A new approach to mesh a discrete fracture network (DFN) Application on flow and transport

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Outline

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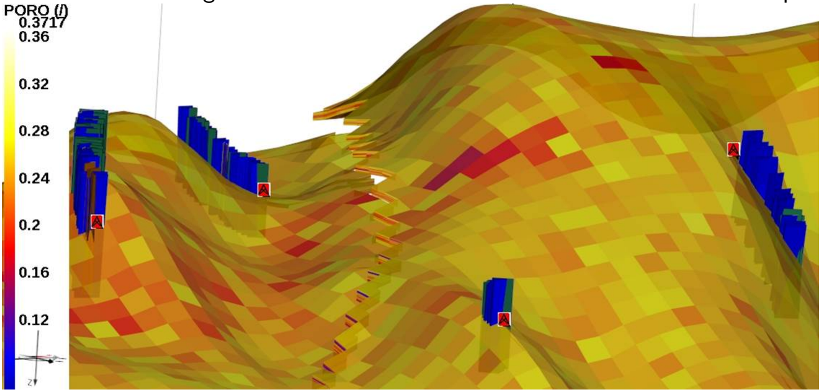
Geological context : fractured reservoir

Some reservoirs present complex fracture networks

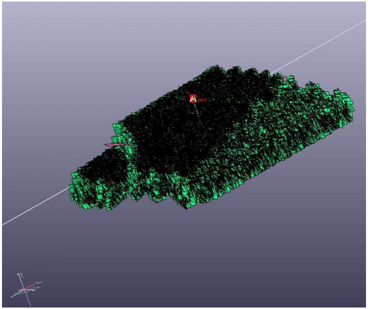
Fracture log | Faults and structural maps



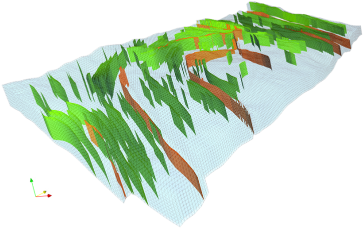
Vercors reservoir

Geological context : fractured reservoir

Discrete fracture networks (DFN)= Different fracture/fault scales



metric scale



kilometric scale

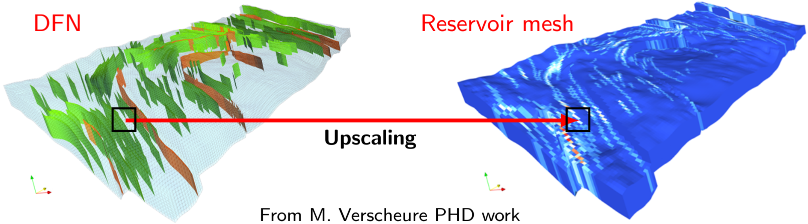
Upscaling properties : obtained from optimal/simplified fracture and flow models

- **Geologic data → reservoir mesh, which may contain more than 10^6 fractures**

→ Traditional reservoir modeling softwares don't model flow on discrete fracture network (avoid of prohibitive CPU time).

→ Utilize simplified continuous models where cell petro-physical parameters are computed by upscaling with strong assumptions (N. Khvoenkova & M. Delorme, 2011)

→ Need of fine reference simulations at geological grid cell scale ($\sim 10^3$ fractures) to validate the simplistic assumptions



From M. Verscheure PHD work
(Verscheure et al., 2012)

The goal of the presentation

- Is it to propose an optimal approach to model fractured media transfers ? NO

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- Is it to propose a new numerical scheme to discretize transfer equation ? NO

- Is it to propose a "rough-and-ready" mesh approach for only DFN in neglecting matrix rocks? YES

  → Simple to implement

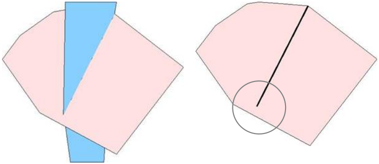
  → Using a conform mesh, which can be used by classical numerical scheme

Outline

Conform mesh approach
Difficulties : model the intersections

- Fractures are **2D-in-3D** objects
- Classical approaches :

Based on exact intersection geometries



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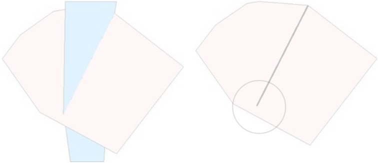
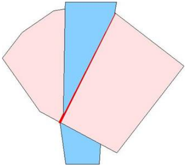


- Fracture Cut Method for Meshing (FCMM)

