# On the Perception of RGB Multi-Attribute Displays

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**Summary**

Multi-attribute analysis is fundamental to seismic interpretation because it has the power to unlock the 'covariant information' embedded in seismic attribute data. An effective way to visualise such information is to colour blend the individual components in RGB space, as explained in this paper.

**Introduction**

Seismic interpreters are often faced with the need to visualise and interpret a number of seismic attributes simultaneously. Side-by-side visualisation of the individual attributes and use of monochromatic colour bars are still widely used techniques, which nevertheless present a number of limitations. In this paper we discuss how colour can be used effectively in order to support simultaneous multi-attribute interpretation and why it proves to be so successful at allowing seismic interpreters to visually unravel the different layers of information contained within seismic data.

**The Challenge of Simultaneous Multi-Attribute Interpretation**

Simultaneous visual assessment of multiple attributes is an increasingly common challenge in seismic interpretation. Interpreters often need to analyze the region of interest by highlighting different features within the seismic data via individual attributes and then merge the information into a composite, single interpretation output [Henderson et al., 2008]. Performing such interpretation by visualising the attributes in individual displays, even if side-by-side, and mentally combining the information is an extremely challenging task and often fails to unravel the full potential of seismic data. Figure 1 shows an example of three frequency volumes, visualised side by side in individual monochromatic displays.

**Monochromatic Data Visualisation**

Despite the advances in visualisation technologies, attribute interpretation is still often performed using monochromatic displays based on 8-bit colour depths. In such systems a monochromatic grey-scale image can have a maximum of 256 levels of grey. There is evidence that even though the human eye can perceive up to 500 shades of grey, when it comes to relative comparison of grey levels, it can only distinguish 16 levels of grey from one another [Aidan, 2006] [Dejoie and Truelove, 2000]. Figure 2 shows three greyscale palettes with related colour bars rendered with one, four and eight bits per pixel; the difference in resolution between the three images can be readily perceived. The individual colour level steps that are quite clear in the 4-bit case are not visible in the 8-bit case which appears practically continuous.

Increasing the colour depth beyond eight bits does not offer additional increases in the amount of visible detail. This is perhaps why visualisation technologies limited to 8-bit colour have perpetuated for so long within visualisation software as they are often adequate for visualisation of individual data volumes. However, 8-bit colour depth limitations do pose a significant challenge for the simultaneous interpretation of multiple attributes. The solution is to utilize a larger and more effectively encoded colour space, by combining the individual attributes into a multi-dimensional attribute visualised using RGB (Red, Green and Blue) blending [Henderson et al., 2008].

**Multi-Dimensional Visualisation Using Colour**

Colour is a powerful visual cue that can be used effectively to encode information in most applications of scientific visualisation. RGB blending is an effective use of colour that has become a well established visualisation method for seismic attributes. It is well known that in a composite RGB display, each input attribute volume is mapped individually to the red, green and blue monochromatic components of the RGB space. The intensity of each primary colour represents the intensity of the attribute in that channel. The information within the attributes is 'mixed' by the computer display and the interpreter's eye to produce rich, detailed and highly intuitive visualisation.

Figure 3 shows the RGB colour space used to blend the attributes. The three main axes define the monochromatic primary colour scales. Blending the three primary colours in equal proportion yields a shade that is located along the greyscale diagonal. Colours characterized by different proportions of red, green and blue deviate from the greyscale axis and have chromatic properties; the greater the deviation the stronger the differentiation between the attributes represented by the primary colours.

Each channel within an RGB blend can represent up to eight bits of information, which gives a composite RGB blend a total colour depth of 24 bits or 16.7 million colours. Theoretically, this provides scope for a significantly higher level of visual output than the monochromatic displays and hence can effectively encode more information. So when used to visualise multiple seismic attributes, significantly higher levels of detail can be seen.

Figure 4 shows an RGB blend where the frequency components shown individually in Figure 1 are combined into a single multi-dimensional attribute. Areas depicted in white represent an equally strong response of all three input frequency components while, for example, areas depicted in cyan represent a strong response of the second two frequency components and a weak response of the first frequency component. The simultaneous display of these three attributes is clearly providing additional information both in terms of the attribute values and relative variations in those values.

Subtle variations between the three frequency inputs are not always obvious when the three attributes are observed individually, side-by-side (Figure 1). However, these variations are much more noticeable when the attributes are blended and are highlighted in the RGB blend as slight variations from grey.

Blending three more divergent attributes, for example an edge detection, a structural and a seismic magnitude attribute (e.g. Semblance, Chaos and Envelope), yields hues that are closer to the primary colour axes because they highlight very distinct features in the seismic data. This is clearly shown in Figure 5.

This level of detail is achieved on one hand due to the colour model chosen but also because the human visual system is remarkably good at discerning colours. We can physically distinguish about ten millions of colours [Judd and Kelly 1939] even though we often only tend to describe objects in terms of a handful of these, typically using eleven basic names: white, black, red, green, blue, yellow brown, purple, pink, orange, white, black and grey [Boynton and Olson, 1990] [Berlin and Kay, 1969].

