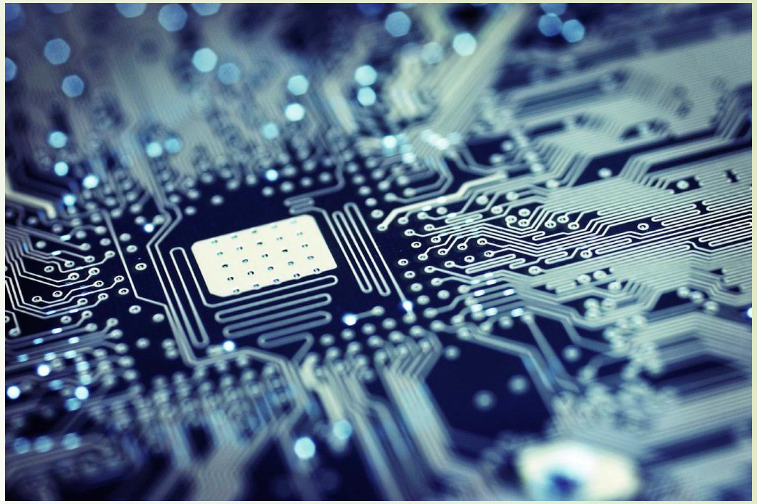

Development of Technology

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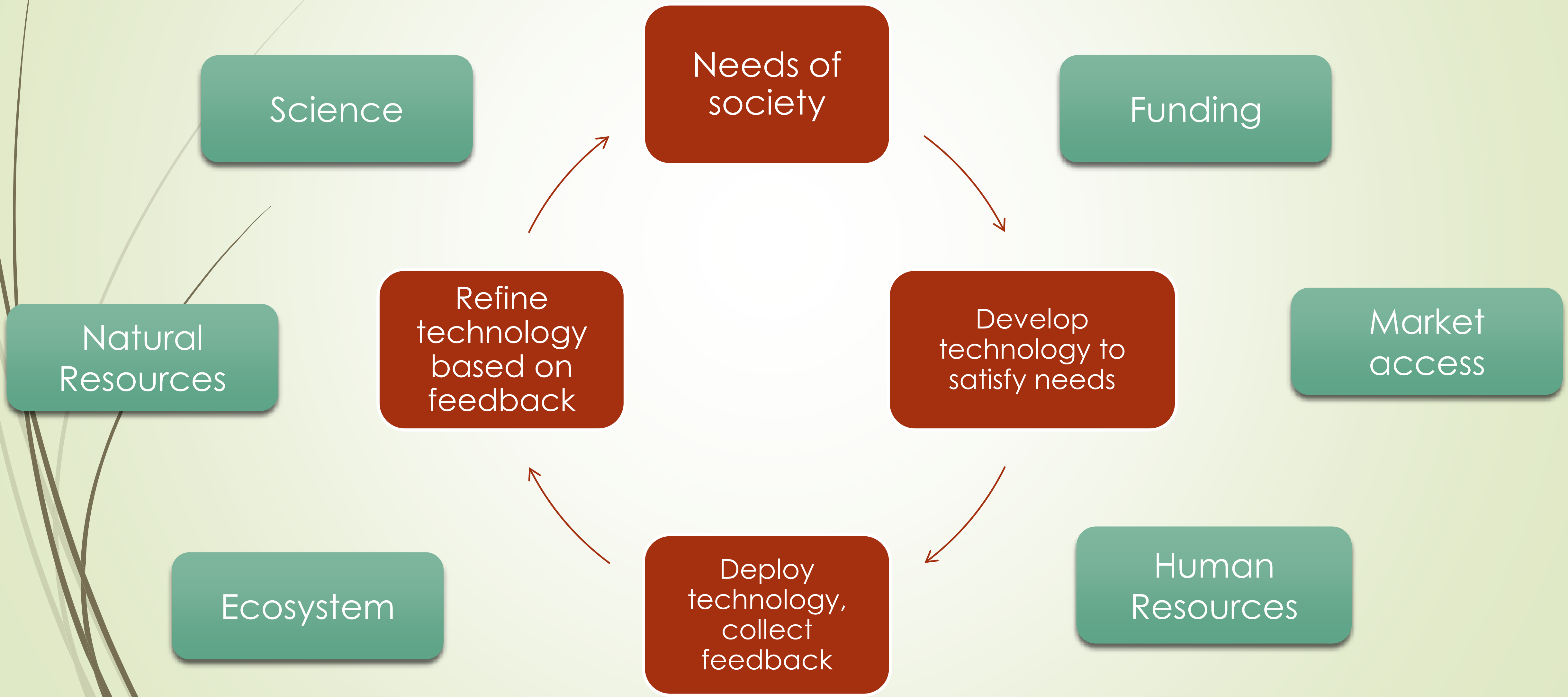
How does technology develop?

- Science develops from curiosity and observations about nature
- Technology develops to satisfy needs of society
- Identify needs → develop technology → deploy → get feedback → iterate on technology
- What else does technology development depend on?
  - Suitable backing science
  - Funding
  - Market access
  - Trained human resources
  - Ecosystem for technology development
  - Natural resources

How does technology develop?

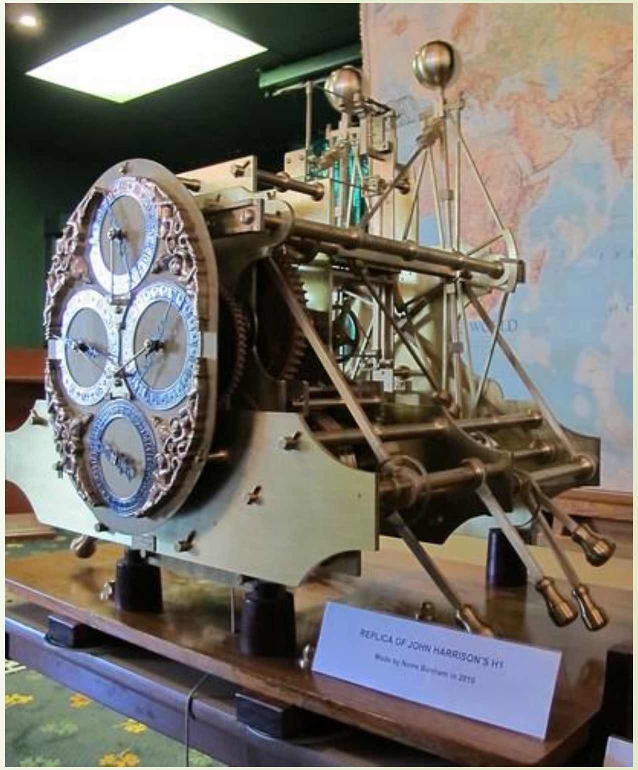


Translation of science to technology

- Developing technology is faster when suitable science already exists
- But science leads to technology only when need for it is felt
  - Newtonian mechanics used to send man to moon, but only when need arose (due to Cold War) and other suitable conditions in place
- Technology development involves not just using science but also doing “engineering” to translate science to useful products
  - Practical modifications for real-life use, larger scale and scope than in lab
  - Example: Edison tried many materials for incandescent light bulb filaments to see which lasted longest and was most convenient to use
  - Example: Initial strain of penicillin discovered by Alexander Fleming didn’t produce enough dosage to treat humans, others needed to search for a better strain for higher output of antibiotic

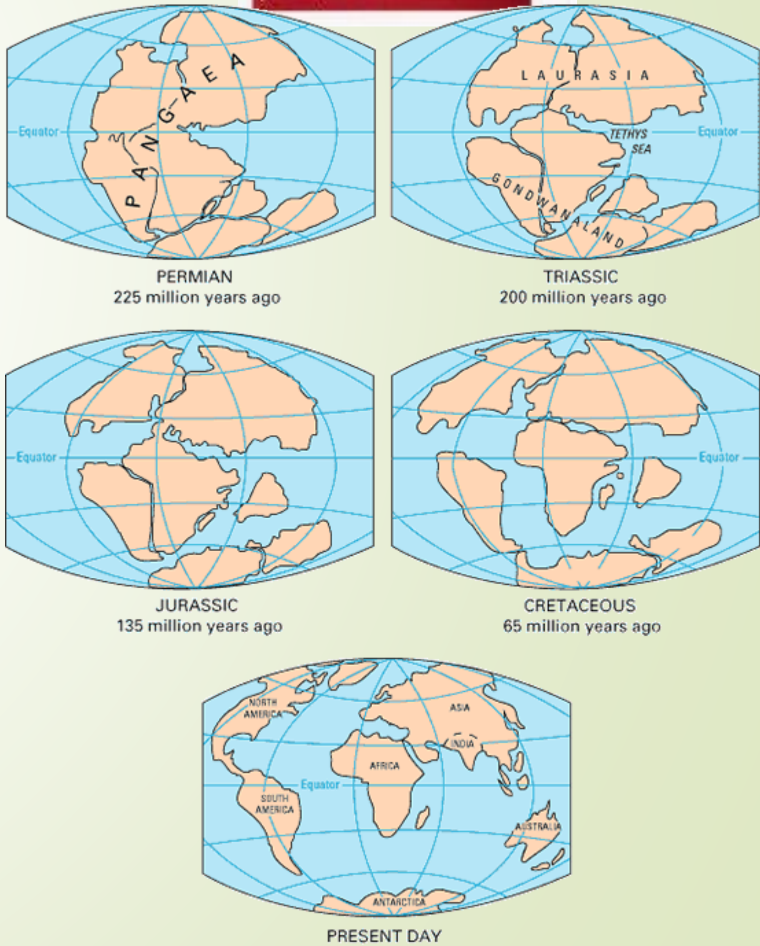
Technology to meet needs of society

- From ancient times, technology developed to solve day-to-day problems in society
  - Not always necessary for the science to develop first
- Technology developed for societal needs later helps progress of science, e.g., telescope
  - Galileo's telescope earned money initially from ability to see invading armies, or see arriving cargo ships and sell goods before prices fell
- Needs of imperialism led to many technological advances in navigation, mapping, surveying
  - Royal Society announced a prize for accurate longitude measurement at sea
  - Harrison's clock with high precision was developed to keep accurate time and hence find longitude



