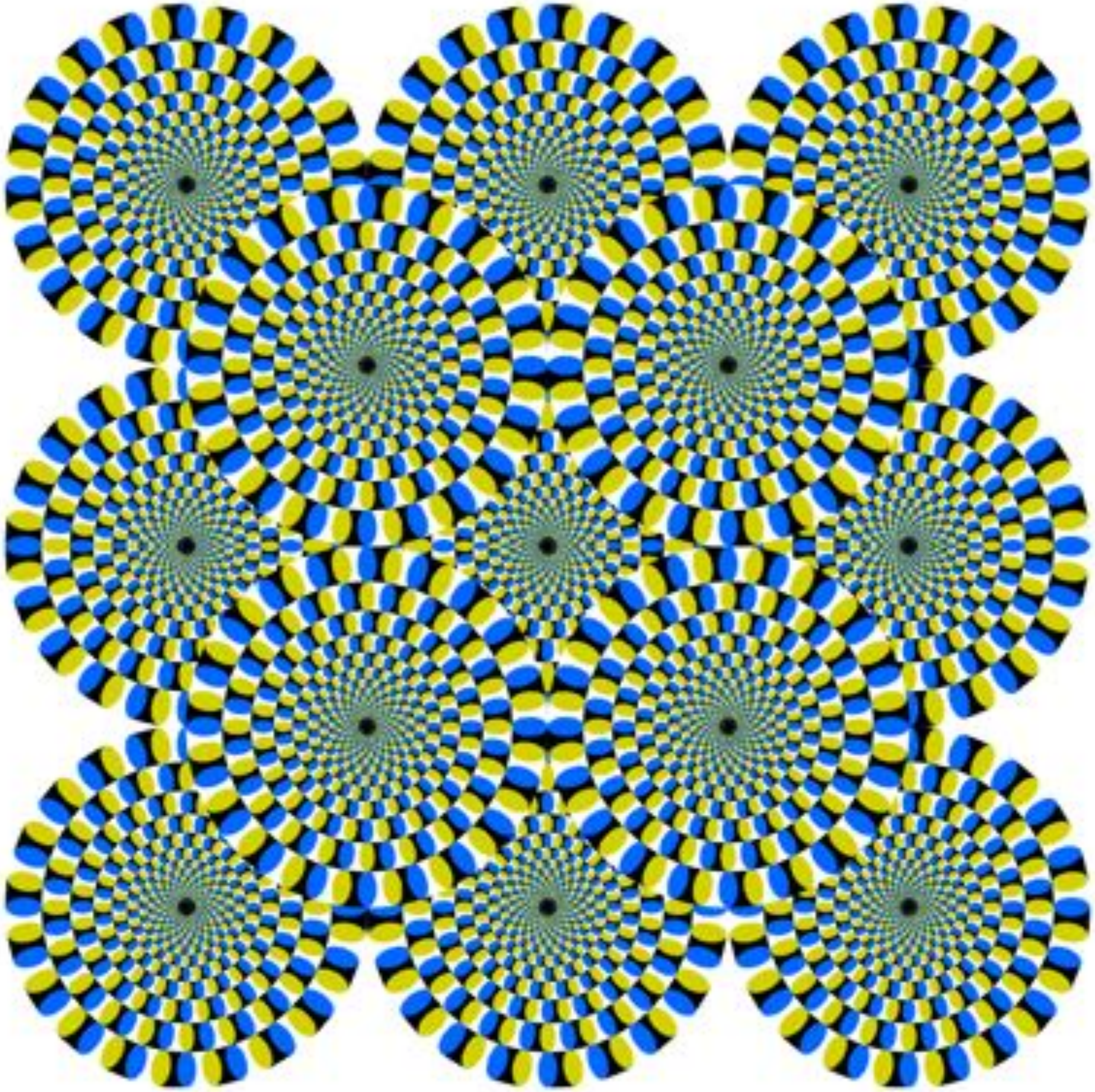
DSCI 554 LECTURE 7

COLORS, COLORS IN D3, COMPLEX D3 CHARTS

Dr. Luciano Nocera



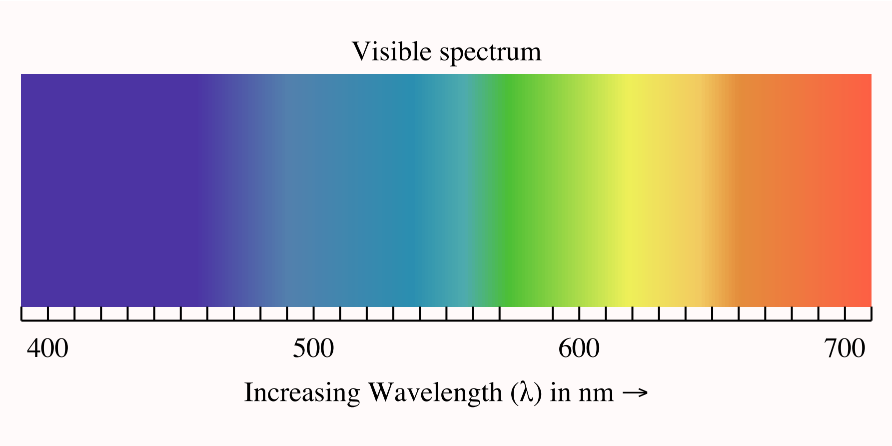
B.Backus, I Oruç, Illusory motion from change over time in the response to contrast and luminance, Journal of Vision December 2005.

OUTLINE

- Color perception
- Color theory
- Color design
- Colors in D3
- Complex D3 charts

WHAT DO WE MEAN BY COLOR

Color is the perception of a kind of light



COLOR PROPERTIES DISTINGUISHABLE BY THE EYE

Hue	Degree to which a stimulus can be described as similar to or different from stimuli that are described as red, orange, yellow, green, blue, and purple.
Saturation	Also called colorfulness, chroma, intensity, purity. It is the perceived intensity (chromatic strength) of a hue.
Brightness	Attribute of a visual sensation according to which an area appears to emit more or less light.

COLOR VISION

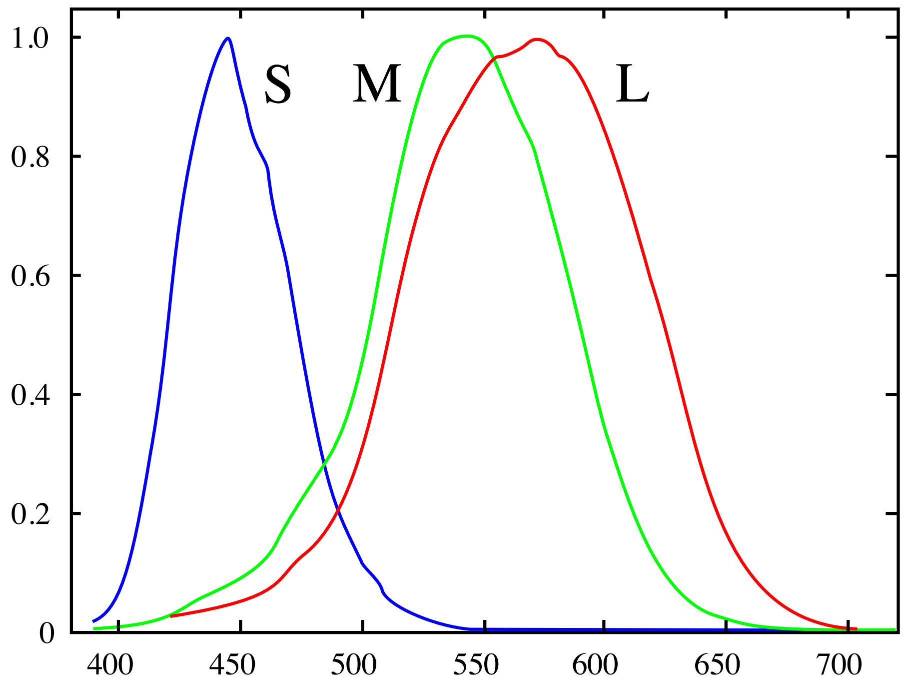
Color vision is the ability to discriminate light composed of different wavelengths

TWO COLOR VISION THEORIES:

- Trichromatic theory (Young-Helmholtz) [Young 1802]
- Opponent process theory [Hering 1878]

