Multidimensional Interpolation and Regularization for Survey Merging

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Abstract

The use of multidimensional regularization and Interpolation techniques have greatly improved land processing when it comes to survey merging. By allowing the utilization of these multiple data sets, acquired over a given prospect, to be seamlessly combined and imaged produces a remarkable high fidelity and well focused structural image. The image improvements come from the symbiotic interrelation of the different data sets used in the migration summation. After describing the technique several examples will be presented.

Introduction

The high dimensional nature of seismic (Wojslaw et al. 2012) has culminated in the realization that to properly interpolate and regularize data, a 5D methodology is required. It is important to understand that these “dimensions” are really degrees of freedom in the seismic experiment. These degrees of freedom are represented by a set of five (5D) independent coordinates (and there are several of these that can be used). The most common and intuitive set is given by: Inline, Crossline, Azimuth, Offset and Time.

When a seismic trace is missing it produces a “hole”. However this hole looks different depending on which domain it is observed. If it is displayed for example, on a timeslice made of inline and crossline, it may have one shape but if displayed in the shot and receiver domain, it may look very different. The realization of this simple fact has far reaching consequences because unless the “hole” is treated as a 5D object, any 3D interpolation and regularization will lead to incorrect results.

In some sense when we look at a collection of seismic data in any 3D coordinate system, for example (Inline, Crossline, Time), or (Shotx, Shoty, Time), we are effectively looking at a lower dimensional projection of a higher dimensional object. An example (from another field) is shown in figure 1 where a complex 3D object has been shaped in a way that when light is shined from different directions, it casts different shadows forming 2D letters. If the goal was to “fill in” the spaces in the 3D object to reconstruct a solid cube, then “filling in” the projections would not do the job. The only way to fully reconstruct the 3D cube is to treat the object as in 3D and not as a collection of 2D projections (see figure 1). A similar situation occurs with seismic data. The main difference is that seismic data is 5D and the projections we usually deal with are (normally) 3D. These 3D projections are the standard volumes we use to visualize and analyze the data, volumes like (Inline, Crossline, Time), or (Shotx, Shoty, Time), and many others.

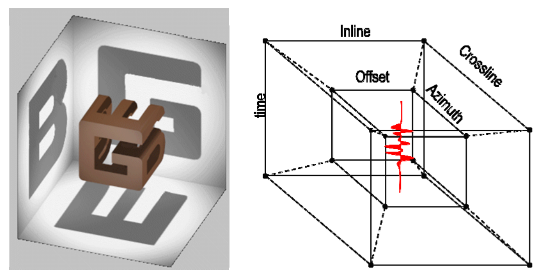

Figure 1: The 3D cube cannot be completely filled in by filling in the 2D holes (spaces that make up the letters). Seismic is similar to that but in 5D

We have developed a regularization and interpolation algorithm that is capable of analyzing seismic data in its full 5 dimensional form to fill in all the holes. The algorithm has been presented elsewhere (Wojslaw et al. 2012, Stein 2012) so we will only give a short description and refer the reader to the aforementioned reference.

The method: INT5D

The methodology consists of two steps, the first is regularization and the second is an interpolation.

The regularization technique is summarized in figure 2.

Figure 3a shows an example of 5D regularization displayed on a shot and receiver base map, remember that process is happening in 5D so the offset and azimuth are also regularized but not shown. Figure 3b shows a stack section running left to right from the middle of the survey. Observe the healing of the shallow data as well as the filling in of the missing traces

