The Need for More Integration and Synthesis in Science and the Role of Information Technologies

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GEOProcessing 2020

Let us start looking backwards in history

- History of Science
- History of Information Technologies (IT)

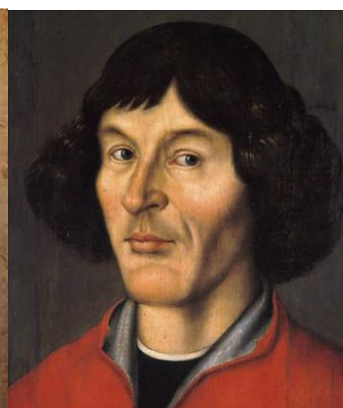
History of Science

- Early history of science is about **wholistic approaches** to **understand the nature**.
  - This has culminated in the end by the creation of the **Renaissance.**
- Since the 20th Century, science became more and more interested in finding out the **details of the system**, rather than the system itself.
  - **System science is marginalized** and became only of interest to few.
- Today science is dominated by the **urge to find more details about the details,** moving from micro- to nano-scales.
  - **All innovation in science is about dealing with a minute detail of a problem** – usually conducted by a PhD work.
  - **All incentives (and metrics) of science is innovation driven** – i.e. easiest way to innovation is to do something which is not yet done – in other words going deeper into the details.
  - **Publish or perish** is the mantra of the day. This leads to pushing scientists into more publications which require new results and hence the easiest way to do this is to produce a paper about a tiny detail of a problem.

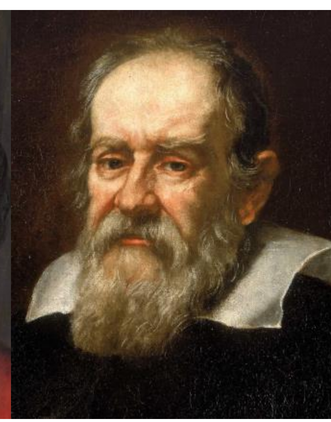
History of Science

- Yesterdays scientists were interested in **solving the big problems**.
    - Todays scientists are more interested in **solving the small problems.**
- Yet all the **global challenges require understanding the system**.
    - Until now we have done a lot of detailed research.
- Now we need to **put the detailed knowledge together, integrate it and do a proper synthesis to understand the system** as a whole.
    - There is a similar analogy: Increasing **precision** of your research does not necessarily mean that your **accuracy** also increases. In experimental research where measurements play an important role, this is a well-known problem.

Leonardo da Vinci (1452-1519)

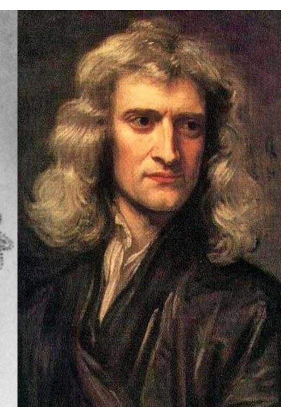


Nikolaus Kopernikus (1473-1543)

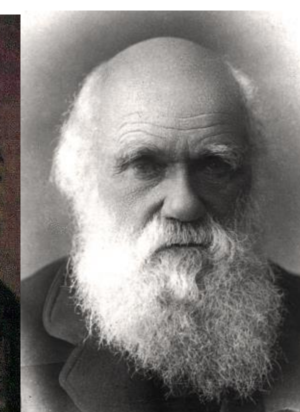


Galileo Galilei (1564-1642)

Johannes Kepler (1571-1630)



Isaac Newton (1642-1727)



Charles Darwin (1809-1882)

Images: Wikipedia

History of Information Technologies (IT)

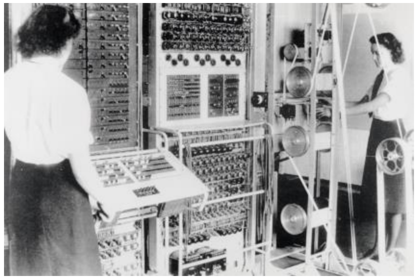


Image: Wikipedia

- The **first computer** (Colossus-UK, ENIAC-USA) during the WW-2
  - Since then computers have evolved to **solving more and more complex problems** through hardware and software developments.
  - **Increasing capacity** of computers for storage and computational power has been accelerating over the last decades.
  - Now there is a hope/move into **quantum computing**.
- While the computing power and storage was accelerating, the idea of linking the computers came about in the form of **world wide web** so-called **"Internet"**
  - This started as a simple scientific need (in CERN and in ARPA) and turned into a system with **enormous impact to society**.
  - Now we are all interested in **Big Data** and solving big problems by "**cloud**" services and grid-computing.
  - **Machine learning and Artificial Intelligence** have become the buzz-words for politicians and entrepreneurs.

