Choosing Colors for Data Visualization

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11/12/13

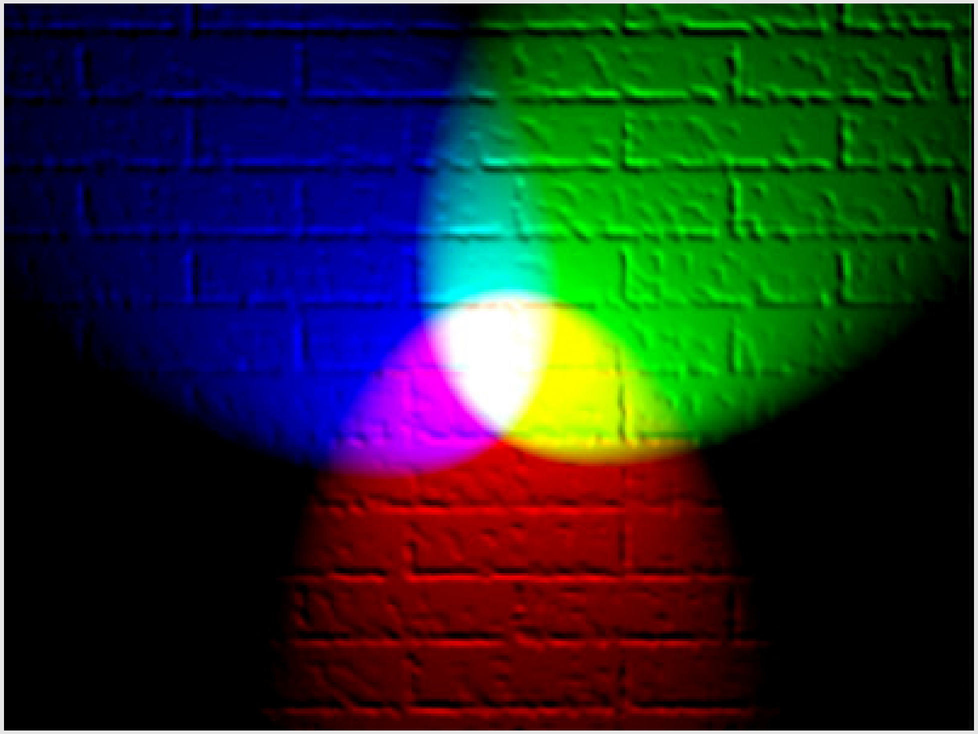
Topics

- Color models
- Color Gamut, Spaces and Systems.
- Color Design Principles
- Coloring Visualization Examples
- A User Study
- Other Resources

Color Models

- **Color model** - abstract mathematical model describing the way to present colors as numbers, typically as three or four values or color components
- **Additive Color models** - adding colors with light as seen on our color display monitors
- **Subtractive color models -** display color as a result of light being absorbed (subtracted) by the printing inks

Red, Green, and Blue (RGB) - The Additive Color Model of lights:



Red, Green and Blue lights showing secondary colors.
http://en.wikipedia.org/wiki/File:RGB_illumination.jpg

slide courtesy of Theresa Marie Rhyne' SIGGRAPH 2011 Course

Cyan, Magenta, Yellow, and Key Black (CMYK) - The Subtractive Color Model Of Printing

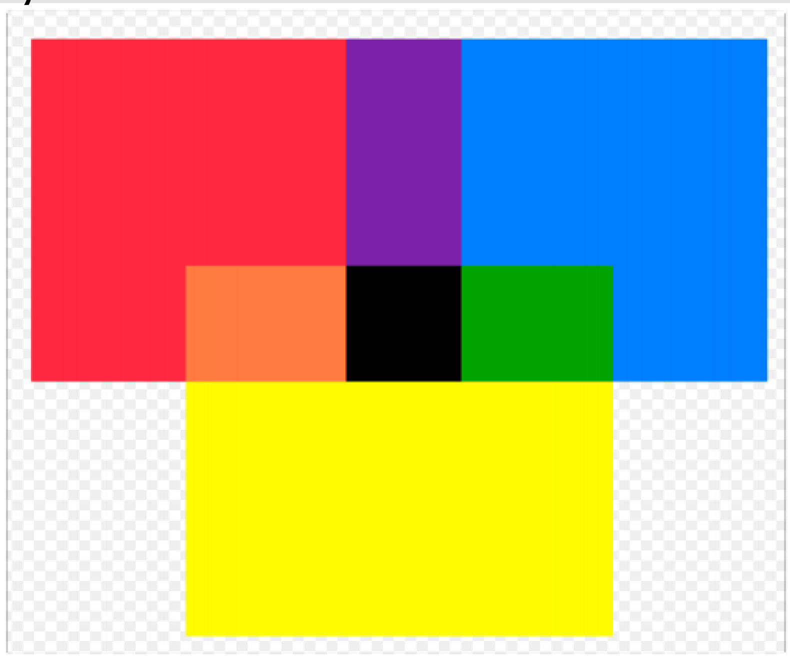
Subtracting colors with ink as seen from high resolution printouts

How semi-transparent Cyan, Magenta and Yellow colors combine on paper.
http://en.wikipedia.org/wiki/File:Color-subtractive-mixing-cropped.png

slide courtesy of Theresa Marie Rhyne' SIGGRAPH 2011 Course

Red, Yellow and Blue (RYB) - The Painter’s Subtractive Color Model:

Subtracting colors with paint like when we use a real paintbrush, crayons, or makers

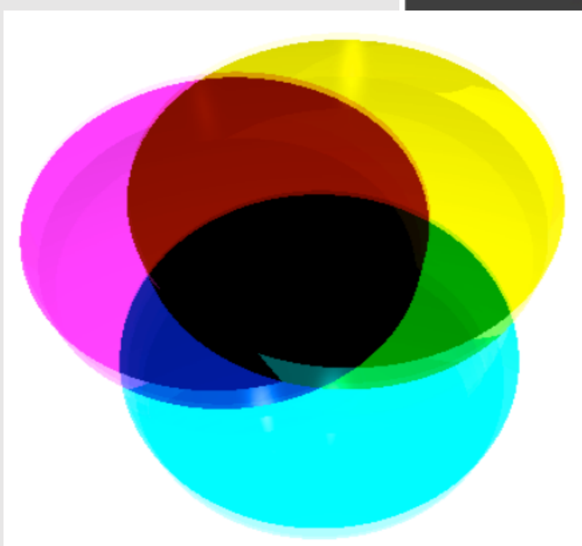


Mixture of Red, Yellow and Blue primary colors used in art and design education.
http://en.wikipedia.org/wiki/File:Color_mixture.svg

slide courtesy of Theresa Marie Rhyne’ SIGGRAPH 2011 Course

Summarizing Color Models:

RGB adds with lights



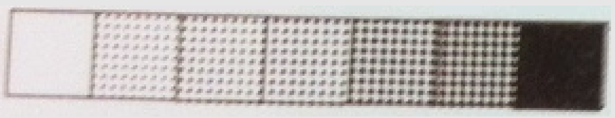
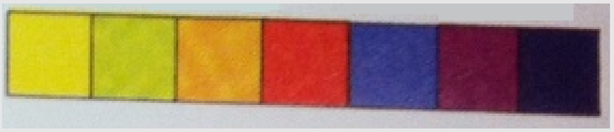
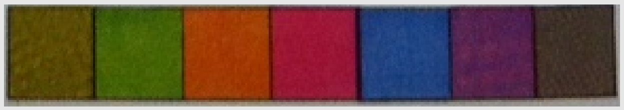
CMYK subtracts for printing

RYB subtracts to mix paints

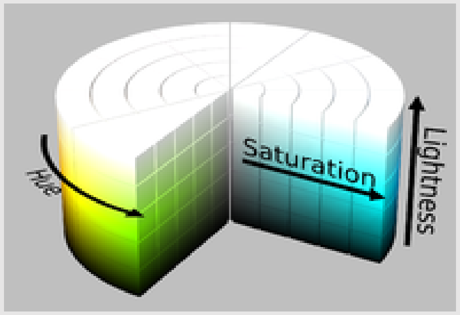
slide courtesy of Theresa Marie Rhyne' SIGGRAPH 2011 Course

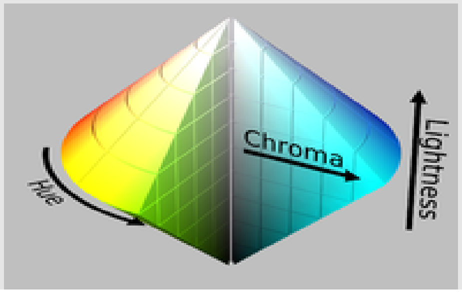
Color Terminology

- **Value**: percentage of black
- **Hue**: categorical color: red, green, blue, orange, ..
- **Tone**: include two parameters - hue and value

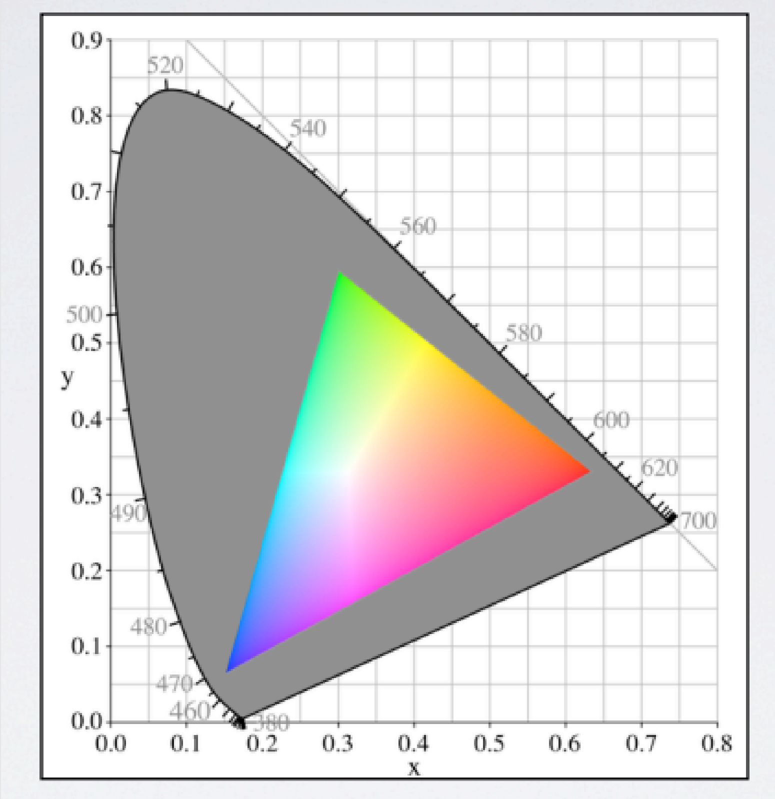




- **Saturation**: dominance of hue in the color: pure or washout
- **Chroma**: colorfulness. High chroma colors are vivid or saturated, low chroma colors are grayish or muted.
- **lightness**: the intensity of the energy output of a visible light source





Color Gamut: The Subset of Colors that can be accurately presented in a given condition



The Color Gamut of a typical computer monitor. The grayed out portion represents the entire color range available. http://en.wikipedia.org/ wiki/File:CIExy1931_srgb_gamut.png

