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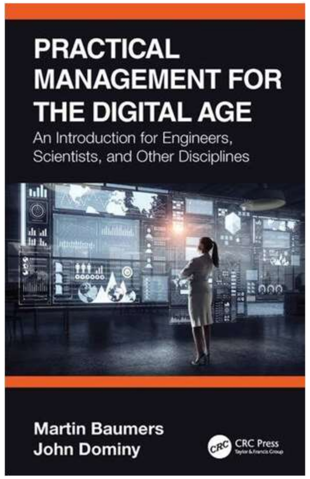
Department of Mechanical, Materials and Manufacturing Engineering

The economics of digitalization and automation

What we will talk about today:

The economics of digitalization and automation

- *Background and definitions*
- *What exactly is information technology?*
- *Moore’s law*
- *The economics of information goods*
- *Information economics at work: FMS and AI*
- *Automation as a social challenge*

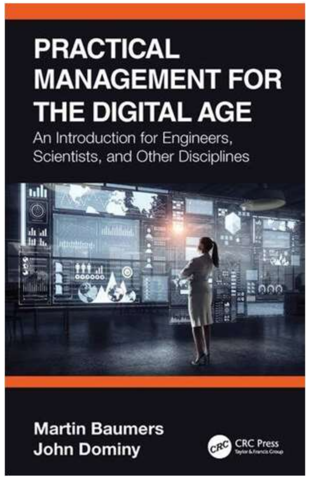


Lecture builds on Chapter 4 in Baumers and Dominy (2021)

What we will talk about today:

The economics of digitalization and automation – Part 1

- *Background and definitions*
- *What exactly is information technology?*
- *Moore’s law*



Lecture builds on Chapter 4 in Baumers and Dominy (2021)

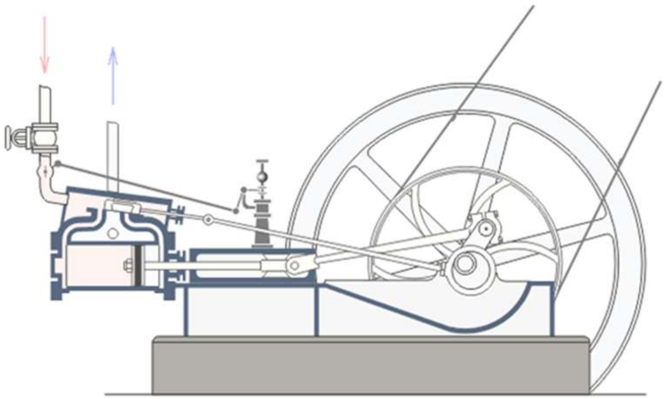
What is information technology and why do I need to know about this as a manager?

Background

Joseph Schumpeter
Economist
(1883 – 1950)

A key insight from early 20th Century economics is that technological progress is the main reason that the economy and business world (and probably also society) change.

- As we've seen in the first lecture of the course last year, there was a sudden and sharp change in the late 18th Century known as the Industrial Revolution.
- We've also seen that the field of Management as we know it today developed in response to this.
- The industrial revolution is closely associated with the emergence of steam power and related technologies, leading to:
  - Mass production
  - Mass transportation
- **Today, a similar, digital revolution is ongoing → this is the topic of this lecture**



Important definitions

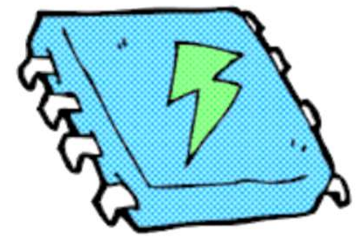
- Automation:

"***Automation is any kind of technology by which a process, procedure, task or activity is performed with minimal human assistance or intervention***."

  - Automation aims to reduce the requirement of human effort and interventions to perform tasks and activities. Automatic control is the use of control systems for the operation of equipment with minimal or reduced human intervention.

- Digitization and digitalization:

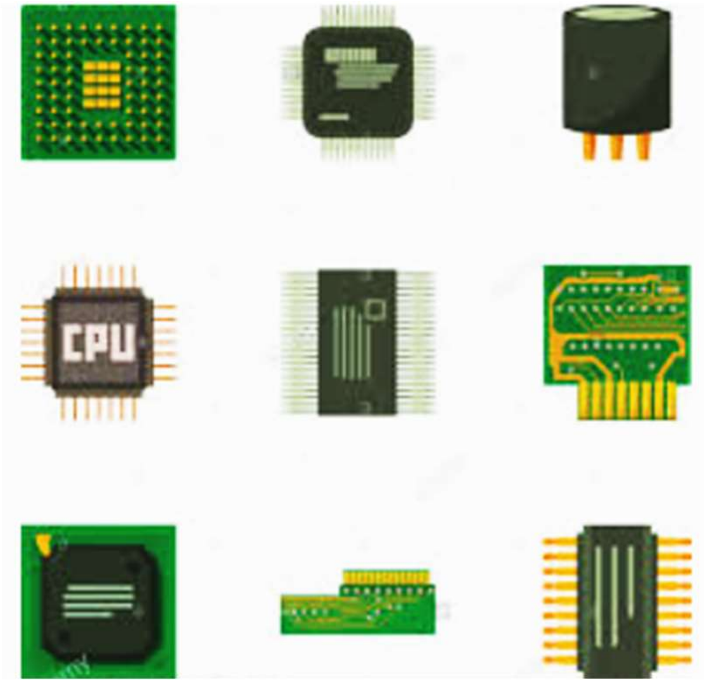
"Digitization is the process of converting relevant information and procedures into digital form so they can be acted upon by computers, including their transmission through computer networks."



  - Digitalization is the process of using digitization for various purposes and activities.

But the standard definition of digitalization/digitization contains the word "computer"

→ so we need to explain what this is first…



Standard definition of Information Technology (i.e. "computers")

- Information Technology (IT):

  "The use of digital computers to store, retrieve, transmit, and manipulate information in electronic form".

  - An IT system is an information or communications system, more specifically a computer system, designed to perform these tasks. This definition includes all hardware, software and peripheral equipment operated by a limited group of users.

- But this still leaves us with the problem of stating what a "computer" and "electronic information" actually is…

General characteristics of computers

Electronic computers (alternatively “IT systems”) are most easily understood when presented as in the form of a very brief history, highlighting some important characteristics.