1) Extend fracture intersection,



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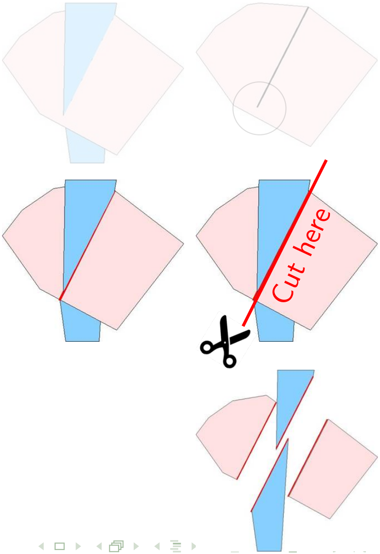
Results : Intersections are located on the borders of each fracture closed outlines



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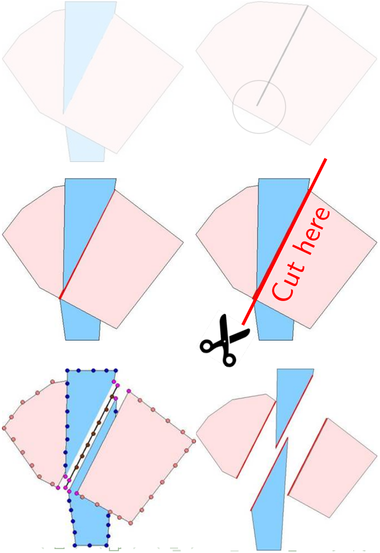


Conform mesh approach

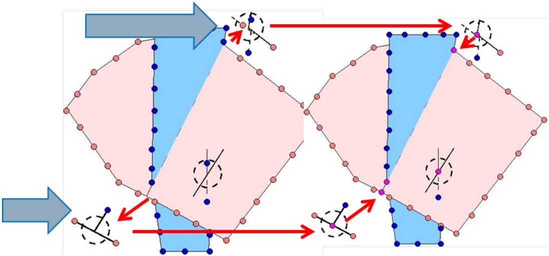
Our method

3) Discretize closed outlines

Depending on intersection neighborhood (black circle), common points between fracture outlines and intersection are carefully treated.

For that :

- Outline point may be moved
- Or a new point may be added



Conform mesh approach

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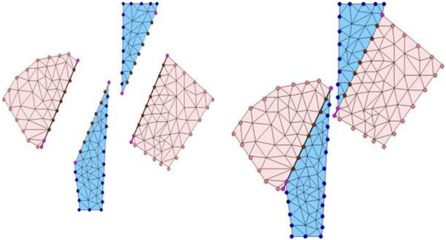
4) Final mesh is classically obtained using

- Delaunay triangulation
  (DKT, Discrete Kirchhoff Triangle)



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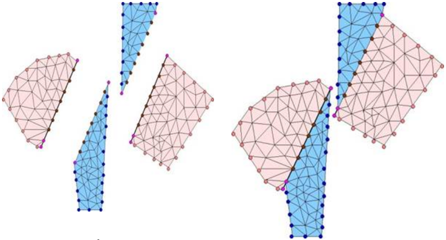
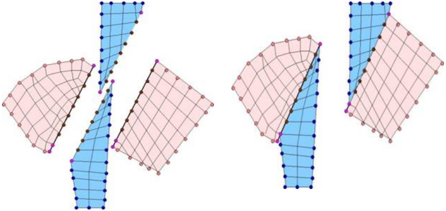


- Quadrangle elements (for transport simulations)



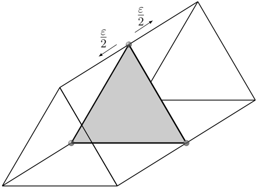
Outline

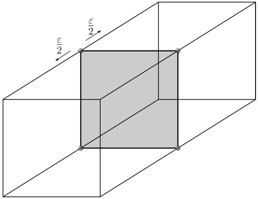
Flow numerical model

$$\mathbf{q} = \frac{\overline{\overline{K}}}{\mu}\nabla(P - \rho g z)$$

$$\begin{cases} \mathbf{q} : \text{ Darcy velocity} \\ \overline{\overline{K}} : \text{ permeability tensor} \\ P : \text{ pressure} \\ \rho \;\&\; \mu : \text{ the fluid density and viscosity} \end{cases}$$

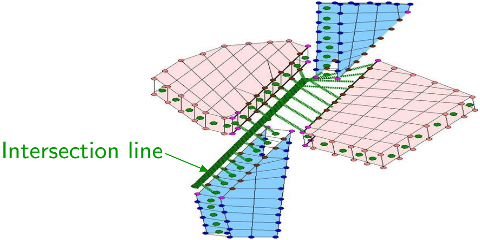
- Different numerical schemes may be applied to this mesh.
  - Finite Element Method (FE)
  - Mixed Hybrid Finite Element Methods(MHFE)
- 2D-in-3D mesh : Only thermal model works (using FE)
- 3D mesh : Darcy model can be used → 3D mesh must be built



