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Numerical modelling of fracture growth and caprock integrity during CO2 injection

UKCCS RC – “Geophysical Modelling for CO2 storage, monitoring and appraisal”
University of Leeds, Leeds, UK
November 3rd, 2015

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CONTAIN – EPSRC

British Geological Society – Imperial College – Cardiff University

Experimental – Numerical – Societal

… to undertake and disseminate research in the computational modelling of poro-elastic behaviour of the caprock during reservoir depletion and its subsequent reinflation due to CO2 injection …

Specifically, the aim of IC is to:

- evaluate caprock failure as a function of long-term geomechanical deformation for a range of injection scenarios.

These will be validated using data generated by the British Geological Society, will be used as a basis to inform the public about CCS

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CSMP++

- C++ based numerical library for finite element & finite volume methods
- Unstructured grids
- Discrete fracture representation
- THMC applications
- Core developers (~2-3)
- Numerical methods developers (~4-6)
- Application programmers (~17)
- Users (~100)

Two-phase flow
Numerical methods
Core development

Black-oil
Parallelization

Reactive, compositional
high temperature transport

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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Computational
mechanics

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IC Geomechanics Library and CSMP++

This project will utilise CSMP++ (Complex Systems Platform), an object-oriented finite-element based library that is specialised to simulate complex multi-physics processes.

It has already been validated to model transport, single-phase and multiphase flow in three dimensions, and can operate on workstations as well as on high performance computing systems.

The geomechanics library developed at Imperial College, integrated with CSMP++, is capable of simulating the growth and interaction of multiple discrete 3D meso-scale fractures.

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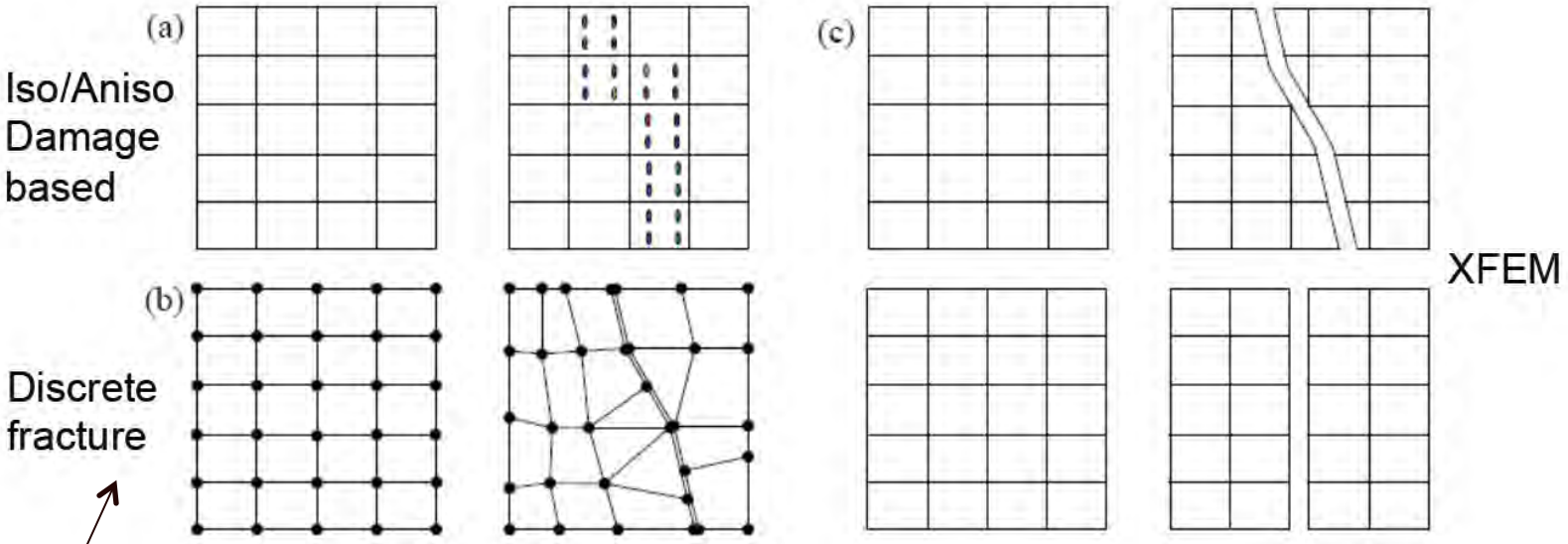
Numerical modelling of fracture growth

(All finite element models)



Compatible with flow within the fractures

(a) continuous, (b) discrete, (c) mixed

Stress-based vs. Stress Intensity Factor-based models
Stress-based models require very accurate meshes!

DEM is not energy conservative,
Properties must be calibrated from micro- to macro, validity for fracture propagation not well accepted.