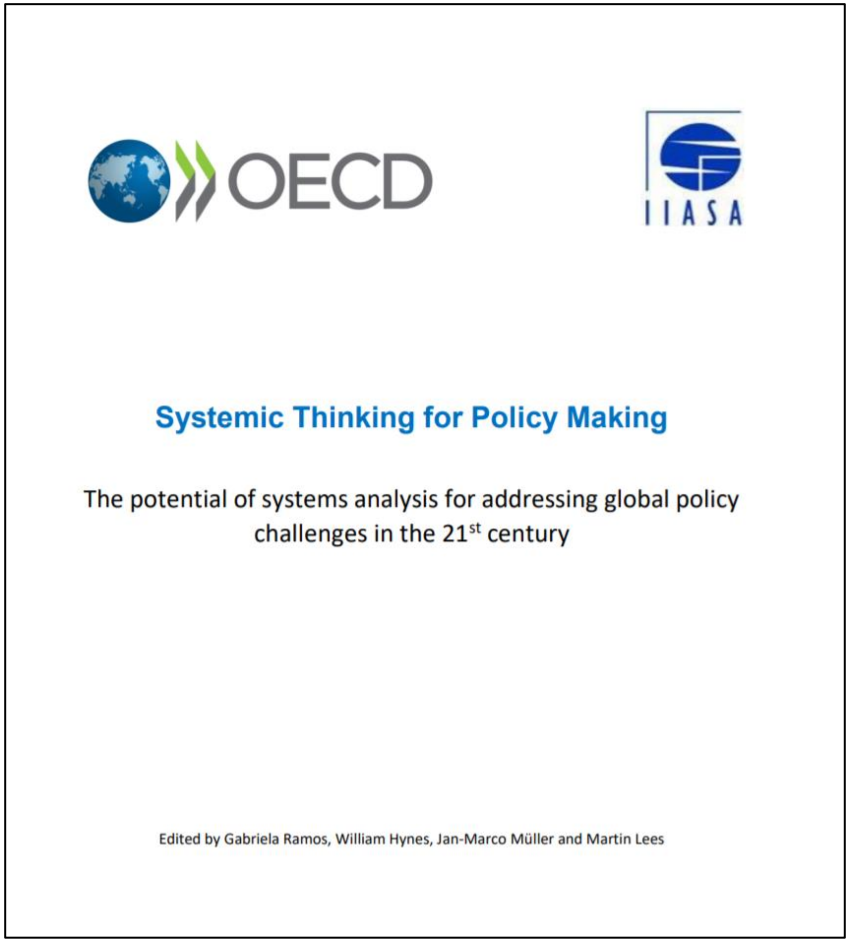
What are the global societal challenges now?

Sustainable Development Goals of UN

- GOAL 1: No Poverty
- GOAL 2: Zero Hunger
- GOAL 3: Good Health and Well-being
- GOAL 4: Quality Education
- GOAL 5: Gender Equality
- GOAL 6: Clean Water and Sanitation
- GOAL 7: Affordable and Clean Energy
- GOAL 8: Decent Work and Economic Growth
- GOAL 9: Industry, Innovation and Infrastructure
- GOAL 10: Reduced Inequality
- GOAL 11: Sustainable Cities and Communities
- GOAL 12: Responsible Consumption and Production
- GOAL 13: Climate Action
- GOAL 14: Life Below Water
- GOAL 15: Life on Land
- GOAL 16: Peace and Justice Strong Institutions
- GOAL 17: Partnerships to achieve the Goal

Global challenges require **systemic thinking and synthesis in science**.

Let's take a look at the **Sustainable Development Goals** (SDG) of the United Nations.

