THE ROLE OF PERCEPTUAL TEXTURE DISSIMILARITY IN AUTOMATING SEISMIC DATA INTERPRETATION

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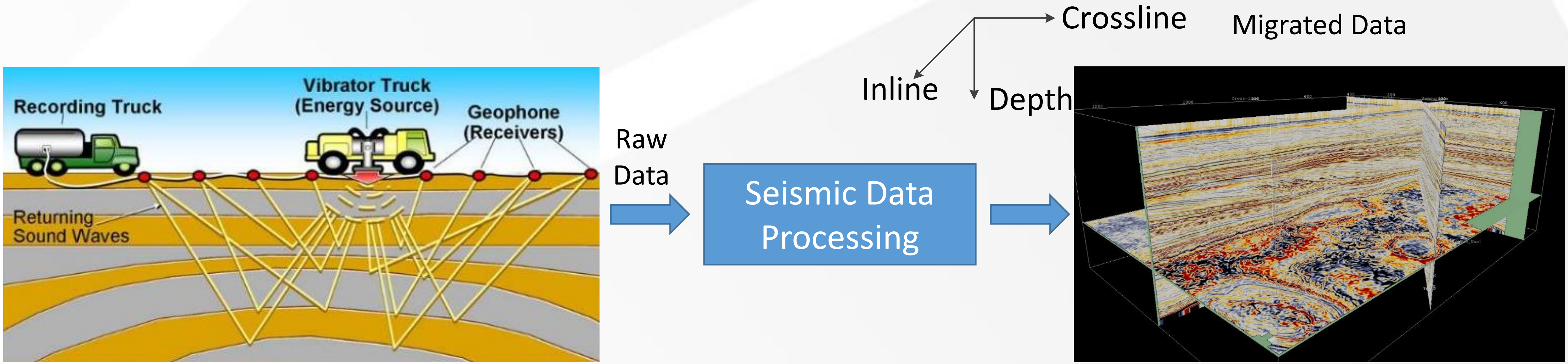
OUTLINE

- Background & Motivation
- Proposed Salt-Dome Detection Method
  - Gradient of Texture (GoT)
  - Thresholding & Post-processing
- Dissimilarity Measures
- Experimental Results
- Conclusion

MIGRATED DATA & SEISMIC INTERPRETATION

- Migrated data are acquired from reflected seismic waves

- Seismic interpretation is the extraction of geologic information from seismic data



http://www.oilinuganda.org/features/environment/uganda-pioneers-3d-seismic-surveys.html
http://steveholbrook.com/teaching/geol_5180/case_studies/case_study_3.html

