Modeling Terrains and Subsurface Geology

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Terrain Modelling

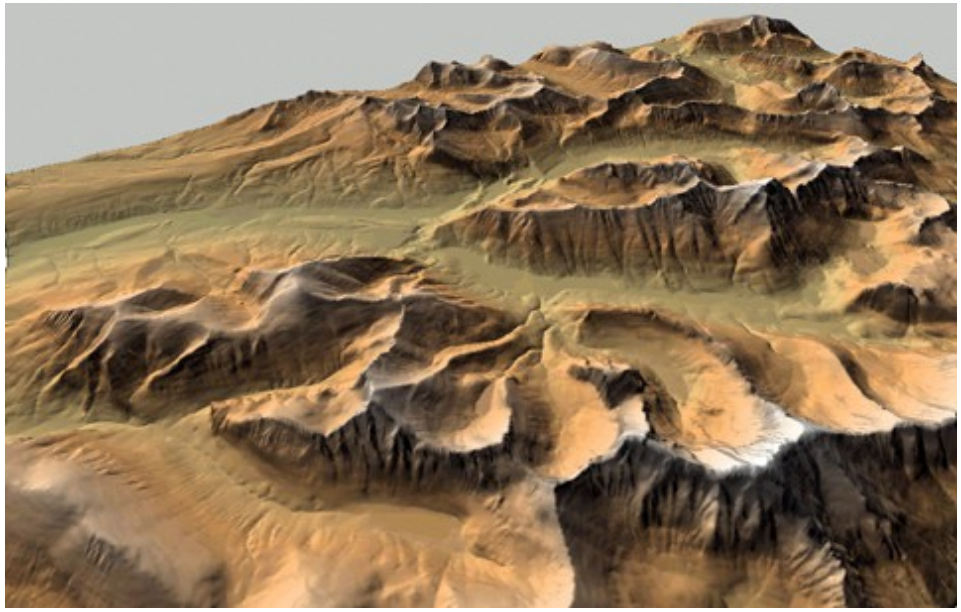
Games and movies

(computer graphics, emphasis on realistic visual appearance)

scenicreflections.com

Real landscape representation

(geological application, emphasis on scientific correctness of the model)



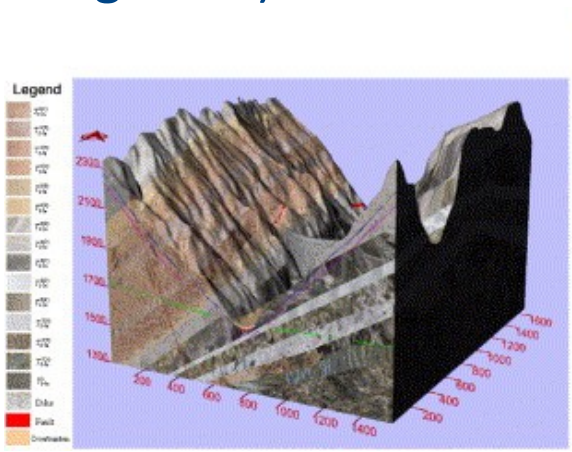
Virtual Vista:
Glacier National Park, Montana, USA

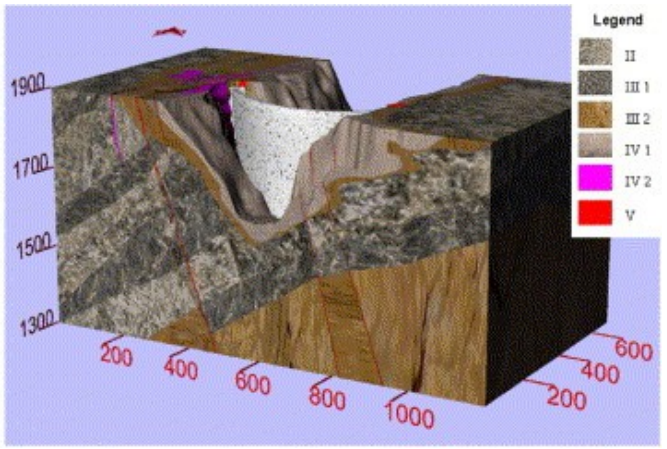
Differences

- **Computer graphics**:
  - Artists model the terrain
  - Procedural techniques to save time
  - Mainly top surface

- Terragen -

- **Geology**:
  - Scientists model
  - Rapid modelling methods (but less procedural, more user-guided)
  - Mainly subsurface



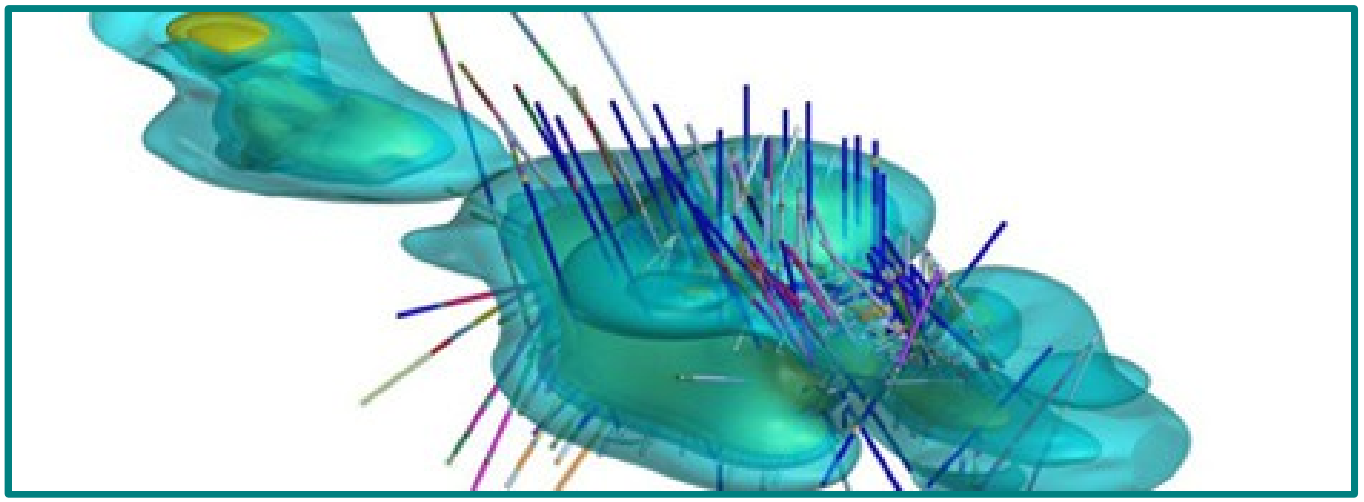


[Deng-Hua Zhong et al. 2006]

Data Acquisition (Geology)

- Modelling based on measurements (most of the cases)

- Input
  - densely covers a dense area (large-scale acoustic surveys) or
  - made of sparse samples (e.g. boreholes)

