DFN.lab
software platform for Discrete Fracture Network models

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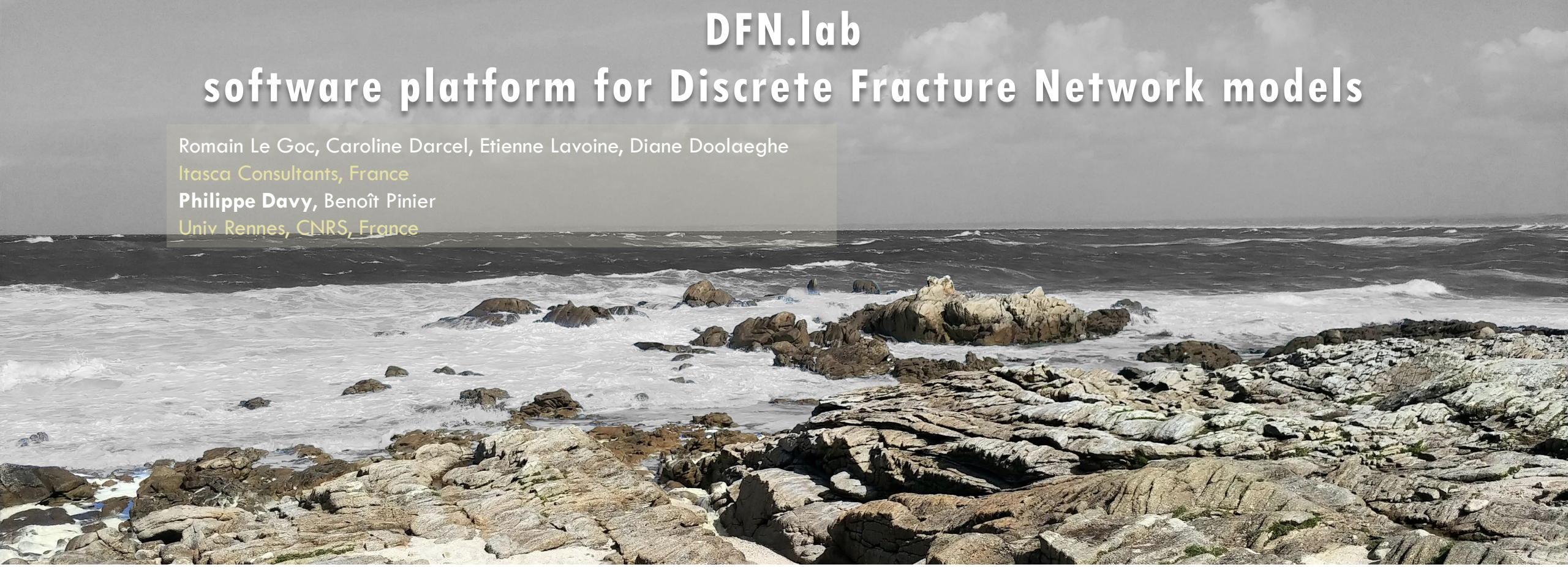
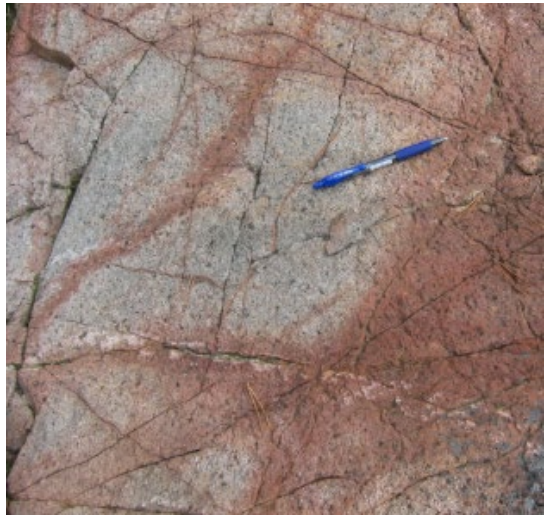
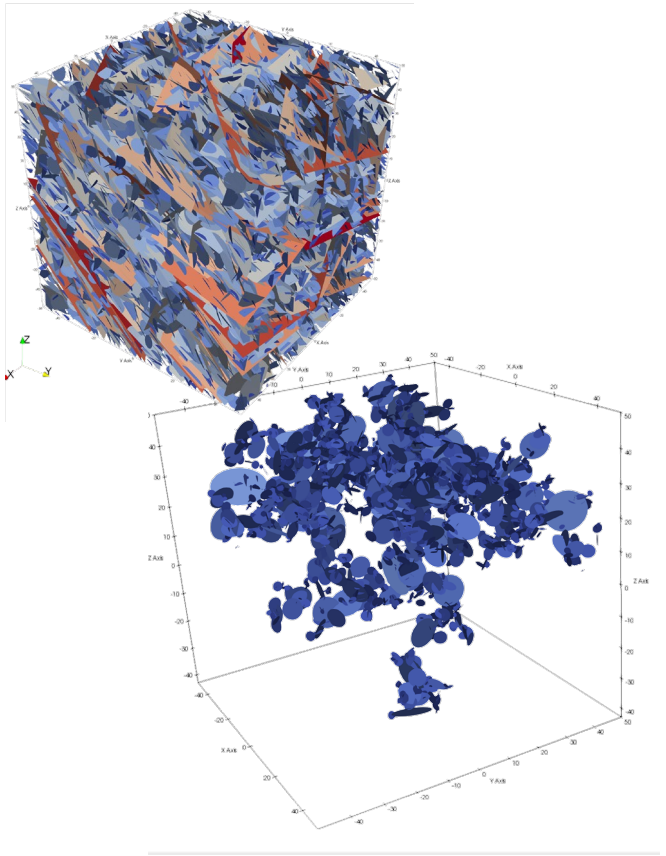
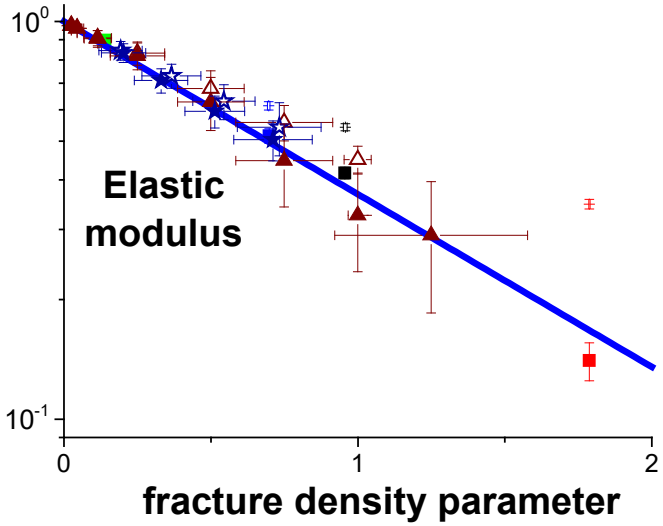


The challenges of fractured rock masses

Fractures control hydrological properties (completely) and mechanical properties (partly)







The **numerical** challenges of fractured rock masses

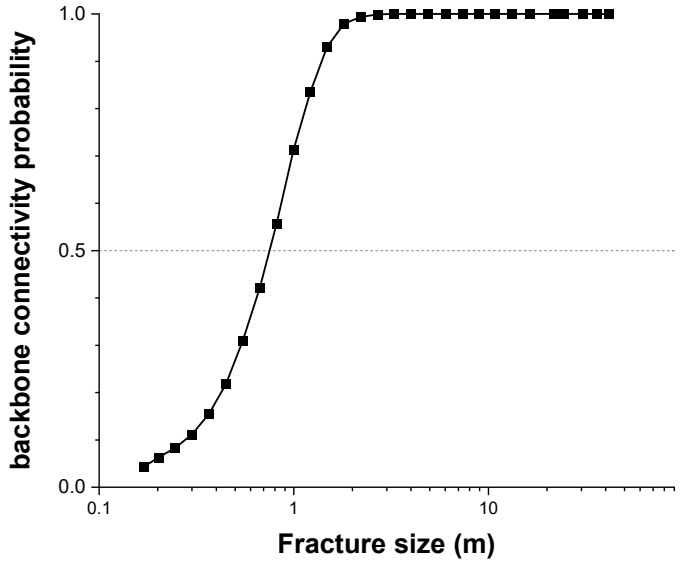
Which scales are important/critical/negligible?

for hydro

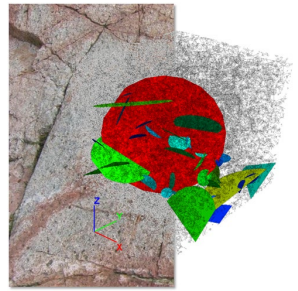
- **density**: 10 fractures/m from borehole size (10 cm) to ∞
- **size distribution**: power law from cm to km
- **connectivity**: all fractures > 80 cm contribute

Application for a block of $(100\ m)^3$

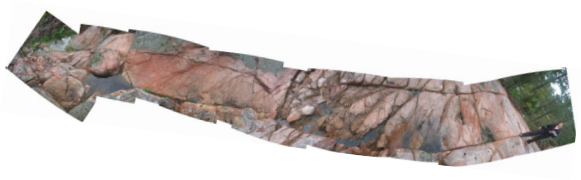
- smallest 'effective' fracture = 40 cm
- Total number of fracture = $4*10^6$
- total effective fracture surface = 4 km^2
- **total number of meshes > 20 millions**