TRICHROMATIC VISION

- Humans are routinely trichromatic*
- Trichromacy through 3 color photoreceptors (cone cells)
- We distinguish ~10 million different colors

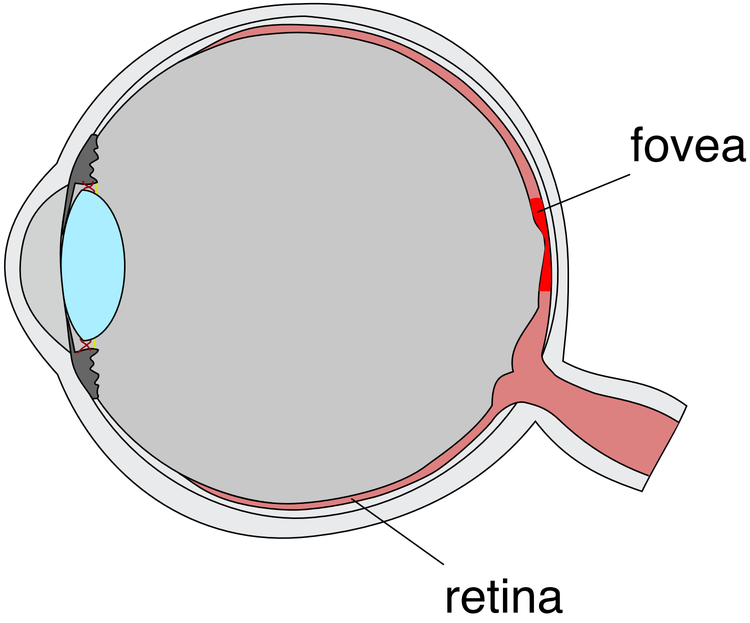


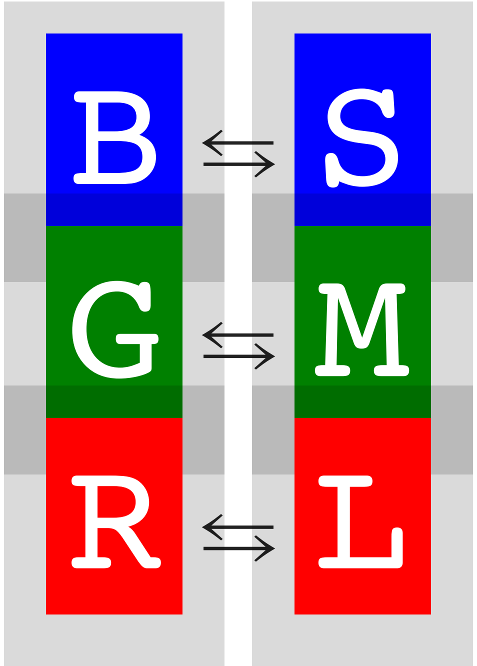
Normalized cones response

* believed to be a folivory and frugivory adaptation

TRICHROMATIC THEORY

Eye has 3 kinds of color receptors roughly corresponding to blue, green and red





Cones cells predominantly situated in the fovea support color vision

PROBLEMS WITH THE TRICHROMATIC THEORY

Some colors are not seen		○ No reddish-green named color ○ No yellowish-blue named color
Photoreceptor distribution does not relate to perceived colors		○ S, M and L overlap ○ S fraction of M + L ○ M, L similar response ○ $\frac{M}{L}$ varies greatly* * $\frac{M}{L}$ in two male subjects $\frac{20.0\%}{75.8\%}$ vs. $\frac{44.2\%}{50.6\%}$ [Roorda 1999]
Afterimages cannot be explained		○ Dominant waveband in the light reflected from the central area is also the dominant waveband in the light coming from the surround, up to 10° in all directions ○ Afterimages are opponent to perceived colors rather than wavelengths

