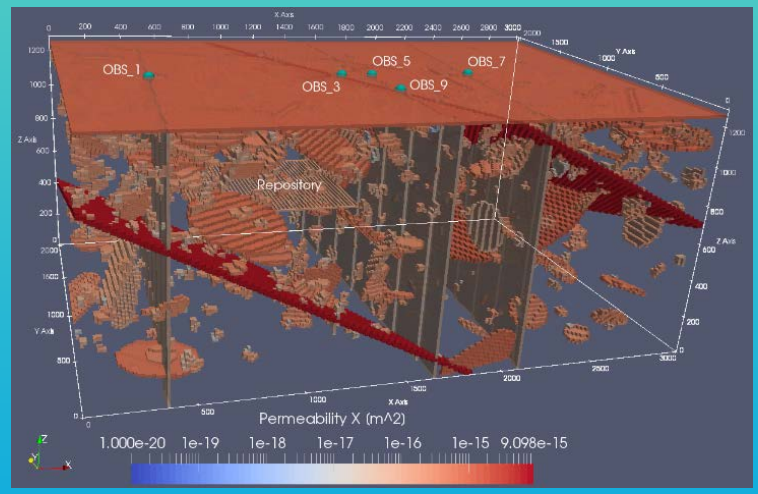

dfnWorks: Discrete Fracture Network Modeling Suite

Virtual Public Meeting
NWTRB Fall 2021 Meeting
3 & 4 November 2021

Jeffrey Hyman, Staff Scientist
Earth and Environmental Sciences (EES-16)
Los Alamos National Laboratory

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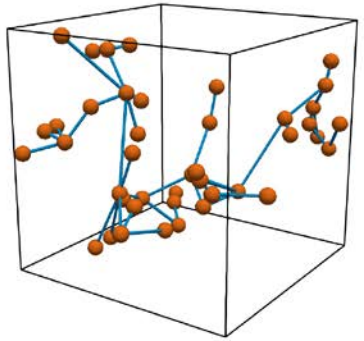
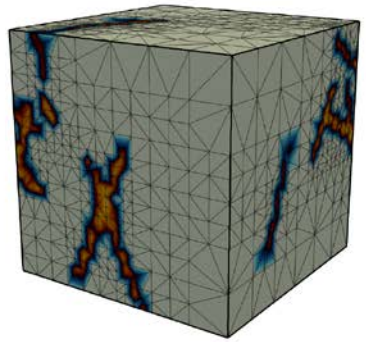
Computational Models for Flow and Transport in Fractured Media