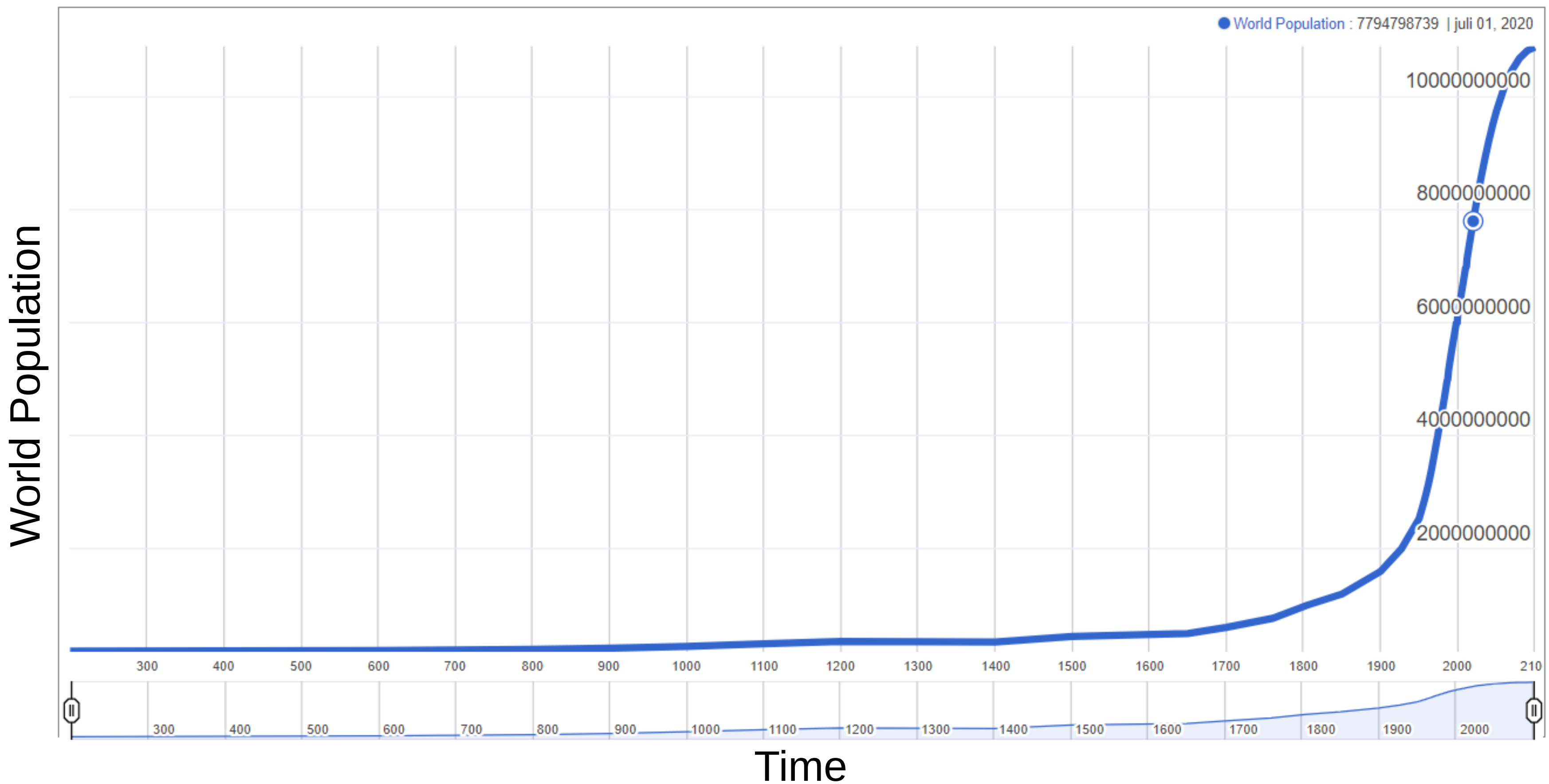

Systemic Thinking for Policy Making

The potential of systems analysis for addressing global policy challenges in the 21st century

Edited by Gabriela Ramos, William Hynes, Jan-Marco Müller and Martin Lees

- SDG research done by **OECD refers to systemic thinking for solving the global challenges** and reaching sustainable development goals.
- Report is available at: https://www.oecd.org/naec/averting-systemic-collapse/SG-NAEC(2019)4_IIASA-OECD_Systems_Thinking_Report.pdf

World Population: Past, Present, Future



(modified from https://www.worldometers.info/world-population/#pastfuture)
Sources: World Population Prospects: The 2019 Revision - United Nations Population Division
The World at Six Billion, World Population, Year 0 to near stabilization [Pdf file] - United Nations Population Division

World Population: Past, Present, Future

At the dawn of agriculture, **about 8000 B.C.,** the population of the world was approximately **5 million**. Over the 8,000-year period up to 1 A.D. it grew to 200 million (some estimate 300 million or even 600, suggesting how imprecise population estimates of early historical periods can be), with a growth rate of under 0.05% per year.

A tremendous change occurred with the industrial revolution: whereas **it had taken all of human history until around 1800 for world population to reach one billion**, the second billion was achieved in only 130 years (1930), the third billion in 30 years (1960), the fourth billion in 15 years (1974), and the fifth billion in only 13 years (1987).

During the 20th century alone, the population in the **world has grown from 1.65 billion to 6 billion**. In 1970, there were roughly half as many people in the world as there are now. Because of declining growth rates, it will now take over 200 years to double again.

