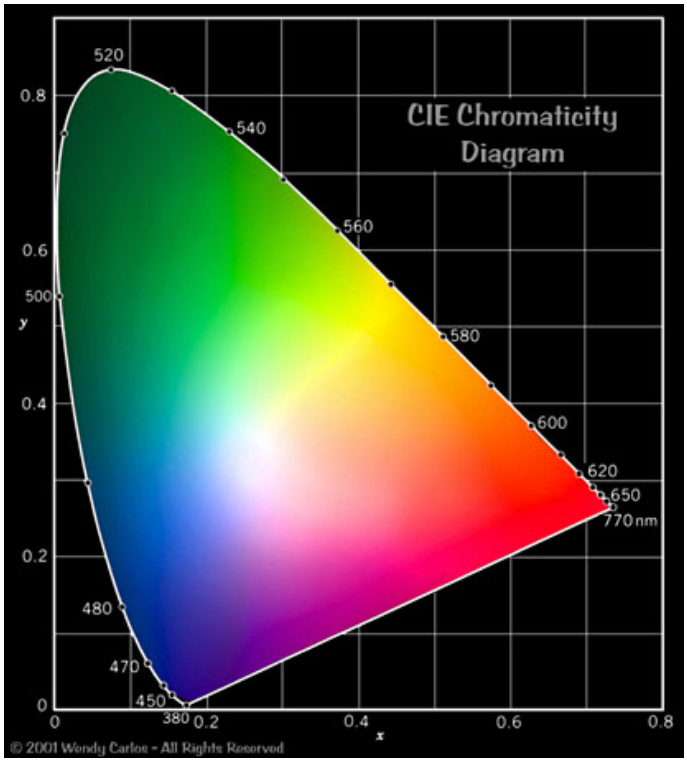
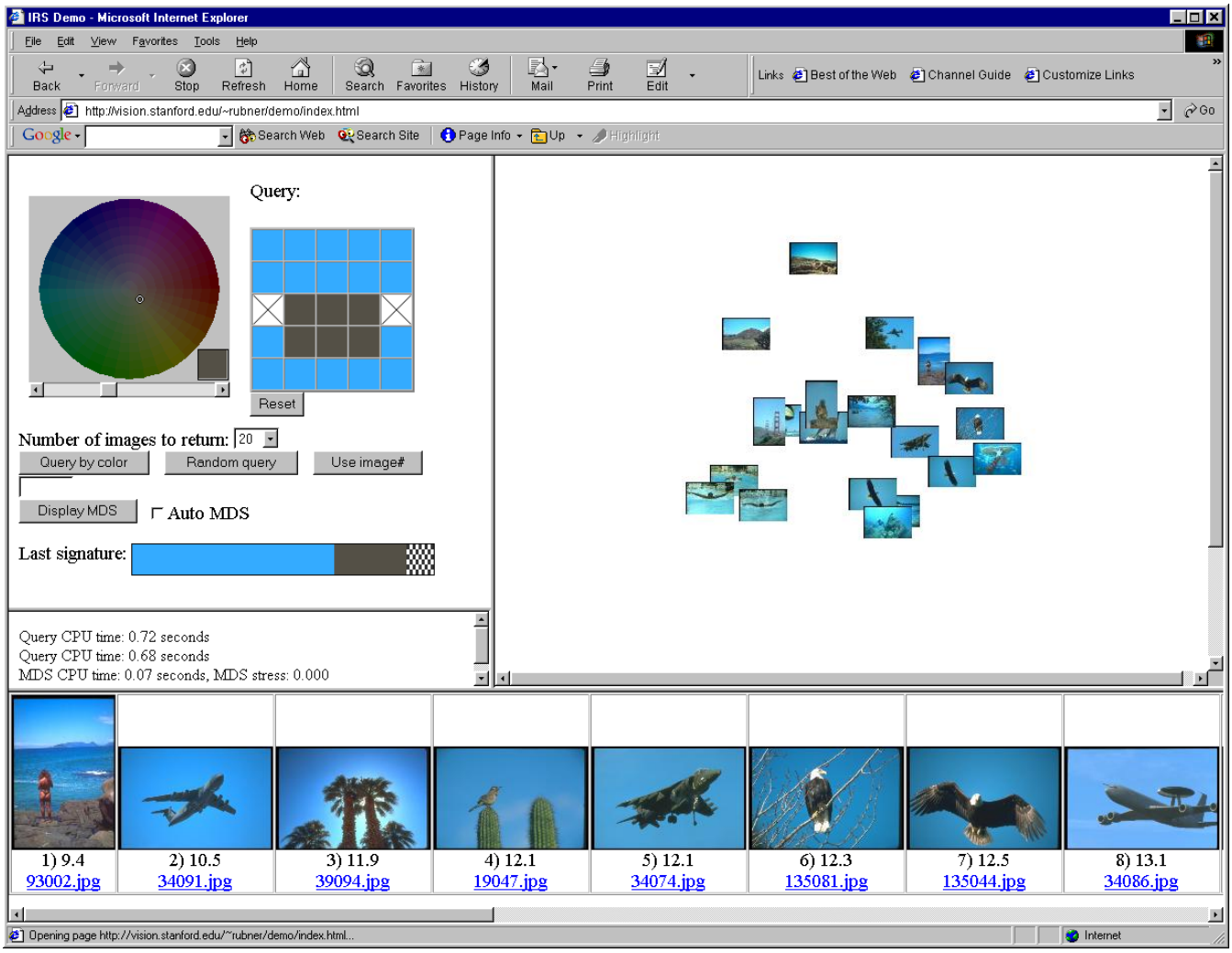
Lecture 5

Perceptual Color Space

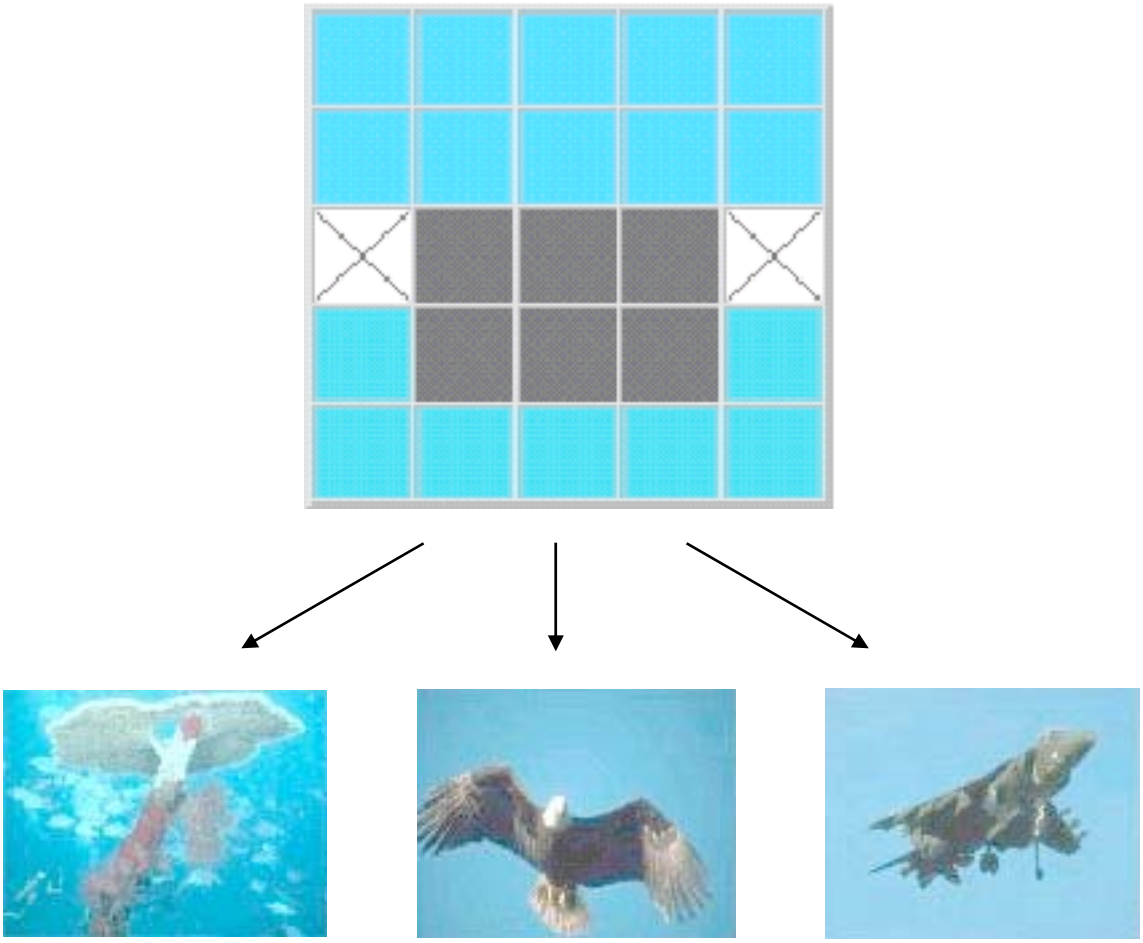
CIELAB Color Space



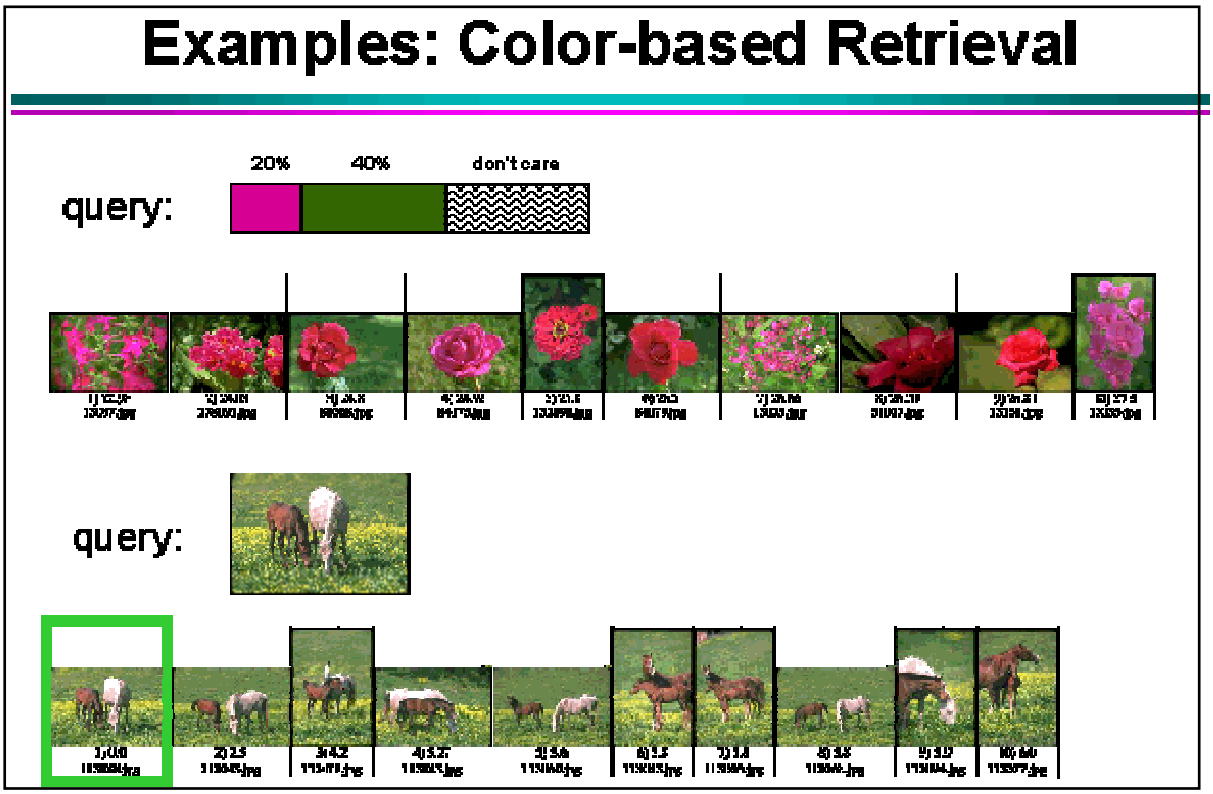
Color Based Image Retrieval



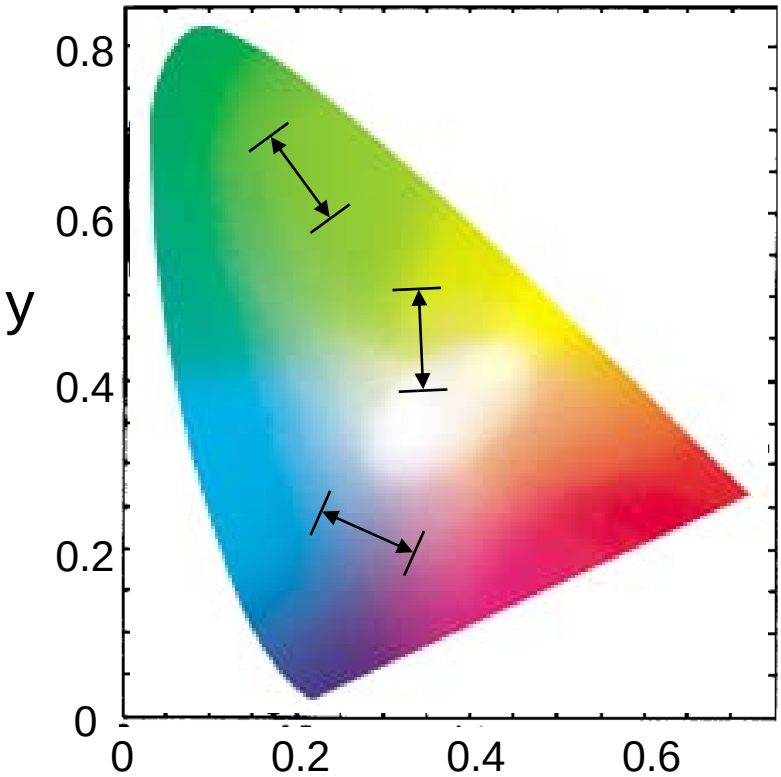
Color Based Image Retrieval



Color Based Image Retrieval



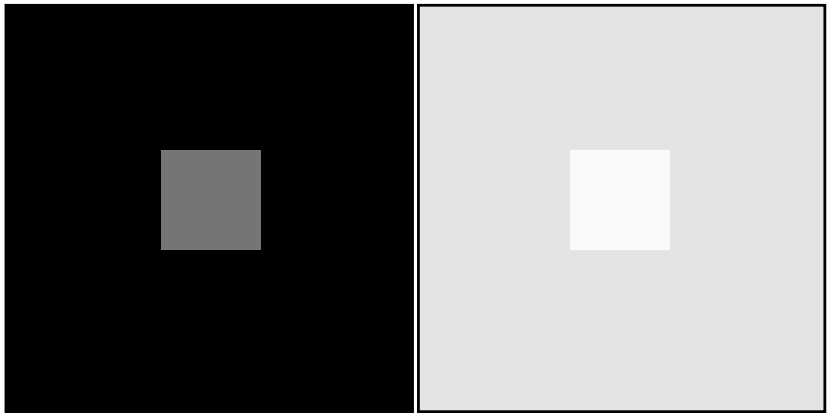
Non- Perceptual Color Space

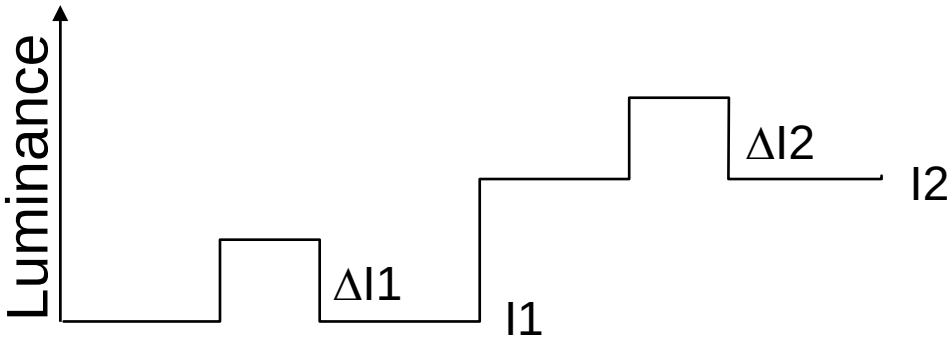


Equal Euclidean distances are nor perceived
as equally distant perceptually.

