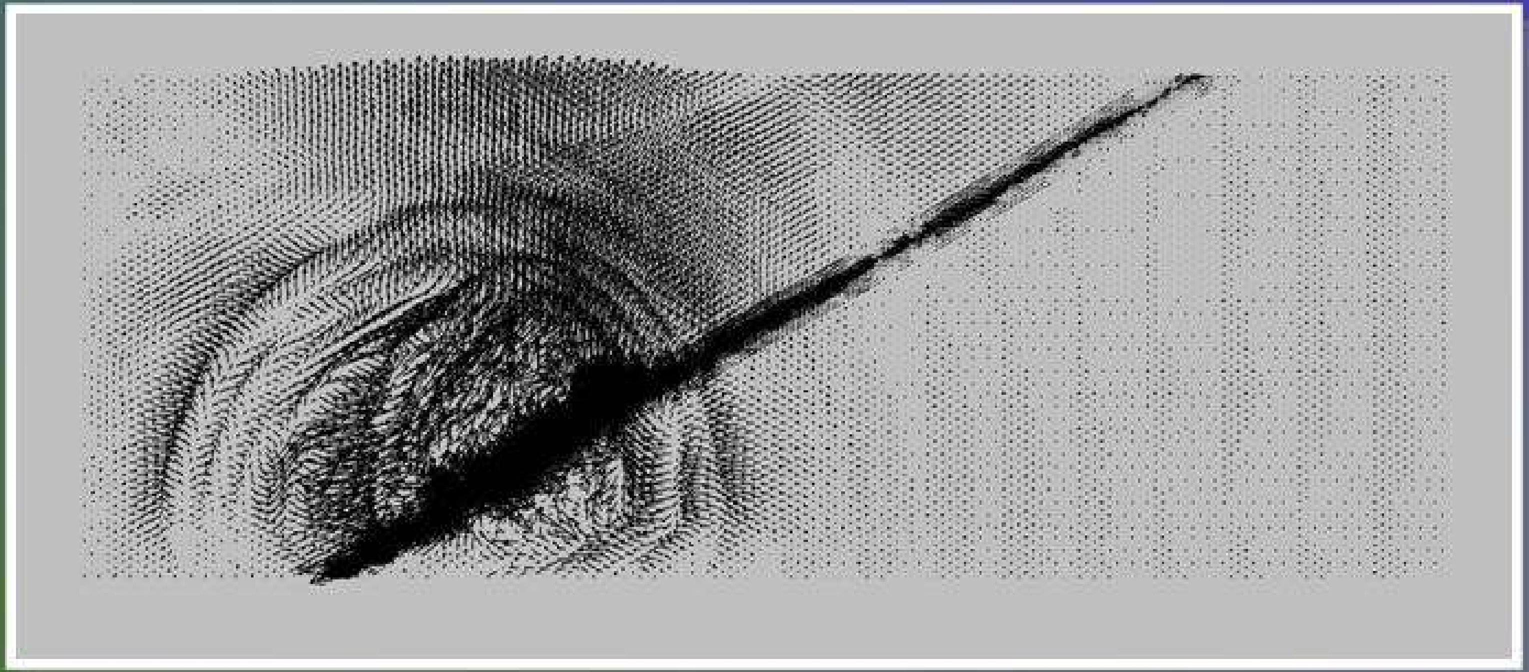
Discontinuum Modeling of Dynamic Ruptures



Matt Purvance, Peter Cundall

Outline

Introduce the Particle Flow Code (PFC)

Importance of Material Calibration

Implementation Issues for Code Validation

Simulation of Rupture Initiation

Distinct Element Method (Cundall 1971)

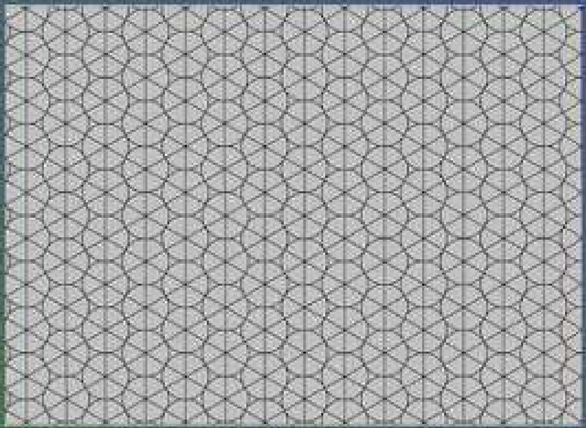
DEMs include numerical models that:

a) allow finite displacements and rotations of discrete bodies, including complete detachment

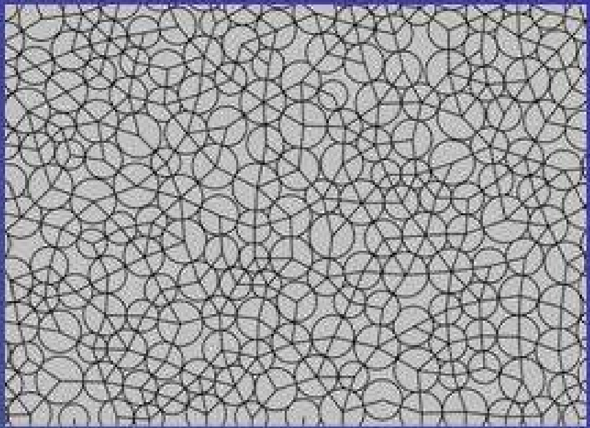
and

b) recognize new contacts automatically as the calculation progresses.

Particle Flow Code (PFC)



Packing of
Spherical and/or
Clumped Particles
– 2D and 3D



Micro-properties

Density

Contact Stiffness (shear and normal)

Contact Strength (shear and normal)

Coefficient of Friction

PFC Implementation

Balls and contacts are stored in C++ linked data structures through a list of pointers

Single data elements for each entity contain geometrical and mechanical information and a pointer to the next element in an arbitrarily ordered list

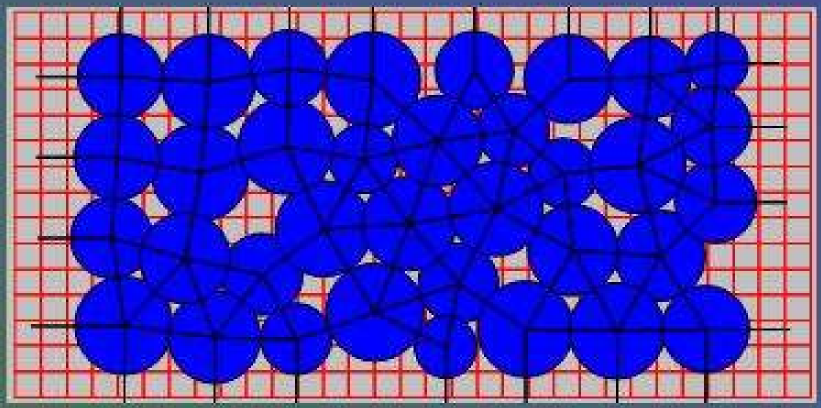
↓

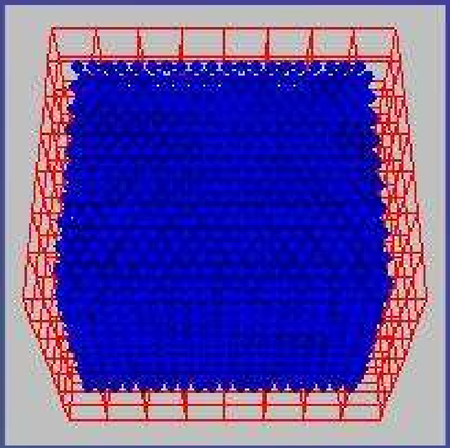
Balls have lists of all contacts, contacts have lists of 2 balls

Need efficient search algorithm for contacts!

