Illustrative Multivariate Visualization for Geological Modelling

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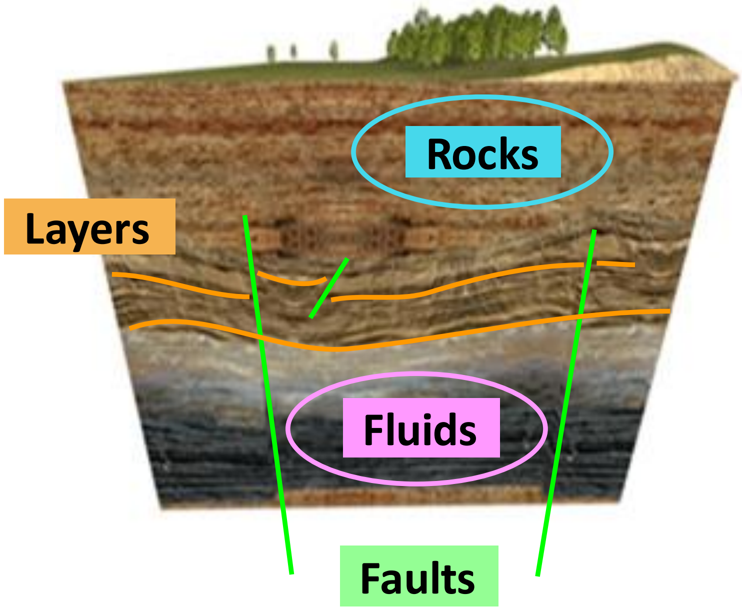
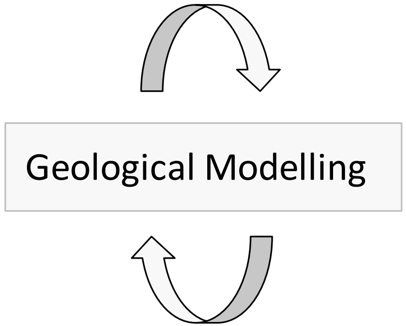
VISAGG
Visualization and Graphics Group

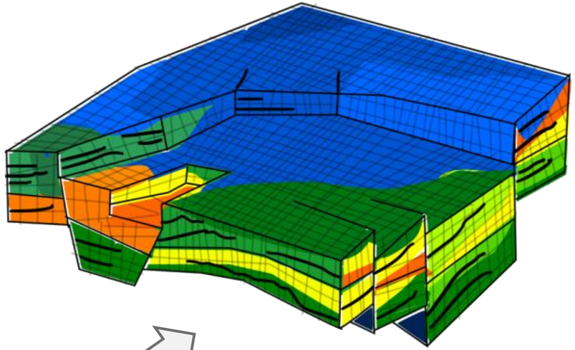
illustrares
Interactive Modeling, Visualization & Analytics R&D Group

Geological Modelling

- Process to create a digital representation of the underground reservoir





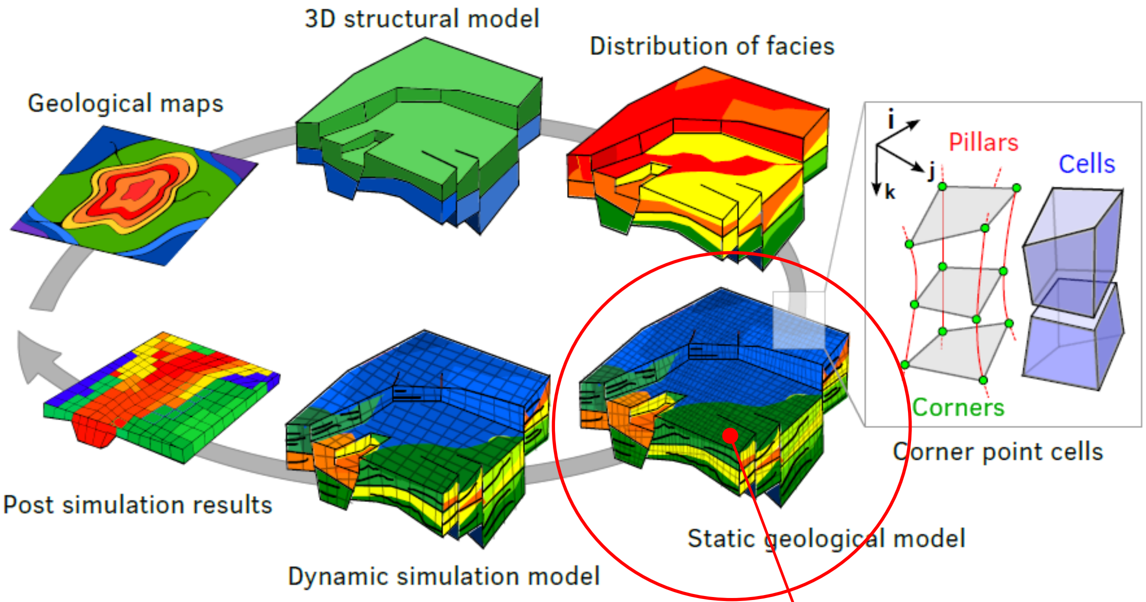


Geological Attributes

Geological Structures

Geological model

Geological Models



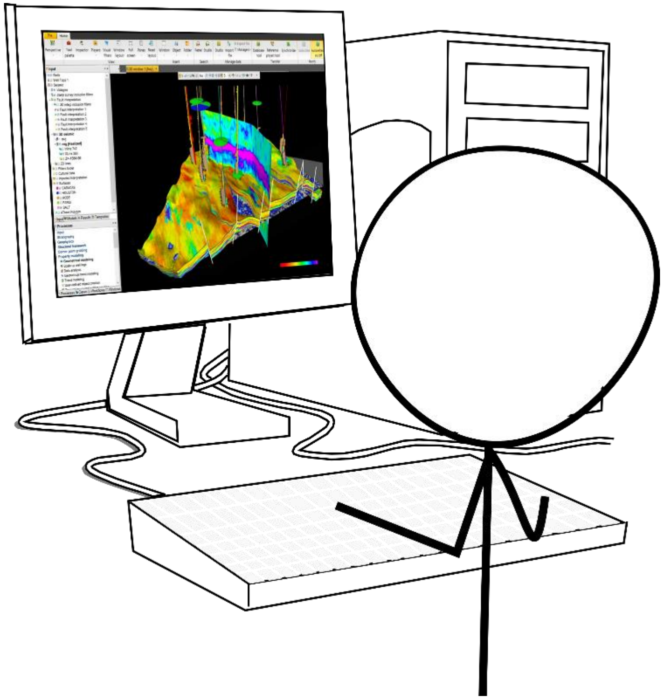
Data Analysis

- Geological distributions
- Correlation between attributes
- Connected areas
- Possible flow trajectories

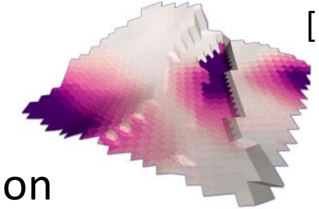
- rock type
- porosity
- permeability
- oil saturation

Conventional Visualization

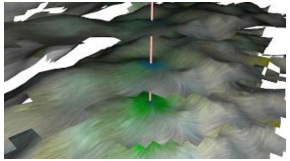
- Don’t consider data type
- Colormaps (rainbow)
- Difficult to correlate attributes
- Difficult to understand internal structures
- Difficult to communicate results



Related Work



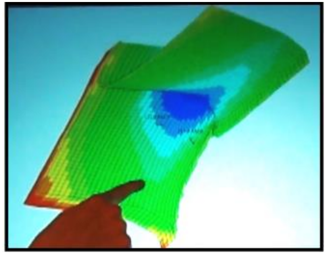
[Höllt *et al., EnvirVis 2016]*



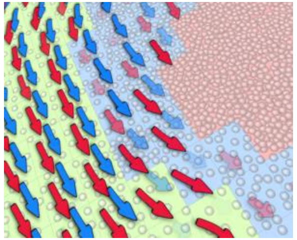
[Toledo *et al., SIBGRAPI 2011]*

Multivariate Visualization

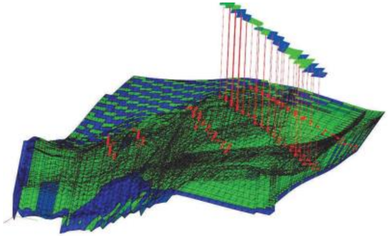
- Noise texture + Colormaps
  - 1 or 2 attributes
- **Decal-Maps**



[Sultanum *et al., ITS 2011]*

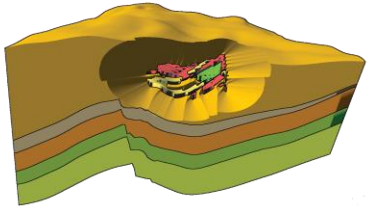


[Rocha *et al., TVCG 2017]*

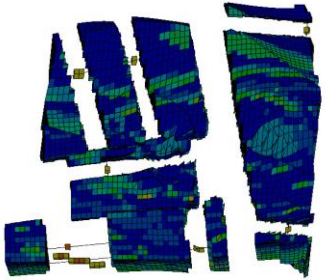


[Somanath *et al., GI 2014]*

- Illustrative Visualization (*what)*
  - Cutaways
  - Exploded View
  - Peeling



[Lidal *et al., SCCG 2012]*



[Martins *et al., SIBGRAPI 2012]*

Our approach – *how* to visualize

- Expressive visualization of static geological attributes
- Highlight 3D structures, in particular possible connected areas
- Superimposed visualization of multiple attributes

Task Analysis and Goals

- Problem Domain Characterization
  - *Multi-level typology framework* [Brehmer *et al.,* TVCG 2013]
- Tasks

  ***Discover* geological scenarios**
  - **T1** – *Explore* areas of low/high magnitude, and/or strong/weak directionality.
  - **T2** – *Identify* correlations between static properties through *comparison.*
  - **T3** – *Explore* the distribution of properties to *identify* connected regions

  ***Verify* possibilities of flow behavior**
  - **T4** – *Explore* the properties to *identify* correlations with dynamic behavior

  ***Present* the results**
  - **T5** – *Look up* geological properties and *summarizing* trends

Task Analysis and Goals

- Design Goals
  - **DG1:** *Suitable representation of geological attributes.*
  - **DG2:** *Facilitate communication between multidisciplinary teams.*
    - *"(Managers) don't care about (cell-specific values), they just want to know 'where is the oil', 'what is it doing there', 'what is going to cost us to get it out'"* [Sultanum *et al.*, 2011]
  - **DG3:** *Facilitate visualization of trends.*
    - *"I am looking through specific trends and not through one specific value".* [Sultanum *et al.*, 2011]
  - **DG4:** *Display of multiple attributes.*
  - **DG5:** *Access the 3D nature of geological models.*

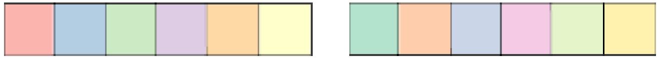
Visualization Design

- Surface representation
  - Colormaps + decal-maps
- 3D representation
  - 3D glyphs

- We draw inspiration from Perception, InfoVis and Traditional Illustration

Visualization Design – Surface representation

- Rock type (categorical data)
  - 2-4 rock types
  - Representation *pastel colormap*



