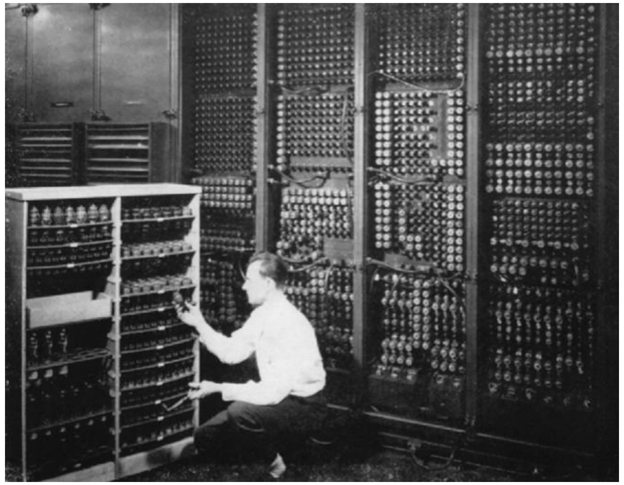
First electrical computers



- Herman Hollerith's tabulating machine, 1890
  - Used to tabulate data for the 1890 U.S. census (in 6 weeks!)
  - Information was input via punch cards
  - Metal pegs passed through holes and made electrical connection with a metal plate
  - Hollerith's company (founded in 1896) later became IBM
- First computer using electromagnetic relays in 1930s
  - Built by Konrad Zuse in Germany (destroyed during WW2)
- Harvard University's Mark I, 1944 & Mark II, 1947
  - Basic arithmetic operations & trigonometric functions
  - 72-number memory; 10 additions/second
  - Slow, but still 100 times faster than other alternatives

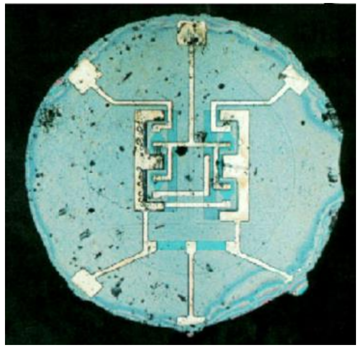
Vacuum tube computers

- All generation 0 computers had moving parts, so the computing speed was limited by inertia
- Relays started to get replaced by vacuum tubes in 1940s
  - Invented in 1906, but manufacturing was costly prior to WW2
  - No moving parts, only the electrons move
  - Enabled switching of electric signals up to 1000 times faster
- COLOSSUS, 1943
  - Built by the British government for one single purpose: decoding Nazi military communications
  - 2300 vacuum tubes; could read & interpret 5000 characters/second
- ENIAC, 1946
  - Only 20-number memory, but 5000 additions/second
  - 18 000 vacuum tubes, weight 30 tons, power consumption 140 kW



Transistors and integrated circuits

- Transistor, 1948
  - Piece of silicon, whose conductivity can be controlled by electric current
  - Smaller, cheaper, more reliable & required less power than vacuum tubes
  - Resulted in significant reduction in size & cost of computers
- Integrated circuit, 1958
  - Even though transistors could be made small, their size had to be large enough to allow soldering of wires
  - This changed when a technique for packaging transistors and their circuitry (as copper lines) on a single chip of silicon was developed
  - Another huge leap in miniaturization & cost reduction
  - Allowed mass production of IC chips



- Both these discoveries were so groundbreaking that their inventors were awarded Nobel prizes in Physics (1956 & 2000)
- These advances coupled with von Neumann architecture (stored program concept) led to modern programmable computers

Effects of miniaturization

- Miniaturization of computer components has multiple advantages
- If we're able to scale down transistor size by a factor K, it results in
  - Component size: $A \sim 1/K^2$
  - Power consumption: $P \sim 1/K^2$
  - Product of power and minimum pulse width: $PT_{min} \sim 1/K^3$
  - Power consumption per area unit: $P/_A \sim 1$
- So, smaller components consume less energy and work faster
- Decreased physical size is not a bad thing, either

"If the automobile had followed the same development cycle as the computer, a Rolls Royce would today cost $100, get one million miles to the gallon, and explode once a year, killing everyone inside."

