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ABSTRACT

This article discusses psychophysical aspects of color perception and critically examines the advice on color use in screen design found in non-empirical literature. There are four main characteristics of color: hue, brightness, saturation, and contrast. In multimedia screen design, color can be used to link logically-related data; differentiate between required and optional data; highlight student errors; separate screen areas such as prompts, commands, or input/output fields; emphasize key points; and communicate overall structure. The following guidelines are identified and then categorized in terms of consistency, color choice, and coding and cueing with color: use color conservatively; limit the palette per screen; design for monochrome displays, and then add color; increase color with user experience; use colors selectively to manipulate attention; color material is generally processed faster than the same material in black-and-white; use color in formatting and graphic displays; electronically generated colors take on different properties in relation to each other; wavelength affects color differentiation; and changes in brightness may cause changes in hue for all colors except blue, green, and yellow. Aesthetically pleasing screens can employ scientifically derived principles of instructional design. One way to approach the convergence of science and opinion is through the four critical aspects of connoisseurship: (1) ability to make fine discriminations; (2) development of a hierarchical system of concepts for making judgements; (3) development of principles to describe the structure of relationships among concepts; and (4) development of strategies to focus on salient aspects of the item being judged. (Contains 66 references.) (AEF)

The Art and Science of Color in Multimedia Screen Design, Part I: Art, Opinion, and Tradition

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Abstract

This paper confronts the non-empirical literature on the use of color in screen design and isolates and criticizes some guidelines which are commonly accepted among writers. The paper also considers the physiology of color perception and principles for using color drawn from the fine arts. Ultimately, an appeal is made for the development of a connoisseurial model of screen design.

Despite the paucity of clear direction available from the emprical literature on screen design (Misanchuk and Schwier, 1995a), there is no shortage of advice on how color should be used in screen design; a sizable literature exists which is composed largely or exclusively of non-empirical and experiential summaries.

There are traps inherent in such literature. Some experiential advice is non-representative or contradictory (one individual's experience compared with another's), some may be obsolete because the experience gleaned was on equipment that was primitive by today's standards, some may not be relevant because the generalizations were based on display media other than CRTs, and some involved tasks that were so different from those commonly found in instructional situations that their generalizability may be suspect. Some of it also appears to be trivial, simplistic or obvious. We don't mean to impugn experiential knowledge; it frequently has great value. What makes us uneasy about depending primarily on experiential knowledge is that we often don't know how (or even by whom) certain generalizations were derived, what kinds of tasks they were derived from, and, particularly, when they were derived (as that often is related to the state of the art of computing equipment).

How then does experiential information or advice have value? One often feels set adrift without guidance in the design of multimedia, and it is comforting to have guidelines—any guidelines—to justify decisions. A convergence of opinion is a good place to start when facts are scarce. At the same time, one must always be careful not to confuse a collective opinion with fact; such guidelines may in fact conspire to constrict creativity and promote the development of products which, over time, become hackneyed and trite. With these cautions in mind, this paper examines some phychophysical aspects of color perception and then critically examines the advice available in non-empirical literature.

Psychophysical Factors

To briefly review some rather well-established concepts, there are four main characteristics of color, each of which has importance in considering the use of color in screen design: hue, brightness, saturation, and contrast (Adkins and Pease, 1991; Durrett and Trezona, 1982; England, 1984; Faiola, 1990; Faiola and DeBloois, 1988; Murch, 1988; Tufte, 1992). Hue is what we generally identify as color, for example, red, blue, or mauve. Brightness (also known as luminance or value), is the intensity of light reaching the retina. A higher intensity is generally perceived as brighter, although individuals confronted with different colors at the same level of intensity will often perceive one as brighter than the other. Saturation (or chroma) is the interaction of hue and brightness, and is often referred to as the depth or richness of a color. Saturation of a color can be diminished by adding white light; pastel colors are de-saturated. Finally, contrast is the relative perceived brightness of two colors on a display, and it is related to the notion of figure-ground in visuals. Contrasting colors are easy to separate visually. Another factor which can interact with the four characteristics mentioned above is the amount and quality of ambient light—the natural or artificial light in the setting.

