Colo(u)r in Information Display

IAT 814
Week 3

These slides are largely courtesy of Maureen Stone with some from Colin Ware

Overview

- Luminance, brightness and contrast
- Colour Theory
- Colour Geometries
- Colour applications

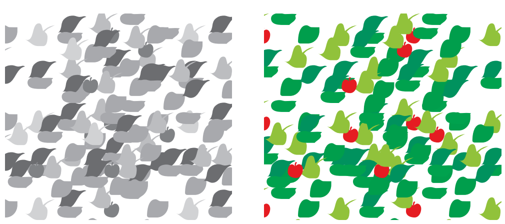
Colour is Irrelevant…

- To perceiving object shapes
- To perceiving layout of objects in space
- To perceiving how objects are moving
- Therefore, to much of modern life
  - Laboratory assistant went 21 years without realizing he was colour-blind

Colour is Critical…

- To help us break camouflage
- To judge the condition of objects (food)
- To determine material types
- Extremely useful for coding information

> surfaces



Implications

- Colour perception is *relative*
- We are sensitive to small differences
  - hence need sixteen million colours
- Not sensitive to absolute values
  - hence we can only use < 10 colours for coding

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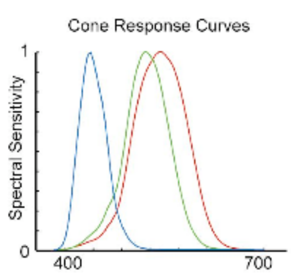
Cone Response (photopic)

- Cone response sensitivity for colours occurs at different wavelengths in the spectrum
  - Cone response curve
  - Long, medium and short (LMS)



- Sort of like a digital camera*
  - BUT light sensors in a camera are equally distributed
- Uneven cone distribution
  - saccades for continuous image

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

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Short wavelength sensitive cones

Blue text on a dark background
is to be avoided. We have very few
short-wavelength sensitive cones in
the retina and they are not very sensitive

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Blue text on a dark background
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Chromatic aberration in the eye is also a
problem

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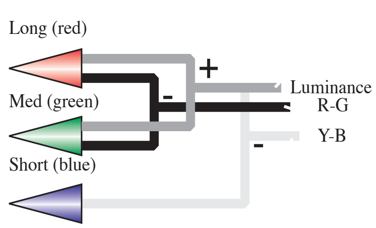
Opponent Process Theory

- Cone signals transformed into new channels
  - Black/White (Luminance; ignores blue)
  - Red/Green
  - Yellow/Blue



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An example of opponent colour

- Negative retinal after-image is the opponent colour
- Helps with colour constancy
- http://www.michaelbach.de/ot/col_lilacChaser/index.html

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Comparing the Channels

- Spatial Sensitivity
  - Red/Green and Yellow/Blue about 1/3 detail of Black/White
- Stereoscopic Depth
  - Pretty much can't do it with hue alone
- Temporal Sensitivity
  - Moving hue-change patterns seem to move slowly
- Form
  - Shape-from shading works well
  - Shape-from-hue doesn't
- Information Labeling: Hue works well!

Some natural philosophers Suppose that these colours arise from the accidental vapours diffused in the air, which communicates their own hues to the shadow

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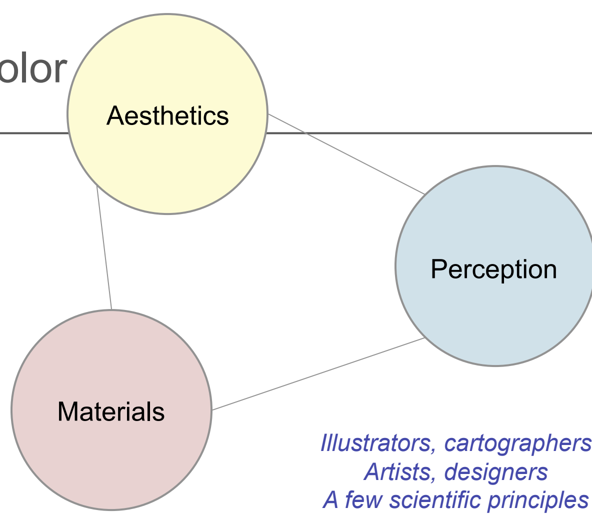
Channel Properties

- **Luminance Channel**
- Detail
- Form
- Shading
- Motion
- Stereo

- **Chromatic Channels**
- Surfaces of things
- Labels
- Berlin and Kay - naming
- Categories (about 6-10)
- Red, green, yellow and blue are special (unique hues)

Effective Color



Illustrators, cartographers
Artists, designers
A few scientific principles

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

Perception and Cognition

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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 …
			CIELAB Munsell (HVC)	CIECAM02

