INL/CON-21-64588-Revision-0

A Mixed Fracture-Matrix Model for Evaluating Well Orientation and Completion Options for the Utah FORGE Site

October 2021

Changing the World's Energy Future

Lynn Brendon Munday, Robert K Podgorney, Chandrakanth Bolisetti, Aleta Finlia, Andy Wilkins, Branko Damjanac, Koenraad Beckers

Idaho National Laboratory

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INL CSIRO GOLDER MEMBER OF WSP ITASCA Consulting Group, Inc. NREL NATIONAL RENEWABLE ENERGY LABORATORY MOOSE UTAH FORGE U.S. Department of Energy

A Mixed Fracture-Matrix Model for Evaluating Well Orientation and Completion Options for the Utah FORGE Site

Lynn Munday[a], Andy Wilkins[b], Chandrakanth Bolisetti[a], Robert Podgorney[a], Aleta Finnila[c], Branko Damjanac[d], Koenraad Beckers[e]

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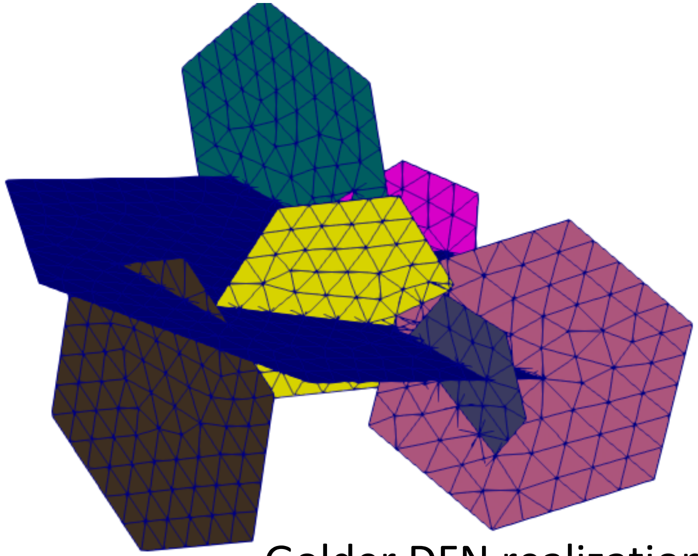
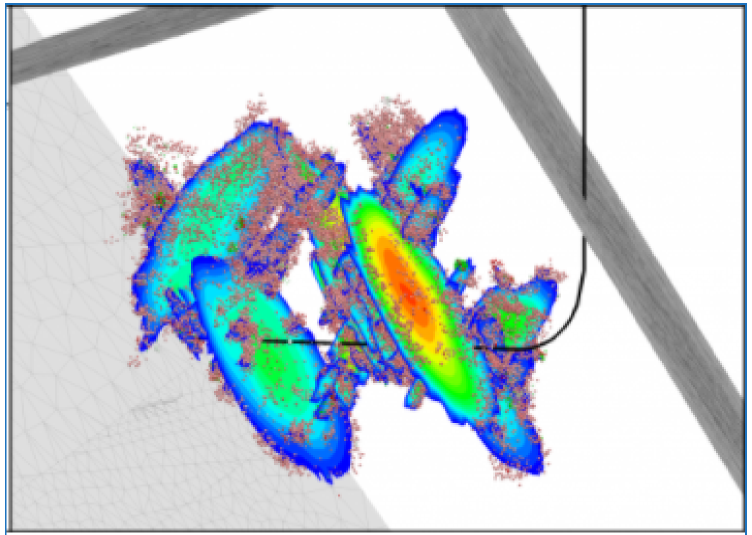
Motivation

- Simplify DFN modeling workflow
- Efficiently simulate long term performance of geothermal reservoir
  - Simulation of several DFN realizations (Golder)
  - Simulation of stimulated DFNs (ITASCA)