  - Avoid pastel blue tone

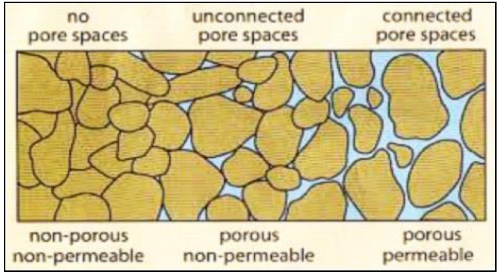
- Oil Saturation (scalar data)
  - Pastel tone (rock type) + *brightness* variation

Visualization Design – Surface representation

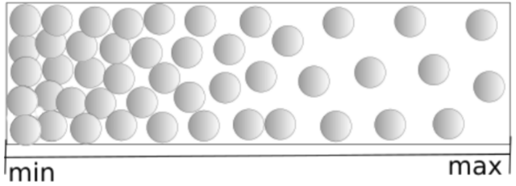
- Porosity (scalar data)
  - Volumetric value given by the ratio: $\phi = \frac{V_v}{V_t}$

V_v Is the void-space

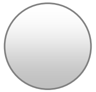
V_t is the total volume



[Rocha *et al.*, TVCG 2017]



Poisson importance sampling



Grain decal

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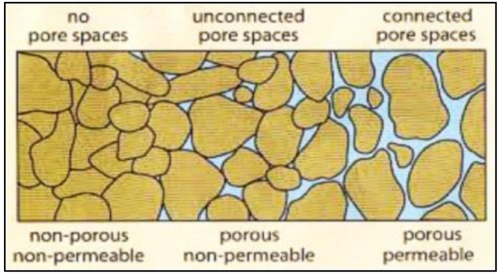

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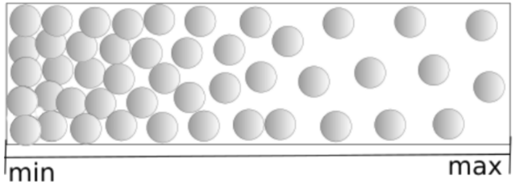

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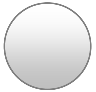

Grain decal

Costly to compute for arbitrary grids

Does not consider local control over the distribution

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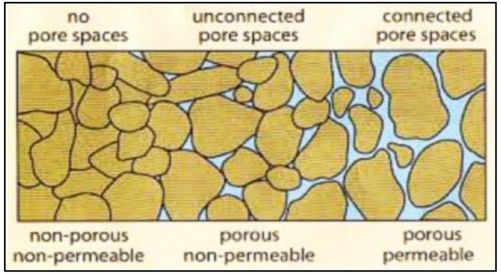

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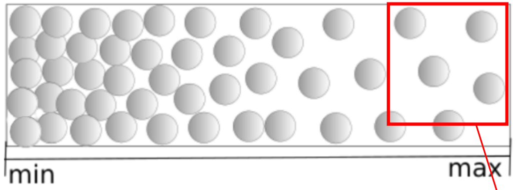
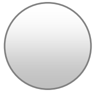


$\cong$ 50% ?

Poisson importance sampling



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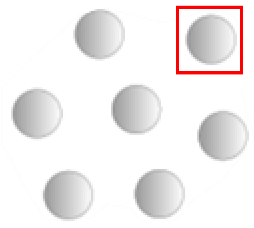

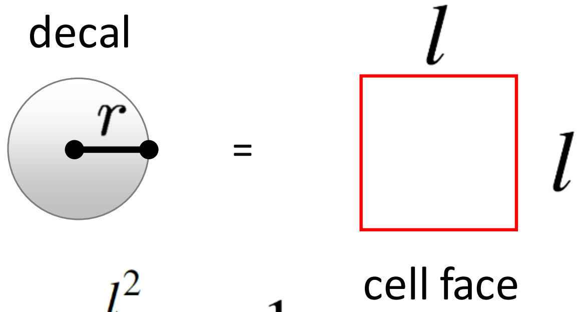

$$\frac{l^2}{\pi r^2} = 1$$

Visualization Design – Surface representation

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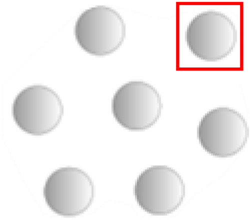
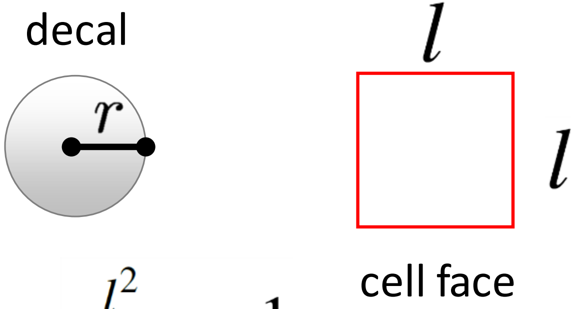




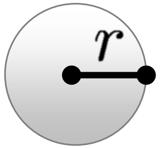
$$\frac{l^2}{\pi r^2} = 1 \rightarrow \text{porosity} = 0$$

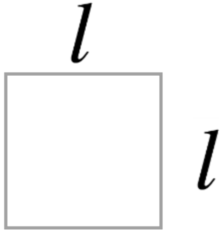
$$0.8 \rightarrow \text{porosity} = 0.2$$

Visualization Design – Surface representation

- Porosity (scalar data)

decal





cell face

$$l_u(p) \coloneqq r\sqrt{\pi(1-p)}\ , where\ \ 0 \leq p \leq 1$$

where p is the porosity value.

$$\frac{l^2}{\pi r^2} = 1 - p$$

Visualization Design – Surface representation

- Porosity (scalar data)

  Importance sampling strategy

  - Sampling ***per cell face*** of the reservoir grid

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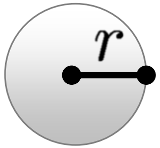

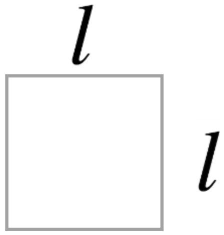

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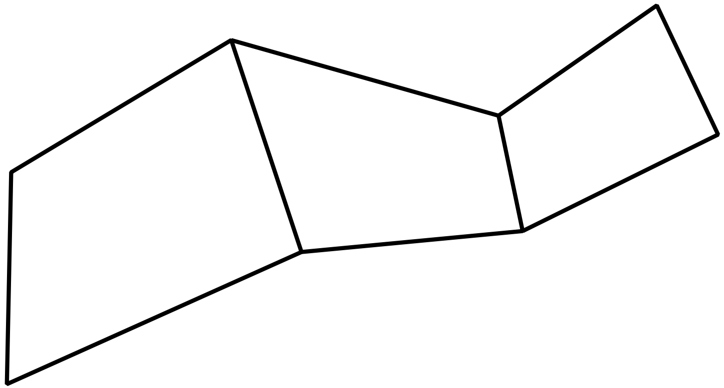

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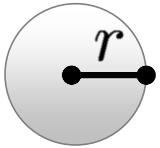

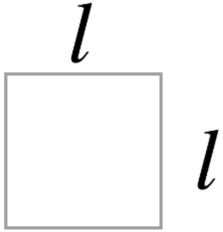

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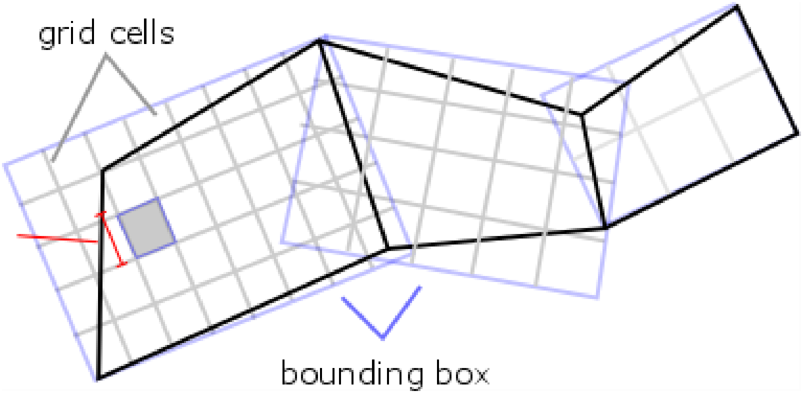

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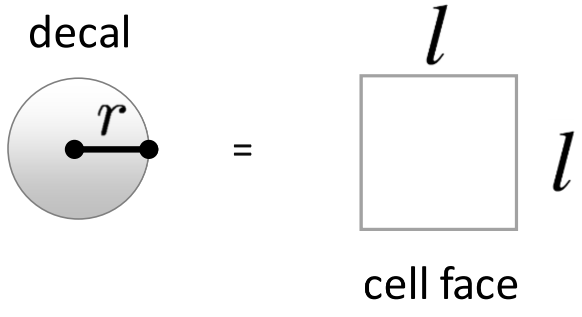

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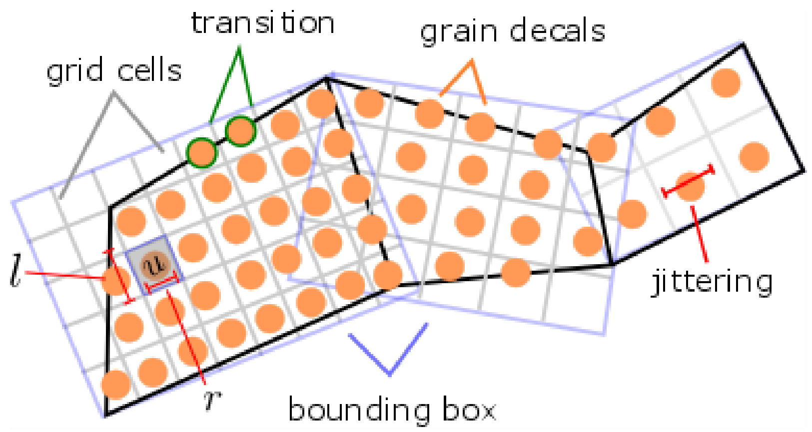

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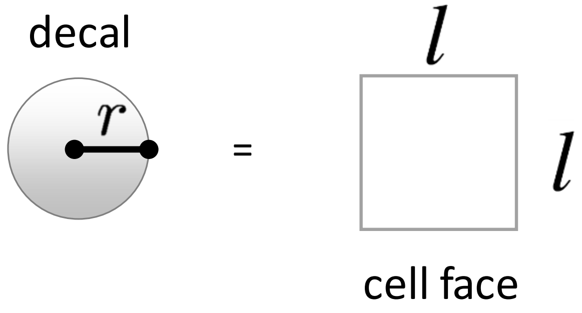

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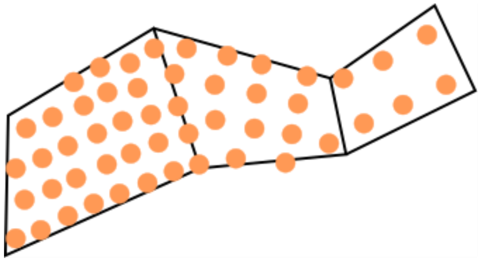

