“Good painting, good coloring, is comparable to good cooking.

Even a good cooking recipe demands tasting and repeated tasting while it is being followed.

And the best tasting still depends on a cook with taste.”

- Josef Albers

color

Color is…

Complex

Color is…

Confusing

Color is…

Important

Color helps you

Explore

3 3 0 3 0 1 8 7 6 8 2 1 4 0 3 8 3 7 7 2 0 5 2 3 2 7 0 2 0
7 1 4 6 0 2 1 3 2 7 6 0 2 5 6 3 2 5 7 6 3 3 0 2 0 3 0 7 2
8 7 5 7 2 8 3 8 7 7 8 2 0 7 7 5 2 3 1 1 5 6 3 8 4 7 8 2 0
0 5 0 5 1 6 1 7 5 6 8 0 4 4 6 7 4 7 1 4 0 0 8 4 4 3 0 3 2
2 4 3 1 3 5 4 9 5 0 7 6 0 7 4 3 1 8 2 7 3 4 6 0 2 4 8 2 3
8 6 2 2 6 5 4 6 7 0 7 6 0 0 3 9 0 2 4 7 1 7 2 3 3 5 8 7 0
0 8 4 5 1 3 1 7 6 4 5 4 1 2 4 5 3 3 5 4 9 6 7 7 6 3 4 2 5
4 7 7 0 2 2 0 1 1 7 7 7 0 2 6 6 4 7 5 8 6 1 4 3 7 8 5 4 6
4 3 6 6 4 6 6 2 8 4 8 5 3 7 8 8 1 3 8 5 4 5 7 4 0 3 2 8 4
5 5 0 3 5 3 5 3 8 3 2 3 8 2 3 1 6 2 7 2 4 6 3 6 4 4 3 2 5
4 4 0 2 1 7 2 4 4 7 4 1 9 2 4 5 2 5 0 4 0 0 5 3 6 3 3 6 7
7 4 6 6 8 7 5 7 9 2 0 2 8 8 8 8 3 2 4 2 6 4 0 4 6 3 7 2 1
0 1 7 1 5 9 1 4 2 8 7 3 7 1 4 5 1 8 7 8 0 5 1 7 0 5 8 8 1
2 8 5 2 1 2 8 7 7 6 2 5 6 2 6 4 1 5 1 6 1 2 1 1 0 5 6 4 0
2 1 1 7 7 2 0 0 1 8 7 0 2 9 0 2 8 5 7 8 4 6 0 6 5 0 7 1 2
0 5 2 4 1 5 3 3 1 5 5 1 4 0 1 6 4 3 3 9 8 8 3 4 6 8 4 8 6
7 3 7 5 2 4 0 2 7 6 3 8 5 5 4 5 8 8 7 5 5 6 5 6 7 9 7 7 4
0 3 2 8 1 4 4 6 0 8 2 3 0 1 3 4 6 2 0 5 7 7 3 6 1 8 7 3 5
4 4 8 3 3 3 5 0 1 0 3 8 6 3 2 0 5 0 6 1 3 3 4 3 6 1 5 8 6
1 0 2 2 7 6 3 3 0 8 8 0 3 1 8 8 1 2 1 7 5 2 9 3 5 8 3 2 5

3 3 0 3 0 1 8 7 6 8 2 1 4 0 3 8 3 7 7 2 0 5 2 3 2 7 0 2 0
7 1 4 6 0 2 1 3 2 7 6 0 2 5 6 3 2 5 7 6 3 3 0 2 0 3 0 7 2
8 7 5 7 2 8 3 8 7 7 8 2 0 7 7 5 2 3 1 1 5 6 3 8 4 7 8 2 0
0 5 0 5 1 6 1 7 5 6 8 0 4 4 6 7 4 7 1 4 0 0 8 4 4 3 0 3 2
2 4 3 1 3 5 4 9 5 0 7 6 0 7 4 3 1 8 2 7 3 4 6 0 2 4 8 2 3
8 6 2 2 6 5 4 6 7 0 7 6 0 0 3 9 0 2 4 7 1 7 2 3 3 5 8 7 0
0 8 4 5 1 3 1 7 6 4 5 4 1 2 4 5 3 3 5 4 9 6 7 7 6 3 4 2 5
4 7 7 0 2 2 0 1 1 7 7 7 0 2 6 6 4 7 5 8 6 1 4 3 7 8 5 4 6
4 3 6 6 4 6 6 2 8 4 8 5 3 7 8 8 1 3 8 5 4 5 7 4 0 3 2 8 4
5 5 0 3 5 3 5 3 8 3 2 3 8 2 3 1 6 2 7 2 4 6 3 6 4 4 3 2 5
4 4 0 2 1 7 2 4 4 7 4 1 9 2 4 5 2 5 0 4 0 0 5 3 6 3 3 6 7
7 4 6 6 8 7 5 7 9 2 0 2 8 8 8 8 3 2 4 2 6 4 0 4 6 3 7 2 1
0 1 7 1 5 9 1 4 2 8 7 3 7 1 4 5 1 8 7 8 0 5 1 7 0 5 8 8 1
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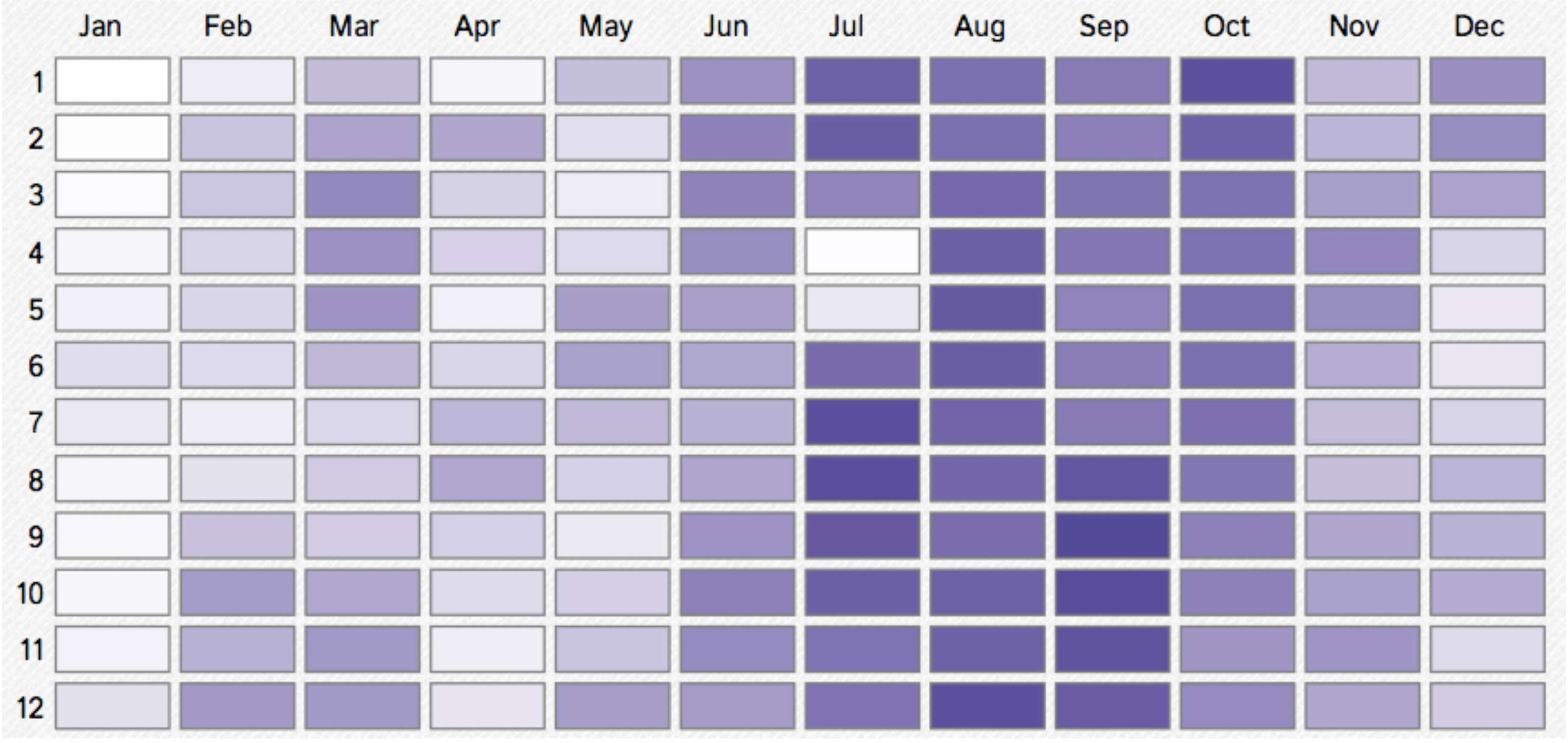
7 3 7 5 2 4 0 2 7 6 3 8 5 5 4 5 8 8 7 5 5 6 5 6 7 9 7 7 4
0 3 2 8 1 4 4 6 0 8 2 3 0 1 3 4 6 2 0 5 7 7 3 6 1 8 7 3 5
4 4 8 3 3 3 5 0 1 0 3 8 6 3 2 0 5 0 6 1 3 3 4 3 6 1 5 8 6
1 0 2 2 7 6 3 3 0 8 8 0 3 1 8 8 1 2 1 7 5 2 9 3 5 8 3 2 5

Color helps you

Measure


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1
2
3
4
5
6
7
8
9
10
11
12

Color helps you

Engage

IN 60 SECONDS...
1 NEW DEFINITION IS ADDED ON urban
1,600+ READS ON Scribd.
13,000+ HOURS MUSIC STREAMING ON PANDORA
12,000+ NEW ADS POSTED ON craigslist
370,000+ MINUTES VOICE CALLS ON skype
98,000+ TWEETS
320+ NEW twitter ACCOUNTS
100+ NEW LinkedIn ACCOUNTS
1 associatedcontent NEW ARTICLE IS PUBLISHED
THE WORLD'S LARGEST COMMUNITY CREATED CONTENT!!
6,600+ NEW PICTURES ARE UPLOADED ON flickr
50+ WORDPRESS DOWNLOADS
125+ PLUGIN DOWNLOADS
695,000+ facebook STATUS UPDATES
79,364 WALL POSTS
510,040 COMMENTS
1,700+ Firefox DOWNLOADS
694,445 SEARCH QUERIES
168 MILLION EMAILS ARE SENT
60+ NEW BLOGS
1,500+ BLOG POSTS
70+ DOMAINS REGISTERED
25+ HOURS TOTAL DURATION
600+ NEW VIDEOS
QUESTIONS ASKED ON THE INTERNET...
100+ Answers.com
40+ YAHOO! ANSWERS
13,000+ iPhone APPLICATIONS DOWNLOADED
20,000+ NEW POSTS ON tumblr.
THE LARGEST SOCIAL READING PUBLISHING COMPANY!!
New Craigslist Ads
Google
Google Search
GO-Globe.com

IN 60 SECONDS...
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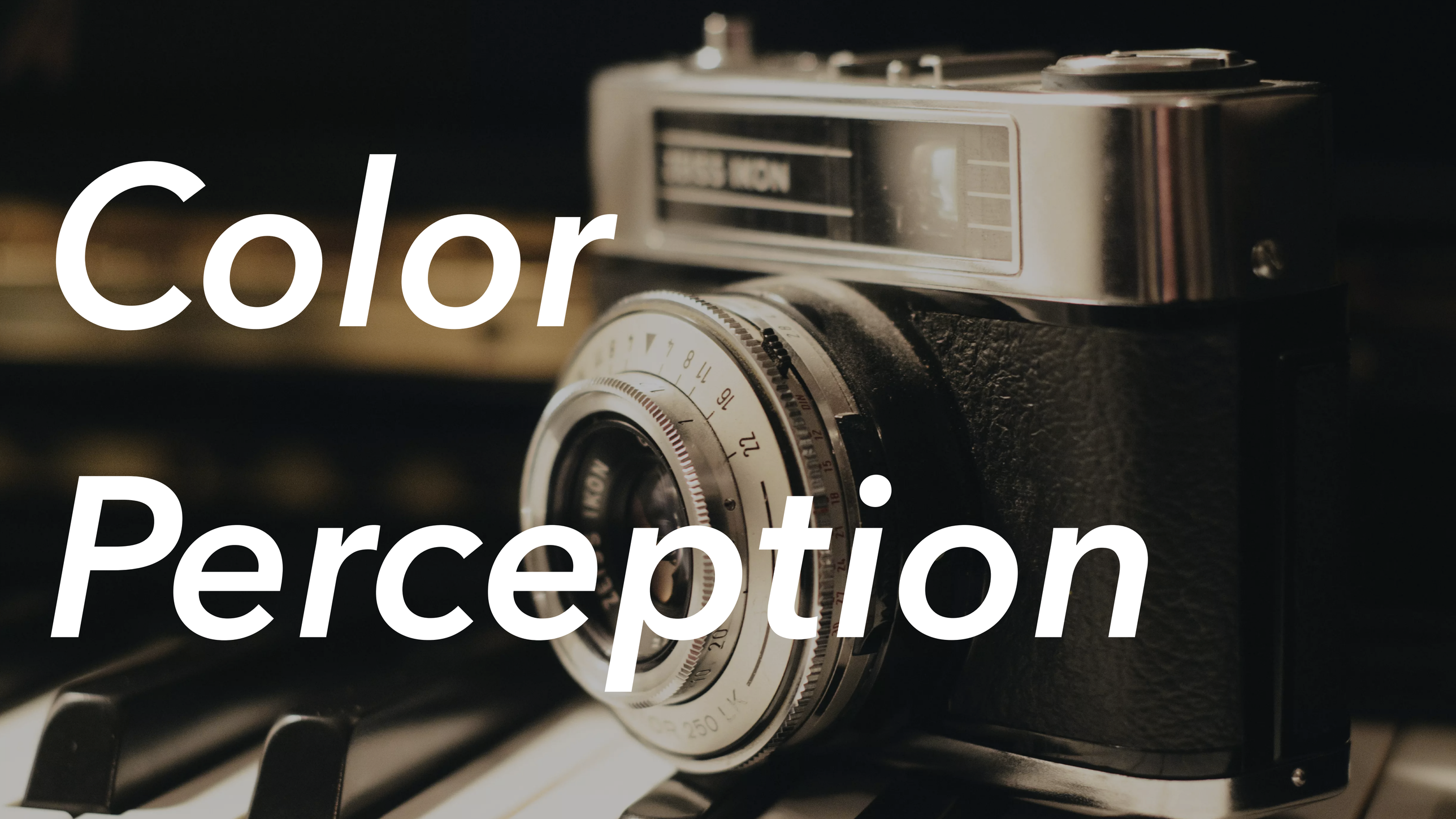
125+ PLUGIN DOWNLOADS
1,500+ BLOG POSTS
79,364 WALL POSTS
510,040 COMMENTS
Google
Google Search
GO-Globe.com

Color Perception



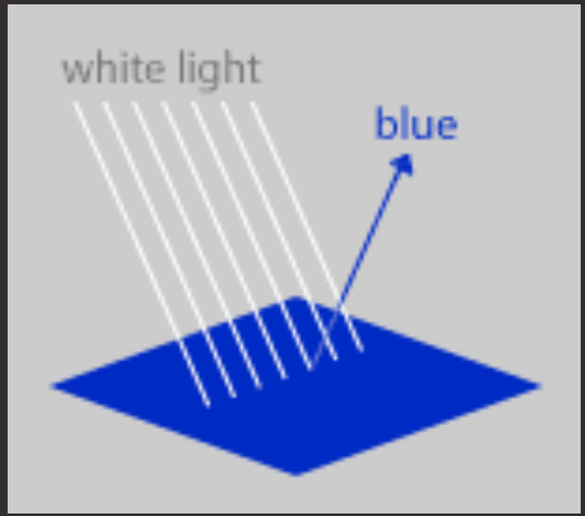
Light

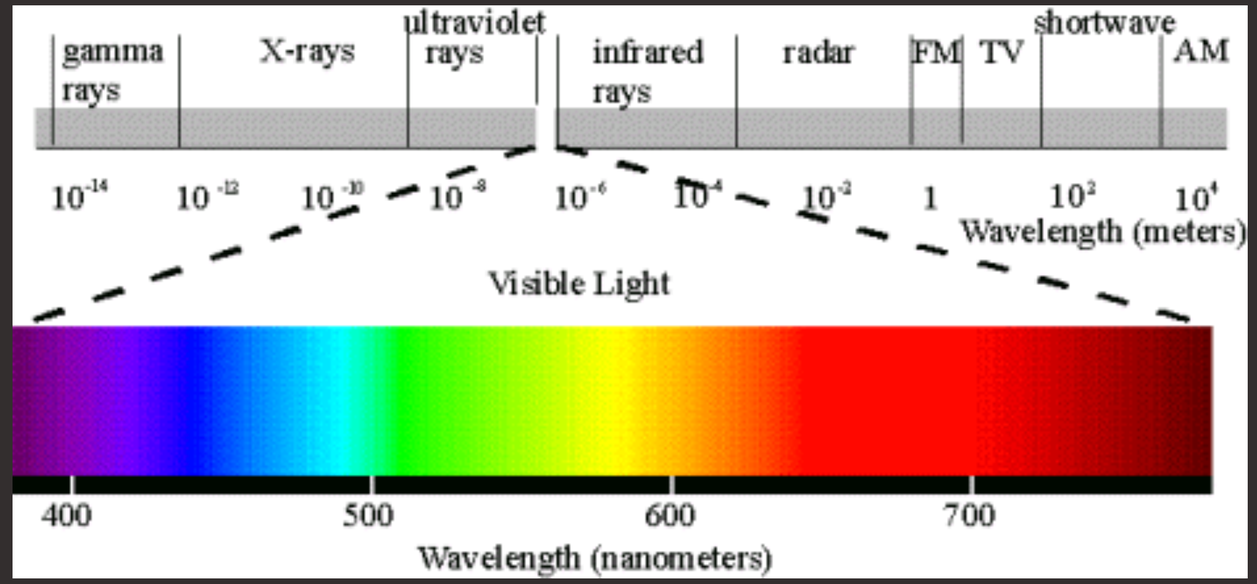
Eyes

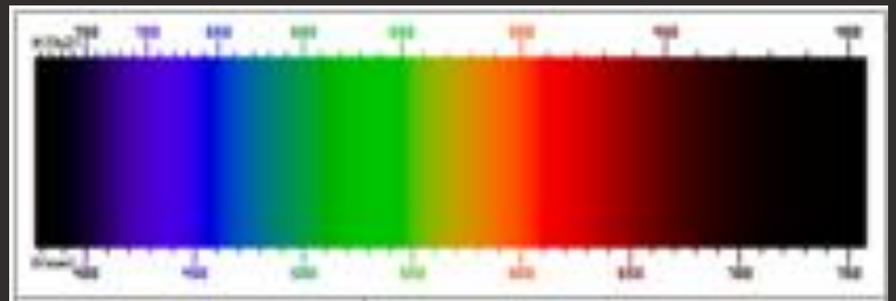
Mind

Light

Light







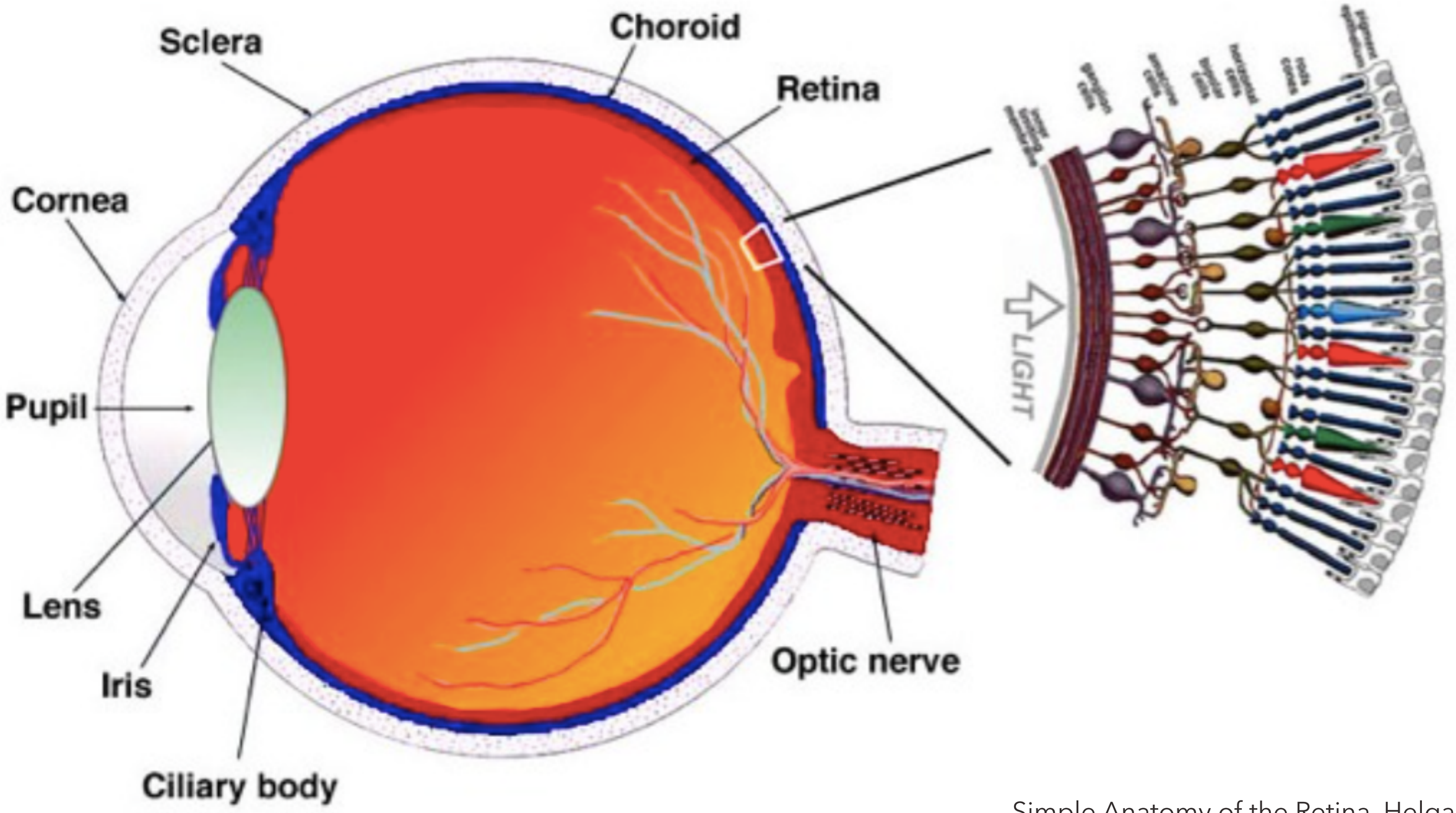
Color	Wavelength
violet	380–450 nm
blue	450–495 nm
green	495–570 nm
yellow	570–590 nm
orange	590–620 nm
red	620–750 nm

Light + color “types”

Subtractive

Additive

Eyes



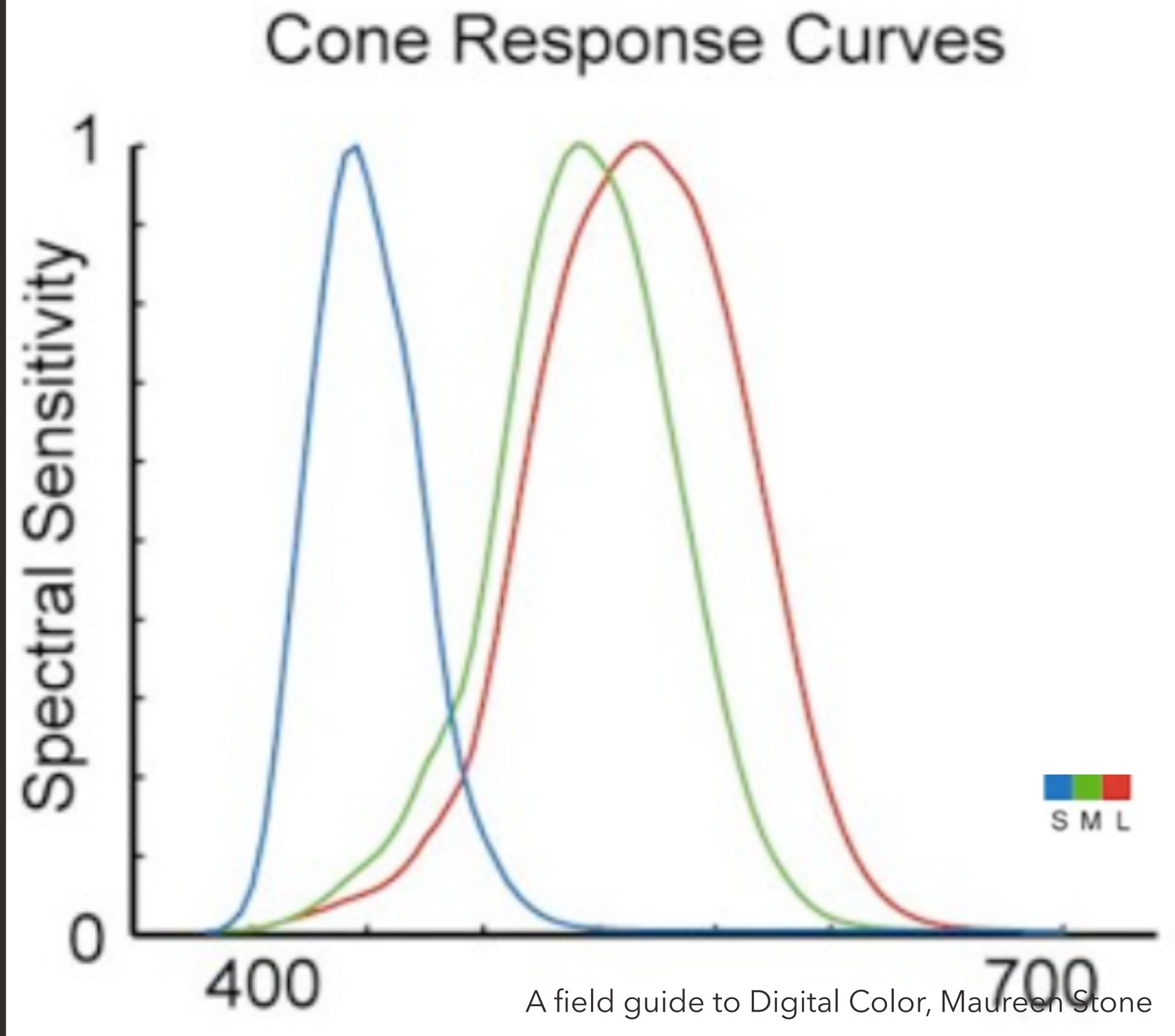
Simple Anatomy of the Retina, Helga Kolb

Cones

Long

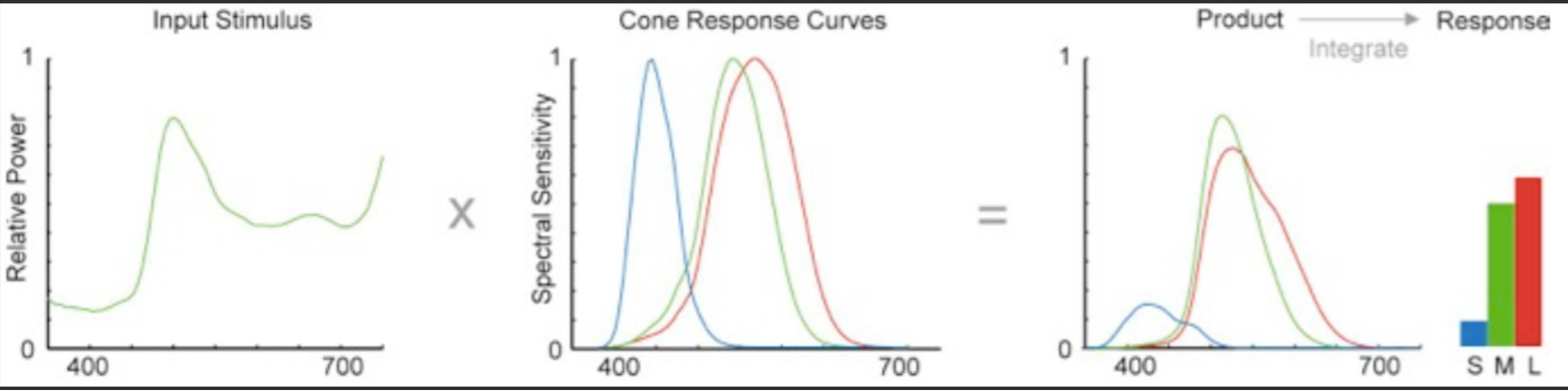
Middle

Short



A field guide to Digital Color, Maureen Stone

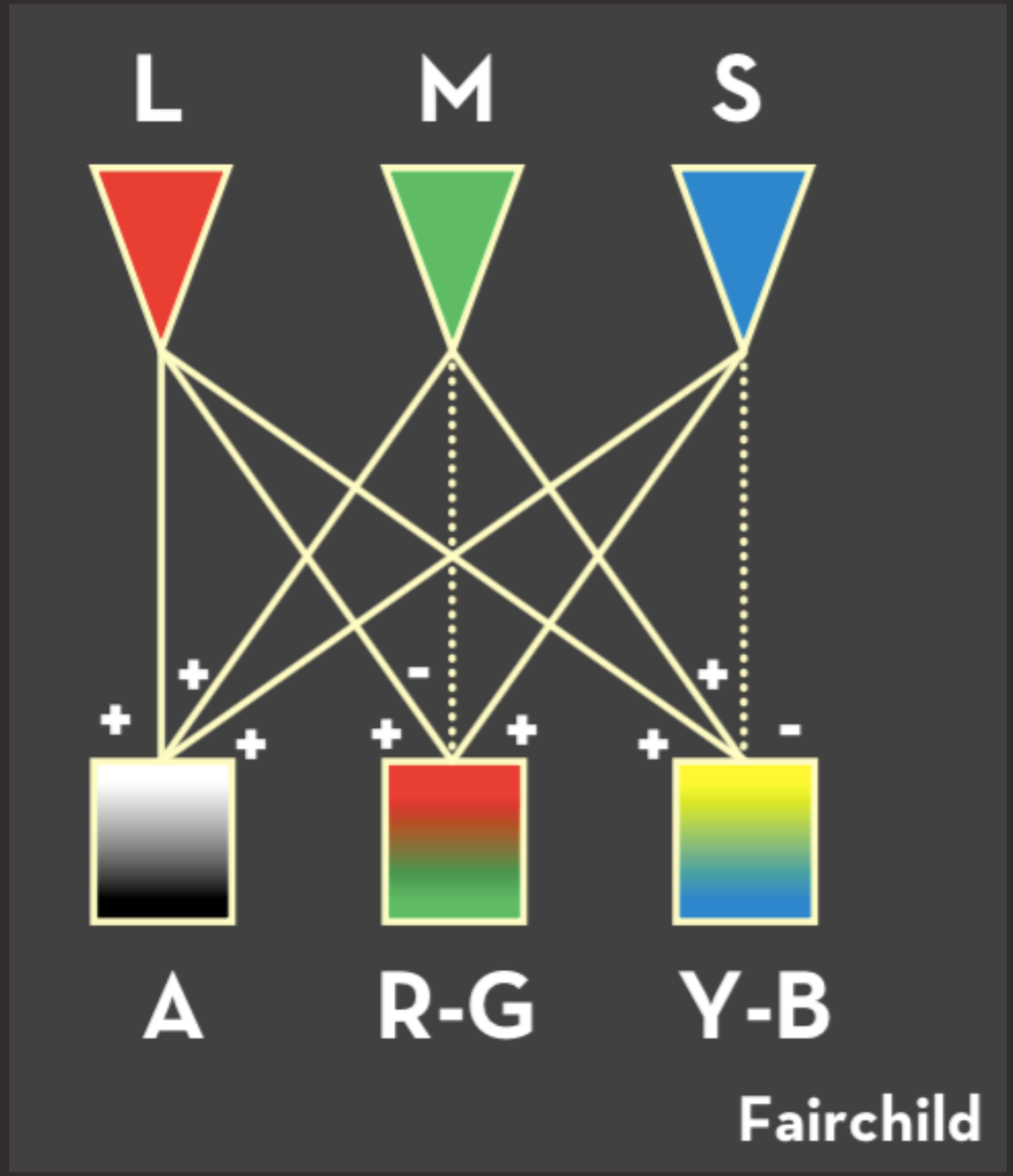
Integration



A field guide to Digital Color, Maureen Stone

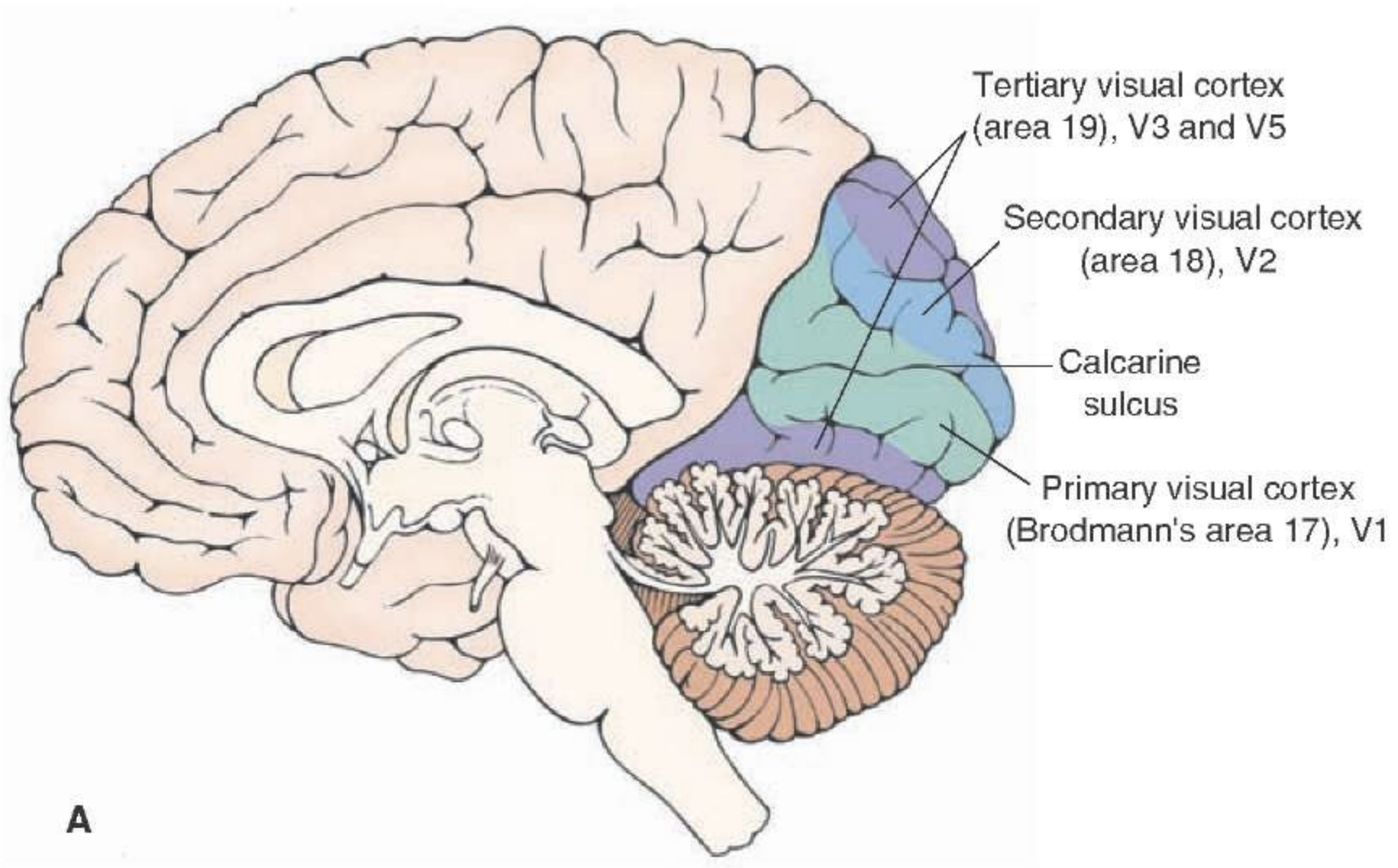
“Opponent Processing”

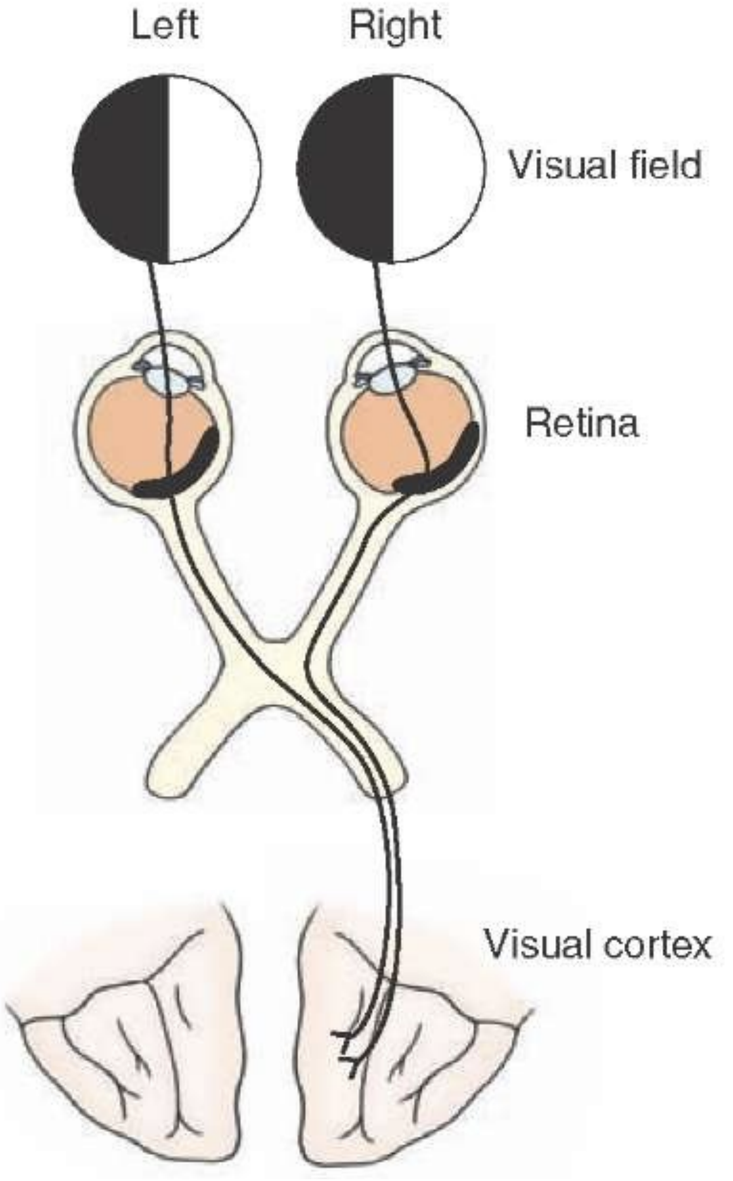
Long
Middle
Short

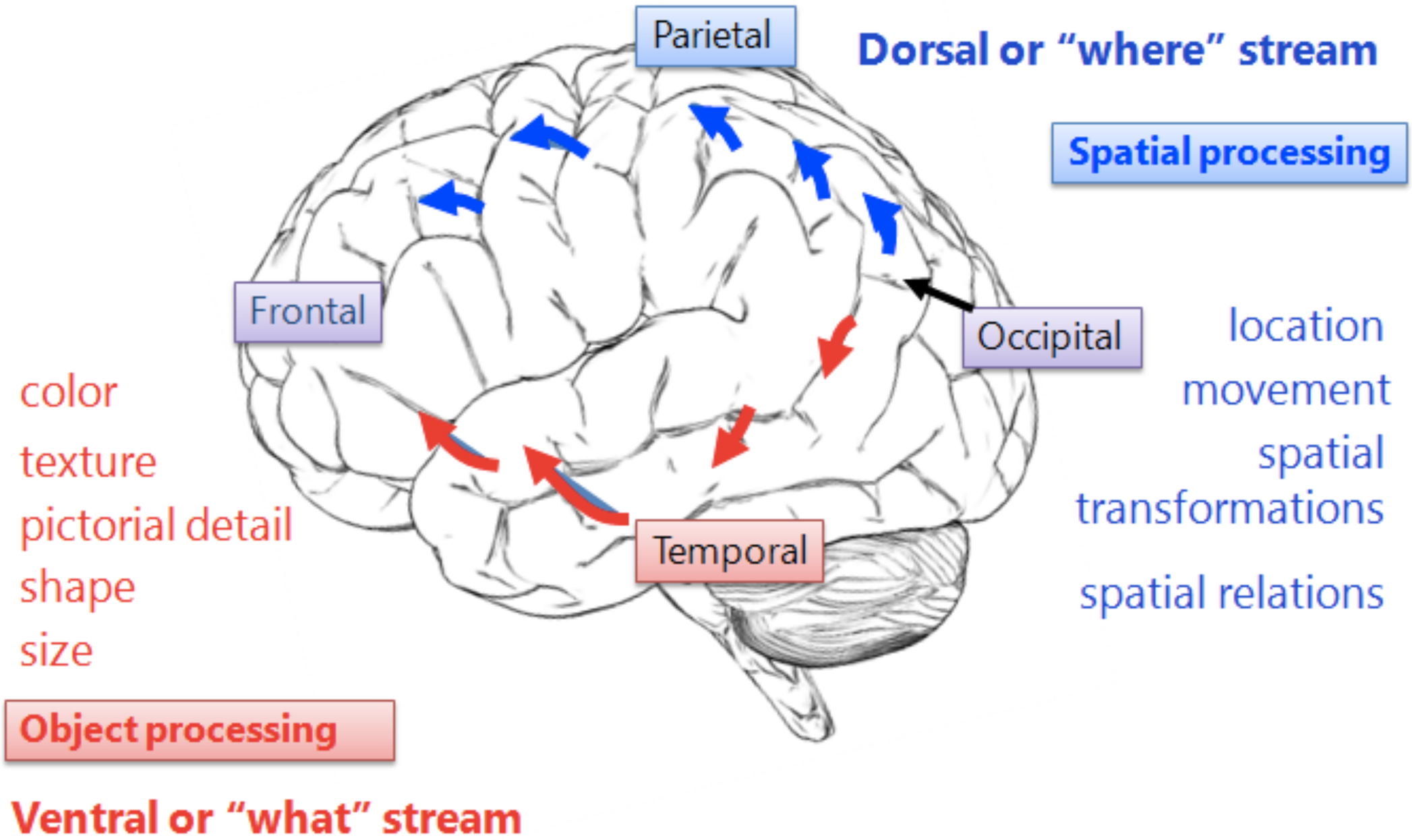


Mind

What color…


Tertiary visual cortex
(area 19), V3 and V5
Secondary visual cortex
(area 18), V2
Calcarine
sulcus
Primary visual cortex
(Brodmann's area 17), V1
A


