Surviving The Cyber Age

Chapter 9 – Parallel Cognitive Expansions

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Continuing the timeline of emerging technology, society, and limits

In the 1590s, the first compound microscope was invented allowing people to examine what they previously could not observe.[1] [2] By 1665, the cell was identified as a component of life forms including humans.[3] This began an exploration of the invisible world and started the destruction of mythology and religion as the explanation for things too small to see. As a revolution in understanding this constituted an expansion of the cognitive space of humans in the dimension of the small, microscopic, and minutia. But it had almost no effect on the macro-expansion of societies.

The development of larger and more complex machines starting in about 1700 brought about the industrial revolution that had dramatic effects on macro-expansion of societies by, among other things, changing the nature of manufacturing, transportation, and infrastructures and moving to the next levels of indirection of control systems, first outside of the body, and then independent of it.

At the same time, humans moved from physical controls increasingly into the realm of indirect control mechanisms, and as societies emerged, increasingly into cognitive control systems where influence instead of physical force moves individuals, groups, and societies in narrative space (the space of meme sequences leading to understanding, decisions, and actions) rather than their physical components and composites in physical space.

In this chapter, we explore three simultaneous cognitive expansions; one of increased scale, size, and power; another of decreased scale, size, and power; and a third in narrative space; each as dramatic as the other in its effect, and each changing every aspect of human co-evolution with technology.

Writing was widely in place over this entire period, so the historical record reflected in modern archives around the world still has these writings as records. Narratives passed over most of this time were often recorded in reliable and authentic written records, so these records largely reflect their written origin and any changes over time.

My grandmother lived in the 1800s, that’s 2 generations ago; her grandparents who she likely knew were alive in the 1700s; and their grandparents were likely alive at the beginning of 1700. That’s 6 people talking to each other away from today and only another 5 generations and 2 people communicating with each other away from the start of the 1600s.

The emergence of complex machinery

The industrial revolution started about when the first motors came into use, something like 1700. Other forms of power; like water, wind, and animal power; and limited force amplification by gears and pulleys; were available at the beginning of this era. But these were largely limited by the availability of adequate water and wind, and the limitations of animal

1 https://www.historyoftelescope.com/telescope-invention/zacharias-janssen/
2 https://en.wikipedia.org/wiki/Zacharias_Janssen
3 https://pmc.ncbi.nlm.nih.gov/articles/PMC4360124/

sources, and as such, they were limited as to location, quantity, and continuity. But then the fuel-powered motor was invented and the "industrial revolution" took off.[4] [5] [6]

I am not going to go through all of the inventions of the industrial revolution, because the book would continue for millions of pages. But a few of them are worthy of particular note:

- **Sensors:** While there were limited sensors of sorts before the industrial revolution, like strings tied to bells for making noise when they were tripped, one of the key enablers and key outcomes of the industrial revolution was the advancement of sensors.
    - Sensors for detecting generic conditions came first with things like thermometers detecting temperatures, typically using some continuous system of measurement and ultimately calibrating it to a standard, like centigrade.
    - Sensors specialized to specific conditions, like whistles on tea pots, bimetallic strips for adjustable temperature sensing, and centrifugal force detectors for adjustable motor speed control came later as automated mechanisms for specific tasks.
- **Actuators:** As materials improved and more complex mechanisms became feasible, fine working allowed tighter tolerances and more force over smaller surfaces to operate. Actions could then carry enormous loads and move mountains of dirt with huge machines and keep track of time to within a second or less with tiny mechanisms within watches. Tiny springs made power storage and use on your wrist move clock hands while enormous pistons with explosive fuels made digging tunnels through mountains with dynamite clearing the way feasible.
    - Engines that could work almost anywhere were a tremendous breakthrough, since carrying fuel means they were not tied to rivers or windy locations. It meant that you pump water from almost anywhere, manufacture near the location of the raw material, and do anything automated wherever it best suited you. This also opened up many new locations away from rivers and oceans for the expansion of industry.
    - Self-propelled vehicles with motors placed within the composites made water more accessible allowing for more reliable lake and ocean transport, but more importantly perhaps was the increase in speed that allowed overcoming current in water and large volumes of goods moved more quickly over land. A change in amount amounts to a change in kind over some threshold, and examples like fresh food transportation, more rapid maneuver in war, and closer to just in time manufacturing because possible. Eventually, this led to automobiles, long-distance controlled flight, submarines, trains, and other innovations in transportation as well as necessitating improved infrastructures to support these volumes and distances at speed.
- **Communications:** More information at higher speed over longer distances changed everything about automation and social interaction, bringing the world closer together while making mechanisms faster than people could ever be.
    - Communications over long distances at great speed in ancient times was epitomized by the lighting of fires and watchtowers allowing simple events to be

4 https://www.britannica.com/event/Industrial-Revolution
5 https://www.oerproject.com/OER-Materials/OER-Media/HTML-Articles/BHP/Unit6/The-Industrial-Revolution
6 https://en.wikipedia.org/wiki/Industrial_Revolution

identified. Lights focused through lenses and parabolic reflectors allowed systems of codes to be used to transmit line-of-sight messages from point to point at the speed of light. But this communication was limited by the signaling protocols, for example flag signals at a rate of perhaps 1 character per second. The discovery of radio waves eventually led to radio transmission using the same and other signaling techniques that permitted communications over vast distances to mass audiences at the speed of light (although endpoints were typically limited by the speed of sound to get from human lips and to human ears until the invention of television).

    - Increased bandwidth and shared infrastructures led to telephony and the mass wiring of the world for millions or more simultaneous messages between multiple independent parties across continents and the industrialized world. Over time this led to distributed systems of control within and between facilities to support more complex automated systems, control of boat and air traffic, signaling on railroads, automated traffic control systems, coordination of police and other emergency response, and military and industrial applications of all sorts.

- **Controls:** More complex mechanisms of control automated more and more manual human tasks until they automated tasks that no human could perform, leading to super human strength, precision, and speed for well-defined tasks.
    - Simple feedback systems allowed local controls like motors that self-adjusted their speed to meet the need of their load, water systems that pumped water up to desired levels keeping pressure levels within constraints for larger water systems, and constraining pressure in pipes to prevent bursting by things like relief valves.
    - Complex decision-making in feedback systems emerged over time to allow for non-local controls over larger scale systems and controls involving many parameters gained from many different sensors and communicated over different communications channels. This led to things like finite state controllers and complex sequencing equipment playing manufacturing facilities like a player piano with different tunes based on changes in the facility. These mechanisms could adapt faster than humans to more complex conditions than humans could handle, and more consistently and reliably than humans could attain on their own.

As societies grew and technologies expanded, complex machinery emerged.

- Systems of power amplification, automated controls, and advancing materials led to larger and larger autonomous systems, requiring human maintenance and adjustment, but not moment to moment human control.
- Inventions involved one person leveraging the mechanisms and materials of other people, in many cases so that no individual working on their own could accomplish the things societies accomplished, and allowing these systems to be expanded on a continental scale.
- Larger and larger groups of people working in a hierarchy in specialized fields requiring more and more education and with design parameters based on measurements involving coordinated precision and accuracy became the only way to accomplish this, and people with cognitive skills came to dominate many of these component fields of expertise.

- The indirect issues of narratives caused large societies to build and collapse, changed leadership, created mythologies that spread en-mass and were used as excuses to kill other groups.
- New techniques were spread throughout the world, first in perhaps a few years rather than decades or longer because of increased travel and printing technologies, then in a few days because of rapid transport or documentary material, then in a few seconds because of radio. Of course people learning to implement these new methods took some time.
- Written documentation became commonplace among the elite, and over time, among larger parts of society, until large and larger segments of the population could read and write.
- Local civil services and servants became the representatives of the government to the people and the people to the government, while regional governance and increasingly uniform laws and legal systems emerged.
- War became increasingly mechanized and organized, the concept of total war reached a pinnacle, and the ability of groups of nation states to kill tens of millions of people in only a few years, then a few minutes, emerged.

Manufacturing became so scalable that more than one instance of the same manufactured item could be made for every human on Earth in less than a year, and then even faster; and the scale of things that could be manufactured escalated to whole sections of cities and miniaturized to less than the breadth of a hair.

Transportation reached a level where tons of goods or people could be delivered around the world in less than a day.

Infrastructures reached a level where they were transcontinental, transoceanic, and beyond, and operated 24 hours a day 7 days a week at scales ranging from movement of electrons to the movement of 600,000 tonnes across oceans.[7]

Societies around the world by the end of this period had developed a wide range of systems including complex mechanical, fluidic, social, monetary, and other control systems, using indirect, communication-based, and social approaches for more and more indirect control over larger and more complex highly scaled systems of sensors, actuators, communications, and control with individuals, groups, and technology combined to form these control systems, and scalability was effectively unlimited.

Civil and Military Engineering[8] [9] [10] [11]

Civil engineering started long ago in the sense that deals with the design, construction, and maintenance of physical and naturally built environments, most commonly “public works” like roads, bridges, canals, dams, airports, sewage systems, pipelines, structural components of buildings, and railways. Primitive forms of civil engineering have been around far longer than

7 https://en.wikipedia.org/wiki/Seawise_Giant
8 https://en.wikipedia.org/wiki/Civil_engineering
9 https://www.mcneilengineering.com/from-then-to-now-a-brief-history-of-civil-engineering/
10 https://en.wikipedia.org/wiki/Military_engineering
11 https://www.britannica.com/print/article/382334

hominids and many animals create structures to live and work in. The beaver with its dams comes to mind.

Military Engineering (designated herein by **MIL**) is part of the profession of arms. "*It is concerned with maintaining the mobility of friendly forces, denying the same to an enemy, and enabling forces to survive in hostile environments. In more simple terms, military engineers permit friendly forces to "Live, Move and Fight" while denying the same to the enemy. Internationally, military engineers share a common background in a discipline that encompasses the use of demolitions and land mines, the design, construction and maintenance of defensive works and fortifications, roads and lines of communication, and bridges. They also provide water, power and other utilities, provide fire, aircraft crash and rescue services, conduct hazardous material operations, and develop maps and other engineering intelligence*"[12]

- **6,000-4,000 Ya**: Egypt, the Indus Valley civilization, and Mesopotamia (ancient Iraq) started constructing shelters, transportation infrastructure, and developed the wheel and sailing. In this time frame, architecture and civil engineering were really one and the same thing.
- **6,000 Ya**^MIL: In the oldest human settlement of Jericho that can be called a city, military engineering constructed the first walled city. The settlement was founded on a perpetual spring of pure water. The wall was supplemented by a tower.
- **4,760 Ya**: Construction of the Egyptian pyramids began,
- **4,700-4,500 Ya**: The pyramids in Egypt
- **3,000+ Ya**: The Qanat water management system [Iran]
- **3,000 Ya**^MIL: Siege craft was underway and fortification with ramparts and walls were built around cities to defend against besieging forces.
- **2,500 Ya**^MIL: The engineer, as professional soldier, began to exercise influence on tactics and strategy during the Grecian Empire (500-340 BC) by introducing floating bridges to win several major battles.
- **2,447 Ya**: The Parthenon by Iktinos in Ancient Greece
- **2,400 Ya**^MIL: The catapult, originally designed as a defensive weapon, and was soon adopted for attack; it quickly became the siege engineer's principal weapon until the invention of firearms. Armies began using catapults and designing wheeled battering rams to breach fortifications. In this era, the technique of mining or tunneling under enemy walls was first used to breach hard defenses.
- **2,312 Ya**: The Appian Way was started by Roman engineers. Over time, the Roman army engineers constructed ~75,000 kilometers of paved military roads that connected Rome with outlying colonies.
- **2,250 Ya**^MIL: The art and science of defensive fortifications and the mathematics of the trajectory for hurling objects (including missiles) was developed. Engineers devised more complicated engines of war like a catapult using a twisted cord for power and 150 years later, a magazine-fed weapon for shooting arrows.

12 https://cmea-agmc.ca/sites/default/files/chapter_1_red_book_20_july_2018_e.pdf

  - *In the Roman army, every soldier was an ‘engineer’ expected to wield a spade and a sword. On the move six thousand legionaries constructed a square earthen rampart, ditch, and palisade of stakes around the circumference (castrametation) in 3-4 hours every night when troops were on the move. They had tools for surveying and mapping, selected and built camps and roads for troops and supplies, secured water facilities, and erected fortifications.*
- **2,220 Ya**: The Great Wall of China was started by General Meng T'ien
- **Since then**:
  - The stupas in ancient Sri Lanka (the Jetavanaramaya and irrigation works in Anuradhapura)
  - The Roman civil structures throughout their empire, aqueducts, insulae, harbors, bridges, dams and roads.
  - And basically all the roads and structures built over the last few millennia however...

As an engineering discipline, civil engineering started perhaps 2300 Ya with Archimedes' principle relating to buoyancy and practical solutions like the Archimedes' screw.

- **275-775 AD**[MIL]: Rome fell in 275, and military engineering changed little over the next 500 years. Foot soldiers were largely replaced by cavalry (knights in armor) and feudal castles were built, often in commanding positions by a river.
- **~700 AD**: Brahmagupta, an Indian mathematician, used arithmetic in the 700s based on Hindu-Arabic numerals for excavation (volume) computations.
- **1325**[MIL]: The word engineer (from engine’er literally, one who operates an engine) referred to "a constructor of military engines",a mechanical contraption used in war.
- **1415**[MIL]: Breech methods were developed, and this lasted til the invention of gunpowder, first used (1415 AD) to demolish walls at the siege of Harfleur. They tunneled under the walls, planted explosives, and detonated them. Explosives led to artillery, the smooth-bore cannon, and so forth.
- **1697**[MIL]: The French engineering corps became a separate part of their army.
- The term civil engineering was coined in the 1700s to distinguish civilian from military applications.
- **1716**[MIL]: The British engineering corps became a separate part of their army.
- **1741**[MIL]: The Royal Military Academy was started. [England]
- **1747**: École Nationale des Ponts et Chaussées was established [France] to teach civil engineering and other European countries followed.
- **1749**[MIL]: The military school at Mézières was started. [France]
- **1771**: The first self-proclaimed civil engineer (Smeaton) constructed the Eddystone Lighthouse and with some colleagues formed the Smeatonian Society of Civil Engineers.
- **1801**[MIL]: The Paris Polytechnique was started.

- **1803**[MIL]: The United States Military Academy at West Point was started.
- **1818**: The Institution of Civil Engineers was founded [London], and Telford became its first president (1820).
- **1828**: The IoCE received a Royal Charter, formally recognizing civil engineering as a profession and defining civil engineering as:

  > *the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states, both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation and docks for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters and lighthouses, and in the art of navigation by artificial power for the purposes of commerce, and in the construction and application of machinery, and in the drainage of cities and towns.*

In order to get approval by a civil authority in a jurisdiction to practice civil engineering, in almost every jurisdiction, you have to have adequate education, practical experience, pass specialized tests for the specific things you do, and keep up to date in the field. This is to protect the health and safety of the populace from errors and omissions. Lives are almost always at stake. Civil engineers typically start with a bachelors degree in civil engineering that takes 3-5 years of study and includes classes in physics, mathematics, project management, design, and courses in specific civil engineering areas. Most specialize in one or more sub-disciplines at advanced levels after that. Norwich University (1819) was the first US college to teach civil engineering and the first degree in civil engineering in the US was awarded by Rensselaer Polytechnic Institute (1835). The first woman earned the degree from Cornell University (1905). In the UK the Class of Civil Engineering and Mining was founded at King's College London (1838), mainly for the railway system, the private College for Civil Engineers in Putney (1839), and the UK's first Chair of Engineering was at the University of Glasgow (1840). Once certified, the engineer is designated as a professional engineer, chartered engineer, chartered professional engineer, or European engineer, and agreements between professional bodies allow engineers to practice across borders. Engineers must obey contract law in their contractual relationships with other parties, and if an engineer's work fails, they may be subject to the law of tort of negligence, and in extreme cases, criminal charges. An engineer's work must also comply with many rules and regulations, like building codes and environmental law. Some sub-disciplines include:

- **Coastal engineering**: managing coastal areas against flooding and erosion
- **Construction engineering**: Planning and execution, transportation of materials, and site development using hydraulic, environmental, structural, and geotechnical engineering.
- **Earthquake engineering**: Designing structures to withstand earthquakes.
- **Environmental engineering**: treatment of chemical, biological, or thermal wastes, purification of water and air, and remediation of contaminated sites after waste disposal or accidental contamination.

- **Forensic engineering**: the investigation of materials, products, structures or components that fail or do not operate or function as intended, causing personal injury or damage to property.
- **Geotechnical engineering**: soil science, materials science, mechanics, and hydraulics is applied to safely and economically design foundations, retaining walls, and other structures.
- **Site development and planning**: planning and developing the potential of a site and possible impacts from permitting issues and environmental challenges.
- **Structural engineering**: structural design and analysis of buildings, bridges, towers, flyovers (overpasses), tunnels, off shore structures like oil and gas fields in the sea, aerostructures (fuselages, wings, flight controls, etc.) and other structures.
- **Transportation engineering**: moving people and goods efficiently, safely, and in a manner conducive to a vibrant community.
- **Municipal or urban engineering**: specifying, designing, constructing, and maintaining streets, sidewalks, water supply networks, sewers, street lighting, municipal solid waste management and disposal, storage depots for various bulk materials used for maintenance and public works (salt, sand, etc.), public parks and cycling infrastructure.
- **Water resources engineering**: collection and management of water (as a natural resource).
- **Civil engineering systems**: systems thinking to manage complexity and change in civil engineering within its broader public context.

In essence, every physical structure in the modern world involves a civil engineer.

Mechanical systems and early engineering[13]

Since the dawn of civilization, mechanical mechanisms were applied to create large scale structures like irrigation systems, buildings, and military projects. Advances in food production through irrigation resulted in mechanical specialists in ancient Babylon (39-3600 Ya). All six of the classic simple machines were known in the ancient Near East; the **wedge** and **inclined plane** (ramp) were known in prehistoric times; the **wheel and axle** were invented in Mesopotamia [Iraq] (7,000 Ya), the **lever** first appeared in the Near East (5,000 Ya) as a balance scale, to move large objects, to lift water, in the first crane (5,000 Ya), and in ancient Egypt (4,000 Ya); **pulleys** [Iraq] (4,000 Ya) and [Egypt] (3991-3802 Ya); and the **screw** [Iraq] (2,911-2,609) Ya. The Assyrians used metallurgy and made iron weapons, made advancements on the wheeled chariot, made pivot-able axles on wagons, and had one of the first armies to use the move-able siege tower and battering ram. The earliest water wheel and watermill, first appeared [Iraq and Iran] (2400 Ya), but theories around these machines didn't begin till Archimedes [Greece] (~2250 Ya) developed the theory of mechanical advantage, the Law of the Lever, and Archimedes' law. Block and tackle were also from that era [Egypt].

The Roman Empire developed many mechanical devices in construction and hydraulics that had large impact on progress in mechanics leading to the use of giant stones or cements as building materials and tools to hoist these to heights of 40 meters or more. They improved on

13 https://ethw.org/Timeline_of_mechanical_engineering_innovation

gear trains, cranes, and pulleys in the A-frame crane, produced mechanisms with gear ratios to reduce speed in exchange for increased weight and torque, improved pulley systems by using different arrangements to change direction and magnitude of force output when lifting, and a treadmill to leverage circular pushing to pull ropes. The Roman Colosseum was 48 meters high and 544 meters circumference, erected in about 10 years (70 AD) using intricate systems of scaffolding and cranes to lift, guide, and move objects. The Roman use of hydraulics is evident in their aqueducts with a slope averaging -1/3,000 (rise over run with negative rise being fall) and reaching levels of -1/20,000 in some locations.

Precision in construction was accompanied by advancements in knowledge of hydraulic pressure, pipelines, and fluids that continue to have an influence in the modern day. The primary issue the Romans needed to overcome was with the flow rate of the water. In some aboveground sections of the aqueducts, an excess of water was a complication that could cause spillage of water. This was overcome by managing the flow rate, primarily through the changing of slope or addition of reservoirs. Along with having to manage the flow rate throughout the aqueduct systems, the Romans also had to engineer ways to overcome the terrain. In order to overcome sudden drops or rises in terrain, an aboveground bridge could be constructed or, in some cases, an inverted siphon was used. A siphon works by using pressure to transport a fluid to a height greater than the initial reservoir and returning it back down to a height below the initial reservoir. The inverted siphon worked in a similar manner, but rather than transporting the fluid up and then down, the fluid descended a slope (a valley for example) and returned to an elevation somewhere between the lowest point of the siphon and the initial reservoir. The Romans also were able to use flowing water (e.g., a river) to power mills for grinding grain or processing stones. The flowing water turned a large wheel that would, in turn, rotate gears and grinders. The complication that arose from powering mills with water was inconsistent flow through the waterwheel. When powering a device with a natural source, changes in climate, temperature, and other factors can cause the mill to stop functioning. To overcome this, the Romans designed dams to manage the flow of water and provide consistent power to the water wheel. This is a technology that was new in that time and, in many ways influenced the continued development and exploration of using water as a source of power. This technology continued to evolve into the hydraulics that are used in the modern era in the field of mechanical engineering.

A timeline will help here for a millennium or so – everything in the CE notation:

- **1**: Fire piston invented in Southeast Asia for starting fires. It heats a gas by rapid adiabatic compression to ignite a piece of tinder used to light kindling.
- **1**: Fulling mills to increase the thickness and compactness of woven or knitted wool by subjecting it to pressure, as well friction, moisture, and heat. [France]
- **25**: Hypocaust system for building heating used charcoal furnaces with tile flues in walls. [Pakistan]
- **50**: “Pneumatic” written identifying 75 devices that work on air, steam or water pressure, including the “hydraulis” (water organ) and "Mechanica" with gear ratio, basic devices, and hoists. [Hero, Alexandria, Egypt]
- **62**: Aeolipile devised a pure-reaction machine (the first steam engine). [Egypt]

- **70**: Secundus aka Pliny the Elder publishes "Naturalis Historia" with 37 books in 10 volumes covering astronomy, mathematics, geography, ethnography, anthropology, human physiology, zoology, botany, agriculture, horticulture, pharmacology, mining, mineralogy, sculpture, painting, and precious stones; a model for later encyclopedias.
- **80**: Two-barreled reciprocating pump is first seen made of wood. [Romans in Britain]
- **105**: Han Dynasty paper making started. [China]
- **132**: Seismograph built with an inverted pendulum. [China]
- **180**: Rotary fan first used for ventilation [China] transferred west (1556).
- **200**: Earliest wheelbarrows in use as one-wheeled cart [China].
- **200**: An iron crankshaft [Hierapolis sawmill Rome] had a crank and connecting rod.
- **200-265** A chariot with differential gears was invented [China].
- **315**: The Barbegal Aqueduct and mill complex is built with 16 waterwheels arranged in two descending columns built into the hillside. [France]
- **400**: Wind-driven prayer wheels documented. [China]
- **400**: Windmills appear in writings [China] (disputed)
- **400**: Double-piston bellows for continuous blast used. [China]
- **400**: Mineral oil used as lubricant [China]
- **438**: "Senchus Mor" written, followed by "Book of Aicill" describe civil code on mills, including horizontal waterwheels. [Ireland]
- **500**: Earliest specimens of fabric produced using a draw loom [Egypt] (believed earlier)
- **644**: Pumping machine powered by the wind. [*Persia]
- **725**: Escapement mechanism to regulate oscillation of clock hands. [China]
- **800–900**: A plough with concave iron board to guide and turn over heavy clay soil in a continuous-ribbon motion [China].
- **830**: Crank used with a rotary grindstone. [Western Europe]
- **850**: A signal system using clocks connecting Constantinople with the Cilician Frontier was developed.
- **985**: Hand crank is in use on an organistrum (hurdy-gurdy) [Spain] as an instrument.
- **1000**: Geared astrolabe designed with calendrical gearing for a clock.
- **1041**: Movable type. [China].
- **~1050**: An escapement mechanism built into astronomical clock tower. [China]
- **~1050**: First known endless power-transmitting chain drive.[China]
- **1088**: Escapement mechanism uses a trip lever and scoop wheel for clock towers [China]
- **1100**: Forge bellows with wooden boards and leather flap-valves. [Britain]

- **1150**: Stamp mill used in papermaking [Spain, Italy]
- **1150**: Floating mills depicted on the Seine. [Paris]
- **1170**: Tide mill (water mill driven by tidal rise and fall) [England].
- **1185**: Earliest records of fulling mills. [England]
- **1195**: Arab treatise by Ridwan on great automaton water clocks.
- **1200**: Stone stove heating system with chimney flue and slide damper. [Germany]
- **1200**: Horizontal bench lathe appears, using foot treadle to rotate object.
- **1200**: Cog ship (single-masted merchant ships) built for northern trade. [Europe]
- **1221**: First geared machine. [Persia]
- **1225**: Water-driven machinery recorded: sawmills, spring motion. [Europe]
- **1250**: Primitive rope escapement for clocks illustrated.
- **1256**: 'Five Books of Clocks' published. [Castile]
- **1280**: The spinning wheel illustrated for the first time. [Europe]
- **1300**: Iron manufacture begins to use blowing furnaces driven by water power. [Britain]
- **1304**: The mechanical clock first emerged. The von Wieck clock [Pais] (1362) the first clock known to have a foliot and a verge escapement. The Graggenturm [Luzern], (1385) with written operating instructions.
- **1322**: Evidence of the sawmill invented (mentioned 1076). [Europe]
- **1350**: Windmill-driven scoop wheel developed. [France]
- **1386**: Salisbury clock with crank mechanism is invented (still operating).[Britain]
- **1400**: Holland adapts the windmill for large-scale drainage (1439) for grinding grain.
- **1400**: Rapid evolution of full-rigged ship from a one-mast cog with square sail to four-mast galleon with bowsprit.
- **1400**: Improved loom advances weaving of elaborate silk fabrics.
- **1400**: Flywheel recorded as a machine in 15th-century manuscript.
- **1421**: German manuscript depicts early crank and connecting rod system. [Munich]
- **1430**: Spring drive introduced into mechanical clock. [Europe] Spring power presented clockmakers with a problem of how to keep the clock movement running at a constant rate as the spring ran down. This resulted in the invention of the stackfreed and the fusee in the 15th century, and many other innovations. *Note particularly that this is an early example mechanical control system with feedback*.
- **1435**: Ship called 'Scraper' dredges harbor channel. [Dutch]
- **1440**: Earliest evidence of block book, "Spirituale Pomerium": block-printed wood cuts. [Brussels]
- **1441**: First rain gauge: to measure precipitation with precision.

- **1448**: Gutenberg printing press developed with movable and reusable type.Gutenberg is also credited with the introduction of an oil-based ink which was more durable than the previously used water-based inks.
- **1450**: Blast furnaces with water-driven bellows first used.

At this point, deVinci started the first modern mathematical analysis of mechanical systems, and it could reasonably be associated with the beginning of mechanical engineering as a discipline as opposed to all of the excellent work done before that in experimental building of systems that worked and were useful. But far more importantly in my view was the 1584 invention of the toilet, which I will draw as the beginning of the modern era of mechanical engineering, and the inspiration for the early examples in this book.

Mechanical Engineering[14] [15]

Mechanical engineering: is a discipline for the use of force multipliers to move things, and more particularly, components, and machines. It uses mathematics, physics, materials science, and engineering technologies and is one of the oldest and widely used engineering disciplines. Earlier we discussed mechanical systems development before mathematics was developed and applied to understanding design for predictable results not based on purely experimental testing. But now things started to change. De Vinci might reasonably be credited with the start of this new field in which mathematics came into play in the design of complex machinery, but of course the basic machines were known long before.

- **1480**: deVinci analyzed continuous rotary action (friction, motion, and power). [Italy]
- **1485**: Evidence of the vertical grinding wheel with treadle and crank.
- **1487**: Earliest evidence of numerical reasoning applied to water-power technology.
- **1490**: First produced stove of record made of brick and tile. [France]
- **1490**: da Vinci's “Codex Madrid”, two notebooks with 197 pages, Volume 1 largely discussing mechanics, statics, and geometry. The notebooks include thoughts on improved ball bearings, worm gears, and bicycle chain drives.
- **1500**: Wheellock invented [Italy], a friction-wheel mechanism causes a spark to fire a firearm.
- **1500**: Leather foot bellows used. [Egypt]
- **1500**: Mitre-gate pound locks, a double-leaf gate the closure of which formed an angle pointing upstream, used in canal construction appeared [Europe]
- **1500**: Clear glass produced in large beehive furnaces fired by charcoal. [Europe].
- **1500**: Large undershot waterwheels used to drive pumps for water supply.
- **1505**: Original Nuremberg spring driven clocks with single hand. [Germany]
- **1510**: First portable clock (was spring driven). [Germany]
- **1523**: Earliest steelworks in Britain,

14 https://en.wikipedia.org/wiki/History_of_mechanical_engineering
15 https://ethw.org/Timeline_of_mechanical_engineering_innovation

- **1528**: A new type of ship called the Galleon (used by the Venetians against pirates. [Atlantic Ocean].
- **1530**: Foot-driven spinning wheel, a treadle to rotate a spindle with one foot and have both hands free to spin.
- **1534**: Ball thrust bearing introduced, free wheeling and made of wood. [Italy]
- **1539**: Molds made for casting lead pipe. [England]
- **1540-1546**: Book VI of the 'De re metallica' illustrated and described mining tools and technologies, including machines for lifting weights powered by people, horses, and water; horizontal driveshafts along tunnels allow lifting in shafts not directly connected to the surface, chains of buckets to lift water, piston force pumps, water pipe designs, wind scoops for ventilating shafts, forced air using fans or bellows, ladders, and lifts using wicker cages are used to get miners up and down shafts. [Germany]
- **1540**: Biringuccio's Pirotecnia on metallurgy and machine tools divided into ten books dealing with minerals, semi-minerals, assaying, smelting, the separation of gold from silver, alloys, the art of casting metals (especially bells and cannons), and alchemy. He describes molds made for casting to avoid defects, the way patterns are made for the final product shape, and more [Italy]
- **1550**: Universal joint described (1550 and 1557) by Cardano along with the inclined plane, the lever, and hydrodynamics. [Italy]
- **1552**: Iron rolling machine developed.
- **1561**: Baldewin's astronomical clock built with dials for Mars, Venus, Mercury, Saturn, Jupiter, the Earth's Moon, ar Astrolabe, and one for the calendar dial.
- **1562**: Dredgers of the Chinese chain-pump type used in Low Countries. [Germany]
- **1568**: Simple mandrel lathe shown on a woodcut of the "Panoplia Omnium".
- **1571**: Improved (screw) lathe described in Theatrum Instrumentorum [France]
- **1571**: Instruments Mathematiques et Mechaniques shows mathematical concepts applied to machines. [France, Geneva]
- **1584**: First water closet (toilet), is invented by Sir John Harington. It had a pan with an opening at the bottom, sealed with a leather-faced valve and a system of handles, levers, and weights poured in water from a cistern and opened the valve. [Britain]

We pause here for a major appreciation of one of the most important inventions of all time and in reverence for this early control system that changed to world in so many ways. Starting in this time frame, mechanical inventions emerged very quickly, both because of new science and industrial growth driving applications.

- **1588**: Rotary pumps described by Ramelli [France].
- **1589**: Britain devised the first stocking frame knitting machine which remained the only one in use for centuries. Its principle of operation remains in use. [England]
- **1590**: Galileo showed that a load supported by cantilevered beam can be calculated.

- **1590**: Updated analysis of simple machines and treatise on statics [Italy]
- **1590**: "On Mills" published by Stevin gives mathematical theory to scoop wheel improvements to raise water; first use of theory to analyze wind-powered, water-lifting devices.
- **1593**: Open, air-expansion thermoscope developed by Galileo [Italy], forerunner of thermometer, for comparing temperatures.
- **1594**: The wind-powered sawmill is invented converting log into planks 30 times faster.
- **1600**: Evidence of gear pump in use.
- **1600**: Rag-and-chain pump used to drain Cornish mines. [Britain]
- **1604**: Ribbon frames mechanized ribbon weaving and twining. [France]
- **1610**: Temperature regulator developed (thermostat) using a column of mercury and a system of floats and levers to maintain a steady temperature within a furnace. [Dutch]
- **1620**: First successful submarine, human-powered submersible demonstrated in 1624 [Britain]
- **1623**: Automatic multiplying and subtracting machine devised. Performed addition, subtraction, multiplication and division on six-digit numbers, indicating overflow by ringing a bell.
- **1629**: Branca described water-operated pumps of direct air-pressure type and a form of impulse steam turbine. [Italy]
- **1630**: Oughtred invented a circular slide rule and (1632) the modern slide rule.
- **1630**: Auxiliary, or vernier, scale invented; dial and linear calipers give a direct reading of distance measured with high accuracy and precision. [France]
- **1635**: Gearwheel pump illustrated.
- **1638**: Galileo demonstrated parabolic trajectory based on fundamental laws of motion. [Italy]
- **1640**: Screw caliper devised, used with telescope. [Britain]
- **1642**: First manufactured cast-iron stove produced.
- **1642**: Pascal designed and began work on his calculator, the first calculating machine to be made public with a controlled carry mechanism for effective propagation of multiple carries. [France]
- **1643**: Mercury barometer invented. [Italy]
- **1647**: Experiments on fluid forces involving siphons, bellows, and tubes published.
- **1650**: Horse-powered cog-and-rung gin raises coal from mine shaft. [England]
- **1652**: Air (vacuum) pump devised.
- **1655**: Epicycloidal profile for gear-wheel teeth developed to raise water. [Paris]
- **1656**: Pendulum-regulated clock built.

- **1657**: Public demonstration of two-horse teams pulling in opposite directions cannot overcome air pressure. [Germany]
- **1660**: Modern thermometer, also known as the Galileo thermometer invented. [Italy]
- **1660**: Effective balance spring for marine clock and a pocket-watch devised. [England]
- **1661**: Boyle's law of compression of gases.
- **1662**: Water-driven boring mill with guided auger for pump logs. [Britain]
- **1663**: Direct-steam 'water commanding' engine devised. [Britain]
- **1665**: Differential and integral calculus developed.
- **1666**: Screw-type micrometer perfected as a specialized eyepiece used in telescopes for astrometry measurements, in microscopes for specimen measurements, and in alignment and surveying telescopes for measuring angles and distances on nearby objects. [France]
- **1667**: Hooke invented the wind pressure gauge and improved bathometer, hygrometer, hydrometer, and barometer. [London]
- **1670**: Highly efficient microscope developed with a single lenses of high quality and short focal length. [Netherlands]
- **1670**: Rolled sheet lead made. [Britain]
- **1671**: Machine invented for cutting clock wheels, commercially available. (1784) [Britain]
- **1674**: Morland's plunger pumps patented for water supply to Windsor Castle. [Britain]
- **1674**: Mechanical-calculator mechanism designed and constructed. [Germany]
- **1675**: Balance wheel and spring oscillator, reliable accuracy, and precision gearing, then the introduction of the pendulum, the first harmonic oscillator used in timekeeping, increased accuracy from about 15 minutes per day to 15 seconds per day. The increased accuracy caused the minute hand to be added to clock faces. (1690)
- **1675**: Marine chronometer built: driven by coiled spring, with verge escapement for regulation, instead of a pendulum, opening the way to marine chronometers and modern pocket watches and wristwatches. [Netherlands]
- **1675**: Suction hose used in Amsterdam for fire engines. [Netherlands]
- **1676**: Repeating clock invented for striking clocks made to repeat the striking of the hour. [Britain]
- **1676**: Hooke's law of elasticity is developed to analyze material behavior with stress. [Britain]
- **1677**: Hautefeuille ignited gunpowder to create a vacuum.
- **1678**: Huygens outlined a gunpowder engine.