- We focus on four general characteristics (“ingredients”) of today’s computers:

    - Von Neumann architecture
    - Solid-state transistors (MOSFETs)
    - Integrated circuits
    - Binary representation of information

The importance of each of these can not be overstated!

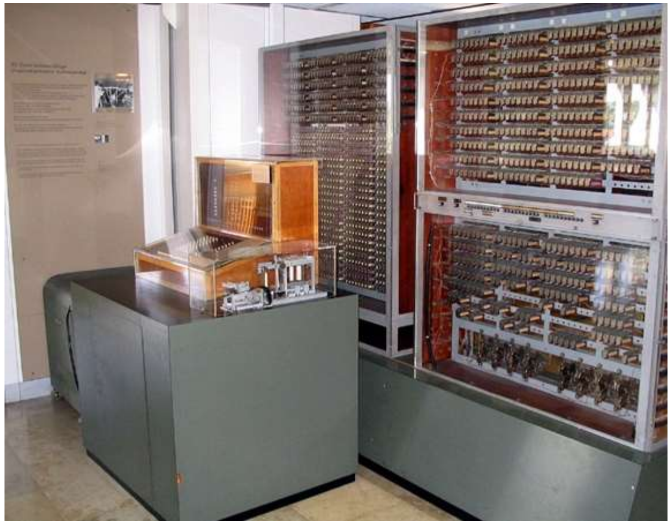
INFORMATION TECHNOLOGY HAS OTHER IMPORTANT CHARACTERISITCS, SO THIS SELECTION IS NOT EXHAUSTIVE!

General characteristics of computers

But first its important to realise that information processing devices that don’t have these characteristics have a long history.

Two examples:

The Antikythera mechanism
believed to be for astronomic calculations
Ancient Greece (205-87 BC)



Zuse Z3
Non-electronic computer
Germany, 1941

→ AS WE WILL SEE, THE DIGITAL REVOLUTION COULD NOT HAVE HAPPENED WITH THIS TECHNOLOGY!

Ingredient 1: The von Neumann architecture

In the von Neumann architecture, proposed in 1945, there is a range of functional elements:

- A central processing unit (CPU)
- Memory
- Input devices
- Output devices

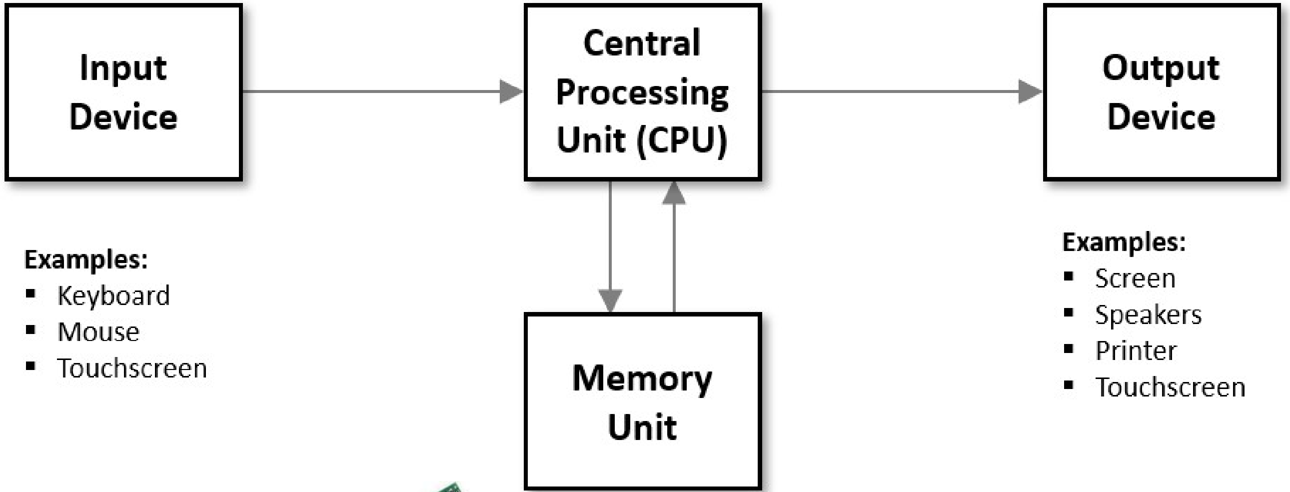
The key idea in the von Neumann architecture is that the program instructions are stored in the same memory as the data:

- This allows the function of the computer to be changed as quickly as the data.

- Almost all computers available today (including your smartphone!) operate in this way.

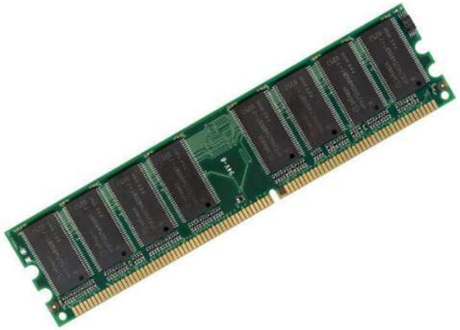
The von Neumann architecture (simplified):

Example:
- Main processor in a PC



Examples:
- Keyboard
- Mouse
- Touchscreen

Examples:
- Screen
- Speakers
- Printer
- Touchscreen



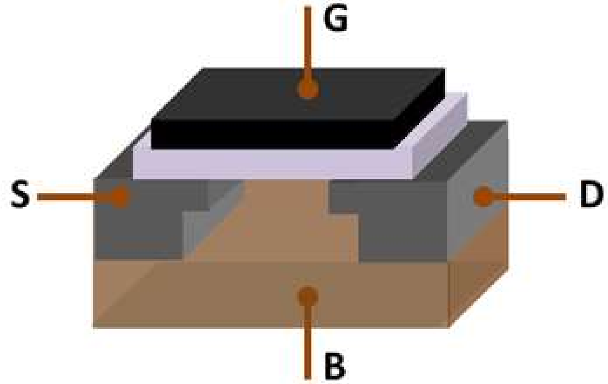
Example:
- Random Access Memory (RAM) in a PC

Ingredient 2: Solid-state transistors (MOSFETs)

In the 1940s and 1950s it transpired that the basic logical elements in modern computers would be transistors, acting in effect as logical switches.