https://www.worldometers.info/world-population/#pastfuture
Sources: World Population Prospects: The 2019 Revision - United Nations Population Division
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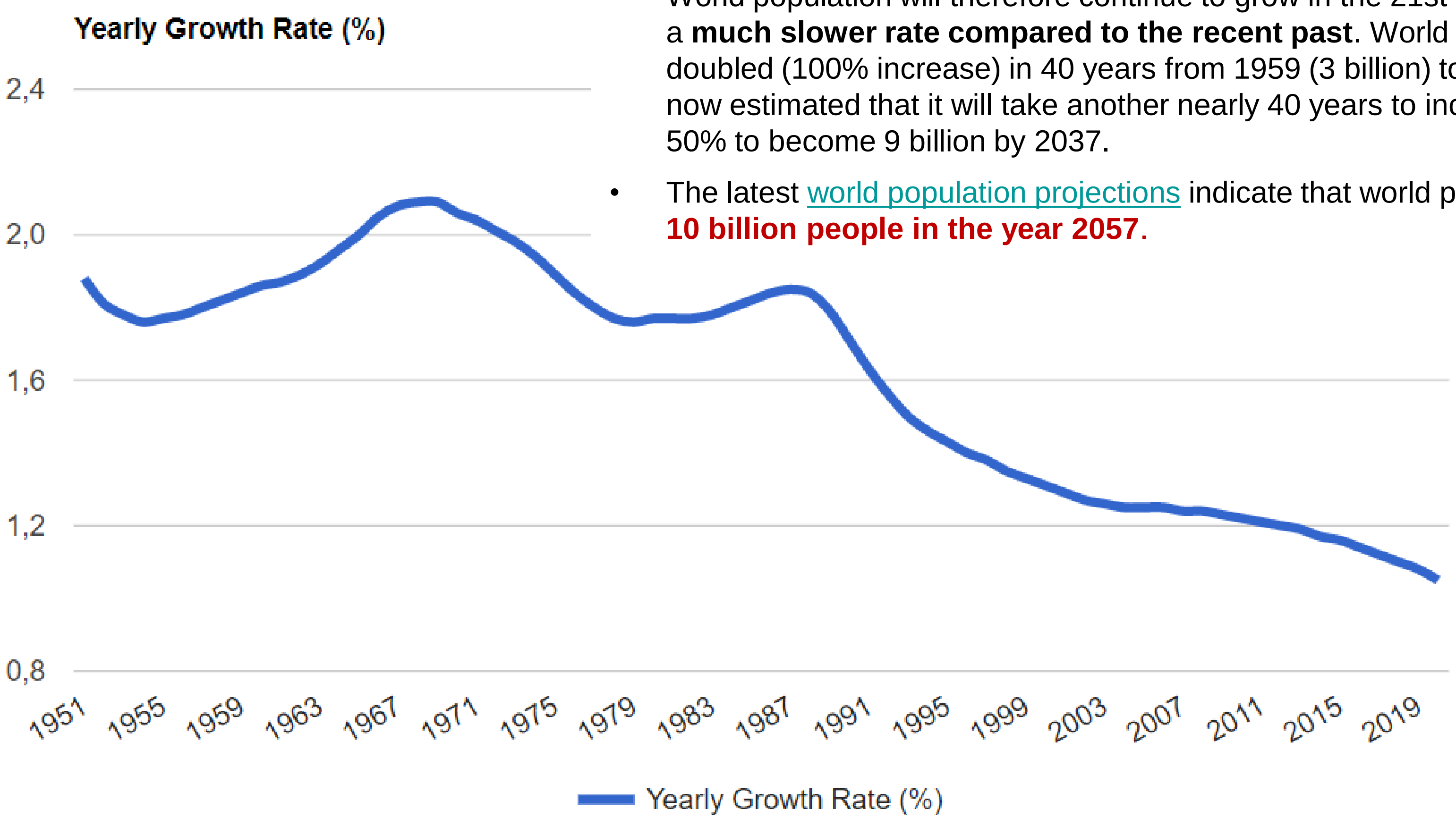
- Population in the world is currently (2020) growing at a rate of around **1.05%** per year (down from 1.08% in 2019, 1.10% in 2018, and 1.12% in 2017). The current average population increase is estimated at **81 million people per year**.
- **Annual growth rate reached its peak in the late 1960s**, when it was at around 2%. The rate of increase has nearly halved since then, and will continue to decline in the coming years.
- World population will therefore continue to grow in the 21st century, but at a **much slower rate compared to the recent past**. World population has doubled (100% increase) in 40 years from 1959 (3 billion) to 1999 (6 billion). It is now estimated that it will take another nearly 40 years to increase by another 50% to become 9 billion by 2037.
- The latest world population projections indicate that world population will reach **10 billion people in the year 2057**.