Golder DFN realization

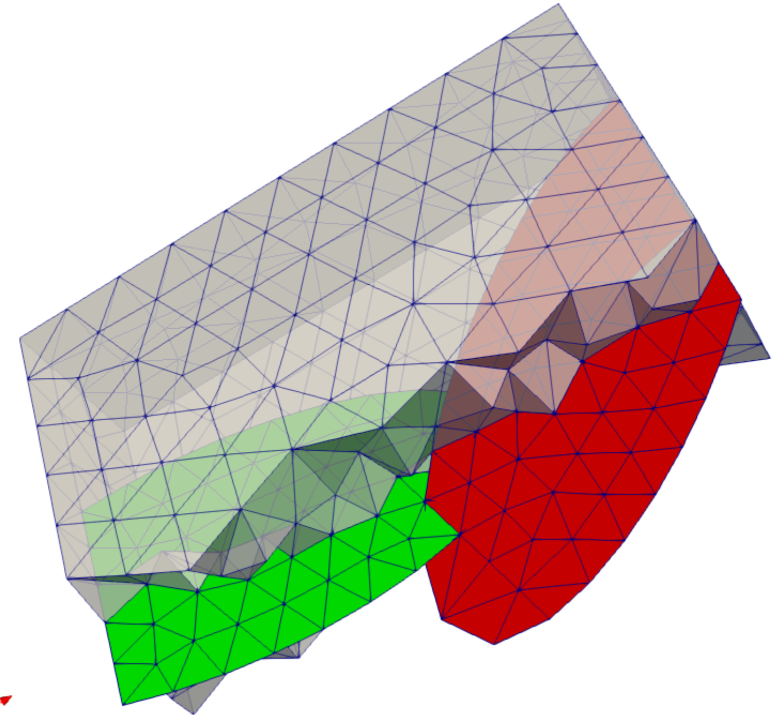


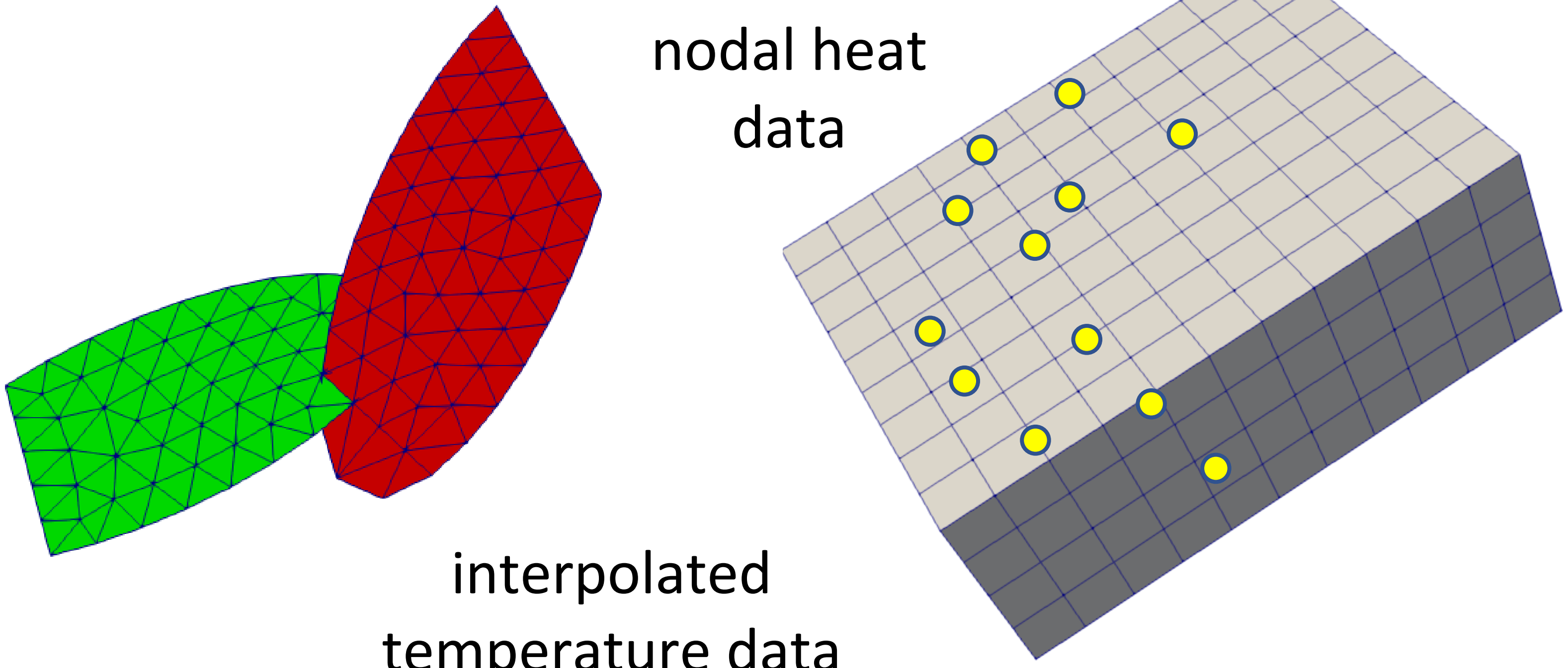
ITASCA

3DEC model of a geothermal site showing shear displacements along existing fractures and synthetic (predicted) microseismicity.

https://utahforge.com/2021/01/28/partner-spotlight-itasca/

Loose Coupling Algorithm in MOOSE-FALCON





https://mooseframework.inl.gov/modules/porous_flow/flow_through_fractured_media.html

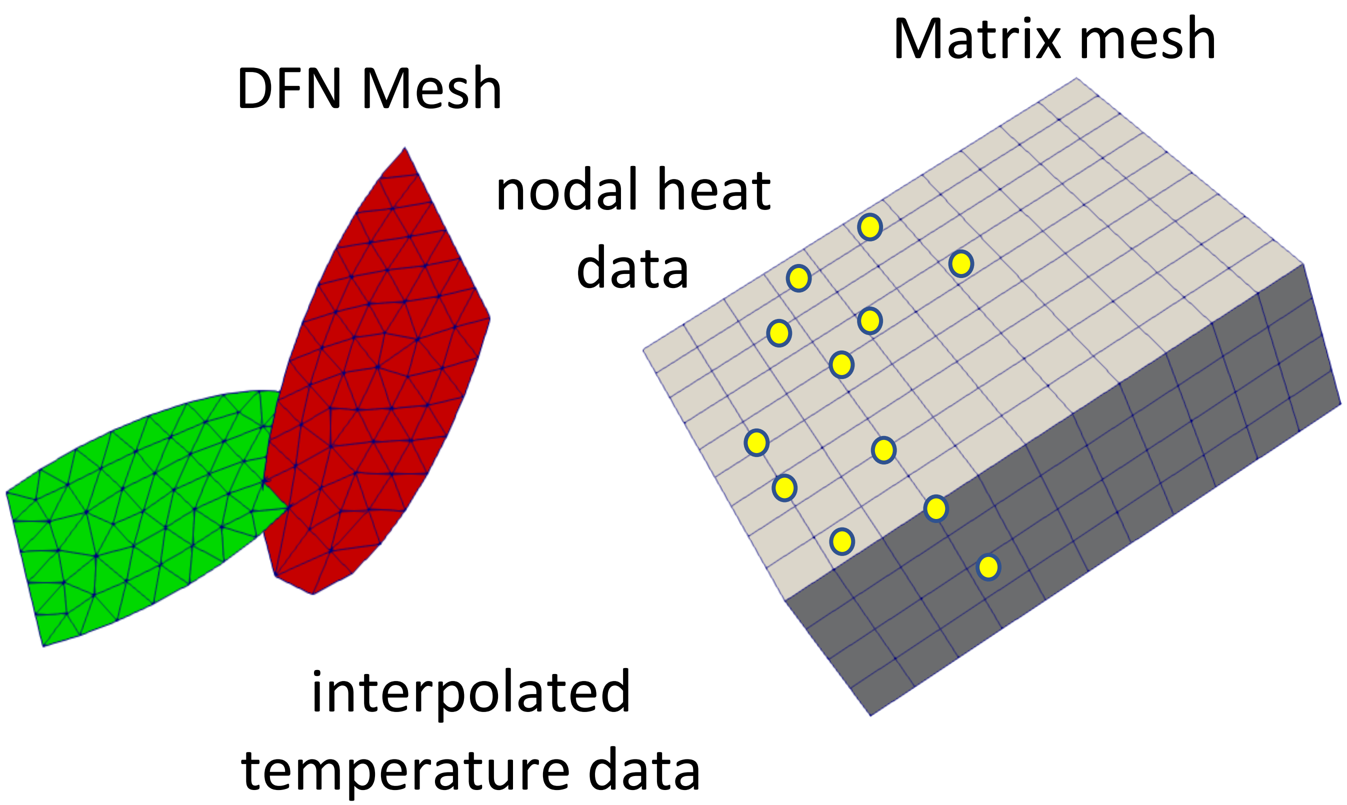
Loose Coupling Algorithm in MOOSE-FALCON

Uses MOOSE MultiApp System:

- Sets up separate computational domains (sub-apps)
- Methods for passing and applying data between domains

Assumptions:

- Matrix properties not affected by Fracture (small fracture aperture)
- Flow through fracture much higher than matrix (insulated BCs on DFN)



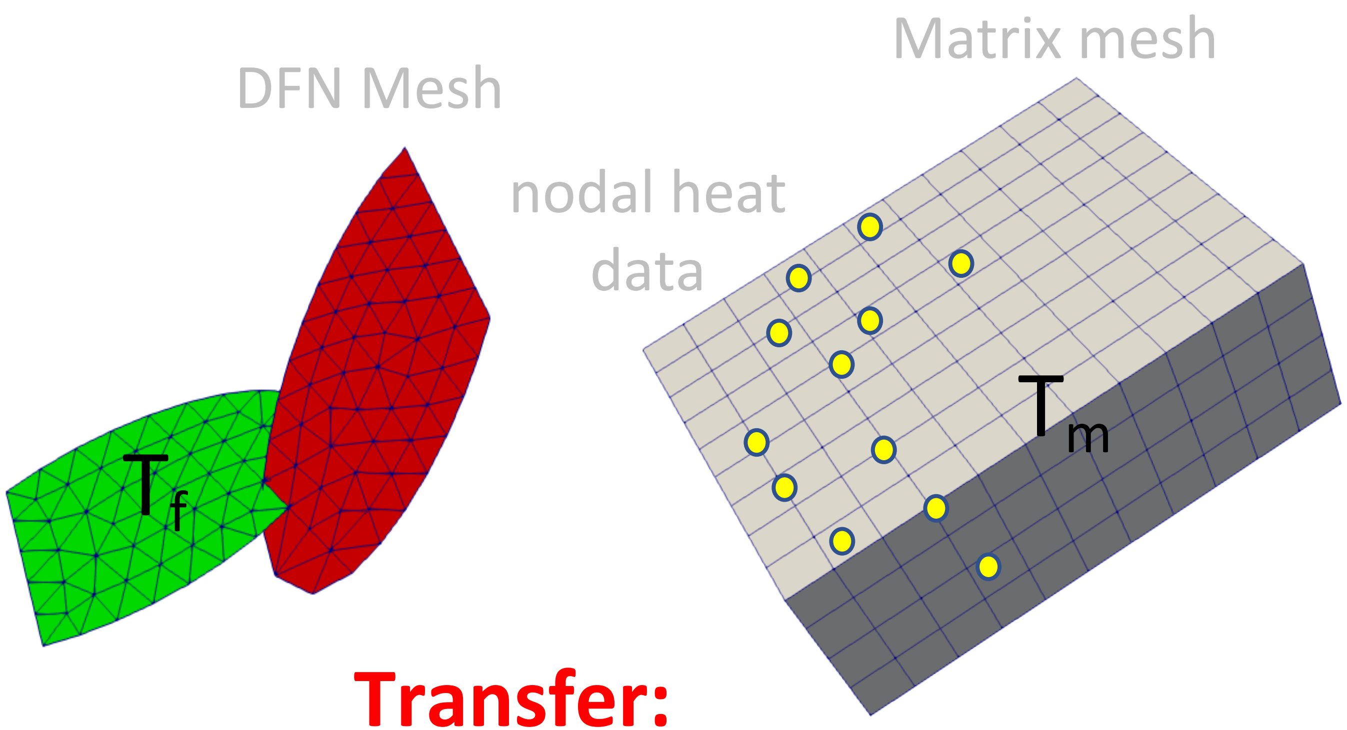
Loose Coupling Algorithm in MOOSE-FALCON

Step 1:
Interpolate Matrix mesh temperature field, T_m, to every node on DFN.