Technology and War

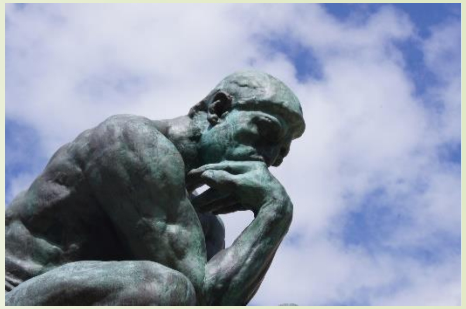
- War is a time of great need, often leads to rapid technological advances
  - Weapons, medicines, tech to spy on enemy, …
- War-time advances later put to civilian use
- World War 2 led to many advances: penicillin, radar, modern computing, nuclear energy, …
  - Search for higher output strains of penicillin during WW2 by UK and USA. Found in a moldy cantaloupe in USA
  - Continental drift theory proved by measuring magnetism of rocks (aligned with older continent shape) and mapping sea surface, using tech developed for military purposes in WW2



Manufactured demand

- What are the needs of society which technology should address?
  - Food, shelter, health, happiness, money, comfort, …
- Some needs are not “real” but artificial or “manufactured”
  - How? Advertising, marketing, celebrities and other role models, or culture of the society can make certain technology sound cool
- Technologies are developed for manufactured needs, which get used enough that the need becomes widespread with time
  - Popular adage: If you build it, they will come
  - Can we differentiate real and artificial needs beyond a point?
- Examples: bottled water? Designer handbags and other luxury items? Smart phones and social media?
- Do we shun manufactured demand? Or hope that these technologies will eventually solve real problems later?

What are our needs today?



- What are needs of society today? What tech are we developing as a result?
  - Datacenters for social media? AI/ML to improve user engagement?
  - Faster cellular networks to stream movies on phones?
- How to prioritize needs? Needs of the majority of the society? Sustainable development goals? "First world" problems? Most profitable?
  - Self-driving cars or better sewage treatment plants?
  - Computer games or software for better e-governance?
- Is technology really solving the problems of society it is claiming to solve? Or is technology creating (and trying to solve) its own problems?
  - Is solar power really good for environment? What about the rare earth elements needed to produce the panels/batteries, and the pollution due to mining these?
  - Do carbon credits/offsets/other "net zero" hacks really reduce CO2 emissions?

Funding

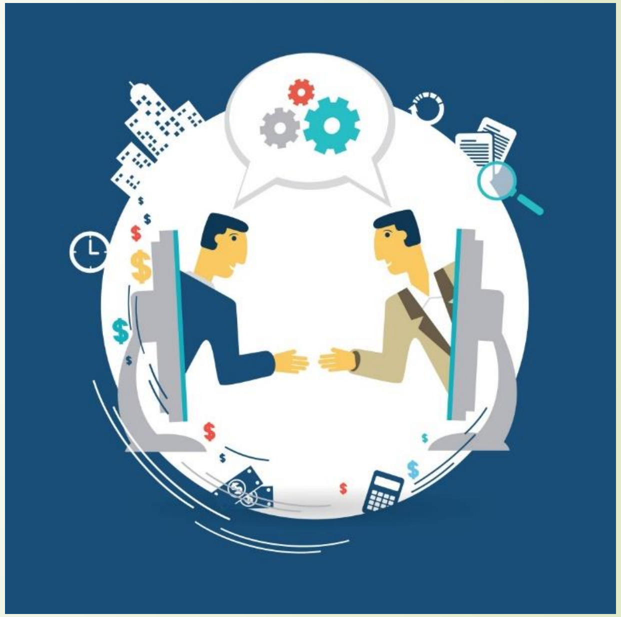
- Technology development needs funding in initial stages until product is fully mature and commercially viable
  - Well-developed financial markets to raise seed capital
  - Support from wealthy individuals who can become early “angel” investors
  - Funding from government, military, industry
- Other monetary incentives to accelerate tech development
  - Example: Subsidies and other incentives for technology that is required for society but not immediately profitable (renewable energy, large manufacturing)
- Can we use funding and monetary incentives to influence the kind of tech that gets developed and used by society?
  - Incentivize sustainable tech, discourage harmful tech?

Market access

- In addition to funding, technology development depends on revenue stream from commercialization in the market
- Factors that impact market access
  - Transport infrastructure and other logistics to connect to local/global markets
  - Taxes, tariffs, restrictions on trade within/outside country
  - Import substitution (may spur domestic technology development or keep domestic technology backwards due to lack of competition)
  - Free markets and globalization (may hurt tech development in poorer nations)
- Patents (limited monopoly in market) disallow others to copy an invention, guarantee revenue stream
  - Can also lead to patent wars and stifle innovation

Human resources and ecosystem

- Human resources: people who know background science and can apply it to develop technology for real-life use
  - Not just science but engineering mindset required
  - Ability to identify and exploit a need in the market
  - Skills to build and sell practical commercial products
- Ecosystem to encourage innovation
  - Industry R&D labs, universities doing applied research
  - Incentives for technology startups and entrepreneurs
- Political stability, rule of law, ease of doing business



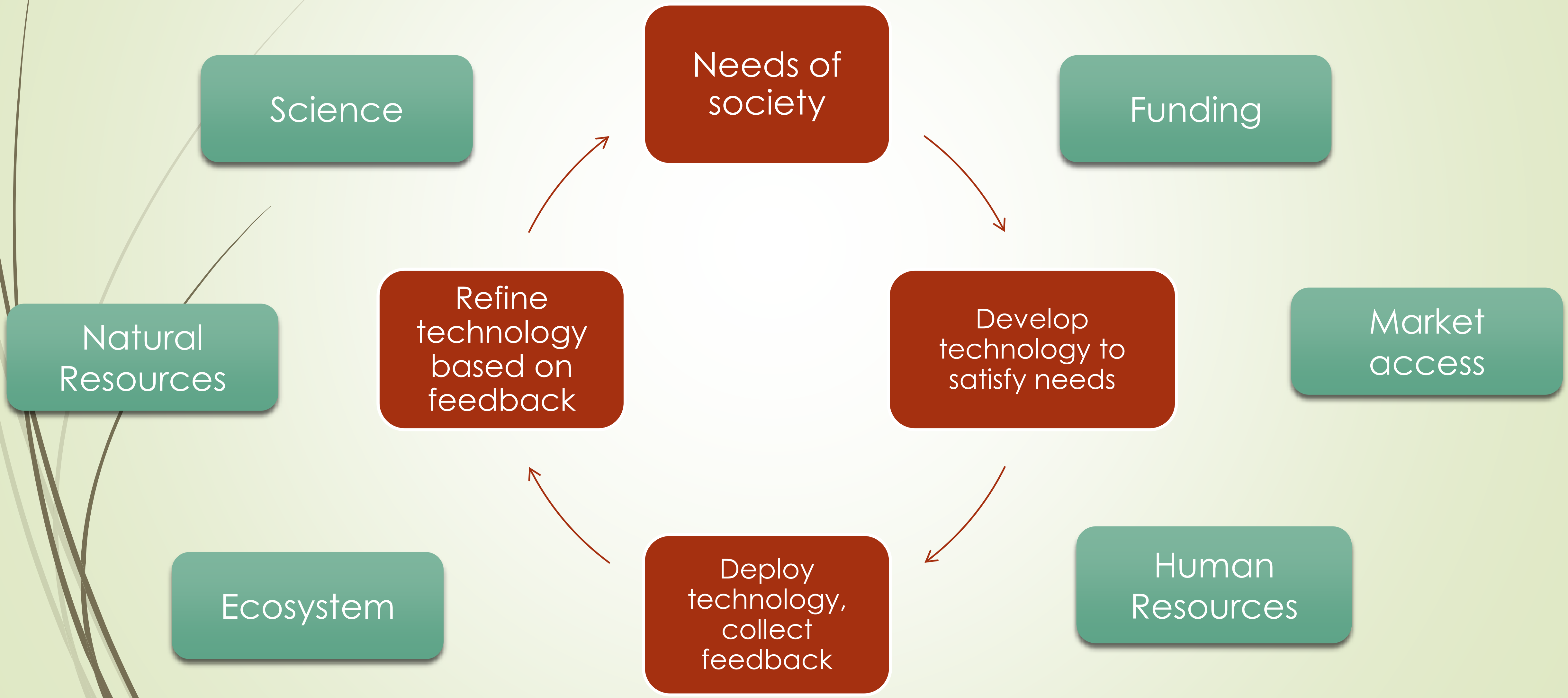
Technology and vested interests

- Lobbying by vested interests in the ecosystem can block disruptive technology development if it hurts the revenues of existing players in the market
- Example: the famous battle between Edison, proponent of Direct Current (DC) and Tesla / Westinghouse, proponents of Alternating Current (AC)
  - Each held patents for their technology, and wished to see it prevail
  - Edison spread misinformation that AC was dangerous and lobbied extensively against it, even though AC had lower transmission losses and hence more efficient
- Example: Earlier efforts to develop an electric car faced intense lobbying pressures from oil industry, automobile manufacturers and competing technologies like hydrogen vehicles
  - Increased awareness of climate change has helped overcome these factors, and we now see greater adoption of electric vehicles

