

## Color Theory and Pixels & Bytes

**Definition** Color Theory is the study of the effect colors exert on the mental and physical conditions of humans. Color is used to express various emotions, to spark reactions, or to inform.

**Introduction** In this reading, we review the fundamentals of color because a knowledge of color theory will inform about web site designs, how computers represent color digitally, and expand your understanding of the use of color in our world.

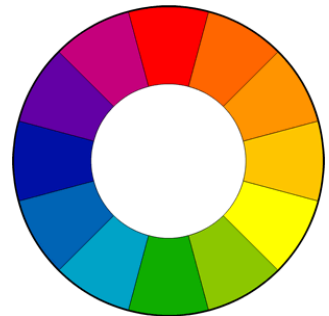
See also: Color Theory readings from the Information Visualization and Visual Communication classes. Also *The Power of Neutral Gray* reading for this class.

There's a famous tale about UNESCO funding a program in the 1980s to teach illiterate Tibetan women about prenatal care. The images describing pregnancy and the movements expected in delivery and care of the newborn were drawn and actions (changes in state) were represented using the color red. The designers felt using red would be the most informative color, drawing the attention of the women to the critical parts. However, the program backfired. The color red had no significance of immediacy or attention-getting to the target audience.

Color in some cultures are special, almost sanctified. In Apple Computer's *Human Interface Guidelines*, both symbols and colors are described for software developers so they don't unwittingly choose symbols or colors that would convey unintended messages. Green, for example, was to be avoided in Muslim countries. Icons of people touching someone else's head were to be avoided in Southeast Asia.

Some color issues are biological. As humans age, the retina's sensitivity to color changes - our eyes become less responsive to colors in the blue range, shifting them slightly towards yellow.

For students of library and information science, color theory raise questions of the suitability of screen designs, messages and signage, and provides an extra basis for evaluating the suitability and effectiveness of the information systems we design or use.






### Color Wheel

Thanks to Isaac Newton, in 1661, the basis of all color studies was created - the color wheel. The twelve colors of the wheel are intended to appear aesthetically well together. It forms, also, the basis for the "Red Yellow Blue" (RYB) or "artistic" color model. Two or three of these colors together create "color harmonies" or "color chords." We create combinations of colors from the color wheel by adding or subtracting colors (subtractive color model). What follows is a systematic consideration of colors.

### Primary, Secondary, and Tertiary Colors

Pick an object (an apple, a poster, anything) and stare at it for about a minute. Then look at a white wall. You will see the image you stared at, but not in the original colors. What you'll see is the image but expressed now in its **complementary** colors - colors that create pleasing harmonies. To make this phenomenon more concrete, colors are usually divided into primary, secondary, and tertiary colors.

*Primary* colors are the lowest, most fundamental colors in the RYB model: red, yellow, and blue. By mixing two of the primary colors, we create *secondary* colors: green, orange, and purple. Mixing primary and secondary colors together creates the other six colors, the *tertiary* colors.

| <b>Primary</b><br>red, yellow, blue   | <b>Secondary</b><br>green, orange, purple   | <b>Tertiary</b><br>yellow-orange, red-orange,<br>red-purple, blue-purple, blue-green,<br>yellow-green |
|---|---|---|
|  |  |                    |

**Cool and Warm Colors**

Colors, like wine, has subtle under currents. *Warm* colors have a red undertone; *cool* colors have a blue undertone. In design, warm colors express movement, energy, change and suggest movement towards the viewer (hence UNESCO’s use of red in the Tibetan example). Cool colors are supposed to relax. (Think of the tv show *The Simpsons* second grade teacher, Miss Hoover, who chants “Calm, blue ocean” to herself when she gets stressed.)

Taking pictures (or digitizing) images indoor with indoor lighting will create a blue-yellow tinge to the images.

White and Black are not actually colors - they’re tints and shades. White is also technically the absence (or entirety) of color; black is also the absence or entirety. Natural light, as you know, can be split by a prism to reveal a spectrum, like a rainbow. In the physical world, white paint, for example, is created by mixing compounds, such as the infamous “lead white”, that reflects light. Black, historically created by using soot (carbon) or later tannins or other compounds, absorbs light. By adding white to any other color, the resulting color is a **tint**; adding black creates a **shade**. Mixing in gray creates a **tone**.

**Standards**

There are far more combinations of colors possible than the human eye can sense. All possible colors create a 3D object called a **color space**. [This is described in the advanced note below.] The International Standards Organization (ISO) has standards for certain colors. The most important for LIS is the “neutral gray” that is used for lighting and backgrounds in creating digital objects.





Graphic designers use standards based on what color manufacturers use (such as Pantone Matching System (PMS)) or by stipulating the combination of colors and percent or value needed to create the new color.

Red-Green-Blue (**RGB**) is expressed in a decimal value from 0-255.

