

CS-5630 / CS-6630

Visualization for Data Science

Perception

Alexander Lex
alex@sci.utah.edu



Perception

Identification and interpretation of sensory information

From the physical stimulus to recognizing information

Shaped by learning, memory, expectation

Cognition

The processing of information, applying knowledge

Hear someone speak: Perception

Understand the language and the words: Cognition

Perception vs. Cognition

Perception

Eye, optical nerve, visual cortex

Basic perception

First processing
(edges, planes)

Not conscious

Reflexes

Cognition

Recognizing objects

Relations between objects

Conclusion drawing

Problem solving

Learning, ...

RED

GREEN

BLUE

YELLOW

PINK

ORANGE

BLUE

GREEN

BLUE

WHITE

GREEN

YELLOW

ORANGE

BLUE

WHITE

BROWN

RED

BLUE

YELLOW

GREEN

PINK

YELLOW

GREEN

BLUE

RED

What is There vs.
What do we See



Emergence Images. Perceptual Hysteresis.



Looking only at patches doesn't work

http://graphics.stanford.edu/~niloy/research/emergence/emergence_image_siga_09.html

Our perception is based on priors

We have a model of the world

We try to fit what we see into this model.

We get confused if something we see doesn't fit our priors.





we rely on priors



Pareidolia



Faces in Things @FacesPics · Mar 9

These chairs have seen some terrible things pic.twitter.com/Gjlc9wuP47



Faces in Things @FacesPics · Feb 14

Deep in thought Deep Fryer pic.twitter.com/1Qyqjmslka



Faces in Things @FacesPics · Mar 22

Hey little guy! pic.twitter.com/nt2BgwZeTR



Faces in Things @FacesPics · Mar 10

A terrified pickle pic.twitter.com/Ffph1wzTyv



The tendency for perception to impose a meaningful interpretation on a nebulous stimulus.

Take Home Point

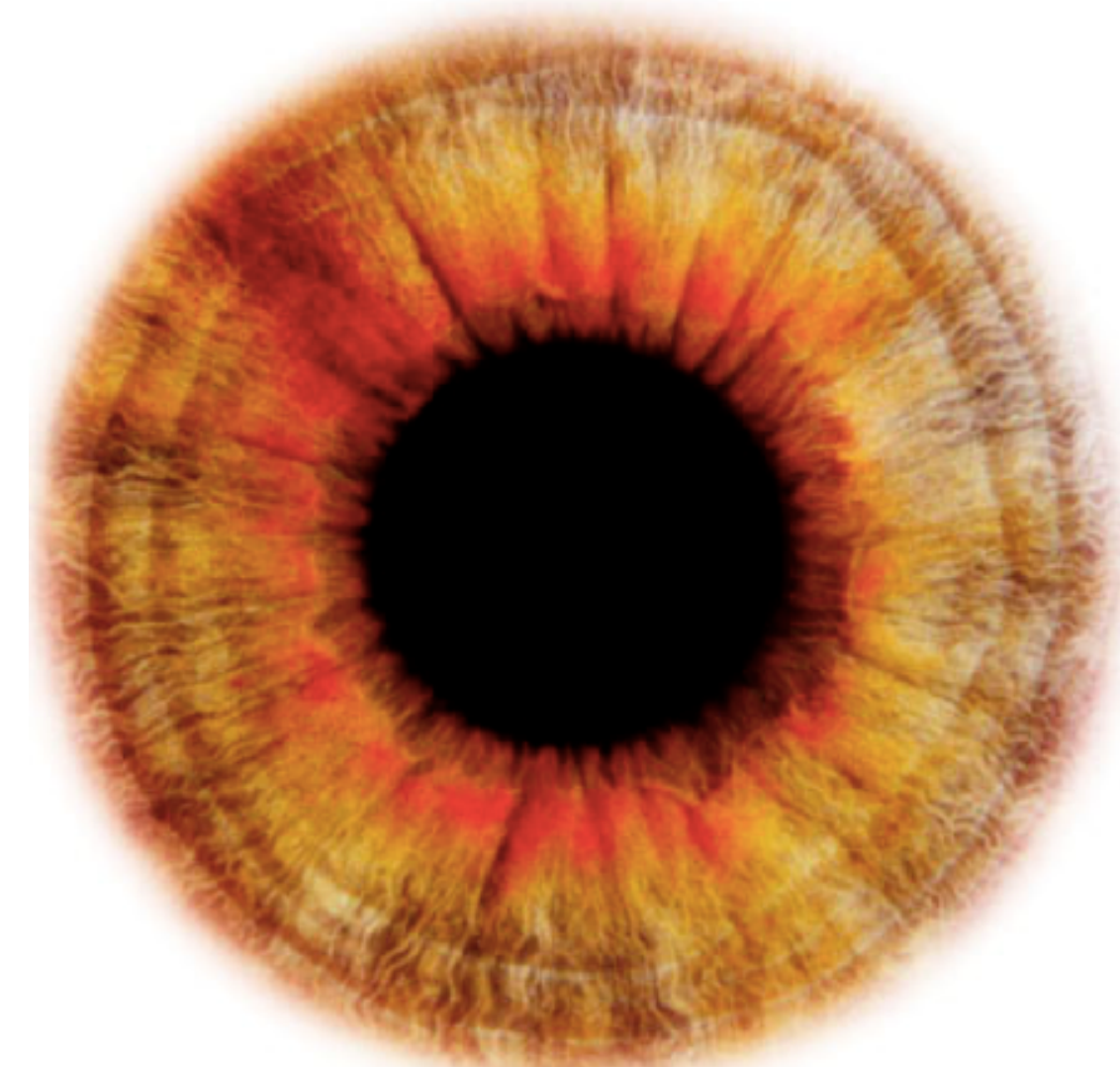
Vision is “constructed” top down from the input

“What you see when you see a thing depends on what the thing is. What you see the thing as depends on what you know about what you are seeing.”

Zenon Pylyshyn
Canadian Cognitive Scientist
and Philosopher



The Eye



Human Visual System

5-6 mio cones

color vision (COnes for COlor)

dense in the center

require more light (hence it's grey at night)

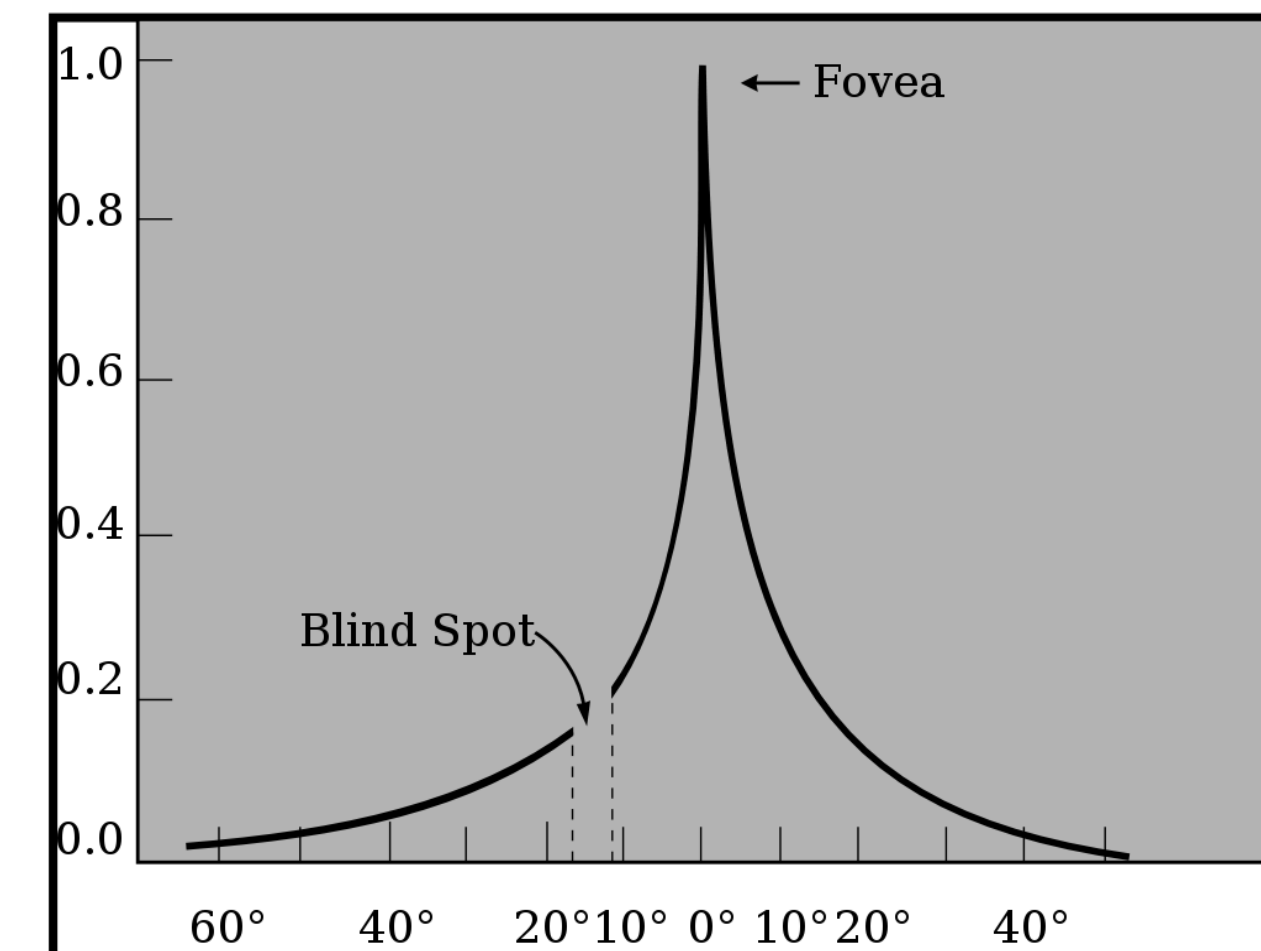
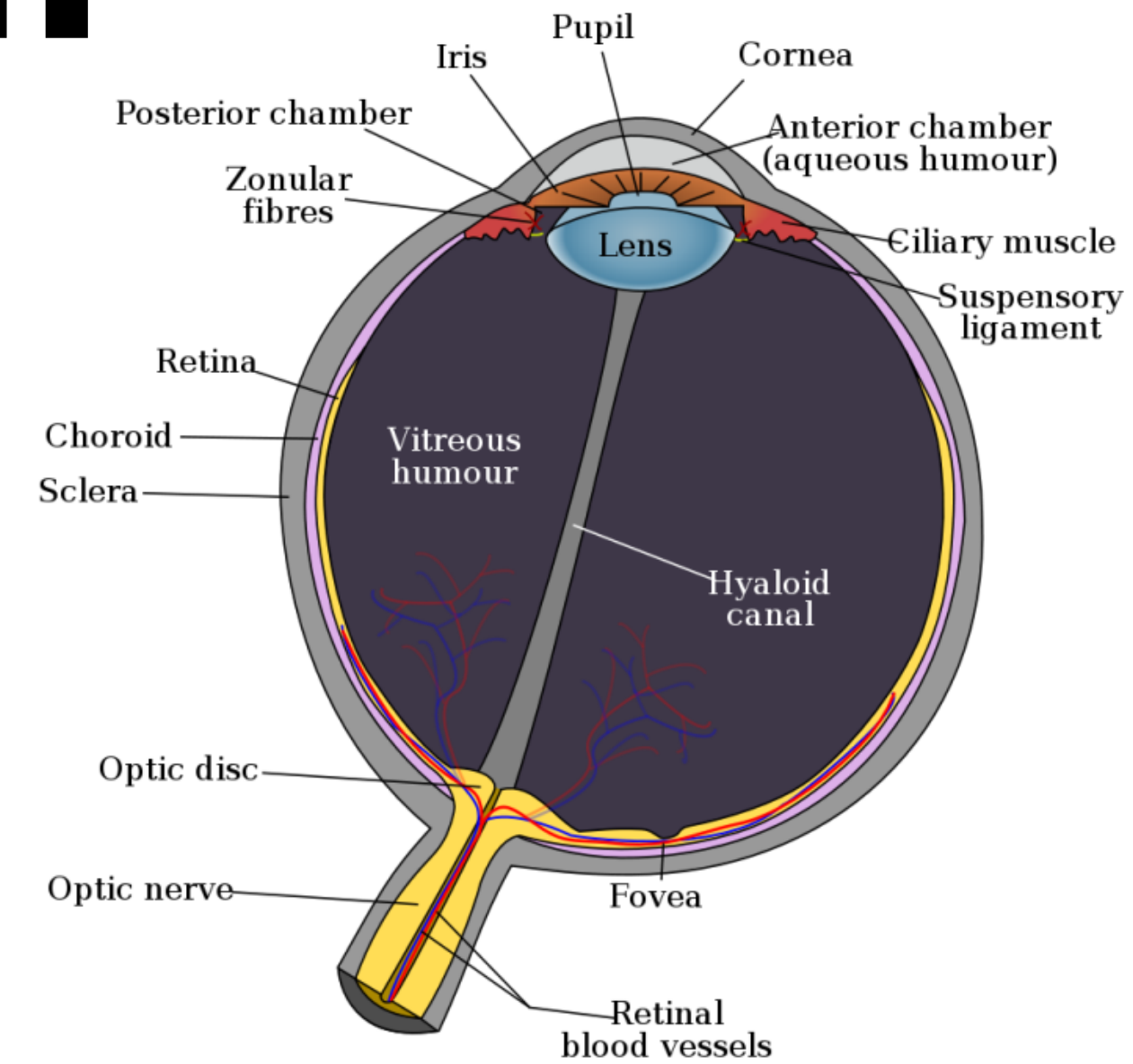
Fovea: 27 times the density

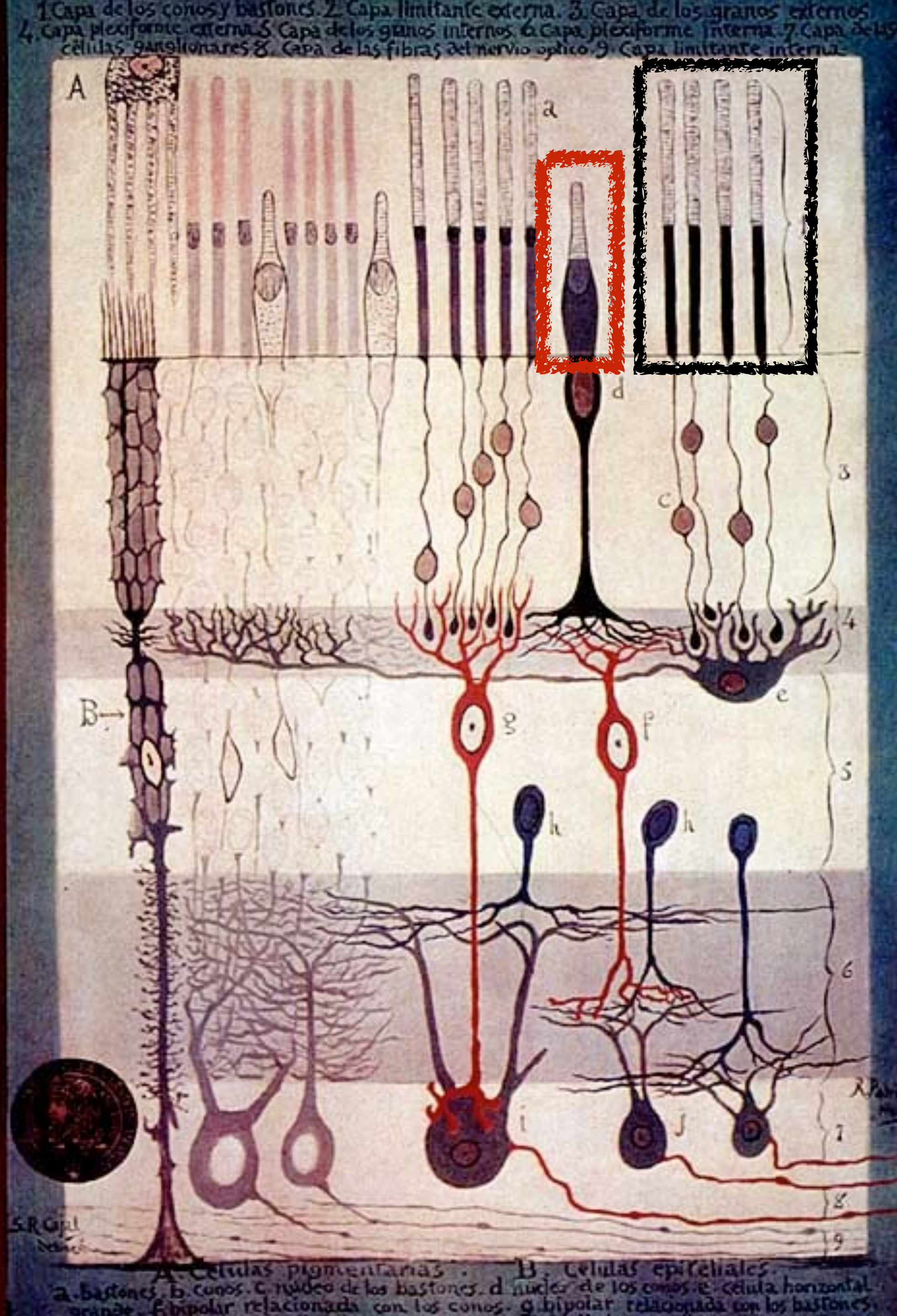
responsible for sharp central vision

only cone cells

~120 mio rods

black/white



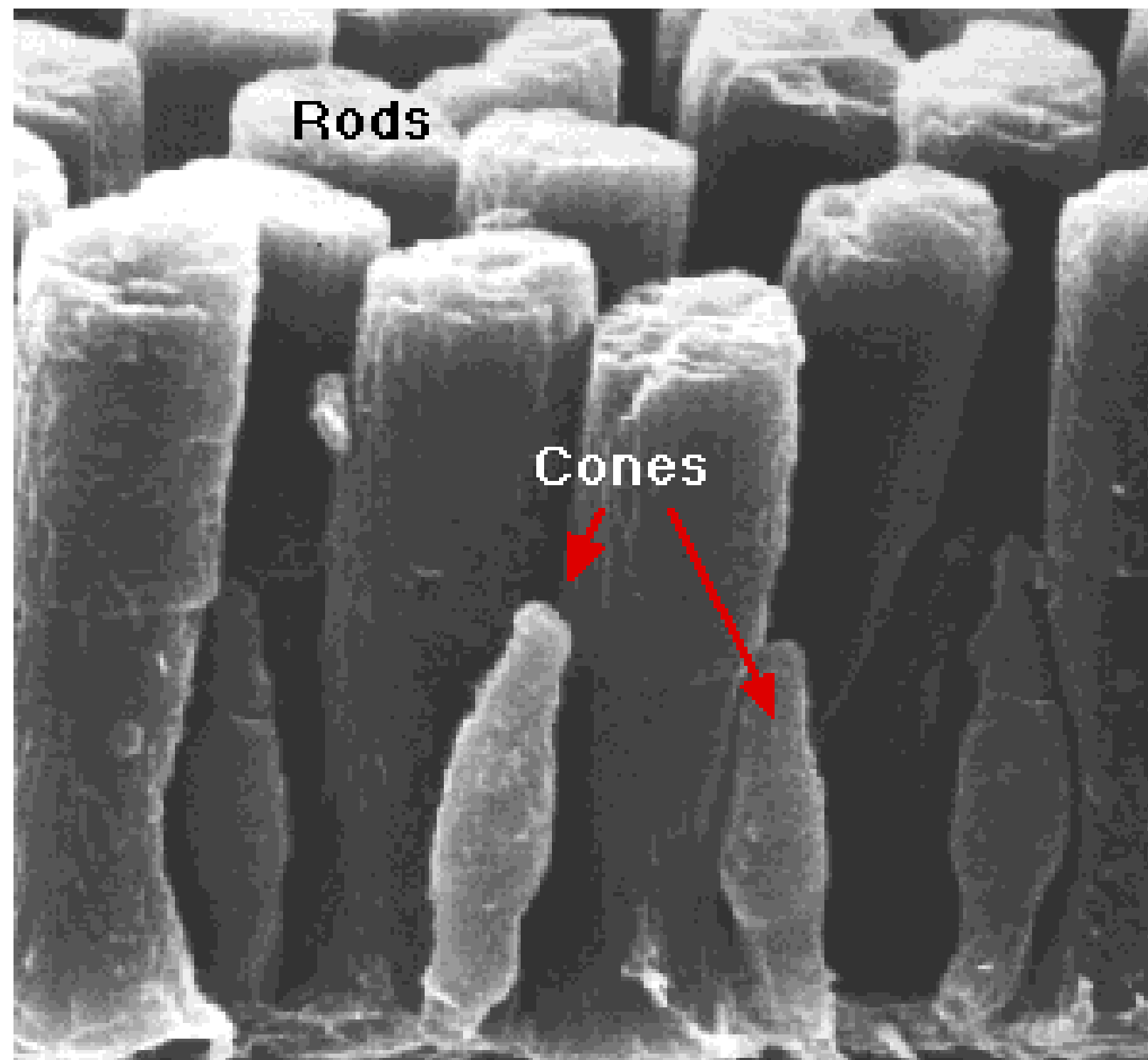


Rods - sensitive black and white

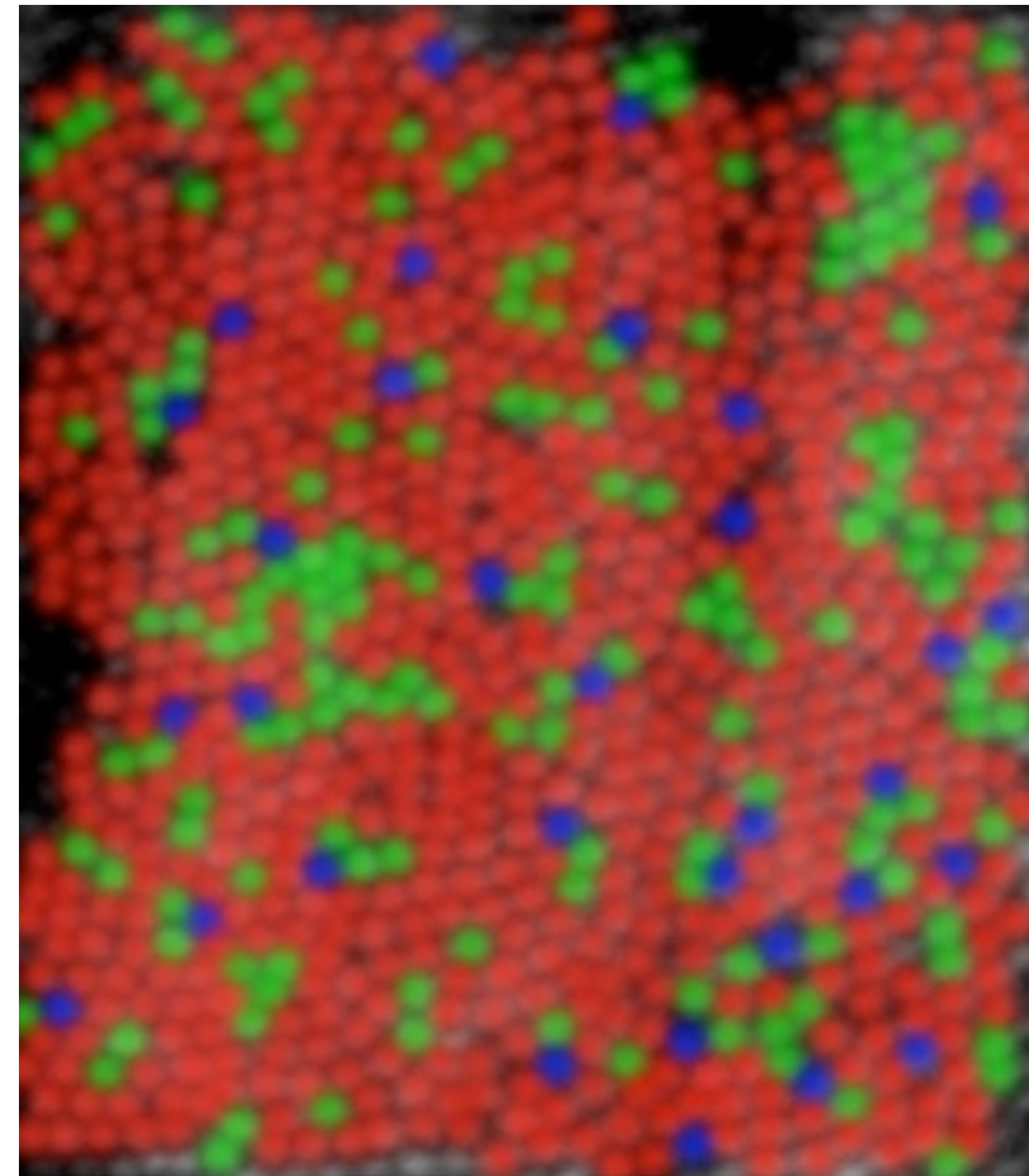
Cones - color vision

Ganglion Cells

"Structure of the Mammalian Retina"
 c.1900 By Santiago Ramon y Cajal



~120 million rods
~5-6 million cones

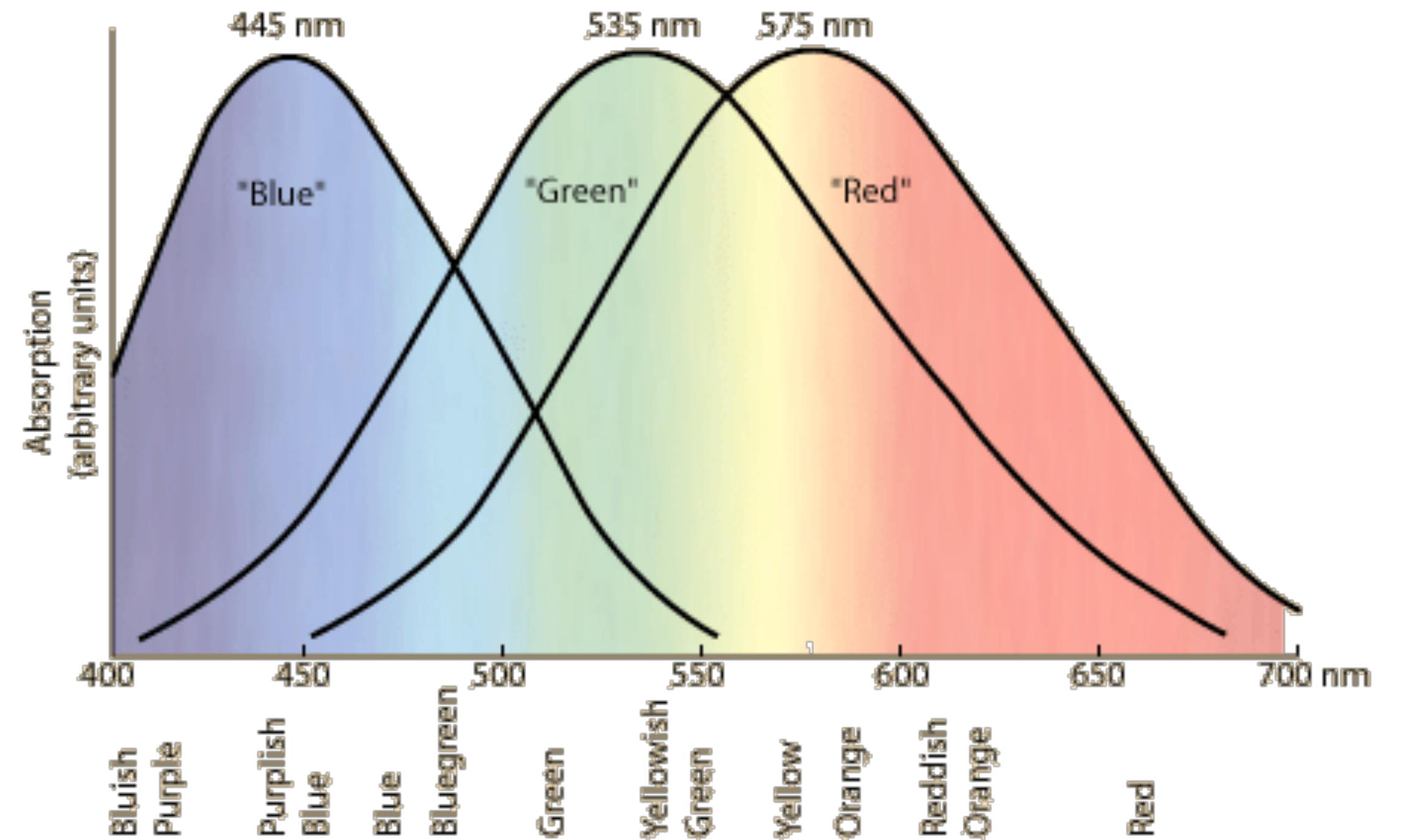
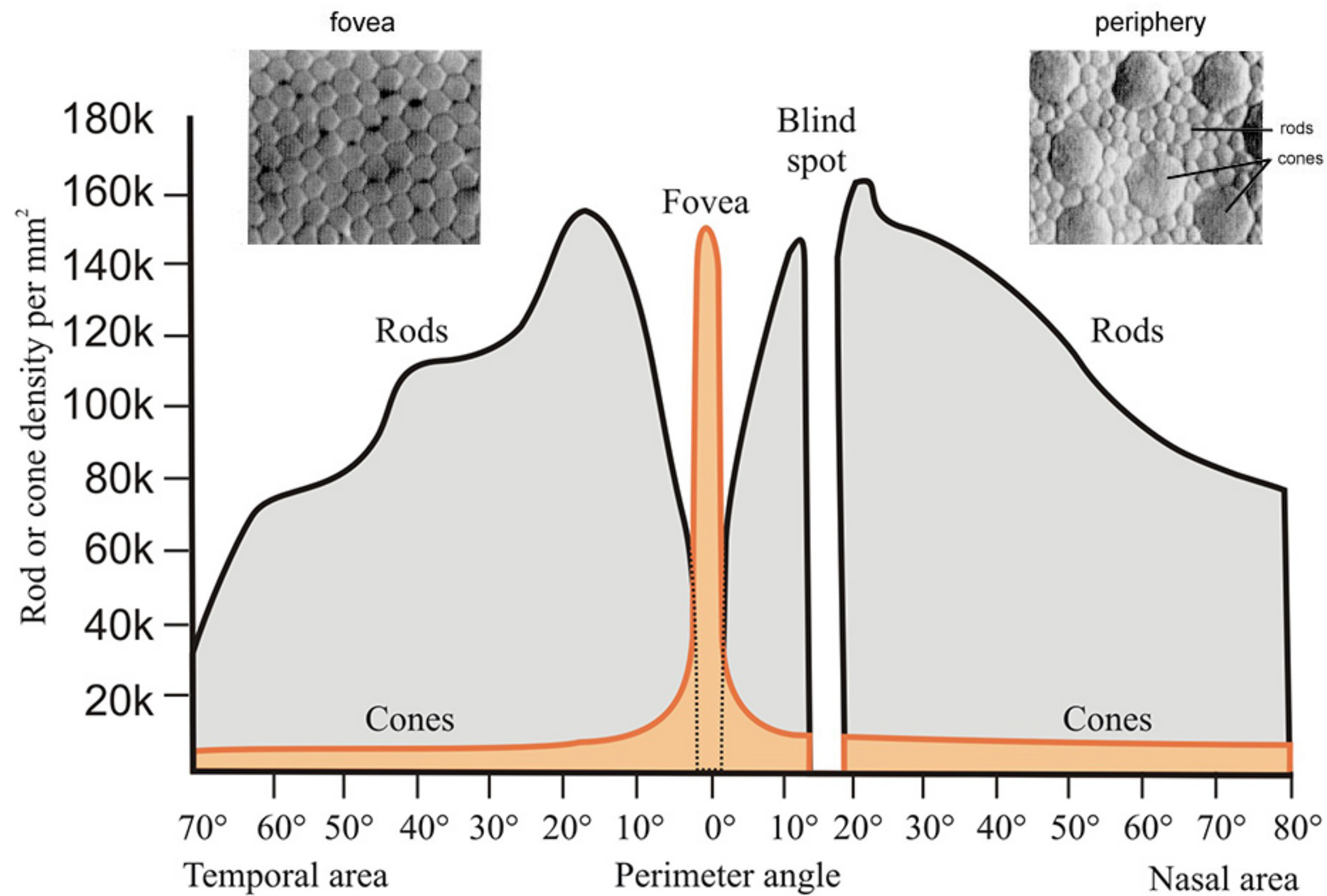


R 63% - G 31% - B 2-6%

Wandell, "Foundations of Vision" (left)

David R. Williams, Univ. of Rochester (right)

Cone Response



Human Visual System

Vision works as sequence of **fixations** and **saccades**

fixations: maintaining gaze on single location (200-600 ms)

saccades: moving between different locations (20-100 ms)

Vision not similar to a camera

More similar to a dynamic and ongoing construction project



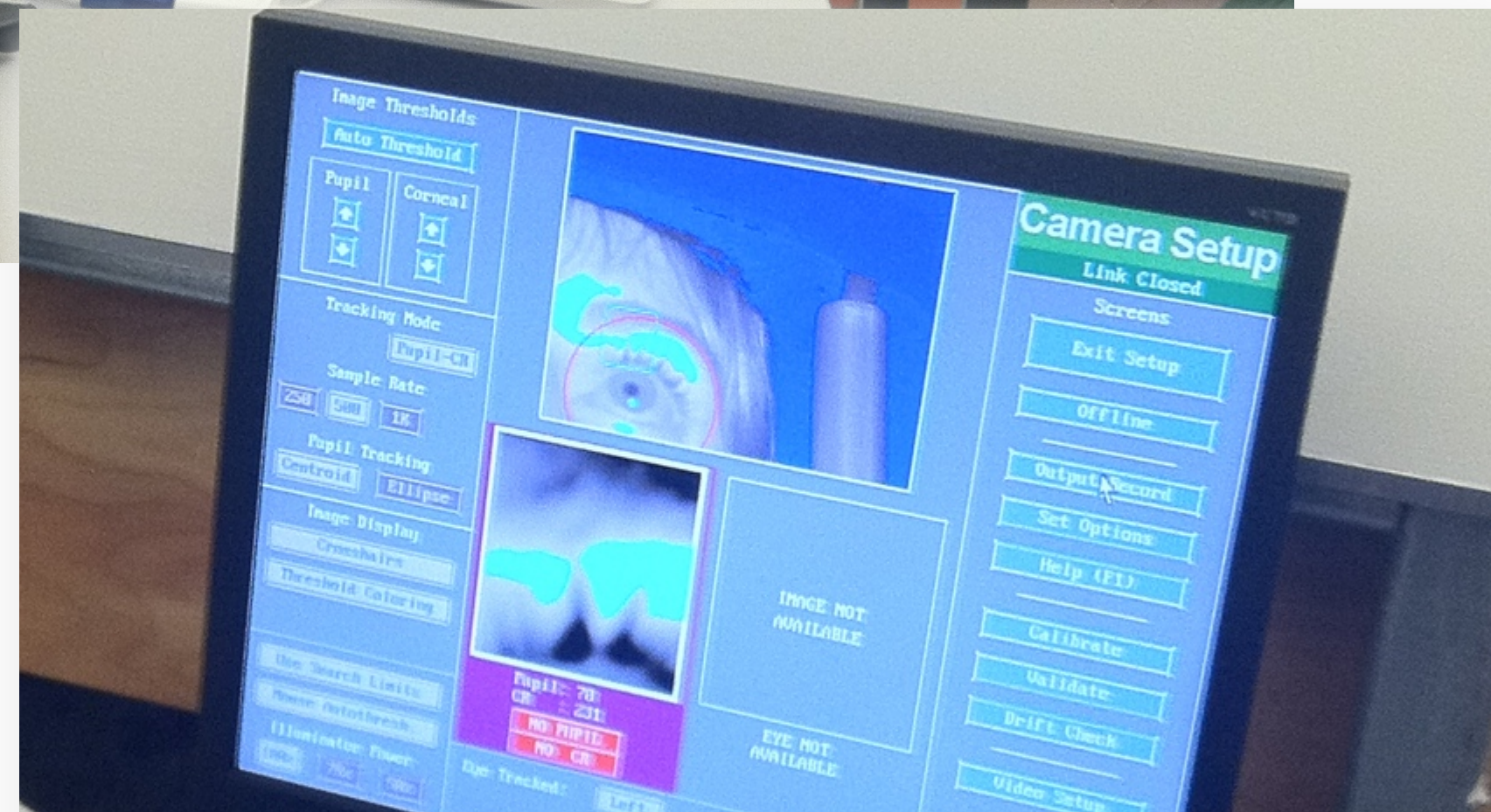


Eye-Tracking Experiment

Visualization
display

Eye-tracking control computer

Infrared
camera



Video!

SensoMotoric Instruments presents

Karaoke

Gaze Tracking and User Observation

Human Visual System

No general purpose vision

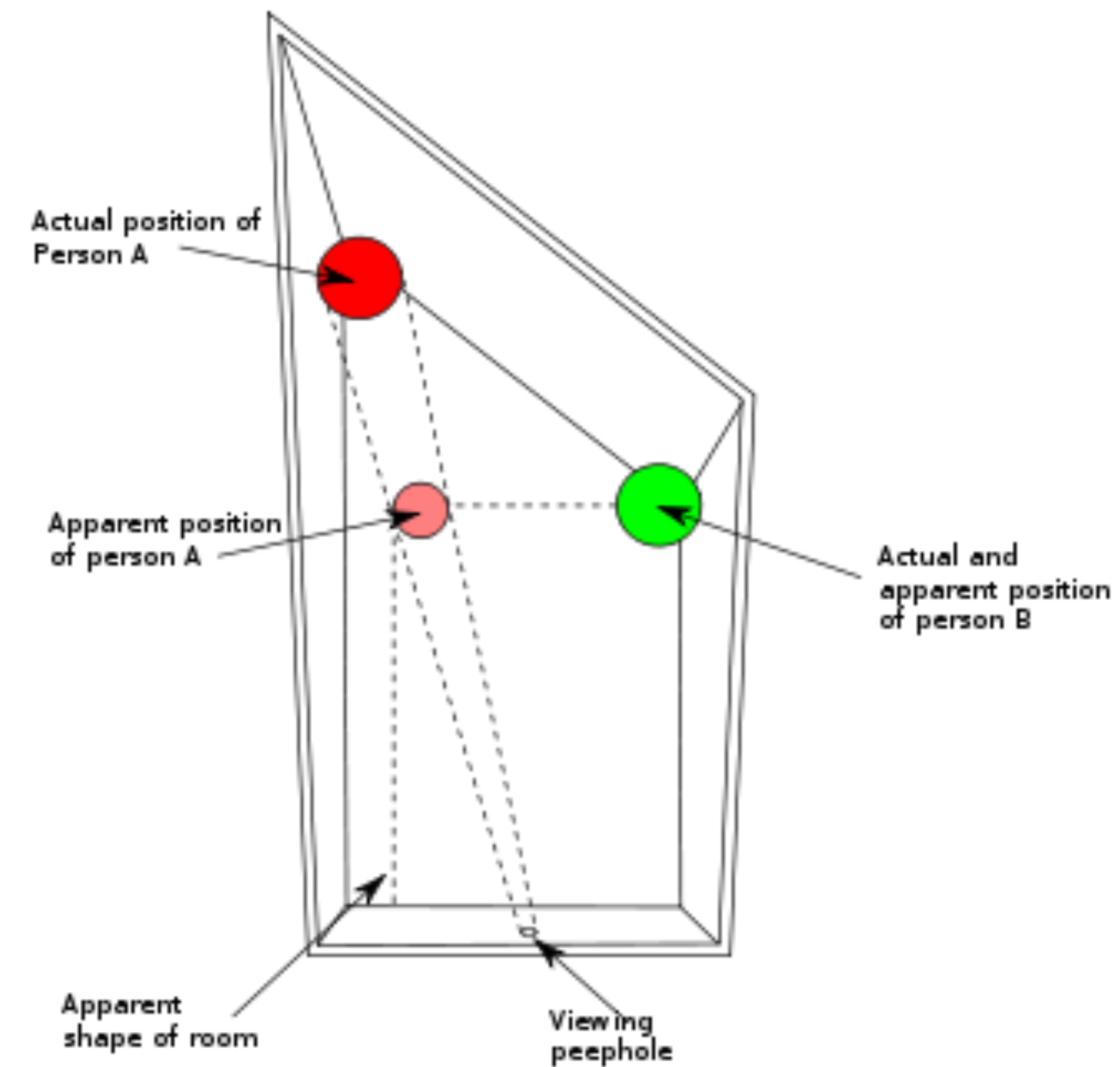
What we see depends on our goals and expectations

Relative judgments: strong

Absolute judgments: weak



Ames Room





Color

Color Basics

Visible part of the electromagnetic spectrum

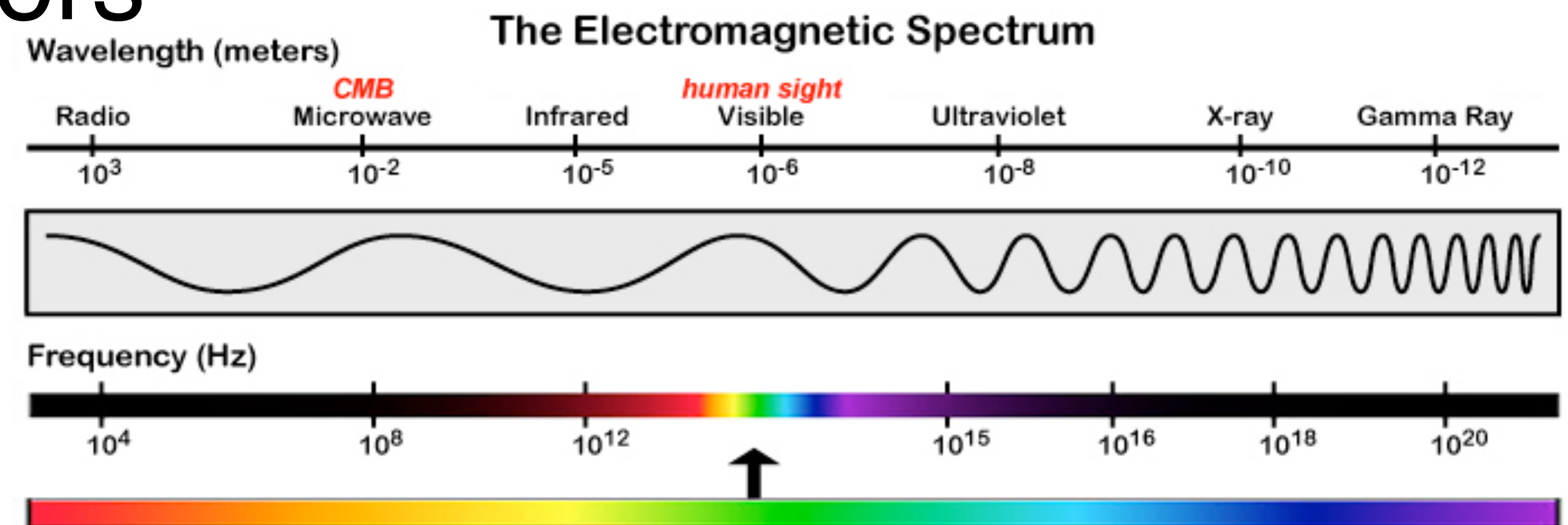
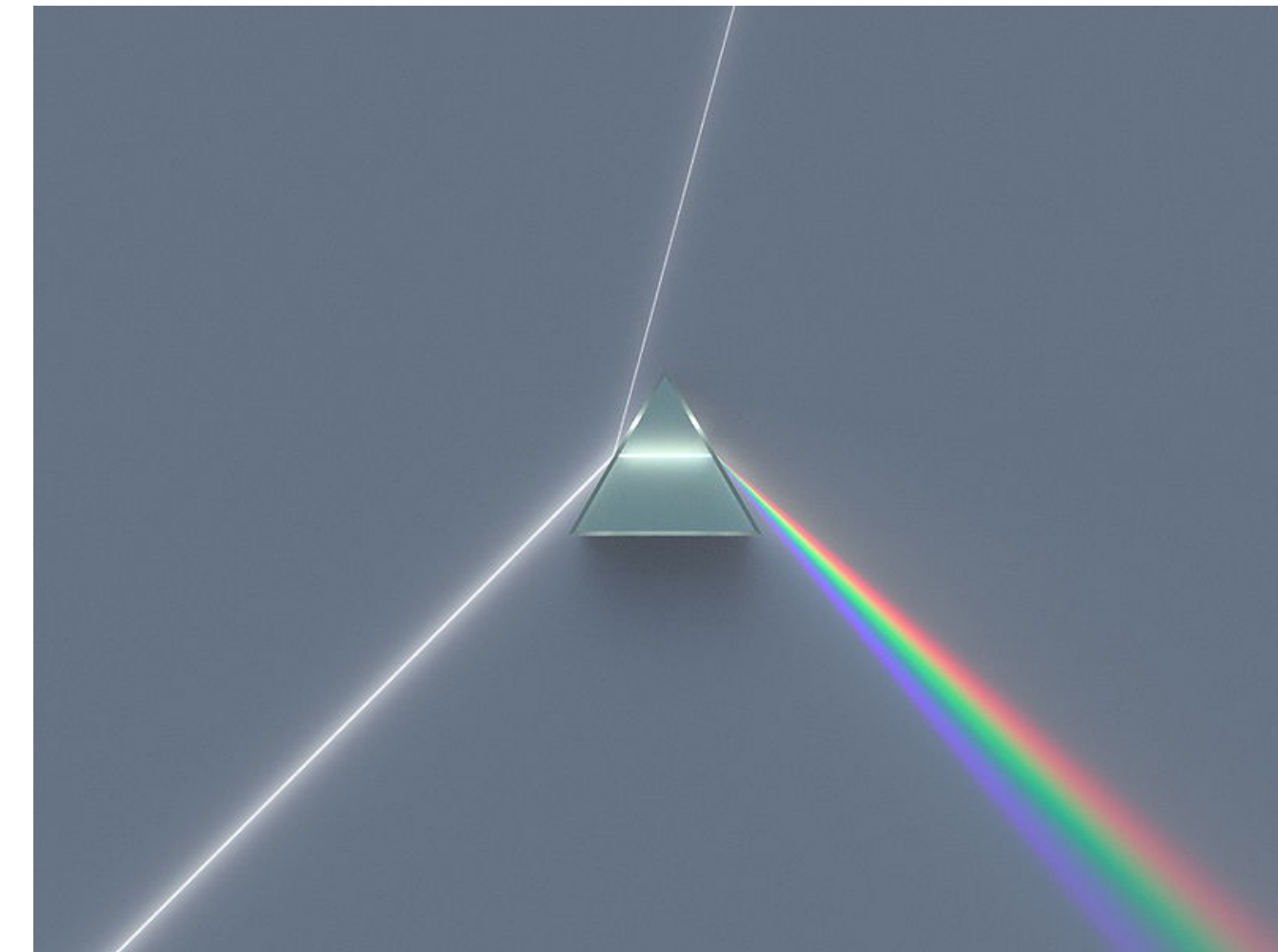
390-750 nm

Spectral colors

evoked by a single wavelength (monochromatic colors, rainbow colors), e.g., red, orange, yellow, green, blue, and violet

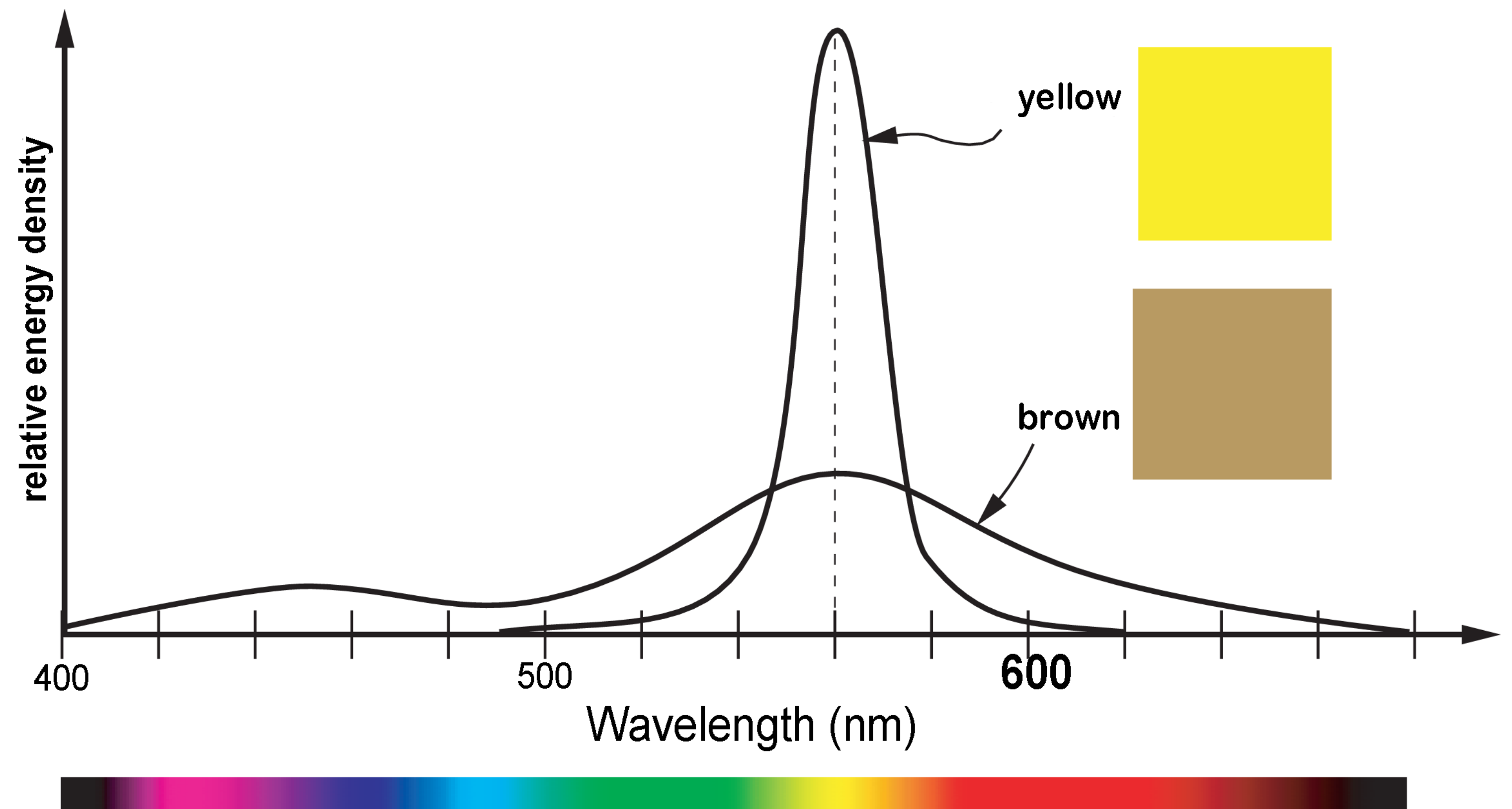
Other colors: unsaturated colors

Mix of multiple wavelengths
e.g. purple, magenta, gray scale
(achromatic colors) including white

