An Overview of GIMP with an Emphasis on Unresolved Issues

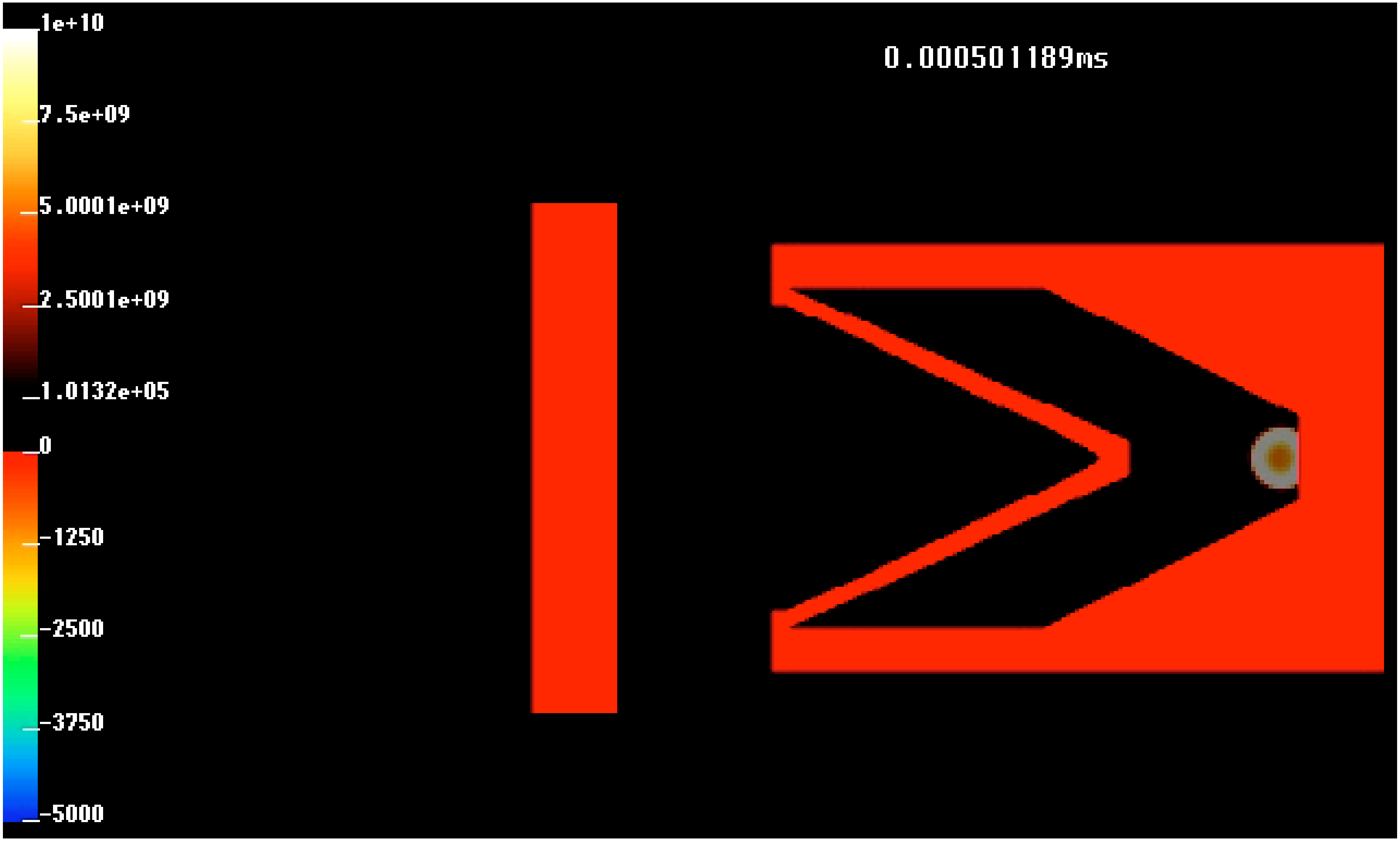
April 2nd, 2009
Jim Guilkey

Schlumberger Reservoir Completions

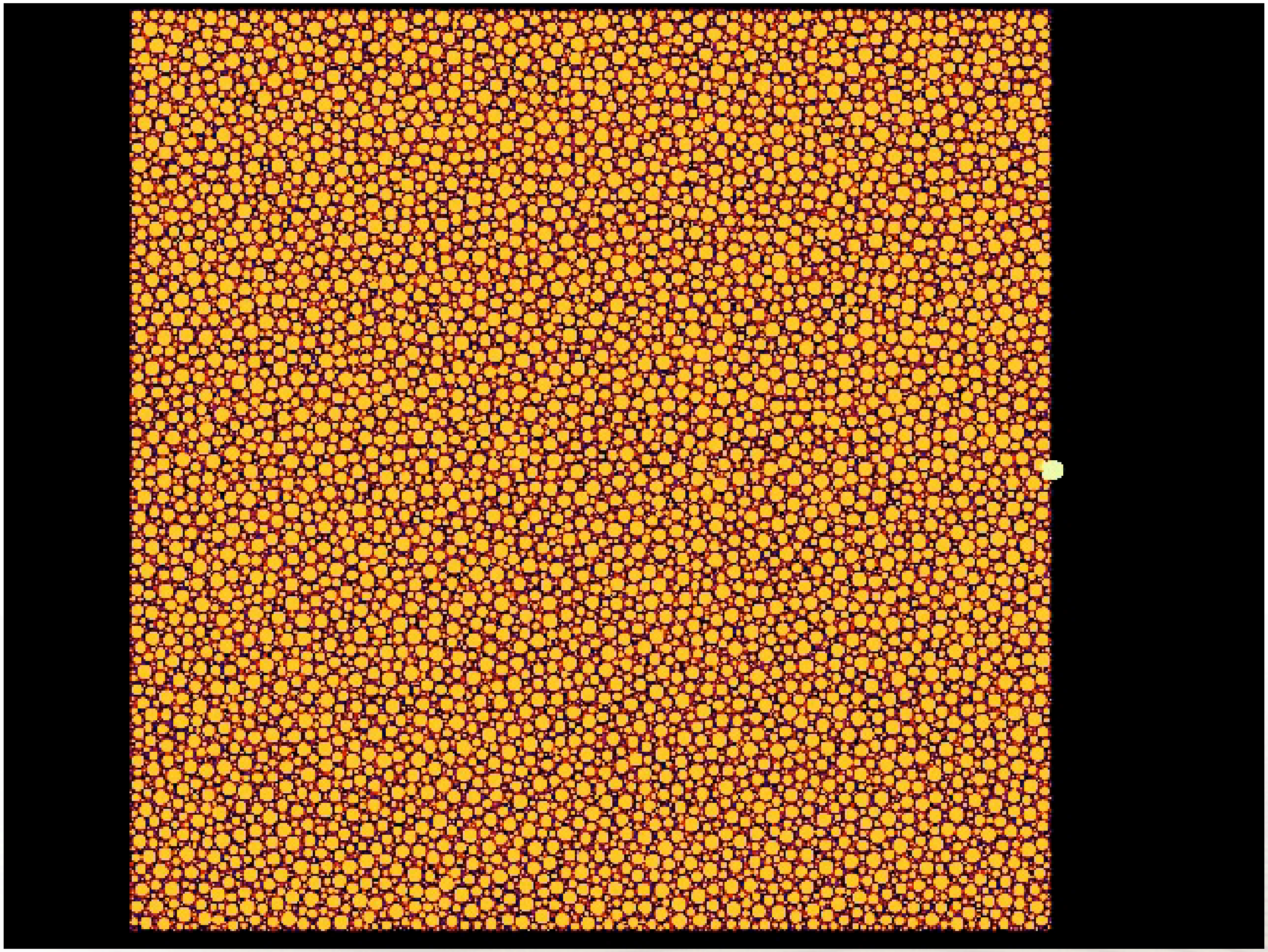
Outline

- Recent Uintah-GIMP simulations
- An overview of the GIMP algorithm
- Outstanding issues
  - Kinematic Boundary Conditions
  - Traction Boundary Conditions
  - Material Failure

Shaped Charge Jet Formation



Metal Rod Impact on Granular Media



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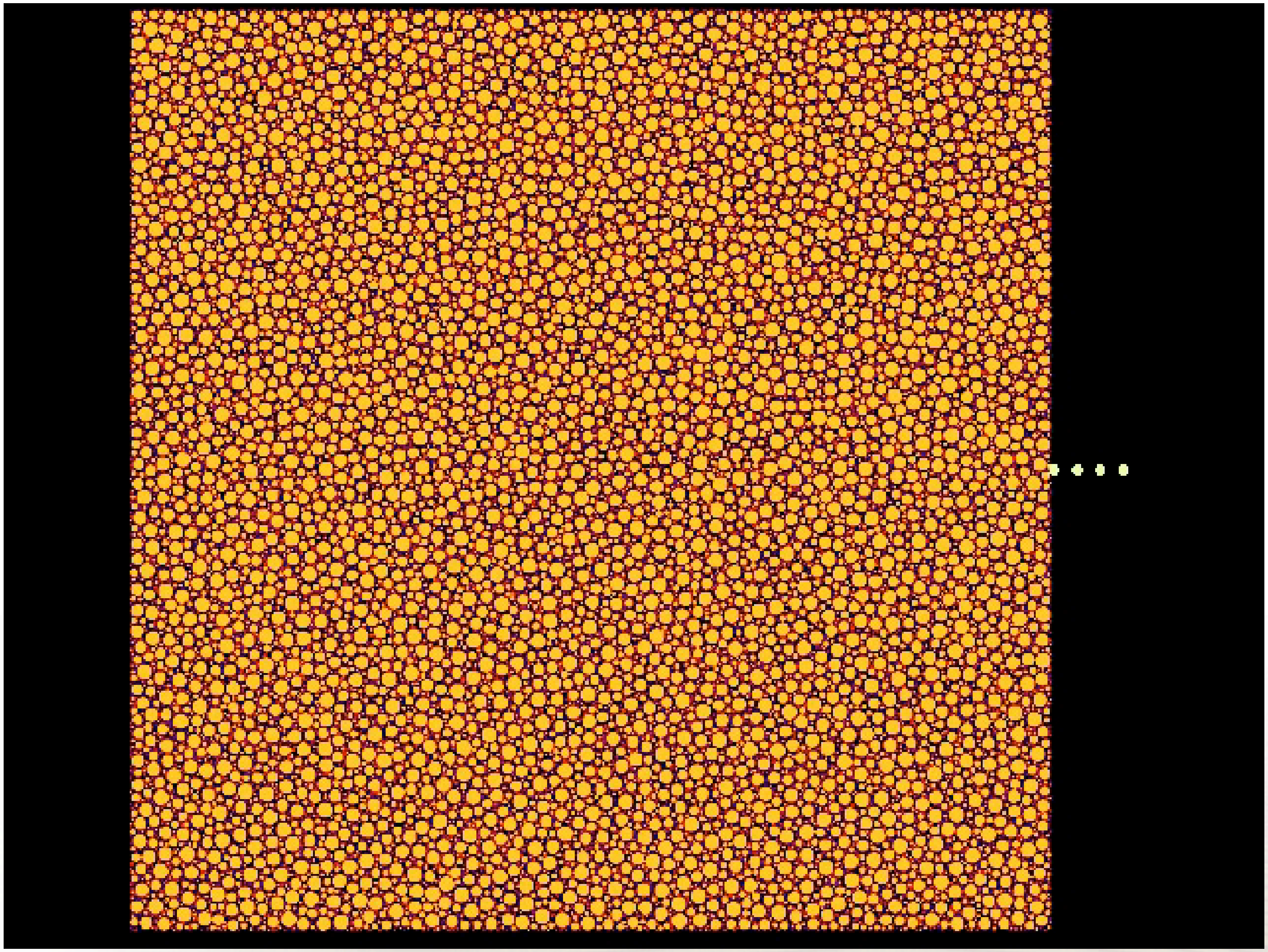
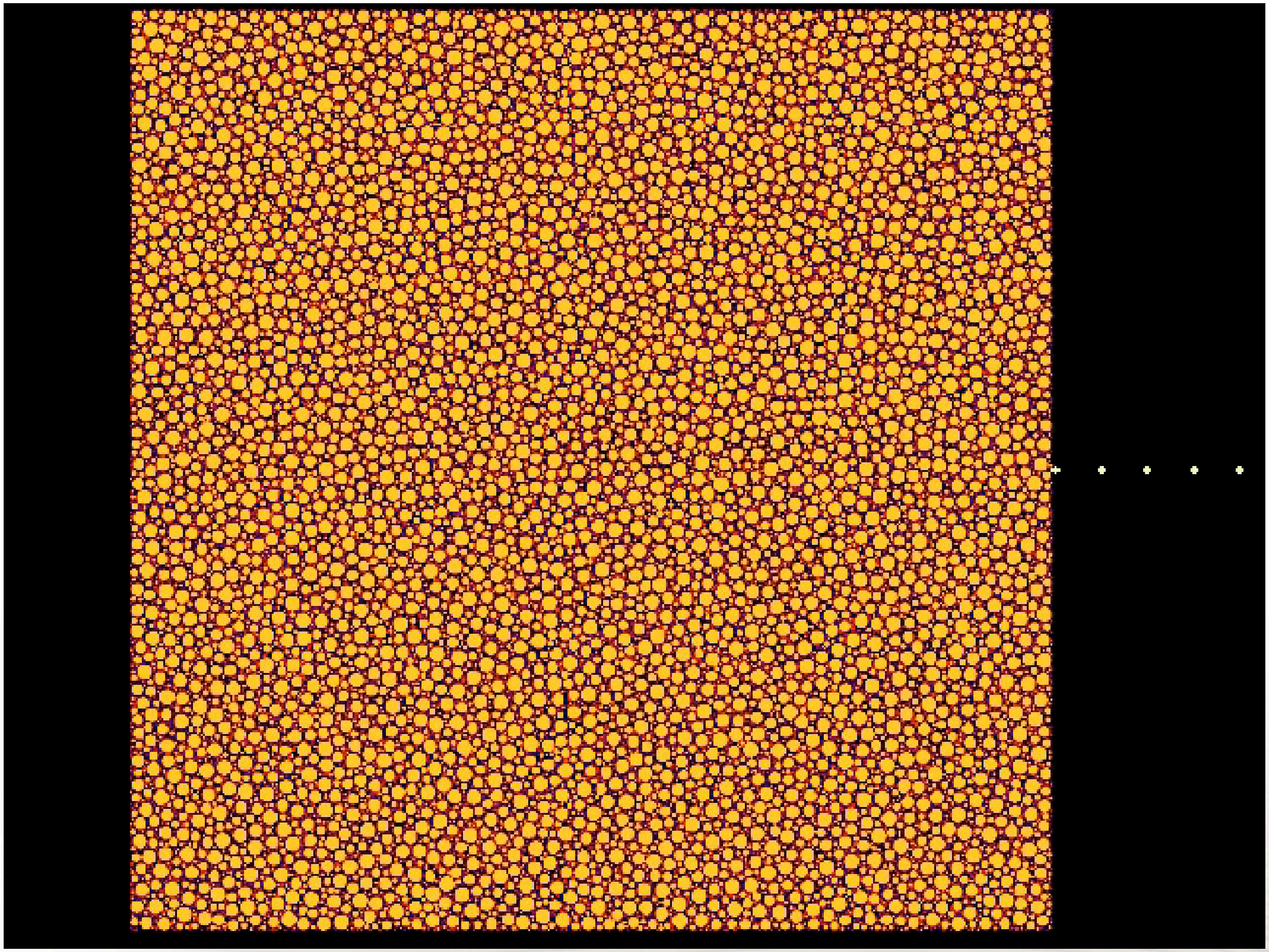
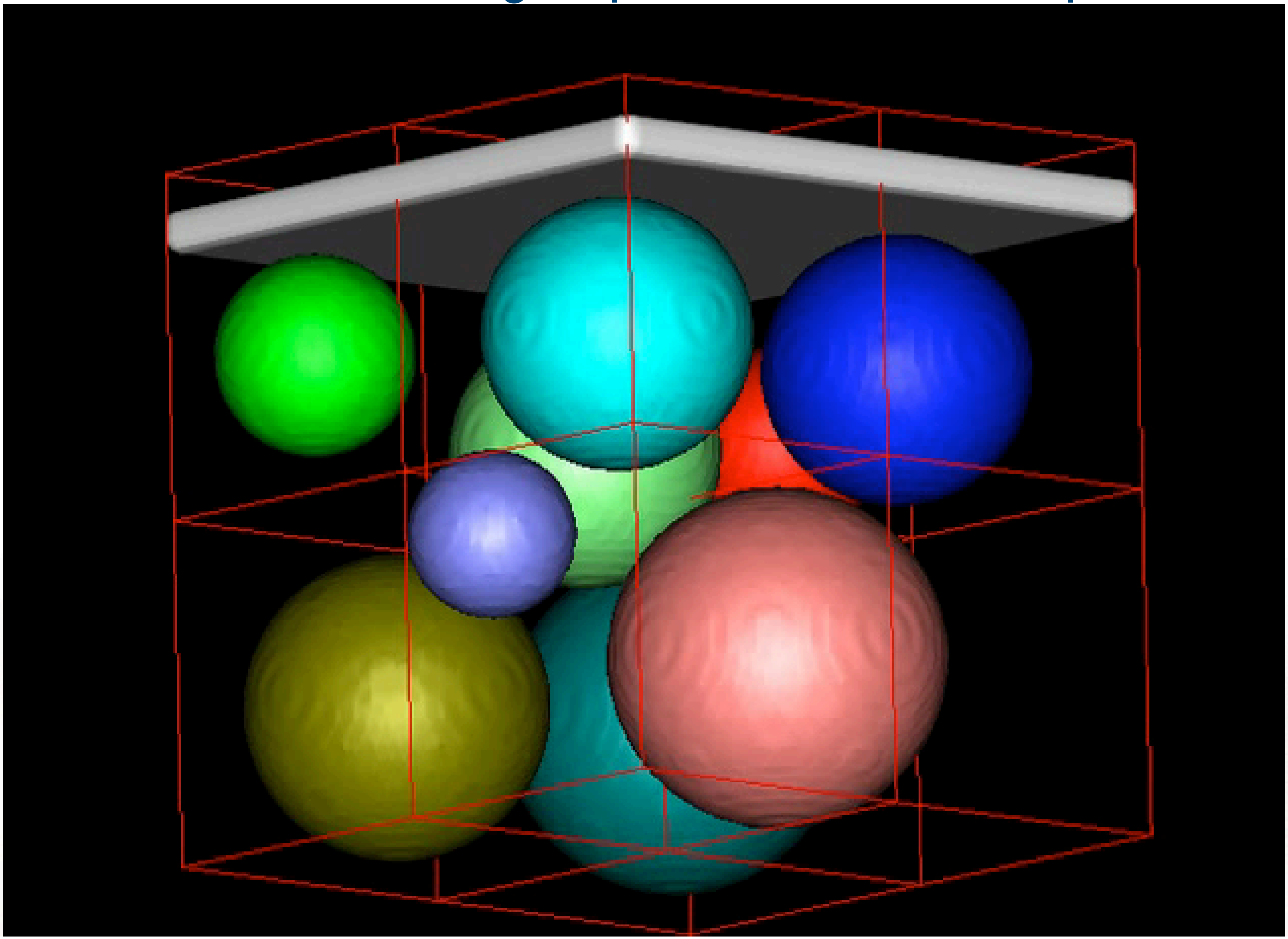