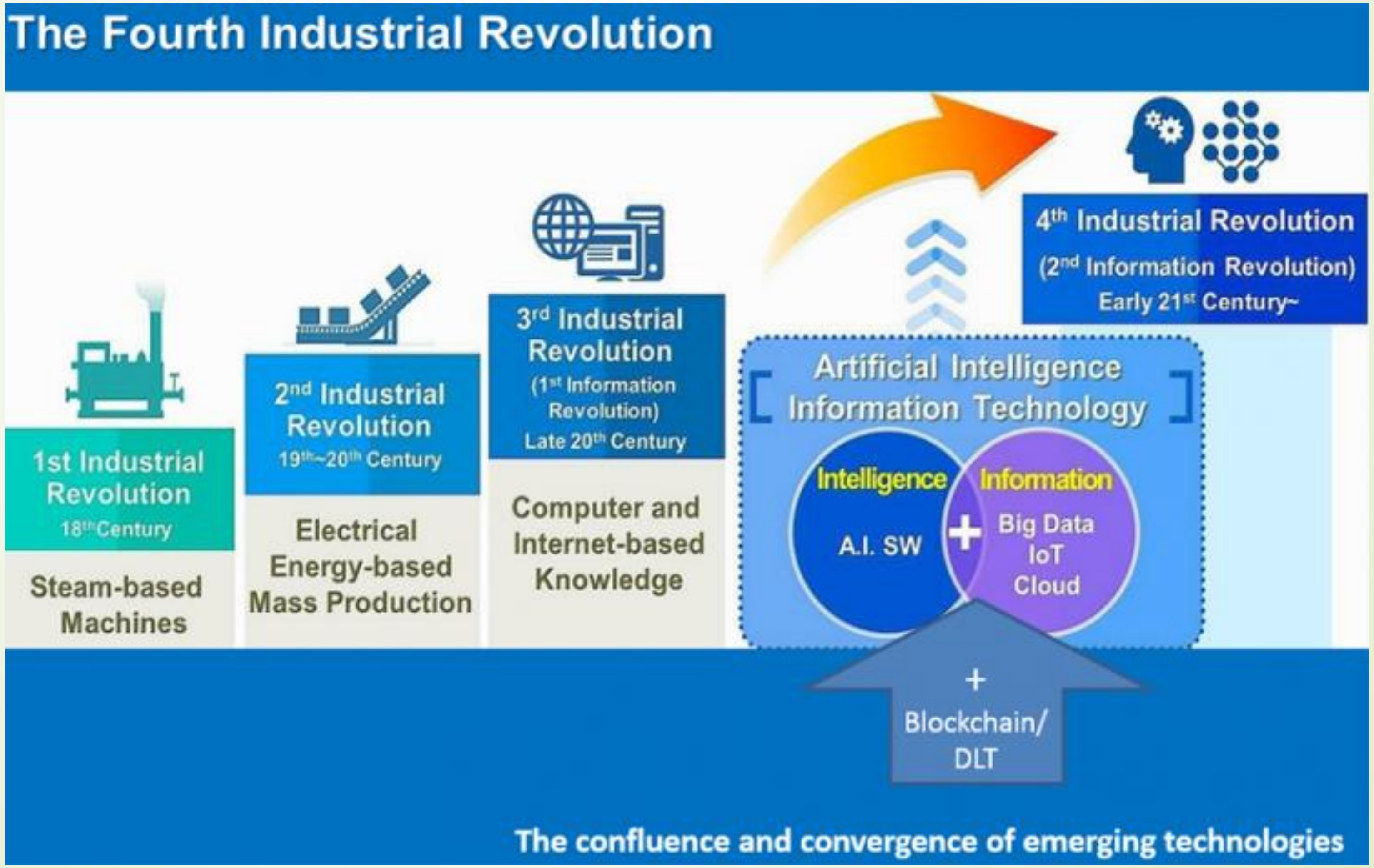
Natural resources

- Natural resources crucial for development of modern technologies or accessories
  - Water, fossil fuels, mineral ores, rare earth elements
  - Especially resources needed for energy production (coal, crude oil, natural gas)
- Can the earth sustain this rate of technological progress for much longer? Can a technologically advanced society be in harmony with nature?
  - What about global warming, ecological collapse?
- Are we doing a cost-benefit analysis when developing technologies?
  - Is the price of product capturing hidden costs, including environmental damage?
  - Are the costs incurred (human, financial, environmental) commensurate with benefits?
  - Should we exercise restraint in developing some resource-intensive technologies?

How does technology develop?



Case study: Industrial revolution

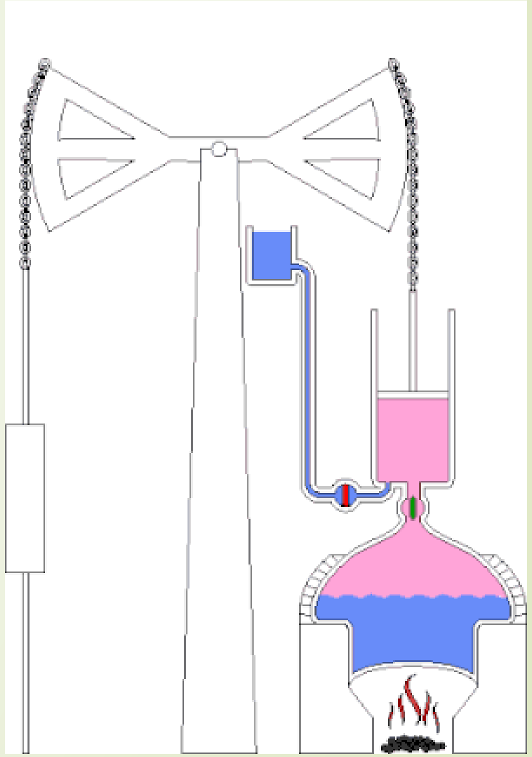


First wave of industrialization Steam engine

- Story of modern industrial age starts with steam engine
- Steam engine: converts heat energy of steam to mechanical energy
  - Steam generated by boiling water pushes piston up and down. Piston connects to crankshaft for rotary motion.
- Steam turbine converts heat directly to rotary motion
- Modern vehicles: internal combustion engines, convert chemical energy of fuel to mechanical energy
  - Combustion gases generated internally
- Before steam engine, source of power was only animal, human or water power
  - Steam power behind productivity increase

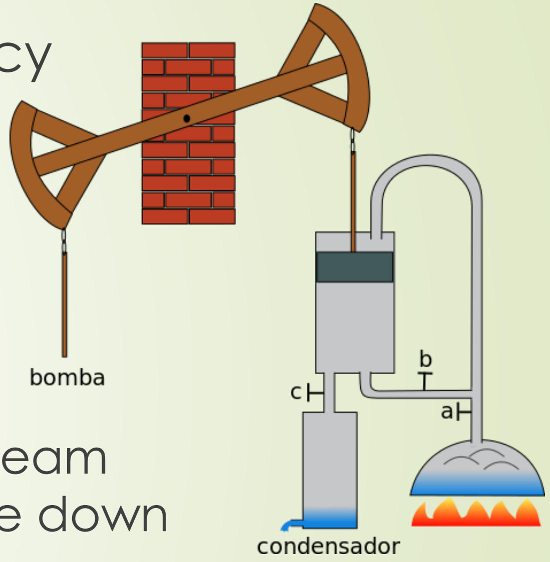
Newcomen engine (18th century)

- Newcomen engine was one of the first practical steam engines
  - Boiler boils water to generate steam
  - Steam is drawn into a cylinder, pushes piston up
  - Later, cold water sprayed, steam condenses, vacuum and atmospheric pressure pulls piston down
- Concepts like vacuum, air pressure already well known
- Need for Newcomen's invention: pump water out of coal mines
- Newcomen was a metal merchant, had practical skills to produce suitable equipment, built upon previous engine designs



Watt steam engine (18th century)

- James Watt improved Newcomen engine to improve its efficiency significantly
  - Realized same cylinder heating and cooling is inefficient
  - Introduced a separate condenser which is always kept cool
  - Steam jacket around main cylinder to keep it warm
  - Steam enters main cylinder, pushes piston up, valve opens to stop steam and draw steam out into condenser, vacuum causes piston to come down
  - Double acting engine, steam from both sides
- Watt worked as instrument maker at University
  - Perfect mix of science and craftsmanship
  - Careful engineering: how to seal piston, how to reduce leakage, how much steam and water (experiments to understand latent heat of steam)