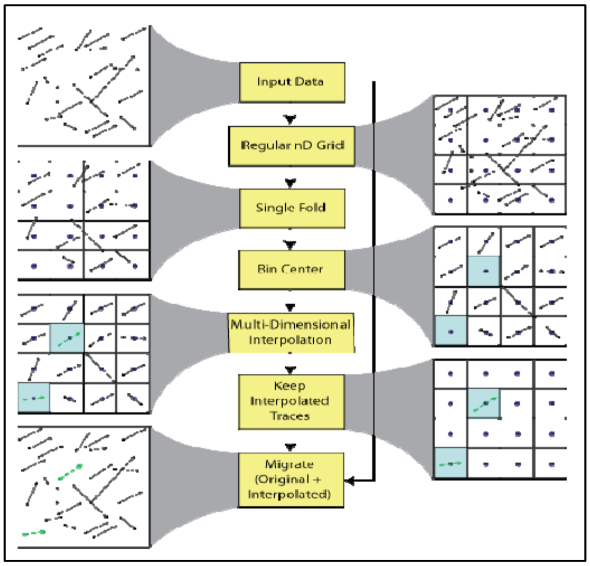

Figure 2: Regularization Algorithm

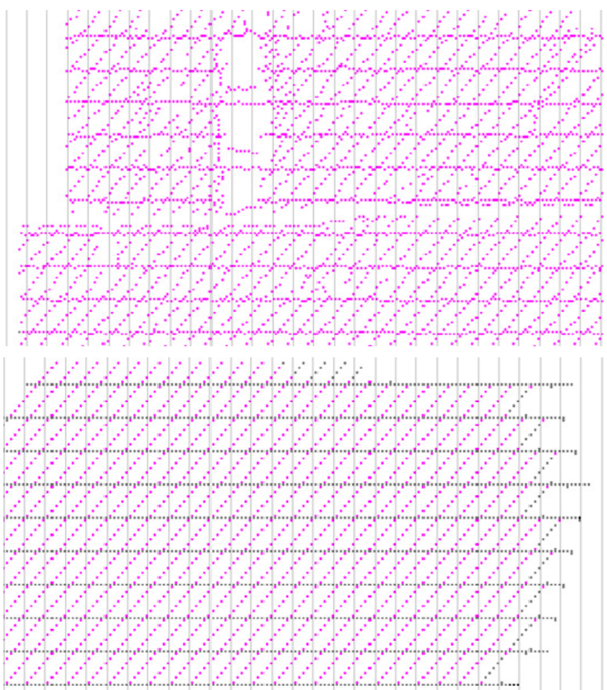

Figure 3a: 5D Regularization data displayed for a source and receiver positions

Once the data is regular we can precede with the interpolation. The method is based on a generalization of the traditional 3-dimensional semblance calculation described in (Robinson & Treitel, 1980).

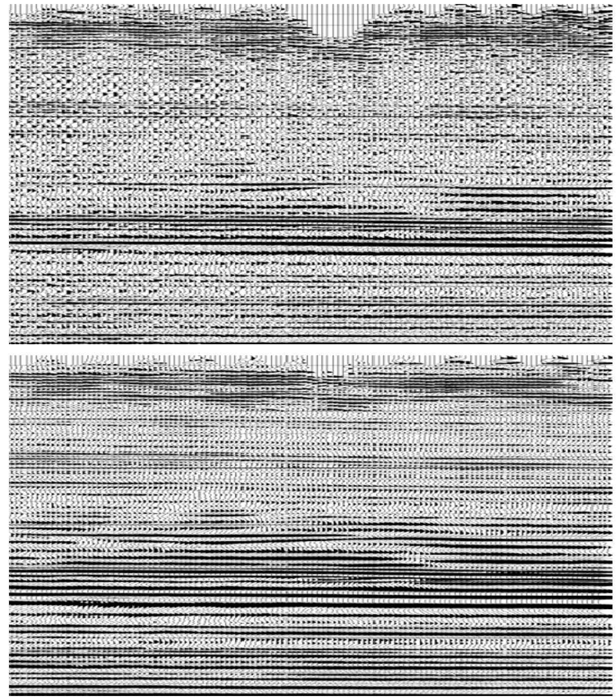

Figure 3b: Seismic Line running left-right from the middle of figure 3a before and after INT5D

For every sample of every trace, semblances are computed along all possible 5D dips (Inline, Crossline, Offset, Azimuth, and Time). These semblances are ordered and the largest one picked. This determines a “direction” of interpolation. A map is produced of all missing data and for every one of them an interpolated trace is constructed by using the samples gathered from adjacent traces (in 5D) in the “direction” specified by the maximum semblance.

Although the technique was originally developed to fill in missing data due to acquisition shortcoming, it has since evolved into a powerful technique for merging multiple data sets. The focus of this paper is to demonstrate the usefulness and robustness of this methodology in the context of survey merging.

Merging Surveys with INT5D

In order to process several surveys as part of a merge it is necessary to put them on a regular common processing grid. Due to the different acquisition details they generally do not agree on much. Surveys were probably acquired by different companies in different years with different equipment have different bin sizes, orientation, phase, sampling rate, etc.

