High visual resolution interpretation: The case for virtual seismic reality

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Abstract

The twin fields of virtual and augmented reality have revolutionized the gaming and entertainment industries; however, they have had almost no impact on the field of scientific visualization. This is especially true in oil and gas exploration where we continue to visualize seismic data using low visual resolution displays developed in the 1960s and 1970s. Variable density and grayscale displays were a revolution in themselves, allowing us to transition from strictly manual interpretation on paper sections to increasingly automatic interpretations on workstations. This transition was instrumental in allowing us to find the oil necessary to meet the demands of emerging economies. These displays have brought us this far, but they cannot take us into the future. Today, we are exploring for targets whose seismic expression is close to the limits of spatial and temporal resolution and may be below the visual resolution of conventional seismic displays. If we are to meet the current demands of developed economies and the increasing demands of emerging economies, we must replace these, now technologically archaic, low visual resolution displays with high visual resolution displays. For that, we need virtual reality. At its inception, virtual reality was largely ignored by the exploration industry. Today, it has evolved to the point that it could revolutionize scientific visualization, and seismic visualization in particular, as much as it revolutionized gaming and entertainment. I introduce the subject of high visual resolution interpretation and present examples of seismic data in virtual seismic reality.

Tales of the Mongolian gerbil

"Conventionally, we consider that there are two principal forms of resolution; temporal which is the ability of the seismic wavelet to resolve reflections (in time) from thin beds and spatial which is the ability of the wavelet to resolve closely spaced geological details. It is a principal theme of this dissertation that there is a third form of resolution, namely visual resolution, that if ignored and not understood can have a significant negative impact upon seismic resolution." (Lynch, 2008)

If you are honest, there will always be moments when you question your direction in life and your sanity. One such moment came for me in the late spring of 2008.

At the time, I was collating the references to my recently completed PhD thesis, a 500-page dissertation called "More than meets the eye — A study in seismic visualization." In my research, I had traced a photon from the time it enters the eye as far into the visual system as we could go at the time. I did that to discover how primates and humans, in particular, form visual perceptions.

As I was collating my references, I noticed that only a handful of them were geophysical. The rest were on subjects such as molecular biology, primate and mammalian evolution, neurophysiology, and other subjects disparate for a geophysicist. This incongruity did not affect me until I came to one particular reference — "Cones in the retina of the Mongolian gerbil" (Govardovskii et al., 1992). I will forgive the reader for not having read that paper. You are probably still engrossed in the author's previous blockbuster "Cones in the retina of the Siberian rat."

What, I asked myself, did a study of the visual acuity of an Asian rodent have to do with seismic interpretation, which ostensibly is what my thesis was about? I had a moment of panic and almost hysteria as I questioned whether I had just wasted five years of my life chasing a rabbit down a hole from which there was no exit.

This is all by way of an introduction to the novel subject of high visual resolution interpretation (HVRI), and it serves as a warning that there is very little familiar in what is to follow.

Although HVRI is a complex subject theoretically, in practical day-to-day terms it is remarkably simple. What it involves is replacing low visual resolution (LVR) displays like that in Figure 1 with high visual resolution (HVR) displays like that in Figure 2.

In its simplest form, an HVR display is a three-dimensional surface with seismic amplitudes forming the terrain. HVR displays are a new way to visualize and interact with seismic data. They are constructed, visualized, and animated, in real time, using the same virtual and augmented reality techniques originally developed for gaming. And they are the first significant improvement in seismic visualization in more than 40 years.

The goal of an HVR display is to produce an ultra-high-resolution seismic image of the subsurface. As such they are complementary to such techniques as full-waveform inversion (FWI), spectral extrapolation, and other modern techniques that push the bounds of what we thought was possible with seismic imaging.

Although the goal of an HVR display is identical to that of other seismic techniques, unlike them it does not intrinsically change the data in any way. Improvement in resolution does not come from improving the seismic data but from recognizing that the seismic display itself acts as a filter. HVR displays do not add information, they simply remove less of it.

Behind HVRI is the realization that the ultimate clarity of our seismic image is the product of two equally important but separate processes. The first is how well our seismic data image the geology. This is the home of our familiar spatial and temporal

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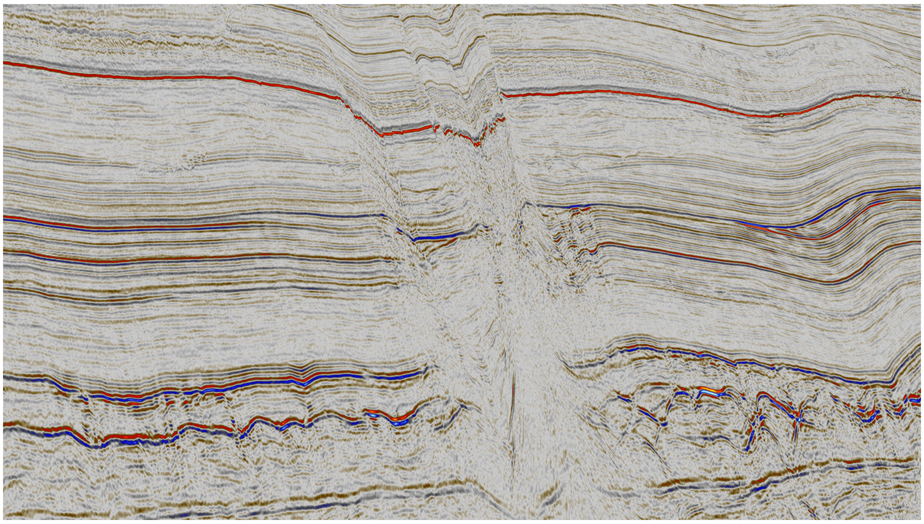

Figure 1. A conventional LVR variable density display of line 47 from the UK NSTA's Mid North Sea High survey.