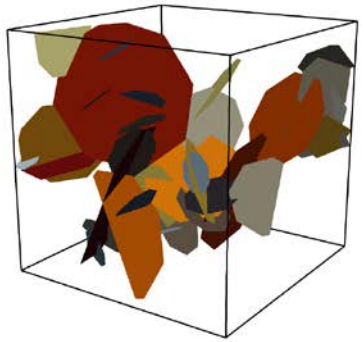


Channel Network

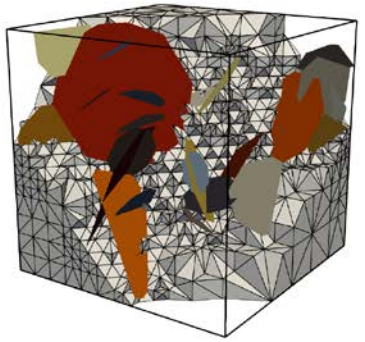


Continuum Methods

Fractured Rock

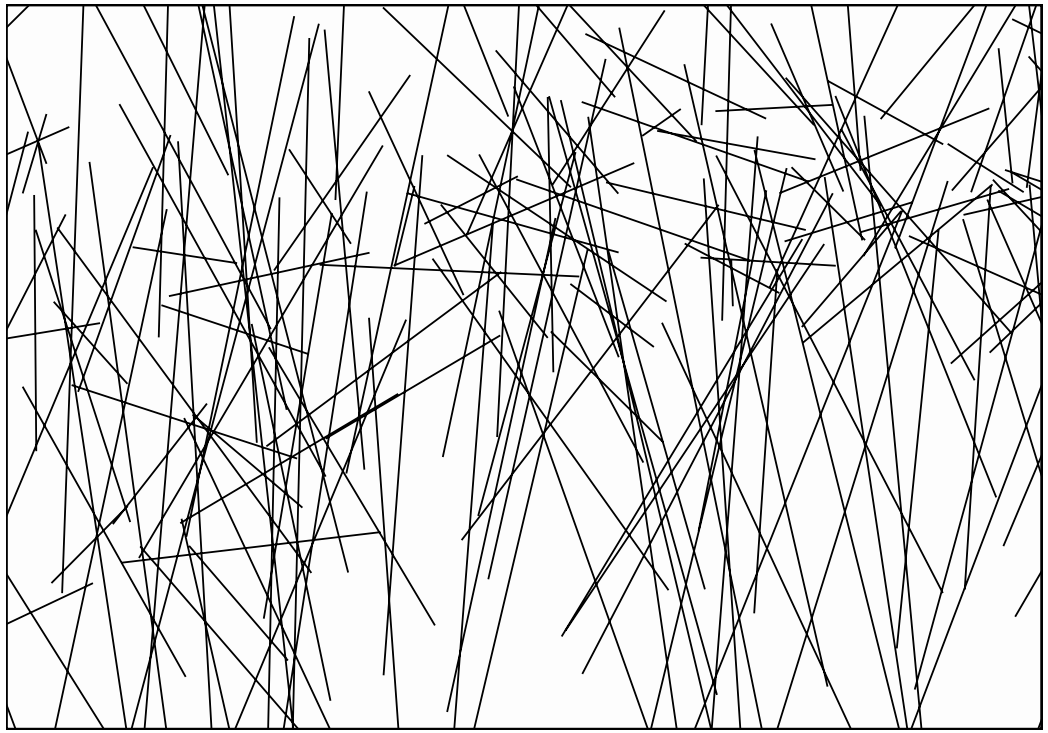


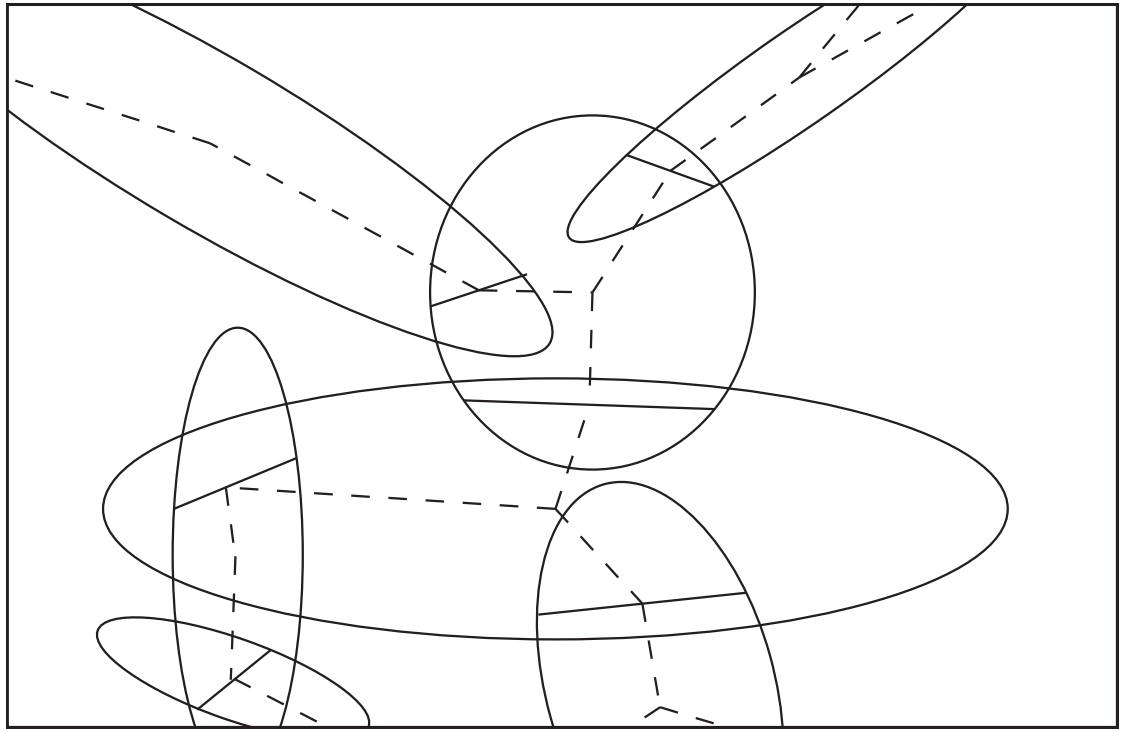
Discrete Fracture Nework



Discrete Fracture Matrix

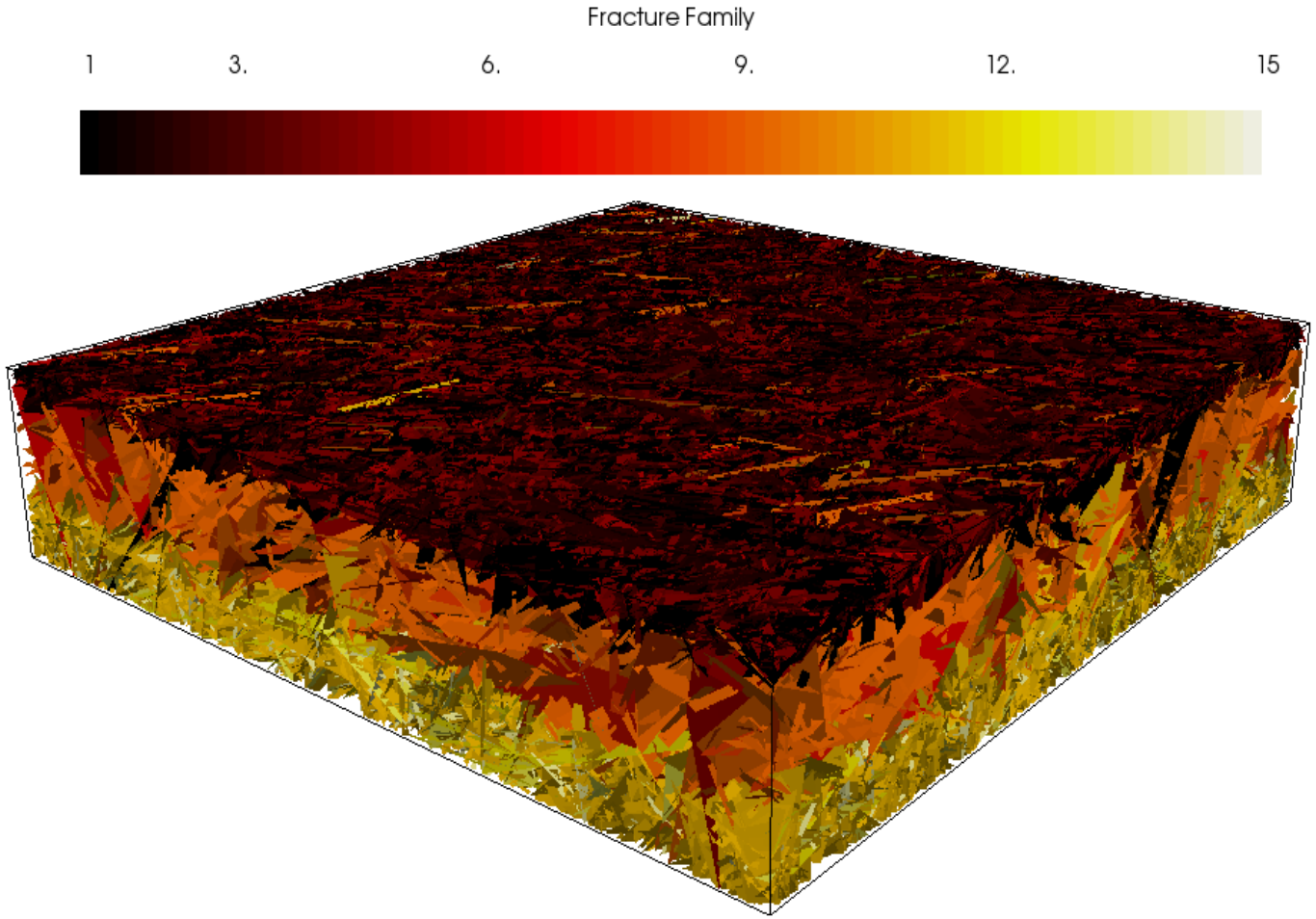
Discrete Fracture Networks (DFN)





Modern 3D-DFN Modeling

- Fractures are disks or rectangles
- Hydraulic properties can vary between fractures
- Site characterizations inform descriptions of various fracture families
- Flow and transport is resolved within and throughout the connected fracture network



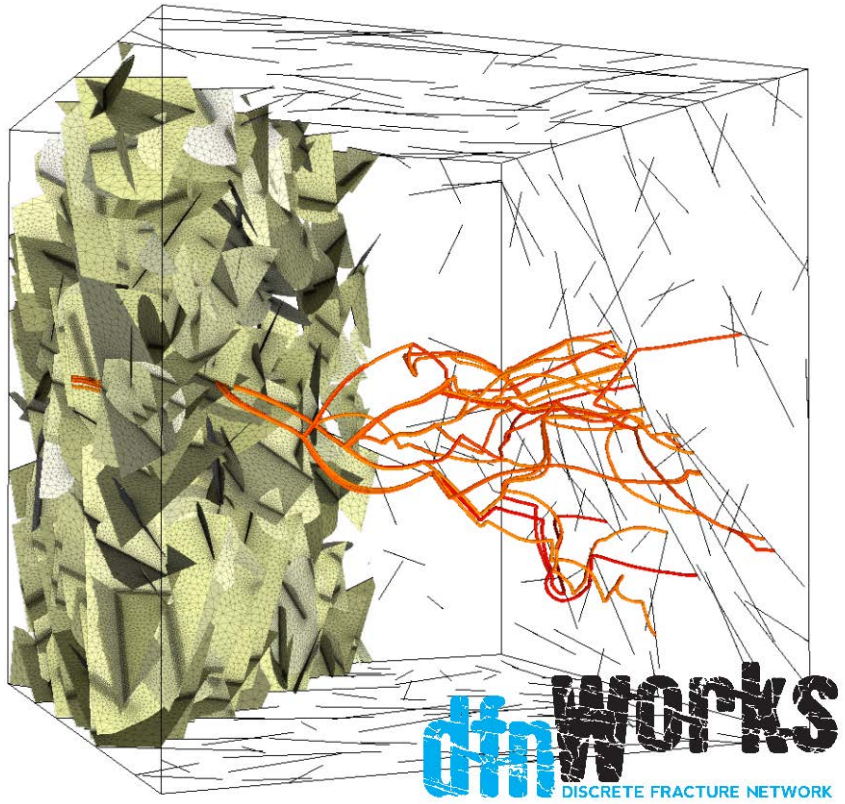
dfnWorks : modular By Design

dfnGen

dfnFlow

dfnTrans

dfnGraph



Hyman, Jeffrey D., Satish Karra, Nataliia Makedonska, Carl W. Gable, Scott L. Painter, and Hari S. Viswanathan. "dfnWorks: A discrete fracture network framework for modeling subsurface flow and transport." *Computers & Geosciences* 84 (2015): 10-19.