Left
Right
Visual field
Retina
Visual cortex
B

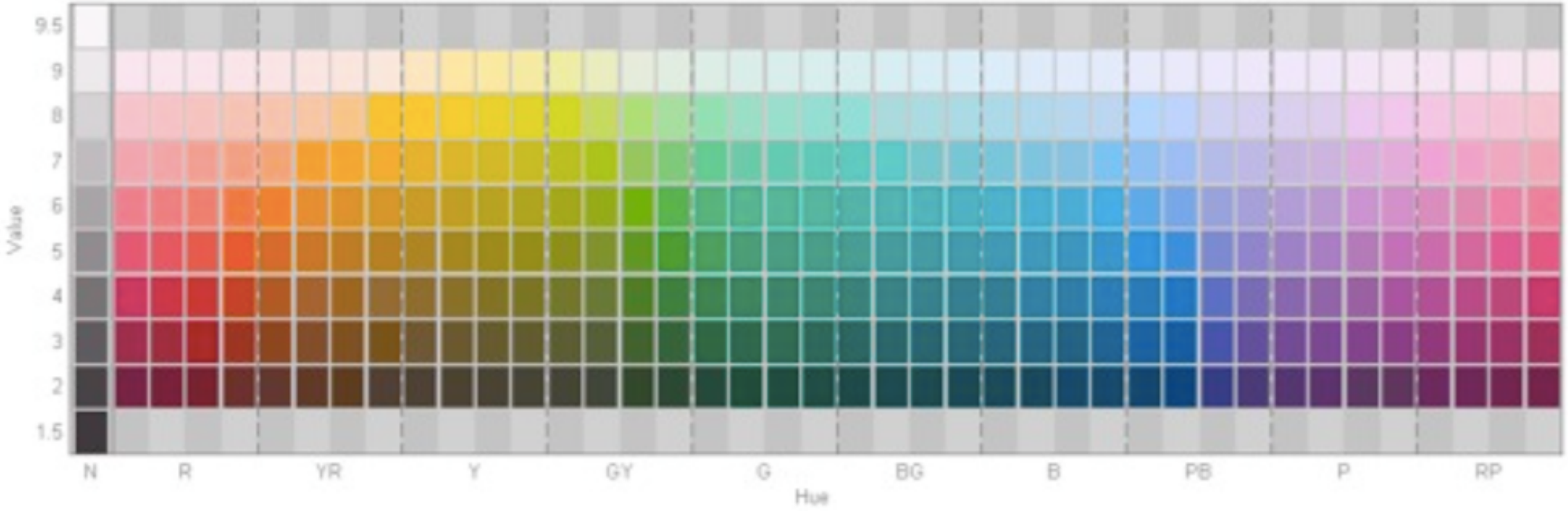


http://mikeclaffey.com/psyc170/notes/notes-vision.html

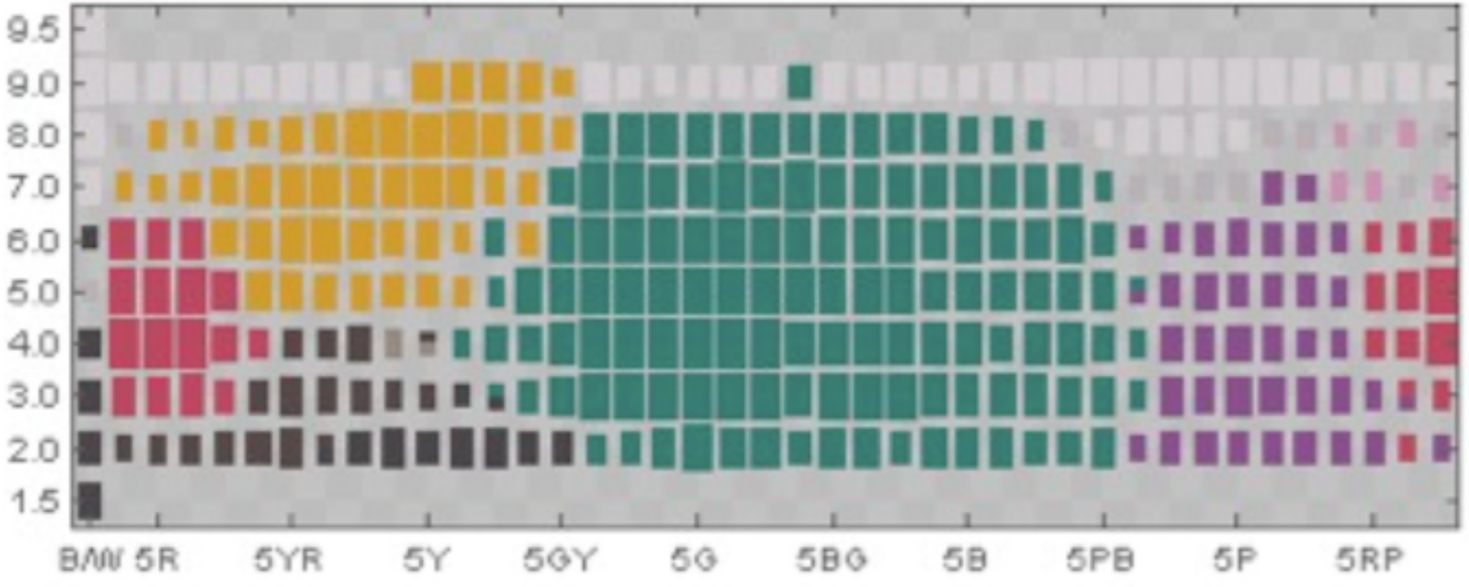
Color is perceptual AND cognitive

World color survey

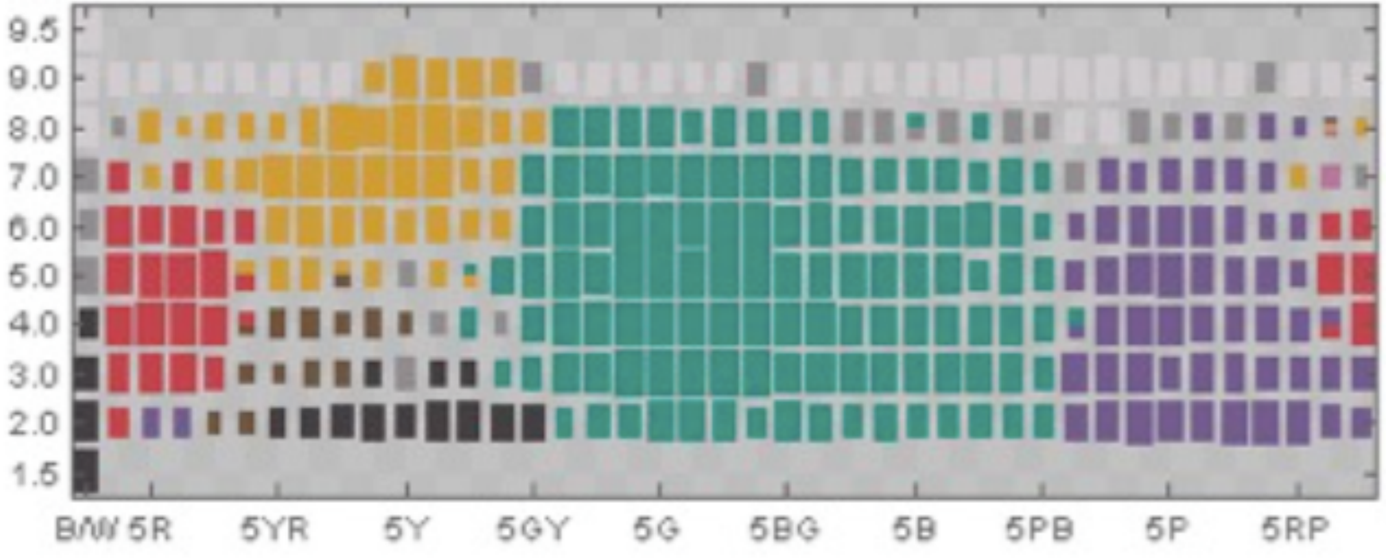
How do people around the world name these colors?



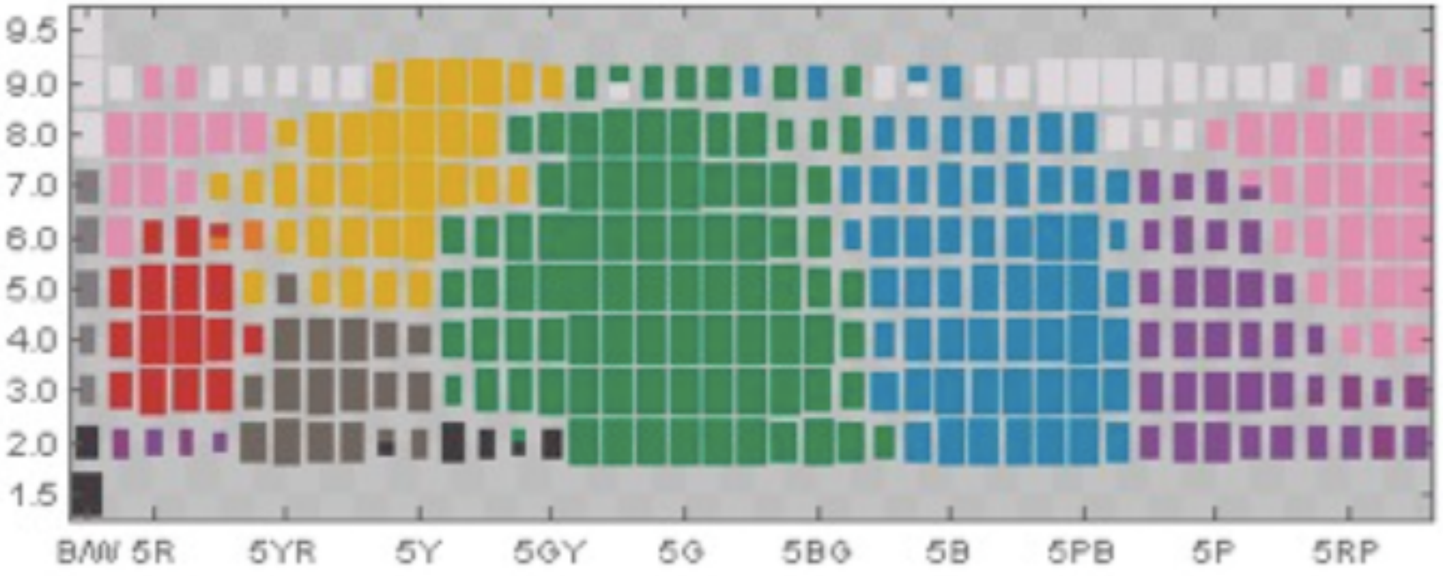
Language #72 (Mixteco)
Mutual info = 0.942 / Contribution = 0.476



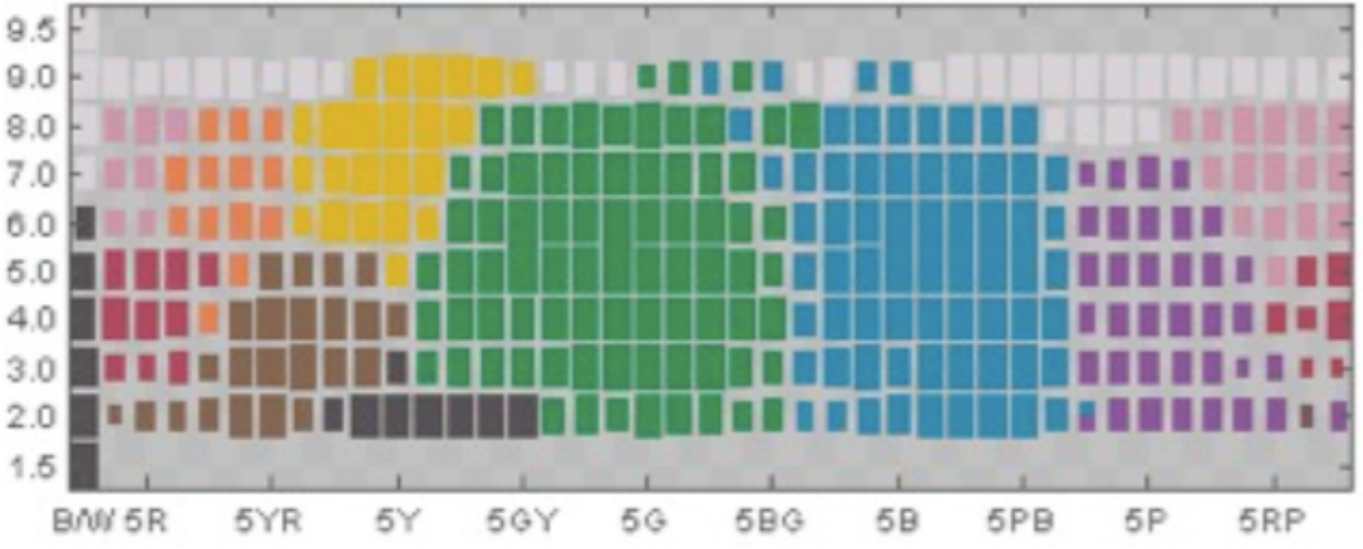
Language #98 (Tlapaneco)
Mutual info = 0.942 / Contribution = 0.524



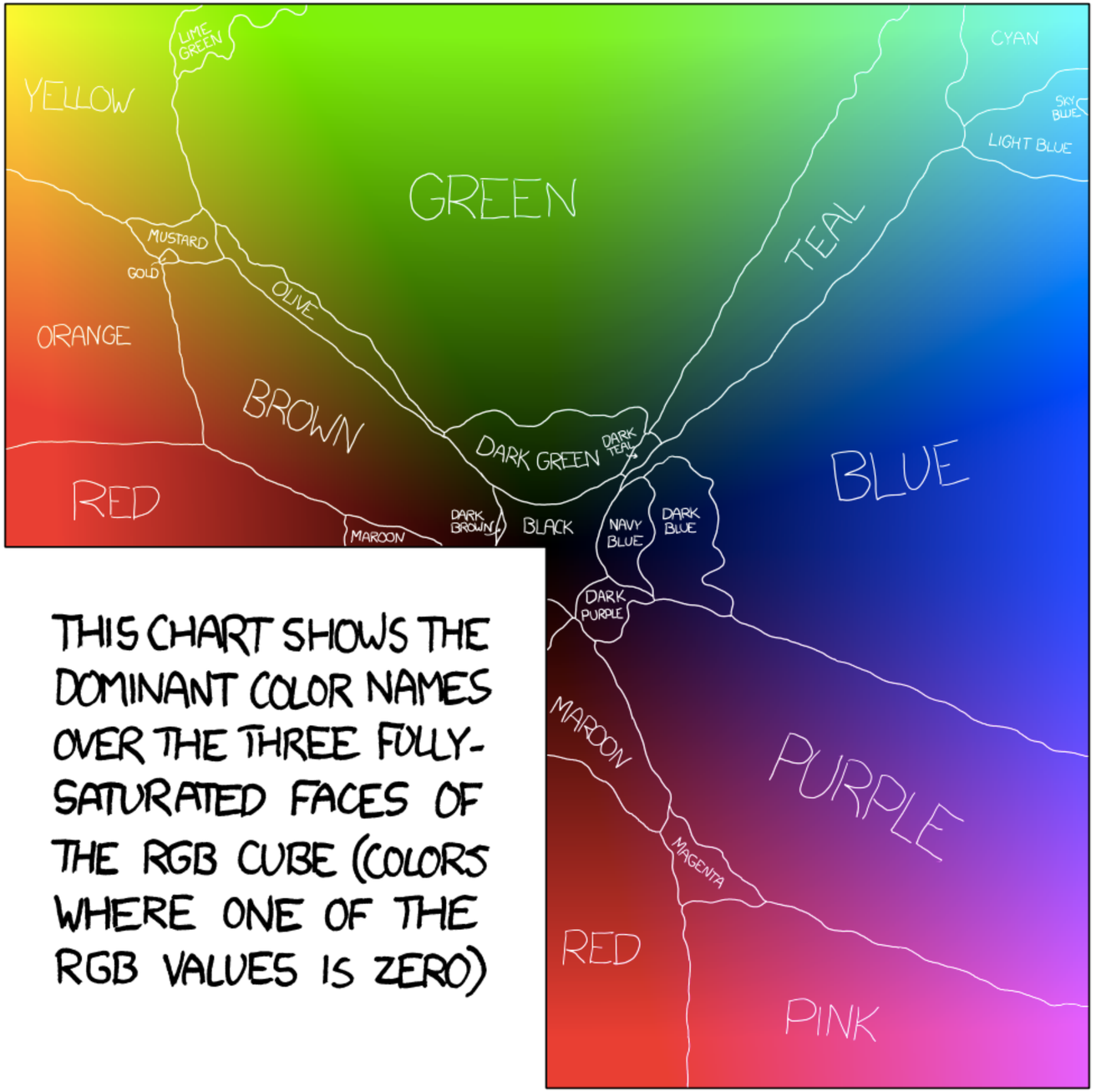
Language #19 (Camsa)
Mutual info = 0.939 / Contribution = 0.487



Language #24 (Chavacano)
Mutual info = 0.939 / Contribution = 0.513



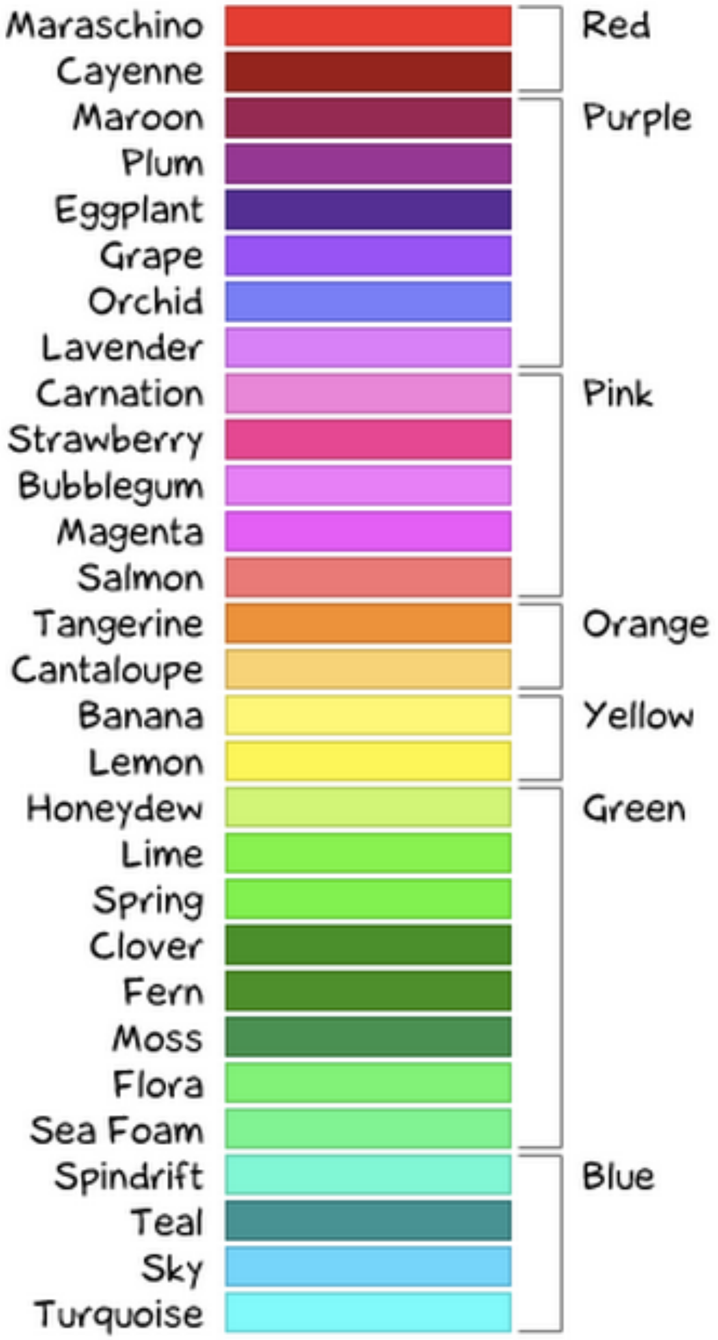
Color & Culture



THIS CHART SHOWS THE DOMINANT COLOR NAMES OVER THE THREE FULLY-SATURATED FACES OF THE RGB CUBE (COLORS WHERE ONE OF THE RGB VALUES IS ZERO)

http://imgs.xkcd.com/blag/satfaces_map_1024.png

Color names if you're a girl...



Color names if you're a guy...

Doghouse Diaries
"We take no as an answer."

Color Spaces

Tension

Tension

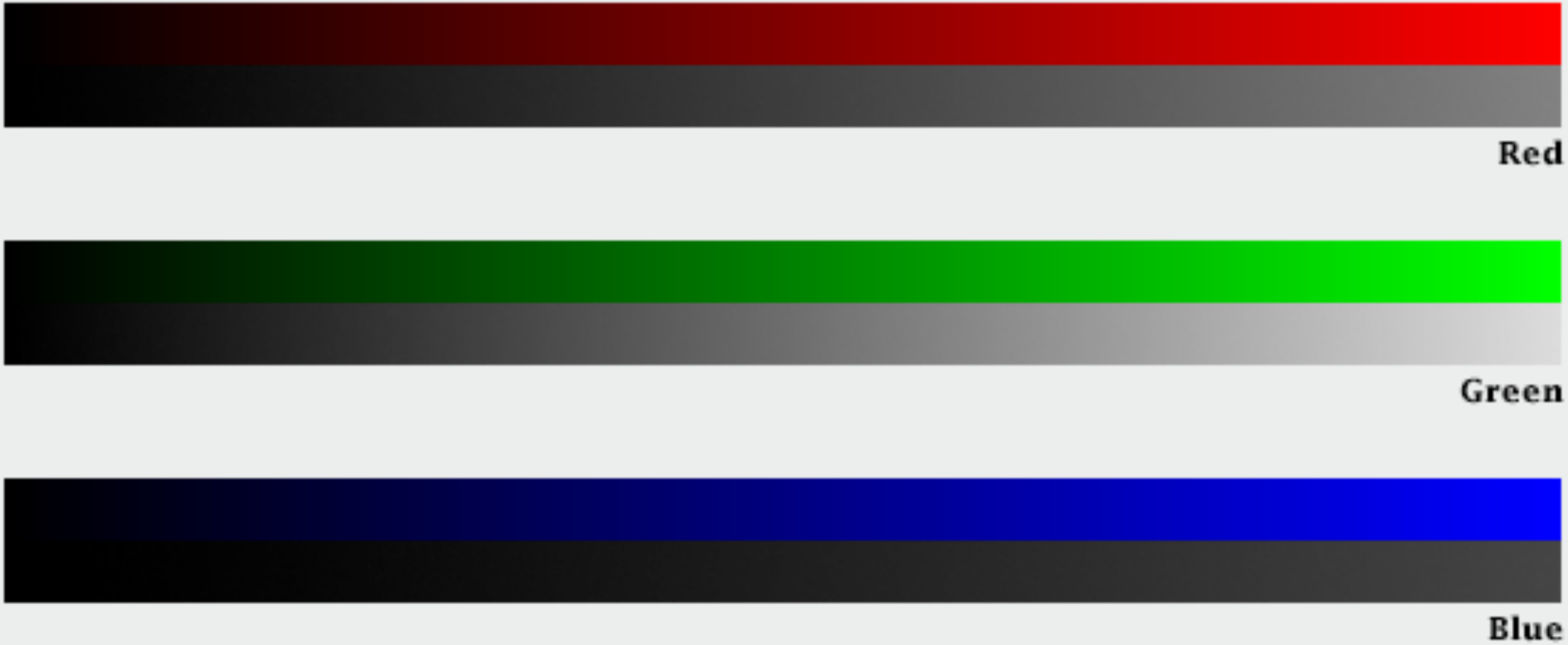
good for machines

Tension

good for machines

good for people

rgb



Rob Simmon, Subtleties of Color

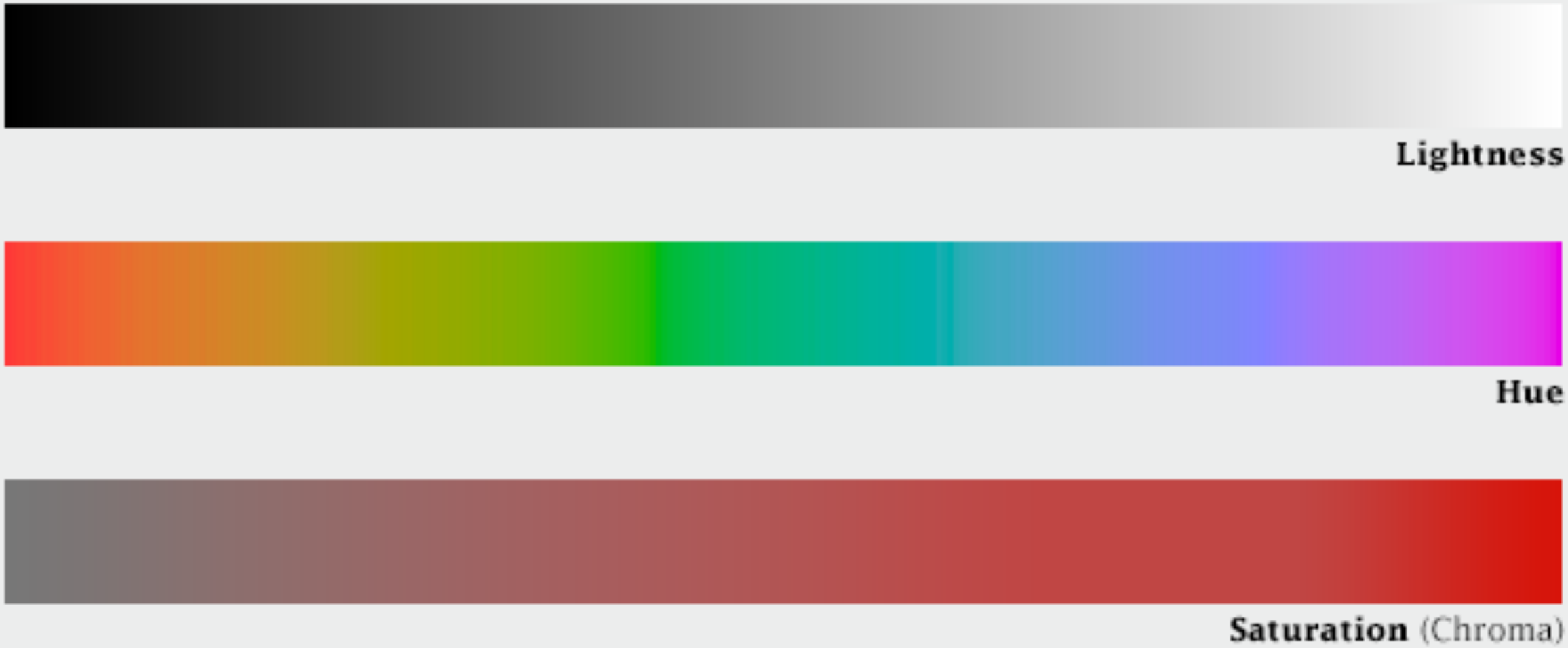
rgb

rgb

-5% +5%

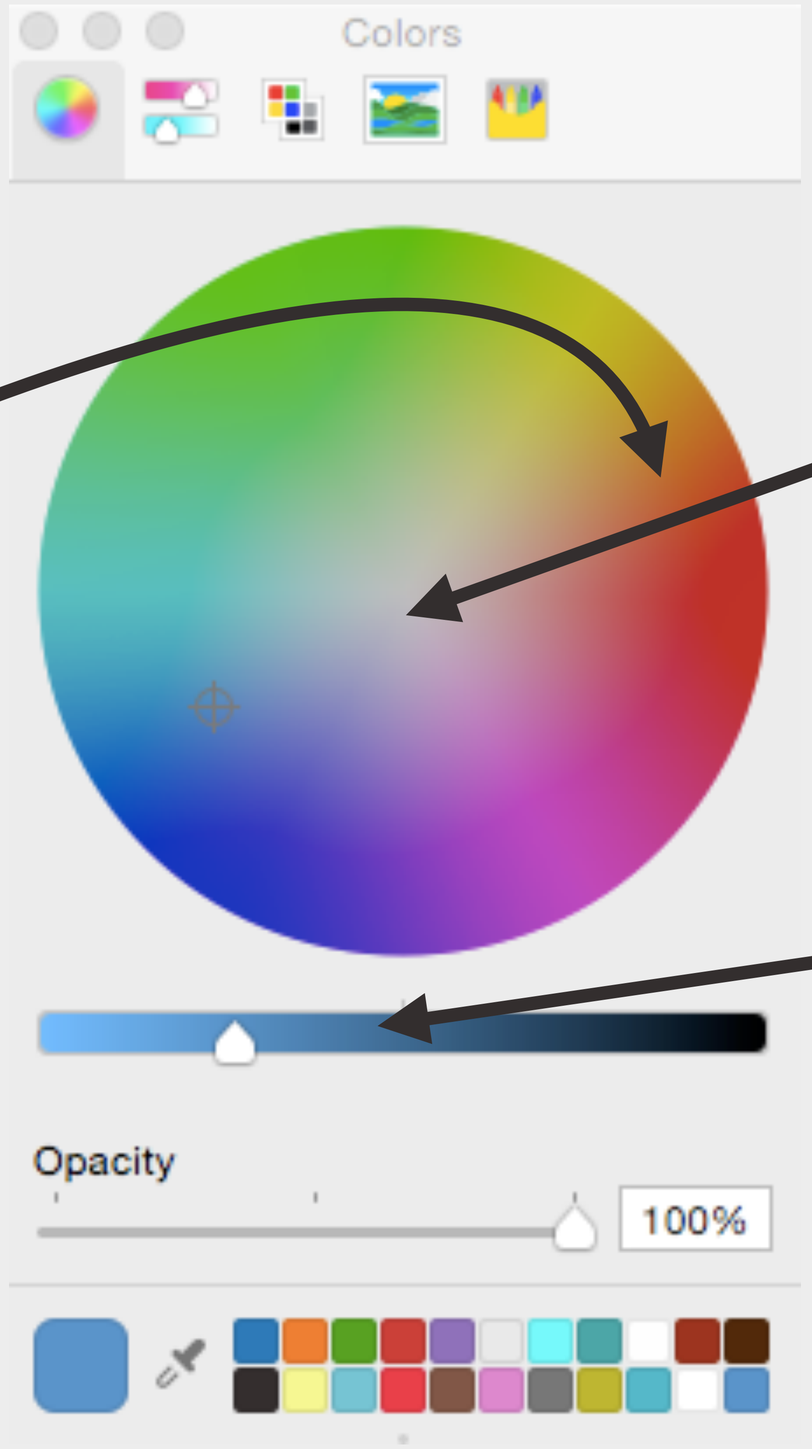
good for machines	*good for people*
rgb	

hsl / hsv



Rob Simmon, Subtleties of Color

hsv

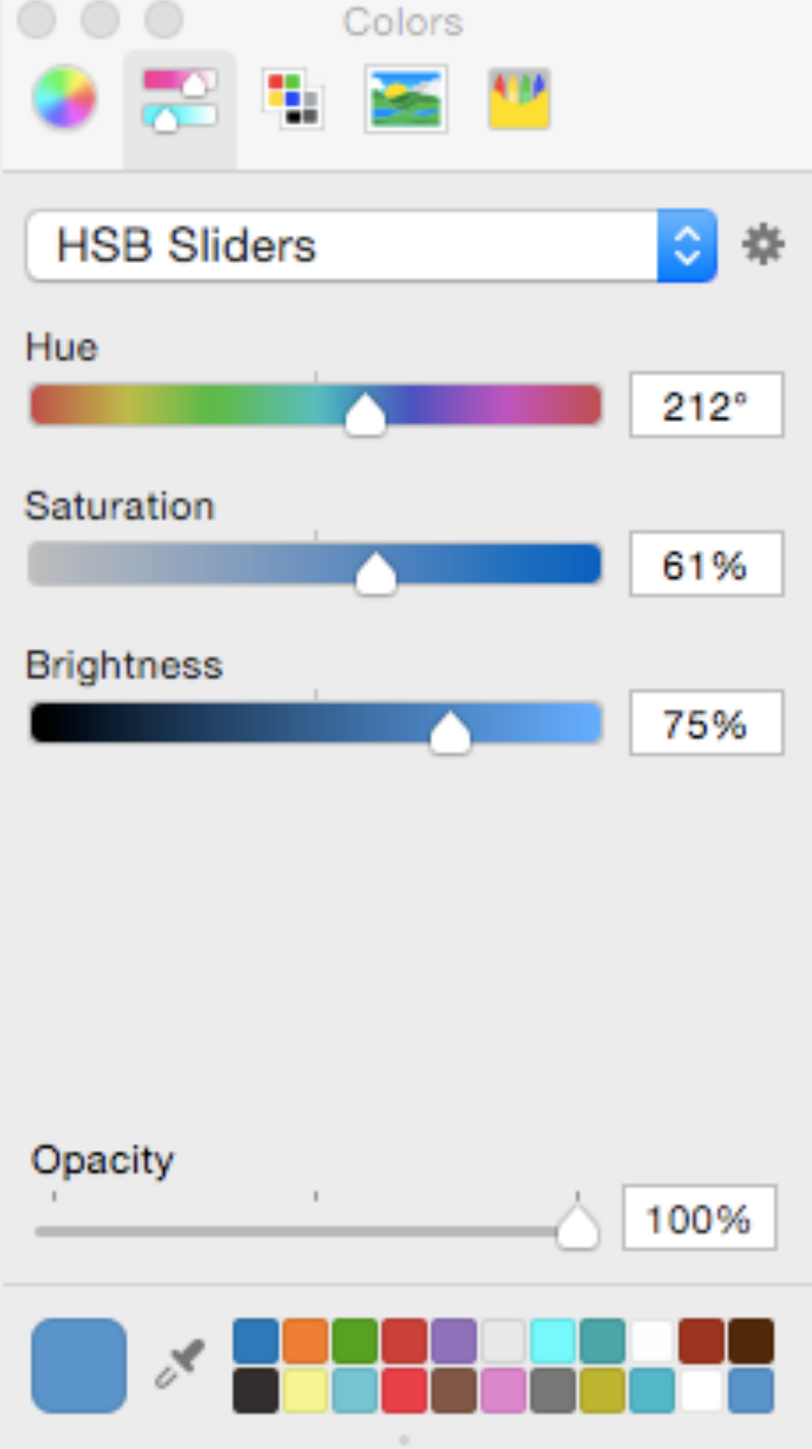


hue

saturation

value

hsv


Colors
HSB Sliders
Hue
212°
Saturation
61%
Brightness
75%
Opacity
100%

hsv

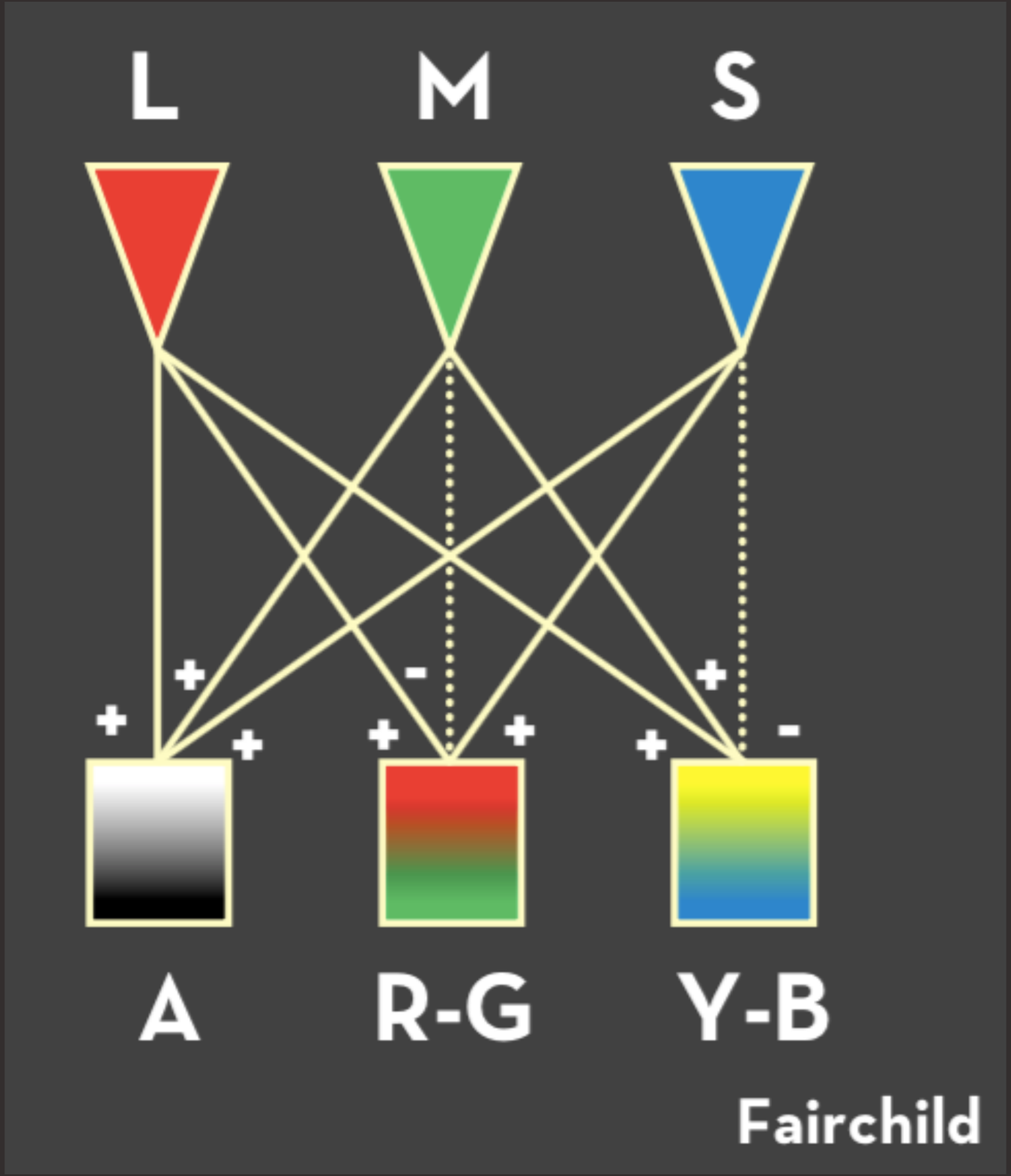
hsv

-5% +5%

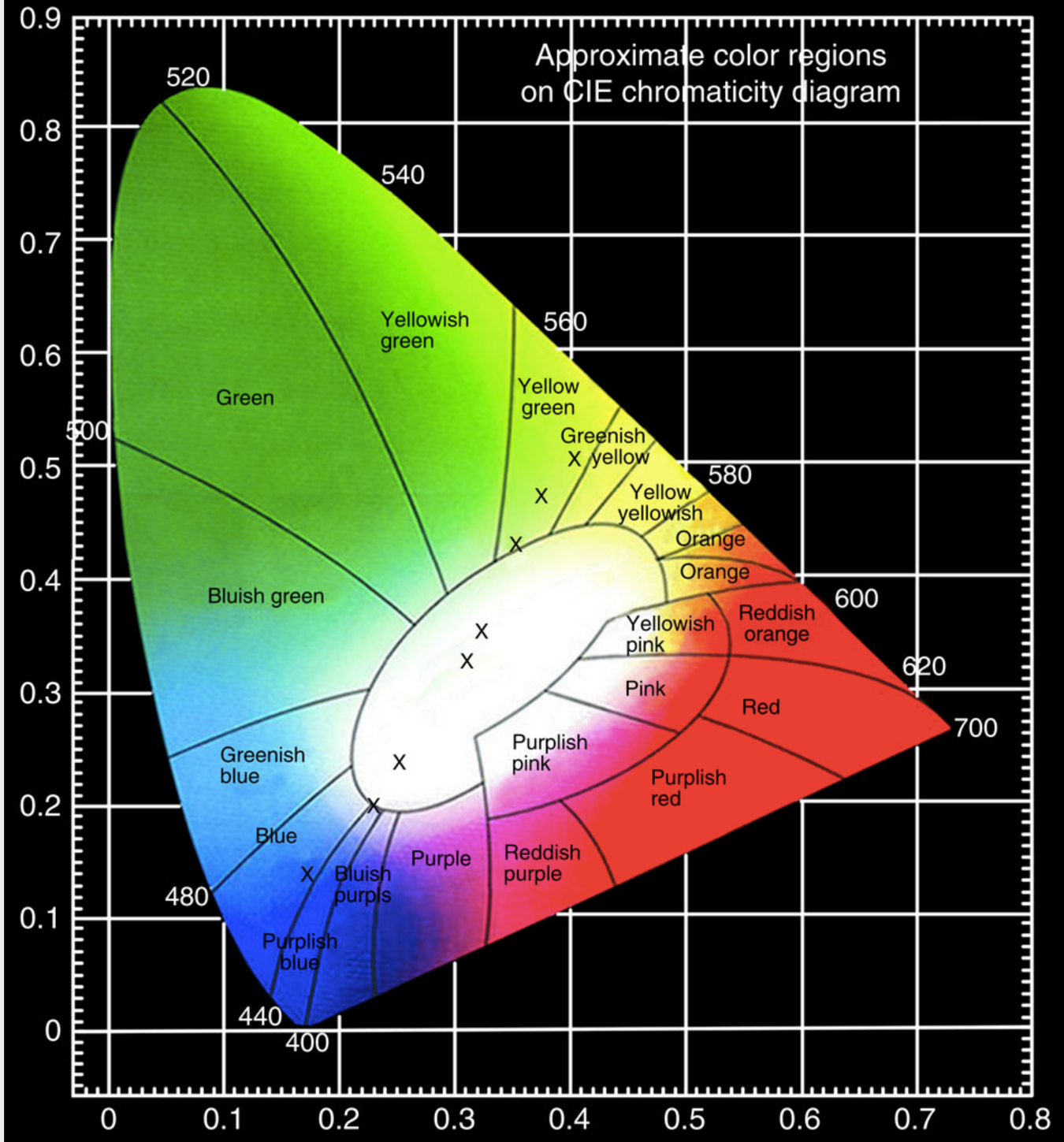
good for machines	*good for people*
rgb	*hsv*

Remember?

