# Choice of algorithm and data domain for 5D trace interpolation

*Ye Zheng*[*1], *John Guo*[1,2], *Wenyuan Liao*[2], *Laurie Ross*[1], *Balazs Nemeth*[3] *and Christian Escalante*[3]
[1] *Geo-X Exploration Services Inc.*
[2] *University of Calgary*
[3] *BHP Billiton*

## Summary

Prestack trace interpolation in 5 dimensions is recently being widely used in the seismic industry to regularize the field data and fill in the gaps where data were not recorded in the field. Interpolation tools achieve two purposes: 1) to regularize the spatial sampling to satisfy the requirement of some processing algorithms, such as WEM and RTM; 2) to "create" traces as if they were recorded in field for reducing the cost of data acquisition. There are many practical algorithms used in the industry. Each of them has its own advantages and disadvantages. The definition of 5 dimensions can be different as well. In this paper, two methods will be compared in both COA and COV domains with a field dataset acquired in the Western Canadian Sedimentary Basin.

## Introduction

During the past decade, prestack trace interpolation became widely used for regularizing and filling in gaps of sparsely sampled land seismic data. Due to environmental restriction and financial constraint, 3D land seismic data are almost always acquired with geometries far sparser than what many processing algorithms require, which may compromise the quality of the final images. To mitigate the effect of the less ideal dataset, prestack trace interpolation is used to aid in satisfying the requirements of some processing algorithms, such as WEM and RTM, and fills the gaps as if the data were recorded with less sparse parameters. An example showing the benefit of interpolation is in Figures 1 and 2. Figure 1 is a time slice of the prestack migration without interpolation, and Figure 2 is the corresponding time slice with interpolation. The migration noise is eliminated and structures are sharper in Figure 2, compared to Figure 1.

A good interpolation algorithm should at least meet these two criteria: 1) preservation of geological structures; and 2) preservation of AVO responses and anisotropic information (if there is any).

Many interpolation algorithms are available in the industry. In this paper, two of them, ASFT (Guo et al, 2015a) and MWNI (Liu and Sacchi, 2004) are presented and their outputs are compared in both **C**ommon **O**ffset-**A**zimuth (COA) and **C**ommon **O**ffset **V**ector (COV) (Cary, 1999) domains.

## Theory

Both ASFT and MWNI interpolations are Fourier Transform based algorithms, which, in general, reconstruct the wave field by solving the best estimated Fourier coefficient $F(\boldsymbol{k})$ for each temporal frequency slice $f(\boldsymbol{x})$:

$$F(k) = \sum w(x) f(x) e^{-2\pi i < k,x >} \qquad (1)$$

Where both $\boldsymbol{x}$ and $\boldsymbol{k}$ are 4D vectors. $\boldsymbol{x}$ represents the trace location in 4D spatial domain, and $\boldsymbol{k}$ represents the position of a particular Fourier coefficient in 4D wave number domain. < > is the operator of inner product. $w(\boldsymbol{x})$ is the weight function. If both $\boldsymbol{x}$ and $\boldsymbol{k}$ are on a regular grid, $w(\boldsymbol{x})$ is a constant.

The key differentiator of ASFT versus MWNI is that for ASFT, both $\boldsymbol{x}$ and $\boldsymbol{k}$ can be any arbitrary numbers, either rational or irrational. They do not have to be at the grid points. However, for MWNI, $\boldsymbol{x}$ and $\boldsymbol{k}$ must be at the grid points in spatial and wave number domains; in other words, they must be discrete with even increments. Therefore, the advantage of ASFT is that the accuracy of the trace locations and wave number components are well preserved, while MWNI has to snap the trace location (in 4D space) to the grid points, which will somewhat smear geological structures and AVO (AVAZ) information.

Since the Fourier coefficient calculation is not tied to any grid system, ASFT is flexible to handle any kind of irregular acquisition geometries. For instance, MegaBin (Goodway and Ragan, 1996) is another type of land acquisition geometry, which samples wavefield less densely in one direction than the perpendicular direction by a factor between 2 and 6 for cost efficiency (Goodway, 2013). Currently, widely used interpolation algorithms may have difficulty in handling this kind of geometry because MegaBin data are usually aliased in the less sampled direction. Tests have shown that ASFT can properly handle MegaBin data (Guo et al 2015b).

On the other hand, the advantage of MWNI is that it can utilize the efficiency of FFT so its run time will be shorter. However, with the newly optimized DFT algorithm, the computational speed of ASFT is comparable to MWNI.

Industry convention calls the above mentioned interpolation methods as 5D interpolation. Here, 5D refers to the input data domain. The actual interpolation is performed in 4D spatial / wave number domain for each temporal frequency. The input data to interpolation can be in various domains. Two popularly used domains are: 1) Common Offset-Azimuth (COA); and 2) Common Offset Vector (COV). The 5 dimensions for COA are time, CMP inline, CMP cross-line, offset and azimuth. The 5 dimensions for COV are time, CMP inline, CMP cross-line, offset in inline direction and offset in cross-line direction.