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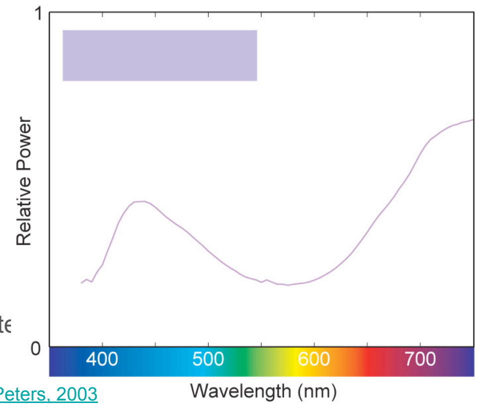
Physical World

- Spectral Distribution
  - Visible light
  - Power vs. wavelength
- Any source
  - Direct
  - Transmitted
  - Reflected
  - Refracted
- Two curves that are scaled multiples of each other are the “same” colour, but one is brighte than the other



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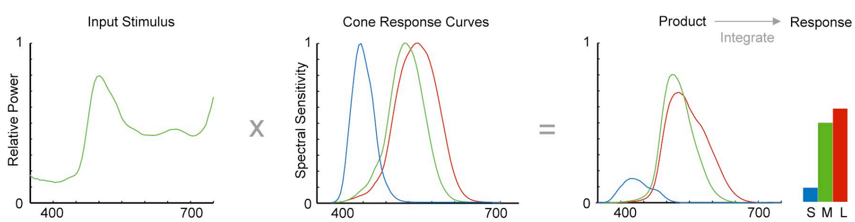
Cone Response (photopic)

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



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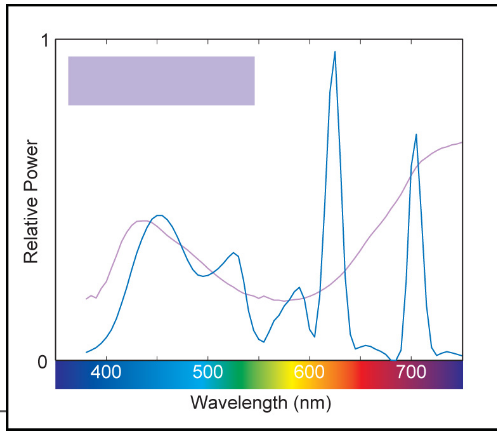
Effects of Retinal Encoding



Metameric match

All spectra that stimulate the same cone response are indistinguishable

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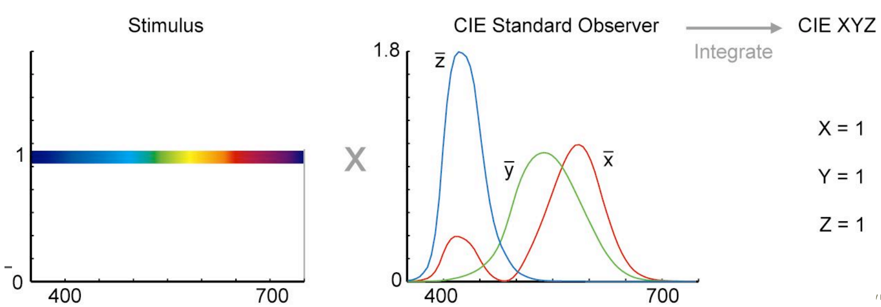
Color Measurement

- CIE Standard Observer
- CIE tristimulus values (XYZ)
- All spectra that stimulate the same tristimulus (XYZ) response are indistinguishable



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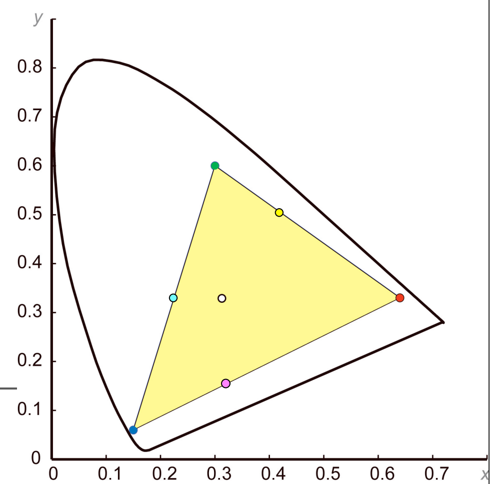
RGB Chromaticity

- R,G,B are points (varying lightness)
- Sum of two colors lies on line
- Gamut is a triangle
  - White/gray/black near center
  - Saturated colors on edges



