Simulation, Analysis, and Validation of Computational Models

— Background —

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Overview

We will start with a historical and philosophical perspective of the course content.

- Global challenges
- Systems theory and cybernetics
- Modelling as part of the scientific method
- What can we do?

In the following lectures, the content will become more and more technical.

SAVM of Systems

- Is a **system** a set or group of objects, an entity, a compound, a whole, an assemblage, a complex, a totality, a phenomenon, an event, a process?
- The concept **system** emphasises interaction, operating together, structure, dynamics, understandability

Principles of Systems Science (Kalton & Mobus, adapted)

1. Systems exist as holistic units of relations among parts
2. Systems are bounded
3. Systems interact with other systems and form thus larger systems
4. Systems are processes organized in structural and functional hierarchies
5. Systems exhibit various kinds and levels of complexity
6. Systems are dynamic over multiple spatial and time scales
7. Systems evolve and can improve
8. Systems have regulatory subsystems to achieve stability (see also: autopoiesis)
9. Systems can contain models of other systems, so they can be understood
10. Systems can be represented abstractly as networks of relations
11. Systems encode knowledge and receive and send information
12. Sufficiently complex systems can contain models of themselves

Cybernetics (N. Wiener, 1947/48)

- $\kappa\upsilon\beta\varepsilon\rho\nu\eta\tau\iota\kappa\acute{o}\varsigma$ (kubernētikos) meaning '(good at) steering (a ship with a rudder)'
- "governing" = control + communication
- Centrifugal ("fly-ball") *governor*: Feedback system that controls the speed of a machine
  - invented by Christiaan Huygens[1] (1629–1695) to regulate the distance and pressure between millstones in windmills
  - adapted by James Watt (1736 - 1819) to control his steam engine by regulating the flow of steam into the cylinder (1788)
- Cybernetics applies to ecological, technological, biological, cognitive and social systems as a transdisciplinary research field
- Study of systems that are *teleological* by design or by evolution

[1] Also first to formulate a physical problem as a set of mathematical parameters.

Models

A model is an informative representation

- Implicit mental models (Kenneth Craik, 1943)
- Abstract models
  - Language
  - Logic, reason, science
  - Cognitive understanding
- Physical models (objects)
- Computational models
  - Opaque or clear
  - Symbolic or subsymbolic
  - macroscale and microscale
  - algorithmic or mechanistic

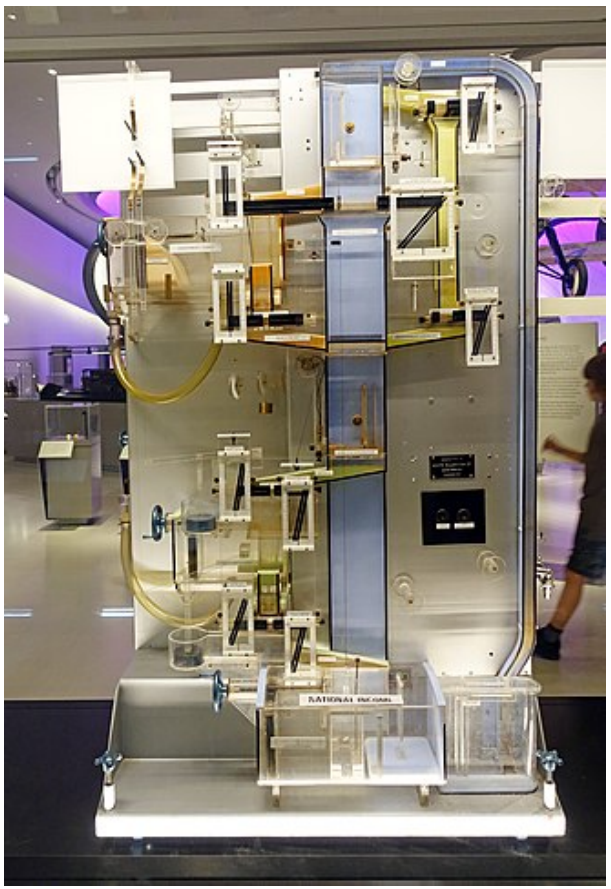
MONIAC (Monetary National Income Analogue Computer)

MONIAC

Monetary National Income Analogue Computer

- Bill Phillips (1949)
- Model of the national economic processes of the UK
- Designed as a teaching aid, but turned out to be an effective economic simulator
- Working copies in London, Cambridge, Istambul, Wellington

Wikipedia



Phillips Machine at the Science Museum London (image: Tiia Monto)

Computers

Willem Klein (1912 – 1986)

- regularly examined by a neurologist for incredible computing capabilities
- 1952 – 1954 *Mathematisch Centrum* (Amsterdam) as scientific calculator
- 1958 – 1976 *CERN* (Geneva) as programmer, analyst and computer
- in between and later performed fast calculations as an act in shows and circuses.

(source: Wikipedia)

Thomas Watson, Jr., IBM Chairman (1953): "the [IBM 701 Electronic Data Processing] machine rents for between $12,000 and $18,000 a month, so it was not the type of thing that could be sold from place to place. But, as a result of our trip [presenting *paper plan* to $\approx$ 20 businesses], on which we expected to get orders for five machines, we came home with orders for 18."

