Emerging Technologies

In the previous issue of the GSHJ, I reviewed progress made in attribute analysis during the past 40 years. Attributes such as coherence, curvature, and spectral components as well as attribute analysis techniques such as multiattribute color display are now available from multiple software vendors and commonly used in interpretation workflows. Other advances are being actively developed and may be considered to be prototype applications that need further development and evaluation to be more widely accepted.

While automatic picking algorithms are routinely used to accelerate horizon interpretation in large, good quality 3D volumes, picking of faults is more problematic. Most emerging workflows to address this problem are built on image processing technology applied to existing edge-sensitive attributes such as coherence. One of the earliest advances was the introduction of “ant-tracking” by Pedersen et al. (2002), which linked adjacent low-coherence events to form a mesh of discontinuities. Dorn and Kadlec (2011) introduced an alternative method that also provides volumetric estimates of fault probability, fault dip magnitude and fault dip azimuth. Machado et al. (2015) built on earlier work by Barnes (2006) and applied eigenvector decomposition to coherence volumes, mimicking the same kind of product (Figure 1).

Wu and Hale (2015) and Dorn (2011) go beyond simple 3D visualization of the faults and construct labeled faults (or fault “objects”), and then use horizon picks to unfault (an approximation to palinspastic reconstruction) the seismic data to better approximate the geology at the time of deposition (Figure 2).

Salt domes are another computer “object” that, if accurately defined, can be used not only in interpretation but in constructing more accurate velocity volumes for prestack depth migration. The most common implementation is to first compute one or more attribute volumes that are sensitive to salt, with coherence, RMS amplitude, and gray-level co-occurrence matrices (e.g. Gao, 2003) being common choices. Haukas et al. (2013) use level sets to accomplish this task (Figure 3). In simple terms, level sets fit an elastic surface to an irregular interior or exterior volume. A common example is the shrink wrap plastic around a six-pack of beer. A more sophisticated example is the medical stent used to repair a deteriorated artery. The physician threads a balloon covered with a mesh through the patient’s artery. The balloon expands until it reaches

Figure 1: 3D view of two vertical lines through a seismic amplitude volume and a box probe through co-rendered fault dip azimuth and fault dip magnitude showing polygonal faulting. The coherence, \( c \), after directional LoG filtering has been used to modulate the opacity, where voxels with \( c > 0.5 \) being rendered transparent. Planar features that are subparallel (< 25°) to reflector dip have been filtered out. (After Machado et al., 2015).

Figure 2: Images from Wu and Hale (2015) showing emerging fault analysis technology. Seismic amplitude co-rendered with (a) fault likelihood computed from edge detection attributes which are subsequently linked to generate (b) fault surfaces. Comparison of events about fault surfaces provides a means to estimate (c) fault throw. Given the fault location, orientation, and vertical throw, the seismic amplitude data are then shifted to generate (d) an unfaulted image. Each sub image displays (upper left) a time slice, (lower left) an inline, (lower right) a crossline and (upper right) a 3D perspective of the seismic amplitude data and fault attributes.
resistance from the artery walls. Finally, the balloon is deflated and withdrawn, leaving the mesh attached to the artery to strengthen it. The surface in Figure 3 is expanded slowly until it feels “resistance” from the more coherent sedimentary layers.

Other software developers are working on the “segmentation” (i.e. autopicking) of channel objects. Kadlec et al. (2008) used level sets. McArdle et al. (2011) used multiple spectral components to separate crossing channels. Key to this work is the choice of one or more attributes that differentiate the feature of interest. As an illustration, Wallet (2015) found that most-negative curvature provides an excellent means to delineate incised channels, offshore NW Australia (Figure 4).

Seismic data may be coherent or incoherent, where coherent primary reflectors are considered to be signal. However, incoherent, or noisy data can also represent geologic signal with faults and karst collapse being two common examples. One of the challenges in object extraction is then to differentiate from “geologic noise” and “seismic noise”. To this end, al-Dossary et al. (2014) introduced their “disorder” attribute (Figure 5) which differentiates between relatively planar discontinuities associated with faults and more random discontinuities associated with seismic noise (and more chaotic geology, such as mass transport complexes).

Human beings are excellent at pattern recognition such that even a novice interpreter can identify low amplitude, chaotic, salt domes on vertical seismic sections. While computers are excellent at voxel by voxel classifying, they do not see textures and might interpret the heterogeneity seen in the coherence image of Figure 6 as a mixture of coherent (white) and incoherent (black) facies. To precondition such facies classification, Qi et al. (2015) use not only the value of the attribute but also its standard deviation, mean, and median within a suite of overlapping analysis windows. By comparing these windows using a

Figure 3: Salt dome extraction using a level set technique. (Upper Left) After the seed point is chosen (yellow arrow), the salt boundary indicated by the pink surface begins to expand, much like a balloon. The balloon (Upper Right and Lower Left) continues to expand until it meets resistance of attributes defining the sedimentary layers, where it stops (shown as a green surface). (Lower Right) The portion of the fault surface that has reached its maximum extent. (After Haukas et al., 2014).

