Color in Information Display

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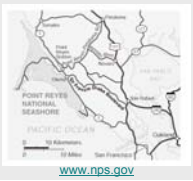
Information Display

Graphical presentation of information

- Charts, graphs, diagrams, maps, illustrations
- Originally hand-crafted, static
- Now computer-generated, dynamic

Color is a key component



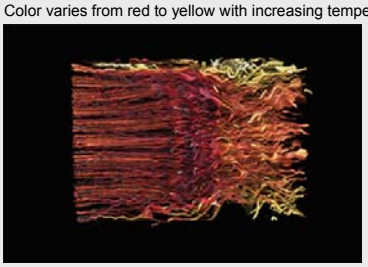
www.nps.gov

"Color" includes Gray

Maps courtesy of the National Park Service (www.nps.gov)

Visualizing Flow

3D line integral convolution to visualize 3D flow (LIC).
Color varies from red to yellow with increasing temperature

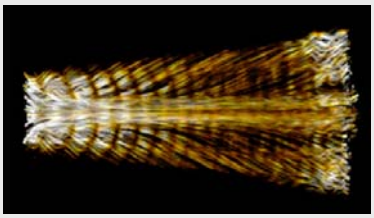


Victoria Interrante and Chester Grosch, U. Minnesota

http://www-users.cs.umn.edu/~interran/3Dflow.html

Visualizing Flow

Color is used to represent the magnitude of the vorticity across the flow volume. Note the pressure waves



Victoria Interrante and Chester Grosch, U. Minnesota

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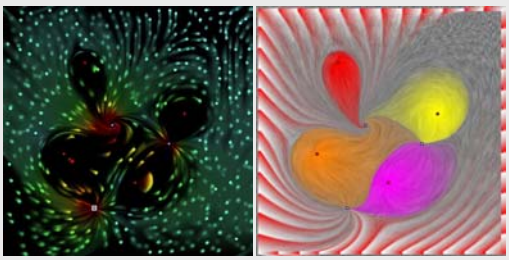
Visualizing Flow

Simulated ink in a turbulent flow field



Jarke J. van Wijk
Technische Universiteit Eindhoven

http://www.win.tue.nl/%7Evanwijk/ibfv/

Tableau "Heat Map"

www.tableausoftware.com

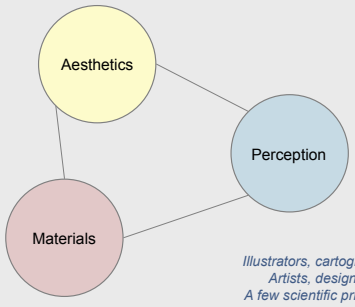
Multi-dimensional Scatterplot

Variable 1, 2 → X, Y

Variable 3, 4, 5 → R, G, B

Using Color Dimensions to Display Data Dimensions.
Beatty and Ware

Effective Color



Illustrators, cartographers
Artists, designers
A few scientific principles

Overview

Color vision models in brief

Design principles for using color

- Tufte's principles
- Lots of examples

A bit about RGB color

Making color robust

What is Color?

Physical World	Visual System	Mental Models
Lights, surfaces, objects	Eye, optic nerve, visual cortex	Red, green, brown Bright, light, dark, vivid, colorful, dull Warm, cool, bold, blah, attractive, ugly, pleasant, jarring

Why Color?

Physical World	Visual System	Mental Models
Lights, surfaces, objects	Eye, optic nerve, visual cortex	Red, green, brown Apple, leaf, bark Ripe, fresh, eatable …and then to action.

Color in Information Display

Physical World	Visual System	Mental Models
Lines, patches, shaded regions	Eye, optic nerve, visual cortex	Roads, lakes Profit, loss, trends Failures, threats …and then to action

Why Should We Care?

