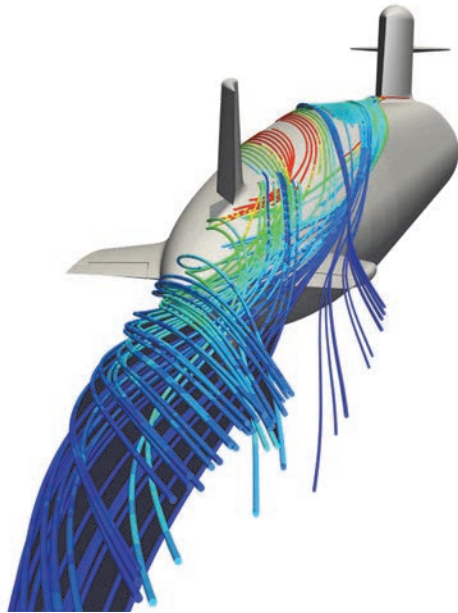# Numerical Simulation, An Art of Prediction 1

Theory

Jean-François Sigrist

Color section

(a) Submarine navigation
(Source: French Navy)

(b) Hydrodynamic simulation
(Source: Naval Group)

Figure 1.1. *Numerical simulation nowadays accompanies the design of a ship as complex as a submarine [BOV 16, REN 15]*

Figure 1.2. *Strength calculation of a pair of glasses (Source: image made with the COMSOL Multiphysics® code and provided by COMSOL, www.comsol.fr)*

Figure 1.6. *Overflow, Luka Fineisen, 2009, plastic film and adhesive tape, work from the installation Perfect Fluid (Source: Luka Fineisen)*
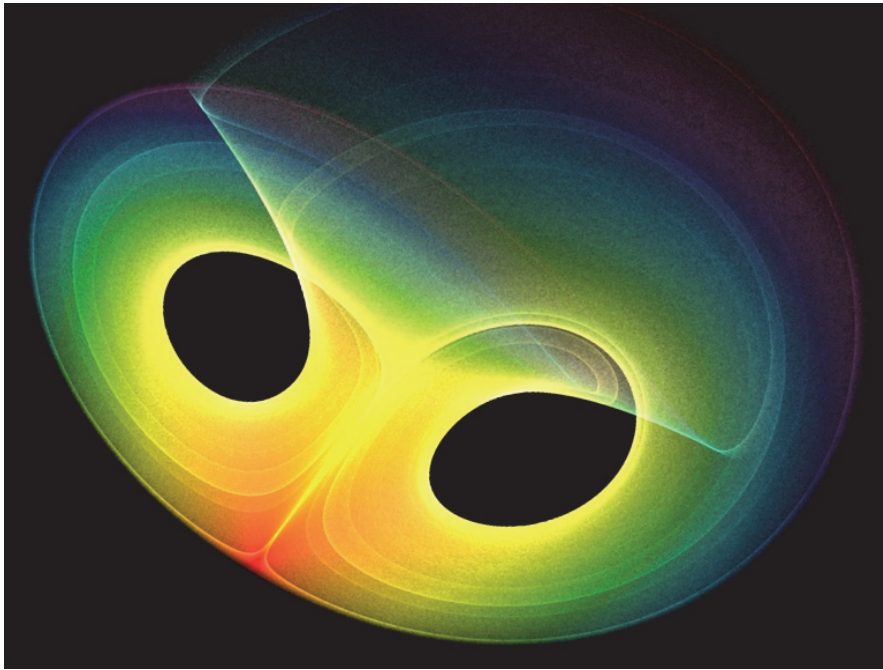
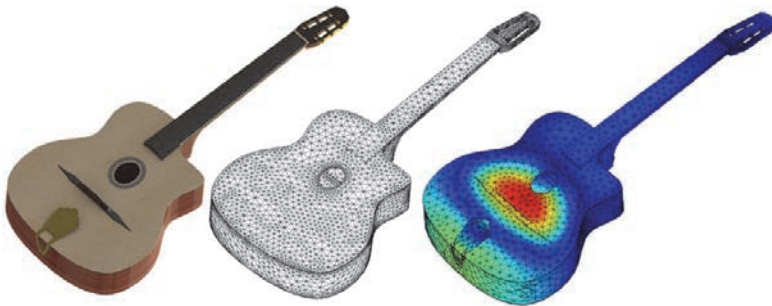**Figure 1.8.** *Lorenz's attractor (Source: www.commons.wikimedia.org)*

Figure 1.9. *From the model resulting from computer-aided design to the result of calculating the vibrations of a guitar [VIA 18c]*
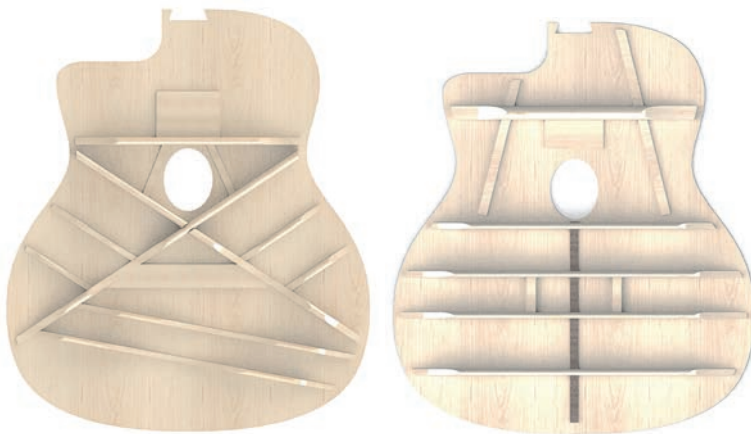
Figure 1.10. *Models of the soundbox of a guitar for two wood species with two positionings of the braces [VIA 18c]*
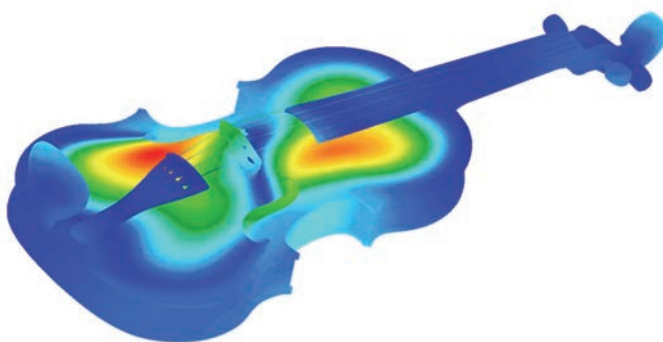

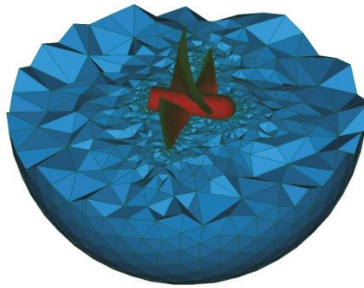**Figure 1.11.** *Vibration mode of a violin [VIA 18a]*