- Transistors are semiconductor devices that use electric fields to control the flow of current.

  → As such, they are truly quantum devices and are considered one of the most significant inventions in history.



The breakthrough invention occurred in 1959 at Bell Labs in the US when the "Metal-Oxide-Semiconductor Field-Effect Transistor" (MOSFET) was invented.

Why MOSFETs caused a revolution

- MOSFETs are compact and can be miniaturised.
- They have a fast switching speed.
- They can be extremely cheap to produce (per unit).
- They can be embedded in complex circuitry in huge numbers.
    - Example: A 256 GB Micro SD card weighing less that 1 g contains approximately 1,000,000,000,000 transistors (10^{12} = 1,000 billion)![1]

- MOSFETs are still the building blocks of every microprocessor, memory chip and telecom circuit (including your phone).

[1] Colinge, J.P., Greer, J.C. and Greer, J., 2016. Nanowire transistors: physics of devices and materials in one dimension. Cambridge University Press.

Ingredient 3: Integrated Circuits (ICs)

An Integrated Circuit can be defined as "an electronic circuit in which all or some of the circuit elements are inseparably associated and electrically interconnected so that it is considered to be indivisible for the purposes of construction and commerce".

- Unlike the other inventions that led to today's computer this was actually a *manufacturing* invention.

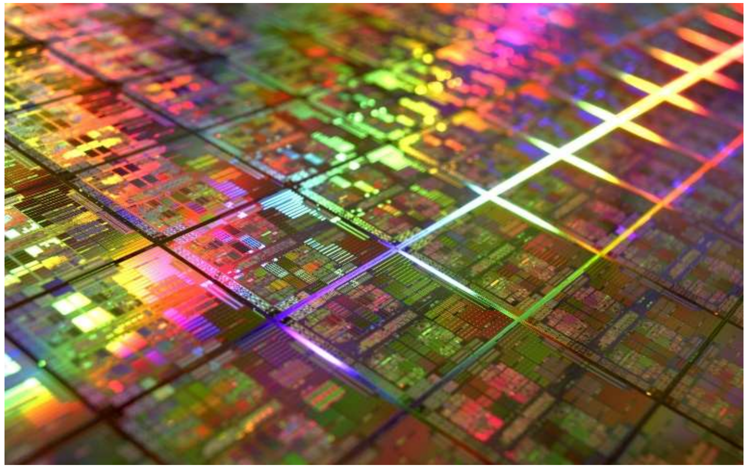
- ICs were invented by a company called Fairchild Semiconductor in the US (also in 1959).

FAIRCHILD SEMICONDUCTOR®

Made possible through a process called "photolithography":

- Allows the creation of extra transistors without "mechanical" work.

- Leads to extremely low Marginal Cost (MC) for transistors.



Ingredient 4: Binary representation of information

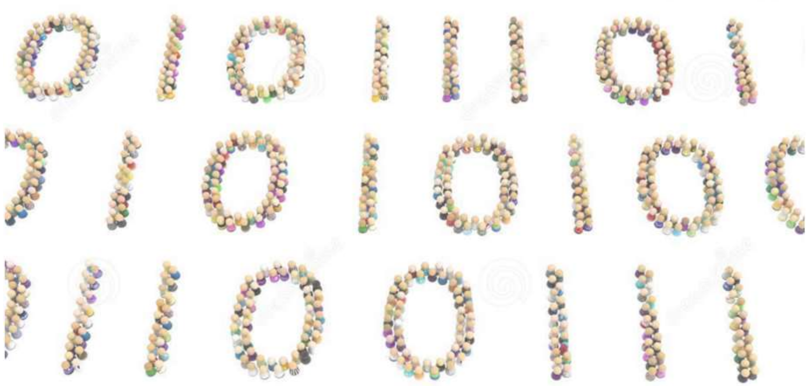
This intellectual basis for information technology was created by the mathematician Claude Shannon around 1948.

- Shannon recognised that, at the most basic level, digital computers are systems designed to process simple logical instructions.

- This can be based on the manipulation of zeroes and ones as logical symbols, embodied by the presence or absence of a voltage.

  → Representing information as “binary digits” or “bits”.

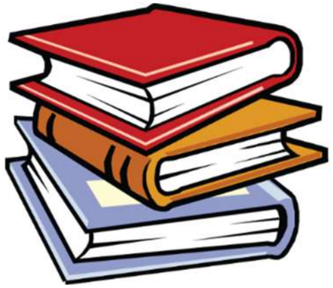
- Combining logical instructions allows circuits to solve logical equations that constitute the basis of more complex software programs.



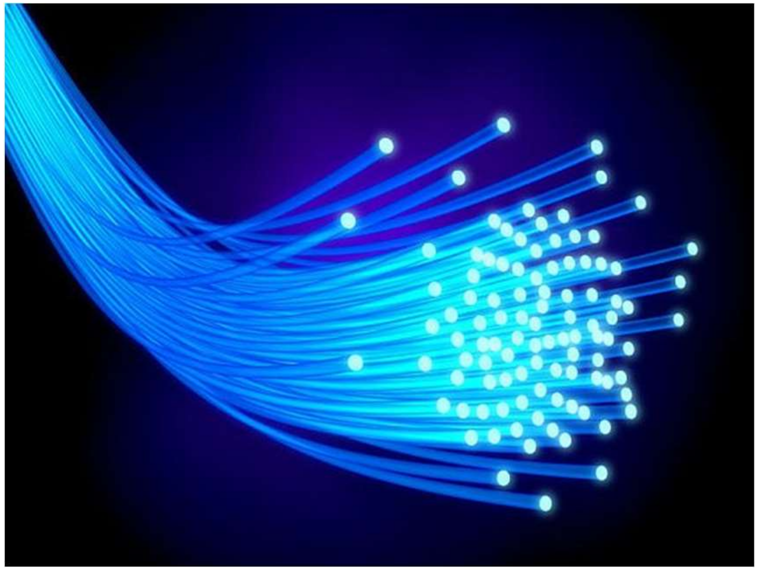
Binary representation of information

Representing information in this way allows the error free processing of information even in imperfect systems.

- Up to a threshold, known as the Shannon limit.
- This allows the construction of reliable computers from unreliable parts.



Some pointers to (optional!) introductory literature are provided in the book.

