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PRINCIPLES OF MANUFACTURING

HISTORY, TRANSITIONS & PERSPECTIVES

Peter Krajnik

Outline

- A (very) brief history of manufacturing
- Manufacturing processes and systems
- Manufacturing as a surface-generation process
- Short sequel of industrial revolution(s)
- Digitalization and developments in emerging technologies
- Sustainable manufacturing

Why manufacturing?

- **Manufacturing** stands on the threshold of a **major transformation** and is in the focus of national research priorities in Sweden, Germany, UK, USA, Japan, China, Korea, etc.
- **Manufacturing** entails more than making high-tech products. It also includes using **new materials, processes and machines** to make products that are better and/or cheaper.
- Manufacturing remains a vital source of **job creation**, **innovation and competitiveness** and **productivity growth**.
- Globally, manufacturing continues to grow. It now accounts for approximately **16% of global GDP and 14% of employment**.

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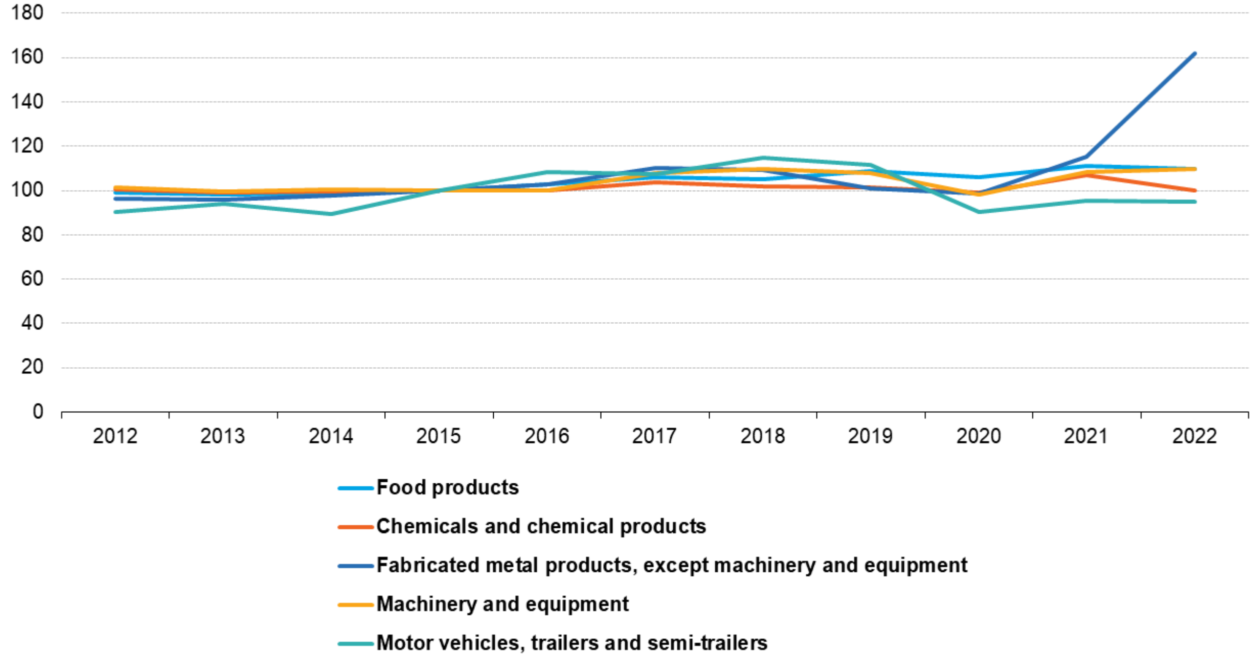
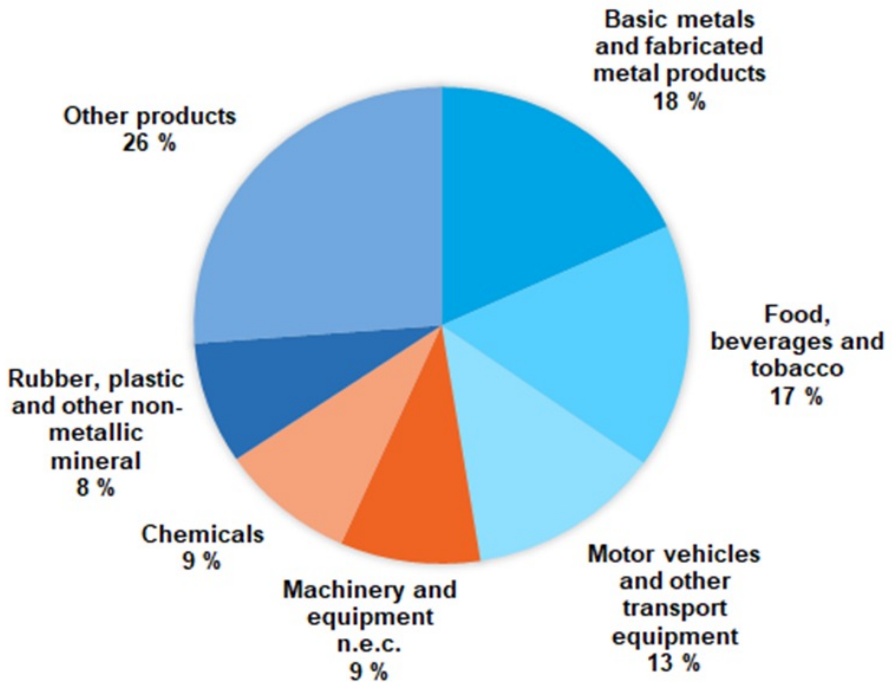
Evolution of the value of sold production for top 5 manufacturing activities, EU 2012–2022
(2015=100)





Note: EU except Cyprus, Luxembourg, Malta
Analysis based on constant price ref. 2015 (see methodology on calculation of constant price)
Source: Eurostat (online data code: DS-056120; sts_inpp_a)

eurostat

Manufacturing in Sweden

- 75% of the business R&D expenditure in Sweden is within manufacturing.
- Strong automation and production – Sweden holds a 10% share of the global automation industry.
- Access to highly qualified labor – skilled staff.
- An innovate environment – extensive research collaboration between industry, universities and government.

Early (manufacturing) technologies

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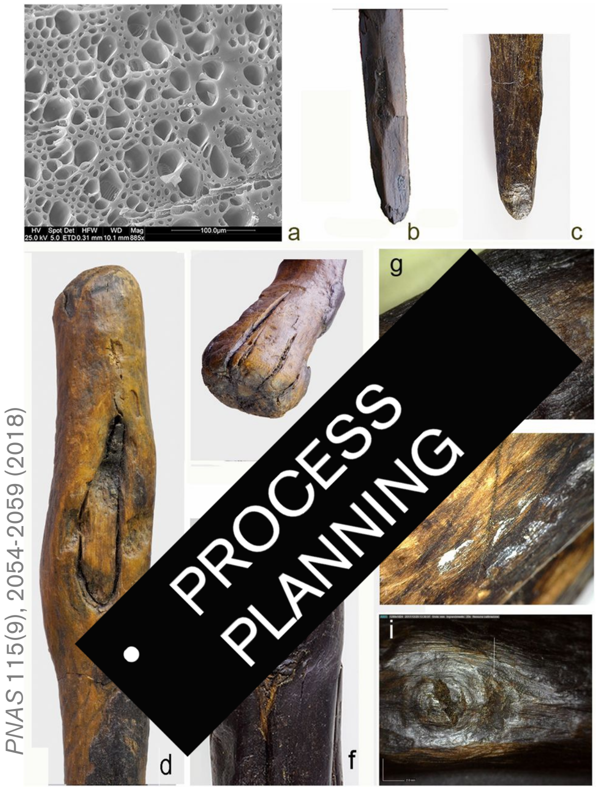
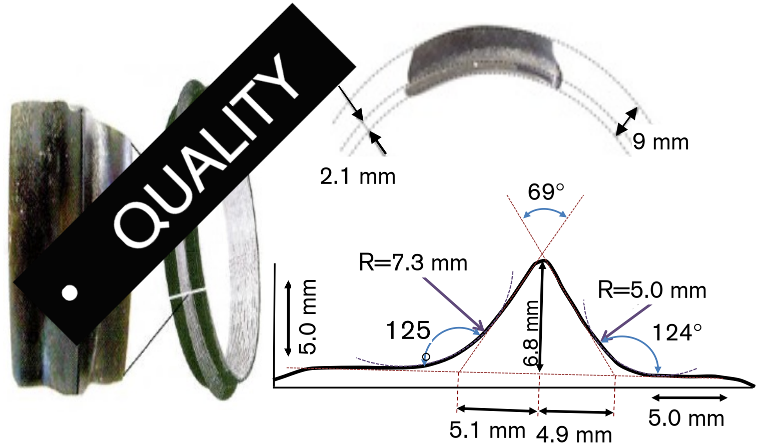
Nature 385, 807-810 (1997)

- Wooden throwing spears (~ 400,000-y-old, Schöningen, Germany)
- Oldest hunting weapons to have been used by Neanderthals
- All spears found were **designed** for throwing and **manufactured** to the same thickness and weight

- Neanderthal digging-sticks production (~ 170,000-y-old, Poggetti Vecchi, Italy)
- Manufacturing steps: cutting a branch; shaping the "handle" with a **raked** stone **tool**; **application of fire** to remove bark; and sharpening of the pointed end with an **abrasive stone**.



PNAS 115(9), 2054-2059 (2018)



Journal of Archaeological Science 38(12), 3415-3424 (2011)

- Neolithic manufacturing of an obsidian bracelet (~ 10,000-y-old, Aşıklı Höyük, Turkey)
- The workpiece symmetry and the kinematics of the manufacturing process indicate probable use of **mechanical devices for grinding and polishing**

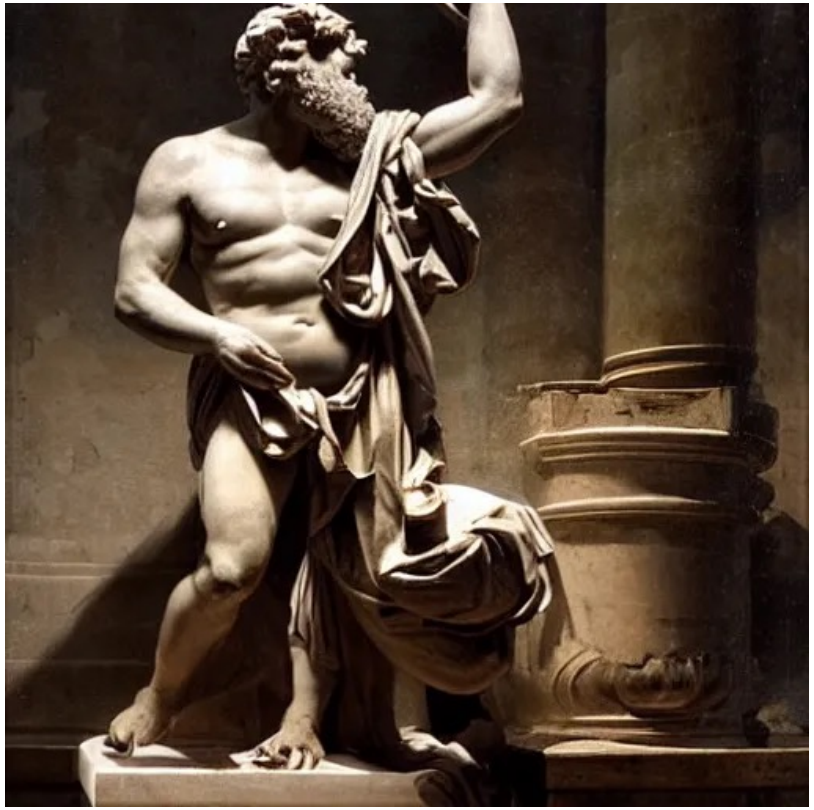
Science 360(6384), 90-94 (2018)

SUPPLY-CHAIN

- Long-distance stone/materia [illegible] 300,000-y-old, Olorgesailie basin [illegible]
- Technological shift [illegible] **ent of** distantly sourced **mate** [illegible] **making**, indicating the early dev [illegible] **exchange networks**.
- Techno [illegible] atures reflecting **innovation**, **standar** [illegible] **tion**, and **new cognitive abilities**.

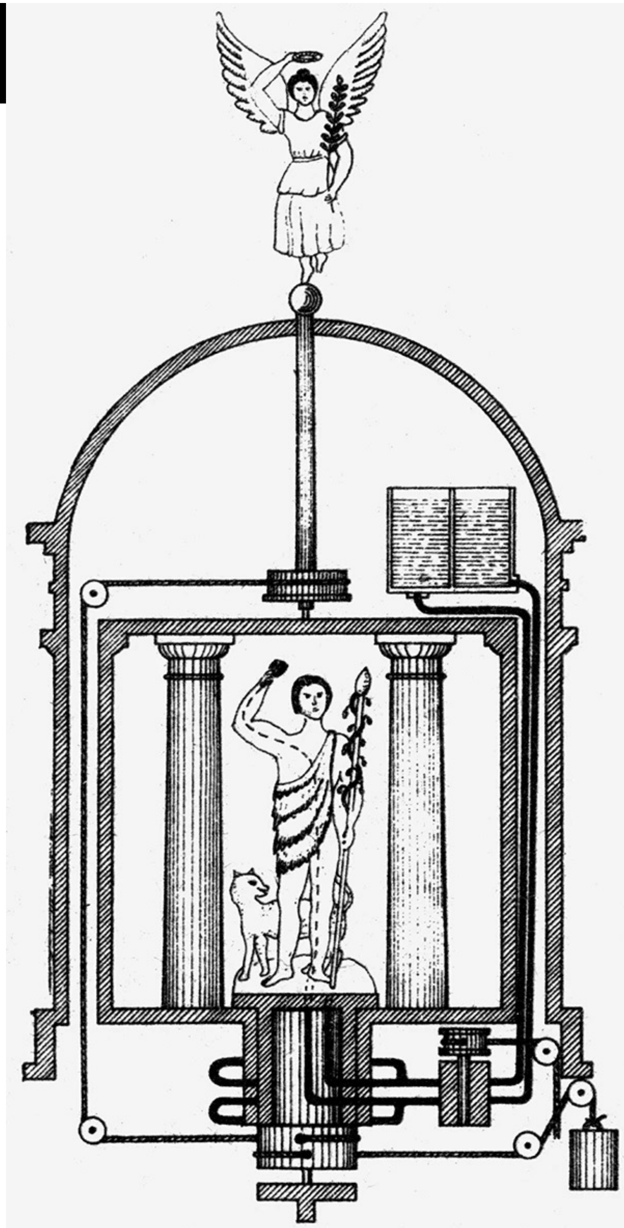
Iliad – the oldest known AI story?

- Eighth-century-BC Iliad, Homer's epic poem of the Trojan War.
- Hephaestus, disabled god of metalworking, creates golden handmaidens to help him in his forge.
- "***In them is understanding in their hearts, and in them speech and strength, and they know cunning handiwork***".