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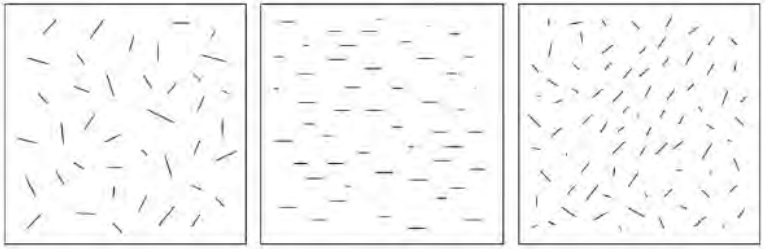
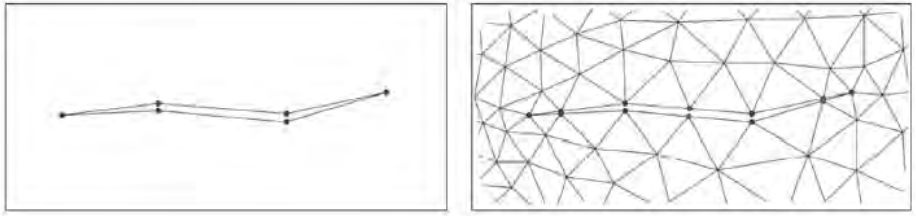
Growth Principles

(1)



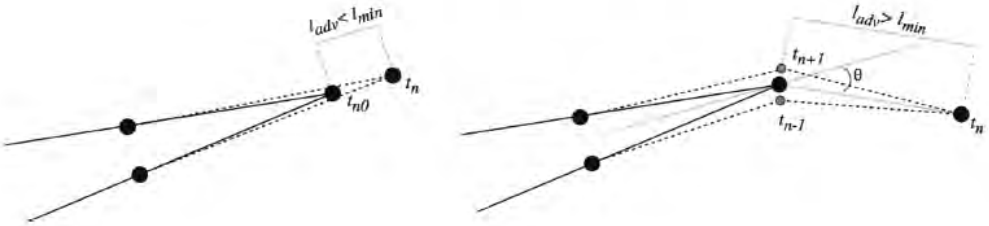
Initial flaws

(2)



Separate Geometry - Mesh

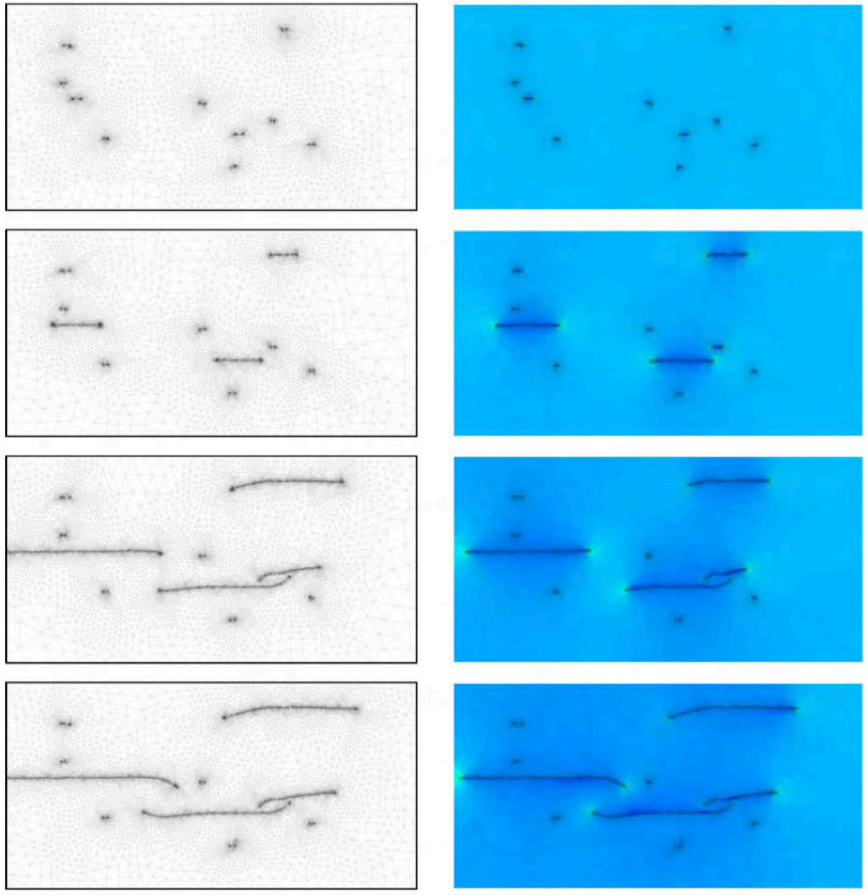
(3)



Growth Laws (energy)
- Failure
- Propagation
- Angle

[Paluszny & Matthai, IJSS, 2009]

Fracture pattern (2D)



[Paluszny & Matthai, IJSS, 2009]

