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Fuel Cycle Technologies

Development of Discrete Fracture Network Modeling Capability

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Presentation Outline

- **Need for discrete fracture network (DFN) models**
- **International experience with DFN models of flow and transport in fractured granite**
- **Limitations of existing tools**
- **Development of new DFN flow and transport capabilities**
  - Choice of solution method for flow
  - Meshing issues
  - Choice of solution method for transport
- **Example simulations**

Flow and Transport in Fractured Rock

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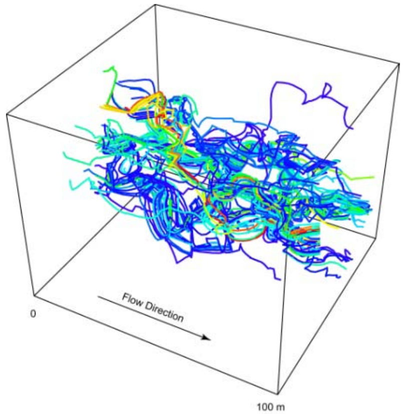
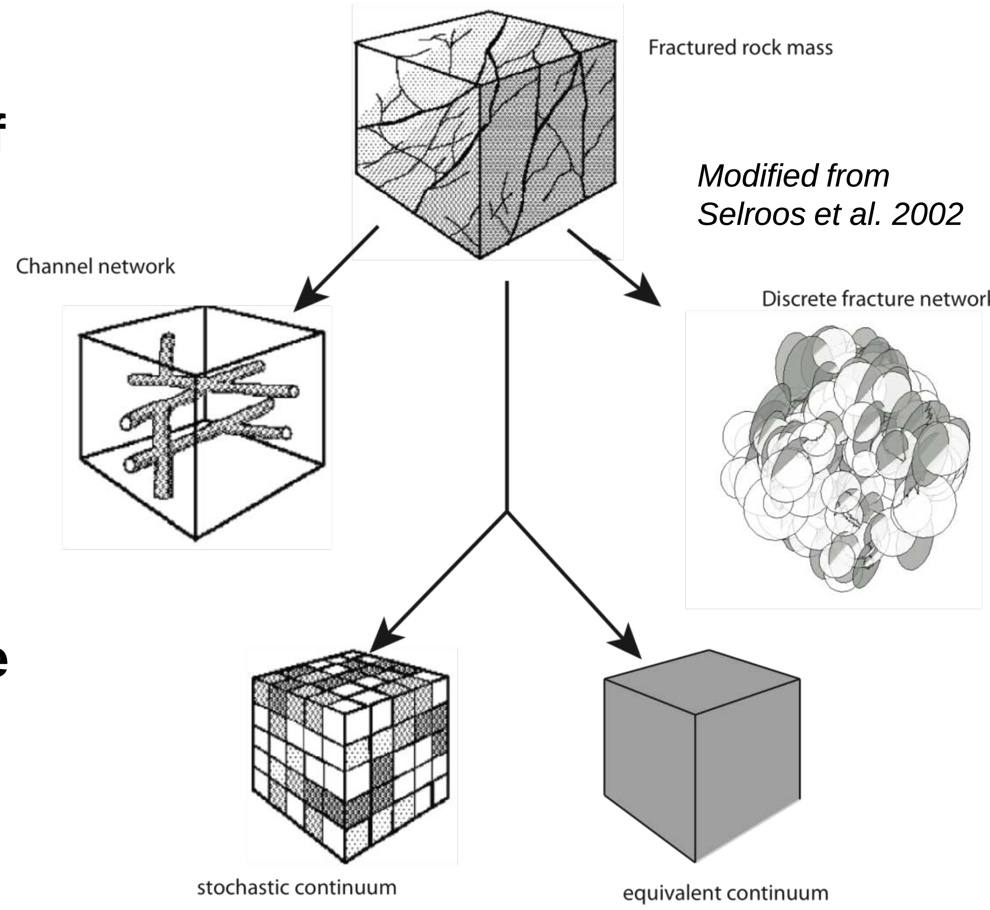
- **For repositories sited in granitic rock, interconnected networks of fractures provide the primary pathways for radionuclide migration to the accessible environment**
- **Quantitative assessment of flow and transport in fractured rock is among the most challenging topics in contemporary groundwater science (e.g. Neuman, 2005)**
- **Experience suggests that the traditional approach of representing the fractured rock mass as an equivalent continuum misses key phenomena**
  - High-degree of channeling
  - Scale dependence
  - Complex directional dependence
  - Highly skewed breakthrough curves