Poorly designed color is confusing
- Creates visual clutter
- Misdirects attention
- Obscures important information

Poor design devalues the information
- Visual sophistication
- Evolution of document and web design

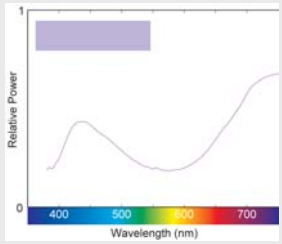
Color Models

Physical World	Visual System		Mental Models	
Light Energy	Cone Response	Opponent Encoding	Perceptual Models	Appearance Models
Spectral distribution functions	Encode as three values (L,M,S)	Separate lightness, chroma	Color "Space"	Color in Context
F(λ)	CIE (X,Y,Z)	(A,R-G,Y-B)	Hue, lightness saturation	Adaptation, Background, Size, …
			Munsell (HVC)	CIECAM02

Physical World

Spectral Distribution
- Visible light
- Power vs. wavelength

Any source
- Direct
- Transmitted
- Reflected
- Refracted



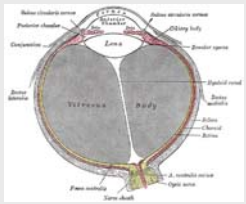
From *A Field Guide to Digital Color*, © A.K. Peters, 2003

Visual System

Light path
- Cornea, pupil, lens, retina
- Optic nerve, brain

Retinal cells
- Rods and cones
- Unevenly distributed

Cones
- Three "color receptors"
- Concentrated in fovea

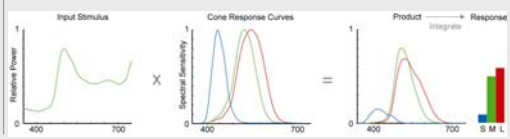


From Gray's Anatomy

Cone Response

Encode spectra as three values
- Long, medium and short (SML)
- Trichromacy: only SML is "seen"
- Different spectra can "look the same"

Sort of like a digital camera*

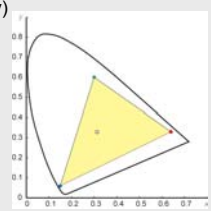


From *A Field Guide to Digital Color*, © A.K. Peters, 2003

Color Measurement

Commission Internationale de l'Eclairage (CIE)

- "Standard cones" (CMF)
- Tristimulus values (XYZ)
- Chromaticity coordinates (xy)
- Chromaticity diagram



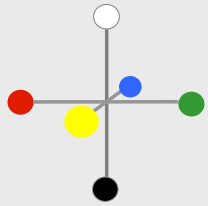
Opponent Color

Definition

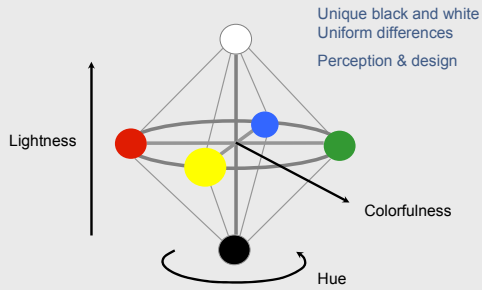
- Achromatic axis
- R-G and Y-B axis
- Separate lightness from chroma channels

First level encoding

- Linear combination of SML
- Before optic nerve
- Basis for perception



Perceptual Color Spaces



Munsell Atlas

Courtesy Gretag-Macbeth

Color Appearance

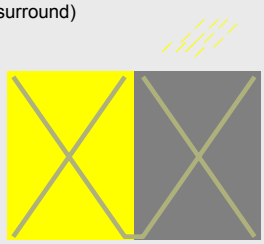
More than a single color

- Adjacent colors (background)
- Viewing environment (surround)

Appearance effects

- Adaptation
- Simultaneous contrast
- Spatial effects

Colors in context

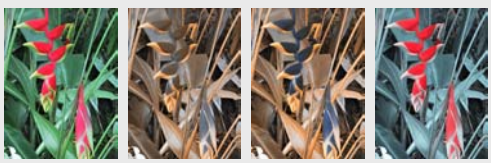


Vischeck

Simulates color vision deficiencies

- Web service or Photoshop plug-in
- Robert Dougherty and Alex Wade

www.vischeck.com



Deuteranope Protanope Tritanope

Color Models

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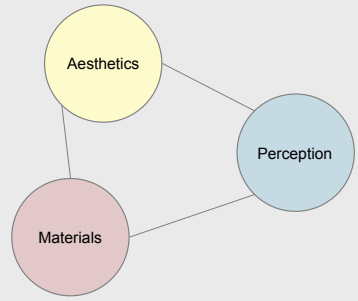
Effective Color