Luminance vs Brightness

Y vs V :
Luminance (intensity) vs Brightness (Lightness)





$I1 < I2, \quad \Delta I1 = \Delta I2$

Equal intensity steps:

Equal brightness steps:

Weber's Law

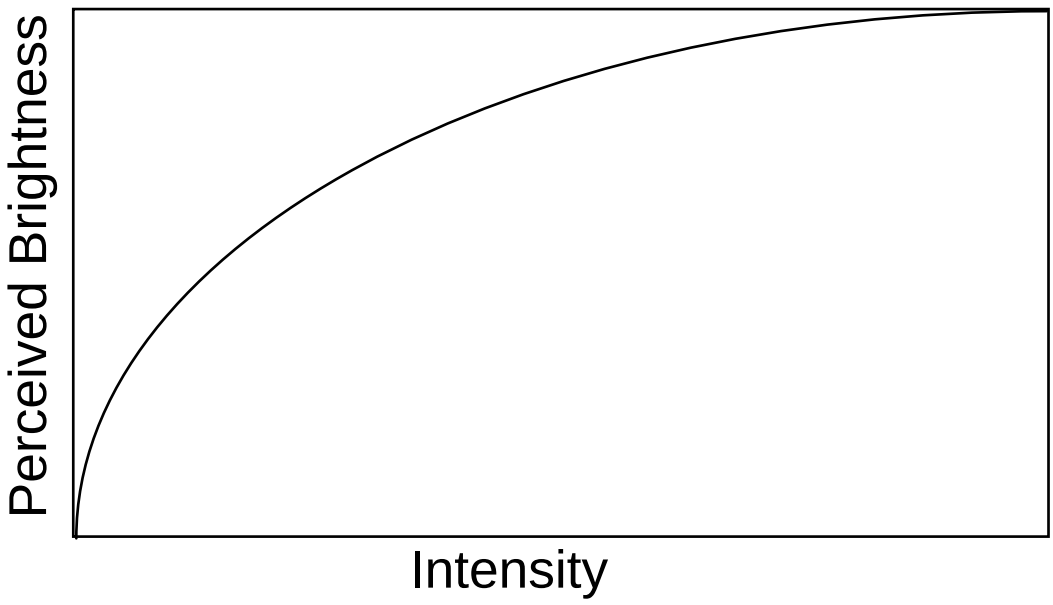
In general, $\Delta \mathbf{I}$ needed for just noticable difference (JND) over background $\mathbf{I}$ was found to satisfy:

$$\boxed{\frac{\Delta \mathbf{I}}{\mathbf{I}} = \text{constant}}$$

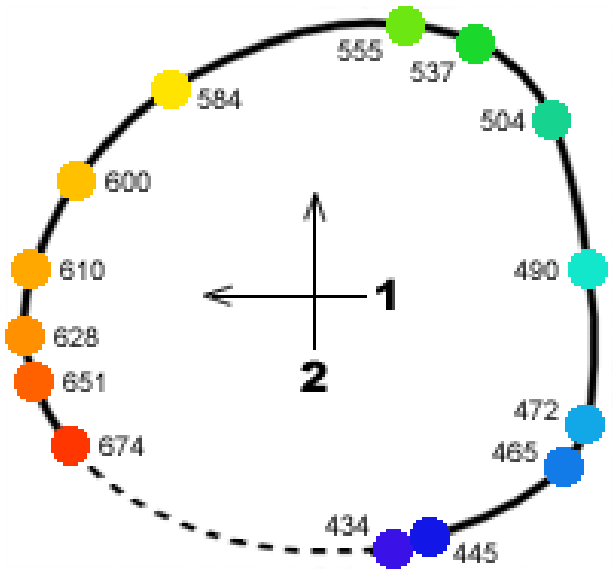
($\mathbf{I}$ is intensity, $\Delta \mathbf{I}$ is change in intensity)

Weber's Law:

$$\boxed{\text{Perceived Brightness} = \log(\mathbf{I})}$$



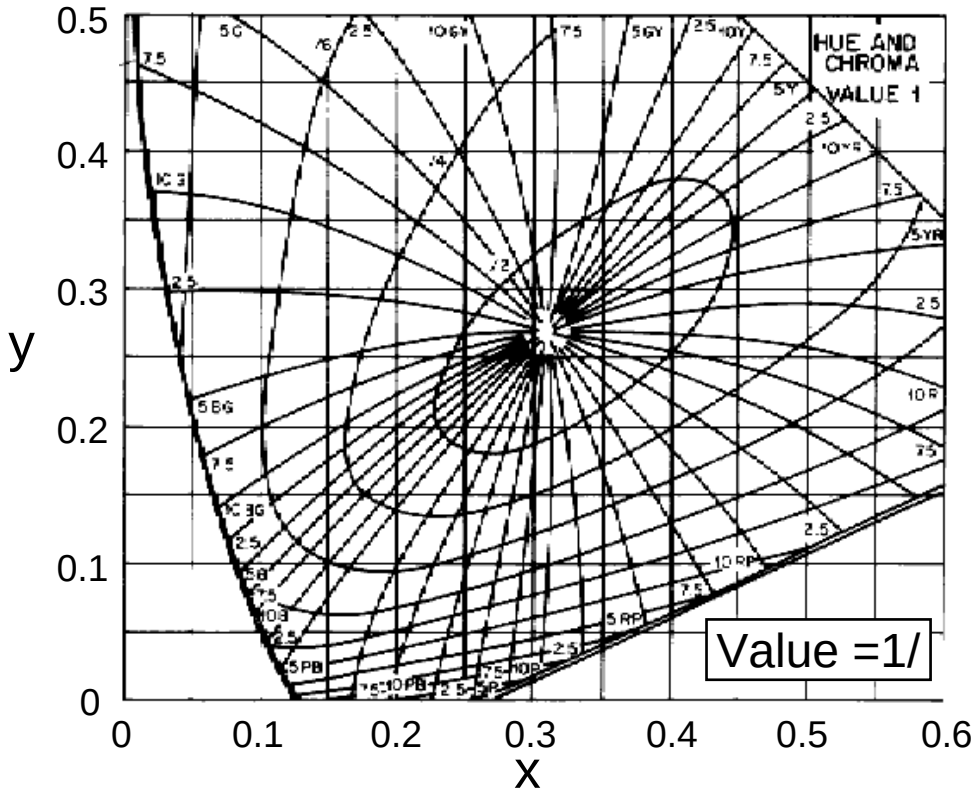
Perceptual Color Distances



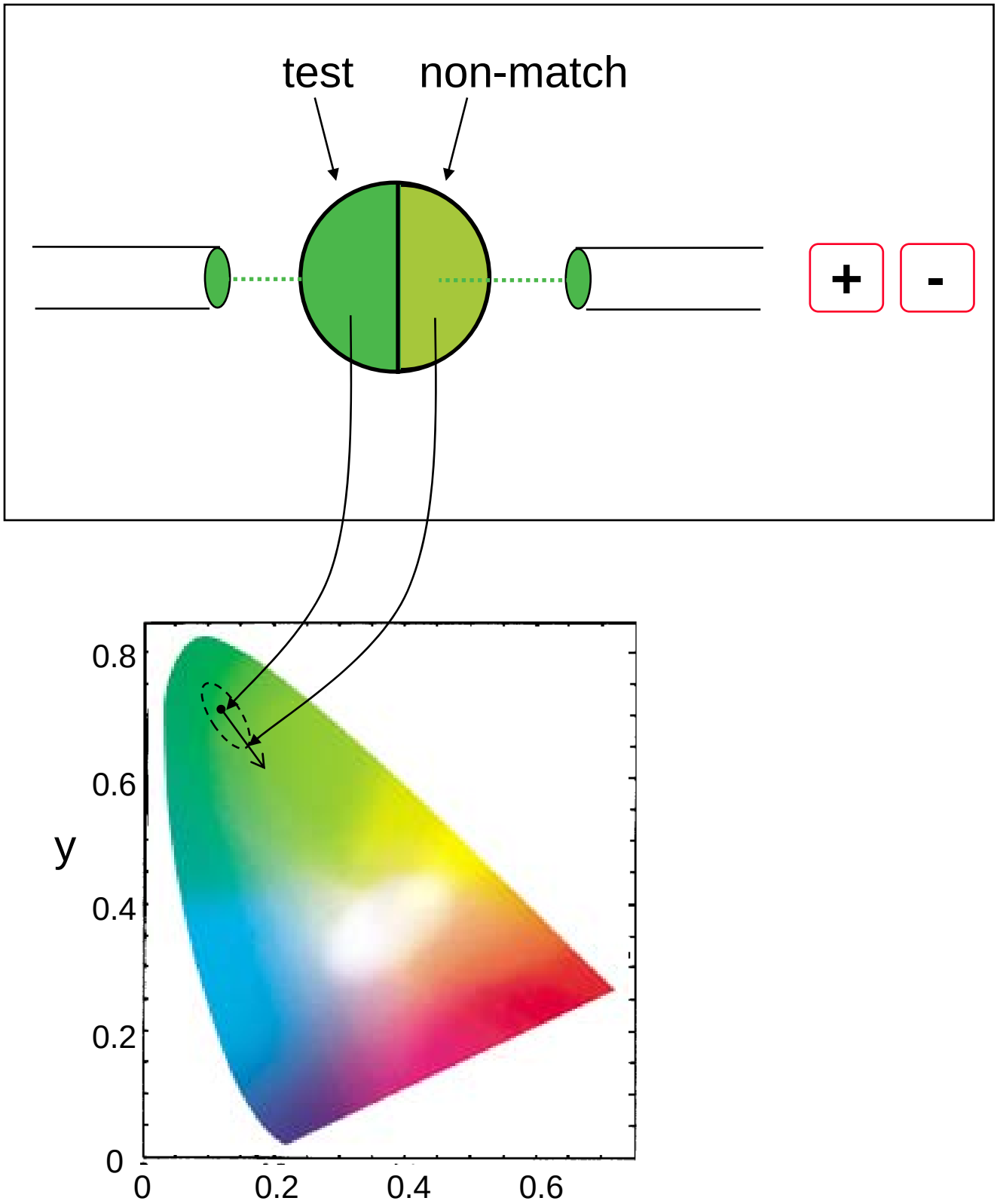
Shepard (1962) – judgments of similarity of Munsell chips associated with monochromatic spectra.

Figure From www.handprint.com/HP/WCL/color2.html

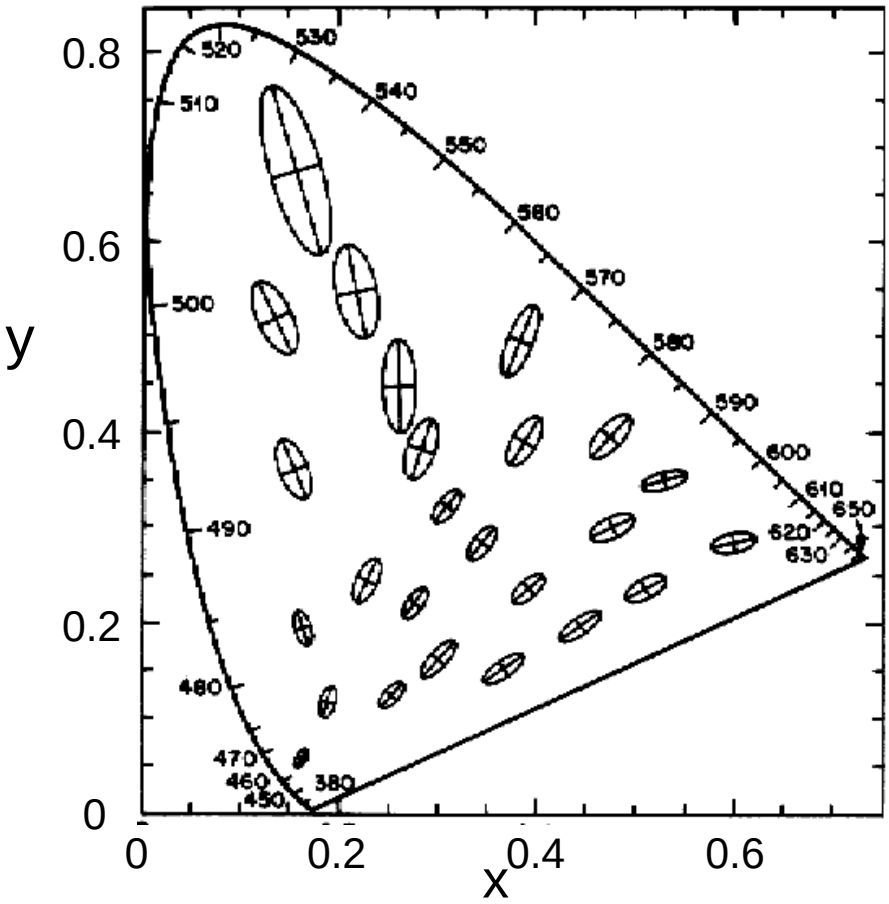
Munsell lines of constant Hue and Chroma.