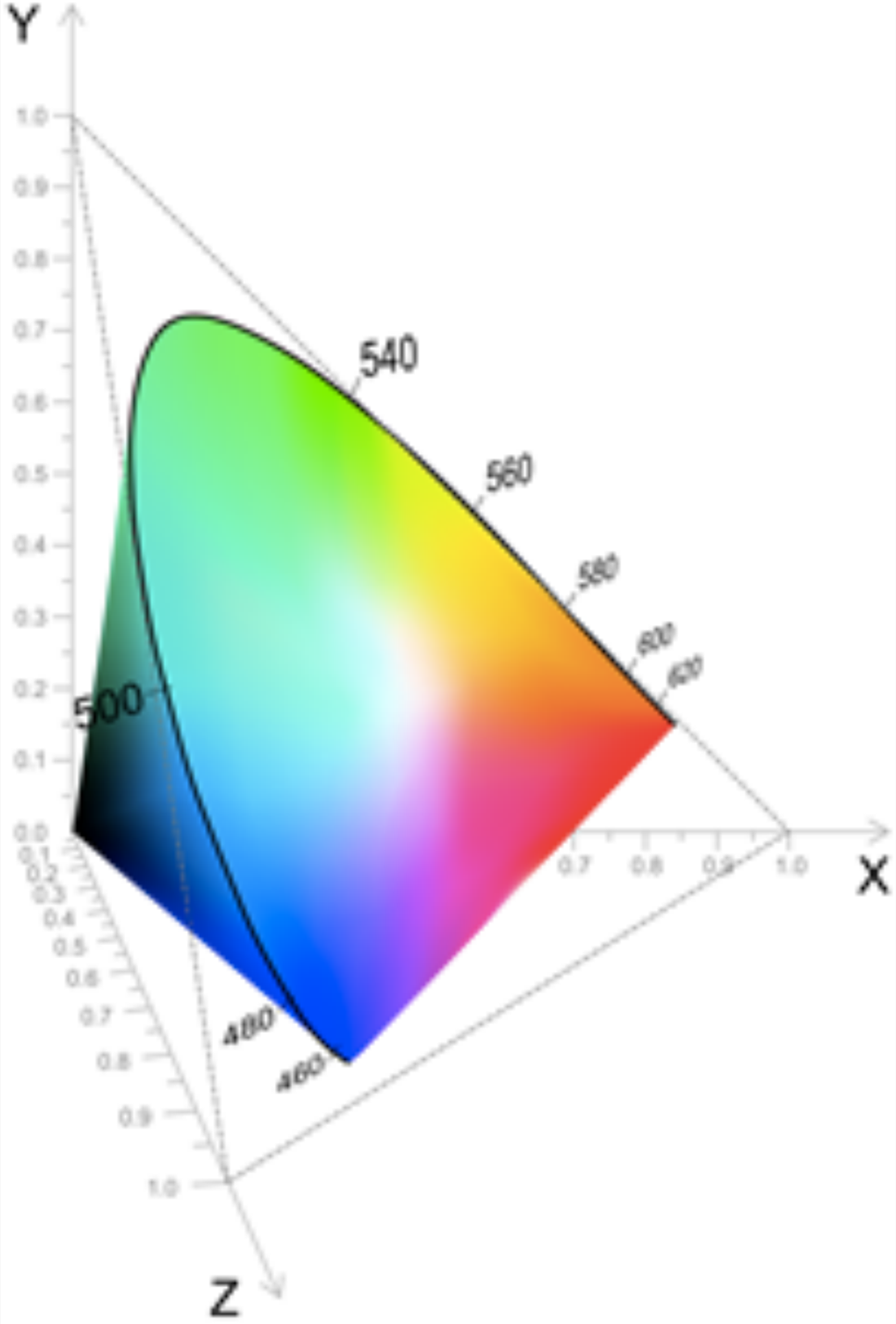
Long
Middle
Short



CIE XYZ

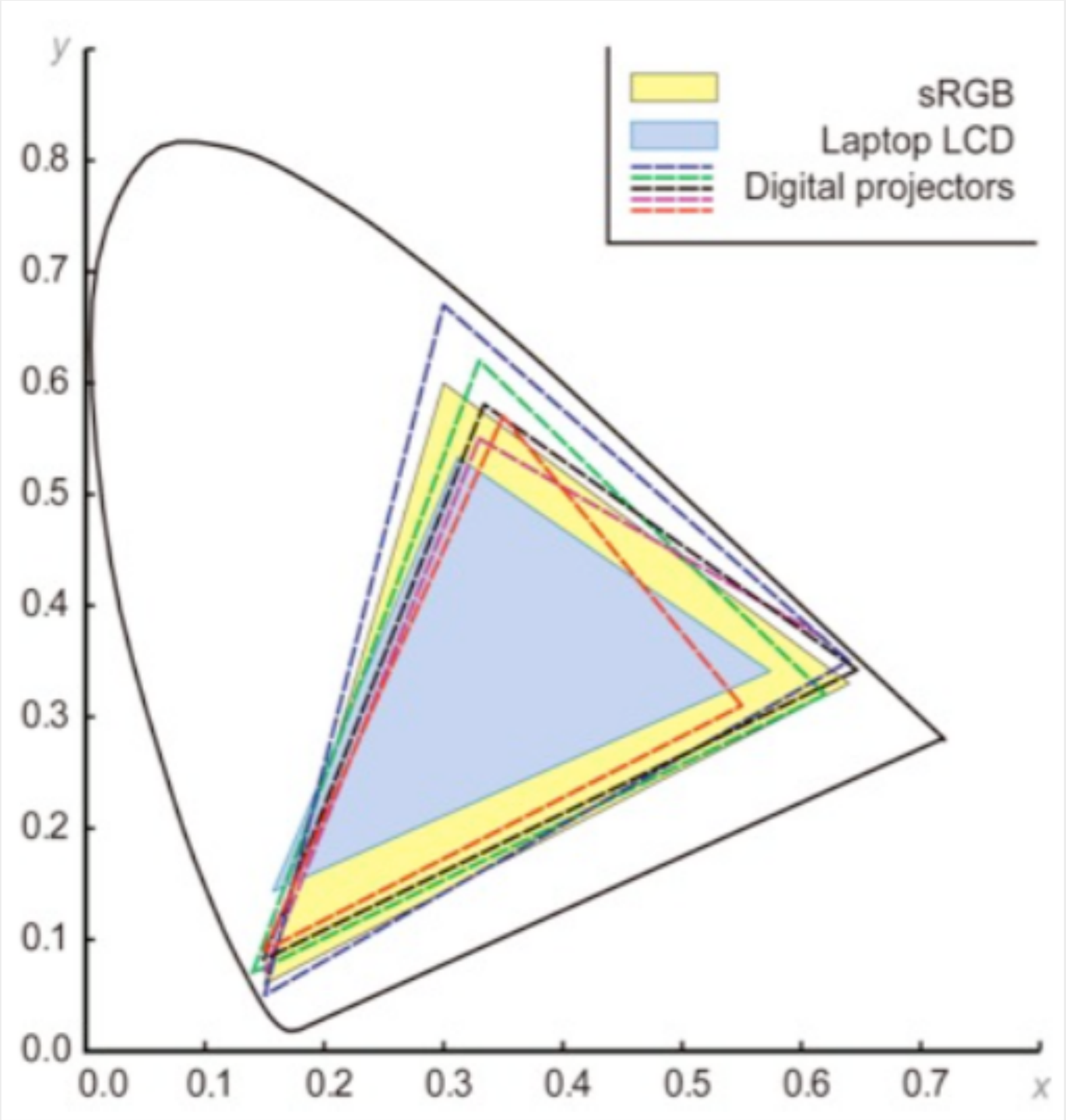

Approximate color regions
on CIE chromaticity diagram
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
520
540
560
580
600
620
700
500
480
440
400
Green
Yellowish green
Yellow green
Greenish yellow
Yellow yellowish
Orange
Orange
Reddish orange
Yellowish pink
Pink
Red
Purplish pink
Purplish red
Reddish purple
Purple
Bluish purpls
Bluish green
Greenish blue
Blue
Purplish blue

CIE XYZ



CIE XYZ

our displays are an embedding

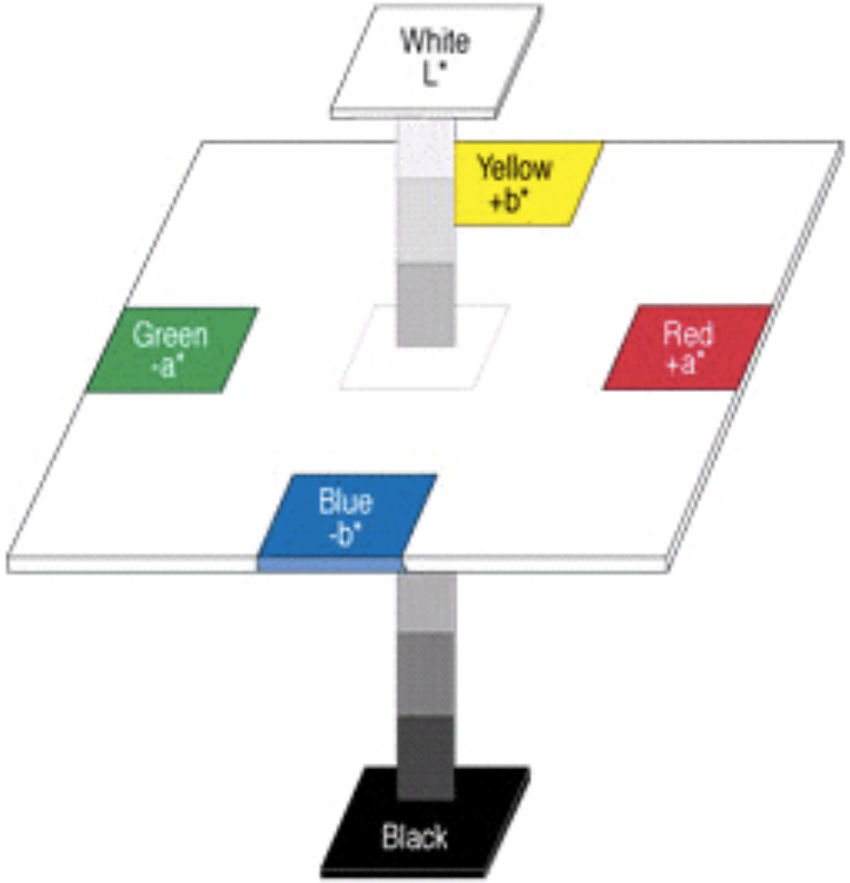


CIE Lab

Luminance

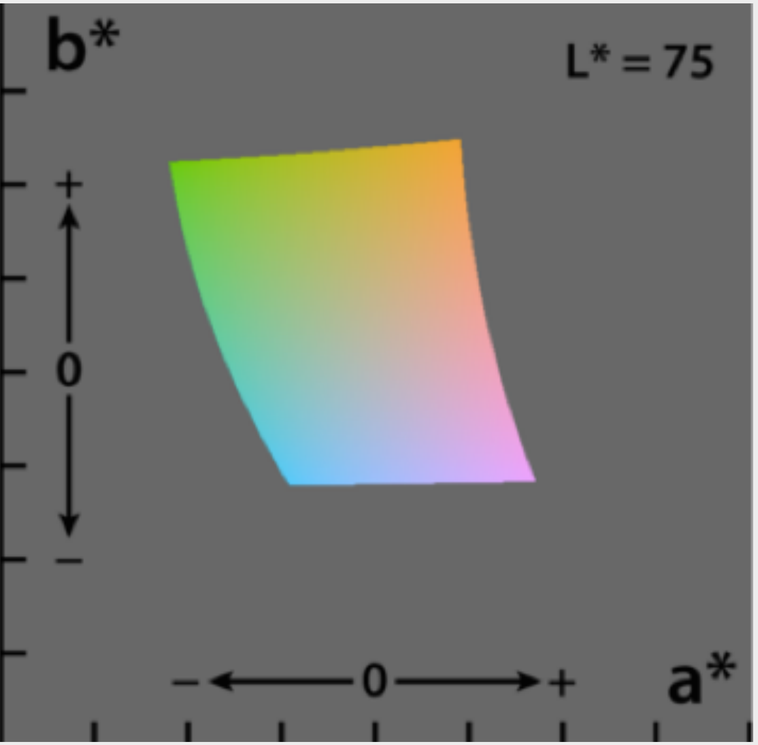
a (red green)

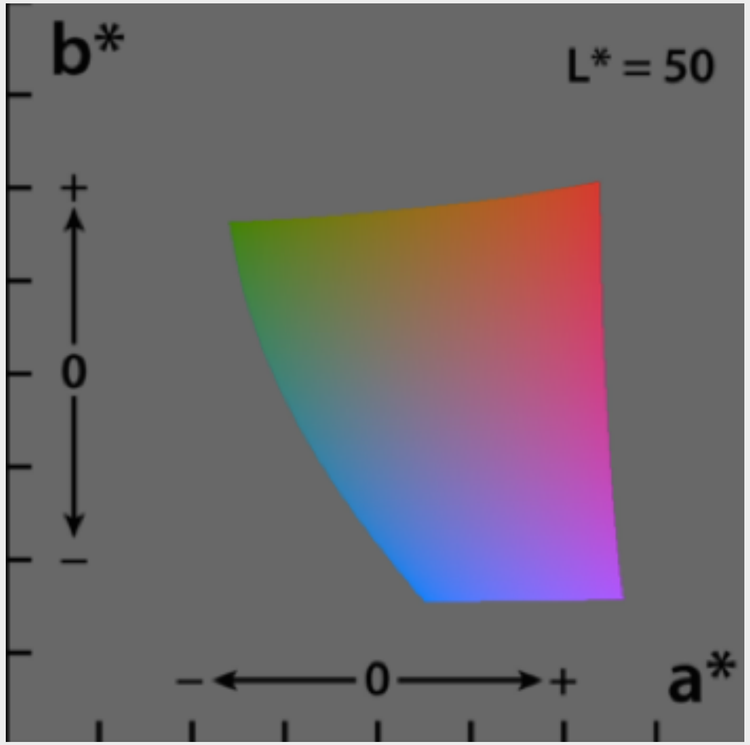
b (blue yellow)

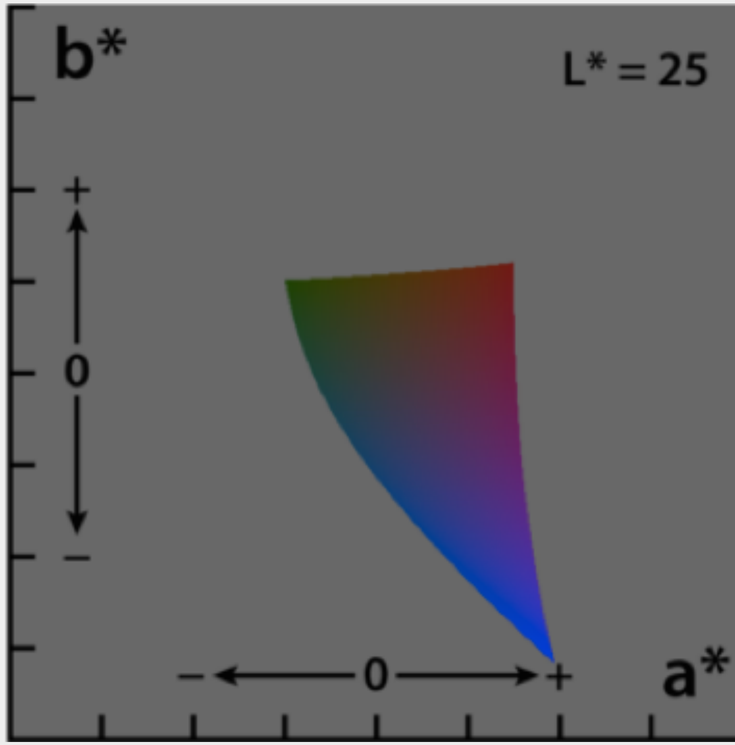


Example	L*	a*	b*
Pale Gray (nearly white)	83.70	-0.50	0.05
Medium Gray	59.60	0.00	0.50
Brilliant Red	43.70	37.10	18.70
Brilliant Yellow	83.30	1.90	77.00
Green	56.80	-30.00	15.40
Deep Blue	29.30	8.0	-17.90

CIE Lab







Lab

-5% +5%

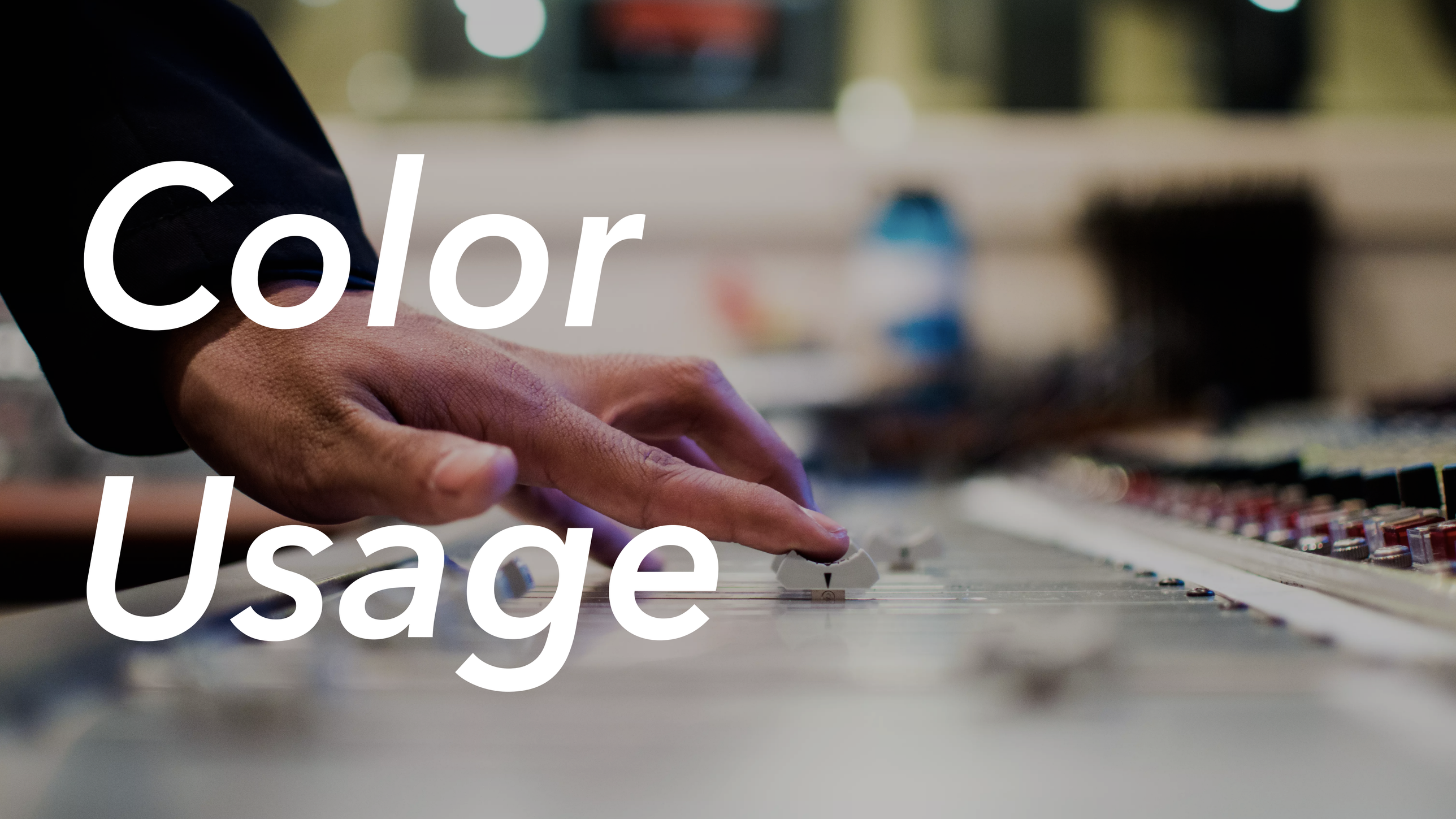
aligns with machines

good for people

rgb

hsv

Lab



Color Usage

Mapping data to color

Nominal

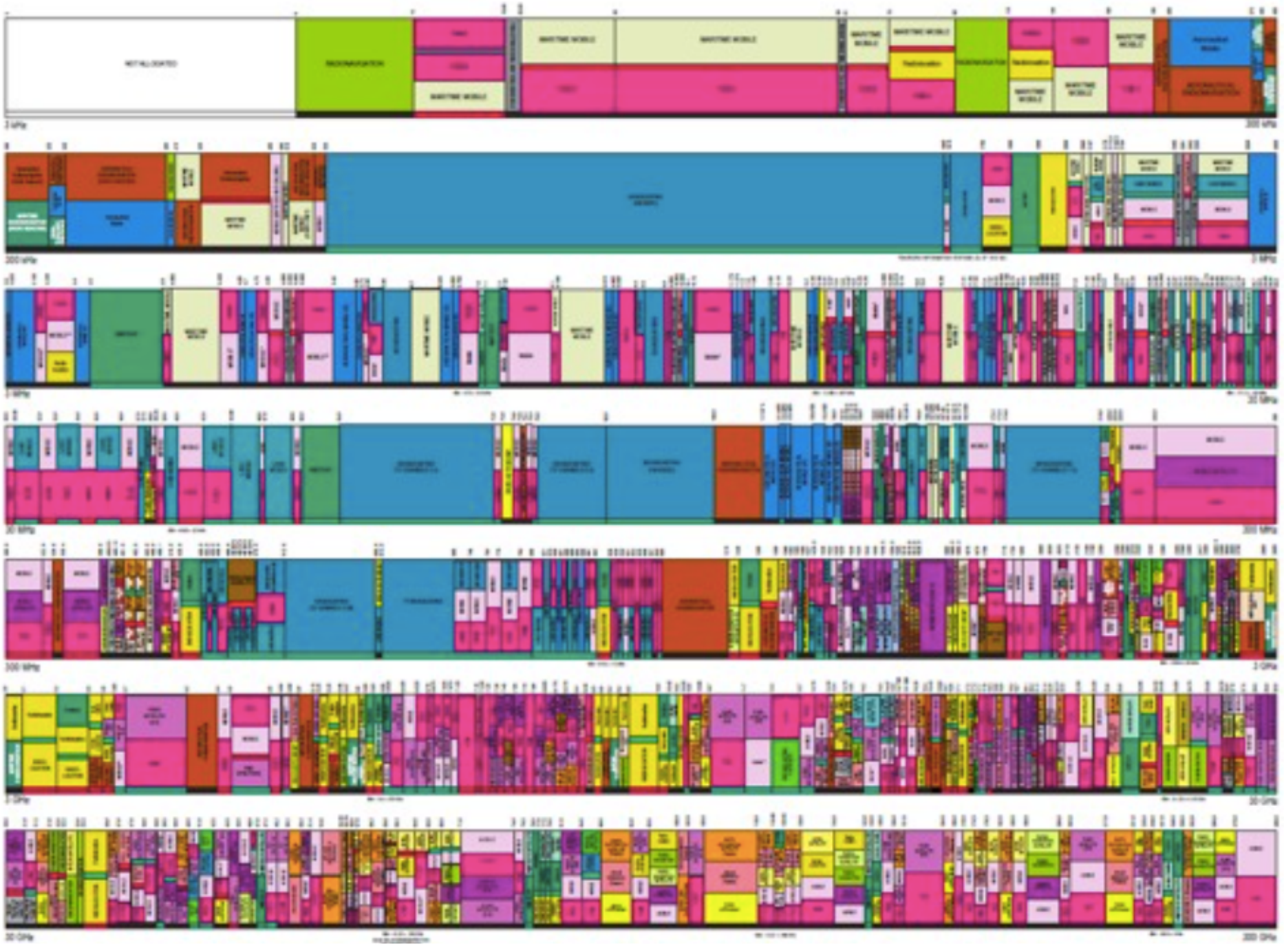
UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

ACTIVITY CODE

ALLOCATION USAGE DESIGNATION



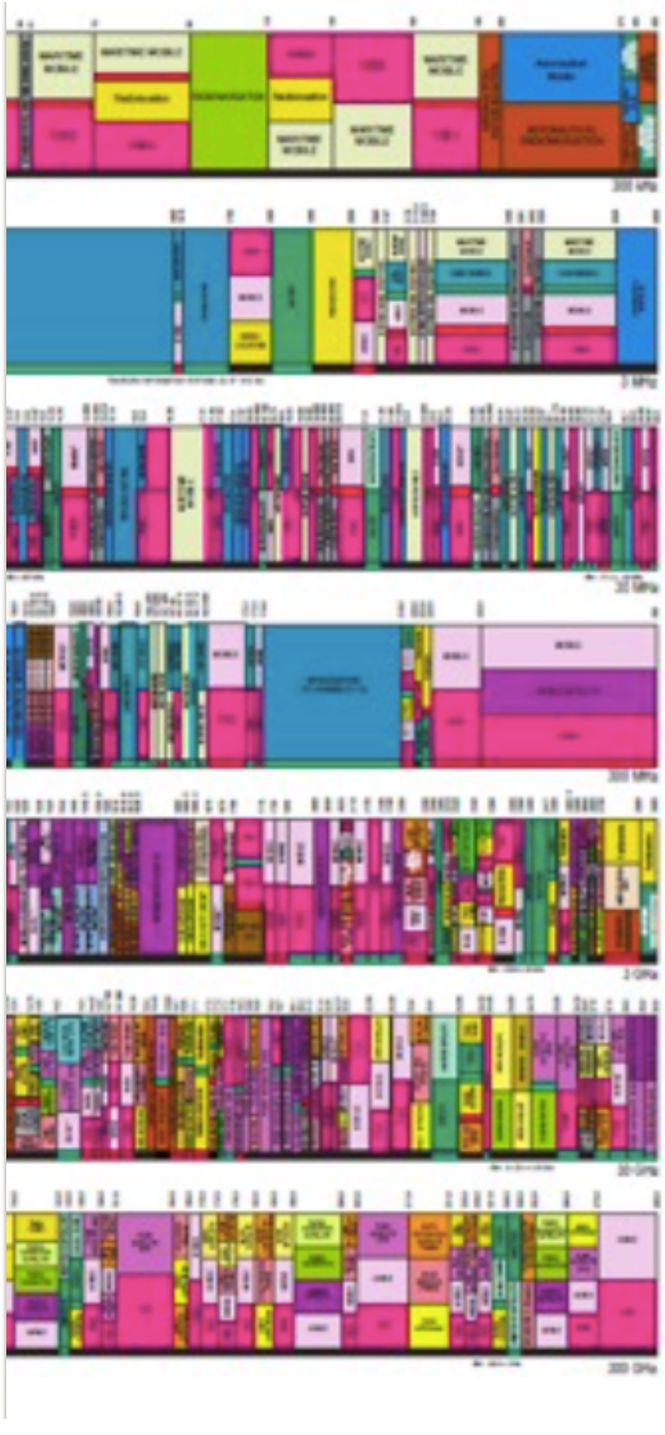
UNITED STATES FREQUENCY ALLOCATIONS

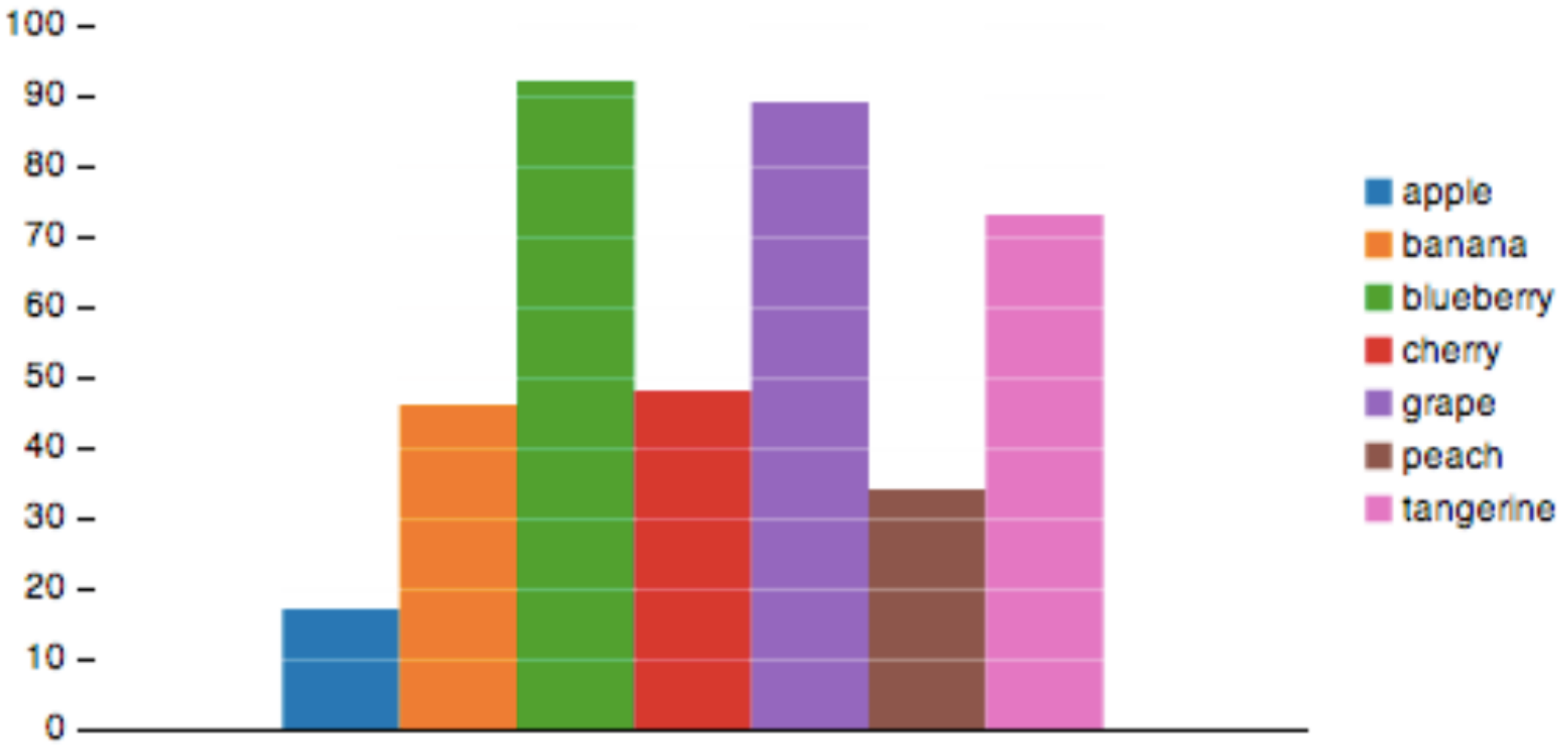
THE RADIO SPECTRUM

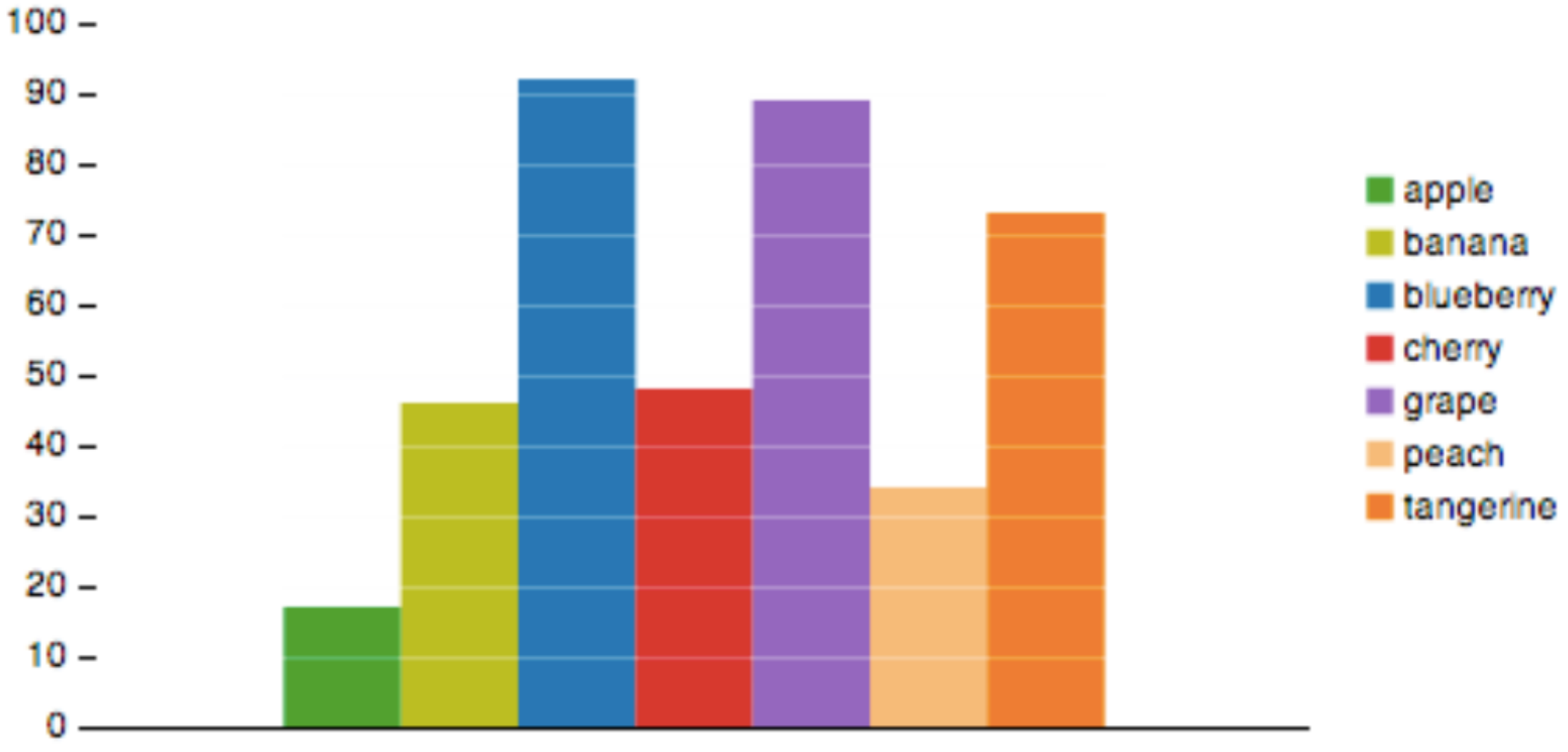
RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE SATELLITE
- MARITIME RADIONAVIGATION
- METEOROLOGICAL AIDS
- METEOROLOGICAL SATELLITE
- MOBILE
- MOBILE SATELLITE
- RADIO ASTRONOMY
- RADIODETERMINATION SATELLITE
- RADIOLOCATION
- RADIOLOCATION SATELLITE
- RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- SPACE OPERATION
- SPACE RESEARCH
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE




100
90
80
70
60
50
40
30
20
10
0
apple
banana
blueberry
cherry
grape
peach
tangerine


100
90
80
70
60
50
40
30
20
10
0
apple
banana
blueberry
cherry
grape
peach
tangerine

Fruits	A	E
Apple		
Banana		
Blueberry		
Cherry		
Grape		
Peach		
Tangerine		

Vegetables	A	E
Carrot		
Celery		
Corn		
Eggplant		
Mushroom		
Olive		
Tomato		

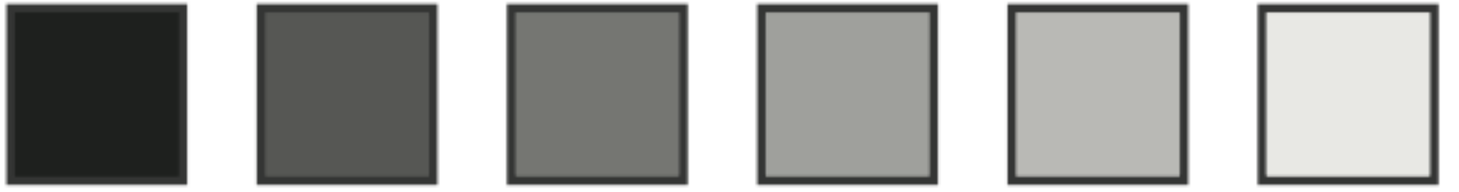
Drinks	A	E
A&W Root Beer		
Coca-Cola		
Dr. Pepper		
Pepsi		
Sprite		
Sunkist		
Welch's Grape		

Brands	A	E
Apple		
AT&T		
Home Depot		
Kodak		
Starbucks		
Target		
Yahoo!		