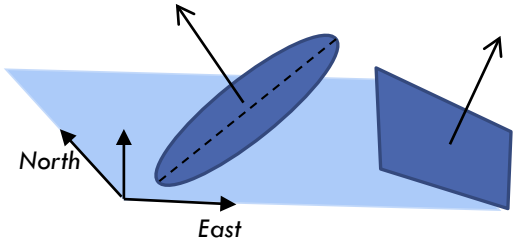


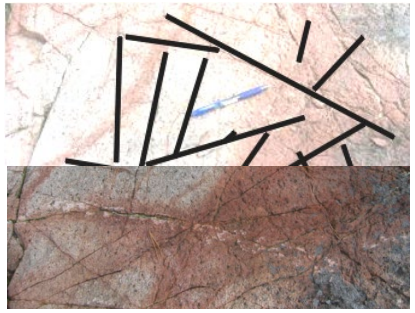
The Discrete Fracture Network (DFN) modeling approach



Fractured rock *geology*	**Fracture object** *'idealized'*	**Fracture population** *DFN*







A thin volume
characterized by

- Its surface per unit volume (p_{32})
- Some properties (aperture, stiffness of fracture walls or filling material)

An idealized object

- With simple or complex geometry
- Whose definition depends on size (e.g. small-scale fracture, large-scale fault zones)
- Ideally, consistent with hydraulic and mechanical continuity

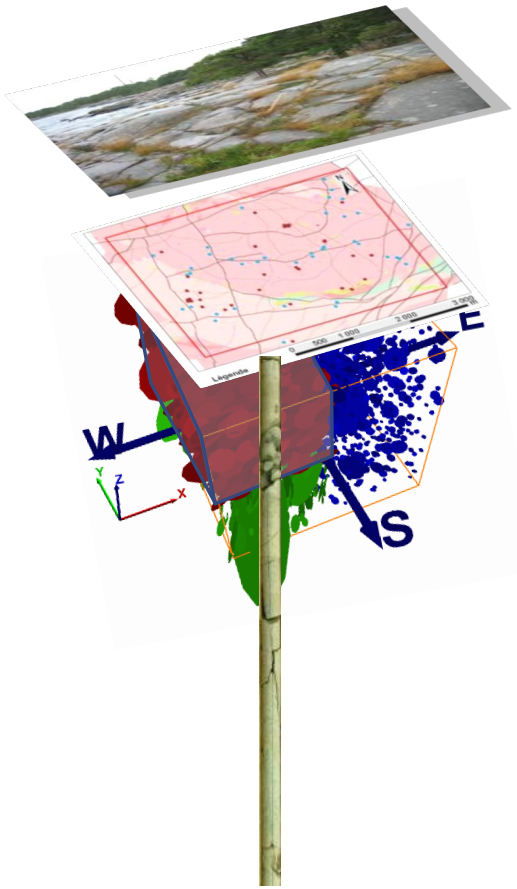
A density distribution
$n(L, l, \theta, \phi, \dots)$

number of fractures per unit volume V

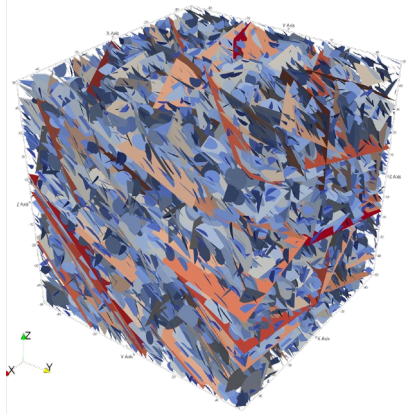
- with a given size l,
- orientation θ, ϕ
- aperture/ transmissivity
- …

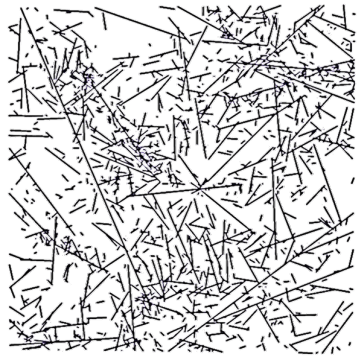
The DFN modeling worflow

Fracture statistics
fracture intensity
size distribution
flow data

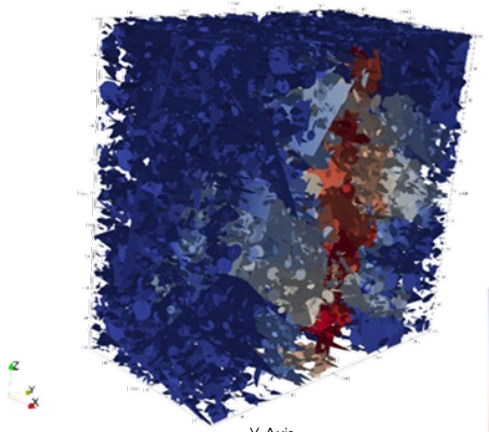


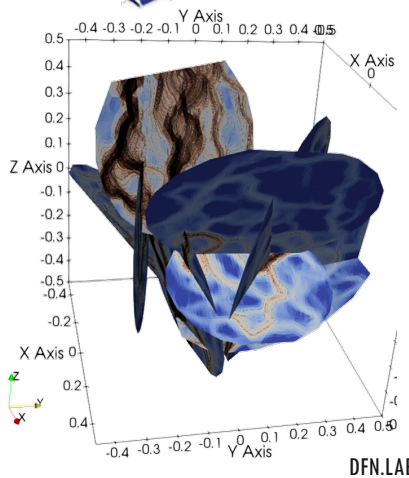
DFN generation
Statistical fractures
Genetic models based on fracture mechanics



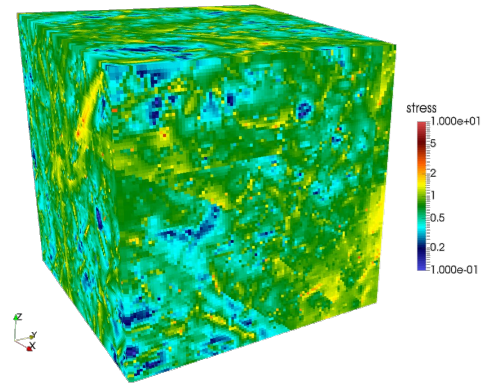


Flow simulations
steady-state, transient
permeameter or pumping conditions



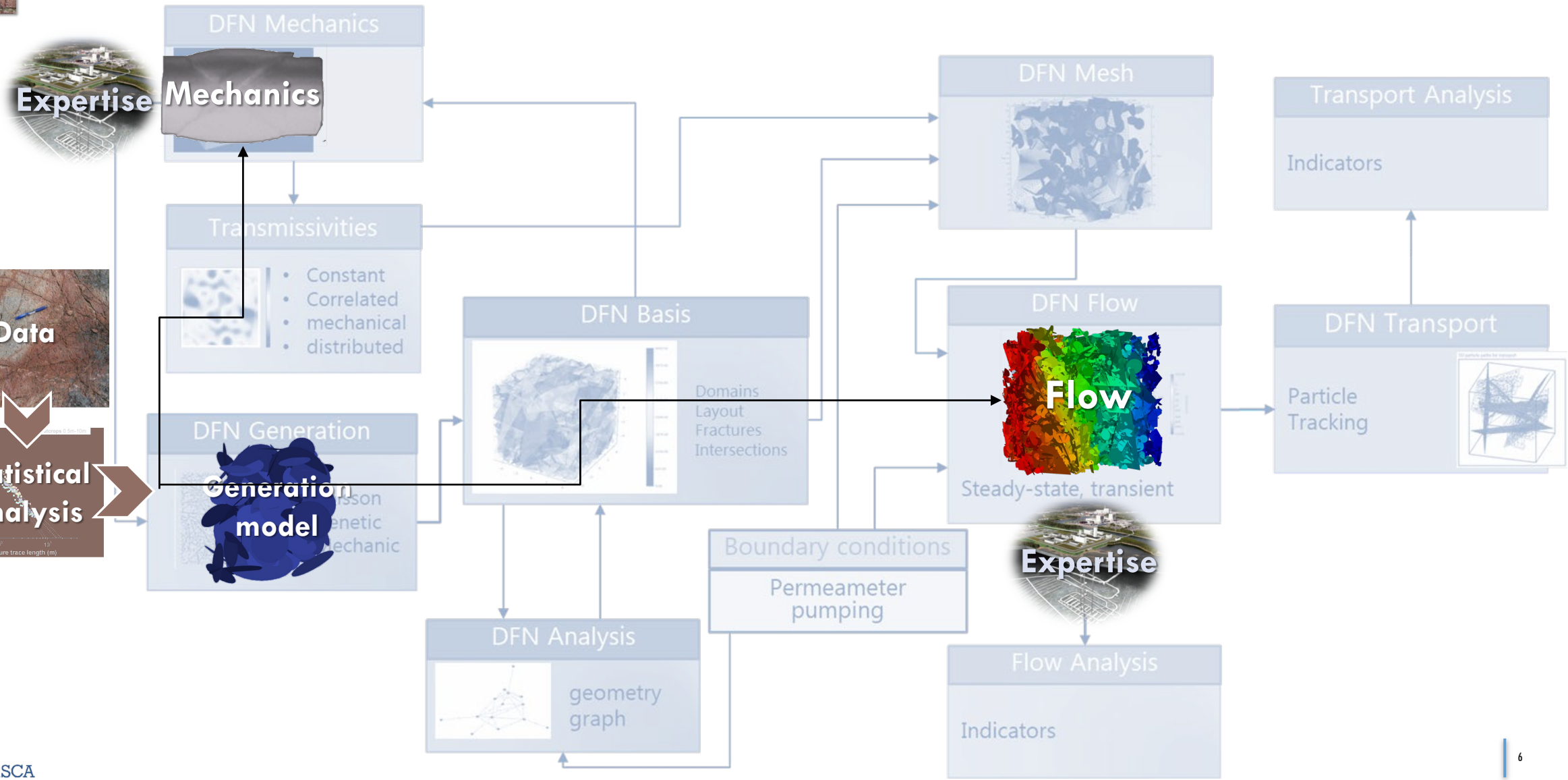


Linear elastic mechanics
Strain-Stress fields
Stress intensity factors
Effective elastic properties