MacAdam - JND (Just Noticable difference)



MacAdam Ellipses of JND (Just Noticable difference)



(Ellipses scaled by 10)

CIE- UVW Coordinates

The transformation from XYZ space to perceptual space is **Non Linear**:

Linear approximation defined by CIE (1960):
CIE Uniform Chromaticity Scale (UCS) :

$$U = \frac{2}{3} X$$

$$V = Y$$

$$W = \frac{-X + 3Y + Z}{2}$$

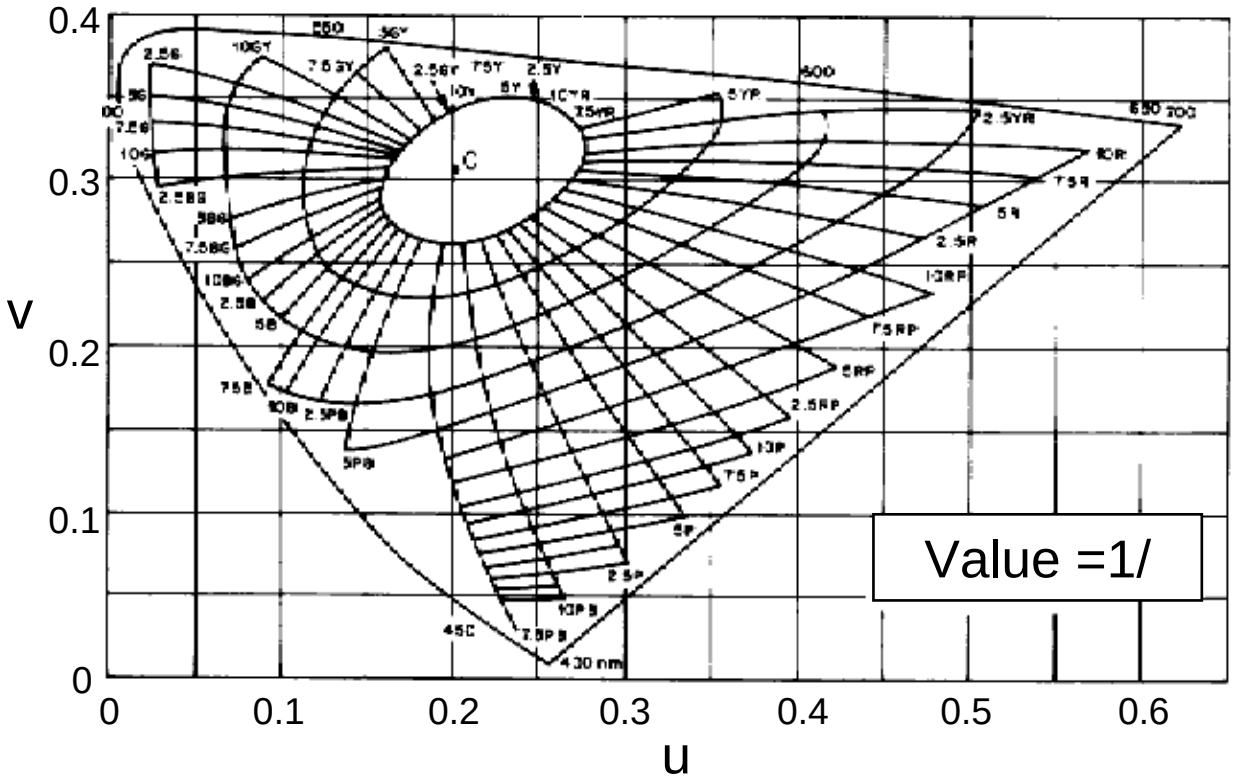
$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = \begin{bmatrix} 0.66 & 0 & 0 \\ 0 & 1 & 0 \\ -0.5 & 1.5 & 0.5 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

CIE-uv Chromaticity Coordinates:

$$u = \frac{4x}{-2x + 12y + 3}$$

$$v = \frac{6y}{-2x + 12y + 3}$$

Munsell lines of constant hue and chroma plotted in CIE-uv coordinates:



See also Online demo at:
http://www.brucelindbloom.com/MunsellCalculator.html

CIE- L*u*v* Coordinates

CIE- $L^*u^*v^*$ Coordinates = modified UCS system (1976)

$$u^* = 13\, L^*(u' - u_0')$$

$$v^* = 13\, L^*(1.5v' - v_0')$$

$$L^* = \begin{cases} 116(Y/Y_0)^{1/3} - 16 & \text{for } Y/Y_0 > 0.01 \\ 903(Y/Y_0) & \text{otherwise} \end{cases}$$

$u_0\, v_0\, Y_0$ = coordinates of reference white

$u' = u$

$v' = 1.5\, v$

$$u = \frac{4x}{-2x + 12y + 3}$$

$$v = \frac{6y}{-2x + 12y + 3}$$

A color model for which, a unit change in luminance and chrominance are uniformly perceptible

CIE- L*a*b* Coordinates

(1976)

$$a^* = 500\,[\,(X/X_0)^{1/3} - (Y/Y_0)^{1/3}]$$

$$b^* = 200\,[\,(X/X_0)^{1/3} - (Z/Z_0)^{1/3}]$$

*

$$L^* = \begin{cases} 116(Y/Y_0)^{1/3} - 16 & \text{for } Y/Y_0 > 0.01 \\ 903(Y/Y_0) & \text{otherwise} \end{cases}$$

$X_0\ Y_0\ Z_0$ = coordinates of reference white

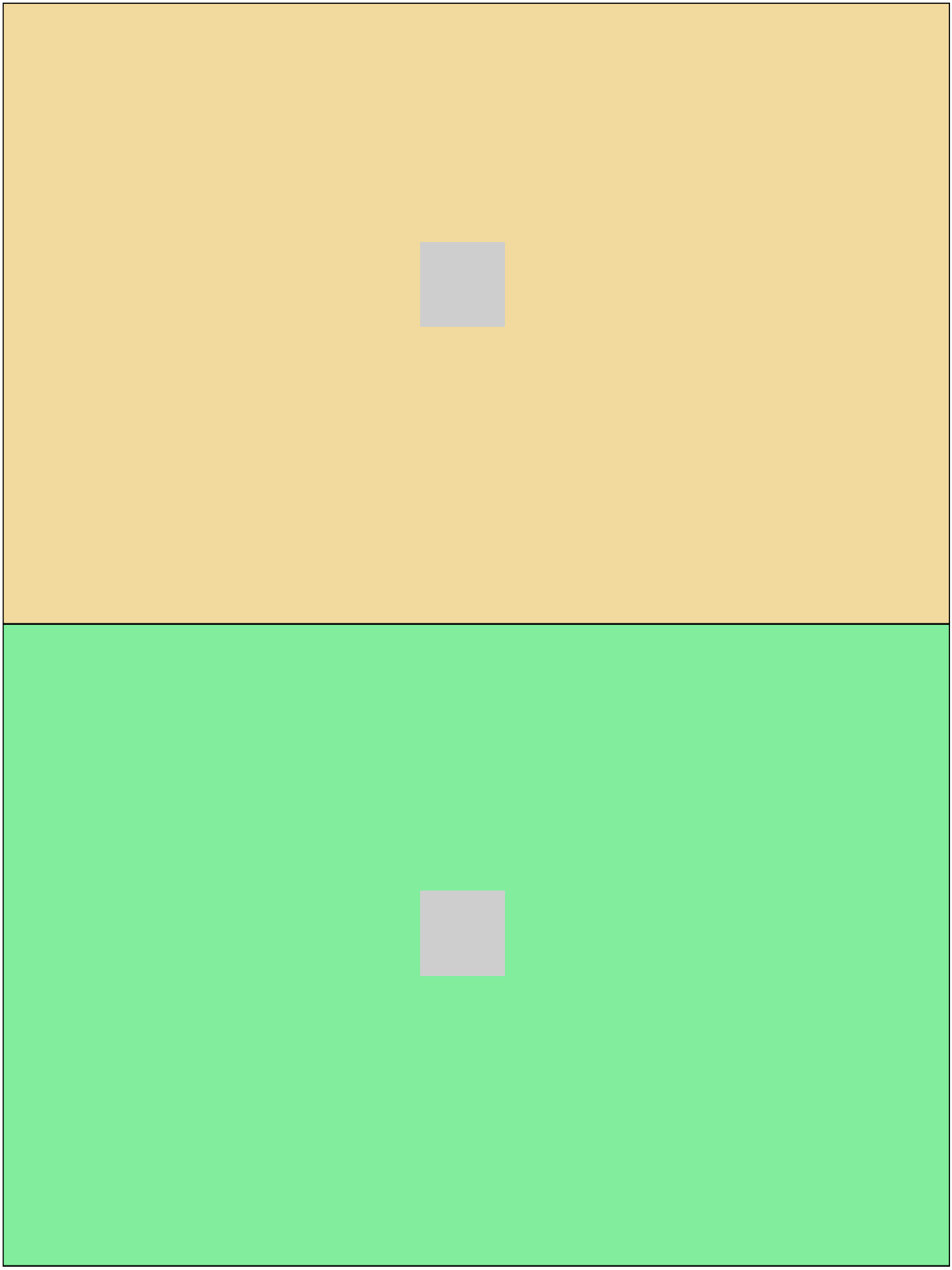
L – Luminance

a – ranges from green to red

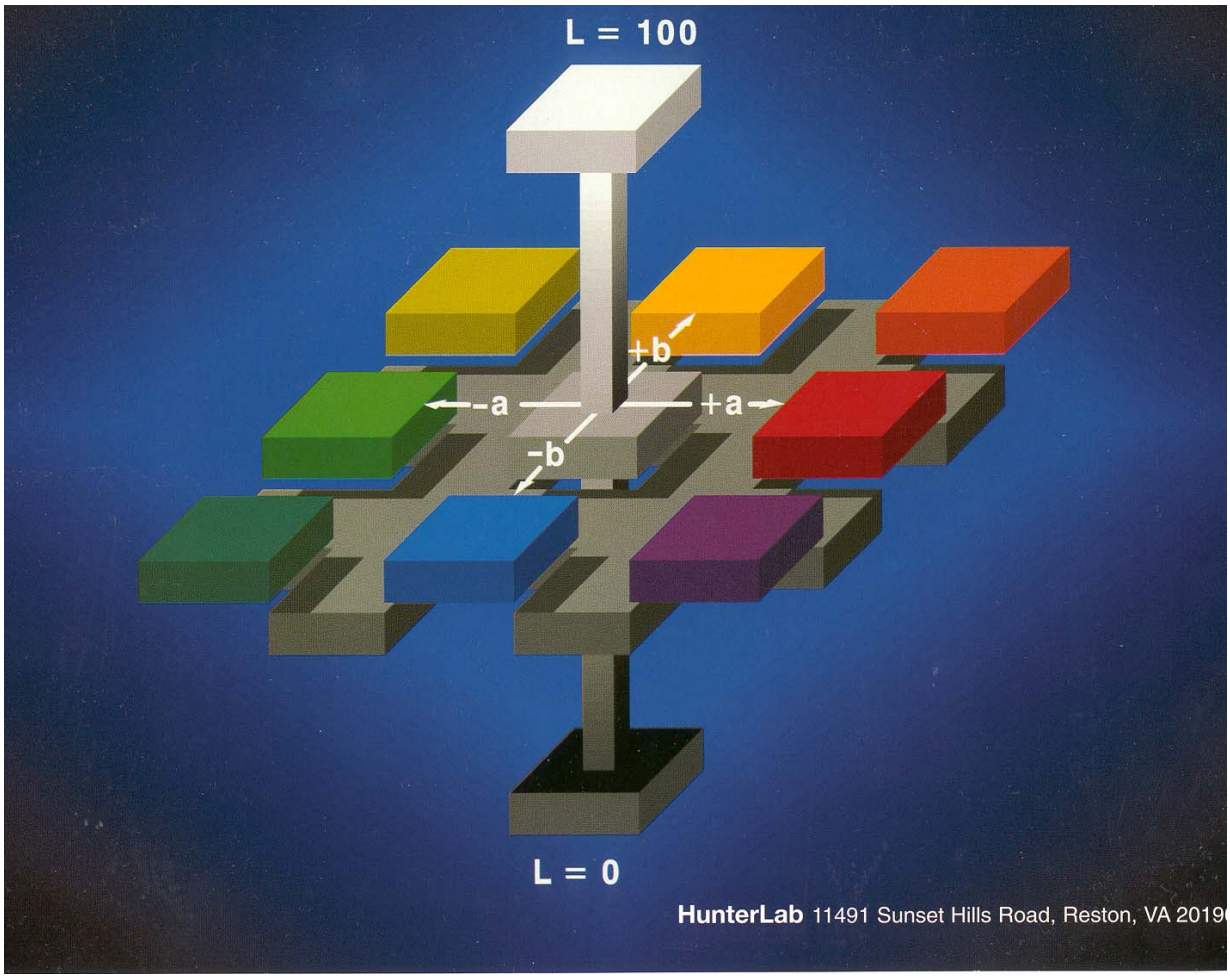
b – ranges from blue to yellow

L – ranges from 0..100 with 50 average gray and 100 reference white.
a,b – unbounded but usually between -120..+120

Colors are relative to a **reference white** point.