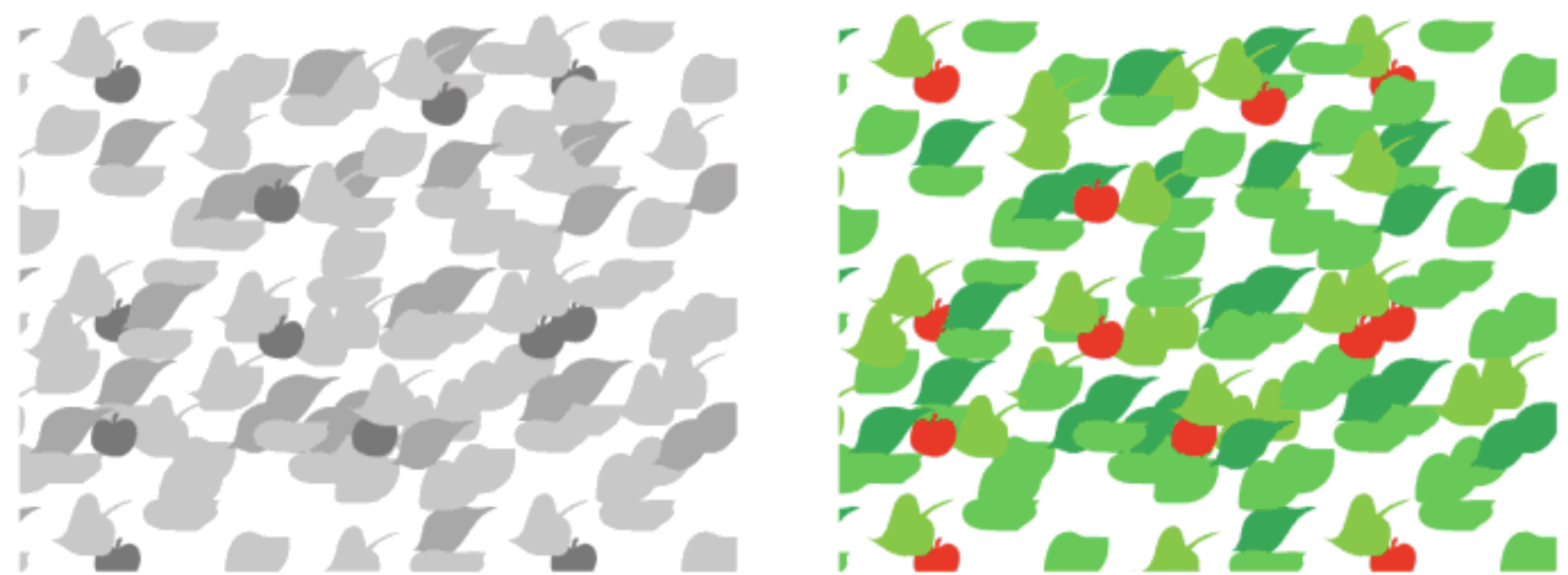


color != wavelength

but rather, a combination of
wavelengths and energy



Color



Color vision is irrelevant to much of normal vision!

does not help to perceive layout of objects

how they are moving

what shape they are

Color breaks camouflage

Tells about material properties (judging quality of food)

Dimensions of Color



Hue

Saturation

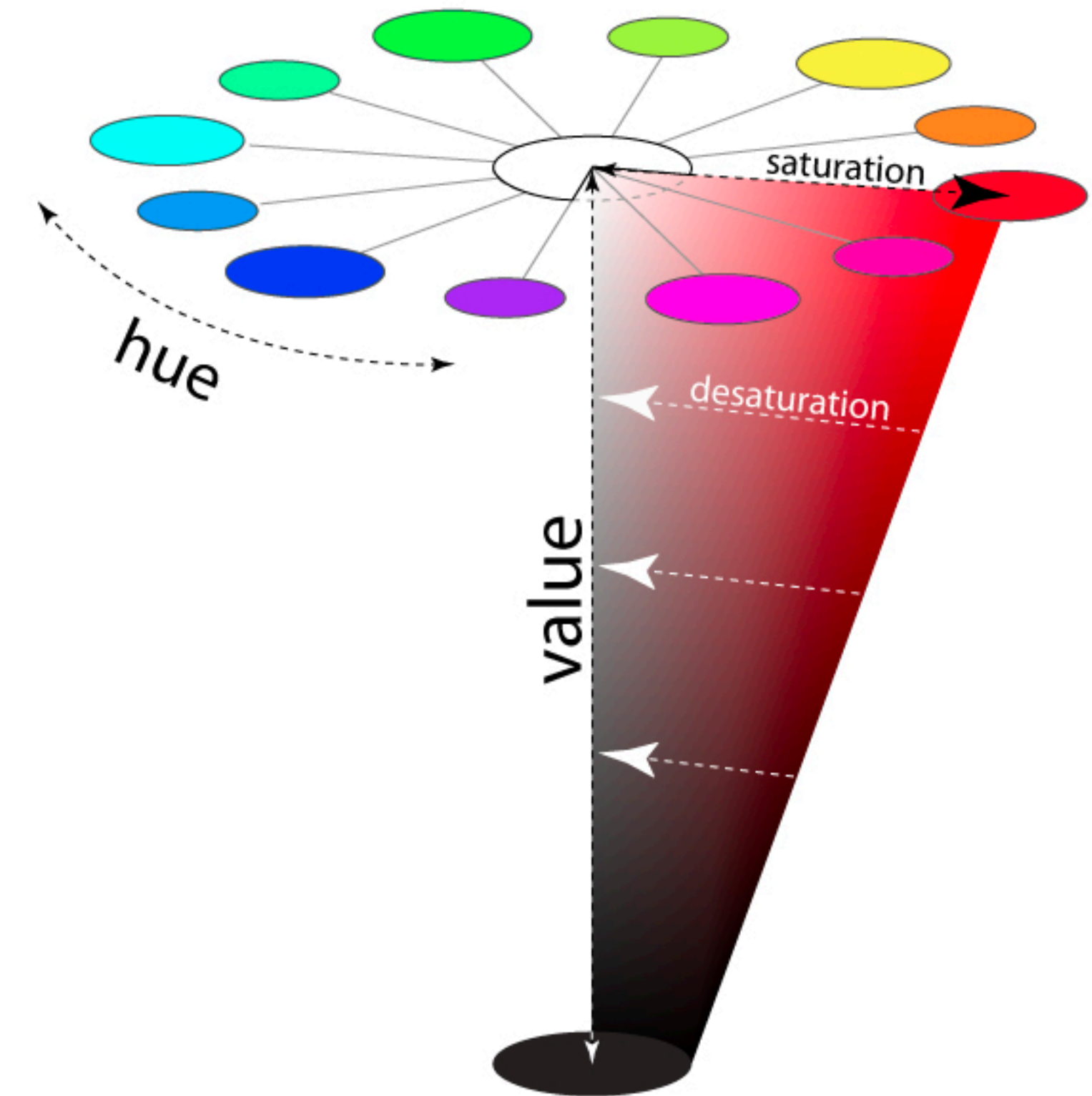
The purity of a color

When thinking of pigments: no white/black is added

When thinking of light: what's the ratio of dominant wavelength to others

Value (Luminance, Brightness)

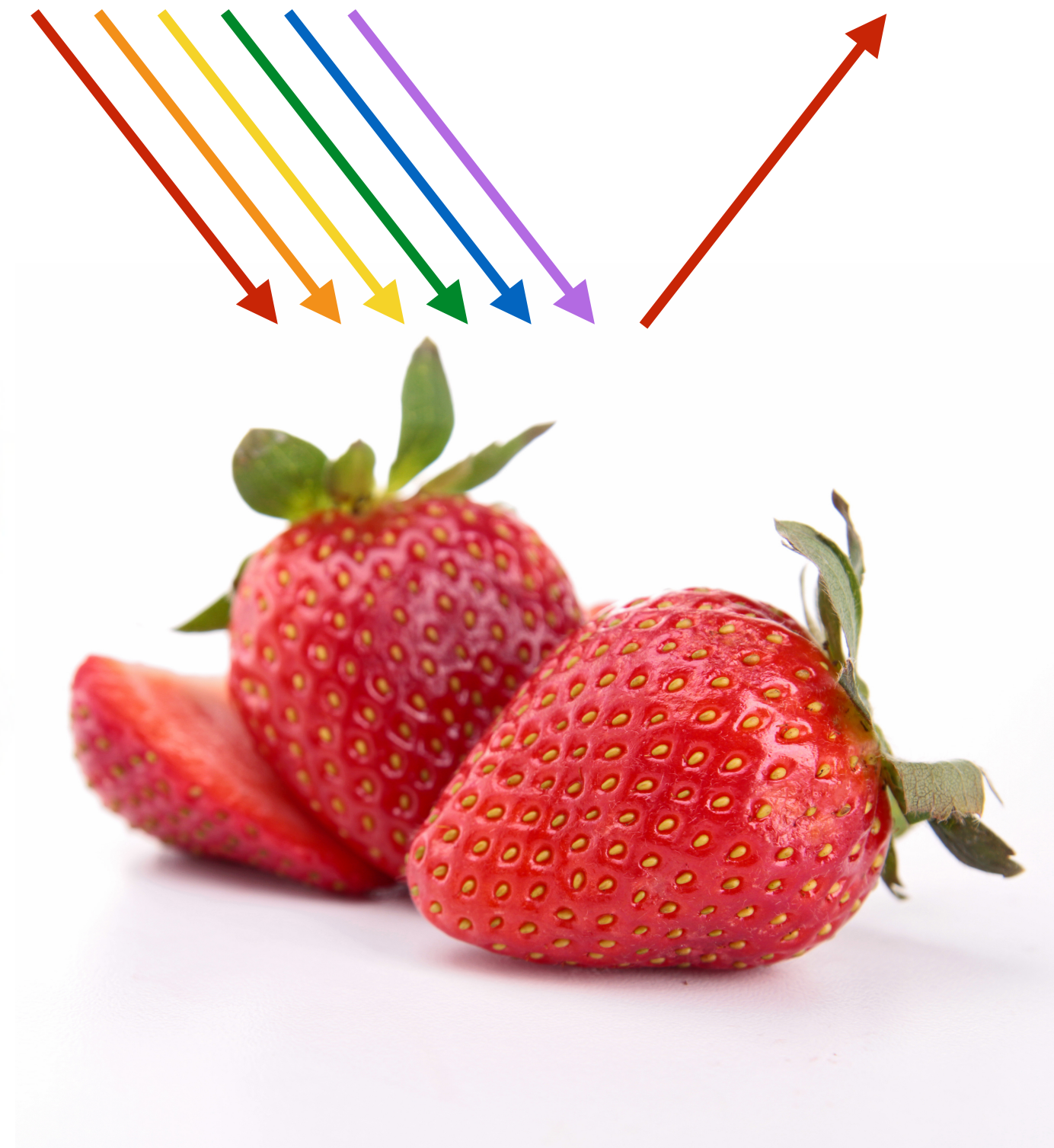
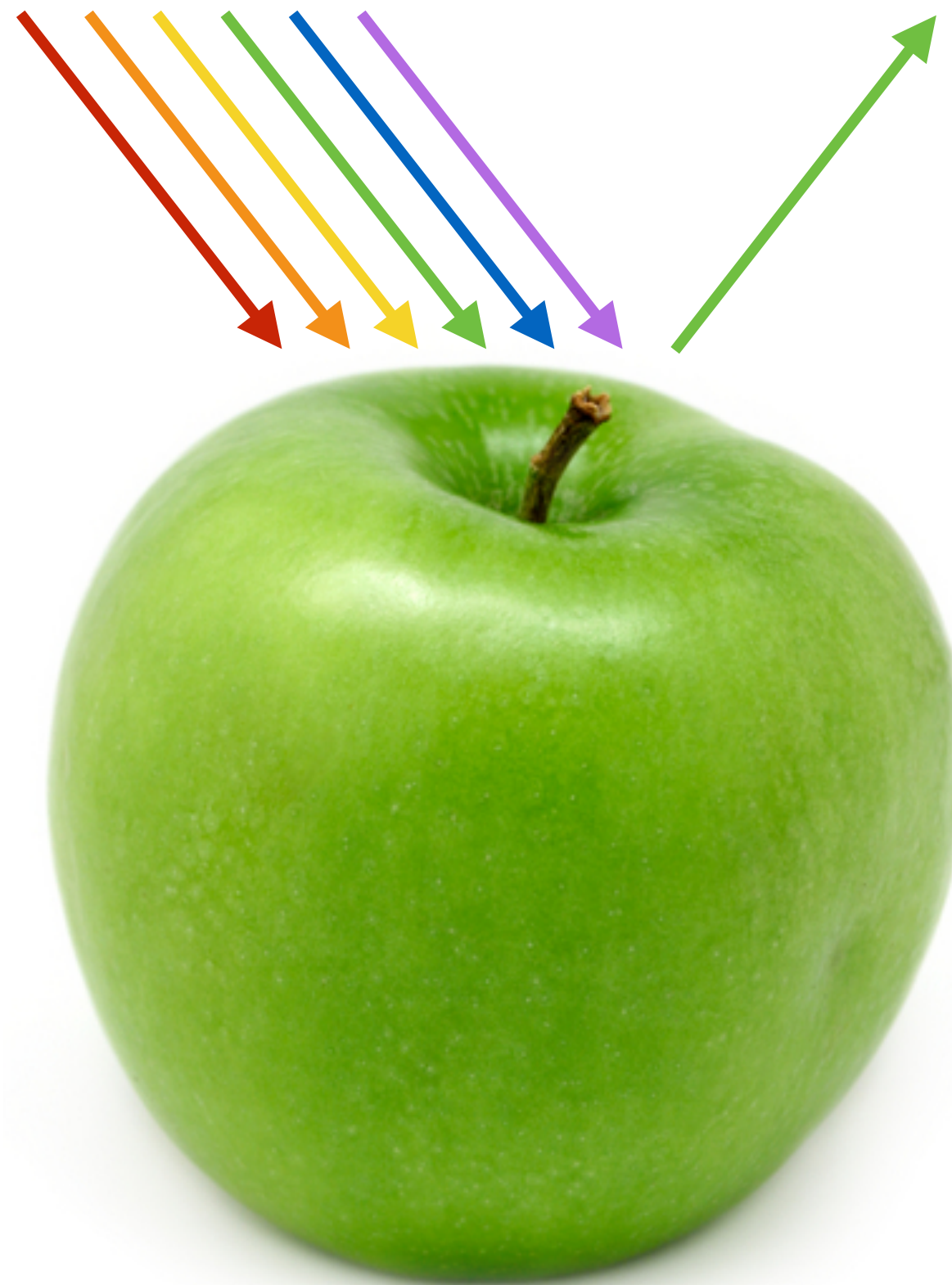
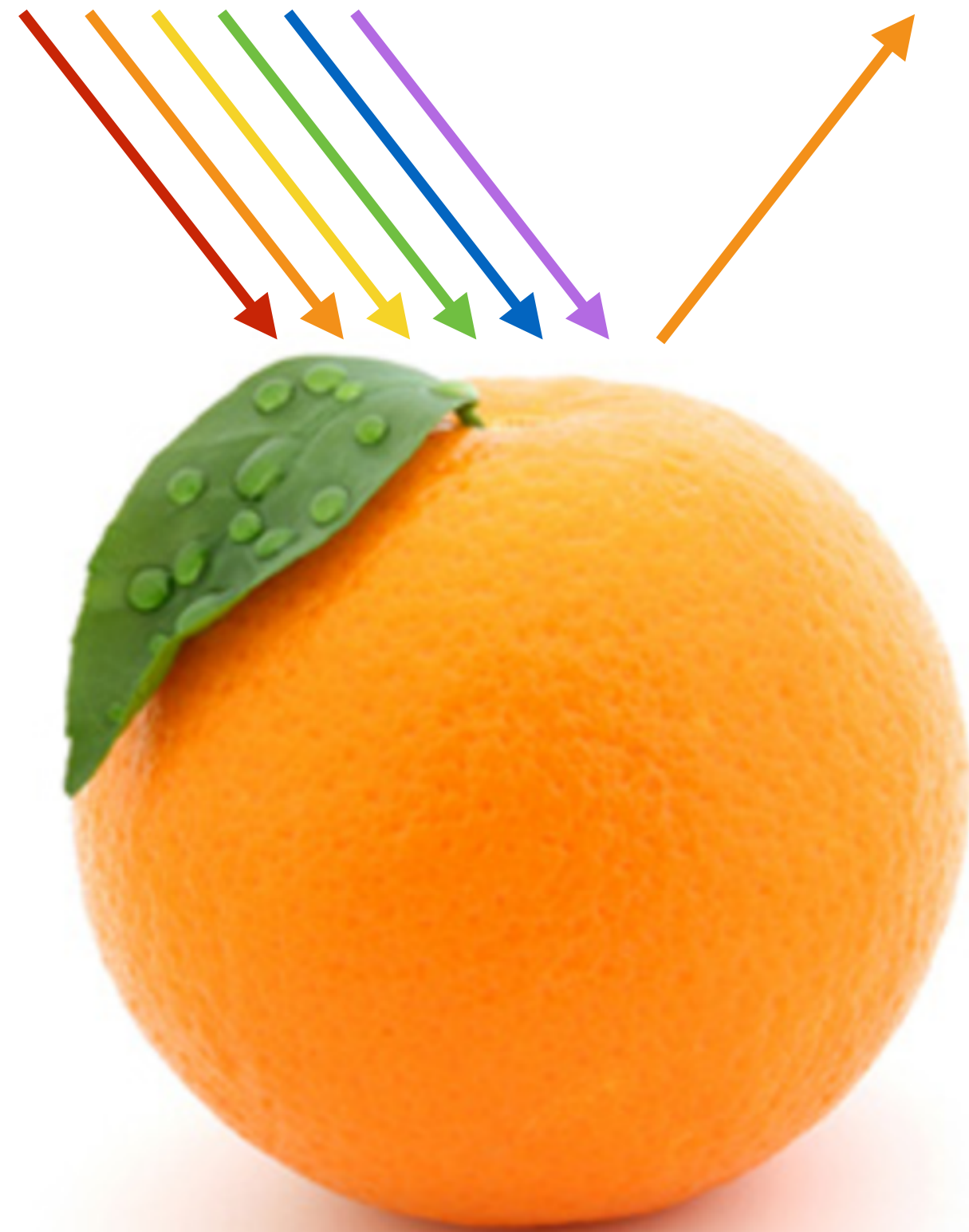
lightness or darkness of a color, i.e., the overall intensity of light



HSV Model

The role of objects

real light is more than a single wavelength:





MAY 21, 2012

Colors

Transcript

Image credits: Adam Cole

Our world is saturated in color, from soft hues to violent stains. How does something so intangible pack such a visceral punch? This hour, in the name of science *and* poetry, Jad and Robert tear the rainbow to pieces.



MAR 15, 2018

Rippin' the Rainbow an Even Newer One

Listen

Image credits: Roy Caldwell

One of our most popular episodes of all time was our [Colors episode](#), where we introduced you to a sea creature that could see a rainbow far beyond what humans can experience.

Peacock mantis shrimps are as extraordinary as they are strange and boast what may well be the most complicated visual system in the world. They each have 16 photoreceptors compared to our measly three.

But recently researchers in Australia put the mantis shrimps' eyes to the test only to discover that sure, they

<https://www.radiolab.org/episodes/211119-colors>

<https://radiolab.org/episodes/rippin-the-rainbow-an-even-newer-one>

What are the primary colors?

1. red, green, blue
2. red, yellow, blue
3. orange, green, violet
4. cyan, magenta, yellow
5. all of the above

What's a “primary color” depends on the medium.

Paint mixing

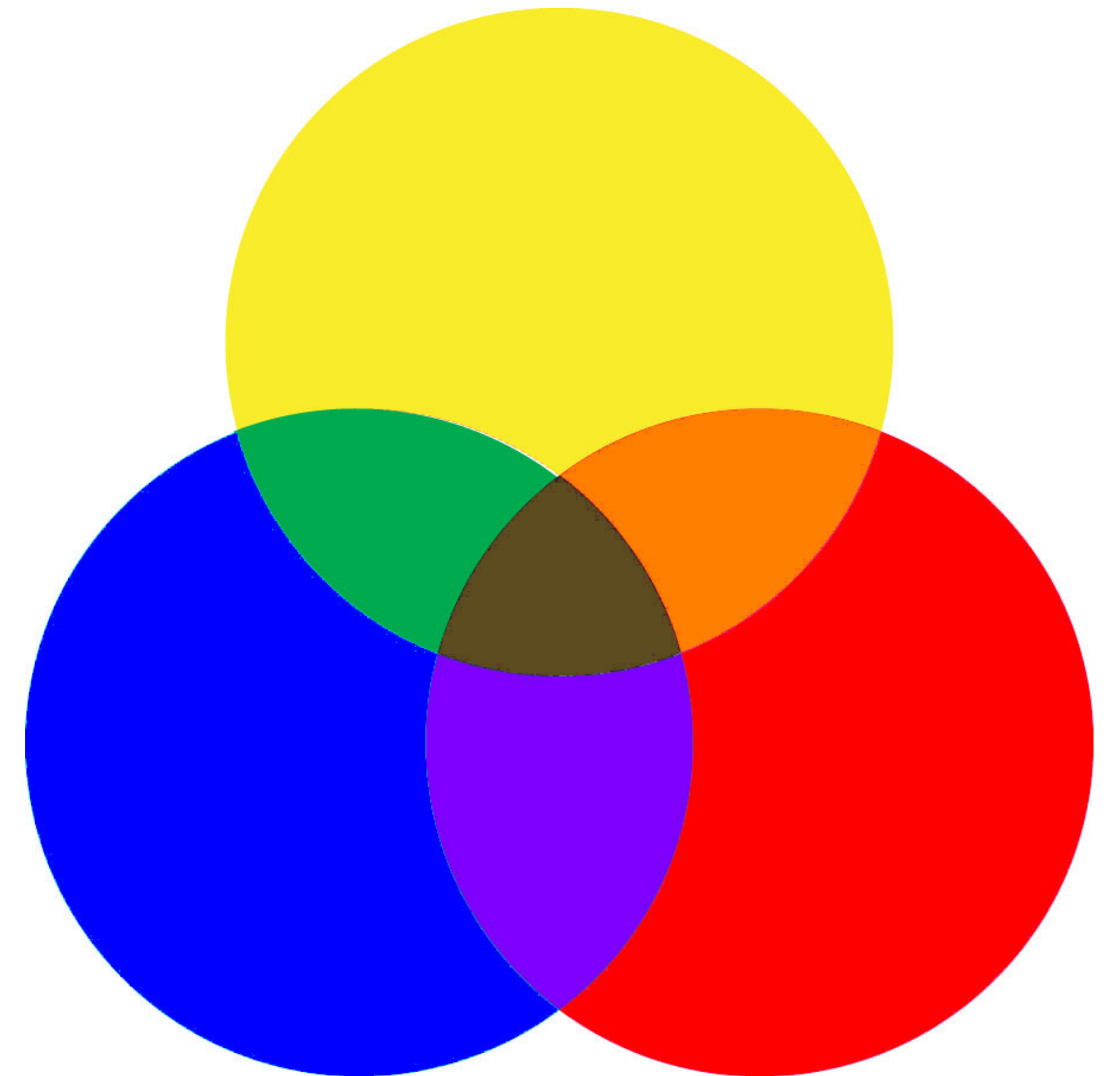
physical mixing of opaque paints

primary: Red, Yellow, Blue

secondary (mixed): Green, Orange, Purple

subtractive

Historical primary colors



Ink mixing (Inkjet Printers)

subtractive mix of transparent inks

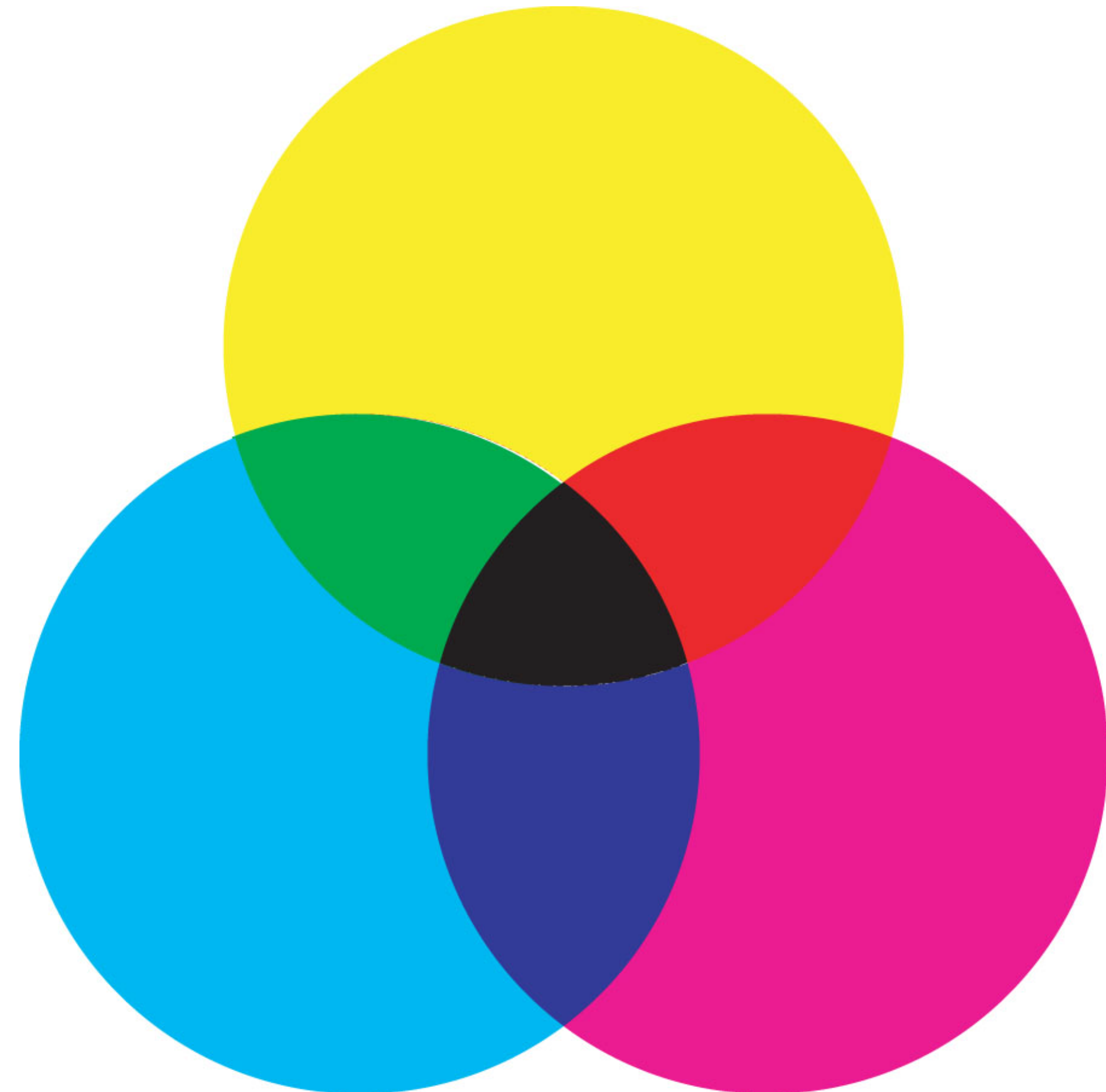
primary: Cyan, Magenta, Yellow

secondary: RGB

approx. black = C+M+Y

true black = C+M+Y+K

subtractive



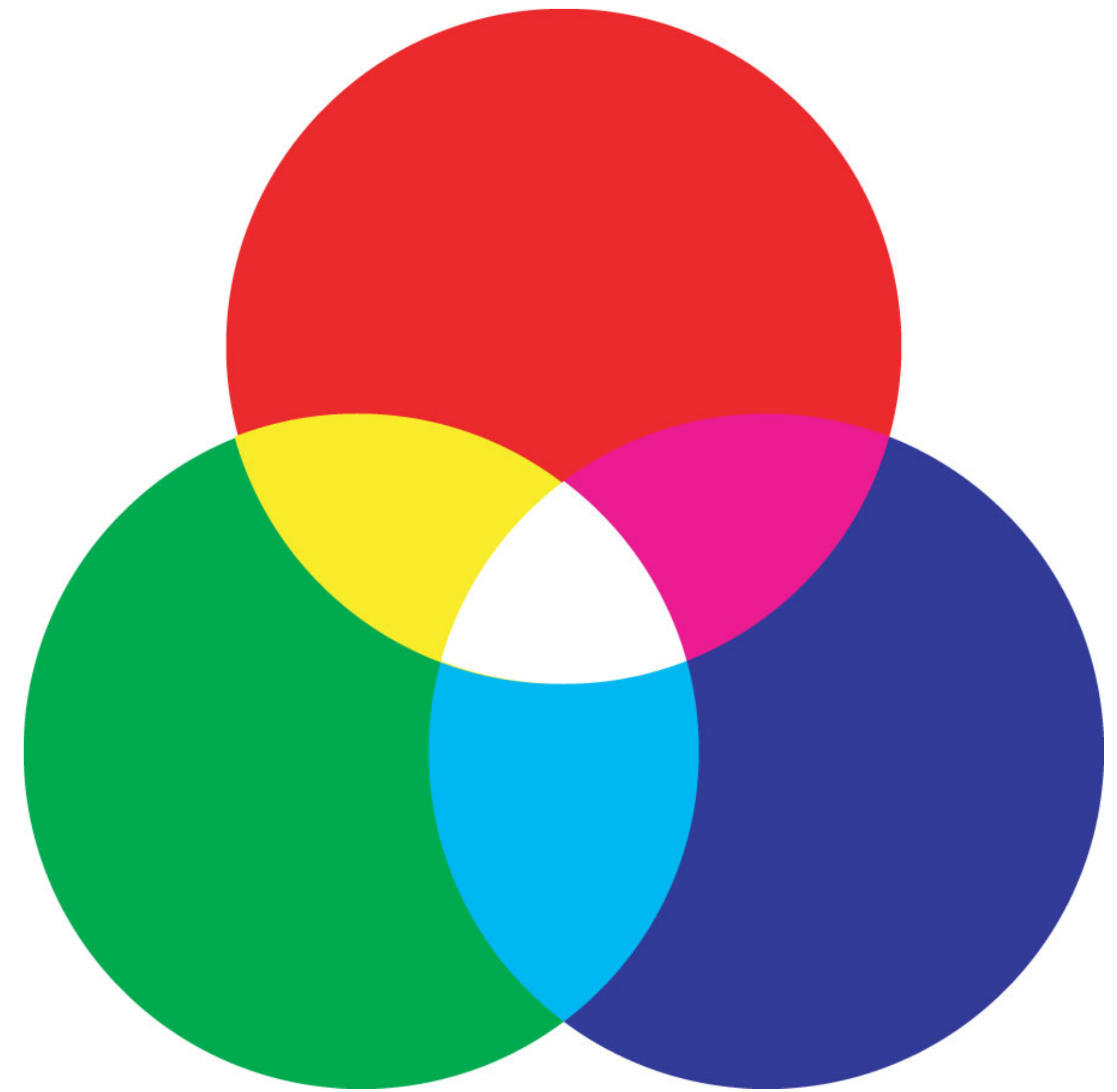
Light mixing (Computer Screens)

additive mix of colored lights

primary: Red, Green, Blue

secondary: Cyan, Magenta, Yellow

additive

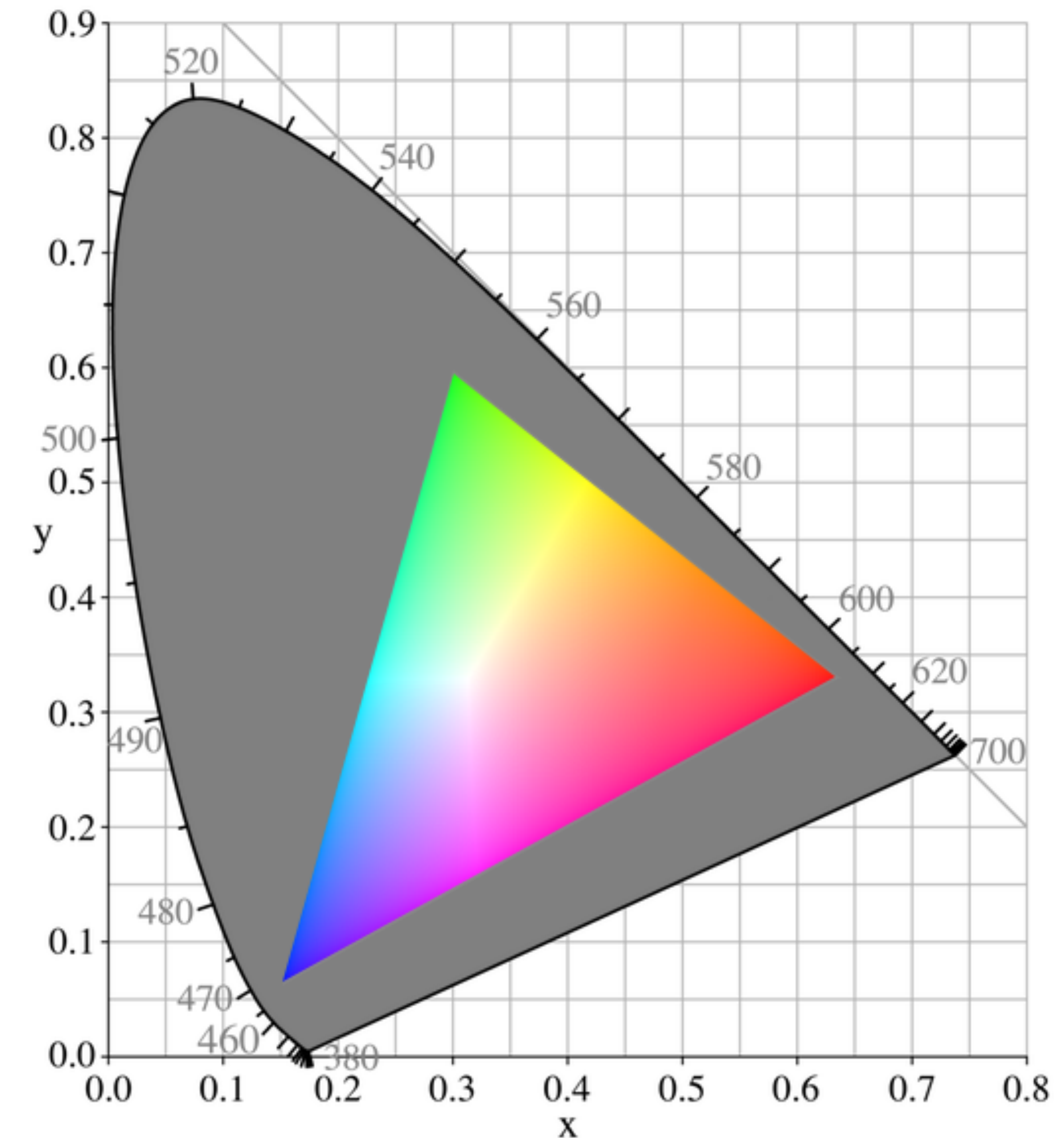
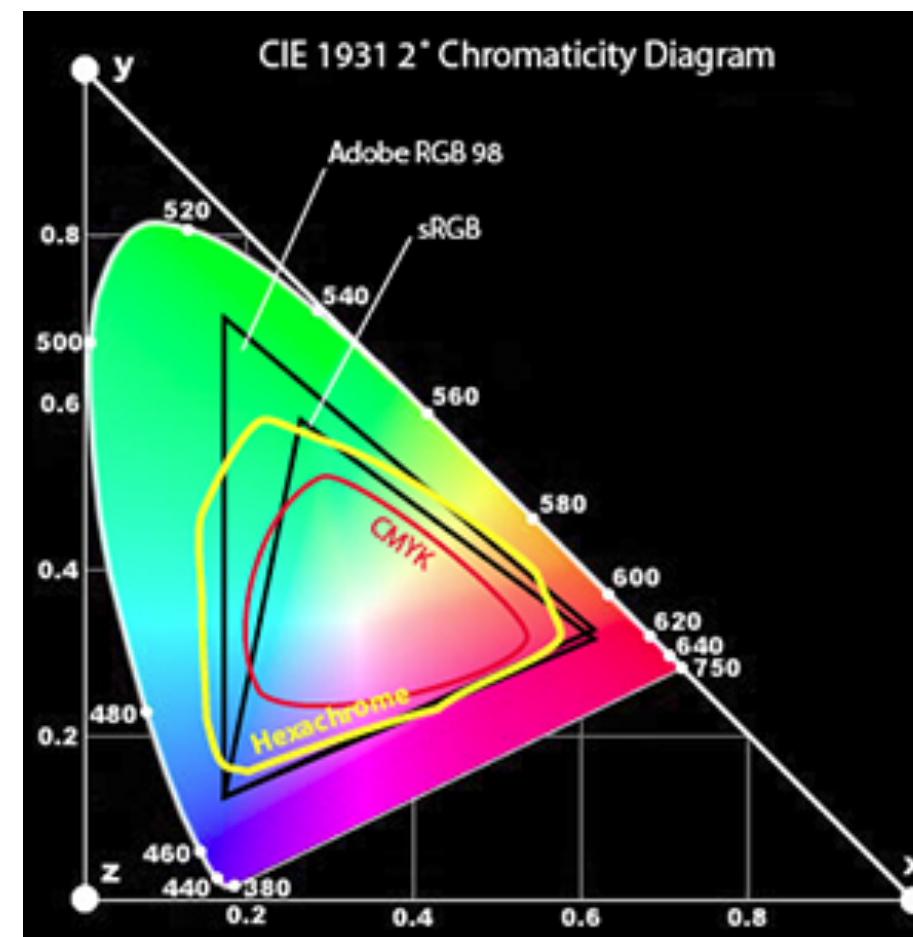


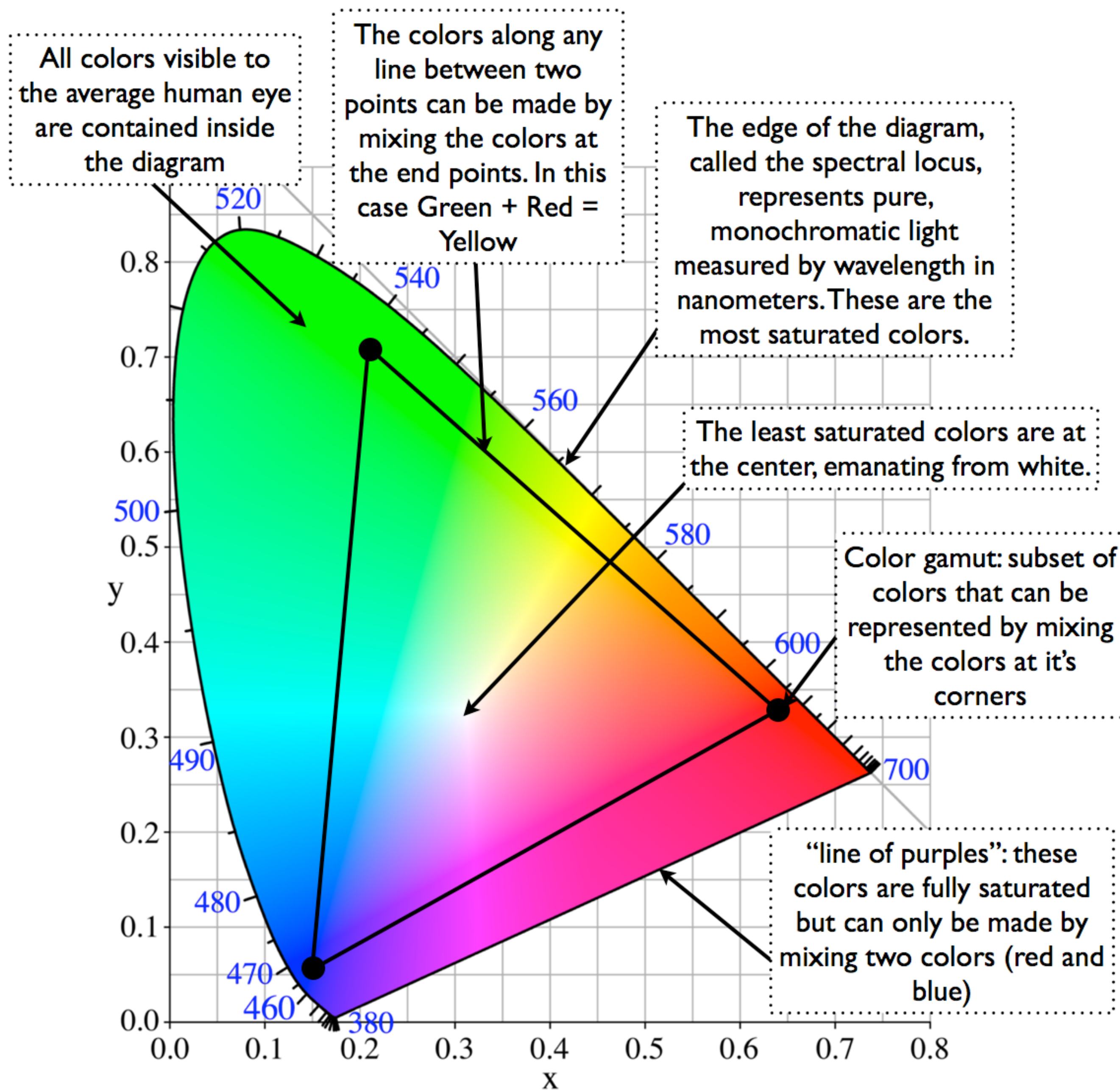
Gamut

Set of all colors that can be produced by a device

Area between the primary colors used can be shown

Primaries are arbitrary





x, y are derived values that specify chromaticity in the CIE XYZ model

Anatomy of a CIE Chromaticity Diagram

What is a colormap?

specifies a mapping between
color and values

categorical vs ordered

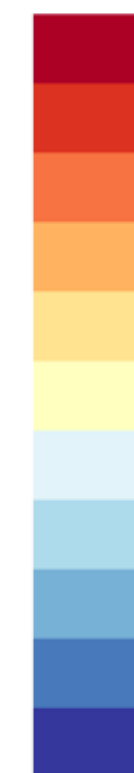
sequential vs diverging

segmented vs continuous

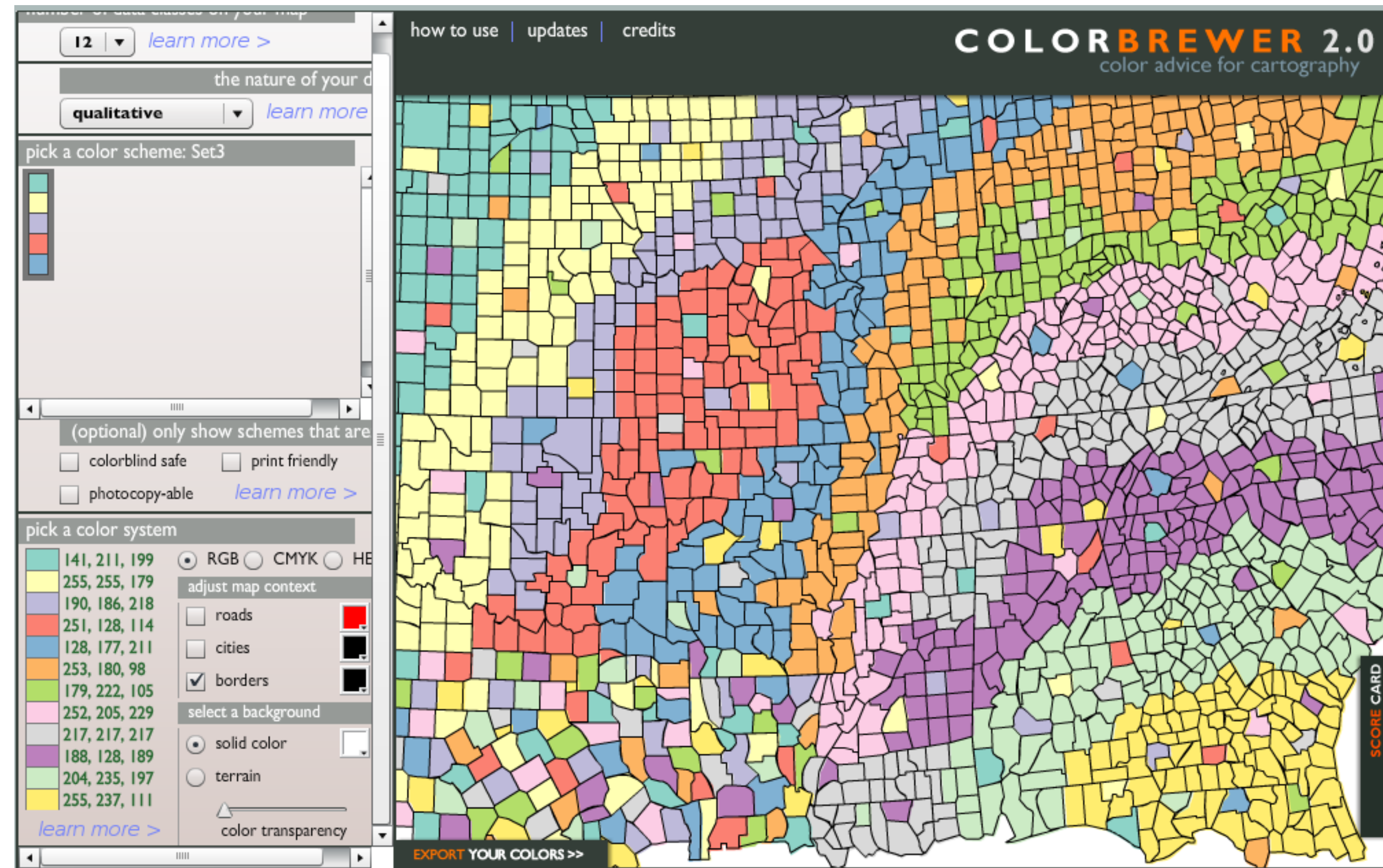
univariate vs bivariate

Match colormap to attribute
characteristics!