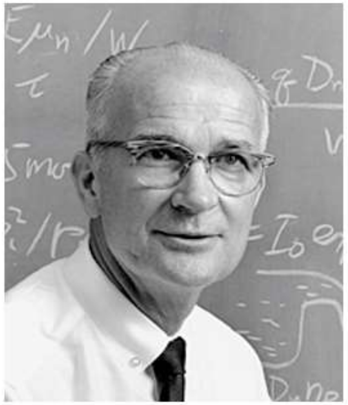


The pioneers of computing

Architecture

John von Neumann
(1903-1957)

Semi-conductors



William Shockley
(1910-1989)

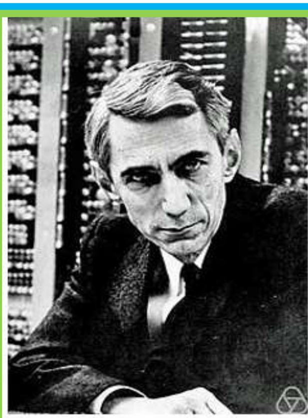
John Bardeen
(1908-1991)

Walter Brattain
(1902-1987)

Mohamed Atalla
(1924-2009)

Dawon Kahng
(1931-1992)

MOSFET



Claude Shannon
(1916-2001)

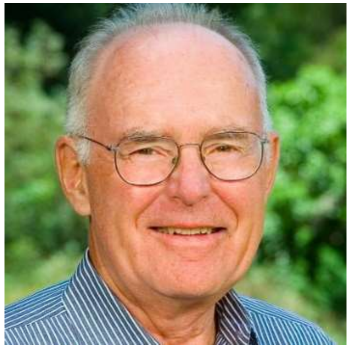
Shannon Limit

So, what happened next?

After the invention of computers it was clear to experts that this technology had great potential.

An employee at Fairchild Semiconductor, Gordon Moore, was in 1965 asked to predict what would happen in the nascent semiconductor industry in the next 10 years.

- Moore responded by writing an article with a model that would later become known as "Moore's law."[1]



Gordon Moore
(1929-2023)

Moore left Fairchild and co-founded his own business, later to become Intel.

→ Intel is still the world's leading manufacturer of microprocessors.

[1] Moore, G.E., 1965. Cramming more components onto integrated circuits. Electronics, 19/04/1965

Moore’s law

In his famous article, Moore predicted that the number of logical elements, such as transistors,

“has increased at a rate of roughly a factor of two per year […]. Certainly over the short term this rate can be expected to continue, if not to increase. Over the long term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least ten years.”

→ Moore predicted that the exponential growth of computing power of available hardware would continue in the future.

→ This meant that computing power would increase at an accelerating rate independently of cost.

  - **MEANING THAT THE MARGINAL COST (MC) OF COMPUTING WOULD BE DROPPING TO ALMOST ZERO!**

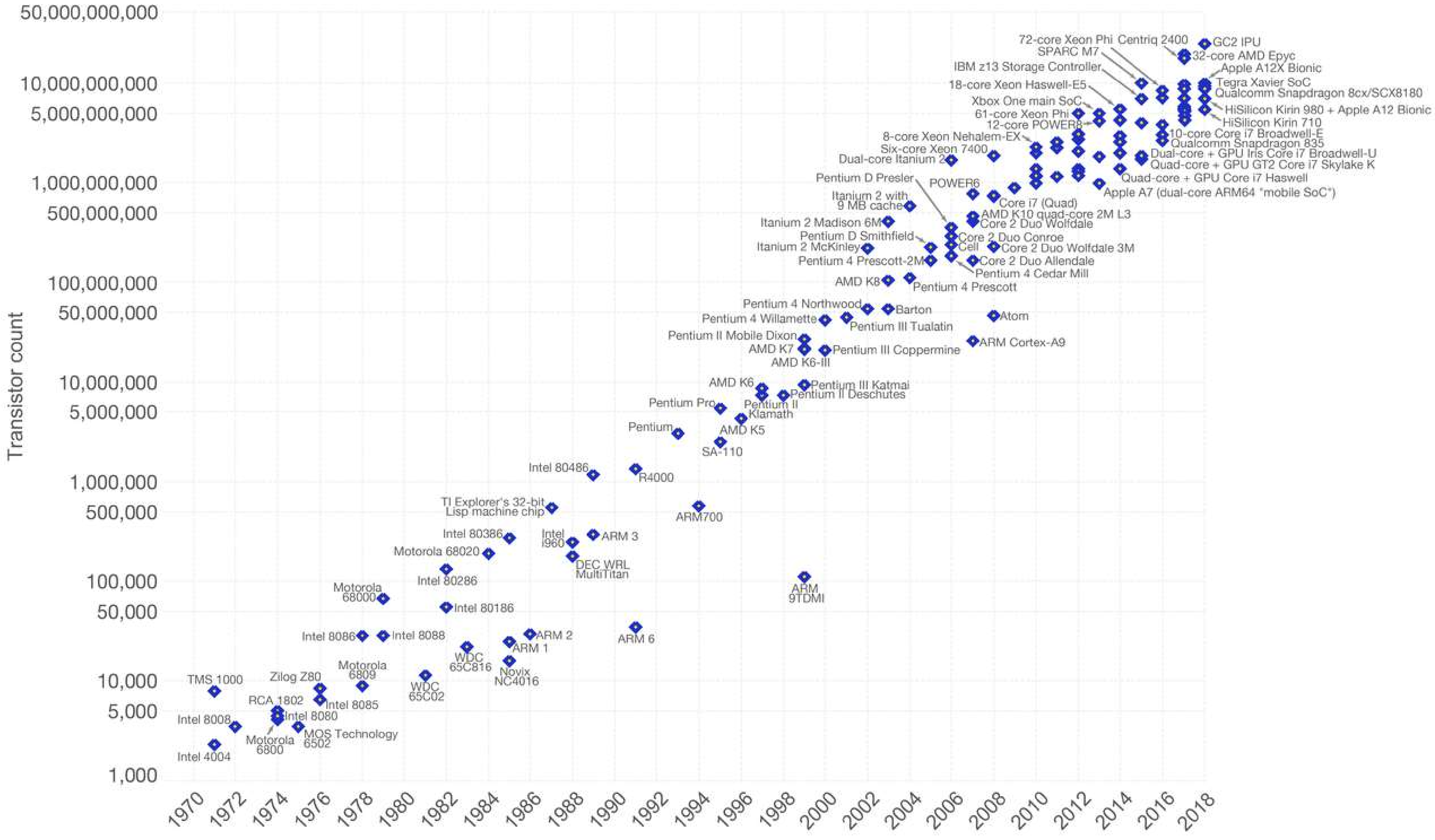
- Later it was shown that these exponential performance increases apply to a broad range of computer related technologies…

  - Many devices and sensors have since then been converted into digital devices, including microphones, cameras and accelerometers, subjecting many things to the benefits of Moore’s law.

