Remeshing and mapping of internal state variables in large deformation processes

SAND2013-8131C

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Mechanics of Materials

Intern

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Internship summary

Sandia National Laboratory

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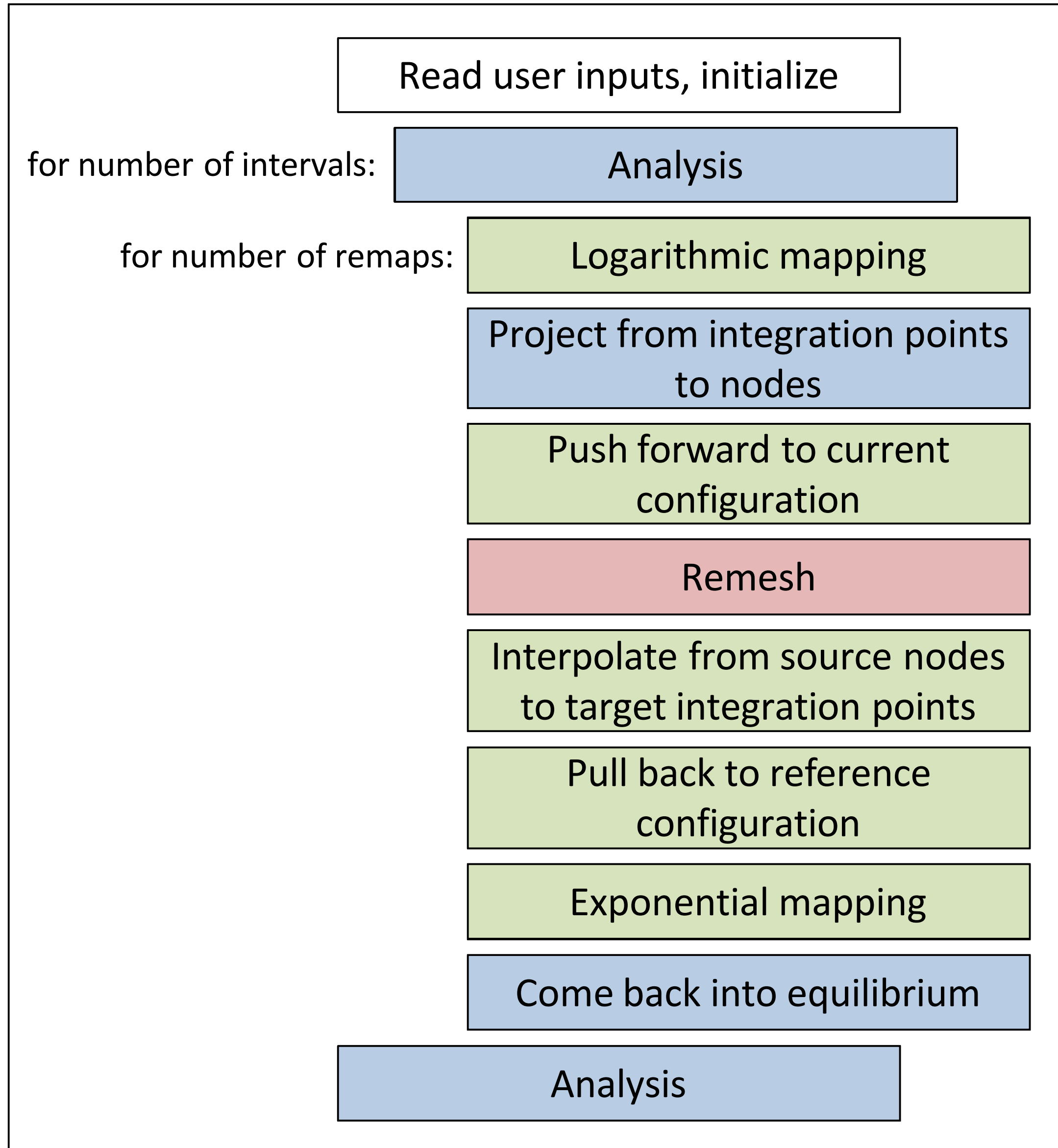

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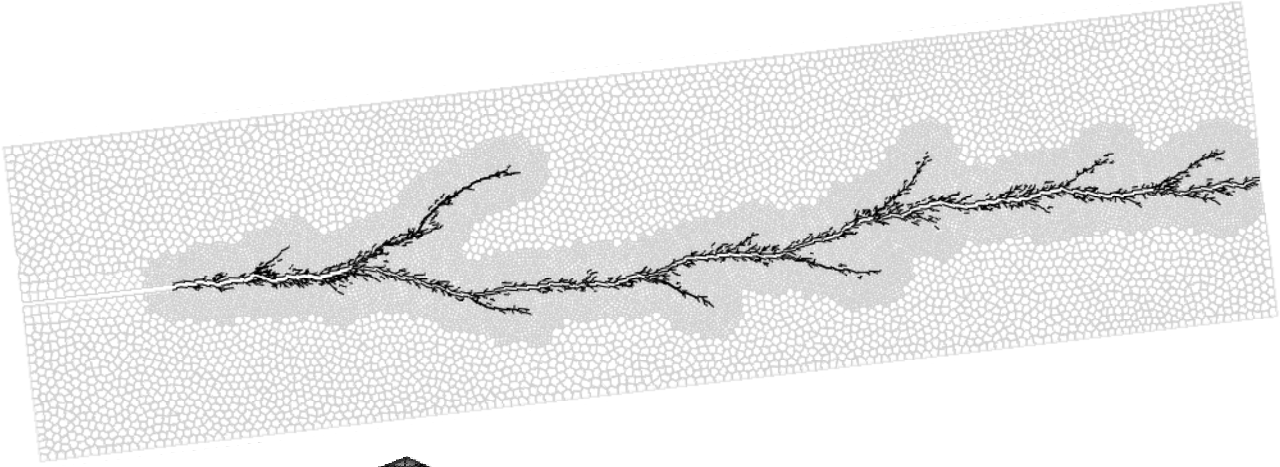
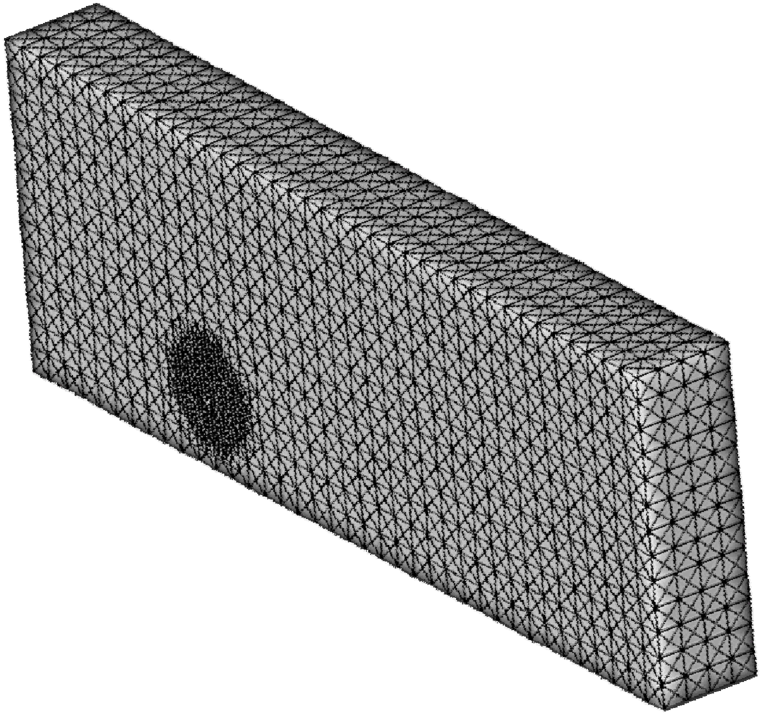
My own research interest is to model crack propagation is large systems with adaptive mesh refinement and coarsening

In my PhD research, I perform dynamic fracture simulation of quasi brittle materials using adaptive mesh operators.