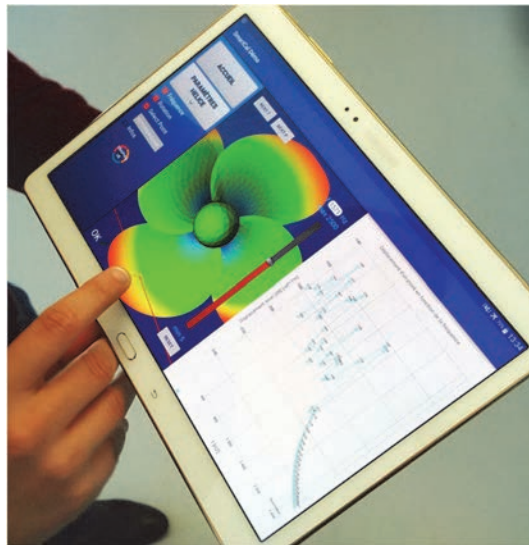**Figure 1.13.** *Numerical model of a submerged propeller [LEB 16]*

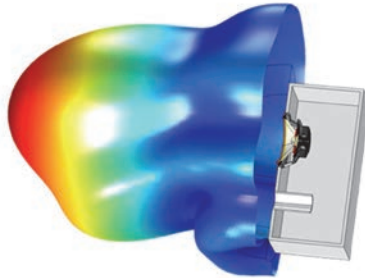**Figure 1.14.** *Calculation with a reduced order model on a digital tablet [LEB 17]*

Figure 1.15. *Simulation of the acoustics of a loudspeaker (Source: image made with the COMSOL Multiphysics® code and provided by COMSOL, www.comsol.fr)*
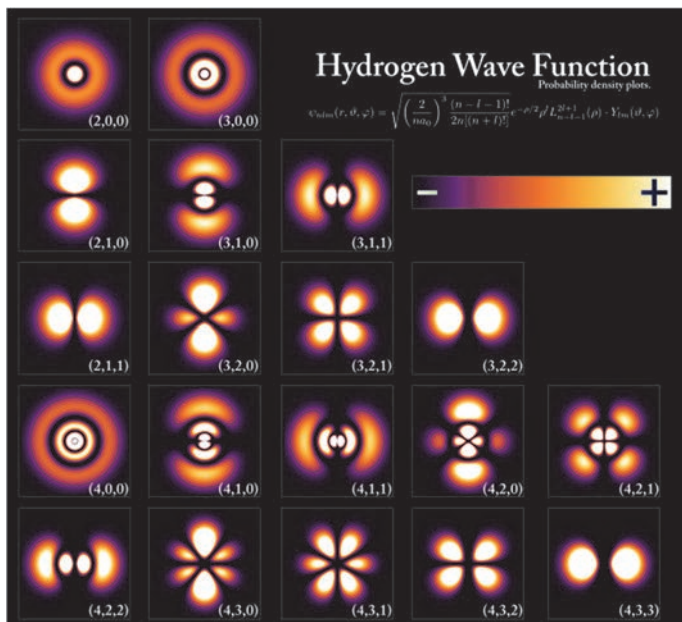

Figure 1.23. *Atomic orbitals are obtained by solving Schrödinger's equation*
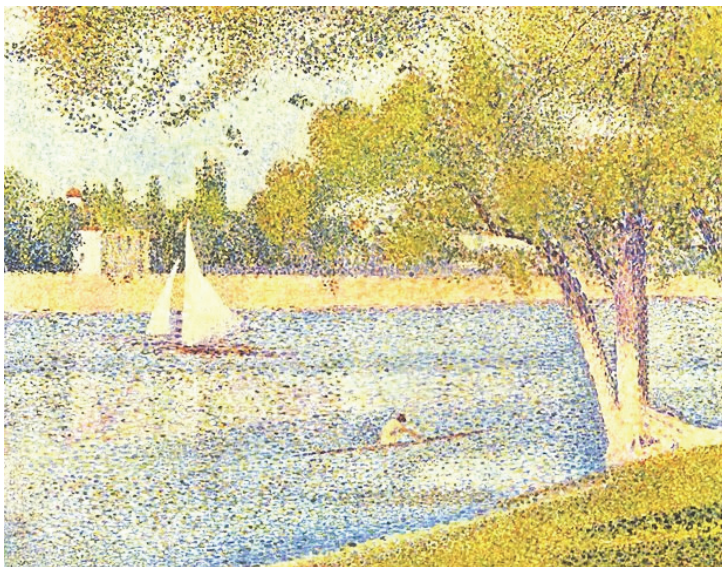
Figure 1.26. La Seine à la grande jatte, *Georges Seurat (1859–1891), 1888, oil on canvas, Musées Royaux des Beaux-Arts de Belgique, Brussels*
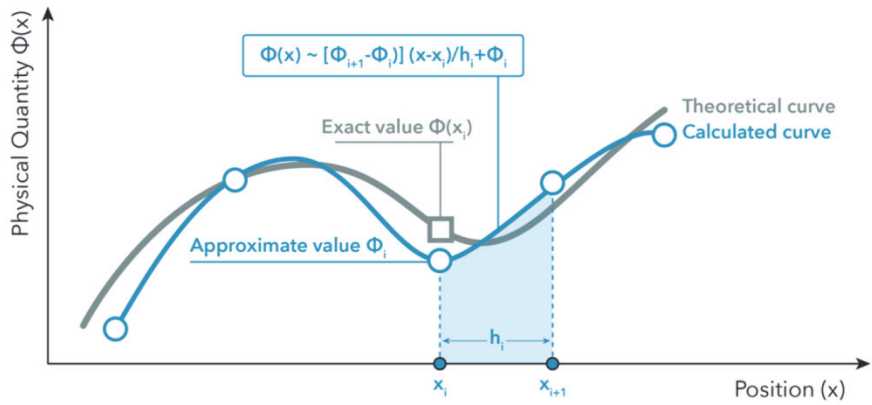
Figure 1.27. *Principle of discretization (between the two points x_i and x_{i+1}, the calculated curve is a line whose formula is given in the figure)*
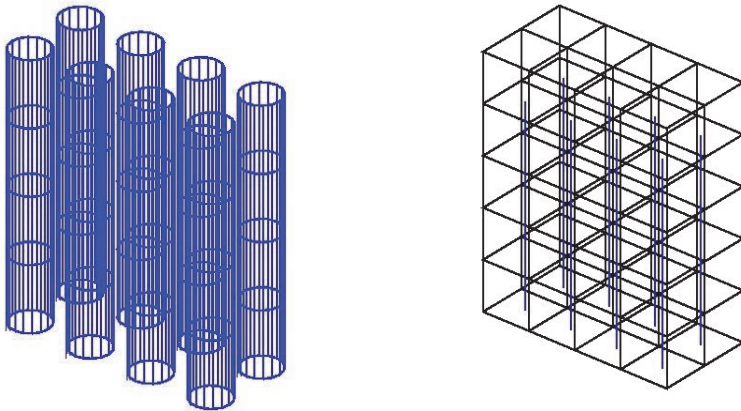

