Color from Real Reality to Extended Reality

Michael J. Murdoch

Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY, USA

ABSTRACT

As the development of extended reality technologies bring us closer to what some call the metaverse, it is valuable to investigate how our perception of color translates from physical, reflective objects to emissive and transparent virtual renderings. Colorimetry quantifies color stimuli and color differences, and color appearance models account for adaptation and illuminance level. However, these tools do not extent satisfactorily to the novel viewing experiences of extended reality. Ongoing research aims to understand the perception of layered virtual stimuli in optical see-through augmented reality with the goal of improving or extending color appearance models. This will help ensure robust, predictable color reproduction in extended reality experiences.

1 INTRODUCTION

We spend most of our time in real reality, experiencing real-world objects under real illumination. We experience color as the interaction of objects, illumination, and our visual system, and in general we have evolved an excellent visual sense capable of understanding the real world around us. Traditional media from painting to imaging, printing, and display allow people to create and present visual stimuli that look like the real world or convey an artist's impression of a scene. None of this surprises us; the real world is beautiful, and art helps us share, enjoy, and interpret it.

At the moment we are on the rapid upswing of the development of amazing visual technologies known as extended reality (XR), which includes virtual reality (VR), augmented reality (AR), and other variations. XR promises to transport us to remote places, allow us to collaborate with automata and other people in a shared environment, and augment our vision to improve our understanding of the world around us. XR is compelling in part because it is surprising; the visual environment created with VR and AR can be quite unlike real-world objects and traditional media. The novelty of visual experience in XR demands careful study both to understand our visual response to it and to enable the development of more comfortable, more accurate, and more predictable XR systems and content.

2 COLOR IN OBJECTS

In the real world, we like to attribute color to the objects themselves. This is not fully correct, because lighting clearly affects color and appearance, and we are also able to perceive and appreciate changes in illumination and the colors of emissive objects themselves. However, the adaptation mechanisms of our visual system allow us to approach color constancy to a sufficient extent that objects indeed seem to securely possess their colors.

Object color has been studied and organized using color order systems, including the Munsell system, based on the basic dimensions of color perception: hue, value, and chroma. Quantifications along these dimensions allow accurate specification of color, and color palettes such as Pantone also allow unambiguous communication about object colors [1].

Color systems, as well as traditional art media, rely on metamerism, the phenomenon by which spectrally-different color stimuli may be perceived as the same color, in a particular viewing environment. Thus, an artist doesn't need to recreate the physics of a sunset sky, just mix a combination of pigments to look like the sky.

2.1 Colorimetry and Color Appearance Models

Quantifying color matches is the role of colorimetry, which provides a system for numerical specification of a measured color stimulus, scaled to be perceptually meaningful but falling short of describing perception. Colorimetry and color differences are used in assessing color matches between samples in many industries including textiles, coatings, and printing.

Color appearance models (CAMs), including CIECAM02 and CAM16, extend colorimetry by accounting for some of the perceptual effects caused by viewing conditions, such as the illuminant color and intensity. CAMs still don't fully describe appearance, but they are capable of specifying color matches in terms of a correspondence between colors in different viewing conditions [2][3]. CAMs have been developed using data from visual experiments mostly involving reflective color samples, though some data sets have also incorporated colors as light sources or displayed on screens.

3 COLOR IN DISPLAYS

Emissive color displays have become ubiquitous for image presentation and user interface, and the accurate representation of colors on displays has required careful transfer of object color characteristics. Color management involves computing the correspondence of colors from one medium to another, accounting for the color and intensity of the lighting in a scene as well as the color balance and intensity of the display. The color reproduction of an entire imaging chain from capture to display describes how object colors in an illuminated scene are rendered on a display, whether accurate or intentionally enhanced [4].

Modern displays in mobile devices actively compensate for ambient illumination, automatically dimming the display and changing the white balance of the display in response to the user's environment. Ideally, these transformations are done in the paradigm of CAMs in order to preserve color appearance, but in some cases they may be simply applied to images as scale factors.

Many displays offer high dynamic range (HDR) and wide color gamut (WCG), increasing their capability to produce a wide range of colors. Because CAMs were mostly developed using reflective object colors at normal illumination levels, recent research has tested their accuracy and suggested improvements where needed [5][6]. Despite ongoing progress, CAMs have so far not been widely tested using XR colors and images.

4 COLOR IN EXTENDED REALITY

XR systems are constructed in a variety of form factors based on different engineering priorities, but at the core of any system is a display. Optical configurations can make the display appear further away, cover a wide field of view, and/or be transparent, all of which can affect the appearance of displayed content.

VR systems may be able to completely control the visual field, offering new opportunities to influence visual adaptation. Initial research shows that color accuracy and chromatic adaptation can measured and controlled in VR, but a VR CAM remains unstudied [7].

4.1 Scission in AR

AR systems with transparent displays enable the composition of real-world and virtual content in the same field of view, which further complicates color appearance. Physically, a transparent display adds virtual colors to the real backgrounds visible behind, but perceptually these two layers, virtual and real, may be seen as distinct in a phenomenon known as perceptual scission. Depending on the spatial configuration and the visual task, experiments have shown that viewers can discount the contribution of either the AR foreground or the real-world background when interpreting and matching colors [8].

Specifically, when AR foreground colors are compared and matched, the influence of the background is discounted [9]. Alternatively, when background colors are compared and matched, the AR foreground is discounted [10]. The extent of discounting, influenced by perceptual scission, varies widely depending on the visual cues of the layered presentation, including the alignment of AR overlays, luminance levels, stimulus complexity, and the presence of borders [11][12]. So far, a deterministic model of the extent of discounting according to these influences remains elusive, which means a full model of color appearance in XR also remains difficult.

Ongoing research aims to complete this model. More experimental data on the correspondence between AR and real-world stimuli in different configurations are needed, and proposed models of foreground-background blending must be verified and/or improved.

5 CONCLUSION

Color descriptions, colorimetry, and traditional color appearance models have developed based on reflective objects illuminated in real-world environments. Concepts describing color appearance and the effects of viewing environment have been successfully applied across media to printing and display applications. However, the viewing experiences of extended reality expose the limitations of these models. Ongoing research has uncovered visual responses, including scission, and shown what kinds of experimental data still need to be collected to create more capable models for color appearance in XR environments.

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