Discrete Fracture Network (DFN) Approach

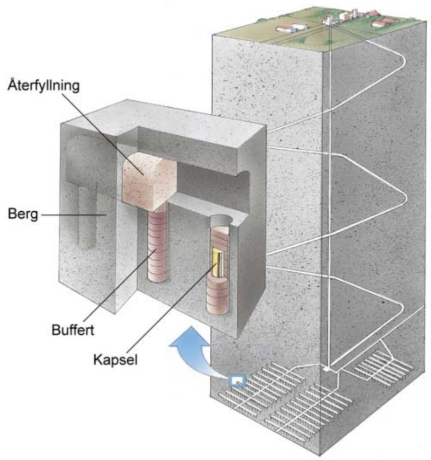
- Explicitly represents the geometry and properties of discrete features
- Alternative to continuum representation
- Fractures are typically generated stochastically
- Computationally demanding approach made feasible by modern computing equipment

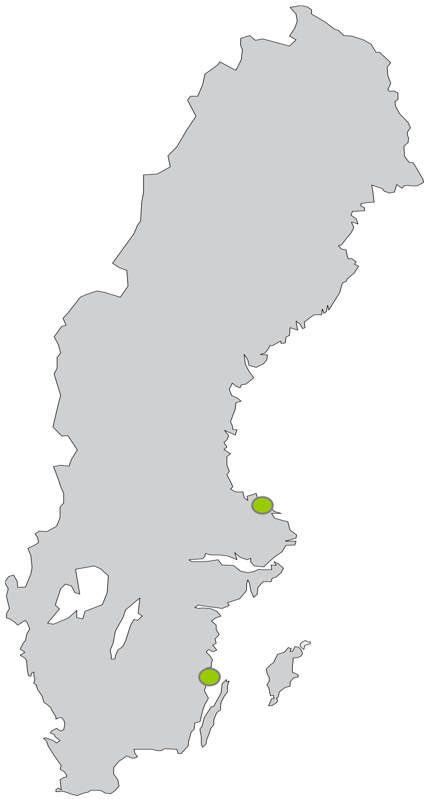


Modified from Selroos et al. 2002

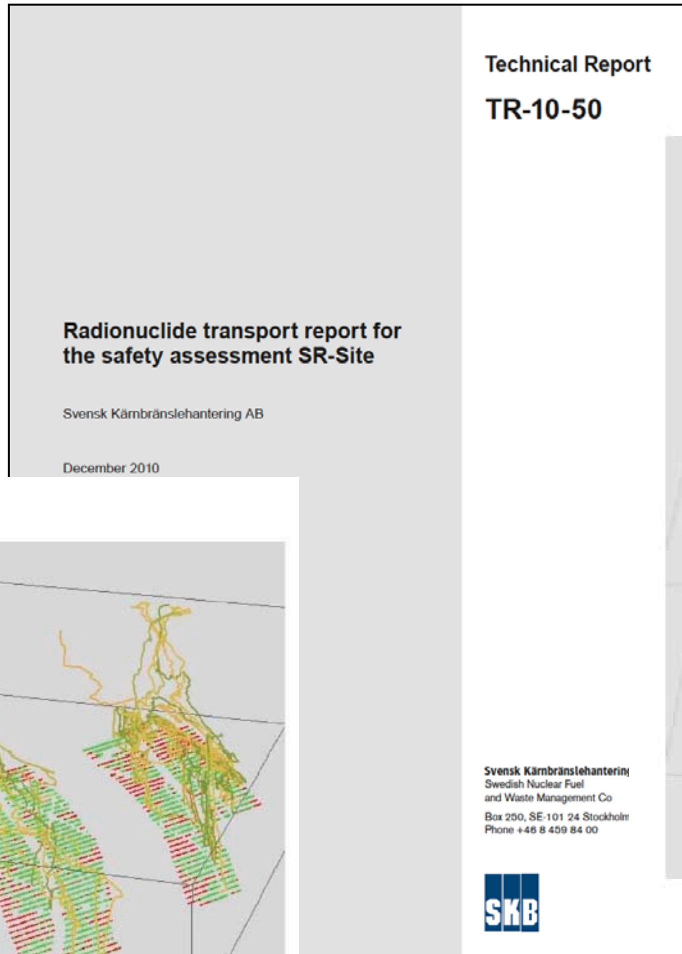
International Experience: Sweden and Finland

- **Sweden's SR-Site safety assessment of the proposed Forsmark repository relied on DFN modeling of flow and radionuclide transport**
- **Clear demonstration that a high-quality safety case for a complex site can be constructed primarily on DFN representations**
- **Similar approach used in Finland**
- **Transport results will be difficult to reproduce with continuum approaches**