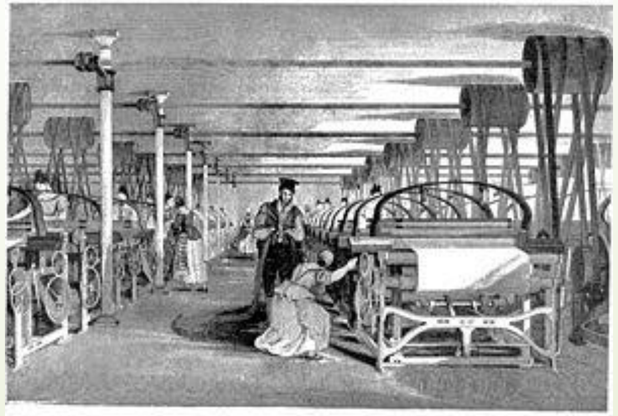


Commercialization of Watt engine

- Watt by himself was not successful in commercializing his invention
  - Filed a patent but no steady revenue stream
- Partnered with Boulton who took over his patent, provided money to develop many machines with precise metal work
  - Another partner Murdoch joined later
- Initially sold to coal mine operators to draw water from coal mines (charged based on savings as compared to Newcomen engine)
- Later, converted up-and-down action of piston to rotational motion, used for spinning, weaving, grinding, many more applications
- Watt and Boulton’s firm became great commercial success, nurtured many engineers, was an important milestone in Industrial revolution

Industrial revolution technologies 19th century

- Steam power led to many technological innovations which reinforced each other
  - Steam engine improved coal mining (by pumping water away), coal in turn helped in generating more steam power
  - Steam power led to mechanized cotton spinning, power looms, increased productivity in textile production and other factories
  - Steam powered locomotion: steam engine used in steam boats, trains. Allowed for better transport of raw materials and produced goods



Industrial revolution technologies 19th century

- More mutually reinforcing technologies: iron, steel, chemicals, cement
  - Steam power increased production of iron, steel due to improved efficiency of furnaces
  - Iron and steel further helped produce railroad tracks, more engines, machine tools for factories
  - Large scale chemical production for making iron and steel, dyes and bleach for textiles, cement for construction of expanding cities

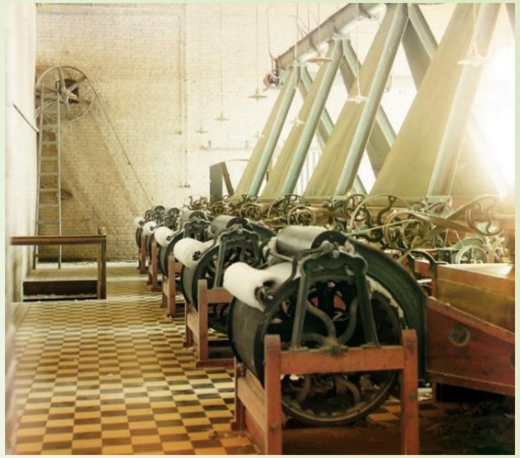
Industrial Revolution
Why here and why now?

- Why did the industrial revolution start primarily in England / Europe 18th-19th century?
  - The science behind steam engines was known for some time
  - Why didn't anyone else invent these technologies, in another place or time?
- Many social, political, economic factors led to the occurrence of the industrial revolution
- Technology is not just science applied to real world problems
  - Society plays a huge role in shaping technology development

Calico acts

- Pre-industrial era: famous cotton textiles "calico" from India (Bengal)
  - Climate more suited to produce cotton (not so easy in Europe)
  - Cotton from (slave) plantations in Americas after New World discovery, but small scale cotton manufacturing in Europe could not compete with cheaper labor costs in India
- Age of discovery: motivated by trade in cotton textiles, spices
- 1700: British govt. passes Calico acts, bans import of cotton from India
  - Domestic textile industry gets support to develop
  - Hits Indian textile industry which was in proto-industrialization stage in Mughal Bengal

Steam powered textile mills



- Many innovations for better spinning, weaving of cotton textiles
- Steam power further boosted productivity of textile mills in England
- Steam powered transport to easily reach markets everywhere
- Steam powered textile mills threatened livelihood of skilled artisans
  - New mills needed less skill, lower wage labor
  - Bad working conditions in factories, increased poverty initially
- Luddites under weaver Ludd destroyed early factories
  - Term used today to anyone opposed to new technologies
- Eventually, led to more productivity and wages for workers

Imperialism and industrial revolution

- Good supply of raw materials (cotton) via plantations using slave labor in Americas
- Capital for investing in industries from colonies
- Captive markets in India and other colonies to sell finished goods (cotton textiles)
- Wealth from trade in factory-produced goods eventually trickled down and improved conditions of factory workers in Europe
- Deindustrialization in India
  - Handmade textiles could not compete with cheaper and finer machine made textiles
  - Political instability and later colonization ensured fair trade practices not put in place

Usage of coal

- Usage of coal significantly increased in Britain towards end of Middle ages, requiring water pumps at coal mines to pump surface/ground water
  - Motivation and initial customers of Newcomen and Watt steam engines
- Why increased coal usage in Britain?
  - Rising population, fuel needed for heating in winters
  - Use of wood for fuel caused widespread deforestation
  - Britain had one of highest known coal reserves
  - Wood replaced by coal (places with more forests did not explore coal)

Private property

- Middle ages: most peasants did subsistence farming on common lands belonging to feudal lord or Church
  - E.g., peasants grow food in common land, pay a share to lord of the manor
- Black death (plague) resulted in shortage of labor, increased wages, so labor-saving tools started to be used, breakdown of feudalism
- Laws permitting enclosures, concept of private property started in England
  - Private ownership of means of production lead to capitalism
- Fewer farmers for larger land, many villagers without land or grazing rights
- Landless peasants moved to non-agriculture work in cottage industries and available for work in factories
- The idea of private property widened income gap everywhere (introduced in colonies like India as well, leading to hegemony of landed class/castes)

Patents

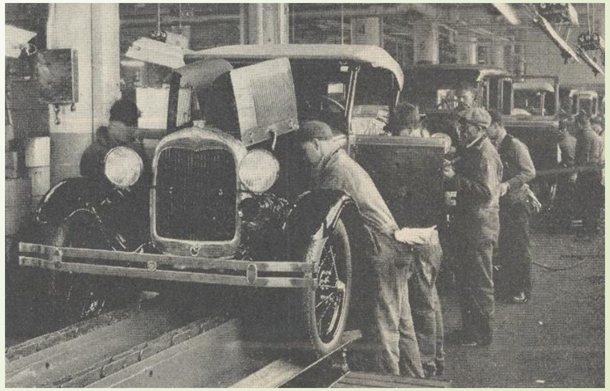
- 1600s: limited monopolies via patents was introduced in England
  - Inventors can disclose their innovation publicly and get limited monopoly for 14 years (two generations of traditional 7 year apprenticeships)
  - No one can copy the idea during this period
- Patents provided monetary incentive to innovators to invent
  - No need to depend on patronage from kings to work on new ideas
- James Watt benefited greatly from patents
  - But also sued others and blocked them, delaying development of steam power

Literate work force

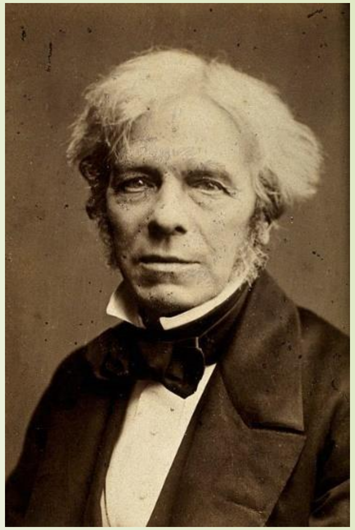
- England had suitable workforce for innovation
  - Literate workforce due to protestant reformation, printing press
  - Royal society and other scientific institutions performed public outreach
  - Frequent scientific lectures and demonstrations inspired laymen
  - Collaborating communities of scientists and craftsmen ("Republic of Letters")
- Other factors
  - England was relatively peaceful (not impacted by Napoleanic wars like rest of Europe)
  - Unified market for produced goods
  - Political stability, rule of law enforced

Second wave of industrialization Electricity, mass production (20th century)

- Electricity: steam turbine generates electricity, which was used for to telegraph, lighting, motors, mechanized factories, radio
- Mass transport: Petroleum and fossil fuels used in internal combustion engines, efficient transport for the masses
- Mass production of goods via assembly lines (starting with Ford cars)
- Mechanized agriculture, with better tools, irrigation, chemical fertilizers
- Increased consumption, increased productivity, better quality of life



A brief story of electricity



- The ideas of static electricity and magnetism known for a long time
  - Certain materials attracted or repelled each other
  - Benjamin Franklin demonstrated that lightning is electricity
  - But no easy way to generate or harness this energy
- Early 19th century onwards: several advances via experiments
  - Alessandro Volta invented the voltaic pile (battery) that produces electricity (based on electrochemical reactions)
  - Hans Oersted discovered connection between electricity and magnetism (electric current deflects compass needle)
- Michael Faraday: one of the biggest pioneers of electromagnetism
  - Invented dynamo (motion to electricity) and motor (electricity to motion)
- Theory of electromagnetism (Maxwell's equations) explained electricity

