Work plan for 2016: seismic feature segmentation using level set method

Tao Zhao and Kurt J. Marfurt, University of Oklahoma*

The UNIVERSITY of OKLAHOMA
Mewbourne College of Earth and Energy
ConocoPhillips School of Geology and Geophysics

Summary

After interpreting seismic facies using seismic attributes and classification techniques, extracting features of interest is important for the subsequent reservoir characterization and modeling stages. However, how to effectively extracting such features (geobodies) is a long lasting problem. In this study, we propose to use level set method to facilitate such seismic feature segmentation process.

Introduction

One of the optimal goal of seismic interpretation is to build a geologic model which consists of different geologic features. To achieve this goal, an experienced seismic interpreter can manually pick horizons and faults precisely, but with considerably human effort. Being either potential reservoirs or hydrocarbon migration barriers, channels are another group of features that need to be delineated on seismic data, yet hand-picking of channels is extremely difficult, mainly due to the scale of channels on a seismic profile, similarity between channel reflectors and adjacent reflectors, as well as the geometry of a channel body (it's a closed surface in 3D space, unlike a horizon or a fault which is an "open" surface). Traditionally, interpreters use coherency attributes to delineate channel edges, and spectral decomposition based attributes to highlight channel bodies in different lithology and thickness (Li et al., 2015). Such methods provide satisfactory visualization of channels, but none of these techniques can be used to extract a channel body. In this study, we propose to use a mathematical function, namely a level set function, to represent a channel body as a region within a closed surface.

Level Set Method

The level set method is a numerical technique that can be used to describe interface propagation (Sethian, 1996). Mathematically, one expresses the evolution of a complex surface by solving initial value partial differential equations of level set functions. Highly complex evolutions such as topological changes, corner and cusp development, and geometric definitions of curvature and normal directions are naturally described in this system. More specifically, when representing a channel, it is not necessary to explicitly derive an equation with great complexity to account for the morphology of the channel; instead, a "velocity" field is built to guide the closed surface of channel body to propagate until it reaches a desired position (channel boundaries). A level set equation is defined as (Osher and Sethian, 1988):

$$\frac{\partial \phi}{\partial t} = -\mathbf{V} \cdot \nabla \phi, \qquad (1)$$

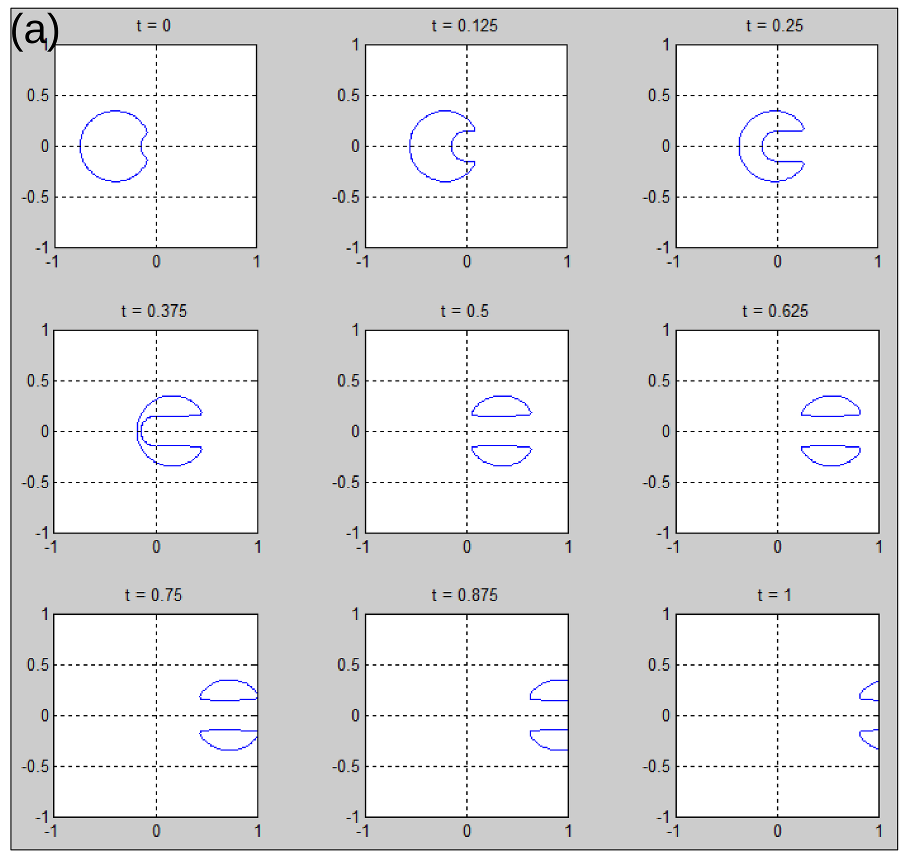
where ϕ is the surface function, and $\mathbf{V}$ is the propagation velocity of the surface. The equation describes the propagation of surface ϕ in a velocity field defined by $\mathbf{V}$. Kadlec (2009) further proposed to develop the velocity term $\mathbf{V}$ into three terms: an expanding force term, a surface smoothing term, and a stopping force term. In this case, equation (1) becomes:

