Eulerian Boundary Conditions for Hydrodynamic Codes

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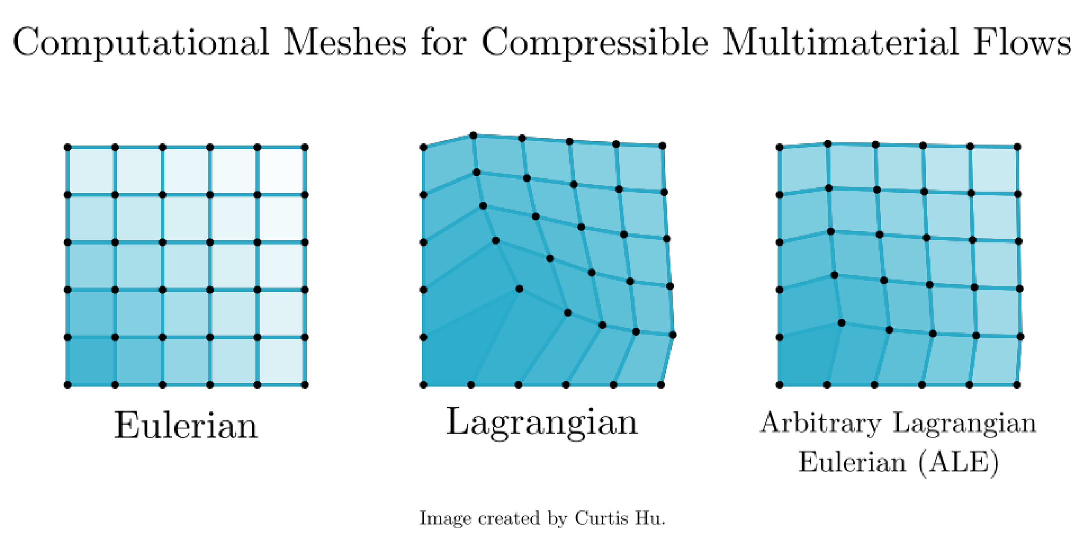
Abstract:

We propose a few methods for instantiating an Eulerian Boundary Condition, allowing hydrodynamic simulations in KULL to have material and shocks flow off meshes while preserving mesh quality for finite-difference calculations. One solution is the usage of a mesh manager to displace nodes before ALE iterations. We also propose creating an 'EulerianNodeBC' to set a boundary condition directly on the ALE mesh manager's displacement field.

Introduction:

Theoretical understanding of experimental data is encapsulated within the capacity to simulate them with multi-physics codes such as KULL. We examine specifically at KULL's hydrodynamic code with the targeted application for radiation transport within the family of fusion ignition simulations. Hydrodynamic codes separate material into discrete zones, allowing approximations of partial derivatives over a continuous medium using finite difference methods. $\left(\frac{\partial F}{\partial x}\right)_j = \frac{F_{j+1}-F_j}{\Delta x_{j+1/2}} + O(\Delta x^2)$ i.e.

Among different computational meshes in Figure 1, KULL uses Arbitrary Lagrangian Eulerian (ALE) to improve mesh quality.



The problem with defining the traditional reflective or ghost pressured node boundary conditions on our ALE codes are the inaccuracies when artifacts propagate back into the experiment by reflection, as seen in Figure 1 and 5. Design physicists have previously worked around this by extending the boundary further away.

