

Data Whitening Enhances 3-D Imaging

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HOUSTON—A new approach to data whitening is enhancing 3-D imaging and improving the structural interpretation of geophysical data by extending the usable bandwidth of the seismic spectrum into the higher-frequency domain without introducing noise or amplitude and phase distortions.

Data whitening is a familiar concept in data processing. The idea is to “flatten” the spectral content of the data across the entire bandwidth so that all frequencies are represented more or less equally. Numerous algorithms have been developed over the years to whiten the data sets used in all types of processing applications, not only geophysics. However, in the case of 3-D seismic, higher frequencies (above 80 Hertz) are typically lacking—or at best, badly distorted by noise—in data sets acquired by conventional surface-based surveying methods.

High-frequency data are recorded with acceptable signal-to-noise ratios when geophones are placed down a well bore because the instrumentation is located in close proximity to the geology. But in acquisition programs using geo-

phones deployed on the surface, it becomes difficult to capture the high-frequency components of the seismic waveform because of the distances the reflected signals have to travel before reaching the receivers. Essentially, higher frequencies are absorbed in the earth as they travel through the subsurface, and the high frequencies that do get recorded can be so noisy and distorted that they are often rendered useless.

That is a problem, of course, because the higher the frequency content of the seismic data, the greater the resolution and the more accurate the final image of the subsurface becomes for delineating structure and resolving critical reservoir questions. In response, whitening technology has been developed that broadens the bandwidth of the frequency spectrum by manipulating certain attributes one trace at a time to build higher frequencies, even when the input data contains no usable frequencies above the 0-70 Hertz range.

Rather than trying to amplify weak recorded high-frequency signals, the method uses attribute information contained in the low-frequency domain to predict higher frequencies, thereby extending the bandwidth to enhance structural continuity, boost resolution, and op-

imize amplitude and phase consistency without introducing noise and distortion.

Unraveling Higher Frequencies

The lower frequencies on the spectral bandwidth generally travel through the subsurface relatively unattenuated with reasonably good signal-to-noise ratios. But higher frequencies tend to get lost, which means the geophones on the surface end up recording lots of noise and little signal at the higher end of the frequency spectrum. In fact, it is often impossible to unravel higher-frequency signal because there simply is no signal to work with. This is particularly true for imaging deep structures because the more distance seismic energy has to travel, the greater the loss of high-frequency signal.

Conventional whitening and deconvolution algorithms used in seismic data processing are generally limited by the signal-to-noise ratio at any frequency. These techniques essentially change the relative amplitudes of the high and low frequencies, boosting the higher frequencies to match the signal strength of the lower frequencies. In this way, the overall shape of the frequency content is changed, but not the signal-to-noise associated with a particular frequency.

One way to think about the 3-D data spectrum is to compare it to an FM radio signal. If the signal is strong, the listener will have no problem adjusting the bass (low frequency) or treble (high frequency) controls to make the output sound either brighter or darker. But if there is a lot of static affecting only the higher frequencies in the radio broadcast, the lower frequencies will come through loud and clear, yet turning up the treble control may not be pleasing to the ear because it will amplify the noise along with whatever signal is available.

A key issue in seismic processing has long been how to enhance high-frequency content without increasing noise across the entire band pass. While the spectral content can be manipulated so that all frequencies have the same contribution, unless the signal-to-noise ratio of the weaker high frequencies is changed, boosting high-frequency amplitudes relative to lower frequencies effectively magnifies noise—just as turning

FIGURE 1

Normal Seismic Data Set (All Frequencies)