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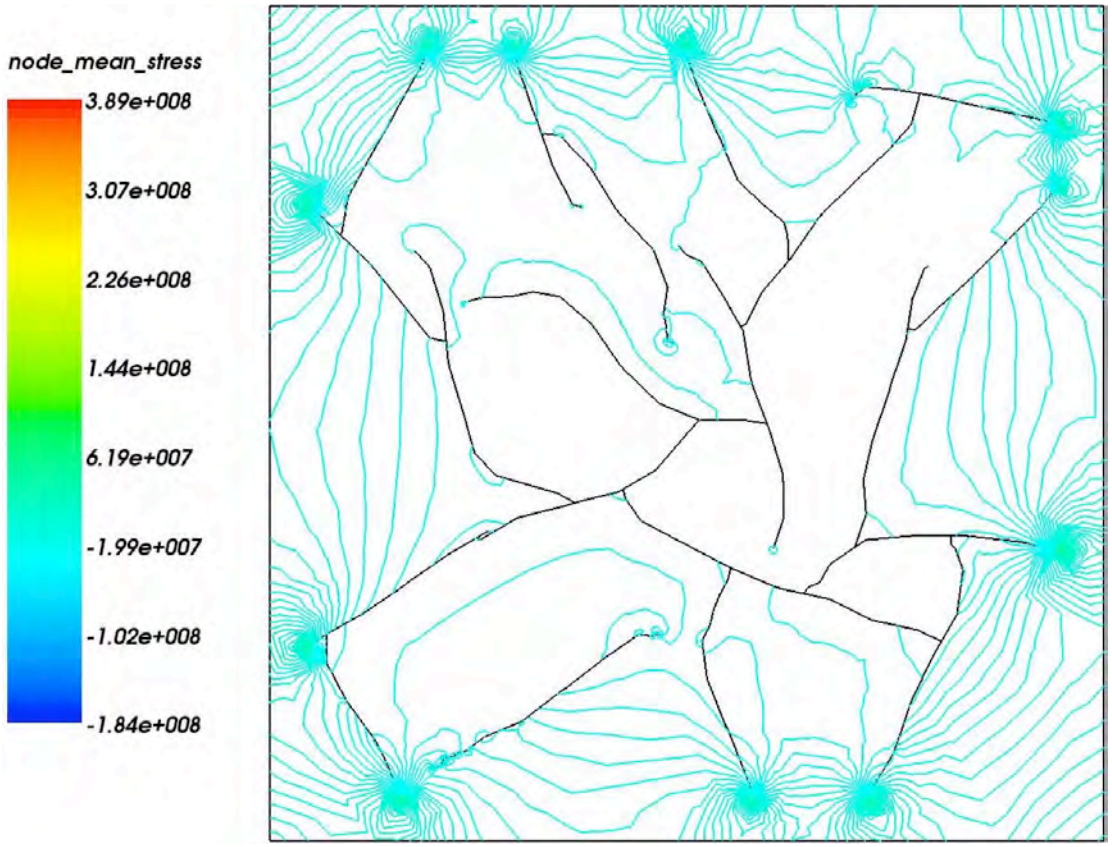
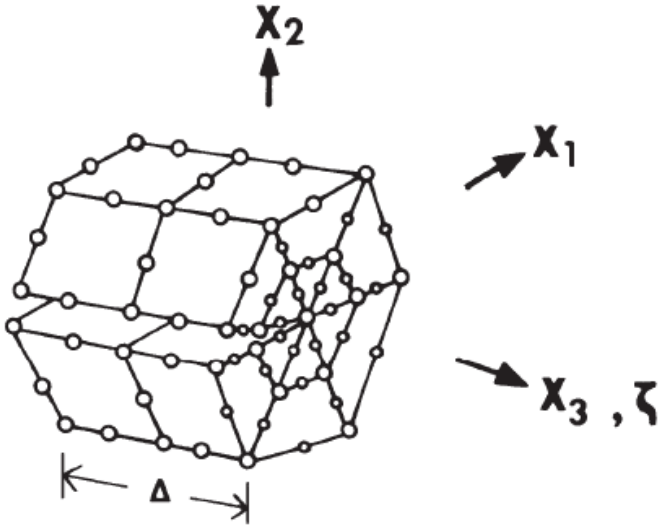
Polygonal patterns



Polygonal fracture growth due to shrinkage of the matrix. Mean stress contours are plotted with the polygonal fracture pattern. Stress concentrates ahead of the fracture tips.

Limitation in 3D: SIF Computation mesh



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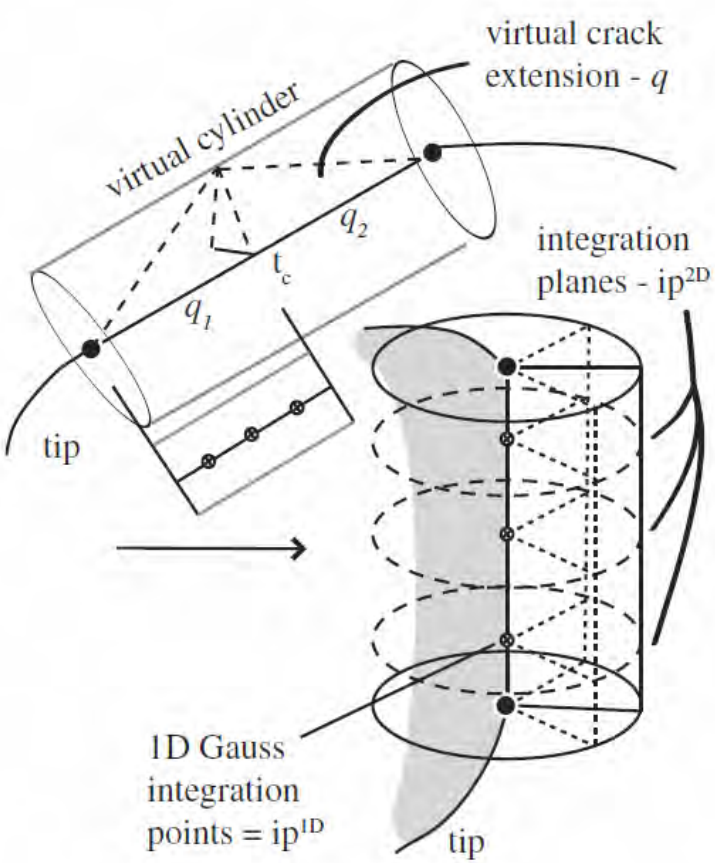
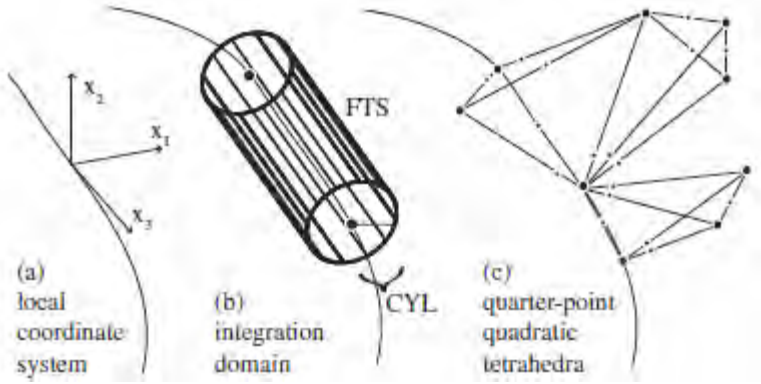
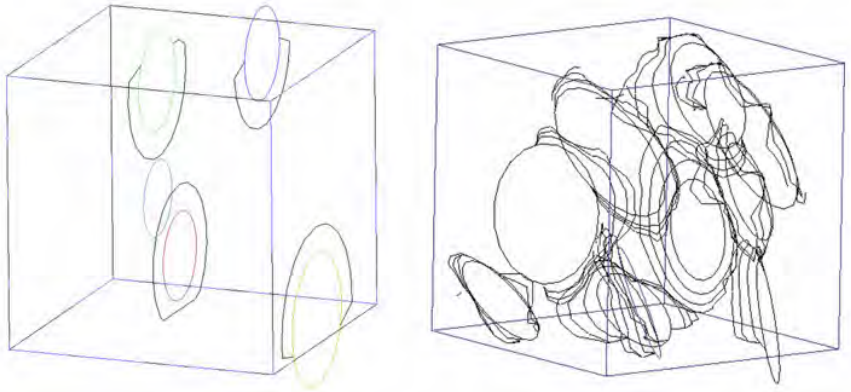
Reduced Virtual Integration Technique (RVIT)