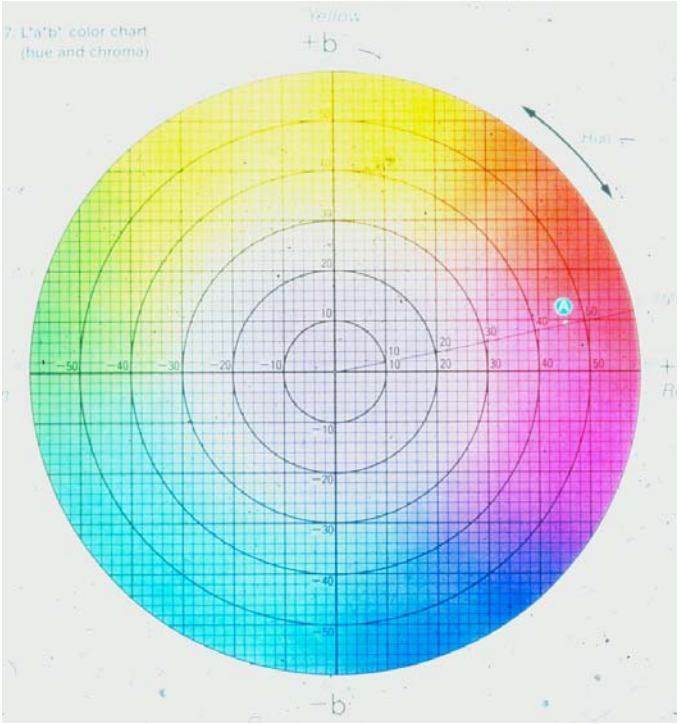


LAB Color Solid

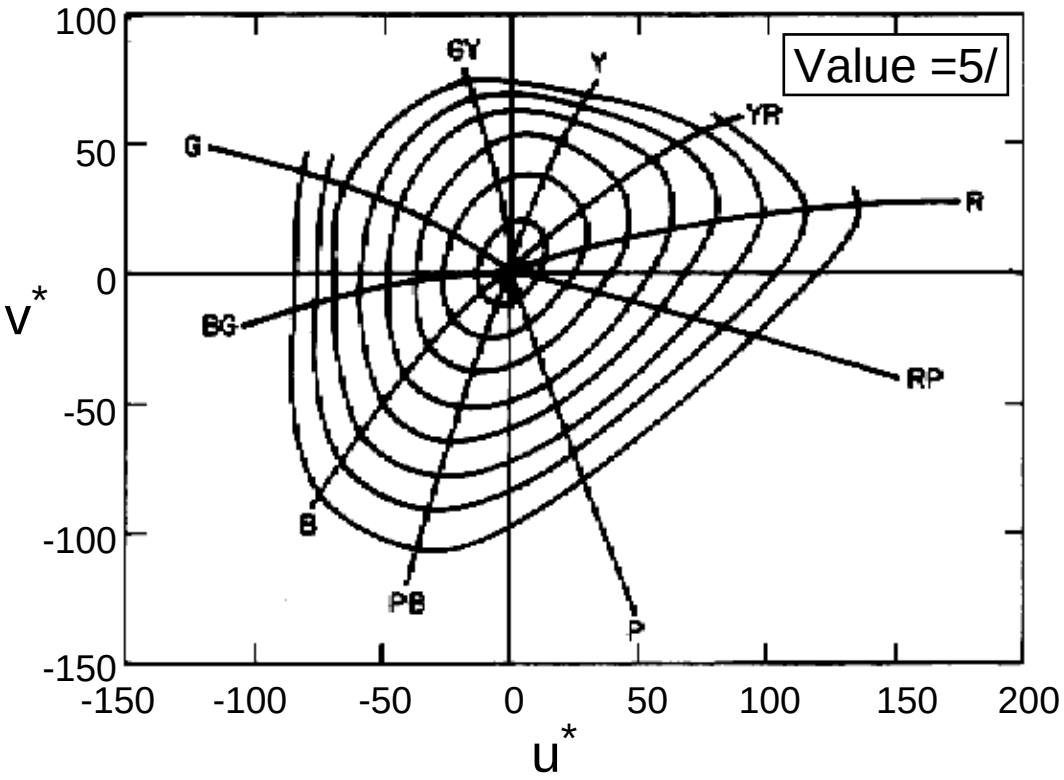


$H_{ab} = \arctan(b^*/a^*)$

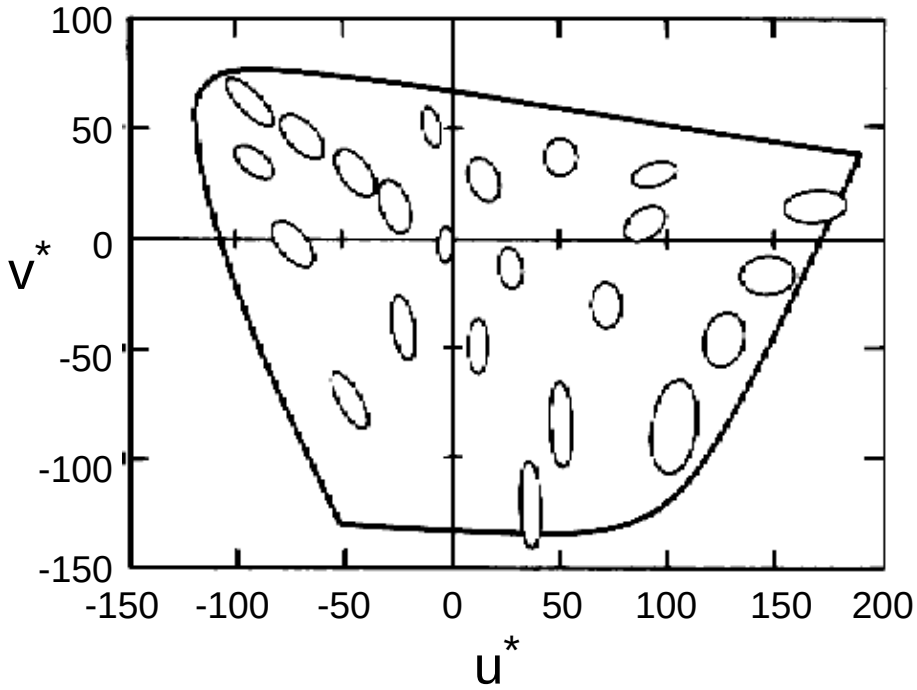
$C_{ab} = ((a^*)^2+(b^*)^2)^{1/2}$



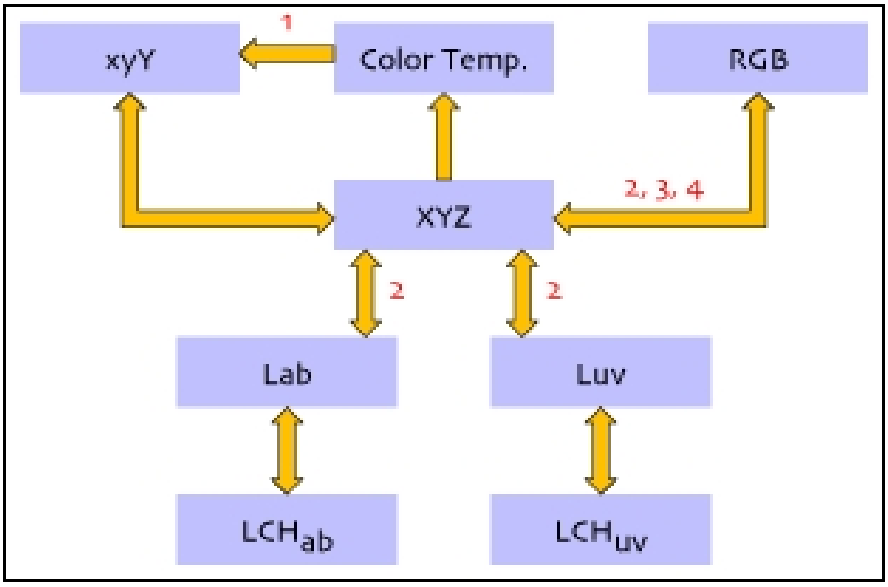
Munsell lines of constant hue and chroma plotted in CIE- $L^*u^*v^*$ Coordinates:



MacAdam Ellipses of JND plotted in CIE- $L^*u^*v^*$ Coordinates:



Color Conversions



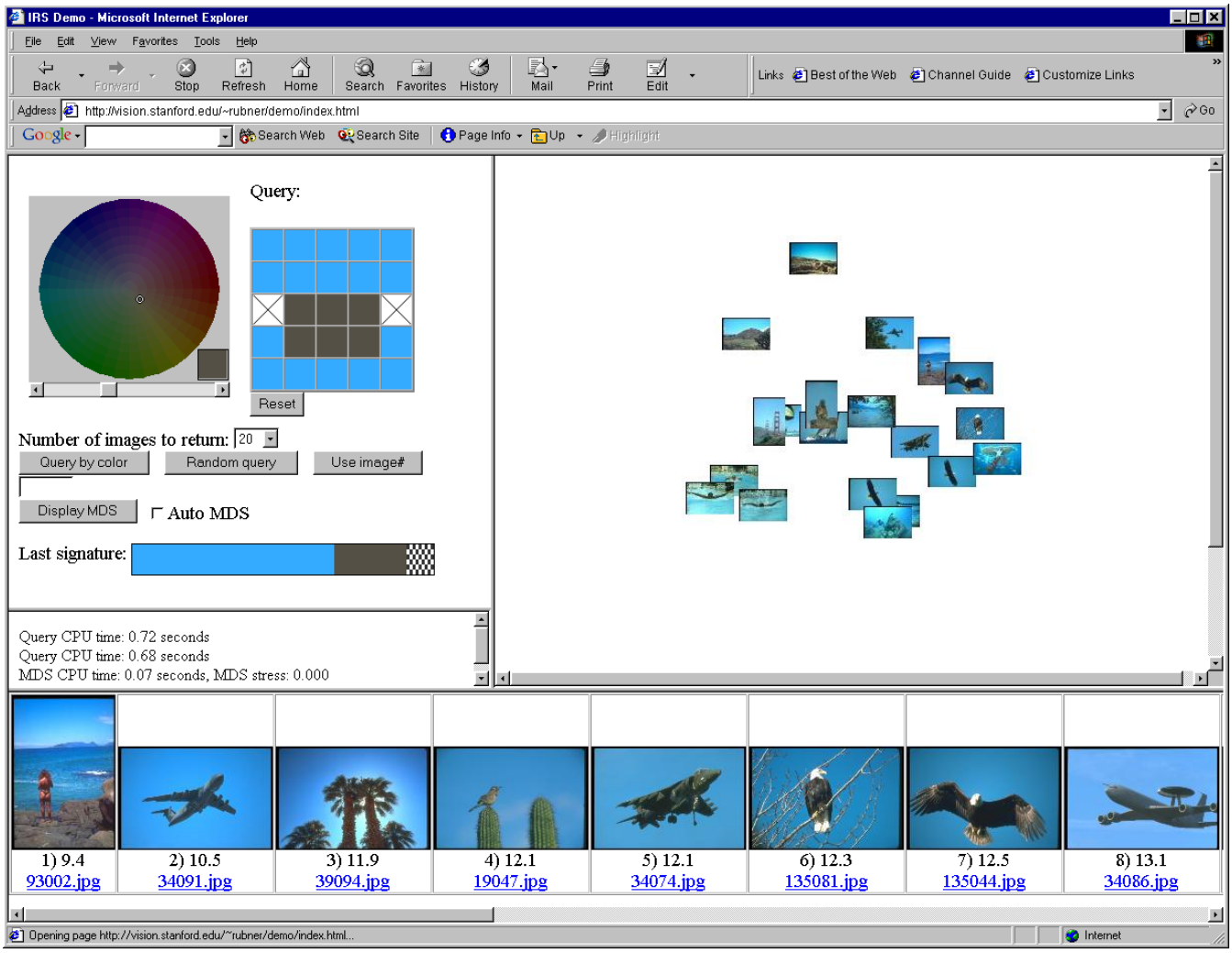
Color Space Conversions

http://www.brucelindbloom.com/index.html?Equations.html

Color Coordinate Calculator:

http://www.brucelindbloom.com/index.html?ColorCalcHelp.html

Color Based Image Retrieval

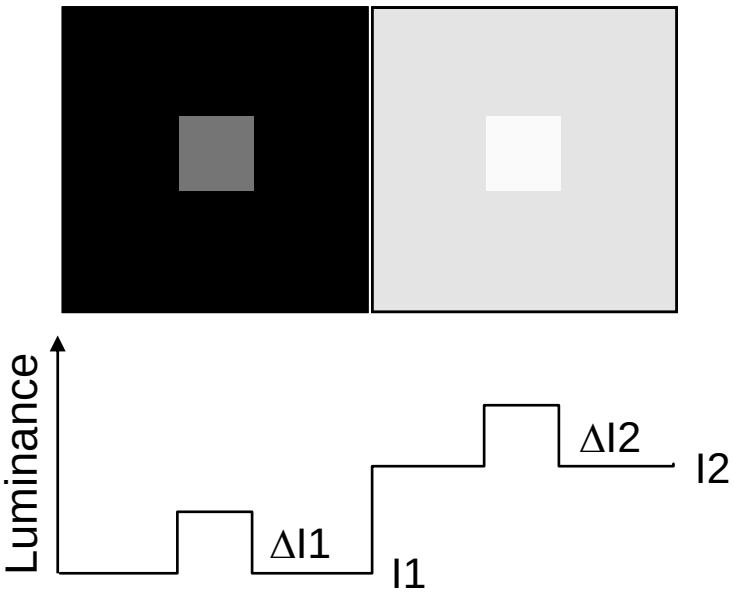


Measuring Color Differences

$$\Delta e^{2} = \Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}$$

$$\Delta e^{2} = \Delta L^{*2} + \Delta u^{*2} + \Delta v^{*2}$$

$\Delta e = 3$ visually indistiguishable
$\Delta e = 5$ acceptable error (most printers)
$\Delta e = 10$ bad
$\Delta e = 15$ unacceptable

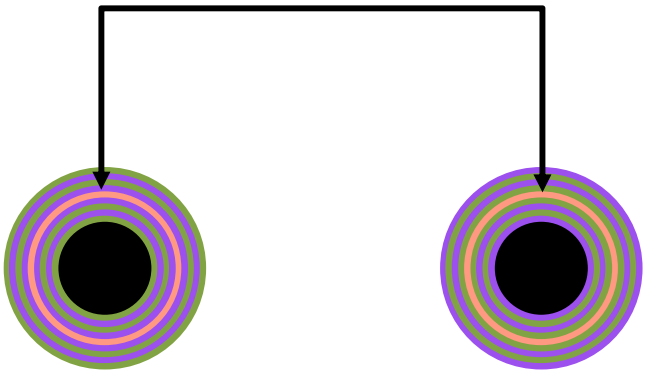


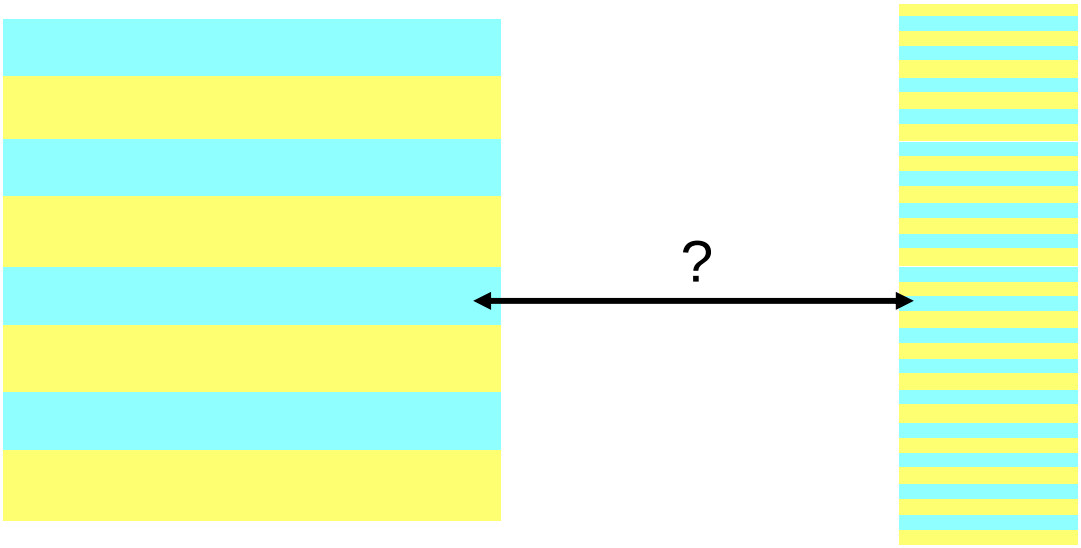
error for $\Delta I1$: $\Delta e = 37.36$
error for $\Delta I2$: $\Delta e = 4.64$

Measuring Color Differences

CIELAB – assumes uniform patches of at least 2deg visual angle on uniform background.

BUT – color appearance depends on spatial patterns.