Moore’s law

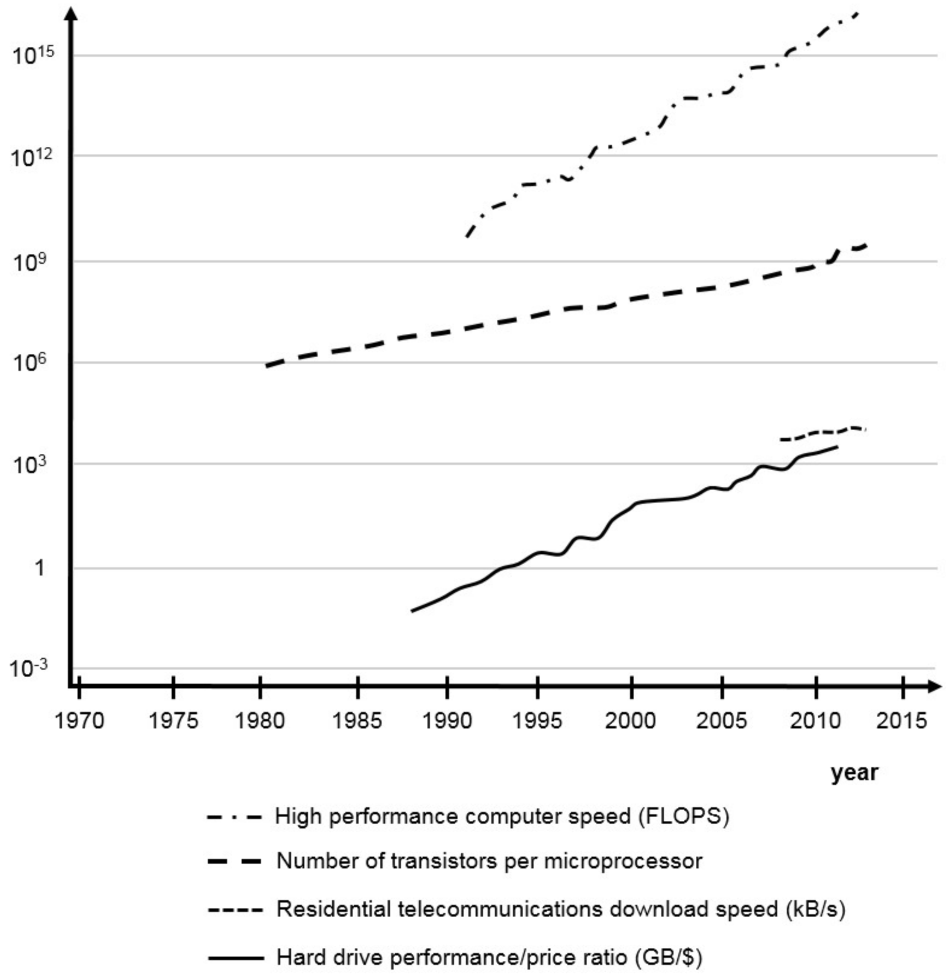
Moore’s Law – The number of transistors on integrated circuit chips (1971-2018)

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

Moore's law (cont'd)



- The ongoing availability of better and cheaper computer hardware led to a significant impact on the world.
- As part of this, it had a significant cultural effect…

→ Consider, for example, the emergence of social media.

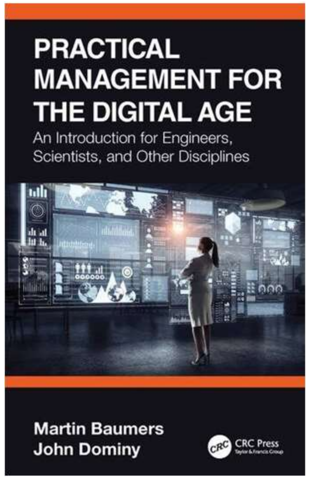
In the remainder of this lecture, we will discuss how digitalization impacts industry…

Brynjolfsson, E. and McAfee, A., 2014. The second machine age: Work, progress, and prosperity in a time of brilliant technologies. WW Norton & Company.

What we will talk about today:

The economics of digitalization and automation – Part 2

- *The economics of information goods*
- *Information economics at work: FMS and AI*



Lecture builds on Chapter 4 in Baumers and Dominy (2021)

The business world realises the implications of Moore's law

Developments in computer hardware suggested that the MC of additional logical elements, and with it the cost of computing, would drop to almost zero.

- As in the industrial revolution, it took time for business and management theorists to understand the consequences…

- In the 1990s this led to the emergence of a group of theories aiming to explain the economic and industrial impact of computers:

    - Based on the concept of "information goods".

    - Also taking into account the effect of computer networks.

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The peculiar economics of information goods

Information goods can be defined as goods that are made of bits rather than physical materials.

- Anything that can be encoded (digitized) as a stream of bits can be an information good.
- Some important aspects of information goods:

    1. The value of information goods varies and depends on the user.
    2. People are normally willing to pay for them.
    3. Information goods are expensive to produce but extremely cheap to reproduce (high fixed cost, very low variable/marginal cost) and are still getting cheaper (because of Moore’s law).
    4. The can be reproduced perfectly, there is no loss in quality from copying.

Consequences for businesses

Economics (remember Year 2!) says you shouldn't normally price based on a cost mark-up. This is especially true for information goods because of the extremely low MC.

