

# CS-5630 / CS-6630

# Visualization for Data Science

# Perception

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# **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

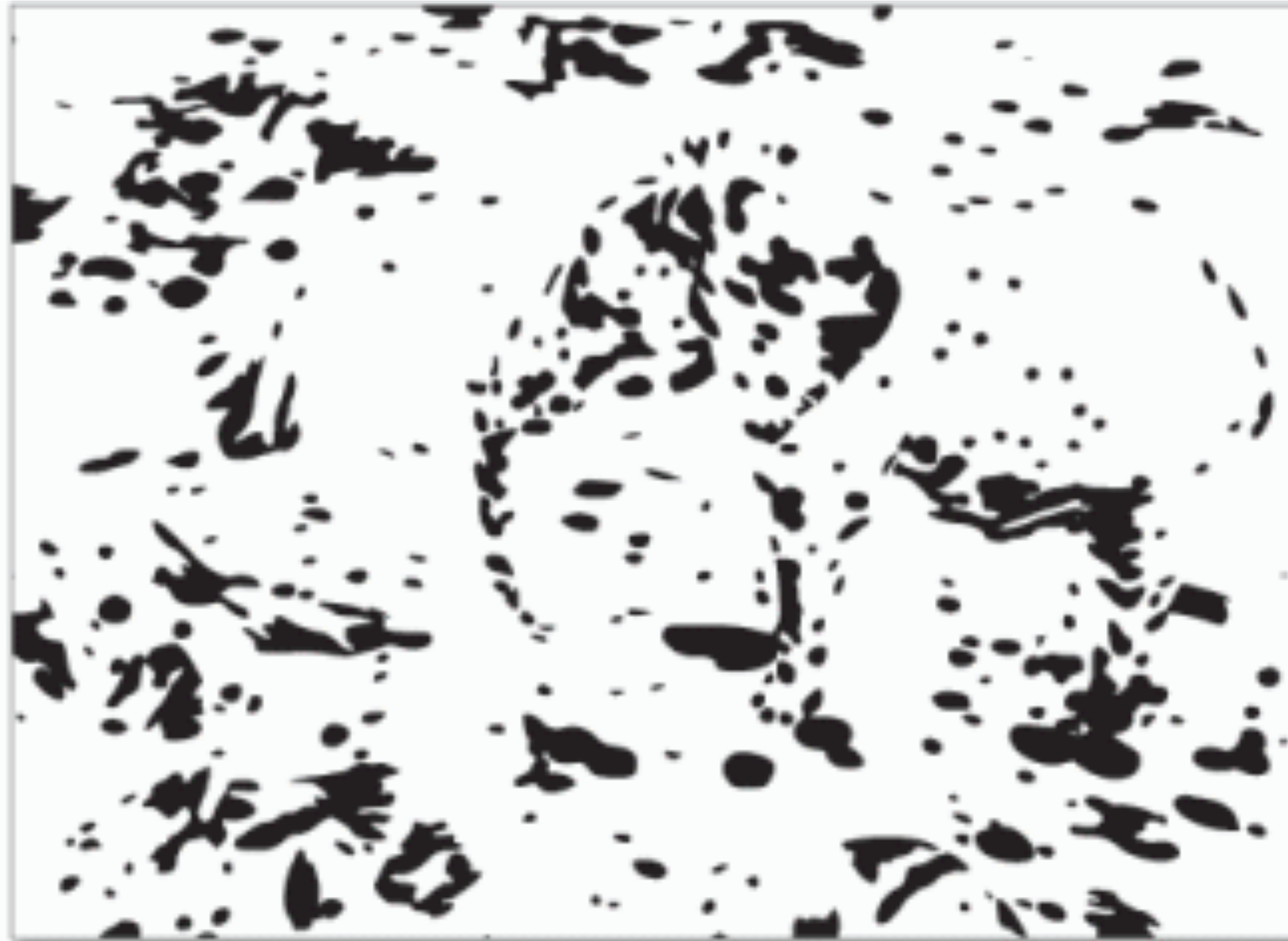
BLUE

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](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 rely on priors







# Pareidolia



**Faces in Things** @FacesPics · Mar 9

These chairs have seen some terrible things [pic.twitter.com/Gjlc9wuP47](https://pic.twitter.com/Gjlc9wuP47)



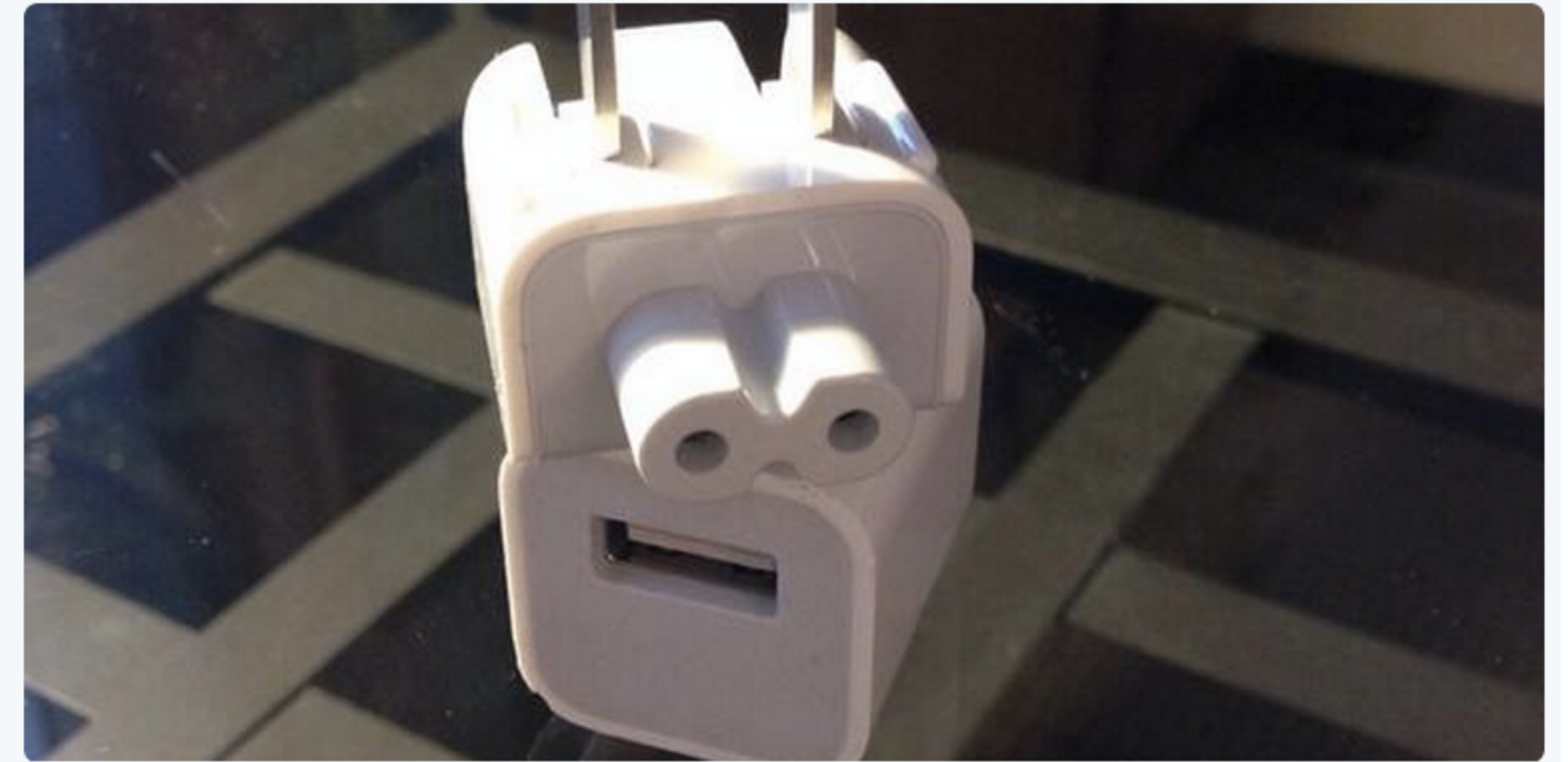
**Faces in Things** @FacesPics · Feb 14

Deep in thought Deep Fryer [pic.twitter.com/1Qyqjmslka](https://pic.twitter.com/1Qyqjmslka)



**Faces in Things** @FacesPics · Mar 22

Hey little guy! [pic.twitter.com/nt2BgwZeTR](https://pic.twitter.com/nt2BgwZeTR)



**Faces in Things** @FacesPics · Mar 10

A terrified pickle [pic.twitter.com/Ffph1wzTyv](https://pic.twitter.com/Ffph1wzTyv)





# Take Home Point

Vision is “constructed” top down from the input

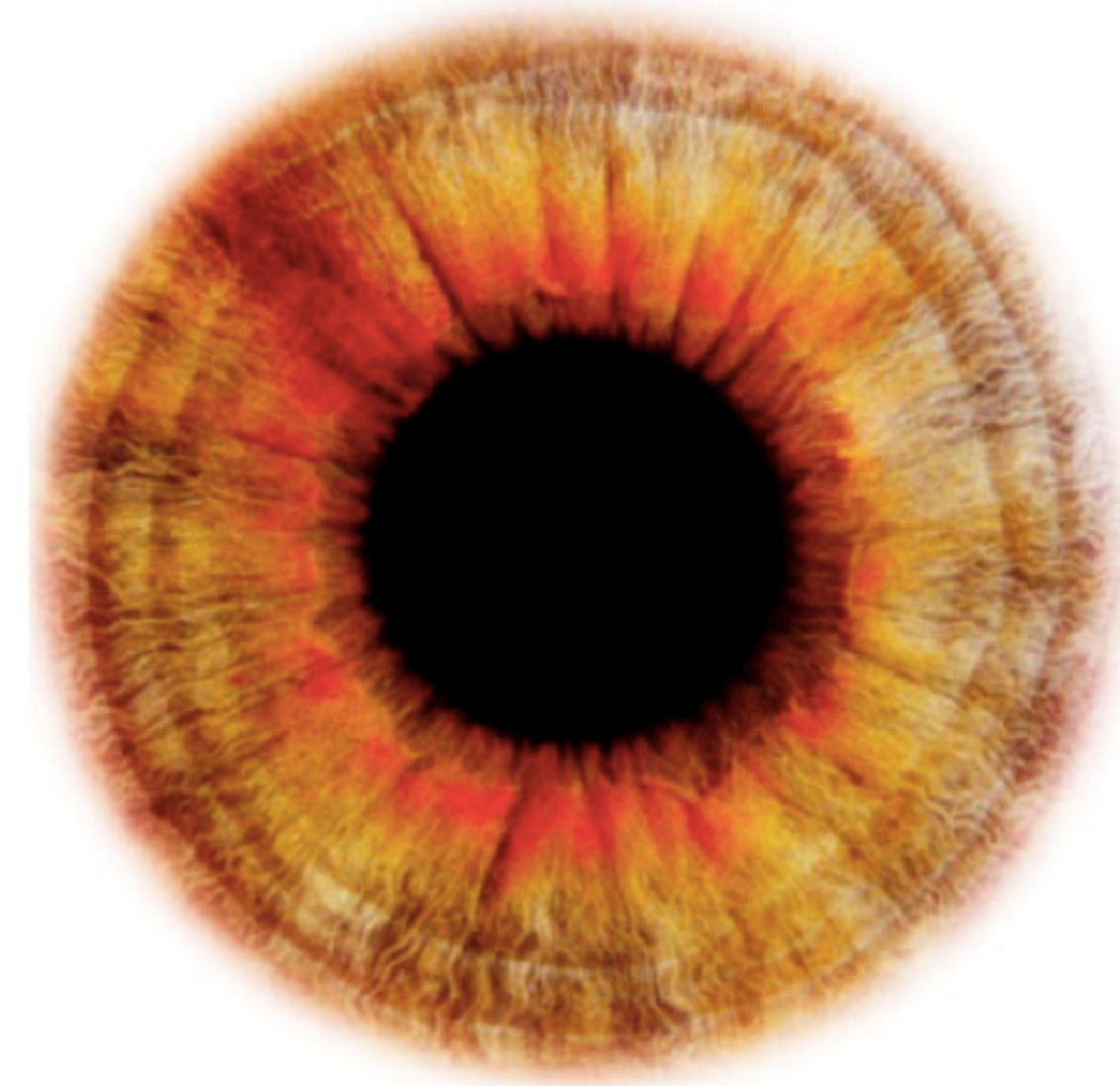
*“What you see when you see a thing depends on what the thing is. What you see the thing as depends on what you know about what you are seeing.”*

Zenon Pylyshyn  
Canadian Cognitive Scientist  
and Philosopher

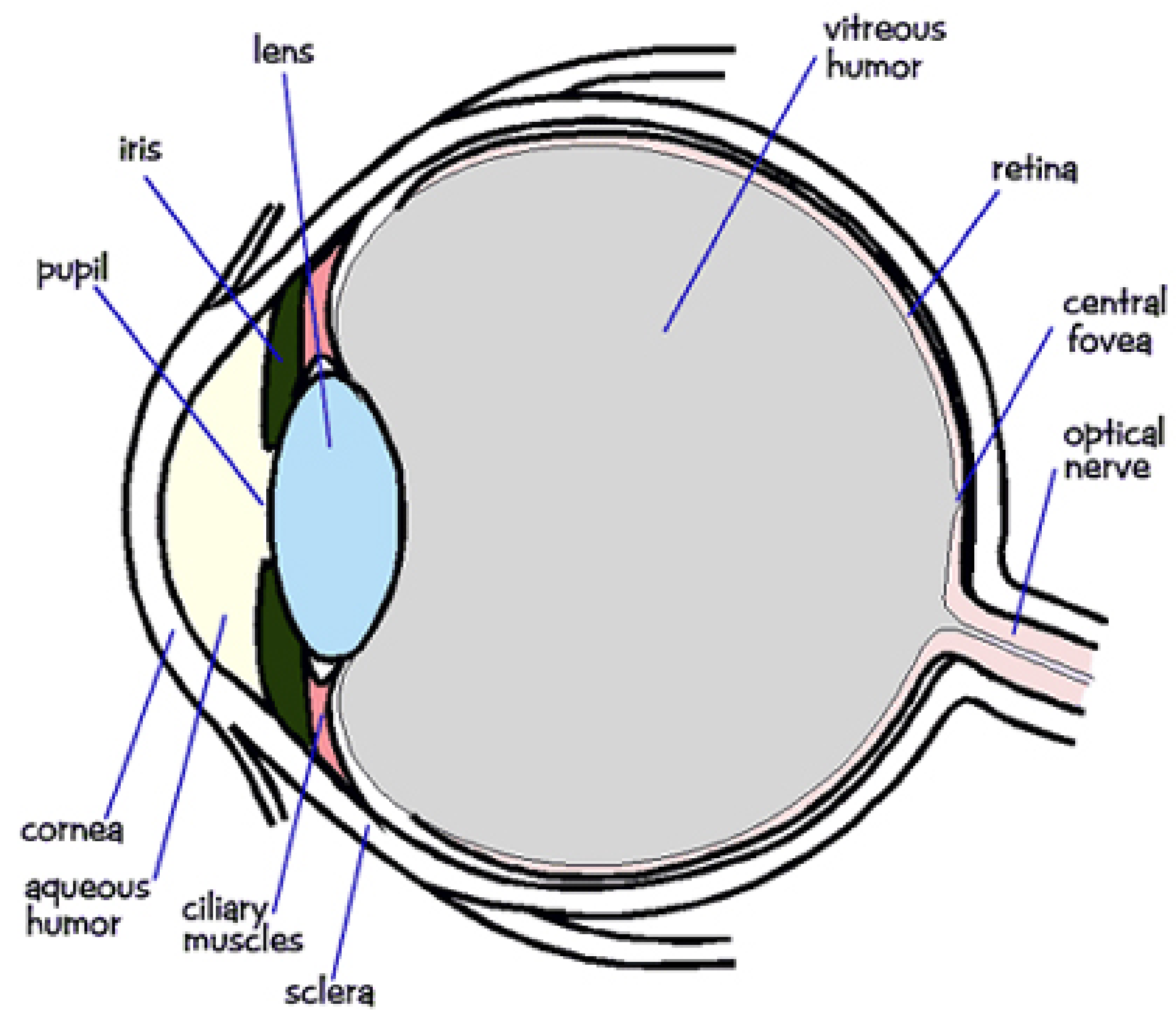




# The Eye







# Human Visual System

5-6 mio cones

color vision

dense in the center

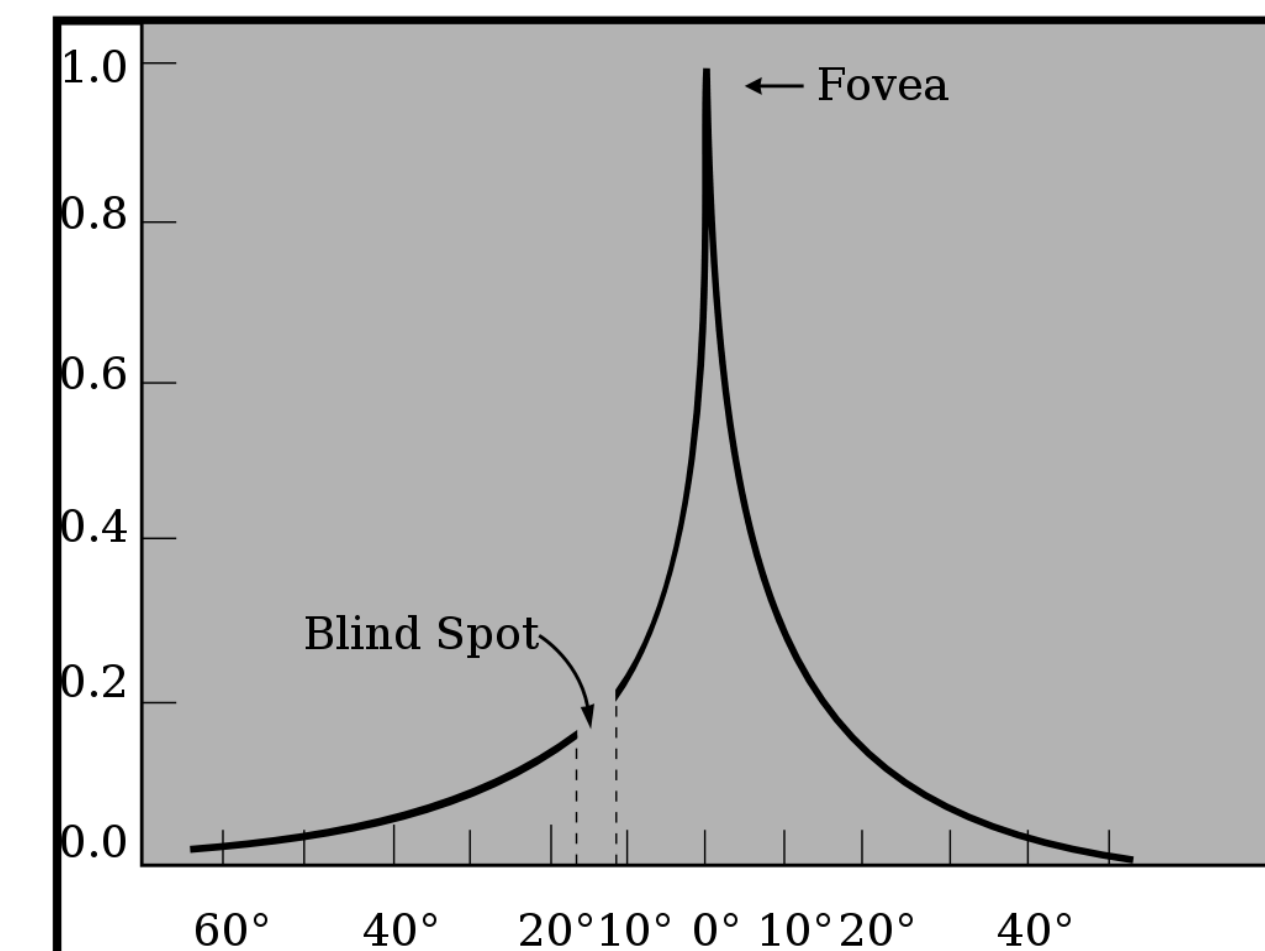
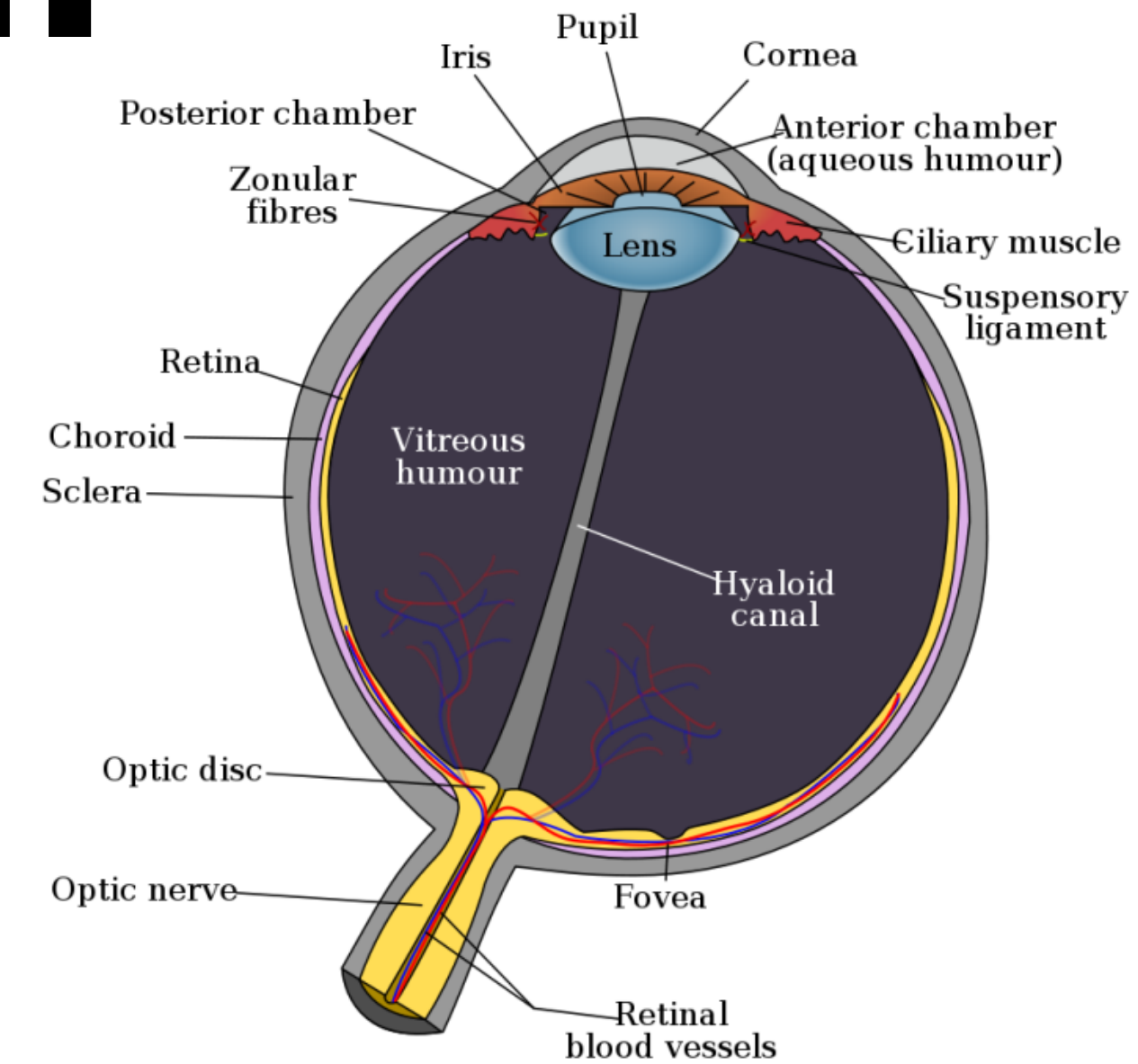
**Fovea:** 27 times the density