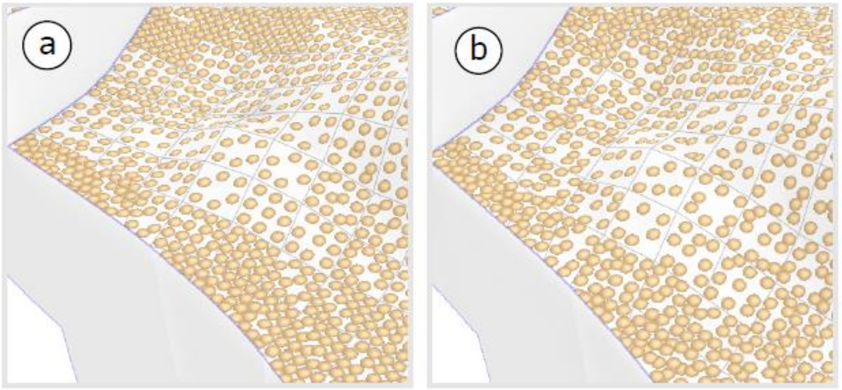

Visualization Design – Surface representation

- Rock Permeability (tensor data)
  - Measures the ability of the medium support fluid flow
  - Represented as a diagonal 3x3 matrix (k_{xx}, k_{yy}, k_{zz})

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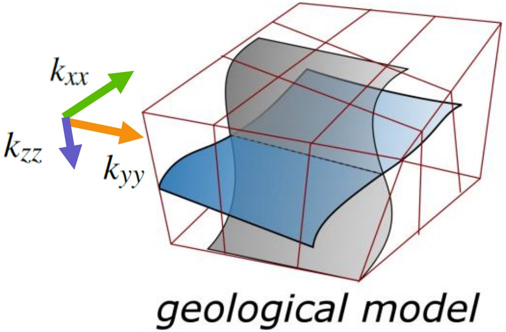

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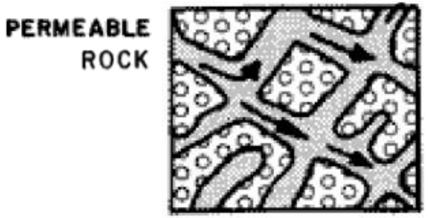

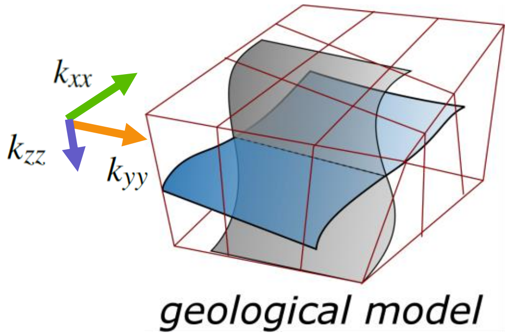

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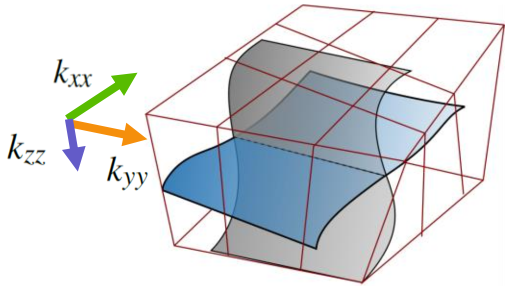
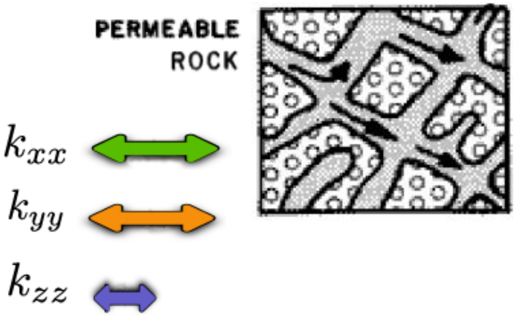


geological model



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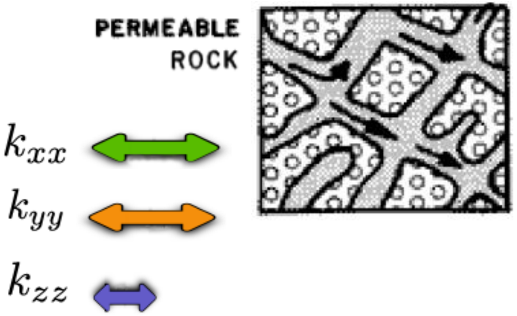

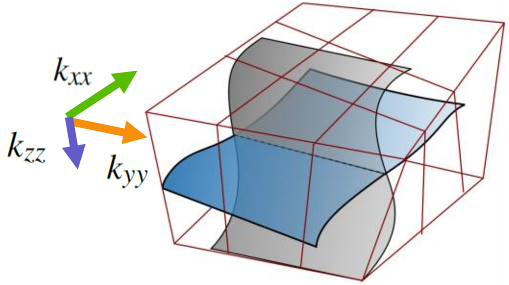

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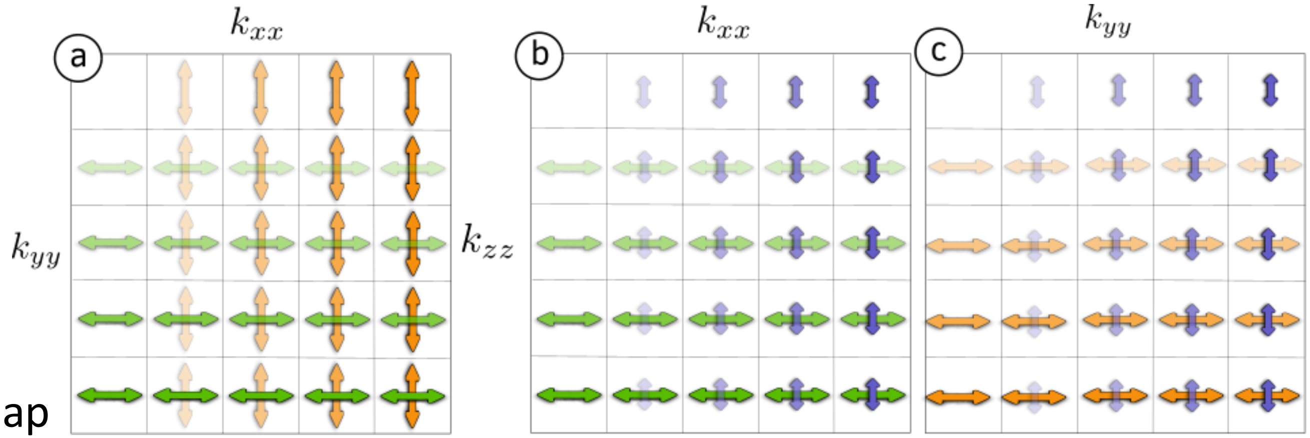
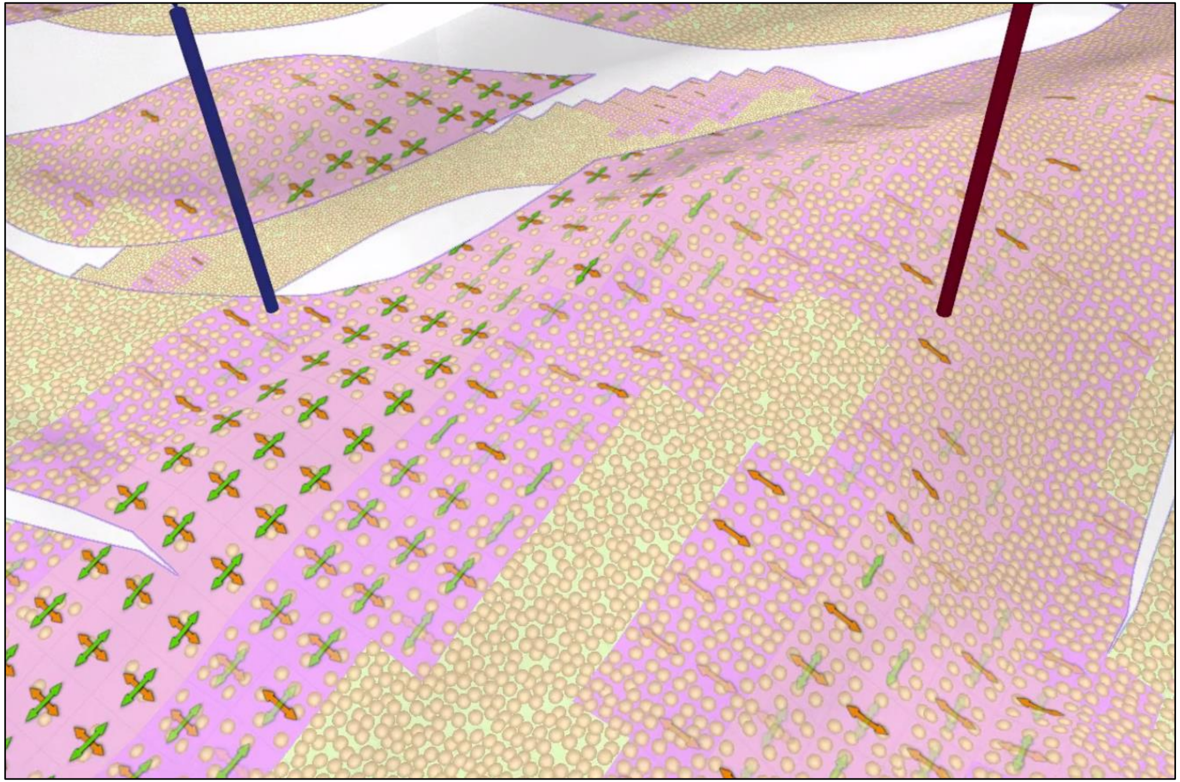


2D decal-map

Visualization Design – Surface layering

- **DG1:** *Suitable representation of geological attributes.*
- **DG2:** *Facilitate communication between multidisciplinary teams.*
- **DG3:** *Facilitate visualization of trends.*
- **DG4:** *Display of multiple attributes*
- **DG5:** *Access the 3D nature of geological models*



Visualization Design – 3D glyph-based representation

- Rock Permeability (tensor data)
  - Diagonal 3x3 matrix (k_{xx}, k_{yy}, k_{zz})

- Tensor visualization
  - Ellipsoid glyphs $\frac{1}{k_{xx} + k_{yy} + k_{zz}} (k_{xx}, k_{yy}, k_{zz})$

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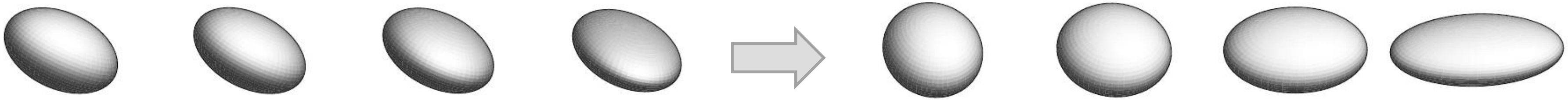
  - Visual ambiguity problem [Kindlmann, CGF 2004]



Look the same from this point of view

Different point of view

Visualization Design – 3D glyph-based representation

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Shading is not enough to convey orientation

