Model Reduction for Deformable Porous Media of Thin Layers Structure

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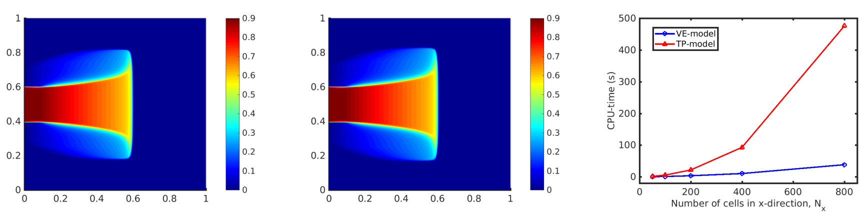
Solid porous materials that are saturated with one or more fluids and undergo elastic deformation are pervasive in many natural and industrial applications. Examples of such materials are soil, biological tissues and polymer or metal foams. Mathematical models describing such materials are strongly coupled differential equations of fluids' pressure, material displacement and fluids' saturation in the case of multi-phase flow. Consequently, these equations are of high computational complexity, mainly, for large heterogeneous porous media, nondeterministic models, or data driven evaluations where the model has to be repeatedly solved. Therefore, applying model reduction methods is crucial, in particular for any kind of limit regimes.

We focus on porous media of thin layers structure, where fluids flow and solid deformation are almost in the horizontal direction. For nondeformable porous media, such structure has been utilized to reduce the complexity of the models. For example, the dimensionality reduction approach that integrate the model over the vertical dimension of the domain. Another approach reduces the number of unknowns in the model by means of asymptotic analysis based on the width–length ratio of the domain. Figure 1 demonstrate the accuracy and computational efficiecy of the reduced model resulting from this appraoch. There are also other approaches that suggest numerical algorithms coupling the reduced models with the full one.



(a) Full model (b) Reduced model (c) CPU-time

Fig. 1. In (a) is numerical solution of the full model (TP-model) in a thin domain. In (b) is numerical solution of the reduced model (VE-model) from the asymptotic approach. In (c) is a comparison of CPU-time required by the two models under the same conditions [Armiti-Juber and Rohde, 2018].

This project aims to establish a framework for model reduction in deformable porous media. It is based on extending the above mentioned approaches to deformable materials, in addition to proposing other new ones. We start with the simplified case of a steady state flow in a thin domain under the assumption of no outflow at the upper and lower boundaries. For this case, we derived a reduced nonlocal model based on the idea of the asymptotic approach. The validity of the model has to be numerically examined. Also, further extensions to more natural cases have to be derived and numerically validated. For example, we are interested in the case of multi-phase flow and to allow outflow through parts of the upper or lower boundaries of the domain.