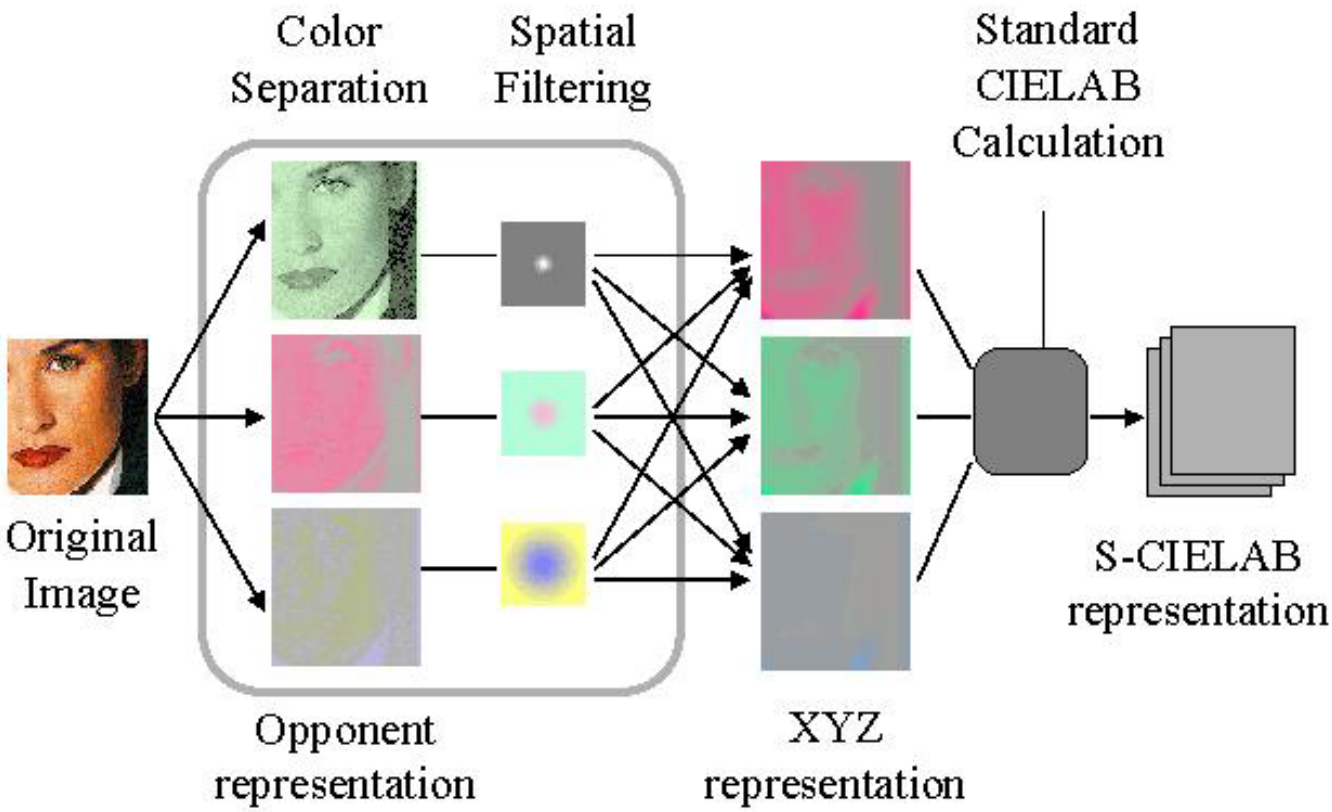




S-CIELAB

S-CIELAB – a spatial extension to CIELAB.

S-CIELAB adds a spatial pre-processing step to the standard CIELAB Delta-E metric to account for the spatial-color sensitivity of the human eye.



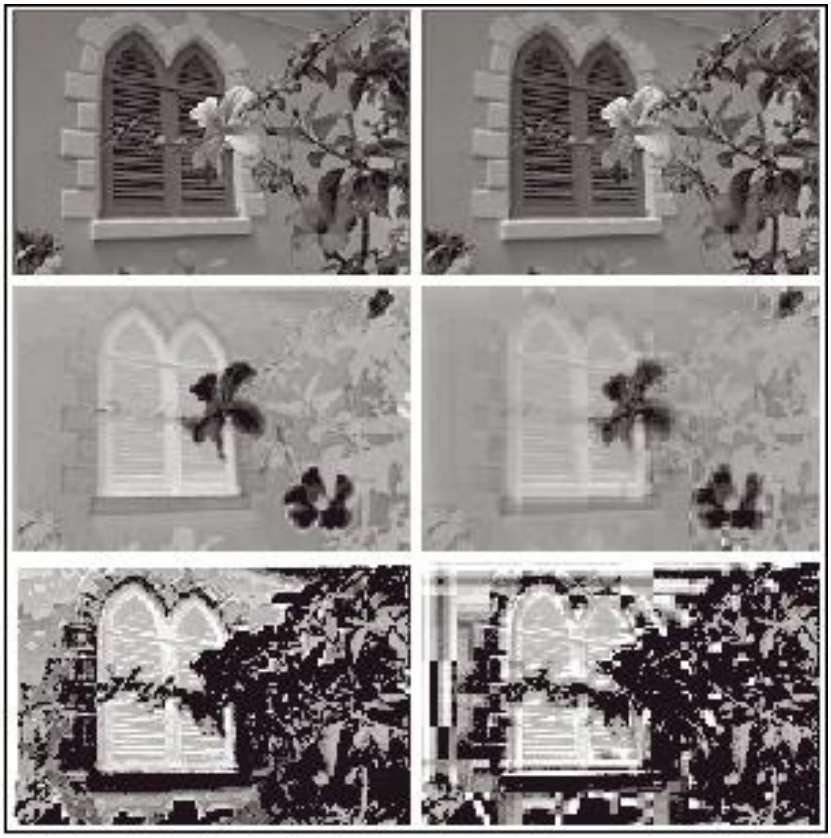
Zhang & Wandell (1997).

S-CIELAB- Example

Original

Jpeg Compressed (factor = 75)

S-CIELAB

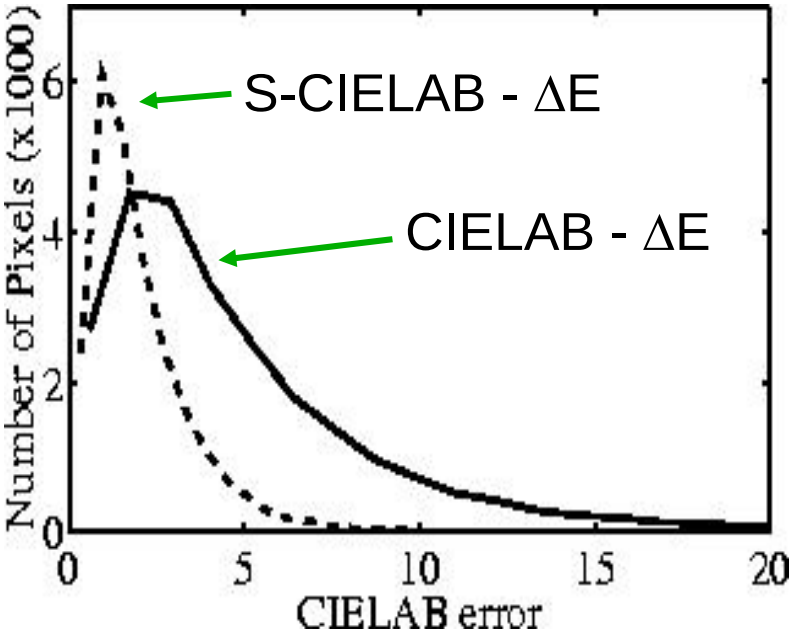


Luminance

Red-Green

Blue-Yellow

Original JPEG(q=75)

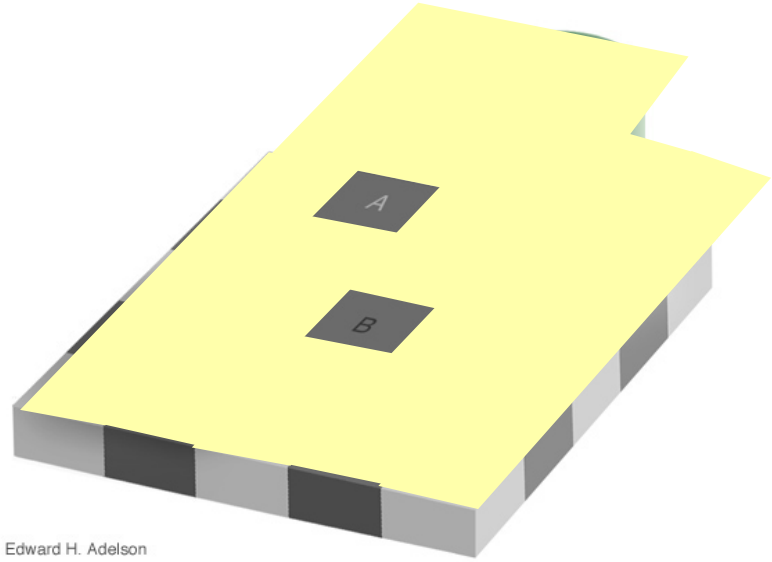


Perceptual Color Spaces

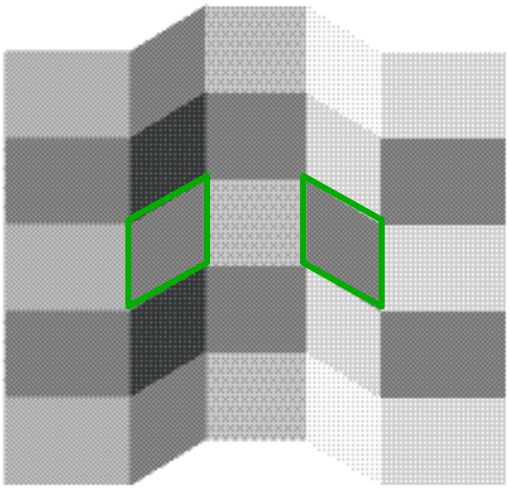
CIELAB – assumes uniform patches of at least 2deg visual angle on uniform background.

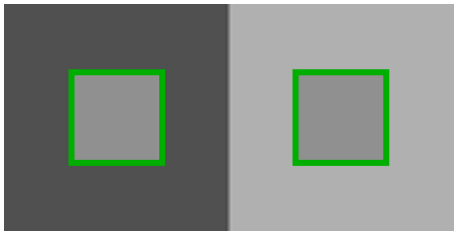
S-CIELAB – takes spatial pattern into account.

BUT – color appearance depends on luminance adaptation, chromatic contrast and chromatic assimilation.

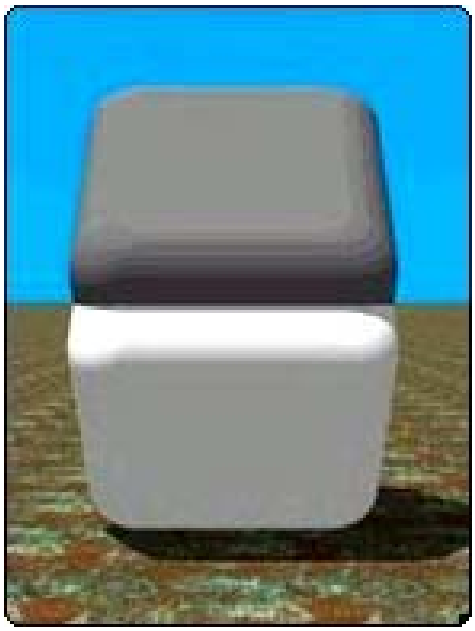


Edward H. Adelson



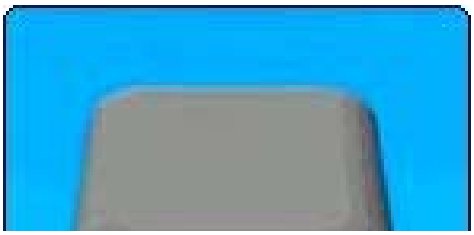


Color Appearance



Adelson

Color Appearance



Adelson

Perceptual Color Spaces

Color appearance also depends on surround contrast – for example different media.

CIECAM02

2002 Perceptual space – new CIE standard.

(R. Hunt, Y. Nayatani, M. Fairchild, N. Moroney)

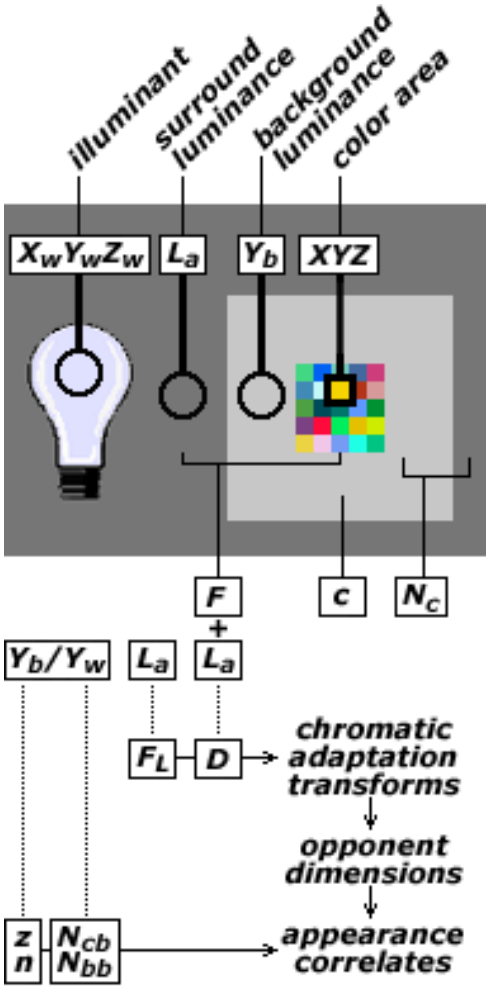
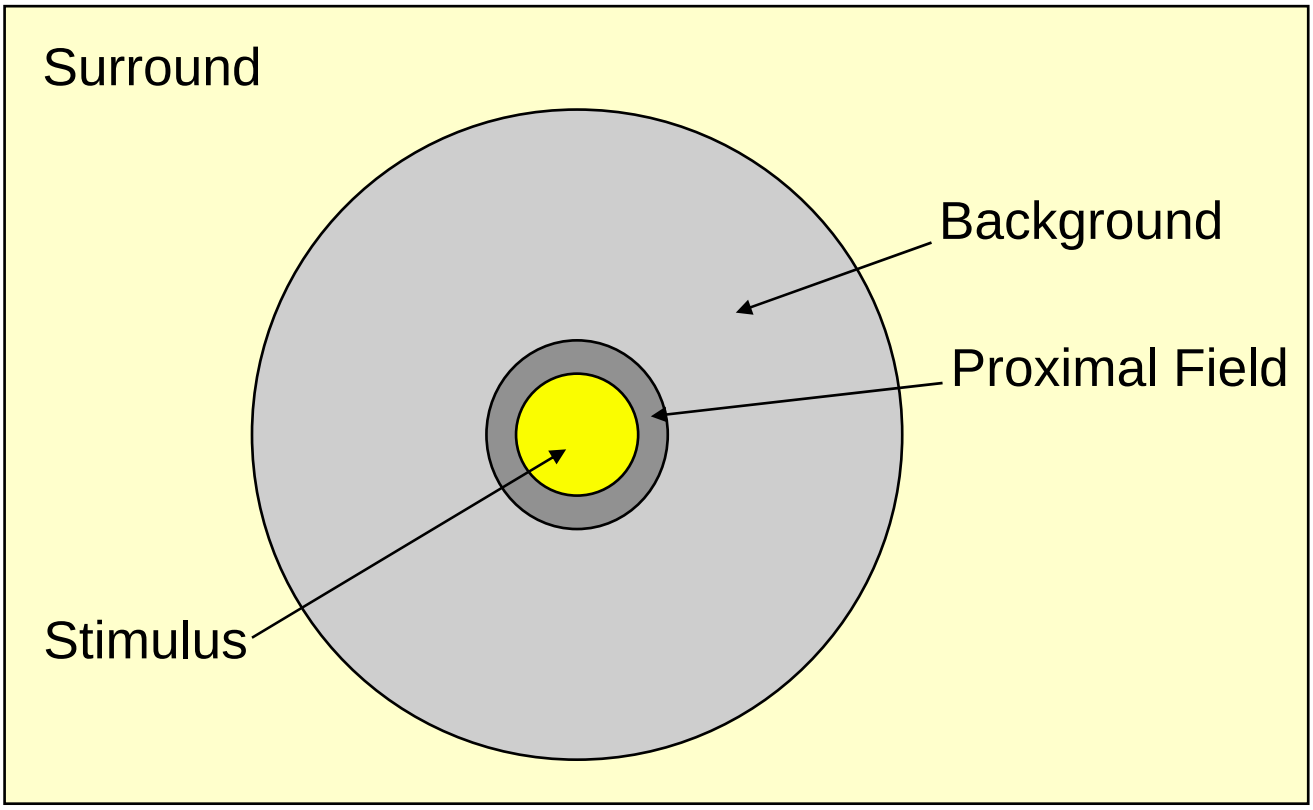


Figure from http://www.handprint.com/HP/WCL/color7.html#CIECAM

CIECAM02



Stimulus - measured in CIE XYZ (2° standard).
proximal field - extends out another 2°.
background - extends out to 10°, in which relative luminance (Yb) is measured. If background color equals the proximal field, it is considered adjacent to the stimulus.
surround - considered to be the entire room.

adapting field = proximal field + background + surround.