Figure 2.2. *Principle of a homogenization method (on the left a group of tubes whose dynamics are described individually; on the right the same group is described on average) [BRO 08]*
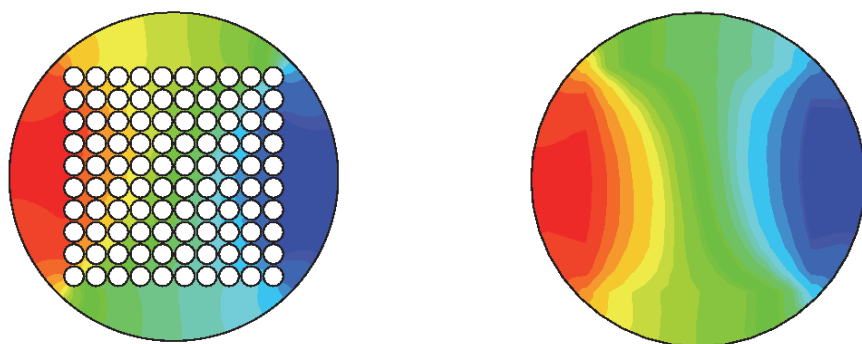
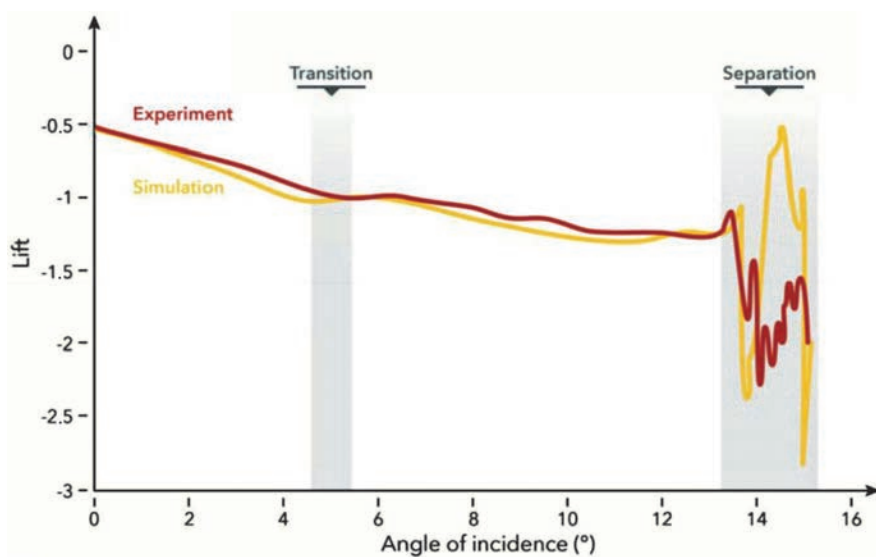**Figure 2.3.** *Comparison of the complete and average calculation methods for a tube bundle [SIG 08b]*

Figure 2.6. *Comparison of a flow calculation with an experimental result [DUC 09]*
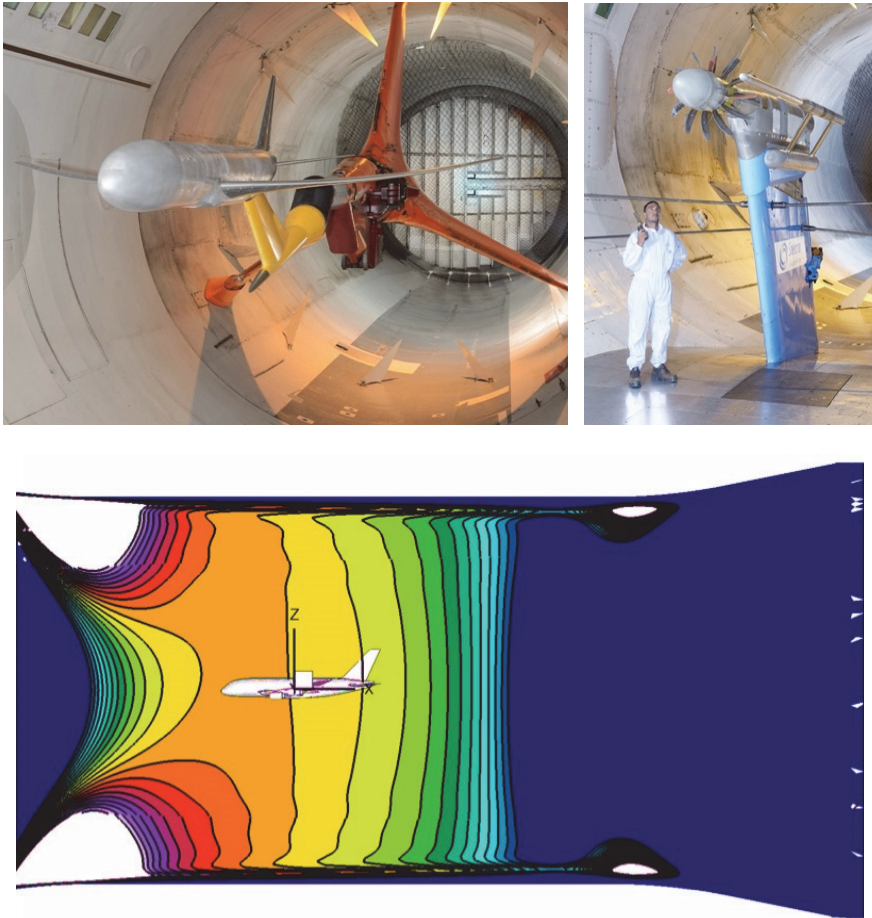
Figure 2.7. *Tests and model calculations are complementary (Source: © ONERA, ONERA/Airbus)*
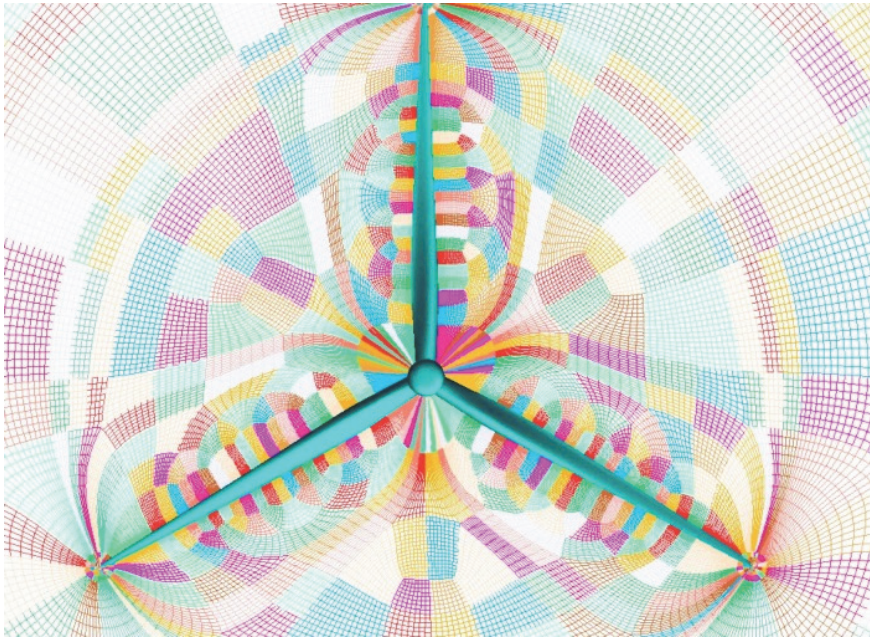
Figure 2.10. *Mesh preparing the wind turbine aerodynamics calculation (Source: www.gridpro.com)*

