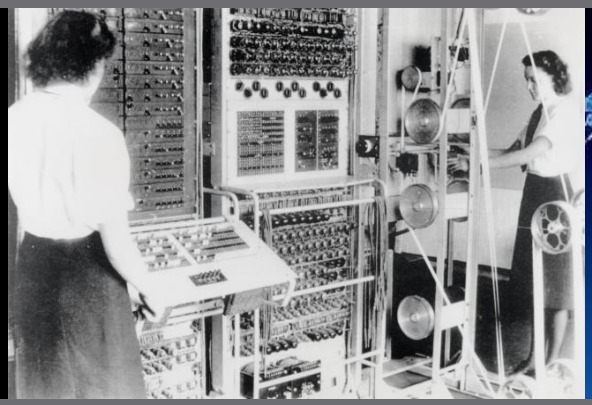
Department of Meteorology

University of Reading

Mike Lockwood

From William Gilbert to Tim Berners-Lee: the 400-year history of the men and women who made the internet possible

20th September, 2023

Harwell Parish History Group

A History of the Volume Science Research

Bornmann,L. and R.Mutz (2015) "Growth rates of modern science: A bibliometric analysis based on the number of publications and cited references", J. Assoc. Inf. Sci. Tech. 66 (11), 2215–2222. DOI: 10.1002/asi.23329

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science citations p.a. (log scale) →

10^{18}

10^{16}

10^{14}

10^{12}

10^{10}

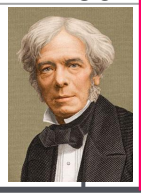
10^{8}

# of science facts worth citing in 2000 was **0.5 million times larger** than the value in Einstein's miracle year, 1905

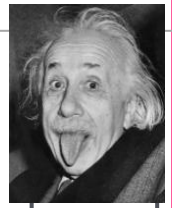
Rise between Faraday and Einstein's miracle year by a factor **150**

1600

1831



1905



2000

1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050

Δt = interval between "paradigm shifts"

(= "game changers")

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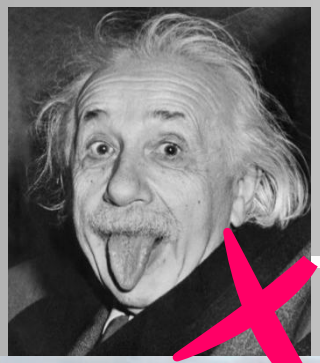
technological capability index, $1/\Delta t$ (yrs^{-1}) →

0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0,11 0.12 0.13

1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050

?

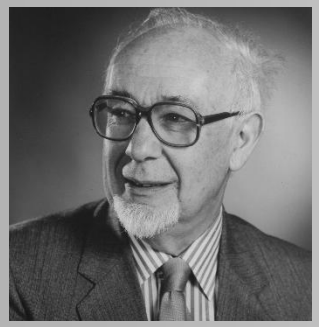
3-D silicon chip
ML / AI
Stem cells
i-Pad
Facebook
Fly-by-wire
Google
Hybrid car
Plasma and Touch Screens
DVDs
Facial and Speech Recognition
Mobile phones
World-wide web
Microsoft windows
Apple -Mac
MS-DOS
Eradication of Smallpox
Microprocessor
MRI scanner
Digital Camera
Computer Mouse
747 Jumbo Jet
Video player
Heart transplants
Microwave Oven
Man on the Moon
Transistor
(Solid State Technology)
Contraceptive Pill
Steroid drugs
Jet Engine
Antibiotics
TV
Colossus: Programmable Digital Electronic Computer
Powered Flight
Chemotherapy
Car
Pasteurization
Telephone
Light bulb
Human (Balloon) Flight, Telegraph
Steam engine
Marc Brunel's Mass Production Machines
Telescope
Printing Press



Science Consensus

sʌɪəns kən ˈsɛnsəs
(compound noun)

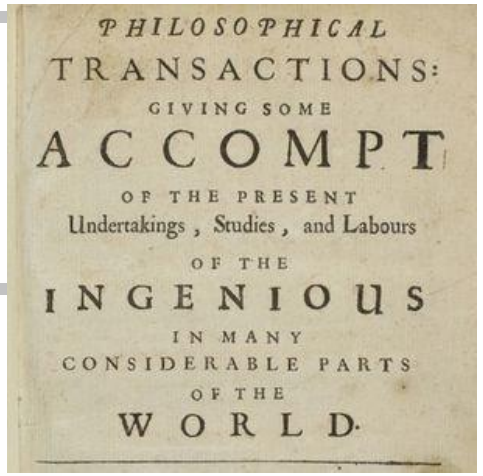
The solar science community at the STEREO-3/SOHO-22 Workshop, Bournemouth, UK April/May 2009



- John Michael Ziman (1925-2005): “The goal of science is a **consensus** of rational opinion.”

- Wikipedia: “the collective judgment, position, and opinion of the community of scientists in a particular field of study. Consensus implies general agreement, though not necessarily unanimity”

How we arrive at a scientific consensus: peer review


PHILOSOPHICAL
TRANSACTIONS:
GIVING SOME
ACCOMPT
OF THE PRESENT
Undertakings, Studies, and Labours
OF THE
INGENIOUS
IN MANY
CONSIDERABLE PARTS
OF THE
WORLD.

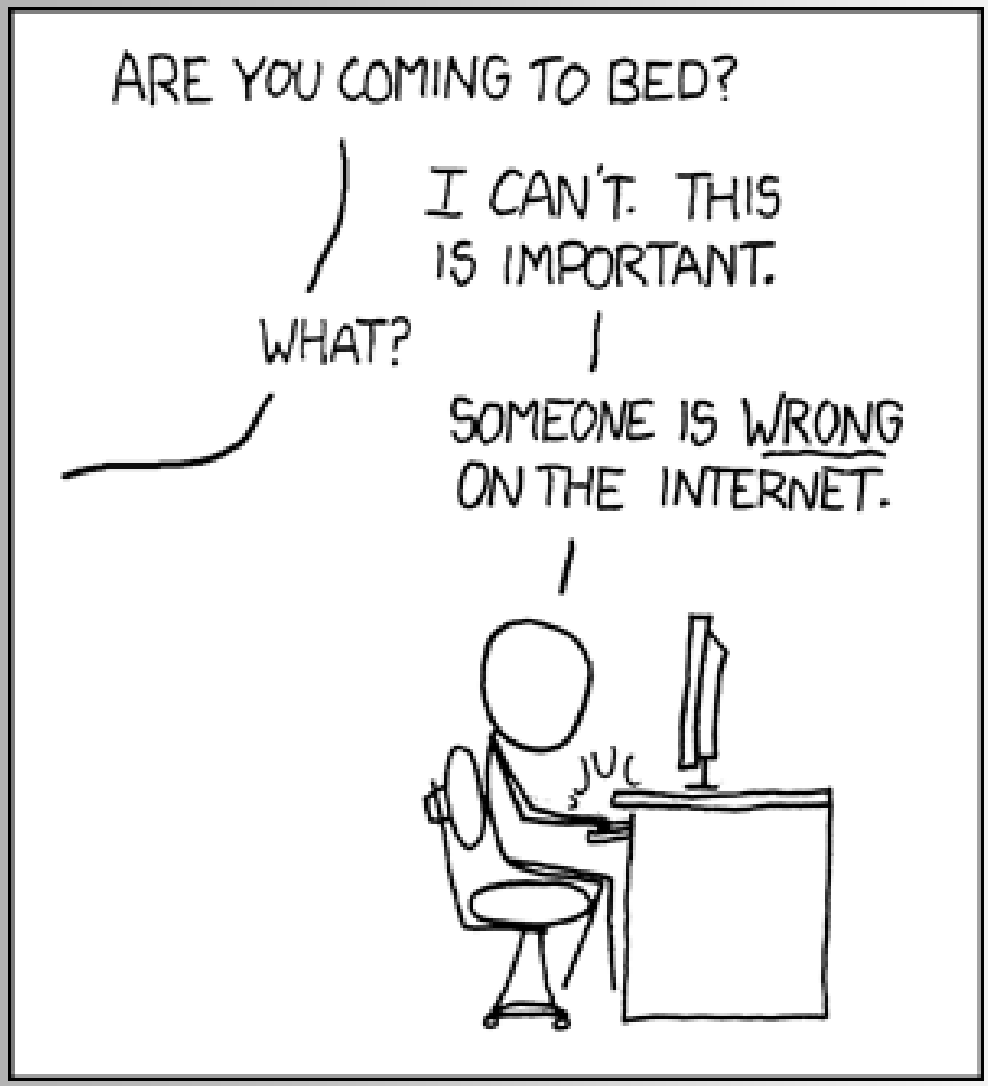
- Peer review is Britain's single greatest contribution to science - bar none!

- first introduced in 1665 by German immigrant, Henry (formerly Heinrich) Oldenburg, founding Editor of the world's oldest scientific journal: *Philosophical Transactions of the Royal Society*

- formal peer-review procedures as we know them today, developed from his ideas by Sir Francis Bacon & applied to *Medical Essays and Observations* published by the Royal Society of Edinburgh in 1731.

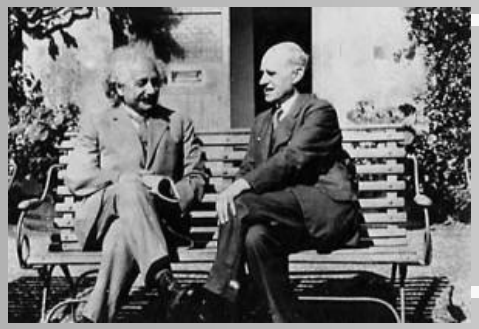
- It is how science expunges "fake news"

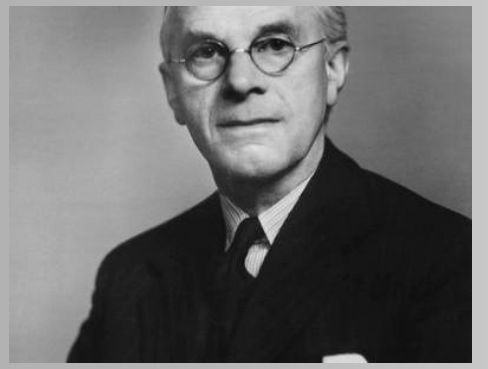
Peer review avoids the information “wild west” we now have on the internet



- As famously observed by xkcd (Randall Munroe)

“Duty Calls”
1st December 2011

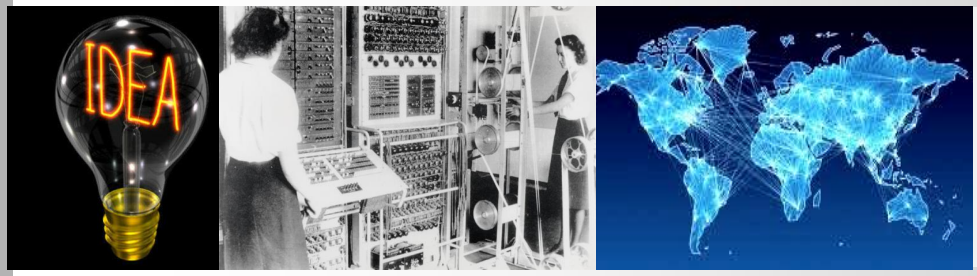




Scientific Consensus at work: Einstein's relativity & GPS

- Scientific objections started to fall away after Eddington's 1919 eclipse observations, consistent with general relativity (GR).
- Denounced as "*Jüdische Physik*" by e.g.1921 Berlin Philharmonic Hall event & by newspapers
- Herbert Dingle (spectroscopist). From 1939 Nature letter to his death in 1978, he tried to publish articles about why Einstein's special relativity (SR) was wrong. His 1972 book talked of a conspiracy by the "physics establishment". Still widely cited – but only on the internet
- Sat-Nav: GPS (designed 1972, first launch 1978) use corrections for both SR and GR on its satellite clocks. 1ns timing error → 30cm position error, Without SR and GR error grows at 2km and 13 km per day, respectively!

Scientific consensus really matters.



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Need

William Gilbert (1544?-1603)

Doctor to Queen Elizabeth I and James I

In 1600 published a book “De Magnete (On Loadstone, Magnetic Bodies, and on the Great Magnet of the Earth)” and postumously “De Mundo (New Philosophy about our Sublunary World)”

Considered by many to be the first modern scientist who greatly influenced many others including Johannes Kepler and Galileo Galilei

Called the spark generated by rubbing a rod of amber with a cloth “electricus” (from latin meaning “like amber”, giving us what we would now call (static) electricity

The word "electricity" was first used in 1646 by the English polymath Sir Thomas Browne

‘Tymperleys’, Gilbert’s home in Colchester, Essex – built in1490 and now a tea room

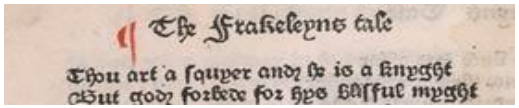
technological capability index, $1/\Delta t$ (yrs^{-1}) →

0.13
0.12
0,11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

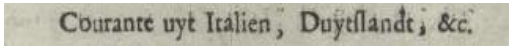
Δt = interval between "paradigm shifts"
(= "game changers")

- Johannes Gutenberg (Mainz, 1436).
- First Book: the Bible

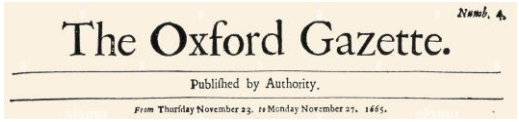
** William Caxton (Westminster, 1476)
. First Book: Chaucer's Canterbury Tales



*** Current Events from Italy, Germany, etc.
(Amsterdam, the Netherlands, 1616)



**** The Oxford Gazette (Oxford, 1665)
– renamed the London Gazette in 1666
and still printed today



1600: The concept of
electric charge

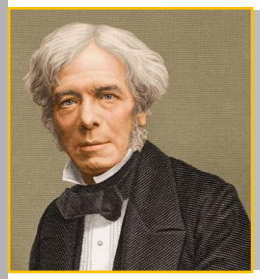
The printing press*

First printing in England **

First broadsheet newspaper***

First British newspaper****

1400 1500 1600 1700 1800 1900 2000



Power supply

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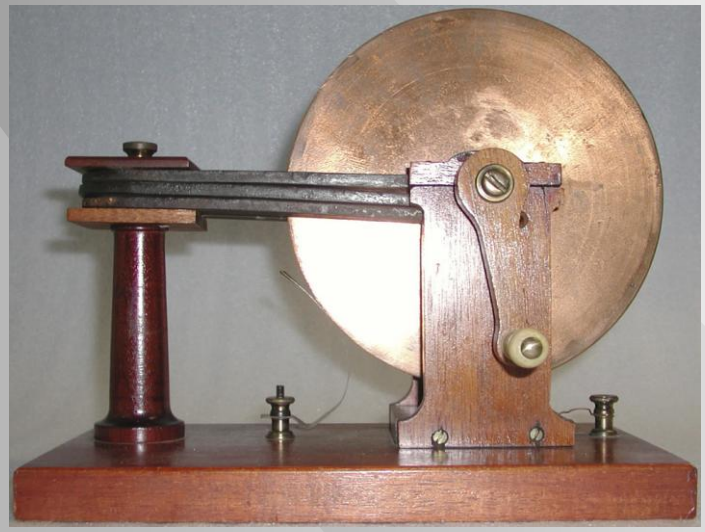
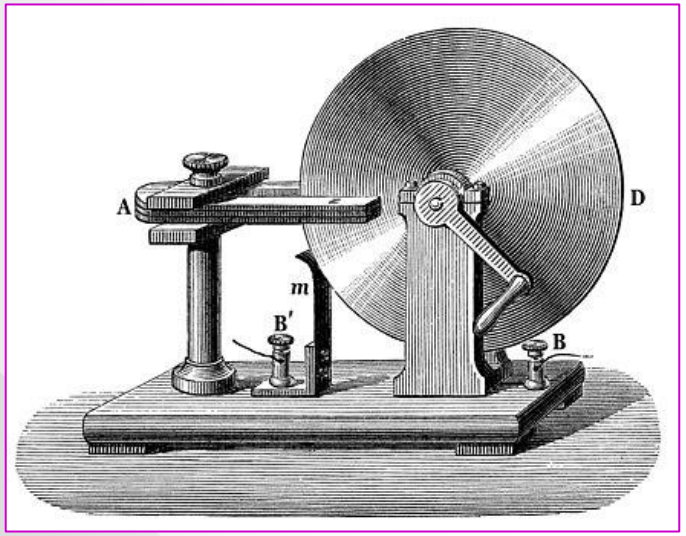
- 1820: Hans Christian Ørsted shows an electric current generates a magnetic field
- 1831: Electric dynamo invented by Michael Faraday ("homopolar generator") - Converts mechanical motion into electricity (AC or DC)

Model of Michael Faraday's dynamo



Drawing of a copy by Léon Foucault



D. Rotating copper disk. **A**. Horseshoe shaped magnet. **m** sliding contact touching the edge of the disk **B** and **B'**. Connector binding posts - **B'** connects to **m** and B connects to the disc axle.

