Coupled Mesh Lagrangian/ALE Modeling: Opportunities and Challenges

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ALEGRA

- We want to accurately simulate the response and interaction of a penetrating body through a target material where the penetrator is harder than the target.
- We assume:
  - the penetrator is harder than the media so that it does not undergo extreme deformation but may yield plastically or fracture.
  - the target media is highly inhomogeneous, subject to extensive failure and flow around the penetrator.
  - the interaction between the penetrator and media significantly affects the penetrator mechanical response.

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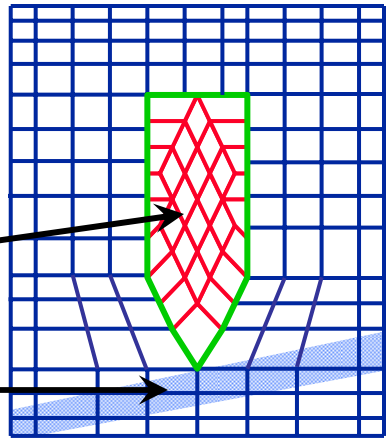
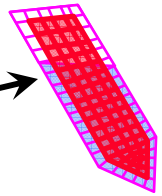
Penetrator Technologies in Alegra

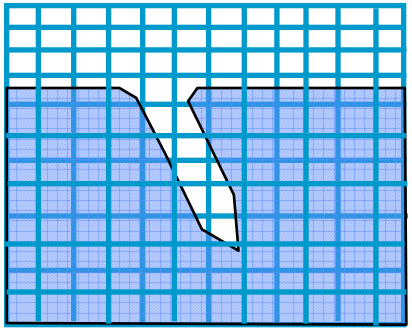
- Cavity Expansion
  - Simple Analytic Model

- SHISM (Soft Hard Interaction Surface Mechanics)
  - Lagrangian Penetrator Block and Interface
  - ALE Target Block
  - No mesh overlap



- EP (Earth Penetrator)
  - Lagrangian Penetrator Region with conforming Phantom mesh
  - Structured Eulerian Target Region





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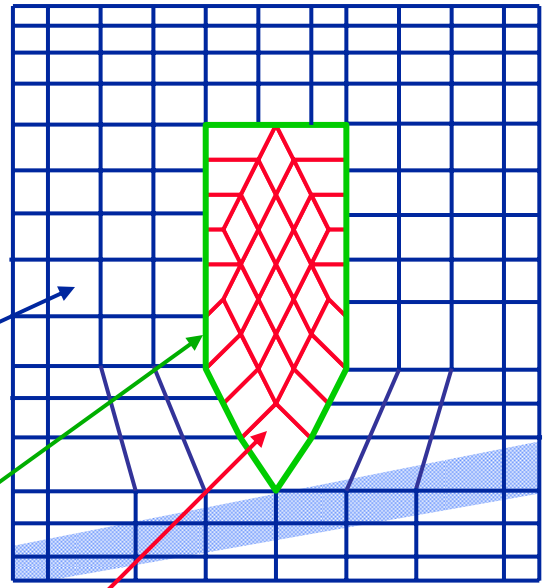
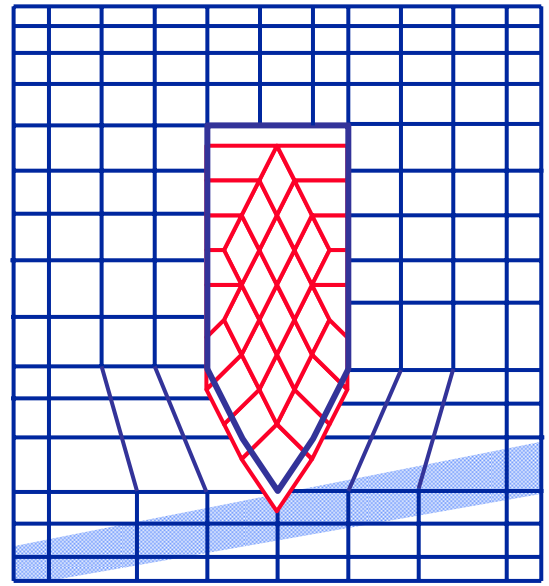
Database and Algorithm Options in Alegra

- Supported mesh regions:
  - Unstructured: typical finite element mesh of arbitrary connectivity.
  - Structured: logically rectangular mesh (e.g. ijk-lines) but with curvilinear coordinates .
- Algorithms available to act on mesh blocks which make up a region:
  - Lagrangian: mesh moves with material – good for explicitly maintaining material state data and interfaces.
  - Eulerian: material moves through a fixed mesh – good for allowing material to deform significantly without tangling the mesh.
  - Arbitrary (ALE): material and mesh move independently. Mesh moves to maintain some optimal element location and shape.