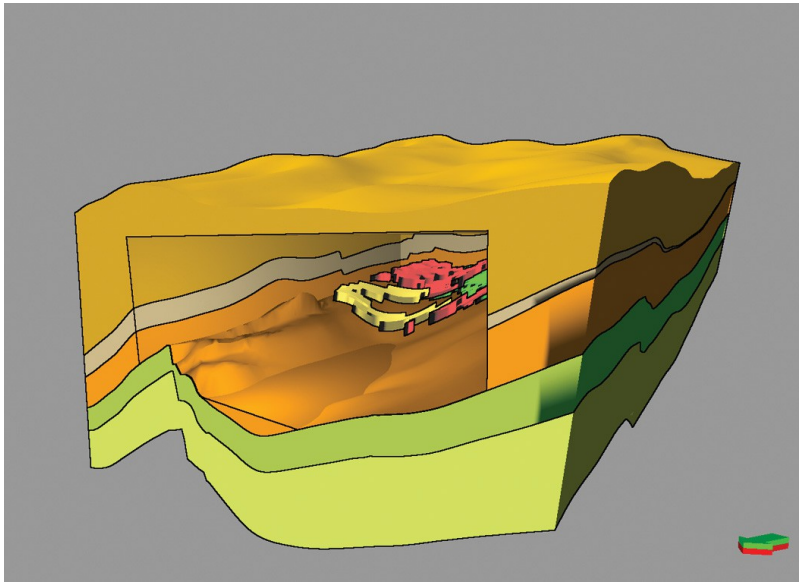


- Leapfrog -

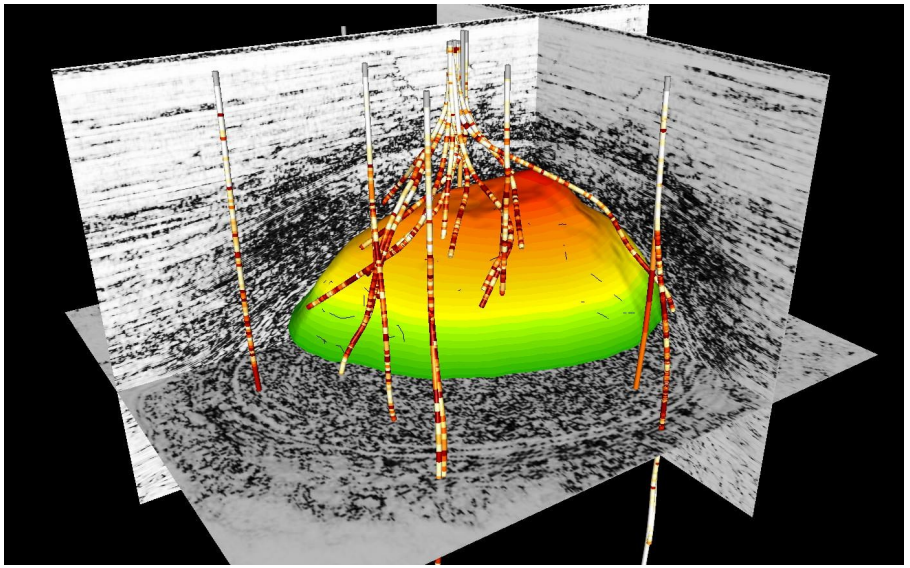
Geobodies

- In structural geology (not only top surface)

- Examples of geobodies: layer, horizon, fold, fault, channel, delta, salt dome, igneous intrusion

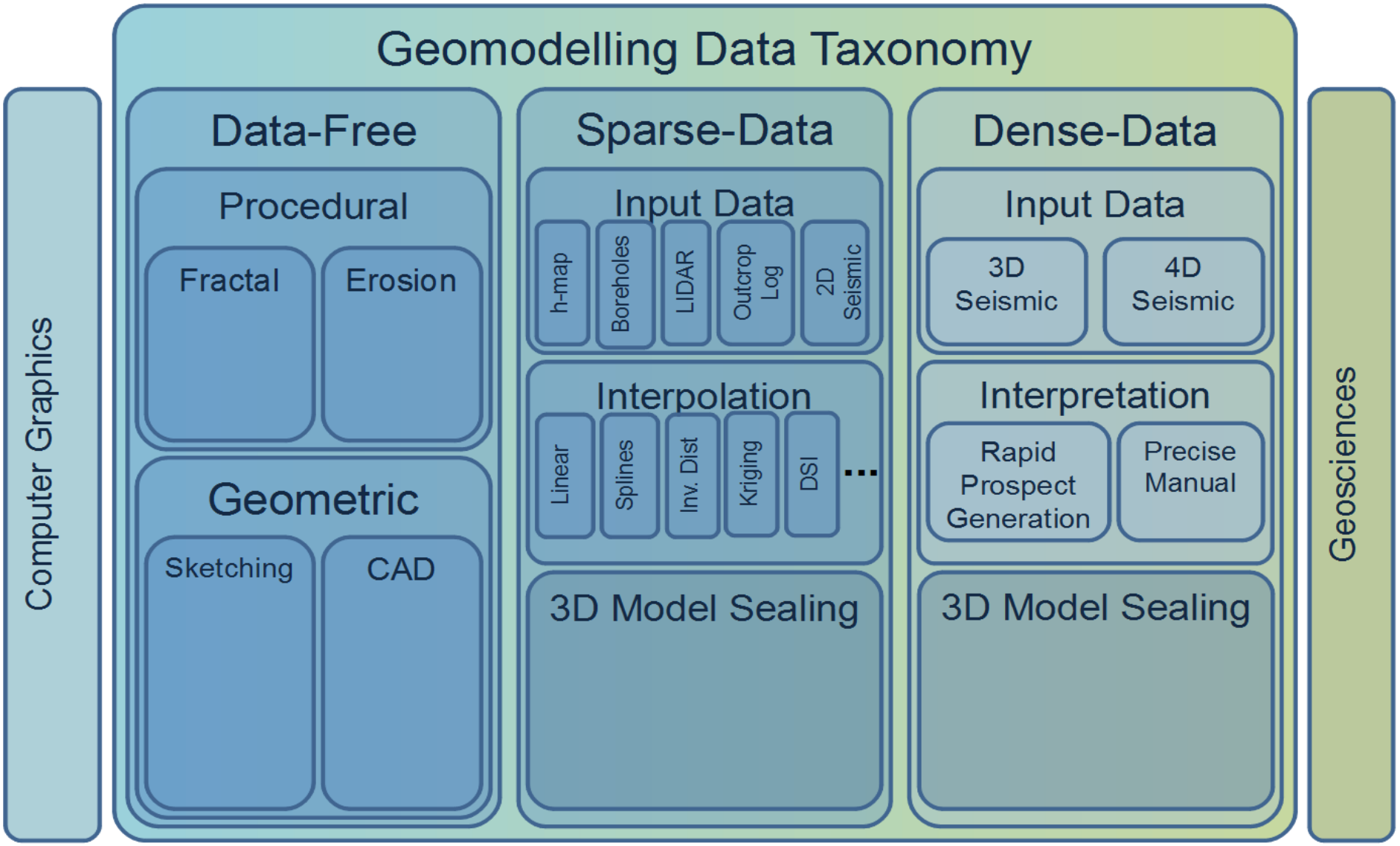


[Lidal et al. 2012]