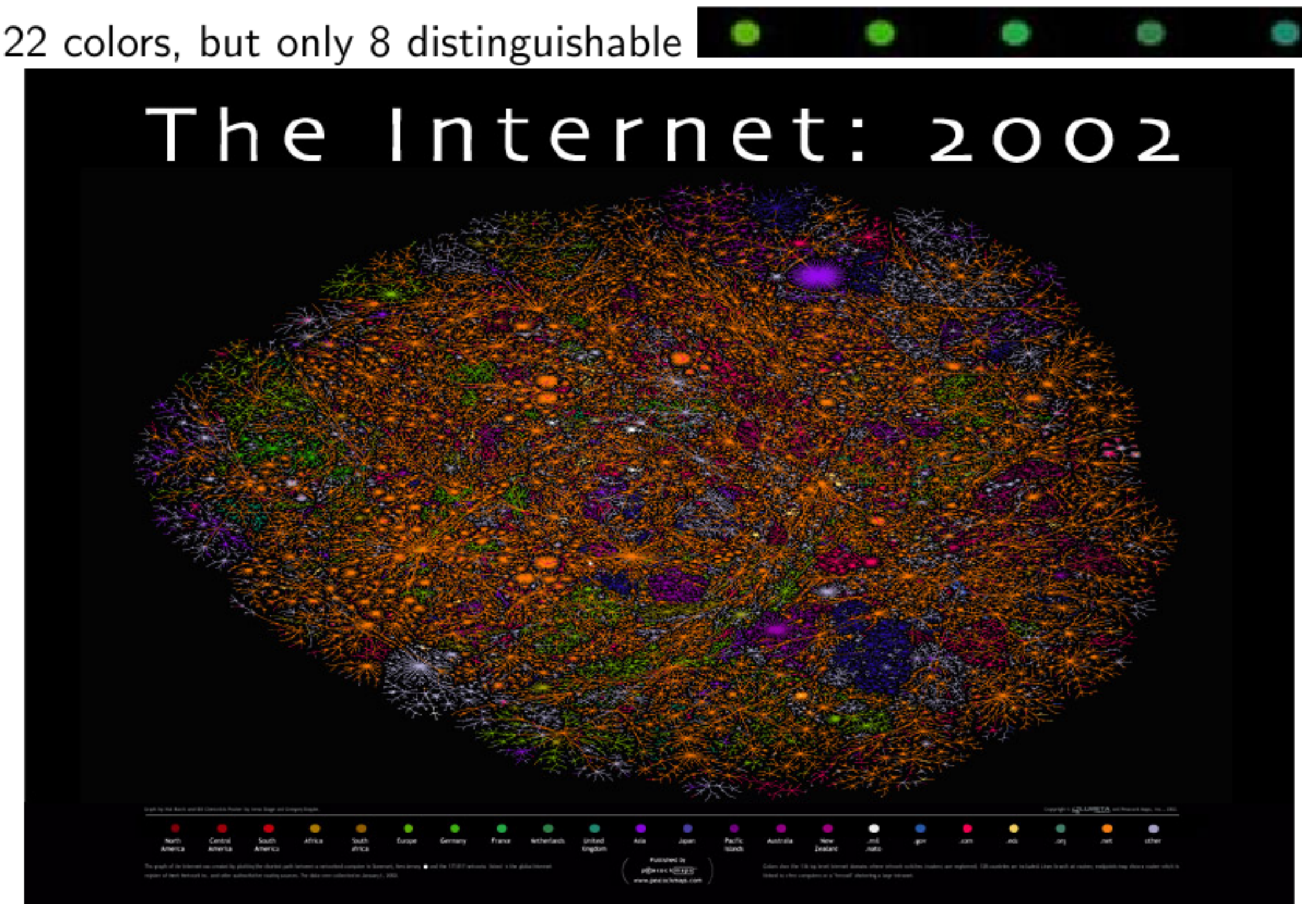
[0,8] →



Application: Labeling



Carefully designed color scheme for 12 colors [colorbrewer]



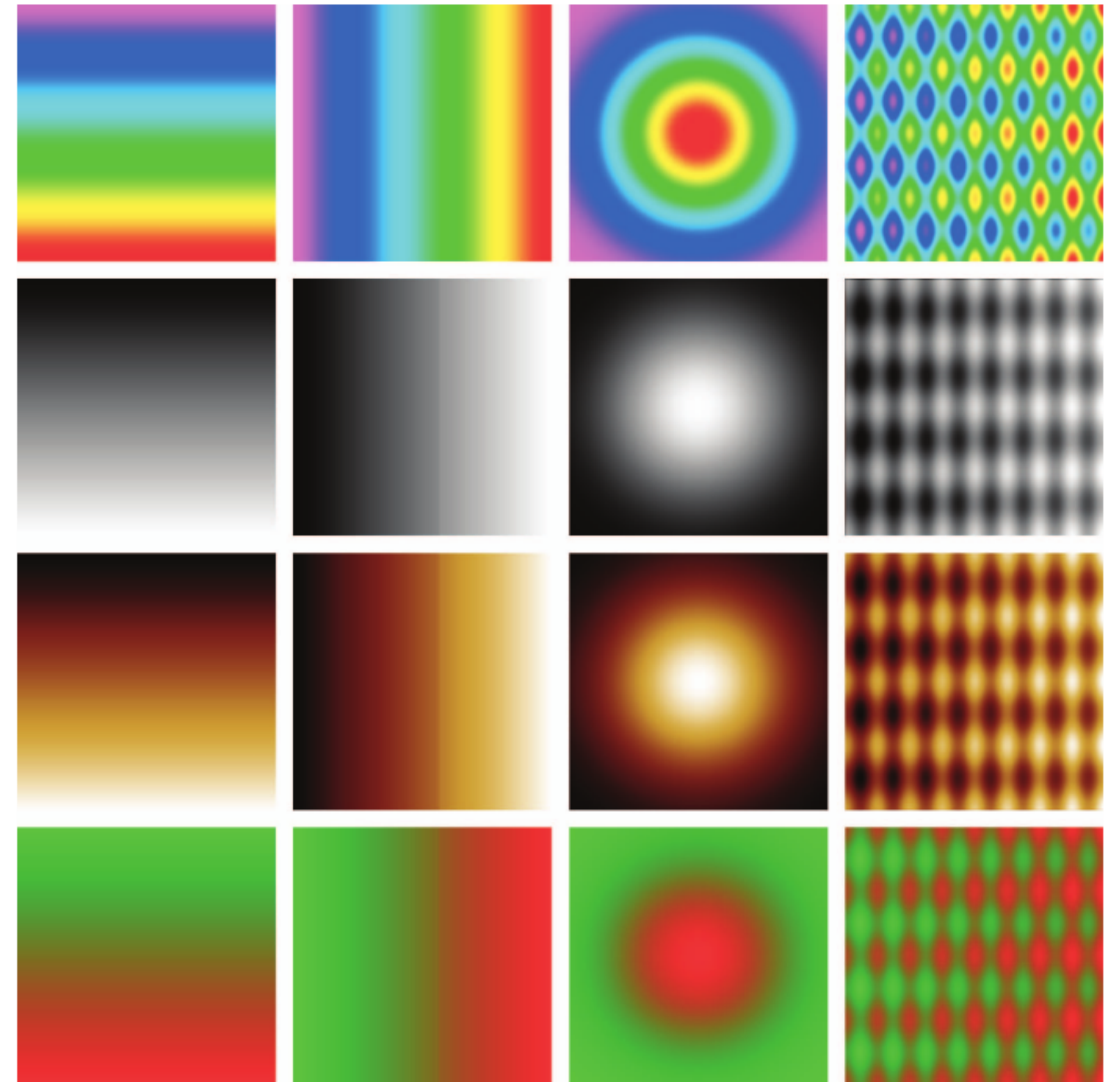
Color for quantitative data

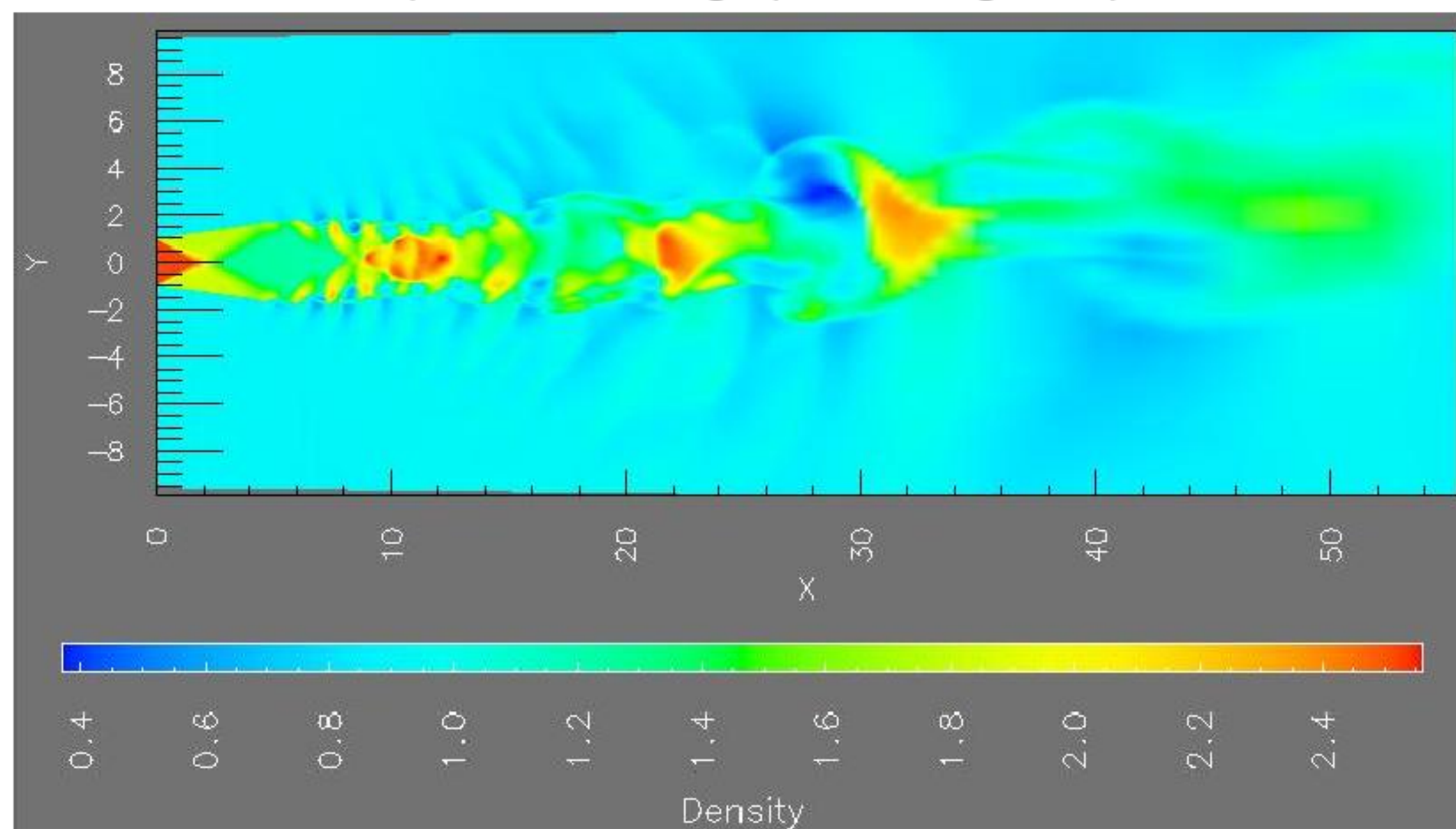
use value

saturation works but not as good

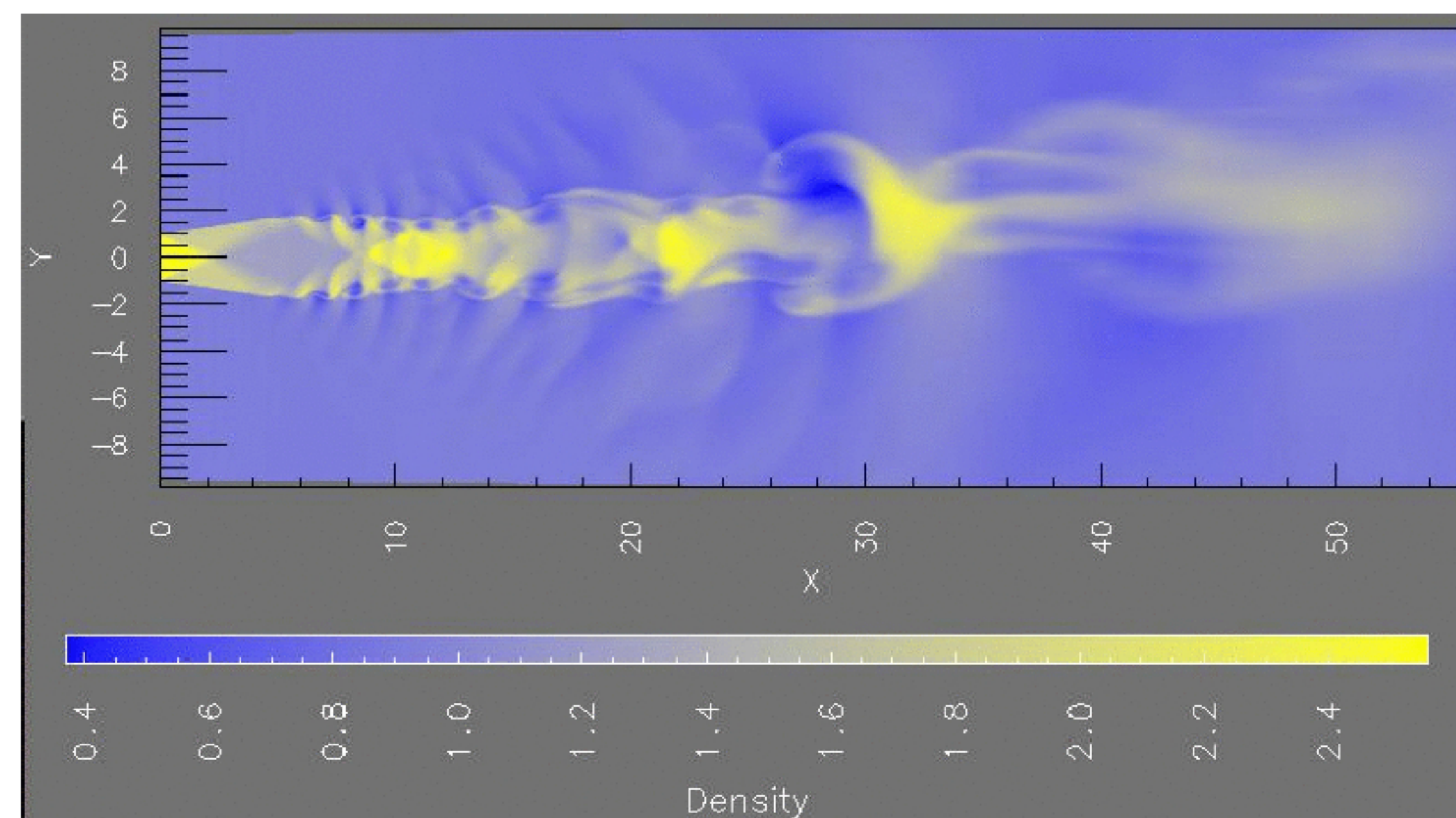
don't use hue!

Danger: rainbow color map





[Rogowitz and Treinish, Why Should Engineers and Scientists Be Worried About Color? <http://www.research.ibm.com/people/l/lloydt/color/color.HTM>]



[Rogowitz and Treinish, How NOT to Lie with Visualization, www.research.ibm.com/dx/proceedings/pravda/truevis.htm]

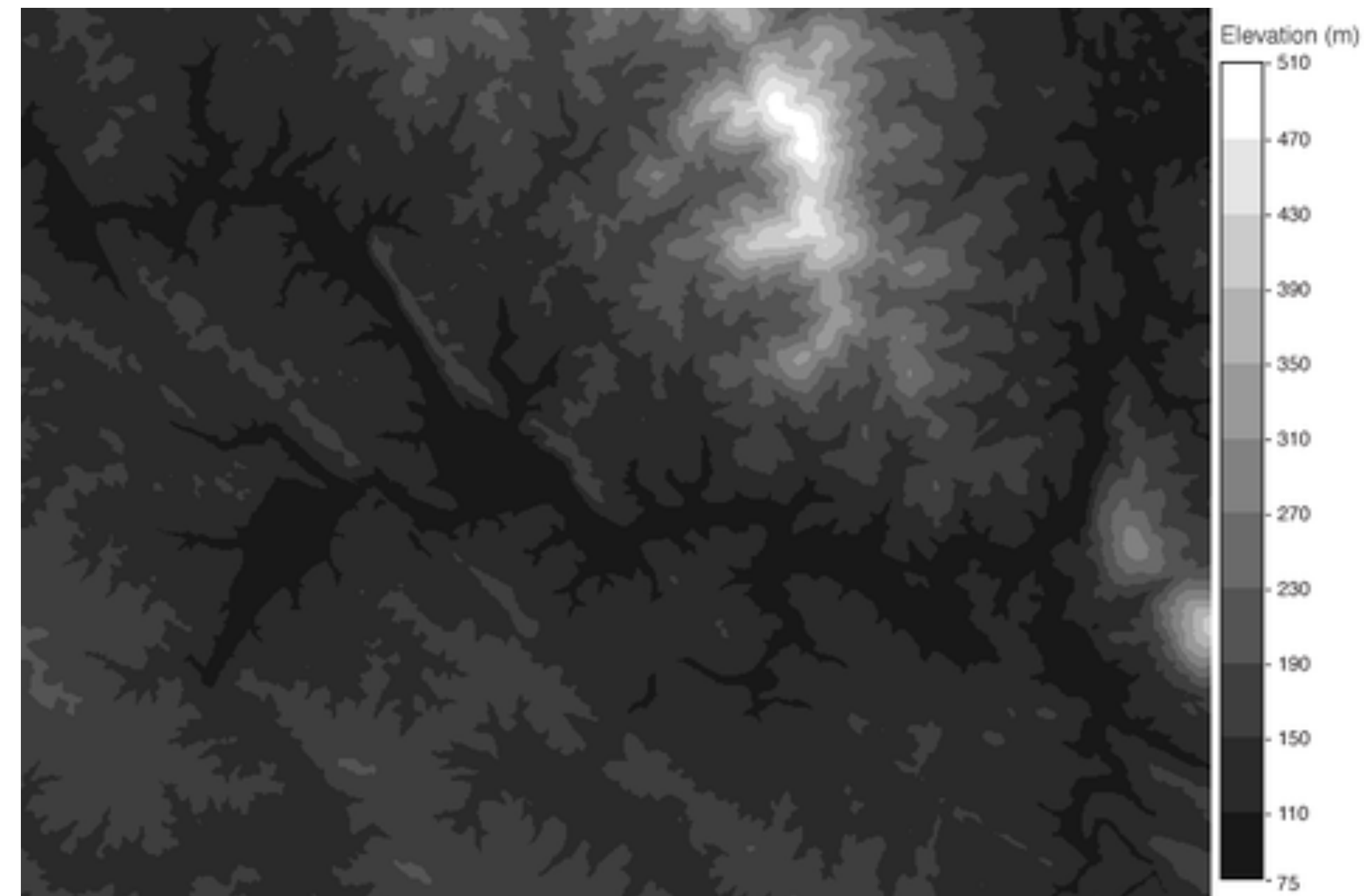
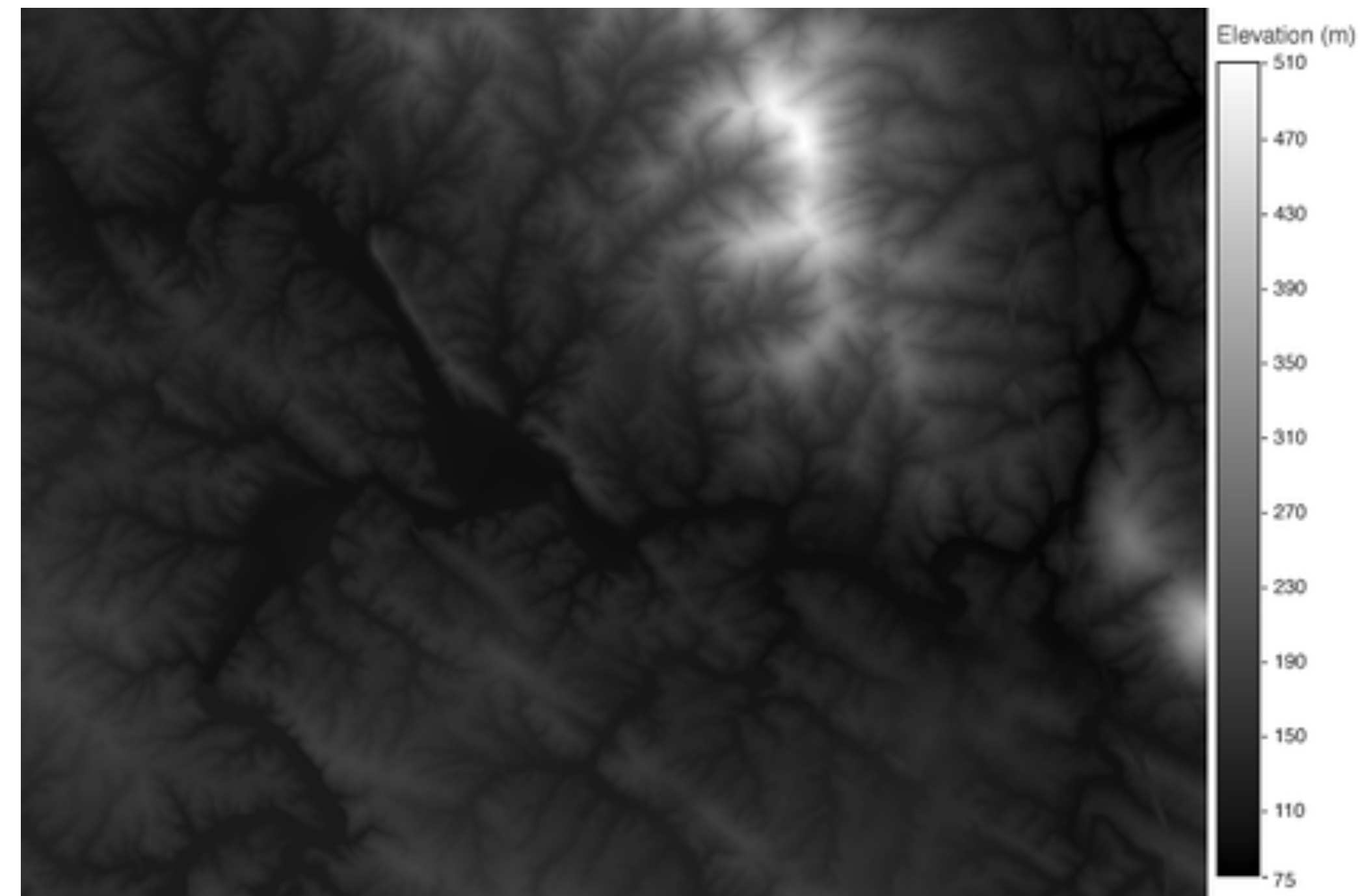
To bin or not to bin?

Study: what is faster? What is more accurate?

Example: Elevation

Continuous was faster

Binned was often more accurate



Color Blindness

10% of males, 1% of females (probably due to X-chromosomal recessive inheritance)

Most common: red-green weakness / blindness

Reason: lack of medium or long wavelength receptors, or altered spectral sensitivity (most common: green shift)

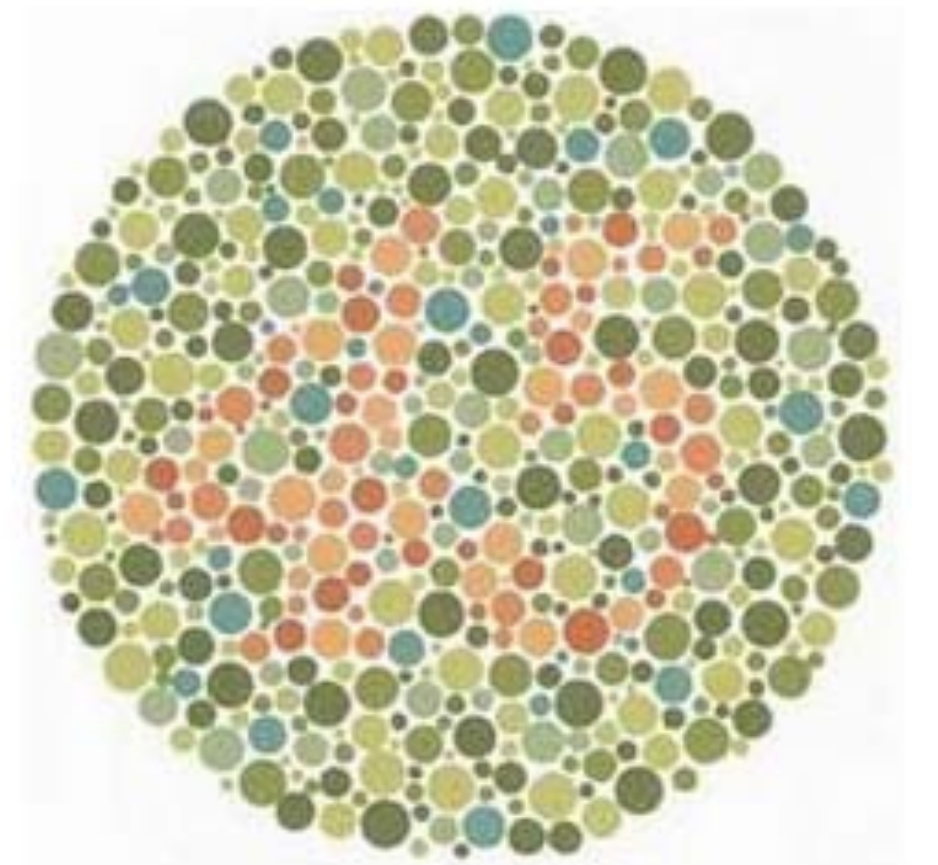
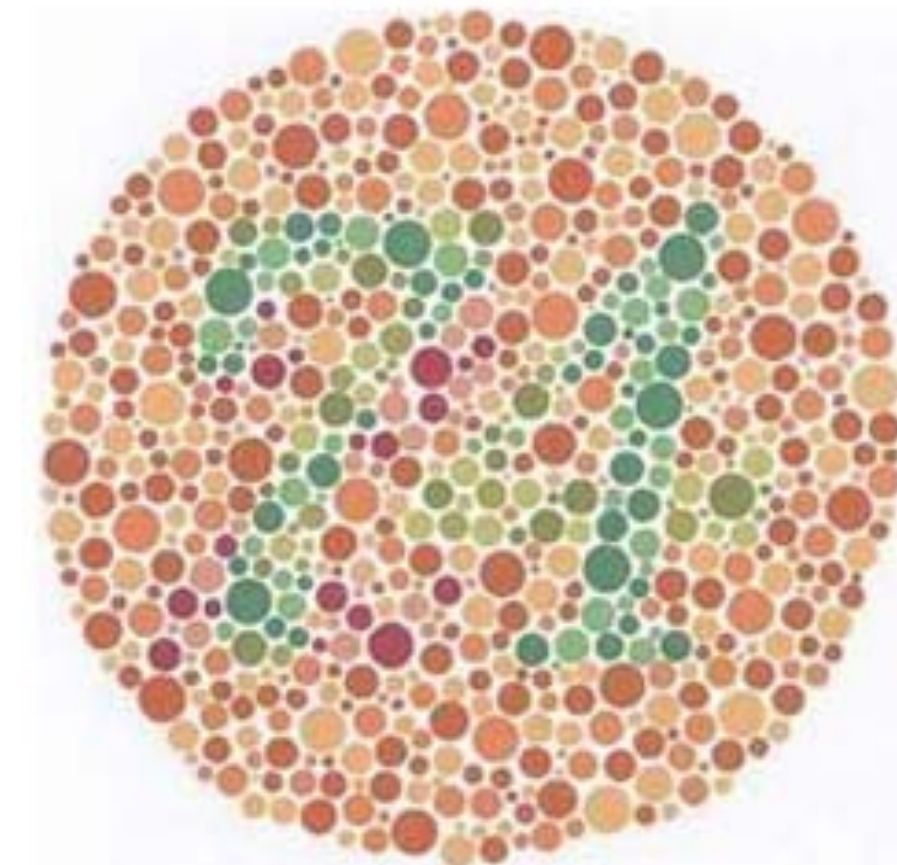
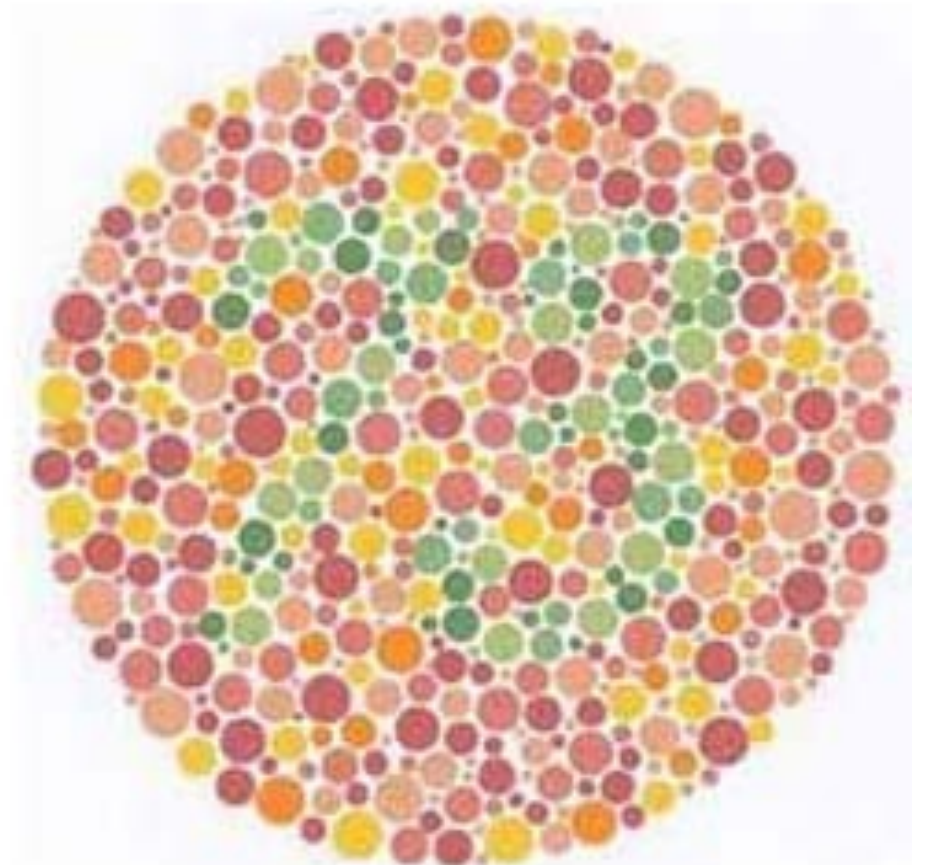
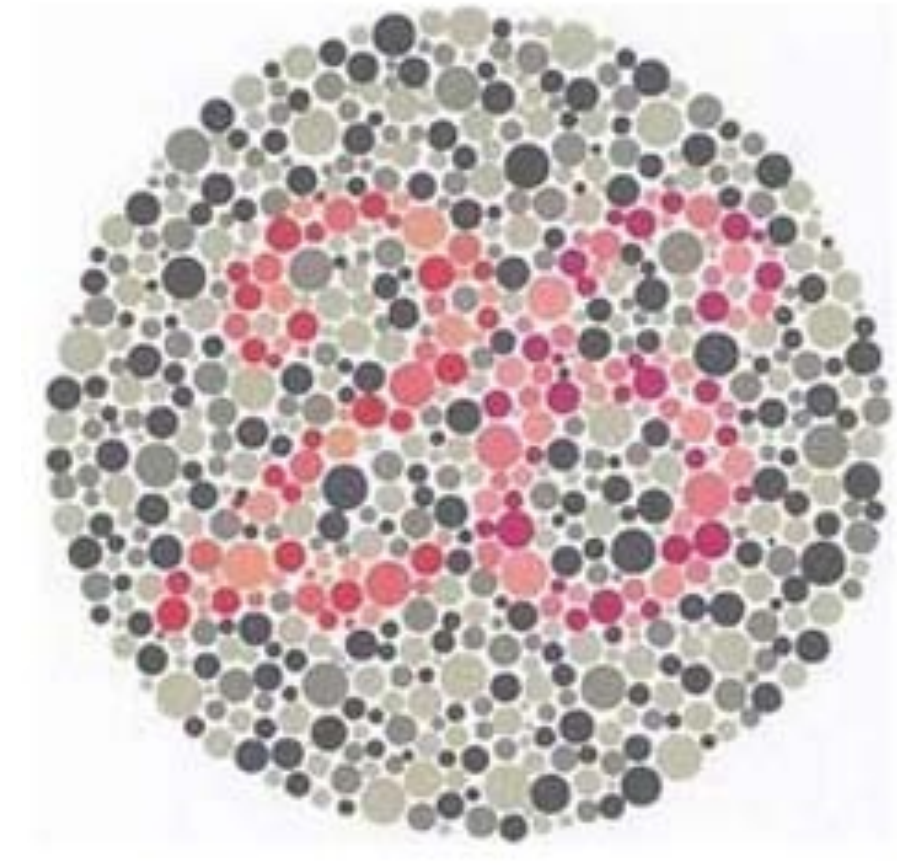
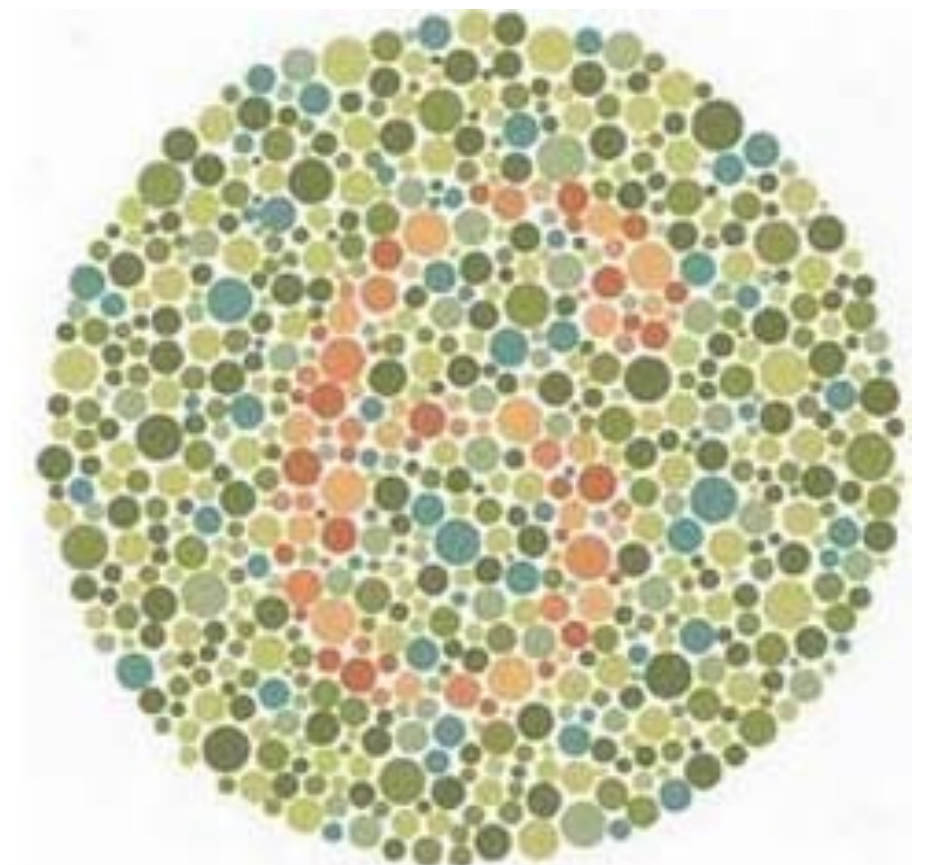
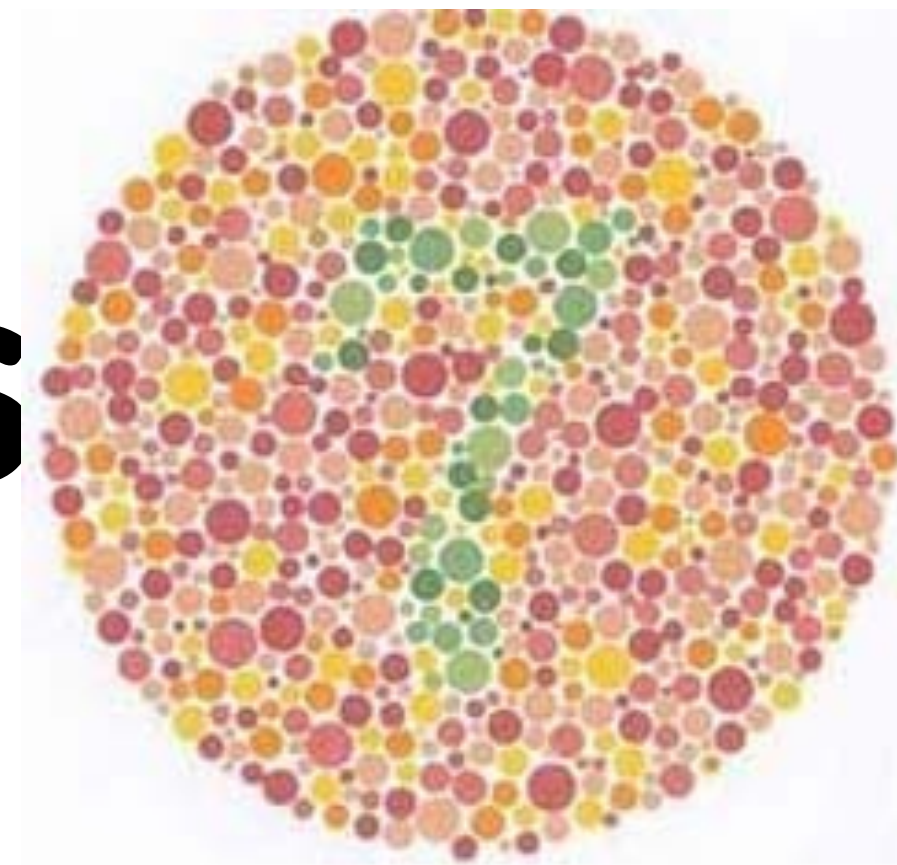
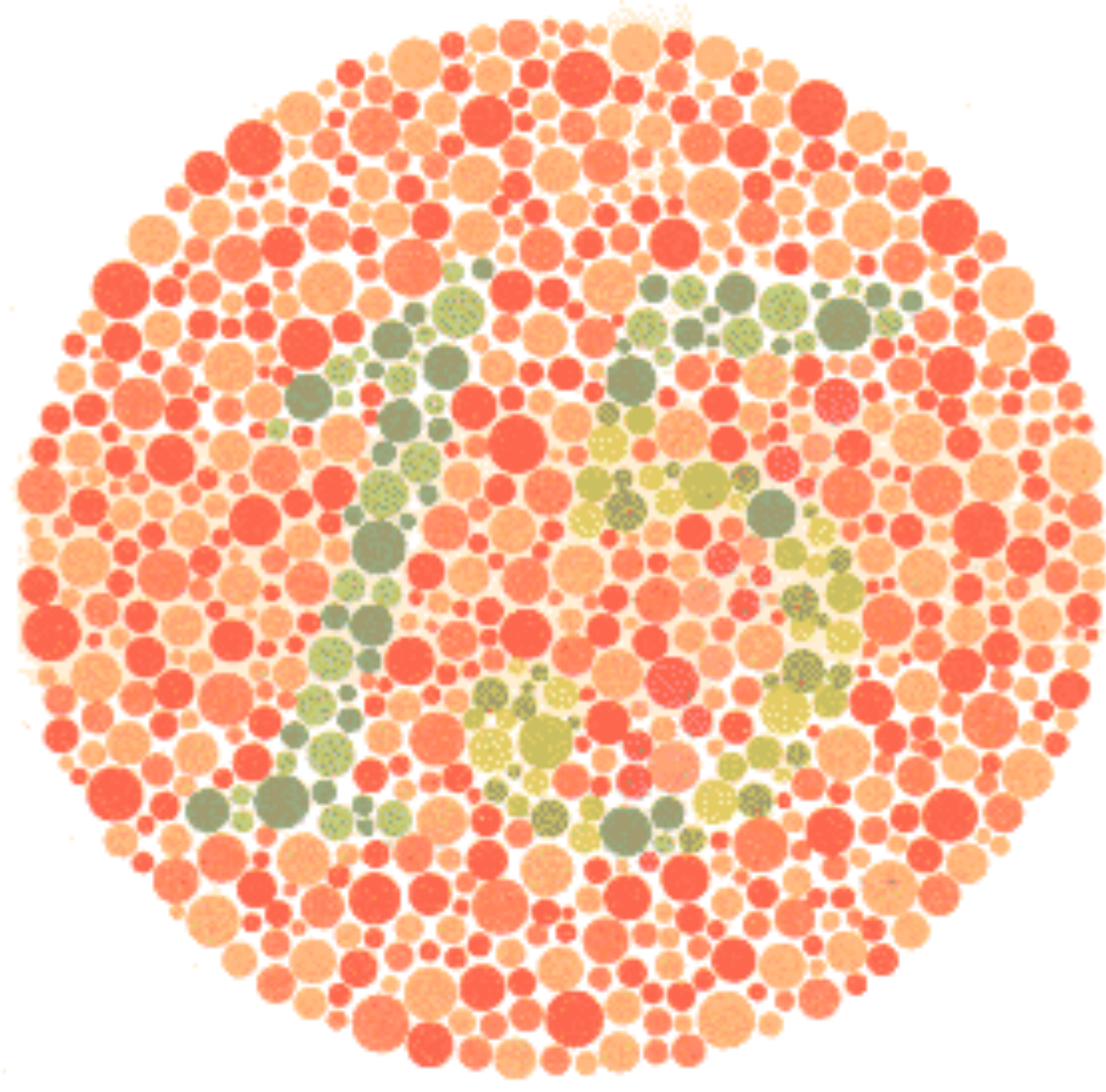
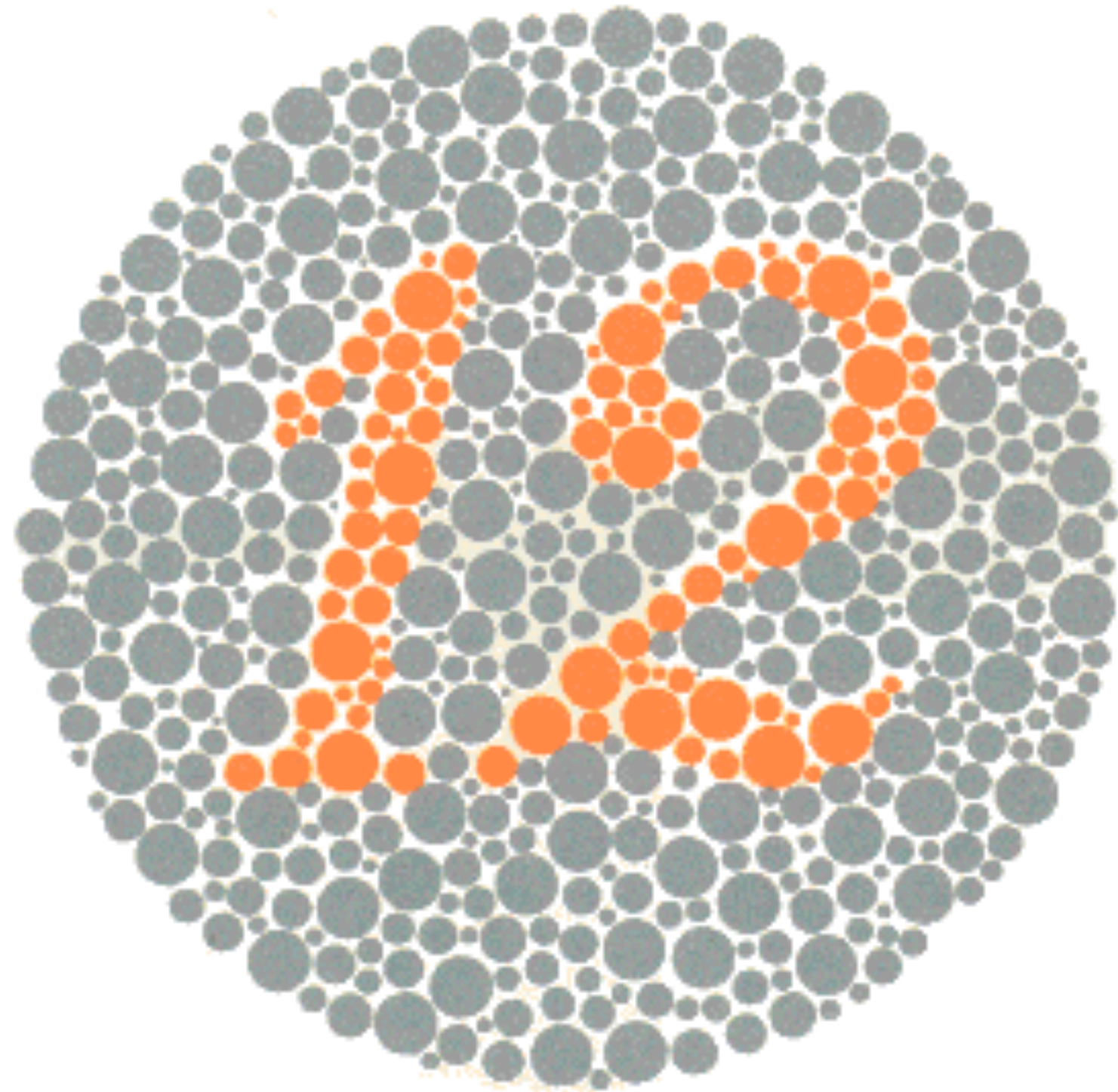


Normal Color Perception

Deuteranopia (no green receptors)

Protanopia (no red receptors)

Color Blindness Tests



Color Blindness



Protanope

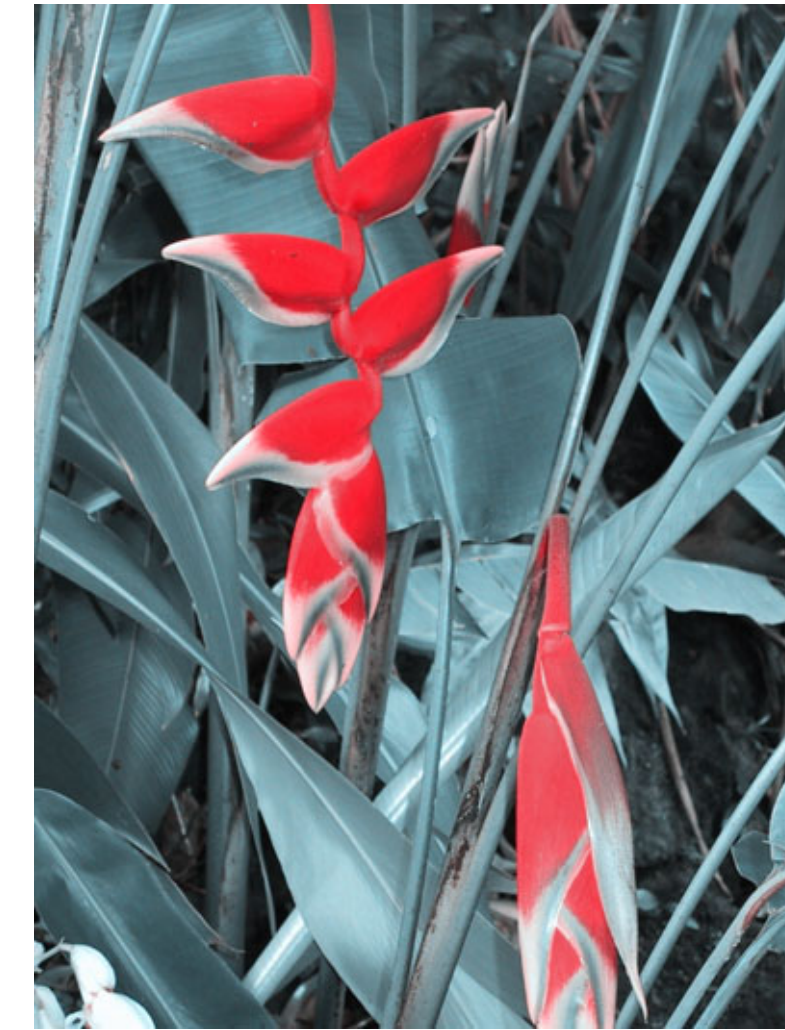
No L cones

Red / green
deficiencies



Deuteranope

No M cones



Tritanope

No S cones

Blue / Yellow
deficiency

All Spending Types of Spending Changes Department Totals

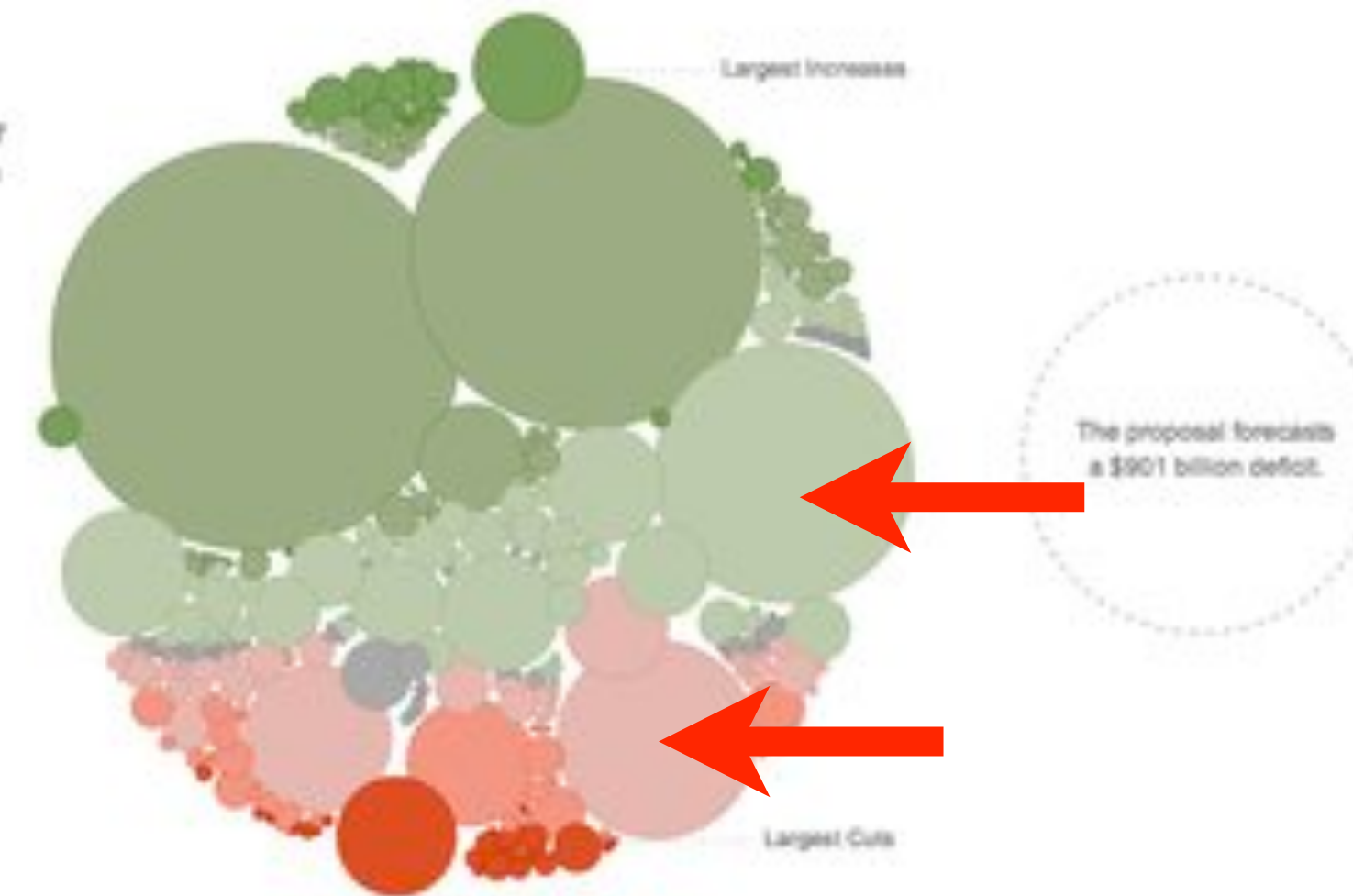
How \$3.7 Trillion Is Spent

Mr. Obama's budget proposal includes \$3.7 trillion in spending in 2013, and forecasts a \$901 billion deficit.

Circles are sized according to the proposed spending.



Color shows amount of cut or increase from 2012.



All Spending Types of Spending Changes Department Totals

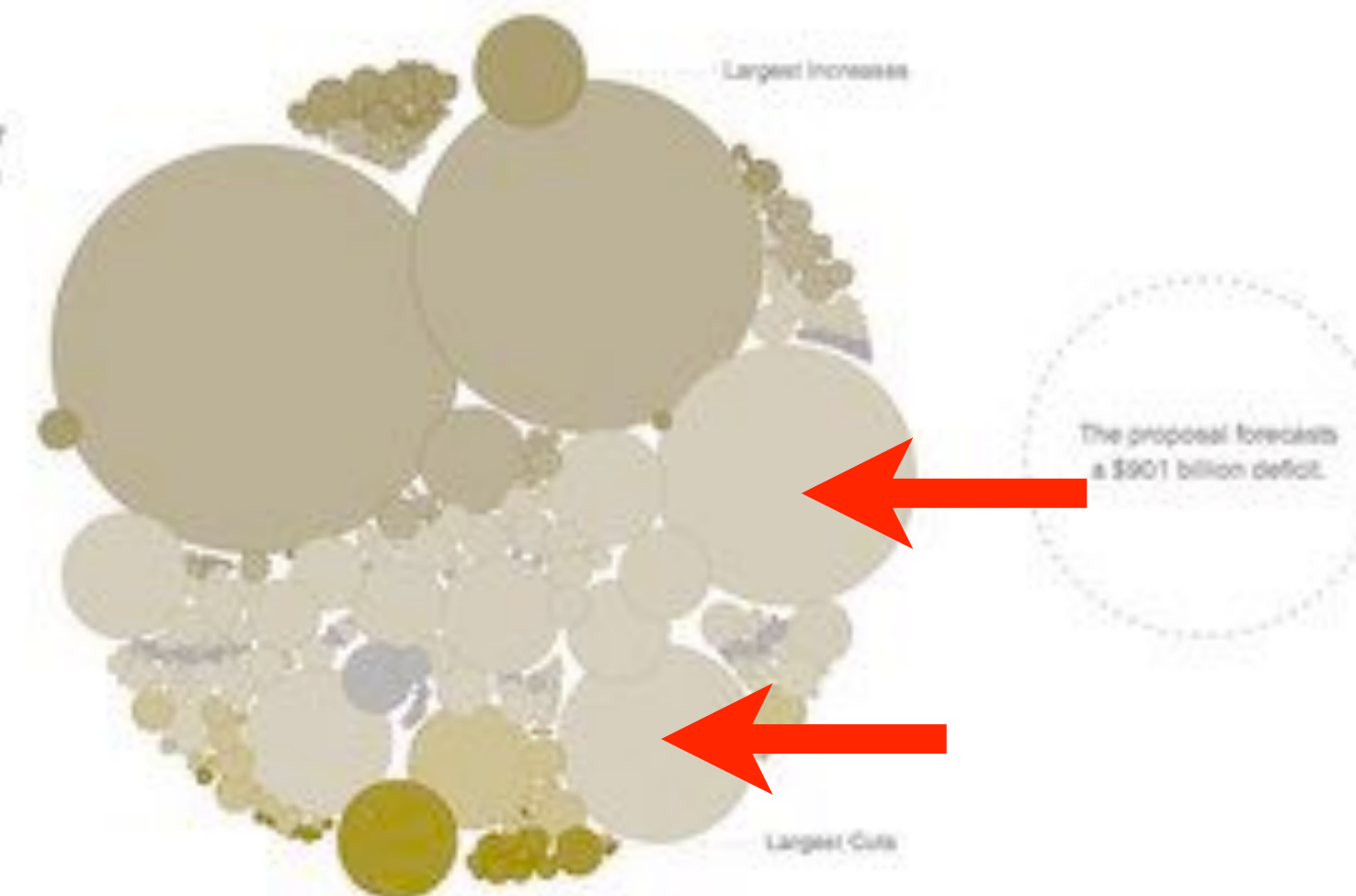
How \$3.7 Trillion Is Spent

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Circles are sized according to the proposed spending.