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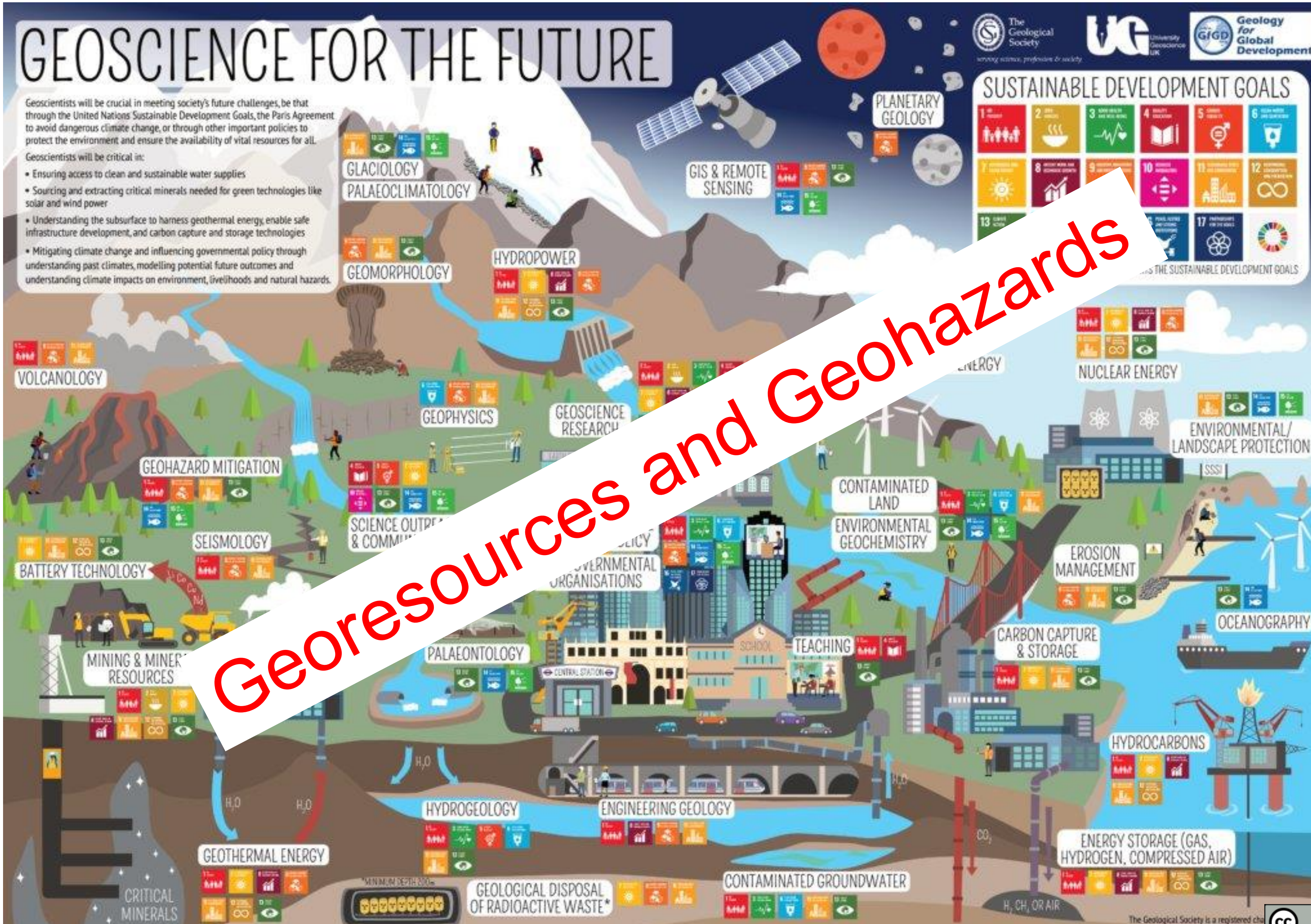

Georesources and Geohazards

What do we need to do?

to address the global societal challenges

What do we need to do?

- We need **more integration**
- We need **more synthesis**
- We need **more systemic thinking and research**
- We need to **change educational systems** to allow for systemic thinking and synthesis
- We need to **bring science and IT closer**
    - currently commercial interests in IT are moving away from the scientific/societal needs.

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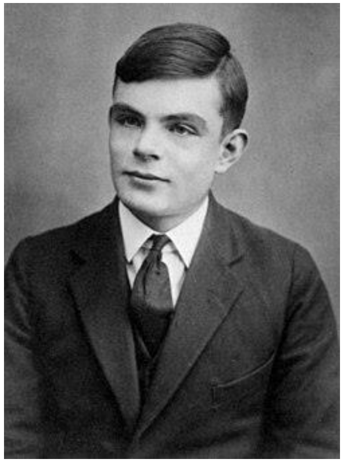
The need for synthesis in IT

to meet the scientific needs to solve societal challenges

The need for synthesis in IT

- There is an **urgent need for synthesis in IT**.
- This is because, the current deveopments of **IT is too much focused on providing special solutions to problems seen isolated.**
- Take **AI developments**:
  - **Buzz-words:** Neural networks, fuzzy logic, machine learning, self organized criticality, self-similarity of systems
  - **Focus now is** on **developing AI solutions** for specialized problems.
    - Current focus on only developing specialized (quite detailed) AI solutions for special problems may lead to a point where **we only develop AI for a very large number of specialized AI**, where no overlying AI is capable of developing itself because **we are not able to add the new higher system's constituing relation/rules in place**.
    - At some point we need to **move to the sytem thinking and introduce development of a higher hieararchi of AI** dealing with development of AI for smaller systems.