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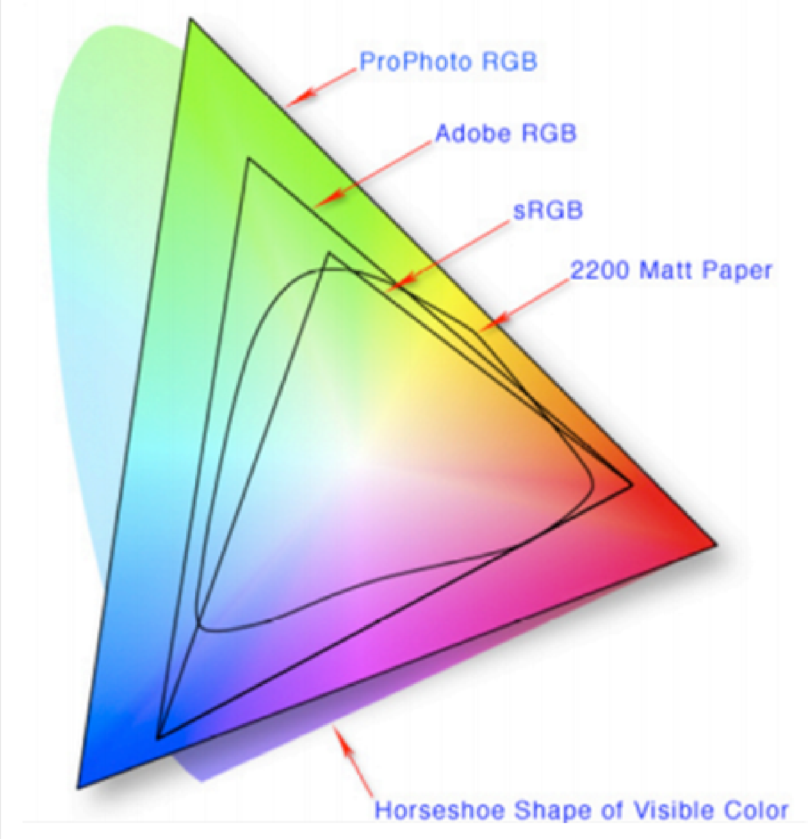
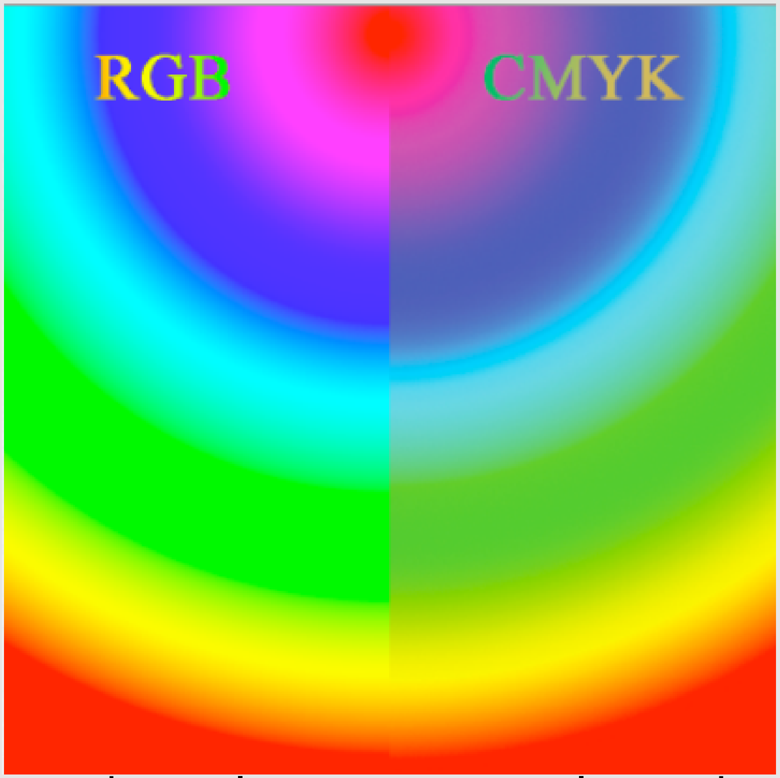
Color Model + Color Gamut = Color Space



Comparison of the color spectrum (shown as the large oval in the back) with RGB color spaces
http://en.wikipedia.org/wiki/File:Colorspace.png

slide courtesy of Theresa Marie Rhyne' SIGGRAPH 2011 Course

Comparison of RGB & CMYK Color Spaces:

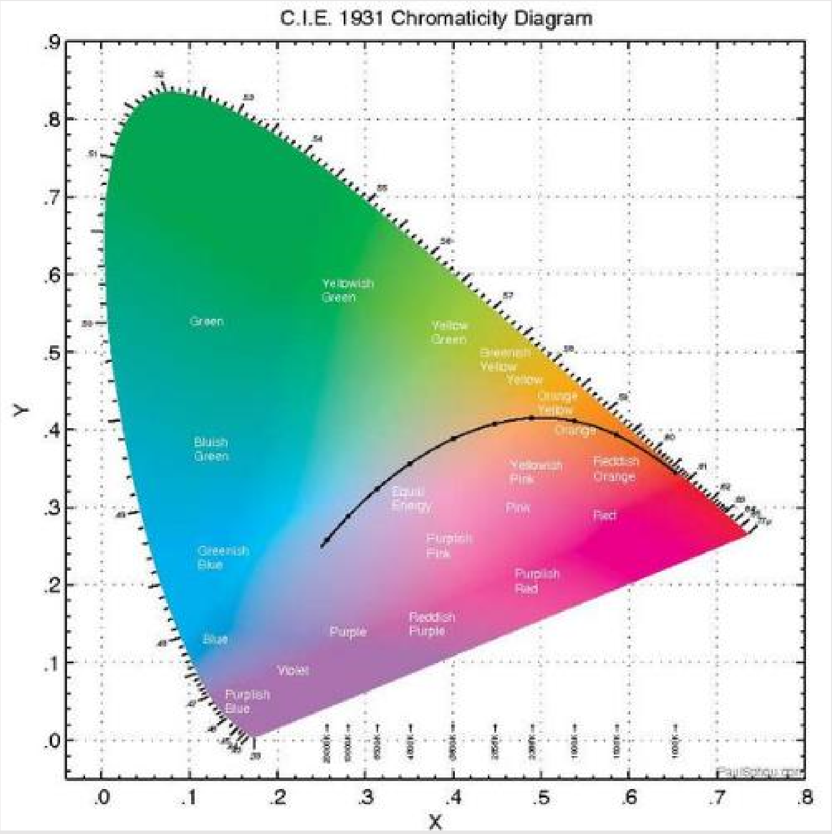


This image depicts the differences between how colors appear on a color monitor (RGB) compared to how the colors reproduced in the CMYK print process.
http://en.wikipedia.org/wiki/File:RGB_and_CMYK_comparison.png

slide courtesy of Theresa Marie Rhyne' SIGGRAPH 2011 Course

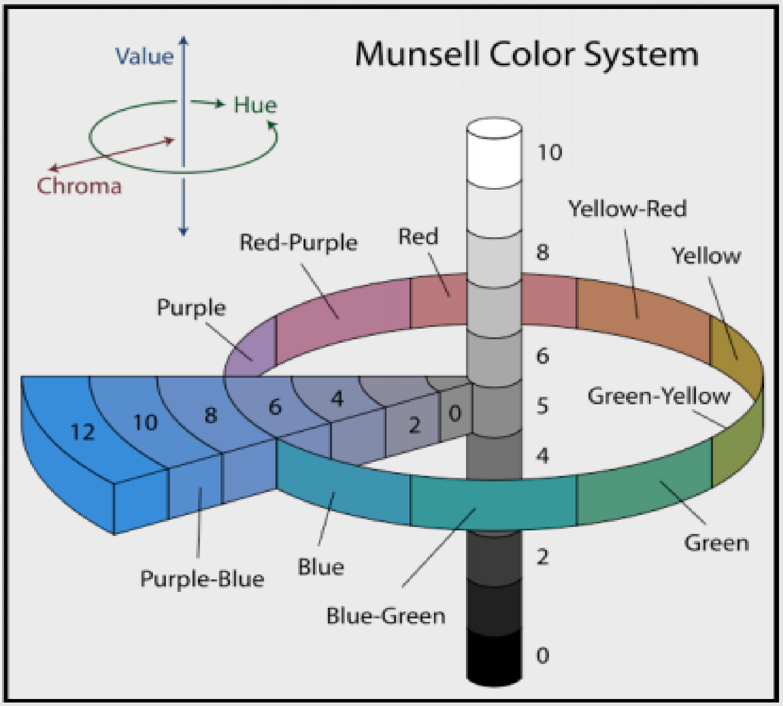
CIE Color Space:

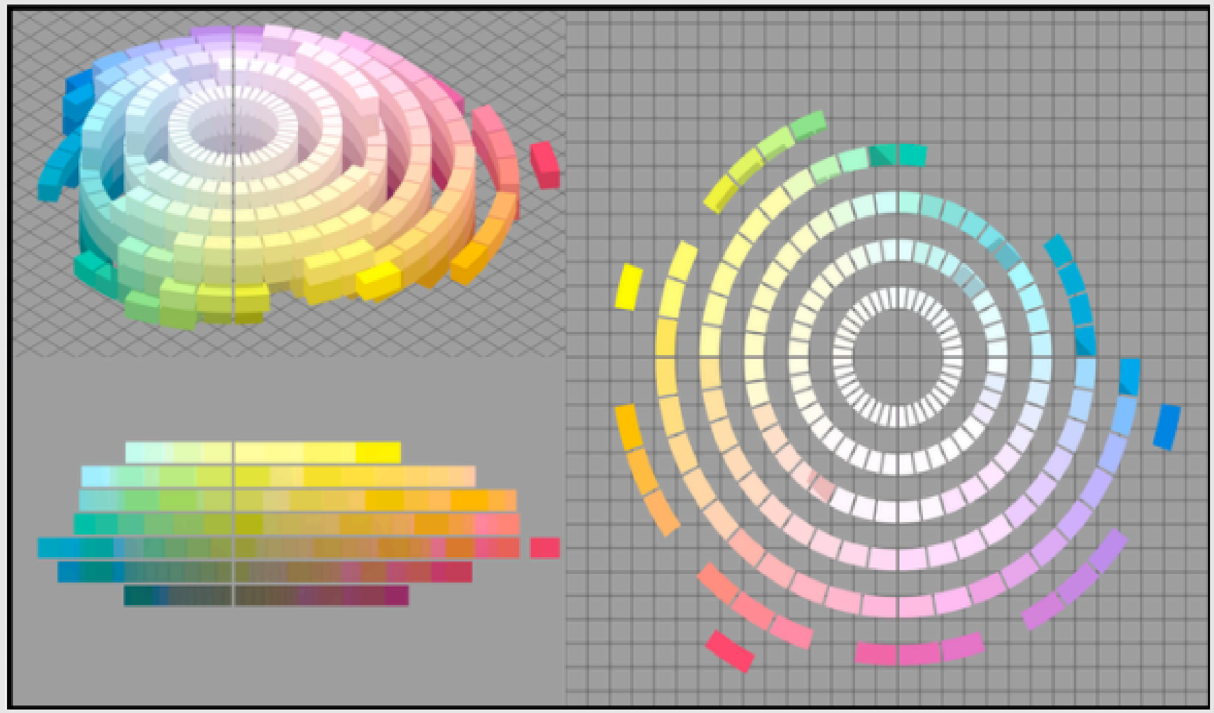
- Based on experimental perception in the 1920s.
- Encompasses all color sensations that an person can experience
- A standard reference against which many other color spaces are defined



http://en.wikipedia.org/w/index.php?title=File:Chromaticity_diagram_full.pdf&page=1

