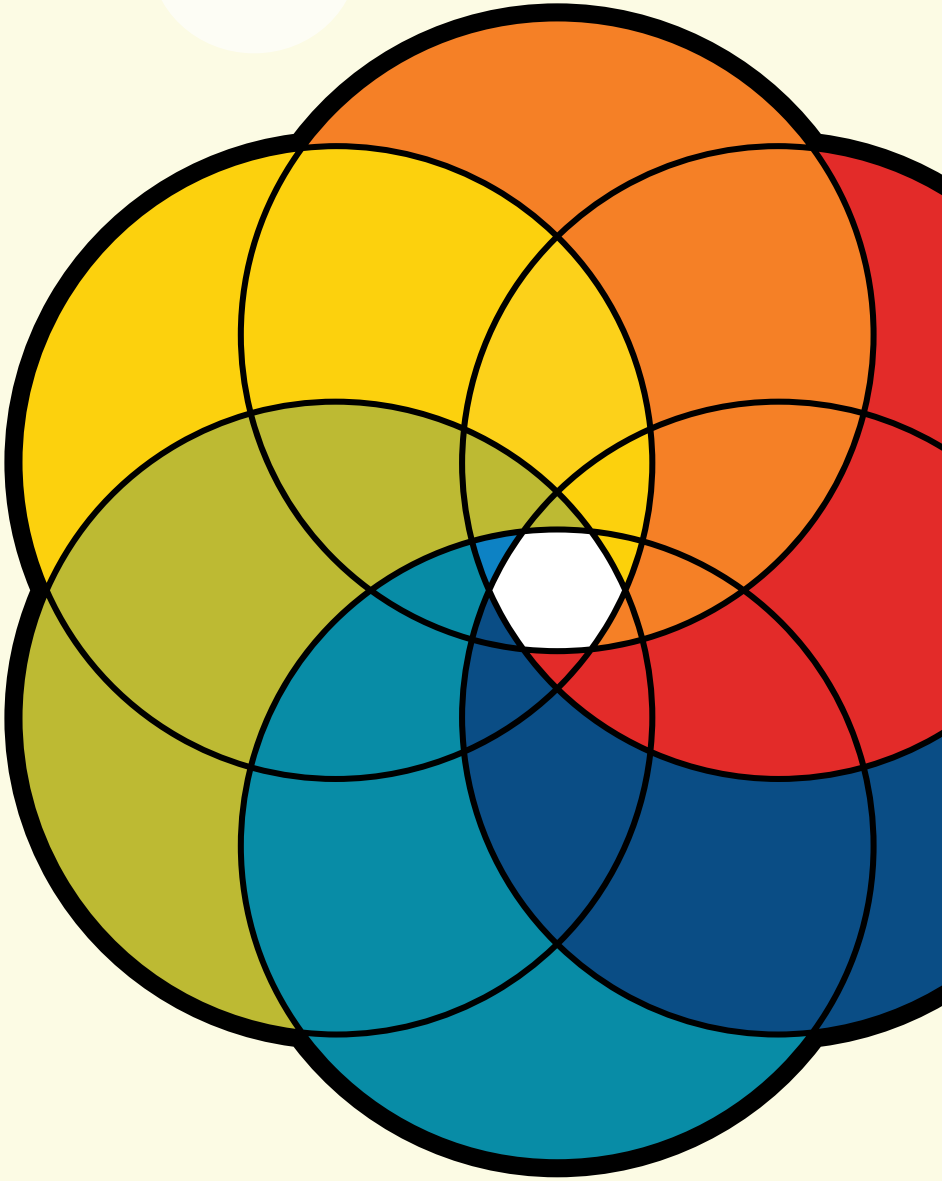
UX COLOR THEORY

Applying Color Knowledge to Data Visualization



5AM
Get there earlier.

Contents

“Color does not add a pleasant quality to design —it reinforces it.”

— Pierre Bonnard

Overview

The application of color will make or break a brand, website, brochure, logo, or even what we wear on a date or to a business meeting. The same goes for how we present data. The more complex the data, the more important color becomes in guiding the participant through its visualization.

Presenting vast amounts of information in a meaningful and usable manner is increasingly an everyday challenge in many domains. This is especially true when working with health care and life science data. The advancement in sequencing technologies along with their continuously decreasing costs will no doubt result in an even larger surge of incoming data along with an increased need and urgency to easily make sense—and use of this data...earlier.

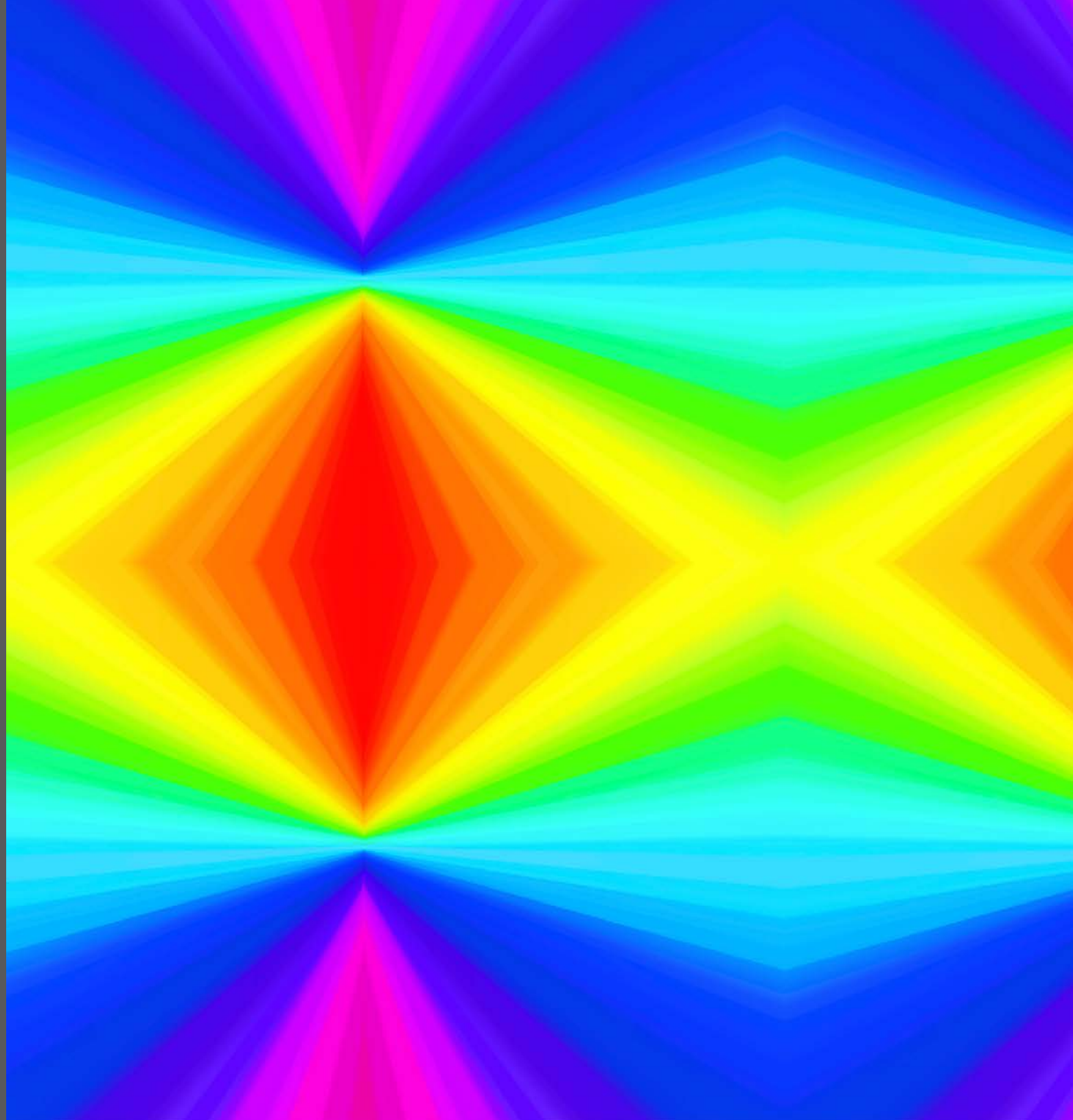
This document will show how you can improve a user's experience by applying certain key color theory principles. Other topics to be reviewed here include the application of color theory to data visualizations, the limitations of color use and the different emotions they may convey to your audience.