- **1679**: Steam digester invented as a cooker extracting fats from bones in a high-pressure steam environment, forerunner of autoclave, pressure valve invented to prevent explosions. [London]
- **1680**: Simple centrifugal pump invented. [Jordan]
- **1680**: Lever safety valve devised for steam engine. [France]
- **1685**: Air compressing pump for high pressure experiments invented. [Britain]
- **1687**: Wheeled vehicle driven by steam turbine described. [China]
- **1687**: Cast plate glass new pouring process to make plate glass mirrors measuring at least 60 by 40 inches wide [France]
- **1688**: First reflecting telescope built using mirrors instead of lenses. [Britain]
- **1689**: Centrifugal pump, known as Hessian pump, described, used in local drainage work, and applied to coal mine ventilation [Germany]
- **1690**: First demonstration of raising a piston using steam, used to raise water to a canal between Kassel and Karlshaven, and pump water to a tank on the roof of the palace to supply water for the fountains in the grounds. [England]
- **1690**: (patent received 7/28/1698) for practical steam pump.
- **1695**: Traite de Mecanique published a treatise on cycloidal gear teeth. [France]
- **1695**: Lead rolling mills used in England (1730 in France). [Britain]
- **1695**: Dry friction laws developed, thermometry studied, Clepsydra improved, optical telegraph developed. [France]
- **1699**: Steam pump 'fire engine' demonstrated and commercial steam engine. [Britain]

As a measure of progress, over the 1600s, about 55 new mechanical innovations are listed here. But if we continue down this line of significant mechanical innovations, we will find something over 150 such things in the 1700s, well over 750 in the 1800s, and about 360 between 1900 and the beginning of World War 2 (1937). Of course this would be very interesting, but it would add another hundred pages to this chapter with little benefit to the key issues. From here forward, I will dramatically compress and not duplicate much of what will be discussed later in the industrial revolution and in other areas. This expansion accelerated in part because of social changes in a feedback loop with scientific discovery and increases in education, transportation, and communication along with infrastructure developments.

Lathes, automatic planting and harvesting mechanisms, centrifugal mechanisms, improved timekeeping mechanisms, pumps of many sorts, furnaces, instrumentation, pipes, automatic weaving and other textile machines, forging and fabrication, hydraulic and water power, fabrication of materials including steel, machine tools, stage coaches and other transportation systems, steam engines, lenses and magnification systems, mining automation, valves and other control mechanisms, shipbuilding, a submarine with screw propeller, rail equipment, gearing systems, the modern toilet, measurement gauges, recording controls, balloon flight and dirigibles, food processing, commercial locks, materials handling equipment, tools making interchangeable parts, lifts and cranes, the diving bell, the gas turbine, coal gas extraction, the internal combustion engine, and a variety of control systems using set points were all developed in the 1700s.

In the 1800s, science was emerging rapidly, aiding in the acceleration, but driven largely by industrialization. Developments included advancements in water and hydraulic power, textiles, heating, boilers, energy extraction, mining, time keeping, factory automation, electrical powered systems and control mechanisms, shipbuilding, submarines, public railways, water works, higher pressure systems, road vehicles, large-scale factories and their mechanized manufacturing equipment, steam-powered ferries, adaptable pattern looms and similar increased flexibility in manufacturing mechanisms, infrastructure for gas lighting, semi-guided rockets, solid fuels, steel plates, paper and book manufacturing and printing, ventilation systems, paddle boats, piston engines, power compressors, arc welding, sheet metal and tin cans, bottling and canning of food, steam powered railways, prosthetic arms, gas meters, safety valves, safety lamps, mining machines, ploughs, the stethoscope, a heat exchanger, steam heating, steerable bicycles, pumps, differential machines, mass produced firearms, pipes, pipelines, steel alloys, sintering, cultivating machine, rotating rake, the Arithmometer calculating machines, friction brakes, first natural gas wells, power loom, crank shaft and camshaft, Babbage difference engine for mechanical computation, gas liquification, rubberized material, widely available gas piston engines, tensile strength testing, improved cement processes, aluminum production, first passenger trains, graphite crucibles, maleable wrought iron, powered printing press, photography, ventilation systems, blast furnaces, yarn spinners for better threads, iron rails, thermocouples and bi-metallic strips, the dynamometer, gear cutting machines, the first working sewing machine, mining human transport railways, more accurate scales and weighing devices, building-wide heating systems, grinding machines, swiveling wheels, mechanical reaper, the horse tramway for cities, soda-water production, type casting capable of 20,000 characters per day, the Wheatstone bridge (electrical device used for mechanical property testing), pin-making, internal combustion direct power engine, hot water circulation systems, the first mechanical refrigerator, mechanical computation machines with an arithmetic logic unit, conditional branching and loops, and integrated memory (perhaps the first finite Turing Complete machine), materials elevators, steam trap safety device, horseshoe and railroad spike manufacturing machines, revolver hand pistols, steam-powered glass manufacturing plants, the steam hammer, the indirect governor (feedback control mechanism), shaping machines, the safety hook, steam shovel, American Standard locomotives, fiberglass, friction matches, repeating rifles, new measurement devices, pneumatic regulators for valve control, first transatlantic ships with propellor engines, steel-edged plow, axial-flow turbines, gearless wind pressure meters, brass and copper piping, shale oil distillation and refining, vulcanized rubber, compressed fuel piston engines, screw-propellor ships, shaft governors (control systems), stop valves, helical propellors, cast iron railroad wheel, peddled bicycles, fuel cells, first photovoltaic cells, and on and on. That’s just the first third of the century.

By the early 1900s, almost any modern mechanical convenience you can think of not using a computer or complex electronics existed in one form or another. This explosion of invention had many causes, but one of the keys to it moving from trial and error to engineering was the emergence of the invisible.

The parallel emergence of the invisible

Average human life spans in the early 1800s was about 29 years with no country exceeding 40 years and many countries with rapidly changing averages, likely due to diseases, conflicts, availability of food, and other conditions. By 1900 it was about 31 with regions like Oceania reaching 48 and the US reaching 47. By 1950 the world average was about 47 with 60 in Europe, Oceania, Japan, and North and South America, despite or possibly aided by World War 1 and 2 and the pandemic of the 1910s. Clearly, better understanding of the invisible was a critical component of this change, and of course, the increased age of more educated and experienced people led to this virtuous cycle.[16]

Until this time, almost everything people used for understanding was based on personally observed or observable phenomena. Everything too small to see without minimal instrumentation (perhaps a lens) was attributed to magic, gods, or hypothesized notional phenomena and based on theories that could not be tested. Mathematics was the abstract science, but it was used in practice to do calculations about observable physical phenomena.

Medical and biological breakthroughs

But it took very little time on the evolutionary scale to go from the 1590s the first compound microscope[17] [18] to the 1665 identification of the cell as a component of life forms including humans.[19] The deeper we looked, the more we saw, and the more we saw, the more we explored and tested theories, using refutation as a guidepost to abandonment.[20] While 1593 saw the first textbook “On the structure of the human body”, revolutionary on its own, the discovery of bacteria in 1683 took less than 30 years after cells were identified, and the first smallpox inoculation was given as a result in 1701.[21] The first modern vaccination against smallpox came in 1796 with deployment starting in 1798. The stethoscope was invented in 1816, allowing listening to internal processes from outside the body, blood transfusion was first used in 1818, and ether for anesthesia was first used in 1842, followed quickly by nitrous oxide anesthesia in 1844, the identification of bacteria as a cause of disease in 1857, the use of antiseptics in surgery in 1867, and the adoption of germ theory of disease starting in 1870.

Once this started rolling, it became an unstoppable force of progress with; more diseases identified as associated with causes; cholera, anthrax, and rabies vaccines developed respectively in 1879, 1881, and 1882; antiseptics reducing the spread of disease in hospitals, operations enabled by anesthesia (appendicitis first cured by an operation in 1886); antitoxins and tetanus and diphtheria vaccines in 1890; typhoid vaccines in 1896, bubonic plague in 1897; insect-borne diseases were understood in about 1900; and seemingly the war on disease was all of a sudden being won by humans defeating microscopic organisms.[22] Average life spans went from no more than 30 years to almost 50 years in some regions over only one century because of better understanding of the invisible world.

16 https://en.wikipedia.org/wiki/Life_expectancy
17 https://www.historyoftelescope.com/telescope-invention/zacharias-janssen/
18 https://en.wikipedia.org/wiki/Zacharias_Janssen
19 https://pmc.ncbi.nlm.nih.gov/articles/PMC4360124/pdf/rstb20140344.pdf
20 https://pmc.ncbi.nlm.nih.gov/articles/PMC9609744/pdf/pathogens-11-01147.pdf
21 https://pmc.ncbi.nlm.nih.gov/articles/PMC4379645/
22 https://hms.harvard.edu/about-hms/history-hms/timeline-discovery

And this continued throughout the 1900s with insulin to treat diabetes (1922), diphtheria vaccination (1923), whooping cough vaccination (1926), tuberculosis vaccination (1927), tetanus vaccination (1927), penicillin as the first broad spectrum antibiotic (1928), yellow fever vaccination (1935), typhus vaccination (1937), streptomycin as a wide spectrum antibiotic (1943), influenza vaccination (1945), polio vaccination (1952), and polio vaccination (1955). By 1950, life span averages were up to about 60 years in countries with vaccination in place, doubling over only 150 years. Again, the invisible and the advancement of science, along with increased availability of food and safer drinking water, changed the nature of humanity as co-evolution altered the survival equations.

Of course all of this progress at such large scale depended critically on the ability to do mass manufacturing, distribution, and delivery; and proper controls in these processes for vaccines and chemical compounds.

- Manufacturing vaccines in volumes high enough to vaccinate millions of people involves creating an environment in which they can grow and with a level of purity that keeps them from being tainted. Early vaccination was arm to arm, with each vaccinated person transfusing small amounts of antibody-included blood to others. Various forms of pus were also used. The next step was the use of farm animals and the development of farms full of vaccinated animals producing inoculated serum for injection into people. This became the preferred method. A few spectacular failures later and regulatory intervention started to control the animal vaccination farms.[23]
    - Fermentation for cultivation and toxoid production evolved from ancient food preservation methods to a cornerstone of modern biotechnology. Pasteur, in the 1800s, enabled controlled microbial growth for vaccines and toxins using a fermentation process.[24] Any decent moonshiner will tell you, high quality results from fermentation require temperature and pressure control, a proper base substance for growth, provides purification, and sterilizes undesired components along the way. This is the essential process used for growing vaccines still today, but in far better controlled vats with more specific compounds and processes used to assure consistent quality and quantity at cost over time. Thus as control systems and better capabilities for producing metals at larger scale in better purity (also through control systems) developed, it improved the ability to create mass produced vaccines.
- A different problem is transporting vaccines to recipients. As it turns out, this generally requires refrigeration because vaccines degrade rapidly over time and with higher temperatures. The so-called vaccine cold chain is a supply chain that keeps the vaccines cold between manufacture and use.[25] This really became available in the 1940s at scale for the last leg of the vaccination process, but before that, animals were transported as carriers of immunity and vaccines harvested close to the ultimate destination. As control systems, animals work very well because they are temperature controlled and continue manufacturing while they go from place to place. Freeze drying was also used for some vaccines, again starting once the processes were reasonably perfected at scale. Again, these are processes that dramatically improved with the

23 https://pmc.ncbi.nlm.nih.gov/articles/PMC7294234/
24 https://pmc.ncbi.nlm.nih.gov/articles/PMC10991178/
25 https://www.gavi.org/vaccineswork/vaccine-cold-chain-history

industrial revolution and its ability to create more and better controlled environments and more rapid movement from place to place through improved transportation.

- Finally, trained people who can administer the vaccines (many require a shot in the arm or elsewhere) have to be put in place, and they need to be supplied with sterile needles or the ability to sterilize them for reuse or diseases spread from recipient to recipient creating new epidemics as they go. Again, control systems for the goods and their processing and delivery, and educational systems for people to enable them to repeatedly and reliably perform the last step in delivery.

Medical breakthroughs were particularly important as a co-evolutionary force because as people lived longer, they became better able to educate themselves and others, do advanced work over longer periods of time, spread their knowledge further, and importantly, have more time to learn from others to understand more complex and multidisciplinary problems as both individuals and as groups. The industrial revolution combined with medical advances produced spectacular results.

Physics, chemistry, properties of materials, astronomy, engineering, and up...

But progress was not just in medicine. With the ability to see smaller things more clearly, a lot more came to be understood about other things, like micro-structures of materials, the atomic theory, and chemistry. And of course these interacted with medicine and biology as well.

Physics and astronomy

Gravity is invisible but its effect is always present on Earth and we can see the effects. Even so, it took till 1665 or so for Newton to notice it and till 1687 to characterize it in “Philosophiæ Naturalis Principia Mathematica”.[26] [27] ‘Newtonian’ physics was born, but Newton never used equations to provide the details. Equations were developed later by many contributors and the equations were applied to a wide range of things from the motion of the planets per Galileo (1638) to things too small to see. F=ma was first published (1775 by Euler), Galileo (1638) enunciated Laws of Inertia, Descartes used that for the second law of motion (1644), and Huygens for his hypothesis that bodies move with equal velocity when friction is not present (1673), but none used acceleration in explaining the motion of bodies before Euler.[28]

As observations were improved with instrumentality, the invisible was made visible and the unobservable made observable, in general, through innovations in instrumentation.

- A good example was the understanding of light as a range of frequencies associated with perceived colors. The rainbow gives you that, but what about over the edge of the rainbow? Beyond the red (the infrared) and blue (the ultraviolet) lie the entire range of frequencies (cycles per second) from approaching zero to approaching infinity. Understanding and being able to observe more of the spectrum of electromagnetic phenomena is the realm of spectroscopy.[29] This began with the splitting of light using a prism (Newton[30] 1670-1672), then the understanding of the electromagnetic spectrum

26 https://en.wikipedia.org/wiki/Philosophi%C3%A6_Naturalis_Principia_Mathematica
27 https://www.britannica.com/science/How-Was-Gravity-Discovered
28 https://www.iosrjournals.org/iosr-jap/papers/Vol13-issue2/Series-1/I13020161138.pdf
29 https://en.wikipedia.org/wiki/Spectroscopy
30 https://en.wikipedia.org/wiki/Isaac_Newton

(Maxwell[31] 1861-1865,1884[32]), the two slit experiment[33] that led to the recognition of the dual nature of light as a particle and a wave[34], leading to quantum mechanics[35] and the uncertainty principle[36] [37] (1925, 1927), and on from there to modern understandings that continue to change as we learn more. Among the astonishing results are the ability to detect the chemical makeup based on the emitted frequencies of light (based on the production of photons by drops in electrons from shell to shell in orbits around atomic nuclei) with sets of frequencies producing multi-frequency spectral ‘lines’. Motion toward or away from the observer produces the Doppler shift phenomena[38] (like a train whistle coming toward then going away from you changes frequency of the sound) leading to the velocity of objects (including stars) by the shift in frequencies of sets of related electromagnetic spectral lines.

Astronomy had it that the Earth is the center of the Universe, and that the Universe outside of the solar system was a fixed sphere of stars.[39] [40] [41] [42] Aristotle (2,350 Ya) notioned that the Earth rotated around the Sun. Aristarchus (2,270 Ya) modeled the Earth rotating around the Sun. Ptolemy (200) has a depiction of a sun-centered universe with a fixed set of stars as a sphere beyond the solar system. Levi ben Gershon (1300) recognized that the stars are much larger than the planets and surmised that the “fixed stars” were much further away than the planets, then estimated the distance to the fixed stars to be no less than 159,651,513,380,944 Earth radii (100,000 light-years) away. Of course this did not catch on at the time. Copernicus (1520) had it that the Sun was the center of the Universe, challenging church doctrine. Tycho Brahe (1580's) built the Danish observatory and created a database of observations that drive a lot of progress but his notions of the moon rotating around the Earth, the other planets rotating around the Sun, and the Universe rotating around the Earth turned out to be off a bit. Kepler (1600's) used Brahe's database to formulate the Laws of Planetary Motion which correct the problems of epicycles by using ellipses instead of circles for orbits of the planets. Galileo (1620's) developed laws of motion (natural versus forced motion, rest versus uniform motion). Then observationally destroyed the the idea of a "perfect", geocentric Universe. He also identified the Milky Way as a bunch of stars. Newton (1680's) developed the law of Universal Gravitation, laws of accelerated motion, invented calculus and the 1st reflecting telescope and theory of light. Lots of other stuff was studied and found out about, then (1862) the spectroscopic signature of the Sun is compared other stars, and Father Angelo Secchi determines that the Sun is itself a star. Lots of other stuff happens, then in 1920 (only about 100 Ya) “The Great Debate” between Harlow Shapley and Heber Curtis had galaxies finally recognized as objects beyond the Milky Way, and the Milky Way as a galaxy. In 1946, a camera-equipped (US) V-2 rocket provides the first image of the Earth from space (Surprise! It’s round!).

31 https://en.wikipedia.org/wiki/James_Clerk_Maxwell
32 https://en.wikipedia.org/wiki/A_Dynamical_Theory_of_the_Electromagnetic_Field
33 https://en.wikipedia.org/wiki/Double-slit_experiment
34 https://en.wikipedia.org/wiki/Wave%E2%80%93particle_duality
35 https://en.wikipedia.org/wiki/Quantum_mechanics
36 https://en.wikipedia.org/wiki/Werner_Heisenberg
37 https://en.wikipedia.org/wiki/Uncertainty_principle
38 https://en.wikipedia.org/wiki/Doppler_effect
39 https://www.librarypoint.org/blogs/post/early-astronomers/
40 https://pages.uoregon.edu/jschombe/ast121/lectures/lec02.html
41 https://en.wikipedia.org/wiki/Timeline_of_Solar_System_astronomy
42 https://en.wikipedia.org/wiki/History_of_astronomy

- It's critical to understand interdependency between astronomy and mathematics. As an example, measuring distances to stars was infeasible until the parallax method was developed based on multiple observations from different locations and the ability to measure the differences between object locations in the two measurements. Like switching from left to right eye with a finger in front of your face, the objects behind your finger move more or less when they are closer or further away. A calculation and you get the distance of the object vs. the distance between your eyes, the distance to your finger, and the distance to the object.
- It's also critical to understand the relationship between astronomy, metallurgy, and grinding techniques. The reflective telescope used a mirror, often made of metal, ground to a very smooth surface. Minor flaws in the reflective surface resulted in larger flaws in the magnified images produced. As metallurgy progressed and machine tools improved, better polishing was possible, producing more accurate measurements, and allowing glass for mirrors (1850s). Telescopes were manufactured, improvements in the manufacturing process led to better understanding of the world and universe, which drove and was driven by advances in mathematics, that led to improvement in analysis of materials, which led to better materials, and round and round the feedback loop goes. A control system of scientific and engineering advancement with positive feedback limited by funding and available technologies and resources.

Thermodynamics

Thermodynamics[43] [44] [45] is a field that explores, in essence, the nature of heat and temperature, the conservation of energy, and the relationship of mass and energy. It was and is tightly linked to technological process in that it brought about new understanding that depended on new instrumentation that arose in part from that new understanding.

The ideal gas law, *pV=nRT*, was first given by Benoît Paul Émile Clapeyron in 1834 as a combination of Boyle's law (1662), Charles's law (1780s), Avogadro's law (1811), and Gay-Lussac's law (1808).[46] It is used for all manner of things still today, including air conditioning and refrigeration that enable transportation of medical breakthroughs, the operation of complex engines that enable rapid transportation and mass manufacturing, and on and on. The only early mention that nature abhors a vacuum is from a poem about 2,500 Ya by Greek philosopher Parmenides. European scientists in the 16th and 17th centuries gauged relative "coldness" or "hotness" of air using a rudimentary air thermometer (a thermoscope). Francis Bacon (1620) in "Novum Organum" surmised: "Heat itself, its essence and quiddity is motion and nothing else." ... "not ... of the whole, but of the small particles of the body." thus identifying heat as related to motion. René Descartes (1647) wrote "Lifting 100 lb one foot twice over is the same as lifting 200 lb one foot, or 100 lb two feet.". Leibniz (1686) wrote essentially the same thing. Boyle and Hooke (1656) built an air pump and noticed pressure times volume was constant and Boyle's law followed soon thereafter. From there, a bone digester using steam (1697), followed by a fire engine incorporating a piston that could send water 30 ft (1697), the Savery steam engine (1698), and warm air rising (1686) was part of

43 https://en.wikipedia.org/wiki/History_of_thermodynamics
44 https://pmc.ncbi.nlm.nih.gov/articles/PMC7516509/
45 https://www.perplex.ethz.ch/thermo_course/various_thermodynamics_texts/Muller%202007%20A%20history%20of%20thermodynamics.pdf
46 https://en.wikipedia.org/wiki/Ideal_gas_law

understanding heat transfer Newton's "law of cooling" (1701), absolute zero as a temperature below which there was none other (Amontons 1702) and caloric theory (1700s) is a historical marker of the transition from alchemy to chemistry.

Bernoulli (his book Hydrodynamics) (1738) derived an equation for the pressure of a gas considering the collisions of its atoms with the walls of a container. Heat capacity, was researched and named by Black (1750s). Scheele distinguished radiant heat from convection and conduction in 1777. The new science of electricity identified that some materials were good electrical conductors while others were effective insulators included some of the earliest measurements by Ingen-Housz and Thompson (1785-9). Prévost (1791) showed that all bodies radiate heat no matter the temperature, Leslie observed that a matte black surface radiates heat more effectively than a polished surface (1804). Rumford (1798) showed that boring cast iron cannons produced great amounts of heat which he ascribed to friction, the beginning of the end for caloric theory, and identified heat as a form of motion.

Carnot, the "father of thermodynamics", published "Reflections on the Motive Power of Fire" (1824), a discourse on heat, power, and engine efficiency. Melloni (1831) demonstrated that radiant heat could be reflected, refracted and polarized in the same way as light. Kinetic theory started in the mid-1800s, and Joule (1843-) did reproducible quantitative studies and experimentally found the mechanical equivalent of heat, and in 1845, reported using a falling weight to spin a paddle-wheel in a barrel of water to estimate a mechanical equivalent of heat. This led to the theory of conservation of energy and explained why heat can do work. The idea of absolute zero was generalized in 1848 by Lord Kelvin, hence degrees Kelvin (273 K = 0 C). Kelvin speculated that heat loss was inevitable (1851) and Helmholtz (1854) speculated that this implies a heat death for the universe where all energy degraded till no useful work was left. Rankine (1854) started to use thermodynamic function in calculations that has since been shown to be identical to the concept of entropy given by Clausius (1865) which is now called the 2nd law of thermodynamics, and in "On the nature of the motion called heat" (1857), first clearly stated that heat is the average kinetic energy of molecules. Boltzmann (1875) formulated a precise formula for entropy in terms of molecular motion, Gibbs (1876) defined a free energy equation to measure the "useful work" attainable in reacting systems and H (now known as enthalpy), "a heat function for constant pressure". Stefan (1879) observed that the total radiant flux from a blackbody is proportional to the fourth power of its temperature (the Stefan-Boltzmann law) later derived theoretically by Boltzmann (1884).

- **Between 1662 and 1884**, 222 years, naivete had been turned into a mechanical and mathematical understanding of the world that started to make sense. At this point, if you were alive at the time and knew what was going on, you might start to think that all the issues were settled. But then..

Planck (1900) found an accurate formula for the spectrum of black-body radiation and introduced a new constant (the Planck constant), a fundamental constant of modern physics. Looking at the radiation emitted from a cavity oscillator in thermal equilibrium, the formula suggested that energy in a cavity occurs only in multiples of frequency times the constant, and is thus quantized. Einstein (1905) argues that the reality of quanta would explain the photoelectric effect, then mathematically analyzes Brownian motion as a result of random molecular motion in "On the movement of small particles suspended in a stationary liquid demanded by the molecular-kinetic theory of heat". Nernst (1906) stated the third law of thermodynamics[47] [48] (the entropy of a closed system at thermodynamic equilibrium approaches a constant value when its temperature approaches absolute zero), Einstein (1907) used quantum theory to estimate the heat capacity of a solid, and things really took off from there[49]…

- The Dirac equation unified quantum mechanics and special relativity (1928)[50] [51] into "quantum field theory" and provided a mathematical basis for the anti-electron which was later verified by experiment and demonstrated to appear and recombine in pairs with electrons spontaneously in 'empty space'. There's a lot of progress up to WW2 when nuclear weapons…

Chemistry

Chemistry started out as alchemy without a scientific basis long ago, and over time, people learned to make various chemical compounds for various purposes without understanding the underlying chemistry or chemical structures involved.[52] Somewhere around 850-900, Arabic works attributed to Ḥayyān introduced a systematic classification of chemical substances with instructions for deriving an inorganic compound (ammonium chloride) from organic substances (e.g., plants, blood, and hair) by chemical means, leading over a few centuries to discovering mineral acids (1300 or so), Alderotti described a method for concentrating ethanol using repeated fractional distillation through a water-cooled still, getting ethanol purity to 90% (1250), arsenic and silver nitrate were made by Magnus (1260), Libavius published "Alchemia", a prototype chemistry textbook (1597), and so forth, still all alchemy without a theory.

Bacon (1605) published "The Proficience and Advancement of Learning", containing a description of what would later be known as the scientific method, Descartes published "Discours de la méthode" (1637) with an outline of the scientific method, and (1648) "Ortus medicinae" is published (posthumously) in which van Helmont authors a transitional work between alchemy and chemistry, results of many experiments and an early version of the law of conservation of mass. This influences Boyle's (1661) "The Sceptical Chymist", detailing the distinction between chemistry and alchemy and with some of the earliest modern ideas of atoms, molecules, and chemical reactions. The next year (1662), Boyle's law identifies the relationship between pressure and volume.

Up until the 1600s, science assumed that air was everywhere, but Torricelli (1643)[53] showed not only that air (and the atmosphere) had weight, but that you could empty space of air, and shortly thereafter, it was demonstrated that air pressure reduces even at the top of a tall building, and later it reduced further on mountains. This was done by filling a tube with mercury, holding the top closed, putting the bottom in a mercury filled dish without letting air into the top, letting go of the bottom of the tube, and watching the tube partially empty. Above the mercury was, presumably nothing, and the fact that it didn't go all the way down meant

47 https://en.wikipedia.org/wiki/Third_law_of_thermodynamics
48 https://pmc.ncbi.nlm.nih.gov/articles/PMC7516509/pdf/entropy-22-00077.pdf
49 https://en.wikipedia.org/wiki/Timeline_of_thermodynamics
50 https://www.aps.org/apsnews/2024/11/mathematical-intuition-dirac-quantum-mechanics
51 https://watermark02.silverchair.com/rspa.1928.0023.pdf
52 https://en.wikipedia.org/wiki/Timeline_of_chemistry
53 https://en.wikipedia.org/wiki/Torricelli%27s_experiment

that the atmosphere was pushing down on the dish of mercury. The distance the mercury lowered (inches of mercury) was the metric of pressure.

> *Is there really nothingness? While the notion of a vacuum as not containing anything seems appealing, at best such a vacuum would be a region of space devoid of atoms, and atoms are not everything. As quantum physics describes even atomic particles, they are statistical phenomena in that their location is actually a probability distribution and not a fixed location. At best, the probability of finding something within the space of a vacuum is lower, but never really 0. But there is also the fact that, even in a vacuum, there are electromagnetic waves and light waves (photons are apparently both particles and waves), gravitational forces and waves, and who knows what else present. We have no way of emptying space of all such things, and if we did we would not, presumably, be able to do it within our reality of space-time. And then there is the Dirac equation and related matters from above relating to spontaneous generation and recombination of electrons and anti-electrons in otherwise empty space.*

> *On the other hand, removing atmosphere and other contaminants led to mass production and commercialization of the light bulb which required a vacuum in order to not burn out (oxidize) the filament. That led to other sorts of tubes, like the tubes used for amplification in radios, tubes to produce X-rays, television tubes, and on and on… In fact, it led to the discovery and characterization of the atom.*

The mid 1700s saw advancements come fast and furious. Brandt analyzed copper ore pigment and identified cobalt (1735), Black isolates carbon dioxide (1754), the first synthetic organometallic compound (cacodyl oxide by Gassicourt 1757), latent heat to explain the thermochemistry of phase changes (Black, 1758), Cavendish (1766) discovers hydrogen, Scheele and Priestley independently isolate oxygen (1773-1774), Lavoisier (The father of modern chemistry) recognizes, names, and identifies oxygen and oxygenation for combustion (1778), publishes “Méthode de nomenclature chimique”, the first modern system of chemical nomenclature (1787), and publishes “Traité Élémentaire de Chimie”, the first modern chemistry textbook, a complete survey of (at that time) modern chemistry, including the first concise definition of the law of conservation of mass, and thus also the founding of the discipline of stoichiometry or quantitative chemical analysis (1789). Proust (1797) proposed the law of definite proportions, that elements always combine in small, whole number ratios to form compounds.

In 1800 (only 225 years ago), Volta devised the first chemical battery, founding electrochemistry, and enabling transportation of electrical power in stored form. Volta is the namesake of ‘volts’, used in electricity and electrical engineering to this day. Gay-Lussac discovered (1805) that water is composed of two parts hydrogen and one part oxygen by volume (H_2O) and collects and discovers several chemical and physical properties of air and of other gases, including experimental proofs of Boyle's and Charles's laws, and of relationships between density and composition of gases (1808). Dalton published the first modern scientific description of the atomic theory, and clear description of the law of multiple proportions (1808) and Berzelius published “Lärbok i Kemien” proposing modern chemical symbols and notation, and relative atomic weight. Avogadro proposed Avogadro's law (1808), that equal volumes of gases under constant temperature and pressure contain equal number of molecules, and (1865) Loschmidt determined the exact number of molecules in a mole (Avogadro constant). The first confirmed discovery and explanation of isomers (1825), correctly deduced that isomerism is caused by arrangements of atoms within a molecular structure. Biomolecules were classed into their modern groupings: carbohydrates, proteins and lipids (1827), Wöhler synthesizes urea, establishing that organic compounds could be produced from inorganic starting materials, disproving the theory of vitalism (1828), and organic chemistry comes to life. Conservation of energy (1840) of a form was proposed by Hess, Kelvin established absolute zero (1848) where all molecular motion ceases, Pasteur advanced the field of stereochemistry (1849), and Beer (1852) established spectrophotometry. Chemical industries still around today were formed by results of Silliman (1855) with methods of petroleum cracking enabling the modern petrochemical industry and Perkin (1856) with the first synthetic dye, one of the earliest successful chemical industries. von Stradonitz proposed that carbon forms exactly four chemical bonds (1857), Kirchhoff and Bunsen laid the foundations of spectroscopy as a means of chemical analysis (1859–1860), leading to the discovery of caesium and rubidium, and other workers soon used the same technique to discover indium, thallium, and helium. Note the Bunsen Burner is widely used today in chemistry and Kirchhoff's current and voltage laws are key to circuit analysis in electrical engineering.

The 1860s saw rapid results as the underlying theories were increasingly stabilizing. Cannizzaro compiled a table of atomic weights presented at the 1860 Karlsruhe Congress, ending decades of conflicting atomic weights and molecular formulas, and leading to Mendeleev's discovery of the periodic law. Parkes exhibits early synthetic polymers, at the International Exhibition in London, forming the foundation of the modern plastics industry (1862), and de Chancourtois published the telluric helix, an early, three-dimensional version of the periodic table of the elements (1862). In 1864, Newlands proposed the law of octaves, a precursor to the periodic law, Meyer developed an early version of the periodic table with 28 elements organized by valence, and Guldberg and Waage proposed the law of mass action. In 1865, von Stradonitz established the structure of benzene as a six carbon ring with alternating single and double bonds, and von Baeyer began work on indigo dye, revolutionizing modern industrial organic chemistry and the dye industry. In 1869, Mendeleev published the first modern periodic table, with the 66 known elements organized by atomic weights. The strength of his table is its ability to accurately predict the properties of (then) unknown elements.

In the 1870s and 80s things about atoms started to solidify. van't Hoff and Le Bel independently developed a model of chemical bonding that explained the chirality experiments of Pasteur and provided a physical cause for optical activity in chiral compounds (1873). Gibbs published “On the Equilibrium of Heterogeneous Substances” (1876), a compilation of his work on thermodynamics and physical chemistry which lays out the concept of free energy to explain the physical basis of chemical equilibria. This is critically important because it sets up for energy extraction and stability criteria in reactions. Boltzmann established statistical derivations of many important physical and chemical concepts, including entropy, and distributions of molecular velocities in the gas phase (1877), and Arrhenius developed ion theory to explain conductivity in electrolytes (1883). van 't Hoff published “Études de Dynamique chimique” (1884), a seminal study on chemical kinetics, while Fischer proposed the structure of purine, a key structure in many biomolecules (1884), which he later synthesized (1898) and began work on the chemistry of glucose and related sugars. Le Chatelier developed his principle that explains the response of dynamic chemical equilibria to external stresses (1884) and Goldstein named the cathode ray (1884), later discovered to be composed of electrons, and the canal ray (positive rays), in this case later discovered to be positively charged hydrogen ions that had been stripped of their electrons in a cathode ray tube. These would later be named protons. So now we had electrons and protons and vacuum tubes enabling their generation and aiming at targets.

The 1890s continued innovations with Werner discovering the octahedral structure of cobalt complexes and establishing the field of coordination chemistry (1893), and (1894-8) Ramsay discovering the noble gases, which do not react and thus filled a large and unexpected gap in the periodic table and led to models of chemical bonding. In 1897, Thomson discovers the electron using the cathode ray tube and in 1898 Wien demonstrates that canal rays (streams of positive ions) can be deflected by magnetic fields, and that the amount of deflection is proportional to the mass-to-charge ratio. This led to mass spectrometry which is critical to measuring and analyzing chemical compounds by emitted photons (light), and in 1898 Madam and Pierre Curie isolate radium and polonium from pitchblende, which are radioactive, then Rutherford discovered the source of radioactivity as decaying atoms, coins terms for various types of radiation (1900).