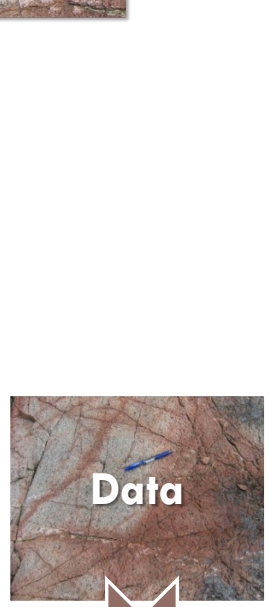
DFN.lab

Numerical platform for modelling fractured media with applications to hydrology and geomechanics

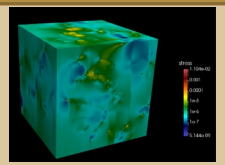


DFN.lab

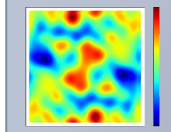
Numerical platform for modelling fractured media with applications to hydrology and geomechanics



DFN Mechanics

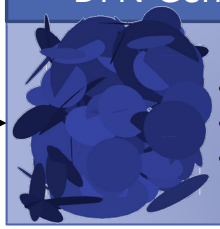


Transmissivities



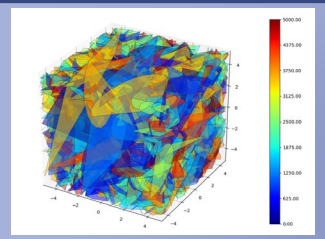
- Constant
- Correlated
- mechanical
- distributed

DFN Generation



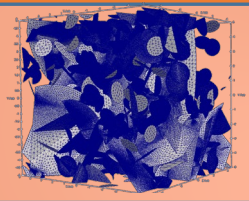
- Poisson
- Genetic
- Mechanic

DFN Basis

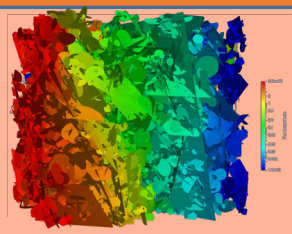


Domains
Layout
Fractures
Intersections

DFN Mesh



DFN Flow



Steady-state, transient

Boundary conditions

Permeameter
pumping

DFN Analysis

geometry
graph

Flow Analysis

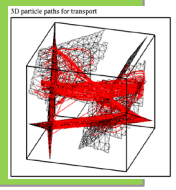
Indicators

Transport Analysis

Indicators

DFN Transport

Particle
Tracking



DFN.lab

Numerical platform for modelling fractured media with applications to hydrology and geomechanics

A modular lego

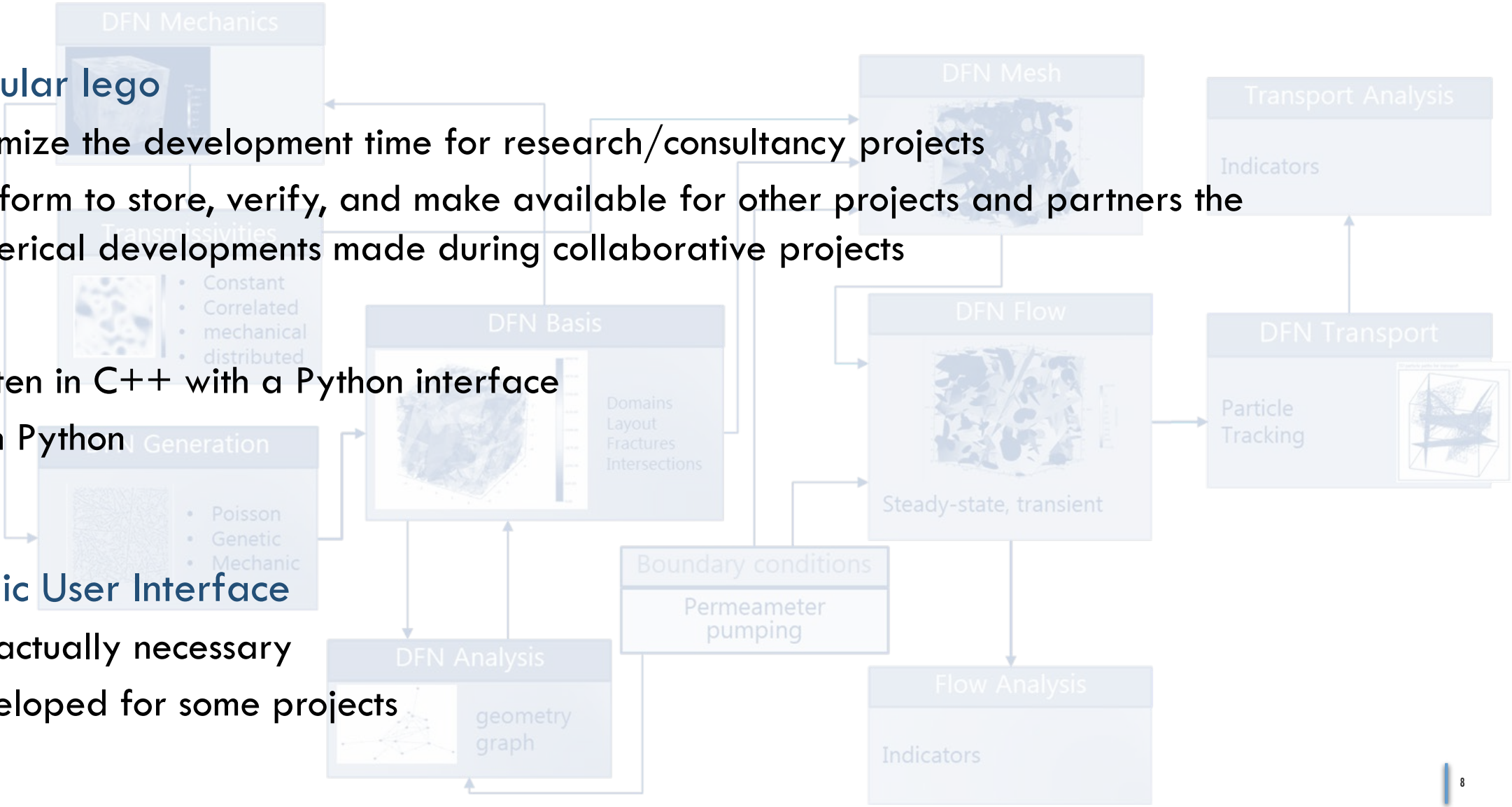
- minimize the development time for research/consultancy projects
- platform to store, verify, and make available for other projects and partners the numerical developments made during collaborative projects

‘Bricks’

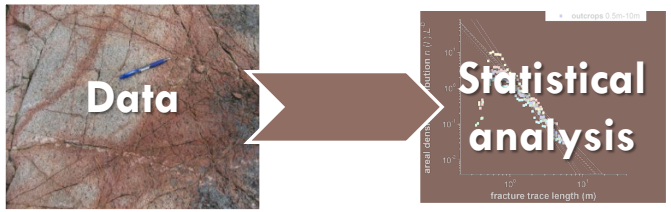
- written in C++ with a Python interface
- or in Python