PFC Calculation Cycle – Stage 1

1) Balls mapped into a spatial mesh





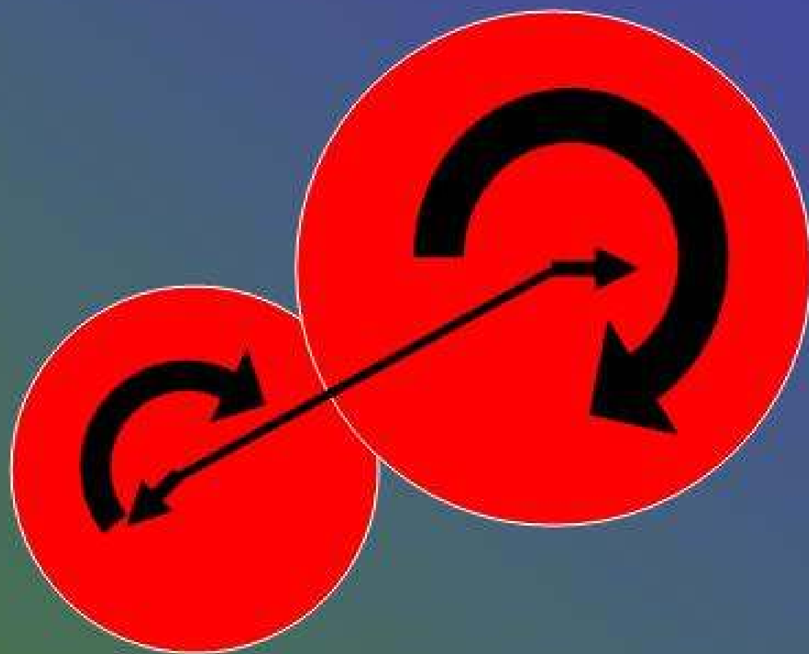
Cells store linked lists of all contacts and balls mapped into them