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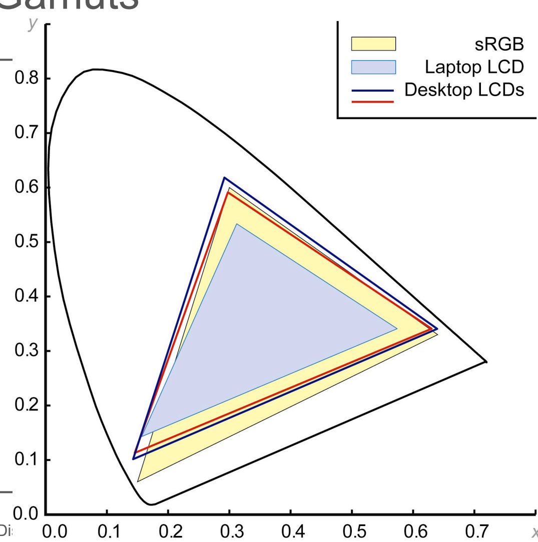
Display Gamuts



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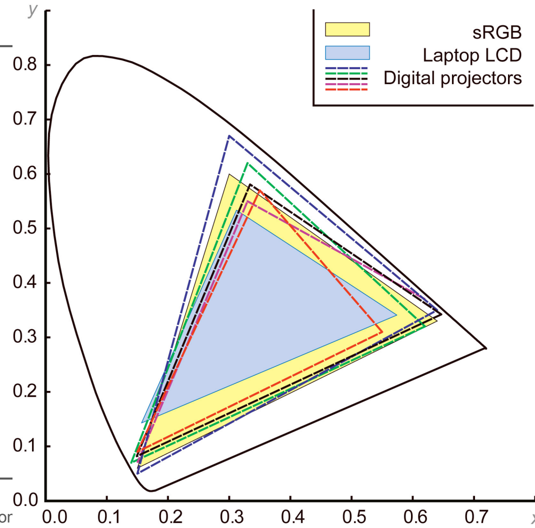
Projector Gamuts



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Pixels to Intensity

- Linear
  - I = kp (I = intensity, p = pixel value, k is a scalar)
  - Best for computation
- Non-linear
  - $I = kp^{1/\gamma}$
  - Perceptually more uniform
  - More efficient to encode as pixels
  - Best for encoding and display
- The gamma function

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Pixel to Intensity Variation

Intensity Transfer Function (ITF), or "gamma"

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, …
			CIELAB Munsell (HVC)	CIECAM02

Trichromacy
Metamerism
Color matching
Color measurement

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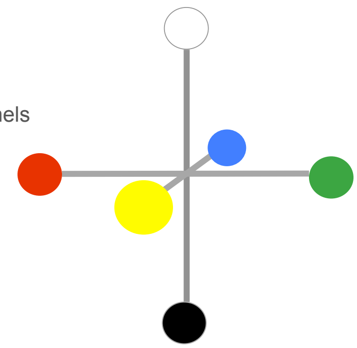
Opponent Color

- Definition
  - Achromatic axis
  - R-G and Y-B axis
  - Separate lightness from chroma channels
- First level encoding
  - Linear combination of LMS
  - Before optic nerve
  - Basis for perception
  - Defines "color blindness"



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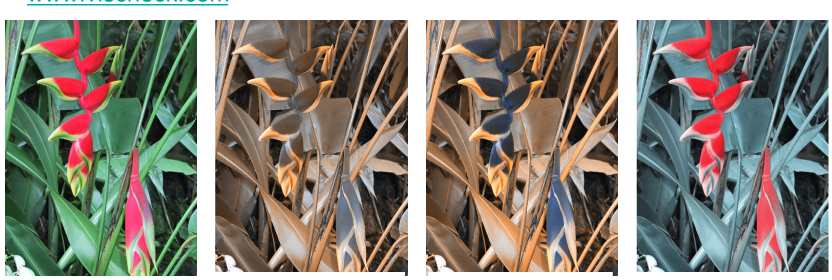
Vischeck

- Simulates color vision deficiencies
  - Web service or Photoshop plug-in
  - Robert Dougherty and Alex Wade
- www.vischeck.com