Representative Transport Results from Sweden's SR-Site


Technical Report

TR-10-50

Radionuclide transport report for the safety assessment SR-Site

Svensk Kärnbränslehantering AB

December 2010

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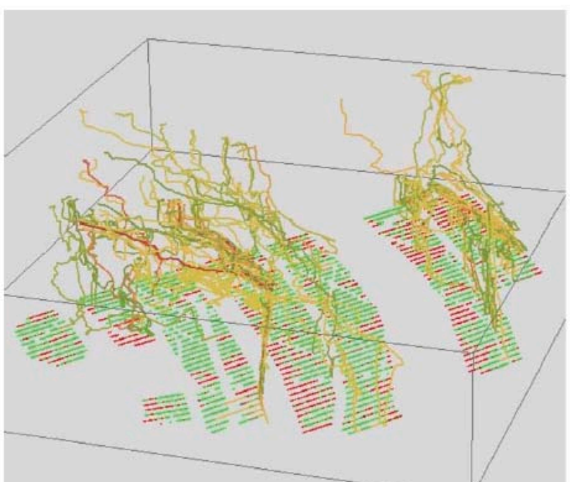
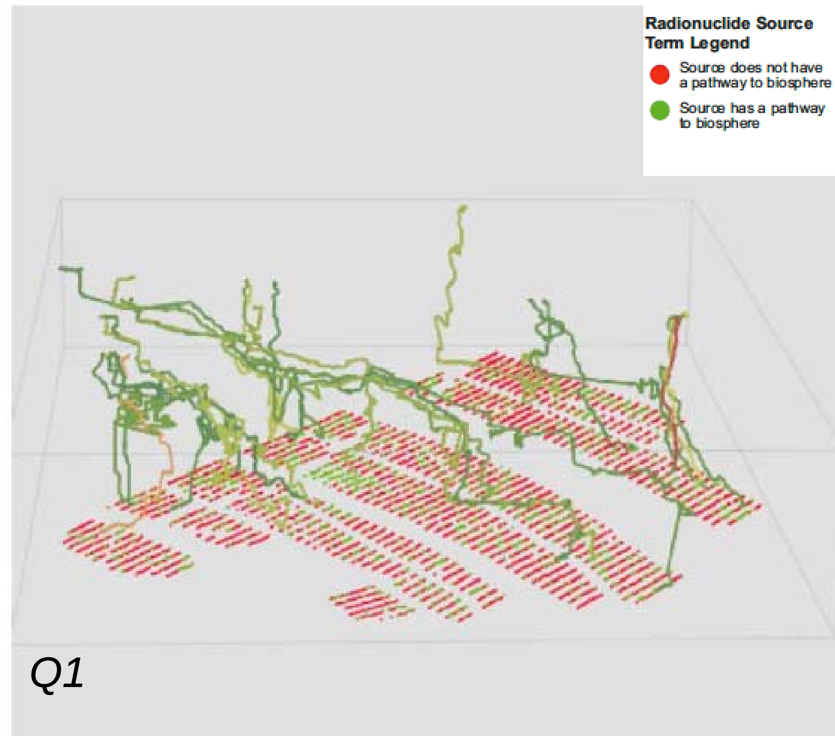
SKB





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Development of DFN Capability

- **Capability is needed to**
  - Assess performance of fractured granite sites
  - Address unresolved scientific issues associated with transport in sparsely fractured rock
  - Understand flow and transport in excavation damage zone near clay repository tunnels
- **Existing research and commercial codes are not adequate**
  - Local mass balance issues associated with conventional finite element method
  - Not designed for modern parallel computing hardware
  - Limited capability for radionuclide transport
- **Currently developing prototype capability for testing and refining algorithms**
  - Leveraging existing capability developed internationally and in other DOE programs
- **Final algorithms will be implemented in a parallel framework**