Compute heat transfer from Matrix to DFN based on the temperature difference.

$Q = h(T_f - T_m)$

where heat transfer coeff: $h = 2\lambda/L$
L is the matrix mesh element length
λ matrix thermal conductivity



Transfer: Interpolated temperature data

Loose Coupling Algorithm in MOOSE-FALCON

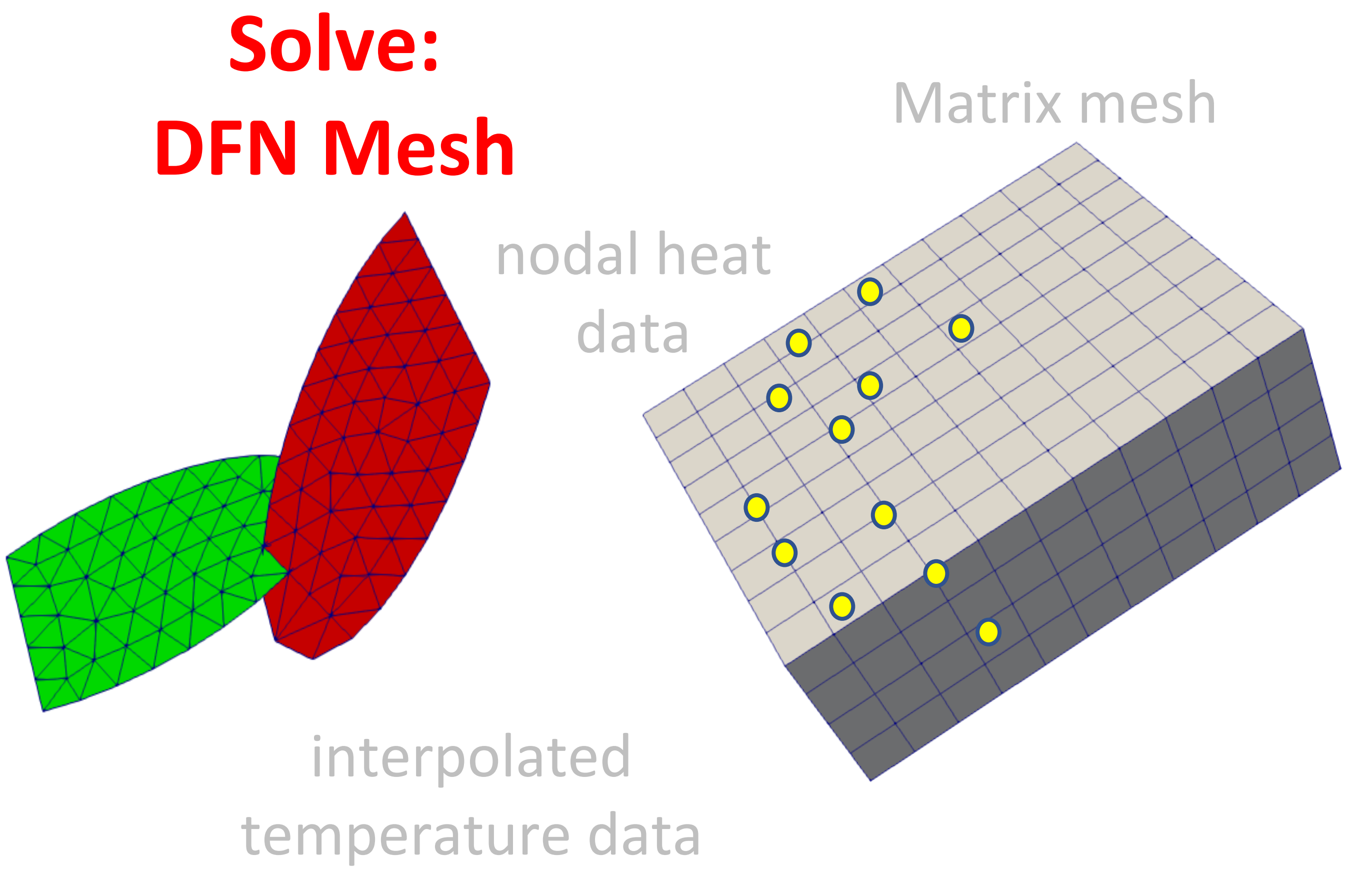
Step 2:

Solve DFN physics.

- Pore pressure and heat diffusion
- Water equation of state
- permeability a function of aperture

  $a=a_o+A(P-P_o)$

  Note: Using constant a_o. Future work to include thermal stimulation and variable a_o