Figure 2.12. *A simulation of the coffee and cream mixture using the SPH method [ORT 12]*
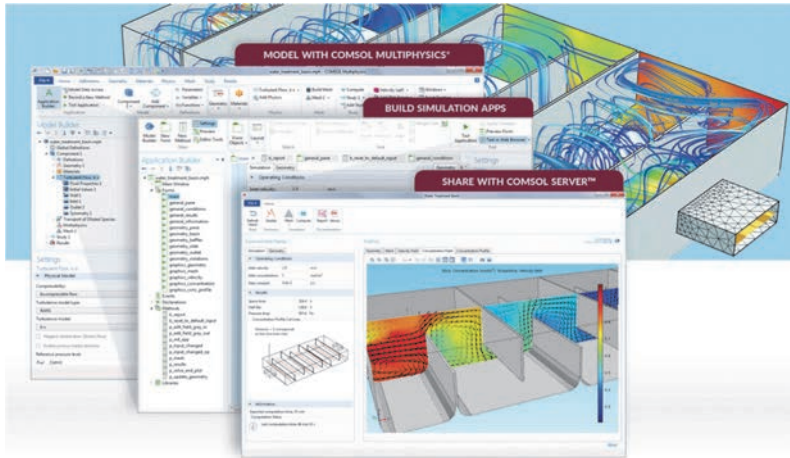
Figure 2.13. *Design of a drinking water treatment basin using a generalist tool (Source: image produced with the COMSOL Multiphysics® code and provided by COMSOL/www.comsol.com)*
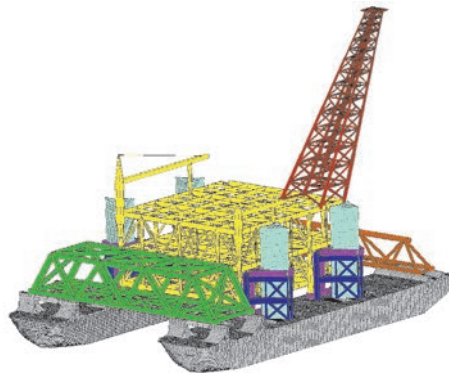

Figure 2.14. *Digital model for the transport of a platform at sea (Source: © TechnipFMC)*
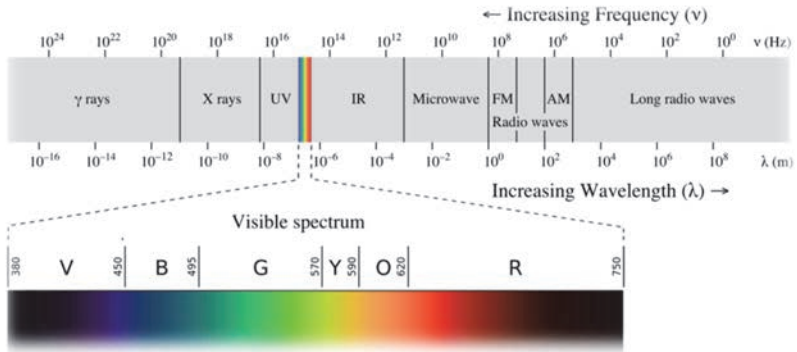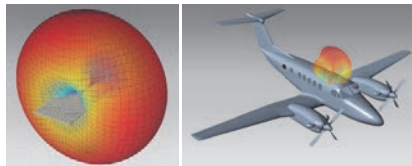
Figure 2.15. *Spectrum of electromagnetic waves (Source: www.commons.wikimedia. org). For a color version of this figure, see www.iste.co.uk/sigrist/simulation1.zip*

(a) RFID tag   *(b) Radiocommunication antenna on an aircraft*

Figure 2.16. *Example of electromagnetic simulation (Source: image produced with the CAPITOLE-RF code and provided by the company NEXIO, www.nexiogroup. com)*
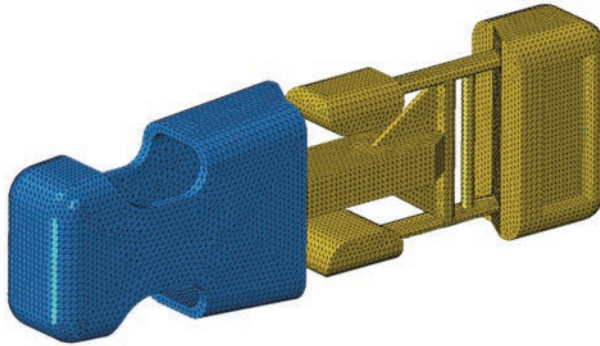
Figure 2.17. *The simplest parts can be studied using numerical simulation (Source: EC2 Modélisation, www.ec2-modelisation.fr)*
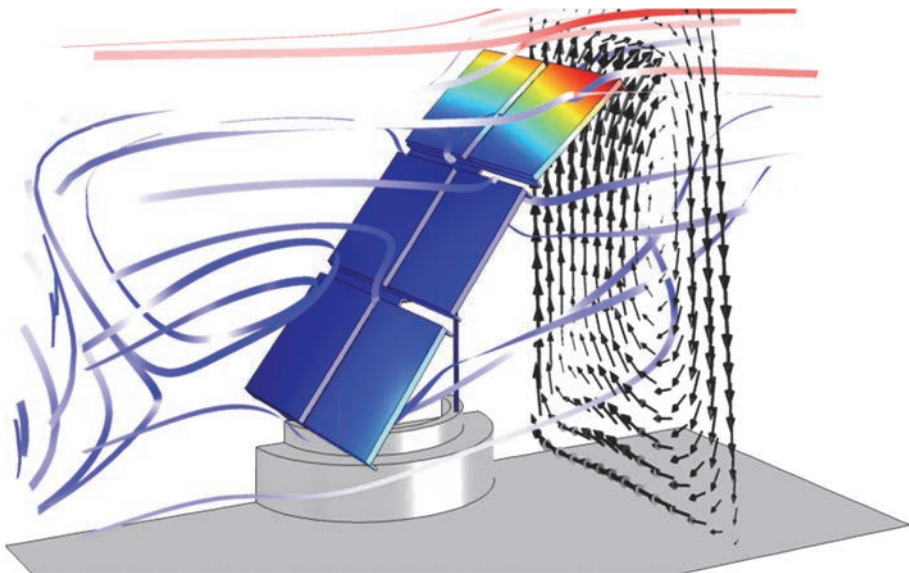