Prototype Development

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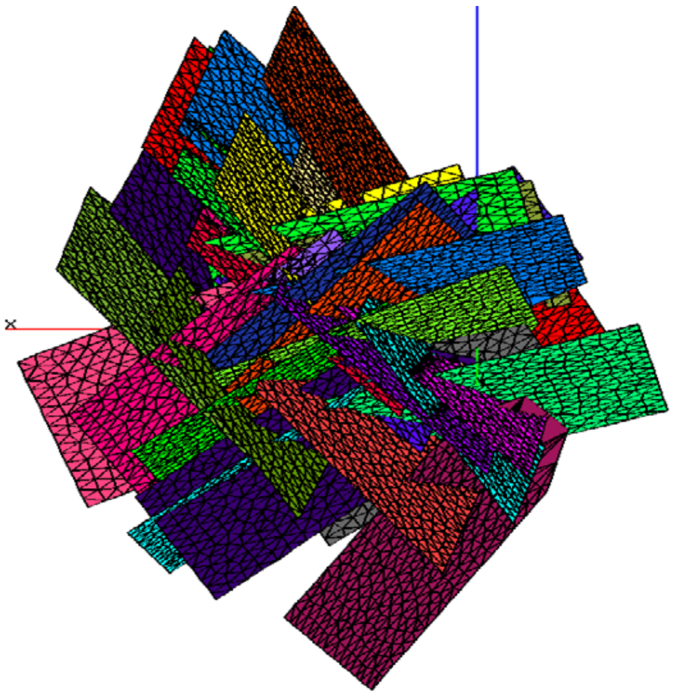
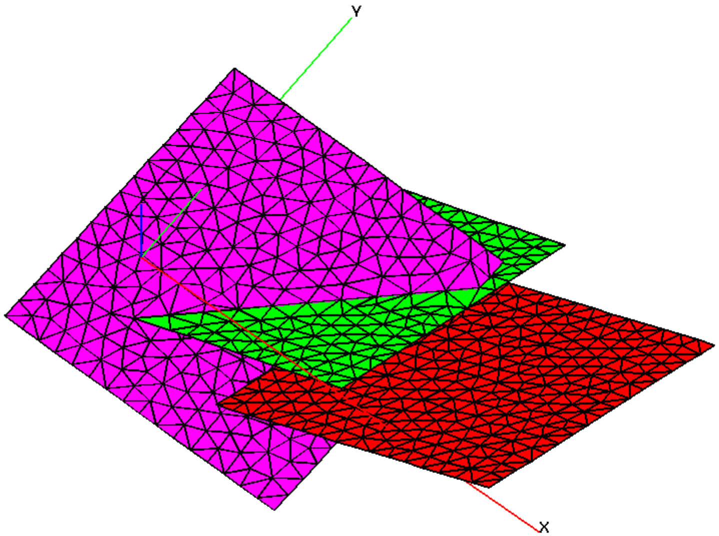
- **Strategy**
  - Finite volume method for flow (Voronoi cells)
  - Advective particle tracking to establish transport pathways
  - Post-process particle tracking results to account for matrix diffusion/sorption
- **Implementation**
  - New code to generate DFN
  - Los Alamos Grid Toolkit (LaGrit) for meshing
  - FEHM (Zyvoloski, 2007) for flow
  - Walkabout (Painter 2011) for advective particle tracking on unstructured grids
  - MARFA (Painter and Mancillas, 2009) for transport
  - Connected through Python scripts



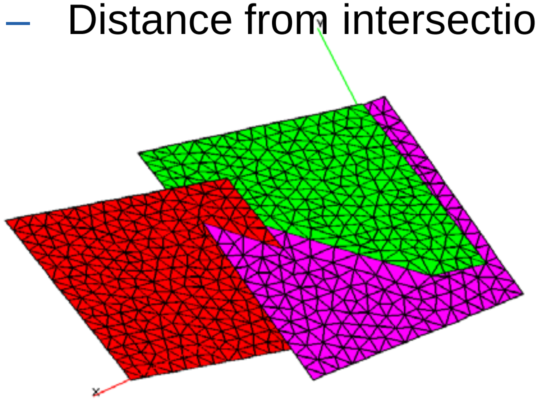
Challenges in Grid Generation

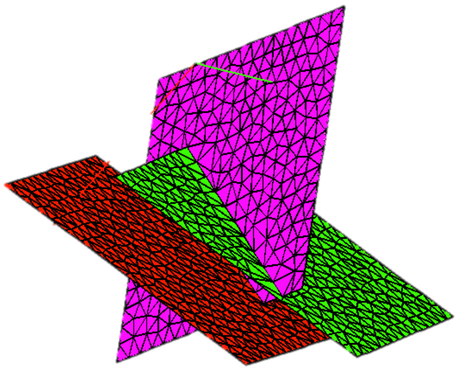
- **Must triangulate each fracture as a 2D object while ensuring that grids match at fracture intersections**
- **Grid generation for DFNs is an active area of research**
- **For arbitrary network geometries, high quality grid of reasonable size cannot be guaranteed because of problematic configurations**
  - Fracture intersections with small extent
  - Triple intersections
  - Closely spaced fractures
- **Previous work sought to modify generated DFN to remove troublesome features**
- **Two new approaches**
  1. Constrain DFN generation to avoid features of size less than a defined length scale h
  2. Modify flow solution to allow nonmatching grids



Constructing DFNs to *O*(*h*)

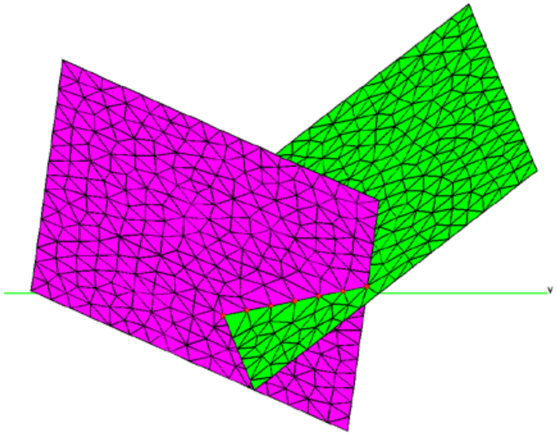
- **User specifies minimum length scale *h***
- **When generating DFNs, reject fractures that create a feature less than (lt.) *h***
- **Examples of reasons for rejecting a fracture**
  - Intersection between fracture is lt. *h*
  - Distance between nonintersecting fractures is lt. *h*
  - Intersections of intersections
  - Distance from intersection to fracture edge is lt. *h*