Specialized cells in the retina of the eye called cones provide initial color sensation through the stimulation of photopigments (light-sensitive chemicals). Most cones are concentrated in the centre of the retina, so that is the area of the eye most sensitive to

color, while little more than grays are perceived at the periphery of vision. Each cone contains one of three different types of photopigments, and each is sensitive to different wavelengths (colors) of light. Type 1 (blue photopigment) is insensitive to wavelengths longer than about 520 nm, so it responds exclusively to wavelengths in the blue to violet range. Type 2 (green photopigment) responds to everything, but is maximally sensitive to 535 nm. Type 3 (red photopigment) responds to everything, but is maximally sensitive to 575 nm. Color is determined by an interaction among the the three photopigments: the perceived color is a mixture of the relative responses of the red, green, and blue photopigments, in much the same way as a television camera creates color. Given a dramatic imbalance among the percentages of cells containing red (approximately 64%), green (approximately 32%), and blue (approximately 2%) photopigments, it is clear that the perception of color is both highly specialized and physiologically biased (data from Murch, 1988).

As well understood as the physiology of color is, it provides little explanation for our opinions of color and color combinations. At the very least, opinions of color are learned and highly associative. For example, as children we often had a "favorite color" and we liked everything—clothes, toys, books—that matched our preference. Over time, we learned a variety of color schemes, and in most cases our tastes become more refined. But even as adults, we are influenced by fashion, and may still associate our more sophisticated sense of color with increasingly more sophisticated emotions, desires, or impressions. For example, even a cursory examination of changes in interior design from the 1950s to the present reveals a dramatic evolution of what was considered warm or even comfortable color combinations. A lively debate still rages about the psychology of color, and various claims are made for using color in the environment to stimulate, calm, or enhance the performance of individuals.

Advice on Using Color

What advice is available about using color in screen displays? There is considerable consensus on guidelines, although most appears to be based on logical rather than empirical arguments, and there are a few significant contradictions. Indeed, some of the more substantial guidelines emerge from the tradition of print (see for example, Horton, 1991; Waller, LaFrere, and MacDonald-Ross, 1982). One cannot easily judge from the material whether the consensus is based on independently derived judgements, or primarily on a shared and confined literature. In the following section, advice is broken into the categories of amount of color, consistency, compatibility, and legibility. Principles or guidelines within each category are listed along with sources of the advice.

We want to emphasize that the authority for the guidelines offered is variable, and the comments offered after each set of principles are intended to summarize the main consensus of opinion rather than endorse one explanation or approach. For example, we generally agree with the advice to limit the number of colors of items on a single screen, but we had a great deal of difficulty dealing with the explanation offered in one article:

> For memory's sake, a limited number of color codes should be employed in most contexts. Users have recognized more than 50 colors with training, but the average user shouldn't be expected to remember more than five to seven colors. This is the "magic

- Use color conservatively: limit the number and amount of colors used (Brockmann, 1991; Durrett and Trezona, 1992; Garner, 1991; Horton, 1991; Shneiderman, 1992).
- Limit the palette per screen to what the eye can actually keep track of at one glance (usually about six colors depending on the complexity of the screen design). (Bailey and Milheim, 1991; Baker, 1983; Faiola, 1990; Faiola and DeBloois, 1988; Hoekema, 1983; Milheim and Lavix, 1992; van Nes, 1986).
- Design first for monochrome displays, and then add color (Brockmann, 1991; Garner, 1991; Shneiderman, 1992).
- Long term users are capable of perceiving and responding to a broader range of color and coding relationships, so the number of colors used can increase with experience (Faiola, 1990; Faiola and DeBloois, 1988).
- Use colors selectively to manipulate attention. Color can be used to highlight text or graphics to make them conspicuous (Durrett and Trezona, 1992; Garner, 1991; van Nes, 1986).
- "Material presented in color is generally processed faster than the same material presented in black-and-white." (Durrett and Trezona, 1992, p. 16).
- Use color to help in formatting (Shneiderman, 1992).
- Use color in graphic displays for greater information density (Shneiderman, 1992).
- Electronically generated colors take on different properties in relation to each other (England, 1984).
- Wavelength affects color differentiation: luminance affects legibility (England, 1984; Murch, 1984).
- Changes in brightness seem to cause changes in hue for all colors except blue (470 nm), green (505 nm), and yellow (572 nm). These should be used where color shifting due to luminance changes would be detrimental (Horton, 1991).
- As viewers age, higher levels of brightness are needed to distinguish colors.