- Rather, information goods should be priced according to customer valuation
    - This implies a strategy of differential pricing, charging different customers different prices.
    - The goal of this is to capture all the “consumer surplus” in a market.
- Recall the “comparative statics” from Year 2 with (inverse) demand and supply curves…

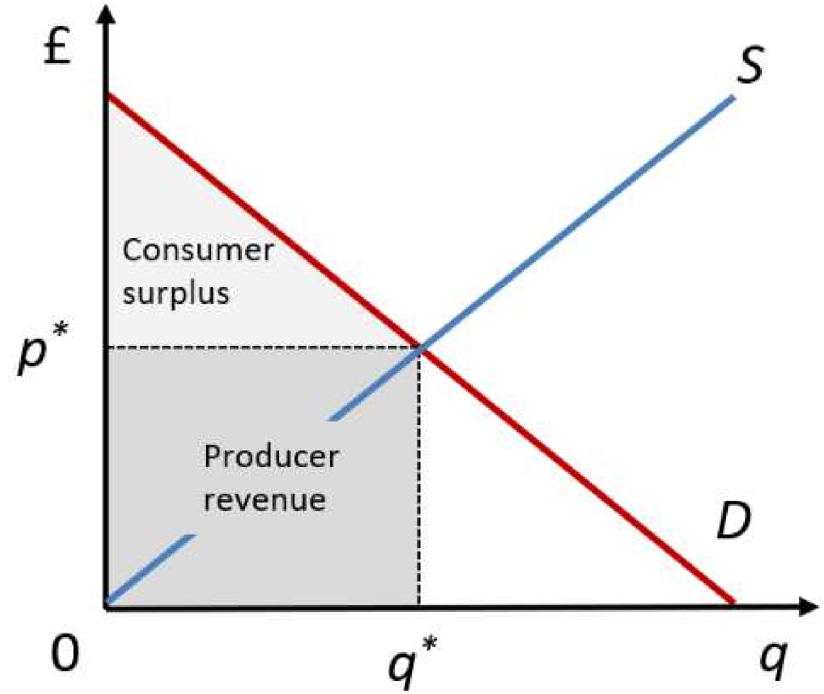
Markets for information goods

Markets for information goods can be analysed using **comparative statics** just like any other market:

- Downward sloping (inverse) demand function *D*

- Upward sloping (inverse) supply function *S*

- Equilibrium price p^* and equilibrium quantity q^*



Normally, it's not possible to charge different prices to different customers ("law of one price") → Customers get the "consumer surplus" and suppliers get the revenue → But this is different in markets for information goods

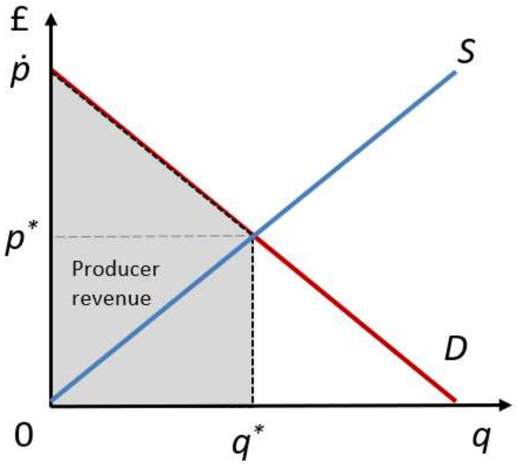
Trying to capture the consumer surplus

In markets for information goods, suppliers will always want to charge prices based on customers' individual valuation of the product.

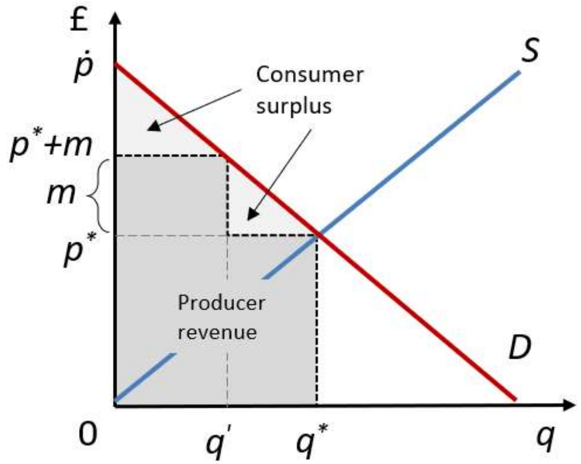
- This strategy can be successful with fully individual pricing (a), partially successful with a two-tier pricing scheme (b), or unsuccessful with only the equilibrium price (c)

Again, using supply and demand curves:

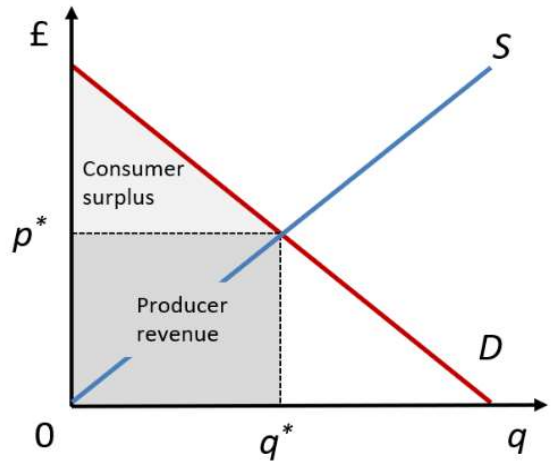
a)



b)



c)



Complementary goods

A further concept that is needed to understand the economics of information technology, and the sweeping effects of computers in the world of business, is the concept of a “complement”. Complements can be defined as follows:

“If good A is a complement to good B, an increase in the price of A will result in a movement along the demand curve of A but it will also shift the demand curve of good B inwards, so that less of both goods is demanded.”

- Recall from the economics lecture that the gradient of the demand function is related to the concept of own-price elasticity of demand.

- Cross-price elasticity of demand *XED* extends this relationship across two goods, such that it is defined as the percentage change of the quantity q_A demanded of good A over the percentage change of price p_B of good B:

$$XED = \frac{\Delta q_A / q_A}{\Delta p_B / p_B}$$

Complementary goods, an example

A good example for complements is hamburgers and buns. Here, an increase in the price of one good (hamburgers) will lead to a decrease in demand for the complement (buns) by shifting its demand curve, and vice versa.

&

- This means the *XED* between hamburgers and buns will be negative and the stronger this relationship, the lower the value of *XED*.

Why is this important for information goods

We've seen that it isn't advisable to price information goods based on the cost of production, due to the extremely low marginal cost of reproducing information goods – which is essentially the cost of making one additional digital copy.