Metal Rod Impact on Granular Media



Mesoscale modeling of powder metal compaction



A Basic GIMP Algorithm

Starting with $\mathbf{x}_p$, m_p, $\mathbf{v}_p$, v_p, $\mathbf{F}_p$, $\boldsymbol{\sigma}_p$

Accumulate particle data to grid nodes (mass, velocity, etc.)

Compute nodal internal force from divergence of particle stress

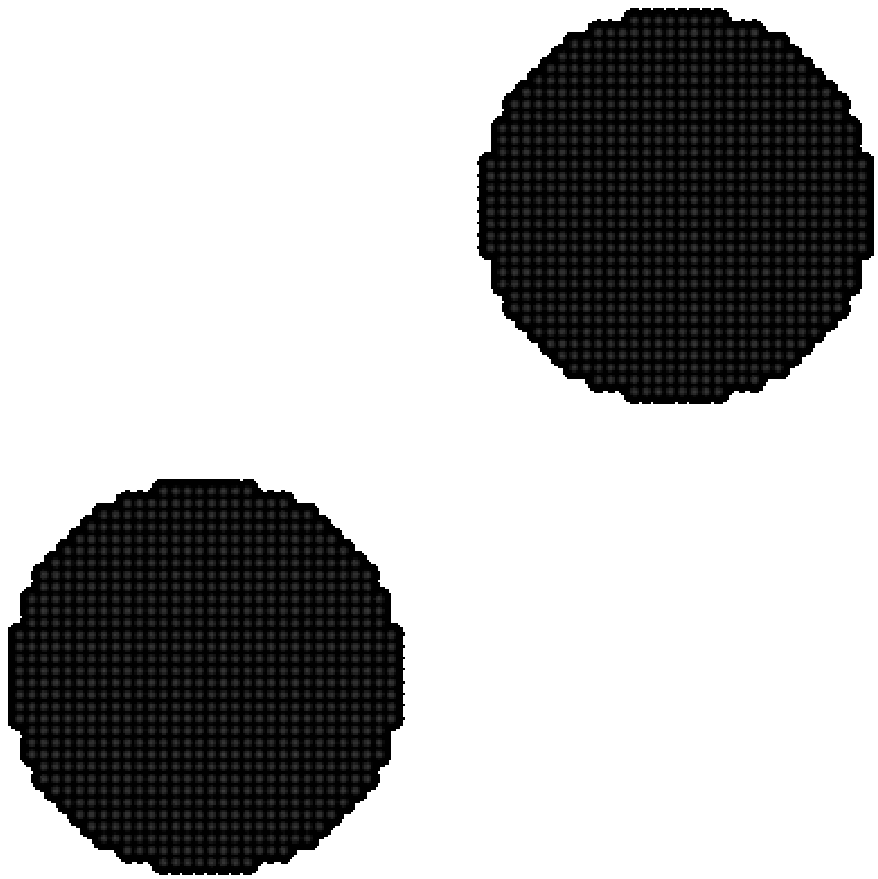
Compute nodal acceleration ($\mathbf{a}_g=\mathbf{f}_{int}/m_g$)

Integrate nodal velocity $\mathbf{v}^*_g=\mathbf{v}_g+\mathbf{a}_g{}^*\Delta t$

Update particle stress, volume and **F** as a function of $\left(\nabla V^*\right)_p$

Update particle position and velocity

Allows solution of ubiquitous IVPs



A Slightly Less Basic GIMP Algorithm

Accumulate particle data to grid nodes (mass, velocity, etc.)

Set Boundary Conditions on “accumulated” nodal velocity

Compute nodal internal force from divergence of particle stress

Compute nodal acceleration ($\mathbf{a}_i=\mathbf{f}_{int}/m_i$)

Integrate nodal velocity $\mathbf{v}_i^*=\mathbf{v}_i+\mathbf{a}_i^*\Delta t$

Set BCs on time advanced nodal velocity and acceleration

Update particle stress and volume as a function of $\left(\nabla V^*\right)_p$

Update particle position and velocity

Acceleration Boundary Conditions

For specified (Dirichlet) velocity boundaries, consider two possible approaches:

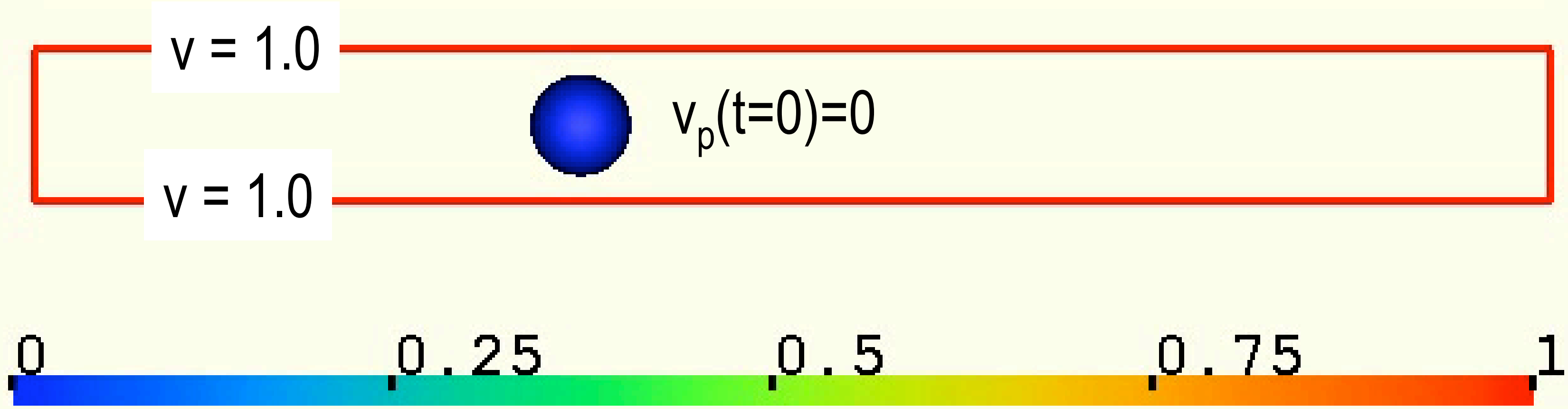
1. $a_i = 0 \quad \forall\ i$ on the domain boundary $\delta\Omega$

2. $a_i = \dfrac{v_i{}^* - v_i}{\Delta t} \quad \forall\ i$

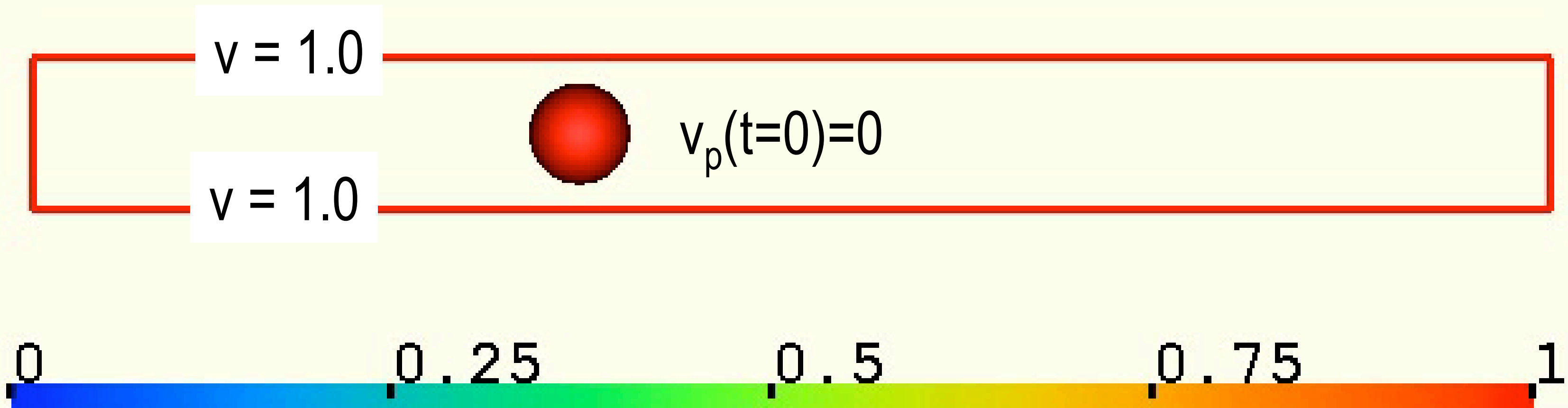
Let's use the formula in 2 all of the time, but achieve 1 by first setting BCs on both the accumulated and integrated velocities

Compare the two acceleration BC schemes

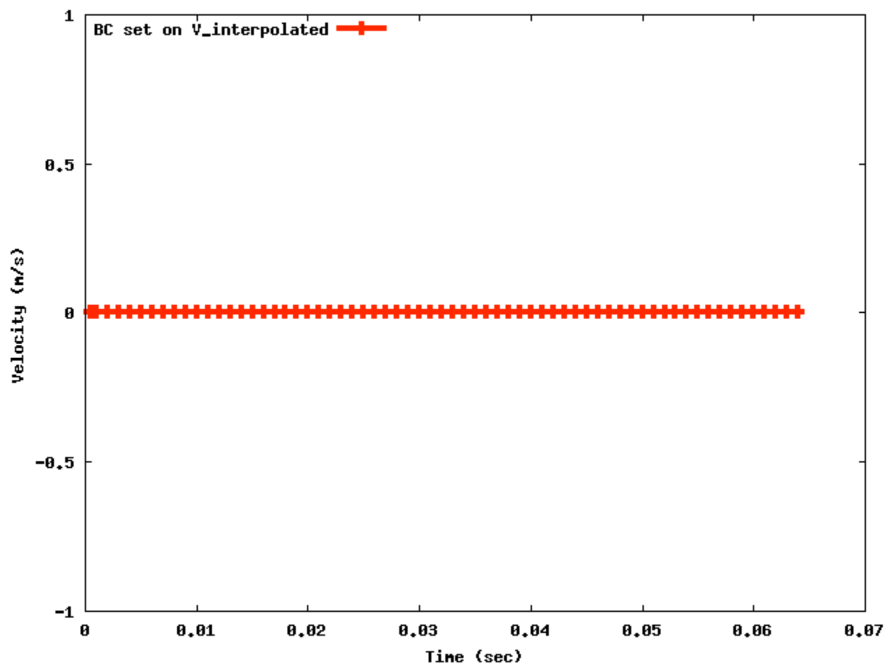
1.