We would like to also investigate crack propagation in materials with internal state variables, but during adaptivity, they would need to be mapped appropriately from one mesh to another.

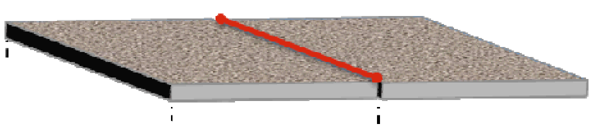


We want to predict the failure of extremely tough material

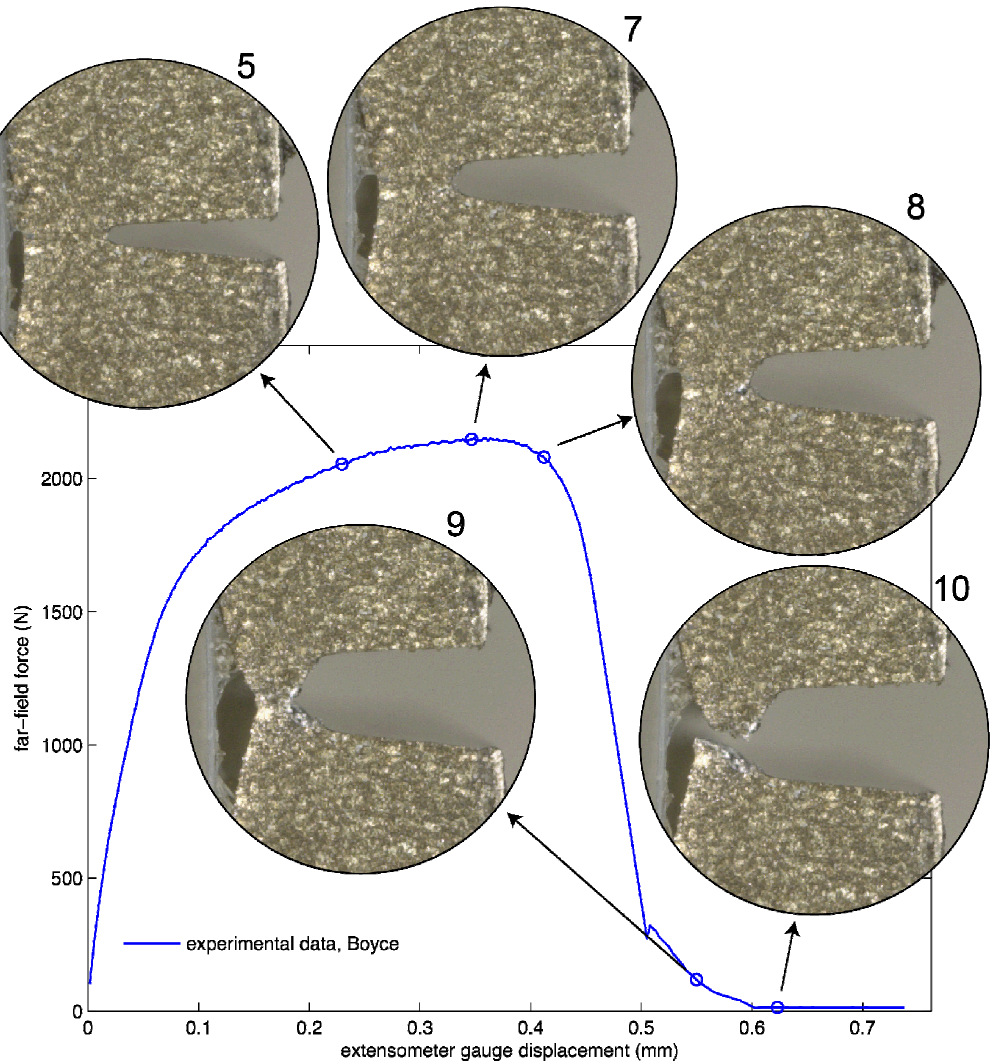
Failure of 304L laser weld is characterized first by necking, then free surface creation is a secondary effect

340L is extremely tough and damage tolerant

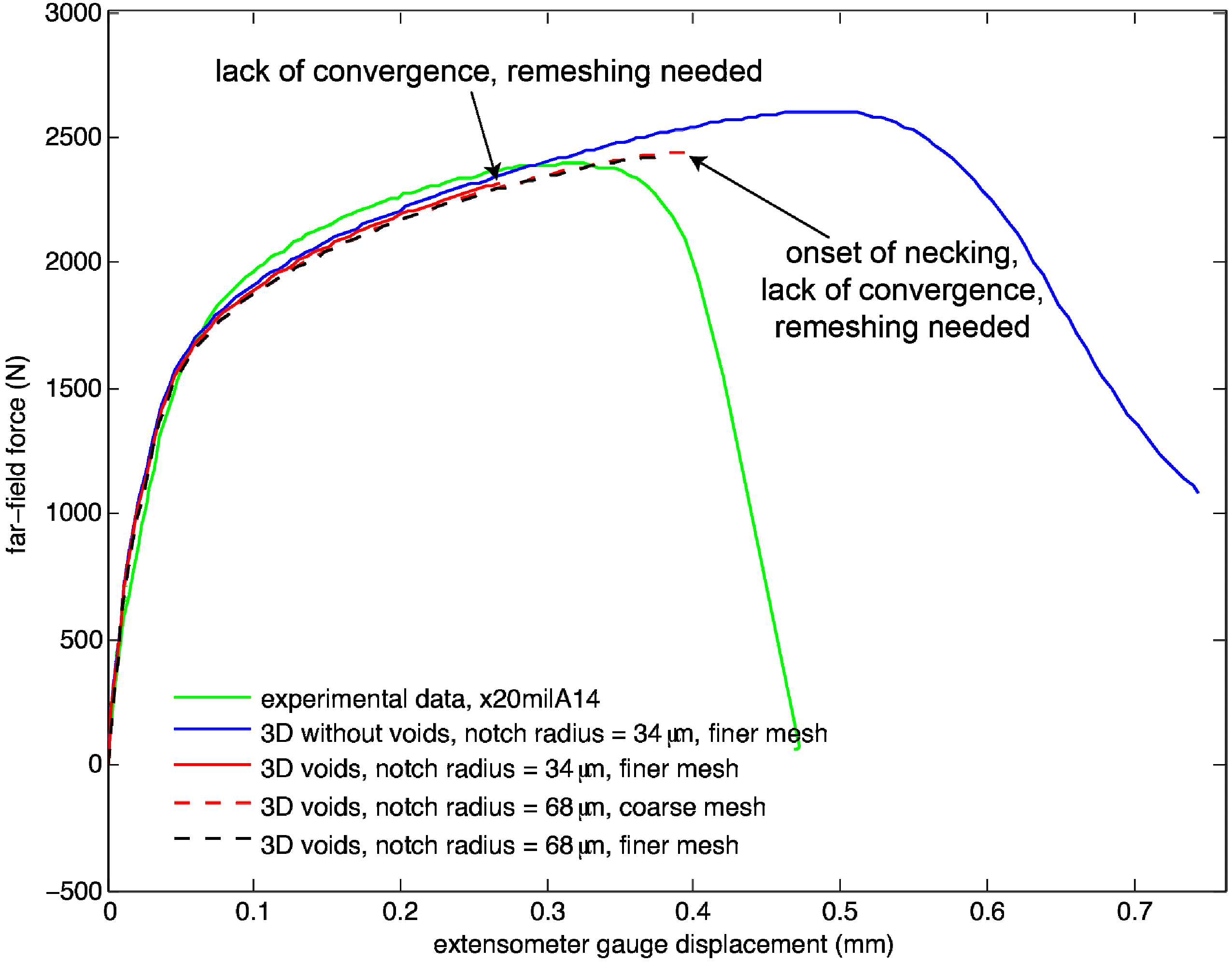
Hypothesis is that void size and distribution within the weld plays a large role in the necking process



