Improving the interpretability of seismic data using achromatic seismic information

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Summary

The human retina contains three types of cones, each being maximally sensitive to a different wavelength. The raw signals from the cones are processed in an antagonistic manner to produce three channels of opponent information, the achromatic Black-White channel and the chromatic Blue-Yellow and Red-Green channels. These channels are then passed to the visual cortex which has two independent neural circuits. The first, the achromatic circuit, process the Black-White channel and the second, the chromatic circuit, processes the other two. Of the two, the achromatic circuit dominates object detection and pattern recognition.

Variable density (v.d.) seismic displays typically use a purely chromatic color palette. Consequently the displays are interpreted solely by our chromatic neural circuitry which provides only secondary cognitive information. In an effort to improve our ability to perceive seismic data I combine a conventional v.d. display with an achromatic shaded relief image to produce a more interpretable display.

Introduction

In a recent survey conducted by the author, two images of the same object were shown to a group of individuals with varied backgrounds. The participants were asked two question, the first being "What is it?" and the second "Did you recognize it automatically or did you have to think about it?"

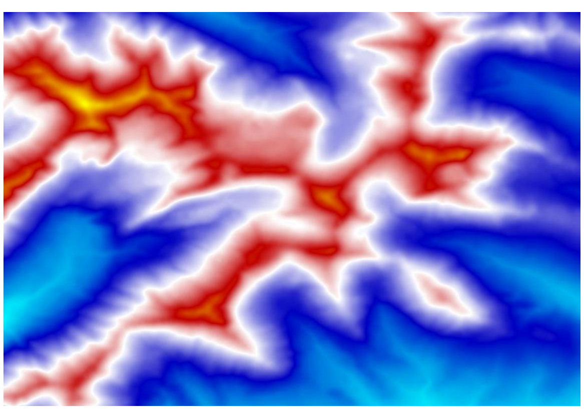

Figure 1: Color display of an object using a typical seismic color palette (cyan-blue-white-red-yellow).

Figure 1 shows the first image which 60% of the participants failed to identify correctly. Of those that did identify it, the majority reported that their recognition was not automatic and they had to think about what it was. This failure to recognize the object is interesting and illustrates the two sides of color vision, the physiological and the cognitive.

The physiological visual processes convert the photons impacting the retina into signals that travel the optic pathways. Ultimately they produce a two-dimensional image that is passed on to the visual and cerebral cortexes for interpretation.

The cognitive visual processes have the unenviable task of reconstructing a three-dimensional world from this two-dimensional projection. If the visual cortex succeeds in this task you "get" it automatically, there is no thinking involved. But if it fails then the visual information is passed to the cerebral cortex for conscious analysis.

With this in mind we can draw two conclusions about Figure 1. The first is that it is a physiological success. Our physiological visual system has produced a clear two dimensional image of the object. The second is that the image is a cognitive failure. Despite the participants being able to clearly see the object their visual cortex's failed to interpret it. The reason for this failure is to be found in the very nature of human color vision.

Human Trivariant Color Vision

Mammalian color vision depends solely upon the cone visual receptors. Humans, and most primates, have three types of cones with different wavelength sensitivities.

- S-Cones are maximally sensitive to light of 420 nm.
- M-Cones are maximally sensitive to light of 534 nm.
- L-Cones are maximally sensitive to light of 564 nm.

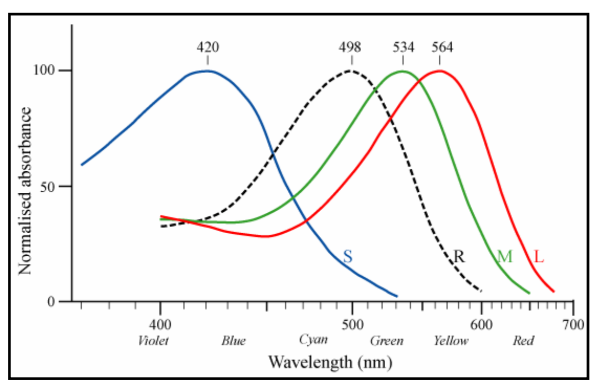

Figure 2: Wavelength sensitivities of human visual receptors - From Wikipedia.