[Paluszny & Zimmerman, CMAME, 2011]

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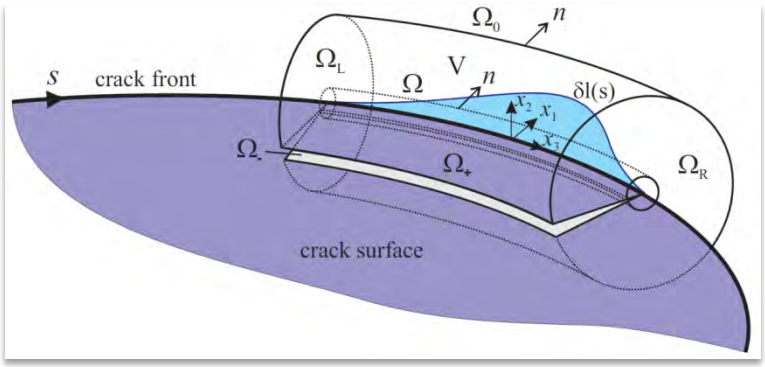
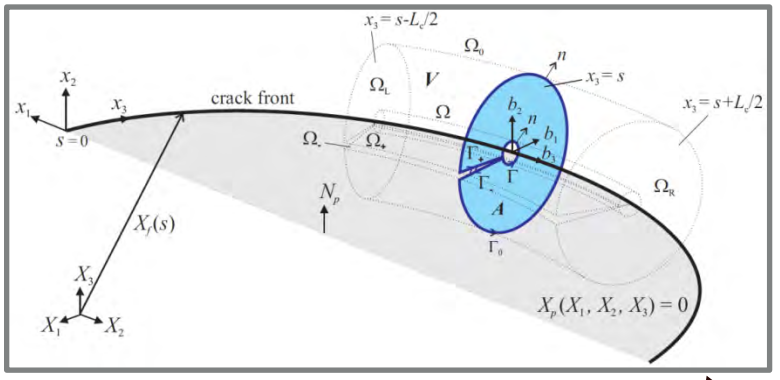
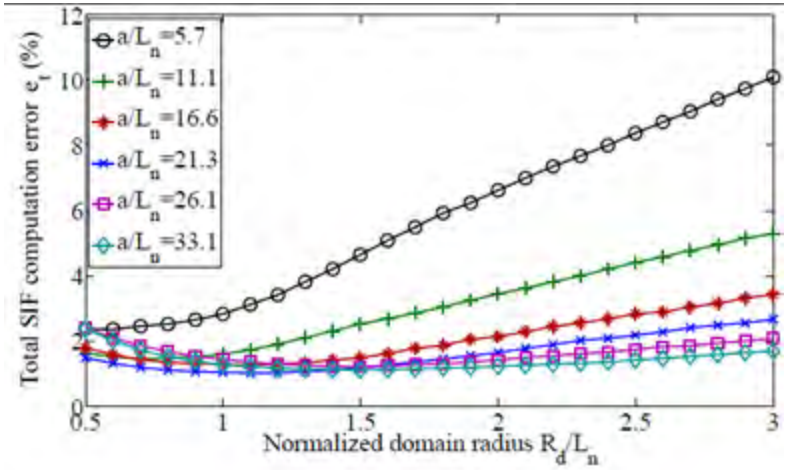
I-integral for stress intensity factor computations





[Paluszny & Zimmerman, CMAME, 2011; Nejati et al., IJSS, 2015]

This allowed to reduce computation time, increase accuracy and improve robustness of the growth engine



