Combination of data-based model reduction and reanalysis to accelerate structural analysis

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In many applications in Computer Aided Engineering, like parametric studies, structural optimization or virtual material design, a large number of almost similar models have to be simulated. Although the individual scenarios may differ only slightly in both space and time, the same effort is invested for every single new simulation with no account for experience and knowledge from previous simulations. Therefore, we have developed a method that combines data-based Model Order Reduction (MOR) and reanalysis, thus exploiting knowledge from previous simulation runs to accelerate computations in multi-query contexts. While MOR allows reducing model fidelity in space and time without significantly deteriorating accuracy, reanalysis uses results from previous computations as a predictor or preconditioner.

The workflow of our method, named Reduced Model Reanalysis (RMR), is divided into an offline and online phase. In the offline phase, data are generated to cover a wide range of the parameter space. From this data a surrogate model is learned in a reduced space using regression algorithms from the field of machine learning. Depending on the requirements of the system, different regression algorithms are favorable, e.g. linear regression, a k-nearest neighbor algorithm, a neural network, or a Gaussian process. The models are learned in the reduced space due to the prohibitively large number of degrees of freedom of the full finite element model. The reduced subspaces are obtained via a snapshot POD (proper orthogonal decomposition). In the online phase, approximations of all relevant solution quantities are obtained from the surrogate model. Their projection to the full space provides predictors that allow for an accelerated solution of the system in comparison to a standard structural mechanics computation.

In the case of nonlinear stability analysis, this method can for example be used to accelerate the exact computation of critical points by the method of extended systems. Data generation in the offline phase is also accelerated by a newly developed adaptive time stepping scheme. With this scheme, the number of steps to approach critical points with a path following scheme can be significantly reduced. Further potential fields of application of RMR are general nonlinear static and transient problems, with particular challenges as soon as path-dependence comes into play.