Contrast, Luminance and Colour

Week 3 Lecture 1

IAT 814

Lyn Bartram

Some of these slides have been borrowed and adapted from Maureen Stone and Colin Ware

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What is gray?

- Colour space is 3 dimensions
  - 1 achromatic (gray scale)
  - 2 colour (red-green, blue-yellow, more later)
- What defines white, black,gray?
- Receptor signals do not tell us **absolute** values
  - amount of light on the retina - the light meter
- They tell us **relative** values
  - change of amounts of light
  - Change meter
- Contrast illusions
- Non-linear perception
- Gray scales can be misleading

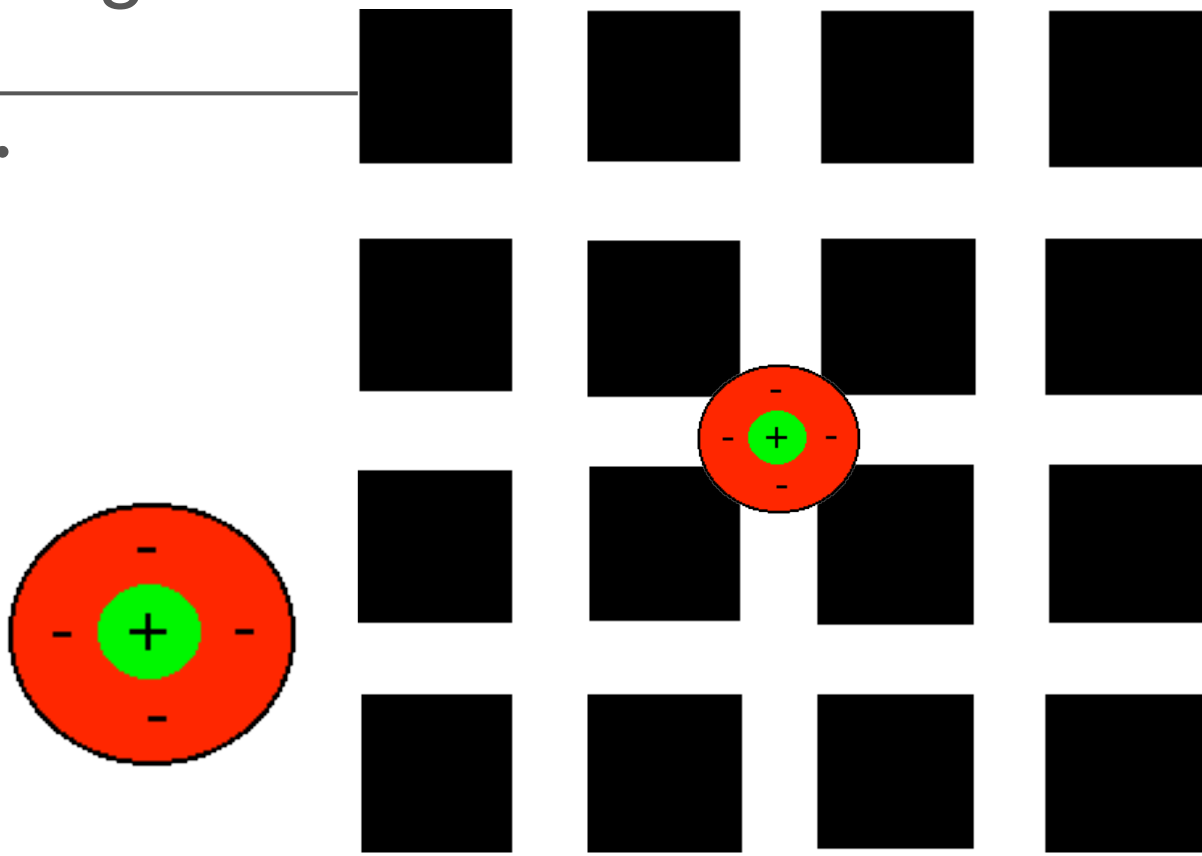
Neurons, Receptive Fields, and Brightness Illusions

- Neurons are the basic circuits of information processing in the brain.
- The receptive field of a cell is the visual area over which a cell responds to light.

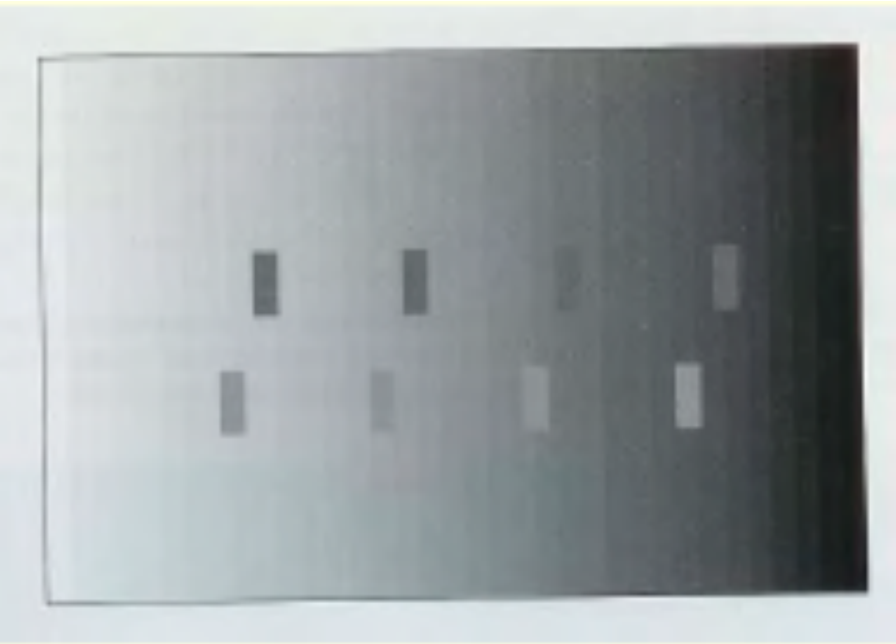
- Excitation explains many contrast effects

- P and M neurons determine sensitivity to types of light patterns
  - in order to discriminate between two different visual signals, the signals encoded in available channels must differ beyond some threshold

Brightness illusions: Hermann Grid

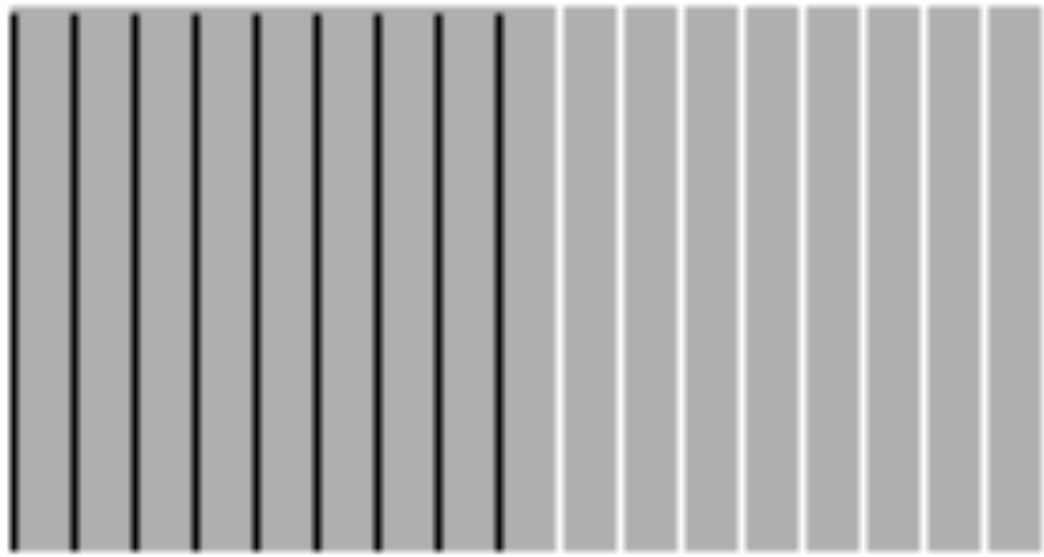


Simultaneous brightness contrast



- a gray patch placed on a dark background looks lighter than the same gray patch on a light background.
- http://www.michaelbach.de/ot/lum_dynsimcontrast/index.html

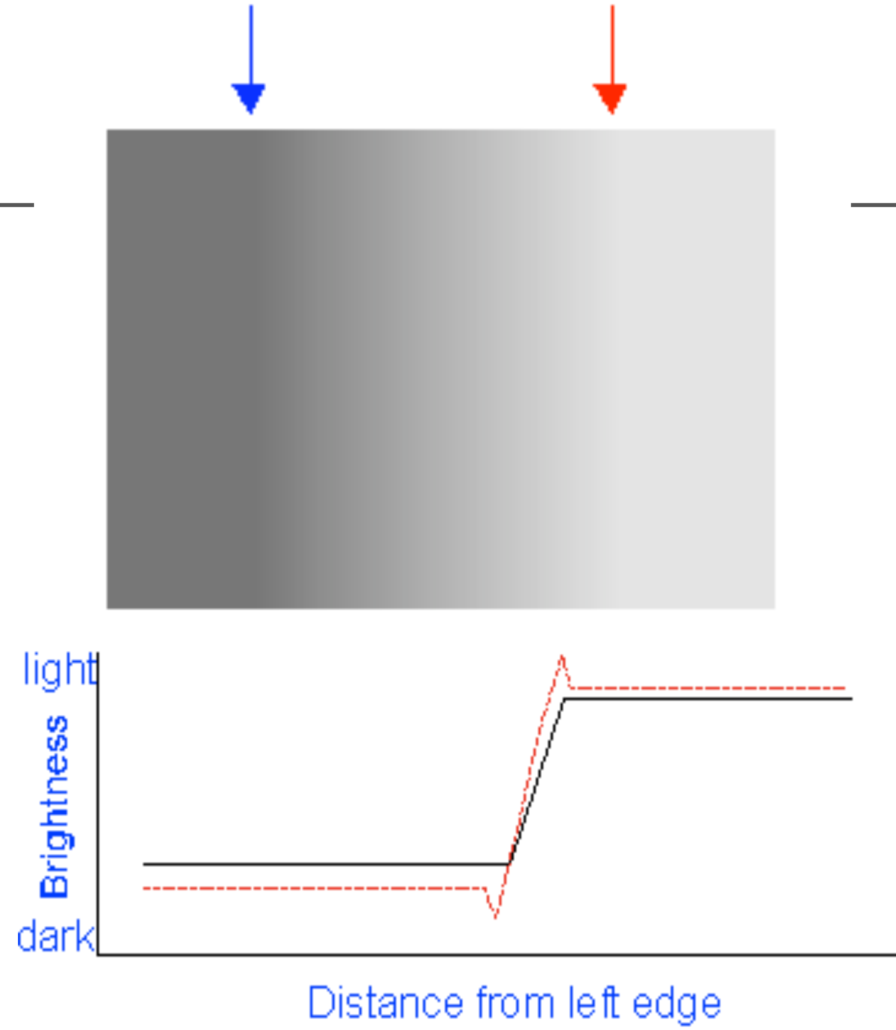
Assimilation of lightness



- The gray background with black lines appears to be darker while the gray background with white lines appears to be lighter.

Mach bands

- Illusory Mach bands appear when gradients from darker to lighter shades are created



Mach bands

- The effect is robust with different shapes and numbers of gradients

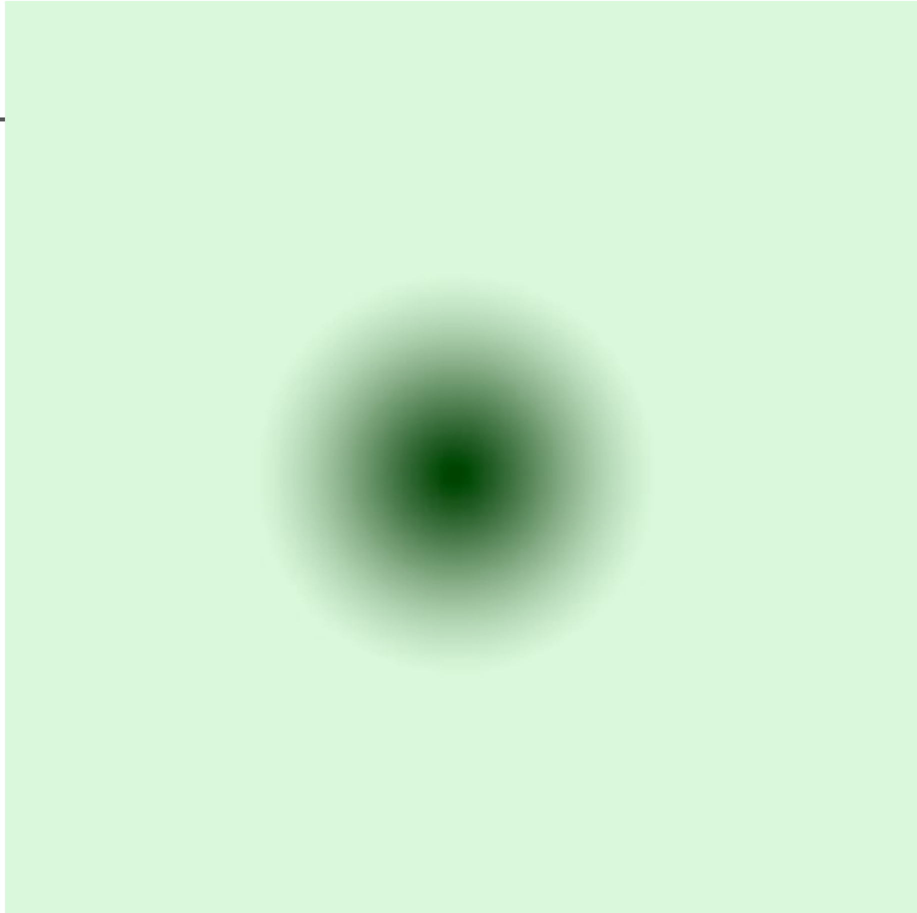


Image from perceptualstuff.org

Mach bands

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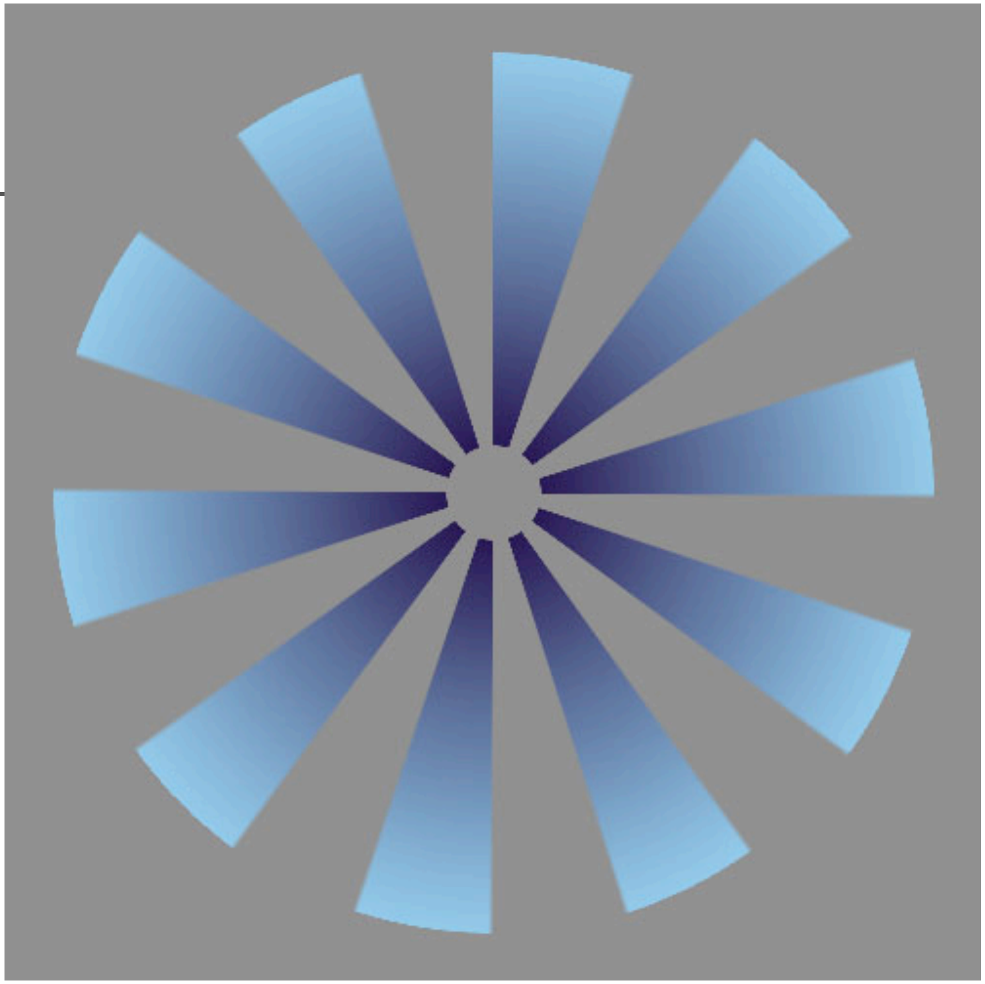