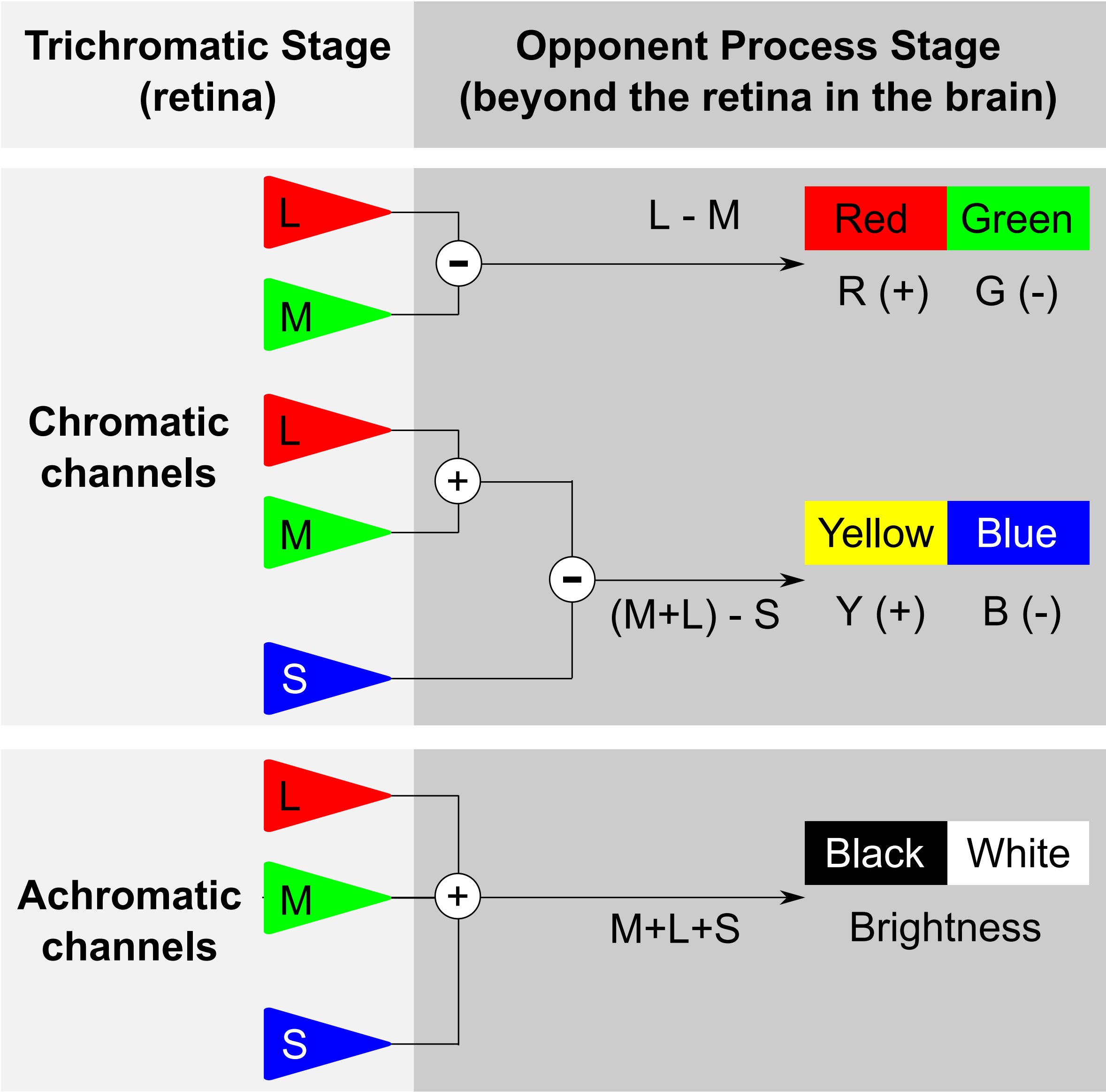
OPPONENT PROCESS THEORY

The visual system responds to opponent channels

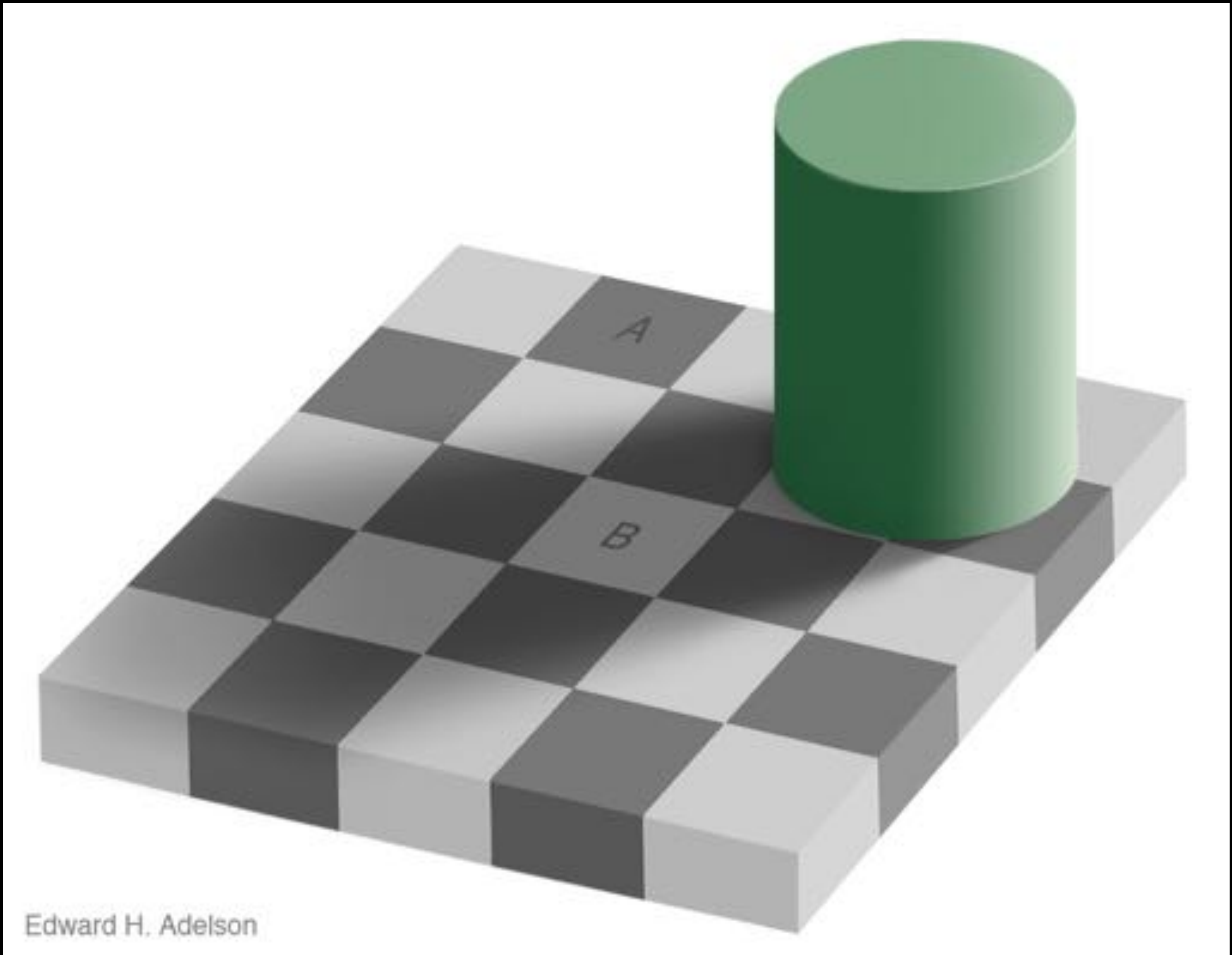
The visual system records differences between the responses of cones, rather than each type of cone's individual response

Chromatic channel	red	vs.	green
Chromatic channel	blue	vs.	yellow
Achromatic channel	black	vs.	white