SHISM

Lagrangian Predicted Positions





- Penetrator (Lagrangian mesh)
- Lagrangian Contact Surface (ACME)
- Target (ALE/Eulerian mesh)

- **Compute Kinematics**
  - **Compute forces**
  - ***Compute predicted velocity and position***
  - **Compute contact force**
  - **Compute final velocity and position**
- **Material State Update**
  - **Compute deformation rate**
  - **Update stretch and rotation**
  - **Compute new stress state**
  - **Compute artificial viscosity**
- **Remesh**
- **Remap**

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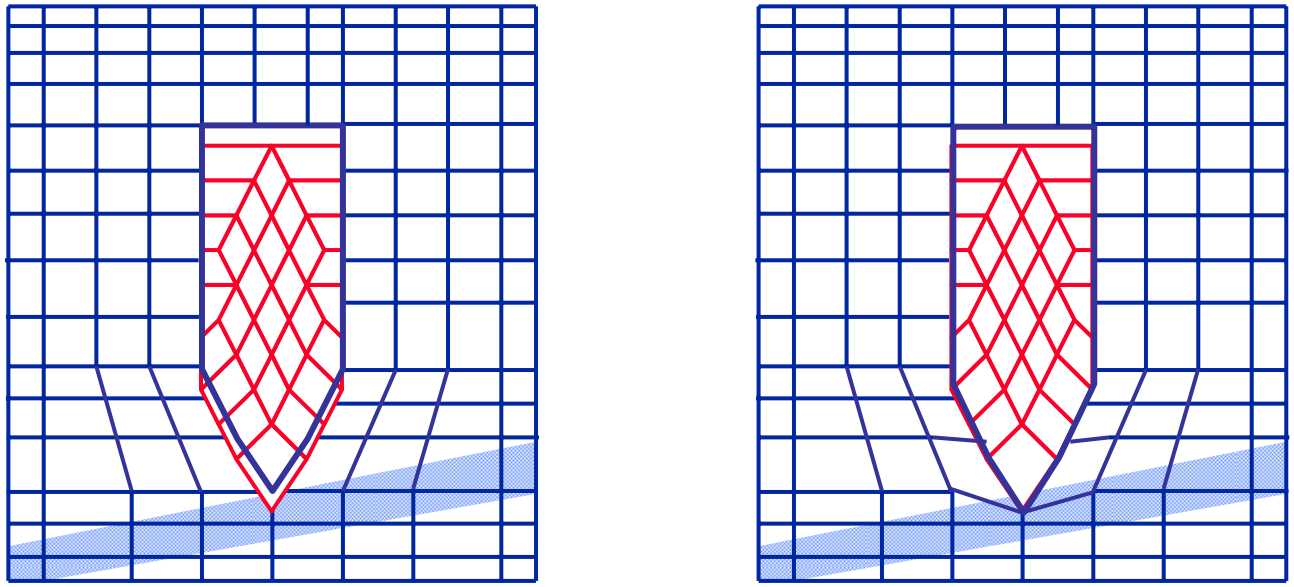
SHISM

Lagrangian Final Positions



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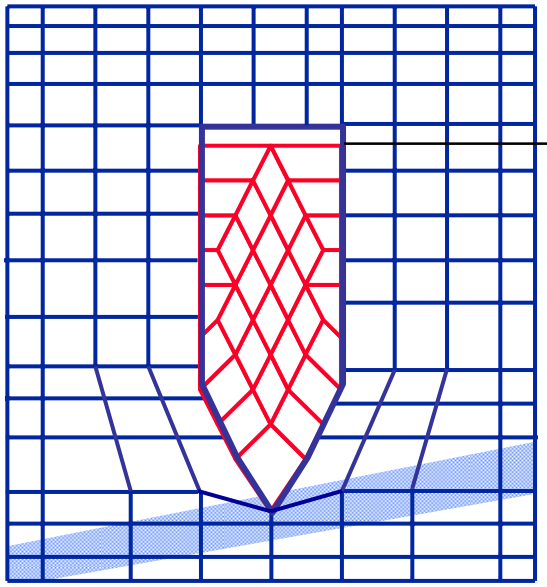
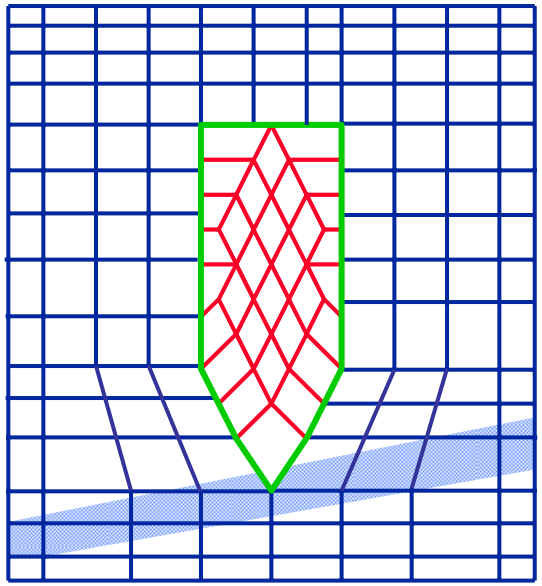
SHISM
Remesh/Remap