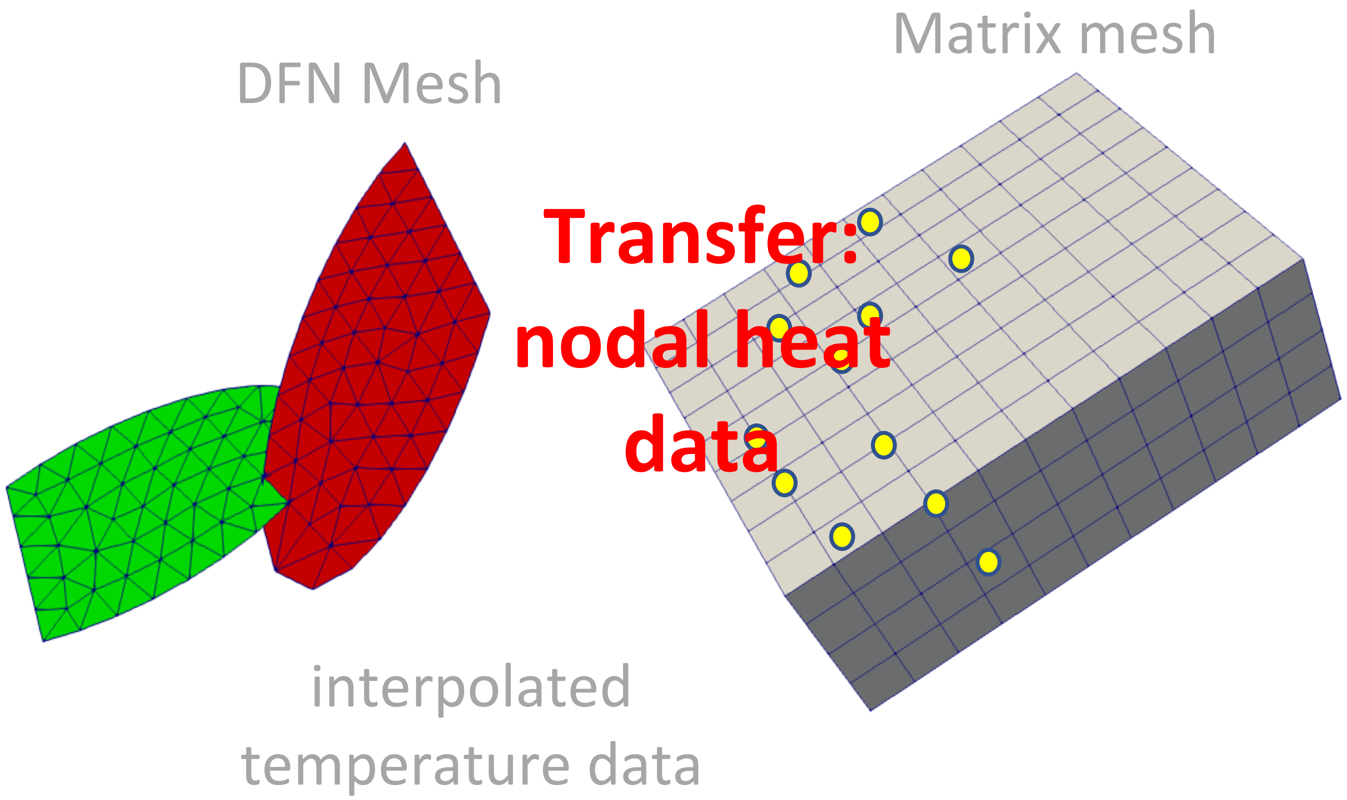


DFN physics are "fast" compared to matrix so multiple small DFN timesteps are taken per larger matrix timestep

Loose Coupling Algorithm in MOOSE-FALCON

Step 3:
Apply the same Q applied to the fracture mesh in step 1 onto the Matrix mesh

-every DFN node produces a point load in the matrix mesh

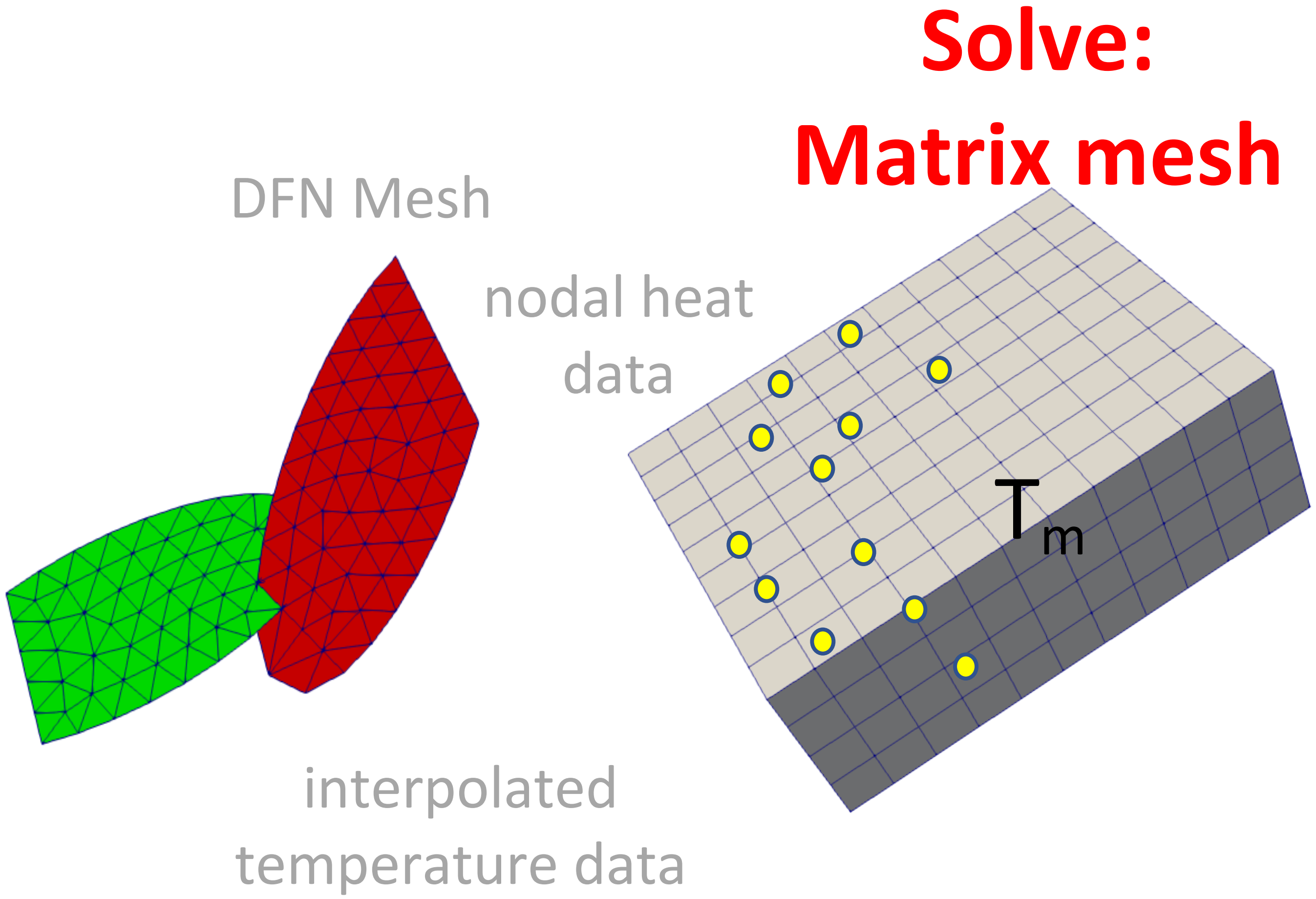


Loose Coupling Algorithm in MOOSE-FALCON

Step 4:
Solve matrix physics to get a new matrix temperature, T_m.

This completes a timestep

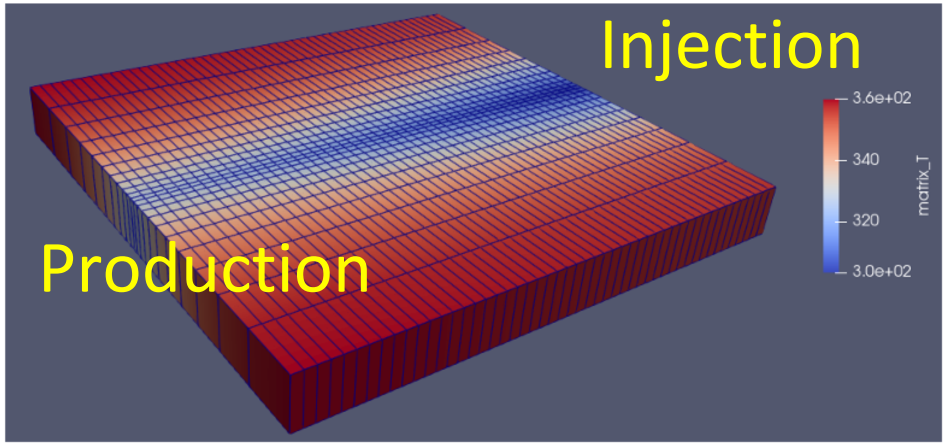
Could iterate within a timestep but results suggest it is not necessary

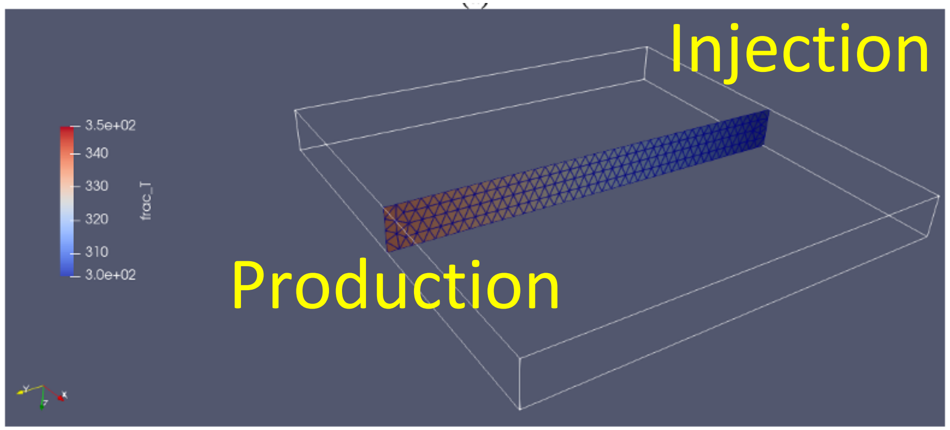


Verification to Gringarten Solution (1975)