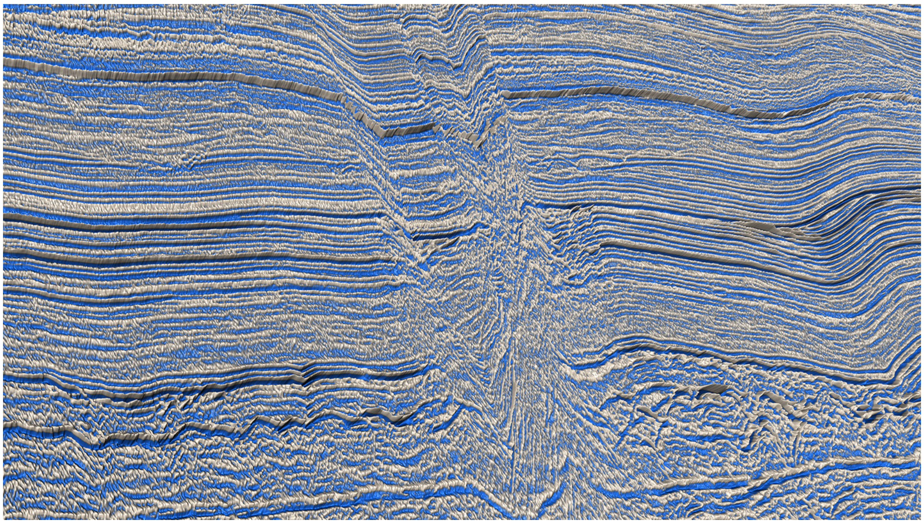

Figure 2. An HVR display of the data shown in Figure 1. An HVR display is a 3D surface with seismic amplitudes forming the terrain.

resolution. The second, less familiar but equally as important, is how well the display images the seismic data. This is the province of visual resolution and, as heavily researched and developed as the processes of spatial and temporal resolution are, beyond my own work, the processes behind visual resolution have hardly been studied at all.

HVRI is an almost virgin subject. It introduces a third form of seismic resolution and a new direction for research. As such, it suggests a potential to improve our understanding of the subsurface as much as migration and deconvolution did. But to reach that potential, geoscientists must be willing to look at seismic data from a completely different point of view.

Exploration seismology is a visual science. Its value is only established through observation. It does not matter what information is present in the seismic data themselves. What is important is the subset of that information that you directly see at a given time. If there are details in the seismic data that you cannot observe in the display, then those details might as well not exist. More importantly, you have no way of knowing that they do exist.

You can only see what you can see, and you cannot see what you cannot see. This is one of the reasons seismic visualization has not been heavily studied. If I show you something and then take it away, you will probably demand it back. But if I do not show it to you at all, then where is the motivation to go looking for it?

For reasons partly personal and partly professional, I was gifted a brief glance of those things we could not see. That brief glance was enough to suggest to me that we have barely scratched the surface of what seismic data can tell us about the subsurface. It gave me the motivation to study visualization as a science and has led, ultimately, to the development of HVRI.

HVRI is based on the definitions of both visualization and resolution. Visualization is often defined as "the act of achieving a complete visual impression of an object." Resolution is often defined as "the process or capability of making distinguishable the individual parts of an object." The two definitions are similar with the definition of resolution seeming to be a refinement on that of visualization. Beyond the definitions is a planned series of papers to answer four questions:

1) How do we form a visual impression?
2) What is the object we want to form the visual impression of?
3) What are its individual parts?
4) How do we, or even can we, distinguish them independently?

This paper is the result of more than 20 years of research into seismic visualization. As I began writing it, I was faced with the difficulty not of knowing what to write but what to write first. Obviously, I cannot answer or even consider all four questions in a single paper. So, where to begin?

I decided to start at the beginning, discussing first the historical development and importance of variable density and grayscale displays. Following that, I will introduce the subject of virtual reality, its importance, and its historical relationship to seismic visualization.

As for the Mongolian gerbil, it may seem out of place in a geophysical PhD thesis. That said, the common Mongolian gerbil, one that you can find in any pet store, has one of the highest visual acuities of any mammal. And visual acuity is critically important to the subject of visualization.

Figure 3. A stacking velocity display with the color boxes representing the velocity.

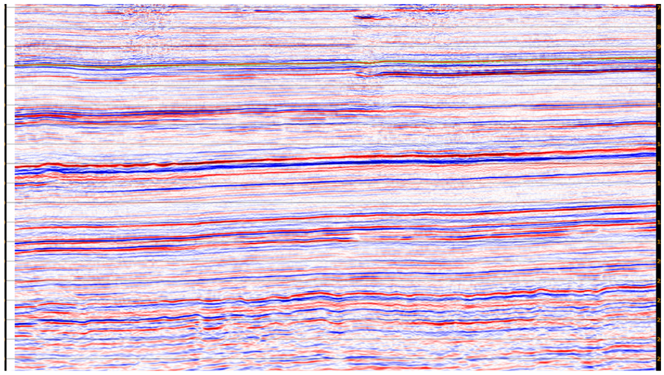

Figure 4. A modern representation of my original variable density display circa 1979. I used the now familiar red, white, blue pallet only because red and blue are at opposite ends of the visible spectrum and thus are visually distinct.