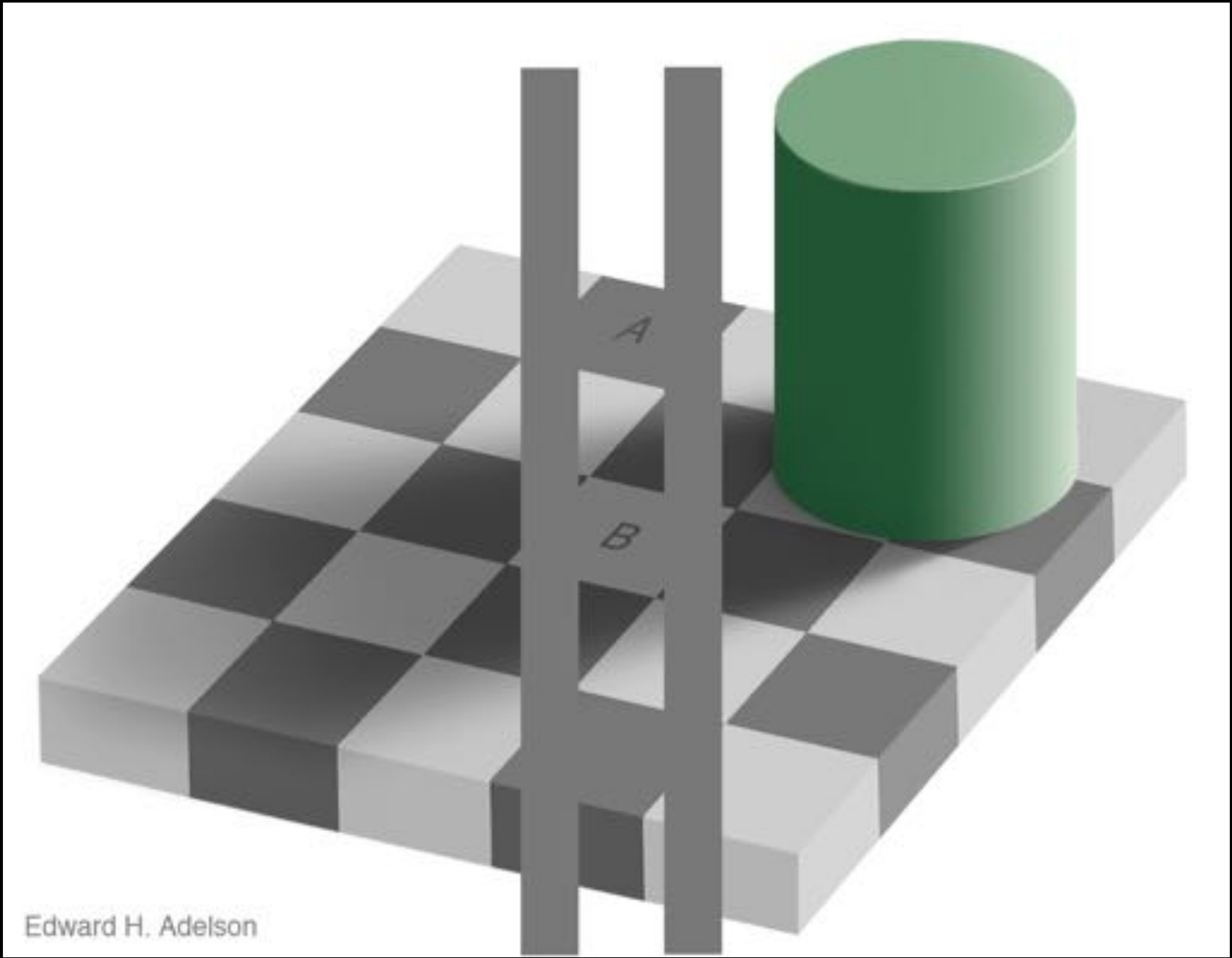
TRICHROMATIC AND OPPONENT PROCESS STAGES



COLOR PERCEPTION

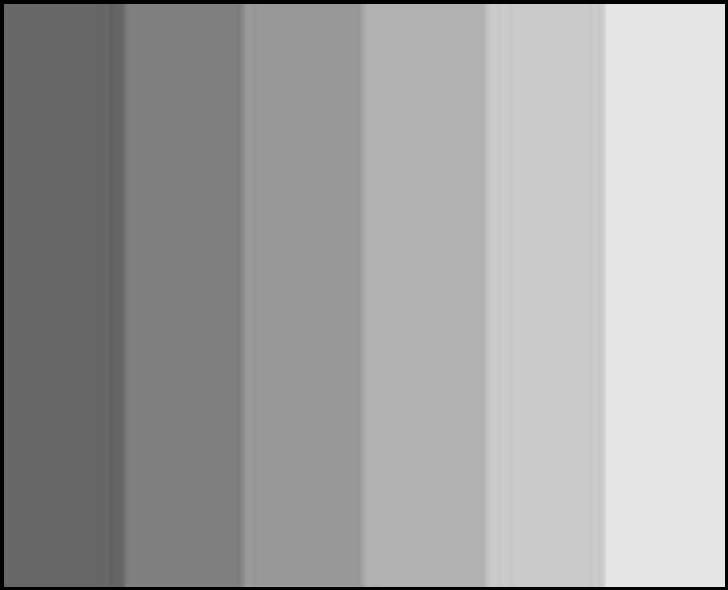


Edward H. Adelson, 1995



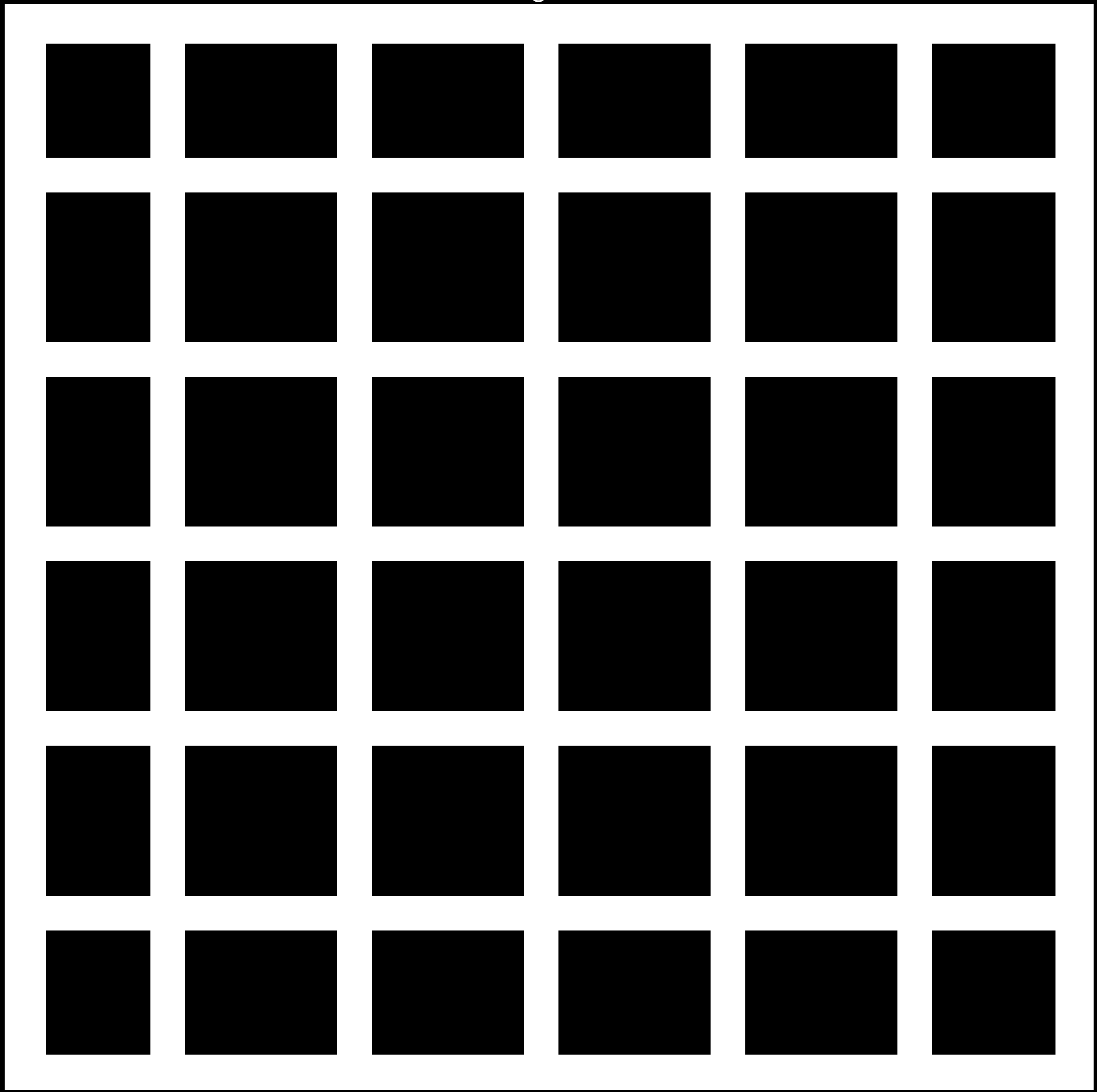
Edward H. Adelson, 1995

MACH BANDS ILLUSION (1865)



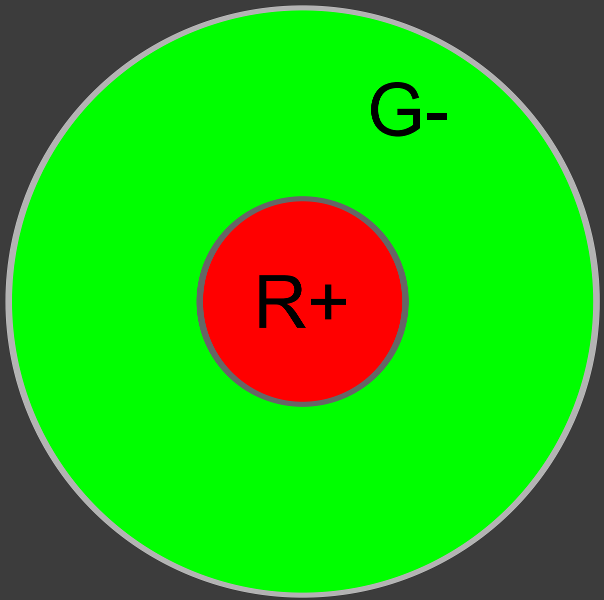
The illusion appears as soon as the bands touch. Mach conjectured that filtering is performed in the retina itself by lateral inhibition.

Herman grid illusion



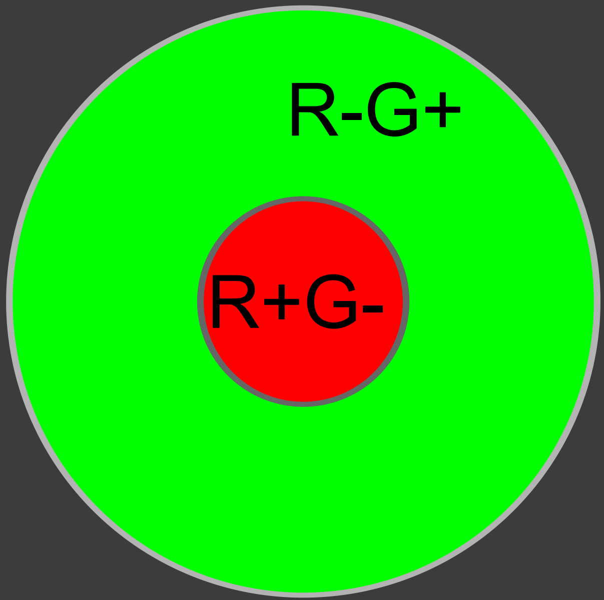
OPPONENT CELLS

SINGLE OPPONENT



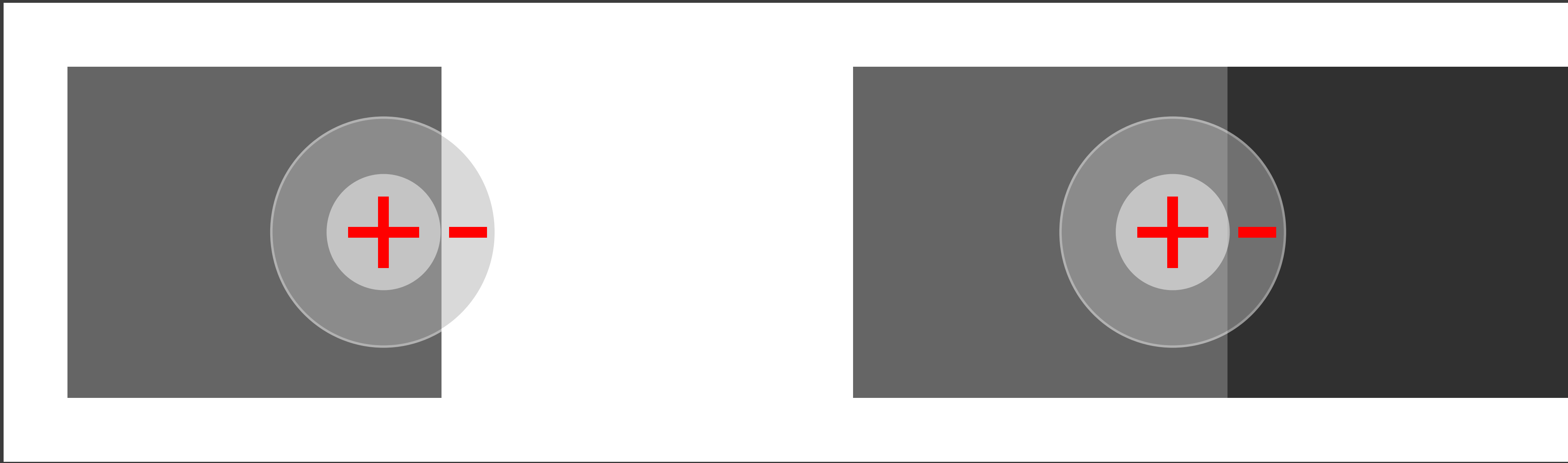
- [Wiesel, Hubel 1966] discovers single opponent cells
- [De Valois 1965] existence of color opponent neurons in the primate visual system