- **Over one century**, chemistry went from finding out water was made of hydrogen and oxygen to the foundations of modern industries, including plastics, petrochemicals enabling fuels of various sorts, organic chemistry, synthesis of all manner of compounds, analytical techniques and measurement devices, the structure of the atom and predicting properties of atoms related to valences, and through to the discovery of radioactivity. Of course this was co-evolving with the developments in medicine and thermodynamics and electrical engineering along with advancements in other areas. And that ended only 125 years ago. Note the oldest living person is about 120 years old, and my grandparents were alive during the last decade of this time frame.

Tsvet invented chromatography (1903), Nagaoka proposed an early nuclear model of the atom, where electrons orbit a dense massive nucleus (1904), Haber and Bosch developed the process for making ammonia from its elements, a milestone in industrial chemistry with deep consequences in agriculture (1905), and in the same year Einstein explained Brownian motion in a way that definitively proves atomic theory. In 1907 Baekeland invented bakelite, one of the first commercially successful plastics and in 1909, Millikan performed the oil drop experiment to measure the charge of individual electrons with unprecedented accuracy, confirming that all electrons have the same charge and mass while Sørensen invented the pH concept and developed methods for measuring acidity. Broek proposed the idea that the elements on the periodic table are more properly organized by positive nuclear charge rather than atomic weight, and in 1911, the first Solvay Conference is held in Brussels, bringing together most of the most prominent scientists of the day. Conferences in physics and chemistry continue to be held periodically to this day. That same year Rutherford, Geiger, and Marsden performed the gold foil experiment, which proves the nuclear model of the atom, with a small, dense, positive nucleus surrounded by a diffuse electron cloud. In 1912, Bragg's law establishes the field of X-ray crystallography, an important tool for elucidating the crystal structure of substances, and Debye develops the concept of molecular dipole to describe asymmetric charge distribution in some molecules.

In 1913, Bohr introduces concepts of quantum mechanics to atomic structure by proposing what is now known as the Bohr model of the atom, where electrons exist only in strictly defined orbitals, and of course this changes everything at a very low level with little effect at higher levels of abstriction (for a bit). Moseley introduces concept of atomic number to fix inadequacies of Mendeleev's periodic table, which had been based on atomic weight, Soddy proposes the concept of isotopes, that elements with the same chemical properties may have differing atomic weights, and Thomson shows that charged subatomic particles can be separated by their mass-to-charge ratio, a technique known as mass spectrometry. In 1916, Lewis published "The Atom and the Molecule", the foundation of valence bond theory, then in 1921 Stern and Gerlach established the concept of quantum mechanical spin in subatomic particles, in 1923, Lewis and Randall publish “Thermodynamics and the Free Energy of Chemical Substances”, the first modern treatise on chemical thermodynamics and Lewis developed the electron pair theory of acid/base reactions. In 1924, de Broglie introduced the wave-model of atomic structure based on the ideas of wave–particle duality, in 1925, Pauli developed the exclusion principle, which states that no two electrons around a single nucleus may have the same quantum state, as described by four quantum numbers, and The Schrödinger equation entered into the fray in 1926 providing a mathematical basis for the wave model of atomic structure. Then in 1927 Heisenberg develops the uncertainty principle which, among other things, explains the mechanics of electron motion around the nucleus, in 1927 London and Heitler applied quantum mechanics to explain covalent bonding in the hydrogen molecule, marking the birth of quantum chemistry.

- **In about 15 years,** the Newtonian view of the world and the view of the atom was completely altered and the universe people were used to was now a completely different place for those who knew what was really going on… or did they?

In 1929, Pauling publishes rules that are key principles for the use of X-ray crystallography to deduce molecular structure, then Hückel proposes his rule (1931) that explains when a planar ring molecule will have aromatic properties and Urey discovers deuterium by fractionally distilling liquid hydrogen. In 1932, Chadwick discovers the neutron, completing the model of the atom and reconciling the total mass with protons. Carothers led a team of chemists at DuPont who invent nylon (1935), one of the most commercially successful synthetic polymers in history and still widely used. The first artificially produced element was synthesized and confirmed (1937) by Perrier Segrè (technetium-97) which filled a periodic table gap (disputed as synthesized by Noddack and others from 1925). Also that year (1937), Houdry developed a method of industrial scale catalytic cracking of petroleum, leading to the development of the first modern oil refinery, and Kapitsa, Allen, and Misener produced the first zero-viscosity superfluid (supercooled helium-4 that displays quantum mechanical properties on a macroscopic scale). In 1939, Hahn and Meitner discovered the process of nuclear fission in uranium, obviously ultimately leading to atomic weapons and nuclear power, and Pauling published “The Nature of the Chemical Bond”, a compilation of a decades worth of work on chemical bonding. It explained hybridization theory, covalent bonding, and lots more.

At this point, World War 2 was underway, and things were about to change dramatically.

Materials Science and Engineering

“Materials science is an interdisciplinary field of researching and discovering materials. Materials engineering is an engineering field of finding uses for materials in other fields and industries.”[54] [55] The long history of the field involves the 10s of thousands of years of jewelry,

54 https://en.wikipedia.org/wiki/Materials_science
55 https://en.wikipedia.org/wiki/Timeline_of_materials_technology

pottery, and the iron age, bronze age (4,000 Ya), the invention of steel (3,300 Ya), glass (3,000 Ya), cast iron (300), corrosion-resistant steel (400), porcelain (800), gun powder (1000), etc. This was part of what we might now call metallurgy and mineralogy.

But things changed dramatically with the understanding of atomic theory and the underlying notion of creating engineered materials came into the realm. Prior to this, it was well understood that you could create better materials by annealing processes such as heating, hammering, cooling, sharpening, and repeating the process. But after this, it was understood that these processes were creating atomic and molecular structures with properties that could be controlled, manufactured to high levels of purity, and that could have many properties not even conceived of in the proceeding millennia.

Materials science was long considered by academic institutions as a sub-field of physics, chemistry, and engineering, but starting in the 1940s materials science began to be more widely recognized as distinct field of science and engineering, and universities around the world created departments and schools for its study. It now focuses on understanding how the 'history' (processing / manufacture) of a material produces its structure, which leads to its properties and performance (the materials paradigm). This paradigm is used to advance research areas, like nanotechnology, biomaterials, and metallurgy. It is also important in forensic science and failure analysis in that it provides the scientific basis for determining why and how a material behaved in a situation and thereby had a causal relationship to events.

A major breakthrough in the understanding of materials occurred in the late 19th century, when Gibbs demonstrated that the thermodynamic properties related to atomic structure in various phases are related to the physical properties of a material. From there it came to be understood that {atomic structure, chemical bonding, crystal structure, nano-structure (smaller than 100 nm), micro-structure (scale from 100 nm to observable only with magnification), and macro-structure (visible)} were responsible for {mechanical, chemical, electrical, thermal, optical, and magnetic} properties of materials and that those structures could be produced by the processing (manufacturing) of those materials in different ways. These properties effect performance in both static and dynamic (changing with time) situations. Consider, for example, two applications of materials:

- A material used to isolate an astronaut from outer space has to stop heat from flowing between the person and space, enable light to pass in so the person can see (usually through a different more fixed material), remain flexible from nearly absolute zero to room temperature, be thin enough to allow a person to perform mechanical tasks when wearing it, prevent air and other gasses from passing in or out, sustain hits from microscopic materials hitting it at high speeds without allowing them to pass, electrically isolate the person within and outside the space ship, resist chemical attack in case of leaks or spills, sustain vibrations of magnitudes and at frequencies that will not kill a person, allow the suit to be put on and taken off with relatively little effort in zero gravity as well as normal Earth gravity, form and break seals in doing so, and not be magnetic enough to get overly attracted to magnets and leave the person unable to move about or get stuck.
- A material used to convert nuclear boiled substance (a gas) into electrical energy such as the material used in a nuclear turbine blade has to sustain temperatures ranging from room temperature to 950°C (for some reactors), rotate at speeds of up to perhaps

3,600 RPM (rotations per minute), operate for tens of years without maintenance in a high radiation environment without substantial deflection or alteration of shape with forces including centrifugal force pulling it outward and mechanical force trying to slow it down as back-resistance from the electrical transformation from mechanical to electrical energy, and sustain impulses from dramatic changes in the push-back as load is nearly instantaneously removed from electrical circuit breaks.

Of course as science and engineering progress and the uses of material expand in all areas, new materials with new properties are required in order to implement the ideas and turn them into realities. Every human created control system has material requirements for sensors, actuators, communications, and control that involve materials that have to suit the purpose; manufacturing processes, transportation systems, and infrastructures typically involve a wide range of different materials that have to work together to produce the desired results under ranges of conditions and dynamic situations; and for all of the other changes over time in societies and human lives, materials are central to success. The co-evolution of physics, chemistry, astronomy, and thermodynamics, also involve materials science and engineering:

- In the 1700s, Darby made iron with coke, not the soft drink, a derivative of coal (1717), metallic zinc was processed by distillation from calamine and charcoal (1738) by Champion, Huntsman developed the crucible steel technique (1740), in 1774, Priestley discovered oxygen, Gahn discovered manganese, Scheele discovered chlorine, in 1779, hydraulic cement (stucco) was patented by Higgins for use as an exterior plaster, and in 1799, the acid battery was made from copper/zinc by Volta.
- In the 1800s, Seebeck invented the thermocouple (1821) that converts temperature to electrical voltage through a bi-material junction to allow electronic temperature sensing, Aspdin patented Portland cement as a building material (1824), Ørsted produced metallic aluminum (1825), Goodyear (the company is named after him) invented vulcanized rubber (1839), Daguerre and Talbot invented the silver-based photographic processes used in taking photographs through most of the 20th century (1839), Bessemer patented the process for mass production of steel (1855), Maxwell demonstrated color photography (1861), Fritts made the first solar cells using selenium (1883), and Welding invented thermite welding (1893) that was then used to weld rails for railroads.
- In the early 20th century, Verneuil created a process to produce synthetic rubies (1902), Brandenberger invented cellophane (1908) that allowed see-through separation of materials including food and fluid separation with visibility, Baekeland invented Bakelite as a hard thermosetting plastic (1909), superconductivity was discovered as a new property of materials by Onnes (1911), and stainless steel was invented by Brearley (1912) allowing the corrosion resistant hard light metal to be used for cooking, mirrors, and many other useful purposes. A method for growing single crystals of metals was invented by Czochralski (1916), and the first all welded hull of a ship (the merchant ship Fullagar) was produced (1919) at the end of World War 1 (the war to end all wars but didn't). Pyrex was invented by scientists at Corning Incorporated (a group effort with the corporation as the owner) as a glass with a very low coefficient of thermal expansion that allows it to be moved from oven temperatures to cold water very quickly without cracking (1924). Synthetic rubber (neoprene) was developed by Nieuwland (1931), the beginning of removing natural rubber as a key component for vibration

reduction in motor mountings, making seals for things that open and close, and enabling many other applications. Also in 1931, nylon was developed by Carothers and enabled the replacement of plant-based thread with better properties for many applications, including among others, parachutes. In 1935, film coating of glass was developed by Blodgett, creating "invisible glass" which is more than 99% transmissive of visible light. The process for making teflon was discovered by Plunkett (1938) as one of the first solid materials with very low surface friction that could also sustain substantial heating and cooling. And in 1939, Cahn developed a model for dislocations in metals that underpins research into industrial processes involving high-temperature deformation.

It is worthwhile to note the role of patents in commercialization and thus industrialization of many of these technologies. Patents are based on juridical decisions that enabled value to be produced for those who invented and commercialized methods, systems, and combinations of matter through the granting of an exclusivity for a period of time in exchange for revealing innovation to everyone else. These are social structures that dramatically effected the advancement in these fields and produced reward structures that influenced how (fed back into) decisions people made about the paths they would pursue in life.

It is also important to understanding the development of societies to see that as natural materials were replaced, and eventually surpassed in performance characteristics by artificial materials, it was no longer necessary to have control over locations where the natural material was grown in order to control the means of manufacturing of those materials and the things they allowed to be manufactured. War was no longer needed for production of some of the critical materials to support societies and one of the justifications for war was reduced. But of course, that is not the only justification for organized mass killing as World War 2 showed.

Electrical engineering

Electrical engineering and the design of analog and digital feedback circuits, power infrastructure, integration with sensors and actuators into complex systems, increased complexity of controls is much of what this book is about. Like so many other fields, there are ancient roots before science started to advance deeper understanding. It is the field I was educated in, so I am biased in favor of it. But despite its being the best field in all of science, engineering, art, music, society, literature, psychology, education, religion, medicine, biology, and anything else you want to name over the course of my life span, I will try not to allow that to be reflected in my recounting of history.

- Before the beginning of what we now call time, in what we might otherwise call empty space, according to modern physics, there was spontaneous creation and destruction of electrons and anti-electrons. This view is, essentially, that nothingness is unstable and cannot persist; there has to be a balance between existential entities in order for anything to exist, and since something exists (“I think therefore I am” as referenced earlier), it is the nature of nature that these fundamental components exist. These electrons and anti-electrons have, respectively, ‘negative’ and ‘positive’ (by our naming convention) electrical charge, and mass/energy and thus gravitational effect.
- There remains significant debate about the nature of time and gravity in that gravity warps space and time, or is it that time and space produce matter that … whatever it may be, these processes produced what is currently called the “big bang” that resulted

in what we now understand to be the local part of the universe (whatever that is) that we live in. But there is a general consensus surrounding the notion that fundamental forces include the strong and weak nuclear forces, electromagnetic force, and gravity (with a possible speculated 5^{th} force we do not yet understand). Electromagnetic force and its interactions with other forces and matter and energy ($E=mc^2$ says in essence that matter and energy are different forms of the same thing) is the subject matter of electrical science, and its practical application is the subject of electrical engineering.

Having expressed my unbiased perspective, let's look at the timeline:[56]

- **13.8B Ya**: The big bang
- **2,600 Ya**: Ancient Greek philosopher Thales of Miletus described static electricity by rubbing fur on substances such as amber.

So much for the ancient history. Not much happened with electrical things (other than natural phenomena like lightning occurring) between then and the 1600s. That's when things really started to take off… In 1600, Gilbert coined the word electricus after careful experiments where he explained the magnetism of Earth. Then in 1660, von Guericke invented a device that created static electricity, the first ever artificial electric generator (except wool clothing).

In 1705, Hauksbee made a glass ball that glowed when spun and rubbed with the hand, then Gray made the distinction between insulators and conductors (1720), von Kleist and van Musschenbroek invented Leyden jars (1745), and Franklin showed that lightning was electrical by flying a kite and explained how Leyden jars work (1752), and in 1785, Coulomb formulated and published his paper "Premier Mémoire sur l'Électricité et le Magnétisme" describing the electromagnetic force in static form. All of these are static electric phenomena, essentially an imbalance of positive and negative charges on a material's surface, built up when electrons transfer between objects, creating attraction or repulsion, and shocks when discharged. But the real innovations in electrical understanding and engineering came when it became understood that electrical energy in active form could be used to effect other things and was part of invisible actions that underlie other activities.

In 1780, Galvani discovered Galvanic action in living tissue, and on the mathematical side but not yet used in the electrical fields, Laplace developed the Laplace transform (1785) to transform a linear differential equation into an algebraic equation. Later, his transform became a major tool in circuit analysis, but more importantly, led to the creation of many other transforms that are useful for all manner of practical analytical and design purposes.

Lots of things changed when Volta invented the battery (1800). This was a portable means for transporting power from place to place and converting between chemical and electrical forms. In 1804, Young developed the wave theory of light, vision, and color theory, in 1808, Dalton developed atomic theory, and in 1816, Ronalds built the first working electric telegraph. All of a sudden, communications could travel at the speed of light ($\sim 3*10^8$ m/s), whereas before, other than hop-to-hop line of sight communications, nothing went faster than the speed of sound (~300m/s). That's a factor of 10^6 (a million times) faster! As fast as it goes or can go.

In 1820, Ørsted accidentally discovered that an electric field creates a magnetic field, and a week later, Ampère published his law and proposed the right-hand screw rule.

56 https://en.wikipedia.org/wiki/Timeline_of_electrical_and_electronic_engineering

These are the namesakes of the current metrics of the field; volts for electromagnetic force; oersteds for electromagnetic field strength; and amps for current, the flow of charges.

In 1821, Seebeck discovered thermoelectricity, Sturgeon developed the first electromagnet (1821), Ohm, the namesake for the metric of electrical resistance introduced it as a concept (1827), Faraday, the namesake for the Faraday cage that restricts emissions of electromagnetic waves in frequency ranges, published the law of induction (1831), Henry developed the same law independently and developed a prototype DC motor (1831) that enables electrical energy to be turned into mechanical motive force, and Pixii developed a prototype DC generator (1832). Faraday then developed the laws of electrolysis and invented the thermistor allowing resistance as a function of temperature for measurement (1833), and Christie invented (1833) the Wheatstone bridge (named after Wheatstone who popularized it). The transformer that allowed voltage amplification in exchange for current de-amplification (and vice versa) was invented by Callan (1836), the electric relay enabling switching things on and off electrically was invented by Davy (1937), and in 1839, Becquerel discovered the photovoltaic effect.

In 1844, Morse developed telegraphy and the Morse code to allow messages to be coded and decoded in a common method, which included shorter sequences for more commonly used letters for efficiency. The earliest electrical generator was first used in an industrial process (1844) by Woolrich, and the next year (1845) Kirchhoff developed the two laws now known as Kirchhoff's Circuit laws (voltage and current laws) based on conservation that allow circuit analysis and design still today. Nollet invented and patented (1850) a practical alternating current (AC) generator, Ruhmkorff developed and patented the first coil (1851), AC was first used (in electrotherapy) by Duchenne (1855), and in 1856 Bourseul proposed telephony, and the first electrically powered lighthouse was built in England. The first microphone was invented by Reis (1860) providing an input mechanism for telephony.

At this point, invention using electrical and magnetic systems was growing very rapidly with new sensors, actuators, and communications technologies being developed all the time and all over the industrialized world. Controls were in place, typically analog in nature except for a few switching systems using the electromagnetic relay.

In 1862, Maxwell published the four Maxwell equations that, as it turns out, led to being able to calculate, explain, and predict almost everything relating to electromagnetic fields for at least the next hundred years. The Transatlantic telegraph cable was implemented in 1866 enabling continuous communication between Europe and North America (a distance of about 5500 km) with end to end delay of only about 0.02 seconds (the speed of light). Compare that to a boat trip.

At this point, communication changed dramatically on a global basis. All of a sudden, an invention or new theory or equation developed on one continent could be understood half a world away as fast as it could be known a half a mile away. The pace of invention and industrialization shifted dramatically, and the global race was on for electrification as well as the developments in all areas of science and engineering.

In 1873, Gramme, who developed the DC generator, accidentally discovered that a DC generator also works as a DC motor, leading to conversion from DC to AC as well as battery driven motors. The paper capacitor was manufactured starting in 1876, a component allowing in-circuit storage and filtering based on frequency, and Yablochkov invented the electric carbon arc lamp, a very bright electrical light.

Bell's patent for the telephone was issued (1876) but two other inventors may have beaten him to the invention. Gray's patent was submitted on the same day (July 27, 1775) and has a submission number lower than Bell (registered before Bell) but Bell's patent was issued first.[57] Meanwhile, Meucci appears to have invented a very similar device slightly earlier. The phonograph was invented by Edison (1877) allowing sound to be recorded and played back, and the same year, Siemens developed a loudspeaker for amplified sound beyond the mechanical amplification of the gramophone. The first electric street lighting (Paris, 1872), first hydro-electric plant (England), the precursor of the vacuum tube (Crookes), and the incandescent light bulb (Swan) all happened in 1878. In 1879, Edison introduced a long-lasting filament for the incandescent lamp, and electrification was about to take off.

The Hall Effect was discovered (1879), piezoelectricity was discovered by the Curies (1880), the first thermal power stations were in place in London and New York (1882), and in 1878, Berliner invented the gramophone record which would replace the earlier wire recording devices. In 1888 Hertz proved the existence of electromagnetic waves, including what would come to be called radio waves (frequency is in hertz or cycles per second), Ferraris published a paper on the induction motor, and Tesla got a US patent on the same device. In 1890, Edison invented the fuse, the first real safety device for electrical systems, that dominated that field until the circuit breaker was invented many years later.

During the Fourth International Conference of Electricians in Chicago (1893), electrical units were defined, codifying the famous names we have been discussing as the namesakes for the units.

Thomson invented waveguides (1893) allowing electromagnetic waves to be confined and guided from place to place, and Marconi began developing the first radio wave based wireless telegraphy communication system (1894). The next year, Bose conducts experiments in extremely high frequency (millimeter) waves using a semiconductor junction to detect radio waves, Marconi finds that he could transmit radio waves at much greater range than the half-mile maximum physicists of the time were predicting, achieving ranges up to 2 miles (3.2 km) and transmitting over hills, Popov built a radio receiver that could detect lightning strikes, and Röntgen discovered X-rays. The electrolytic capacitor patent was granted to Pollak in 1896, and the cathode ray oscilloscope was invented by Braun (1897) allowing waveforms to be visualized on a display.

> *While the Transatlantic Cable enabled very rapid limited almost instant communications between continents, things were about to change dramatically again with the first transatlantic radio transmission by Marconi in 1901. This meant that, in effect, nearly instant transmission of information could be made from and to anywhere in the World, not just point to point, but from anyone to as many people as had radio receivers, all subject to interception and false signaling.*

Hewitt invented the Fluorescent lamp (1901) allowing for a longer lasting lower energy version of lighting, Fleming invented the diode (1904) allowing efficient conversion from AC to DC with capacitor and resistor sequences allowing the DC to be smoothed, de Forest invented the triode (1906) supporting amplification in a tube used in most amplification devices from

57 https://teachinghistory.org/history-content/ask-a-historian/22481

then forward, and Campbell-Swinton laid out the principles of television (1908). In 1909, Dubilier invented the Mica capacitor, superconductivity was discovered by Onnes (1911), and Armstrong developed the electronic oscillator (1912) enabling frequency modulation among other things.

Then (1914) World War 1 began. Langevin and Chilowsky invented sonar (1915), Nicholson invented the crystal oscillator (1917) and Bloch invented the multivibrator (1918). Then (1918), World War 1, “The War to End All Wars” ended, and that was the end of war… not.

In 1919, Armstrong developed the standard AM radio receiver, and on 1920-11-02, the first commercially licensed radio station in the United States (KDKA in Pittsburgh which I listened to as I grew up), began broadcasting.[58] It was famous for announcing the results of the 1920 Harding-Cox presidential election, but more importantly, it meant that news and entertainment were now shared in the same time frame by millions of everyday people. The news cycle changed, common knowledge was spread to the masses quickly, and owners of broadcast stations had a monopoly on real-time public information granted by government with the only competitors, other station owners.

Electrical units were codified in 1921 in the Metre Convention, creating the global standard for the words used and their meaning in the field. This is critical to progress in fields, as a common language allows the transfer of meaning. Also that year, Clarke invented the "Clarke calculator", a graphical calculator for solving line equations involving hyperbolic functions, allowing electrical engineers to simplify calculations for inductance and capacity in power transmission lines.

In 1924 Takayanagi began a research program on electronic television, the Field Effect Transistor was patented by Lilienfeld (1925) patented the first Field Effect Transistor (FET) which became popular much later, the Yagi–Uda antenna was developed (1926), Takayanagi demonstrated cathode ray tube (CRT) television with 40-line resolution, the first working example of a fully electronic television receiver, and then increased television resolution to 100 lines (1926). Japan was on the rise in electronics.

Black invented the negative feedback amplifier (1927) enabling controls to constrain output based on input with stability and Dieckmann invented the video camera tube. In 1928, Raman scattering was discovered (by Raman and Krishnan) providing a basis for the later Raman laser, Takayanagi was the first to transmit human faces in half-tones on television, and the first experimental Television (TV) broadcast in the U.S. was made. The first public TV broadcast was in Germany (1929), the first wind energy plant was in the Soviet Union (1931).

> *Note the US had a market crash in 1929 that began the “Great Depression” and the “Dust Bowl” (1930-1940) that slowed commercial expansion and scientific progress there for about 10 years. The New Deal used government programs to supplement the economy and focused on physical plant like roads (650,000 miles), public buildings (125,000), bridges (75,000), parks (8,000), and jobs (8.5 million).*[59]

In 1934, Nakashima, Shannon, and Shetakov created switching circuit theory that laid the foundation for digital electronics. The frequency modulation (FM) detector circuit was developed in 1936 by Foster and Seeley, the same year the printed circuit board was

58 https://www.fcc.gov/media/radio/history-of-commercial-radio
59 https://www.britannica.com/event/New-Deal

invented by Eisler (Australia) allowing circuit components to be mounted on an industrially manufactured board that made connections between components for high volume production of identical circuits as composites which would then be treated as if they were themselves components in larger composites, and Watson-Watt developed the radar concept which was proposed earlier (Scotland). Zworykin developed the iconoscope (1938), in 1939, Armstrong developed the FM radio receiver, and the Varians developed the first Klystron tube.

World War 2 was now underway, and nothing was invented then… OK lots and lots of things were invented, but we will pause here.

The Industrial Revolution(s)

This may be reasonably characterized as the rest of the industrial revolution.[60] [61] [62] Depending on the source you choose, the industrial revolution is characterized either as a process that changed the world over a period of about 100 years starting in 1760 and ending in 1850, or something that started at the same time and ended in perhaps 2000. Some characterize the 1st industrial revolution as the 100 year period when Britain made the changes and the 2nd industrial revolution as when this came to the rest of the world. Regardless of how you define it, the changes in how the human world operated was and remains profound. It was characterized by the shift from an agrarian era to an industrial era:

> *"Beginning in Great Britain around 1760, the Industrial Revolution had spread to continental Europe and the United States by about 1840. This transition included going from hand production methods to machines; new chemical manufacturing and iron production processes; the increasing use of water power and steam power; the development of machine tools; and rise of the mechanised factory system. Output greatly increased, and the result was an unprecedented rise in population and population growth. The textile industry was the first to use modern production methods, and textiles became the dominant industry in terms of employment, value of output, and capital invested."*[63]

Technological developments included several areas. **Textiles**: mechanized cotton spinning powered by water then steam increased productivity by a factor of 500, automatic weaving by a factor of 40, and the cotton gin for seed and stem removal by a factor of 50. **Steam power**: efficiency drove to fuel reduction by a factor of 5 to 10, adapting stationary steam engines to rotary motion made them industrially useful, high-pressure engines increased power to weight ratio, making it suitable for transportation. **Iron-making**: driven by the substitution of coke for charcoal lowered the fuel cost of pig iron and wrought iron production and allowed for larger blast furnaces producing economies of scale. The steam engine powered blast air in the 1750s, dramatically increasing iron production by overcoming the limitation of water power. The cast iron blowing cylinder was first used in 1760 and made double acting for higher blast furnace temperatures. The puddling process produced structural grade iron at lower cost than the finery forge, the rolling mill was fifteen times faster than hammering wrought iron. **Machine tools**: starting with the screw-cutting lathe, the cylinder boring machine, and the

60 https://www.britannica.com/event/Industrial-Revolution
61 https://en.wikipedia.org/wiki/Industrial_Revolution
62 https://education.nationalgeographic.org/resource/industrialization-labor-and-life/
63 https://en.wikipedia.org/wiki/Industrial_Revolution

milling machine, made economical manufacture of precision metal parts possible, though it took decades to develop effective techniques for making interchangeable parts.

As a side effect, urban populations grew as a percentage of overall populations as shown in the table below, and with it many societal changes occurred:[64]

Region	1600	1700	1800	1900	2000
World	5%	5%	7%	16%	47%
Western Europe	12%	13%	21%	41%	75%
North America	1%	2%	7%	38.5%	79%
Africa	.5%	1.25%	3%	8.5%	39%
China	7%	6%	6%	7%	37%

Percentage of urban population growth, 1600 to 2000 CE. Source: Population data adapted from Goldewijk, K.K., A. Beusen, and P. Janssen. "Long-Term Dynamic Modeling of Global Population and Built-up Area in a Spatially Explicit Way: HYDE 3.1." The Holocene, 20, no. 4 (2010): 568.

Of course many things changed at the same time.[65] Transportation improved leading to more than 2,000 miles of canals across Britain by 1815. Steam powered railroads and ships came into widespread use by 1830 including passenger services. Banking and communications changed and in 1776 Adam Smith published "The Wealth of Nations" promoting an economic system based on free enterprise, private ownership of means of production, and lack of government interference. A stock exchange was established in London in the 1770s and the New York Stock Exchange was founded in the early 1790s. Commercial telegraphy was implemented, and railroad signaling started to coordinate control of rail traffic.

By the mid-18th century, Britain lead global commercialization, controlled their global trading empire with colonies in North America and the Caribbean, had military and political hegemony on the Indian subcontinent, and this enabled fusion of capabilities on a global basis. Legal developments facilitated the change through ruling in favor of property rights, and it became easier for entrepreneurs to thrive. Consumers started to expect and get more and better products and services, and all boats rose in those places where industrialization thrived. Textiles moved from hand processes to automation including production of wool, cotton, and silk, leading to movement of raw material to remote factories and global shipping.

Coal mining in Britain started with shallow bell pits following a seam of coal along the surface, which were abandoned as the coal was extracted. If the geology was favorable, the coal was mined by means of an adit or drift mine driven into the side of a hill. Shaft mining was done in some areas, but the limiting factor was the problem of removing water. It could be done by hauling buckets up the shaft or to a sough (a tunnel driven into a hill to drain a mine). The water had to be discharged into a stream or ditch at a level where it could flow away. The steam pump by Savery (1698) and the steam engine by Newcomen (1712) allowed for water removal and deeper shafts, for more coal extraction. Smeaton's improvements to the

64 https://www.oerproject.com/OER-Materials/OER-Media/HTML-Articles/BHP/Unit6/The-Industrial-Revolution
65 https://www.history.com/articles/industrial-revolution

Newcomen engine, followed by Watt's steam engines (1770s), reduced fuel costs, making mines more profitable. The Cornish engine, (1810s), was even more efficient. The safety lamp (1816) by Davy, and independently by Stephenson proved a minor improvement because they became unsafe quickly and provided weak light and casualties grew during the 19th century.

The British Agricultural Revolution raised crop yields and released labor for industrial employment. Key innovations included Tull's mechanical seed drill (1701), which ensured more even sowing and depth control, Foljambe's iron plough (1730), and Meikle's threshing machine (1784), which reduced manual labor requirements. The labor reduciton resulted in lower wages and fewer laborers, who faced near starvation, leading to the 1830 Swing Riots.

France was known for having an excellent road system in the early 1700s but most roads on the European continent and in the UK were in bad condition, dangerously rutted, and dirt or cobblestone. From the 1720s turnpike trusts were set up to charge tolls and maintain some roads, increasing numbers of turnpiked main roads from the 1750s when almost every main road in England and Wales was the responsibility of a turnpike trust.

Transportation in the early 1700s had inland transport by navigable rivers and roads, and coastal vessels to move heavy goods. Wagonways conveyed coal to rivers for shipment, but canals were rare. Animals supplied the power on land, and sails on the sea. The first horse railways were introduced toward the end of the 18th century, with steam locomotives in the early 19th century. Improved sailing technologies boosted speed by 50% between 1750 and 1830. Navigation on British rivers was improved by removing obstructions, straightening curves, widening and deepening, and building navigation locks. Britain had over 1,600 kilometres (1,000 mi) of navigable rivers and streams by 1750. Canals and waterways allowed bulk materials to be economically transported long distances inland because a horse could pull a barge with a tens of times larger load than drawn in a cart. Canals started to be built in the late 18th century to link major manufacturing centers. The Bridgewater Canal (1761) £168,000 (~£30M today), and within one year, the coal price in Manchester fell by half. More canals were rapidly built with major ones opened in 1774 and 1789.

Machine tools allowed the mass production of metal parts including machine screws, bolts, and nuts leading to new and better fasteners and higher precision for new technologies to operate more efficiently. Machine cylinder boring started in 1774, milling machines came into use, high-security metal locks results from lathes, and these machines were operated largely by control mechanisms using adjustable screws and settings under human supervision.

A machine for making a continuous sheet of paper on a loop of wire fabric was patented (1798) by Robert and is the predominant means of production still today. It also influenced the development of continuous rolling of iron, steel and other continuous production processes.

As machines could produce stronger materials, larger scale chemical production became feasible, with things like temperature control based on people watching measurements from gauges and adjusting valves. This led to things like bleaching and pickling techniques for better surfaces and structures in metal structures and components that then supported better manufacturing, transportation, and other material needs.

Gas lighting on a large-scale by Murdoch used large-scale gasification of coal in furnaces, purification of the gas, and its storage and distribution for the first gas lighting utilities in

London (1812-1820). This allowed factories and stores to remain open longer, nightlife to flourish, and brought increased safety to the streets.

By the 1820s a national network of canals was in place and served as a model for the construction of railways. They were largely superseded by railways from the 1840s.

Glass making started in ancient Greece and Rome, but a new method of glass production, the cylinder process, was used by the Chance Brothers (1832) to create sheet glass, leading to window and plate glass and allowing larger panes of glass to be created without interruption, freeing up space planning in interiors and the fenestration of buildings. The Crystal Palace was a significant example of the use of sheet glass in a new and innovative structure.

Concrete was the result of a patented process (1824) by Aspdin , and further developed by his son into the 1840s. Portland cement concrete was used by Brunel to construct the Thames Tunnel (1843), the world's first underwater tunnel, and on a large scale in the construction of the London sewer system a generation later. It is still in widespread use today.

New engineered roads were built by Metcalf, Telford, and McAdam, with the first 'macadam' stretch of road being Marsh Road at Ashton Gate, Bristol (1816). The first macadam road in the U.S. was the "Boonsborough Turnpike Road" between Hagerstown and Boonsboro, Maryland in 1823. Major turnpikes radiated from London and supported the Royal Mail going to the rest of the country. Heavy goods transport on these roads was by slow, broad-wheeled carts hauled by teams of horses. Lighter goods were conveyed by smaller carts or teams of packhorse. Stagecoaches carried the rich, and the less wealthy rode on carriers carts. Between 1690 and 1840 productivity tripled for long-distance carrying and increased four-fold in stage coaching.

