Uncertainty Quantification: What It Is and Why It Is Important for Multiphysics Simulations

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Abstract

Uncertainty appears in many aspects of physical simulations including stochastic design parameters, hard-to-specify input distributions, probabilistic boundary and initial conditions, and unknown geometries. Uncertainty Quantification (UQ) has emerged as the science of quantitative characterization and reduction of uncertainties in both simulation and test results. Stretching across applied mathematics, statistics, and engineering, UQ is a multidisciplinary field with a broad base of methods including sensitivity analysis, statistical calibration, uncertainty propagation, and inverse analysis.

Many of these methods are being applied in a wide variety of engineering industries including aerospace, heavy equipment, automotive, oil and gas, and semiconductors. Such cross industry application is aided by the independence of these methods from the type of system and data being studied. Many UQ methods are applicable both to individual physical models, such as those created using the Heat Transfer, CFD, Subsurface Flow, and Structural Mechanics Modules in the COMSOL Multiphysics® software, as well as larger combinations of systems, as are created in COMSOL software simulations. Because of their unique capabilities and broad applicability, uncertainty quantification methods are playing an ever larger role in enabling designers, engineers, and scientists to make precise statements about the degree of confidence they have in their simulation-based decisions.

This presentation first covers the applied mathematics approach to UQ including sparse grids and generalized polynomial chaos. The presentation then focuses on the statistical emulation approach to UQ: to save computational cost, emulators, also called surrogate models or meta-models, are often used as computationally lightweight proxies for the actual simulation being characterized. The larger and more complex the simulation, the more advantage is gained from the use of emulation. While this method works well for small scale problems, it encounters serious numeric issues for large scale or high-dimensional problems. A theoretical framework to understand this difficulty is presented as well as possible solutions. Further UQ methods for solving complex problems with functional responses and quantitative and qualitative factors will also be discussed. The presentation will finish with several examples demonstrating the application of these UQ methods to engineering and multiphysics simulations.

Reference

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Figures used in the abstract

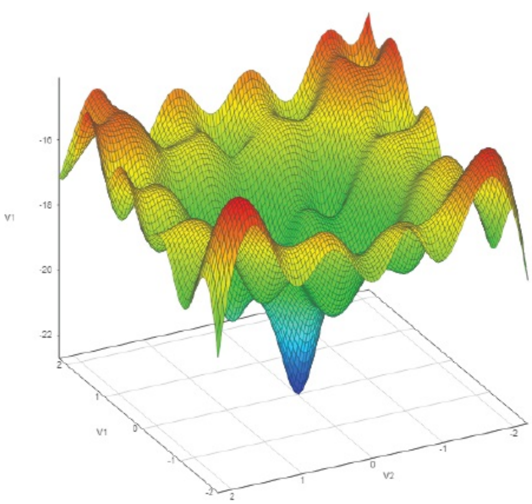

Figure 1: Surface plot showing the response to two inputs of a high-dimension complex function emulator.

Figure 2

Figure 3

Figure 4