Faraday on the money

A. "One day, sir, you will tax it."

Michael Faraday

in reply to chancellor William Gladstone when asked what use was electricity

B. "What use is a new born baby?"

Michael Faraday

in reply to an unknown individual when asked what use was electricity

*Sadly both suffer from the Twain/Churchill/Orwell phenomenon of apocryphal or wrongly attributed quotes. There is no evidence that he ever said **A** (although he expressed similar sentiments in a less pithy way in his lectures). It first appears in the 1899 book by W.E.H. Lecky 'Democracy and Liberty' **B** comes from a lecture Faraday gave on the chemistry of chlorine in which he said "to those who are in the habit of saying to every new fact, 'What is its use?', Dr. Franklin says to such, 'What is the use of an infant?'."*

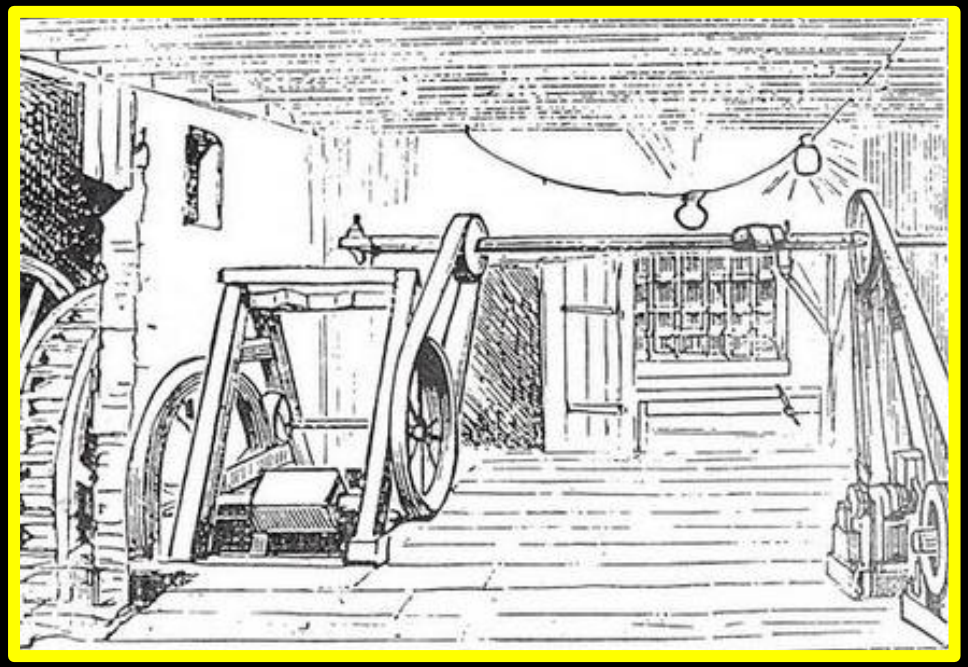
where was the world’s first public domestic power station?

GODALMING, SURREY

The world's first public power station and grid, supplying street lighting and homes.

Opened on 26th September 1881

Hydroelectric powered by the river Wey at Westbrook Mill



Δt = interval between “paradigm shifts”
(= “game changers”)

technological capability index, $1/\Delta t$ (yrs^{-1}) →

0.13
0.12
0,11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

1881: The first public and domestic electricity grid

Printing Press
Electric charge
Dynamo

1400
1500
1600
1700
1800
1900
2000

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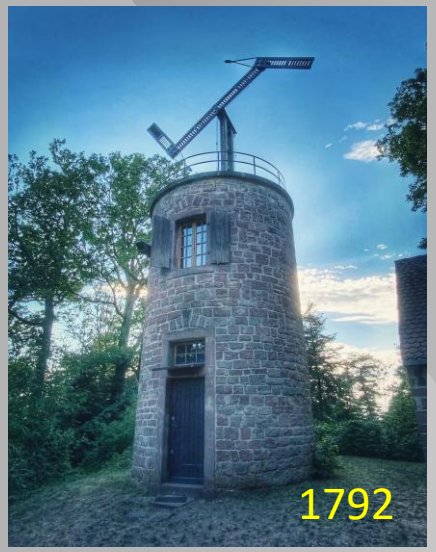
Telegraph Systems

- 1753 An anonymous writer in the Scots Magazine suggested an electric telegraph
- 1774 Georges-Louis Le Sage made a crude electric telegraph with one wire for each letter that went between two rooms in his house.
- 1792 Claude Chappe invented the optical (semaphore) telegraph system. French network of 556 stations covering over 3000 miles with relay towers 5–20 miles apart



- 1800 Alessandro Volta invented the voltaic pile (battery)
- 1825 William Sturgeon invented the electromagnet,
- 1836 Leonard Gale, working with Samuel Morse, invented repeaters

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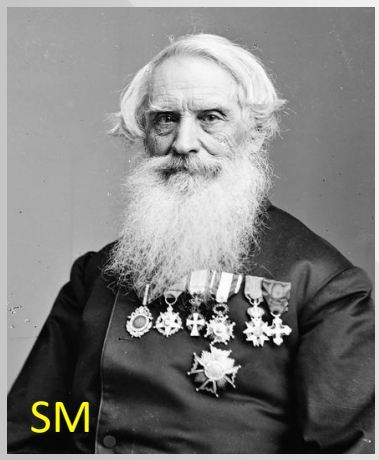
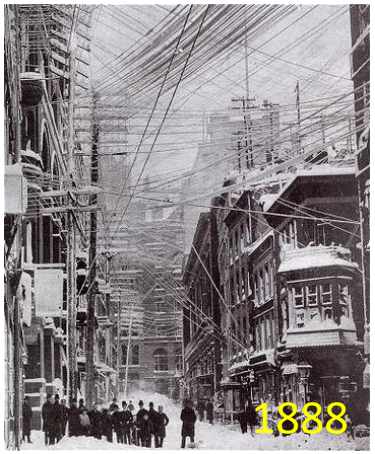
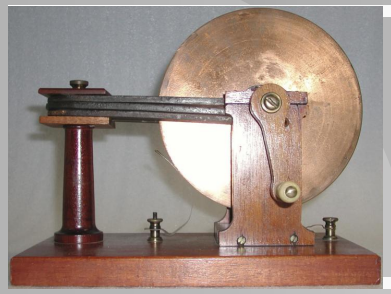
Telegraph Systems (cont.)

- 1832, Joseph Henry first demonstrates the theory of the telegraph
- 1832 Portrait painter, Samuel Morse patents a cheaper recording electric telegraph (and Morse code)
- 1832-1837, William Cooke and Charles Wheatstone developed a battery telegraph, installed by GWR (Paddington to West Drayton)
- 1843 Congress funds Morse's system, using Gale's repeaters, for Baltimore to Washington (38 miles) along the Baltimore & Ohio Railroad
- By 1850, 12,000 miles of telegraph cable established in USA
- 1875 Alexander Graham Bell invents and patents the telephone







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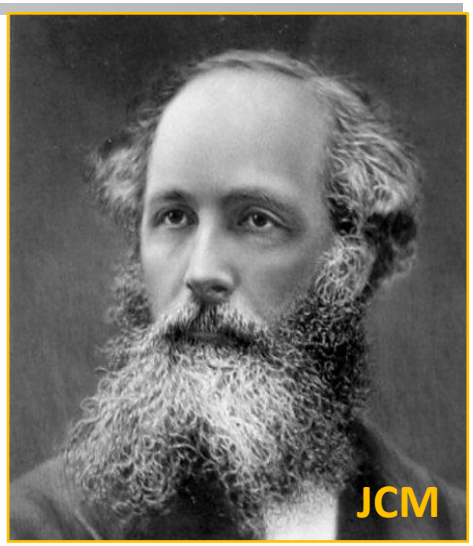
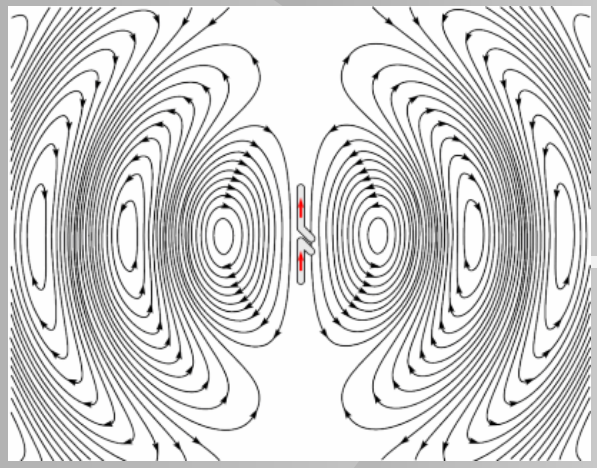
Electromagnetic Theory

- Going back to Faraday's dynamo …

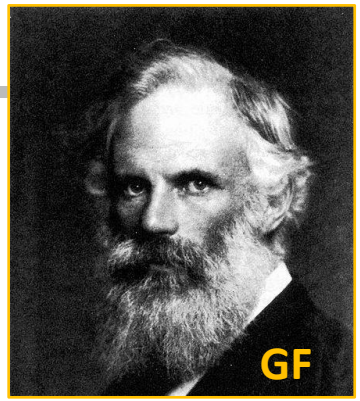
- The dynamo effect was described by Faraday's law – which we now regard as one of the 4 fundamental equations of electromagnetic theory that we call "Maxwell's equations"



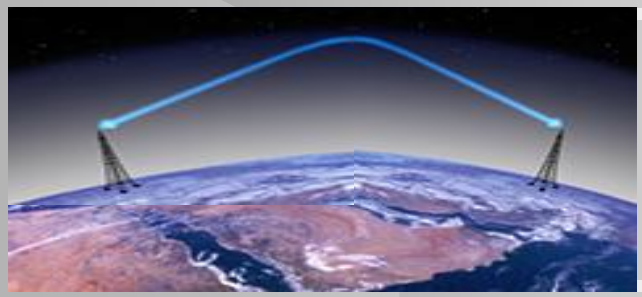
- In fact, **James Clerk Maxwell**'s classic theory of 1864 used 20 equations and is almost unrecognizable to academics today. The elegant 4-equation form that we now use was developed by **Oliver Heaviside** in unpublished notes and short articles written between 1891 and 1912 that were brought together into a single book in textbooks



Radiowaves



- 1864 predicted by Maxwell's theory
- 1883 George Fitzgerald proposed they could be made by oscillating currents
- 1883 observed by Heinrich Hertz
- Hertz was a student and friend of Hermann von Helmholtz who supported the rival idea of "action at a distance" and this made Hertz reluctant to advertise his own work, but Fitzgerald generously championed his work
- Fitzgerald should be more famous for many contributions to science – but his reputation suffered in later life as he became obsessed with unpowered human flight



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Wireless communication

- Pioneered by Guglielmo Marconi
- 1909 Nobel Prize in Physics with Karl Braun for the development of wireless telegraphy
- 1901 received a signal in St. John's, Newfoundland transmitted from Poldhu, Cornwall
- Marconi's experiment was based on an incorrect theory and the frequency used was too low (signals from Poldu may well have been picked up by one of the Marconi stations in Ireland and re-transmitted or maybe Poldu accidentally transmitted harmonics at a higher frequency). Marconi was incredibly lucky!
- 1920-1929 transatlantic "Radiotelegrams", bouced off the ionosphere, were received and forwarded to London for 11d (=£1.40 today) per word by the Marconi station on Morgan's Hill, Wilts. – now used for Police comms.

(photos of Morgan's Hill by Sonia Hill photography, Calne)

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0

1400
1500
1600
1700
1800
1900
2000

1901: International Radio Communication
1901: The concept of the quantum

Printing Press
Electric charge
Battery
Dynamo
Wire Telegraph network
Domestic power grid
International radio communications
Discovery of the electron

Quantum Mechanics

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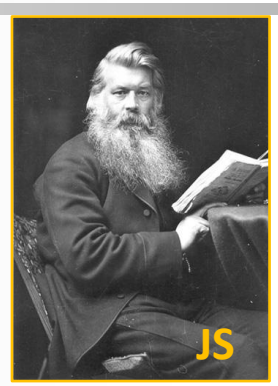
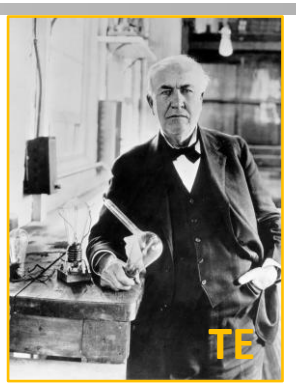
- the modern incandescent light bulb was arguably invented by Sunderland-born Joseph Swan and was developed by Thomas Edison. Both patented devices in 1880





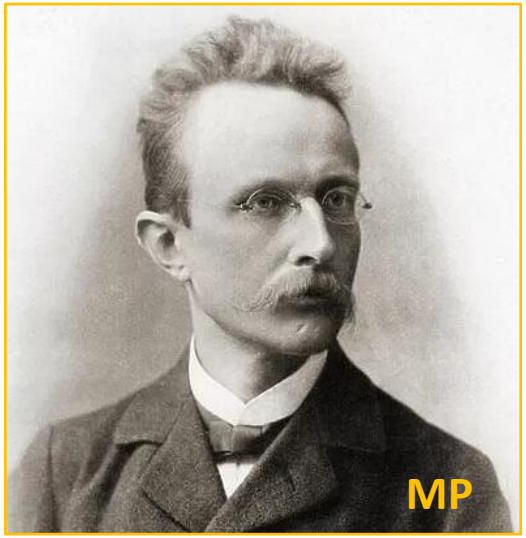
"I have not failed, not once.

I have discovered ten thousand ways that don't work"

Thomas Edison

- in 1901 Max Planck was trying to develop a longer-lived and more efficient light bulb by studying how materials emit light

- he stumbled upon a solution to a known paradox, that worked. He had no idea why it worked but, fortunately still recorded that it did



"Ultraviolet catastrophe"

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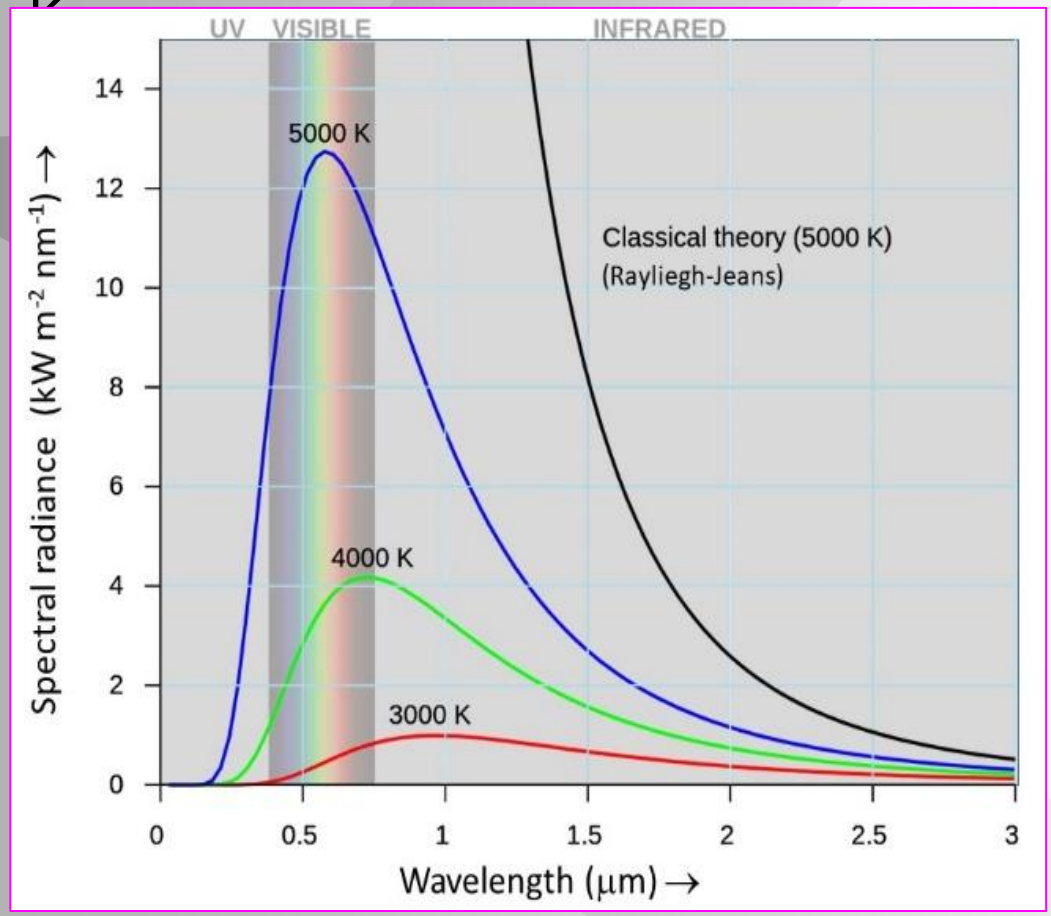
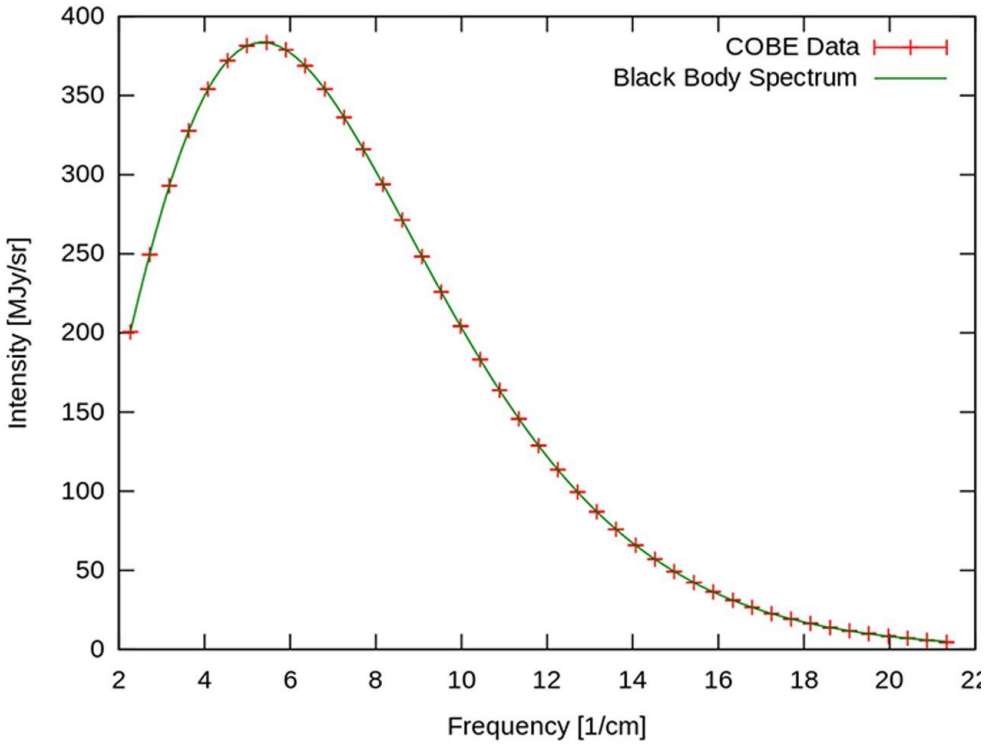
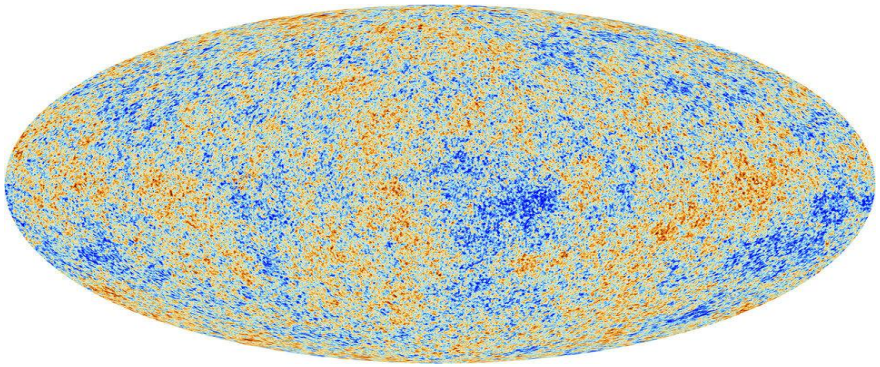
- classical thermodynamics and how things vibrate and omit gives the classical "Rayliegh-Jeans law" of the radiance (1900) – shown by the black line as a function of wavelength λ for a body of temperature 5000 K