DFNWORKS : MODULAR BY DESIGN

dfnGen

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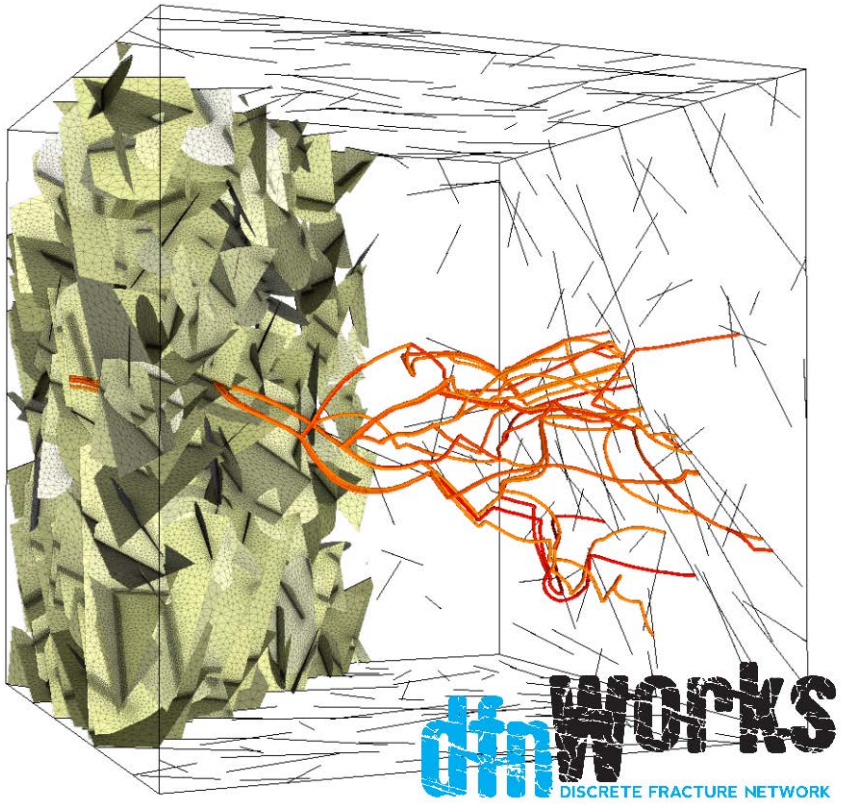
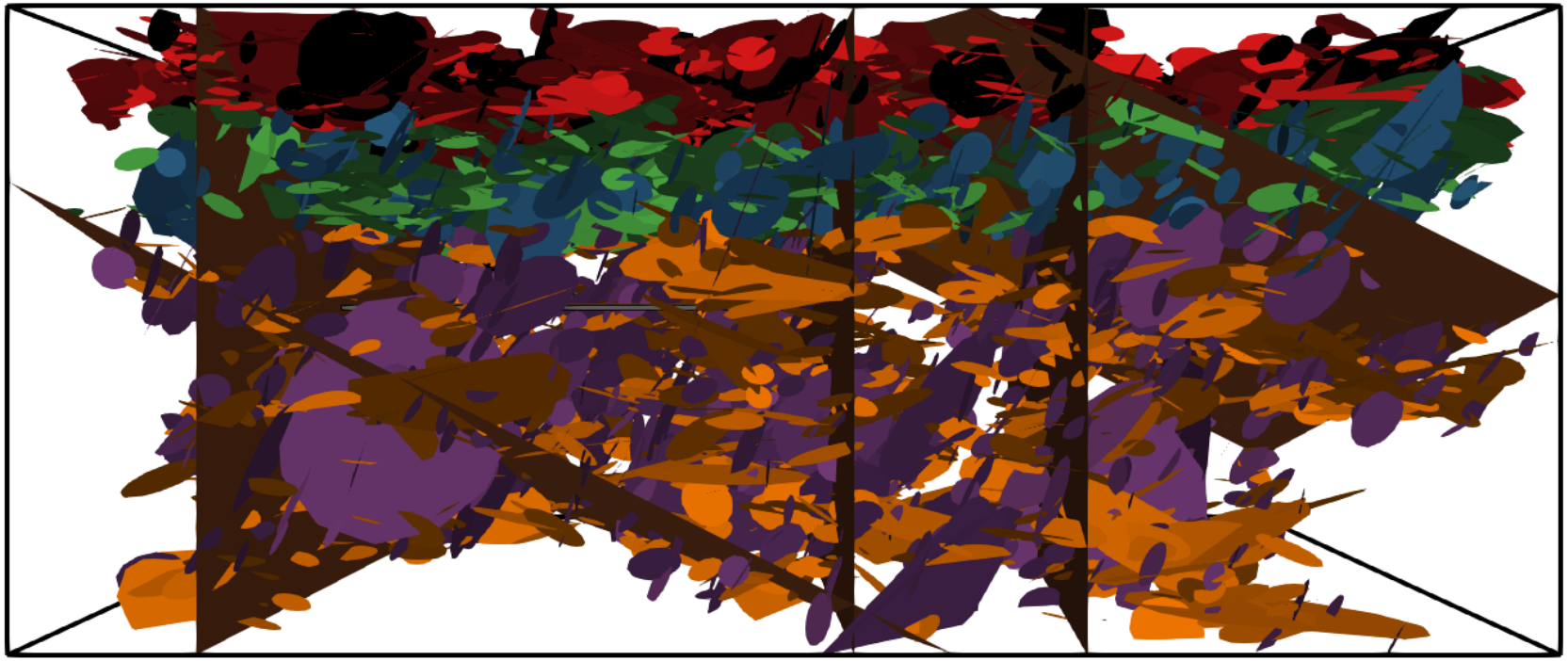


dfnWorks : dfnGen – Network Generation

- Features used in Geologic Disposal Safety Assessment (GDSA)
  - Stochastically generated fractures
  - Variable Density By Layers
  - Multiple Fracture families
  - Deterministic features
    - Faults
    - Repositories
  - Detailed geologic output report