Figure 3 shows an example of an interpolated CMP gather in COA and COV domains with ASFT interpolation. The outputs from ASFT in both COA and COV domains were interpolated from the input data with high fidelity, which preserved the details of input data. These interpolated traces are just as if they were recorded in the field.

## Examples

A field dataset with a typical orthogonal acquisition geometry from the Western Canadian Sedimentary Basin was used for the tests. The source lines of the survey ran in the E-W direction with the line interval of 300 meters and source station interval of 60 meters. The receiver lines ran in the N-S direction with the line interval of 180 meters and receiver station interval of 60 meters. The receiver patch is 12 lines by 60 stations, in total 720 channels per shot. The spatial extent of the patch is 3,540 meters (N-S) by 1,980 meters (E-W). The maximum offset of this dataset is about 2,300 meters. The interpolation parameters were designed according to the acquisition geometry. For COA, parameters of 4 azimuth sectors with an increment of 45 degrees and 30 offsets with 75 meter intervals were chosen. For COV, 12 offsets in an E-W direction with an interval of 180 meters (corresponding to the receiver line interval) and 12 offsets in N-S direction with an interval 300 meters (corresponding to the source line interval) were used.

Figure 4 shows time slices of the stack without interpolation and with interpolation of ASFT and MWNI in both COA and COV domains. The geological structures on the ASFT stacks of COA and COV are sharper and clearer than the correspondent time slice of the non-interpolation stack. While the interpolation of MWNI somewhat smeared the geological structures. The major structures were preserved although some details were lost. From the test of this dataset, ASFT is superior to MWNI in the preservation of geological structures, the first criteria for interpolation algorithms.

To examine if interpolation preserves AVO response, AVO analysis were applied to the non-interpolation gathers, and the four sets of interpolated gathers (two methods in two domains). Figure 5 shows the comparison of time slices of AVO gradients. Like Figure 4, MWNI lost details on AVO gradients in both COA and COV domains. Comparing both outputs from ASFT, COV interpolation preserved AVO response better.

Figure 6 shows the comparison of prestack migration of the non-interpolated and interpolated data. It is obvious that the prestack migration with ASFT interpolation provides clearer images and has less migration artifacts.

## Conclusions

Because ASFT honors the true acquisition locations, true offsets and azimuths (or true offset vectors, if COV is used) of the input traces without snapping traces into the grid points, it provides sharper images and preserves structures better than MWNI. Small geological structures were preserved by ASFT interpolation, while MWNI smeared these details.

Based on the dataset tested, ASFT interpolation preserves geological structures well in both domains. When the AVO response was investigated on the interpolated gathers, the COV domain appears to be better than the COA domain.

## Acknowledgements

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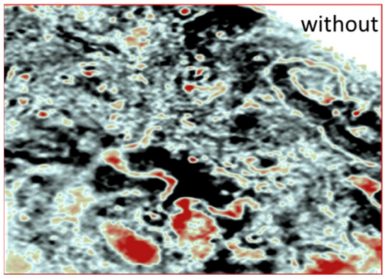

Figure 1. Time slice of prestack migration without interpolation.