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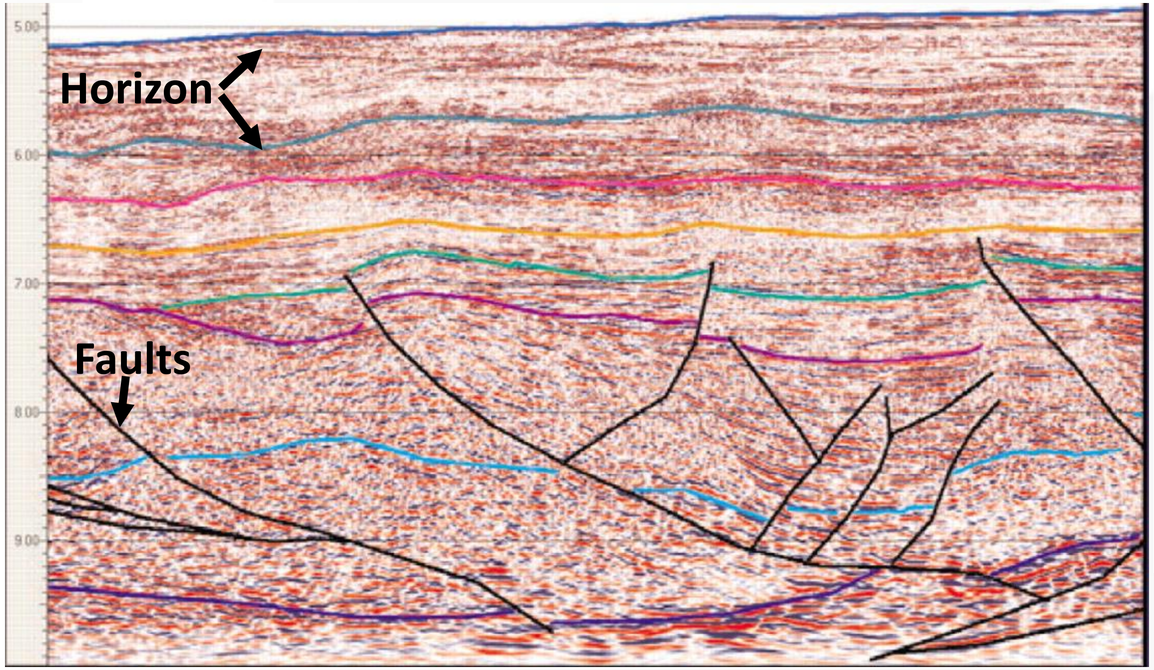
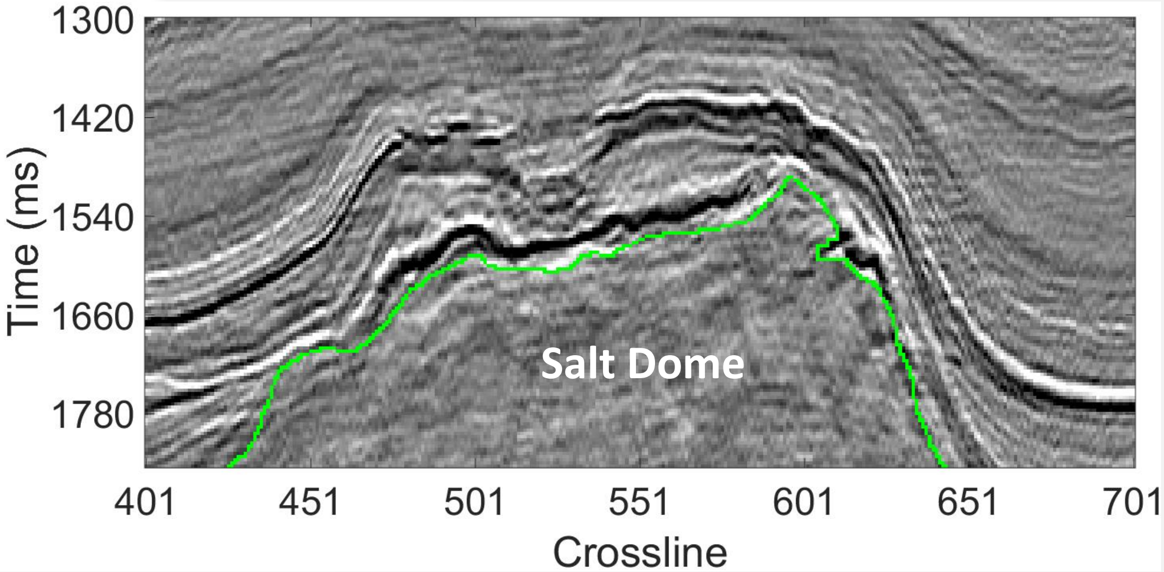




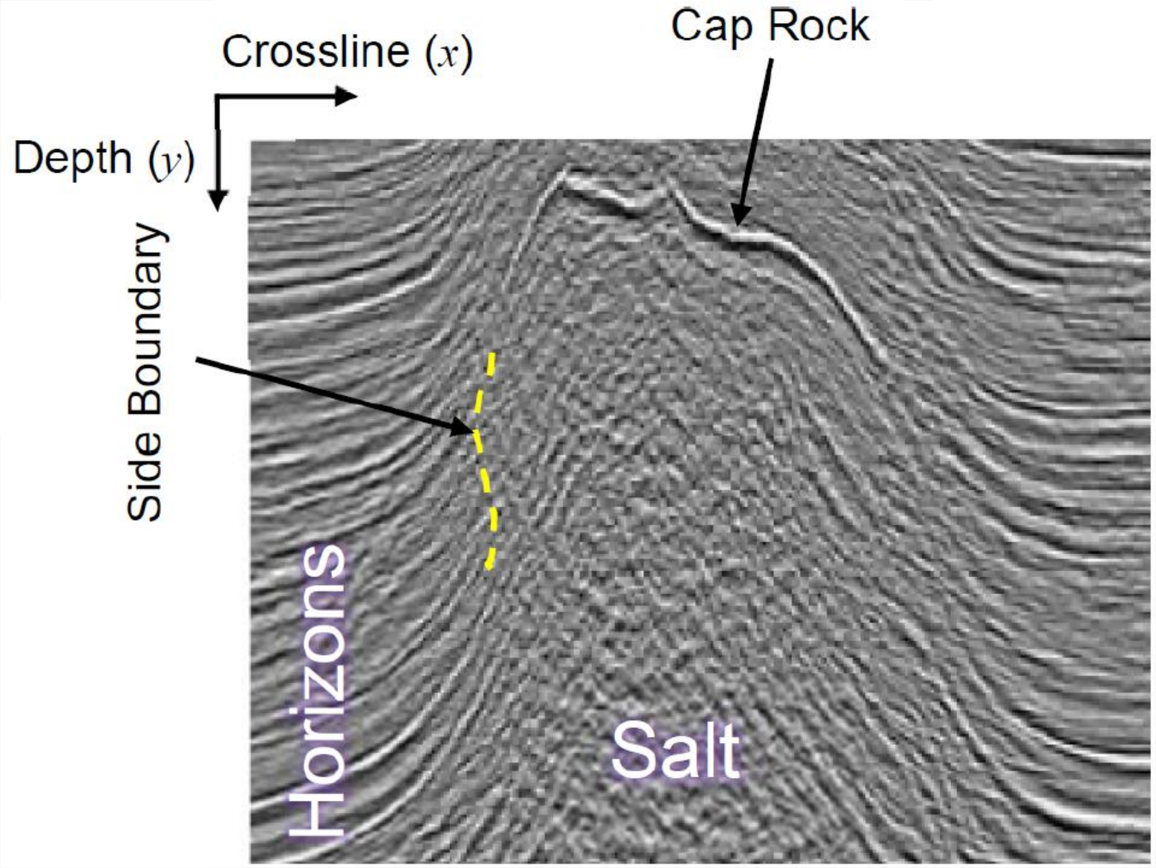
http://tle.geoscienceworld.org/content/21/11/1118.extract
https://opendtect.org/osr/pmwiki.php/Main/NetherlandsOffshoreF3BlockComplete4GB