Figure 4: Object extraction of a system of incised channels using most-negative curvature: (Top Left) A zoomed image of seismic amplitude co-rendered with most-negative curvature. (Bottom Left) The histogram of most negative curvature where the yellow box defines values to be rendered opaque. (Right) The resulting 3D view of the incised channels. (After Wallet, 2015).

Figure 5: (Left) A vertical slice through a seismic amplitude volume, (Middle) the corresponding slice through coherence, and (Right) the corresponding slice through the disorder attribute. Note that disorder differentiates between planar discontinuities associated with faults delineated by coherence (geologic signal) and more random discontinuities associated with either chaotic geology or with seismic noise. (After al-Dossary et al., 2014).
Kuwahara filter commonly used in structure-oriented smoothing, they are able to both smooth and block the attribute volume, preconditioning it for future segmentation.

The Future

I predict we will see future improvements in algorithms, input (prestack) data, and calibration to geologic and engineering models that parallel the improvements between the past and present described in a previous issue of the GSHJ. However, there are three emerging technologies that will play a larger role in attribute analysis, two of which you read about in the daily newspapers and encounter in the marketplace, either online or in a traditional brick and mortar store. The first is the concept of “big data” where either “big companies” such as Google and Amazon or “big government” (Figure 7) are trying to identify patterns in your purchasing of geophysical textbooks or (hopefully not for the readers of GSHJ!) the sale of illicit drugs. Such pattern recognition and targeted marketing is everywhere, from your internet search engine, to your Kroger loyalty card, to the commercials that you receive on your cable television. We geoscientists will ride these innovations in “big data” analysis into the future to uncover hidden relationships between effective completion processes and surface seismic data (Figure 8). While I do not think “machines can think” I do think that they can be taught to mimic a skilled interpreter, thereby allowing us to analyze ever larger multiattribute, multiazimuth, and multiangle data volumes. Artificial neural networks are well established in our industry, allowing us to construct and then validate relations between well and seismic measures. Figure 9 shows a recent implementation of a support vector machine algorithm, which by converging to a unique answer removes some of the uncertainty in neural networks. Many other clustering and manifold mapping algorithms are under development, including Gaussian Mixture Models, Self-Organizing Maps, and Generative Topological Maps to name a few.

The second major innovation is increased interactivity. I now have as many unused digital buttons on my Smart TV as I had unused physical buttons on my betamax recorder. The optimum choice of seismic attribute algorithmic parameters depends on the target geologic feature and the input data quality. Choices made in spectral balancing or structure-oriented filtering impact the choices made in subsequent coherence and AVAz computations. Traditionally, one computes one attribute or filter and feeds the output into a second attribute or filter. Clever (or maybe just patient) interpreters might crop a larger...
survey about a key vertical or time slice for subsequent parameter testing. At least one software provider captures this idea with a “virtual” attribute. Parameters are defined and the attribute computed on enough data to produce the currently displayed output slice. Thus, an attribute like coherence may use 11 adjacent amplitude time slices to output a single output coherence time slice. This concept can be generalized to link more than one process.

In Figure 10, we first define a Gaussian structure-oriented filter by a standard deviation of 1.5 samples in each direction. Let us assume the Gaussian is truncated after 3 samples in any direction. Then the coherence (variance) computation uses a ±7 (for a total of 15) samples in the vertical direction. Thus, to evaluate our choice of parameters on a key time slice, we only need to compute intermediate results on at most ±7±3=±10 time slices, not the entire volume. It is natural that future extensions will allow on-the-fly attribute computation about picked horizons, stratal slices, fault planes, and even Wheeler slices.

In Figure 9, Applied Neural Networks is the most popular supervised learning technology in the geophysical environment. Recently, workers have evaluated a competitive technology called support vector machines. In this application, the data in four-dimensional attribute space (P-impedance, S-impedance, Poisson’s ratio, and μ/λ) are mapped into a still higher 10 dimensional space with the goal of defining hyperplanes that separate the different clusters. Here Zhao et al. (2014) broke the brittleness index measured using electron capture spectroscopy and gamma ray logs into a 10 cluster template against the four elastic attributes measured in the log, and then applying the template to the four 3D seismic data volumes. (Data courtesy of Devon Energy).

