Adaptive Dynamic Fracture using Nonlinear Cohesive Zone Modeling

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Research Objectives

- Develop an integrated, multiscale computational framework for dynamic fracture, microbranching, and fragmentation
- Employ the potential-based constitutive model for mixed-mode cohesive zone modeling
- Develop systematic adaptive mesh refinement and coarsening (AMR+C) schemes for dynamic cohesive fracture simulation in two and three dimensions
- Employ adaptive topological operators such as nodal perturbation, edge-swap, edge-split and vertex removal

PPR: Potential-Based Cohesive Model

$$\psi = \min(\phi_n,\phi_t) + \left[\Gamma_n\left(1-\frac{\Delta_n}{\delta_n}\right)^{\alpha} + \langle \phi_n-\phi_t\rangle\right]\left[\Gamma_t\left(1-\frac{|\Delta_t|}{\delta_t}\right)^{\beta} + \langle \phi_t-\phi_n\rangle\right]$$

$$T_n(\Delta_n,\Delta_t) = -\alpha\frac{\Gamma_n}{\delta_n}\left(1-\frac{\Delta_n}{\delta_n}\right)^{\alpha-1}\left[\Gamma_t\left(1-\frac{|\Delta_t|}{\delta_t}\right)+\langle\phi_t-\phi_n\rangle\right]$$

$$T_t(\Delta_n,\Delta_t) = -\beta\frac{\Gamma_t}{\delta_t}\left(1-\frac{|\Delta_t|}{\delta_t}\right)^{\beta-1}\left[\Gamma_n\left(1-\frac{|\Delta_n|}{\delta_n}\right)+\langle\phi_n-\phi_t\rangle\right]\frac{\Delta_t}{|\Delta_t|}$$