Alan M. Touring
(1912-1954)
Theory of computation

Image: Wikipedia

The need for synthesis in IT

- **Future focus should be** on building a higher-order AI constituting relations/rules or a larger system development that can encompass the underlying smaller systems as components of this larger system.
  - This **requires systemic thinking** and understanding the dynamics of the higher-order system.
  - We do not yet know if the higher-order systems and the lower-order systems have the same logic (consituting set of relations/rules) or not.
  - If the AI development is able to mimic the nature, then we may think there is a chance of understanding the entire system's constituting relations/rules, where this may apply to various scales within the system (i.e. **self-similarity principle – Mandelbrot's fractal geometry**).
  - May be we **need bootstrapping techniques** (Efron Bradly, 1979) to move on to a higher system.

Benoit B. Mandelbrot
(1924-2010)

Image: Wikipedia

What are the current trends in IT?

IT topics of current interest

GEOProcessing 2020 conference tracks:

Geo-spatial fundamentals
- Fundamentals of **geo-information**; New trends in **GIS technologies** and research;
- Techniques for geographical representation; Integrated architectures for **geo-spatial information**;
- **Geo-spatial data** in net-centric environment; **Geo-spatial technology**;
- Discovery, indexing and integration of geographical information systems;
- **Geo-processing** of distributed data; **Geo-information processing**;
- Use of computational geometry for **GIS problems**;
- Virtual globes and their application to scientific research; Spatial decision support systems

Trends in Geo-cognition
- **Cognitive geo-spatial images**; Real 3D and Pseudo -3D cartographic visualization;
- **Geographic cognitive models** for cyberspace; **Spatial pattern cognition**; Tactile maps and graphics;
- Spatio-textual similarity; Toponym disambiguation; Geo-spatial intelligence and open source data;
- Distributed convoy pattern mining; **Activity recognition** of passengers (bus, airlines, railway, taxi, etc.);
- Fusing data from smart phones; Collaborative navigation; Visual perception in landscapes;
- Pedestrian mobility behavior patterns; Business news **spatio-temporal data**;
- **Geo-social co-location mining**; Spatial drift analysis; Processing cascading information;
- Web 2.0 Geo-search

Trends on Big Geo-Data
- Public **Geospatial information**; Visualizations of movement data;
- Storage and Indexing spatial big data; **Geospatial Big Data** analytics;
- MapReduce for spatial data; **Geographical hotspots**; Large-scale geospatial data;
- Global-scale Earth data in Cloud; Detecting geo-anomalies; **Geosocial data**;
- Historical maps and big data; **Big data and satellite imagery**; Graph-based tractography;
- **Web-based mapping**; Geotagged Twitter data; Twitter hashtag discovery;
- **Geo-sensor networks**; Geospatial data semantic catalogue; Processing large spatial queries

IT topics of current interest

GEOProcessing 2020 conference tracks:

Trends of Urban-Geo

- Interactive **maps**; Cartographic rules and geographic features; Audio enhanced map animation;
- **Map** legibility and automated cartography**; Spatial decisions** and urban planners;
- Maps and demographic uncertainty for demographic; Emotional **maps** and Smart Cities decisions;
- End-User centered flood evacuation **maps**; Noise **maps**; Avalanche hazard **maps**;
- Location data and privacy; Scientific terrain visualization; Vehicular spatio-temporal computing;
- **Urban spatial crowdsourcing**; Personal driving preferences **map**; Street networks semantics;
- Self-similarity in urban traffic systems; Optimizing public and private transportation **maps**;
- Traffic and road sensor data; Interactive facility **maps** (gas stations, electric vehicular points, banks, etc.);
- Time-depended routing **maps** (emergency, ambulance, fire-stations, etc.); CO2 emissions **maps**;
- Visible landmarks; Connected cell towers **maps**; Public transport assistance

Geo-spatial Web Services

- Geo-spatial Web Services and applications; Geo-spatial Web Services and simulation and modelling;
- Geo-spatial Web Services and sensors; Geo-spatial Web Services and interoperability;
- Geo-spatial Web Services and processing; Geo-spatial Web Services and spatial analysis;
- Geo-spatial Web Services and society; Geo-spatial Web Services and information retrieval;
- Geo-spatial Web Services and human computer interaction; Geo-spatial Web Services and mobility

Assessment of Spatial Data Quality

- Assessing Quality of Volunteered Geographic Information; Frameworks and
- automated methods to assess **spatial data quality**; Assessing spatial data fitness for use;
- Development of new indicators of **spatial data quality**; **Spatial data quality** communication and visualization.