Graphic User Interface

- not actually necessary
- developed for some projects

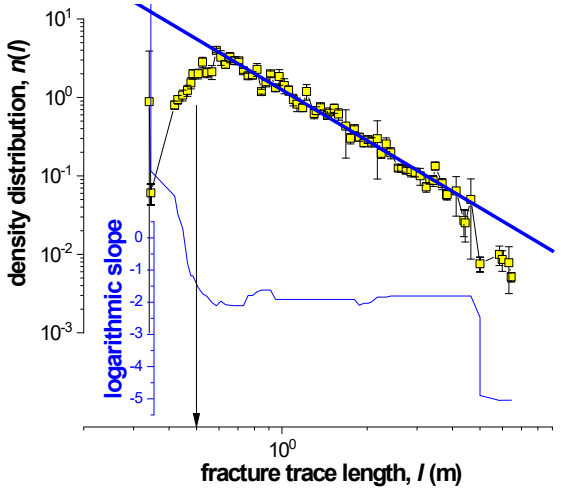


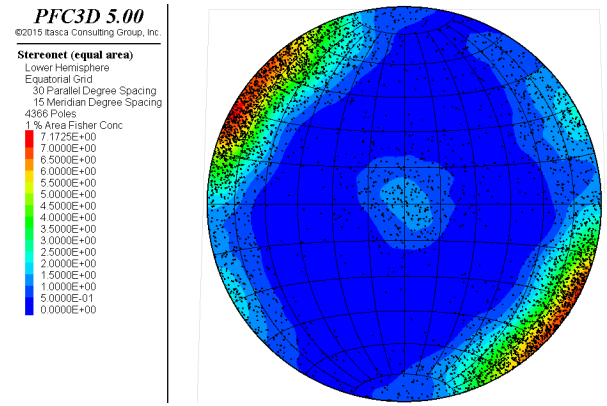
DFN.lab: generating fracture networks



Statistical distributions

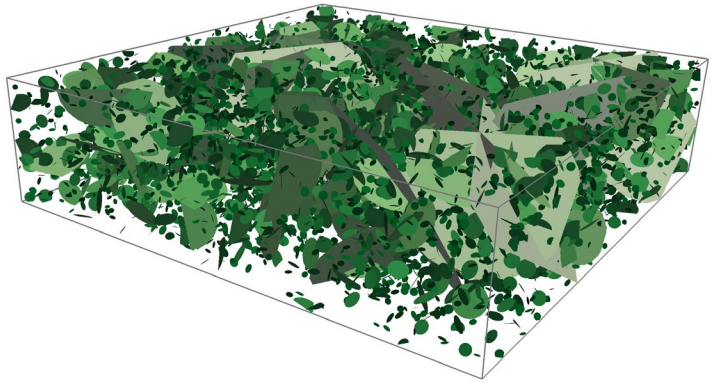
- size distribution
- orientation distribution
- fracture sets





Poissonian hypothesis

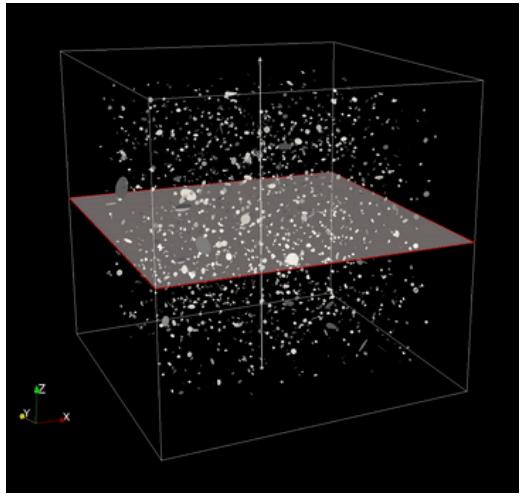
- Fractures are statistical objects,
  whose properties are independent of each others

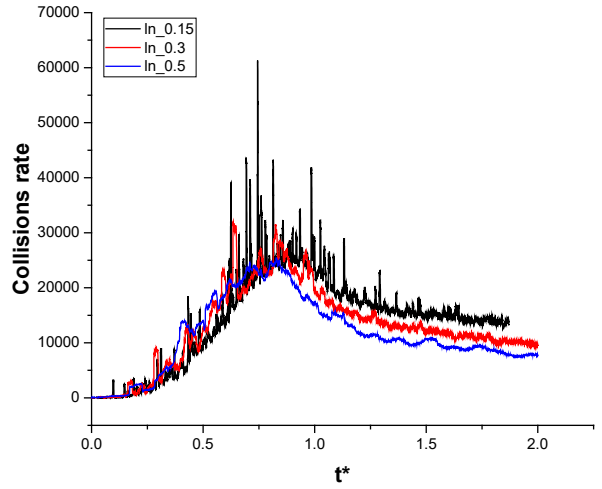


DFN.lab: generating fracture networks
genetic models

Fracture networks = population dynamics

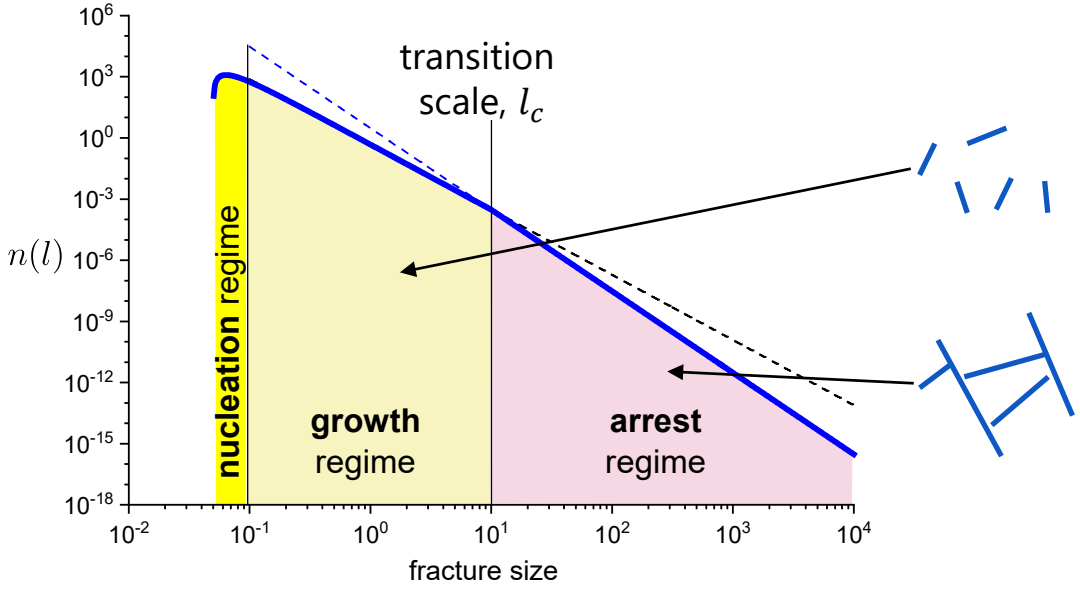
- Nucleation
- Growth
- Arrest





A physical rationale for statistical distribution

- Fracture size distribution are statistical objects, whose properties are independent of each others

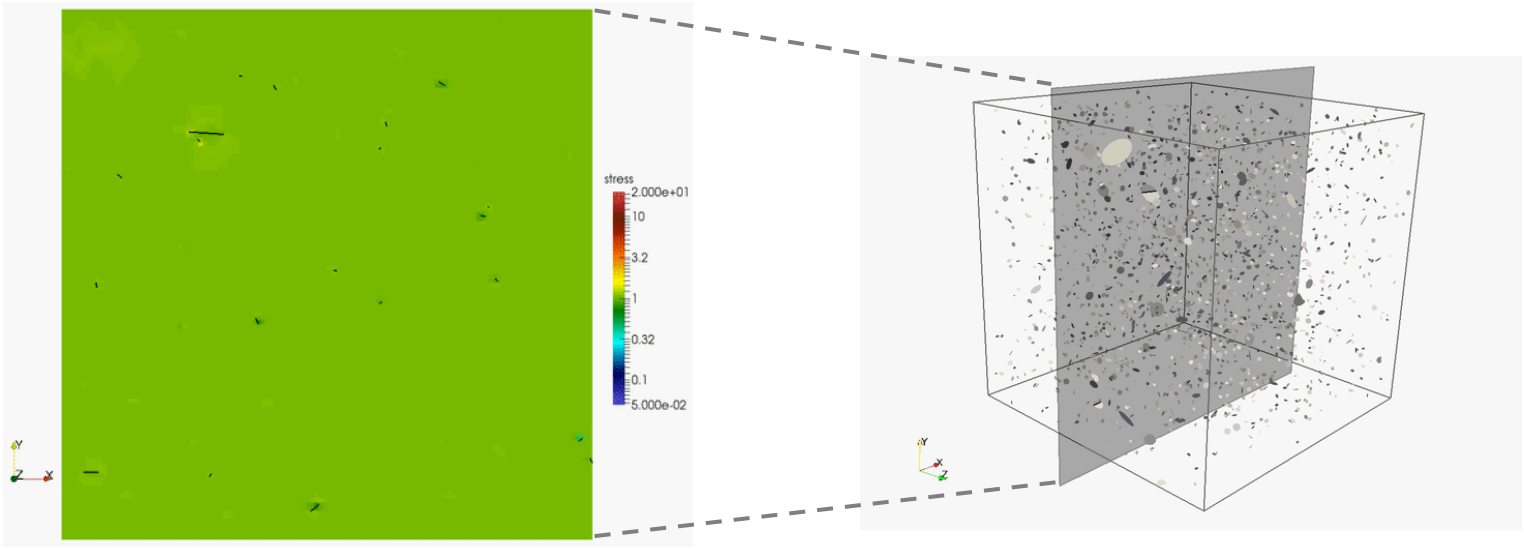


Davy, P., Darcel, C., Le Goc, R., & Mas Ivars, D. (2018). Elastic Properties of Fractured Rock Masses With Frictional Properties and Power Law Fracture Size Distributions. *Journal of Geophysical Research: Solid Earth*. doi:10.1029/2017jb015329