Deuteranope Protanope Tritanope

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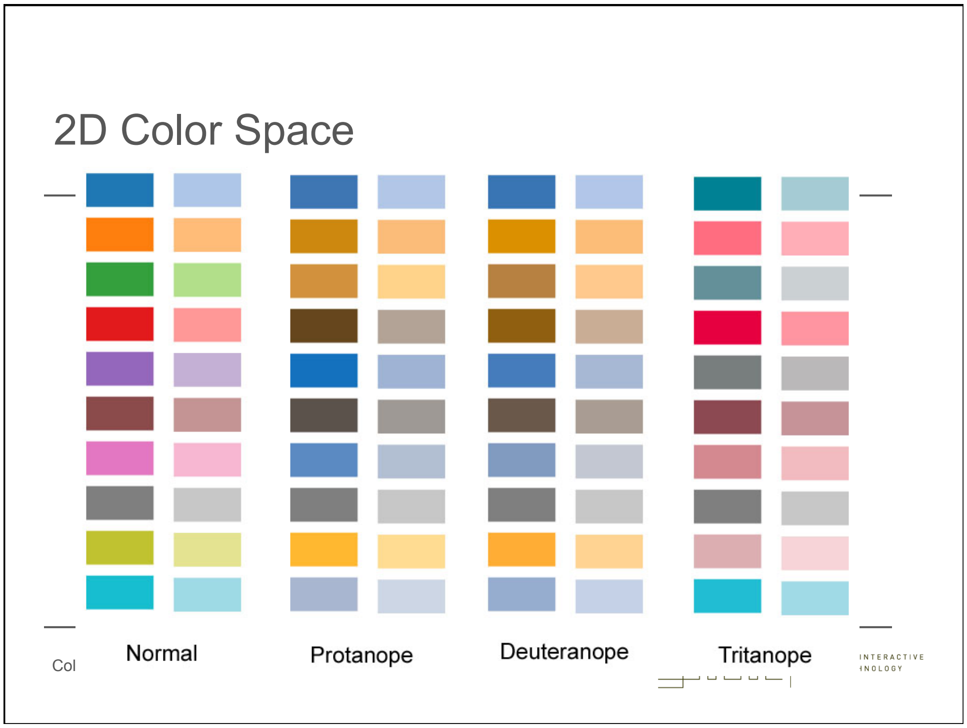
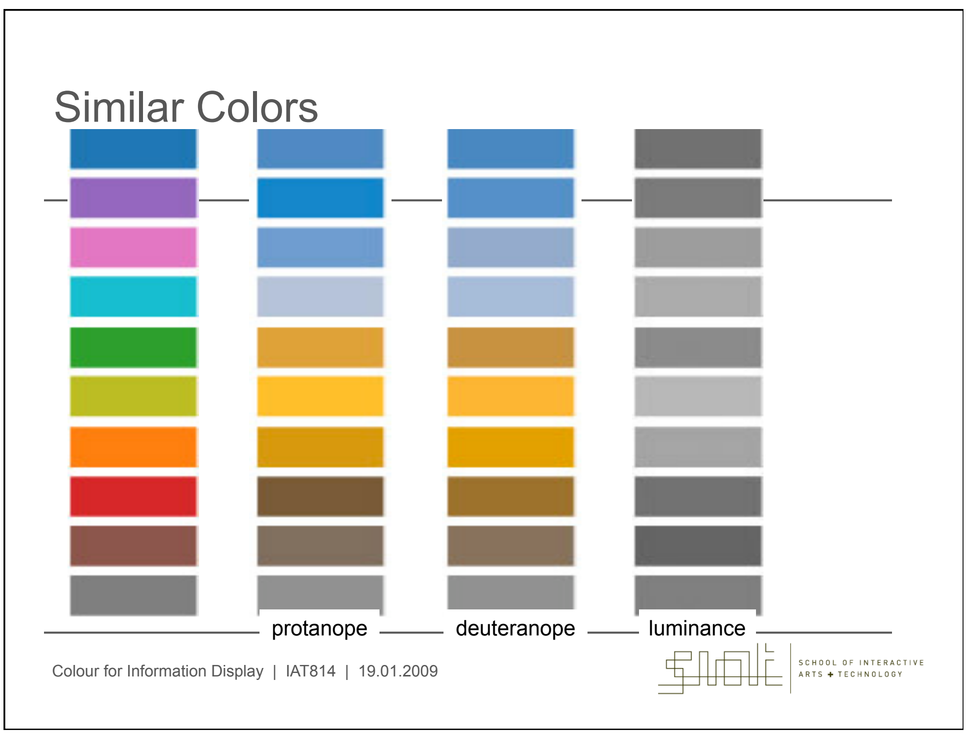