Figure 2.18. *Simulation of the flow around a solar panel (Source: image made with the COMSOL Multiphysics® code and provided by COMSOL, www.comsol.com)*
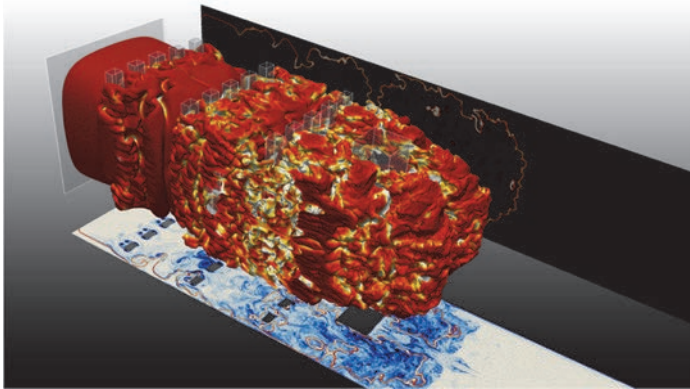
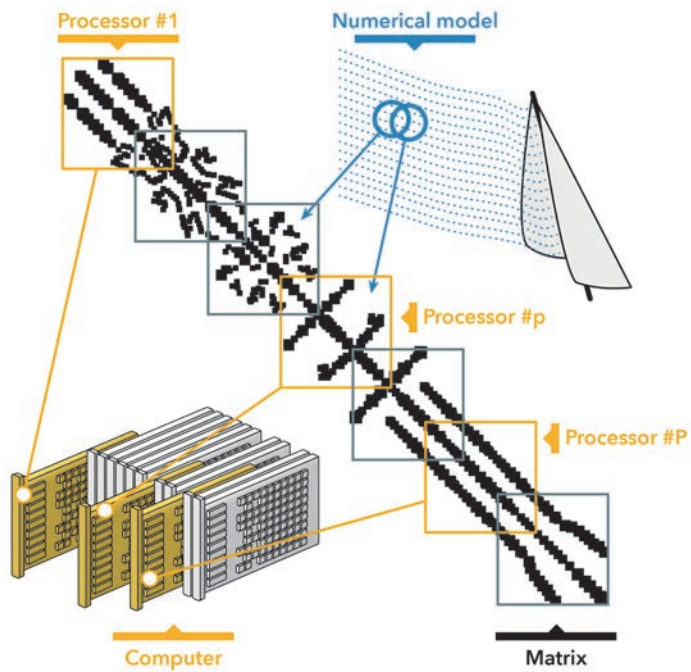**Figure 3.4.** *Simulation of an accidental explosion in a building [VERM 17]*

Figure 3.6. *Pictorial principle of parallel calculation (example based on [AUG 12])*
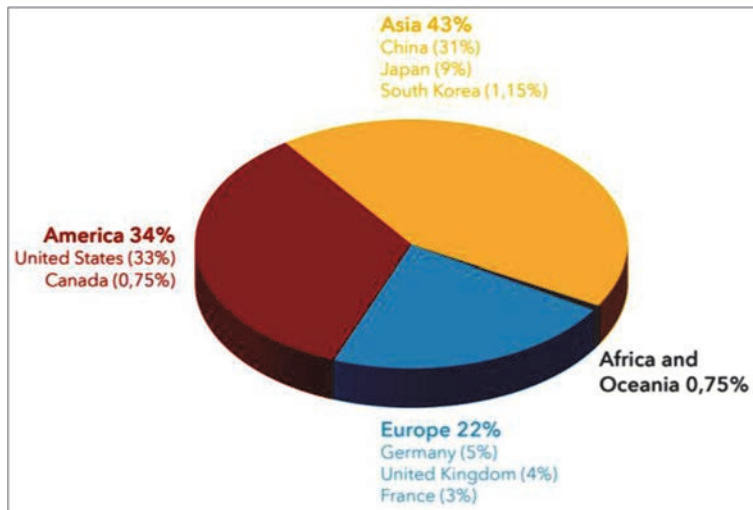
Figure 3.8. *Distribution of computing power by continent (June 2017 figures, see www.top500.org for updated data) (Source: www.top500.org)*
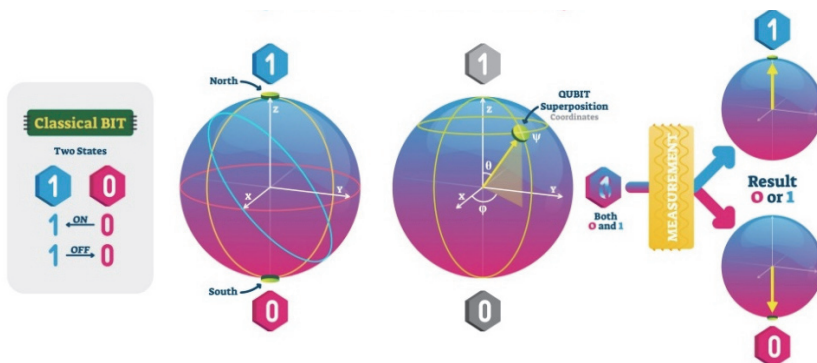

Figure 3.13. *Bit and Qubit (Source: www.shutterstock.com)*

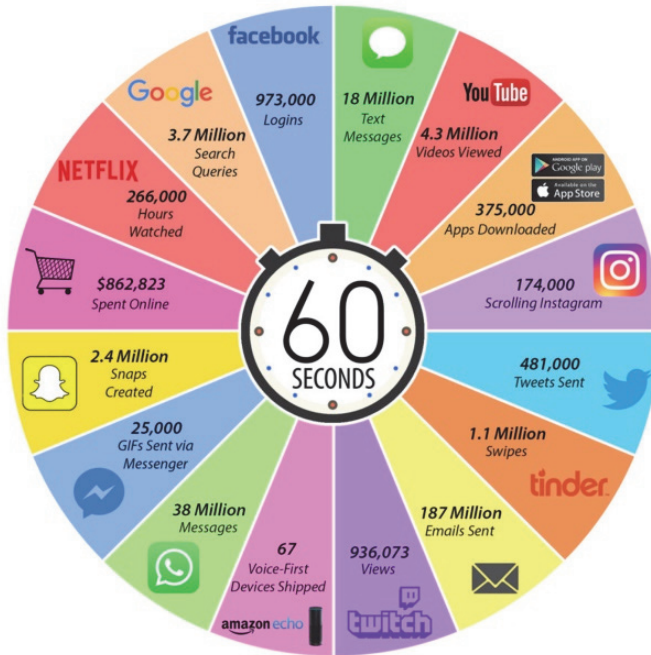**Figure 4.1.** *The 4 Vs of Big Data (Source: www.shutterstock.com)*