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Mach bands

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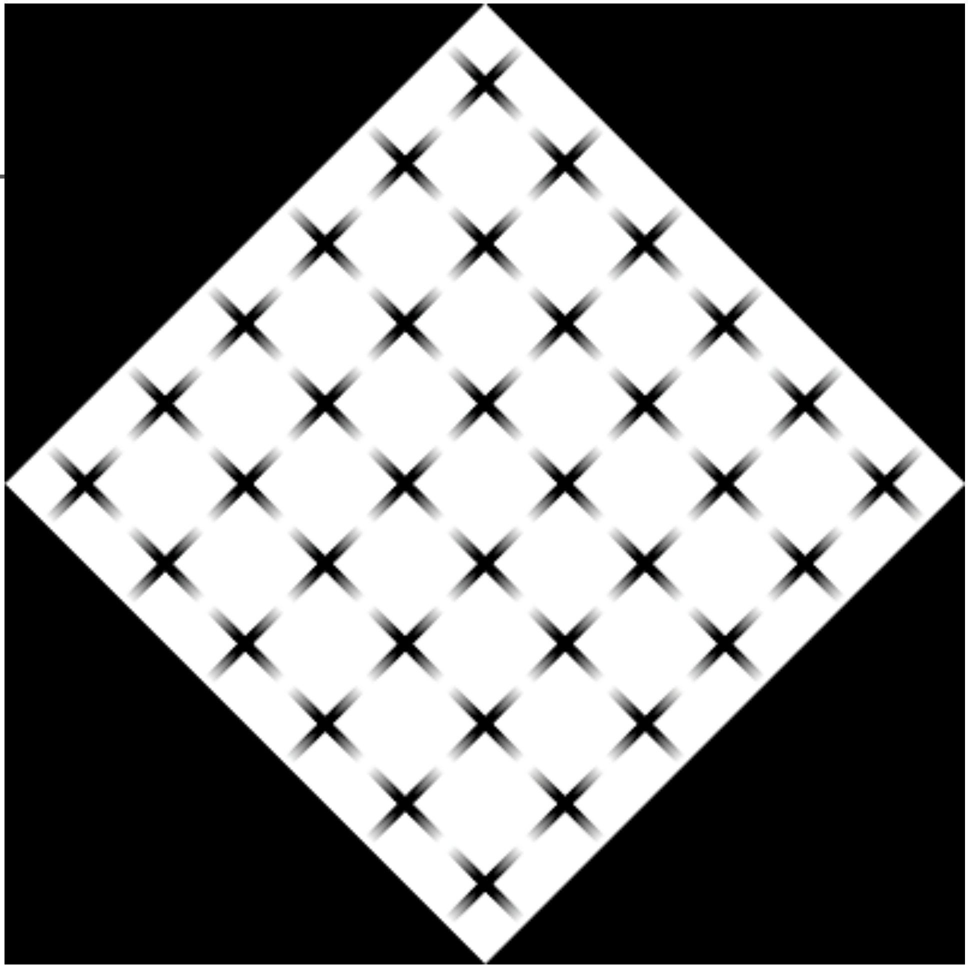
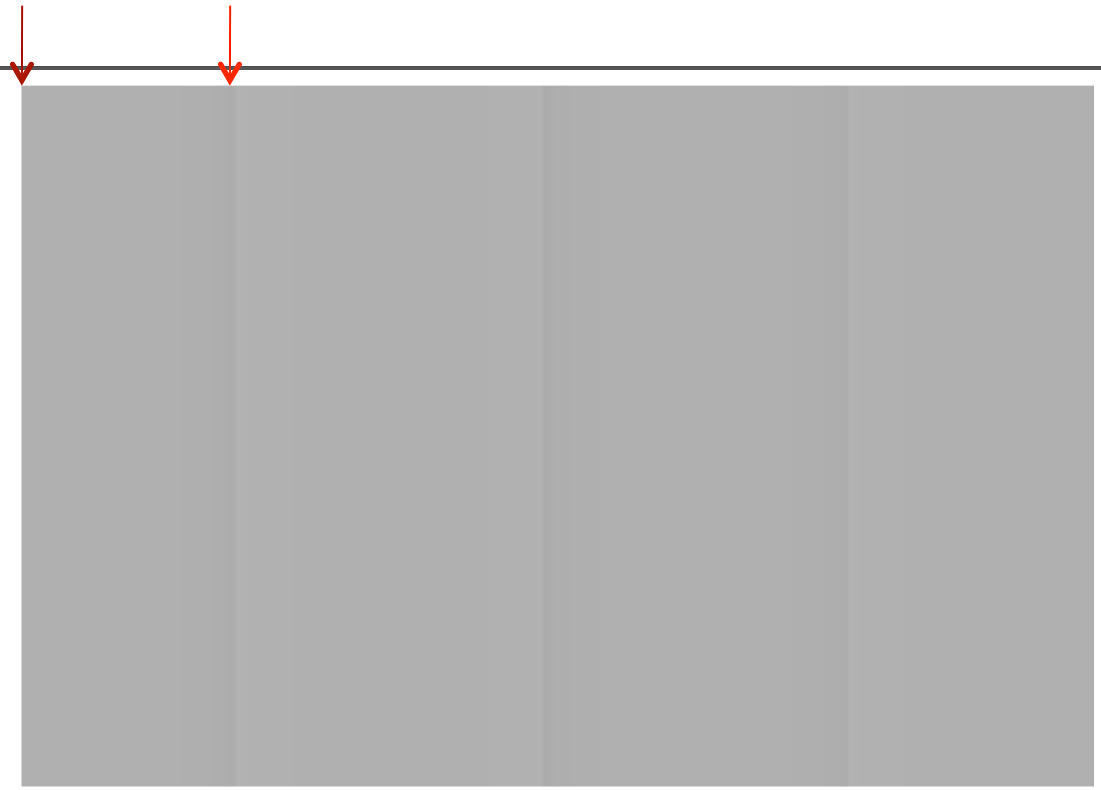


Image from perceptualstuff.org

Chevreuil Illusion



- When a sequence of gray bands is generated , the bands appear darker at one edge than at the other, even though they are uniform

Chevreuil Illusion

- Again, this also works in colour and with irregular borders.
- Note we are not talking about hue change but luminance change

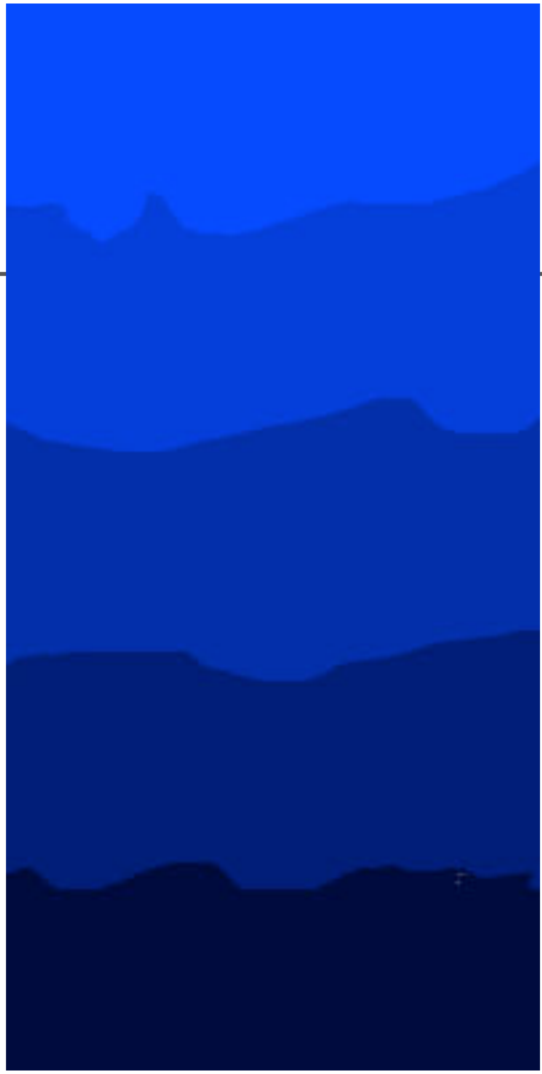


Image from perceptualstuff.org

Dynamic Luminance

- Changes in apparent brightness with quick changes in viewing distance

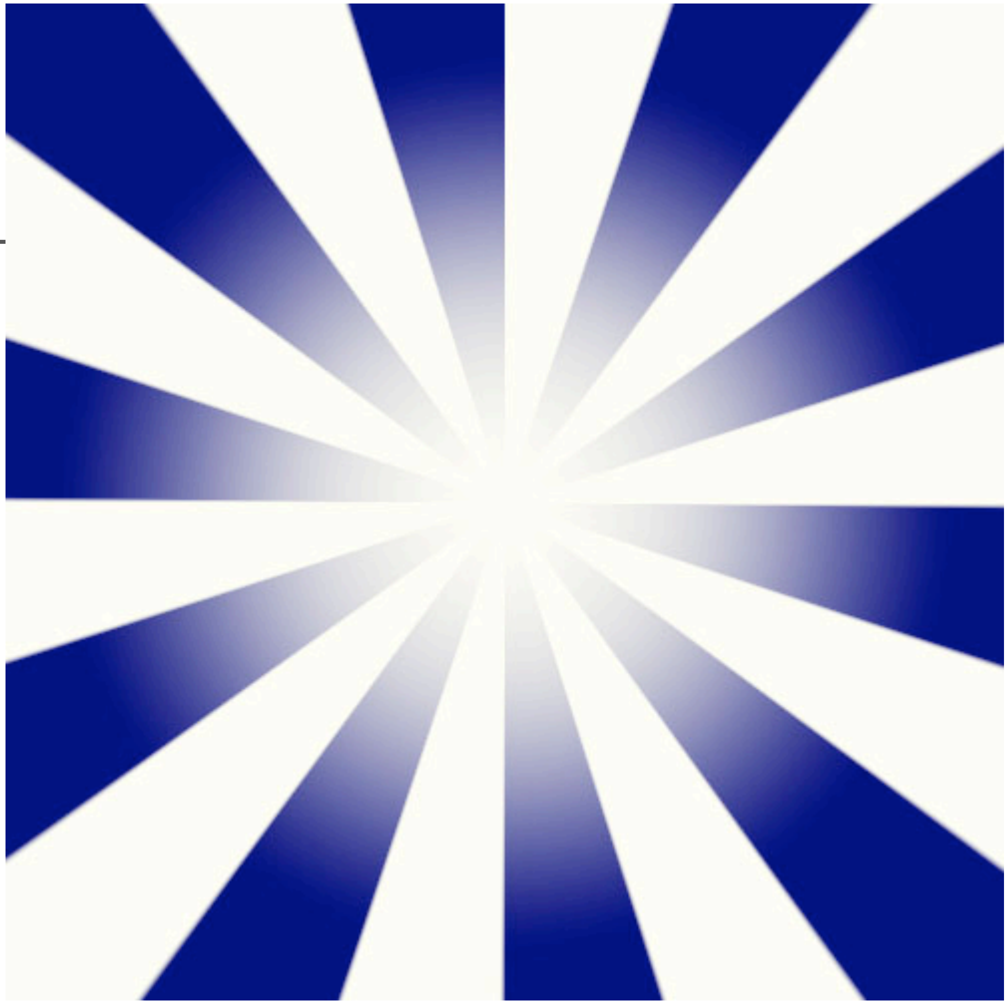


Image from perceptualstuff.org

The Breathing Light Illusion

- Change in apparent brightness as you move closer in and farther away quickly

- Gori, S. & Stubbs, D. A. (2006). A new set of illusions - The Dynamic Luminance-Gradient Illusion and the Breathing Light Illusion. Perception. 35, 1573-15771.

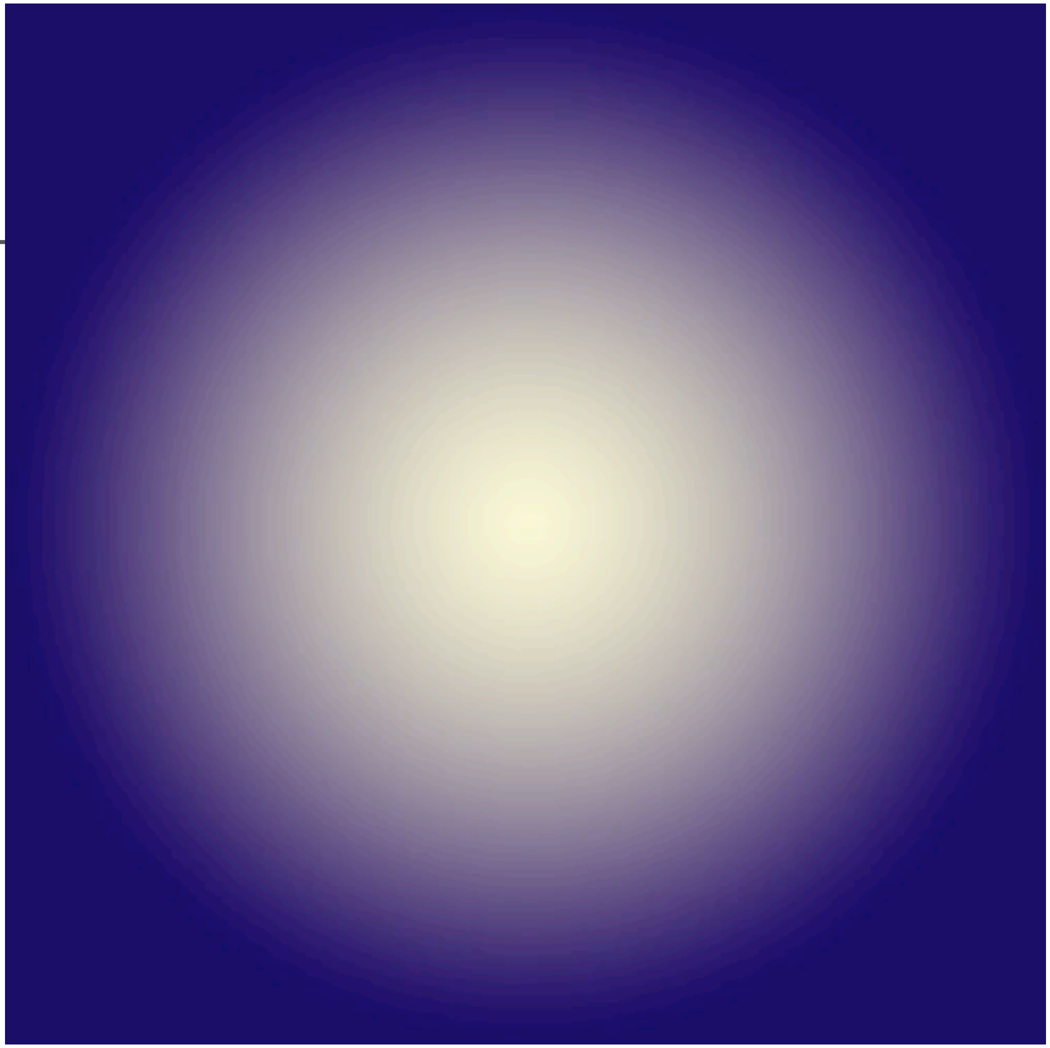
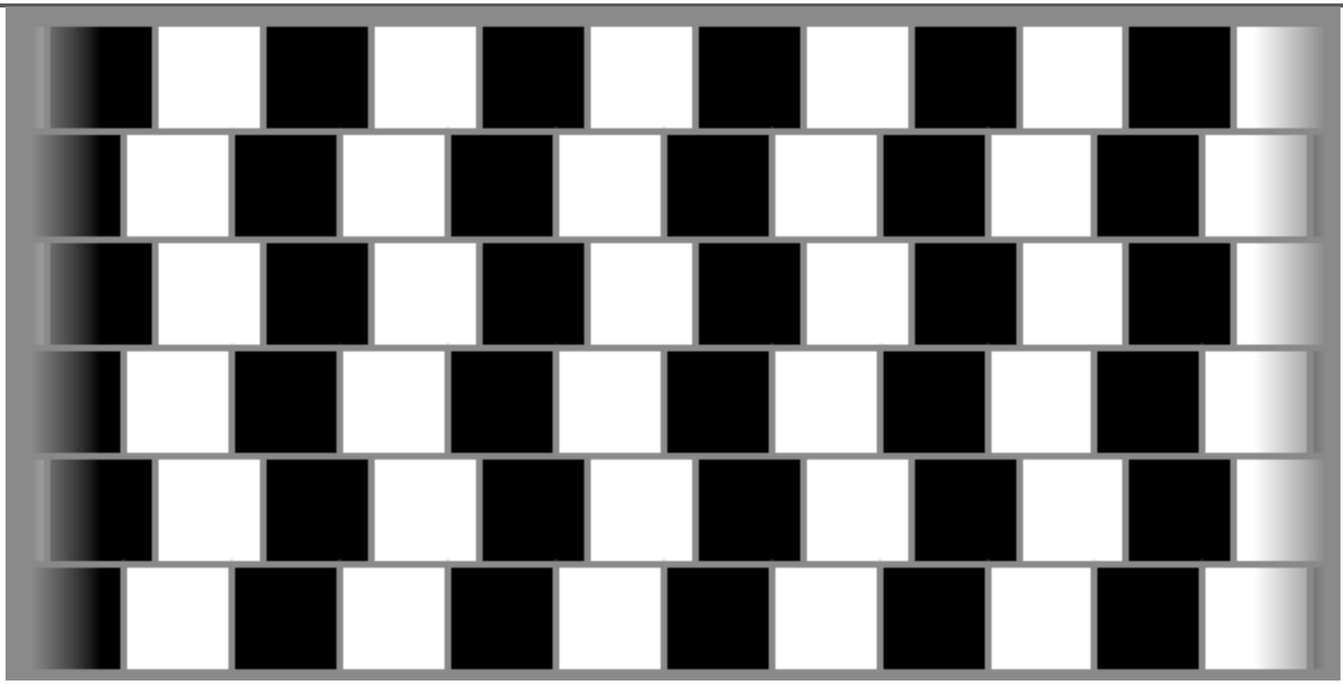


Image from perceptualstuff.org

The Café Wall Illusion



- The tiles appear to be wedge shaped and the lines curved but are actually evenly rectangular

Effects cause error!

