Model-Based Interfacing in Co-Simulaton

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Interfacing mechanical subsystems through co-simulation has many applications. Real-time simulations for virtual environments and prototyping usually require non-iterative co-simulation, for which stability is a main challenge. The stability behaviour is controlled by the way information is exchanged between subsystems, i.e., how the system elements are coupled. Model-based coupling is a promising approach to solve these problems and increase accuracy and efficiency of the simulation implementation. Model-based coupling relies on a reduced model of a mechanical subsystem. The interfacing subsystem, mechanical or other domain, interacts with this model only. A key element is that the reduced model has to give a good description of the behaviour of the mechanical subsystem. In this paper, we discuss the possibilities to use reduced models in co-simulation and also the related approaches to develop reduced models of a mechanical system. Traditional methods for reduced models deal with smooth systems where the models can be represented with equations. We extend this concept and also include non-smooth systems where inequalities and complementarity conditions also have to be considered.

A reduced model may be developed with different objectives. In general, it may be required to represent (1) some specific behaviour, or (2) approximate the overall behaviour/response of the larger scale system. In the case of interfacing, it is mostly the first class of reduced models that play an important role as in that case usually we are interested in a specific behaviour that is associated with the interface, i.e., how the other subsystem sees the system we intend to represent with the reduced model. Such a reduced interface model is usually defined based on the modes of motion, i.e., degrees of freedom, that are describing the interface and the way how these degrees of freedom are represented and parameterized.

A reduced interface model usually requires a transformation of the generalized velocities of the mechanical system so that the interface velocities become part of them. Based on that the behaviour of the system can be decomposed to interface dynamics and motion admissible to that, and the interface dynamics can be factored out using a mass-orthogonal decoupling. However, this procedure assumes that all articulations and contacts in the mechanical system are always active, i.e., bilateral, and the system is representable with a smooth model.

If the system is non-smooth, unilateral contacts/articulations and friction are also important to model then there are two possible ways to approach the problem. In this case, in general, we have to assume that the reduced model will be valid for a short time interval only, which is usually applicable in co-simulation settings as this short time interval can be the macro time step. To develop the reduced model, as a first step, we determine which unilateral contacts are active in the beginning of the selected time interval. We developed an algorithm for that. After this active set is known, one approach can be to assume that this set will not change for the time interval investigated and then use the method described above to derive the reduced interface model. This way we arrive to a smooth reduced model.

Such a smooth reduced model may not always represent a non-smooth system as new contacts may be established. In this case, the active set determined in the beginning of the time interval may change. To handle this problem we propose to establish a non-smooth reduced model in the form of a complementarity problem. In the active set determined in the beginning of the time interval we also include potential contacts that are near to be closed. These potential new active contacts are kept in complementarity form and the smooth reduced model are augmented with them leading to non-smooth reduced model in the form of a complementarity problem.

We demonstrate the use of model based coupling for these three cases: (1) smooth mechanical system, (2) non-smooth mechanical system represented by smooth reduced model, and (3) non-smooth mechanical system represented by non-smooth reduced model. We will use examples with interfacing mechanical-mechanical and mechanical-hydraulic subsystems to illustrate the results.