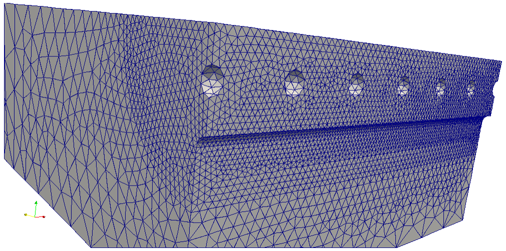
304-L butt weld



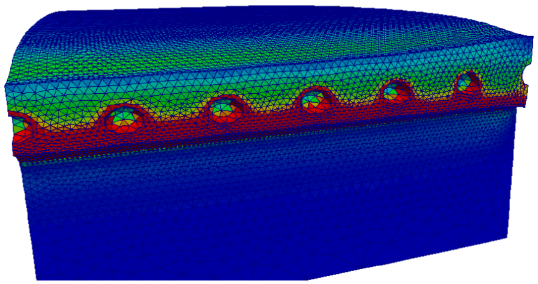
Convergence in the load displacement at onset of necking is not achieved, which may be due to element distortion



Idealized 3D voids



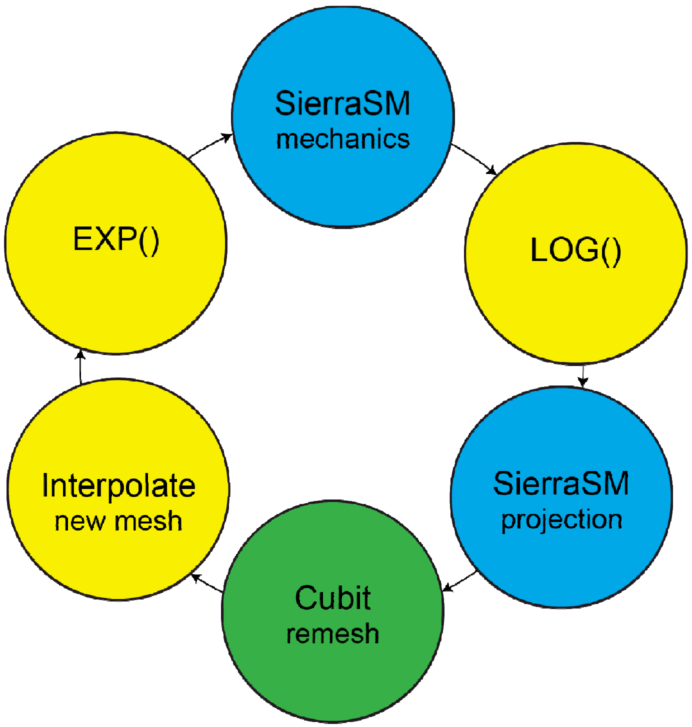
Onset of necking



Remeshing would eliminate element distortion and make convergence possible

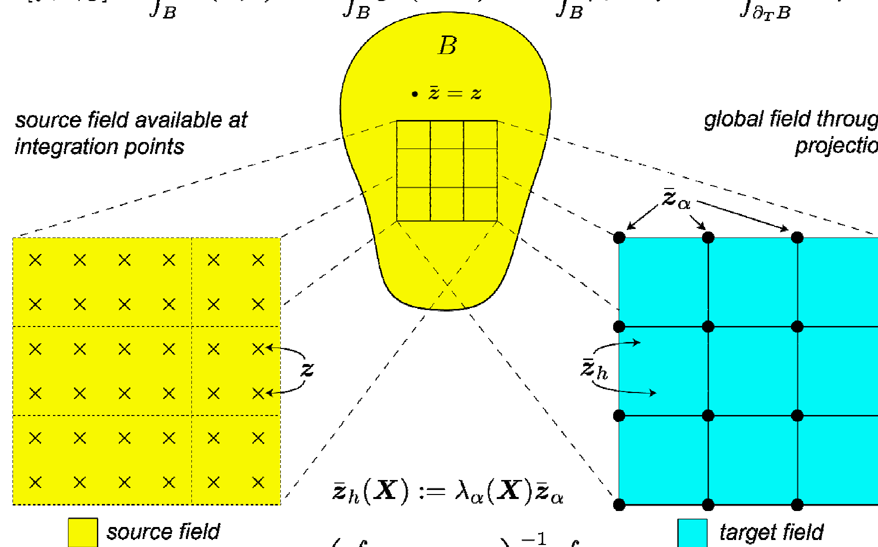
The proposed mapping scheme involves a global L2 projection and Lie-Group interpolation

Overall scheme



Projection from integration points to nodes, then the field is known everywhere

$$\Phi[\boldsymbol{\varphi}, \bar{\boldsymbol{z}}, \bar{\boldsymbol{y}}] := \int_B W(\boldsymbol{F}, \bar{\boldsymbol{z}})\, dV + \int_B \bar{\boldsymbol{y}} \cdot (\bar{\boldsymbol{z}} - \boldsymbol{z})\, dV - \int_B \rho_0 \boldsymbol{B} \cdot \boldsymbol{\varphi}\, dV - \int_{\partial_T B} \boldsymbol{T} \cdot \boldsymbol{\varphi}\, dS$$



$$\bar{\boldsymbol{z}}_h = \lambda_\alpha \left(\int_B \lambda_\alpha \lambda_\beta \boldsymbol{I}\, dV \right)^{-1} \int_B \lambda_\beta \boldsymbol{z}\, dV$$

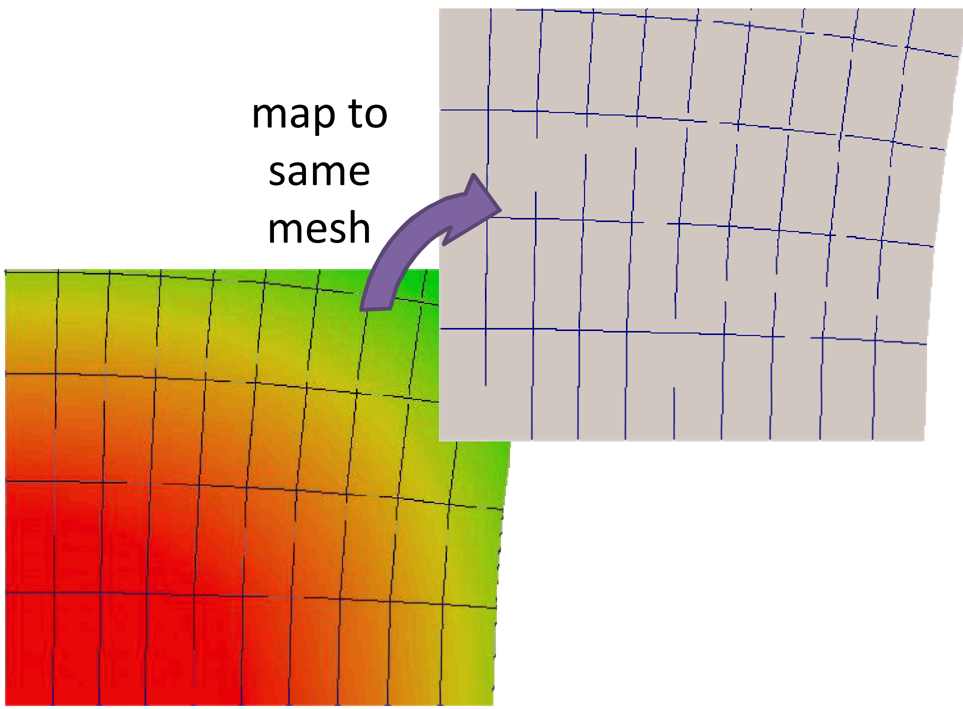
Certain internal variables are members of a Lie Group, which does not admit addition as an operator, therefore we map the Lie Group to its Lie Algebra, then perform the projection and interpolation, then map back to the Lie Group