Semantic Naming

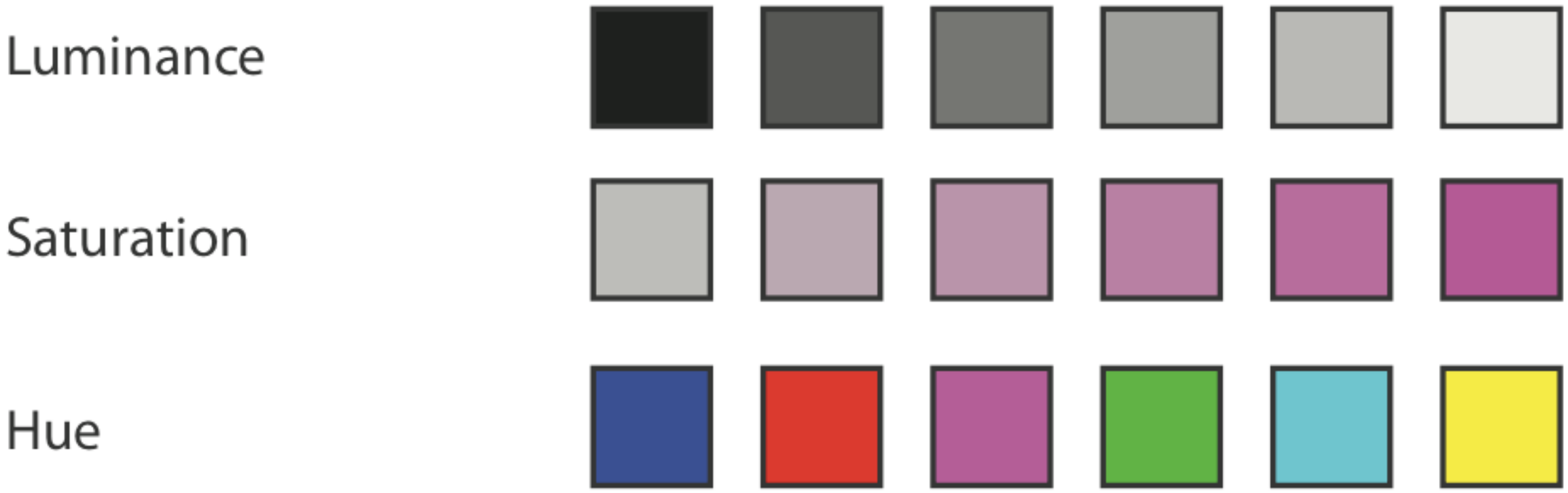
Ordinal

Luminance

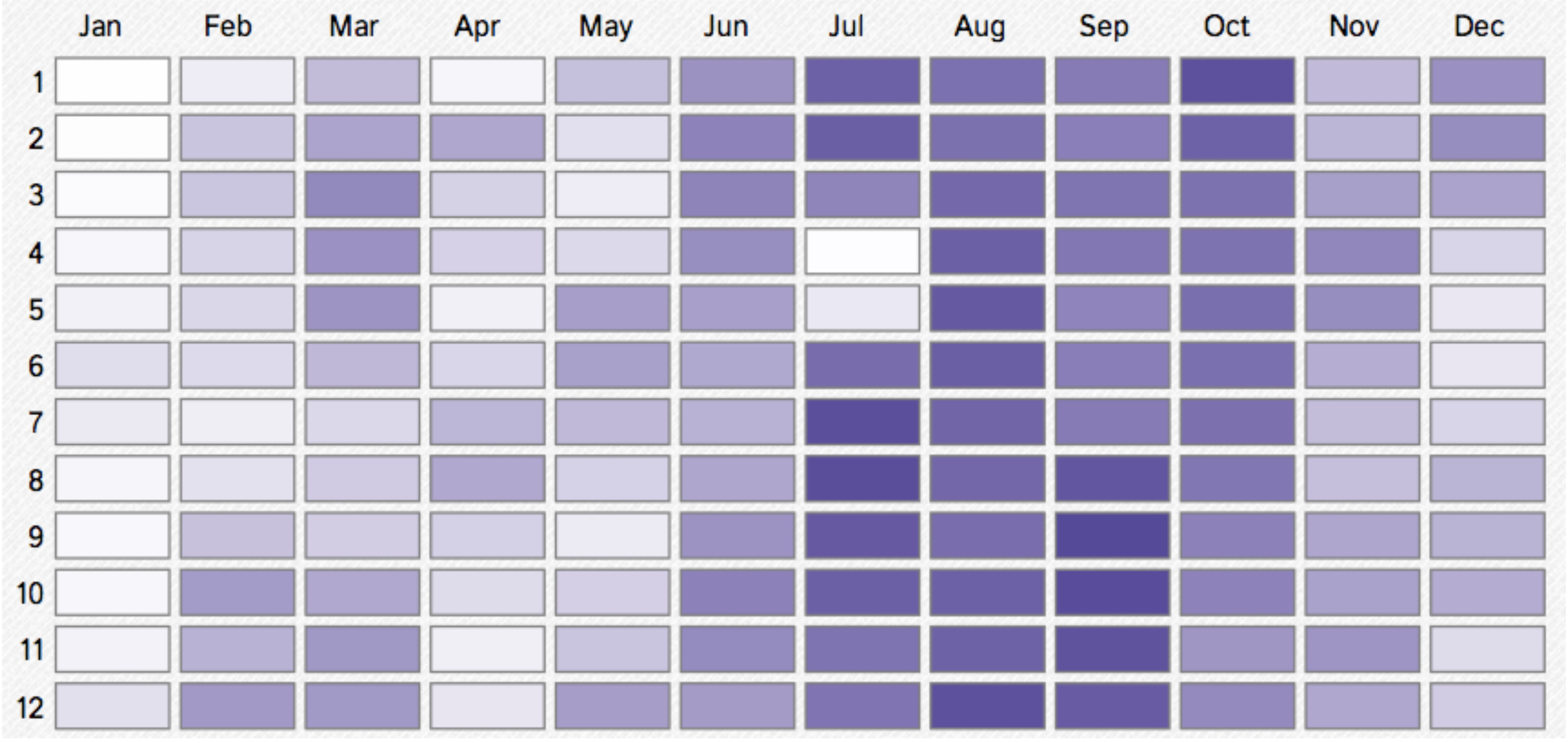


Luminance

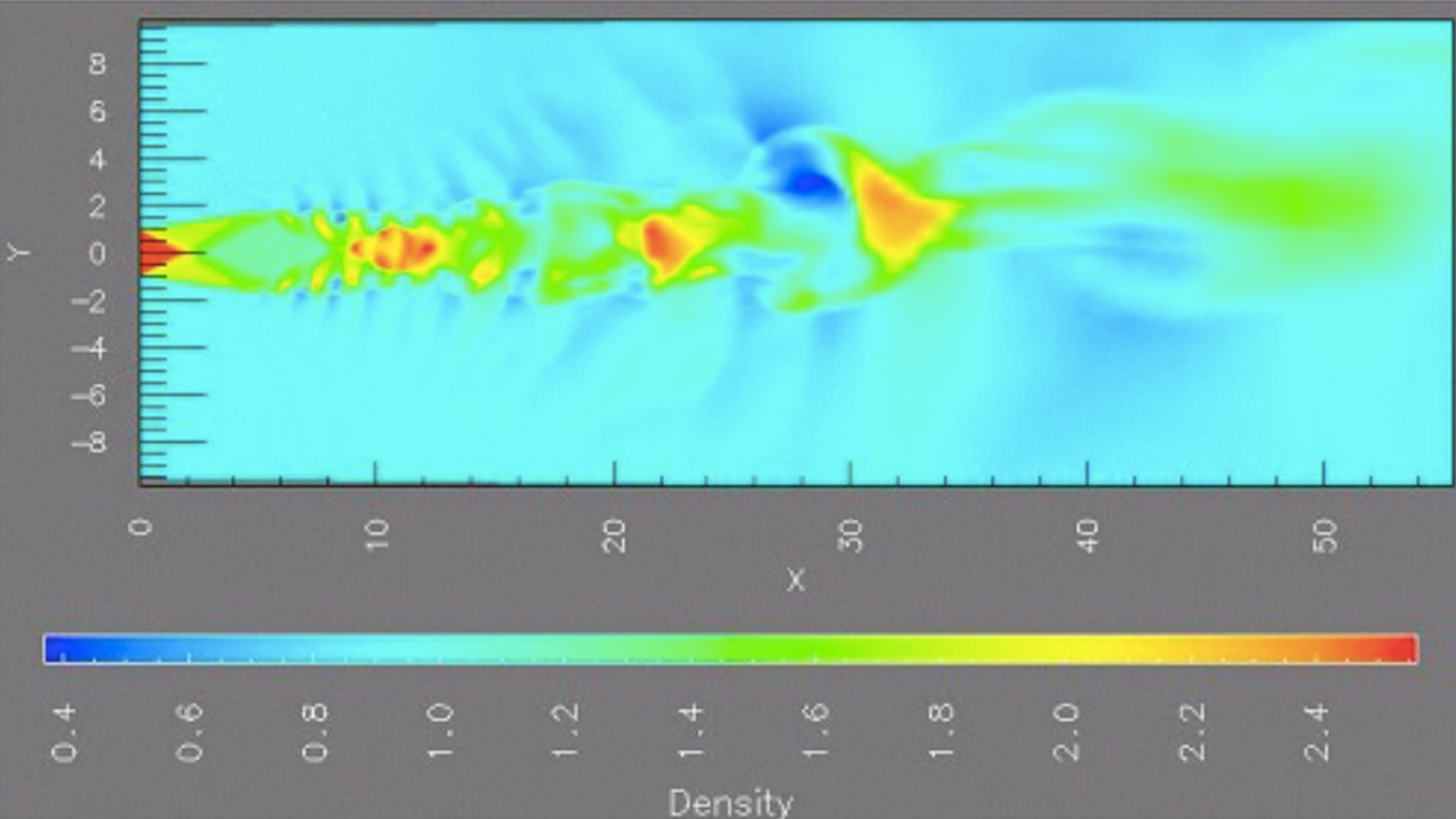
Saturation

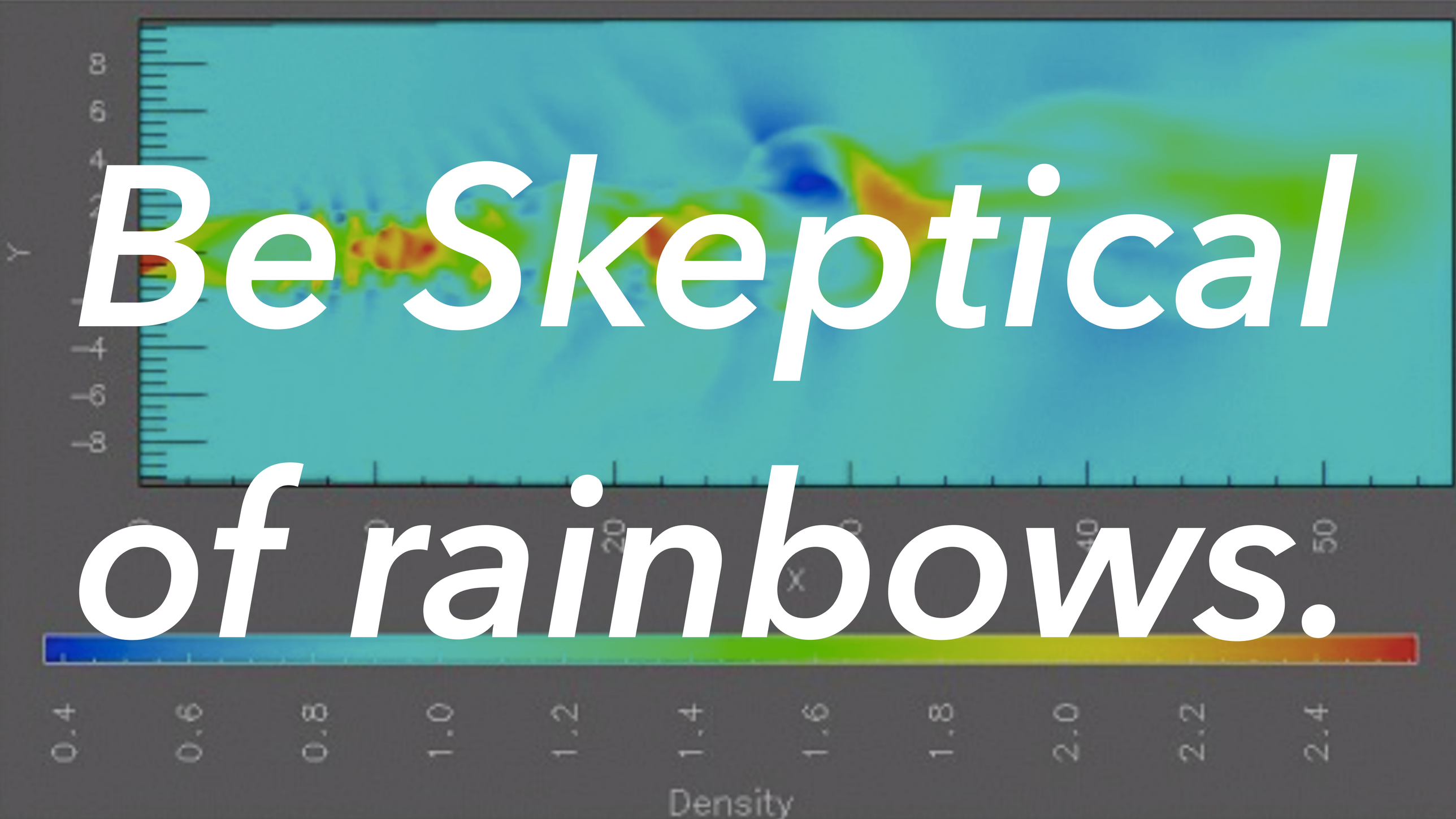


hue is not naturally ordered


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1
2
3
4
5
6
7
8
9
10
11
12

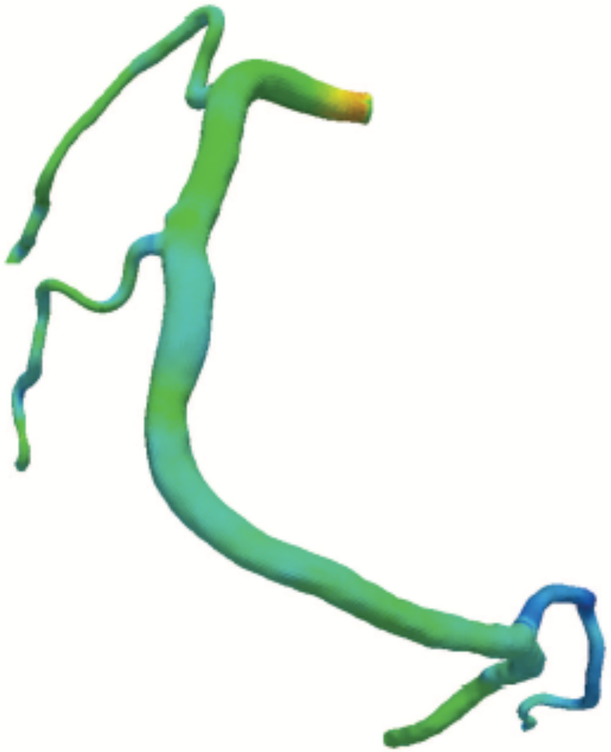
Continuous


Y
8
6
4
2
0
−2
−4
−6
−8
0
10
20
30
40
50
X
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Density

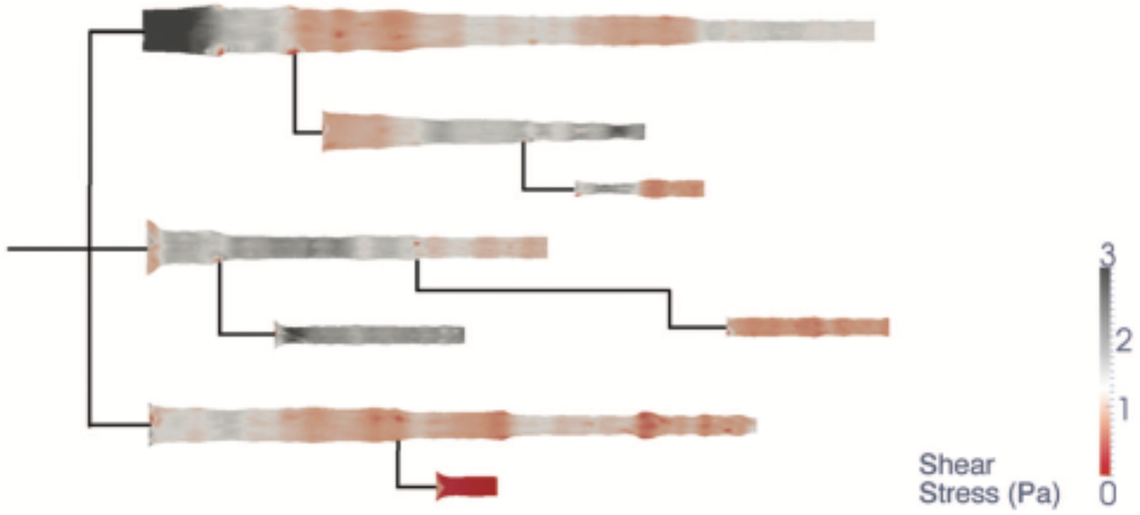


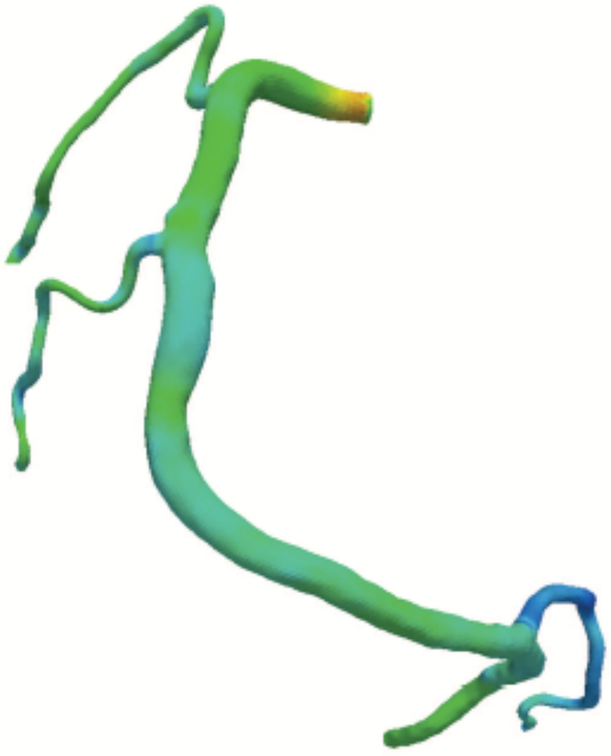
Be Skeptical of rainbows.

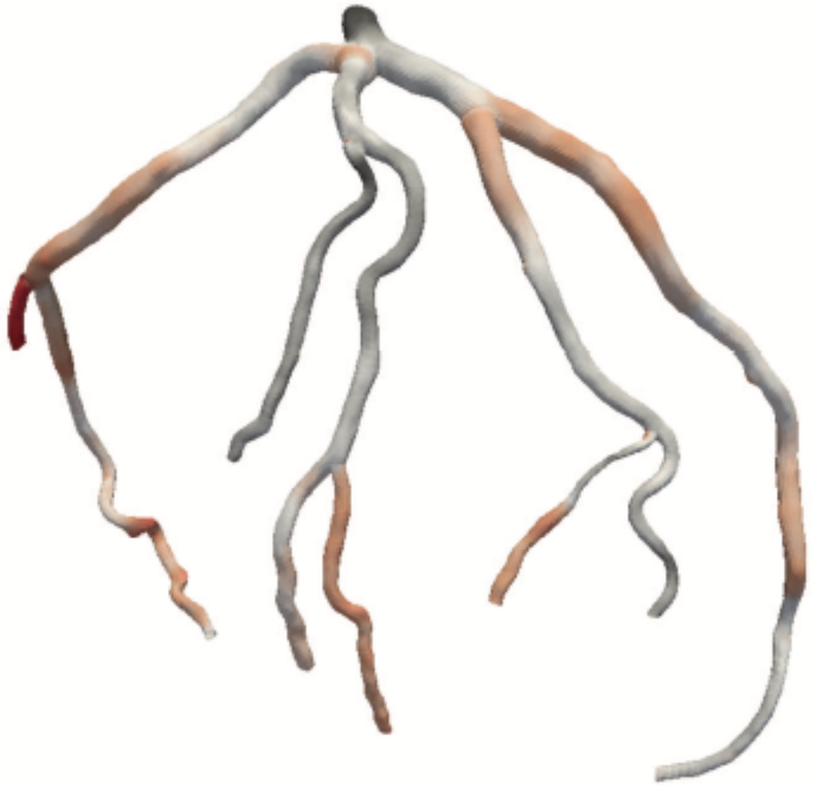
3
2
1
0
Shear
Stress (Pa)

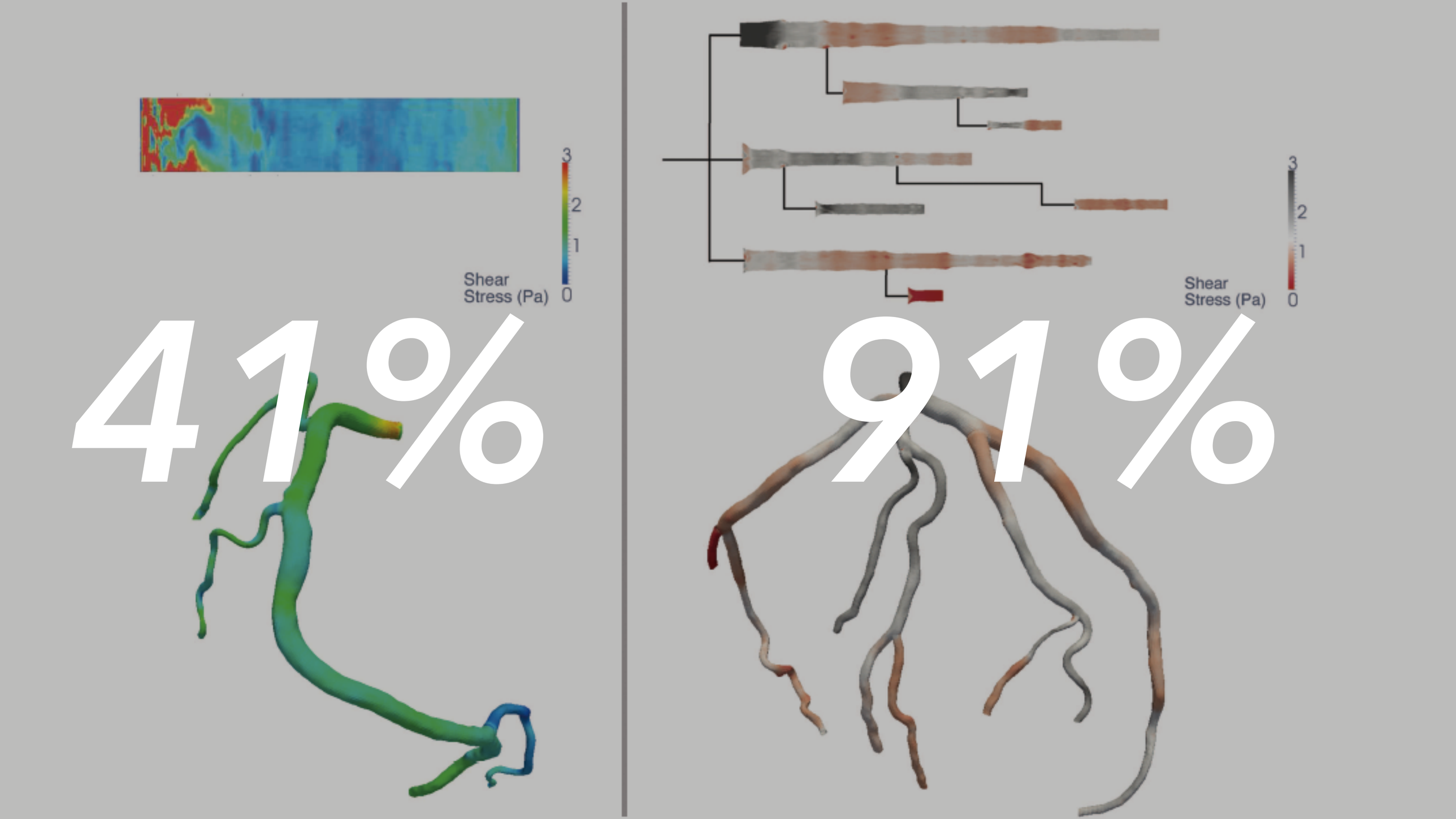


3
2
1
0
Shear
Stress (Pa)


3
2
1
0
Shear
Stress (Pa)

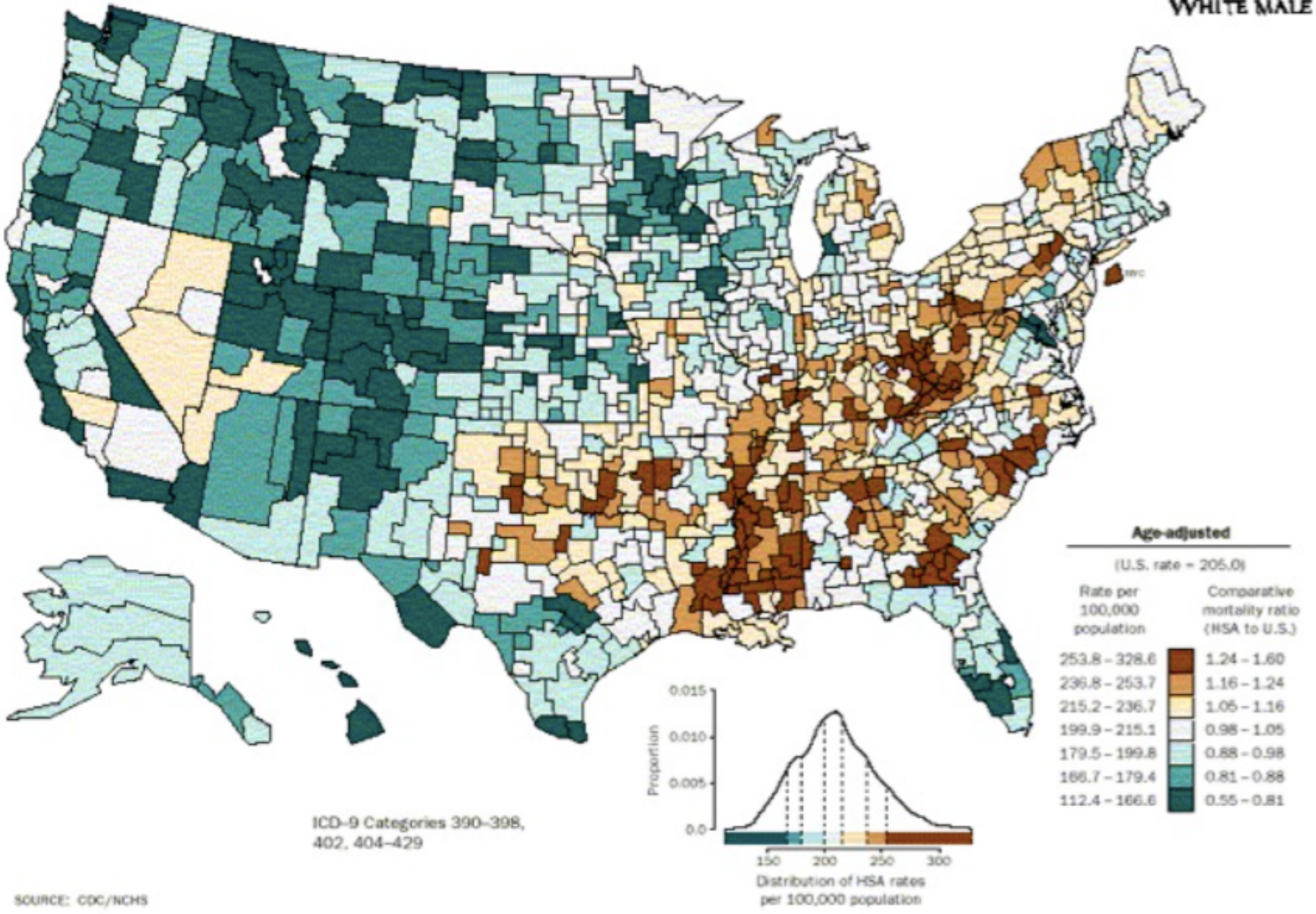





3
2
1
0
Shear
Stress (Pa)
41%
3
2
1
0
Shear
Stress (Pa)
91%

Age-adjusted death rates by HSA, 1988-92

Heart disease
White male



ICD-9 Categories 390–398, 402, 404–429

SOURCE: CDC/NCHS

Age-adjusted

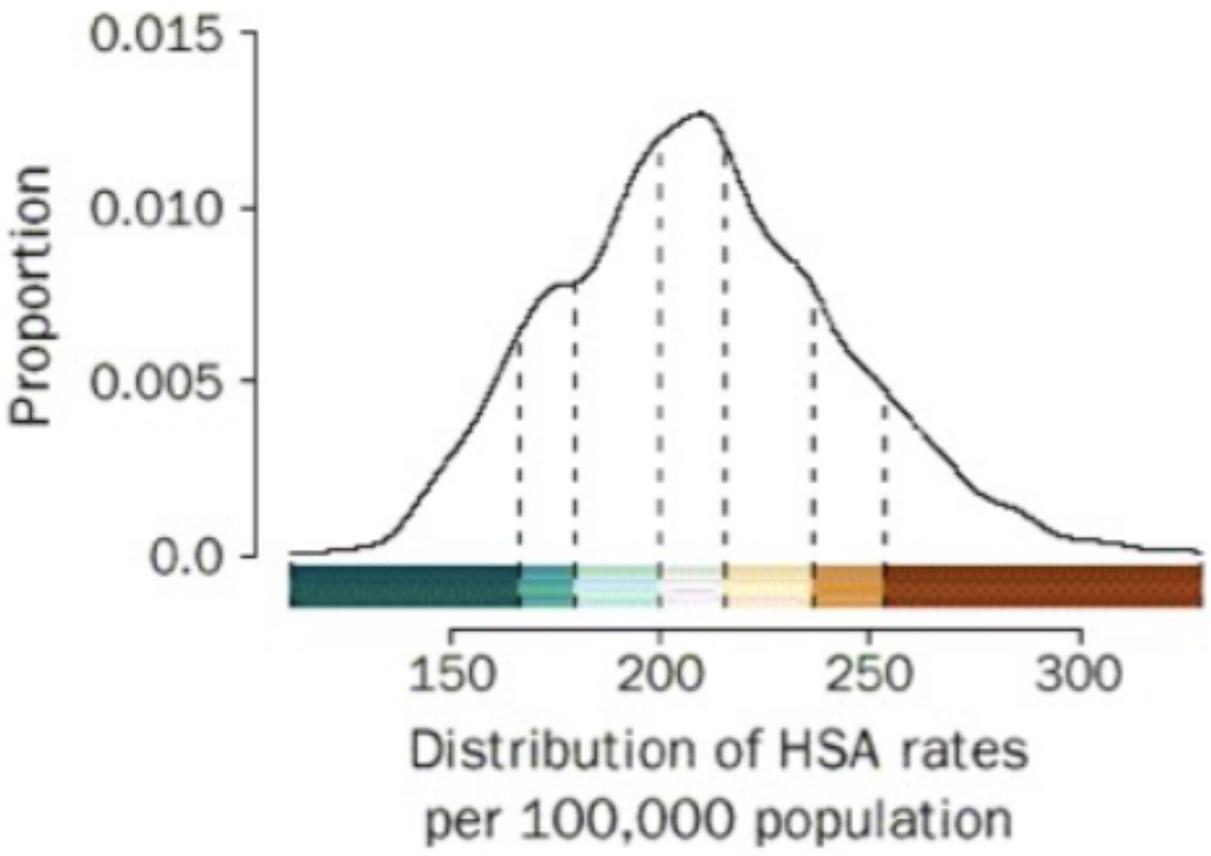
(U.S. rate = 205.0)

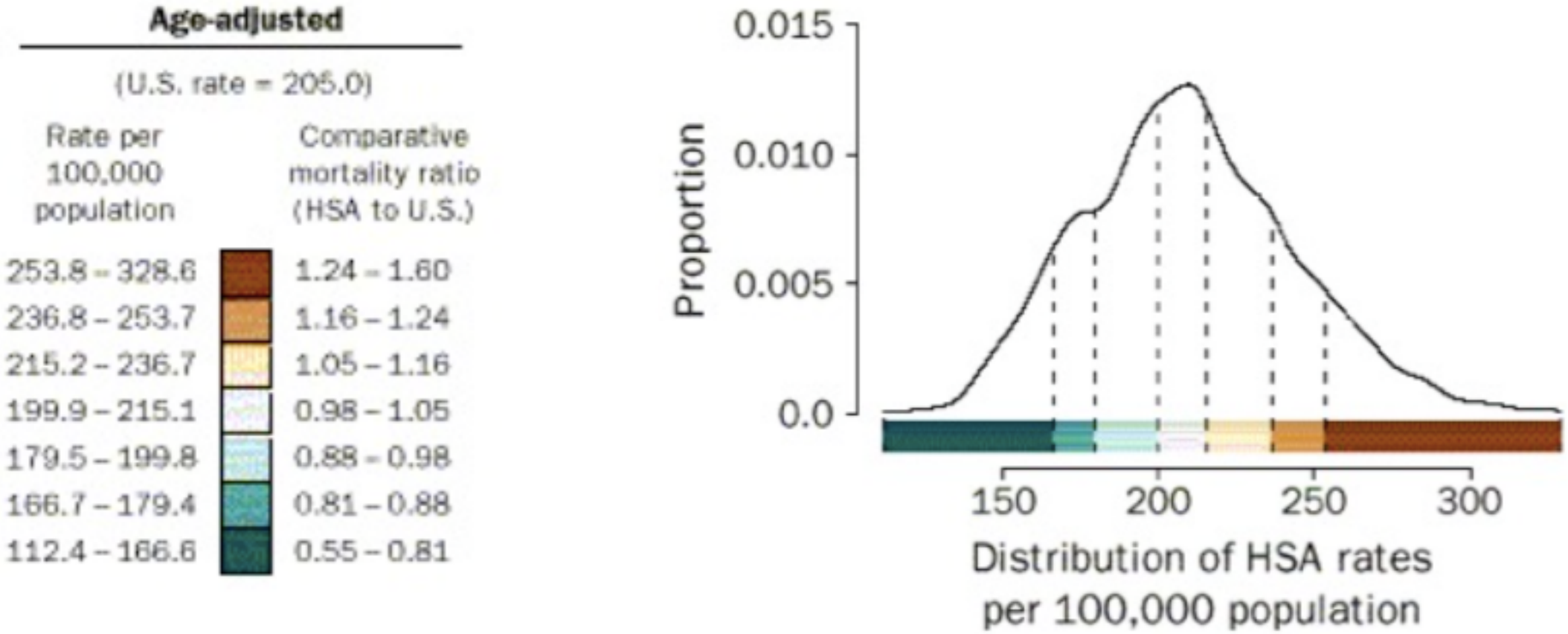
Rate per 100,000 population	Comparative mortality ratio (HSA to U.S.)
253.8 – 328.6	1.24 – 1.60
236.8 – 253.7	1.16 – 1.24
215.2 – 236.7	1.05 – 1.16
199.9 – 215.1	0.98 – 1.05
179.5 – 199.8	0.88 – 0.98
166.7 – 179.4	0.81 – 0.88
112.4 – 166.6	0.55 – 0.81

Age-adjusted

(U.S. rate = 205.0)

Rate per 100,000 population	Comparative mortality ratio (HSA to U.S.)
253.8 – 328.6	1.24 – 1.60
236.8 – 253.7	1.16 – 1.24
215.2 – 236.7	1.05 – 1.16
199.9 – 215.1	0.98 – 1.05
179.5 – 199.8	0.88 – 0.98
166.7 – 179.4	0.81 – 0.88
112.4 – 166.6	0.55 – 0.81