Munsell Color System:
A Hue, Value and Chroma Color Space





100 hues
0-10 value levels
0-12 levels of chroma

the color space configuration defined based on Munsel Color system
Http://commons.wikimedia.org/wiki/File:Munsell_1929_color_solid.png

slide courtesy of Theresa Marie Rhyne’ SIGGRAPH 2011 Course

Pantone Color Matching System: Used for Standardizing Colors:

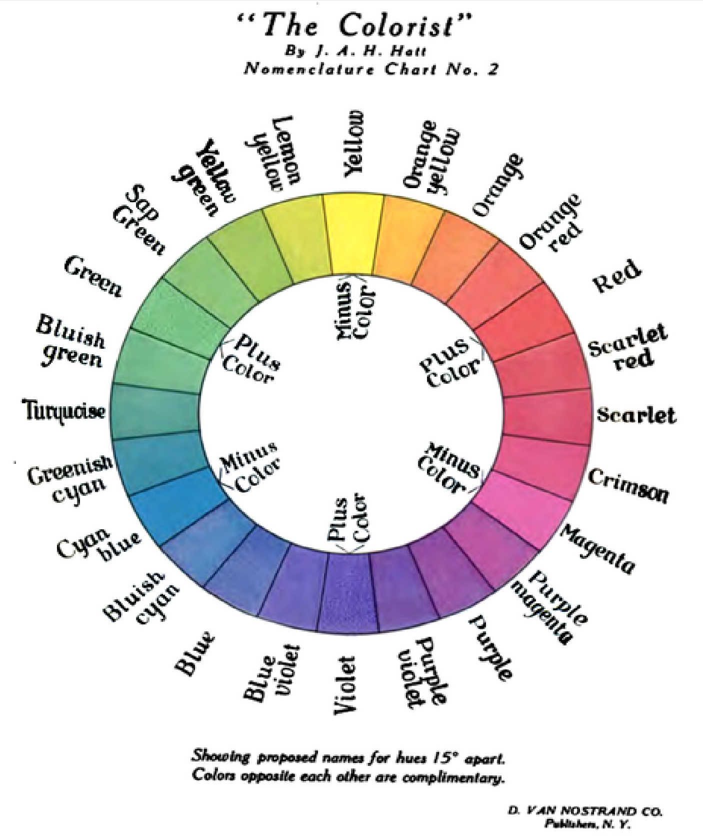
- 1,114 colors specified by their allocated number such as “PMS 130”
- based on 15 pigments (13 base color pigments along with black & white) that are mixed in specified amounts
- CMYK printing reproduces a special subset of Pantone colors

http://en.wikipedia.org/wiki/File:PantoneFormulaGuide-solidMatte-2005edition.png

slide courtesy of Theresa Marie Rhyne’ SIGGRAPH 2011 Course

The Color Wheel: Arranging Color Hues Around A Circle

- Primary colors: a set of primary colors (RGB, CMY, RYB) combined to make a useful range of colors
- Secondary Colors: produced by mixing primary colors.
  - For RGB: Yellow, Cyan, Magenta
  - For CMY: Blue, Green, Red
  - For RYB: Orange, Green, Purple
- Complementary Colors: colors opposite each other on the color wheel



http://en.wikipedia.org/wiki/File:RGV_color_wheel_1908 by J. Arthur H. Hatt

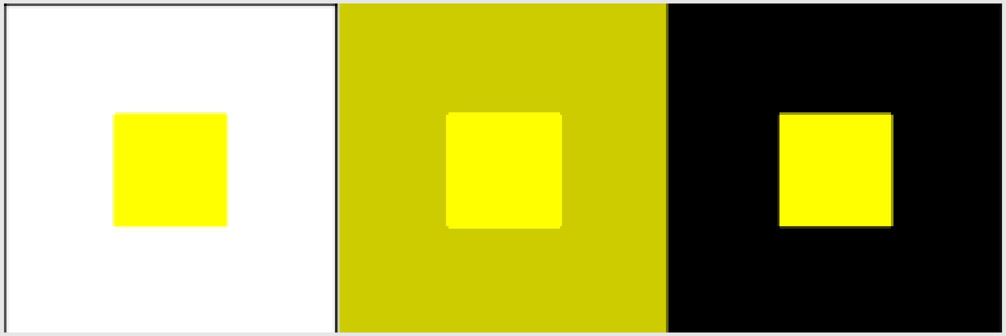
slide courtesy of Theresa Marie Rhyne' SIGGRAPH 2011 Course

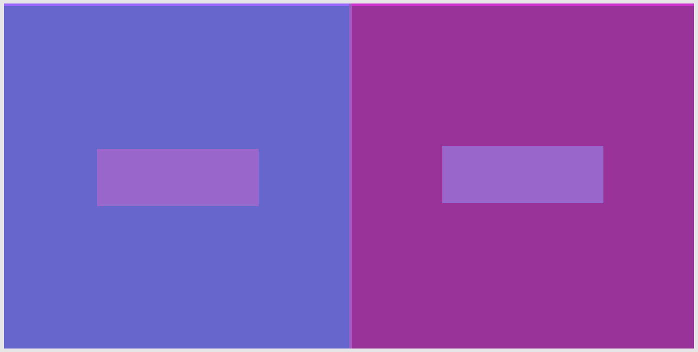
Color Design Principles

"…avoiding catastrophe becomes the first principle in bringing color to information: Above all, do no harm."

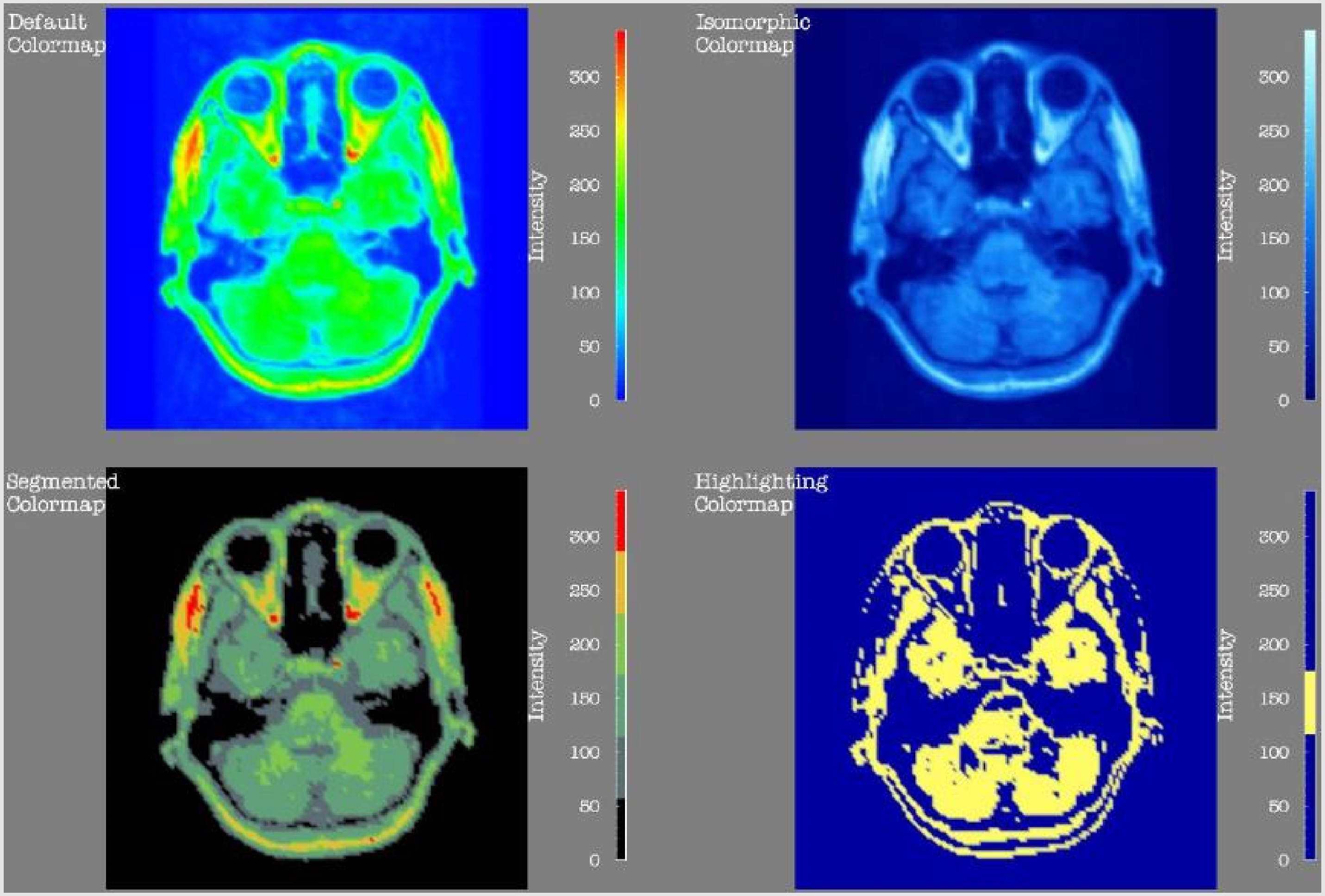
-- Edward Tufte

Simultaneous Contrast





The choices of different color map



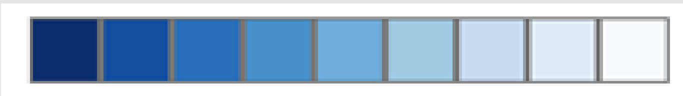
MRI scan (Bernice Rogowitz's [How not to lie with Visualization])

Color Design Principles

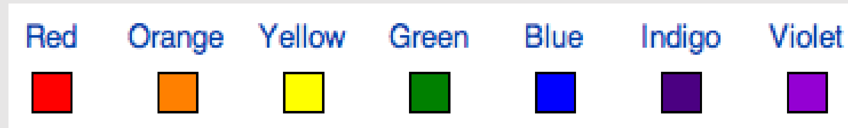
- Jacques Bertin's the Semiology of Graphics (1983)
- Maureen Stone's Choosing Colors for Data Visualization (2006)

Color Perception:

- Color is not ordered



Ordered: Low -> high



Not ordered

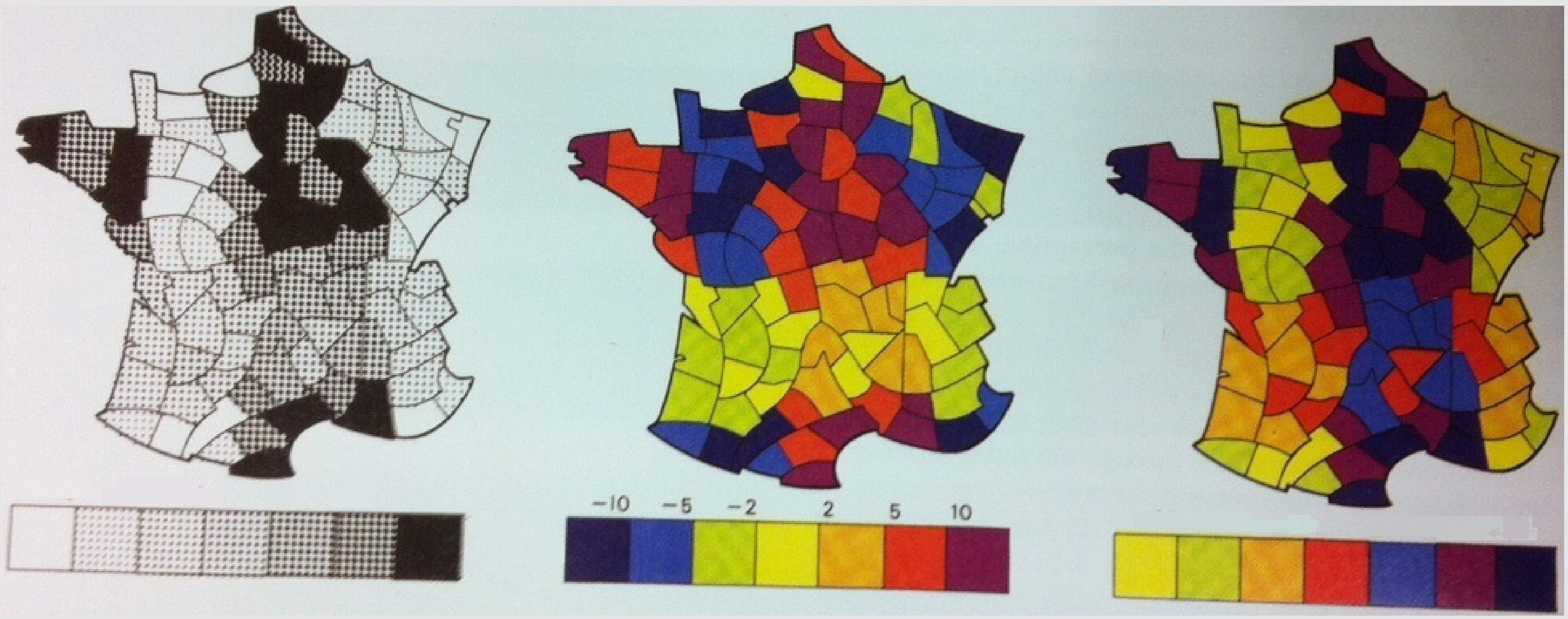
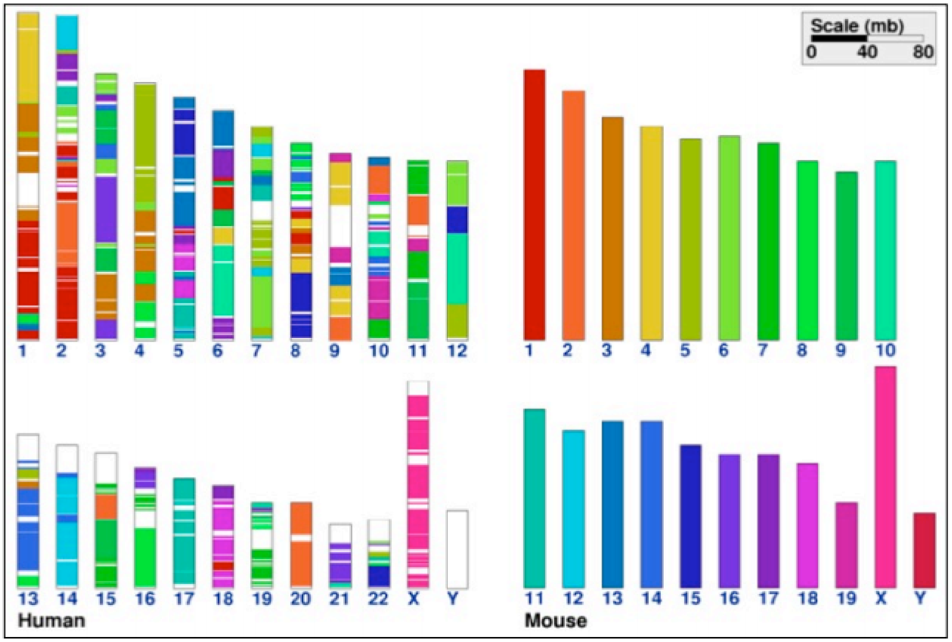


Image source: Jacques Bertin’s the Semiology of Graphics

Color Perception:

- Color has limited discriminability (6-12 steps)

noncontiguous small regions of color: only 6-12 bins



Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. Bioinformatics 2007

Color for legibility

- The factor that determines legibility is the difference in value between the symbol (text, line, etc.) and its background
- Differences in hue do not contribute

- Television and Computer Monitors use a pointillist method to represent image with the RGB color model

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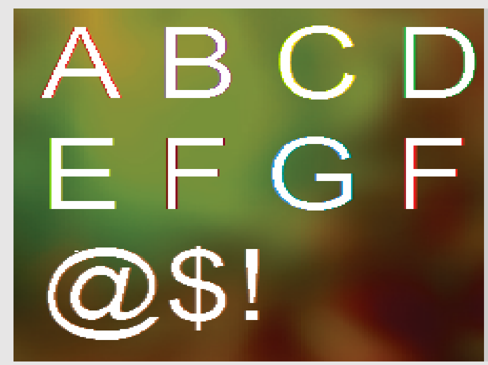
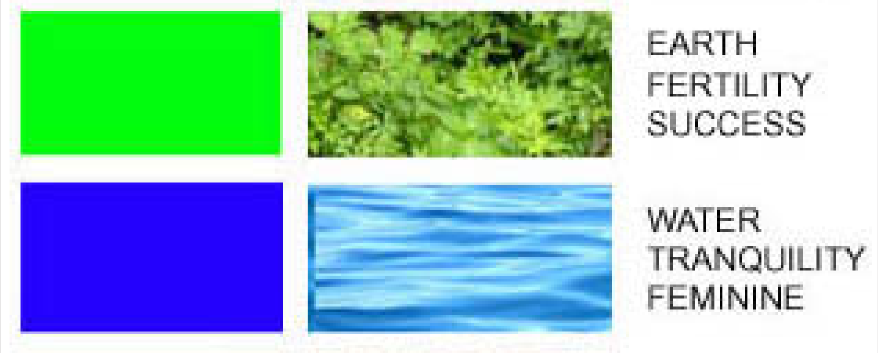


Color usage

- Color Symbolism – use color for presenting meaning

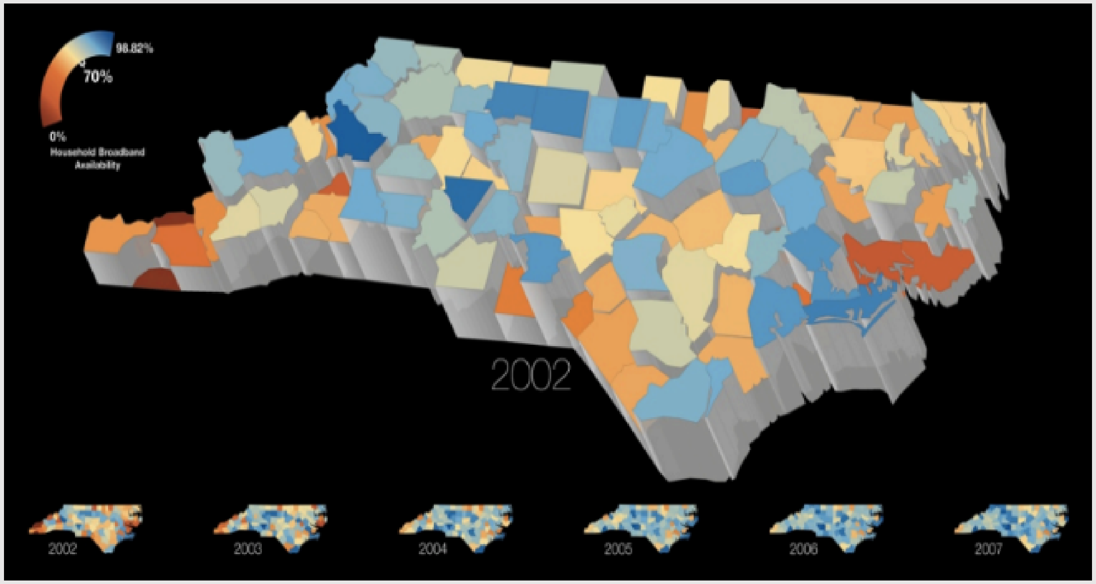


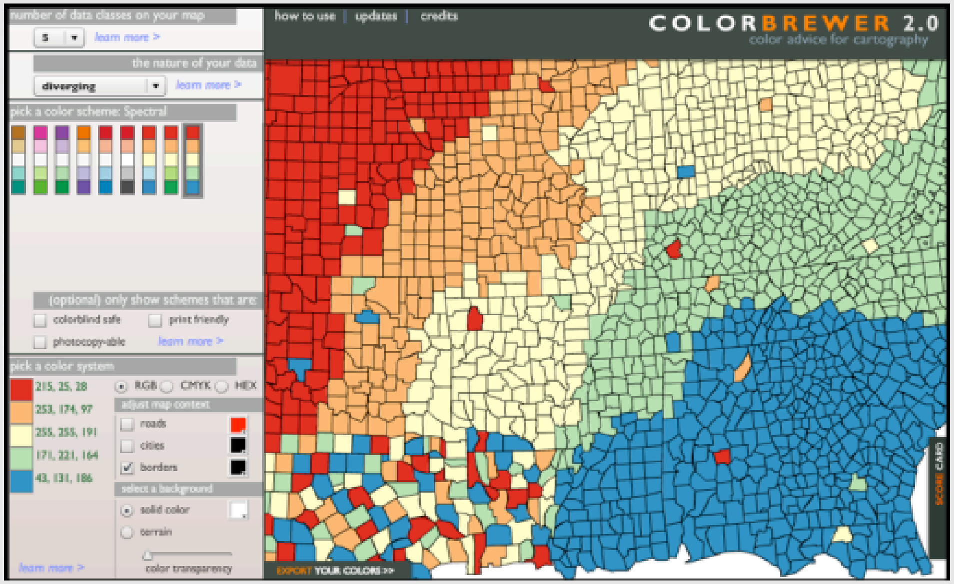
- Color Harmonies - produces a "aesthetic" effect

Contrast & Analogy

- Contrast: address difference/ draws attention
- Analogy: address similarity/ groups

Coloring Visualization Example 1: Coloring Household Broadband Availability Using ColorBrewer



