Temporal and spatial aliasing in seismic signal processing

Temporal aliasing: Let us say we have a seismic signal that is a continuous function of time, which we wish to discretely sample. In general, many different continuous signals (aliases) can be represented by these discrete samples so that by convention, we choose the continuous function that exhibits the lowest frequency signal. If we sample the data too coarsely, we will reconstruct this lower frequency "aliased" signal rather than the desired higher frequency signal.

In many applications of digital signal analysis at Bell Labs, Nyquist and Shannon found that at least two samples per cycle of the highest frequency in the continuous signal are required for accurate reconstruction.

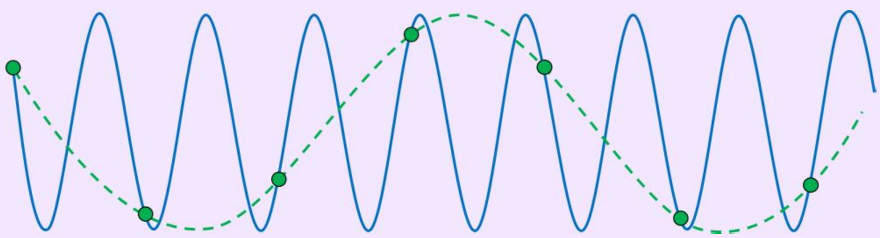

Figure 1: Sampling of a sinusoidal signal at greater than half its time-period and the resulting low-frequency dashed aliased waveform.

If the Nyquist-Shannon criterion is not followed, an undesired (aliased) lower frequency signal will be reconstructed. Figure 1 shows a sinusoid which is sampled at less than 2 points per cycle where the lowest frequency waveform represented by the green samples is indicated by the dashed line. Our desired higher frequency signal has been replaced by an alias.

In digital recording, the continuous signal is subjected to analogue anti-aliasing filters in the electronics before analogue-to-digital conversion, thereby removing undesirable high frequency noise whose lower frequency aliases might otherwise be mixed with the desired signal.

Spatial aliasing: occurs when the seismic wavefield is recorded on the surface of the earth with recording/sensing devices that are spaced too far apart. It also occurs if the source locations are too widely spaced. That is, if the propagating seismic waveform is measured at spatial intervals greater than half the wavelength of that waveform, it will be aliased. Because we measure seismic data on the surface of the earth, the Nyquist-Shannon criterion applies to apparent wavelength. Vertically traveling reflections have very long apparent wavelength along the earth's surface. In contrast, horizontally traveling ground roll has much shorter apparent wavelength (on the order of 10 m). Although we may consider ground roll to be noise and therefore not of interest, it must be properly sampled in order to filter it later in the processing workflow or it will be treated as a longer wavelength alias that overprints the signal. To avoid the cost of densely sampling the ground roll at 5 m spacing, geophone and source arrays provide an analogue filter that removes most of the wavelengths shorter than the array length prior to digital conversion.

Aliasing of dipping events occurs when the data are either temporally or spatially aliased. An undersampled reflector dipping steeply to the right will appear as a suite of shingled reflectors dipping gently to the left. Seismic processing will then incorrectly image the flatter dipping events perpendicular to the aliased dip (Figure 2).

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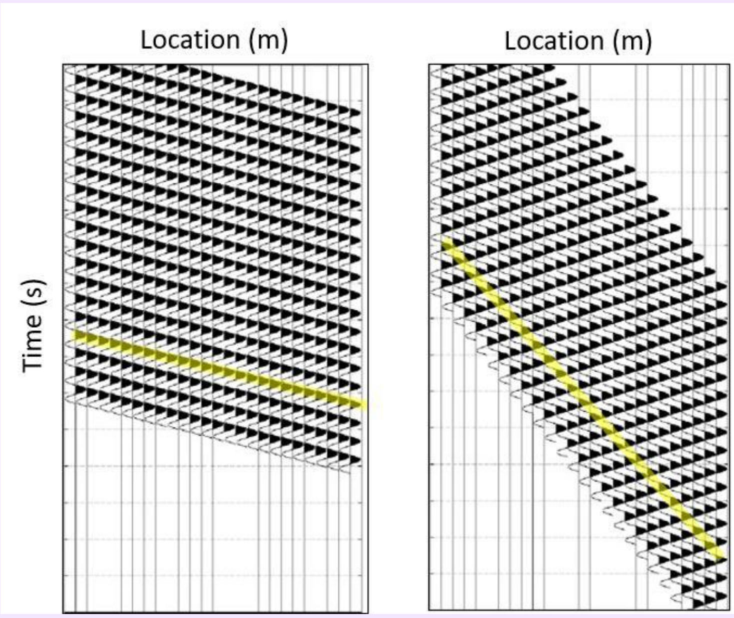

Figure 2. Aliasing in two dimensions. Both images show a suite of reflectors dipping to the right along the yellow trend. However, the human mind and computer processing algorithms will "see" the left-dipping alias in the image on the right image. In contrast, they will not "see" the steeply left-dipping alias on the left image. *(After Hatton et al., 1986).*

Because the earth is 3D, the Nyquist-Shannon criterion must be honoured in all three directions. Grids of 2D seismic lines are woefully aliased in the crossline direction, requiring the interpreter to use all their understanding of tectonic style and depositional processes to construct accurate structural maps and depositional fairways.

Migration operator aliasing: Even if the noise is suppressed and the signal properly sampled for the expected geological dips, we can still introduce aliasing when we image (or "migrate") the seismic data. In its simplest implementation, migration broadcasts each sample of a seismic trace onto an ellipsoid defined by the source and receiver locations, travel time, and velocities. Areas where ellipsoids from multiple source-receiver pairs constructively interfere will give rise to reflectors and diffractors. In all other areas, the ellipsoids will destructively interfere and result in a very low amplitude response. However, if the distance between the midpoints of adjacent source-receiver is greater than ½ wavelength (the Nyquist-Shannon criterion), the steeper parts of the ellipsoids will not destructively interfere, giving rise to steeply dipping migration operator aliasing artifacts overprinting your geologic image. *G*

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