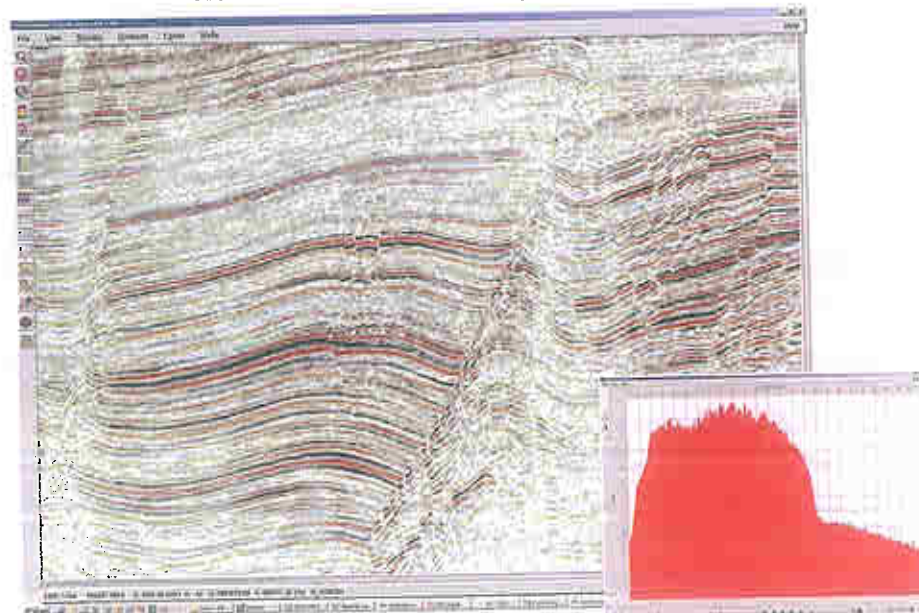




FIGURE 2A
Normal Seismic Data Set (Frequencies >80 Hertz)

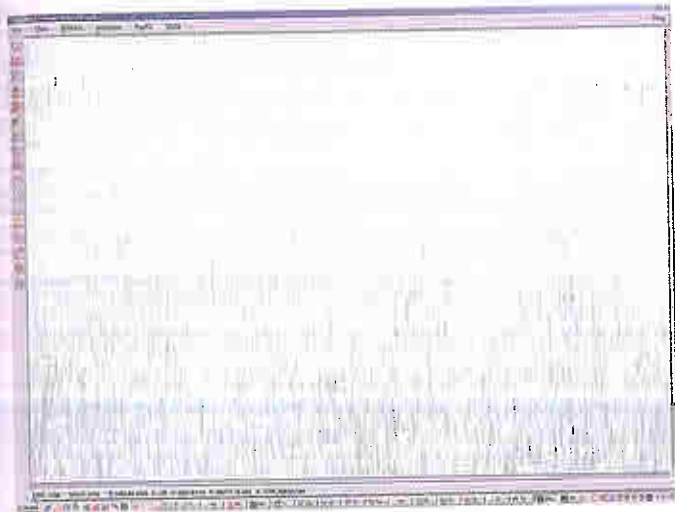
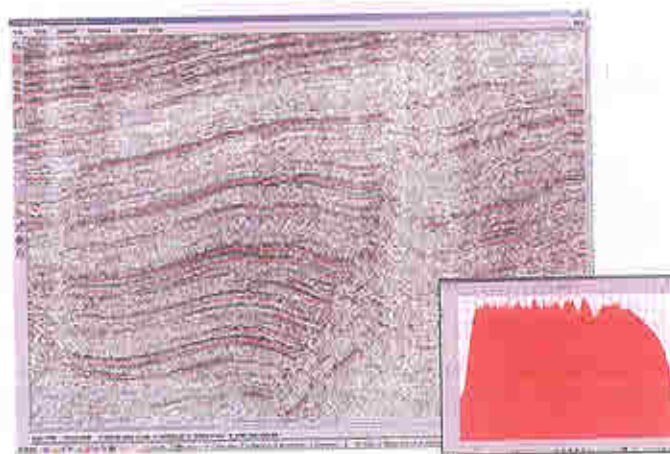


FIGURE 2B
Conventional Spectral Balance Data Whitening



up the volume on a weak radio signal increases the static background.

In some cases there are virtually no high-frequency amplitudes to boost. Figure 1 shows an image using all frequencies of a marine data set recorded in the Gulf of Mexico. Figure 2A is the same data set, but it displays only data above 80 Hertz. There is almost nothing there.

Can the high-frequency content in this data set be boosted using conventional data whitening methods to match the amplitude content below 80 Hertz? Figure 2B shows the data after running a spectral balancing algorithm. Although the spectrum looks much flatter into the higher-frequency range, increasing the relative contribution of the higher frequencies does not improve the image. In fact, it only makes it noisier and more complicated to interpret.