Figure 4.2. *60 seconds of Internet (Source: www.virtualcapitalist.com)*

Figure 4.3. *Map of data center locations in Western Europe (Source: www.datacentermap.com)*
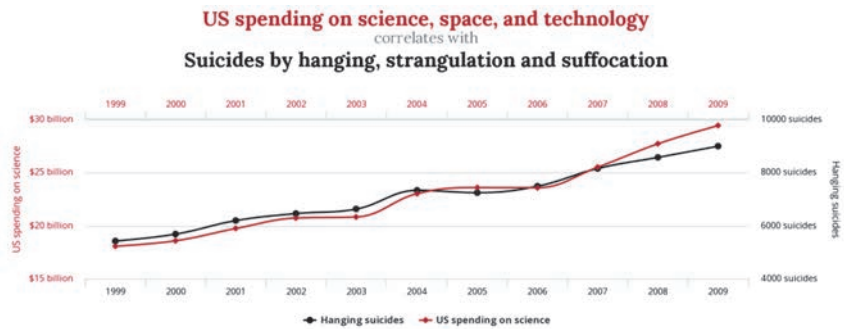
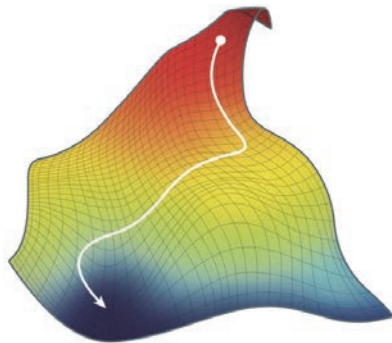**Figure 4.5.** *An example of a non-causality correlation (Source: www.tylervigen.com/spurious-correlations)*

Figure 4.6. *A "descent" algorithm makes it possible to find in a few iterations the minimum value of a function*
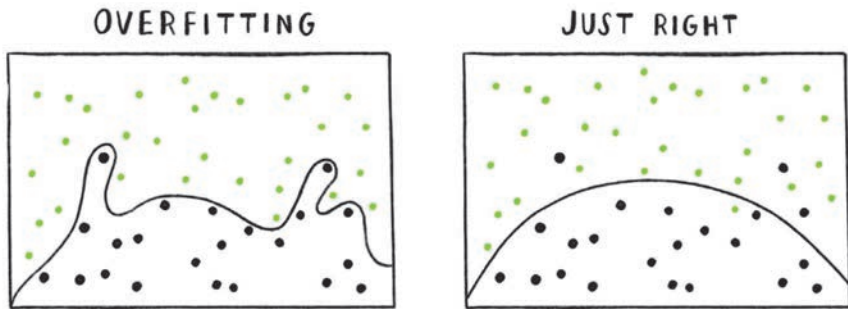
Figure 4.7. *Finding a balance between the complexity and representativeness of an explanation (Source: https://www.geckoboard.com/learn/data-literacy/statistical-fallacies/overfitting/)*
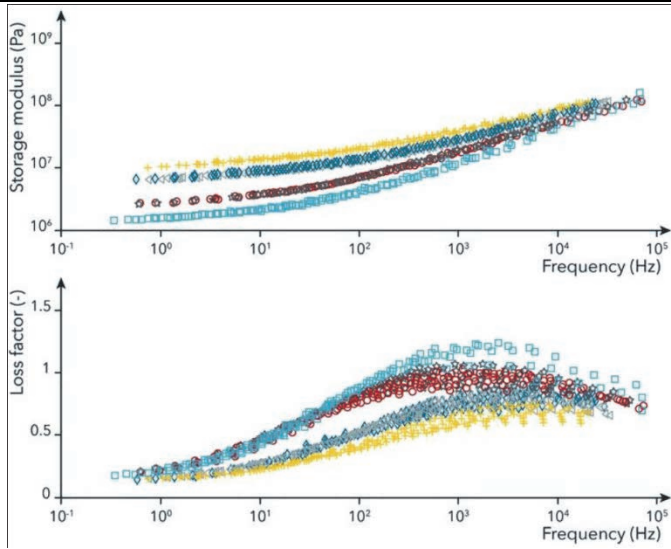

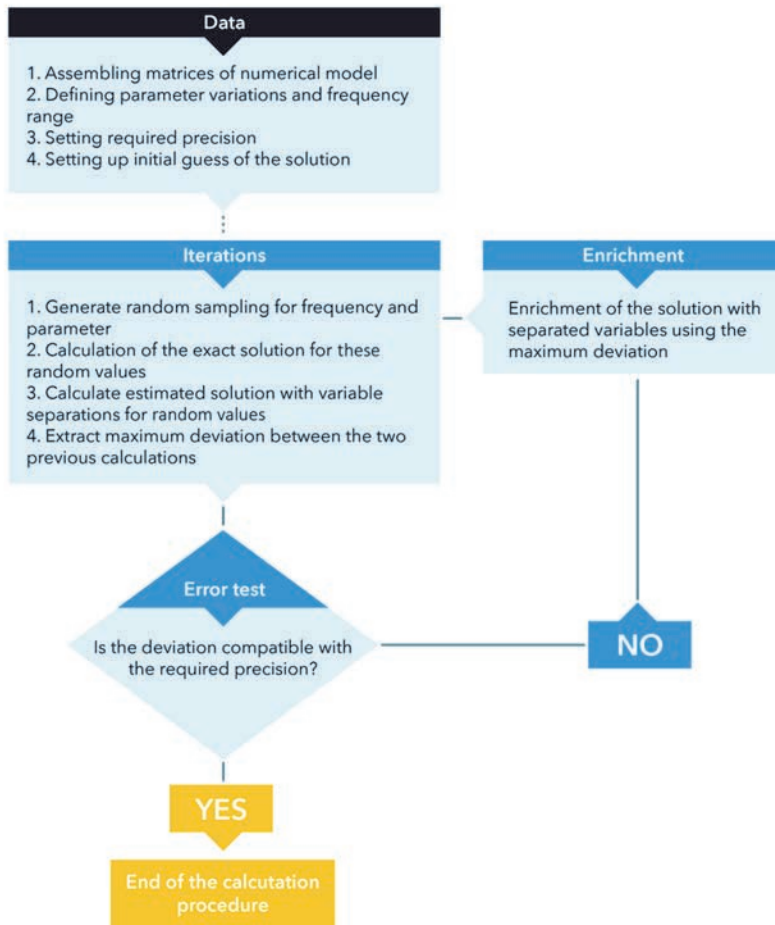**Figure 4.8.** *Example of dispersion of material characteristics (adapted from [ROU 13])*