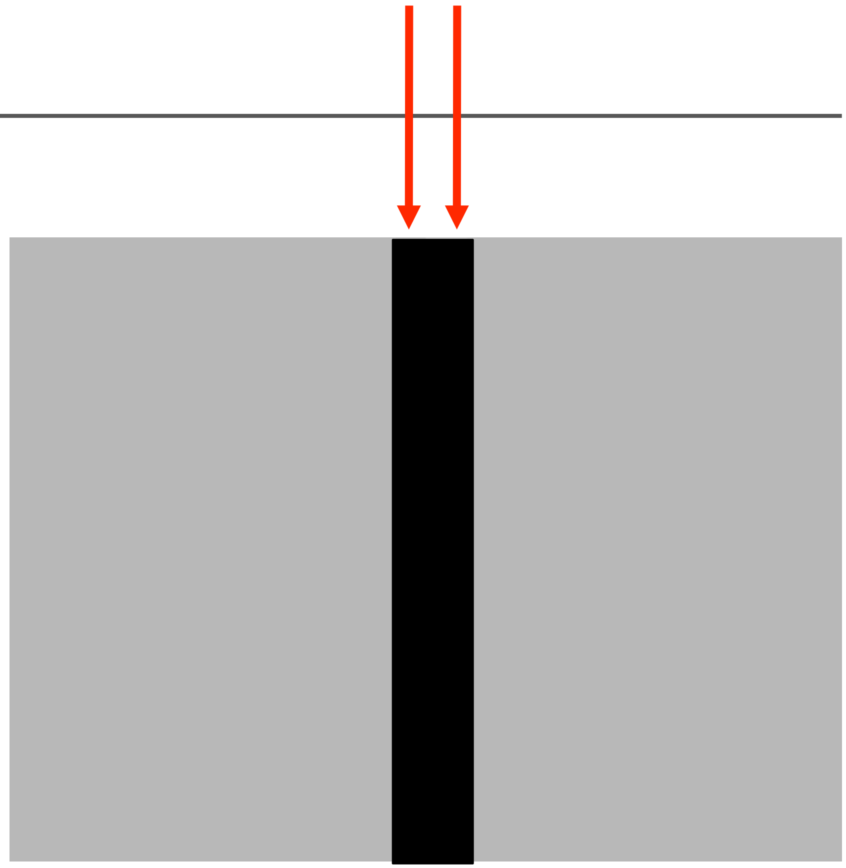
- Simultaneous contrast effects can result in large errors of judgment when reading quantitative (value) information displayed using a gray scale.
- Ware et al showed an average error **of 20%** of the entire gray scale in a map encoding gravity fields using 16 levels of gray.
- tend to highlight the deficiencies in the common shading algorithms used in computer graphics.
- Smooth surfaces are often displayed using polygons,
  - visual artifacts because of the way the visual system enhances the boundaries at the edges of polygons.
- Need to use more interpolated approaches, such as Phong shading, to avoid Chevreuil or Mach illusions

Edge enhancement

- Lateral inhibition can be considered the first stage of an edge detection process that signals the positions and contrasts of edges in the environment.
- One of the consequences is that pseudo-edges can be created; two areas that physically have the same lightness can be made to look different by having an edge between them that shades off gradually to the two sides
- The brain does perceptual interpolation so that the entire central region appears lighter than surrounding regions.
- This is called the Cornsweet effect, after the researcher who first described it (Cornsweet, 1970).

Cornsweet effect

- These areas appear different in lightness, but are in fact the same



- On the other hand ..
- The enhancement of edges is also an important part of some artists' techniques

- Seurat deliberately enhanced edge contrast to make his figures stand out.

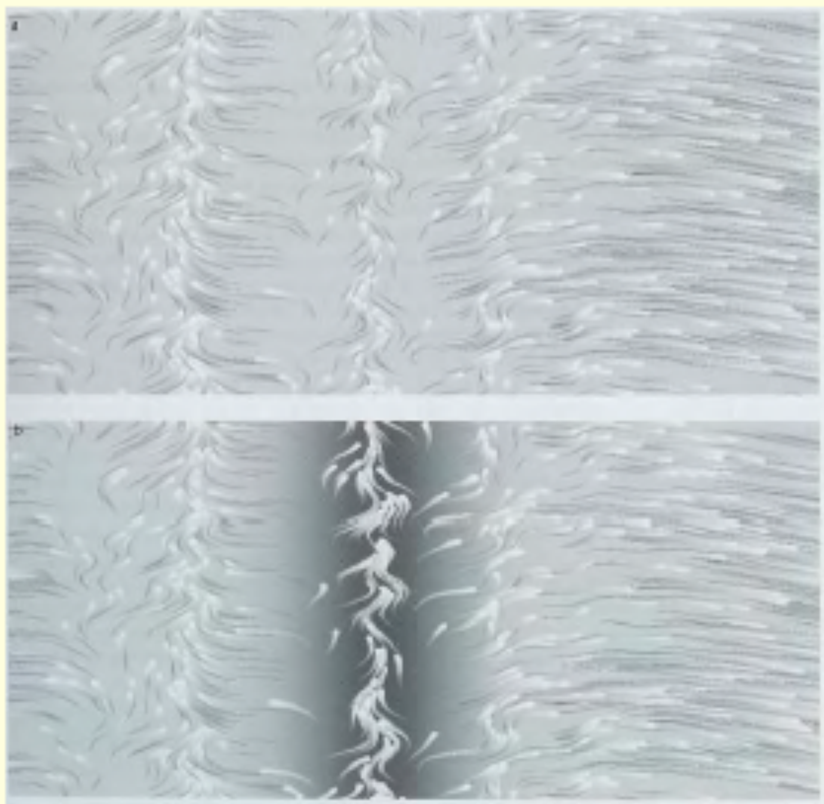
Spatial Frequency modulation

- Edge enhancement is usually a case of adjusting or amplifying the higher frequency information in the spatial domain
  - High-pass filtering techniques from image processing
- We can also adjust the low spatial frequency of the background luminance
  - Low pass filters

- Remember the Clinton/Frist example

Low spatial frequency modulation

Figure 3.12 Low spatial frequency adjustment of the background luminance can be used to enhance a flow-field visualization. (a) Shows a flow pattern without enhancement. (b) Shows the same pattern enhanced in the central region.



Summary

- Contrast effects are an example of a mismatch between how our contrast perception mechanisms work and the impoverished nature of the graphical displays

- We know the “perceived brightness” of something has little to do with the amount of light that actually comes from it

How do we tell light from dark?

- What defines white, black,gray?
- Receptor signals do not tell us absolute values
  - amount of light on the retina - the light meter
- They tell us relative values
  - change of amounts of light
  - Change meter
- Contrast illusions
- Non-linear perception
- Gray scales can be misleading

Constancy

- The human vision system evolved to extract information about surface properties of objects
  - *spectral reflectance characteristics*.
  - often at the expense of losing information about the quality and quantity of light entering the eye.
- color constancy.(we experience colored surfaces and not colored light)
  - lightness constancy (surface reflectance)
- concept of quantity of light:
  - luminance,
  - brightness
  - lightness.

Luminance

- Luminance is the easiest to define; it refers to the measured amount of light coming from some region of space.
  - Physical measure, not perceptual quantity
- It is measured in units such as candelas per square meter.
- Main measure for monitor calibration
- Of the three terms, only luminance refers to something that can be physically measured.
- The other two terms refer to psychological variables.

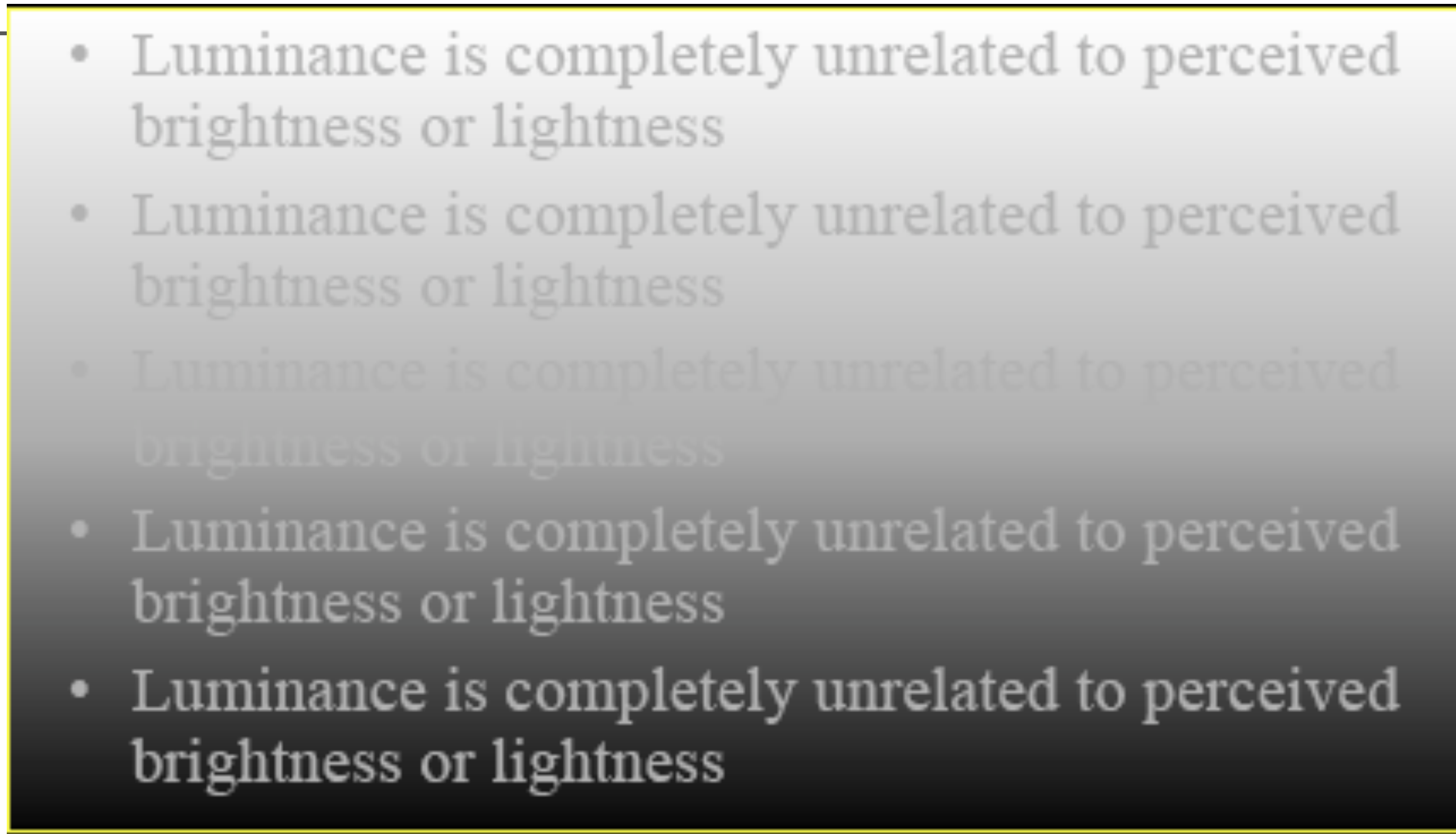
Brightness

- Brightness generally refers to the perceived amount of light coming from a source.
- It is used to refer only to things that are perceived as self-luminous.
  - A bright light
  - A bright display
- Sometimes people talk about bright colors, but vivid and saturated are better terms.
- Brightness is particularly important in the design of critical displays where ambient light may be highly variable

Lightness

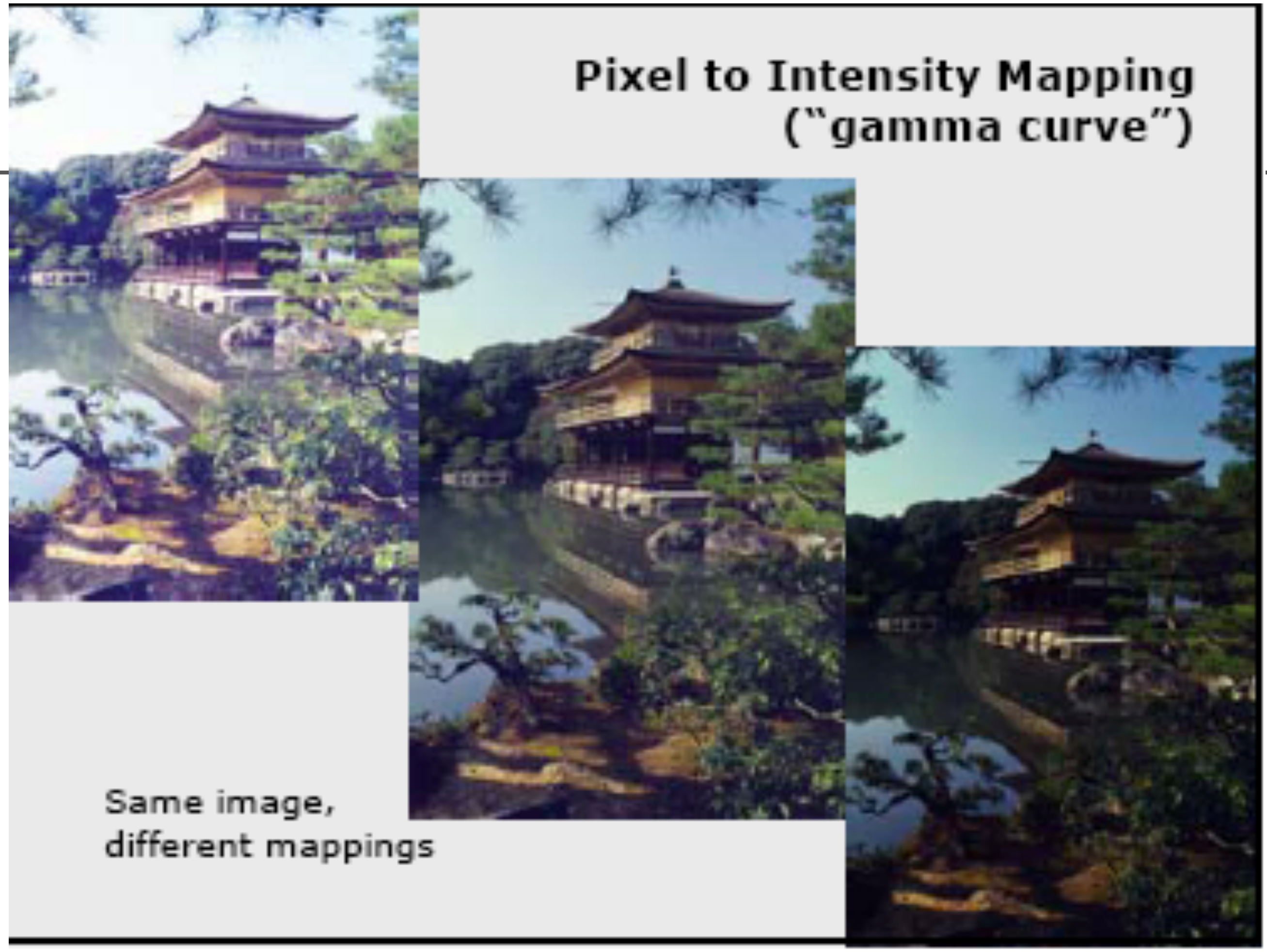
- Lightness generally refers to the **perceived** reflectance of a surface.
- A white surface is light.
- A black surface is dark.
- The shade of paint is another concept of lightness.