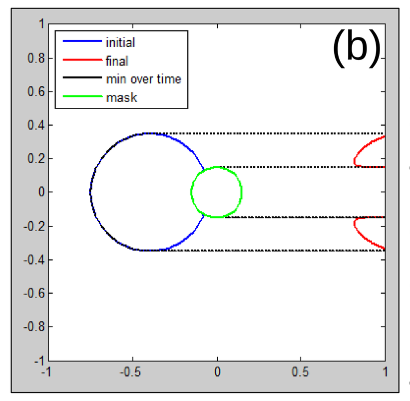
$$\frac{\partial \phi}{\partial t} = \alpha \mathbf{D}|\nabla \phi| + \beta\left(\nabla \cdot \frac{\nabla \phi}{|\nabla \phi|}\right)|\nabla \phi| + \gamma \nabla \mathbf{A}|\nabla \phi|. \qquad (2)$$

In this equation, $\mathbf{D}$ is the expanding force term which Kadlec (2009) defined using an attribute *channelness*; $\nabla \cdot \frac{\nabla \phi}{|\nabla \phi|}$ is the mean curvature to smooth the surface, and $\nabla\mathbf{A}$ is the stopping force defined by an edge. These three terms are weighted by α, β, and γ, respectively, and they sum up to *1*.

Numerical Test

(a)





(b)

Figure 1. (a) Level set surface propagating in a constant velocity field over time. A mask is in the center of the space. **(b)** Trajectory of the level set surface. The mask is a region excluded from the propagation space.