Color shows amount of cut or increase from 2012.



Simulate Color Vision Deficiencies

 **Colblindor**

Home ▾ CVD Essentials ▾

Coblis — Color Blindness Simulator

If you are not suffering from a color vision deficiency it is very hard to imagine how it looks like to be colorblind. The **Color BL**indness **S**imulator can close this gap for you. Just play around with it and get a feeling of how it is to have a color vision handicap.

As all the calculations are made on your local machine, no images are uploaded to the server. Therefore you can use images as big as you like, there are no restrictions. Be aware, there are some issues for the "Lens feature" on Edge and Internet Explorer. All others should support everything just fine.


So go ahead, choose an image through the upload functionality or just drag and drop your image in the center of our **Color BL**indness **S**imulator. It is also possible to zoom and move your images around using your mouse – try it out, I hope you like it.

Drag and drop or paste your file in the area below or: No file chosen

Trichromatic view:	Anomalous Trichromacy:	Dichromatic view:	Monochromatic view:
<input checked="" type="radio"/> Normal	<input type="radio"/> Red-Weak/Protanomaly	<input type="radio"/> Red-Blind/Protanopia	<input type="radio"/> Monochromacy/Achromatopsia
	<input type="radio"/> Green-Weak/Deuteranomaly	<input type="radio"/> Green-Blind/Deuteranopia	<input type="radio"/> Blue Cone Monochromacy
	<input type="radio"/> Blue-Weak/Tritanomaly	<input type="radio"/> Blue-Blind/Tritanopia	

Use lens to compare with normal view: ☒ No Lens ☐ Normal Lens ☐ Inverse Lens

[Reset View](#)



<http://www.color-blindness.com/coblis-color-blindness-simulator/>

Chrome Dev Tools: Rendering

ColorBrewer: Color Advice for | x

colorbrewer2.org/#type=qualitative&scheme=Set1&n=3

how to use | updates | downloads | credits

COLORBREWER 2.0
color advice for cartography

Number of data classes: 3

Nature of your data:
☐ sequential ☐ diverging ☒ qualitative

Pick a color scheme:

Only show:
☐ colorblind safe
☐ print friendly
☐ photocopy safe

Context:
☐ roads
☐ cities
☒ borders

Background:
☒ solid color
☐ terrain

color transparency

3-class Set1
HEX
#e41a1c
#377eb8
#4daf4a

EXPORT

© Cynthia Brewer, Mark Harrower and The Pennsylvania State University
[Source code and feedback](#)
[Back to Flash version](#)
[Back to ColorBrewer 1.0](#)

axismaps

Rendering

Emulate CSS media feature prefers-color-scheme
Forces CSS prefers-color-scheme media feature

No emulation

Emulate CSS media type
Forces media type for testing print and screen styles

No emulation

Emulate CSS media feature forced-colors
Forces CSS forced-colors media feature

No emulation

Emulate CSS media feature prefers-contrast
Forces CSS prefers-contrast media feature

No emulation

Emulate CSS media feature prefers-reduced-motion
Forces CSS prefers-reduced-motion media feature

No emulation

Emulate CSS media feature prefers-reduced-data
Forces CSS prefers-reduced-data media feature

No emulation

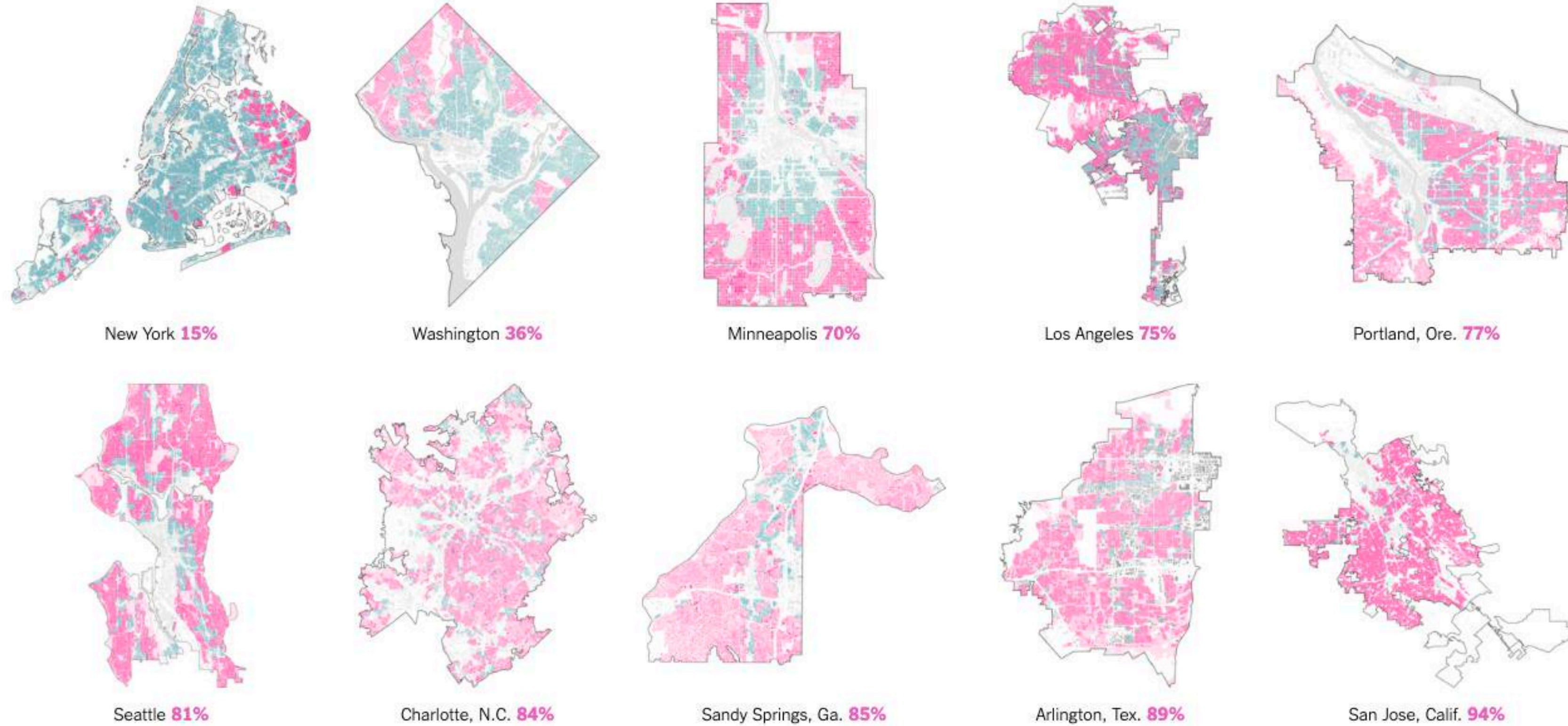
Emulate CSS media feature color-gamut
Forces CSS color-gamut media feature

No emulation

Emulate vision deficiencies
Forces vision deficiency emulation

Protanopia

Residential land zoned for: ■ detached single-family homes ■ other housing



Cities not shown to scale. Source: Zoning data for individual cities from UrbanFootprint

NY Times Zoning Maps: <http://nyti.ms/2XVAuie>

Drag and drop or paste your file in the area below or: D9WlOrwXsAA4Z07.jpg

Trichromatic view: *Anomalous Trichromacy:*

☐ Normal

☐ Red-Weak/Protanomaly

☐ Green-Weak/Deuteranomaly

☐ Blue-Weak/Tritanomaly

Dichromatic view:

☐ Red-Blind/Protanopia

☒ Green-Blind/Deuteranopia

☐ Blue-Blind/Tritanopia

Monochromatic view:

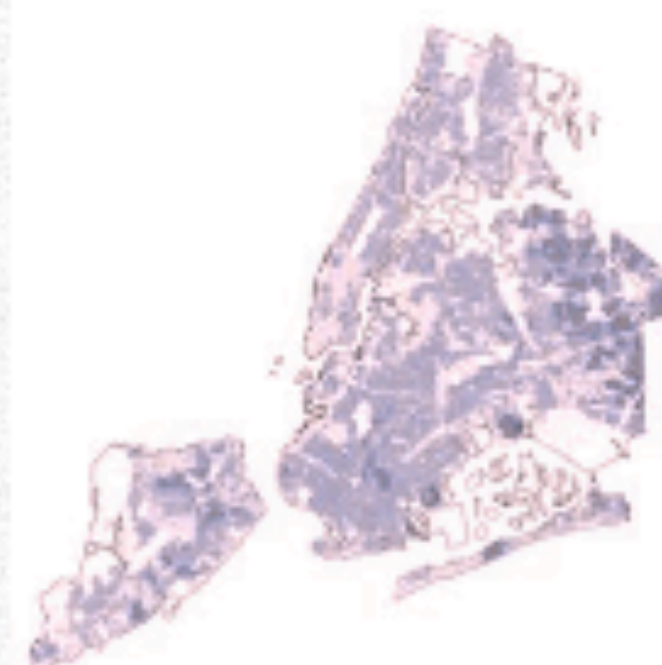
☐ Monochromacy/Achromatopsia

☐ Blue Cone Monochromacy

Use lens to compare with normal view: ☒ No Lens ☐ Normal Lens ☐ Inverse Lens

[Reset View](#) [Open simulated image in new window](#)

Residential land zoned for: ■ detached single-family homes ■ other housing



New York 15%



Washington 36%



Minneapolis 70%



Los Angeles 75%



Portland, Ore. 77%



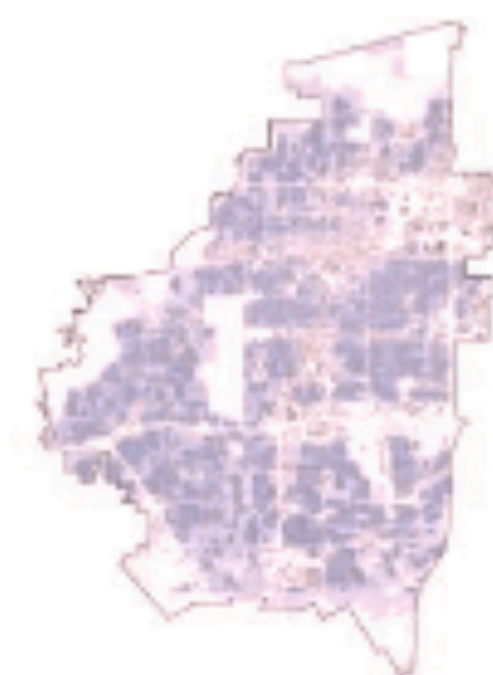
Seattle 81%



Charlotte, N.C. 84%



Sandy Springs, Ga. 85%



Arlington, Tex. 89%



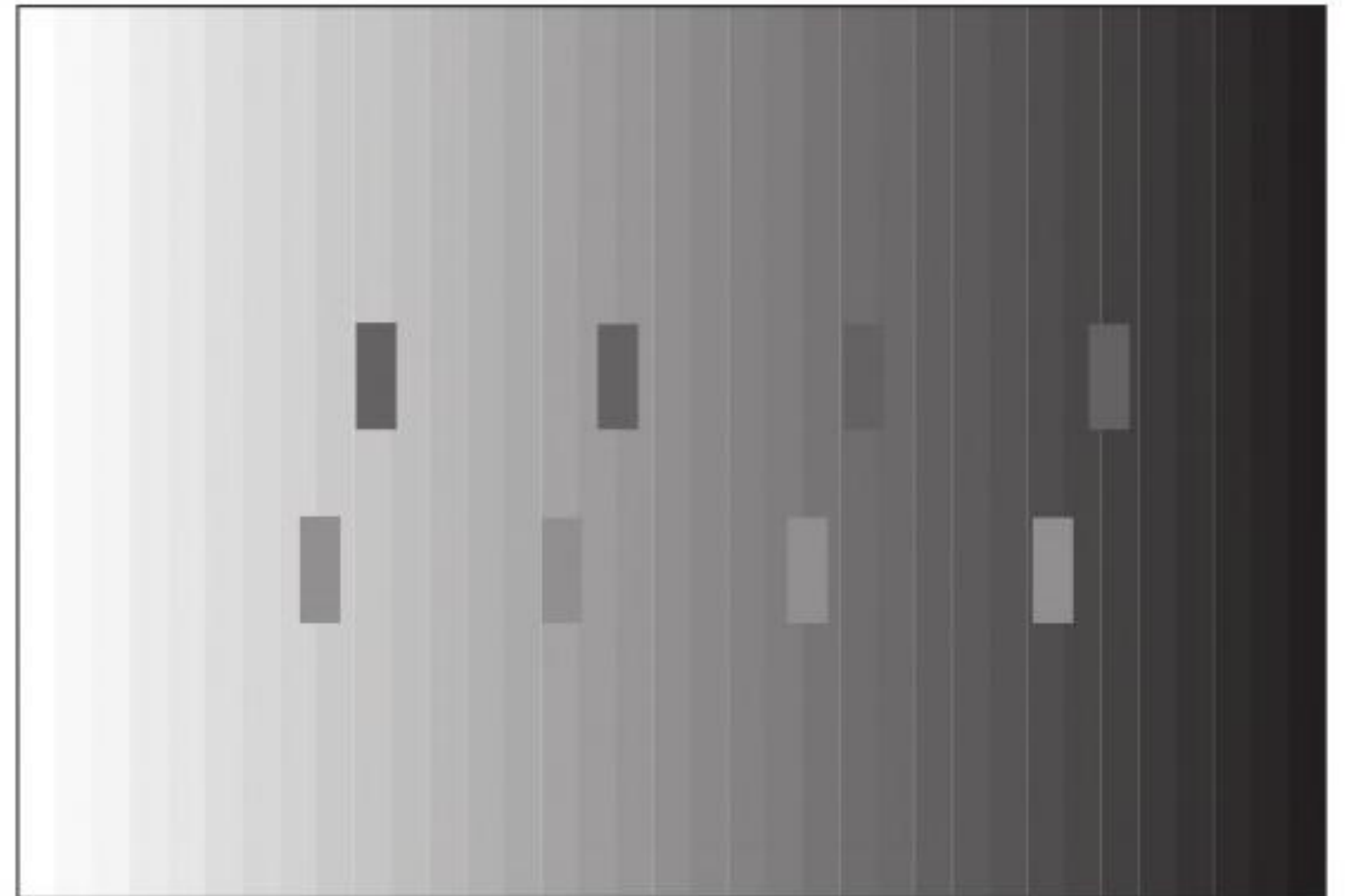
San Jose, Calif. 94%

Cities not shown to scale. Source: Zoning data for individual cities from UrbanFootprint

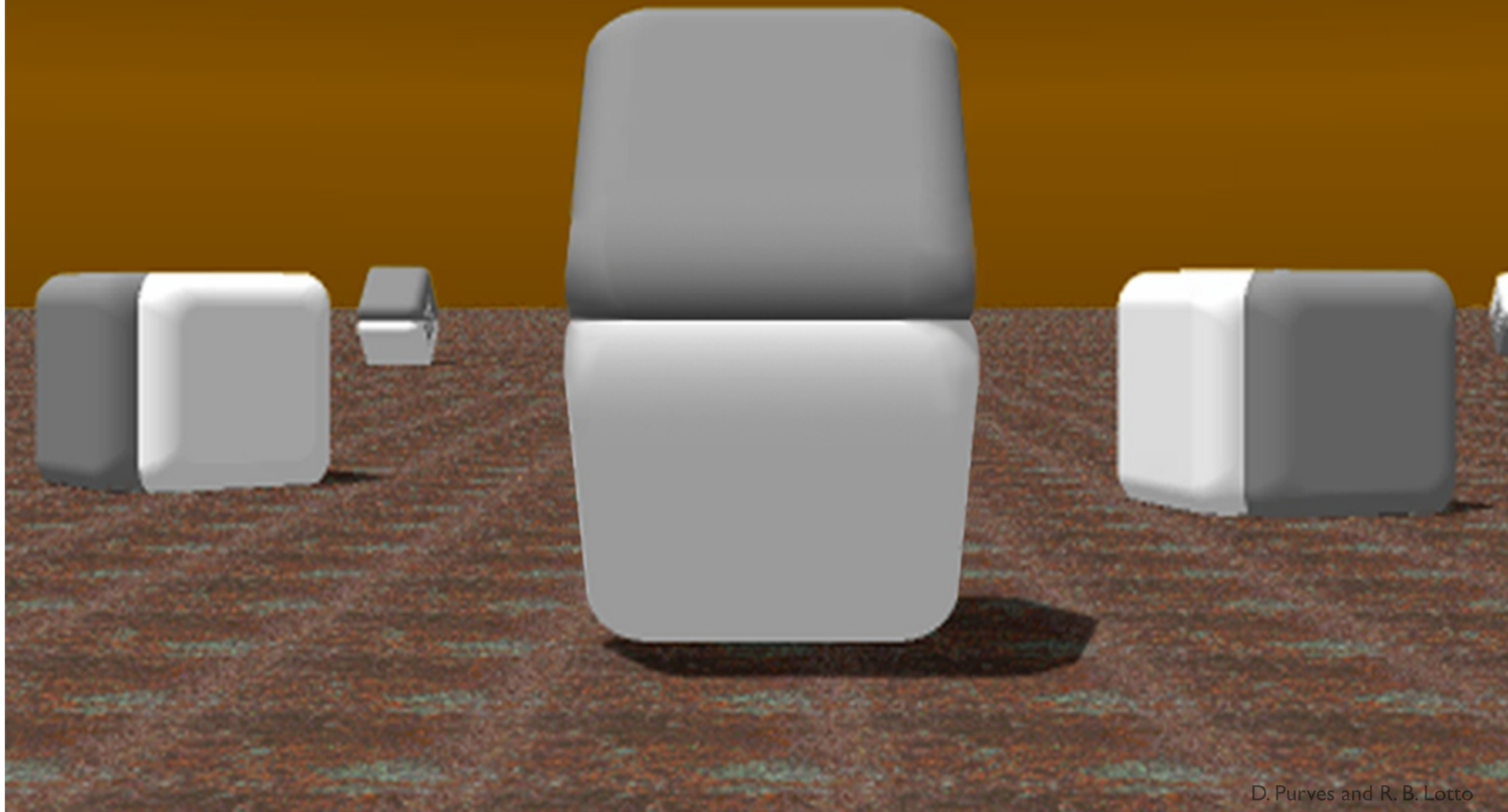
Color / Brightness is
Relative!

Simultaneous Brightness Contrast

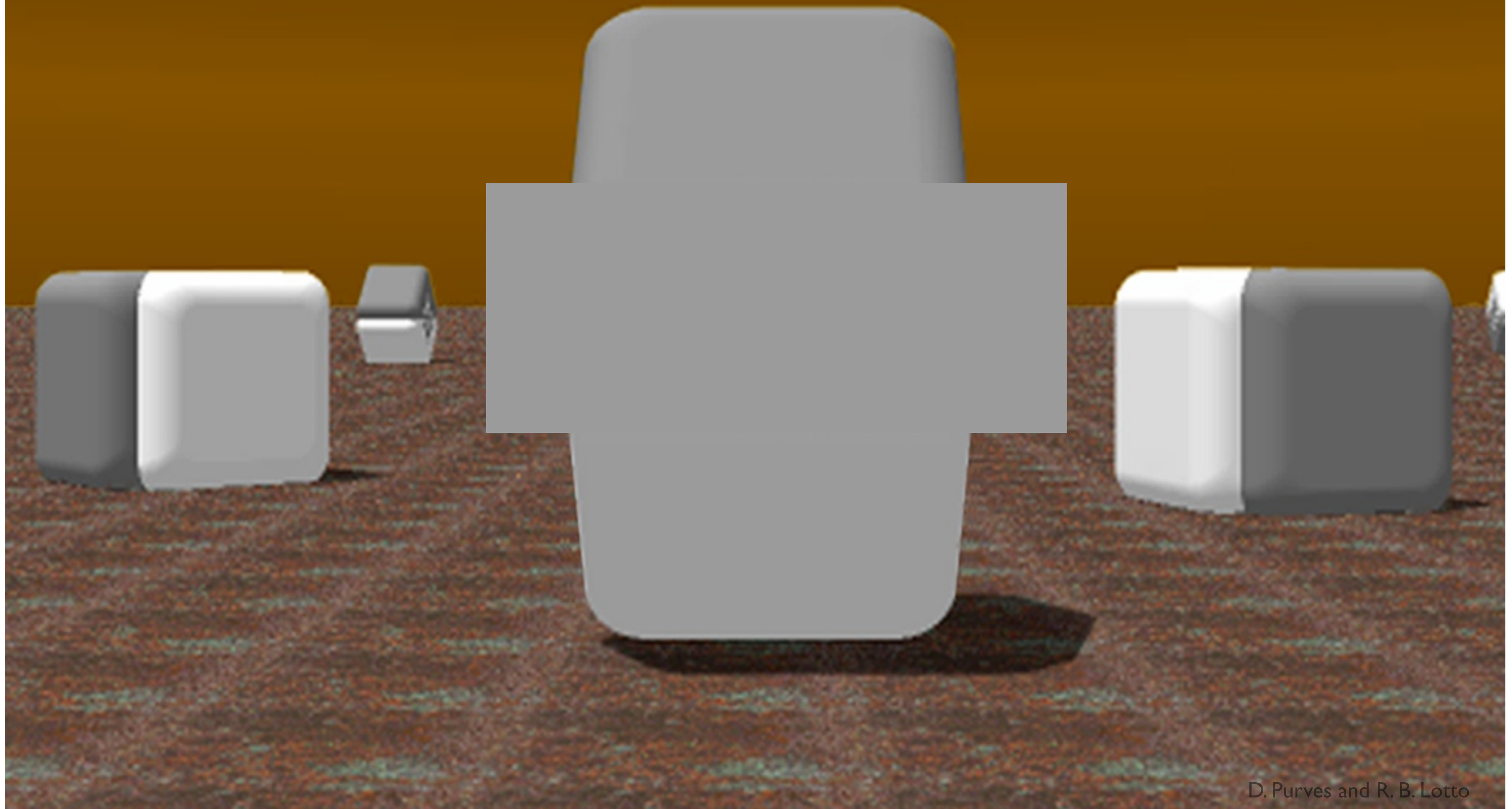
The perceived brightness of an object is relative to its background



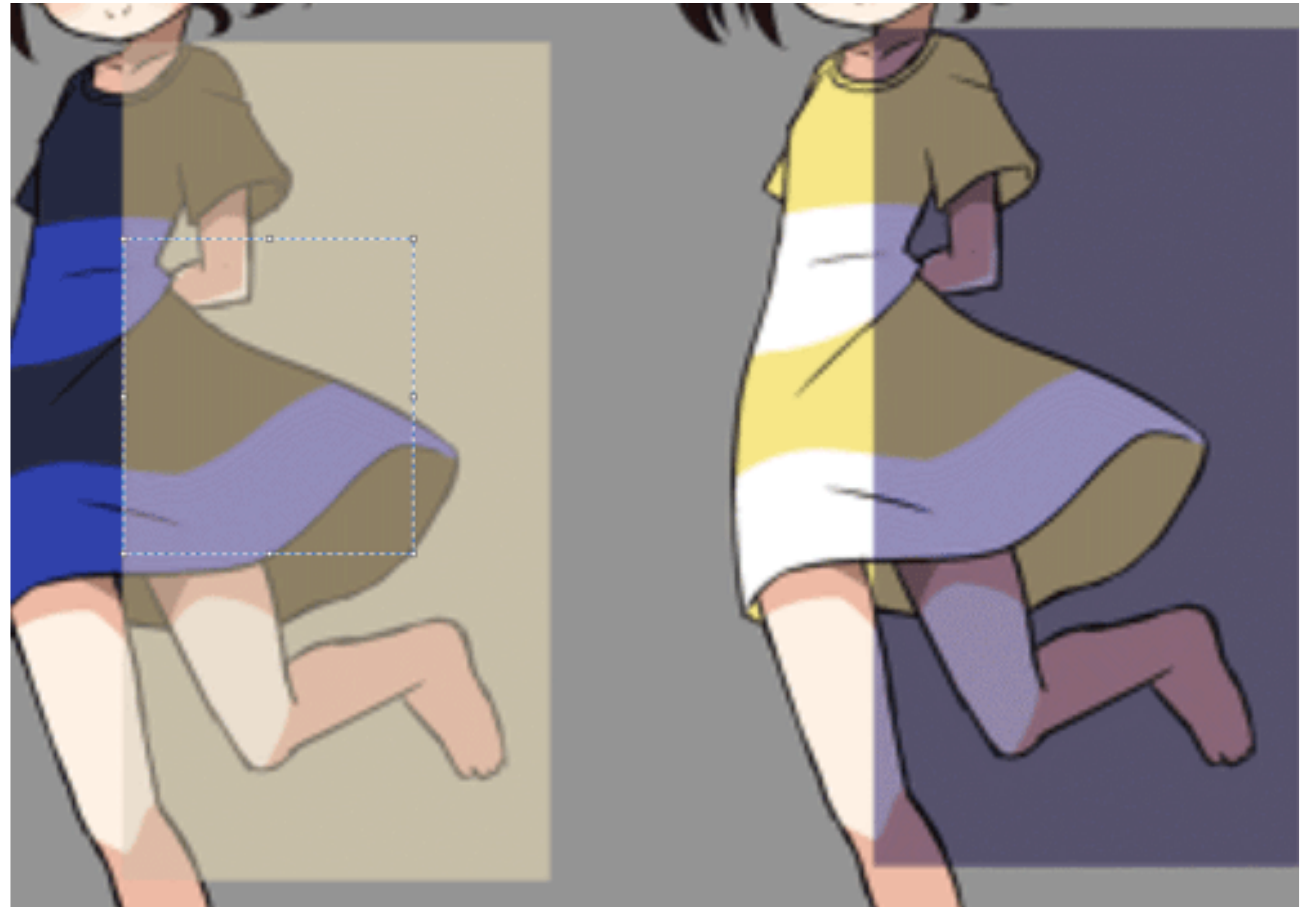
Cornsweet Illusion



Cornsweet Illusion



The Dress Meme

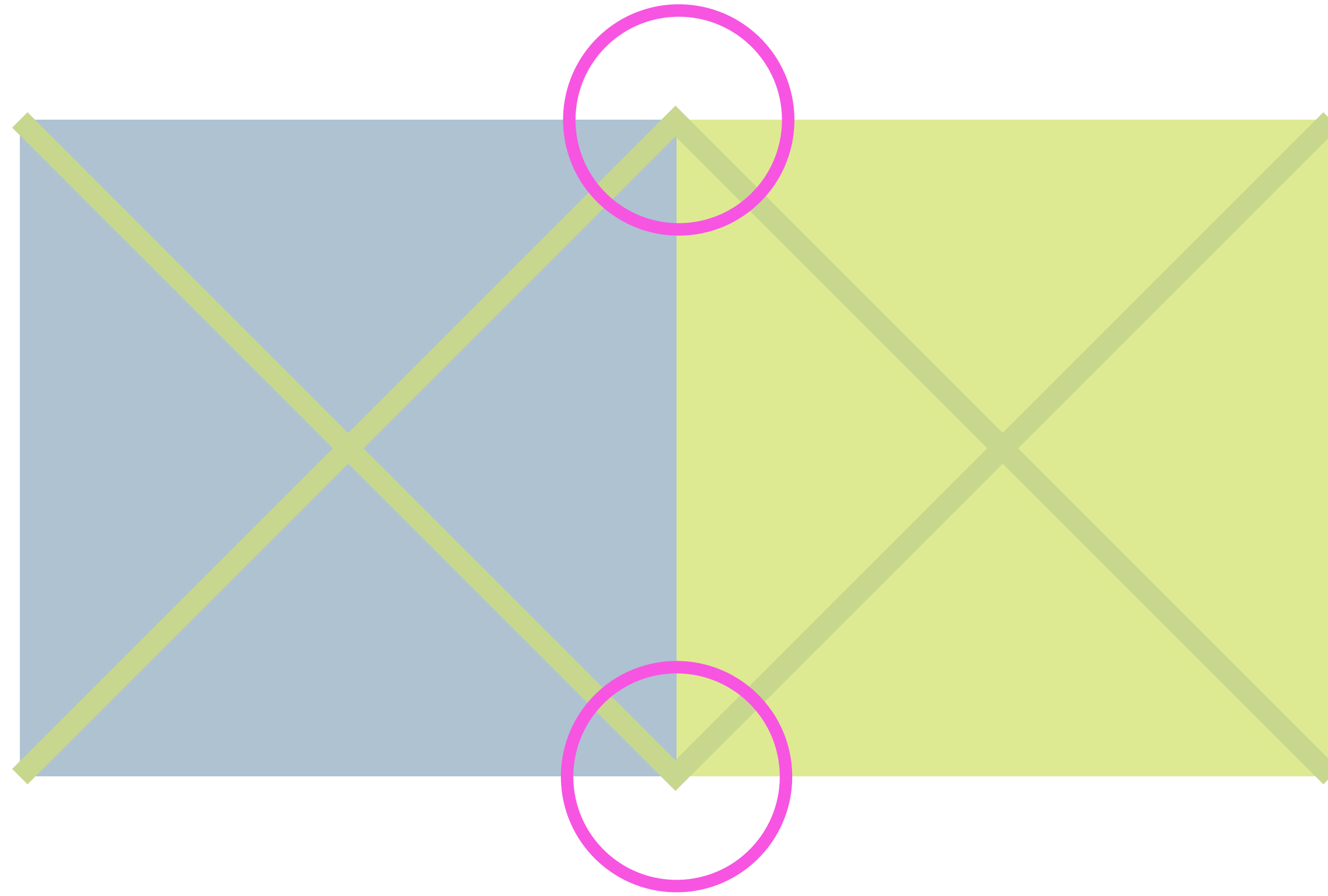


black and blue or white and gold?

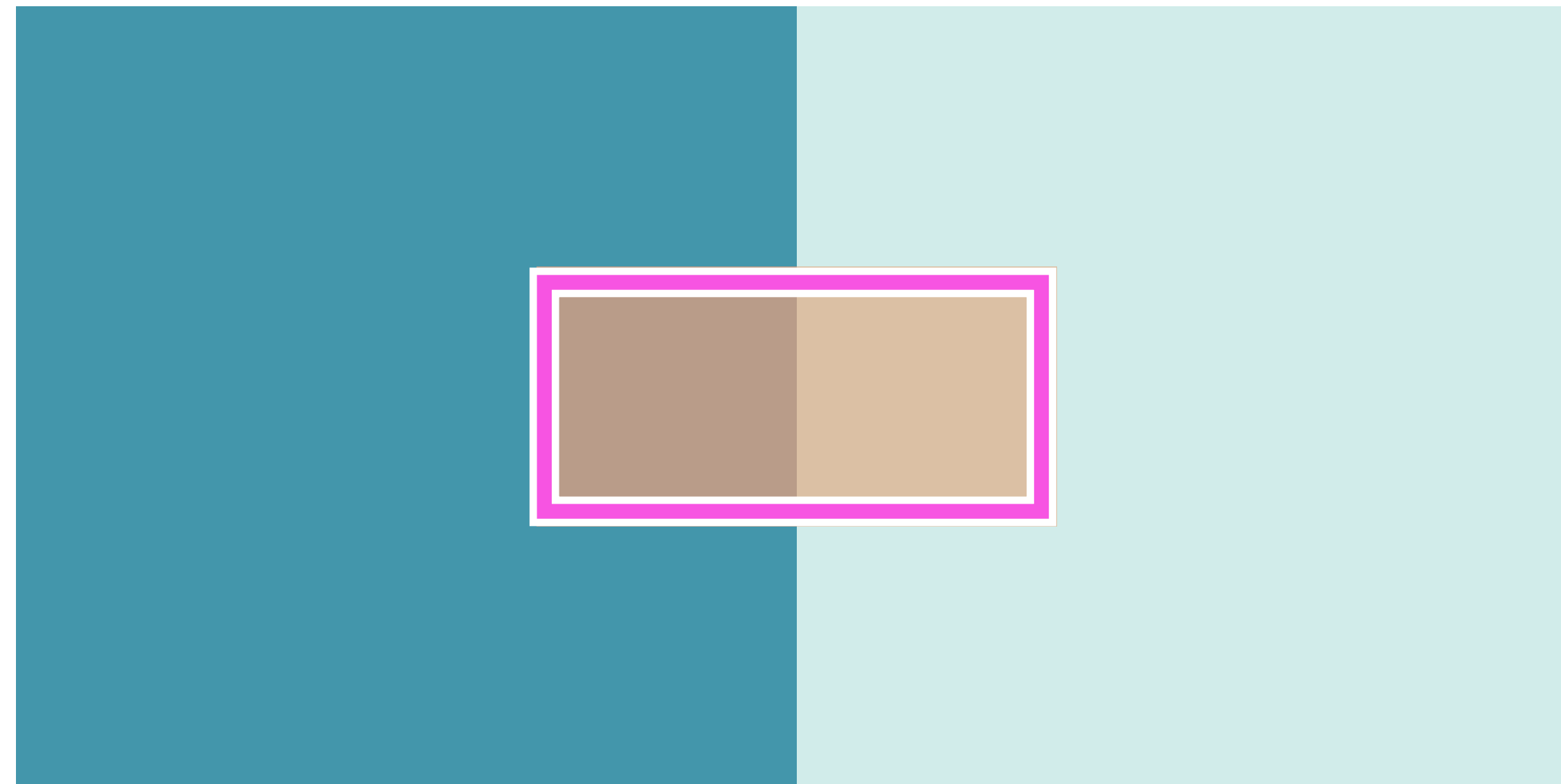
<https://imgur.com/hxJjUQB>

https://en.wikipedia.org/wiki/The_dress

INTERACTION OF COLOR



INTERACTION OF COLOR



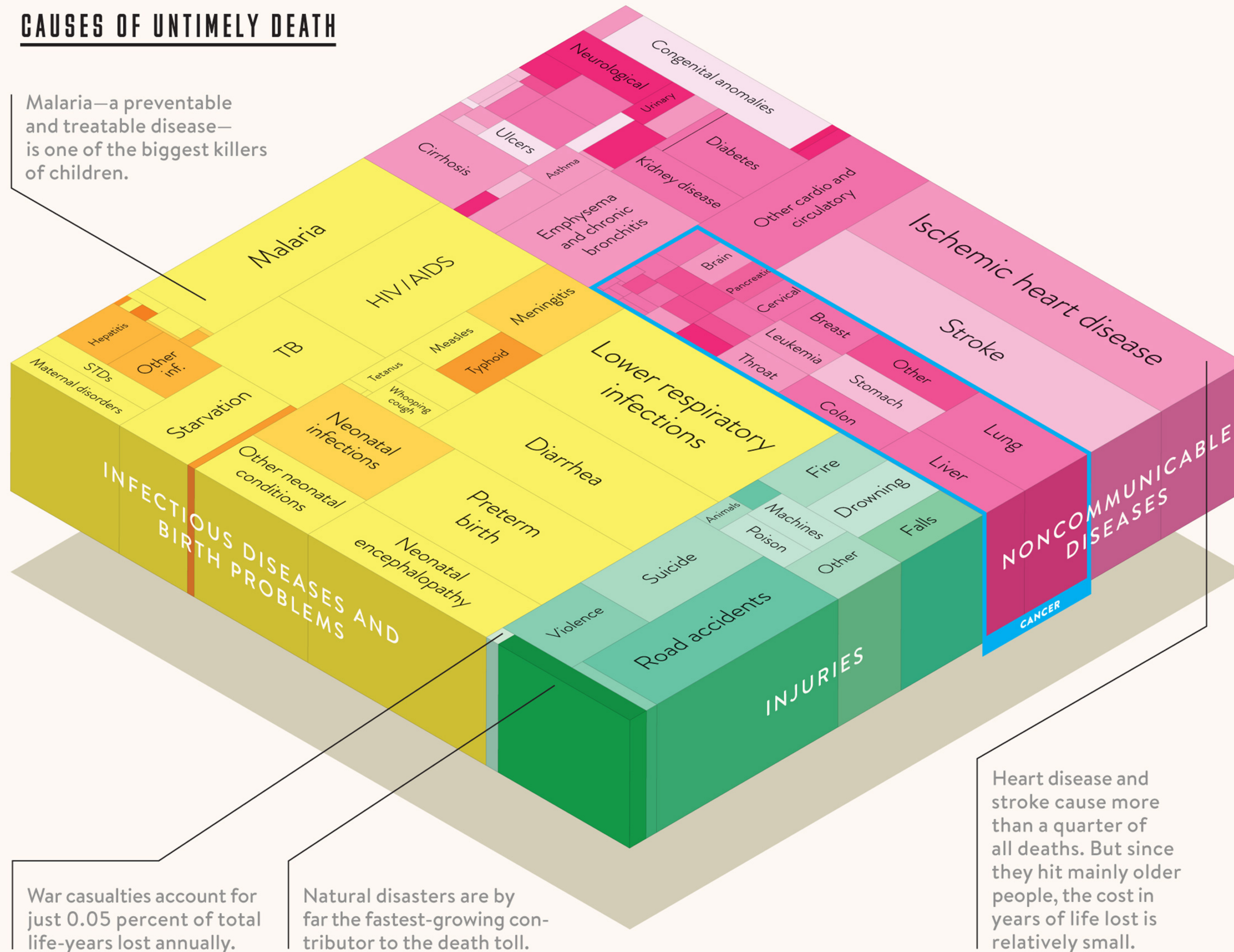
INTERACTION OF COLOR



Design Critique

CAUSES OF UNTIMELY DEATH

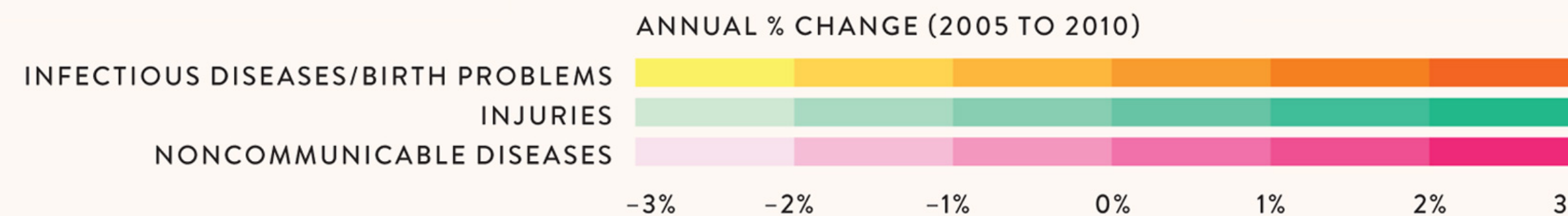
Malaria—a preventable and treatable disease—is one of the biggest killers of children.



War casualties account for just 0.05 percent of total life-years lost annually.

Natural disasters are by far the fastest-growing contributor to the death toll.

Heart disease and stroke cause more than a quarter of all deaths. But since they hit mainly older people, the cost in years of life lost is relatively small.



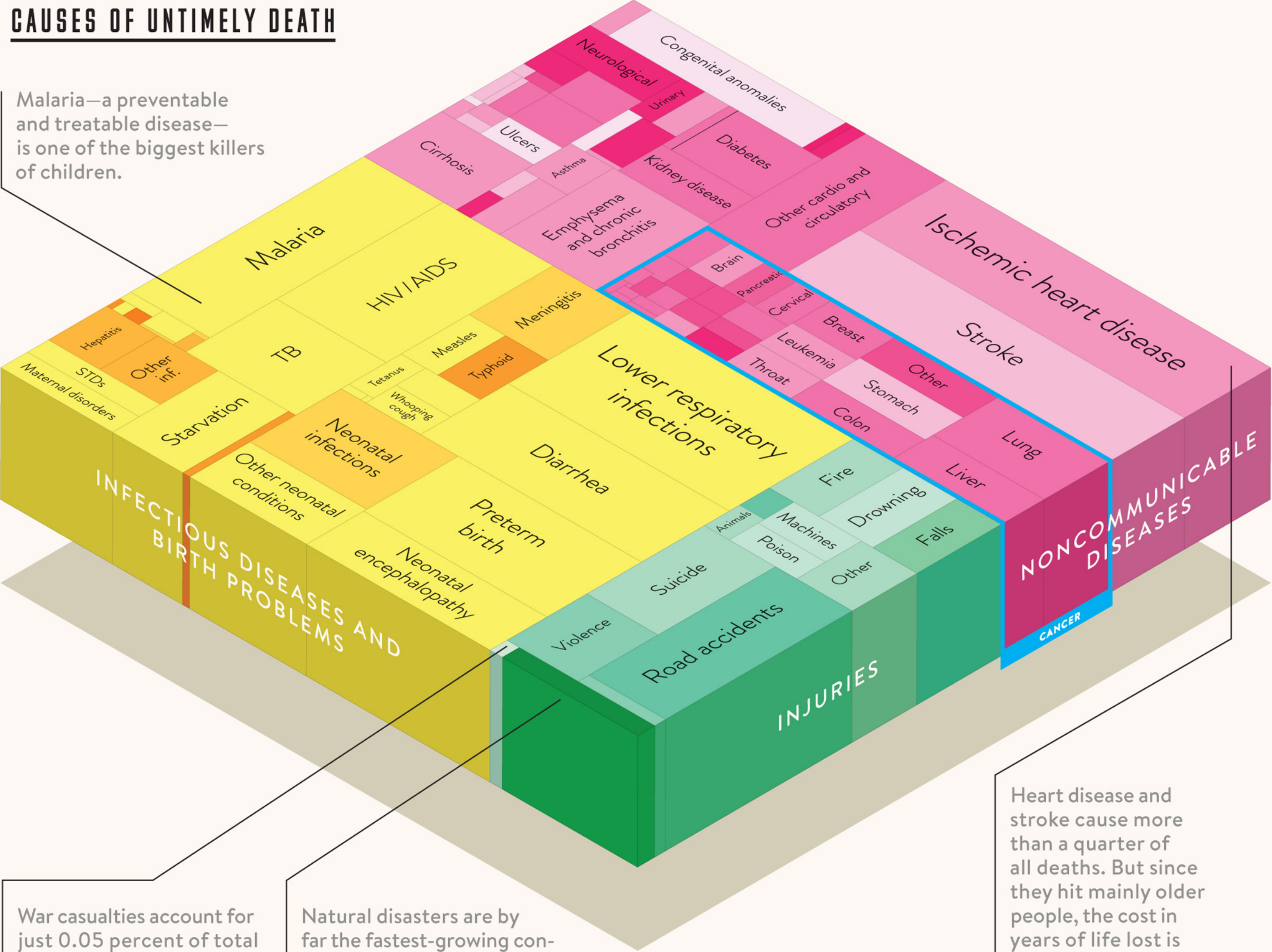
Graph of the Year?

"I love this graph because it shows that while the number of people dying from communicable diseases is still far too high, those numbers continue to come down. [...] But there remains much to do to cut down the deaths in that yellow block even more dramatically. We have the solutions. But we need to keep up the support where they're being deployed [...]"

-Bill Gates

CAUSES OF UNTIMELY DEATH

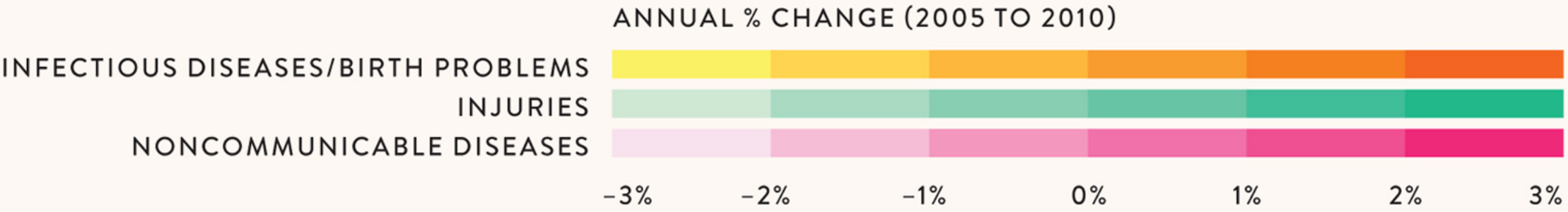
Malaria—a preventable and treatable disease—is one of the biggest killers of children.



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Natural disasters are by far the fastest-growing contributor to the death toll.

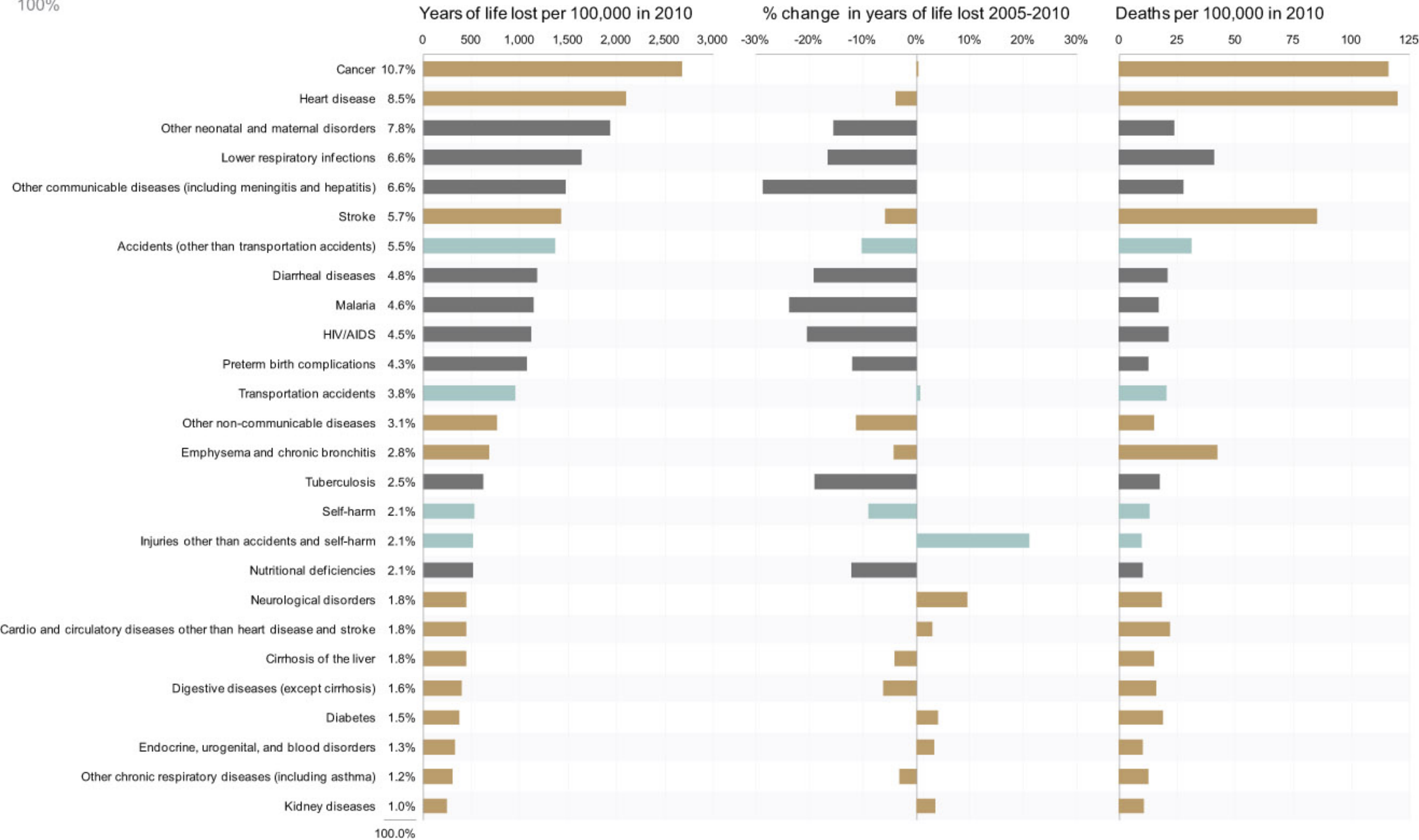
Heart disease and stroke cause more than a quarter of all deaths. But since they hit mainly older people, the cost in years of life lost is relatively small.



Global Causes of Lost Life

44% ■ Communicable, maternal, neonatal, and nutritional disorders
43% ■ Non-communicable diseases
13% ■ Injuries
100%

Comparing the number of deaths alone, as shown in the right-most graph below, doesn't tell the entire story. Some causes of death have a greater effect on the young, which can be seen when comparing years of life lost in the leftmost graph.



Some causes of death contribute disproportionately to years of life lost because of their effect on the young. For example, malaria, while not huge in the number of deaths, is much more significant in the number of years that are lost.

Two interesting changes reside in "Injuries other than accidents and self-harm." War, which accounted for only 0.05% of years of life lost, decreased since 2005 by 31.5% in years of life lost per 100,000 people. Natural disasters, which accounted for 0.65% of years of life lost, increased by 217% in years of life lost per 100,000.

Communicable, maternal, neonatal, and nutritional disorders (the gray bars) are often easier to prevent through healthcare than other causes of death. This reveals itself in the graph above by the fact that all of these disorders have decreased during this five year period.