- Tensor visualization
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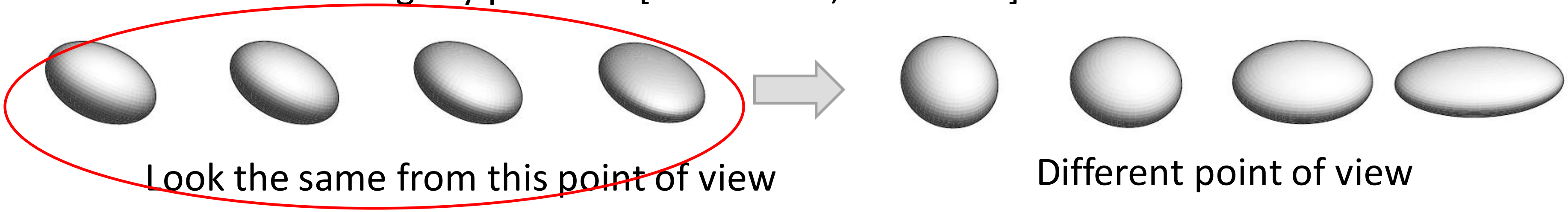

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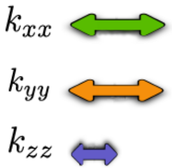
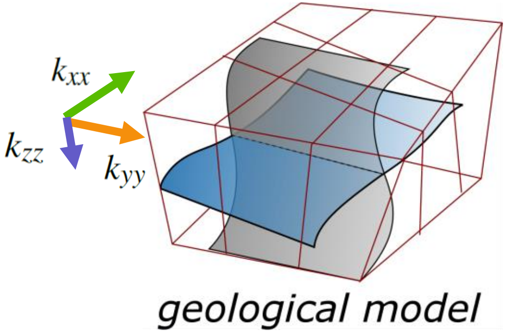


- Rock Permeability (tensor data)
  - Diagonal 3x3 matrix (k_{xx}, k_{yy}, k_{zz})
  - Given a vertex v of the glyph, (ϕ, θ) are given by

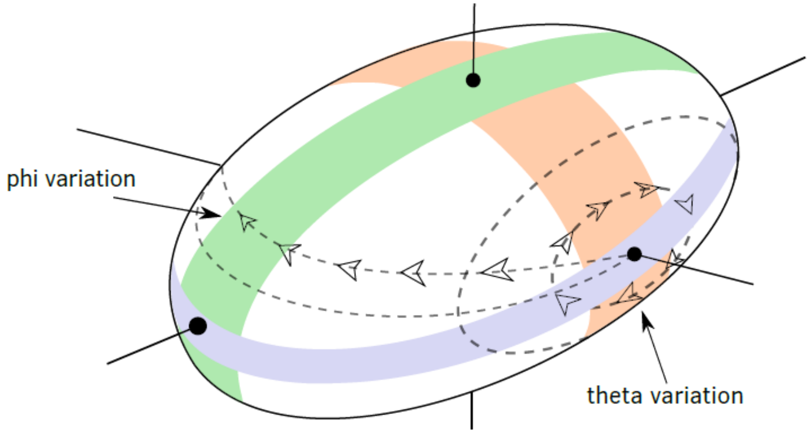
$$\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right) \text{ and } \phi = \cos^{-1}\left(\frac{v_z}{\rho}\right), \text{ where } \rho = (v_x + v_y + v_z)^{\frac{1}{2}}$$



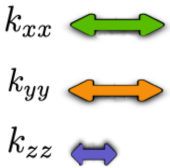
$$\varepsilon + \frac{\pi}{3} \le \phi \le \frac{2\pi}{3} - \varepsilon$$

$$\varepsilon + \frac{4\pi}{3} \le \phi \le \frac{5\pi}{3} - \varepsilon$$

$$0 \le \theta \le 2\pi$$

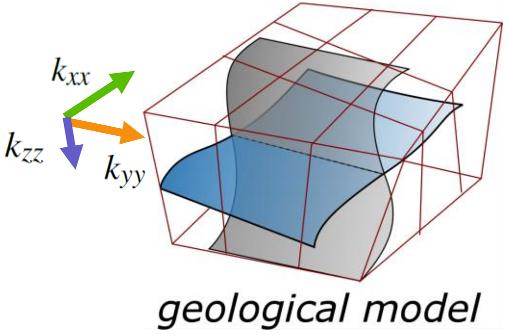


Visualization Design – 3D glyph-based representation



- Rock Permeability (tensor data)
  - Diagonal 3x3 matrix (k_{xx}, k_{yy}, k_{zz})
  - Given a vertex v of the glyph, (ϕ, θ) are given by

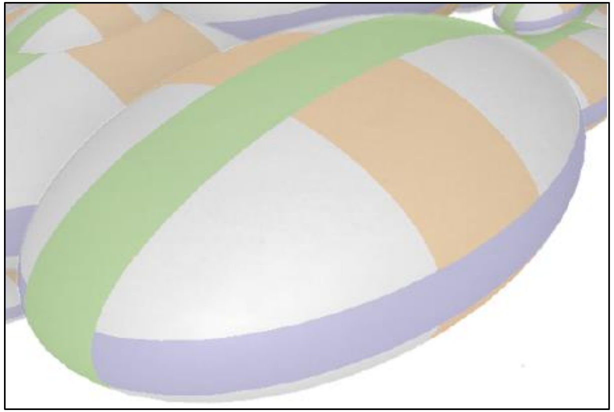
$$\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right) \text{ and } \phi = \cos^{-1}\left(\frac{v_z}{\rho}\right), \text{ where } \rho = \left(v_x + v_y + v_z\right)^{\frac{1}{2}}$$



$$\varepsilon + \frac{\pi}{3} \leq \phi \leq \frac{2\pi}{3} - \varepsilon$$

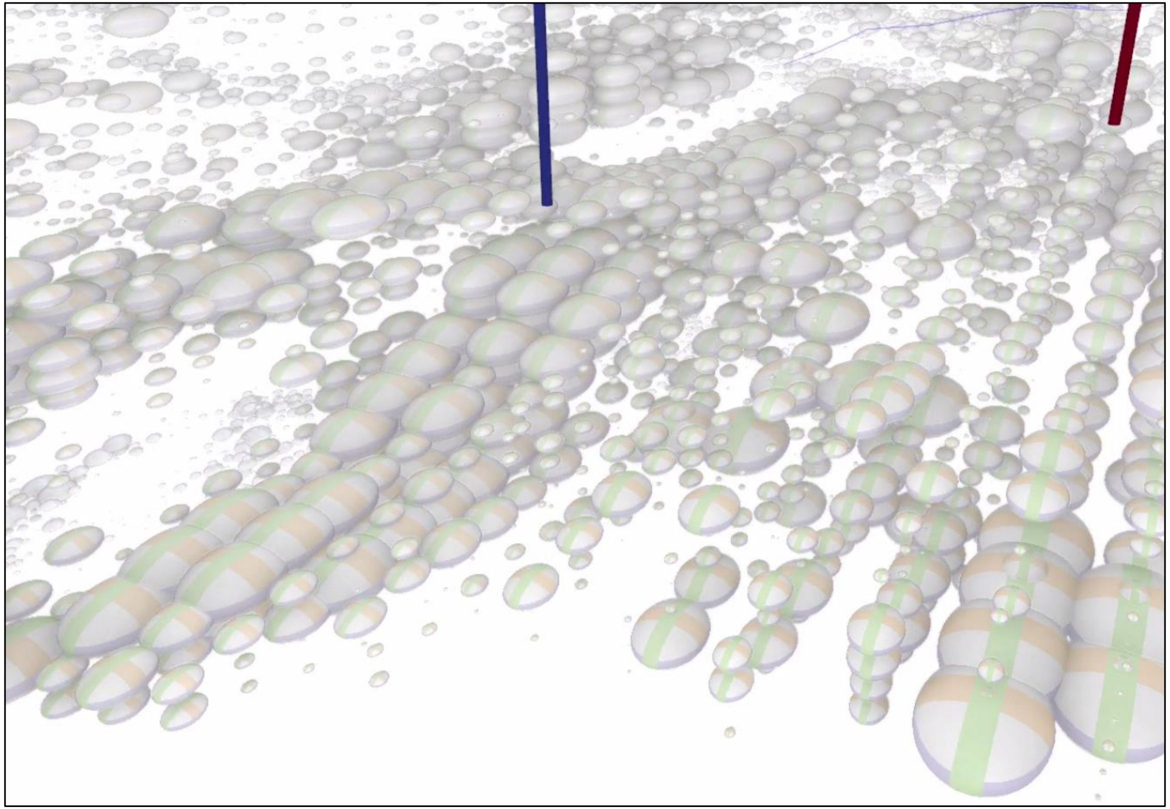
$$\varepsilon + \frac{4\pi}{3} \leq \phi \leq \frac{5\pi}{3} - \varepsilon$$

$$0 \leq \theta \leq 2\pi$$

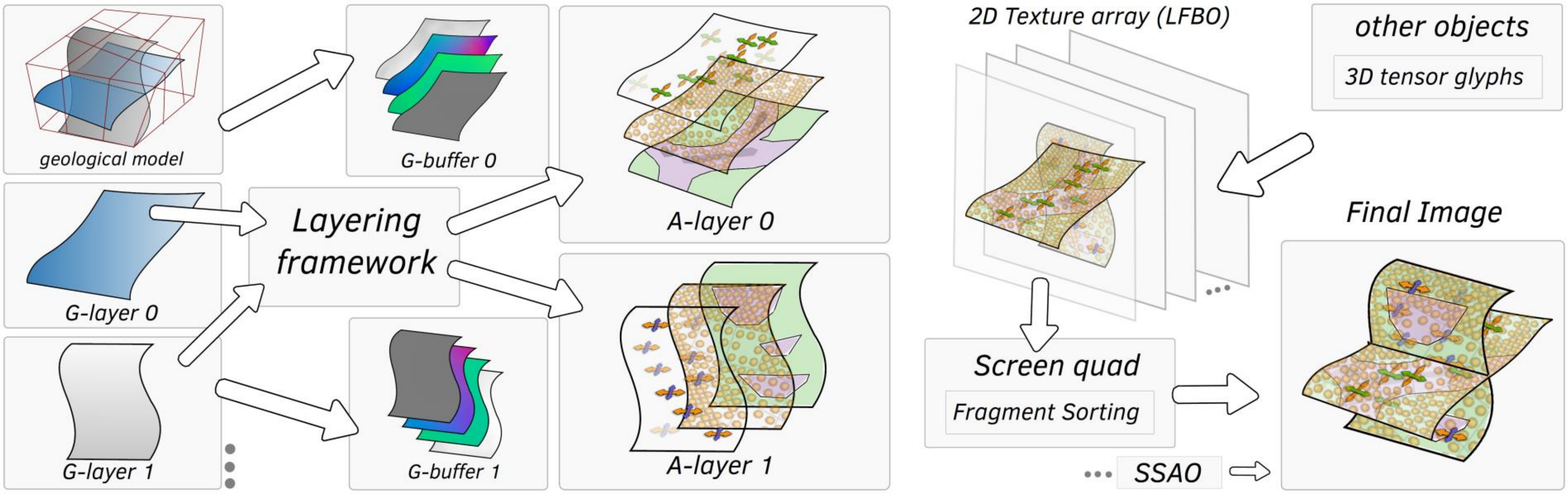


Visualization Design – Surface layering

- **DG1:** *Suitable representation of geological attributes.*
- **DG2:** *Facilitate communication between multidisciplinary teams.*
- **DG3:** *Facilitate visualization of trends.*
- **DG4:** *Display of multiple attributes*
- **DG5:** *Access the 3D nature of geological models*

