The need of modeling: Experience from the Samothraki Summer University

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During the Summer University I had the opportunity to give a short lecture on modelling and simulation of dynamic systems with some examples on the Biosphere Reserves and other environmental related cases.

To study, analyse and control systems we need to know them very well and therefore to have a mathematical model that describes them, which can be used either as a simulator or as a control model. A simulator-model is complex in order to describe as accurate and realistic as possible the real system behavior. A control model takes a simpler representation but always taking into account the essence of the real system and its characteristic behavior. Therefore, modeling techniques can achieve models in a simple or complex manner depending on the objective.

The models serve to determine criteria of lawful change and thus fulfil at least three purposes:

- Prediction: given a description of the system over a period of time and the set of rules governing change, to predict the way the system will behave in the future.
- Learning new rules: given a description of the world at different times, to produce a set of rules which accounts for regularities in the system.
- Data compression: to generate a model that represents data on a compact form with a low complexity.

Models can be developed in two ways: The theoretical approach consists in building a model from physical laws. Here, the modeler can face the difficulty of managing all the physical laws that take part and the obtained model can be very complex and thus difficult to manage. Another drawback of this approach is that real phenomena such as components wearing, tolerances and noise are not taken into account.

When a system is not suitable for the theoretical approach for any reason (e.g. complexity, lack of knowledge of its structure, etc.), we resort to the experimental or identification approach that permits the achievement of valid models. This approach consists in analysing the system in basis of studying of the system response signals to other stimulation signals. In this approach, not adopting any hypothesis about the system's characteristics makes the study difficult and limits its quality.

The experience demonstrates that the best solution is the combination of both approaches if possible. In the first analysis stage, based on the physical laws and working conditions (operation modes) an hypothesis is set. In the next experimental stage, starting from the hypothesis, the obtained experimental measures are considered to determine the coefficients of the mathematical model.

For a system having response, it is necessary to stimulate it through the input variables that are generated for the environment and influence its behavior. There exist two kinds of input variables: those that can and those that cannot be controlled (disturbances, automatically generated by the environment). The variables generated by the system are the output variables, influencing the environment. Those variables are measurable and, sometimes, observable.

With a system like that of Fig. 1, mainly, two problems can arise:

Firstly the direct problem of analysis: knowing (input, system), find (output). This problem has a unique solution.

Secondly there are inverse problems:

1. Knowing (input, output), find (system). This problem does not have a unique solution but infinite correct solutions. This is a problem of structure identification and state estimation, and it is called a problem of synthesis.
2. Knowing (system, output), find (input). This is a problem of control (instrumentation).

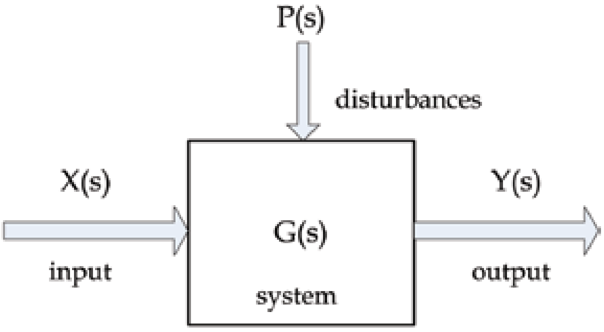

Figure 1. The system diagram.

Type of systems

Depending on the models, they can be classified using different criteria:

According to the technology of its elements: There are mechanical systems (built with springs, wheels, etc.); electrical (motors etc.); electronic (RLC, amplifiers etc.); thermal (oven, chemical reactors etc.), hydraulic ones (tanks, pipes, canals etc).

According to the number of inputs and outputs: SISO (Single Input, Single Output); MIMO (Multiple Inputs, Multiple Outputs); SIMO; MISO; etc.

According to the properties distribution we distinguish those with distributed parameters (properties distributed in time and space) and those with concentrated parameters (the changes in the variables occur in specific points).

According to the relation among the system variables, we distinguish the stochastic (the relations among the system variables are described in a probabilistic way and the response to the input is unpredictable) and the deterministic ones (the relations among the system variables are not random, and the response to the input is predictable and repeatable).

According to the discretization of the variables, we distinguish the continuous (in a finite time interval, the state variables take infinite values) and the discrete time ones(the changes succeed only in the discretization or sampling time).

Modeling and simulation spectrum

A system can belong to different disciplines and each one presents different aspects to be taken into account when treating it. The modeler can face systems that present only historical data (e.g. public opinion). Models can only be built from experimentation and the modeling technique that is mainly used when the system structure is unknown is *identification*, leading to models called *black box*, represented with differential equations (discrete systems).

In the real world there exist complex systems whose evolution depend on various variables (time, space etc.) and the most suitable way to describe them is through Partial Differential Equations (PDE), being systems with distributed parameters. Such systems can be found in Environmental Science (Ecology, Pollution, Biodiversity, etc). The models developed in these systems are mostly for prediction and experimentation of management strategies.

Finally, there is another kind of systems whose structure and physical laws are perfectly known and they can be built using *white box models*. From those models the differential equations are generated and, in most cases, they are straightforward enough to be represented with Ordinary Differential Equations (ODE), since, normally their parameters are concentrated.

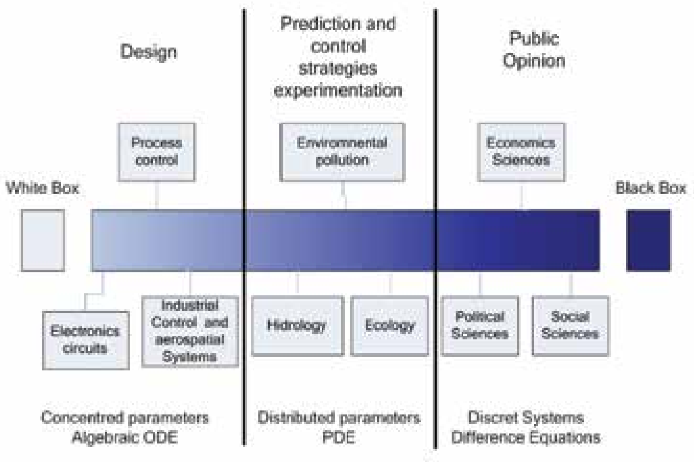

Figure 2. The models that can be found in the real world, ranging from black box to white box ones.

Simulation of real processes

Figure 2. The models that can be found in the real world, ranging from black box to white box ones.

- The real system-plant may not be available. Before building the plant it is important to ensure its viability with the desired features.
- To experiment with the real plant may be dangerous. In order to test the control algorithm reaching extreme conditions might be needed, causing injuries, deaths or destruction (e.g. a nuclear reactor or a plane flight).
- The cost of experimentation could exceed the given budget (e.g. energy production plants, oil tanker berth).
- The system time constants might not be compatible with observations (e.g. too fast or too slow systems).
- The control variables, state variables, perturbations or parameters of the real system might not be accessible.

Conclusions

In this short communication the basic theoretical concepts taught in the Summer University were summarised. Only three hours were available, but many more would be needed to give more concepts and realise some software practices with real models. Interested students are welcome to go more in depth in the fascinating world of modelling and simulation.

References

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