responsible for sharp central vision

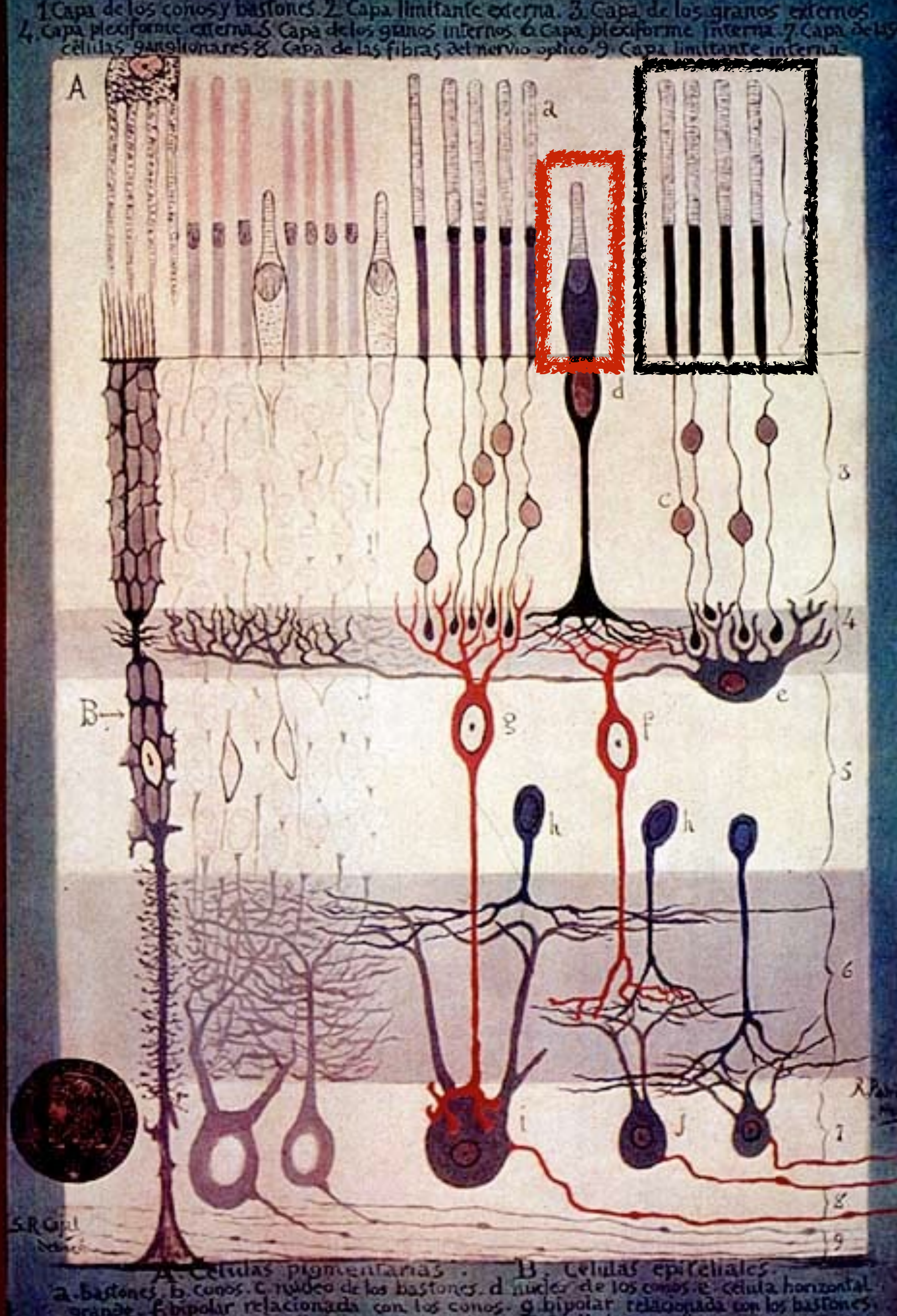
only cone cells

~120 mio rods

black/white







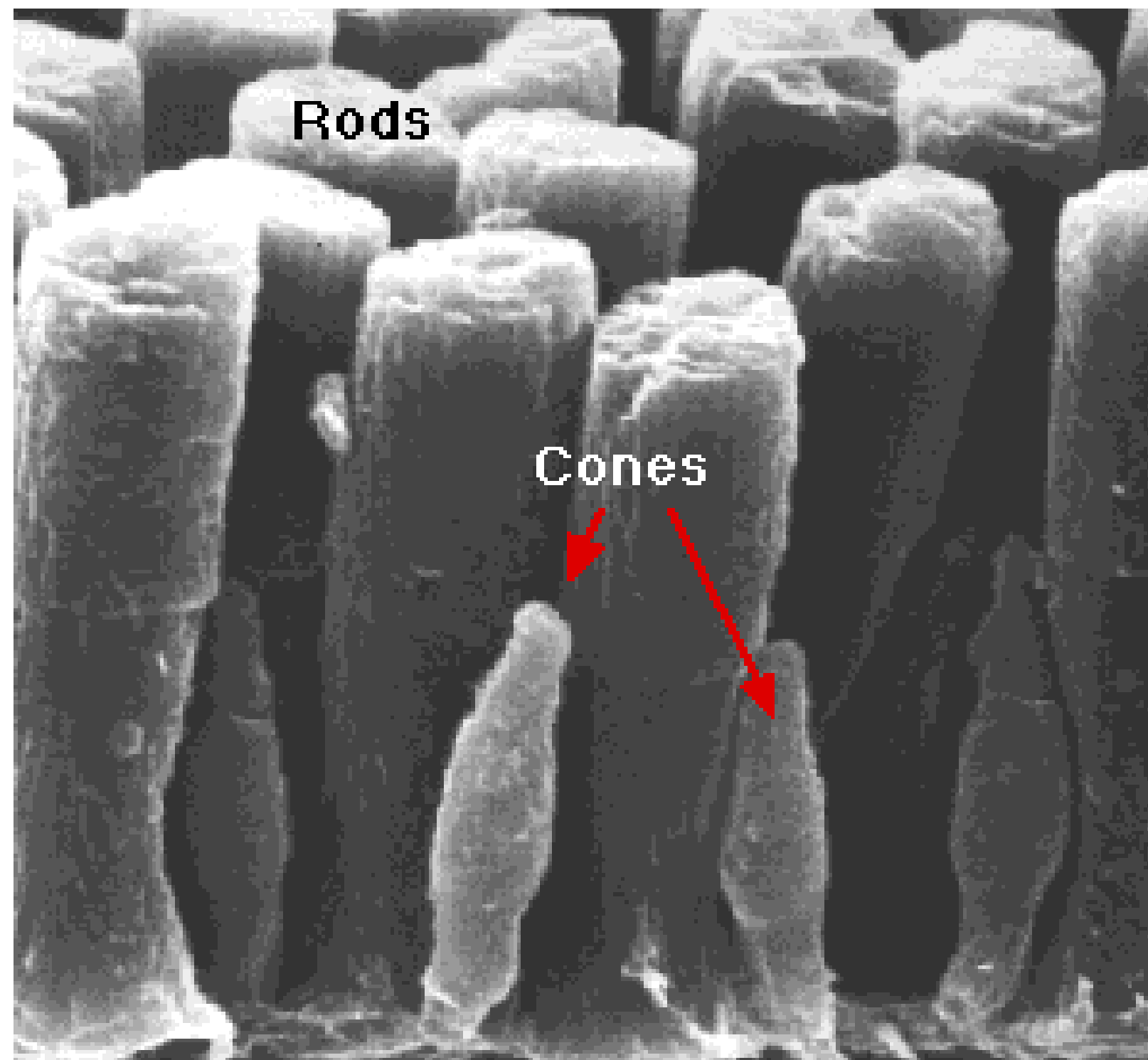
Rods - sensitive black and white

Cones - color vision

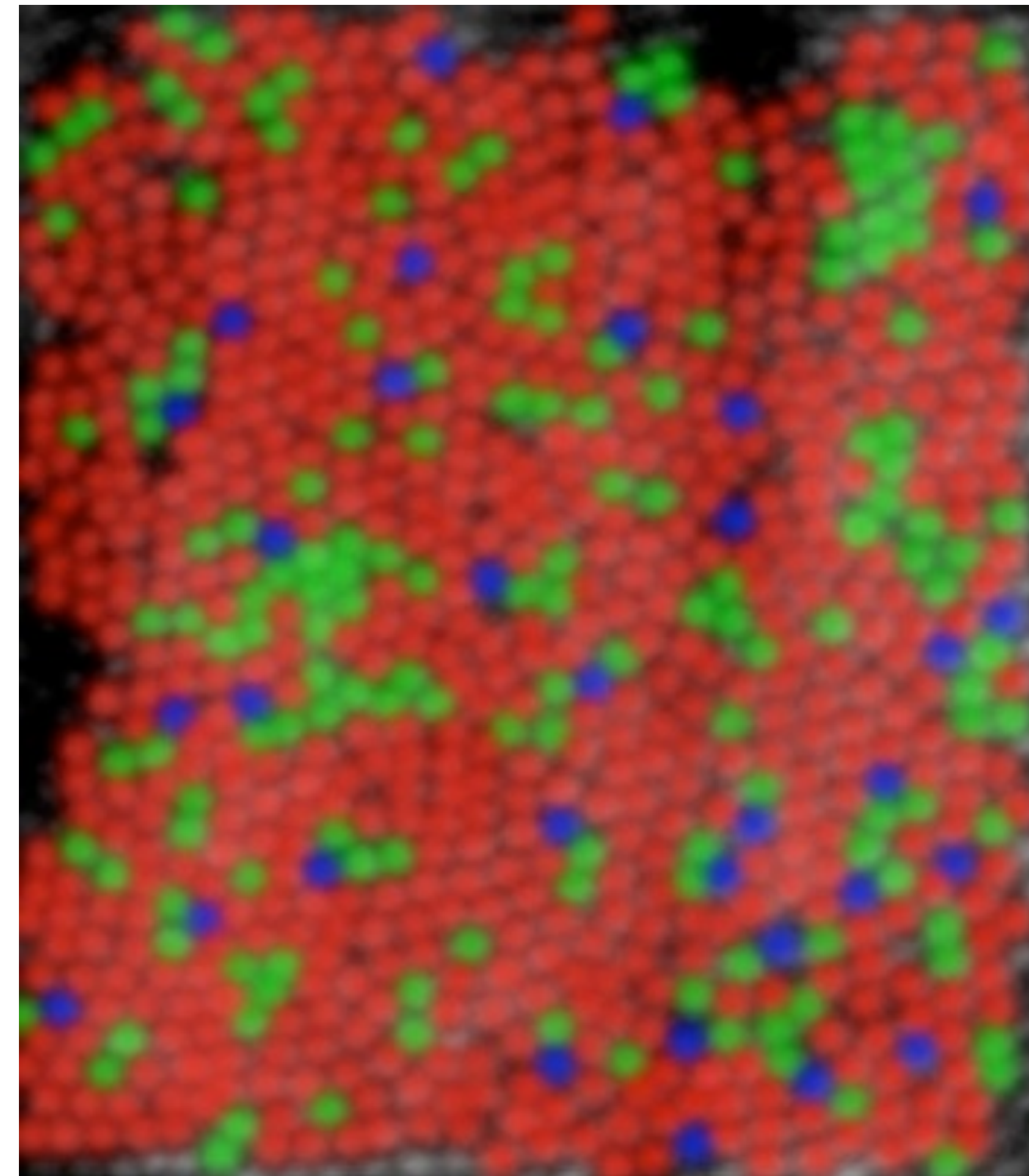
Ganglion Cells

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





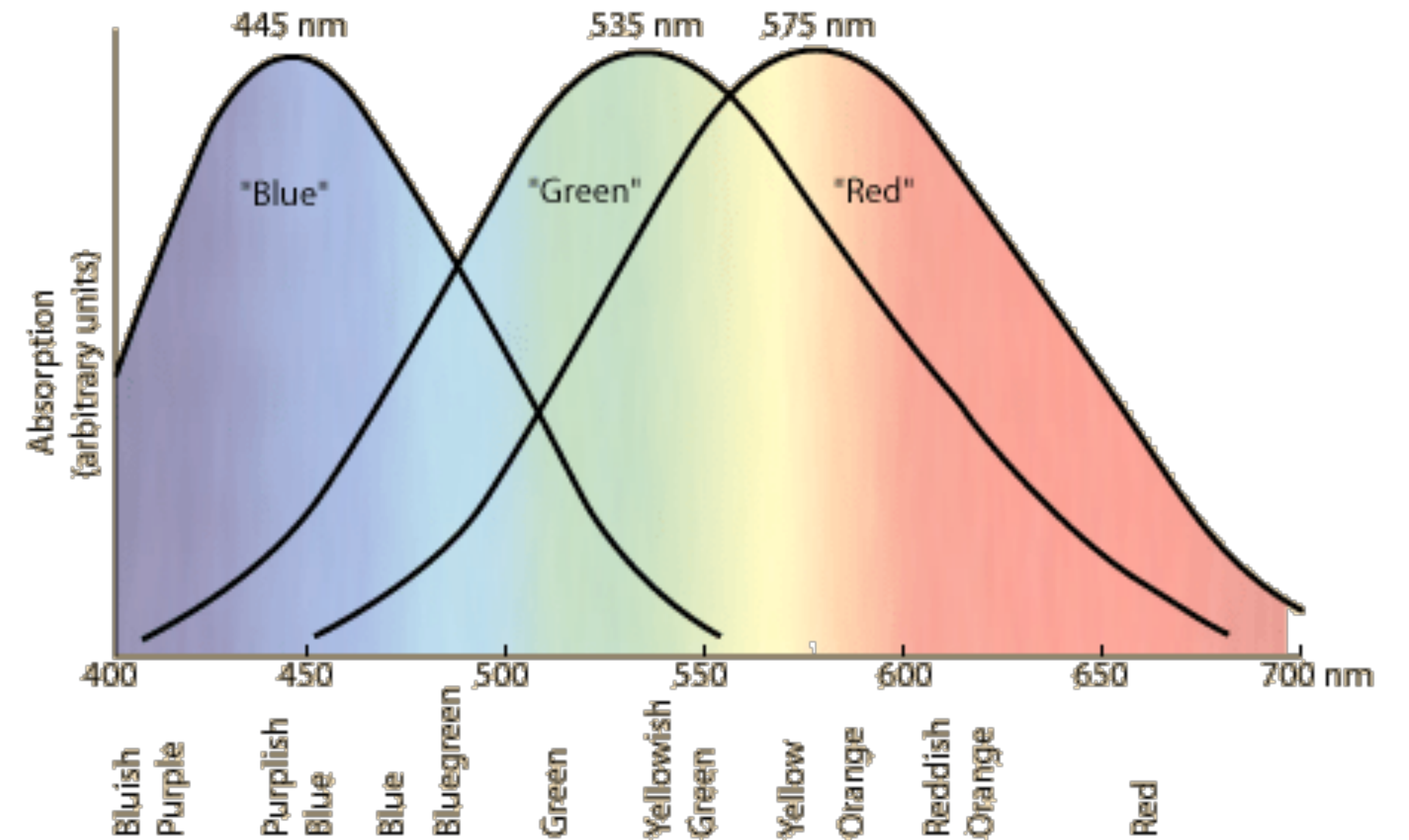
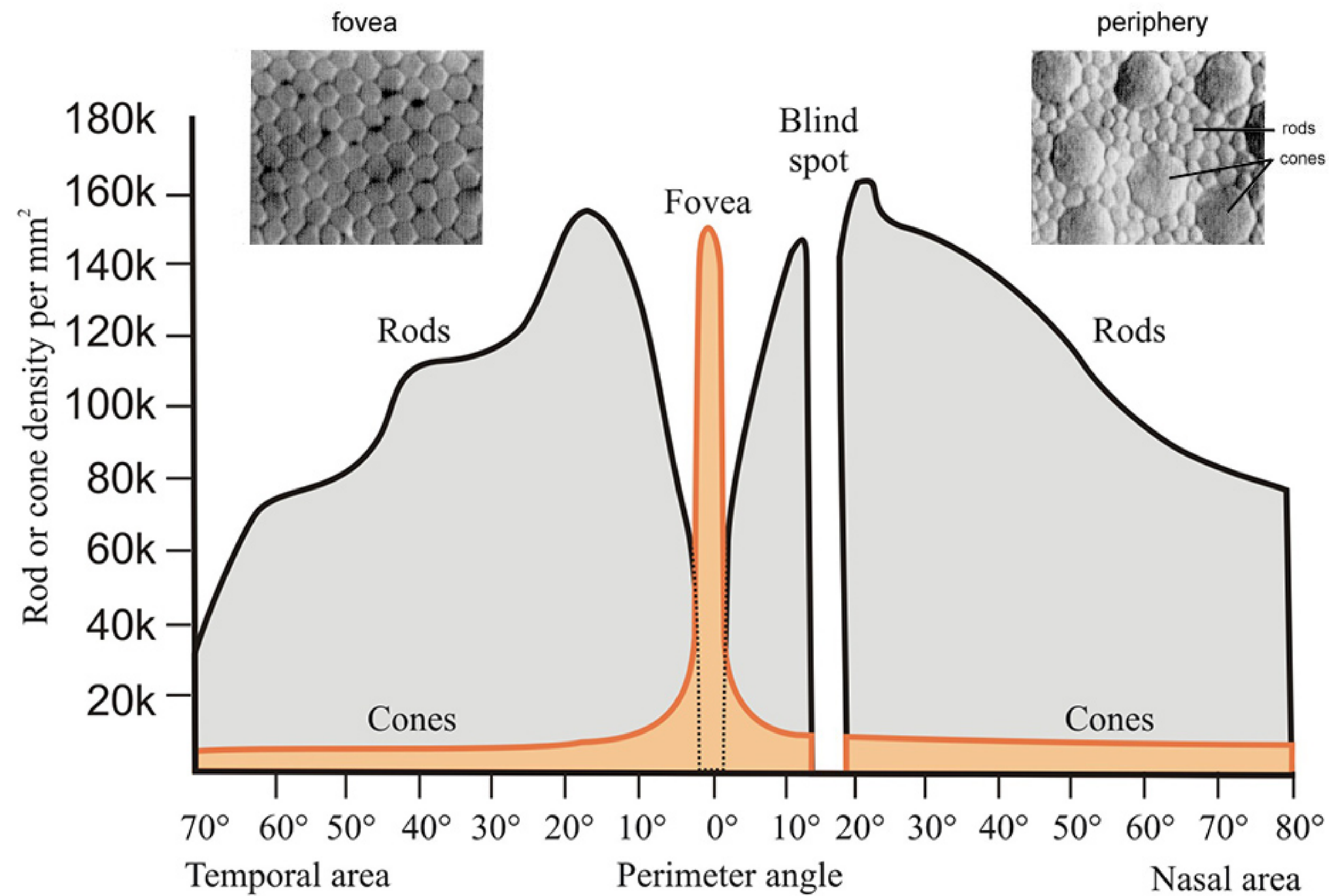
~120 million rods  
~5-6 million cones