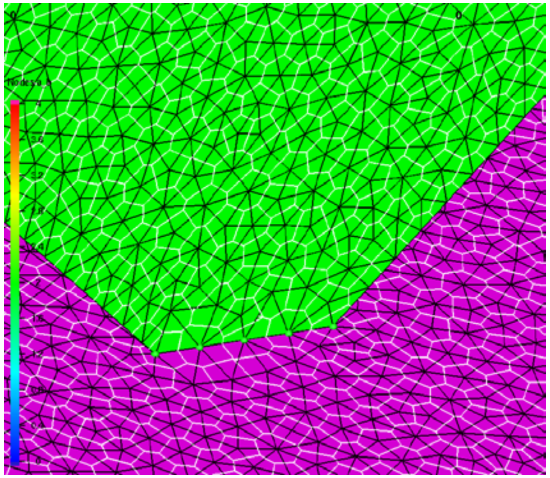




Meshing

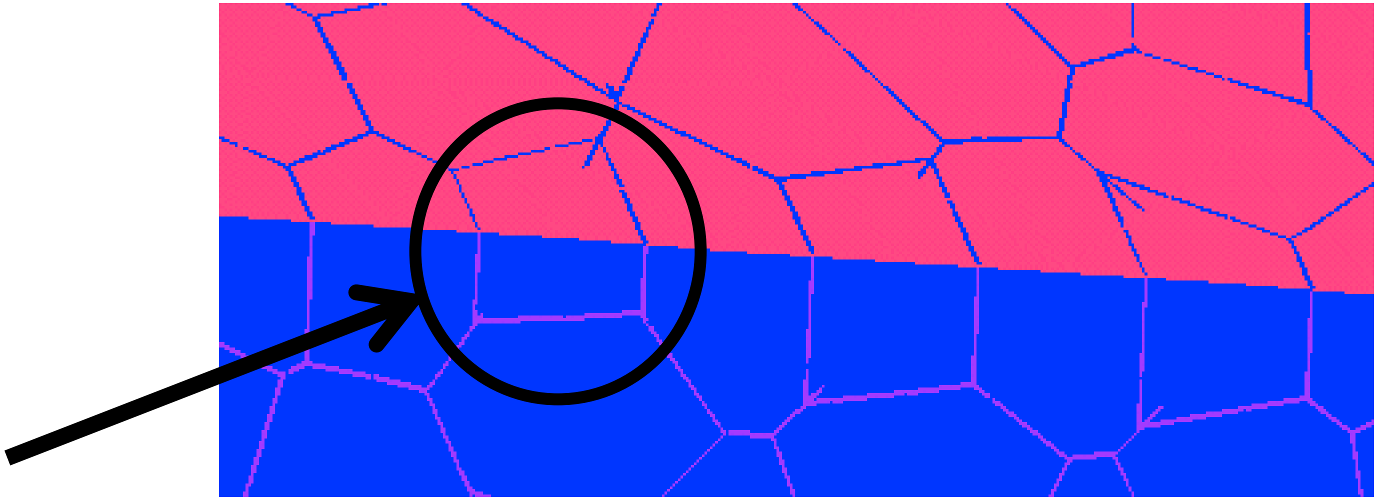
- Once features of length *h* are removed, the DFN is meshed in LaGrit
- Nodes on the line of intersection are common to both fractures
- Lines of intersection are preserved using a conforming Delaunay triangulation
- At intersections, control volumes lie in two fracture planes