IT topics of current interest

GEOProcessing 2020 conference tracks:

GIS
- Wireless and mobile **GIS**; Integration of remote sensing, **GIS** and **GPS**; Statistics and
- application models of spatial data; GIS for the environment and health;
- **Satellite positioning technology** and LBS; Urban **GIS** and its applications;
- Theories and algorithms in **GIS**; Government and public **GIS**

Geo-spatial simulation and visualization
- **2D and 3D** information visualization; Distributed simulations and sensor webs;
- Simulation modeling **dynamic geo processes**; Exploratory **spatial data** analysis;
- Fine-grained, **terrestrial monitoring** platforms; **Geo-visualization** and **geo-visual analytics**;
- Visualization of **geospatial uncertainty**; Representation and **visualization of geospatial data**

Geo-modeling
- **Standards** and geo-spatial metadata; Novel **geo-spatial data processing** and management mechanisms;
- **Spatio-temporal data modeling** and reasoning; 3D modeling and **GIS**; Modeling and analysis of terrains;
- Modeling **uncertainty in geo-spatial information**; Spatial and **spatio-temporal statistics**;
- Geo-spatial and **spatio-temporal data mining**; Virtual modeling of large geographic areas;
- Time-geography modeling; **Geospatial data analytics**

Digital cartography data
- Digital geographical libraries; Exploratory cartography and interfaces; **Digital cartography**;
- **Automated mapping** and map generalization; **Cartographic theory** and applications;
- **Data models in cartography**; Geographical **search engines**

Earth Geo-observation
- Climate change and the global environment; Data systems for the future **Earth observation satellites**;
- Calibration and validation of **remotely sensed data**; **Earth observation sensor networks** and applications;
- **Earth observation technology** and systems

IT topics of current interest

GEOProcessing 2020 conference tracks:

Geo-sensing

- Acquisition and processing of **remotely sensed data**; Information extraction from **remotely sensed data**;
- **Data mining** across sensor**; Intelligent sensors**/sensor fusion; Co-operative sensing and organization;
- Sensor information management systems; **Spatio-temporal sensor data mining**;
- **Sensor networks** and interaction with actuators; **Geo-sensor specialized networks** (e.g. disaster management, early warning systems, environmental monitoring)

Specific geo-data processing

- Seismic data processing (stacking, migration, post-processing, interpretation); Tomography (algorithms, methods);
- Electromagnetic sounding; Near surface methods (archaeology, urban and environmental planning);
- **Combined geophysical methods** (gravimetry, magnetics, borehole methods); Seismology and planetology;
- **Geo-natural data** on phenomena (hurricane, winds, flooding, etc.); Underground **geo-reserves**, **natural resources**, exploration (gas, oil, metals, etc.);
- Natural **geo-evolution** and morphology (glaciers, oceanic streams, etc.); **Geo-marine** life; **Geology and earth system** simulation and modelling

Geo-spatial domain applications

- Geospatial Technologies for **Disaster Management**;Geology and hydrogeology geographical data;
- **Standardization of geodata** and geoservices; Environment and land surveying; **Oceanographic geo-information**;
- **Natural resource** information systems; **Remote sensing** geospatial data collection;
- Geo-spatial data and vehicular technologies; Geology and Hydrology applications; Location-based services;
- **Environmental monitoring**; Special applications: 3D cadastre, traffic management, etc.

Managing geo-spatial data

- Managing **uncertainty in spatial information**; Automatic mapping (possibly web-based ...);
- Digital elevation/shape modeling; Web-based visualization of statistical data within a geographic framework;
- Tools and links between **GIS and statistical software** packages; Business mapping (spatial analysis for business processes as customer segmentation, churn analysis, etc.);
- **Wireless sensor networks** for spatial applications; Errors and their measurement in spatial data

IT topics of current interest

The 2020 World Congress in Computer Science, Computer Engineering, and Applied Computing (CSCE'20)
https://americancse.org/events/csce2020

SCOPE: Artificial Intelligence + Data Science + Security & Management +
Scientific Computing + Frontiers in Education: CS, CE, STEM, ABET +
Health Informatics + Bioinformatics & Computational Biology +
Biomedical Engineering + Applied Cognitive Computing +
Image Processing, Computer Vision, & Pattern Recognition +
e-Learning, e-Business, Enterprise Information Systems, & e-Gov +
Embedded Systems, Cyber-physical Sys + Internet Computing & IoT +
Foundations of Computer Science + Grid, Cloud, & Cluster Computing +
Information & Knowledge Engineering + Software Eng. Research +
Modeling, Simulation & Visualization + Wireless Networks +
Parallel & Distributed Processing Techniques & Applications.

What is needed in IT?

IT: What is needed?

What do we need to do to address the big societal challenges?

- Research focusing on **synthesis of various data** types
  - **Identify the diverse data types** that are essential in understanding the underlying processes of the system
  - **Collect continuous data** (real-time) from a variety of monitoring sensor-networks
- Collect the **correct and high-quality data** which requires
  - **QA process** in data acquisition, processing and analysis
  - **Provenance information**
    - keeping track of processes (i.e. what happens to data underway and who uses data for what purpose and where it is then made available under which conditions)
    - tracking people – conflicting with GDPR

IT: What is needed?

State of Health Monitoring (SHM) of:

- **Earth's dynamic processes**
  - **Solid Earth** processes
    - Earth's crust and mantle (solid Earth processes)
    - Earth's surface (geological processes)
    - Earth's surface processes (geomorphology,hydrology, erosion)
  - **Biospheric** processes
  - **Atmospheric** processes (climate)
- **Anthropogenic behaviour**
  - **Societal** changes
  - **Political** changes
  - **Industrial** changes
    - Diminishing jobs
    - Robotics and automation
- **Human behaviour**
  - Aging population
  - **Human behaviour**
    - Co-existence with robots and automation

Image: PNGHUT

IT: What is needed?