Figure from http://en.wikipedia.org/wiki/CIECAM02

Summary Color Spaces

CIE – Standard Color Spaces
CIE 1931 XYZ
CIELUV
CIELAB
CIEUVW

RGB color Spaces
RGB
sRGB
Adobe RGB
Adobe Wide Gamut RGB

Luminance plus chrominance
YIQ, YUV, YDbDr
YPbPr, YCbCr
xvYCC

Hue and saturation
HSV
HSL

Subtractive / Multiplicative color spaces
CMYK

Commercial color spaces
Munsell color system
Natural Color System (NCS)
Pantone Matching System (PMS)

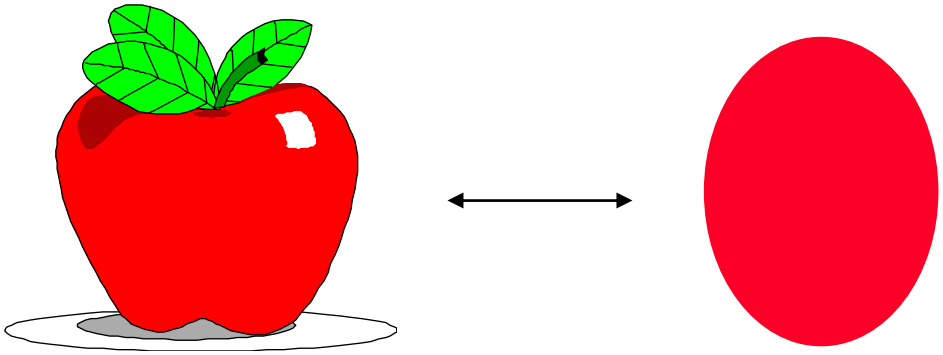
Color Perception - Caveats

Color Memory

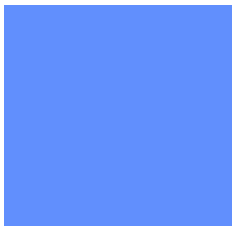
- migration towards extreme:
  bright colors are remembered as brighter
  dark colors are remembered as darker

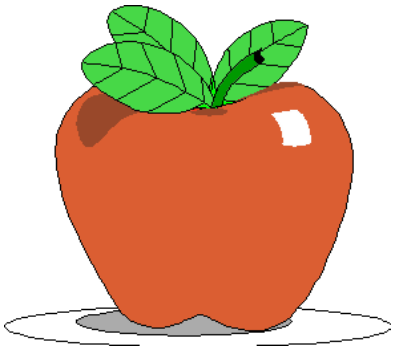
- migration towards standard:
  off-colors are remembered more saturated

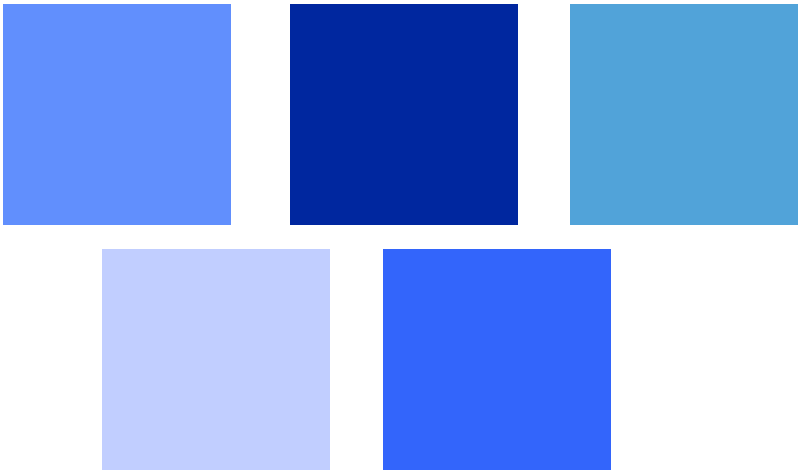
- migration towards characteristic hues:
  apples are remembered more “red”
  bananas more “yellow” than they are
  grass more “green” than it is.

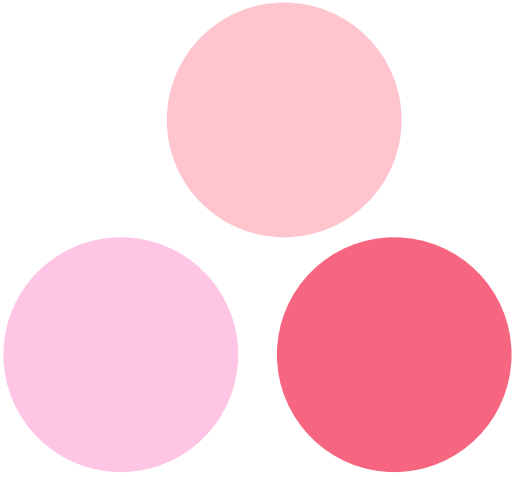


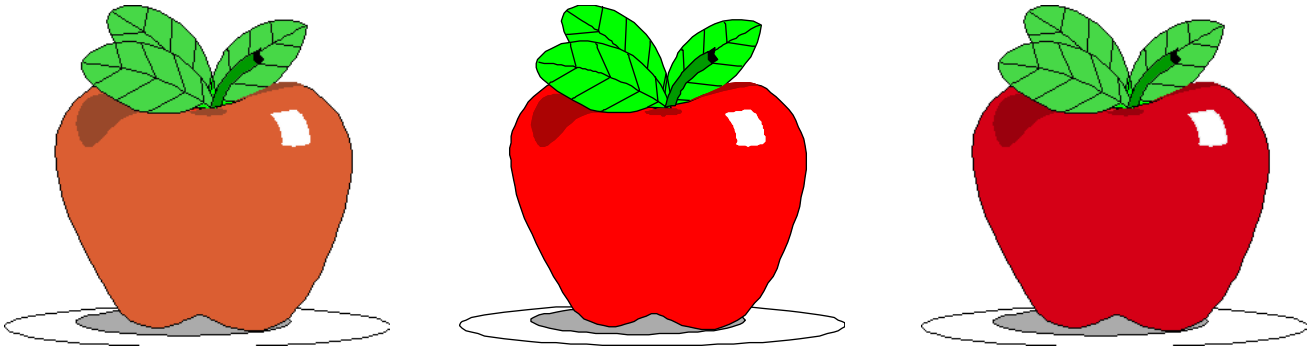
Color Memory - Experiment

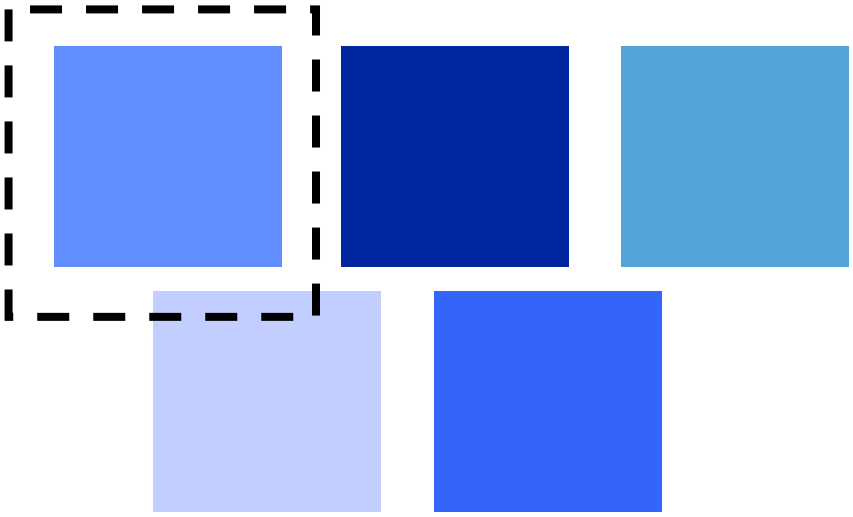


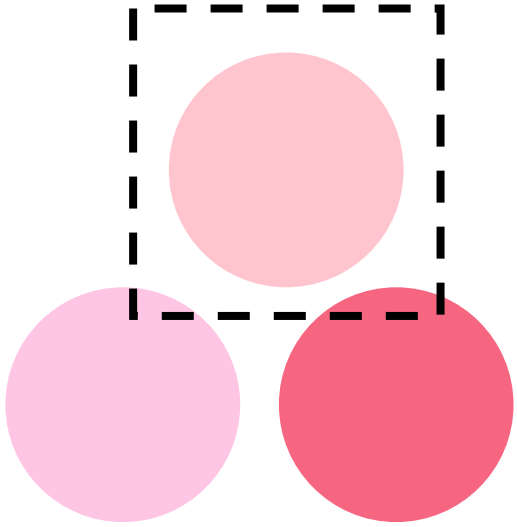


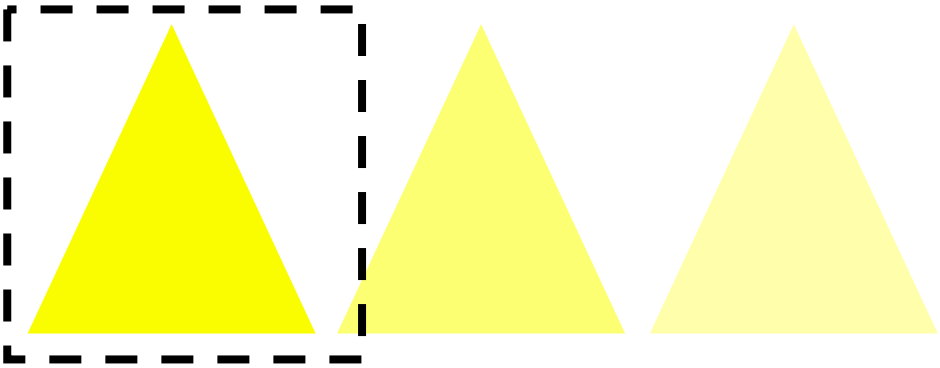


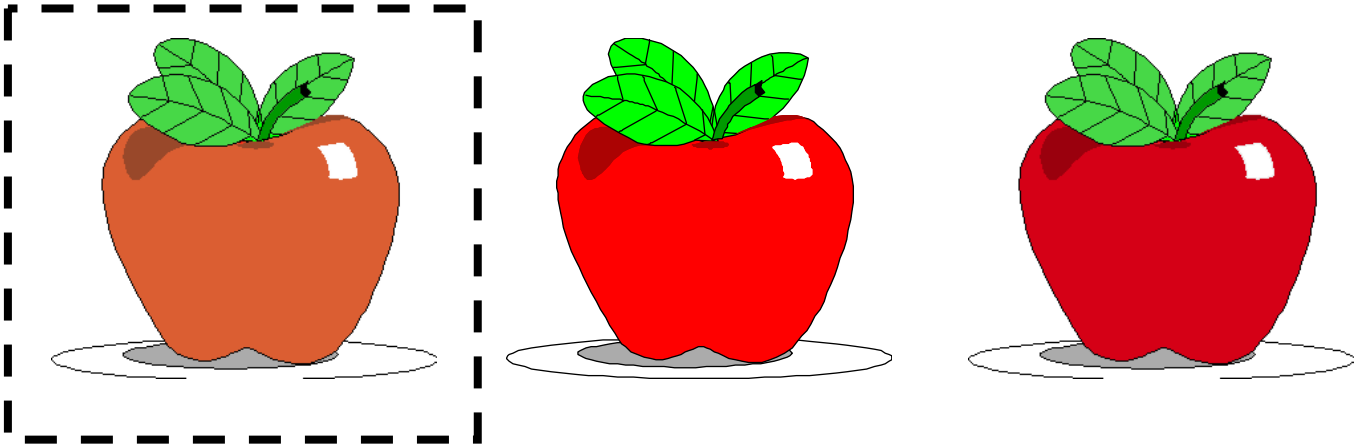




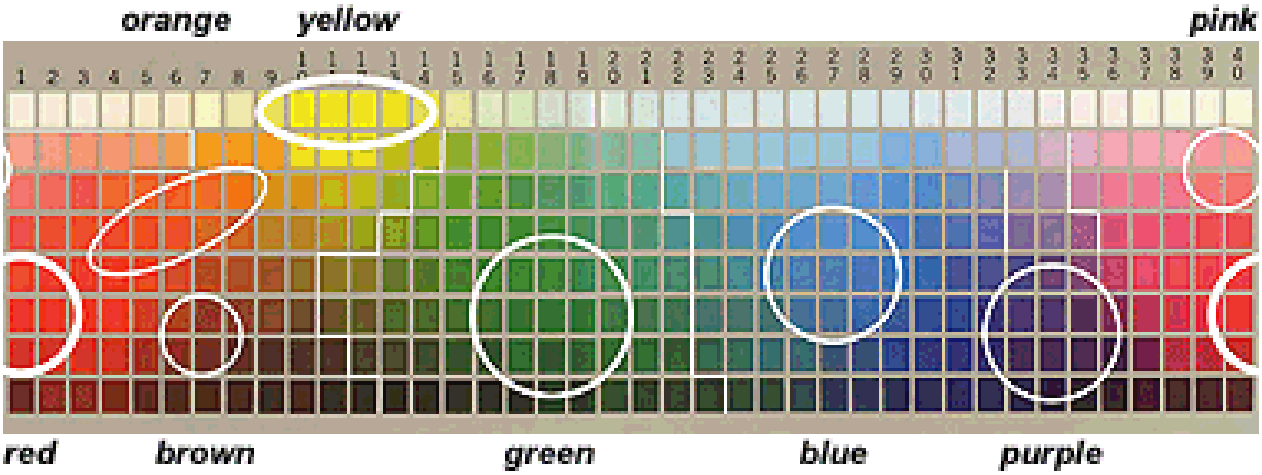








Color Focals



Across cultures:
Boundary between one color term and another is in poor agreement (same orange -> red in one culture
but -> yellow (or "tan", or "warm", or "light") in another.

However, **focal color** or best exemplar for a color, is quite consistent.