Figure 4.9. *A learning algorithm based on an equation (example inspired by [LEB 16)]*
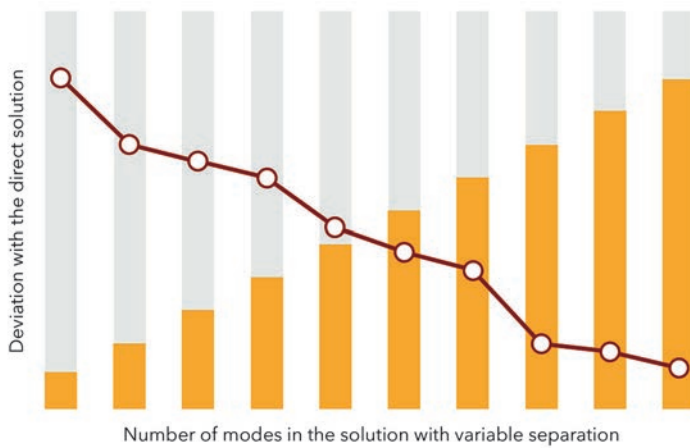
Figure 4.10. *Learning curve of the algorithm (example inspired by [LEB 16])*
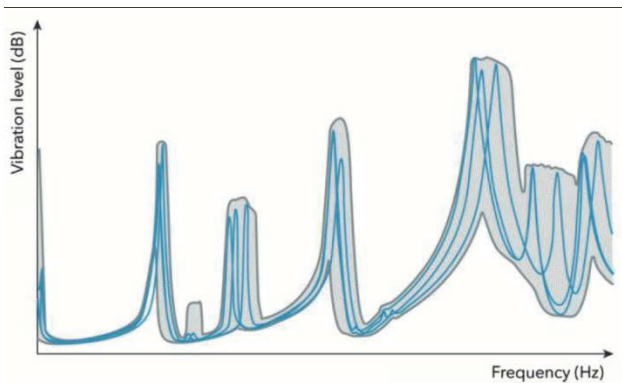

Figure 4.11. *Example of frequency response (the curve represents the vibration level – vertical axis, measured in dB, the unit of sound intensity – as a function of frequency – horizontal axis, measured in Hz, the unit of bass and treble measurement)*
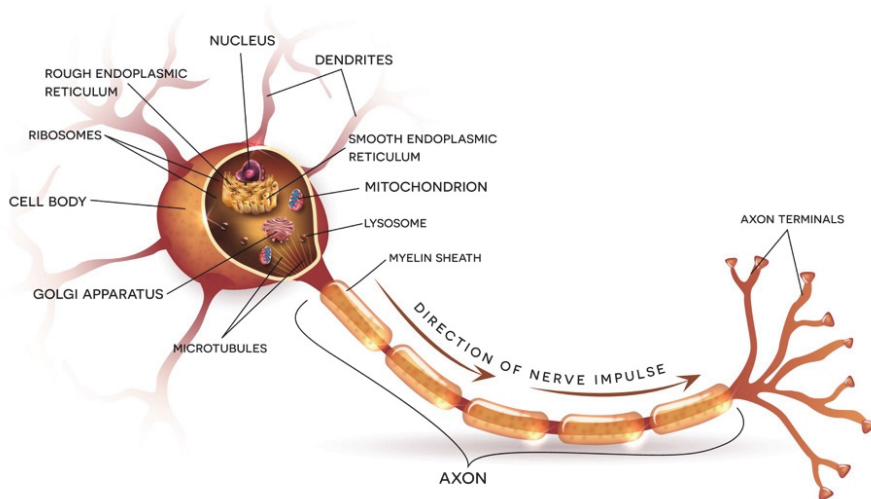
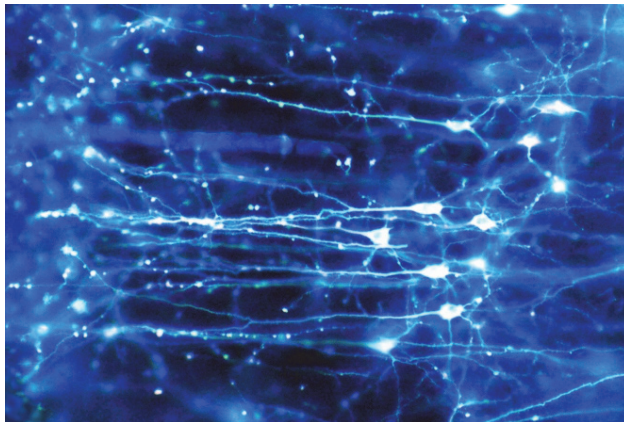**Figure 4.13.** *Simplified diagram of a neuron (Source: Natalia Romanov/www.123rf. com)*

Figure 4.14. *Neurons in the brain (Source: Dr. Jonathan Clarke, University College London)*
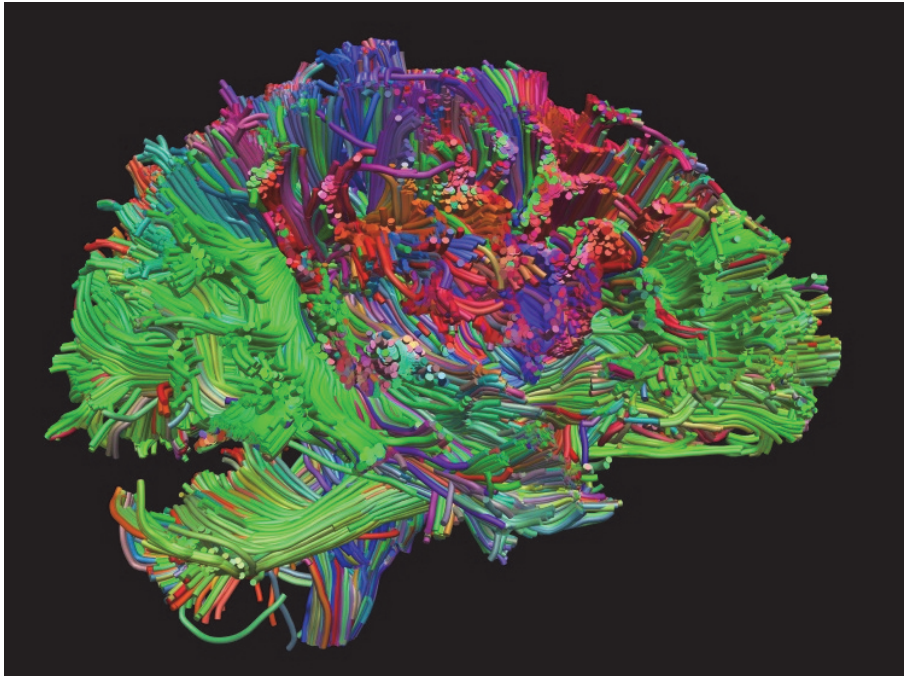
Figure 4.15. *Healthy adult human brain viewed from the side, tractography (Source: Henrietta Howells, NatBrainLab)*
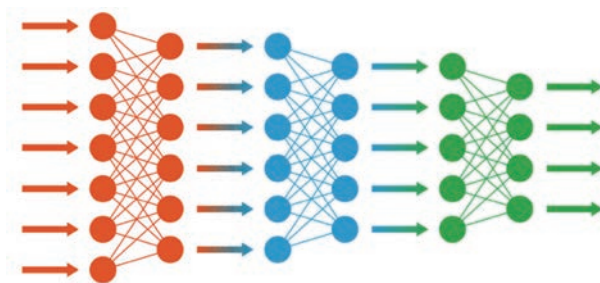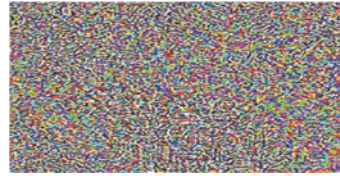