Railways were made practical by the widespread introduction of inexpensive puddled iron after 1800, the rolling mill for making rails, and the development of the high-pressure steam engine. Reduced friction was a major reason for the success of railways compared to wagons. This was demonstrated on an iron plate-covered wooden tramway in 1805 at Croydon, England. A good horse on an ordinary turnpike road can draw two thousand pounds (one ton). Experiments carrying multiple wagons with large teams of horses were tried, and wagonways for moving coal in the mining areas starting in the 17th century, were often associated with canal or river systems for the further movement. These were horse-drawn or relied on gravity, with a stationary steam engine to haul the wagons back to the top of the incline. The first applications of steam locomotive were on wagon or plate ways. Horse-drawn public railways begin in the early 19th century when improvements to pig and wrought iron production lowered costs. Steam locomotives began being built after the introduction of high-pressure steam engines, after the expiration of the Boulton and Watt patent in 1800. High-pressure engines exhausted used steam to the atmosphere, doing away with the condenser and cooling water. They were much lighter and smaller in size for a given horsepower than the stationary condensing engines. A few of these early locomotives were used in mines. Steam-hauled public railways began with the Stockton and Darlington Railway in 1825. The rapid introduction of railways followed the 1829 Rainhill trials, which demonstrated Stephenson's successful locomotive design and the 1828 development of hot blast, which dramatically reduced the fuel consumption of making iron and increased the capacity of the blast furnace. On 15 September 1830, the Liverpool and Manchester Railway, the first inter-city railway in the world, was opened and was highly successful, transporting passengers and freight. Railway Mania built major railways connecting the larger cities and towns starting in the 1830s.

Social effects were dramatic leading to new ideas for managing large groups. Visible poverty, growing population and materialistic wealth caused tensions between the rich and poor, and lead to violence, amd to philosophical ideas like socialism, communism, and anarchism.

The factory system replaced, to a large extent, the agricultural era of self-employed farmers, tenants, and landless agricultural laborers; with families spinning yarn, weaving cloth, and making their clothes; India, China, regions of Iraq, and elsewhere in Asia and the Middle East producing most of the world's cotton cloth, and Europeans producing wool and linen goods. The cottage industry of the 16th century produced goods for a market in homes, merchant capitalists provided the raw materials, paid workers by the piece, and were responsible for sales. Embezzlement of supplies by workers and poor quality were common, and the logistics effort in procuring and distributing raw materials and picking up finished goods had problems.

Some early spinning and weaving machinery, like a 40 spindle jenny (1792) was affordable for cottagers, but more expensive higher volume equipment was need as capital expenditure for higher volume, lower cost, higher quality finished goods, leading to factories. Capitalism is the term used to express the belief in this system. Most textile factory workers were orphans, children, and unmarried women who worked 12–14 hours with one day off. The change in the social relationship of the factory worker compared to farmers and cottagers was viewed unfavorably by Marx, but even he recognized the increase in productivity from technology.

One effect was that the living standards of the masses underwent sustained growth, but the growth of the economy largely benefited the industrialists and harmed the average worker until the late 19th century. Some studies estimate that wages in Britain only increased 15% between the 1780s and 1850s and life expectancy did not dramatically increase until the 1870s. Average height declined, because nutrition was decreasing, life expectancy of children increased dramatically because the percentage of Londoners who died before the age of five decreased from 75% in 1730-49, to 32% in 1810-29. Between 1813 and 1913, there was a significant increase in wages.

Chronic hunger and malnutrition were the norms for most of the world until the late 19th century. Malnutrition limited life expectancy in France to 35, and 40 in Britain in the mid-1800s, while the US population was adequately fed, taller, and had a life expectancy of 45-50 in the same period. Food supply in Great Britain was adversely affected by the Corn Laws (1815-46) which imposed tariffs on imported grain. The laws were enacted to keep prices high to benefit domestic producers. The Corn Laws were repealed in the early years of the Great Irish Famine. The initial technologies of this age, like mechanized textiles, iron, and coal, did little to lower food prices, and even though food production increased, so did population. The rapid population growth led to housing crises in the industrial and manufacturing cities and service centers. A critical factor was financing handled by building societies that dealt directly with large contracting firms. People moved in so rapidly there was not enough capital to build enough housing, so low-income newcomers were only able to get housing in overcrowded slums with inadequate clean water, sanitation, and public health facilities, leading to higher death rates, especially infant mortality, and tuberculosis among young adults. Cholera from polluted water and typhoid were endemic, but there were no famines in these areas. Engels (1844) founded the socialist movement and described backstreets of mill towns, where people lived in shanties and shacks, some not enclosed, some with dirt floors. These shanty towns had narrow walkways between irregularly shaped lots and dwellings. There were no sanitary facilities, and population density was extremely high. This sounds similar to conditions in some megalopolises in the World still today, such as areas of Mexico City and Delhi. This era also created a middle class of businessmen, clerks, foremen, and engineers who lived in much better conditions.

New public health acts improved conditions over the 19th century regulating sewage, hygiene, and home construction. For example, the Public Health Act 1875 led to the more sanitary terraced house. Pre-industrial water supply relied on gravity systems, pumping water was done by water wheels, and wipes were made of wood. Steam-powered pumps and iron pipes allowed widespread piping of water to horse watering troughs and households. London's population more than doubled between 1800 and 1850, making it by far the largest in the world. In 1854 Snow traced a cholera outbreak in Soho, London to fecal contamination of a public water well by a home cesspit. In 1855 Faraday wrote a letter to The Times on the foul condition of the River Thames (raw sewerage bought sewage directly into the Thames) in response to unsanitary conditions brought on by heavy industrialization and urbanization. The modern sewage system was built in London starting in 1859 with 82 miles (132 km) of main and 1,100 miles (1,800 km) of street sewers diverting waste to the Thames Estuary, and by the 1890s it included biological treatment of sewage to oxidize the waste.

Literacy in the 18th century was relatively high among farmers in England and Scotland leading to the recruitment of literate craftsmen, skilled workers, foremen, and managers who supervised textile factories and coal mines. Much of the labor was unskilled, and children were taken out of school to work with their parents in factories. But, by the mid-19th century, unskilled labor forces were common in Western Europe, and British industry moved upscale, needing more engineers and skilled workers to handle technical instructions and complex situations, so literacy was required to be hired. The invention of the paper machine and use of steam power in industrial printing supported massive expansion of newspaper and pamphlet publishing, contributing to rising literacy and demands for mass political participation.

Clothing and other consumer goods started to be less expensive, more available, and of wider variety. Cast iron cooking utensils, stoves for cooking and space heating, coffee, tea, sugar, tobacco, and chocolate became affordable across Europe. Luxury goods became available to more people from different socio-economic backgrounds. Transport and manufacturing technology made buying and selling faster and more efficient. A three-piece suit became affordable to the masses, fine china and porcelain tableware became common, and increased disposable income led to goods for individuals as opposed to households. Shopping became a part of life with window shopping as a cultural aspect, with exclusive shops in elegant urban districts, and spa towns emerging. Pottery and metalware choices increased, new household goods and furnishings like metal knives and forks, rugs, carpets, mirrors, cooking ranges, pots, pans, watches, clocks, and furniture went from mass production to mass consumption. New businesses appeared with confectionery goods like chocolate and biscuits widely available. In 1847 Fry's of Bristol produced the first chocolate bar and Cadbury commercialized the association between confectionery and romance by making a heart-shaped box of chocolates for Valentine's Day in 1868.[66] The toy store (1760), department store (1796), and fast food (fish and chips 1860s) emerged. Street sellers

66 We could reasonably say that this was the beginning of a new religion – chocolate that is...

became common with milkmaids, orange sellers, fishwives and so forth selling goods and knife grinders and the menders offering services. Lemonade was even sold from a wheelbarrow (1845).

Increased literacy, manufacturing, and transportation created conditions for production and distribution of literature at scale. Penny dreadfuls were created in the 1830s, and by the 1860s and 70s more than a million boys' periodicals were sold per week. Dickens sold books, new printing presses, and advertising. “The Pickwick Papers” (1836), brought unprecedented success with spin-offs and merchandising like Pickwick cigars, playing cards, china figurines, Sam Weller puzzles, Weller boot polish, and joke books. Nicholas Dames in The Atlantic writes, "Literature" is not a big enough category for Pickwick. The music hall (1850s) became a new form of entertainment.

In 1861, Pryce-Jones created the first mail order business which changed retail forever. He created catalogs for mail order following the Uniform Penny Post (1840) and the postage stamp charging one penny for carriage between any two places in the UK irrespective of distance, delivered by the new railway system. This expanded globally with the railways.

This period was the first time there were simultaneous increases in population and average income. Population of England and Wales remained ~6 million from 1700-1740, went from 8.3 million (1801) to 17 million (1850), to 31 million (1901), a factor of 5 in 160 years. Europe's population went from 100 million in 1700 to 400 million by 1900, a factor of 4 in 200 years. 20% of the population of Europe moved from their origins from 1815 to 1939, a mass migration formed by social changes rather than climate or disaster associated with previous mass migrations. In 1800, less than 1% of the world population was overseas Europeans and their descendants, but by 1930, that became 11%, largely concentrated in the US. Manchester went from 10,000 people in 1717 to 2.3 million by 1911, a factor of 300.

Organized labor came into being as workers united to form trade unions to keep wages and working conditions at decent levels because of the knowledge and skills required to do the jobs of the modern industrial society of the time. Workers could not longer be replaced by anybody off the street and supply and demand drove the workforce as well as the goods being mass produced. The forceful lever is the labor strike, but monied interests fight this with legal restrictions. In Britain, the Combination Act (1799) forbade workers to form any kind of trade union until its repeal (1824), but retained substantial restrictions. The Luddites emerged first with lace and hosiery workers near Nottingham, and spread to other areas of the textile industry. Unemployed workers and others turned animosity towards the machines that had taken their jobs and started to destroy factories and machinery. The attackers became known as Luddites (followers of Ned Ludd, a folklore figure). This started in 1811, rapidly gained popularity, and the Government used the militia or army to protect industry. Rioters who were caught were tried and hanged, or transported for life (to Australia). The Reform Act (1832) extended the vote in Britain, but didn’t grant universal suffrage. Legal and other methods were used to break union activities until the 1830s-40s chartist movement created the first large-scale working-class political movement that campaigned for political equality and social justice. It was ignored (not considered) by Parliament despite having 3 million signatures. In 1842, a general strike involving cotton workers and colliers was organized through the chartist movement which stopped production across Britain. Trade unions ultimately began to support socialist parties that merged to become the British Labour Party.

Centers of hand textile production including India, the Middle East, and China could not keep up with machine-made textiles, destroying their hand-made textile industries and leaving millions out of work, and many of them starved. The economic division in the world, measured by the share of manufacturing output, shifted dramatically from 1750 to 1900 with Europe going from 23% to 62%, the US going from 0.1% to 23.6%, Japan staying even at about 3%, and the rest of the world going from 73% to 11%.

Cheap cotton textiles increased demand for raw cotton, prices rose, and the invention of the cotton gin by Whitney (1792) was the decisive event. It allowed green-seeded cotton to become profitable, leading to the widespread growth of slave plantations in the US, Brazil, and the West Indies. US cotton production went from 2 to 35 million pounds between 1791 and 1800. That's a factor of 17 increase in 9 years, half of it exported. Plantations were highly efficient, profitable and able to keep up with demand, but driven by slavery. The US Civil War (1861-1865) created a "cotton famine" that led to increased production in other areas of the world, including European colonies in Africa.

Environmental effects included air and water pollution that led to the first modern laws in this arena in the mid-19th century. Factories produced uncontrolled pollution and after 1900 the large volume of industrial chemical discharges added to the growing load of untreated human waste. The first large-scale environmental law was Britain's Alkali Act (1863) regulating air pollution given off by the Leblanc process used to produce soda ash. Alkali inspectors were appointed to curb this pollution. Prior to that, the manufactured gas industry produced highly toxic effluent dumped into sewers and rivers, was repeatedly sued, usually lost, and modified the worst practices. London indicted gas companies in the 1820s for polluting the Thames and poisoning its fish, and Parliament wrote company charters to regulate toxicity. This industry reached the US around 1850 causing pollution and lawsuits. Local experts and reformers after 1890 led the identification of environmental effects and initiated grass-roots movements to get reforms. The highest priority went to water and air pollution, and the Public Health Act (1875) required all furnaces and fireplaces in Britain to consume their smoke.

The path in Britain came earlier than the rest of the world, largely because it led in the science and engineering and was small enough for national efforts to have large effects in short time frames. But the rest of the world was not far behind:

- European progress started in Belgium and France, then spread to German states by the middle of the 19th century. In many industries, this involved the application of technology developed in Britain. Typically, the technology was purchased from Britain, or British engineers and entrepreneurs moved abroad in search of opportunities. By 1809, part of the Ruhr in Westphalia was called 'Miniature England' because of its similarities. Most European governments provided state funding to the new industries. In some cases, such as iron, the different availability of resources locally meant only some aspects of the British technology were adopted.
    - **Belgium** was the second country to accelerate because of coal. Starting in the 1820s, and more so after Belgium became independent in 1830, factories comprising coke blast furnaces and puddling and rolling mills were built in the coal mining areas around Liège and Charleroi. Cockerill, a transplanted Englishman, had factories integrating all stages of production, from engineering to the supply of raw materials, as early as 1825. This exemplified the radical evolution of industrial

expansion, and it also helped emerge a strong socialist party and trade unions. Many 19th-century coal mines in Wallonia are now protected as World Heritage Sites. During the Middle Ages and the early modern period, Flanders had large urban centers with more than 30% of the population. But it was only 17% percent in Wallonia, and 10% in most West European countries, 16% in France, and 25% in Britain. The proportion of city-dwellers rose from 17% to 45% between 1831 and 1910. But in Belgium it grew from local centers rather than large urban centers.

  - **France** did not go through a clear take-off. Economic growth and industrialization were slow and steady through the 18th and 19th centuries. The French Revolution and Napoleonic Wars (1789–1815) had a slowing effect with industry expanding (1815–1860), economic slowdown (1860–1905), and new growth (1905 forward).
  - **Germany** had political disunity with 36 states and a pervasive conservatism that made it difficult to build railways in the 1830s. By the 1840s, trunk lines linked the major cities with each German state was responsible for the lines within its borders. Germans initially imported engineering and hardware from Britain, but soon learned the skills needed to operate and expand the railways. In cities, the railway shops were centers of technological awareness and training, and by 1850 Germany was self-sufficient in railway construction, a major impetus for the growth of the new steel industry. Up to about 1890, their engineering was inferior to Britain, but German unification in 1871 brought consolidation, nationalization into state-owned companies, and more rapid growth. The goal was to support industrialization, so heavy lines crisscrossed the Ruhr and other industrial districts and provided good connections to the major ports of Hamburg and Bremen. By 1880, Germany had 9,400 locomotives pulling 43,000 passengers and 30,000 tons of freight, and pulled ahead of France. It lead in chemical research in universities and industrial laboratories, and became dominant in the world's chemical industry in the late 19th century.
  - **Sweden** (1790-1815) had parallel economic movements: an agricultural revolution with larger agricultural estates, new crops, farming tools, and commercial farming; and proto-industrialization, with small industries established in the countryside and workers switching between agriculture in summer and industrial production in winter. This led to economic growth and increased consumption in the 1820s. The proto-industries developed into specialized and larger industries (1815-1850) with mining in Bergslagen, textile mills in Sjuhäradsbygden, and forestry in Norrland. Free and mandatory schooling was introduced (1842) for the first time in the world, monopoly on trade in handicrafts was introduced (1846), and a stock company law was passed (1848). There was a rapid expansion in exports (1850-1890), dominated by crops, wood, and steel starting with abolishing most tariffs and other barriers to free trade (1850s) and joined the gold standard (1873). Large infrastructural investments were made, mainly in the railroad network financed by the government and private enterprises. New industries developed with their focus on the domestic market (1890-1930) in mechanical engineering, power utilities, paper making and textiles.

- **Japanese** industrialization began about 1870 to catch up with the West. Government built railways, improved roads, and land reform prepared the country for development.

A Western-based education system for young people was started, sending thousands of students to the US and Europe, and hiring more than 3,000 Westerners to teach modern science, mathematics, technology, and foreign languages. In 1871, a group of politicians known as the Iwakura Mission toured Europe and the US to learn Western ways. The result was a deliberate state-led industrialization policy to quickly catch up. The Bank of Japan, (founded 1882) used taxes to fund steel and textile factories and start textiles (cotton and especially silk), based in home workshops in rural areas.

- **The US** in the late 18th and early 19th centuries was primarily an agricultural and natural resource producing and processing economy when Europe started to industrialize. The larger land mass and lower population density led to building roads, canals, steamboats, and railroads for transporting agricultural and natural resource products. The cotton gin, a system for making interchangeable parts, and the milling machine formed major infrastructure components of the US becoming the leading industrial nation in the late 19th century. The US originally used horse-powered machinery for small-scale applications like grain milling, but switched to water power as textile factories were built in the 1790s. Industrialization was concentrated in the Northeastern US, which has large and fast-moving rivers. Water-powered production was more economical than horse-drawn, and in the late 19th century steam-power overtook water-power, spreading industry to the Midwest (actually the middle eastern part of the US but mid-east was taken). The “Beverly Cotton Manufactory” (1787) was the first cotton mill in America, the largest cotton mill of its era, and designed to use horsepower, but the operators had losses for years. But its innovations included higher volume manufacturing and developing water-powered milling used in Slater's Mill (1793). Wool carding mills emerged (1809), textile machines were introduced (1810), the first planned factory town was built with monies from one of the first US public stock offerings. Interchangeable metal parts were developed using precision metal machining techniques developed by the U.S. Department of War for making firearms. This included using fixtures to hold parts in position, jigs to guide cutting tools, and precision blocks and gauges to measure accuracy. The milling machine is believed to have been invented by Whitney as a government contractor building firearms, and the Blanchard lathe was could produce copies of wooden gun stocks. Between them, these produced standardized interchangeable parts. Precision manufacturing was also used to make machines that mechanized the shoe and watch (1854) industries.

Chemical Engineering

Chemical engineering:[67] was developed out of industrial chemistry in the late 19th century turning batch processing (people mix predetermined amounts of ingredients in a vessel and, heat, cool, stir, pressurize, add ingredients, isolate, purify, etc. a batch at a time) into continuous "assembly line" chemical processes for higher volumes and tighter controls. Knapp, Ronalds, and Richardson published “Chemical Technology” (1848), and by the 1880s engineering elements required to control chemical processes were recognized as a distinct professional activity. Chemical engineering was first established as a profession in the United Kingdom after the first chemical engineering course was given at the University of Manchester (1887) by Davis in twelve lectures covering aspects of industrial chemical practice and he is regarded as the world's first chemical engineer. The Society of Chemical

67 https://en.wikipedia.org/wiki/History_of_chemical_engineering

Industry (1881), and the American Institute of Chemical Engineers (AIChE) (1908), and UK Institution of Chemical Engineers (IchemE) (1922) both now have substantial international membership.

Chemical engineers tend to take a process-oriented rather than product-oriented analysis and design approach. As an example, “unit operations” are operations with similar principles with different chemical components, such as separating alcohol from water in a fermenter, or separating gasoline from diesel in a refinery, since both generate a vapor of a different composition from the liquid for separation. They are studied together (as a unit) under the heading of distillation. In the early 1900s, “Unit Processes” was a term used to classify reactive processes, like oxidation, reduction, alkylation, etc. To design and operate chemical reactors today, knowledge of characteristics like rate behavior, thermodynamics, single or multiphase nature, and similar things are more important because the systems are more complex and the methodology for design and analysis has changed in the last hundred years. The emergence of chemical reaction engineering as a discipline began the separation of chemical engineering from industrial chemistry.

A pause

We pause at the beginning of World War 2 for a break and to note a few things about these expansions.

It is fundamental to understanding this progress to understand that philosophical works setting down ‘laws of nature’ were turned into mathematical formulas usually by other people, and that was then applied to understanding nature by scientists and engineering systems by engineers. These amazing names from the past were scholars of their times, but it was the combined efforts over time of many contributors that led to the advancements that effected societies and created new generations of control systems that allowed tighter and more automated controls. At the same time, inventions continued to prosper even without these components, for example rocketry in China was invented and practically used through experimentation and innovation without ever knowing about any of these technical breakthroughs.[68] The major difference between basic experimentation and science leading to engineering is in developing theories that make accurate and reproducible predictions that pass independent tests that could refute those theories if they were in error (reproducibility and testability) and the ability to design things that work within specified environmental parameters with defined precision and accuracy. This in turn enables the design and implementation of control systems that go far beyond the prior history of inventions and enables advanced knowledge of what will likely work and fail, be achievable and not, and then in practice meet that advanced knowledge with implementations that work reliably. It also tells us in advance what will not work and why, leaving the opportunity to find ways around those limitations to achieve things that would otherwise seem impossible.

68 https://www.e3s-conferences.org/articles/e3sconf/pdf/2024/70/e3sconf_icpes2024_14005.pdf

Psychology, sociology, and statistics

Psychology[69] [70] [71]

Psychology started with various theories of the mind, but by the end of this period, statistical analysis of behaviors became the dominant method by which these fields were analyzed, assessed, and taught. As such, statistics became perhaps more advanced as a field of mathematics through these applications than by any desire of pure mathematicians or applications from other fields. The reason stems from the inability to do mechanical reproduction of experiments, considered core to science in general for repeatability and testability. If you cannot eliminate all confounding conditions, how can you draw conclusions about cause and effect? And without causality, science falls apart, as we will see soon…

The history of psychology up to the mid-1900s can be broken down into two periods; before statistics and after. Before statistics were applied, observations were associated with behaviors and experimental treatments were tried with mixed results, often very bad for the patient. After statistics, the same was true, but the correlation of behaviors with identifiable conditions became better, and known treatments became more reliable at addressing the differences between people with defined conditions and the average behaviors of the population at large.

Starting 3,550 Ya, the Ebers Papyrus mentioned depression and thought disorders, about 2,600 Ya cities had temples that provided cures for psychosomatic illnesses [Greece], and from there came religious arguments about body vs. soul, nature vs. nurture, and the heart vs. the mind were the main focus of understanding behavioral anomalies. Various conditions were identified, including; insania (insanity), hysteria, melancholia, phrenitis, delirium, lethargus, mania, incubus, lycanthropy, and epilepsy, hallucination, insomnia, dementia, nightmare, rabies, and so forth; and treatments including things like darkness, restraint by chains, deprivation of food and drink, bleeding, frightening the patient, emetics, enemas, poppy or henbane, music, travel, sport, reading aloud, massage, baths, wine, special diets, sedatives, ligature of the limbs, tying the patient to a mattress placed inside a wicker basket and suspended from the ceiling, and so forth. Psychiatric hospital wards began in the 1300s and mental illness was identified as demonic possession treated with exorcism and torture.

In 1590, Goclenius coined the term "psychology", in the 1600s Descartes published “A Discourse on Method” asserting that ideas are innate to humans from birth [France], Willis published an anatomical treatise describing psychology in terms of brain function, Locke published “An Essay Concerning Human Understanding” asserting that ideas come from experience and human ability to reason, [England] countering Descartes. In 1701, Leibniz published the Law of Continuity, which postulated an unconscious mind, in 1732 Wolff published Psychologia Empirica, then Psychologia Rationalis (1734), popularizing the term "psychology", in 1774 Mesmer [Austria] presented a treatment for mental illnesses, originally called mesmerism and now known as hypnosis, in 1794, Pinel [France] published “Memoir on Madness” and argued for humane treatment of mentally ill patients. He also made significant contributions to the classification of mental disorders. In 1798, Kant proposed the first

69 https://allpsych.com/timeline/
70 https://en.wikipedia.org/wiki/Timeline_of_psychology
71 https://collegepublishing.sagepub.com/instructors/instructor-communities/introduction-to-psychology/home/free-intro-psych-resources/moments-in-psychology-around-the-world-timeline

dimensional model by mapping the four Hippocrates' temperament types into dimensions of emotionality and energetic arousal, which later became two of the dimensions used still today in personality models.

There were bumps along the way, after Reil coined the term "psychiatry" in 1808, as Gall [Germany] proposed the idea of phrenology, the belief that the shape of a person’s skull (and bumps on their head) reveals personality traits, a theory that was later discredited. In 1812, Rush advocated for humane treatment for the mentally ill in “Medical Inquiries and Observations Upon Diseases of the Mind”, and various authors published treatises on these subjects for years after that.

A major breakthrough was the 1848 case of a Vermont railroad worker (Phineas Gage) who had a 3-foot rod driven through his brain and jaw in an accident, permanently changing his personality, and revolutionizing scientific opinion about brain functions being localizeable. He had massive brain damage that left his intellect intact, but his personality changed, leading researchers study how areas in the brain play a role in personality. By 1856, von Helmholtz [Germany] published “Handbook of Physiological Optics” and his many other works included reports on the physiology of vision and hearing, and measurement of nerve impulse speed. In the 1860s, Donders first used reaction time to infer differences in cognitive processing, in 1861, Broca discovered an area in the left cerebral hemisphere that is important for speech production, now known as Broca's area, founding neuropsychology. In 1869 Galton [England] published “Hereditary Genius” asserting that intelligence is inherited. Galton is credited with the expression “nature and nurture” associated with the racist eugenics movement. In 1872, Spalding published his discovery of psychological imprinting, and in 1874 Wernicke [Germany] presents findings that damage to a specific area in the left temporal lobe (now called the Wernicke’s area) damages the ability to comprehend or produce language. In 1879 Wundt [Germany] founds the first formal laboratory for psychological study at the University of Leipzig and is the first person to call himself a psychologist. In 1882 the Society for Psychical Research was founded in England, and in 1885 Ebbinghaus first described the learning curve, forgetting curve, and spacing effect. Psychology laboratories emerged around the world for advancing research, Freud began private practice in Vienna (1886), Hall founded the American Journal of Psychology (1887), in 1890 von Ehrenfels published “On the Qualities of Form” founding Gestalt psychology, in 1891 Westermarck described an effect where people raised early in life in close domestic proximity later become desensitized to close sexual attraction raising theories about the incest taboo, in 1892 Hall et al. founded the American Psychological Association (APA), in 1896 Dewey published “The Reflex Arc Concept in Psychology” founding functionalism and Titchener identified “structuralism”, in 1898 Thorndike (US) published “Animal Intelligence” proposing that animals and humans learn similarly and leading to the development of operant conditioning, and in 1899 Freud published “The Interpretation of Dreams” (Die Traumdeutung), marking the beginning of psychoanalysis and attempts to deal with the Oedipal complex.

The early 1900s saw Freud publish “The Psychopathology of Everyday Life”, in 1904 Pavlov [Russia] won the Nobel Prize for his studies of conditioning (his dog did not get any of the credit) and Spearman published “General Intelligence” introducing the ‘g’ factor theory. In 1905 Binet and Simon created the Binet-Simon scale to identify students needing extra help, marking the beginning of standardized psychological testing and Freud published “Three Essays on the Theory of Sexuality”. In 1908 Freud published the paper “On the Sexual

Theories of Children", introducing the concept of penis envy and the paper "Civilized Sexual Morality and Modern Nervous Illness". Trotter published the first paper explaining the herd instinct, in 1910, Kent and Rosanoff published the Kent-Rosanoff Free Association Test, and in that time frame several other associations were formed in the related fields. In 1911 McDougall, founder of Hormic Psychology, published "Body and Mind: A History and Defence of Animism", claiming that there is an animating principle in Nature and that the mind guides evolution. Clearly, this period saw a wide range of expressions of the desire to understand thought ranging from in-depth scientific studies (Pavlov) to theories of the mind without any experimental or statistical support.

This mix continued in 1912 as Wertheimer published "Experimental Studies of the Perception of Movement", and in 1913 when Jung developed his own theories, which became known as Analytical Psychology, and Moreno pioneered group psychotherapy methods in Vienna, emphasizing spontaneity and interaction that later became known as psychodrama and sociometry. That same year, Watson published "Psychology as the Behaviorist Views It", sometimes known as "The Behaviorist Manifesto", and Münsterberg published "Psychology and Industrial Efficiency", the first book on Industrial and Organizational Psychology. In 1914 Sidis published "The Foundations of Normal and Abnormal Psychology", providing the scientific foundation for psychology, and detailing his theory of the moment consciousness. Then in 1917 Freud published "Introduction to Psychoanalysis". In 1920 Watson Rayner conducted the Little Albert experiment, using classical conditioning to make a young boy afraid of white rats, then in 1921 Freud published "Group Psychology and the Analysis of the Ego" while Moreno conducted the first large scale public psychodrama session at the Komedienhaus in Vienna, and Rorschach [Switzerland] published "Psychodiagnostik" introducing the Rorschach Inkblot Test.

In 1923, Piaget [Switzerland] published "The Language and Thought of the Child" contributing to child development and championing child education, in 1926 Hollingworth [IUS] published "Gifted Children", in 1927 Anna Freud (Austria, England), the sixth and youngest child of Sigmund Freud, publishes Introduction to the Technique of Child Analysis. Freud developed the field of child psychoanalysis.

This tension between conceptualization and experimentation continued as the range of applications extended and more patient types were identified and treated. In 1921, Klein began to develop her technique of analyzing children, in 1922 Horney began publishing a series of 14 papers (through 1937) questioning Freud's theories on women and Sidis published "Nervous Ills: Their Cause and a Cure", addressing the subconscious view and treatments, in 1923 Freud published "The Ego and the Id", and in 1924 Kantor founded interbehavioral psychology based on Dewey's psychology and Einstein's relativity theory, while Rank published "The Trauma of Birth", coining the term "pre-Oedipal" and recognizing cognitive development before and during birth. In 1926 Rank gave the lecture "The Genesis of the Object Relation", founding object relations theory and in 1927 Pavlov published "Conditioned Reflexes" with what is now considered the classical theory of conditioning.

Piaget published "Judgment and Reasoning in the Child (1928) and Morita published "Morita Therapy: The True Nature of Shinkeishitsu" regarding anxiety-based disorders that includes the peripheral theory of consciousness. In 1929 Ladd-Franklin [US] publishes "Color and Color Theories" and over time makes contributions in the field of color vision and other fields, and Köhler [Germany] publishes Gestalt Psychology that criticizes behaviorism.

Allport et al. published the “Allport-Vernon-Lindzey Study of Values”, which defines six major value types (1931) and the Journal of Personality was founded (1932) as the first personality psychology research periodical (originally titled Character and Personality). And Cannon [US] publishes “The Wisdom of the Body” which introduces the term homeostasis and discusses the fight-or-flight response (note that this is the same term used in physiology and biology to capture a control system maintaining its stability within bounds). In 1933, Gannushkin published “Manifestations of Psychopathies” while Hull published “Hypnosis and Suggestibility” proving that hypnosis is not sleep and founding the modern study of hypnosis, and Reich published “Character Analysis” and “The Mass Psychology of Fascism” presumably anticipating the rise of fascism.

As the field rapidly expanded in this period, many more events were taking place around the world and more was being understood through the improved experimental laboratory capabilities and the increased use of statistical information and, ultimately, its use in political and conflict-related issues. At the same time, understanding of brain functions was growing and the underlying science associated with medicine was bringing new insights that impacted the field. In 1934, Vygotsky published “Thought and Language”, in 1935 Stroop developed a color-word task to demonstrate the interference of attention (the Stroop effect) which identifies attention issues in humans that are, in the context of this book, related to the same issues in all control systems. That same year, Dunbar published “Emotions and Bodily Changes: A Survey of Literature on Psychosomatic Interrelationships”, and in 1942 founded the American Society for Research in Psychosomatic Problems, was the first editor of the society's journal “Psychosomatic Medicine: Experimental and Clinical Studies” (1939). Also in 1935 Murray and Morgan published the “Thematic Apperception Test” (TAT) and Newcomb began the “Bennington College Study” (1935-1939), documenting liberalization of women students' political beliefs, effects of proximity on acquaintance and attraction.

In 1936, Lewin published “Principles of Topological Psychology” with a pseudo-mathematical result B = f (P, E), meaning Behavior is a function of a person in their environment, Reich published “The Sexual Revolution”, Spence published an analysis of discrimination learning in terms of gradients of excitation and inhibition, showing that mathematical deductions from a quantitative theory could generate worthwhile testable predictions, and the “Psychometric Society” was founded by Thurstone, who proposed dividing general intelligence (g) into seven primary mental abilities (PMAs). This application of metrics to psychology moved the field closer to a classical science and brought statistics firmly into the field. That same year, Anna Freud [Austria, England] published “The Ego and the Mechanisms of Defense”, while Moniz [Portugal] publishes work on the first human frontal lobotomies, and Canady [US] publishes ‘The Effect of “Rapport” on the I.Q.: A New Approach to the Problem of Race Psychology’ and was the first psychologist to examine the role of the examiner’s race as a bias factor in IQ testing, ultimately suggesting establishment of more equal (less biased) testing.

In 1938 Skinner published “The Behavior of Organisms: An Experimental Analysis” that introduced behavior analysis helping to create focus for the Lewin equation, and Cerletti and Bini [Italy] used electroshock treatment on a human patient.

In 1939 Hodgkin and Huxley published the first recording of an action potential, Miller et al. published the frustration-aggression theory linking aggression as an effect to frustration of efforts to attain a goal as the cause, presumably with the brain as the mechanism, and

Wechsler developed the Wechsler-Bellevue Intelligence Scale for Children (WISC) and adults (WAIS).

On 1939-09-01 World War II began with the German invasion of Poland, Hitler signed the Euthanasia Decree (1939-09-20) written by psychologist Max de Crinis, resulting in the Aktion T4 euthanasia program, on 1939-09-23 Freud committed physician-assisted suicide in London on the Jewish Day of Atonement, on 1939-10-31 Rank died of a kidney infection in New York City after uttering the word "comical", and Reich fled to New York, coining the word orgone and building "orgone accumulators", which got him in trouble with the psychiatric establishment and the federal government.

Interestingly, these various aspects of psychology and its emergence played a substantial role in World War 2 where psychological warfare, electrical shock treatments, theories of intelligence, and other aspects of the field played roles in abuses of all sorts. However...

Sociology[72] [73] [74]

Sociology is "*the scientific study of human society that focuses on society, human social behavior, patterns of social relationships, social interaction, and aspects of culture associated with everyday life. The term was coined in the late 18th century to describe the scientific study of society. Regarded as a part of both the social sciences and humanities, sociology uses methods of empirical investigation and critical analysis to develop a body of knowledge about social order and social change. Subject matter ranges from micro-level analyses of individual interaction and agency to macro-level analyses of social systems and social structure. Applied sociological research may be applied directly to social policy and welfare, whereas theoretical approaches may focus on the understanding of social processes and phenomenological method.*" (quote approximate)

Prior to the emergence of civilization, there were groups that had interactions and agency at the micro- and macro- levels, but there were no sociologists to study them. Archaeologists study these ancient cultures rather than sociologists. However, proto-sociology existed since groups started forming from other groups in different situations. A lot of ancient philosophy surrounds how people think about other people and how to form societies. The concepts of democracy, tribalism, kingdoms, fiefdoms, and the concepts behind military rule, autocracy, socialism, and other forms we now recognize emerged long ago and evolved along with the emergence of civilizations. In a sense, the whole process of civilization is one of applied experimental sociology, and the evolution of governmental forms and governance structures are clearly still underway at a rapid pace.