As evidenced by the above principles, designers are less captivated by color than one might anticipate. The most resonant advice among writers is to limit the amount of color to what is useful or necessary, depending on the purpose of the product being developed. The notion of designing for monochrome first, and then adding color, seems to offer a practical method of harnessing an indiscriminate use of color. Another striking feature of the advice is the role played by luminance in the portrayal of color. An instructional designer must consider more than hue when designing screens for legibility, contrast, and constancy.

Consistency

- Be consistent in color choices (Brockmann, 1991; Faiola, 1990; Faiola and DeBloois, 1988; Milheim and Lavix, 1992).

- Carefully select colors for all visual devices such as touch screens, buttons, menus, and titles (Faiola, 1990; Faiola and DeBloois, 1988).
- Color can assist learning if used as a redundant cue (Durrett and Trezona, 1992).
- If color coding is used in an information system, it should be used consistently (van Nes, 1986).

Using color consistently may sound like obvious advice, but it is advice often ignored. Consistency is a hallmark of good instructional design; if items are consistent throughout instruction, then the learner can devote more energy to dealing with the content of a presentation than to learning (and re-learning) the conventions of the delivery system.

Choice of Color

- In selecting color combinations, make sure they are compatible (avoid saturated complementary colors such as blue/orange, red/green, violet/yellow) (Bailey and Milheim, 1991; Brockmann, 1991; Durrett and Trezona, 1992; Faiola, 1990; Faiola and DeBloois, 1988; Milheim and Lavix, 1992). Murch (1984) qualified this advice. He argued that opponent colors, especially desaturated colors, can go well together for simple color displays.
- Gray is a versatile color (Tufte, 1992). Use gray in inactive screen areas and backgrounds to enhance two or three other colors (Bailey and Milheim, 1991; Faiola, 1990; Faiola and DeBloois, 1988; Milheim and Lavix, 1992; Tufte, 1992).
- Avoid background colors too high in brightness and saturation (Bailey and Milheim, 1991; Faiola, 1990; Faiola and DeBloois, 1988; Horton, 1991; Milheim and Lavix, 1992).
- By contrast, against gray backgrounds use light, highly saturated borders for active windows. One suggestion is that yellow is only color satisfying this (Tufte, 1992), while others argue that one should always use red, white, or yellow text on black (Durrett and Trezona, 1992). Regardless, attend more closely to brightness than hue for building contrast for legibility (Brockmann, 1991; Faiola, 1990; Faiola and DeBloois, 1988; Horton, 1991).
- Similarly, use high color contrast for character/background pairs. Incorporate shape as well as color when possible to make the system usable by color-deficient people (Bailey and Milheim, 1991; Garner, 1991; England, 1984; Milheim and Lavix, 1992; Tufte, 1992).
- Dark text on a bright background is more legible than the reverse (van Nes, 1986).
- Avoid using red and green on the periphery of vision (at the edges of screens), if you want people to notice those elements. People are less sensitive to red/green at the periphery of vision. If you must, then make items blink before resorting to continuous display to attract attention (Durrett and Trezona, 1992). Don't use blue for text— "limit blue to large nonfoveal areas" (Durrett and Trezona, 1992, p. 14), but use it as a background color to enhance depth perception (Horton, 1991).

- Strong colors should not be used over large adjacent areas. Use strong colors sparingly between dull background tones (Horton, 1991; Tufte, 1992).
- Avoid using pure blue for text, thin lines, and small shapes. Individuals have difficulty focusing on blue (Horton, 1991; Murch, 1984).
- Use colors found in nature, particularly toward the lighter side: grays, blues, yellows. These colors are widely considered harmonious. (Tufte, 1992).
- For color-deficient users, use dramatic changes in color to discriminate among elements by making changes in at least two of the three main colors. For example, displays in which only the red pigment is changed, while blue and green remain constant, will cause problems for color-deficient observers (Murch, 1984).

The literature of advice on color choice goes dramatically beyond issues of aesthetics. Many of the recommendations are based on the physiological response of the eye. For example, the advice on how to use blue is based largely on the inability of the eye to focus clearly on blue images. Thus, the general advice is to relegate blue to a supporting role in screen design. There are, however, aesthetic concerns that complement the physiological explanations. Many writers expressed displeasure with garish color combinations, and one went so far as to call for the harmonious colors found in nature. Regardless of whether the justification is scientific or aesthetic, the general consensus of opinion is to avoid using highly saturated, bright colors for text, large areas, and backgrounds; or adjacent to other strong colors from the extremes of the color spectrum. Contrast should be built by carefully using color on muted or subtly-colored backgrounds.