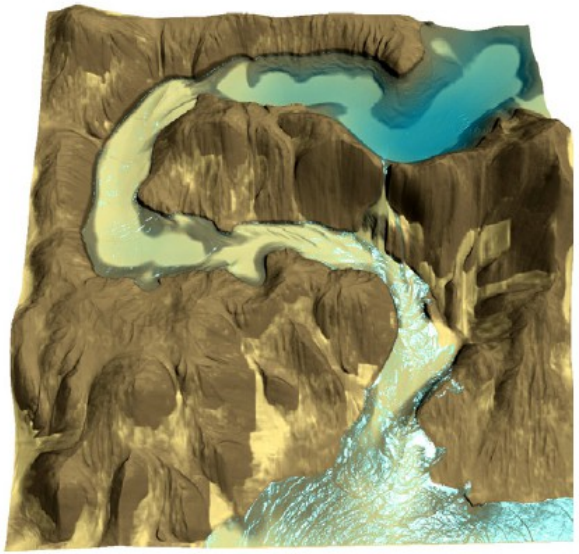
- Arc Graphics -

Geomodelling Data Taxonomy

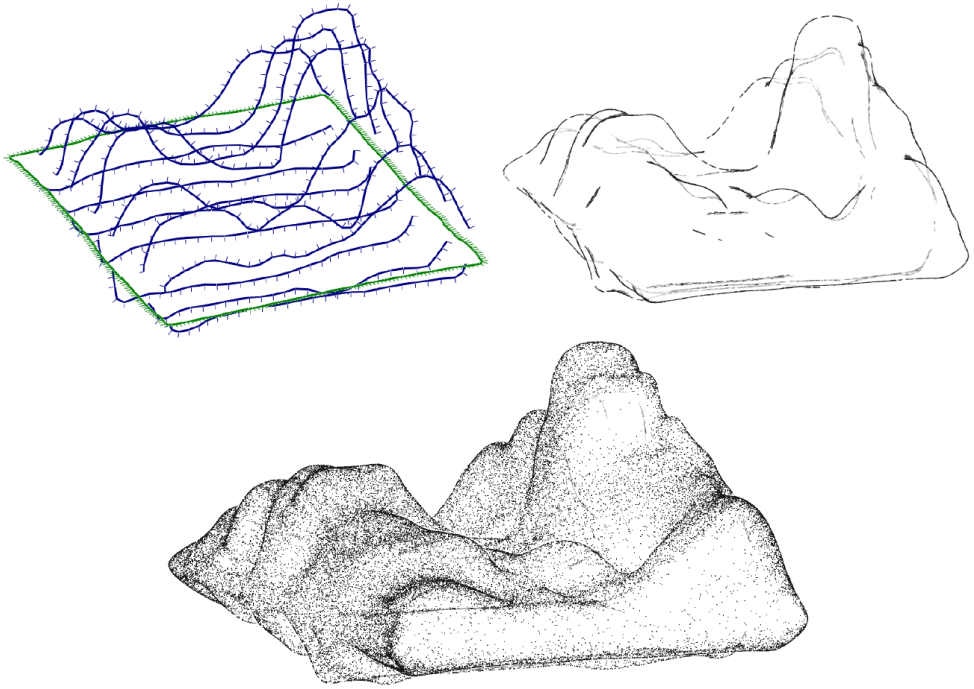


No-data

- Procedural and geometric modelling
  - **Procedural** (mainly fractal and erosion): lack of control
  - **Geometric**: labor-intensive, then sketching or by example

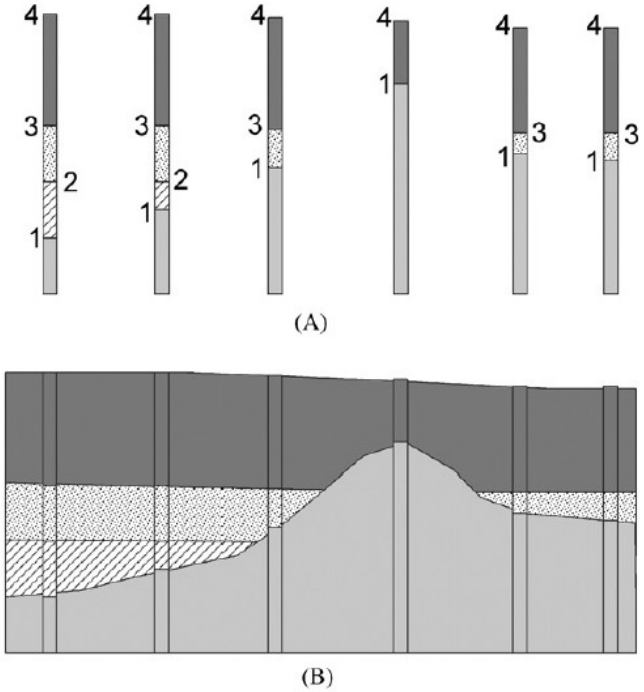


[Stava et al. 2008]



[Brazil et al. 2010]

Sparse-data

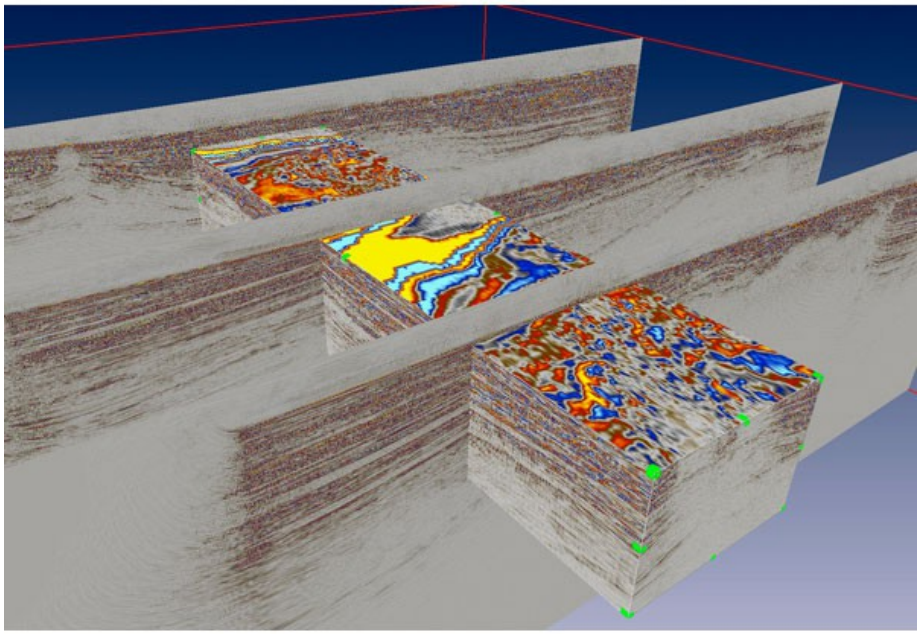


[Lemon and Jones 2003]

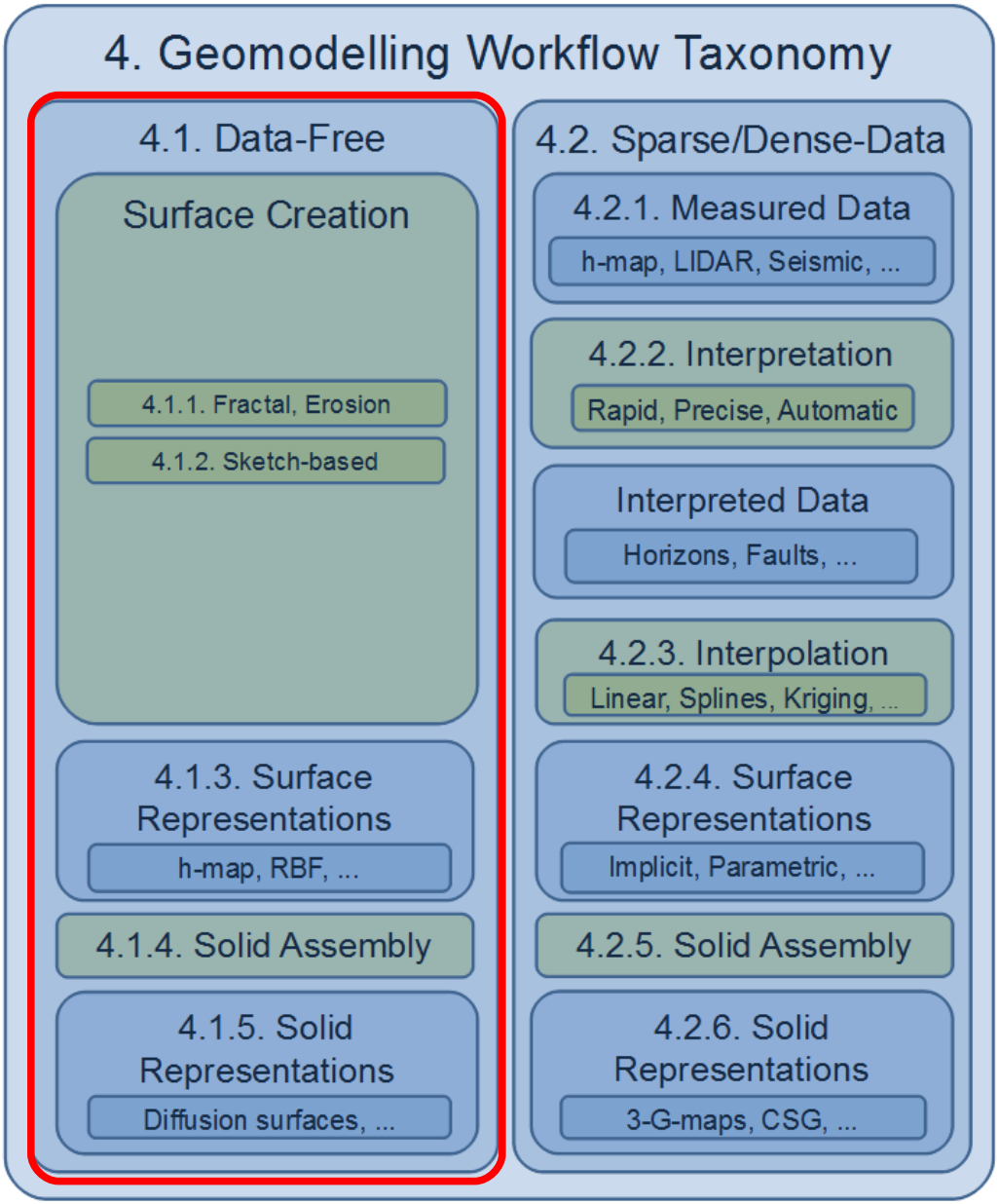
- Most seen in geosciences
- Networks of boreholes to be interpolated
- Surface elevation models (through remote sensing)
- Interpolating methods:
  - B-spline
  - Inverse Distance
  - Kriging
  - Discrete Smooth Interpolation

