Conditioning of surface-based geostatistical models

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Introduction

- Surface-based models recreate realistic subsurface structures and heterogeneities
- **BUT** the conditioning is arduous:
  - Requirement on data
  - Costly inverse modeling

Surface created by Hybrid model (Bertoncello and Caers, 2010)
Motivations

DEVELOP A METHODOLOGY THAT

➢ Match seismic and wells data
   - At minimal CPU cost
   - With no conditioning artifacts
   - Does not rely on well log correlation
Surface-based model: recall

Statistics & rules

Sequentially simulate sets of 2D lobe thickness with featured geometry

Construct 3D model

(Pyrcz and Deutsch, 2004; Michael et al., 2010; Leiva, 2009; Zhang, 2009)

From Hongmei Li
Surface-based model: recall

AIM: randomization of the geometry
Conditioning issues

Initial conditions

(seed, paleotopography, source location...)

Inverse problem that requires iterations
Challenge of inverse modeling

• Large number of inputs parameters
  – Location of the sediments source
  – Paleotopography
  – Size of the geobodies
  – Parameters of erosion
  – ....

Sensitivity analysis (Bertoncello and Caers 2010)
Sensitivity analysis results (1)

- Main influencing parameters: deposition model

**Probability maps of lobe location**

- Statistic approach:
  - Progradation cdf
  - Migration cdf
  - Elevation

- Topographic approach:
  - Elevation
  - Gradient
  - Curvature

\( \tau \text{au } [0-1] \)
Sensitivity analysis results (2)

• Main influencing parameters: additional gaussian Noise
Proposed optimization approach

REMAINING PARAMETERS TO OPTIMIZE:

• 1 Tau value for the deposition model
• 1 noise per lobe

For 10 lobes => 31 parameters!
Proposed optimization approach

REMAINING PARAMETERS TO OPTIMIZE:

• 1 Tau value for the deposition model
• 1 noise per lobe
  -> Variance
  -> Covariance
  -> Spatial structure
  (controlled by a gradual deformation -> Y parameter)

For 10 lobes => 31 parameters!

Divide and conquer approach
Proposed optimization approach

STEP 1

- Red: Initial paleotopography
- Blue: Lobes to optimize
Proposed optimization approach

**STEP 1**

4 parameters to optimize

Variances covariance Y. Tau

Single noise to optimize
+ Model of deposition
Proposed optimization approach

STEP 2

3 parameters to optimize

Variance covariance Y.

Single noise to optimize

New paleotopography

Initial paleotopography

Lobes to optimize
Proposed optimization approach

STEP 5

3 parameters to optimize

Variance covariance Y.

New paleotopography

Initial paleotopography

Lobes to optimize

Single noise to optimize
Proposed optimization approach

Summary

- Number of steps = Number of lobes
- Low number of parameters to optimize at each step (4-3)
- Model evaluation is faster than a traditional approach
- Any derivative-free optimization algorithm can be used
  
  *(Nelder-Mead in our case)*
Application to a real data set (Exxon II)
Application to a real data set (Exxon II)

Elevation of the initial topography

Elevation of the top of the reservoir

Thickness of sediments
Results with seismic data

Optimized solution
1.7 feet average error (5 %)

Initial guess
15 feet average error (30 %)

Reference
Results with seismic data
Results with seismic data

Cross section

Bottom surface of the reservoir

Internal structures

Initial guess

Real 1

Real 2
Results with wells and seismic data

3 wells are drilled interpreted from the data

Well 1 and Well 2 in a high depositional area

Well 3 in a low depositional area
Results with wells and seismic data
Results with wells and seismic data

Well 1
Initial  Optimized  Reference

Well 2
Initial  Optimized  Reference  Initial

Well 3
Optimized  Reference
Results with wells and seismic data

Bottom surface of the reservoir
Computational Performance

CPU Cost ≈ $O(5)$

CPU Cost ≈ $O(2)$

Average CPU Cost ≈ $\text{nb\_iterations} \times O(\text{Nb lobes}/2)$
Computational Performance

Minimum obtained after 6000 simulations through sampling

Optimization performance with the traditional optimization method

Optimization performance with the step by step approach

Average performance of the step by step approach
Conclusion

• Fit well and seismic data while preserving geology
• No need for well interpretation
• A gaussian noise on top of the surface is required

Future work

• Application to an history matching problem
• Study the impact of large number of wells
Thank you

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