- **2,500 Ya**: Confucius studied social patterns and created expressions of them. [China]
- **1200s CE**: Duanlin (Tuan-Lin?) recognized patterns of social dynamics in an encyclopedia, Wénxiàn Tōngkǎo (文献通考; 'General Study of Literary Remains') [China]
- **1350-1400**: Islamic scholar Ibn Khaldun wrote Muqaddimah as an introduction to a seven-volume analysis of universal history, with theories of social cohesion and conflict. [Tunisia] He studied the dichotomy of sedentary vs nomadic life, the concept

72 https://en.wikipedia.org/wiki/History_of_sociology
73 https://courses.lumenlearning.com/atd-herkimer-introsociology/chapter/reading-the-history-of-sociology/
74 https://en.wikipedia.org/wiki/Sociology

of generations, the loss of power when desert warriors conquer a city, and six books dealing with politics, urban life, economics, and knowledge. He suggests cohesion arises spontaneously among tribes and small kinship groups, is intensified and enlarged through religious ideology, carrying groups to power and embodying the psychological, sociological, economic, and political seeds of downfall, and replacement by a new group, dynasty, or empire with a younger and more vigorous cohesion.

- **1762**: Rousseau's "*Du Contract Social, ou, Principes du droit politique*" introduces the concept of the social contract mirroring ancient Greece notions of social agreement, and theorizes on how to establish 'legitimate' authority compatible with individual freedom in a commercial society, previously identified in his "Discourse on Inequality" (1755). This argues against the concept of the divine rights of kings and monarchies.[75] It introduces terms "democracy" (50% of the people must agree), "aristocracy" (less than 50% and more than one person must agree), and "monarchy" (one person has to say so). It's distribution was prohibited in France (presumably by the monarch) because of it's views on civil religion (or so it was claimed) and Rousseau fled France to avoid imprisonment. Voltaire mocked these theories but also supported freedom of expression and decried the burning of the book (in Geneva) saying "The operation of burning it was perhaps as odious as that of writing it. […] To burn a book of argument is to say: 'We do not have enough wit to reply to it.' Meanwhile Kant argued that laws should reflect the general will of the people.[76]

More generally, there was substantial development of political philosophy in this period:

> *"Political ideologies are systems of ideas and principles that outline how society should work. Anarchism rejects the coercive power of centralized governments. It proposes a stateless society to promote liberty and equality. Conservatism seeks to preserve traditional institutions and practices. It is skeptical of the human ability to radically reform society, arguing that drastic changes can destroy the wisdom of past generations. Liberalism advocates for individual rights and liberties, the rule of law, private property, and tolerance. It holds that governments should protect these values to enable individuals to pursue personal goals without external interference. Socialism emphasizes collective ownership and equal distribution of basic goods. It seeks to overcome sources of inequality, including private ownership of the means of production, class systems, and hereditary privileges. Other strands of political philosophy include environmentalism, realism, idealism, consequentialism, perfectionism, nationalism, individualism, and communitarianism."*

Not all of these were developed in this period, but at some level, the development of these belief systems when studied under the lens of scientific approaches that emerged in this era led to the development of sociology.

- **1767:** Ferguson[77] has been described as "the father" of modern sociology, argued that capitalism diminished social bonds that traditionally held communities together in "History of Civil Society". In the mid-1770s he met Voltaire and he was a member of

75 https://en.wikipedia.org/wiki/The_Social_Contract
76 https://en.wikipedia.org/wiki/Political_philosophy
77 https://en.wikipedia.org/wiki/Adam_Ferguson

"The Poker Club" (1776) when his anonymous pamphlet on the "American Revolution" opposed Price's "Observations on the Nature of Civil Liberty", and in 1778 he was appointed secretary to the Carlisle Peace Commission, which tried and failed to negotiate an arrangement between Britain and the revolted colonies. He wrote the article "History" for the second edition of Encyclopædia Britannica (1780) replacing the 1-paragraph article in the first edition with a 40-pager. In 1783 his "History of the Progress and Termination of the Roman Republic" identifying that the Roman Republic in its best years was a practical illustration of ethical and political doctrines he focused on. In 1792 (at age ~69, my age as of this writing) he wrote a summary of his lectures in "Principles of Moral and Political Science".

- **1780**: The term "sociologie" (the study of companions) was first coined by the Sieyès [France]
- **1785**: Webster borrowed heavily from "The Social Contract" to write "Sketches of American Policy" arguing for a strong central government in the US.
- **1813**: Saint-Simon published "Physiologie sociale" focused on the idea that human society could be steered toward progress if scientists formed an international assembly to influence society by distracting groups from war and strife by improving living conditions, which would then bring people, cultures, and societies together and prevent conflict. Society was making a major change from declining feudalism to emerging industrialization and his slogan "All men must work" was intended to address the change. Note that communism eventually produced "Each according to his capacity" and also note that catchy slogans will come up again…
- **1838**: "Sociology" as a term was reinvented by Comte in its modern meaning. [France] who expressed his work as "social physics". Comte hoped to unify all studies of humankind through scientific understanding of the social realm. He believed all human life passed through distinct historical stages and diagnosing progress could lead to prescriptions for curing social ills. Sociology was the "queen science"; basic physical sciences had to emerge first before the most fundamentally difficult science of human society could emerge, and as such, he is identified as the "Father of Sociology".
- **1844-5**: Marx as a "Young Hegelians" member in Berlin discussed Hegel ("Science of Logic" 1816), and went from sympathetic to the strategy of attacking Christianity to undermine the Prussian establishment, to divergent from it attacking those views in "The German Ideology" (1845-6, eventually published in full 1932) and elsewhere. Marx asserted that laborers' struggle in the Industrial Revolution doesn't stem from religious power and influence, but rather from ownership of capital and material that enable processes that use technology, land, money, and human labor to create surplus-value. This "stood Hegel on his head" theorizing that the engine of history and structure of society were fundamentally material rather than ideal. He theorized that cultural production and political power created oppressive ideologies and concentrated wealth in the owners of the means of production (the capitalists) and predicted that the capitalists would feel forced to cut wages and/or replace labor with technology, thus increasing the capitalists' wealth up to the point where the lack of wages for the workers would lead to the collapse of society because there was nobody left to buy the things that were produced. Marx co-operated with Engels who accused capitalists

of "social murder" for causing a "life of toil and wretchedness" for workers which gives them power over worker health and income, and "which can degree his life or death". “The Condition of the Working Class in England” (1844) studied the life of the proletariat in Manchester, London, Dublin, and Edinburgh.

- **1848**: Comte published “A General View of Positivism” and called positivism "the great discovery of the year 1822." He asserted that; any kind of knowledge always begins in theological form where it can be explained by a superior supernatural power such as animism, spirits, or gods; then it moves into to the metaphysical form, where it is explained by abstract philosophical speculation; and lastly it becomes positive when explained scientifically through observation, experimentation, and comparison.
- Reactions against positivism began when Hegel [Germany] opposed empiricism (rejected as uncritical) and determinism (rejected as overly mechanistic). Marx's methodology borrowed from Hegel and rejected positivism as non-critical, wanting to supplement empirical fact gathering with elimination of illusions, maintaining that appearances need to be critiqued and not just documented. Marx tried to build a science of society grounded in economic determinism of historical materialism with the goal to have a clear and unified theory that was practically applicable without clearly artificial links between theory and practice.
  - *Marx’s and Compte’s opposition to each other as schools of thought is what forced each to be more rigorous in their approaches. This is an example of one of the most well known examples in sociology of the control system of human interaction, where individuals and groups that follow them compete and thus cooperate in the advancement of an area of knowledge.*
- **1854**: Hughes published “A Treatise on Sociology, Theoretical and Practical” and Fitzhugh wrote “Sociology for the South, or the Failure of Free Society”, both authors being US lawyers engaged in the debate over slavery, while Martineau (cited as the first female sociologist) noted how the theoretical ideal of equality in the Declaration of Independence was not reflected in social reality of the country, which marginalized women and practiced slavery.
- **1874**: Spencer initiated a lot of the thought in early sociology, broadly as a reaction to Comte and Marx, and writing before and after the Darwinian revolution in biology, he considered socially Darwinistic approaches including a coherent theory of general evolution several years before Darwin published anything on the subject. He published “The Study of Sociology” (1874), the first book with the term "sociology" in the title, sold about one million books in his lifetime, and influenced Durkheim and others. Also a biologist, he coined the term "survival of the fittest" as a mechanism of progress of sociocultural forms. His social Darwinist views on race were subsequently (20th century) considered a form of scientific racism, for example, “Social Statics” (1850) argued that imperialism served civilization by killing off inferior races: "The forces which are working out the great scheme of perfect happiness, taking no account of incidental suffering, exterminate such sections of mankind as stand in their way. … Be he human or be he brute - the hindrance must be got rid of."
- **1883**: Ward is often described as a father of American sociology and served as the first president of the American Sociological Association from 1905 to 1907. He

published “Dynamic Sociology” (1883), “Outlines of Sociology” (1898), “Pure Sociology” (1903), and “Applied Sociology” (1906) and that year, at 65 years old, was appointed as professor of sociology at Brown University.

- **1892**: Simmel [Germany] took Kant’s question (What is nature?) and asked “What is society” as an approach to sociological antipositivism for analyses of social individuality and fragmentation. He defined culture as "the cultivation of individuals through the agency of external forms which have been objectified in the course of history" and discussed social and cultural phenomena in terms of "forms" and "contents" with a transient relationship (form becomes content and content becomes form dependent on context)[78] an early form of structuralist reasoning in the social sciences. His work on the metropolis was a precursor of urban sociology, symbolic interactionism, and social network analysis. And is famous for “The Problems of the Philosophy of History” (1892), “The Philosophy of Money” (1900), “The Metropolis and Mental Life” (1903), Soziologie (1908) which included “The Stranger”, “The Social Boundary”, “The Sociology of the Senses”, “The Sociology of Space”, and “On The Spatial Projections of Social Forms”, and “Fundamental Questions of Sociology” (1917).
- **1893**: Durkheim's work [France] was concerned with how societies could maintain integrity and coherence in modernity, where social and religious ties are no longer assumed, and new social institutions come into being. “The Division of Labour in Society” (1893) and “The Rules of Sociological Method” (1895) led to the first European sociology department (1896) at the University of Bordeaux, where he taught from 1887 to 1902 and became France's first professor of sociology. He understood the field as addressing "beliefs and modes of behavior instituted by the collectivity". He asserted that social science should study phenomena attributed to society at large, rather than the specific actions of individuals.
- **1897**: Durkheim published the seminal monograph “Suicide” that studied suicide rates in Catholic and Protestant populations, starting modern social research and distinguishing social science from psychology and political philosophy by using the scientific method of hypothesis and deduction from fact model in social science. In 1898 he established the journal “L'Année Sociologique”.
- **1899**: Du Bois produced “The Philadelphia Negro”, a detailed and comprehensive sociological study of the African-American people of Philadelphia, based on his field work (1896-7). It was the first scientific study of African Americans, and coined the phrase "the submerged tenth" describing the black underclass. He popularized the term, the "Talented Tenth" (1903) identifying the elite class, reflecting his view that the elite were critical to cultural and social progress. He published “The Souls of Black Folk” (1903) famously proclaiming "the problem of the Twentieth Century is the problem of the color line." identifying a double identity as being both American and black as unique "Henceforth, the destiny of the race could be conceived as leading neither to assimilation nor separatism but to proud, enduring hyphenation."

78 Irwin Marin, one of my graduate professors, identified “content, context, and consideration” as core to knowledge engineering.

Also in this era, early social historians and economists including Michels, Tocqueville, Pareto, and Veblen varied from ‘classical’ sociological philosophy by attempting to be scientific, systematic, structural, or dialectical, rather than purely moral, normative or subjective. The development of capitalism and its alteration of older power structures (money replacing family, physical prowess, etc.) also distinguish sociology of the Renaissance from political philosophy of the Enlightenment.

It’s noteworthy that this was the period where the “nation state” we are now familiar with started to come into being. This includes the creation of a set of institutions that survived the individual leaders and formed a sort of collective memory and continuity. While archival science began in the 1400s for understanding records in a systematic way, people who formed the heart of institutions had to pass the way things were done from generation to generation as a cultural component of the operation of the institutions that evolved over time bringing traditions into place. This sort of momentum, in some sense, led to the refocusing of nation states away from the single head of state and toward the ‘body politic’. Of course people wishing to be rulers formed autocratic societies by gathering enough supporters and scaring enough others to take power, but as each dies off, the people come back into power, or so I hope. Because history is not over, we keep building it every day. If this sounds like a control system with feedback mechanisms which are unstable for periods and become stable for periods then become unstable again, we are thinking in the same general direction.

Now on to the 1900s. As the cognitive expansion was continuing, more researchers with more information from more places got more deeply involved in sociology. Here are select examples of emergence of the field pre-WW2:

- **1912**: Durkheim's “The Elementary Forms of the Religious Life” posited a theory of religion comparing the social and cultural lives of aboriginal and modern societies. By his death in 1917, he presented lectures and published works on topics including the sociology of knowledge, morality, social stratification, religion, law, education, and deviance and used terms like "collective consciousness".
- New branches of the field emerged:
  - Macrosociology (the evolution of societies)
  - Microsociology (day-to-day human social interactions)
  - Pragmatic social psychology
  - Symbolic interactionism.
- **1923**: Lukács released “History and Class Consciousness” (1923), while Durkheim and Weber works were published posthumously.
  - Critical theory integrated materialistic elements of Marxism with Weber, Freud, and Gramsci characterizing capitalist modernity as a move away from the central tenets of the Enlightenment.
- **1937**: Parsons' “Structure of Social Action” consolidated American sociology and set the agenda for its fastest growth by developing action theory and functionalism, integrating social order with structural and voluntaristic aspects of macro and micro factors, in the context of system theory and what would later be called cybernetics. Parsons preferred bottom-up rather than top-down approaches and his canon was

guided by his desire to "unify the divergent theoretical traditions in sociology behind a single theoretical scheme, one that could in fact be justified by purely scientific developments in the discipline during the previous half century."

  - Garfinkel developed ethnomethodology.
  - Schütz developed social phenomenology.

- Weber[79] argued for the study of social action through interpretive (rather than purely empiricist) means, based on understanding the purpose and meaning that individuals attach to their own actions. He did not believe in monocausal explanations and rather proposed that for any outcome there can be multiple causes. His main concern was understanding emerging rationalisation, secularisation, and disenchantment, which he associated with the rise of capitalism and modernity. Combining economic and religious sociology in his book "The Protestant Ethic and the Spirit of Capitalism", he proposed that ascetic Protestantism was among major "elective affinities" associated with the rise of market-driven capitalism and the rational-legal nation-state in the West. His trend toward integrating religion into social structures led to "Politics as a Vocation" which defined a state as an entity with a "monopoly of the legitimate use of physical force within a given territory" and was the first to associate social authority with charismatic, traditional, and rational-legal forms and his analysis of bureaucracy emphasized the trend toward rational-legal authority as the basis for institutions.

Durkheim, Marx, and Weber are typically cited as the three principal architects of modern social science. The sociological "canon of classics" with Durkheim and Weber at the top in part because Parsons introduced both to American audiences.

In some sense Weber brought out the concept of synergistic effects and emergent behavior. While in the lowest levels of scientific mechanistic understanding a single cause operates through a specific mechanism to produce a specific effect, in complex control systems, there are multiple simultaneous control mechanisms operating, each with its own causality mechanism, but in combination all operating at once, the causality is emergent from the combined causes, mechanisms, and effects of the component parts. As composites get more complex, the basics still hold true, but cannot be understood individually in producing the overall behavior of the composite.

Philosophy of science[80]

The philosophy of science, as a field, developed towards the end of this period, based on the developments in science and the underlying basics.

As a starting point, but often unstated, science is based on a fundamental assumption of causality.[81] [82] Specifically (my view):

Cause acting through mechanism produces effect ($C \rightarrow^{m} E$).

Without the assumption of causality, science breaks down at a fundamental level, but with it, we have several underlying notions:

79 https://en.wikipedia.org/wiki/Max_Weber
80 https://en.wikipedia.org/wiki/Philosophy_of_science
81 https://authors.library.caltech.edu/records/m1qr4-q0b23 "The Critique of Pure Reason" (Kant, 1781)
82 https://en.wikipedia.org/wiki/Critique_of_Pure_Reason

- **Refutation through testability:** For a theory to be a universal scientific theory, it must be that it can be refuted by a test. More particularly, if any test refutes a theory, regardless of the number of confirmations by tests, the theory must be wrong. Or in many cases, the theory is too general or an approximation that is close enough for many purposes.[83] [84] [85]
  - Newtonian physics is pretty good, until you get close to the speed of light, where it breaks down, and you need to take relativity into account.
  - Many things that are pretty much true when things are not changing, turn out to be refuted when things are changing. We now talk about the quasi-static state as a condition under which some things hold true, when there is little or no dynamics.
- **Independent repeatability:** For a theory to be testable it must be repeatable in that the same conditions lead to the same results, and independently repeatably testable in that independent qualified experts must be able to repeat the tests under the same conditions and produce the same results.
  - Strictly speaking there is no such thing as an actual repetition, if only because time has moved forward, the location (of Earth) has changed with time, etc.
  - Repetition in this case has everything to do with the relevant parameters of the test. If the theory is independent of temperature, temperature should not matter, and in fact testing at different temperatures could refute it.
- **Precision and accuracy:** All of this can only be done to within a defined level of precision and accuracy because of the limits of available technology.
  - **A theory of measurement** is required for anything to be measured. For example, a standard has to be defined against which things can be measured, and any such standard is only so precise and so accurate. Measurements of things smaller than the deviations in the standard cannot be reliably differentiated, so precision and accuracy are always limited as is our ability to test scientific theories.
  - **Mathematics approximations** are commonly used for making calculations and measurements, but mathematics is generally based on theories that are infinitely precise and accurate in that they describe finite things (theories themselves) in many cases about infinite and/or infinitesimal things (like space and time as we understand them now).
  - **Reporting problems** are also common, particularly in the era of computers, where lots of digits can be produced as output of calculations when the inputs were not precise enough to merit the precision of the results provided. For example a sample of 7 things for which 3 were true means that $3/7^{ths}$ of the sample was true, but in a calculation, this might come to 0.4285714. The problem is that it is misleading to present it as if there were 100,000 samples of which 4,285,714 were true.

The scientific method is basically:

- Propose a theory that is testable

83 K. Popper, "The Logic of Scientific Discovery", 1935, translated by the author in 1959
84 https://plato.stanford.edu/entries/popper/
85 https://en.wikipedia.org/wiki/Falsifiability

- While true do: Test it with the goal of refuting it.
  - If the test confirms it, continue testing it
  - If the test refutes it, propose a new theory

To be clear, there is never a proof that a scientific theory is right, because that is not the scientific method. It is always assumed that any theory can (and usually will) be refuted eventually and have to be replaced by a new theory that does a better job. In many cases, the old theory remains practical over a set of conditions that are identifiable, and can continue to be used for practical purposes to within a specific level of precision and accuracy.

Compare this to mathematics, where the entire field for the last several centuries has been focused on proofs. A mathematical theory has to be proven true to be useful to mathematics. Otherwise it remains a conjecture until proven (or dis-proven) definitively. Of course mathematics has its limits as well, for example, no mathematical system can be both consistent and complete (Kurt Gödel 1931):[86]

> The first incompleteness theorem states that no consistent system of axioms whose theorems can be listed by an effective procedure (i.e. an algorithm) is capable of proving all truths about the arithmetic of natural numbers. There will always be statements about natural numbers that are true (and false), but that are unprovably true (and false) within the system.
>
> The second incompleteness theorem shows that such a system cannot demonstrate its own consistency.

I have an additional bias associated with not wasting time, which is that before you propose a theory (to others) check the literature to see if someone else already refuted it. It saves a lot of time and money if you don't repeat the mistakes of the past.

By its nature, science evolves, and that is its strength as a system. Unlike religion which depends on leaps of faith, beliefs that cannot be proven or disproven by experiment, science is assumed to evolve. This evolution was explored as part of the philosophy of science as well[87] [88] with the nature of change and its propagation through society as the old guard seeks to stop the change challenging various refutations with scientific arguments about things like test conditions and measurement issues, and the new guard overcomes these objections over time, converting the scientific consensus to the new approach. The "flat earth" theory[89] has remained in place with fewer and fewer supporters until relatively recently when even the staunchest of the old guard gave it up.[90] But scientific consensus was formed about 2,300 Ya.

The issue of mechanism in causality

There is a basic problem in making progress based on the requirement of a known mechanism in causality. That is, we may generally associate a cause with an effect even before we know a mechanism, and later on, we may determine that the causality is not what we thought it was as a mechanism is identified. But that doesn't stop progress, although it

86 https://en.wikipedia.org/wiki/G%C3%B6del%27s_incompleteness_theorems
87 T. Kuhn, "The Structure of Scientific Revolution" (1962)
88 https://en.wikipedia.org/wiki/The_Structure_of_Scientific_Revolutions
89 https://theflatearthsociety.org/home/
90 https://en.wikipedia.org/wiki/Modern_flat_Earth_beliefs

may lead to many false lines and things that work sometimes rather than all the time. There are a few sayings that you might want to keep in mind:

- Before is not because
  - But if you don't have before, you don't have because, unless time goes backwards.
- Correlation is not causation
  - But if there is causation, there better be correlation.

Science is imperfect, but it adapts over time, and as such, it is an evolutionary process of survival of the fittest (or is it 'best fit').

As discussed earlier, in the lowest levels of scientific mechanistic understanding, a single cause operates through a specific mechanism to produce a specific effect, but in complex control systems, there are multiple simultaneous control mechanisms operating, each with its own causal mechanism, in combination, all operating at once; and causality is emergent from the combined causes, mechanisms, and effects of the component parts. As composites get more complex, the basics still hold true, but cannot be understood individually in producing the overall behavior of the composite. This issue is being addressed in current research, but not necessarily in philosophy of science.[91] [92] [93] [94] [95]

The parallel emergence of the arts

Unlike the other fields we have been discussing, the arts had largely emerged before the middle ages, although they continued to emerge since then. In large part, this is because works of art including sculpture, paintings, engravings, and such other non-ephemeral productions (although technically ice sculptures are ephemeral as are sand castles…) have always been dependent only on the available materials and tools to apply them, while performing arts including music are dependent only on instruments including the human voice and anything else available or manufactured to produce sound or motion. Art was never really limited by technology, but rather by ideas. Thus emergence of the arts correlated to the emergence of ideas long before technology allowed their realization. At the same time, the arts both influenced and were influenced by its environment and continued its interaction with the political and personal situations of the day. Thus the arts continued to evolve along with the rest of the cognitive expansion.

91 https://www.mdpi.com/1099-4300/26/2/108
92 https://arxiv.org/pdf/2403.11219v1
93 https://royalsocietypublishing.org/rsif/article/13/124/20160555/35587/Top-down-models-in-biology-explanation-and-control
94 https://www.epa.gov/caddis/about-causal-assessment
95 https://link.springer.com/article/10.1007/s10670-021-00392-y

Art

Art continued to progress with the times as language and writing progressed, and as written descriptions and annotations were preserved, in many cases the artifacts themselves were also preserved.[96] [97] [98]

- **1250-1664**: [China] Complex combinations of writing and realistic depictions of complex scenes on a single canvas (paper) are present (1250) and complex patterns on glazed pottery are produced (1400). Chinese furniture starts to emerge as an artistic form and reaches the height of artistic design and craftsmanship during the Ming dynasty (1368-1664). Chinese architecture is elaborate in its now iconic structures exemplified by the Temple of Heaven (1406-1420) and the Forbidden City (1420).
- **1400–1500**: [Italy] 15th-Century Italian art of the Golden Age of Florence arose as its most powerful family (the Medici were bankers and benevolent dictators) spent endless funds for the glory and beautification of their Republic. Artists flocked in for a share of the largess and built, sculpted, painted, and ultimately began actively questioning "rules" of art which became noticeably more individualized.
- **1495–1527**: The High Renaissance is when all the recognized masterpieces from the “Renaissance" were created. Leonardo, Michelangelo, Raphael, and others made such unique masterpieces that almost no artist since even tried to paint in this style. This period and its art made the profession of artist acceptable.
- **1520–1600**: Mannerism, the first abstract term for an artistic era, had Renaissance artists continue to refine painting and sculpture but without a new style of their own. They followed the technical manner of predecessors absent substantial innovation.
- **1325–1600**: [Europe] The Renaissance in Northern Europe has countries and kingdoms fighting for dominance, and with a notable break from the Catholic Church styles moved from Gothic to Renaissance to Baroque on an artist-by-artist basis.
- **1600–1750**: Baroque art resulted from the emergence of Humanism, the Renaissance, and the Reformation ending the Middle Ages, and art was accepted and accessible by the masses. Artists of this period introduced human emotions, passion, and new scientific understanding to their works, many retaining religious themes, regardless of which Church they were involved in.
- **1700–1750**: Rococo took Baroque art from "feast for the eyes" to visual gluttony. If art or architecture could be gilded, embellished or otherwise taken over the "top", Rococo added these elements.
- **1700–1912**: [China] Extensive depictions of people in scenes on textiles and glazed pottery and various animal forms depicting dragons and other mythical creatures. Qing dynasty furniture shifted toward heavier proportions, more elaborate carving, and the use of lacquer and inlay decoration, reflecting Manchu court tastes and increased contact with European design.

96 https://www.thoughtco.com/quick-rundown-of-art-eras-182703
97 https://asia-archive.si.edu/learn/for-educators/teaching-china-with-the-smithsonian/interactives/timelines/timeline-of-chinese-history-art-and-culture/
98 https://en.wikipedia.org/wiki/Chinese_art

- **1750–1880**: Neo-Classicism and Romanticism in this period was the result of the ability of two different styles to compete. Neo-classicism was characterized by faithful study (and copy) of the classics combined with the use of elements brought to light by the new science of archaeology. Romanticism was more of an attitude made acceptable by the Enlightenment and dawning of social consciousness and had far more impact going forward.
- **1830s–1870**: Realism emerged first quietly then quite loudly with the conviction that history had no meaning and artists should only depict what they personally experienced. In an effort to experience "things" they became involved in social causes and often found themselves at odds with authority. Realistic art increasingly detached itself from form and embraced light and color.
- **1870-1950**: [China] A more radical style change started with Youwei, a reformer who admired the more reality-based art of the Song dynasty and believed that Chinese art could be rejuvenated by employing the reality-oriented art techniques of Europe. Beihong took this idea to heart and went to Paris to acquire the necessary skills. Haisu went to Japan to learn western techniques. Both became presidents of prestigious art schools, instilling new concepts and skills in the next generation of artists. Yuanpei was one of the leaders in the New Culture Movement that believed that intellectual activities should benefit all, not just the elites, ultimately adopted by Fengmian. Together, they spearheaded the national modern art movement that was stifled by the Sino–Japanese war and the civil war but continued after the war and developed differently in the four regions: the Mainland, Taiwan, Hong Kong, and overseas.
- **1860s–1880**: Impressionism resulted as Realism moved away from form with art as an impression that could be rendered entirely through light and color. The world was first outraged then accepting, and acceptance ended Impressionism as a movement; art was now free to spread out in any way it chose. Even if the public loathed the results, it was still art and accorded a certain respect. Movements, schools, and styles came, went, diverged, and sometimes melded in this explosion of art forms that will remain nameless herein.
- **1885–1920**: [Europe] Post-Impressionism is a handy title for a group of artists (primarily Cézanne, Van Gogh, Seurat, and Gauguin) who moved on to other endeavors. They kept the light and color Impressionism brought but tried to put form and line, back in.
- **1890–1939**: [France] The Fauves ("wild beasts") were French painters led by Matisse and Rouault, who created with wild colors and depictions of primitive objects and people, became known as Expressionism.
- **1905–1939**: Cubism and Futurism emerged as [France] Picasso and Braque invented Cubism where organic forms were broken down into a series of geometric shapes which were then elemental to the Bauhaus and inspired the first modern abstract sculpture. Futurism [Italy] began as a literary movement and moved into a style of art that embraced machines and the industrial age.

- **1922–1939**: Surrealism was all about uncovering the hidden meaning of dreams and expressing the subconscious and emerged after Freud published his groundbreaking psychoanalytical studies.

World War 2 was a period with relatively little art innovation as the World was at war and resources were spent on that endeavor.

Music [99] [100] [101] [102] [103] [104] [105]

Music continued to play a role in the political and social arena throughout history; notably it has been banned in many ways, to different extents, many times by autocratic and religious fanatic governments and sects throughout history. It has been recognized throughout history as a means of narrative control and social protest, has often been excused from controls governments place on content, and because meaning is in the mind of the listener, it has often been used as a covert method of communication.[106] [107] [108] [109]

China and India had long ago fused musical traditions through the silk road, and Genghis Kahn's empire had spread across Asia and Europe. Transportation was operable and movement of people, good, and culture was widespread and at this point not truly controllable over the long run. Musical notation was still early, but notes on scales and rhythmical properties were being annotated.

And of course technology has continued to move forward leading to changes in some instruments, but perhaps more importantly, the ability to manufacture and transmit music, scores, and performance details more widely and more quickly. Transportation and manufacturing allowed instruments to be made in high quantity (but not necessarily high quality), sent around the world, and used anywhere, leading to instruments played together in larger and more complex orchestrations. But first, old-tech as music leads the way:

- **800s**: The automatic flute player was invented in the 9th century by the Banū Mūsā brothers in Baghdad, and is the first known example of a programmable machine. This work was influenced by their Hellenistic forebears, but makes significant improvements over Greek creations. The pinned-barrel mechanism, which allowed for programmable variations in the rhythm and melody of the music, was the key contribution given by the Banu Musa.
- **1206:** The Muslim inventor and mathematician Al-Jazari described a drum machine which may have been an example of a programmable automaton.

I will return later with the next breakthrough in mechanical music technology.

99 https://en.wikipedia.org/wiki/History_of_music
100 https://www.skagitsymphony.com/time-periods-in-music-history
101 https://guitargetlessons.com/valuables/music-history-timeline/
102 https://www.lamaisonschoolofmusic.com/resources/music-history-timeline
103 https://ia801301.us.archive.org/16/items/cu31924022264661/cu31924022264661.pdf
104 https://plato.stanford.edu/entries/hist-westphilmusic-to-1800/
105 https://courses.lumenlearning.com/suny-fmcc-hum140/chapter/3-10-music-of-the-enlightenment-the-classical-era/
106 https://www.musiccouncil.org/music-politics-history/
107 https://en.wikipedia.org/wiki/Music_and_politics
108 https://firstamendmentmuseum.org/exhibits/virtual-exhibits/history-of-protest-music/protest-music-1774-1911/
109 https://firstamendmentmuseum.org/exhibits/virtual-exhibits/history-of-protest-music/protest-music-1911-1947/

The band was ready to expand from the era of roaming troubadours avoiding the juridical forces seeking to suppress them to a new era of musical expansion. As in other areas, the level of detail available from this period exceeds our ability to codify it here, so we will hit the highlights. At least two important (to me) things were happening over this period:

- Musical orchestration and complex large orchestras were forming playing increasingly complex and elaborate compositions written by those now called classical composers like Bach, Brahms, Beethoven, Chopin, Mozart, Vivaldi, Schubert, Debussy, Strauss, Tchaikovsky, Rachmaninoff, Handel, Wagner, and the rest of that gang.[110] [111]
- Simple tunes and lyrics were being used by more and more people to change social mores and protect against the powers that were while those powers used simple tunes and lyrics to create and sustain their own social mores and enforce their views and control their populations.

Social influence vs. beauty and imagery are in stark contrast. While classical musical styles were revolutionary in their time from a standpoint of how the establishment felt about them, this is no different in my view from the generational change in everything else in the narrative space over a long period of time. The differences in compositional styles and music in the 1500s to 1900s is not very different from the emergence of hillbilly and country music in the early 20th century being opposed by the classical music community in the United States. Pure sound vs. vocalization in song is the same thing in terms of narrative control. It is about beauty which, per the famous quote and many previous versions, is "in the eye of the beholder".[112] Social influence on the other hand is the use of control systems to cause desired behaviors, and the notion of beauty is only one of the emotional concepts used to generate these influences through music. With this in mind, a light walk through history may help.

- **1400-1800**:[113] [114] [115] [India] The Mughal period exchanged ideas between Indian and Persian musical traditions with emperors as patrons of the arts fostering a musical environment with renowned musicians composing masterpieces.
- **~1547**:[116] [117] The first eight "modes" were designated in the medieval era, as a way to classify pre-existing Gregorian chants. The next four were added by Glareanus, which gave way to the modern system of tonality and the Ionian mode most common still today (i.e., an octet from C to C: C D E F G A B C with double the frequency from C to C). The eight church modes are: Dorian, Hypodorian, Phrygian, Hypophrygian, Lydian, Hypolydian, Mixolydian, and Hypomixolydian. And they provided rules and material for melodic writing. You can listen to these modes online today.[118] This largely facilitated the ability to transmit music before recordings became available.
- **1567-**: Classical composers (a very brief listing of time line) include Monteverdi (1567-1643), Vivaldi (1678-1741), Handel (1685-1759), Bach (1685-1750), Mozart (1756-

110 https://classicalmusiconly.com/lists/top/composers
111 https://digitaldreamdoor.com/pages/best-classic-comp.html#google_vignette
112 Margaret Wolff Hungerford, 1878, "Molly Bawn" for the exact phrasing, but many before her as well.
113 https://en.wikipedia.org/wiki/Music_in_ancient_India
114 https://en.wikipedia.org/wiki/Music_of_India
115 https://abgmvm.org/the-rich-heritage-of-indian-classical-music/
116 https://www.medieval.org/emfaq/misc/modes.html
117 https://www.britannica.com/art/harmony-music/Harmony-before-the-common-practice-period
118 https://en.wikipedia.org/wiki/Mode_(music)

1791), Haydn (1732-1809), Beethoven (1770-1827), Schubert (1797-1828), Mendelssohn (1809-1847), Chopin (1810-1849), Schumann (1810-1856), Liszt (1811-1886), Wagner (1813-1883), Brahms (1833-1897), Tchaikovsky (1840-1893), Mahler (1860-1911), Debussy (1862-1918), Strauss (1864-1949), Stravinsky (1882-1971), and many more.

As a very brief summary[119], the "Early Modern Period" includes:

- Music and Sensory Pleasure (Tinctoris 1435–1511 and Zarlino 1517–1590)
- Melody and Expression (The Florentine Camerata: Glareanus 1488–1563, Monteverdi 1567–1643, Caccini 1550–1618, and Jacopo Peri 1561–1633)
- Sense and Rationality (Mersenne 1588–1648, Descartes 1596–1650, Leibniz 1646–1716)
- Imitation and Expression in the Eighteenth Century (Du Bos 1670–1742, Avison 1709–1770, Batteux 1713–1780, Morellet 1727–1819, Chabanon 1730–1792 and many others who expressed the emotional effects of music and its ability to influence)
- The Primacy of Melody (Rousseau 1712–1778)
- Music between Form and Content (Kant 1724–1804).