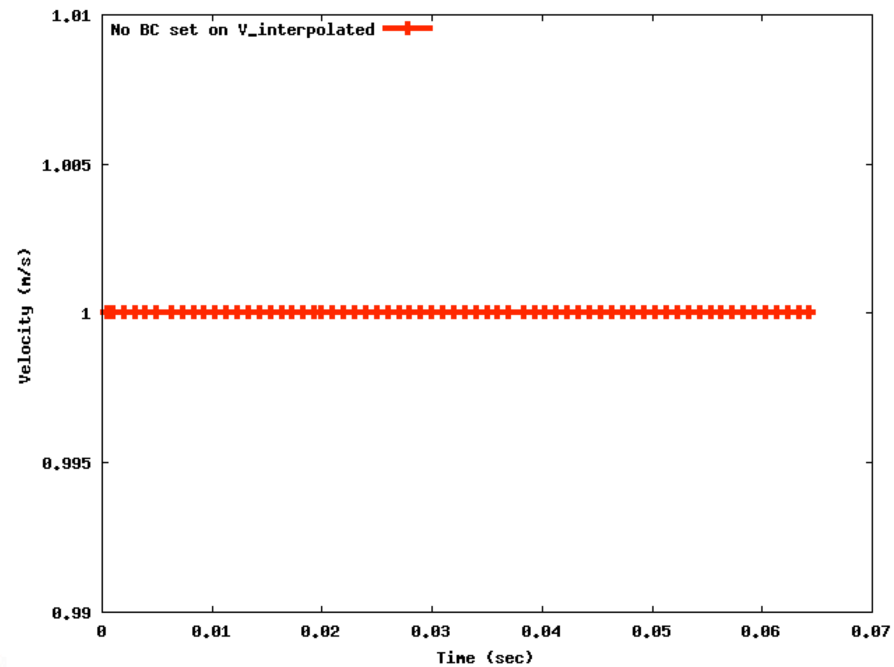


2.



Compare the two acceleration BC schemes





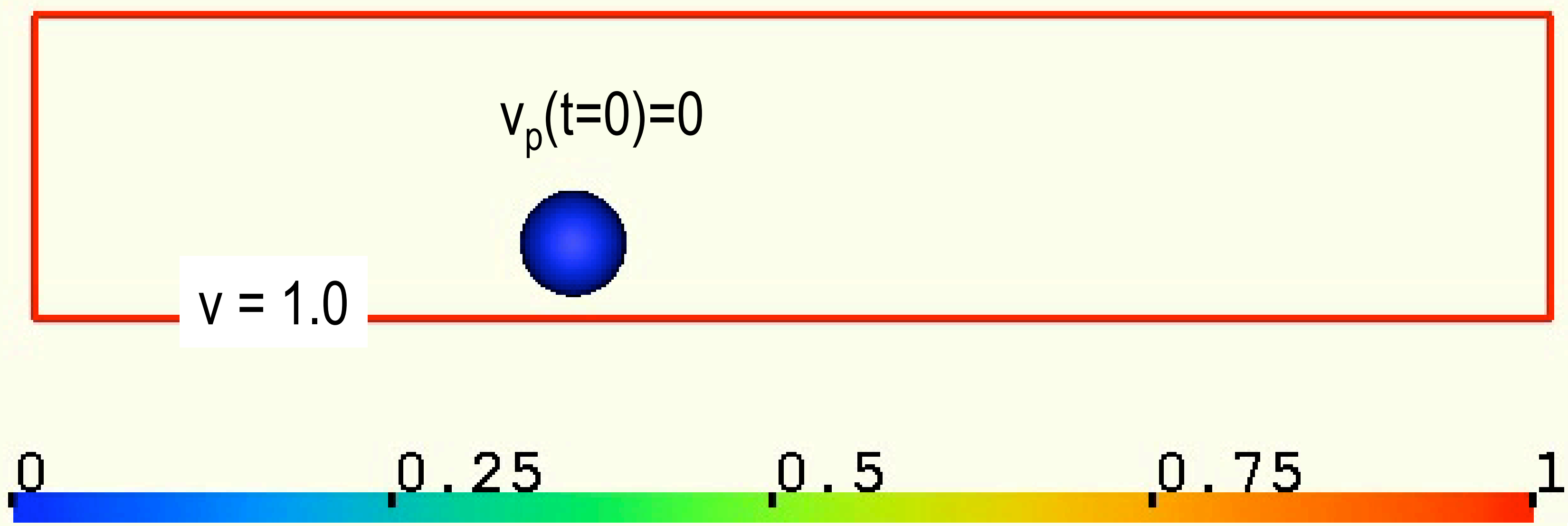
1

2

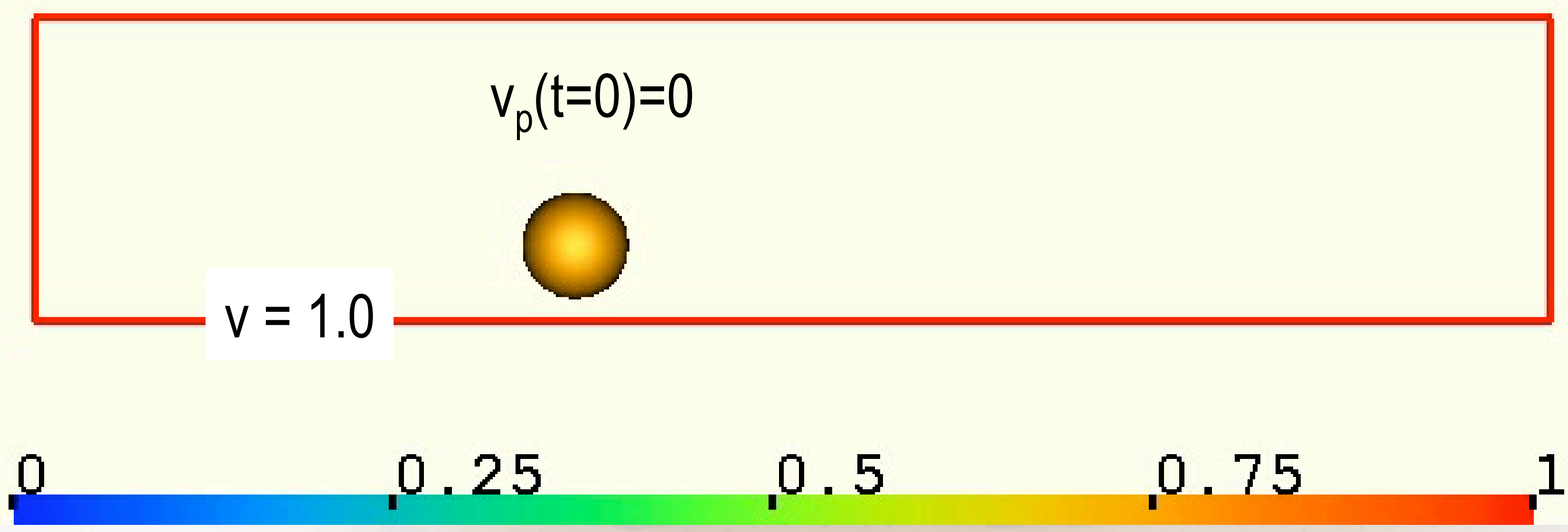
Schlumberger Reservoir Completions

Add a layer of empty cells

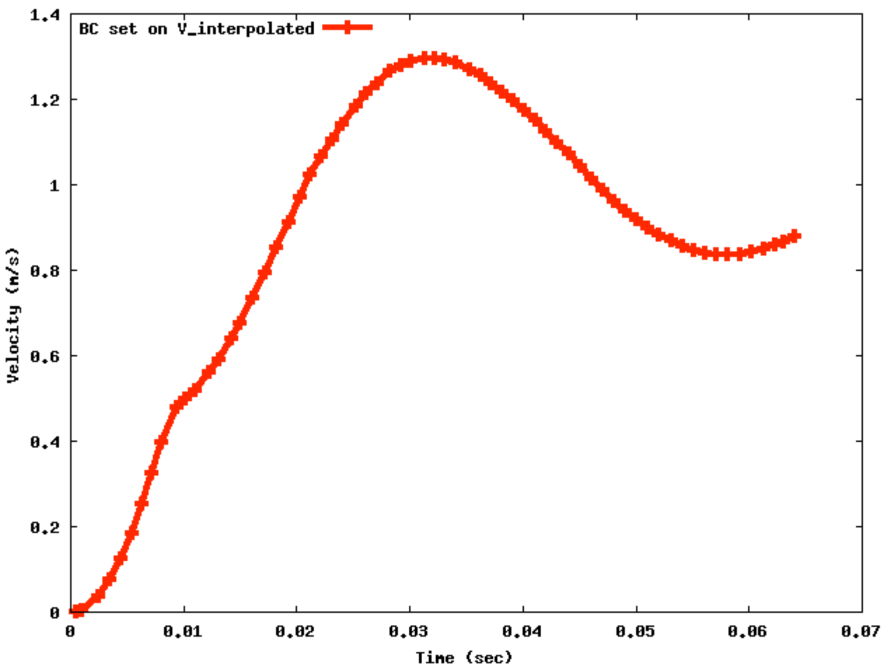
1.



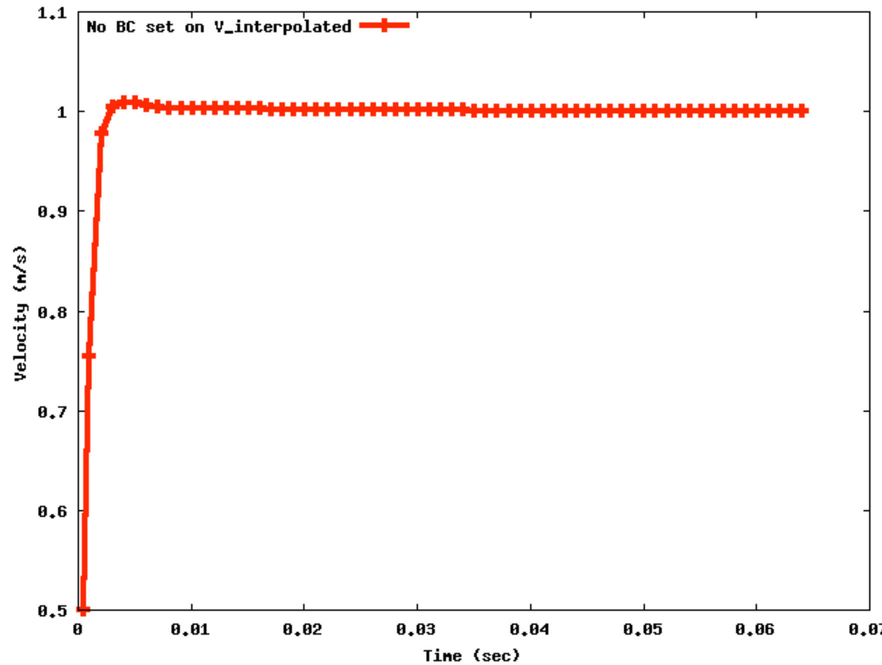
2.



Compare the two acceleration BC schemes

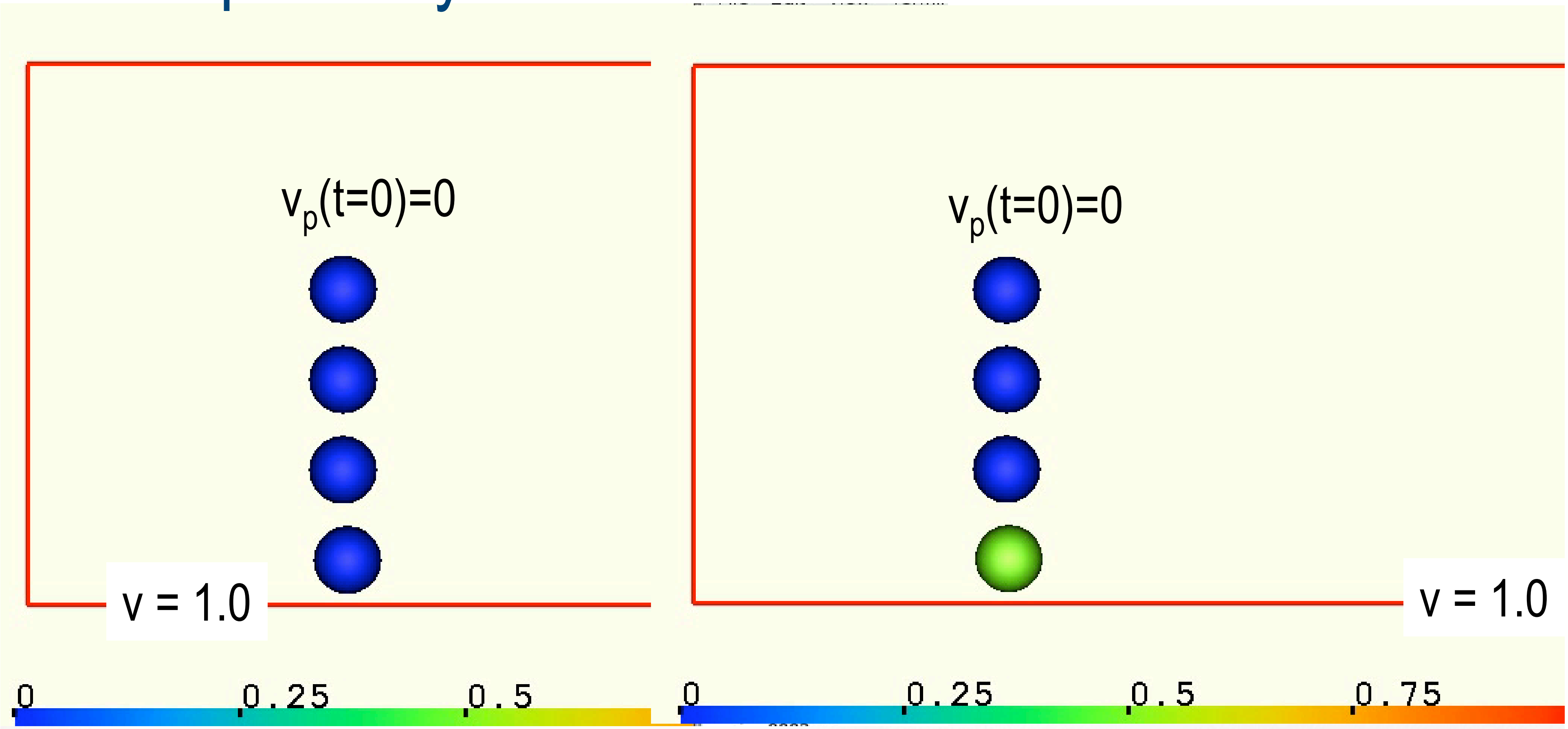


1



2

Impulsively started beam



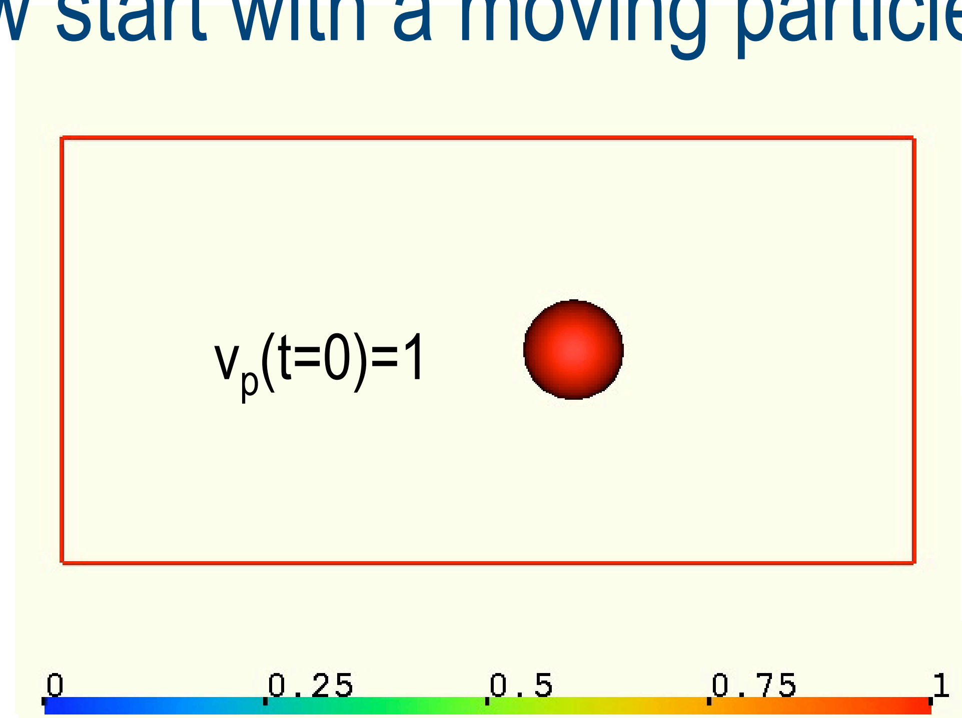
1 2

So, clearly, method 2 is the superior way to treat acceleration Boundary Conditions

Not so fast!