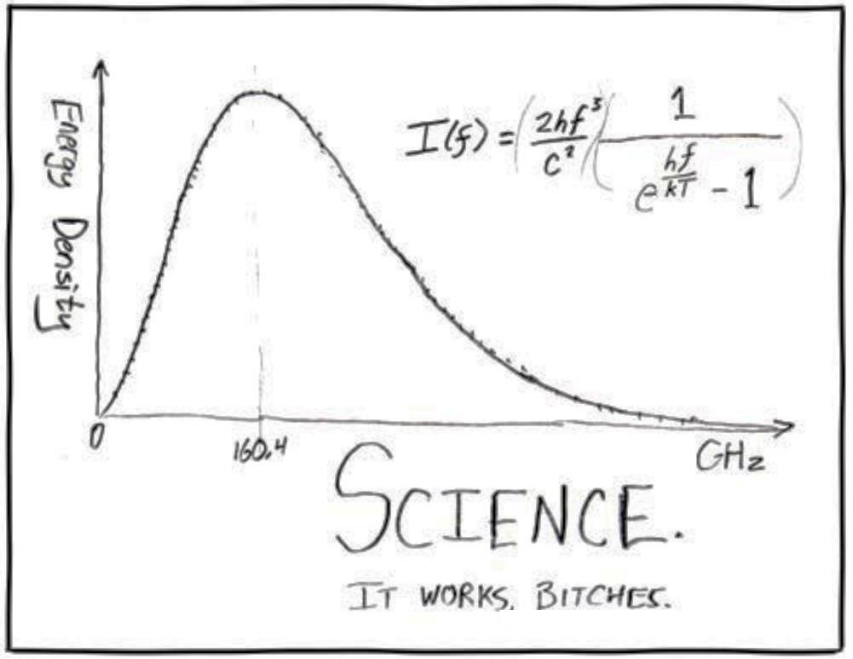
- the blue line is what is observed for an ideal heated emitter of the same temperature (called a blackbody emitter).
- the R-J equation over-estimates at all λ and goes towards infinity in the UV.
- Planck found he could solve this and match the observed spectrum if he assumed the light was given off in "packets" or quanta - we now call them photons

1992: Cosmic Wave Background Observations by the COBE Satellite & Planck's formula (Temperature 2.726 K ≈ -270°C)





Or, as noted by Randall Monroe (xkcd, # 54, January 2006) using gangsta language (quoted by Richard Dawkins in 2013 during a debate at Oxford University)



xkcd

A WEBCOMIC OF ROMANCE, SARCASM, MATH, AND LANGUAGE.

Quantum Mechanics

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- The idea of quantized photons was significant because physicists were realising that e-m waves had both wave and particle properties and that sub-atomic particles were the same and had both wave and particle properties.
- They developed "quantum mechanics" to describe how sub-atomic particles behave and how they interact with e-m waves
- Everyday experience and "common sense" from the macro-scale world have no relevance to this sub-atomic world.

Niels Bohr

Wolfgang Pauli

Albert Einstein

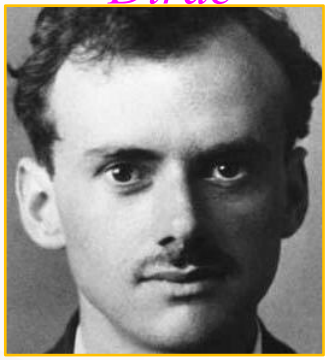
Werner Heisenberg

Max Born

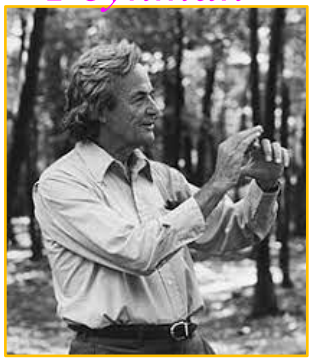
Erwin Schrödinger

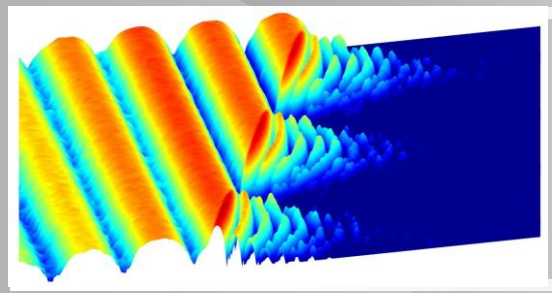
Louis de Broglie

Paul Dirac



Richard Feynman





Applications of Quantum mechanics

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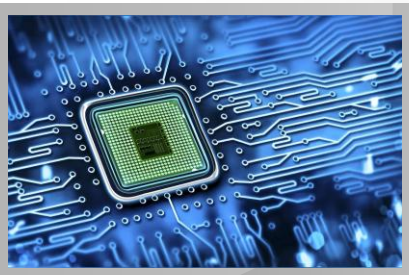
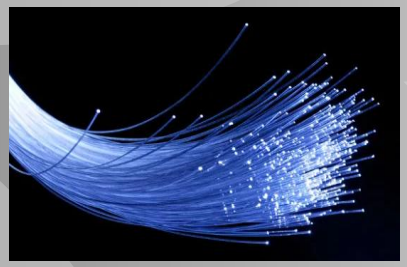


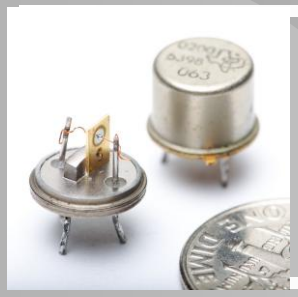
- Bizarre but common popular myth is that quantum mechanics has never had any applications



- without quantum mechanics there would mean no internet (and no mobile phones nor laptops to access it from)

- semiconductors are made by “doping” an (e.g.) silicon crystal with other atoms that can either donate or accept electrons making it conduct differently. To make them do what you want and design (and make) the chip you need to know how the electrons will behave when voltages are applied (in particular which of the silicon atom ‘bands’ they go into) which requires quantum mechanics

- & no optical fibres which use monochromatic light from lasers from a quantum mechanical process called “stimulated emission”



Solid–State Semiconductors *(*Nobel Prize Winner)*

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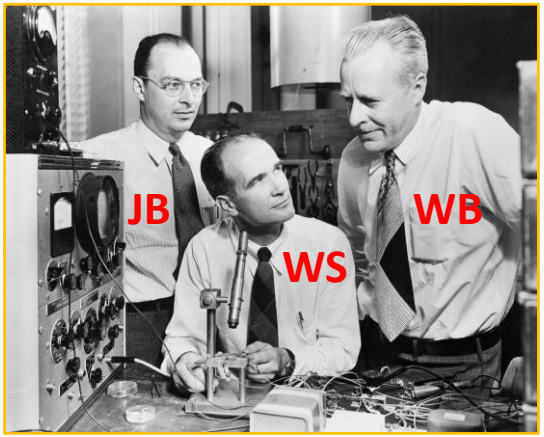
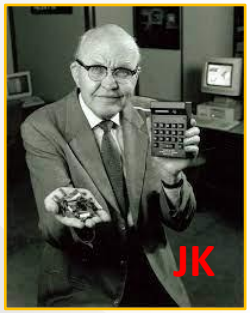
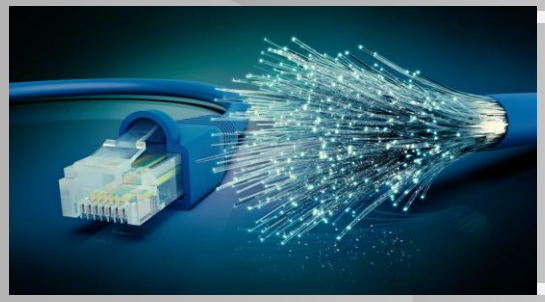
- 1930-1942: theory established by Rudolf Peierls, Ralph Kronig and William Penney, Alan Wilson, Werner Heisenberg*, Walter Schottky, Nevill Mott*, Boris Davydov, Hans Bethe*
- 1947: John Bardeen** and Walter Brattain* of Bell Telephone Laboratories invent the point contact transistor.
- 1948: William Shockley*, also of AT&T's Bell Labs invents the junction transistor
- 1957: the value of the semiconductor industry exceeds $100m p.a.
- 1959: Jack Kilby* (Texas Instruments) and Robert Noyce (Fairchild Semiconductors) invent the integrated circuit (IC)
- 1967: Texas Instruments use an IC to make a desktop calculator
- 2020: Integrated circuits reach 50 bn (5×10^{10}) transistors on a chip







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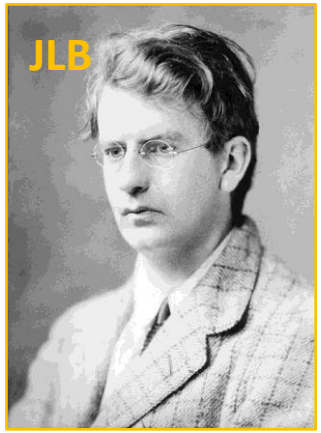
Optical fibre technology

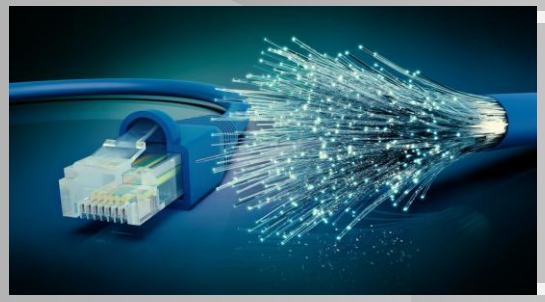
- 1880 English Civil Engineer William Henry Wheeler invented domestic lighting from a lamp in the basement carried into rooms by glass rods coated with reflective material

- 1888 Doctors in Vienna started using bent glass rods to illuminate body cavities



- 1902 Englishman John Logie Baird and American, Clarence W. Hansell (who held 300 patents, only Edison held more) patented transparent rods for transmitting television images

- 1916 Stimulated emission predicted by Albert Einstein*



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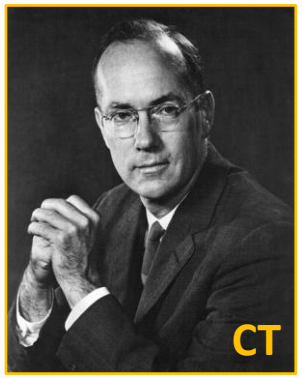
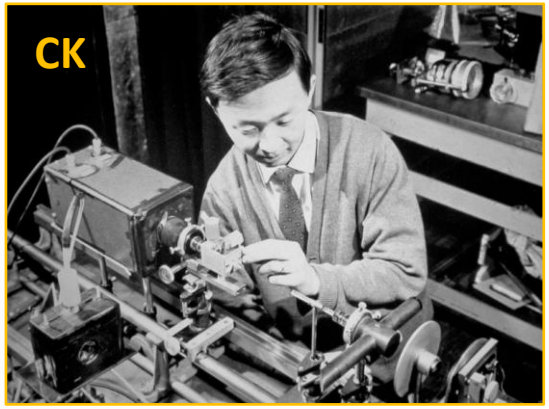
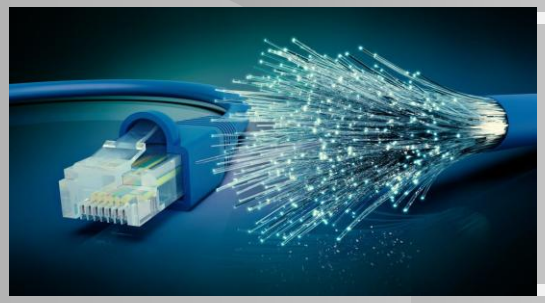
Optical fibre technology



- 1954 Charles Townes* and colleagues at Columbia University created the 'maser' or 'microwave amplification by stimulated emission of radiation.'
- 1958 Charles Townes* and Arthur Schawlow* introduced the laser
- 1961 Elias Snitzer of American Optical demonstrated fibres thin enough to carry monochromatic laser light but losses too great for communications
- 1964 Sir Charles Kao* and George Hockham, of STL in Harlow showed how loss of existing light could be radically decreased by removing impurities
- 1975 The first operational optical fibre link was installed by the Dorset police force
- 1977 The first telephone system using optical fibres opens in Long Beach, California





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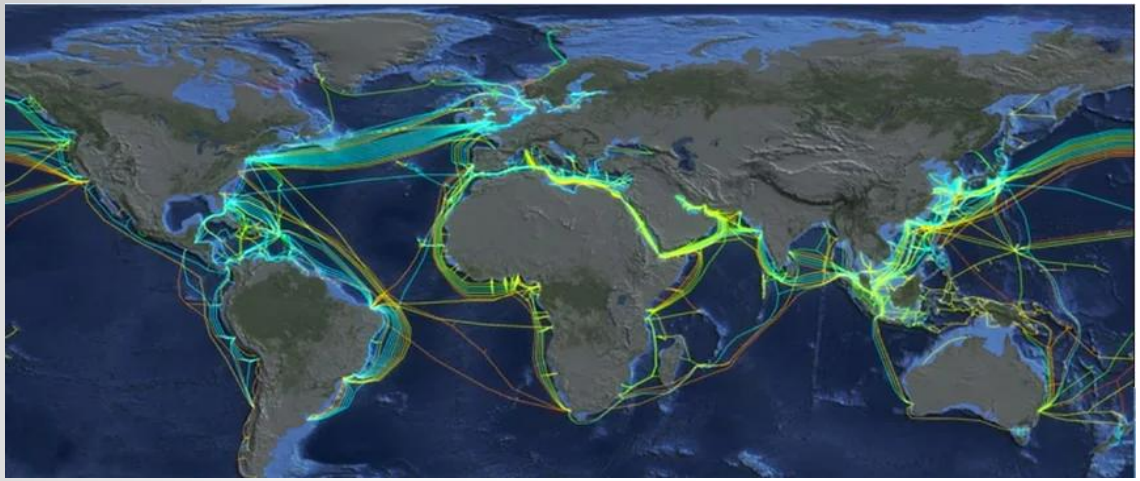
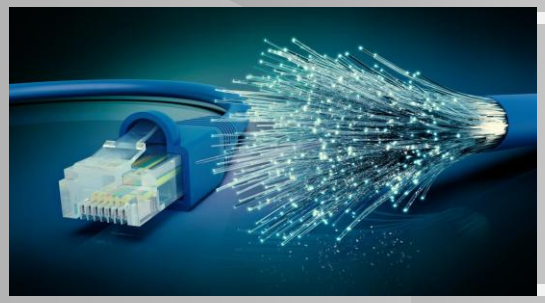
Optical fibre technology

- 98% of internet traffic in 2020 was by optical cable



- Repeaters on cables every 40-60 km. Initially they detected signal and then re-radiated them, but there were several problems – in particular they got too hot
- Modern repeaters just amplify the signal



Laying Intercontinental Cables

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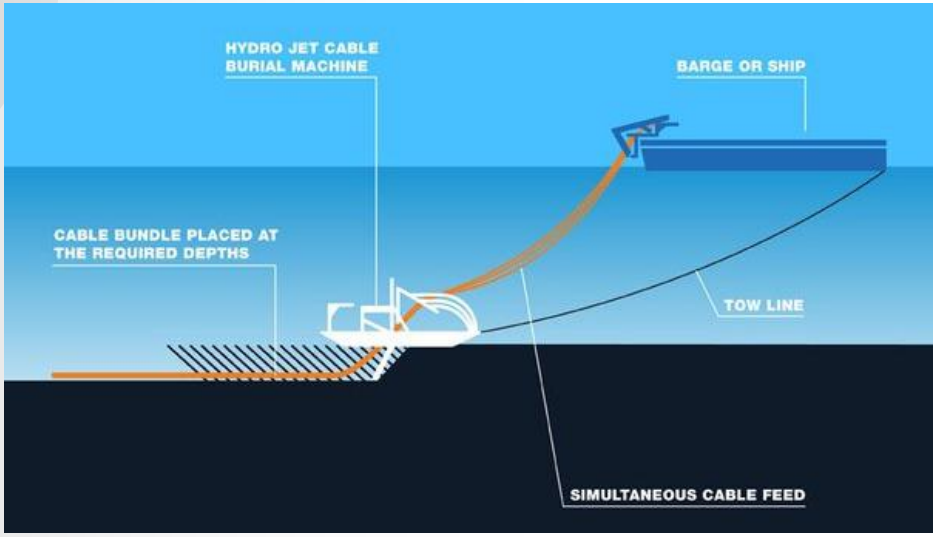