DFN.lab: generating fracture networks
genetic models

Fracture networks = population dynamics

- stress-dependent nucleation
- Growth
- Arrest



Lavoine, E., Davy, P., Darcel, C., & Munier, R. (2020). A Discrete Fracture Network Model With Stress-Driven Nucleation: Impact on Clustering, Connectivity, and Topology. *Frontiers in Physics, 8*(9). doi:10.3389/fphy.2020.00009

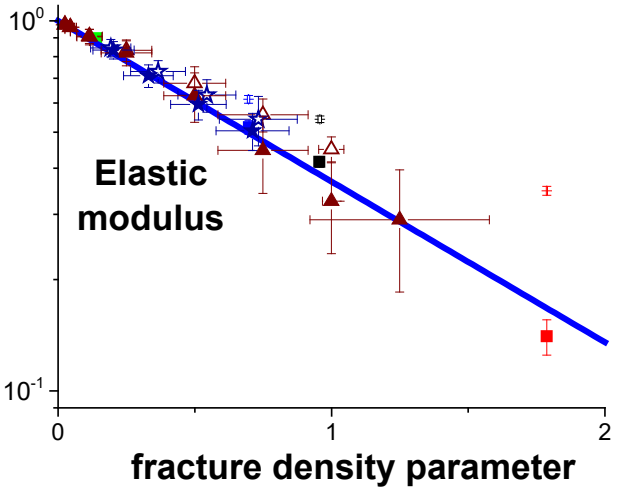
DFNlab: mechanical properties from DFN

Feature 1 : **Calculating elastic modulus from DFN**

- Theory: Partitioning of the applied stress between fracture plane and surrounding elastic matrix (Davy et al., 2018)
- Calculation: $d\left(\frac{1}{E}\right) = F_\theta \frac{\pi}{4V} \frac{l^2}{(k_s + k_m(l))}$

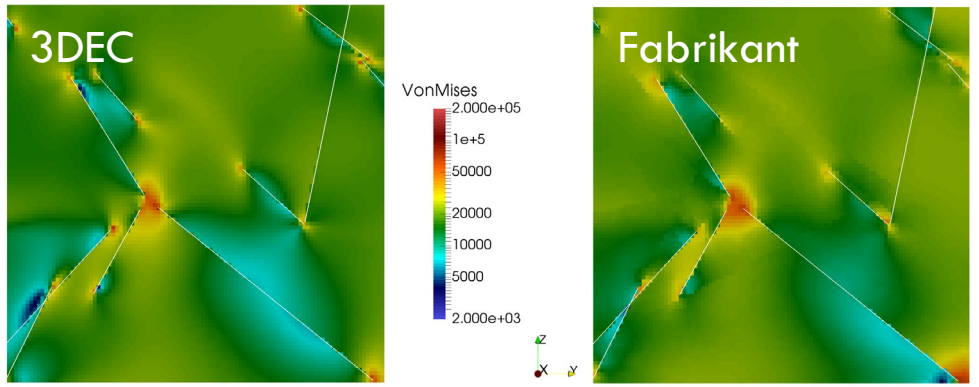
F_θ → orientation term with respect to σ

$k_m(l)$ → matrix stiffness $k_m \sim \frac{E_m}{l}$



Feature 2 : **Calculating stress from DFN**

- Theory: Green function for a penny-shaped crack Fabrikant (1988)



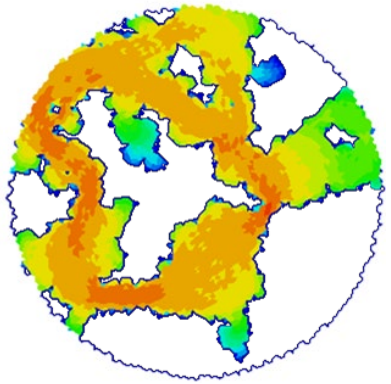
DFN.lab: transmissivity distribution

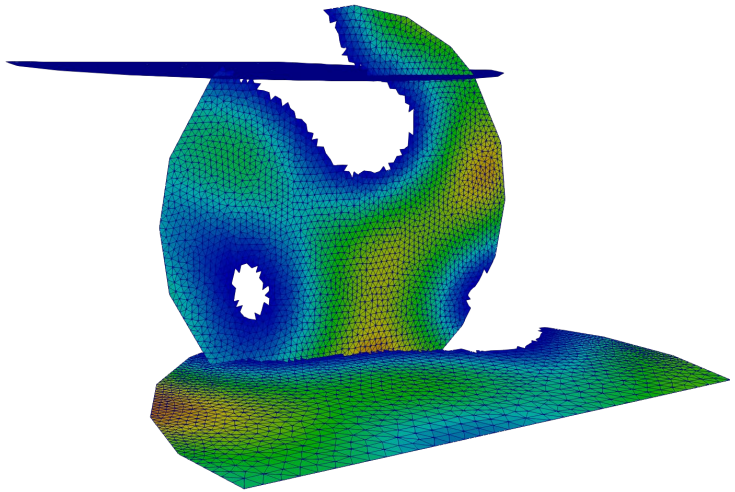
Fracture transmissivity

- function of fracture size
- orientation/stress
- open/sealed distribution (may represent up to 80% of the total surface!

Fracture transmissivity distribution: the IPPA – *In-Plane Patch* – model

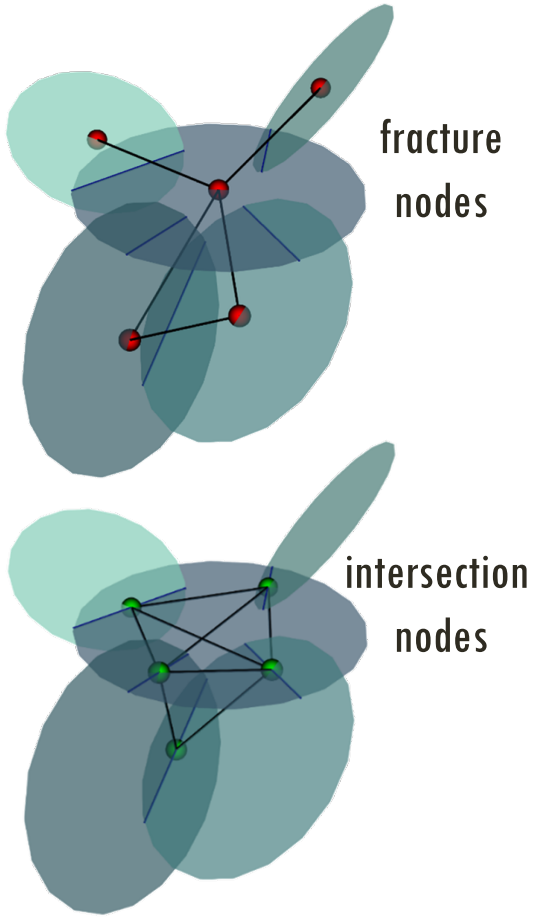
- spatial variability (→responsible for flow channeling)
- sealed patches