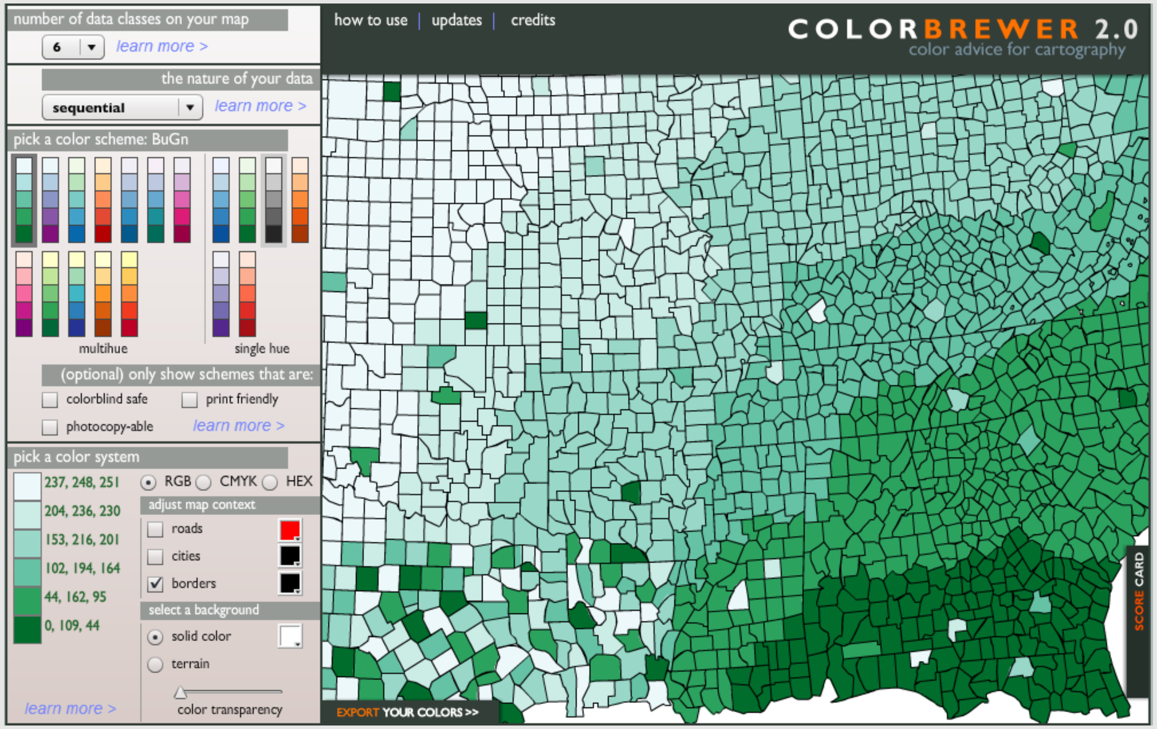


Visualization based on Household Broadband Availability data for the 100 Counties in the State of North Carolina from the years of 2002 through 2007. Information and data provided by the e-NC Authority.

ColorBrewer: conceptualized with color schemes by Cynthia A. Brewer (http://colorbrewer2.org/).

This example is provided by Theresa Marie Rhyne

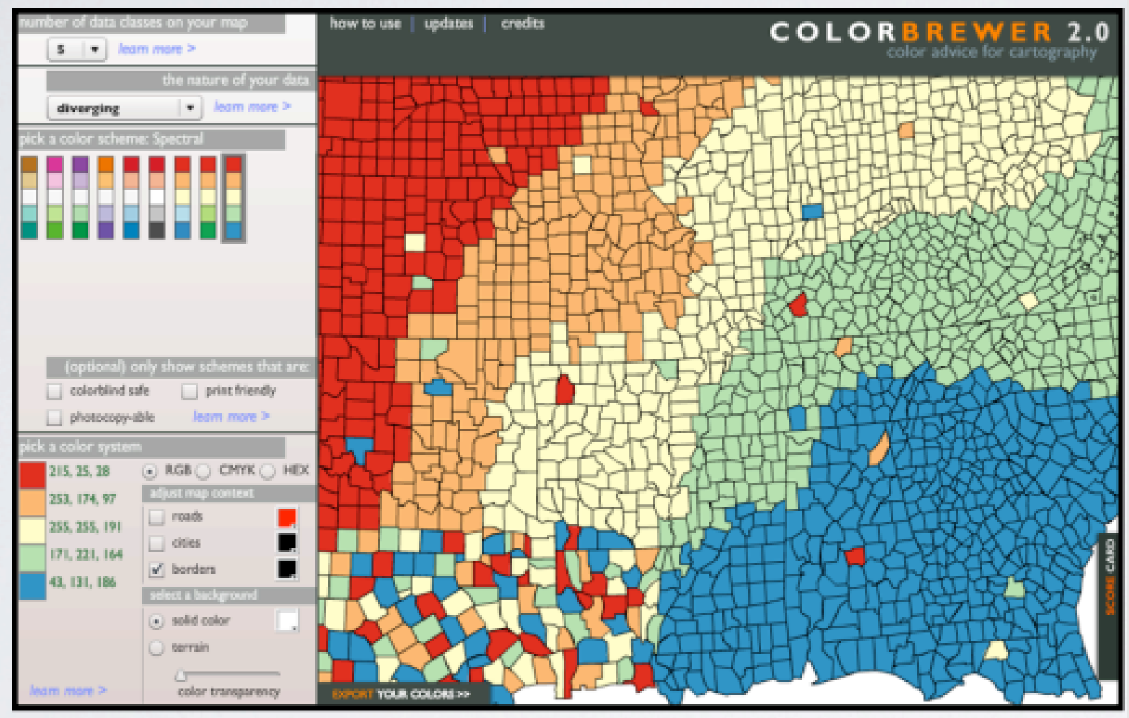
ColorBrewer's Color Scheme Concepts



- Sequential Schemes: optimized for ordered data from low to high.
- Diverging Schemes: places equal emphasis on mid-range critical values as well as extreme values.
- Qualitative Schemes: does not imply magnitude differences and suited for representing nominal or categorial data.

Example provided by Theresa Marie Rhyne

ColorBrewer's Color Scheme Concepts



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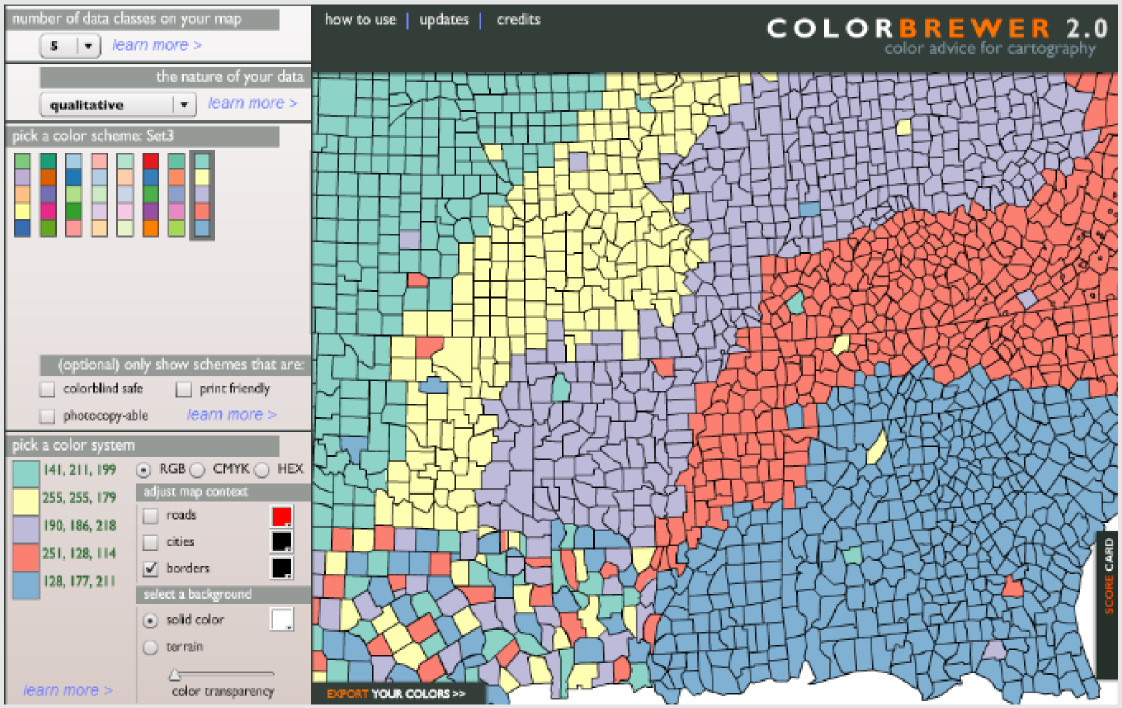

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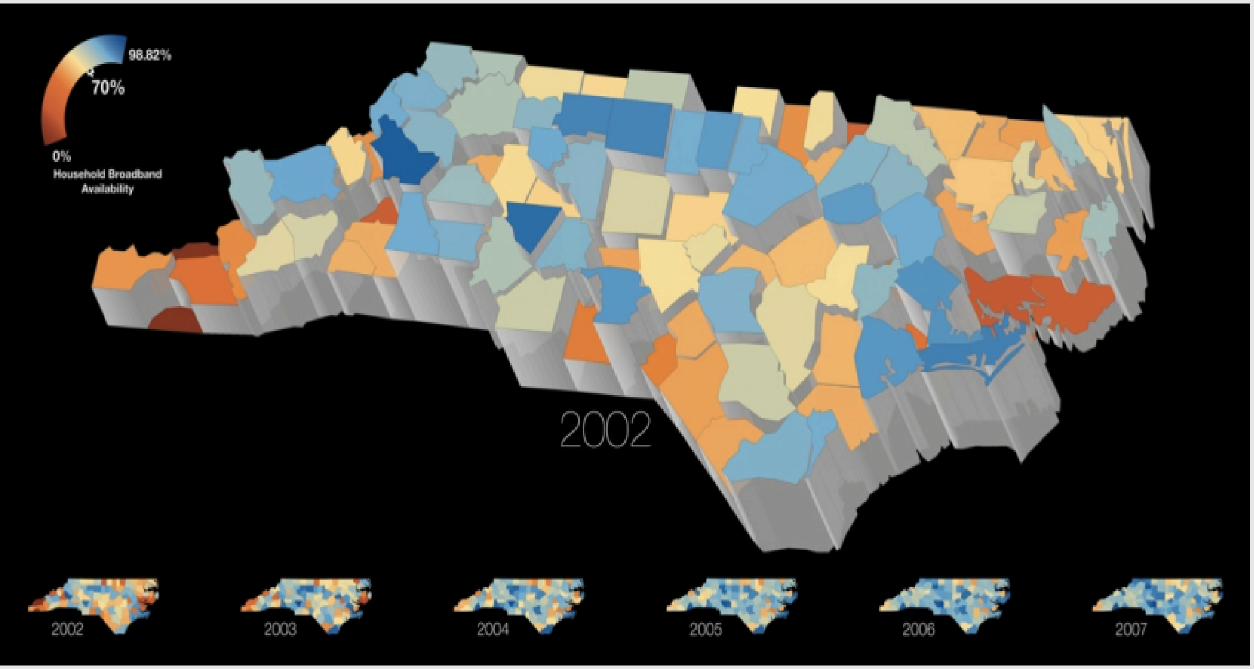

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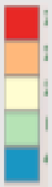