Dense-data

- Volumetric seismic dataset
  - Visualized as it is
    or
  - Geoscientific interpretation
    (starting with extraction of geo-bodies)



Workflow Taxonomy



No-data

- Sketches combined with exemplar-based technique

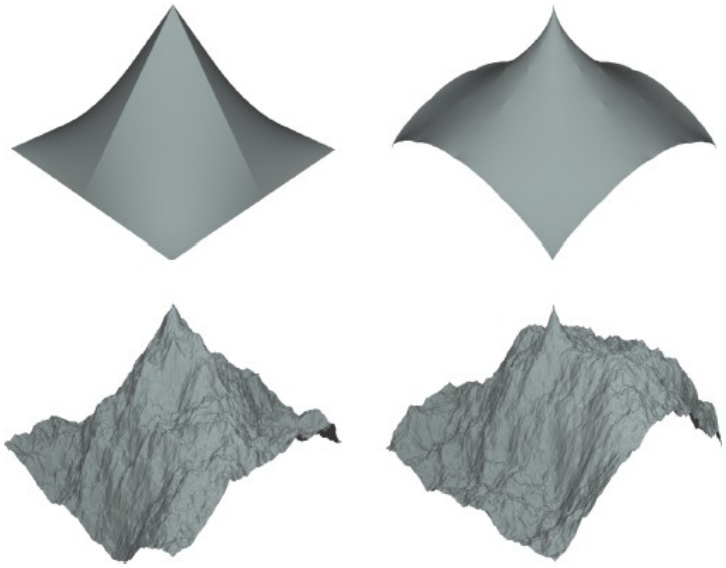
[Zhou et al. 2007]

Fractal and Erosion

- Synthetic terrains from:
  - Fractal landscape modelling
  - Physical erosion simulation
  - Images or terrain patches

- Fractal approach from a base surface (noisy surface)

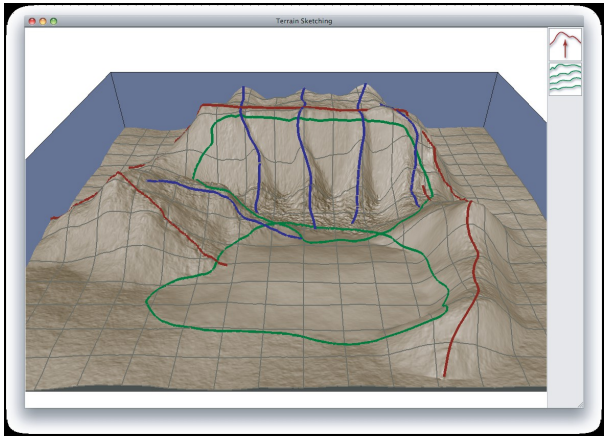
- Erosion simulation:
  - Thermal or Hydraulic



[Belhadj et al. 2007]

Sketch-based

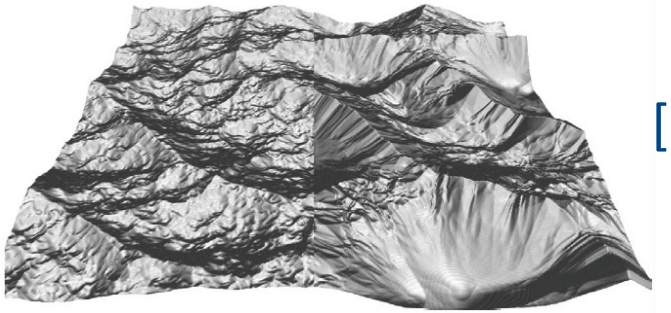
- Rapid modelling
- Expressive
- Intuitive
- No need to set parameters



[Gain et al. 2009]

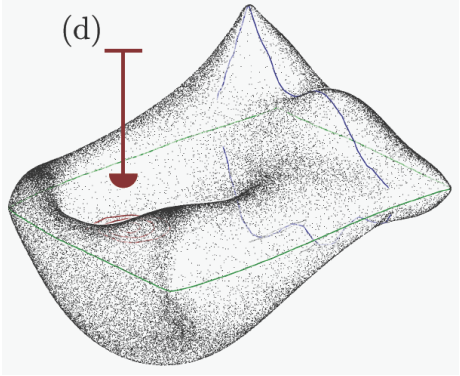
Surface Representation

- Height maps



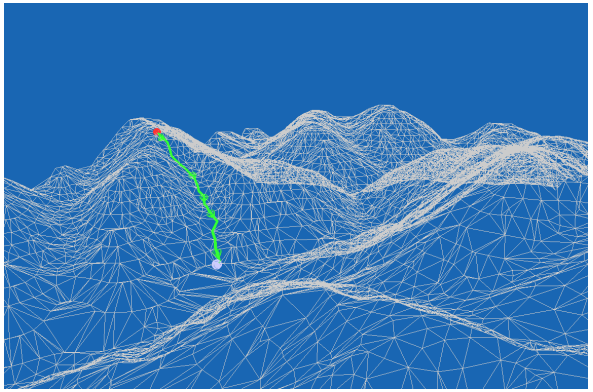
[de Carpentier and Bidarra 2009]

- Implicit surfaces



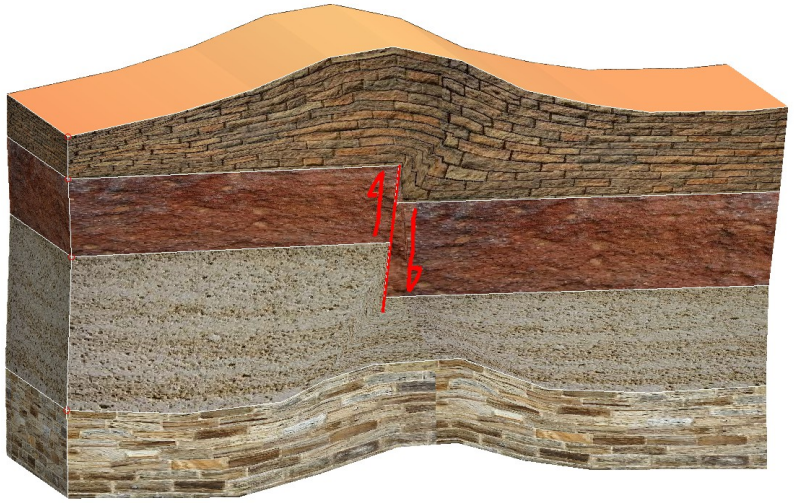
[Brazil et al. 2010]