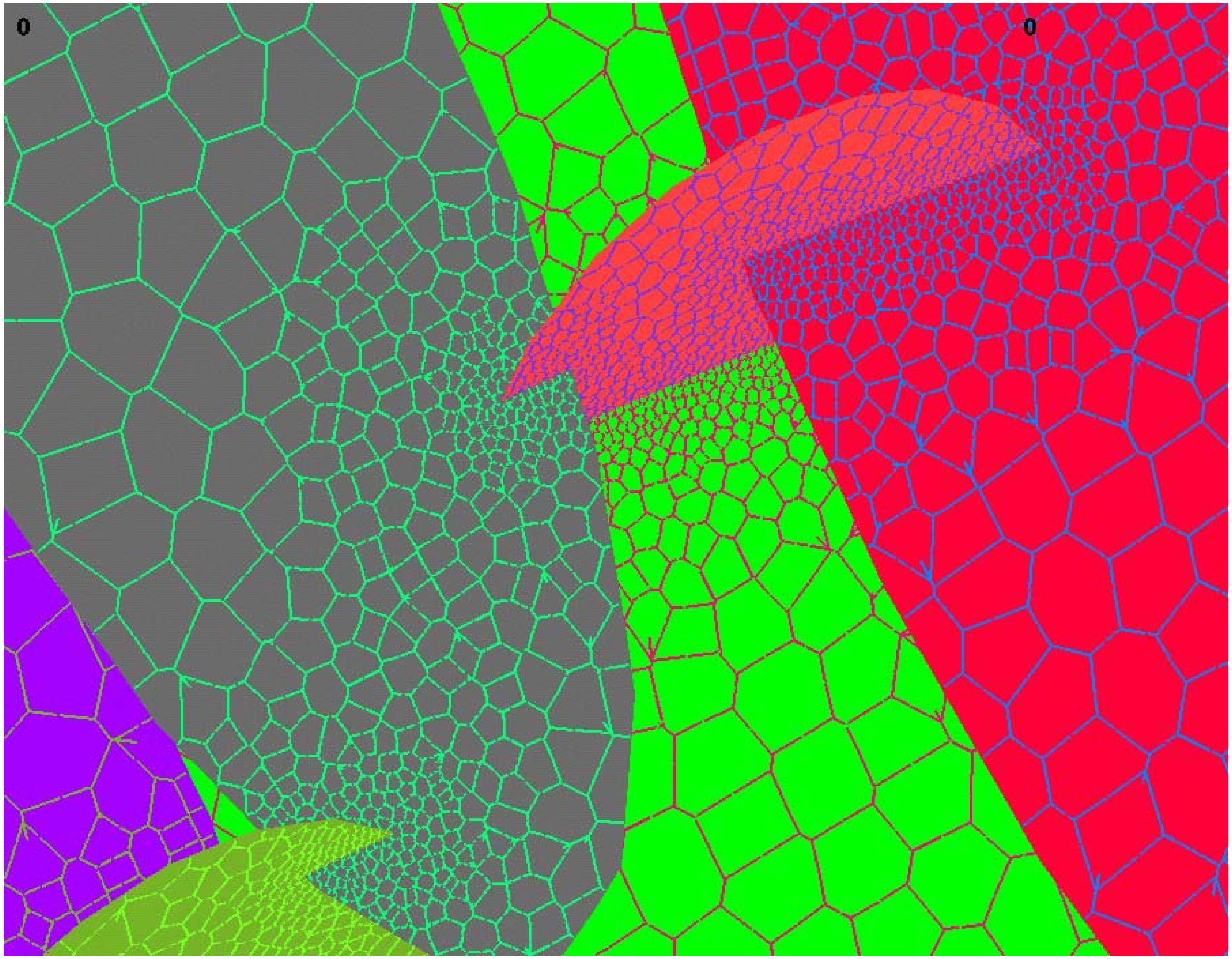


Generating Matching Grids at Intersections

- Nodes placed on each fracture independent of other fractures
- Nodes within distance *h* of an intersection are removed
- New nodes placed on each intersection
- Mesh created by Delaunay triangulation on each fracture
- Merge meshes and eliminate duplicate nodes at intersections