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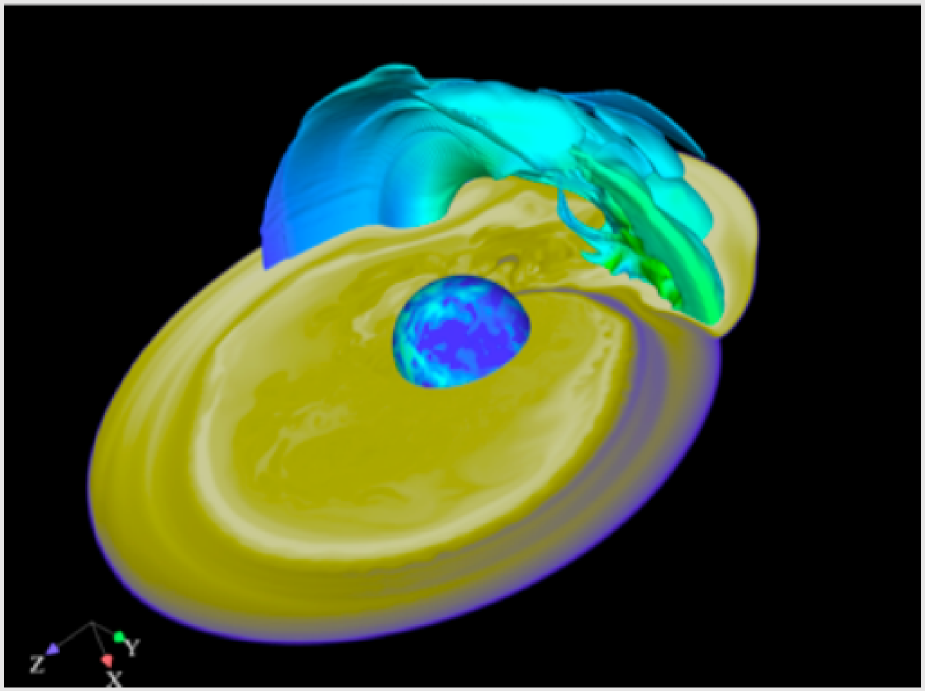
This example is provided by Theresa Marie Rhyne

Coloring Visualization Example 2: Coloring A Supernova Using Color Scheme Designer

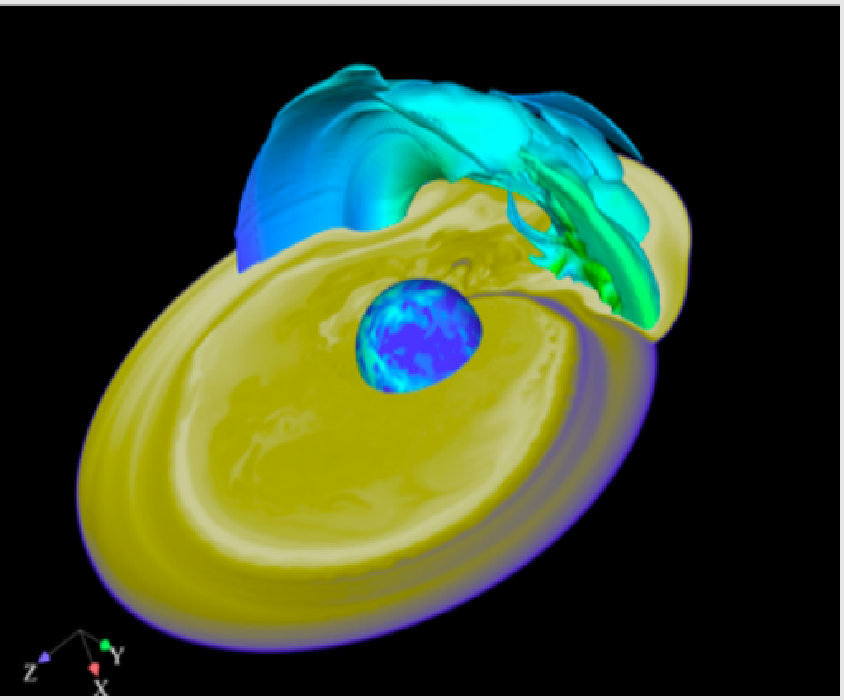


Visualization based on astrophysics data of a supernova shock wave (http://www.ensight.com).

- Building the analogous and complementary color schemes with Color Scheme Designer.

This example is provided by Theresa Marierhyne

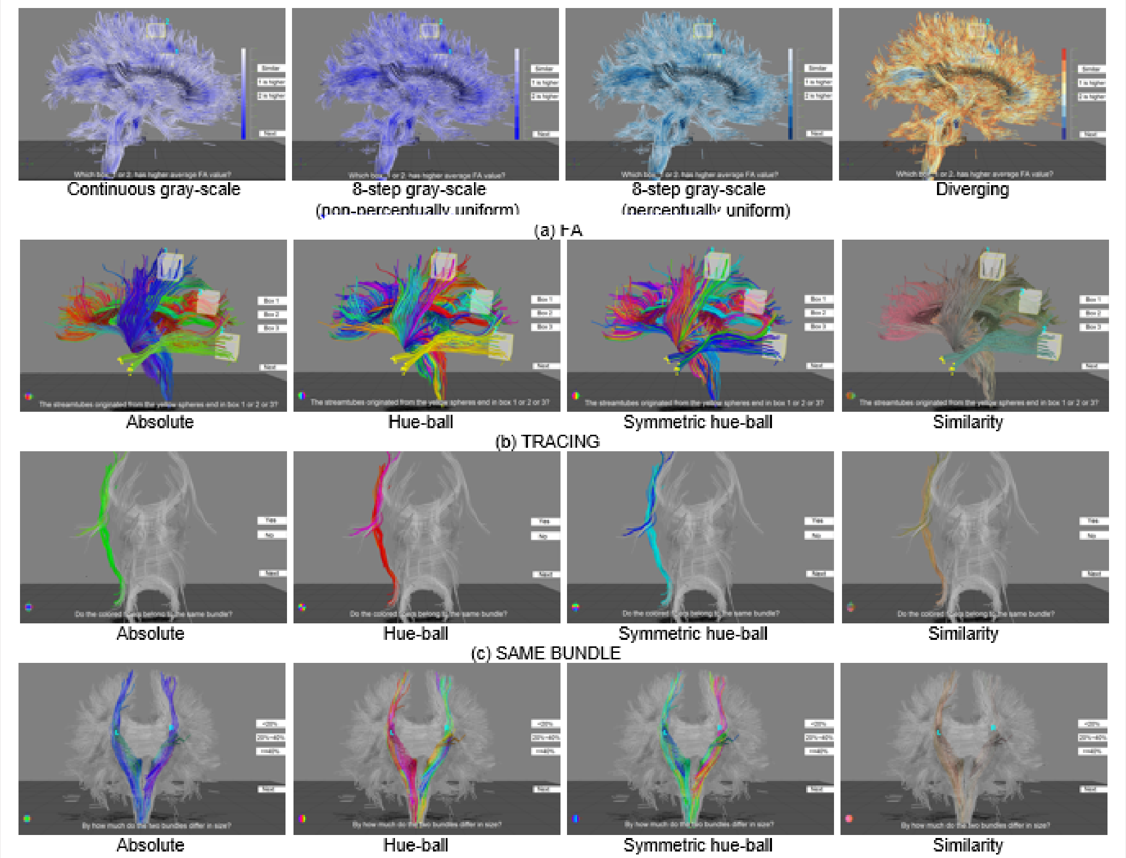
Combining Analogous & Complementary Color Schemes



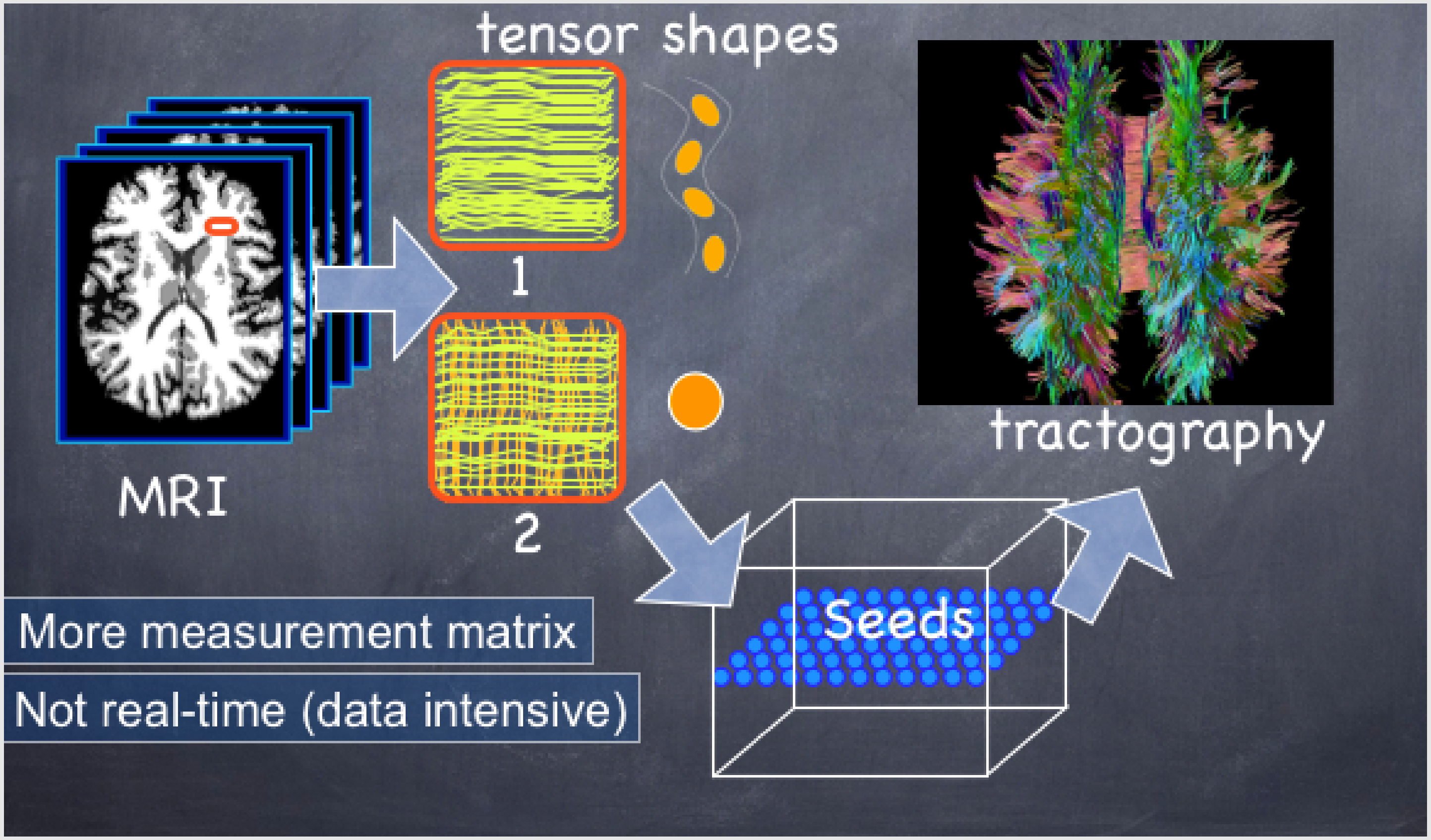
- Use the analogous color scheme of Yellow, Green and Blue to color the Super Nova object.
- Find the complementary color to Yellow to emphasize the ring of data values surrounding the Super Nova with this complementary color

This example is provided by Theresa Marie Rhyne

A User Study: Effects of Coloring Schemes on 3D Streamtube Visualization of Brain DMRI Tractography



