Summary of Comments on ColorTutorial.pdf

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Author:
Date: 2/3/1998 2:44:33 PM -08'00'

Hi! Welcome to my tutorial on Color. Most of the pages have annotations which summarize what I say when I give this presentation orally.

You might consider choosing "summarize notes" from the "tools" menu item. This will create a new PDF file which you can print. You can read along without obscuring the slides.

I hope you enjoy looking over this presentation. I've tried very hard to make the material clear.

Jim King - 2/3/98

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'
This author is very popular and this is the title of his first book.

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Author:
Date: 2/3/1998 11:10:22 AM -08'00'

I have been a serious student of color for the last eight years. As I began to digest the material and begin to own some of the concepts, I was amazed at how many incorrect things I had learned. Upon reflection, it seemed I learned many of them when I was in 3rd grade.

Like I remember people telling me that white light is really all colors and you can see that by shining white light through a prism.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

This is only a half-truth. We will look into this issue in more detail.

Here is white light being shown through a prism which produces the classic rainbow of colors.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

I remember this fleeting thought that the rainbow didn't seem to have enough truly different colors to have all of them. It doesn't seem to have pastels. What do you think? Can you find a place in the standard rainbow where the teal green of the old Adobe logo shows?

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Author:
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Well the standard rainbow obtained with a prism does not have the Adobe teal green! It does not have any pastel colors.

There is some truth to the statement that white light contains all colors but they do not reveal themselves with a simple prism.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

I have invented a Rube Goldberg machine to help explain this. We start by adding an "anti-prism" that reverses the effects of the prism. The light from the rainbow spectrum is collected and mixed together and projected upon the wall. This results in the same white light that we started with.

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Author:
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This is the key part. We add a "valve" or zipper or draw string in the path between the prism and the anti-prism. It has the property that it can be openned and closed to any degree desired at any spot along the color spectrum of the rainbow.

In this first example, the valve is closed everywhere except in the specific orange part of the spectrum. So only that particular orange color is allowed to pass and be projected onto the wall. All other colors are blocked.

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Date: 2/3/1998 3:38:36 PM -08'00'

Just to make sure you get the idea of the valve, this example shows it completely open at all points letting all the light through. That gives us the white we got before we introduced the valve.

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And another example where the valve is only open at the small area where the nice strong green color is. Only that green light is allowed to pass.

When we choose just one particular place in the spectrum to allow the light to pass through we get what is called a "spectral" color. The rainbow contains only spectral colors.

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Author:
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Most of the colors we see are not spectral but varied mixtures of the spectral colors. In this example, the valve is open wide in the green area imparting the distinct green to the color on the wall. However, quite a bit of the light in other parts of the spectrum are also allow to pass. This introduces the white component yielding a pale green. (Remember if we allow all colors to pass fully, we get white.)

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

And finally the Adobe teal green. I measured this with an instrument and the valve required to produce this particular color does have a shape just as shown.

So you see, white light sort of does have all colors in it but they are not obtained by only choosing a single spot in the rainbow. Rather most colors are a composite of varying amounts of varying rainbow or spectral colors.

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Author:
Date: 2/3/1998 11:18:03 AM -08'00'

This diagram is the valve from the preceding slide, split in half, and is the left half rotated clockwise 90 degrees.

In addition, to be very precise, this is a "reflectance plot" showing what your eye sees when a white light is reflected off of a piece of paper colored the Adobe green. The paper is acting as the valve from Rube's color machine.

The plot has wave length along the bottom axis ranging from 400 nanometers (billionth of a meter) up to 700 nanometers. This is the range of radiation that the eye of an average human can detect. Above 700 is called infrared and below 400 is called ultraviolet. We cannot see either of them.

The vertical height of the plot represents how much of the white light that is shined on the paper at each wavelength is reflected.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

This is a photograph of a plate of fruit. I wanted to see what the reflectance plots of various natural things were so I went to the Adobe Cafe and purchased an apple, banana, orange and grapes. Then I measured their reflectance with a special instrument called a spectrophotometer.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

Here is what the plot for the apple looks like. Notice that there is a lot of orange and red, as you might expect. Some blue and green but not much. Probably quite a bit of infrared.

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Author:
Date: 2/3/1998 11:23:22 AM -08'00'

This one surprised me! The yellow banana has a big amount of red. I thought it would be only a big bump just around 580. Not so. Strange! Your visual system can have a lot of red stimulation and still register "yellow."

We have a little more to say about this later.

