Discretization Toolkit for AD-GPRS

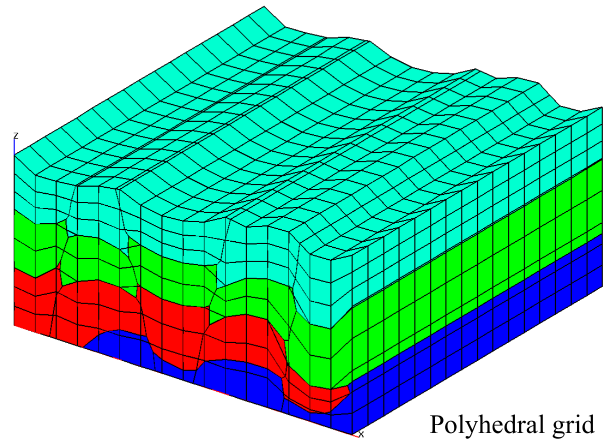
Kirill Terekhov, Christine Mayer, Hamdi Tchelepi

34th SUPRI-B Annual Meeting

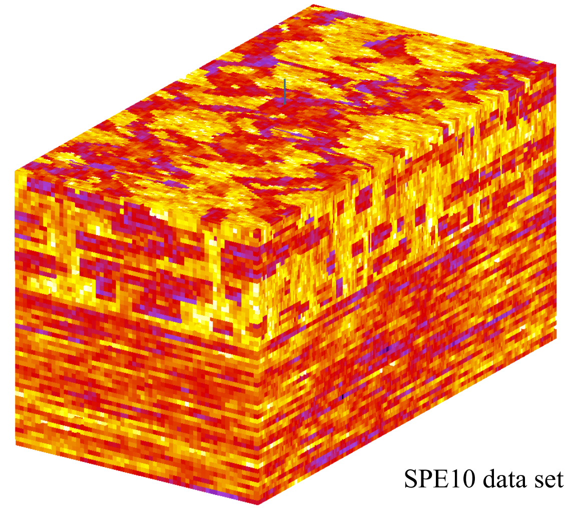
Purpose of Discretization Toolkit

The primary purpose of the toolkit is to fill the gap between reservoir geometry and properties description and the AD-GPRS simulator.

The toolkit can process general polyhedral mesh with designated fractures and properties and produce connection lists and data for simulation of model as complex as compositional thermal flow coupled with geomechanics.



Polyhedral grid



SPE10 data set

Capabilities of Discretization Toolkit

- Computes approximation for Darcy flux (dead oil, black oil, compositional).
- Allows to define the wells with complex trajectory (vertical, horizontal, slanted, branched).
- Supports discrete fracture models.
- Processes thermal properties and approximations.
- Processes mechanical properties of the media for thermo-mechanical effects.
- **Prepares full set of data to run a model in AD-GPRS**

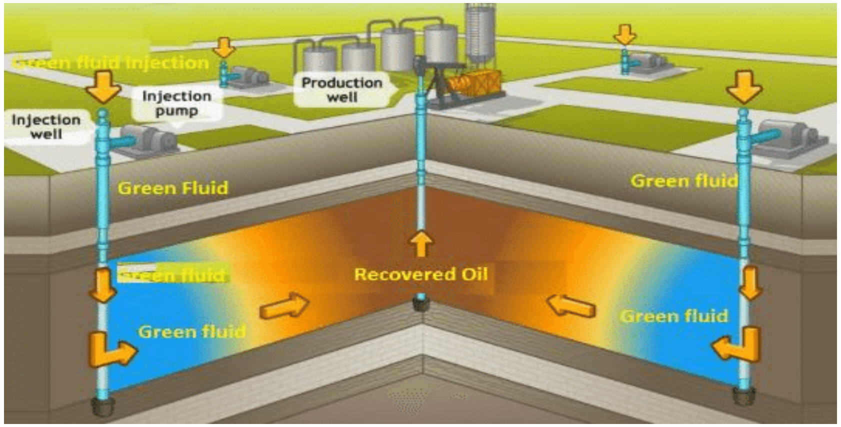


Image: www.researchgate.net/profile/Omar_Chaalal

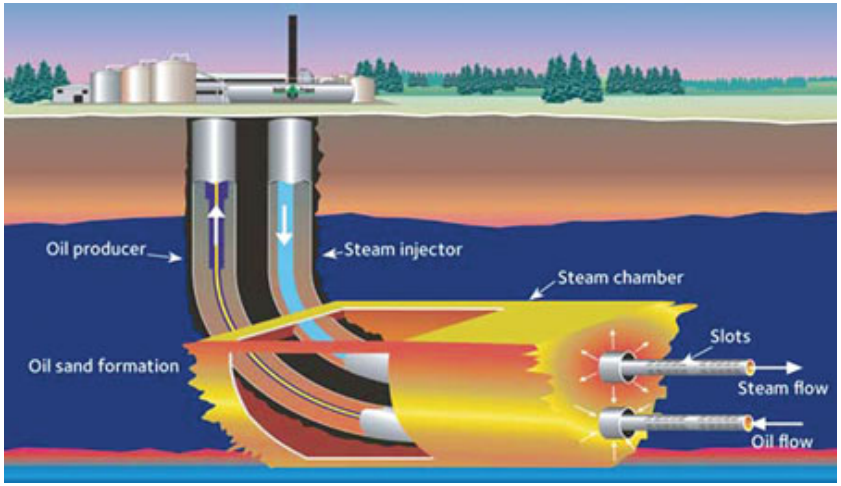


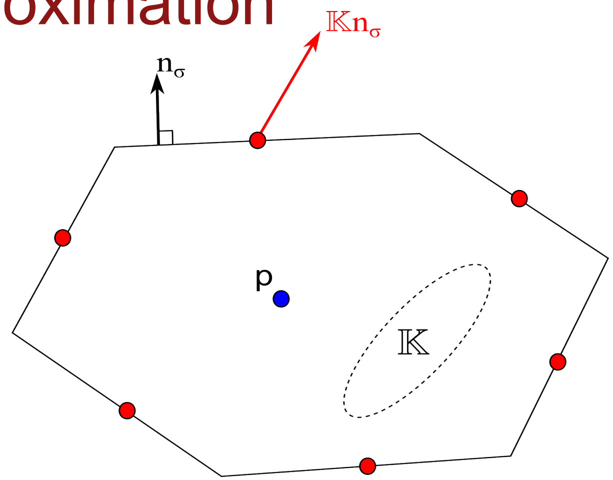
Image: www.upstreampumping.com

Methods for the Darcy flux approximation

- For mass balance equation:

$$-\nabla \cdot \mathbb{K}\, \nabla p = g$$

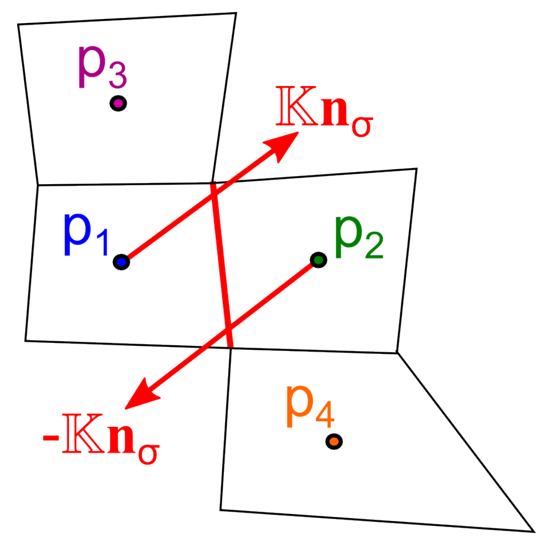
- Finite volume methods:
  - Conventional TPFA.
  - MPFA - O/L/G/A/B/AB types.
  - Nonlinear TPFA, MPFA.