2D Color Space
Normal
Protanope
Deuteranope
Tritanope


Similar Colors
protanope
deuteranope
luminance
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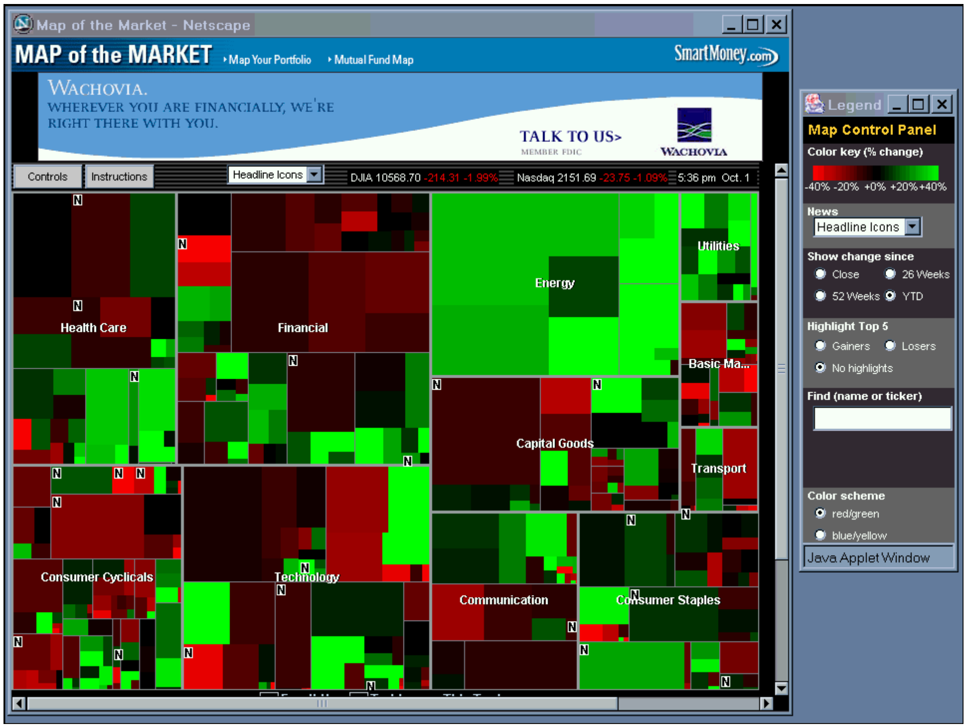
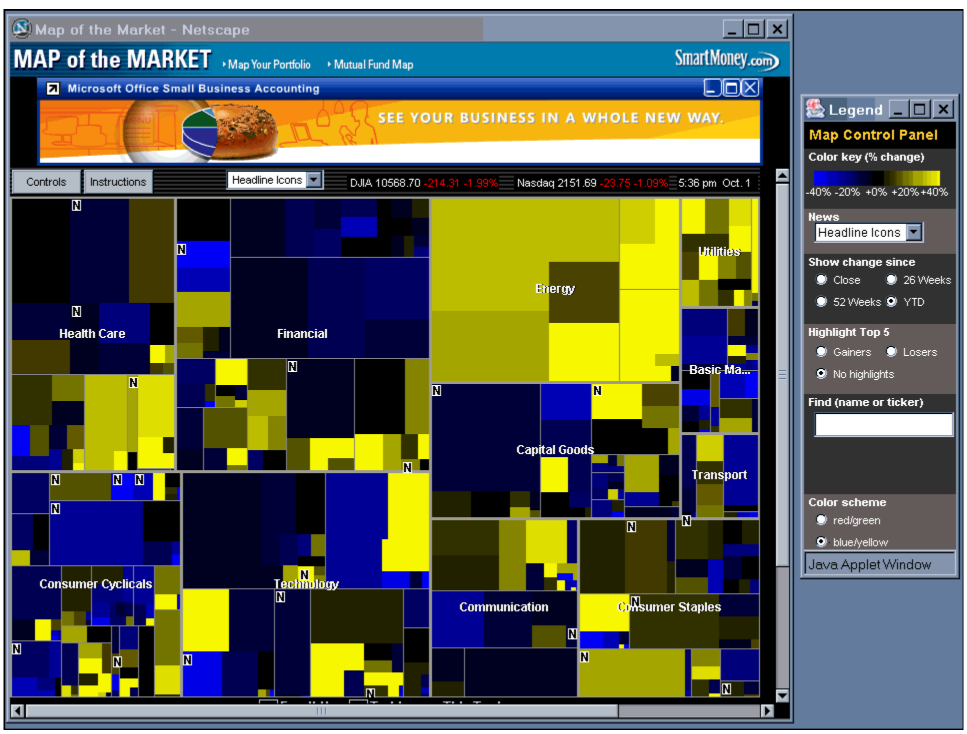

Map of the Market - Netscape
MAP of the MARKET
Map Your Portfolio
Mutual Fund Map
SmartMoney.com
WACHOVIA.
WHEREVER YOU ARE FINANCIALLY, WE'RE RIGHT THERE WITH YOU.
TALK TO US>
Controls
Instructions
Headline Icons
DJIA 10568.70 -214.31 -1.99%
Nasdaq 2151.69 -23.75 -1.09%
5:36 pm Oct. 1
Health Care
Financial
Energy
Utilities
Basic Ma...
Capital Goods
Transport
Consumer Cyclicals
Technology
Communication
Consumer Staples
Legend
Map Control Panel
Color key (% change)
-40% -20% +0% +20% +40%
News
Headline Icons
Show change since
Close
26 Weeks
52 Weeks
YTD
Highlight Top 5
Gainers
Losers
No highlights
Find (name or ticker)
Color scheme
red/green
blue/yellow
Java Applet Window