You will also find beneficial tips on selecting the right color palettes to provide a professional look and feel for your next project, while maintaining or even improving your audience's engagement.

Finally, as a combined example of improved user experience in genomic data visualization, this document will revisit the National Human Genome Research Institute (NHGRI) Genome Wide Association catalog and propose a hybrid semiology approach as an example to increasing usability through the application of color theory and user experience.

“My Design in this Book is not to explain the Properties of Light by Hypotheses, but to propose and prove them by Reason and Experiments.”

— Sir Issac Newton, *Optiks*



Color Limitations

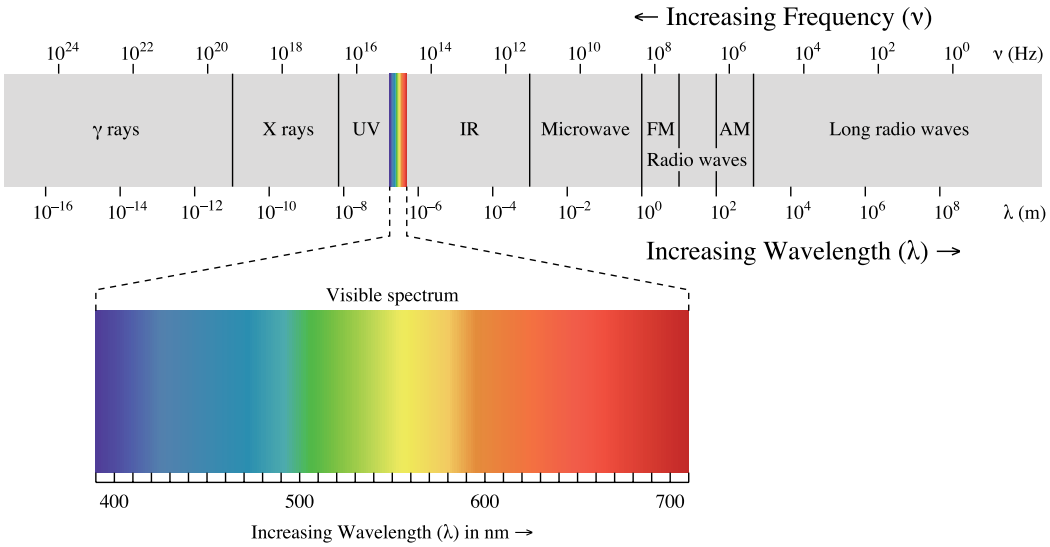
This section on Color Limitations will address some common drawbacks to using color in your projects. We will also examine common emotional interpretations of color in the Emotion and Color section. Finally, the Designing A Color Palette section will present some useful approaches and tools for building a color palette.

The Visible Spectrum

The visible color spectrum is measured in wavelengths and begins with violet at 380 nm and ends with red around 750 nm. This band makes up the full spectrum of what can be seen by the human eye. However, the human eye and the devices we use to capture and reproduce color have limitations when it comes to rendering this spectrum.

Color Blindness and 508 Compliance

The retina has two types of cells that respond to light, rods and cones. Rods pick up on the intensity of light and give us low light vision. Cones are more specialized and occur in three types, each containing photosensitive proteins that respond to different frequencies of light. When these rods or cones are missing or damaged, an individual is said to suffer from color blindness. Though color blindness is typically classified as a mild disability, it affects a large number of people and can become a severe disadvantage when data is represented with color.



Source: Andy Schmitz, *Beginning Psychology v. 1.0*, http://2012books.lardbucket.org/books/beginning-psychology/s08-02-seeing.html

In the DC metro map below you will see it can be quite difficult for someone with color blindness to follow the subway lines, especially where the Green and Red lines intersect for people with Deuteranopia. To compensate for this, you will notice that the map designers have added labels at the ends of each line, making it possible to identify them without color.

