Localized Smart Interpretation – A data-driven semi-automatic geological modeling method

Mats Lundh Gulbrandsen¹ • Knud Skou Cordua¹ • Torben Bach² • Thomas Mejer Hansen¹

¹ Niels Bohr Institute
² GeoScene 3D team @ I•GIS
Localized Smart Interpretation

- Geological Knowledge (d)
- Geophysical Data (M)
- Geophysical Data Elsewhere $M_{\text{pred}}$
- Statistical Model $h(d,M)$
- Predicted Geology with uncertainty $h(d_{\text{pred}}|M_{\text{pred}})$
Localized Smart Interpretation

- Geological Knowledge (d)
- Geophysical Data Elsewhere (Mpred)
- Statistical Model \( h(d, M) \)
- Predicted Geology with uncertainty \( h(d_{pred} | M_{pred}) \)

Geological Knowledge

Geophysical Data Elsewhere (Mpred)

Statistical Model \( h(d, M) \)

Predicted Geology with uncertainty \( h(d_{pred} | M_{pred}) \)
Localized Smart Interpretation

Geological Knowledge (d)

Geophysical Data Elsewhere
$M_{\text{pred}}$

Statistical Model
$h(d, M)$

Predicted Geology with uncertainty
$h(d_{\text{pred}} | M_{\text{pred}})$

Geophysical Data (M)

---

SAGEEP 2015
Slide 2
Localized Smart Interpretation

- Geological Knowledge (d)
- Geophysical Data Elsewhere \( M_{\text{pred}} \)
- Statistical Model \( h(d,M) \)
- Predicted Geology with uncertainty \( h(d_{\text{pred}}|M_{\text{pred}}) \)

Geological Knowledge (d) → Geophysical Data Elsewhere \( M_{\text{pred}} \) → Statistical Model \( h(d,M) \) → Predicted Geology with uncertainty \( h(d_{\text{pred}}|M_{\text{pred}}) \)
Localized Smart Interpretation

Geological Knowledge (d)

Geophysical Data Elsewhere M_{pred}

Statistical Model h(d,M)

Predicted Geology with uncertainty h(d_{pred}|M_{pred})

Geophysical Data (M)

Statistical Model h(d,M)

Geological Knowledge (d)

Geophysical Data (M)
Localized Smart Interpretation

- Geological Knowledge (d)
- Geophysical Data Elsewhere $M_{\text{pred}}$
- Statistical Model $h(d, M)$
- Predicted Geology with uncertainty $h(d_{\text{pred}} | M_{\text{pred}})$
Localized Smart Interpretation

- Geological Knowledge ($d$)
- Geophysical Data Elsewhere ($M_{\text{pred}}$)
- Statistical Model $h(d,M)$
- Predicted Geology with uncertainty $h(d_{\text{pred}}|M_{\text{pred}})$

Geological Knowledge ($d$) and Geophysical Data Elsewhere ($M$) are used to predict Geology ($d_{\text{pred}}$) with a statistical model $h(d,M)$. The predicted geology includes uncertainty $h(d_{\text{pred}}|M_{\text{pred}})$. The graph shows the predicted geology over distance ($x$) and log($\theta$) resistivity.
Motivation

An enormous amount of information may be available to the geologist when modeling.

Manual interpretations makes it impossible to incorporate all information.

Automatic procedures are needed.

Consistency with Geological expert knowledge is essential.
Motivation

An enormous amount of information may be available to the geologist when modeling.

Manual interpretations make it impossible to incorporate all information.

Automatic procedures are needed.

Consistency with Geological expert knowledge is essential.
The Goal

The goal is to be able to predict geological interpretations based on the same information available to the geologist when he/she interprets.

- Infer a statistical model \( h(d|M) \)
- Solve the problem: \( d = f(M) \).
The Goal

The goal is to be able to predict geological interpretations based on the same information available to the geologist when he/she interprets.

- Infer a statistical model $h(d|M)$
- Solve the problem: $d = f(M)$.
- Perform predictions $d_{\text{pred}}$ with uncertainty
The Goal

The goal is to be able to predict geological interpretations based on the same information available to the geologist when he/she interprets.