R 63% - G 31% - B 6%



# 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







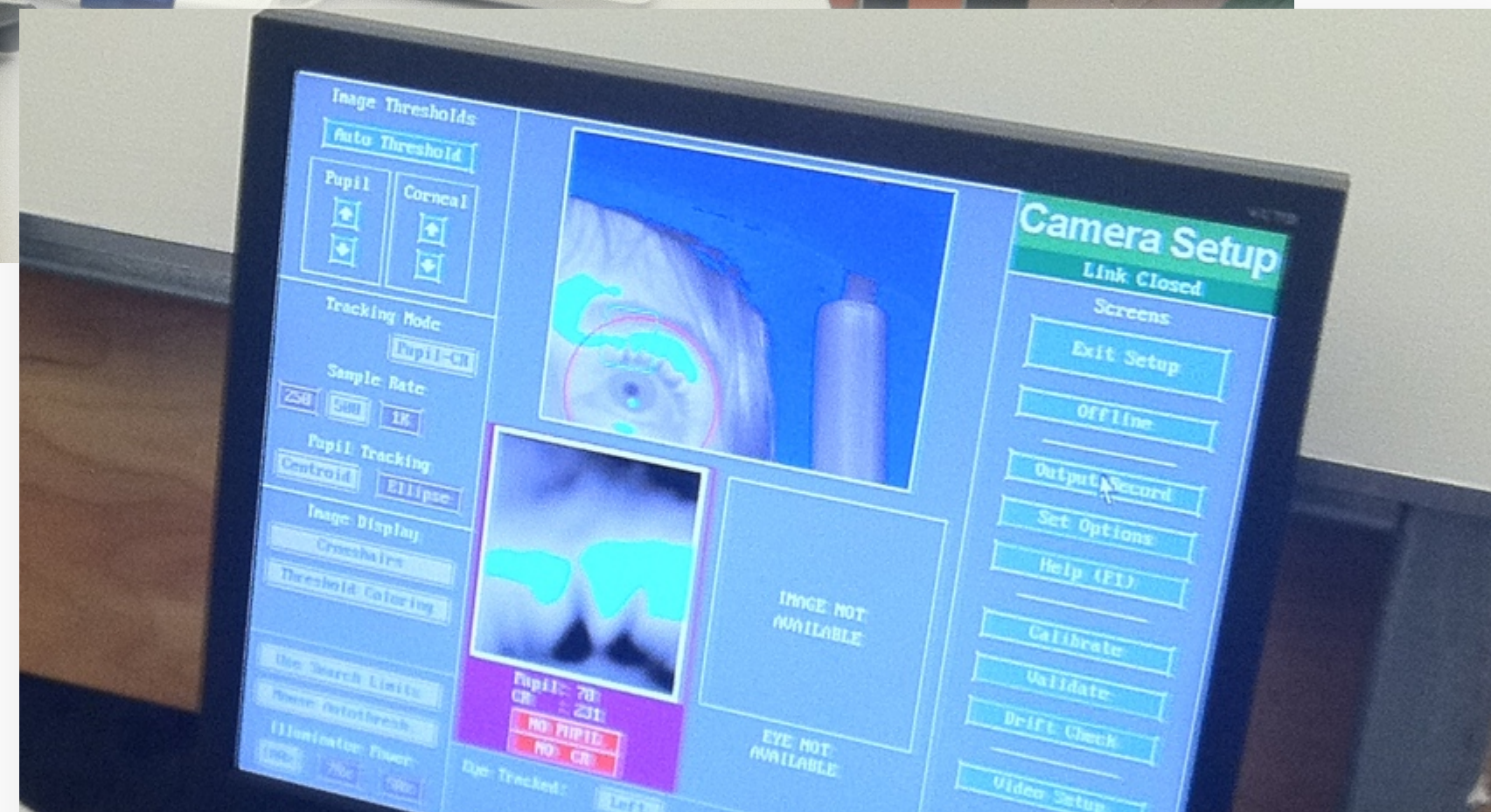


# Eye-Tracking Experiment

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

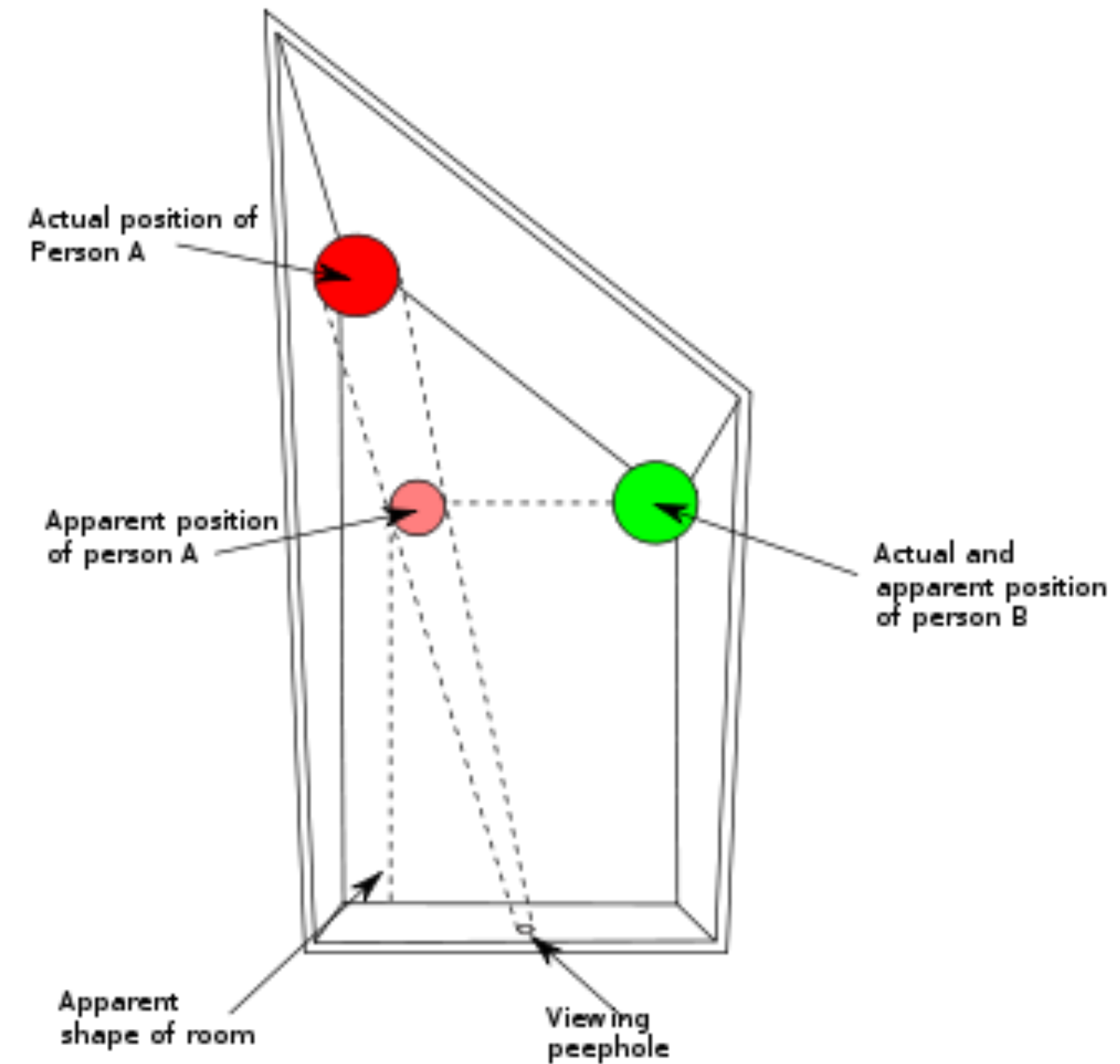
What we see depends on our goals and expectations

Relative judgments: strong

Absolute judgments: weak



Ames Room









Color

# Color Basics

## Visible part of the electromagnetic spectrum

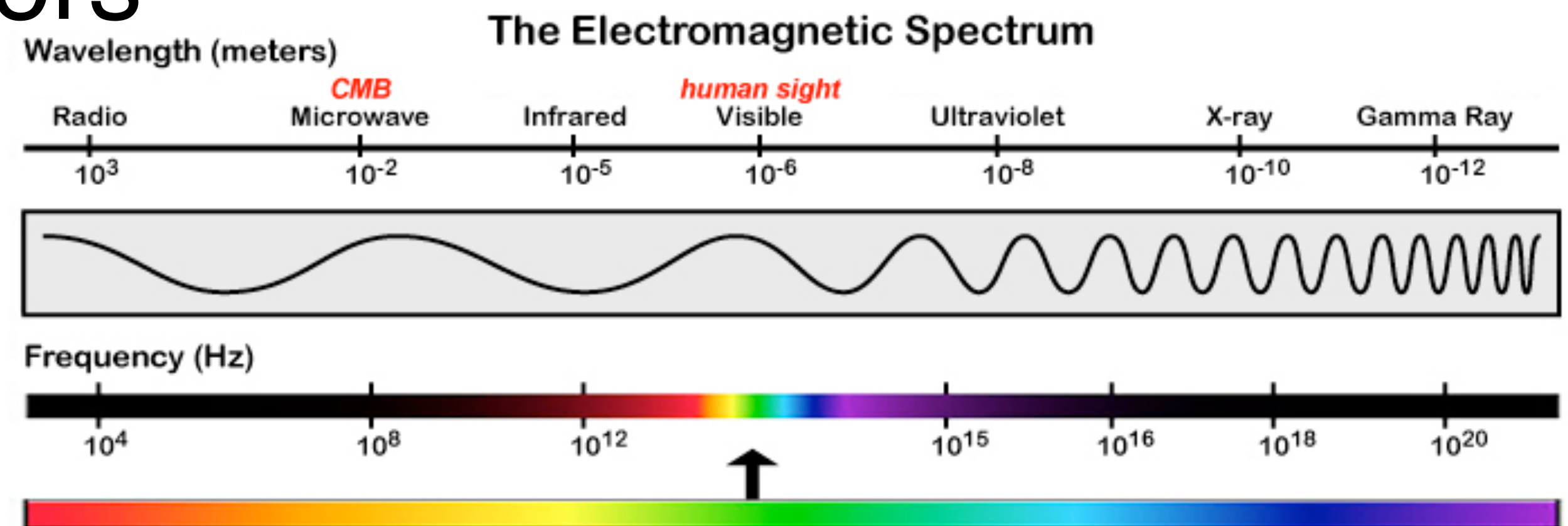
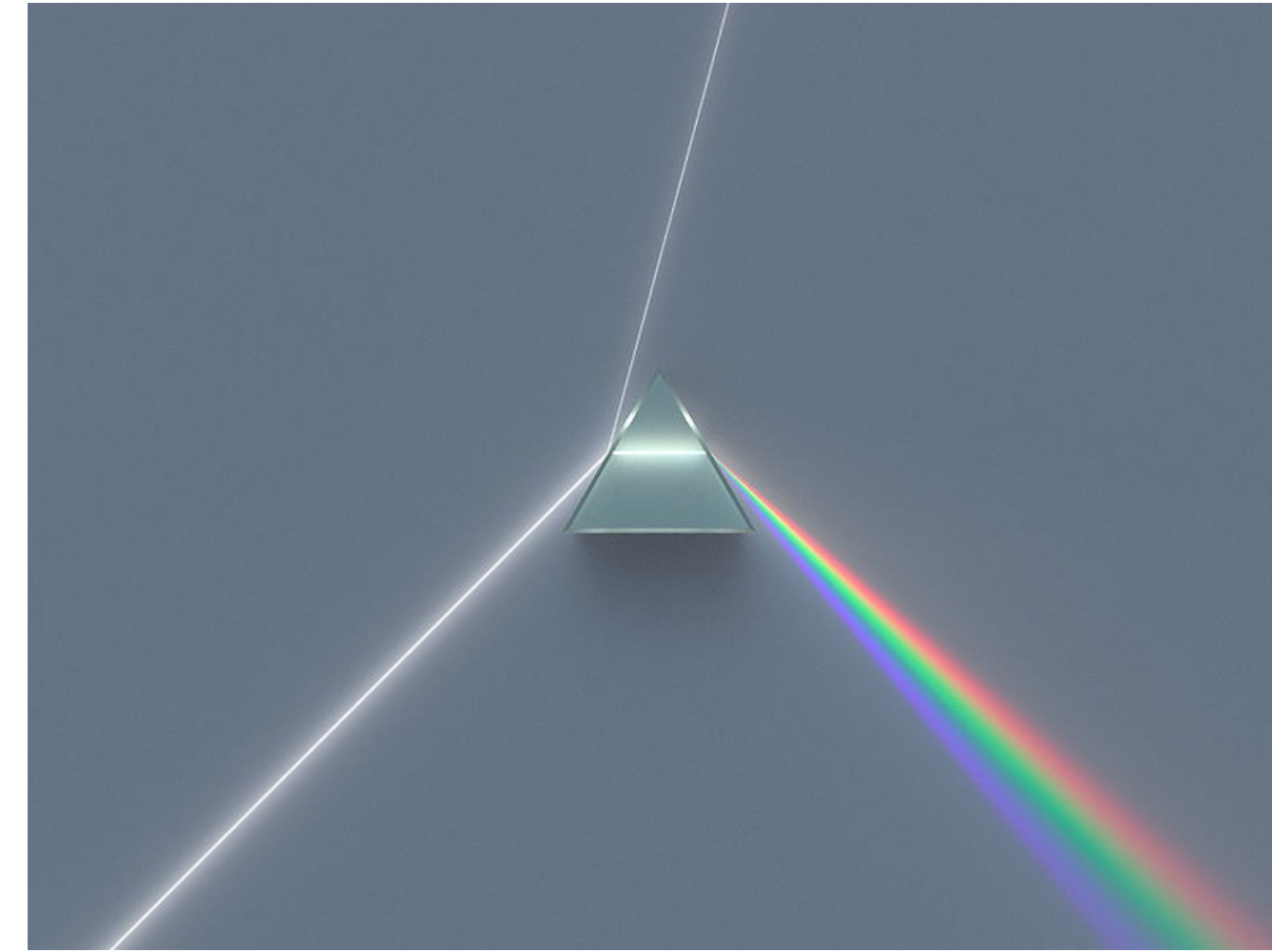
390-750 nm