- Meshes



Solid Assembly

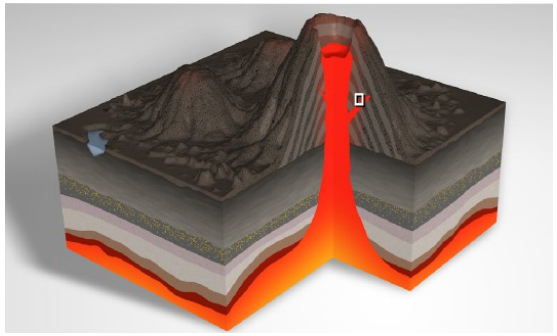
- Boundary representation of a solid model
- Surfaces obtained from previous steps specify geobodies that compose the solid
- Process supported by CAD-based or sketch-based tools



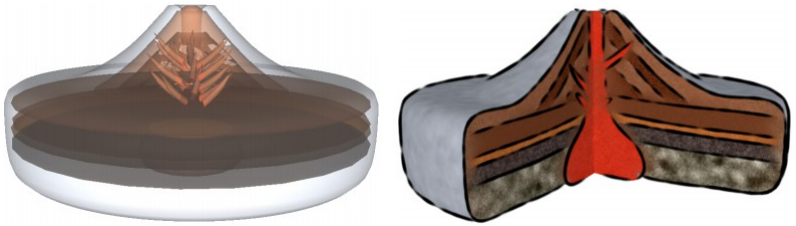
Sibgrapi 2012

Solid Representations

- Implicit solids [used in No-Data]
- Vector volumes [used in No-Data]
- Constructive Solid Geometry (CSG)
- 3-G-maps
- Voxel representation
- Diffusion surfaces [used in No-Data]

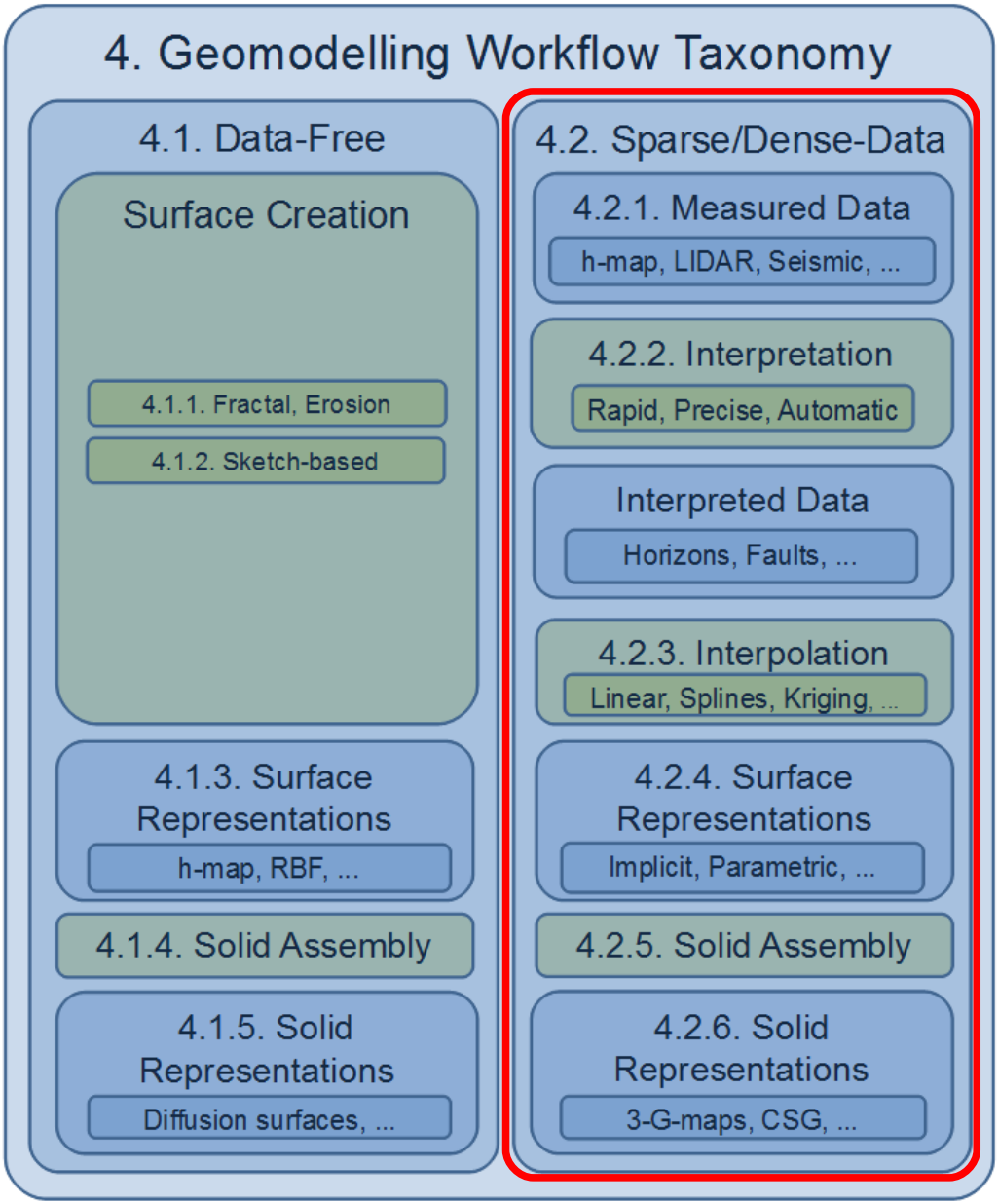


[Wang et al. 2011]



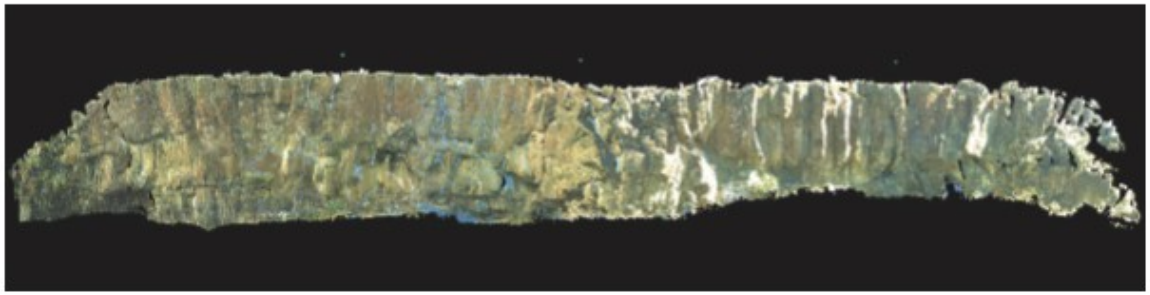
[Takayama et al. 2010]