Manipulating Attributes

Attribute inversion is commonly used in processing and interpretation to emphasize subtle changes in the seismic wavelet that can reveal underlying information that is not immediately apparent, but is nevertheless present in the data. In this same way, the seismic data bandwidth can be broadened to predict higher frequencies by manipulating select attributes—coherence, instantaneous phase, inverted volumes, etc.—that are not constrained to the same bandwidth spectrum as the seismic data input for processing.

For example, Figure 3 shows a horizontal time slice on the left and a coherence

slice on the right of the same 3-D data set. In this case, the coherence attribute not only reveals details that were not obvious in the 3-D time slice, but importantly, the two images have quite different spatial frequency contents. The spatial bandwidth has changed in the coherence slice because this attribute has a higher spectral bandwidth than the input data.

Using attributes that have different effective bandwidths for a given seismic wavelet—including both higher and lower frequencies—temporal variations in the wavelet can be inverted to broaden spectral content. Similar to coherence techniques, which take advantage of spatial variations in seismic data, the technology involves transforming the data to a se-

FIGURE 3
Horizontal Time Slice versus Coherence Slice

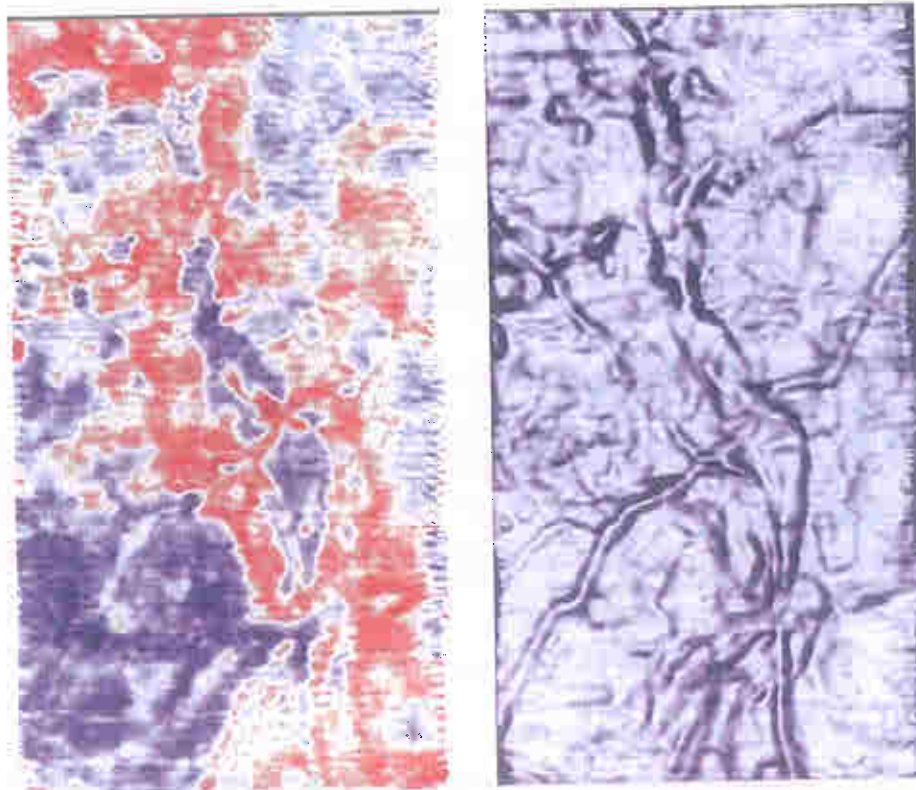




FIGURE 4A
Instantaneous Phase Attribute Data
(Frequencies >80 Hertz)