## Spectral colors

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

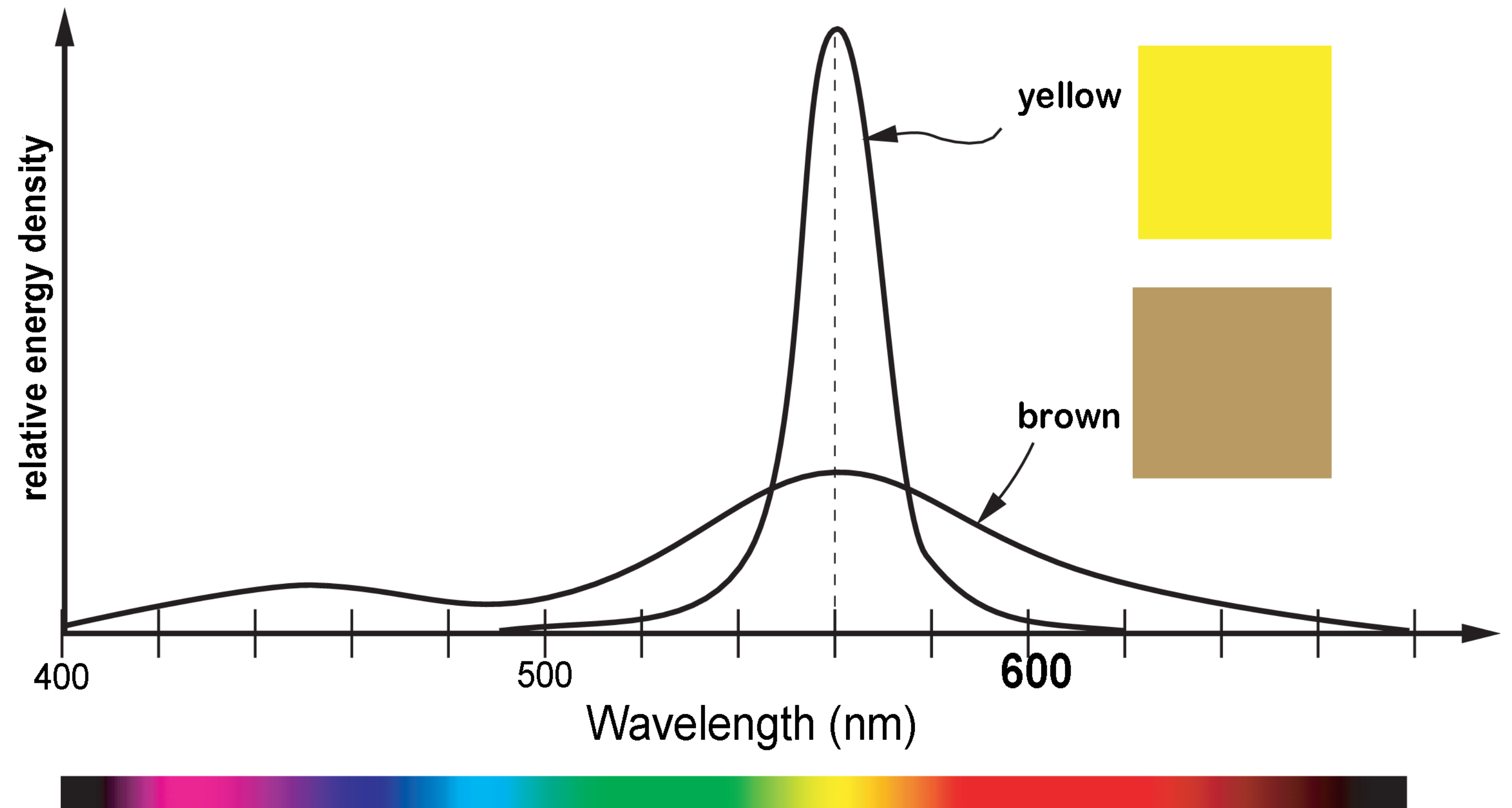
## Other colors: unsaturated colors

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

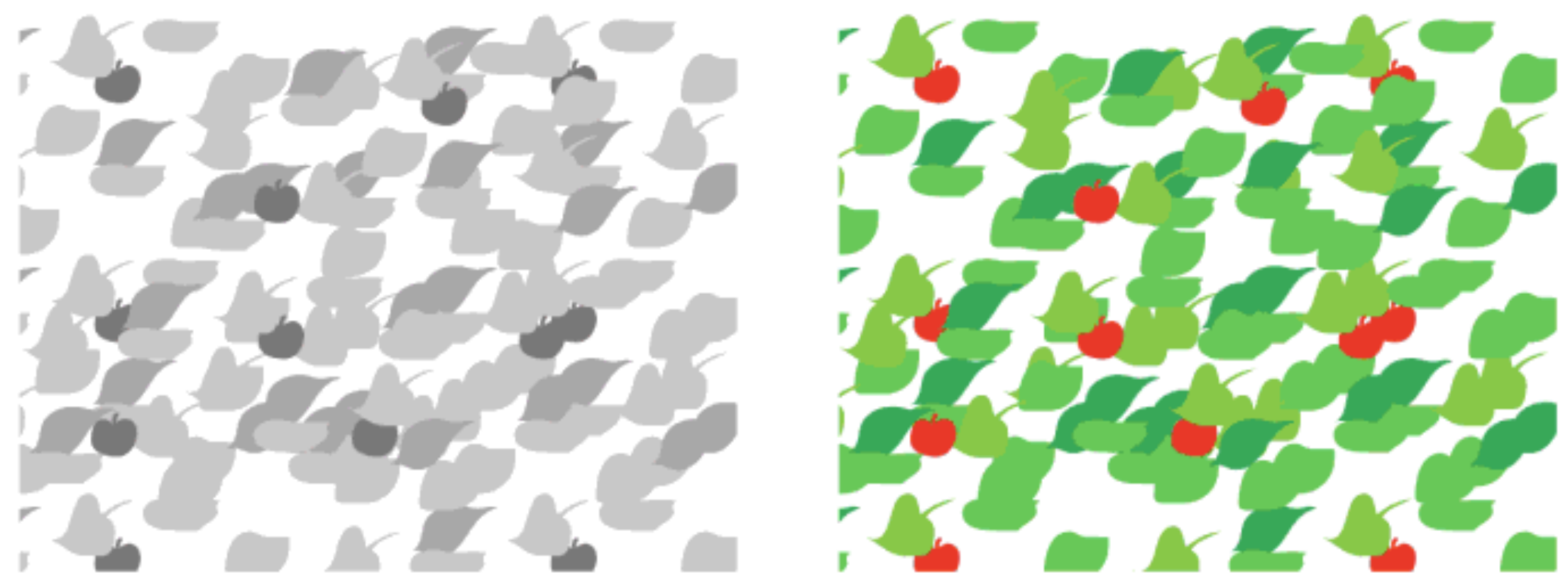


# color != wavelength

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

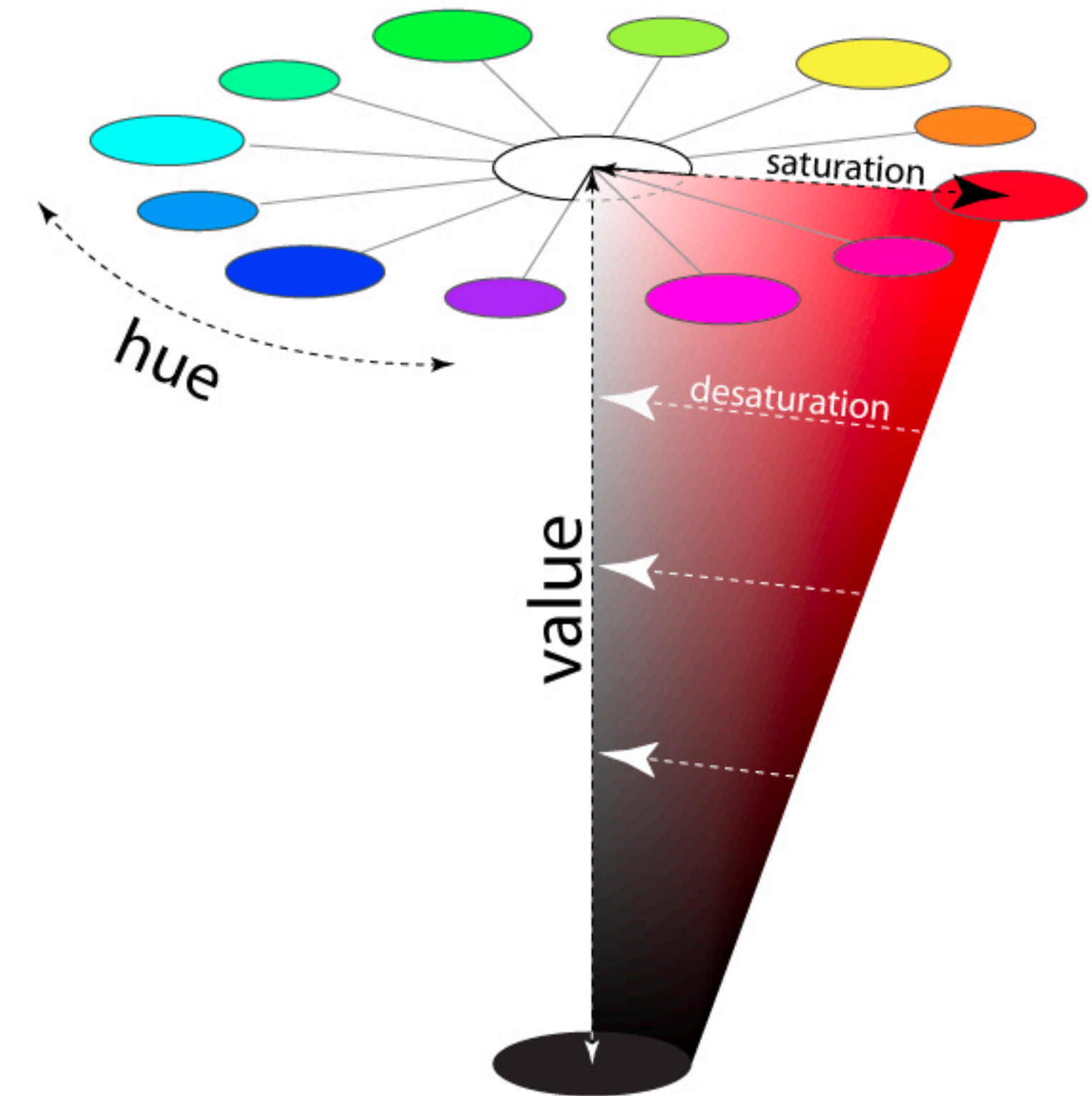
The purity of a color

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

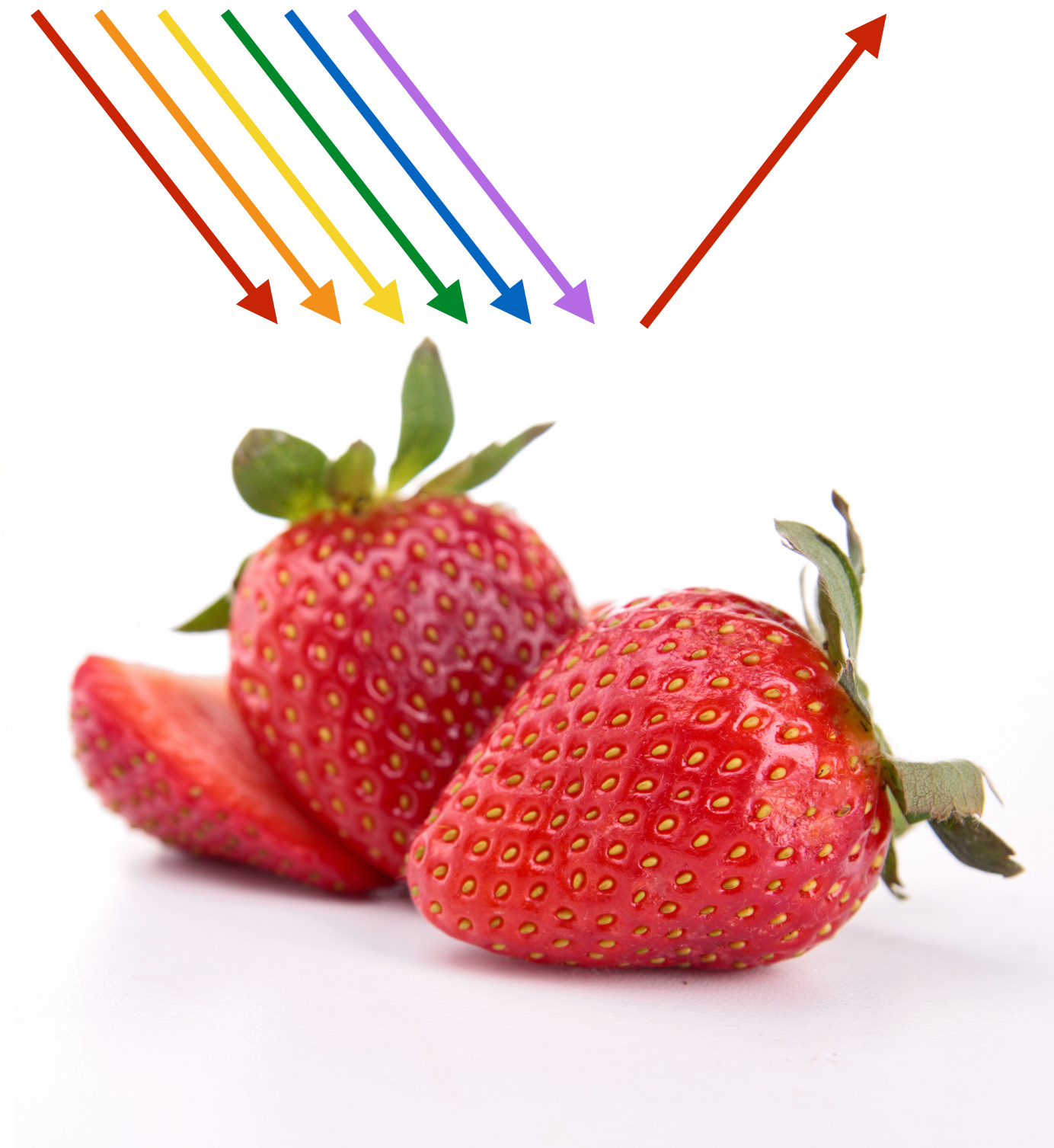
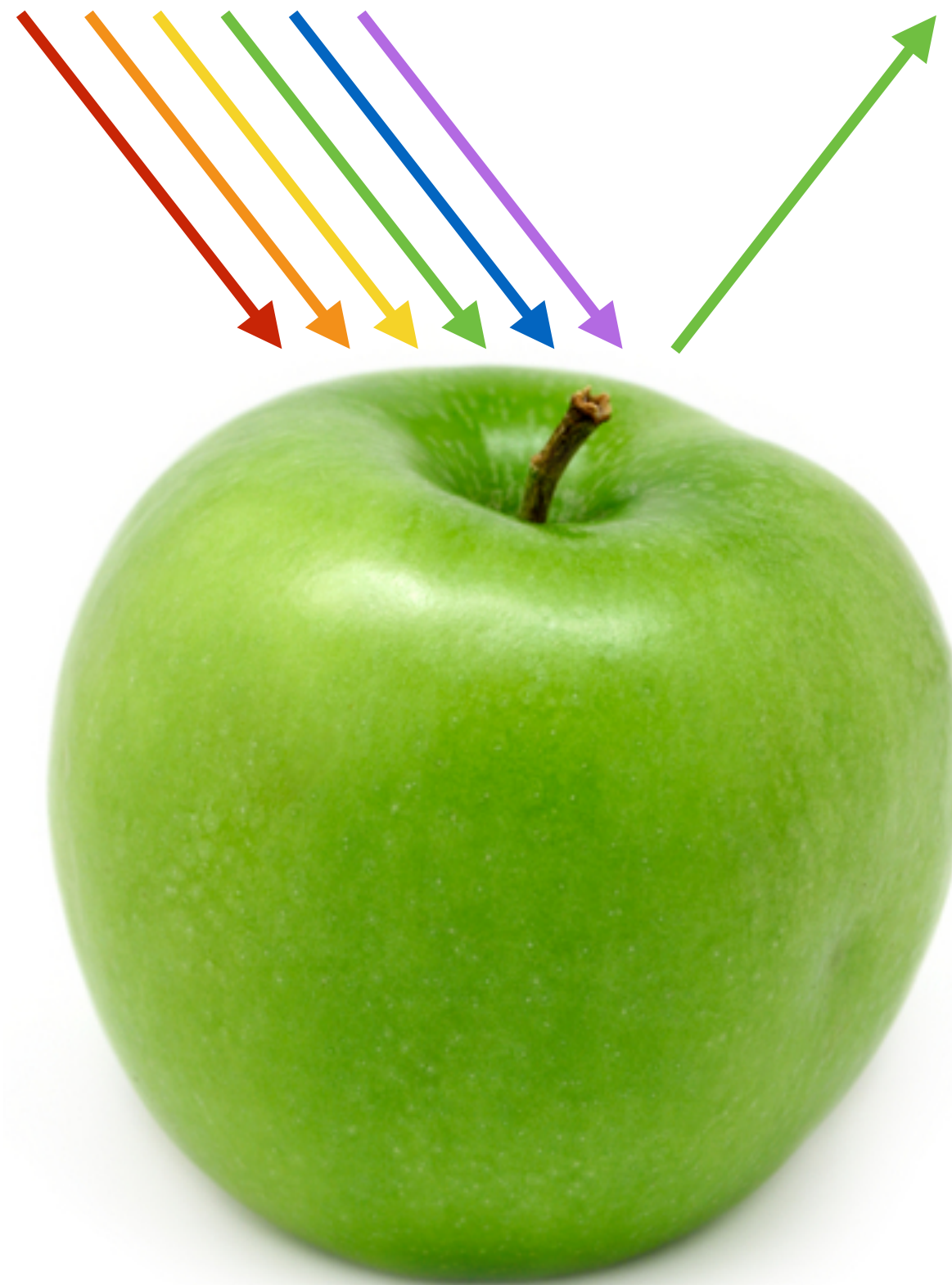
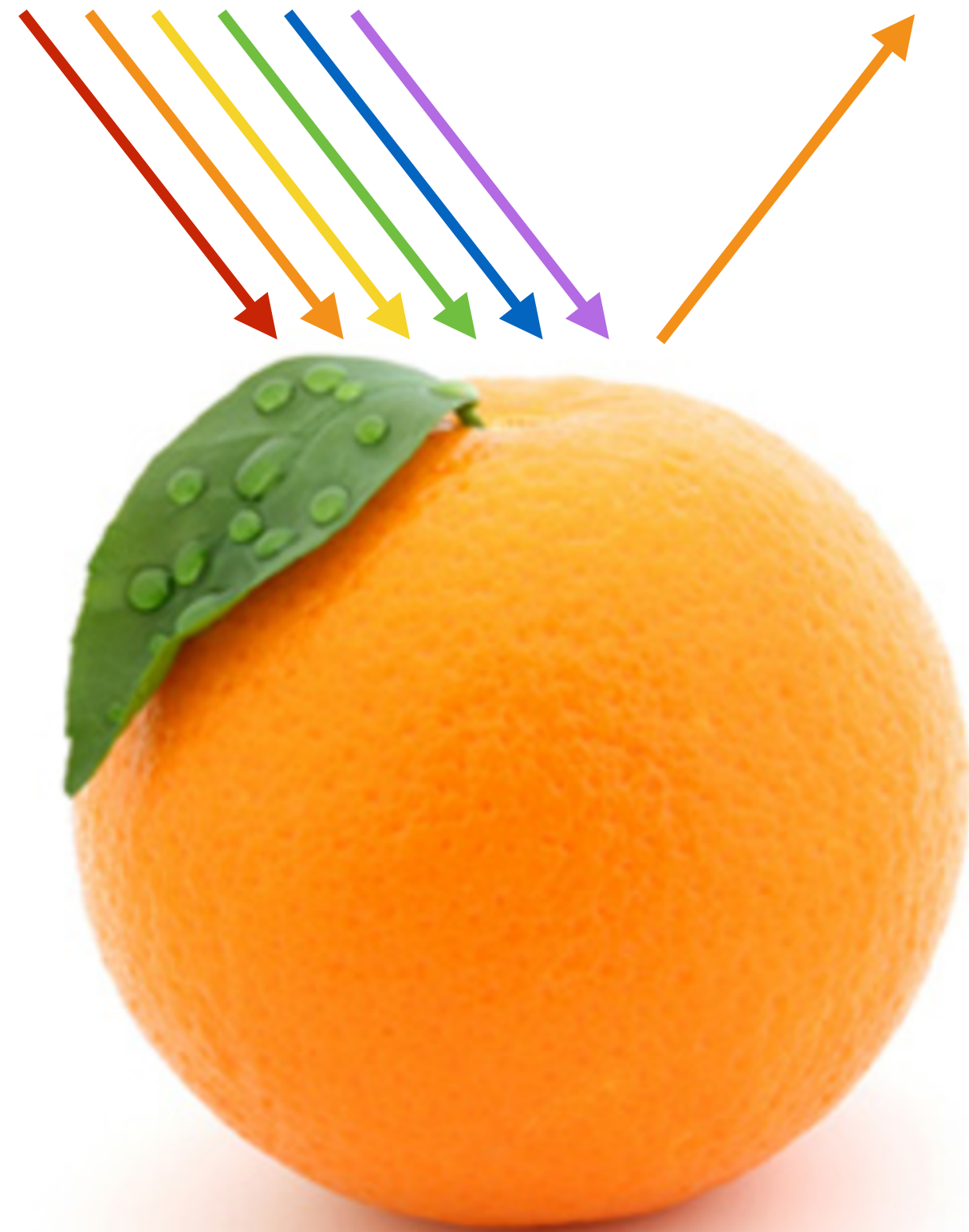


HSV Model



# The role of objects

real light is more than a single wavelength:





Rippin' the Rainbow a New One – Radiolab

www.radiolab.org/story/211178-rip-rainbow/

Reader

Device(Anonymous) camera http://192.168.2.1/ Google Scholar UT hiking poetry-vis Marriott Library

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# Rippin' the Rainbow a New One

« Back to Episode

08:25 / 18:58

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(jared/flickr/CC-BY-2.0)

We tear into this show with a dark scene from 1665. A young Isaac Newton, hoping to ride out the plague by heading to the country to puzzle over the deep mysteries of the universe, finds himself wondering about light. And vision. He wants to get to the bottom of where color comes from—is it a physical property in the outside world, or something created back inside your eyeball somewhere? **James Gleick** explains how Newton unlocked the mystery of the rainbow. And, as **Victoria Finlay** tells us, sucked the poetry out of the heavens.

**Jonah Lehrer** restores some of the lost magic by way of

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<https://www.wnycstudios.org/story/211178-rip-rainbow/>

<https://www.wnycstudios.org/story/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



