ethos
Enabling Technologies for High-Order Simulations

Simulation-Driven Adaptivity of High-Order Meshes

Tzanio Kolev[1] (PI), Patrick Knupp[2], Vladimir Tomov[1], Veselin Dobrev[1]
[1]*Lawrence Livermore National Lab*
[2]*Dihedral, LLC*

Abstract

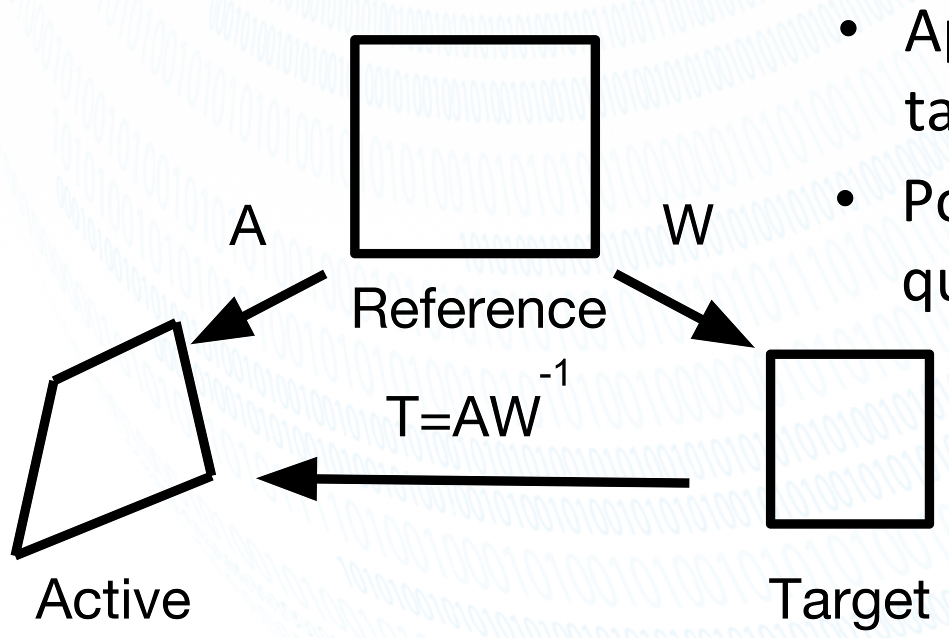
We present a framework for adaptive optimization of high-order curved meshes. The optimization process is driven by information that is provided by the simulation in which the optimized mesh is being used. We make the important choice to require only discrete description of the simulation feature to which to adapt to, e.g., the feature can be described as a finite element function on the mesh. This is a critical step for the practical applicability of the algorithms we propose and distinguishes us from approaches that require analytical information.

Motivation

High-order methods are increasingly important for HPC simulations. Utilizing curved high-order meshes has shown numerous advantages, including high-order convergence, accurate representation of curved domains with less elements, symmetry preservation. However, high-order meshes are difficult to control due to their rich sub-zonal properties [3]. Furthermore, many high-order applications require the ability to adapt the mesh to certain simulation features such as moving material interfaces or shocks.

Approach

We extend Variation Minimization and the Target-Matrix Optimization Paradigm [1, 2] to HO meshes.

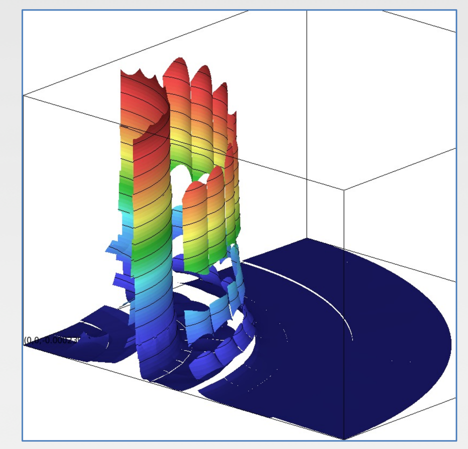


- Application-specific target elements, W.
- Point-based mesh quality metrics, $\mu(T)$.
  - Minimize by node movement:

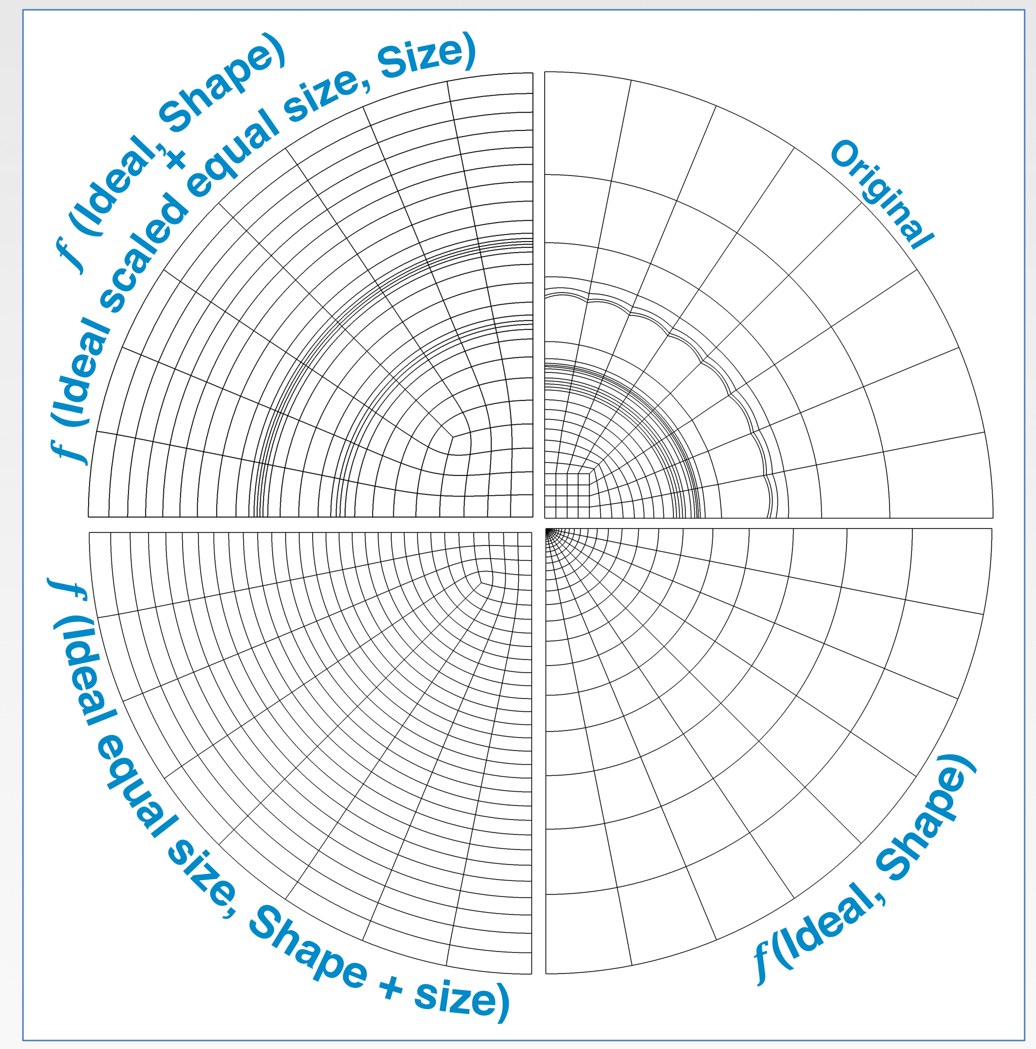
$$F(x) = \int \mu(T(x))$$

- Our framework must encode the user's adaptivity goals into simulation-dependent target matrices W.
- What's the best mesh optimization for given user goal?