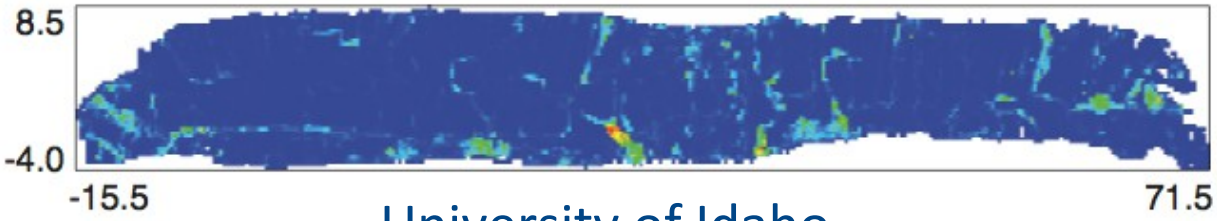
Workflow Taxonomy



Sparse- and Dense-data

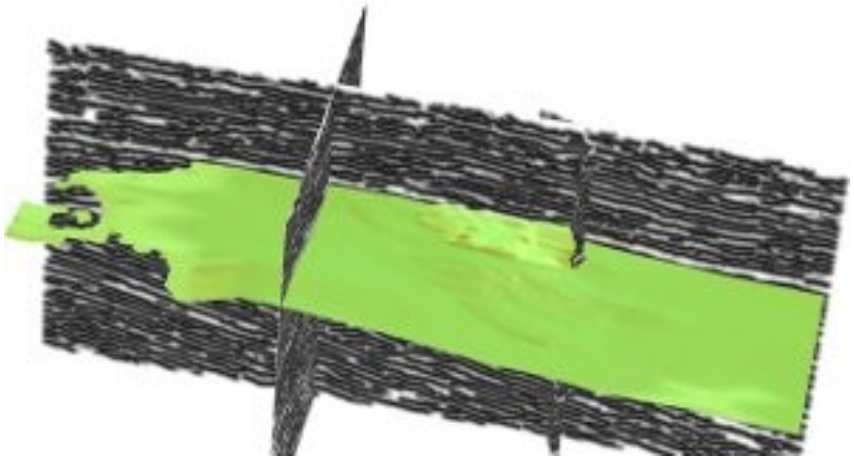
- Geological measured data as input
- Seismic 2D or 3D (reflection of sound waves)
- Collection of well logs (material samples of the ground)
- Outcrop scan (combination of laser and photography, LIDAR)

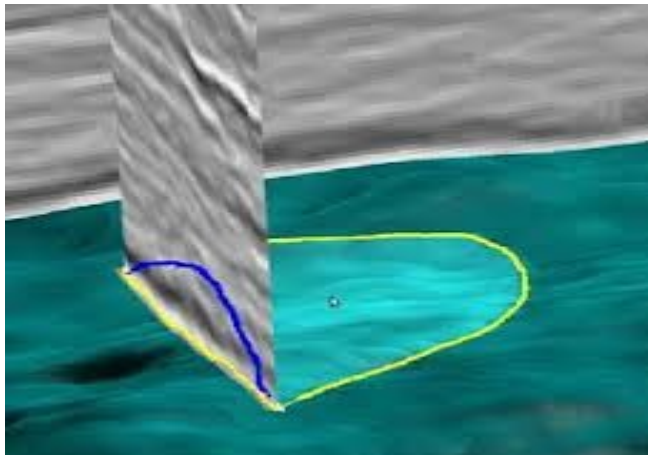




Interpretation

- Time consuming
- Interpret 3D seismic data (mainly to detect layers and faults)
- Extraction of horizon surfaces
- Spline or free-form modelling for surface manipulation

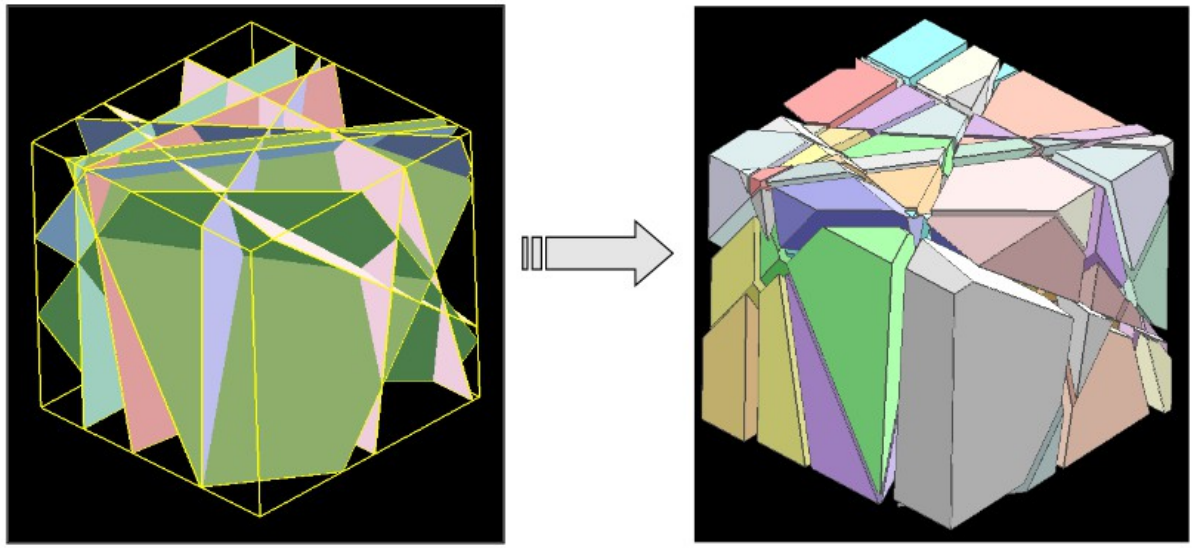




[Amorim et al. 2012]

Interpolation

- To obtain surfaces in geology:
  - B-spline method
  - Inverse distance method
  - Kriging method
  - Discrete Smooth Interpolation (DSI) method
  - Natural Neighbor Interpolation method
- Solid from surfaces:



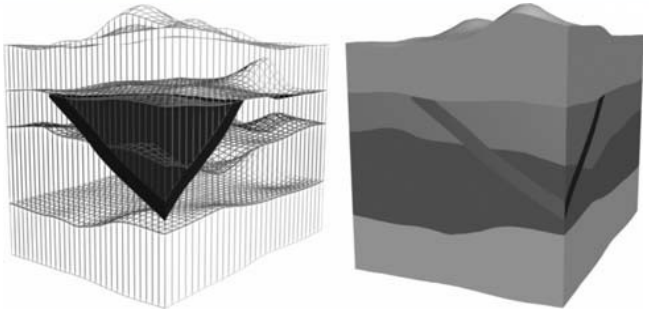
Initial set of surfaces *(faults)*

Resulting 3G-map

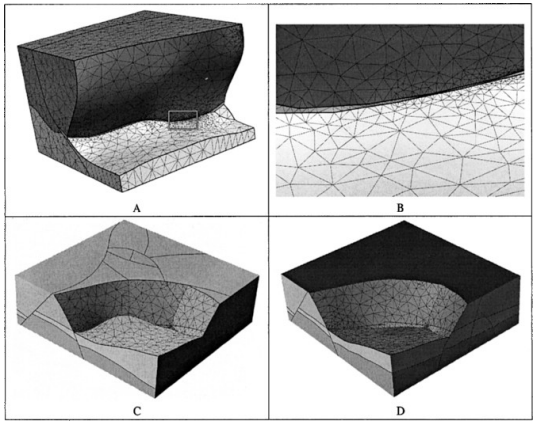
[Floater et al. 1998]