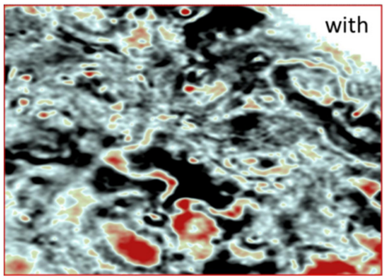

Figure 2. Time slice of prestack migration with interpolation

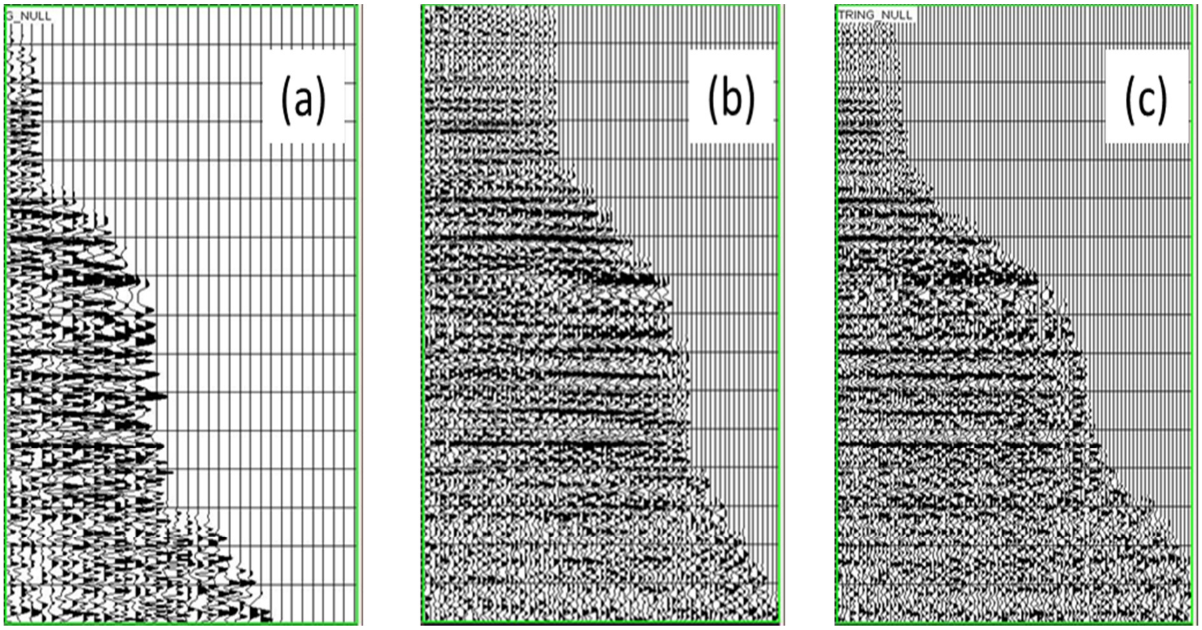

Figure 3, (a) input gather to ASFT; (b) output of ASFT in COA domain; (c) output of ASFT in COV domain. Displays are sorted by offset for easy visual comparison.

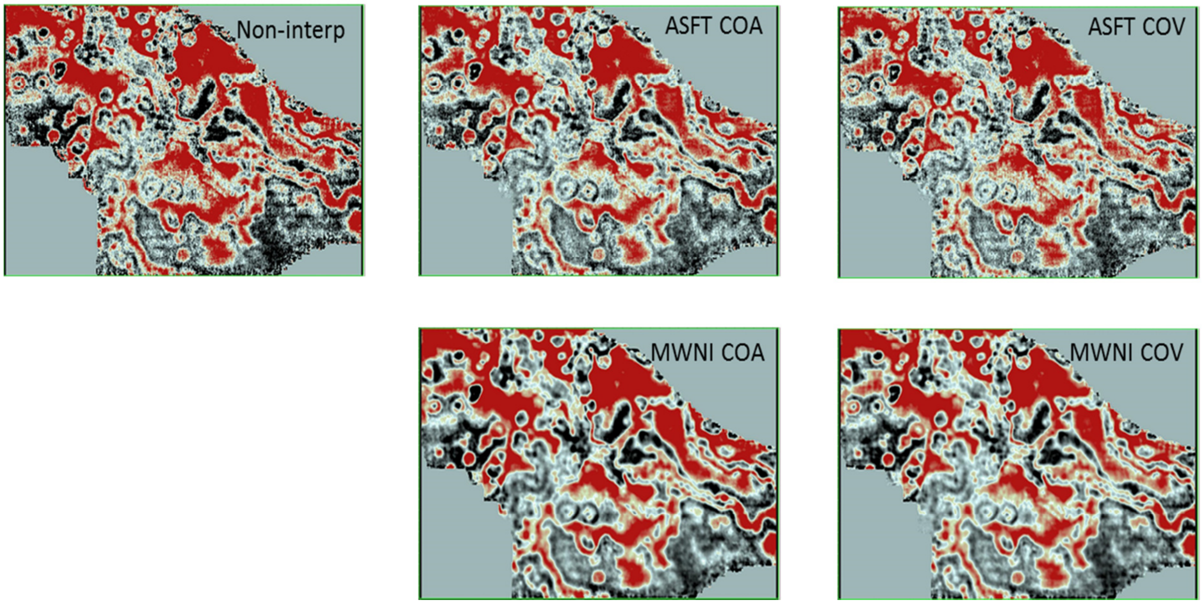

Figure 4. Time slices of the stacks of non-interpolation gathers, ASFT interpolation in both COA and COV domains, MWNI interpolation in both COA and COV domains. ASFT in both domains preserved geological structures well and the structures are sharper in comparison to non-interpolation stack. MWNI interpolation preserved major structures, but smeared some details.