The five forms of cancer that cause the most deaths are trachea/bronchus/lung (2.9%), stomach (1.4%), liver (1.4%), colon/rectum (1.4%), and breast (0.8%).

All cardiovascular and circulatory diseases combined account for 30% of deaths.

Redesign by
Perceptual Edge

Popout

Popout

Properties detected by the low-level visual system

very rapid - 200-250 milliseconds

very accurate

processed in parallel

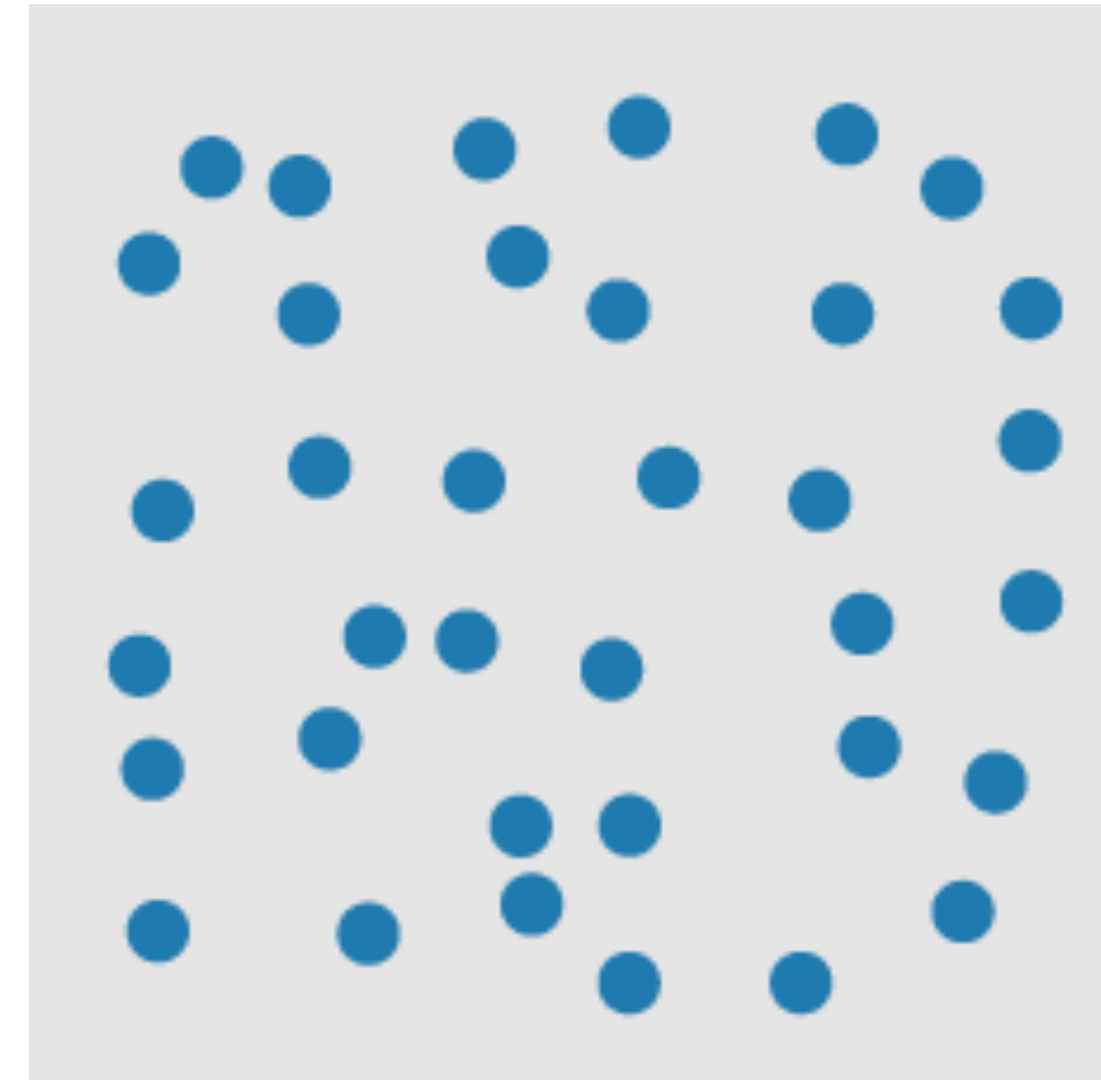
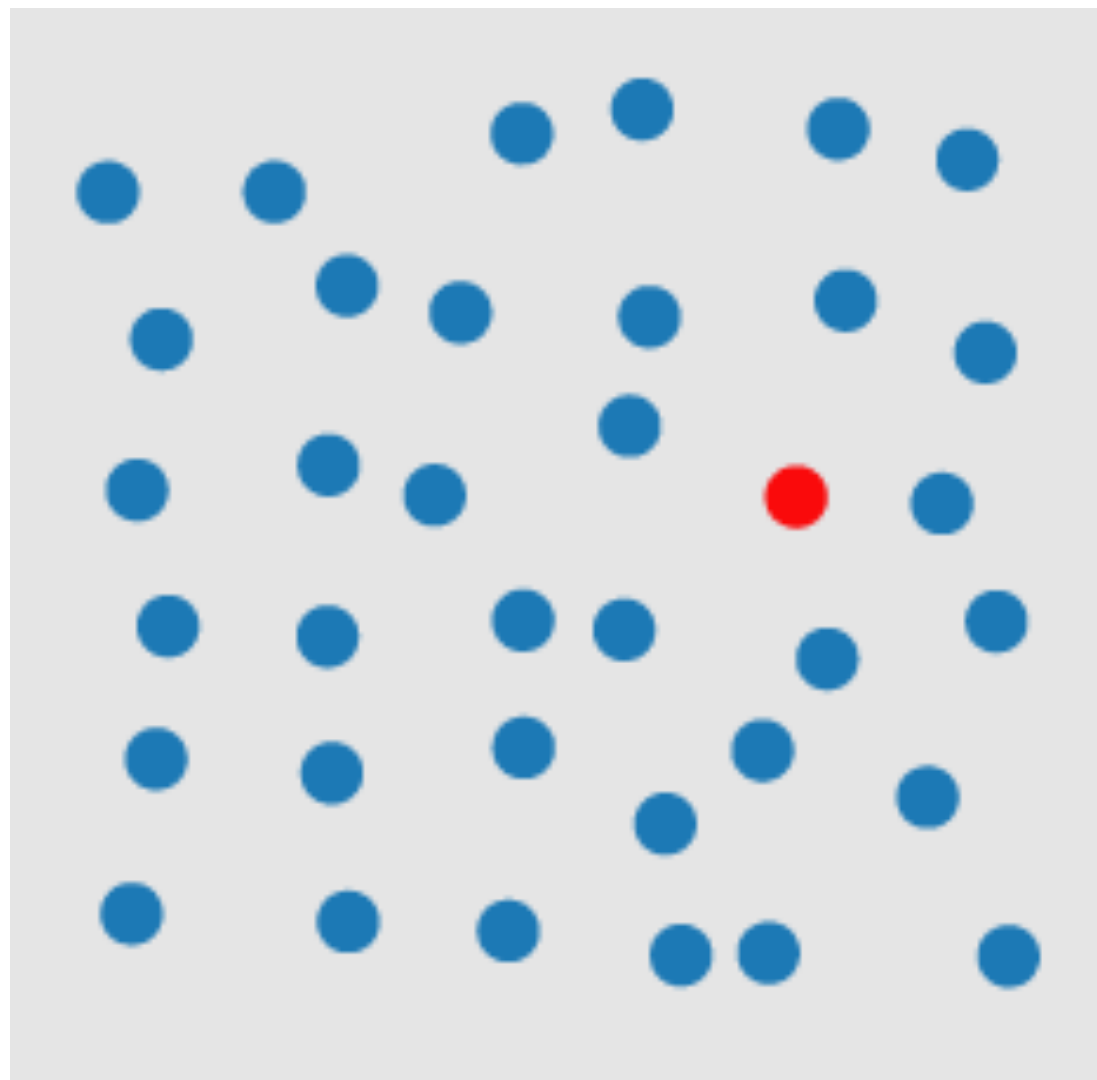
happens before focused attention -> „pre“attentive

attention is very important for cognition

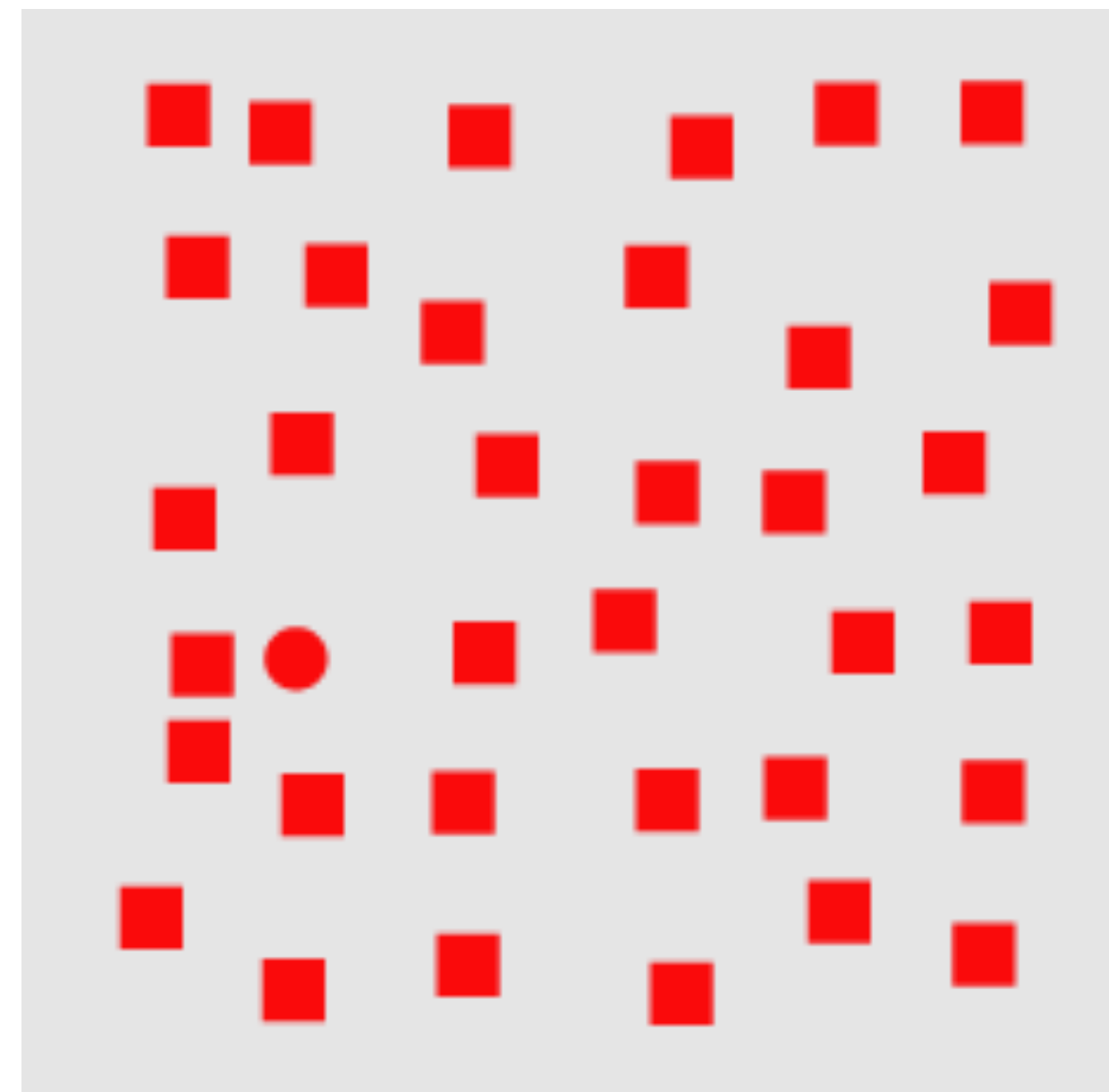
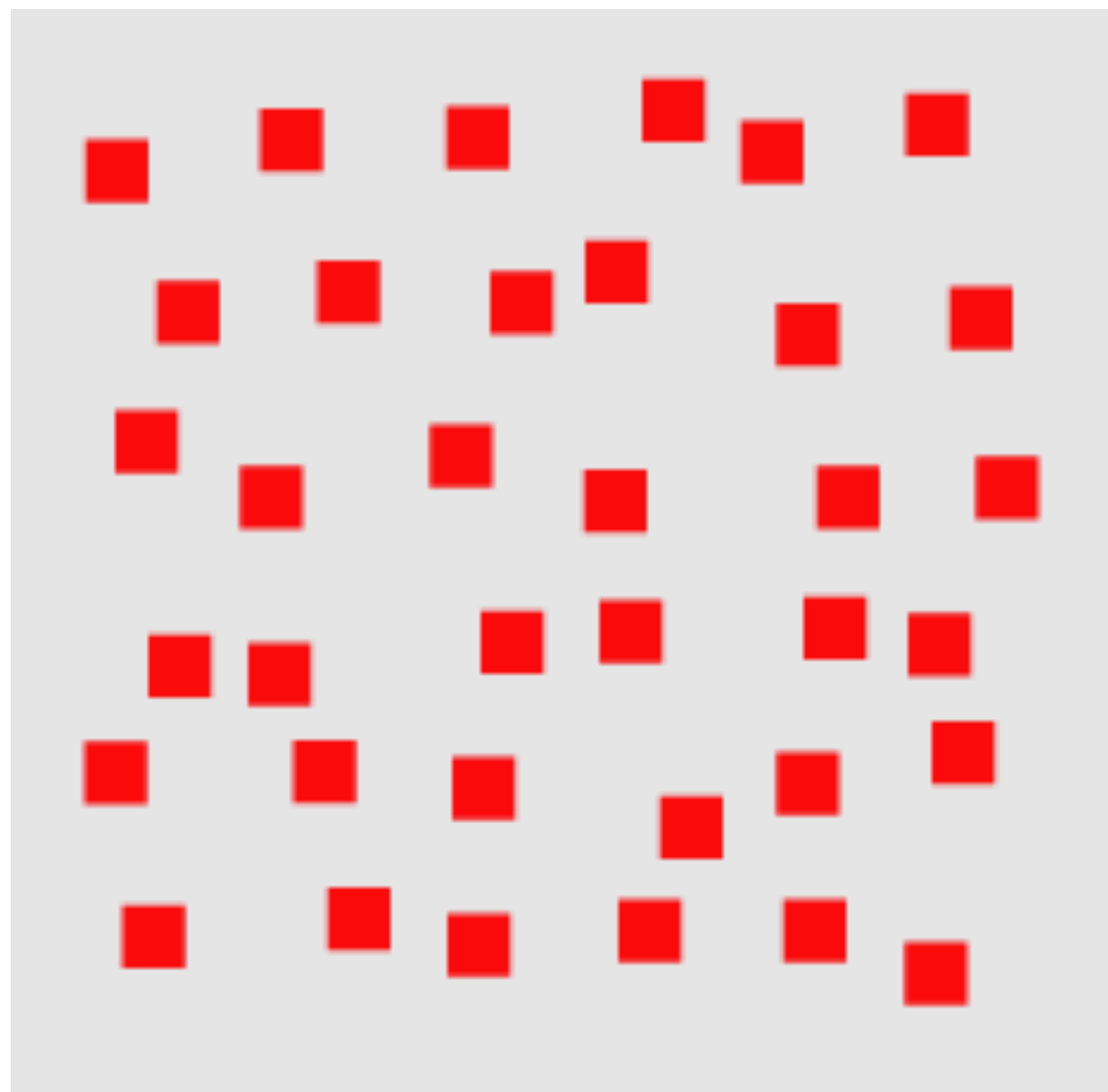
Independent of the number of distractors!

Opposite: sequential search (processed serially)

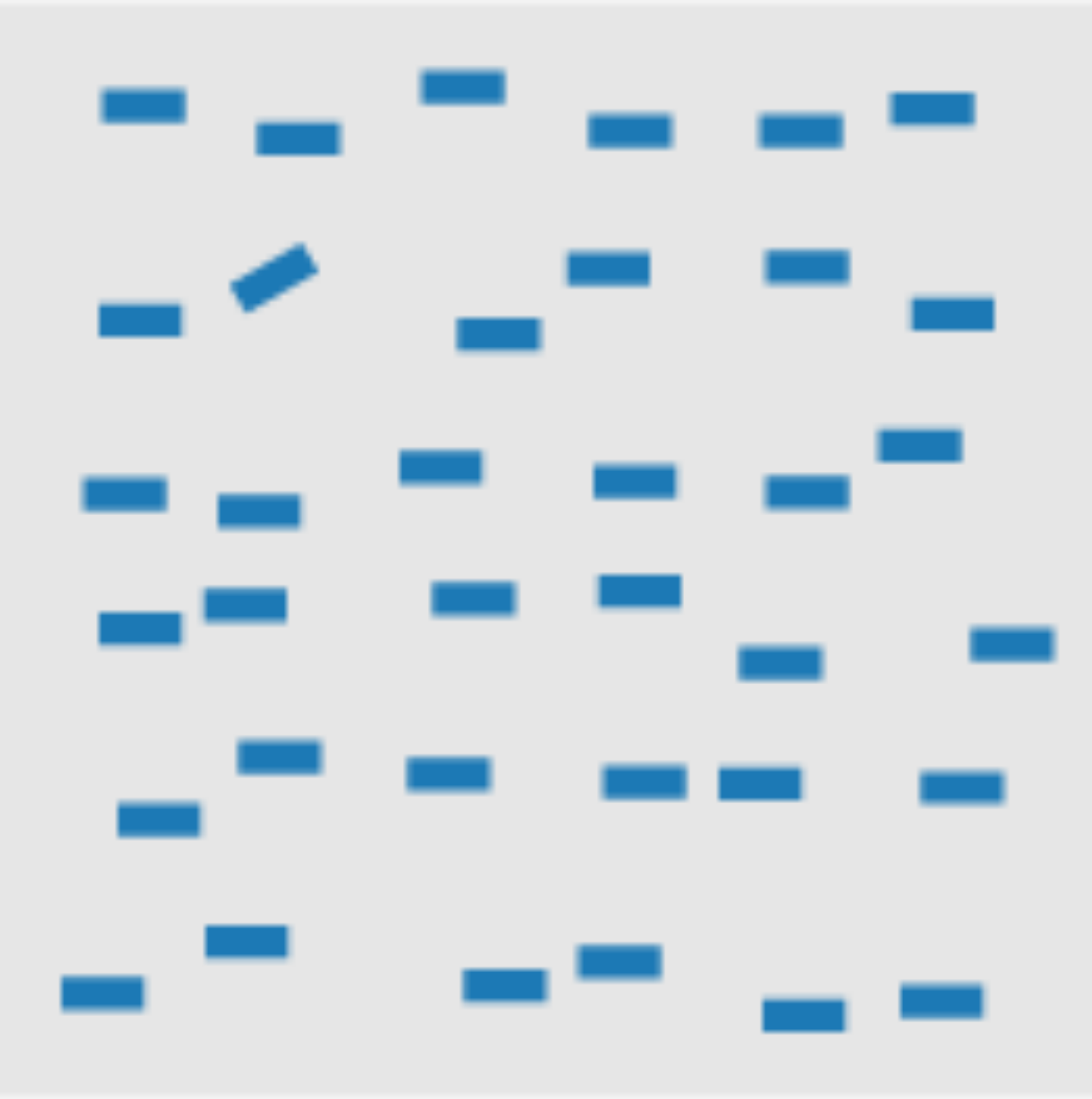
Difference in Hue



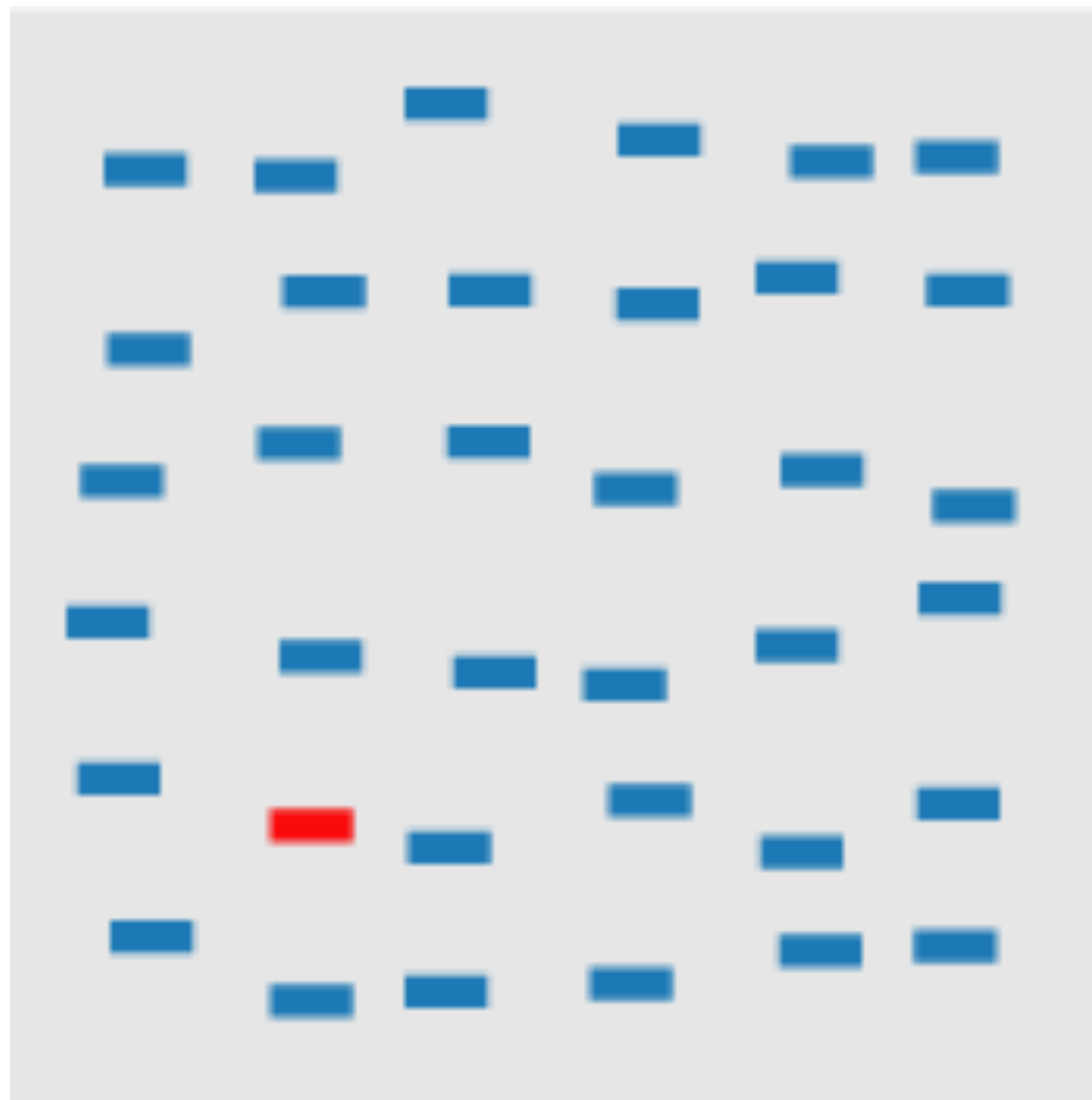
Difference in Curvature / Form



Clap when you spot the
odd one!



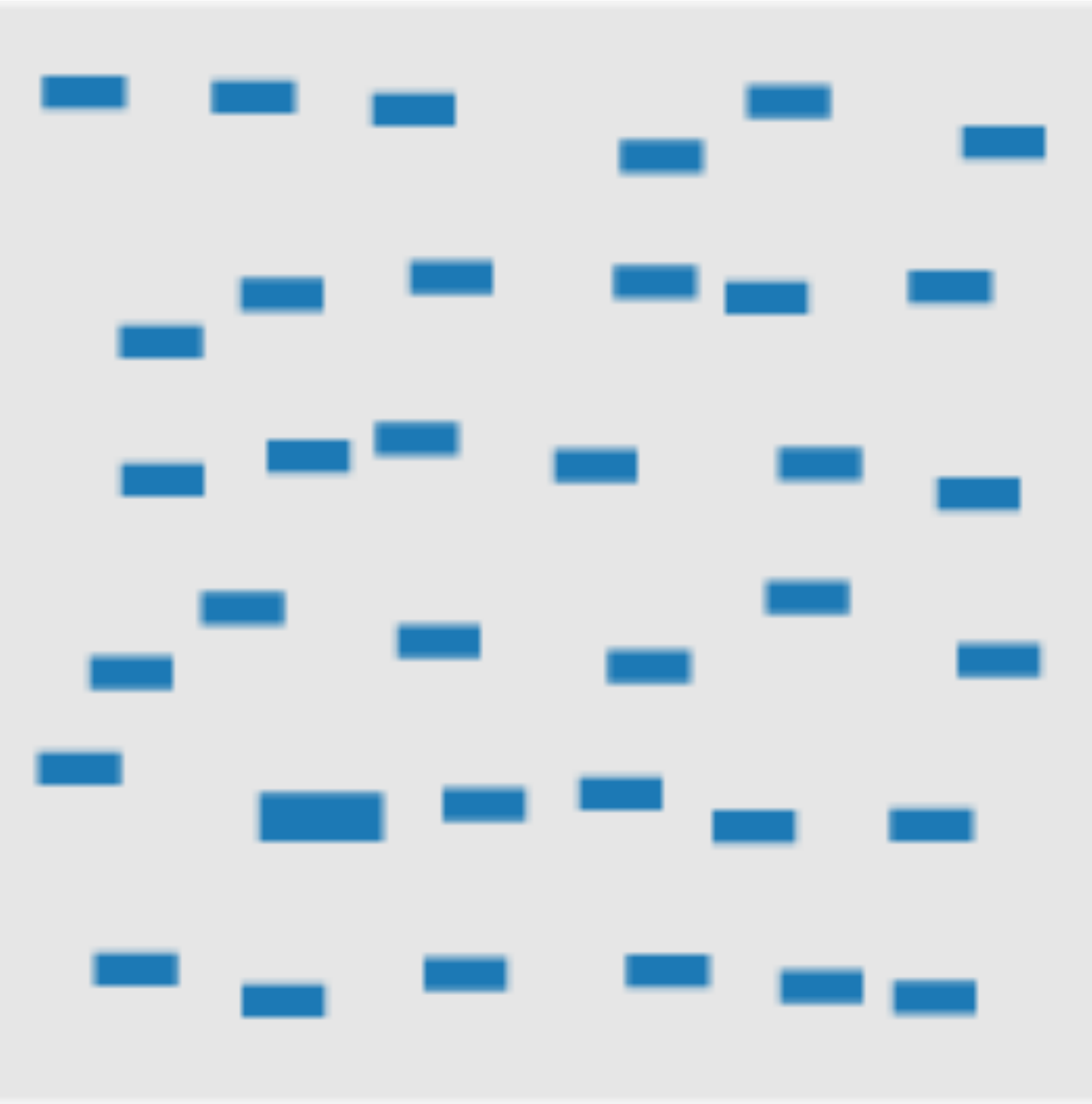
orientation



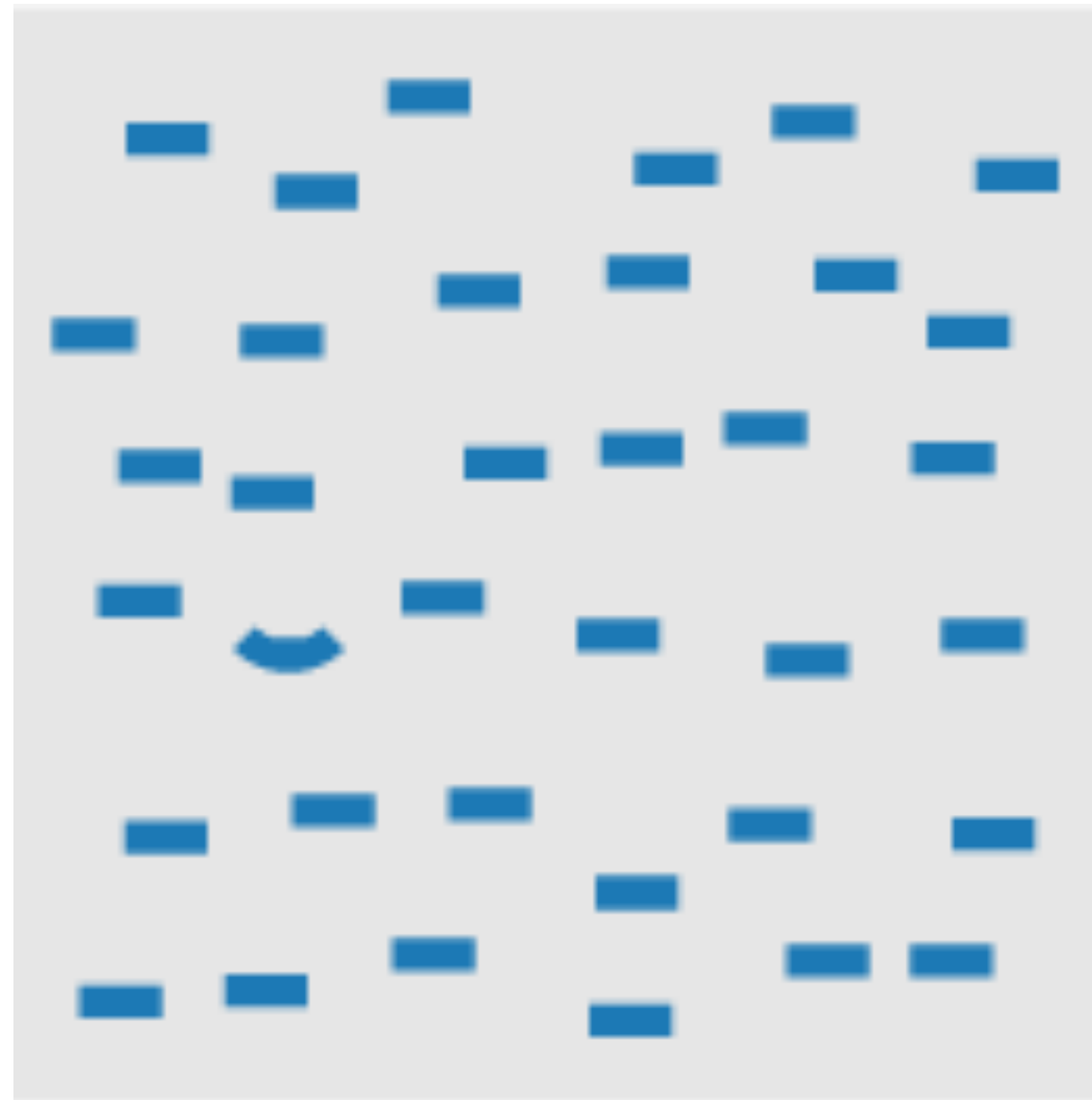
hue



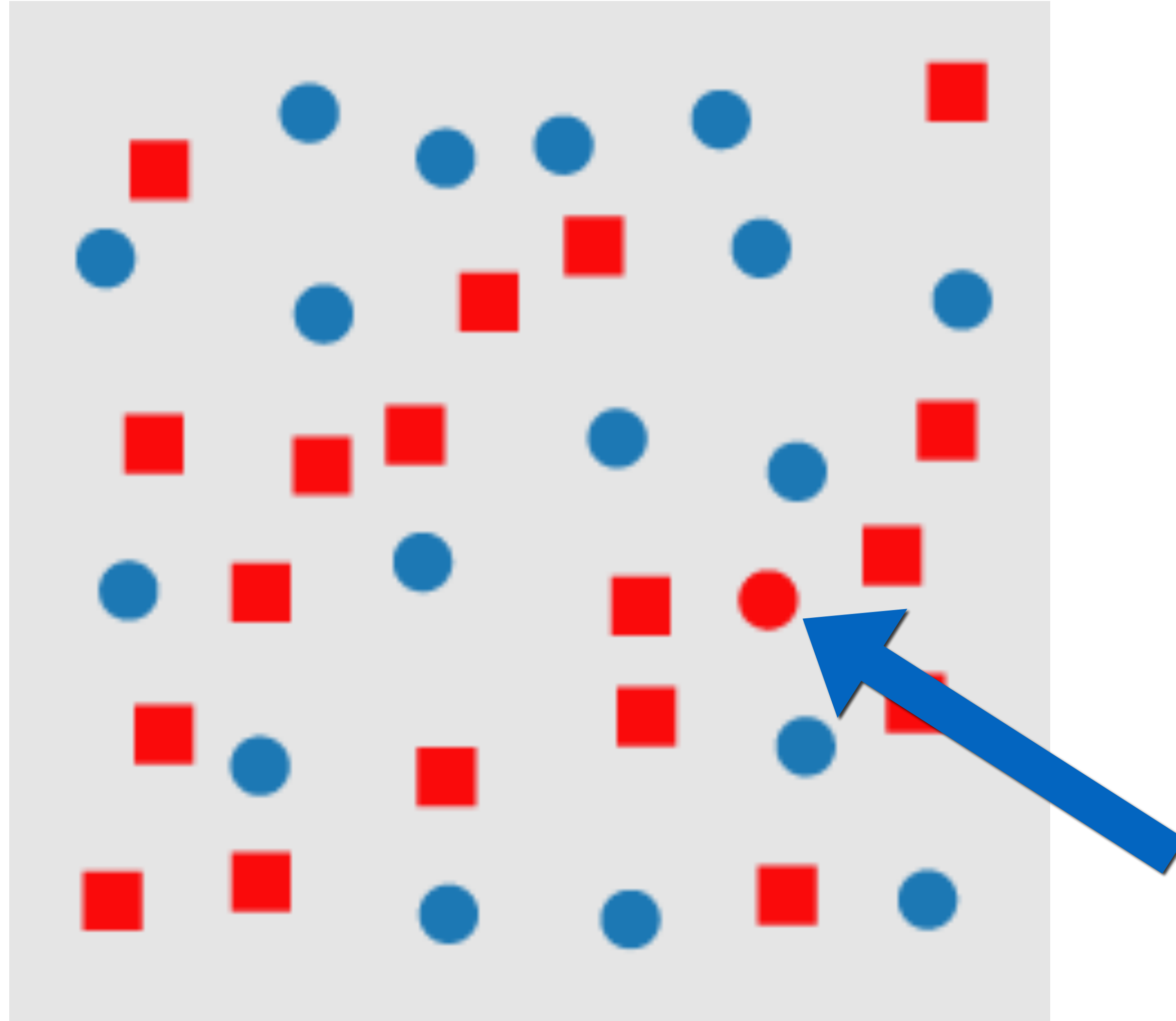
closure



size

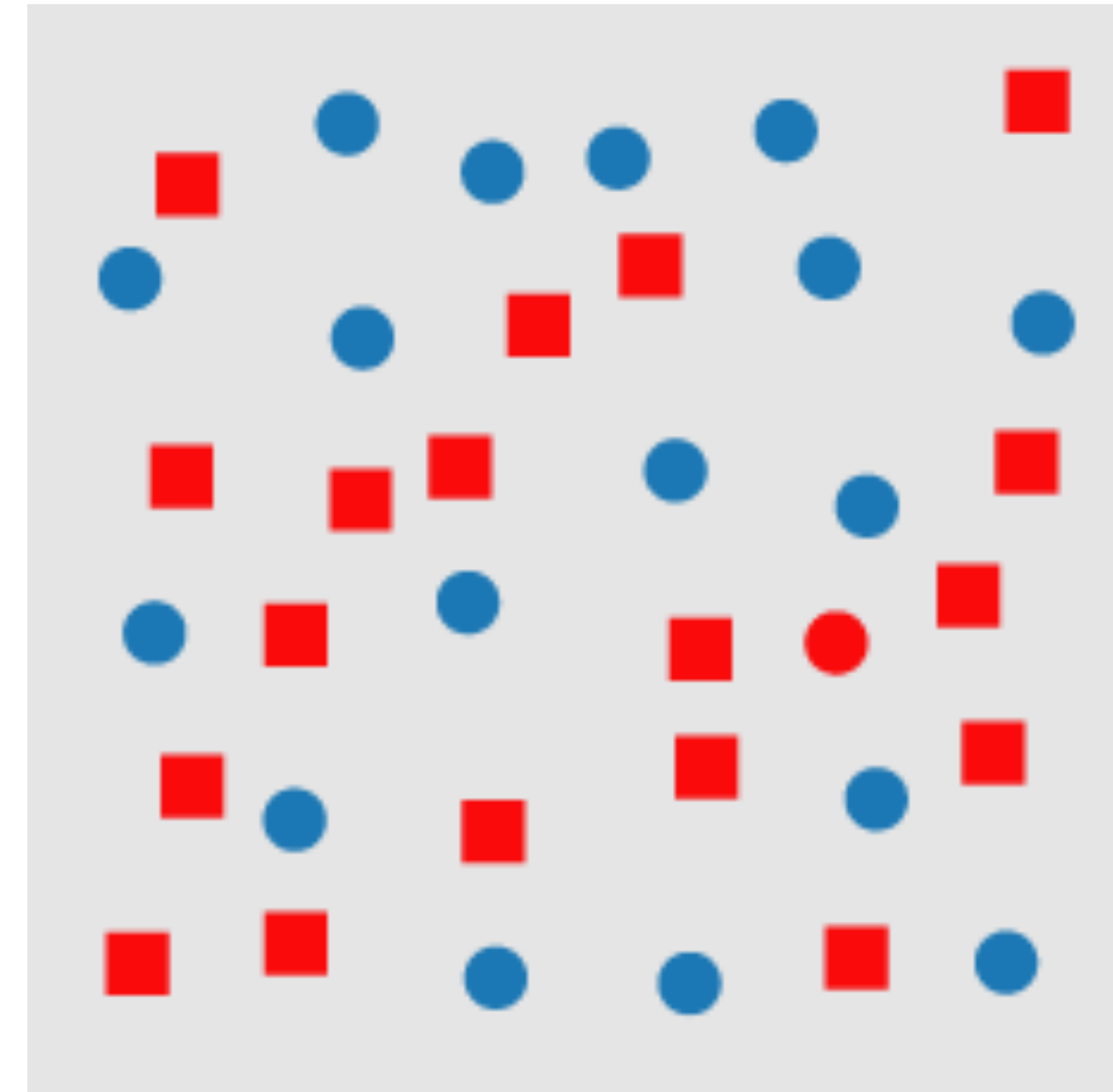
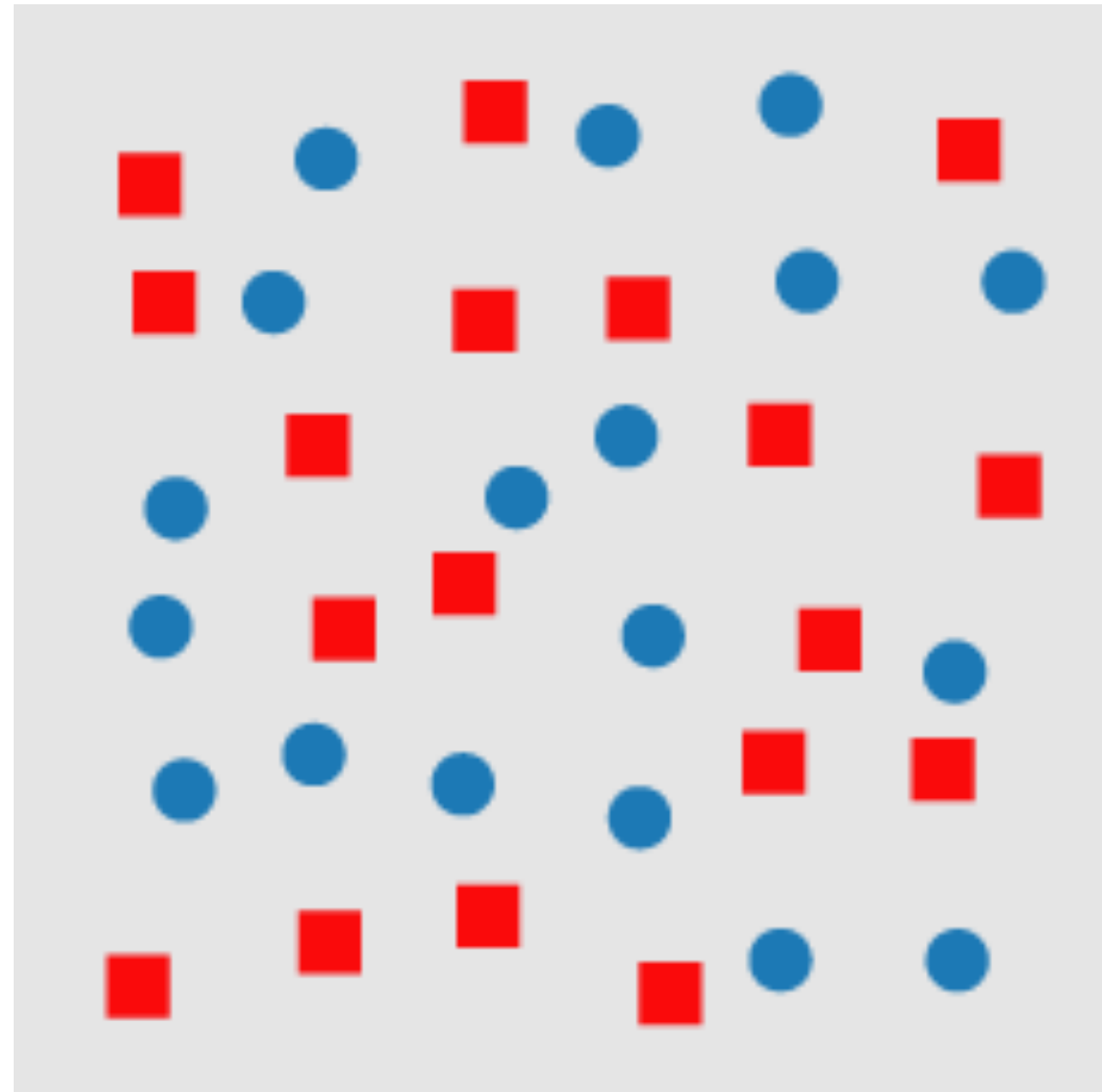


curvature



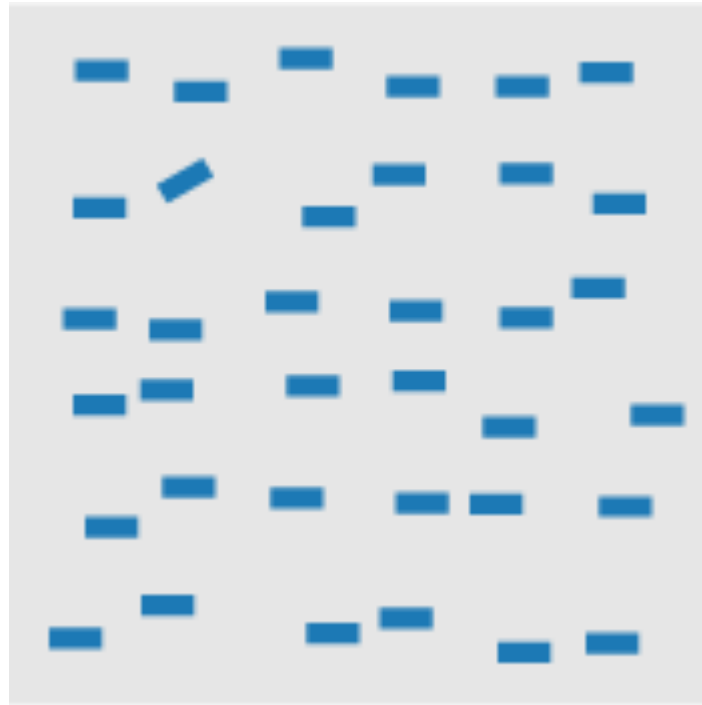
?