Core to the most of the effort in this era was the attempt to understand and control the emotional effects of music as influence. Many ideas were identified, studied, and codified near the end of this period and best expressed in the historical footsteps of Plato:

> "*...Plato also holds that the musical imitation of some human emotions may be ethically beneficial, especially at the stage when children are too young to be responsive to ethical education that relies on a discursive and rational basis. Plato first describes the emotions in question indirectly, one as the emotion of a person who is steadfast and resolute in misfortune or while fighting, the other as the state of "someone engaged in a peaceful, unforced, voluntary action" (Republic, 3.399b). Plato holds that these emotions, which he then refers to explicitly as courage and moderation, are best imitated through the Dorian and Phrygian modes, which imitate the violent or voluntary tones of voice of those who are moderate and courageous, whether in good fortune or in bad. (Republic, 3.399c)*
>
> *Thus, Plato construes musical imitation of emotions as grounded on the resemblance of music to human expressive behavior, particularly vocal. At least on one occasion, he also seems to hold that music imitates the bodily movements associated with emotions (Laws, 2.654e–655a). This could be considered the first defense of the idea that musical expressiveness is due to the music's resemblance to human expressive behavior, a position that remains popular to this day (see the entry on history of western philosophy of music: since 1800, section 2.6). …*
>
> *Discussing the object of musical imitations, Aristotle introduces an interesting distinction between mere indications or signs (sēmeia) of emotional states and the states themselves. Signs of emotional states are the observable behavior that accompanies the occurrence of such states. Aristotle holds that the visual arts merely*

119 https://plato.stanford.edu/entries/hist-westphilmusic-to-1800/

imitate signs of emotions. For instance, a painter may represent a man weeping or smiling. However, music is able to imitate the emotional states themselves. A plausible reading of Aristotle's view is that he regarded music as capable of arousing the emotions it imitates, and that this capacity ultimately explains how music may imitate emotional states themselves, as opposed to their manifestations. On this analysis, the object of musical imitation cannot be specified separately from the emotional response the music arouses in the listener (Halliwell (2002: 248) stresses this point; Sörbom 1994 offers an alternative interpretation). …

Early in his life, René Descartes (1596–1650) devoted a treatise to music, the Compendium Musicae (written in 1618 and published posthumously in 1650). This work is dominated by scientific concerns rather than philosophical ones, but the very start of the treatise is characteristic of its age, as Descartes states that music's goal is "to please and to arouse various Affections in us" (Descartes 1650). But Descartes's most important impact on philosophy of music is actually due to his treatise on emotions, The Passions of the Soul (1649). In this work, Descartes defines emotions as the result of the action produced by external objects on the animal spirits, a thin air-like substance that stirs our passions whenever it is set in motion. Descartes also distinguishes six basic emotions: wonder, love, hatred, desire, joy, and sadness.

This taxonomy of emotions and the mechanistic description of their functioning will prove important to the so-called Affektenlehre, or doctrine of the affections, the eighteenth century view that a piece of music should arouse a specific emotion in the listener. Affektenlehre theorists believed that this goal could be achieved through the use of specific musical devices, each associated with a given emotion. The German composer Johann Mattheson may be considered the most prominent representative of this tradition. He explicitly endorses Descartes' theory of emotions in his treatise Der vollkommene Capellmeister (Mattheson 1739: I, iii, §51)….

Charles Avison (1709–1770) in his Essay on Musical Expression, first published in 1752. ... distinguishes between music resembling extra-musical objects, including manifestations of emotions, such as laughter, and music that is able to provoke an emotional response in the listener. The former case is musical 'imitation', which Avison claims produces "a reflex act of the understanding" (Avison 1775: 50), while the latter is 'expression'. Avison argues that the goal of music is to pursue expression, which is achieved by the competent use of melody and harmony. While the idea that music is valuable because it moves the listener was not new, Avison's clarity in decoupling it from imitation is noteworthy.

...in The Fine Arts Reduced to a Single Principle (1746), by Charles Batteux (1713–1780). In this work, Batteux defines art as the imitation of beautiful nature (belle nature). Different arts imitate different parts of nature. Music imitates the human expression of emotions. It is interesting to note that Batteux repeatedly states that music expresses the emotions, as opposed to imitating them, although the discrepancy seems to be merely terminological. Batteux can conceive of music that fails to be imitative, but does not consider it valuable:

... Rousseau's view of musical imitation does not seem to withstand critical scrutiny. It is unconvincing as an explanation of the musical imitation of emotions. It may be

> *though that an emotion we perceive always corresponds to another emotion we feel, and thus that we could depict the former by arousing the latter. But in fact, we may respond to, e.g., rage with a variety of emotions, from more rage, to fear, disappointment, schadenfreude, etc. The theory is only more implausible when it comes to the depiction of objects other than emotions, as the same object may arouse very different emotions, depending on the subject's disposition and beliefs about it.*
>
> *A further ambiguity is represented by Kant's apparent commitment both to a variety of musical formalism, according to which musical beauty uniquely resides in the relationship between its component parts, and to the idea that music is expressive of emotions. This is a manifestation of a general tension in Kant's aesthetics (see Guyer 1977). A formalist tendency is evident when Kant claims that the proper object of the pure judgment of taste in music is composition, by which he means the arrangement of tones (Kant 1790: §14). Later on, Kant states that music "merely plays with sensations" (Kant 1790: §53), offering this in support of his claims regarding music's low rank among the arts.*
>
> *Despite these apparent professions of formalism, Kant also stresses music's connection to the sphere of emotions. Particularly, he seems to accept a version of the Affektenlehre, according to which works of music may arouse specific emotions in the listener. In §53, Kant affirms that music may convey an emotion because of its analogy with the tone of voice typical of impassioned speech (see also Kant 1798: §18)."*

I will return to subject momentarily, but I would be remiss not to mention:

- **1737**: Mechanical automaton demonstrated simulated finger and lip movement to play flute in The Flute Player, a life-size figure of a shepherd that played the tabor and pipe and had a repertoire of twelve songs. The figure's fingers were not pliable enough to play the flute correctly, so Vaucanson gloved the creation in skin. In early 1738, he presented his creation to the Académie des Sciences. While mechanical creatures were a fad in Europe, most were simpler toys, and de Vaucanson's creations were recognized as being revolutionary in their mechanical lifelike sophistication.

The link between politics and music continued throughout history as it continues today. In the middle of the 18th century, Europe moved toward a new style in architecture, literature, and the arts, a.k.a. Classicism. This style sought to emulate the ideals of Classical antiquity, especially Classical Greece. Tightly linked to Court culture and absolutism's formality and emphasis on order and hierarchy, the new style was more orderly, favoring clearer divisions between parts, brighter contrasts and colors, and simplicity rather than complexity. The size of the orchestras also began to increase. Newton's physics was taken as a paradigm and structures were expected to be well-founded in axioms, well-articulated, and orderly, and this began to affect music, which moved away from the layered polyphony of the Baroque period toward homophony where melody is played over a subordinate harmony. Chords became more prevalent, even if interrupting the melodic smoothness of a single part, and the tonal structure of a piece of music became more audible. The new style reflected changes in economic and social structure as the nobility became the primary patrons of instrumental music, while public taste preferred comic opera. This led to changes in performance including moving to standard instrumental groups and reducing the importance of the rhythmic and harmonic ground typically played by a keyboard (harpsichord or organ).

Although protest music is often associated with more recent history, it has been a part of the fabric of American society since the beginning, and long before that, of other civilizations over time. We have already covered earlier instances in previous chapters, so continuing...

Protest music from the 18th and 19th centuries often used already-popular tunes with altered lyrics because using a familiar and loved tune makes the idea seem familiar and relatable and because recording technology was not available and songs needed to be easy to learn and sung by protesters, picketers, activists, and others. In North America (then the the US):

- **1774**: “Free Americay!”; when the British government imposed the “Intolerable Acts” on the American colonies closing the port of Boston punishing the Boston Tea Party, Dr. Warren, an American resistance leader, penned the song set to the tune of the “British Grenadiers” imploring Americans to resist the British, and remaining popular during the American Revolution. Warren died a year after he wrote it, fighting in the rearguard action that covered the American retreat from Bunker Hill.
- **1837**: “Woodman, Spare That Tree!” was released by Henry Russell based on a poem of the same name by George Pope Morris, one of the first times music was used to advocate for environmentalism.
- **1860s**: “I’m a Good Ol’ Rebel” attributed to Major James Innes Randolph to xpress his disdain for Reconstruction-era federal policies epitomizing the white racial terror that undermined Reconstruction. It is a diatribe of vitriolic hatred against the United States and everything associated with it; the Constitution, the Declaration of Independence, bald eagles, the American flag, and the Freedman’s Bureau. It applauds the death of “300,000 Yankees” and wishes it was “3,000,000 instead.” In 2015 the lyrics were changed to “I’m a Good Ol’ American” to protest the Obama presidency.
- **1874**: “The Lips That Touch Liquor, Shall Never Touch Mine” by George Evans and dedicated to “the Women’s Crusade Against Liquor Throughout the World” is an infamous Temperance ballad beseeching men and women to wage war on “Rum and his legions” until they “shall ruin no more”. This ballad plays on sexual anxieties by telling men if they keep drinking they won’t get affection. The phrase “lips that touch liquor, shall never touch mine” became a slogan used by the Anti-Saloon League, but today it’s viewed a reminder of Victorian sensibilities and the failure of Prohibition.
- **1884**: “Get Off the Track!” the Hutchinson Family Singers made this abolitionist ballad famous, set to the tune of the popular song “Old Dan Tucker” and using the new steam locomotive technology as a metaphor for the cause of emancipation.
- **1884**: “The Suffrage Flag” by William P. Adkinson when the women’s suffrage movement was nearly forty-years-old was set to the popular tune of “The Irish Jaunting Car” and “The Bonnie Blue Flag” and proclaimed that when women are given the right to vote, “war shall be at an end, bayonets and swords shall rust, we’ll use the brain, the pen.” The nineteenth amendment was finally passed 35 years later.
- **1911**: “The Preacher and the Slave” by Joe Hill was written as a condemnation of the Salvation Army and set to the tune of the hymn “In the Sweet By-and-By.” The Industrial Workers of the World (IWW) was a labor organization Hill was a member of that often clashed with the Salvation Army over the “hearts and minds” of workers. During strikes, factory owners often sent Salvation Army bands to play over protesters

to drown out the IWW chants or songs, which Hill lampooned as “the Starvation Army” characterizing their telling workers to accept their condition because a greater reward is waiting for them in Heaven, as “pie in the sky.”

With the rise of a formal music industry and Tin-Pan Alley, Broadway, and Hollywood, early 20th century protest songs began to be written by professional songwriters and lyricists using their own melodies, though most continued to be penned by activists and folk artists. The transition from sheet-music to wax-cylinders, phonographs, records, and radio enabled more complexity in protest songs recorded in a studio, performed by professionals, and distributed for people to play rather than perform.

- **1914**: “I Didn’t Raise My Boy to Be a Soldier” by Alfred Bryan and Al Piantadosi was a heartfelt reaction to the mass casualties of World War I. The song struck a chord and sold 650,000 copies within three months of release. Theodore Roosevelt remarked that “foolish people who applaud a song entitled ‘I Didn’t Raise My Boy To Be A Soldier’ are just the people who would also in their hearts applaud a song entitled ‘I Didn’t Raise my Girl To Be A Mother.'”
- **1915**: “Don’t Bite the Hand That’s Feeding You” by Jimmie Morgan and Thomas Hoier in response to immigrants supporting entry into foreign wars to save their former countries wrote this ballad that calls on immigrants to “go back to your home o’er the sea” if you “don’t like your Uncle Sammie.” During WWII, the song was used to silence criticism of the war effort.
- **1926**: “Cotton Mill Colic” by David McCarn protested against loud, hot, cramped, damp, dangerous cotton mills and textile plants. This song describes the conditions mill workers had for the last century, and it was sung by cotton mill strikers in South Carolina during the late 1920s and was recorded as early as 1930.
- **1927**: “Ol’ Man River” by Jerome Kern, Oscar Hammerstein II, and Paul Robeson was actually written for the Broadway musical “Show Boat”, and contrasts the struggles and hardships of black Americans with the endless and uncaring flow of the Mississippi River. It is sung from the point of view of a black stevedore on a showboat and became a standard for singer and civil rights activist Paul Robeson who often altered the lyrics when performing it. The lyrics, “I’m tired of livin’ but scared of dyin’” are some of the most famous in American music.
- **1931**: “Which Side Are You On” by Florence Reece, the wife of a union organizer during the Great Depression to protest extreme hardships or Kentucky coal miners when Harlan County miners’ wages were decreased, leading to the miners forming a union, maddening their bosses, and leading to layoffs and strikes. Violence ensued, the song was written using a centuries old melody with new lyrics, and it became an anthem for the labor movement and unions, later further popularized by Jim Garland and Pete Seeger.
- **1939**: “Strange Fruit” by Abel Meeropol and Billie Holiday may be the most famous protest song from the era. It depicted the bodies of black lynching victims in the South It was so controversial that many record labels refused to record it, but it was ultimately recorded by Holiday’s her friend Milt Gabler, a record producer.

- **1940**: “This Land is Your Land” by Woody Guthrie is played as a patriotic ballad, but was intended as a protest. Two verses in the 1940 draft are: “There was a big high wall there that tried to stop me. The sign was painted, said: ‘Private Property.’ But on the backside, it didn’t say nothing. This land was made for you and me.” and “One bright sunny morning in the shadow of the steeple, by the relief office I saw my people; as they stood there hungry, I stood there wondering if God blessed America for me?”
- **1941**: “Bad Housing Blues” by Josh White is a blues composition about the plight and oppression of black Americans under Jim Crow laws that protests the substandard housing black Americans were often forced into.
- **1947**: “We Shall Overcome” by various artists when members of the Food, Tobacco, Agricultural, and Allied Workers Union, who were mostly female and black, began a five-month strike against the American Tobacco Company in Charleston, South Carolina. To keep up their spirits, a striker Lucille Simmons led a version of the gospel hymn, “We’ll Overcome (I’ll Be All Right)”, union organizer Zilphia Horton learned the song from Simmons, famous songwriter and activist Pete Seeger heard the song from Horton, and after changing some of the lyrics, created the modern version that became a staple of the Civil Rights Movement.

Of course protest songs are just one example of this tension. Many societies have fought battles over music hundreds or thousands of years after its creation because of the ability to spark or manipulate emotional reactions among group members as exemplified:

- **1792**:[120] La Marseillaise, the French national anthem, was written after the declaration of war by the First French Republic against Austria, and was originally titled "Chant de Guerre pour l'Armée du Rhin" (War Song for the Army of the Rhine). It was adoped as a national anthem in 1795 and was a powerful theme throughout French history, including during World War 2.
- **1890**: The Native American genocide in the US closed with a federal and local ban on “Ghost Dancing,” a movement based upon dancing and spiritual singing feared to lead to renewed “Indian uprisings.” US soldiers massacred 300 unarmed Lakota ghost dancers, singers, and their families including young children at Wounded Knee, South Dakota.
- **1895 (and late 1940s)**:[121] “Waltzing Matilda” was apparently developed as a bush ballad as Australian slang for traveling by foot (waltzing) with belongings in a "matilda" slung over the back. It tells of a "swagman" (itinerant worker) boiling a billy at a bush camp and eating a stray jumbuck (sheep). When a squatter (grazier), and three troopers pursue the swagman for theft, he declares "You'll never catch me alive!" and commits suicide by drowning in a billabong (watering hole), that his ghost then haunts. Many versions were made over time, it became the quick march of the 1st Battalion, Royal Australian Regiment, the official song of the US 1st Marine Division, and is used in the British Royal Tank Regiment's slow march (an early British tank was called "Matilda"). It was used as a recruitment tool in World War 2.

120 https://en.wikipedia.org/wiki/La_Marseillaise
121 https://en.wikipedia.org/wiki/Waltzing_Matilda

- **1914**: The World War I Christmas Truce of 1914 was a spontaneous demonstration of humanity on the battlefield that angered military leaders on both sides leading to severe punishment by their commanders. The Scottish pipers were noted by the British high command as the potential ringleaders of this fraternization among combatants, and one even got court marshaled, but little actual punishment took place.[122] [123] [124]
- **1917**: The US Government used coercive propaganda efforts when the Sedition Act of 1917 was passed, criminalizing virtually all US anti-war activity, including songs and musical performances criticizing the war effort. “I Didn’t Raise My Boy to Be A Soldier” and others essentially disappeared when public performance jailed writers and artists.
- **1919-1948**: The “Hatikvah” was banned in British-controlled “Palestine” between 1919 and 1948 as a Zionist anthem English censors deemed too inflammatory to be performed or broadcast. Zionists circumvented the ban by broadcasting the nearly identical Smetana composition from the 1800s “Die Moldau”.
- **1931-1945**: In fascist Japan, the Japanese Imperial Army took steps to ban music deemed lyrically or culturally unacceptable, including an extremely popular Japanese military song known as “The Snow March” that criticized the Army’s callous failures in caring for its troops.
- **1930s**: Stalin banned entire genres of music deemed too decadent for proletariat consumption. Similar approaches were taken by China in the same time frame.
- **1936**: The battle song of the Spanish Civil War republican volunteers “No Passaran” still conjures up the call to action that helped prevent the Nazi supported fascist army of dictator Franco from capturing the Spanish capital of Madrid in 1937. Franco banned the song immediately after taking power (along with all other Republican music of the Spanish Civil War), which he deemed capable of setting off a rebellion for the next 40 years.
- **1933-38**:[125] With the rise of fascism in Germany and Austria, Nazi eradication of music deemed “degenerate” became the norm, eventually resulting in the banning of works of all Jewish and black songwriters and performers.
  - This music suppression policy was built on the writings of Wagner (Hitler’s musical hero), who campaigned in 1850 against the works of Felix Mendelssohn and other Jewish classical composers he claimed were “mongrelizing” traditional German music and culture. The removal of the works of Mendelssohn, Brecht, Weil, Offenbach, Mahler, Schonberg, Ellington, Calloway, Goodman, Shaw, Basie and others took final effect in 1938. The purpose was to demonize Jewish citizens and the Jewish/Negro/Socialist influence they allegedly brought to “the Fatherland” as part of the overall Nazi scapegoating strategy, enabling the Holocaust by turning Jews, Gypsies, Blacks, and Deformities into “others”.
  - Goebbels and Hitler personally chose “Die Fahne Hoch” written by SS storm trooper Horst Wessel (who had been killed in pro-Nazi street fighting) as the theme

122 https://www.iwm.org.uk/history/the-real-story-of-the-christmas-truce
123 https://en.wikipedia.org/wiki/Christmas_truce
124 https://news.illinois.edu/100-years-ago-the-christmas-truce-of-world-war-i/
125 https://www.dw.com/en/the-nazis-take-on-degenerate-music/a-16834697

of the Nazi Party and the inspirational anthem of the SS execution squads. It was played at all major Nazi events during the 1930s, and as the major musical theme in director Leni Riefenstahl's cinematic love letter to the Nazi regime, "Triumph of the Will."

- **1940**: The first American anti-Nazi film "The Mortal Storm" used an English version of the Nazi "Triumph of the Will" in a powerful scene illustrating the Nazi use of music to intimidate.
- **1944**: In the refusal of the Scottish Highland bagpipers to abide by the British ban on playing during the World War 2 D-Day invasion, the "insubordination" of being led by their pipers as tradition dictated is still celebrated.

Music, true to form since ancient times, provides direct and indirect emotional and narrative support for causes, is used by all sides in conflict at all levels of intensity, and has done so with increasing sophistication and intent as other areas of understanding have progressed.

Critical to understanding the import of music in general and song in particular in the influence arena, particularly before the advent of recording and playback devices, is that it requires little memory, no instrumentation, and easily spreads virally through populations as simple tunes attached to words producing memes easily transferred and reproduced verbally. People get catchy tunes stuck in their heads and keep singing them, they bring emotion to bear in the mind of the listener, and the multi-modal nature makes it easier to learn and remember than a play while taking less time and effort for anyone and everyone to use (and enjoy) than the use (or enjoyment) of an instrument or the production of a painting or a play for meme transfer.

Performance [126]

Performance includes music and many other forms of art, but for our purposes, we separate it from music because of the differences just identified for music in general, and song in particular. Performance, like music, is ephemeral when presented, and until recording devices were available could not be replayed and thus required physical presence. Notations for performance like plays were developed in ancient times and evolved over time for things like set decorations, entrances and exits, and so forth. The notation was and is still typically in the form of scripts and stage directions with possible scenery drawings and similar information. Interpretation is in the hands of the director and cast. Verbalization, intonation, and similar aspects are still not well described in written form, and to some extent they were surpassed in music with the musical scoring techniques discussed earlier. The Indian Vedas and their detailed descriptions, depictions, and pictures of activities come the closest to documentation of performance arts I am aware of, and this was spread throughout Europe well before the 1400s.

126 https://www2.ntj.jac.go.jp/unesco/kabuki/en/history/index.html

Forward to timelines: [127] [128] [129] [130] [131] [132] [133] [134] [135] [136]

- **1305**: The influence of the Christian church weakened as the Papacy was moved to Avignon, France. The Renaissance (Rebirth), founded primarily in Italy, actually stated in the 1200s, but new ideas based on classical teachings were emerging.
- **1405**: Constantinople [Istanbul, Turkey] fell to the Turks and scholars fled West with historical manuscripts, including some Greek dramas.
- **1454**: [Spain] Many actors were paid at Corpus Christi.
- **1465**: The Printing Press was invented and the Bible and some manuscripts were printed. By 1467-1470, the printing press and printed manuscripts are in Italy, and classical plays are staged at Universities and Courts or Academies (club-like learning organizations). Manuscripts also dealt with ancient architecture, Aristotle's works, Horace, etc.
- **1479**: [Spain] Ferdinand and Isabella united much of Spain and established the Inquisition to hunt down and punish heretics, expel Moors and Jews, and secure Catholicism as the state religion. Moorish influence (women and honor) and Christian influence (religious faith and doctrine) dominated.
- **1486**: Virtuvius's De Architectura (16-13 B.C.) was printed and published with 1 of 10 volumes on theater buildings and scenic displays.
- **1500**: Perspective was "rediscovered" although it was known to the ancients. At this point, technological and conceptual evolutions were taking place (no exact dates):
    - **Neoclassicism**: "New Classicism" Interest in the ancient "rediscovered" classics based more on Roman than Greek with the central themes being **Verisimilitude**: "truth seeming"; In drama it could represent only what could be reasonably expected in real life based on the 3 unities; (1) Unity of Time requiring a reasonable time (<= 24 hours covered in a play of no more than that span) or actual time (e.g., Oedipus Rex takes place in only an hour and a half, the actual length of the play); (2) Unity of Place requiring no more than one room, place, town, country, etc.; and (3) Unity of Action, so no sub-plots, counter-plots, secondary plots, was less important than (1) and (2). They used the 5-act form probably derived form Horace and Seneca with a 2-fold purpose (teach and please), had a decorum (characters displayed traits and suffered ridicule and punishment common to their class, good rewarded, evil punished, and an eternal truth. Comedy and tragedy were not to be mixed so that no element of one should be in the other; tragedy having characters of high station, deal with affairs of state, have elevated language, and have an

127 https://novaonline.nvcc.edu/eli/spd130et/neocitaly.htm
128 https://novaonline.nvcc.edu/eli/spd130et/medi2eliz.htm
129 https://novaonline.nvcc.edu/eli/spd130et/elizab.htm
130 https://novaonline.nvcc.edu/eli/spd130et/spanish.htm
131 https://novaonline.nvcc.edu/eli/spd130et/neocfrance.htm
132 https://novaonline.nvcc.edu/eli/spd130et/restor.htm
133 https://novaonline.nvcc.edu/eli/spd130et/18century.htm
134 https://novaonline.nvcc.edu/eli/spd130et/romanticism.htm
135 https://novaonline.nvcc.edu/eli/spd130et/melodrama.htm
136 https://novaonline.nvcc.edu/eli/spd130et/realism.htm

unhappy ending; and comedy having lower and middle-class characters, deal with domestic affairs, use less elevated language, and have a happy ending. Moral precepts were the justification for theater, partly to mollify the opponents of theater based on morality (i.e., the Church), and to teach, an important societal function, as opposed to its value as an art form.

  - **Staging**: Single-point perspective was calculated from the back of the house with scenery consisting of a series of wings / flats with scenery behind the proscenium arch, a background for action, and a "raked" stage (higher in back “UP-stage”, lower in front “DOWN-stage”) to increase the sense of depth, with the acting area sometimes level, overhead rigging and machinery hidden by border flats, one or more proscenium arch(es) made for a framed picture, an elongated U-shaped auditorium with boxes in tiers around walls (usually 2 or more), an undivided gallery above the top row (for servants / lower classes), central floor space (orchestra or pit) was not a popular place for the elite until the late 19th century, and some theaters had no seats till the late 18th century (spectators could stand and move about, for fashionable young men and would-be critics and the middle-classes, priced less than boxes but more than the gallery. (seems like a modern Rock and Roll concert venue). There was artificial lighting (candles and oil lamps, chandeliers over the house and stage, candles behind proscenium arch and as footlights and behind wings), with little effective control, though "dimmers" were used. Italian artists tried new ways to shift the scenery, used mostly in public opera houses, which had opened in Venice in 1637 (not neoclassical by that time), and pageant wagons used for carrying portable things.

- **~1500-1700:** Spanish theater started to grow substantially and ultimately produced 30,000 plays over the period. Spain and Italy were close, they both had an interest in classical learning.
- **1508**: [Spain] A University studying Greek, Latin, Hebrew, classical dramas was founded, many works were translated, some secular works written, but these not widely performed.
- **~1520s**: [England] Ralph Roister Doister (by Udall, headmaster at Eton Academy) has a plot about a boastful coward, indebted to Plautus’s The Braggart Warrior, foolishness of boastful coward and his courtship of a widow.
- **~1540s**: [England] Gammer Gurton’s Needle (by Mr “S” at Cambridge University, perhaps Sackville) had a plot where two households disagree / misunderstand about the loss of a needle, a medieval farce with techniques of Roman comedy.
- **1545**: [Italy] Serlio (Dell’Architettura) was published as an interpretation of Vitruvius and set guidelines for theaters and design, trying to fit classical theater (circular and outdoors) into indoor theaters able to use perspective.
- **1550**: [Italy] Periaktoi (triangular "flats") were used for changing wings.
- **1550-1600**: [France] was having internal political problems leading toward civil war, delaying their theatrical progress. There were few if any theaters or professional theater companies.

- **1550-1750**: [Italy] Commedia dell'Arte came into prominence in Italy with troupes throughout Europe by 1600, diminishing after 1750 and "dead" by 1800. The basic story was a common scenario (almost 800 survive, but no clear picture of quality of performances) but no highly held individual artists, with stock characters and proven comic routines (bits); Pantalone, the old man, a fool; Dottor, the doctor, a drunk or glutton; Capitano, a braggart soldier; Inamorati, the young lovers and the only "normal" characters; "zanni", foolish servants; and Harlequin (or Arlecchino) was the most popular.
- **1550-1588**: [Spain] was a dominant power but after the defeat of the Spanish Armada, its influence and power declined. There were a number of professional troupes. Spanish religious drama was extensive in the NE areas because of less Moorish influence, and as Moors were expelled, religious drama expanded. It took on distinctive characteristics starting in 1550 with auto sacramentale associated with Corpus Christi (the sacraments) combining characteristics of morality and cycle plays, human mixed with allegorical, and drawn from any source as long as it illustrated dogma. Trade guilds ran the productions, but professional troupes took over by the mid-1500's. They were still religious, toured neighboring towns, usually operating on carros, or wagons (wooden frames covered with painted canvas). Rueda (c. 1510-1565), the most successful of Spanish professional theater toured widely, and wrote plays resembling medieval farces. Cueva (1550-1610) used Spanish history and classical themes as subjects, and Cervantes (1547-1616) [Don Quixote] wrote 36 plays on contemporary Spanish life, but was viewed as stilted. No Spanish theaters existed in this period.
- **1558**: Elizabeth came to power, and gentlemen could maintain a group of actors, but others were considered vagabonds. A license was required to perform plays, but local authorities (many Puritans) found ways to keep troupes from performing.
- **1561**: [England] Gorbuduc (Sackville and Norton) the "first English Tragedy" with a "political" statement about leaving the order of succession of the throne unknown as support for Elizabeth's reign. QE outlawed religious drama (her father Henry VIII separated from the Catholic Church (1534) to form the Anglican Church (Church of England), with the English monarch as the head of the church, leading to Catholic / Protestant disputes, and QE wanted no religious dissension), leading to a rapid development of secular drama.
- **1570s**: [England] Acting became a legal profession. The English theater was directly under the control of the government. Acting companies had to have a license, requiring the patronage of a noble. Provincial troupes were deprived of legal status, so theater was concentrated around London. The merchant class disliked theater (as part of the growing Puritan population), while the aristocracy liked it.
- **1574**: [England] Government decrees made acting more secure, daily performances stimulated building permanent theaters and assembling larger companies. Earl of Leicester's Men, licensed in 1574, was headed by James Burbage, builder of the first theater in London.
- **1574**: [England] Theater buildings were illegal in the city limits of London, so theaters were built outside the city limits. Burbage, head of the Earl of Leicester's Men, licensed in 1574, built "The Theatre." and, by 1580 at least two companies were playing there.

- **1580s**: [England] The University Wits, an informal group of scholars applying classical standards to contemporary stage, started writing plays for the theater companies. The Spanish Tragedy (1587) was the most popular play of the 1500's. The University Wits helped develop elegant prose, romantic comedies, complex protagonists, humanism and neoclassicism combined, blank verse, iambic pentameter, not rhymed (called a "couplet" if rhymed), complex motivations, development of the "chronicle" play, (i.e., Edward II) rearranging, telescoping, and altering events to create a causal sense, and public theater emerged with lack of religious and political subjects.
- **1585**: Teatro Olimpico [Vicenza, Italy] built, the oldest surviving Renaissance theater, had fixed perspective scenes in each of five doors.
- **1585-1642**: [Spain] theater was equal in quality and vigor to England, but did not probe deeply into man's destiny. A preoccupation with a narrow code of honor limited it. Catholicism became secure in Spain while religious infighting was rampant in the rest of Europe.
- **1588**: the Spanish Armada was defeated followed by a period of peace and gradual supremacy of English, rather than Spanish, influence as a major world power.
- **1592-3**: [England] A plague forced many troupes to dissolve or combine.
- **1590-1613**: William Shakespeare (1564-1616) wrote 38 plays, some written with others (i.e., John Fletcher). Histories (English history, Henry IV, V, VI, VIII, Richard II, Richard III) Tragedies (Romeo and Juliet, Othello, Hamlet, King Lear, Macbeth), and Comedies (Twelfth Night, As You Like It, Comedy of Errors). Actor and shareholder in Lord Chamberlain's Company (Later the King's Men) by 1595. After 1599, a shareholder at the Globe Theatre. Actor, playwright, and sometimes director.
- **1597**: [England] The Crown agreed to limit the number of troupes, but more firmly supported those it sanctioned.
- **1599**: [England] Elizabethan theaters of two kinds were in place; Outdoor ("public"), and Indoor ("private"), both open to anyone who can pay, with private more expensive, smaller, and with a more select audience. Nine Public playhouses were built between 1576 and 1642 including The Globe (1599) where Shakespeare was a shareholder, The Fortune (1600), and The Swan (date unknown).
    - Public playhouses held up to 3,000 people, were round, rectagonal, or octagonal with a "pit" or "yard" holding "groundlings" (un-roofed space surrounding the stage on 3 sides enclosed by 3 tiers of roofed galleries). The yard (general admission) was less expensive and the Gallery more, and likely also some private galleries. The stage was raised 4-6 feet extending to the center of the yard, a "Tiring house" was at the back of the raised platform for actors to wait and change, the stage was roofed ("the heavens" supported by columns), flying was common with cranes and ropes, traps were in the floor for fire, smoke, and other effects, a hut above the Tiring House was used for equipment and machinery, a flag on top of the hut signaled performance day, a musicians' gallery below the hut, and a third level.
    - Indoor/Private theaters were about 1/4-1/2 the size, roofed, held winter shows. (1576) Blackfriar's (a former monastery) was the first one and closed by 1584. The

New Blackfriar's opened in 1596 by Burbage with The King's Men using it after 1610 as their winter performance area. Children's troupes were popular until 1610.

- **1600**: Renaissance thought is now spread throughout Europe.
- **1603**: [Japan] The establishment of Edo Shogunate, the beginning of the Edo period with Kabuki-odori
- **1603-1642**: [England] With James I and the beginning of the Stuart reign, all troupes were licensed to members of royal families. In 1603 Lord Chamberlain's Men became the King's Men, until 1642. Actors were paid by yearly fees plus expenses by the court and most troupes worked sharing risk and profits as democratic self-governing entities. By 1642, there were six private theaters in London used only during the five warm months. Many playwrites were prolific, Fletcher wrote one with brother and sister incest and a moral resolution (they were not really related); Webster wrote The White Devil and The Duchess of Malfi showing insane Prince Ferdinand, Ford exemplifies the decadence of Jacobean/Caroline drama with "Tis Pity She's a Whore", and essentially good characters caught up in abnormal situations illuminating evil by associating it with ordinary people.
- **1609**: [Spain] Vega becomes a priest (and former member of the Spanish armada, secretary to noblemen, having had many love affairs) claimed to have written 483 comedies, and an estimated 1800 plays, 450 of which survived. He had clearly defined actions, arousing suspense, dealt with conflicting claims of love and honor, had happy resolved endings, characters representing every rank and condition of people, female roles, extended the simpleton character (gracioso), and had natural and lively dialog.
- **1618**: Teatro Farnese [Parma, Italy] was the first theater built with a permanent proscenium arch and additional rearward arches to protect the illusion of perspective and depth.
- **1625-1636**: [France] Known by now for farce, then Cardinal Richelieu became Chief Minister of France, squelched religious disputes, and more theater developed. In 1635, Richelieu established the French Academy to maintain purity of the French language and literature, and in 1645, Torelli was hired to redesign the court theaters. After this, there were always at least two professional theater companies in Paris and often more. Educated men began to write plays. Corneille wrote Le Cid (1636) based on a Spanish tragedy. Richelieu got the French Academy to judge Le Cid, they praised it whenever it stuck to the neoclassical ideals, but condemned it when it didn't. The Academy's conclusion was that Le Cid was not a good neoclassical tragedy; The unities were observed; it took place in a single town; There was unity of action, no sub-plots; there was unity of time; but it stretched verisimilitude: in that too much happened in 24 hours (the original story took several years); and decorum was violated (the heroine agrees to marry the man who killed her father and no respectable woman of her class would do that). Le Cid was a popular success, but the Academy's ruling made the public aware of neoclassical ideals. Corneille accepted the verdict and tried to adhere to the principles, and Neoclassicism took over France for the next 100+ years.