Big data issues

- **Hardware:**
  - Building big storage capacity
  - Building increased HPC/HTC capacity
  - Compute power will always lack behind the needs of science (by definition)
- **Software:**
  - Building smarter software solutions
  - Community driven software development
  - Corporate driven software development
  - Internet of Things
- **Transmission:**
  - Transmission of big data volumes is still the biggest bottle-neck
    - bringing software to data still doesn't solve the issue, because **synthesis requires bringing data together first for interoperability and then connecting to compute power**
  - Internet transmission technologies
    - Fiber-optic networks
    - New wireless technologies

Image: Freepik

New IT technologies

IT: New Technologies

Image: The Guardian

- **Hardware:**
  - More **CPU, GPU**
  - More Storage - **all-flash storage arrays**
    - More compact flash memory - 3D **NAND technology** stack flash memory cells vertically enabling mobile devices to enhance capacity.
    - **Nonvolatile memory** - computers can retrieve information even after being turned off and back on.
  - Storage on **hard-disks is still much cheaper** compared to flash memory
    - **Flash array capacity** currently ends at about **one petabyte**, while disk arrays have much more
  - Google AI in partnership with NASA has developed **"quantum computing"** capacity in 2019.

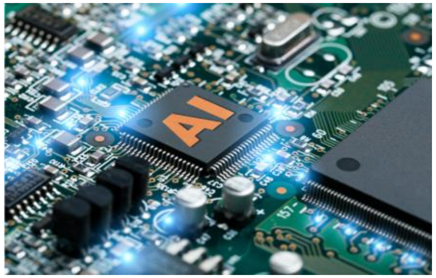


Image: Softweb Solutions Inc

IT: New Technologies

- **Software:**
  - Trending Technologies
    - **Artificial Intelligence**
    - Blockchain
    - Augmented Reality and Virtual Reality
    - **Cognitive Cloud Computing**
    - **Internet of Things (IoT)**
    - Intelligent Apps (I – Apps)
  - Programming trends
    - **Python** is becoming more popular than JAVA
    - Framework programming - **Angular and React**
    - **DevOps** methodology
    - **Open source** – community developments

Getty Images/iStockphoto

IT: New Technologies

- **Transmission:**
  - New technologies **for faster Internet**

    - MIT's wireless Internet MegaMIMO 2.0 - **multiple transmitters and receivers** to relay data simultaneously, increasing the amount of data in a given bandwidth that is **330 percent faster and twice the bandwidth** of existing technology
    - Li-Fi (French) – **LED-based** technology **100 times faster** than existing Wi-Fi
  - New technologies **for better coverage of Internet** (current coverage is ca. 40%)
    - Facebooks's **solar-powered Internet-beaming drone**
    - Google's Project Loon – **baloon based Internet access**
    - Samsung's satellite idea – **4600 satellites to beam 1 Zettabyte** Internet per month
    - NASA – beaming **Internet into deep space**




Images: engadget.com

Challenges

Challenges

External and critical factors for big societal challenges

There are several wild-cards in the system:

- Global developments with **little regulation**
- **Single global economic system** controlled by big financial institutions
- **Wars**
- **Pandemics**
- Space technology developments

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Role of IT

in more synthesis in science

for adressing the big societal challenges

Role of IT on more synthesis in science

Role of IT

- **Data collection (geospatial data)** is essential
  - Sensor-networks, smart-sensors, monitoring networks
- **Standardization and harmonization of metadata** for relevant disciplines (if not all disciplines)
  - Common metadata standards and vocabularies/ontologies
- **Creating interoperability for cross-disciplinary science which is essential for more synthesis in science and hence solving the big societal challanges.**
  - Interoperability requires an integrated IT-system that can handle **multidisciplinary** data to be **visualized, processed, analyzed jointly** (i.e. more cloud computing, VRE's, AI etc. **for cross-disciplinary science**)
- Interoperability requires **rich unified metadata** at higher levels (at interdisciplinary/multidisciplinary level)
  - Such **rich metadata standards exist** (e.g. CERIF)

Role of IT on more synthesis in science

- **Implementing rich metadata** standard in a single domain **requires time**
  - It took 30-40 years from the first use of Internet to the advanced use of social media data
  - It took 15 years for EPOS RI to agree and create a standardized rich metadata in solid Earth Sciences
- It is now high time that **each scientific domain develops its own metadata standards** rich enough to handle the underlying diverse metadata used in its sub-disciplines
- Only then is it possible to develop **a unified standardized and harmonized metadata for higher-order systems** that can allow scientists to conduct cross-disciplinary research **for solving big societal challenges!**

Thank you for your attention!

Video-record of this keynote presentation is available at:
https://youtu.be/NlFHKIzT09s

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