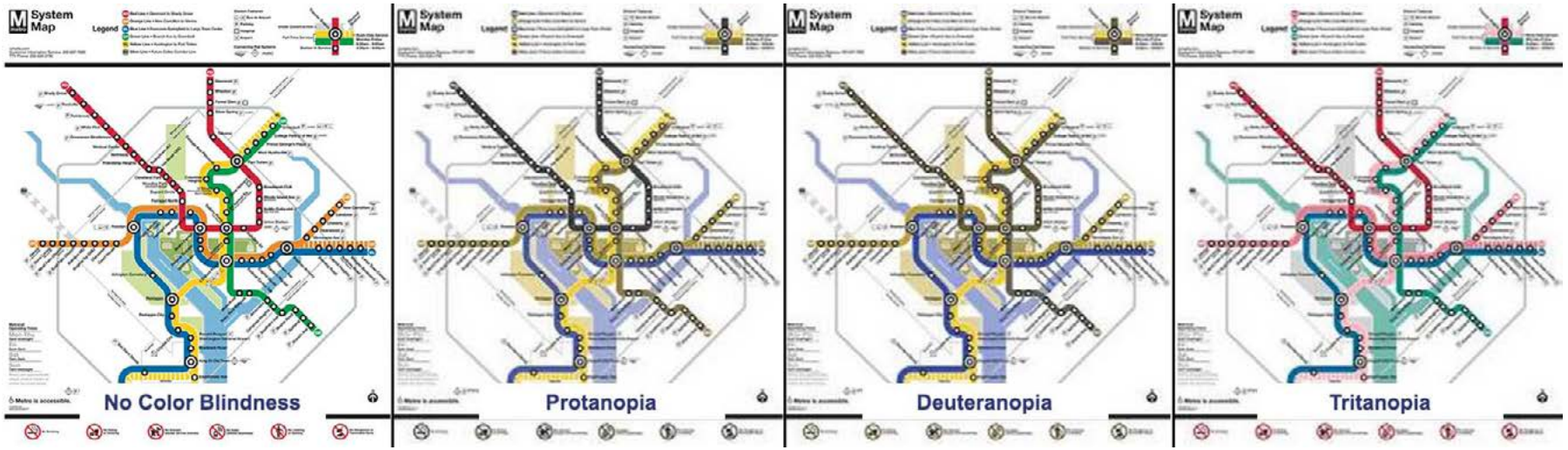
If you are concerned about how your data is perceived by people with color blindness or need to be 508 compliant, you can check it with one of the many free tools listed at the W3C.

Device Color

Device color is another limitation to be aware of. Have you ever taken a photo of a beautiful sunset, only to print it out and see that your masterpiece photo is dull and murky?

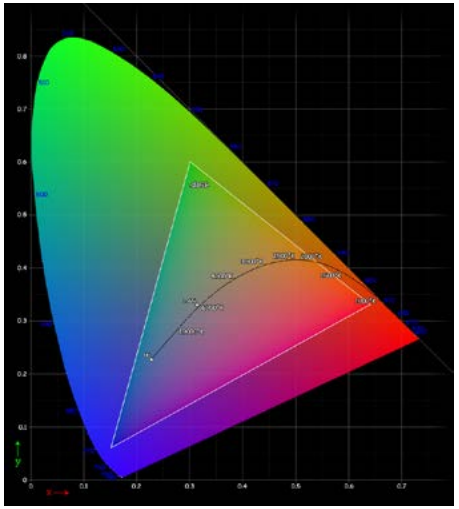
Inherent hardware limitations restrict the range of reproducible colors. Your computer monitor is not able to produce the full color spectrum and printing technology is capable of producing even less. The equipment we use to capture images, such as scanners and cameras, have their own range of colors they are limited to. In addition to that, all of

WMATA Metro Maps



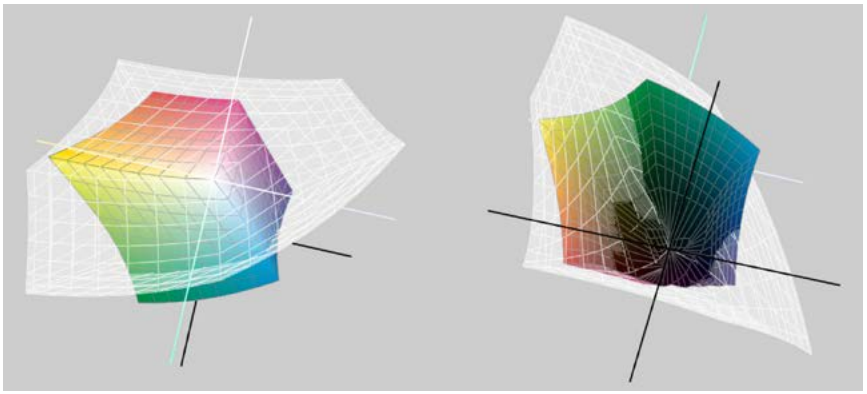
these things, including our eyes, are susceptible to environment, age and the amount of time they have been active that day.

Here are two representations of the ranges, or gamuts, of color devices. In the first shape shown below, the rounded outer shape represents the visible spectrum mentioned above; what we can see with our eye. The inner triangle shows device color. As you can see it is quite a bit smaller than the visible spectrum. The second image to the right is more device specific and shows the top and bottom of a 3D color model. The outer shape (white mesh shape) represents the color that a typical LCD monitor can produce.



Cie Chart with sRGB gamut
by spigget.png

The inner core (color shape) is what can be produced by a high-end printer. Once again, it is a much smaller space and you will notice that there are some



Source: Created with ColorSync Utility
available on most Mac computers

colors that can be produced in print that cannot be captured on a monitor.

You Can't Always Trust What You See

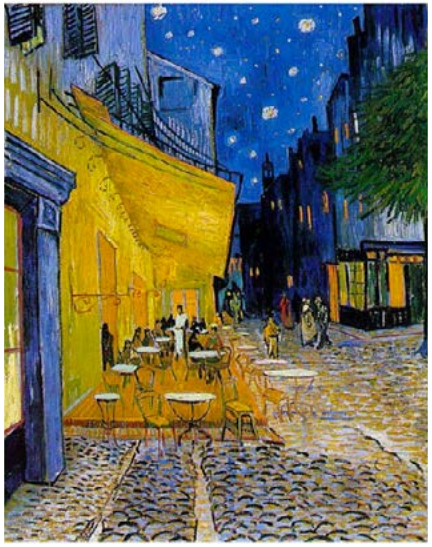
One of the most shocking things I learned as an artist is that color has the illusion of energy and motion, and not just in the poetic sense. If you know how to harness this illusion, you can use it to great effect. If not, you can literally repel your viewers and can make text very difficult to read.

Vibrations

Some colors vibrate when put next to other colors. In the chart below, you can see that, not only does it almost "hurt" to look at these colors, the text becomes very difficult to read without looking away. This is not something that you want your audience to experience.

Blue vs Green | **Yellow vs Orange** | **Blue vs Magenta** | **Cyan vs Yellow** | **Magenta vs Green** | **Blue vs Orange** | **Red vs Green**

However, this same effect is often used by artists to add energy to their paintings. Notice how in Van Gogh's Café Terrace, the artist uses the vibration of orange on the distant blue buildings to make the lights pop. Additionally, the yellow/orange colors of the cafe push it forward and in front of the taller blue building behind it.



Café Terrace, Van Gogh

Contrast

Each color has their own value, or level of "greyness." If the values of two colors are too close, like the example below, then the contrast is too low, with "weak energy," and can be difficult for someone with vision problems to see it. Again, there are many free contrast checking tools listed at the W3C.

