Construction of Hybrid Geostatistical Models
Combining Surface Based Methods with MPS:
Use of Flow Direction and Drainage Area

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Subsurface Modeling

**Goals:**
- Reproduce geologic features
- Account for as much geological knowledge as possible
- Match available data

**Challenge:**
- Break down the problem of simulating complex geological features into a set of smaller problems that can be faced using the most suitable approaches
Subsurface Modeling:

**Primary modeling methods:**

- Two-point geostatistical simulation
- Multiple-point geostatistical simulation
- Surface-based methods
- Object-based simulation
- Process-based simulation
Hybrid Modeling

Deepwater Turbidite Model

- Changes in the Model (Use of flow direction and drainage area, Erosion, etc.)
- Techniques to condition the model
Process Model (Tao Sun)

Deepwater Turbidite System

Model calculates:
- Turbulent Flow velocity (governing differential conservation equations)
- Simulates Erosion/Deposition

Information retained in each cell:
- Grain size distribution
- Time of deposition

From Parker et al., 1986

Courtesy of Holly Micheal
The model

Courtesy of Holly Micheal
Parameterization:

**Lobe Shape:**
- Fully described by L and W.
- Thickness drawn from CDF (non-conditional case).

**Channel:**
- Connects sediment source to lobe.
- Channel width is drawn from CDF.

Courtesy of Holly Micheal
Lobe Orientation

Initial Topography

Influence and Dependence Map

Anchor-Point

Drainage Basin

Influence Map
(Flow Path)

Drainage Basin Contour
Lobe Orientation

Drainage Basin Contour

Angle Range

Object-based Sim. 1

Object-based Sim. 2

Object-based Sim. 3

Object-based Sim. 4

Variability!
Flow Direction *

Infinite directions ($D^\infty$)

\[
S_1 = \frac{(e_0 - e_1)}{d_1} \quad S_2 = \frac{(e_0 - e_2)}{d_2}
\]

\[
r = \tan^{-1}\left(\frac{S_2}{S_1}\right)
\]

\[
S = \sqrt{S_1^2 + S_2^2}
\]

If $r \notin \left(0, \tan^{-1}\left(\frac{d_2}{d_1}\right)\right)$ then

If $r < 0$

\[
r = 0
\]

\[
S = S_1
\]

If $r > \tan^{-1}\left(\frac{d_2}{d_1}\right)$

\[
r = \tan^{-1}\left(\frac{d_2}{d_1}\right)
\]

\[
S = \frac{(e_0 - e_2)}{\sqrt{d_1^2 + d_2^2}}
\]

→ the local angle with the largest downwards slope

\[
r_g = a_f r' + a_c \frac{\pi}{2}
\]

*(Tarboton, 1997)*
Flow Direction*

Infinite directions ($D\infty$)

- Avoids dispersion
- Avoids grid bias
- Has a simple and efficient grid based matrix storage
- Its Robustness (Saddle point)

*(Tarboton, 1997)
**Upslope Area** → **Drainage basin**

Influence and Dependence Map

- Recursive process.
- Pixel Upslope Area = 1+ (Fraction Upslope Area Neighbors).

*Procedure DPAREA(i,j)*

*If AREA(i,j) is known*

- Then
  - no action

*Else*

- Area(i,j)=1
  - for each neighbor (location in, jn)

- p=proportion of neighbor
  - if(p>0) then
    - call DPAREA(in,jn)

- AREA(i,j)=AREA(i,j)+AREA(in,jn)*p

*return*

*(Tarboton, 1997)*
Anchor Point P-Field

P-field 1st Iteration

Initial Topography

P-Field Second Iteration
Erosion

Curvature Profile

Depositional Lobe thickness Map

Gradient Profile

Erosion Map
Erosion

Degree of Alignment Profile

Influence and Dependence Map

Erosion Map 2nd Lobe

Gradient Profile

Curvature Profile
By taking into account flow direction, gradient and curvature values, very realistic features present in erosional process, similar to the ones observed in landslides, are reproduced in the model.
Conditioning

- MPS approach (rejection rules)
- Object-based and surface-based approach
  - Iterative Method (linear combination of areas, capable to be optimized)
  - Grid deformation
Simulation Area (MPS)

Angle Range

Variability!

Simulation Area

Object-based 1
Object-based 2
Object-based 3
Object-based 4

A Priori Simulation Area

Conditioned to topography
Simulation Area (MPS)

Without Considering Drainage Basin

Considering Drainage Basin
Rejection Rules (MPS)

Snesim-simulated Lobe 1

Non-connected sediment source-geobody

Snesim-simulated Lobe 2

Two Geobodies

Snesim-simulated Lobe 3

Nice geobody

Influence Map

- Channel length and orientation
- Sediment source-anchor point distance
- Other distances
2D $\rightarrow$ 3D

MPS realization

Proximity Distance

Low Zones Compensation

Smoothened LMW

Lobe max thickness drawn from pdf
Lobe Simulation
(Combined approach)

Non-conditional Simulation

Conditional Simulation

Threshold Drainage Area

Data Conditioning Cases

Drainage Area Object-Based Lobe Simulation

Lobe Altitude Map
Lobe Simulation
(Combined approach)

Conditional Simulation

Drainage Basin + Object-Based lobe

Cross Section I = 4

X: 200, Y: 148
H = 0.8
Max. H = 1.5
Lobe Simulation
(Grid deformation)

X: 100, Y: 50
H = 0.7
Max. H = 1.5
Lobe Simulation
(Grid deformation)

X: 100, Y: 50
H = 0.7
Max. H = 1.5
Lobe Simulation
(Grid deformation)

\[ x' = x + Dx \]
Shale Layers

Fine-Grained Unit 1

Fine-Grained Unit 2

Lobe 1 + Fine grained Unit 1

Lobe 2 + Fine grained Unit 2

Lobe 1

Lobe 2
Realization (t=1)
Realization (t=2)
Realization (t=3)
Realization (t=4)
Realization (t=5)
Realization (t=6)
Realization (t=7)
Realization (t=8)
Realization (t=9)
Realization (t=10)
Realization (t=11)
Realization (t=12)
Summary

Methodology for constructing hybrid models:

- Accounting for hard data available (MPS, SGSIM, DSSIM, Grid deformation)
- Updating changes in the surface occurred previously in the simulation (Surfaced-based simulation)
Summary

- Proper simulation of the shale layers is very important because its presence constitute a flow barrier.
- Grid deformation and combining object-based simulation with drainage basin will potentially improve the results obtained using MPS in the realization conditioning.
Application Limitations

- Depositional environment must be known
- Ability to parameterize geobody objects (lobes, channels, etc.)
- Good knowledge of parameters
Critical Assumptions

- **Deterministic Rules, Trends**
  - Improved by incorporating as much as possible depositional environment knowledge.

- **Rejection Rules**
  - Have to be realistic and let the model run in a reasonable time.
  - Allow fully automatic models.
  - Should be as objective as possible.
Questions?