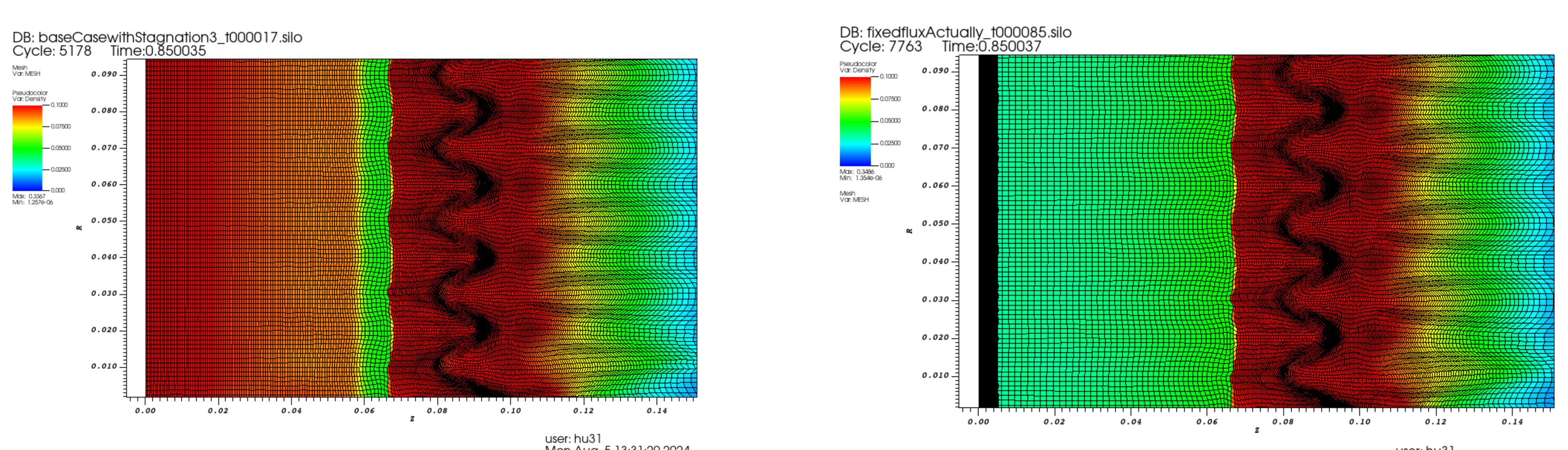


Figure 1. In the hot shock tube problem, a reflection propagates backwards into the experiment on the left. Our technique removes this reflection on the right.

Results:

Using the custom EulerianNodeBC, a newly defined boundary condition within KULL that applies a displacement condition. In Figure 2, we see the Sedov blast wave propagating towards the boundaries on the top and right. In Figure 3, we see the method allowing underlying material to flow through and remaps the mesh so that the material is cutoff.