Luminance, Contrast and Constancy



Brightness

- Perceived brightness is very non-linear
- Monitor gamma function
  - Approximates relationship of luminance to power voltage (for a CRT) that drives the electron gun
- Monitors (CRTs) are non-linear
- Deliberate to take advantage of available signal bandwidth
- Inverse match to human nonlinearity
- Ideal gamma fn of 3 produces a linear relationship between perceived brightness and voltage
- Most monitors do NOT have a gamma of 3!



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Adaptation, Contrast and Sensitivity

- So how do we tell “lightness”?
- A major task of the visual system is to extract information about the lightness and color and of objects despite a great variation in illumination and viewing conditions.

Constancy

- constancy ensures that the perceived color or lightness of objects remains relatively constant under varying illumination conditions.
- An apple for instance looks green to us at midday, when the main illumination is white sunlight, and also at sunset, when the main illumination is red.
- This helps us identify objects.
- We are good at determining constancy across contexts: yellow, for example, is judged as yellow even when the surrounding contrasts are quite different (Gombrich)

Constancy

- Luminance is completely unrelated to perceived lightness or brightness
- Under some situations a white object will emit less light than a dark object
- We can still distinguish black from white (lightness constancy)

Adaptation, Contrast and Constancy

- The first-stage mechanism of lightness constancy is **adaptation**.
- The second stage of level invariance is **lateral inhibition**.
- Both mechanisms help the visual system to factor out the effects of the amount and color of the illumination

Adaptation and Constancy

- A normal interior will have an artificial illumination level of approximately 50 lux.
- On a bright day in summer, the light level can easily be 50,000 lux.
- Except for the brief period of adaptation that occurs when we come indoors on a bright day, we are generally almost totally oblivious to this huge variation.
- A change in overall light level of a factor of 2 is barely noticed.
- Remarkably, our visual systems can achieve lightness constancy over virtually this entire range; in bright sunlight or moonlight, we can tell whether a surface is black, white, or gray.

Adaptation

Image courtesy of Maureen Stone

Adaptation

- Two mechanisms
- Photopigment sensitivity
  - One mechanism is the bleaching of photo-pigment in the receptors themselves.
  - At high light levels, more photo-pigment is bleached and the receptors become less sensitive.
  - At low light levels, photo-pigment is regenerated and the eyes regain their sensitivity.
- Pupil size

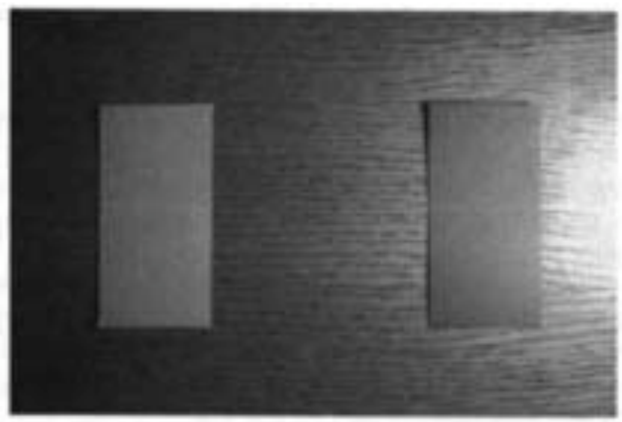
Contrast and constancy

- Contrast mechanisms help us achieve constancy by signaling differences in light boundaries
  - Edges of objects
- Can tell which piece of paper is gray or white regardless of surface reflectance
- White paper is brighter relative to its background than the dark paper
  - **Simultaneous contrast** mechanism
- Not relative brightness but surface lightness

Contrast and constancy

- Concentric opponent receptive fields react most strongly to differences in light levels
  - Edges of objects

- Simultaneous contrast mechanism: item relative to surround



- Corrects for background intensity differences

Perception of Surface Lightness

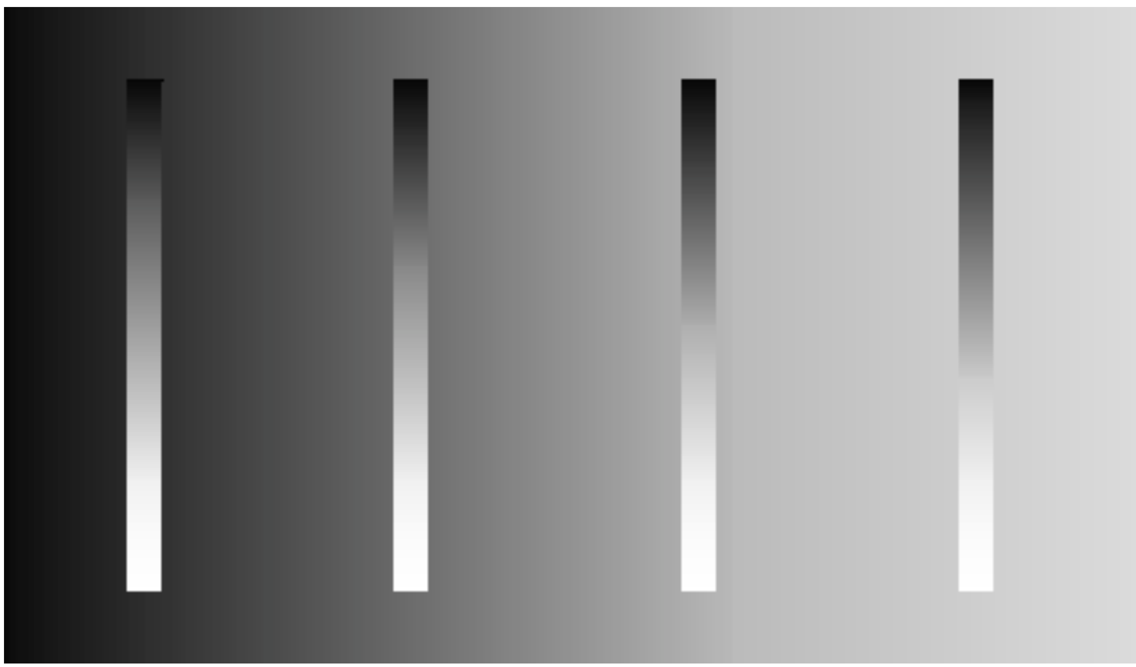
- Adaptation and contrast are not sufficient
- Three additional factors

1. Illumination direction and surface orientation;
   - A surface turned away from the light will reflect less light than one facing it, but we can still judge it accurately
2. Reference white:
   - We judge by the lightest object in the scene ***
3. Ratio of specular and non-specular reflection

Lightness differences and perceptual gray scales

- Ideal gray scale would show equal differences in data values as perceptually equally spaced gray steps
  - Interval scale
- Consider issues
- Size of difference affects perception of brightness differences
  - Smallest difference between 2 grays - JND (just noticeable difference)
  - (~0.5%) Weber's Law
- **Contrast crispening:**
  - Differences are perceived as larger when samples are similar to the background colour

Crispening



Is there a useful interval grayscale map?

- CIE uniform grayscale standard
  - Rated large differences in intensity to produce scale
  - $L = 116(Y/Y_n)^{1/3} - 16$, Y_n = ref white, $Y/Y_n > 0.01$
- Effects
  - Adaptation: Overall light level affects perception
  - Contrast/constancy: Surround affects perception
  - Crispening: Surround affects JND
- Therefore, take ‘Uniform’ with a BIG grain of salt…

Conclusions 1

- Visual system is a **difference** detector
  - Don’t rely on it for absolute intensity measurement
  - Enables seeing patterns despite background
- Grayscale not a good method to code data
  - Various effects (described here)
  - Waste of resources needed for luminance/shape
    - (described later)
- Choose background based on goal
  - Object detection --> large luminance contrast
  - Subtle gradations -->make use of **crispening**

Conclusions 2

- Several illusions result from these effects
  - Be familiar with them and on the lookout
  - Test visualization formally, not just “by eye”, if you want to provide quantitative data
- Provide rich visual display
  - Aim at realistic, not impoverished display
  - Take advantage of effects rather than fighting them
  - Be aware of side effects

Scale matters

Parafovea

Relevance of low level vision

- Symbol design
- Scene segmentation
- Multi-dimensional discrete data

What about colour?

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Week 3A

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

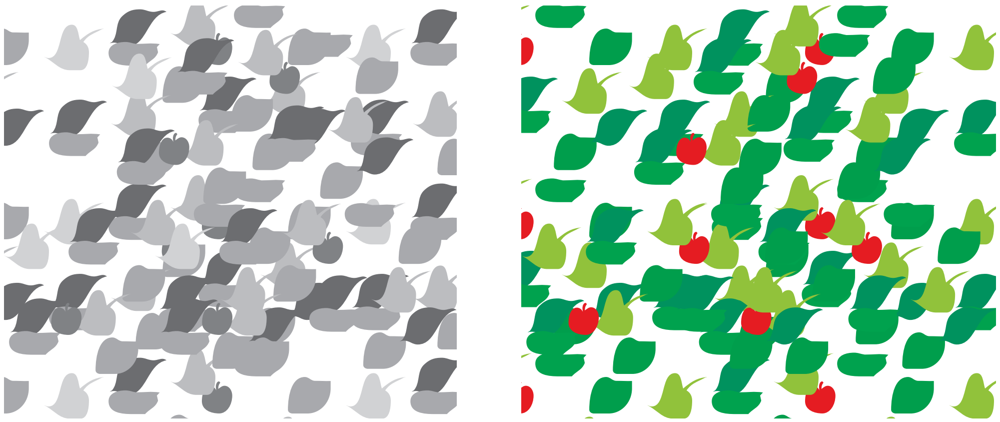
Colour is Irrelevant…

- 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

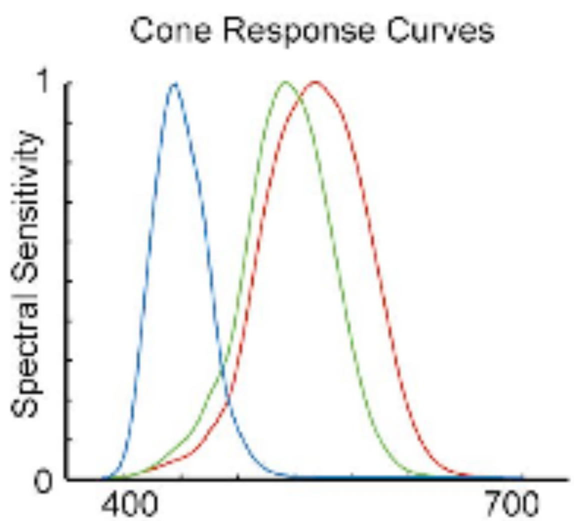


Implications

- 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

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
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sensitive.
Chromatic aberration in the eye is
also a problem

Blue text on a dark background
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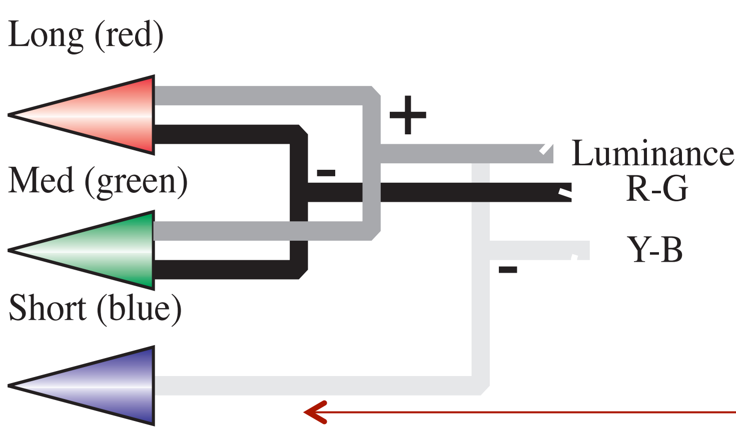
short-wavelength sensitive cones in
the retina and they are not very sensitive

Opponent Process Theory

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



Yet another reason not to use blue to indicate the shapes of objects; it seems to be ignored in the Luminance calculation.

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

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

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

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)

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

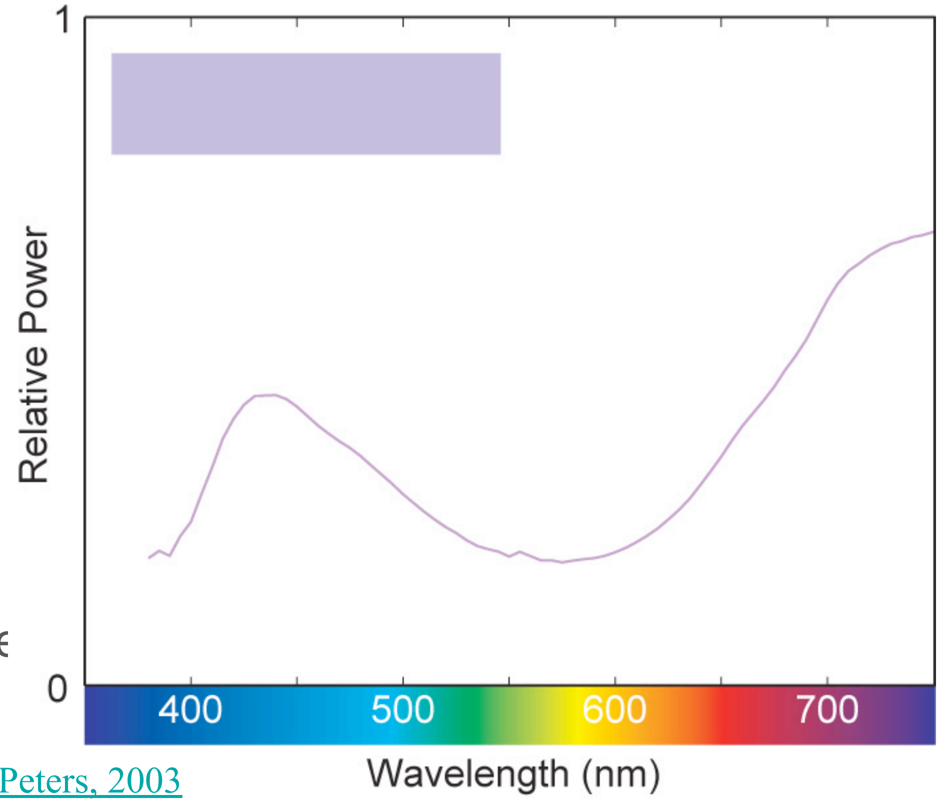
Color Models

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

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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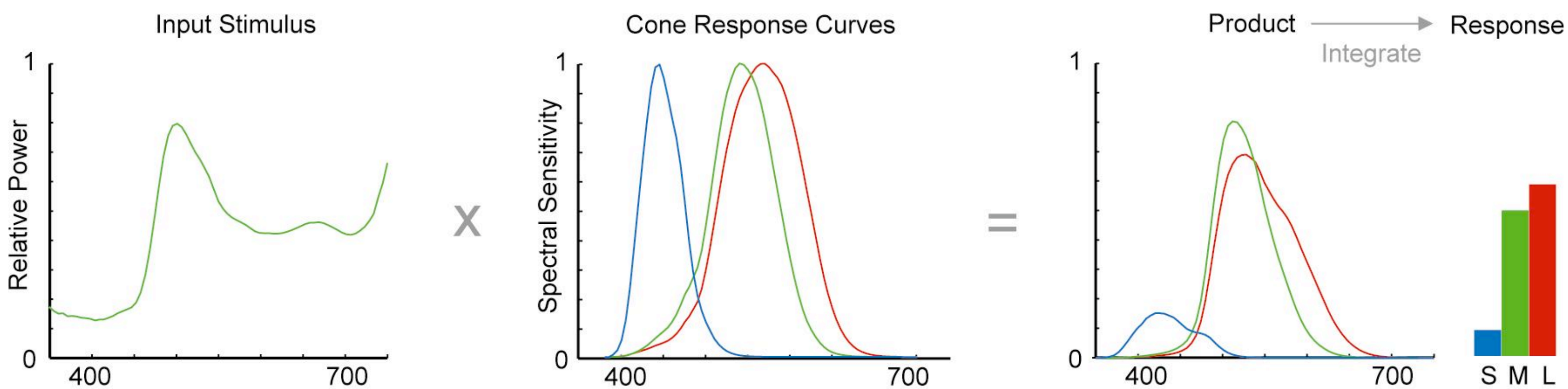
Cone Response (photopic)