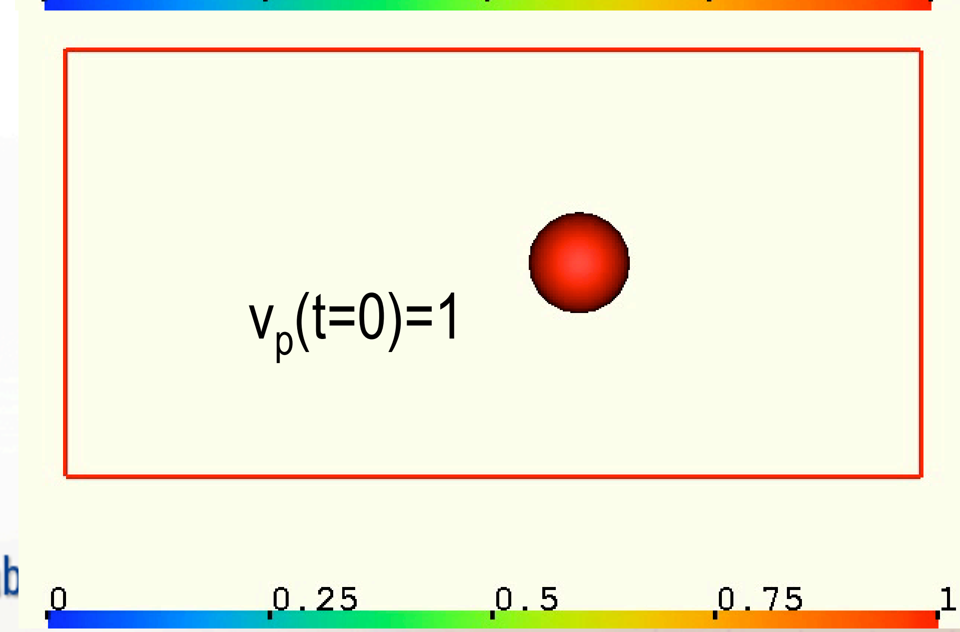
Now start with a moving particle and still boundary

1.



v = 0.0

2.

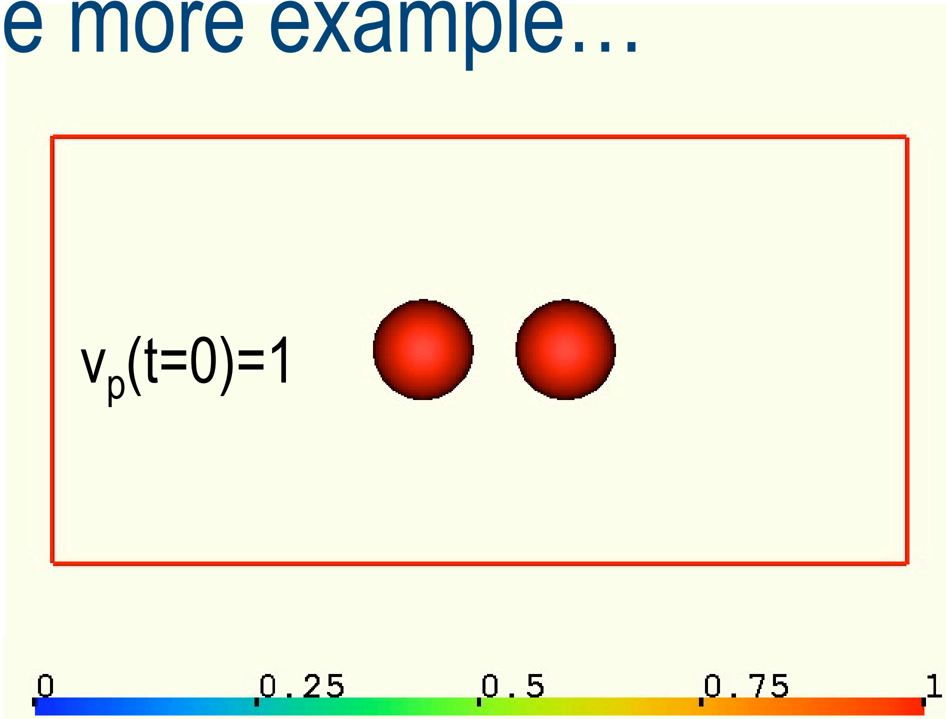


v = 0.0

Schlumb

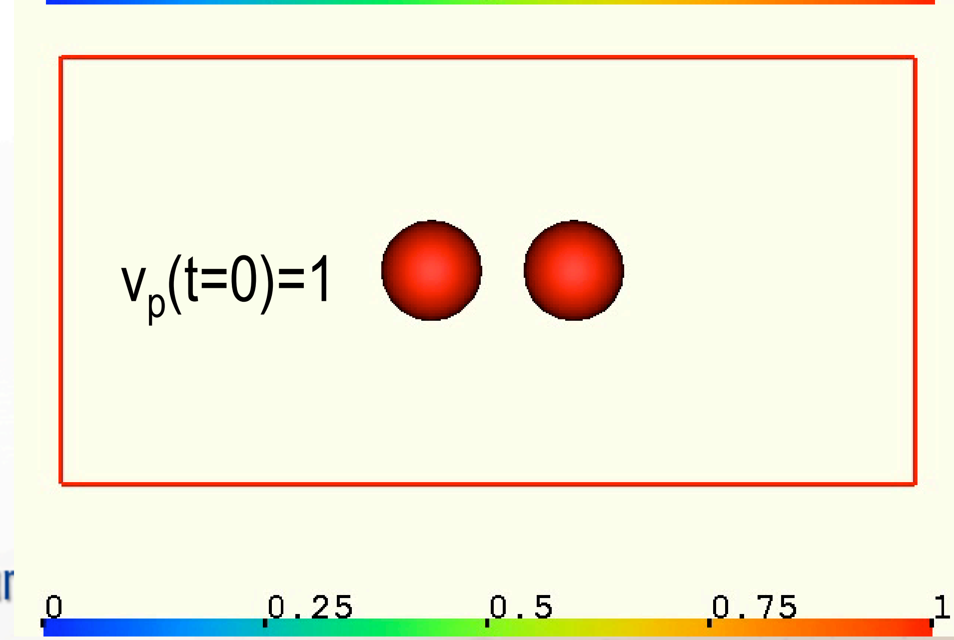
One more example…

1.



$v = 0.0$

2.



$v = 0.0$

Traction Boundary Conditions

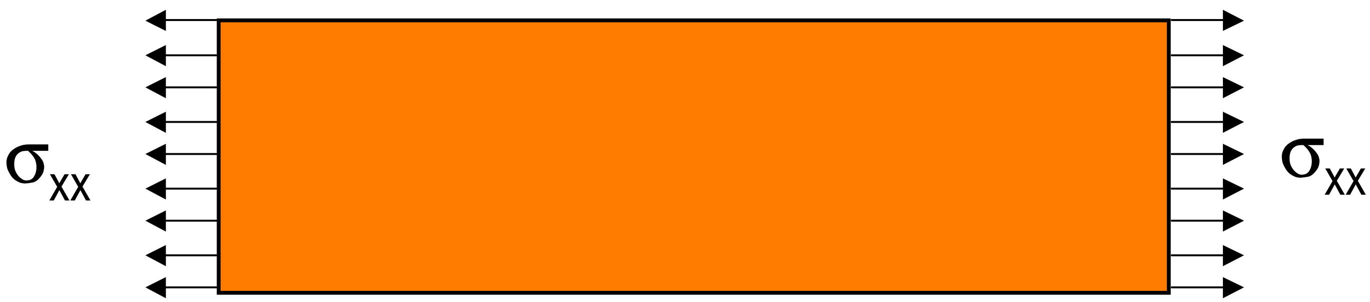
From the MPM literature (e.g., Sulsky and Kaul, 2004)

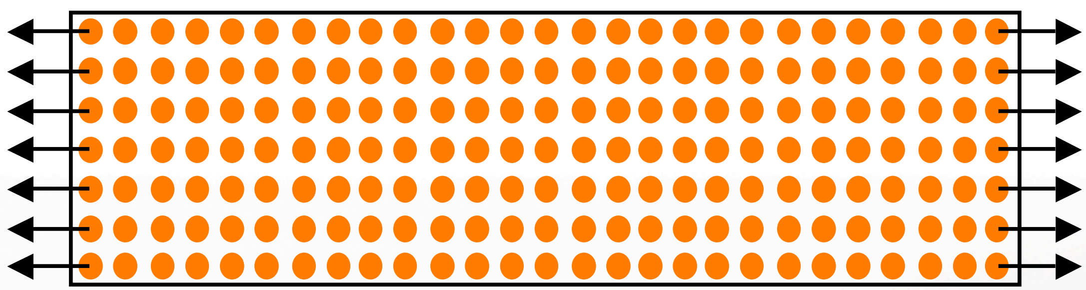
$$\sum_{j=1}^{N_n} M_{ij}(t)\,\frac{\mathrm{d}\boldsymbol{v}_j}{\mathrm{d}t} = \boldsymbol{f}_i^{\mathrm{int}} + \boldsymbol{f}_i^{\mathrm{ext}},$$

$$\boldsymbol{f}_i^{\mathrm{ext}} = \boldsymbol{b}_i + \hat{\boldsymbol{t}}_i.$$

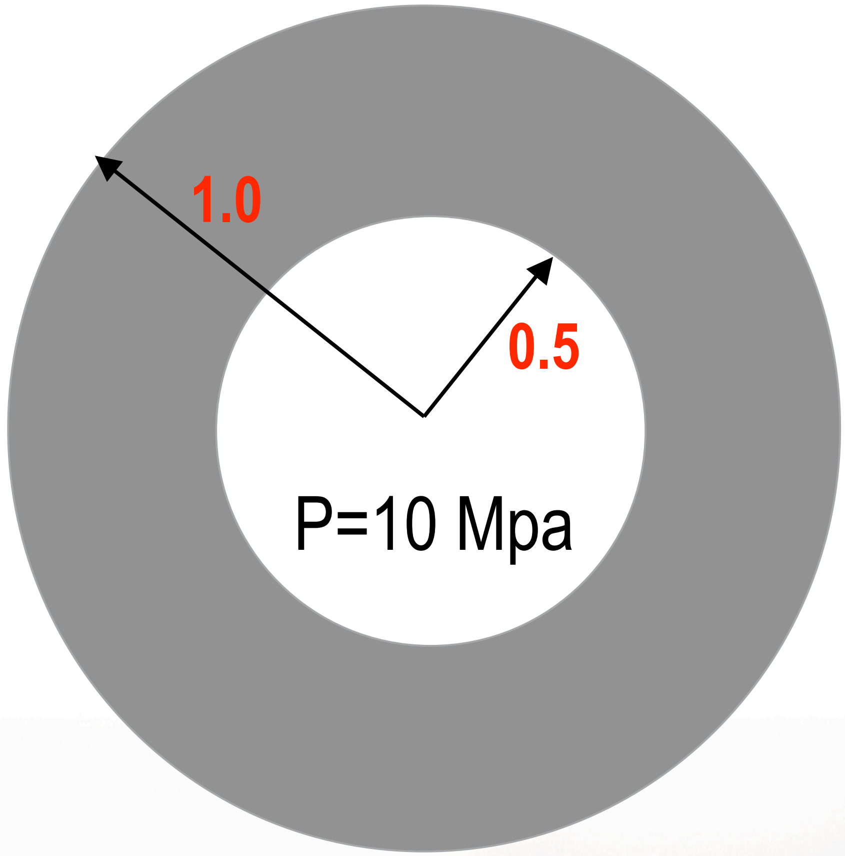
$$\hat{\boldsymbol{t}}_i(t) = \int_{\partial\Omega_2^t} \boldsymbol{t}(\boldsymbol{x}, t) N_i(\boldsymbol{x})\,\mathrm{d}S$$

