Modeling of Complex Systems

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Abstract

Many of the component-level physical and system-level network phenomena used in advanced industrial products are complex in nature, on surface contradicting the apparent simplicity and robustness of the product's engineered performance. If that performance needs improvement for competitive or regulatory reasons, the process of development commonly requires detailed understanding of some of the underlying physical and system properties. But, this often does not mean that computing from the first principles is going to solve the problem. In many cases, due to the development timescales involved or the complexity of the component/system involved, reduced order modeling is a must. And the question of model validation necessarily arises. I will present a framework for model validation, developed in collaboration with the United Technologies Research Center, that stems from dynamical systems and ergodic theory ideas. The framework is built on the following ideas:

1. It is often not necessary and/or possible to perform a detailed, trajectory-wise comparison of the model and physical data it is attempting to represent. A statistical comparison (comparison of "emergent" or "engineered" properties) might be more appropriate.
2. Statistical comparison of performance of dyamical systems in the sense of invariant measures still might not be enough. Harmonic (spectral) analysis needs to be developed.
3. The formalism needs to allow for a rigorous choice of scales over which the validation is performed.

The developed framework for model validation is a hybrid of statistical, dynamical systems and multi-scale thinking. I will present an example in which we identified parameters for a stochastic, 2-degree of freedom dynamical system model of a combustion process. I will argue that sometimes even very complicated processes can be modeled effectively with a

small number of degrees of freedom if the dynamics of neglected scales is replaced by a stochastic process.

Model validation/identification is naturally related to model uncertainty. I will discuss how the above ideas can be extended to provide a method for treating model uncertainty within dynamical systems theory.