Illustrative Multivariate Visualization for Geological Modelling

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Geological Modelling

• Process to create a digital representation of the underground reservoir
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

Multivariate Visualization
• Noise texture + Colormaps
  • 1 or 2 attributes
• Decal-Maps

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

  ![Color Map Example]

  • 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: \[ \phi = \frac{V_v}{V_t} \]

\[ V_v \text{ is the void-space} \]
\[ V_t \text{ is the total volume} \]

[Image: Diagram of porosity with labels: non-porous, non-permeable, porous, non-permeable, connected pore spaces, no pore spaces, unconnected pore spaces.]

[Image: Poisson importance sampling diagram with min and max labels.]

[Grain decal]

[Rocha et al., TVCG 2017]
Visualization Design – Surface representation

• Porosity (scalar data)
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    \( V_v \) is the void-space
    \( V_t \) is the total volume

[Image: Rocha et al., TVCG 2017]

- Grain decal
- Poisson importance sampling

Costly to compute for arbitrary grids
Does not consider local control over the distribution
Visualization Design – Surface representation

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  • Volumetric value given by the ratio: \[ \phi = \frac{V_v}{V_t} \]

\[ V_v \] is the void-space
\[ V_t \] is the total volume

\( \cong 50\% ? \)

[Grain decal]

[Poisson importance sampling]

Costly to compute for arbitrary grids
Does not consider local control over the distribution

[Rocha et al., TVCG 2017]
Visualization Design – Surface representation

- Porosity (scalar data)

\[ \frac{l^2}{\pi r^2} = 1 \]
Visualization Design – Surface representation

- Porosity (scalar data)

\[
\frac{l^2}{\pi r^2} = 1
\]

0.8

porosity = 0

0.2

porosity = 0.2

cell face
Visualization Design – Surface representation

• Porosity (scalar data)

\[ l_u(p) := r \sqrt{\pi (1 - p)}, \text{where } 0 \leq p \leq 1 \]

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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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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geological model
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2D decal-map

geological model
Visualization Design – Surface layering

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Visualization Design – 3D glyph-based representation

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

• Tensor visualization
  • Ellipsoid glyphs \(\frac{1}{k_{xx} + k_{yy} + k_{zz}} (k_{xx}, k_{yy}, k_{zz})\)
Visualization Design – 3D glyph-based representation

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  • Ellipsoid glyphs \(\frac{1}{k_{xx} + k_{yy} + k_{zz}} (k_{xx}, k_{yy}, k_{zz})\)

• 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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  • Diagonal 3x3 matrix \((k_{xx}, k_{yy}, k_{zz})\)

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

• Visual ambiguity problem [Kindlmann, CGF 2004]

Shading is not enough to convey orientation

Look the same from this point of view

Different point of view
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, \((\phi, \theta)\) are given by

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

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

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

\[
0 \leq \theta \leq 2\pi
\]
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\epsilon + \frac{\pi}{3} \leq \phi \leq \frac{2\pi}{3} - \epsilon \\
\epsilon + \frac{4\pi}{3} \leq \phi \leq \frac{5\pi}{3} - \epsilon
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\(0 \leq \theta \leq 2\pi\)
Visualization Design – Surface layering

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GPU-Implementation - Pipeline

Extending the Layering Pipeline [Rocha et al., 2017]
GPU-Implementation - Pipeline

Layering framework

geological model
G-layer 0
G-layer 1
G-buffer 0
G-buffer 1
A-layer 0
A-layer 1

2D Texture array (LFBO)
Screen quad
Fragment Sorting

SSAO
Final Image

other objects
3D tensor glyphs
GPU-Implementation - Pipeline
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- 2D Texture array (LFB0)
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- other objects
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GPU-Implementation - Pipeline
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Layering framework

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2D Texture array (LFBO)

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Final Image
Results

• Illustrative Visualization
Results

• Illustrative Visualization
• Case Analysis I
• Case Analysis II
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] reinforce 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] enforce 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

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Questions?

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