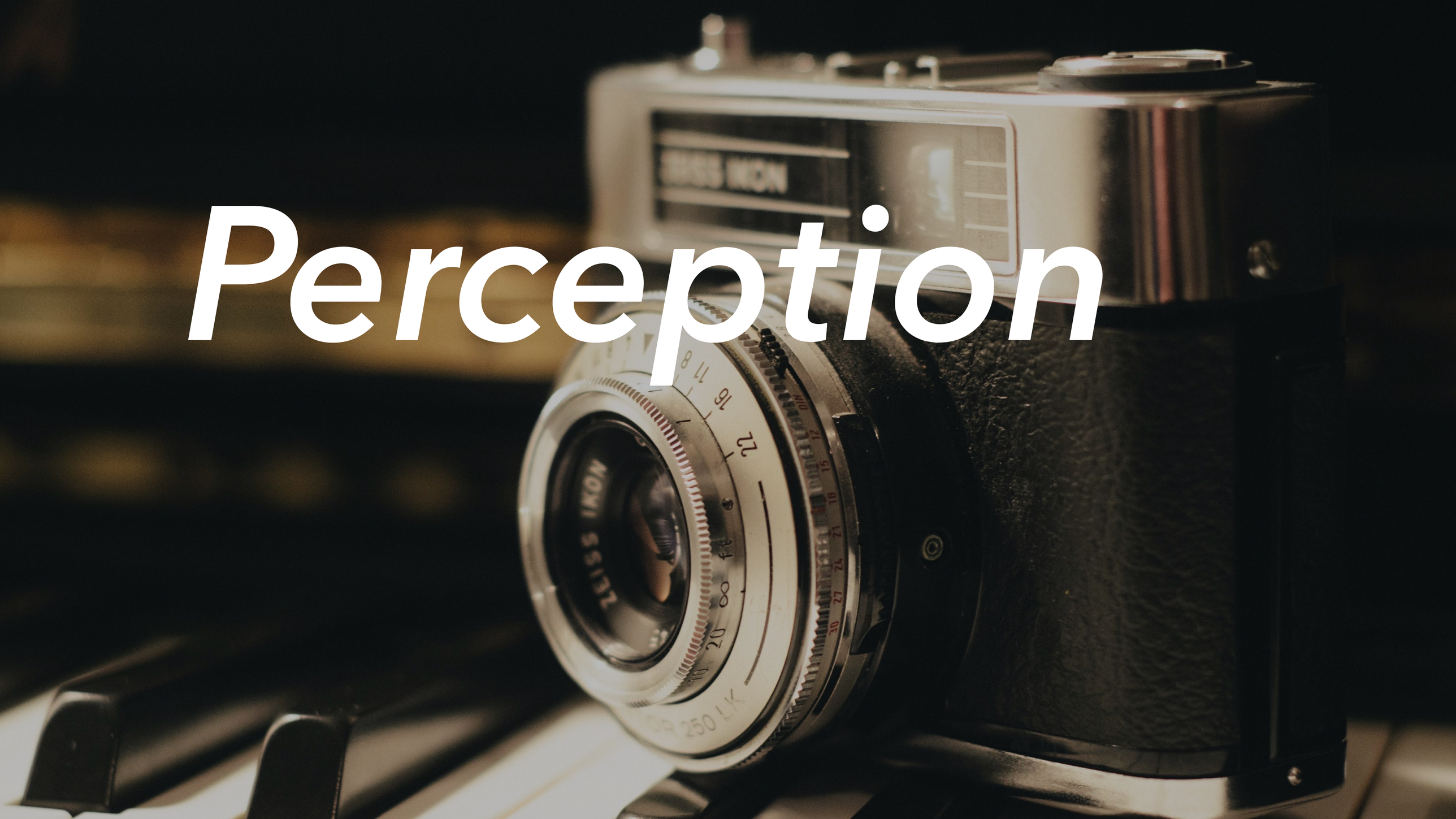

Age-adjusted
(U.S. rate = 205.0)
Rate per 100,000 population
Comparative mortality ratio (HSA to U.S.)
253.8 – 328.6
236.8 – 253.7
215.2 – 236.7
199.9 – 215.1
179.5 – 199.8
166.7 – 179.4
112.4 – 166.6
1.24 – 1.60
1.16 – 1.24
1.05 – 1.16
0.98 – 1.05
0.88 – 0.98
0.81 – 0.88
0.55 – 0.81
Proportion
0.015
0.010
0.005
0.0
150
200
250
300
Distribution of HSA rates per 100,000 population

awesome ^

Visual Channels and Data Mapping

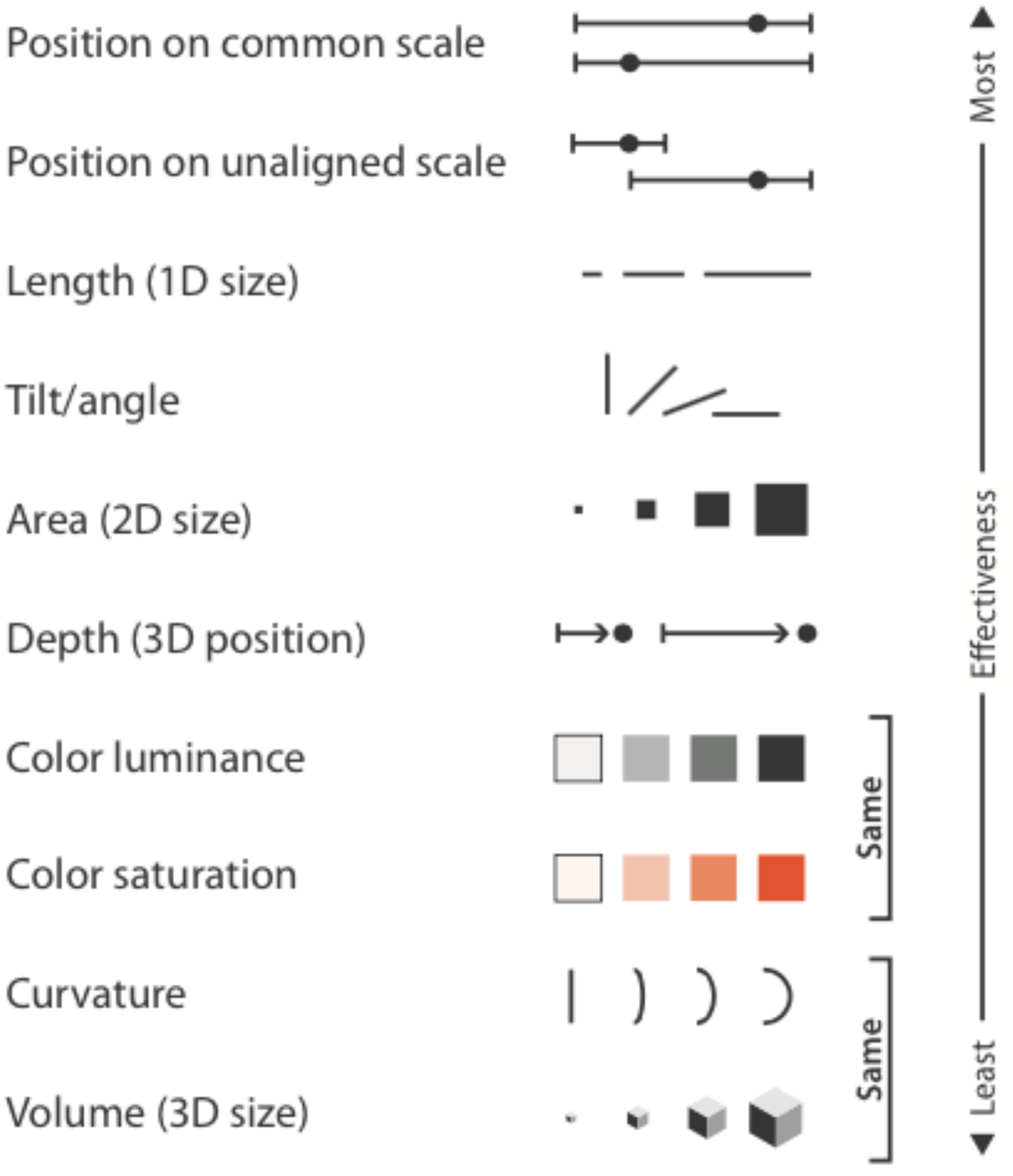
Perception and Cognition

Perception



Perception (Channels)

Magnitude Channels: Ordered Attributes



Position (Un-aligned Scale)

-stacked bars

-stacked area

-many others

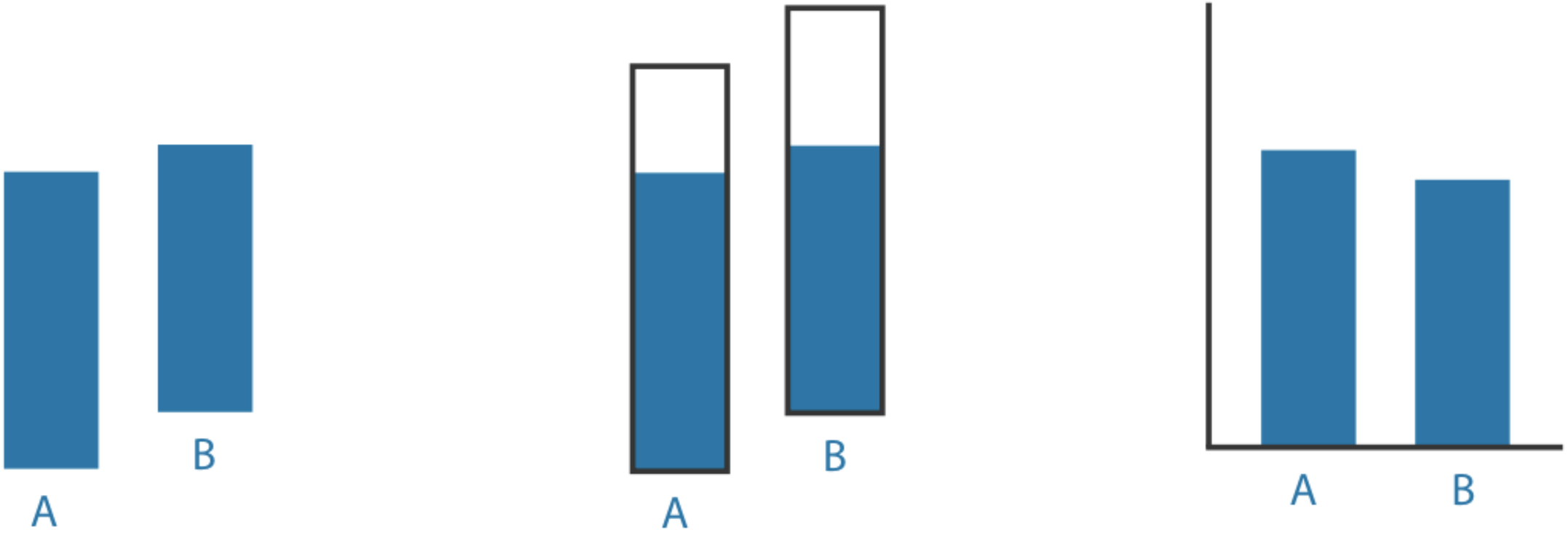
Position (Common Scale)

-scatterplots

-bar charts

-line charts

-etc



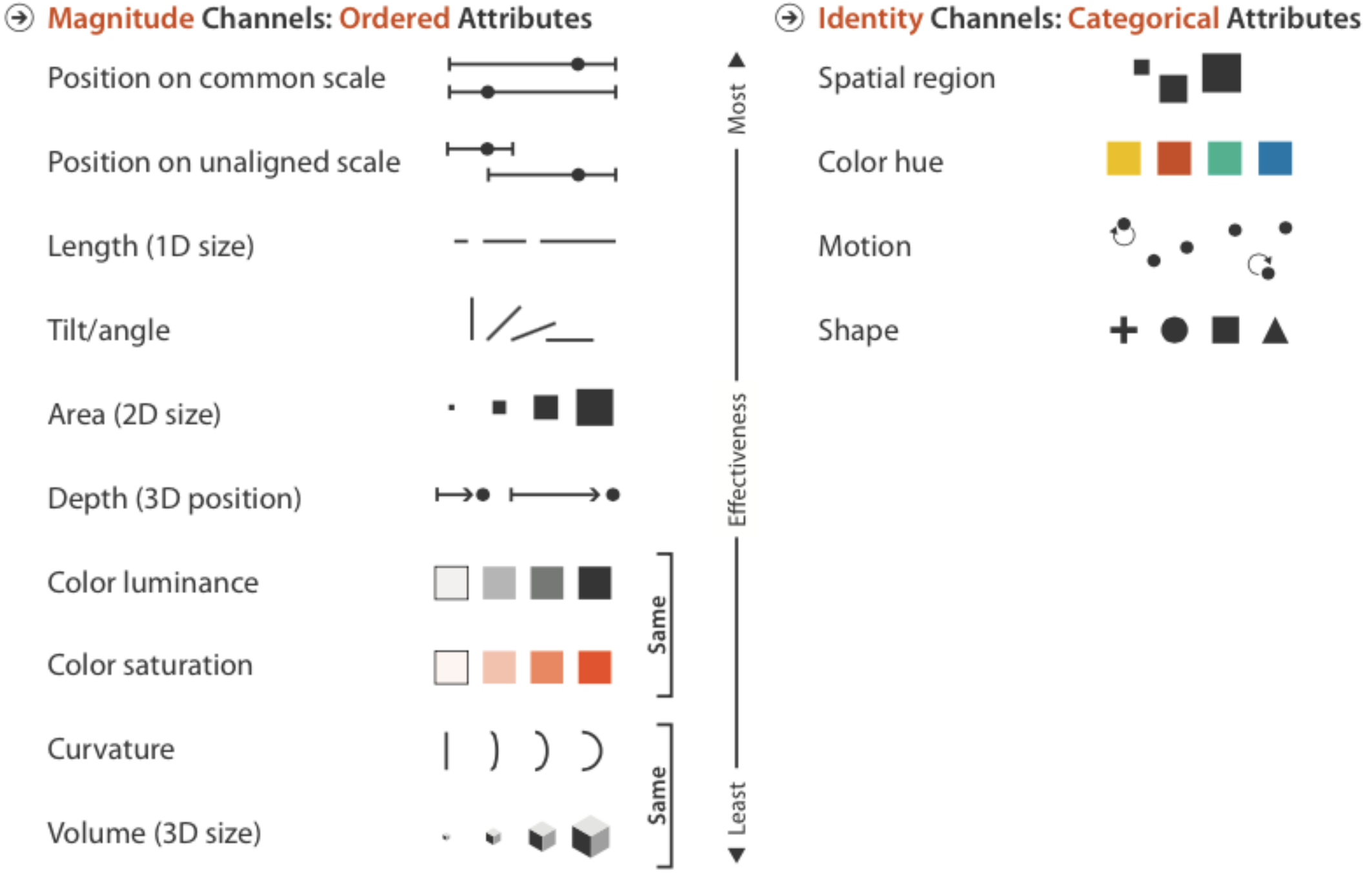
Unframed
Unaligned

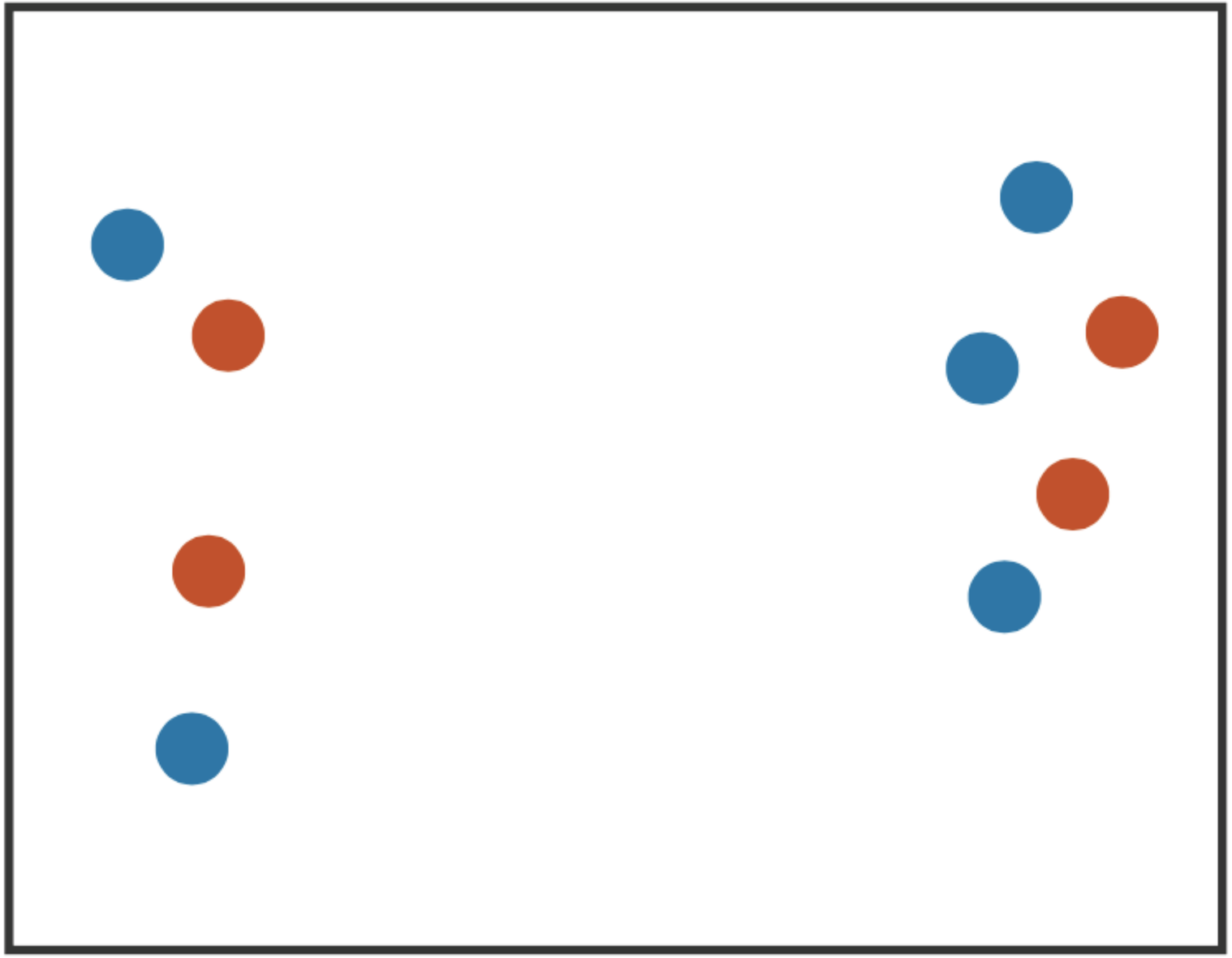
Framed
Unaligned

Unframed
Aligned

Use design elements to compensate!

Identity Channels


Magnitude Channels: Ordered Attributes
Position on common scale
Position on unaligned scale
Length (1D size)
Tilt/angle
Area (2D size)
Depth (3D position)
Color luminance
Color saturation
Curvature
Volume (3D size)
Same
Same
Most
Effectiveness
Least
Identity Channels: Categorical Attributes
Spatial region
Color hue
Motion
Shape



Spatial Region

Shape

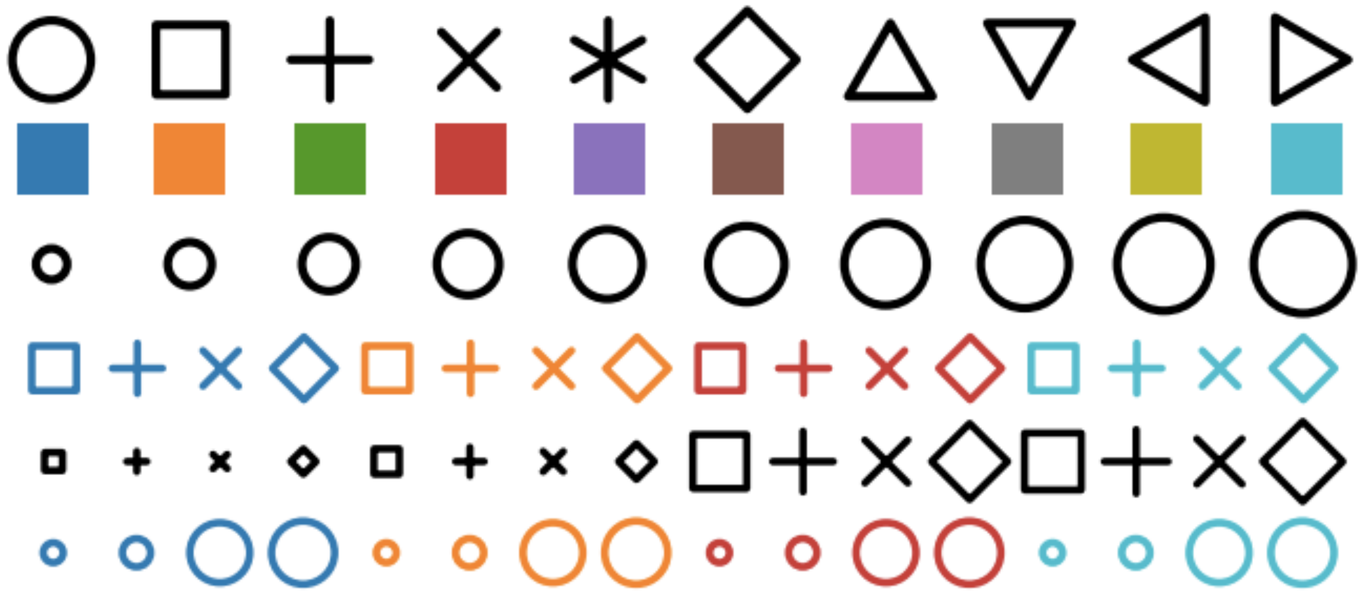


Fig. 2: Palettes of visual stimuli used in our experiments: shape, color, size, shape-color, shape-size, size-color.

Demiralp et al., 2014

Shape

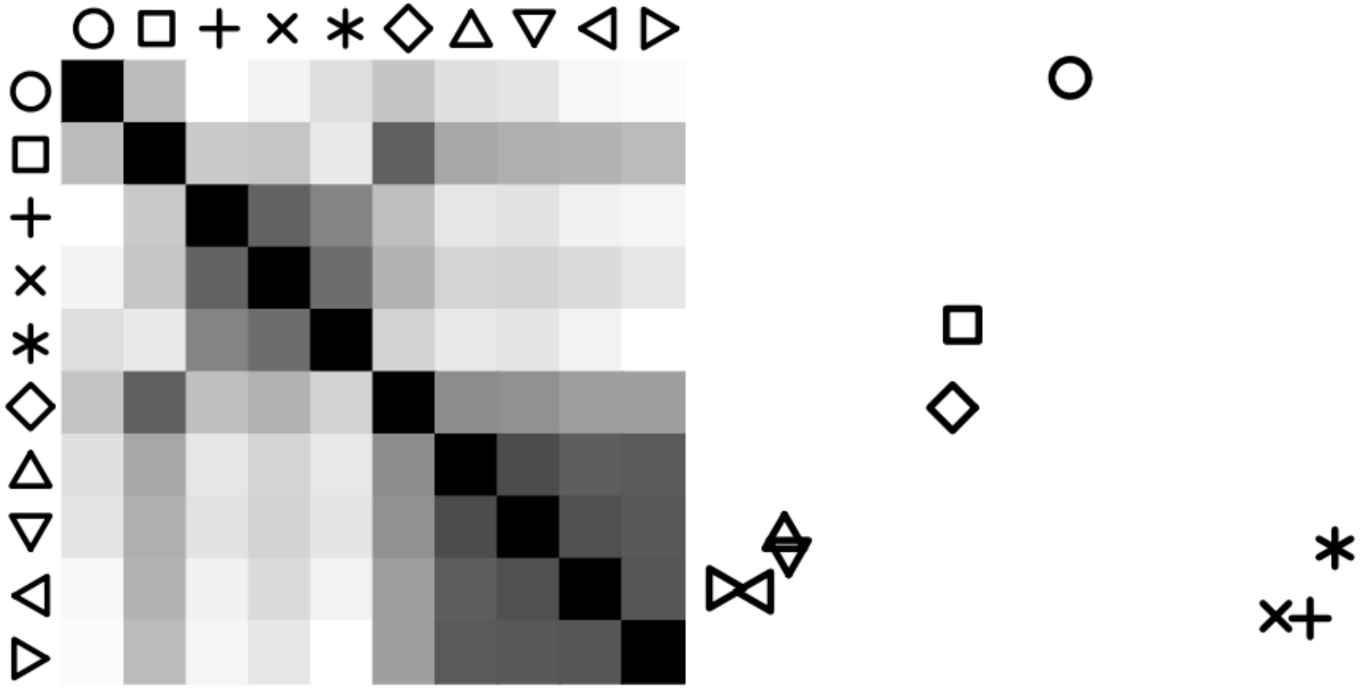
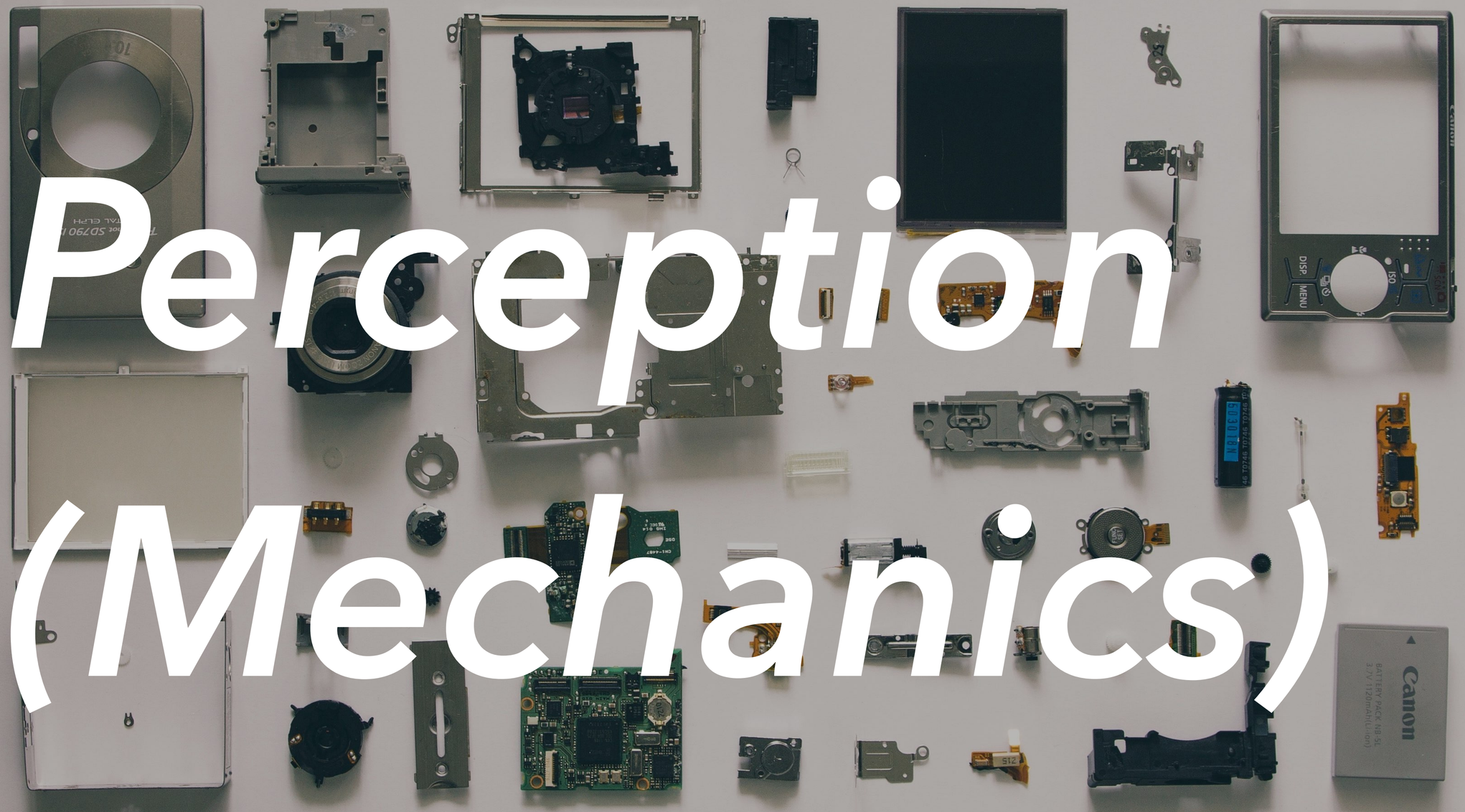


Fig. 1: (Left) A crowd-estimated perceptual kernel for a shape palette. The kernel was obtained using ordinal triplet matching. (Right) A two-dimensional projection of the palette shapes obtained via multidimensional scaling of the perceptual kernel.

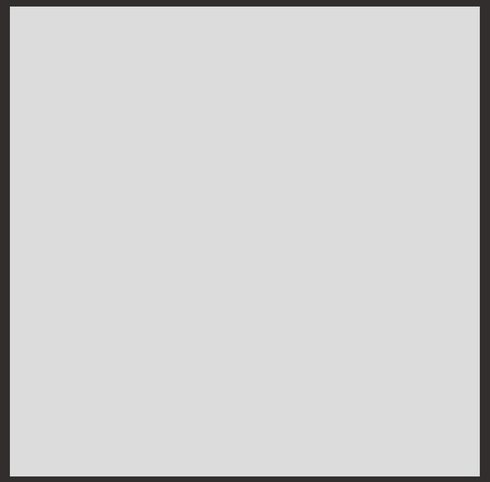
Demiralp et al., 2014

Perception (Mechanics)

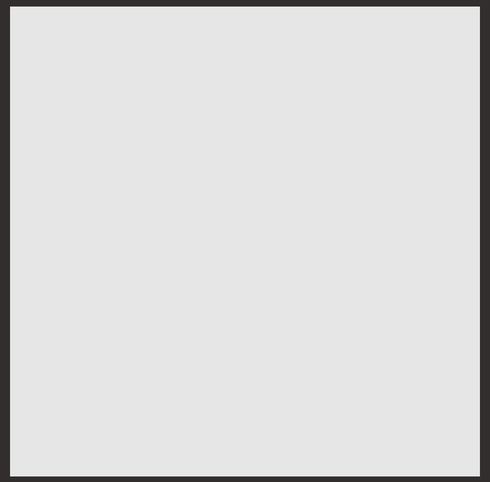


Discrimination

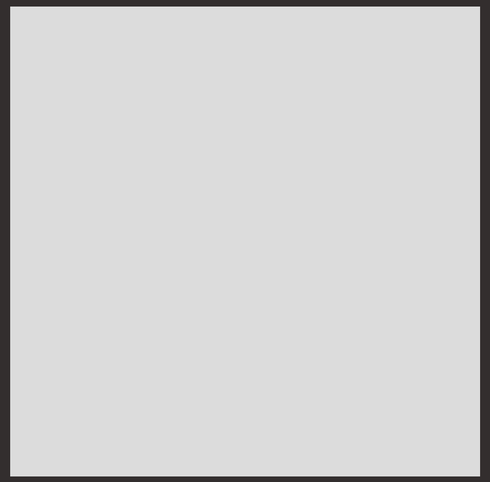
Which is brighter?



(220,220,220)



(230,230,230)

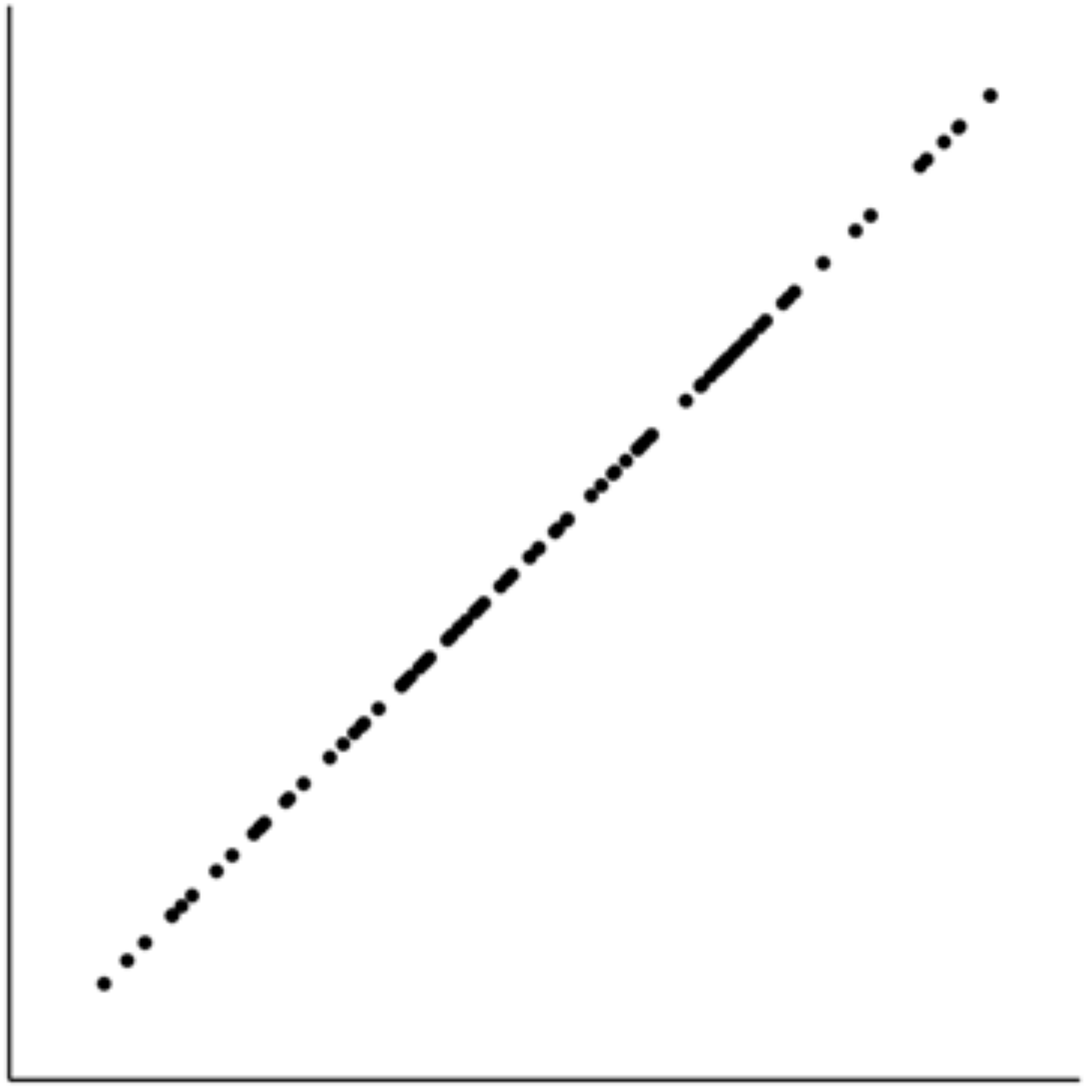


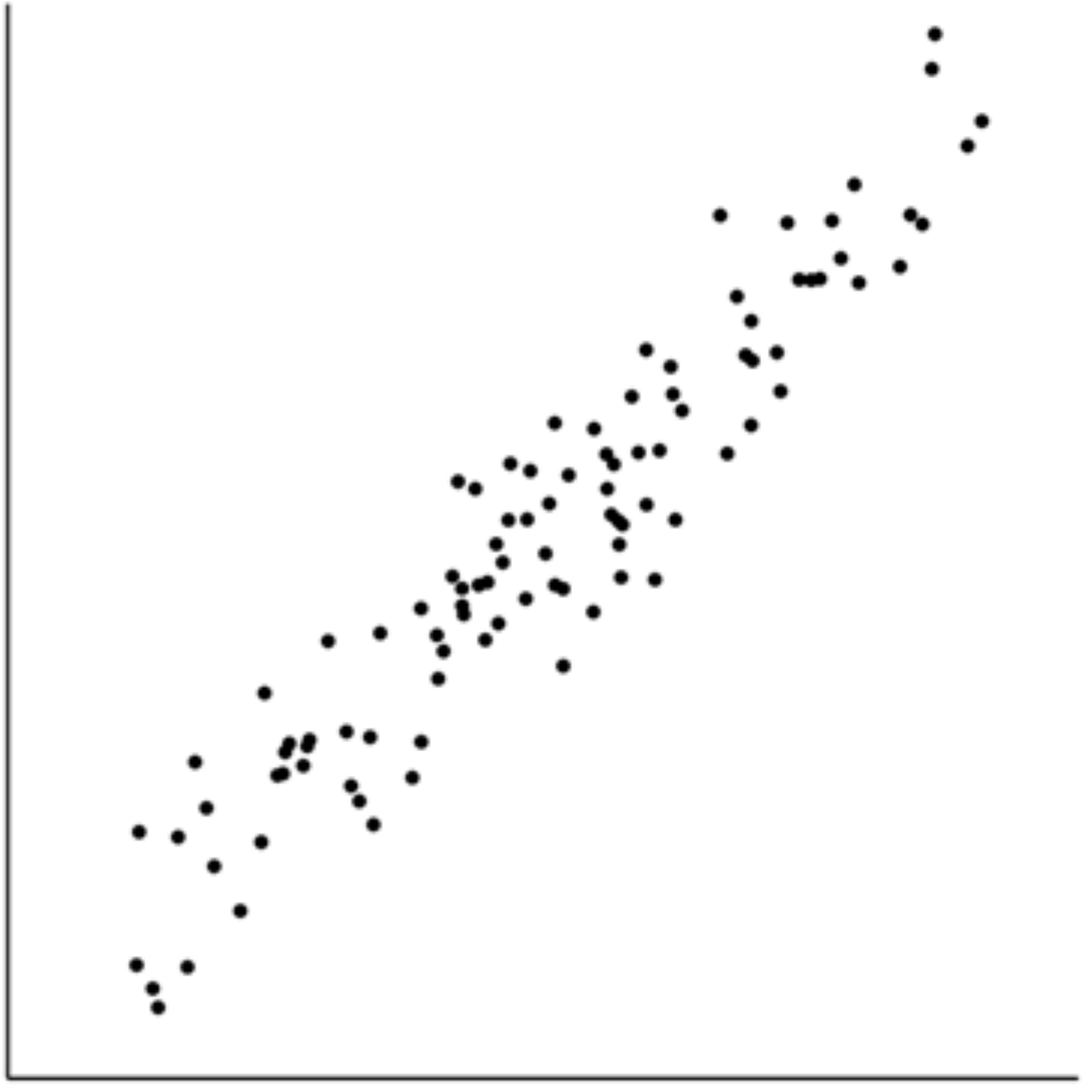
(220,220,220)

(80,80,80) *(90,90,90)* *(80,80,80)*

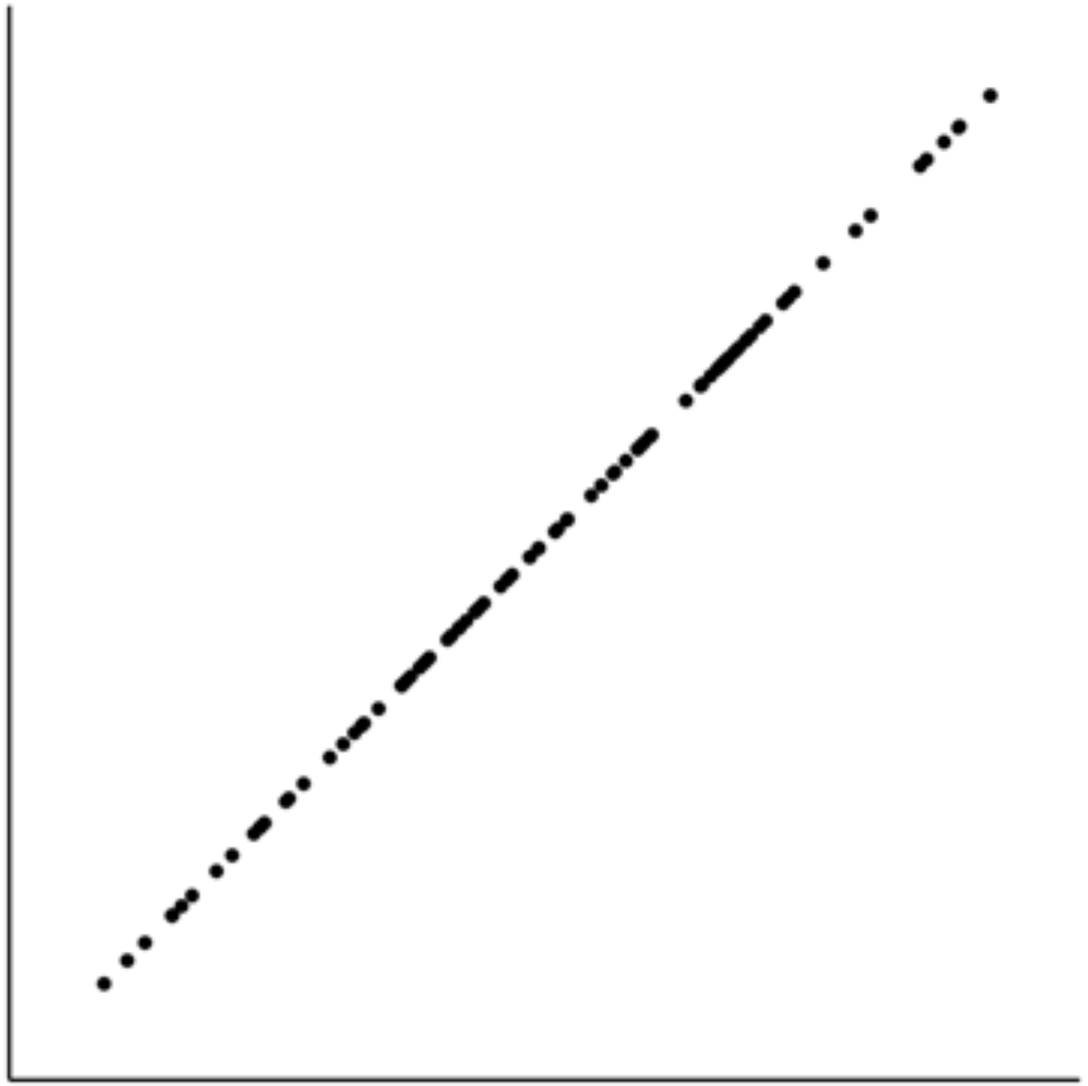
Which diff was easier to see?

Which is more correlated?