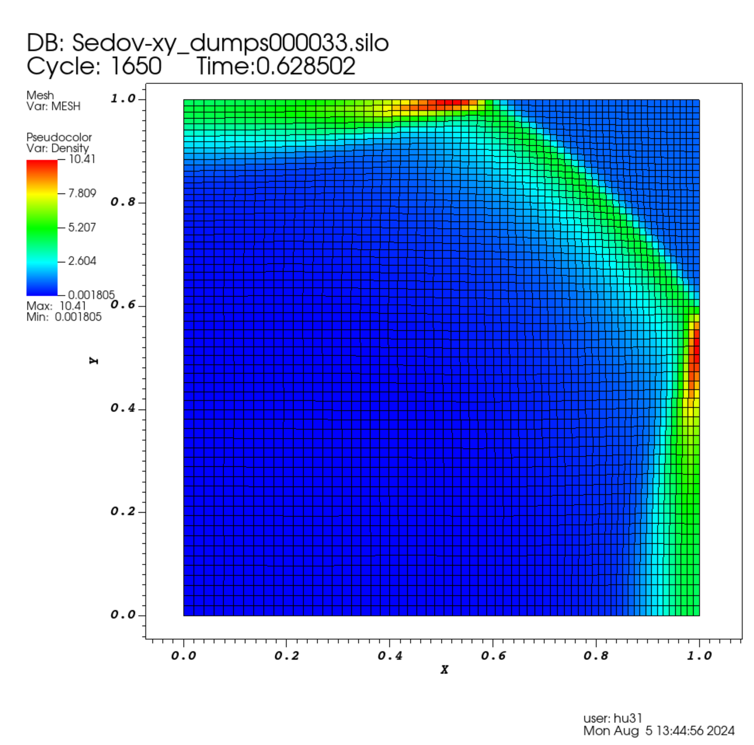


Figure 2: Reflections on a Sedov Blast Wave

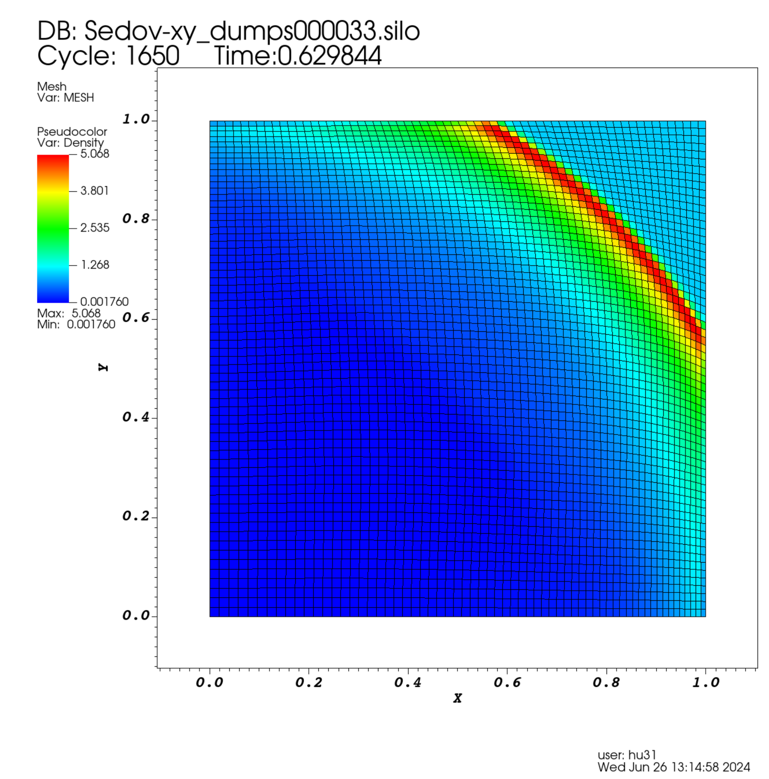


Figure 3: Using a custom BC written inside KULL allowing wave to propagate out of mesh

We use multiple mesh managers for larger simulations such as the laser hohlraum in Figure 4; two are used for the Eulerian boundary and the three others handle mesh deformations. The experiment sends a wave towards the left boundary, and we are able push back the mesh while maintaining mesh quality by relaxing distorted nodes.

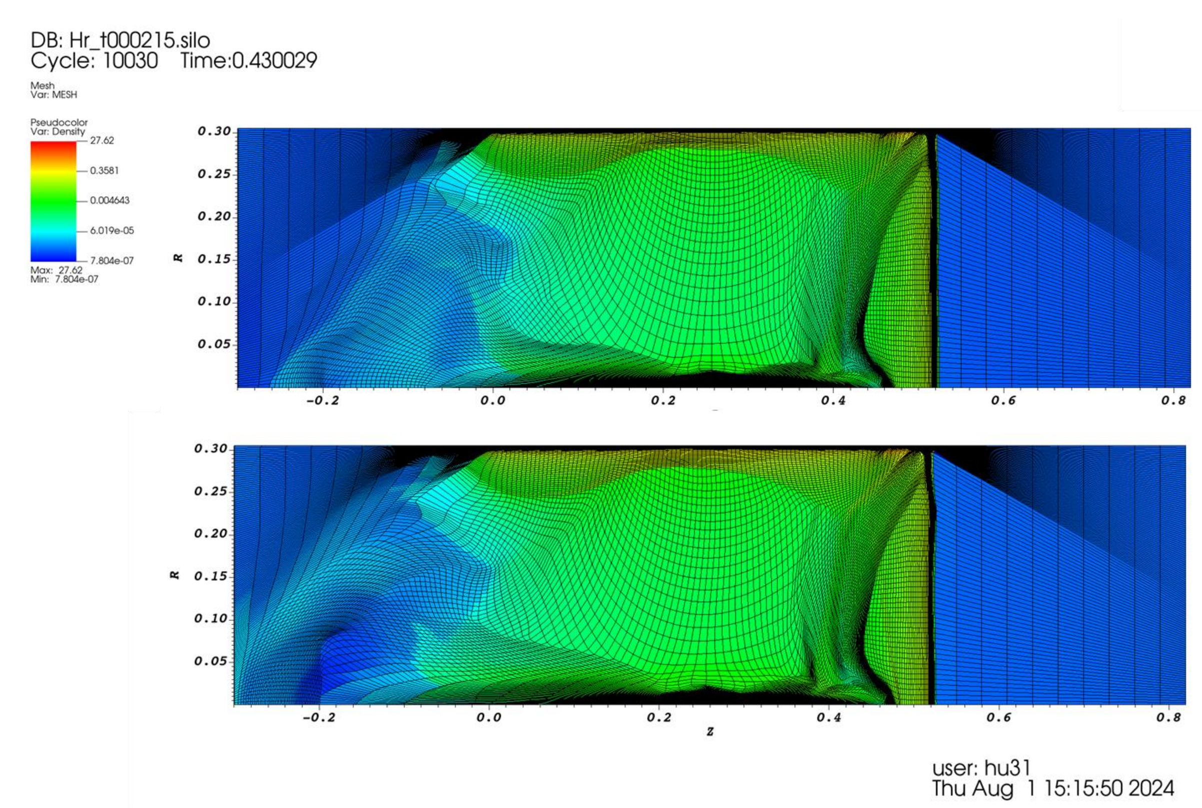


Figure 4: Shock wave hits the Eulerian Boundary on a Laser-Hohlraum problem. Material flows off mesh.

Methods:

Mitigating the reflections, such as in Figure 5, requires new conditions on the boundary. The first method we tried allowed the hydro package to displace the nodes according to a Lagrangian scheme. Then we used a boundary mesh manager that displaces our boundary nodes before the ALE mesh managers.

