Thesis Specification

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Title
Structural multi-model coupling with CalculiX and preCICE

Background
In various engineering applications, a multi-model coupling helps to reduce computational costs to a feasible level. By multi-model coupling, we refer to the surface coupling of a high-fidelity model and a low-fidelity model in a single simulation resulting in a spatial model adaptivity. Both models describe the same physical phenomena (contrary to multi-physics coupling), but only important parts of the spatial domain are tackled with the high-fidelity model whereas the low-fidelity model allows for covering large areas to, e.g., provide realistic boundary conditions for the high-fidelity model or, vice versa, to propagate effects induced by the high-fidelity model over a large domain. In both situations, using the high-fidelity model for the complete domain is out of reach from a computational point of view.
As an example we consider automotive crash simulations. For parts of the vehicle with high deformations, we want to use a non-linear structural model. For parts of the vehicle further away, a linear model is sufficient. Therefore, for a cost-efficient simulation of the complete car, we require a coupling between a linear and a non-linear structure model.
We want to realize such a coupling by using the open-source coupling library preCICE and the open-source FEM solver CalculiX. Up to now, preCICE has been merely used for multi-physics coupling, such as fluid-structure interaction. Therefore, an adapter for CalculiX is already available. The goal of the thesis project it to develop methods for structure-structure coupling and implement them in the existing CalculiX adapter.

Description of the task
The thesis should start with a thorough literature review to identify existing, suitable structure-structure coupling concepts. Implementation in the CalculiX adapter would then allow to test the coupling for a simple bending beam. In particular, the interplay with the existing quasi-Newton coupling methods in preCICE should be studied. Conclusion should be drawn. Finally, potentially, a showcase with a complex real-word geometry should show the applicability of our approach.

Methods
The fundamental software tools are the FEM solver CalculiX and the coupling library preCICE. A substantial part of the thesis will, however, be the study of existing structure-structure coupling concepts to choose or develop a suitable one for a black-box partitioned approach. Literature to get the project started is given further below, but a further literature study is necessary.

Relevant courses
Applied Finite Element Methods
Scientific Computing III
Computational Physics

Delimitations
If the master project is successful, potential next steps (excluded for this master project) are:
- Development of a structure-structure coupling for the commercial solver Abaqus
- A proper cost analysis for real crash simulations.
- Development of further quasi-Newton methods, tailored for structure-structure coupling.

Time plan

Some tasks will naturally overlap in time. Writing is continuous, in parallel to the following steps.

1. Survey of the topic; look for articles of coupling methods. **2 weeks**
2. Getting started with CalculiX, preCICE, and the CalculiX adapter. Simulate tutorials. **2 weeks**
3. Define beam testcase and compare the linear with the non-linear CalculiX solver. **1 week**
4. Implement structure-structure coupling for the linear CalculiX solver. **2 weeks**
5. Validate the linear-linear coupling (comparison to monolithic linear simulation). **1 week**
6. Implement structure-structure coupling for the nonlinear CalculiX solver and validate against monolithic nonlinear simulation. **1 week**
7. Simulate testcase for linear-nonlinear coupling, test different quasi-Newton coupling approaches. **2 weeks**
8. (Optional) Look into the explicit nonlinear solver of CalculiX and adapt coupling. **1 week**
9. Transform testcase into a web tutorial and a regression testcase. **2 weeks**
10. Simulate real application with complex geometry (potentially real car geometry). **3 weeks**
11. Draw conclusions and finish the writing. **2 weeks**

References

Anthony Gravouil and Alain Combescure. *Multi-time-step explicit–implicit method for non-linear structural dynamic.* International Journal for Numerical Methods in Engineering 2001; 50: 199–225

Ali Cagatay Cobanoglu, Simon Mößner, Majid Hojjat and Fabian Duddeck. *Model Order Reduction Methods for Explicit FEM*

Arun Prakash, Ertugrul Taciroglu and Keith D. Hjelmstad. *Computationally efficient multi-time-step method for partitioned time integration of highly nonlinear structural dynamics.* Computers and Structures 2014; 133: 51-63.

P.J. Blanco, R.A. Feijoo and S.A. Urquiza. *A variational approach for coupling kinematically incompatible structural models.* 2008.

http://www.calculix.de/

http://www.precice.org/

https://github.com/precice/calculix-adapter