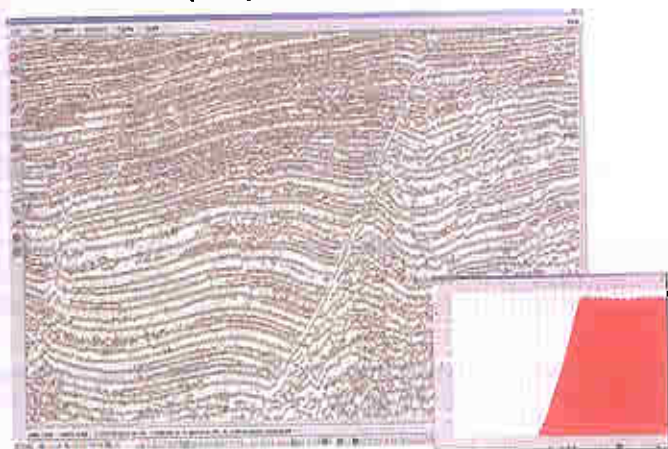
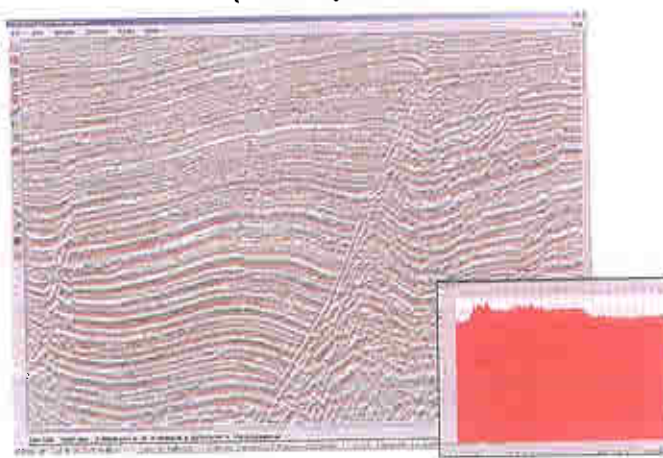


FIGURE 4B
Instantaneous Phase Attribute Data
(All Frequencies)



lected attribute space, manipulating the attribute to emphasize information outside the original bandwidth, and then performing an inverse transform to calculate each frequency of the output from all the frequencies of the input. The result is a broader bandwidth that provides high-frequency content without introducing noise or altering the low-frequency spectrum.

Figures 4A and 4B are examples of the spectral content in the instantaneous phase attribute. Figure 4A contains instantaneous phase data greater than 80 Hertz. It certainly looks like signal; high-frequency signal that can be inversely transformed back into the processing sequence. Figure 4B displays all frequencies of the instantaneous phase attribute from the same data set shown in Figure 1. There is an obvious resemblance between the two images,

but the spectrum of the instantaneous phase data is nearly flat. It clearly contains much more usable bandwidth.

Calculated Trace By Trace

Multiple attributes can be derived from a single data trace, and they are “local,” requiring reasonable computational effort to perform the transform. The attribute is calculated trace by trace, so that the information related to one seismic trace is unrelated to information from any other trace. When the inverse transform information for adjacent traces looks similar even though it has been calculated independently, it provides a good indicator that the output is related to signal, and not to random noise.

The process requires little parameterization, and is a short-duration time op-

erator, meaning that the information calculated at any particular time correlates only to the signal that was input at that time. Whitening methods such as deconvolution look at either the entire trace, or a substantial portion of the trace, and broaden the spectrum to output a new trace, with the output at any given point dependent on a large portion of the input trace. This is important, because in a seismic data set, there may be good high-frequency signal in the shallower section, but the higher frequencies may have been lost in the deeper part of the seismic trace.

Figure 5 compares the same seismic section as originally input and after inversely transforming select attribute data contained within the low-frequency band pass to broaden the bandwidth. The frequency content clearly has been increased and seismic events are delineated in greater detail.

The real acid test for any seismic technology is tying the data recorded at the surface to information obtained from the well bore. Figure 6 compares well log data (the three tracks on the left) with actual and predicted seismic traces (the three tracks on the right). The blue seismic track shows a synthetic seismic trace (repeated) generated from well log data. The red seismic track represents the trace that is closest to the well location, replicated over and over. The actual seismic data are shown in the black track. There is a strong correlation between the well data and the predicted/actual seismic measurements using higher frequencies generated by whitening the data to broaden the spectral bandwidth.