Reposition the interface nodes and track the exterior ALE mesh with the penetrator. Note the target material is "moving" through the mesh.



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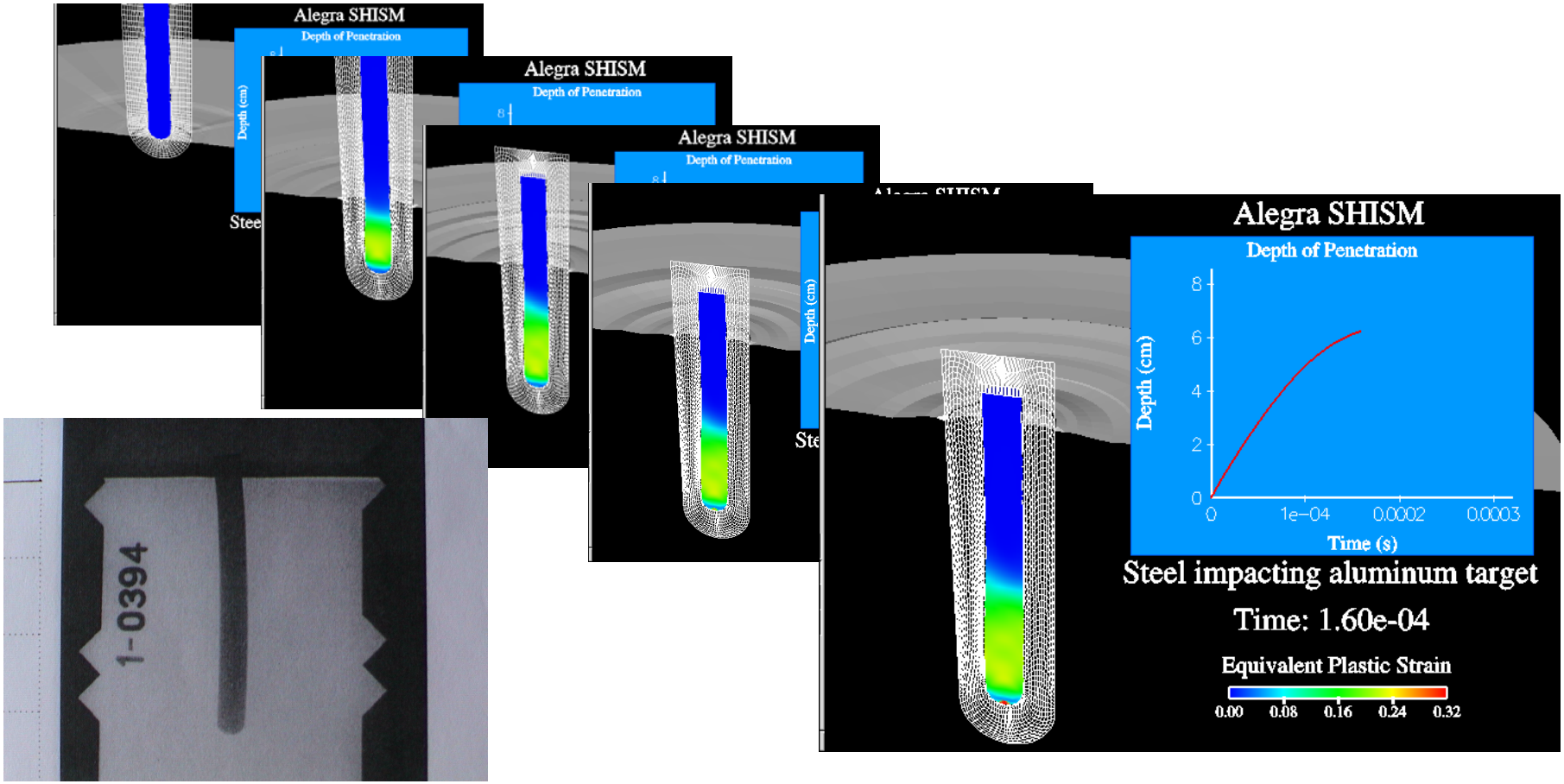
Generally good qualitative agreement with experiment can be obtained.