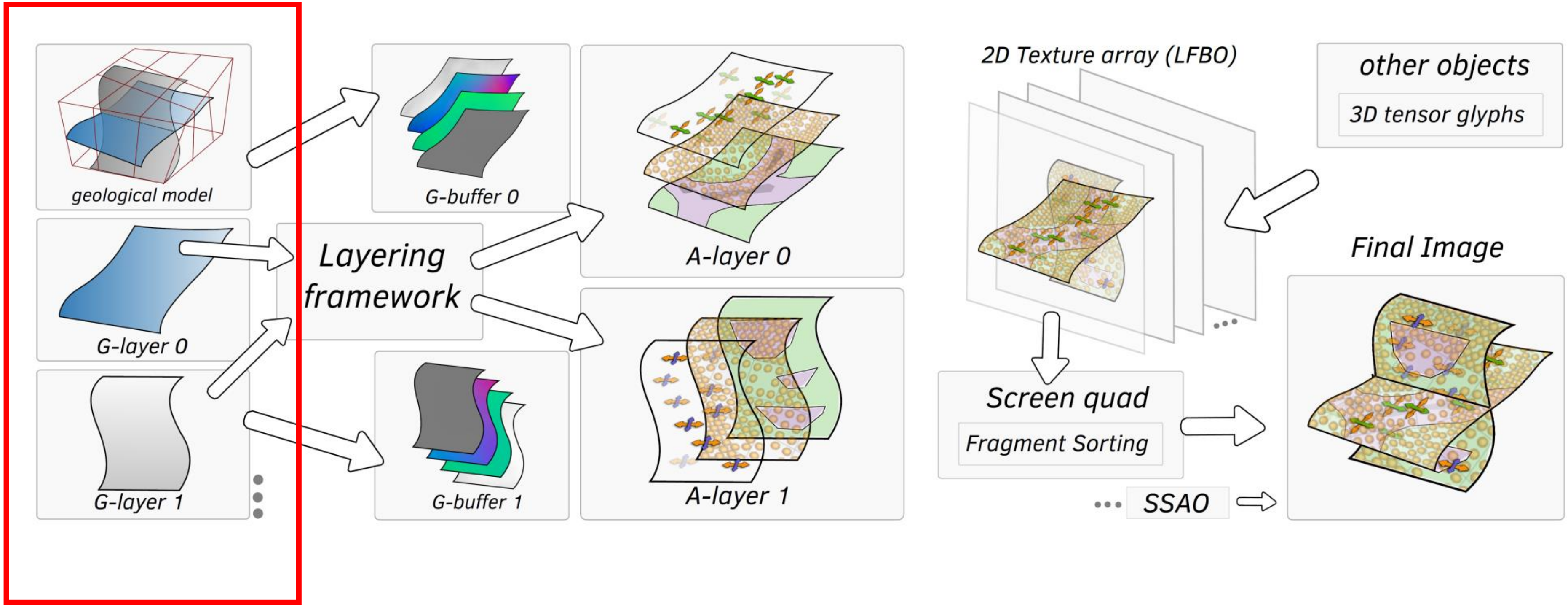


GPU-Implementation - Pipeline

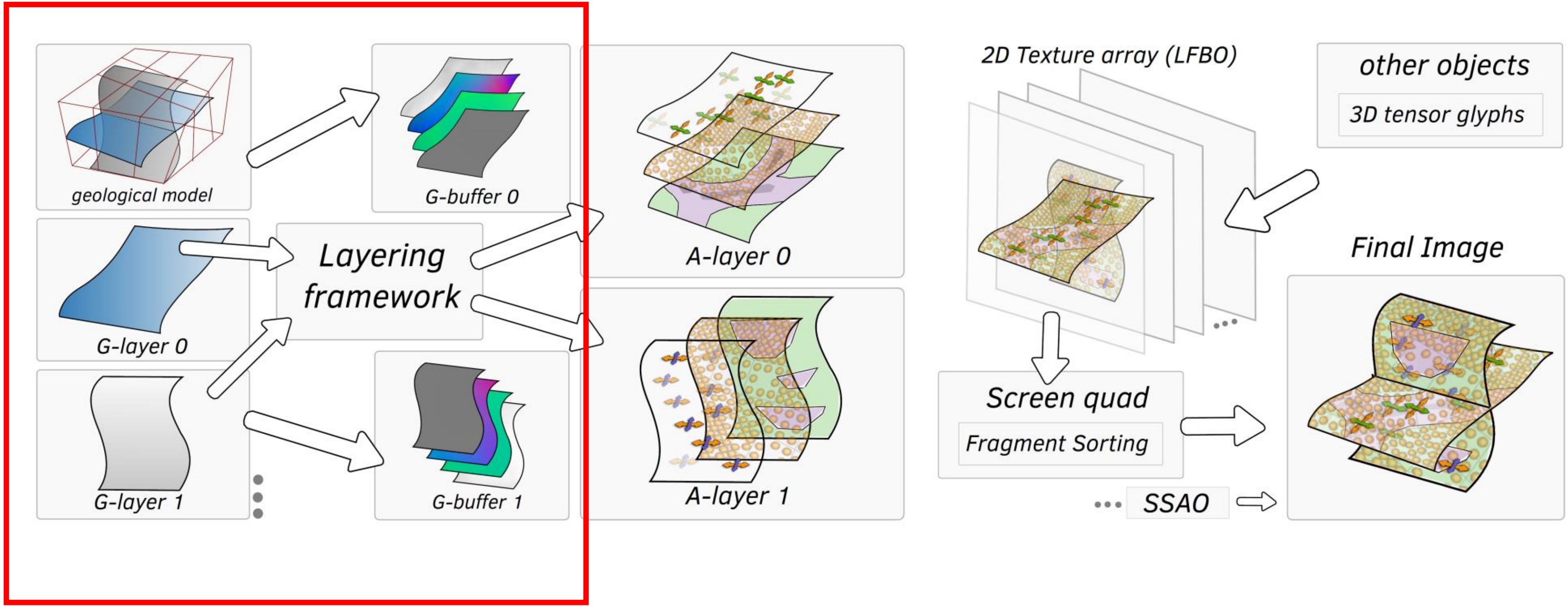


Extending the Layering Pipeline [Rocha *et al.,* 2017]