An important part of merging data is to make sure the wavelet response i.e. the amplitude and phase response is equalized. This is a non-trivial exercise but not the focus of this paper so we will assume that it has been done and the surveys in question have been prepossessed so that any and all equipment and array signatures have been removed, bulk shifts applied and the wavelets have been equalized so phase and amplitudes are consistent.

Even when all these have been achieved, there is still the geometrical issue of how to put them on a regular common grid before the migration.

It has long been a desired to be able to formulate a general enough migration algorithm that accounts for all of these effects, but so far we do not have it yet. The standard practice to prepare data for migration of a survey merge was to use flex binning. Needles to say flex binning has not proven very successful, especially in situations where there are steep dips and complex structures.

The idea of using an interpolator to solve this problem came from the situation described in figure 4 where two surveys, although regular ones are overlaid on a single processing grid. Because they have different bin sizes and different orientations, they produce something that looks very irregular and full of “holes”. Hence the idea came of treating them as a single data set. Then it is simple to regularize and interpolate as was described before.

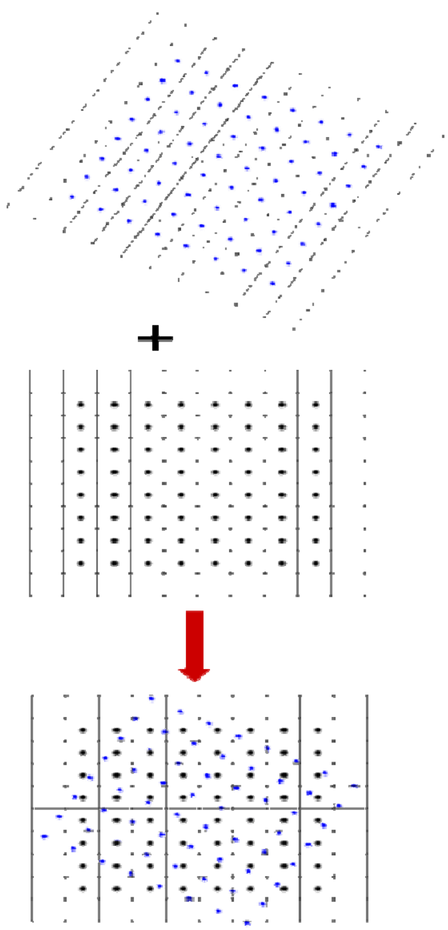

Figure 4: CDP of two regular surveys when put on a common grid produce an irregular set with “holes”

Examples 1

Figure 5 shows an unmigrated stack while figure 6 shows the corresponding snail gathers before and after regularization and interpolation of two surveys included in the merge. The bin spacing and orientations were different producing an irregular pattern. After INT5D the inter-trace gaps and the large shallow holes produced by surface obstacles have been filled in with very credible data.

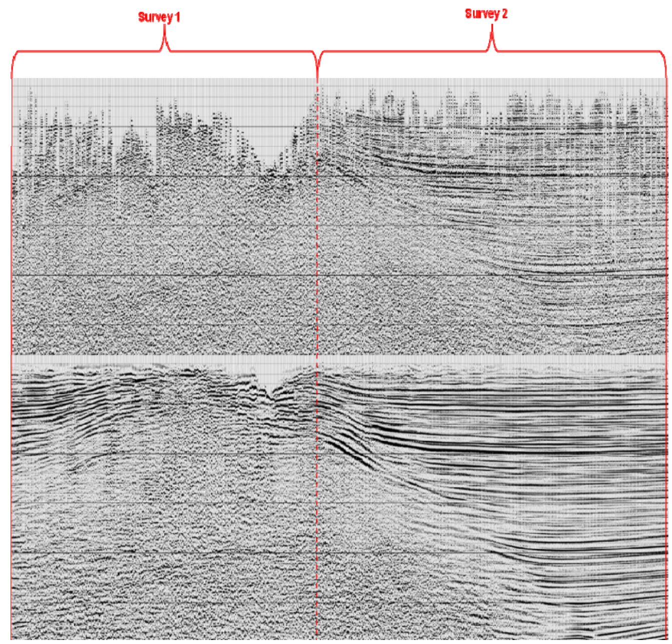

Figure 5: Stack Sections of a merge before and after 5D regularization and interpolation