- It is quite common to provide information goods free of charge, at least in their most basic version.
- This creates a very interesting relationship between complements. Consider, for example:

A free app

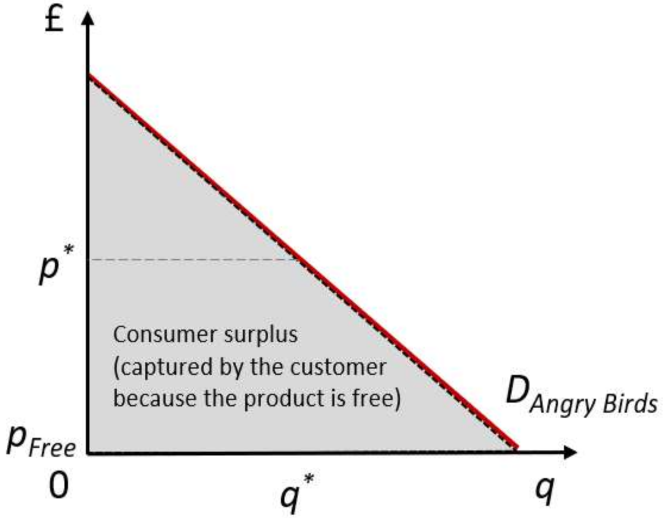
&

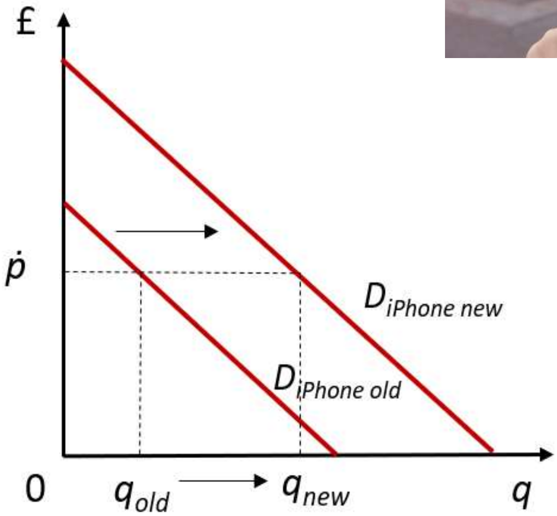
An iPhone

Again, using comparative statics

The below figure illustrates the situation arising when the developer of Angry Birds made this game available for free (p_{Free}=0) instead of charging a price $p*$.

- Note how the price for the iPhone does not change, yet demand for it increases because it is a complementary good.





Industrial impact

The “platform” as a concept

The Angry Birds/iPhone example relies on the (mobile) internet as the key technology for the reliable and cheap transmission of information.

- Note that most consumer internet subscriptions now feature a flat pricing structure such that there is a fixed monthly cost.
- This is a further example of almost zero MC occurring in information technology.

The ability to process and transmit information goods has let to new business thinking in the form of the “platform” model.

- *In this usage, “platform” denotes markets which involve a type of technology known as a “mediating technology”, normally in the form of digital information services that make possible an exchange between different groups of participants that could not interact otherwise.*

Importance of platforms

The success of platforms is evidenced by the fact that the five businesses with the highest market valuation now all rely on platform approaches.

- Current market capitalisation (the value of the businesses as measured by the total value of shares) is at an unprecedented $3.25 trillion (as of 2018)

Alphabet

NETFLIX

Microsoft

… the platform concept can be difficult to understand so this will be treated in detail in the lecture on business models!

Information technology in the manufacturing industry

As an important manufacturing technology to emerge from computerisation in the 1960s, Flexible Manufacturing System (FMS) constitute manufacturing systems which have some degree of flexibility allowing the manufacturing to react when planned or unplanned changes occur.

- Most FMS implementations have three main systems:
  - Machines performing work (normally CNC machining centres)
  - A flexible digital material handling system
  - A computer system for control

What is the effect of FMS adoption?

FMS have been shown to improve manufacturing efficiency and thus lower a company's production cost.

- Can enable new order fulfilment and design approaches such as make-to-order strategies.
- Have given rise to the concept of “economies of scope” which is a new kind of economies of scale.
  - Economies of scope arise when the joint production of multiple products or product variants is lower than the cost of producing each output separately.

Over time, FMS have led to new business thinking and the formation of large companies active in seemingly unrelated lines of business. This kind of company is known as a “conglomerate”.

… more on this in the lecture on business models!

Artificial Intelligence

Computers and information technology are extremely well suited for the execution of precise, step-by-step instructions for accomplishing tasks, also known as algorithms.

- It has been a long standing goal to create information systems that can go beyond this.

- The dream is to have computers that are capable of accomplishing acts of reasoning and intelligence that are similar to those performed by humans.

This is the ambition of a field called Artificial Intelligence, which can be defined as the science and engineering of making “intelligent” machines.

- Of course this definition is recursive because it does not say what “intelligence” actually is.

Anthropomorphization

Computers, however complicated, are lifeless objects, so strictly speaking they do not learn, decide, recognise or like anything.

- The problem that humans tend to ascribe their own characteristics to things, perhaps including animals, is called “anthropomorphization”.

The two branches of AI

"Symbolic" AI

- Views intelligence as expressed in words, rules, numbers and other symbols that humans can understand and manipulate.

- Now considered a failure, for two reasons:

    1. The world is simply to complex and has too many rules.

    2. The structure of human reasoning is not understood.

"The statistical approach"

- Employs statistics to recognise patterns, using experience, repetition and feedback.

- Also known as "machine learning".

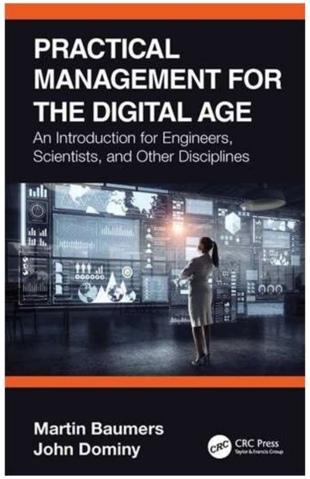
- Benefits from lots of data ("Big Data") and cheap computing power (Moore's law!)