4340 Steel spherically tipped impactor against 6061-T6511 Aluminum target. 720 m/s with 1° angle of impact.

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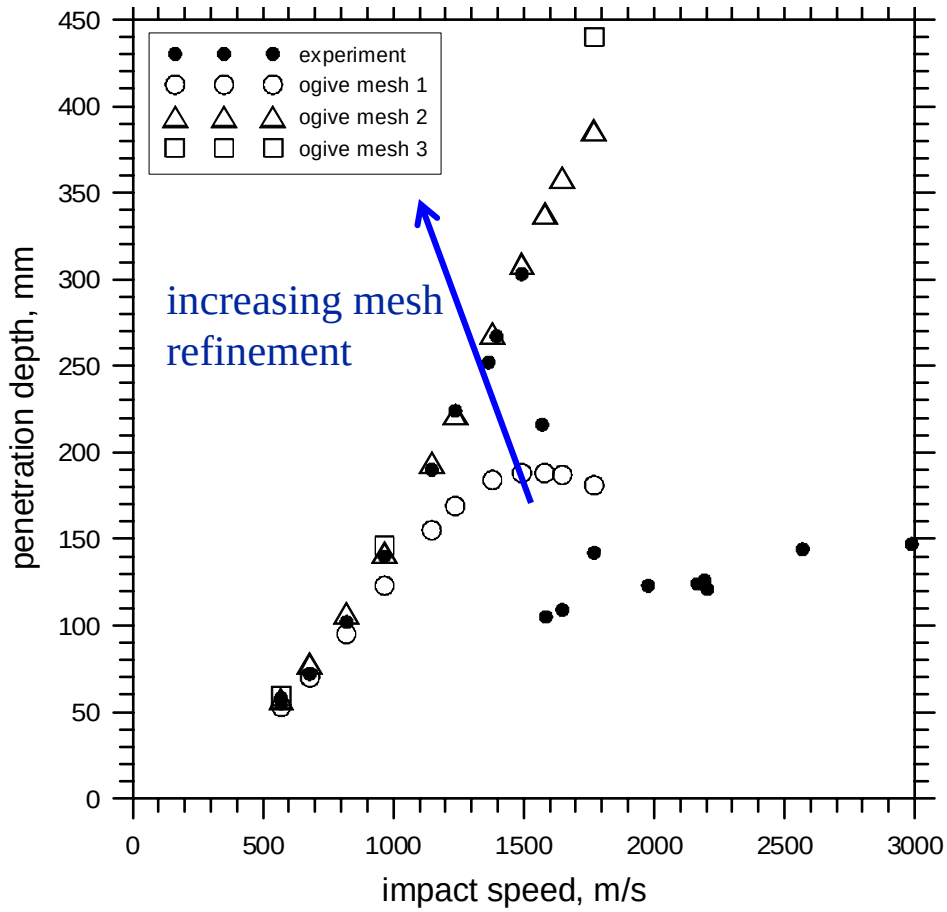
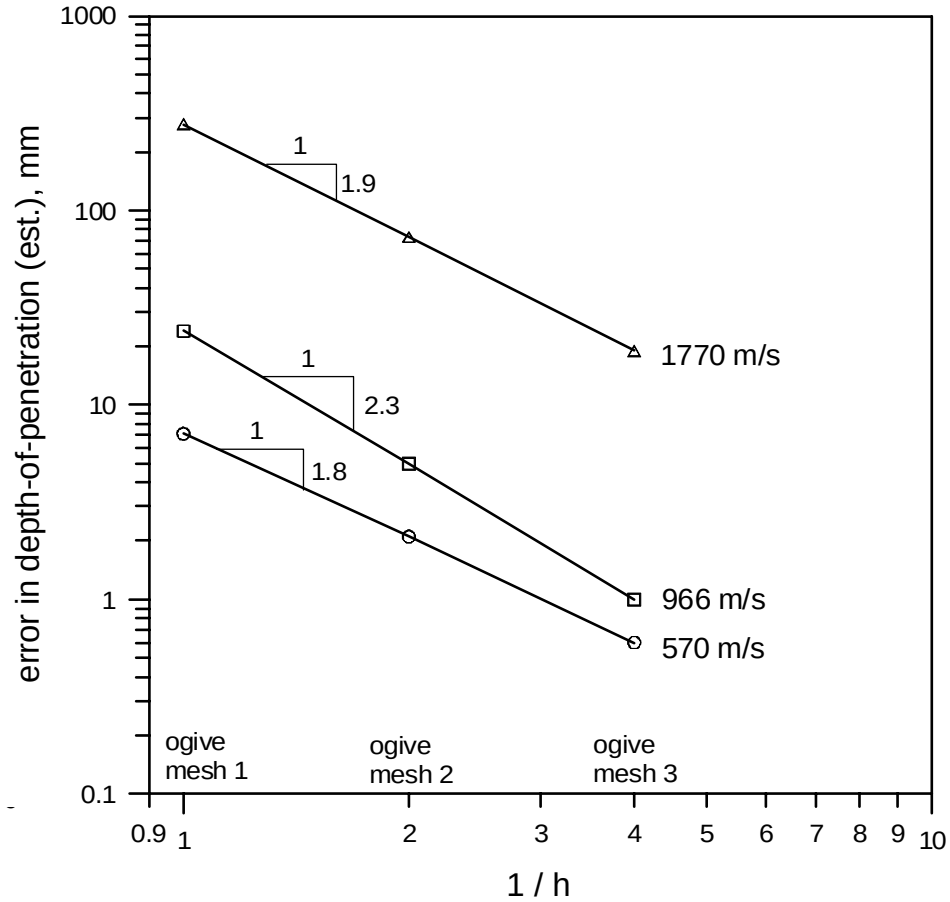
Experimental comparisons and method convergence promising for wide range of V_s