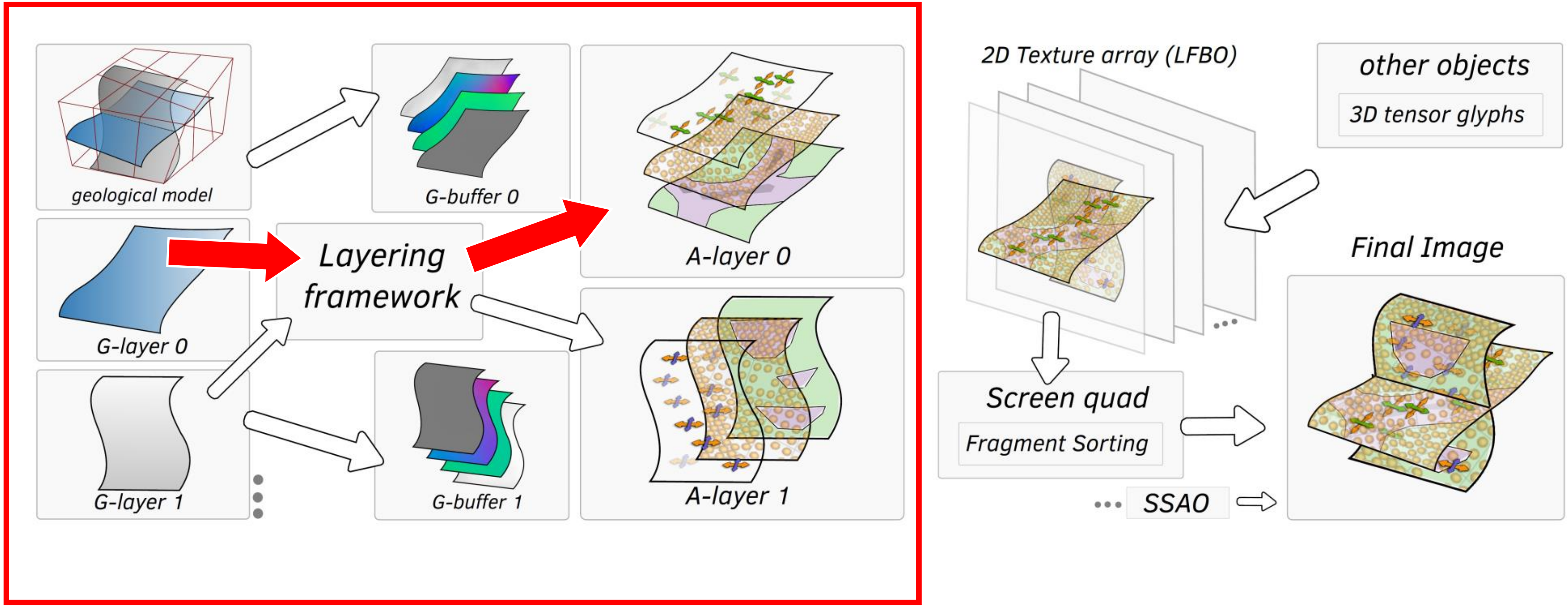
GPU-Implementation - Pipeline



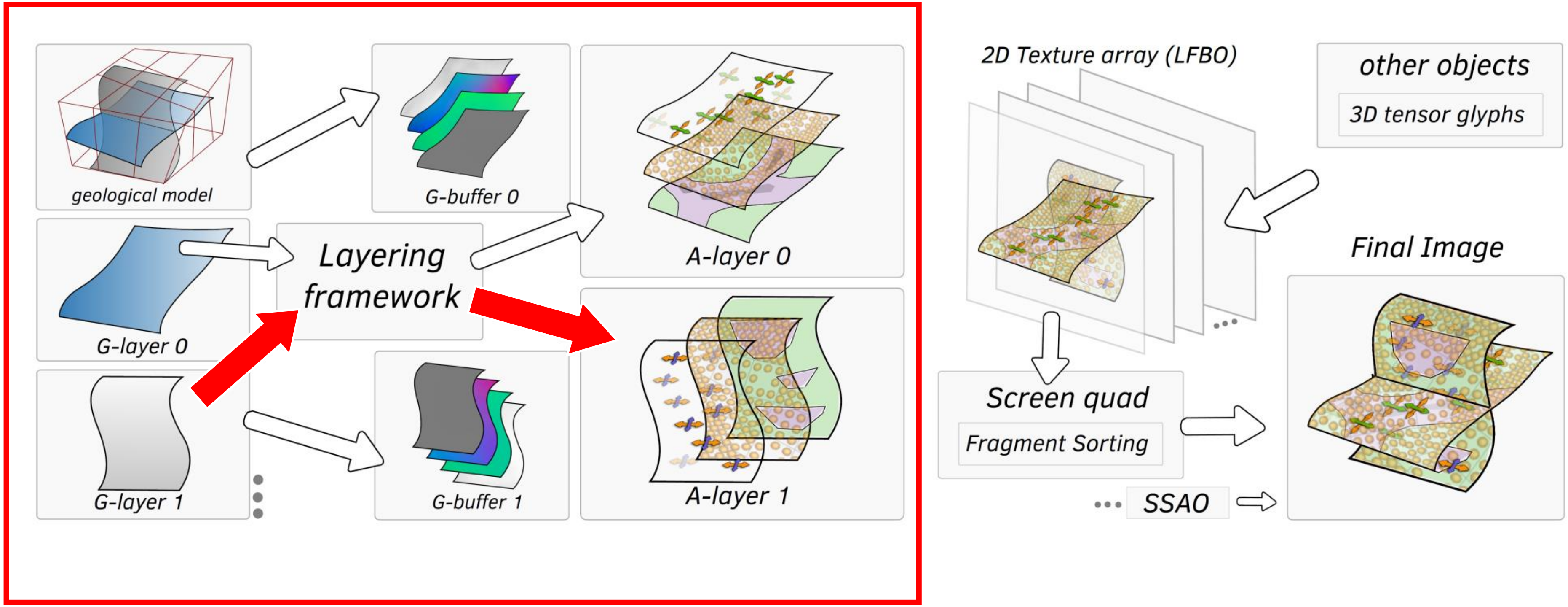
GPU-Implementation - Pipeline



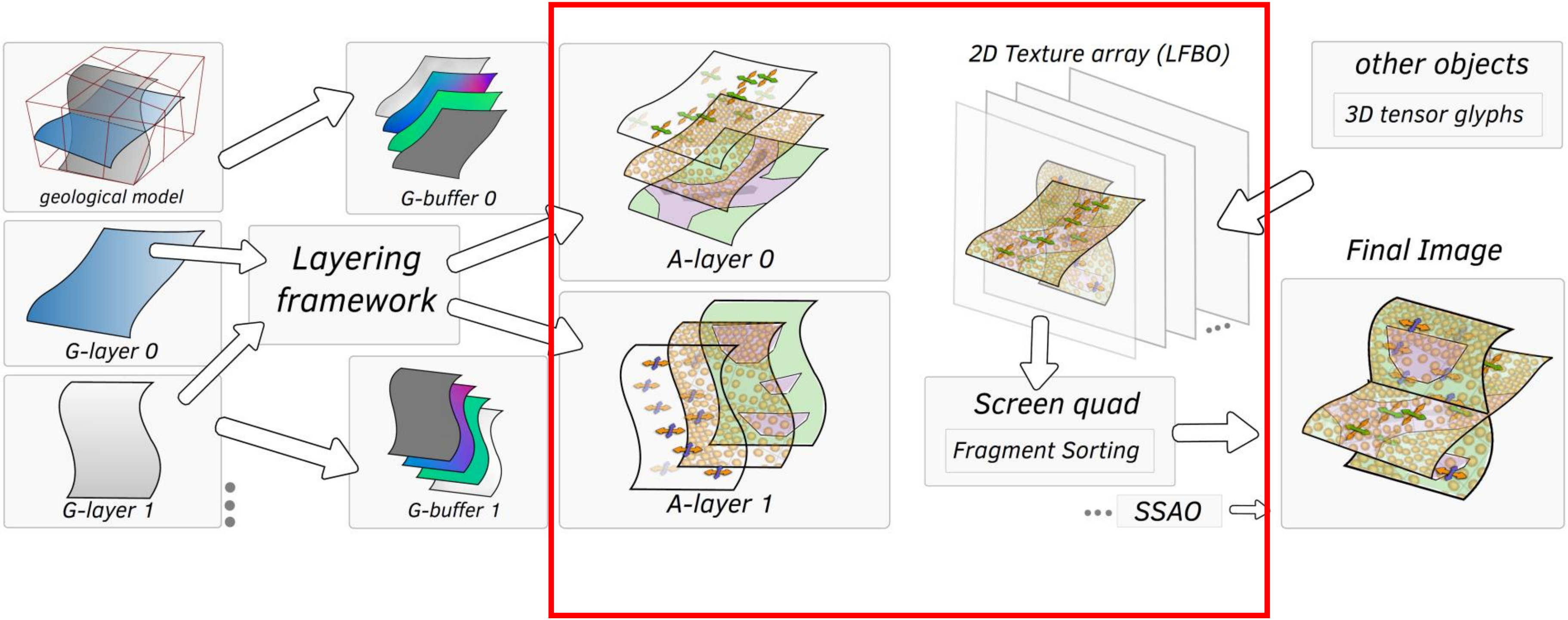
GPU-Implementation - Pipeline



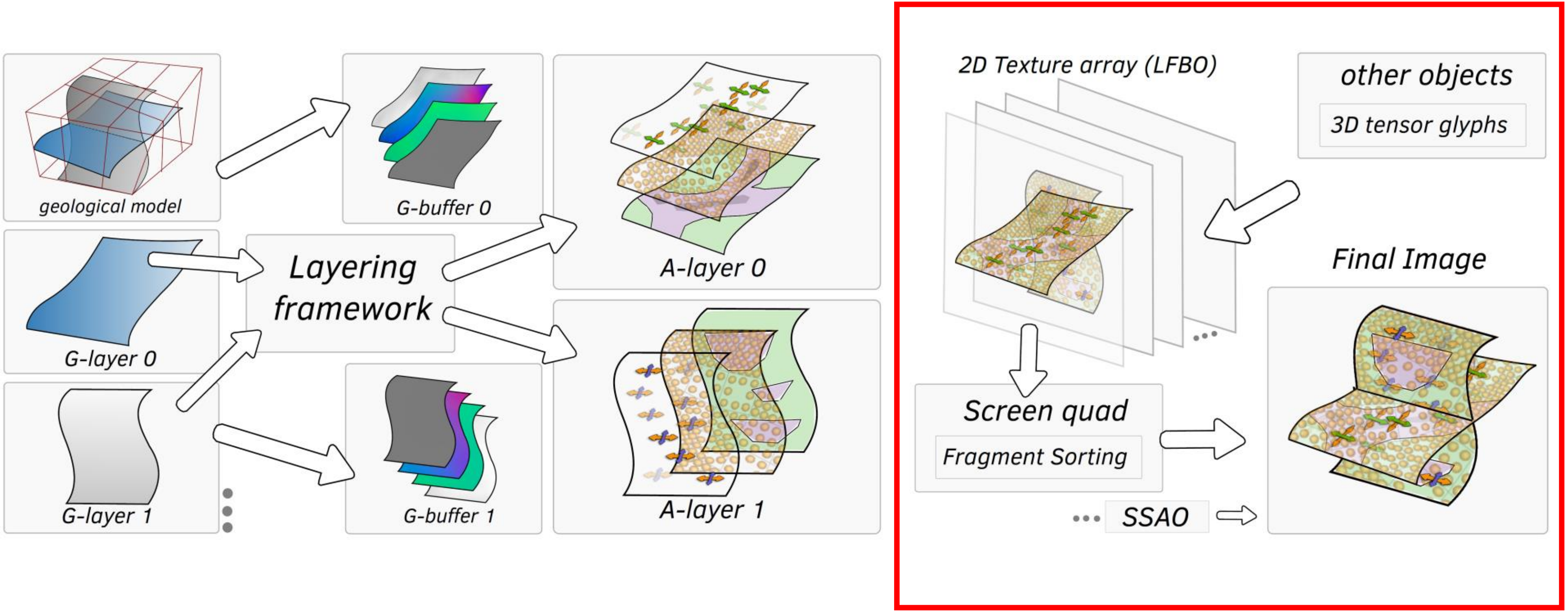
GPU-Implementation - Pipeline



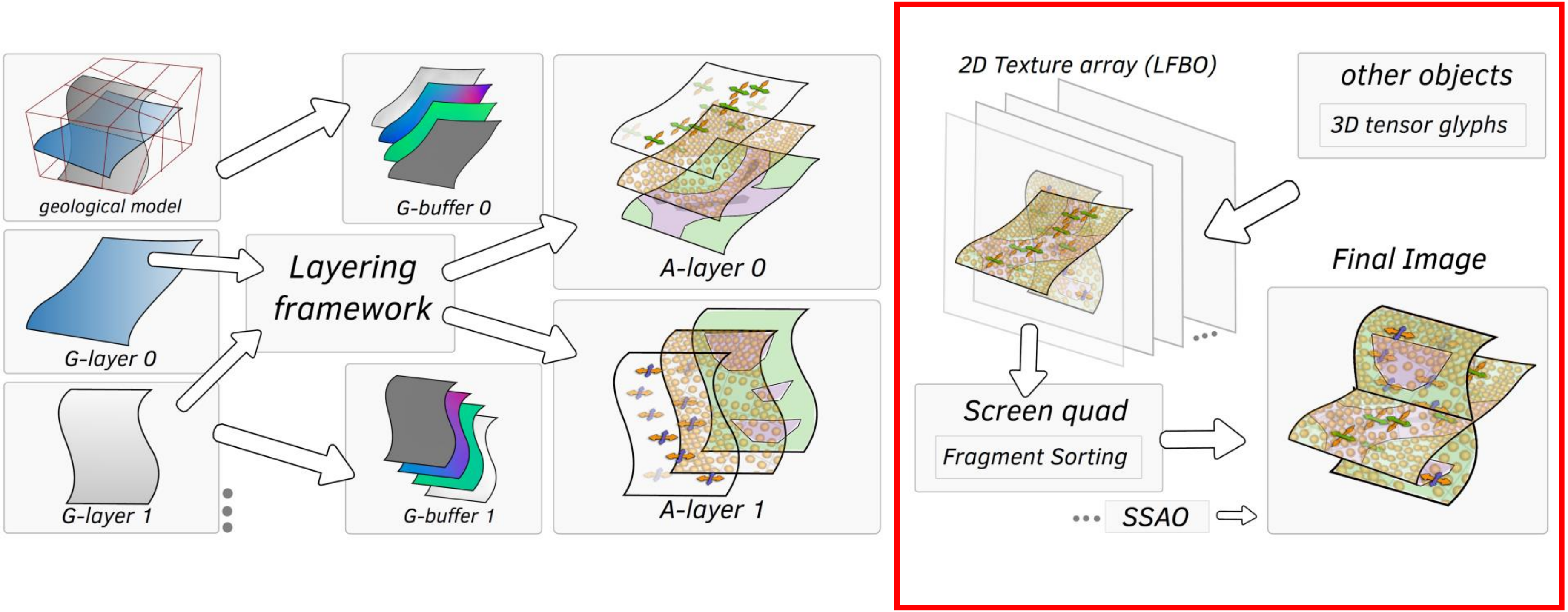
GPU-Implementation - Pipeline



GPU-Implementation - Pipeline

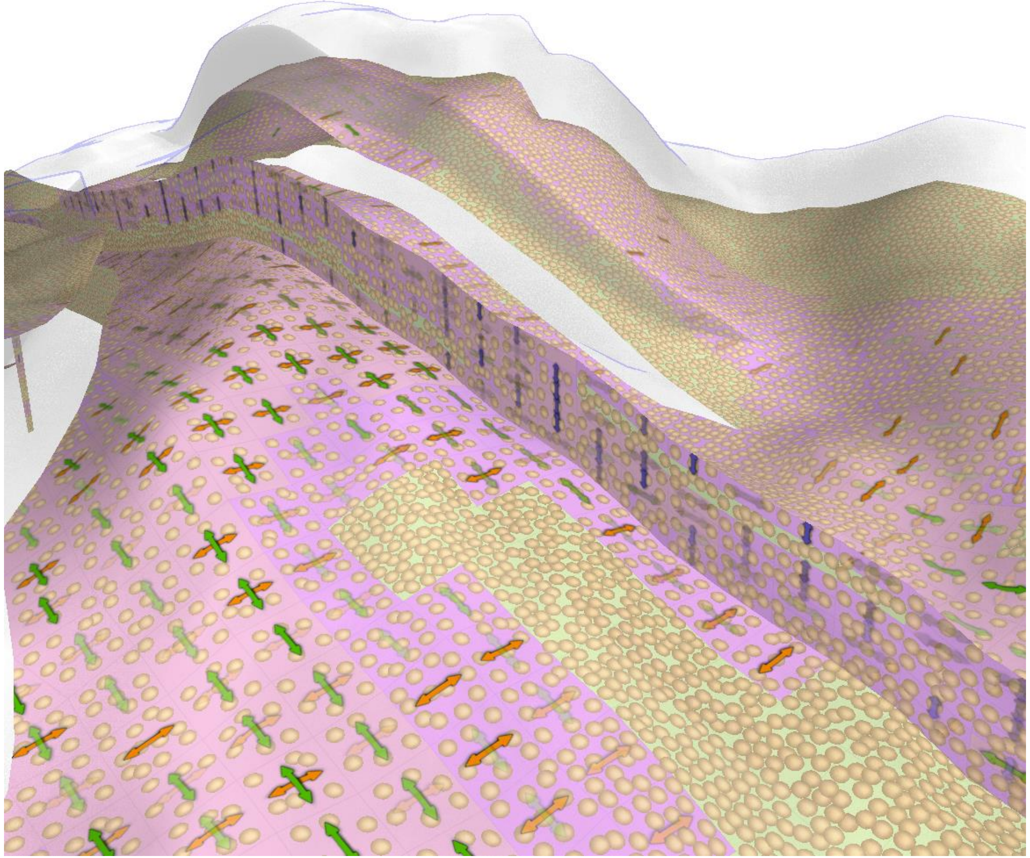


GPU-Implementation - Pipeline



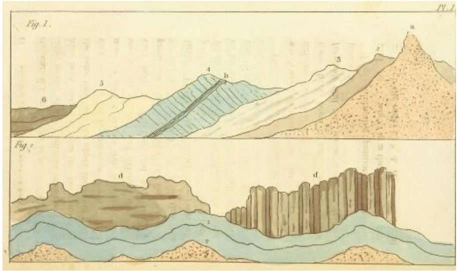
Results

- Illustrative Visualization

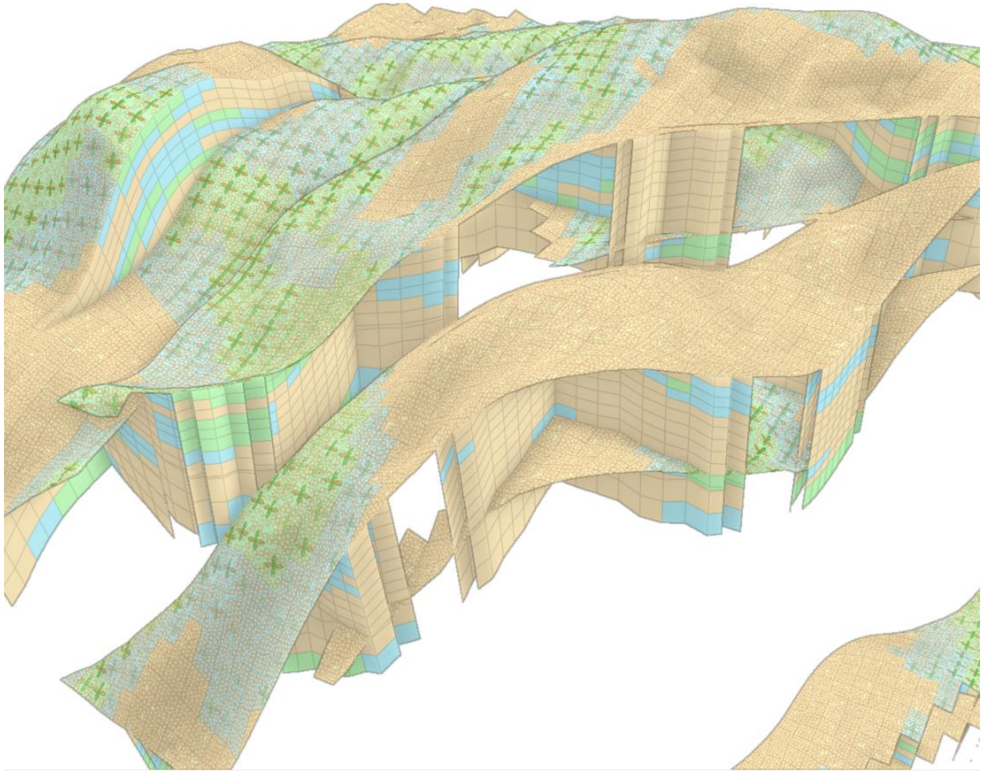


Results