Not Valid for Combinations

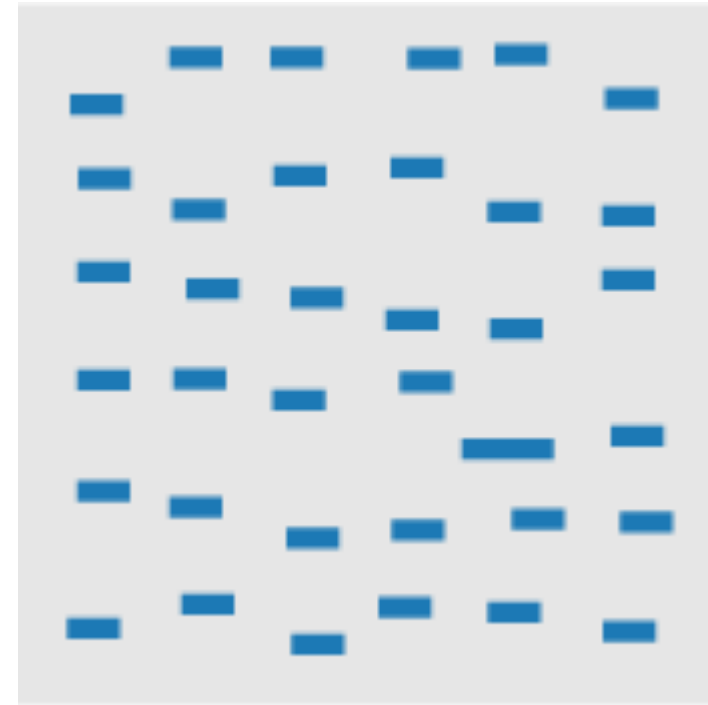


Conjunction Targets – no unique visual property
target: red, circle
distractor objects have both properties

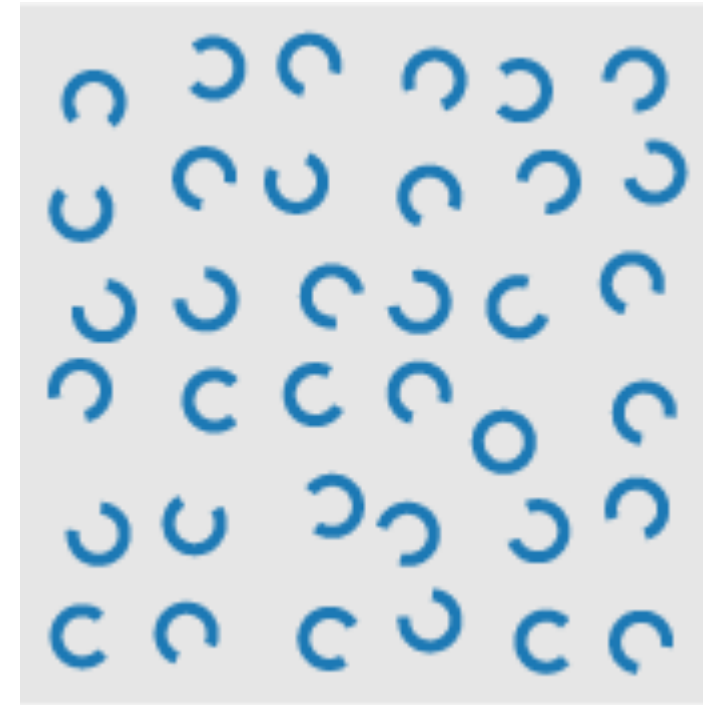
Some Preattentive Properties



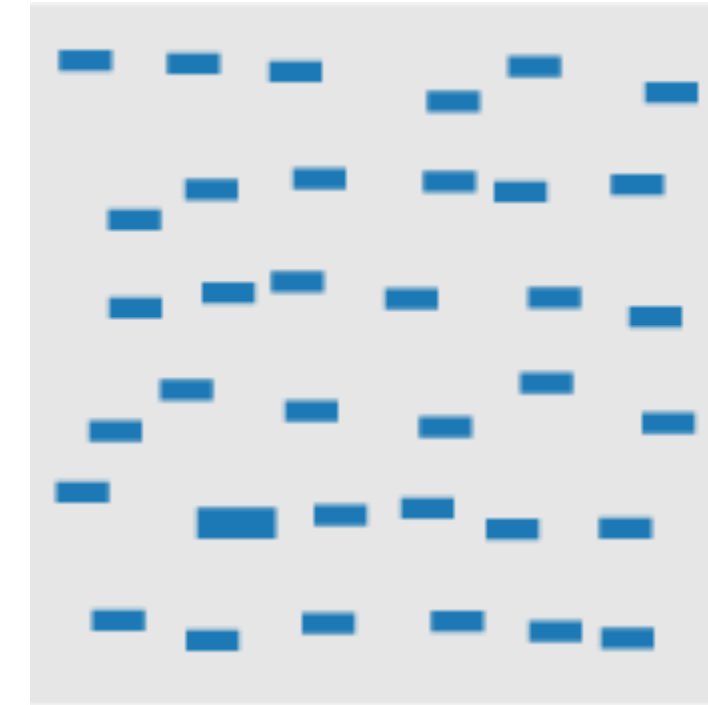
orientation



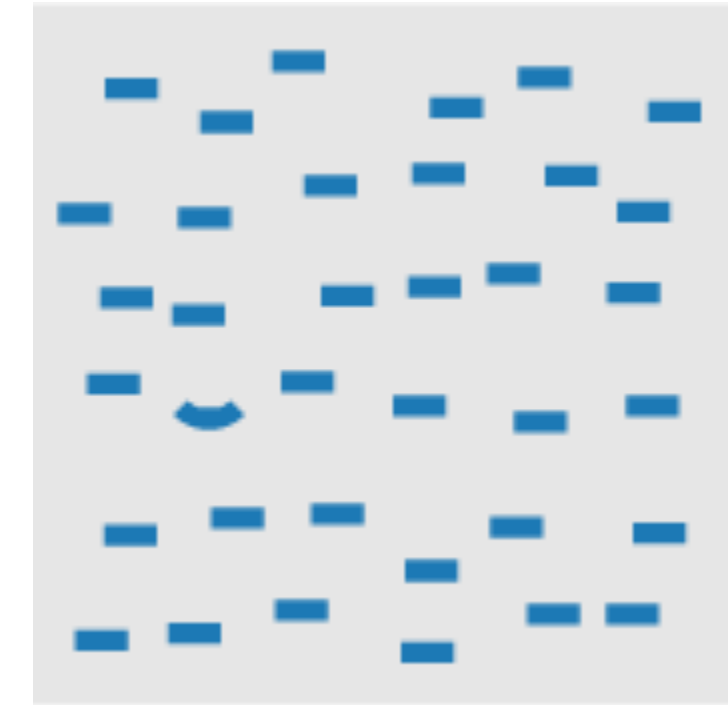
length



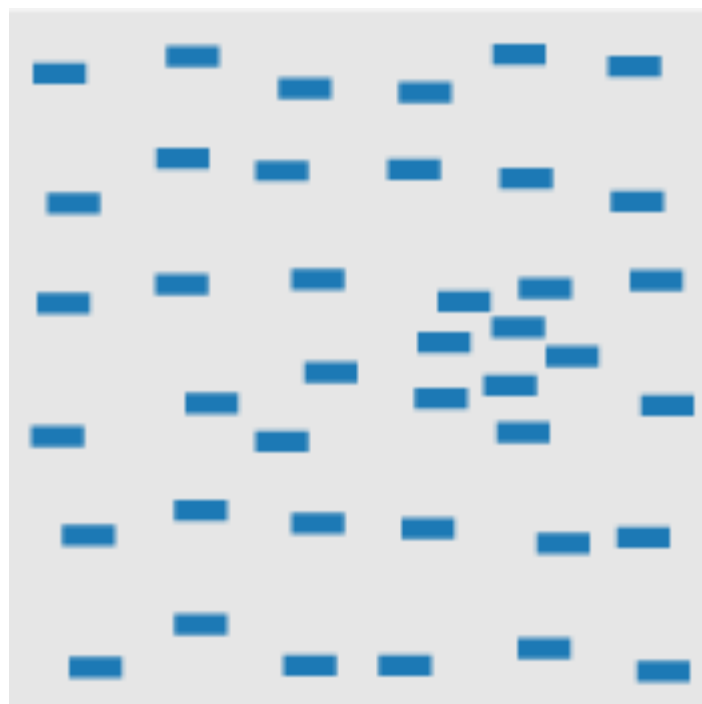
closure



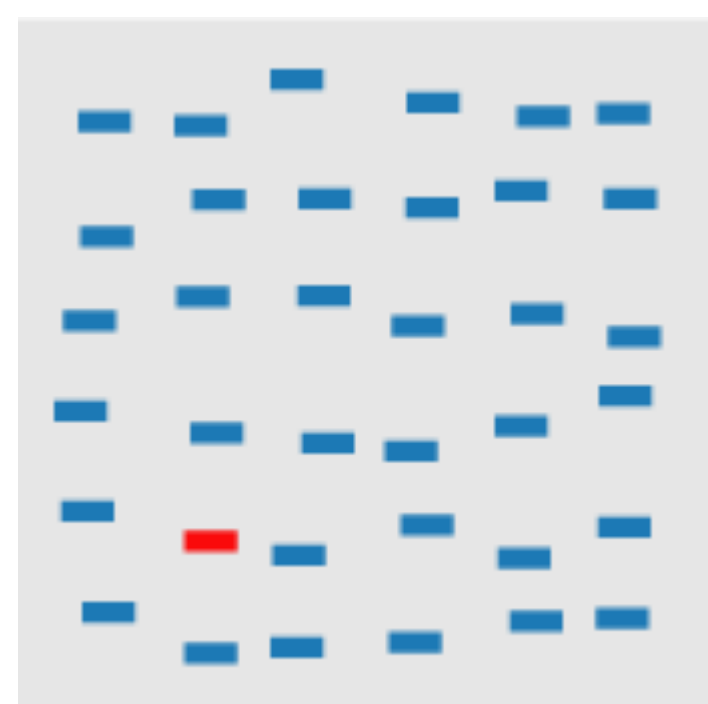
size



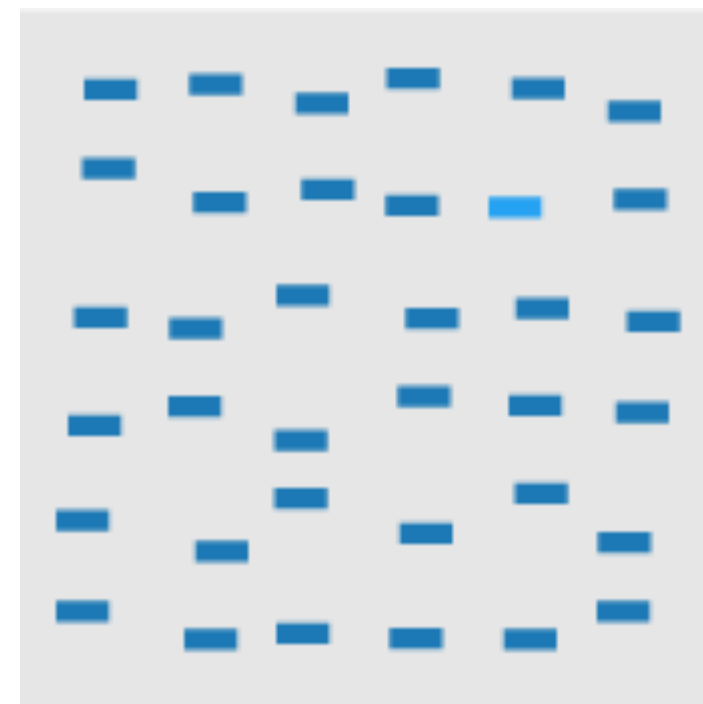
curvature



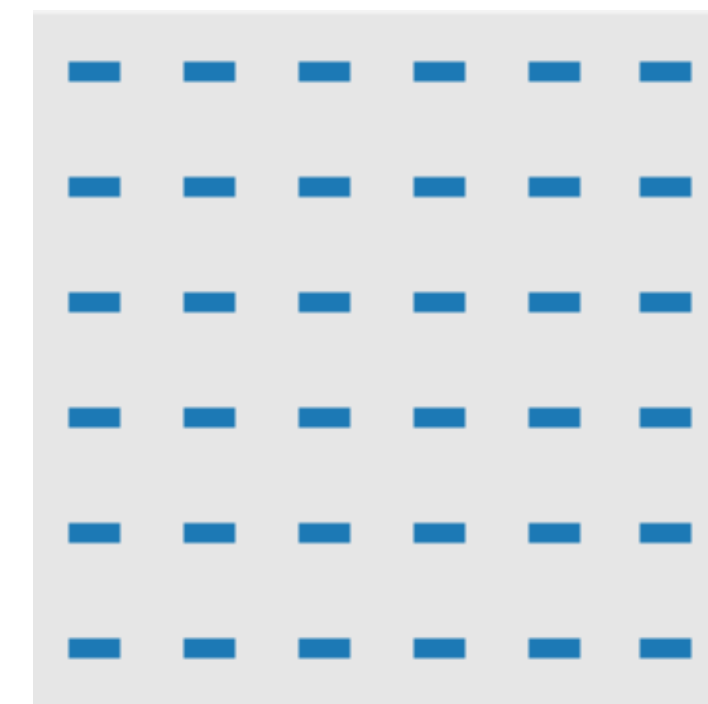
density



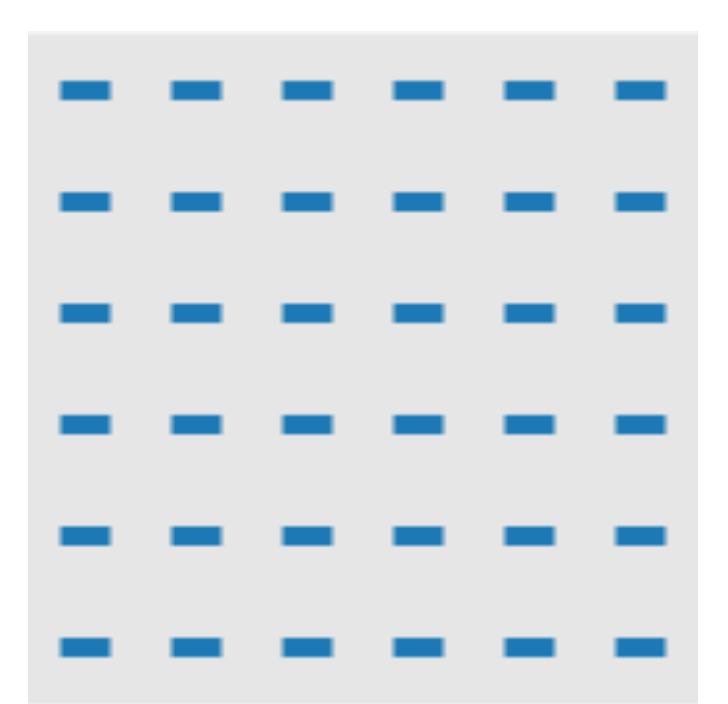
hue



color value / brightness



flicker



direction of motion

Tasks

target detection

detect the presence or absence of a target

boundary detection

detect a texture boundary between two groups of elements, where all of the elements in each group have a common visual property

region tracking

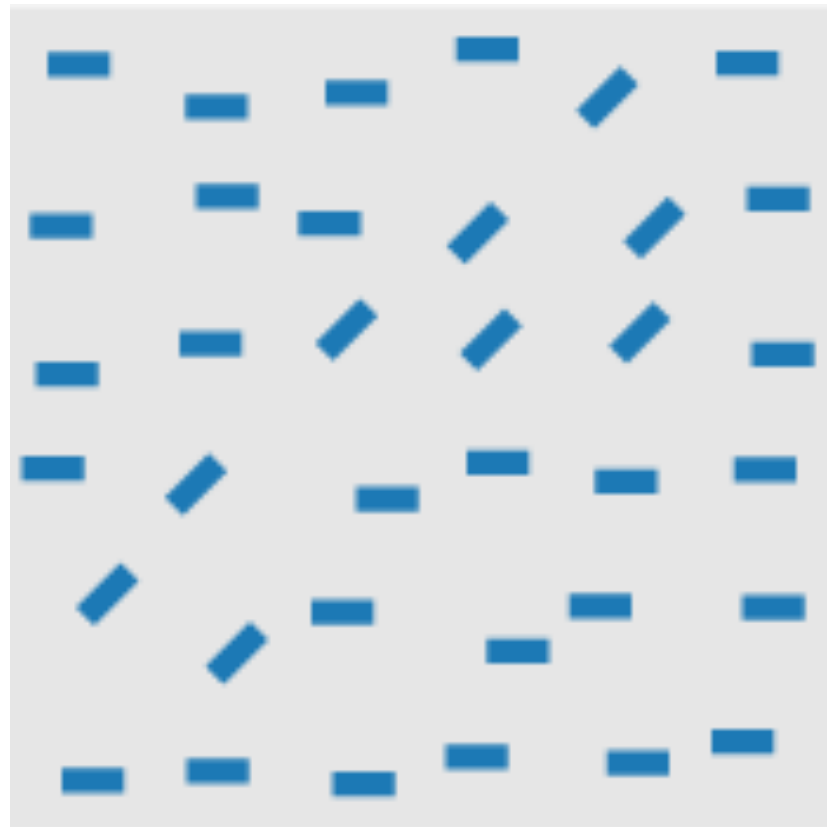
track one or more elements with a unique visual feature as they move in time and space

counting and estimation

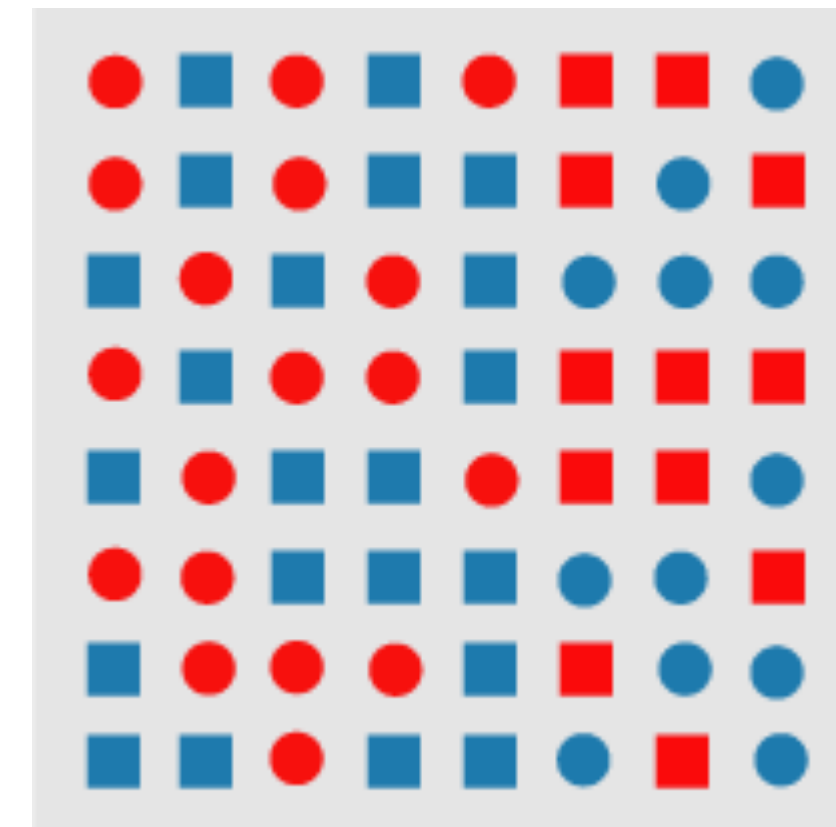
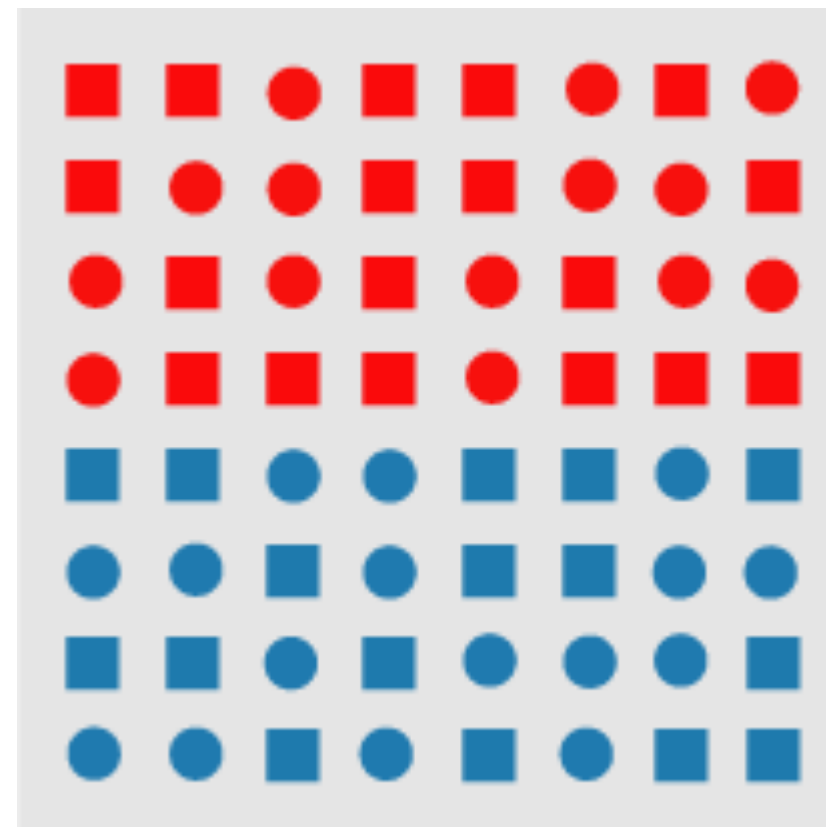
users count or estimate the number of elements with a unique visual feature.

Tasks

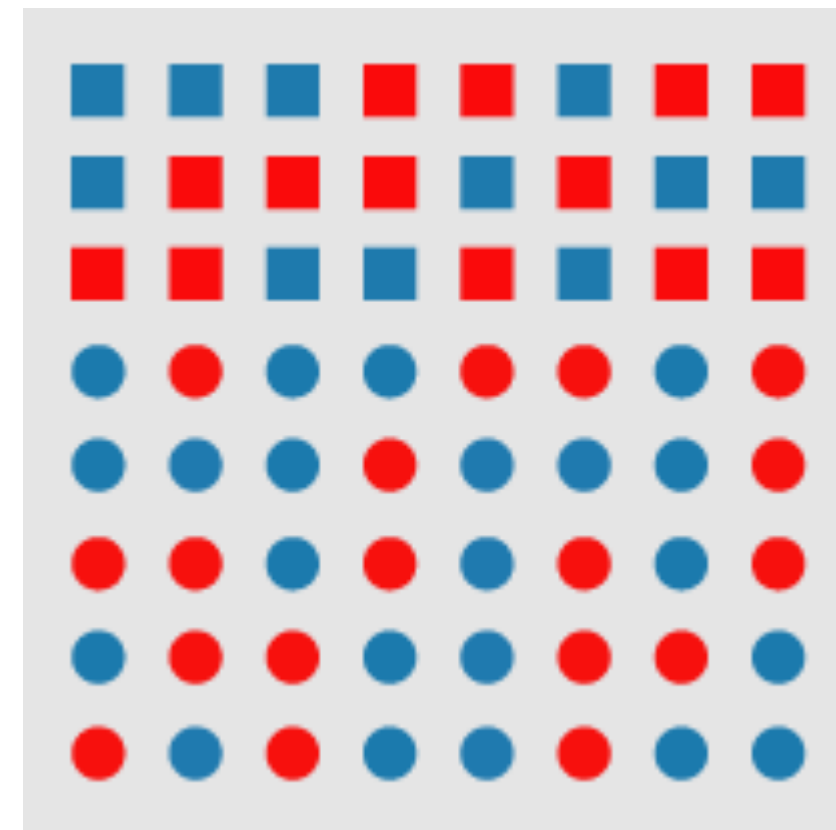
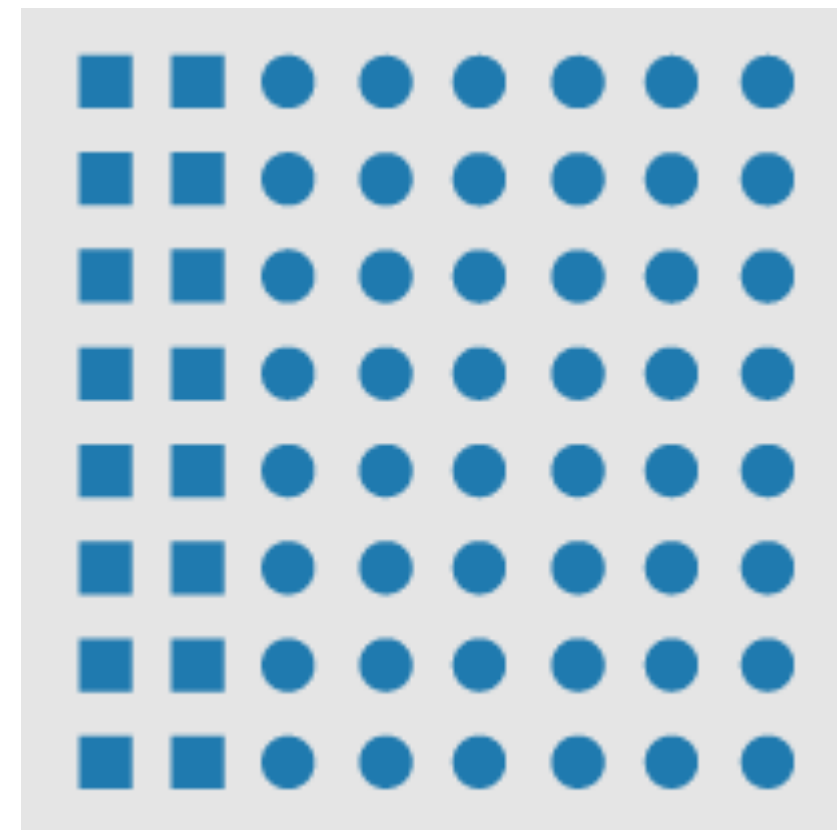
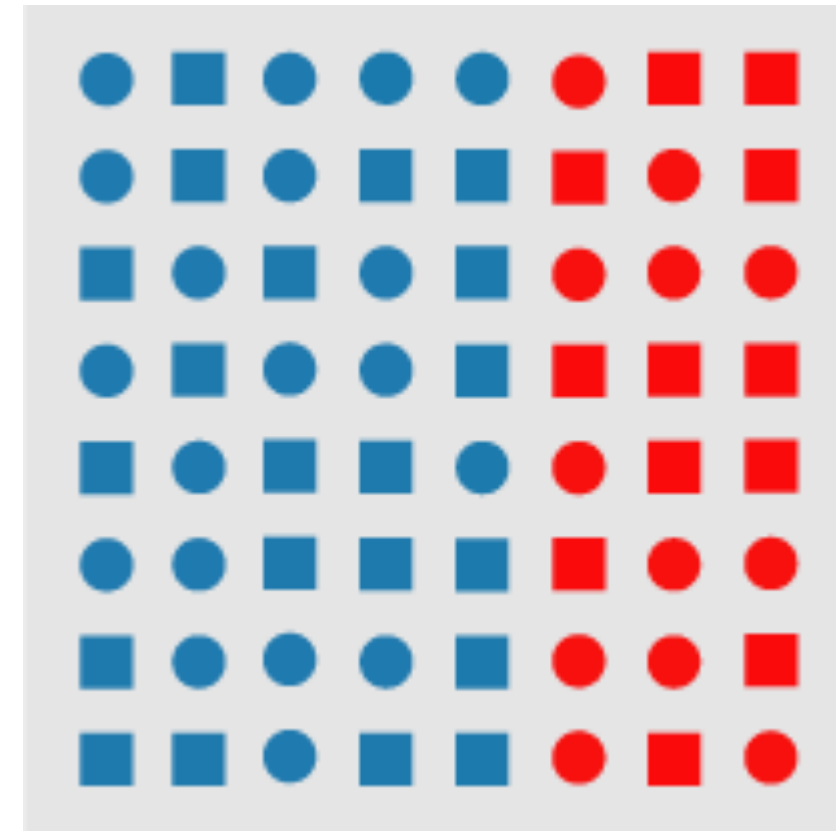
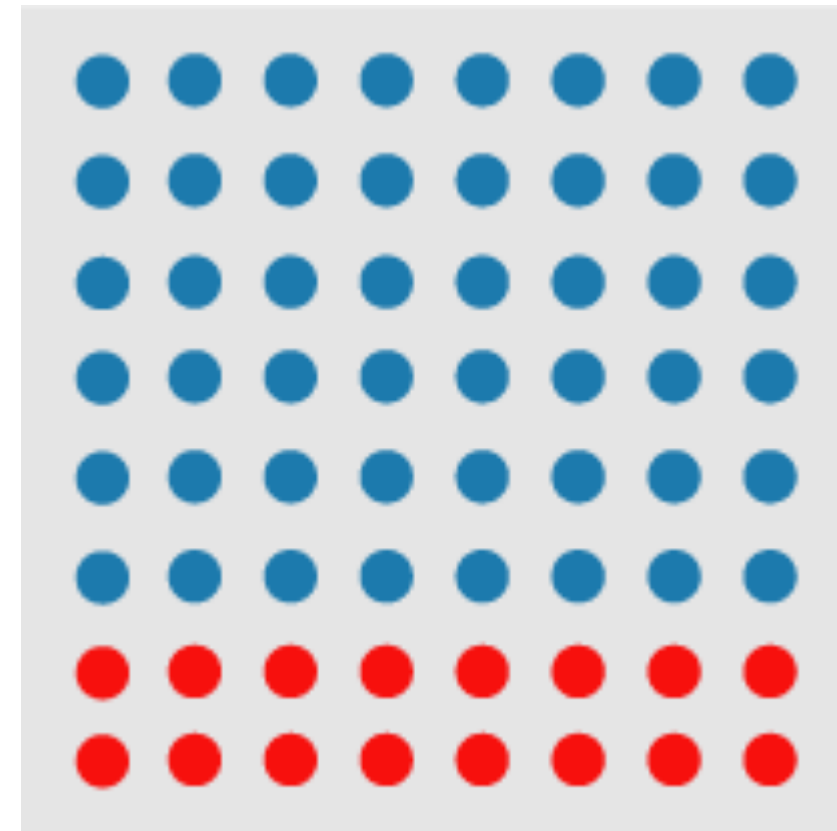
Number Estimation



Boundary Detection



Hierarchy of Preattentive Features



Popout in Vis

Can be used to draw attention to areas of interest

Can be used to express similarity/group memberships

Visual features must be carefully designed

Conjunctions must be avoided

Examples are „Cues“ (Focus and Context technique)

Change Blindness

Change Blindness

Details of an image cannot be remembered across separate scenes

except in areas with focused attention

Interruption (e.g. a blink, eye saccade or blank screen) amplifies this effect

Not failure of vision system

failure due to inappropriate attentional guidance









Change Blindness

Various theories about causes

Overwriting: Information that was not abstracted is lost

First Impression: Only initial view is abstracted

Nothing is Stored: Only abstract concepts are committed to memory

Everything is Stored, Nothing is Compared: We compare only when we are forced to

Feature Combination: scenes are combined as long as they make sense

Influencing factors

attention

expectation (knowing something will change)

semantic importance of changed object

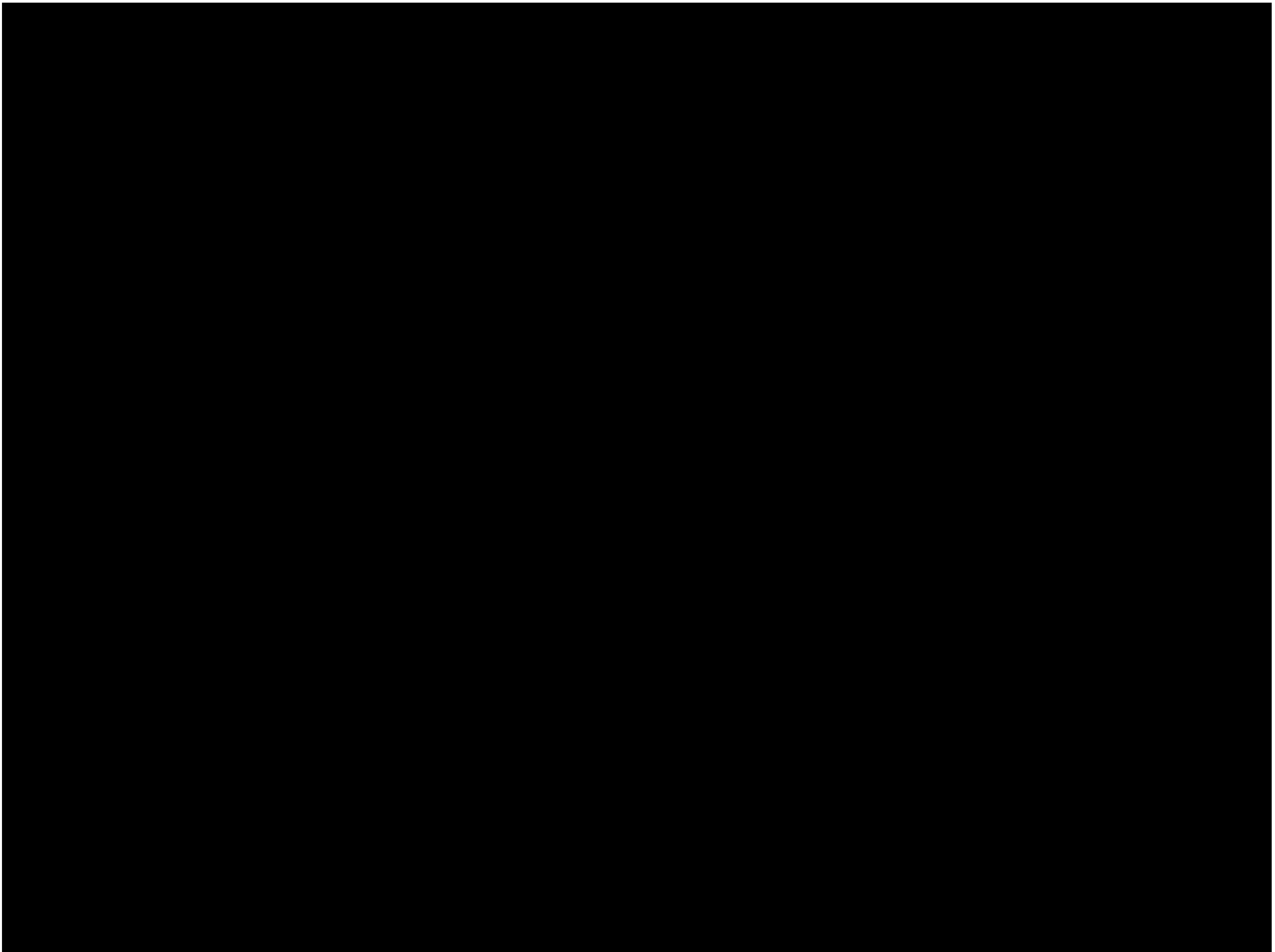
low level object properties overlooked more easily

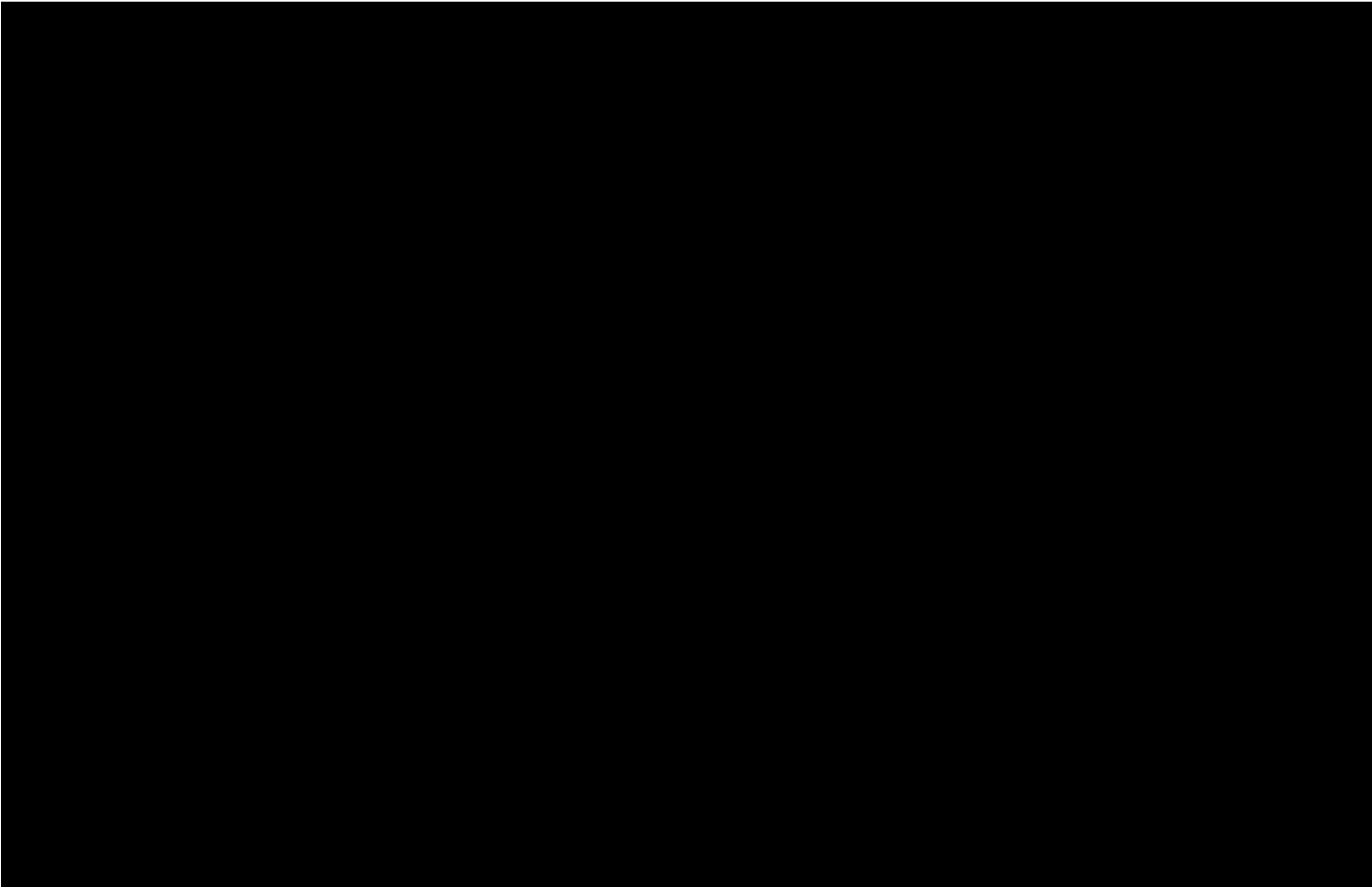






Attention Blindness







Take Home Points

To find meaning in what we see **we must selectively pay attention** to what is important

Low-level vision is driven by object features rather than a conscious effort where to look (e.g., pre-attentive processing)

Attention is driven by preexisting knowledge, expectations, and goals stored in long-term memory

Gestalt Principles

Wertheimer, 1923, and recent extensions

Gestalt Principles

Patterns that transcend the visual stimuli that produced them

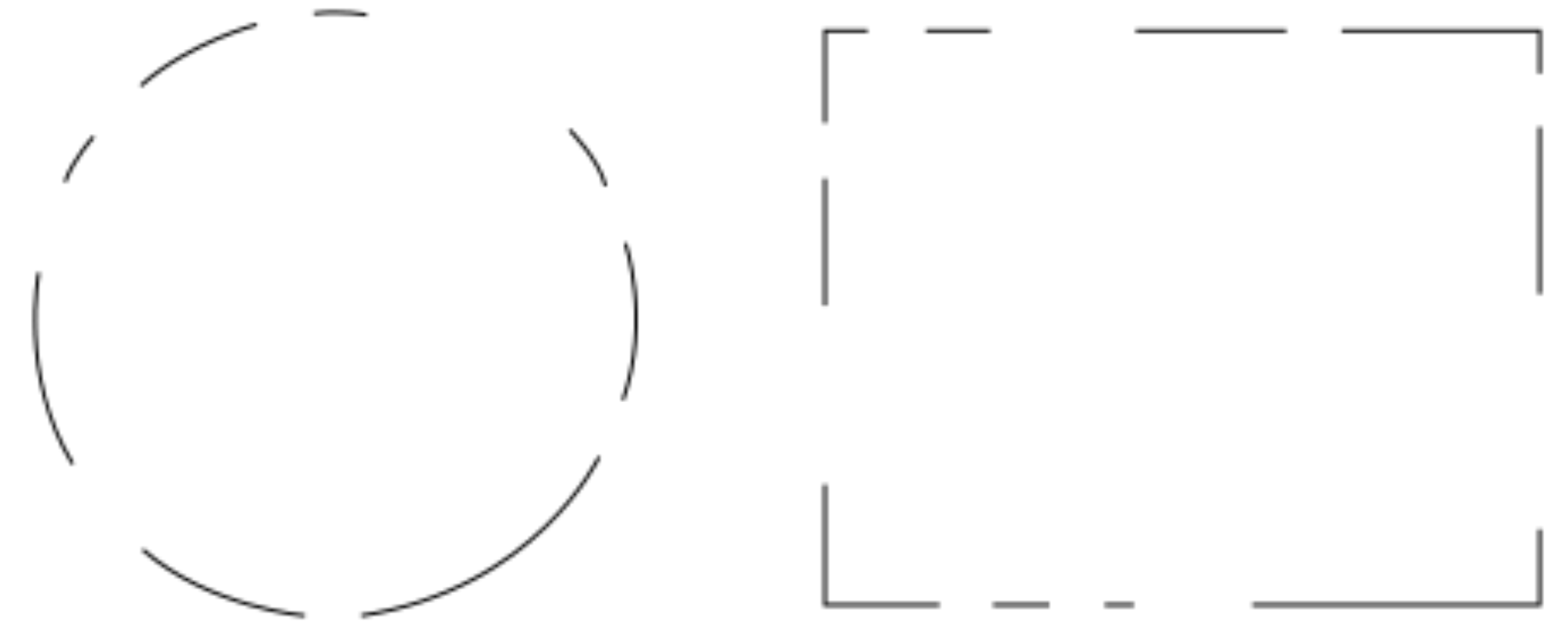
- *Das Ganze ist etwas anderes als die Summe seiner Teile.*
- *The whole is something else than the sum of its parts.*

Kurt Koffka

Koffka disagreed with the

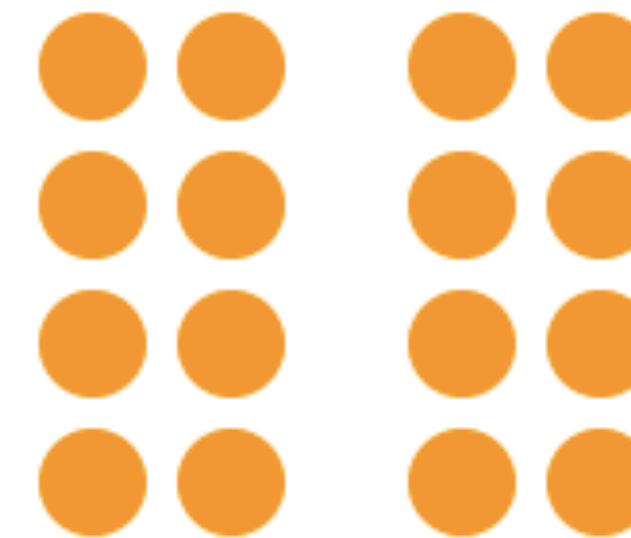
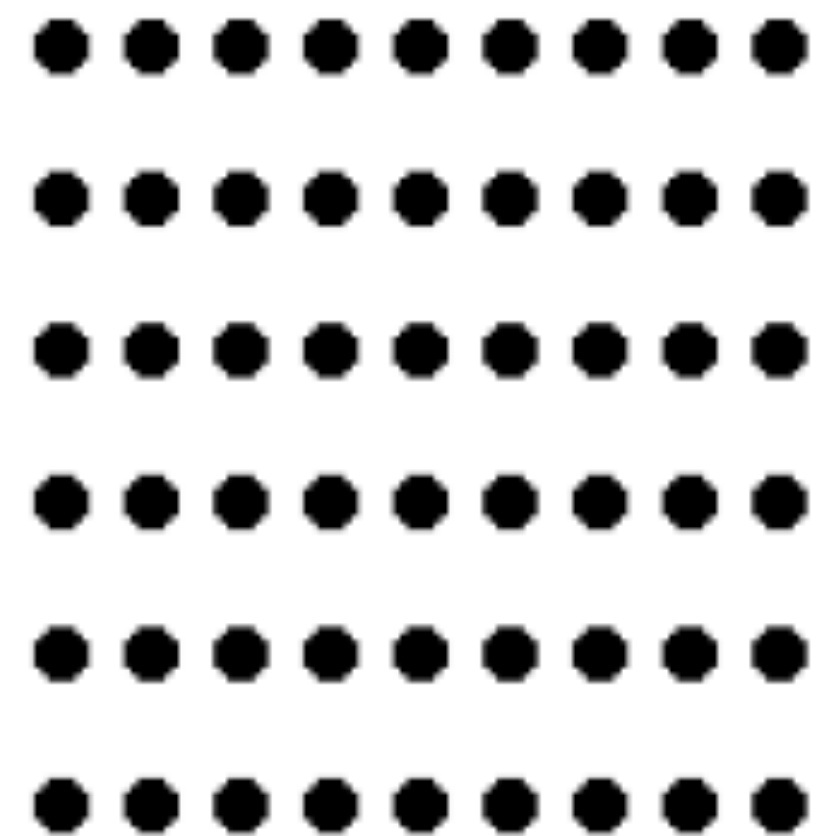
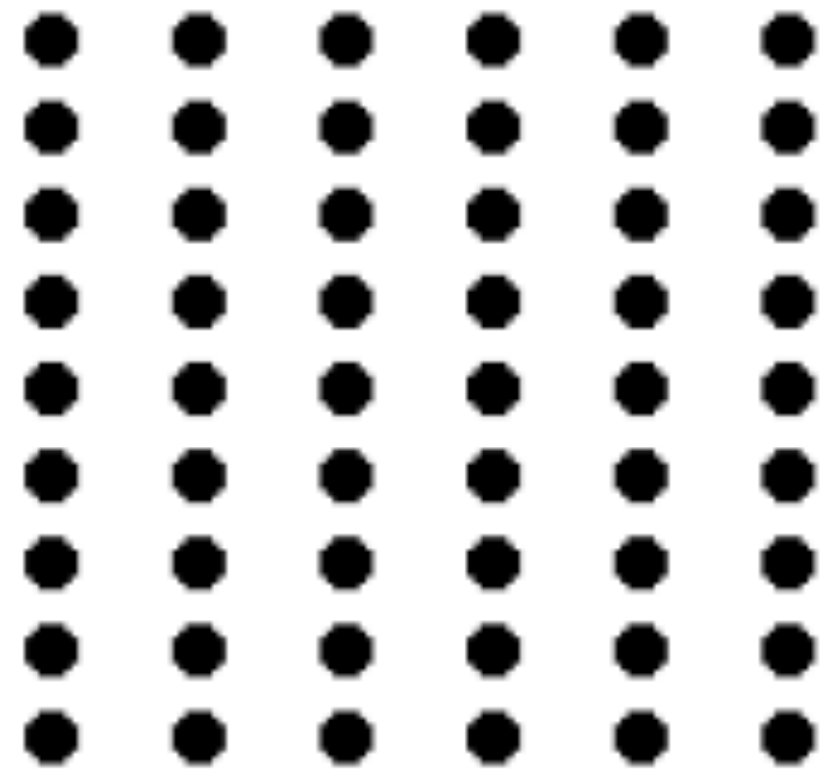
- *The whole is greater than the sum of the parts.*

quote which is attributed to Aristoteles

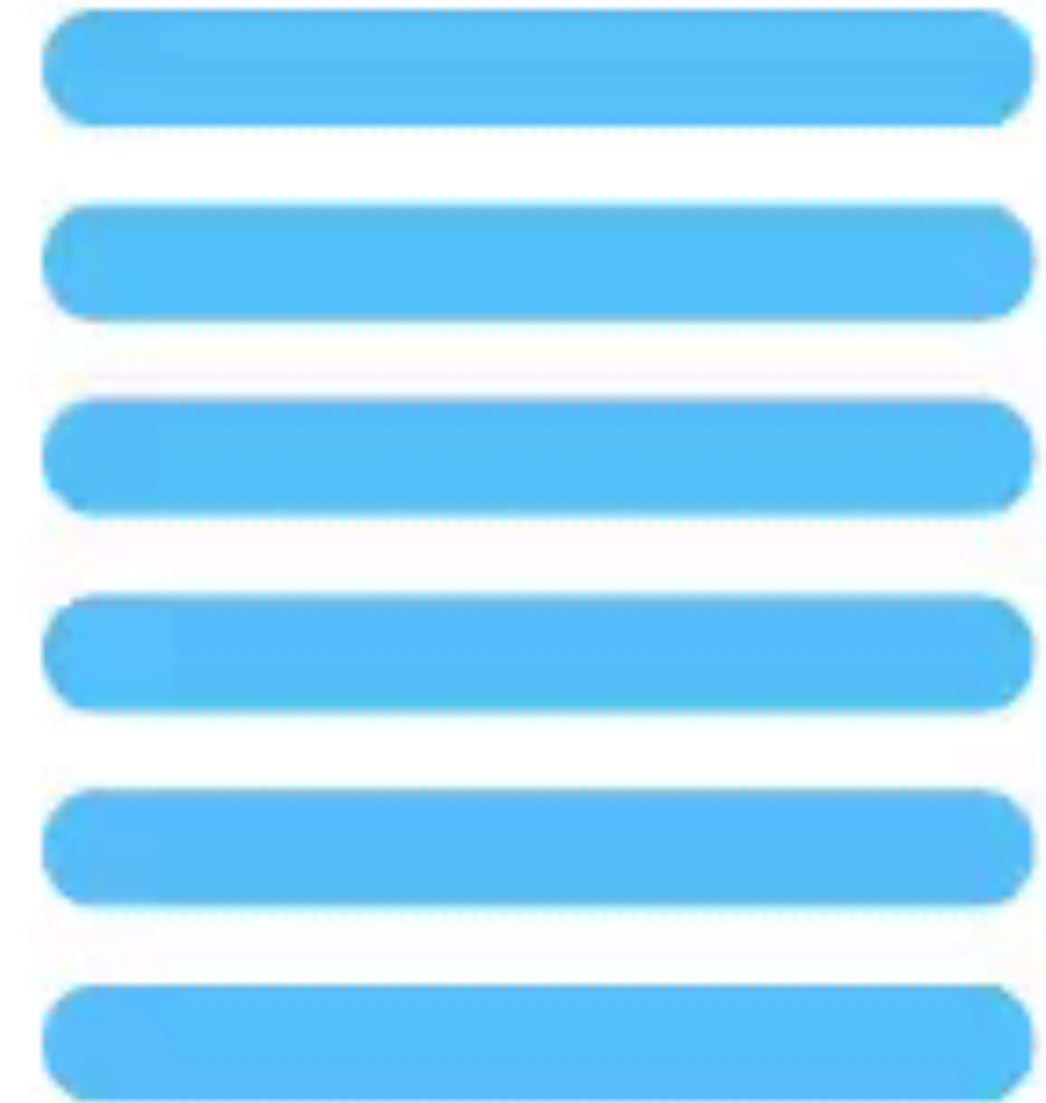
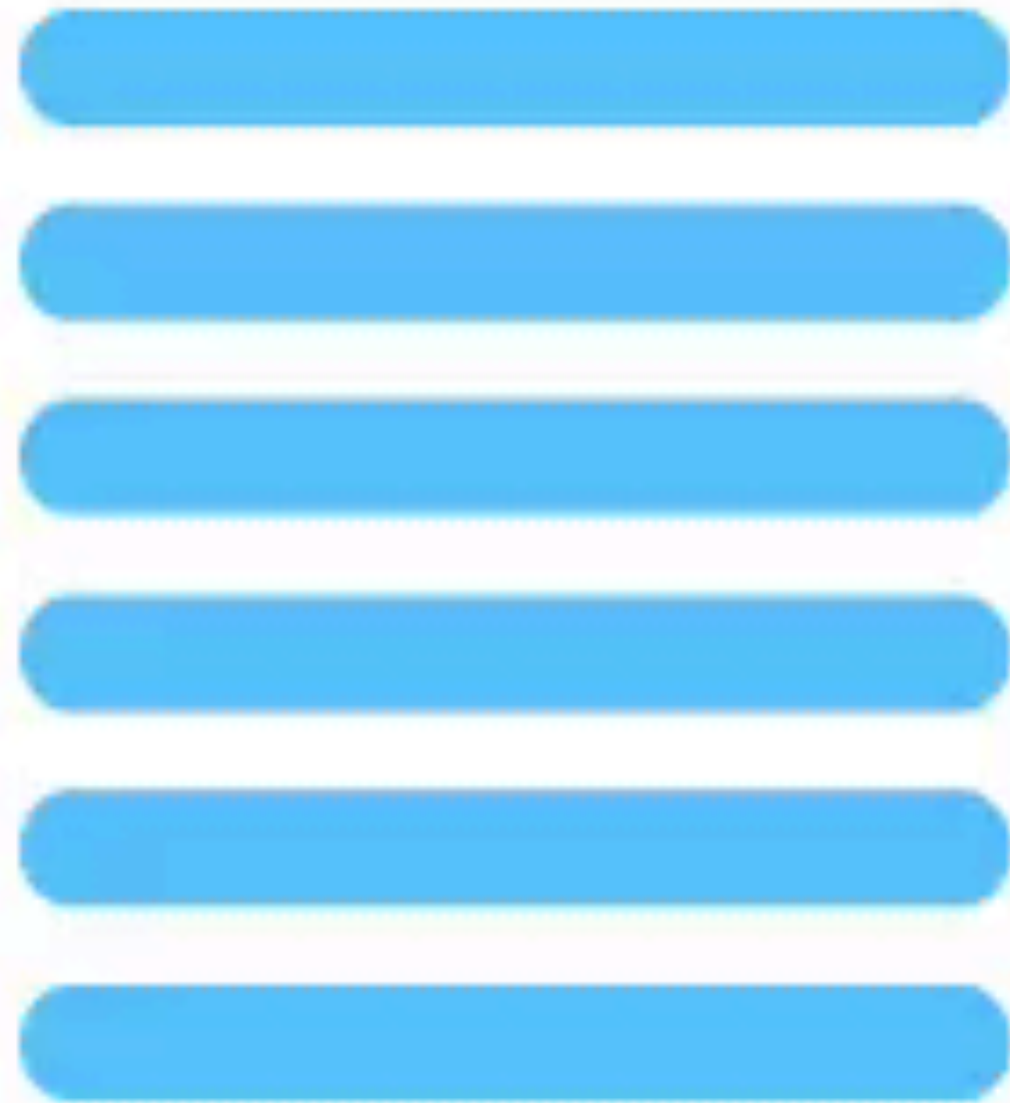