-Robert X. Cringely (InfoWorld columnist pseudonym)

LUT University

VLSI and the personal computer revolution

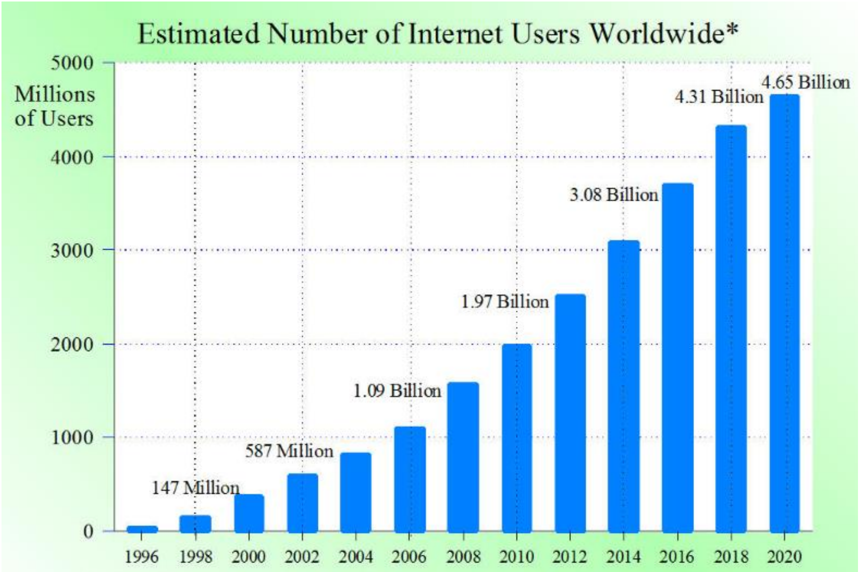
- Next big jump was the first one which didn't happen due to some new discovery on the field of CS but due to advances in manufacturing technology
  - Already the 3rd generation saw production of microprocessors
  - Now, millions of transistors could be fitted on a single IC chip
  - This was named Very Large Scale Integration (VLSI)
  - Enabled cost-effective mass production of microprocessors
  - Current transistor count: 10 200 million (Intel i7-12700H)
- Emergence of companies that started selling personal computers ("PC" is a brand name of IBM) for consumers
  - MITS Altair 8800 kit, 1975
  - Apple, 1977
  - IBM PC, 1980

Year	Intel Processor	Number of Transistors[4]
2009	Quad Core Itanium	2,000,000,000
2006	Core 2 Duo	291,000,000
2000	Pentium 4	42,000,000
1999	Pentium III	9,500,000
1997	Pentium II	7,500,000
1993	Pentium	3,100,000
1989	80486	1,200,000
1985	80386	275,000
1982	80286	134,000
1978	8088	29,000
1974	8080	6,000
1972	8008	3,500
1971	4004	2,300

Parallel processing & networking

- Latest huge leap has been made in parallel computing – first via networks
- Small networks in large businesses in 1960s
- First large-scale computer network: ARPANet, 1969
  - Originally limited to government & academia
  - Later became “the Internet” we all know
  - Emergence of software platform World Wide Web (WWW), made public in 1991, immensely increased the popularity of Internet
  - Web pages could be explored by browsers
- Physical parallelism emerged later
  - Multi-processor supercomputers & servers
  - Multi-core processors in consumer devices