- Mixed Hybrid Finite Element method by Ahmad Abushaikha.

- Mimetic Finite Difference method.

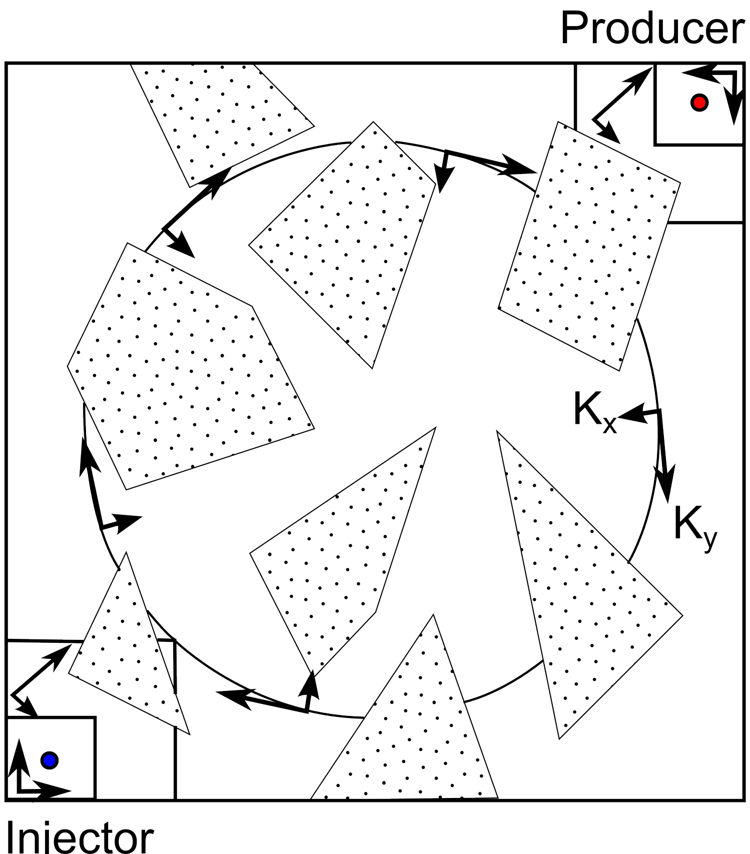
- **Stable approximation methods for problems with full anisotropic permeability tensor on unstructured mesh.**



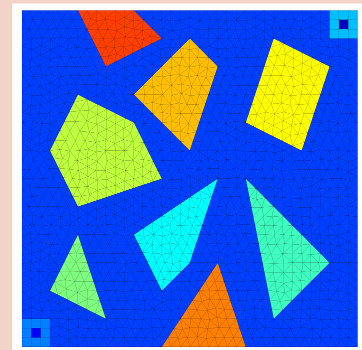
Methods for the Darcy flux approximation

	TPFA	MPFA	NTPFA	NMPFA
Approximation	**NO!**	**YES**	**YES**	**YES**
Robustness	YES	NO	YES	YES
Discrete Maximum Principle	YES	NO	NO	YES
Efficiency	YES	YES	YES	NO

Methods for the Darcy flux approximation



$$\frac{K_x}{K_y} = \frac{1}{100}$$



Mesh geometry

φ	porosity
$\mathbb{K}$	permeability
p	pressure
S	saturation

Mesh data

Toolkit:
- Discretization
- Connection list

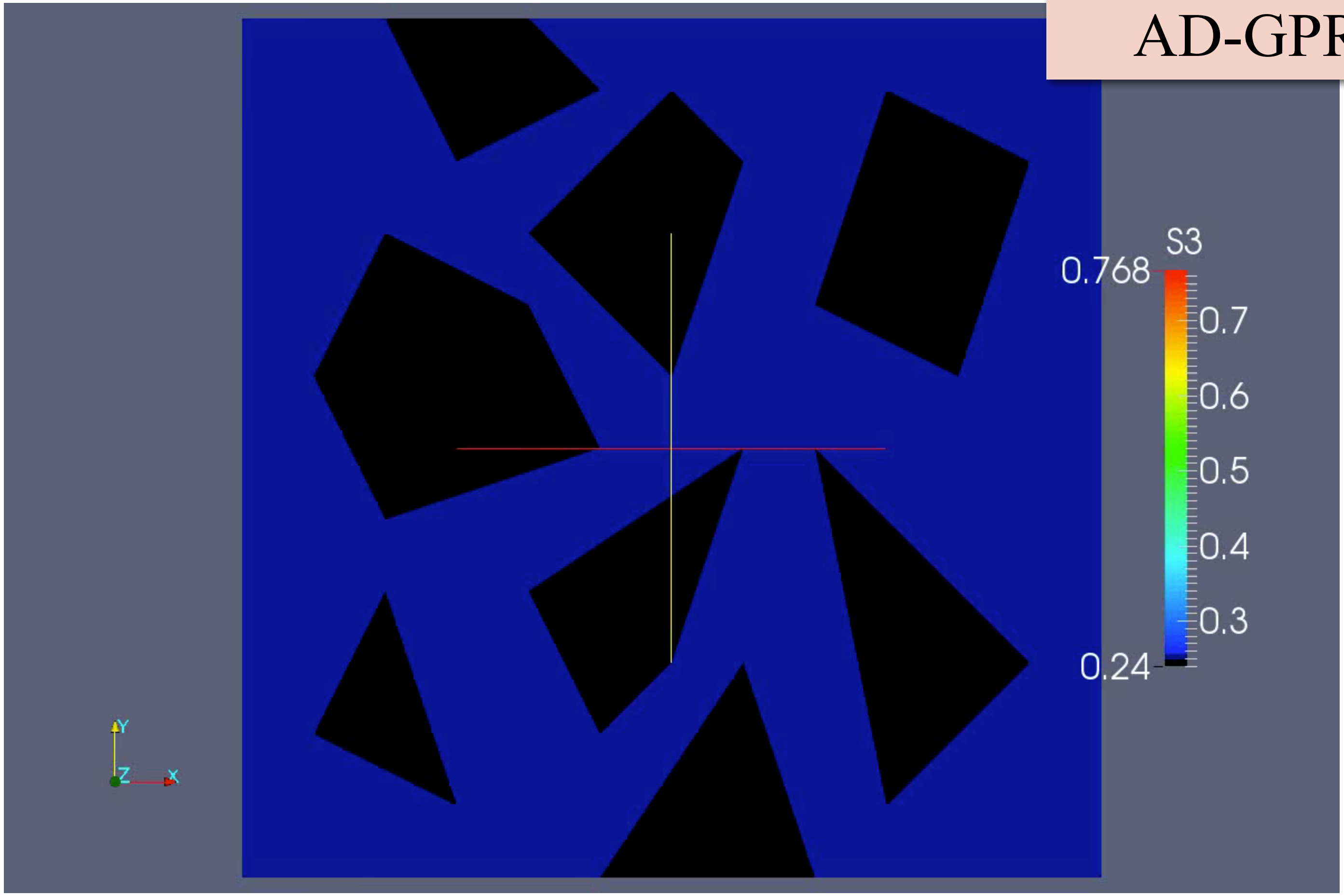
…

. . .

