SAND2016-11392D

# Phase-field Fracture and Inverse Methods for Nonlinear Dynamics

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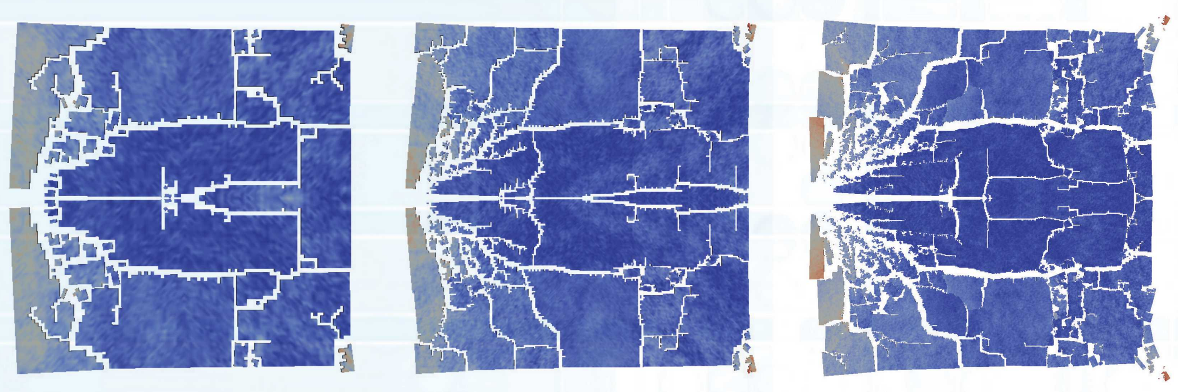
## Damage models with element death

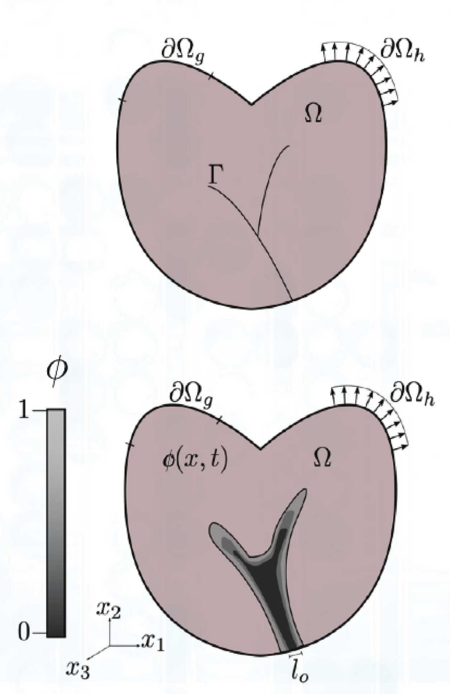
- Fracture modeling is critical to predicting the performance and reliability of many Sandia components and systems
- Many fracture models are ill-posed and non-convergent

Max principal stress criterion with element death shows significant mesh dependence




## Cohesive phase-field model

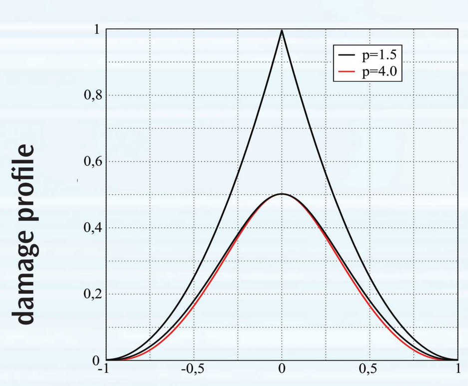
- Regularized phase-field model by Lorentz, et al. 2011
- Shown to converge to cohesive zone model as $l \longrightarrow 0$