Achromatic Seismic Information

The L&M cones respond to all visible light and dominate in the fovea. Color vision does not depend upon the magnitude of the signals produced by each type of cone. Rather, the raw signals are processed for contrast in an antagonistic manner as shown in Figure 3.

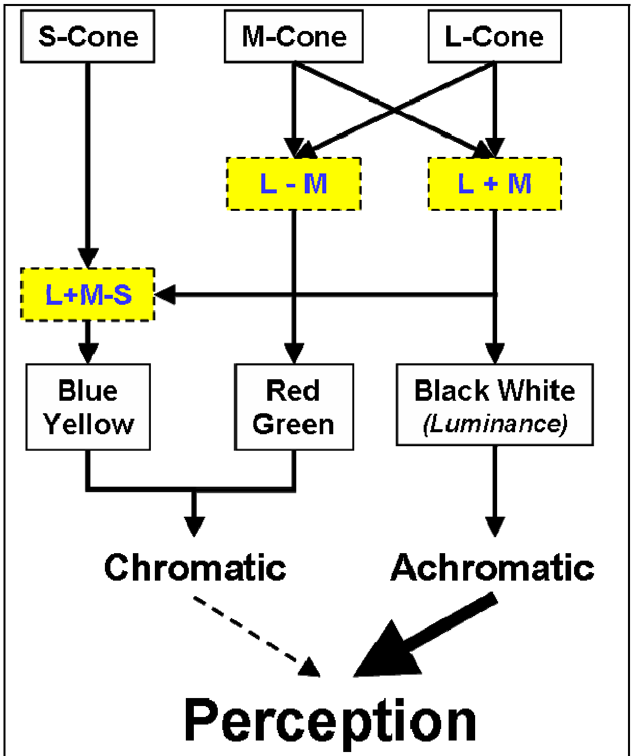

Figure 3: Antagonistic processing of raw color signals into opponent channels and ultimately into two neural circuits in the visual cortex. Note that the achromatic circuit dominates perception.

The three raw inputs are processed into three opponent channels, the Blue-Yellow channel, the Red-Green channel and the Black-White luminance channel. These three channels are then fed into two separate neural circuits in the visual cortex.

The Blue-Yellow and the Red-Green channels are processed by the chromatic neural circuitry whereas the Black-White luminance channel is processed by the achromatic neural circuitry. Both circuits are used to form our final perception of an object. However, it is the achromatic channel that dominates perception.

This processing of the raw signals by two separate channels indicates that our physiological visual processes produce two entirely distinct 2D images. The first is a purely achromatic, i.e. intensity only, image. Only after this image is formed does the visual processing system produce the second, the purely chromatic image.

In terms of evolutionary biology, the achromatic circuit, which detects contrast between light and dark, is the original vision: color vision came along much later. It is not surprising then that the achromatic circuitry dominates pattern recognition, object detection and perception in general.

With this in mind we can now explain the survey participants' failure to correctly identify Figure 1. The color palette used to produce the image smoothly graded between cyan-blue-white-red-yellow. All of the changes in this palette are chromatic: there are no achromatic (intensity) changes at all. This image is processed entirely by our chromatic neural circuitry which only provides secondary object detection information. As a result, because the image does not contain primary achromatic information, our visual processing system is unable to identify what it is even though we can see it clearly.

Achromatic Imaging

Figure 4 is the second image that I sent to the survey participants. This is a shaded relief (Batson 1975) image of the same object shown in Figure 1 and it contains purely achromatic information.