Parameter	Value
Rock initial temperature	90°C
Rock density	2875 kg/m^3
Rock heat capacity	825 J/kg-K
Rock thermal conductivity	2.83 W/m-K
Rock permeability	1e^{-16} m^2
Rock porosity	0.1
Water Flow rate	0.1 kg/s
Water Injection Temperature	30°C
Domain Length	100 m
Domain Width	100 m
Domain Height	10 m
Well spacing	100 m

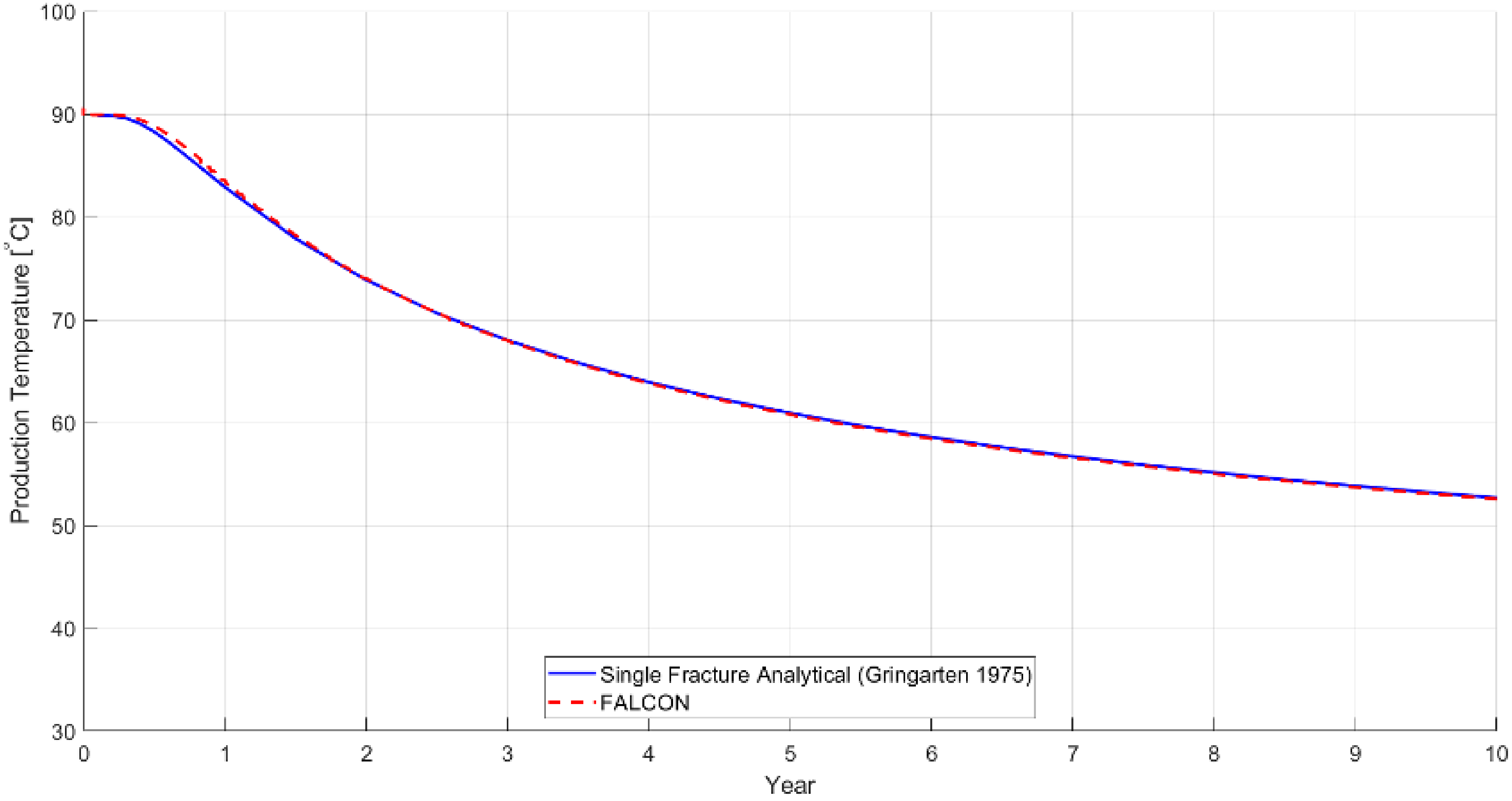
Temperature field after 3 years





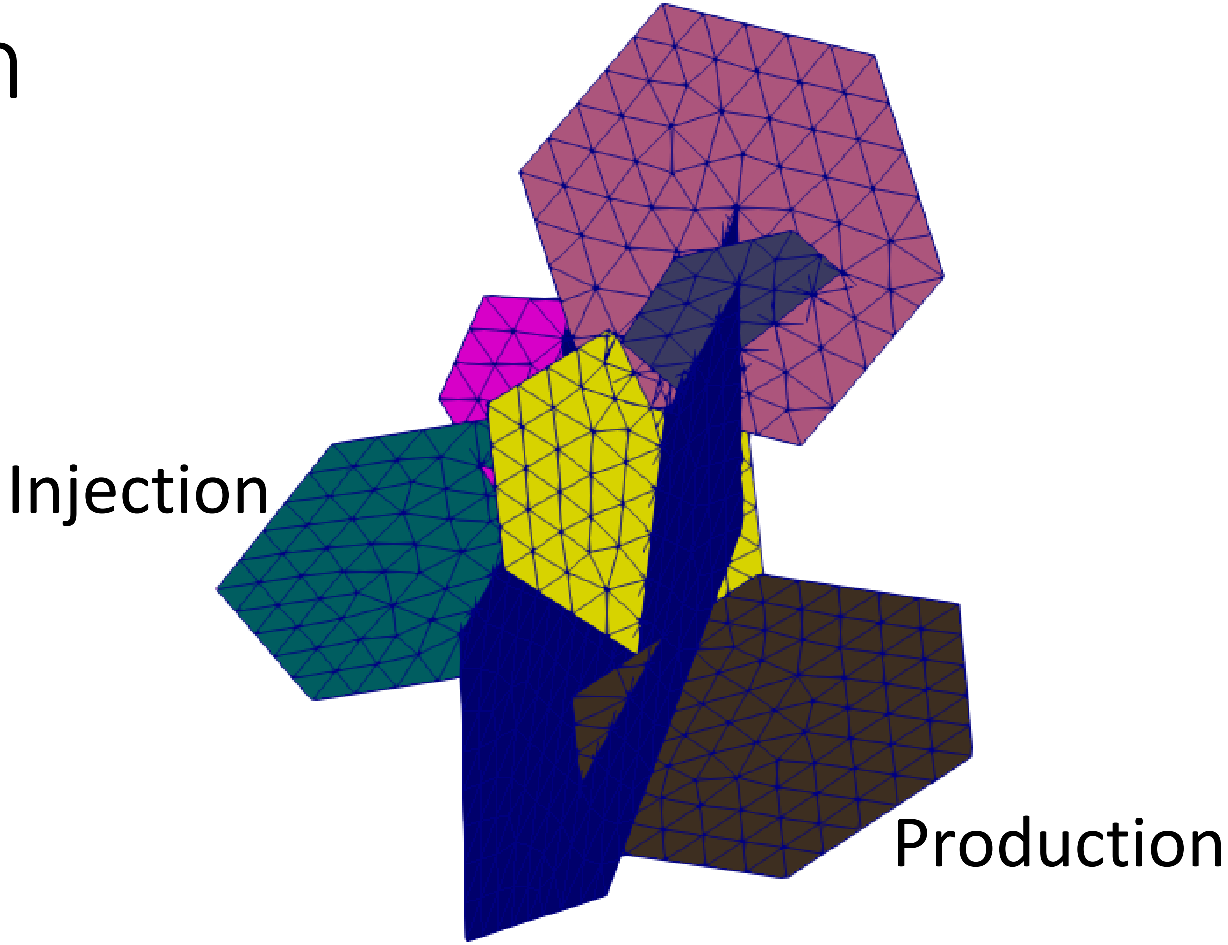
Gringarten, A. C., P. A. Witherspoon, and Yuzo Ohnishi. "Theory of heat extraction from fractured hot dry rock." *Journal of Geophysical Research* 80.8 (1975): 1120-1124.