Map of the Market - Netscape
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Microsoft Office Small Business Accounting
SEE YOUR BUSINESS IN A WHOLE NEW WAY.
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DJIA 10568.70 -214.31 -1.99%
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5:36 pm Oct. 1
Health Care
Financial
Energy
Utilities
Basic Ma...
Capital Goods
Transport
Consumer Cyclicals
Technology
Communication
Consumer Staples
Legend
Map Control Panel
Color key (% change)
-40% -20% +0% +20% +40%
News
Headline Icons
Show change since
Close
26 Weeks
52 Weeks
YTD
Highlight Top 5
Gainers
Losers
No highlights
Find (name or ticker)
Color scheme
red/green
blue/yellow
Java Applet Window

Color Models

Physical World — Visual System — Mental Models

Light Energy	Cone Response	Opponent Encoding	Perceptual Models	Appearance Models
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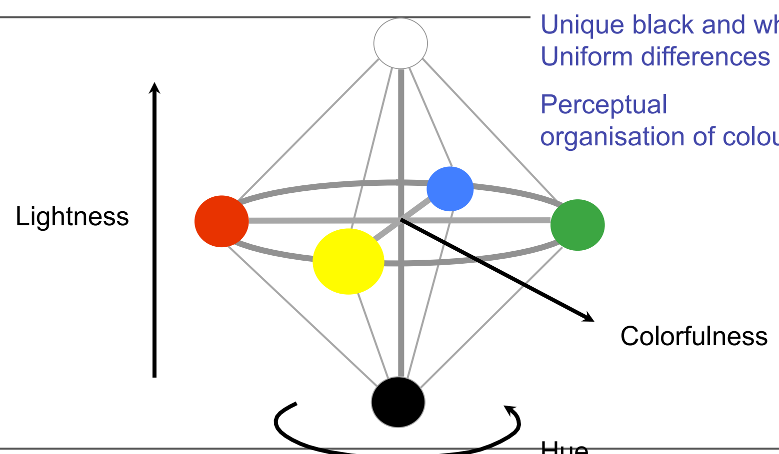
		Separate lightness, chroma Color blindness Image encoding	CIELAB Munsell (HVC)	CIECAM02

Perceptual Color Spaces



Unique black and white
Uniform differences

Perceptual organisation of colour

Munsell Atlas

Courtesy Gretag-Macbeth

Lightness Scales

- Lightness, brightness, luminance, and L*
  - Lightness is relative, brightness absolute
  - Absolute intensity has light power as units (measured)
- Luminance is perceived intensity
  - Luminance varies with wavelength
  - Variation defined by luminous efficiency function
  - Equivalent to CIE Y
- L* is perceptually uniform lightness

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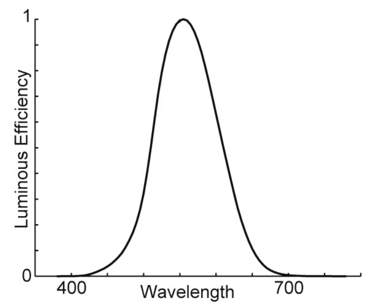
Luminance & Intensity

- Intensity
  - Integral of spectral distribution (power)
- Luminance
  - Intensity modulated by wavelength sensitivity
  - Integral of spectrum × luminous efficiency function
  - Is a **perceived** intensity

Green and blue lights of equal intensity have different luminance values



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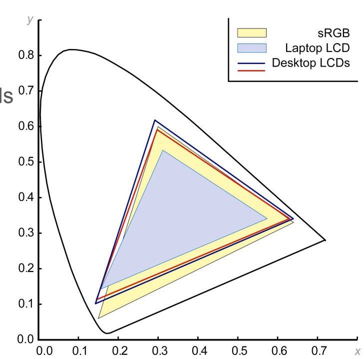
Luminance from RGB

- $L = rL_R + gL_G + bL_B$
- L_R, L_G, L_B
  - Maximum luminance of RGB primaries
  - Different for different displays
  - Affected by brightness & contrast controls
- r,g,b
  - Relative intensity values (linear)
  - Depends on "gamma curve"
  - Not pixel values

Not a fixed equation!



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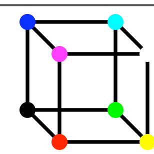
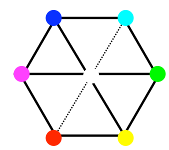
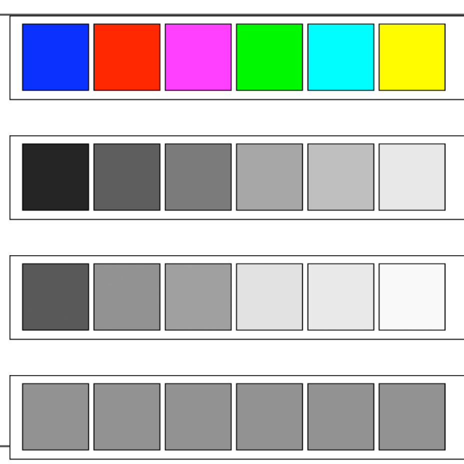
Psuedo-Perceptual Models