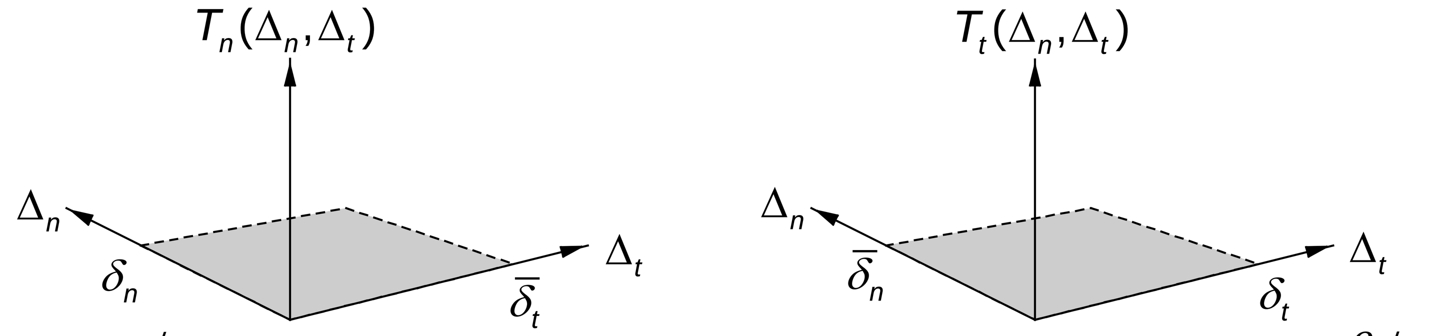
- **Fracture parameters**

  Fracture Energy : ϕ_n, ϕ_t

  Cohesive Strength : σ_n, σ_t

  Shape Parameters : α, β

- **Softening region**

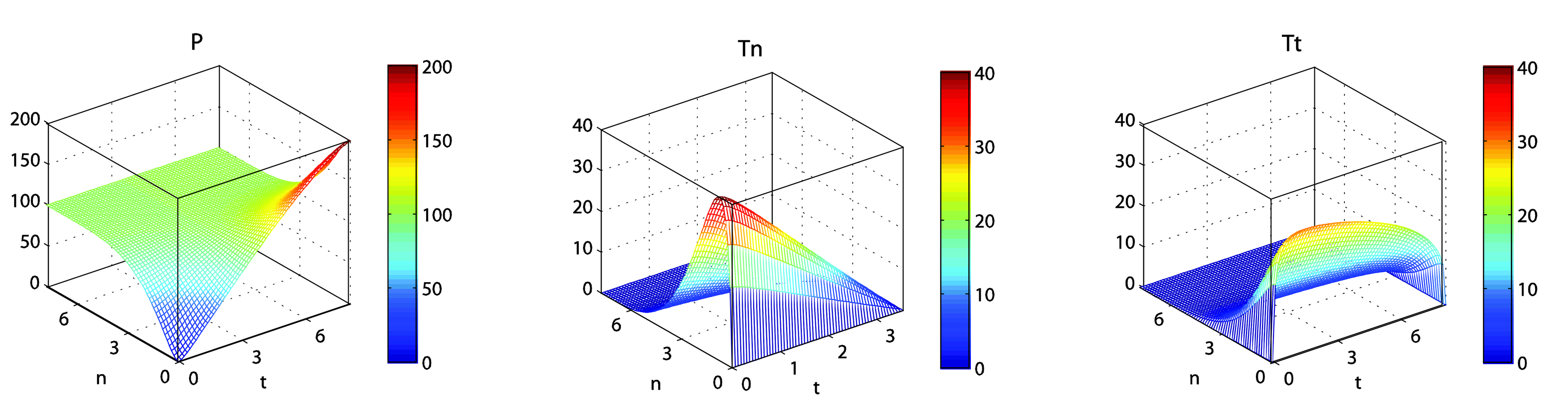


$$\delta_n = \frac{\alpha\phi_n}{\sigma_{max}} \quad \bar{\delta}_t = \delta_t - \delta_t\left(\frac{\langle\phi_t-\phi_n\rangle}{\phi_t}\right)^{1/\beta} \quad \bar{\delta}_n = \delta_n - \delta_n\left(\frac{\langle\phi_n-\phi_t\rangle}{\phi_n}\right)^{1/\alpha} \quad \delta_t = \frac{\beta\phi_t}{\tau_{max}}$$

- **Constitutive relationship**

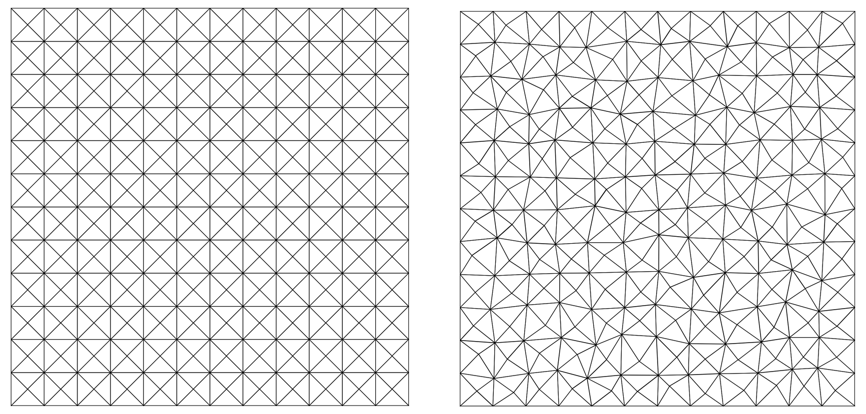
  $\phi_n = 100\text{N/m},\ \phi_t = 200\text{N/m} \qquad \alpha = 5,\ \beta = 1.3$