Gestalt Effects for Grouping

Proximity



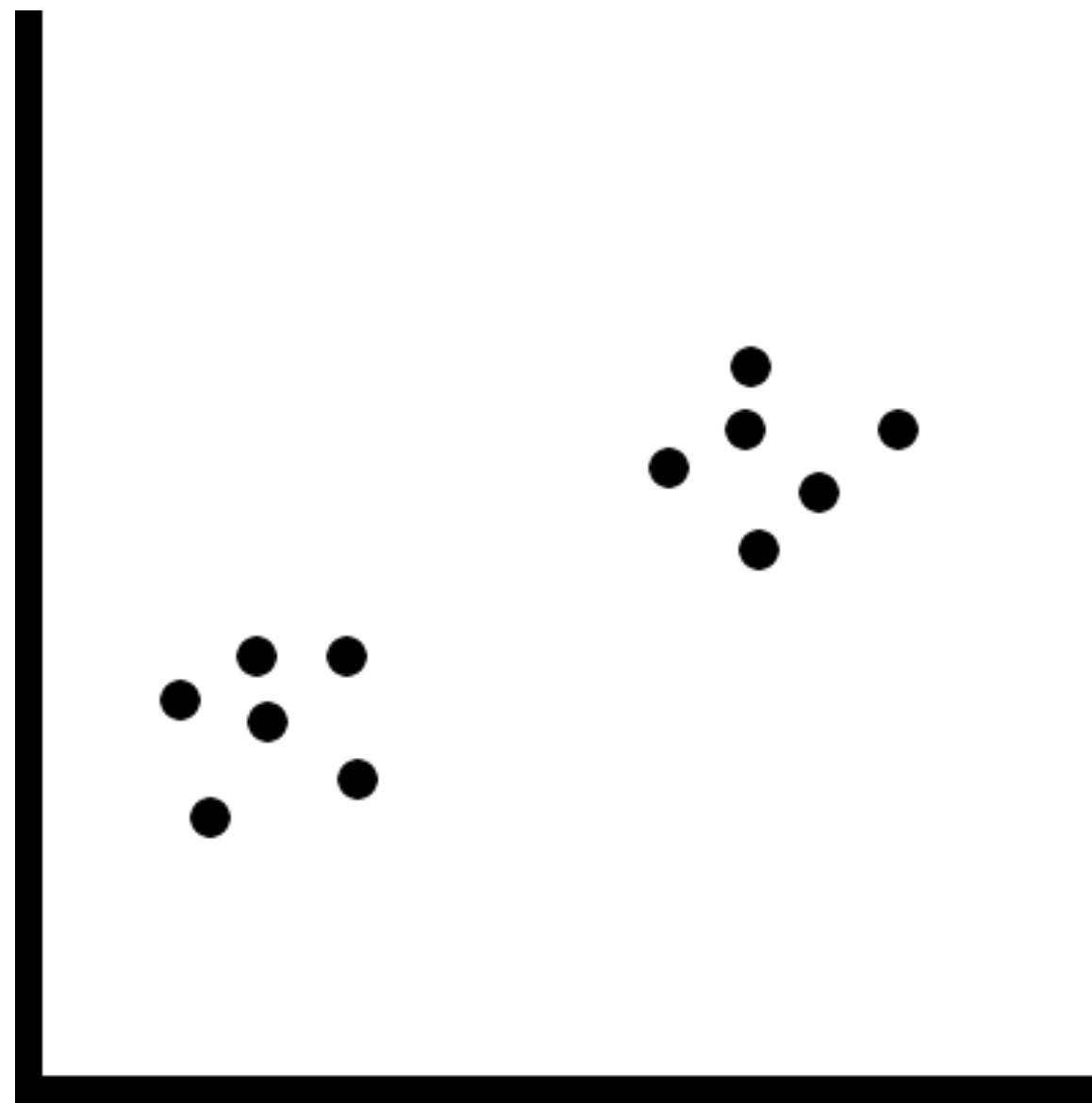
Law of proximity



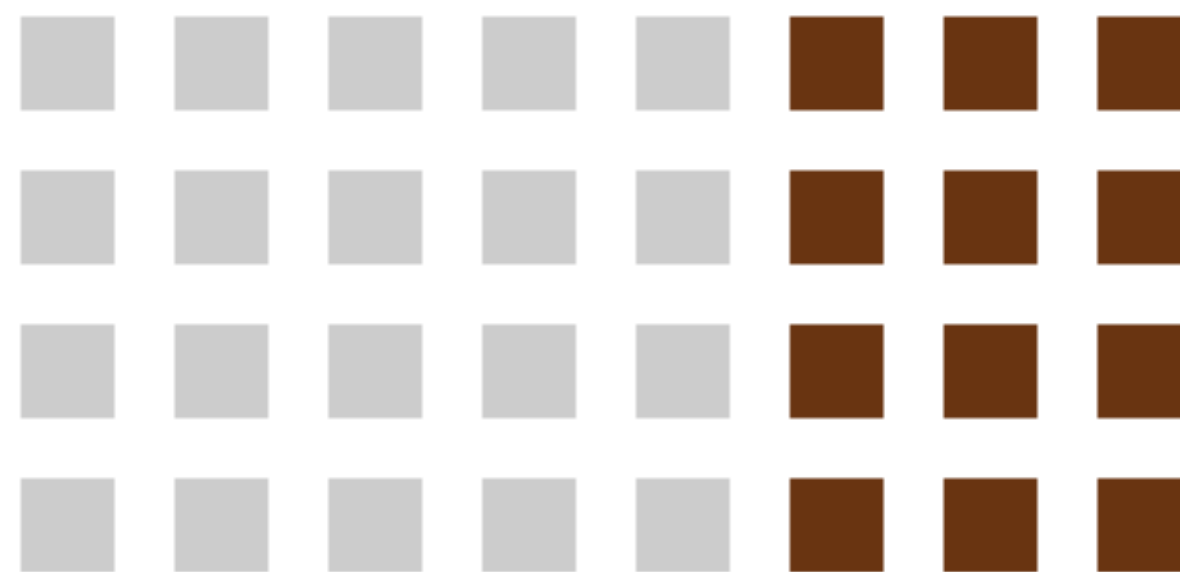
4 columns

Proximity

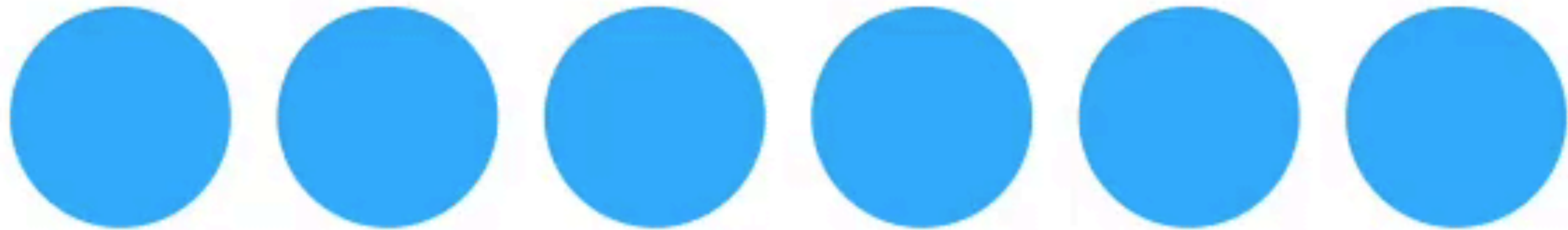
Grouping/linking by placing entities in close proximity



Similarity



Similarity Principle



1 group

Focal Point



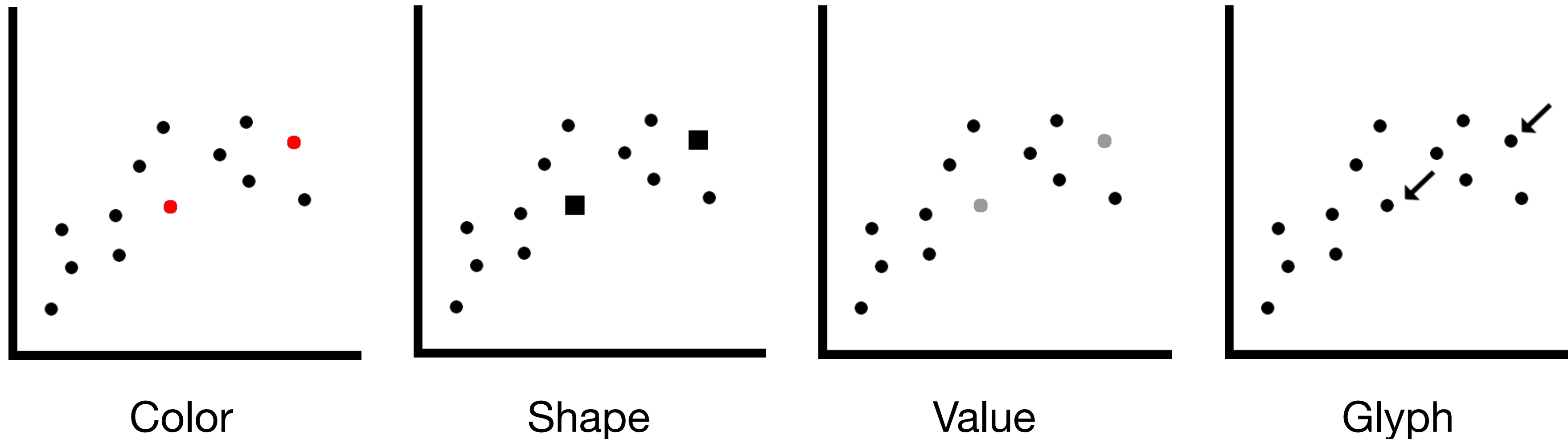
No focus

Similarity

Co-modulation of a **channel**

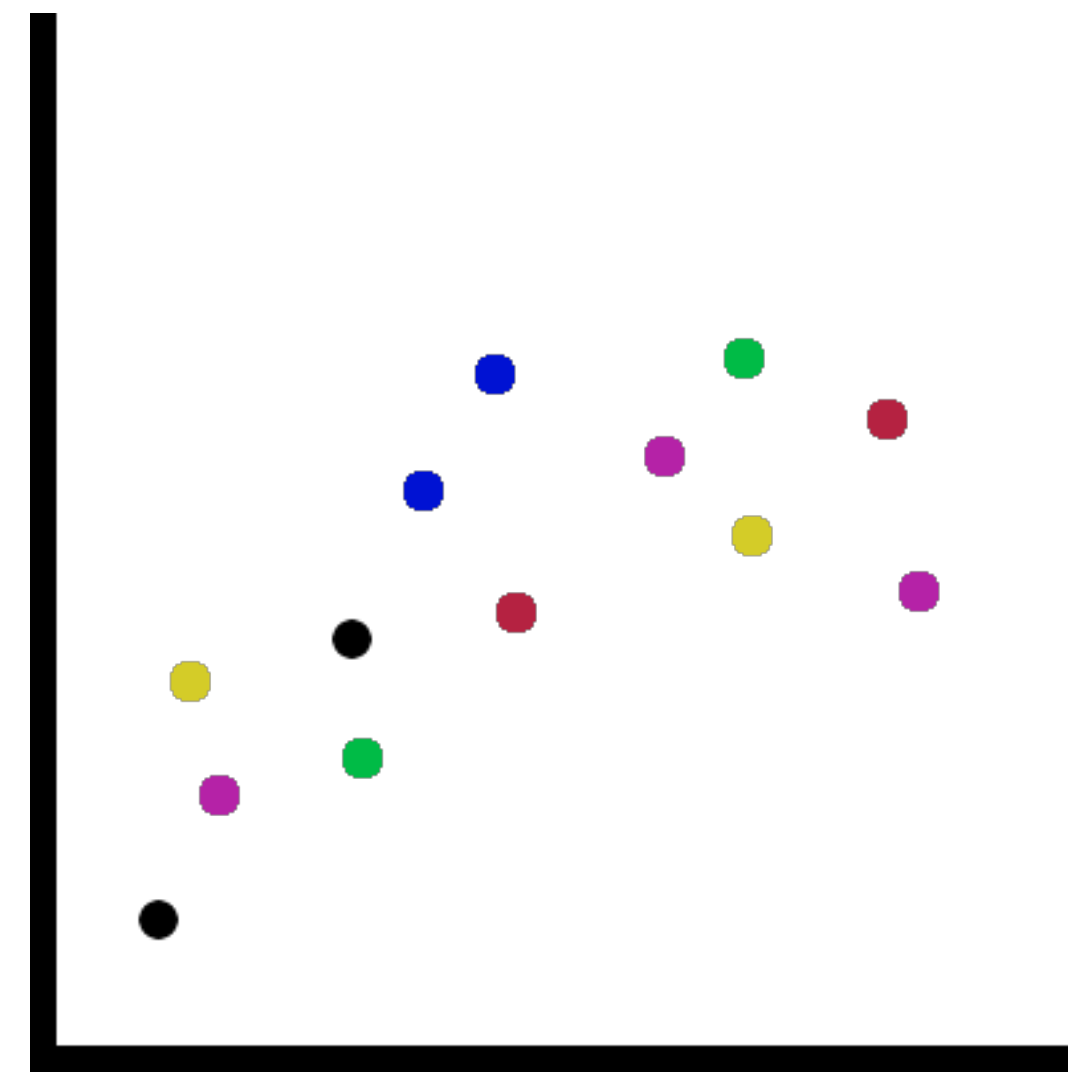
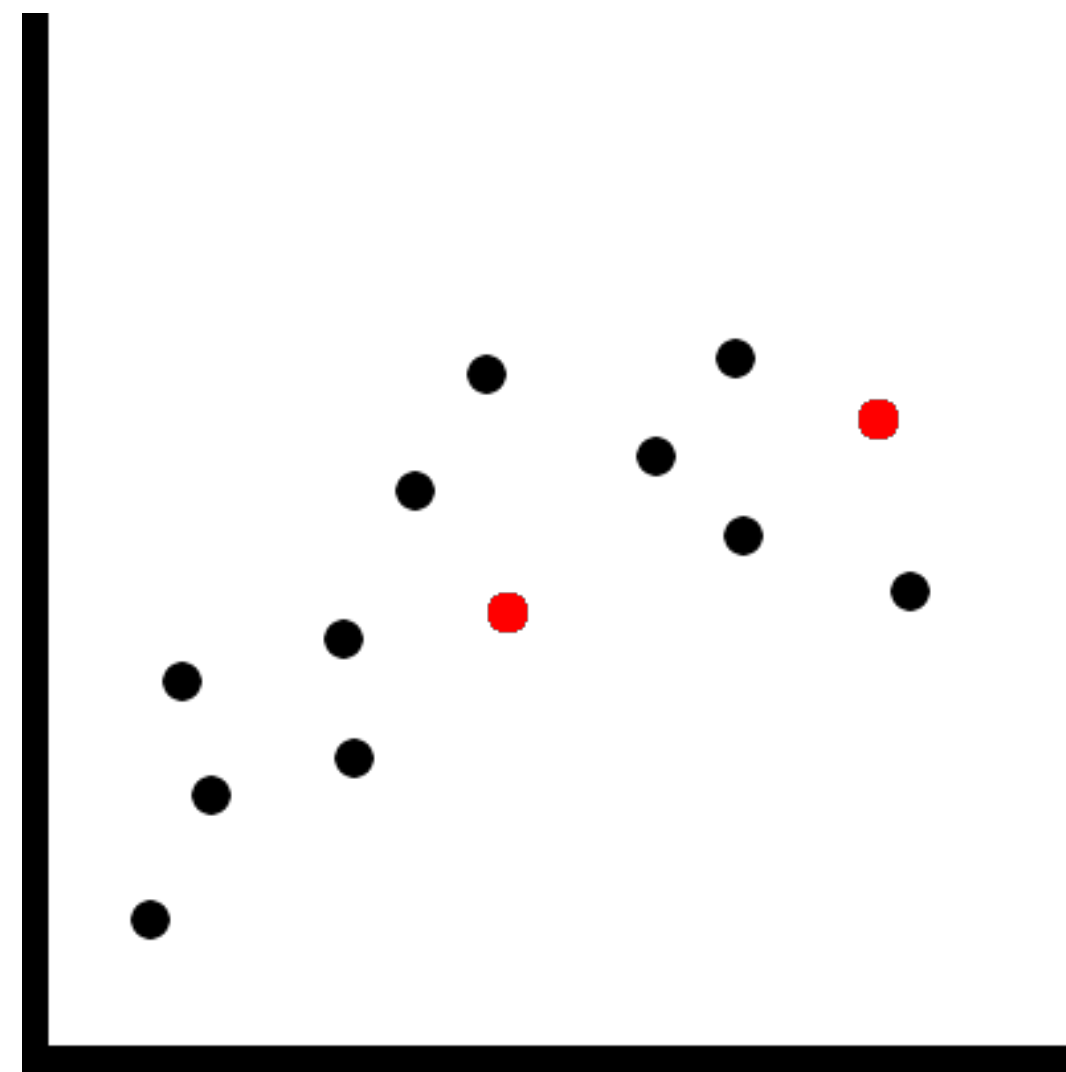
color, shape, size, value, orientation, texture, ...

Adding a glyph, label, frame, background



Color – Perception Issues (1/2)

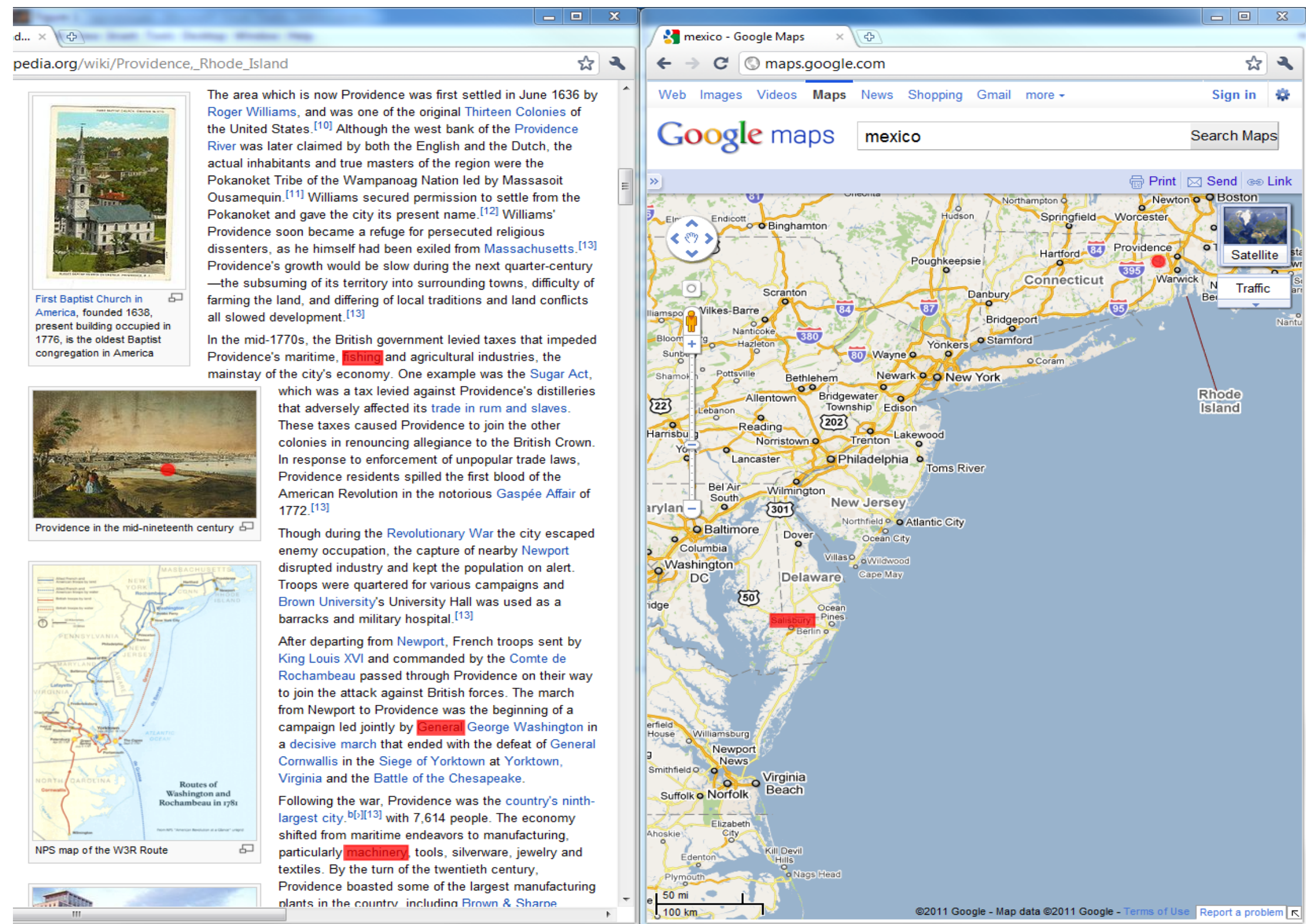
Popout properties: Very good for 1-2 simultaneous, **serial search for more**



Color – Perception Issues (2/2)

Slower in a cluttered environment

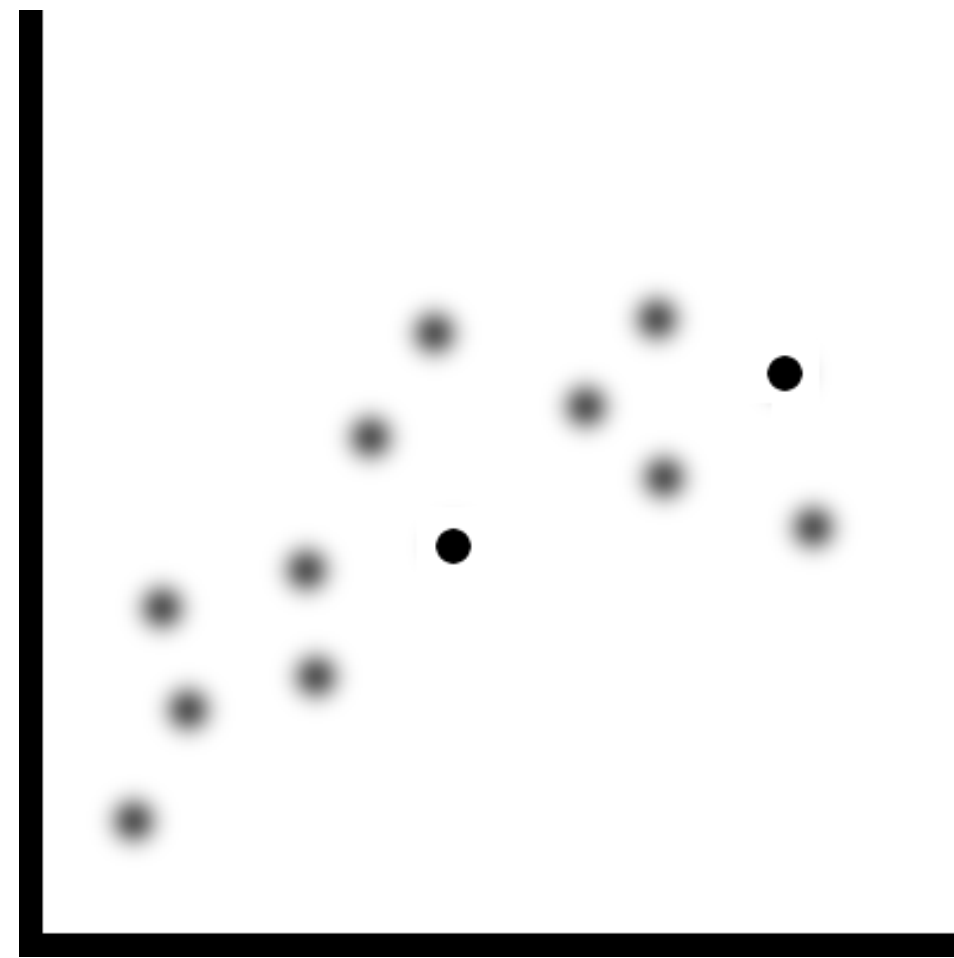
Size of colored object relevant.



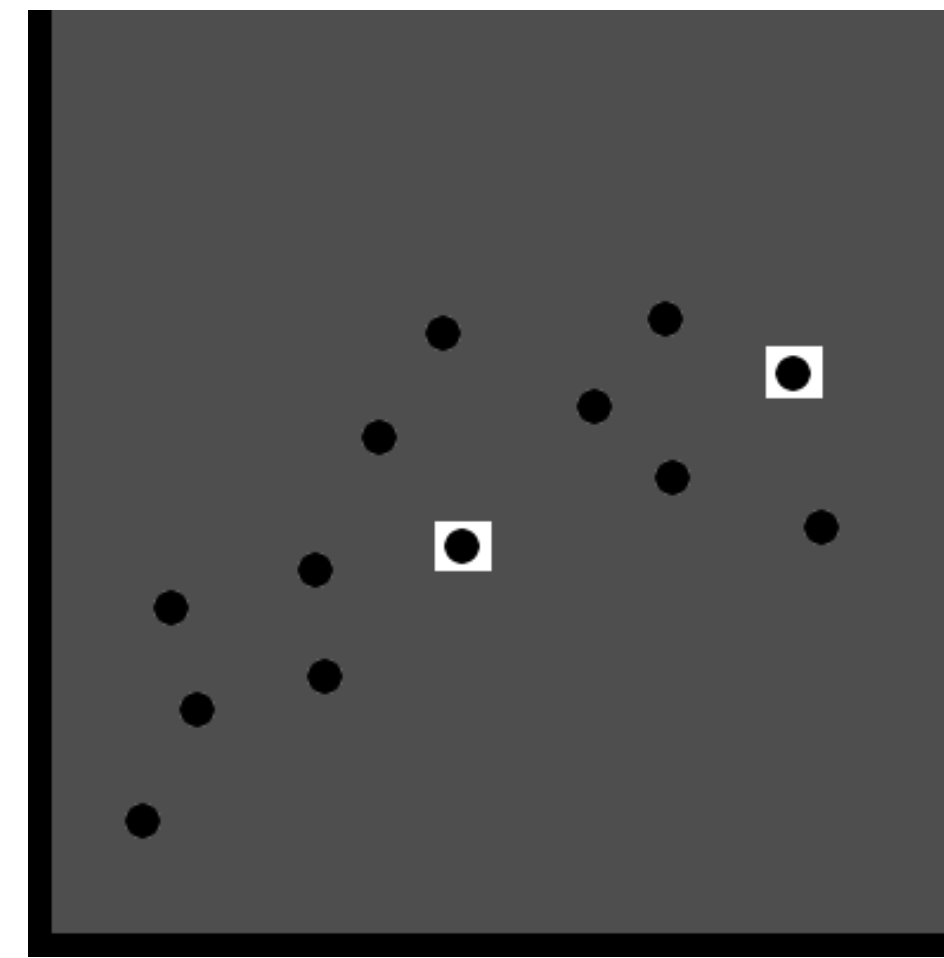
Similarity

Modulate everything else

Blurring, darkening, desaturating, etc.



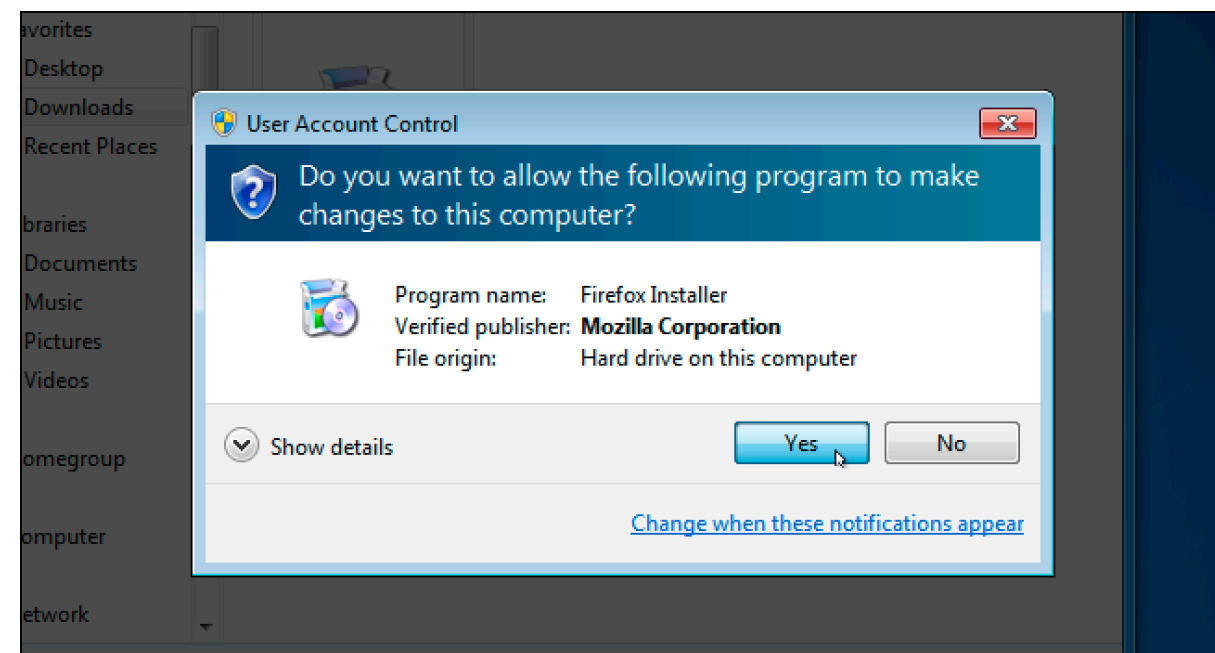
Blur



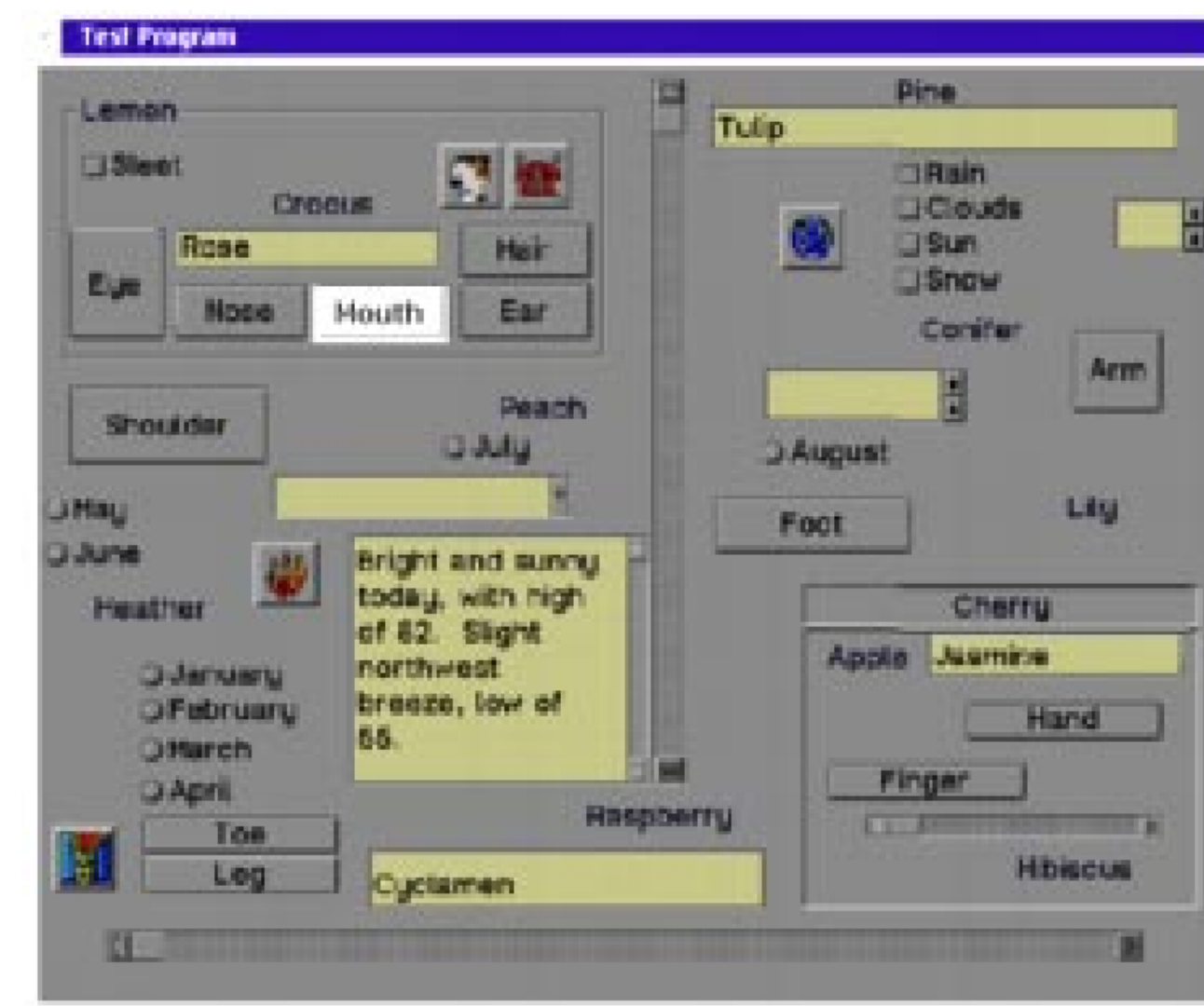
Darkening

Modulating Everything Else: Recommendation, Example

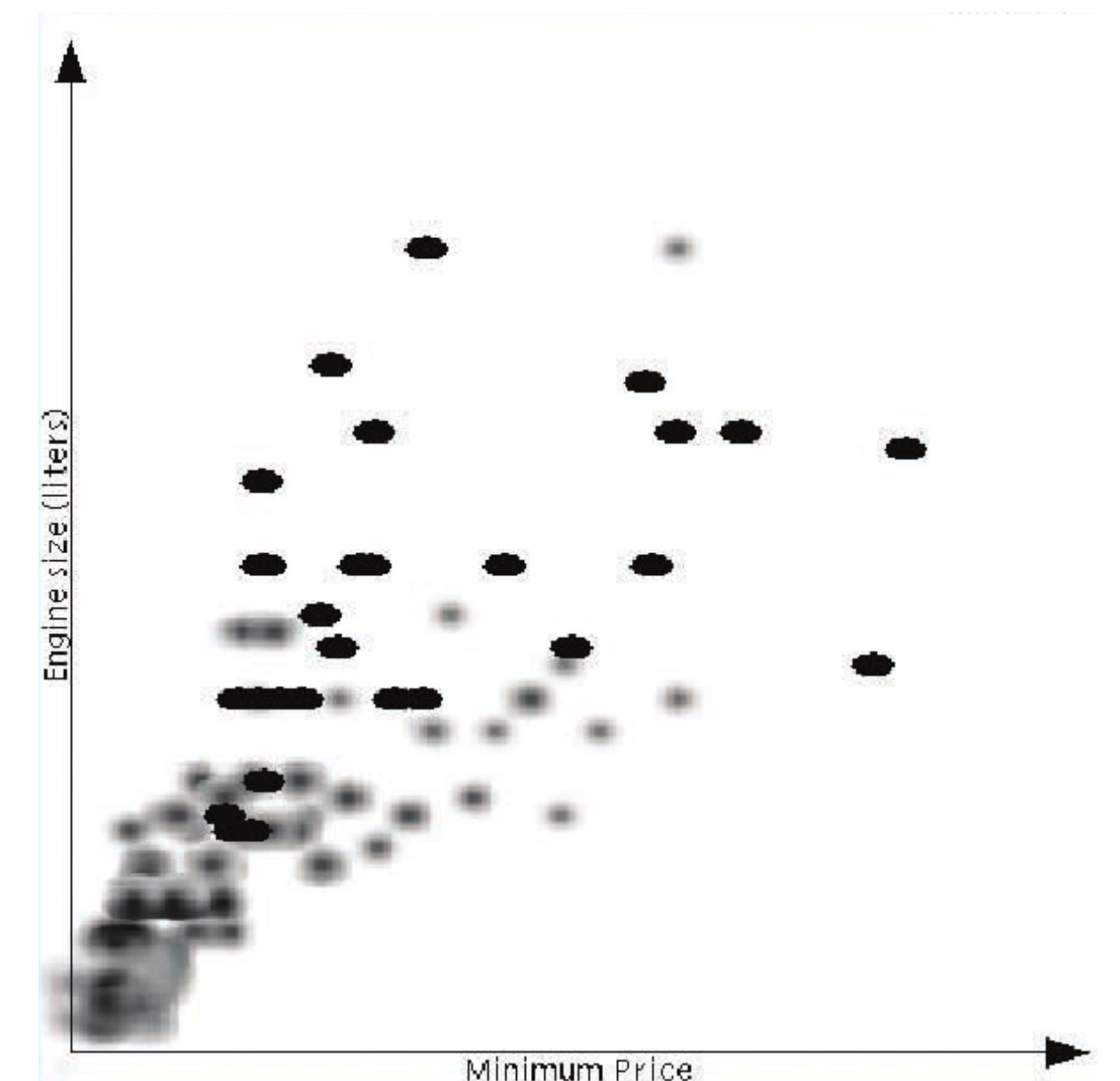
Don't use unless the sole objective is to guide attention toward one (set of) items



[MS Windows
User Account Control]

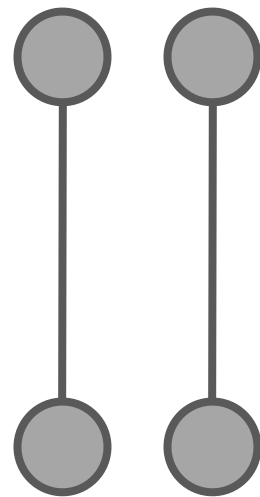


[Zhai et al., 1997]

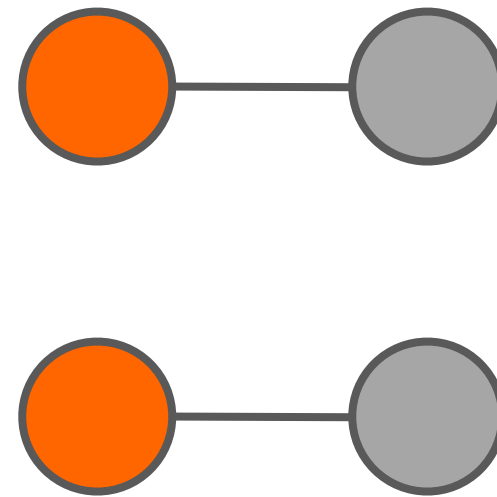


[Kosara et al., 2002]

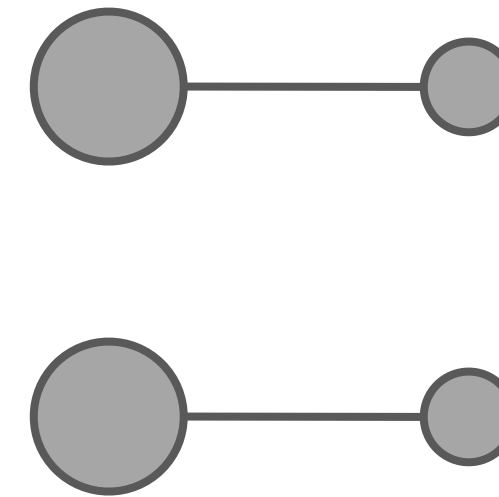
A Little Experiment...



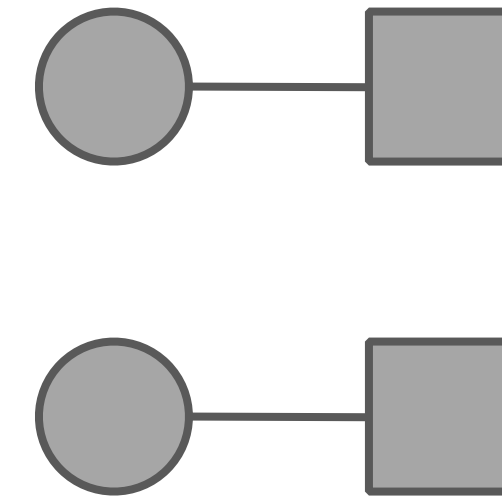
Proximity



Color



Size

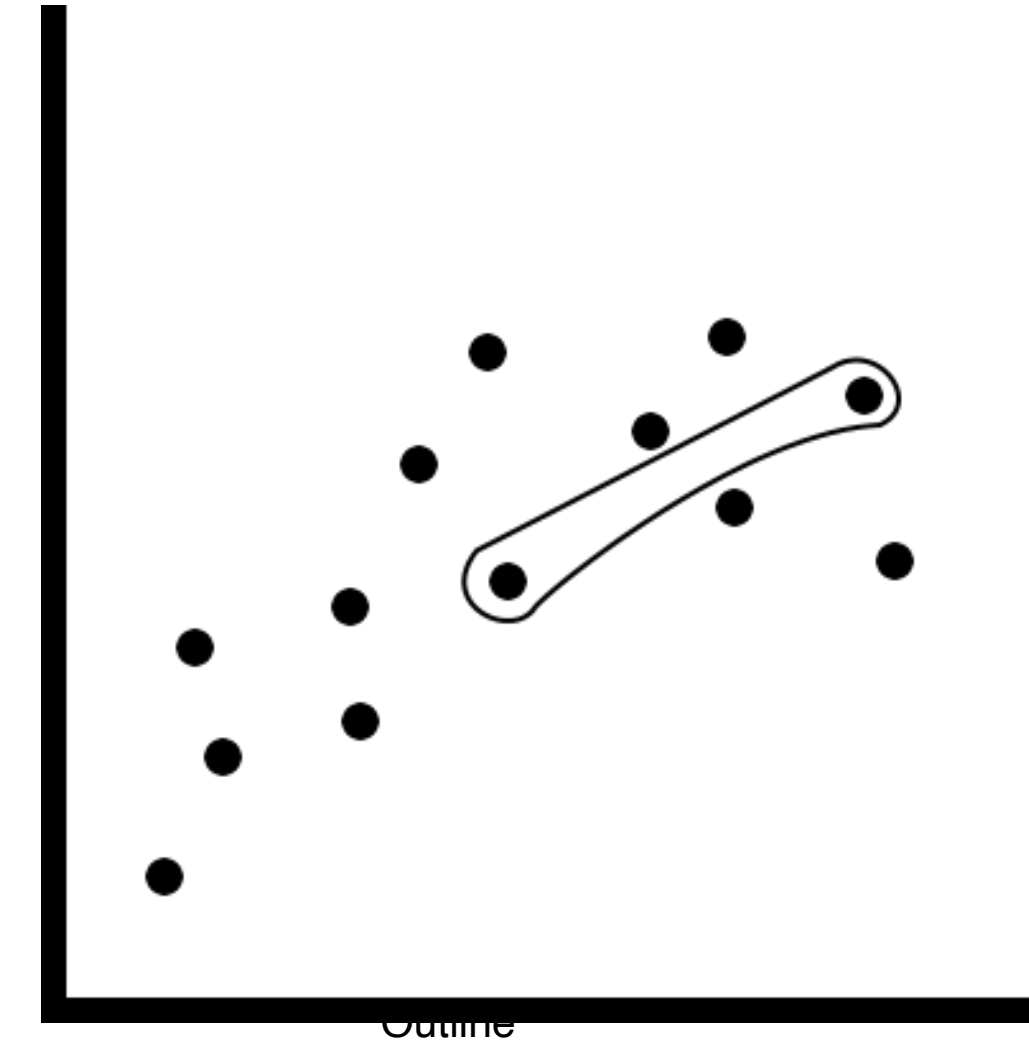
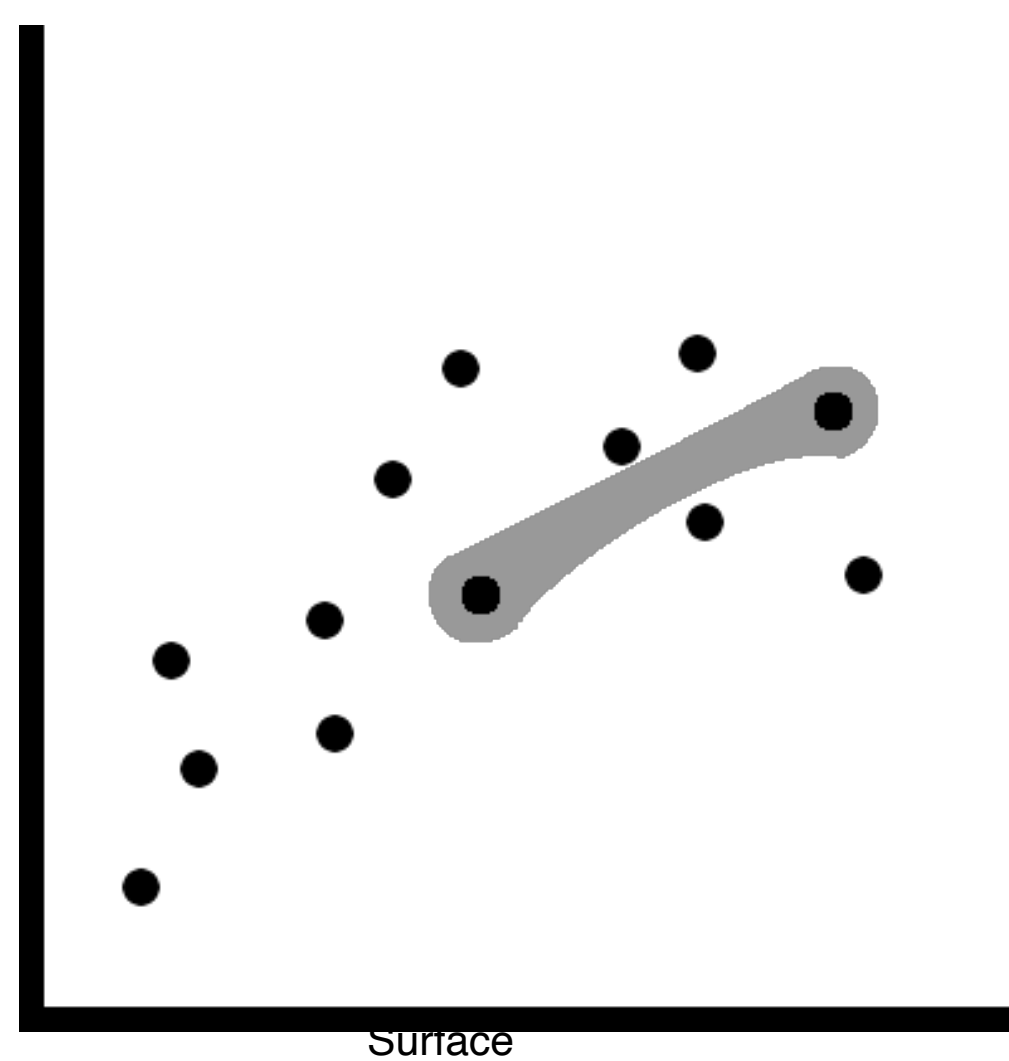


Shape

Connectedness and Common Region

Connected items with a line or curve

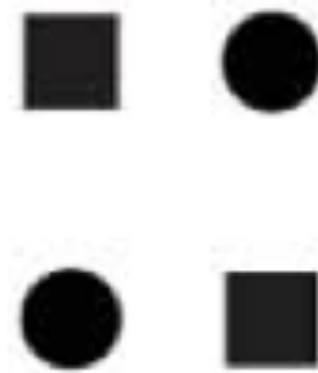
Surround items with a outline, surface, volume