Color Naming

- Color Names:
  western world - 11 basic color names
  some primitive cultures: light, dark
  others: light, dark, red
  Lakuti tribe: same name for blue and green.

  But: limitation of color names does not affect ability to match, discriminate or reproduce color (Berlin & Kay ‘69, Bornstein ‘73,’75)

- Color & feeling:
  yellow, red - “warm” colors
  blue, brown, black - “cool” colors

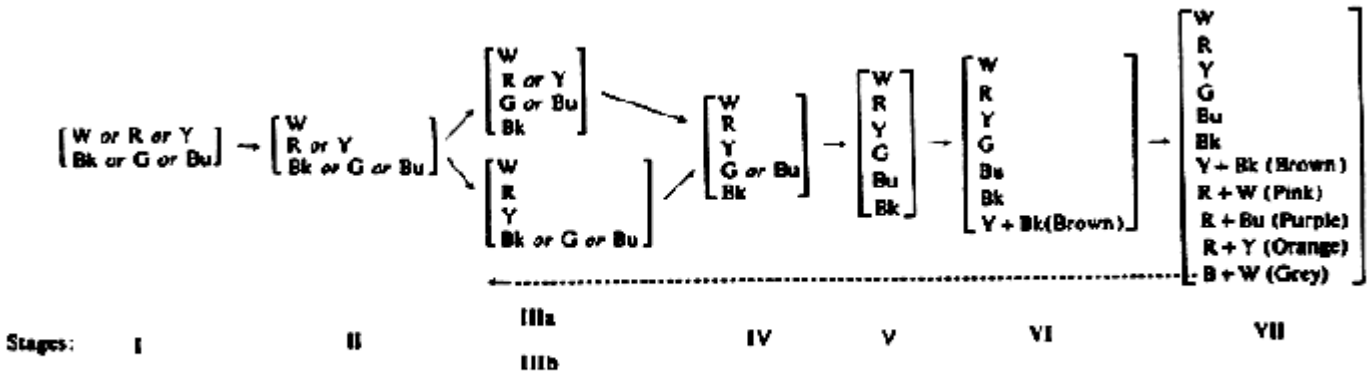
Evolutionary Trajectories of Color Names

<table>
<tr><th>I</th><th>II</th><th>III</th><th>IV</th><th>V</th></tr>
<tr><td rowspan="3">light–warm
(white/yellow/red)

dark–cool
(black/blue/green)</td><td rowspan="3">white

red/yellow

black/blue/green</td><td>white
red
yellow
black/blue/green</td><td>white
red
yellow
green
black/blue</td><td rowspan="3">white
red
yellow
green
blue
black</td></tr>
<tr><td>white
red/yellow
blue/green
black</td><td>white
red
yellow
blue/green
black</td></tr>
<tr><td>white
red
yellow/green/blue
black</td><td>white
red
yellow/green
blue
black</td></tr>
</table>

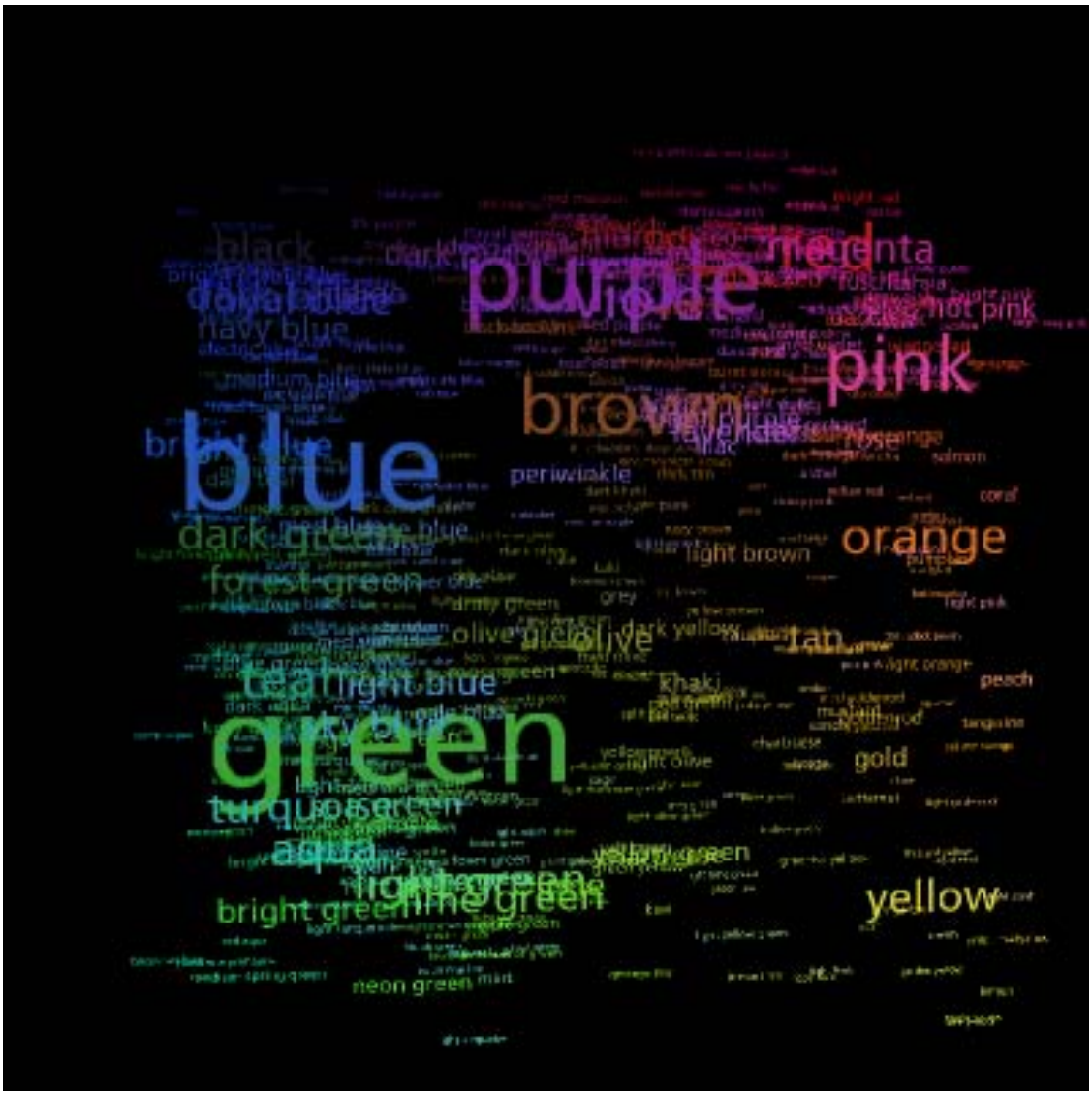


Berlin & Kay

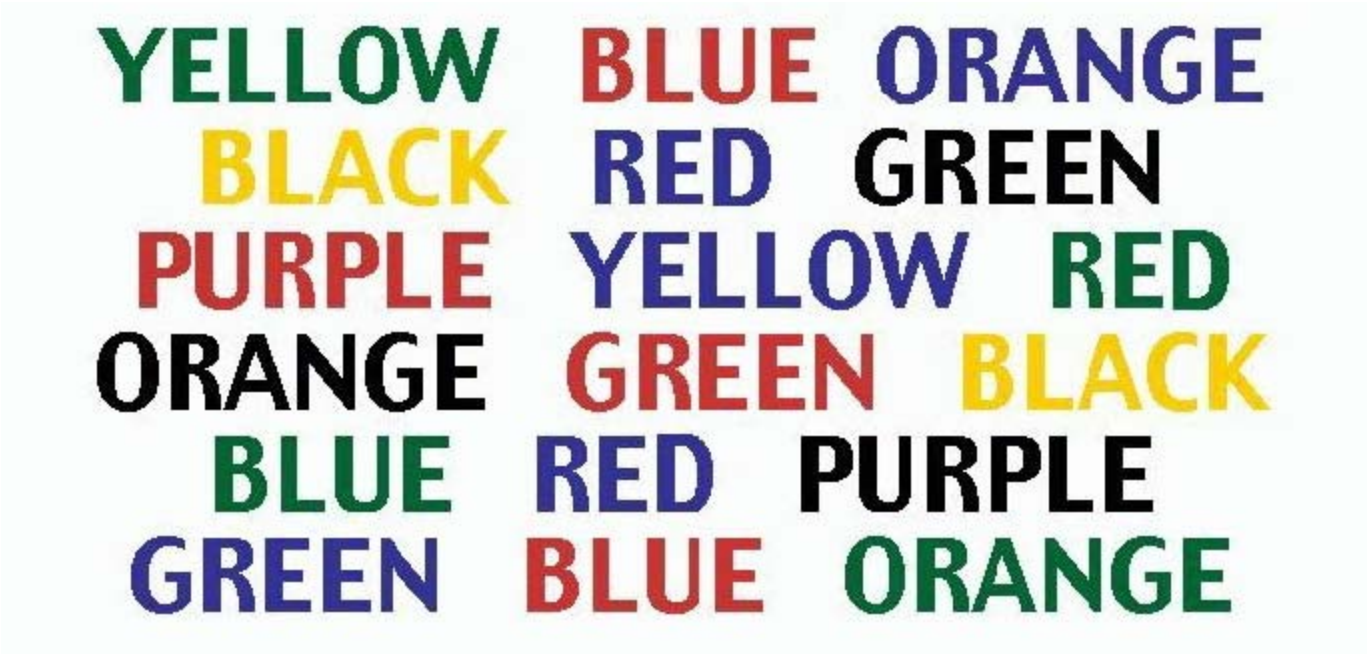
Frequency of Color Names in English Text

black 0.024%
white 0.023%
red 0.015%
dark 0.012%
blue 0.0106%
green 0.0105%
light 0.0099%
bright 0.0072%
gray 0.0056%
brown 0.0050%
yellow 0.0048%
pale 0.0041%
pink 0.0034%
dull 0.0021%
orange 0.0017%
silver 0.0014%
purple 0.0013%
gold 0.0013%

Wattenberg's Version of the Color Name Cloud



Look at the chart and say the **COLOR** not the word.



Left - Right Conflict

Your right brain tries to say the color but
Your left brain insists on reading the word.

Color & Culture

- Color symbolism:
  white - wedding in western world
  mourning & death in Chinese culture
  red - youth, party, bold in western world
  wedding in Chinese culture
  Saturated colors – preferred in Japan

Color & Health

- Color & mood:
  yellow, red - “warm” colors
  blue, brown, black - “cool” colors

- Color Therapy:
  Nausea – Treat with Blue
  Nervous Disorders - Treat with green.
  Kidney stones – Treat with Orange

  http://www.holisticonline.com/Color/
  color_diseases_and_treatment_N.htm
  http://geocities.com/iiii_velvet_underground_iiii/
  COLOURTHERAPY.html

- Autistic children –
  found that blue-green scarves– relaxes/quiets
  red-black-yellow irritating!

Eating in blue makes you eat less as it relaxes and slows you down.

Eating in orange makes you eat faster and more .

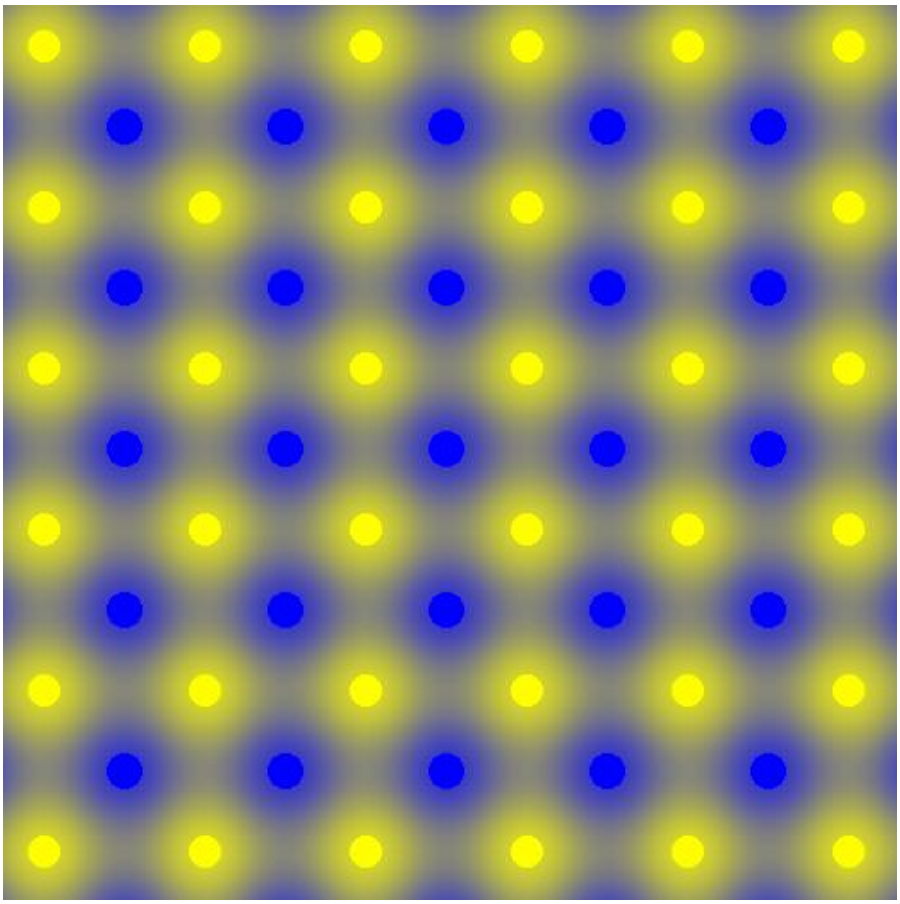
The color coral (orange-pink) had been shown to reduce stress and violence.