Figure 4.18. *Image representation of the functioning of a neural network by stacking layers (Source: Dimitri Korolev, www.123rf.com)*

(a) An image of a panda, identified with 60% confidence by a neural network

(b) Disruption of the image proposed by researchers in the form of a mathematical function

(c) The modified image is unchanged in our eyes, the neural network identifies it as that of a gibbon with 90% confidence!

(d) An image of a gibbon

Figure 4.19. *The trompe l'oeil technique is not only for humans! A form of digital simulation can lure a neural network... and help improve its robustness (Example adapted from [GOO 15] and illustrated with photographs of a panda [Source: Volodymyr Goinyk, www.123rf.com] and a gibbon [Source: Komkrit Tonusin, www.123 rf.com]*
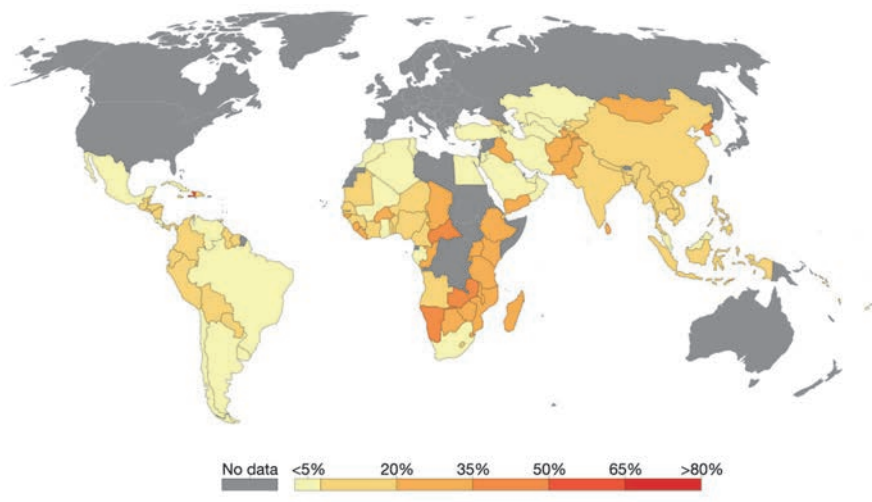
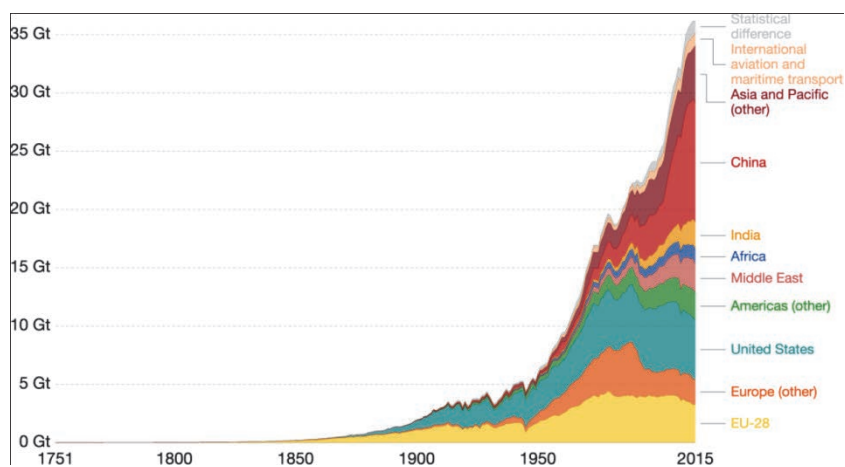**Figure C.1.** *Share of the world's undernourished population in 2015 (Source: Our World in Data, https://ourworldindata.org/hunger-and-undernourishment)*

Figure C.3. *Greenhouse gas emissions between 1751 and 2015 (Source: Our World in Data, https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions)*
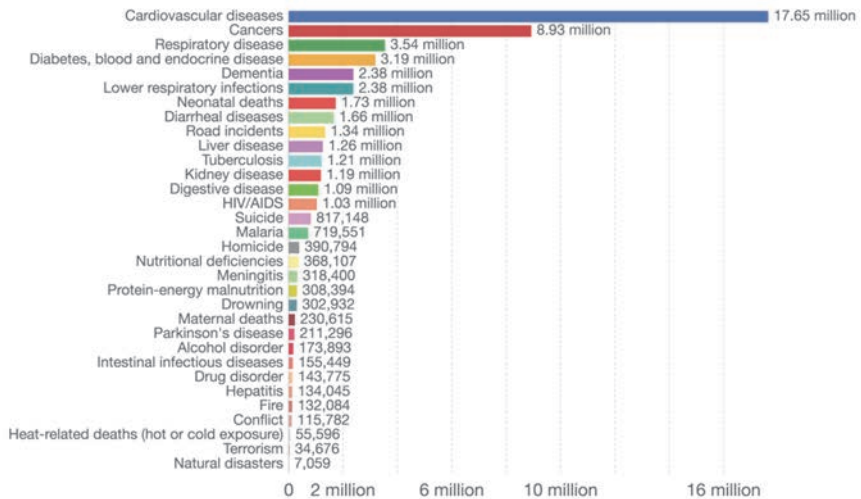
Figure C.4. *Leading causes of death worldwide (Source: Our World in Data, https://ourworldindata.org/causes-of-death)*