

Kernel-based parameter screening for conditional Bayesian calibration of chained computer models

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Computer models are commonly used in many areas of science and engineering to simulate, analyze, understand and predict complex physical systems, such as nuclear power plants. These models, which are designed to faithfully represent the underlying physical phenomena, often involve a large number of uncertain physical parameters. Traditionally, a distinction is made between two types of uncertain parameters (aleatoric or epistemic), depending on whether the uncertainty arises from irreducible natural variability or a potentially reducible lack of knowledge. Among epistemic uncertainties, some can be reduced and quantified by a model calibration process based on available observed data (experiments), such as deterministic calibration or Bayesian calibration [4]. The latter type of calibration is particularly useful for quantifying and reducing epistemic uncertainties, as it provides probability distributions for the parameters to be calibrated [5]. In support of the calibration process, it can be very useful to perform a preliminary global sensitivity analysis (GSA) in order to quantify how much each source of uncertainty contributes to the variability of the quantity of interest. As will be highlighted in the presentation, it turns out that the sensitivity indices based on the Hilbert-Schmidt Independence Criterion (HSIC), introduced by [2] and promoted by [7] for GSA purposes, are particularly suited to parameter screening in the context of Bayesian calibration. We will see that HSIC indices actually keep all their promises and clearly stand out from other competing sensitivity measures. However, beyond simply promoting HSIC indices, which are now widely used in many application fields, the main objective of this work is to develop a GSA methodology for the Bayesian calibration of chained computer models. More specifically, in the application under consideration, the goal in fine is to identify the calibration parameters θ of a downstream model conditionally on the uncertainty affecting the parameters λ of an upstream model. Consequently, the main challenge for the GSA is to incorporate the residual uncertainty of λ into the definition and estimation of HSIC indices. To deal with this specific bi-level uncertainty framework, addressing the uncertainties conveyed by both θ and λ , purpose-built sensitivity measures are introduced and several estimators are derived for them. We will show that they are (asymptotically) unbiased, consistent and have Monte Carlo-like convergence rates. Importantly, their estimation does not require any extra computational load, since the estimates can be directly computed from the Monte Carlo samples built for the conditional model calibration task. Like HSIC indices, the key advantage of these indices is the ability to perform independence tests and make decisions based on p-values, rather than subjective criteria [1,6]. Finally, our approach is applied in nuclear fuel simulation. In this particular industrial context, the challenge is to find the most influential calibration parameters θ of a downstream fission gas behavior model while taking into account the uncertainty of the conductivity λ of an upstream thermal model [3].

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