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Author:
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Golly, this one is not very different from the banana yet is was a very bright orange colored orange.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

I guess this one seems ok. The grapes were very transparent so did not reflect much light. In addition, they were a rather pale washed out green. So the reflectance is small but rather uniform (making white) with some emphasis in the green area.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

Let us switch for a while to just considering light radiation that enters your eyes. We won't worry for a while whether it comes from white-ish light reflecting off of things or not. Just light entering the eye. For each wavelength some amount of light enters our eyes. We can measure that with an instrument also.

We can plot that for some spot in space or at the back of our eye. We plot the "amount" of light in some terms (e.g., footcandles, lux) a physist would understand against the wavelength.

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Author:
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An interesting exercise would be to figure out how many different stimulae could there be. Lets do a very simplified count of the number of unique shapes we could have.

Suppose we divide the wavelength range into 30 readings evenly spaced and suppose we only allow for ten readings (0-9). That is, at each of 30 spots we measure the amount of light we sense on a scale from 0 to 9.

Well we could write down such a profile in a set of 30 dials that each went from 0 to 9. Clealy that dial could be thought of as a 30 digit decimal number. So the number of unique setting on the dial and hence, by this crude measure, the number of unique radiation profiles is about 10 to the 30th or more than a million million! Does each one represent a different "color"?

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'
The word "gazillion" is also something I learned in elementary school!

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Author:
Date: 2/3/1998 11:26:37 AM -08'00'
Our graphic artist's notion of a gazillion colors.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

Experiments have been done and color scientist all agree that the average human cannot distinguish a gazillion colors. We see a few million. I'm not sure if there is any agreed upon number, maybe 500,000 or maybe 6 million, but give or take a few millions, it is certainly not anywhere near a million million.

So what gives? The visual system does not take advantage of the variety of stimulation provided in light radiation.

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Author:
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Your brain eventually is convinced that you are seeing, say, "yellow." This is done through your eyes and nervous system and parts of the brain. We'll avoid details I don't really understand and just call it the "human visual system."

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Author:
Date: 2/3/1998 11:27:41 AM -08'00'

I think we have all heard this part. Light enters your eyes and strikes the surface at the back of the eyeball called the "retina." It is a lot like a camera.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

Since most scenes we look at have a huge array of colors, let us just consider one tiny dot in the scene that corresponds to one tiny dot on our retina.

To grossly oversimplify things our retina at that point establishes a simple score for the color at that point. In fact, the score is believed to be composed of three component scores. Of course, the scores are not likely to be numbers as shown, but are levels of stimulation provided to further upstream processing.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

We're pretty sure it is broken down into a three component score because there are three distinctly different types of color sensing "cones" that make up the central part of the retina. The retina also has "rods" but they don't seem to have to do with color vision and contribute mostly in very dim situations.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

Many experiments have let us conclude that the cones in the average retina are sensitive as shown in the three plots, one for each different kind of cone. Lets call them the green, blue and red cones depending upon the area in the spectrum where each is most sensitive.

This is another plot using wavelength along the bottom. In this case the verticle axis is relative sensitivity of the cones.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

This really confused me the first time it was explained to me so lets make sure it is clear. Consider just the red cone's sensitivity plot.

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I find comparing this sensitivity business to scoring on a dart board a help. At each wave length we measure the amount of light striking the red cone (the number of darts hitting the target in that ring). That light is only "worth" the amount indicated by the plot (each dart only counts as much as the ring is marked). So different places on the dart board or different places along the wavelength axis are worth more than other places.

For the red cone, light of 580 wavelength is given the highest consideration. Light at 470 doesn't even count. Light around 430 only counts a little. So the score is a combination of how much light and what its worth is.

Author:
Date: 2/3/1998 11:32:13 AM -08'00'

This is an important concept. It is one of the things that makes color a little more difficult to figure out.

Here is the dart scoring idea. Two darts in the 100 ring scores 200. But one in the 100, one in the 60, and one in the 40 also scores 200. So do two in the 80 and one in the 40.

There are at least three different ways to get 200. If I only told you the score 200 you would not be able to tell me which darts landed where. Only a set of possibilities.