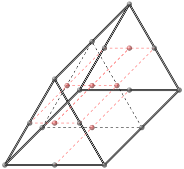


Cast3M use: MHFE Method

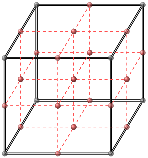
- Mass conservation at fracture intersections is ensured in MHFE



Conversion to QUAF mesh using CHANGE operator



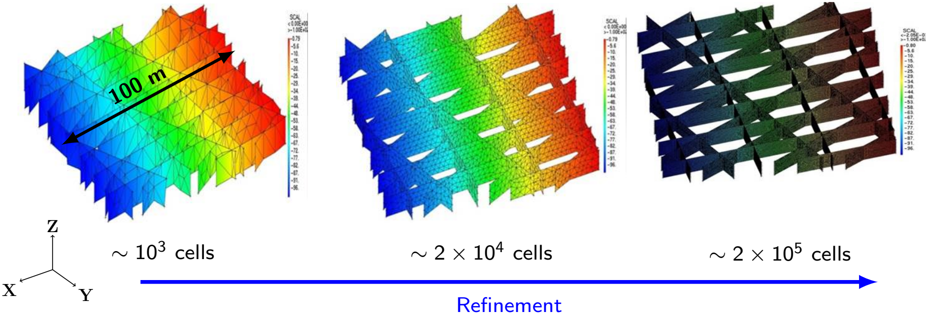
`PRI15` → `QUAF(PRI21)`



`CUB8` → `QUAF(CUB27)`

Validation: Regular DFN

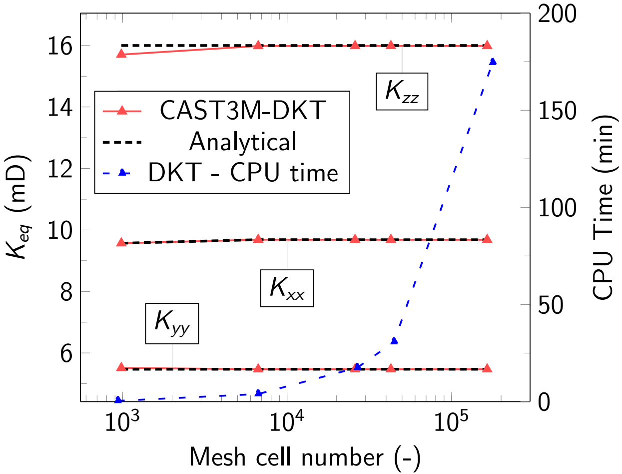
- Flow is modeled considering three pressure gradient orientations (space axis).
- DFN upscaling permeabilities (K_{eq}) are:
    - computed by using reverse Darcy method
    - analytically calculated by Oda's approach [1], which is an exact solution only when each fracture crosses throughout the domain.



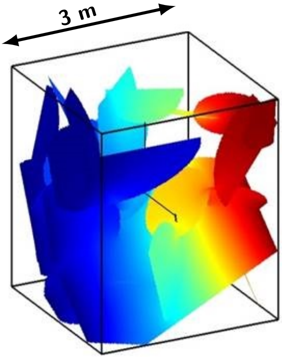
[1] Oda, M. (1985). Permeability tensor for discontinuous rock masses. Geotechnique, 35(4), 483-495.

Validation: Regular DFN - K_{eq}

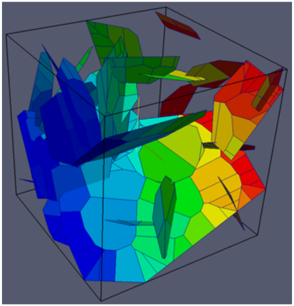
Fracture permeability	3.8×10^{-12} m^2	4000 mD
Fracture aperture	0.02 m	



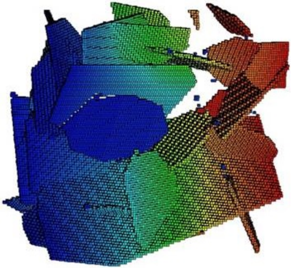
Validation: Benchmark validation of 33 fractures



MP-FRAC
(de Dreuzy et al., 2013)



FracaFlow
(Khvoenkova N. & Delorme M., 2011)



Voxel approach
(Fourno et al., 2013)

