Unified geophysical and geological 3-D Earth models

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Goal

⋆ A single 3-D Earth model for both geology and geophysics.

Outline

⋆ Geological models

⋆ Geophysical models and numerical modelling

⋆ Rectilinear grids vs. unstructured grids

⋆ Working with unstructured grids
Voisey’s Bay Ovoid ore-body and troctolite.
Geological models: tessellated surfaces

★ Surfaces consist of connected triangles.

★ Can capture arbitrarily complicated subsurface contacts.
Geophysical models: rectilinear grids
Geophysical models: rectilinear grids

★ Regular mesh of brick-like cells, physical properties uniform within each cell but different between cells . . .

→ Pixellated representation of the subsurface.

★ Mathematics for computing data response are easier.

★ In principle, arbitrary spatial variations can be represented if a sufficiently fine discretization is used.
From surfaces to a rectilinear grid

(Mike Ash, M.Sc. thesis)
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From surfaces to a rectilinear grid

★ Previous example: $87 \times 61 \times 54 = 286,578$ cells …
→ a reasonably fine discretization.

★ But “staircasing” of contacts still evident.

★ Finer is possible, but computation times and memory requirements quickly become inconvenient / infeasible.

So …
Geophysical models: unstructured tetrahedral grids
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(Cassandra Tycholiz, M.Sc. student)
Geophysical models: unstructured tetrahedral grids

★ Discretize the volume between surfaces while maintaining exactly the tessellated surfaces.

★ Geological and geophysical models can share the same grid . . .
   → can be the same model,
   → no translation or transformation from one kind of model to the other.

★ Unstructured discretizations can capture fine-scale structure without greatly increasing memory requirements.
But we need to perform the mathematics on the unstructured tetrahedral grids,

And build and manipulate Earth models discretized using an unstructured tetrahedral grid.
Computing synthetic geophysical data: gravity

* Closed-form expression for a tetrahedron (Okabe, 1979).

* Finite-volume solution of Poisson’s equation . . .

(Hormoz Jahandari, Ph.D. student.)
Computing synthetic geophysical data: EM

★ Decomposition into inductive and galvanic parts . . .

\[ \mathbf{E} = -i\omega \mathbf{A} - \nabla \phi. \]

★ Finite-element solution using edge and nodal elements . . .

\[ \mathbf{A}(\mathbf{r}) = \sum_{j=1}^{N_{edges}} A_j \mathbf{N}_j(\mathbf{r}), \]
\[ \phi(\mathbf{r}) = \sum_{k=1}^{N_{nodes}} \phi_k \mathbf{N}_k(\mathbf{r}). \]

(Seyedmasoud Ansari, Ph.D. student.)
Computing synthetic geophysical data: seismic travel times

* Fast marching method ...
Geophysical inversion: seismic travel times
Geophysical inversion: seismic travel times
Geophysical inversion: joint seismic traveltime and gravity

density

slowness
Manipulating unstructured tetrahedral Earth models

* Automated surface reconstruction from point clouds.
Manipulating unstructured tetrahedral Earth models

* By hand, making use of 3-D graphics and visualization software.

(Angela Carter-McAuslan, M.Sc. student)
Conclusions

⋆ Unstructured tetrahedral grids . . .
   → can honour geological surfaces,
   → can represent fine-scale structure, and yet
   → are efficient discretizations of the modelling domain.

⋆ A single 3-D Earth model for both geology and geophysics.