Studying the models to understand the real world: a praise of simulation

Prof. Federico Milano

Email: federico.milano@ucd.ie

Webpage: faraday1.ucd.ie

School of Electrical & Electronic Engineering

University College Dublin

Dublin, Ireland

Power & Energy Society®

Contents

- Why do we simulate?
- The unbearable lightness of modelling

Why do we simulate?

Simulation is useful

- To reduce the lifetime cost of a system.
- In requirements: trade-off studies.
- In test and design: fewer proto-types.
- In training: avoid accidents.
- In operation: anticipate problems.

Example of costly training

- The prospective pilot sat in the top section of this device and was required to line up a reference bar with the horizon. 1910.
- More than half the pilots who died in WW1 were killed in training.

Example of erroneous usage of simulation results

- It is well known that the accident of Challenger space shuttle on 28th January 1986.
- The cause of the disaster has been attributed to the **acceptance of deviations** concept introduced by NASA to overcome the mismatches between theory and simulation/experimental results.

Example of costly operation problem

- European “blackout” occurred on 4/11/2006.
- The frequency drops to 49 Hz, which causes an automatic load schedding.
- Real power surplus of 6000 MW.

When do we simulate?

- Let define:
  - Lifetime savings is what you save by better trade-offs, less proto-typing, fewer accidents.
  - Simulator costs are what you pay to build, buy, apply, and maintain simulators.
  - Adoption costs are what you pay to change the organization's culture and train people in new methods.
- Then we simulate if:

$$\text{Lifetime savings} > \text{Simulator costs} + \text{Adoption costs}$$

The unbearable lightness of modelling

Key Features of a Simulation Tool of Physical Systems

- Modular and bottom-up construction of models.
- Separation of the model and its simulator.

Modularity and bottom-up construction of models

- It allows large simulators to be built and tested piecewise.
- Atomic models encapsulate basic behaviors.
- These smallest pieces can be built, tested, and maintained in isolation.
- This principle of encapsulation extends to the entire simulator.

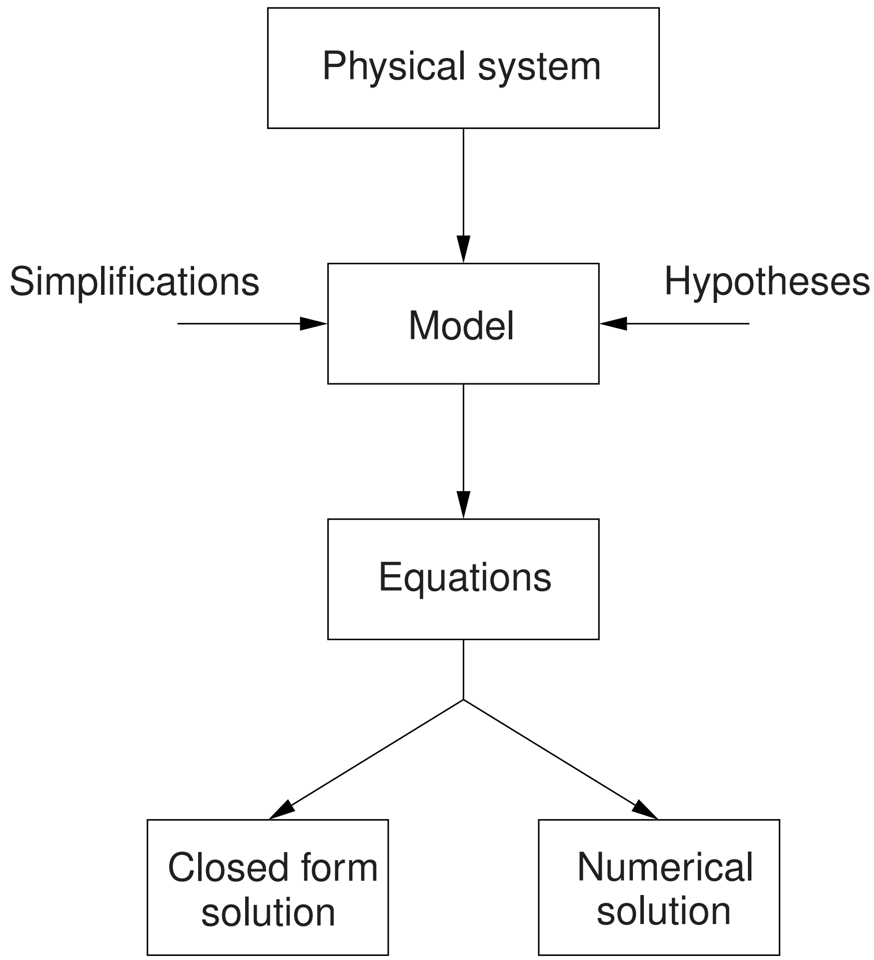
Separation of the model and its simulator

- The algorithms contained within the simulation engine are designed for a specific class of systems.
- They can therefore be built, tested, and maintained without reference to any particular system.
- The definition of the class of systems presumed by the simulator is a guarantee of how it will function.
- Improvements in the simulation engine are therefore transparent to the models, and this greatly simplifies the long-term maintenance of a simulation program.