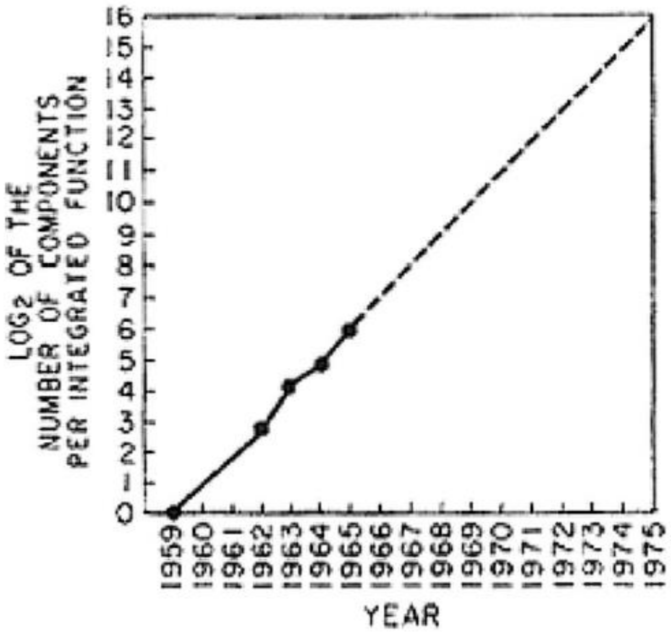
Year	Computers on the Internet[5]	Web Servers on the Internet[6]
2010	758,081,484	205,368,103
2008	570,937,778	175,480,931
2006	439,286,364	88,166,395
2004	285,139,107	52,131,889
2002	162,128,493	33,082,657
2000	93,047,785	18,169,498
1998	36,739,000	4,279,000
1996	12,881,000	300,000
1994	3,212,000	3,000
1992	992,000	50

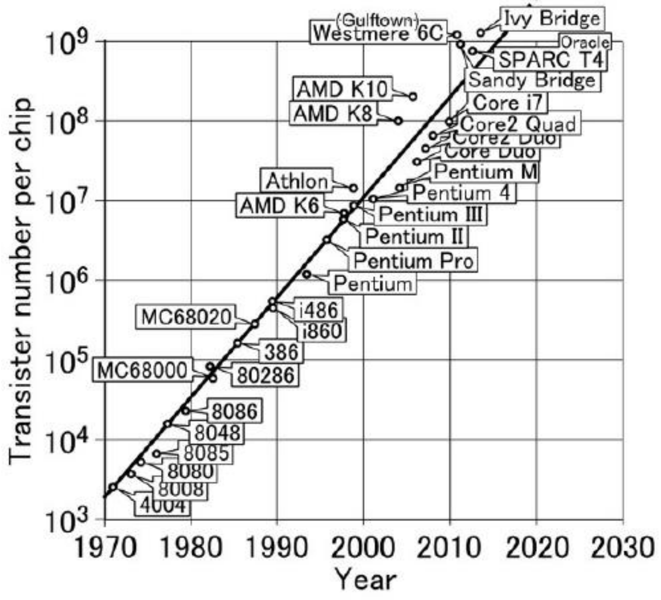


* Adapted from an illustration in Apple, C. 2020. How the Web was Won. *The Atlanta Journal Constitution* (June 28): E13. https:maaw.info/ComputerWebHistory2020.htm

