The ExaHyPE Hyperbolic PDE-Engine: Mesh generation avoiding schemes for the Earthquake simulation in Alpine Regional Areas.

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Adaptive Curvilinear Mesh and Transformation

New Diffuse Interface Approach for Complex Geometries

Seismic Wave propagation

Multi-physics: Non-linear Dynamic Rupture Coupling

Zugspitze Scenario: Topography Shielding/Amplification

Perfectly Matched Layer (PML)

Implicit embedding of curvilinear meshes in adaptive Cartesian meshes. Elements are connected and boundary conditions are imposed using physics based numerical fluxes.

ADER-DG as Exascale Hyperbolic PDE Engine

ExaHyPE (www.exahype.eu) is an open source software to solve hyperbolic PDE systems stemming from conservation laws (as arising in seismology, astrophysics, fluid dynamics, etc.). This hyperbolic PDE Engine (as in game “engine”) is designed for exascale supercomputers of tomorrow (10^18 FLOPS+sec).

Key assumptions: We assume that exascale simulations will require tailoring of existing codes to specific grand challenge applications, but may exploit general purpose algorithmic solutions, as provided by our engine. Exascale size problems can only be tackled by fully automated representation of complexities - without manual user interaction.

Key goals: Enable medium size interdisciplinary research team to realize extreme scale applications (10^19 DOFs) without manual user interaction.

We tackle grand challenge simulations quickly; ii) Efficiently solve hyperbolic PDEs on.

Core Level Optimization

We accurately solve the layer over a homogenous half space benchmark (LOH1).

Seismology: Earthquake rupture dynamics

We explore 3D dynamic AMR to accurately capture the rupture tip and wave fronts.

Critical topography shielding/rupture amplification

Targeting regional scale seismic hazard scenarios (e.g. AlpArray): We design a scenario in a 300x300x30 km domain with high-resolution topography centered at Mount Zugspitze, Germany, to study the impact of surface topography on seismic wave propagation.

Seismic Wave propagation

Multi-physics: Non-linear Dynamic Rupture Coupling

Explicit and implicit representations of general non grid-aligned geometries via new diffuse interface method using ADER-DG schemes with subcell FV limiter on AMR grids is very simple. Inside the solid one sets α = 1, and α = 0 outside.

We exploit the fact that the DIM reduces to the basic Elastic Wave Equation for α = 1 and solve solid areas with a novel, physics-based numerical flux accurately representing surface waves, dynamic rupture boundary condition, curvilinear meshes via multi-block boundary conforming with AMR, provable stable PML boundary conditions, parallel handling of input data for material parameters.

Why ExaHyPE?

We verify ExaHyPE in a 3D SCEC dynamic rupture benchmark problem (TPV101) by solving the spatiotemporal dynamic rupture problem on a static AMR mesh. The fault is governed by the nonlinear rate-and-state friction law, and the state variable evolves according to the aging law.

We explore 3D dynamic AMR to accurately capture the rupture tip and wave fronts.


Future work: We will develop criteria and error estimates to exploit dynamic AMR features of the ExaHyPE Engine, compare time to solution of the curvilinear method against established and novel numerical schemes for the Elastic Wave Equation (e.g. Diffuse Interface Method (Tavelli et al., JCP 2018); we plan an “Exadis” release consolidating the computational seismology applications. We will further improve scalability.

For the Zugspitze Scenario we design a 80x80x80 km domain with high-resolution topography centered at Mount Zugspitze, Germany, to study the impact of surface topography on seismic wave propagation.

We verify the accuracy and stability of the PML absorbing boundary condition in static media with free-surface boundary conditions.

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