- HLS, HSV, HSB
- NOT perceptual models
- Simple renotation of RGB
  - View along gray axis
  - See a hue hexagon
  - L or V is grayscale pixel value
- Cannot predict perceived lightness





L vs. Luminance, L*



Corners of the RGB color cube

Luminance values (retinal response)

L* values

L from HLS
All the same

Color Models

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			CIELAB	CIECAM02
			Color differences "Intuitive" color spaces Color scales	

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Color Appearance

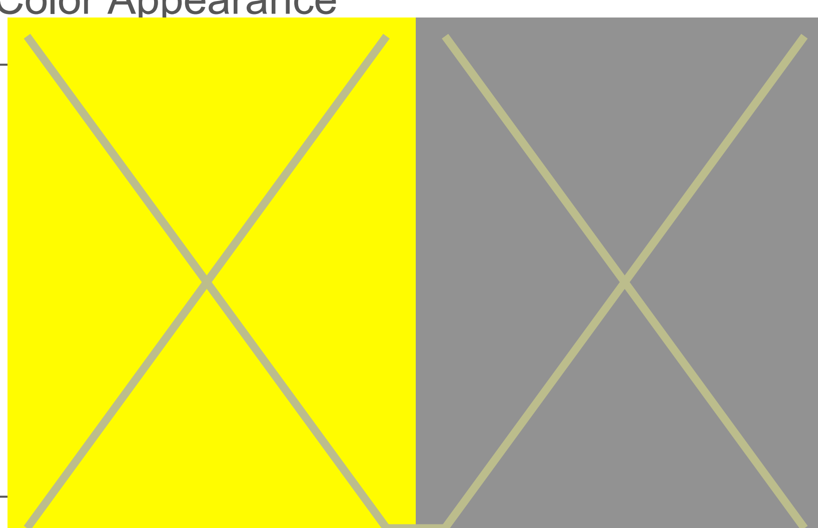
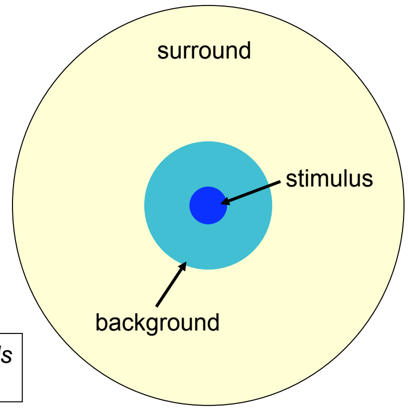



Image courtesy of John MCann


Image courtesy of John MCann

Color Appearance

- More than a single color
  - Adjacent colors (background)
  - Viewing environment (surround)
- Appearance effects
  - Adaptation
  - Simultaneous contrast
  - Spatial effects
- Color in context



Color Appearance Models
Mark Fairchild

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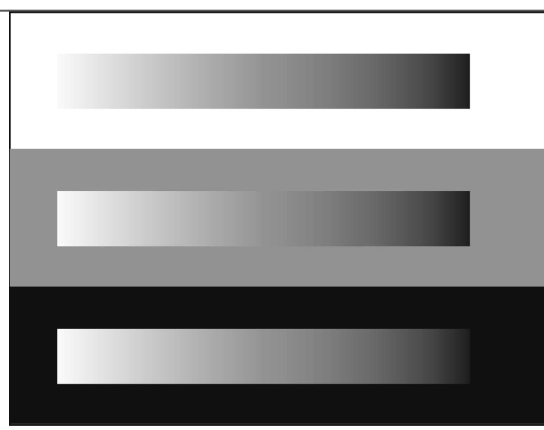
Simultaneous contrast
Affects Lightness Scale



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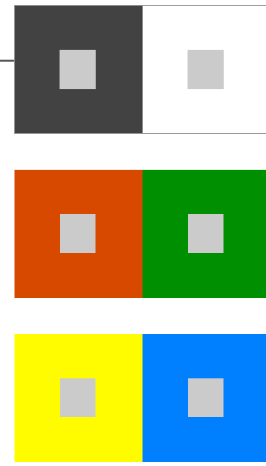
Simultaneous Contrast



- Influence of immediate surround on perception of colour
- Simple example:
- Add Opponent Color
  - Dark adds light
  - Red adds green
  - Blue adds yellow