Methods for the Darcy flux approximation

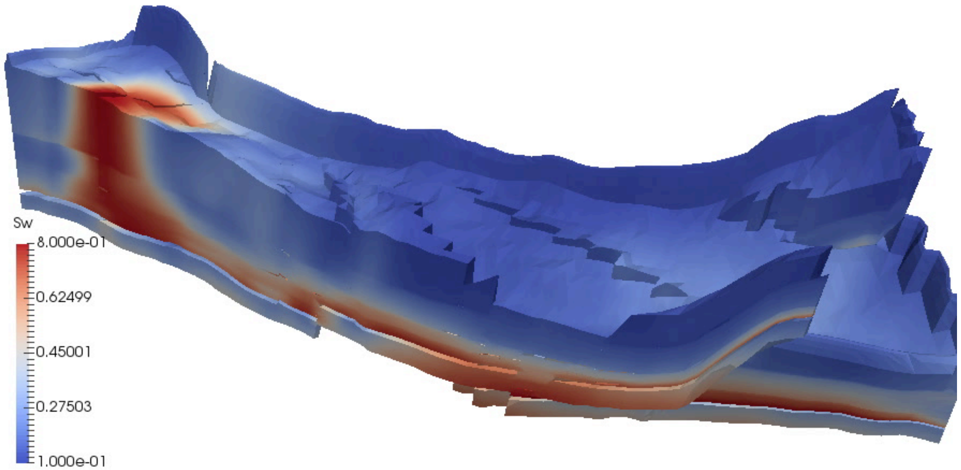
The problem can be solved accurately only with nonlinear finite volume methods

