Stanford Wave Physics Lab

Regularized Time-lapse Diffraction Tomography for Trigonal Meshes
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Regularized Time-lapse Diffraction Tomography for Trigonal Meshes

Investigators

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Introduction

This work aims to use the trade-off between spatial and temporal resolution to update a baseline survey using smaller surveys along time. Thus, instead of perform large surveys with a large time interval between successive surveys, it is proposed to perform *quasi* real-time smaller surveys to update with a higher periodicity the baseline survey [1].

However, a smaller survey implies in less sources and receivers to determine the same number of parameters, which would lead to an undetermined problem. To overcome this adversity, a reduction in the number of parameters to be estimated is desirable. Unstructured grids and meshes provide a reduction in the number of parameters and an implicit regularization if an adaptive criterion of resolution is applied.

Trigonal meshes are well-known to be a good choice to fit arbitrary shapes [2]. An adaptive criterion to generate the mesh may produce smaller triangles in regions with sharper transitions that require more detail and *vice-versa*. Another valid criterion is to generate a mesh based on resolution matrix, using larger triangles at regions with higher variance in parameter estimation and *vice-versa*.

An important aspect of this work is the use of external information of reservoir simulation to approximately predict the next time-lapse image and thus generate an adaptive mesh well suited to this predicted model. Since tomography techniques [3] allow estimating velocity field and attenuation, rock physics may provide a mapping between these estimated parameters and permeability/porosity. Thus, a strong link is established between Petroleum Engineering and Geophysics, working in a closed-loop with mutual feedback.

Background

Trigonal meshes have been thoroughly applied to many research areas, including seismic imaging. Traveltime tomography using meshes has been more extensively studied along time. However, diffraction tomography still requires much more research effort to become a traditional approach.

A good reference from the past year about trigonal meshes applied to traveltime tomography may be found on [5]. In this work, the resolution matrix was used to determine where the mesh should be coarser or finer, depending on parameter estimation variance at each region of the model.

Beyond the use of resolution matrix, we also propose to use spatial gradients of models predicted by reservoir simulation to generate adaptive meshes. A large gradient means a strong velocity variation in a certain region, which requires finer mesh. This approach generates finer mesh at the boundaries of CO_2 subsurface image, allowing better contour determination. Another important feature is the reduction of the number of parameters, which is appropriate for dynamic imaging, since many smaller surveys may be applied with higher periodicity instead of larger surveys with lower periodicity.

Results

Numerical tests using a synthetic model of CO_2 injection were performed to validate the proposed technique. Diffraction tomography requires as input data the scattered field amplitude and phase, which may be described by a complex number for each frequency. Reflection survey geometry was adopted since it is industry mainstream.

The true model is described by a 50 × 50 regular grid (Figure 1). The background velocity is 4,000 m/s and the negative velocity contrast represents CO_2 effects detected by imaging. The survey consists of 15 sources and 15 receivers interleaved near surface. Thus, a regular grid would have 50 × 50 = 2,500 velocity field parameters to be determined, which exceeds by far the available data measurements that corresponds to 15 × 15 × 2 (doubled due to real and imaginary parts) = 450, resulting in an underdetermined system.

The proposed solution is the use of trigonal meshes to reduce the number of parameters to be estimated. The use of a regular trigonal mesh reduces the number of parameters to 200 vertexes (Figure 2), less than the number of available data, resulting in an overdetermined system. Another approach under study is the use of spatial gradients that measure how fast velocity varies in a predicted model, allowing adaptive mesh refinement at fast varying regions like boundaries (Figure 3).

Diffraction tomography was applied using regular trigonal mesh. Since triangles may introduce high frequency artifacts due to its shape, regularization is required. It was applied regularization to minimize velocity field numerical derivative along horizontal axis, which with natural layering [4]. The result is shown on Figure 4 and agrees reasonably well with the true model, considering the reduced amount of data used to estimate this image. The velocity values are estimated at vertexes and interpolated within triangle using barycentric interpolation [6].

For dynamic imaging on field, piezoelectric/orbital sources may provide higher frequency signatures than usual explosive sources and generate a continuous signal that may be better recovered even with strong attenuation using lock-in amplifiers, which is a natural extension of this work when considering real aspects of acquisition on field.