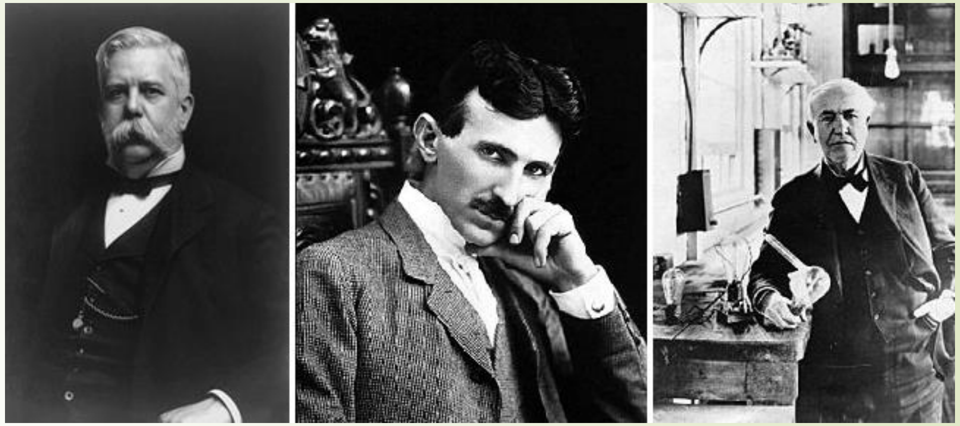
Early uses of electricity Mid 19th century

- First wave of industrialization: steam turbines generate electricity
- Better dynamos based on Faraday's designs (Faraday himself stayed away from any commercial uses of electricity at that time)
- Early commercial uses of electricity
  - Telegraph and telephone for quick communication across large distances, helped accelerate industrialization
  - Arc lights using arc discharge between electrodes (too bright to use indoors, limited usage outdoors)
  - No widespread use of electricity in daily life of common man
- Early uses needed small amounts of electricity, produced from batteries or dynamos at the point of need, no major distribution networks

Indoor lighting
End of 19th century

- Edison's incandescent lamp was the first popular widespread use of electricity in daily lives, trigger for electrification of the world
  - Quickly replaced gas lights / kerosene lamps / candles in homes
- Edison pioneered many innovations to take electricity into people's homes
  - Material for high resistance filaments (early bulbs lasted for short durations)
  - Innovations in underground electric cabling, materials for conductors and insulators, dynamos, vacuum tech, distribution network, fuses, switches, ..
  - Efficient industrial lab in Menlo Park to churn out steady stream of innovations
- Edison was a true "engineer", and recognized as one of the greatest
  - Effort and skill needed to extract commercial value and practical utility from science, build and grow a large business
  - Many scientists doubted that practical incandescent lights can be built

DC vs. AC wars
Late 19th century



- Edison's light bulb and other early systems worked on Direct Current (DC)
  - Low voltage transmission, high current, so high transmission losses
  - Edison's electrical network for lighting needed a generator every mile or so
- Westinghouse/Tesla championed Alternating Current (AC)
  - Allows for high-voltage transmission via up/down conversion using transformers
  - Lower current (at higher voltage) leads to lower transmission losses, so electricity can be produced near coal mines/water falls, far from cities (Niagara falls one of the initial plants)
  - Westinghouse purchased patents on AC, e.g., Tesla's AC motor, and engineered efficient AC networks for lighting and other uses
- Ugly AC vs DC wars between Westinghouse, Tesla, and Edison
  - AC considered dangerous, Edison suggested AC-based electrocution for death penalty
- Eventually, AC prevailed, led to consolidation and standardization of electrical generation and distribution networks, widespread use of electricity

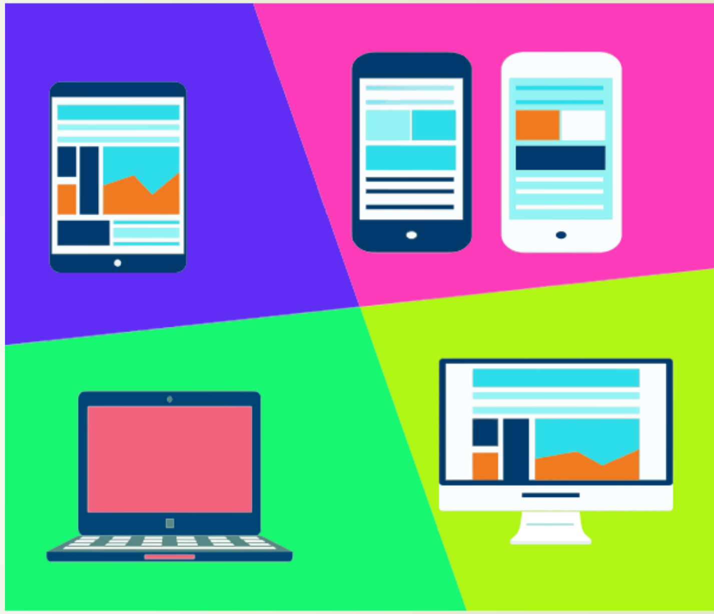
The Gilded Age in USA (1870-1900)

- Second wave of industrialization primarily driven by USA, with Europe following closely
  - Electricity and its applications (starting with Edison's light bulb)
  - Mass production (starting with Ford's assembly line), mass transport (cars, railroads)
  - Significant increase in wealth, wages, productivity, standard of living
- Why? Right conditions for fast technological progress towards end of 19th century
  - End of the US civil war, political stability, no threat from neighbors
  - Large quantities of land and natural resources on a new continent (grabbed from indigenous tribes) provided raw material to factories, mining industry, agriculture
  - Immigration, inflow of hard-working population from Europe looking for fresh start
  - Labor unions and other reforms alleviated poverty, prevented communist rebellions
  - Extensive railroads and telegraph networks to connect local and global markets
  - Boom in trade, industry, railroads created many wealthy individuals ("robber barons") who further invested in future industries (JP Morgan big investor in Edison's company)

Industrialization around the world 20th century

- Industrialization started in England / Europe / USA and rapidly spread to rest of the world by 20th century
- Colonies partially industrialized to support imperial interests
  - E.g., transportations links to source raw materials and sell produced goods
- Other countries industrialized after losing out in wars to European powers and realizing benefits of industrialization
  - E.g., Russia, China, Japan (event called "Meiji restoration")
- Industrialization increased power and reach of imperialism
- Tensions among imperial powers culminated in two world wars
  - USA relatively unaffected by world wars, saw huge increase in production and standard of life in 20th century also

Third wave of industrialization Modern computing

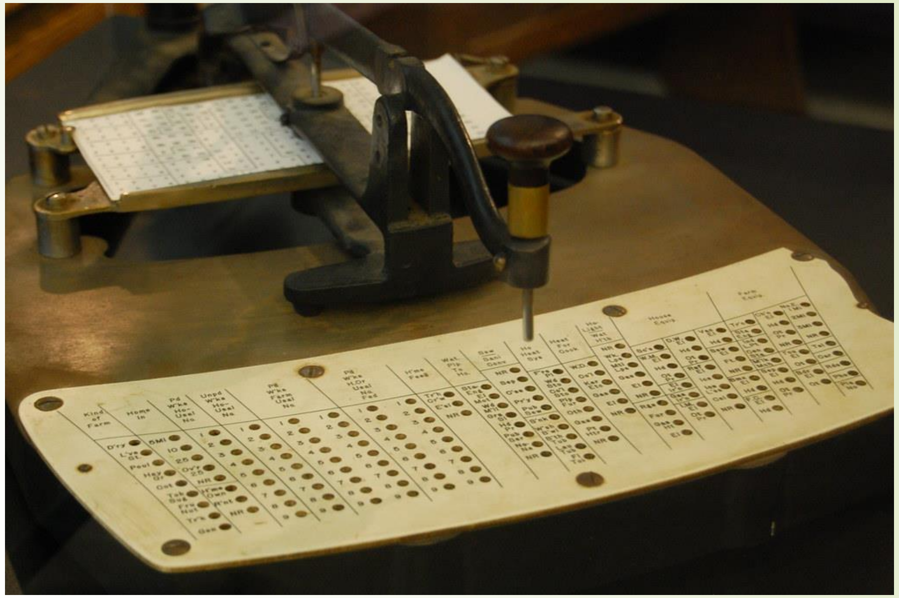


- Modern computing: born out of efforts to win WW2 flight (later, Cold War and Apollo mission to put man on the moon)
  - Decode ciphered messages, test nuclear weapons, computer-guided space flight
- Significant adoption for scientific and business needs in USA, and rest of the world
  - US census, taxes, business data processing
- Mainframes to minicomputers, personal (micro) computers towards end of 20th century
- 21st century: computing all around us, phones and hand-held devices proliferate

Mechanical calculation

- 17th and 18th centuries: precision engineering and clockwork. Watchmakers knew how to make devices that could add and subtract using dials, gears.
  - Pascal’s adding machine and other inventions
- Charles Babbage designed difference engine to calculate polynomials
  - Uses method of finite differences to calculate values of polynomials
  - Useful to calculate log tables and trigonometric functions
  - Expensive to build, completed after his death using steam power
- Babbage also proposed a design for a general purpose analytical engine (Ada Lovelace wrote programs for it) but it was never built in his time