Continued Reading on Color Theory

http://en.wikipedia.org/wiki/Color_theory

http://en.wikipedia.org/wiki/Munsell_color_system

http://en.wikipedia.org/wiki/Natural_Color_System

http://en.wikipedia.org/wiki/Gamut

http://en.wikipedia.org/wiki/SRGB

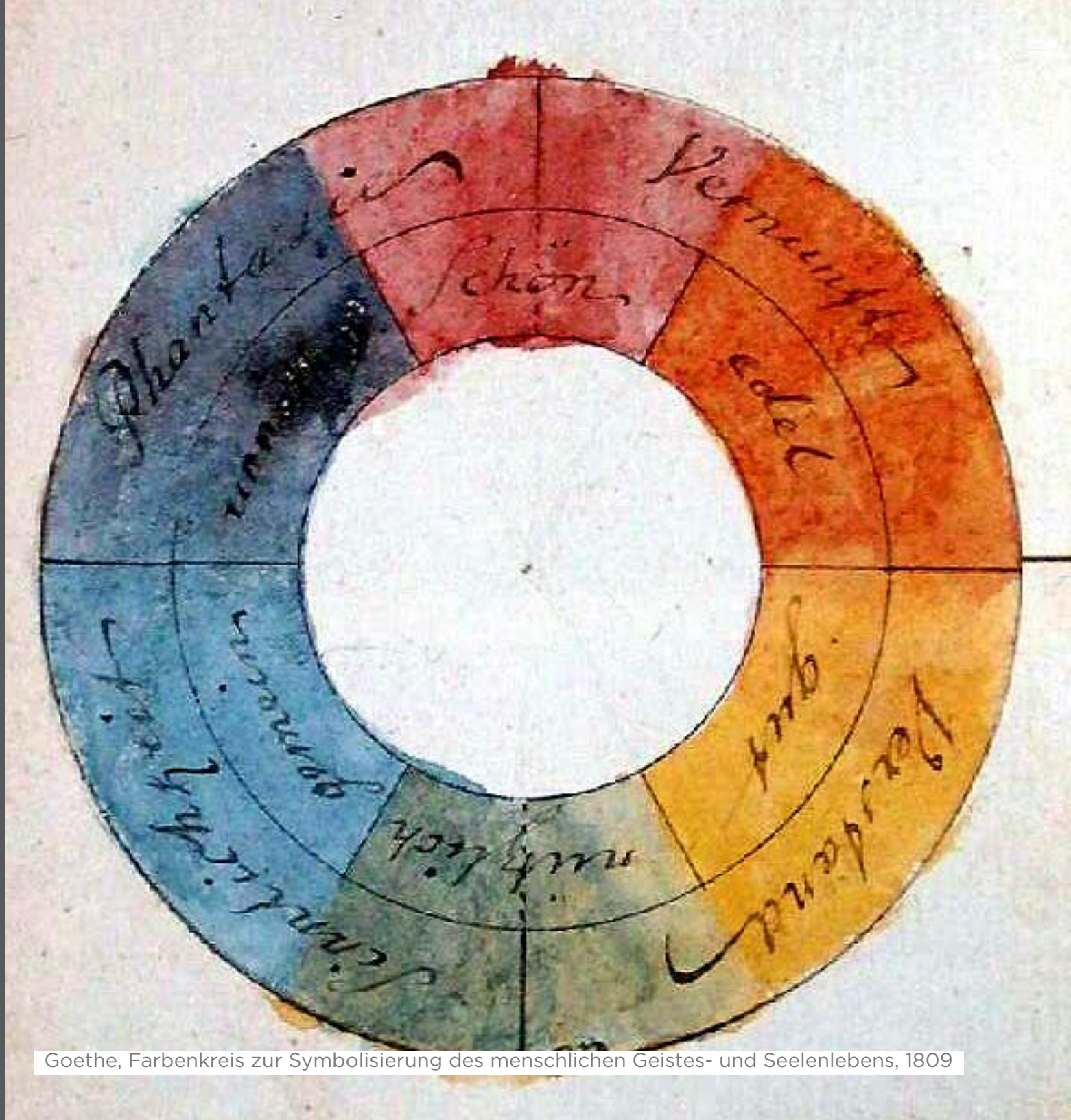
More on Color Contrast:

The work of Akiyoshi Kitaoka

http://www.lighthouse.org/accessibility/design/accessible-print-design/effective-color-contrast

"When the eye sees a colour it is immediately excited and it is its nature, spontaneously and of necessity, at once to produce another, which with the original colour, comprehends the whole chromatic scale."

— Goethe,
Theory of Colours



Goethe, Farbenkreis zur Symbolisierung des menschlichen Geistes- und Seelenlebens, 1809

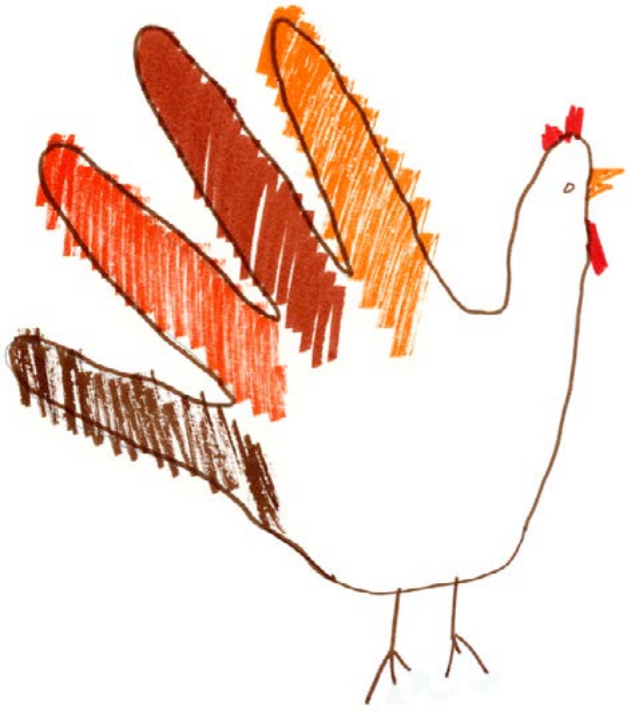
Color and Emotions

Mention Thanksgiving to any American and they will paint a picture in their head with gold, orange, red, and brown hues. It will also likely invoke a sense of family, gathering, and thankfulness. Colors, and the emotions we associate with them, are not exclusive. If I were to show you a picture of red roses, a champagne bottle with an orange label and a gold foil box of chocolates, you would see the same colors but perhaps think of a different holiday and a different emotion.

These colors and the emotional meaning behind them are a conglomerate of time, story, memories, culture, and environment. There is no "Official Holiday Color Committee" and though we sometimes treat it as such, there is no "Official Company or Industry Color Committee." As with holidays, company and industry palettes evolve from culture, story, and environment and those colors have meaning.