Traction Boundary Conditions



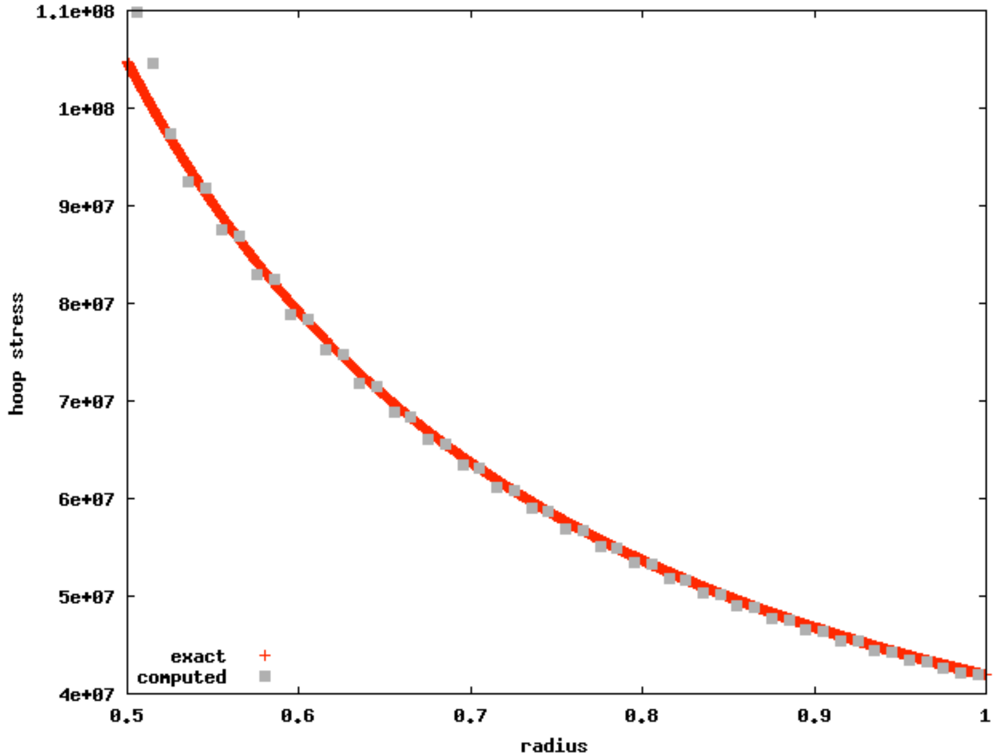


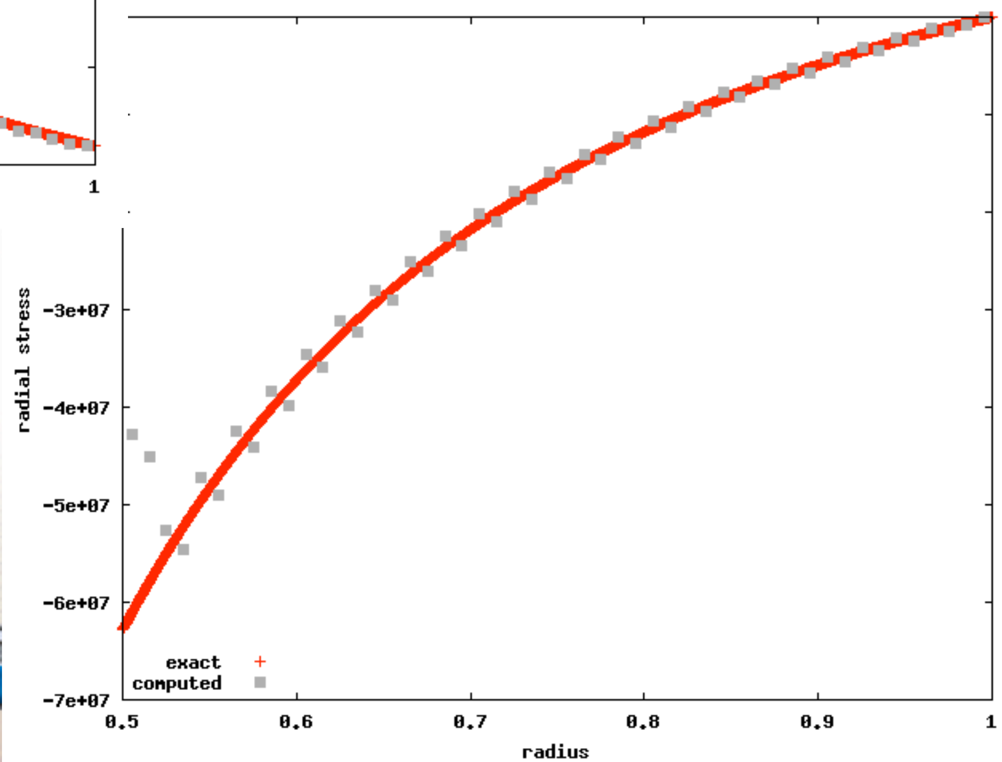
Traction Boundary Conditions - Pressurized Cylinder



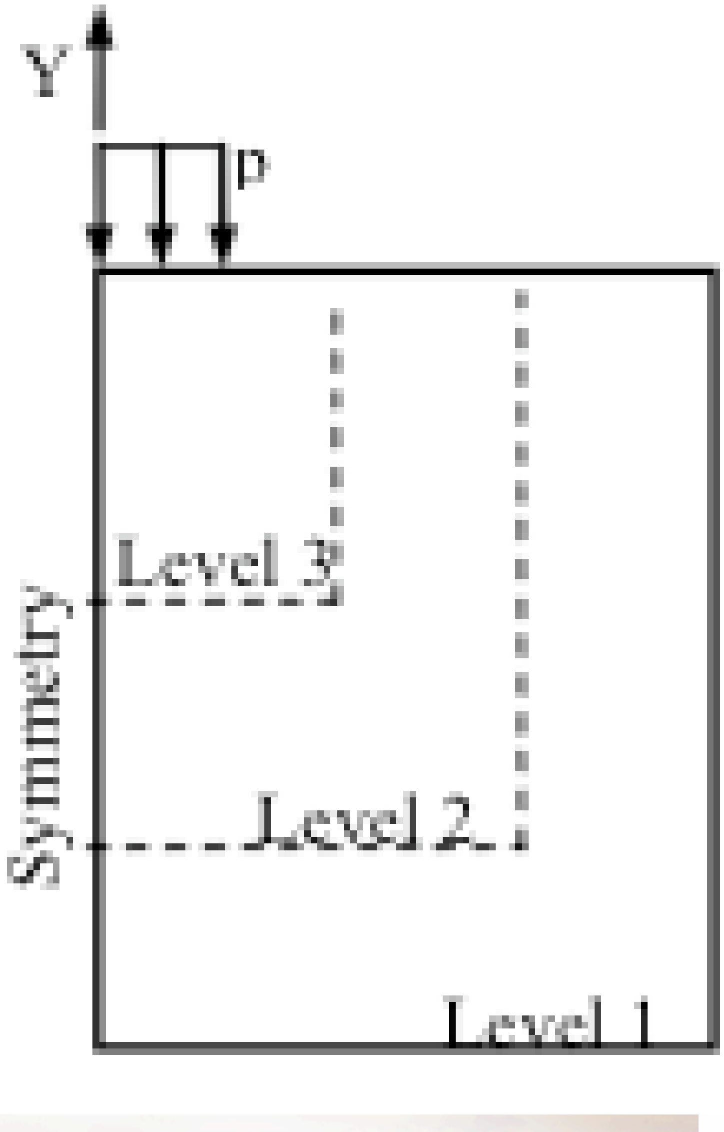
Solve using an axi-symmetric GIMP code, making it a 1-D problem

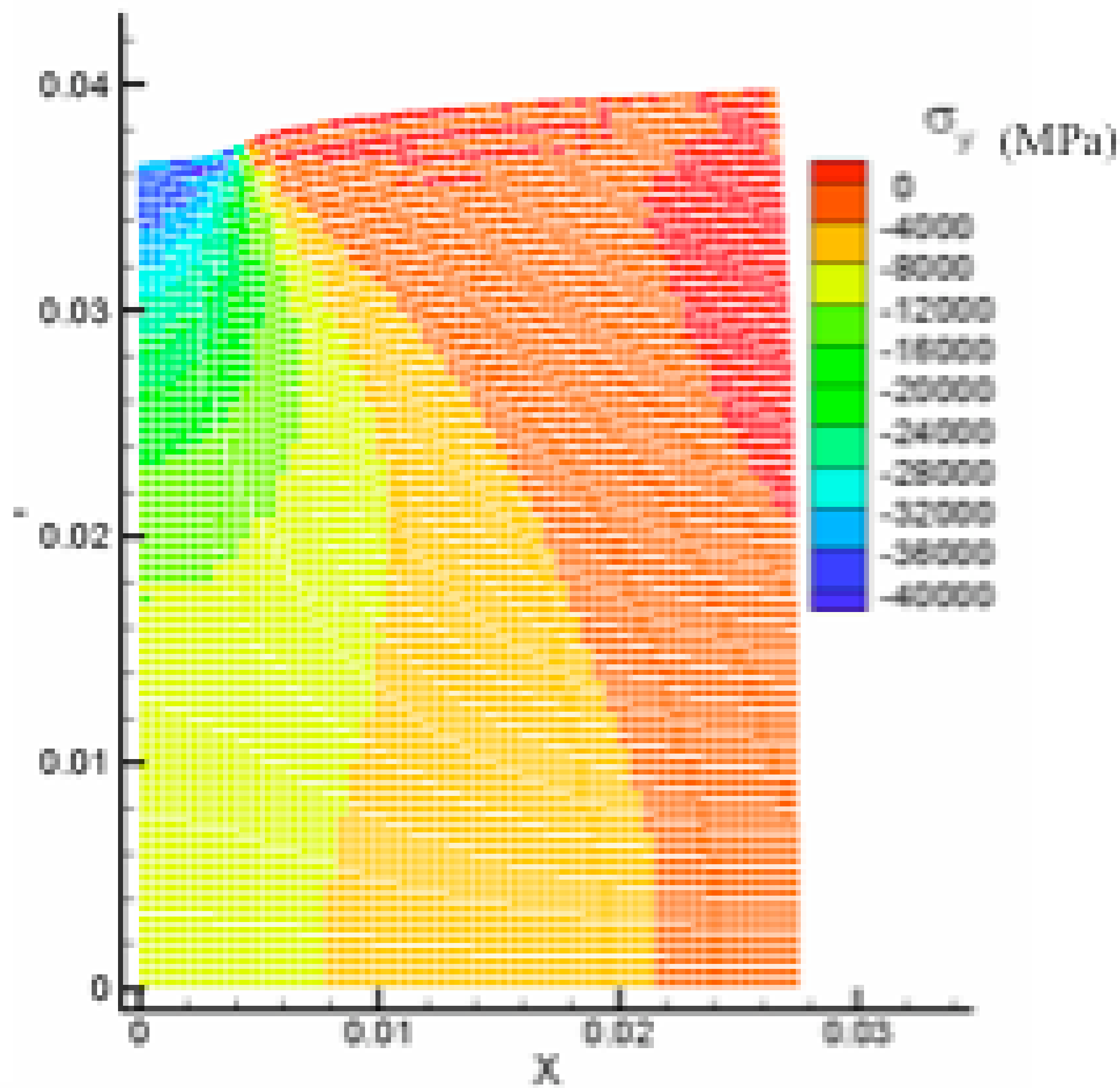
Traction Boundary Conditions - Pressurized Cylinder



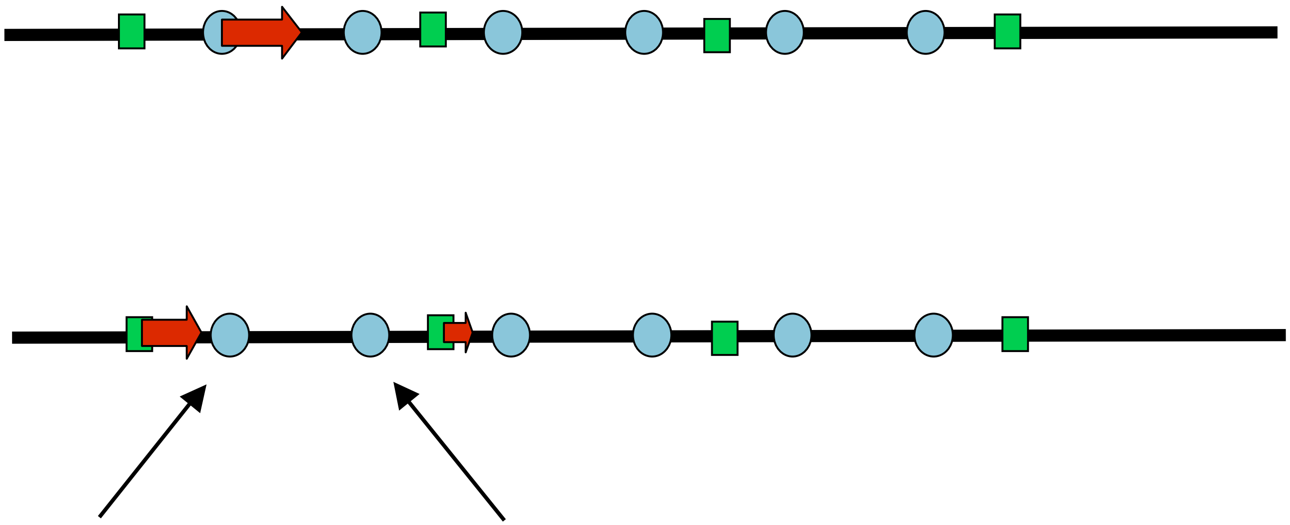


It's not just me…





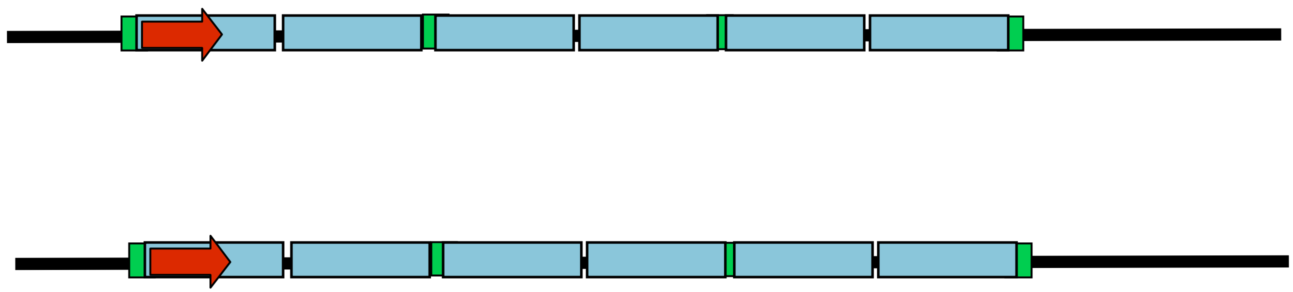
It is easy to see why this happens



These particles are effectively
experiencing a distributed load

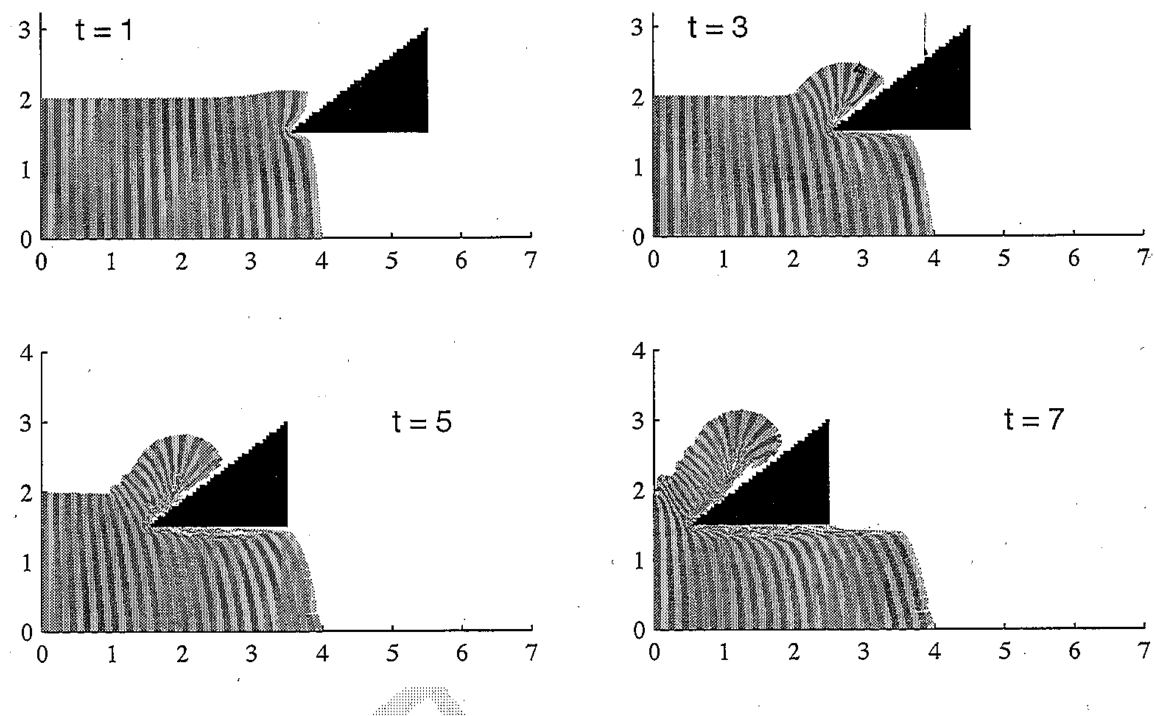
A possible solution (not yet investigated)