Predicted (Bishop et al., 2005) and measured (Warren et al., 1999) steel ogive penetrator into aluminum target. Asymptotic convergence is assumed in the right figure.

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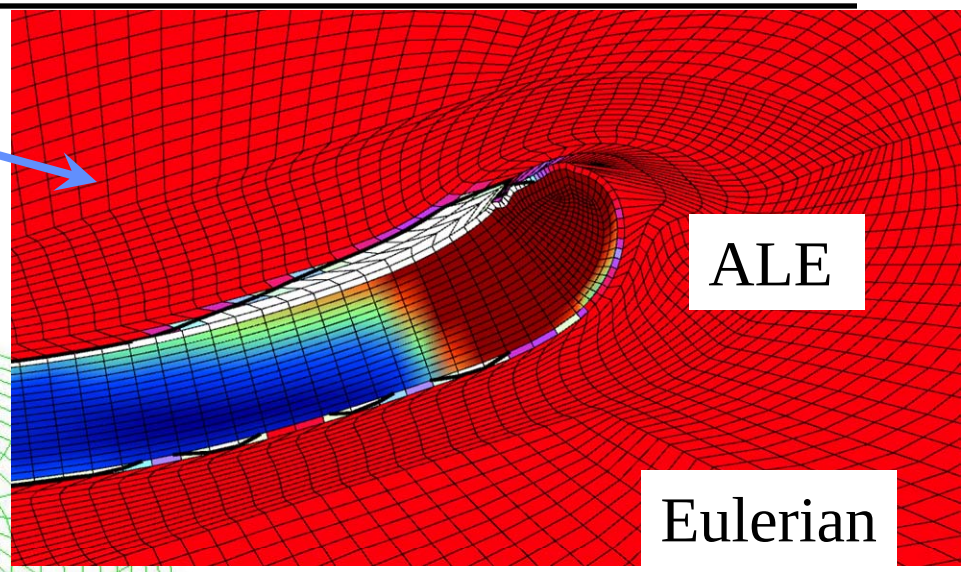
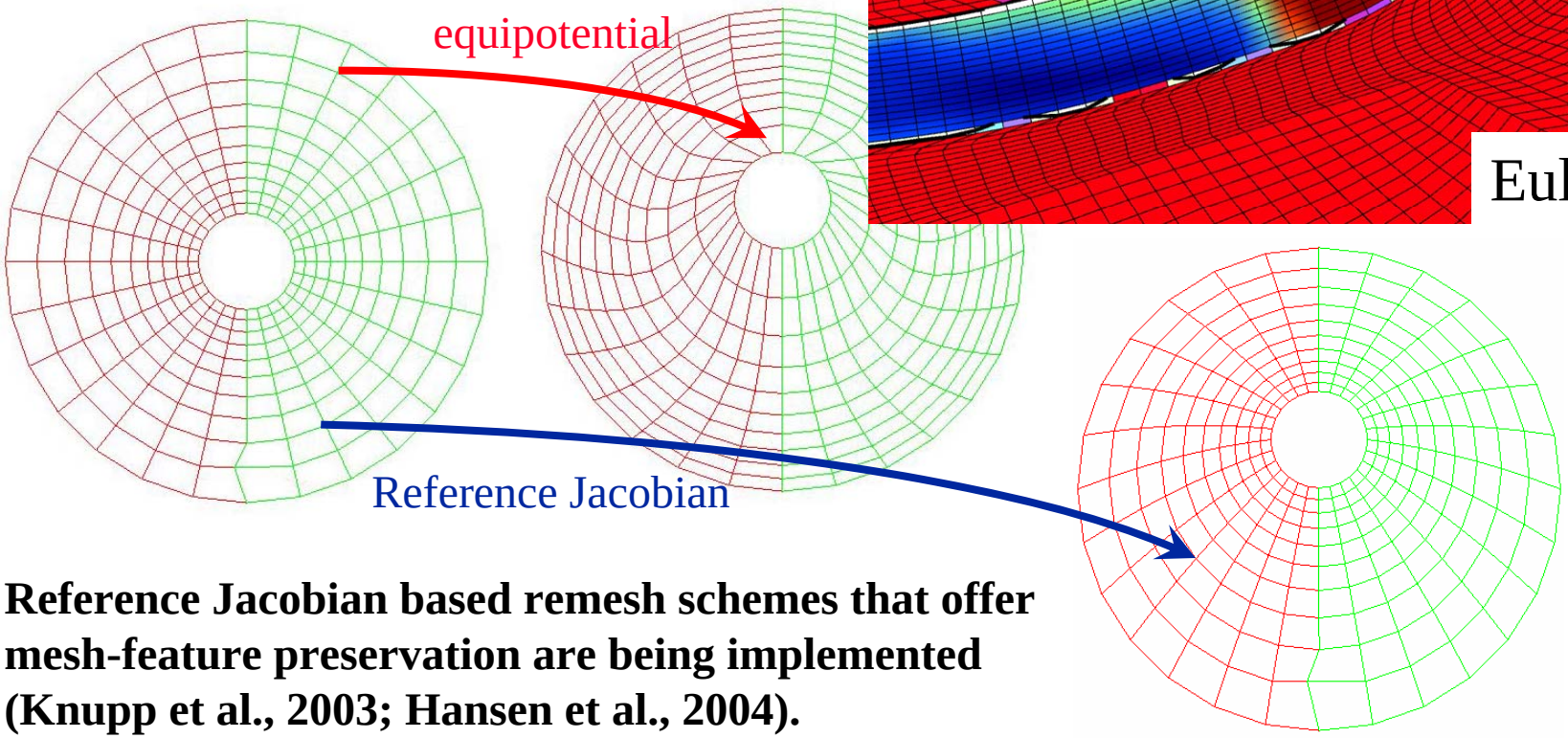
Remesh algorithms confound non-ideal impact simulation (significant deformation regimes).