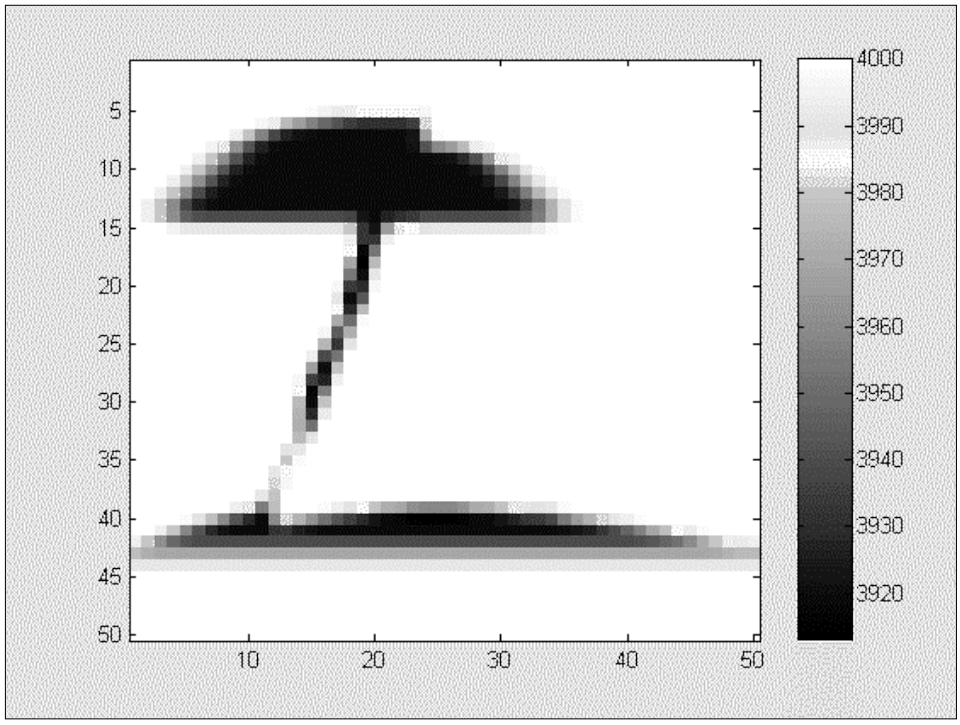

Figure 1: Synthetic model of CO_2 sequestration. The darker region with negative contrast velocity is associated with CO_2 presence. The velocity field (m/s) is represented in a regular grid (50 × 50).

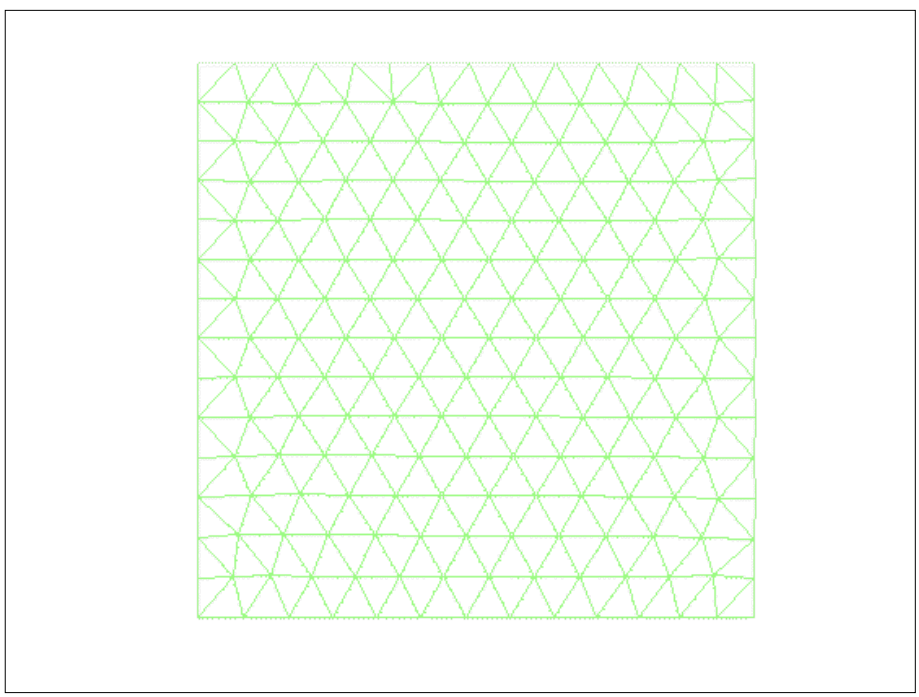

Figure 2: Regular trigonal mesh with 200 vertexes.