Remapping triggered via cumulative displacement

Neighbors defined by entities in the same cells $\rightarrow$ test for contact

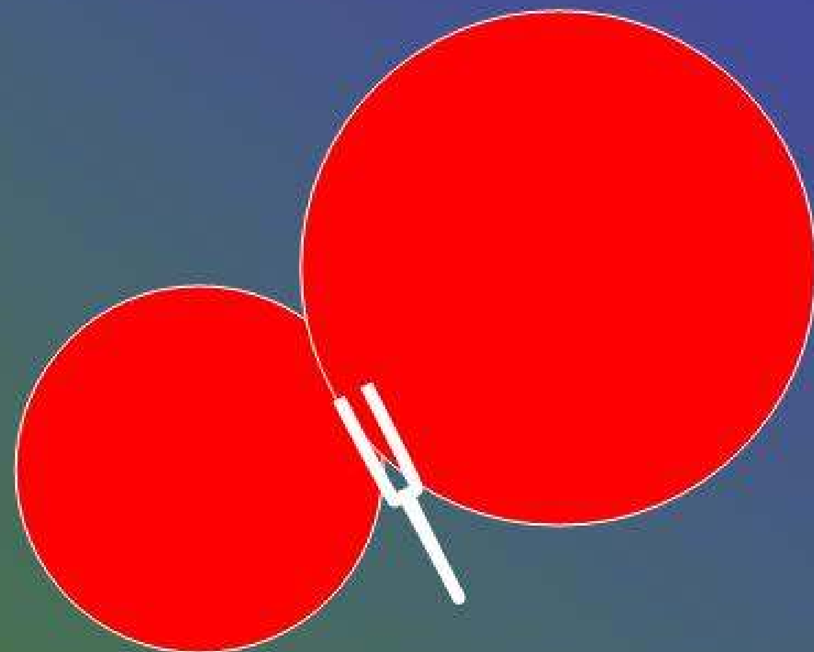
PFC Calculation Cycle – Stage 2

2) Apply force-displacement law at each contact



PFC Calculation Cycle – Stage 2

2) Apply force-displacement law at each contact



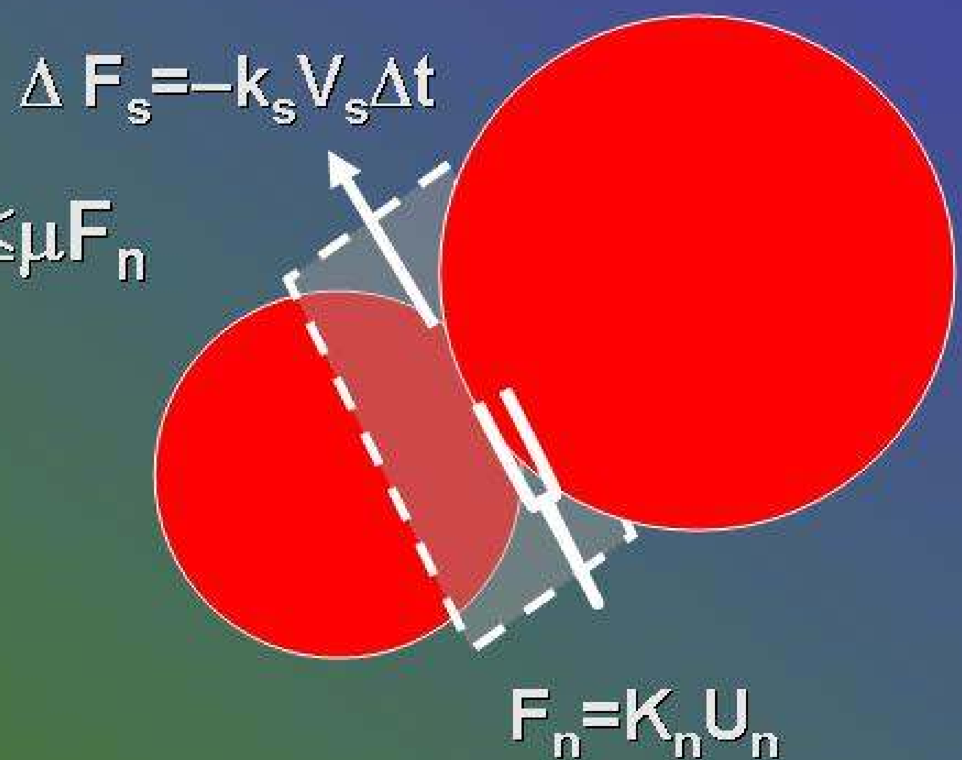
$$F_n = K_n U_n$$

$$F = F_n + F_s$$

PFC Calculation Cycle – Stage 2

2) Apply force-displacement law at each contact

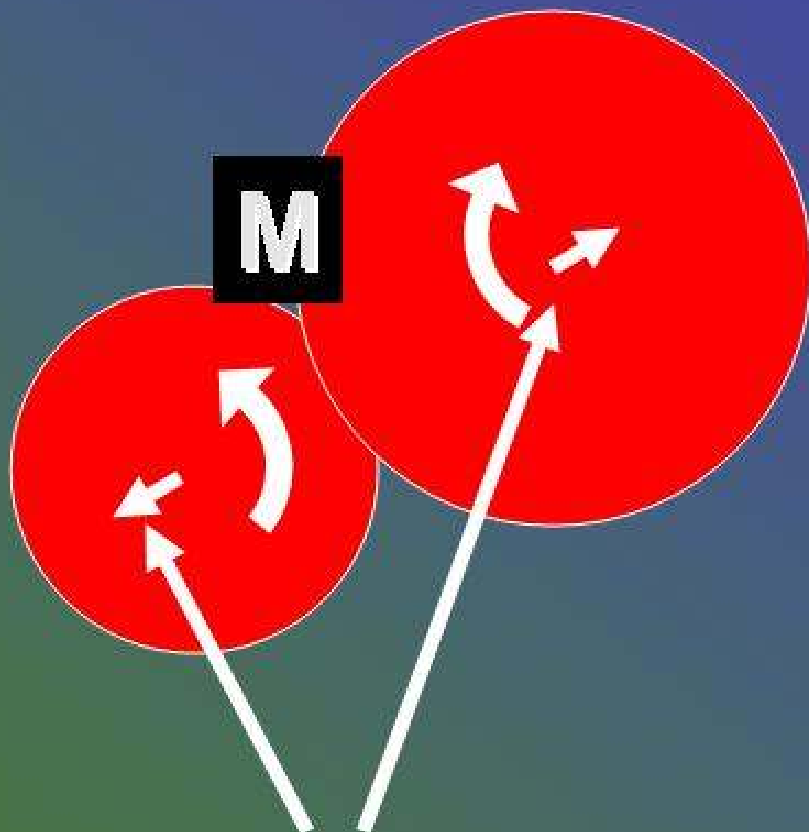
$F_s \leftarrow F_s + \Delta F_s \leq \mu F_n$



$$F = F_n + F_s$$

PFC Calculation Cycle – Stage 2

2) Apply force-displacement law at each contact

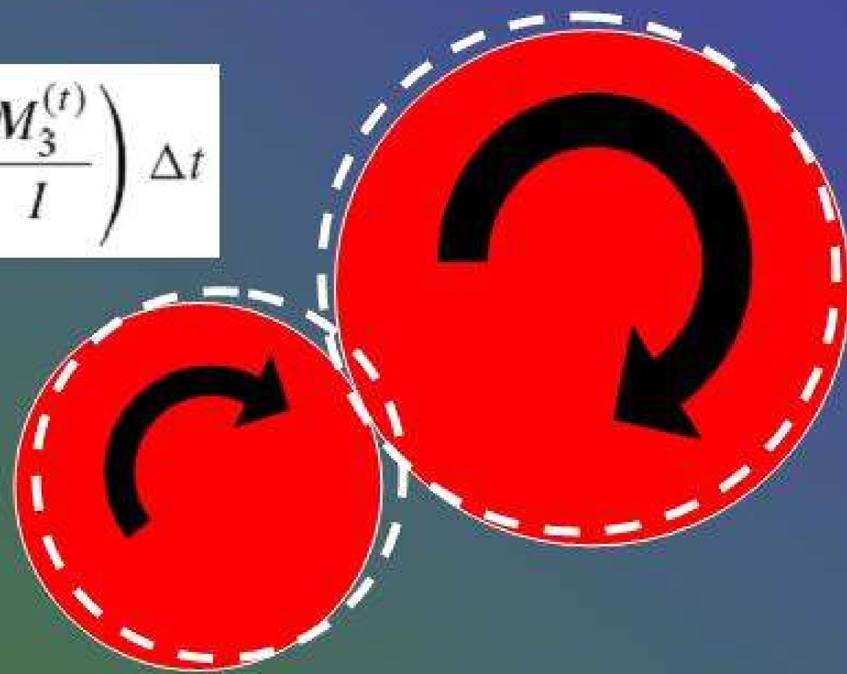


$F = F_n + F_s$

PFC Calculation Cycle – Stage 3

3) Update the particle velocities, positions, and rotational velocities

$$\omega_3^{(t+\Delta t/2)} = \omega_3^{(t-\Delta t/2)} + \left(\frac{M_3^{(t)}}{I}\right)\Delta t$$



$$\dot{x}_i^{(t+\Delta t/2)} = \dot{x}_i^{(t-\Delta t/2)} + \left(\frac{F_i^{(t)}}{m} + g_i\right)\Delta t$$

→

$$x_i^{(t+\Delta t)} = x_i^{(t)} + \dot{x}_i^{(t+\Delta t/2)}\Delta t$$

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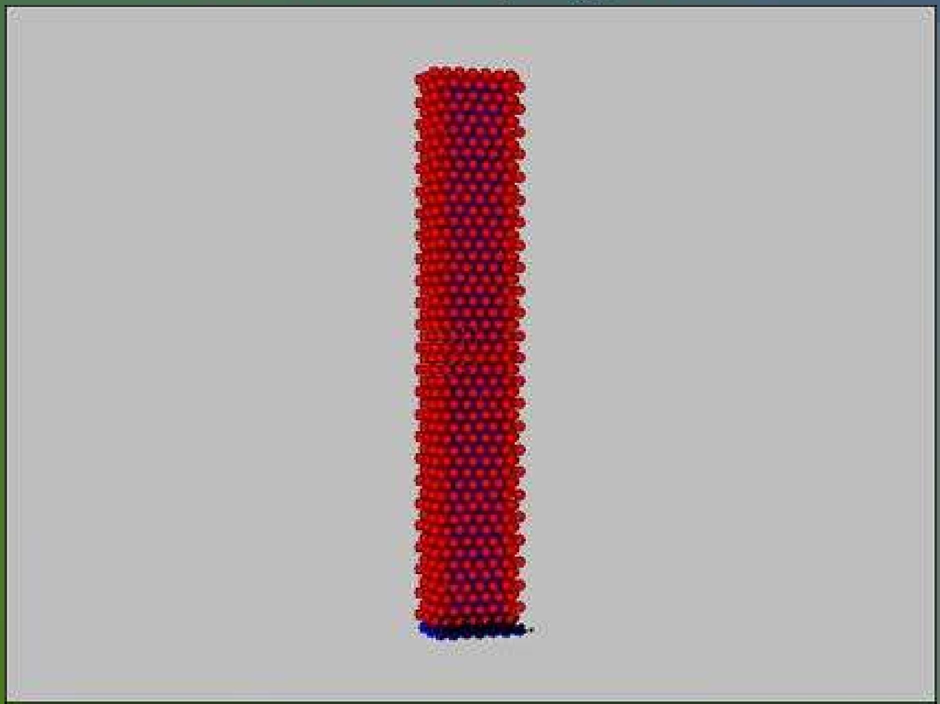
Material Calibration