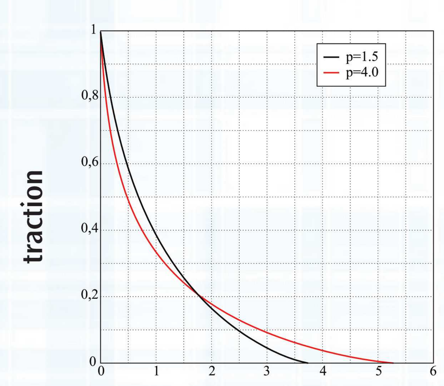



$$\rho\ddot{u} = \nabla\cdot\boldsymbol{\sigma}\ , \quad \boldsymbol{\sigma} = g(\phi)\frac{\partial\psi_e^+}{\partial\varepsilon} + \frac{\partial\psi_e^-}{\partial\varepsilon}$$ Momentum balance

$$-g'(\phi)\psi_e^+ - k + c\nabla^2\phi$$ Phase field equation

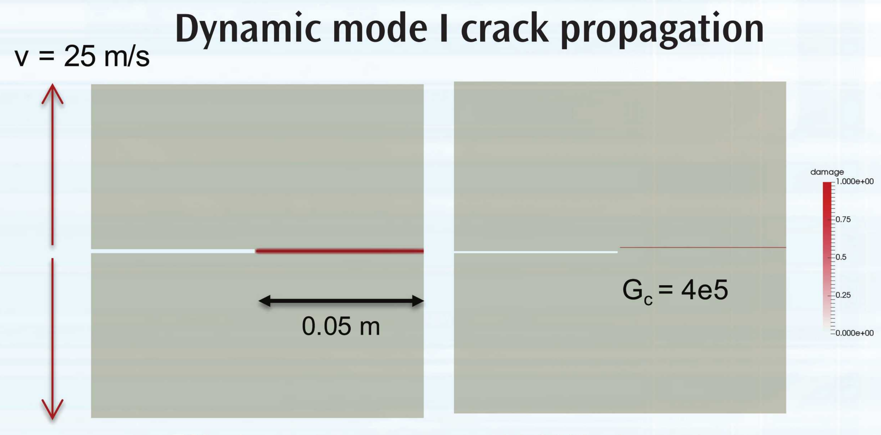
$$g(\phi) = \frac{(1-\phi)^2}{1+(m-2)\phi+(1+pm)\phi^2}$$ Phase potential