COMPUTER-AIDED INTERPRETATION

- Manual interpretation is time consuming and label intensive

- Image processing, computer vision, and machine learning techniques have been involved in seismic interpretation

- The interpretation of salt domes remains a challenging problem



CONVENTIONAL METHODS FOR SALT-DOME INTERPRETATION

Methods	Remarks
Edge Detection	Sensitive to local discontinuities
Graph-based Image Segmentation	Computationally less efficient
Active Contour Model	Accuracy depends on the initial contour
Multiple texture attributes	Important to select relevant features

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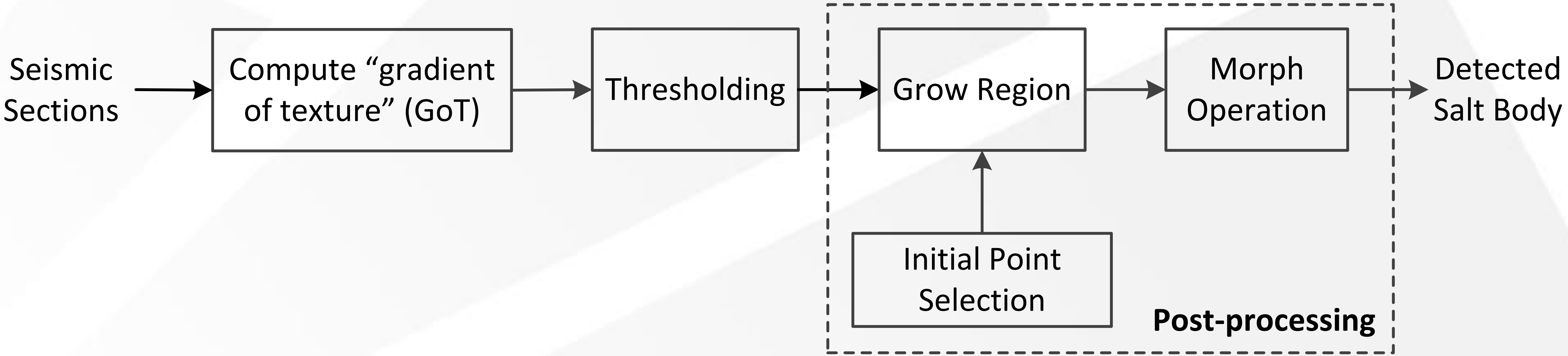
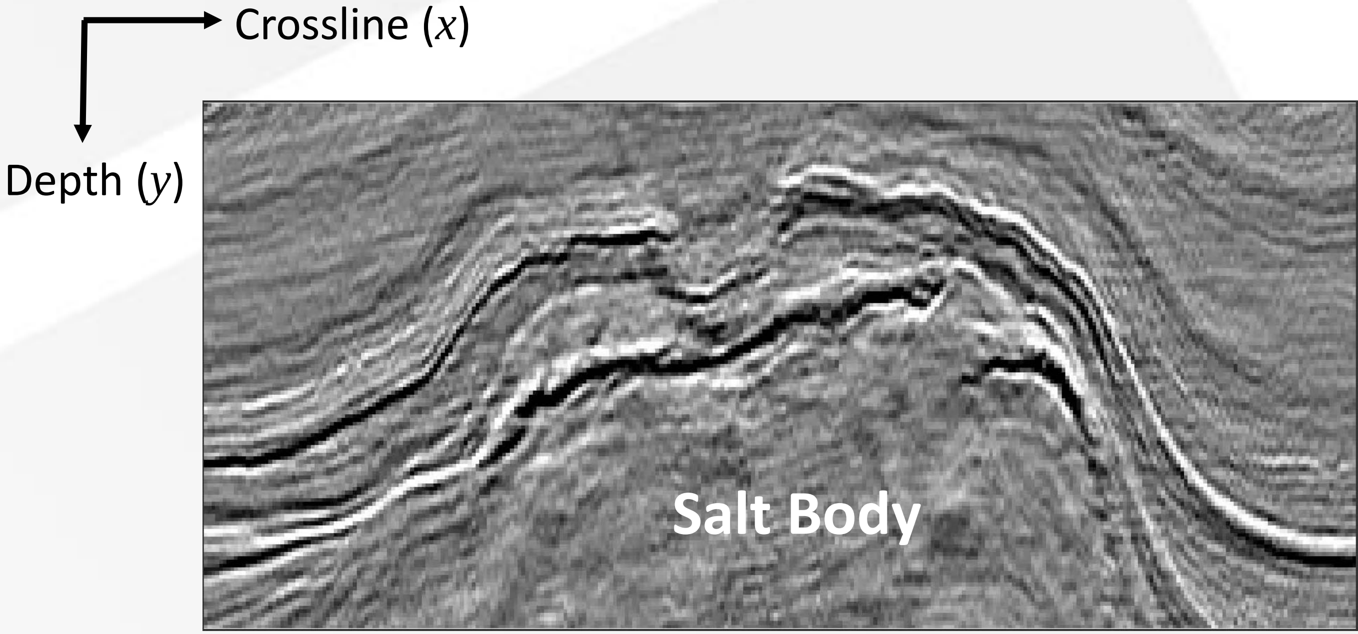
PROPOSED SALT DOME DETECTION METHOD