Color Is a Language

Color is a language just as English is. I can communicate "health" with words like "strong," "vibrant," and "energetic." I can also communicate "health' with the lush, healthy greens of vegetables and



Children learn color signifiers from an early age.

plants, the bright yellows of sunshine, and the trusting blues of authority and cleanliness. You often see the same palettes used in industries and branding, not because they are a standard, but because they communicate a message and an emotion that is common to that industry.

Even within an industry, color meanings can change. Would you be relaxed going into surgery if the protective gowns and masks that doctors wore were bright hazardous yellow or the flaming reds of

infection rather than the cold blue of sterilization? If you were visiting your new baby in a nursery at a hospital, would you be more nervous if the nurses wearing the cold blue of sterilization, or the pastel yellow of the sun and the rosy pinks of warm cheeks?

Culture Plays A Role

The idea that color has meaning and emotion is not a modern concept. An early exploration of emotion in color comes from the German poet and artist Johann Wolfgang von Goethe, in his 1810 treatise, *Theory of Colours*. But color and its meaning goes back even further and it varies widely by region and environment.

Blessings for Chinese New Year

Fire Danger Level sign

When I moved to Asia as a child, one of the first things I noticed was how positive and prominent the color red was while the color white was reserved for more somber occasions. Often these more historical meanings come from the availability and value of such colors. Red vermilion, also know as Chinese red, was first synthesized from mercury and sulfur in China in the 8th century.

A similar history envelopes the color purple in western culture. Tyrian purple was dye made from crushed mollusks that was so expensive only royalty could afford it. This economic association lead the color purple to signify royalty and wealth in Western culture to this day. There are many more of these cultural color differences. Therefore, if you are creating data that will be represented to your colleagues in another country, you may need to consider what message you are really sending. The blog "Information Is Beautiful" has created a brilliant information graphic to help guide you.

Questions To Ask Yourself When Choosing Color

1. What are others doing and do you want to set yourself apart?
2. What additional accent colors can you introduce to change the meaning/message of your design?
3. Can you use other attributes of color to modify such as value? A pastel yellow can mean something different than a bright vibrant yellow.
4. What are other sources for the meaning of color?
    a. Commercial (branding, products)
    b. Religion
    c. Fashion and textiles
    d. Cultural events (sports, holidays)
    e. Geography, industry, and environment
    f. History
    g. Signage/transportation/chemical
    h. Nature
5. What colors have personal meaning to my message, brand, or information?

Continued Reading on Emotion and color:

http://www.brainpickings.org/index.php/2012/08/17/goethe-theory-of-colours/

http://www.winsornewton.com/resource-centre/product-articles/vermilion-cadmium-red

http://www.livescience.com/33324-purple-royal-color.html

http://thelogocompany.net/blog/infographics/psychology-color-logo-design/

http://tympanus.net/codrops/2012/04/03/color-and-emotion-what-does-each-hue-mean/

http://www.color-wheel-pro.com/color-meaning.html

http://www.colorcom.com/research/why-color-matters

http://www.colormatters.com/

http://www.colorsystem.com/

Gestalt psychology states:

"the mind understands external stimuli as whole rather than the sum of their parts...The law of similarity states that elements within an assortment of objects are perceptually grouped together if they are similar to each other, in shape, color, shading or other qualities."

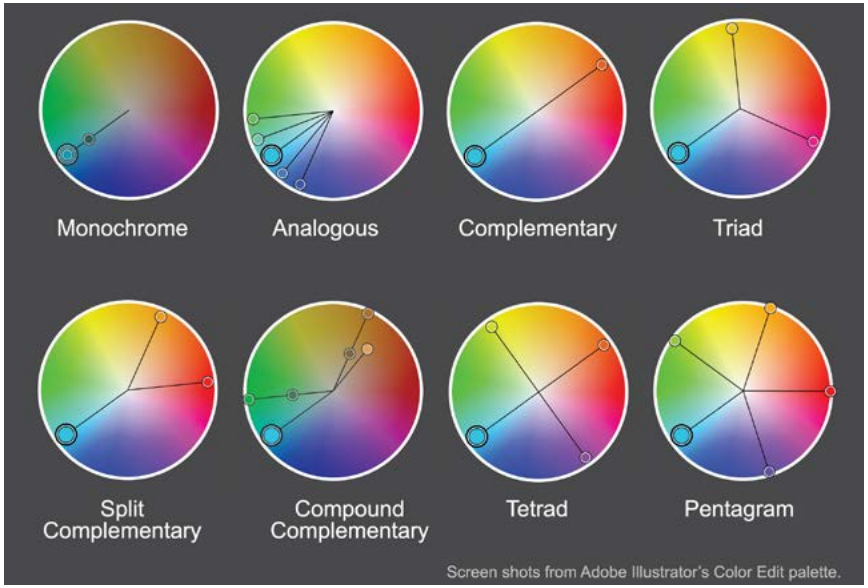
Source: http://en.wikipedia.org/wiki/Gestalt_psychology

Tips on Designing a Color Palette

In the first two sections of this book, Color Limitations and Color and Emotions, we looked at some interesting facts about color and some of the context around their meaning. This provides tips for choosing a harmonious color palette, that will bring your designs and graphics together. In the next section, we will look at when and why choosing color to separate your design and graphics is important.

Create Harmonies

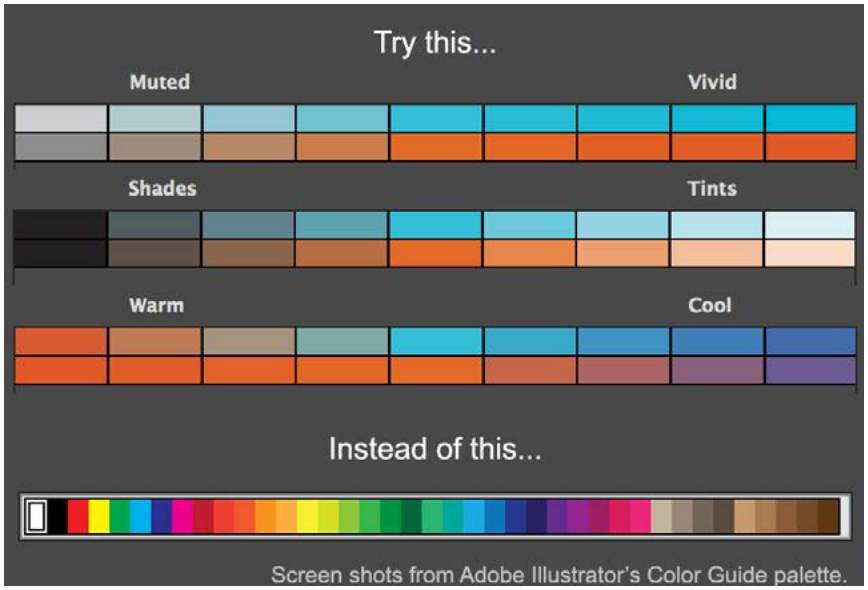
When creating a color palette one option is to create a color harmony. Pick a color, any color. As most of us learned in school, that color has an opposite or complementary color. Red and green, blue and orange, yellow and purple are all complements of each other. These colors are opposite each other on a color wheel. But did you know there are other patterns or color harmonies? Color Tiger's "Color Harmonies - basic techniques for creating color schemes" article does a nice job of explaining the different harmonies, and tools like their Color Impact 4, Adobe's Kuler, and Colourlovers' Copaso all help you create color harmonies.