This is where the gazillion possibilities turns into a number like a million. Each cone only reports a stimulation level according to its sensitivity curve. All of the the stimulation it recieves across the spectrum is summed up like a dart board score.
Many different radiation profiles can yield the same score. Thus, millions of different radiation profiles are all classified as the same "color" by our visual system.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

Most of the stimulation reaching our eyes comes from light reflecting off of objects or surfaces. Usually the light source is rather white.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

The radiation reaching our eyes is then determined by two things. The light and the reflectance of the objects or surfaces. If the light is white, which means relatively equal amounts at all wavelengths, then the color is determined by the reflectivity of the objects. However, the lightmay not be true white, by being weak in some wavelength range. The object cannot reflect what isn't there. So both things determing how much of what wavelength of light reaches our eyes.

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Author:
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This is a plot of the radiation created by a "white" tungsten (incandescant) light. It is not really "white" since it has more light in the red range than the blue range.

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Author:
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This is the profile of sunlight on a lightly cloudy day. It is more even, more white.

This is a "standard" illuminant and tables showing this curve can be found in textbooks.

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Author:
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This is the plot for a particular fluorescent light bulb. Since the light is generated by a quantum atomic action, it is clustered at specific wavelengths. It has some strong blue areas and we usually agree that fluorescents are more bluish.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

Let us now talk about Commission Internationale de l'Eclairage (CIE). CIE are the initials for this French name of a standards organization that has been active since the early part of this century.

One of the objectives of the people in the organization was to establish some way of naming or numbering radiation profiles that matches the way humans confuse them as colors. That is, if a human says that two stimulae match, then they should be assigned the same number or name in the CIE system.

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Author:
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They choose to assign three numbers to each radiation profile. They probably chose three because of the evidence that that is how our eyes work with scoring from the red, green, and blue cones.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

The early developers of this method, did a set of experiments asking people to match two colors projected onto a screen. The people turned knobs until they were satisfied that the left and right colors were indistinguishable. These experiments used a setup that had the observer examining a 2 degree range of view. So the results are call the 2 degree standard. Later experiments used 10 degrees. They gave similar yet slightly different results.

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Author:
Date: 2/3/1998 11:35:02 AM -08'00'

From these experiments they determined three curves something like the sensitivity curves of our cones (but they are not claimed to be those) that they could use to get a 3 valued score for each radiation profile. The curves were cleverly determined in such a way that the scores produced, matched what the humans reported for matches. That is, if a person said they were indistinguishable colors, then scoring them with these curves gave the same score (or nearly so).

Scoring with these curves also uses the dart board scoring method described before. The radiation profile or reflectance plot is matched with each curve producing a score. Three curves, three scores.

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Author:
Date: 2/3/1998 3:38:36 PM -08'00'

These were truly amazing results. They found scoring curves (color matching curves) that resulted in exactly the same confusion of radiation profiles into colors as the human visual system. The gazillion radiation profiles only produce a million or so unique scores (three number sets).

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Author:
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The original three valued scoring system devised in 1931 was called CIE XYZ. The three numbers were call X and Y and Z.

Other systems have been devised based on mathematical contortions of the XYZ system. For example, the CIE L*a*b* system is given by the following formulas.

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Author:
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Here are the formulas for the CIE L*u*v* system.

Note that these systems are all really the same if you are good at arithmetic and don't care what the numbers "mean." One can use these formulas to convert back and forth. If the arithmetic is done to high precision and full accuracy of the numbers is maintained, it really doesn't matter which system is used.

The reason these revised systems were defined is that the XYZ system has some bad properties as a measuring system. It is such that the differences numerically in two colors in one end of its world (colorspace) are quite different from the differences in two colors in another part of the colorspace, even if a human says the two pairs of colors are about the same distance apart from each other. The L*a*b* and L*u*v* correct things like this by scaling and adjusting the coordinate systems. Not much of a big deal to a computer!

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Author:
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Here is one of the unusual words of the presentation: metamerism. This is an interesting concept and one that is the source of some imperfectness in attempting to match colors of reflective objects.

Remember that the color I see from a reflective object is determined in part by the light source. Remember that our eyes confuse millions of different radiation profile as the same "color." The light source will change the radiation profile reaching my eye. What if two different objects that were confused as the same color under one light source, appeared different under a different light source. Then we would have metameric objects.

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Author:
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What this really comes down to is that objects don't really have a "color" until a particular light source is choosen. Then all objects can be grouped together according to their color. Millions of objects that reflect differently causing radiation of differing profiles to reach my eyes, all look to be the same color.

The disturbing thing is that these color groupings change with the light source. Thus two things that look to be the same color under one light might look different under a different light.

So you really cannot say that two objects are the same color unless you tell me what kind of light you are shining on them!
This metamerism is shared by our eyes and the CIE systems.