Cyan-Yellow-Magenta-Black (**CYMK**) combinations are percents.

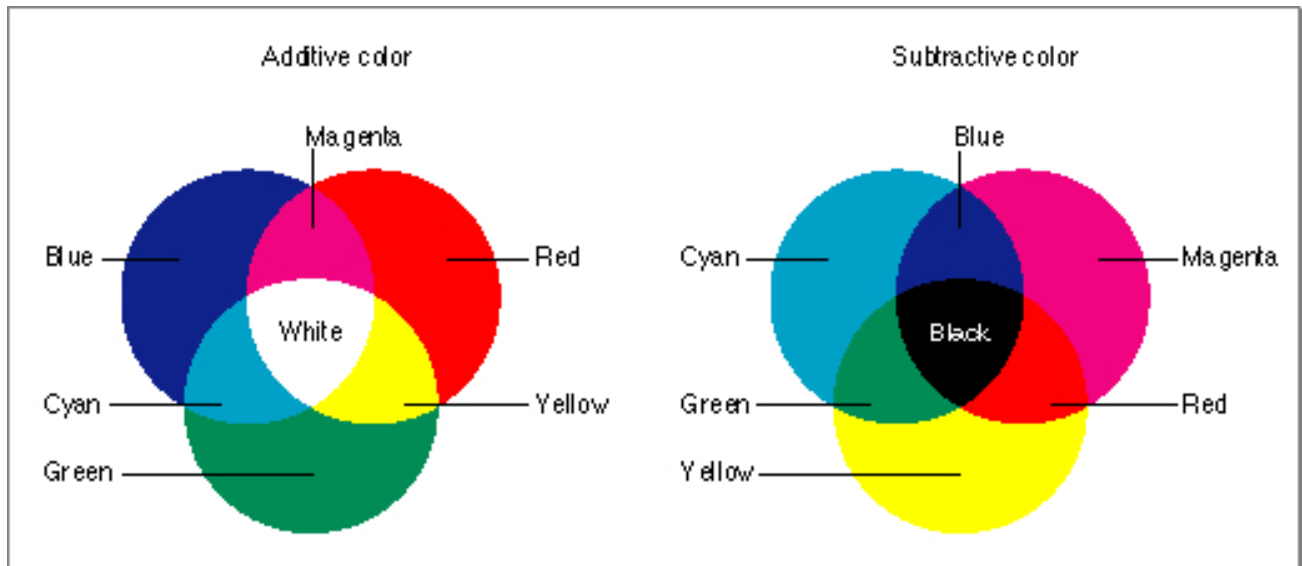
Hue-Saturation-Brightness (**HSB**) is degrees of hue and percents of saturation and brightness. [Brightness refers to the amount of white in a color; Saturation refers to the amount of color used - if at full saturation, it is vibrant; if “desaturated”, the color tends towards gray.]

HTML colors in hexadecimal triplets of pairs of ## red, ## green, ## blue.

| Color name | red   | blue  | green  | orchid  |
|------------|---|---|--|---|
| Sample     |  |  |  |  |
| RGB        | 255 0 0   | 0 0 255   | 0 120 0  | 102 102 255   |
| CYMK       | 0 80 94 0   | 87 62 0 0   | 75 5 99 17   | 60 38 0 0   |
| HSB        | 359° 100% 100%  | 240° 100% 100%  | 120° 100% 100%   | 240° 60% 100%   |
| PMS        | 185   | 286   | 357  | 279   |
| HTML       | FF 00 00  | 00 00 FF  | 00 FF 00   | 66 99 FF  |

Adobe Illustrator drawing software has a template document of all colors based on the Pantone number.

**CYMK:** Printers use CYMK color to express any color we can see and by overlapping colors at particular angles, the eye will harmonize them into a single color. From the *additive* primary colors of RGB we see the *subtractive* colors in CYMK:



Imaging each color is assigned a value, between 0 and 1.0. If we added 1 magenta + 1 yellow we create red (in the CYMK model).

### Color Harmonies

There are six harmonies to consider: complementary, analogous, triadic, split-complementary, rectangle (tetradic), and square.

**Complementary** Reminiscent of the “Circle of Fifths” in music, complementary colors are systematized in the color wheel as being opposite from each others. Red and green, for instance, are complementary. However, complementary colors are tricky: they’re useful if you want to yell, as it were, in color. Because of the clashing effect of paring complementary colors, they are not useful for text.