Satellite Communications

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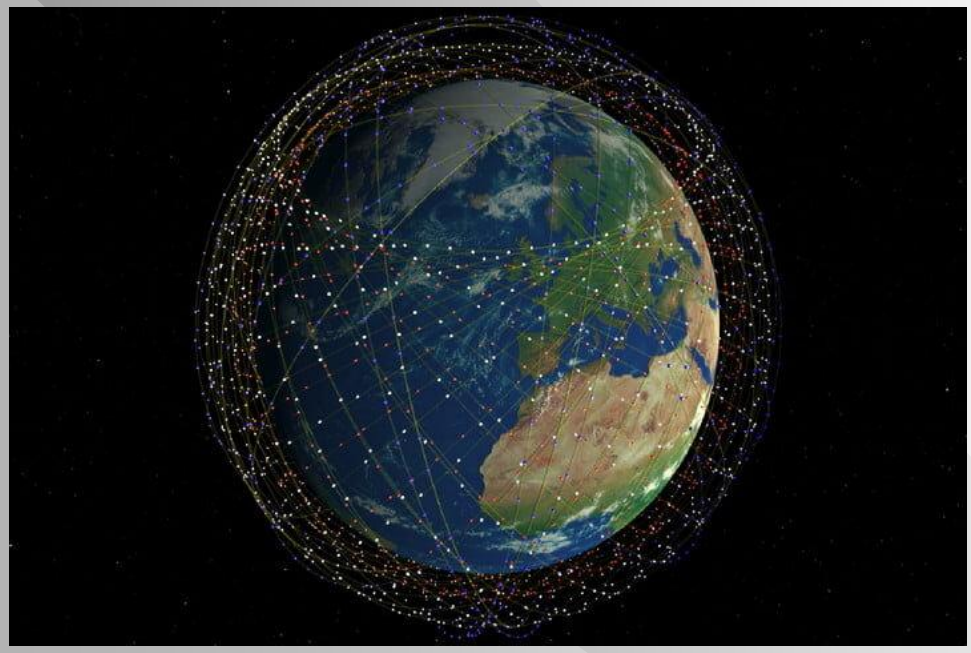
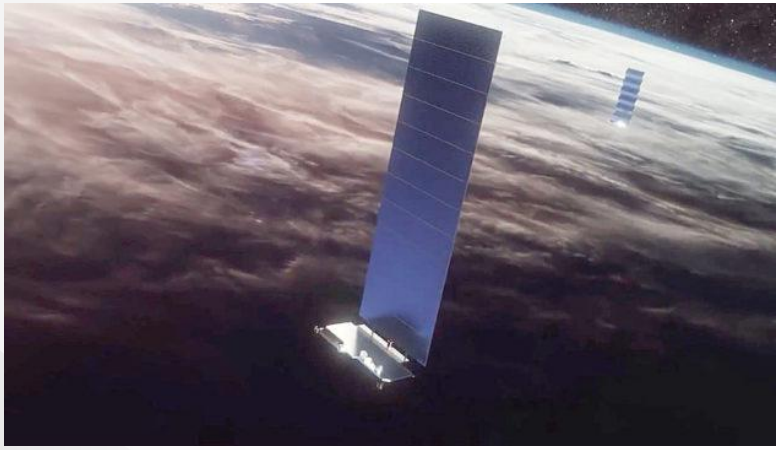
- At present only about 0.5% of internet traffic goes by satellite
- Space-X's Starlink satellites are bringing internet to uncabled areas
- First launch on May 2019
- As of August 2023, 5000 operating
- 12000 then 42000 planned
- 1.5m subscribers in August 2023





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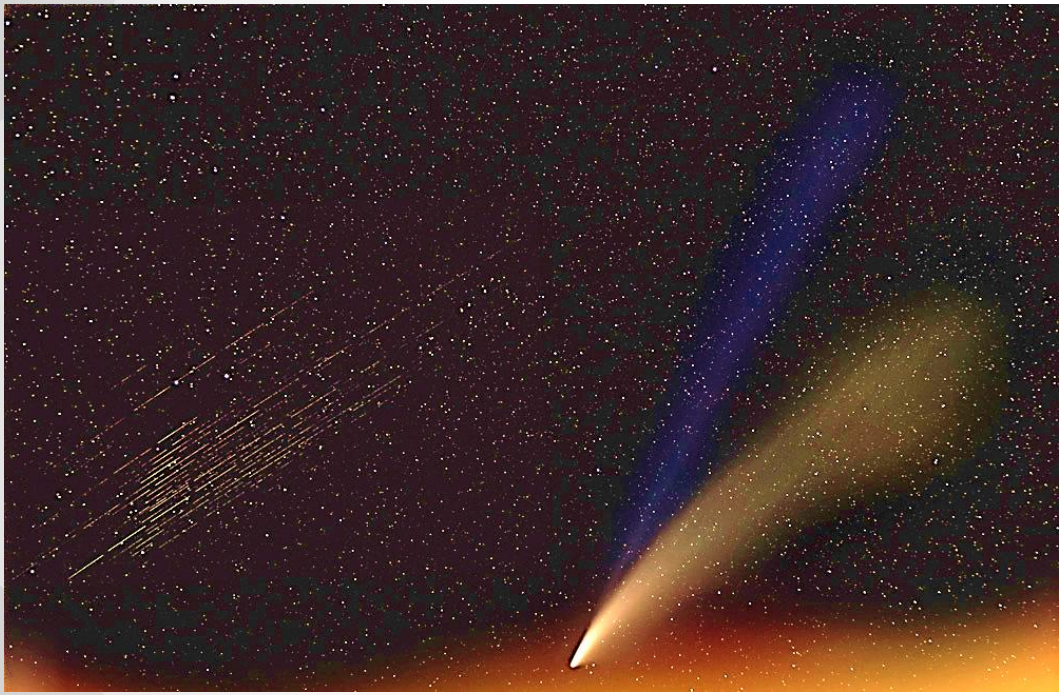
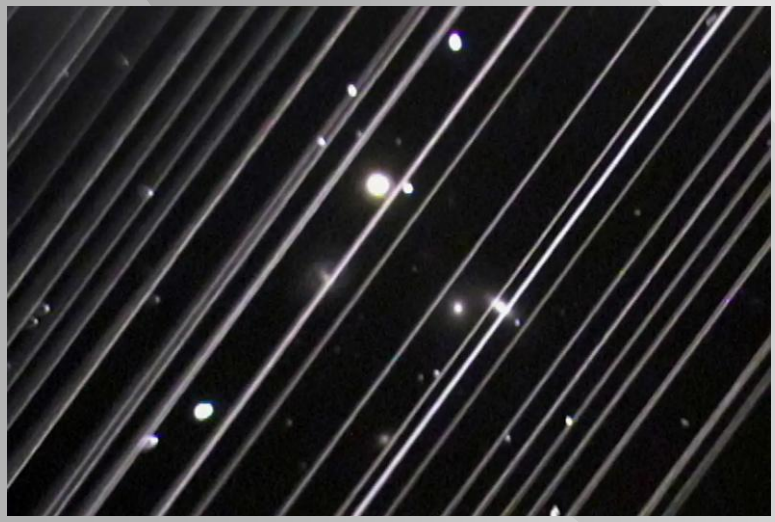
Starlink



- Astronomers not happy!
- Even with the now blackened underside, they mess up images & data



Δt = interval between "paradigm shifts"
(= "game changers")

*The Simon Personal Communicator (IBM, 1992)
** The Osborne 1 (Osborne Computer Corp, 1981)

technological capability index, $1/\Delta t$ (yrs^{-1}) →

0.13
0.12
0,11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

1400
1500
1600
1700
1800
1900
2000

Printing Press
Electric charge
Light Bulb
The concept of Quanta
Quantum Mechanics
Patent for the Transistor
Colossus: Programmable Digital Electronic Computer (valves)
WorkingTransistor
(Solid State Technology)
Sputnik
Lasers
Integrated Circuit
Satellite Comms
(Telstar)
Optical Fibre Communications
Laptop Computer**
Smartphone*
i-phone
Starlink
The concept of optical fibres

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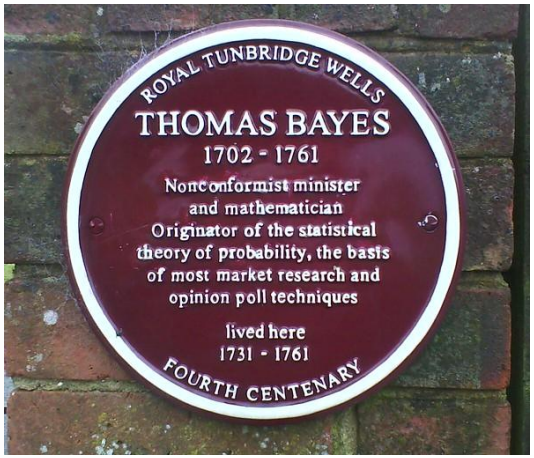
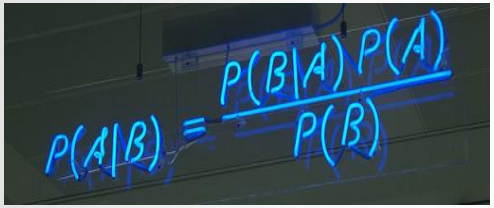
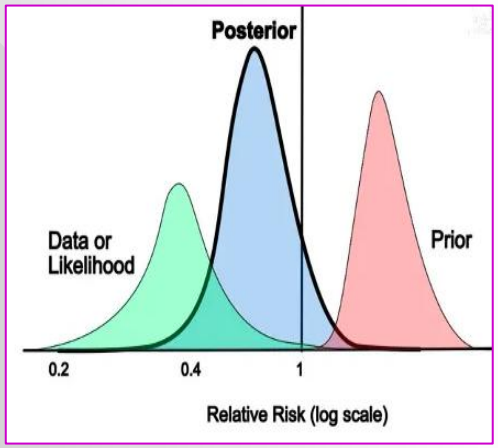
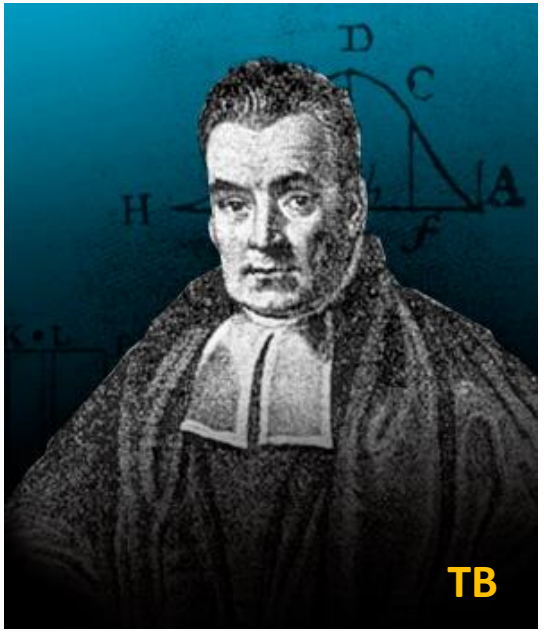
Thomas Bayes
(1702 –1761)

- Statistician and nonconformist church minister of Mount Sion Chapel, Tunbridge Wells
- An FRS but his notes on “Bayesian statistics” were edited and published posthumously
- Long-rejected and criticised by a later FRS, Sir Ronald A. Fisher (1890-1962). Wasn’t used as compute power was insufficient to update the “conditional probabilities”. Re--discovered in the1960s and now at the core of many modern techniques: e.g. risk assessment, probabilistic machine learning (ML) and information theory.
- Employed by www search engines such as Google & ML to find the most likely relevant answers to queries









Ada Lovelace
(1815 –1852)

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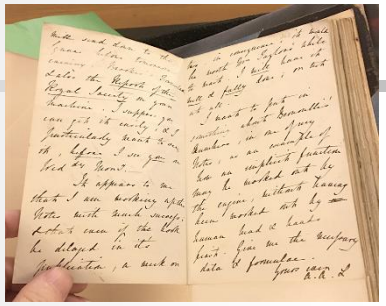
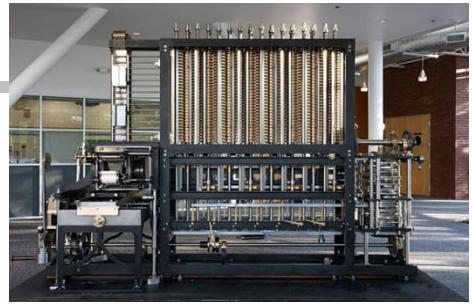
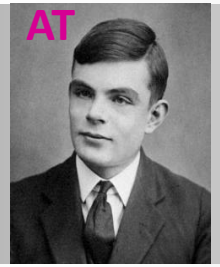




- Augusta Ada King, Countess of Lovelace (née Byron)
- Worked with Charles Babbage on his “Difference Engine” & later the unfinished “Analytical Engine” (mechanical computers)
- The first computer programmer who invented the concept of (but not the name) “software”
- CB saw these computers only as means of generating tables of mathematical functions but AL’s visionary genius foresaw the full potential of computers
- Predicted numerical modelling
- Died at just 37 of womb cancer

Portrait by Margaret Sarah Carpenter (1836)



AI ChatGPT

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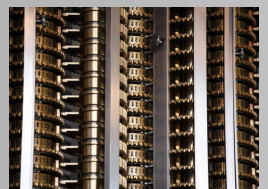
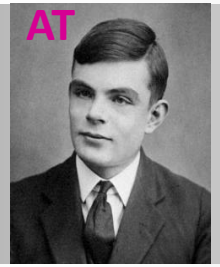
AL, AT & AI

- **1843**: The Lovelace "objection" that computers could never think or create *"It is desirable to guard against the possibility of exaggerated ideas that might arise as to the powers of the Analytical Engine ..... The Analytical Engine has no pretensions whatever to originate anything. It can do whatever we know how to order it to perform. It can follow analysis, but it has no power of anticipating any analytical relations or truths."*
- **1950**: (107 years later!) Alan Turing argued this was untestable and proposed the "Turing test" would be achieved by 2000 *"can a computer give the impression of human thought and surprise us"*
- **2023**: AI has passed AT's test – **BUT** what AL said is still true
- For me AI is **NOT** intelligent and does not think - it knows what words often go together on trusted websites and can follow the rules of grammar. It has no concept of what it is talking about!



Turing, A.M. (1950) Computing machinery and intelligence, Mind, 59 (236), 433–460, doi: 10.1093/mind/lix.236.433
Delacroix, S. (2022) Computing Machinery, Surprise and Originality, Philosophy & Technology, 34, 1195–1211, doi: 10.1007/s13347-021-00453-81



AI ChatGPT

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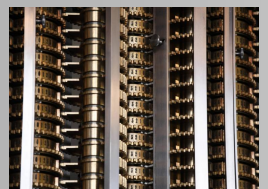
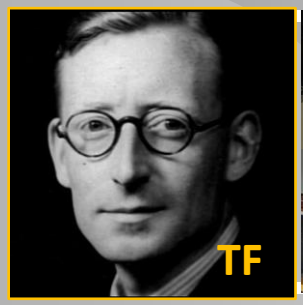
AL, AT & AI

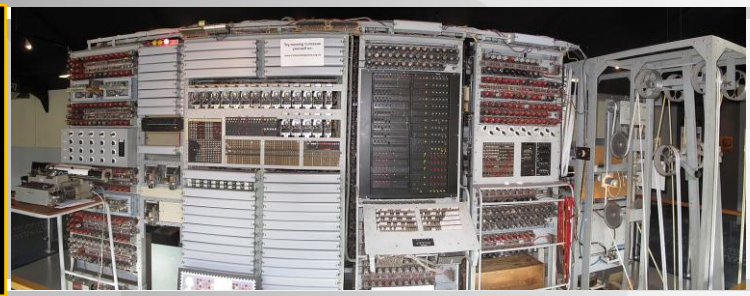
- I think AT grossly underestimated AL & her insights on the nature of consciousness
- and anyway, is the Lovelace "objection" due to misunderstanding and selective misquoting. The missing part of her statement is really interesting

"It is desirable to guard against the possibility of exaggerated ideas that might arise as to the powers of the Analytical Engine. In considering any new subject, there is frequently a tendency, first, to overrate what we find to be already interesting or remarkable; and, secondly, by a sort of natural reaction, to undervalue the true state of the case, when we do discover that our notions have surpassed those that were really tenable." (Lovelace, 1843: 722)



Natale, S. and L. Henrickson (2022) The Lovelace effect: Perceptions of creativity in machines, New Media & Society, pp1-18, doi: 10.1177/14614448221077278





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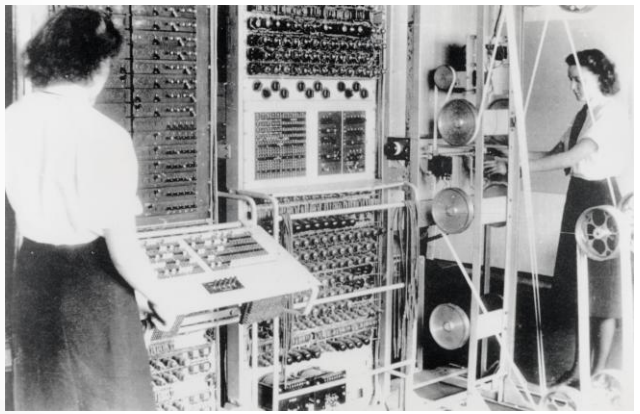
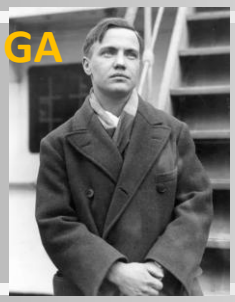
Colossus