Mota, A., Sun, W., Ostien, J. T., Foulk, J. W., & Long, K. N. (2013). Lie-group interpolation and variational recovery for internal variables. Computational Mechanics. doi:10.1007/s00466-013-0876-1

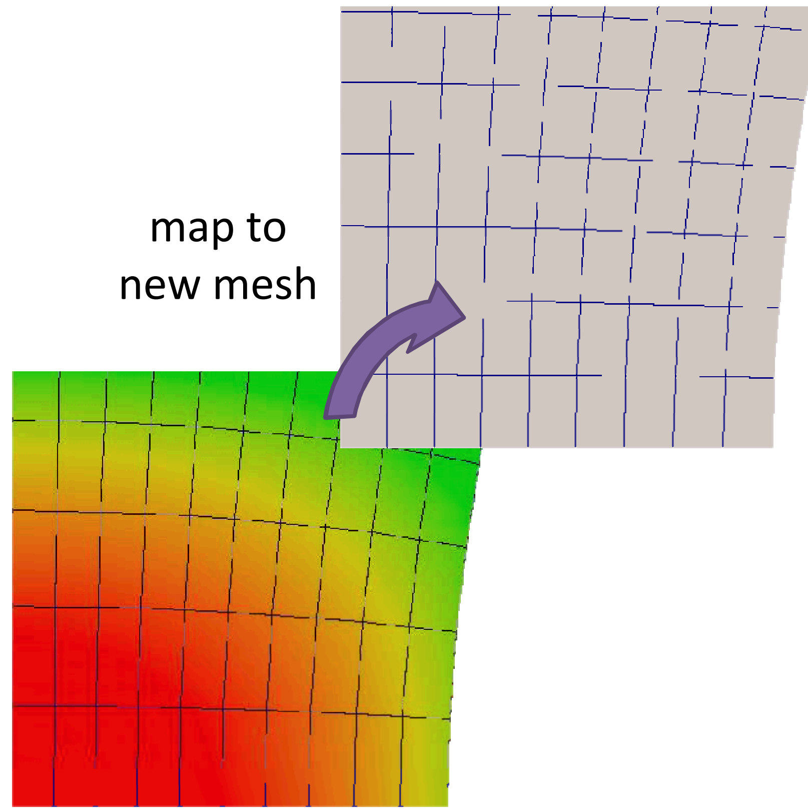
The remapping studies aim to address some fundamental questions

- How much numerical dissipation does the remapping scheme induce?
- Does the remapping scheme push the system far out of equilibrium? Is it significant?

Keep mesh constant and perform mapping from deformed mesh to itself



Remesh after some time and map from the old mesh to a new mesh

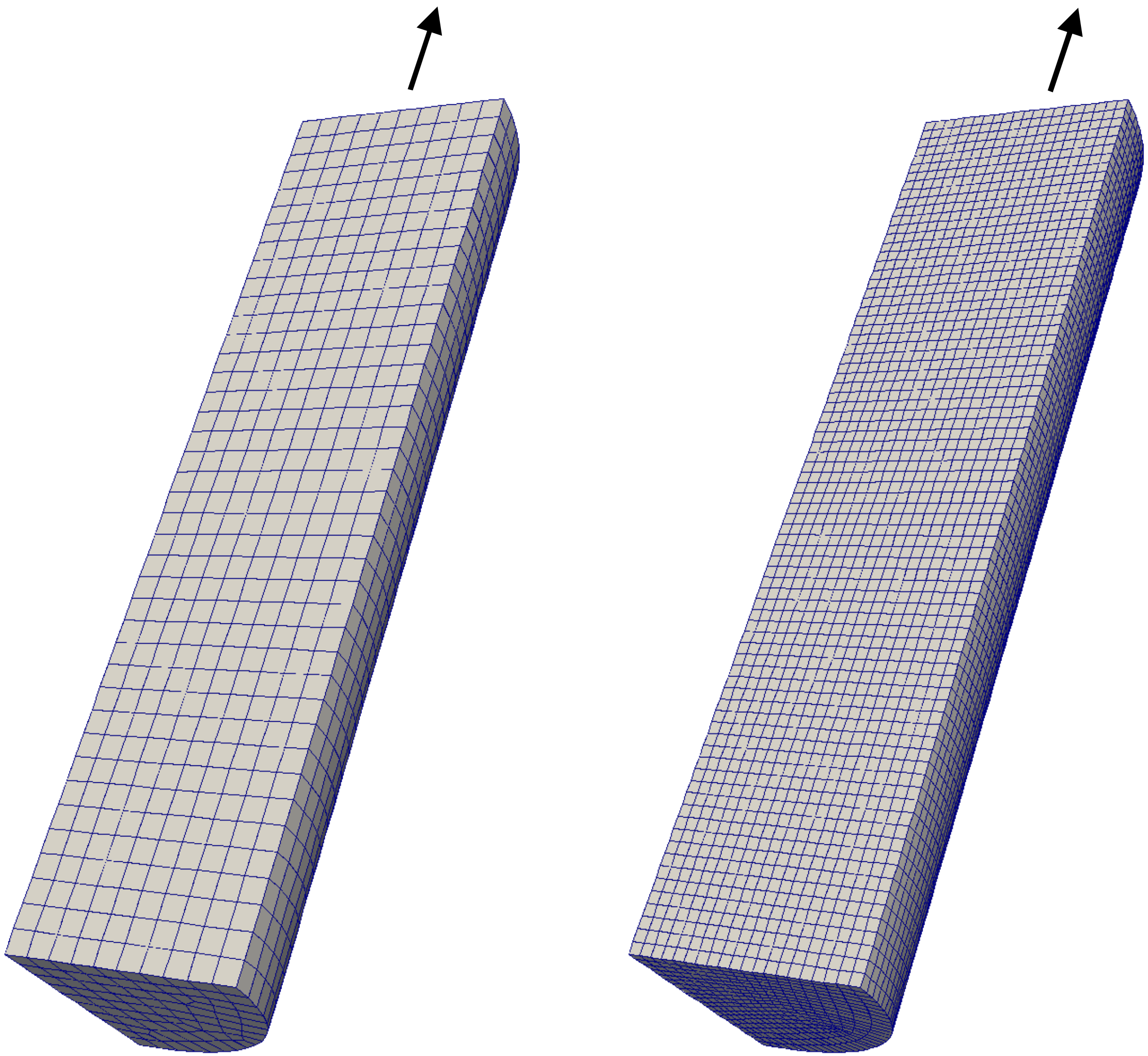


Uniaxial tension of a smooth bar is the representative problem for the numerical studies