FIGURE 5
Seismic Section Before and After Bandwidth Broadening

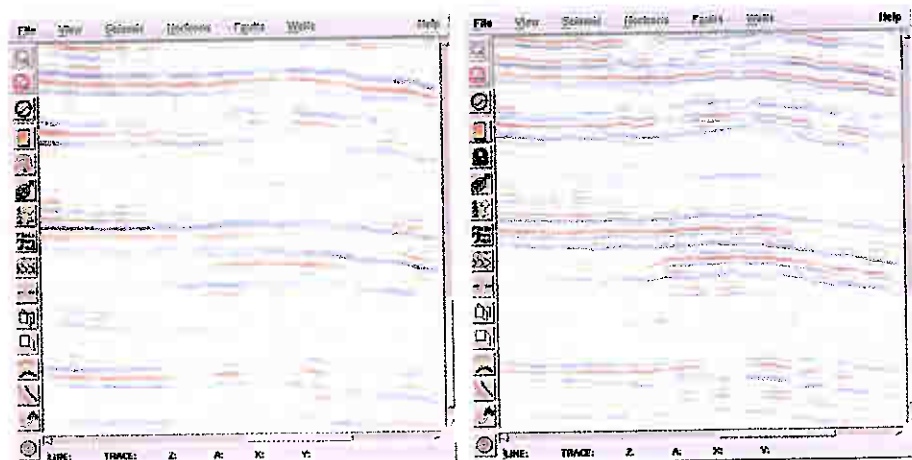
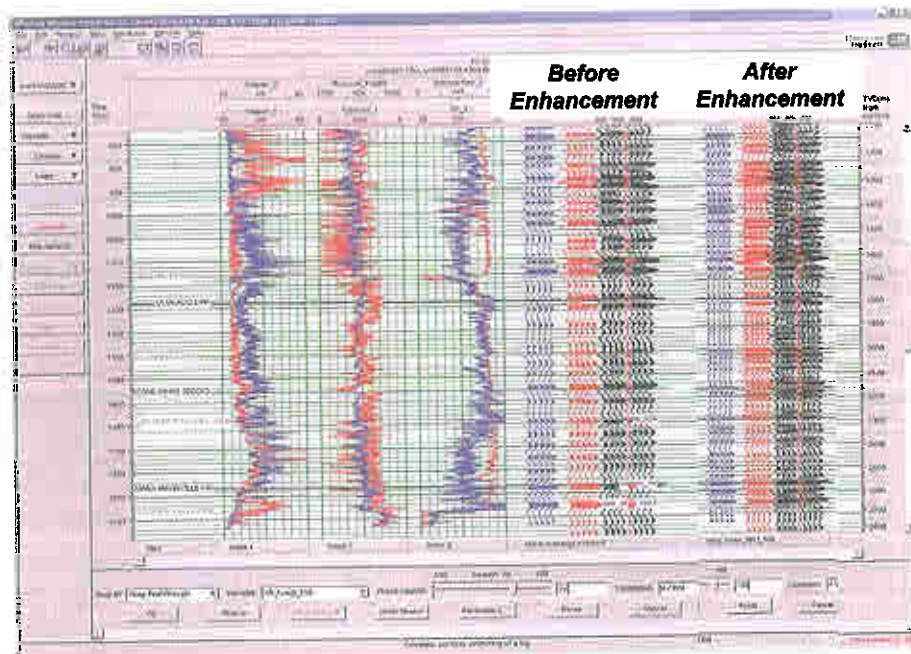




FIGURE 6

Well Tie Example



Potential Applications

Data whitening is normally applied late in the processing sequence, but bandwidth broadening also could be performed in the early stages of processing. The algorithm can be run on legacy data as well as new

data sets, although it should be noted that the technology is not a substitute for acquiring higher-fold, higher-frequency data. Like any other processing algorithm, the results will be better when used with higher-resolution data with good signal-to-noise

ratios across the frequency spectrum.

The technology is more helpful in some imaging applications than in others, but there are few areas where bandwidth broadening does not have a role to play. A case in point is any sort of thin-bed geologic play. Conventional seismic techniques are adequate for identifying large hydrocarbon structures, but many plays today target smaller and much more subtle features—often only a couple feet thick. The broader the bandwidth and the higher the frequency content, the easier the interpreter can distinguish thin pay sands from surrounding features on the final 3-D image.

Figure 7 shows seismic data of a pinch-out feature before (left) and after (right) whitening to broaden bandwidth. A fault line is visible in both images, running vertically nearly all the way through the section. However, the whitened image better distinguishes the events to the right-hand side of the fault. In the original data, it is difficult to see that these events are separate, but come together and pinch out just before the fault.

