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Simulating Earthquake Rupture on Frictional Interfaces Using an Asynchronous Space-time Discontinuous Galerkin Method

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ABSTRACT

Earthquakes are among the most destructive natural hazards to mankind with losses exceeding thousands of lives and billions of US dollars annually. An outstanding challenge is to accurately model earthquake nucleation, propagation, and arrest alongside with the stress-accumulation patterns during the seismic cycle to develop physics-based seismic hazard models for informed risk analysis and policy making. A critical barrier for the application of conventional numerical analysis techniques, such as time-marching finite element or finite difference methods on non-adaptive meshes, is the wide range of length and time scales (from sub-millimeter to kilometers and from milli-seconds to centuries) involved in the earthquake processes. This multi-scale character makes the problem computationally intractable even on state-of-the-art supercomputing platforms. We overcome this challenge by using an asynchronous space-time Discontinuous-Galerkin (aSDG) method with dynamic adaptive meshing that enables variations of spatial and temporal resolution over several orders of magnitude across the solution domain. To illustrate our method, we apply the aSDG method to the earthquake benchmark problem TPV205-2D provided by the Southern California Earthquake Center (SCEC). The problem setup includes a planar slip-weakening frictional interface embedded in a two-dimensional linear elastic domain. The rupture is initiated by overstressing a localized patch on the fault surface beyond its static frictional strength. The rupture propagates bilaterally and interacts with areas of inhomogeneous stress and frictional properties. The aSDG method accurately resolves the different phases of rupture growth and arrest as well as the radiation fields associated with the non-uniform propagation. With dynamic adaptivity, the method provides unprecedented resolution of the crack process zone and the elastodynamic fields outperforming other methods, such as conventional finite elements, with respect to run time, memory requirements, and accuracy. We discuss the potential of the aSDG to provide a unique computational pathway to efficient multiscale dynamic rupture simulations in seismology and a critical missing link for transitioning between physics-based simulation and societal risk management.