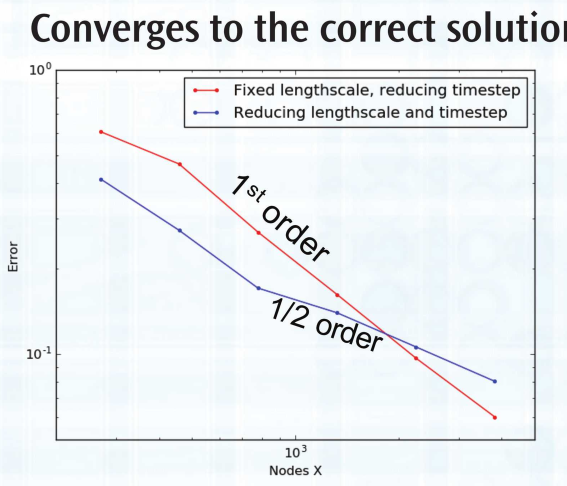




## Accuracy

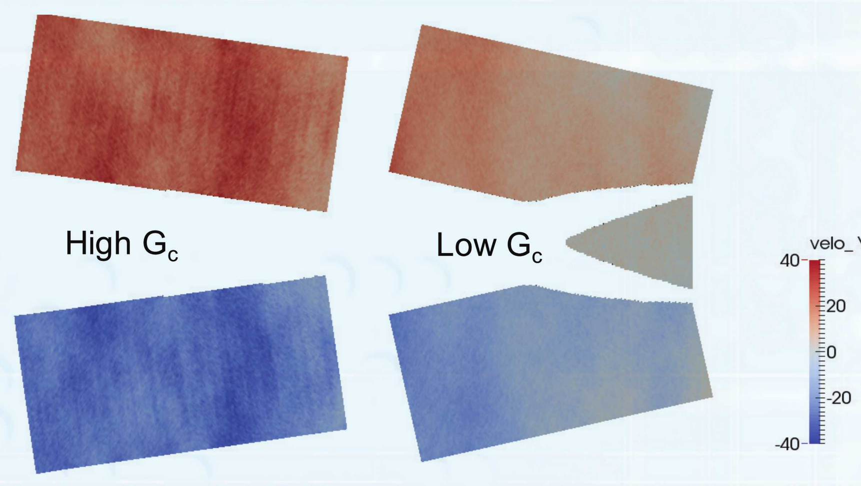
Dynamic mode I crack propagation



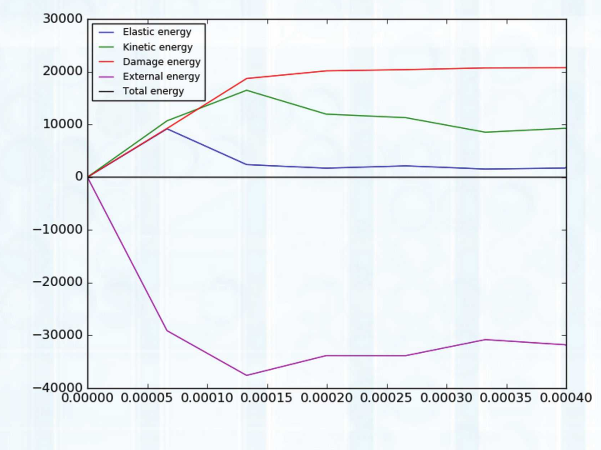

Converges to the correct solution



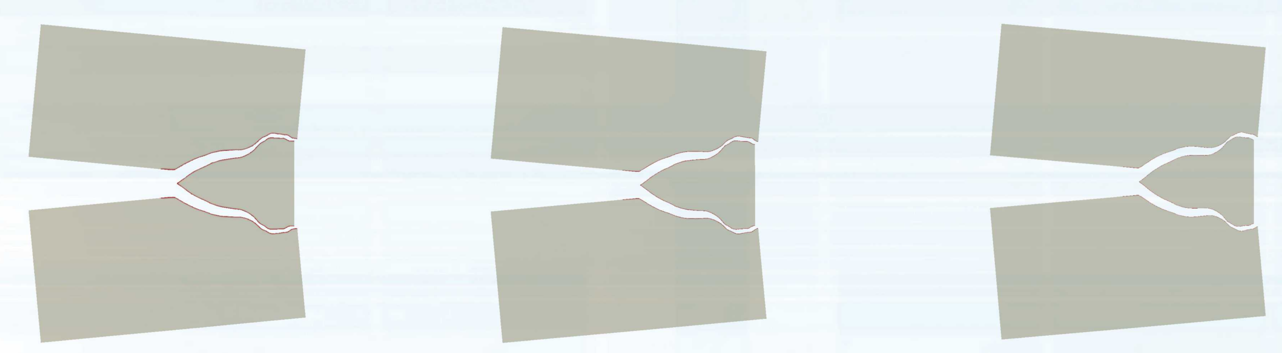

Mode-I crack transition to branching




Total numerical energy is preserved




## Branching: mesh insensitivity




Branching is emergent, not prescriptive

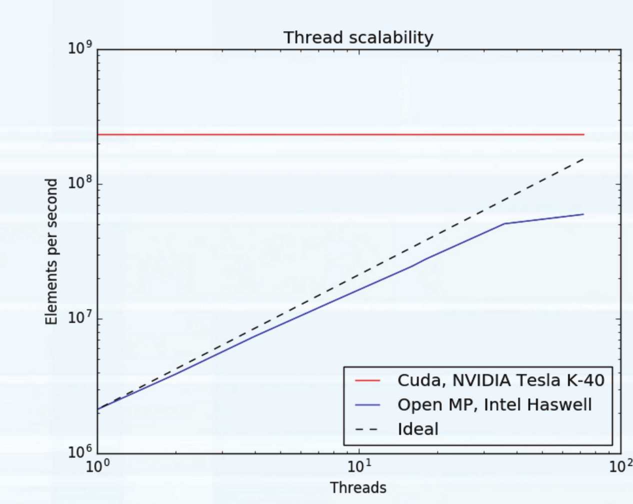
Runs in ~5 hours on 1 GPU

## Branching: mesh insensitivity


- Captures complex 3D crack patterns
- No explicit geometry representation
- Naturally predicts initiation, branching and coalescence