Figure 6 shows colour palettes of a type similar to those shown in Figure 2 for monochromatic colour scales. These palettes span the RGB colour space and as in Figure 2 show how colour continuity is affected by bit depth in each colour channel. By examining the palettes, we see that individual colour levels are still visible in the nine and 15 bit palettes, whereas the 18-bit palette appears continuous. Increasing colour depth beyond 18-bit provides little further improvement, similar to the 256 colour threshold in monochromatic displays. However, the threshold in RGB blended displays is over 262,000 colours, demonstrating why these multi-attribute display techniques are so much more effective at conveying detailed visual information. That is, they better exploit our visual colour acuity, which is generally remarkably good [Froner et al., 2012] [Judd and Kelly, 1939].

Healey and Enns [1996] studied perceptual colour overlap and colour choice to represent multidimensional data. Based on their experiments, the degree of hue name overlap between ten representative colour categories can be summarized with Table 1. Colours that fall into categories with a low overlap (e.g. Red and Green-Yellow) are characterized by a better perceptual contrast and are more likely to be distinguishable from each other than colours that belong to categories with a high perceptual overlap.

These results are particularly important to bear in mind when interpreting RGB blended displays such as in Figure 4 (right), where we are able to clearly discern multiple reef and mound structures within the carbonates system shown. Our eye is naturally drawn to the lighter red, yellow and green details that appear to stand out more.

## Conclusions

In order to achieve a more accurate and comprehensive seismic interpretation, interpreters often have the need to extract and analyze information from different attributes simultaneously. Such a task presents a number of challenges that traditional visualisation techniques cannot address. RGB colour blending is a successful model for multi-attribute visualisation: it has a significantly higher potential for encoding visual information and does so by using colour in a way that is perceptually ‘in tune’ with the visual mechanisms that allow us to see it.

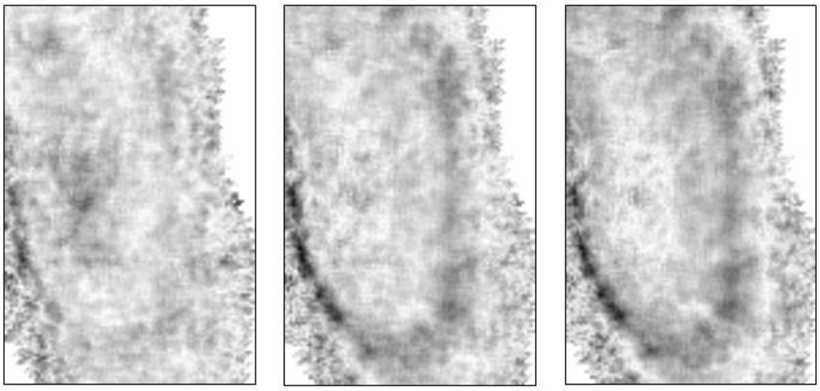

*Figure 1 - Three single attributes highlighting different frequency content in a slice of seismic data from the well know Teapot Dome dataset, visualised side by side using a greyscale colour bar.*

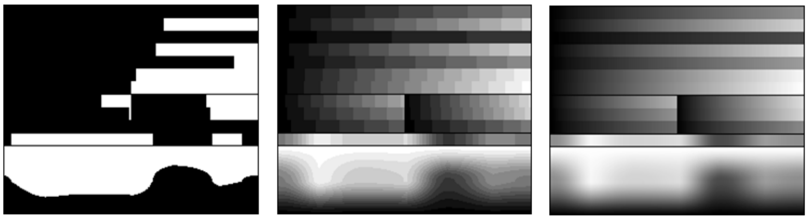

*Figure 2 - Greyscale palettes rendered using a resolution of one, four and eight bits per pixel.*

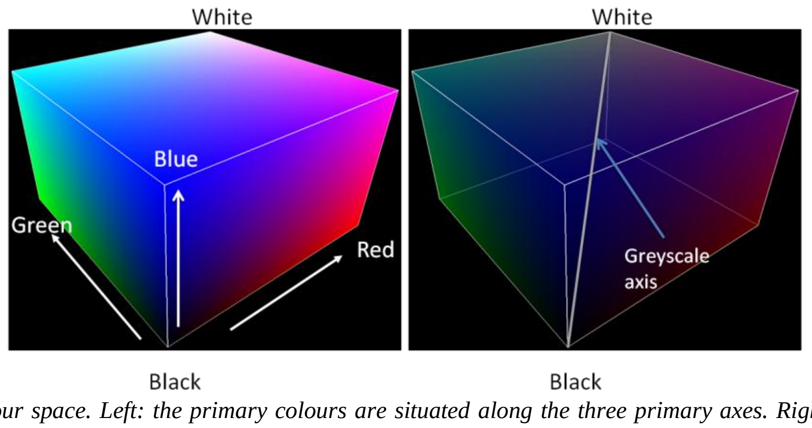


*Figure 3 - RGB colour space. Left: the primary colours are situated along the three primary axes. Right: white and black are located at the origin and extent of the cube, with the greyscale axis running between them.*