AD-GPRS

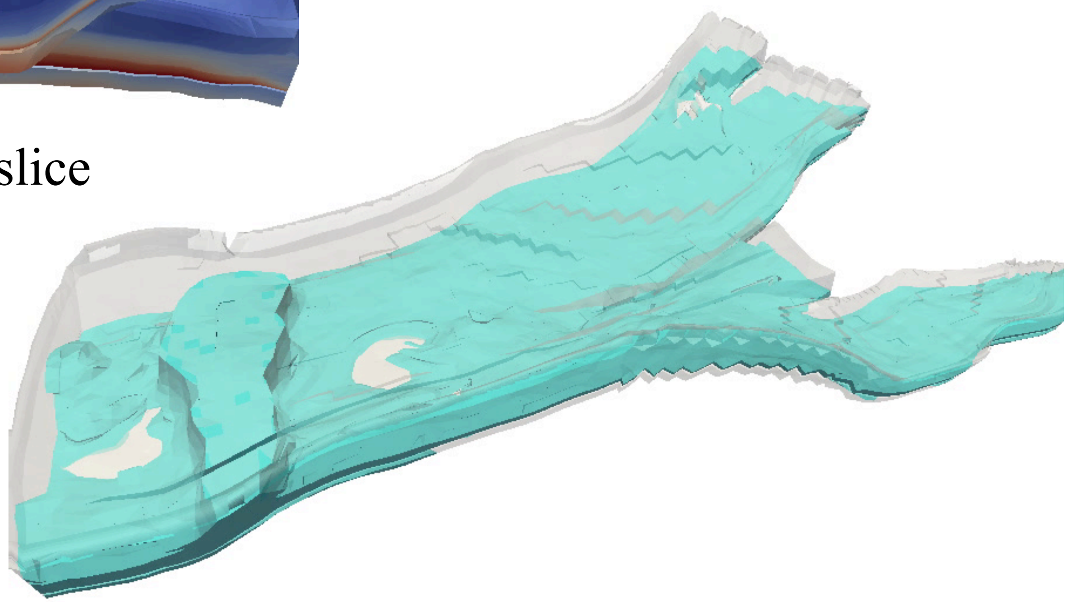


with Brad Mallison

Two phase water flooding in Norne field



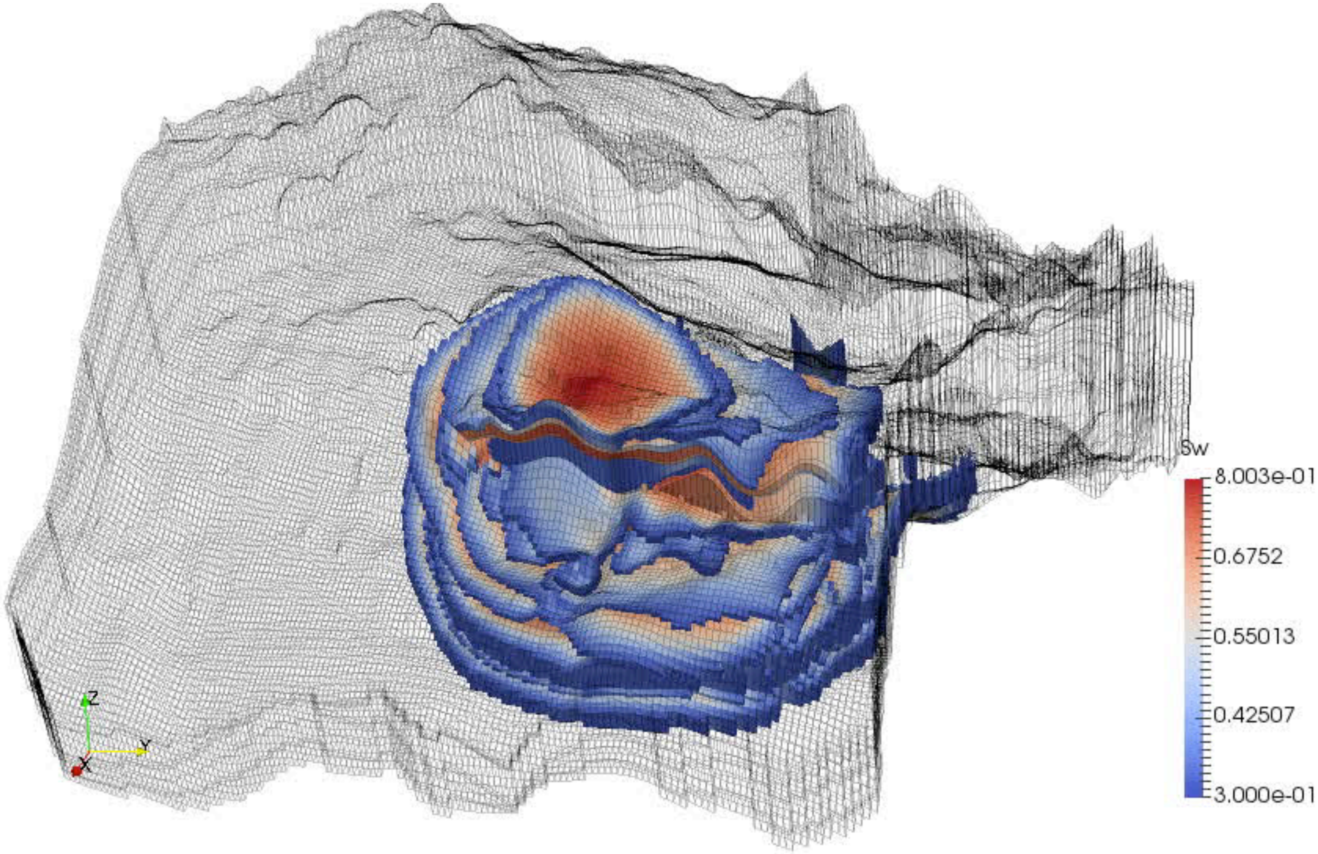
Water saturation in a slice



Water saturation isovolume

- Complex geometry
- ~50000 blocks

Two phase water flooding in full Norne field

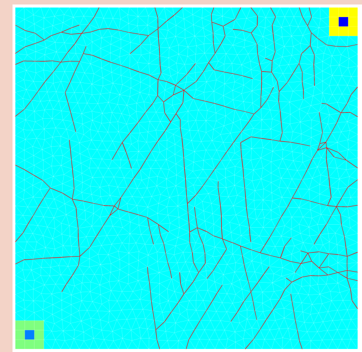


- Complex geometry
- ~300000 blocks

Cells with water saturation above threshold

Methods for the Discrete Feature Modeling

- TPFA by Mohammad Karimi-Fard.
- MPFA-O by Christine Mayer.
- **All** the other finite volume schemes **support fractures**: MPFA-O/L/G/A/B/AB, Nonlinear TPFA, MPFA.

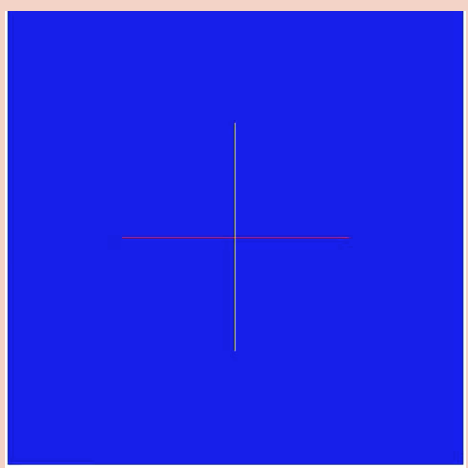


Mesh geometry

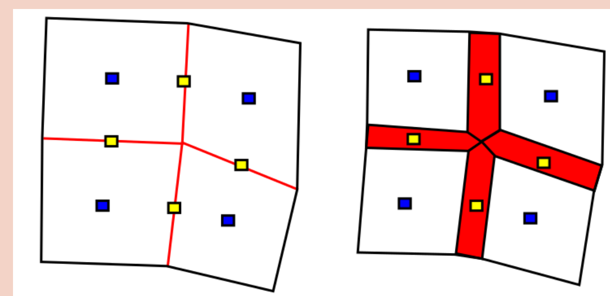
φ porosity
$\mathbb{K}$ permeability
p pressure
S saturation
α aperture

Mesh data

with Brad Mallison



AD-GPRS

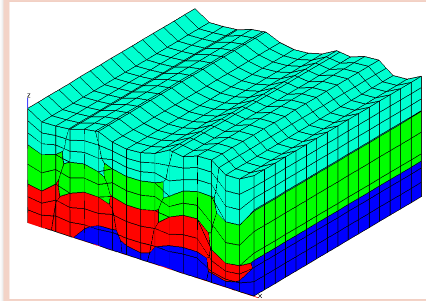


Toolkit:

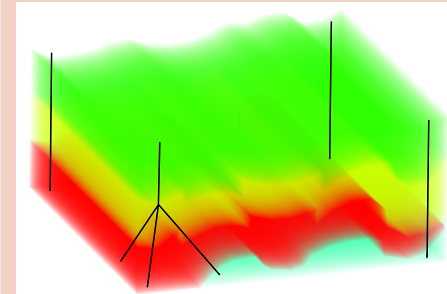
- Mesh modification
- Discretization
- Connection list

Wells

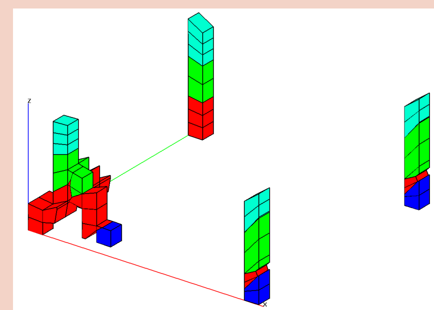
- Finds intersection of unstructured general polyhedral grid with set of segments.
- Calculates well index via Peaceman's formula or uses provided value.
- Can penetrate fractures.



Mesh geometry

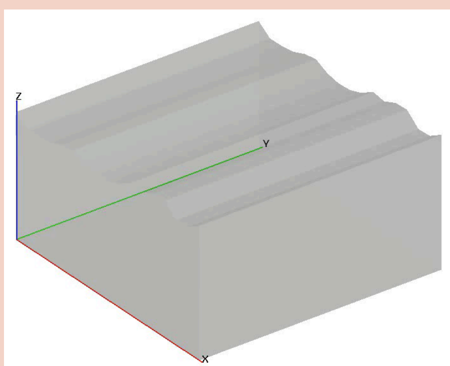


Well segments



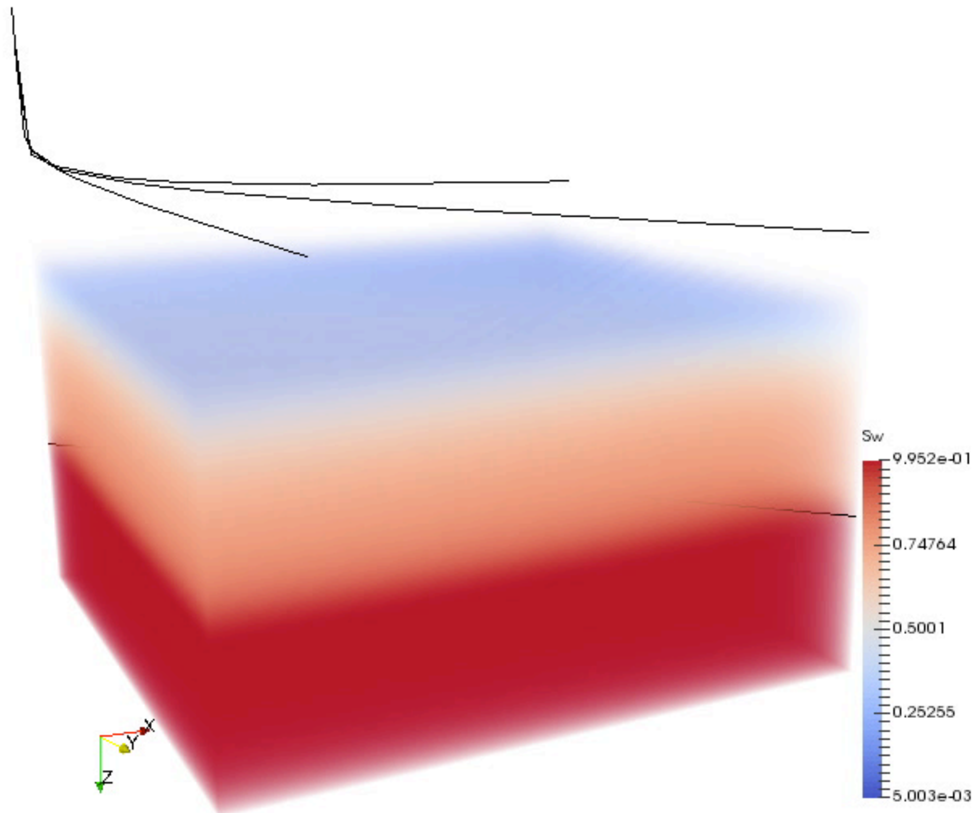
Toolkit:

- Geometry intersection
- COMPDAT entries



AD-GPRS

Well with multiple brenches



Water is pushed by injection well from below

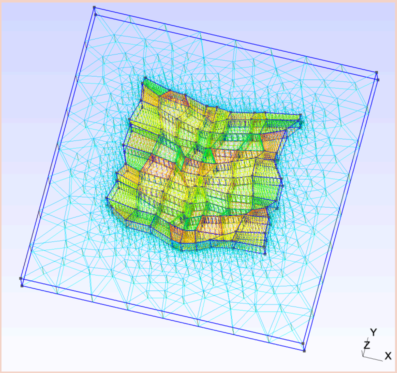
Thermal

- Processes data for heat transfer equation:

$$-\nabla \cdot \mathbb{C}(p, S, T)\nabla \mathrm{T} = \mathrm{q}$$

- Currently thermal fluxes with nonlinear conductivity are calculated via linear two-point formula only.

- **Unified input with flow.**



Mesh geometry

φ	porosity
$\mathbb{K}$	permeability
p	pressure
S	saturation
α	aperture
$\mathbb{C}$	conductivity
T	temperature

Mesh data

Toolkit:

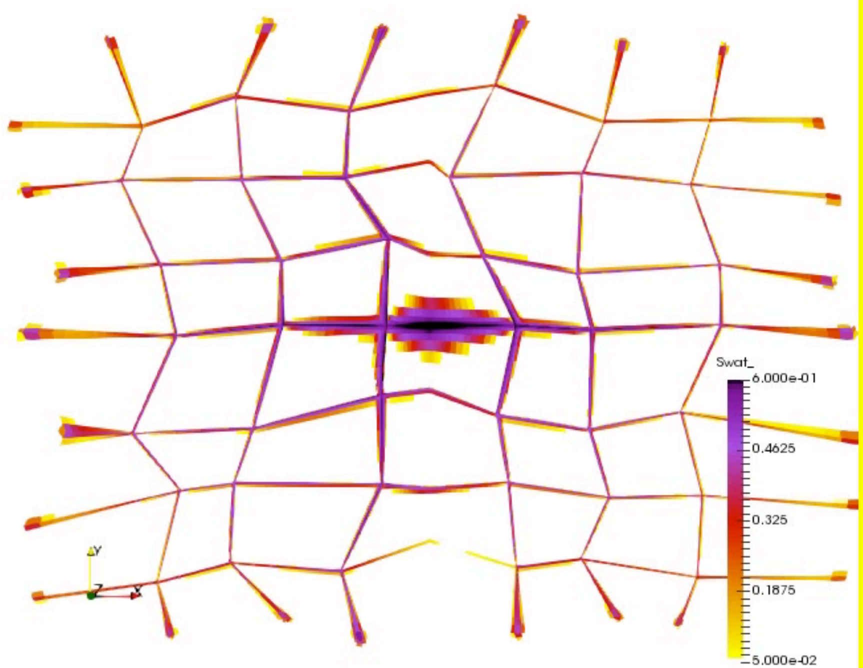
- Fractures
- Discretization
- Connection list
- Data

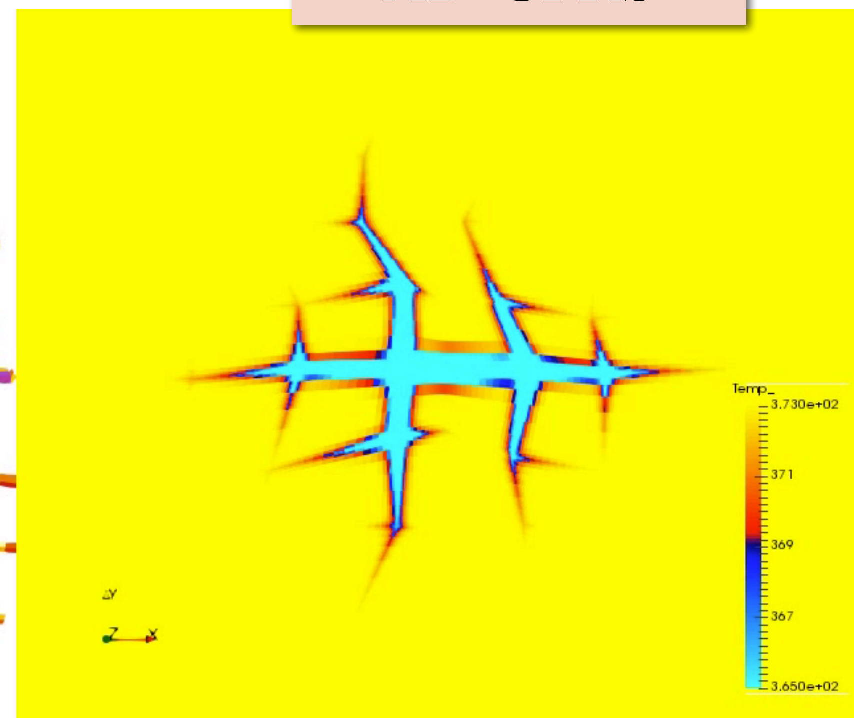
…

. . .