  $\sigma_{max} = 40\text{MPa},\ \tau_{max} = 30\text{MPa}$

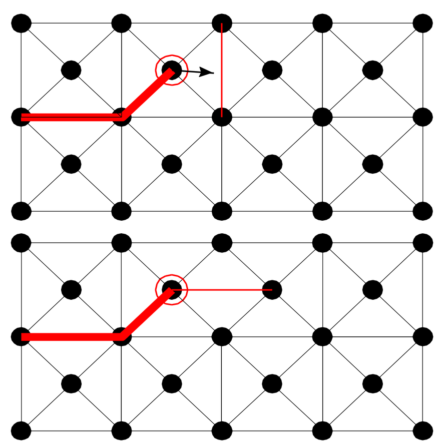


Adaptive Topological Operators

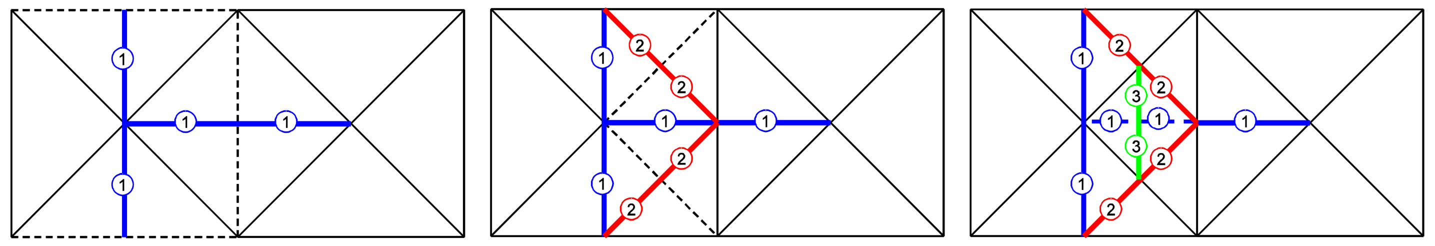
- **Nodal Perturbation**



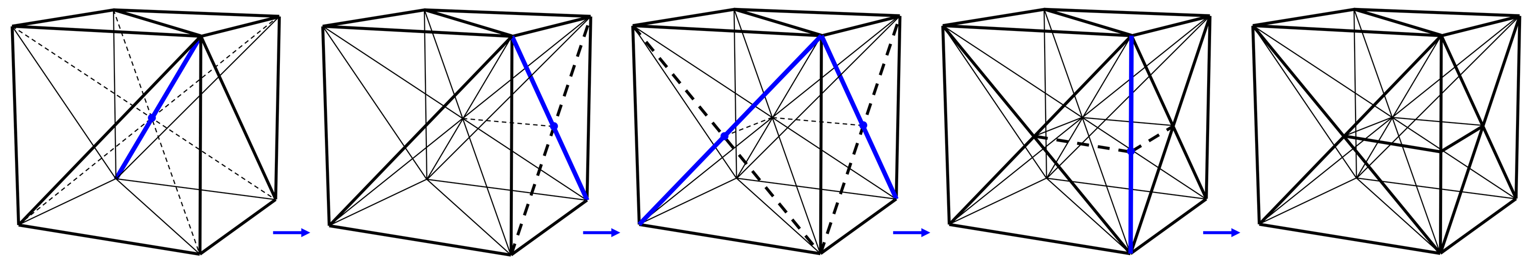
- **Edge Swap**



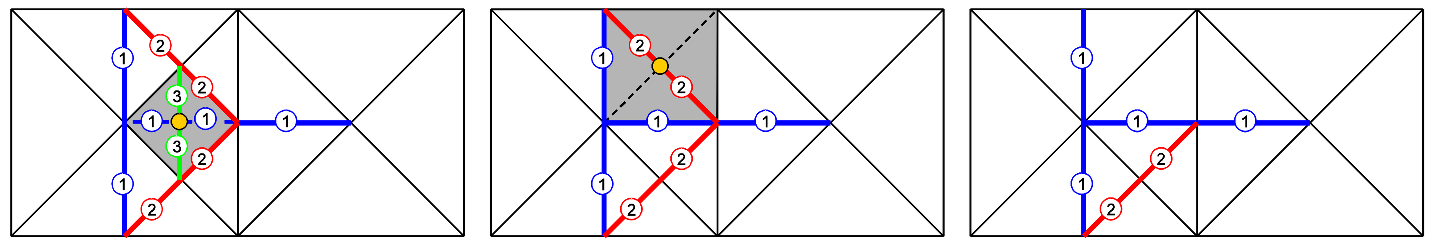
- **Edge Split (Refinement)**
  - Two dimensions