Verification to Gringarten Solution (1975)



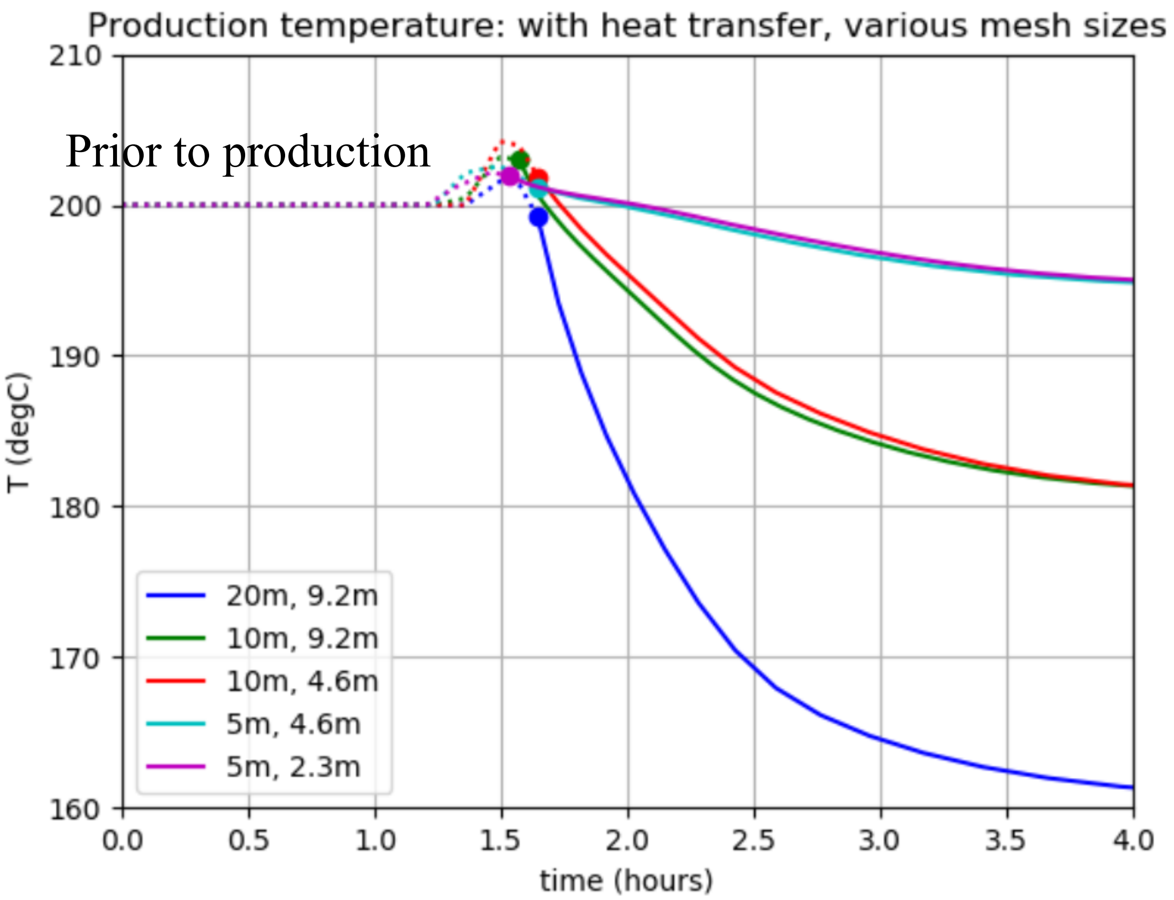
Example DFN Simulation

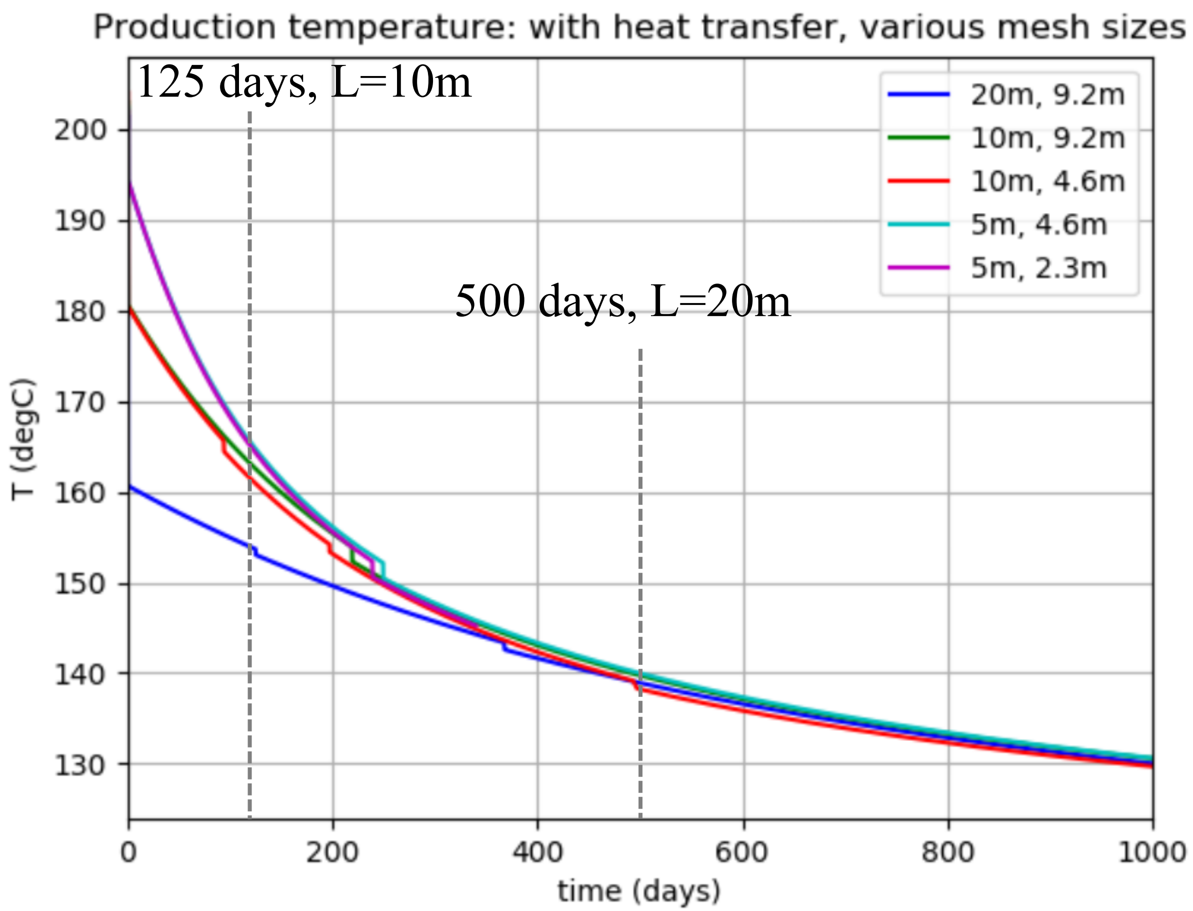
- DFN:
  - 12 fractures ranging in size 40-150m
  - Permeability:1e-12
- Matrix:
  - 220x170x220m – mesh 20-5m
  - Permeability: 1e-18 m^2
  - λ=5$Wm^{-1}K^{-1}$ scaled by element length
  - P=10MPa, T=200C
- Injection: 10 $kg.s^{-1}$, 100C
- Production: 10$kg.s^{-1}$