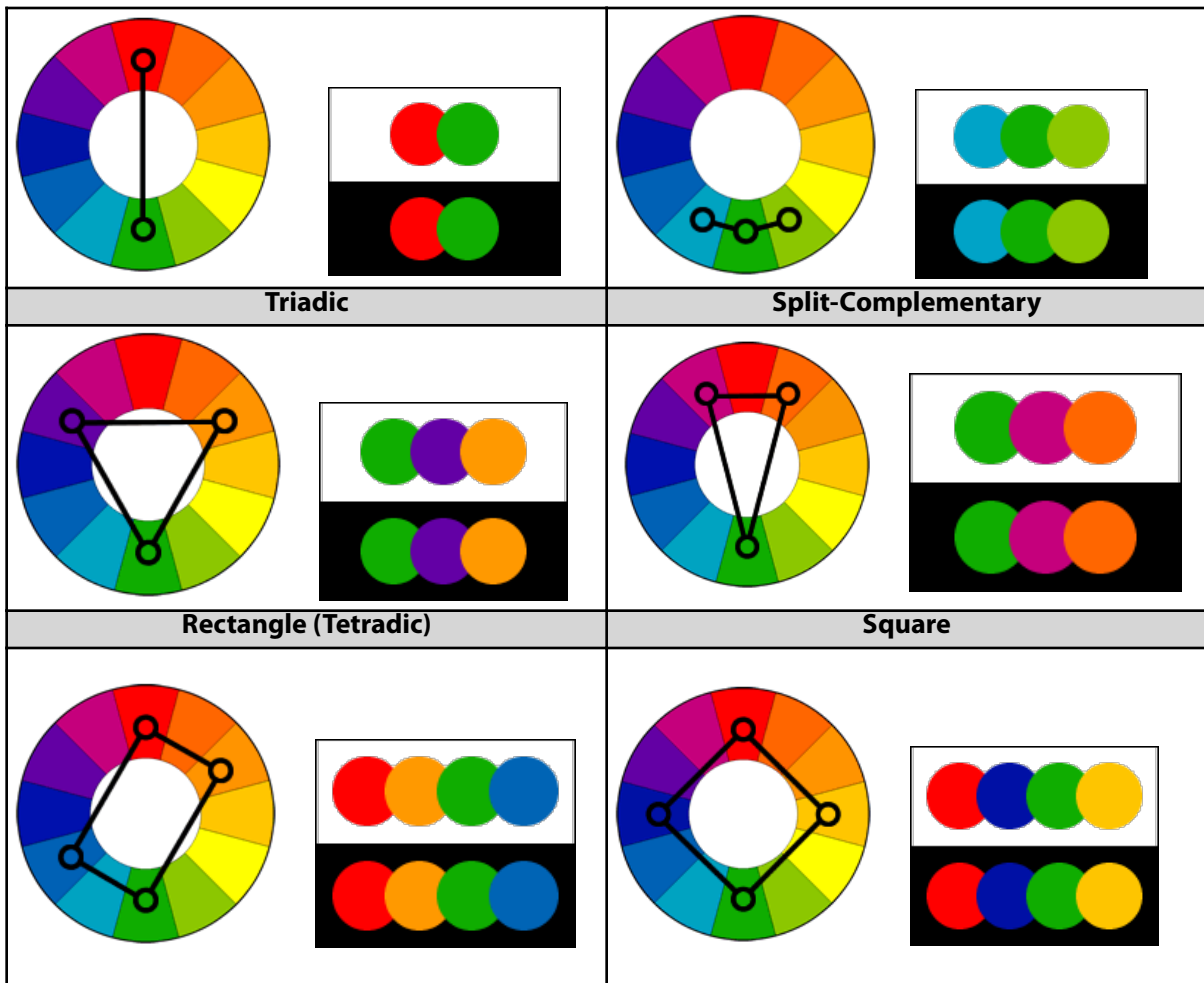
**Analogous** colors are neighboring colors. Because analogous colors are considered pleasing, soothing, and bound to nature, it has become a kind of rule of thumb in design to select three colors: one main color and then one to support as a complement the dominant color and one to use as an accent. [For an example, check out any some website templates in blogs; or a well-planned repainted Victorian house.]

**Triadic** color suggests a chord: three colors spaced evenly around the color wheel. Triadic color is similar to analogous color in design but is usually considered to be more energetic. Not a bad choice for a high school football team.

**Split-Complementary** as the name suggests is a variation of the Complementary scheme. Select a base color and then use two colors adjacent to its complement. This creates a strong visual contrast, but there’s less tension or anxiety felt in the colors. This is often the best choice for neophytes.

