OPTIMIZING HIGH-ORDER TET MESHES FOR SMOOTHED PARTICLE HYDRODYNAMICS SETUP WITH THE TARGET MATRIX OPTIMIZATION

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ABSTRACT

Smoothed Particle Hydrodynamics (SPH) is a newer simulation method that enables the flexible modeling of highly dynamic, fractured problem domains, such as a planetary defense scenario with an impactor hitting an asteroid at several kilometers per second. While a meshless method, it still has stringent requirements for spatial discretization that must be honored to produce accurate simulation results. Current setup methods tend toward the manual and are customized for each geometry. Ideally we would be able to use an automatically generated tet mesh as the starting point, and optimize it for SPH. For maximum freedom, we use a high-order mesh generated with CUBIT and leverage the Target Matrix Optimization Paradigm (TMOP). Our early results show only a small improvement but the method has a lot of potential.

Keywords: mesh optimization, smoothed particle hydrodynamics, tet, target matrix optimization paradigm

1. INTRODUCTION

The details of the NASA DART asteroid impactor and previous setups are in [1]. So far I am doing only a simple disc as a stress test for a very constrained geometry with few degrees of freedom..

Very early results show only a slight change in the volume of the elements (see Figure 1). The minimum size element increases by 6.0%, and the maximum size element decreases in size by 0.3%, Solving the TMOP on a higher-order version of the mesh (p refinement) does improve the convergence up to 6th order (see Figure 2).

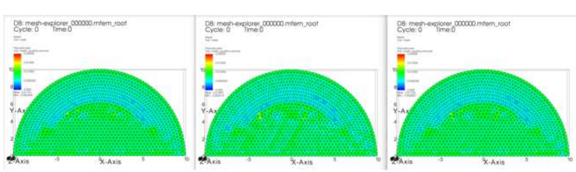

Figure 1: Volume plot for original, 6th order size and shape (metric 321), and 6th order size (metric 301) only, respectively.

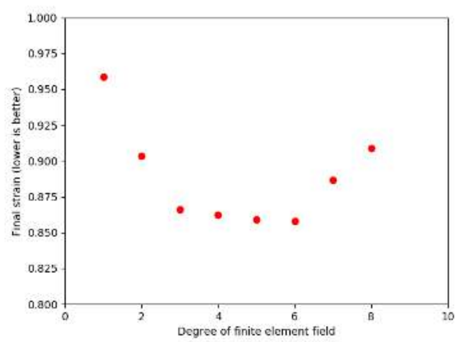

Figure 2: Final strain versus order

The volume distribution in the original mesh is a bit irregular (Figure 3) and it is improved (Figure 4 and Figure 5).

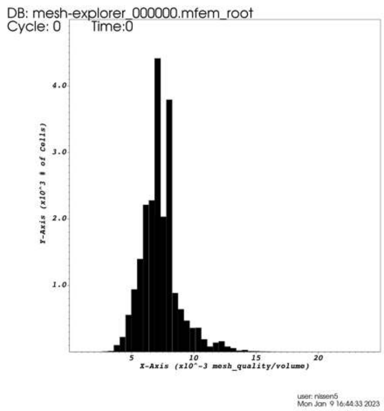

Figure 3: Before optimization

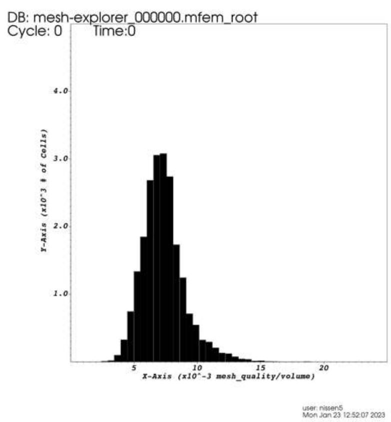

Figure 4: After optimization (6th order, shape and size [metric 321])

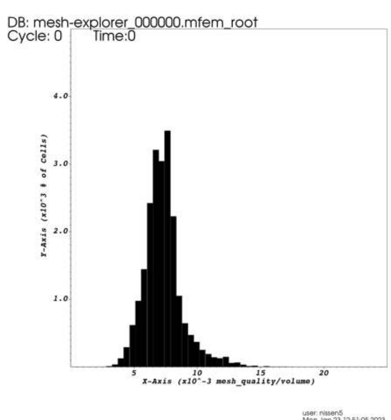

Figure 5: After optimization (6th order, size only [metric 301])

The original TMOP paper is in [2], the details of the target metrics are in [3], and the extension to high order is in [4].

The visualizations are made with [5].

The optimizations are made using the `mesh-explorer` miniapp from [6].

1.1 Future work

While this work is just getting started, we have many possible avenues to explore and have already gotten much helpful feedback.

1.11 Pre-optimization of the initial tet mesh

The initial CUBIT mesh can be improved by using a Voronoi triangle tesselator instead of advancing front, the default. That would generate more evenly sized surface tris. The resulting tet mesh could possibly benefit from some pre-relaxation with conventional Laplacian smoothing.

1.12 TMOP optimization

At a minimum, using a metric that is more size focused will help. Possibly disabling shape-based optimization altogether, since it is not relevant for SPH, would also allow the mesh to get closer to the SPH ideal. As long as the TMOP optimization can cycle, we don't care about traditional quality metrics.

1.12 Geometric optimization

At the moment the optimization is highly constrained by fixing the surface mesh on the curvilinear boundary. Possibly this prevents any substantial optimization at all. Allowing tangential relaxation along the surface would make things much easier for the optimizer.

1.12 Measuring SPH quality

Qualitatively, SPH requires a tight distribution of adjacent sizes. Currently it isn't known how to measure this quantitatively. Possibly the maximum ratio of relative sizes between adjacent elements, or a similar norm would suffice. It should be possible to add a VisIt Python expression to compute and plot as a scalar field on the mesh.

REFERENCES

[1] Owen, J. M., et al. "Spacecraft Geometry Effects on Kinetic Impactor Missions." The Planetary Science Journal 3.9 (2022): 218.

[2] Knupp, P. "Introducing the target-matrix paradigm for mesh optimization via node-movement." Engineering with Computers 28.4 (2012): 419-429.

[3] Knupp, P. “Target formulation and construction in mesh quality improvement.” No. LLNL-TR-795097. Lawrence Livermore National Lab.(LLNL), Livermore, CA (United States), 2019.

[4] Dobrev, V., et al. "The target-matrix optimization paradigm for high-order meshes." SIAM Journal on Scientific Computing 41.1 (2019): B50-B68.

[5] Childs, H., Brugger, E., Whitlock, B., Meredith, J., Ahern, S., Pugmire, D., Biagas, K., Miller, M. C., Harrison, C., Weber, G. H., Krishnan, H., Fogal, T., Sanderson, A., Garth, C., Bethel, E. W., Camp, D., Rubel, O., Durant, M., Favre, J. M., & Navratil, P. (2012). VisIt: An End-User Tool For Visualizing and Analyzing Very Large Data. https://doi.org/10.1201/b12985

[6] Anderson, R., et al. "MFEM: A modular finite element methods library." Computers & Mathematics with Applications 81 (2021): 42-74.