- 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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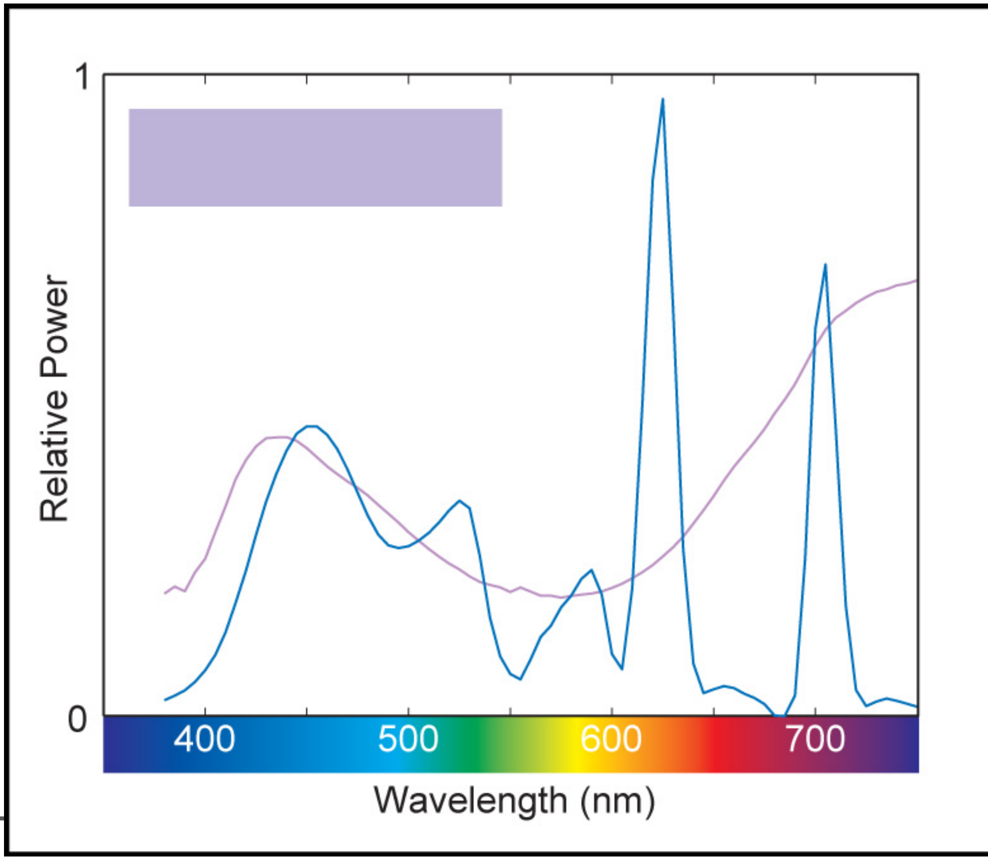
Effects of Retinal Encoding

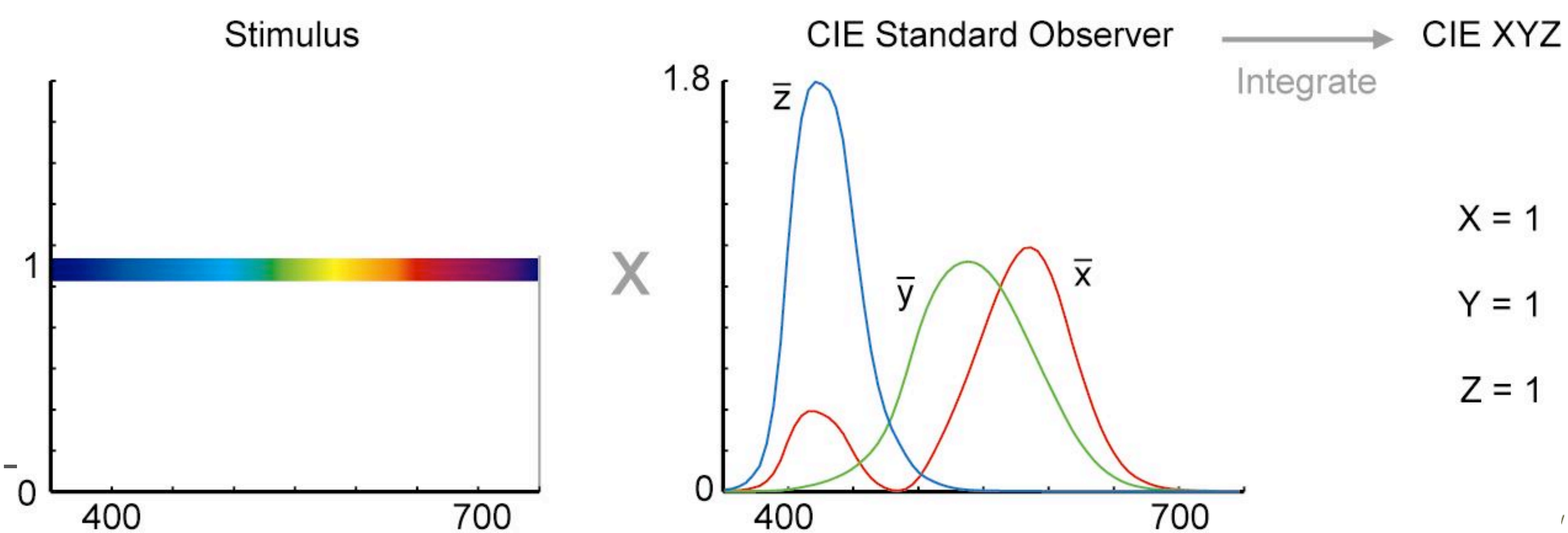


Metameric match

All spectra that stimulate the same cone response are indistinguishable

Color Measurement

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



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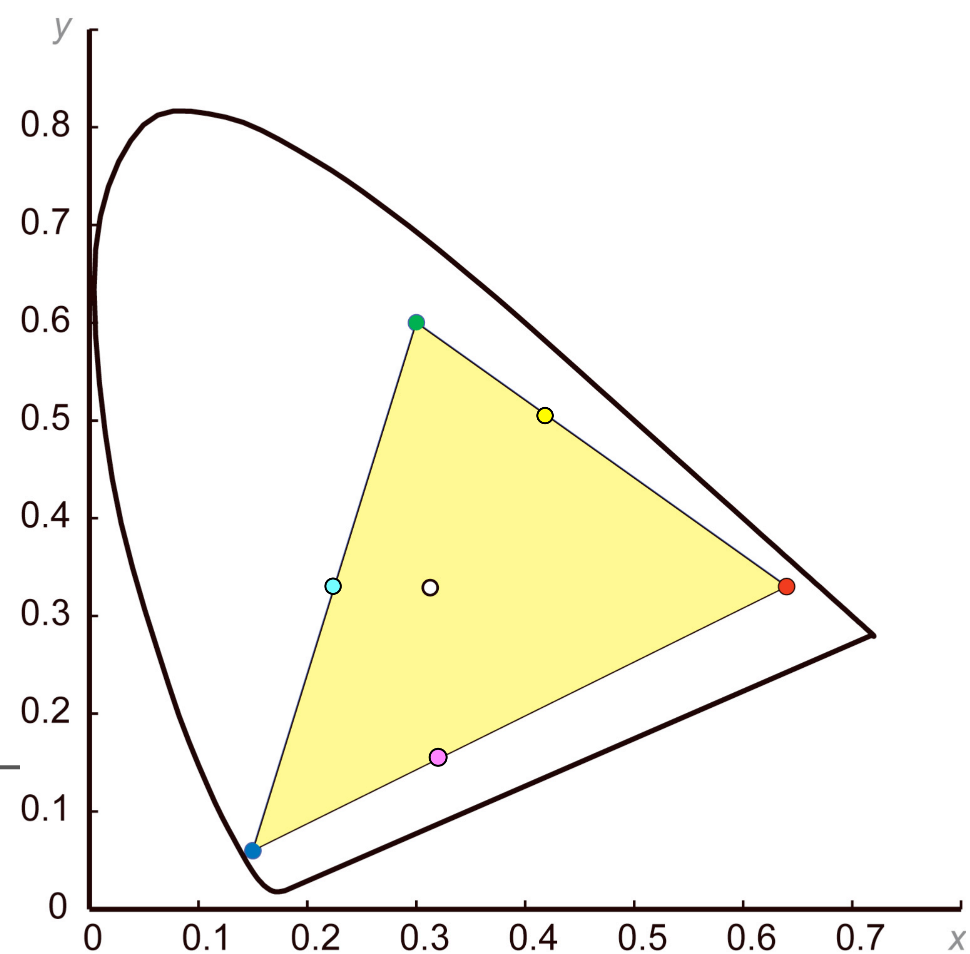
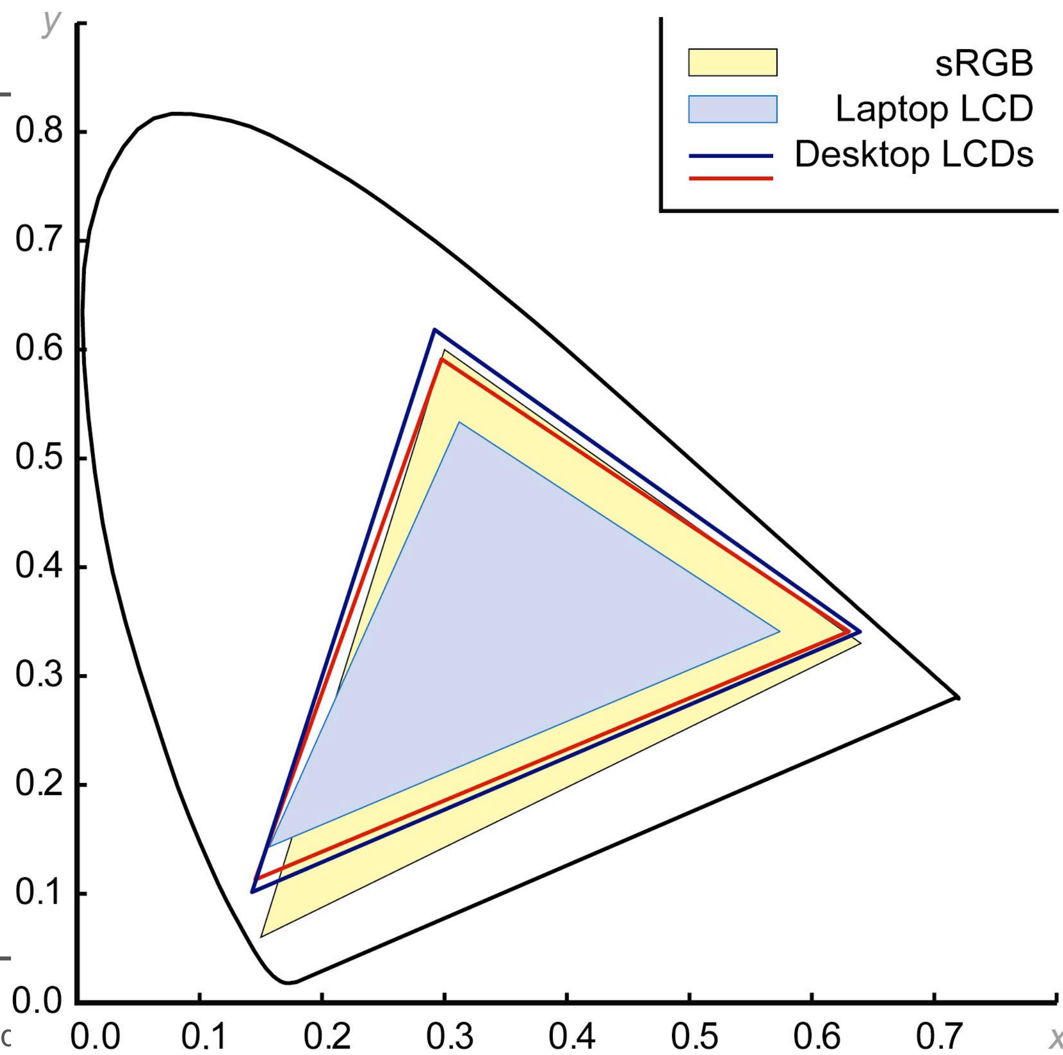
RGB Chromaticity

- 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



Display Gamuts



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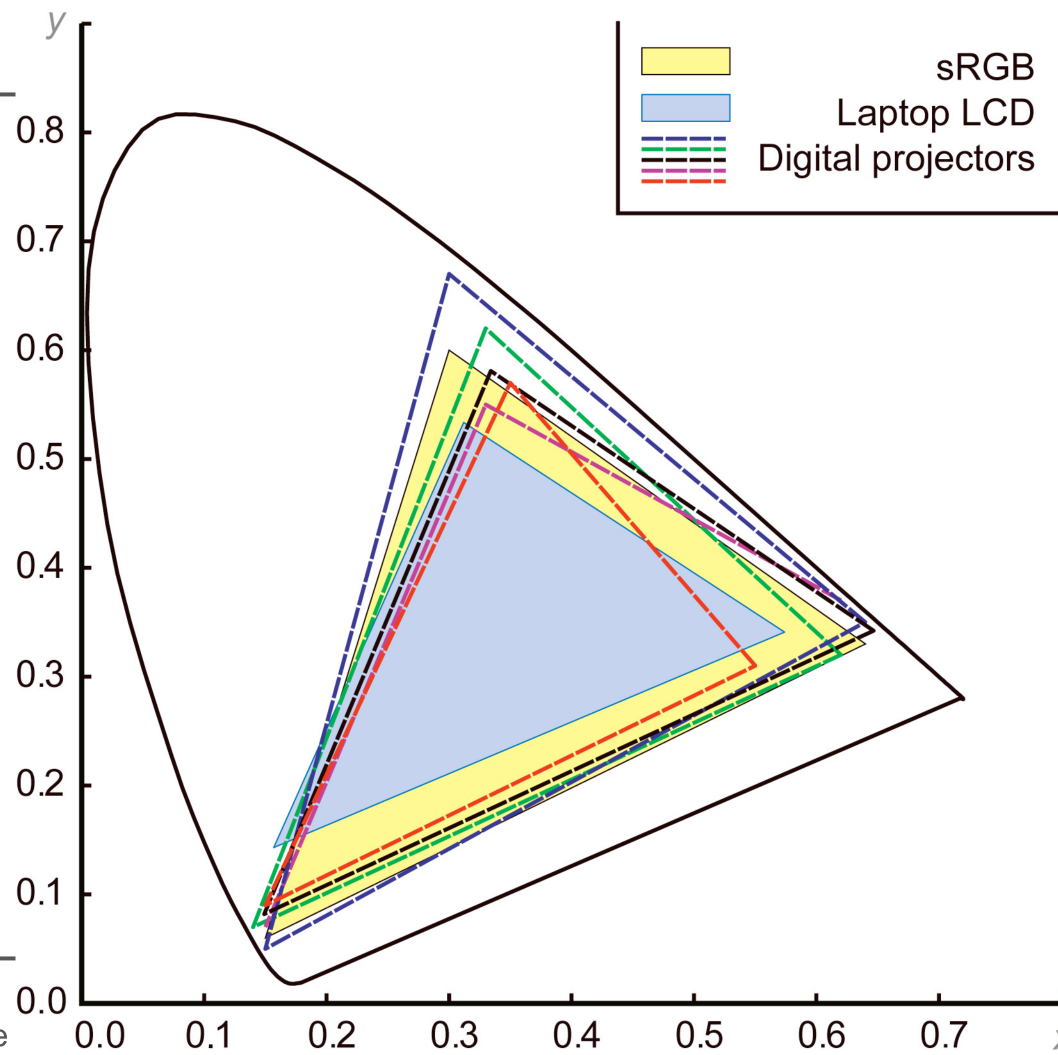
Projector Gamuts



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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

Pixel to Intensity Variation

Intensity Transfer Function (ITF), or “gamma”

Color Models

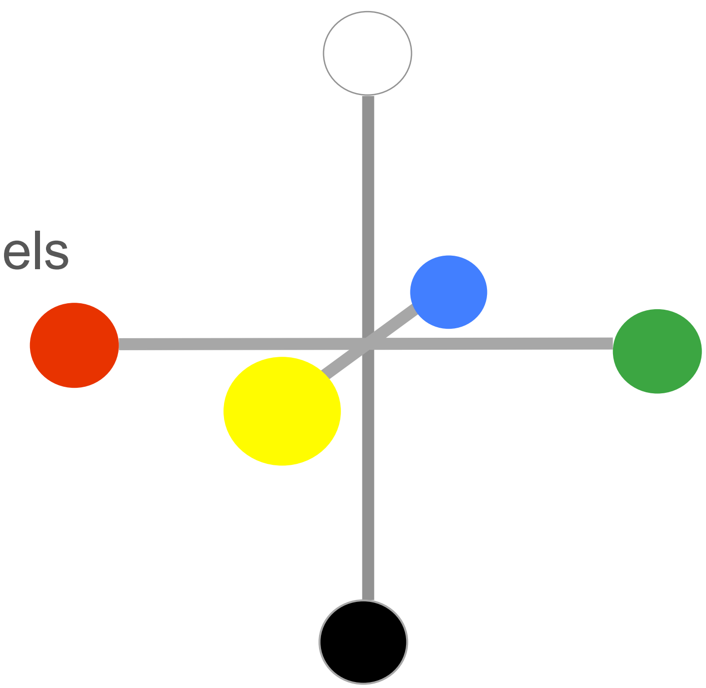
Physical World → Visual System → Mental Models

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
$F(\lambda)$	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