DOUBLE OPPONENT



- [Daw 1967] evidence that color constancy is supported by double-opponent cells in V1
- Double opponent cells have a large receptive field than single-opponent cells

LATERAL INHIBITION



Lateral inhibition explains simultaneous contrast:
- Left: light background causes greater inhibition at the center making the gray surface appear darker
- Right: dark background causes smaller inhibition at the center making the gray surface appear lighter

SIMULTANEOUS CONTRAST (UNIVERSAL)

Colors of different objects affect each other

Simultaneous chromatic contrast on the chromatic channels

Simultaneous luminance contrast on the achromatic channel

COLOR CONSTANCY (UNIVERSAL)

- Color perception to ensure colors remain constant under varying illumination
- Helps identify objects at different times of the day and lighting

VISION DEFICIENCIES (INDIVIDUAL)

VISION DEFICIENCIES (INDIVIDUAL)

BLURRED VISION

VISION DEFICIENCIES (INDIVIDUAL)

BLURRED VISION

COLOR BLINDNESS

"As someone with protanomaly, I can see all colors, including red, it's just that red is noticeably weak and so it looks very dark to me. I often can't read black writing on a red background (or vice versa) and sometimes mistake purple with blue."

Colors seen by non-colorblind person

"As someone with protanomaly, I can see all colors, including red, it's just that red is noticeably weak and so it looks very dark to me. I often can't read black writing on a red background (or vice versa) and sometimes mistake purple with blue."

Colors seen by person with protanomaly

COLOR BLINDNESS: AFFECTS ~9% OF THE POPULATION

Normal vision	All colors in visible spectrum
Deuteranopia Deuteranomaly	Green, M cone M: 6.2% F: 0.36%
Protanopia Protanomaly	Red, L cone M: 2.6% F: 0.04%
Tritanopia Tritanomaly	Blue, S cone M: 0.01% F: 0.03%

Prefixes: nopia is missing, nomaly is reduced response

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COLOR THEORY

Practical guidance to color mixing and the visual effects of color combinations

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COLOR MODEL

Abstract mathematical model describing the way colors can be represented as tuples

HTML (SVG) COLOR MODEL

Colors encoded as tuples: (red, green, blue, opacity)

8 bits per channel, i.e., 256x256x256 (~16.7M) colors

ENCODINGS:

- Decimal/Real: color as integer number ∈ [0, 255], opacity as real number ∈ [0, 1], 0 ≡ transparent, 1 ≡ opaque
- Hexadecimal: color and opacity as hex* number ∈ [00-FF], 00 ≡ transparent, FF ≡ opaque

name

```
<div style="background-color: red">name</div> <!-- named colors: red ≡ (255, 0, 0) -->
```

rgba

```
<div style="background-color: rgba(255, 0, 0, 0.3);">rgba</div> <!-- rgb(,,) or rgba(,,,) -->
```

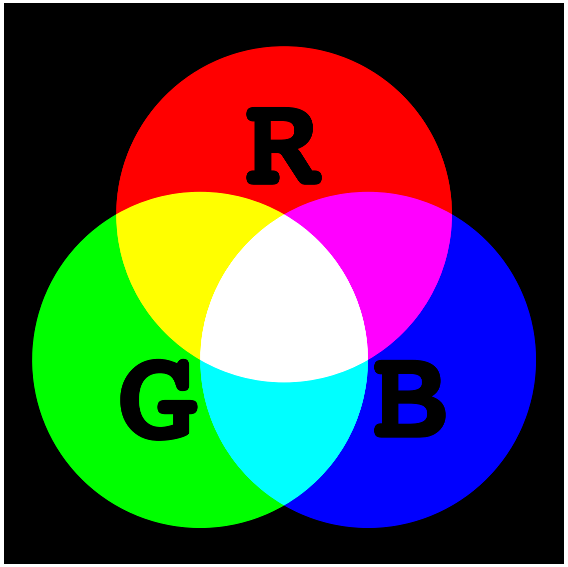
hex

```
<!-- opacity = 55 → 85, 85/255 = 0.333 -->
<div style="background-color: #ff000055;">hex</div> <!-- #rgb or #rgba -->
```

* Example conversion from hexadecimal to decimal: A = (10×16^1), F = (15×16^0), AF = $(10 \times 16^1) + (15 \times 16^0) = 175$

ADDITIVE COLOR MODEL

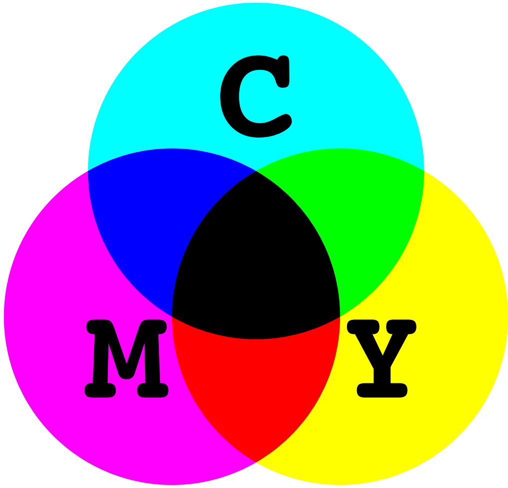
LCD displays, and projectors



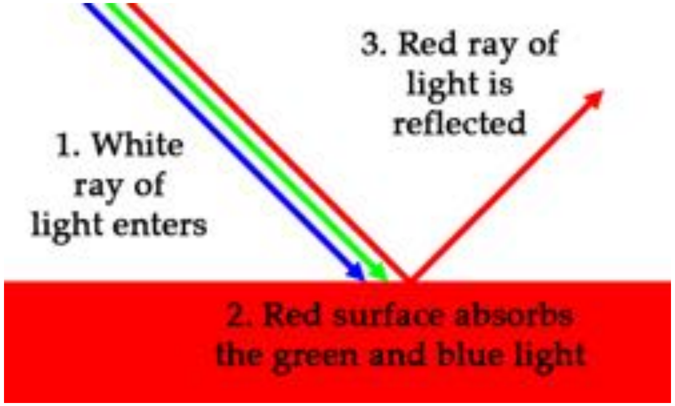
Primary colors: RGB
Secondary colors: CMY

SUBTRACTIVE COLOR MODEL

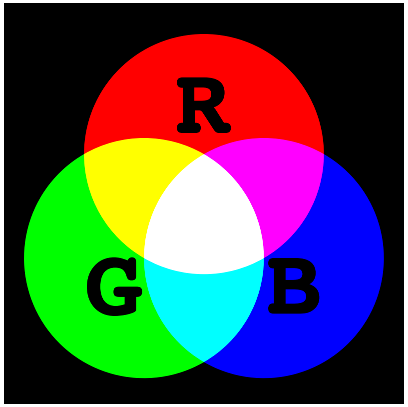
Painting and printing



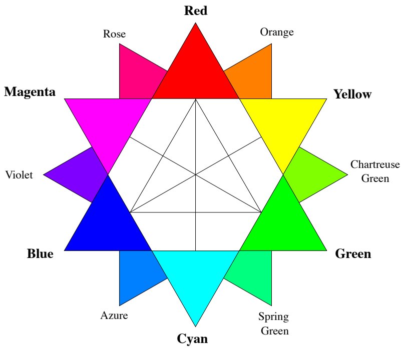
Primary colors: CMY
Secondary colors: RGB