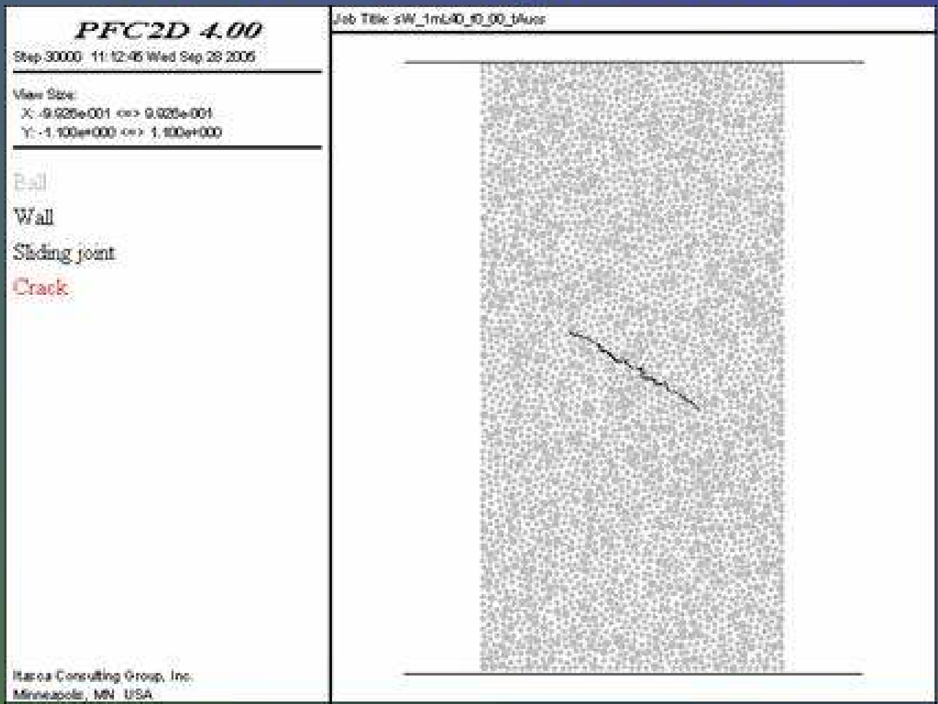
The elastic and strength properties of particle assemblies emerge from microscale interactions