Hero of Alexandria

- First-century-AD work “*On Automaton-Making*”
- Fully automated puppet theatre that, through a combination of displaced axles, levers, pulleys and wheels, could enact an entire tragedy.
- These classical stories reveal how, then as now, humanoid machines were mostly conceived as representing straightforward hopes — the ideal servant who always obeys, the perfect soldier who never tires.
- Followed by a millennium of “lost skills”



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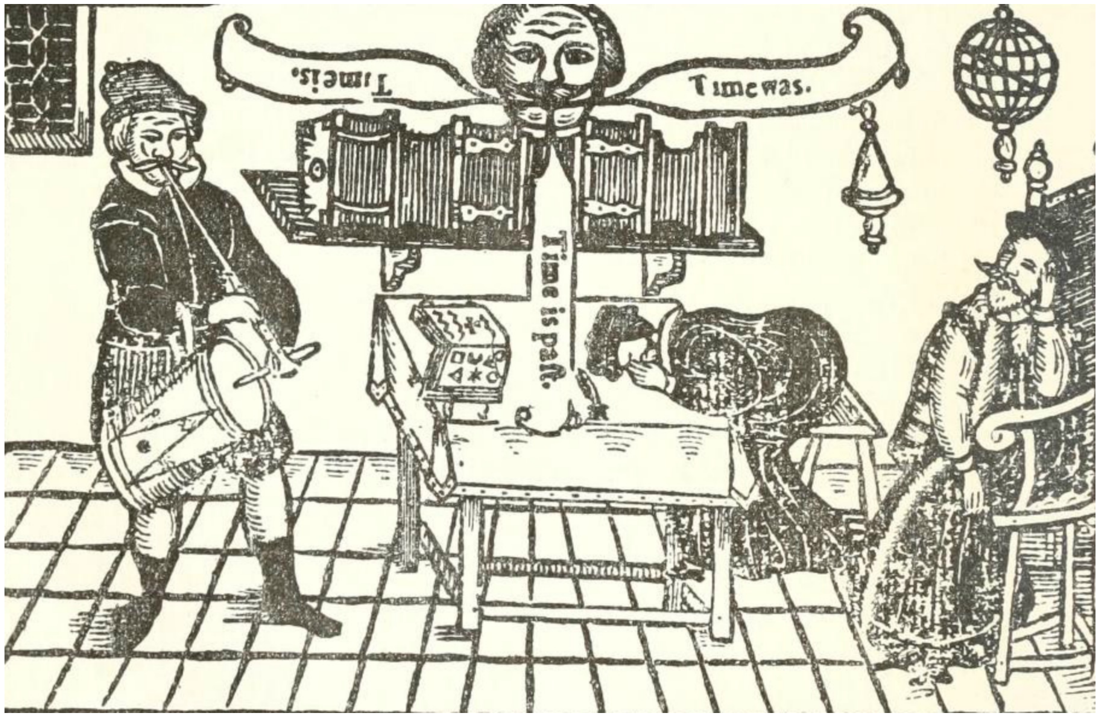
Roger Bacon's talking bronze head

- A great medieval scholar, Roger Bacon (born c. 1219), was rumored to have created a bronze head that could answer any question *(– a proto-Siri or ChatGPT)*.
- This story reveals our complex emotional responses to AI. Understanding these and their deep history is crucial to making the most of life with intelligent machines.



"Didascalicon" by Hugh of Saint-Victor (AD1127)


Weaving

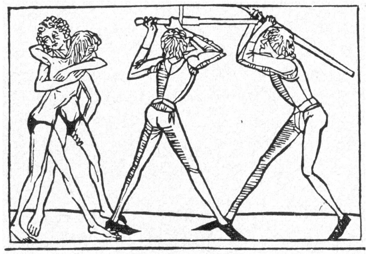

Blacksmith – forging iron


Shipping


Agriculture


Hunting


Medicine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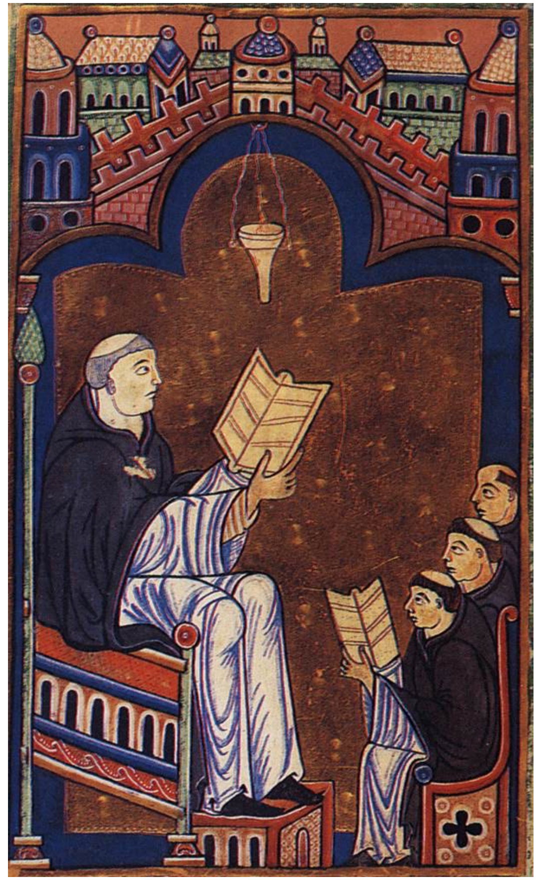

Source: Wikipedia

Taxonomy of manufacturing

- 14-16th centuries
- *Hausbücher der Nürnberger Zwölfbrüderstiftungen*

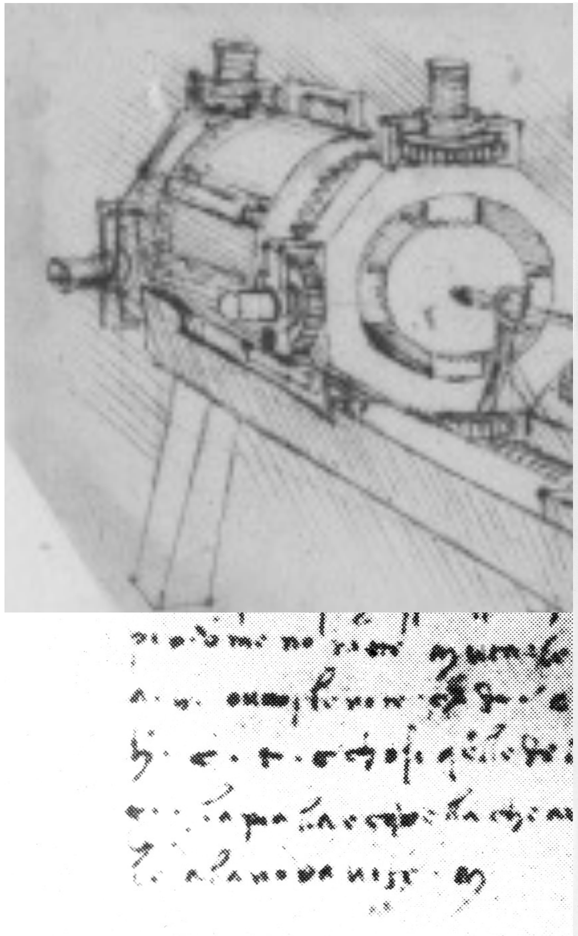
Metalworker

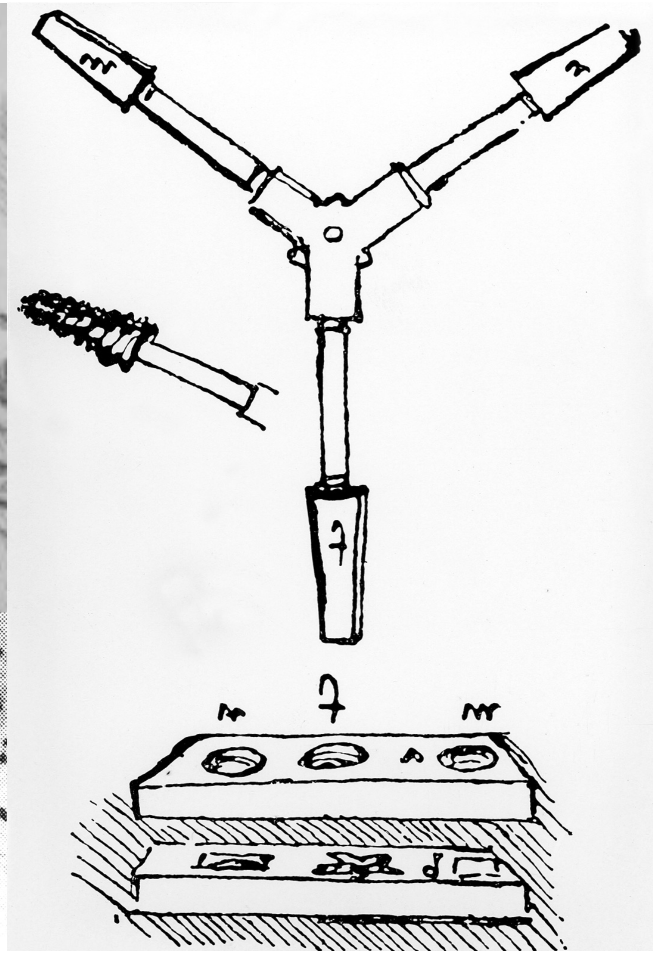
Turning lathe

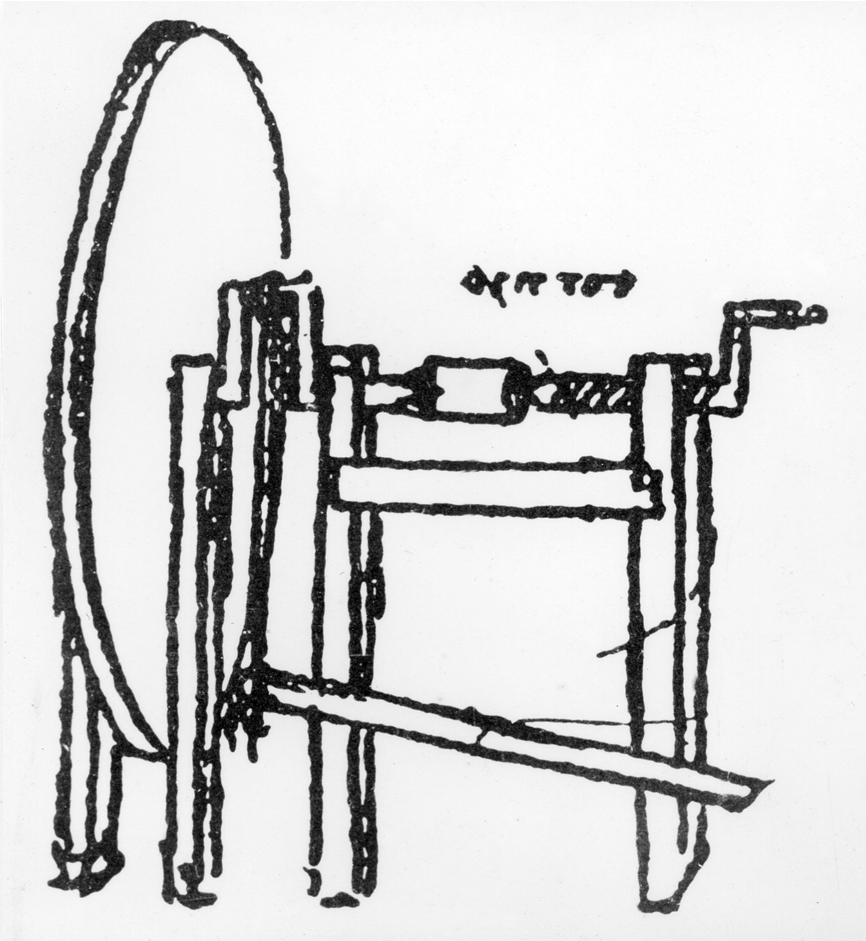
Armor grinding / polishing

www.nuernberger-hausbuecher.de

Leonardo da Vinci: designer of machine tools (1500)



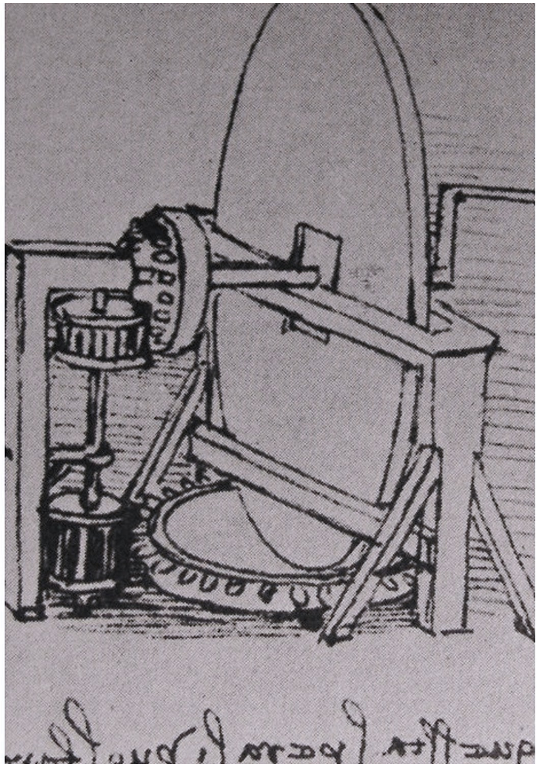




Leonardo's machine for grinding concave mirrors

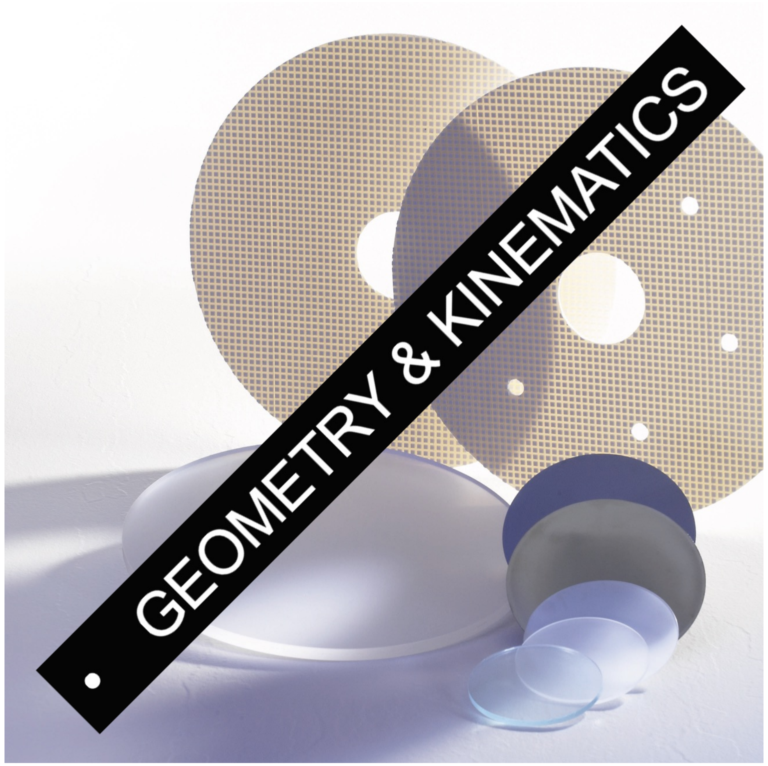
Optical finishing: from Leonardo to iPhones

- Up to now there was no fundamental quantity which could (generally) correlate geometry and kinematics of a (finishing) process to the abrasive interaction in a given contact point.



