Nonlinear model order reduction and machine learning methods for explicit FEM and crash analysis

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Model reduction of PDE-constrained problems
A wide range of engineering problems can be modelled using partial differential equations (PDEs). The Finite Element Method (FEM) is a very popular numerical method for solving problems in structural analysis. In the past decades, increasing computing power has enabled the solution of ever more complex problems.

However, one is often interested in optimisation and robustness studies or solution space identification [1]. These typically require a very large number of function evaluations, which is still impracticable for many large models. Real-time applications represent another important use case where long simulation times are unacceptable. Such problems are often encountered in the automotive and aerospace industry, but also in atmospheric modelling and civil / medical engineering. Reduced-order modelling can significantly decrease simulation times by reducing the dimensionality of the problem. These techniques have reached some maturity for linear problems, but many advances in nonlinear model order reduction (MOR) have only been made very recently [2, 3], and others yet have to be made. Well-established data-fit metamodeling approaches, on the other hand, include response surfaces, stochastic models and neural networks. The advantage of reduced-order models is that they still preserve the information on the underlying PDE, and hence the physical nature of the problem is not lost [4].

A common procedure to generate a reduced-order model is to collect state snapshots from previous simulations, from which a reduced basis can be derived [2]. Further reduction steps can then be applied to achieve the desired speed-up (figure 1). Model reduction of FE crash simulations poses a set of additional challenges. The structural behaviour is often nonlinear due to material plasticity, failure, contact, and several other effects. The models are large and complex, and explicit solution methods

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are most commonly used. Not all degrees of freedom are of the same physical type – some may represent positions, others rotations and velocities.

Many methods for generating a reduced-order model are also highly intrusive. This makes the interaction with a finite element solver difficult, and requires special interfaces and careful implementations. Lastly, the large dimension of the full-order simulation models requires highly efficient and scalable algorithms for processing the associated amounts of data. This work aims at developing new methods to enable the use of model reduction techniques for explicit FEM in general, and for large and detailed models in crash analysis in particular. Both the offline and the online stage (figure 1) of the model order reduction process are addressed.

**Machine learning from simulation data**

Another aspect examined in this project is the use of machine learning methods for crash analysis. Instead of discarding most of the simulation data after their analysis, one can try to use them to improve prediction quality of statistical and reduced-order models [5]. A possible field of application is the modelling and layout of restraint systems for frontal crash.

The derivation of important functional properties of different components for crashworthiness requirement specification is another important application.

**References**