Example DFN Simulation: Production Temperature

Time Scale based on Element Size: $t \sim c\rho\lambda^{-1}L^{2}$; L=20,10,5m results in t~500,125,5 days





Example DFN Simulation: Fracture Aperture Changes

Change in fracture aperture after 1000 days

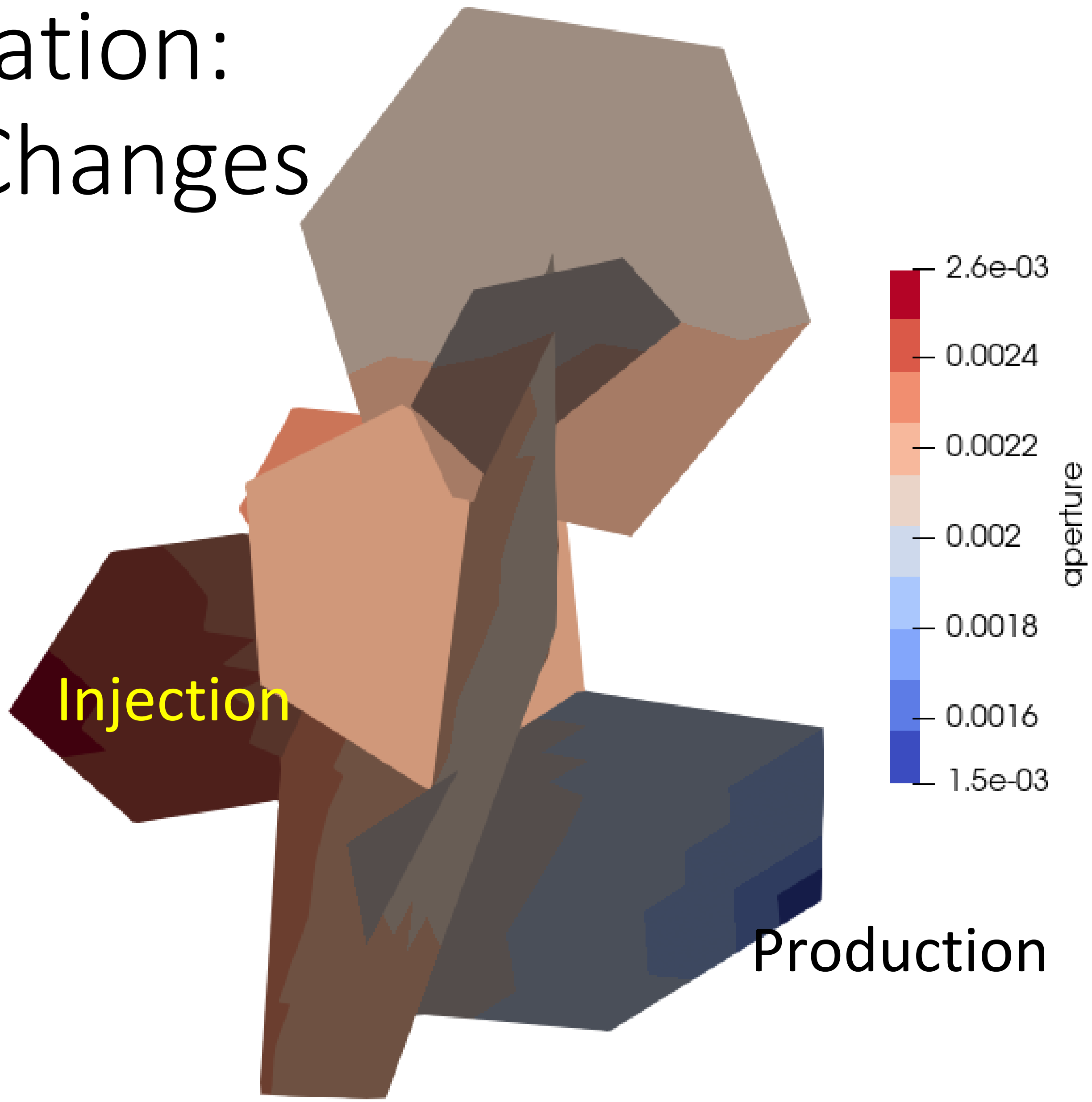
$a = a_o + A(P - P_o)$

a_o= 1 mm

A= 10^{-3} m.MPa^{-1} (a pressure increase of 1MPa dilates the fracture by 1mm)

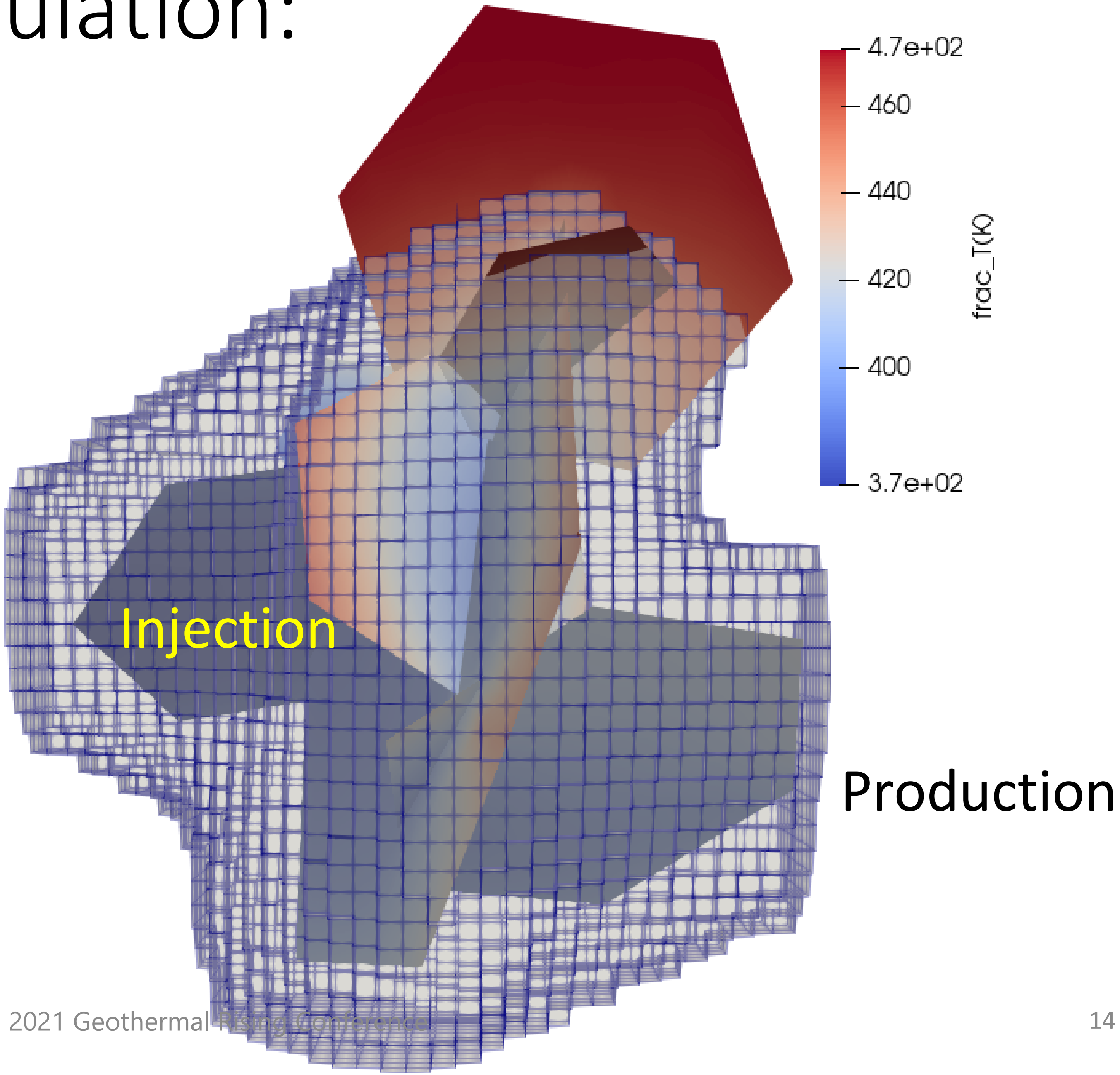
P_0 =10MPa (hydrostatic insitu value)