Deformation of a circular bar under far-field tension

Coarse and fine hex8 meshes are investigated

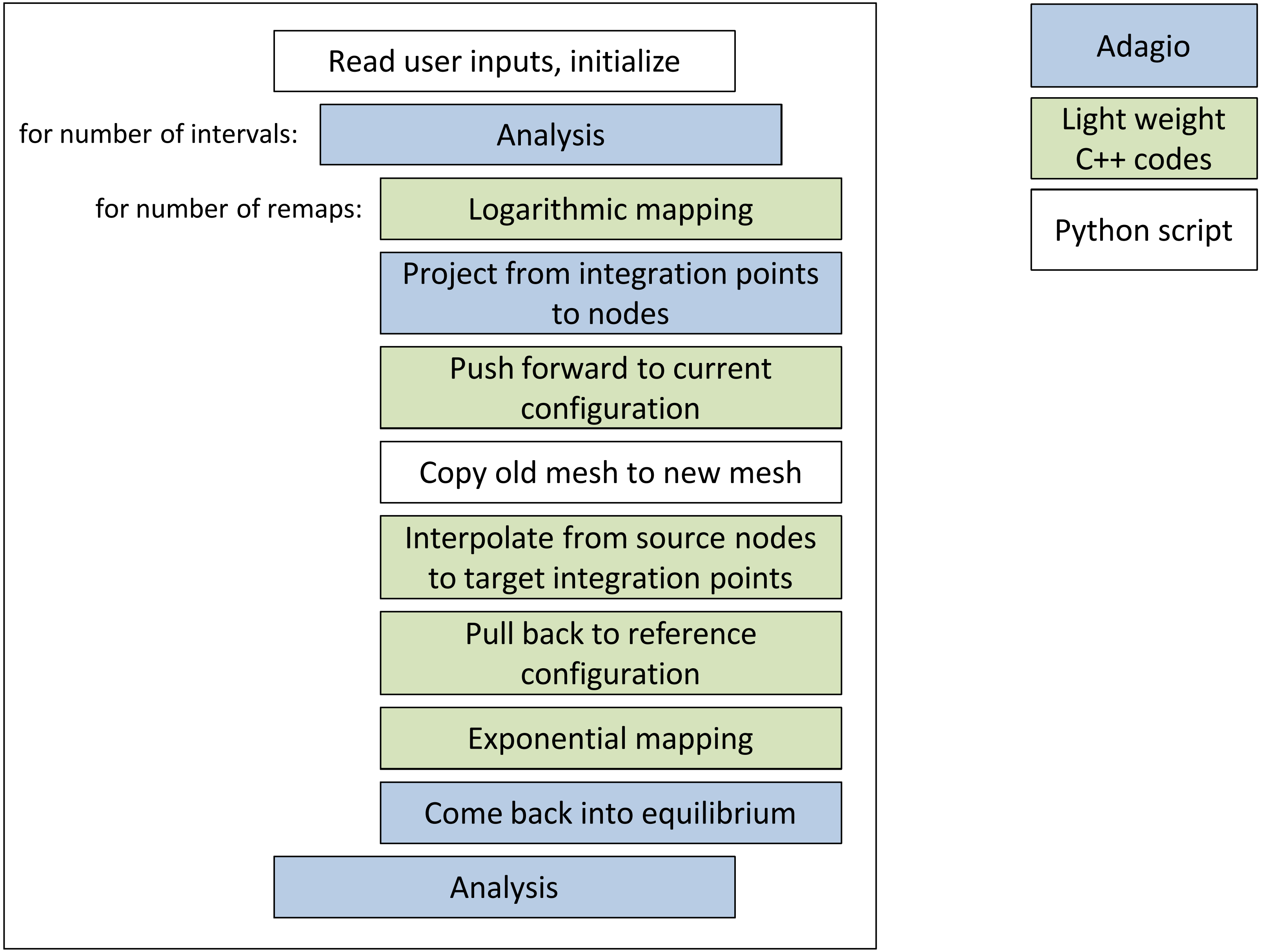
We remesh and map internal state variables to resolve the necking process



coarse mesh, 10 elements across thickness

fine mesh, 20 elements across thickness

Remapping procedure is automated with a python script



Implementation issues in the projection and interpolation were uncovered in the automated remapping process

First problem – After projection the logged rotations were not skew symmetric

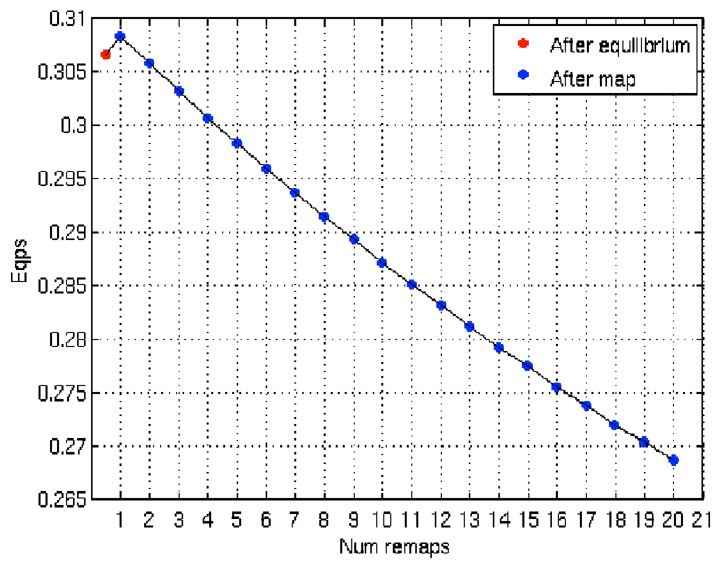
$$\mathbf{R} \in SO(3) = \left\{ \mathbf{A} \in M(n) \middle| \mathbf{A}\mathbf{A}^T = \mathbf{I},\ \det \mathbf{A} = 1 \right\}$$

Log Rotation

$$\log \mathbf{R} \in so(3) = \left\{ \mathbf{B} = M(n) \middle| \mathbf{B} = -\mathbf{B}^T \right\}$$

Project to nodes

$$\log \mathbf{R} \neq -\log \mathbf{R}^T$$



Second problem - Dissipation in internal variables between consecutive remaps due to interpolation

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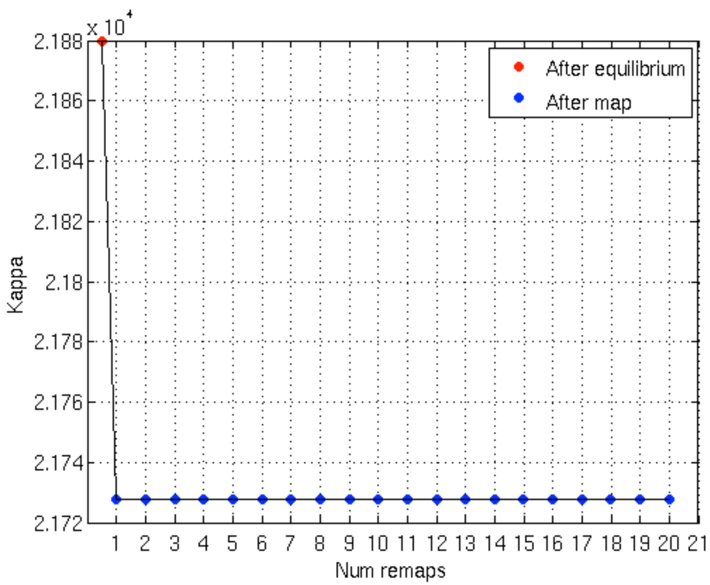
Project to nodes

$$\log \mathbf{R} = -\log \mathbf{R}^T$$

Solution - Tolerance on parallel iterative solver was too loose, switch to parallel direct solver

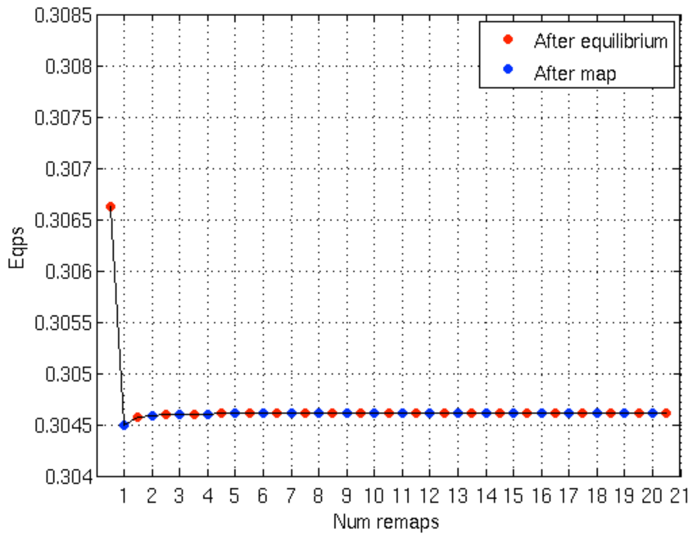


Second problem - Dissipation in internal variables between consecutive remaps due to interpolation