GRADIENT OF TEXTURE (GOT)

- Human perception is sensitive to texture changes
- GoT describes the texture dissimilarity between two neighboring square windows, denoted as: $d(\mathbf{W}_{x-}, \mathbf{W}_{x+})$
- Higher GoT -> point on texture boundary

  Lower GoT -> point inside the texture



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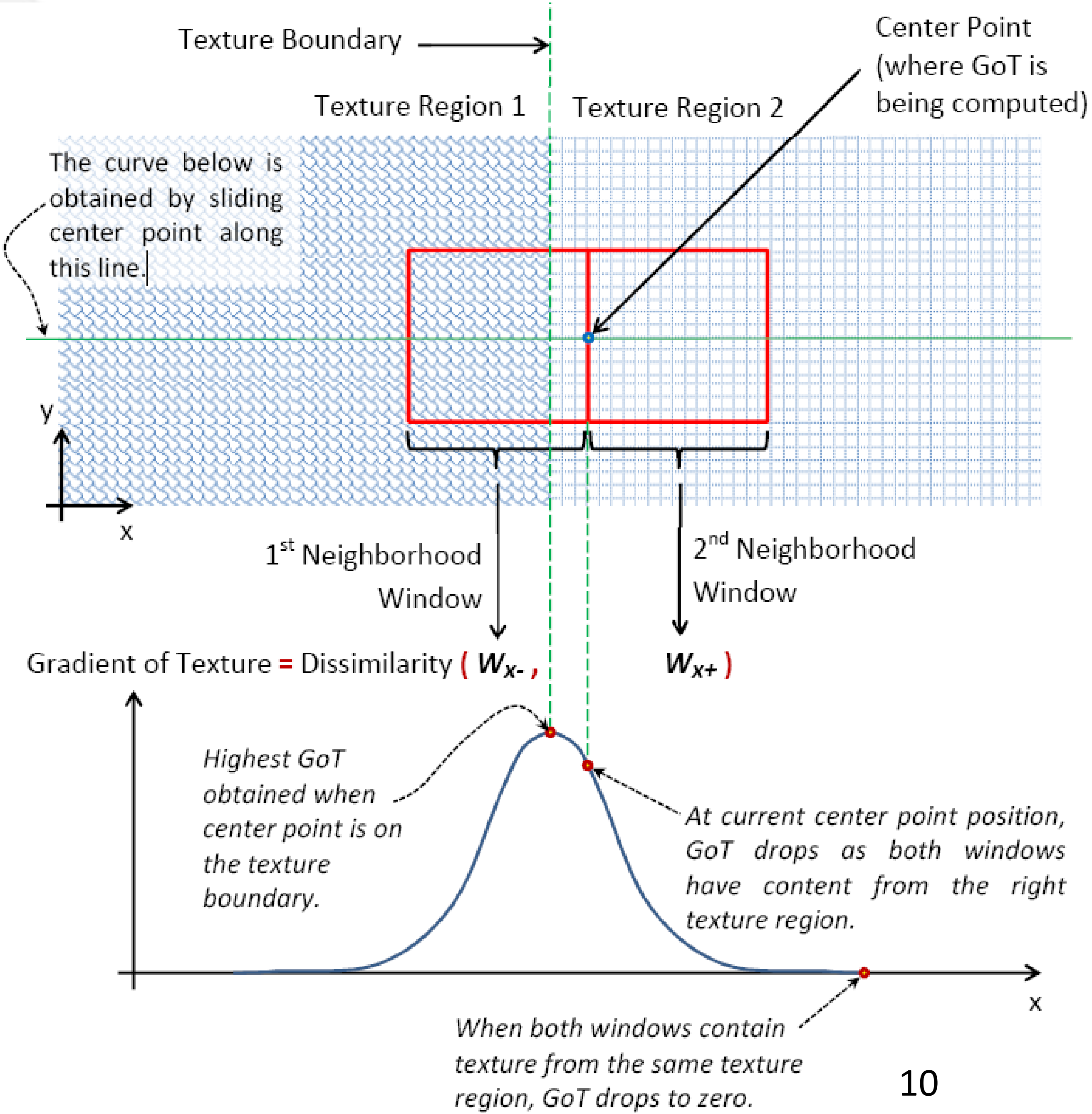