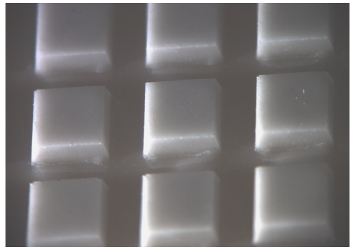
Leonardo da Vinci, Design for a machine for grinding convex lenses, c.1500

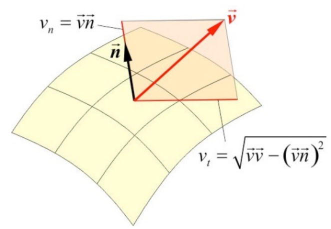
Source: Wikimedia Commons



Manufacturing: finishing of cover material for iPhone
Workpiece: alkali-aluminosilicate glass
Tool: 3M™ Trizact™ Diamond Tile 677XA

Source: Sydor Optics





Source: doi: 10.1117/12.865606

$$aggr = \frac{\vec{v}\vec{n}}{\sqrt{\vec{v}\vec{v} - (\vec{v}\vec{n})^2}}$$

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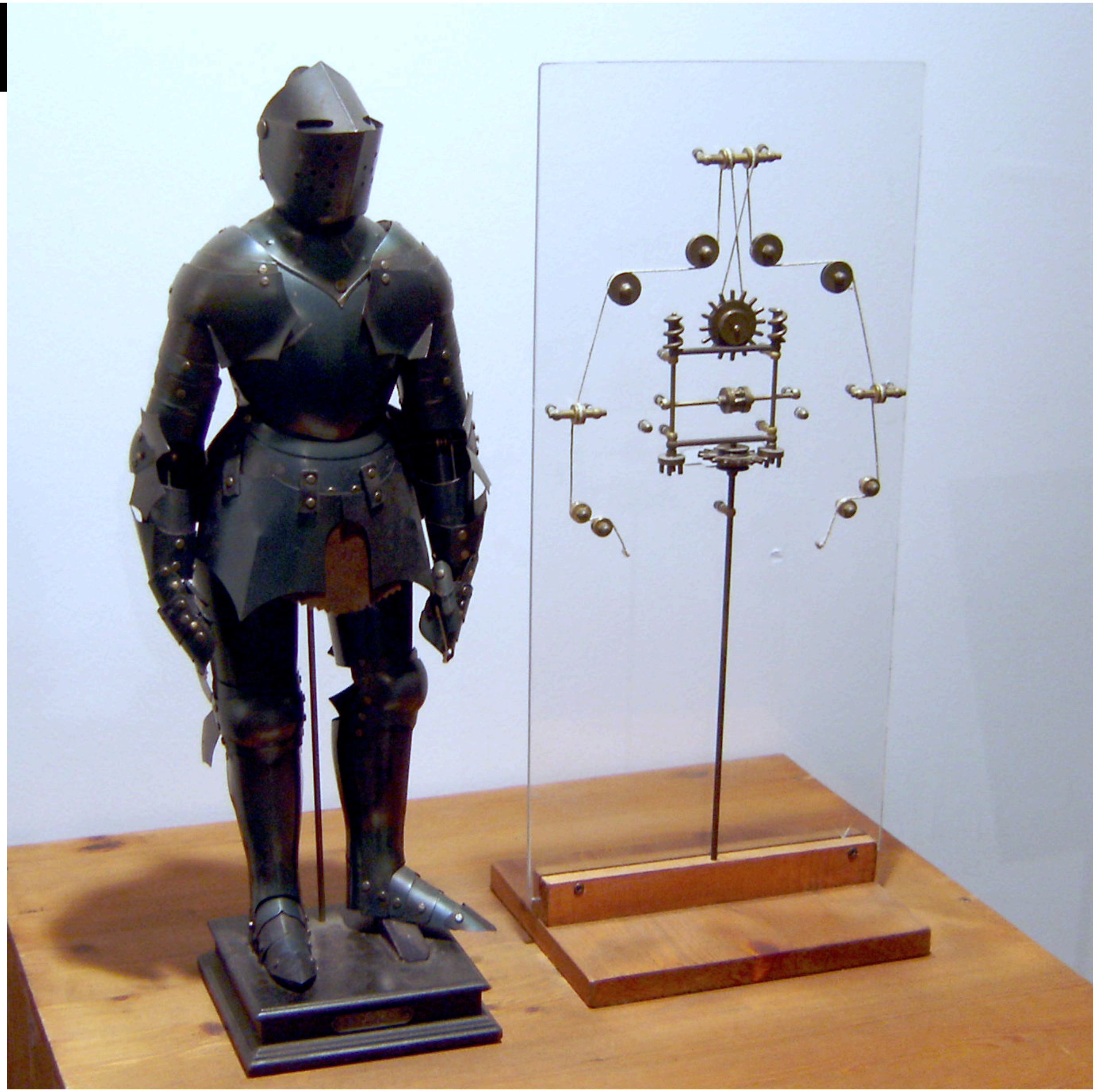
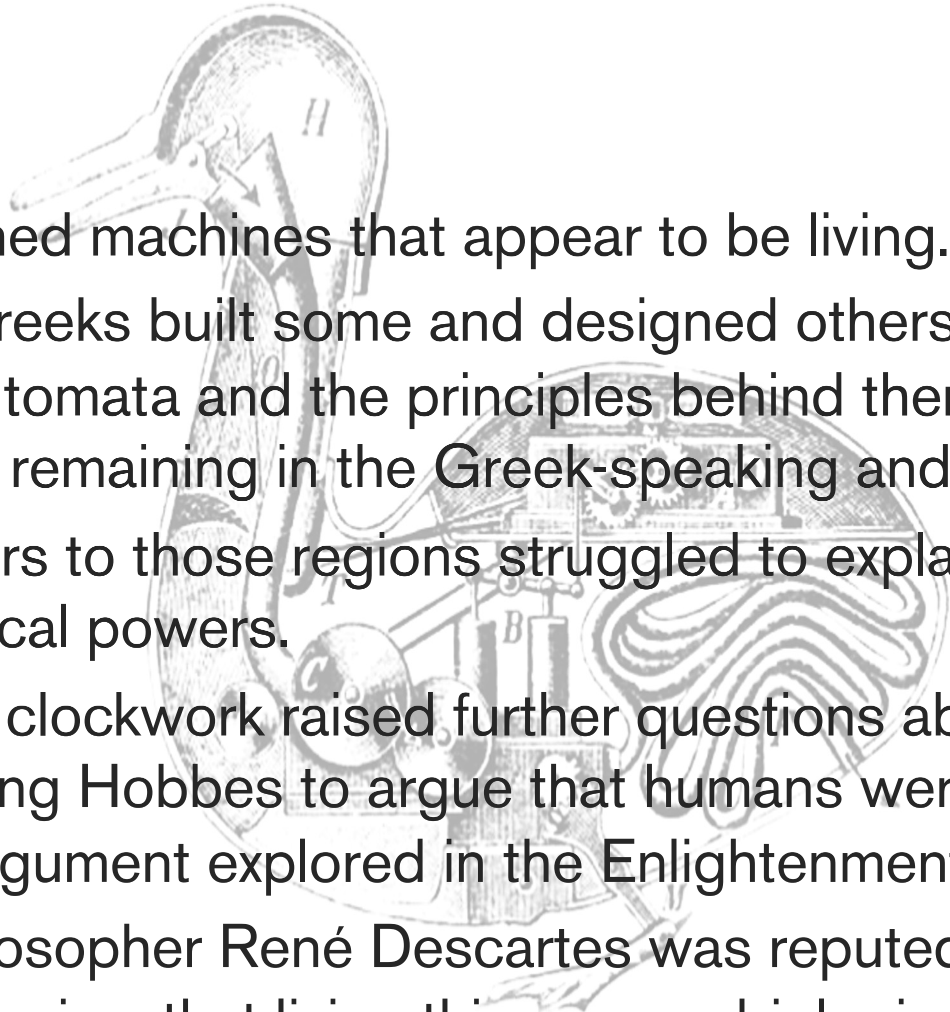
The da Vinci Robot

- OS-I: 3-DOF legs, ankles, knees, and hips.
- OS-II: 4-DOF in the arms with articulated shoulders, elbows, wrists, and hands.
- A mechanical analog–programmable controller within the chest provided the power and control for the arms.
- The legs were powered by an external crank arrangement driving the cable, which connected to key locations near each lower joints



Automata



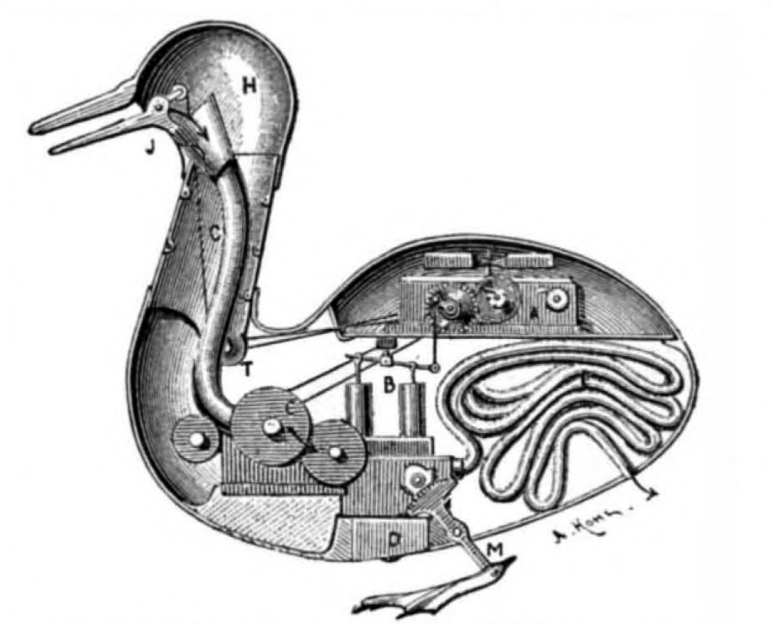
- Real and imagined machines that appear to be living.
- The classical Greeks built some and designed others, but the knowledge of how to make automata and the principles behind them was lost in the Latin Christian West, remaining in the Greek-speaking and Arabic-speaking world.
- Western travelers to those regions struggled to explain what they saw, attributing magical powers.
- The advance of clockwork raised further questions about what was distinctly human, prompting Hobbes to argue that humans were sophisticated machines, an argument explored in the Enlightenment and beyond.
- The French philosopher René Descartes was reputedly fond of automata: they inspired his view that living things were biological machines that function like clockwork.

Mechanical Turk: AI marvel or parlor trick?

- The Automaton Chess Player, also known as The Turk, was invented by Wolfgang von Kempelen in 1770.
- The machine appeared to be able to play a strong game of chess against a human opponent.
- It was a mechanical illusion that allowed a human chess master hiding inside to operate the machine.

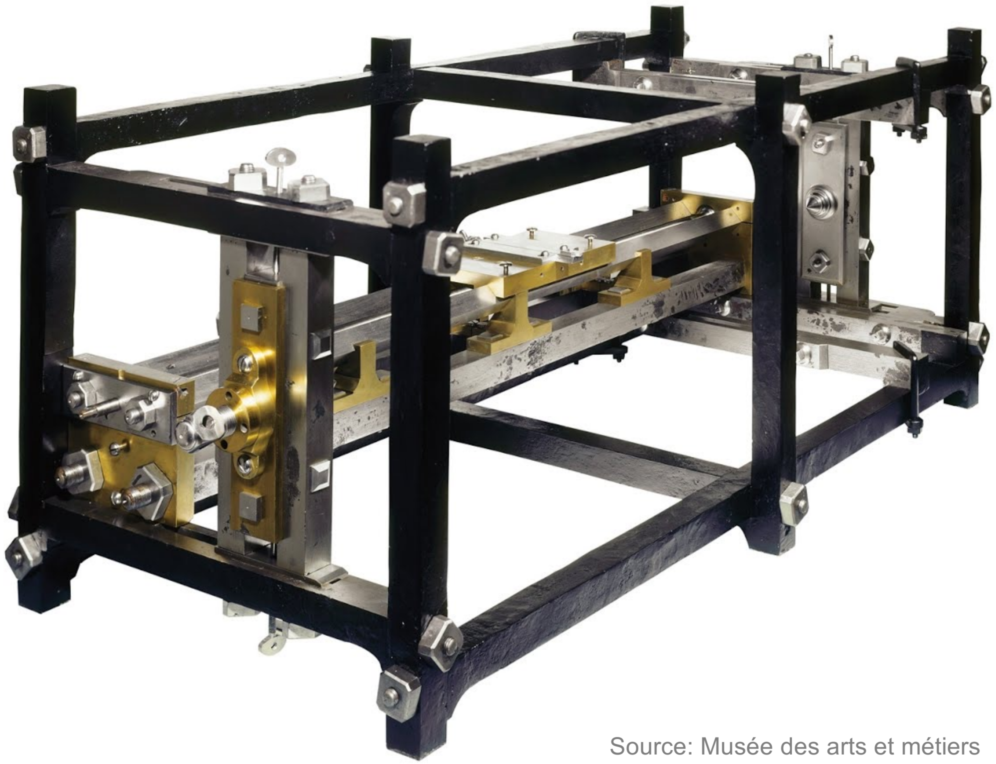
From automata to machines

- Vaucanson’s duck (1739)



INTERIOR OF VAUCANSON’S AUTOMATIC DUCK.
A, clockwork; *B*, pump; *C*, mill for grinding grain; *F*, intestinal tube; *J*, bill; *H*, head; *M*, feet.

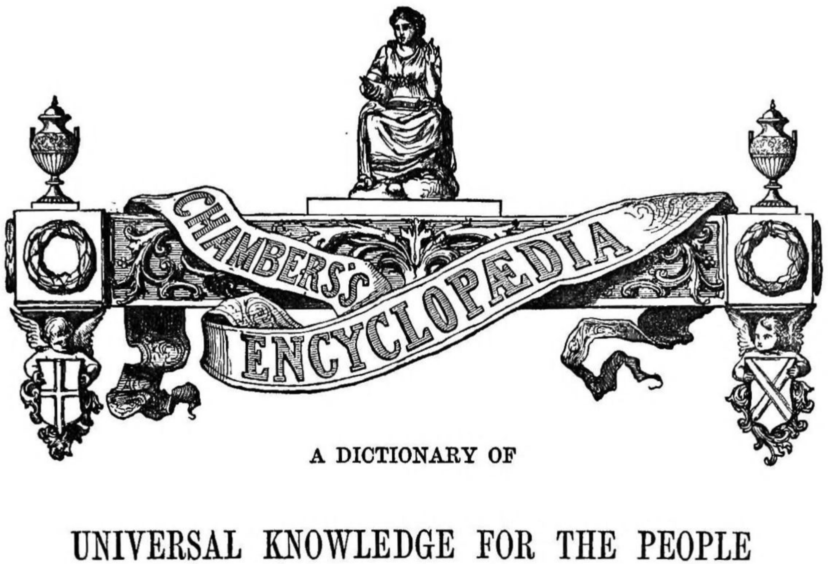
- Vaucanson’s lathe (1751)