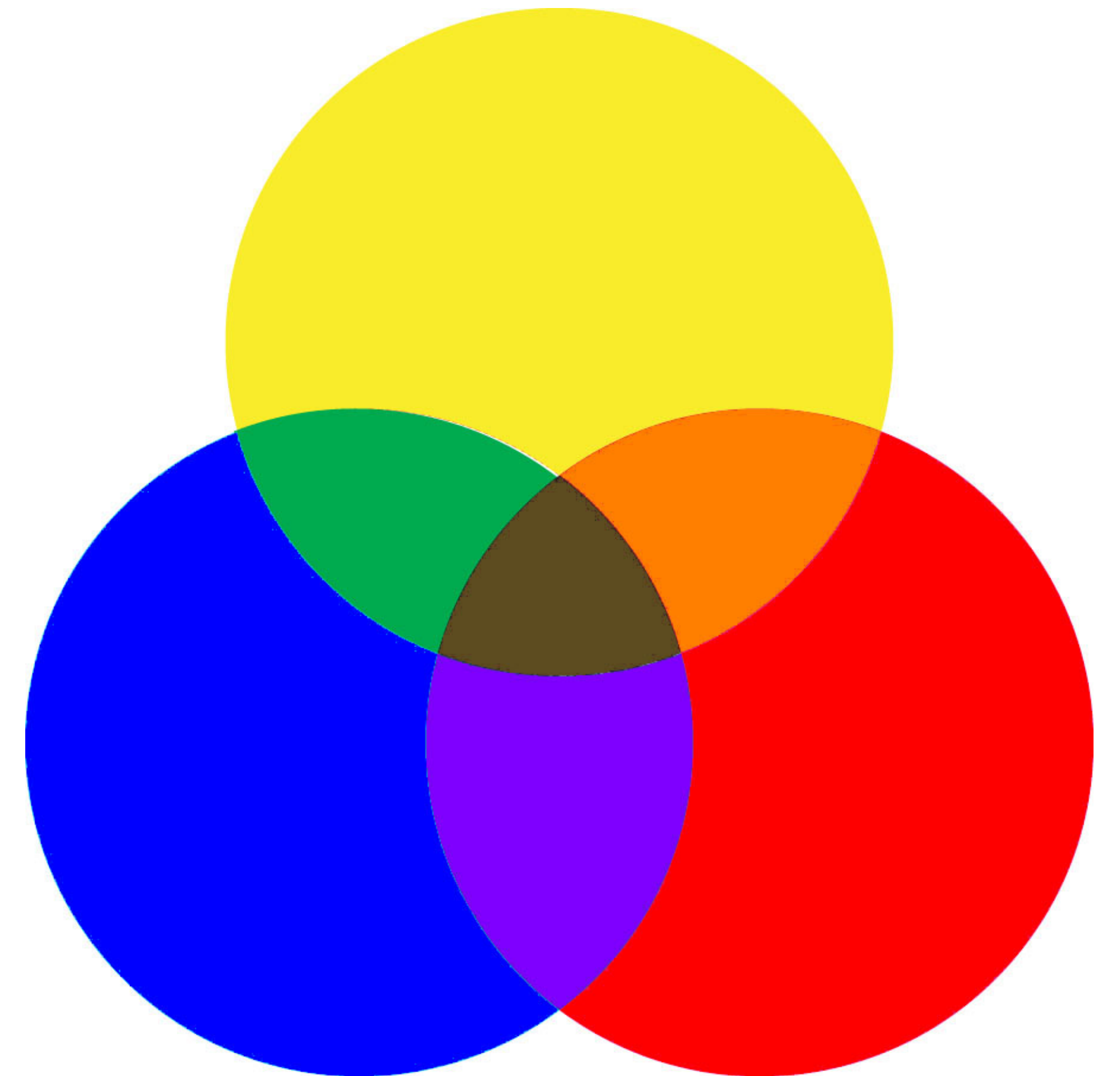
# Paint mixing

physical mixing of opaque paints

primary: Red, Yellow, Blue

secondary (mixed): Green, Orange, Purple

subtractive



# Ink mixing

subtractive mix of transparent inks

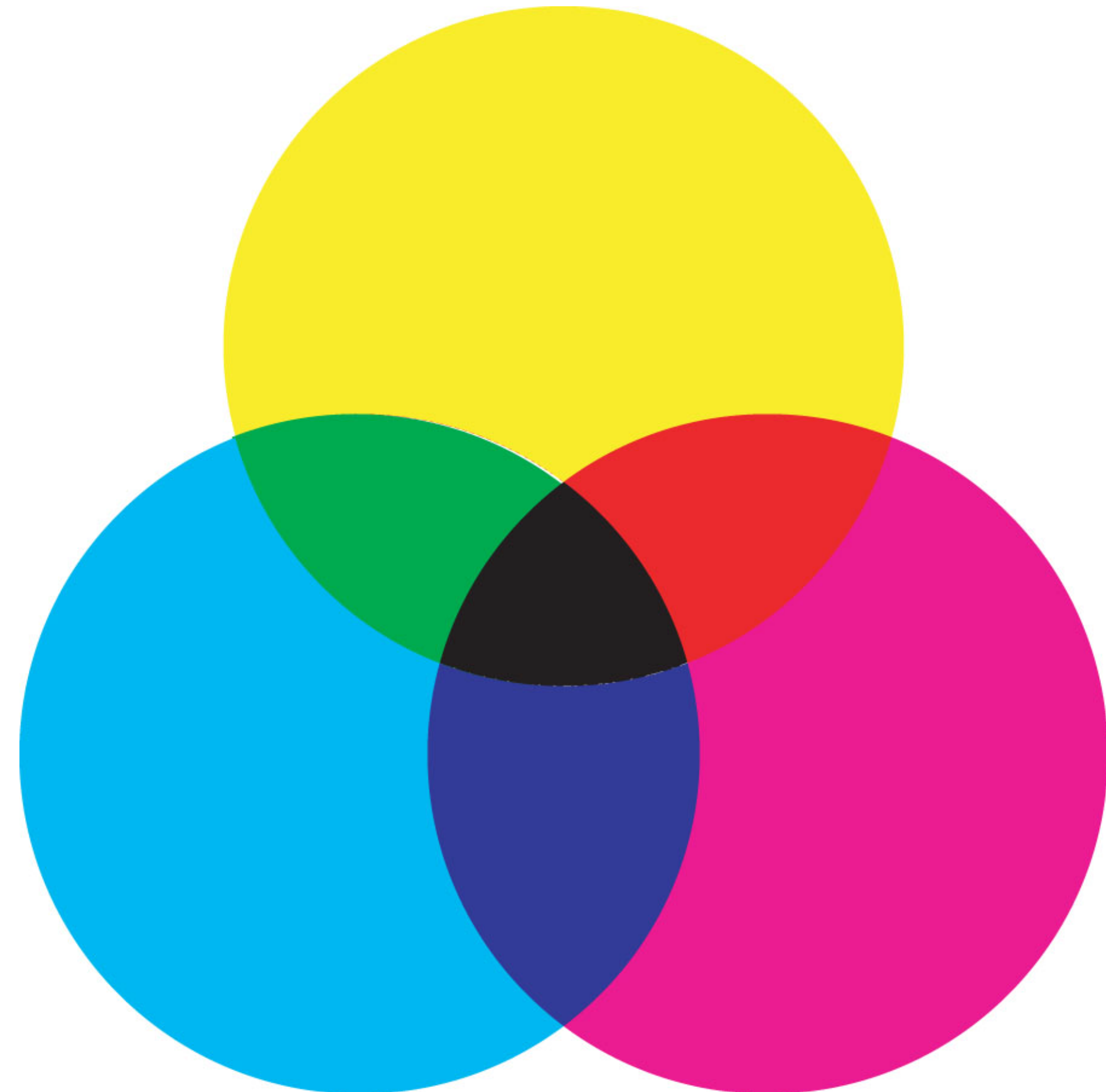
primary: Cyan, Magenta, Yellow

secondary: RGB

approx. black = C+M+Y

true black = C+M+Y+K

subtractive



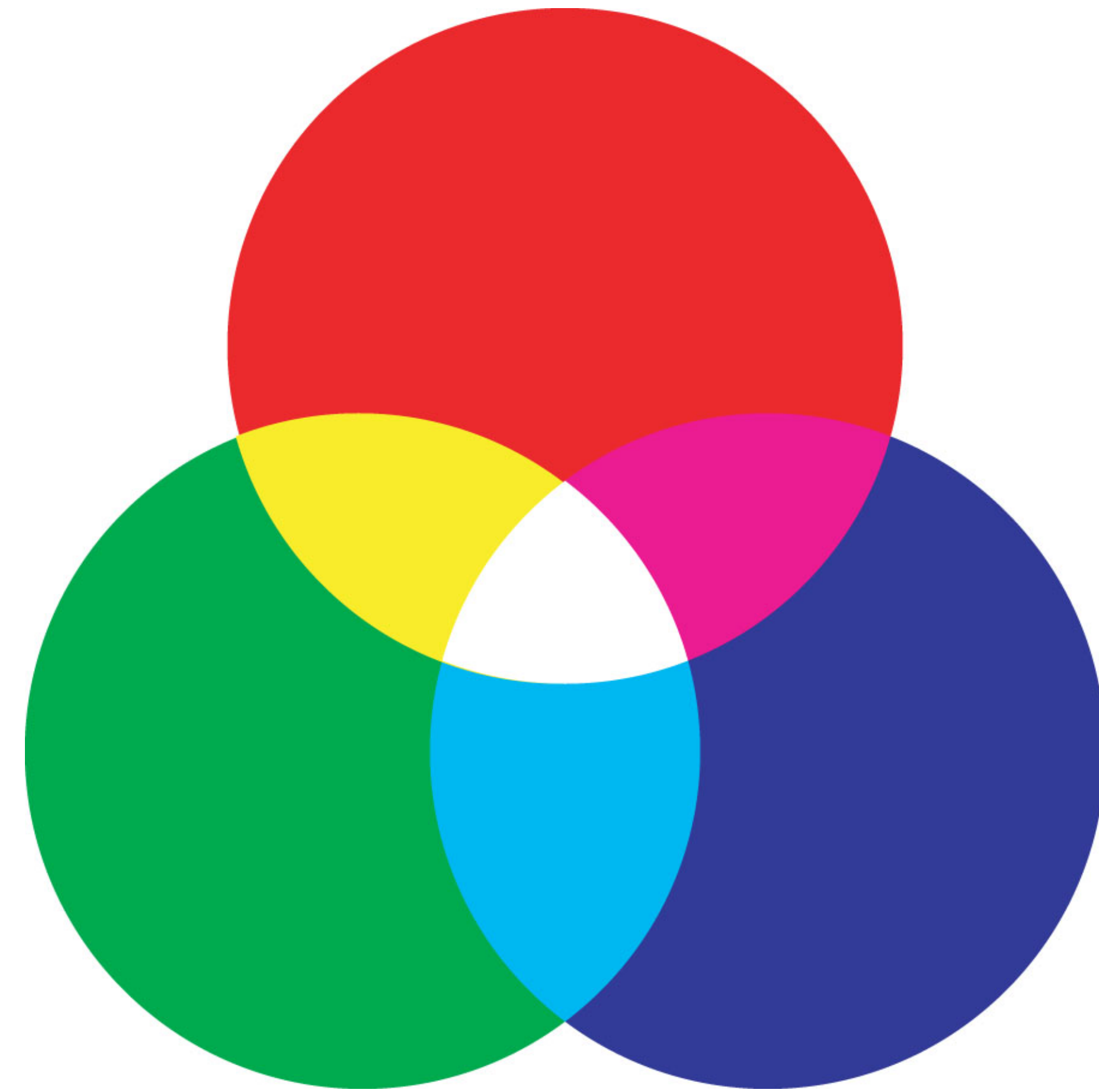
# Light mixing

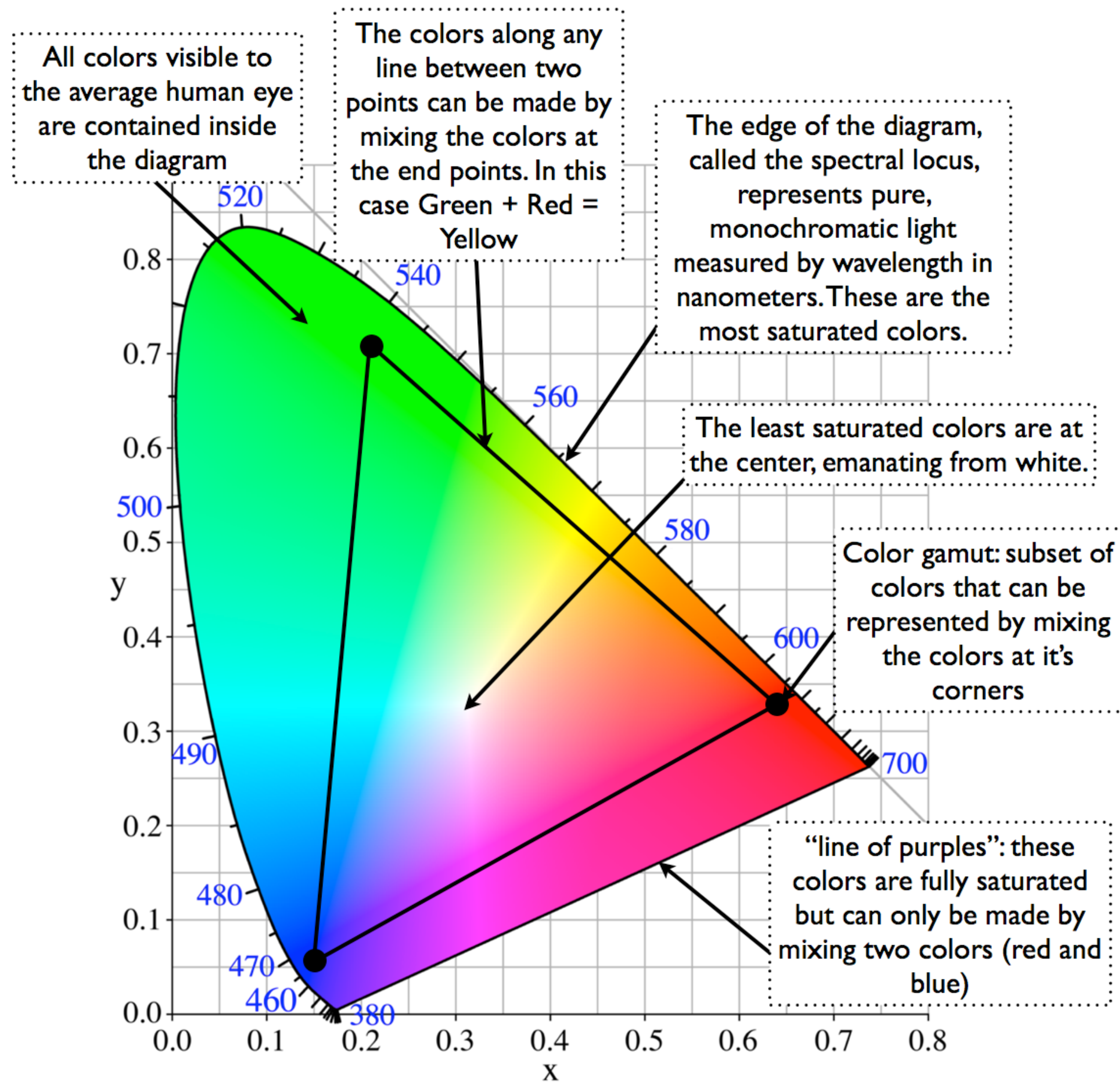
additive mix of colored lights

primary: Red, Green, Blue

secondary: Cyan, Magenta, Yellow

additive





# Anatomy of a CIE Chromaticity Diagram

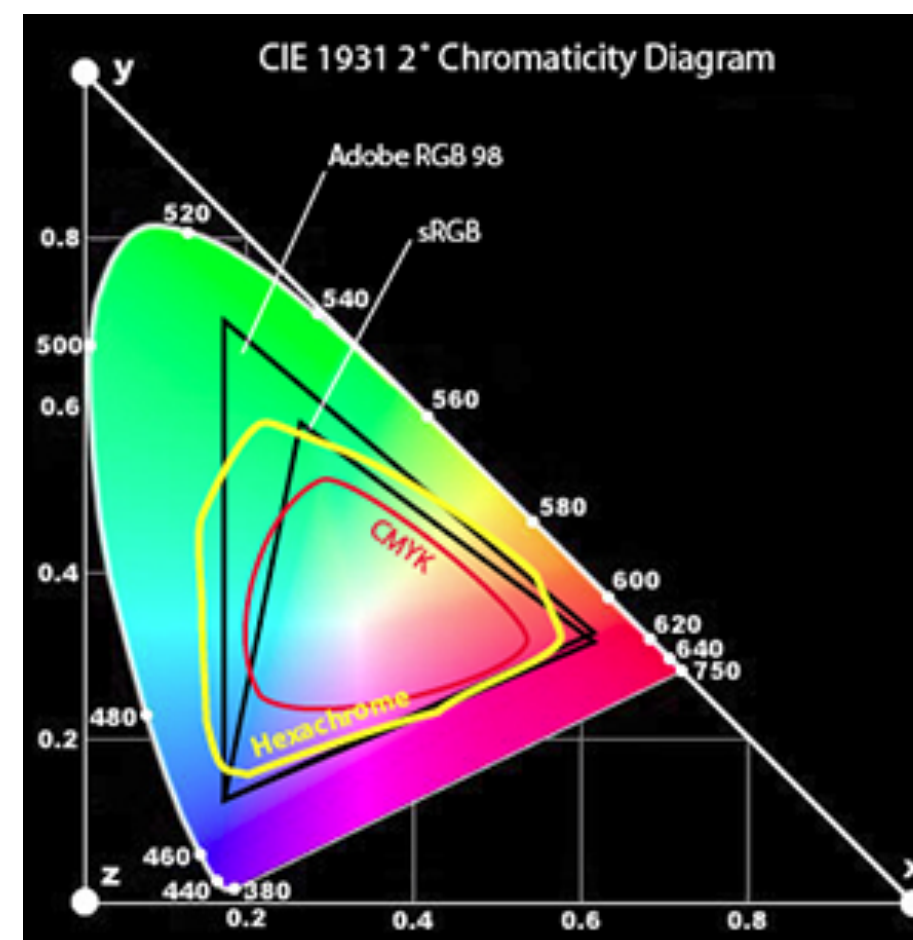


# Gamut

Set of all colors that can be produced by a device

Area between the primary colors used can be shown

Primaries are arbitrary



# What is a colormap?

specifies a mapping between  
color and values

categorical vs ordered

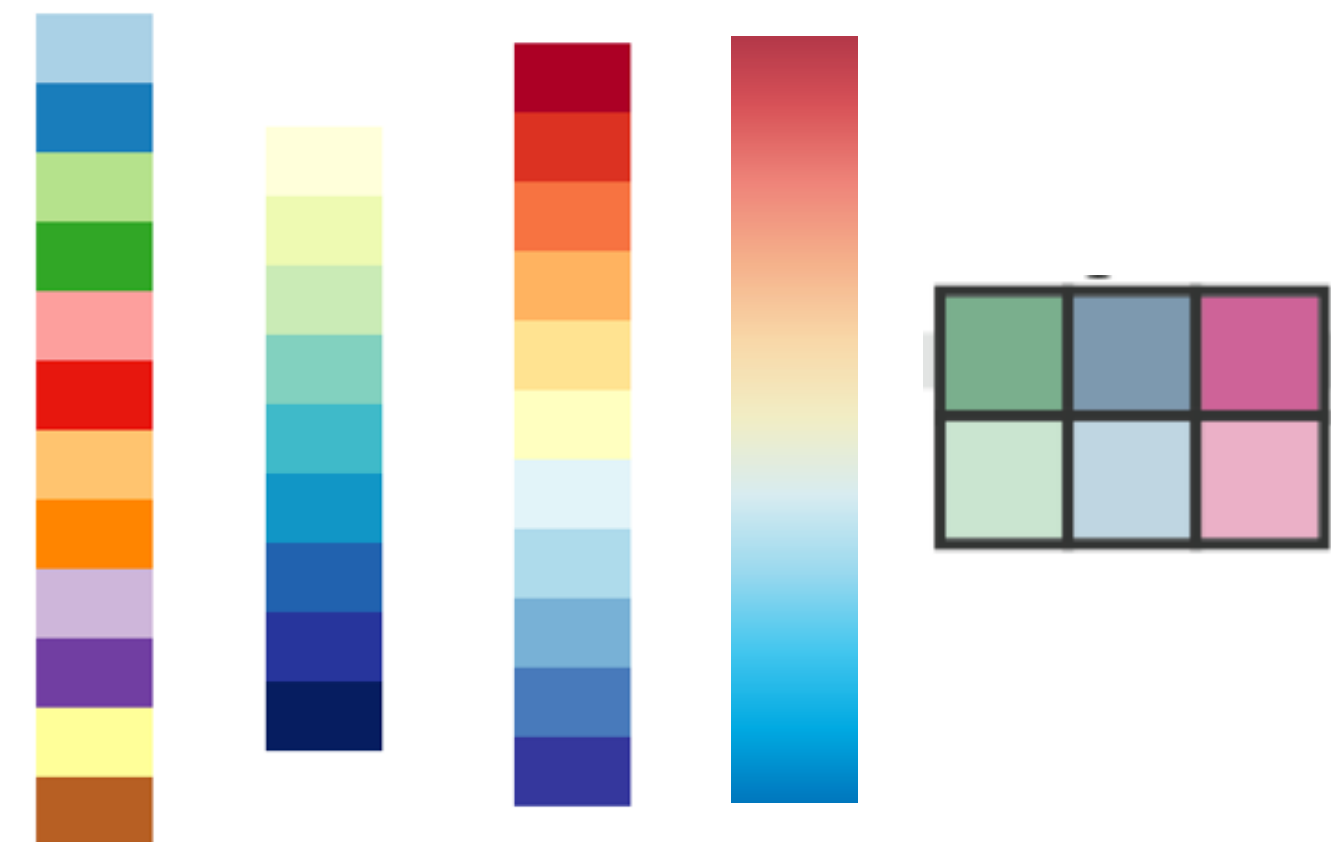
sequential vs diverging

segmented vs continuous

univariate vs bivariate

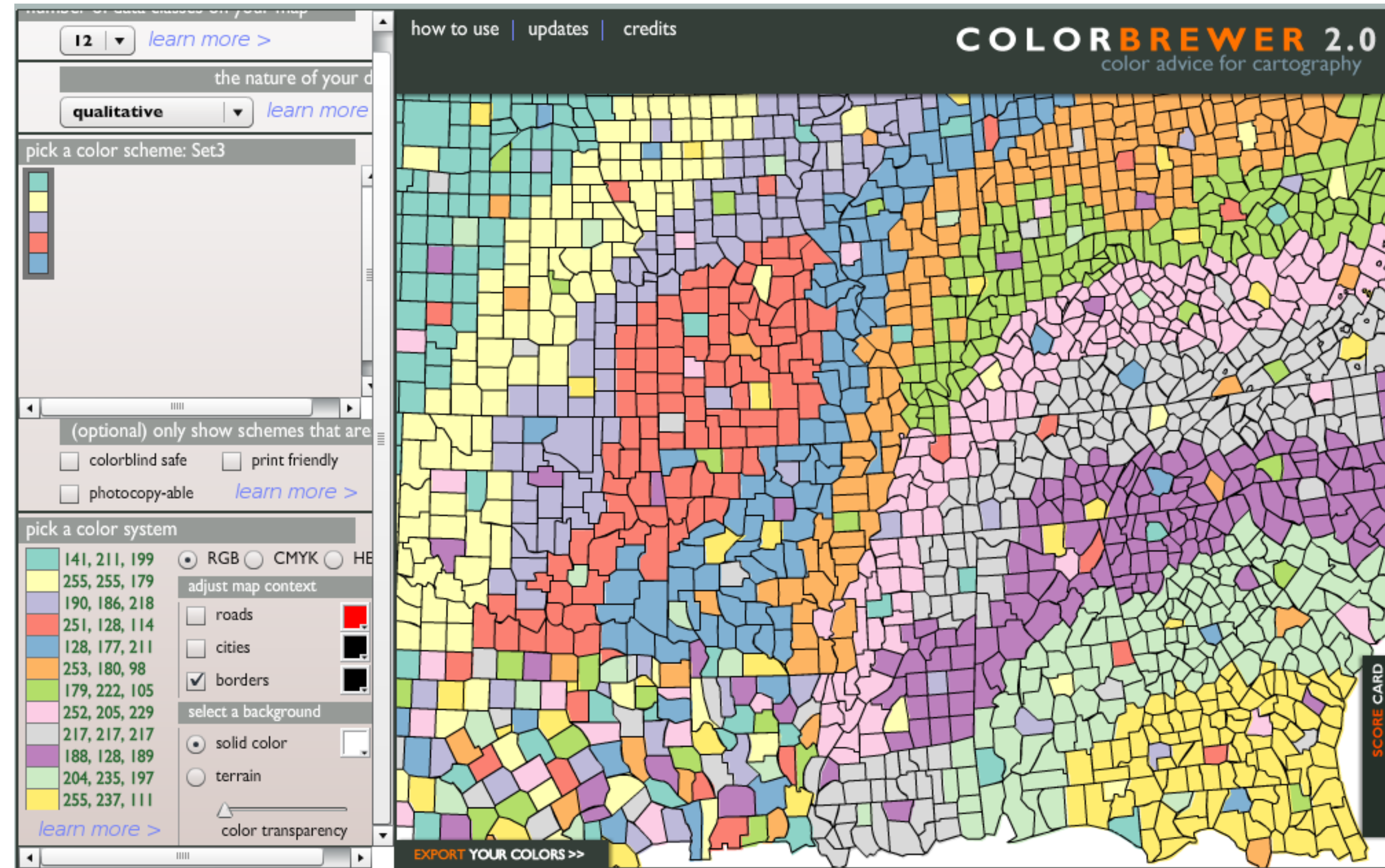
**expressiveness:** match colormap  
to attribute characteristics!