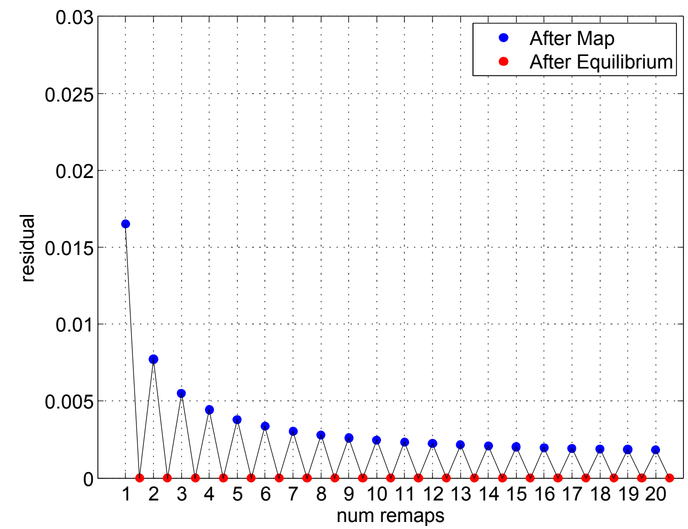
Solution – Numbering of integration points in adagio is different for different elements

Coming into equilibrium after each consecutive remap reveals that the mesh is not converged after remapping

Maximum equivalent plastic strain appears to converge



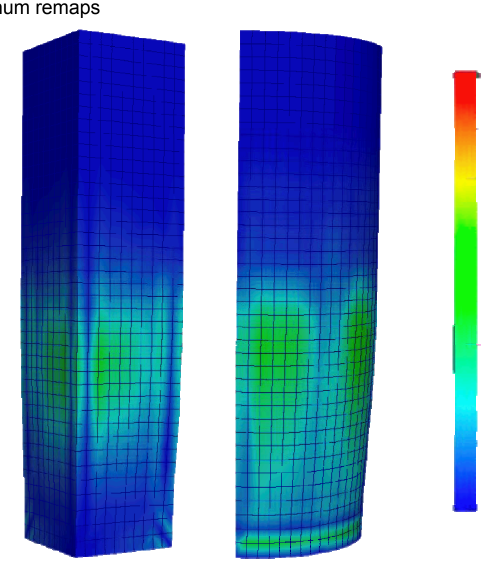
However, the residual reveals that remapping pulls the system out of equilibrium



The system comes back into equilibrium rapidly, i.e. only a few iterations.

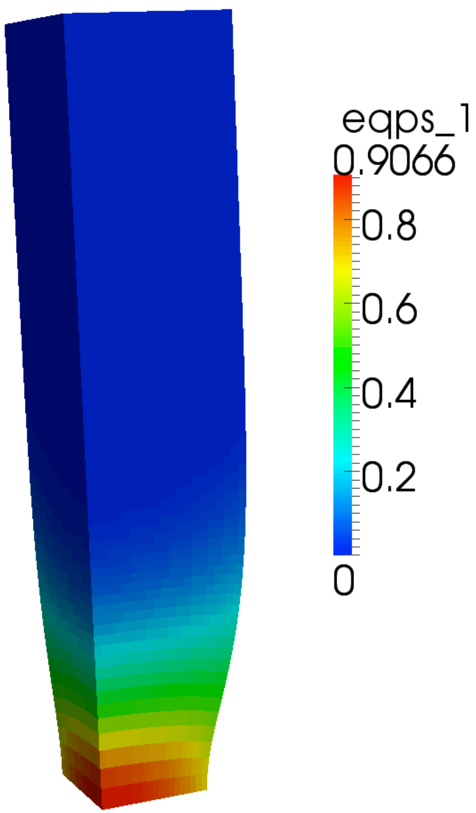
The residual after remapping may be an indication of the discretization error. Further investigation into different levels of refinement are needed.

Difference in magnitude of residual

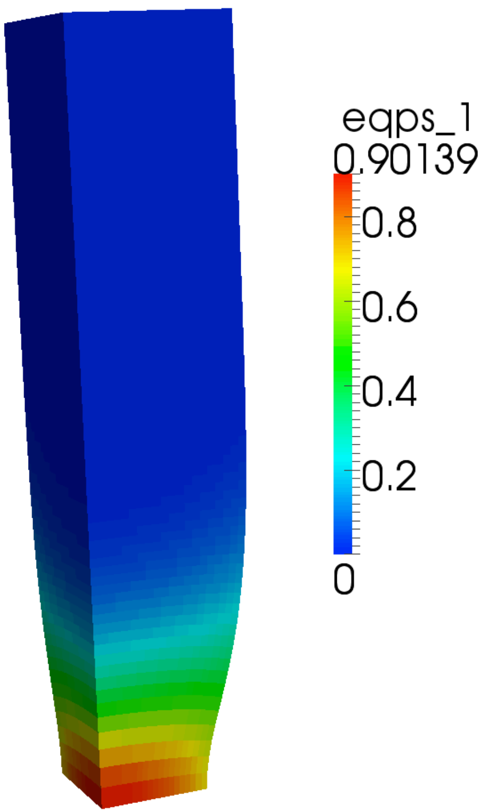


We notice some diffusion in the internal state variables when many remaps are performed

Equivalent plastic strain in fine mesh at one integration point per element at t = 0.25