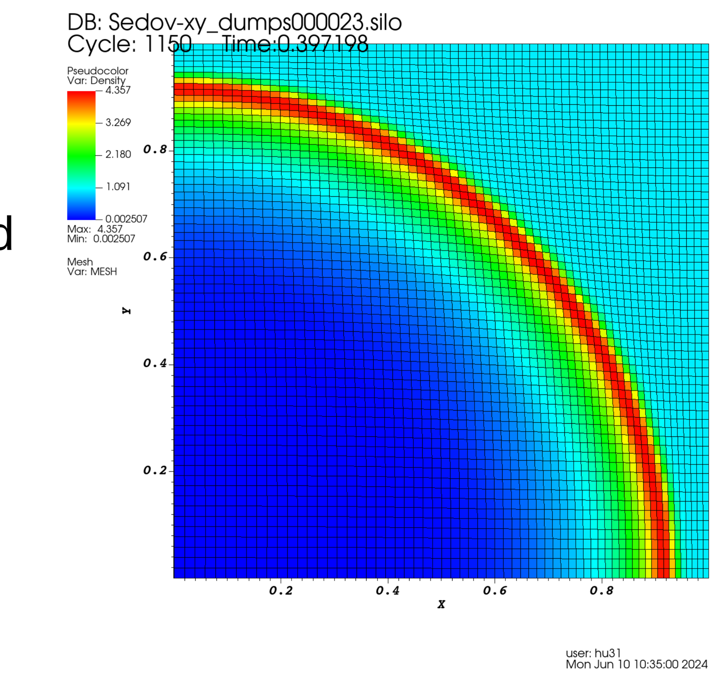


Figure 5: Sedov Blast Wave propagating through medium

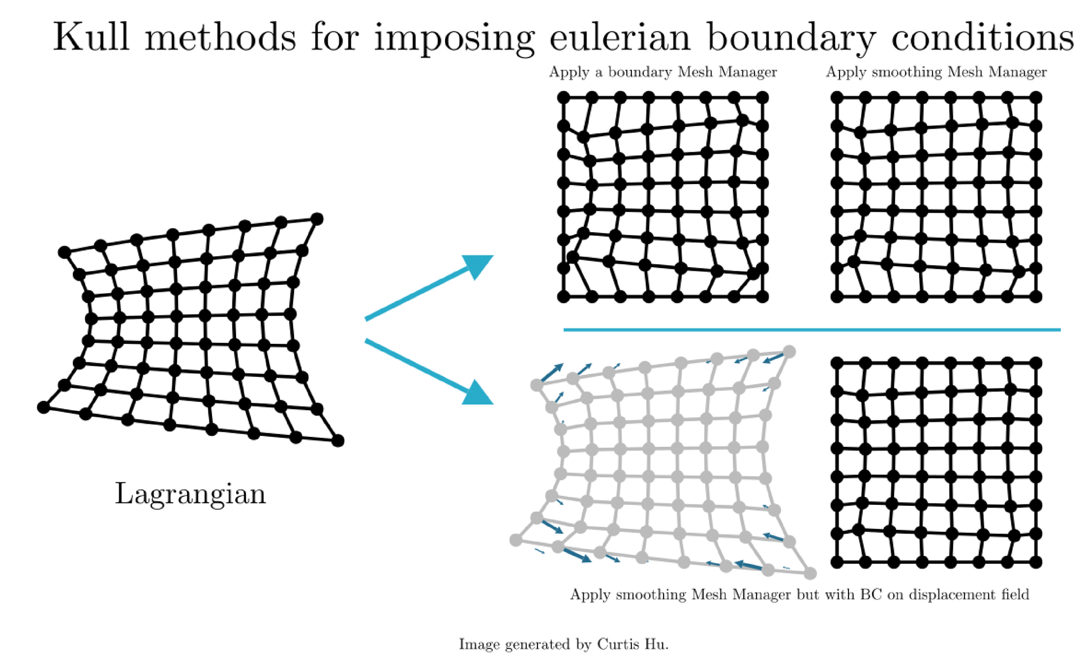


Figure 6: Some methods for creating Eulerian Boundary Conditions

We also implemented a custom EulerianNodeBC inside KULL. For this we reassigned the boundary vectors on the ALE displacement field, allowing us to smooth the mesh and move the boundary nodes simultaneously on the same displacement field. This method is non-traditional in LLNL but simplifies user run scripts by hiding logic away from the user.

Conclusion:

We've implemented and tested two avenues for Eulerian Boundary Conditions within KULL and hope it'll become more widespread among users and similar multi-physics packages. New improvements are likely required as the nuances, such as its effects on our Laser and Radiation Transport libraries, are explored. We also propose projecting nodes back onto a line and the possibility to relax nodes that are near the boundary to prevent negative zoning or collapsed timesteps.

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