The permeability of the fracture is proportional to a^2, with insitu permeability of 10^{-11} m^2 when $a=a_0$



Example DFN Simulation: Matrix Cooling

Matrix elements shown cooled by 10C after 1000 days of production

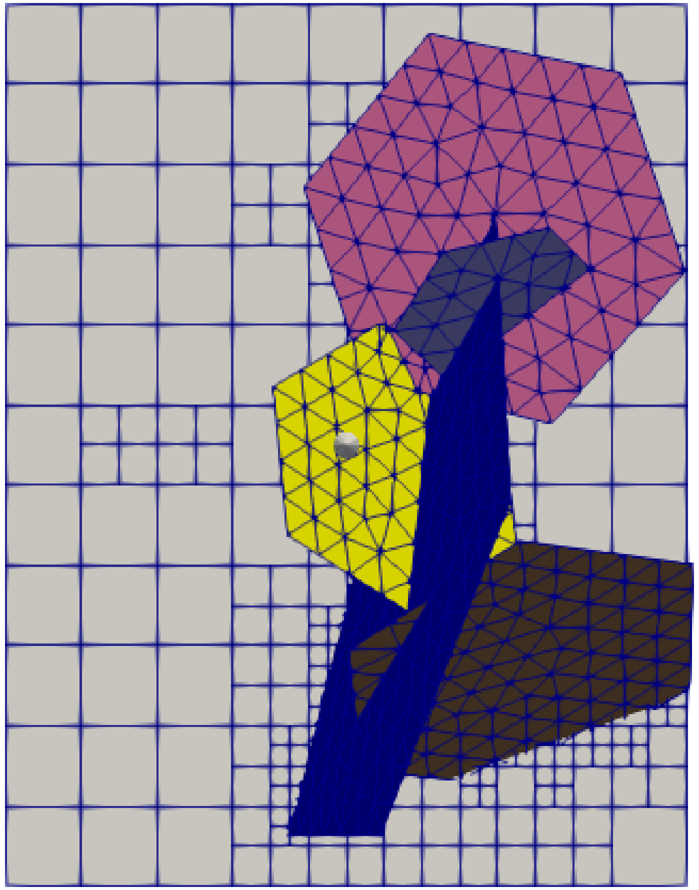


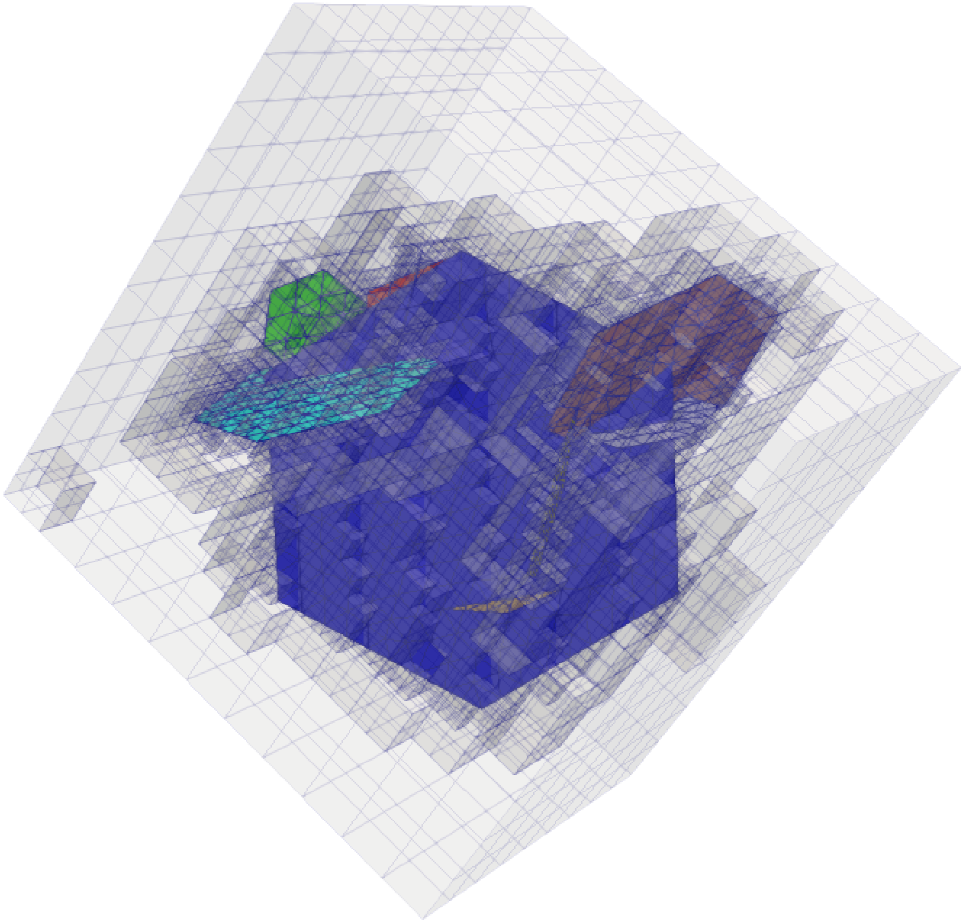
Example DFN Simulation: Matrix Automatic Mesh Refinement (AMR)

Initial Mesh (20m):
1,089 elements

Two levels of uniform refinement (5m):
69,696 elements

Matrix with 20m mesh AMR with 2 levels of refinement (5m):
6,913 elements





Example DFN Simulation: Matrix AMR Timings

Matrix Refinement	Number of Matrix Elements	Run Time (minutes)	Matrix Total Nonlinear Iterations	Fracture Total Nonlinear Iterations
Original (20m)	1089	5.3	441	2572
Refine 1 (10m)	8712	18.0	441	2448
Refine 2 (5m)	69696	191.8	441	2351
AMR 1 (10m)	2286	7.7	441	2444
AMR 2 (5m)	6906	20.2	441	2375
Refine 2 (5m) (noSubCycle)	69696	717.7	1690	3279

For two levels of refinement (5m matrix elements)

-Substepping in fracture 3.7x speed up

-AMR 9.6x speed up

Future Work

- Run for stimulated DFNs with variable aperture data
- Add thermal contraction to aperture function
- **Simulate long-term geothermal performance of FORGE site with realistic DFNs**
  - Incorporate ITASCA simulation results for 16a stimulation
  - Incorporate results of actual stimulated fracture volume from the upcoming field experiments