The origin and importance of variable density and grayscale displays

Exploration seismology is a visual science, but visualization is a moribund subject and has been for decades. Today, we are investing in technologies such as FWI, spectral extrapolation, and artificial intelligence. We see value in researching those fields and others like them. However, we do not perceive the same value in researching visualization, even though, as I will argue here, our initial research into visualization was one of the most significant technological advancements of the 20th century. And I had a part to play in it.

I began my career in September 1977 in the processing division of Gulf Canada Resources. At the time, Gulf used a program called CCVA to produce an automatic velocity analysis every two common-depth points. In 1979, I used an Applicon color drum plotter, the first commercially available large-scale color device, to produce a stacking velocity display like that in Figure 3. The color represented the stacking velocity, and the display turned out to contain a tremendous amount of previously unobservable information. The display proved popular among the interpreters, and later that year I was asked to present it at an internal Gulf symposium in Houston. From there, it made its way to Western Geophysical, which patented it under the name Shadcon. This is one of the earliest examples of color being used to present seismic information, albeit derived information. I got the idea of using color from the groundbreaking paper by Tanner et al. (1979).

Excited by the potential of color, I then produced a very early version of a variable-density display. It looked similar to the one in Figure 4. I used red for positive amplitudes, blue for negative amplitudes, and white for the zero crossing. I chose red and blue because, being at opposite ends of the visible spectrum, they were visually distinct. I was unaware of any theoretical reason for the choice; I just tried various combinations, and red and blue seemed to work best.

I had great hopes for this new display, but the interpreters at Gulf were less than enthused. Because the drum plotter had a limited extent, the display had a necessarily compressed horizontal scale. The interpreters weren't used to it, and they didn't like it. They also complained that the display lacked any sense of character and was visually little more than a square wave display. I left Gulf soon after, and to the best of my knowledge, although the velocity analysis display continued to be used, the variable density display quickly fell out of favor.

The paper version of the display was unpopular and rarely used. The display itself, however, and its companion grayscale display, developed by Amoco in the mid-1960s (L. Lines, personal communication, 2007), evolved to become, in my opinion, one of the most important, if unrecognized, technological developments of the late 20th century.

To understand why, consider that when I produced my early variable density display, the world consumed approximately 60 million barrels of oil per day (bpd). Most of that oil had been found either from surface geology or analog seismic data. Oil demand, however, began to increase as new economies came onstream. Global oil consumption began an inexorable rise that has, over the past four decades, averaged approximately 1 million bpd per year. Variable density and grayscale displays were a critically important development as it is highly debatable if we could have met that demand using paper wiggle trace displays alone.

The movement from manual interpretation using paper displays to increasingly automatic interpretations on computers was instrumental, in my opinion, in meeting the world's insatiable demand for oil. Variable density displays and grayscale displays made that transition possible because, without them, we could not have interpreted seismic data using the CGA and VGA resolution monitors of the time.

I do not claim to be the first to develop variable density displays. Given how simple and obvious they were to produce, I'm sure that others were doing the same thing. They are also, obviously, not the only reason we were able to meet global oil demand. However, in my opinion, these visually simplistic displays, virtually unchanged and still in use today, deserve their place in history. They were a revolution at the time, unwanted and a step backward in many ways, but forced upon us by technological necessity. They freed us, however, from the restrictions of paper, a freedom that was essential a few years later when we developed 3D seismic surveys.

The origin of virtual reality

Virtually everyone today is familiar with the revolution in entertainment and gaming brought about by the development of virtual reality. Given how progressive the exploration industry is and how quickly it adopts new technologies, it is surprising that virtual reality, the foundational technology behind HVRI, has had almost no impact on seismic interpretation.

Virtual and augmented reality are hardly new subjects, having been around for almost a generation. Even so, we still interpret seismic data using displays that are the equivalent of 1930s hand-drawn cartoon images. With all the technologies we have adopted over the past 50 years, why is virtual reality, a technology that we obviously should use, the outcast that we never use? There is an explanation, and I believe we need to understand it before we can move on.

I was born in 1952, long after society had been revolutionized by the internal combustion engine. It is hard, therefore, for me to understand what life was like for people who lived before that revolution. Similarly, many of you reading this would have reached intellectual maturity after the incredible revolution brought about by virtual and augmented reality. It is hard, therefore, for me to give you a sense of where technology was in 1979, long before the birth of virtual reality, when I produced my first variable density display.

To get a sense of it, watch the movie Alien that was released in 1979. The movie is set aboard a spaceship thousands of years in the future. Focus on how the characters in the film communicated with their computer. They communicated with it using a teletype-like device, asking questions with a keyboard and receiving text-based answers complete with sounds similar to that of a dot matrix printer. This was our vision of computers thousands of years into the future in 1979.

Figure 5. A recreated scene from the movie Toy Story released in 1995. Each frame of the movie contained up to 2 million triangles and took up to 40 hours to render on a Sun workstation. Credit Willrow Hood — stock.adobe.com

The point is that in 1979, today's multi-teraflop graphic cards and ultra-realistic virtual and augmented realities, were beyond the realm of science fiction. Nobody, and that includes scientists, technologists, and science fiction writers, had any idea of what was coming.

To understand why, consider how virtual reality is created. Figure 5 is a recreated image from the movie Toy Story and will be, I suspect, familiar to most of you. Despite their realistic nature, the characters are constructed from hundreds of thousands of tiny little triangles. Virtual reality objects are all constructed from tiny little triangles. The more triangles there are, the more realistic the scene.