Fracture permeability	10^{-11} m^2	10^4 mD
Fracture aperture	0.01 m	

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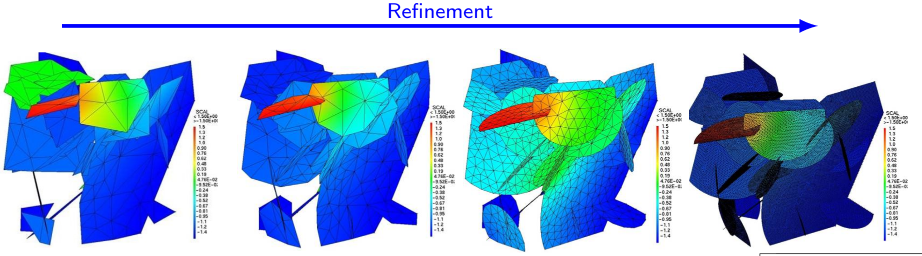

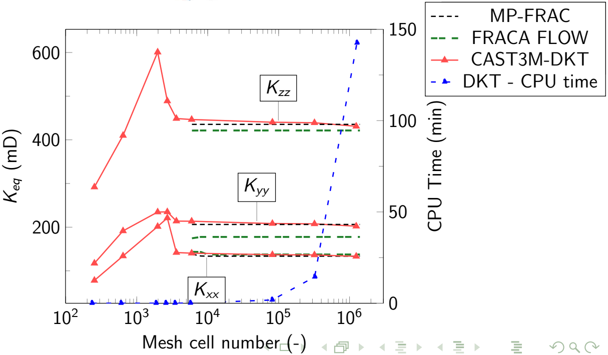

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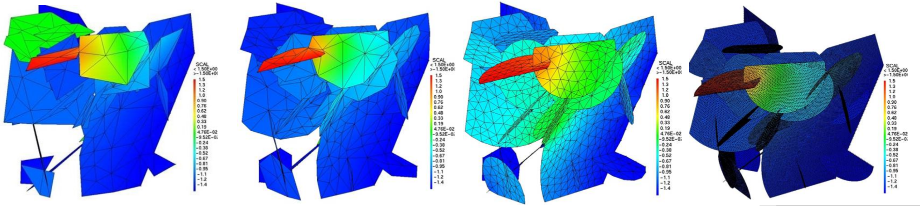
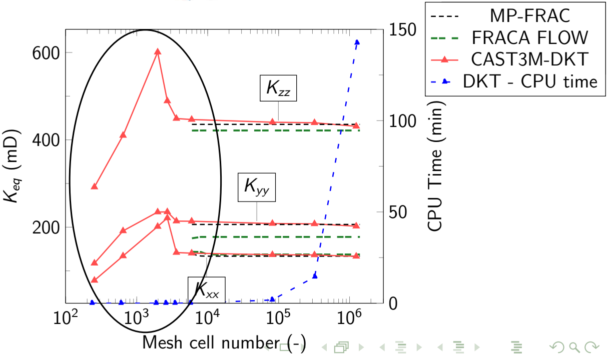
Refinement





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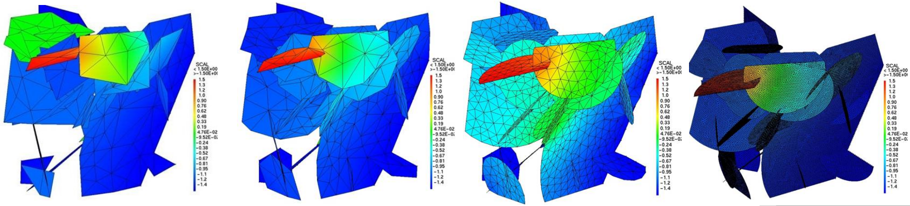
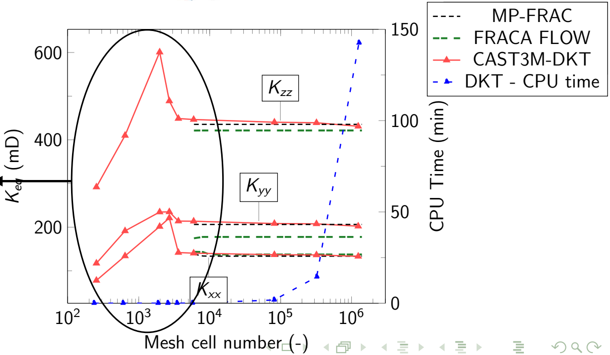


- **Coarse meshes** :
  - DFN connectivity lost
  - Error merging outline points



Outline

Numerical model & Implementation in Cast3M

Numerical model

$$\omega \frac{\partial C}{\partial t} = \nabla.(\overline{\overline{D}}\nabla C - C\mathbf{q})$$