Much of seismic interpretation involves repetition of the same key steps, usually involving software packages provided by different vendors. While seamless integration...
of software provided by competing companies is infeasible, linking them by capturing and then modifying the data files needed to run them is. Figure 12 summarizes a variation of this methodology implemented by Bellman (2014) and colleagues at Canadian Discovery. In this example, a skilled interpreter has completed a prestack inversion and rock properties prediction of brittleness for a shale resource play where the key parameters have been recorded. Then a new well comes in with a dipole sonic log. There were few dipole sonic logs available previously, so the background low frequency impedance model needs to be updated. This new impedance model results in a new prestack inversion for elastic parameters. Given this new information, the crossplot template may need to be manually updated by a petrophysicist, but once done, the entire 3D volumetric brittleness prediction incorporates the new information.

This leads me to the third and final “innovation” of the digital age – hacking. As a former user of both Target and Home Depot credit cards, I am now quite sensitive to unscrupulous people watching all my financial transactions. Figure 13 shows some of the “key logger” software packages that can easily be found on the web. Software key loggers are likely installed in your workplace by your IT folks to monitor data copying activities. Hardware key loggers can be plugged into your key board as it enters the computer (or over an ATM keyboard if you are not paying attention). Nastier people use acoustic and electromagnetic key loggers that can monitor your key strokes from 50 ft away.

But wait! Key loggers might have a positive side! Think of a seismic inversion problem, where the goal is to link surface seismic data to rock properties. Unlike the images shown in Figures 10 and 11, the software you use is probably from multiple vendors, perhaps starting with a processing package, a well tie package, an interpretation package for horizon definition, a well log property crossplot package, a seismic prestack inversion package, back to the crossplot package and finally into the interpretation package, perhaps with Excel spread sheets thrown into the mix. Now let us assume every key stroke has been recorded (including the bad ones followed by their corrections). If so, a new piece of information may be able to update your model automatically. I predict that key-loggers will further the vision held by Bellman (2014) and her colleagues shown in Figure 12.

Figure 11: A modern workflow linking AVO responses to perturbations in the velocity model. This example from Headwave uses very fast graphical processor units. Another vendor uses large compute clusters. Like the previous “Virtual” attribute computation developed by Schlumberger, this one is smart enough to know which part of the output data are influenced by a given input parameter – in this example by a perturbation to the velocity that flattens the local events that generates a new AVO response which fits into the crossplot and is displayed as an updated AVO attribute display. Example courtesy of Headwave.

Figure 12: During the 2014 CSEG conference on unconventional reservoirs, Laurie Bellman of Canadian Discovery summarized their software effort to link heterogeneous applications to provide easy model updating and sensitivity analysis. A typical unconventional reservoir workflow includes multivendor programs, say ProMAX for processing, Strata for prestack inversion, Petra for log analysis, and Excel for crossplotting. Once the links are created, one can modify a parameter in the early part of the flow (say, the availability of a new shear sonic log) that subsequently updates both the rock physics template and the background impedance model. In this image, the inclusion of the new well log updates the volumetric brittleness prediction. In her presentation, Bellman showed how changes of 5-10% in the background velocity model showed that brittleness estimates in the Otter Creek formation were unchanged, while two other formations changed significantly, and thus were higher risk. While “seamless” integration is the goal of most of the larger software providers, most interpreters would prefer to mix and match software products they think are best.
us infer features that either fall below seismic resolution, or are so subtle that they are easily overlooked?

Through improved software linkage, interpreters will modify base-line processing parameters such as velocity and horizon picks, limit azimuth and incident angle ranges, and even modify deconvolution filters to analyze the impact on the attribute expression of a given geologic feature. “Object” extraction will grow beyond extracting fault planes, autopicking horizons, and encapsulating channels. Rather than geostatistically describe channel orientation and sand fairways, the linkage of cluster analysis and level sets to geobody tools promises to semi automatically and deterministically define highly reworked fluvial-deltaic and deepwater systems to include in reservoir simulators.

Attribute cluster and statistical analysis will grow the fastest, with attributes linked directly to risk analysis to high-grade drilling and completion decisions. I predict that an interpreter will be able to interactively add and subtract attribute volumes to determine which combination of attributes differentiate a given facies of interest, say diagenetically altered chert from the encompassing tight limestone. Major innovations will be financed by needs in marketing and security, with geophysicists benefiting from technology advancements as we did with the rapid rise of computers during the 1970s and 1980s. Correlations of reservoir completion to attributes will be statistically rather than model driven, with automatic updates of the correlations as new wells come in.

Most of all, we will have fun!

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References