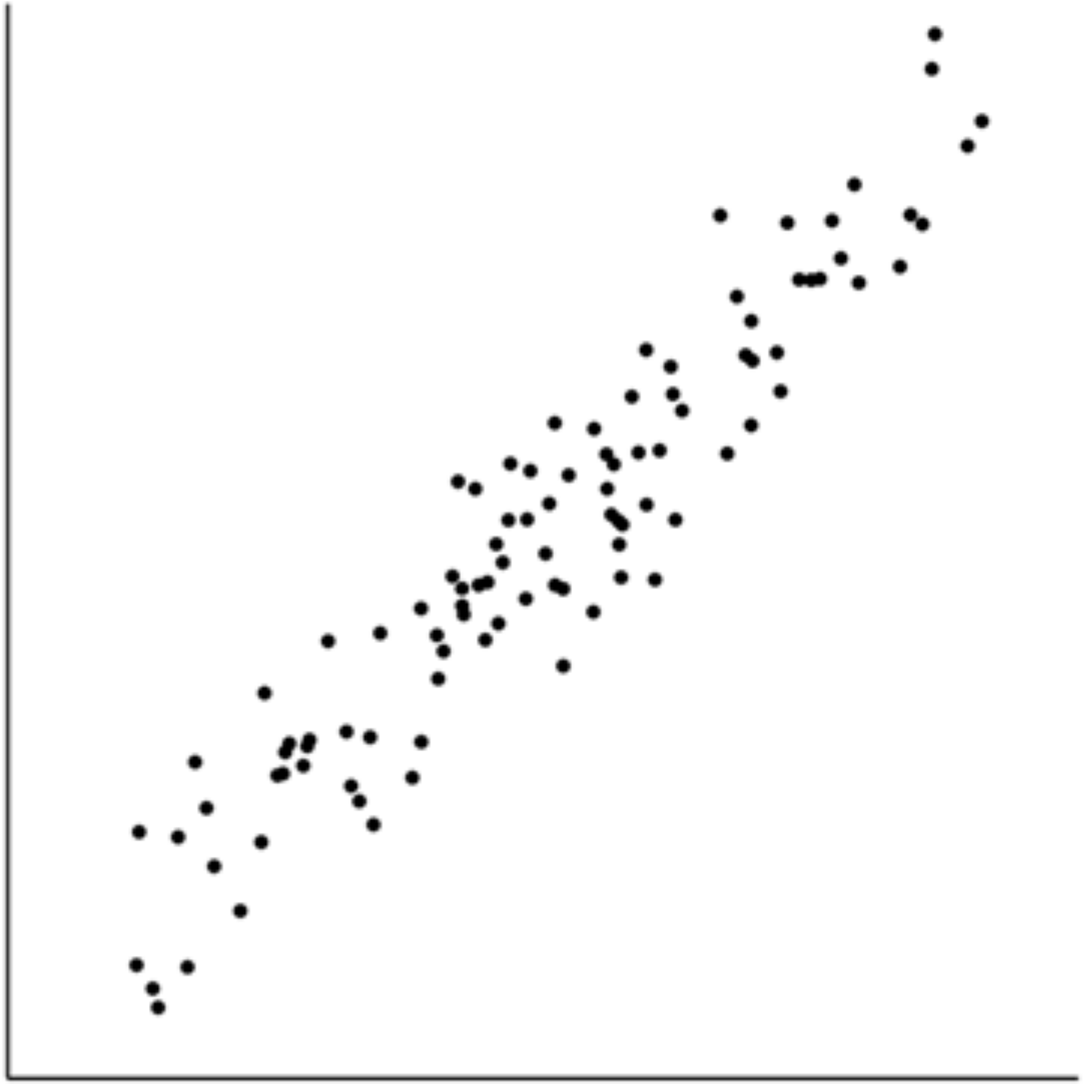


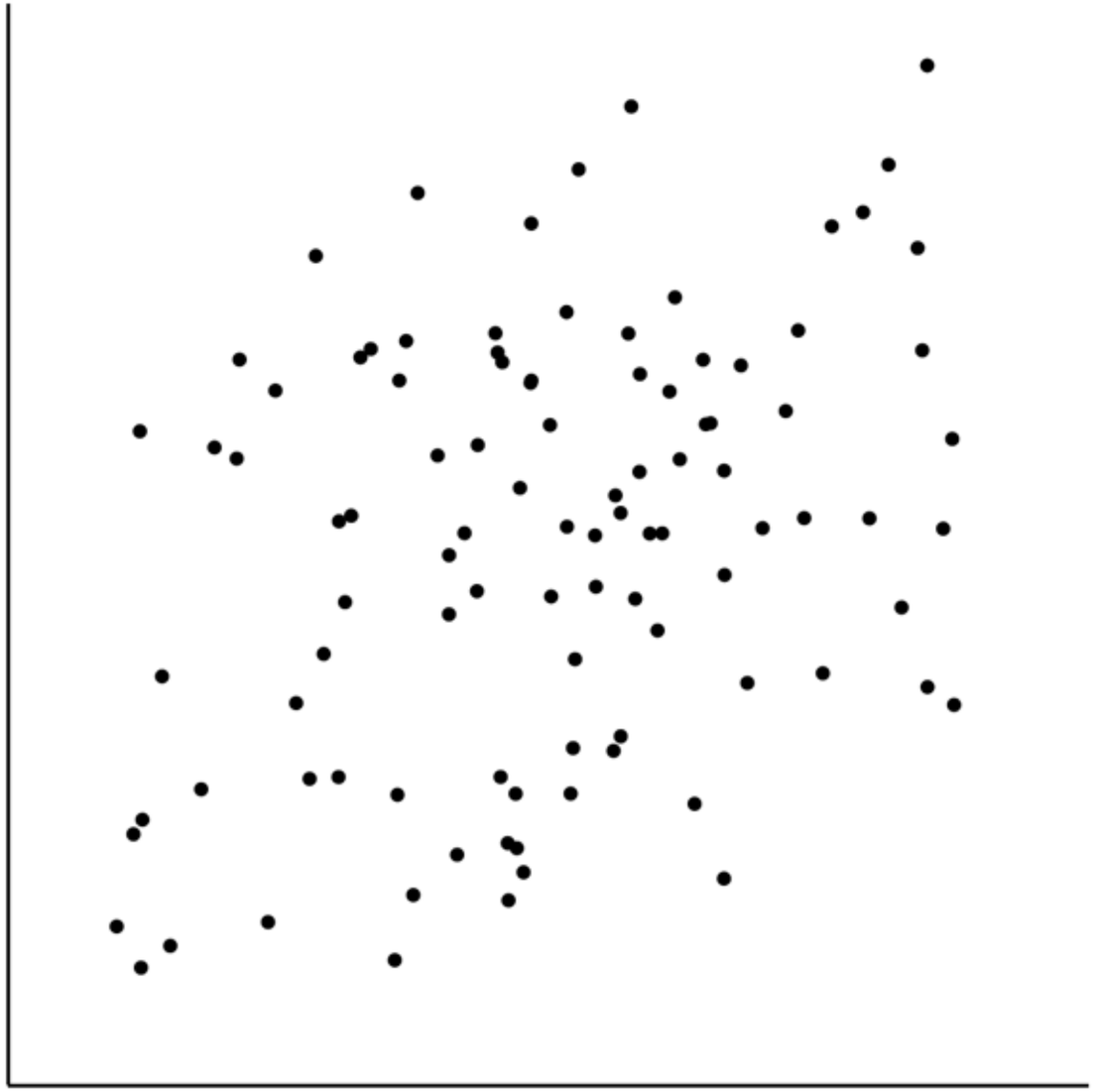


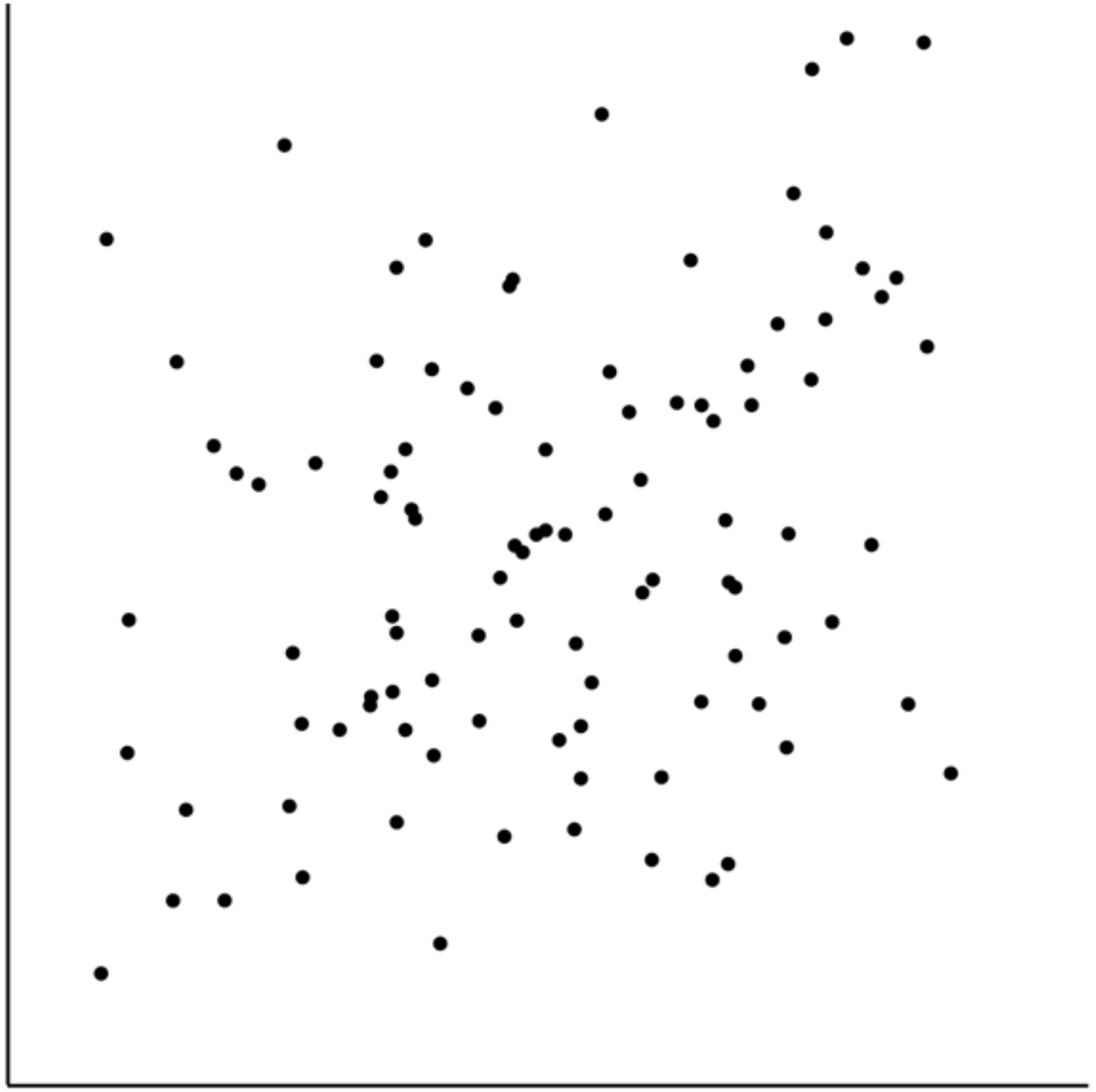
r = 1



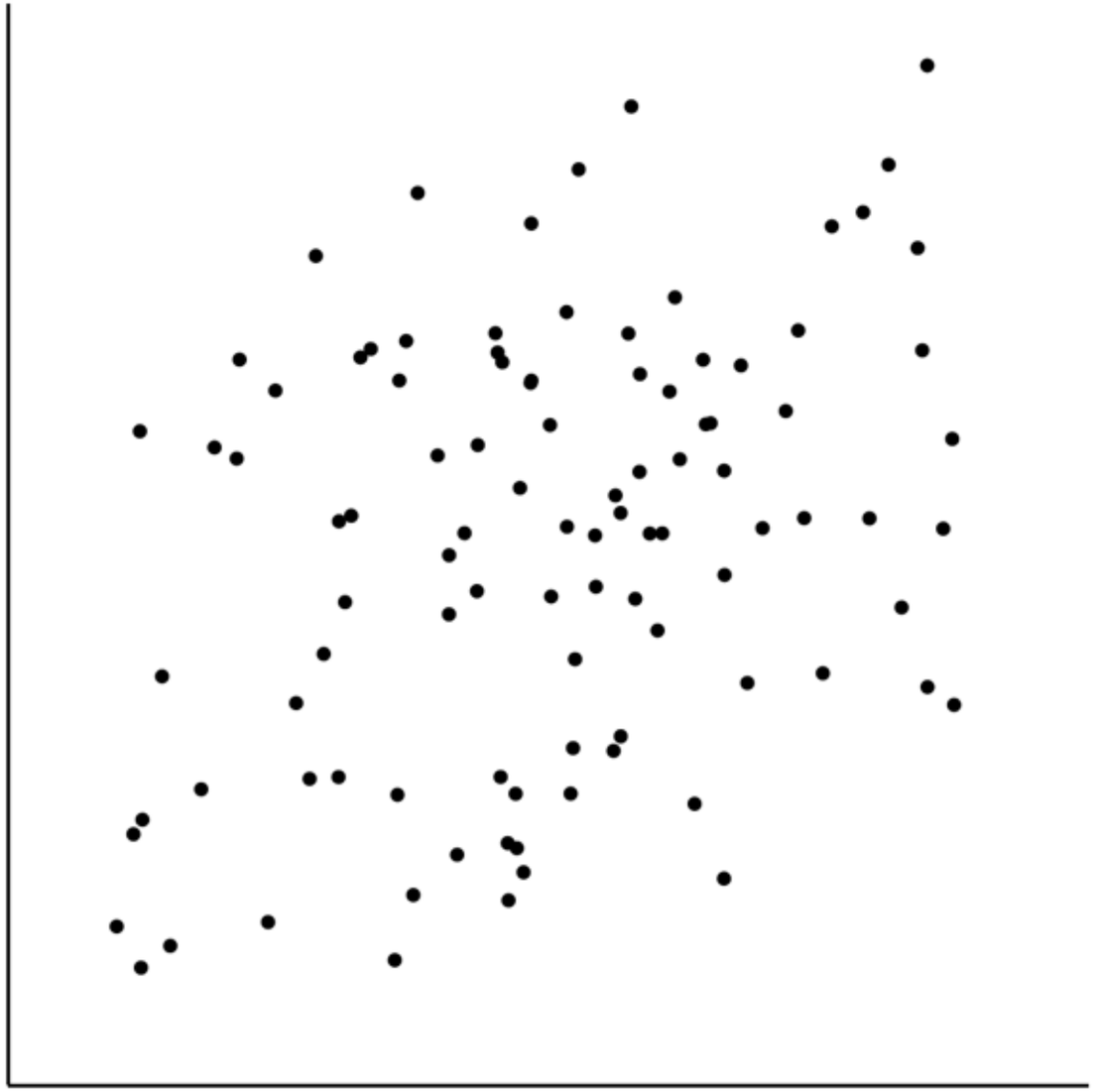
r = 0.95



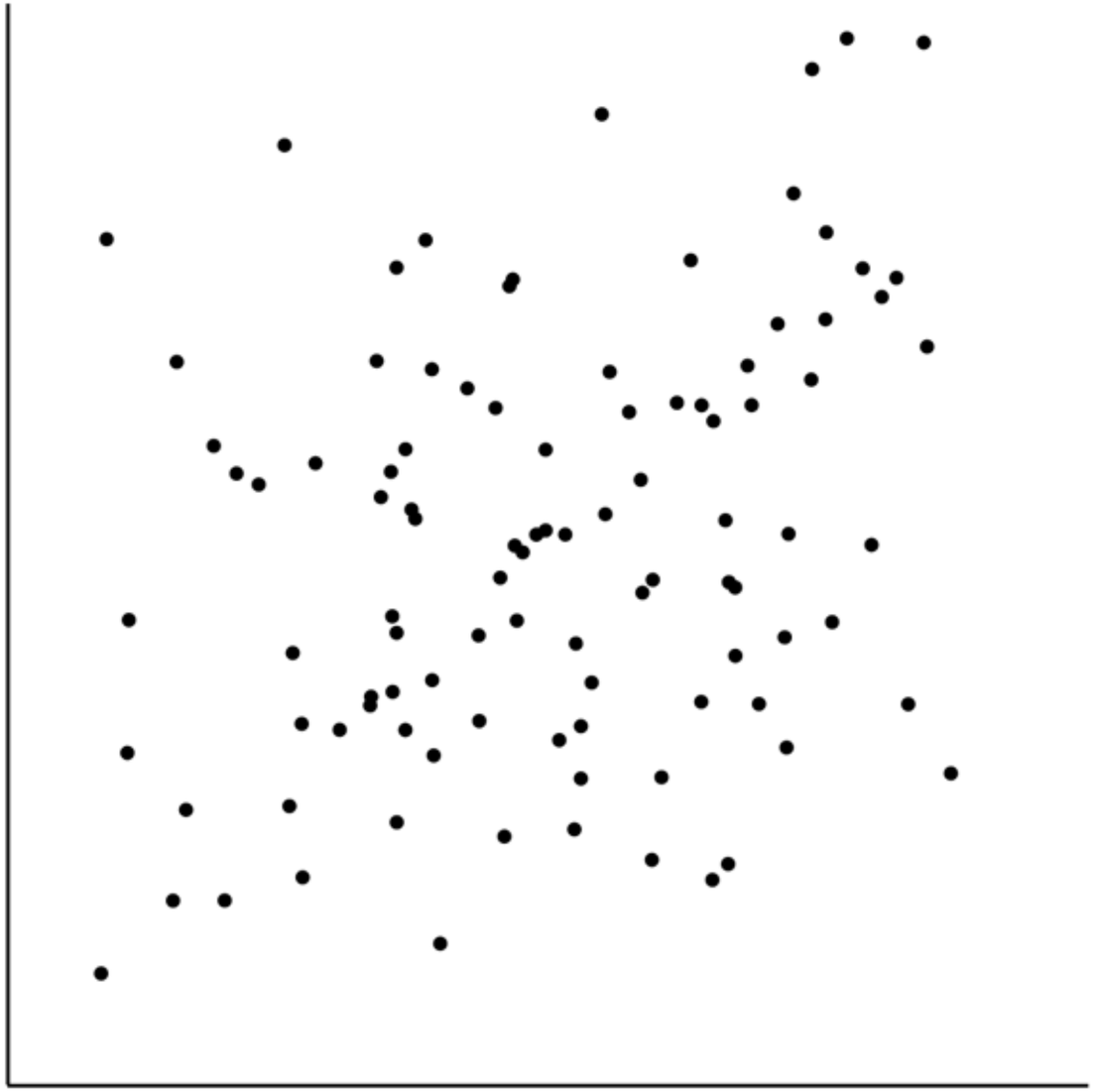




r = 0.35



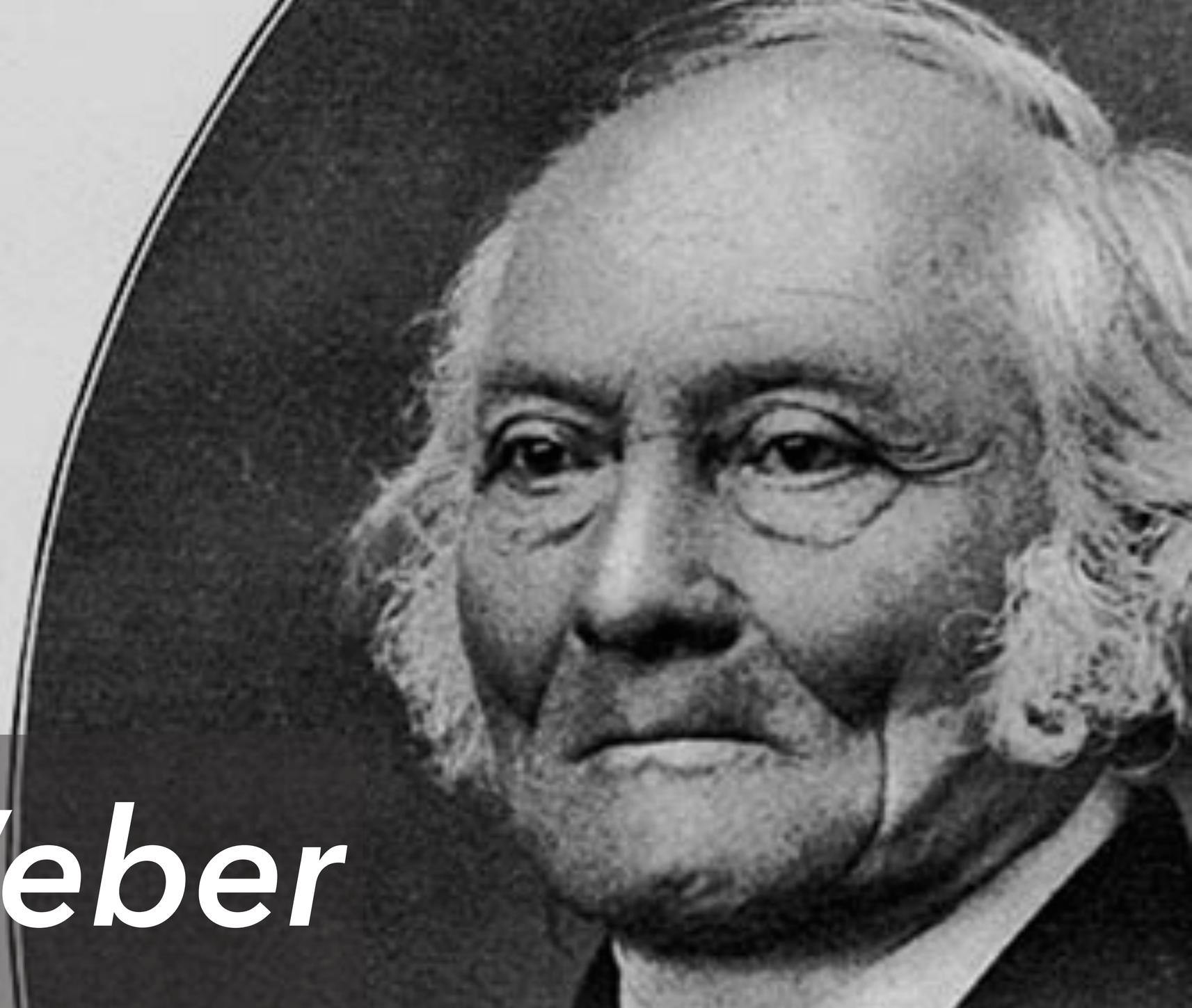
r = 0.3



just-noticeable differences (jnd)

The smallest difference necessary to perceive two stimuli as being different.

Why were some distances different?



E. H. Weber

$$\Delta P = k * \frac{\Delta I}{I}$$

Weber's Law

Perceived diff

$$\Delta P = k * \frac{\Delta I}{I}$$

Perceived diff

$$\Delta P = k * \frac{\Delta I}{I}$$

Actual intensity of Stimulus

Perceived diff

Change in Intensity

$$\Delta P = k * \frac{\Delta I}{I}$$

Actual intensity of Stimulus

imagine yourself in a dark room…

bright room, high intensity

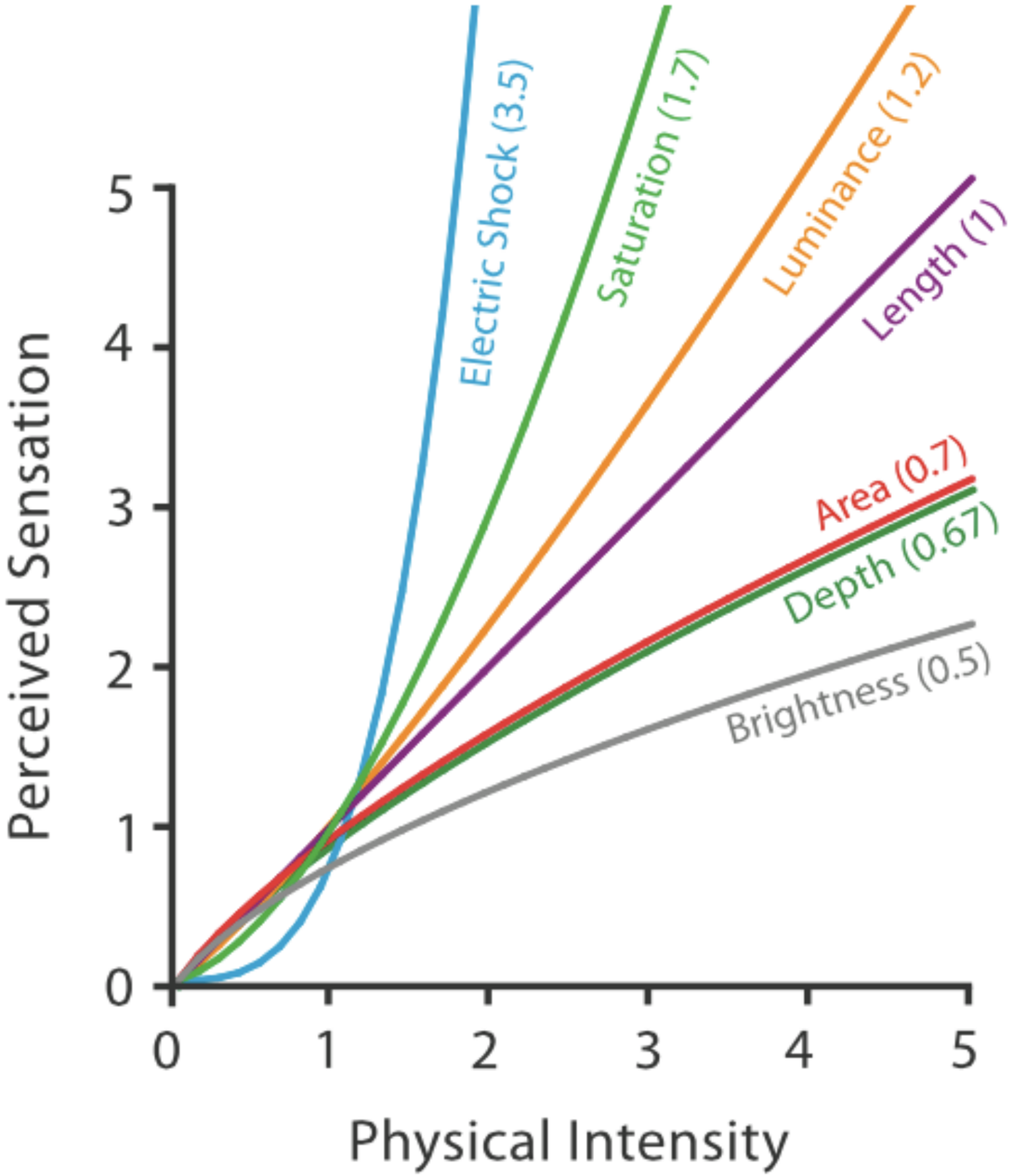
$$\Delta P = k * \frac{\Delta I}{I}$$

super bright light needed

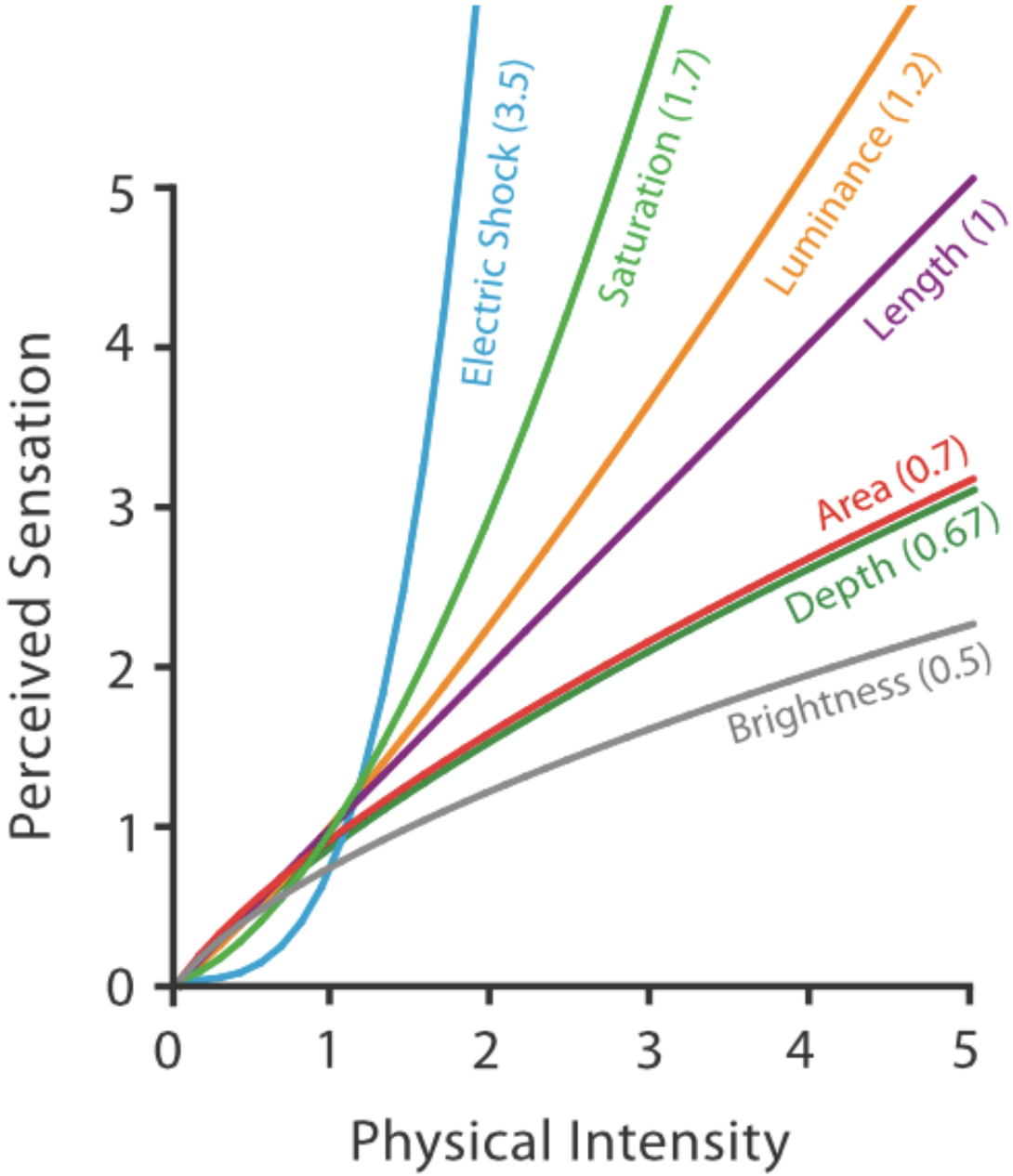
$$\Delta P = k * \frac{\Delta l}{l}$$

Estimation

Steven's Psychophysical Power Law: $S = I^N$

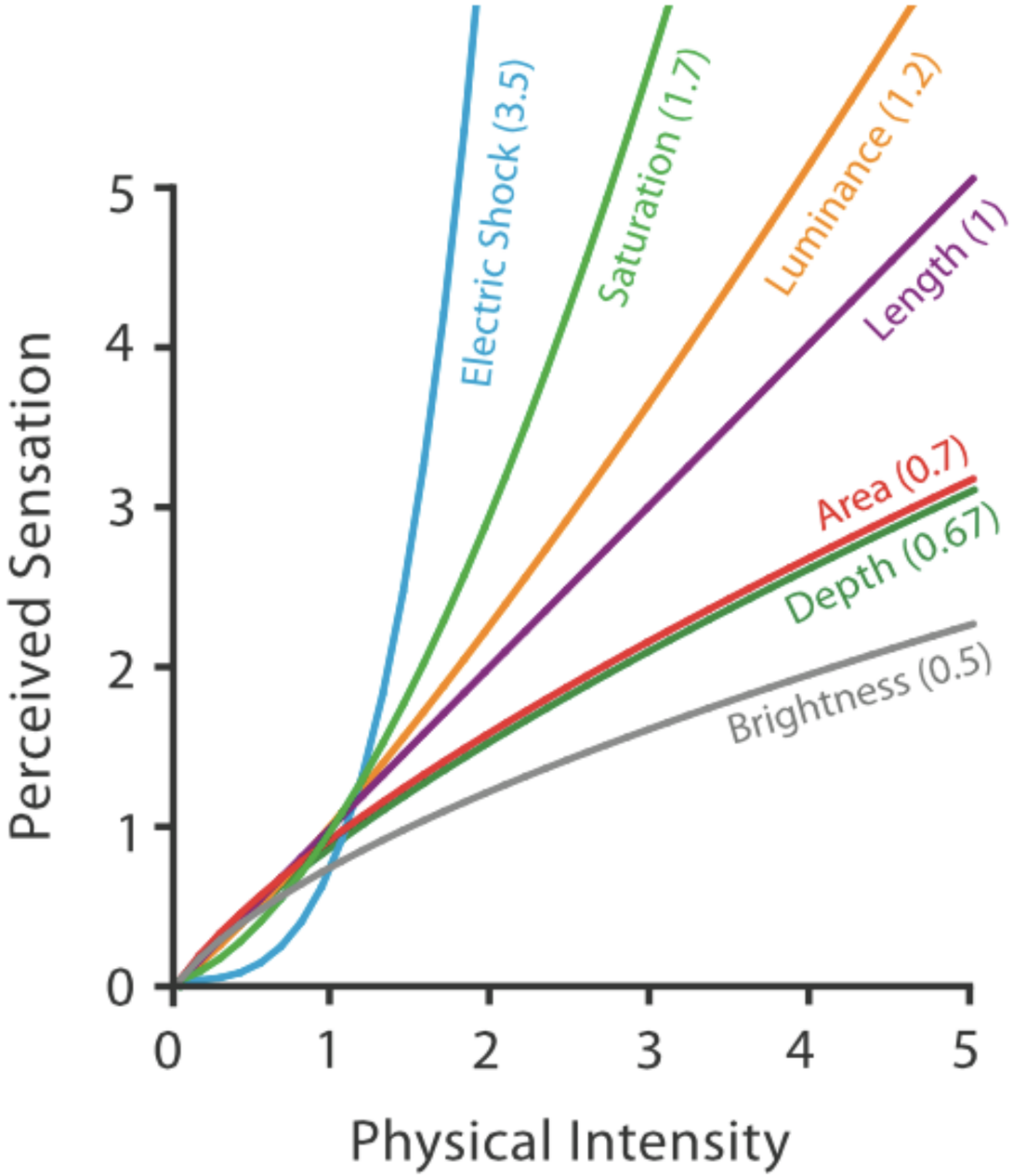


Steven's Psychophysical Power Law: $S = I^N$



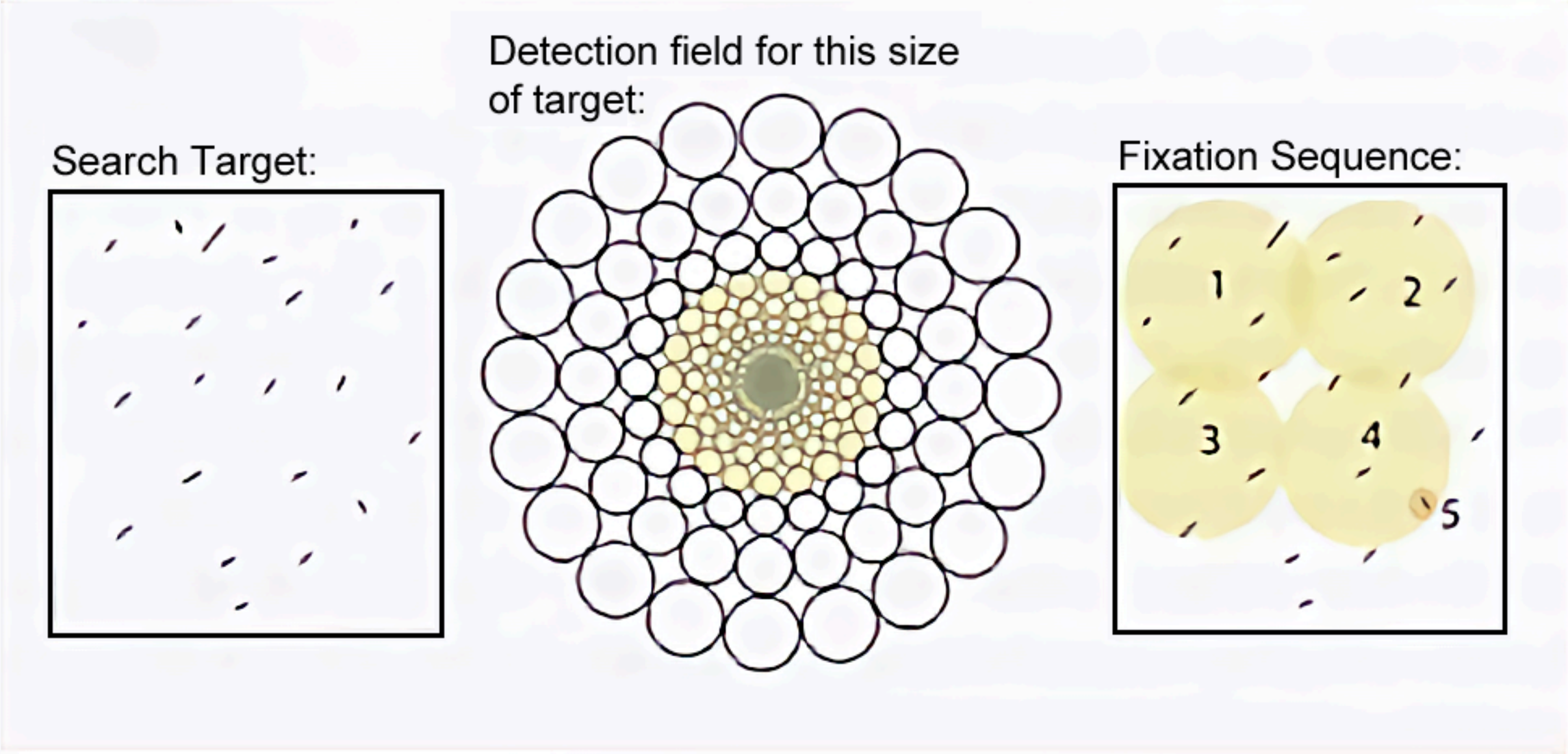
we under-estimate brightness

Steven's Psychophysical Power Law: $S = I^N$



we are great at length

Eye-Movement

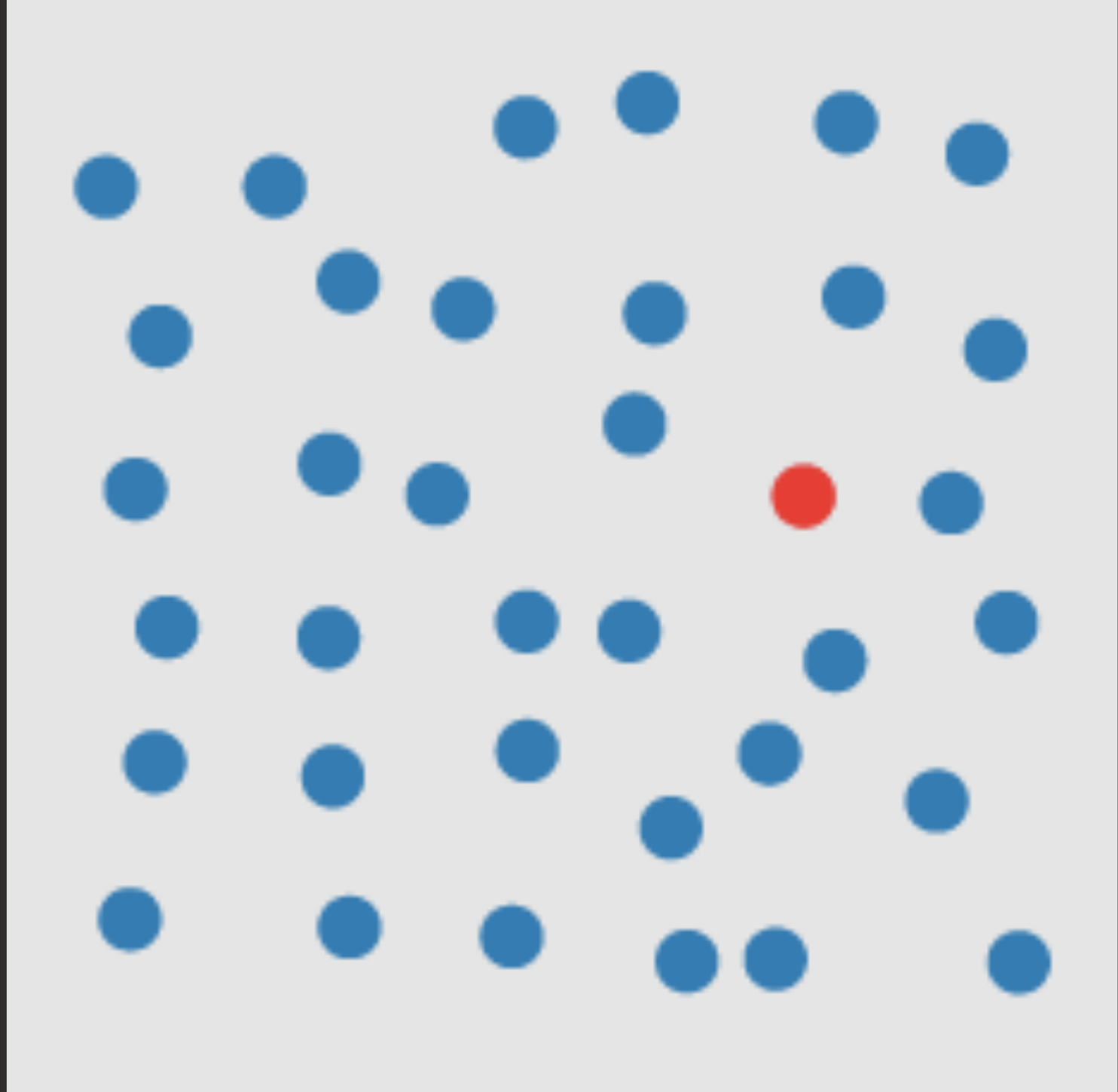


Visual-Search

img improved by Barb Garrison @Smith

“Find the Tomato”