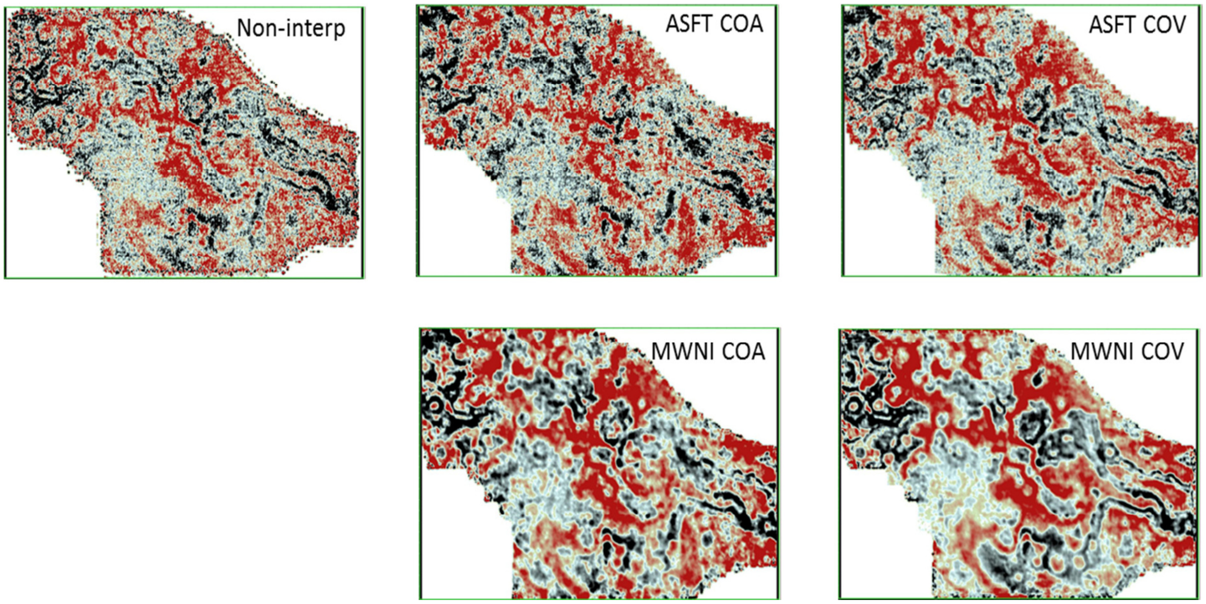

Figure 5. Time slices of AVO gradients. ASFT COV interpolation preserved the AVO response well, while ASFT COA did not work as well as ASFT COV. MWNI in both domains show smoothed versions compared to ASFT. Some details were smeared with MWNI interpolation.

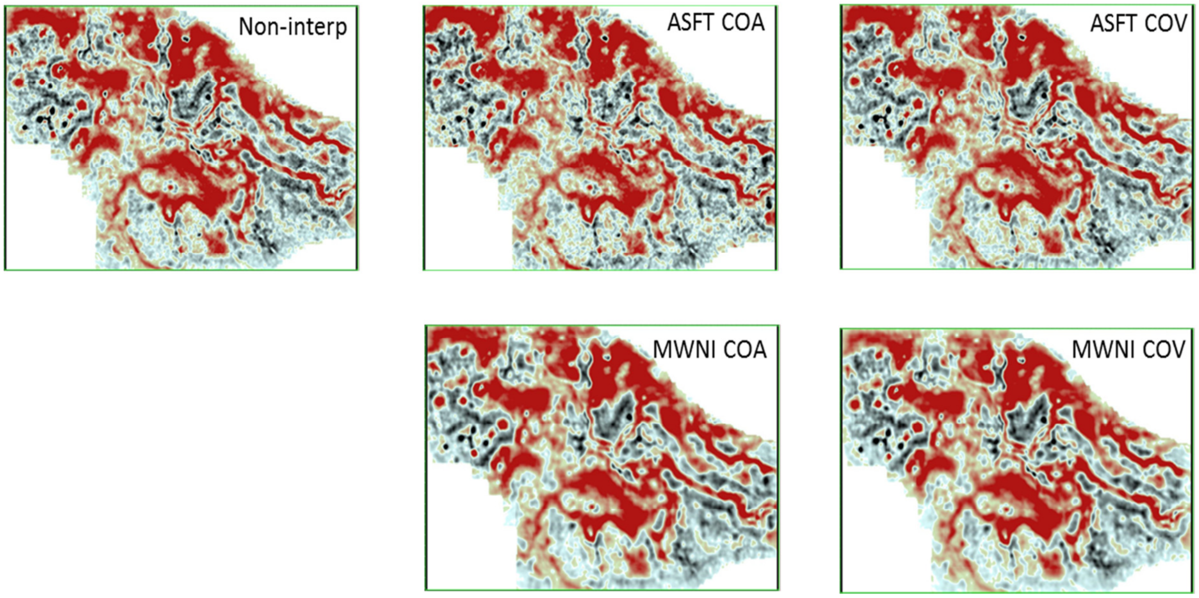

Figure 6. Prestack migration with and without interpolation. Both COV and COA of ASFT interpolation show sharper and clearer pictures than the time slice without interpolation. Some details of the structures were smeared with MWNI interpolation.