- **This type of AI is expected to have a huge impact in business over the coming years.**

What we will talk about today:

The economics of digitalization and automation

- *Automation as a social challenge*
- *Lecture conclusion*



Lecture builds on Chapter 4 in Baumers and Dominy (2021)

Is there a problem with all of this?

Automation as a societal challenge

It has long been feared that technological progress in the form of automation will leave people behind.

- There are a number of problems associated with the use of computers and the business models of internet-based businesses.
  - Spying and breach of privacy
  - Data ownership
  - Political manipulation
  - Bullying
  - Etc.

- We will concentrate more generally on the direct effect of automation on labour conditions, jobs and equality.

Something from Nottingham: the Luddites

- The Luddites were a radical group that took to destroying textile machinery as a form of protest against the use of machinery.
- This movement began in Nottingham and culminated in a regional rebellion lasting from 1811 to 1816.
- The movement was ended by force but the term “Luddite” has remained to mean someone who is opposed to industrialisation and new technology.

An apparent end of problems…

According to some 20th century economists' thinking, income inequality would automatically decrease in advanced phases of economic development, irrespective of political choices and other differences in countries and reach an acceptable level.

- This is often summarised metaphorically by saying that "economic growth is a rising tide that lifts all boats".
- This seems to have been the case in the decades following the Second World War, which was a period in which inequality in the West significantly fell.
- More recent developments (especially since the 2000s) indicate that inequality is increasing again and the median real income in developed countries is actually falling.

Falling wages and unemployment as an effect of IT

Current evidence is pointing to a situation in which the overall economy is growing strongly but a large number of people is made worse off by the advance in technology.

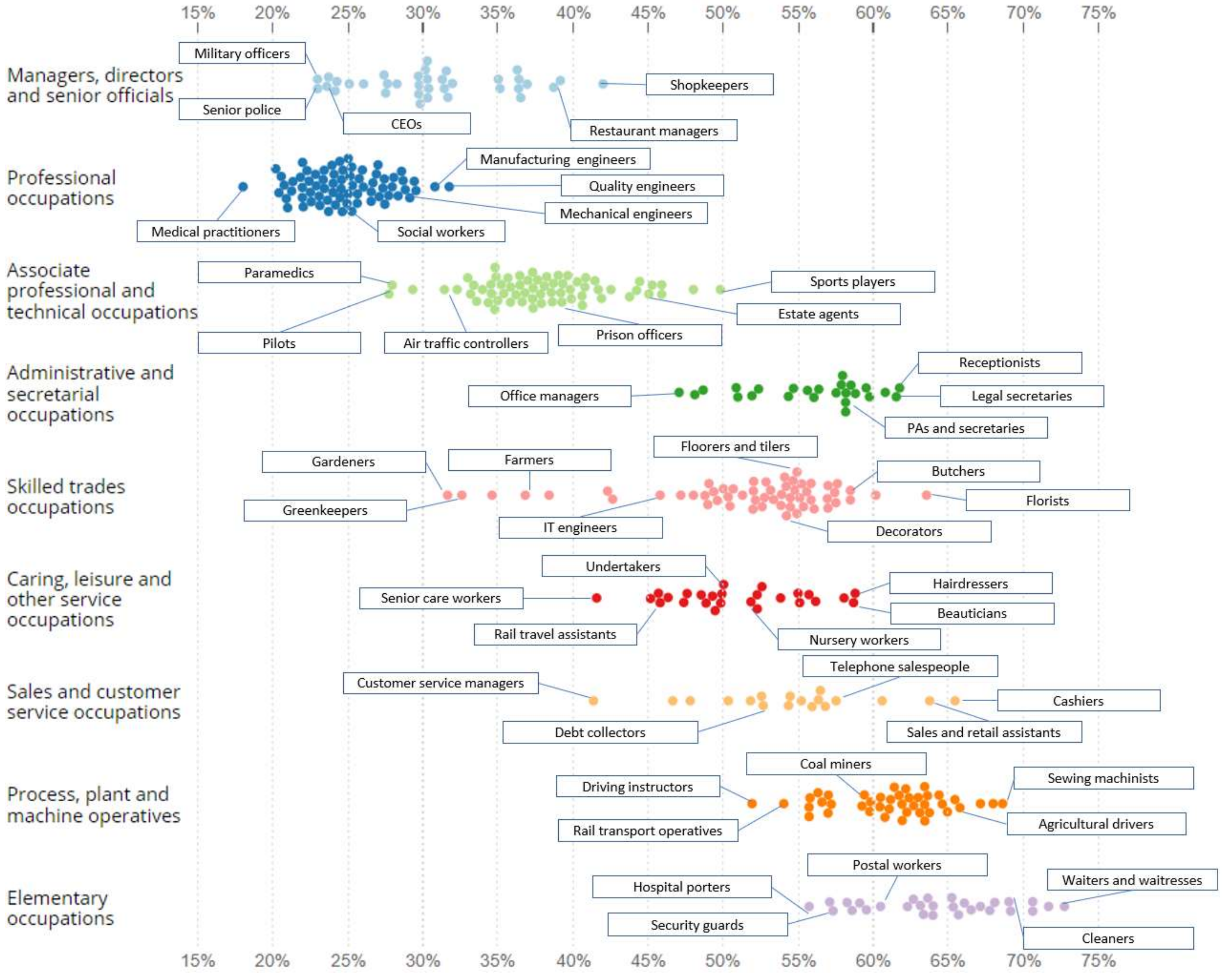
- This is because, just as in the past, automation, now in the guise of digitalization, is seen to reduce the demand for labour which results in falling wages and increasing unemployment.

- However, new technologies undoubtedly also create new jobs.

- The burden of these problems is likely to be spread unequally across different people, professions and also countries.

Which jobs are in danger of being "automated away"?

Recent data from ONS, risk of losing job due to automation:



Which jobs will be safe from this?

As a general characteristic, the creation of ideas and innovation is a task that information technology is not suited for.

- Despite improvements in AI it is likely that human input will be valuable in the future.
- Partnership – or "complementarity" – with digital systems will be the decisive characteristic for individual workers.
- "You'll be paid in the future based on how well you work with robots"

Lecture summary:

- *Now know about background of IT*
- *Can characterise Moore's law and its importance*
- *Understand the economics of information goods*
- *Information economics at work: FMS and AI*
- *Seen that automation generally poses a social challenge*

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Thank you!