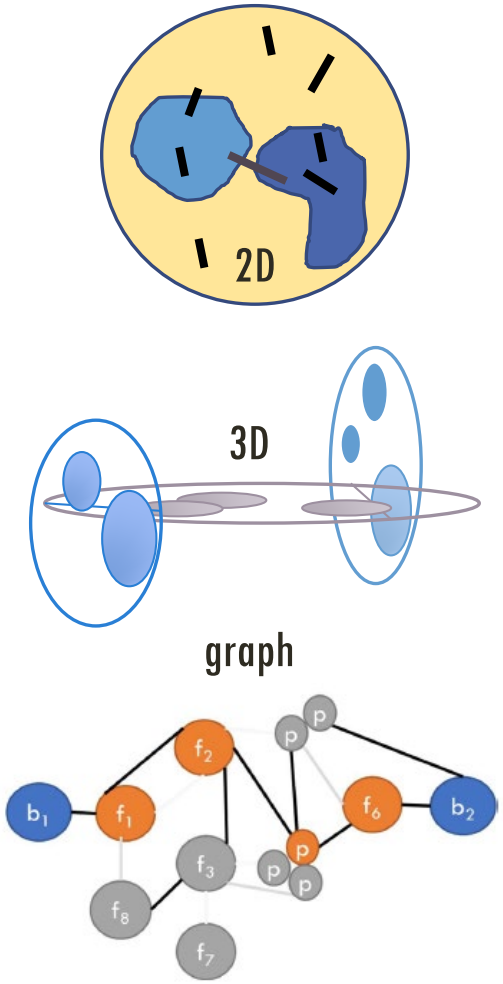


DFN.lab: connectivity graph

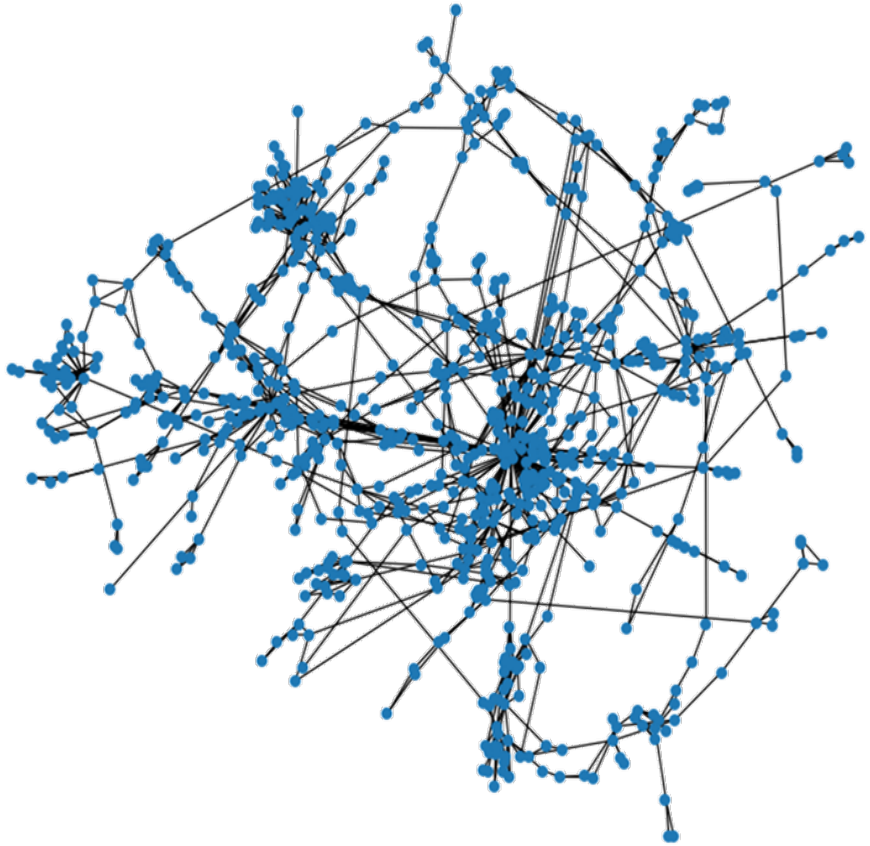
1. DFN connectivity



2. Patch connectivity

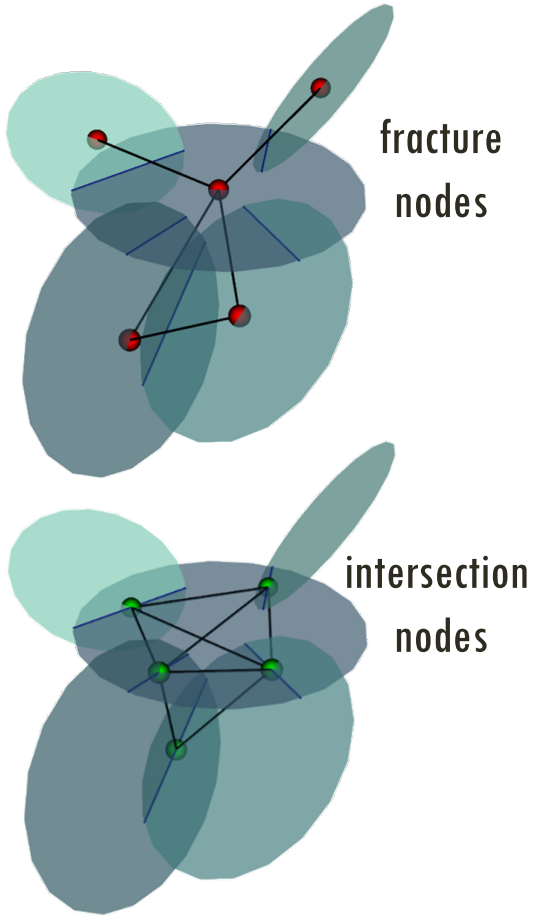


3. graph

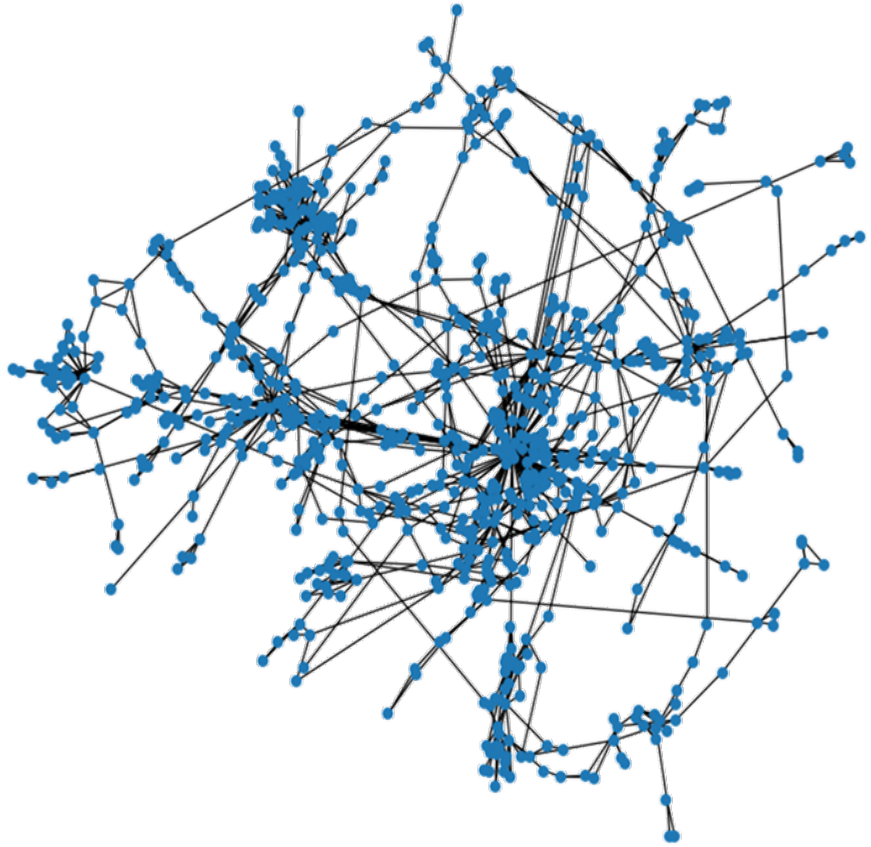


DFN.lab: connectivity graph

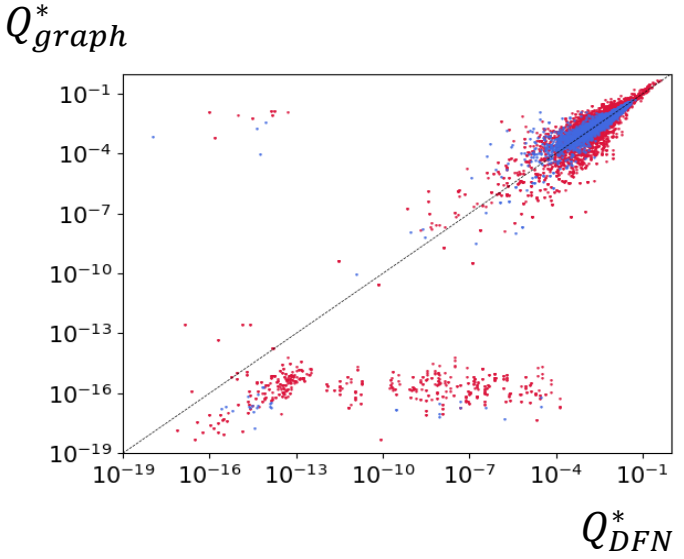
DFN connectivity



graph



Conductance



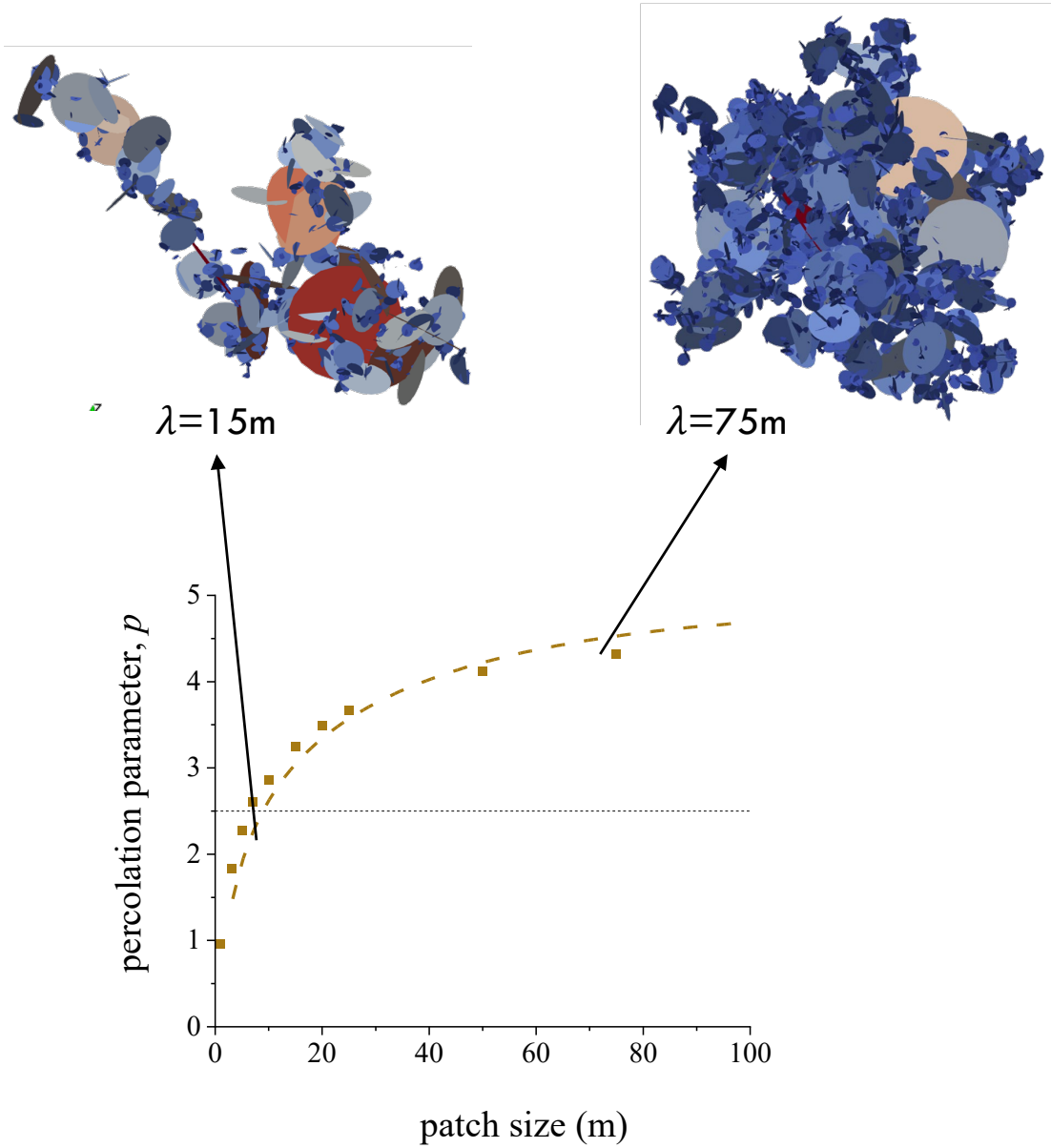
DFN.lab: connectivity graph

Main control

- fracture density
- fracture size distribution
- fracture orientation distribution
- open fraction (f_{op}) vs size
- patch size (λ)

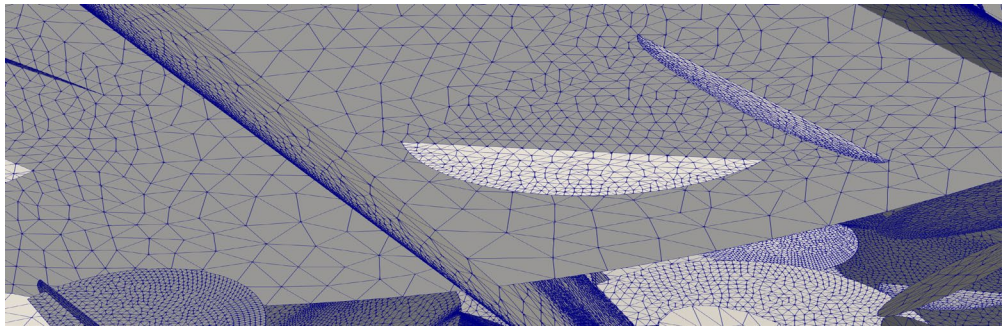
Proxy for connectivity

- percolation parameter $p = \frac{\sum_f l^3}{V}$, with l size of the patches