Expose particle assemblies to various material testing environments

Wave Propagation



Uniaxial Compression



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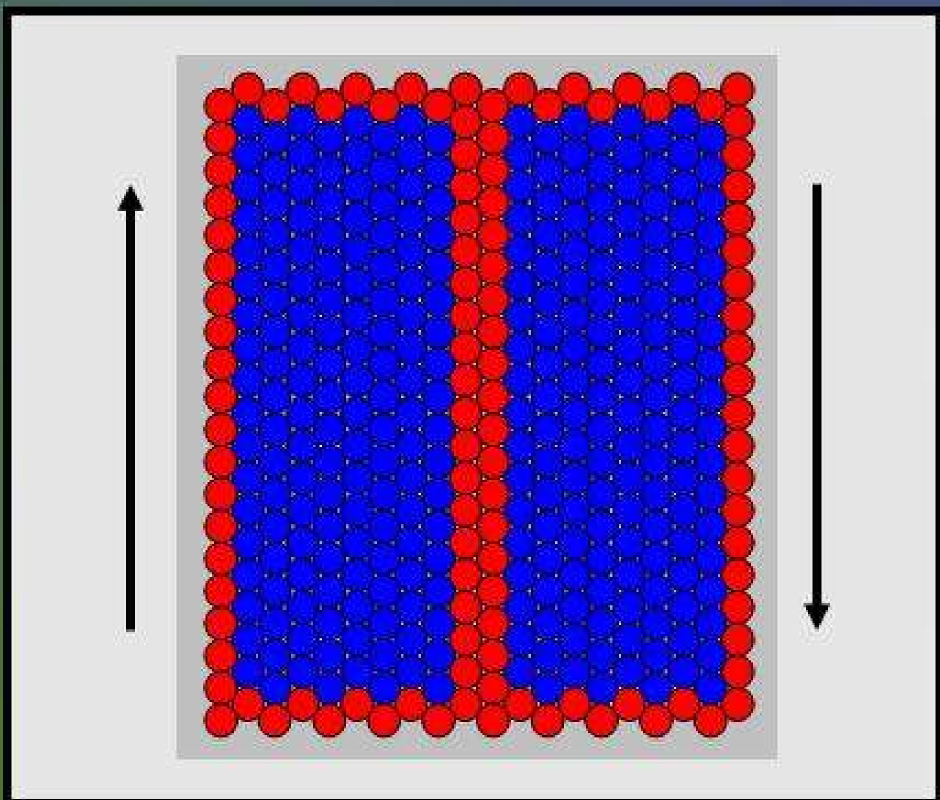
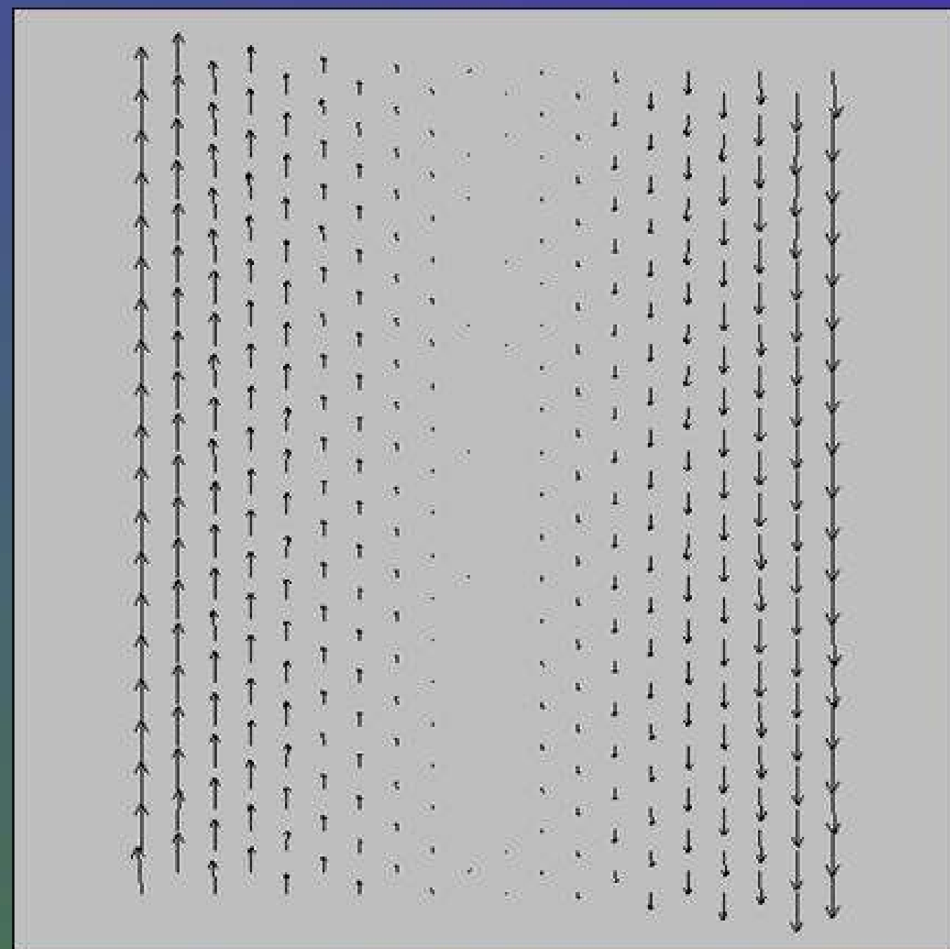
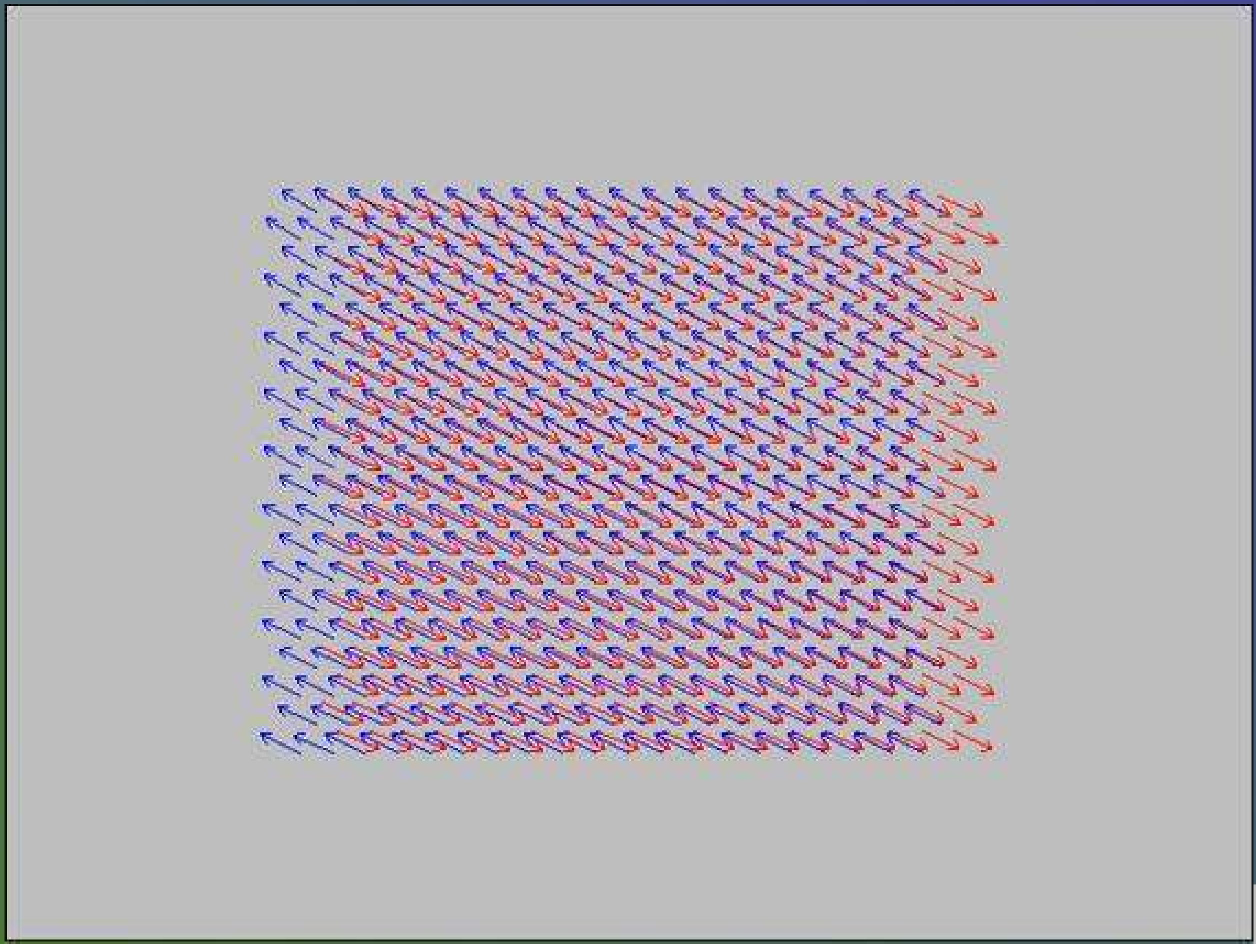
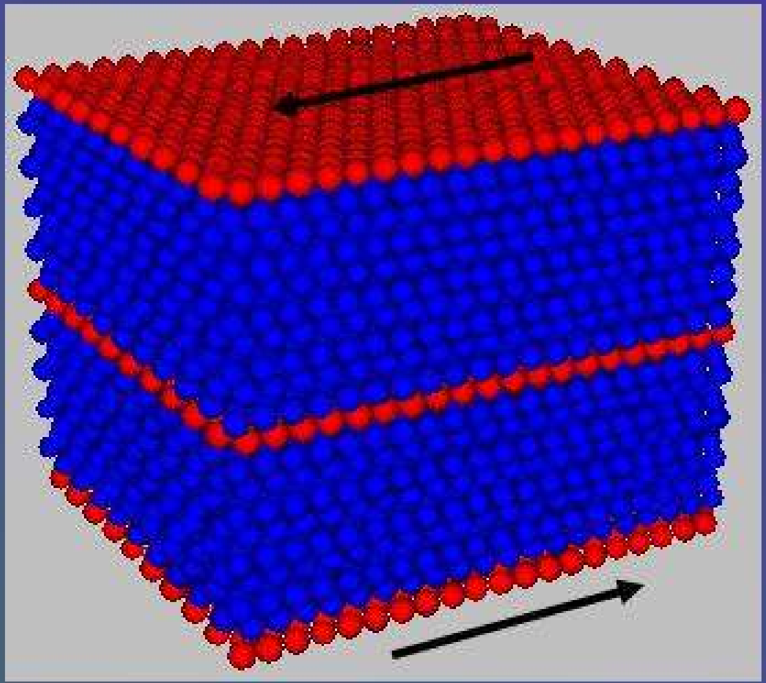
Surface Roughness vs. Wave Scattering