Place tractions at the “edge” of GIMP particles



This is not going to eliminate the issue, and may kick up some numerical problems, but is probably worth a try

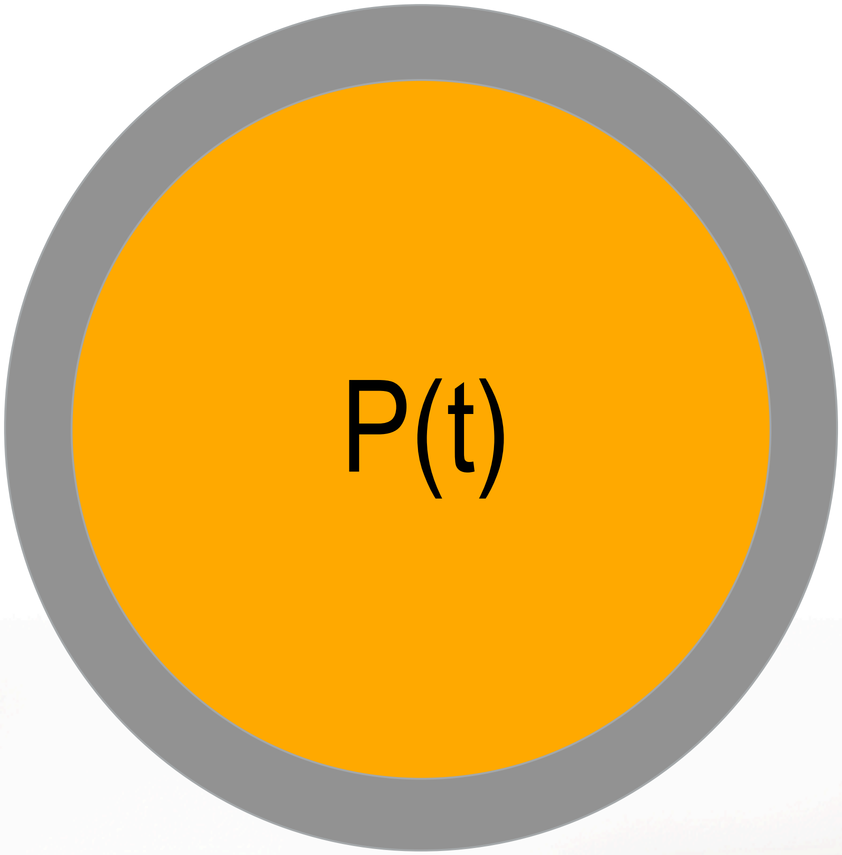
Material Failure

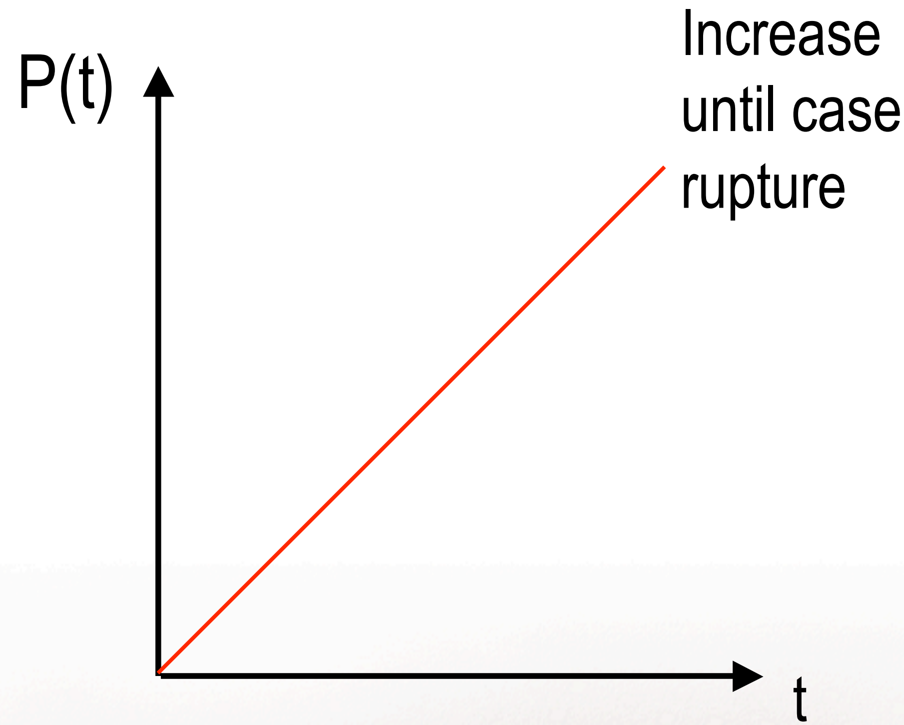


What material model could give rise to this sort of material failure?

Von Mises Plasticity!

Convergence when material failure is involved





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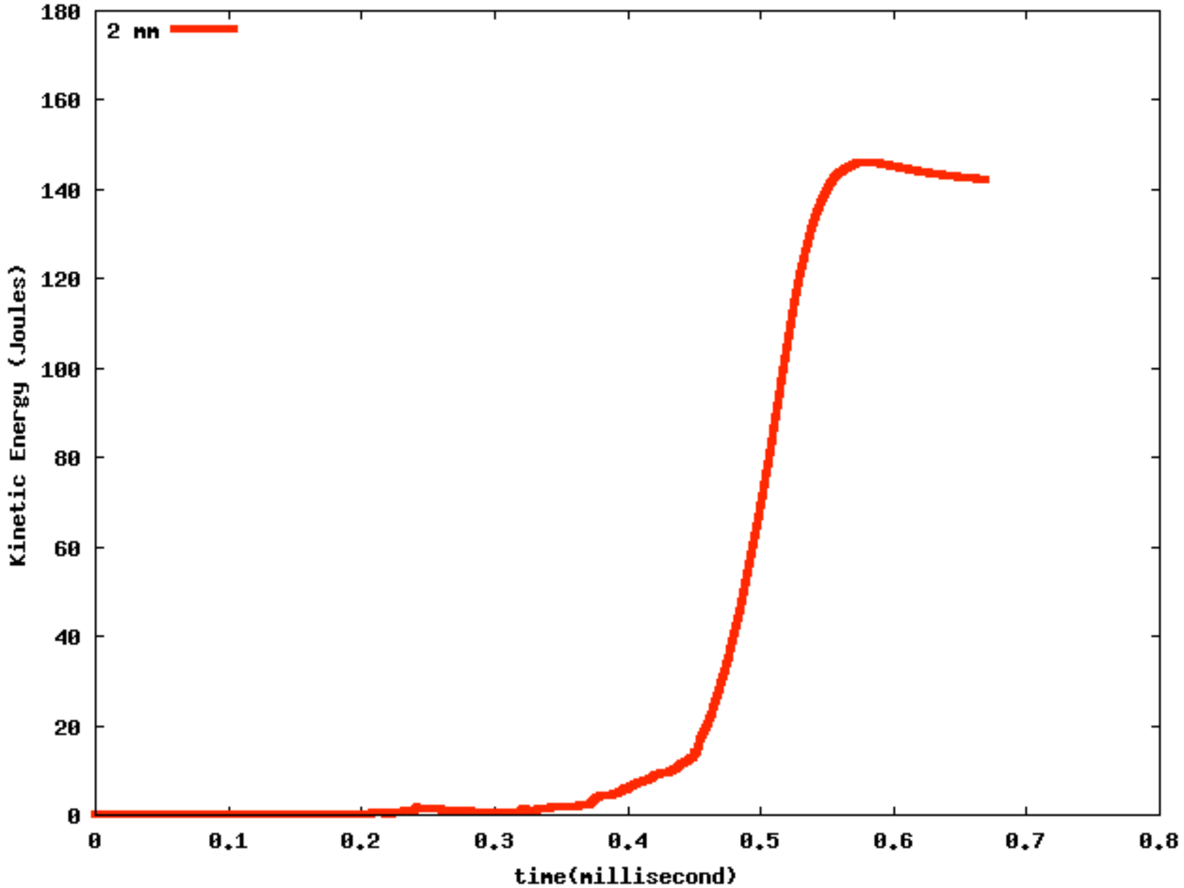

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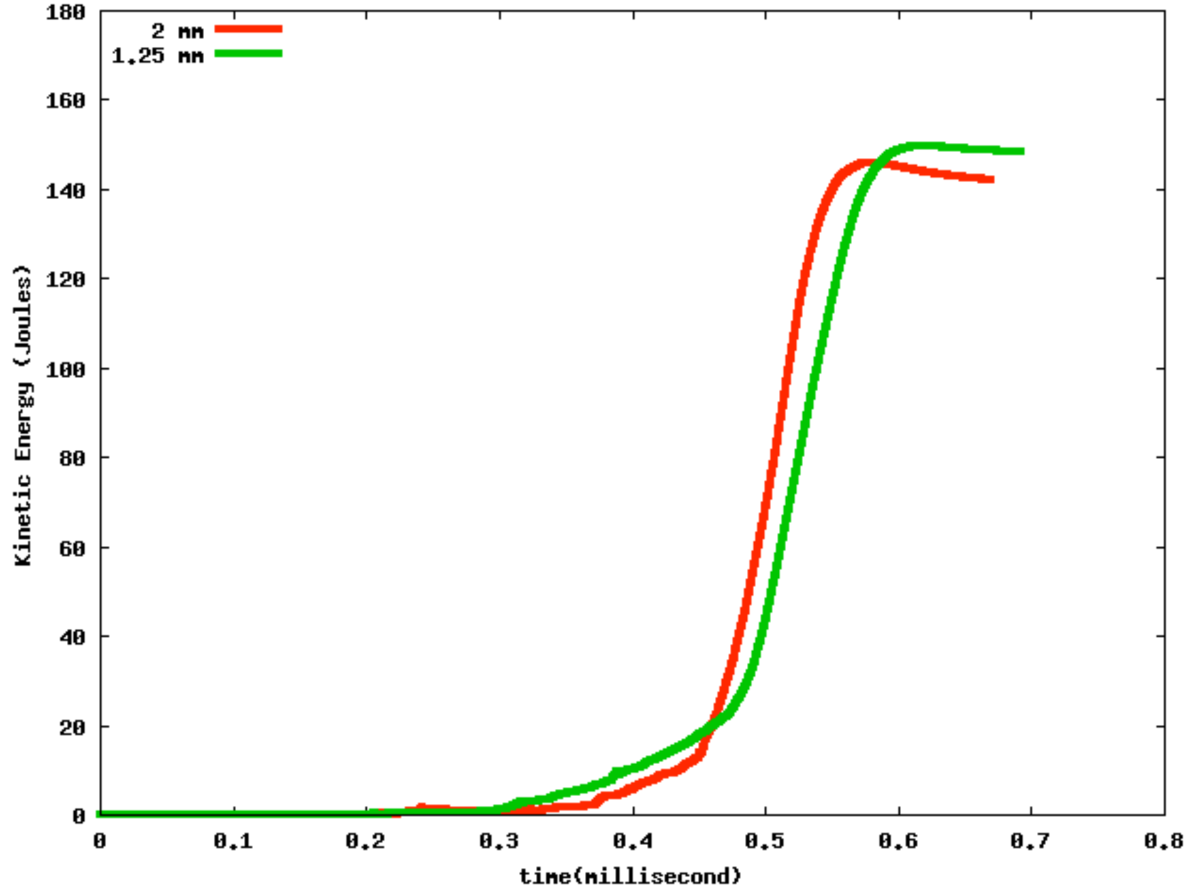

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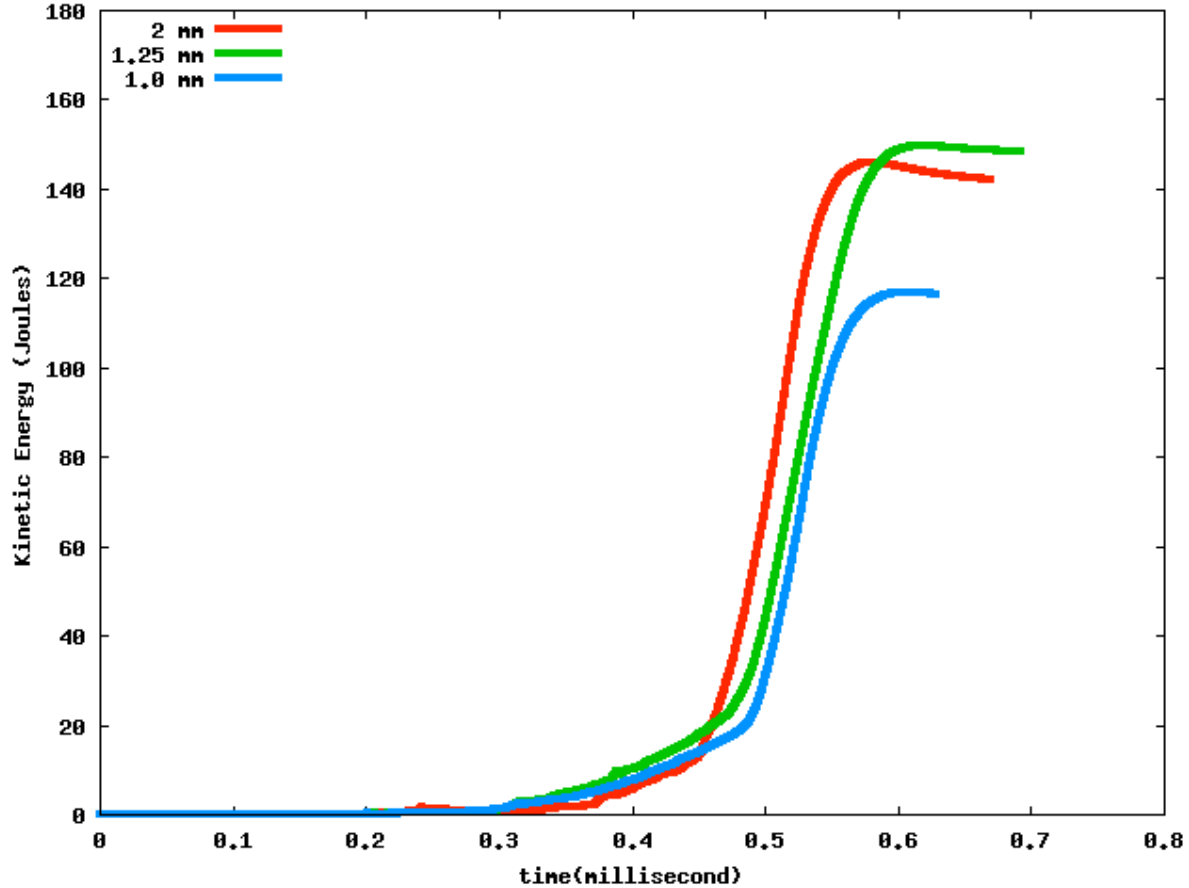