Envisioning Information

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

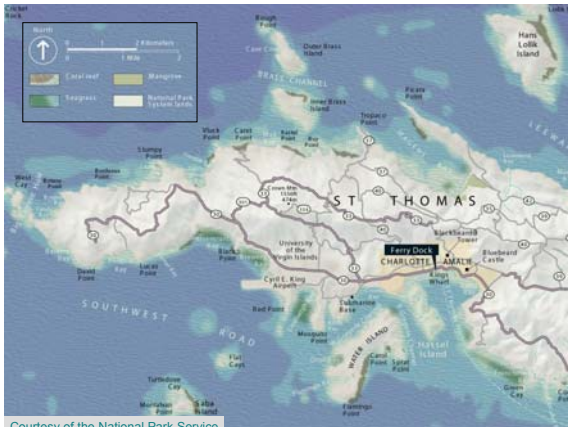
—E. R. Tufte

www.edwardtufte.com

Fundamental Uses

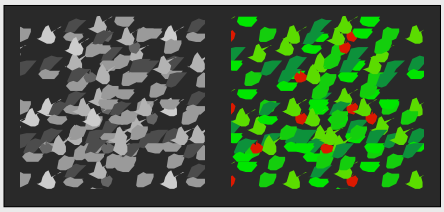
To label
To measure
To represent or to imitate reality
To enliven or decorate

Envisioning Information
Edward R. Tufte



Courtesy of the National Park Service

To Label



Information Visualization
Colin Ware

Grouping, Highlighting

	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
red	25.37	13.70	0.05	26.27	14.13	0.04	18.41	10.16	0.05	17.43	9.30	0.00
green	22.14	51.24	0.35	20.68	49.17	0.44	21.11	46.00	0.20	16.36	37.95	0.12
blue	13.17	3.71	74.89	15.38	5.20	86.83	11.55	3.37	65.53	9.96	3.44	56.14
gray	63.46	73.30	78.05	64.66	71.99	90.08	52.96	62.49	67.99	45.54	53.65	58.14
black	0.66	0.70	0.77	0.63	0.66	1.09	0.47	0.58	0.70	0.44	0.54	0.71

	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
red	25.37	13.70	0.05	26.27	14.13	0.04	18.41	10.16	0.05	17.43	9.30	0.00
green	22.14	51.24	0.35	20.68	49.17	0.44	21.11	46.00	0.20	16.36	37.95	0.12
blue	13.17	3.71	74.89	15.38	5.20	86.83	11.55	3.37	65.53	9.96	3.44	56.14
gray	63.46	73.30	78.05	64.66	71.99	90.08	52.96	62.49	67.99	45.54	53.65	58.14
black	0.66	0.70	0.77	0.63	0.66	1.09	0.47	0.58	0.70	0.44	0.54	0.71

Preattentive "Pop-out"

13579345978274055
24937916478254137
23876597277103876
19874367259047362
95637283649105676
32543787954836754
56840378465485690

Time proportional to the number of digits

1357934597827 4055
2493791647825 4137
2387659727710 3876
1987436725904 7362
9563728364910 5676
3254378795483 6754
5684037846578 5690

Time proportional to the number of 7's

1357934597827 4055
2493791647825 4137
2387659727710 3876
1987436725904 7362
9563728364910 5676
3254378795483 6754
5684037846578 5690

Both 3's and 7's "Pop out"

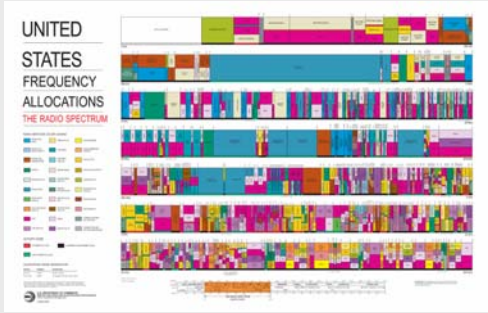
Pop-out vs. Distinguishable

Pop-out
- Typically, 5-6 distinct values simultaneously
- Up to 9 under controlled conditions

Distinguishable
- 20 easily for reasonable sized stimuli
- More if in a context

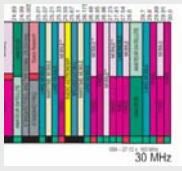
What is the color for?