PRIMARY, SECONDARY AND COMPLEMENTARY COLORS



Additive color model cube



Additive color model star (wheel)
Charles Blanc (1867)

Primaries

Mixed create all other colors
Cannot be mixed from other colors

red green blue — 3 primary colors

red + green + blue = white

Secondary

Colors mixed from 2 primaries

cyan magenta yellow — 3 secondary colors

cyan + magenta + yellow = white

red + blue = magenta — mixed from 2 primaries

blue + green = cyan

green + red = yellow

Complementary

Pairs that combined cancel out.

red + cyan = white

blue + yellow = white

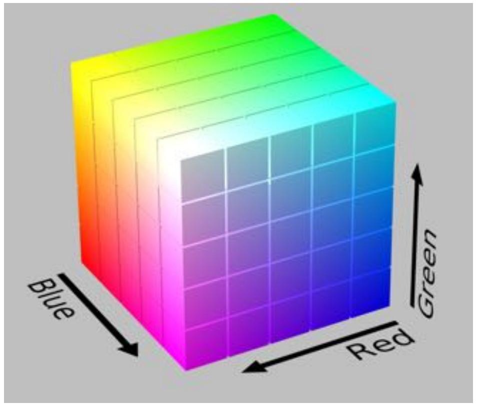
green + magenta = white

orange + azure = white

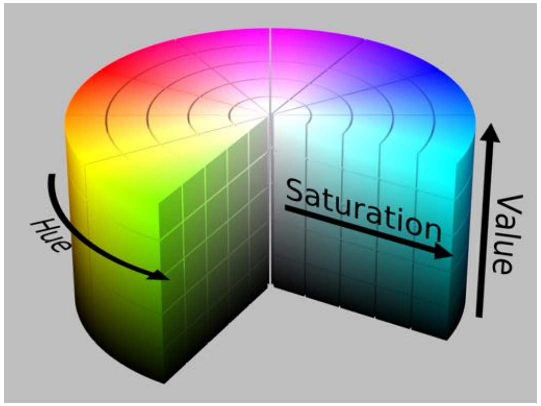
ADDITIVE COLOR MODEL TECHNIQUES

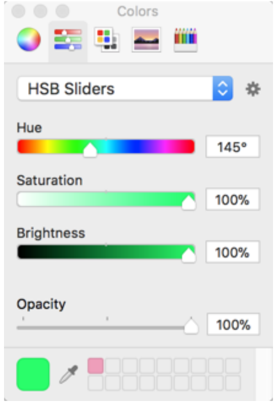
Addition of illumination	Projected colors overlap, e.g., stage projectors
Partitive mixing	Closely spaced colored dots, colors are next to each other, e.g., LCD screens
Time mixing	OLED micro displays, rotating color wheels, sequential illumination
Binocular mixing	Different colors on each eye, mixed by the brain

RGB COLORS ARRANGED IN A CUBE



HSV COLORS ARRANGED IN A CYLINDER





HSV is an alternative to the RGB color model using color properties distinguishable by the eye

COLOR SPACE

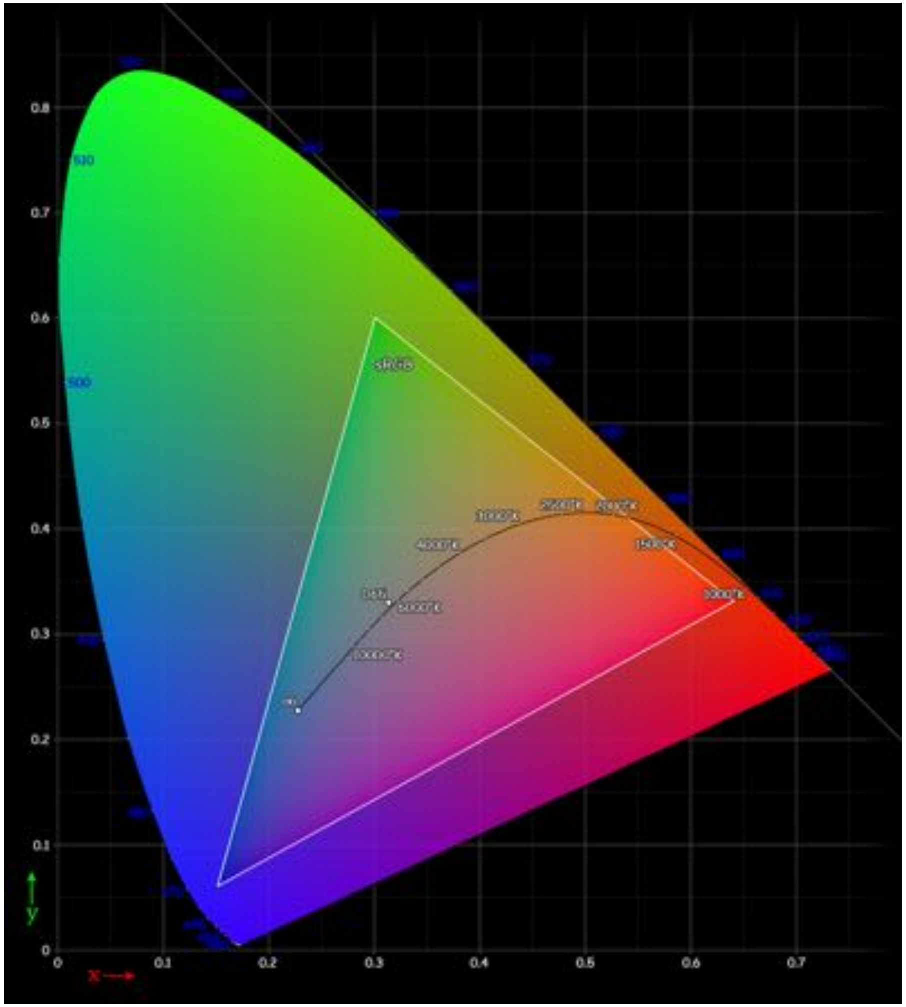
A tool used to define the gamut (subset of colors) accurately represented by a device or digital file

Color as:

- chromaticity: (hue, saturation)
- luminance (1d)

SRGB COLOR SPACE (HP, MICROSOFT 1996)

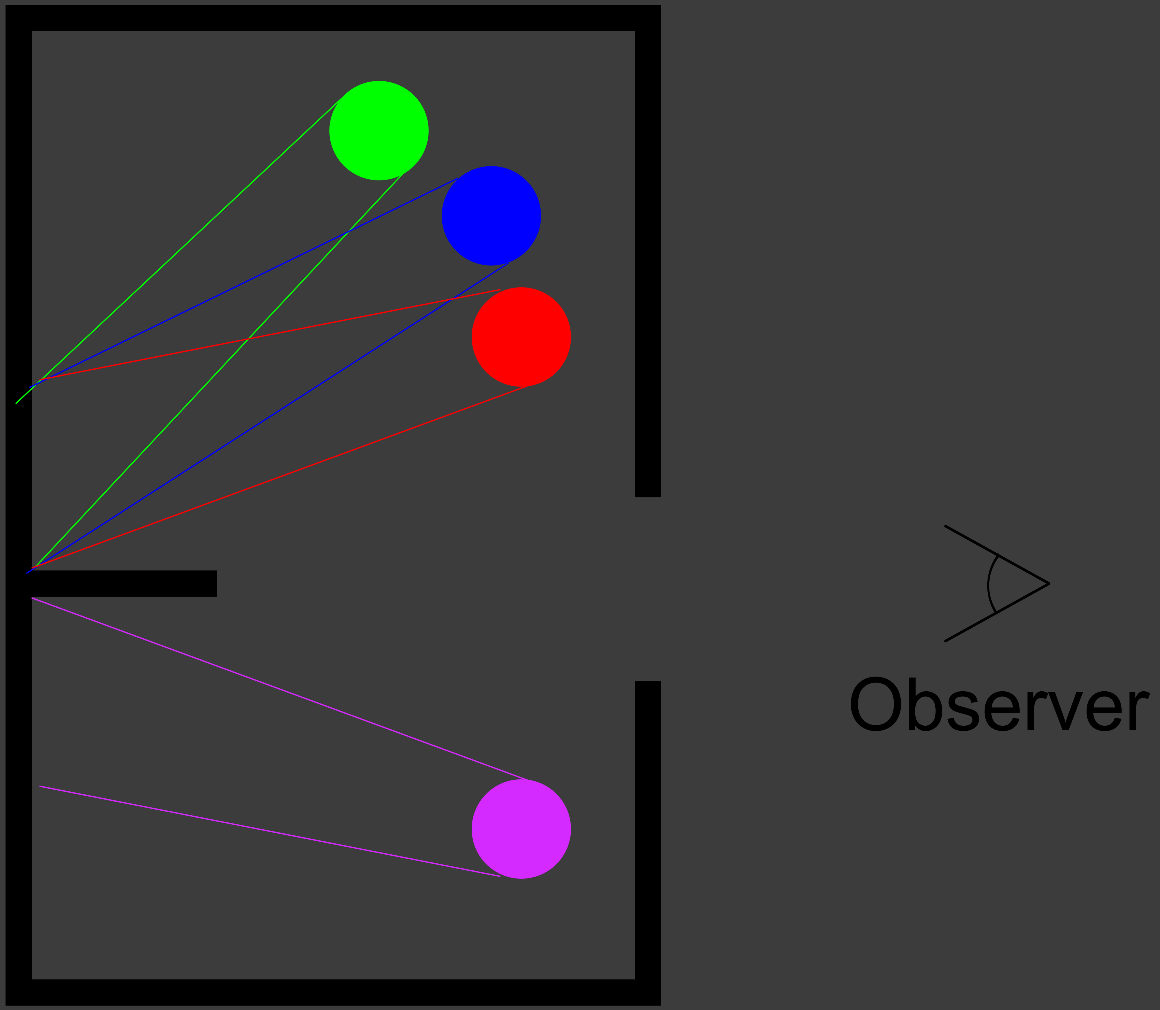
Default in browsers (typical office or home viewing equipment)