Simulation of 2º AOA and equipotential remesh. Eulerian region constrains ALE mesh motion around penetrator.





Reference Jacobian based remesh schemes that offer mesh-feature preservation are being implemented (Knupp et al., 2003; Hansen et al., 2004).

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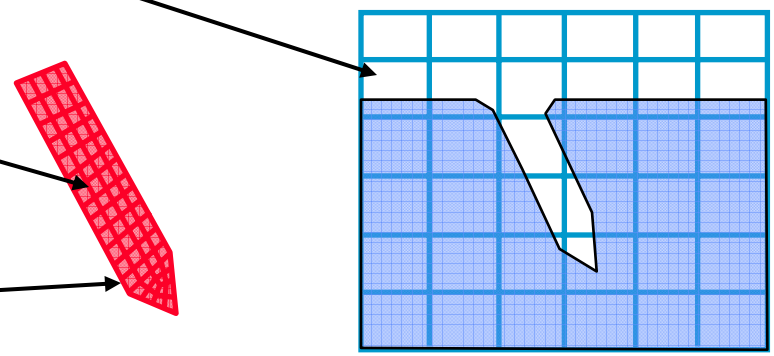
Current EP Capabilities

- Target is contained in a structured Eulerian mesh, containing the domain of interest with only the target material inserted.
- Penetrator is an unstructured Lagrangian mesh.
- Penetrator region owns virtual *phantom mesh* information that facilitates data transfer between the regions.
- Motion of each mesh is computed independently, resulting in unconstrained, predicted velocity and displacement fields.