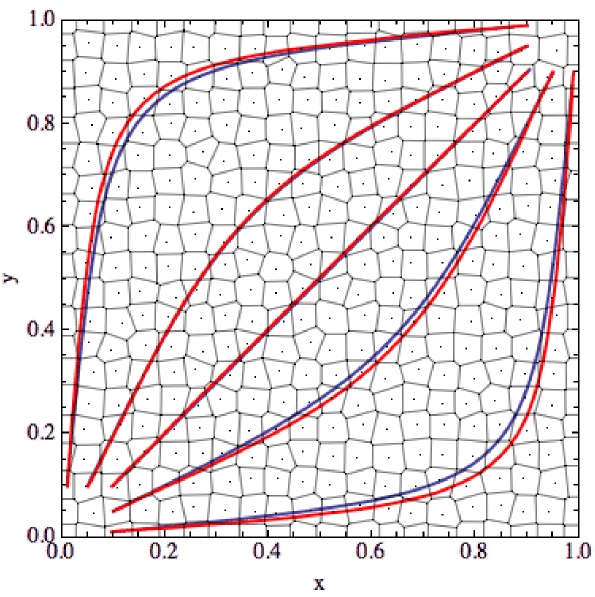


Non-uniform Grid Resolution

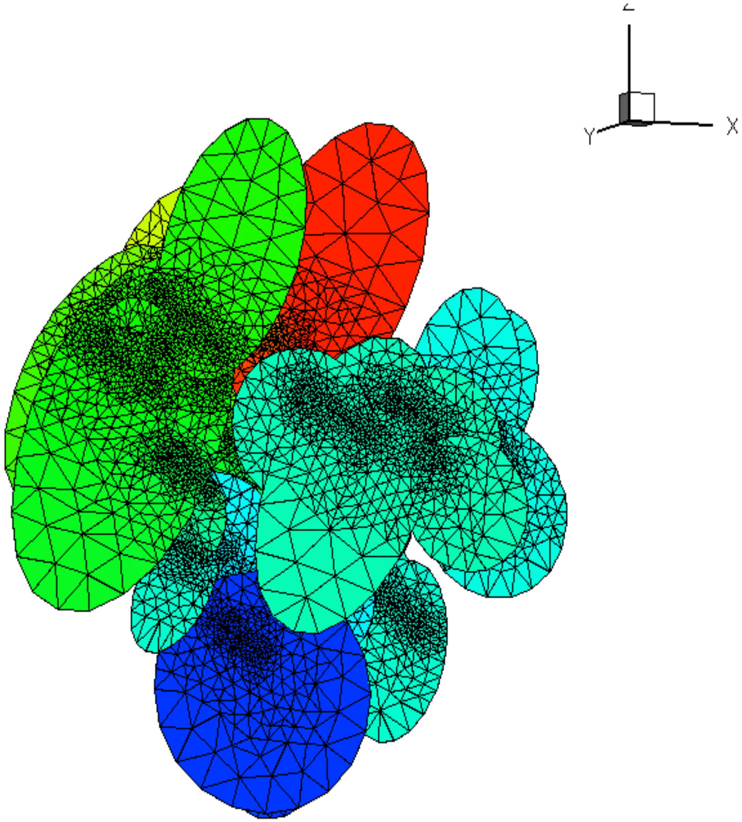


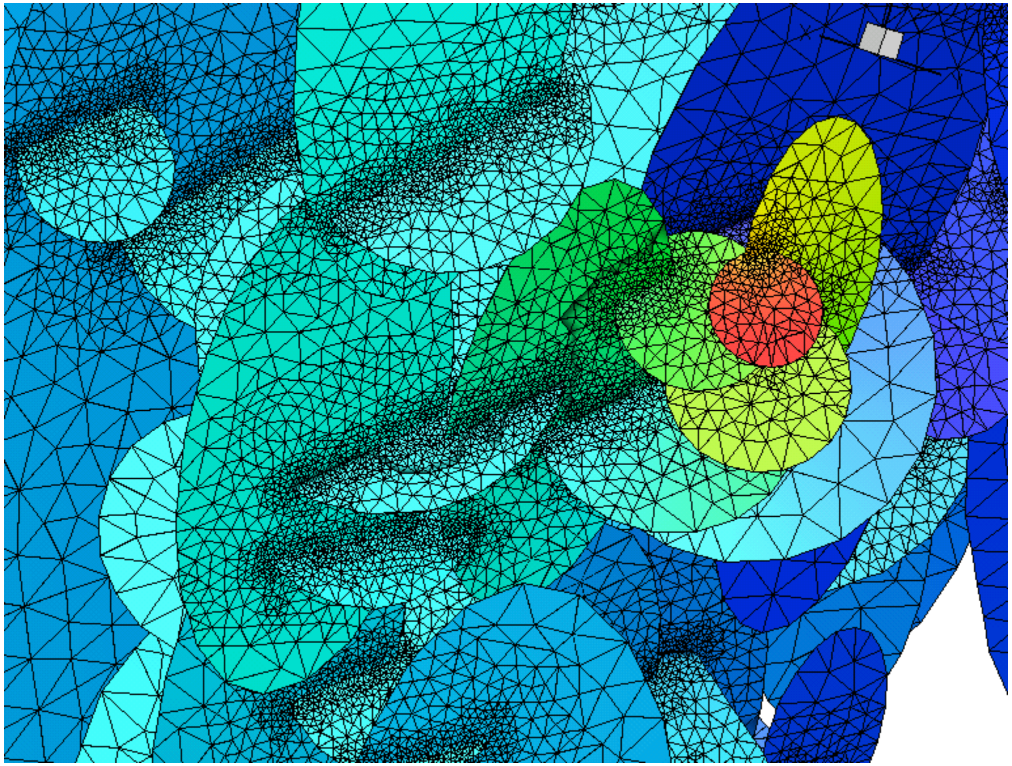
Particle Tracking on Unstructured Control Volume Grids

- **Streamline tracing in the groundwater velocity field is needed to establish advective flowpaths (transport pathways)**
- **Velocity field is not available for unstructured control volume grids – only have normal components of velocity on each cell edge**
- **Leveraging new method (Painter et al. 2011) for reconstructing the velocity field developed for DOE Office of Environmental Management (EM), Underground Test Area (UGTA) subproject**
  - Solves constrained linear least square problem on each control volume cell to approximate nodal velocity
  - Interpolates nodal velocities to approximate velocity field
  - Implemented in Walkabout code
- **Figure shows velocity streamlines calculated from control volume flow solution on fracture plane compared with analytical solution**