Volumetric Domain J-Integral now is I-Integral over virtual disk

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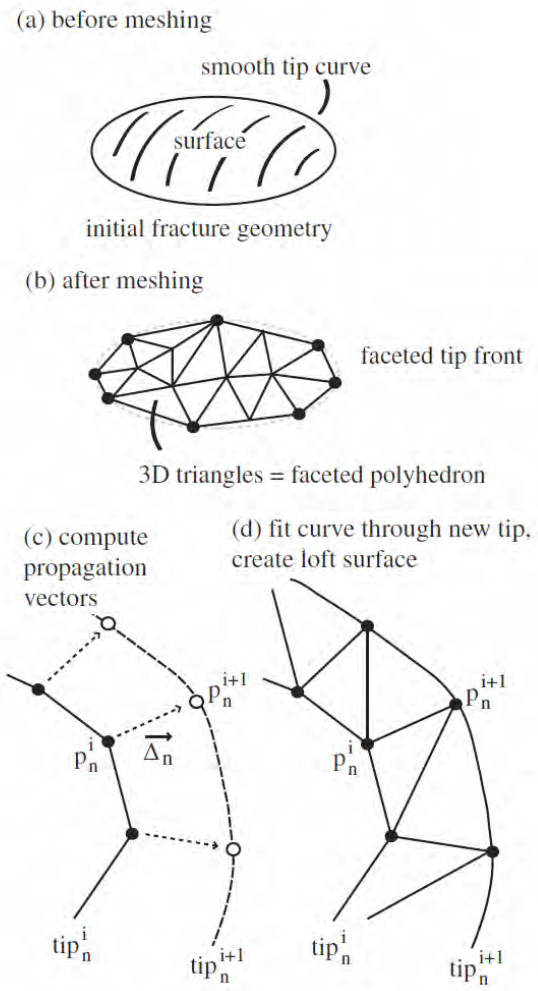
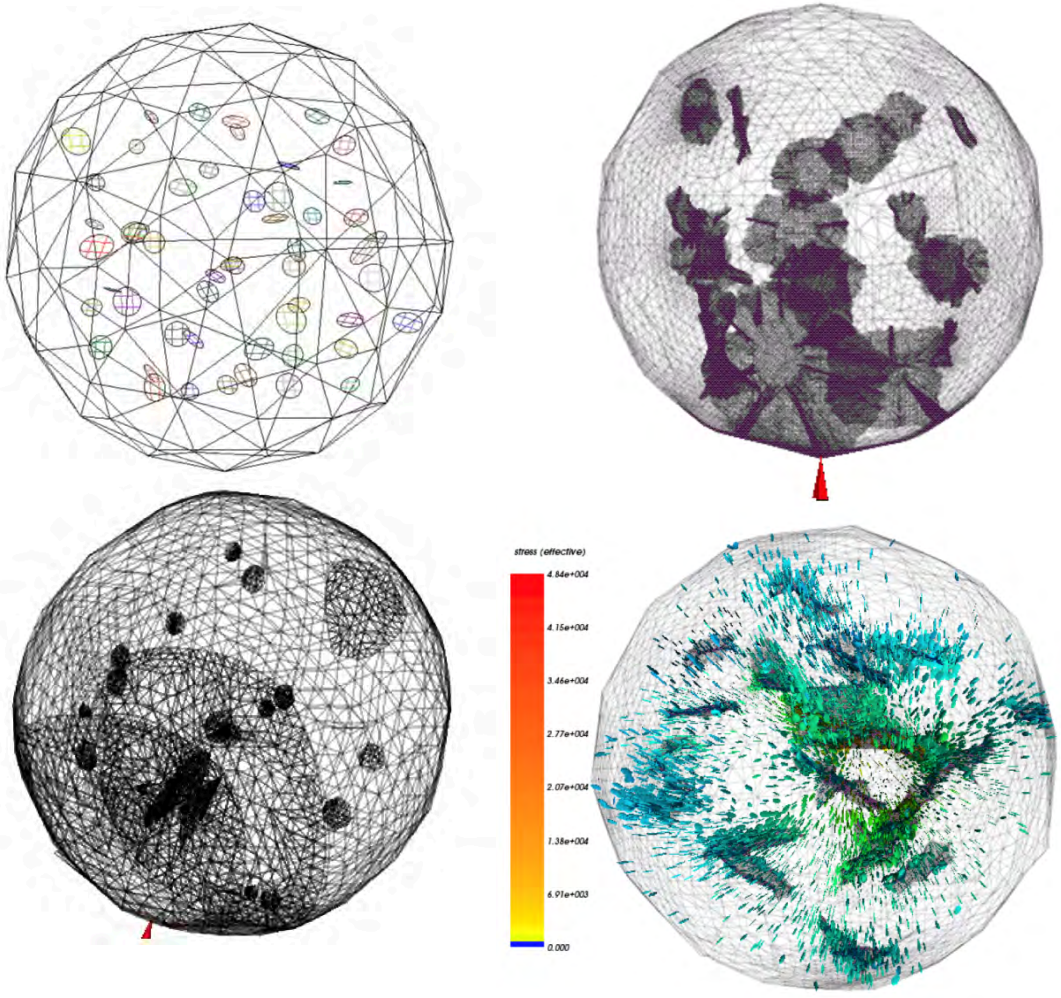
Fracture Growth (3D)





[Paluszny & Zimmerman, CM, 2013]