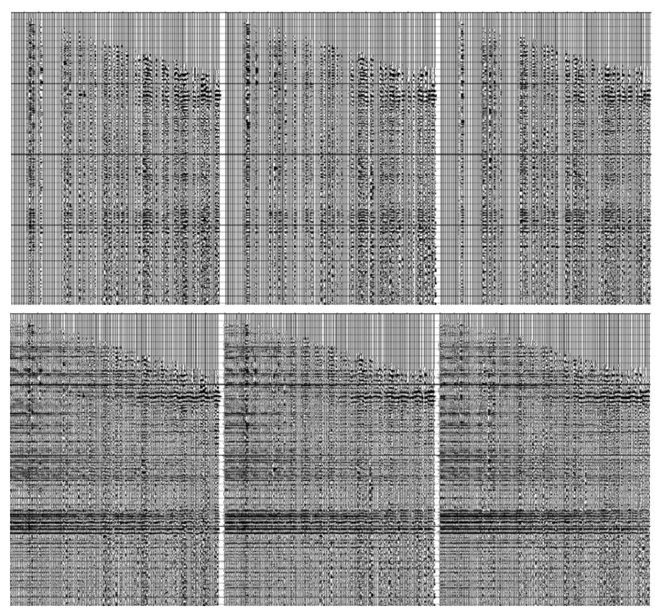

Figure 6: Snail gathers before and after 5D regularization and interpolation

Examples 2

The following example is from offshore Louisiana in the Gulf of Mexico. The images have been constructed from the merger of many (at least five) surveys over a large area acquired by different companies throughout the years with different equipment and geometries. The data sets cover a large prospective area over some of the producing reservoirs.

Many post migration merges have been done with lackluster results. The difference in the acquisition parameters is such that techniques like flex binning failed in the past. All the data sets were laid down on a common grid, then regularized and interpolated in 5D as described before and the results are shown below.

Figure 7 shows a time slice at around 1sec. of unmigrated data across an area where at least five surveys have been merged after proper wavelet processing has equalized amplitude, phase and any bulk timeshift required. Figure 8 shows a vertical line through the middle of the timeslice. Notice the severe acquisition footprint present due to the different geometries and how it has been greatly reduced by INT5D

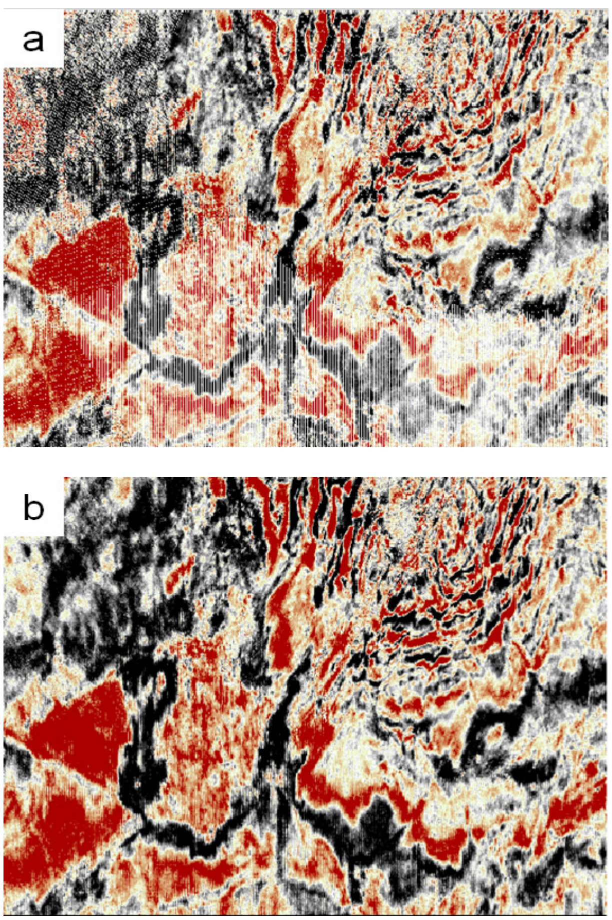

Figure 7: Timeslice of unmigrated data a) before and b) after INT5D.

The following set of figures show data from the same survey after it was migrated. All velocity work was done on a merged data set so a single velocity model was used for the entire area. Clearly the migration of data from b) gives a much cleaner results than the one from a).