Deep and unconventional resource plays also are good application candidates. In imaging deep targets, the percentage of high-frequency signal loss increases with wavelet travel time and



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Craig Beasley is chief geoscientist for WesternGeco and a Schlumberger fellow. He is a past president of the Society of Exploration Geophysicists, and has received two Litton Technology awards, including the Charles B. Thornton Medal. After completing his B.S., M.S. and Ph.D. in mathematics, Beasley joined Western Geophysical 1981. He has held computer sciences, research and development, and data processing positions, including worldwide vice president of R&D and worldwide vice president of data processing at both Western Geophysical and WesternGeco.



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depth. Bandwidth broadening technology already has provided rather dramatic results in the Gulf of Mexico and elsewhere that demonstrate its potential to enhance deep structural images.

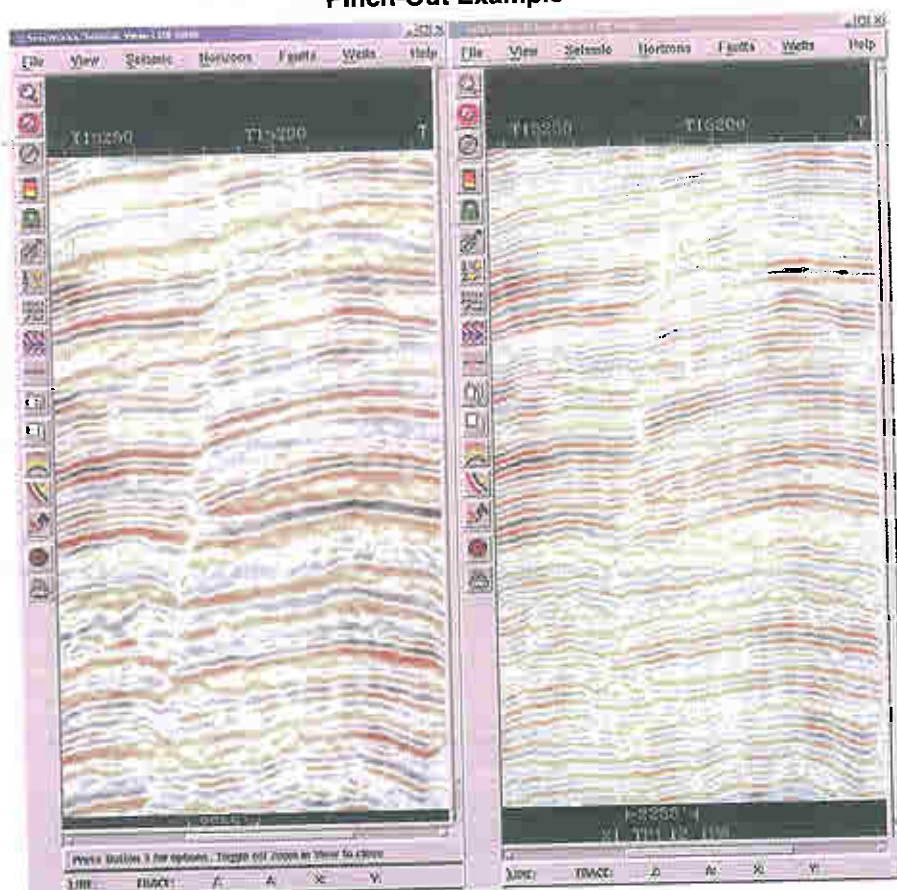
In unconventional resource plays, the ability to increase resolution to image subtle details such as natural fractures, low-relief faults, thin beds and stringers can be very valuable when it comes to selecting drilling locations and planning horizontal well paths.

In practical terms, the interpreter's work focuses on the character of the seismic wavelet, and how the attributes of that wavelet change in very subtle ways in a 3-D reflector or on a 2-D horizon. These character changes provide all sorts of information about the properties of the reservoir rock, and sometimes even fluid content.

Analyzing the right attribute can improve the interpretability of features that are not immediately obvious because of limited frequency bandwidth. Using key attributes with frequencies outside the useable signal-to-noise range to broaden bandwidth and take advantage of temporal variations enhances the interpreter's ability to perceive subtleties in the data and make more accurate interpretations. □

FIGURE 7

Pinch-Out Example



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