These samples will have both light/ dark and hue contrast

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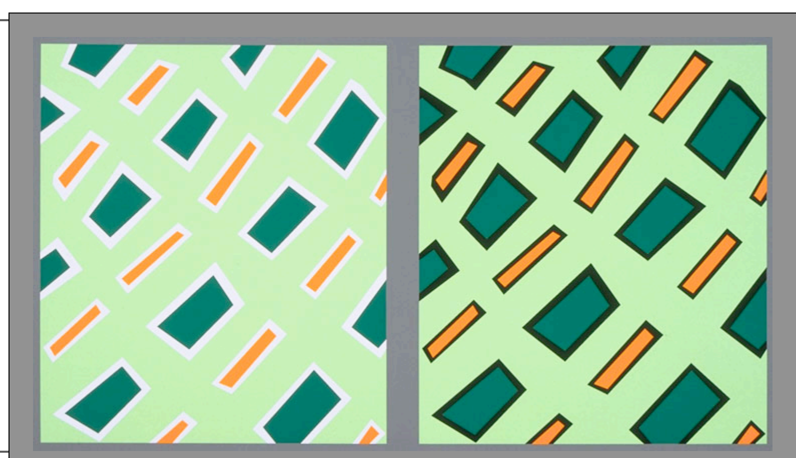
Bezold Effect: outline makes a difference



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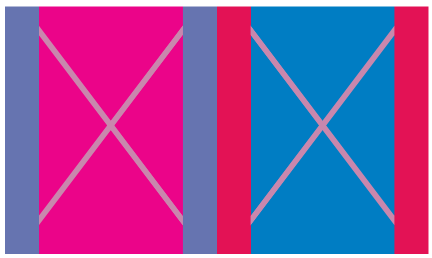
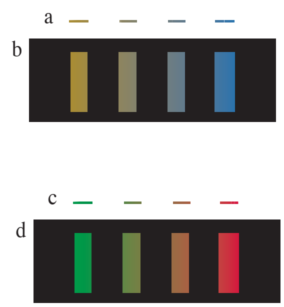
Other contrast effects

Chromatic contrast



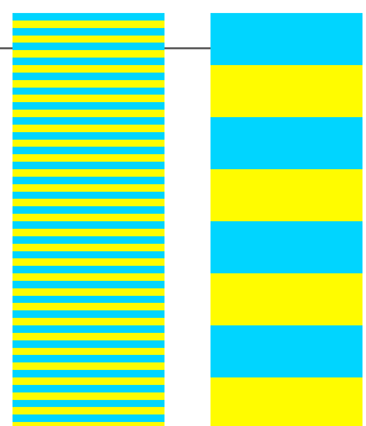
Small field tritanopia

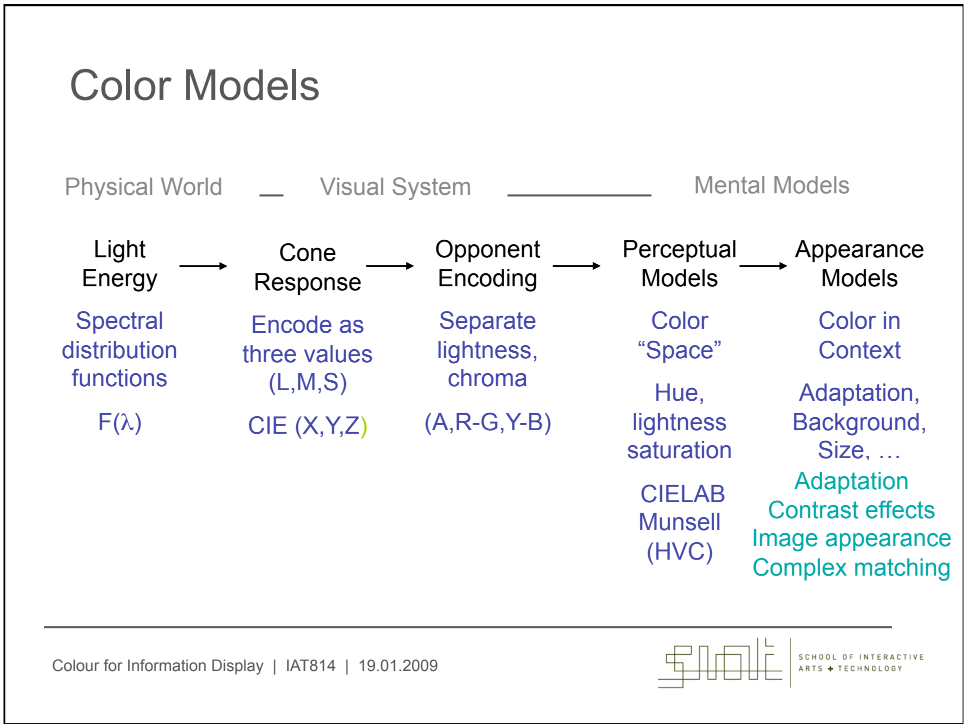


Spreading

- Spatial frequency
  - The paint chip problem
  - Small text, lines, glyphs
  - Image colors
- Adjacent colors blend
- The higher the spatial frequency, the less saturated the colour

Redrawn from *Foundations of Vision*
© Brian Wandell, Stanford University




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