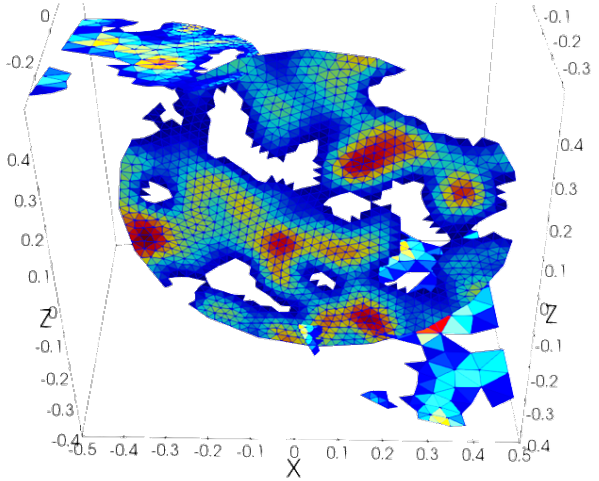


DFN.lab: meshing and solving the flow equations

Conformal meshing
open source mesh generator (BAMG)



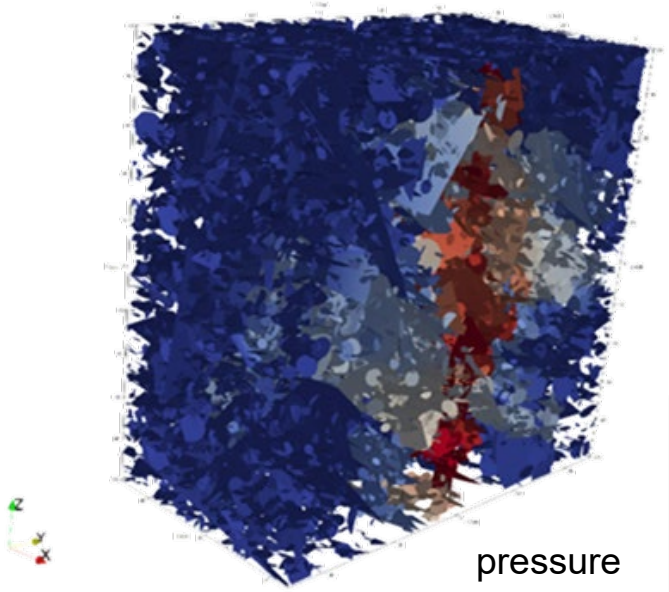
Removing sealed portions



DFN.lab: flow and transport

Flow simulations

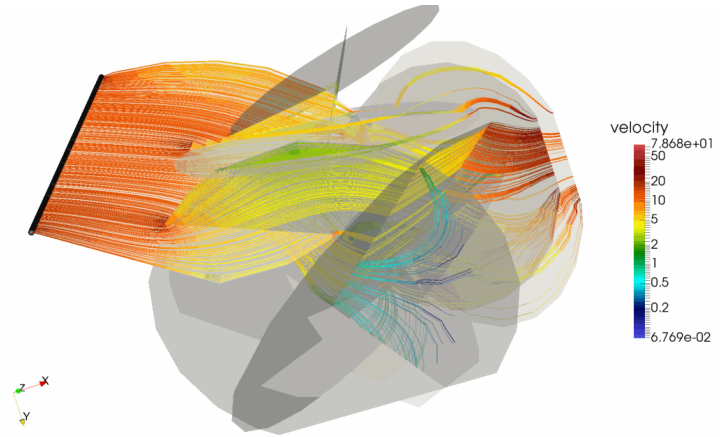
- steady state or transient
- permeameter conditions or pumping test



pressure head

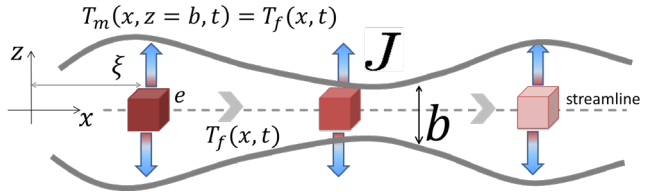
Transport simulations

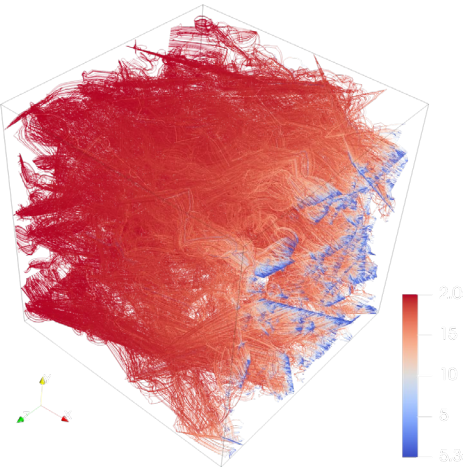
- inert particle tracking



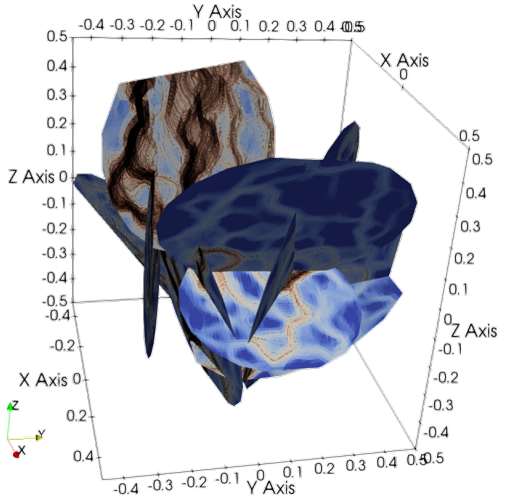
Reactive transport simulations

- "active" particle tracking





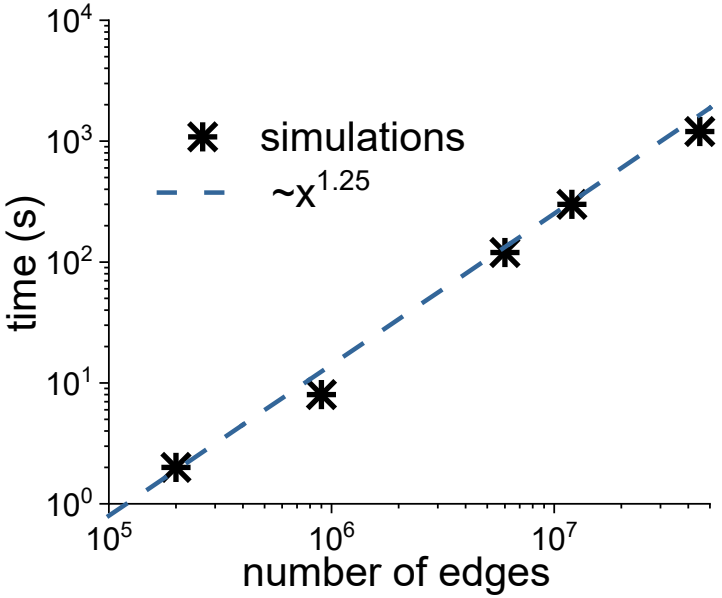
DFN.lab performance: meshing and solving the flow equations