- 1943: the world's first programmable electronic computer(s)
- Valve technology (1600 Vacuum tubes in Colossus 1 and 2400 in Colossus 2
- Hosted at Bletchley Park but designed and built by General Post Office research telephone engineer Tommy Flowers at Dollis Hill
- Remained an official secret after WW2 because of the cold war. Building Colossus left Flowers himself in huge personal debt.
- At University of Pennsylvania, John Mauchly and Presper Eckert, built the first general-purpose electronic digital computer 'Electronic Numerical Integrator and Calculator' (ENIAC). 20-by-40 ft in size and had 18,000 vacuum tubes. First came into operation in 1946





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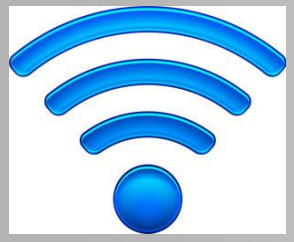
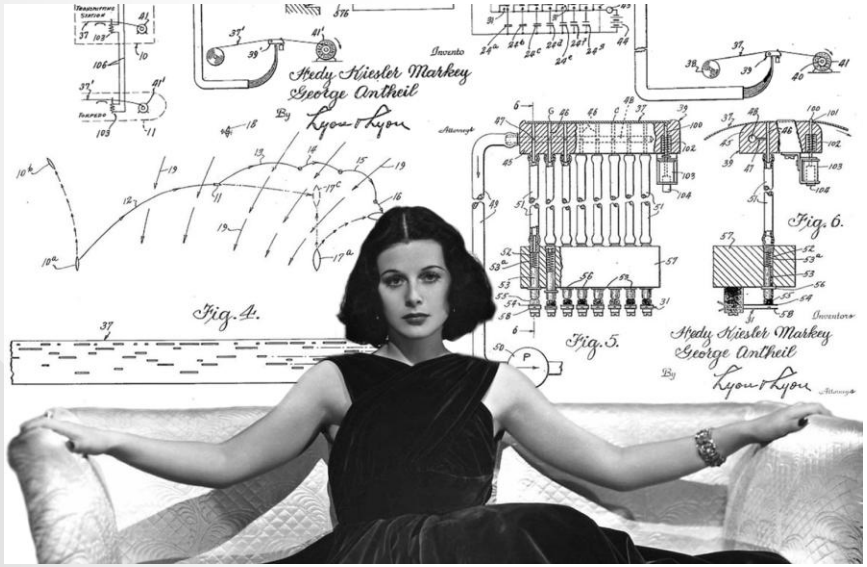
Hedy Lamarr and Spread Spectrum

- film star, born Hedwig Eva Maria Kiesler in Austria, escaped a controlling first husband and the NAZIs and fled to Hollywood in 1938
- a brilliant electronic engineer and inventor, with composer George Antheil she invented and patented (1942) frequency-hopping spread-spectrum FHSS to evade WW2 U-boat electronic counter-measures
- 1989: Nils Rydbeck of Ericsson Mobile in Lund uses FHSS in what is now called Bluetooth to give security and noise suppression
- 1999: Wi-Fi is developed by an Australian CSIRO team led by John O' Sullivan. Uses Direct Sequence Spread Spectrum (DSSS which spreads the signal using a coded spectrum, rather than FHSS (switching the frequency with time)





A (Very) Brief History of the Internet

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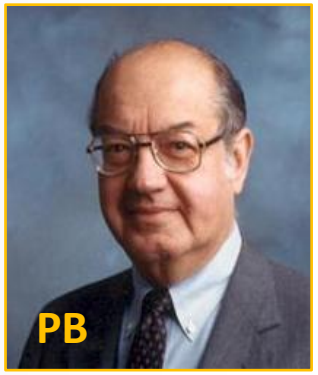
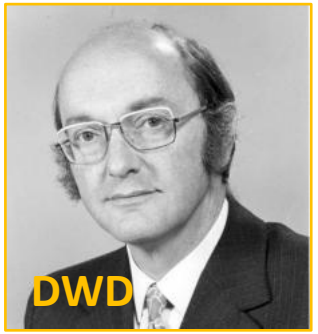
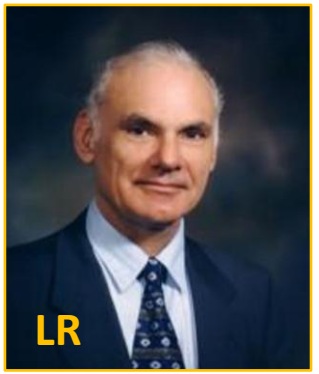
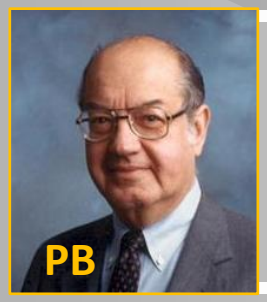
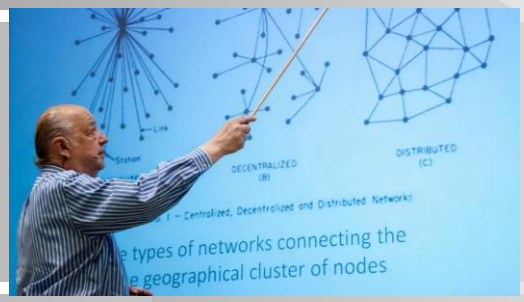
- 1958 SAGE connects 23 radar station computers
- 1962 Joseph Carl Robnett Licklider (known as “J.C.R.” or “Lick”), of the Pentagon’s ARPA (Advanced Research Projects Agency, now DARPA) conceives of the Intergalactic Computer Network (IGCN)
- 1964 Paul Baran of RAND Corporation think-tank proposes a communication network with no central command point
- 1965 Leonard Kleinrock (ARPA/UCLA) pioneers application of queueing theory to model delays in message switching networks
- 1965 Donald Watts Davies of the National Physical Laboratory, Teddington invents packet switching
- 1967 Lawrence Roberts of MIT & ARPA succeeds in getting two computers to “talk” with packet switching

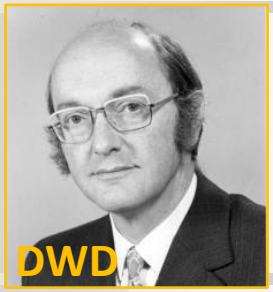




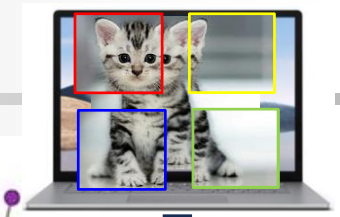


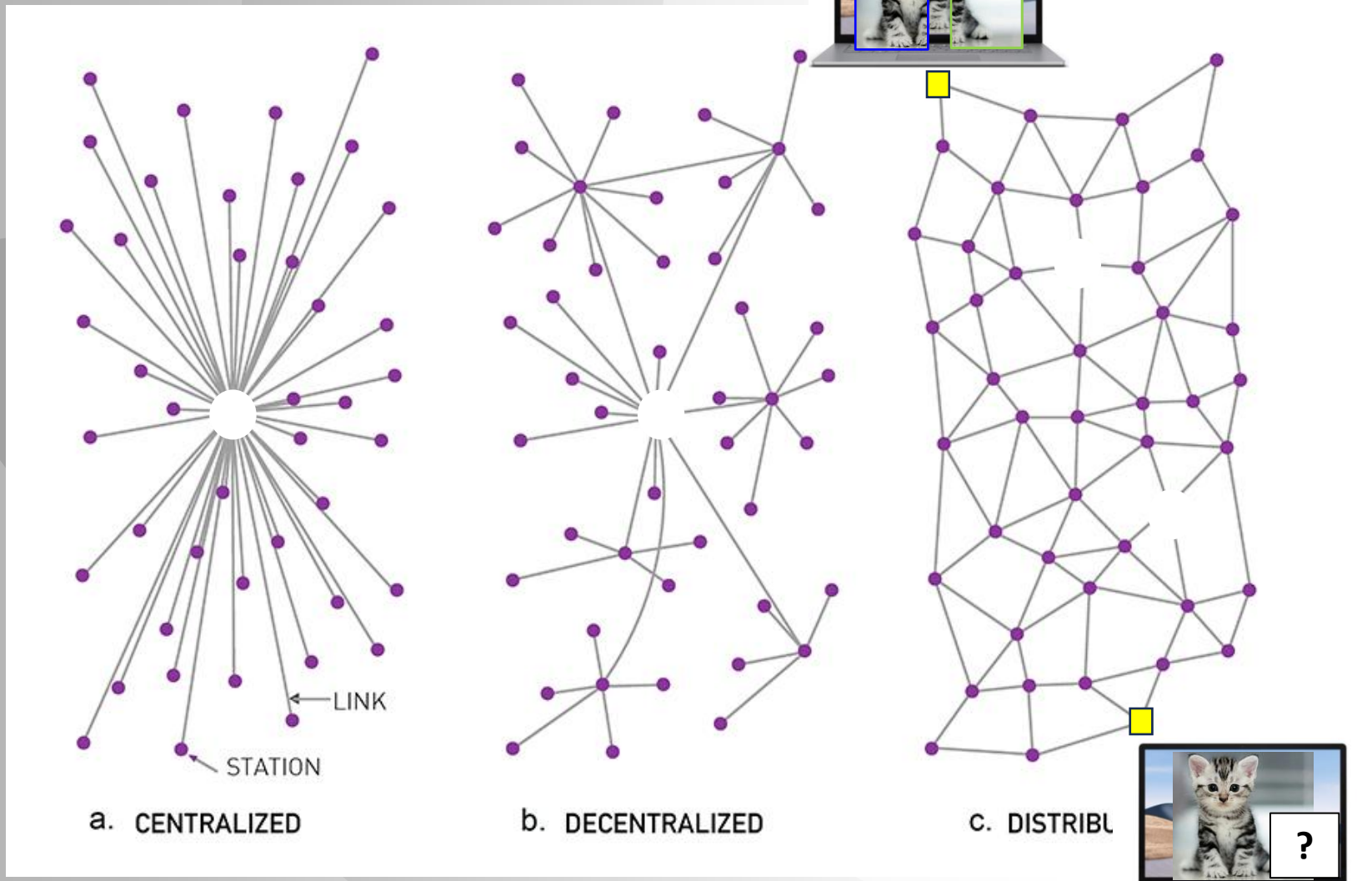


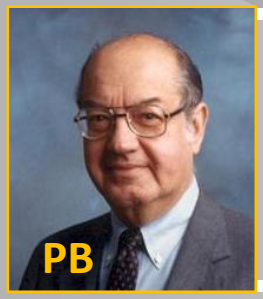


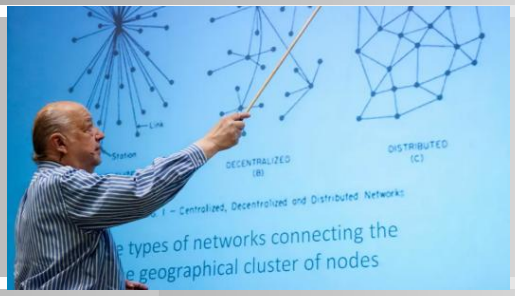


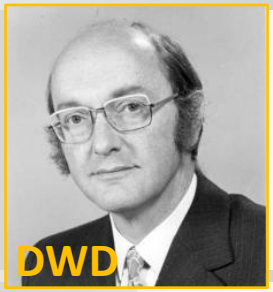
Network Design & Packet Switching

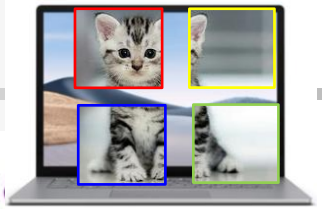


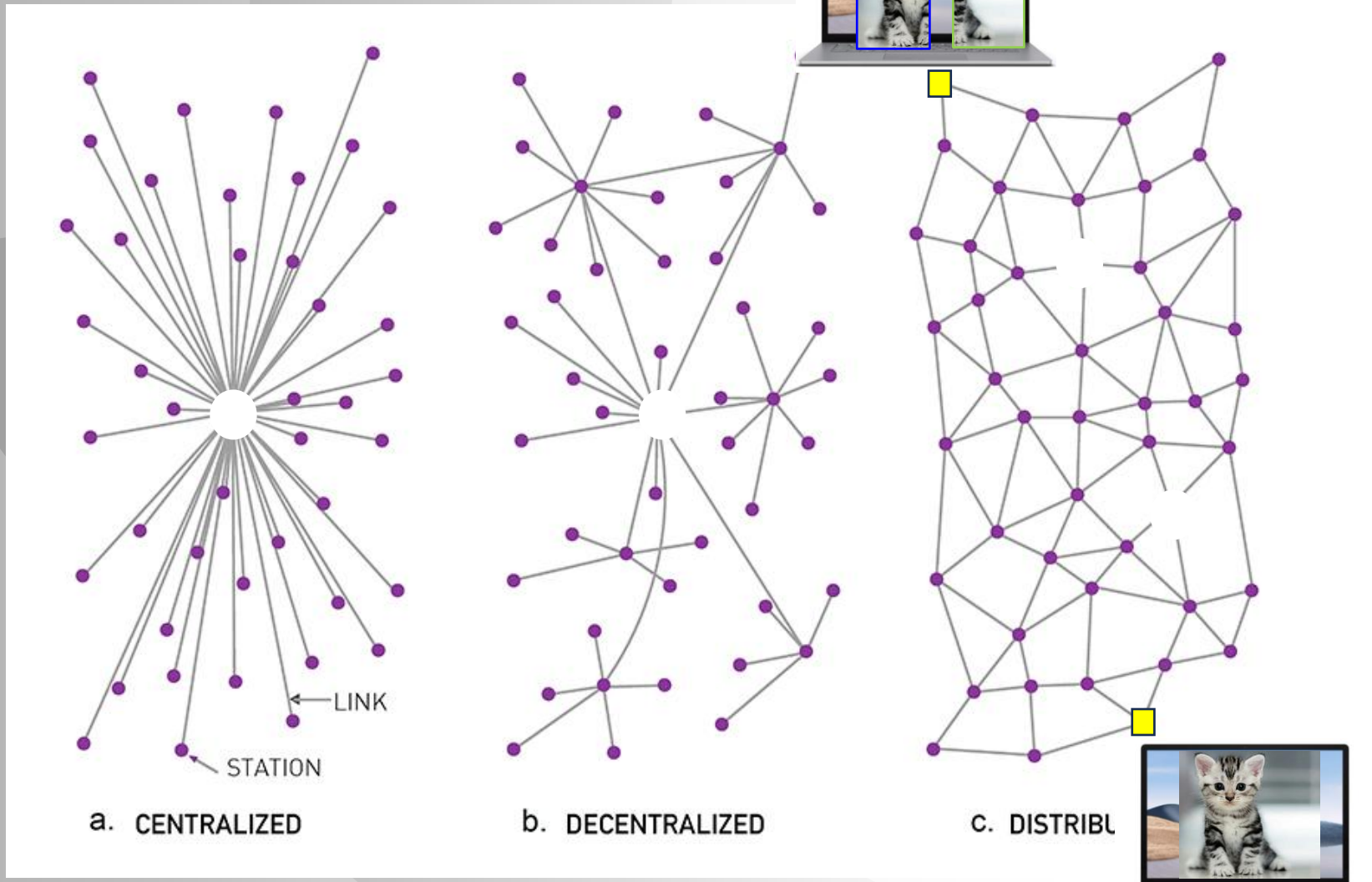


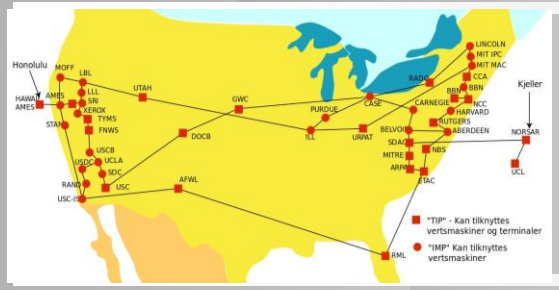

PB


Station
Link
DECENTRALIZED
(B)
DISTRIBUTED
(C)
– Centralized, Decentralized and Distributed Networks
types of networks connecting the
geographical cluster of nodes


DWD



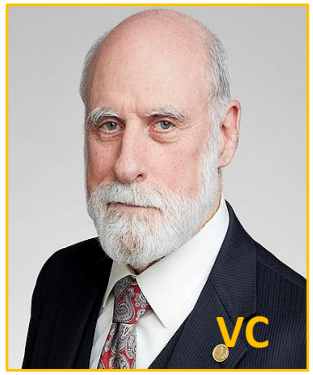

LINK
STATION
a. CENTRALIZED
b. DECENTRALIZED
c. DISTRIBU



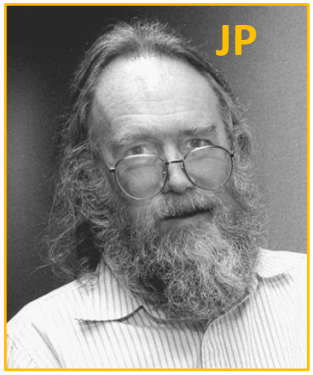
A (Very) Brief History of the Internet (cont.)

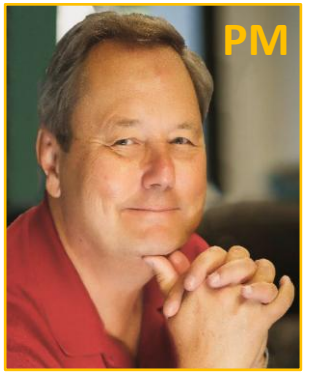
University of Reading

- 1969 4-node ARPANET network starts operation
- 1971 e-mail developed on ARPANET by Ray Tomlinson
- 1974 Agencies like NSF and NASA form own networks. So new generation ARPANET uses TCP/IP (Transmission Control Protocol / Internet Protocol): standard rules for computer developed by Bob Kahn and Vint Cerf.



