EGU21-4807, updated on 18 Aug 2022
https://doi.org/10.5194/egusphere-egu21-4807
EGU General Assembly 2021

Enabling efficient uncertainty quantification for seismic modeling via projection-based model reduction

Francesco Rizzi[1], Eric Parish[2], Patrick Blonigan[2], and John Tencer[3]
[1]NexGen Analytics, WY, USA
[2]Department of Extreme-Scale Data Science and Analytics, Sandia National Laboratories, Livermore, CA, USA
[3]Department of Thermal Sciences & Engineering, Sandia National Laboratories, Albuquerque, NM, USA

This talk focuses on the application of projection-based reduced-order models (pROMs) to seismic elastic shear waves. Specifically, we present a method to efficiently propagate parametric uncertainties through the system using a novel formulation of the Galerkin ROM that exploits modern many-core computing nodes.

Seismic modeling and simulation is an active field of research because of its importance in understanding the generation, propagation and effects of earthquakes as well as artificial explosions. We stress two main challenges involved: (a) physical models contain a large number of parameters (e.g., anisotropic material properties, signal forms and parametrizations); and (b) simulating these systems at global scale with high-accuracy requires a large computational cost, often requiring days or weeks on a supercomputer. Advancements in computing platforms have enabled researchers to exploit high-fidelity computational models, such as highly-resolved seismic simulations, for certain types of analyses. Unfortunately, for analyses requiring many evaluations of the forward model (e.g., uncertainty quantification, engineering design), the use of high-fidelity models often remains impractical due to their high computational cost. Consequently, analysts often rely on lower-cost, lower-fidelity surrogate models for such problems.

Broadly speaking, surrogate models fall under three categories, namely (a) data fits, which construct an explicit mapping (e.g., using polynomials, Gaussian processes) from the system's parameters to the system response of interest, (b) lower-fidelity models, which simplify the high-fidelity model (e.g., by coarsening the mesh, employing a lower finite-element order, or neglecting physics), and (c) pROMs which reduce the number of degrees of freedom in the high-fidelity model by a projection process of the full-order model onto a subspace identified from high-fidelity data. The main advantage of pROMs is that they apply a projection process directly to the equations governing the high-fidelity model, thus enabling stronger guarantees (e.g., of structure preservation or of accuracy) and more accurate a posteriori error bounds.

State-of-the-art Galerkin ROM formulations express the state as a rank-1 tensor (i.e., a vector), leading to computational kernels that are memory bandwidth bound and, therefore, ill-suited for scalable performance on modern many-core and hybrid computing nodes. In this work, we introduce a reformulation, called rank-2 Galerkin, of the Galerkin ROM for linear time-invariant

(LTI) dynamical systems which converts the nature of the ROM problem from memory bandwidth to compute bound, and apply it to elastic seismic shear waves in an axisymmetric domain. Specifically, we present an end-to-end demonstration of using the rank-2 Galerkin ROM in a Monte Carlo sampling study, showing that the rank-2 Galerkin ROM is 970 times more efficient than the full order model, while maintaining excellent accuracy in both the mean and statistics of the field.