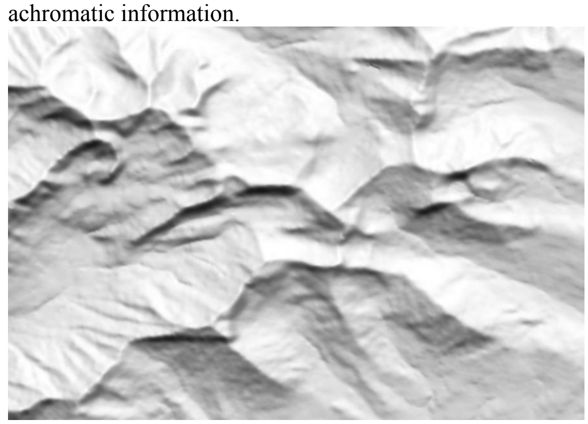

Figure 4: Shaded relief (achromatic) representation of the same object shown in Figure 1. Light source is at the upper left.

In contrast to Figure 1, 85% of the survey participants identified this right away. 70% correctly identified it as a mountain range and 15% identified it as crumpled paper. Most important here is the automatic recognition which shows that the perception occurred in the visual cortex.

To summarize, Figure 5 shows a bump-mapped (Blinn 1978) image of the object (the Crowsnest Pass region of S.W. Alberta) produced by modulating the colors of Figure

1 by the intensities of Figure 4. Although we are never aware of it, when we look at an image like this, our physiological visual processes splits it into Figures 1 and 4. Our cognitive visual processes subsequently analyses each one independently with the achromatic image dominating.

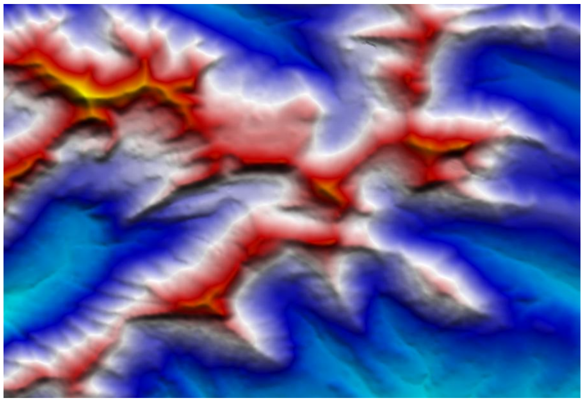

Figure 5: Bump-mapped image of the Crowsnest Pass region of S.W. Alberta. The image is prododuced by modulating the colors of Fig 1 by the intensities of Fig 4.

Achromatic Seismic Information

With the decreasing size of exploration targets and the increasing focus on reservoir development and enhanced recovery it is more important than ever that we be able to fully perceive all of the information inherent in a seismic section.

The previous example showed clearly the importance of achromatic information to perception. But most seismic data is displayed using a variable density display and most of the color palettes that we use are akin to that used in Figure 1, they are almost purely chromatic. Consequently, conventional v.d. displays are interpreted by our secondary cognitive visual circuitry and as we learnt from Figure 1, this means they aren't being interpreted at all. This then leads us to a question.

Given that:
1. Seismic data is a three-dimensional surface.
2. It is less band limited than topography.

Then:
- If a purely chromatic display cannot adequately represent topography.
- How can it adequately represent seismic data?

The answer, in my opinion, is that it does not. Figure 6 shows a purely chromatic v.d. image. As with Figure 1, the image is well defined and clear. There is good contrast in the display and yet it is hard to look at and make sense of.

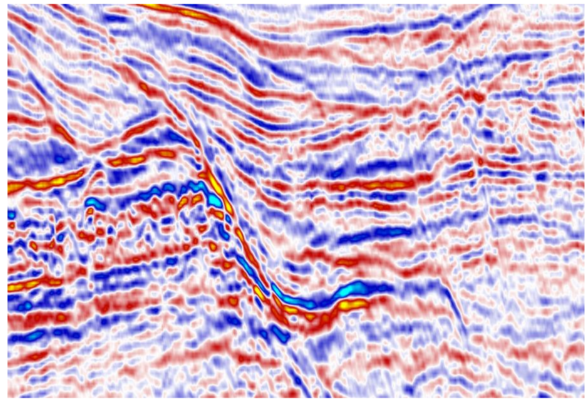

Figure 6: Conventional variable density seismic image of a faulted data set (cyan-blue-white-red-yellow palette). Data courtesy unnamed source.