- 1983 Domain Name System (the “phone book of the Internet”) developed by Jon Postel & Paul Mockapetris of the Information Science Institute, California





- 1991 The www proposed at CERN by Tim Bernes-Lee to solve the LHC data distribution problem and developed by him and Robert Cailliau

Δt = interval between “paradigm shifts”

(= “game changers”)

technological capability index, $1/\Delta t$ $(yrs^{-1}) \rightarrow$

0.13
0.12
0,11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

1400
1500
1600
1700
1800
1900
2000

AI (“statistical parrots”)
Starlink
i-phone
Plasma and Touch Screens
Bayesian Searches (Google)
Mosaic (first web browser)
World-wide web
Microsoft windows
Smartphone
MS-DOS
Microprocessor
Digital Camera
Computer Mouse
Laptop Computer
Optical Fibre Communications
Satellite Comms.
Lasers
Transistor
(Solid State Technology)
Colossus: Programmable Digital Electronic Computer
Quantum Mechanics
Domestic power grid
Light Bulb
(mechanical) Computer programming
Wire Telegraph Network
Mass Production
Dynamo
Battery
Bayesian statistics
Electric charge
Printing Press

The world wide web today by language

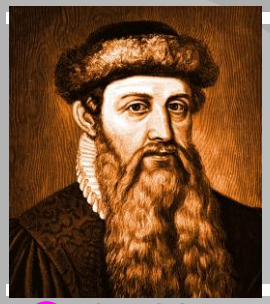
University of Reading

websites
by language

- Arabic
- English
- Farsi/Dari/Tajik (Persian)
- French
- Hebrew
- Swahili

- 5 bn users (62% of world population of 8.1 bn)
- Contributed £82bn to UK economy in 2022 (5.7% of GDP)

University of Reading



553 years of science and technology

University of Reading

- (left) A best-guess replica of Johannes Gutenberg's first printing press (Mainz, 1436) and the printer's marks of Johann Fust (1437) and William Caxton (Westminster,1476)
- (right) An exact replica of the very first www server (Geneva, 1989): a NEXT computer costing US$6,500 (equivalent to $16,500 today). The red handwriting on the half-torn-off sticker said

This machine is a server. DO NOT POWER IT DOWN!!

Let's Share What We Know

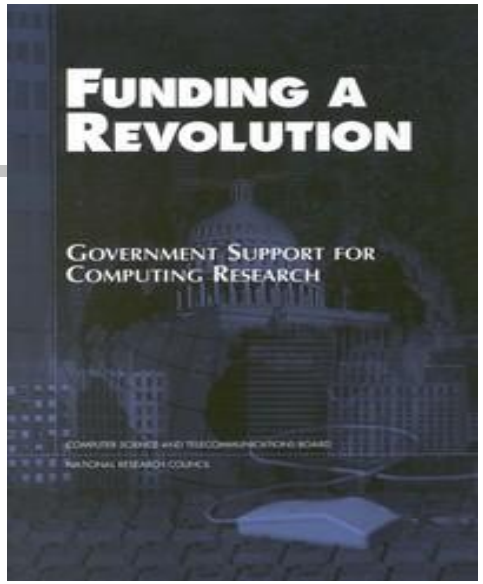
World Wide Web

WWW

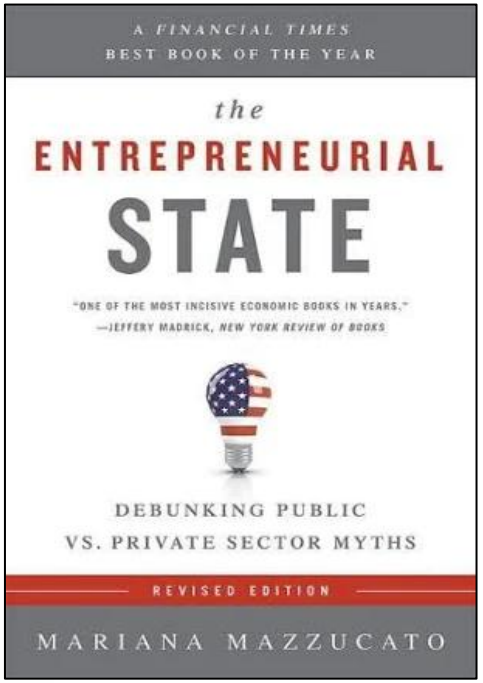
Costs and Return on Investment

(In blue £ in today's prices)

University of Reading



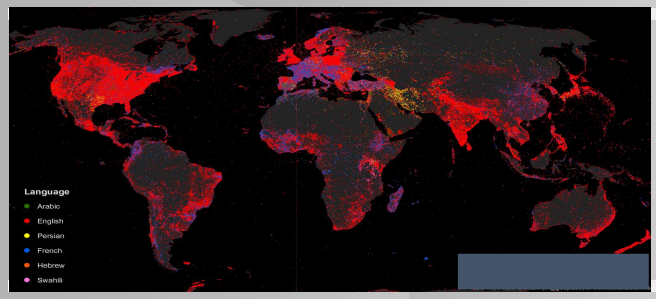
- Morse's telegraph (1844): US$30,000 (today = £1m)
- ARPANET → NSFNET → Internet £0.51 bn *
  Almost exclusively **PUBLIC MONEY**
- Projected cost of HS2 £72 bn - £98 bn
- A 2019 study for the Internet Association found the Internet to be worth US$2.1 tn (trillion) p.a. (£1,660 bn) to US economy = 10% of GDP
- Contributed £82 bn to UK economy in 2022 = 5.7% of GDP



(*excludes UK work at NPL and CERN funding of www)

Press, L. (1996), Seeding networks: The federal role, Comms. of the ACM, 39, 11-18, doi: 0.1145/236156.240575

National Research Council (1999) Funding a Revolution: Government Support for Computing Research, The National Academies Press, Washington, DC, doi: 10.17226/6323.



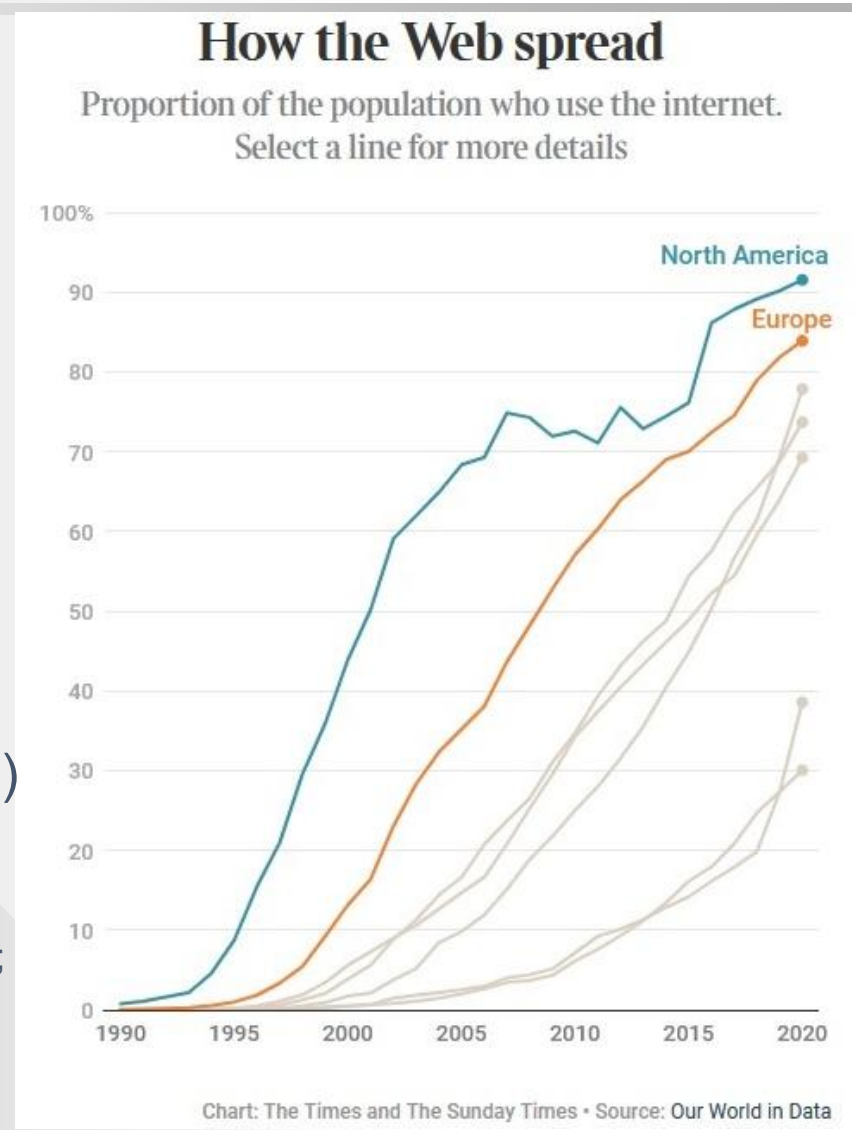
The growth of the world wide web

University of Reading

- Most visited sites

	1993	2023
1	AOL (now Yahoo!)	Google
2	Prodigy	YouTube
3	Compuserve	Facebook
4	Bloomberg	Instagram
5	Apple	X
6	IMDb	Baidu (China)
7	MTV	Wikipedia

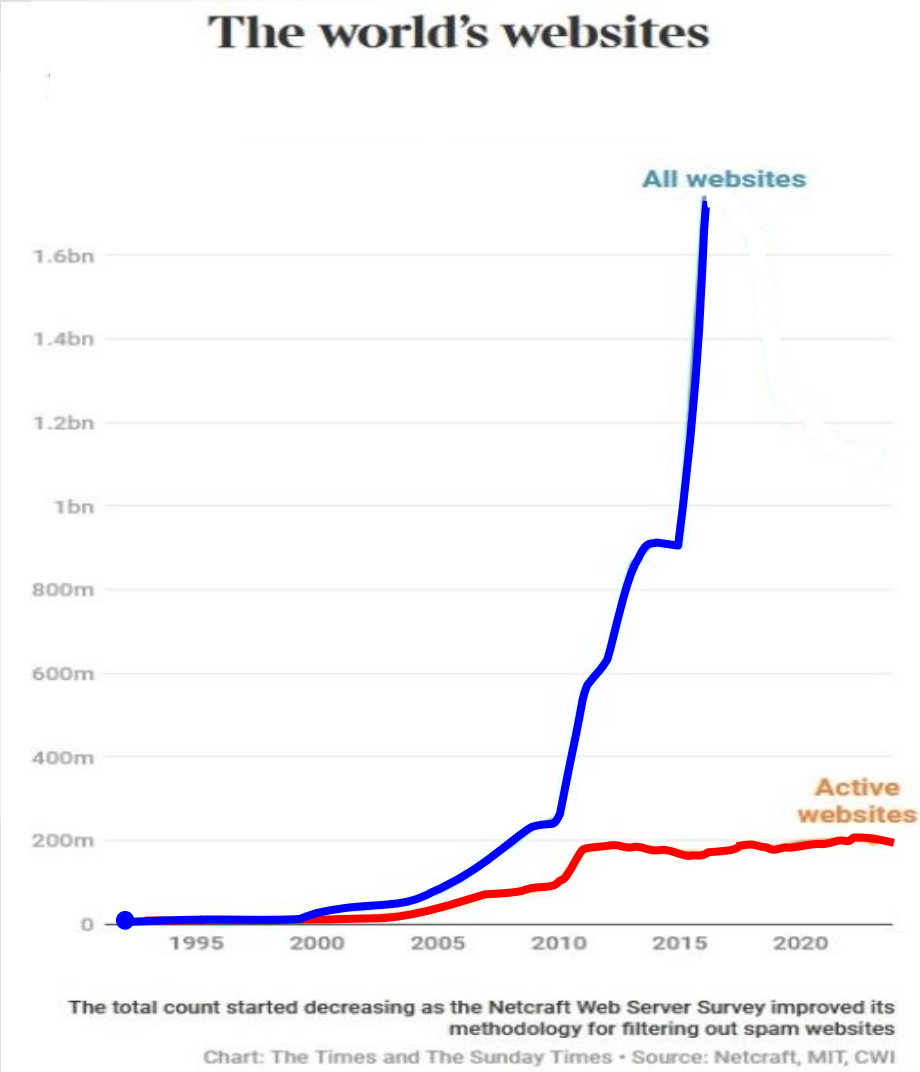
AOL: search, e-mail; Prodigy: comms and entertainment; Compuserve: e-mail; Bloomberg: News, Business News; Apple: hardware and software; IMDb: TV and movie news; MTV: music



The growth of the world wide web

University of Reading

- First site opened on August 6, 1991 - http://info.cern.ch/
- 623 sites in April 1995
- exponential rise in total number of websites
- Number of "active" websites (frequently updated and visited) has levelled off after 2010 at about 200m
- 5 bn users (62% of world population of 8.1 bn)



Costs and Return on Investment

(In blue £ in today's prices)

University of Reading

- Morse's telegraph (1844): US$30,000 (today = £1m)
- SAGE cold-war computer network of 25 radar sites (dedicated to one task). Cost including computers, (1958): US$8bn (£68,300m)
- ARPANET (1974): US$25m (£122.5m)
- NSFNET backbone (1988): US$58m (£120m); plus academic & international expansions (1990): US$(30m+6.6m) =36.6m (£68.4m)
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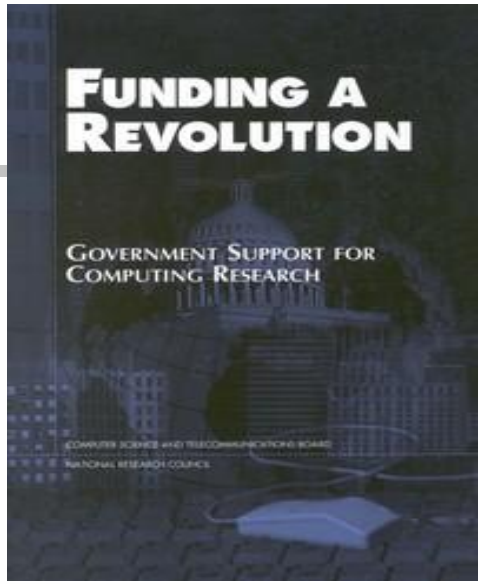
(*excludes UK work at NPL and CERN funding of www.) *Press, L. (1996), Seeding networks: The federal role, Comms. of the ACM, 39, 11-18, doi: 0.1145/236156.240575*)

- ARPANET+NSFNET+Academia+Internet, Total = £501m
- Projected cost of HS2 £72,000m - £98,000m
- A 2019 study for the Internet Association found the Internet to be worth US$2.1 tn (trillion) p.a. (£1,660,000m) to the USA out of US$20.5 tn GDP. (£16,200,000m) – 10% of GDP

Costs and Return on Investment

(In blue £ in today's prices)

University of Reading



- National Research Council report (1999)

Funding a Revolution: Government Support for Computing Research

The National Academies Press, Washington, DC, doi: 10.17226/6323.
PDF available at http://nap.nationalacademies.org/6323

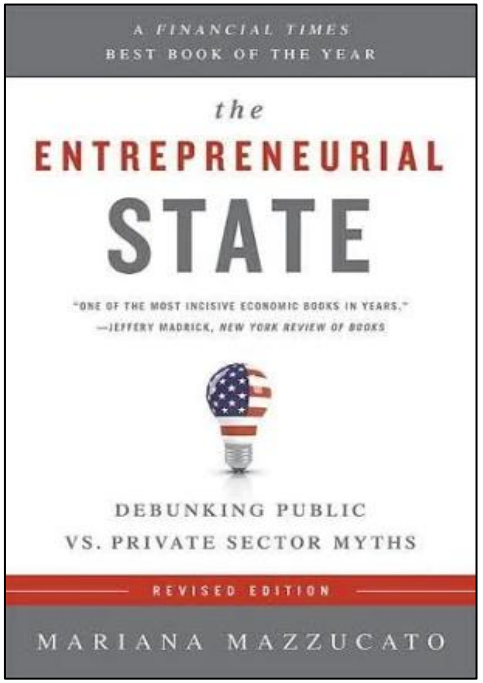
- ARPANET → NSFNET → Internet → www

Almost exclusively funded using **PUBLIC MONEY**

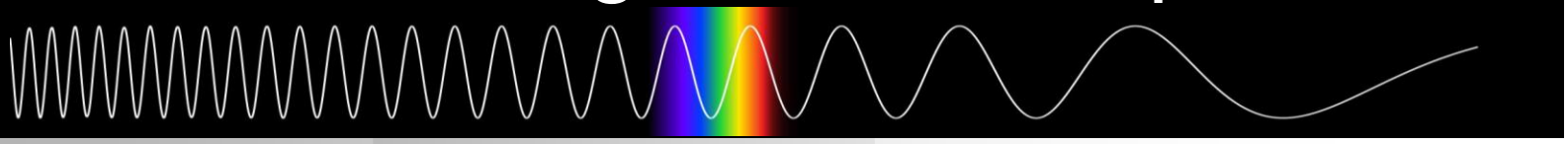
- *(scientists, technologists and computer scientists from industrial companies and universities who contributed were largely working on Government-funded contracts)*

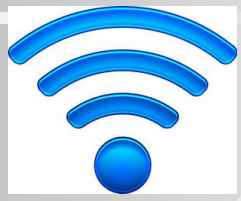
- As asked by Mariana Mazzucato in her excellent book 'The entrepreneurial state' (2015),

"where is the dividend for the taxpayer?"