Moore’s law

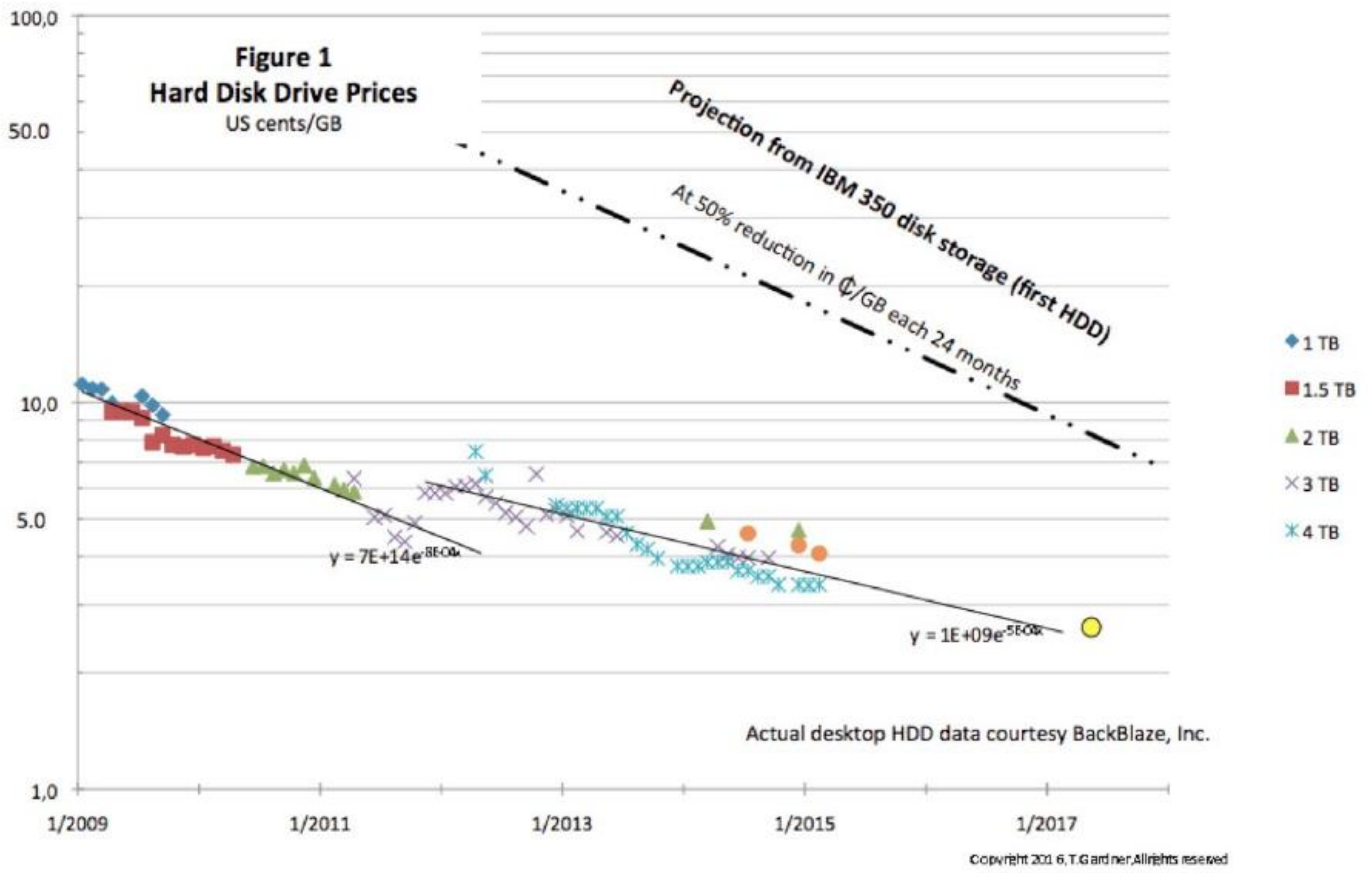
- Gordon Moore presented the claim that the number of transistors that can be (at reasonable costs) fitted on a single IC chip doubles each year in 1965
    - Later in 1975 he revised this as “doubles in 2 years”
- This means exponential growth, which can’t be sustainable
    - "No exponential is forever ... but we can delay 'forever.’”
    - Future holds several obstacles – starting from cost-effectiveness of manufacturing technology and physical limitations
- So far the “law” has held its ground surprisingly well
- Great visualization here:
    - https://www.visualcapitalist.com/visualizing-moores-law-in-action-1971-2019/





Advances in storage capacity

- Another feature of computers that has undergone major advances is storage capacity
- IBM 350 disk storage was introduced in 1956; after that, a prediction was made that unit price of storage would halve each 2 years
- The current situation is way ahead of this (although the trend is slowing down)



Obstacles for continuation of miniaturization

- Physical limitations:
  - Kinetic theory of thermodynamics
  - Heisenberg's uncertainty principle
  - Irradiance
  - Tunneling
  - Speed of light
- Limitations of manufacturing technology:
  - Optical lithography
  - Materials
- Economical limitations:
  - Unit price of a microchip (μ¢ per feature)
  - Price of a microchip factory (5 to 20 billion dollars)

$$E_{\mathrm{rw}} \rightarrow kT$$

$$\Delta x \Delta p \geq \hbar \quad \& \quad \Delta E_{\mathrm{rw}} \Delta t \geq h/4\pi$$