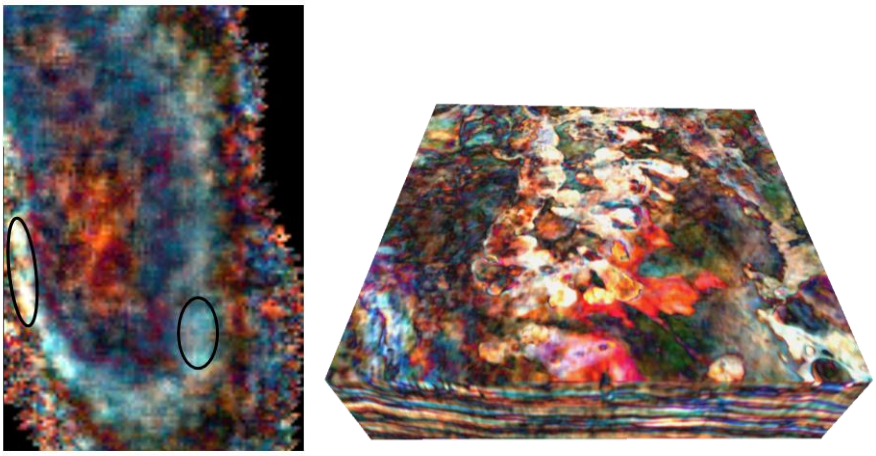

Figure 4 - Left: RGB Blend slice where the three different frequency attributes from Figure 1 have been combined into a single, multi-attribute frequency display. Right: application of the same technique to produce a multi-attribute frequency volume; the technique clearly highlights structures within this carbonates system in detail (offshore Australia).

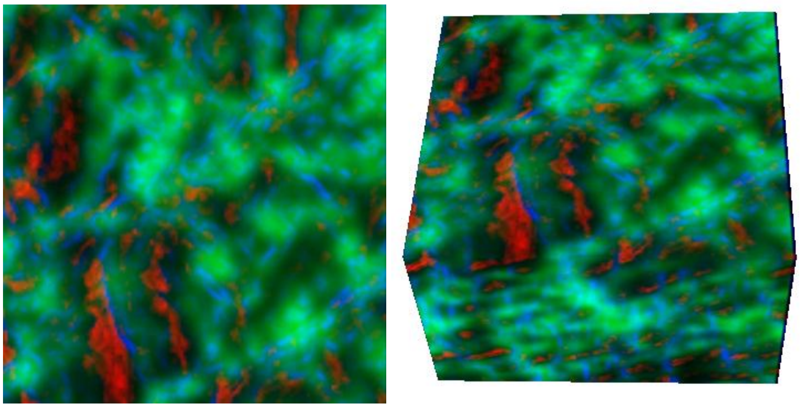

Figure 5 - RGB colour blend of Semblance, Chaos and Envelope attributes highlighting different features in the seismic data.

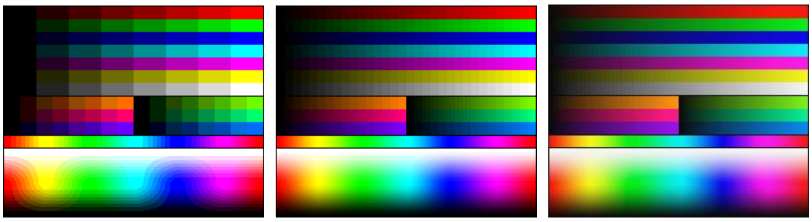

Figure 6 - RGB colour palettes rendered using three, five and six bits per channel, corresponding to a total of nine, 15 and 18 bits colour depth, which respectively display 512, 32768 and 262144 colours.

| | Red | Yellow-Red | Yellow | Green-Yellow | Green | Blue-Green | Blue | Purple-Blue | Purple | RedPurple |
|---|---|---|---|---|---|---|---|---|---|---|
| Red | | 0.038 | 0 | 0 | 0 | 0 | 0 | 0 | 0.014 | 0.145 |
| Yellow-Red | | | 0.058 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Yellow | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Green-Yellow | | | | | 0.973 | 0.256 | 0 | 0 | 0 | 0 |
| Green | | | | | | 0.263 | 0 | 0 | 0 | 0 |
| Blue-Green | | | | | | | 0.187 | 0.146 | 0 | 0 |
| Blue | | | | | | | | 0.823 | 0 | 0 |
| Purple-Blue | | | | | | | | | 0.045 | 0.008 |
| Purple | | | | | | | | | | 0.173 |
| RedPurple | | | | | | | | | | |

*Table 1 - Perceptual overlap between ten representative colour hue categories. Adapted from [Healey and Enns, 1996].*

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