MULTI-SCALE AND -DIRECTIONAL COMPONENTS OF GOT

- Compare the dissimilarity of windows with various sizes
- Detect salt-dome boundary in any direction

N: number of sizes

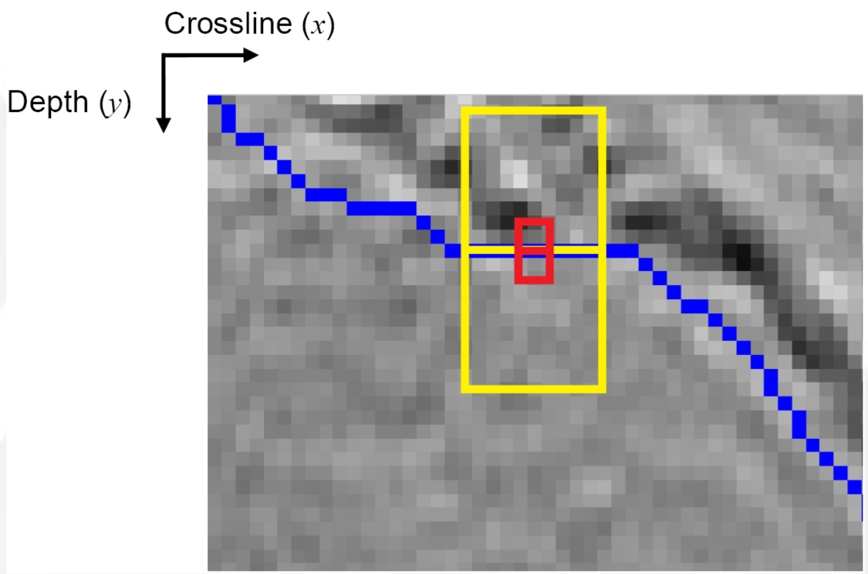
- GoT:

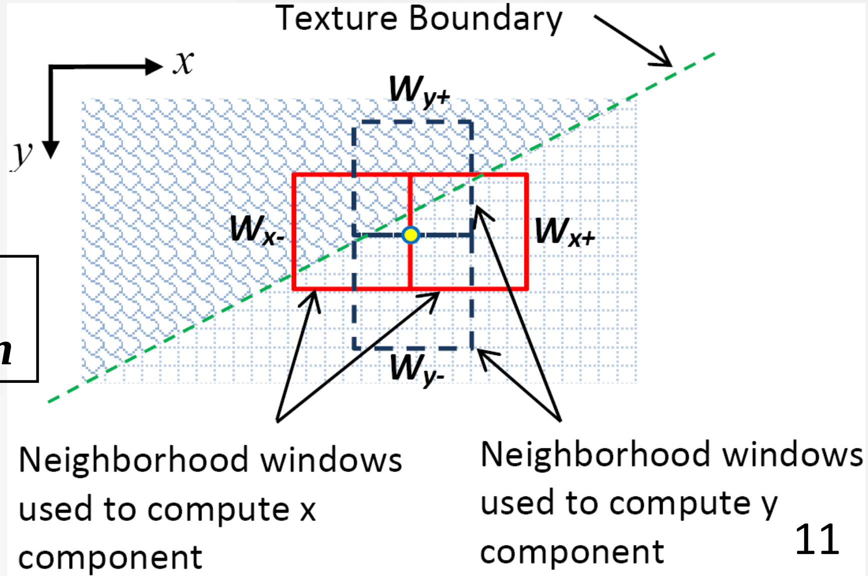
$$\mathbf{G_x}[i,j] = \sum_{n=1}^{N} w_n . d\left(\mathbf{W}_{n,x-}^{i,j}, \mathbf{W}_{n,x+}^{i,j}\right),$$