$$E_{\mathrm{rw}} f n \leq 100\ \mathrm{W/cm^2}$$

$$\Theta \propto |\Psi|^2 > 0$$

$$v_{\mathrm{d}} = \mu_e E < c$$

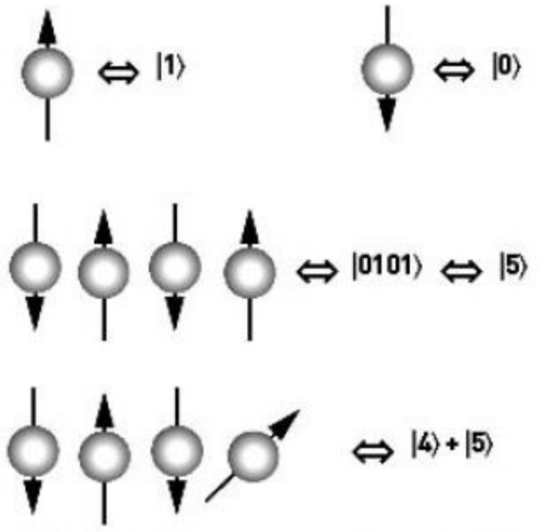
$$R = k_1 \lambda / NA \quad \& \quad DOF = k_2 \lambda / NA^2$$

$$\mathrm{Si}, \mathrm{SiO_2}, \mathrm{Ge}, \mathrm{GaAs}$$

Possible future computers

- Progress of computer performance has been mind-blowingly quick, but for this pace to continue, new groundbreaking advances would be needed soon
- One possibility would be to find a completely new way to implement a computer
- Some possiblities could include:
  - Nanocomputer (made from nanotransistors - using carbon nanotubes; would allow miniaturization to continue longer)
  - DNA computing (biocomputer based on DNA calculation, demonstrated by Len Adleman already in 1994; slow, but can process almost an infinite amount of actions in parallel fashion)
  - Optics: optical computer (electricity is replaced by light – so, photons instead of electrons; a company named Xanadu is working on a photonics-based quantum computer)
  - Quantum computer (instead of bits there are qubits)
  - Something yet to be invented?

Quantum computer



qubits can be in a superposition of all the classically allowed states

- Qubits are quantum bits – a superposition of two quantum states
  - A qubit can include 1, 0 or both at the same time
  - A series of qubits can denote a superposition of multiple binary numbers at the same time
- In a quantum computer, many numbers are in superposition state → computer performs the operations for all these in parallel fashion
- The state of a qubit has an effect on all other qubits without delay - no matter how far away from each other they are
- Quantum computers have been built and they are in use today
  - Current record: 127 qubits (Intel Eagle) – Intel plans to hit 4 digits in 2023
- Some problems are still to be solved, though:
  - Usage temperature must be close to absolute zero in order to prevent overheating
  - Superpositions collapse at the time of measurement, so quantum computers can only solve problems that can be solved by asking just one question

Current (and future?) trends of computer technology

- Mobile computers and wearables
  - Mobile services, geolocation
- Cloud services for data storage & computing
  - User doesn’t have to be next to a supercomputer physically
  - Web-based programs that run on browser (no need to install anything)
- Artificial intelligence and computational methods
  - Analyzing and visualization, data mining
  - Humane user interfaces, robotics
- All-encompassing computer technology
  - Computers take such forms that people don’t think of them as computers anymore
- Adaptation to computer technology
  - Almost everything can be done in remote fashion

Summary

- Need for computers emerged from difficulties with calculation, which harmed the computability of some problems
- The base requirement for computability of a problem is that there exists some kind of an algorithm that can solve it
  - …and the practical requirement is that is should be done in reasonable time
- If the complexity of our problem is high, we have two options:
  - Develop a better algorithm with lesser complexity
  - Improve the computation power of the computer used for solving the problem
- Computer science as a discipline actively seeks advances in both these areas
  - Computer technology mainly works on the latter
- Stripped to its essentials, computer technology is just implementation of logic gates and circuits as effectively as possible
  - Current design relies on very large-scale integrated circuits and their parallel processing

Thank you for listening!