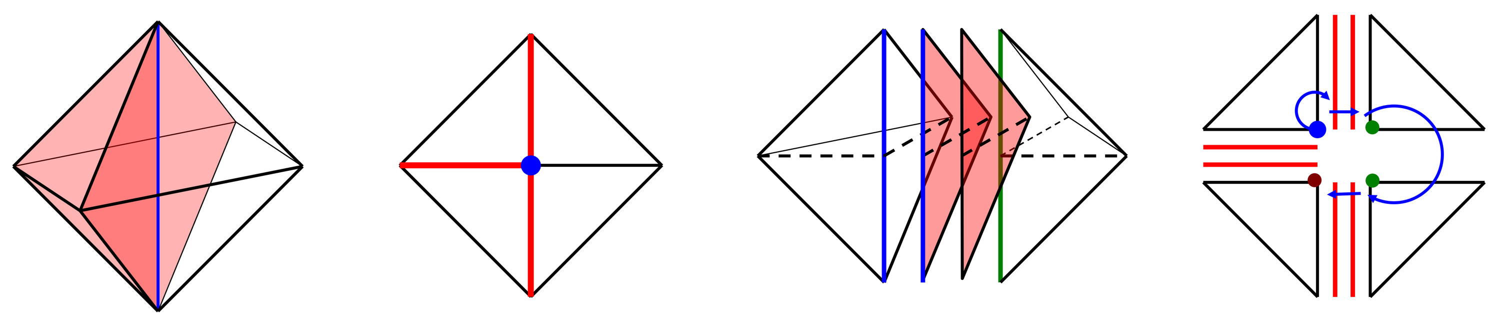
  - Three dimensions



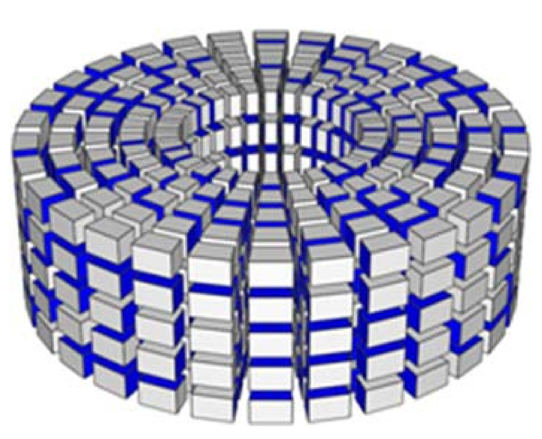
- **Vertex Removal (Coarsening)**



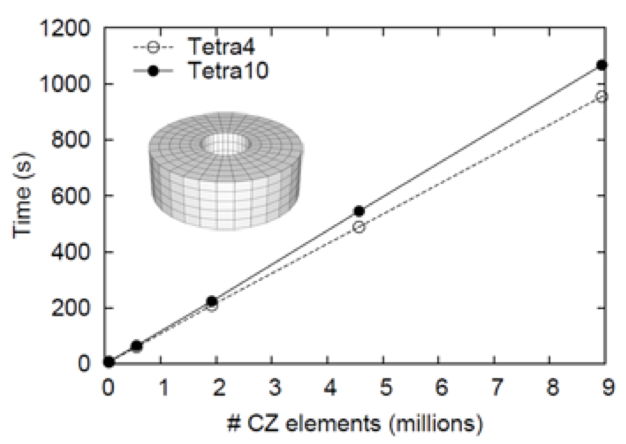
- **Insertion and refinement of cohesive elements in three dimensions**



(a) Cohesive elements between adjacent tehtrahedra (b) Top view (c) Cohesive elements are split along with adjacent tetrahedra (d) Exploded top view