How Simulation Tools Affect the Model (I)

- In the past, analogical Transient Network Analyzers (TNAs) were the only simulation tools available for research and education in power engineering.
- The advent of digital analysis has led to a more convenient way of performing simulations through digital computers.
- Thus, the *model* is a simplified representation of the physical system suitable for being:
  - expressed in terms of mathematical equations; and
  - translated into computer programming code.

General Approach for Studying a Physical System



How Simulation Tools Affect the Model (II)

- Both simplifications and hypotheses are often driven by the numerical solution methods that are available for solving the given system equations.
- Even more critical is the importance of simplifications if one looks for an analytical explicit solution.
- A fruitful approach: *try to solve simple problems by hand*. Good ideas often come out just to avoid a repetitive work.

Examples

- Examples of problems that has to be reformulated because of the lack of suitable solvers:
  - Mixed-integer nonlinear programming problems;
  - Determination of the Lyapunov function of a generic system;
  - Stochastic differential algebraic equations with stochastic processes within the algebraic terms.
  - Functional differential equations with time delays depending on the state variables.
  - etc.

Black-Box Approach – I

- A “black-box” approach is generally consiered to be a blind and acritical acceptance of the modeling assumptions and simplifications of others.
- In other words, the contrary of research!

Black-Box Approach – II

- However . . .

Black-Box Approach – II

- However . . .
- . . . in some way or in another, all of us has used a black-box approach.

Black-Box Approach – II

- However . . .
- . . . in some way or in another, all of us has used a black-box approach.
- It all depends on the level at which we decide to do research.

Examples

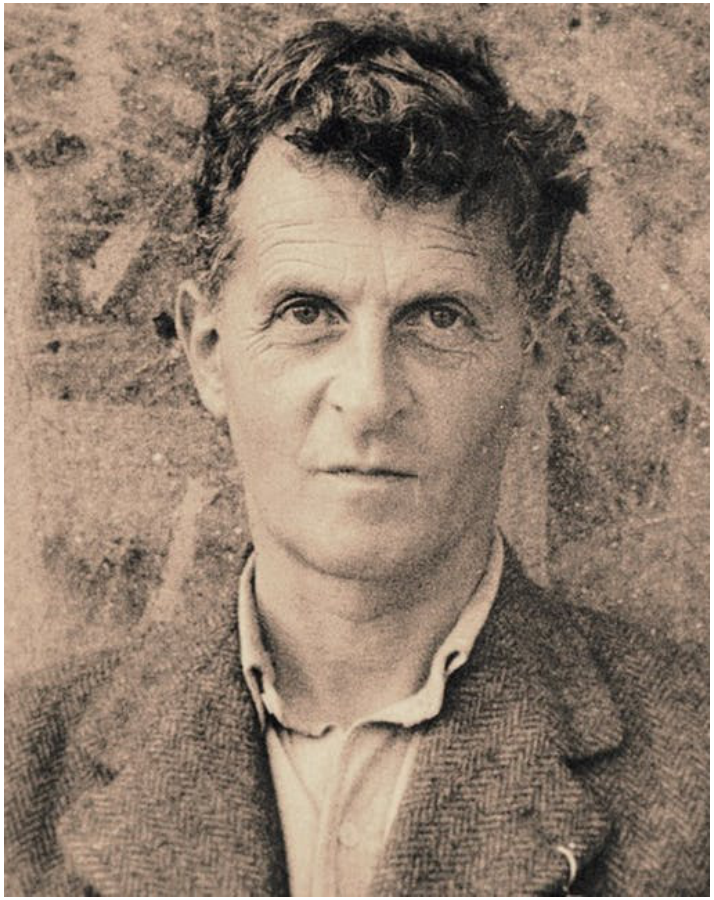
- Multiplication of floats: $z = x * y$ (recently D. Harvey and J. van der Hoven found a technique with complexity $n\log(n)$)
- Matrix factorization: KLU library (T. Davis does research developing SuiteSparse library)
- Power system modelling: PSAT & Dome (F. Milano develops software tools for power system stability analysis)
- Develop new techniques and test them with commercial power system software tools (everybody else in this panel)

Models are all we have . . .

Τί δῆτα, ὦ ξένε, εἴδωλον ἄν φαῖμεν
εἶναι πλήν γε τὸ πρὸς τἀληχινόν
ἀφωμοιωμένον ἕτερον τοιοῦτον;

Plato, *Sophist*, 365-361 B.C.

. . . and are probably not even right . . .



2.1	We make ourselves pictures of facts.
2.12	The picture is a model of reality.
2.225	There is no picture which is a priori true.

Ludwig Wittgenstein,

Tractatus Logico-Philosophicus, 1922

. . . but always better than pure theoretical abstractions!

There's this farmer, and he has these chickens, but they won't lay any eggs. So, he calls a physicist to help. The physicist then does some calculations, and he says, um, I have a solution, but it only works with spherical chickens in a vacuum.

Leonard Hofstadter, *The Big Bang Theory*, 2008.

Thanks much for your attention!