- Illustrative Visualization
- Case Analysis I
- **Case Analysis II**

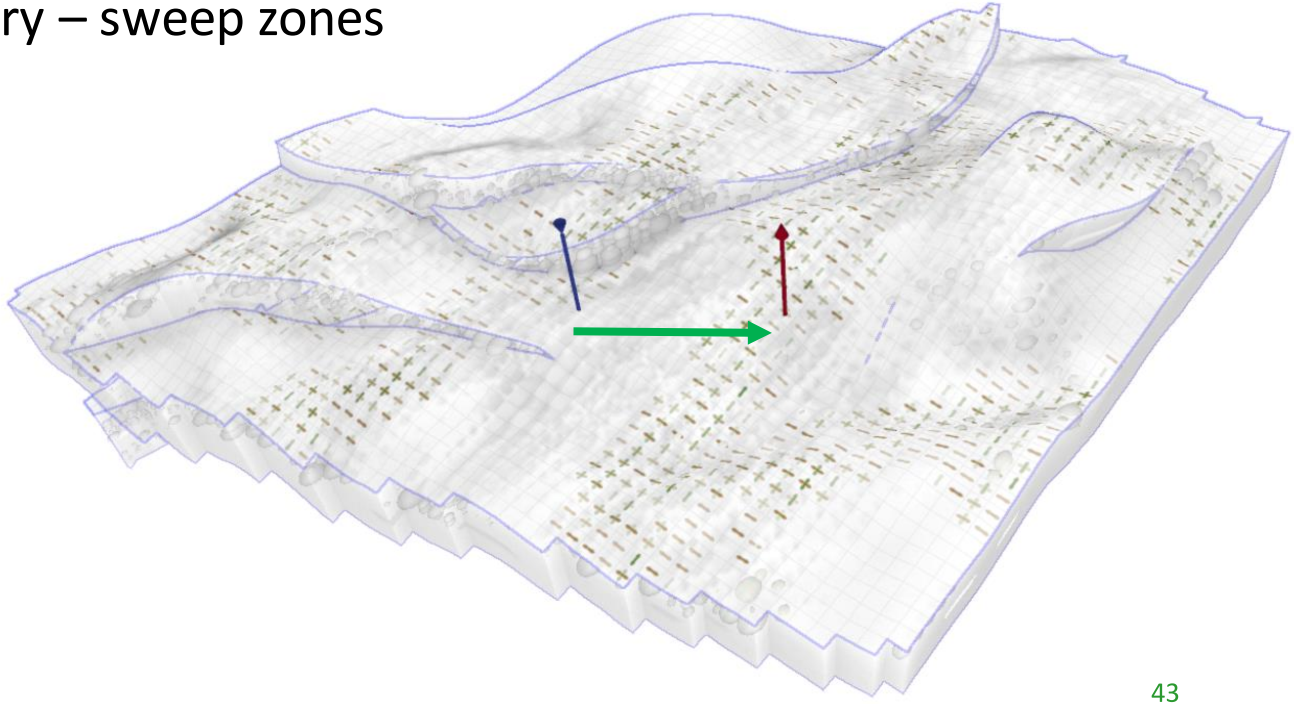


[BAKEWELL R, 1813]



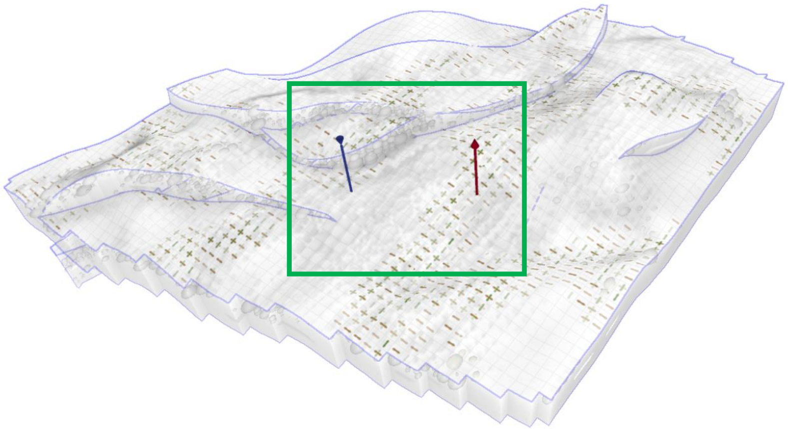
Results – Case Analysis II: Inter-well connectivity

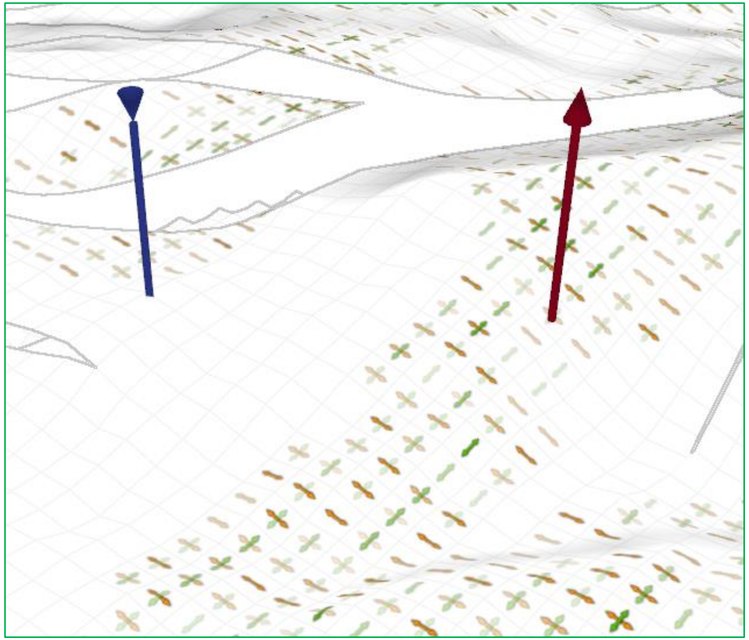
- Connectivity is a fundamental condition for oil drainage
- Secondary recovery – sweep zones



Results – Case Analysis II: Inter-well connectivity

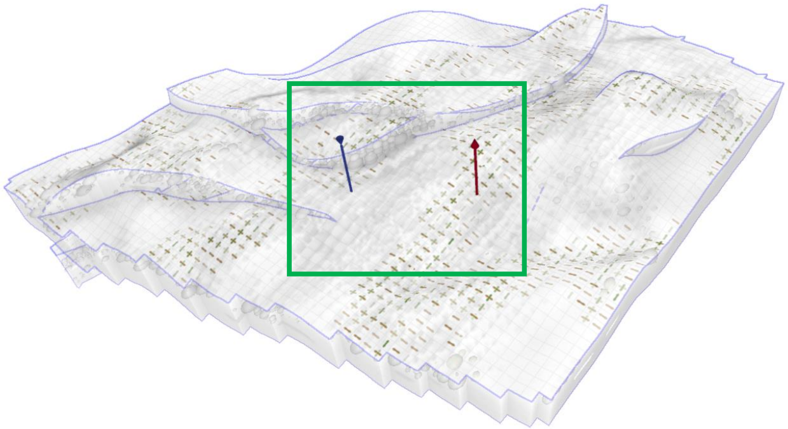
- Evaluating permeability design (decal and tensor)
  - *"Can you identify surface areas with low variability of horizontal permeability?"* **(T1)**

