HIGH-PERFORMANCE COMPUTING SOLUTION STRATEGIES FOR THE FINITE CELL METHOD

Doctoral Defense by M.Sc. Poria Saberi

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In the context of numerical approximation of PDEs, the generation of a boundary-conforming mesh in classical FEM is a major bottleneck. The finite cell method (FCM) falls under the category of unfitted finite element methods, where the physical domain is embedded in a regular background mesh in order to circumvent the need for a conforming tessellation. On the one hand, the particular formulation of the FCM opens the door to copious optimization opportunities. Numerical challenges such as the notorious ill-conditioning of the resultant system, on the other hand, necessitate the development of specialized solution strategies for the FCM. The main objective of this work is the development of an efficient and scalable end-to-end simulation pipeline for large-scale finite cell problems on modern high-performance computing (HPC) machines. To this end, a massively parallel computational framework using suitable data structures and parallelization techniques is developed, where adaptive geometric multigrid methods are employed as solvers. The presented solvers are shown to be scalable, capable of achieving bounded iteration counts. Motivated by the potential to reduce the computational cost associated with the estimation of the stabilization parameter in Nitsche's method, a data-driven estimate is proposed and shown to be an efficient alternative to the conventional approach, offering constant computational complexity. The performance of the computational framework is extensively studied in terms of efficiency as well as weak and strong scalability in parallel. It is demonstrated using benchmarks with up to more than a billion degrees of freedom that the presented methods provide a scalable strategy for the solution of large-scale problems in modern HPC environments.

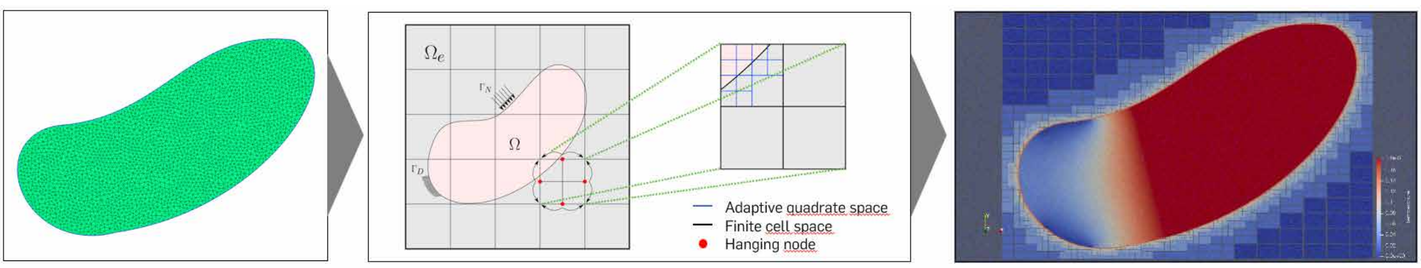

Fig.: Illustration of the finite cell simulation workflow: embedding of the physical domain in a regular background mesh, adaptive integration and the weak imposition of boundary conditions

High-Performance Computing
Prof. Dr. Andreas Vogel

Ruhr-Universität Bochum
Gebäude IC, Etage 6, Raum 155

Universitätsstr. 150
44801 Bochum

hpc-bi@rub.de
www.hpc.bi.rub.de