Solid Assembly

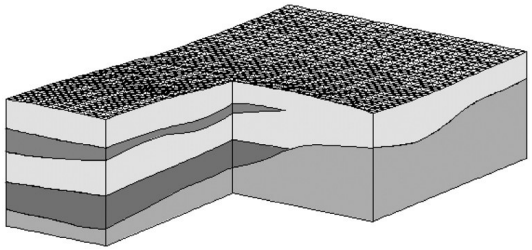
- Baojun and Zhen 2009



- Caumon et al. 2004

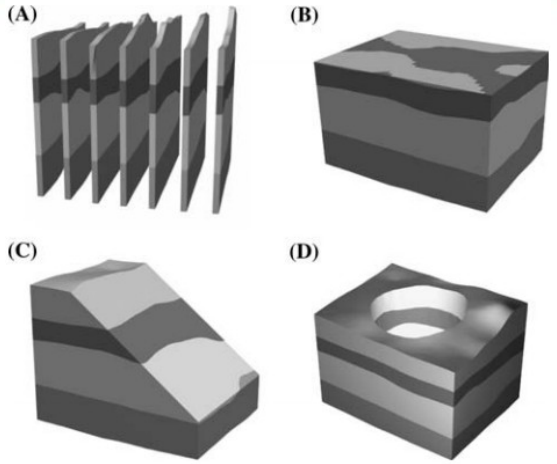


- Lemon and Jones 2003



Solid Representations

- Implicit solids
- Constructive Solid Geometry (CSG) [S/D-data]
- 3-G-maps [S/D-data]
- (Diffusion surfaces)
- Voxel representation [S/D-data]



[Baojun and Zhen 2009]

[Peytavie et al. 2009]

Surface Representations

	Fractal & Noise-based	Erosional	Exemplar-based synthesis	Radial-basis function	Splines	Kriging	Discrete smooth interpolation
Terrain realism	+	+	++	-	-	+	o
Faults (discontinuities)	-	-	o	-	-	-	++
Gap-filling (interpolation)	+	-	+	++	+	++	+
Overhangs (multi-z values)	o	o	--	++	+	-	+
Control	-	-	o	+	+		
Processing requirements	-	-	-	-	+	-	--
Storage requirements	++	+	-	+	+	+	+
Multiscale	++	o	+	--	--	-	-

Fractal and Noise-based

- Realistic appearance of the surface
- Self-similarity of fractals like in nature
- (Height-maps) Do not allow discontinuities
- No multi-z values
- Not intuitive, no local control

	Fractal & Noise-based	Erosional	Exemplar-based synthesis	Radial-basis function	Splines	Kriging	Discrete smooth interpolation
Terrain realism	+	+	++	-	-	+	o
Faults (discontinuities)	-	-	o	-	-	-	++
Gap-filling (interpolation)	+	-	+	++	+	++	+
Overhangs (multi-z values)	o	o	--	++	+	-	+
Control	-	-	o	+	+		
Processing requirements	-	-	-	-	+	-	--
Storage requirements	++	+	-	+	+	+	+
Multiscale	++	o	+	--	--	-	-

Erosion

- Weathering simulation
- Natural appearance of top surface
- No discontinuity
- Hard to control
- Low storage, high processing

	Fractal & Noise-based	Erosional	Exemplar-based synthesis	Radial-basis function	Splines	Kriging	Discrete smooth interpolation
Terrain realism	+	+	++	-	-	+	o
Faults (discontinuities)	-	-	o	-	-	-	++
Gap-filling (interpolation)	+	-	+	++	+	++	+
Overhangs (multi-z values)	o	o	--	++	+	-	+
Control	-	-	o	+	+		
Processing requirements	-	-	-	-	+	-	--
Storage requirements	++	+	-	+	+	+	+
Multiscale	++	o	+	--	--	-	-

Exemplar-based

- Surface reconstruction (geometry and texture) through a collection of data from photography and laser
- Computational expensive to create a terrain
- Little control on the process
- High storage requirements

	Fractal & Noise-based	Erosional	Exemplar-based synthesis	Radial-basis function	Splines	Kriging	Discrete smooth interpolation
Terrain realism	+	+	++	-	-	+	o
Faults (discontinuities)	-	-	o	-	-	-	++
Gap-filling (interpolation)	+	-	+	++	+	++	+
Overhangs (multi-z values)	o	o	--	++	+	-	+
Control	-	-	o	+	+		
Processing requirements	-	-	-	-	+	-	--
Storage requirements	++	+	-	+	+	+	+
Multiscale	++	o	+	--	--	-	-

Radial Basis Functions

- Interpolation of a set of *n* points with their normal vector
- Unordered points (unlike splines)
- C^n *continuity*
- No gap in the surface
- Overhangs feasible

	Fractal & Noise-based	Erosional	Exemplar-based synthesis	Radial-basis function	Splines	Kriging	Discrete smooth interpolation
Terrain realism	+	+	++	-	-	+	o
Faults (discontinuities)	-	-	o	-	-	-	++
Gap-filling (interpolation)	+	-	+	++	+	++	+
Overhangs (multi-z values)	o	o	--	++	+	-	+
Control	-	-	o	+	+		
Processing requirements	-	-	-	-	+	-	--
Storage requirements	++	+	-	+	+	+	+
Multiscale	++	o	+	--	--	-	-

Splines

- From a set of control points with normal
- Ordered list of points
- Parametric form facilitates computation and visualization
- No fault (continuity of surface)

	Fractal & Noise-based	Erosional	Exemplar-based synthesis	Radial-basis function	Splines	Kriging	Discrete smooth interpolation
Terrain realism	+	+	++	-	-	+	o
Faults (discontinuities)	-	-	o	-	-	-	++
Gap-filling (interpolation)	+	-	+	++	+	++	+
Overhangs (multi-z values)	o	o	--	++	+	-	+
Control	-	-	o	+	+		
Processing requirements	-	-	-	-	+	-	--
Storage requirements	++	+	-	+	+	+	+
Multiscale	++	o	+	--	--	-	-

Kriging

- Terrain realism
- Statistical interpolation
- Incorporates domain knowledge
- Fills gaps in input dataset
- Completely automatic

	Fractal & Noise-based	Erosional	Exemplar-based synthesis	Radial-basis function	Splines	Kriging	Discrete smooth interpolation
Terrain realism	+	+	++	-	-	+	o
Faults (discontinuities)	-	-	o	-	-	-	++
Gap-filling (interpolation)	+	-	+	++	+	++	+
Overhangs (multi-z values)	o	o	--	++	+	-	+
Control	-	-	o	+	+		
Processing requirements	-	-	-	-	+	-	--
Storage requirements	++	+	-	+	+	+	+
Multiscale	++	o	+	--	--	-	-

Discrete Smooth Interpolation

- Computes missing information
- Iterative minimization algorithm (high complexity)
- Efficient in iterative modelling (adjust existing model)
- No multi-scale representation
- Automatic method

	Fractal & Noise-based	Erosional	Exemplar-based synthesis	Radial-basis function	Splines	Kriging	Discrete smooth interpolation
Terrain realism	+	+	++	-	-	+	o
Faults (discontinuities)	-	-	o	-	-	-	++
Gap-filling (interpolation)	+	-	+	++	+	++	+
Overhangs (multi-z values)	o	o	--	++	+	-	+
Control	-	-	o	+	+		
Processing requirements	-	-	-	-	+	-	--
Storage requirements	++	+	-	+	+	+	+
Multiscale	++	o	+	--	--	-	-

Solid Representations

	Implicit solids	CSG	3-G-Maps	Voxel representation	Diffusion surfaces [TSNI10]	Vector volumes [WYZG11]
Layer support	+	+	++	+	o	+
Channels/cavities support	+	+	+	++	+	+
Ease of modelling	+	+	+	-	+	-
Processing requirements	--	o	o	+	+	o
Storage requirements	++	+	o	--	+	-
Multiscale	+	+	+	--	o	++

Implicit Solids

- Not aimed at geological models
- Multi-scale models
- Interactivity through sketch-based interfaces
- Low storage requirements
- Require conversion to mesh for visualization

	Implicit solids	CSG	3-G-Maps	Voxel representation	Diffusion surfaces [TSNI10]	Vector volumes [WYZG11]
Layer support	+	+	++	+	o	+
Channels/cavities support	+	+	+	++	+	+
Ease of modelling	+	+	+	-	+	-
Processing requirements	--	o	o	+	+	o
Storage requirements	++	+	o	--	+	-
Multiscale	+	+	+	--	o	++