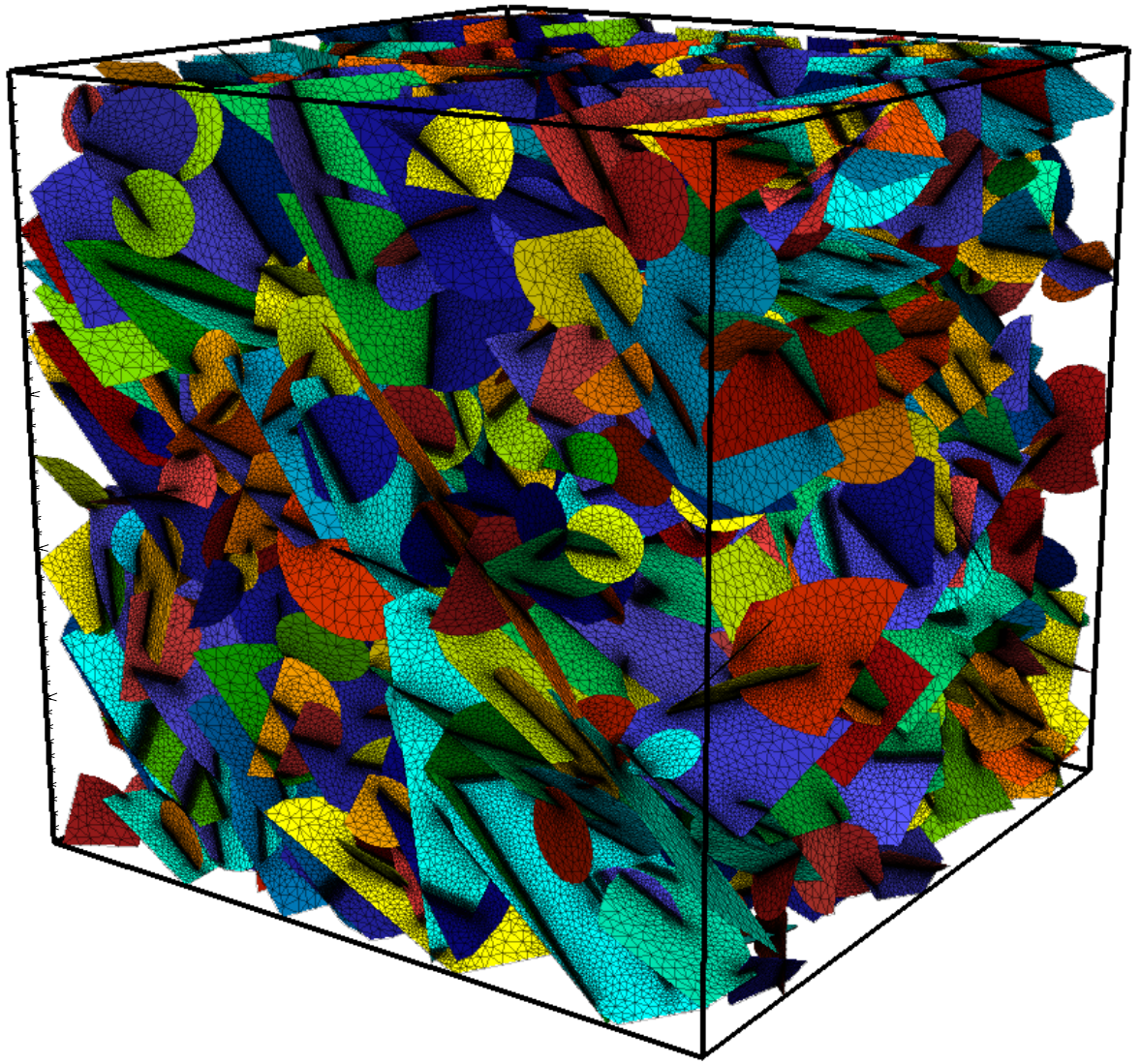


Synthetic Repository System ~ 7000 Fractures

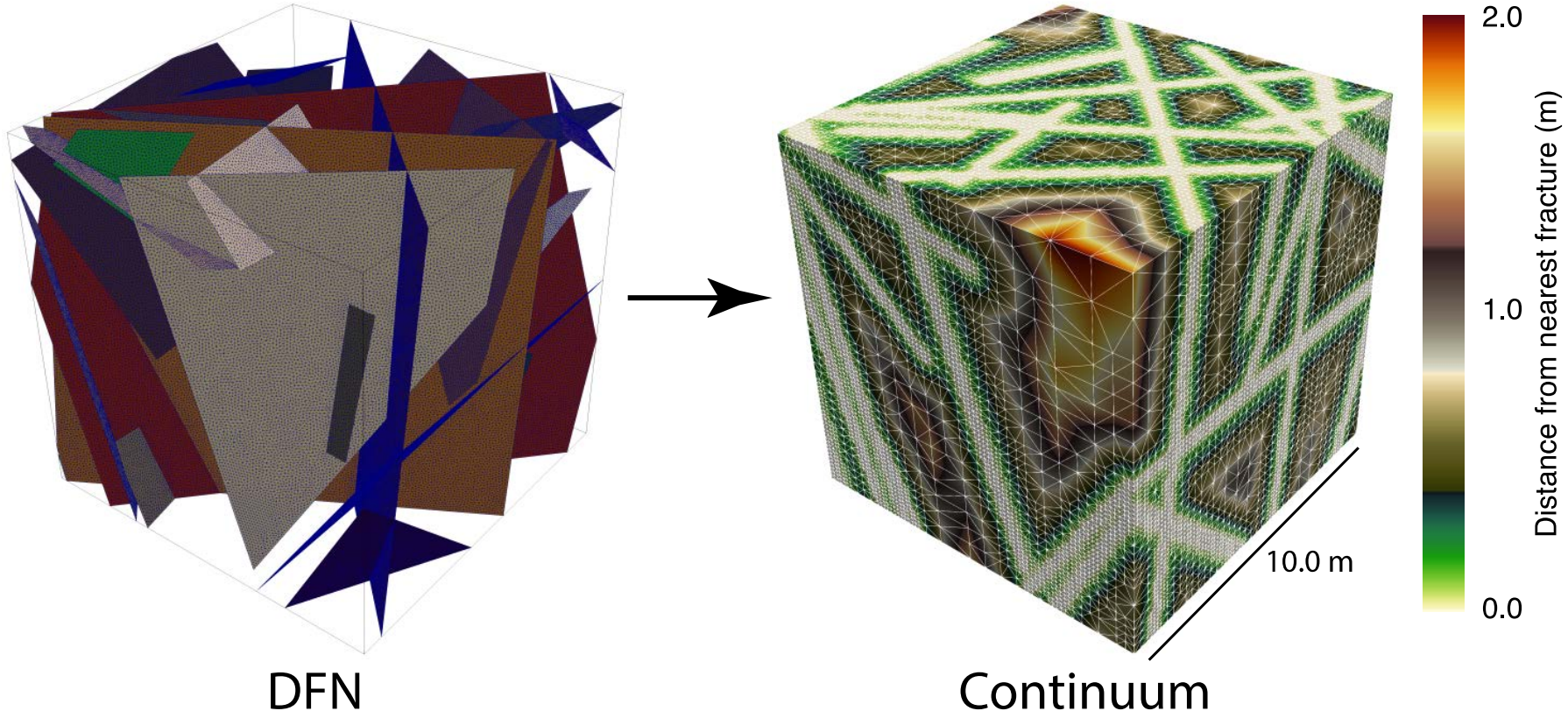
DFNWORKS : DFNGEN - MESH GENERATION

Meshing

- Spatially variable mesh resolution
- Conforming Delaunay triangulation
- Allows for in-fracture aperture variability
- Dual Mesh – Voronoi cells – used by two point flux finite volume codes (PFLOTRAN)
- Octree-resolution - Upscaled Discrete Fracture Matrix model (UDFM)



Mapping a DFN to a Equivalent Continuum Porous Media (ECPM)



Sweeney, Matthew R., Carl W. Gable, Satish Karra, Philip H. Stauffer, Rajesh J. Pawar, and Jeffrey D. Hyman. "Upscaled discrete fracture matrix model (UDFM): an octree-refined continuum representation of fractured porous media." *Computational Geosciences* 24, no. 1 (2020): 293-310.

DFNWORKS : MODULAR BY DESIGN

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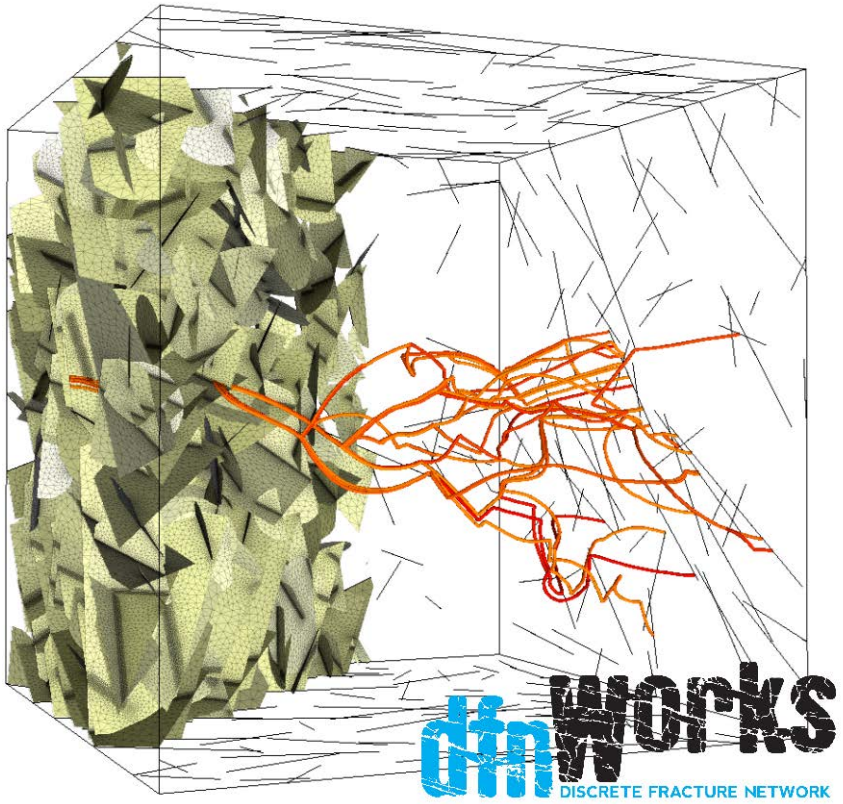
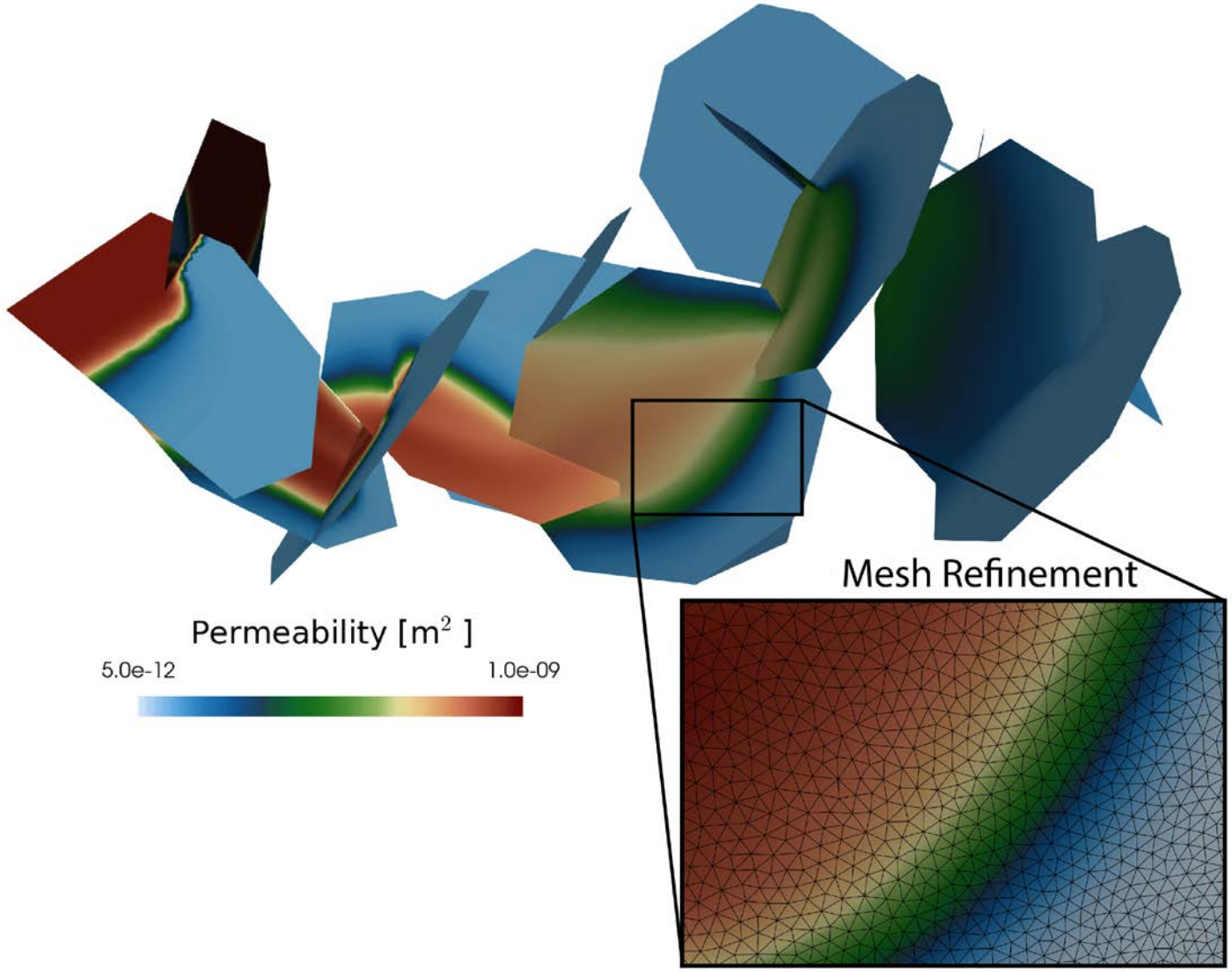