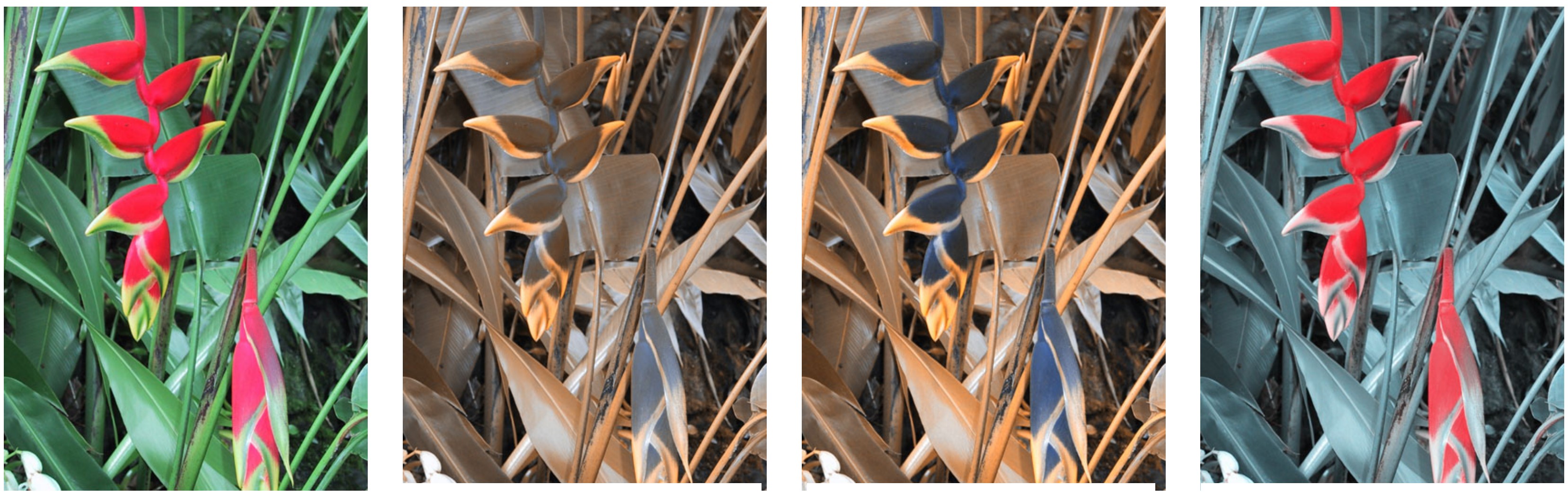
Opponent Color

- 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”