- **1638**: [Italy] Sabbattini published a Manual for constructing theatrical scenes and machines. Angle wings were replaced with flat wings and suggested ways of shifting scenery.
- **1642**: [England] Royalty supported theater until the Puritan Revolution when Charles I was beheaded and Cromwell (the Lord Protectorate) took over. Theater was outlawed as connected with the monarchy and "immoral," non-Puritan values. Music was allowed, and Davanant (a writer of masques) produced some operas with Italianate stagings (and perhaps some illegal performances). Masques used Italianate staging and were associated with the monarchy, so when the Puritan Revolution happened, all the theaters were closed.
- **1645**: [Italy] Torelli's chariot-and-pole system emerged across Europe (except England) with chariots or wagons on tracks below the stage with poles extending through slots cut parallel to the front of the stage and scenery and wings and backs attached to poles with a system of ropes and pulleys to get a simultaneous shift of scenery. The groove system [England] after 1640 used grooves in the floor and pieces of wood overhead to similar ends. Neoclassicism avoided the supernatural, so dramas were done with few special effects, while operas (popular in Italy), intermezzi (short shows between acts of dramas), and lavish dances had extravagant special effects (trap doors, glories, scenes shifted with no curtain, etc.).
- **1647**: [Spain] Fixed platforms were used and acts performed first in front of churches, then courtyards, then streets, but there is no available evidence that they were ever performed in churches themselves.
- **1660-1668**: [England] The monarchy was restored, Charles I's son, Charles II, was restored to the throne (from France in the court of Louis XIV, who loved theater) and Charles II helped bring Italianate and French styles and staging to England. The Drury Lane and Covent Gardens became the first theaters officially licensed and the type of theater brought back resulted in a protest against the Puritan ideal, designed primarily for the aristocracy, and this form of theater was then rebelled against. Restoration comedy of manners was characterized by witty dialog, sophisticated sexual behavior of a highly artificial and aristocratic society, "virtue" from catching a lover or cuckolding a husband without getting caught, "honor" comes from reputation (not integrity), "witty" (saying things in clever ways) is used, and "transparency" names ("Sparkish, Fidget, Squeamish", Mrs. Malaprop (""ill-appropriate").
- **1680**: [France] The period of excellence in neoclassical plays in France had ended, Corneille and Racine stopped writing, Molière's company merged with the Marais Theater to form the Comèdie Française, the first (and still existing) national theater, and conservatism won out. Neoclassicism won in staging and playwriting, and acting was highly oratorical and declamatory.
- **1670-1700**: [England] The protestant (Puritan) middle class emerges and works like Collier's 1698 “A Short View of the Immorality and Profaneness of the English Stage” led popular sentiment against Restoration theater, and Neoclassicism returns.
- **1700-1730s**: [England] The concept of Rationalism (The Age of Reason) with faith in reason, began to take over from faith in God, and Rationalism begins to lead away

from the strict rules of Neoclassicism. This stems from faith in man, leading to the movement of Sentimentalism in theater, asserting that people are essentially good and arousing sympathetic responses to misfortune, beginning in the 1690's to 1730's resulting in tearful comedies that are more conservative, middle-class, sentimental, and moralistic. Steele who sought to arouse noble sentiments wanted a "pleasure too exquisite for laughter." The Conscious Lovers (1722) was a sentimental comedy with protagonists drawn from the middle class. The heroine, Indiana, after many trials, is discovered to be the daughter of a rich merchant, so she can marry, and thus a happy resolution, with servants having some funny scenes.

- **1716**: [Japan] The Kyoho reforms usher in the beginnings of Japanese formal theater.
- **1750**: Italian theater was no longer prominent, except for opera. France and England were the leaders in world theater. And Romanticism was starting to take hold, in some circles also associated with the Age of Independence. Trading and manufacturing joined agriculture as major sources of wealth, people were being concentrated in towns and cities, and governance was changing substantially because of the demographics.
    - Romanticism is characterized by an abiding trust in nature's goodness; emotions and instinct more important than reason (reason is the product of education and thus is not natural and inherently corruptible), glorification of "The Natural Man" (a.k.a., the "noble savage" primitive and untutored personality such as the American Indians, African Blacks, South Sea Islanders. God created nature and thus learning about nature is learning about God. Conceptually, primitivism (the simple and unsophisticated life was best) led to an interest in old civilizations, archaeology developed as a science, Egyptian and Medieval times and places became important areas of study, there was glorification of Greek society (but not Roman), medieval studies urged by nationalism helped develop national identity, equality of people opposed to social and economic class disparagement, an era of revolutions since overthrowing governments seemed to eliminate social classes, a premium on detail as the pathway to truth, seeking the particular, specific, and unique, as opposed to generalization, and the one-ness of the universe and all within it, requiring the search for the unattainable ultimate truth.
    - Artists become seen as misunderstood geniuses, blessed and cursed by their art that common folk could not understand, ultimately led to a melancholy strain in Romanticism (ultimate truth unattainable) and art served the exalted purpose to reveal the underlying unity of all existence and eliminate conflict: "to make man whole again". Both artist and critic were necessarily subjective and personal, there was no objective criteria for achieving or critiquing art, and the artist and perceiver of art were unjudgeable, leading to "democratization" of art (anyone's feeling are as as good as anyone else's. and emotions over intellect with special effects focused on the supernatural and mysterious (visual over verbal, sensational over factual) led the concepts of the era.
    - Audience size increased, and because seeing was more important than hearing, the orchestra seats (previously the cheap seats) became valuable. Upper galleries were the cheapest, audiences were loud and vocal, scenery included drops, flats,

ground rows (cutaway flats standing free on the stage floor, carefully and realistically painted). natural settings, and candles or oil lamps.

- **1765**: [Spain] Autos were forbidden, called too carnival in spirit, and some of the farces and dance elements were considered objectionable as was having the plays performed by possibly immoral actors.
- **1770**: The American Revolution is underway.
- **1787**: [Japan] The Kensei reforms
- **1791**: The French Revolution is underway.

Other 18th century forms included ballad opera with sections of dialog alternating with lyrics set to popular tunes, like Gay's "The Beggar's Opera" (1728) satirized British politics, using Handel's Messiah and other tunes, were a precursor to musical comedy. Farce was also popular with Fielding in the 1730's. Pantomimes became popular by 1715 combining dancing, mime (silent mimicry), done to music, with elaborate scenery and special effects, done as an afterpiece to plays and combining comedy, farce, and mythology. The Harlequin came from these pantomimes, and with his magic wand, the scenery would change. This was primarily visual and aural entertainment with commissioned innovative scenery.

- **1801**: [Germany] Faust parts I and II, (1801 and 1831) is now accepted more as a literary work than a stage play. Schiller's "William Tell" (1804) was a stirring celebration of democracy, individualism, and nationalism.
- ~**1810**: [US and Europe] The typical producing organization was the resident company performing a large number of plays each season. "Stock companies" played a wide variety of roles in many plays, usually with fixed salaries. Visiting stars, touring companies, and long runs started to emerge with exploitation of stars, which became popular after 1810. English actors would tour with American companies as stars, performing famous roles with resident companies.
- **1816**: [US] The Chestnut Street Theater in Philadelphia started to use gas lighting.
- **1820-1830**: [England] By the 1820's, Covent garden and Drury lane Theaters in London used gaslight, and by 1830, gaslight was increasingly used around Europe. Gaslight increased illumination, had better control of intensity, but still had wavering flames. Many special effects included flying, trap doors, water pump systems, moving panoramas to give the illusion of travel, treadmills by the late 1800 (allowed for horses and chariot races, etc.), volcanic eruptions, fires, etc. The stage was to present an illusion of reality, with many details, and was to be historically and geographically accurate. While Romanticism was not at all realistic in its acting, drama, or direction, in set, costume, and lighting it attempted to be as realistic as possible. Romanticism inadvertently paved the way for easier acceptance of Realism. But first theater had to become more popular and accepted by common people.
- **1820s-40s**: [Europe and US] Melodrama became the most popular form by 1840, and is still present today. In the early 1800's, most were romantic, exotic, or supernatural, in the 1820's, they became more familiar in settings and characters. in the 1830's more "gentlemanly". Melodrama comes from "music drama", where music was used to increase emotions or signify characters (signature music). In this simplified moral

universe, good and evil are embodied in stock characters, and in episodic form, the villain poses a threat, the hero or heroine escapes, and so forth, with a happy ending, almost always in 2-4 acts (5 acts are reserved for "serious" drama) with many special effects: fires, explosions, drownings, earthquakes, and so forth. Kotzebue [France] wrote over 200 domestic melodramas treating common people with dignity, introducing controversial views without offending the audience, helping them to ask questions of life and society, and often called the "father of sensationalism", he mixed sentimental philosophy with startling theatrical effects. Pixérécourt wrote more than 100 plays and specialized in canine melodramas, disaster melodramas (floods, volcanoes, etc.), sometimes directing his own plays, and with easily identified character types and startling theatrical effects more important than the dialog.

- **1830**: [France] Victor Hugo’s “Hernani” caused a riot over whether long-accepted Romantic ideals should be allowed in France’s National Theater. The French Academy had determined that all French plays would be neoclassical in form, and it contained elevated language, noble characters, and the five-act form, and was thus Neoclassical. But it also had common people as some important characters, struggles with a ruler, violence, death, and humor, and was thus not neoclassical. Eventually, Romanticism won out, even in France, but not without a struggle.
- **1841**: [Japan] The Tenpo reforms
- **1848**: [Germany and Europe] Marx espoused a political philosophy arguing against urbanization and in favor of a more equal distribution of wealth, which helped lead toward a moderate realistic theater and greatly influenced others including Wagner. “The Communist Manifesto” was published. Revolutions in Europe showed a desire for political, social, and economic reform. Theater reflected these changes throughout this era, introducing new forms and focus on “the common man”.
- **1849**: [France] Domas’ novel Camille about a “kept” woman was dramatized, written in prose, and dealing with life at that time. Eventually, he wrote "thesis plays," about social problems of the day, which helped to start the emergence of realism where truth resides in material objects we perceive with all five senses; is verified through science (the scientific method and observation would solve everything); and human problems were the highest home of science. Art, in realism, has the purpose to better mankind, drama involves the direct observation of human behavior, using contemporary settings and time periods to deal with everyday life and problems as subjects. Staging and costumes included 3-dimensional details added by 1800, and by 1850 theater productions used historically accurate settings, costumes, and details, partly as a result of romantic ideals.
- **1850s**: [US] Boucicault, the most successful English-language melodrama writer wrote the Corsican Brothers (1852), The Octoroon (1859), and others, and combined sentiment, wit, and local color with sensational and spectacular endings. He was the first US writer to demand and receive royalties for performances of his plays, was instrumental in The International Copyright Agreement of 1886, and was known for volcanoes, earthquakes, burning buildings, etc. The most successful and popular melodrama was Uncle Tom’s Cabin (1852) by Stowe, with six acts, done without an afterpiece, established the single-play format. It had 325 performances in New York,

and in the 1870's, at least 50 companies did it in the US, in 1899 500 companies, in 1927 12 still doing it, and with 12 movie versions since 1900, it was the most popular melodrama in the world until the First World War.

- **~1850**: Many stars made round-the-world tours, helped by the Romanticist's idea of individual genius, better transportation (the US transcontinental rail was complete by 1870), stars received high salaries, with a French actress making as much as France's Prime Minister. After 1850, the size of the repertory decreased as the length of the runs increased, it took longer to recoup investment in the show (Wallock's Theatre in New York had 60 plays per season in the mid 1850's; only 5-10 by the 1880's), and the repertory system finally fell when the long-term contract was deemed infeasible, as some actors were idle during some shows. Actors began to be employed only for the length of the play, and by 1900, the repertory system had all but disappeared in favor of the "single play, long run policy." The number of plays and activity increased.
- **1859**: [England] Darwin published The Origin of Species which led to many new theories and approaches to theater.
- **1867**: [Japan] The Mejii Restoration
- **1870-1885**: [France] **Naturalism** was demanding new drama based on Darwinism: all forms of life developed gradually from common ancestry, and evolution of species is explained by survival of the fittest, thus 1) heredity and environment control people; 2) no person is responsible since forces are beyond control; 3) the responsibility must go to society; 4) progress is the same as improvement/evolution in that it is inevitable and can be hastened by using the scientific method; 5) man is a natural object. France was defeated in the Franco-Prussian war (1870-71), making France a Republic, and attitudes shifted: working people had few privileges and socialism gained support. Zola admired Comte and advocated the scientific method so literature becomes scientific or perishes and should illustrate the inevitable laws of heredity and environment or record case studies, so the writer is like a doctor (seeking the cause of disease to cure it, bringing the disease in the open to be examined) aiming to cure social ills. Zola's novel “Thèrése Raquin” (dramatized 1873) states his views. Naturalism should be "a slice of life." Becque captured the essence of naturalism in two of his plays, The Vultures (1882) and La Parisienne (1885), both on sordid subjects, pessimistic, cynical, and had no obvious climaxes, no sympathetic characters, and progressed slowly to the end.
- **1877-1890**: [Normay] Ibsen (1828-1906) is considered the father of modern realistic drama. His plays attacked society's values and dealt with unconventional subjects in the form of a causally related play, perfecting the “well-made” play formula making a shocking subject matter acceptable. Exposition was motivated, causally related scenes were used, inner psychological motivation was emphasized, the environment influenced characters' personalities, everything characters did and used revealed their socio-economic milieu. He addressed euthanasia, the role of women, war and business, and syphilis, the concept of sins of the father transferred to the son (Ghosts 1881) resulting in syphilis, (Pillars of Society 1877) dealt with war and business, (Hedda Gabbler 1890) where a powerful woman takes her life at the end of the play to get away from her boredom with society, (A Doll's House 1879) where Nora leaves her husband Torvald and her children at the end of the play, and turned to more symbolic

and abstract dramas later in life, with his "realism" affecting others and helping lead to realistic theater which is the predominant form of theater still today.

- **1880s**: With touring, came changes as New York became the theatrical center where actors went to get hired, local managers would book events, and by the 1880's, the booking system was chaotic since managers had to negotiate with several producers, and there were many defaults on contracts.
- **1887**: [France] Antoine, the father of naturalistic staging, wanted to produce a Zola novel drama, the amateur groups refused, so he founded the Théâtre Libre (Free Theatre), whose first program was a success and, by the end of 1887 he was famous, and worked in the theater till 1914. The Independent Theater Movement wanted to make naturalism and realism more acceptable, used a subscription basis with members-only productions and was exempt from censorship. The focus was on plays that had been refused licenses other places (for instance, Ghosts had been banned in much of Europe). Some of the plays tended to reverse morality, repelled many, and lead to the idea that naturalism was depraved. They also began producing at least one foreign work per year, introducing world theater to France. Production techniques were innovative, with real beef carcasses hanging on stage; the "box set" was used so that "the fourth wall" was adhered to constantly; he discouraged declamation in favor of more natural acting; replaced footlights with more natural lighting; emphasized ensemble acting; and adhered to his belief that each play had its own environment.
- **1894**: [England] Shaw made fun of society's notion of drama for educating and changing with plays tended to show the accepted attitude and demolishing that attitude while showing his own solutions. Arms and the Man (1894) is about love, war, and honor; Mrs. Warren's Profession (prostitution), Major Barbara (1905) a munitions manufacturer gives to the world (jobs, etc.) while the Salvation Army prolongs the status quo; Pygmalion (1913) shows the transforming of a flower girl into a society woman and exposes the phoniness of society.
- **1896**: The Theatrical Syndicate was formed, essentially, a monopoly of American theatrical production from 1896 to 1915, with commercial value over artistic motives.
- **1898**: [Russia] Chekhov is known for poetic expiration and symbolism, compelling psychological reality, people trapped in social situations, and hope in hopeless situations, but he claimed that he wrote comedies that others think are sad and tragic. His characters seem to have a fate as a direct result of what they are and have an illusion of plotlessness. The Seagull (1898), Three Sisters (1900) about three sisters who want to move to Moscow but never do, and The Cherry Orchard (1902). His realism and symbolic meanings in texts and titles of plays have affected other writers.

Other popular 19th century theatrical forms included specialty acts like jugglers, tumblers, acrobats, etc. pantomimes (elaborate tricks with scenery and costume), short musical revues ("vaudevilles" in France), comic operas (sentimental stories with original music), revivals of Shakespeare often deleting or changing parts of a script and removing socially "unacceptable" or sexually "offensive" parts, and so forth. Theaters grew in size encouraging spectacle, and after mid-1800's, regular drama and specialty acts separated with theaters specialized in one form of entertainment. The pit was renamed the orchestra and became the best seats.

- **1900-**:[137] [US, England, France] Realism became the dominant form of theater in the 20th-century. There have been some experiments for more adventurous innovation in mainstream theater, but realism became widespread in England, France, and the US. In the US theater boomed with 200-275 new productions a year average.
- **1910-1915**: [US] The Theatrical Syndicate had controlled American theater till around 1915, but around 1910 a loose-knit group of what came to be known as the "little theaters" emerged.
- **1919**: [US] The Theater Guild was founded with the intention of bringing important foreign works to improve theater in the US.
- **1924-5**: [US] By the mid 1920s, playwrights in the US were competing to have their works produced by the Theater Guild. O'Neill had five of his plays appearing at one time in New York and helped establish serious realistic drama as the main Broadway form. "Long Day's Journey Into Night" and "Desire Under The Elms" are among these. "The New Stagecraft." emerged with 2 major American designers (Jones and Simonson) moving away from realism and towards suggestion and mood, a realism of mood and feeling. During the "roaring 20s American musical theater began to develop more fully, with the Ziegfeld Follies variety acts and songwriters and performers appearing in theaters.
- **1926**: [US] A small group of authors and theater directors formed the Workers' Drama League, and the New Playwrights' Theater formed the next year. Both hoped to present drama that had some social significance and would deal with some of the problems of the day. The workers' theater movement would not develop fully in the US until after the stock market crash of October 1929.
- **1939**: [Japan] World War II ***

One of the fundamentals of theatrical performance, scripts, players, locations, and housing over the time span of the parallel cognitive expansion is its close linkage to politics and, in particular, social narratives and control. While music in large orchestras was subject to such controls, in the small, individual performers persisted across all genres and locations and time frames, being suppressed from time to time, but not really destroyed or disabled as a narrative mechanism reproducing memes throughout the populace. But theater, because of the emergence of buildings and the need to have facilities to support production, along with the sponsorship of governments and suppression of alternatives, was subjected to a far more effective system of social influence and narrative control. Governments imposed restrictions, forced only their narratives to be widespread in performances, and used the selected authors and venues to move society in desired directions.

Audio recordings, Radio, and The Movies

Audio recordings, radio, and the movies changed the fundamental nature of performance in two dramatic ways; the ability to capture and replay a performance meant that a far closer representation of performance was now available than any notation can match, in the sense that we record sensor data at the resolution of the sensor and recording device, as opposed to having a transcription of it produced by further processing or the original writing that led to

137 https://novaonline.nvcc.edu/eli/spd130et/EarlyTwentieth.htm

the performance but not the performance itself; and the ability to simultaneously actuate a performance to large populations over wide areas meant that the time to spread memes and narratives across a population became nearly zero in human terms.

Beyond the technology issues which were largely covered earlier, artists who were previously limited to local presentations and published works on paper, could become individual stars on a scale rarely before seen. A complete history is beyond the scope here, but the numbers are staggering in terms of the ability to affect the masses. For example, the largest theater crowds were in the hundreds of attendees and even the largest venues in ancient times , such as the Colosseum could hold about 60,000 spectators (87,000 theoretical max).[138] But radio reached vast numbers of people reaching tens of millions by the mid-1930s.[139]

> "*By 1935, the U.S. Department of Commerce estimated that radio broadcasts served 18.5 million families, or more than 50 million people. Approximately 60 percent of all homes in the United States had radios.*"

A single US broadcast of "War of the Worlds" on Oct. 30, 1938 just after 8PM Eastern time had something like 5 million listeners[140] and in 1933, "At 10 p.m. ET that Sunday night, on the eve of the end of the bank holiday, Roosevelt spoke to a radio audience of more than 60 million people, to tell them in clear language "what has been done in the last few days, why it was done, and what the next steps are going to be"[141] in response to the Emergency Banking Act passing and the shutdown of banks nationwide at the start of the Great Depression. That's 1,000 times the number of people who could attend the largest venue or hear the same real-time information before 1900. The "Day of Infamy" speech in 1941 was heard by over 81% of US adults.[142]

This unprecedented ability of a single person to communicate directly to tens of millions of people and influence the vast majority of adults in a nation simultaneously initiated a dramatic change in narrative control on a larger scale than ever before, taking advantage of emerging communications infrastructure to spread a common message that altered the course of the US involvement in World War 2, which previously was unsupported by the population writ large. Of course the Japanese acts at Pearl Harbor were the focus of this narrative, but that was just the trigger that allowed the political change to take place, and without the very rapid spread of news through the media infrastructure of the day and the unification of the country surrounding the actions to take place, the World would be a very different place.

And then there are these things

In many fields, there were dramatic advancements over the time frames at issue, and I thought I would point out a few that I think are important to further understanding going forward. In particular, the evolution of crime and punishment as a social control system and the requirements for reliable and authentic records in order to admit evidence into legal proceedings, and the longest living institutions and their nature as narrative mechanisms.

138 https://www.thecolosseum.org/facts/
139 https://www.encyclopedia.com/media/encyclopedias-almanacs-transcripts-and-maps/radio-broadcasting-history
140 https://press.uchicago.edu/Misc/Chicago/471921.html
141 https://en.wikipedia.org/wiki/Fireside_chats
142 https://en.wikipedia.org/wiki/Day_of_Infamy_speech

Crime and justice, archives and records

Crime has existed in the legal sense since legal systems were put in place. In the more general sense, injustice has existed since the concept of justice existed. But the manner in which crimes were identified, acts attributed to actors, and criminals thereby punished has changed dramatically over the ages. This is all supported by judicial systems within jurisdictions creating juridical context. This is an extensive area of research as it has been over many centuries, starting in ancient times but changing dramatically starting in the 1600s.

Forged documents were fairly common in the early part of the middle ages, and as written records become more common, issues of land ownership, inheritance, and church doctrine combined to create a situation where ownership of land became a large enough issue to justify more serious attention, particularly in disputes between large entities such as different religious groups and governmental agencies. While obvious forgeries were detected in many cases, the problem became more focused in the 1600s when …

> *"The Thirty Years' War in Germany led to endless legal conflicts, and in France the nobility engaged in a concerted action known as the bella diplomatica ("diplomatic wars") to assert their ancient privileges against royal absolutism. The decisive impetus, however, came from a much more particularist dispute. Daniel van Papenbroeck, a member of the Jesuit commission known as the Bollandists (from another member, Jean Bolland), which was charged with the publication of the Acta Sanctorum ("Acts of the Saints,"), finding that some monastic documents he inspected were forgeries, assumed (1675) that this was true of almost all early-medieval documents. Since most of the monasteries with which the documents had been concerned were of the Benedictine Order, the Benedictines resented the suggestion, and Mabillon undertook to refute it. In his De Re Diplomatica (1681), Mabillon set out the fundamental principles of the science of verifying documents;"*

In 1681, the archival science was codified into a legal framework[143] which focused on individual documents, their characteristics, genesis, and treatment.[144] Archival science and diplomatics were developed together, and in the 1800s laws were increasingly being formulated taking into account their concepts and methodologies. By the late 1800s, rules of evidence and their foundation were explained in detail and by the early 1900s, they were clearly codified into laws globally.[145] This process started with Mabillon[146] [147] who defined the field of Diplomatics, derived from the Greek word diploma, meaning "doubled" or "folded", and includes the study of legal and other records, such as bills, reports, cartularies, registers, and rolls, and it is a basic historical science. The underlying notion of diplomatics is that the authenticity and reliability of records can be confirmed (or refuted) by identifying consistency (or inconsistency) between the documentary form and the manner in which it came to be. For example, in associating art with an artist, we might compare the makeup of the paint in a painting to the available paints at the time asserted for it being painted, and of course test after test may be applied. This is sometimes called questioned document analysis.

143 Dom Jean Mabillon, "De Re Diplomatica", 1681, Saint-Maur, France
144 L. Duranti, "Diplomatics: New Uses for an Old Science", Archivaria 28. 7-27, 1989.
145 L. Duranti, "Diplomatics", Encyclopedia of Library and Information Sciences, Third Edition DOI: 10.1081/E-ELIS3-120043454, 2010, Taylor & Francis.
146 https://en.wikipedia.org/wiki/Jean_Mabillon
147 https://www.britannica.com/print/article/164633

Much of questioned document analysis in early days surrounds things like terminology use, media (paper or alternatives and ink or tool marks), the habits and methods of specific scribes and their known locations over time, and similar analytical frameworks that could refute the authenticity of a document. These ultimately became codified in legal structures used by courts to make determinations about admissibility of evidence for purposes. A forged document, for example, is admissible as evidence of the forgery, but not the truth of what the document states.

Documents also generally fall under the concept of hearsay in that they are not the testimony of an independent witness to an event. Similar to someone who heard a rumor, a document is not generally admissible for what it contains unless it is somehow authenticated as to origin and accuracy. This is done through the testimony of expert witnesses, responsible parties (custodians) and various exceptions such as the normal business records exception and the public records exception. These types of documents are presumed reliable and authentic but can be challenged by expert testimony based on scientific evidence of their lack of authenticity or reliability.

The Locard principal[148] is also foundational to much of this age of forensic analysis based on the principal that when two objects come into contact, each leaves some of itself with the other. This is a process called “transfer” that leaves “trace” evidence (the something of each left with the other). In the physical realm this is generally true, but perhaps at the atomic level, it may not be identifiable by current methods of analysis. Hence a saying “The absence of evidence is not evidence of absence”, however, the presence of evidence is evidence of presence… Trace evidence generally became available only once science came to recognize that invisible things and things not observable without instrumentation (e.g., too small to see, chemical analysis results, etc.) and expert testimony based on scientific consensus became available.

Different crimes come with different punishments, and civil as well as criminal law became available through court systems to settle disputes. Whereas theft is typically a criminal offense, theft of intellectual property is more often litigated in a civil context with different standards of proof. Admissibility of evidence in the US, for example, generally follows the Daubert standard of being more probative than prejudicial today,[149] but before Daubert (1993) was the Frye case (1923) which bases admissibility essentially on experts testifying about matters that have been accepted as valid by the relevant scientific community.[150] Standards of admissibility tend to follow the more likely than not / more probative than prejudicial standard, whereas proof beyond a reasonable doubt is the typical standard for outcomes in criminal trials, civil litigation generally follows the more likely than not standard. As science progressed, more evidence of more sorts became admissible, and over time, many of the previously admissible types of evidence and testimony ended up being no longer viable because science no longer supported them. I have personally testified about travel time for messages not being able to exceed the speed of light, a relevant fact once the speed of light was established as a limit on signal propagation in 1905, but not something that could have been testified to in the 1800s even though the speed of light was initially measured in 1676.

148 E. Locard, "The Analysis of Dust Traces", Revue International de Criminalistique I. #s 4-5, 1929, pp 176-249, (translated into English and reprinted in 3 parts in A, J. Police Science, 1930 in V1#3, May-Jun 1930, pp276-298, V1#4 Jul-Aug 1930, pp 401-418, and V1#5 Sep-Oct 1930, pp. 496-514.)

149 Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579, 125 L. Ed. 2D 469, 113 S. Ct. 2786 (1993).

150 Frye v. United States, 293 F 1013 D.C. Cir, 1923

Part of the criminal justice systems of the world are prisons, jails, holding areas, and other similar confinements including handcuffs, straight jackets, and so forth. While the utility of these mechanisms has been long debated, as a social mechanism they provide a strong feedback mechanism to deter crime by demonstrating the results if caught and successfully prosecuted and by physically preventing access to opportunities to commit crimes outside of the incarceration environment. As a narrative for social control, this is a powerful mechanism. Systems of justice are effective at social control until they become so extreme that they become symbols of injustice. By incarcerating people disproportionately based on factors like race, religion, social groups, etc. the system of social control gets disrupted and those who believe they are unfairly treated ultimately may end up in revolt. Perceived social injustice ends up in revolutions, perceived external interlopers result in wars, and violence erupts as a destructive force in the world.

Trust in public records is a similar arena where ownership and other property rights are the basis for acceptance of the social order, in essence the social contract between the governed and the government. If records are more than rarely inaccurate and result in perceived injustices, trust in those records and institutions fail, and the basis for civil society degrades. These are then critical parts of the infrastructure of societies that emerged as part of the social control systems in the time periods at issue. Records management and archival science became core components of the social order, and did so across essentially all types of governance structures. The science and art of record-keeping advanced along with document-related technologies and diplomatic analysis in the analog world of technology. Records were largely kept centrally throughout this period making them susceptible to attack, but these locations could also be protected against injection, alteration, and destruction. The advent of the printing press made some written documents far more resilient in that many copies could be easily made and distributed geographically, but keeping them as records for juridical purposes involves time, expertise, and a level of diligence that can be cost prohibitive and this distributed record keeping for juridical records was almost non-existent in this time frame. An exception to this came as multiple copies were generated at creation through various processes such as the use of carbon paper (~1801) that could record writing or typing on multiple copies simultaneously with various copies provided to the parties in a transaction, the local repository and a central repository.[151] [152] (Patent of 1806)

In 1876 alone (150 years ago), the American Library Association was founded, several major newspapers were formed, the earliest exhibition of scientific instruments was held, the Dewey Decimal system of classifying written works was created, the first index catalog covering a scientific field comprehensively was published, the last dictionary written by one person was completed, a million copies of a brochure on business methods were distributed, and Bell submitted his patent for the telephone.[153] Clearly, information technology was on the rise, and record keeping was growing as a field. The history of library science and its approach toward assuring public access to published information has stood from then till now as a bulwark against censorship.

151 https://en.wikipedia.org/wiki/Carbon_paper
152 https://www.historyofinformation.com/detail.php?id=3287
153 https://www.historyofinformation.com/?cat=all

Education, religion, and the longest surviving institutions

Survival of individual creatures, including humans, is based on biological limitations and environmental conditions. But survival of memes and narratives extends beyond the life spans of individuals and thus the emergence of a new class of control systems that survive past the end of all physical components of the composite emerged over time.

One way to understand this is in terms of the genome vs phenome in biological living systems. Genetic replication spans generation after generation of the phenomes that live and ultimately die. So the human genome, as it continues to evolve, spans the life of individual humans through the reproductive process. But there are human institutions with physical manifestations that live (are in continuous operation) longer than any individual person. An obvious one is buildings and other structures. Similarly governments and corporations, religious institutions, and other entities are in continuous operation for long periods. Religions are the oldest institutions, with Hinduism something like 4,000 years old; The Kongō Gumi construction company of Japan founded in 598; The King's school, Canterbury founded in 597, the University of Bologna, founded in 1088, the Portuguese army initiated in 1147, the oldest bank from 1472, and so forth.

A measure of survival of an entity is largely associated with the control system that operates it and the ability of that control system to survive the environmental changes it operates within. These sorts of institutions seem to survive based on the ongoing desire or need for them in order for the surrounding societies to continue to operate, or in the case of religions, their ability to propagate geographically and survive government suppression.

A way to understand this is to consider the term coherence[154] in terms of how the underlying mechanisms survive. The composite is coherent if it can stay together as a whole. This is generally accomplished by having redundant consistent content and a self-correcting process that uses and relies on authoritative sources or original writing and augments them over time with differing views and interpretations in order to engage an ongoing audience. That audience is what keeps memes and narratives active, alive, and evolving while maintaining the coherence to their origin.

Religious institutions are coherent in the sense that they are based on stable memes that reproduce imperfectly and yet continue to persist as a unified whole over time. Their internal consistency helps them survive and the resilience with which they sustain themselves has to do with the inability to refute them. Companies are coherent based on different criteria, such as family businesses that survive generation to generation because of the family ties that bind the executives and the financial and social benefits associated with being a member of that distinguished family. Universities and schools survive by creating and sustaining traditions, continuity of structure and use of alumni to continue family attendance and bring in multi-generational commitments, the naming of chairs and buildings after graduate donors, faculty continuity through tenure which retains long-term institutional memory and culture and retirement resulting in new faculty being brought on board with multiple simultaneous generations present. Army units have promotion up the ranks, traditions, and cultural norms fused with mutual suffering and loyalties unto death. Group cohesion is critical to this institutional survival.

154 Coherence is, in general, a state or situation in which all the parts or ideas fit together well so that they form a united whole. (https://en.wiktionary.org/wiki/coherence)

Sociology

Many aspects of social survival are studied in the field of sociology, the study of social life, social change, and the social causes and consequences of human behavior.[155] [156]

- **1875**: A course entitled "sociology" was taught for the first time in the United States by Sumner, drawing on the thought of Comte and Spencer rather than Durkheim.
- **1883**: Ward emphasized the central importance of the scientific method with the publication of “Dynamic Sociology”.
- **1890**: The oldest continuing sociology course in the United States began at the University of Kansas, The Department of History and Sociology at the University of Kansas was established in 1891, and the first full-fledged independent university department of sociology was established in 1892 at the University of Chicago.
- **1895**: The American Journal of Sociology was founded.
- **1904**: The first sociology department in the United Kingdom was founded at the London School of Economics
- **1905**: the world's largest association of professional sociologists, “the American Sociological Association” was founded.
- **1918**: Thomas and Znaniecki published "The Polish Peasant" combining sociological theory with in depth experiential research and thus launching methodical sociological research as a whole that changed sociologists’ methods enabling them to see new patterns and connect new theories. Znaniecki developed a sociology department in Poland to expand research and teachings (1920).
- **1919**: A sociology department was established in Germany at LMU Munich by Weber, who had established a new antipositivist sociology.
- **1923**: The "Institute for Social Research" at the University of Frankfurt (later the "Frankfurt School" of critical theory) was founded, soon getting worldwide attention and studying new perspectives on Marx's theories, with most of the faculty soon forced out of Germany by the Nazis moving to America. This forced relocation of sociologists enabled sociology in America to embrace European sociological approaches.
- **1925**: 1/3 of all sociology graduate students attended the University of Chicago. The first teachings at the University of Chicago were focused on real world social problems over theory focused on individual and equal rights, concentrated on small groups and the individual's relationship to society, and combined with other departments to require courses in hegemony, economics, psychology, multiple social sciences and political science.

This initial focus on understanding the interaction of people with groups and societies was not yet fully combined with statistical analysis methods and systematic approaches, but was starting to apply the underlying concepts developed over the previous hundreds of years toward a deeper understanding of these interactions. But the nature of this and related fields was soon to change dramatically in the aftermath of World War 2.