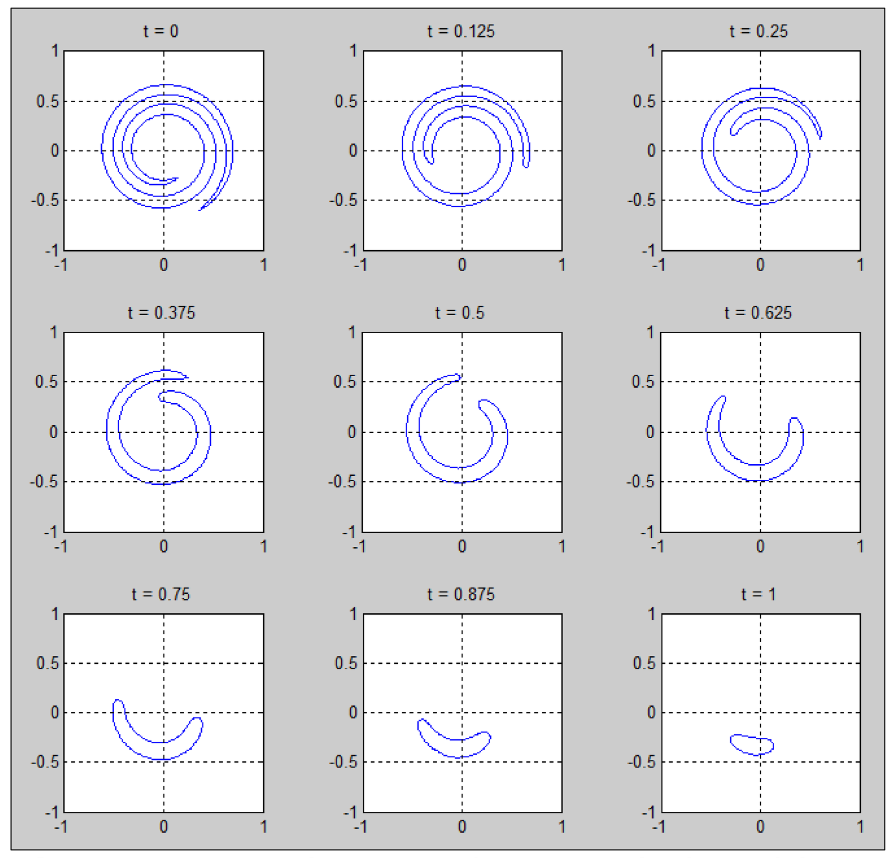


Figure 2. Level set surface evolution driven by its mean curvature. The level set surface reduces its mean curvature over time, and finally it will shrink to one point and disappear.

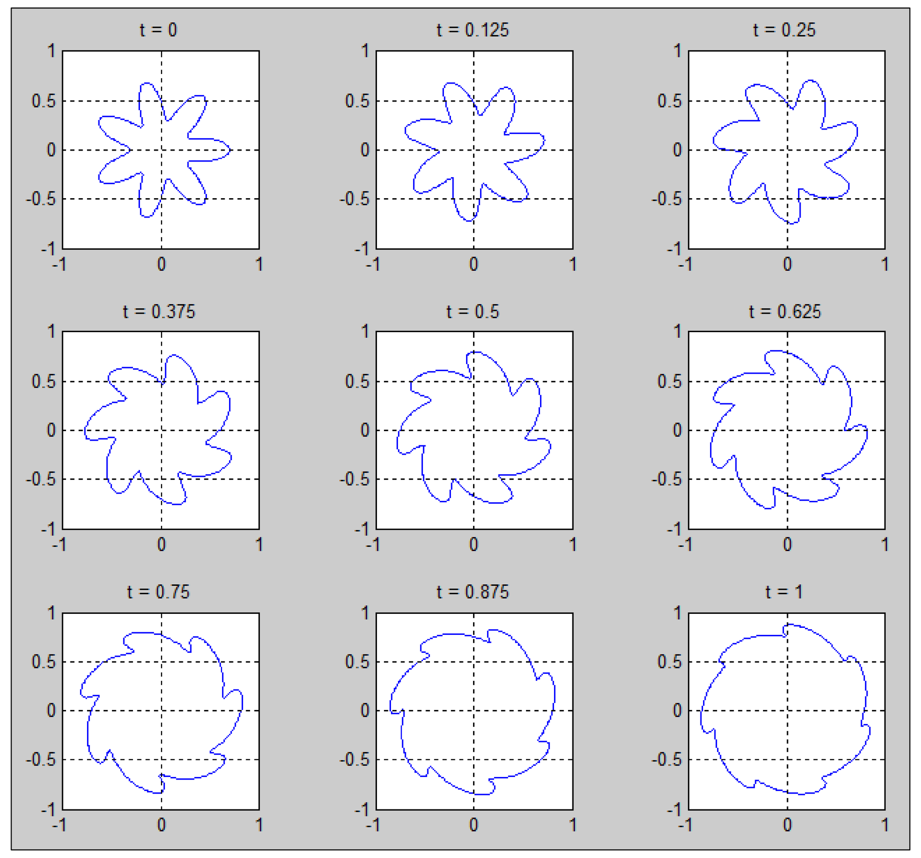


Figure 3. Level set surface evolution driven by a combination of an extensional force along surface normal and a counterclockwise rotational force. This example shows multiple velocity fields can be jointly applied to guide the propagation of level set surfaces.