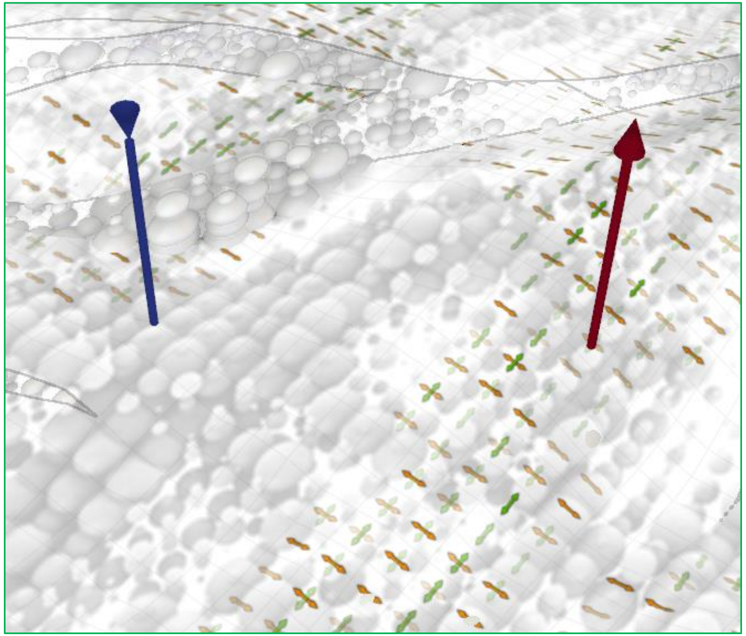




Results – Case Analysis II: Inter-well connectivity

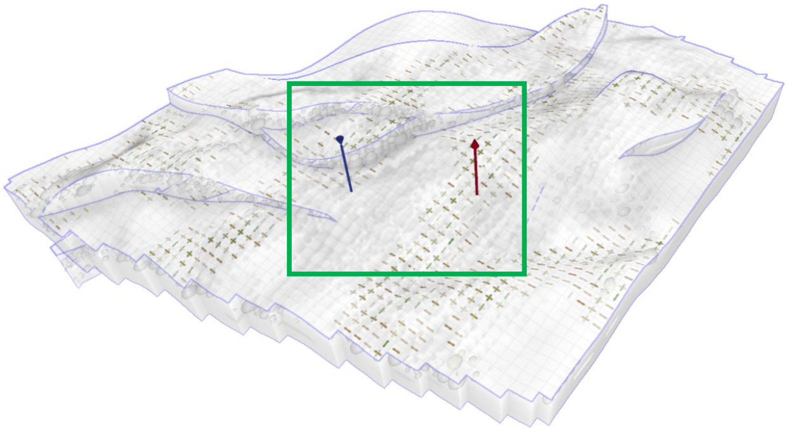
- Evaluating permeability design (decal and tensor)
  - *"Can you identify whether the two wells are connected?"* **(T3)**

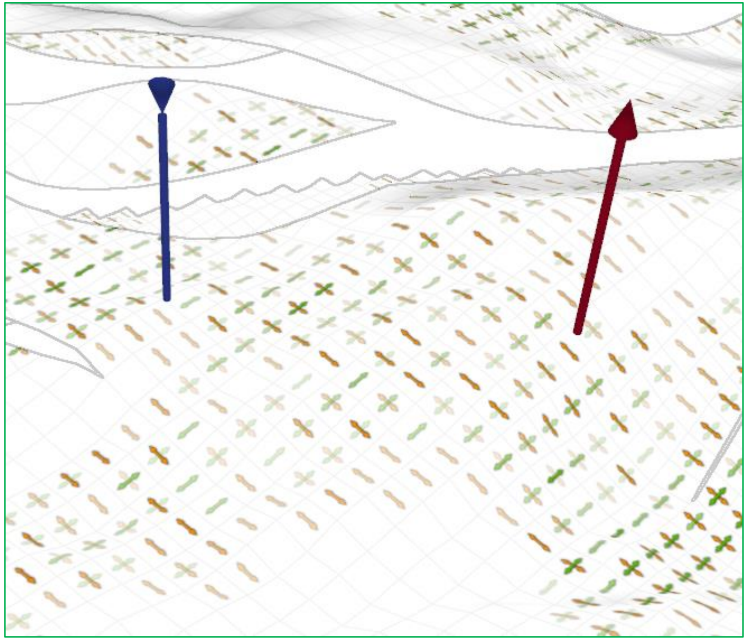




Results – Case Analysis II: Inter-well connectivity

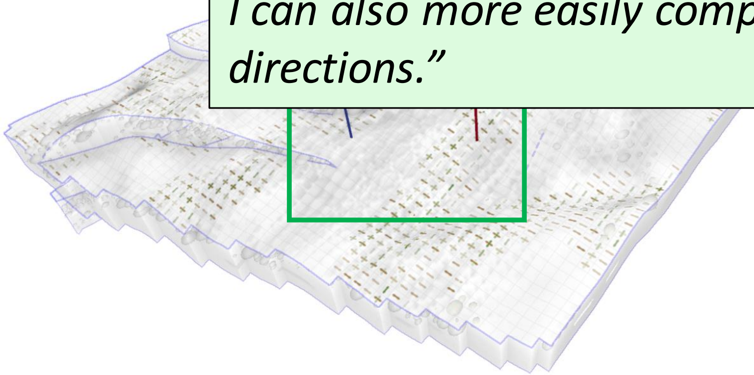
- Evaluating permeability design (decal and tensor)
  - *"I can also more easily compare permeability values in different directions."* **(T5)**

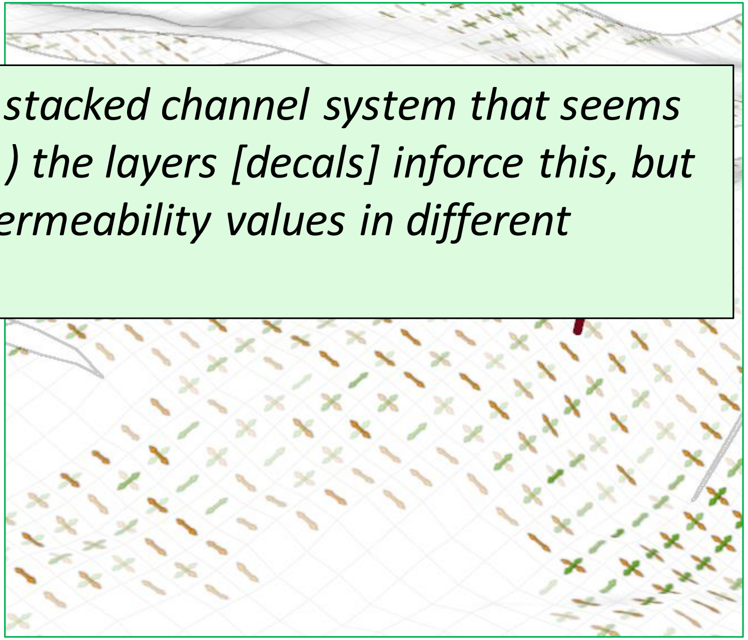




Results – Case Analysis II: Inter-well connectivity

- Evaluating permeability design (decal and tensor)

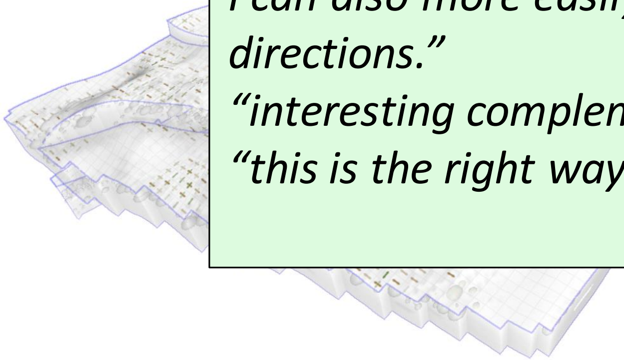


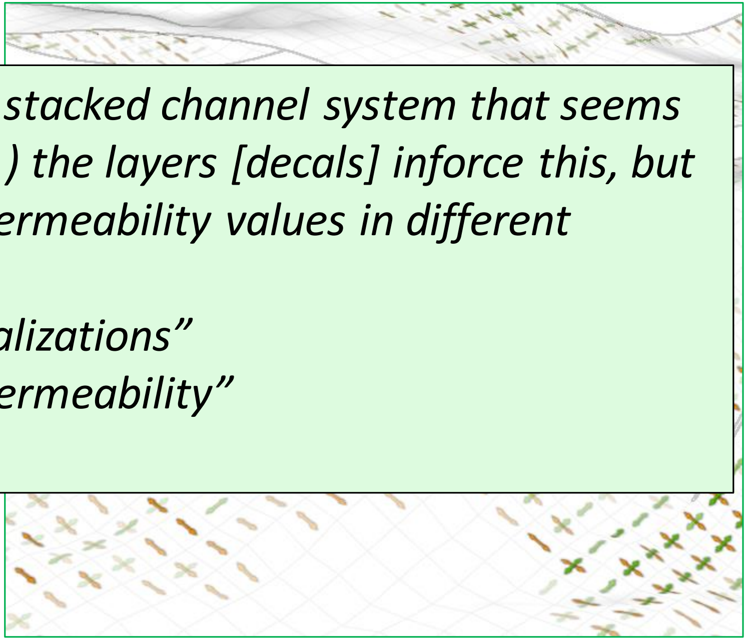


"from the 3D tensors, I can see a stacked channel system that seems to extend across the two wells (…) the layers [decals] inforce this, but I can also more easily compare permeability values in different directions."

Results – Case Analysis II: Inter-well connectivity

- Evaluating permeability design (decal and tensor)





“from the 3D tensors, I can see a stacked channel system that seems to extend across the two wells (…) the layers [decals] inforce this, but I can also more easily compare permeability values in different directions.”

“interesting complementary visualizations”

“this is the right way to display permeability”

Expert feedback – Case analysis II

- How much impermeable are the cells? (transparency encoding)
- Color-coded bands could be used for additional attributes
- Incorporate suggestions from the experts

More Future Work

- Design space is vast!
- Incorporate new attributes, e.g., water saturation
- On-demand data visualization
- Which new data metaphors can be created using decals?
- Hybrid visualization seems promising

Conclusions - Contributions

- A domain problem characterization to inform visualization practitioners new to this domain
- Multivariate visualization design of multiple geological attributes in a single view
- Surface layering combined with a 3D glyph-based representation.
- A simple importance-sampling method for representing scalar fields
- Extension of the Decal-Maps technique

Thank You!

Illustrative Multivariate Visualization for Geological Modelling

Allan Rocha*, Roberta C. R. Mota*, Hamidreza Hamdi**,

Usman R. Alim*, and Mario Costa Sousa*

Questions?

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