155 https://www.asanet.org/about/what-is-sociology/
156 https://en.wikipedia.org/wiki/History_of_sociology

One thing leads to another – and narrative space

Before this time frame, most of the things that happened in human evolution were relatively isolated and spread over long time frames. But the acceleration over this period was, as much as anything else, due to the reduced time frames for communication, increased population and emergence of education, and the fact that an idea placed in a new context produces more ideas that turn into solutions to problems, and as those solutions and their underlying ideas spread, that leads to new ideas, and so forth.

When I discuss this with companies I am working with (at one of my companies, Angel to Exit, we help grow companies) I explain it as a sales cycle in the form of a machine that takes in sales leads, and through a sieve process, turns them into paying customers. Once the sieve works, and assuming the market is not exhausted, to get more customers, you just need to take in more leads and process them through the machine. Since turning leads into customers takes money, you need to take some of the money that comes out and feed it back into getting and processing more leads. The more you do this, the faster the machine can crank out more customers, and you just keep cranking faster and faster to grow. Until you exhaust the market or your ability to sell into it or deliver on the promises you make. It's the same with the evolutionary process in general.

As science and technology progresses, precision and accuracy requirements in designing and producing predictable outcomes from concepts became more important because of the scaling. A mistake in a one-off inexpensive item is not a big problem for success of an enterprise, but building a factory that takes years to complete and that mass produces bad parts is highly wasteful and destructive of any entity that tries it. Engineering applies scientific knowledge and mathematics to create predictable outcomes from specifications. As more science emerges and larger scale industrial processes are desired, engineering emerges to meet the need. But then the magic happens. As engineers are able to do things better, faster, and less expensively in higher volume or at larger scale or higher precision, it reaches the edges of what science supports, and science is forced to advance to figure out why things fail near the edges and how to extend the edges to bigger (massive) and smaller (micro) scales. And as engineers apply science in ways the scientists never thought of, the scientists make progress the engineers never thought of, and the virtuous cycle of knowledge expands. Meanwhile, the mathematicians continue to create new ways of understanding and modeling that enables the engineers to do better prediction and design more efficiently, and pretty soon in order to be an engineer you need to know a whole lot of mathematics and science. Then there is the availability of parts. Manufacturing is required in order to implement the things that engineers design, and for the most part, engineers design things from available parts and types of parts rather than creating new types of parts or versions of existing parts. This keeps cost down because mass produced parts tend to cost less per unit than custom ones, and new types of parts can get even more expensive.

Meanwhile, art and social constructs also evolve, and enabled by new technical advances while envisioning new worlds, they interact to form large-scale narrative forces that push societies toward and away from different futures based on these social influences. New theories take hold and are popularized in large part through their analogies to the realities of the world people are living in and as a reaction to change. Some people embrace change while others fight it, and these turn into groups that turn into social movements through music, art, performance, publications, communications, and threaten the old order.

Also important to note is that many of the results known over these time frames came from a small number of groups of people working over centuries in the same places. The advancement of science and technology was largely related to communications and transportation and locality of people with resources. This is ultimately linked to the overall scientific and engineering endeavors of universities and similar places where people from many disciplines competed and cooperated, then leading to the multiplicity of such institutions and the development of more professional peer-reviewed journals, conferees, and other venues for information sharing and the advancement of the technical fields.

Memes and narratives in the parallel cognitive expansions

As the presumptions about magic, religion, and disease fell to easy to understand and observe phenomena, trust in institutions that made unsubstantiated claims in these areas migrated from “because I said so” to “show me”. And as education crept into the minds of the children of each generation, the belief in things like “the Earth is flat” became increasingly difficult to sustain as evidence emerged falsifying the claims. The scientific method emerged as a form of religion all on its own. And many of the other religions of the world fought against science during this period. This ended up in a wide range of variations for public schools, legal restrictions, decisions on national and private investments, and social norms.

By the end of this time frame, the countries, companies, and individuals who chose to invest in the advancement of science and technology, the education required to sustain and grow it, and the narratives surrounding STEM without attempting to destroy beliefs in religions, were essentially universally more successful than those who chose alternative approaches.

In many ways this is astonishing, because among the short-term wildly successful approaches were the approaches in the World wars that used restrictive propaganda and narrowing of allowable narratives. This it seems is successful for short periods of time, but over the course of time, humans appear to have a visceral hatred for restriction of new ideas and a built-in desire for novelty that is apparently part of the fundamental drives that have made us successful in evolutionary time frames to date.

The emergence of scalable printing, then broadcast radio, telephony, and television, led to an expansion of the ability to spread memes in increasingly compelling multi-modal narrative forms to the point where nation-states and continents could be contacted and influenced, by the end of the period, reaching hundreds of millions of people in a matter of minutes to hours.

Production values improved over that time frame to where events like a radio broadcast of “The War of the Worlds”,[157] a serially published book by H. G. Wells from 1895-1897, turned into a radio show by Orson Welles in 1938, caused widespread panic among listeners across the United States who thought it was a news broadcast.

By World War 2, influence operations in Nazi Germany had reached a point where mass murder and genocide became not just acceptable, but a part of every day life and supported by a population who saw people shot in the head in their streets on a daily basis. Whole nation states were being moved from viewpoint to viewpoint by mass communications, and a large part of the global efforts at war were focused on cognitive exploitation of the masses.

157 https://en.wikipedia.org/wiki/The_War_of_the_Worlds

Limits of transportation, manufacturing, infrastructure, and narratives

One of the hallmarks of these cognitive expansions is that they defined and defied limits mathematically as theories were confirmed and refuted. These are not limits of what can be done in the day, but rather, identified as more fundamental limits on what is possible given the nature of the space we live in and the things it is composed of.

Speed, capabilities, and capacity

By the end of this period, speeds reaching hundreds of miles per hour in transportation systems capable of carrying tons of goods allowed people and things to travel around the world in days. Meanwhile, information was able to be transmitted at the speed of light through radio, reaching the entire planet in about 0.065 seconds (half way around the world in every direction reaches the entire world) at a bandwidth of perhaps 6-30 Khz (cycles per second) and reached more than half the adult population of nation states in effectively real time. Mechanical systems were able to be controlled to precisions of well under a millimeter, with simple analog feedback control systems operating in loop times of milliseconds or less. Manufacturing was at mass scales capable of producing more of almost anything that could be made at a rate fast enough to supply everyone on the planet with almost any goods they might want in time frames of a year or less if the financing would support it. Water systems were able to transport water to the middle of deserts, power generation was capable of serving more power than anyone could reasonably consume on a global basis, delivered at the speed of light, wherever wires were strung to take it. Food production was able to supply the entire World population a reasonably healthy diet, medicine was able to prevent many diseases, cure many others, and help people recover from mechanical accidents. Information was available to create and maintain well-educated societies with up to date information across all manner of areas of potential interest, and every person given opportunities to make the most of themselves and their lives. More free time could be made available to more people in more places, and the World could have been turned into a paradise for all of us, if as societies, we decided to take this route.

But that’s not what happened. Capabilities were not turned into these realities and spread across the planet, but rather, local niche advantages were turned into leverage for increased control, force against perceived enemies, defining the “other” and introducing grievances whether real or not, and narrative control was used to take advantage of others, largely to the extreme benefit of the few and to the lesser benefit of enough people to gain and maintain control over mass populations.

External forces and environmental conditions

In this period, for the first time in human history, people became capable of controlling their local environments while substantially impacting the global environment. Locally, the ability to keep temperature, humidity, and chemistry of water, food, and air within desired boundaries was now available for the first time at large scale. If desired, anybody with adequate means and societies as a whole could provide these modern living conditions for any and all people.

Another astonishing feature of this period is that, by its end, nature at the level of the planet, and even to a large extent, events from outer space, could be countered by technology to the point where extinctions could be essentially eliminated if and to the extent desired. While disease wiped out mass local and regional populations because of increased transportation, medicine was becoming far more effective at countering disease, and the vast majority of people could readily survive any biological incident. Diversity of plants, animals, and the food web were adequate to sustain large-scale environmental changes ranging from ice ages to heat waves lasting scores of years, and if well managed, lasting for indefinite periods. Even such events as the asteroid that killed off the dinosaurs could likely be survived with properly managed response and application of science and technology. In effect, the survival of the human species and what it depended on for survival could be assured for any but the largest scale disasters generated from outer space events. No extinction events of history could extinguish humanity from the World if humanity focused on its survival as a high priority.

But that’s not what happened. Capabilities were not turned into these realities and spread across the planet, but rather, a large enough population of people chose a destructive path leading to World War 2, killing off a substantial part of humanity, and leading to the development of nuclear weapons, advances in biological and chemical weapons, poisons, and methods of killing at industrial scale. This was made possible by the many cognitive advancements that brought science and engineering capabilities under social control and supported mass dissemination of destructive narratives, infused within music, performance, and written forms, supported by religious narratives, applying social science results, and acting as a destructive force worldwide.

Disrupting transportation, manufacturing, infrastructure, and narratives

The ability to create often comes with the ability to destroy, and of course in military conflict, destruction and disruption of transportation, manufacturing, infrastructure, and narrative is a major means to the end of the conflict. All systems are susceptible to disruption and destruction because of their fundamental limitations. But as systems are more resilient and redundant, destruction or disruption at scale becomes more complex unless there are common mode failures, single points of failure, or similar risk (uncertainty) aggregations. Some simple examples from the end of this era may be instructive:

- Air, Water, Food, and Shelter in that order for most environments are critical to survival, and by the end of this era, most people and in advanced societies got their water from water systems that processed fresh water from lakes, rivers, and dammed areas transported through pipes to processing facilities, and transported from there through systems of valves and pipes to their homes; food from farms growing it in fields watered by water systems and fertilized by reprocessed manure and similar supplies, planted by farm machinery in machinery tilled fields, picked and processed by people, packaged and transported by truck and/or train to warehouses and from there to stores for purchase and processing by individuals and restaurants; and shelter from bricks and cement (or forests being cut and sometimes replanted, with trees being processed in mills), shipped by water or road to distribution hubs, and from there to local facilities where they were purchased by builders and assembled along with manufactured components like nails, door and window hardware, plumbing, electrical components, roofing, and so forth by people in the building trades. Air came from whatever was available in the atmosphere wherever they were, with pollutants in the air largely ignored in that era.

  - Disruptions of air, water, food, and shelter systems is easy on an individual level, but as a critical infrastructure, these were highly distributed and diverse in nature. Air was being increasingly polluted as a side-effect of industrialization leading to long-term health effects, but in the short term, it was of limited effect. Water supplies were relatively abundant in many parts of the world, but pipes used as water infrastructure were particularly susceptible to disruption, again with relatively local effects, such as earthquakes causing water main breaks preventing adequate fire response within a city. Food systems were problematic in the dust bowl in the US, for example, but this largely displaced farmers and moved them to urban areas and did not sufficiently disrupt food supply to cause starvation. In essence these were fairly resilient systems in this time frame in most industrialized nations. Biological weapons existed against food supply and crop safety was implemented for some key crops with seed corn being stored for regenerating food supply if needed.

- Financial supplies were controlled by governments through fiat currency and material possessions (e.g., gold supplies), ownership records kept almost entirely on paper in physical control of individuals traded in trading locations and recoded in government records, and typically circumvented locally by direct trading of goods and services.
  - Disruptions of financial systems was fairly common with market shifts and dramatic changes of fortune, but because the currencies of nation states are controlled by central governments, they are really the key determinant of what happens. In this era such governments had few controls in place to prevent run-away inflation, price gouging, supply chain changes resulting in pricing changes with ripple effects through economies, and so forth. Some very wealthy people could have major effects, but few ever really did, and competitors in better financial positions cause competitive issues until laws were passed to limit massive market crashes, but this is largely controllable by governments depending on the situations at hand. On the other hand, post World War 1 global policies were driving some nation-states into economic collapse, while other countries had massive labor being paid at extremely low rates on the world stage and in practice, slavery was still widespread.
- Fuel supplies were almost entirely produced from fossil fuels, typically oil extracted from underground and turned into gasoline by processing through chemical processing facilities, and distributed by trucks over roads or pipelines over land and under water.
  - Disruptions of fuel supply could be forced by destroying processing facilities, pipelines, transportation infrastructure, or extraction, but each were redundant to a substantial extent, even though supply was regionally concentrated. Subtle attacks on these mechanisms would be very difficult because of the highly localized analog measurement devices and the independent distributed nature of local control. Supply chain attacks on measurement devices and similar control mechanisms would be very unlikely to work because of the local calibration methodologies widely used for industrial control systems of the day.

- Power infrastructure generated power predominantly from water and fossil fuels and distributed it through wires almost entirely connected to towers by insulating elements and transformed in voltage and current by transformers, controlled by local switching stations and managed by regional control facilities.
    - Disruptions of power supplies on a local or regional scale happened by accident on many occasions, and power supply was often disrupted locally by weather, Earth movement, and other natural effects, with the largest scale outages typically from hurricanes and other massive storm systems. Large scale outages also occurred from cascade effects as local outages forced power infrastructure to draw additional power from regional distribution for compensation leading to larger scale outages. These events were frequent enough that the detection and response processes were developed by industry for rapid repair and continuity of service. Adequate redundant inventory was kept and restoration deadlines and fines were created for assuring that the larger the outage the more rapidly it would be fixed. Various forms of motor generation and battery systems and similar methods were put in place for local outages at critical health facilities, police and fire stations, and other emergency response locations to support critical functions. Repair crews were brought in from regional and more distant locations to mitigate harm from large scale outages.
- Transportation depended on fossil fuels and manufactured vehicles composed of tires, wheels, axles, body parts, interiors, transmissions and other gear systems, brakes, and engines for cars and similar collections of parts for ships and trains. They traveled predominantly on tracks for trains, roads for cars, and waterways or large bodies of water (lakes and oceans) for ships. These were also dependent on oil for lubrication and ball bearings for rotating machinery, various kinds of housing using rubber or similar compounds for vibration control, and of course people to operate them, in turn depending on food and water.
    - Disruptions of transportation systems at an individual level was trivial with techniques ranging from putting a potato in an exhaust pipe to create back pressure and prevent an engine from starting and running, to removal of a distributor cap on a car engine, to disconnecting a battery, putting a cloth in the gas intake and lighting it to blow up the tank and possibly other things, to disabling brakes, putting glue in moving part assemblies, sugar in gas tanks, and the list is almost endless. But on a larger scale, the highly distributed nature of transportation systems (other than rail), large-scale disruption would require interdicting fuel supplies or destroying bridges, roads, landing strips, ports, and similar efforts. Rail systems were more centrally controlled and susceptible to destruction of tracks and similar attacks on the supporting infrastructure, and as a result, societies had limited response capabilities for repairing and restoring services based on the statistics of outages. This work was often hard to do but required little expertise or training and could be supervised at large scale by a small number of people. Supply chain for rail components was limited, but predominantly heavy metal components with relatively easily met precision requirements, and thus readily replaced supply chain elements could be put in place relatively quickly if needed.

- Communication (real-time) depended on transmission media (wires or through the atmosphere), transmitted and received through systems composed of vacuum tubes, with microphones for input and speakers for output, broadcast over the air from stations with antennae or sent through networked centrally operated switching systems owned by government agencies or a small number of private companies, typically one per country.
  - Disruptions of communications systems can occur at the source or destination or during transmission. Wired communication is readily disrupted by breaking the wires, or in the case of switching systems, at a larger scale, disrupting the switching systems. In this era, line switching was the dominant form of connecting endpoints to each other, and they were controlled by human operators or electromechanical equipment at switching centers which could be physically destroyed or altered. Power was required to operate these systems, so disrupting the power supply at these sites could disrupt local traffic, and at larger interchanges could disrupt inter-regional traffic even if local traffic could continue. Large-scale disruption was largely infeasible without mass force attacks, and like other wired systems, wiring could be readily replaced and there was adequate redundant supply available for supporting replacement at large scale if necessary. Wireless communication on the other hand could be disrupted by disrupting signaling through the induction of noise into the channel adequate to make the signal to noise ratio low enough to prevent effective reception. Often called “jamming”, this takes significant amounts of energy, and in the electromagnetic spectrum, energy is reduced by the square of the distance, so that the amount of energy to disrupt at large scale becomes infeasible for large areas. Supply chain attacks over longer terms might be effective at reducing radio communications capabilities, but inventory of tubes and other radio components was adequate to continue operations for at least years in most cases.
- Education and Training had become critical infrastructure components of advanced societies in the era because of the need for workers who could understand their tasks in complicated environments and perform them consistently, and because of the technical aspects of the science, engineering, management, marketing and sales, accounting, record-keeping, legal, and other aspects of operating large complex technical organizations required to support this operational capacity. Education and training were highly distributed by the end of this era with universities, high schools, grade schools, and training academies in large numbers covering the full range of fields of human endeavor. Books were the predominant required infrastructure of knowledge transfer with teachers at all levels in large numbers in divergent fields specializing in a wide range of different subjects transferring the knowledge from generation to generation, researchers worldwide repeating experiments and learning how to create most existing capabilities of societies locally, libraries with copies of massive collections distributed worldwide, and a growing percentage of the world population able to read, write, and understand the full range of human endeavor.
  - Disruption of education systems by this point was essentially infeasible without killing half the population of the world and destroying the billions of copies of books on different subjects. While national level disruption of education was feasible and attempted and national standards around the world were growing to constrain the

educational systems of the world, standardized texts and curricula were coming to popularity, and the history being taught was a small subset of the totality available, the underlying educational framework and infrastructure was very difficult to disrupt.

- Manufacturing was highly distributed powered largely by electrical energy and requiring supplies in the form of component parts manufactured by other parties, generally composed of materials extracted from nature, typically through mining from where it was found and processing facilities for conversion into useful and transportable materials close to the extraction location, and subsequent transportation and processing at factories.
  - Disruption of manufacturing could reasonably focus only on specific dependencies with limited supply, processing, or distribution. While disruption writ large was essentially infeasible, the dependencies on technologies was increasing and not particularly well managed or tracked. In essence, monopolistic practices that were disrupted to some extent earlier in the century, were not limiting vertical integration of capabilities and domination of markets on a global basis. If a particular material was required for many processes and that material was only available from a small number of sources worldwide, those sources became critical for support of the entire vertical industry, and substitution, while often feasible technically, was financially problematic. Supply chain was the key issue and much of geopolitical dispute was based on these resource issues.
- Health care and public health was a well structured process with governmental bodies collecting mandatory information on large-scale public health threats and scientifically investigating them, creating countermeasures, testing them systematically, and deploying them with governmental force to limit epidemics and identify upcoming public health threats early enough to limit their effects. Some major diseases were almost completely eliminated from the human population on a global basis.
  - Disruptions of public health infrastructure by this point was hard to produce in advanced nations. The highly distributed nature of the industry, with large numbers of trained and educated medical professionals dedicated to health and well being of their patients as a cultural norm meant that at a local level, the system was hard to disrupt. On the other hand, supply of drugs and treatments were limited by manufacturing capabilities that were highly centralized and often available only from certain countries. New drug development, vaccination, and similar capabilities were not globally available in most cases, and the development and testing cycles were long. It took many years to develop vaccinations for many conditions, and treatments were often expensive with confinement of ill patients in quarantined areas the only way to protect against the spread of many diseases. Biological warfare capabilities were extensive and outbreaks of diseases were still common, largely in areas of dense population and poor sanitation.
- Emergency services such as fire and police response, emergency medical facilities, and disaster response were in place in most societies. Fire and police were generally local covering small areas of populated areas or larger areas of less populated areas using vehicles and communications systems for control and coordination with hierarchical mechanisms for local, county, state, and federal agencies in democratic

countries and more centralized control over largely Federal forces in autocratic and other centralized governmental forms. Because of the local nature of intelligence in this time frame, local knowledge was critical to effective policing and a fair amount of variation existed, making the system resilient as a whole while supporting large-scale enforcement efforts as and if needed. Fire response was localized out of necessity because response time is critical to preventing large-scale spread of fire, and depended largely on local water supplies and water trucks. Emergency medical services were also largely local because of the time requirements of saving lives. While rural doctors would do house calls that took longer travel times, in denser population areas, doctors were often within 15 minutes of patients essentially all the time.

  - Disruptions of emergency services on a very local basis was used by criminal elements from time to time to move law enforcement away from an areas where a major crime was to be committed by inducing an emergency response in other locations through false alarms and similar methods, but these were rarely effective over the long run as investigative processes ultimately caught many criminals operating at large scale undertaking such processes. Fire response was dependent on local water systems and in several instances earthquakes caused water system breakages that prevented fire control from being effective resulting in large scale fire damage. Medical emergency services were hard to disrupt because the facilities were relatively distributed, each with a local capacity to perform emergency medicine at some level of services, and medical professionals largely used their own vehicles or ambulance services to get to patients and treat locally or bring them to more capable emergency medical facilities. Professionals in these fields also have a social approach and cultural bent of running toward problems to solve them rather than running away from them, putting their own lives at risk to save others.

- Narrative control was managed through real-time communications mechanisms and transportation of manufactured literature and recordings and in person presence using transportation to move key individuals from place to place, controlled predominantly by a relatively small number of broadcast networks and publishers, by politicians using the bully pulpit and franking privileges, and by popular entertainers often controlled by studio systems with a small set of owners. Narrative control existed at many time scales, ranging from decade long processes of getting information into and out of text books used for education to real-time radio broadcasts. Embedding information into baselines at high volume meant generations of educated people not understanding underlying realities and instead being fed narratives that were the results of rewritten history. If the history of Europe ignored the influence of African culture, it didn't exist until historians rediscovered it and fused it back into the narrative. Over long time frames, systematic suppression of select factually true narratives and injection of false narratives created large scale belief systems that dominated societies for generations. These were intentionally put in place by governments, religious groups, and institutions of all sorts to reflect biases, and as they became rote truths about the World, they were carried forth through ignorance. Cultures were infused with these narratives through art, song, performance, writing, education, rumor, ceremony, and the very languages used to define the memes and ways of communicating about issues.

- Disruptions of narrative control were also widespread over the course of history and into this period. Social movements were triggered by the same mechanisms at a grass roots level through humor, satire, musical tropes, written works, and all manner of communications. Philosophies spread throughout this era, very often based on assumptions common to age groups and their common life situations, like teenagers revolting against their parents and parents complaining about the next generation. But the in-depth understanding of psychology and sociology that emerged over the period was still early in its development, and as such, the battle was largely carried by individuals with limited knowledge of the available methods.

Interdependency at large scale on a global basis was a major outcome of the advancements of this era, and survival depended on the physical ability to enforce will on others, often through violence and military actions. Physical control at scale depended on large numbers of people working in coordination which in turn depended on hierarchical control and influence to keep the narrative of following orders until death and supporting soldiers at home functional. At the same time, the advancements of science and engineering and the communication of these advancements around the world made the vast majority of these capabilities highly resilient over periods of many years on a global basis. A highly resilient system of global infrastructure to support large societies was well in place and would be very difficult to disrupt.

World War 2 – a test of global cognitive and infrastructure resiliency

World War 2 has been studied in great depth in many ways and by many people, and I don't propose to provide thorough coverage in this arena. However, with all of the assertions about limitations and disruptions just detailed, the test of these assertions came in the form of a global war using extremes of force of every kind, and as such, it serves as an example and test of the conclusions just asserted.

In World War 2, science and engineering were applied to a level never before attempted in what was as close to the total war concept of Clausewitz[158] [159] as the world has seen. It involved every manner of attack on and defense of critical infrastructures listed above. Here is a very brief summary of some examples:

- **Air, Water, Food, and Shelter**: The death camps were an extreme example of chemical warfare used to kill in the showers of the Nazi death camps through injecting poison into the air[160], while water was used as a weapon when dams were attacked by the British to flood the Ruhr valley and destroy or disrupt much of the industrial base supporting the German war effort.[161] The Battle of Britain involved destruction of cities where population lives as part of disrupting the will to fight[162] while the bombing of Dresden destroyed an entire city.[163]

158 https://en.wikipedia.org/wiki/On_War
159 https://icct.nl/sites/default/files/import/publication/On-War.pdf
160 https://www.auschwitz.org/en/history/auschwitz-and-shoah/the-extermination-procedure-in-the-gas-chambers
161 https://www.iwm.org.uk/history/the-incredible-story-of-the-dambusters-raid
162 https://www.britannica.com/print/article/79855
163 https://www.nationalww2museum.org/war/articles/apocalypse-dresden-february-1945

- **Financial**: Hyperinflation in the Weimar republic[164] is widely cited as an underlying cause of World War 2, with war debts in the hundreds of billions of German marks and massive unemployment leading to internal instability and enabling the Nazi party to take over the government. War debt was also involved in programs like lend lease, allowing Britain to engage the US in the war before the Pearl Harbor attacks.
- **Fuel and energy**: Fuel was a major key for success and survival in World War 2[165] with the US producing more fuel than it ever had and using it to supply its war machines as well as to support other countries. In many battles, fuel depots were the key to success, and in particular, stopping Rommel in Africa[166] and Germany during the Battle of the Bulge.[167]
- **Electrical power**: Power infrastructure during WW2 was highly resilient on all sides. The most demonstrable attempts at disruption were the attack on German dams that disrupted electrical supply while flooding the Ruhr valley and Operation Outward[168] which used balloons to attack German power systems by interfering with high tension power lines.[169]
- **Transportation**: German attacks on shipping in World War 2, especially by submarine “wolf packs” was devastating to attempts to resupply Britain and more people and material to war zones in the Battle of the Atlantic.[170] [171] Similarly, attacks on rail and road infrastructure were used to disrupt German supply chains and more generally on all sides in this and most wars.
- **Communication**: Communication in World War 2 was largely a combination of wires strung in the battlefields, wireless transmission methods, and the telephonic systems of cities and countries. While disruption of select communication channels was used, this infrastructure element was predominantly used for the spread of news, covert channels for messaging, propaganda, the takeover of broadcast stations for messaging, and the use and exploitation of cryptographic signals. Battlefield wires were used for local communications and remained largely effective in that context. Interception was sometimes effective, but because these wires were typically strung for short time frames and then left as the front moved from place to place, the longevity of these mechanisms rarely justified enough effort to take them over, and disruption of a wire covering an unknown path in enemy territory was problematic. Radio was used effectively, but was problematic for tactical purposes because it was easily intercepted. Thus encryption technology was used to encrypt signals of military significance. In addition, the ability to locate a signal source by triangulation led to its exploitation for destroying anyone who used it for too long from any given location. Encryption was the fundamental issue in securing tactical communications and defeating this security during World War 2, and it made a substantial difference in the ultimate outcome of the

164 https://en.wikipedia.org/wiki/Hyperinflation_in_the_Weimar_Republic
165 https://www.nist.gov/blogs/taking-measure/big-inch-fueling-americas-wwii-war-effort
166 https://www.nationalww2museum.org/war/articles/rommel-ruweisat-ridge-july-1942
167 https://www.iwm.org.uk/history/what-you-need-to-know-about-the-battle-of-the-bulge
168 https://en.wikipedia.org/wiki/Operation_Outward
169 https://media.defense.gov/2017/Dec/29/2001861964/-1/-1/0/T_GRIFFITH_STRATEGIC_ATTACK.PDF
170 https://www.history.navy.mil/browse-by-topic/wars-conflicts-and-operations/world-war-ii/1942/atlantic.html
171 https://www.iwm.org.uk/history/what-you-need-to-know-about-the-battle-of-the-atlantic

conflict as the Allies were able to decrypt and exploit Axis communications and the Axis powers were unable to do the same for Allied communications.[172]

- **Education and training**: Nazi and Japanese indoctrination began at an early age and proceeded throughout the life of children as they grew. In the Nazi regime the Hitler Youth was the program at issue[173]. By 1939, membership was mandatory. The organization focused on physical training, military drills, shooting, and indoctrination in Nazi ideology, including racism and anti-semitism. Teachers were indoctrinated through the National Socialist Teachers League (NSLB). Textbooks were replaced to promote Aryan superiority, blind obedience to Hitler, and hatred of Jews and Slavs. Girls were trained in fitness, domestic skills, and nurturing qualities to prepare them to be mothers who would serve the state. While Germany focused on biological racism (Aryan superiority), Japan emphasized spiritual superiority, its unique culture, and reverence for the Emperor. Both used uniforms, military training, sports, and propaganda to create a "soldierly" mentality, sought to remove intellectualism, and infuse unconditional dedication to the state. Education and training around the world has long been used in part as indoctrination, and in the WW2 time frame it was used more directly against enemy systems of governance. Many of the education systems of the world followed their political doctrines ultimate setting up the other-ing of different political doctrines, and this was a large part of the enabling propaganda.
- **Manufacturing**: Manufacturing in the United States was largely unaffected by WW2 because of the great distances involved in transporting weaponry, while throughout Europe, manufacturing was the target of military activities to disable enemy capabilities over the long term. The example above of the destruction of the Ruhr region in Germany is only one example. The Battle of Britain was substantially directed at disabling British industry, but the British used deception tactics to move away from these targets ultimately into places where fewer people were living.[174] On the other side, ball bearing plants were identified by the Allies as a key dependency for the German war machine and attacked to grind that machine to a halt.[175]
- **Health care**: Field medicine in World War 2 advanced rapidly, ultimately increasing the survival rate from battlefield injuries from 50% in WW1 to 96% in WW2.[176] In this period the mass production of penicillin (available by 1941–1942) and the use of sulfa powder (sulfanilamide) in bandage kits dramatically reduced deaths from bacterial infections; the development of safe, transportable human serum albumin and dried blood plasma enabled rapid treatment of shock and blood loss on the field; troops were immunized against tetanus, yellow fever, typhus, cholera, and smallpox, reducing disease-related fatalities; atabrine (quinacrine) was widely used to treat and protect against malaria in tropical theaters; the use of portable X-ray machines, metal plates for bone fracture treatment, and advanced thoracic/vascular surgeries increased recovery rates; and improvements in tourniquets, early use of splints, and rapid air transport for wounded

172 https://www.nsa.gov/portals/75/documents/about/cryptologic-heritage/historical-figures-publications/publications/wwii/history_us_comms.pdf
173 https://encyclopedia.ushmm.org/content/en/article/hitler-youth-2
174 http://sunnycv.com/steve/WW2Timeline/britain.html
175 https://www.nationalww2museum.org/war/articles/schweinfurt-regensburg-raid-august-17-1943
176 https://www.war.gov/News/Feature-Stories/story/Article/2115192/medical-improvements-saved-many-lives-during-world-war-ii/

personnel significantly lowered the time between injury and surgery. Unethical medical experiments were performed on prisoners by Germany,[177] [178] [179] while in the US experiments on soldiers covered a wide range of biological and chemical agent tests as well as nuclear tests.[180] [181]

- **Emergency services**: In bombed cities throughout Europe emergency services were strained to their limits, but in all but a few extreme cases, they continued to operate even during large-scale bombing attacks on both sides. The bravery of the individuals along with their culture of service even at the risk of their own lives proved sustainable throughout the war on all sides. In Britain, the Ministry of Health took over hospitals, first aid services and ambulances, the Air Ministry projected 25,000 casualties per day for the first ten days of war, and 300,000 beds would be required in Great Britain.[182] Local authorities provided first aid posts supervised by the local medical officer controlled by a local medical practitioner and volunteers; mobile ambulance parties collected casualties; using the London County Council as agent, large supplies of bedsteads, blankets, mattresses, surgical and hospital equipment were purchased and stored in regional depots with hospitals encouraged to increase inventory of dressings and drugs. The Medical Research Council was responsible for organizing laboratory services, and vaccines and sera were stored in depots disbursed nationwide. Medical personnel were registered, volunteered to serve, doctors' practices continued by other practitioners with all doctors subject to 'call up' (1940), medical staff were recruited from around the World and registered to work in the UK, and final year medical students were employed; a Central Emergency Committee for the nursing profession registered, trained, or partially trained nurses and auxiliary nurses were engaged through a volunteer nursing service; and the Ministry and the Board of Education planned voluntary evacuation of schoolchildren, younger children, and expectant mothers from areas considered most 'at risk', like London and the coastal areas of East Anglia and the South Coast. An extreme example on the Axis side was fire fighting in cities, where for example, the Hamburg Fire Department units extinguished fires or prevented their spread to about 4,300 fire sites in an 11 day period.[183] They were hindered by debris in the streets, reduced water volume, heat, sparks, smoke, and of course ongoing explosions from bombs. Over this period, no person in shelters died from fire effects, and despite having no communications operating by the end of the period the firefighters self-assigned to fires they found to great effect. The resilience of emergency services provided incredibly effective because of its distributed real-time nature and central support for anticipatory supply and logistics.
- **Narrative control**: This is the arena that demonstrated the greatest extremes, and perhaps we could call them advancements, in this era. Essentially every nation state involved in war used multiple forms of narrative control to support their ability to

177 https://encyclopedia.ushmm.org/content/en/article/nazi-medical-experiments
178 https://pmc.ncbi.nlm.nih.gov/articles/PMC1323276/
179 https://en.wikipedia.org/wiki/Nazi_human_experimentation
180 https://www.npr.org/2015/06/22/415194765/u-s-troops-tested-by-race-in-secret-world-war-ii-chemical-experiments
181 https://en.wikipedia.org/wiki/Edgewood_Arsenal_human_experiments
182 https://www.bgs.org.uk/resources/as-we-once-were-the-wartime-emergency-medical-service-and-the-future-nhs-2
183 https://apps.dtic.mil/sti/tr/pdf/AD0726461.pdf

prosecute the war, in essence making participation a matter of pride, survival, justice, good v. evil, resolution of old disputes, hatreds, affection, responsibility, sex, race, fear, and any other emotional hook or rationalization they could conceive of. This was used both to bolster moral and support for the “us” and deprecate moral and support for “them”. Common elements of these tactics included dehumanizing the “other” by giving them generic names (frogs for French, krauts for Germans, subhuman names for Jews, Gypsies, and other “others”, etc.) as creatures that could be exterminated as vermin rather than human beings who you might like under different circumstances. The art of getting people to be willing to kill each other despite religious upbringing that called killing a sin, of creating fear, uncertainty, and doubt to befuddle each other, and all manner of other psychological warfare operations were underway at a scale never before achieved.

With all of the advancements in all of these areas, and all the resilience of so many such systems and mechanisms, the underlying control system that dictated human society had become the control of narrative. All of the sensors, actuators, communications, and control mechanisms at all of the levels from atomic interactions through all forms of life, had come under the control of life forms now capable of cognitive processes enabling them to understand the nature of nature and ultimately taking control over it at increasing scale and granularity. But the cognitive limits continued to be fundamental in preventing unlimited scale and granularity in combination. The atomic bomb was able to destroy at an unprecedented scale for living creatures of Earth by exploiting underlying mechanisms of the nanoscopic world, but it could not have come to exist had it not been for the narratives that drove forces on each side of the conflict to strive for it, and ultimately its use was determined by the decision of one individual to favor the lives of their own soldiers over the lives of civilians on the other side. Without the narratives running through the cognitive systems of the warring parties, none of this could have come to pass.