DFNWORKS : DFNFLOW

- Seamless integration with PFLOTRAN
- Allows for access to all PFLOTRAN capabilities
  - Reactive transport
  - Radionuclide decay
  - Tracer Transport
  - Multiphase flow
  - Wasteform process models
- Backend analysis of PFLOTRAN runs
- Additional solvers include FEHM and AMANZI



DFNWORKS : MODULAR BY DESIGN

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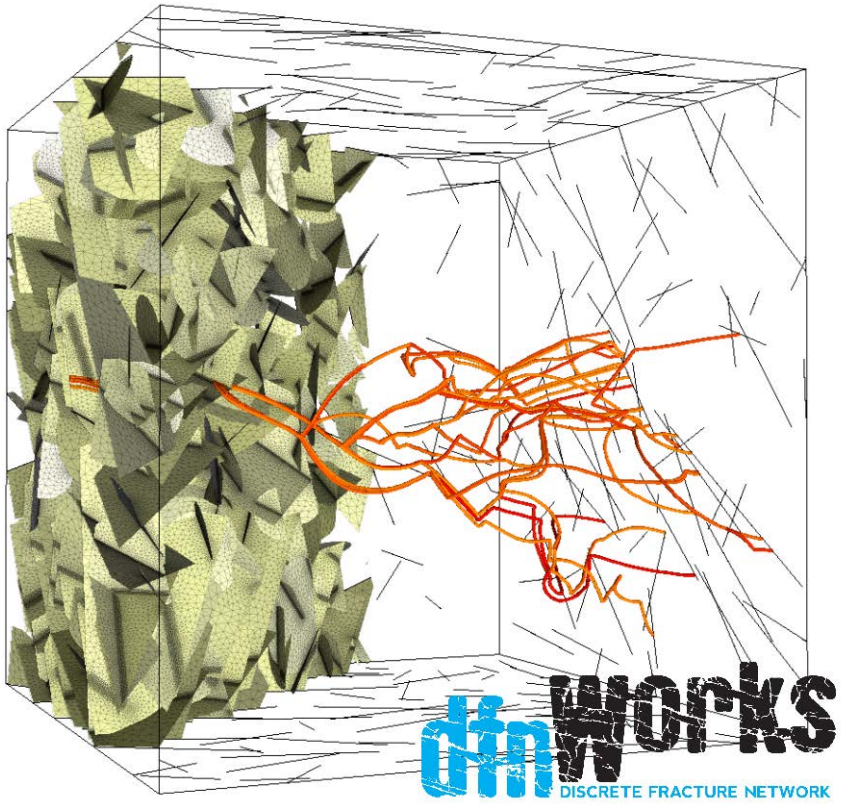
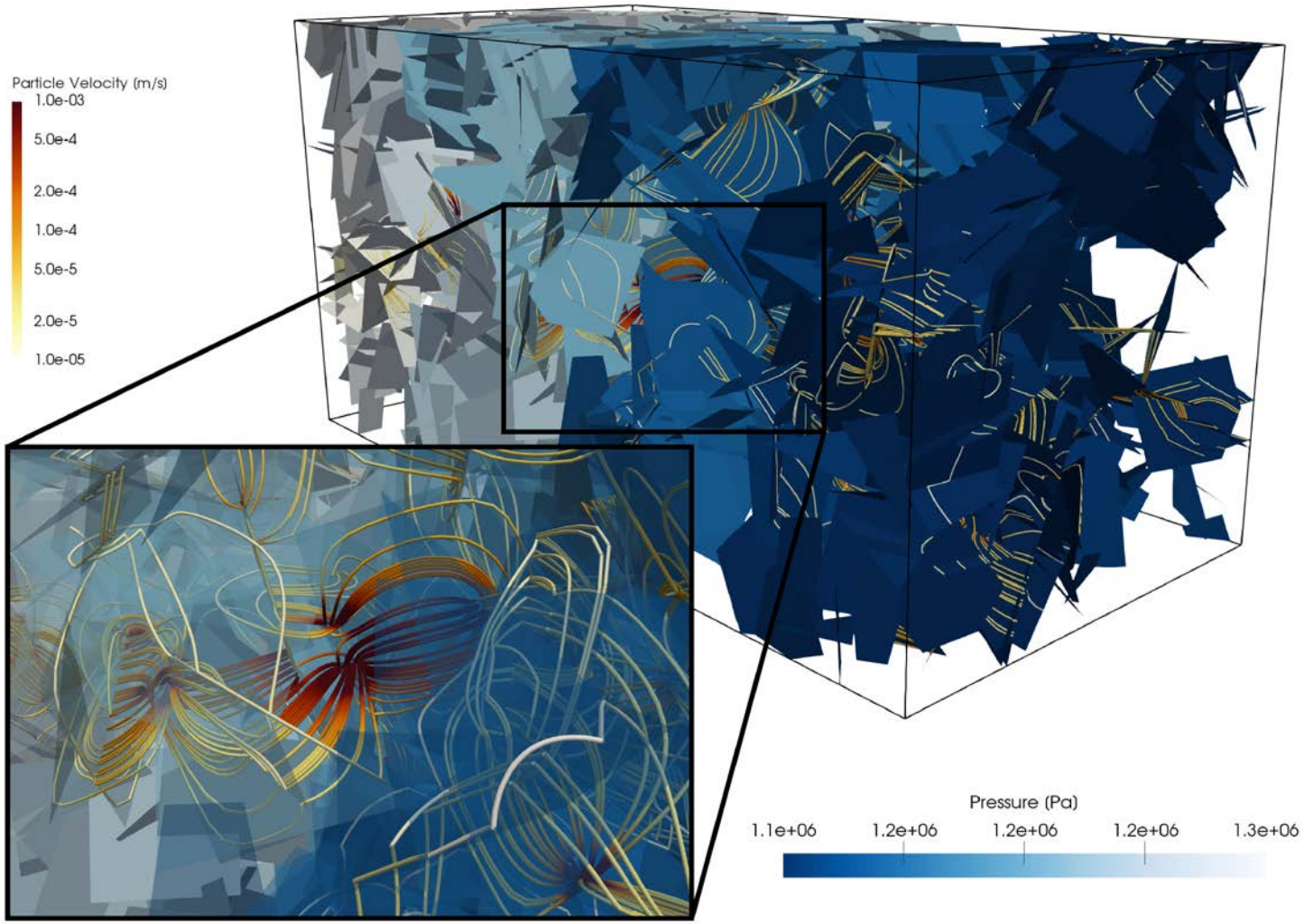


