LG space as unified view of imaging for vertical and lateral geometric complexity

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SUMMARY

Seismic imaging is challenged by vertical complexity (denseness) of too many reflections and lateral complexity (roughness) of surfaces. The end members are usually sparse (easy for imaging) or fractal (too complex for imaging). Is there a more unifying concept that stands between very simple to very complex? We will present a unified view of geometric complexity by introducing the concept of LG (locally dense but globally sparse). LG is not as simple as sparsity (far apart) but not as complex as fractal (denseness). We will use 2 examples to illustrate the concept.

INTRODUCTION

Seismic imaging technologies such as Reverse Time Migration (RTM), Tomography and Full Waveform Inversion (FWI) have demonstrated their strength in imaging geologically complex settings. However, there are still situations where real data challenge the limits of what can be imaged with these technologies. Factors such as illumination, anisotropy, attenuation, among others, are often mentioned to explain poor results, but these might not necessarily be the main factors at play. In this paper we explore geometric complexity and demonstrate with simple synthetic examples the central role it plays in seismic wave propagation, and the consequences for velocity model building and imaging.

The first example is 1D which has vertical LG variations of reflectivity (locally dense but globally sparse). The second example is 2D which illustrates lateral LG variations (locally rough but globally smooth).

Geological justification of the 1D example (vertical LG) is that sparsity is due to long period of slow uneventful thick deposition but it is interspersed with rapid variation of deposition in short time.

Geological justification of the 2D example (lateral LG) is the geometric variation of impedance boundaries. One geologic example is roughness of salt boundary. Another geologic example is gas pockets. It is still a challenge to image below salt and gas pockets. Local roughness could also be created by local erosional surfaces.

We will illustrate with these two examples a unified view that both cases exhibit LG (locally dense but globally sparse).Both examples at first glance do not look complex. But the synthetic seismic data turn out to be quite complex. These two examples are archetypes of difficult imaging with complex geometry.

Complex geometry frequently comes with large variation of rock properties like velocity and density. This variation further complicates the geometric effect. We will use only constant velocity layers without introducing rock property complexity.

1D EXAMPLE

Example 1 is a 1D model (perfectly flat) geological layers. The model has uneven distribution of reflectivity. But this simple example illustrates that LG distribution with sparse reflections interspersed with some locally dense reflections will cause significant problems for seismic imaging and seismic inversion like short period multiples. It is not close to the complexity of fractal. But it has enough uneven geometric distribution to significantly challenge seismic inversion.

The challenge here is that LG vertical distribution of primaries will cause significant problem to remove (de-multiple) internal multiples. LG 1D example looks simple at first. But it needs only just a few local packages that are locally dense (close to each other). We have modeled both P (primaries only) and P+M (primaries and multiples).

FIRST FIGURE:
Synthetic of P+M has weaker amplitude than P for complex LG model.
VSP shows first arrival packages stretched with many trail cycles.
Downgoing waveforms at different depths have significant stretch but there is no attenuation in the model.

2D EXAMPLE

Example 2 is a 2D synthetic example with complex geometry of impedance boundaries. We will start with the simplest 2D example with only one layer of geometric complexity which appears at the top of formation. We will show the complex snap shots and VSP with downgoing wave. The downgoing wave (source at the surface in the middle of the model) is corrupted by LG lateral variation.

SECOND FIGURE:
Snap shots show asymmetry.
VSP show first arrival packages stretched with many trail cycles.
Downgoing waves at different depths are complex.

CONCLUSION

We illustrated with two synthetic examples. The 1D (vertical variations) and 2D (horizontal variations) achieve their complexity with only simple rock properties. The effect is totally due to geometric complexity of LG distribution in vertical and horizontal models.

MITIGATIONS

There are processing methods which could mitigate vertical and horizontal complex problems to improve imaging. These are ad hoc methods which could be helpful. But they do not estimate the complexity of the downgoing wave. One such mitigation approach is to alternate between wave equation datuming and residual static (see [Lau and Yin]). Static shift is an approximation of the thin lens term of wave propagation (see [Judson, et al]). Another earlier method is “virtual datuming” without explicit datuming using wave eqation (See patent).

MATHEMATICAL INTERPRETATION

For general discussion of solvability, there is limitation to mathematical method as a whole in imaging and inverse problems (see [Lau 2018] and [Lau 2019]).

Riemann–Lebesgue lemma (An interpretation)

Given f(x), F(z) = integration of [f(x)*g(x,z)] from negative infinity to infinity.
E.g., g(x,z) = exp (-i*z*x) which is the Fourier transform.
An interpretation of the lemma is that given a specific “geometry” like sinusoids, the integral is essentially 0 (negligible) as abs(z) goes to infinity. The geometry is defined by g(x,z).
Question: What about geometries that are not sinusoid? In fact, geometry of the earth layers is almost never sinusoidal. Hence, the inverse solution will always create artifacts which look non-geologic. The numerical solution could not be the final solution. We will still need to modify the inverse solution by interpreting the geometry to make geologic sense.

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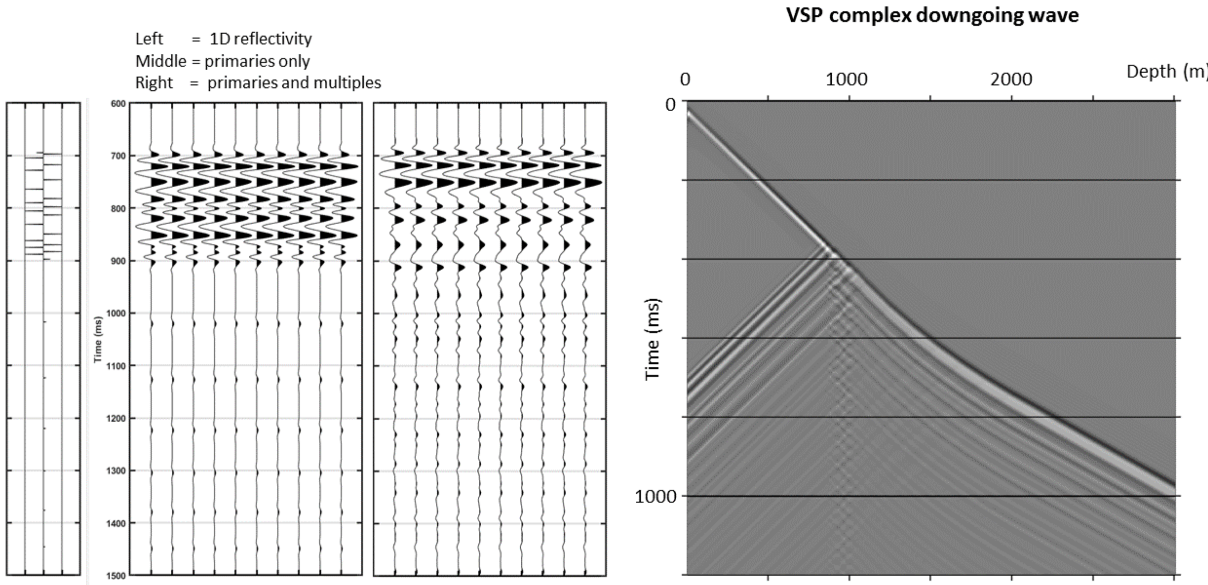
VERTICAL GEOMETRIC COMPLEXITY (1D MODEL)



HORIZONTAL GEOMETRIC COMPLEXITY (2D MODEL)