Color Harmonies from Adobe Illustrator

Use Tints, Shades, Saturation, Warm and Cool Instead of Additional Colors

Often, when choosing colors for a design or graphic, we are sometimes too quick to jump to a new hue, giving our work a rainbow effect. Instead, consider adjusting a limited color palette of two to three colors by adding white, known as creating tints;



A limited color palette employing tints and shades.

adding black, known as creating shades; and adding greys, known as desaturation.

Additionally, you can adjust your colors by moving your colors left or right on the color wheel, which is know as making your colors warmer or cooler. This can be seen in the analogous color harmony above where the main color is in the middle; the warmer colors, or colors that move more toward the reds and oranges, are to its right; and the cooler colors, or colors that move toward blues and greens are to its left.

Remember to Balance Your Color with Different Weights

When designing a color palette it is good to remember that you should not treat your colors equally.

Remember the typography rule:

> "WHEN EVERYTHING IS EMPHASIZED, NOTHING IS EMPHASIZED."

The same applies in color. Make one color your primary color and use the rest to accentuate that color. When in doubt, you can always use the 60-30-10 rule, mentioned in this article by HGTV on interior decorating. Companies such as Ubuntu even use different amounts of the same color palette to communicate differences of emphasis in content, as well as different sub-brands as shown in there branding here: http://design.ubuntu.com/brand/colour-palette

When you are dealing with many brands such as the case with Adobe you may need to expand your

palette beyond a few colors into the aforementioned rainbow effect, but the color balance principles still applies.

Notice how Adobe's graphic design based products, Illustrator and InDesign, are analogous and are pink and orange; the web products, Dreamweaver and Muse, are cool and warm versions of green; the video products, After Effects and PremierPro are a saturated and de-saturated version of two violets that are very close; and Photoshop, Adobe's flag-ship photography product, is blue. Even though the current branding material has a lot going on you can still identify the key color in the image.

"Good Artists Borrow, Great Artists Steal."

—Pablo Picasso

Why reinvent the color wheel? Good color palettes come from many sources such as interior design, fashion, or nature. Or, if you are using a photo-graphic image with your graphic or page, why not pull your colors from there? Use an eyedropper tool like ColorPick and click around to pick up your favorite colors.

In addition to the great tools already mentioned for creating palettes, try browsing those same sites for palettes created by other colorphiles.

Resources

ColourLovers

Kuler by Adobe

ColorPick Eyedropper by Vidsbee.com

Colorzilla by iosart labs llc

Source: MHGRI GWA Catalog, www.genome.gov/GWAStudies, www.ebi.ac.uk/fgpt/gwas

When Not to Choose a Harmonious Palette

Genome.gov's Published Genome Wide Associations Chart

Though the Genome Wide Associations Chart was published several years ago, it is as relevant today as it was four years ago. In this section we will use previously presented concepts to make this visualization more effective.

Color Semiology

Semiology, simply put, it means "pertaining to communication through signs and symbols." We use it to mean any system of signification—whether it's through icons, color coding, numbering systems, mapping symbols, etc. Semiology encompasses the art and science of choosing the right way to signify things.

The Makeover

Genome.gov publishes a quarterly summary graphic showing the loci of all the SNP-trait associations with p-values < 1.0 x 10-5, plotted as colored dots on a graphic representation of the human chromosome complement.

The authors of the chart (page opposite) have chosen to differentiate the traits through color semiology—each trait is assigned a unique colored dot. Take a moment to view the full-size graphic. Now—see if you can uniquely identify all of the orange dots, and the traits they represent. It's pretty tricky, isn't it? It's virtually impossible for a fully-sighted individual—imagine how tough this chart is for someone with color-compromised vision.

The problem here is that color semiology is not appropriate for such a large value range. We simply don't do well differentiating that many different colors from a field of dots. Compounding the issue is the effect of the Gestalt Color Principle—our brains want to group together things with really similar colors, which can be useful in some instances, but here it just makes matters worse.

Color Perception Across Culture—The Berlin-Kay Palette

In 1969, Brent Berlin and Paul Kay published a groundbreaking study of color perception across culture, in which they proposed that there were really 11 fundamental (or "focus") colors that everyone could easily differentiate, most likely based on some underlying physiological or neurological principle.

