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Enriched Galerkin with Direct Serendipity Elements on Quadrilaterals for Two-Phase Flow in Porous Media

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Enriched Galerkin (EG) methods were defined in 2009. The idea is to use a variational form arising from a discontinuous Galerkin (DG) method, but instead of using discontinuous approximating spaces, one uses a continuous space enriched with piecewise discontinuous constants. EG has fewer degrees of freedom than DG, and so is easier to solve, but it maintains the local conservation property of DG. On quadrilateral meshes, the natural choice is to use the tensor product polynomials defined on the reference square and mapped to the physical elements. These maintain accuracy under bilinear distortion. The classical serendipity finite element spaces have even fewer degrees of freedom, but they suffer from poor approximation on nondegenerate, convex quadrilaterals. We develop the direct serendipity spaces DS_r, a new family of finite elements for r>=2 that has the same number of degrees of freedom as the classical space but maintains optimal approximation properties. The set of local shape functions for DS_r contains the full set of polynomials of degree r defined directly on each element. Because there are not enough degrees of freedom, exactly two supplemental rational functions are added to each element. We use these new spaces in an EG method to solve flow and transport problems in porous media, including the saturation equation of two-phase flow. A partial extension to 3D will also be presented.

References

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