The electromagnetic wave spectrum



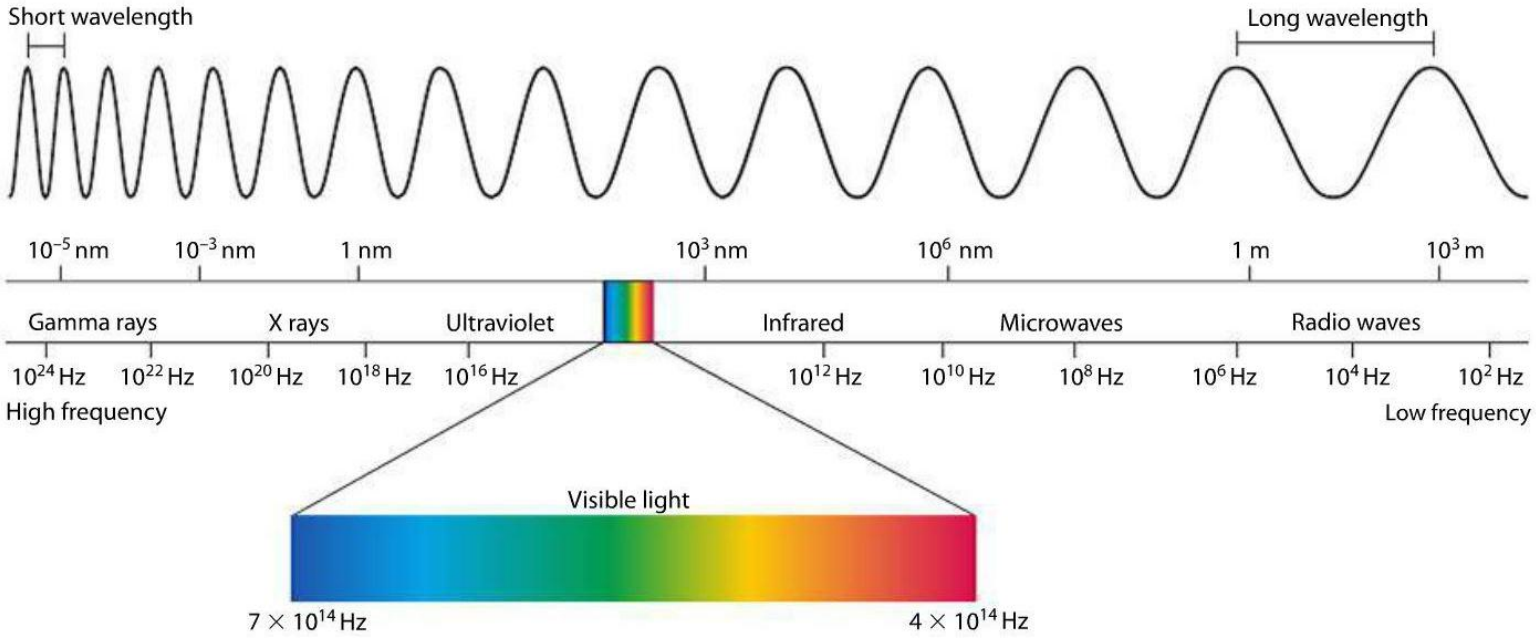


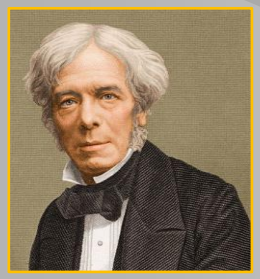
wi-fi (2.4-5 GHz)

Hertz's discovery of radiowaves (VHF~50MHz)

Satcoms (UHF ~1-40GHz): need to pass through ionosphere

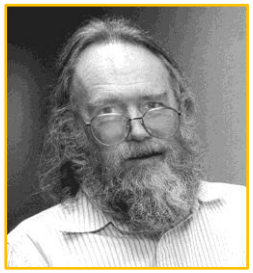
HF (~0.5-3MHz): reflects off ionosphere





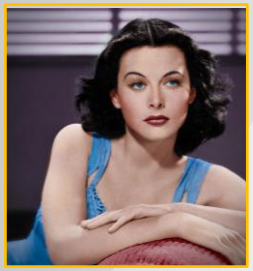
Michael Faraday

Tommy Flowers



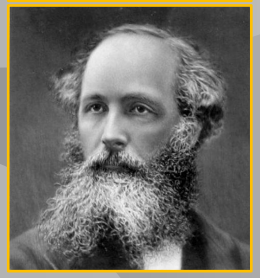
Jon Postel

Ada, Countess Lovelace



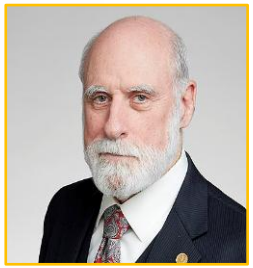
Hedi Lamar

Donald Davies



James Clerk Maxwell

Sputnik



Vint Cerf

Max Planck

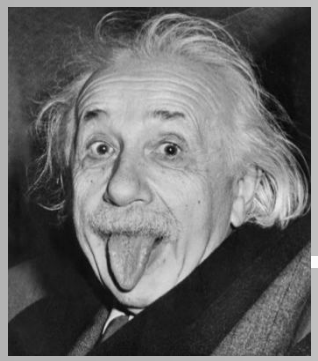
Paul Baran

Bob Kahn

Guglielmo Marconi

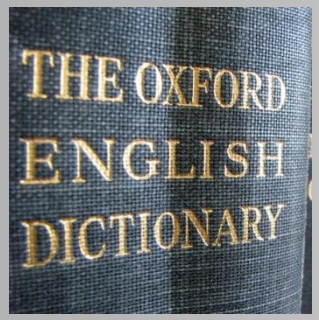
Paul Mockapetris

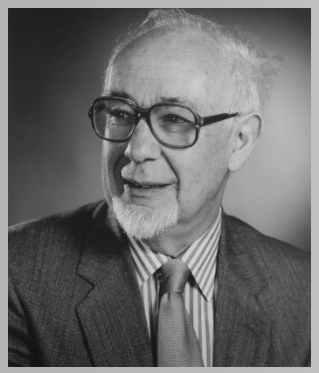
Tim Berners-Lee



Science

ˈsʌɪəns
(noun)

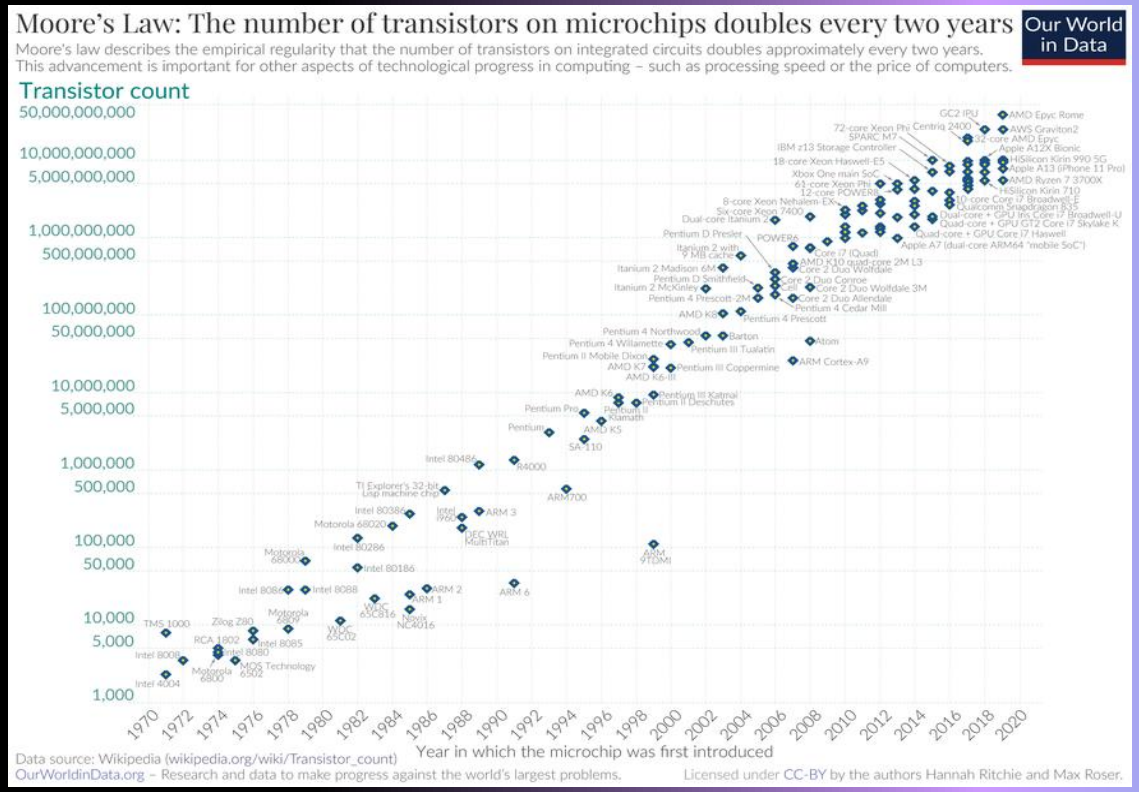


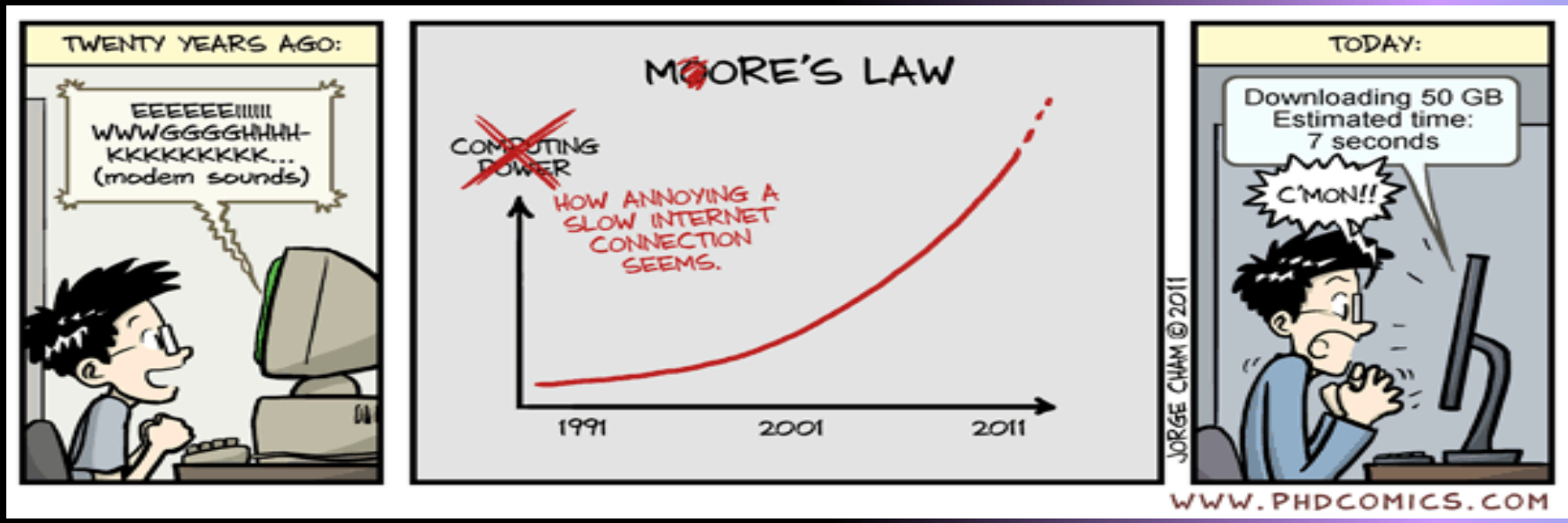


- Cambridge Dictionary: “(knowledge from) the careful study of the structure & behaviour of the physical world, especially by watching, measuring, and doing experiments, and the development of theories to describe the results of these activities”
- Wikipedia: “(from Latin *scientia*, meaning knowledge) is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the universe.”
- OED: “A systematically organized body of knowledge on a particular subject.”
- John Michael Ziman (1925-2005): “The goal of science is a **consensus** of rational opinion.”

Moore's law

The number of transistors in an integrated circuit (IC) doubles about every two years





Things you hear about peer review

(from people who don't like a consensus it has generated)

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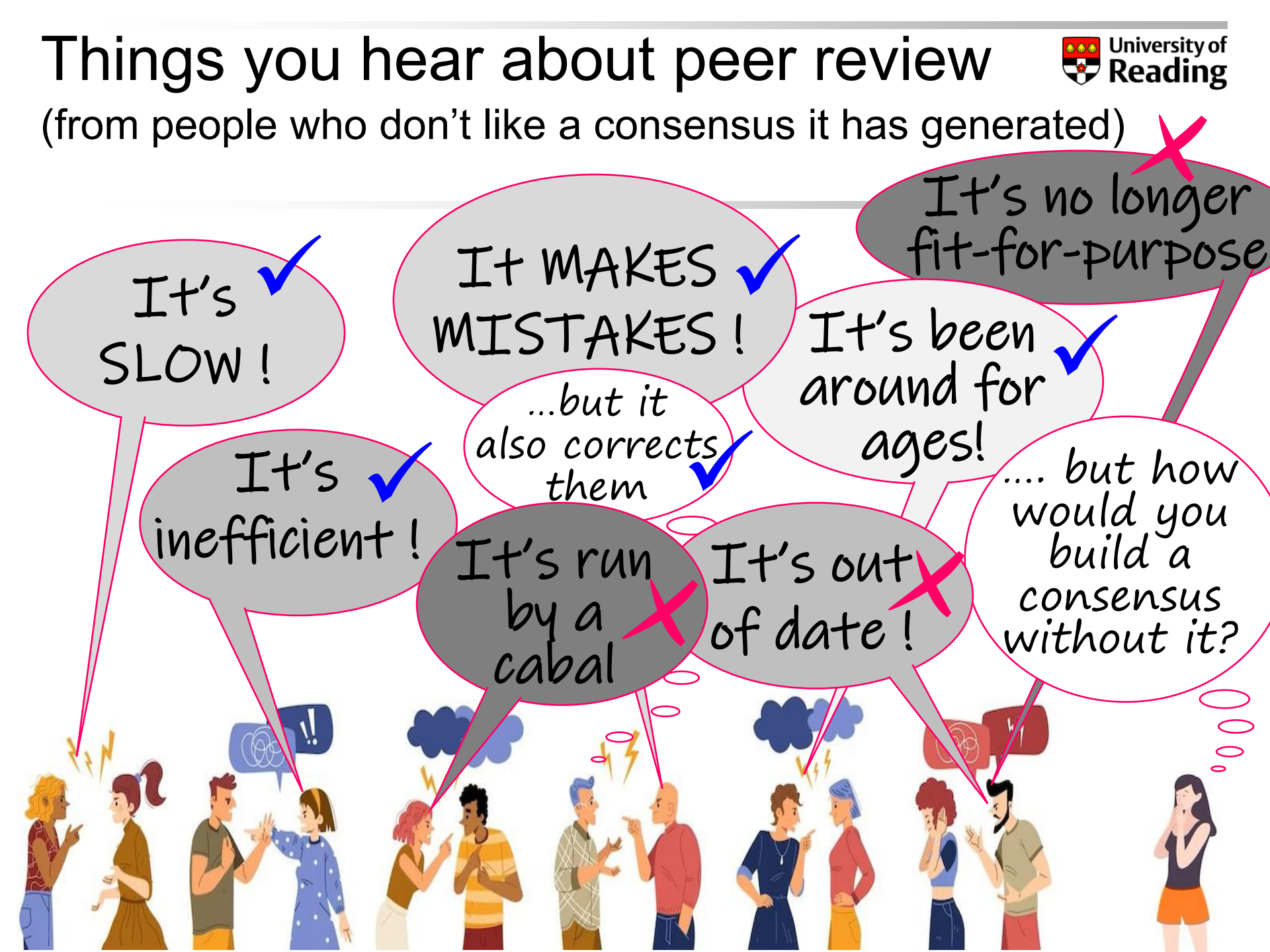

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Costs

(In blue £ in today's prices)

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- Projected cost of HS2 £72,000m - £98,000m
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- A 2019 study for the Internet Association found the Internet to be worth US$2.1 tn (trillion) p.a. (£1,660,000m) to the USA out of US$20.5 tn GDP. (£16,200,000m) – 10% of GDP

