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Embedded shell finite elements: solid-shell interaction, surface locking and integration into seamless imaging-through-analysis workflows

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In this talk, we present an embedded shell finite element method for the unfitted dicretization of solid-shell interaction problems [1]. Its core component is a variationally consistent approach that couples a shell discretization on the surface of an embedded solid domain to its unfitted discretization with hexahedral solid elements. Derived via an augmented Lagrangian formulation and the formal elimination of interface Lagrange multipliers, our method depends only on displacement variables, facilitated by a shift of the displacement-dependent traction vector entirely to the solid structure. We demonstrate that the weighted least squares term required for stability of the formulation triggers severe surface locking due to a mismatch in the polynomial spaces of the shell element and the embedding solid element. We show that reduced quadrature of the stabilization term that evaluates the kinematic constraint at the nodes of the embedded shell elements completely mitigates surface locking. We show that for coarse discretizations, our variationally consistent method achieves superior accuracy with respect to a locking-free nodal penalty method. We finally highlight the ability of embedded shell finite elements to seamlessly interact with other image-based simulation technologies, in particular variational segmentation [2] and inelastic voxel finite elements [3]. This is illustrated via the patient-specific strength prediction in a CT-based vertebra structure that requires the resolution of the thin cortical shell at its surface.

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