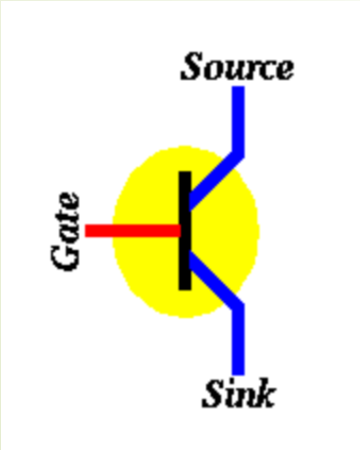
Punched cards & US census

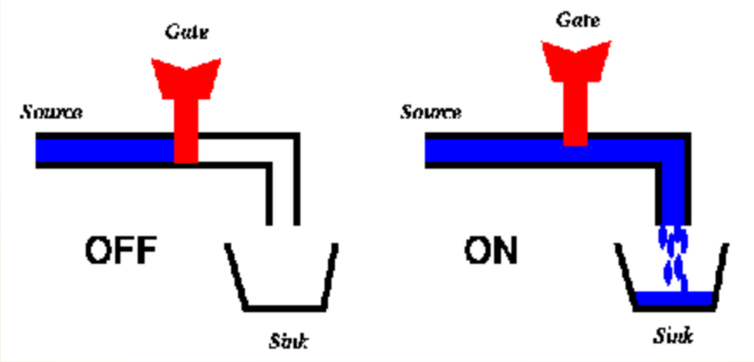


- US census every ten years, but time consuming given large population
- US encouraged automation of calculations and tabulations, announced a competition for a better solution
- 1890 US census replaced manual computation with automation
  - Punched cards to store user information
  - Mechanical devices generated various statistics
- Punched cards continued to be used with later computers as well

The idea of a data switch

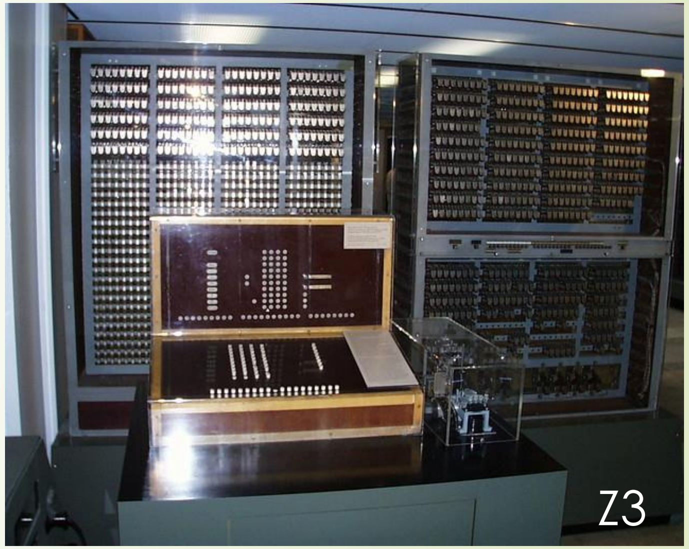
- Signal flow from one end (source) to other (sink), controlled by another signal (gate)
  - If gate is ON, output is ON. If gate is OFF, output is OFF
- Data switches are building blocks for circuits to do logical (NOT, AND, OR, ..) and arithmetic operations (additions, ..)
- Boolean algebra helps construct correct circuits for arithmetic/logic operations





Electro-mechanical relays

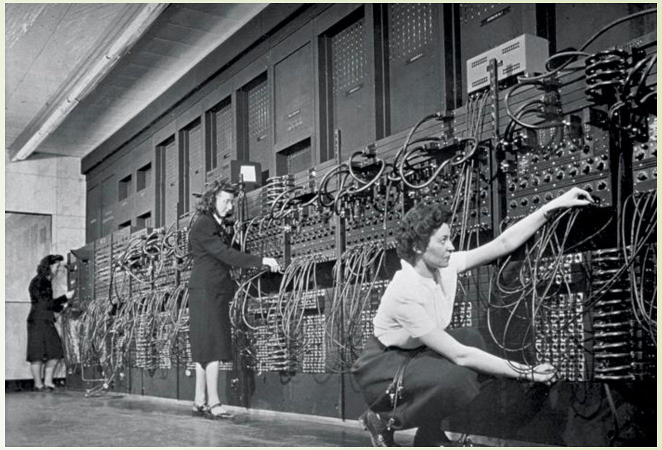
- Electromechanical relays used electrical and mechanical components to build a data switch
  - Input/Output through punched cards and tapes
- 1930s-1950s: Relays used as building blocks to build computers
  - Z1, Z2, Z3… by Konrad Zuse in Germany
  - Mark I, Mark II, .. By Howard Aiken in Harvard
- Realized the vision of Babbage's analytical engine (fully automatic, programmable digital computer)
- Extensively used in World War 2


Z3

ENIAC and Vacuum tubes

- 1940s: vacuum tubes replaced electromechanical relays for computation, resulted in faster switching and higher computation speed
  - Cathode rays controlled by applying suitable voltage at the gate
- ENIAC (Electronic Numerical Integrator and Computer) is first general purpose digital computer
  - Developed by Mauchly and Eckert (U Penn)
  - Vacuum tubes for computation, punched cards/magnetic tapes for input/output
  - Developed for ballistics calculations in US army, used in Manhattan project for nuclear bomb calculations
  - One operation took about millisecond (today: nanosecond)
- Many such computers developed during WW2

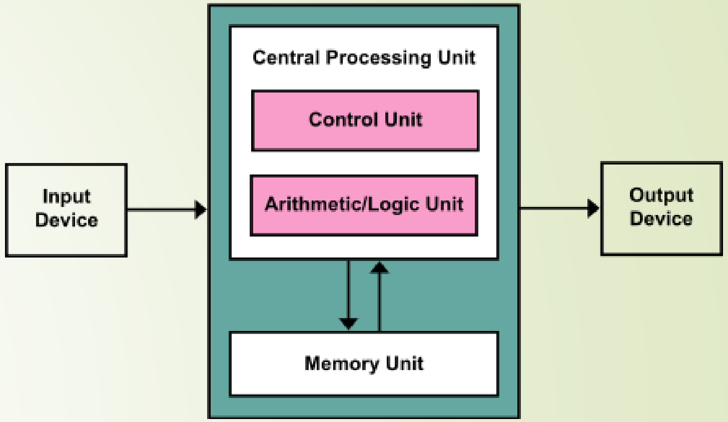
Stored program concept



- ENIAC can be programmed to perform a large variety of computations quickly within seconds
- But "programming" involves manually tinkering with cables and switches to configure the circuits, which could take weeks
- Later, Mauchly and Eckert worked on EDVAC and UNIVAC, which were based on the stored program concept
  - Instructions to program the computer also stored in memory, and can automatically configure the computation circuits
- John von Neumann part of study group and wrote a report on EDVAC, hence popularly called Von Neumann architecture
  - Many others proposed related ideas: Alan Turing's concept of Turing machine

Von Neumann architecture

- All modern computers follow stored program concept
  - Computer memory stores instructions and data
  - External data stored/retrieved in memory via I/O devices
- Every cycle of the computer:
  - CPU fetches instruction, decodes it, executes it
  - Few tens of accumulators or registers in CPU temporarily hold data
  - Instructions can load/store from memory or perform arithmetic operations on data present in registers
  - Special register program counter (PC) holds address of next instruction to run
  - Can execute a linear stream of instructions or branch by updating PC
- General purpose, programmable: by writing suitable instructions, computer can programmed to perform any computation

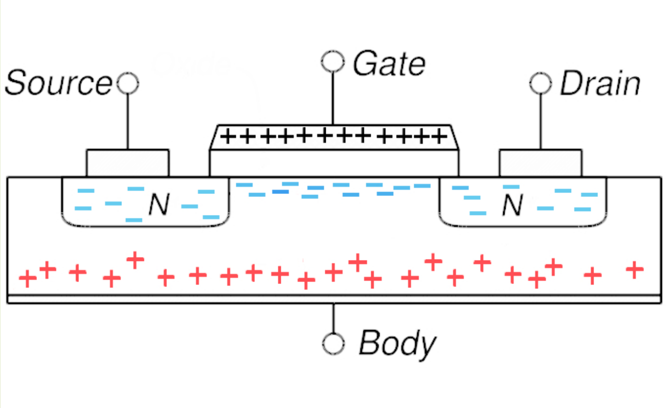


Start of digital age

- Initially, many skeptics doubted the use of general purpose computers
  - How can same machine do scientific calculations and grocery billing?
  - Why do we need more than a handful of such computers for all of USA?
- By 1950s, widespread use, mainly in USA, during post WW2 economic boom
  - Scientific calculations and military applications
  - Automatic data processing in businesses and government: fetch data records, run computation, store back results
  - Insurance, census, payroll, taxes, business forecasting, ..
- IBM succeeded in commercializing stored program computers using vacuum tubes (controlled ~70% of market)
- Innovations in faster memory, I/O devices also

Vacuum tubes to transistors

- Transistor is a data switch made using semiconductors like silicon
  - Smaller, more reliable, and consumes less power than vacuum tubes
  - Basic building block of modern electronics
- First transistor made by Bardeen, Brattain and Shockley at Bell Labs in 1947 (Nobel prize in 1956)
- Computers using transistors in 1950s (IBM 1401)
- Many different types of transistors developed today, which are used to build complex circuits in computers and other electronic devices