[0,8] →



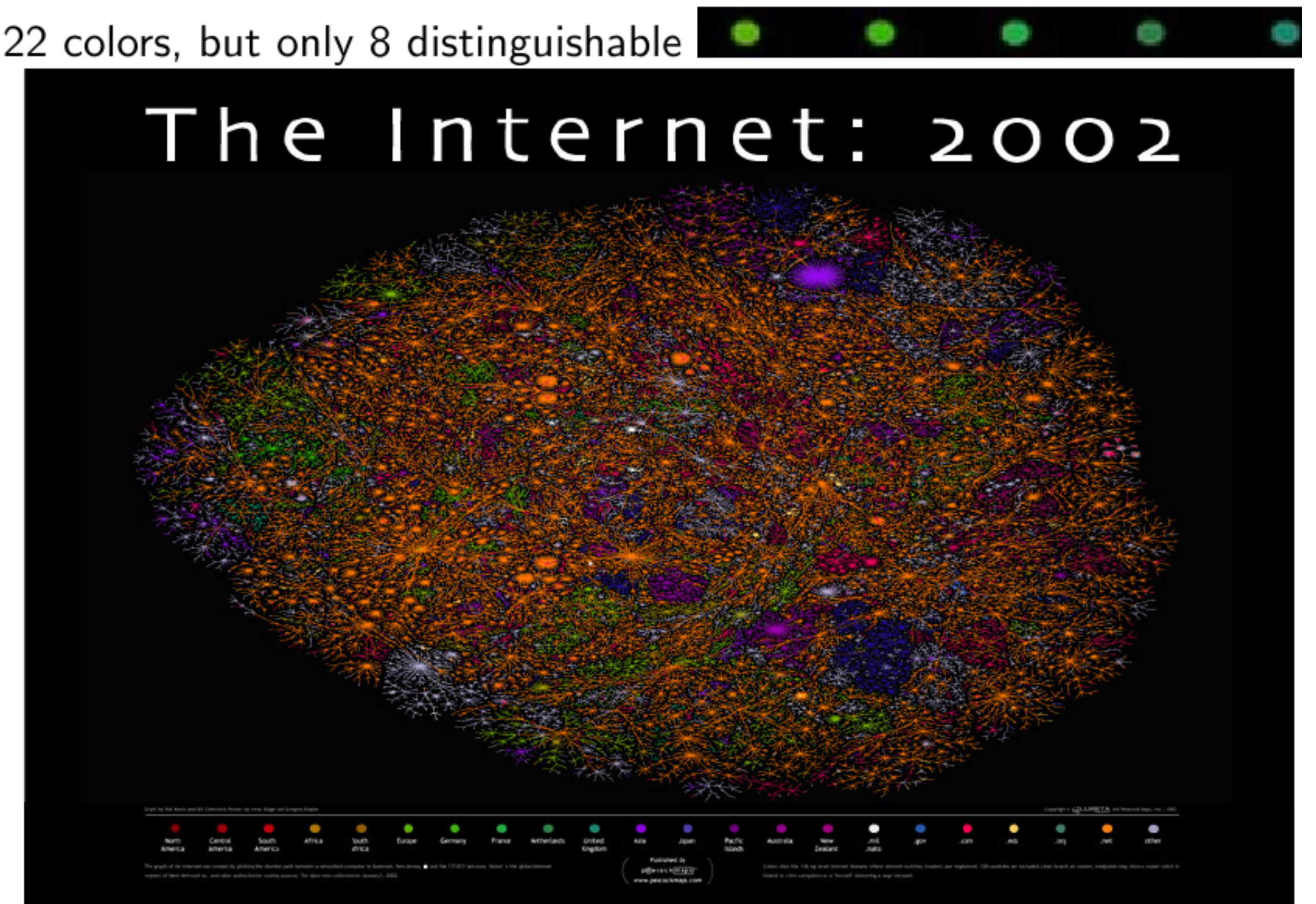


# Application: Labeling



Carefully designed color scheme for 12 colors [colorbrewer]







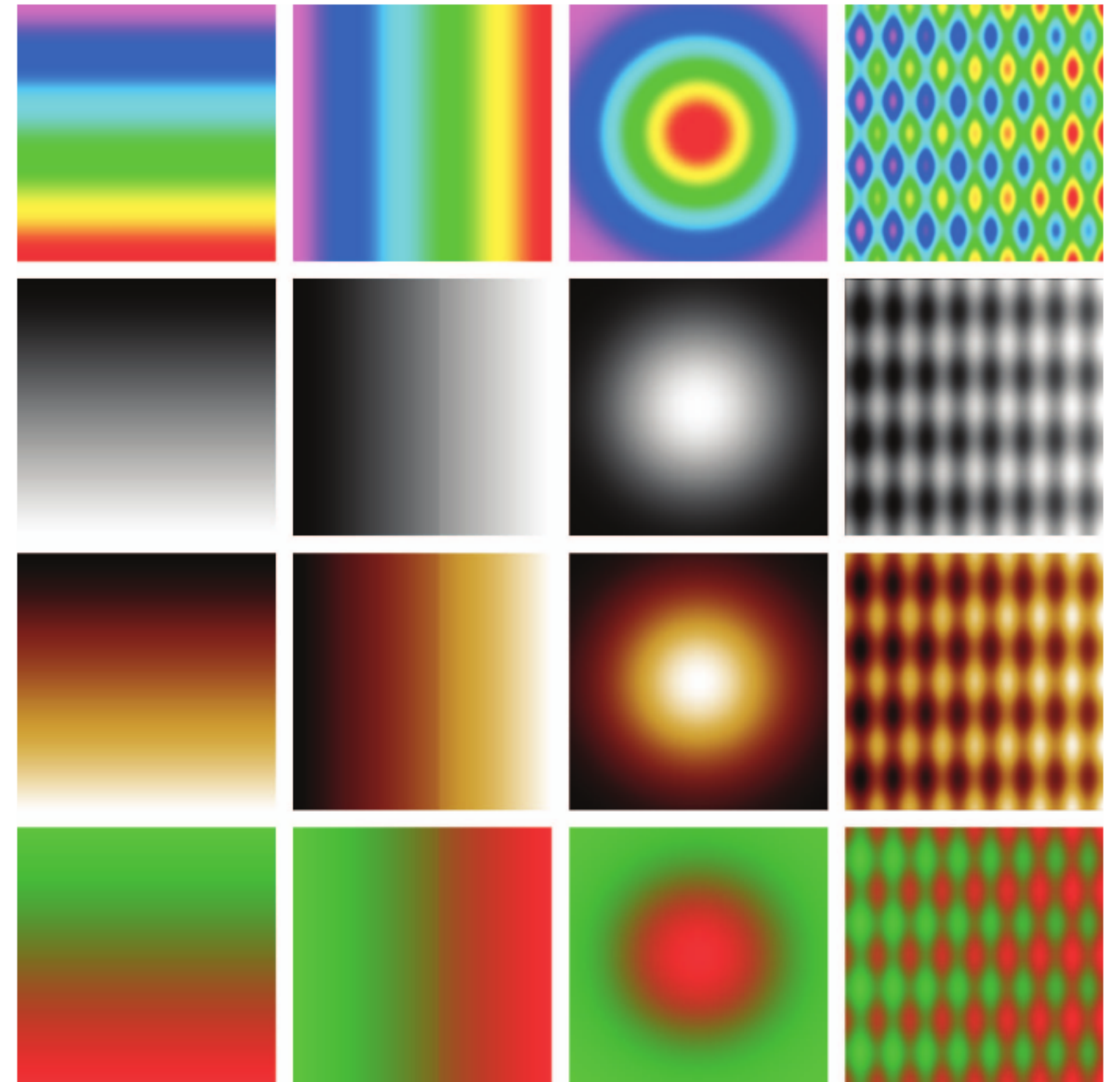
# Color for quantitative data

use value

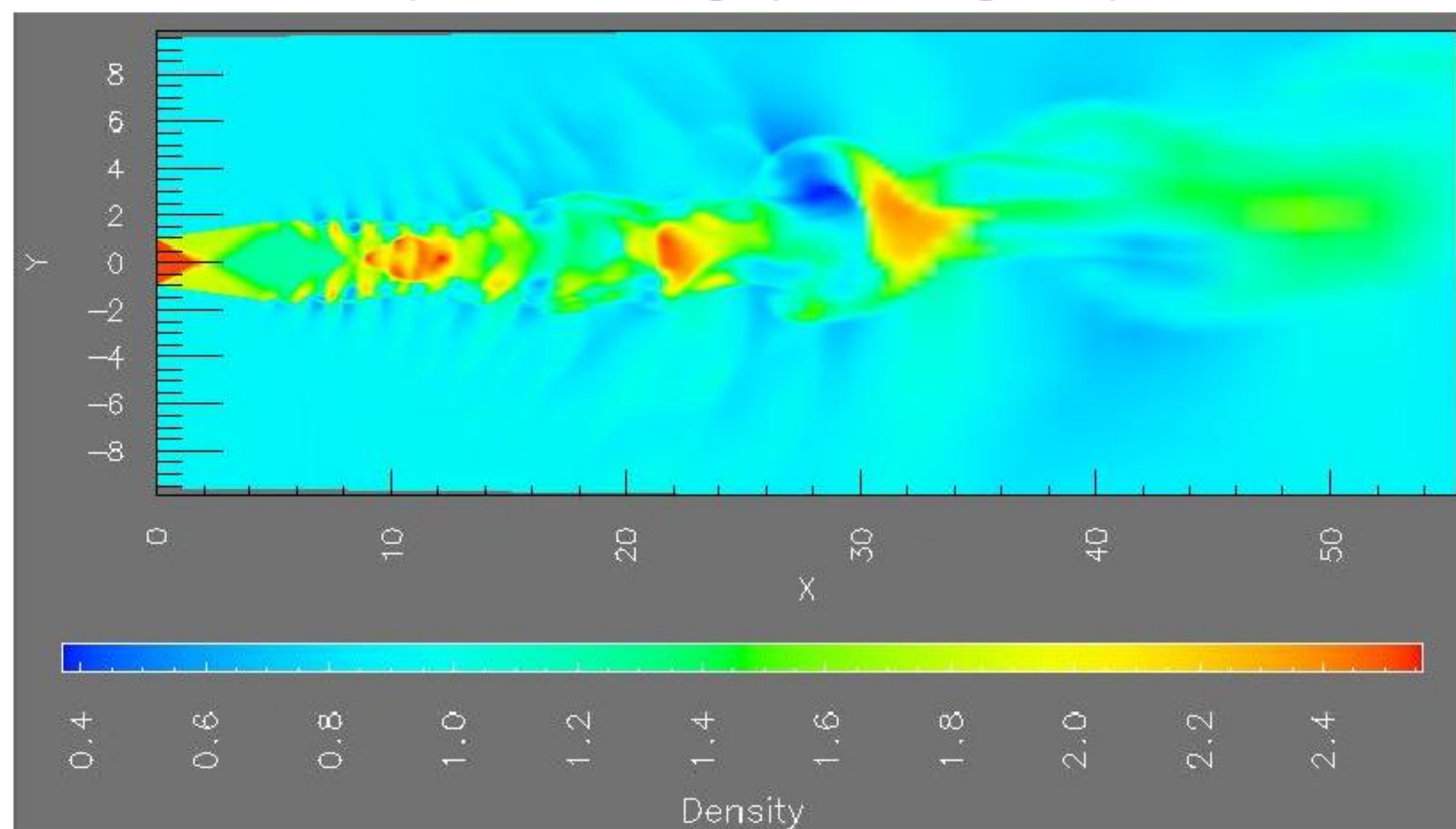
saturation works but not as good

don't use hue!

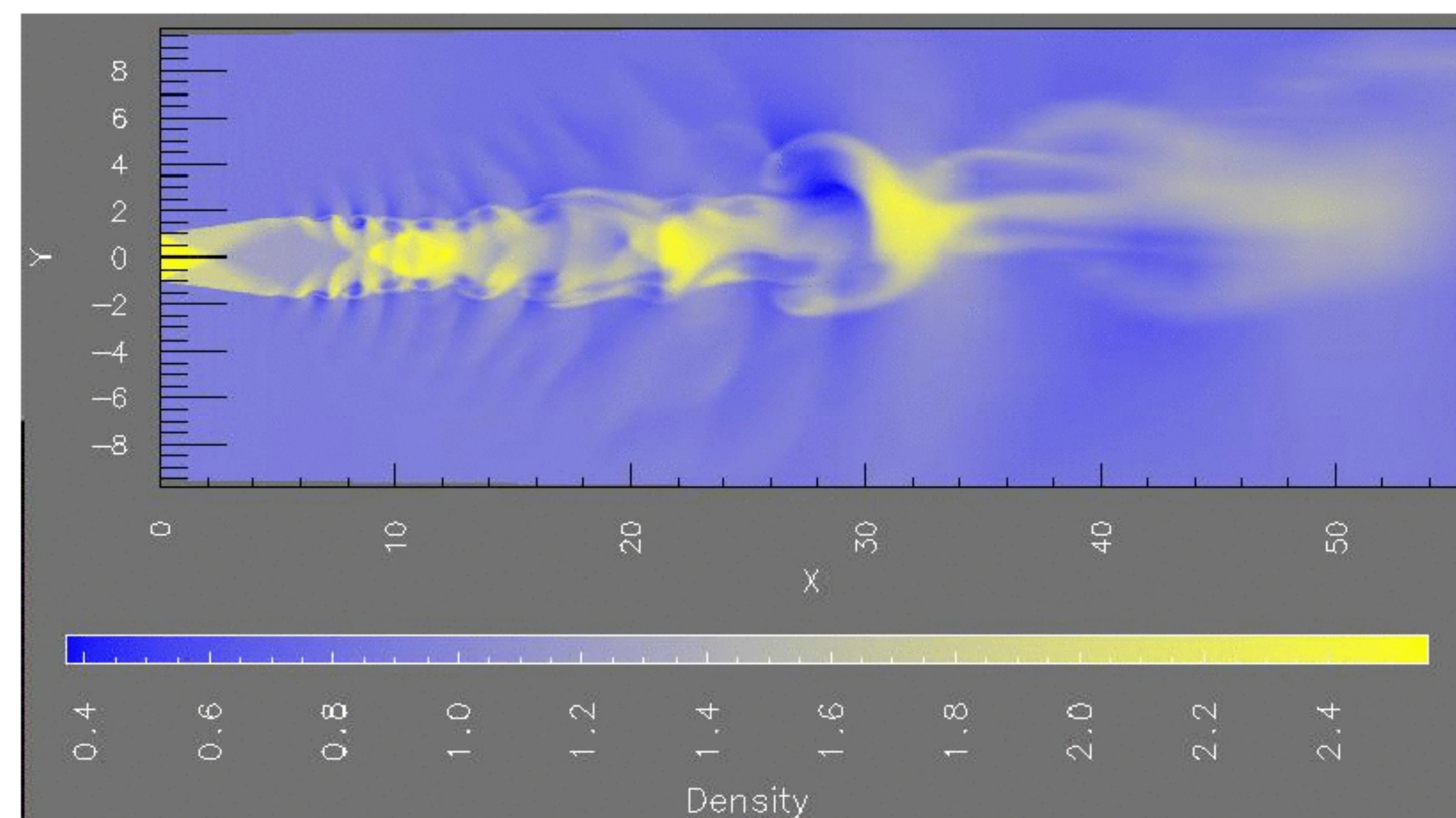
Danger: rainbow color map







[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](http://www.research.ibm.com/dx/proceedings/pravda/truevis.htm)]



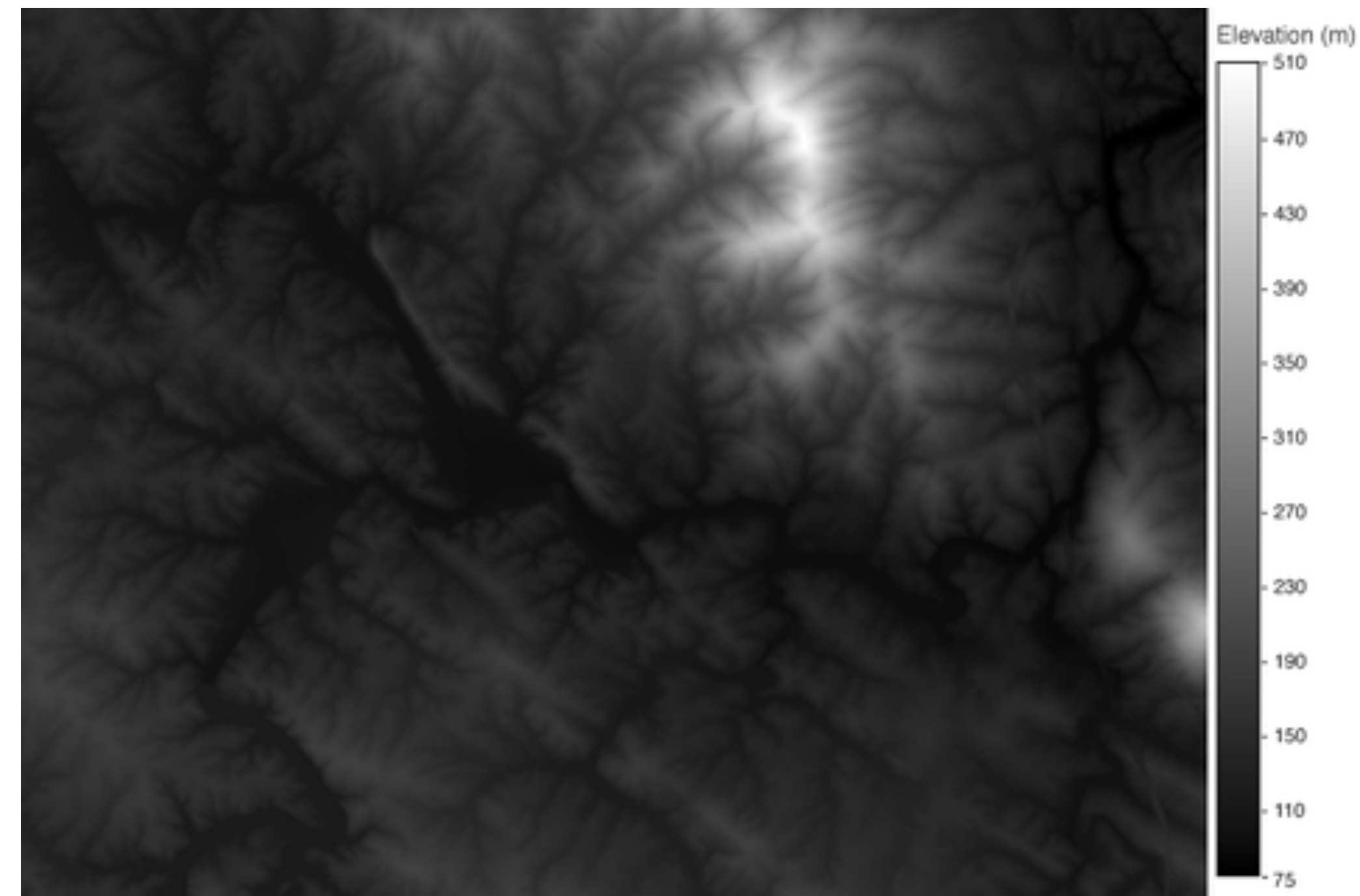
# To bin or not to bin?