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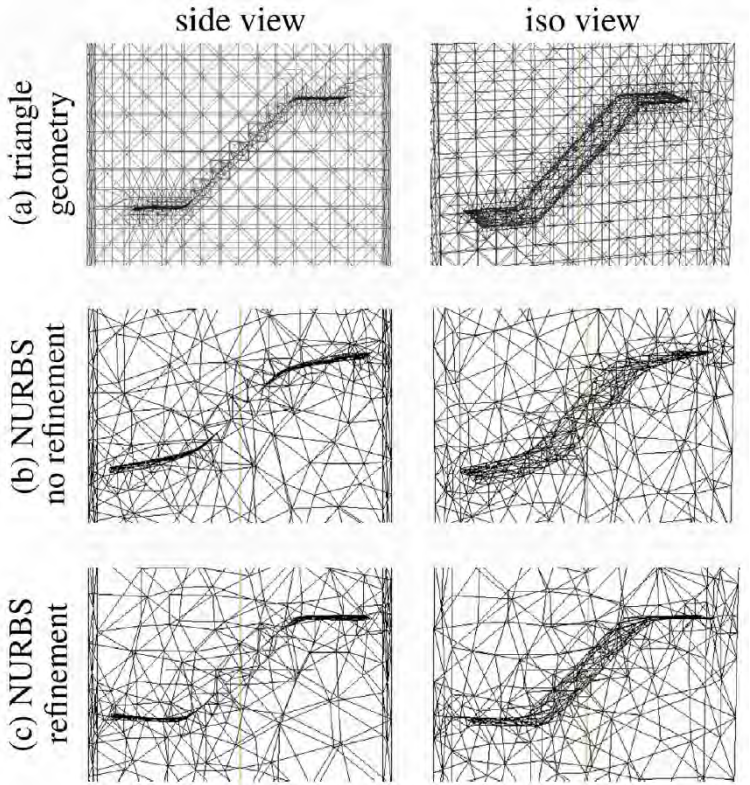
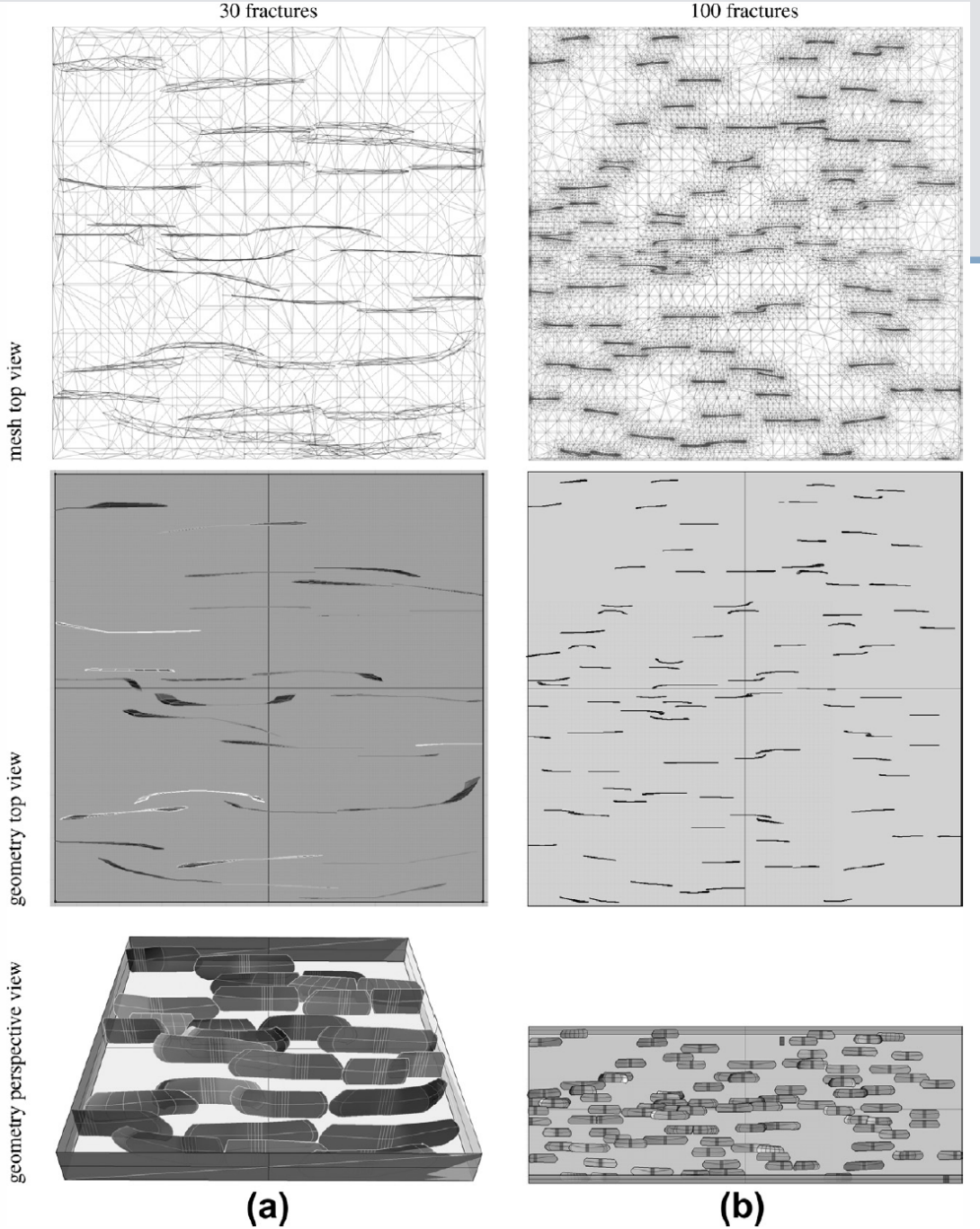
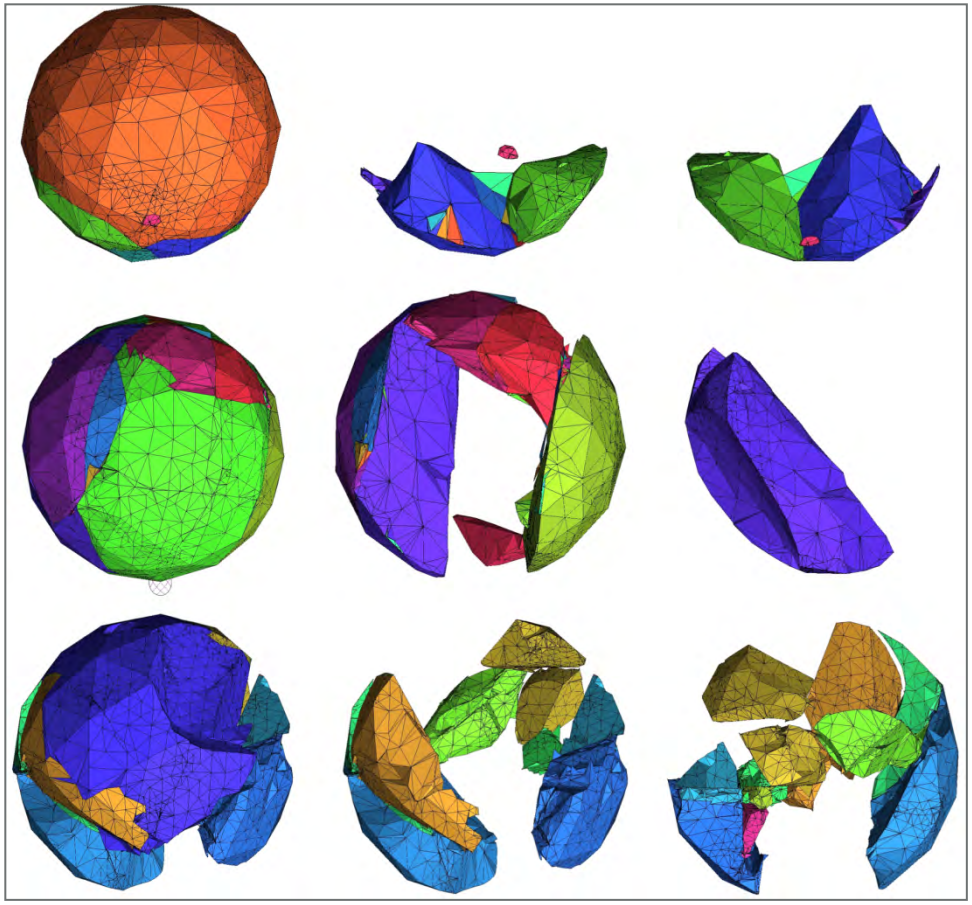
Fracture set growth