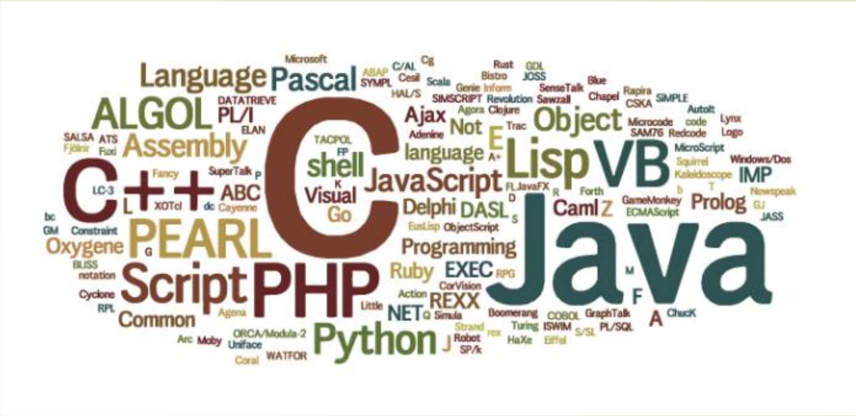
IBM and mainframes

- 1960s: large installations of computers using transistors, ferrite-core memories, magnetic disks and tapes for I/O began to be used widely
- Called mainframes, mainly dominated by IBM
- Expensive to maintain, hence shared across multiple users via batch processing
  - User submitted jobs via punched cards or tapes
  - Programs run by mainframe, and results given out as printouts later on

Computer programming

- Computer programming = giving instructions to computer on what to do
- Software = set of instructions that direct a computer to do a specific task
- Early electro-mechanical computers were programmed by punching holes into a piece of paper tape
- Early automatic computers (ENIAC) were programmed by manually reconfiguring switches and cables
- Stored program computers (UNIVAC) were programmed by loading programs with instructions into memory
- Grace Hopper one of the earliest programmers
  - Early programmers were mostly women (partly because men were in WW2)

High-level languages & Algorithms

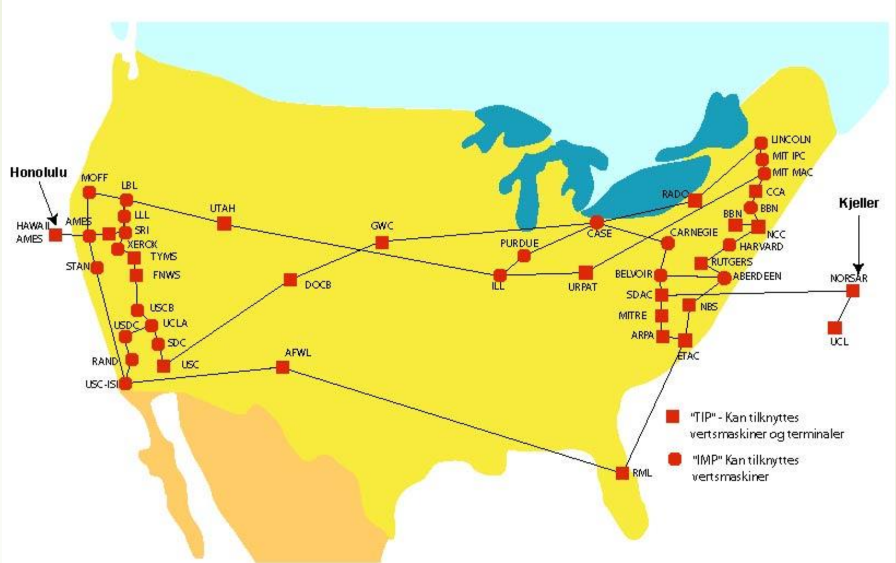


- Initially, programs written in low-level instructions that hardware can understand
- Soon, libraries/subroutines of frequently used code was being "compiled" together, and programs "assembled" from subparts
  - Hardware instructions provided ability for execution to jump to a subroutine
  - Efficient "algorithms" (sequence of steps) for common tasks like sorting records
- Later, high-level languages like FORTRAN (formula translation for scientific applications), COBOL (for business applications), and many more
  - Compiler translates from high-level language to low-level instructions
  - Grace Hopper's contributions in design of high-level languages and compilers
- How to write code: structured programming and software engineering
- Birth of computer science as a discipline, separate from electrical engg

Real time processing Minicomputers

- 1960s: need for a smaller, real-time alternative to batch-processing based powerful mainframes
  - Data entry for large applications like US tax returns needed to be decentralized
  - NASA’s manned space program required a machine that can quickly compute flight trajectories in real time (US President JFK’s pledge in 1961 to put a man on the moon by end the decade)
- Architectural innovations in real time “mini-computers”
  - Direct transfer of data from I/O devices to core memory
  - Ability to interrupt processing in response to some events
  - More complex instructions, and better circuits with transistors
  - Lower cost (can buy, not lease) and better packaging
- Digital Equipment Corporation’s PDP-8 became very popular

Sharing & networking computers



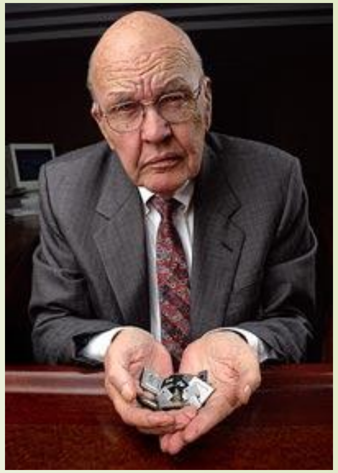
- Minicomputers co-existed with large mainframes that were timeshared across users (IBM's System/360, DEC's PDP-10 etc)
- 1960s: Several ideas to efficiently timeshare expensive computers
  - Operating systems (systems software) to multiplex users and give user illusion of full control over underlying computer (Multics, UNIX, ..)
  - Thompson and Ritchie developed C programming language to efficiently write code for UNIX operating system
  - US Department of Defense funded the ARPANET to connect several mainframes across US universities, precursor to the modern Internet

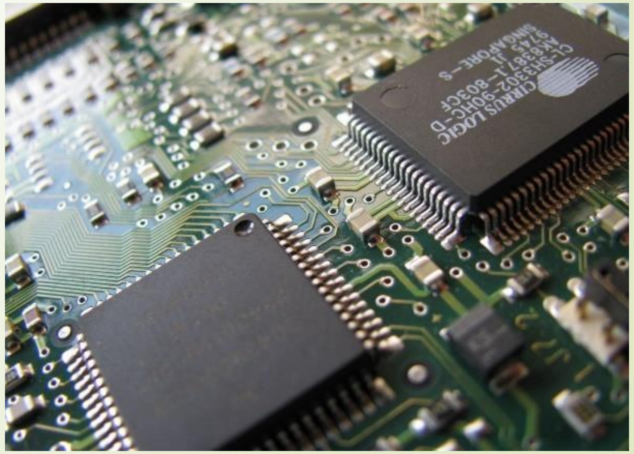
Birth of software industry

- 1960s: IBM unbundled its software from hardware and sell it separately (due to pressure from US Government)
- Many companies were formed to develop system software (operating systems, networking) and programs for mainframes like System/360
  - System/360 integrated many product lines, software for one could run on rest
- Companies also formed to perform “system integration” services to integrate hardware, software, and customize for specific applications (business, scientific, military, government etc.)
- Many clones of IBM mainframes, so hardware more easily available
- Teaching software development in universities as a separate discipline
  - Students learn how to program mainframes via timesharing
  - BASIC programming language developed for beginners

Integrated circuits (“Chips”)

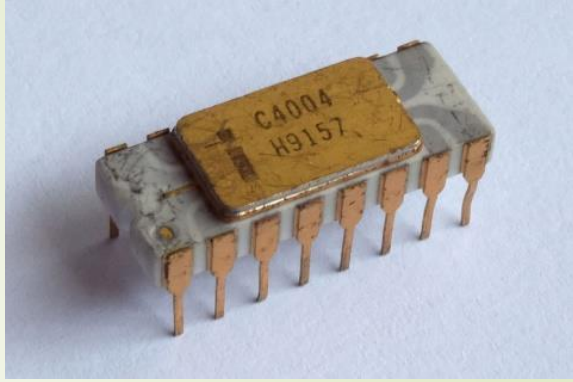
- Jack Kilby and Robert Noyce independently patented integrated circuits (ICs) in 1960s
  - All transistors etched on same piece of semiconductor, not made individually and connected
  - Printed circuit boards connected up all ICs in one system
- Early customers were US aerospace community and Apollo missions
- By 1970s, rapid innovations in chip manufacturing, price drops, widespread use in mainframes and minicomputers
- Soon, very large scale integration (VLSI)