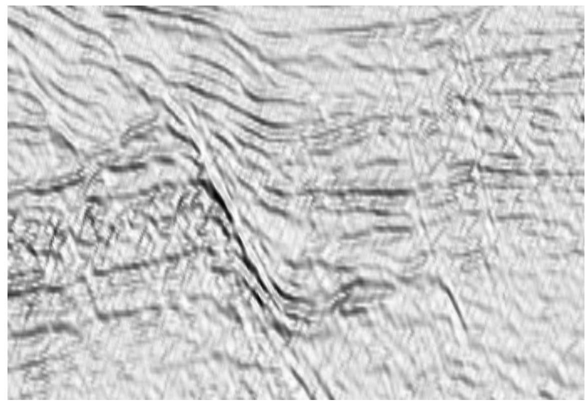

Figure 7: Shaded relief image, lighting from the upper right. Note the clear perception of highs and lows and the presence of high angle events at the right that are not visible on the v.d. image.

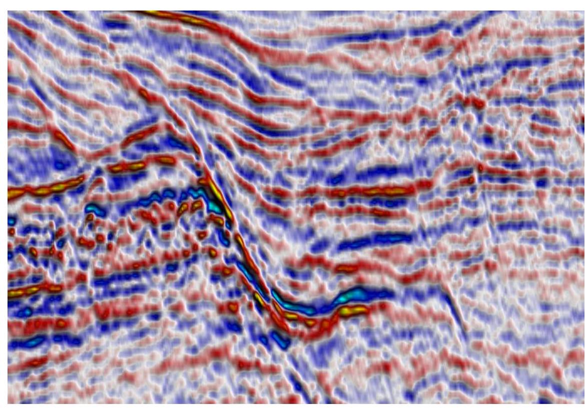

Figure 8: Bump-mapped seismic display formed by modulating the colors of Fig 6 with the intensities of Fig 7. Note that the 3D nature evident in Fig 7 is still clear.

Figure 6 is a representation of a three-dimensional surface and yet the 3D structure is not evident. This is because a chromatic display lacks any inherent concept of high and low. If we know the color palette we may make an association between color and amplitude but this is done in the cerebral cortex and the association is slow and far from automatic.

Figure 7 is the achromatic shaded relief image and as one would expect, the 3D nature of the seismic is now clearly evident. Even though the image lacks the fine detail contained in the v.d. image it is easier to interpret because our perception of high and low is clear and unambiguous.

Figure 8, the bump-mapped seismic counterpart to Figure 5, is a true seismic display. Even though we are not aware of it, the image is split and processed by both our primary and secondary visual cognitive systems. The primary system, i.e. the achromatic circuitry, provides us with the automatic recognition of the 3D nature of the seismic and automatically interprets for us most of the structure. The secondary or chromatic circuitry fills in the details.

Very little research has been done to date on using shaded relief with vertical seismic data. Lynch introduced the concept of using shaded relief for vertical seismic in 2003. Barnes (2003) used shaded relief to emphasize reflection dip on time slices and Lynch used it to highlight faults (CSEG 2005) on vertical seismic. With so little information to go on it is unclear whether or not shaded relief will ultimately improve an interpretation. However, given that shaded relief adds significant information to the display and makes it considerably easier to interpret, the question is worthy of being pursued further.

Conclusions

Whenever we look at an object, our visual processing system splits it into two 2D images, a purely achromatic image and a purely chromatic image. These two images are subsequently processed by independent neural circuits in the visual cortex. Of the two circuits, the achromatic circuit dominates, providing our primary object detection and pattern recognition information. The chromatic circuit provides only secondary information.

A variable density display is not a true seismic display because it typically uses a purely chromatic color palette. It is, therefore, processed by our chromatic or secondary visual cognitive processes which provide very little object detection information. As a result, even though we clearly see the seismic information, we do not correctly perceive it.

Because our achromatic visual circuitry provides the majority of visual cognition we cannot adequately represent seismic unless we include achromatic information in the display. In the case of this paper I have done that by combining a shaded relief seismic image with the variable density display.

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