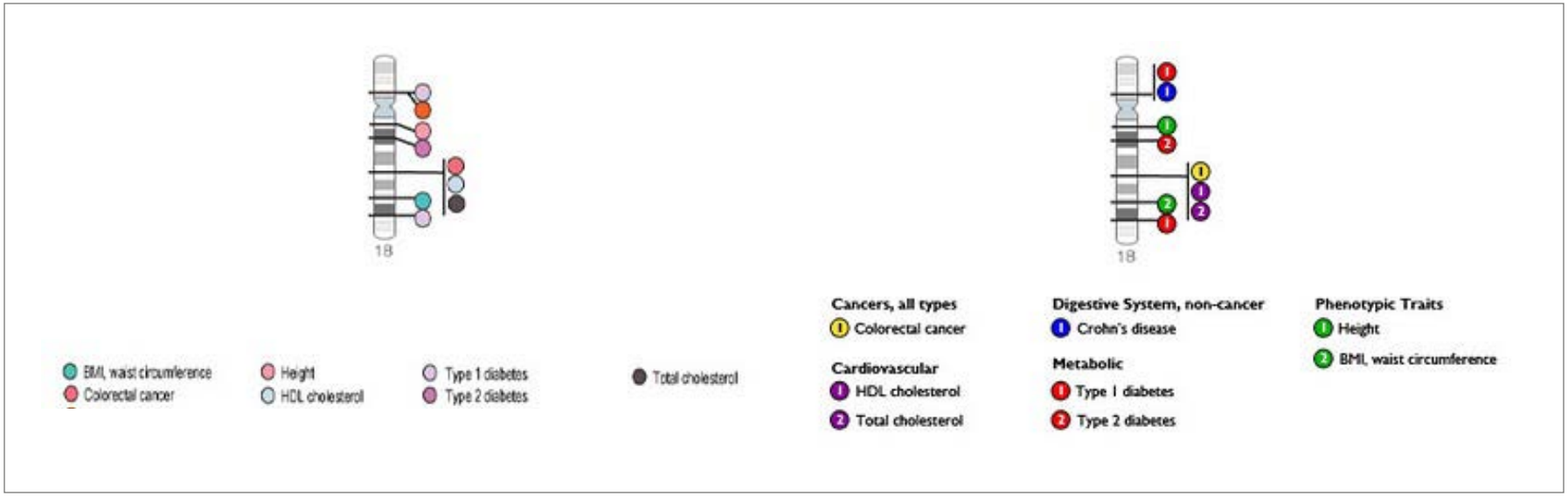
The Berlin-Kay palette was extended to include cyan by the visualization guru Colin Ware, giving us 12 colors that are reasonably safe to use for ordinal color semiology in infographics and data visualization. What do I mean by "ordinal" color semiology? Data dimensions that are sets of things (like categories, without quantitative interrelationships), rather than continuous, ordered, quantitative values, are ordinal. We can also use color for quantitative values—in fact, we can even split color into its three component subdimensions—hue,saturation and value—and use each of these to represent a separate quantitative dimension. Heatmaps and terrain relief are examples of such quantitative color semiology. We still have to be careful though, because we're fairly bad at discerning specific quantitative values in a color (hue, saturation, or value) range.

The graphic we're considering here, the authors are trying to use ordinal color semiology for a number of separate ordinal values. By now, you should understand why this is ideal. It's nearly 10 times as many colors as the Berlin-Kay set.

The Solution—A Hybrid Semiology

So, how might we improve matters? One approach might be to employ a hybrid semiology—for instance, grouping the traits into manageable sets (with 12 or fewer sets in total) and encoding these sets with color semiology. Then, within each set, numbering the traits (numeric semiology). Let's see how this might work, using chromosome 18 as a guinea pig. First, here's what we're starting with (excerpted from the original document):

Notice how your eyes and mind have to work to make sense of this, even though it's just one chromosome from the whole diagram—you can do it, but it's not intuitive or fast. Also, notice that the two Type 1 diabetes dots may actually look slightly different in color, due to their proximity to dots of different colors—this kind of color interaction is another hazard of using lots of different colors jumbled together to represent things. If there were only 12 well-differentiated colors on the diagram



this would not be as big of a problem, but on the full diagram with all the colors, there are too many things that are "lavender-mauve-ish"—so these kinds of visual effects become meaningful.

Now, let's rework it a bit by sorting our traits into categories, and assigning a "Berlin-Kay safe" color to all traits in the same category. Then we'll number within each category and put the numbers on the dots.

Suddenly, you can find things! It works well in both directions—whether you start from the legend or from the loci on the chromosome. This solution will scale up to quite a large number of traits without losing its efficacy, as long as the number of categories stays at 12 or less.

Is this the only solution (or even the best) to this problem? Probably not. There are other possibilities as well—one approach would be to split the diagram intomultiples—duplicate copies of the whole diagram, broken out by some value, such as the categories assigned above (i.e., a diagram showing only cancers, another showing only cardiovascular loci, etc.). A possible disadvantage to this approach would be that you would no longer see the proximity of seemingly unrelated traits on the same chromosome, which might hinder insight into linkages, etc.

Summary

As complex data sets become integrated into interactive applications, the need for accessibility increases. By using principles of color theory, we can shape data to increase its readability and provide a better experience for our users.

Many methodologies exist for the application of color theory, and this book introduced a few of the most common approaches: (1) that we should consider the limitations of color with respect to both the human eye, and devices; (2) that cultural factors play a role in how a person perceives and reacts to color; (3) that by limiting the number of colors within a palette, we can still create visualizations that engage the viewer by applying the techniques of color harmony, balance, and value; and (4) color harmony is not always the answer. The last example showed how and when to separate data using dissimilar colors.

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Leigh leads the UX Team at 5AM Solutions with 15 years experience in tech, design and education. She is also a former Adobe Certified Instructor and is very active in the DC tech community.

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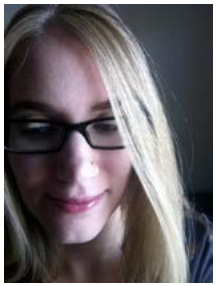

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Chris works as a UX designer/developer for 5AM Solutions. In her spare time, she works on a Media Democracy application/startup and researches policy on Open Data, Government Transparency, and Media Democracy issues in emerging democracies.

About 5AM Solutions

5AM enables breakthroughs in healthcare and life sciences through software solutions. Customers save money; connect with colleagues, data, resources and patients; and get better outcomes—*earlier.*

Introduction

5AM envisions, develops and delivers web applications, mobile apps and analytic/collaborative tools to meet the growing needs of the life science and health care sectors. 5AM applies our capabilities in the intersection of technology, science, and medicine. Our focus is to bridge the divides and remove the silos as the domains converge. We employ top software engineers, subject matter experts, repeatable processes and assets built for the domain to solve complex problems with simple solutions. 5AM wants commercial, government, academic, and nonprofit customers achieve new business workflows, interrogate and integrate data, and communicate in new ways. 5AM employs more than 50 employees across the US and is supported by a team of over 30 subcontractor specialists. Services and Software Solutions

Services and Software Solutions

Custom Software—Intuitive user and application interfaces, mobile solutions, data standardization, and legacy modernization are all part of 5AM's daily work. 5AM's track record is driven by pragmatism, technology expertise, and the continuous improvement of our software development methodology. We use our domain experience to guide our teams and customers, share knowledge, and define where we can bring value now and in the future. 5AM's exclusive focus in the domain allows our engineers to produce solutions that are built smarter, delivered earlier, with lower risk and smaller total cost of ownership.

Data Visualization—5AM's software engineers, bioinformaticians, PhDs and MDs with software appreciation and skills specialize in helping customers make sense of large volumes of complex data. We design assays and pipelines. We create compelling user experiences driven off data processing, mining and normalization. We empower more users to ask and answer questions currently accessible only via non-scalable resources and specialists.

Strategy Consulting—From workflow to data grappling, 5AM's consultants help customers develop strategy and scope ways to improve data, tools or front-line operational issues in areas such as enterprise architecture, consortium development and governance. Our ability to conceive what needs to be done, craft a deliberate roadmap of the current and future states of an enterprise, or prototype potential solutions all contribute to the trust customers place in our team.