I am using Toy Story as a reference because it marked a watershed moment in computer graphics and virtual reality. Released in 1995, it was the first entirely computer-animated feature-length film. Each frame of the movie contained up to 2 million triangles. The movie itself was rendered on 117 Sun workstations running 24 hours a day. Each frame took on average two hours to render at 1536 × 922 pixels. The movie required 800,000 machine hours to complete.

To go from IBM 360s and palette-based, dithered-color, drum plotters to Sun workstations and high-resolution computer monitors took several generations of hardware and software revolutions. Toy Story was (Buzz) light years ahead of anything we could do in 1979, and you may wonder why the exploration industry, always desperate for innovative technologies, completely ignored the technology behind it.

The reason is that the technology that produced Toy Story, as sophisticated as it was, would have taken months to render a seismic section even once. Consider Figure 6. A single frame in the movie Toy Story contained up to 2 million triangles, but there are more than 200 million triangles in this image alone. To work with it effectively, it must be rendered at a minimum of 30 frames per second. By 1995, we had made incredible progress in software and hardware, but even so we were still entire technologies away from even beginning to think about this type of display. In 1995, nobody believed we would ever be able to do this. And that is why, in my opinion, visualization is still a moribund subject and why we ignored the birth of virtual reality. We ignored it because it was absolutely no use to us at the time of its birth.

Although the exploration industry is always desperate for new technologies, most new technologies are of no use to us. Once we have examined them and find them to be of no use, we tend to ignore them from then on. That, I believe, is what happened to virtual reality. It made a big splash when it came in, but if we looked at it at all, we looked at it from the perspective of gaming and entertainment. It was a tool for entertainment and clearly not capable of the real-time interaction we need in interpretation.

So, we ignored it, and I was no exception.

The birth of virtual seismic reality

That I became interested in visualization is completely by accident. In late 1999, through a conversation with my then 14-year-old son who was lobbying for a new graphics card, I first became aware of the computational potential of the emerging graphics processing units (GPUs). Having a history in seismic processing and understanding its computational needs, I started a small side project to assess if we could use the emerging GPUs for seismic processing.

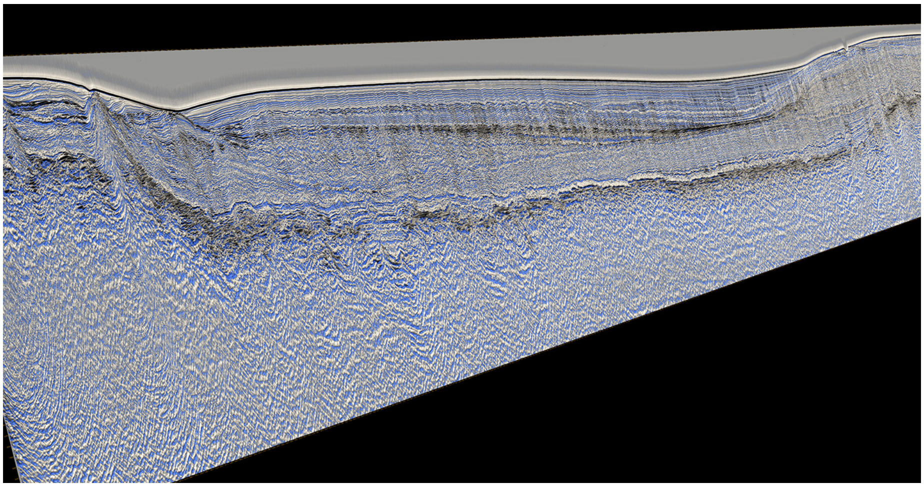

Figure 6. An HVR display of line 70 from the UK NSTA's Rockall Trough survey. There are more than 200 million triangles in this scene. To be practical, the scene must be rendered up to 30 frames per second. This was still beyond the realm of science fiction when virtual reality was born in the mid-1990s.

To assess the real-world potential of the cards, which in those days were not directly programmable, I chose to render a small seismic line as a 3D surface. It takes an inordinate amount of arithmetic to render a single triangle in 3D, and I reasoned that if the card was fast enough to render seismic data, it would be fast enough to process seismic data.

The line I used for my test was a small segment of a line across a pinnacle reef. It contained 170 traces and 350 samples. I had used this line for test purposes for years. Figure 7 is what it had always looked like. I was not expecting it to look any different in virtual reality, which although I did not realize it at the time, is what I was doing — I was displaying seismic in virtual reality.

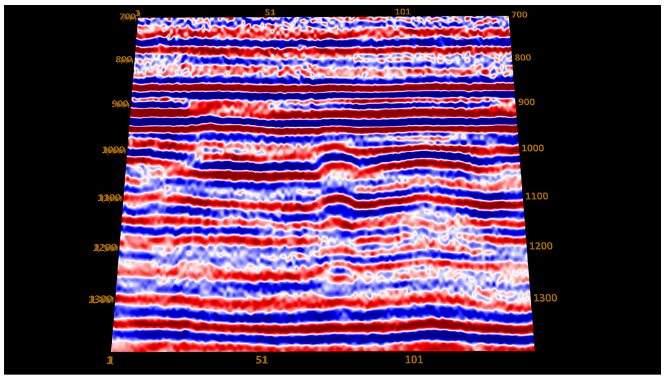

Figure 7. A conventional variable density display of a small seismic line having 170 traces and 350 samples. I had used this anonymous seismic line for testing for years. I decided to display this line in virtual reality only to assess the speed of the graphics card. I expected nothing from the resultant display.

Figure 8 is what it looked like. Figures 7 and 8 were both produced using modern HVR software, but they are identical to the original images I produced in December 1999 (and originally called SeisScape displays). As such, Figure 8 is the first HVR seismic image.

