A Hybrid Algorithm for Crustal Velocity Modeling

José Federico Ramírez Cruz[1], Olac Fuentes[2], Rodrigo Romero[2], and Aaron Velasco[3]

[1] Department of Computer Science,
Instituto Tecnológico de Apizaco,
Av. Tecnológico s/n, Tlaxcala, 90300, México,
[2] Department of Computer Science,
[3] Department of Geological Sciences,
University of Texas at El Paso
500 West University Avenue,
El Paso, TX -79902.
federico_ramirez@yahoo.com.mx,
{fuentes,raromero2,aavelasco}@utep.edu

Abstract. We present a hybrid method to produce a velocity model of the Earth's crust using evolutionary and seismic tomography algorithms. This method takes advantage of the global search ability of an evolution strategy and the quick convergence of an iterative three-dimensional seismic tomography technique to generate a model of the Earth's crustal structure from recorded arrival times of wave fronts produced by controlled sources. The evolution strategy finds a three-dimensional velocity model with constant lateral velocity layers that minimizes the root mean square residuals computed by the tomographic algorithm. The model found is provided as the initial search point to a first arrival traveltime seismic tomography algorithm, which then computes the final three-dimensional velocity model. The method was tested with a real-world data set from an active source experiment performed in the Potrillo Volcanic Field, in Southern New Mexico. Results show that our hybrid method obtains faster convergence and more accurate results than the conventional methods, and does not require an expert-supplied one-dimensional model for the seismic tomography procedure.

1 Introduction

Seismic tomography computes images of the Earth's crustal velocity structure that are used to determine and analyze the internal crustal properties of the Earth. Input data are usually obtained from a set of receivers placed on the Earth surface to record seismic signals generated by passive or active energy sources. Seismic energy can be produced at predetermined locations with controlled explosions, which are referred to as shotpoints and are one type of active source, and it can be sensed by a set of receivers, such as geophones, distributed over the area to survey. Source and receiver locations together with measured

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first arrival travel times of seismic waves can then be utilized to generate crustal models by combining algorithms for forward modeling, inversion, search, and optimization.

Velocity models obtained with seismic tomography provide information that can be used for a wide variety of applications such as archeological surveys [13], quality control and assessment of engineering projects [11], and discovery of deposits of water, oil, or waste material [10].

Conventional methods for seismic tomography rely on gradient information to guide the search; however, due to noise and the complexity of the search space, multiple local minima commonly exist, thus the accuracy of the final solution depends on the choice of the initial search point, which is normally provided by a human expert [3]. This results in a time-consuming trial-and-error process. Such dependence is typical in standard optimization methods - they need a good initial approximation to find a good solution. With a good initial model, these local optimization algorithms have the advantage of being faster than global methods to reach successful results. In contrast with gradient-based methods, global search methods such as evolutionary algorithms (EAs) can search in very large spaces and are not dependent on the initial solution's proximity to the optimum. EAs have been used to tackle Geophysics inversion problems [5], [12], [14]. In geology, evolutionary algorithms have been used in combination with different techniques [4], [7], [9], yielding satisfactory results.

We designed a hybrid method for seismic tomography that consists of two top-level steps. The first step uses an evolution strategy (ES) to find a one-dimensional (1D) model, or an equivalent flat-layered 3D velocity model, of the surveyed region. The second step uses a first arrival traveltime seismic tomography algorithm, which was developed by Vidale [16] and Hole [8], to compute a 3D velocity model with complex lateral velocity variations. To compute the 1D model, the ES searches for a tridimensional velocity model that minimizes the average root mean square (rms) residuals between first arrival times recorded by receivers and those calculated using the model. The model is discretized at 1km intervals in three dimensions and it assumes constant velocity within each depth layer. The evolution strategy searches for a set of ordered pairs that determines the inflexion points of the 1D model. The remaining values of the model are calculated using linear interpolation. Running times are short because of the low dimensionality of the search problem and the fact that the 1D models obtained after a few generations are accurate enough to be used as starting point to ensure that the 3D gradient-based search will reach a near-optimal solution.

To evaluate the presented method we used data obtained from the Potrillo volcanic field experiment [1]. Test volume dimensions for the experiment are 231 km in width, 26 km in length, and 69 km in depth. The volume was discretized in intervals of 1 km, which produced a 3D grid with 414,414 vertices. The main goal of the method is to compute velocity values for each vertex of the test volume using as inputs the measurements of first arrival travel times of seismic waves generated by 7 shot points and recorded by 793 geophones, the locations of sources and receivers, a velocity range, and a monotonicity constraint on vertex