Coordinate-independent extended images for wave-equation migration velocity analysis

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Wavefield-based migration velocity analysis using the semblance principle requires computation of images in an extended space in which we can evaluate the imaging consistency function of overlapping experiments. Usual industry practice is to assemble those seismic images in common-image-gathers (CIG) which represent reflectivity function of space, e.g. depth, and extensions, e.g. offset, cross-correlation lags in space and time, or the reflection angles. Depending on the type of extension, the CIGs represent correct imaging if the seismic events are either flat or focused, indicating correct wavefield reconstruction from the sources and receivers. In general, it is assumed that imaging errors are due to inaccuracies of the Earth model, e.g. the velocity or the anisotropy parameters, although such errors could be also due to inaccuracies of the wave-equation used for imaging, data truncations due to aperture limitations, partial subsurface illumination, etc. Semblance analysis using CIGs constructed based on this procedure suffers from several drawbacks:

- For computational cost reduction, the CIGs are constructed at sparse horizontal positions, which prevents them from properly sampling the migrated images, especially in complex geologic settings;
- For analysis purposes, the image extensions are evaluated at all depths, which makes CIGs unnecessarily dense for analysis of typical band-limited seismic signals;
- For interpretation convenience, the CIGs are distributed on spatial grids that are not consistent with the features of the analyzed image, which leads to useless computation of extensions, e.g. inside salt bodies.;
- For historical reasons, the CIGs are constructed function of depth, thus being biased toward nearly-horizontal reflectors and less usable for steeply dipping reflectors.

One way to address this problem is to use extended common-image-point (CIP) gathers constructed at sparse and irregularly distributed points in the image. This approach allows us to align the CIPs with the geological structure and to construct them as densely in space and as sparsely in depth as necessary, thus reducing cost by avoiding unnecessary computations. Such CIPs can be constructed using wave-equation migration by preserving into the output image the non-zero space- and time-lags of the cross-correlation between the reconstructed source and receiver wavefields. This procedure can be employed regardless of whether the wavefields are reconstructed in time (as in reverse-time migration) or in frequency (as in migration by wavefield extrapolation), with single point sources or with many encoded sources, with isotropic or anisotropic wave-equations, etc.

When wavefields are correctly reconstructed, the extended CIPs are characterized by focused energy at the origin of the space- and time-lag axes. Otherwise, the energy defocuses from the origin of the lag axes proportionally with the cumulative velocity error in the overburden. This information can be used for wavefield-based tomographic updates of the velocity model using semblance analysis. Furthermore, if the velocity used for imaging is correct, the coordinate-independent CIPs can be decomposed function of the angles of incidence, thus providing information for AVA analysis. These properties are particularly attractive when imaging with wide-azimuth data which require cost-effective velocity analysis methods, as well as user-friendly methods for analysis of angle-dependent reflectivity.

The coordinate-independent extended CIPs are natural companions for reverse-time migration (RTM). In RTM, wavefield extrapolation is done with a two-way wave-equation which propagates waves equally well in all directions. Similarly, the CIPs characterize images at independent positions, which make them appropriate for reflectors that are arbitrarily oriented in space, e.g. vertical reflectors.

This talk summarizes the main properties of the coordinate-independent CIPs and explores their applicability to wave-equation seismic imaging and velocity model building.