- Infer a statistical model $h(d|M)$
- Solve the problem: $d = f(M)$.
- Perform predictions $d_{\text{pred}}$ with uncertainty $f(M)$

$+/− 1 \text{ std.}$
The Goal

The goal is to be able to predict geological interpretations based on the same information available to the geologist when he/she interprets.

• Infer a statistical model $h(\mathbf{d}|\mathbf{M})$
• Solve the problem: $\mathbf{d} = f(\mathbf{M})$.
• Perform predictions $\mathbf{d}_{\text{pred}}$ with uncertainty
The Goal

The goal is to be able to predict geological interpretations based on the same information available to the geologist when he/she interprets.

- Infer a statistical model \( h(d|M) \)
- Solve the problem: \( d = f(M) \).
- Perform predictions \( d_{\text{pred}} \) with uncertainty

\[ d_{\text{pred}} +/\!- 1 \text{ std.} \]
The Goal

The goal is to be able to predict geological interpretations based on the same information available to the geologist when he/she interprets.

- Infer a statistical model $h(d|M)$
- Solve the problem: $d = f(M)$.
- Perform predictions $d_{\text{pred}}$ with uncertainty

\[ h(d_{\text{pred}}|M_{\text{pred}}) +/\! - 1 \text{ std.} \]
Method

The function \( f(\mathbf{M}) \) can be parameterized such that:

\[
d_i = \sum_{j=1}^{M} \sum_{p=1}^{P+1} M_{ij}^p g_{jp}
\]

On matrix form: \( \mathbf{d} = K \mathbf{g} \)

Assuming Gaussian noise or uncertainty on the interpretations \( \mathbf{d} \)

\( K = (m_1, m_1, m_1, \ldots, m_1, m_2, \ldots, m_M) \)

\( \mathcal{N}(0, \mathbf{C}_d). \)

Assuming a Gaussian distribution of the prior expectation of the regression coefficients

\( \mathcal{N}(\mathbf{g}_0, \mathbf{C}_g). \)
Method

The Gaussian distribution over $g$ can be expressed as:

$$f(g | d, M) = k \exp \left( \frac{1}{2} (g - \bar{g})^T C_g^{-1} (g - \bar{g}) \right)$$

With mean:

$$\bar{g} = g_0 + (K^T C_d^{-1} K + C_g^{-1})^{-1} K^T C_d^{-1} (d - K g_0)$$

And Covariance:

$$C_g = (K^T C_d^{-1} K + C_g^{-1})^{-1} K^T$$
Method

The Gaussian distribution over $g$ can be expressed as:

$$f(g \mid d, M) = k \exp \left( \frac{1}{2} (g - \bar{g})^T \tilde{C}_g \cdot (g - \bar{g}) \right)$$

With mean:

$$\bar{g} = g_0 + (K^T \cdot C_d^{-1} \cdot K + C_g^{-1})^{-1} K^T \cdot C_d^{-1} \cdot (d - K \cdot g_0)$$

And Covariance:

$$\tilde{C}_g = (K^T \cdot C_d^{-1} \cdot K + C_g^{-1})^{-1} K^T$$

Statistical Model:

Mean:

$$\bar{d}_{\text{pred}} = K_{\text{pred}} \cdot \bar{g}$$

Covariance:

$$\tilde{C}_{d\text{pred}} = K_{\text{pred}} \cdot \tilde{C}_g \cdot K_{\text{pred}}^T$$
Conclusion

• The method ensures that the predictions are in accordance with the knowledge of the geologist.

• Able to use all accessible quantifiable information in the predictions

• The method is able to use this information to very fast and reliably predict a geological interpretation.

• Potentially LSI will reduce the man-hours required to interpret a AEM-survey today drastically.

• Will be beneficial to assist in geological interpretation based on large geophysical data sets?
Acknowledgement

• Co-authors: Knud Skou Cordua, Torben Bach and Thomas Mejer Hansen

• US Geological Survey

• I•GIS and GEUS
Thanks for Listening