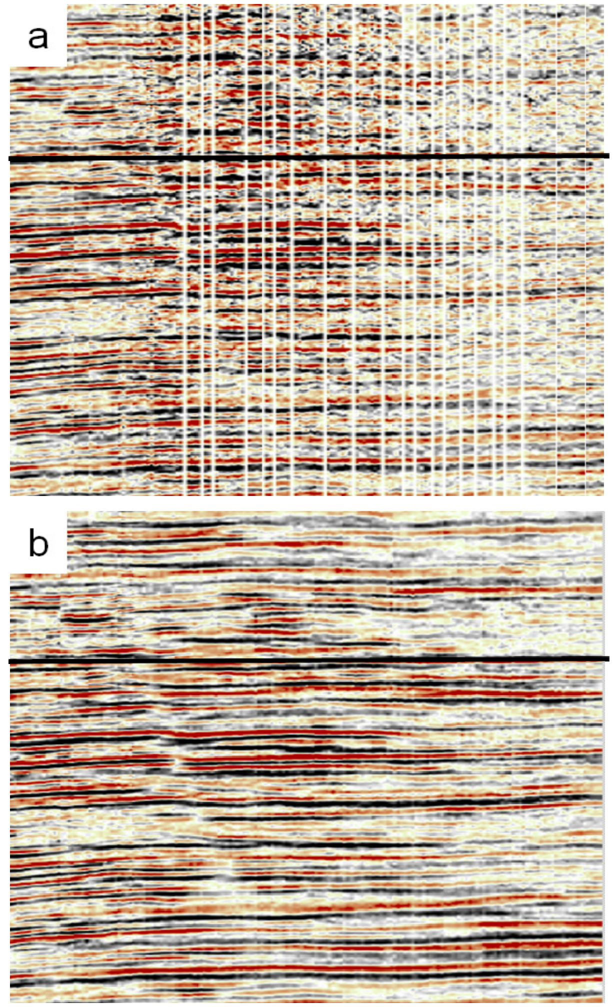

Figure 8: Stack unmigrated section data around 1 second a) before and b) after INT5D.

Figure 9 shows a timeslice at around 1 sec. of the migrated set demonstrating that a beneficial constructive interference was achieved as a result of adding more data to the migration by using the merged data set as its input. Figures 10 and 11 show a line out of the migration

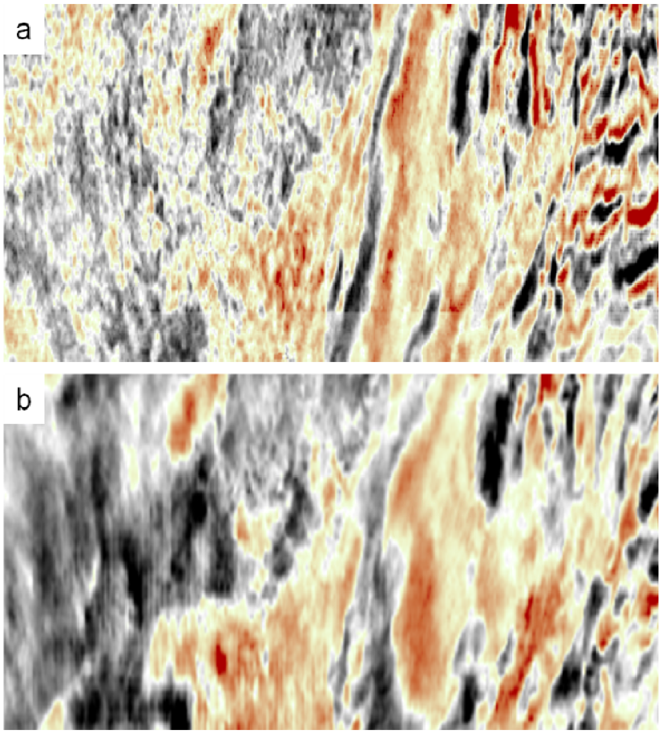

Figure 9: Stack migrated data a) without and b) with INT5D.