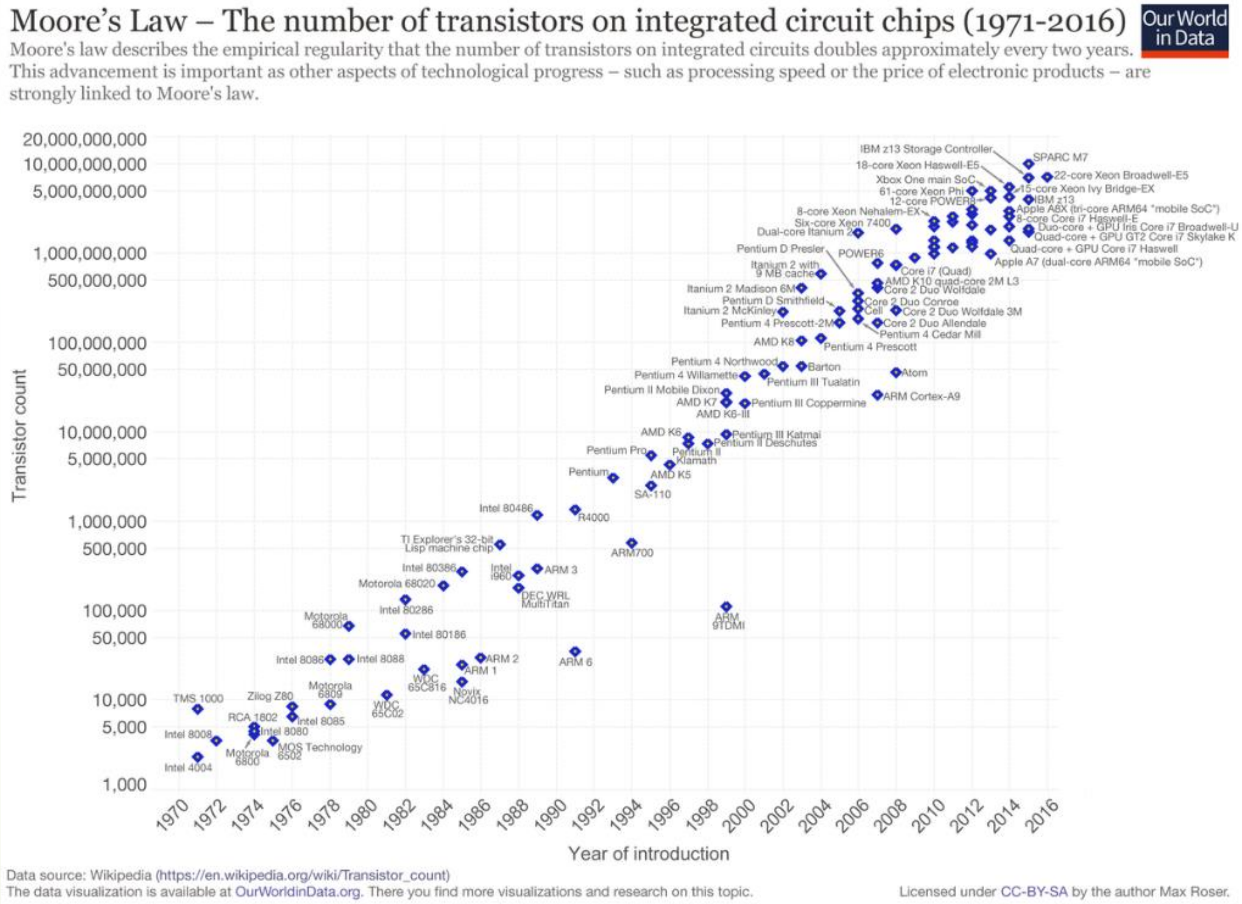




Intel

- Founded by Andy Grove, Robert Noyce, Gordon Moore in 1968
- Started out with semiconductor memory and custom logic chips
- 1971: Intel 4004 is first commercially available general purpose microprocessor (CPU)
- Later, 8-bit 8008, 8080, 8086, … called x86 CPUs
- Moore's law: prediction that number of transistors on a chip will double every two years (due to technological advances)





Embedded computers

- Early 1970s: computers started to be embedded in devices outside of science labs/business
  - Small size of microprocessors meant that entire computer (CPU, memory, I/O adapter) fit on one printed circuit board
- Personal calculators (e.g., HP-35) made it possible to take home a device that can do calculations, useful to professionals, students
  - 4-bit Intel 4004 initially developed for a calculator
- Computer games like Pong became popular
- Embedded controllers for industrial systems

Need for a general purpose personal computer?

- By early 1970s, most of the technology was in place for a general purpose personal computer (which we have today)
  - General purpose = can perform any task by suitable programming via software
  - Personal = small enough to be available for each user
- Microprocessors small enough to build general purpose personal computers, but Intel's microprocessor were not sold that way initially
  - General purpose microprocessor was produced only to develop custom systems faster (via software specific to an application loaded into ROM)
  - Intel initially did not see a general purpose computer being used by general public (who would do the hard job of programming it? what use would it serve?)
- Technology develops to solve problems, or problems found to utilize technology?

Altair and hobbyists
Start of personal computing

- 1975: Altair minicomputer introduced for electronic hobbyists
  - Based on Intel 8080 processor
  - Enter code by toggling switches, see the lights turn on in a pattern
- 1975-77: an ecosystem of innovation developed around Altair, as its open design allowed hobbyists to extend it
  - Various input/output devices, storage via floppy disk drives
  - A basic small operating system to manage all the devices, by extending previous system software developed for Intel 8080
  - Bill Gates and Paul Allen developed a BASIC compiler, so that it can be programmed in a high-level language

Second wave of Personal Computers

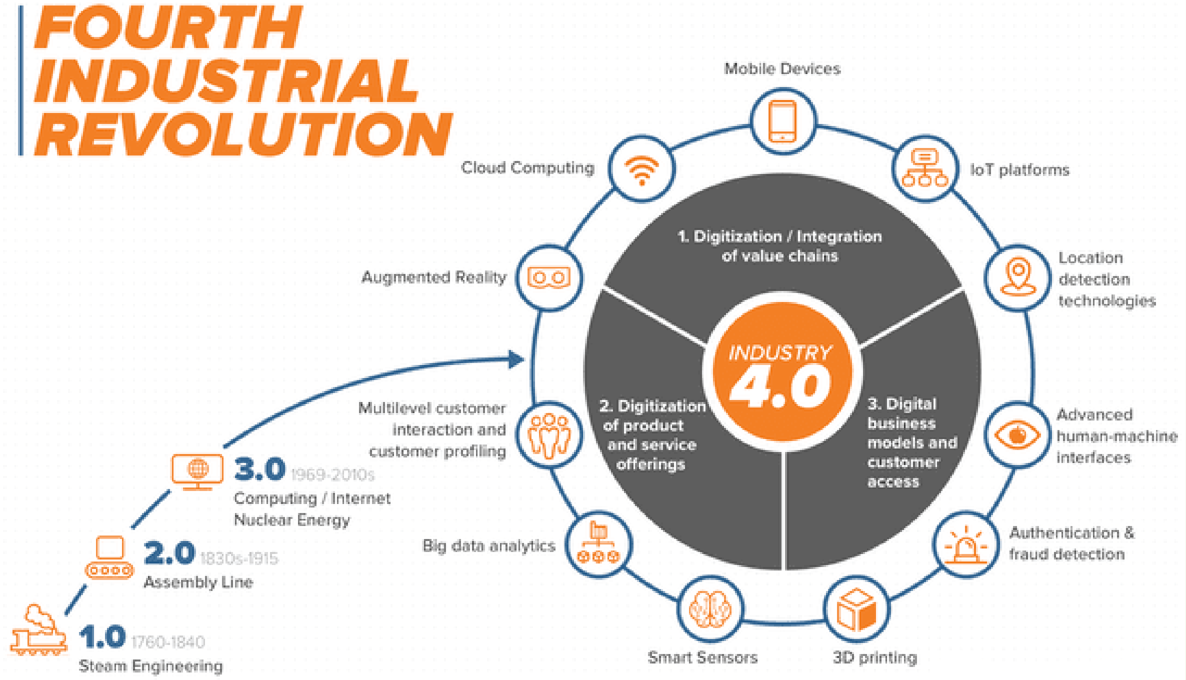
- Late 1970s, early 1980s: second wave of personal computing
  - Many personal computers: Xerox Alto, Apple II (Steve Jobs and Wozniak), IBM PC, Macintosh
  - Many useful software for personal use like spreadsheets (VisiCalc, Lotus 1-2-3), AutoCAD, desktop publishing, gaming
  - I/O devices (mouse), Networking tech (Ethernet)
- Bill Gates and Paul Allen developed DOS (disk operating system) for IBM PC, later sold it to others as MS-DOS
  - Founding of Microsoft as a software company
  - IBM PC clones flood market, IBM loses its dominance

Internet, smartphones, cloud, big data Into the 21st century

- 1990s: Internet for general public evolves from ARPANET
  - World Wide Web, email are "killer apps" for Internet
  - Search engines, e-commerce, "dot com" bubble and burst
- High performance, parallelism (multicore), portability (laptops)
- Mobile data networks: convergence of telephony and Internet
- Handheld, touch-screen based "smart" phones with "apps"
  - Music, camera, Internet, telephone, all rolled into one
- Cloud computing, data centers, "big data" processing
- Social media, online entertainment and gaming
- Artificial intelligence, machine learning, data science

Fourth industrial revolution?

- Broad term used to describe current technology trends and possible future
  - Digitization, automation, analytics, smart everything: home, factory, government
  - Increased connectivity and cloud, Internet of Things, Internet-of-everything
  - Artificial intelligence, robotics, augmented/virtual reality



How to balance this hi-tech future with environmental sustainability, making life better for the bottom of the pyramid, other sustainable development goals?