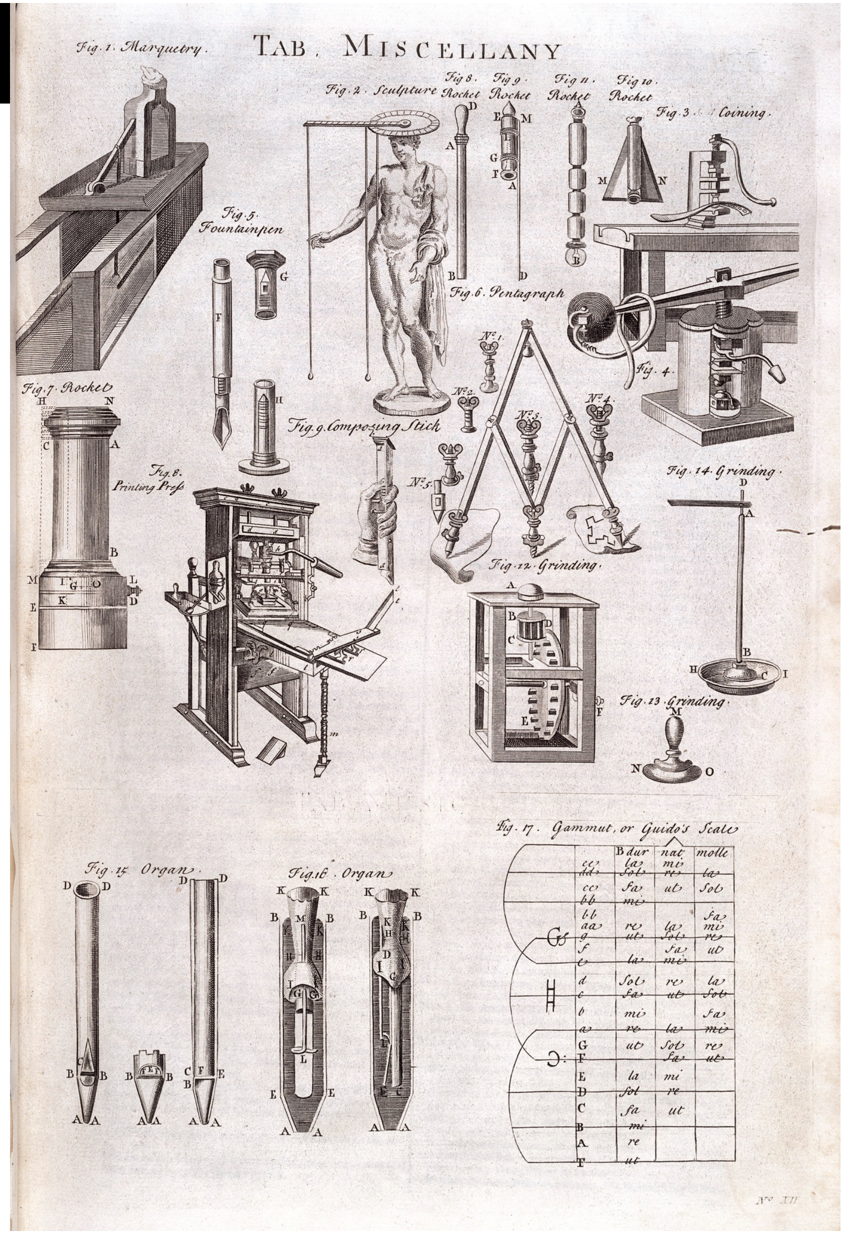


Source: Musée des arts et métiers

Cyclopædia

- The illustrated work of arts and sciences
- Compiled and edited by the English encyclopaedist Ephraim Chambers and first published in 1728





Encyclopédie & Descriptions des Arts et Métiers

- Classified Dictionary of Sciences, Arts, and Trades edited by Denis Diderot & Jean d'Alembert (1745)
- The "*Encyclopédie*" had widespread influence as an expression of progressive thought and served as an intellectual prologue to the French Revolution.
- Each article of "*Descriptions des arts et métiers*" (1749-1814) had sections on materials, tools and apparatus, processes and methods, and illustrations of the métier. The wide range of crafts and industries covered: e.g., coal-mining, textile manufacture, carpentry and cabinet-making, ceramics, papermaking and bookbinding, iron- and tin-smithing.

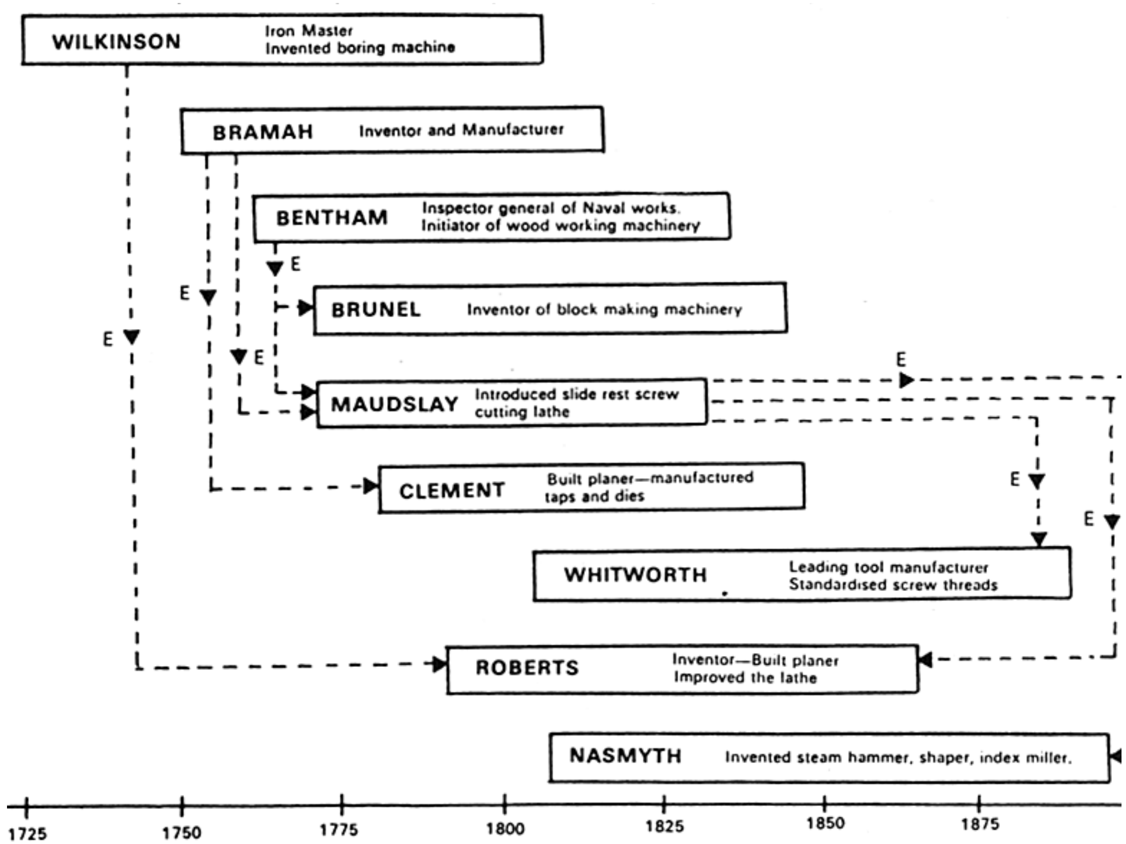
What is Technology?

- 17th century: from Greek **“*tekhnologia*”** ‘systematic treatment’, from **“*tekhnē*”** ‘art, craft’ + **“*-logia*”**.
- Johann Beckmann (1739–1811) was a German scientist and coiner of the word technology.
- ***Technology is the science*** *that teaches the principles and means by which and through which all artefacts are processed in the best way and as required for the satisfaction of various human needs.*

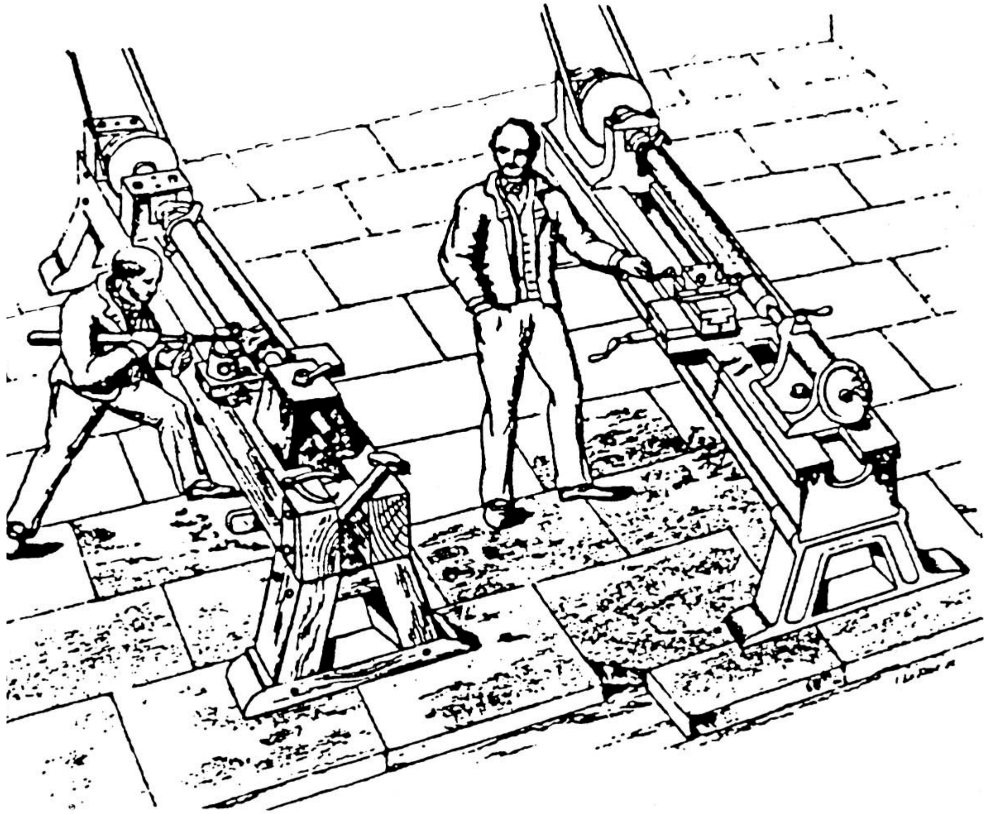
What is manufacturing?

- **Making things** – an essential human activity since before recorded history
- The word **manufacture** is derived from two Latin words ***"manus"*** (hand) and ***"factus"*** (make) = "made by hand"
- Today most modern manufacturing operations are accomplished by automated equipment that is supervised by human workers
- **Definitions of manufacturing**:
  - The **transformation of material** into something useful and portable.
  - The **making of artefacts** on a large-scale using **machinery**; *synonym of industrial production*.

Great Britain – the workshop of the world

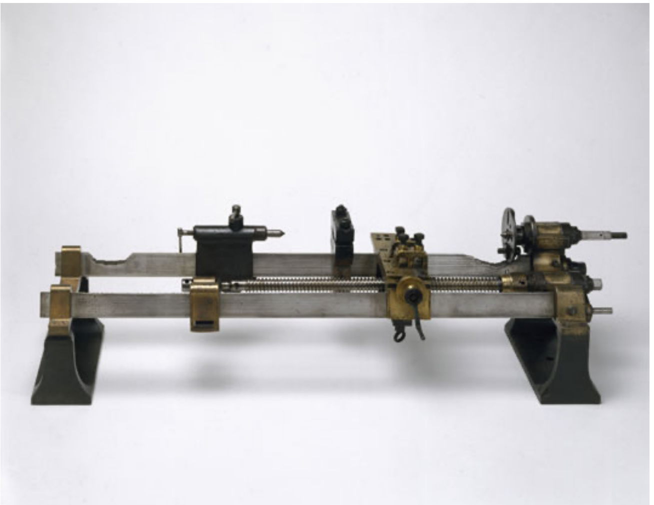


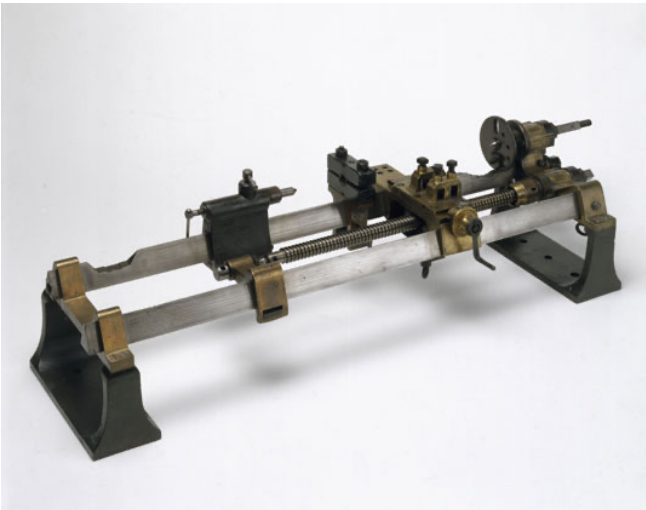
Early English machine-tool builders



Manual vs. driven turning (Nasmyth, 1841)

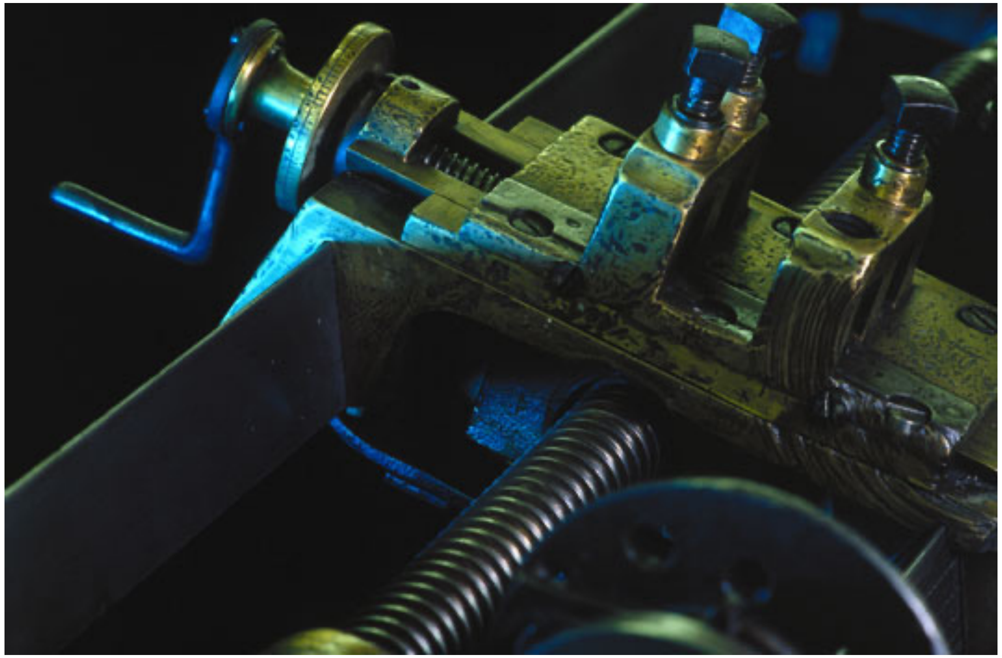
Maudslay's lathe (built in 1800)





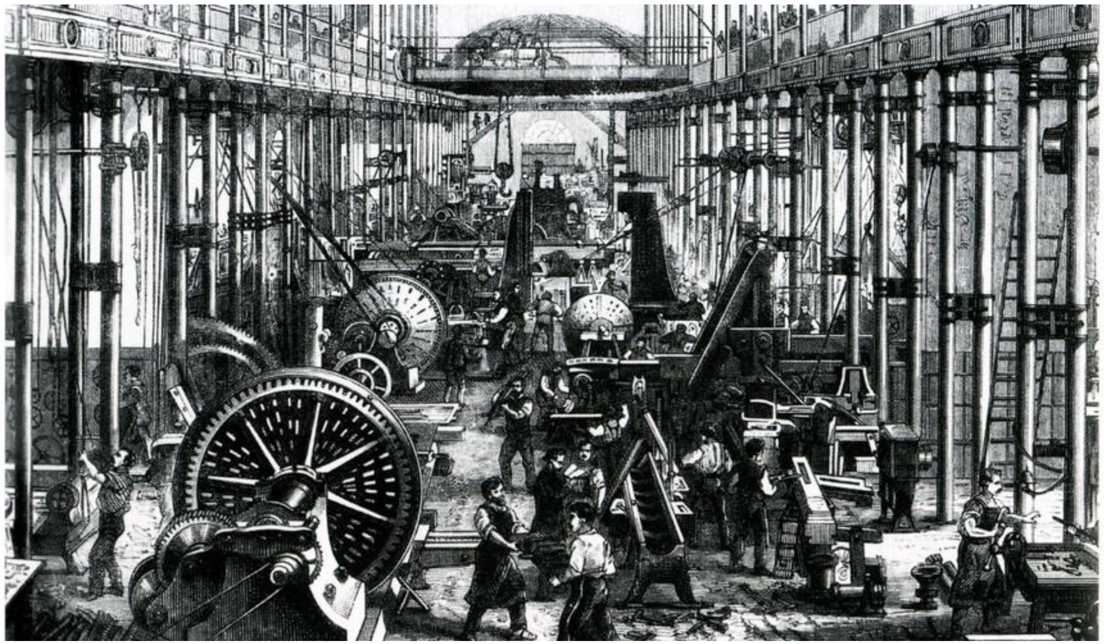
Source: http://www.sciencemuseum.org.uk

Henry Maudslay (1771-1831)



