Multiscale imaging-through-analysis methods in computational mechanics

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Full scale resolution is still a widely used strategy for simulating heterogeneous materials with random microstructure, unclear scale separation and localization due to fracture or damage. An example is the simulation-based strength prediction of trabecular bone from micro-CT imaging, where voxel finite elements and plasticity have established themselves as the gold standard [1]. This combination, however, involves a prohibitive computational cost when applied to micro-CT scans of a complete bone.

In this talk, we discuss some of our recent steps towards a multiscale method that reproduces exactly the same results as full-resolution voxel finite elements, with particular focus on localization. Our approach leverages the opportunities of the multiscale finite element method [2], using a small set of multiscale basis functions that effectively upscale fine-mesh behavior at the voxel scale. From a technical point of view, our discussion focuses on a local iterative corrector scheme that restores full accuracy of multiscale basis functions across coarse-scale element interfaces. The scheme is based on the residual of the current multiscale solution, driving local voxel-scale corrector problems that are well-suited for parallel computing. We demonstrate that residual-driven correction is crucial to enable accurate tracing of cracks that advance across coarse-scale element interfaces.

We showcase the effectiveness of our method as the fundamental component of an automatic imaging-through-analysis pipeline that streamlines variational micro-CT segmentation [3], inelastic strength prediction, and fine-mesh visualization for a full-scale vertebra. Our example illustrates the potential of our approach to significantly reduce the computational effort with respect to voxel finite elements, both in terms of memory usage and computing time, while seamlessly integrating imaging data, image processing and physiology-based simulation.

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