dfnWorks: dfnTrans

Particle Tracking

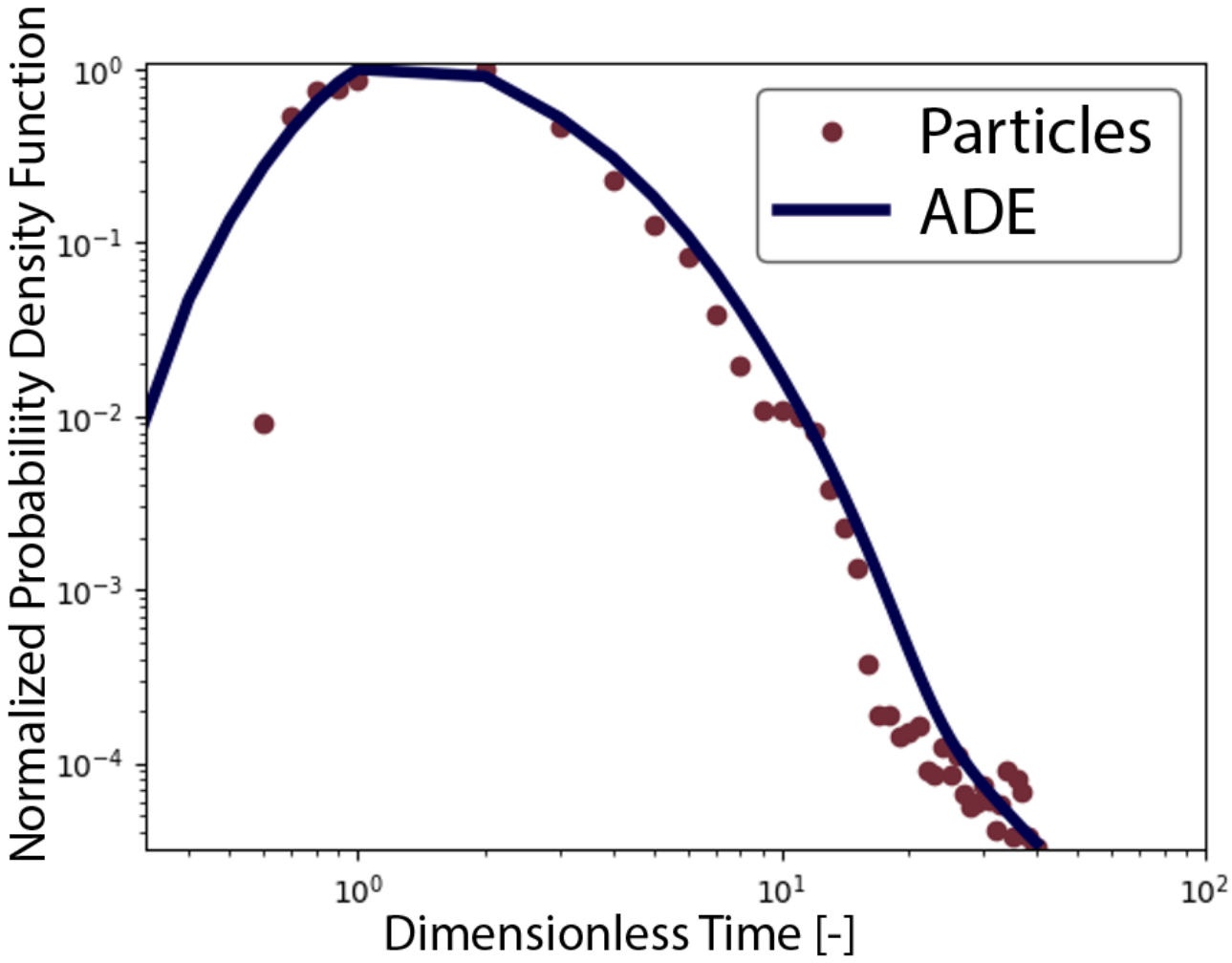
- Internal velocity field pathline tracking
- Matrix Diffusion
- Low-fidelity pipe-network
- Flow Topology Graph Analysis toolkit
- Future Integration with Migration Analysis of Radionuclides in the Far Field (MARFA)



Makedonska, Nataliia, Scott L. Painter, Quan M. Bui, Carl W. Gable, and Satish Karra. "Particle tracking approach for transport in three-dimensional discrete fracture networks." *Computational Geosciences* 19, no. 5 (2015): 1123-1137.

Transport in GDSA

- In the GDSA reference case simulations we are relying on upscaling and ADE
- With development of simulations for the DECOVALEX task we are working toward using DFN with particle tracking



DFNWORKS : MODULAR BY DESIGN

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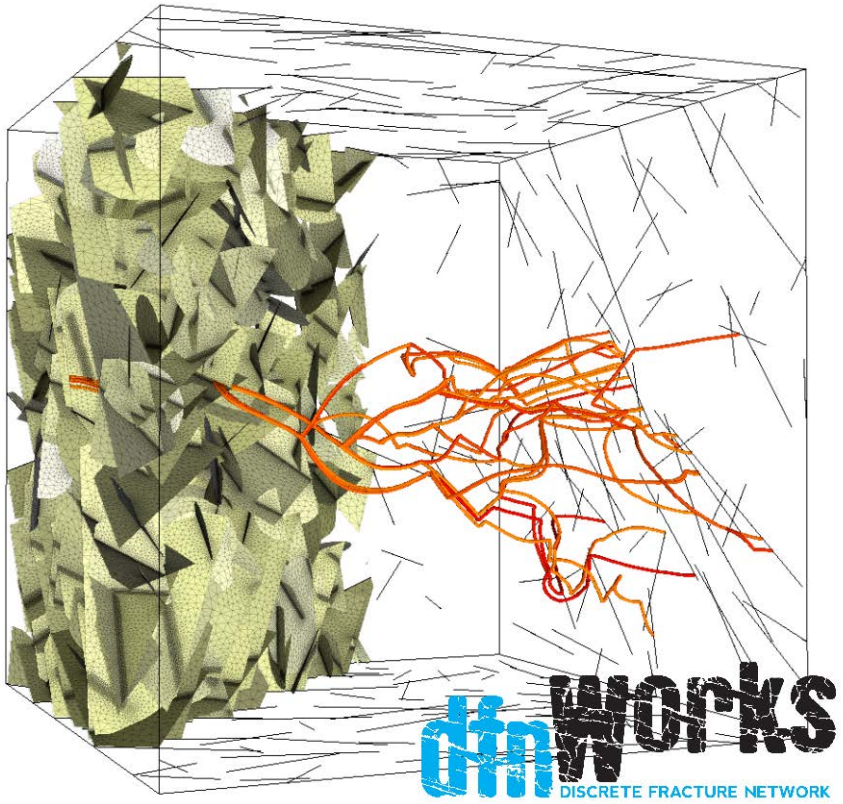
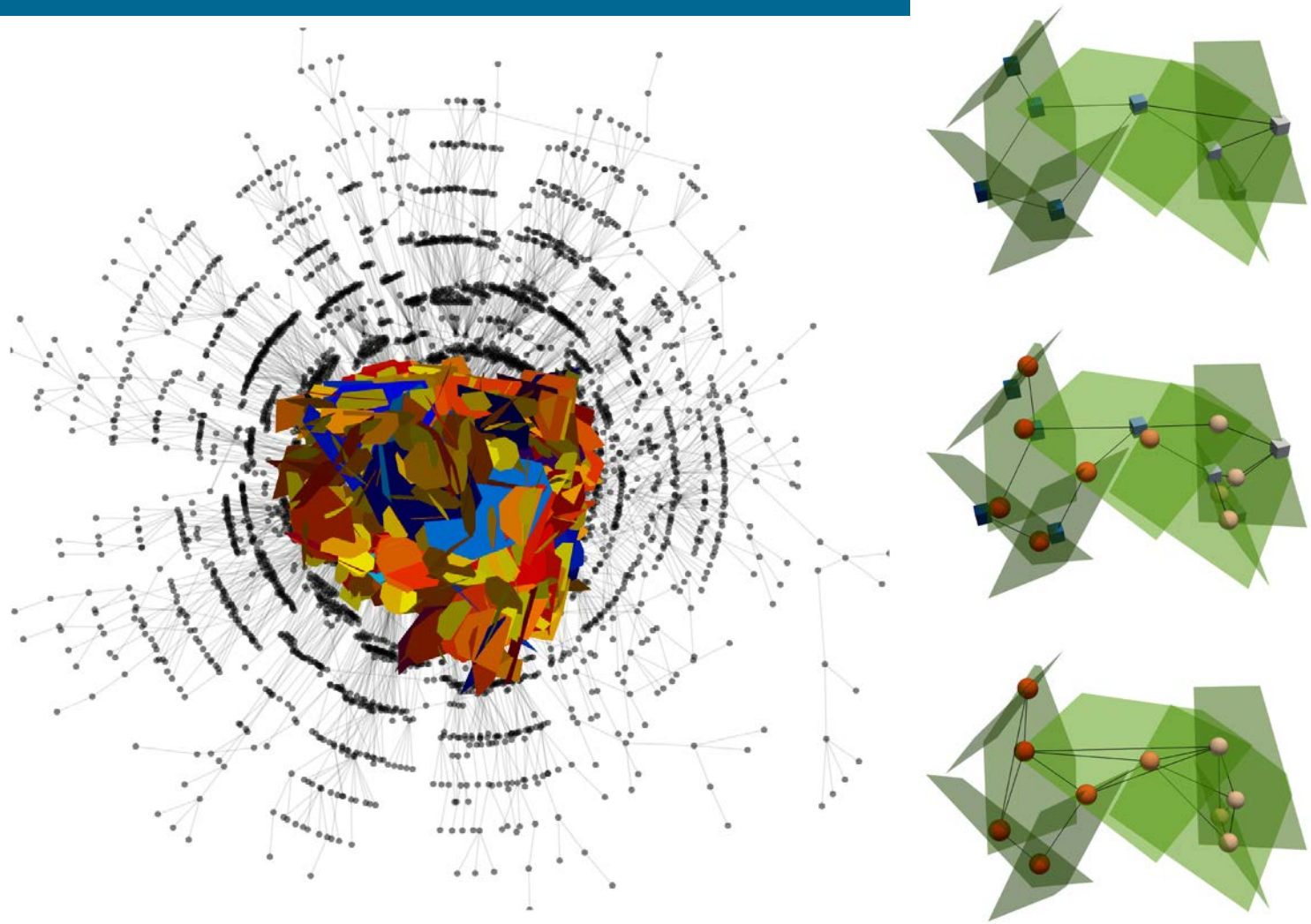


dfnGraph – Graph based network analysis toolkit

Graphical Analysis

- Used in GDSA Sensitivity Analysis
- Multiple-graph representations of the DFN
- Rapid analysis of network properties using networkX
  - Path identification
  - Backbone identification
  - Local and global topological attributes
- Rapid low-fidelity pipe-network flow and transport simulations