Thermal with Fractures, Nonlinear Permeability

AD-GPRS





With Timur Garipov

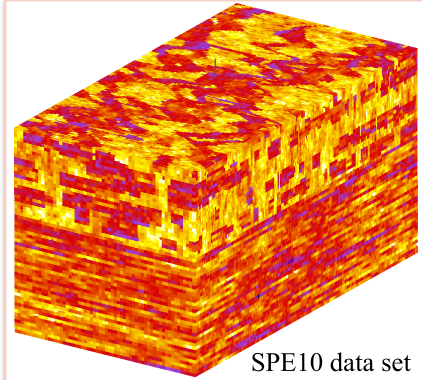
Geomechanics

- For poroelasticity equation:

$$-\nabla \cdot \sigma = \boldsymbol{f}$$

$$\sigma = \mathbb{E}(p, T, S, \boldsymbol{u}) : \frac{\nabla \boldsymbol{u} + \nabla \boldsymbol{u}^T}{2}$$

- Prepares full set of data for geomechanics simulations.
- Performs geometrical processing for fractures.
- New finite volume approximation method would be integrated.
- **Unified input with flow.**



Mesh geometry

μ, λ Lame coefficients
ν Poisson ratio
E Young modulus
σ stress tensor
b Biot coefficient
$\boldsymbol{u}$ deformation

Mesh data

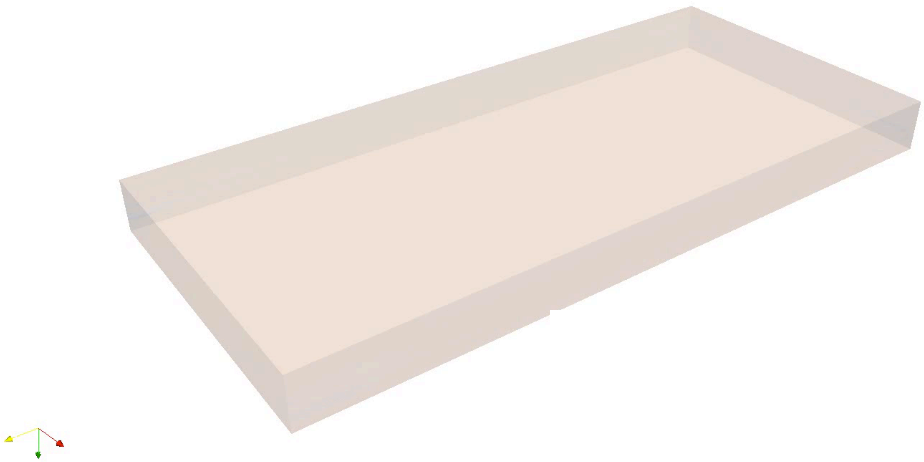
Toolkit:
- Geometry
- Fractures
- Boundary conditions
- Data