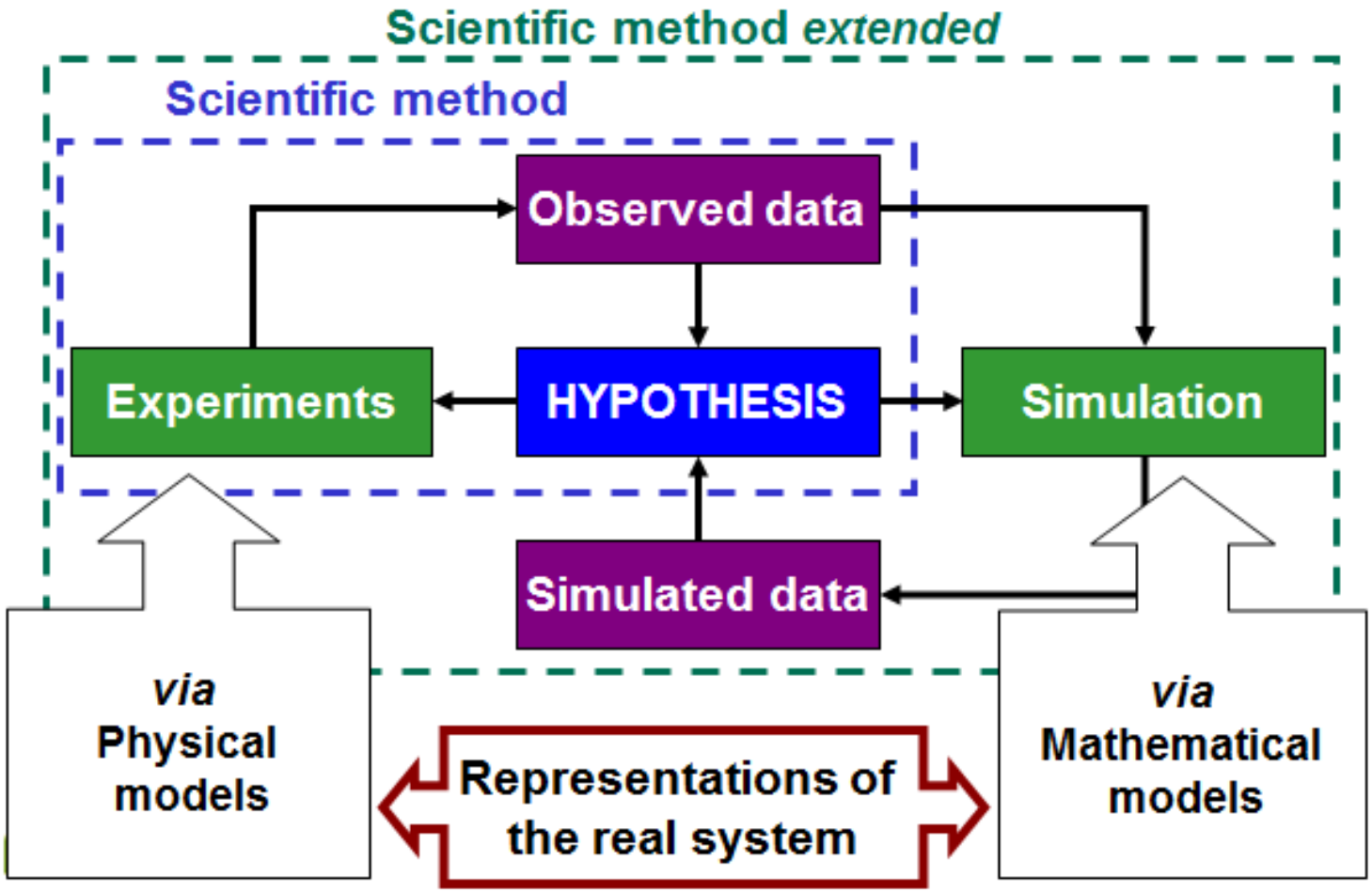
(source: IBM)

Computational modeling and computer simulations

- Mechanism and behavior of complex systems are studied by computer simulation using mathematics, statistics, computer science as well as any sciences related to the systems in question.
- Models can characterise systems by numerous variables that serves as inputs and as targets for prediction
- Simulation is done by adjusting these variables and observing how the changes affect the outcomes predicted by the model.
- Computer experiments in large numbers identify a small number of lab experiments that are most likely to solve the problem being studied, or just a single real-world application.
- Models can provide an interrelation among multiple levels, e.g. time scales or length scales

National Institutes of Health, NIBIB

The scientific method extended by models



"Physical model" means here a scientific theory (unlike on slide 6), Wikipedia (Marcello Donatelli, 2008)

Today: How do things work? How to make things work?

- Cyber-physical systems, mechatronics
- Internet of things, embedded systems
- Operations research
- Virtual reality, augmented reality, computer graphics
- Autonomous robotics, human-robot interaction
- Network science, control/theory of complex networks
- Systems biology, medicine, prosthetics
- Computational neuroscience, brain–computer interface, integrated information theory, theory of mind
- Physics-informed neural networks
- Research on global challenges

Ethics

How should we deal with the real world or nature?

- Understanding
- Interfering
- Changing
- Improving
- Partitioning
- Internetworking
- Governing

Next topics

- MC
- Linearity
- Non-linearity and chaos
- Examples