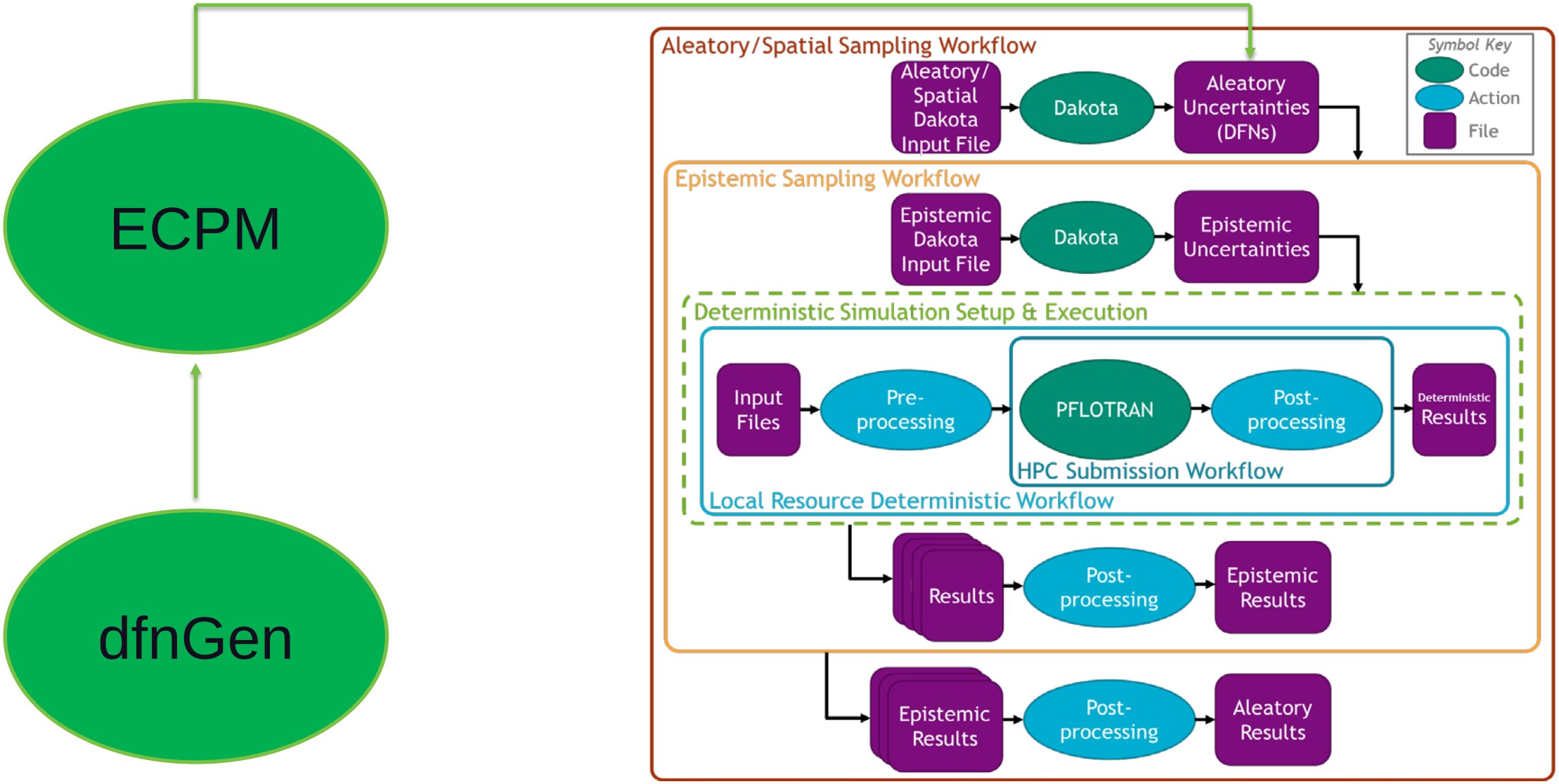
Hyman, Jeffrey D., Aric Hagberg, Dave Osthus, Shriram Srinivasan, Hari Viswanathan, and Gowri Srinivasan. "Identifying backbones in three-dimensional discrete fracture networks: A bipartite graph-based approach." *Multiscale Modeling & Simulation* 16, no. 4 (2018): 1948-1968.

dfnWorks in GDSA & DECOVALEX

- Currently in Use
  - Network Generation
    - Stochastically generated fractures
    - Multiple families
    - Layers
    - Deterministic features (Faults/Repositories)
    - Detailed geologic output report
  - Graph-based DFN analysis
  - Transport in DFNs to benchmark ECPM transport

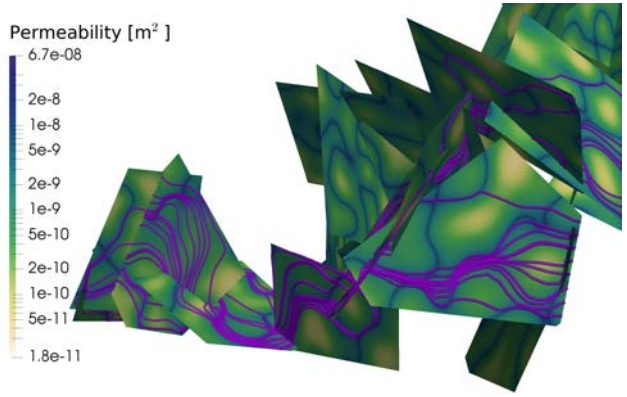
- On Deck
  - Network Generation
    - Depth/stress dependent aperture/permeability
  - DFN - Particle tracking / ADE in DECOVALEX Task F benchmarks

dfnWorks in GDSA workflow

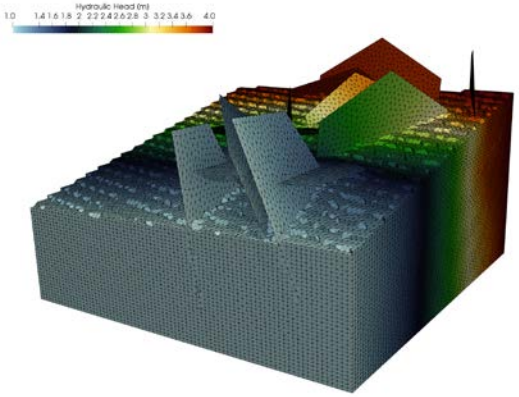


Additional Applications

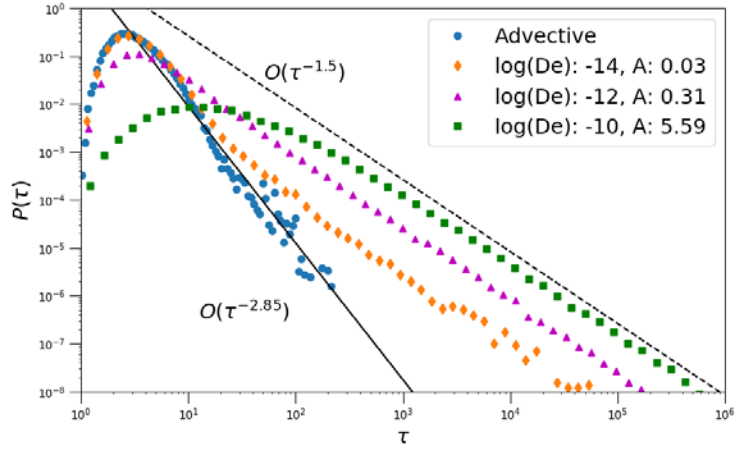
- Repository Science
- Carbon Sequestration
- Unconventional Hydrocarbon Extraction
- Enhanced Geothermal Energy Extraction
- Fundamental Research Science