sRGB gamut shown on CIE xy chromaticity diagram

COLOR MATCHING EXPERIMENT (HELMHOLTZ & MAXWELL 1850)

Subjects adjust wavelengths of primaries to match a sample
Most people will match, same light, same primary colors with the same weights



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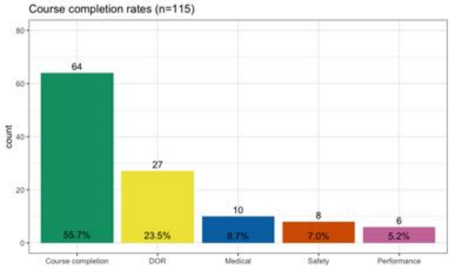
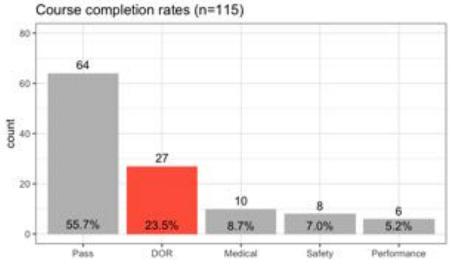
USE OF COLORS [TUFTE]

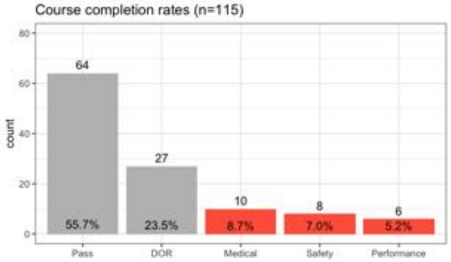
1. LABEL: IDENTIFY, HIGHLIGHT OR GROUP



Identify

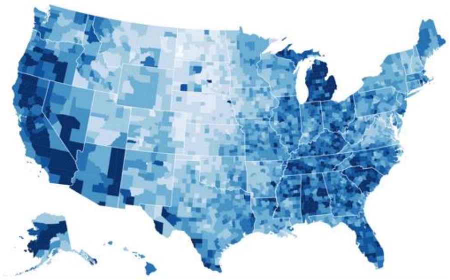


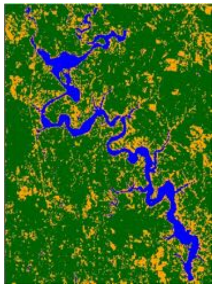
Highlight

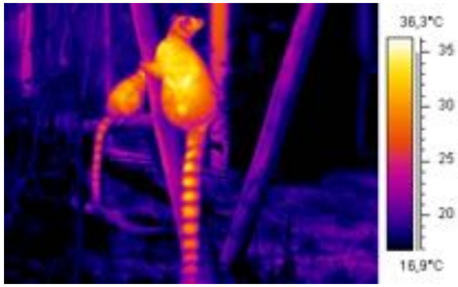


Group

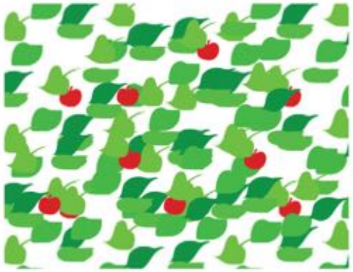
2. MEASURE, REPRESENT OR IMITATE REALITY







3. ENLIVEN (MAKE MORE ATTRACTIVE) OR DECORATE



COLOR RENDERING OF IMAGES

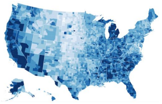
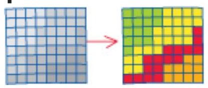
True-color

Colors appear similar a viewer of the image and to an observer of the scene, i.e., RGB → RGB

False-color

Images in different spectral bands are combined into an RGB image, e.g., NRG → RGB, with N near-infrared band

False-color techniques include:

- Choropleth map 
- Density slicing 

Pseudocolor

Derived from a grayscale image by mapping each intensity value to a color according to a table or function, e.g., G → RGB

COLOR CONTRAST (RESULTS FROM SIMULTANEOUS CONTRAST)

Blue text is harder to read (relatively smaller number of S cones)

Red text is easier to read (relatively larger number of L cones)

Green text is easier to read (relatively larger number of M cones)

Achromatic white on black is easier to read than chromatic channels (3 x better than color because we use all 3 receptors)

Achromatic black on white as clear than black on white with less strain used in *“Dark mode”*

If using colors for text and background opponent channels provide the best contrast

If using colors for text and background opponent channels provide the best contrast

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When placed next to each other, complementary colors create the strongest contrast for those two colors.

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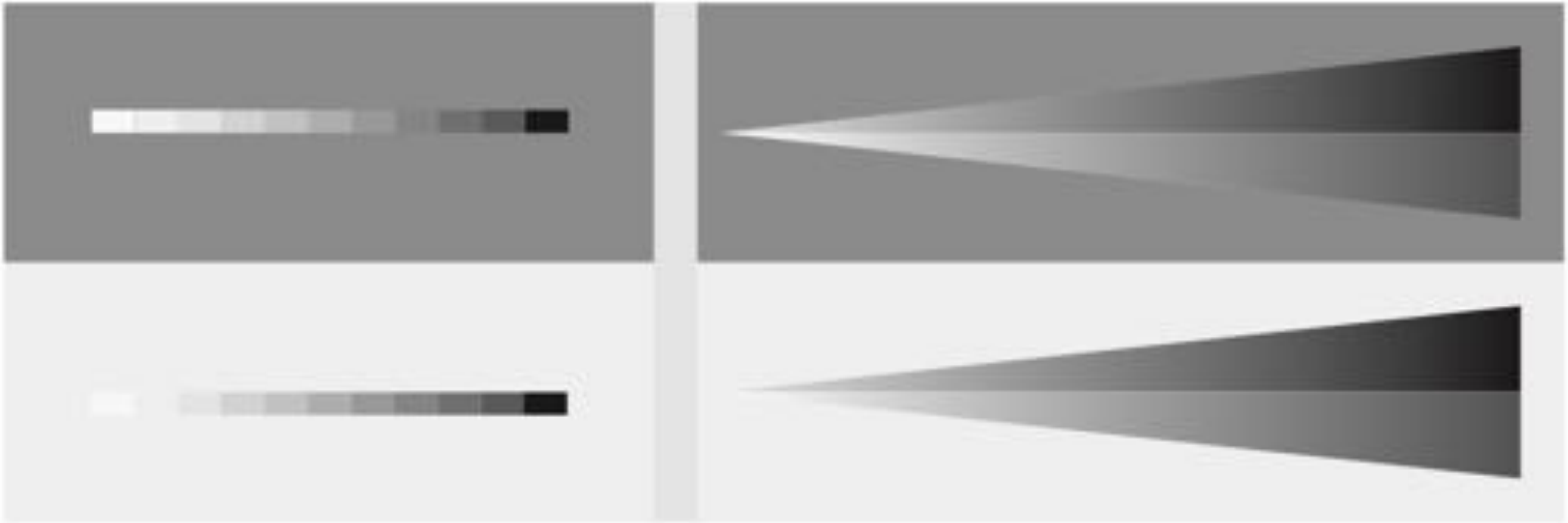
SHARPENING

