Sieve: A Platform for Geometric Computing

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Summary

The PETSc Sieve library provides support for parallel, scalable, unstructured meshes and functions defined over them. This is a key enabling technology for large scale simulation of PDEs. It has been successfully used to reengineer the popular PyLith code for tectonic and seismic simulation, enabling better modeling, simulation in varying dimensions, and parallelism.

Scientists at Argonne National Laboratory have developed a new library, called *Sieve*, as part of the well-known PETSc software system. Sieve applies basic concepts from algebraic topology to mesh and function representation, enabling a thorough refactoring of existing PDE simulations. Raising the level of abstraction has allowed us to disentangle global, topological operations, such as parallel assembly, from local, analytic operations, such as finite element integration, resulting in a much cleaner and more maintainable code base. Moreover, these powerful abstractions allow us to simulate a much wider array of phenomena.

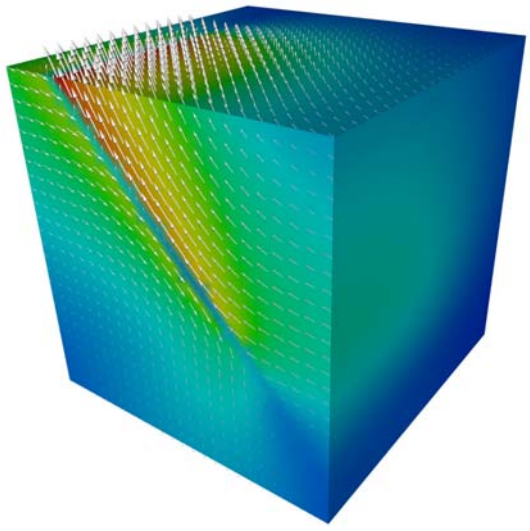

Fig. 1: Coseismic simulation of a thrust fault with PyLith.

Multiple Benefits. In this new framework, we can represent arbitrary topologies, including not only traditional simplicial and hex meshes, but also hybrid meshes, manifolds, and even graphs. Sieve also provides a scalable system for transparent parallelism. The user works only locally, and then the pieces are assembled automatically into a global function, exactly as in the theory of fiber bundles over manifolds. This modularization also affords easy construction of multilevel algorithms on a geometric foundation. We also provide an unstructured geometric multigrid solver, based on an innovative coarsening algorithm, that can operate on arbitrary meshes.

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Multiple Applications. The PETSc Sieve implementation has already been used in PyLith (see Fig. 1). PyLith is a portable, multiscale software package for earthquake physics. It is used to simulate crustal deformation across spatial scales ranging from meters to hundreds of kilometers and temporal scales ranging from milliseconds to thousands of years. The current version is the first to allow the solution of both implicit (quasi-static) and explicit (dynamic) problems. Now PyLith can also run in one, two, and three dimensions, instead of just three, demonstrating the power of our dimension independent algorithms. Sieve enabled not only parallelism in PyLith, but also the incorporation of the cohesive element formulation for fault constitutive models, greatly enhancing the fidelity of the simulations. Fig. 2 shows the results for a simple seismic block model of with two different rheologies, the inner block having five times the Young's modulus of the surrounding material.

A separate implementation of these ideas has been constructed at Simula, the Norwegian research institute, for the study of biomedical flows as part of the FEniCS project. This clearly shows the power of the Sieve concepts, apart from our particular PETSc implementation.

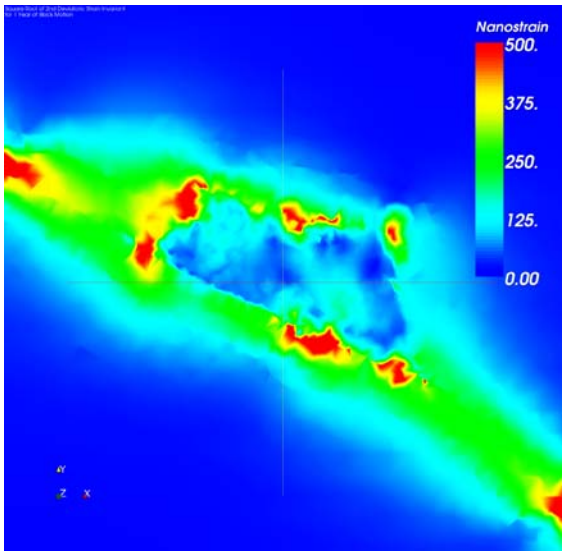

Fig. 2: Contours of the 2nd deviatoric strain invariant for a simple block model

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