…

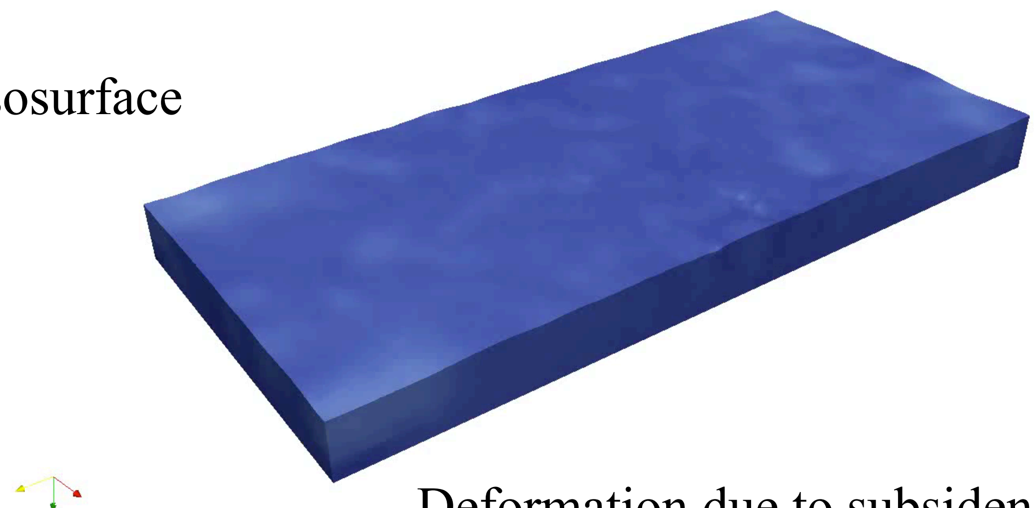
…

Subsidence simulation with SPE10 data

AD-GPRS



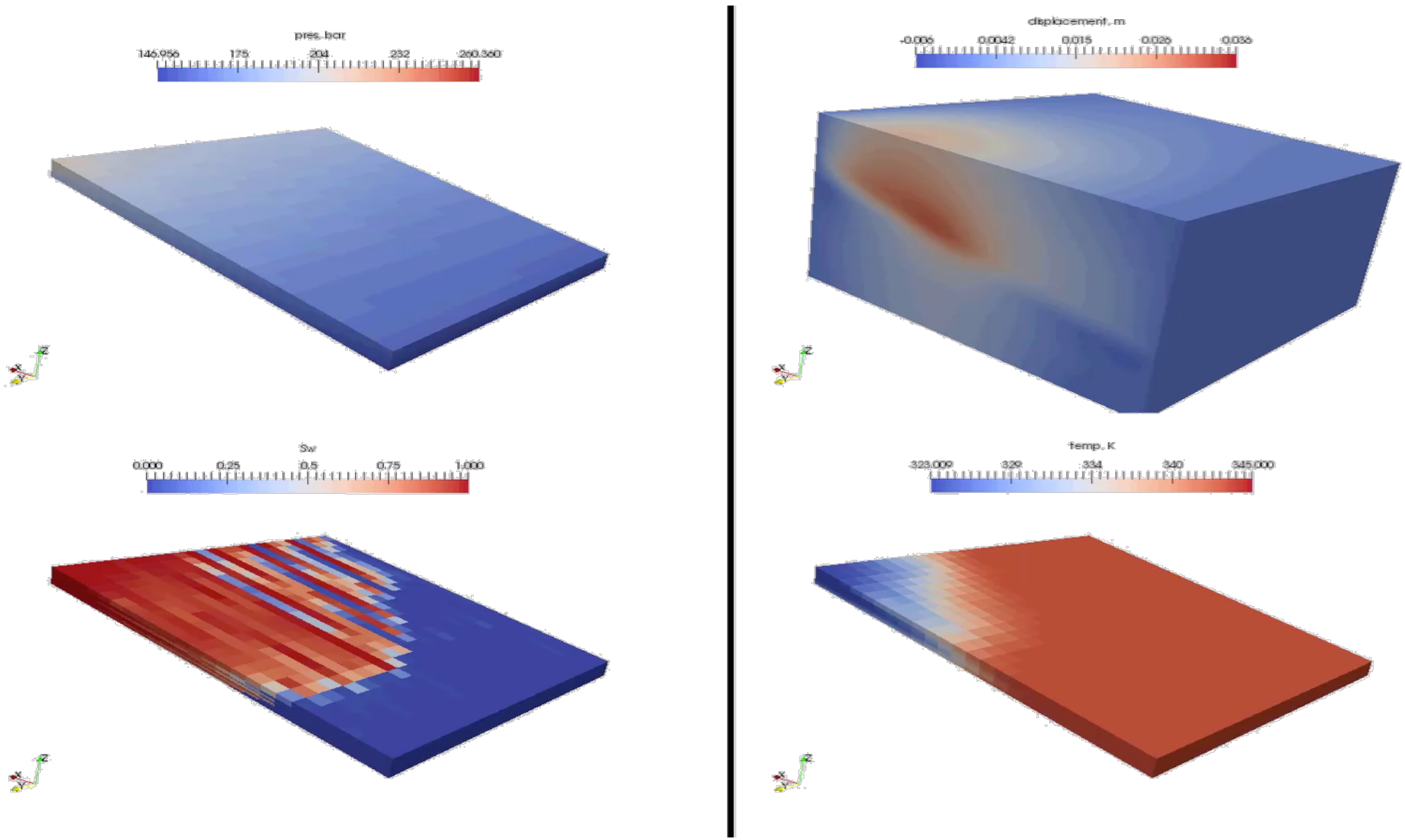
Water saturation isosurface



Deformation due to subsidence

By Pavel Tomin

Geomechanics+Thermal, Cold Water Injection



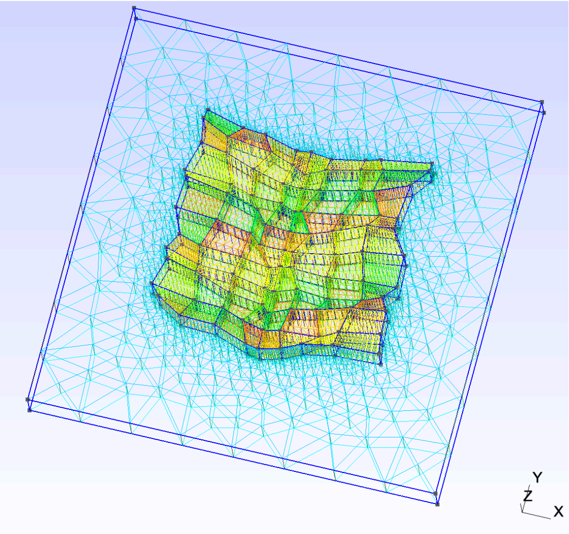
By Ruslan Rin

How do you input data into Discretization Toolkit?

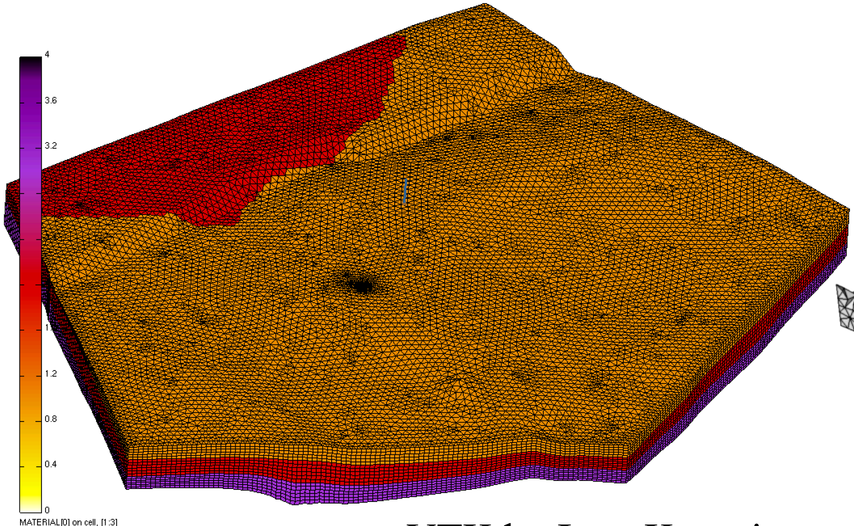
- XML, Gmsh, VTK or other format with designated zones:
  - toolkit will propose to enter properties for each zone.
- XML, VTK, GRDECL, Karimi-Fard mesh format:
  - processes automatically for familiar names of properties and fractures;
  - prompts for missing data or let you specify the data.
- XML format is specifically designed:
  - to specify input programmatically or by hand;
  - very flexible and extendable for future needs.

GMSH/VTK/Karimi-Fard format support

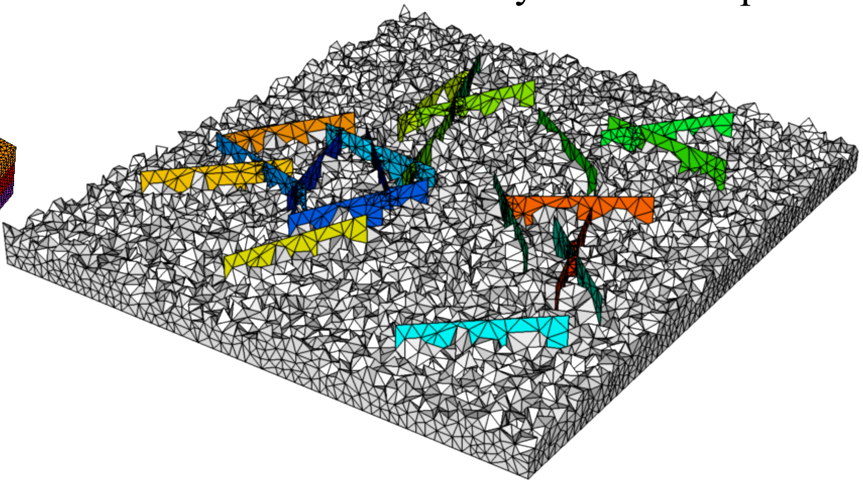
- Pros:
  - Various open-source generators and viewers.
  - General unstructured grids.
- Cons:
  - Not suited for complex data input.
  - Not easy for faults.