We are more sensitive to dark than light differences

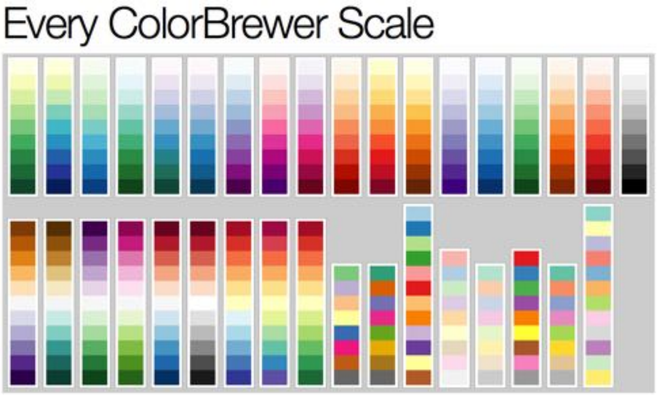
Dark background accentuates midrange

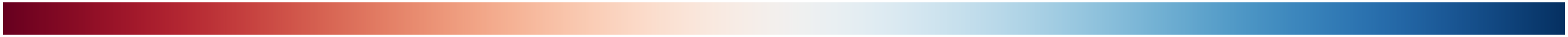


Light background accentuates near white

COLOR SEQUENCES (AKA SCHEMES)

- Use established color sequences, e.g., ColorBrewer
- Use appropriate color sequence type
- Use colorblind safe colors (test with Color Oracle or Dev Tools)
- With discrete scales, limit colors used as keys to 5-7



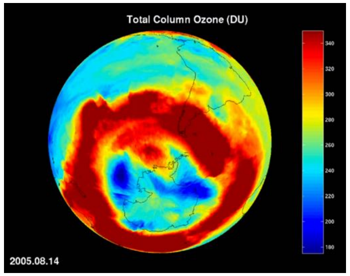


COLOR SEQUENCES TYPES

Scheme	Characteristics	Examples
Sequential	Ordered data, light colors for lower values to dark colors for higher values	
Diverging	Critical class or break in the middle, sequential sequences of contrasting hues on both ends.	
Qualitative	For nominal or categorical data.	

RECOMMENDATIONS

Respect well-established color sequences	
Observe cultural conventions	
Use color palettes for more attractive and effective displays	



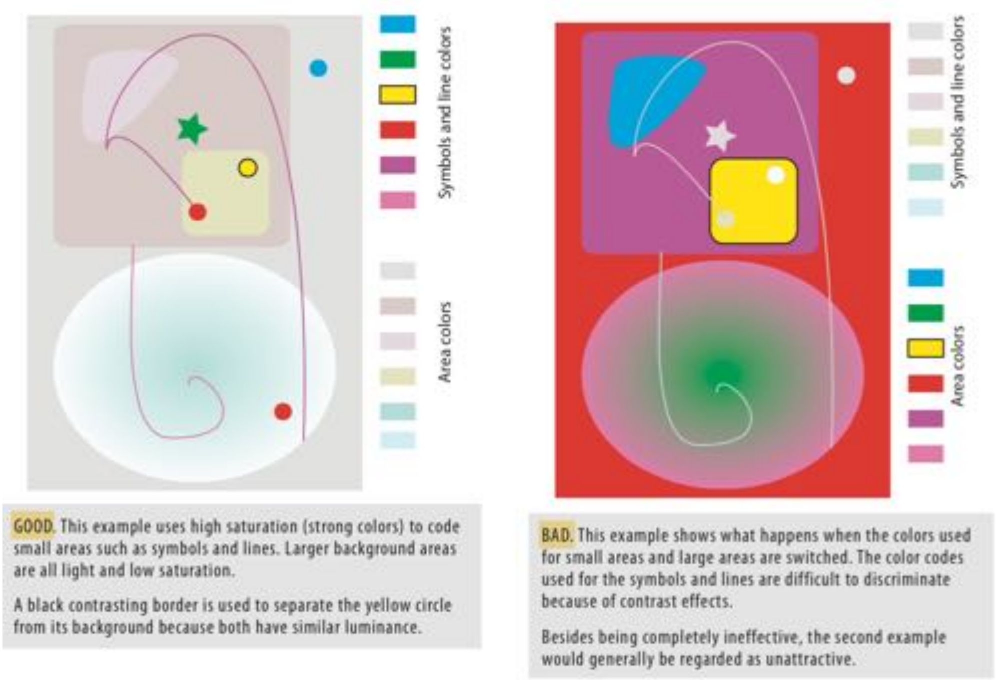
RECOMMENDATIONS (CONTINUED)

- Use consistent color encodings across graphics
- Use colorblind safe colors
- Use accessibility standards: AA (minimum) contrast ratio of 4.5:1 for all text

RECOMMENDATIONS (CONTINUED)

COMPOSITION:

- Do not overuse accent colors, instead use accent colors for the most important visual queries
- Use lighter colors for background



Colin Ware. Visual thinking: For design. Morgan Kaufmann, 2010.

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D3 COLOR MANIPULATION AND COLOR SPACE CONVERSION

```
//d3-color and d3-scale-chromatic are included in d3

//d3-color provides color manipulation and color space conversion.
var c = d3.hsl("steelblue");
console.log(c);  //{h: 207.272, s: 0.44, l: 0.343, ...}

c = c.darker();
console.log(c);  //{h: 207.272, s: 0.44, l: 0.490, ...}

c = c.brighter();
console.log(c);  //{h: 207.272, s: 0.44, l: 0.490, ...}

//d3-scale-chromatic provides ColorBrewer and other colors schemes
var accent = d3.schemeAccent;  //["#7fc97f", "#beaed4", "#fdc086", ...]

//d3-hsv needs to be loaded separately (npm install d3-hsv)
var yellow = d3.hsv("yellow"); // {h: 60, s: 1, v: 1, opacity: 1}
```

d3/d3-color
d3/d3-hsv
d3/d3-scale-chromatic

D3 COLOR SCALES: D3-SCALE + COLORS SCHEMES

Input Domain Data	Encoding $\longmapsto$ scale	Ouput Range Colors

	Continuous	**Discrete**
Continuous	Linear Sequential Diverging	Quantize Quantile
Discrete		Ordinal Threshold

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D3 LIBRARIES USED TO CREATE COMPLEX CHARTS

LIBRARY	TYPE	DESCRIPTION	CHARTS
D3-SHAPE	GENERATOR	GRAPHICAL PRIMITIVES FOR VISUALIZATION, SUCH AS LINES AND AREAS.	LINE, AREA, PIE CHARTS, SYMBOLS...
D3-CHORD	LAYOUT	RELATIONSHIPS OR NETWORK FLOW IN CIRCULAR LAYOUT.	CHORD DIAGRAM
D3-FORCE	LAYOUT	FORCE-DIRECTED GRAPH LAYOUT USING VELOCITY VERLET INTEGRATION.	PHYSICAL SIMULATIONS IN NETWORKS AND HIERARCHIES, BUBBLES CHARTS...
D3-HIERARCHY	LAYOUT	2D LAYOUT ALGORITHMS FOR VISUALIZING HIERARCHICAL DATA.	TREEMAPS, DENDROGRAMS, CIRCLE-PACKING...
D3-SANKEY	LAYOUT	DIRECTED FLOW BETWEEN NODES IN AN ACYCLIC NETWORK.	SANKEY DIAGRAMS
D3-HEXBIN	GENERATOR	GROUP TWO-DIMENSIONAL POINTS INTO HEXAGONAL BINS.	HEXBINS PLOTS
D3.HISTOGRAM	GENERATOR	COMPUTES THE HISTOGRAM FOR THE GIVEN ARRAY.	HISTOGRAMS