Performance

- Mesh generation → Flow resolution → Transport of particles
- millions of fractures in a reasonable time
- almost linear performance

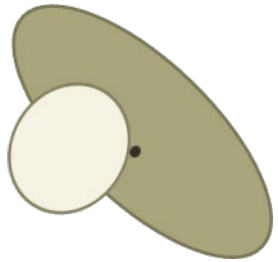
fractures	mesh elements	mesh generation	Darcy resolution	Transport 300 000 particles
398 491	10 840 003	1486 s	2083s	1064s
21 411	1 835 047	148 s	61s	101s

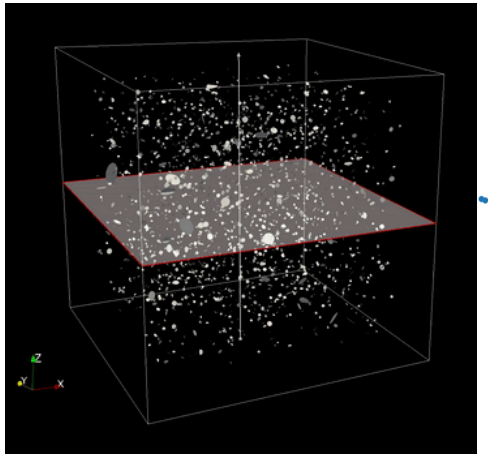


DFN.lab: original features

Genetic DFN model

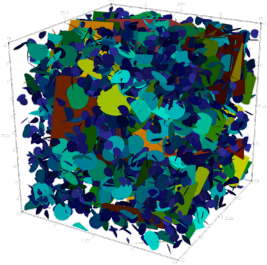
alternative DFN

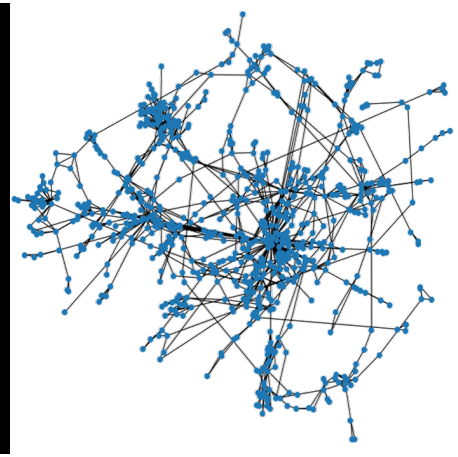




Graph

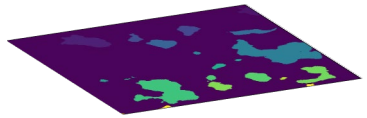
connectivity analysis

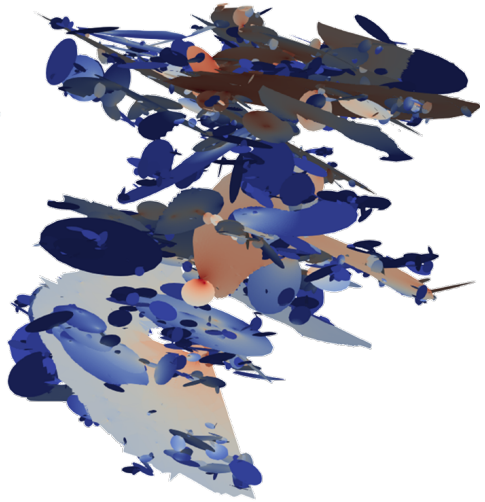




Transmissivity model

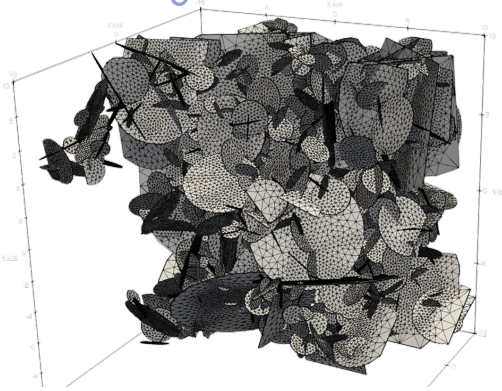
in-plane patches

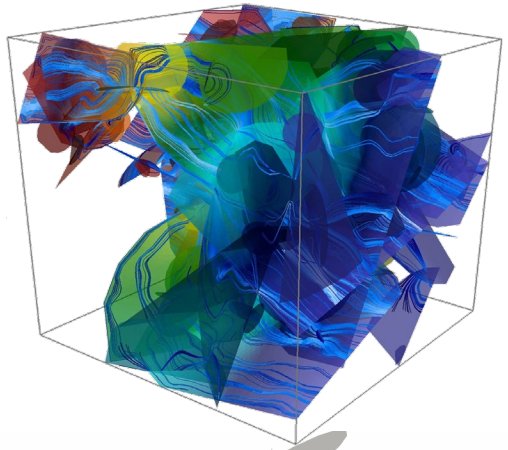


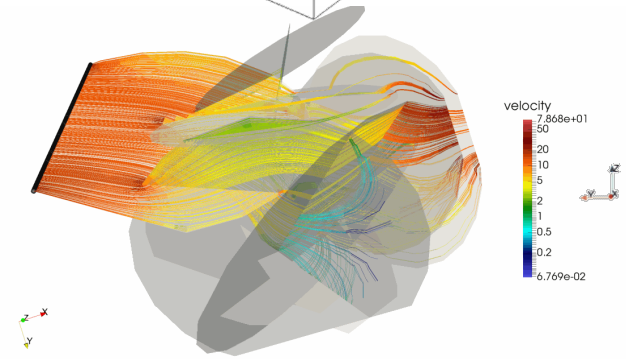


Flow & transport

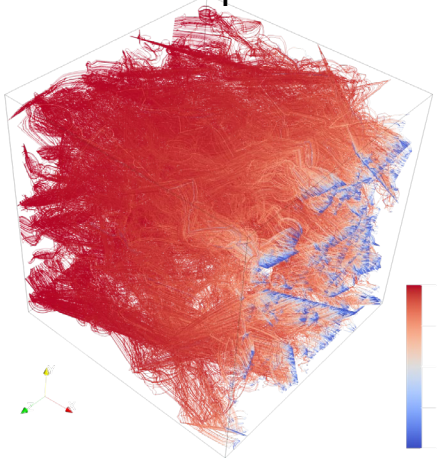
large-scale DFN

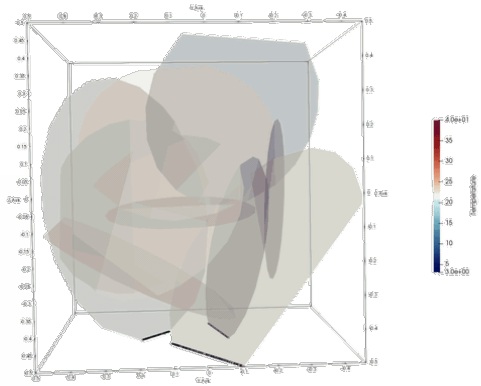






Reactive & energy transport





DFNlab: development timeline

DFN.Lab platform

collaboration with DFNworks (Los Alamos)

- 1st major release
- integration in Itasca codes (feasibility)
- collaboration with Amphos 21 interface with reactive transport code
- collaboration with INRIA on numerical methods
- interface with DarcyTools (SKB)
- documentation, articles and courses

- recruitment
- SKB validation for safety assessment
- DFN.lab workshop

DFN.lab Licence and user support

Owner

- Fractory.lab, joint laboratory between Itasca Consultants s.a.s., CNRS, University of Rennes

Philosophy

- DFN.lab is the platform, where most of the numerical developments made during collaborative projects are stored, verified, and made available for other projects and partners.

Licence

- Proprietary licensed (PL)
- Some elements may evolve towards a free GPL license

DFN.lab The team

https://fractorylab.org/

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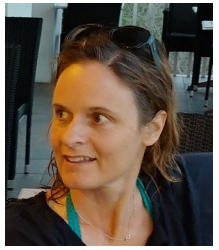
Engineer



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