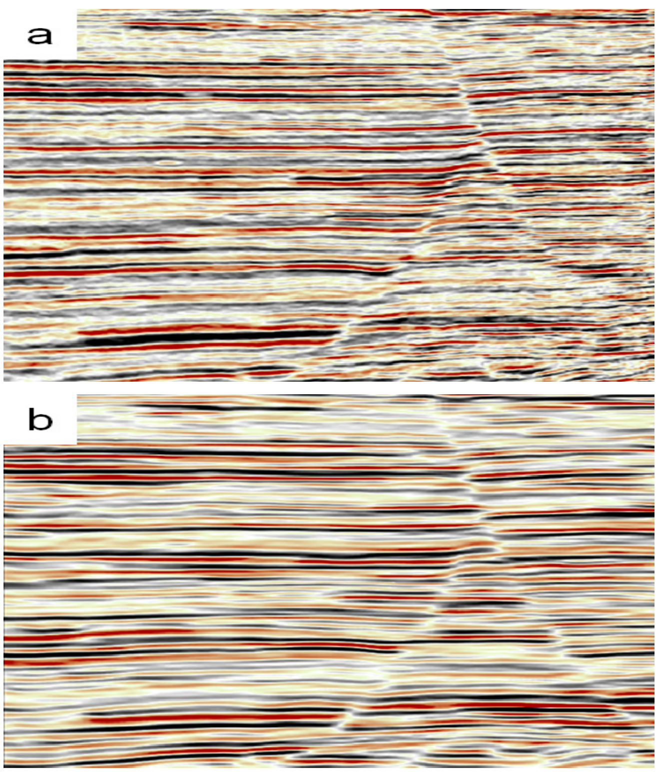

Figure 10: Shallow (around 1.5 sec.) migrated section a) without and b) with INT5D.

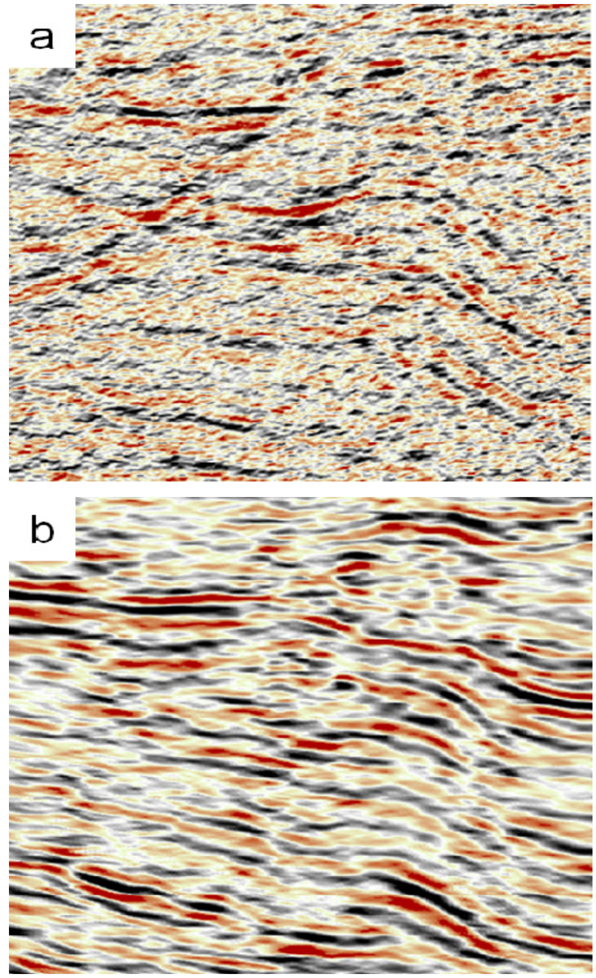

Figure 11: Deep (around 4.5 sec.) migrated section a) without and b) with INT5D.

The sharpness of the faulting as well as the clarity of the deeper section leaves no doubt that utilizing the regularization and interpolation greatly benefited the focusing and imaging of the prospect

Conclusions

We have developed a 5 Dimensional interpolation and regularization technique based on a well known semblance calculation. Although initially conceived as a technique for filling in missing data and patching up shallow holes due to surface obstacles, we have now extended its use for survey merging.

We have demonstrated how when surveys coming from different acquisition geometries are put together in a common grid, even though they may be regular, they produce irregular patterns that produce “holes” when put on a common processing grid. This observation allowed us to treat the merge as a regularization and interpolation problem and successfully apply the same techniques.

The power of the method has been demonstrated with two examples. The first is a structurally complex salt prospect made out of two surveys with multiple acquisition holes from cultural and natural obstructions. Stacks and Snail gathers demonstrate the ability of the algorithm to credibly recover the missing data and prepare the survey for a successful imaging through migration

The second example, a shallow water marine GOM prospect covered by at least five surveys was used to further demonstrate the power of the technique. After regularization and interpolation it was time migrated and compared to previous results were flex binning was used. The superiority of the 5D approach was clearly demonstrated.

Acknowledgments

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References

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Stein J.A., Multi-dimensional high resolution processing to meet today's seismic imaging needs, First Break, 30, October 2012