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# 3D Velocity Independent Diffraction Imaging

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## SUMMARY

This paper shows a new approach for 3D time imaging, that is based on diffractions and does not need any informations about the subsurface

## Introduction

The formulation and the implementation of computational methods to automatically obtain an image of the subsurface is a long-term dream in the seismic imaging community. The present work is then devoted to showing that velocity independent time imaging, only driven by data, is possible. In this paper the authors illustrate with some examples the potentiality of the new non-hyperbolic formulation approximating the traveltime of a *diffracted* wave in a non-homogeneous medium where the value of the near surface velocity $v_0$ is known. The subsurface is modelled as a collection of diffracting points, each one being treated as a buried source of waves characterized at the surface, in the 3D case, by the emergence directions and by the two principal wavefront curvatures. For each emerging wave, the corresponding traveltime can be formulated in two domains, either in the zero-offset-stack volume or in the time migrated volume.

## Velocity Independent Diffraction Imaging

Zero-offset stacking of primary coherent events is a form of image reconstruction based on the specular reflection of normal incident rays carrying, each one, an echo back to the surface at $x_0$ in a two-way travel time $t_0$. Stacking implies summing, at the corresponding ($x_0$,$t_0$) location of the zero-offset volume (non-migrated volume), all events of the prestack traces common to $P_{\mathrm{NIP}}$, the Normal Incidence point. The resulting trace at $x_0$ approximates a hypothetical coincident source-receiver recording. The interpretability of the zero-offset stacked image is qualitatively satisfactory for trivial instances but it degrades as soon as the geology becomes more complicated. In a similar situation, time migration provides a less distorted and thus more interpretable image of the Earth's subsurface. Time migration is based on the idea that univocally links the definition of the migrated domain to the concept of *image ray*, the ray that, after leaving a buried diffracting point—also denoted as $P_{\mathrm{NIP}}$ in Figure 1—, emerges vertically to the acquisition plane at position $x_D$ after a two-way traveltime $t_D$. Time migration means stacking all coherent diffracted events common to $P_{\mathrm{NIP}}$ to form, at the corresponding ($x_D$, $t_D$) location of the image section, a representation of the diffracting point. The resulting synthetic trace collects the images of all diffractors that are encountered along the trajectory of the image ray when it moves from the surface to the underlying layers, thus measuring the vertical axis in units of $t_D$. Only when the medium is uniform, time migration correctly collocates primary events along the true vertical of each diffracting point.
As already said, time migration must be considered a simpler process that in complex-velocity situations can barely compete with the more expensive depth imaging technology which requires a reliable subsurface velocity model. Since the proposed time imaging technology does not have this requirement, its benefit is obvious in the presence of highly fractured geological structures with small-scale objects such as faults, channels and fracture systems, and mild lateral-velocity variations.

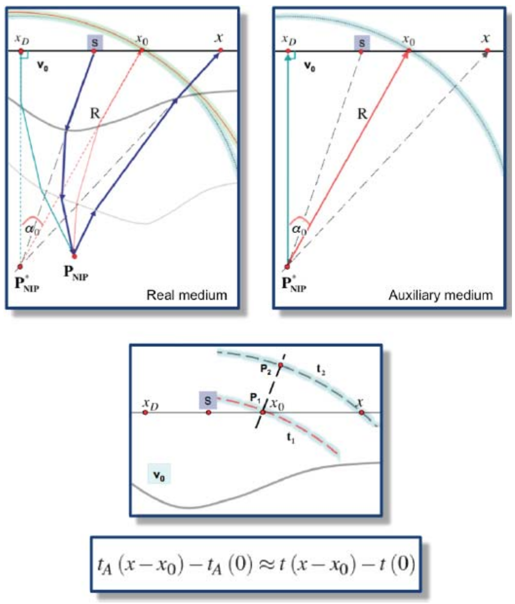


Figure 1 *Quasi-similar 2D Earth models and time delay: the image of $P_{\mathrm{NIP}}$ is determined in the auxiliary medium by the center $P^*_{\mathrm{NIP}}$ of the osculating circle tangent in $x_0$ to the emerging diffraction wave.*