$$\mathbf{G_y}[i,j] = \sum_{n=1}^{N} w_n . d\left(\mathbf{W}_{n,y-}^{i,j}, \mathbf{W}_{n,y+}^{i,j}\right),$$

$$\mathbf{G}[i,j] = \left(\mathbf{G_x}^2[i,j] + \mathbf{G_y}^2[i,j]\right)^{\frac{1}{2}},$$

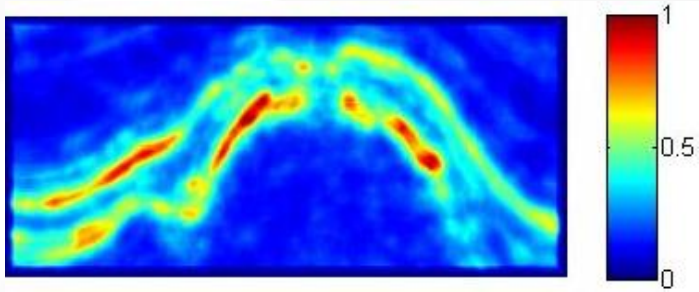
w_n: inversely proportional to $\boldsymbol{n}$





THRESHOLDING AND POST-PROCESSING

- Hard Thresholding to highlight likely salt body
- Region growing and morphological operation remove noisy regions and smooth salt-dome boundary.



(a). Normalized GoT Attribute

(b). After thresholding

(c). After region growing

(d). After morphological operation

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DISSIMILARITY MEASURES USING FEATURE VECTORS

- $\mathbf{F}_-$ and $\mathbf{F}_+$ represent the feature vectors of $\mathbf{W}_+$ and $\mathbf{W}_-$
- Dissimilarity measure: $d(\mathbf{W}_-, \mathbf{W}_+) = \|\mathbf{F}_- - \mathbf{F}_+\|$

(1). Using intensity and gradient statistics:

Intensity-based features: mean, standard deviation, and skewness

Gradient-based features: mean, standard deviation, and entropy

(2). Using singular values of $\mathbf{W}_+$ and $\mathbf{W}_-$

MEASURE BASED ON FOURIER TRANSFORM

(3). Using Fourier coefficients:

Fourier Transform

$$d(\mathbf{W}_-, \mathbf{W}_+) = E\left\{ \left| \left| \mathscr{F}\left\{ \mathbf{W}_- \right\} \right| - \left| \mathscr{F}\left\{ \mathbf{W}_+ \right\} \right| \right| \right\}$$

Expectation Operator

(4). Using error spectrum chaos [1]: consistent with human perception

Weight For Phase

$$d(\mathbf{W}_-, \mathbf{W}_+) = M + \alpha P,$$

$$M = E\left\{ \left| \mathscr{F}\left\{ \left| \mathscr{F}\left\{ \nabla \left\{ \left| \mathbf{W}_- - \mathbf{W}_+ \right| \right\} \right\} \right| \right\} \right| \right\},$$

$$P = E\left\{ \left| \mathscr{F}\left\{ \angle \mathscr{F}\left\{ \left| \mathbf{W}_- - \mathbf{W}_+ \right| \right\} \right\} \right| \right\},$$

[1]. T. Hegazy and G. AlRegib, "A New Full-Reference IQA Index Using Error Spectrum Chaos," Proc. *2nd IEEE Global Conference on Signal and Information Processing*, Atlanta, USA, Dec. 3-5, 2014.

PROPOSED MEASURE BASED ON ERROR MAGNITUDE SPECTRUM CHAOS

- This measure is inspired by the previous measure

- Dropping the phase: reduces the sensitivity to shape
  Dropping the gradient: improves computational efficiency

- Dissimilarity measure:

$$d(\mathbf{W}_-, \mathbf{W}_+) = E\left\{\left|\mathscr{F}\left\{\left|\mathscr{F}\left\{\left|\mathbf{W}_- - \mathbf{W}_+\right|\right\}\right|\right\}\right|\right\}$$

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EXPERIMENTAL SETUP

- Netherlands offshore F3 block with the inline number ranging from 389 to 409
- Compare five dissimilarity measures in the proposed salt-dome detection framework
- SalSIM index[2] derived from Frechet distance can be used to measure the similarity between detected boundaries and ground truth