Industrial revolution

- New manufacturing processes (1760 – 1840)
- From manual production to machines using steam power
- Machines with metal parts and frames became common
- Precision for better working machinery, interchangeability of parts and standardization of threaded fasteners
- The rise of the factory system



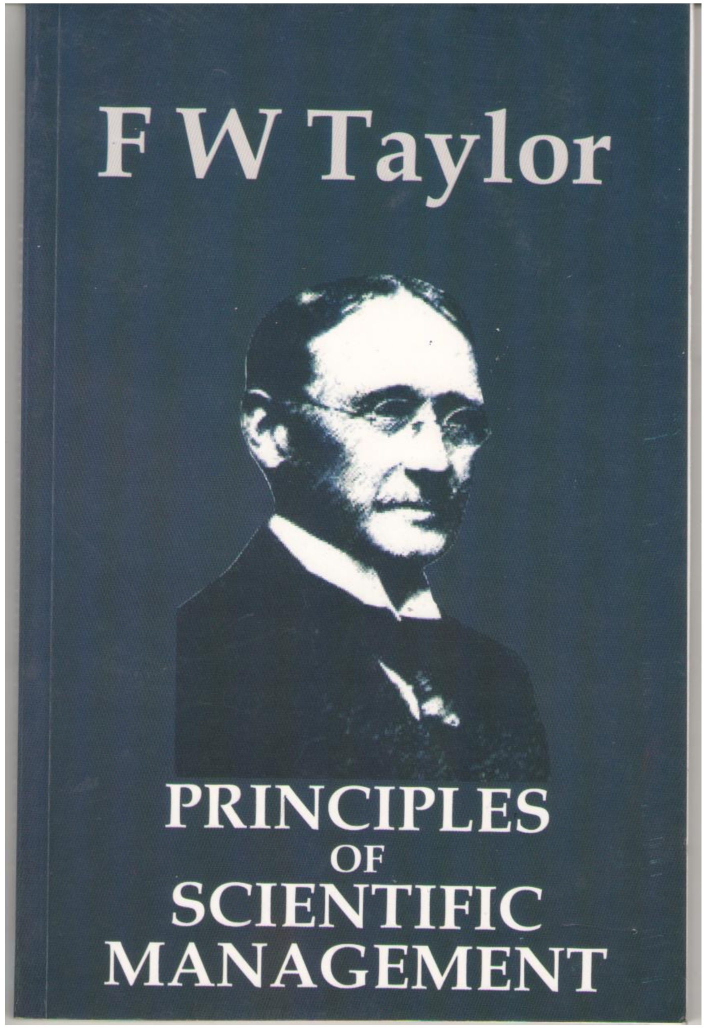
Quiz

Which of the following statement(s) about the **first industrial revolution** is/are true?

a. The first industrial revolution witnessed a surge in the development of software technologies.
b. During the first industrial revolution, machinery was constructed using wood due to its advantages over iron and steel.
c. During the early stages of the first industrial revolution, technological advancements led to many laborers facing reduced job security.
d. The first industrial revolution marked the transition from an agrarian and handicraft economy to one dominated by industry and machine manufacturing.

Taylor

- Father of **scientific management** – theory that analyzes and synthesizes workflows to improve economic efficiency, especially labor productivity.
- Application of science to the engineering of processes and to management.
- **Frederick Winslow Taylor**, "On the art of cutting metals." American Society of Mechanical Engineers, (1907).



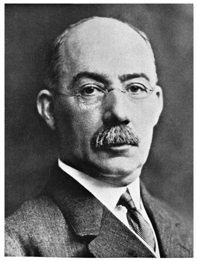
Taylorism

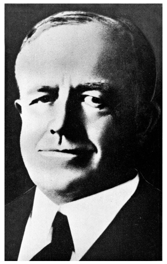
- Taylorism aimed to improve economic and labor efficiency by analyzing and streamlining workflows.
- Taylorism involved training workers to perform tasks by specialization, which was instrumental in manufacturing's move from custom craftsmanship to mass production.
- The principles of Taylorism evolved into lean management, where multi-skilling and problem-solving among workers became critical to the goals of continuous optimization and eliminating waste.

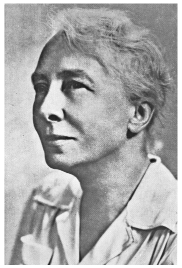
Industrial efficiency & management

- Growth of mass production; *Progressive Era* in the USA from the1890s to 1920s & the *Efficiency Movement* that sought to identify and eliminate waste in all areas of the economy and society, and to develop and implement best practices
- Merger of technology and economics: scientific management, efficiency, standardization, labor economics, etc.


F. W. Taylor

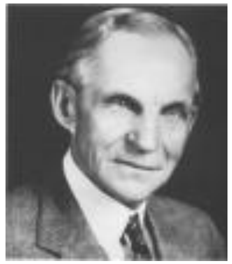

H. Gantt


F. B. Gilbreth


L. M. Gilbreth


G. Schlesinger

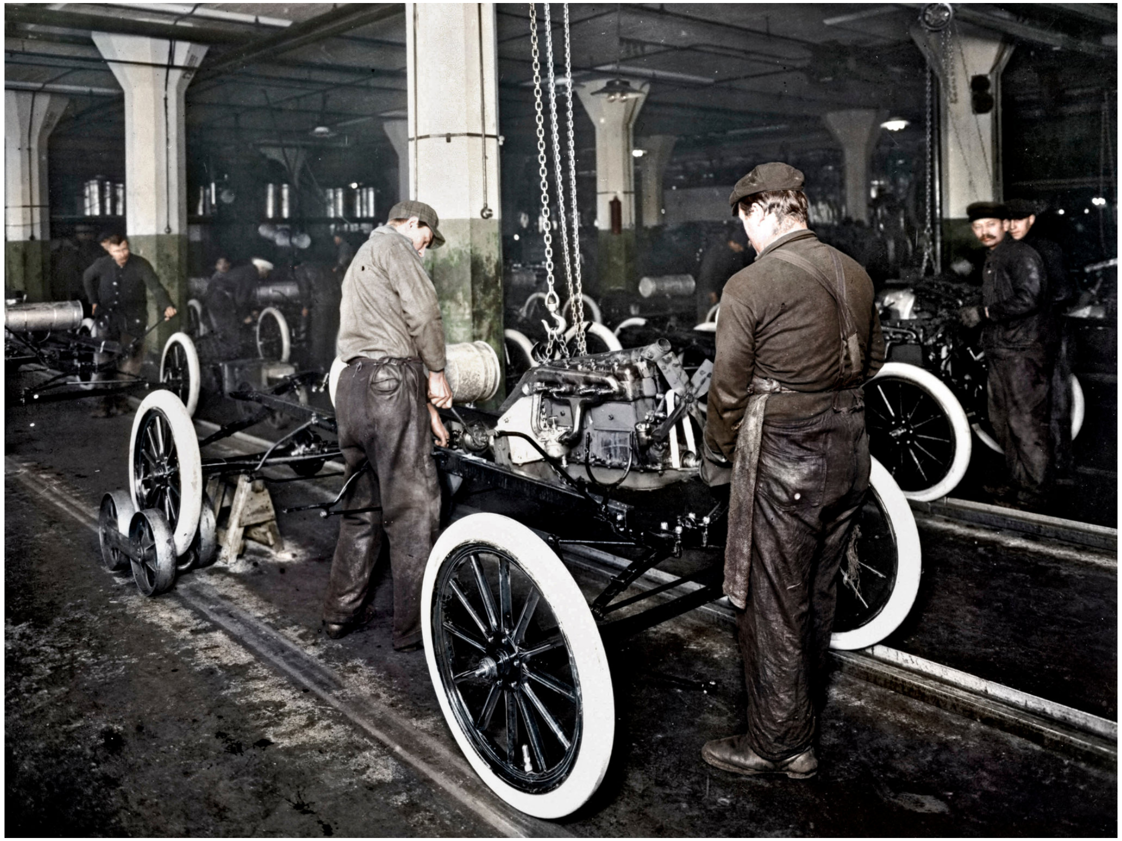

A. Wallichs


H. Ford

Division of labor ↔ **Assembly-line work**

The moving assembly line

- **Second industrial revolution**.
- Moving assembly line – to speed up production and cut costs.
- Redesigned factory with machine tools systematically positioned in the work sequence.
- Unnecessary human motions were eliminated by placing all work and tools within easy reach.
- Birth of the **mass production**.



Source: The New York Times

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Manufacturing at scale is (still) difficult

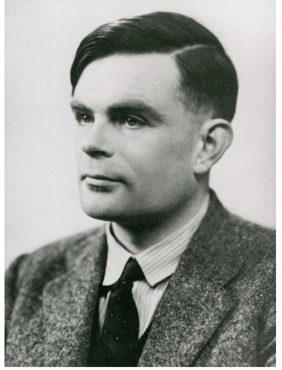
Ford Model T vs. Tesla Model 3

- Manufactured between 1908-1927
- 15,000 immediate orders
- 16,500,000 sold – top ten most sold cars of all time
- Production capacity: 17,000 per week

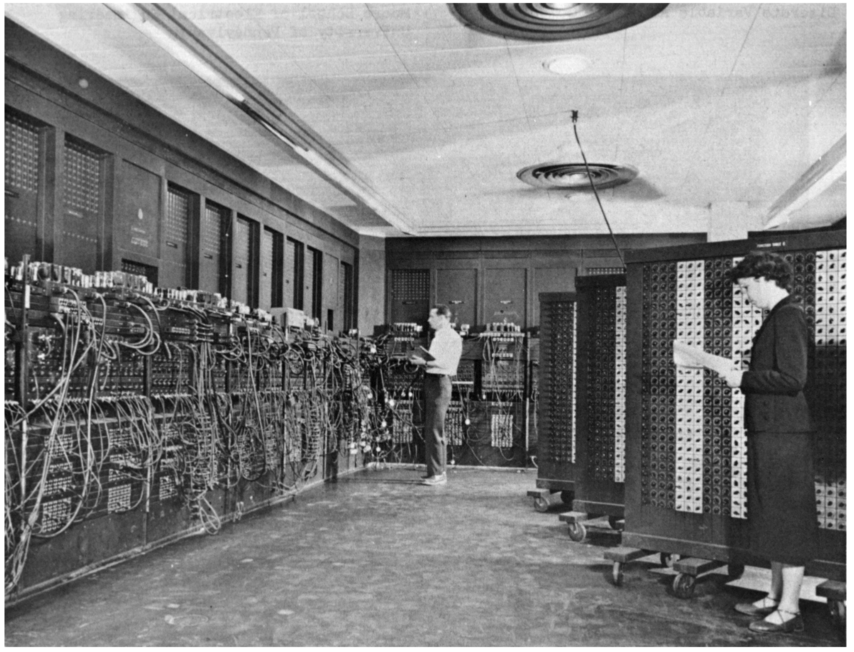
- Manufactured since 2017
- 325,000 immediate orders
- 216,000 sold – topping global sales of plug-in electric cars
- Production capacity: 5,000 per week

Sources: Forbes & Tesla

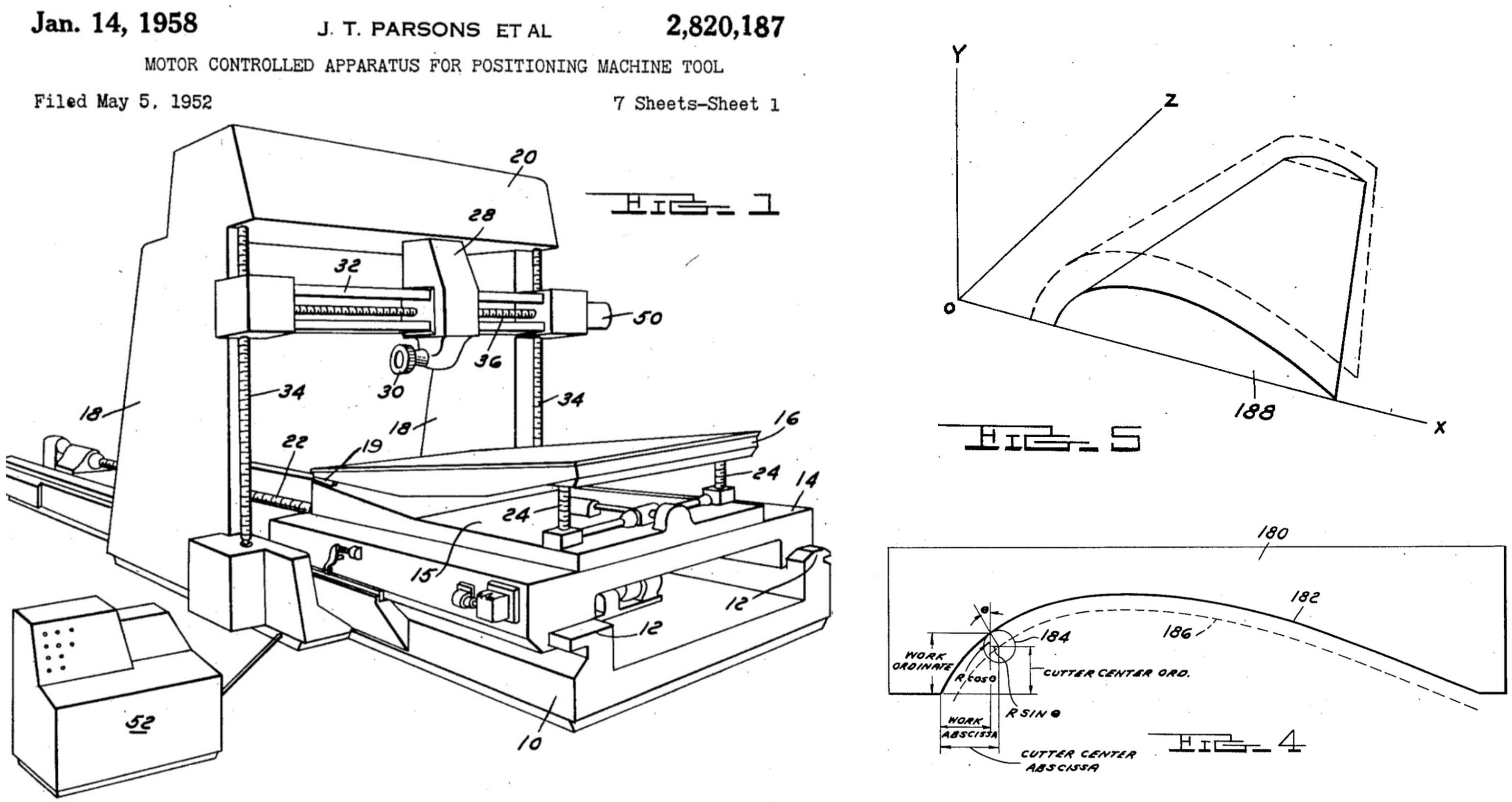
Emergence of computers



- The principle of the modern computer was proposed by **Alan Turing** in 1936.
- Integrated circuits to microprocessor.
- Computers led to the numerical control of machine tools and robots, the microprocessor constituted the heart of computer numerical control (CNC), the application of computer graphics resulted in computer-aided design (CAD) systems.