What is hard to explain is the effect that this first image had on me. I had zero interest in virtual reality and visualization before I produced it. But that changed, not slowly over time, but all at once, and to this day I find it hard to explain why, especially considering what first grabbed my attention.

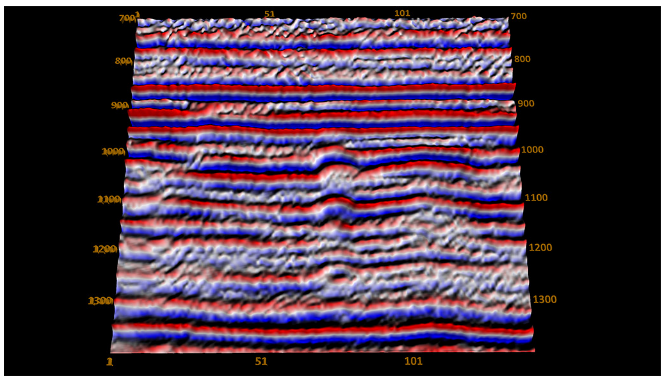

Figure 8. A modern representation of the first HVR seismic image that I produced in December 1999. What I noticed first were the arcuate noise trains that dominated the section but that were unobservable on variable density displays.

What stood out to me first were the obvious arcuate noise trains. As geophysically uninteresting as they were, I could not see them at all on the variable density display. They obviously dominated the section and yet, in the years that I had used this seismic line as a test, I had never realized they were there. If I could not see things this obvious on a variable density display, what else could I have been missing?

It was that question, "what else have we been missing," and the surprisingly visual nature of the display that got things started. It is quite probable, given my initial lack of interest in the display, that if I had not seen those noise trains, I would have dropped the project and today would be as uninterested in visualization as I was before I saw them. But I did see them, and they made me curious enough to look at other lines.

So, this single image, produced serendipitously, marks the birth of HVRI and my attempts to place visualization on a firm theoretical foundation. The question "what else have we been missing" changed my research direction, and it is the question that, in my opinion, should dominate seismic research for the next 20 years.

From 1979 until today, we have acquired and processed tens of millions of kilometers of 2D seismic lines and millions of square kilometers of 3D seismic surveys. But we have analyzed

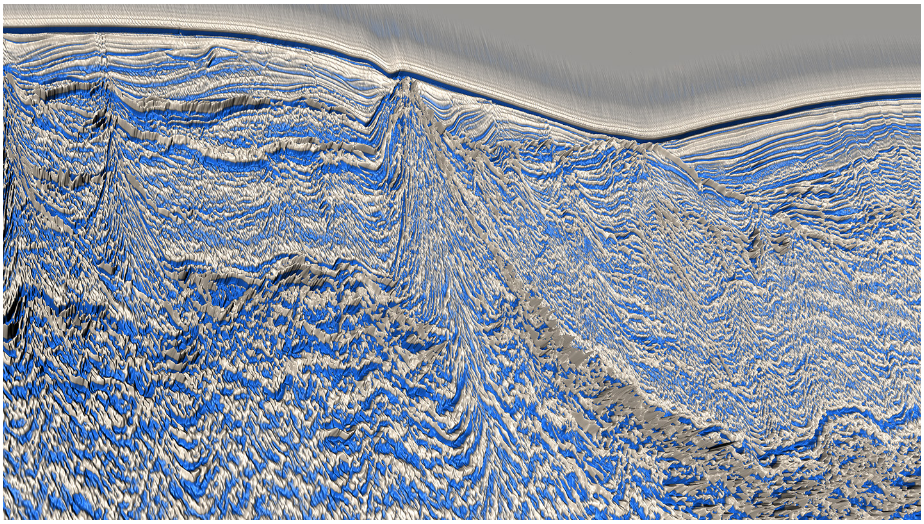

Figure 9. AN HVR display of line 70 from the UK NSTA's Rockall Trough survey. There are low-amplitude reflections in this line from sand–shale sequences and extreme high-amplitude reflections from volcanic intrusions. The difference between the two is orders of magnitude and yet they are equally observable and interpretable.

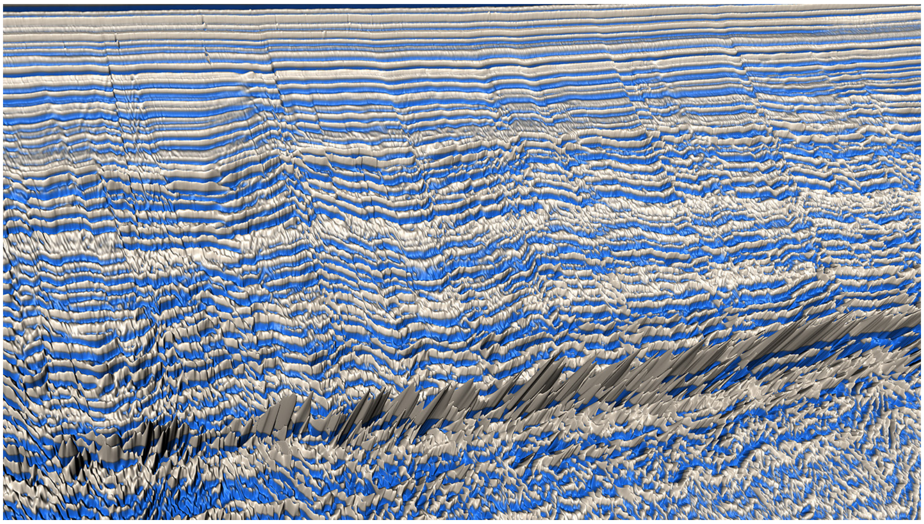

Figure 10. An HVR display of line 70 from the UK NSTA's Rockall Trough survey. Note how the low-amplitude events in the shallow part of the section are as visible and interpretable as the high-amplitude volcanic intrusion events.

and interpreted them using LVR displays that are based on palette-based, dithered-color plotter technology. What is in that data that we have not seen? What prospects are there that sit too close to the limits of visual and temporal resolution to be observed using archaic technologies?