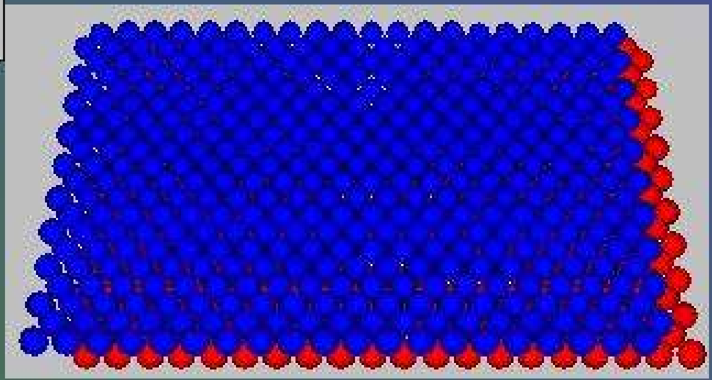




Surface Roughness vs. Wave Scattering







Face-centered cubic packing produces particle swerve

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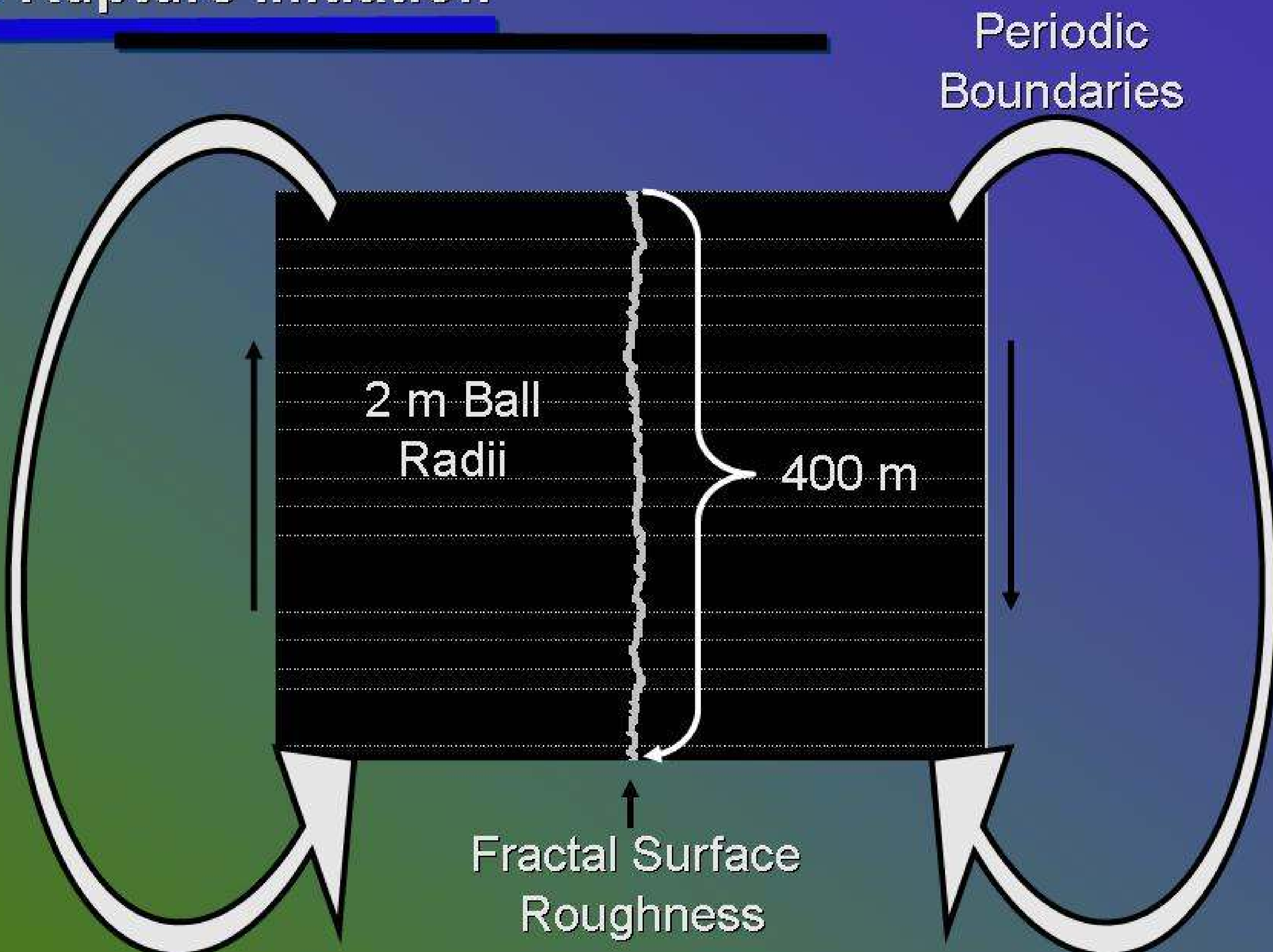
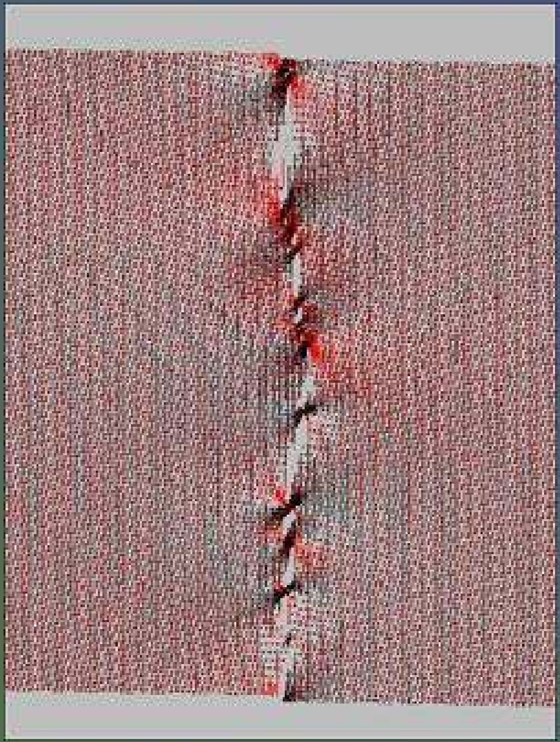
2D Rupture Initiation