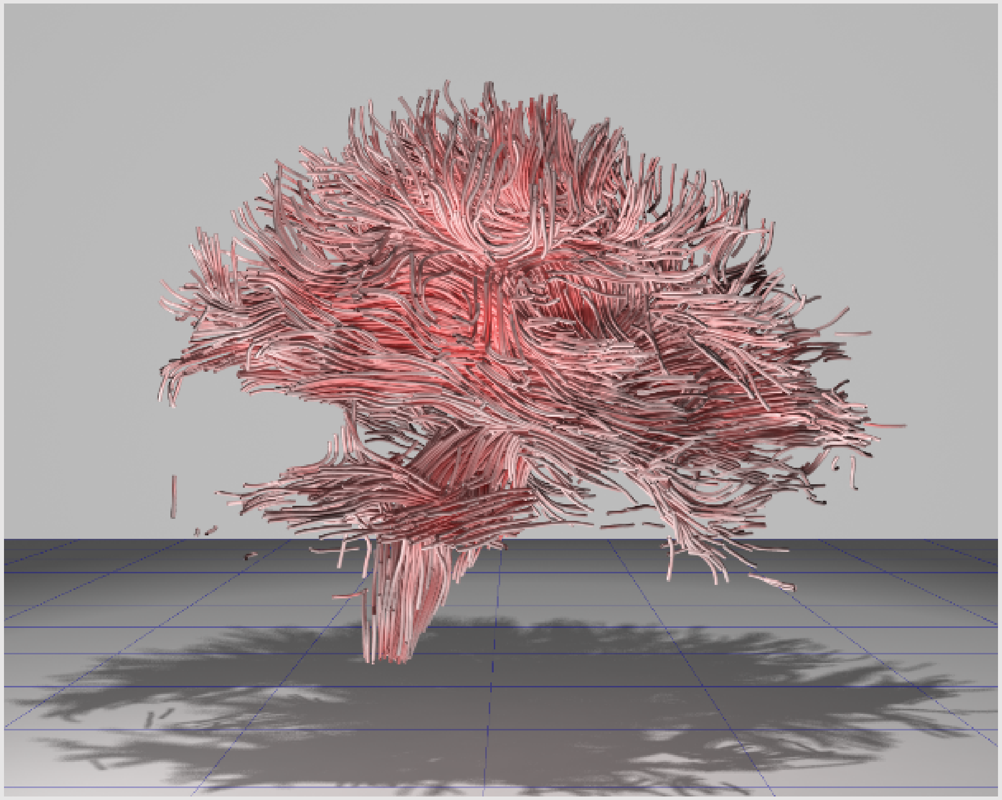
DMRI Background



Challenges of Coloring DMRI Fibers

- Visual clutter
  - Thousands of fiber tubes;
- 3D spatial perception
  - Spatial relations between tubes
  - The orientation of fiber bundles
- Support clinical tasks
  - Judge FA value
  - Check orientation of fiber bundles
  - Trace ending points of fibers
  - Compare the size of fiber bundles

  ...



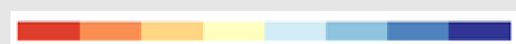
Scalar Color Encoding

Criteria for choosing scalar color encodings

- Intuitive color order —the order of the colors in a color map should represent the perceived order of the value;

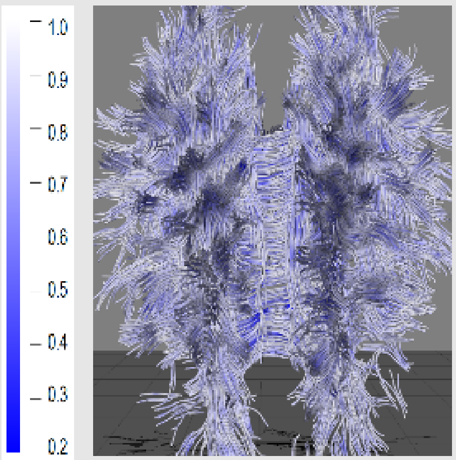
- Perceptual uniformity —a change in the value of a parameter should be perceived proportionally in a color map;

- Perceptual resolution —the map should have a high perceptual resolution to be easily discriminated;

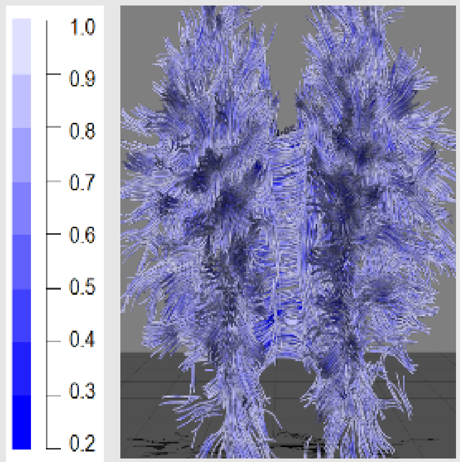


- Color-blindness safe —the colors should not be sensitive to vision deficiencies;

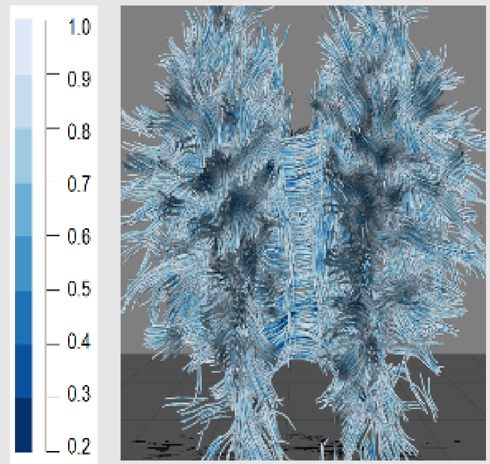
Scalar Color Encoding



Continuous gray-scale



8-step gray-scale
(non-perceptually uniform)



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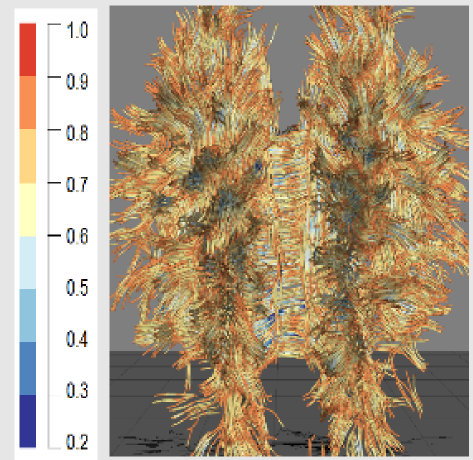


Diverging

Color encoding of fractional anisotropy (FA)

(the last two color schemes are adopted from colorBrewer http://colorbrewer2.org/)

Scalar Color Encoding

Hypothesis 1: for quantitative comparison tasks (e.g., FA), the color encoding that is perceptually uniform or has more distinct color steps would be more accurate.

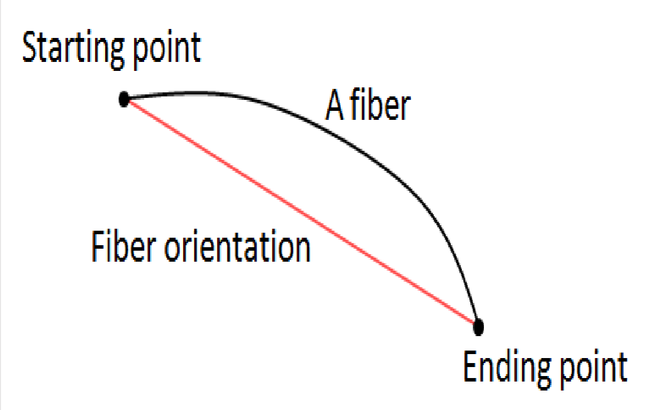
Directional Color Encoding

Criteria in choosing directional DMRI color encoding methods

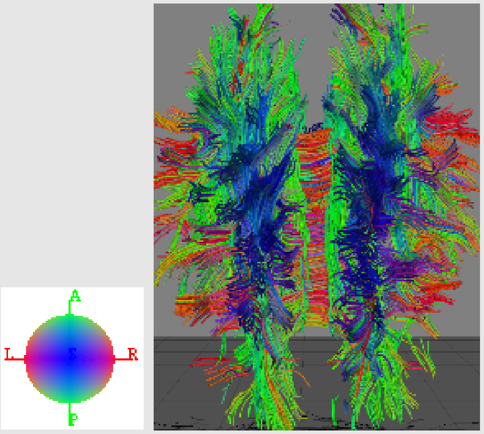
- **Contrast:** contrast increases the perceptual resolution of individual fiber bundles, which should be helpful for tasks like fiber bundle tracing;
- **Symmetry:** symmetric colors might be more useful, for example, for showing antipodal symmetry of the eigenvector and bilateral symmetry of human brain;
- **Uniqueness:** lines of different directions should map to different colors in showing brain structures;
- **Locality:** lines of similar orientation and location should map to similar colors.

Directional Color Encoding

Fiber orientation

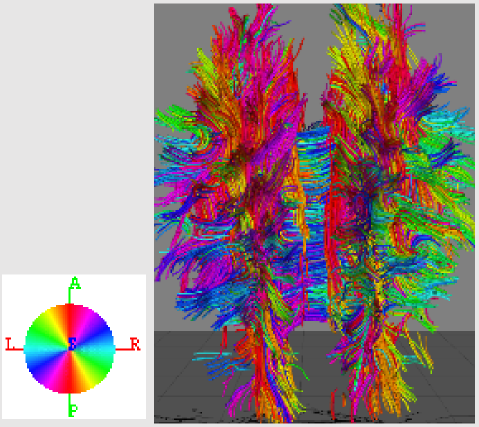


Absolute (Pajevic 1999)



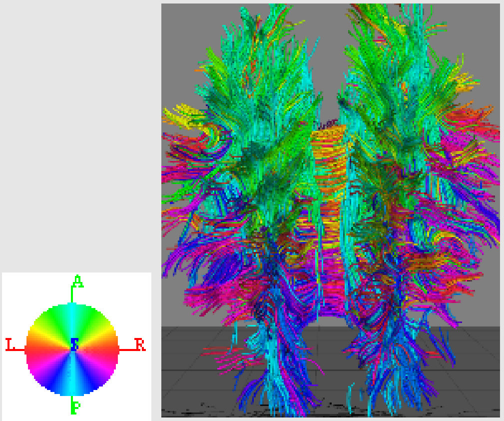
Contrast +
Symmetry ++
Locality ++
~~Uniqueness~~

Hue-ball (Kindlmann 1999)



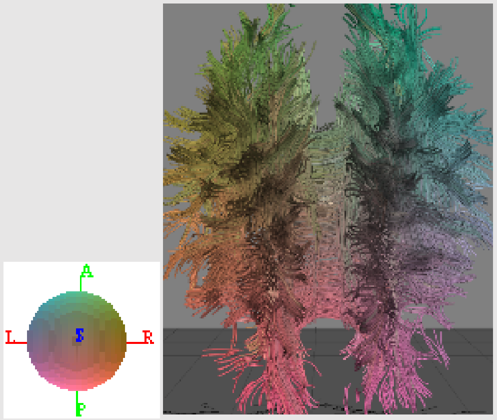
Contrast ++
Symmetry +
Locality ++
~~Uniqueness~~

Symmetric hue-ball



Contrast ++
Symmetry ++
Locality +
~~Uniqueness~~

Similarity (Demiralp, 200



Contrast
~~Symmetry~~
Locality
Uniqueness

Directional Color Encoding

Hypothesis 2: for tasks requiring spatial structure interpretation (e.g., TRACING), color encodings that exhibit better locality (similar orientations mapped to similar colors) would outperform others.