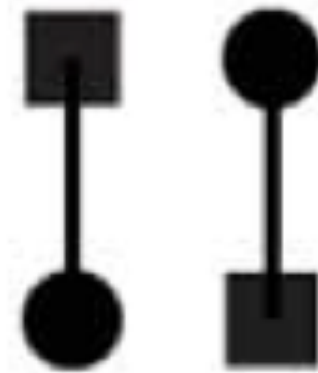
Common Region

Enclosure / Common Region

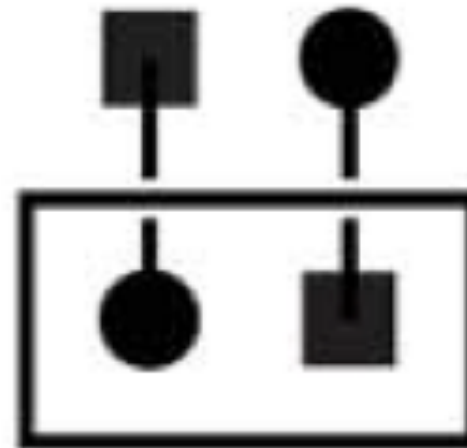
Similarity



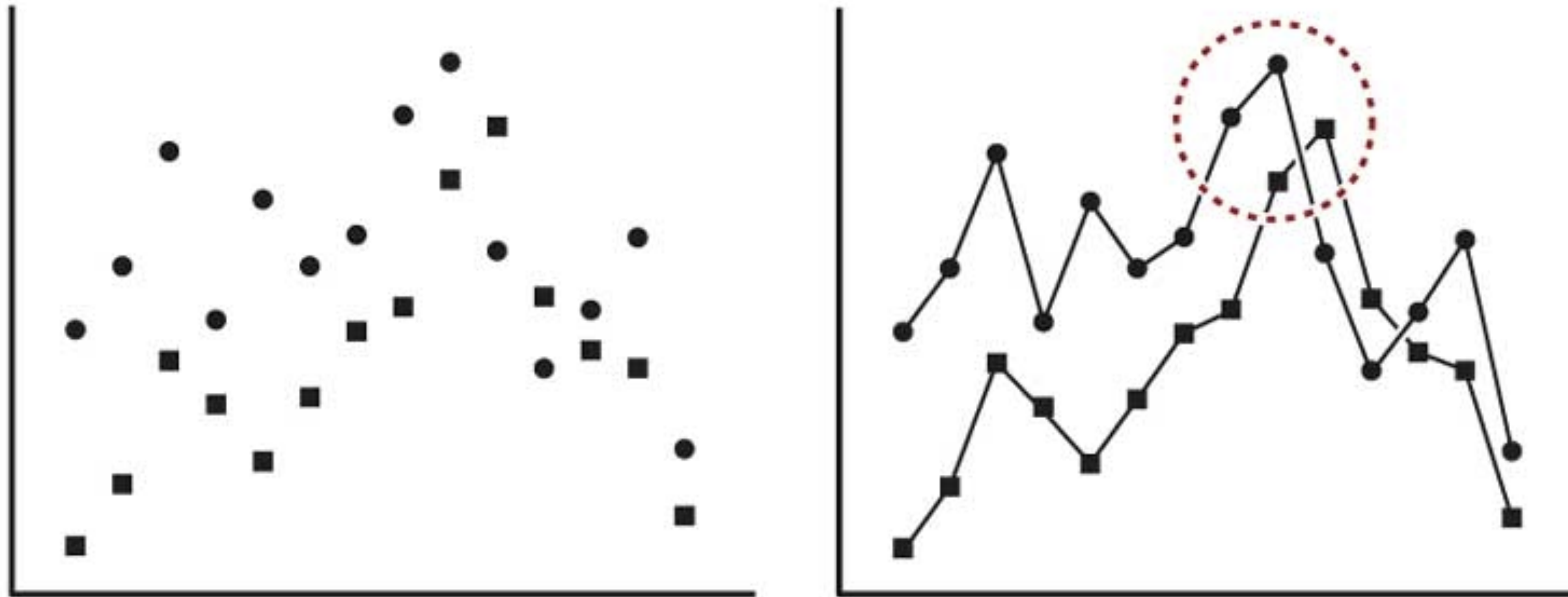
Connection



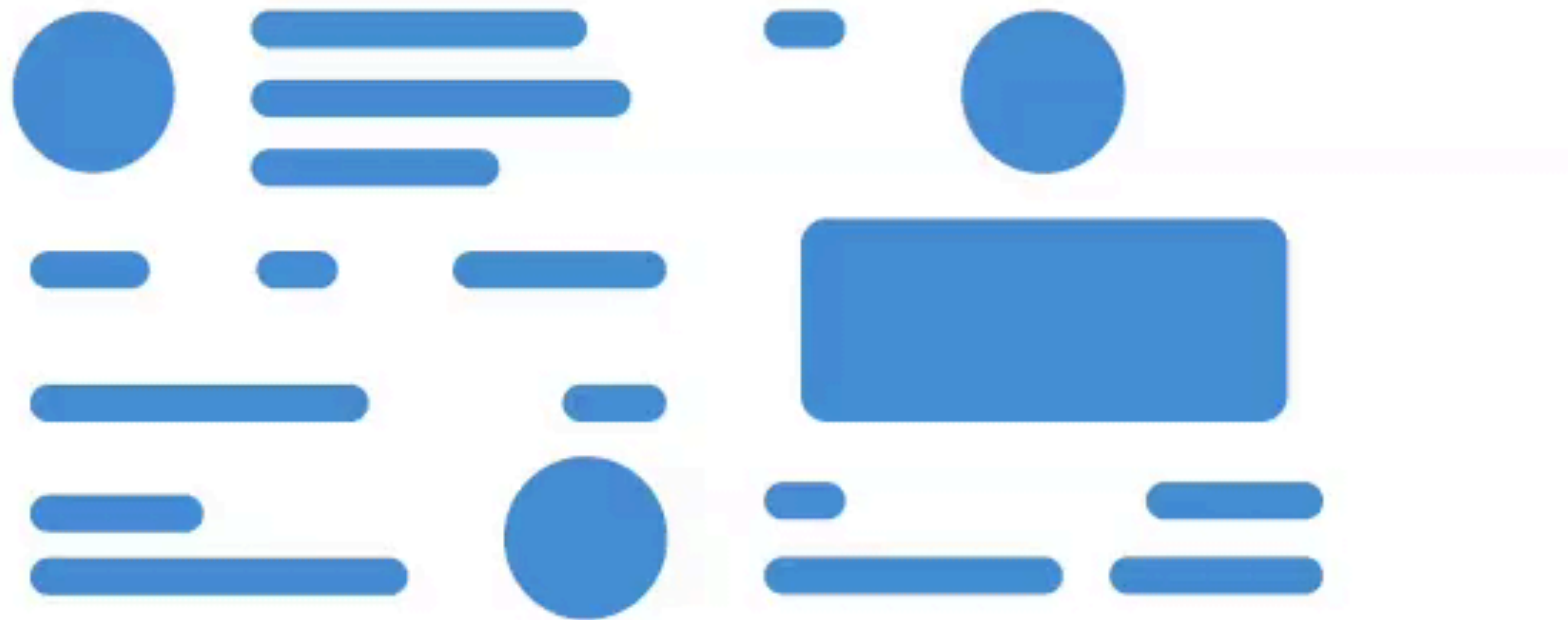
Enclosure



Connectedness / Enclosure



Common Region



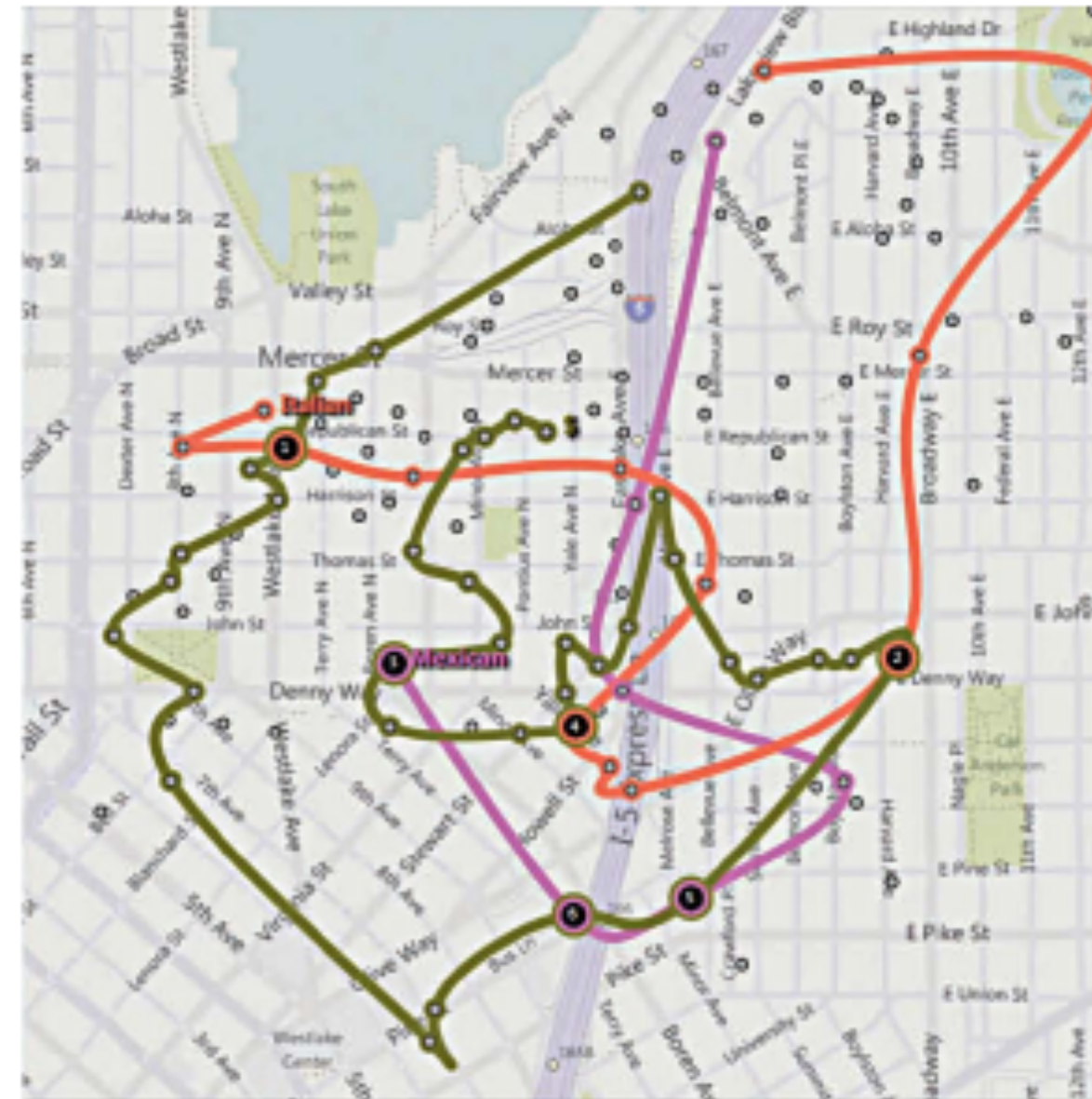
Scattered elements

Connectedness Varieties

Bubble Sets



Line Sets



Kelp Diagrams

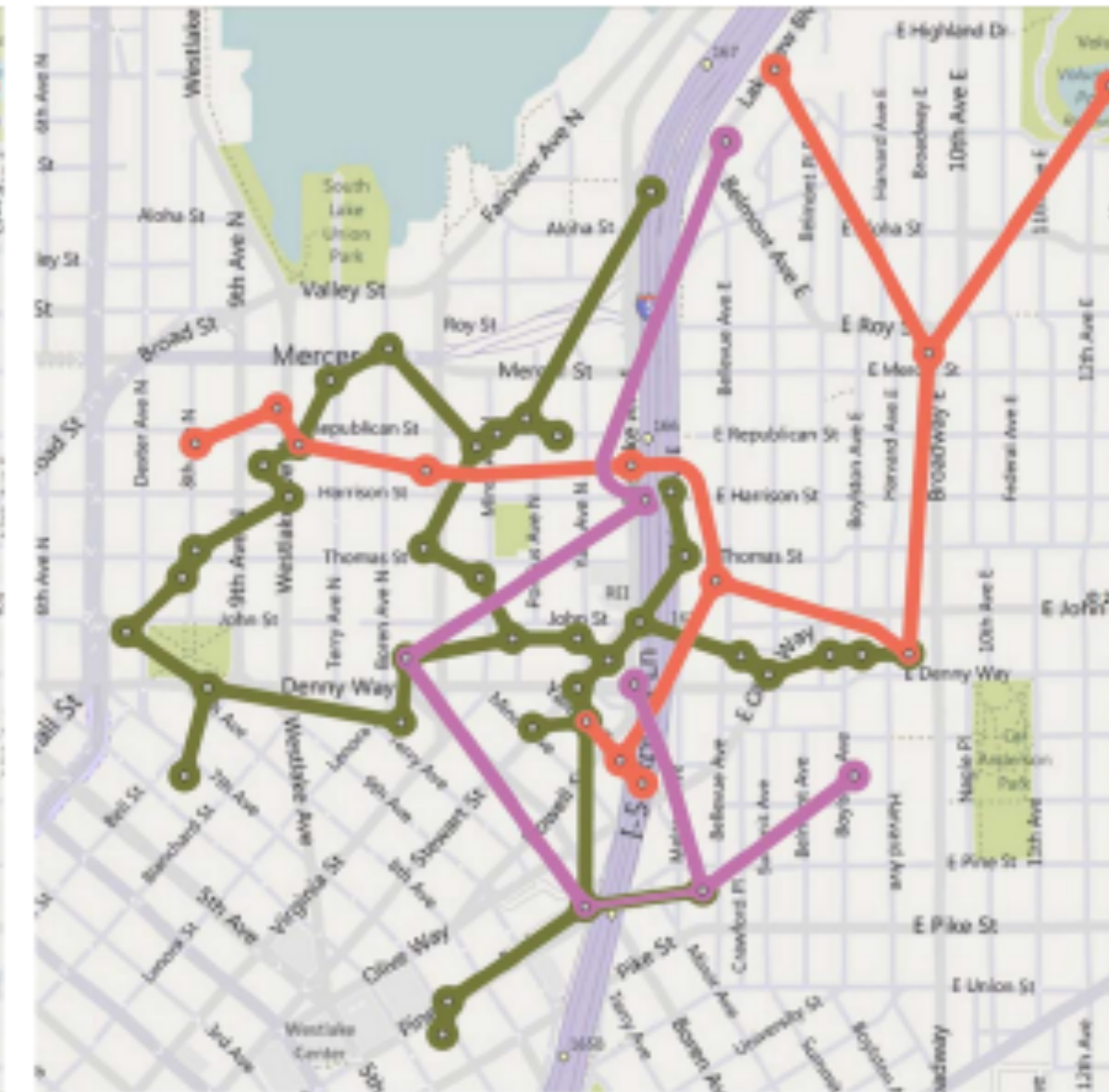


Image by [Dinkla et al., 2011]

Technique by [Collins et al., 2009]

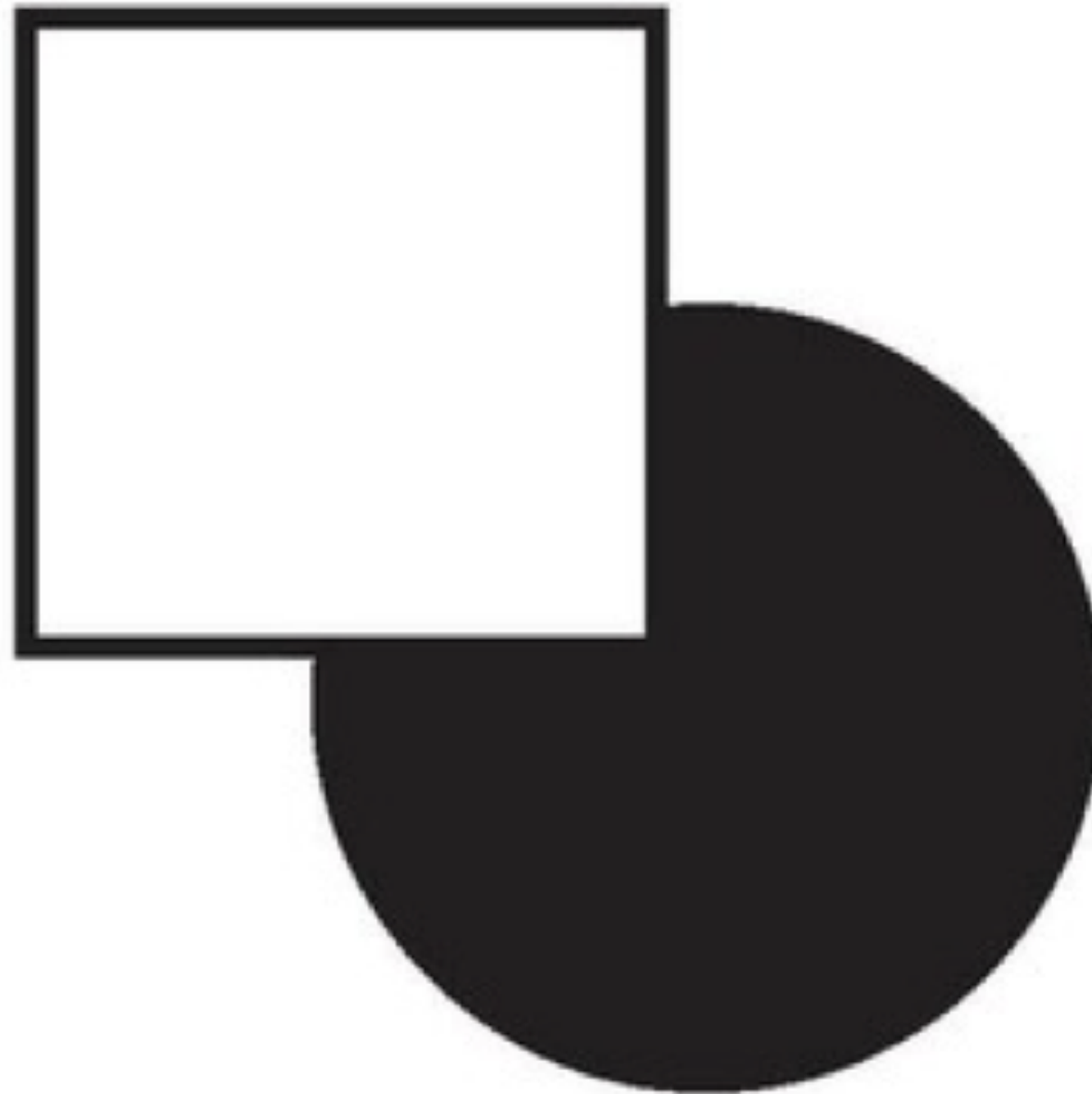
[Alper et al., 2011]

[Dinkla et al., 2012]

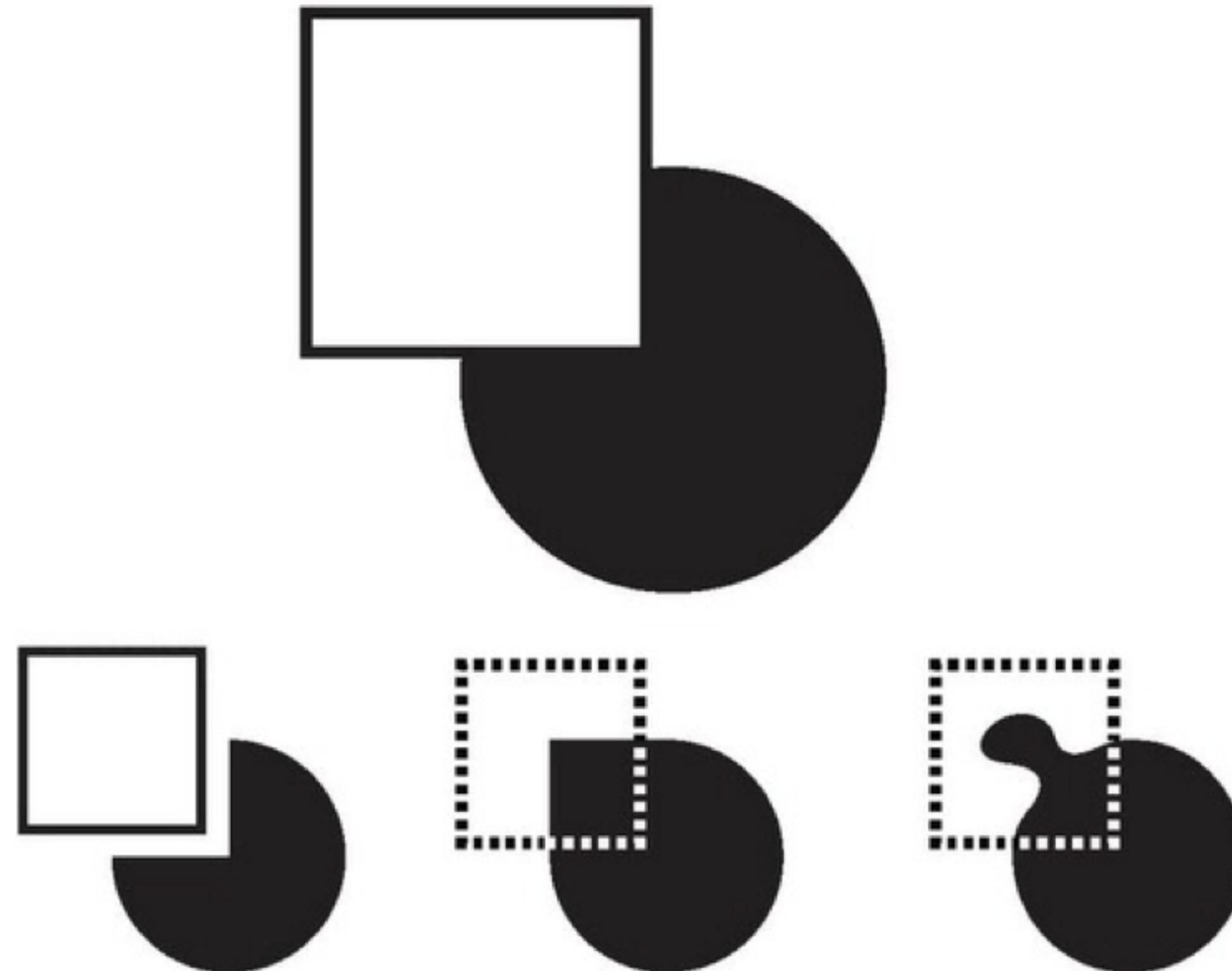
Gestalt Effects for “Emergence”

How Objects Appear to Us

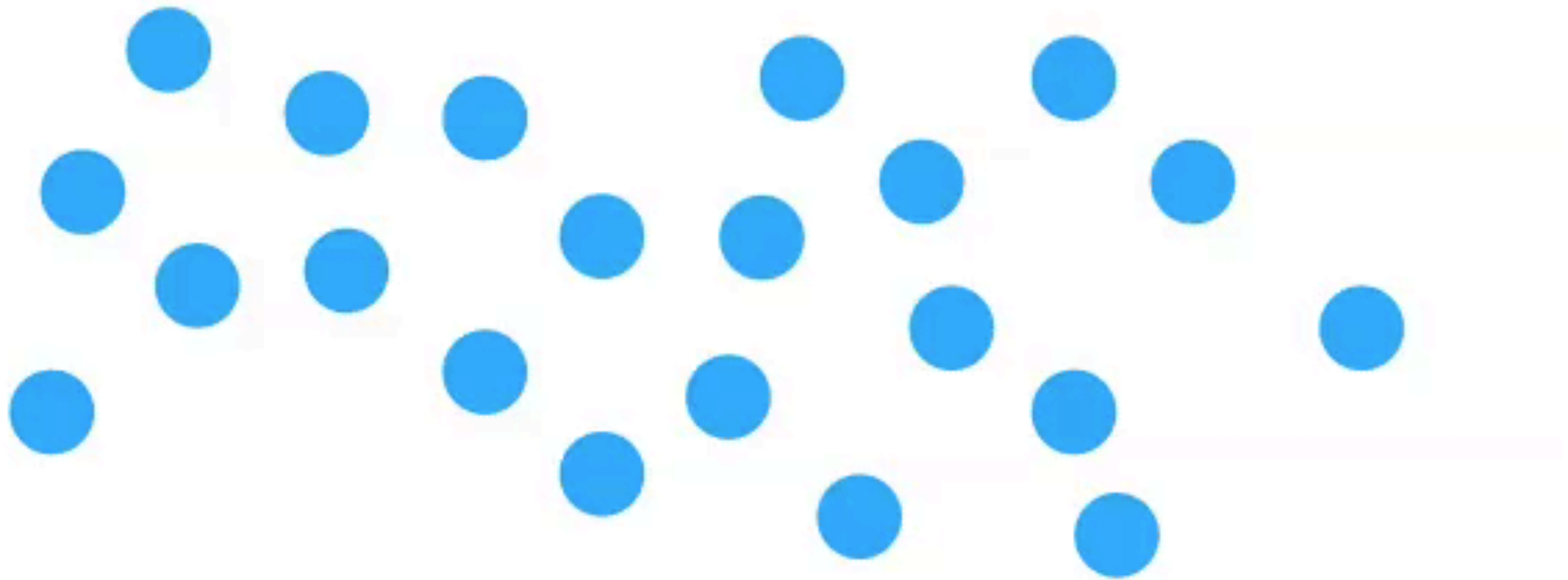
Continuity



Continuity



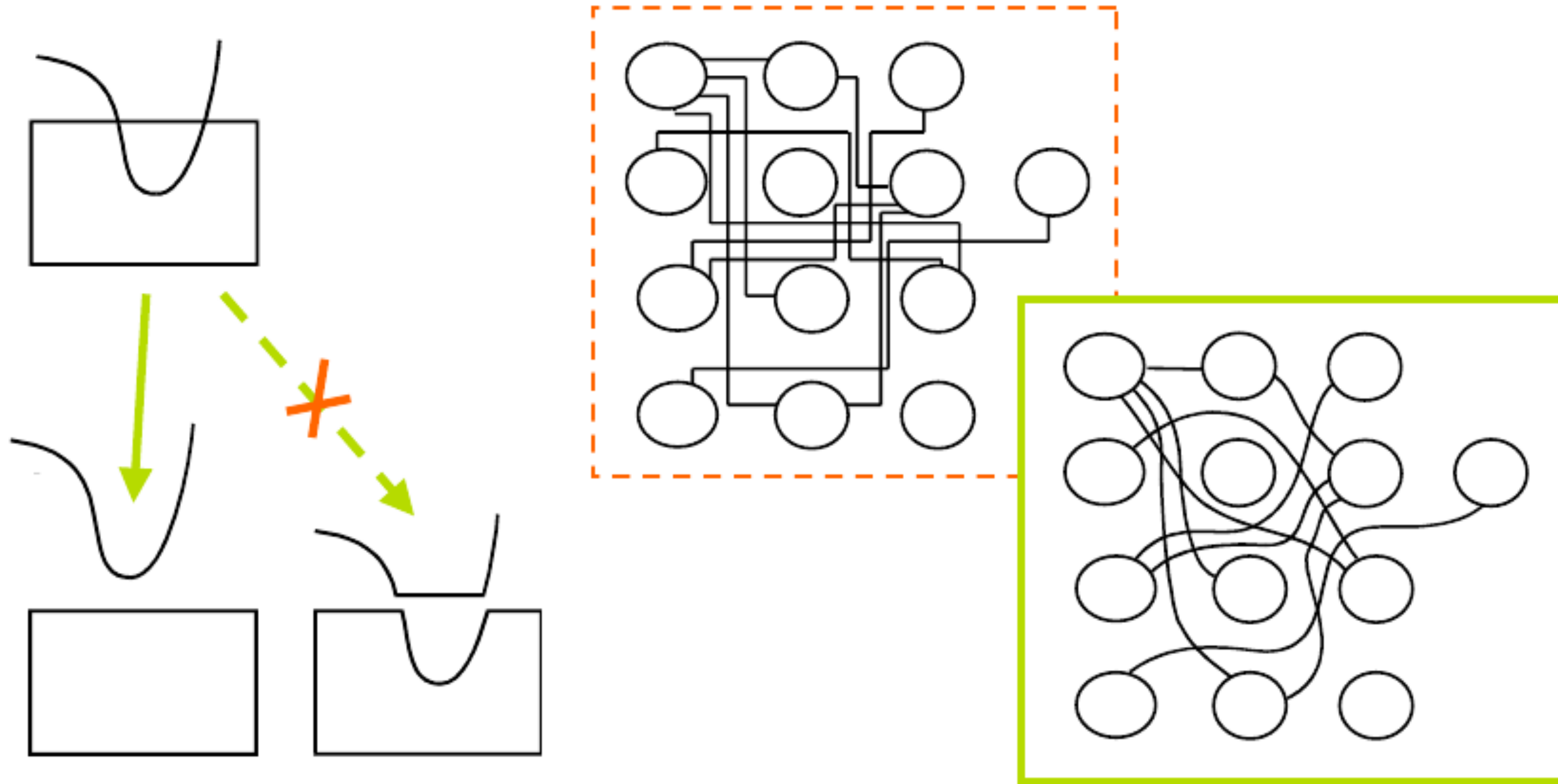
Continuity Principle



Scattered elements

Continuity

Things: smooth & continuous



Closure / Completion

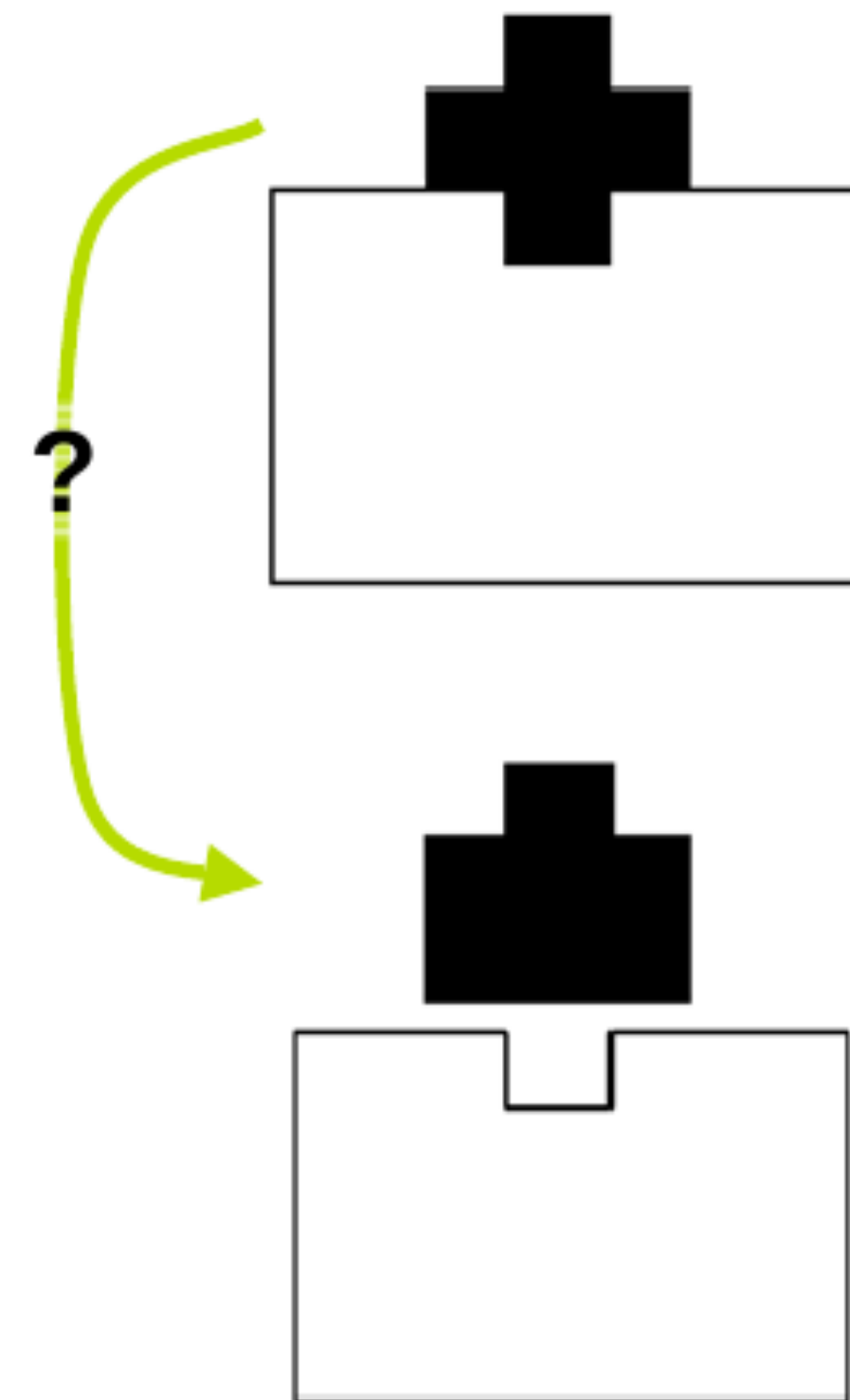
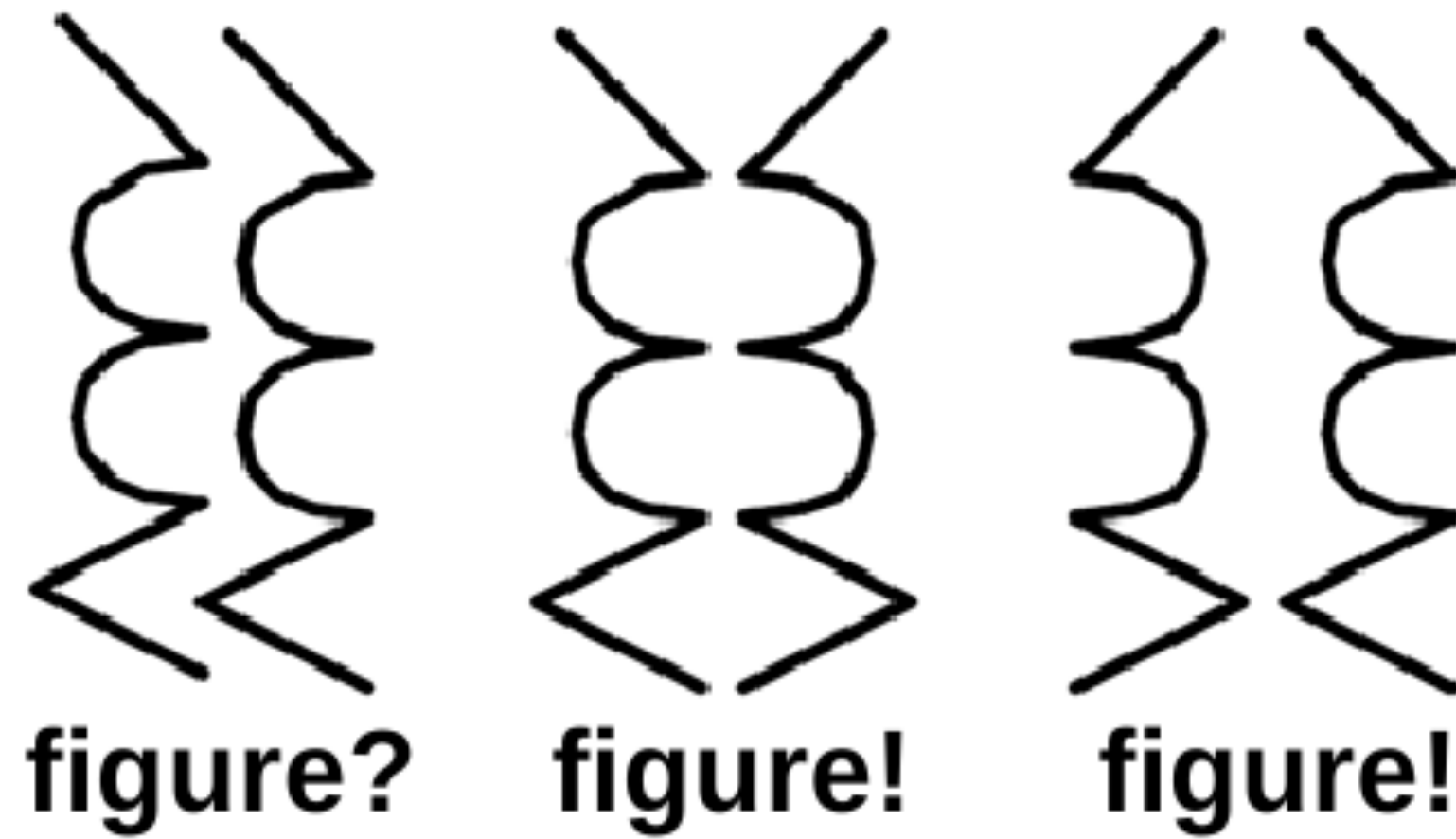


Closure



Symmetry

Things: symmetric



Population Pyramid

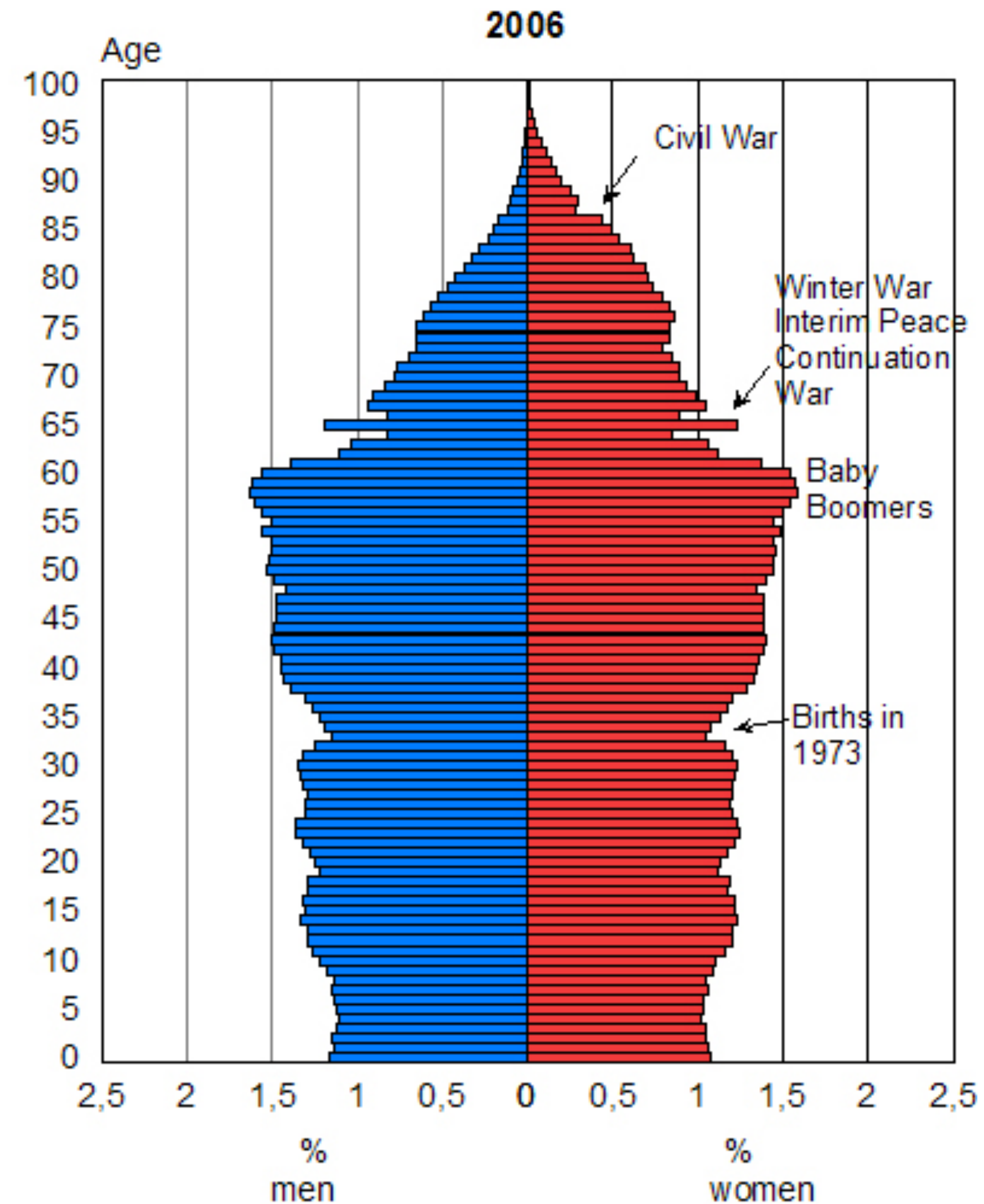
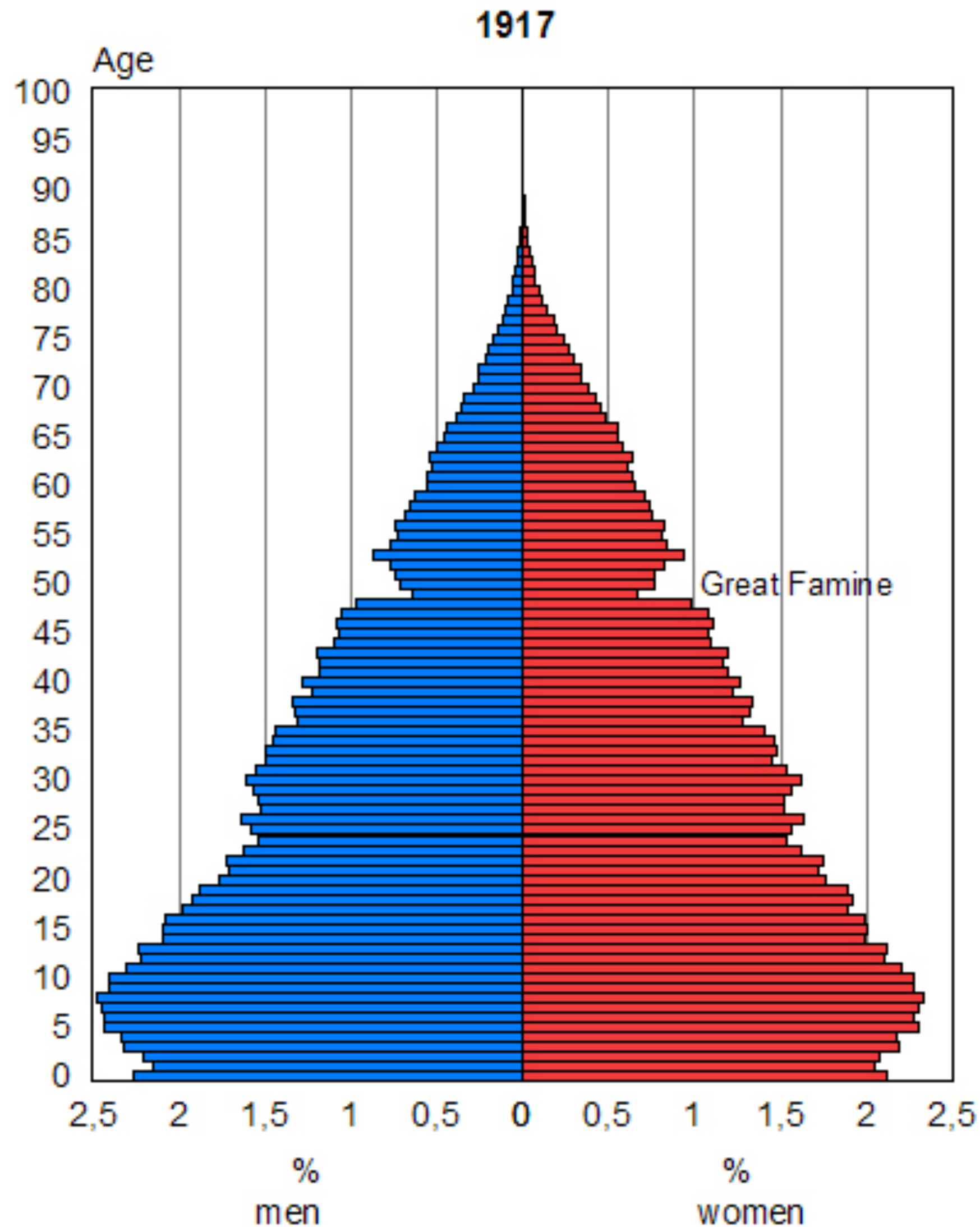
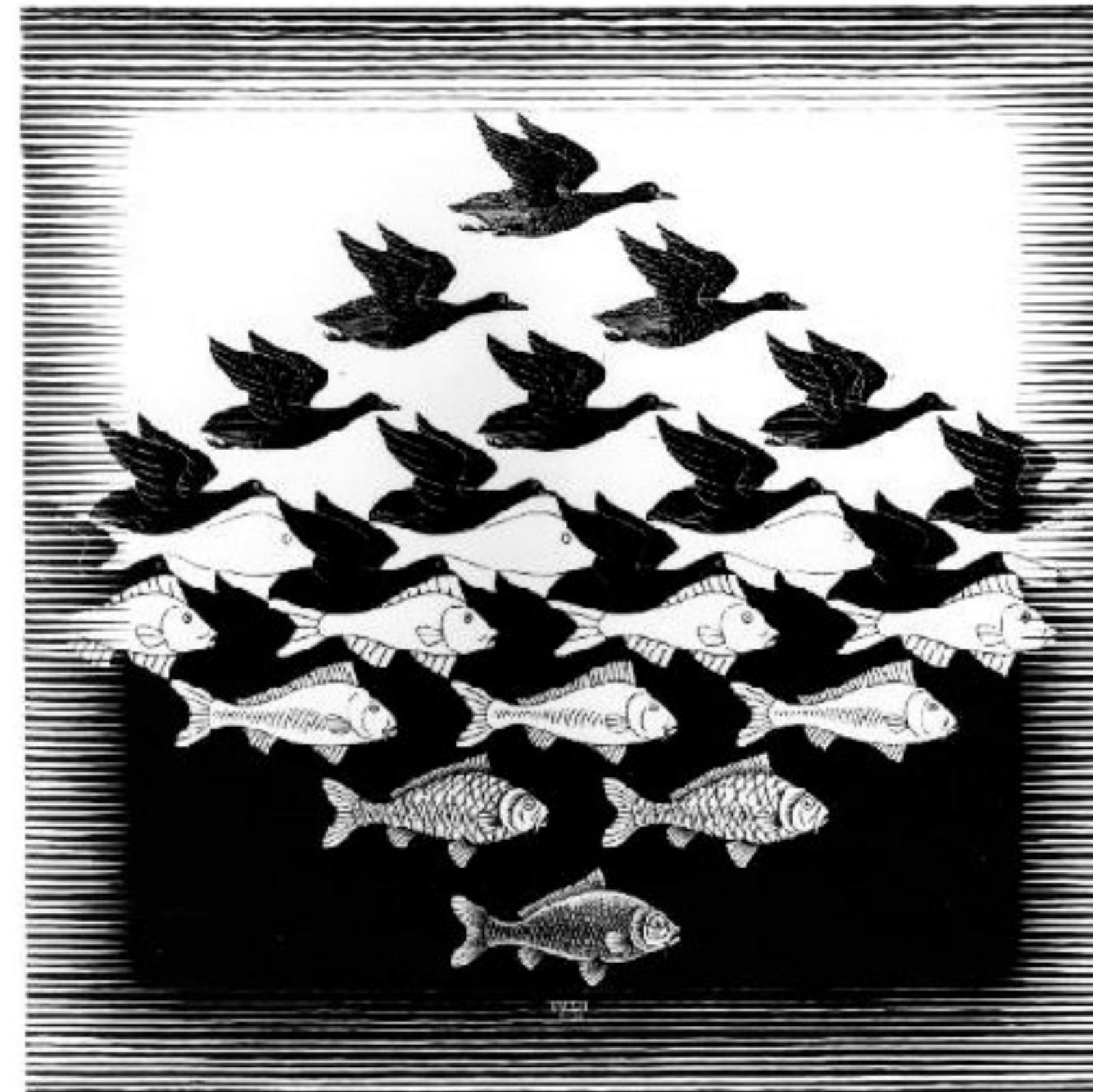


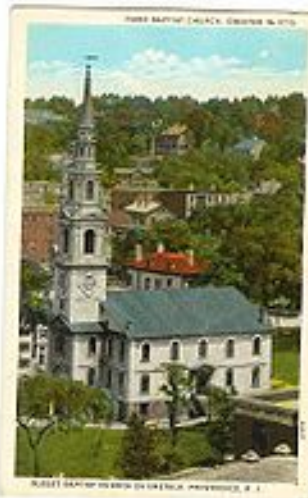
Figure / Ground



M.C. Escher: *Sky and Water I* 1938 woodcut

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Providence in the mid-nineteenth century



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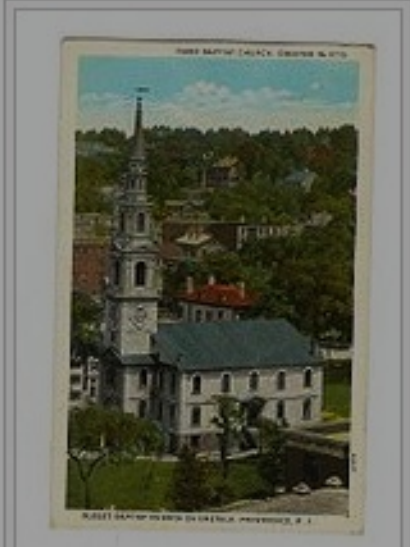
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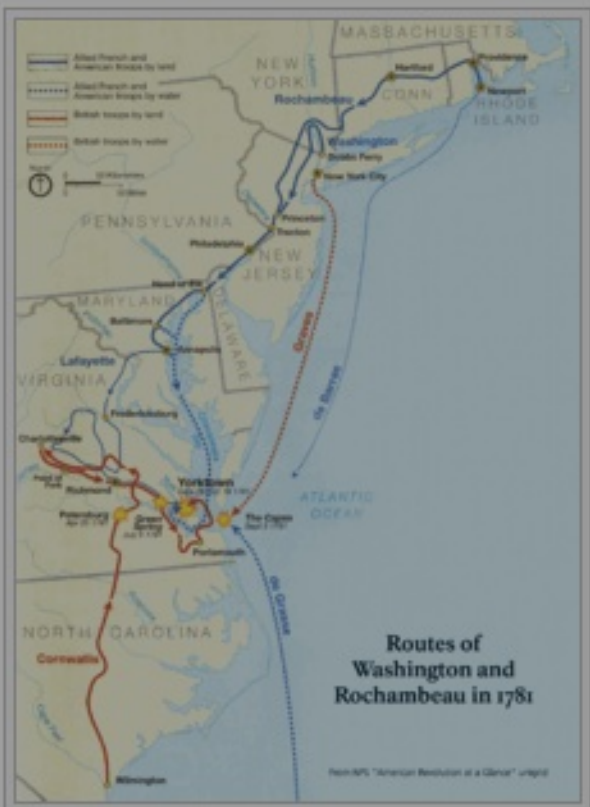




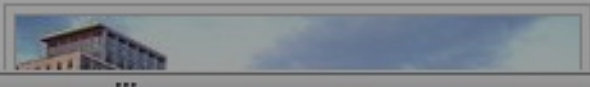
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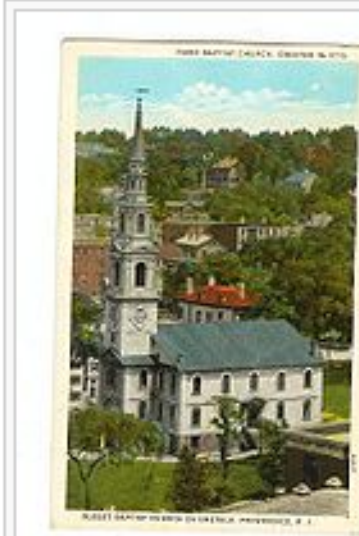
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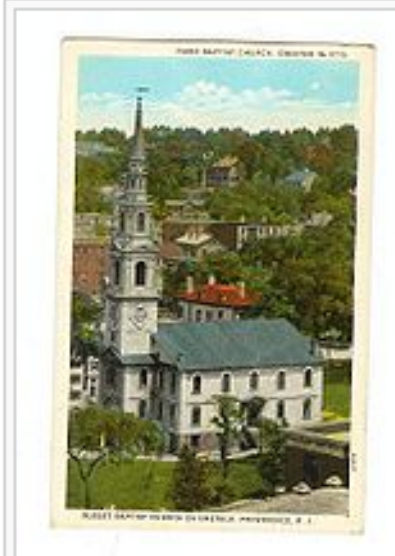
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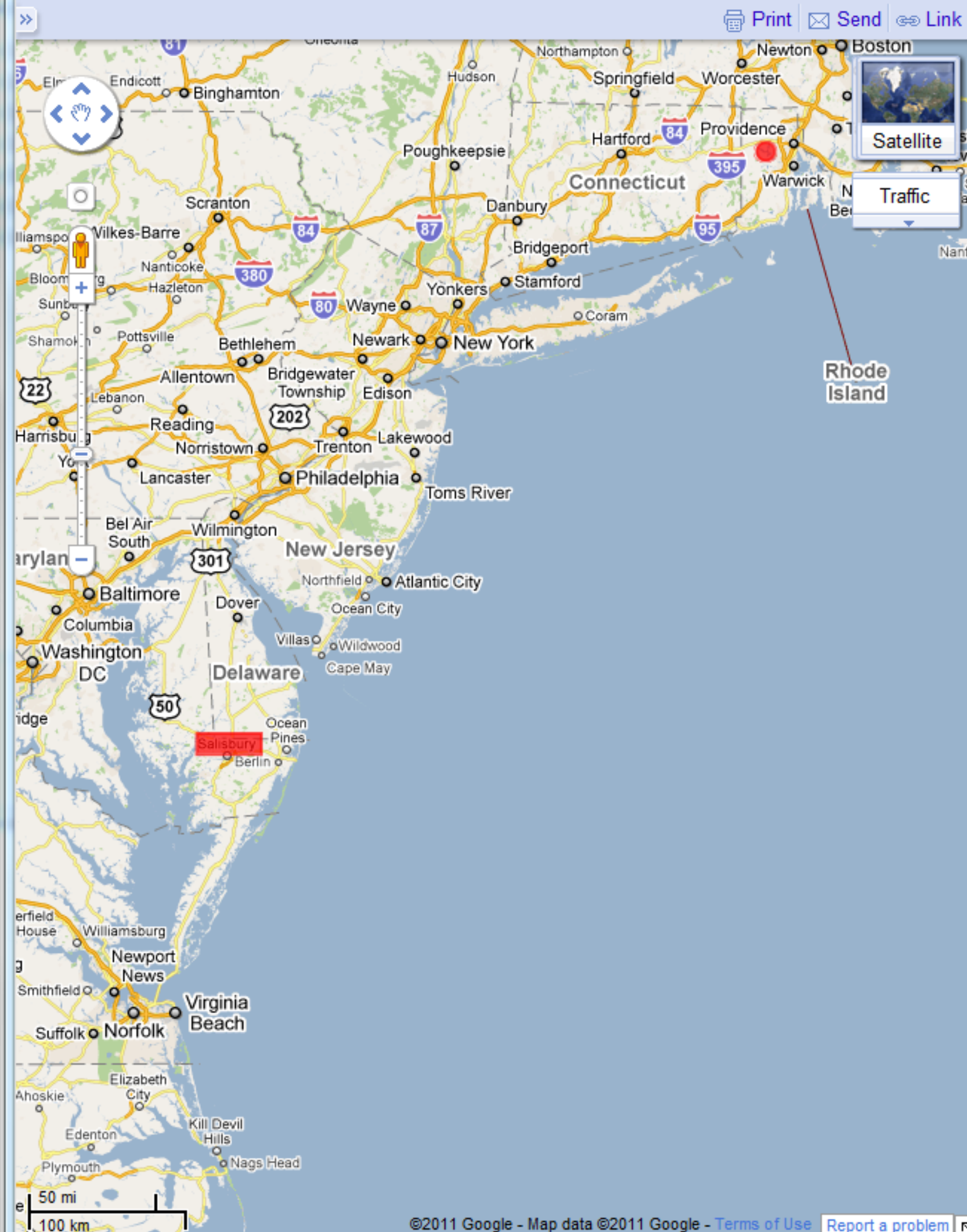
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Context-Preserving Visual Links

Takeaways

Knowing about Perception is important for Vis and UI design

- How to choose your colors

- How to show relationships

- How to draw attention

- How to minimize risk of overlooking