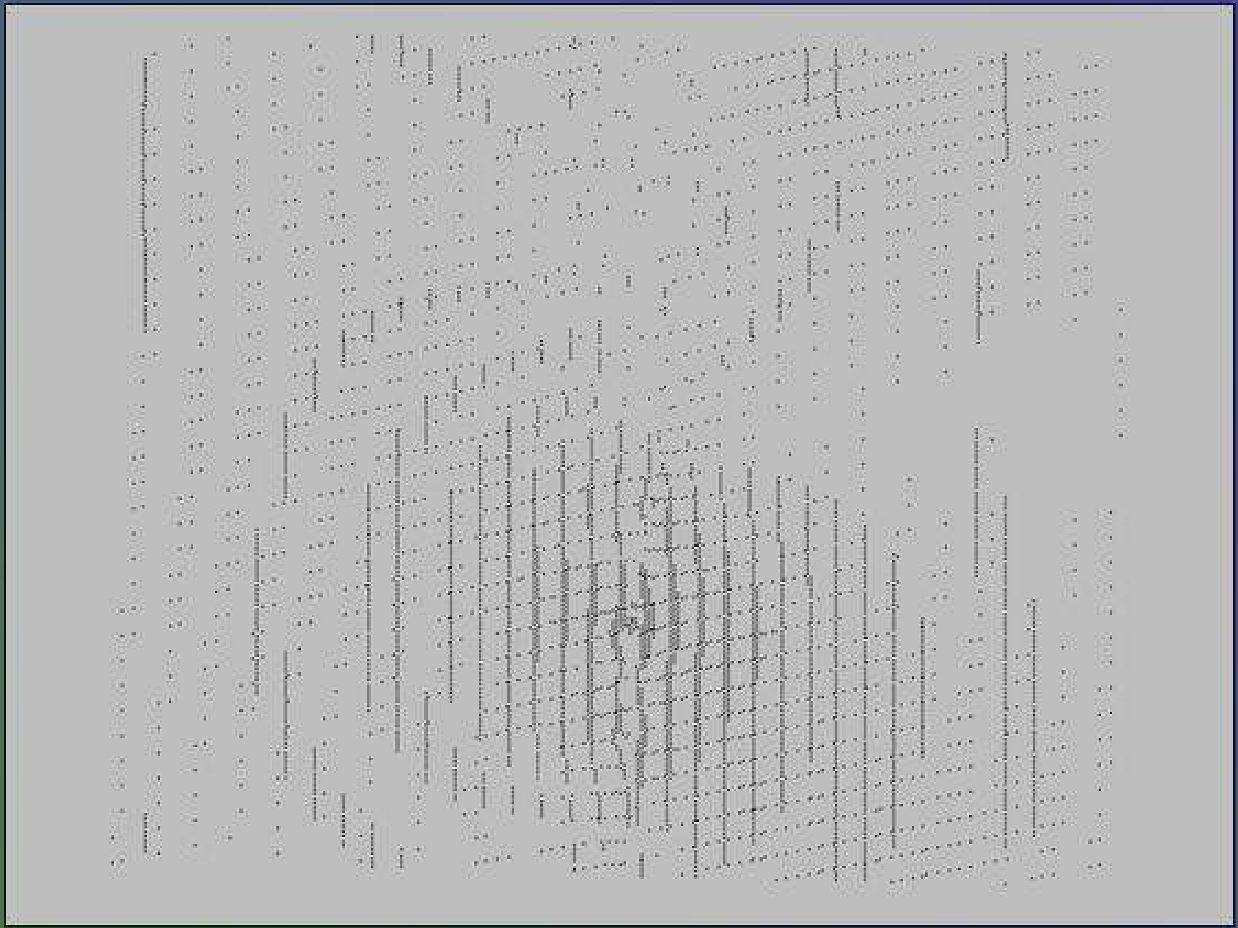


2D Rupture Initiation

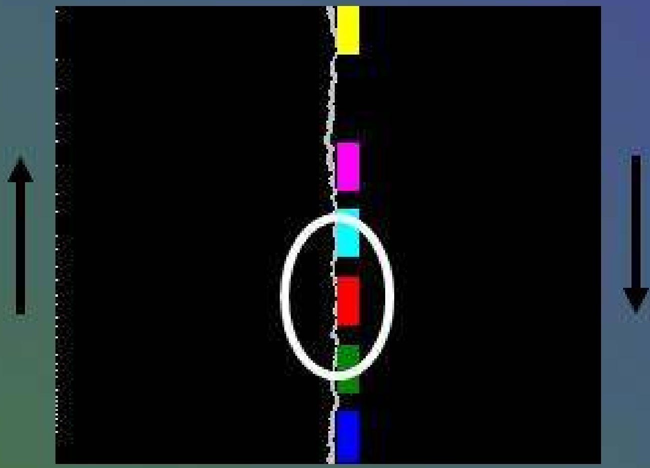


Initial Stress Distribution
Compression
Tension

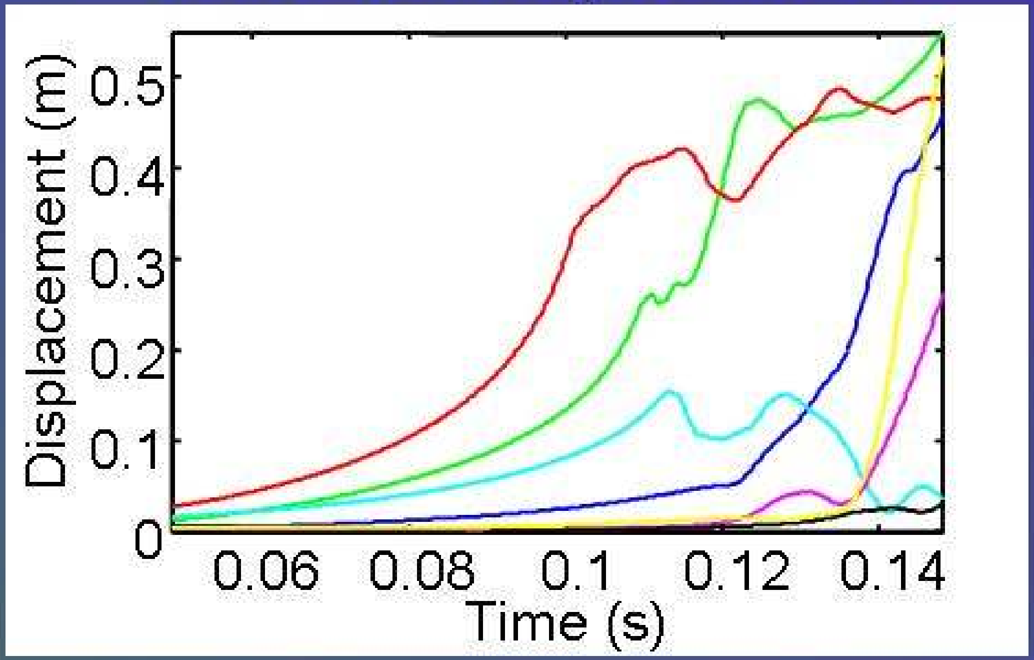
Particle Velocities



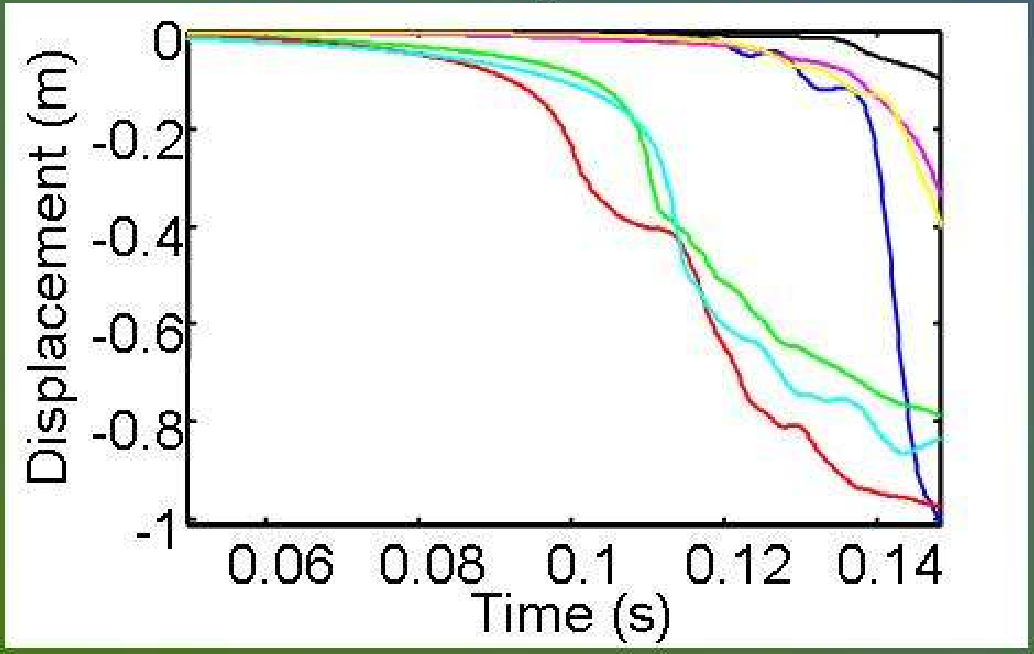
2D Rupture Initiation - Displacements



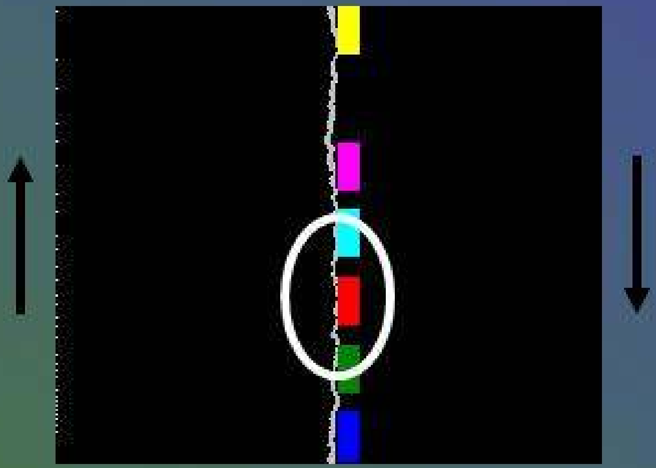
Horizontal Displacement



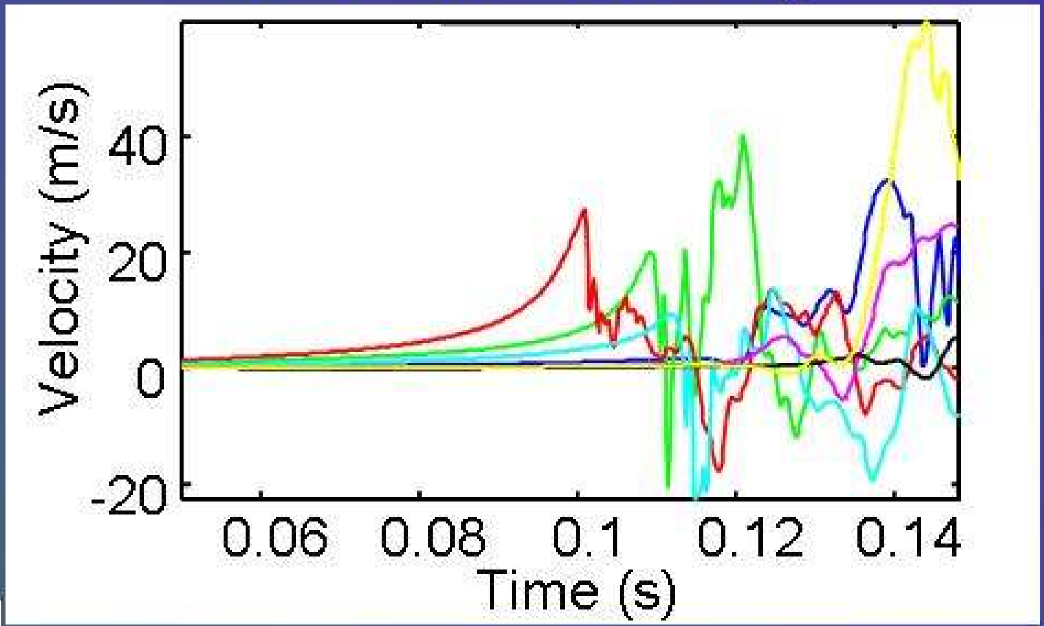
Vertical Displacement



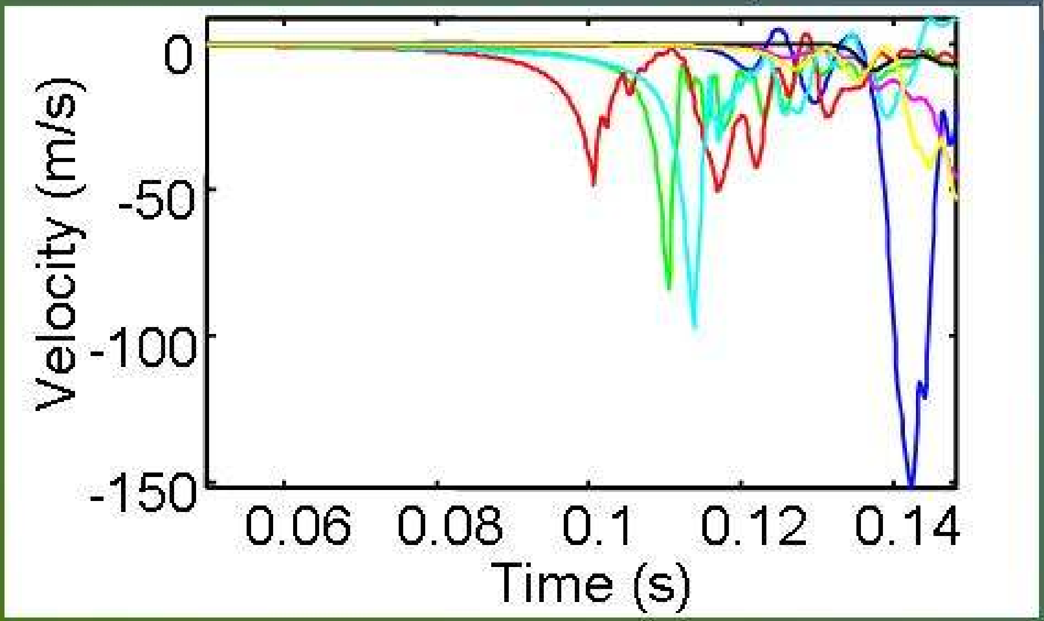
2D Rupture Initiation - Velocities



Horizontal Velocity



Vertical Velocity



Further Model Development

Couple the discrete model with a more efficient wave propagation method away from the rupture surface – isotropy penalty

Incorporate damage to reproduce realistic stress concentrations on the fault

Investigate various roughness models

Implement effective absorbing boundaries

Suggest comparison/validation between continuum and discontinuum models via heterogeneous original stress distributions

END