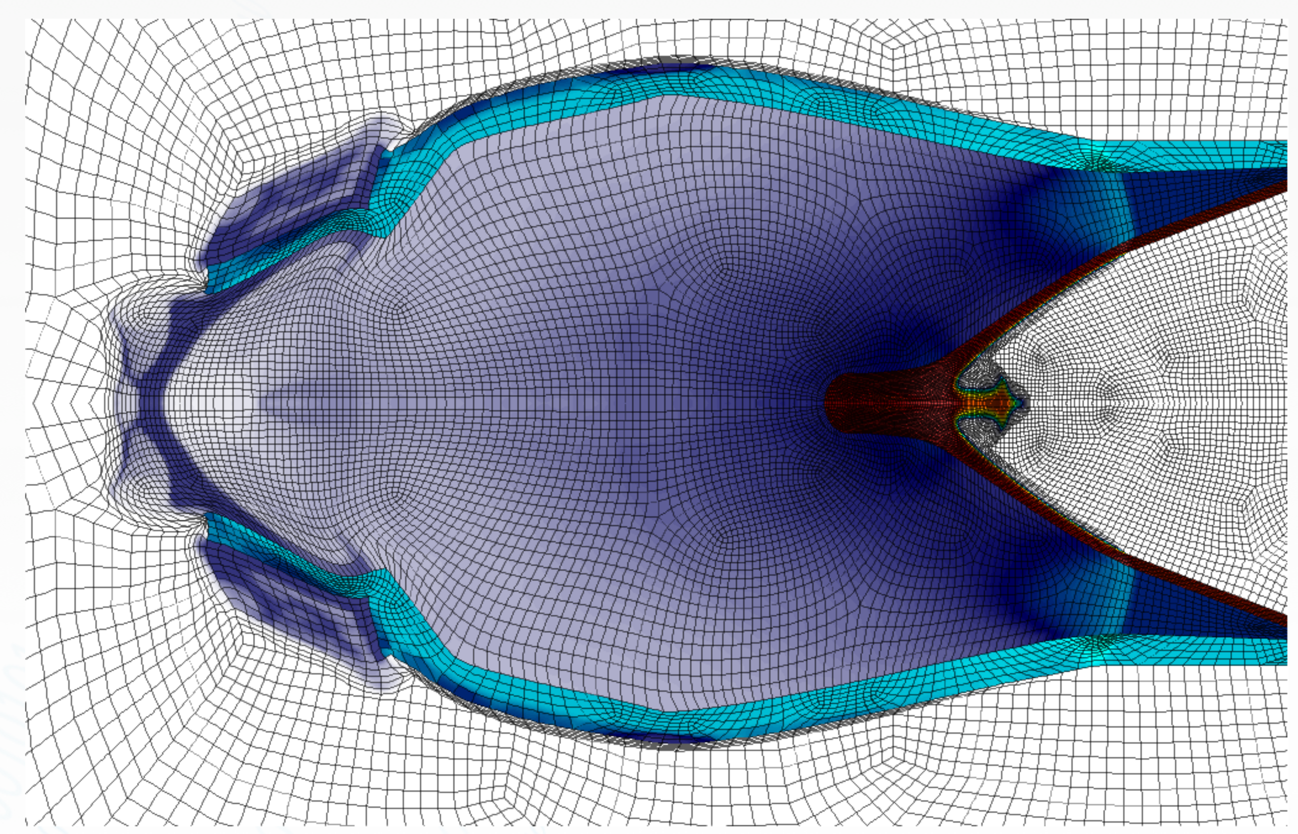
Preliminary Results



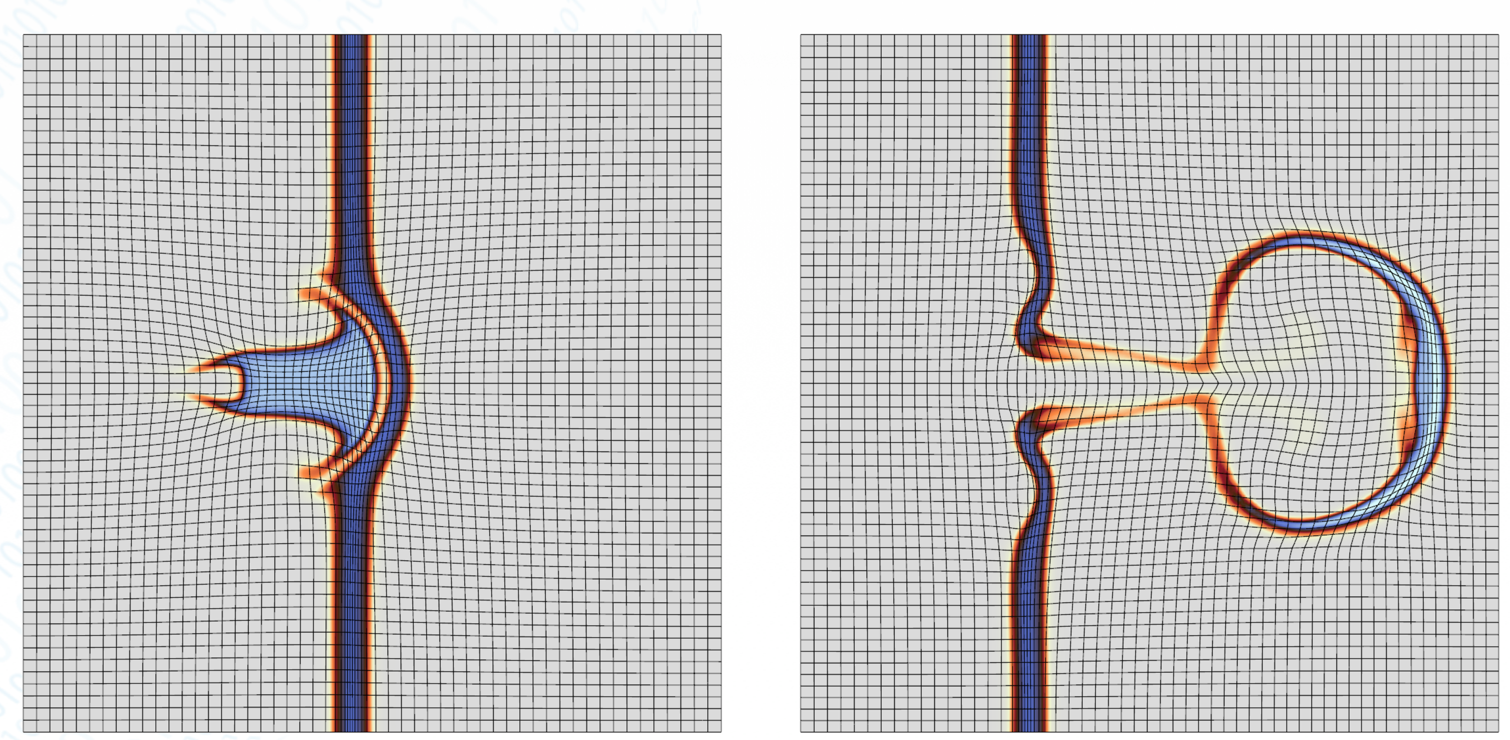
Initial $\boldsymbol{\mu}_2$ shape quality on a 2nd order mesh



ICF-like mesh optimized by various ETHOS methods



Localized shape/size mesh optimization in a high-order ALE simulation of a shaped charge.



Adaptivity to dynamic material positions in a high-order ALE simulation of a high-velocity impact.

Potential Impact

The ETHOS methods provide tools which would enable current and future application to achieve many computational and mathematical advantages.

- Our open source development makes the methods available to a wide range of DOE apps and beyond.
- ETHOS provides independent building blocks that can help current and future apps grow in complexity.
- In further future, the knowledge obtained through ETHOS can guide new research directions, e.g., space-time meshing, combining r- h- and p-adaptivity, optimization through machine learning methods.

Synergy

Our team is committed to working closely with DOE applications to help them adopt our technology.

- Our methods are tailored to the specific application needs: custom targets, quality metrics, adaptation.
- Freely available, general (any order, mesh geometry), parallel open source algorithms [4].
- We are challenged by the optimization solve for the global problem: help is welcomed for derivative-free, Newton-like, constrained (valid Jacobians) solvers with high parallel efficiency.

References

[1] P. Knupp, *"Algebraic mesh quality metrics"*, SISC, 2001
[2] V. Dobrev, P. Knupp, T. Kolev, V. Tomov, K. Mittal, *"The target-matrix optimization paradigm for high-order meshes"*, SISC, 2019
[3] V. Dobrev, T. Kolev, R. Rieben, *"High-order curvilinear finite element methods for Lagrangian hydrodynamics"*, SISC, 2012
[4] *MFEM library*, http://mfem.org

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-POST-766368