**Rectangle (tetradic)** and **Square** color schemes uses four colors - arranged into two complementary pairs. The rectangle (being longer than it is wide) creates a lot of opportunity for color combinations. Consequently, select one color to dominate the others, otherwise the visual design is mess. When selecting rectangle or square schemes, select warm colors or cool colors - don’t mix-and-match.

|                                   |                  |
|-----------------------------------|------------------|
| <b>Complementary color scheme</b> | <b>Analogous</b> |
|-----------------------------------|------------------|

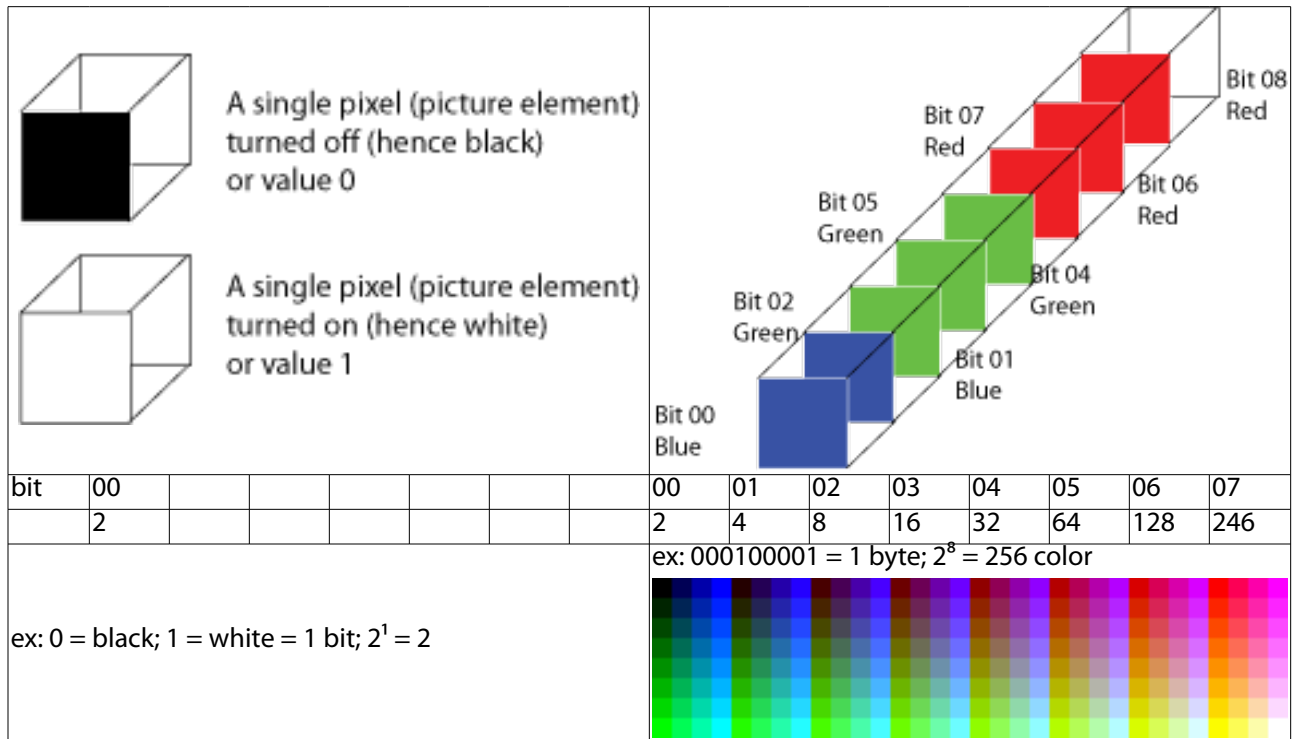


**From Color Theory to Computer-based Color**

The above relates also to computer screens, output devices (anything from a laser printer to heat-transfer printers to cell phones and the confines of digital art) because our interest in color, like everything else computational, must be converted into something a machine (the computer) can handle. Computers deal in bits - a state, like a light switch, that has two options - on and off (aka 1 and 0, aka true and false). If we have one light switch with 2 states (on and off), we have a **bit**. [Review the Character Encoding topic sheet for more.] Here, the color options are either white (on) or black (off). This is 2-bit color. The lowest type of color in a GUI environment is 8-bit color. Again, two switches (off and on) but now they can display red, green, or blue (when turned on) else black (turned off). Eight switches with 2 states is 2<sup>8</sup>, which equals 256. So, a single pixel (a picture element, the tiniest dot on the screen) is composed of three colors combined in that single dot.

|                                   |  |
|-----------------------------------|--|
| A single bit - 2 <sup>1</sup> = 2 | A single bit with 8 colors - 2 <sup>8</sup> = 256 colors |
|-----------------------------------|--|

## Color theory, Pixels, & Bytes



8-bit color is sometimes referred to as **system color**, because originally computers that supported color supported only 8 bits of color. As computers became more powerful, it became possible to assign 16 0s-and-1s to each pixel. This creates  $2^{16}$ , 65,536 colors. [It's also the number of characters in the current version of Unicode. Hmm...] Here's an example of how there's a range of possible colors, then how certain bits are turned on (as well as how saturated the color is) to create new colors. This example is only 8-bit; imagine 16-bit ( $2^{16}$ , or 65,536) colors, or 24-bit color, ( $2^{24}$ , or 16.77 million colors).