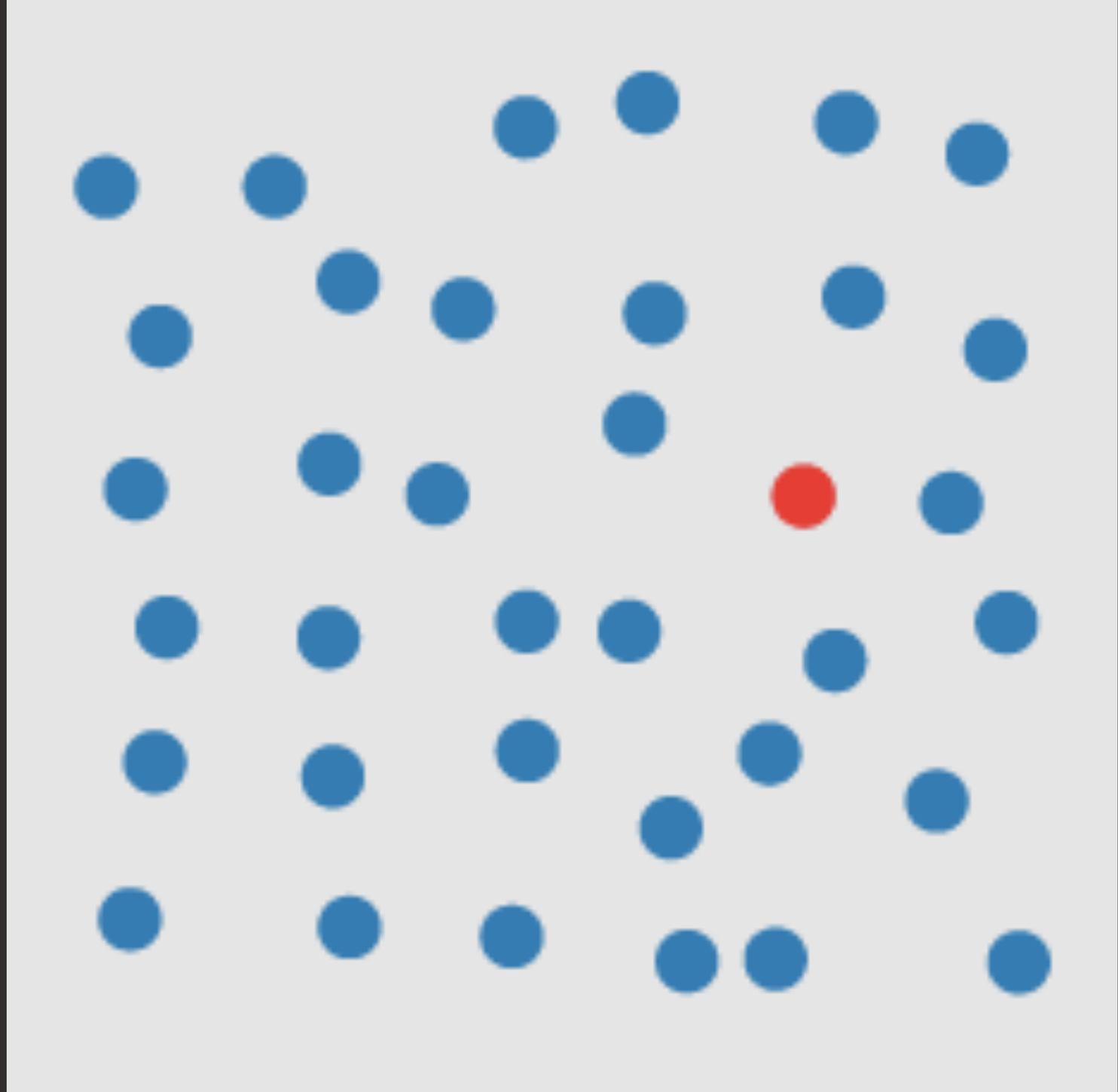
“Find the Tomato”

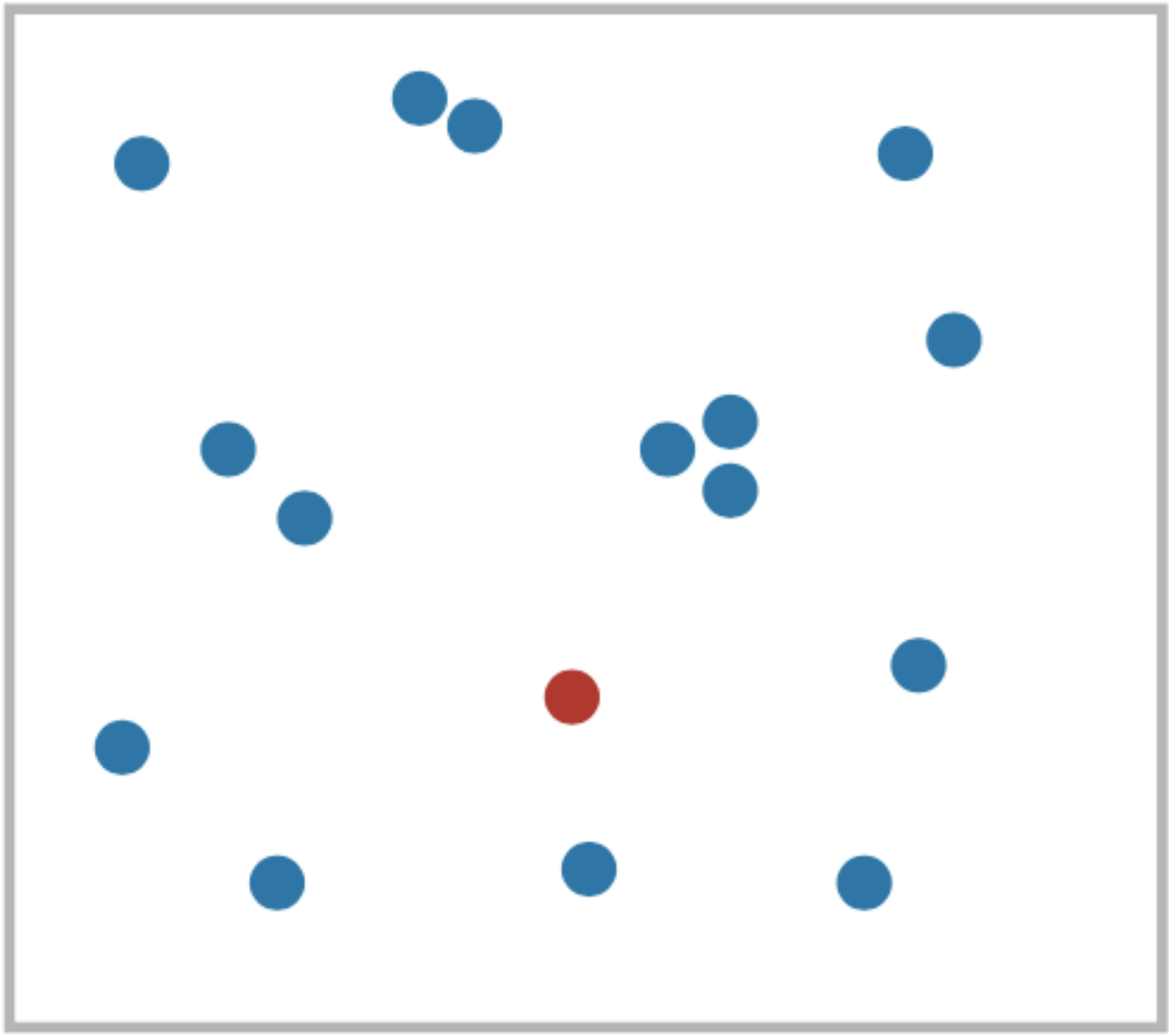


“Find the Tomato”

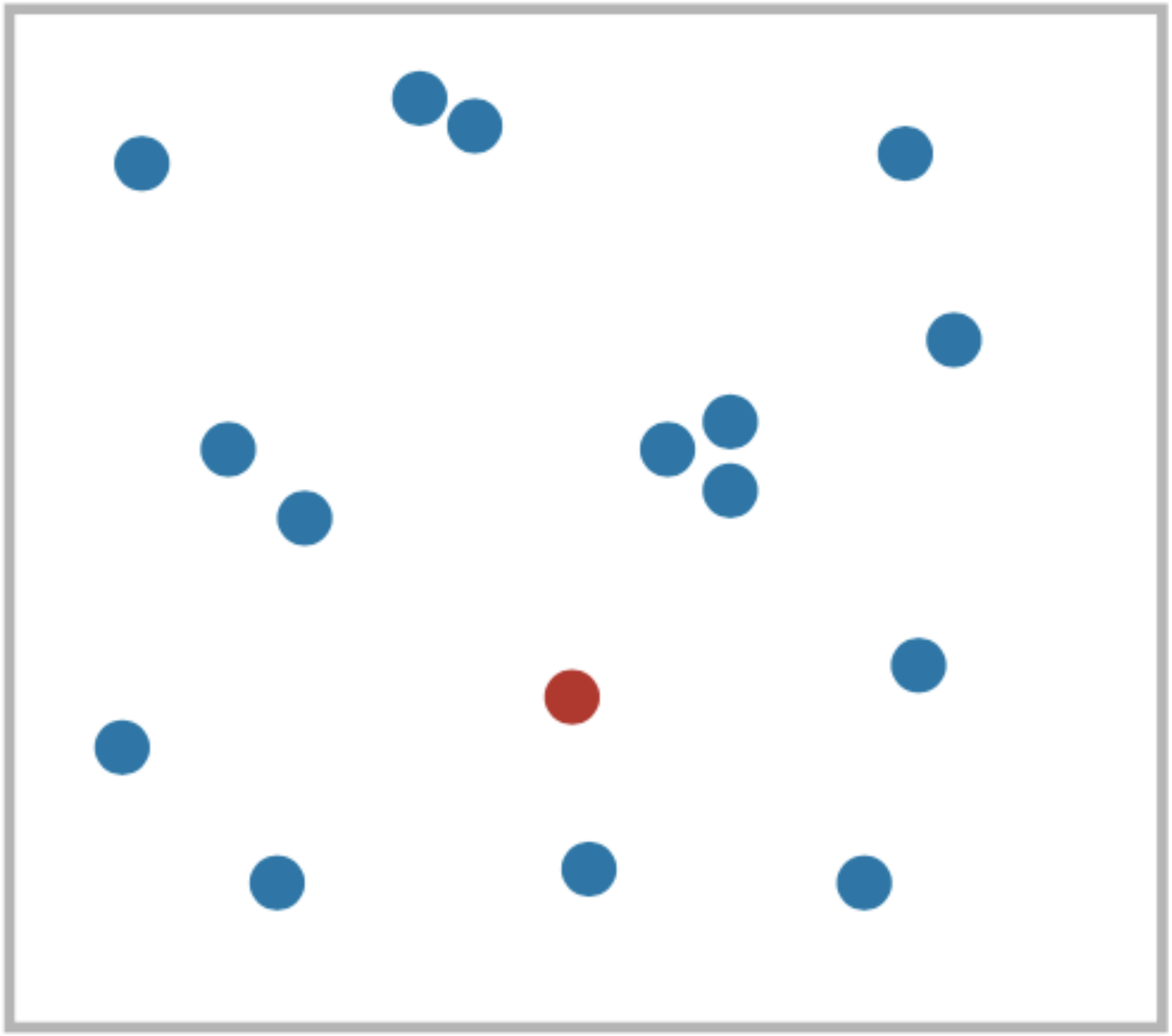
"preattentive processing"

one O(1) eye-move!

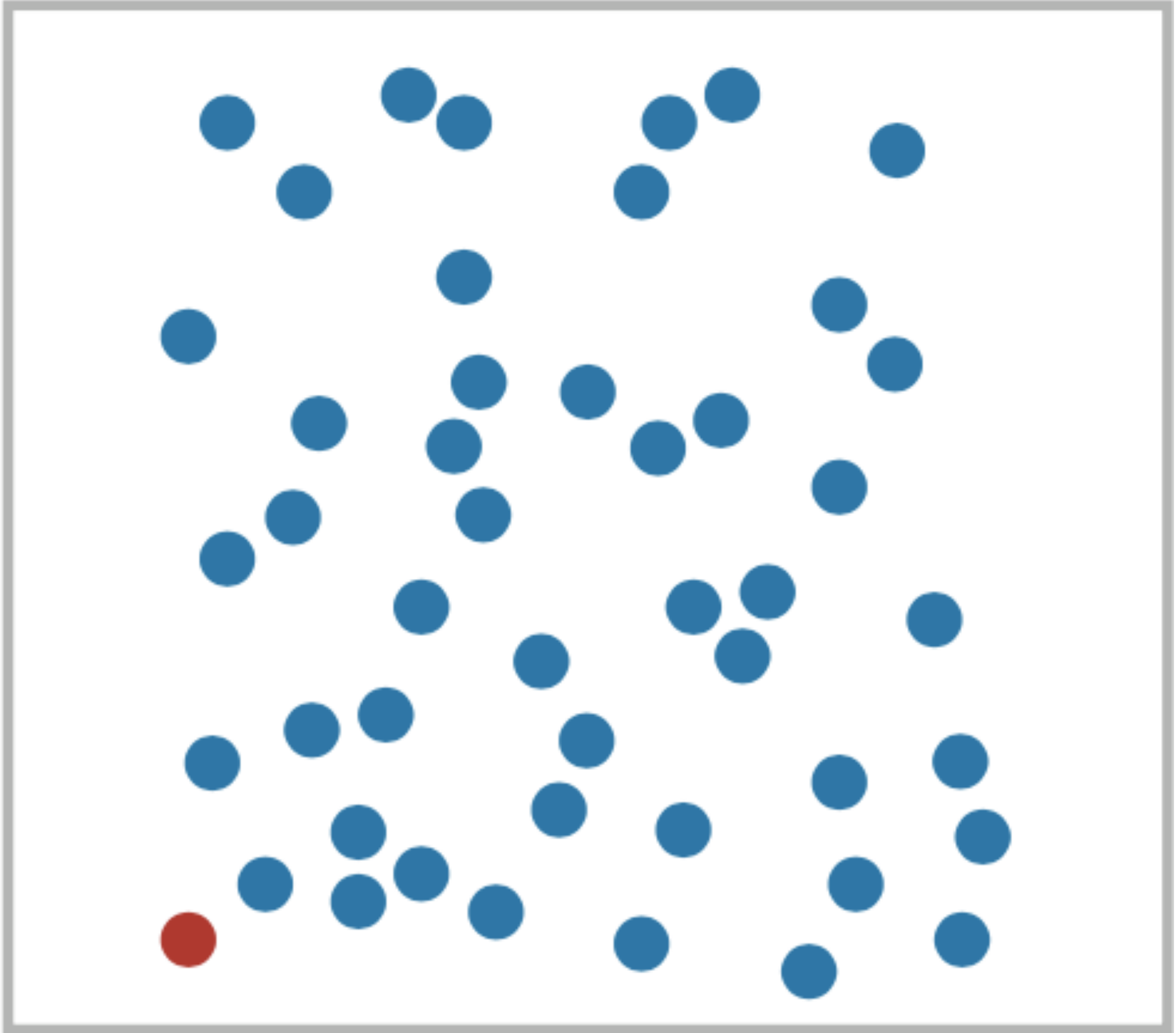


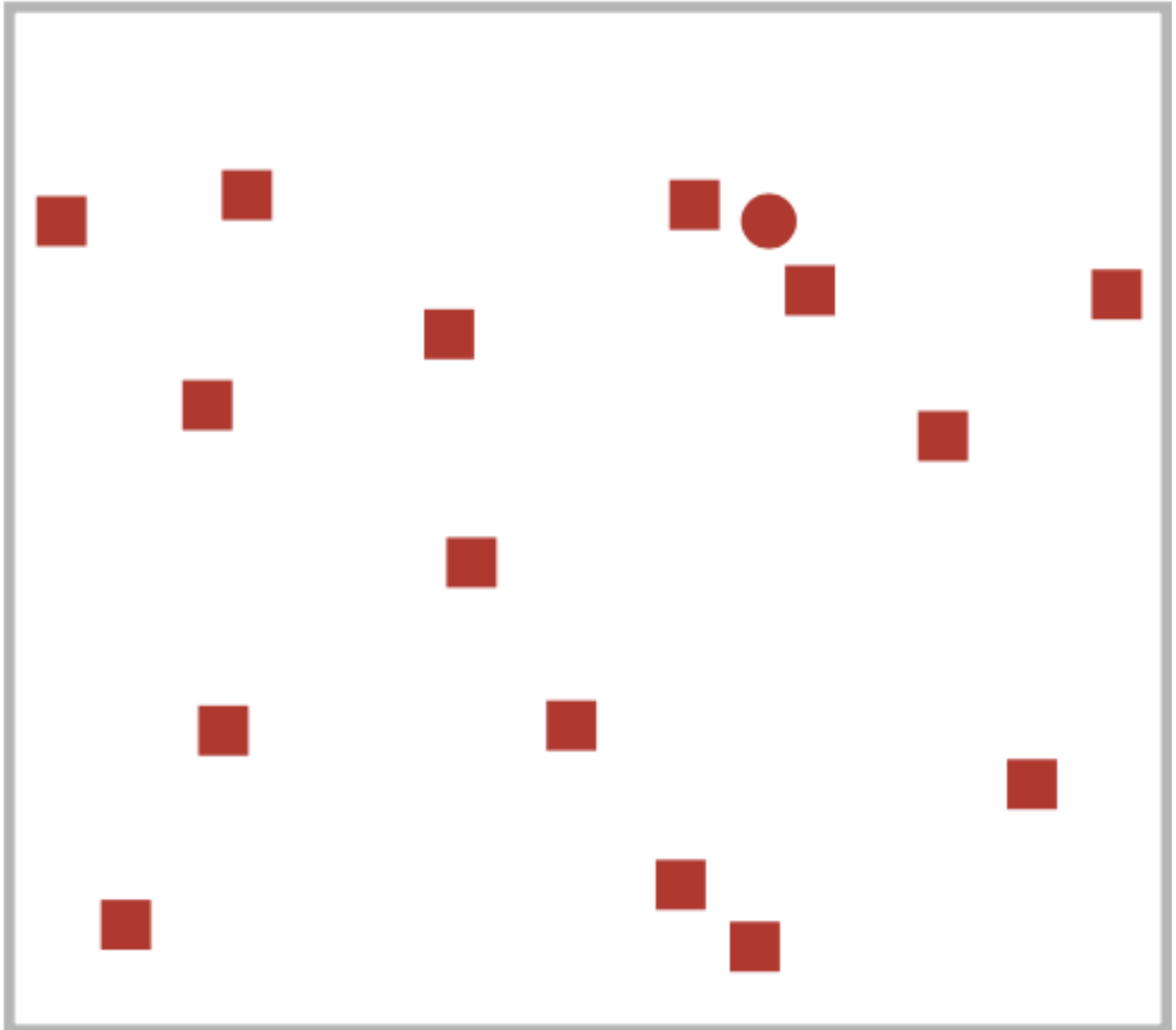


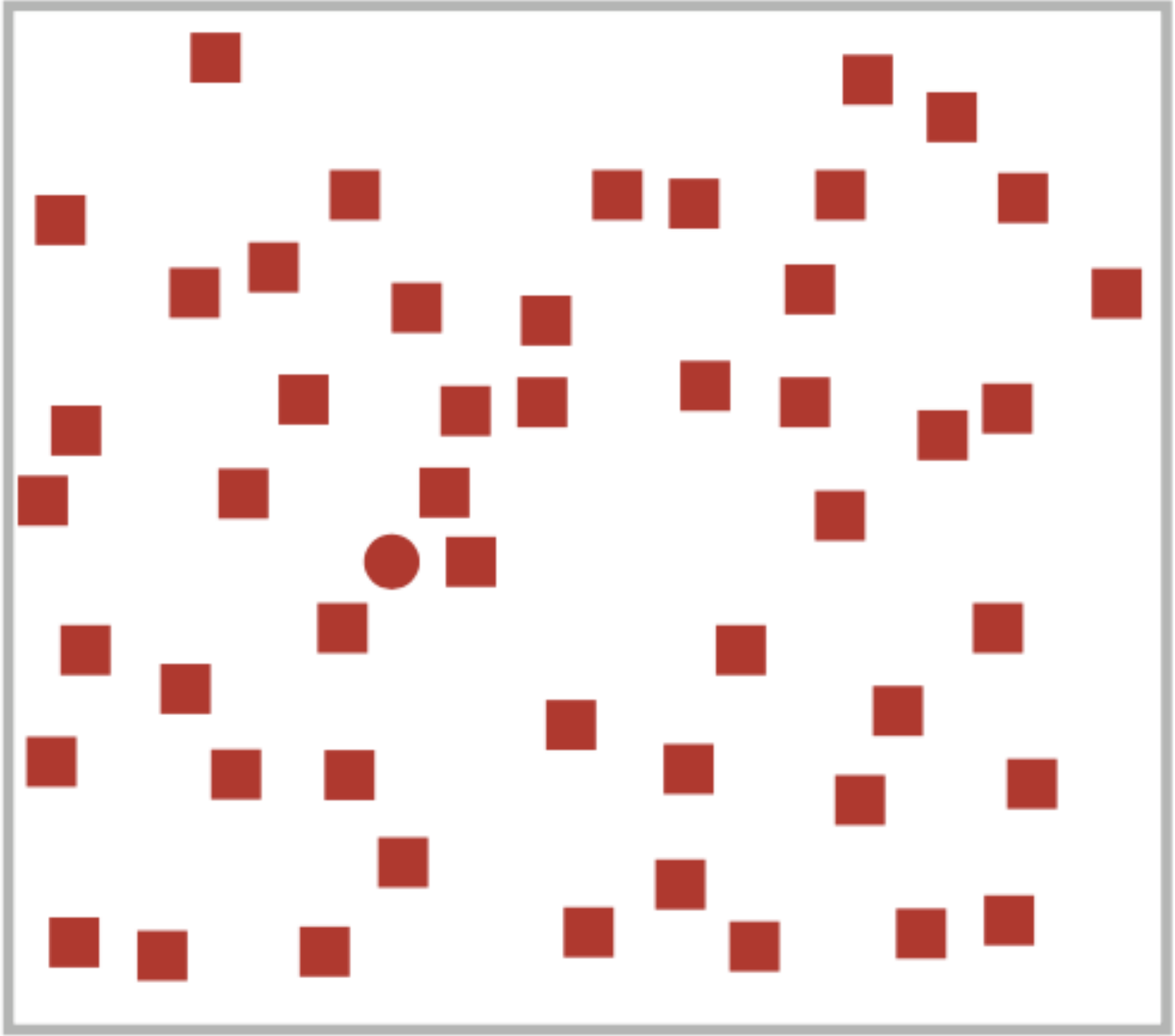
Find the Tomato, part 2



Let's add more distractors…

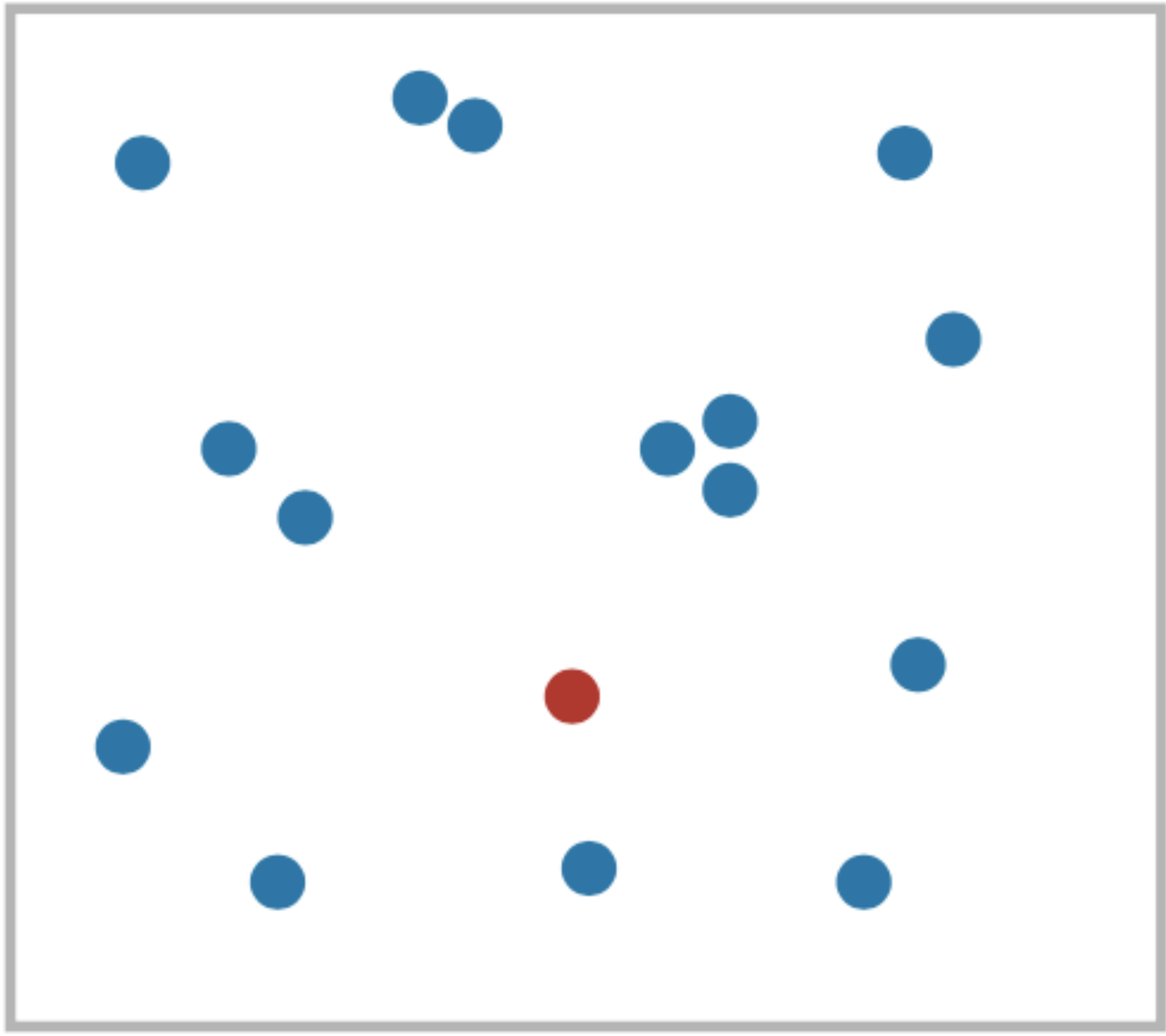


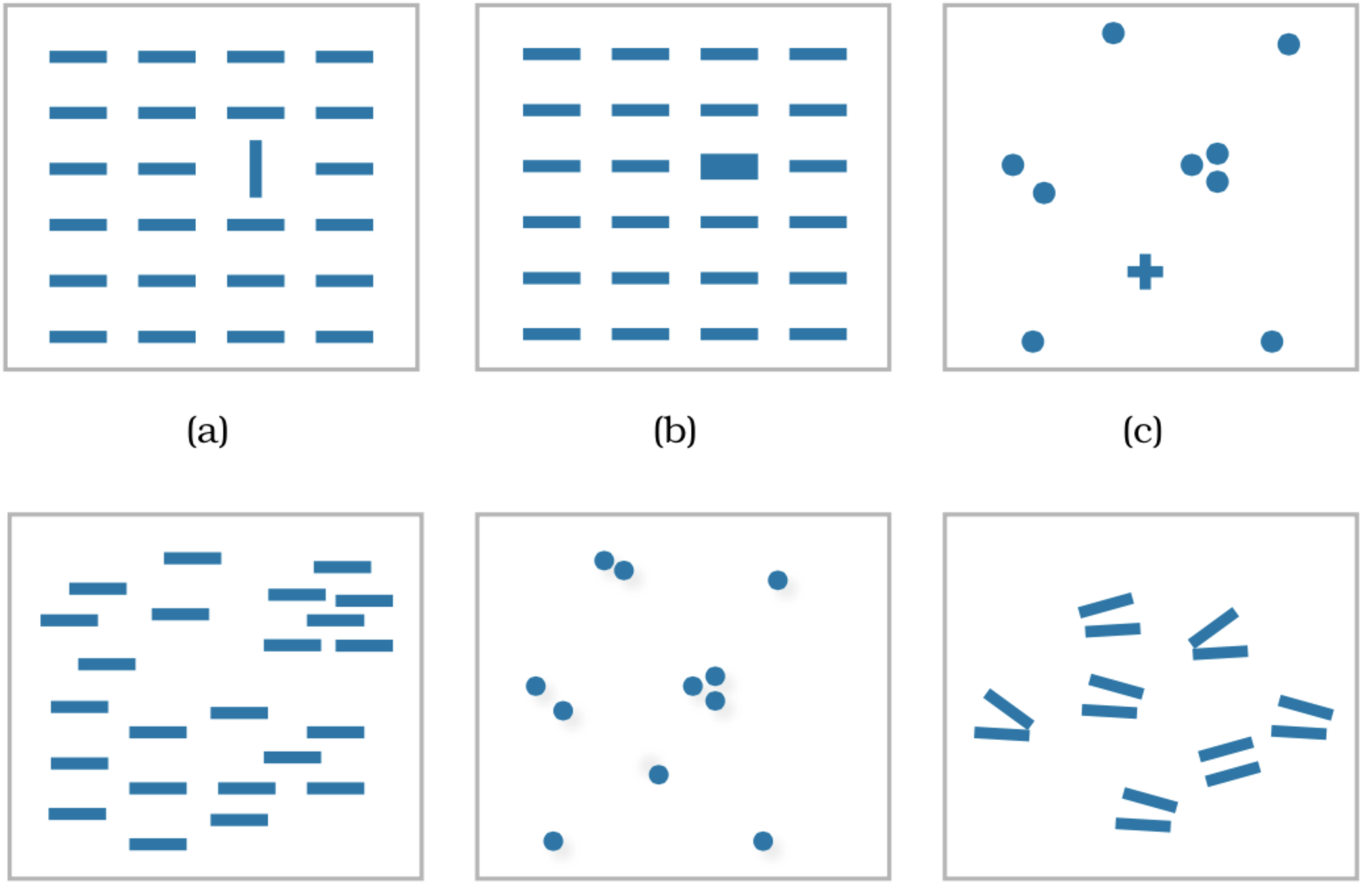




Pre-attentive processing

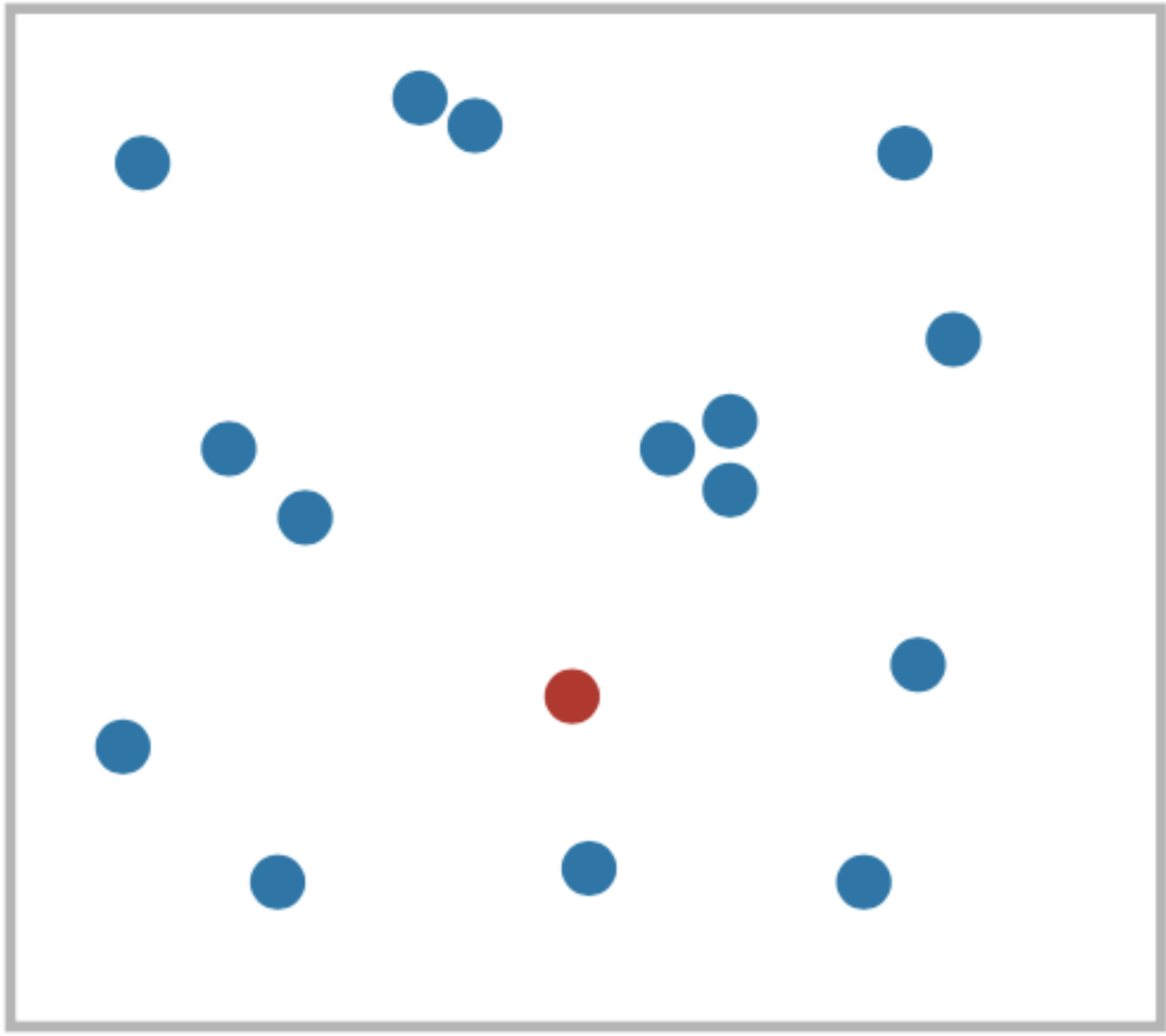
hard-wired many-channels

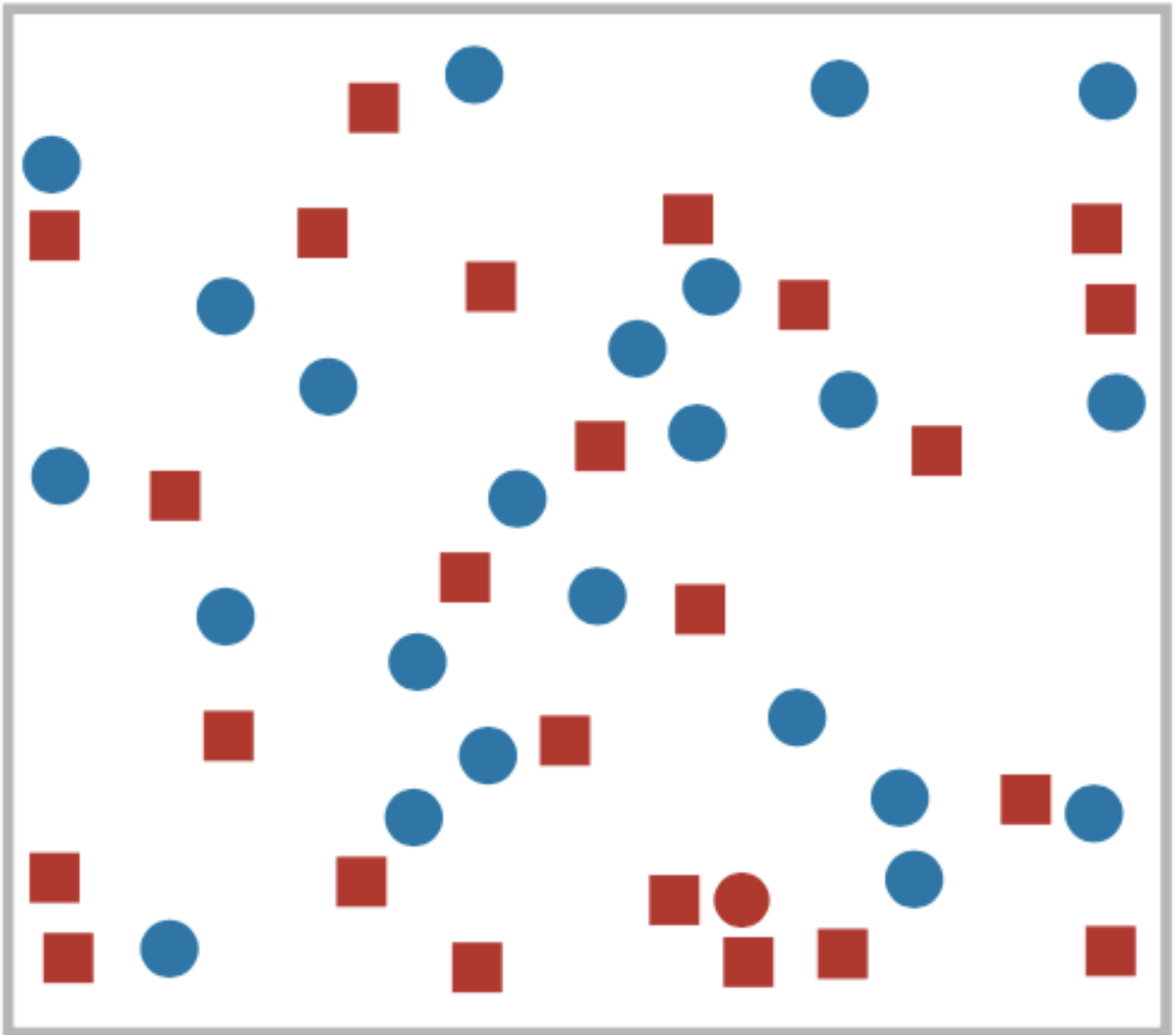



(a)
(b)
(c)
(d)
(e)
(f)