Packaged Services—5AM has completed so many successful engagements in this domain that we have developed many repeatable solutions. We have been able to invest in evolving many of these components into packaged services that enable us to deliver value-driven and field-tested solutions quickly and at predictable costs.

Competitive Process

In many fields outside life sciences and healthcare, software has reshaped what's possible, particularly in the last 10 years. During those ten years, the convergence of science and medicine has accelerated. This is a complex endeavor; fast changing and highly impactful. Software can't add to that complexity. For years, platforms, point solutions and custom efforts have targeted this translational medicine field. Frustration, shelf ware, wasted time money and opportunity has been a reoccurring result. Software works or it doesn't. Users get final say. And the best way to achieve success is to get the software in their hands. Quickly. Repeatedly. Responsively.

For 5AM, these fields aren't "sidelines." We have built our business reputation by delivering useful, usable and used solutions in the domain for the domain. That focus and our depth of past performance consistently reward clients with faster results, fewer risks and better outcomes. We are familiar with the kinds of user interfaces that will be best-accepted by end users, the challenges of interoperability and the precision reporting required to satisfy regulatory requirements and move faster -- with fewer risks. By collaborating with our customers, we're able to help them produce breakthroughs by using software in new ways, and why 100% of our clients will provide reference for our work.

Customers

5AM is in business to serve the needs of life sciences and health professionals and those they serve. We are customer advocates, coming into commercial, government, academic and nonprofit environments to enable people to ask better questions, find better answers, improve patient care and save lives. Commercial clients include several large Pharmaceutical companies and small biotechs, Life Technologies, Celera, and Quintiles. Government customers include the National Cancer Institute, National Institute of Neurological Disease and Stroke, the National Institute for Child Health and Development, the Office of the National Coordinator for Health IT, the DoD's Transformative Medicine Initiative and the Biomedical Research Commission of Arizona. Non-profits include Janelia Farm of the Howard Hughes Medical Institute, the American College of Medical Genetics, the Translational Genomics Research Institute and the Multiple Myeloma Research Foundation. In academia, we serve New York University, Oregon Health Sciences, UCSF and the University of Michigan's Health System.

Our People

5AM is all about getting our clients better outcomes—*easier and earlier.* Our exclusive focus on software engineering for the healthcare and life sciences domains has enabled us to grow a team of expert developers, requirements analysts, UI designers, and project managers. We also have PhDs, MDs and bioinformaticians with who use deep domain experience to help our technical experts understand the needs and nuances of clients working in scientific and medical fields. This depth of experience and expertise enables us to understand the interests of the divergent set of stakeholders, balance their requests, and elicit and use software to solve problems and unlock all-new opportunities.

We believe in small, expert teams moving quickly to solve customer problems. We believe live software drives the best value and defines working. Ethics and passion about doing meaningful work is required to get in and stay in. 5AM and our customers, teams and partners are rewarded with excellence and value.

Contact 5AM

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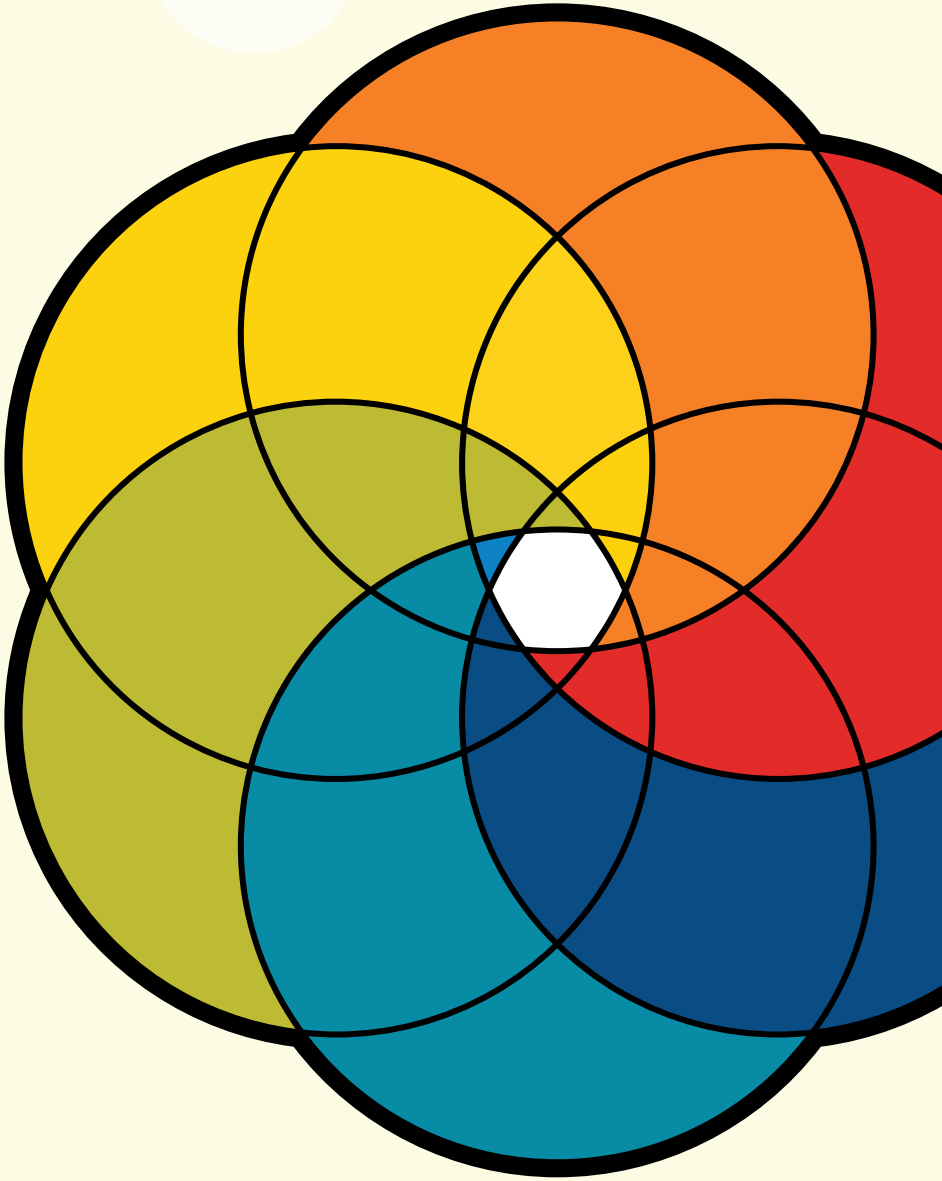

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Get there earlier.