## Color theory, Pixels, & Bytes

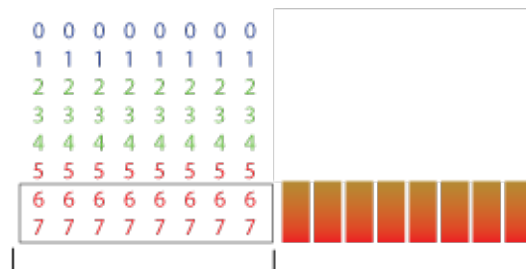
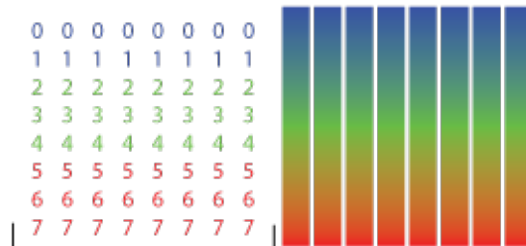
Single bit  
B&W color


0  
1

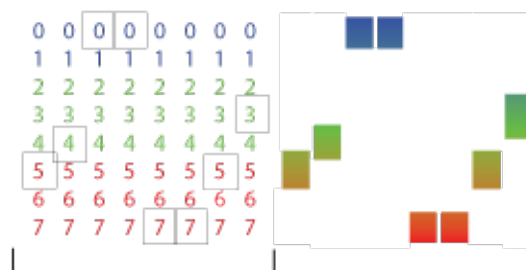



Only possible outcomes: black or white

Single byte  
8-bit color



Add the values to get this new color: 



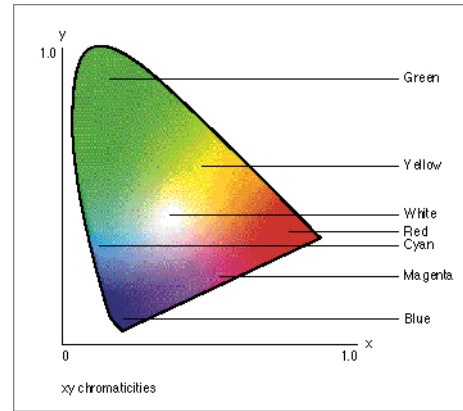
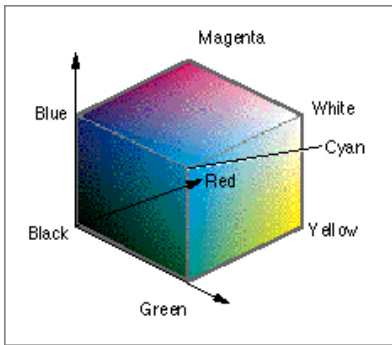
Add the values to get this new color: 

The pixel depth is important to remember when digitizing an image. If someone scanned an image at 24 bit color, then the image size will be the height in pixels times the width in pixels times the pixel depth. For example, an image that is 72 pixels by 72 pixels (1" square)  $\times$  24 pixels = 124,416 bytes (125k). But imagine digitizing an image as a tiff at 64-bit color. The same image would be 331,775 bytes. An 8½"  $\times$  11" image scanned in at 300 dpi (dots per inch) with 64-bit color would be  $(8.5 \times 11 \times 300) \times 64$ , or 1,795,200 bytes (1,795k).

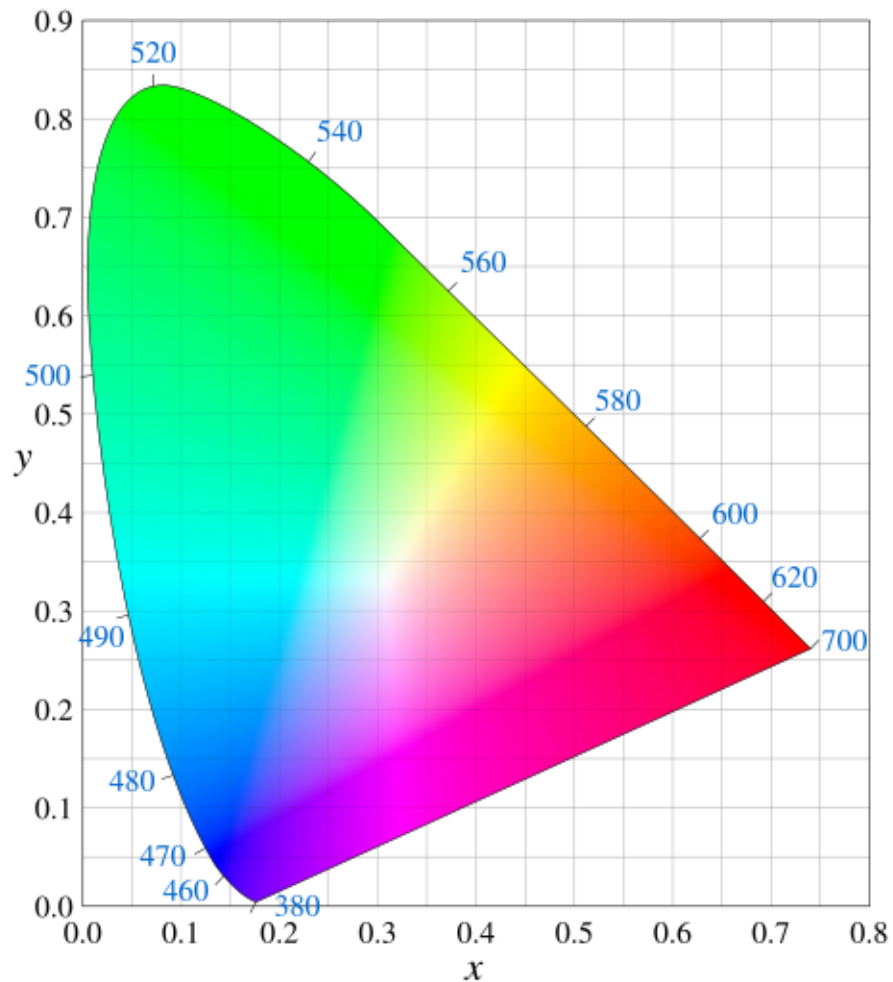
### Advanced Note:

As an advanced note, in human-computer interaction and visualization studies, colors are expressed in 3D space with a value of X, Y, and Z (aka tristimulus values), created in 1920s by David Wright and John Guild, that became a standard of the International Commission on Illumination (CIE) in 1931. This is the one of the first mathematically defined color spaces. These images show the familiar RGB color as a 3D object, then flattening the object to create what's called the Yxy chromaticities in the CIE color space.

# Color theory, Pixels, & Bytes



In this final image, notice the x, y values (in black) and the z value (in blue). Every color possible (in the range of visible light) can be identified uniquely.



For this class, you aren't responsible for knowing this but it is nevertheless interesting to see the continuous spectrum of color represented (the spectral power distribution) converted into a numeric value that in turn is used by computers, and thus something *you* can manipulate. A histogram of these data is what you see when you use iPhoto or a digital camera.

[end of the advanced note]

Besides “RGB”, there is “**RGBA**” - red, green, blue, and “alpha”. The **alpha** channel is used to express how opaque an image is. We can change the alpha value from 100% (fully opaque) to 0% (transparent). Most software (Photoshop, Illustrator, etc) express the alpha channel in hexadecimal, thus the values range from 0 to 255. Using the standard prefix 0x to indicate what follows is hex, here is an example of the alpha channel first and then RGB: 0x80FFFF00 . The **.png** (Portable Network Graphics, a bitmapped image format, using lossless data compression) image format uses RGBA. The MIME type for png is “image/png”.

In passing note that half of 256 is 128. In hex, 256 is the same as 0xFF; 128 is 0x80. So, if you see 0x80 you know something is 50% of its full strength. 0x80FFFF means something is 50% of 100% red (FF), 100% of green (FF), and 100% of blue (FF). white (or gray). [Often in computing what we humans think of something progressing from low to high (low color to high color, 0 being white and F being black) is usually expressed in computers the other way around! 0 is black; F is white.] The alpha channel plays a vital role in multimedia and increasingly in website design. As browsers and cascading style sheets have become more robust, we think no longer of just the x, y positions on the screen but also the z position. The z axis is to emulate 3D. For example, we can use absolute positioning to lay an image over an other image. By changing the alpha channel of the upper picture, we can look thru the transparent image to the image below it. There’s an example on the upload and quiz homepage source.

Besides the obvious need to know how to use color for websites and legible signage, color plays a great role in the history of art and design. Georges Seraut (1859-1891) was a French painter who was as much chemist as artist. He experimented with color, perception and optical effects. [Note that his work was at the same time that German and Swiss chemists were discovering new ways to create dyes and there was an explosion in fashion and the arts of color. The Danube River, unfortunately, bore the brunt of this polluting research.] At this time, we see interesting developments and at the time contradictory experiences between color as created by mixing light and colors created by mixing material pigment. The studies from both Newtonian and Michel Chevreul (1786-1889) perspectives, Seraut recognized the halo effect (hinted at above) as one color creates its complementary color. He combined his scientific experiments with art - to the effect of creating a neoimpressionist school, pointillism - the use of countless small dots of color that the brain fuses into recognizable, colored shapes. We benefit daily from Seraut’s work: the use of half-tone images in newspapers and magazines. [More on that shortly.] His most famous work is the 1884 *Un dimanche après-midi à l’île de la Grande Jatte*.