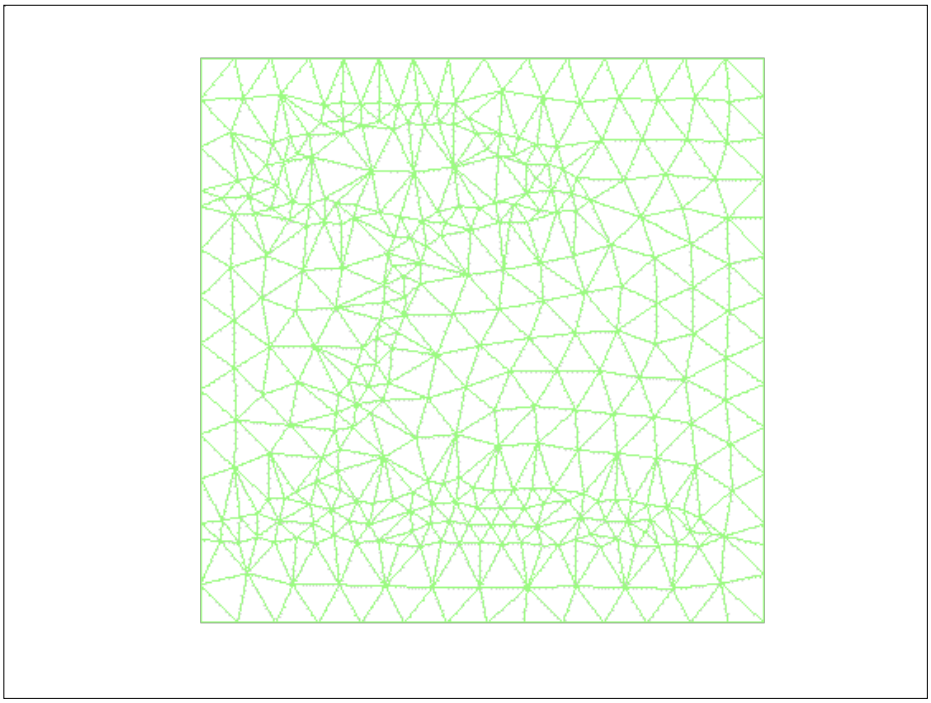

Figure 3: Adaptive trigonal mesh with 350 vertexes.

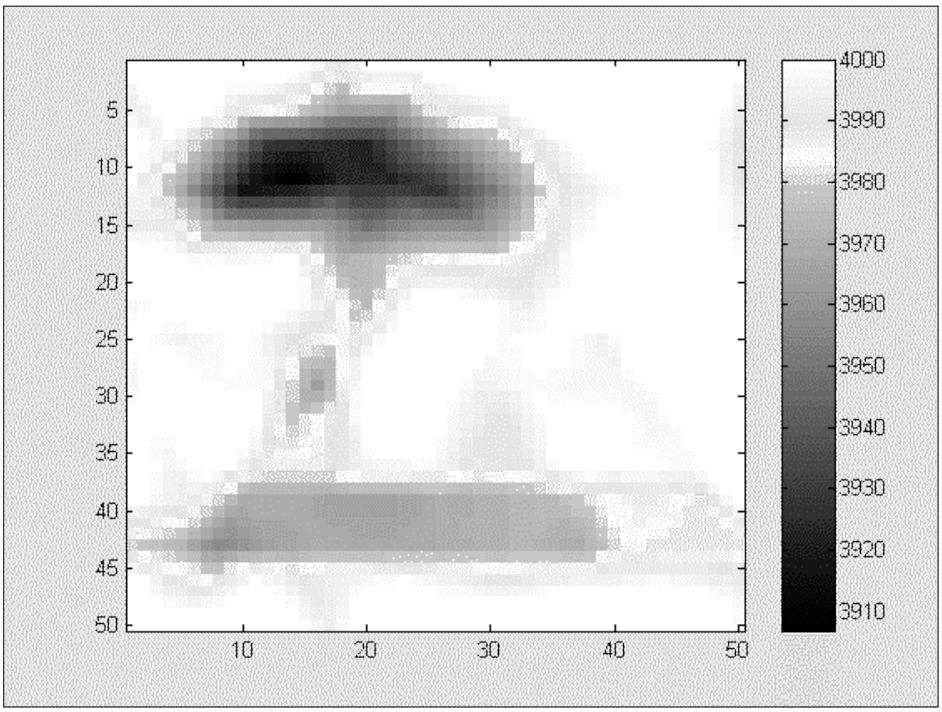

Figure 4: Diffraction tomography inversion using regular trigonal mesh (200 parameters).

Progress

This work aims a *quasi* real-time monitoring of subsurface. Its applications include monitoring of Enhanced Oil Recovery (EOR) and CO_2 sequestration. This monitoring is very important to optimize energetic resources planning and to predict possible CO_2 leaks as well. Thus, it rationalizes resources exploration and also aims to avoid ecological impacts due to leaks that could liberate CO_2 to atmosphere.

Future Plans

The future plans include some extensions:

- Multi-frequency inversion;
- Adaptive mesh;
- Automatic spatial regularization;
- Dynamic update of model based on previous inversions using temporal regularization;
- Field surveys using piezoelectric continuous source and lock-in signal recovery techniques;
- 3D imaging.

Publications

It will be submitted to SEG Meeting 2007 (San Antonio) and CiSBGF 2007 (Sao Paulo / Brazil).

Reference

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2. Persson, P.-O., Strang , G., A Simple Mesh Generator in MATLAB, SIAM Review, V. 46, n. 2, p. 329-345, 2004
3. Rocha Filho, A.A., Harris, J. M., and Bassrei, A., A simple matrix formulation diffraction tomography algorithm, XXXIX Congresso Brasileiro de Geologia, Salvador, BA, Brasil, volume 2, p. 312-315, 1996.
4. Hansen, P. C., Analysis of discrete ill-posed problems by means of the L-curve, SIAM Review, 34, 561-580, 1992.
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