Those are questions that I alone cannot answer. Hopefully, the comparisons that follow will make you curious enough to find out for yourselves.

Evaluating the visual resolution of a virtual seismic reality display

In this section I present a series of examples of HVR displays. It is not practical, however, to show an extensive series of high-resolution before and after images in print. For that reason, I include only a series of single HVR images here. The comparisons between these images and conventional seismic displays can be found online along with a more extensive series of comparison images (see Lynch, 2023).

HVR displays are visually different from conventional seismic displays, and that presents difficulties when evaluating their effectiveness. Their goal, like any other seismic technology, is to increase seismic resolution, which, remembering the definition of resolution, means making the individual parts of the seismic section more distinguishable.

Typically, however, when we want to prove the effectiveness of a technique, we show a before and after, keeping the display parameters and format constant. This is impossible here because we are evaluating the display itself. The seismic data behind the display stay constant, and it is the display itself that changes and is under investigation.

For that reason, we must be systematic about how we evaluate the effectiveness of HVR displays in improving seismic resolution. Here are suggestions as to what to look for.

Amplitude. Seismic amplitudes are the only things we record in the field, and they provide us with 100% of our direct and indirect seismically derived knowledge of the subsurface. Understanding their complexities and nuances is, therefore, the most essential element of interpretation. But have we ever seen them directly? As strange as it seems, the answer is no. All we have worked with in the past are 1970s-era, low-frequency proxy color displays that have never done justice to the subject.

The first, and primary, thing to look for is amplitudes (see Figure 9).

High-amplitude event bias. Seismic amplitudes form events that become the base of the geologic framework of our interpretations. The problem is that low-amplitude events are often the most important in an exploration sense, and yet they are the most difficult to find and interpret. Conventional seismic display techniques are biased toward high-amplitude events. They make it difficult to identify and understand the subtleties of their low-amplitude cousins.

The second thing to look for is how well you can interpret events of widely differing amplitudes (see Figure 10).

High-relief event interpretation. A typical seismic section is a complex mosaic of overlapping and often contradictory signals, some of which are geologically based and some of which are noise. Signals, such as fault plane reflections, migration artifacts, and clinoforms, have high relief and have similar amplitudes to the more horizontal events that they may intersect. Observing them, deciding if they are signal or noise, and understanding their often critically important amplitude profile has always been a challenge.

The third thing to look for is high-relief events and noise trains (see Figure 11).

Pinch out and terminations. Interesting events are rarely continuous across a prospect. They end against faults and the edges of salt domes. They form pinch outs where they onlap to flooding surfaces or contact erosional surfaces in an unconformity. Being able to find the exact point of a termination and observing the amplitudes close to it can have a significant impact on our understanding of potential hydrocarbon accumulations.

The fourth thing to look for is pinch outs and terminations (see Figure 12).

Event continuity. Interesting events rarely have constant amplitudes. Event amplitudes may change significantly over a prospect, and the changes may have exploration significance. They can increase, decrease, and even change polarity, which can often make individual events difficult to follow across a prospect, especially in an area of complex geology. Being able to find and track events over a prospect is of paramount importance.

The fifth thing to look for is improved event continuity (see Figure 13).

Character and waveform. As Bruce Lee said, knowledge will give you power, but character will give you respect. Understanding the character of an event is one of the most critically essential elements of an interpretation. But when, by necessity, we switched from wiggle trace displays to variable density and grayscale displays, we lost our ability to visualize it. Look carefully and you will see that HVR displays bring character back into interpretation (Figure 14).

The sixth thing to look for is character and waveform.

Recognition of geologic features. Let's face it, we are not as interested in seismic data as we are in the geology they represent. Figure 15 is not our greatest example. Yet, when we showed it to an interpreter they said "Wow" and

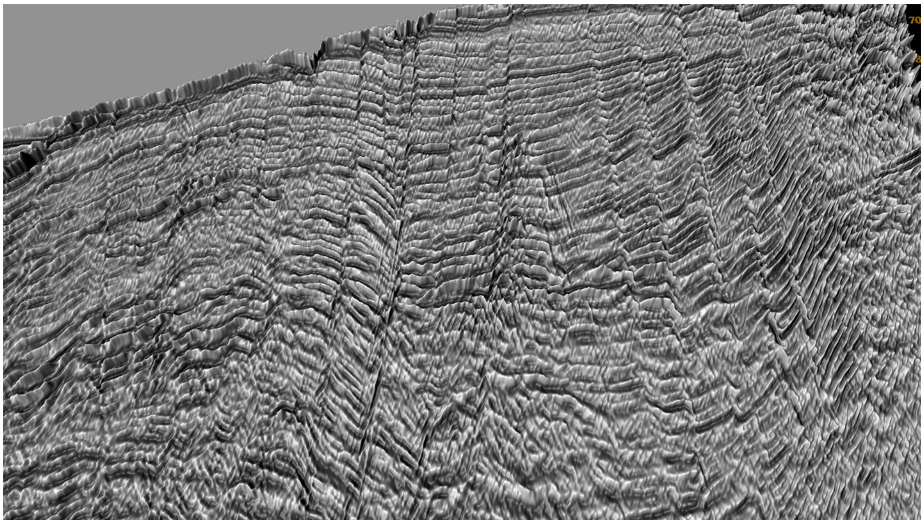

Figure 11. Line ONG-098 from PeruPetro's Trujillo survey. This line has high relief events, fault plane reflections, migration artifacts, and uncollapsed defractions. Distinguishing between them has always been challenging, so much of the relevant geologic signals were ignored because they could not be trusted.