GMSH by Timur Garipov

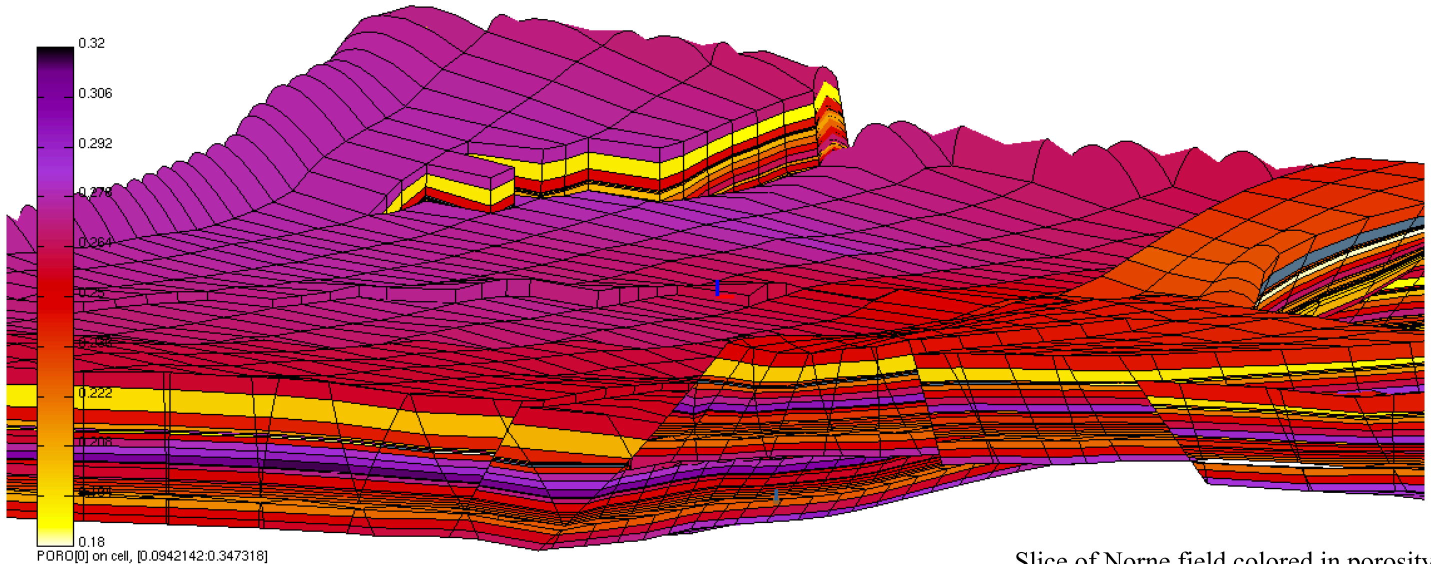


VTK by Ivan Kapyrin



GRID by Mohammad Karimi-Fard

GRDECL format support



Slice of Norne field colored in porosity

- Pros:
  - Feature-reach geometry description, Petrel and Gocad support.
  - Allows to streamline conventional industrial simulations into AD-GPRS.
- Cons:
  - Lots of features, hard to support.

XML format support

- Unified format designed specifically for great flexibility in feeding various data into toolkit.
- General polyhedral unstructured grid.
- Nodal boundary conditions for mechanics? – no problem.
- Generate programmatically or enter by hand – eclipse style with formula interpreter.

```
<Mesh>
        <!-- Mesh geometry -->
        <Nodes Number="12">
                ...
        </Nodes>
        <Faces Number="17">
                <Connections Number="17" Type="Nodes">
                        ...
                </Connections>
        </Faces>

        <Cells Number="6">
                <Connections Number="6" Type="Faces">
                        ...
                </Connections>
        </Cells>
        <!-- Sets of elements -->
        <Sets Number="2">
                <Set Name="Cells" Size="6"> ... </Set>
                <Set Name="Fracture" Size="18"> ...     </Set>
        </Sets>
        <!-- Definition of data -->
        <Tags Number="3">
                <Tag Name="PERM" Size="6" Type="Real"/>
                <Tag Name="PORO" Size="1" Type="Real"/>
                <Tag Name="aperture" Size="1"/>
        </Tags>
        <!-- Filling the data -->
        <Data>
                <DataSet TagName="PORO"> ... </DataSet>
                <DataSet TagName="PERM"> ... </DataSet>
                <DataSet TagName="aperture" SetName="Fracture">
                        ...
                </DataSet>
        </Data>
</Mesh>
```

Conclusion

- Currently Discretization Toolkit is a powerful tool:
  - For students and staff to run complex multi-physics simulations.
  - For SUPRI-B members to run their problems with AD-GPRS.

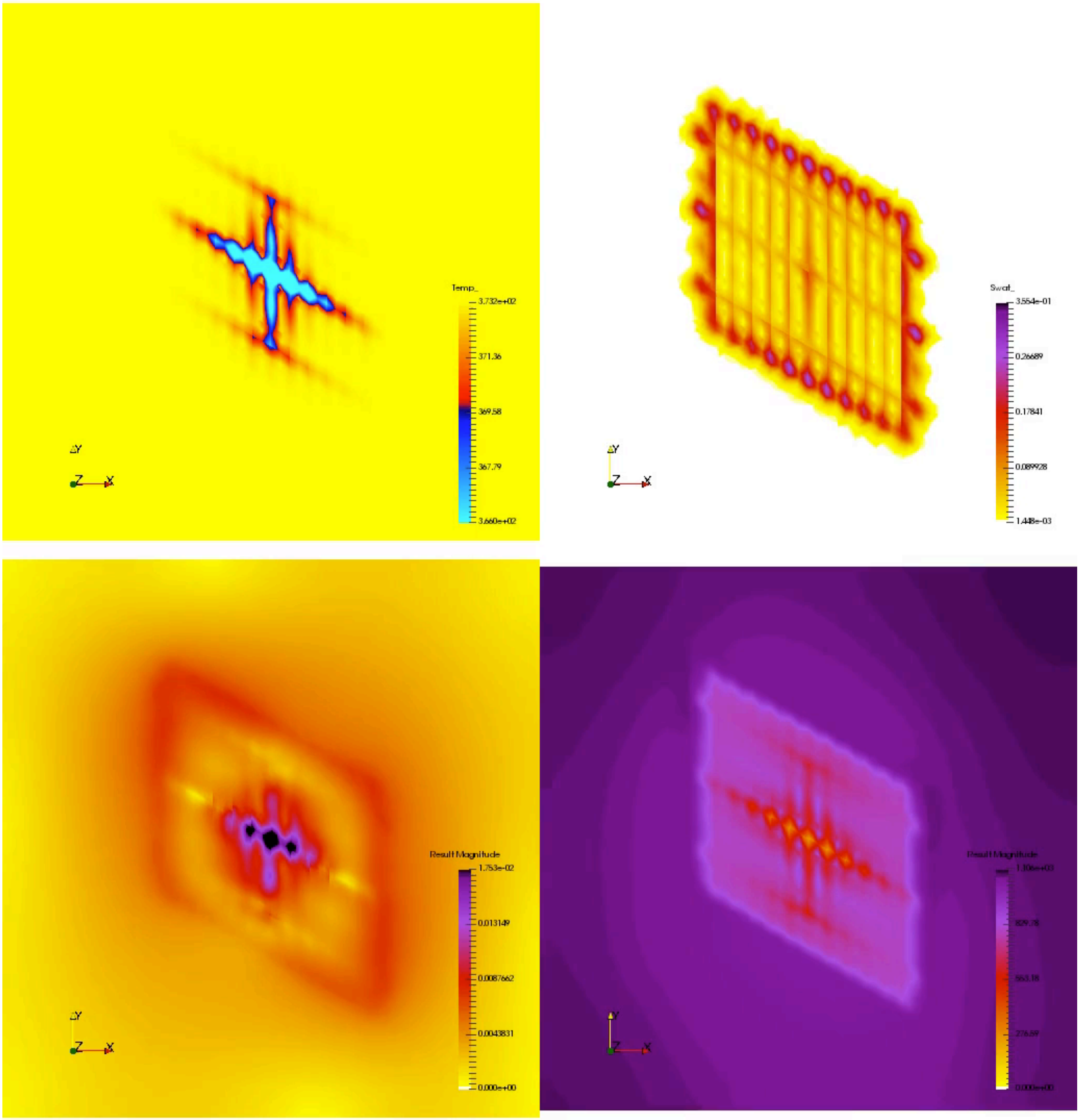
- Future work:
  - Integrate toolkit with AD-GPRS.
  - Integrate new schemes for mechanics and contact, transport and fractures, thermal.
  - Extend support for multi-segment wells, schedule.

Thank you for Attention!

ACKNOWLEDGEMENTS:

- TIMUR GARIPOV
- PAVEL TOMIN
- MOHAMMAD KARIMI-FARD
- BRADLEY MALLISON
- SUPRI-B AFFILIATES
- CHEVRON CORE

Flow with mechanics and thermodynamics in fractured media



With Timur Garipov