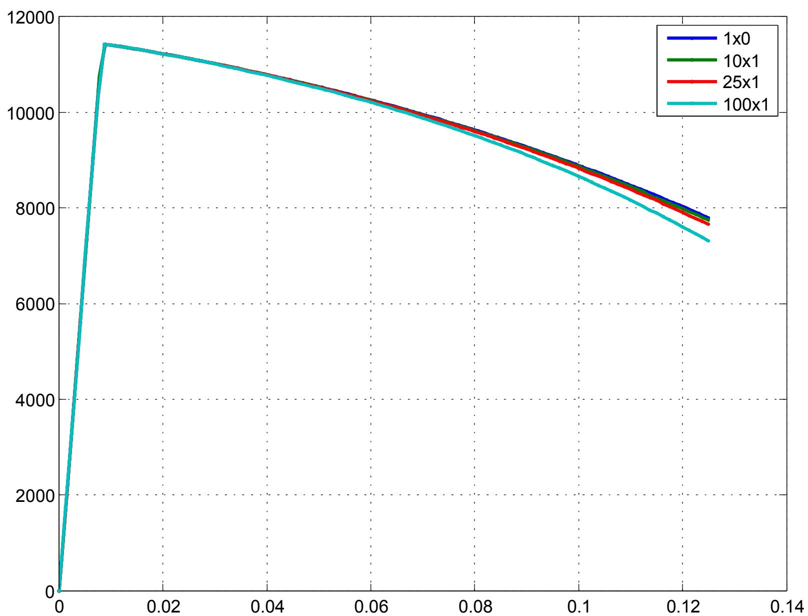
No remapping



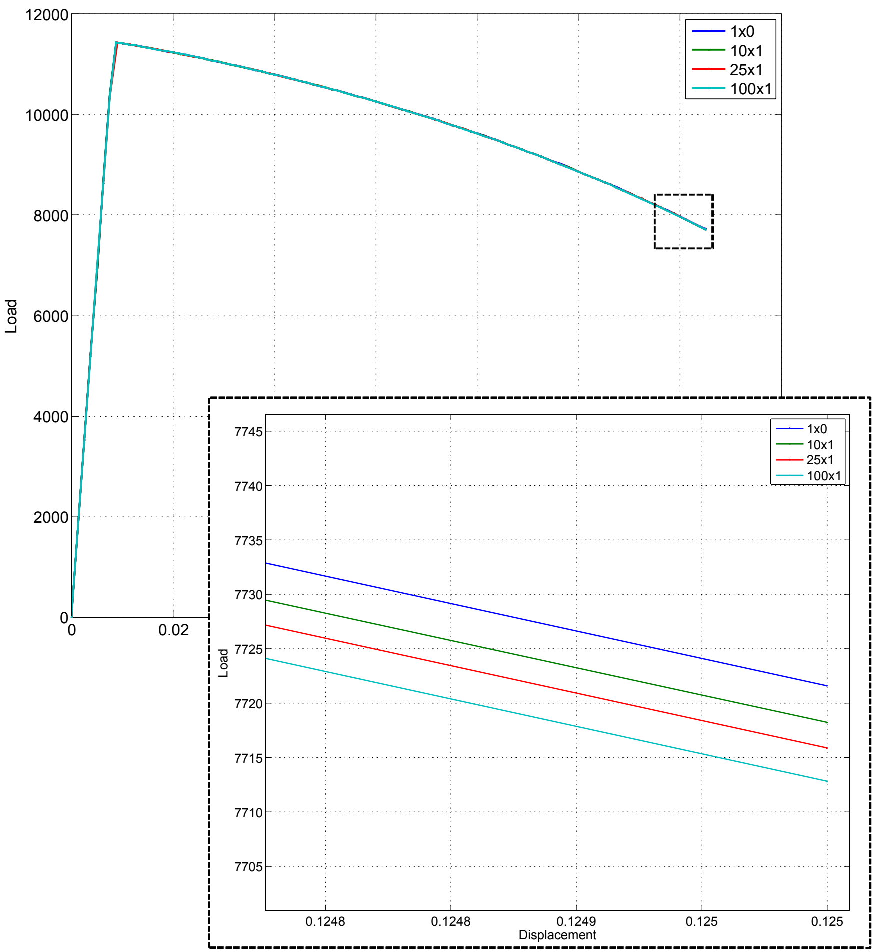
Remap 100 times between t = 0 and t=0.25

The dissipation is less prevalent in a fine mesh than in it is in a coarser mesh

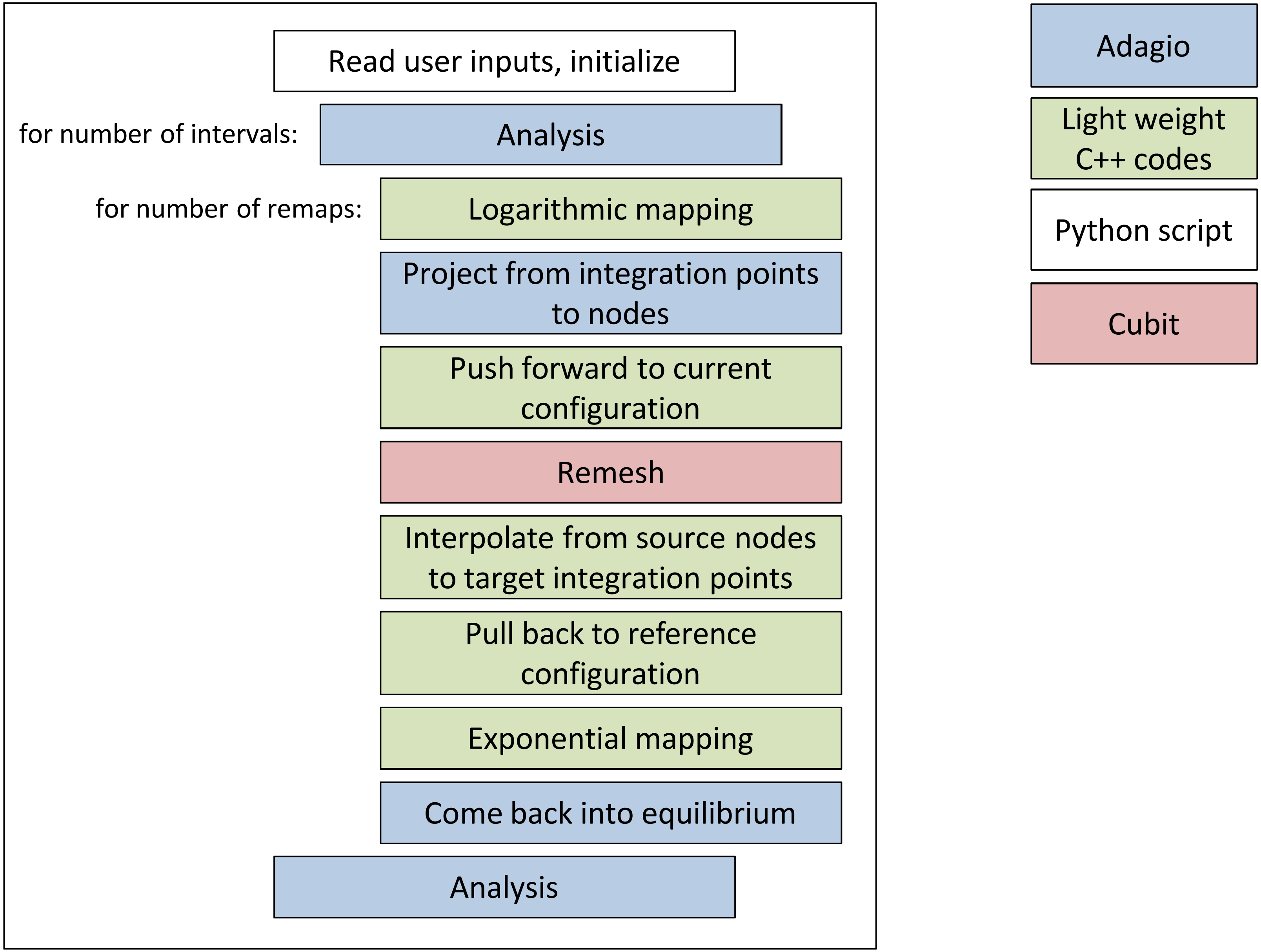
Coarse mesh



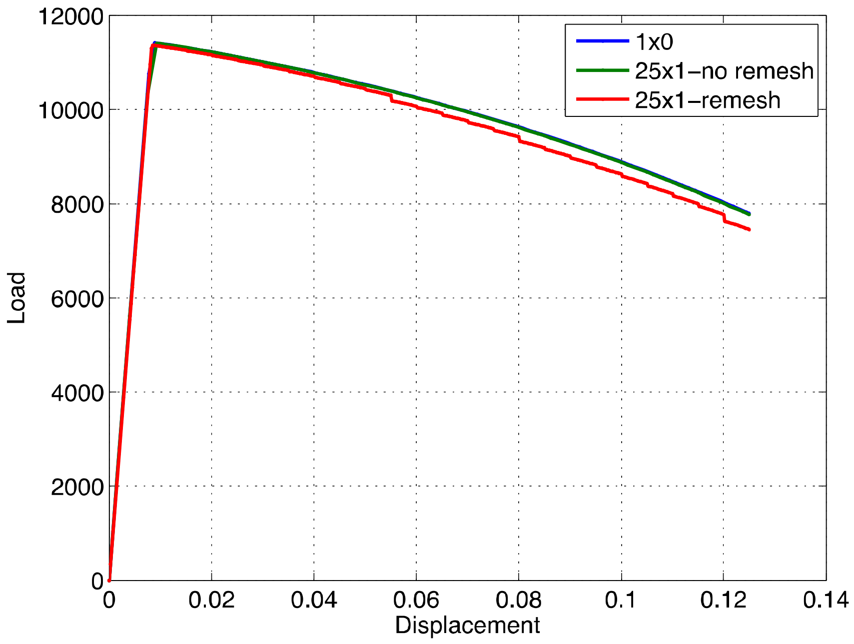
Fine mesh

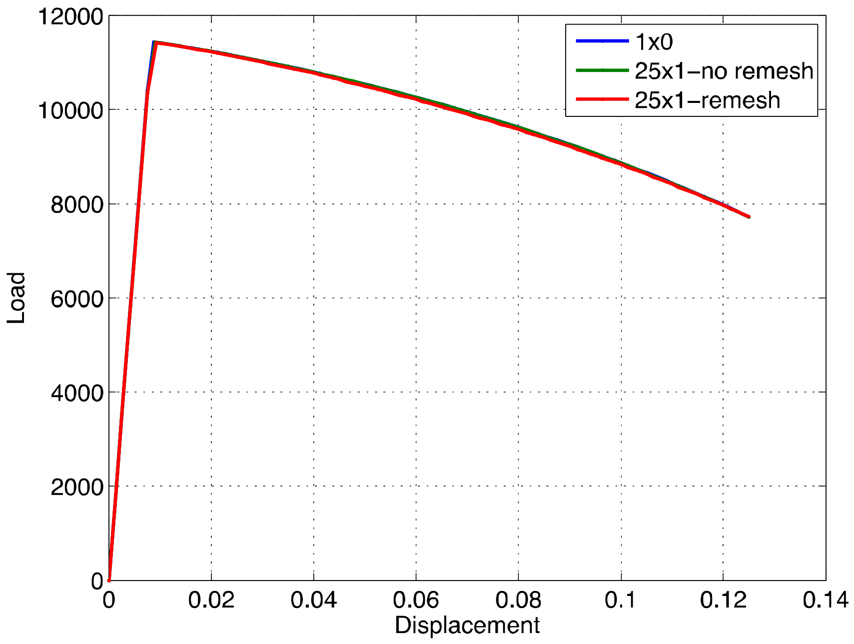


Include remeshing



Some dissipation is present in the load-displacement curve, but it reduces with mesh refinement