History of science research

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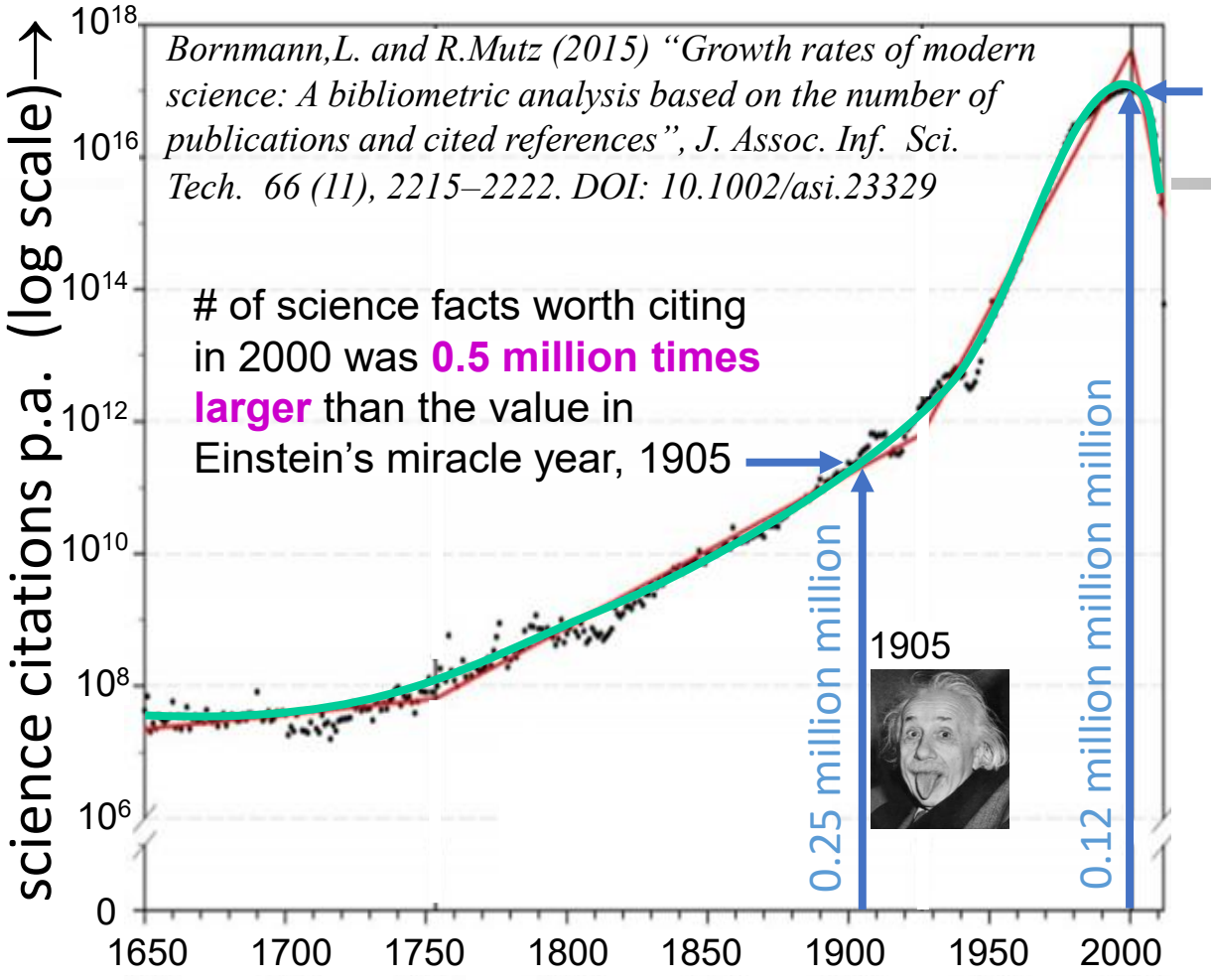
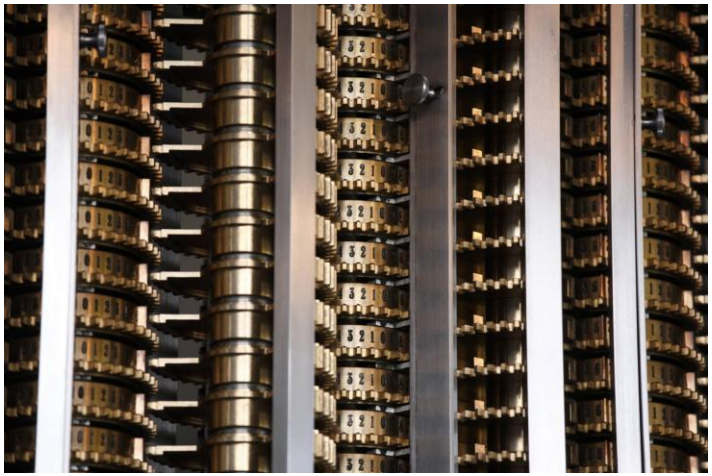
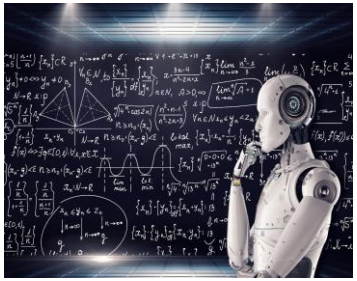
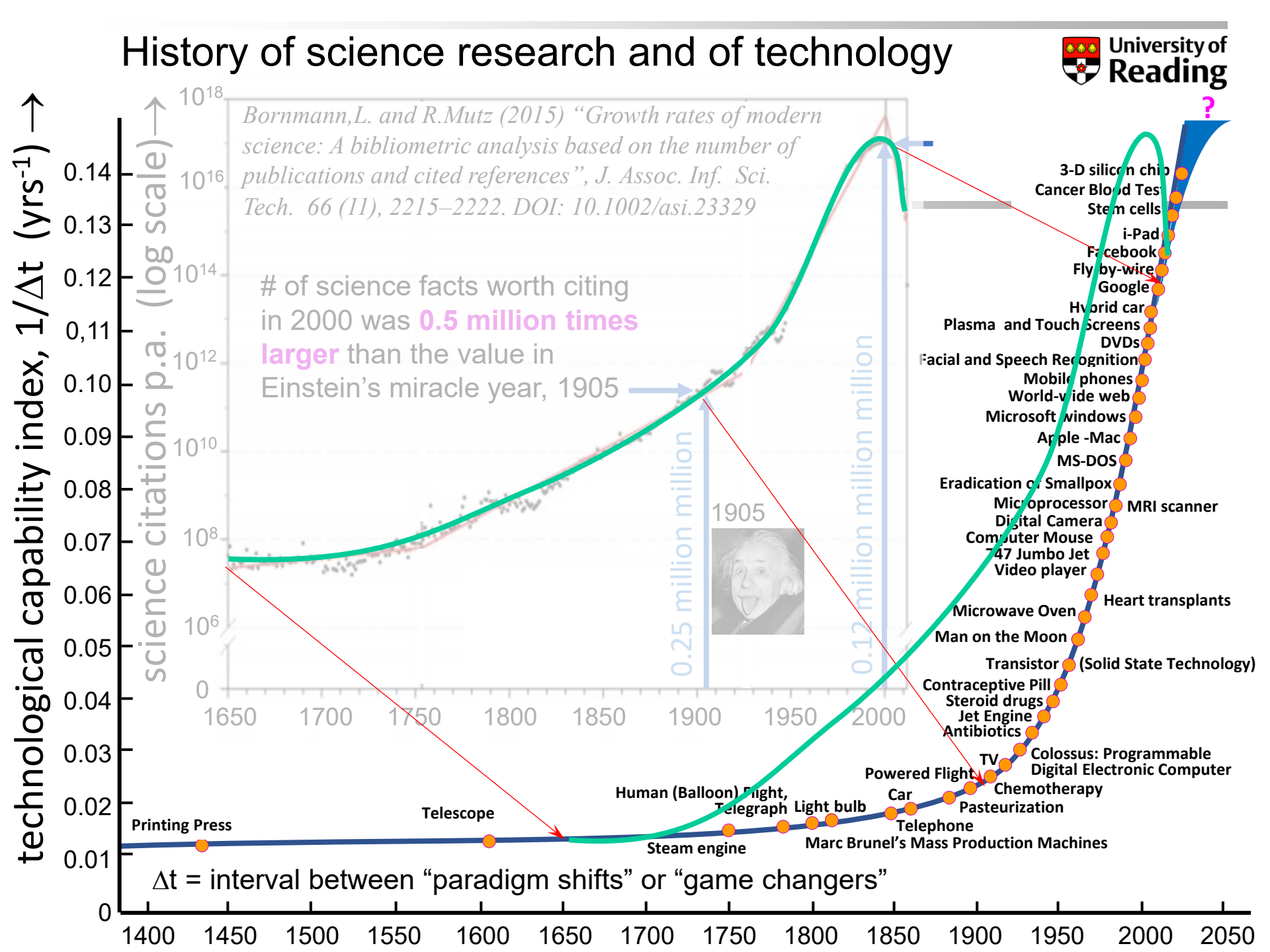






History of science research and of technology

University of Reading



Department of Meteorology

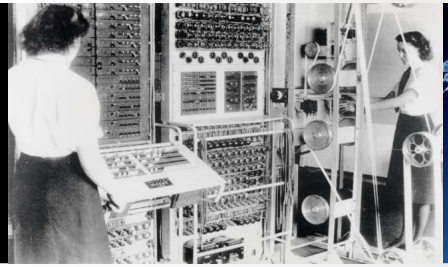
University of Reading

Mike Lockwood

From Michael Faraday and Ada Lovelace to Tim Berners-Lee: the 200-year history of the men and women who made the internet possible

20th September, 2023

Harwell Parish History Group

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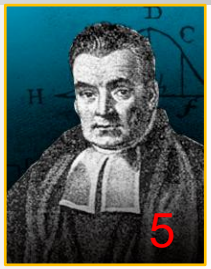

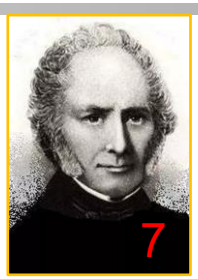

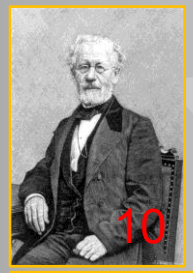

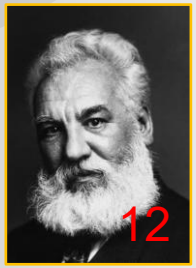

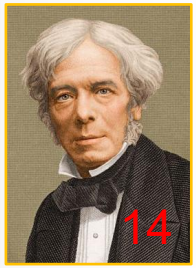

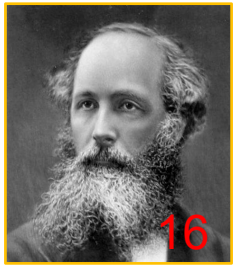

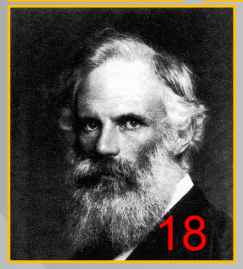

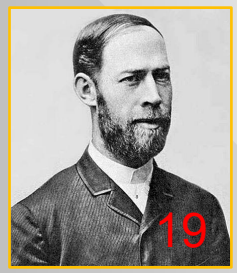

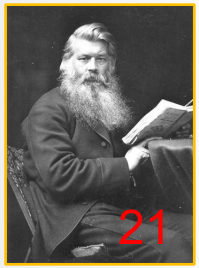

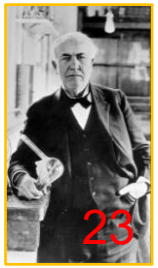

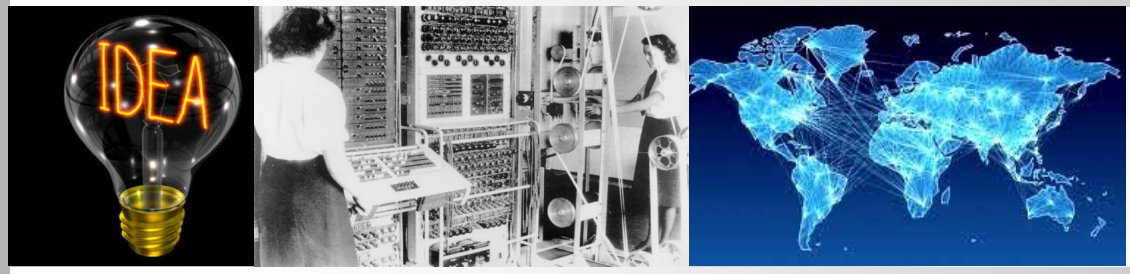

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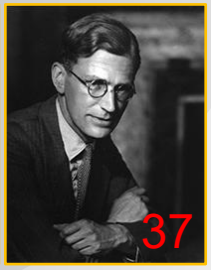
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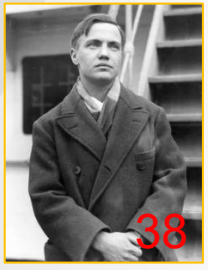
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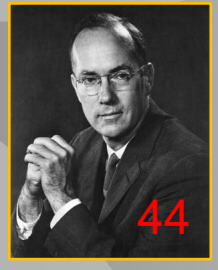
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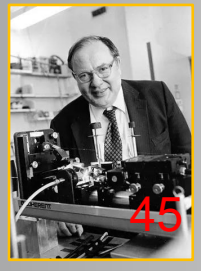
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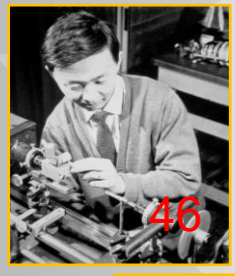
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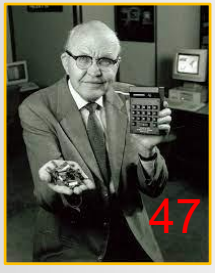
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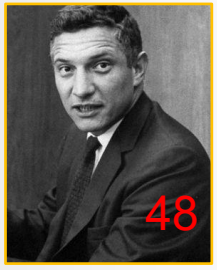
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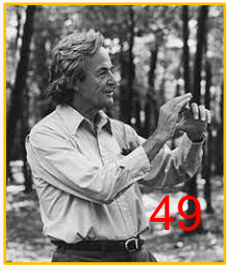
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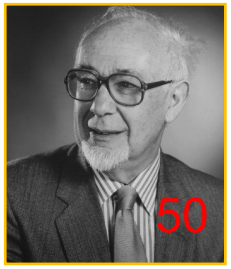
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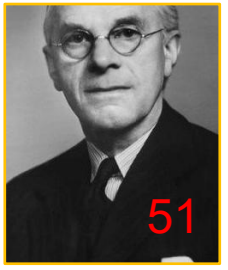
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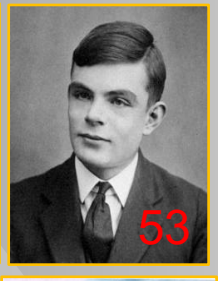
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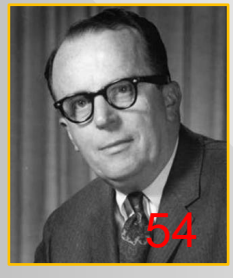
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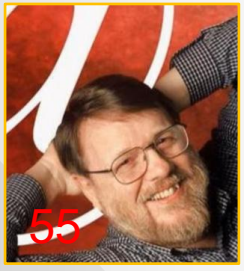
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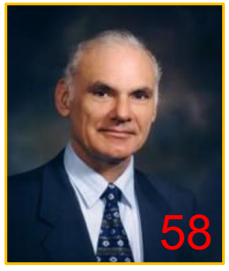
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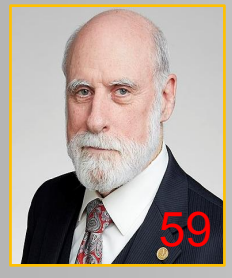
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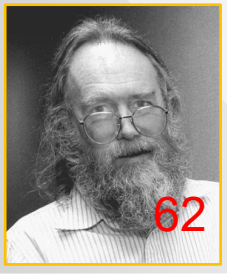
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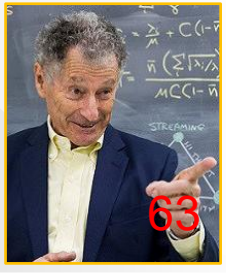
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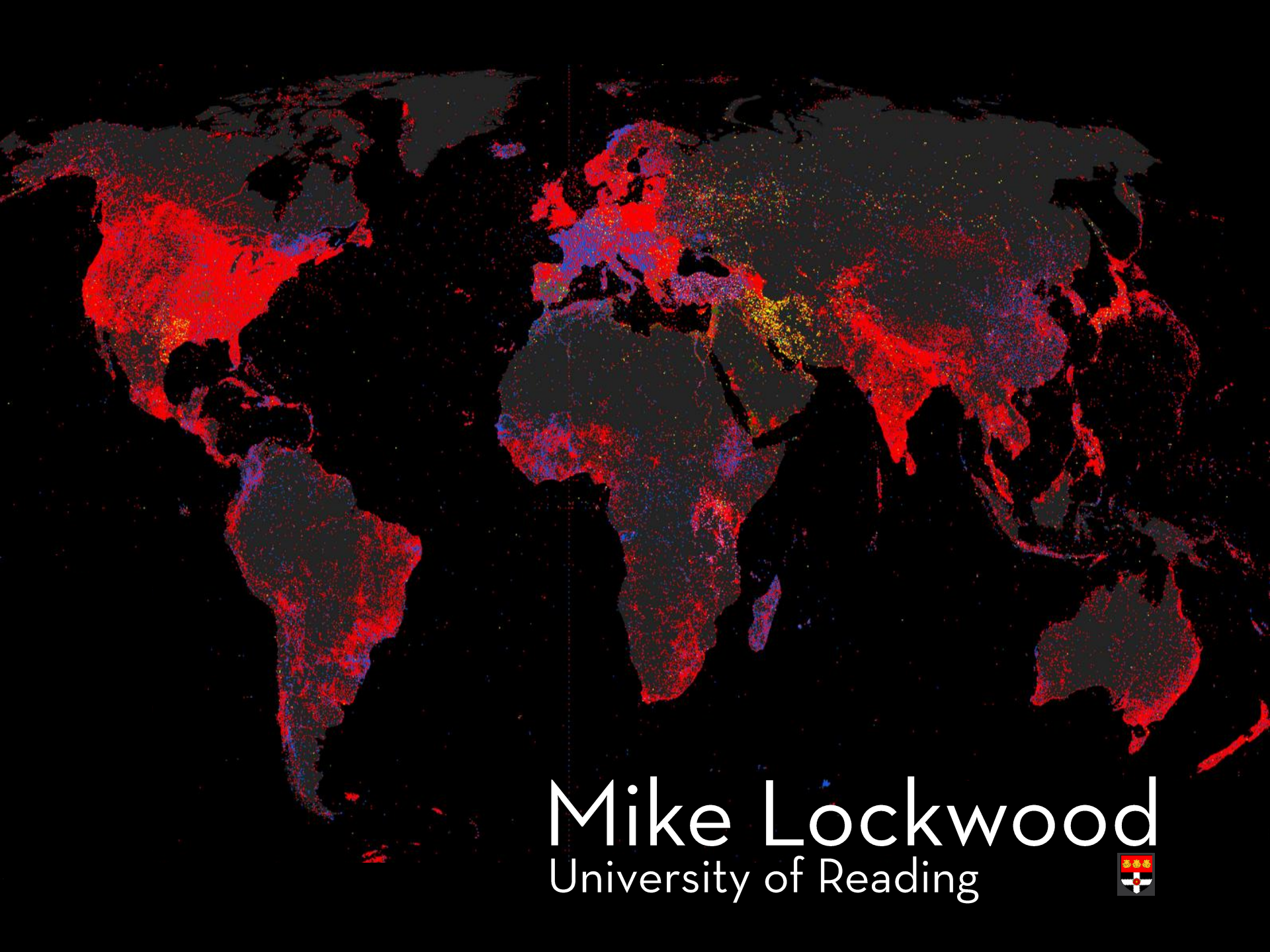

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