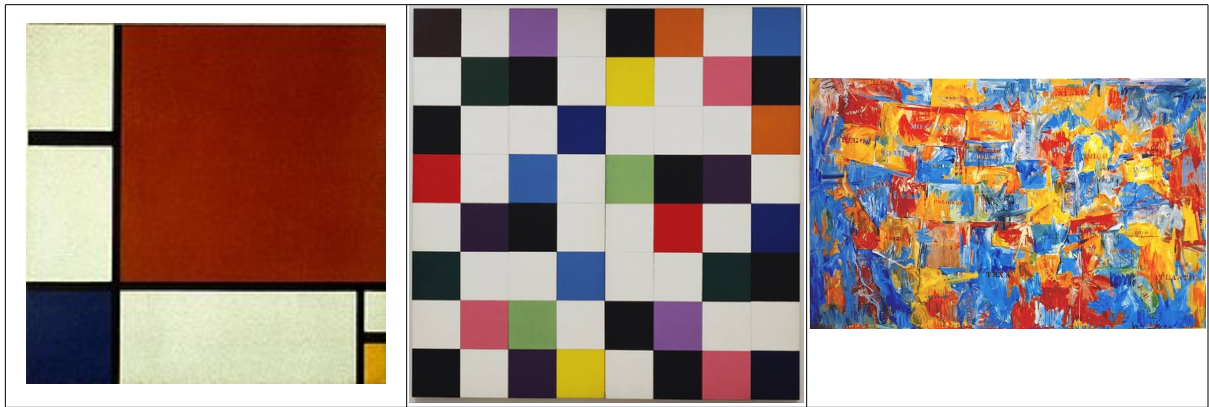
A knowledge of color theory was also critical to modern art movements, our understanding of those movements’ significance, and as a key to understanding more about the visual world around us. The works of Piet Mondrian (1877-1944) *Composition II in Red, Blue, and Yellow* (1930), Ellsworth Kelly (1923 - ) *Colors for a large wall* (1951), Jasper Johns’s (1930 - ) *Map* (1961) are three of innumerable examples. Such knowledge is equally vital to our understanding the development of printing, advertisement, and electronic media.

**Mondrian**

**Kelly**

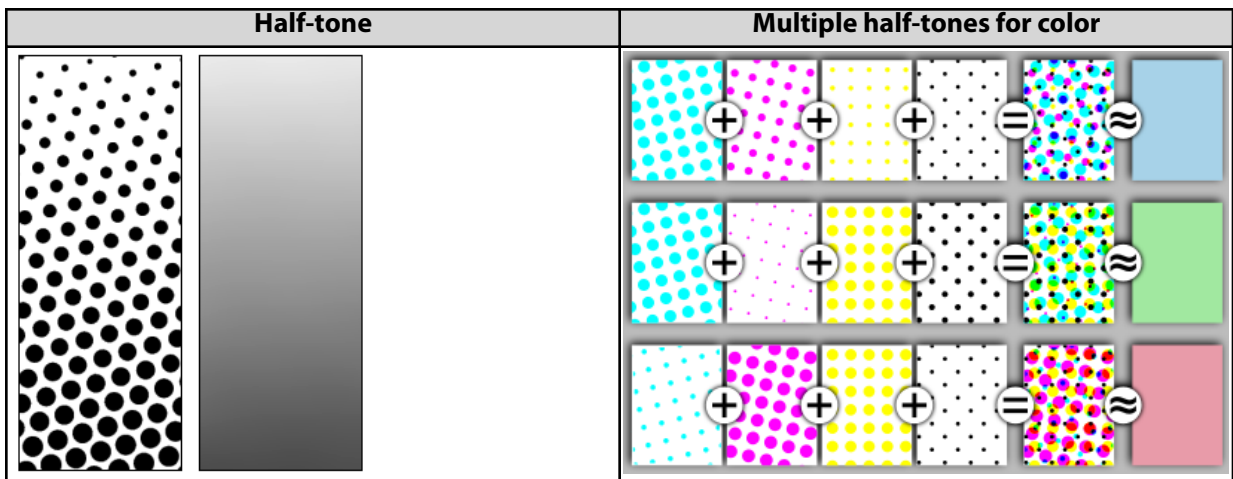
**Johns**





**Half-tones**

To express an image in print, such as a photograph in a newspaper, the continuous tone of the color (the smooth transitions from one color to another) have to be converted into something the printer can do, such as the way letters are individual shapes. So images had to be broken down from a single continuous tone (that would print like a giant blob of black ink) to thousands to little dots of various sizes that collectively trick the mind into seeing a smooth image. This technique, called half-tone, was developed in the 1850s by William Talbot. Without going into details here, we want to focus on three things: the dots, the resolution (number of dots per inch (**dpi**) or here, lines per inch (**lpi**), and the overlaying of colored dots to create smooth images.