Constructive Solid Geometry

- Simple primitives and set operators
- Channels and cavities
- Multi-scale
- With basic primitives, low memory and quick interactions

	Implicit solids	CSG	3-G-Maps	Voxel representation	Diffusion surfaces [TSNI10]	Vector volumes [WYZG11]
Layer support	+	+	++	+	o	+
Channels/cavities support	+	+	+	++	+	+
Ease of modelling	+	+	+	-	+	-
Processing requirements	--	o	o	+	+	o
Storage requirements	++	+	o	--	+	-
Multiscale	+	+	+	--	o	++

3-G-maps

- Popular in geological solid modelling approaches
- Boundary representation
- Detail at different scales
- Synchronization of geometry and topology during modelling
- No processing or storage challenges

	Implicit solids	CSG	3-G-Maps	Voxel representation	Diffusion surfaces [TSNI10]	Vector volumes [WYZG11]
Layer support	+	+	++	+	o	+
Channels/cavities support	+	+	+	++	+	+
Ease of modelling	+	+	+	-	+	-
Processing requirements	--	o	o	+	+	o
Storage requirements	++	+	o	--	+	-
Multiscale	+	+	+	--	o	++

Voxel Representation

- Regular 3D discretized volume
- Folds, faults, cavities, channels
- Unpractical modelling approach
- Space demanding
- No computational stage, values explicitly stored

	Implicit solids	CSG	3-G-Maps	Voxel representation	Diffusion surfaces [TSNI10]	Vector volumes [WYZG11]
Layer support	+	+	++	+	o	+
Channels/cavities support	+	+	+	++	+	+
Ease of modelling	+	+	+	-	+	-
Processing requirements	--	o	o	+	+	o
Storage requirements	++	+	o	--	+	-
Multiscale	+	+	+	--	o	++

Diffusion Surfaces

- Layer restriction with rotational symmetry
- Lack ease of modelling when dealing with multi-scale models
- No need for precomputations
- Low storage requirements

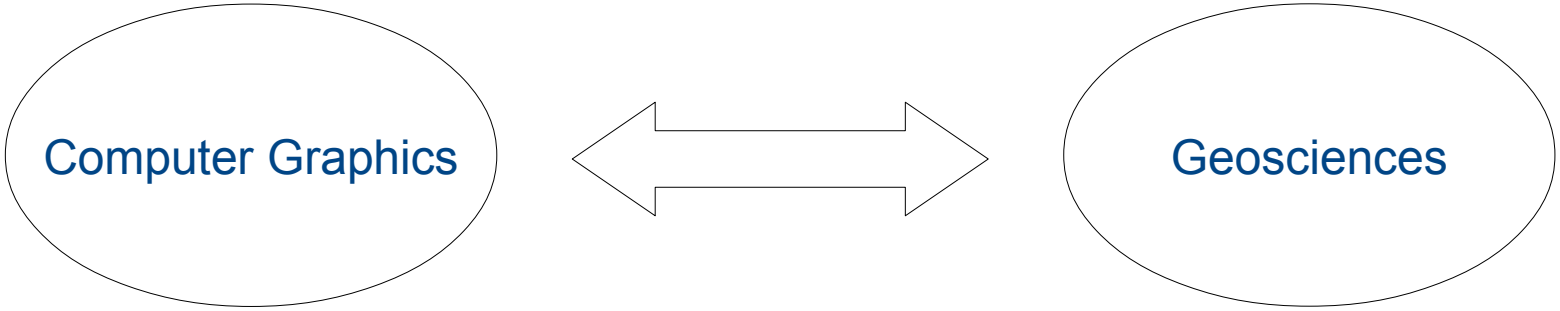
	Implicit solids	CSG	3-G-Maps	Voxel representation	Diffusion surfaces [TSNI10]	Vector volumes [WYZG11]
Layer support	+	+	++	+	o	+
Channels/cavities support	+	+	+	++	+	+
Ease of modelling	+	+	+	-	+	-
Processing requirements	--	o	o	+	+	o
Storage requirements	++	+	o	--	+	-
Multiscale	+	+	+	--	o	++

Vector Volumes

- Tree of signed distance functions
- Combine benefits from voxel and implicit representations
- High storage requirements
- Efficient in direct visualization when performing ray-casting

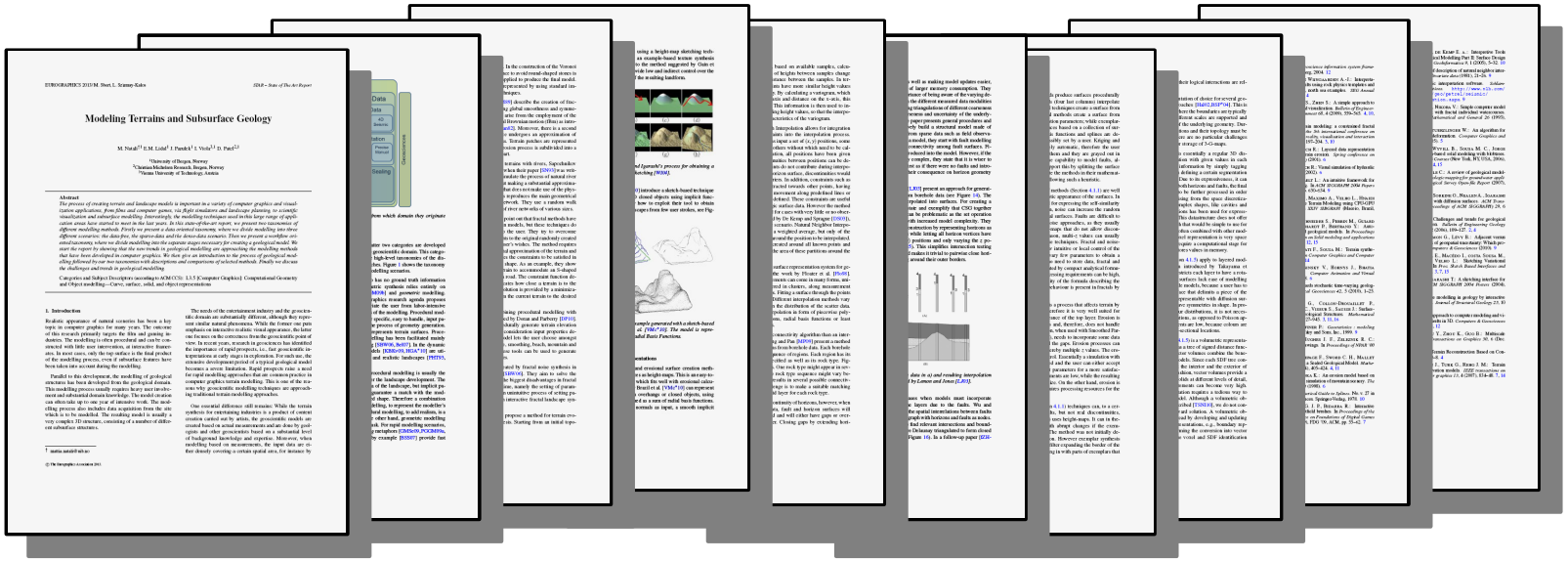
	Implicit solids	CSG	3-G-Maps	Voxel representation	Diffusion surfaces [TSNI10]	Vector volumes [WYZG11]
Layer support	+	+	++	+	o	+
Channels/cavities support	+	+	+	++	+	+
Ease of modelling	+	+	+	-	+	-
Processing requirements	--	o	o	+	+	o
Storage requirements	++	+	o	--	+	-
Multiscale	+	+	+	--	o	++

Challenges and Trends



- Update model when new data become available
- Modelling technology for communication and subsurface analysis
- Rapid modelling
- Consideration of temporal aspect in geology
- Combine different representations in one model

Thank you!



Based on Eurographics 2013 state-of-the-art report

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