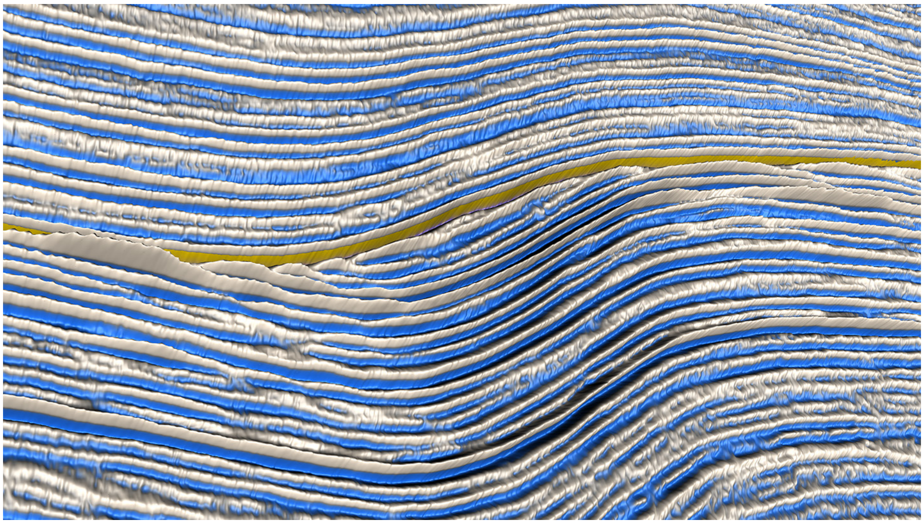

Figure 12. Terminations against an erosional surface in line 47 of the UK NSTA's Mid North Sea High survey.

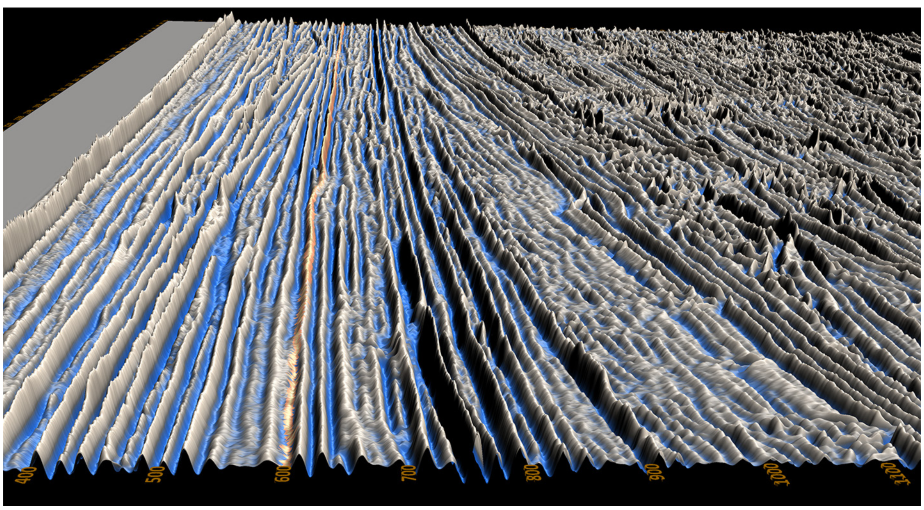

Figure 13. Inline 1300 from the New Zealand Hector 3D survey. Notice how the events are visually continuous even though their amplitudes change significantly.

went on to list all the geologic features they could find — in seconds. And that is what HVRI is all about — observing, perceiving, and recognizing geology.

The last thing to look for is how quickly and confidently you recognize geologic features.

Concluding remarks

"We usually find oil in new places with old ideas. Sometimes, also, we find oil in an old place with a new idea, but we seldom find much oil in an old place with an old idea." Dickey (1958)

Having started my career in the days of 12-fold, short-offset, low-frequency 2D lines, I am constantly amazed by the quality of the seismic data that we produce today. Techniques such as FWI and spectral extrapolation have increased both temporal and spatial resolution beyond anything I thought possible in 1977 when I joined the industry. In addition, new broadband acquisition techniques and the use of ocean-bottom recorders have expanded the limits of what we thought was possible.

Even so, with all of these advances in technologies, the seismic images we produce today are not good enough. It has been decades since we found as much oil in a year as we consumed. Conventional oil production, i.e., the type we find with seismic data, plateaued in 2004 and has hardly changed since then. The 15 million barrels a day increase in consumption since 2004 has been met primarily by the U.S. shale oil industry that today shows signs of having peaked.