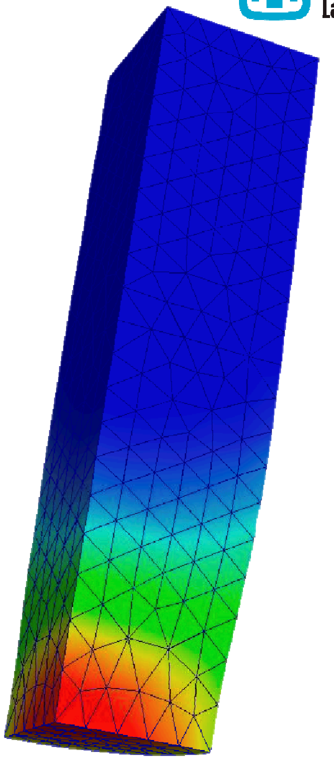


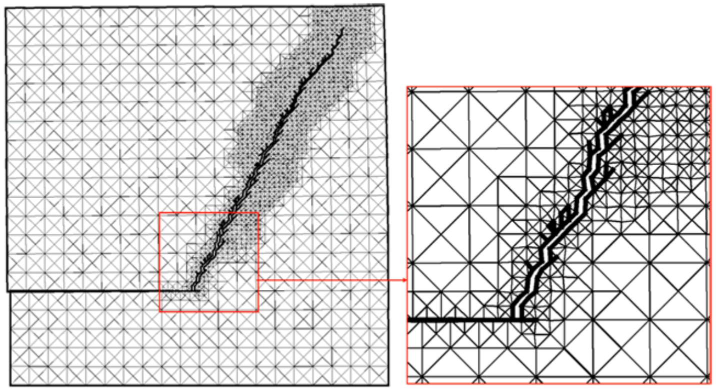
Conclusions and future work

The numerical studies have led to promising results for the hex elements.

The investigation of tet elements is currently underway and will be a continued after completion of the internship through an ongoing collaboration.

The welds with voids would then be modeled with tet elements and the mapping scheme employed to capture the specimen failure.





This work will be incorporated into my dissertation and future work will involve performing mapping of internal state variables with crack propagation.

The projection and interpolation scheme proposed here may also be incorporated into mesh coarsening in the quasi brittle crack simulations.

Questions and roundtable discussion

Mesh refinement reduces increase in residual after remapping

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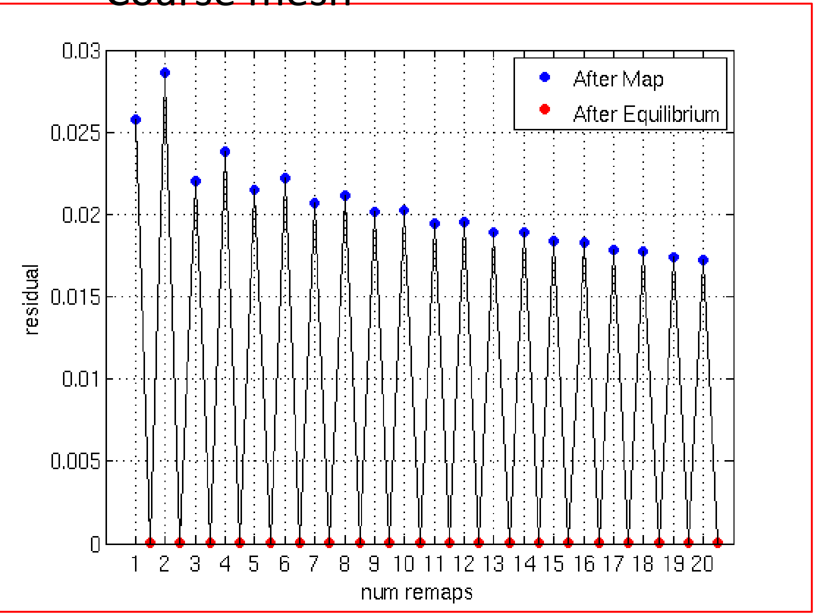
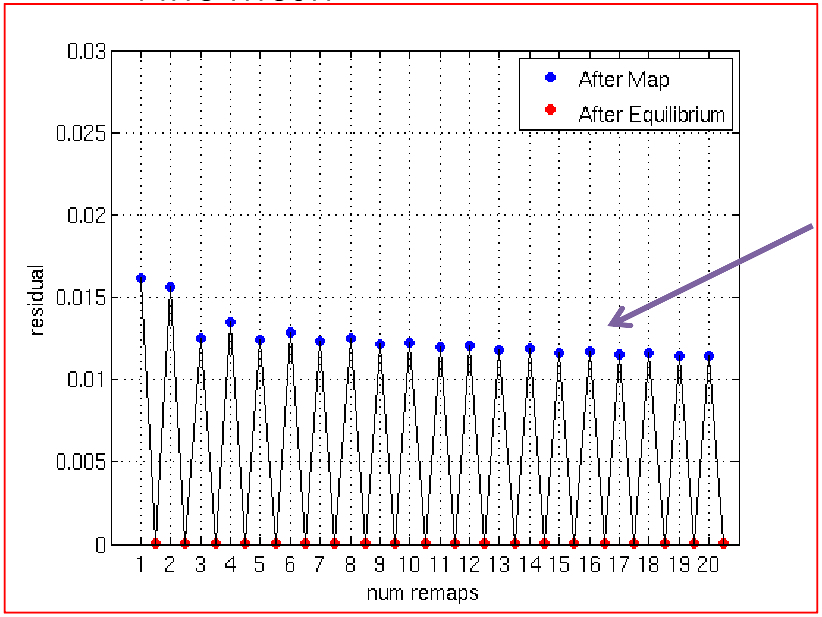
Coarse mesh

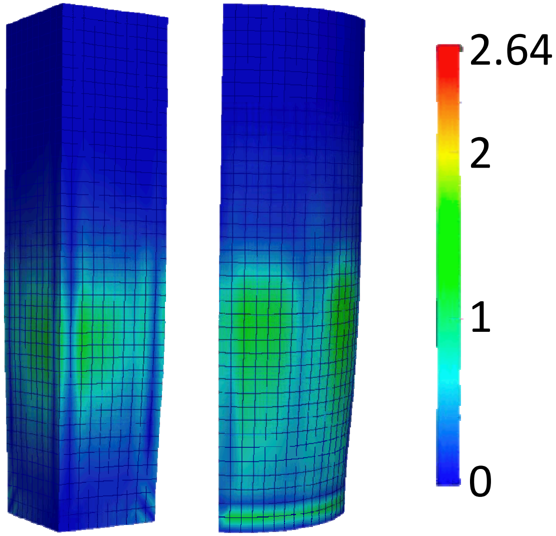


Fine mesh



Difference in residual is quite stable

Difference in magnitude of residual



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