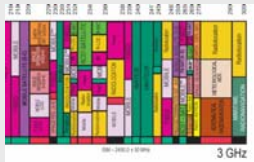
Radio Spectrum Map (33 colors)



http://www.cybergeography.org/atlas/us_spectrum_map.pdf

Distinguishable on Inspection





Color Names

Basic names (Berlin & Kay)
- Linguistic study of names
- Similar names
- Similar evolution

Perceptual primaries

black
white
gray

red
green
blue
yellow

orange
purple
brown
pink

Distinct colors = distinct names?

Tableau Color Example

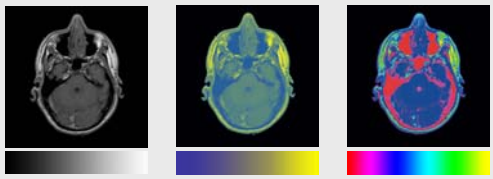
Color palettes
- How many? Algorithmic?
- Basic colors (regular and pastel)
- Extensible? Customizable?

Color appearance
- As a function of size
- As a function of background

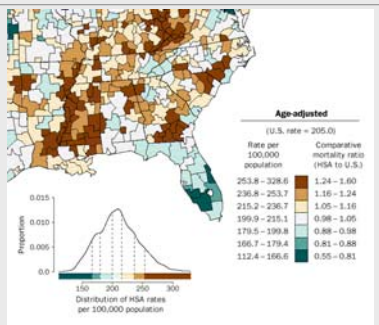
Robust and reliable color names

To Measure

Color as quantity
- Density map
- Thematic maps
- Color scales/maps



Thematic Maps



US Census Map

Mapping Census 2000: The Geography of U.S. Diversity

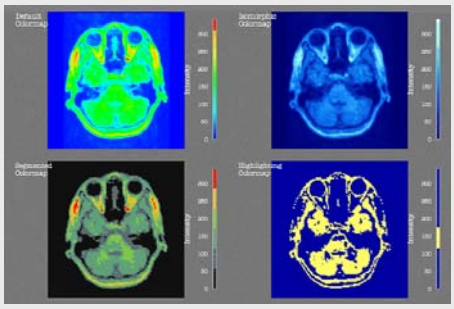
Color Scales

Long history in graphics and visualization
- Ware, Robertson et. al, Levkowitz et. al
- Rheingans

PRAVDA Color
- Rogowitz and Treinish
- IBM Research

Cartography
- Cynthia Brewer
- ColorBrewer

Different Scales



Rogowitz & Trennish, "How not to lie with visualization"

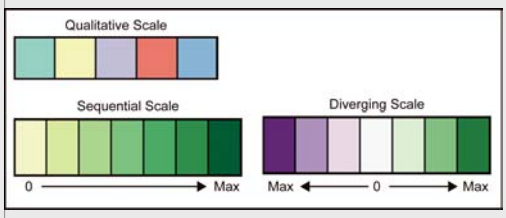
Data to Color

Type of data values
- Nominal, ordinal, numeric
- Qualitative, sequential, diverging

Hue = nominal

Lightness or saturation scales
- Lightness best for high frequency
- More = darker (or more saturated)

Brewer's Categories



Cynthia Brewer, Pennsylvania State University

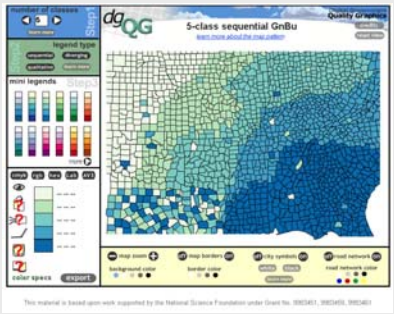
Brewer Scales

Nominal scales
- Distinct hues, but similar emphasis

Sequential scale
- Vary in lightness and saturation
- Vary slightly in hue

Diverging scale
- Complementary sequential scales
- Neutral at "zero"