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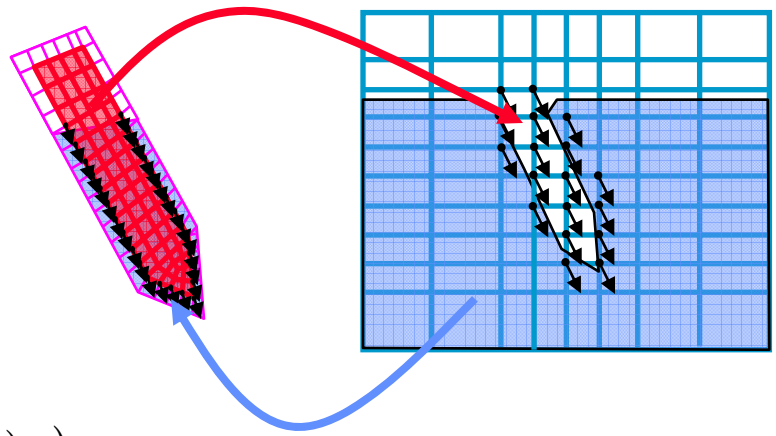
Current EP Capability (continued)

- **Mass and momentum from the penetrator are transferred to the structured Eulerian target mesh.**
- **Mass and momentum of the target media are transferred to the phantom mesh.**
- **Normal velocity consistency is enforced.**



$$V_L^{new} = \left[\left(\frac{(mV)_L + (mV)_E}{m_L + m_E} \right) \bullet n \right] n + \left(V_L - (V_L \cdot n) n \right)$$

$$V_E^{new} = \left[\left(\frac{(mV)_L + (mV)_E}{m_L + m_E} \right) \bullet n \right] n + \left(V_E - (V_E \cdot n) n \right)$$

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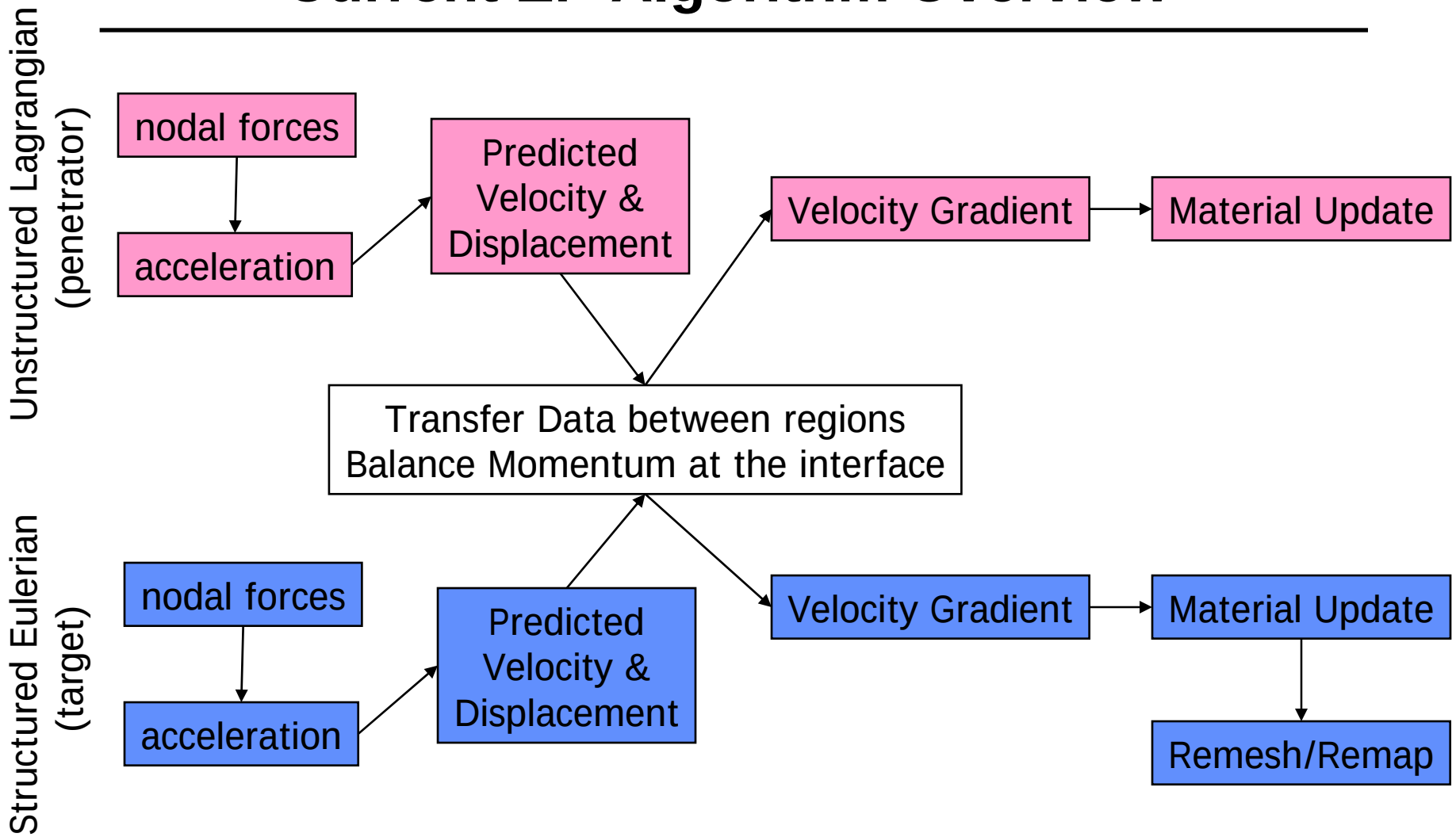
Current EP Algorithm Overview