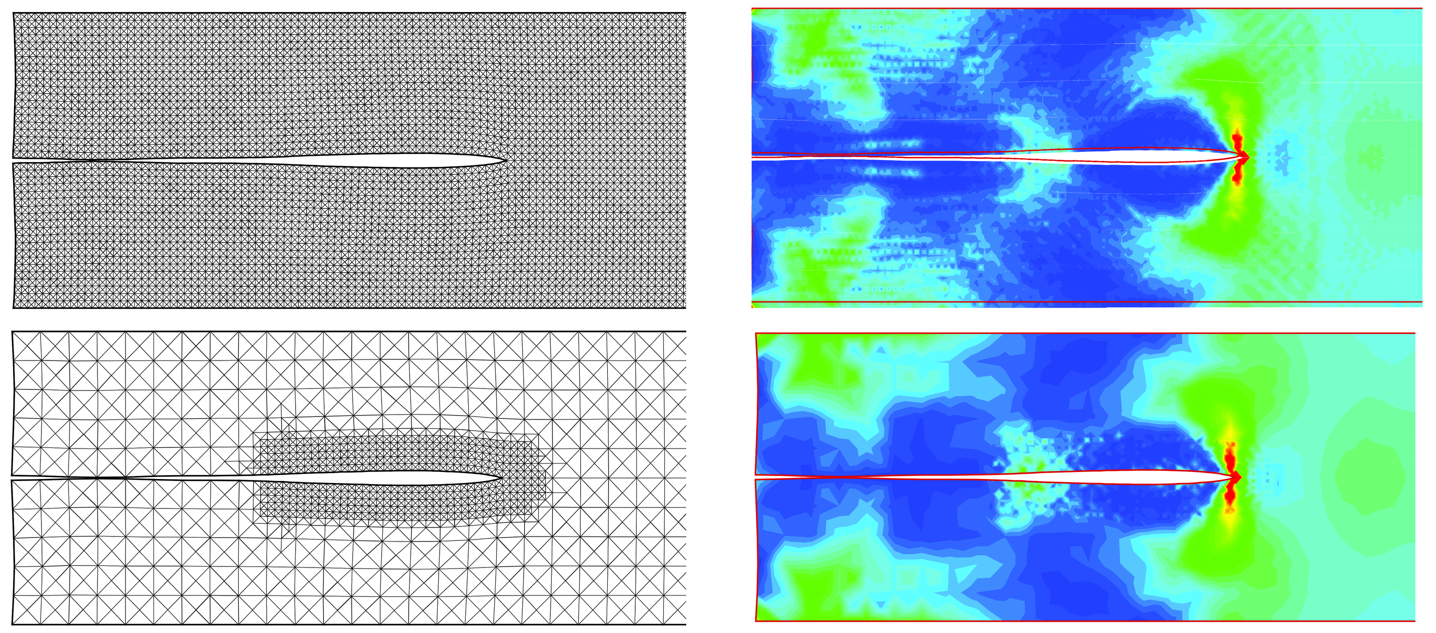
Cohesive elements randomly inserted at 20% of the facets