- C : Concentration
- ω : porosity
- $\mathbf{q}$: Darcy velocity
- $\overline{\overline{D}}$: Dispersion tensor

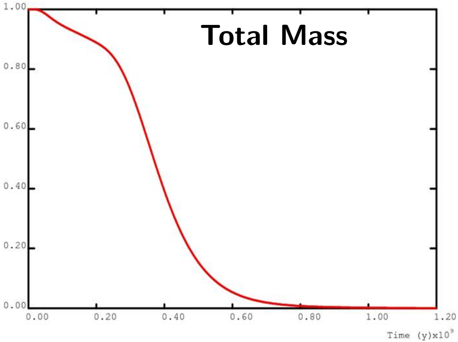
Cast3M use

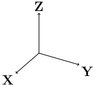
MESH	TRI3	PRI15 → QUAF(PRI21)	CUB8 → QUAF(CUB27)
MODEL	THERMAL	DARCY	
Numerical Scheme	X	MHFE	MHFE
Transport	X	KO	OK

- PRI21 results are not corrects

Transport: a plume injection [1]

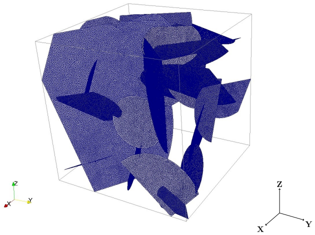
- Boundary conditions: $C(x^-, x^+, y^-, y^+) = 0$, $\Phi(z^-, z^+) = 0$
- Initial condition: $M_0 = 1$
- Flow along Y-axis





Transport: a plume injection [2]

- Boundary conditions: $C(z^-, z^+) = 0, \Phi(x^-, x^+, y^-, y^+) = 0$
- Initial condition: $M_0 = 1$
- Flow along gravity direction



Outline

Conclusion

Thank to Cast3M:

- The conform mesh approach was validated
  - by permanent flows
  - using both FE and MHFE schemes
- First results for transport was presented
  - MHFE scheme

On-going works: Transport properties upscaling

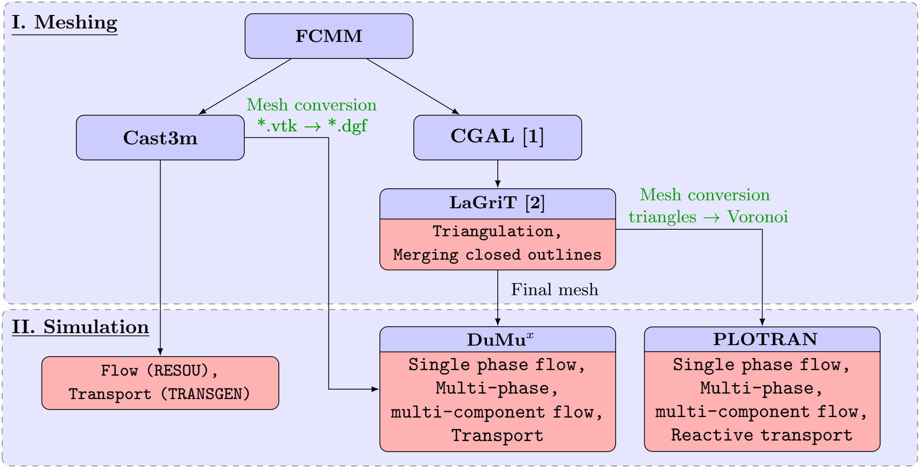
- The mesh approach is being written in C++ to be used with other flow and transport numerical simulators/tools (DUNE [1], DuMu^x [2], PLOTRAN [3])
- Take the matrix rock into account
- Model and upscale two-phase flows using DuMu^x to validate PhD results (Jerbi et al., 2015; Jerbi et al., 2016)

[1] **DUNE**: Distributed and Unified Numerics Environment(*https://www.dune-project.org/*)

[2] **DuMu**^{x}: **DU**NE for **Mu**lti-Phase, Component, Scale, Physics, ... flow and transport in porous media (*http://www.dumux.org*)

[3] **PLOTRAN**: A Massively **P**arallel Reactive **Flo**w and **Tran**sport Model for describing Surface and Subsurface Processes (*http://www.pflotran.org*)

On-going works: Workflow



[1] **CGAL**: The Computational Geometry Algorithms Library (*https://www.cgal.org/*)

[2] **LaGriT**: Los Alamos Grid Toolbox (*http://lagrit.lanl.gov/*)

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Why adding points?