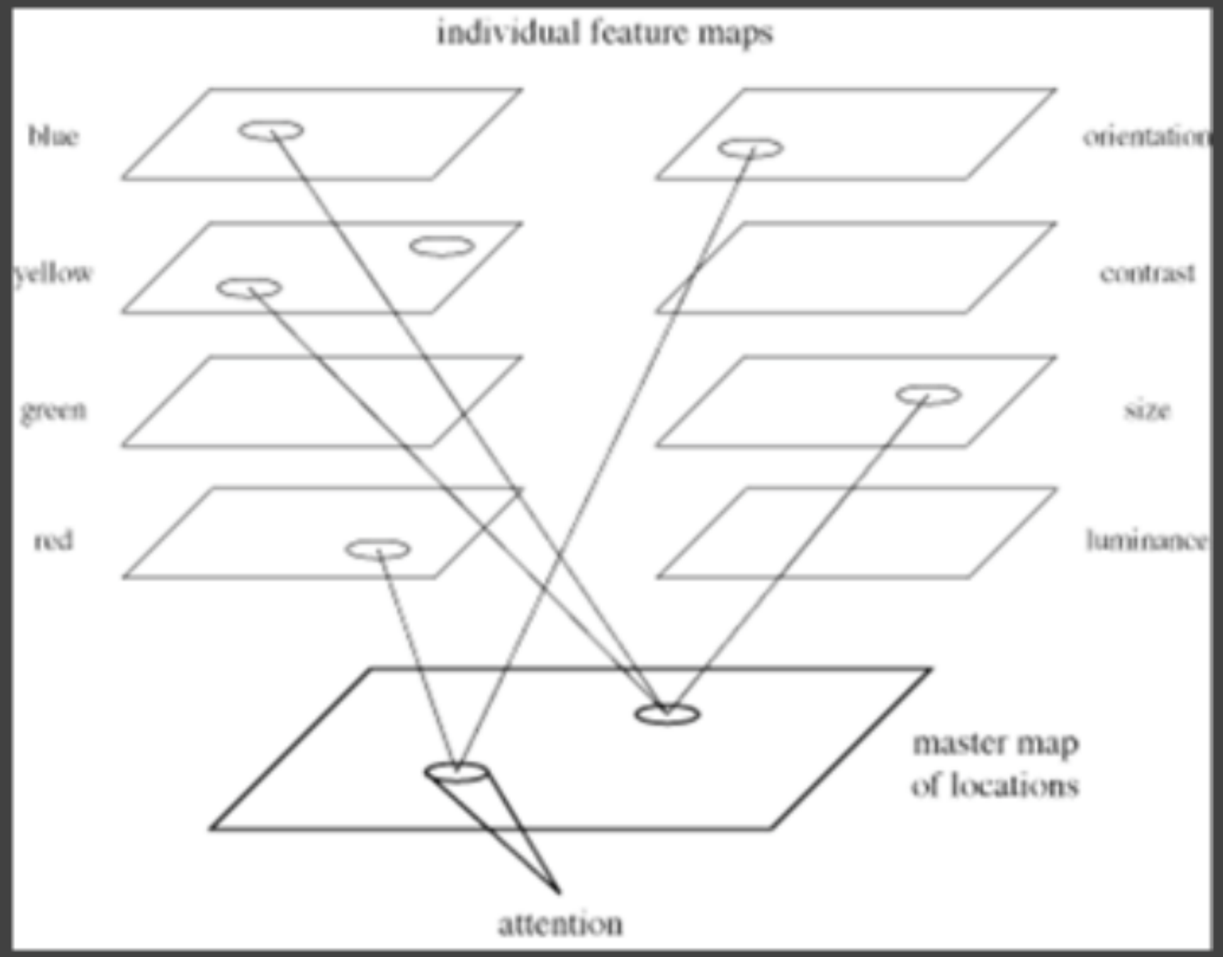
Pre-attentive processing

hard-wired
many-channels
easy to mess up

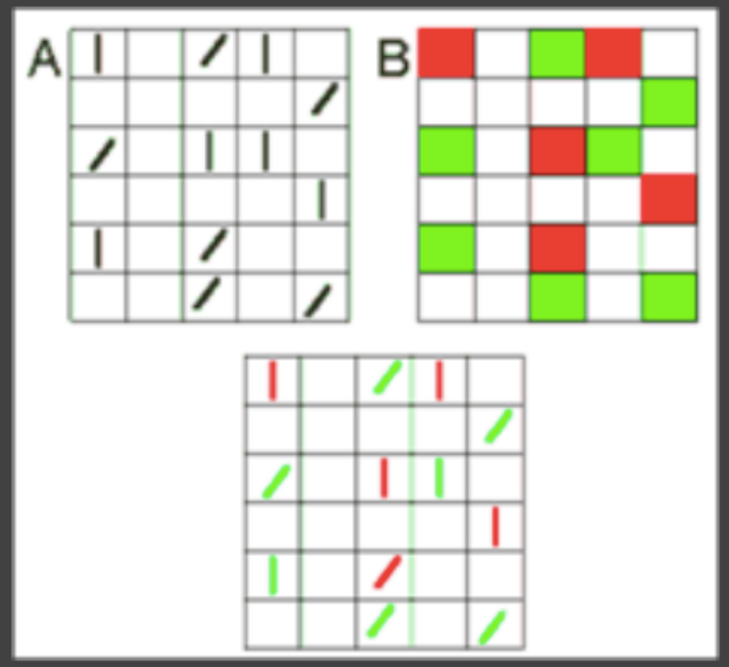




Feature Integration Theory

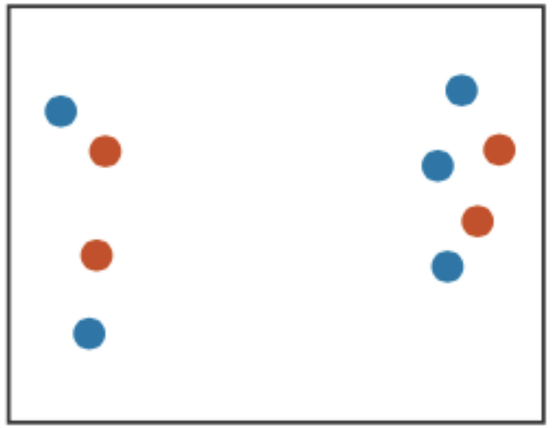


Treisman's feature integration model [Healey 04]



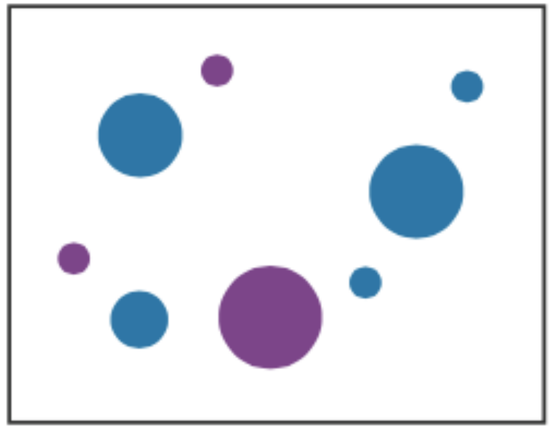
Feature maps for
orientation & color [Green]

Position
+ Hue (Color)



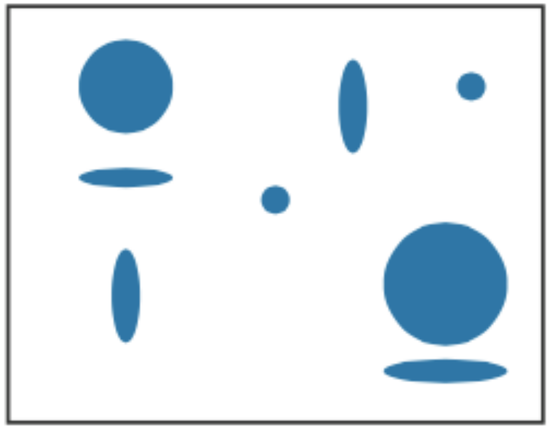
Fully separable

Size
+ Hue (Color)



Some interference

Width
+ Height



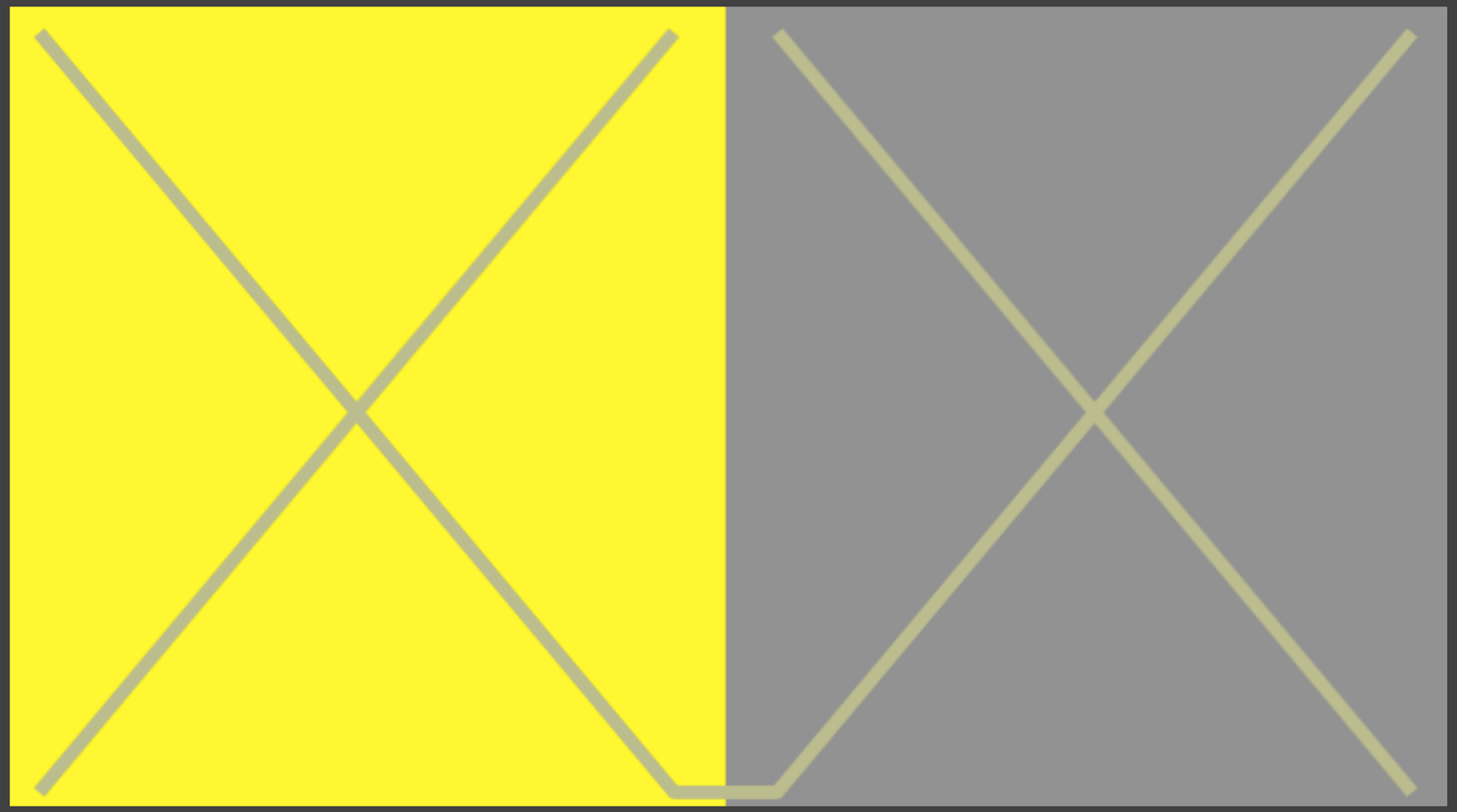
Some/significant interference

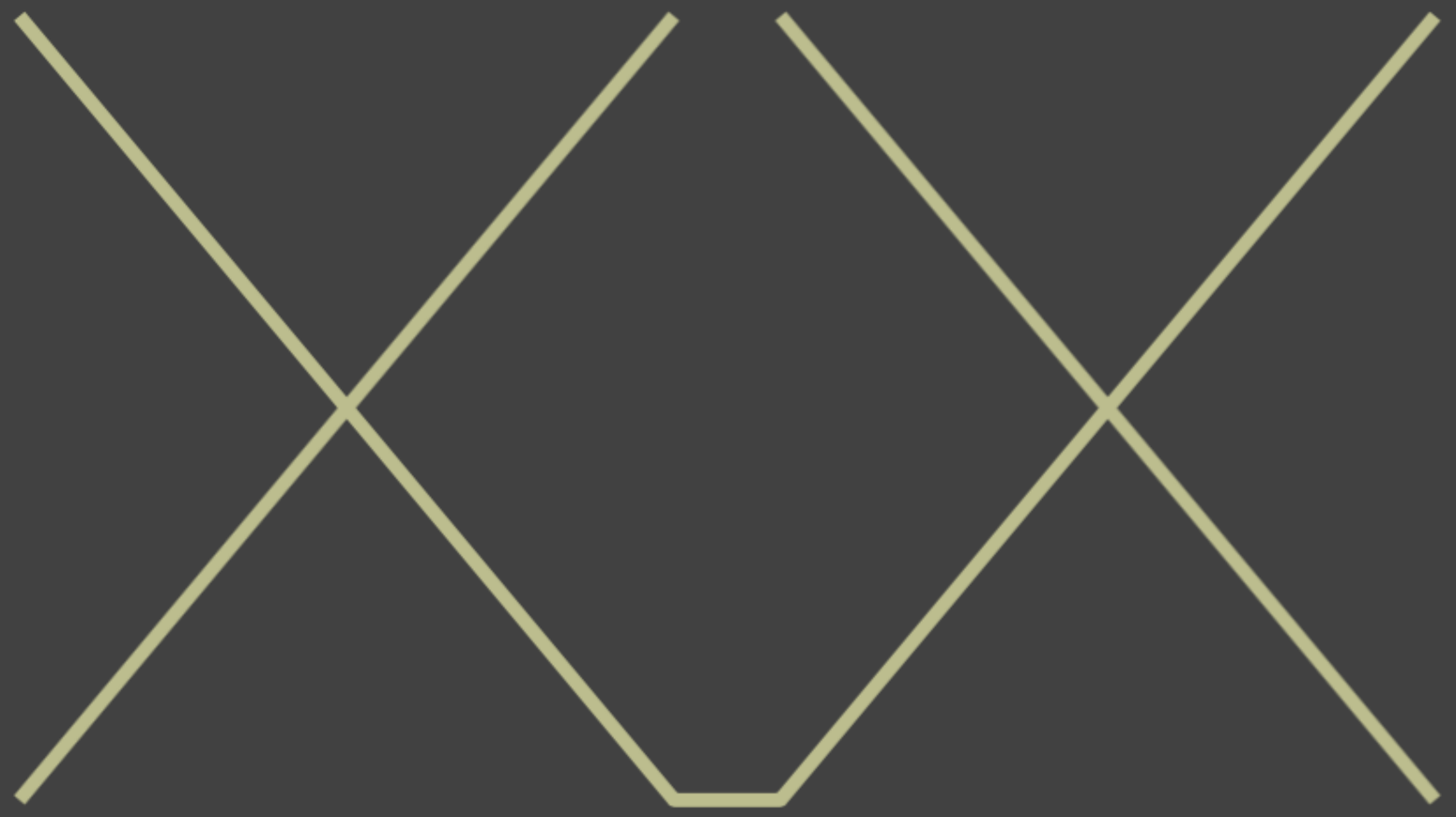
Red
+ Green

Major interference

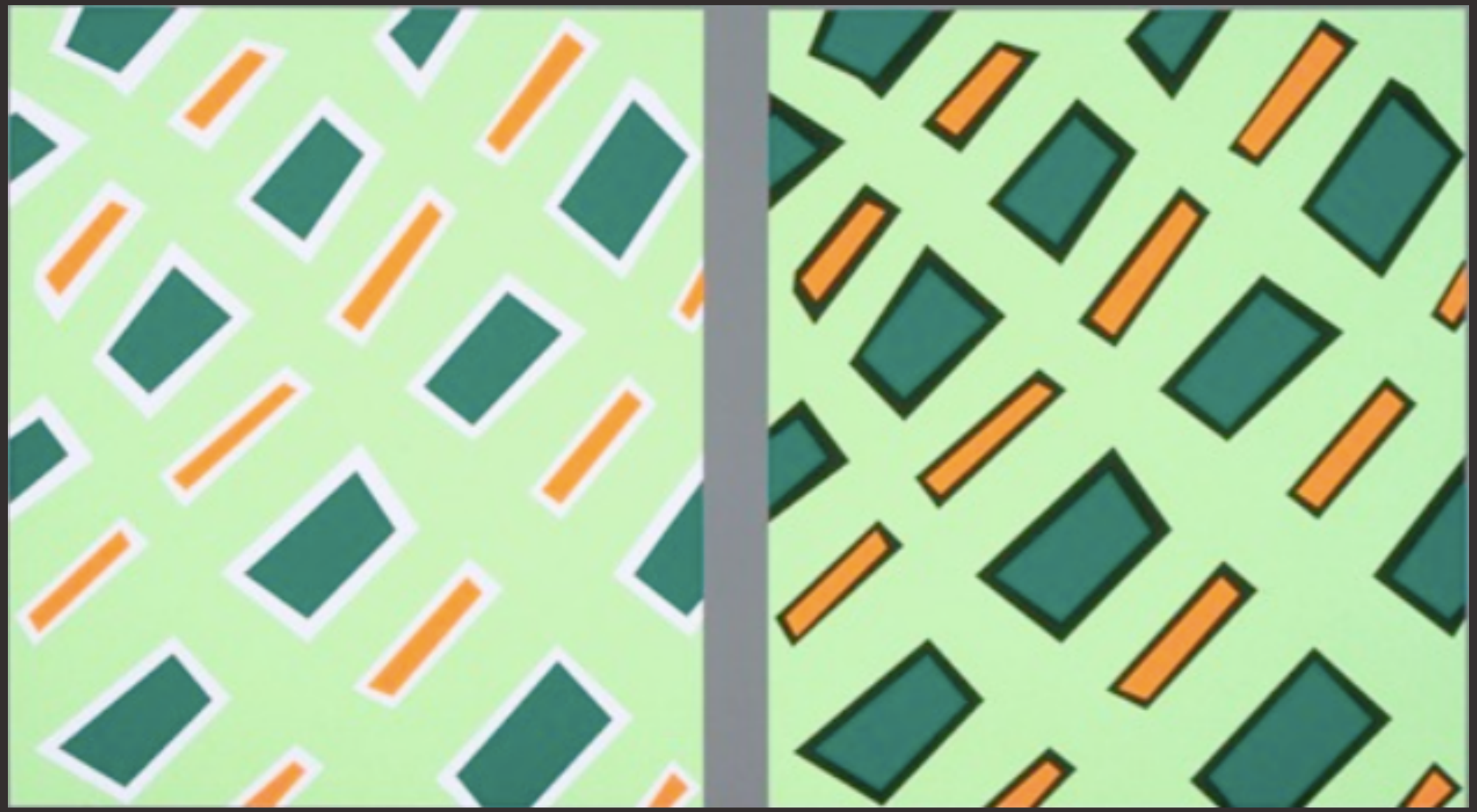
Separable vs. Integral

Color Caveats



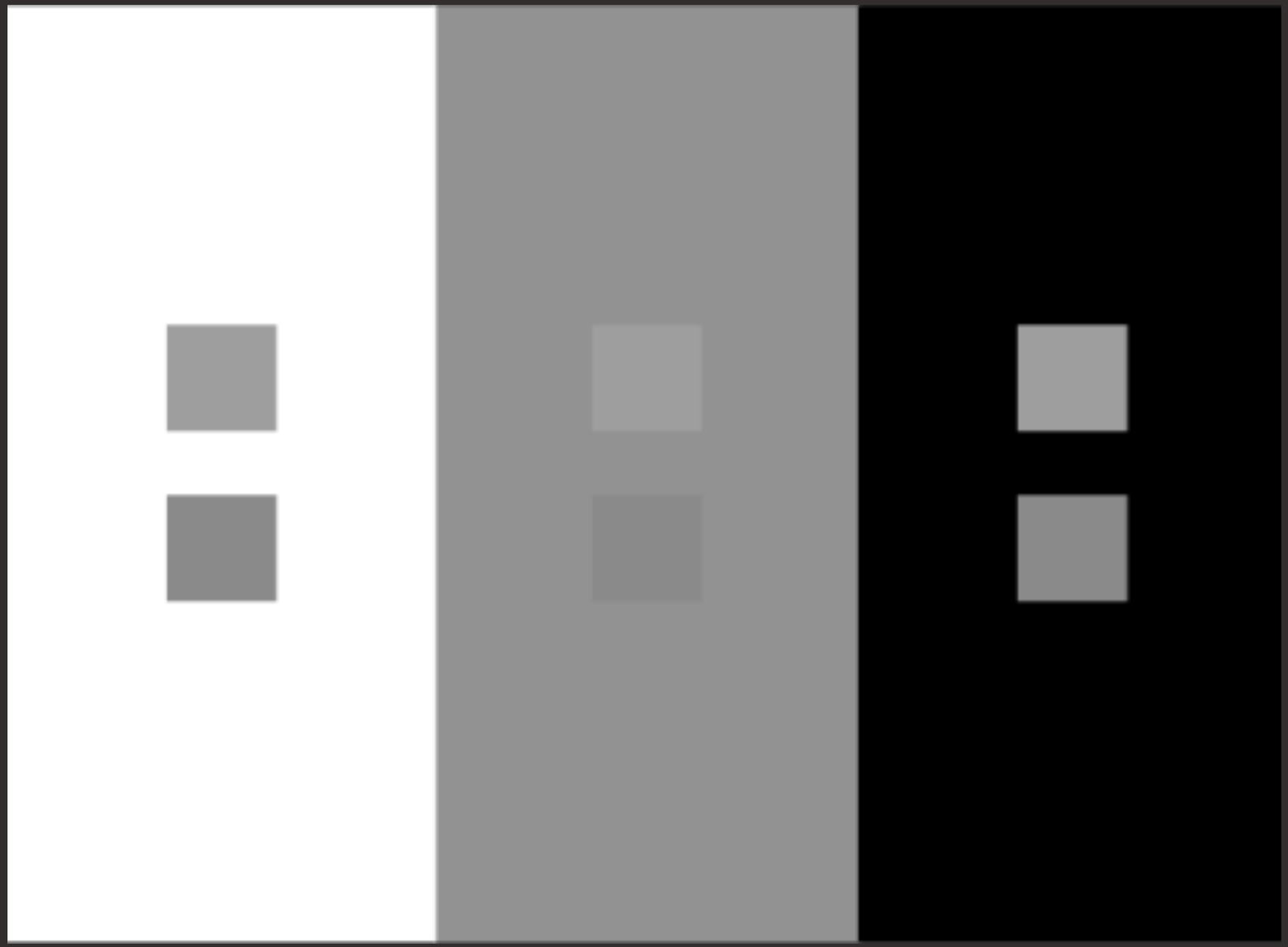


Contrast Effects



A field guide to Digital Color, Maureen Stone

Bezold Effect



Color Appearance Models, Fairchild

“Crispening”

Legibility and readability are very important

Legibility and readability are very important

Legibility and readability are very important

Legibility and readability are very important

Legibility and readability are very important

Legibility and readability are very important

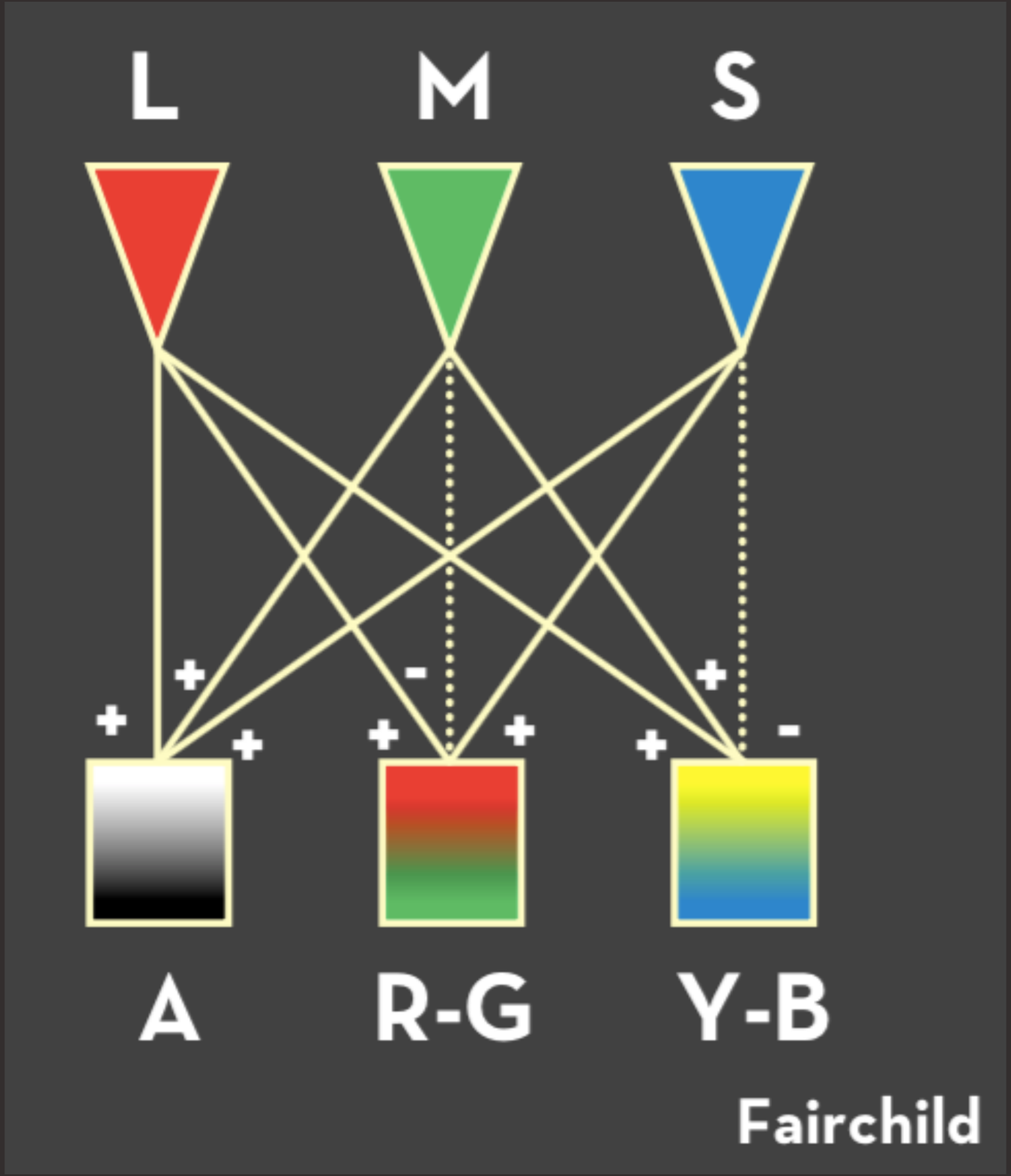
Legibility and readability are very important

Legibility and readability are very important

Color Blindness

Remember?

Long
Middle
Short

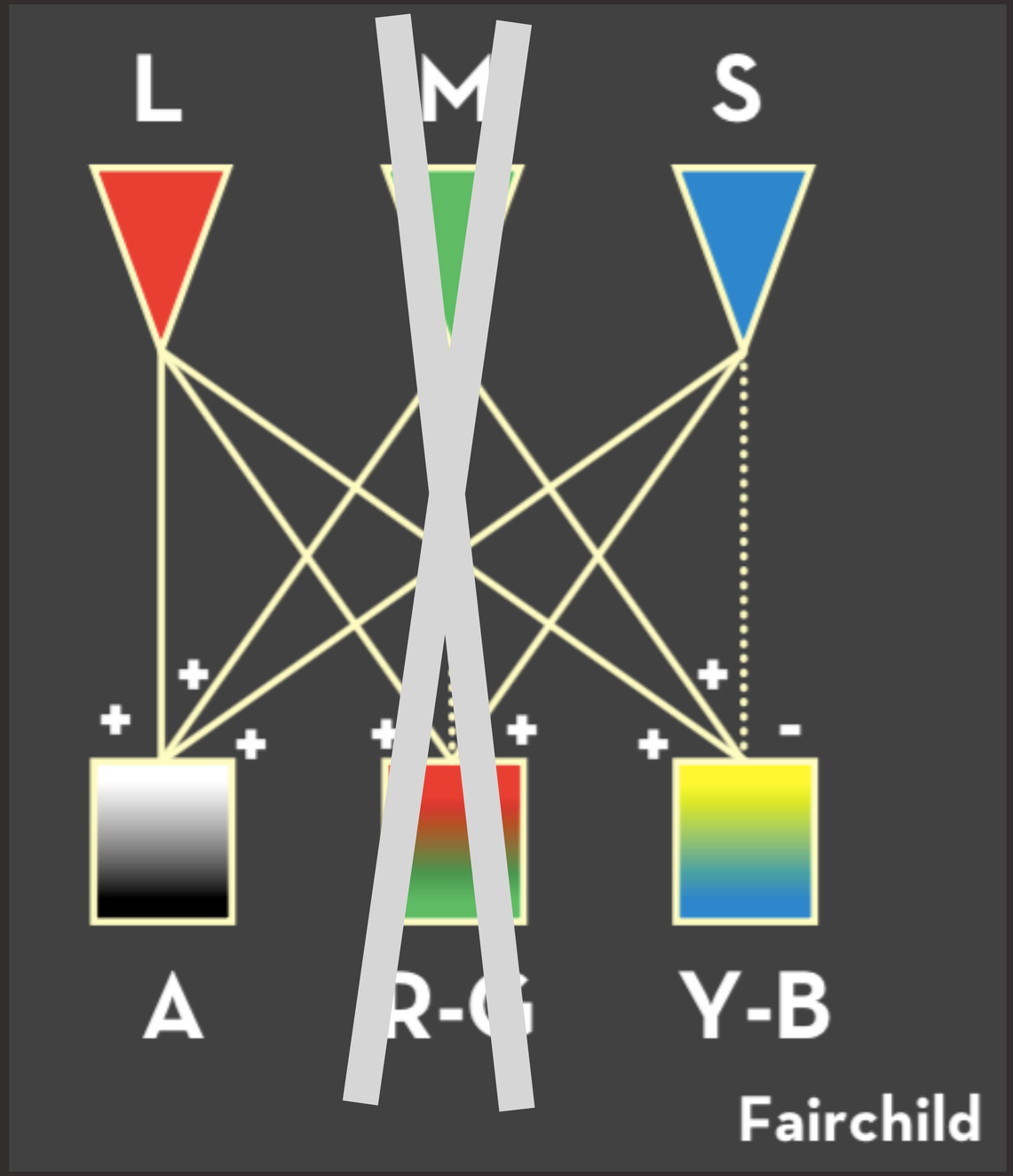


What if you're missing medium cones?

Long

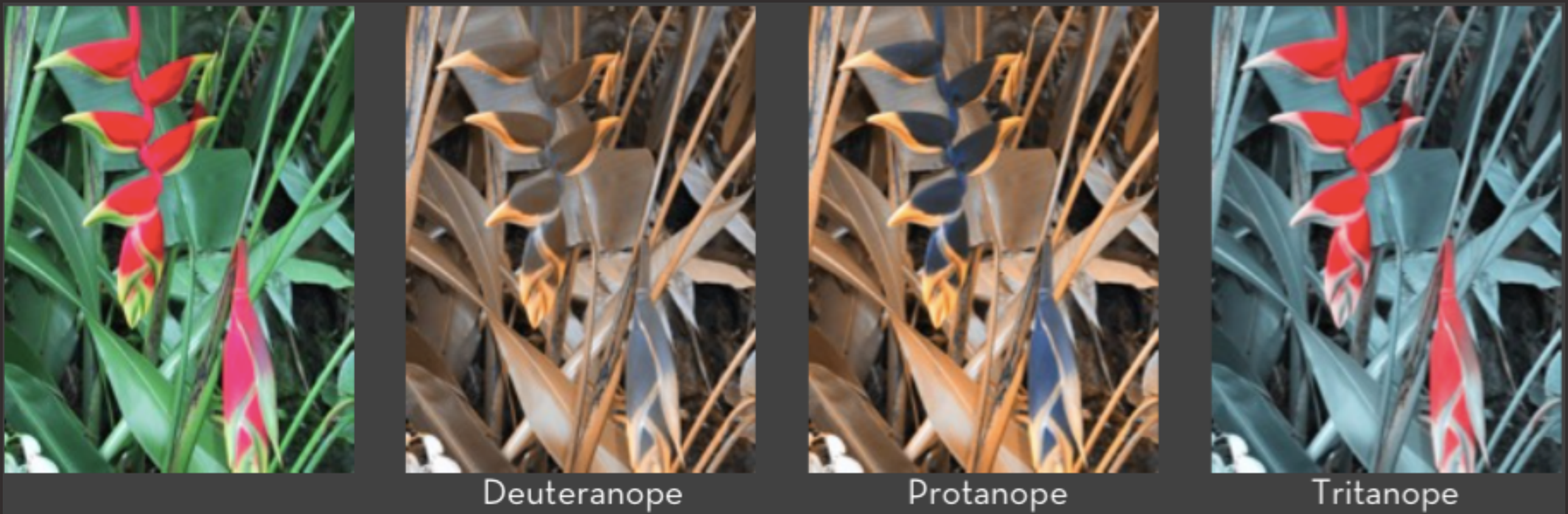
~~**M**iddle~~

Short



Colorblindness Types

normal **red-green** **yellow-blue**



Supporting CB

Color Oracle | Usage | Design Tips | Manual | Links

Color Oracle

Design for the Color Impaired

Color Oracle is a free color blindness simulator for Window, Mac and Linux. It takes the guesswork out of designing for color blindness by showing you in real time what people with common color vision impairments will see.

Color Oracle applies a full screen color filter to art you are designing – independently of the software in use. Eight percent of all males are affected by color vision impairment – make sure that your graphical work is readable by the widest possible audience.

Read this article for more information: Color Design for the Color Vision Impaired

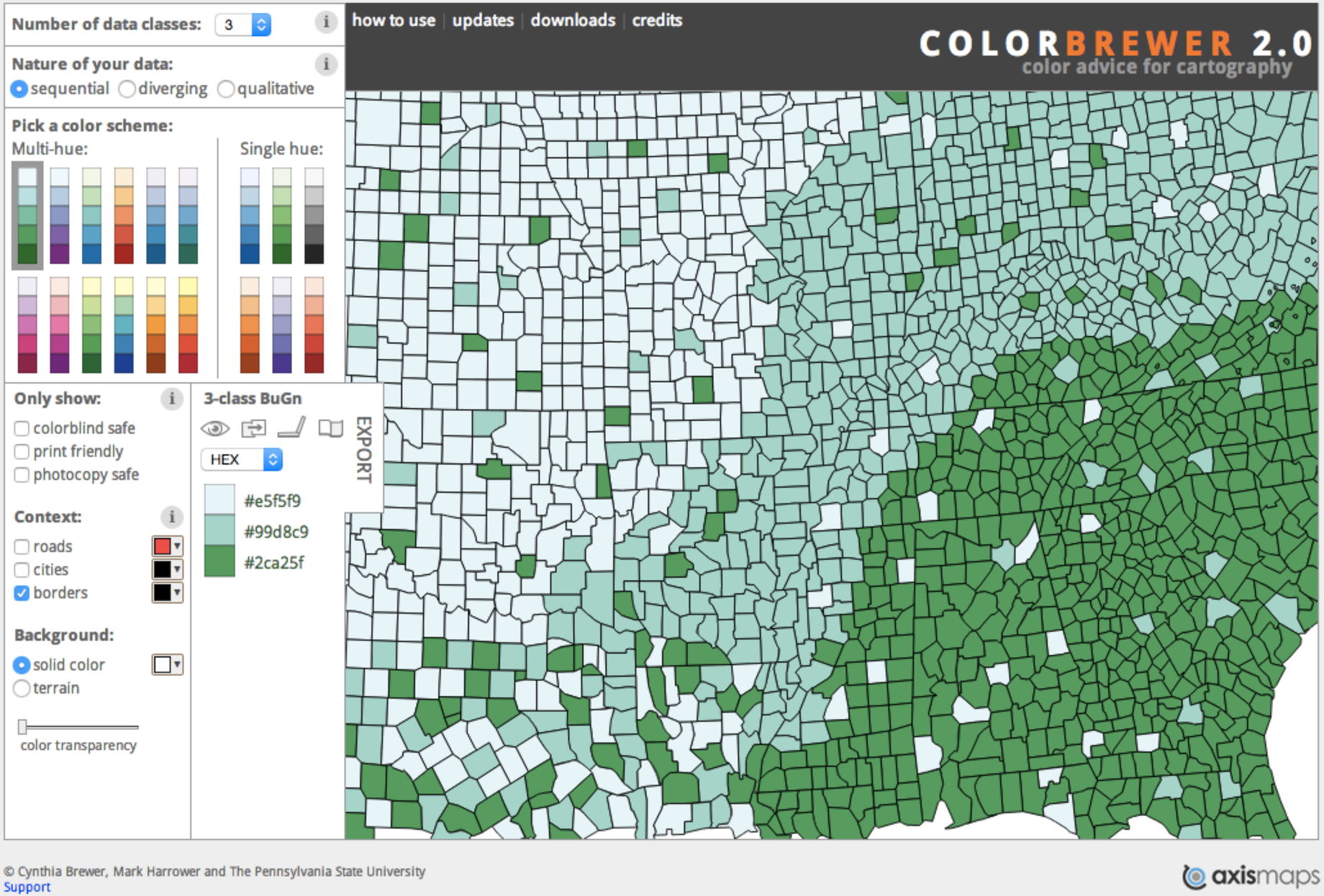
Free Download

Version 1.2.1 for Windows
Requires Java 6 or 7.

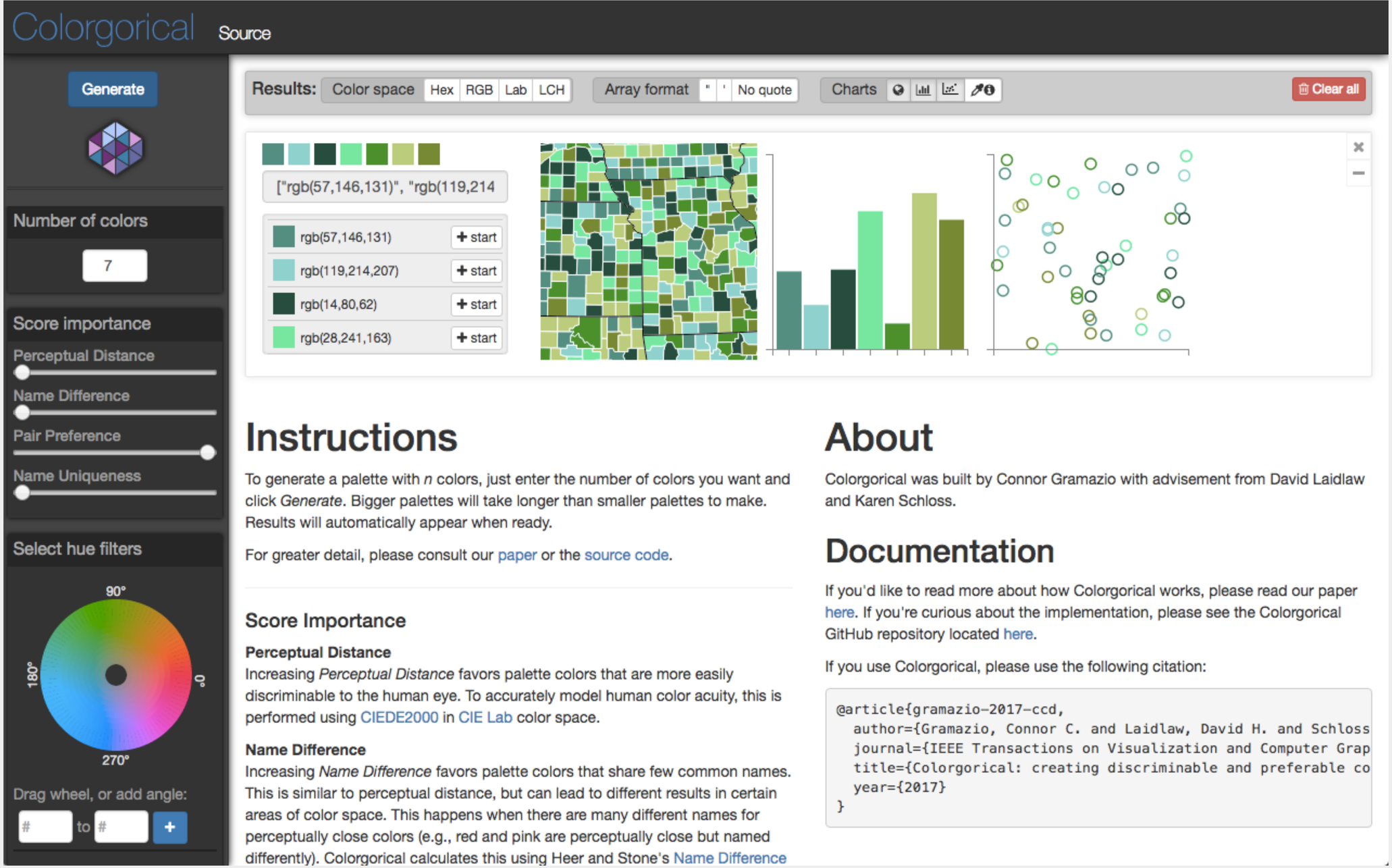
Version 1.1.4 for Mac OS X 10.4 or higher now supports Retina displays and OS X 10.8 or higher.
Important for Mac users: If upon launching Color Oracle you get the error message "Color Oracle can't be opened because it is from an unidentified developer", right-click the Color Oracle icon and choose Open. Then click the "Open" button at the next dialog to launch Color Oracle. See here to permanently turn this feature off.

also see work by David Flatla on colorblindness support

Color Tools



http://colorbrewer2.org/



http://vrl.cs.brown.edu/color

color links discussed in class 25-Feb-2021

https://github.com/d3/d3-scale-chromatic

https://github.com/d3/d3-scale-chromatic/blob/master/README.md#diverging

https://github.com/d3/d3-color

Adobe Kuler / Color

“Good painting, good coloring, is comparable to good cooking.

Even a good cooking recipe demands tasting and repeated tasting while it is being followed.

And the best tasting still depends on a cook with taste.”

- Josef Albers