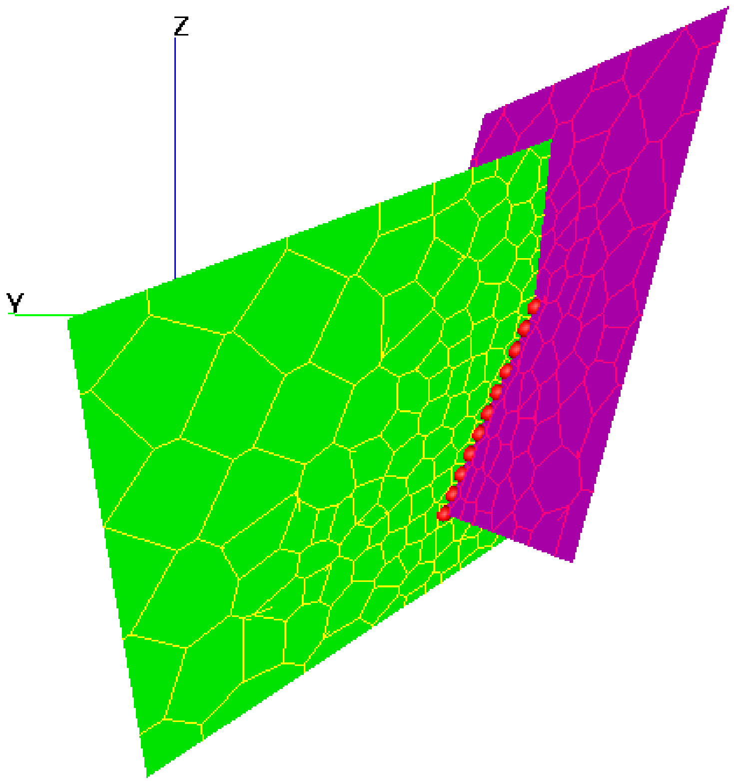


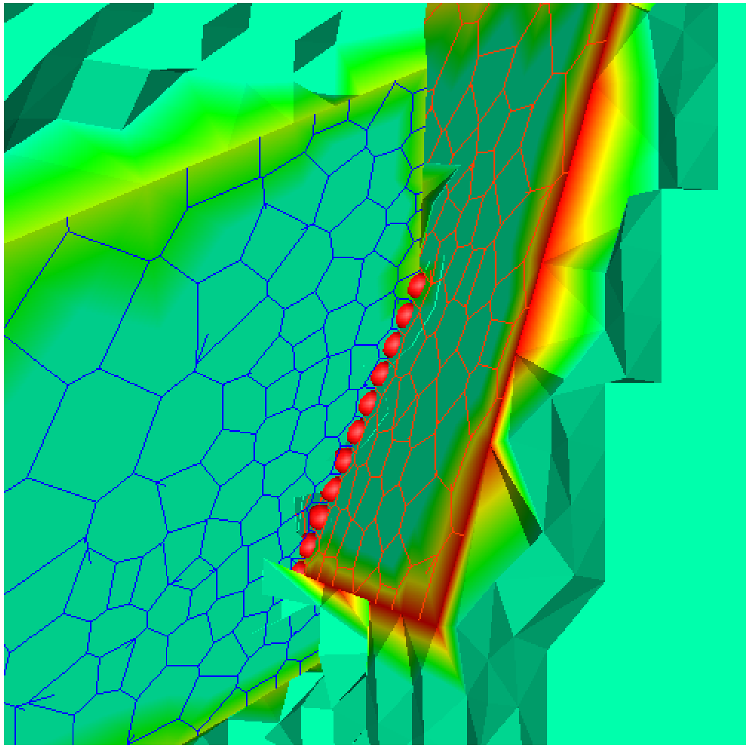
Example Pressure Fields





Discrete Fracture Networks Embedded in Tetrahedral Mesh





Path Forward

- **Implement new particle tracking method in 2-D (current version of Walkabout is 3-D)**
- **Continue developing capability to mesh in space between fractures (needed for some applications)**
- **Use new prototype capability to test and refine algorithms**
  - Detailed specifications for implementation in massively parallel code
- **Use prototype capability to begin addressing unresolved scientific issues related to assessment of geosphere performance**
  - Range of applicability for continuum versus discrete models
  - Strategies for parameterizing discrete models
  - Role of small versus large features in controlling geosphere performance
- **Implement high-performance computing version**
  - Currently evaluating Amanzi code developed in EM's Advanced Scientific Computing for Environmental Management (ASCEM) program
- **Continue addressing unresolved scientific issues related to assessment of geosphere performance**

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