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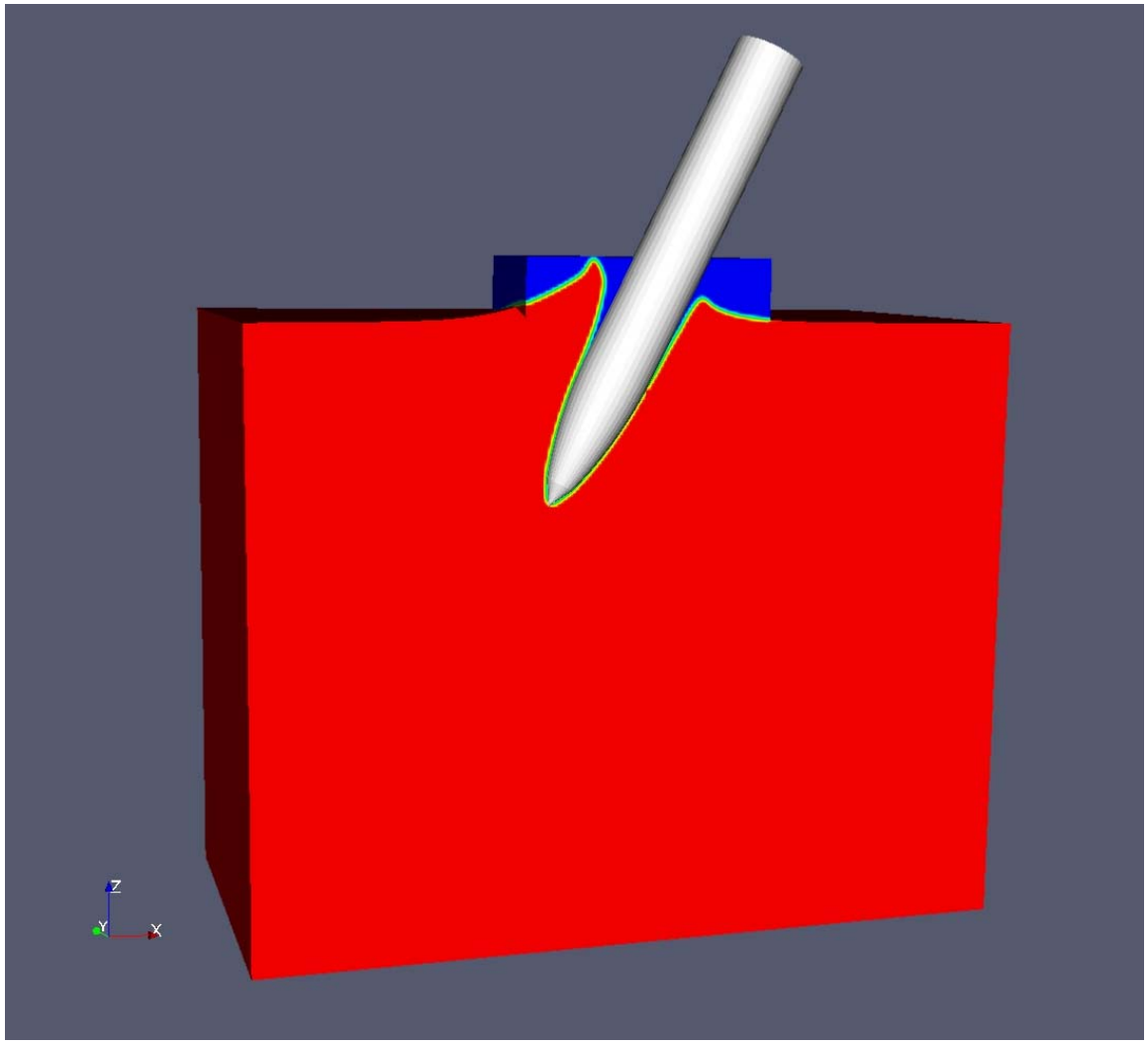
EP Example Calculation



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Conclusion

- SHISM
  - Reliable approach.
  - An improved mesh smoothing technology is still needed.
- EP
  - A basic software infrastructure for an EP style of algorithm is in place and available.
  - Current coupling algorithm appears insufficient to capture proper interface interactions.
  - Other approaches to be investigated.
- Future Work
  - Accuracy.
  - Performance and scalability.
  - Robustness.