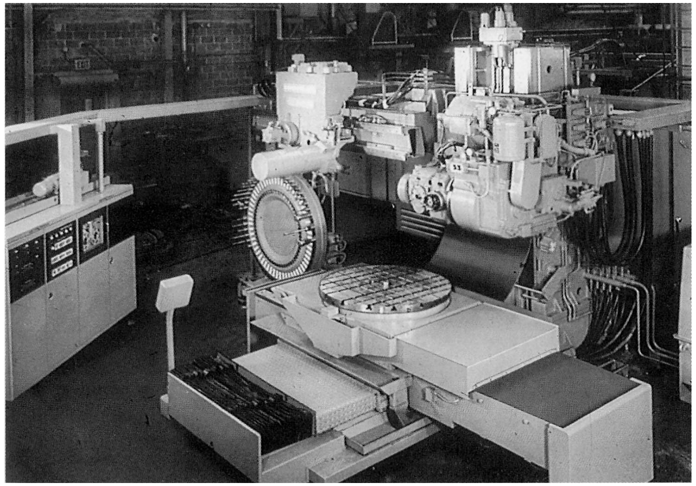


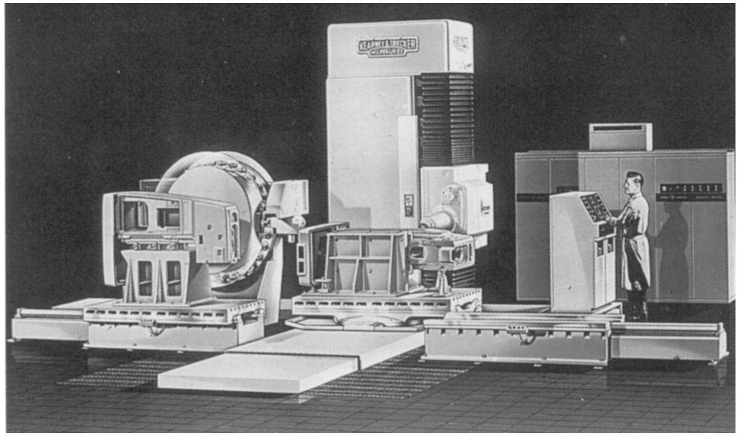
Invention of a NC machine tool (1958)

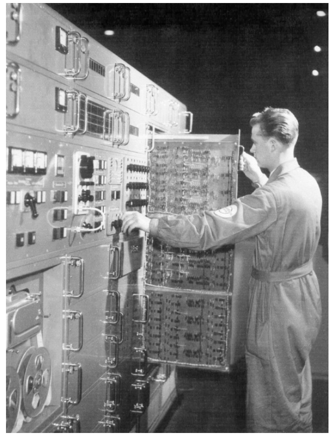


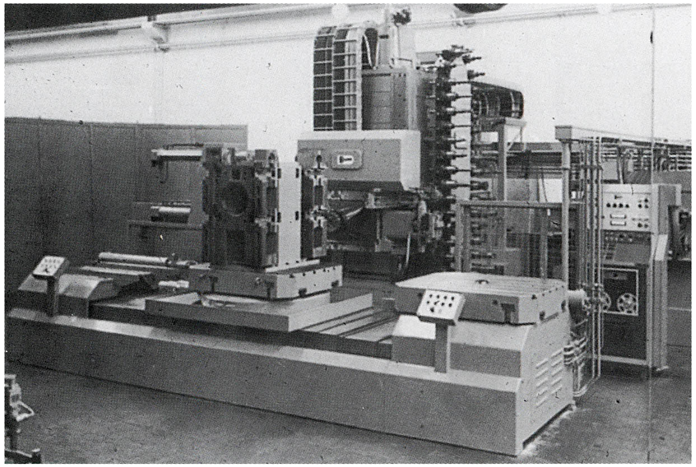
Computers were introduced to industry = 3rd Industrial Revolution

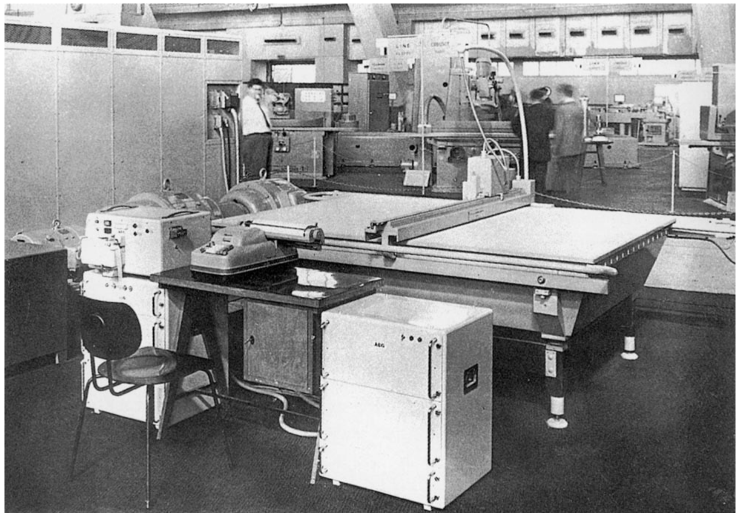
Numerically-controlled machines (1960)

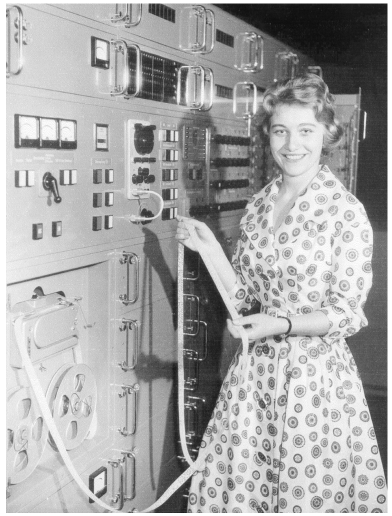






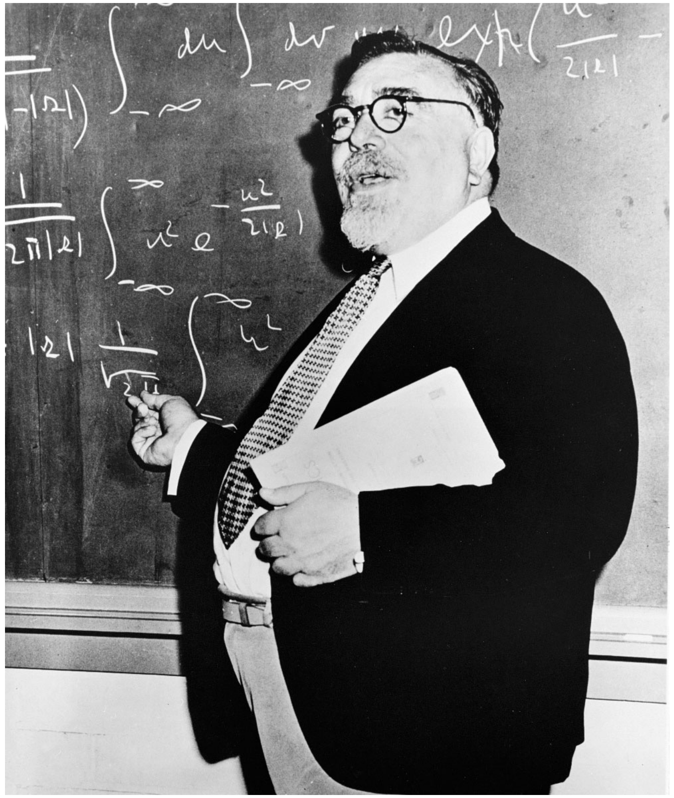




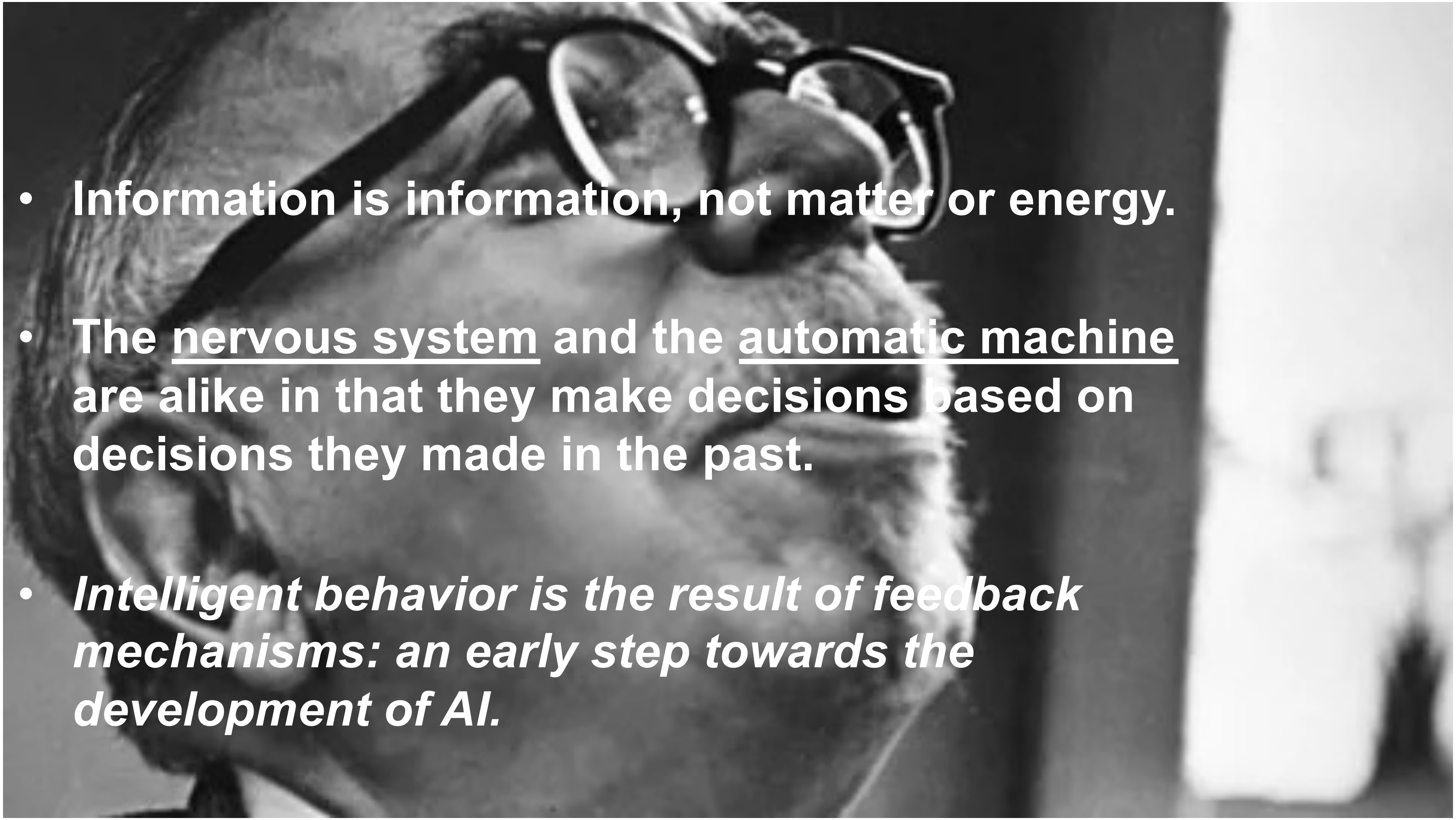


Cybernetics – "*Control and Communication in the Animal and the Machine*"

- In 1948 Norbert Wiener established **cybernetics** used in control & automation theory and computer programs.
- Relevant concepts for **manufacturing systems** – learning, cognition, adaptation, human-machine interaction, emergence, communication, efficiency, connectivity.
- Gateway for networked, adaptive and ubiquitous manufacturing systems – build on integration, communication, collaboration, agility, and global reach.



Source: Encyclopaedia Britannica



- **Information is information, not matter or energy.**

- **The <u>nervous system</u> and the <u>automatic machine</u> are alike in that they make decisions based on decisions they made in the past.**

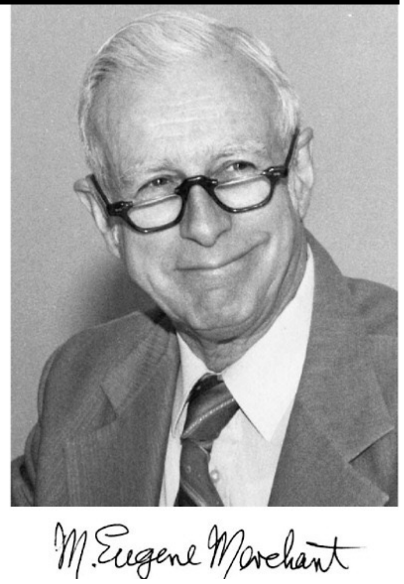
- ***Intelligent behavior is the result of feedback mechanisms: an early step towards the development of AI.***

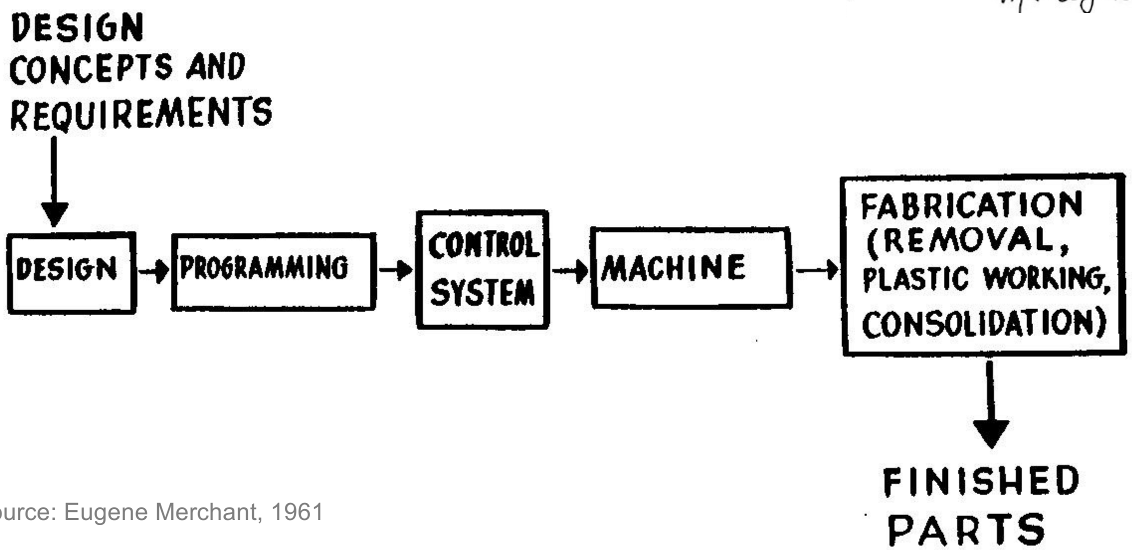
Cybernetics to realize AI’s potential

- **Complexity of General Intelligence**: The goal of replicating general intelligence in machines is a colossal task, largely due to our incomplete understanding of human physiology and cognitive processes.
- **Differences Between Biological and Machine Systems**: There is an intrinsic difference in the "knowing" mechanism between humans and machines due to their fundamentally different constituent materials and mechanisms.
- **Neglect of Cybernetics**: AI shifted focus from understanding intelligence via neural foundations to prioritizing symbolic, abstract representations.

- Combination of **humans** and **machinery** bound by a common material and information flow.
- Manufacturing systems include not only the groups of machines but also the **support procedures that make them work**.

