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An efficient solution strategy for coupled multi-field problems using adaptive integration and time-stepping

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ABSTRACT

Typical problems in e.g. soil or rock mechanics are described by a strongly coupled and highly nonlinear system of equations. The equations can be integrated simultaneously (monolithic approach) or a staggered scheme can be employed [1-3]. The latter often leads to computational savings resulting from smaller problem sizes and possible symmetry in the sub-problems. Moreover, a staggered scheme allows for developing tailored algorithms for the individual sub-problems. This is particularly appealing since each sub-problem imposes different requirements regarding mesh resolution and time step size. However, since all sub-problems are coupled, data must be exchanged among them, and therefore neither mesh nor time stepping method can be altered freely. In the present paper, we propose a strategy to reconcile the different spatial and temporal requirements of the individual sub-problems, exploiting the advantages of a staggered solution scheme.

For the time integration, an adaptive sub-stepping technique has been developed. Prior to any calculations, the maximum time step size for the solution of the coupled system and the desired number of iterations for each sub-problem are chosen. Each sub-problem is initially solved with the maximum time step. If convergence is not reached within the desired number of iterations, the time step size is altered. Allowed values of the time step size are $(1/2)^n$ times the global time step size with n an integer number. Sub-problems exchange data at each corresponding time step. As such, it is ensured that the coupling between the individual sub-problems is properly taken into account.

Next a strategy is needed to reconcile the different spatial requirements. In general, a high mesh resolution is only needed in a part of the domain. However, this specific region is not necessarily the same for all sub-problems and it is usually not stationary. Adaptive meshing techniques [4] are appealing for independent problems, but in the context of coupled problems, they considerably complicate the overall solution scheme. An alternative approach consists in applying a higher order integration scheme in the

regions where a higher accuracy is (temporarily) needed, and a low order scheme in the remaining part of the domain. This implies that information, stored at integration point level, must be transferred from the old to the new set of integration points if the integration rule is changed. Since successive mapping operations are not beneficial for the accuracy of the solution, we developed a technique in which all model variables are stored at the nodes of the finite element. At any time, nodal data can be interpolated to the position of the integration point. As a result, the integration scheme can be altered freely, almost without loss of accuracy.

The adaptive sub-stepping and the integration scheme with nodal storage allow for solving a coupled system of equations efficiently on a single mesh in a staggered way.

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