Color Brewer



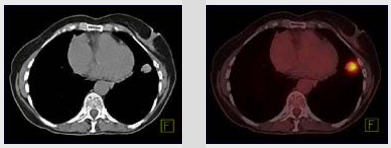
www.colorbrewer.org

Tableau Color Example

Color scales for encoding data
Displayed as charts and graphs
Issues
- Color ramps based on Brewer's principles
- Not single hue/chroma varying in lightness
- Create a ramp of the "same color"
- Legible different than distinguishable
- Center, balance of diverging ramps

Color and Shading

Shape is defined by lightness (shading)
"Color" (hue, saturation) labels



CT image (defines shape) PET color highlights tumor

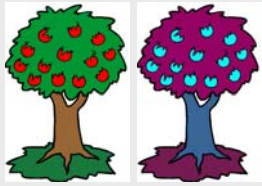
Image courtesy of Siemens

Color and Shading

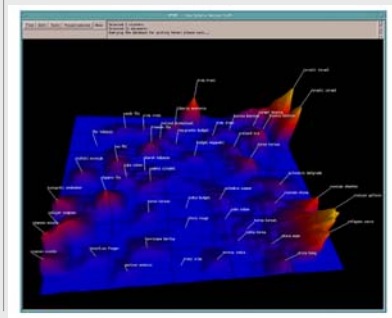
Images Courtesy of TeraRecon, Inc

To Represent or Imitate Reality

Color as representation
- Key color to real world
- Iconographic vs. photographic



ThemeView (original)



Courtesy of Pacific Northwest National Laboratories

ThemeScape (commercial)

Courtesy of Cartia

To Enliven or Decorate

Color as beauty
- Aesthetic use of color
- Emotional, personal

"Attractive things work better" *—Don Norman*

More Tufte Principles

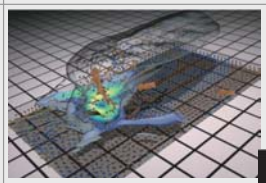
Limit the use of bright colors
- Small bright areas, dull backgrounds

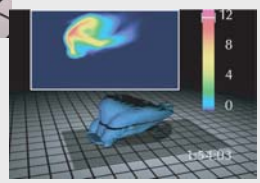
Use the colors found in nature
- Familiar, naturally harmonious

Use grayed colors for backgrounds
- Quiet, versatile

Create color unity
- Repeat, mingle, interweave

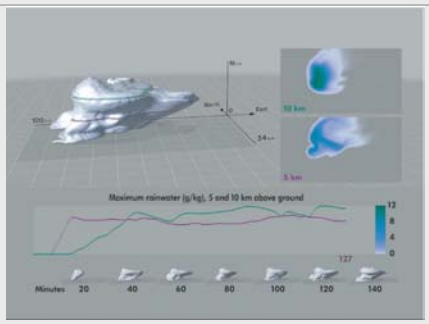
Storm example





From "After the Storm," Baker and Bushell

Storm Example (continued)



From "After the Storm," Baker and Bushell

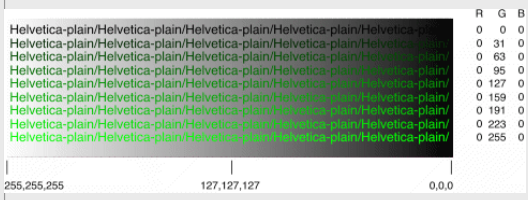
Get it right in black & white

Value
- Perceived lightness/darkness
- Controlling value primary rule for design

Value alone defines shape
- No edge without lightness change
- No shading with out lightness variation

Value difference defines contrast
- Defines legibility
- Controls attention

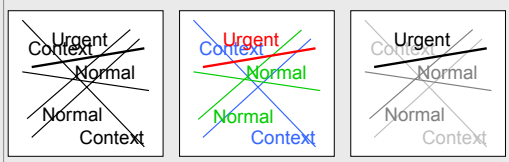
Controls Legibility



colorusage.arc.nasa.gov

Drop shadow adds edge

Controls Attention, Clutter



colorusage.arc.nasa.gov

Cockpit Controls (before)