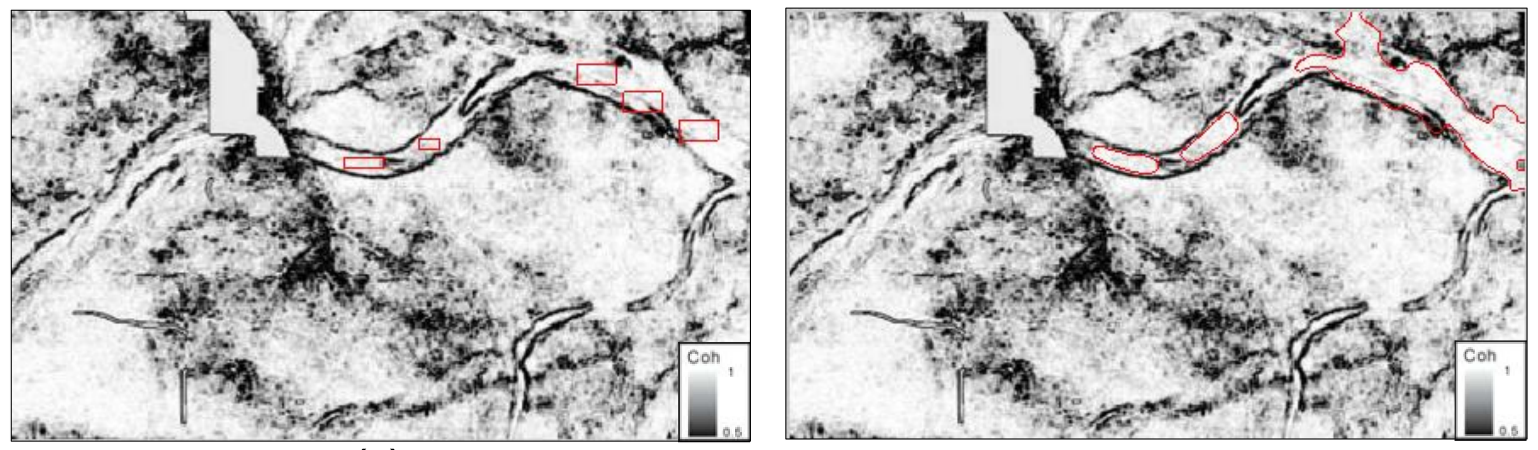
Potential Improvements

Kadlec (2009) chose the three weights equally for easy implementation; however, he also mentioned interpreter modification of the weights to accommodate different channel morphologies and accelerate the propagation. In this study, we propose to make these three weights time-dependent, achieving a velocity field that guides the interface to propagate fast, and suitable for channels in different morphologies. Intuitively, if the level set interface is initialized within a channel, a higher α and lower γ in the early stages can accelerate the expansion of the interface. In contrast, a lower α and higher γ can decelerate the expansion. β becomes important in the final stages when the interface needs to be smoothed, so it may increase over time, but not to exceed a certain threshold.

Kadlec (2009) used *channelness* (based on the gradient structure tensor) as the expanding force. We will investigate other attributes such as structural curvature (sensitive to differential compaction) and amplitude curvature (sensitive to channelfill) as alternative input. A prospective candidate is the Bhattacharyya distance calculated from supervised GTM, which gives a measure of likelihood of a sample point to be "channel", if samples from a picked channel facies is provided. In this way, the expanding force is a mixed response of multiple user-defined channel sensitive attributes, which statistically should result in a more robust velocity field for level set.

Real Data Test

Figure 4 shows a preliminary 2D test of channel segmentation using level set method. The velocity field is generated using coherency along a horizon. In this application we can only initialize the level set surface as rectangles, and it will provide better performance once we are able to initialize the level set surface along the channel geometry.



(a) (b)

Figure 4. Application of level set method on channel segmentation. **(a)** Level set surfaces (red lines) are initialized using several rectangles within a channel. **(b)** after 500 iterations, level set surfaces are able to approximate the channel boundary.

Conclusions and Future Work

Giving a proper velocity field, level set method is promising in channel segmentation using seismic data. The accuracy of level set approximation heavily depends on the velocity field, therefore for a specific application, exploring the most suitable combination of attributes that are used to build the velocity field requires extensive amount of research. At the same time, an end user ready application is still to be developed. Visualization of the result and efficiency of program execution will be the two main difficulties to be overcome.

References

Kadlec, B. J., 2009, Interactive GPU-based "visulation" and structure analysis of 3-D implicit surfaces for seismic interpretation: Ph.D. Dissertation, University of Colorado.

Li, F., J. Qi, and K. Marfurt, 2015, Attribute mapping of variable-thickness incised valley-fill systems: The Leading Edge, **34**, 48-52.

Osher, S and J. A. Sethian, 1988, Fronts propagating with curvature-dependent speed: algorithms based on Hamilton-Jacobi formulations: Journal of Computational Physics, **79**, 12-49.

Sethian, J. A., 1996, Theory, algorithms, and applications of level set methods for propagating interfaces: Acta Numerica, **5**, 309-395.

For communication: tao-zhao@ou.edu