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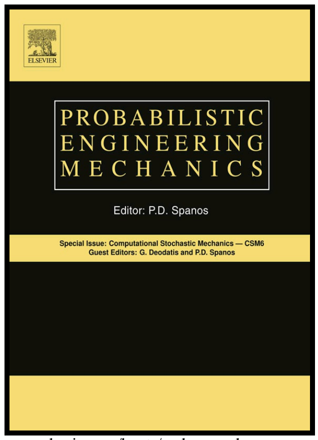

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Reliability analysis of high-dimensional models using low-rank tensor approximations

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Abstract

Engineering and applied sciences use models of increasing complexity to simulate the behavior of manufactured and physical systems. Propagation of uncertainties from the input to a response quantity of interest through such models may become intractable in cases when a single simulation is time demanding. Particularly challenging is the reliability analysis of systems represented by computationally costly models, because of the large number of model evaluations that are typically required to estimate small probabilities of failure. In this paper, we demonstrate the potential of a newly emerged meta-modeling technique known as low-rank tensor approximations to address this limitation. This technique is especially promising for high-dimensional problems because: (i) the number of unknowns in the generic functional form of the meta-model grows only linearly with the input dimension and (ii) such approximations can be constructed by relying on a series of minimization problems of small size independent of the input dimension. In example applications involving finite-element models pertinent to structural mechanics and heat conduction, low-rank tensor approximations built with polynomial bases are found to outperform the popular sparse polynomial chaos expansions in the estimation of tail probabilities when small experimental designs are used. It should be emphasized that contrary to methods particularly targeted to reliability analysis, the meta-modeling approach also provides a full probabilistic description of the model response, which can be used to estimate any statistical measure of interest.

Keywords: uncertainty propagation, reliability analysis, meta-models, low-rank approximations, polynomial chaos expansions

1. INTRODUCTION

Analysis of the response of engineered and physical systems under uncertainties is of key importance in risk assessment and decision making in a wide range of fields. To this end, it is typical to use a computer model to represent the behavior of a system and perform repeated simulations to propagate uncertainties from the input to a response quantity of interest. However, because of the growing complexity of the computer models used across engineering and sciences, in many practical situations, a single simulation is time consuming, thus rendering uncertainty propagation non-affordable. Such situations are often encountered in reliability analysis due to the large number of model evaluations required to compute small failure probabilities. As a result, meta-modeling techniques are gaining increasing popularity. The key idea thereof is to substitute a computationally expensive model with a statistically equivalent one, so-called meta-model, which can be easily evaluated. Using the meta-model, the analyst can perform statistical analysis of a response quantity of interest at low cost.

Of interest herein is non-intrusive meta-modeling, in which the original model is treated as a "black box". Building a meta-model in an non-intrusive manner relies on the evaluation of the original model at a set of points in the input space, called experimental design. The efficiency of a meta-modeling technique

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