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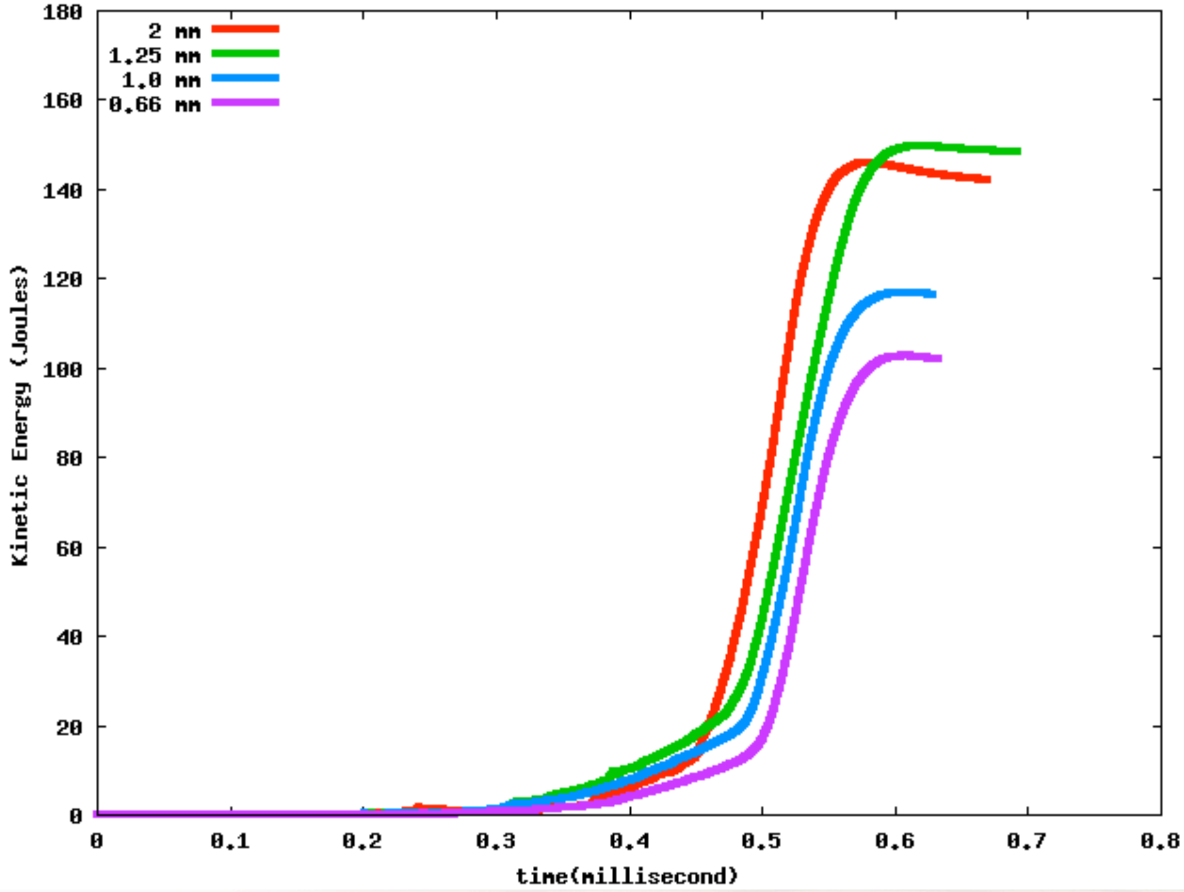

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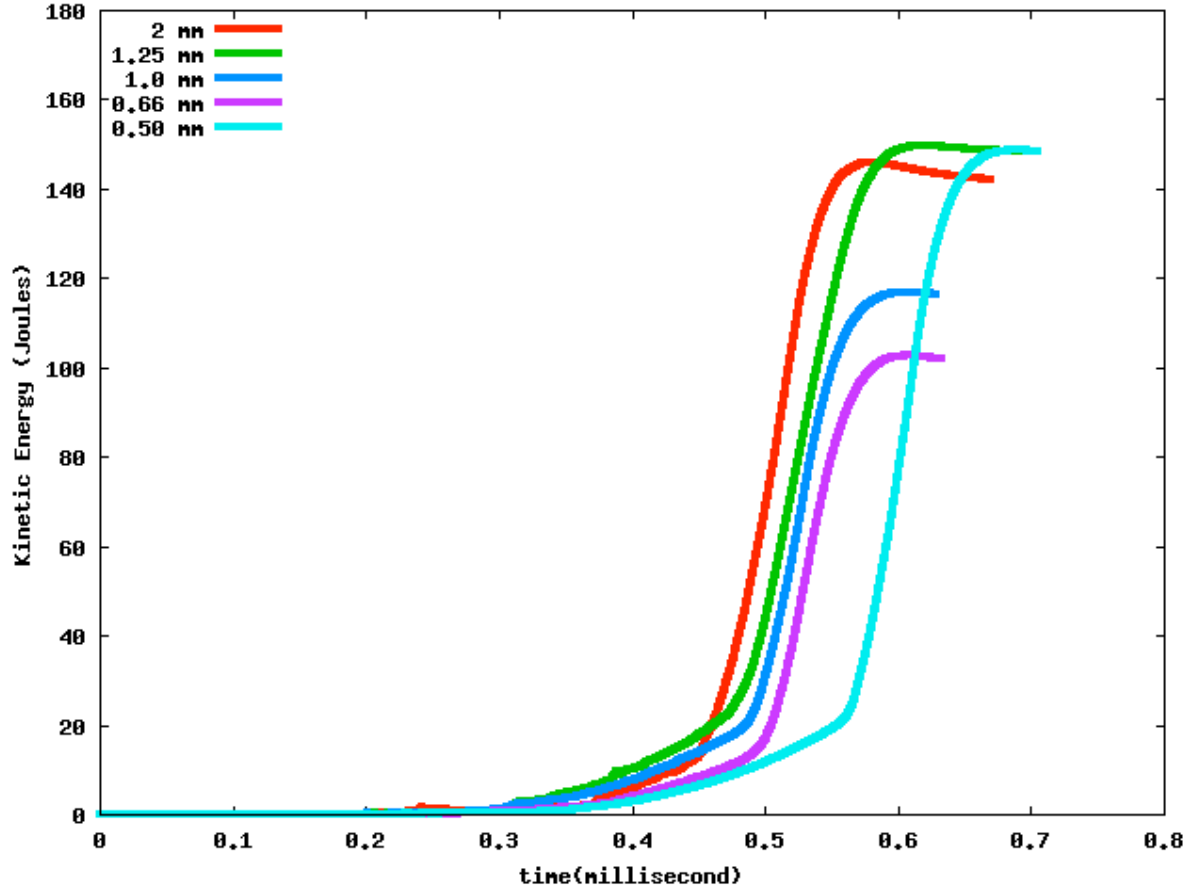

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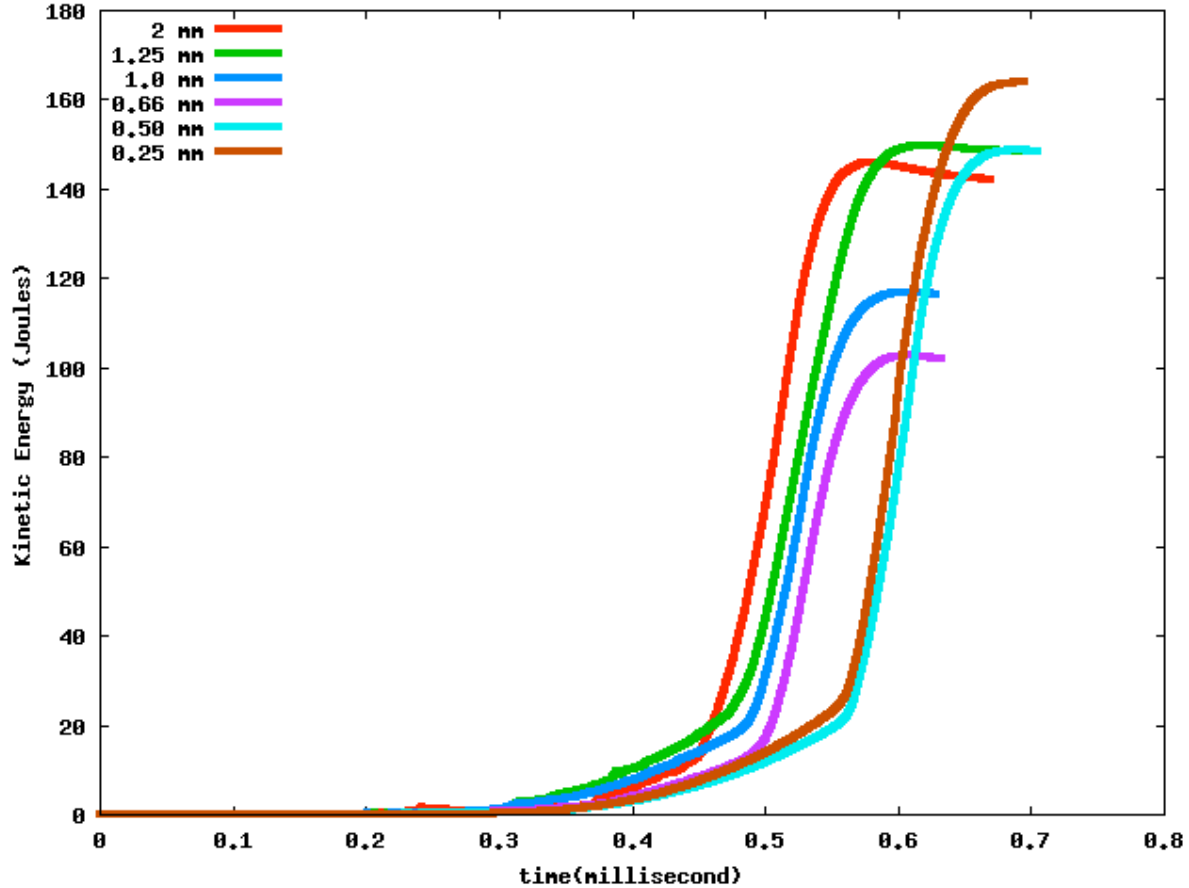

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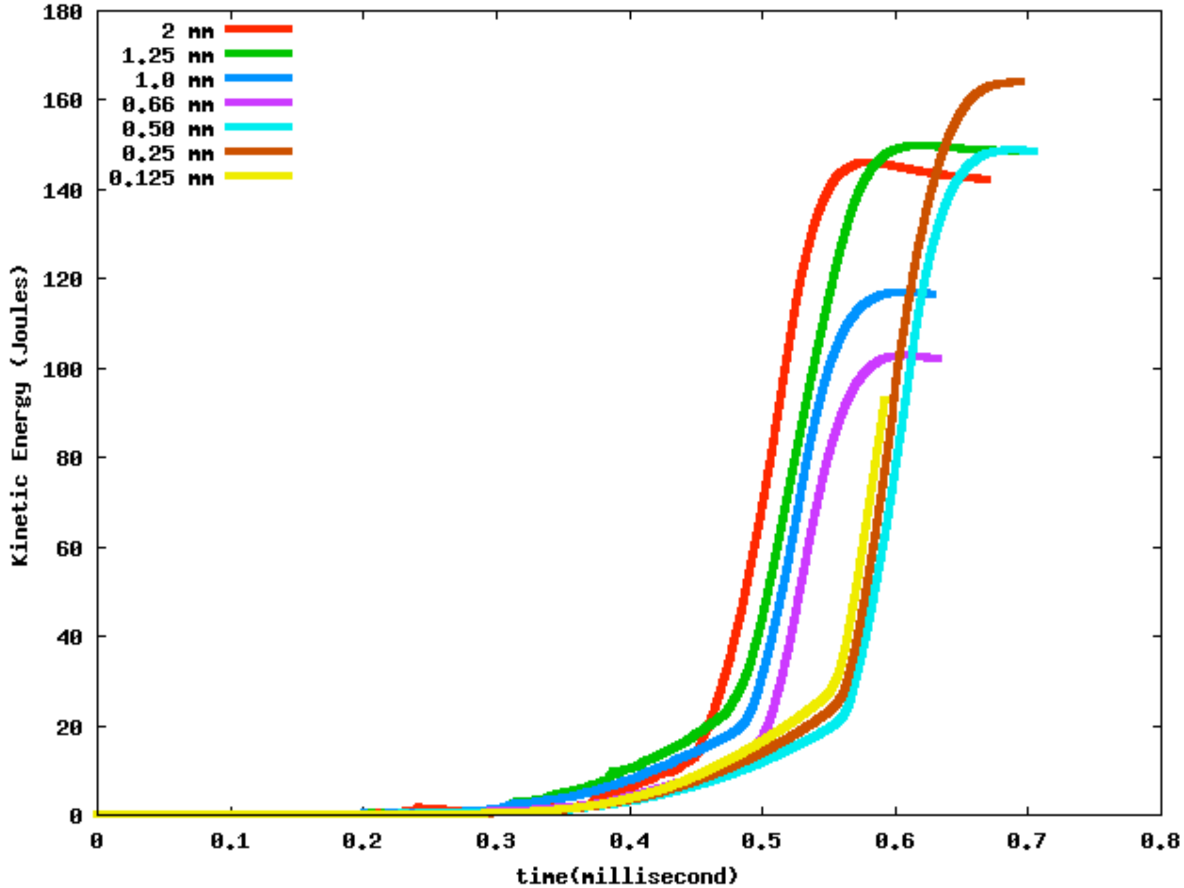