Global Color Survey

Since 1997, over 30,000 people from all over the globe took the survey. Results:

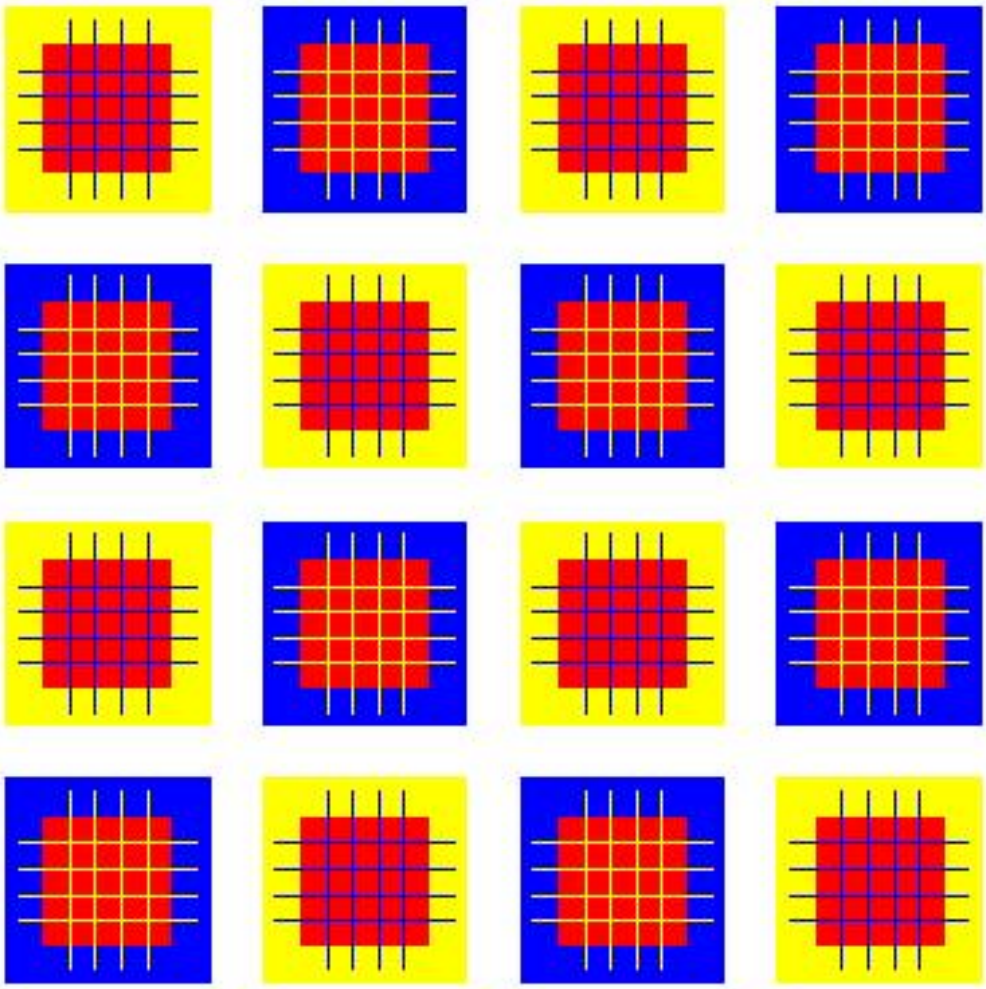
Happy - Yellow
Pure - White
Good Luck - Green
Good-tasting - Red (tomato)
Dignity - Purple
High Technology - Silver
Sexiness - Red (tomato)
Mourning - Black
Expensive - Gold
Inexpensive - Brown
Powerful - Red (tomato)
Dependable - Blue
High Quality - Black
Nausea - Green
Deity - White
Bad Luck - Black
Favorite Color - Blue
Least Favorite Color - Orange

For more information click here.
http://www.colorcom.com/research.html



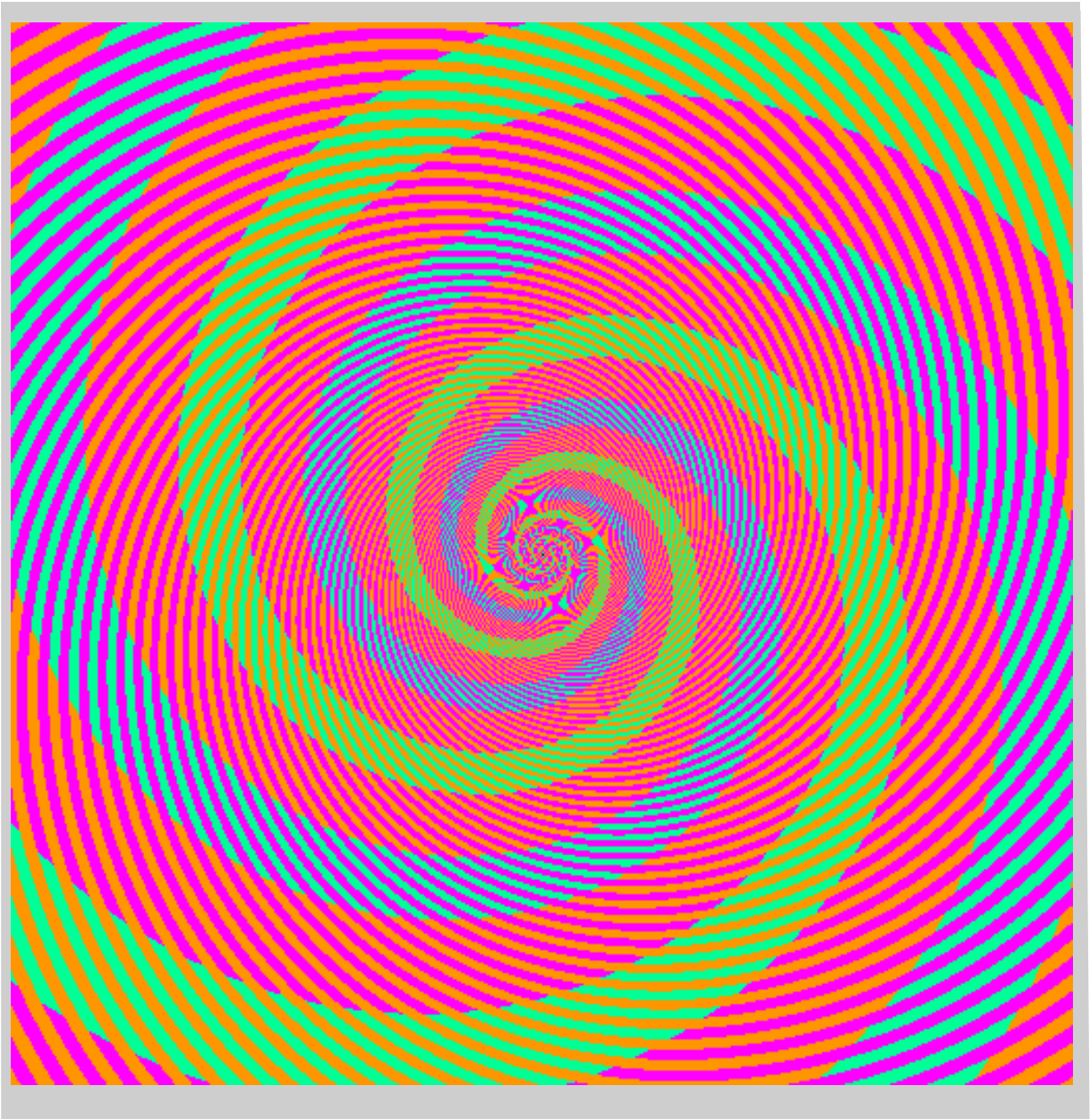
"Enhancement of blue"

Blue circles appear to be enhanced in saturation when seen in the central vision.



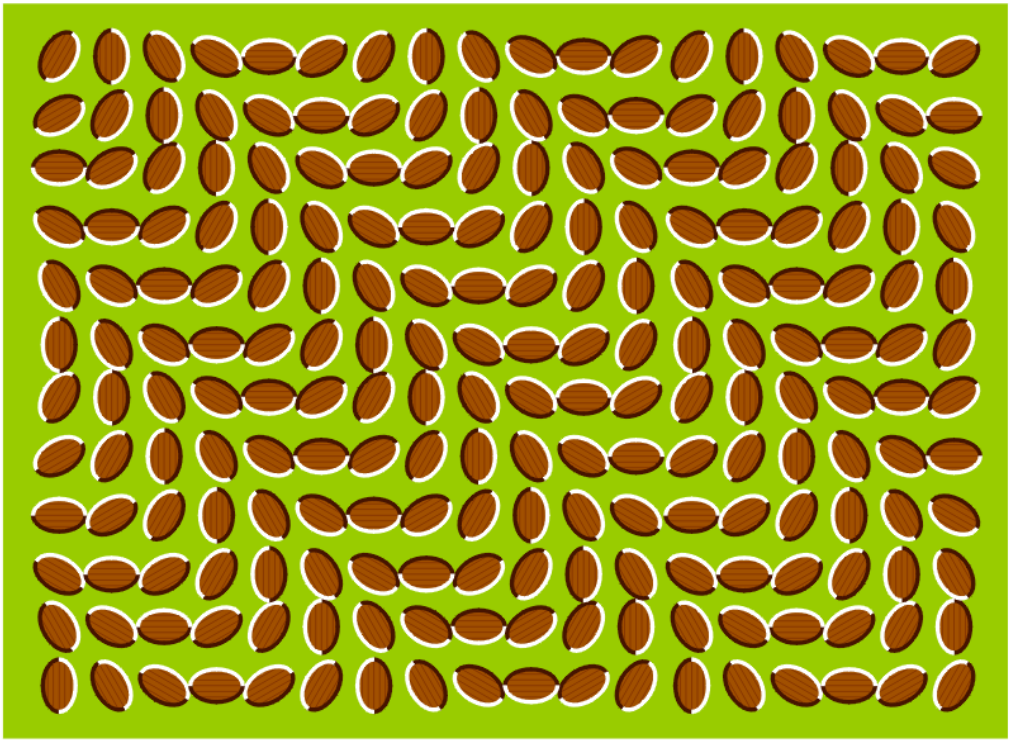
"Flowers"

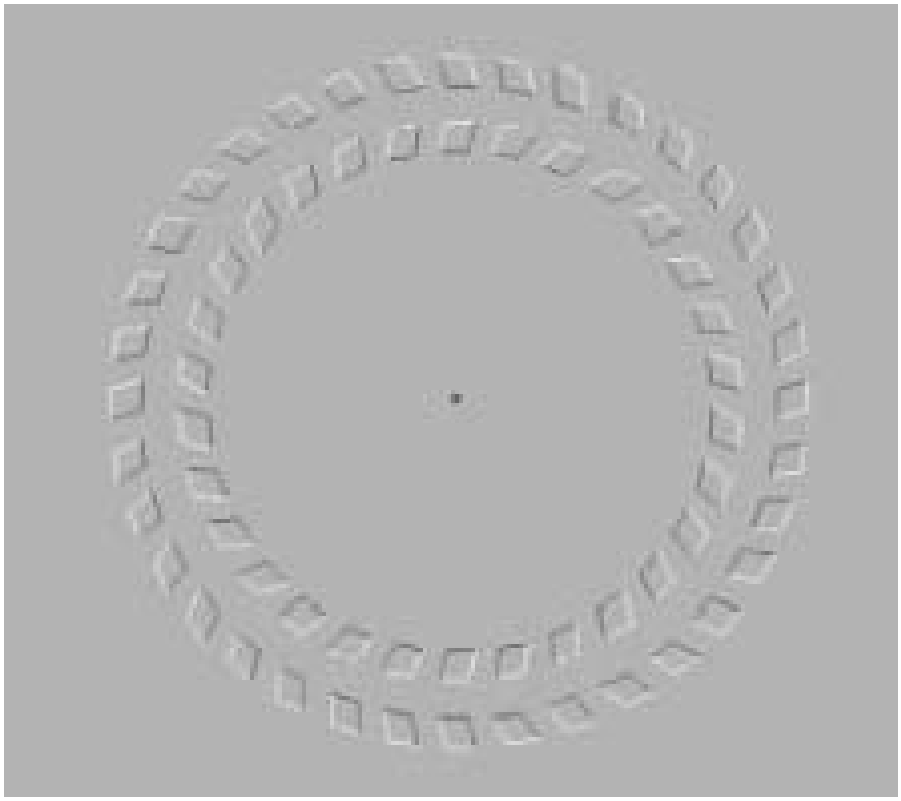
Red appears to be magenta or orange.
This is kind of von Bezold's chromatic assimilation.



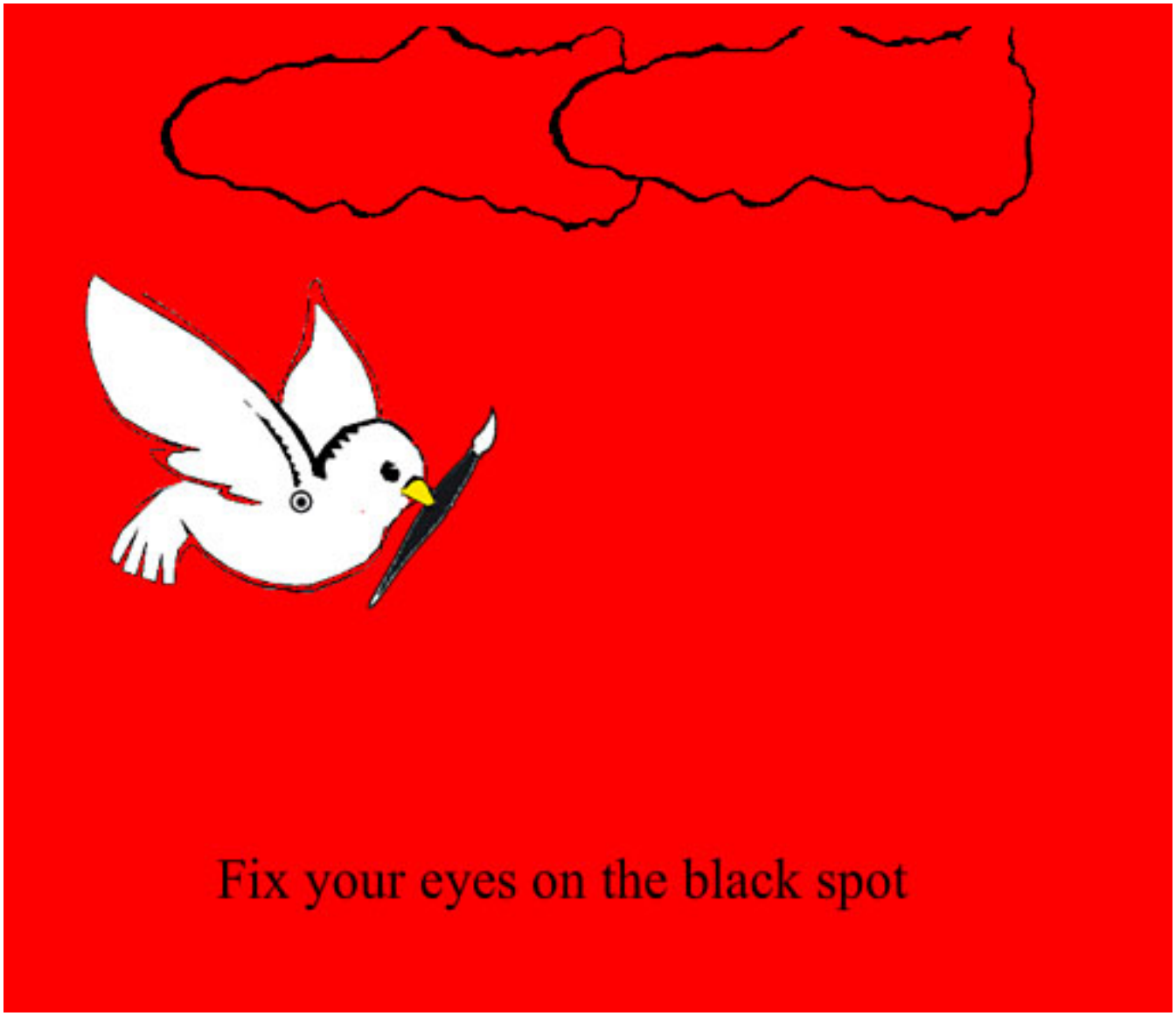
"Green and blue spirals“

There appear to be spirals of light green or light blue.
Actually, they are identical (r = 0, g = 255, b = 150).
Basic illusion proposed by Monnier and Shevell (2003).





AfterImage Fill In



Yuval Barkan + Hedva Spitzer 2009

white slide for after Image