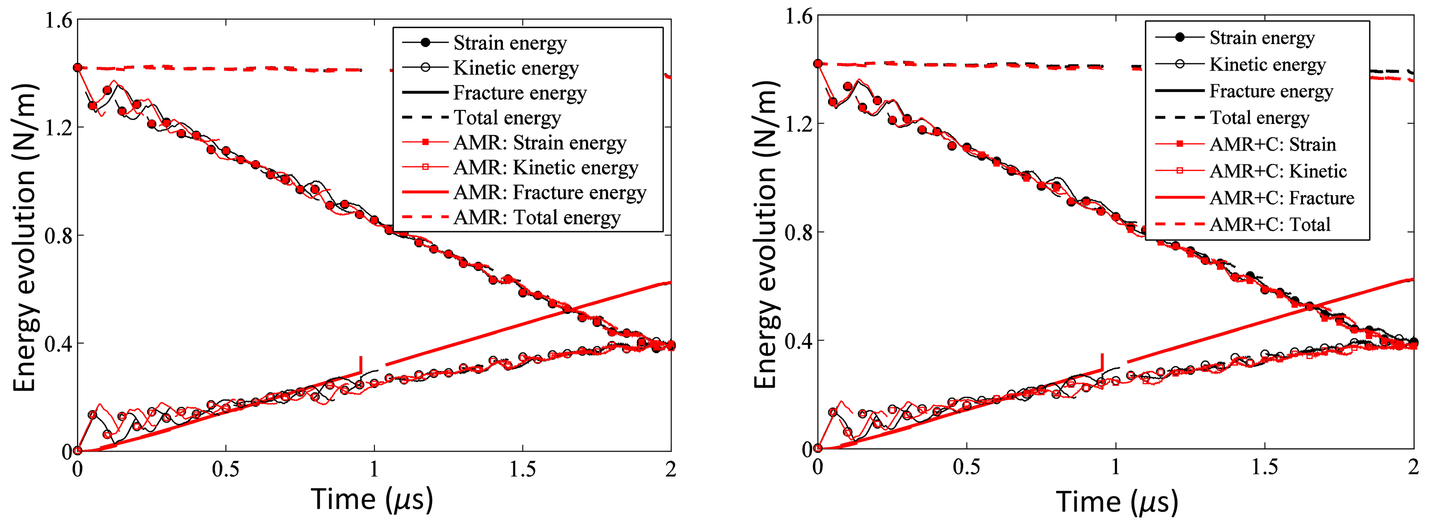


Time to insert cohesive elements scales linearly with mesh size

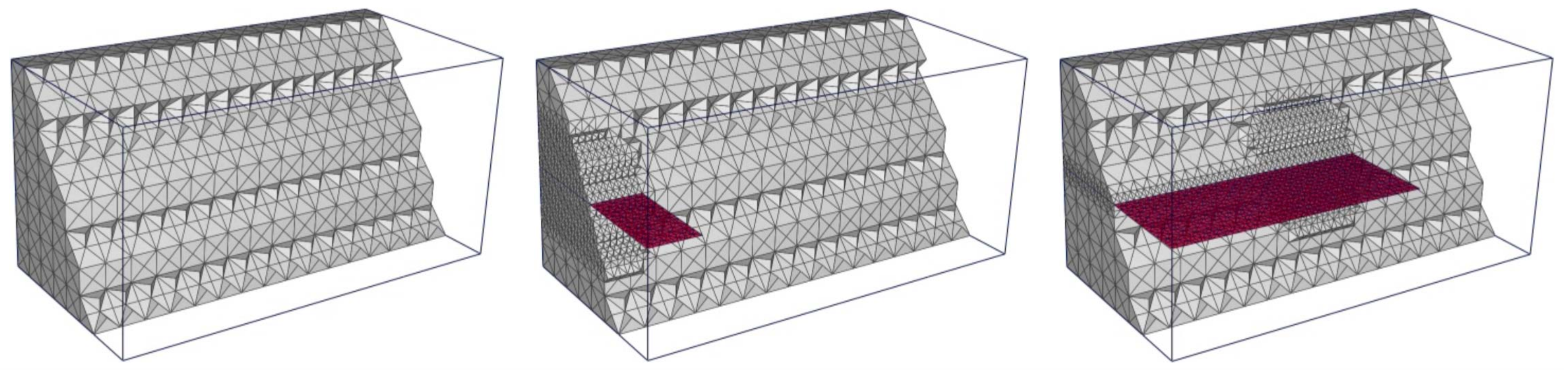
Mode I Predefined Crack

- **Two dimensional simulation**





- **Data structure support for three dimensional simulations with adaptive mesh refinement and coarsening**



Conclusions and Extensions

- The potential-based constitutive model with adaptive operators (nodal perturbation, edge-swap, edge-split, and vertex-removal) leads to an effective and efficient computational framework to simulate physical phenomena associated with fracture.
- The topological data structure and adaptive topological operators support the extension of this work to three dimensions.

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