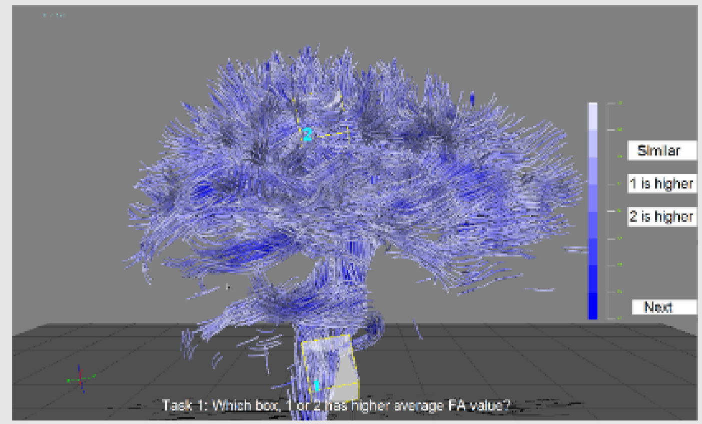
Hypothesis 3: for tasks requiring categorizing fiber bundles (e.g., SAME BUNDLE), the color encodings that exhibit good locality and uniqueness would be more accurate.

Hypothesis 4: for numerosity tasks (e.g., BUNDLE SIZE), we did not expect to observe significant main differences.

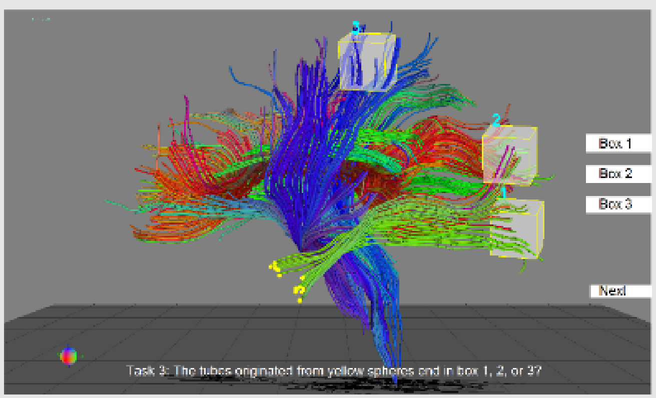
Experimental Design

Tasks	Questions
FA	Which box, 1 or 2, has higher average FA value?
TRACING	The streamtubes originated from the yellow spheres end in box 1 or 2 or 3?
SAME BUNDLE	Do the colored fibers belong to the same bundle?
BUNDLE SIZE	By how much do the two bundles differ in size?

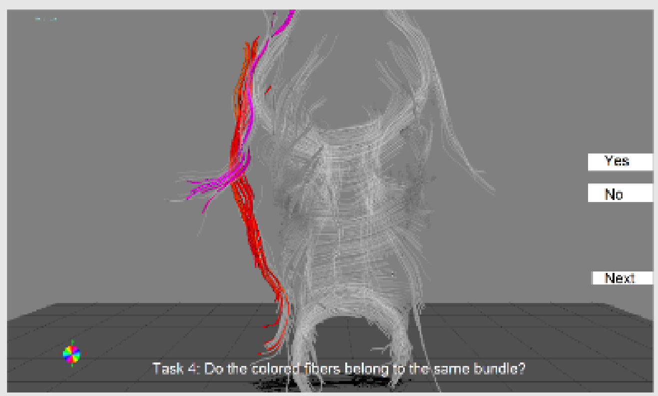
A total of 20 participants including 3 brain scientists took part of the study



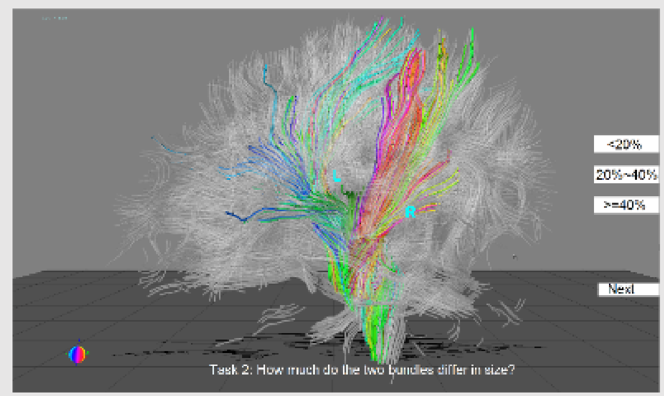
(a) FA



(b) TRACING

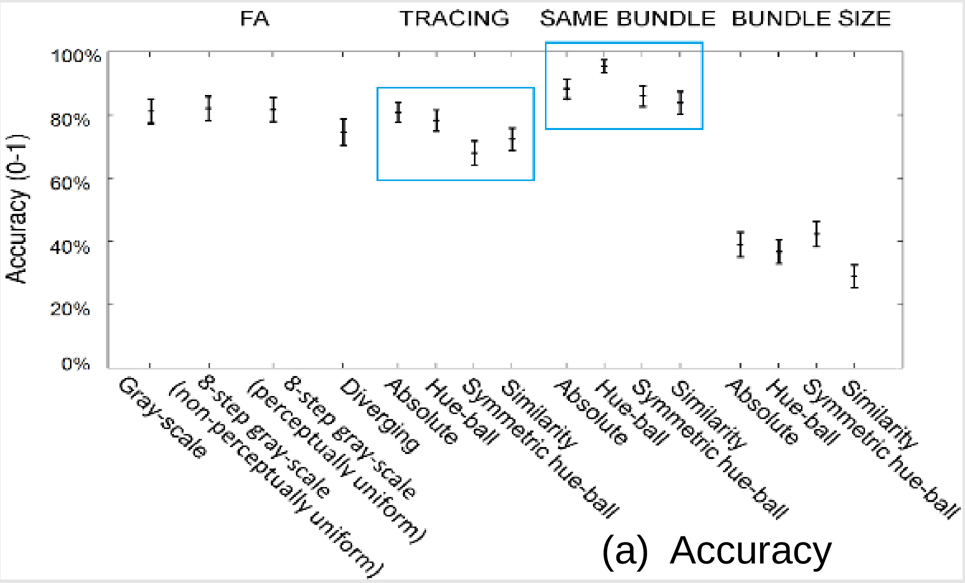


(c) SAME BUNDLE

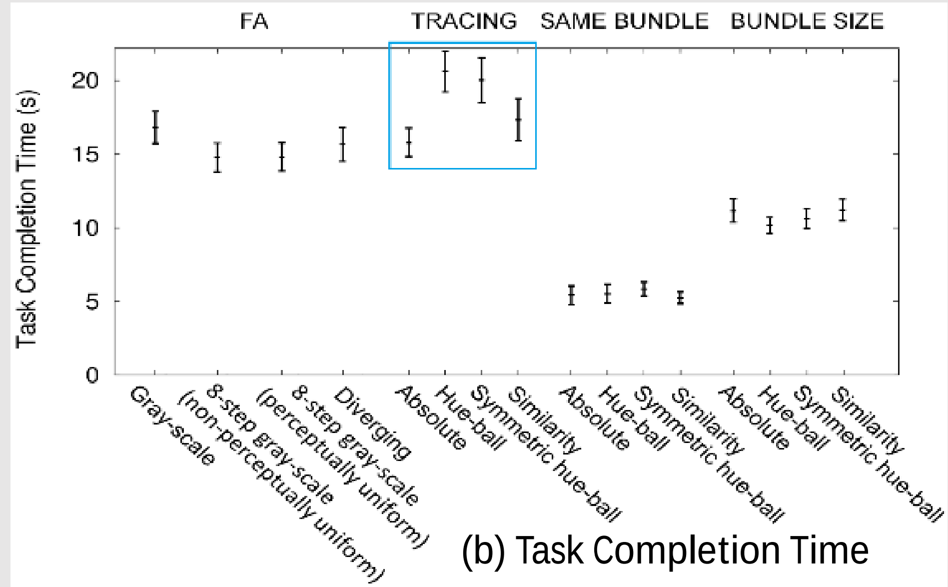


(d) BUDDLE SIZE

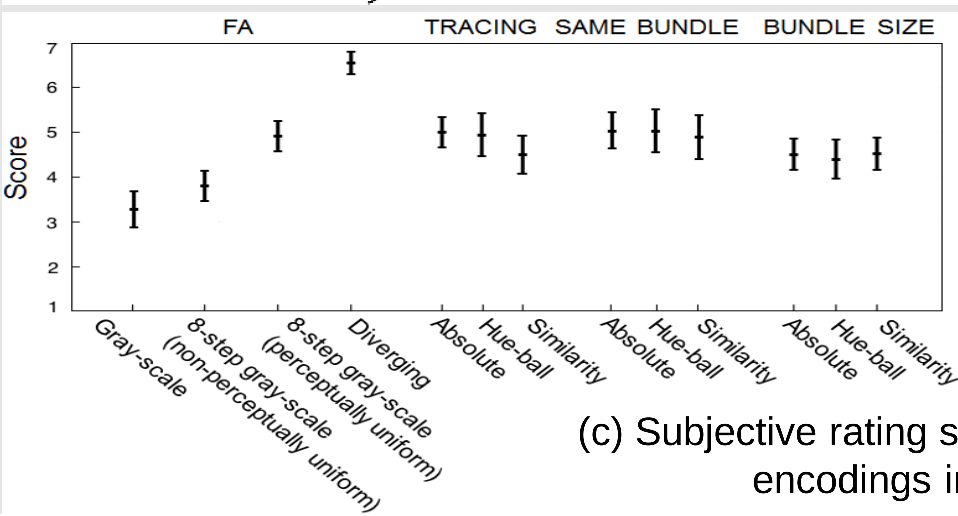
Result



(a) Accuracy



(b) Task Completion Time



(c) Subjective rating scores comparing color encodings in usefulness

Discussion

Scalar Color Encoding Performance in FA task

- the perceptually uniform color encodings did not outperform the non-perceptually uniform ones
- Larger color variation in our diverging color encoding did not lead to better task performance
- The discrete color encodings were slightly better than the continuous one in accuracy, with a noticeable (though not statistically significant) improved time efficiency

Discussion

Directional Color Encoding Performance

- Absolute color performed better in accuracy in TRACING tasks , suggesting that the absolute method may be good for spatial structure interpretation.
- The hue-ball method led to the highest accuracy in SAME BUNDLE tasks but not the symmetric hue-ball, suggesting that using the more distinct colors helped participants made more accurate judgments.
- The similarity color encoding method obtain low accuracy in all three spatial tasks, suggesting that high contrast rather than uniqueness contributed to higher accuracy.
- Low accuracy associated with Bundle Size task & no significant differences for tasks related to quantitative estimation (FA and BUNDLE SIZE). Consistent with Psychophysics studies suggestions human's limitation on counting

Conclusion

- The effectiveness of color encoding is highly task-dependent;
- Simplicity are important. When datasets of interest involve orthogonal fiber bundle discrimination, use coloring schemes, such as absolute or hue-ball, that are simple yet preserve high orientation contrast;
- Use color schemes with better orientation contrast and locality, e.g. a hue-ball method, for spatial structure interpretation tasks;
- Try not to use color alone for quantitative tasks

Other Resources

- *The Interaction of Color*, by Josef Albers (http://yalepress.yale.edu/yupbooks/book.asp?isbn=978030011595)
- *A Field Guide to Digital Color*, by Maureen Stone (http://www.stonesc.com/book/index.htm)
- Theresa Marie Rhyne's Blog

(http://web.me.com/tmrhyne/TheresaGMarie_Rhynes_Viewpoint/Blog/Blog.html)