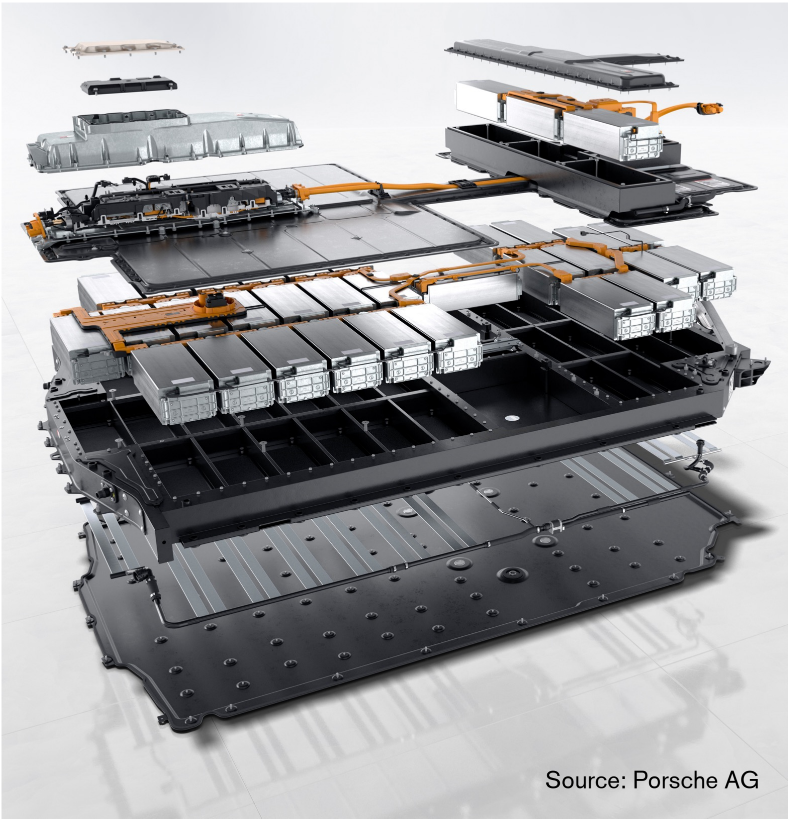
The Manufacturing System





Source: Eugene Merchant, 1961

Manufacturing as a set of unit operations (processes)


Source: Porsche AG

- Cell insertion (assembly)
- Module welding
- Welding verification (quality control)

- Surface conditioning (grinding) prior to fastening
- Dovetail hole machining
- Countersunk drilling
- Riveting

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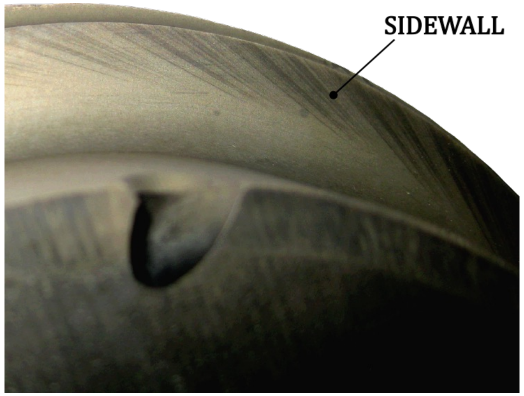
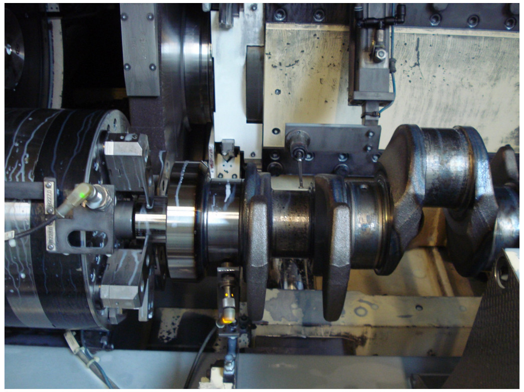
Manufacturing process components

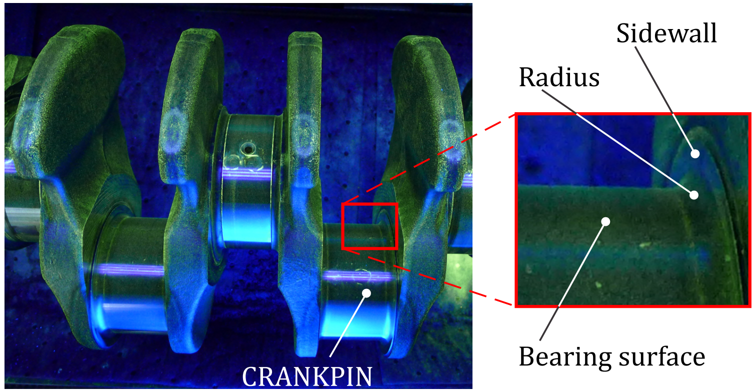
Workpiece material
- Forged steel

Machine tool / equipment
- Grinding machine

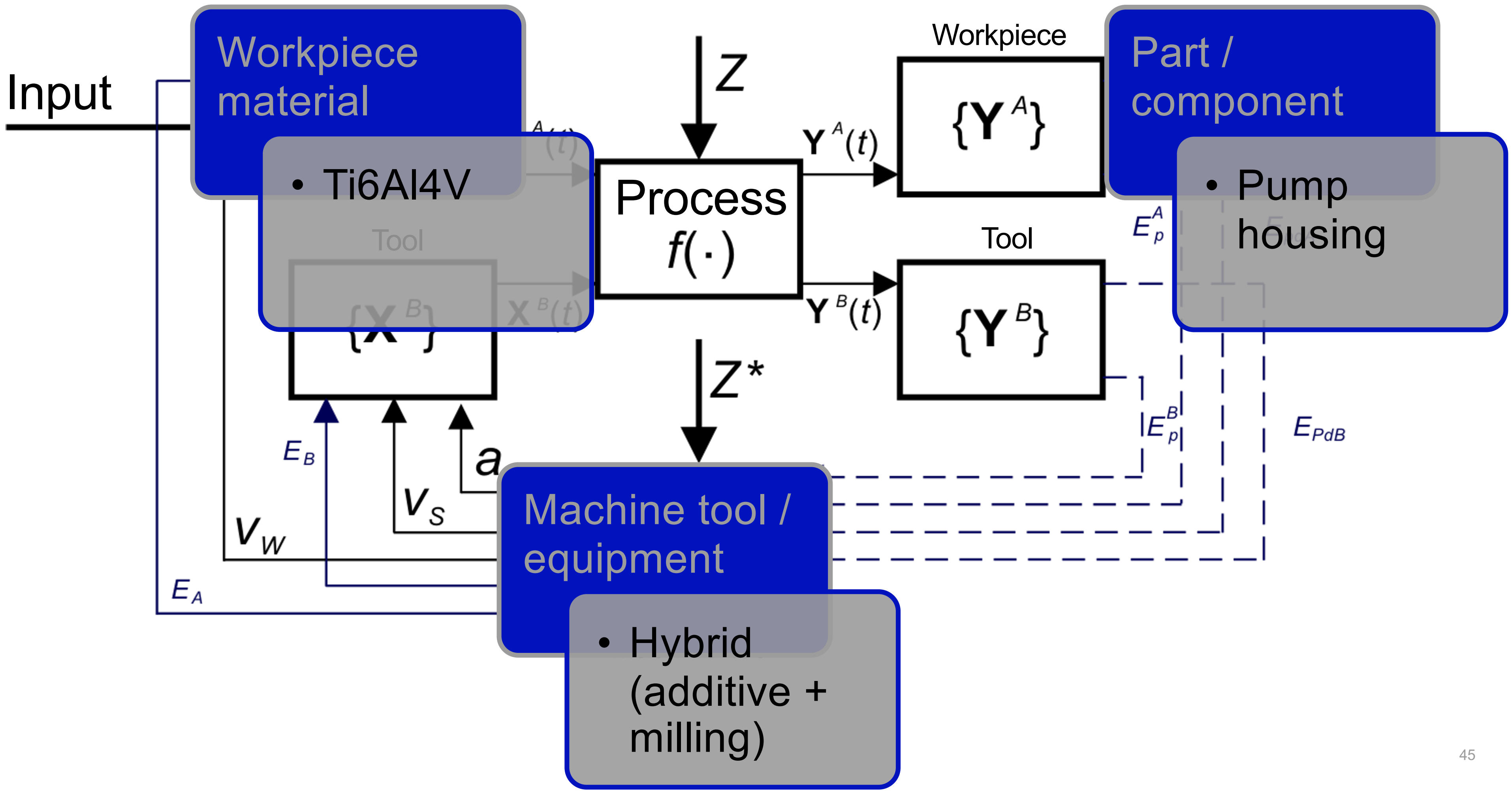
Part / component
- Crankshaft







Manufacturing process input / output system



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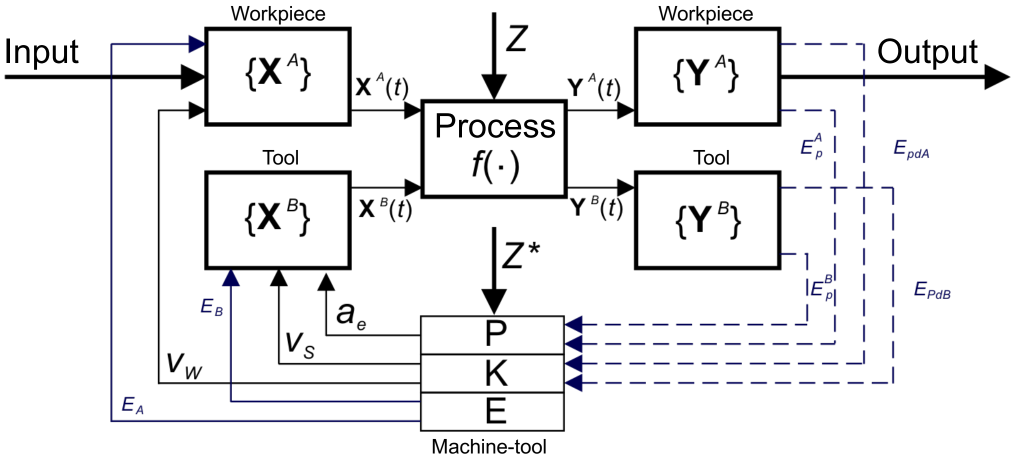
Inverse process-control problem

Source: DMG Mori



- Output surface

$$\boldsymbol{Y^A}(\alpha,\beta,t)$$

- Processed surface

$$\boldsymbol{n}\frac{d\boldsymbol{Y^A}}{dt} = (\boldsymbol{nK})MRR$$

$MRR\left(P_r, P_\theta, t, \boldsymbol{Y^A}; \boldsymbol{E}\right)$ Material removal rate function

Vector of **control** parameters characterizing the dynamics of how energy is delivered by the beam (e.g. beam path, orientation, energy output rate and process time *t*)

- **Direct problem:** set $\boldsymbol{E}$ → predict/observe $\boldsymbol{Y^A}(\alpha,\beta,T)$

Target surface to be generated

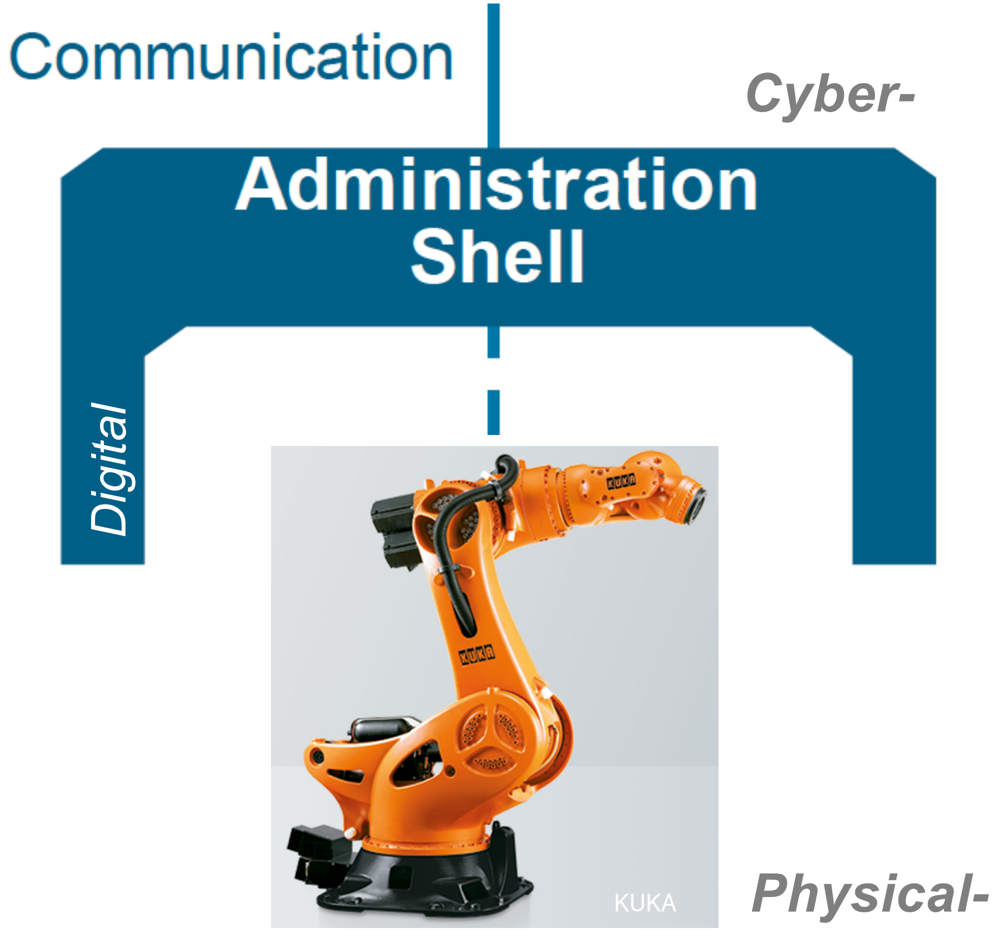
- **Inverse problem:** seek $\boldsymbol{E}$ → minimize $\left\|\boldsymbol{Y^A}(\alpha,\beta,T) - \boldsymbol{Y^{A*}}(\alpha,\beta)\right\|$

Manufacturing process control

- *Maximizing* **Quality**
  - *Conformance to requirement specifications*
- *Improving* **Productivity** (throughput)
- *Improving* **Flexibility**
- *Reducing* **Cost**

Industry 4.0

- Industry 4.0 is a phase in the **digitalization** of manufacturing
- The **internet** is combining with intelligent (smart) machines (IIoT)
- Physical assets are **connected** (they communicate & make decisions) without humans
- **Platforms** in which products, services, and information can be exchanged via predefined streams



