Uncertainty quantification in engineering risk analysis

GAMM Uncertainty Quantification Summer School – Berlin, September 12-16, 2016

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Uncertainty quantification (UQ) has become an important topic in engineering sciences in order to design robust and safe structures and systems. The key point for applications is that simulation models for assessing the systems' performance preexist before UQ is considered. Moreover, those models tend to be of increasing fidelity with respect to reality, meaning that the computational power requested for each single simulation is large, even when using cluster facilities. In practice, time and cost constraints of industrial projects allow the engineers to run at most a few hundred to thousand simulations, thus excluding standard Monte Carlo techniques.

In this context uncertainty quantification methods for shall be *non-intrusive* (i.e. based on runs of legacy codes) and *parsimonious* (i.e. using the smallest number of runs) while being able to address problems with $O(10)$, usually non Gaussian, input random variables.

Lecture 1: sparse polynomial expansions for uncertainty propagation and sensitivity analysis

In the first lecture a general framework for UQ in engineering applications is introduced. Polynomial chaos expansions (PCE) and recent advances in sparse representations are presented to compute at low cost the PDF and moments of quantities of interest (QoI). Global sensitivity analysis, which aims at reducing the complexity of a computational model by determining which input parameters drive the uncertainty of the QoI are then introduced. It is shown how sparse PCEs allow for an efficient estimation of Sobol' sensitivity indices.

Lecture 2: structural reliability methods for engineering risk analysis

One of the important questions addressed by engineers is to evaluate the probability that a system of interest fails to fulfill some performance criterion due to uncertainties. Computing such a probability of failure is also known as *rare event simulation*, since the expected value is usually extremely small, say 10^{-6} – 10^{-3}. In this lecture classical methods referred to as structural reliability methods are first introduced. Recent developments based on the use of Gaussian process modelling (a.k.a. Kriging) for building a surrogate of the performance function are then presented together with active learning algorithms.

Tutorial: UQLab

In this tutorial the (Matlab-based) uncertainty quantification software UQLab (www.uqlab.com) will be used to allow the students to get familiar with the different methods presented in the two lectures. Accordingly, the tutorial will be split into two parts, namely the use of PCE for sensitivity analysis, and the use of reliability methods.