Coding/Cueing with Color

- Color coding can link logically related data, differentiate between required and optional data, highlight errors, and separate prompts, commands, and other elements in the interface (Adkins and Pease, 1991; Rambally and Rambally, 1987).
- Use commonplace denotations (red = danger, yellow = yield) (Adkins and Pease, 1991; Bailey and Milheim, 1991; Brockmann, 1991; Durrett and Trezona, 1992; Faiola, 1990; Faiola and DeBloois, 1988; Horton, 1991; Milheim and Lavix, 1992; Rambally and Rambally, 1987). Care must be taken to ensure that denotations are indeed shared, as some are culturally determined, such as the colors of political parties. Similarly, resultant "cultural connotations" may emerge, such as red denoting socialism, in turn connoting revolution (Waller, Lafrere, and MacDonald-Ross, 1982). These denotations and connotations may not be shared by different cultures.
- Choose distinctive hue, brightness, and saturation differences for discrimination among major items. Poor color memory may be overcome by carefully using color to enhance discrimination (Faiola, 1990; Faiola and DeBloois, 1988).
- As with all uses of color, consistency is crucial when using color for coding information. (Durrett and Trezona, 1992; Shneiderman, 1992).
- When a quick response is necessary, use colors with higher degrees of saturation (Faiola, 1990; Faiola and DeBloois, 1988).

- Ensure color coding supports the task (Shneiderman, 1992).
- Have color coding appear with minimal user effort (Shneiderman, 1992).
- Place color coding under user control (Shneiderman, 1992).
- Be alert to common expectations about color codes (Shneiderman, 1992).
- Use color changes to indicate status changes (Shneiderman, 1992).

All of the advice about using color for coding information emphasizes one simple principle: color is one dimension of communication, and to exploit it well requires us to use in consciously and deliberately. Color can be used to accomplish a wide array of instructional tasks, but it can also be used to interfere with communication if it is used thoughtlessly or clumsily.

A Connoisseurial Approach

The literature does not favor exclusively either a scientific or experiential treatment of screen design. To consider screen design as a bipolar issue with rational and creative emphases at either end of the spectrum creates a false dichotomy. We favor an connoisseurial treatment where science and opinion both have value and can contribute to a rich understanding of how screens can be designed for multimedia presentations. Aesthetically pleasing screens can employ scientifically derived principles of instructional design, and well designed instruction can be creative and pleasing to view.

One way to approach the convergence of science and opinion in screen design is through a model of connoisseurship. A connoisseur has a refined set of skills and principles for making judgments. Belland (1991) discussed four critical aspects of performing connoisseurship. First, a connoisseur must be able to make fine discriminations; that is, perceive differences and elements that are too subtle for unschooled individuals to notice. Next, the connoisseur develops an hierarchical system of concepts for making judgments. Systems of key ideas and subordinate notions are developed, even if not articulated to others. Third, principles are developed to describe the structure of relationships among concepts. How, for example, might animation and sound be used to convert a dramatic scene to a comedic scene? Finally, a connoisseur develops strategies to focus on salient aspects, and ignore less important aspects of the item being judged.

It is clear that to develop a connoisseurial appreciation for multimedia, one must be informed about both science and opinion. A connoisseur draws on a broad body of experience which allows the work being examined to be interrelated with other significant works. It is also important for a connoisseur to give attention in an analysis to those elements which are important (ignoring or downplaying trivial elements), and to reflect on the meaning of the new experience. Judgments are made within a context of acquired knowledge, taste, and experience, and aesthetic judgments are amalgams, not precise articulations of specific rules.

Conclusion

Remember to consider the entirety of the above advice within the context of projects, not as a set of generalizable principles. Consider your project and its design as whole cloth rather than a series of micro-decisions to be made. "Design quality and consistency grow from a coherent set of ideas, not from personal taste or committee compromises, not from the baggage of past user interfaces, not from the ad hoc reasoning about each little part of the computer screen" (Tufte, 1992, p. 15). One can extract guidance on the use of color exclusively from the empirical literature or from less rigorous sources, but peril lurks in both camps. We need more and better studies about color in screen design to be sure, but we also recognize the value of judgement, common sense, and a refined connoisseurial sensitivity.

Given the literature we have reviewed, we conclude with the single best piece of advice regarding the use of color in screen design that we have found :

"Above all, do no harm." (Tufte, 1992, p.16)

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