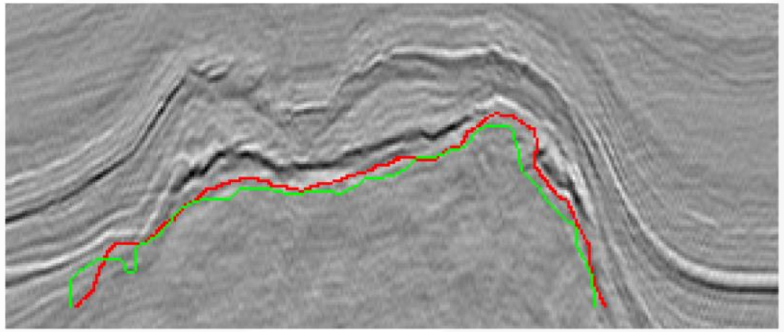
[2]. Z. Wang, T. Hegazy, Z. Long, and G. AlRegib, "Noise-robust Detection and Tracking of Salt Domes in Post-migrated Volumes Using Texture, Tensors, and Subspace Learning," *Geophysics*, 80(6), WD101-WD116.

EXPERIMENTAL RESULTS

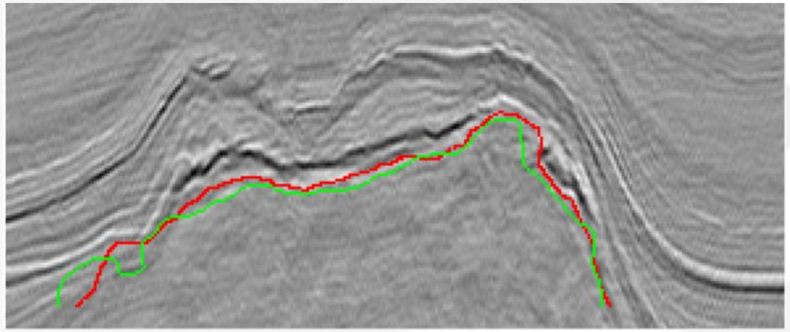
TABLE I: SalSIM indices for various dissimilarity measures

Seismic Sections	Mag. Spect. Chaos	Spectrum Chaos	Fourier Coeff.	SVD	Basic Statistics
#389	**0.9091**	0.9064	0.9050	0.8693	0.8440
#390	**0.9198**	0.9148	0.9186	0.8995	0.8406
#391	0.8930	0.8876	**0.9037**	0.8931	0.8585
#392	0.9312	**0.9354**	0.9345	0.9180	0.9221
#393	0.9331	**0.9345**	0.9283	0.8824	0.8546
#394	**0.9302**	0.9260	0.9267	0.9162	0.9283
#395	**0.9448**	0.9415	0.9337	0.9191	0.9213
#396	**0.9419**	0.9321	0.9283	0.9164	0.9228
#397	**0.9313**	0.9273	0.9230	0.9108	0.8586
#398	**0.9464**	0.9453	0.9369	0.9306	0.9282
#399	0.9435	**0.9447**	0.9402	0.9278	0.9432
#400	**0.9329**	0.9326	0.9303	0.9252	0.9230
#401	**0.9552**	0.9484	0.9507	0.9480	0.9471
#402	**0.9532**	0.9490	0.9501	0.9487	0.9488
#403	**0.9512**	0.9500	0.9506	0.9428	0.9377
#404	**0.9471**	0.9389	0.9405	0.9293	0.9362
#405	**0.9456**	0.9438	0.9391	0.9156	0.9055
#406	**0.9550**	0.9481	0.9461	0.9545	0.9487
#407	**0.9461**	0.9417	0.9434	0.9380	0.9394
#408	**0.9332**	0.9196	0.9298	0.9255	0.9188
#409	0.9430	0.9408	**0.9438**	0.9382	0.9287
Mean	**0.9375**	0.9337	0.9335	0.9214	0.9122
Standard. Dev.	0.0151	0.0155	**0.0129**	0.0213	0.0358
GoT Time per Section (s)	**14.5**	438.8	14.8	24.2	1359.2