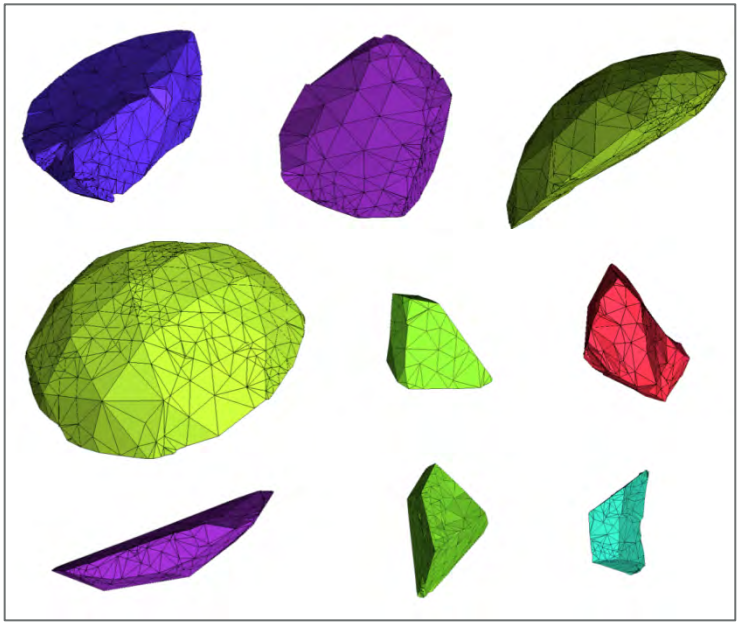


[Paluszny & Zimmerman, Engineering Fracture Mechanics, 2013]

Fracture-driven fragmentation (3D)



Velocity-dependent fragmentation pattern



shapes

[Paluszny & Zimmerman, Computational Mechanics, 2013]

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Key CCS Improvements to the ICGT core 2015

CONTAIN: "During the first two years, the focus will be on the extension, integration, and validation of existing flow and propagation kernels."

(1) Accurate fluid pressure dependent stress intensity factor computations

(2) Poroelastic coupled deformation

(3) High-accuracy friction model

(4) Initial validation using Goldeneye field data (Shell)

With work contributed by AP+SS and PhD students:

Morteza Nejati and Thibaut Defoort

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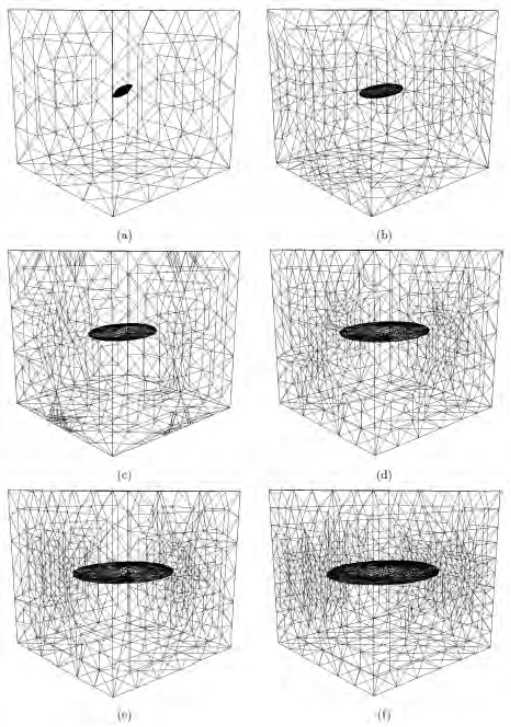
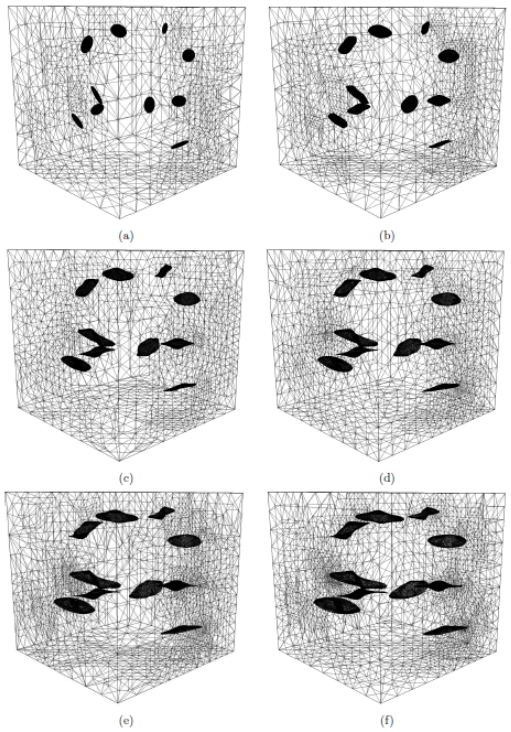
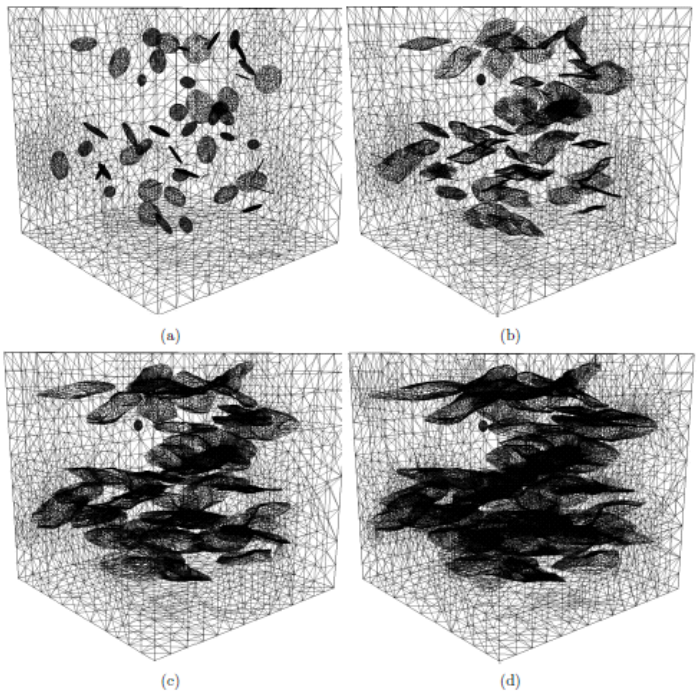
Multiple fracture growth – coarse mesh but accurate SIFs







(minutes to run)

- Peak: 320k nodes
- Runtime: 10 hours

Mechanical Variables
Poisson's ratio
Density
Young's Modulus
UCS
Fault Friction

All simulations run on a Dell Precision Workstation (2013) with a maximum of 8 cores dedicated to one job.

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Related Publications

Nejati, M., Paluszny, A., Zimmerman, R.W. (**2015**) “A disk-shaped domain integral method for the computation of stress intensity factors using tetrahedral meshes”, Int. J. Solids Struct., 69-70, 230-251.

Nejati, M., Paluszny, A., Zimmerman, R.W. (**2015**) “On the use of quarter-point tetrahedral finite elements in linear elastic fracture mechanics”, Eng. Fract. Mech., 144, 194-221.

Tang, X.H., Paluszny, A., Zimmerman, R.W. (**2014**) “An impulse-based energy tracking method for collision resolution”, Comput. Meth. Appl. Mech. Eng., 278, 160-185.

Paluszny, A., Tang, X.H., Zimmerman, R.W. (**2013**) “Fracture and impulse based finite-discrete element modeling of fragmentation”, Comput. Mech., 52(5), 1071-1084.

Paluszny A, Zimmerman RW (**2013**) Numerical fracture growth modeling using smooth surface geometric deformation", Engineering Fracture Mechanics (available online).

Nejati M, Paluszny A, Zimmerman RW (**2013**) Theoretical and Numerical Modeling of Rock Hysteresis Based on Sliding of Microcrack" 47th U.S. Rock Mechanics / Geomechanics Symposium (ARMA), San Francisco, USA, 23-26 June.

Zimmerman RW, Paluszny A (**2012**) Some New Developments in Modelling the Failure, Fracture and Fragmentation of Rocks", 7th Asian Rock Mechanics Symposium, Invited Paper, Seoul, Korea, 15-19 October.

Paluszny A, Zimmerman RW (**2011**) Numerical simulation of multiple 3D fracture propagation using arbitrary meshes", Computer Methods in Applied Mechanics and Engineering, Vol: 200, Pages:953-966.

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Disclaimer

Some slides have been removed from the original presentation.