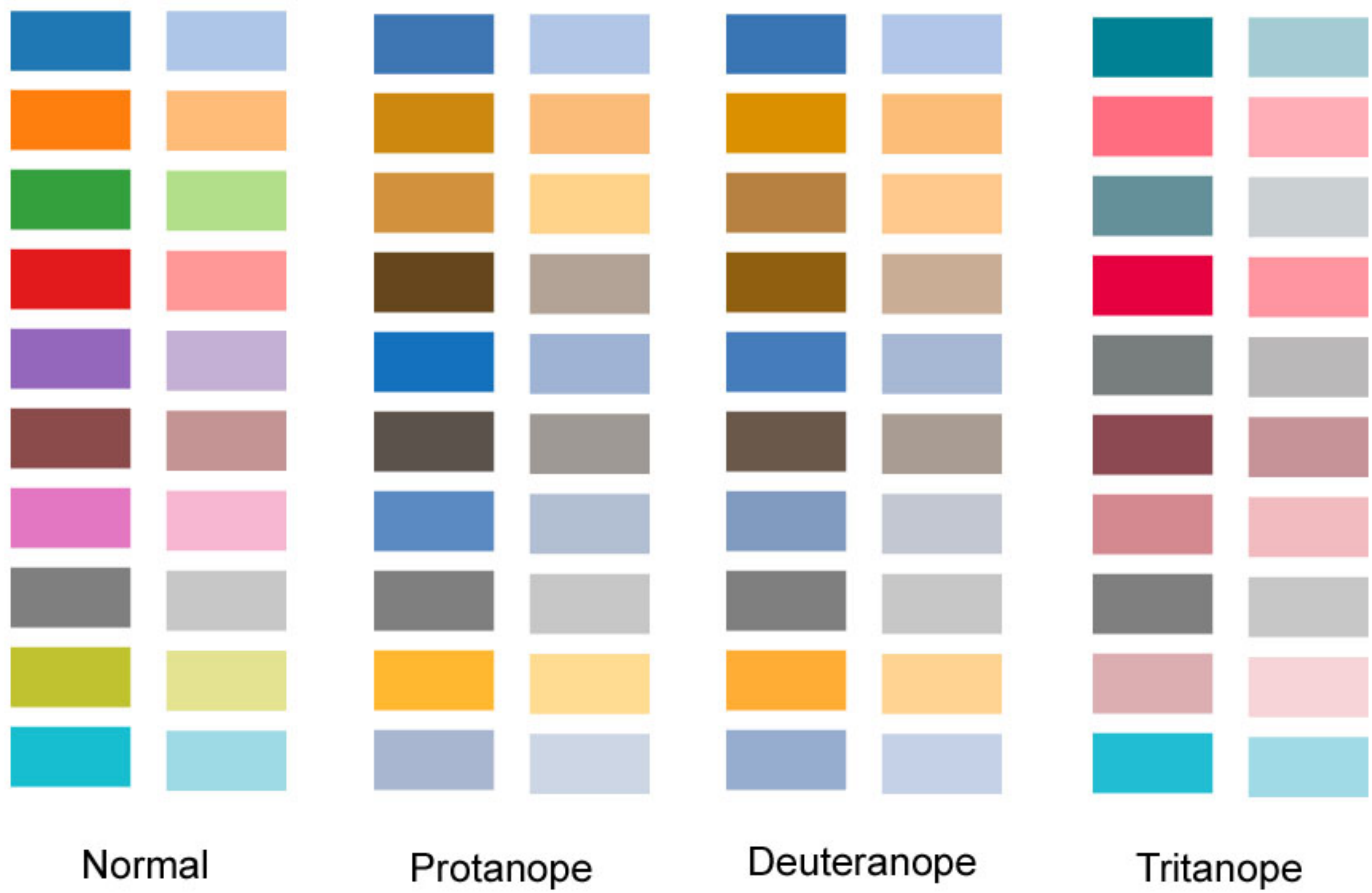
Vischeck

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

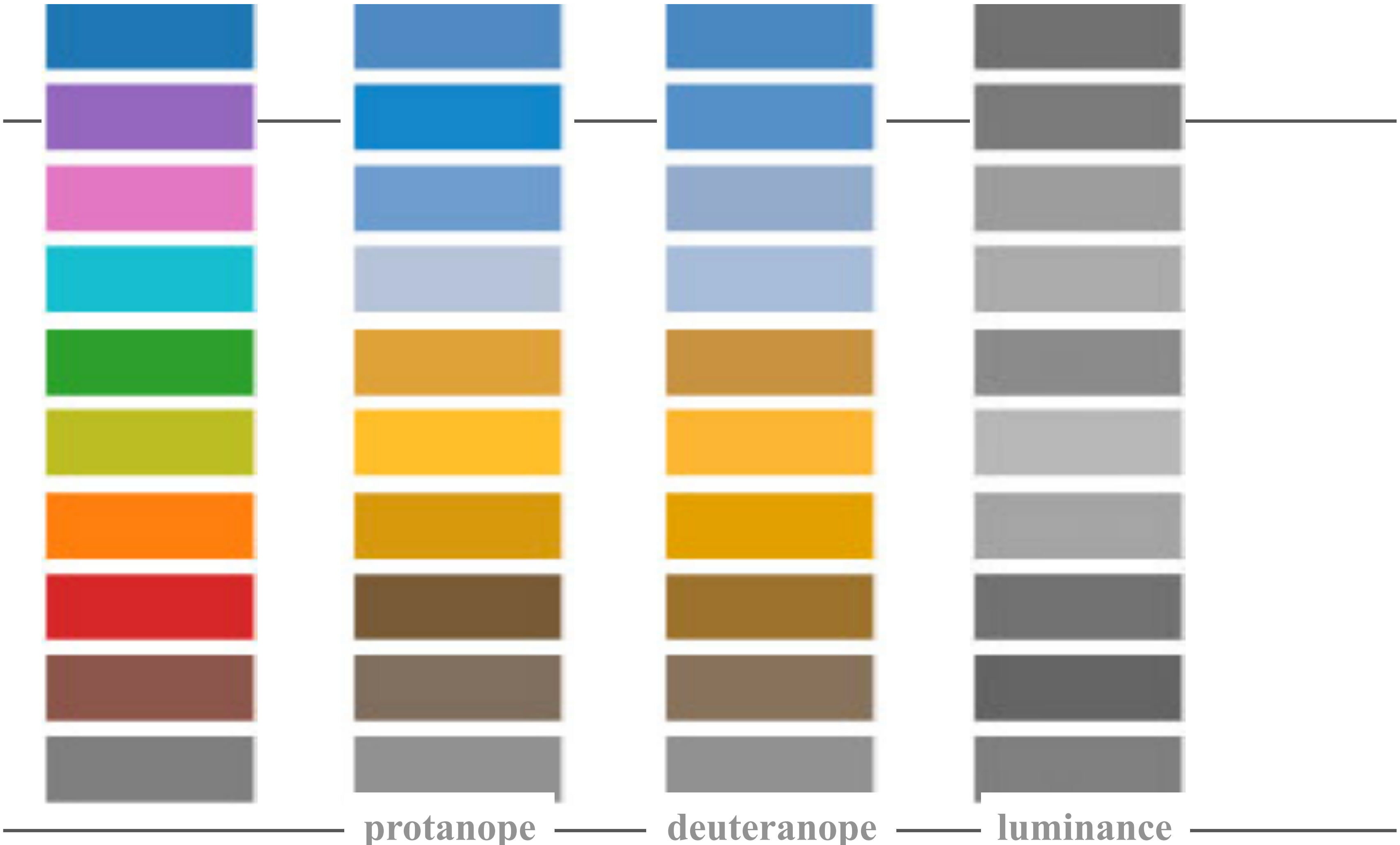


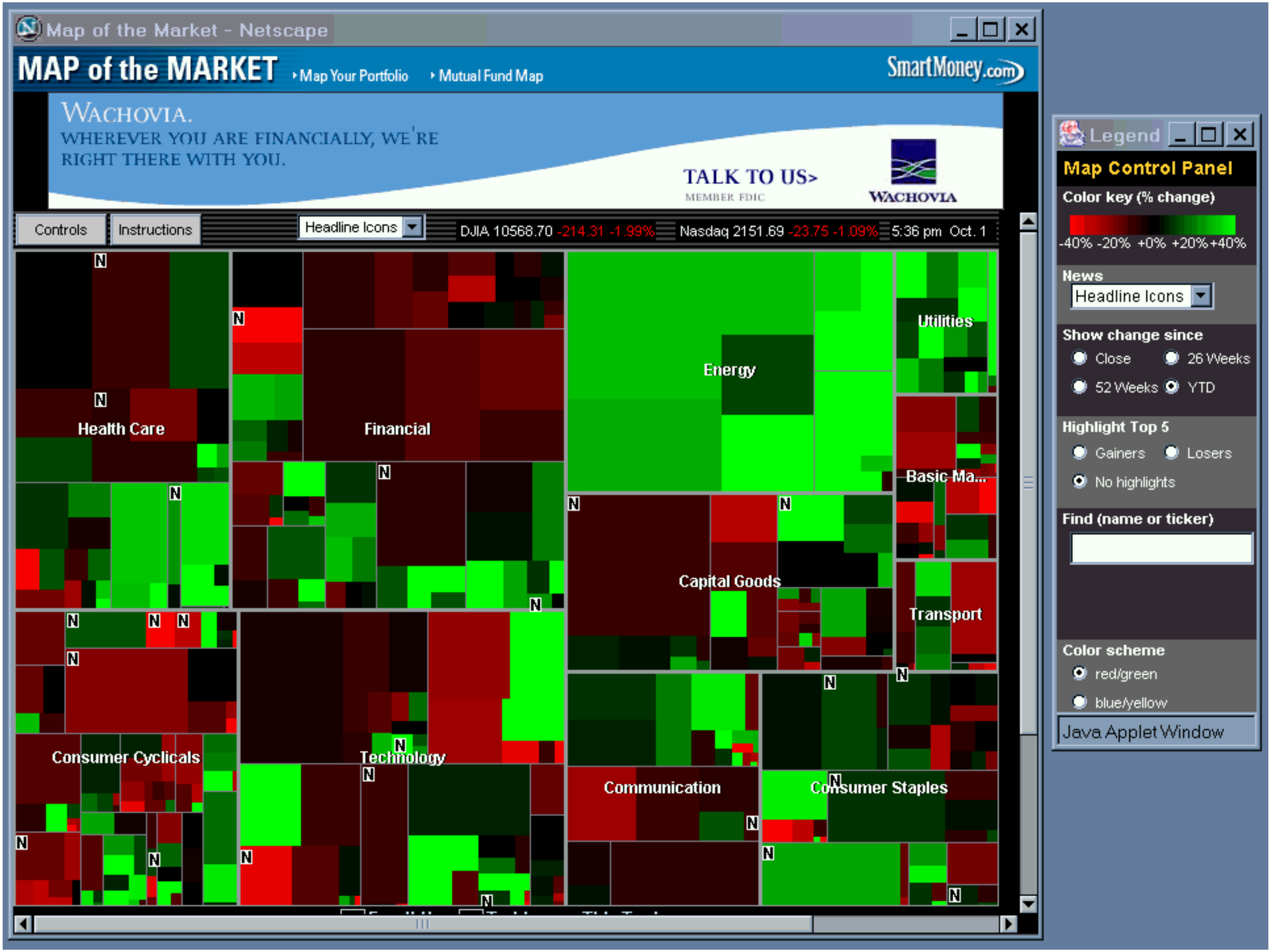
Deuteranope Protanope Tritanope

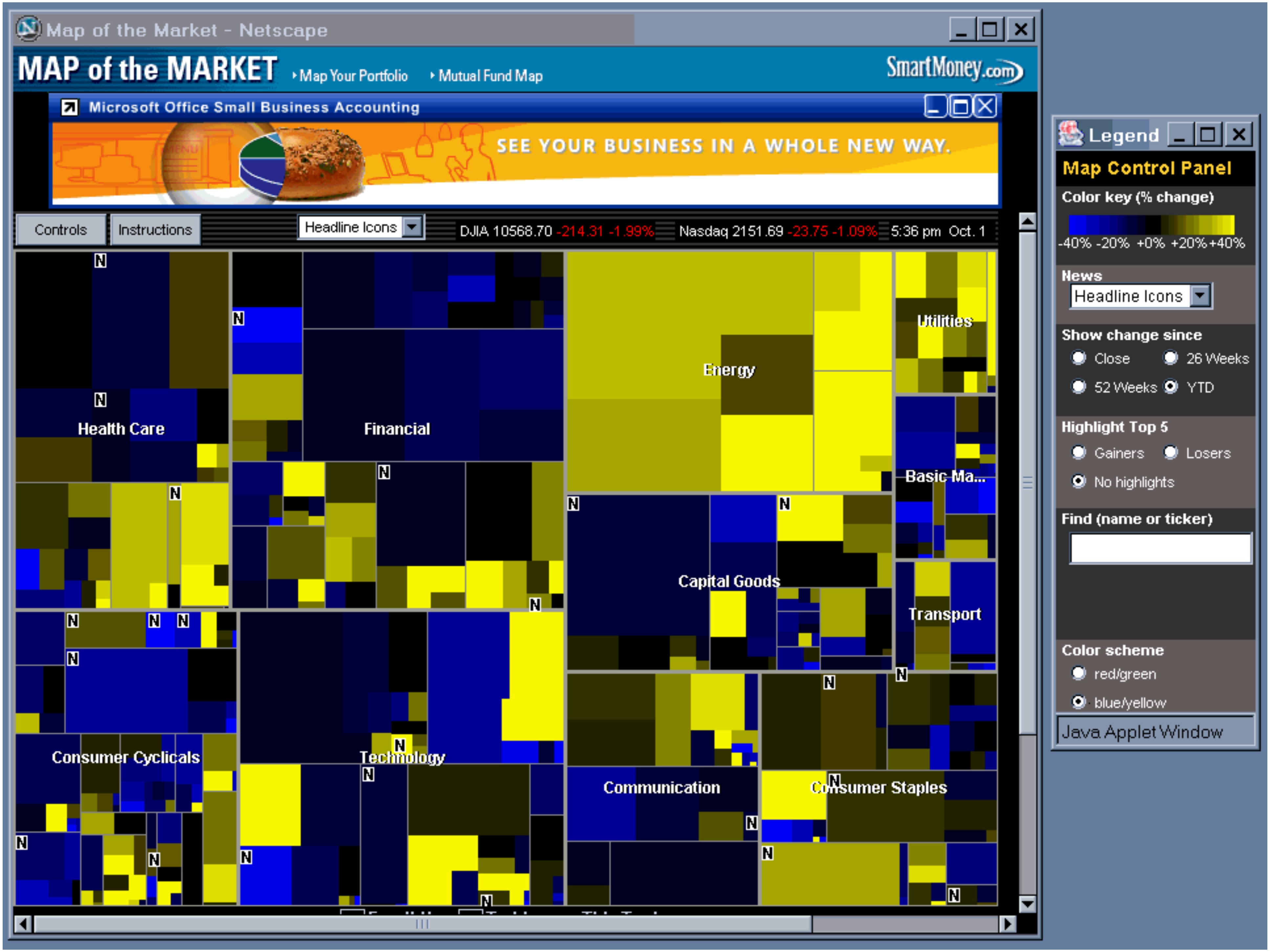
2D Color Space



Similar Colors




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>
MEMBER FDIC
WACHOVIA
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
MAP of the MARKET
Map Your Portfolio
Mutual Fund Map
SmartMoney.com
Microsoft Office Small Business Accounting
SEE YOUR BUSINESS IN A WHOLE NEW WAY.
Controls
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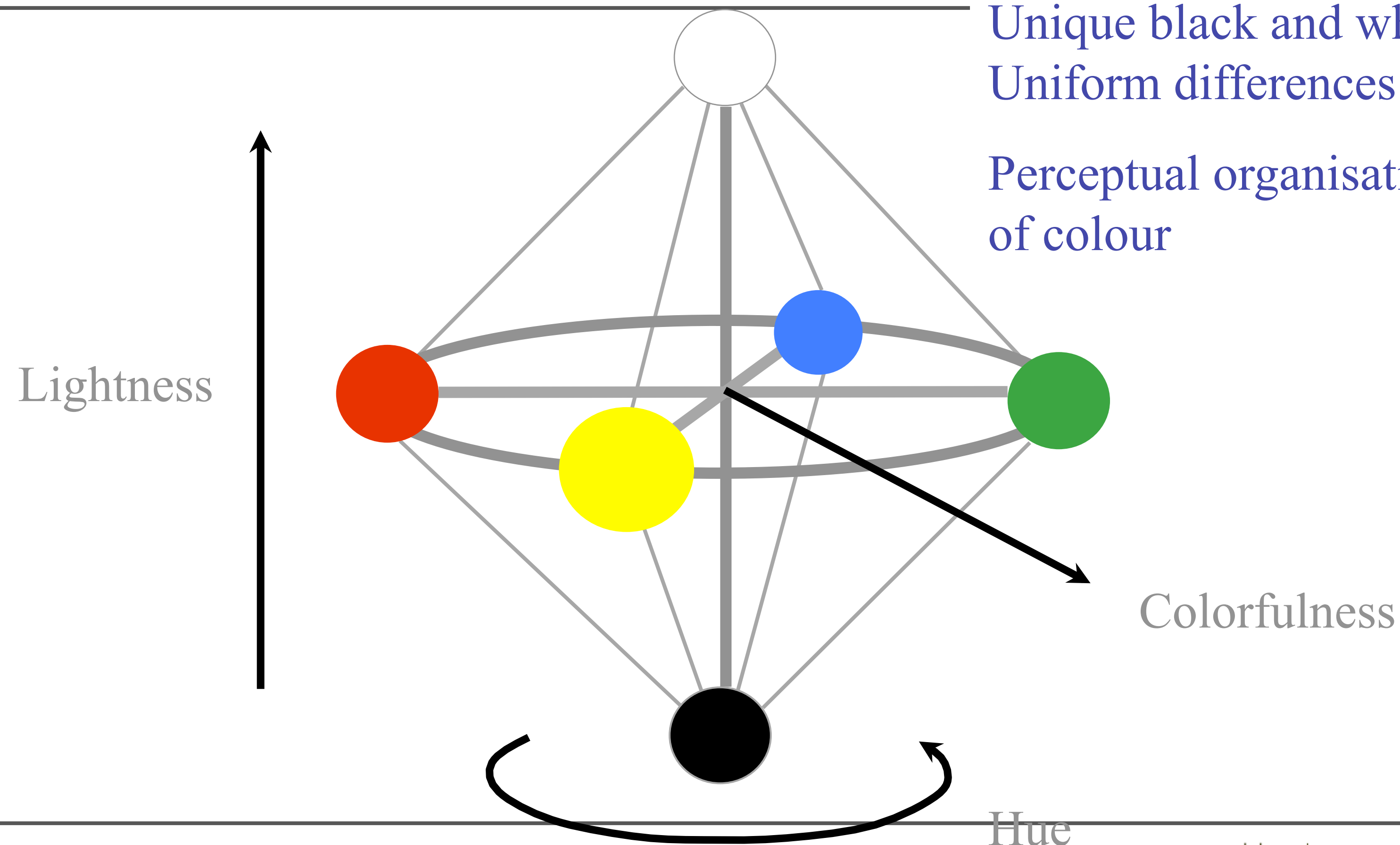
Java Applet Window

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
			Hue, lightness saturation	Adaptation, Background, Size, …
F(λ)	CIE (X,Y,Z)	(A,R-G,Y-B)	CIELAB Munsell (HVC)	CIECAM02
		Separate lightness, chroma Color blindness Image encoding		

Perceptual Color Spaces



Unique black and white
Uniform differences

Perceptual organisation of colour

Munsell Atlas

Courtesy Gretag-Macbeth

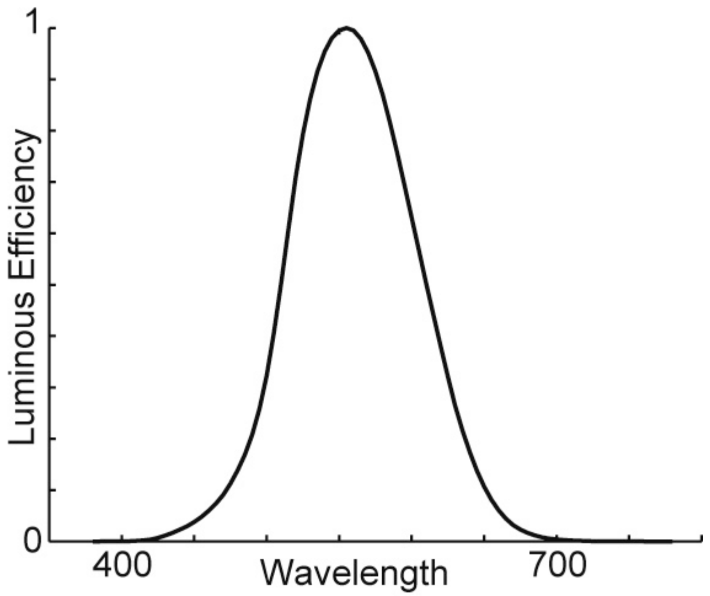
Lightness Scales

- 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
- L* is perceptually uniform lightness
- **Perceptual uniformity**: equal spatial distances define equal perceptual differences

Luminance & Intensity

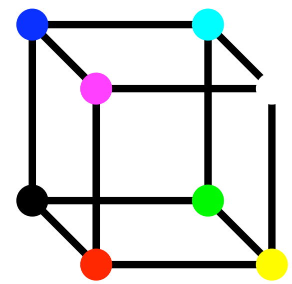
- Intensity
  - Integral of spectral distribution (power)
- Luminance
  - Intensity modulated by wavelength sensitivity
  - Integral of spectrum × luminous efficiency function
  - Is a **perceived** intensity

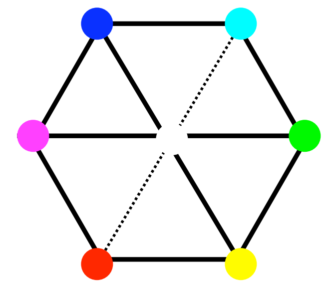
Green and blue lights of equal intensity have different luminance values



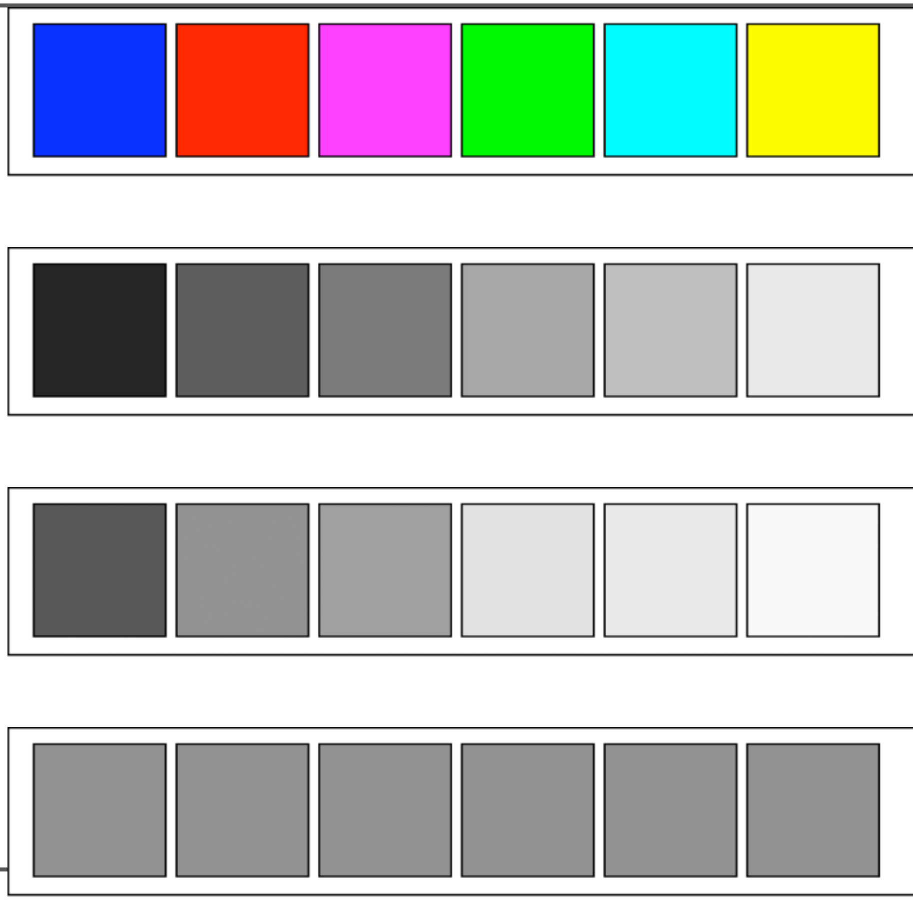
Psuedo-Perceptual Models

- 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

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			CIELAB	CIECAM02
			Color differences "Intuitive" color spaces Color scales	

Color Appearance

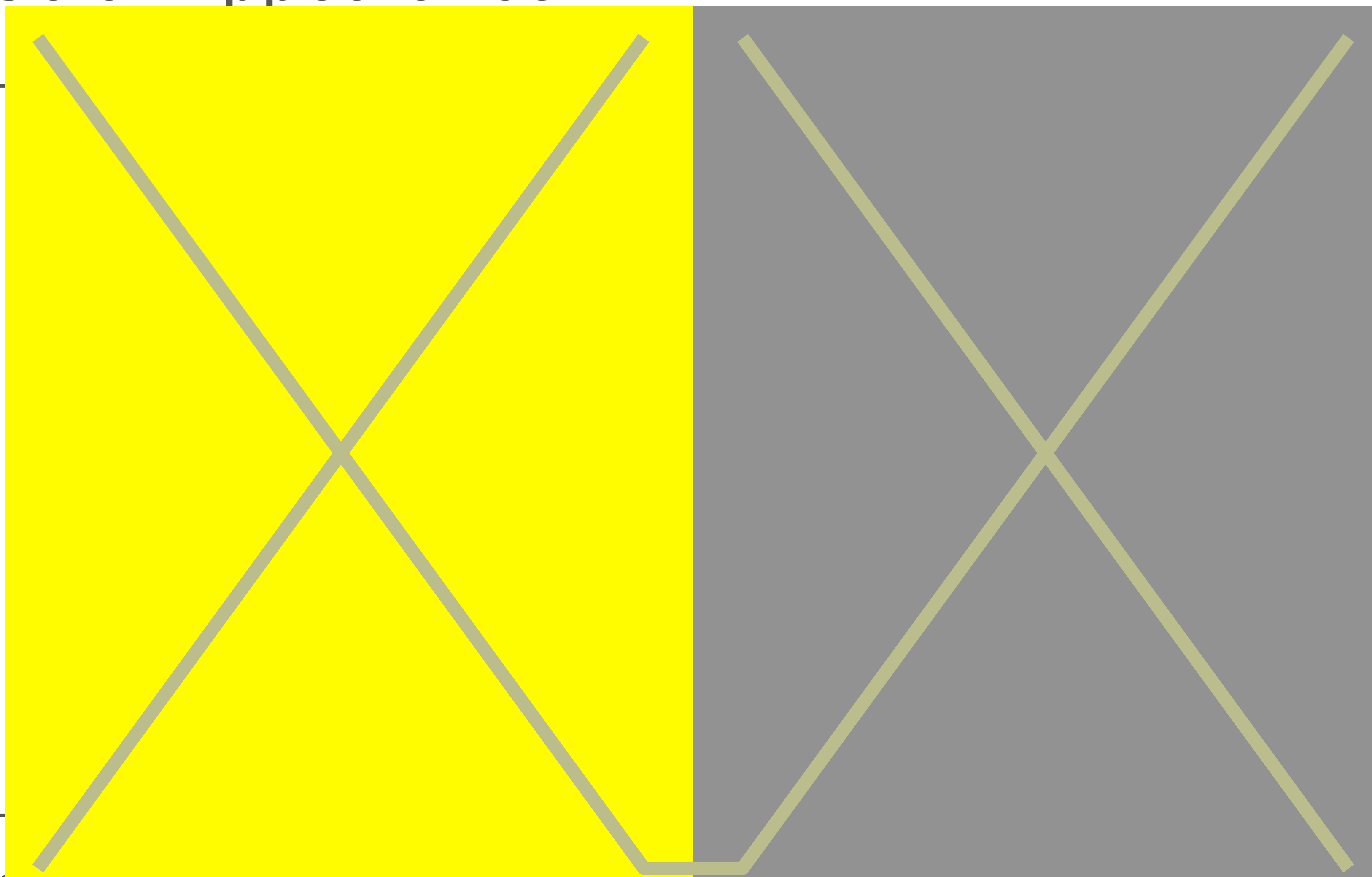
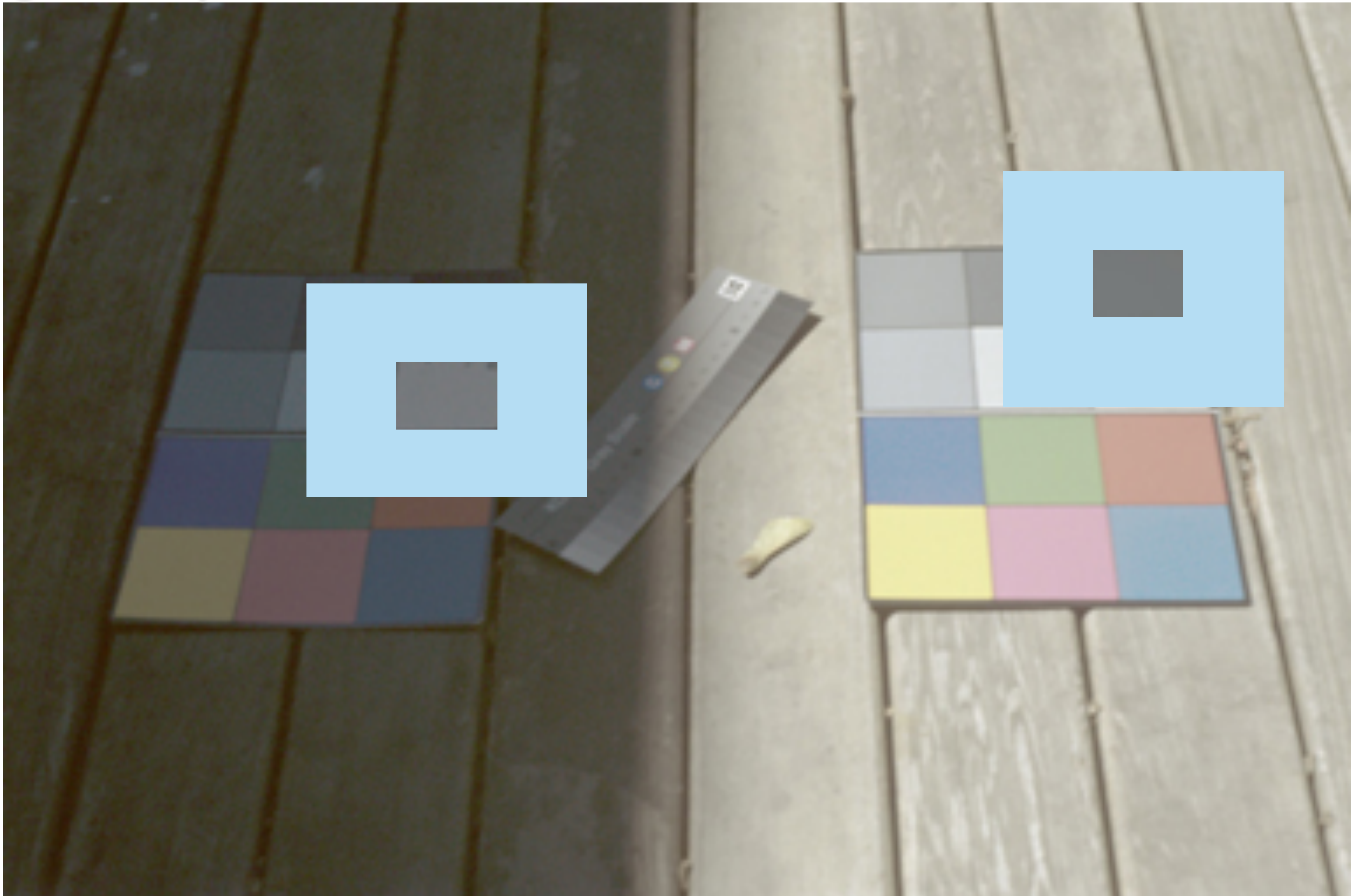