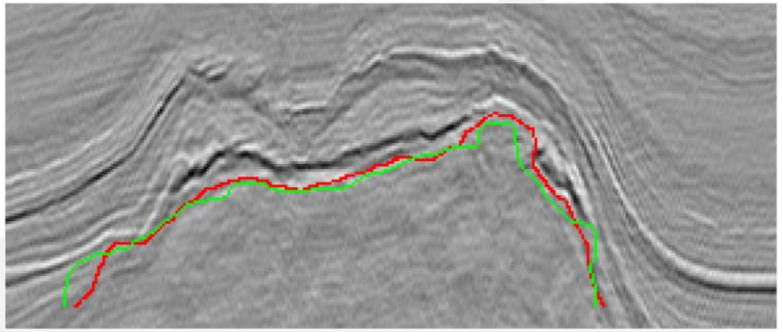
COMPARISON OF DETECTED SALT-DOME BOUNDARIES



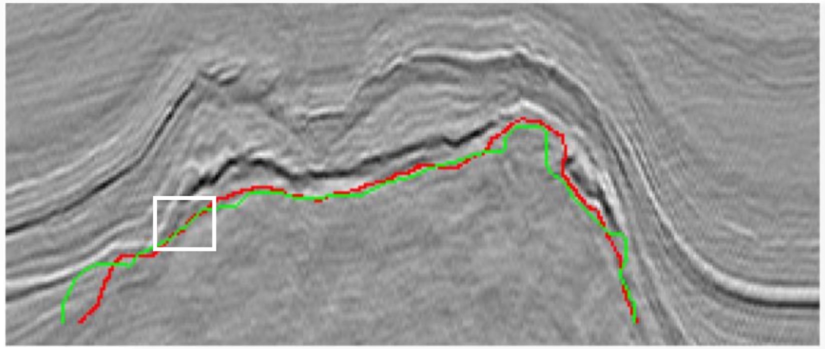
(a). Basic Statistics, SalSIM=0.9362



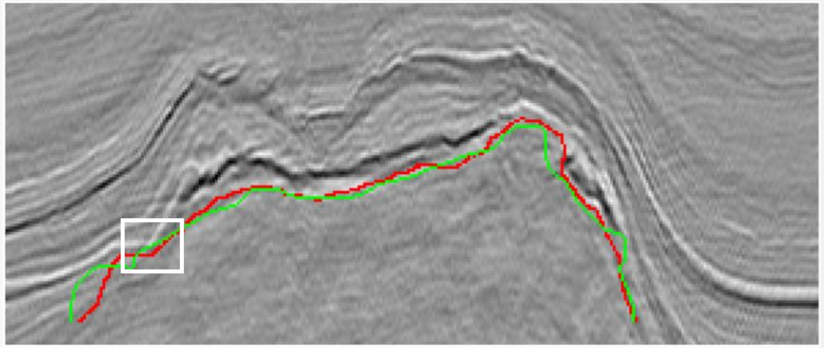
(b). SVD, SalSIM=0.9293



(c). Fourier Coefficient, SalSIM=0.9405



(d). Spectrum Chaos (Mag. & phase) SalSIM=0.9389



(e). Mag. Spectrum Chaos, SalSIM=0.9471

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CONCLUSION

- In the proposed salt-dome detection framework, the perceptual measures are more consistent with human interpretation
- Other perceptual measures in image/video quality assessment can be involved in seismic interpretation
- We have extended the current framework to 3D for more accurate results.

RELATED WORK

- Salt-dome detection and tracking

[1]. Z. Wang, T. Hegazy, Z. Long, and G. AlRegib, "Noise-robust Detection and Tracking of Salt Domes in Post-migrated Volumes Using Texture, Tensors, and Subspace Learning," *Geophysics*, 80(6), WD101-WD116.

[2]. M. Shafiq, Z. Wang, A. Amin, T. Hegazy, M. Deriche, and G. AlRegib, "Detection of salt-dome boundary surfaces in migrated seismic volumes using gradient of textures," *Expanded Abstracts of the SEG 85th Annual Meeting*, pp. 1811-1815, New Orleans, Louisiana, Oct. 18-23, 2015.

- Fault detection and tracking

[3] Z. Wang and G. AlRegib, "Fault detection in 3D seismic data using the Hough transform and tracking vectors," submitted to *IEEE Transactions on Geoscience and Remote Sensing*.

[4] Z. Wang and G. AlRegib, "Fault detection in seismic datasets using Hough transform," *Proc. IEEE Intl. Conf. on Acoustics, Speech and Signal Processing (ICASSP)*, pp. 2372-2376, Florence, Italy, May 2014.

- Seismic structure retrieval

[5] Z. Long, Z. Wang, and G. AlRegib, "SeiSIM: structural similarity evaluation for seismic data retrieval," *Proc. IEEE Intl. Conf. on Communications, Signal Processing, and their Applications (ICCSPA)*, Sharjah, United Arab Emirates (UAE), Feb. 17-19, 2015.

- Scene Labeling

[6] Y. Alaudah and G. AlRegib, "Seismic Section Labeling Using Support Vector Machines and Curvelet Statistics," submitted to *IEEE Intl. Conf. on Acoustics, Speech and Signal Processing (ICASSP)*, Shanghai, China, Mar. 20-25, 2016.