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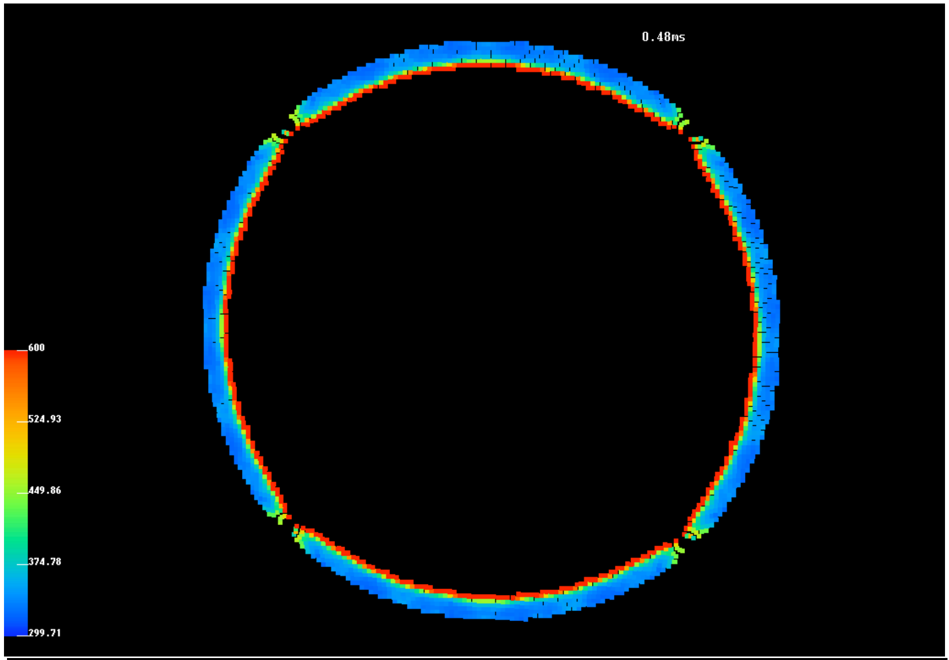

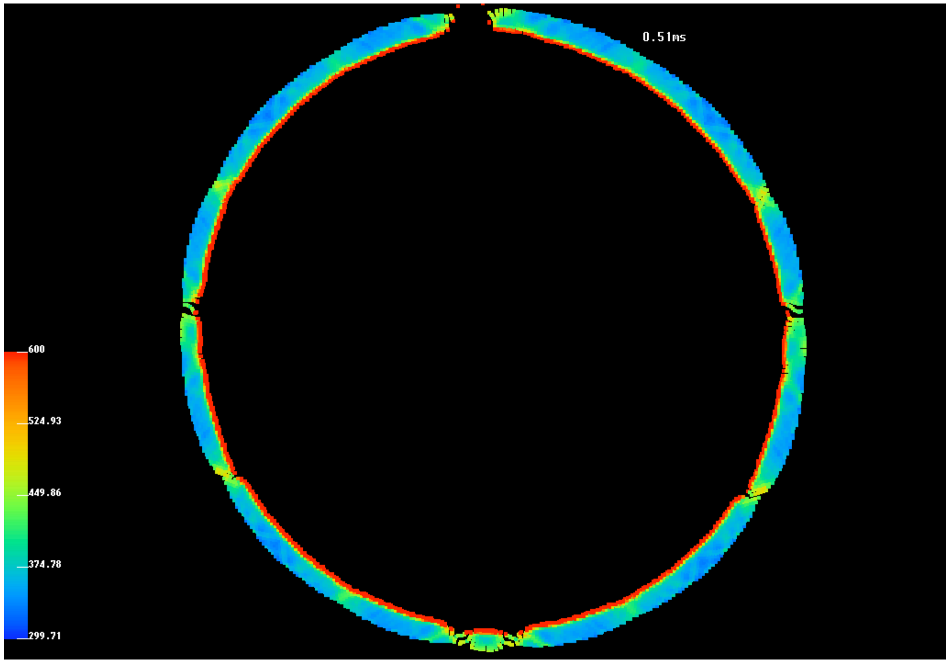

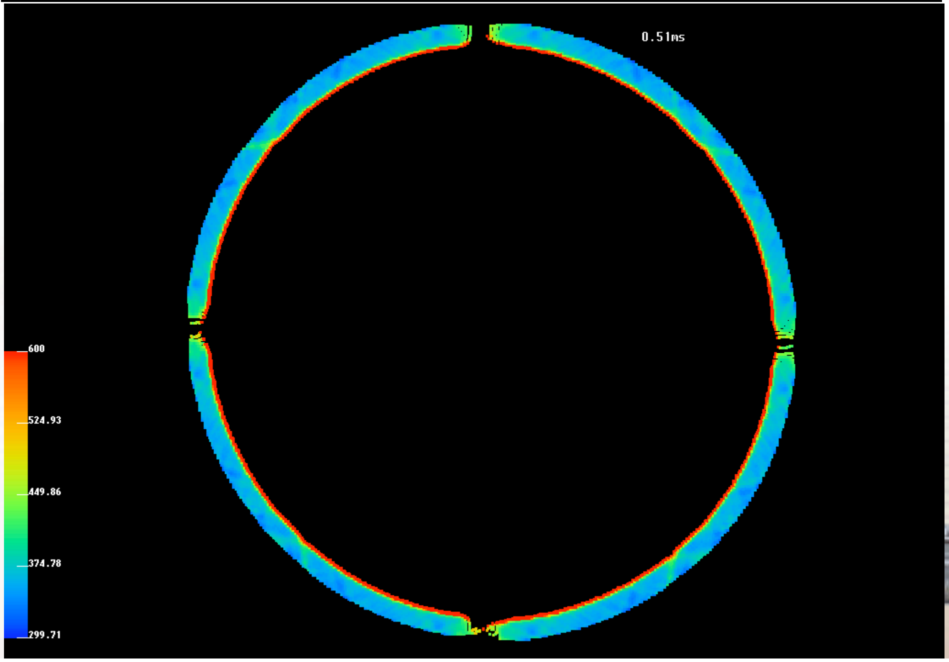

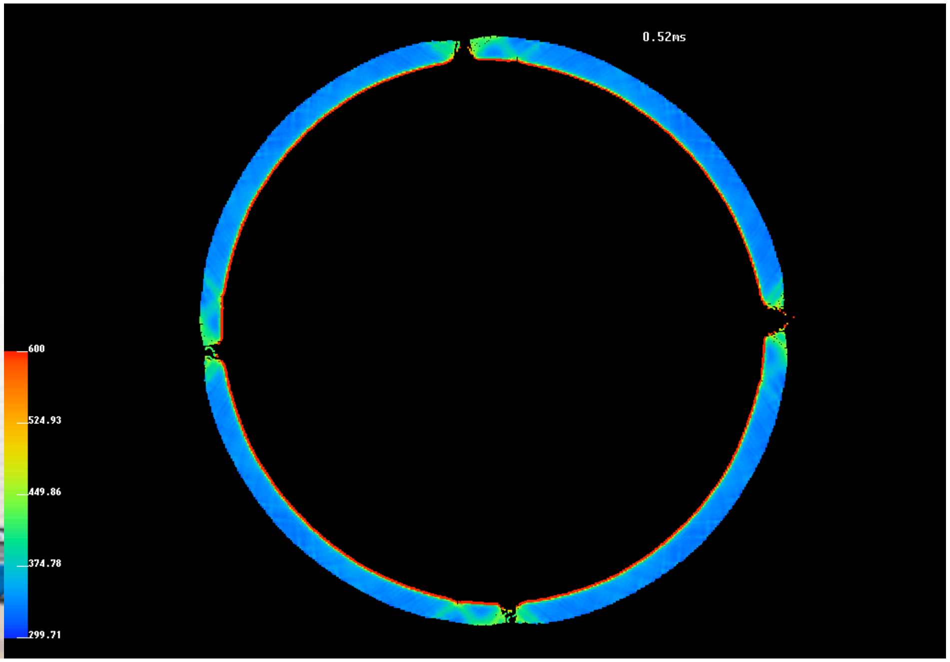

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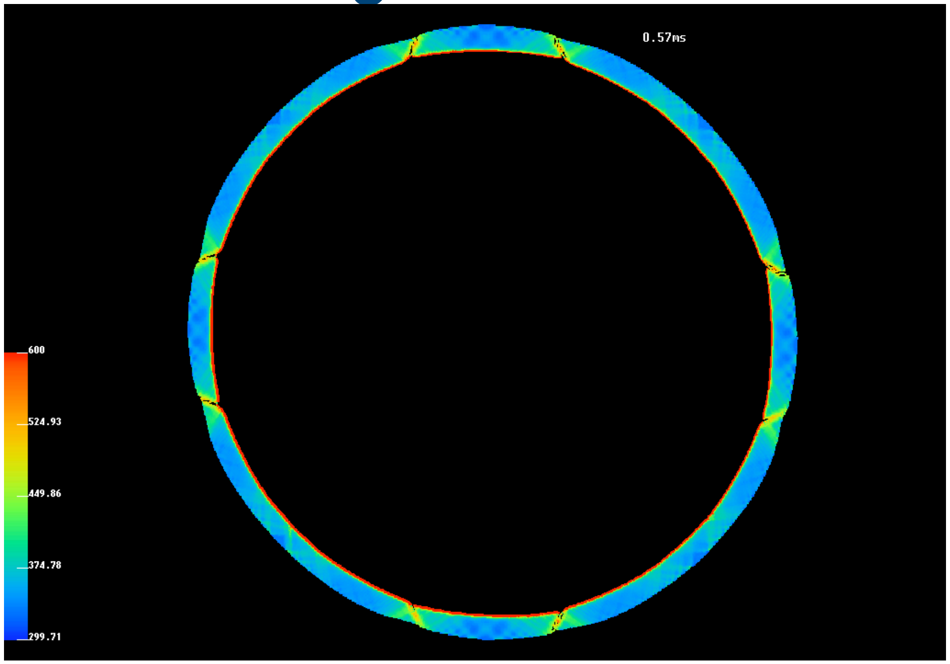
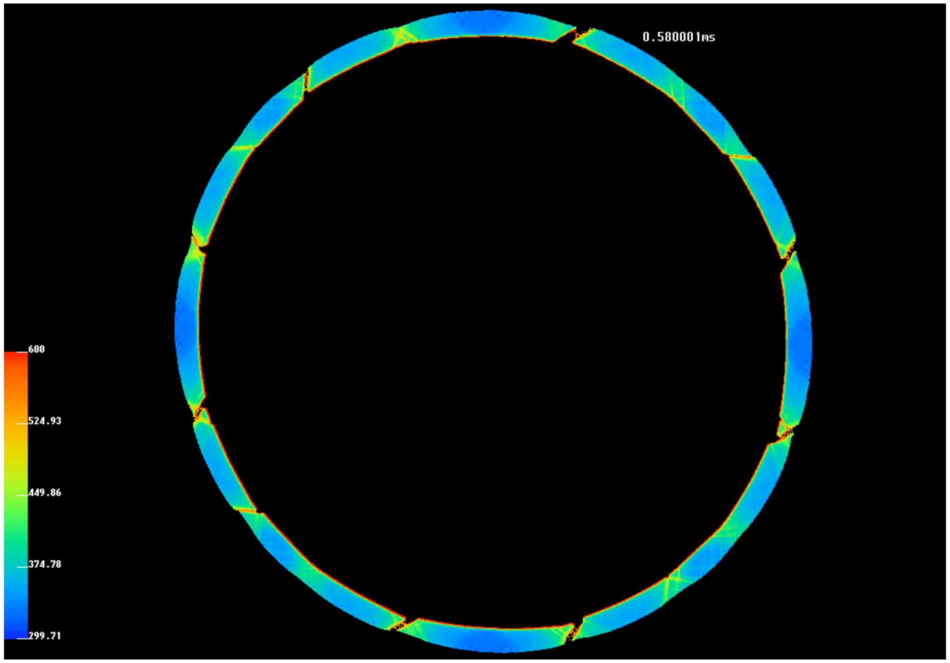
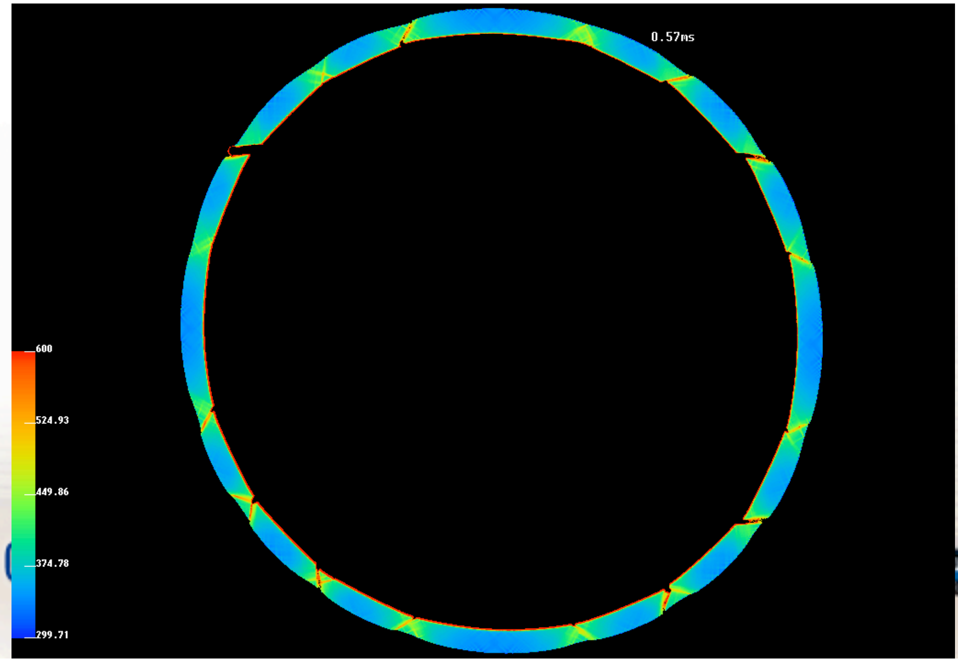


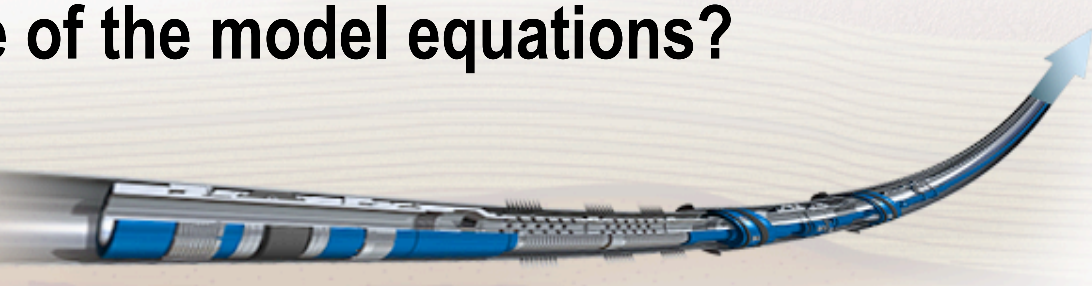




Schlumberger Reservoir

Closing thoughts on modeling failure

- **When doing simulations that result in material failure:**
  - **Does your material model support failure?**
  - **Is the failure model the cause of the failure?**
  - **Are the results convergent with spatial resolution?**
- **Particle refinement may have a role to play here**
- **What about local vs. non-local failure models and their effects on the nature of the model equations?**



Acknowledgements

- Center for the Simulation of Accidental Fires and Explosions through the DOE (until October 2008)

- Schlumberger Reservoir Completions

  Perforating Research (since October 2008)

- Todd Harman for sharing the exploding container data