Image courtesy of John MCann

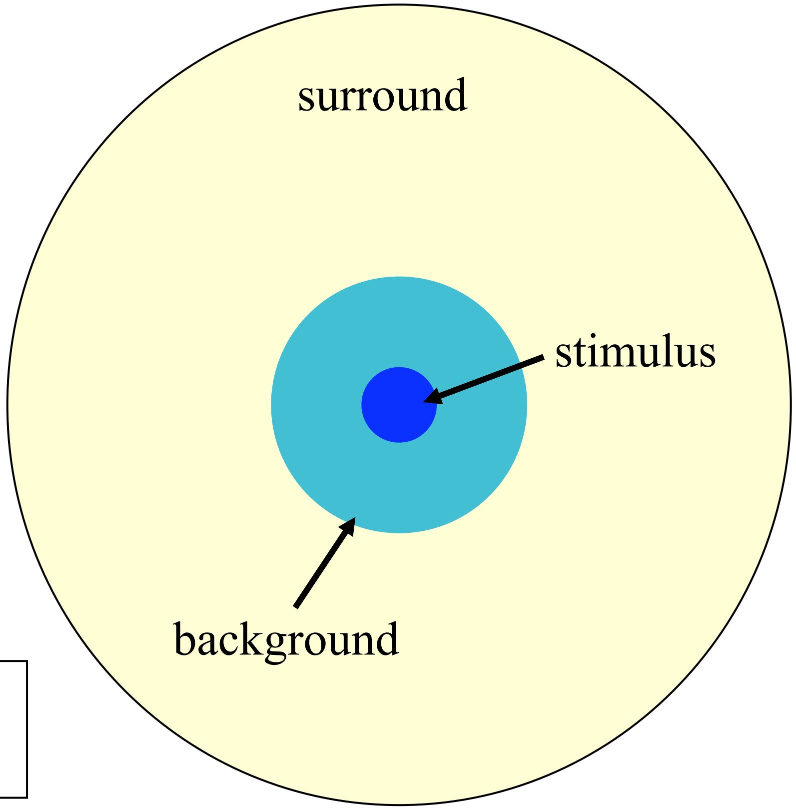
Image courtesy of John MCann



Color Appearance

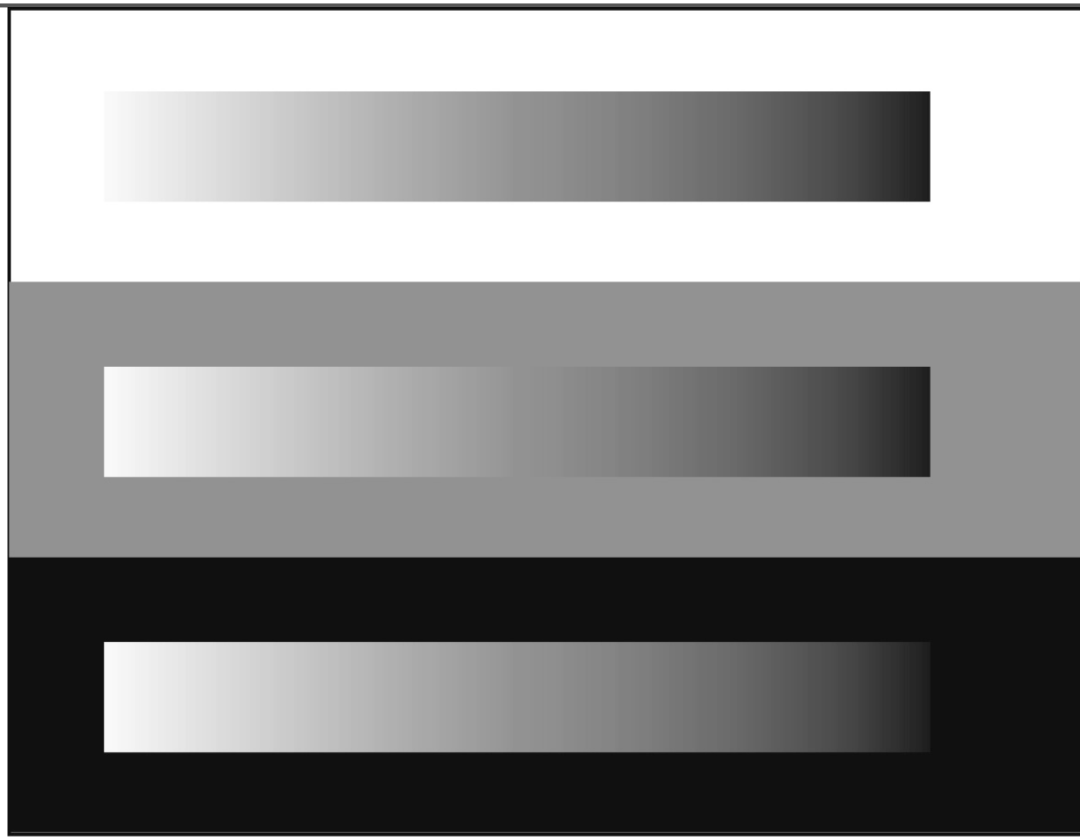
- More than a single color
  - Adjacent colors (background)
  - Viewing environment (surround)
- Appearance effects
  - Adaptation
  - Simultaneous contrast
  - Spatial effects
- Color in context

Color Appearance Models
Mark Fairchild

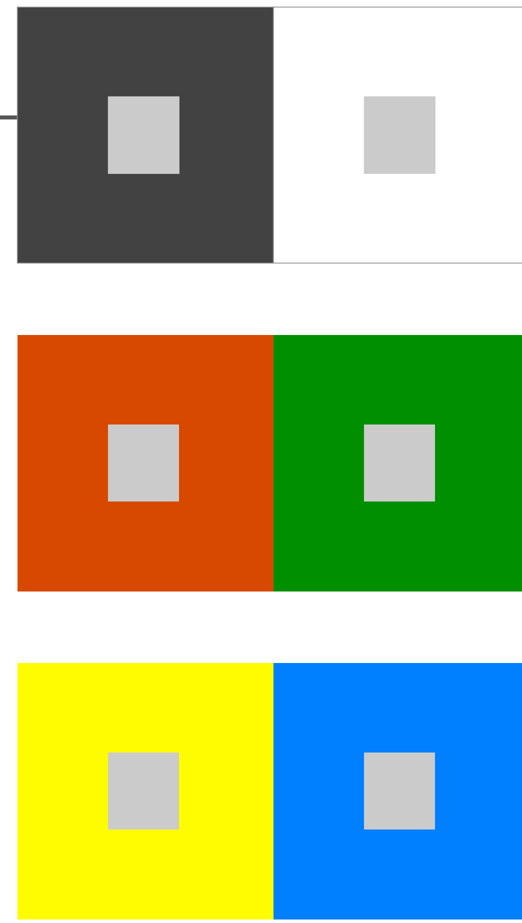


Simultaneous contrast

Affects Lightness Scale



Simultaneous Contrast

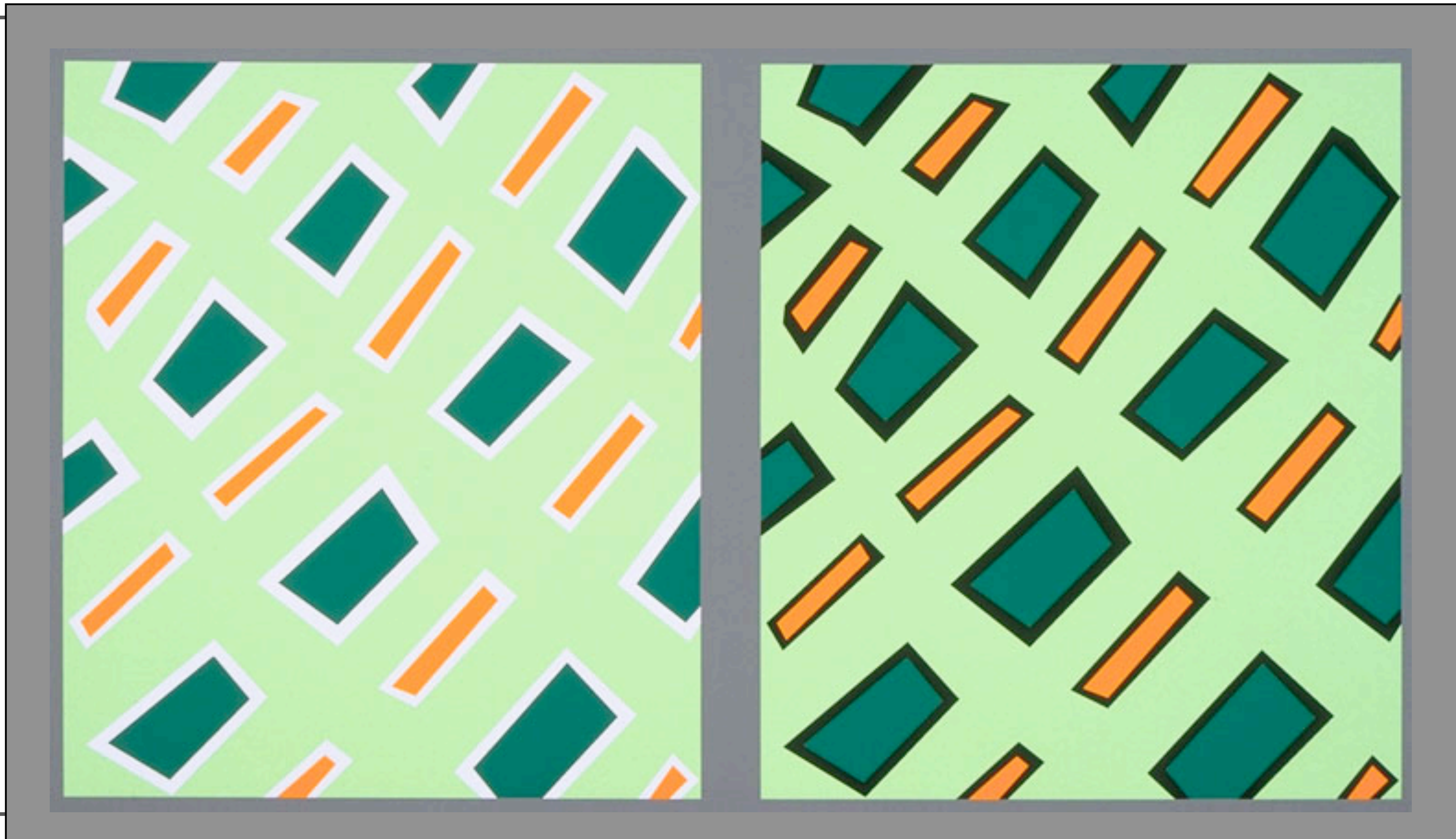


- Influence of immediate surround on perception of colour

- Simple example:
- Add Opponent Color
  - Dark adds light
  - Red adds green
  - Blue adds yellow

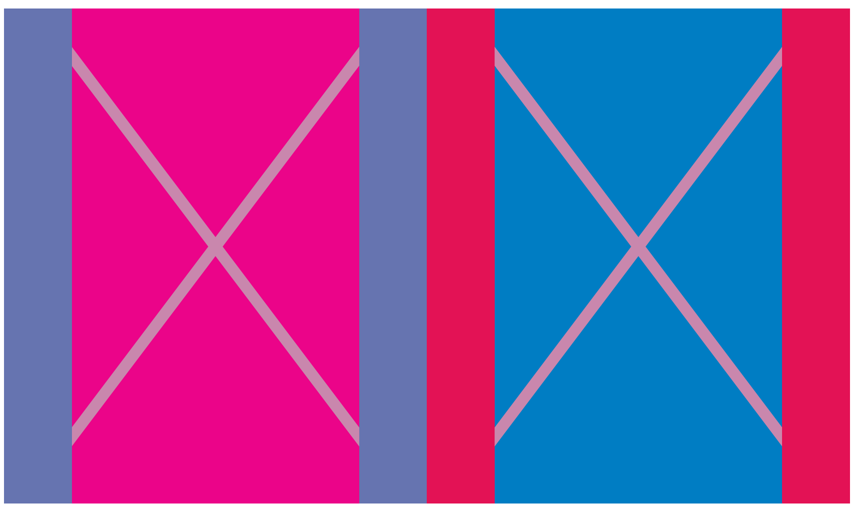
These samples will have both light/dark and hue contrast

Bezold Effect: outline makes a difference

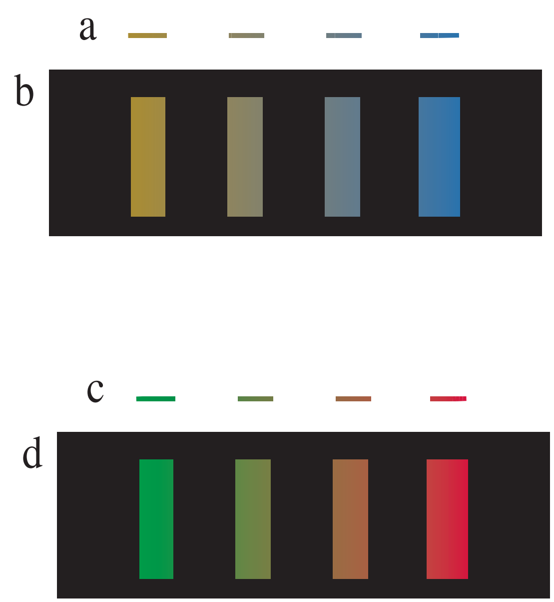


Other contrast effects

Chromatic contrast



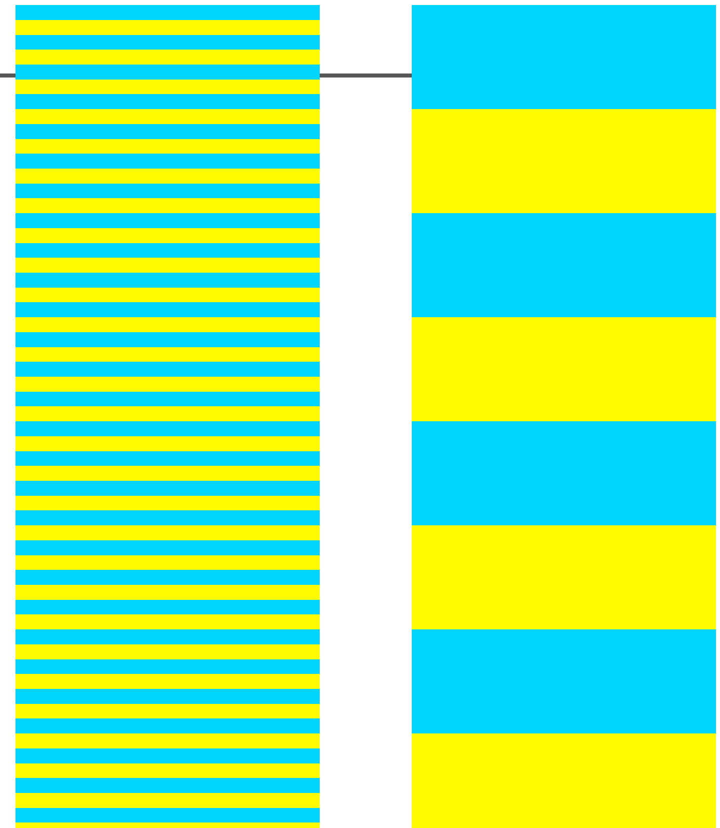
Small field tritanopia



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*
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			CIELAB Munsell (HVC)	Adaptation Contrast effects Image appearance Complex matching