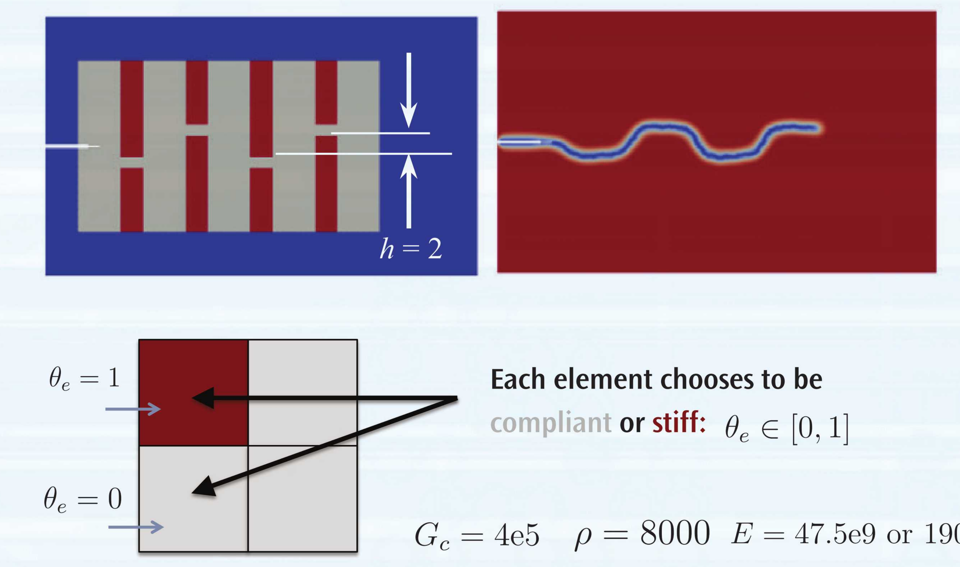
## Thread scalable, platform portable

- Sandia's Kokkos library allows cross-platform, thread scalable implementations
- GPU: > 110 X faster
- 250 million elements per second
- Open MP scales




## Heterogeneous material design

- Hossain, Hsueh, Bourdin, Bhattacharya 2014 show heterogeneous materials can be tougher than constituents!



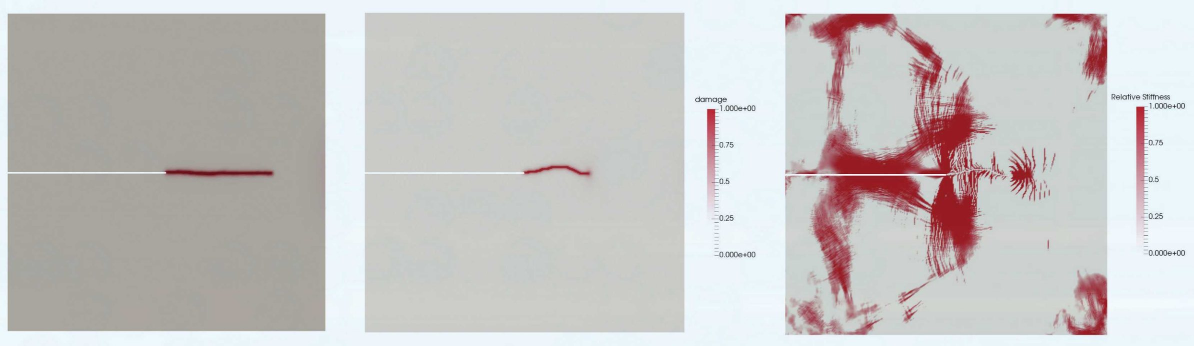

- Use adjoint method and Sandia's Rapid Optimization Library to design tougher materials

Each element chooses to be compliant or stiff: $\theta_e \in [0,1]$

$G_c = 4e5 \quad \rho = 8000 \quad E = 47.5e9 \text{ or } 190e9$

## Nonlinear dynamic inverse problem

- Compute adjoint sensitivities for nonlinear dynamic problems
- >200,000 sensitivities at the cost of ~7 forward solves!

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