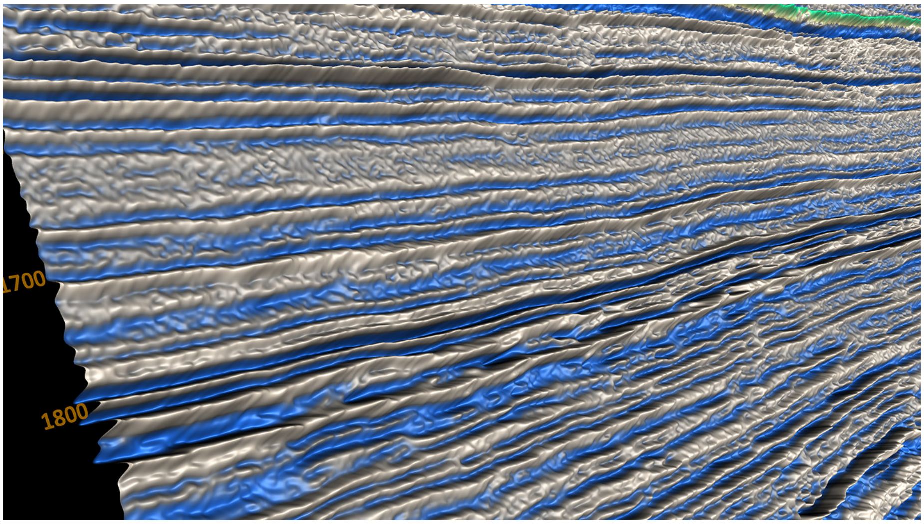

Figure 14. Variable density and grayscale images eliminate character and waveform from an interpretation. Virtual seismic reality restores it in a way that goes beyond what wiggle trace displays were capable of. Data courtesy anonymous source.

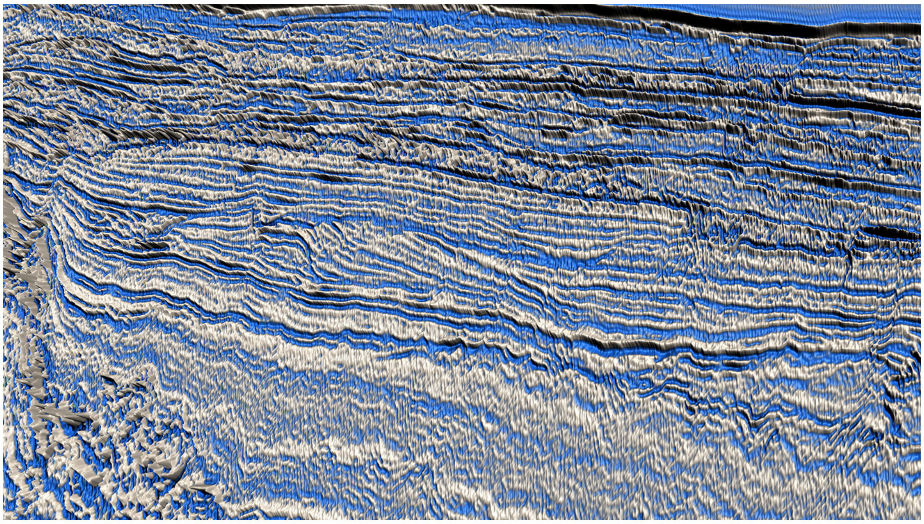

Figure 15. Line 5 from the UK NSTA's Rockall Trough survey. Notice how instantly recognizable the geologic features in this section are.

To meet existing demands and the increased demands of the future, we must find more conventional oil faster and from smaller reservoirs whose seismic expression may be close to the limits of temporal and spatial resolution. We do have new techniques that let us investigate the subsurface with unprecedented clarity. However, those techniques are both expensive and time-consuming, and there is no guarantee that they will lead to increased conventional production or that they are cost-effective if they do.

The world today, in my opinion, faces the two greatest technological challenges in its history:

1) How do we replace oil as the primary fuel of transportation?
2) How do we find enough oil to survive until we do?

Oil, as a nonrenewable resource, is far too important to the global economy and the survival of societies to remain as the dominating energy source for transportation. We need to replace it and transition to long-term sustainable fuels. That transition, however, will not be as simple as politicians and environmentalists would have us believe, and it will take decades and perhaps generations before we make a significant impact.

We need answers today. What I have tried to show here is not that HVRI is the answer we need but that it has the potential to be one of the answers we need. If we are to increase conventional oil production, we will have to find more oil with the seismic data we have and the acreage we already own. We will not increase production strictly by acquiring new data in new areas. We cannot afford that, and it takes too much time. We need to comb over existing data and look at them from an unfamiliar perspective.

Virtual reality, the technology we left behind, lets us do that. It has the potential to significantly increase seismic resolution by producing HVR images. What those images will reveal to us is still unknown. All I can tell you is that HVR displays significantly increase visual seismic resolution. Will that increased visual resolution help us break through the conventional oil production roadblock? Only time will tell. Increasing temporal and spatial resolution, however, has a proven history of revealing targets that no one previously suspected were there. So, with that in mind, what targets exist beneath the low visual resolution of conventional seismic displays? TLE

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Data and materials availability

Data associated with this research are available and can be obtained by contacting the corresponding author.

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References

Dickey, P. A., 1958, Oil is found with ideas: Tulsa Geological Society Digest, **26**, 84–101.

Govardovskii, V. I., P. Röhlich, A. Szél, and T. V. Khokhlova, 1992, Cones in the retina of the Mongolian gerbil, Meriones unguiculatus: An immunocytochemical and electrophysical study: Vision Research, **32**, no. 1, 19–27, https://doi.org/10.1016/0042-6989(92)90108-U.

Lynch, S., 2008, More than meets the eye — A study in seismic visualization: PhD Thesis, University of Calgary.

Lynch, S., 2023, HVRI example set 1, https://sway.office.com/rlcXcOdX1Eq1kcWm?, accessed 19 July 2023.

Taner, M. T., F. Koehler, and R. E. Sheriff, 1979, Complex seismic trace analysis: Geophysics, **44**, no. 6, 1041–1063, https://doi.org/10.1190/1.1440994.