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)



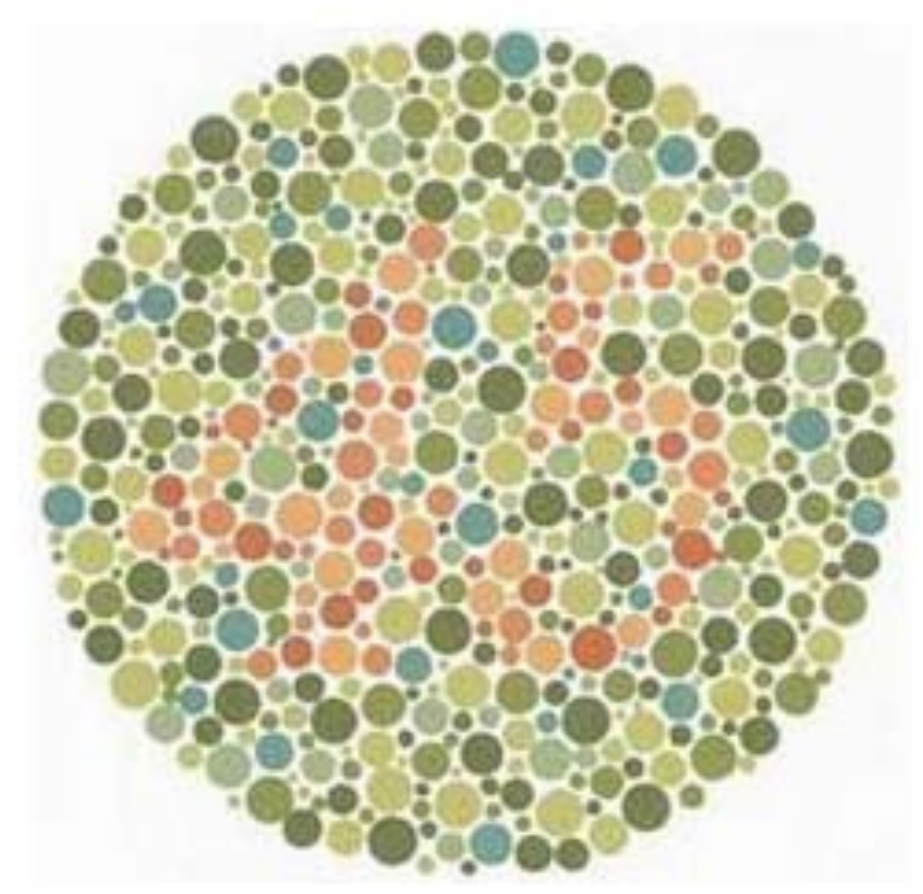
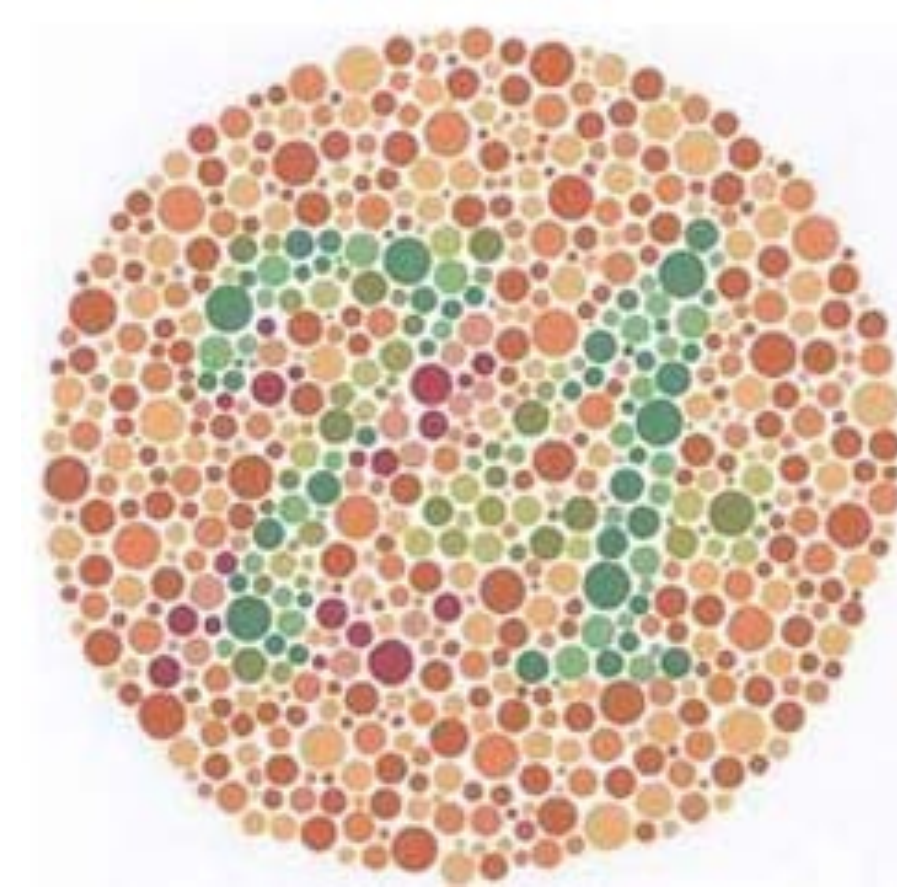
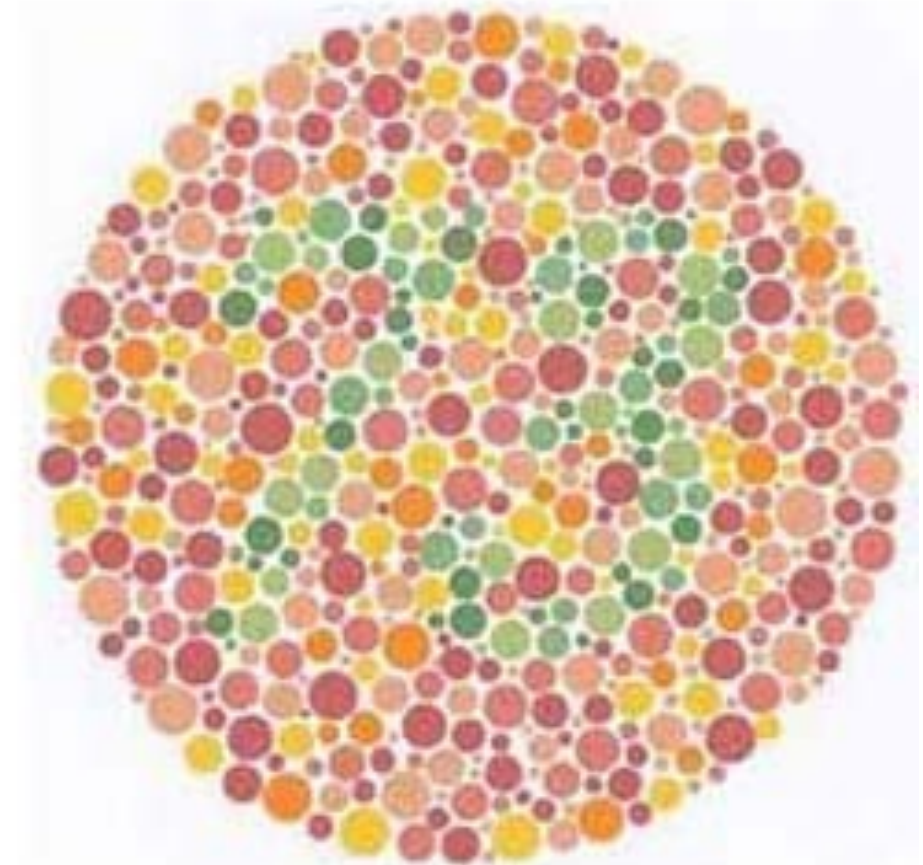
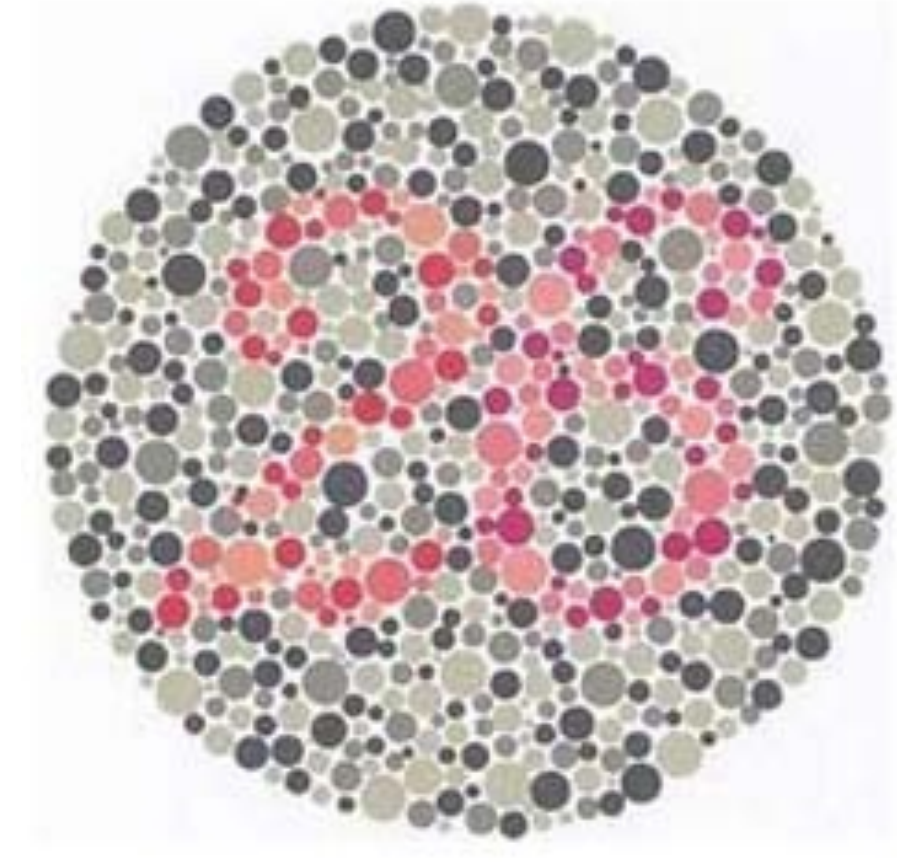
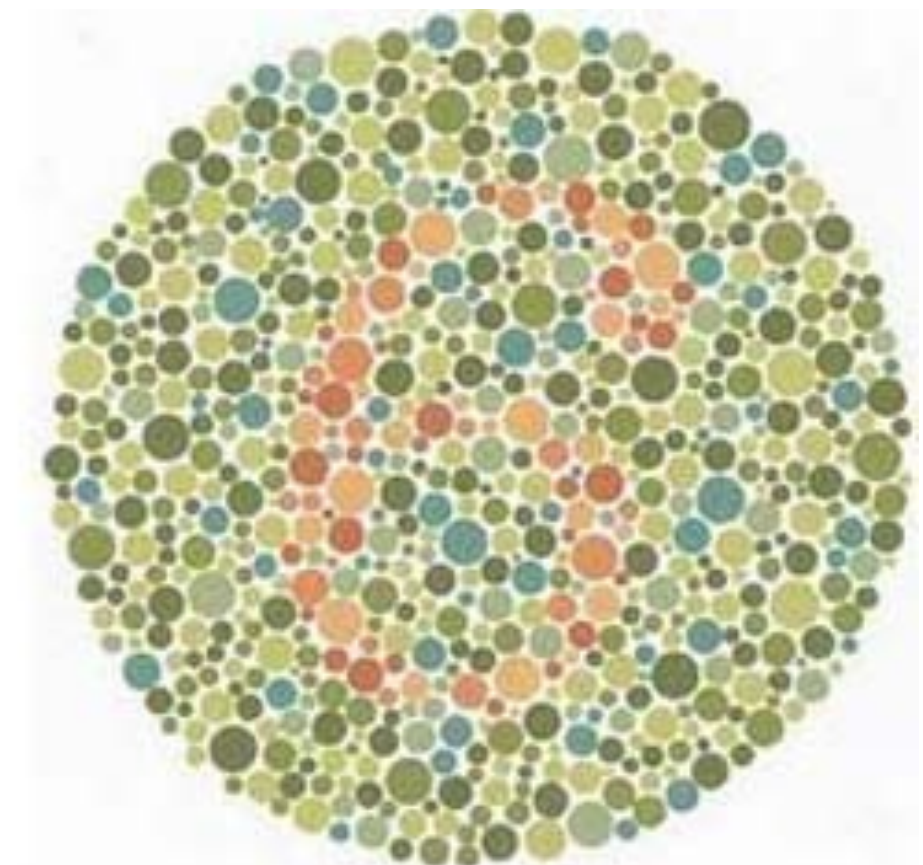
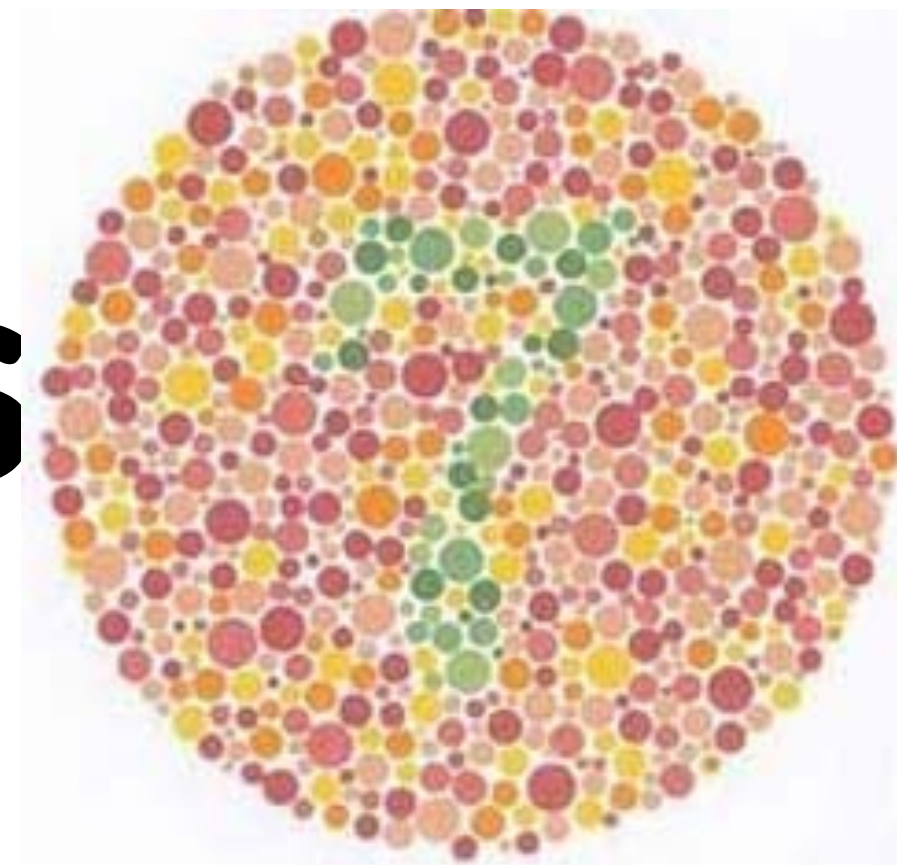
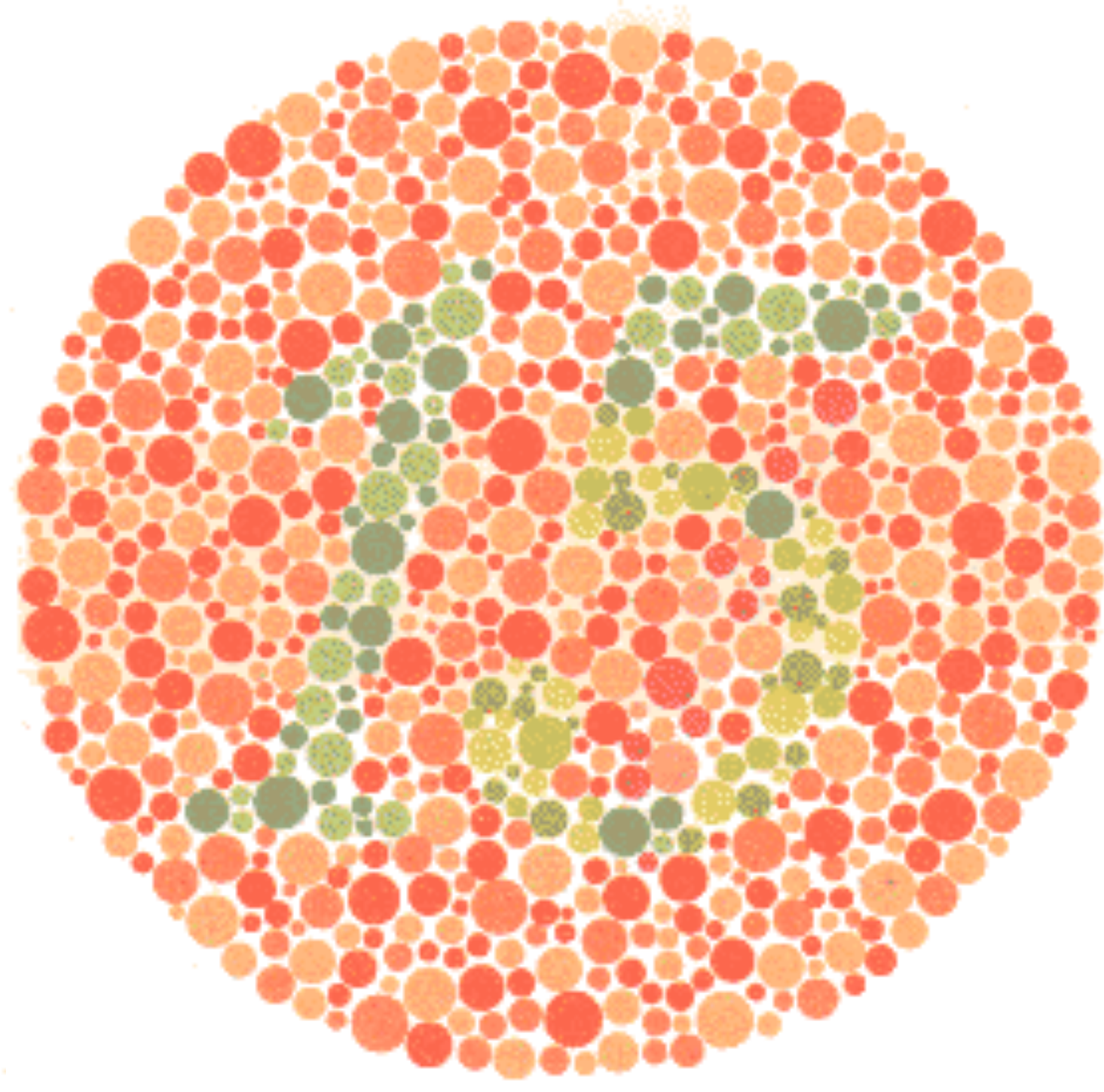
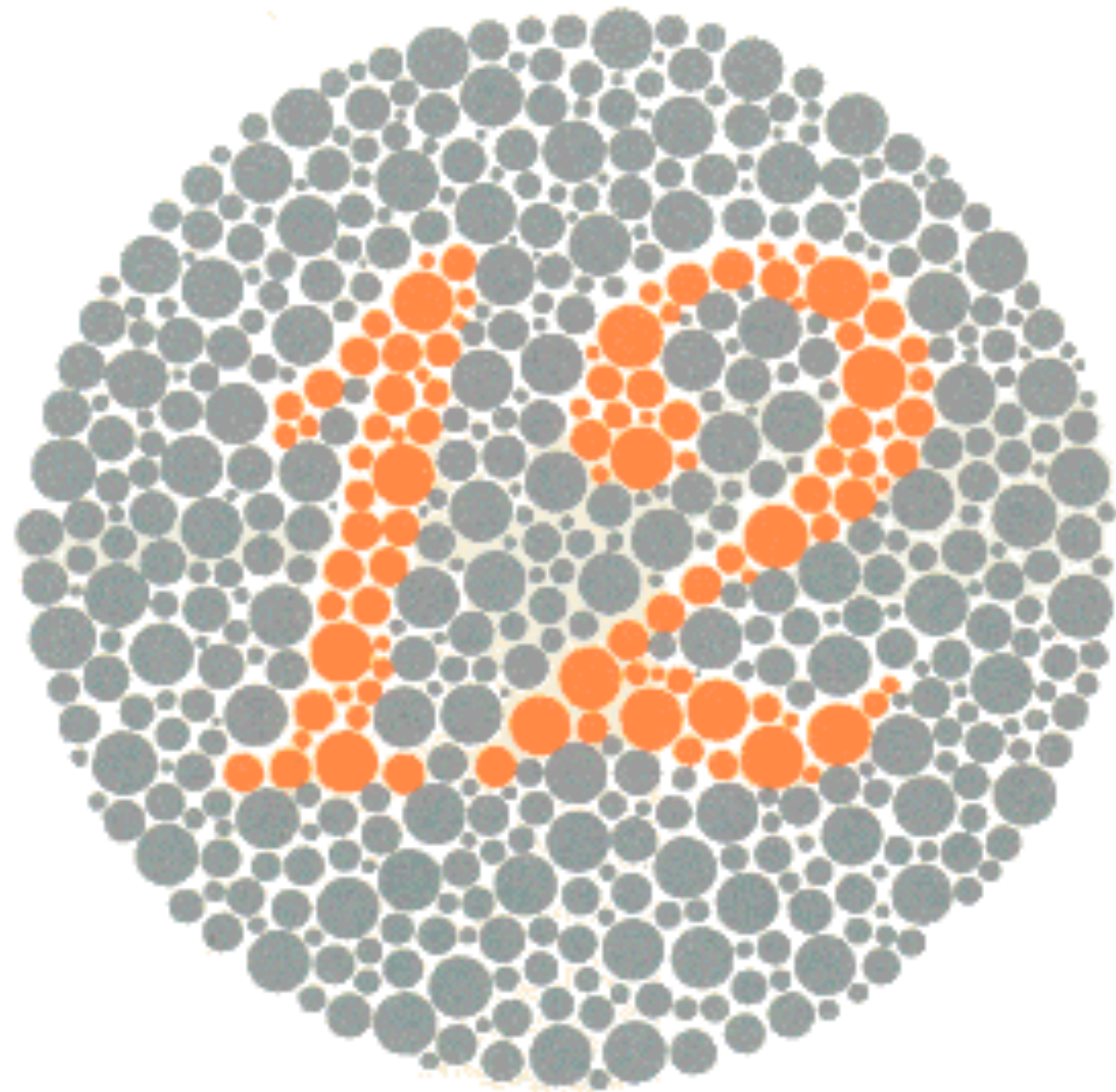
Normal Color Perception

Deuteranopia (no green receptors)

Protanopia (no red receptors)