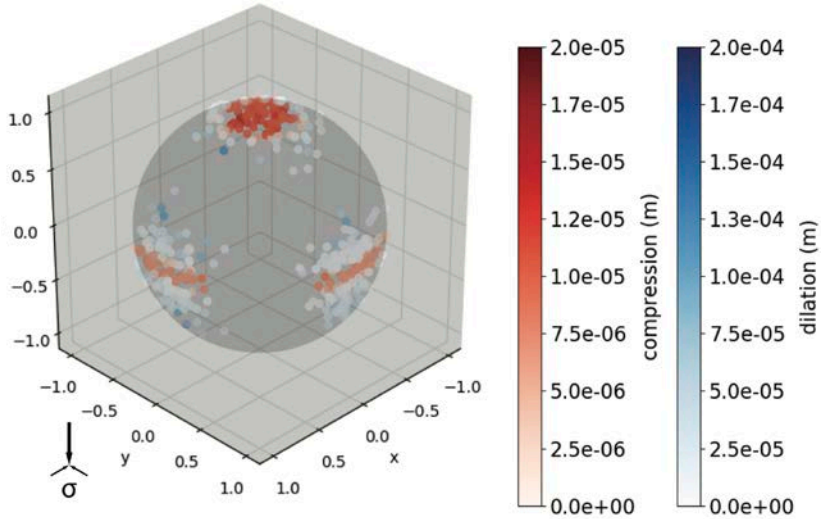
Internal fracture aperture variability



Discrete Fracture Matrix



Matrix Diffusion



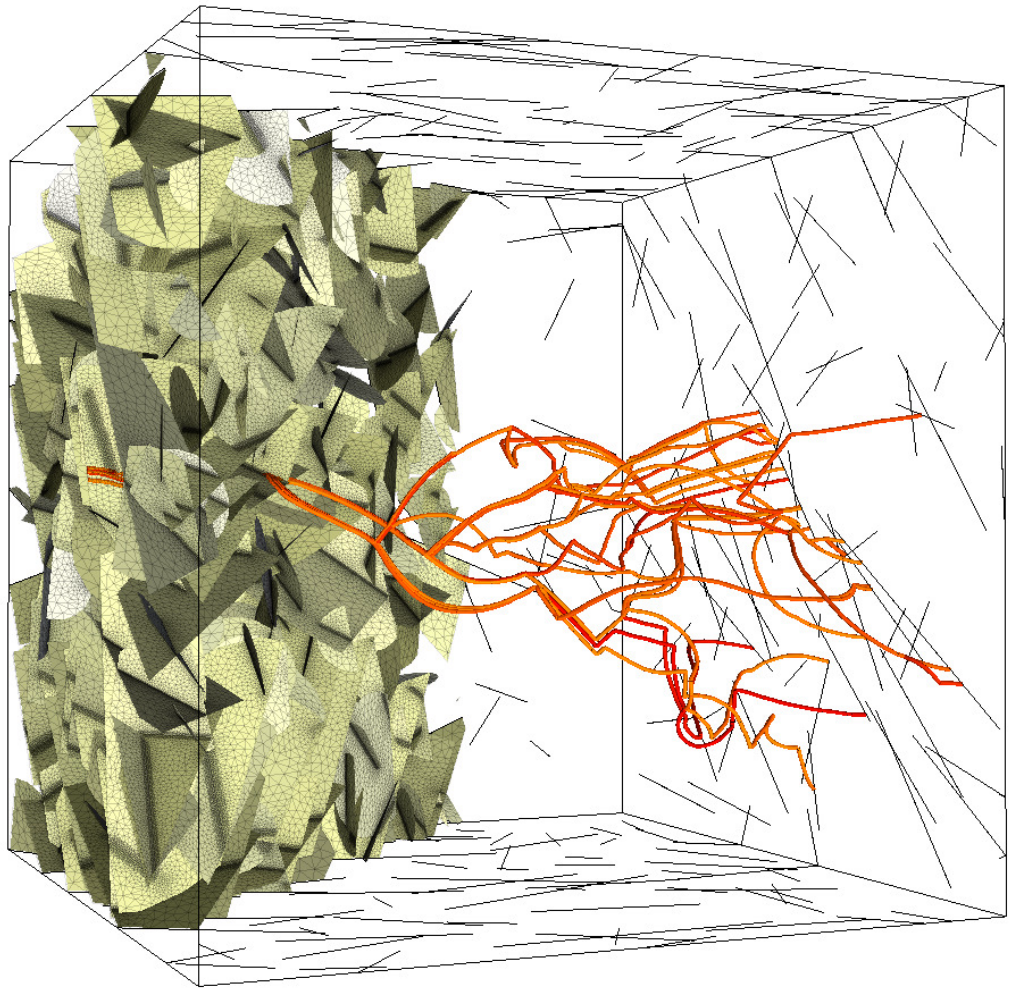
Stress Dependent Apertures

dfnWorks: 3D Discrete Fracture Network Modeling Suite

Additional Details

- Open Source (github.com)
- Robust Online Documentation
- dfnWorkShop Training
- dfnworks.lanl.gov
- Contact: dfnworks@lanl.gov

dfnWorks
DISCRETE FRACTURE NETWORK



R&D

Thank you for your time

dfnWorks
DISCRETE FRACTURE NETWORK

Los Alamos
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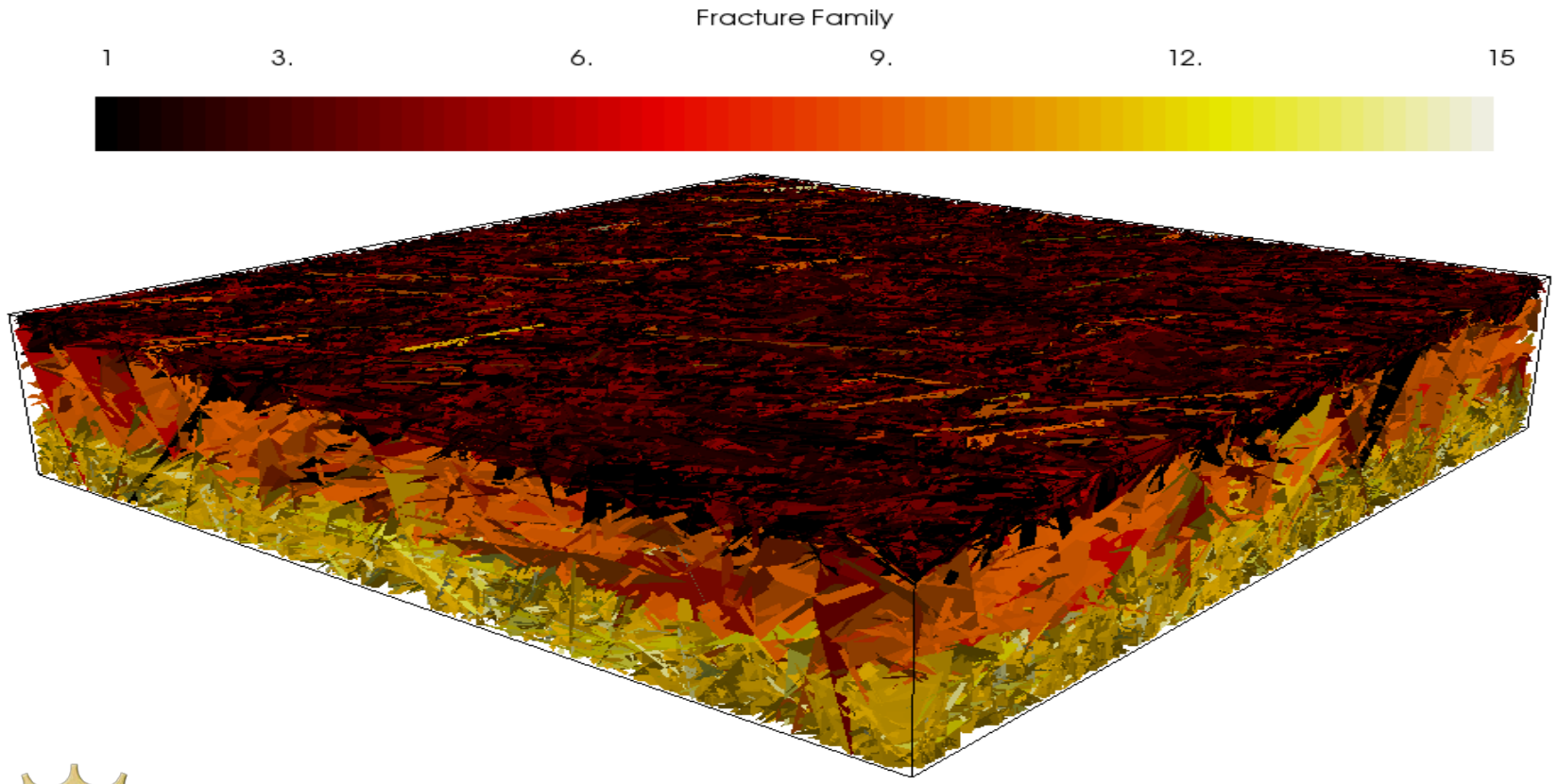
RESEARCH & DEVELOPMENT



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