The homeomorphic transformation is the cornerstone to setup the migration algorithm. In 2D, it is based on the use of the osculating circle to give a circular approximation of the diffraction wavefront. As illustrated in Figure 2, the center $P^*_{\mathrm{NIP}}$ of the osculating circle tangent to the front in $x_0$—the reference emergence point—becomes in the auxiliary medium the image point of $P_{\mathrm{NIP}}$. Assuming a constant velocity $v_0$ near the surface in both media, within the circular approximation it is difficult to distinguish which, $P^*_{\mathrm{NIP}}$ or $P_{\mathrm{NIP}}$, has originated the diffraction front. Then, the time lapse between two arrivals at two positions, $x_0$ and $x$, very near each other can be assumed (approximately) equal for both auxiliary and real media. Mathematically, this means that in the real medium the one-way traveltime of the diffraction ray, reaching $x$ within the circular approximation, takes the very simple form:

$$t(x - x_0) = \left[\frac{t_0}{2} - t_A(0)\right] + t_A(x - x_0) = R/v_0 \quad (1)$$

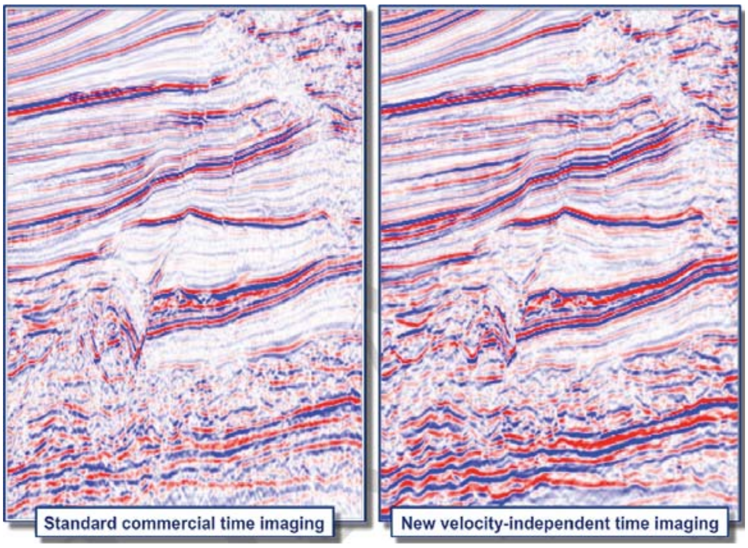


Figure 2 *It can be seen the excellent detention of thrust faults, the greatly improved S/R and the overall improvement due to the best focusing.*

Here $t_A$ denotes the two-way traveltime in the auxiliary homogeneous medium, a function depending on the emergence angle $\alpha_0$ and on the radius $R$ of the osculating circle, both taking values in the non-migrated volume ($x_0$,$t_0$). The term inside the square brackets represents the time delay between the two quasi-similar media. The advantage of this formulation is that $t_A$ can easily be calculated using Euclidean geometry. Having this in mind, the traveltime for the single ray, Eq. 1, can be composed to obtain the traveltime for a pair source-receiver within the circular approximation of the *diffraction wavefront*. Always within the circular approximation, the coordinate $x_D$ and the traveltime $t_D$, both characterizing the image ray leaving $P_{NIP}$, result from the minimization of the right-hand side of Eq. 1. This gives rise to a mapping that in 2D takes the form:

$$x_D \approx x_0 - R\sin\alpha_0 \;,\; t_D = t_0 - (4R/v_0)\sin^2(\alpha_0/2) \quad (2)$$

Inserting the mapping between ($x_0$,$t_0$) and ($x_D$,$t_D$) into (1) produces $t_M(x - x_D)$, the traveltime expression, referring however, to the *image ray*. As a consequence, for the same diffraction events caused by $P_{NIP}$, the traveltime for the two-way diffraction traveltime can be rewritten:

$$\tau_D(x_s, x_r) \approx t_M(x_s - x_D) + t_M(x_r - x_D), \quad (3)$$

The importance of this last formula reveals itself in the time migration process since it directly and explicitly expresses the traveltimes in the prestack domain with respect to a pixel in the migrated domain ($x_D$,$t_D$).
Although the previous theory is only 2D, its effectiveness illustrated in Figure 2, a full 3D version is available and its potentiality demonstrated. The industrial implementation is now under development.

## Conclusions

This work represents a relevant scientific and technological step opening new perspective in industrial processing. The advantages can be evaluated from several point of view but the authors think the greatest one is the remarkable improvement in the final image mainly due to the excellent approximation of the new traveltime formula and to the *optimal focusing* effect coming from the *velocity-independent* approach, only *driven by seismic data*.

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