

Color in Layers: From Pepper's Ghost to Augmented Reality

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Abstract

Optical see-through AR presents virtual objects to a user through a transparent display that blends them with the real-world environment. This is simultaneously novel and familiar: beam splitters have been used for ghostly visual effects, and yet the mechanism is exactly the same as the reflections in an everyday window. The history of theatrical visual effects leads through a series of vision science experiments and now to research on the perception of transparent AR systems. Still, there is a tension in the perception of AR stimuli: users of AR seem to be able to separate, or scission, the layers of virtual and real, depending on their understanding of the scene and its visual characteristics.

Keywords: *AR, Color Appearance, Simultaneous Contrast, Transparency, Scission*

Introduction

Augmented reality (AR) is a tantalizing, developing technology that promises to seamlessly blend virtual, computer-generated objects into the real world. AR is already being used in industrial and medical applications, has enjoyed its first hype cycle with gaming, and will likely impact education and retail applications, among others. One type of AR, optical see-through AR (OST-AR), is implemented in a goggle- or glasses-like headset using an optical combiner such as a beam splitter to create a transparent display where virtual content can be overlaid on the real world visible behind it. Because the transparent display is unable to block out the real-world background, the appearance of AR content can vary, from apparently solid to transparent or ghostly.

Ghostly images via glass beam splitters have an interesting history in theatre, popularized in the mid-nineteenth century in London during the era of phantasmagoria. Attributed to John Henry Pepper, Pepper's Ghost is the reflected image of an off-stage, spotlighted actor who appears glowing and transparent, able to interact with and even physically pass through the other actors on the stage. The ethereal effect was a sensation at the time, offering a surprising visual experience that seemed inexplicable except by magic.

Outside the theatre, however, transparent reflections are actually no surprise at all, as they accompany everyday windows and other transparent, glass-like objects. Reflections are so ubiquitous that we usually ignore them. Transparency and alpha matting are so familiar that image manipulation software is architected around the metaphor. So, what do we expect with AR? Is it magical or familiar? Confusing or natural? In practice there is a tension between these extremes that depends strongly on the viewing situation.

Key Concepts

Transparency & Brightness

Transparency is of course a physical, material property, but it is also a percept that can be engendered by reasonable simulations of transparent layer structures, as explained by Metelli and Anderson et al. In OST-AR, the physical transparency of the display is fixed; however, the perceived transparency of

presented stimuli depends on their brightness as well as the luminance contrast of the background behind. Zhang and Murdoch found that in general, the brighter the AR stimulus and the lower-contrast the background, the less transparent (equivalently: more opaque) the AR appears. The brightness dependence causes the practical limitation that it is difficult to reproduce black in AR, as darker colors become more transparent and eventually invisible. In the creation of theatre illusions, selective illumination uses invisibility to great advantage, eliminating visual cues that would expose the optical trickery. Silvia Pont et al. used illumination differences to create optical blends of transparent and opaque materials, which can be interpreted as blended meta-materials. In 2011, Kingdom reviewed the history of literature on percepts of lightness, brightness, and transparency, emphasizing the complexity of the topic and disagreement between researchers. Unfortunately, much of the relevant research questions remain unresolved.

Scission & Visual Discounting

Part of the reason that reflections in windows go unnoticed is that the layering caused by a window is usually obvious due to a range of cues including luminance differences, depth difference, motion parallax, and cognitive understanding. The resulting visual separation of layers is known as scission, and one response to scission is visual discounting, wherein the perceptual or cognitive contribution of one layer or the other is minimized to focus on the other. Gilchrist and Jacobsen showed that people have no trouble interpreting the lightness of scene objects when a layer of reflected light (or “veiling luminance”) distorted their view. Grace Moore Heider studied the visual interrelationships between veiling luminance, transparency, and scission in the 1930s, and her work has been cited by many of the researchers already mentioned.

Scission can be induced in AR by some of the same visual cues, and the result is partial-to-complete visual discounting of the background. In color perception, this means that the background color, which physically distorts the transparent AR stimulus, is nonetheless partially ignored when interpreting and matching the AR foreground color (see Hassani and Murdoch). Murdoch (2020) also found that the AR layer can be partially discounted when matching the brightness of real-world objects behind, and Zhang (2022) showed complete discounting for brightness matching tasks, meaning a textured background could be entirely ignored, despite its physical effect.

Scission and discounting may sound like excellent news, as it seems to imply that the physical limitations of transparent AR could be overcome by the power of visual perception. However, it is not so simple, and the degree of visual discounting varies immensely over different visual stimuli and experimental tasks (see Downs and Murdoch, Hassani and Murdoch). The AR research cited so far has primarily focused on understanding the variables that affect perception and scission; moving forward, one goal is a color appearance model for AR, and another goal is guidelines for AR content creators to ensure visibility, transparency, and other attributes are rendered as desired.

Simultaneous Contrast

Color perception is always contextual, and the immediate surrounding of a color stimulus has an enormous effect on its appearance known as simultaneous contrast (see Fairchild). An AR stimulus, transparent or not, may appear visually surrounded by another AR color and/or the background behind. Models of simultaneous contrast, especially chromatic simultaneous contrast, on color appearance are surprisingly rare; yet, in several of the mentioned AR studies, an accounting for simultaneous contrast has been made, but the visual effects are not fully explained, showing that the

AR appearance and discounting effects are separate from simultaneous contrast (see Hassani and Murdoch, Murdoch 2020, Downs and Murdoch).

Both Kingdom and Anderson have pointed out the visual similarities between transparent-appearing stimuli, such as those discussed by Metelli, and typical examples of simultaneous contrast. In future research and model development, the similarities between these types of stimuli should be explored and modeled. It may be that a generalized visual interpretation of colors in layers helps explain both transparency and simultaneous contrast perception.

Conclusion

Layers of colors and other stimuli are ubiquitous, seen via optical reflections as well as common software implementations such as alpha matting. Spatial arrangements of color can be interpreted as stacked, transparent layers in some situations, or as single layers in other situations. In some situations, configurations of layers and transparency can be difficult to interpret, and may appear magical. Visual interpretation of AR stimuli is similarly varied: AR is compelling in part because it is novel and seems magical, yet in some cases the transparent AR stimuli are interpreted independently of the background and they appear very natural. Ongoing research aims to measure the sources and results of visual discounting effects in layered transparent AR environments that contribute to the natural or ghostly interpretations. A robust model of these results will enable proper accounting for perceptual effects, which will help ensure that AR content can be reliably, naturally, and comfortably delivered as intended to viewers in a variety of situations.

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