Source: Platform Industrie 4.0

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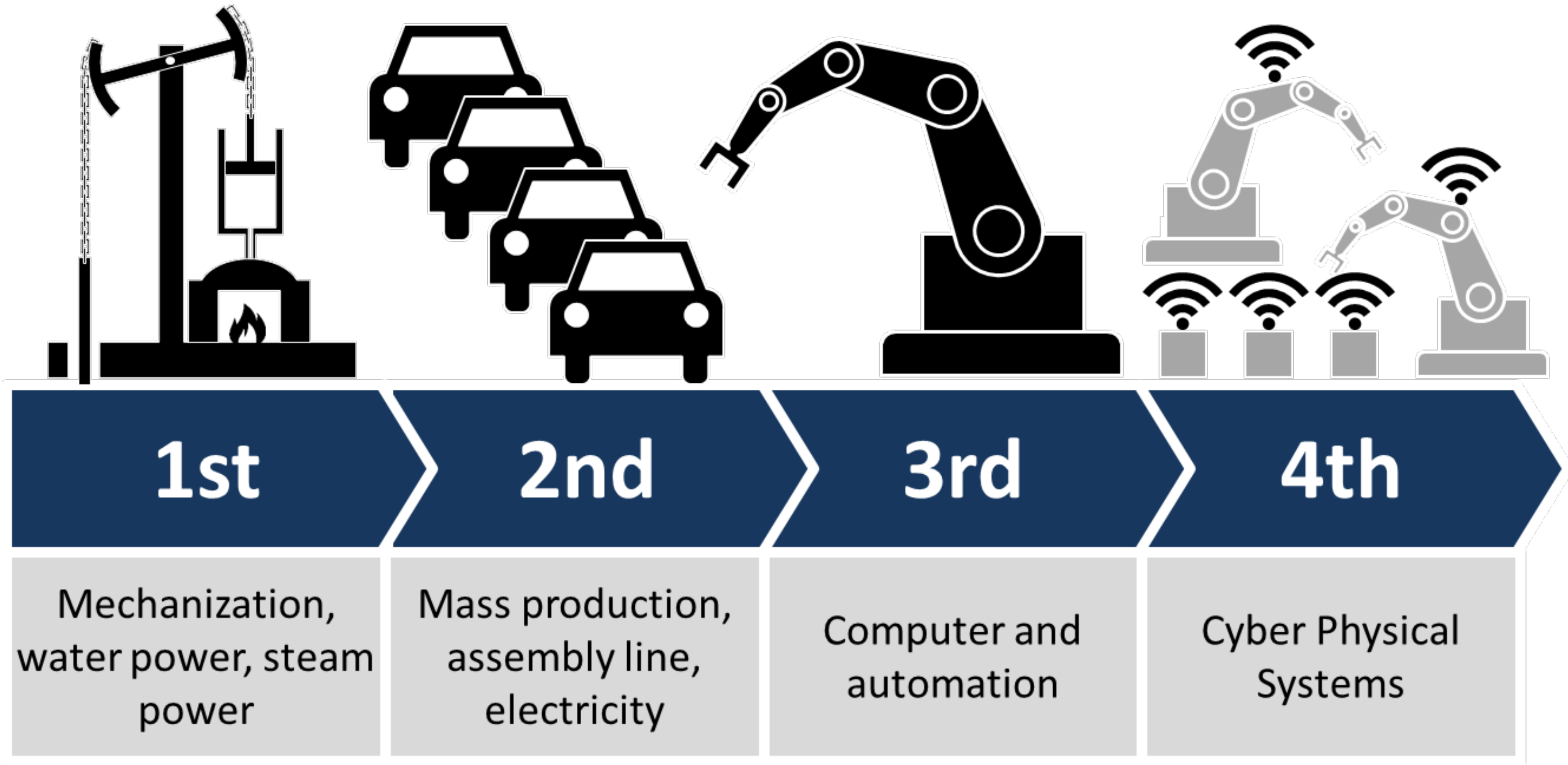
Evolution of manufacturing paradigms

Paradigm	Craft production	Mass production	Flexible production	Mass customization	Adaptive manufacturing
Timeline	1800	1910	1970	2000	2020
Societal needs	Individual products	Price / productivity	Variability of products	Customized products	On-demand personalized products
Market	Small demand	High demand – high volumes	Reduction of batch sizes	Globalized production – demand fluctuation	Globalized production – demand fluctuation
Business model	Produce the order	Produce without advance orders	Push/pull (demand driven)	Pull (sell – produce – assemble)	Pull (sell – produce – assemble)
Enabling technology	Steam power	Electricity; interchangeable parts	Computers and electronics	ICT	Industrial Internet of Things; networks
Key manufacturing technology	Mechanization; first machine tools	Assembly lines	Automation; FMS; industrial robots	Reconfigurable manufacturing systems	Self-organizing (agent-based) systems
Information & knowledge processing	Skills of individuals	“Taylorism” (Principles of Scientific Management)	Data storage/retrieval & processing	Knowledge and data management	Cyber-physical systems

Industrial revolutions in a nutshell



Source: Wikipedia

Is Industry 4.0 new Taylorism?

- In essence, both Taylorism and Industry 4.0 aim to increase productivity and efficiency in the manufacturing process. The connection between Taylorism and Industry 4.0 lies in their use of technology to improve efficiency.
- Taylorism applied to early 20th-century manufacturing as factories began to adopt conveyor belts, interchangeable parts, and other then-modern technology.
- Similarly, Industry 4.0 leverages advancements in technology such as artificial intelligence, machine learning, and big data to optimize production processes

Quiz

Which of the following statement(s) about the **fourth industrial revolution** is/are true?

a. Industry 4.0 leverages technologies such as industrial IoT networks, AI, Big Data, robotics, and automation.

b. Industry 4.0's primary focus is on enhancing the aesthetics of industrial machinery and equipment.

c. Industry 4.0 primarily aims to replace all human labor with robots, eliminating the need for human workers in factories.

d. One of the main objectives of Industry 4.0 is to enable smarter decision-making and customization in manufacturing and supply chain operations.

The sustainability challenge

$$I = P \cdot A \cdot T = Pop \cdot \frac{GDP}{person} \cdot \frac{I}{GDP}$$

Source: Paul Ehrlich & John Holdren, 1971

- I - the environmental impact
- Pop - the **Population** size
- $\frac{GDP}{person}$ - the **Affluence** (the material standard of living)
- $\frac{I}{GDP}$ - the **Technology** (environmental impact per created value)

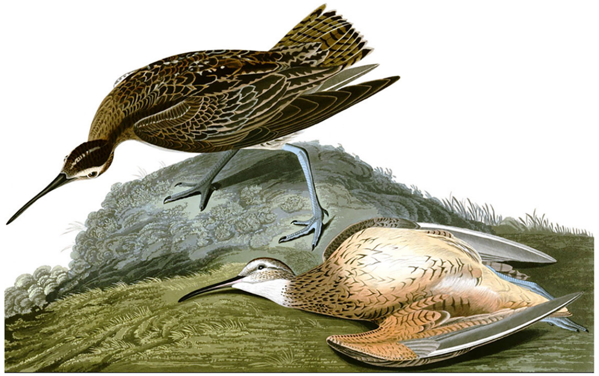
Population, Affluence, and Technology

- **Environmental Impact (I)**: Today's ecological footprint includes soil degradation, groundwater depletion, and loss of biodiversity.
- **Population (P)**: The global population may level off around 10 billion. Further pressure on Earth's resources.
- **Affluence (A)**: Higher individual consumption worsens environmental strain, overshadowing technology's positive effects. Additionally, living standards are set to rise significantly in Asia and South America
- **Technology (T)**: While technology can mitigate some damage, it cannot offset the environmental costs of unchecked population growth and consumption.

Prevailing economic models that promote endless growth and consumption are unsustainable!

Not just about climate change

- The Sixth Mass Extinction is currently in progress and is distinct from previous extinctions because it is caused by human activities.
- Current extinction rates are significantly higher than the natural background rates. It's estimated that 7.5–13% of all known species may have already gone extinct.
- As stewards of the planet, it's our duty to acknowledge the crisis and act. Every individual, community, business, and government has a role to play in preserving Earth's biodiversity. It's urgent to promote dedicated conservation efforts, policy changes, and sustainable practices.

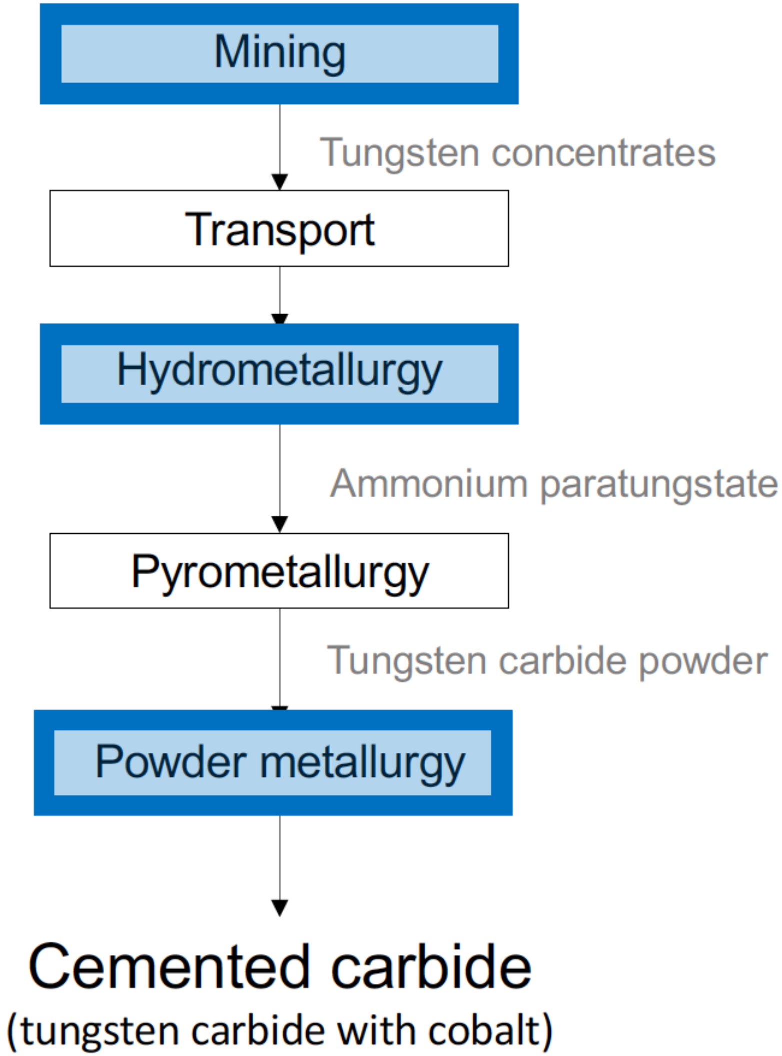


Sustainable manufacturing: environment

- One of the most critical challenges facing humanity is the sustainable handling of the Earth's resources.
- The use of advanced materials in various manufacturing processes, has enabled economic development, but is also associated with large impacts on the environment, long-term resource availability as well as human health.
- **What materials should be used and how should these materials be used in order to reduce society's environmental and resource impacts?**

Hard materials in manufacturing

- For reducing society's resource impacts, one should substitute a scarce material with a less scarce material.
- Tungsten carbide (WC) or Al_2O_3?



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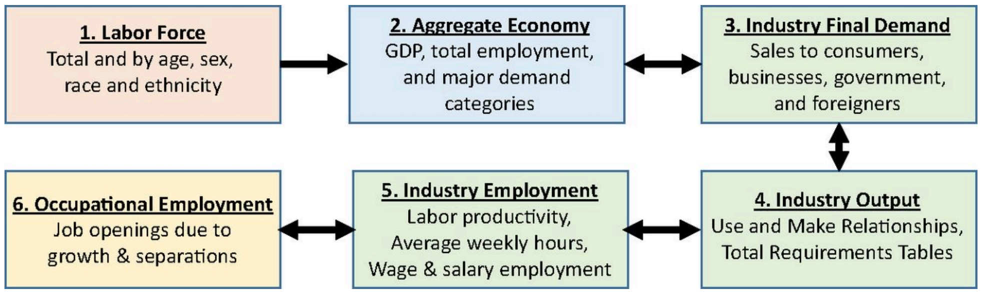
Sustainable manufacturing: people

- People will remain at the core of productivity increases
- Global manufacturing industry has more than 10 million vacancies that cannot be filled due to a skills shortage
- There is a need to resolve the issue of talent shortage
- A need for better understanding on how developments in (manufacturing) technology influence the creation of new jobs and subsequent changes in educational and training programs



PNAS 115(50), 12624-12629 (2018)

What do we need to think about?

Manufacturing/Engineering is all about delivering SOLUTIONS which provide REAL BENEFITS to SOCIETY.

What we CAN DO and what we SHOULD DO will depend upon:

- Keeping pace with change
- Developing an appropriately skilled workforce
- Managing risk
- Taking responsibility
- Sharing knowledge
- Broadening our horizons (beyond manufacturing)

Sustainability of manufacturing

- Manufacturing is about meeting the needs.
- UN SDG 12 aims to ensure **sustainable consumption and production** patterns, promoting resource and energy efficiency, sustainable infrastructure, and providing access to basic services, green and decent jobs and a better quality of life for all.
- Sustainability of manufacturing requires that it supports sustainable lifestyles.
- Sustainable manufacturing helps meeting the needs of present and future generations within the tolerance levels of our planet's regulating systems (climate and ecosystem).

Source: Michael Zwicky Hauschild, 2023

Quiz

Which of the following statement(s) about **sustainable manufacturing** is/are true?

a. Sustainable manufacturing prioritizes the creation of products through processes that aim to reduce negative environmental impacts while conserving energy and natural resources.
b. The methods of manufacturing have always been environmentally friendly, and no recent innovations or changes have been made to reduce the environmental impact of production.
c. Manufacturing sustainability is a modern concept and was only introduced after Greta Thunberg raised concerns about the environment.
d. Companies that engage in sustainable manufacturing often see financial and environmental benefits, and it helps build a stronger brand reputation and long-term business success.

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The Dynamism of a Dog on a Leash

Giacomo Balla (1912)

From Cybernetics to AI in Manufacturing

- Cybernetics is the science of communication and control in both machines and living beings, like people and animals. It was coined by a man named Norbert Wiener in 1948.
- Imagine trying to pick up a pencil – you don't think about moving each muscle; you just do it. That's because your brain sends messages to your muscles, and your muscles report back to your brain about what they're feeling and doing. This back-and-forth messaging is cybernetics. It's like having a conversation between your brain and your body to make something happen.
- Now, machines can have similar 'conversations' within themselves. This helps them do tasks by learning and adjusting, just like when you get better at catching a ball with practice. This is important for making smart machines and robots that can do things without a human telling them what to do every step of the way.
- Wiener's work helps us understand how machines can 'think' and react, which is the beginning of what we call artificial intelligence, or AI. This doesn't mean machines are alive, but they can learn from what happens around them to make decisions, similar to how we learn from our experiences.
- The term 'cybernetics' comes from a Greek word meaning 'steersman,' like someone who steers a ship. Just as a steersman keeps a ship on course, cybernetics helps keep machines and living organisms 'on course' by helping them control their actions and communicate effectively.
- Wiener's ideas are used in many things today, from robots that can see and avoid obstacles to computer programs that can solve math problems or predict the weather. Understanding cybernetics can also help us tackle more complex problems, like making artificial limbs move more naturally or even understanding how our brains work.
- So, in simple terms, cybernetics is all about messages: sending them, receiving them, and using them to make decisions. And this idea is what has started a new age of technology, where we focus on the messages more than just the power needed to send them.

Assignment

1. Find an example of AI in manufacturing. Describe it and relate it to the principles of cybernetics. *(Examples could include robotic arms on assembly lines, AI-driven quality control systems, energy saving, quality assurance or predictive maintenance algorithms.)*
2. Conceptualize a new AI application in manufacturing. Show how it would use feedback, decision-making, or communication. *(Use your imagination – there is no right solution – feel free to be futuristic.)*
3. Explain how your chosen or proposed technology reflects cybernetic concepts. *(Think of how the technology you've proposed applies Wiener's concepts.)*
4. Reflect on the role of cybernetics in the future of AI. *(Be prepared to discuss ethical considerations and societal impacts.)*

Debriefing

- *Think of how Wiener's principles of cybernetics apply to contemporary AI systems (e.g. in manufacturing). Your task is to connect fundamental concepts to modern AI applications and propose innovative ideas inspired by cybernetics.*
- Document (e.g. PowerPoint) with your proposal.
- Any sketches or diagrams supporting your proposal.
- *Bring your assignment proposal to the debriefing session for a discussion on the implications of cybernetics in the evolution of AI, and be ready to share your ideas!*

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