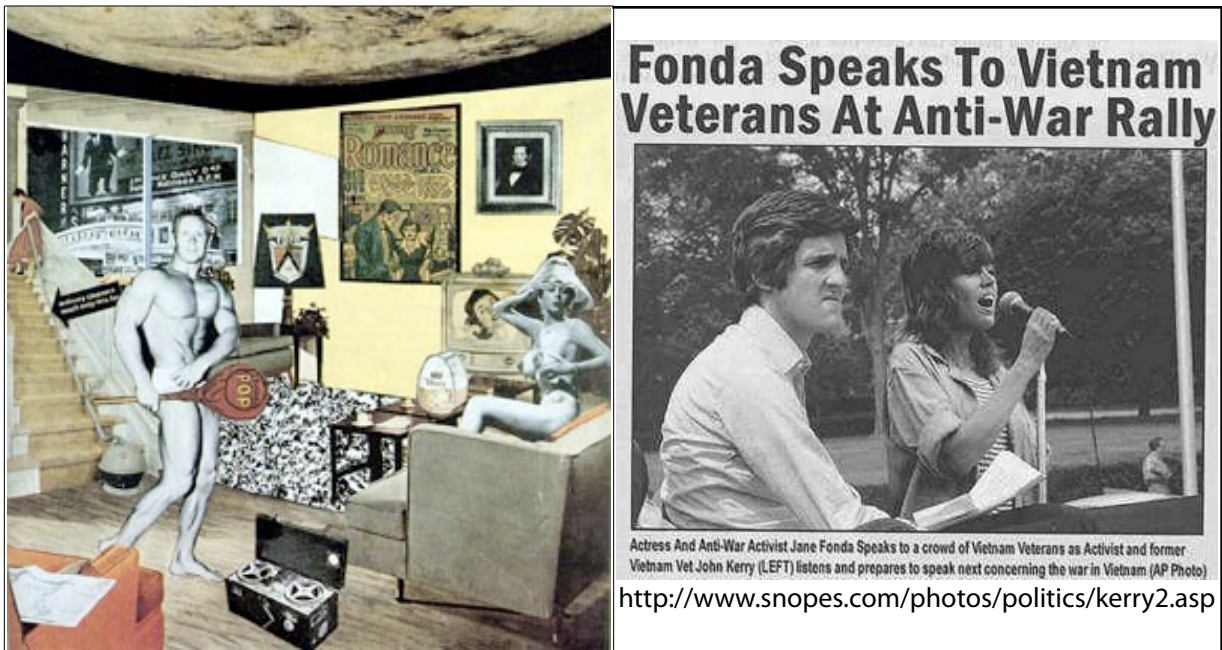


This is important to remember when you create a digital image because the quality of the image is dependent upon the output device. If you take a photograph at 300 dpi, 24-bit color, at 8 1/2 x 11, you would expect a beautiful image. But the computer screen is probably about 45-65 lpi; the office laser printer is probably also 300 dpi or 65 lpi; the better printer at 600 dpi is only 85-105 lpi. Professional printers use photographic film of beyond 2100 lpi.

It is fun to note in passing that modern artists understood not only the interplay of color but the impact technology exerted. Most famously here, perhaps, is Roy Lichtenstein.



**Summary** Anyone involved in the creation, interpretation, or evaluation of a visual medium - and websites, OPAC interfaces, signage, etc. are visual media - ought to be aware of the role color plays as a visual communicative medium. Color can be used to imply, to calm, to agitate, to express a great deal of data and information in a small space. Computer software facilitates altering color and transparency. It also helps to express ideas and to manipulate reality. Here's Richard Hamilton's vision of the *American Dream* - an early collage of photo imagery. And following that is a spoofed image, creating using Photoshop, that was used as evidence that Jane Fonda and John Kerry attended an anti-war rally (they didn't). Anyone familiar with Soviet and Chinese history is aware of the changing political scene by air-brushing out someone in disfavor or inserting someone who wanted to rewrite history.



Increasingly the world of information visualization (using computers to express and to expose through graphics relationships in tremendously large sets of data) has infiltrated the world of the OPAC, such as "semantic clouds" or "word clouds" or hypergraph ("fisheye") representations of resources from a library's collection.

## Color theory, Pixels, & Bytes

The volume of digitized data available to the public has grown to such tremendous levels that visualization techniques are the future and successful visualization relies on our understanding of color, technology, and human reaction. There remains, too, the need for an ethical vanguard to watch for manipulations of reality and falsification of evidence.

**Additional** Watch this YouTube video about color space  
<http://www.youtube.com/watch?v=x0-qoXOCOow>

### References

<http://www.d-zignsinc.com/view/pantone.html>  
<http://www.library.cornell.edu/preservation/tutorial/contents.html>  
<http://www.snopes.com/photos/politics/kerry2.asp>  
[http://wapedia.mobi/en/CIE\\_1931\\_color\\_space](http://wapedia.mobi/en/CIE_1931_color_space)