Courtesy of Larry Arrend, NASA

Cockpit Controls (after)

Layered, prioritized use of color, contrast

Courtesy of Larry Arrend, NASA

Controlling Value

Scale from black to white

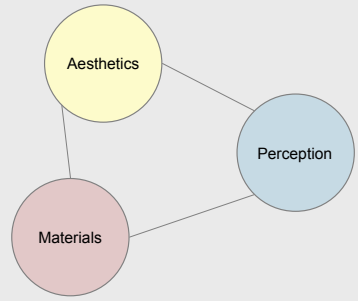
- Luminance
- Munsell value, L*
- Density, reflectance

RGB displays

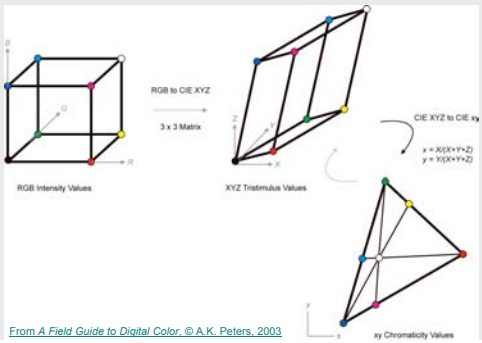
- Non-linear function of intensity
- "Gamma function"
- Sensitive to display settings, ambient light

What is best way to define "contrast?"

Effective Color

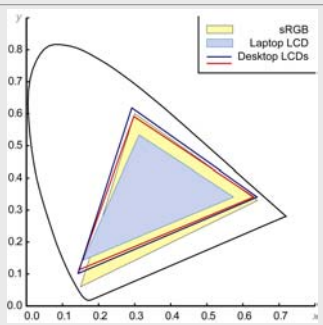


RGB Specifications



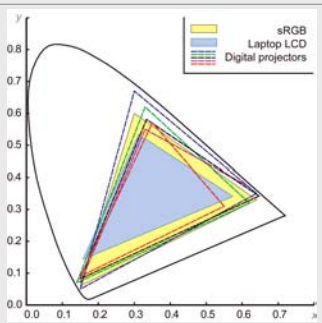
From *A Field Guide to Digital Color*, © A.K. Peters, 2003

Display Gamuts



From *A Field Guide to Digital Color*, © A.K. Peters, 2003

Projector Gamuts



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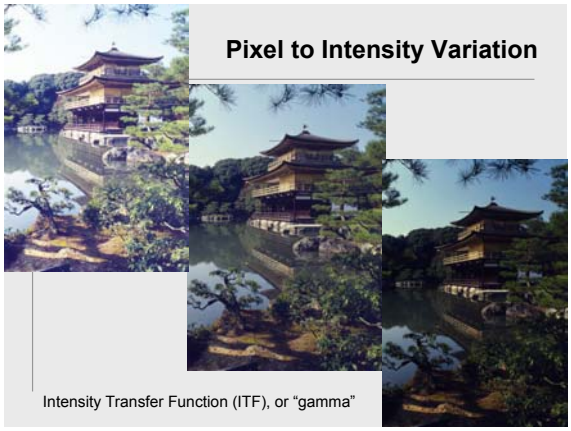
Pixel to Intensity Variation



Intensity Transfer Function (ITF), or "gamma"

Display Appearance

Tristimulus characterization
- Relatively easy to accomplish
- But, not a total solution

Want RGB to color appearance
- Robust and reliable color names
- Robust and reliable contrast control
- As robust as print appearance

Visual feedback and simple controls

Appearance Models

Adaptable Color
- Same color, different sizes
- Same color, different backgrounds

Interactive Color
- Does it appear the same?
- User has controls: Zoom, tool tips, etc.

Cross-media rendering
- Maintain encoding
- Names and relationships?

Conclusion

Color in information display
- Tufte's rules
- "Get it right in black and white"

Easier than images
- Fewer colors, larger areas
- Doesn't match a real world scene

Harder than images
- Doesn't match a real world scene
- Critical for information content