# Color Blindness Tests





# Color Blindness



Protanope

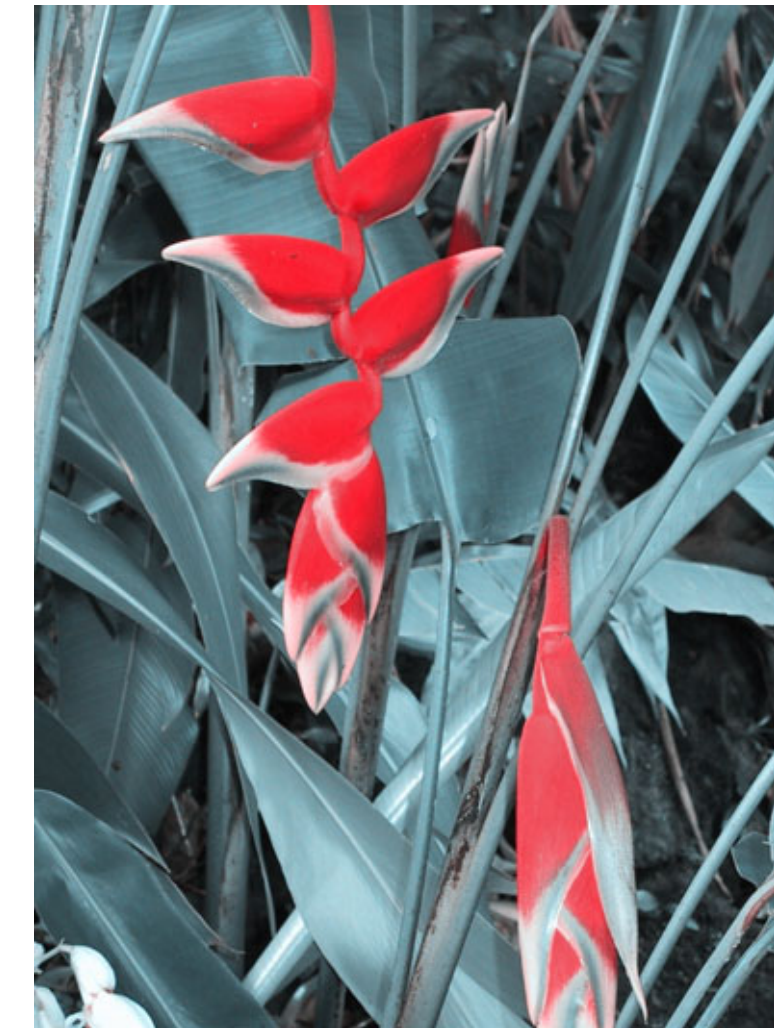
No L cones

Red / green  
deficiencies



Deuteranope

No M cones



Tritanope

No S cones

Blue / Yellow  
deficiency



All Spending Types of Spending Changes Department Totals

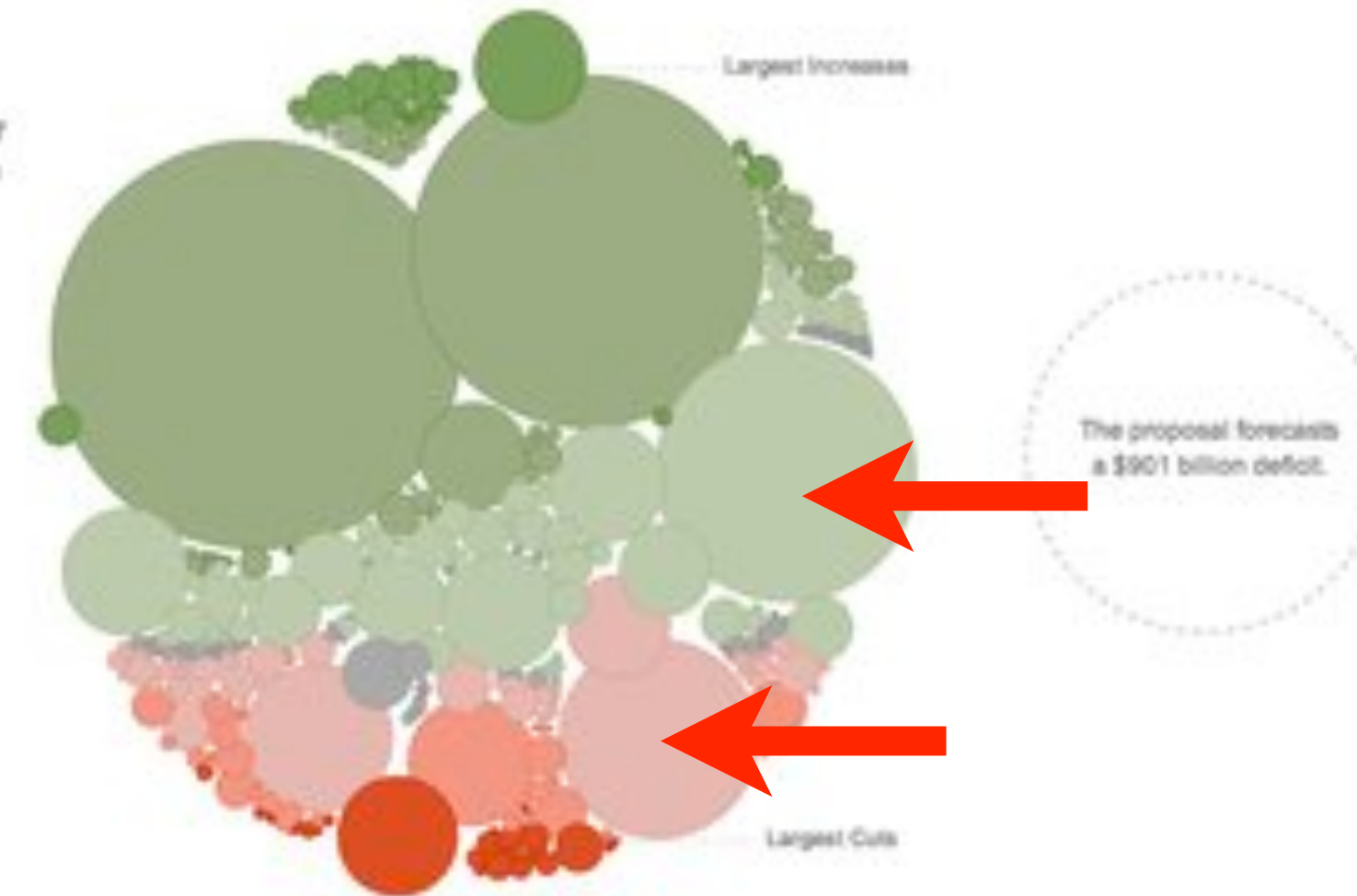
### How \$3.7 Trillion Is Spent

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

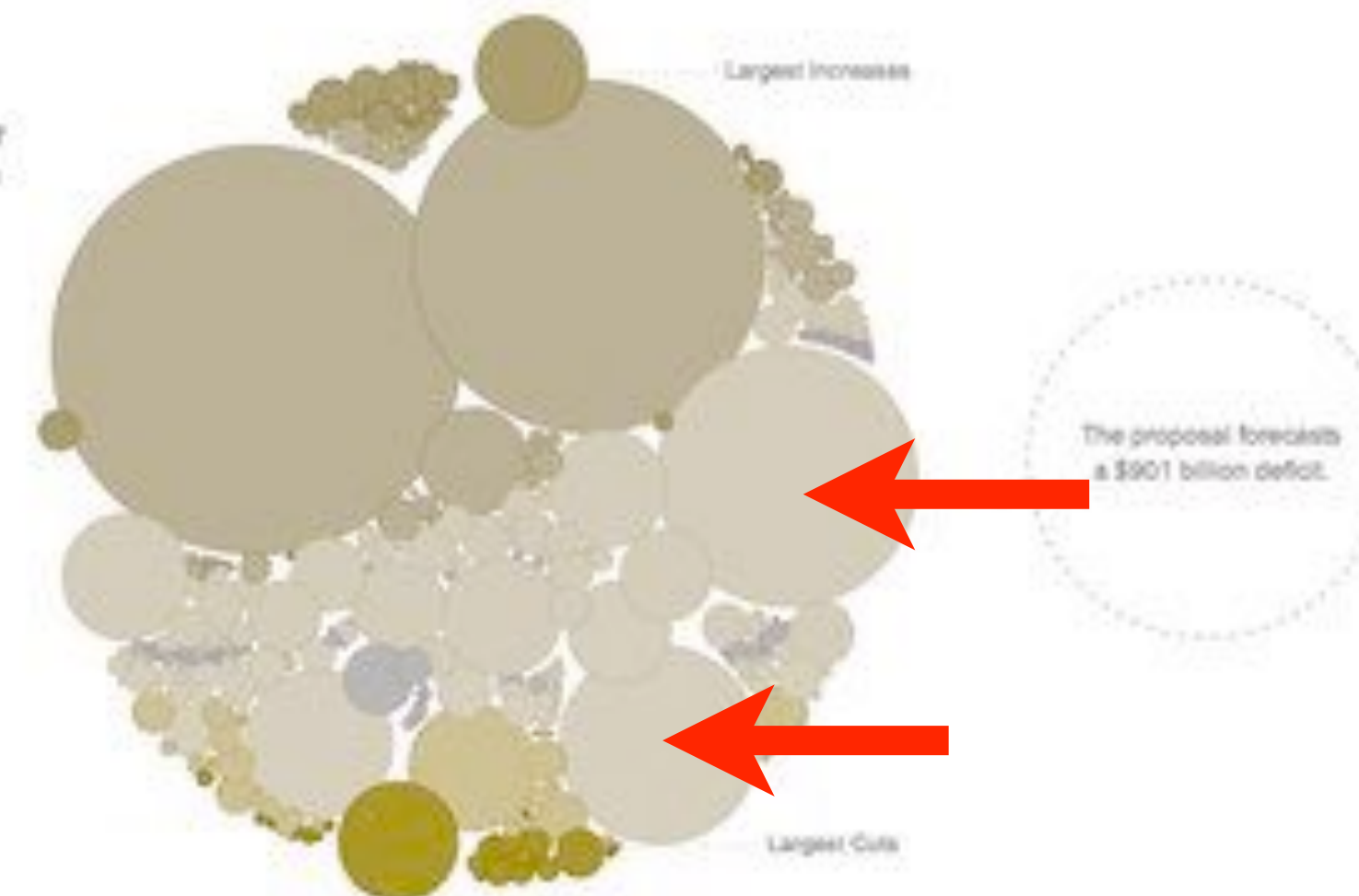
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Color shows amount of cut or increase from 2012.





# Simulate Color Vision Deficiencies

 Colblindor

Home ▾ CVD Essential

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 **C**olor **B**Lindness **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 **C**olor **B**Lindness **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

|   |  |  |  |
|---|--|--|--|
| <b>Trichromatic view:</b>               | <b>Anomalous Trichromacy:</b>                  | <b>Dichromatic view:</b>                       | <b>Monochromatic view:</b>                       |
| <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

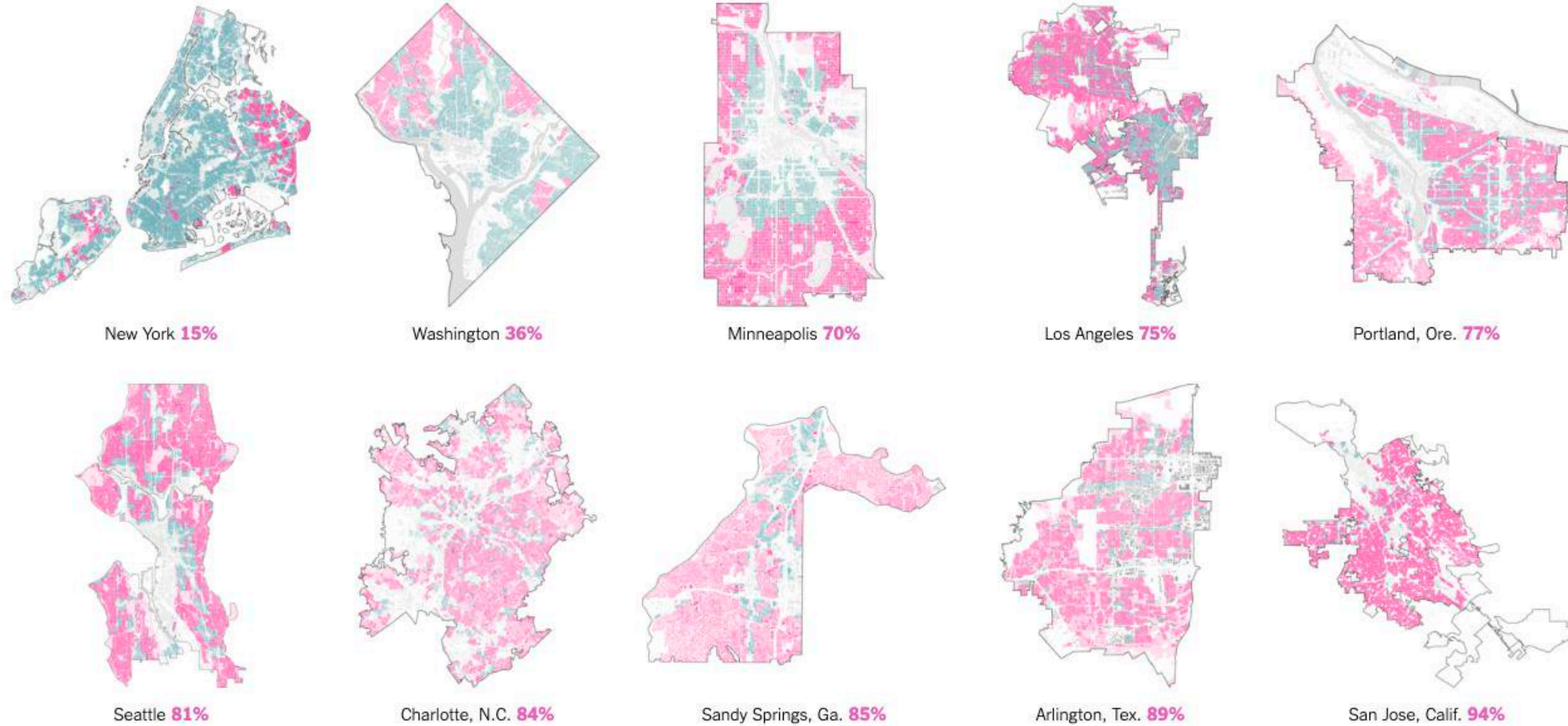
[Reset View](#)



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



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:*

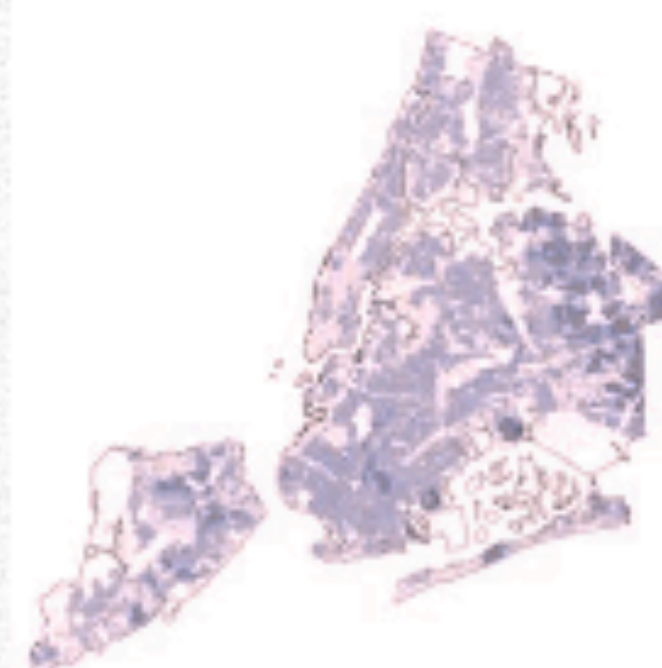
☐ Monochromacy/Achromatopsia

☐ 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%



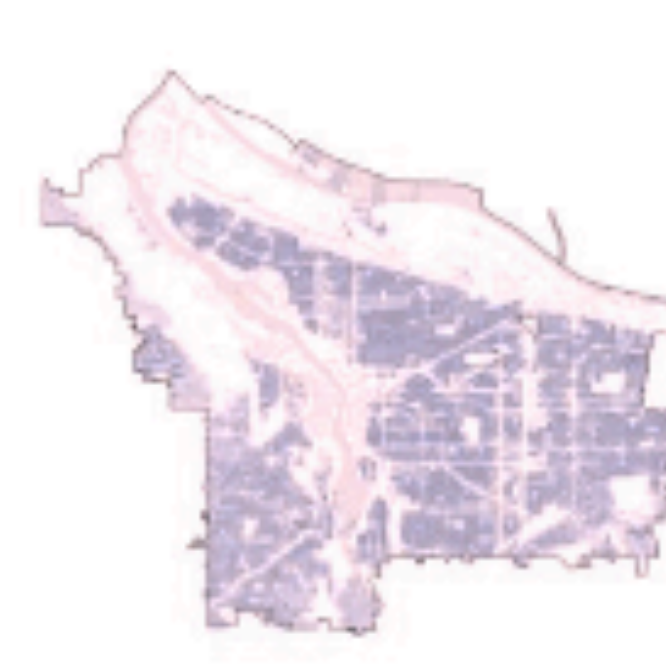
Washington 36%



Minneapolis 70%



Los Angeles 75%



Portland, Ore. 77%



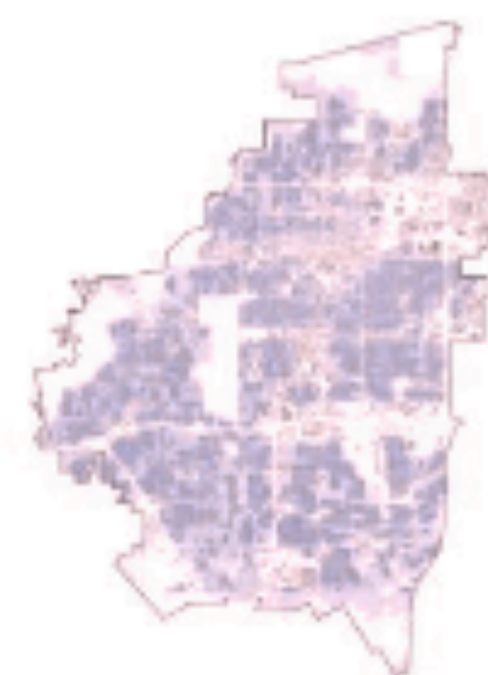
Seattle 81%



Charlotte, N.C. 84%



Sandy Springs, Ga. 85%



Arlington, Tex. 89%

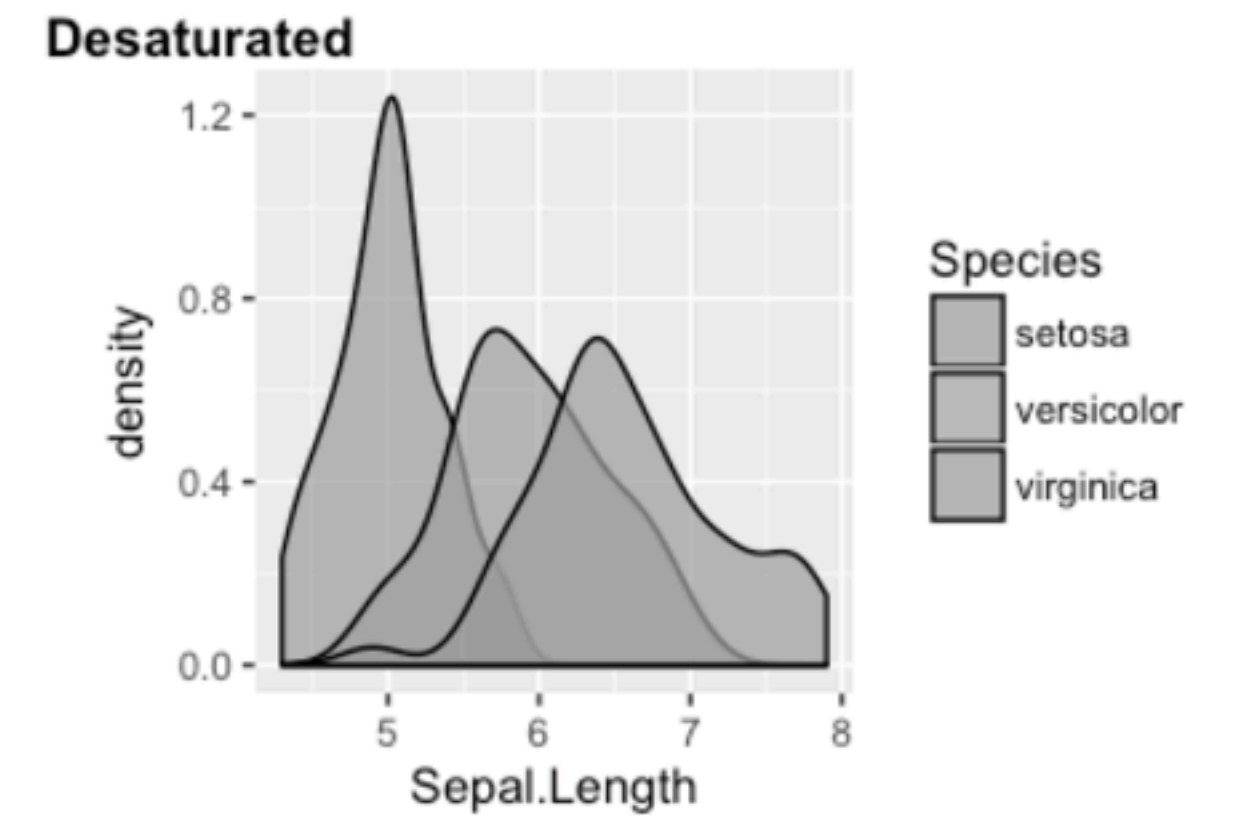
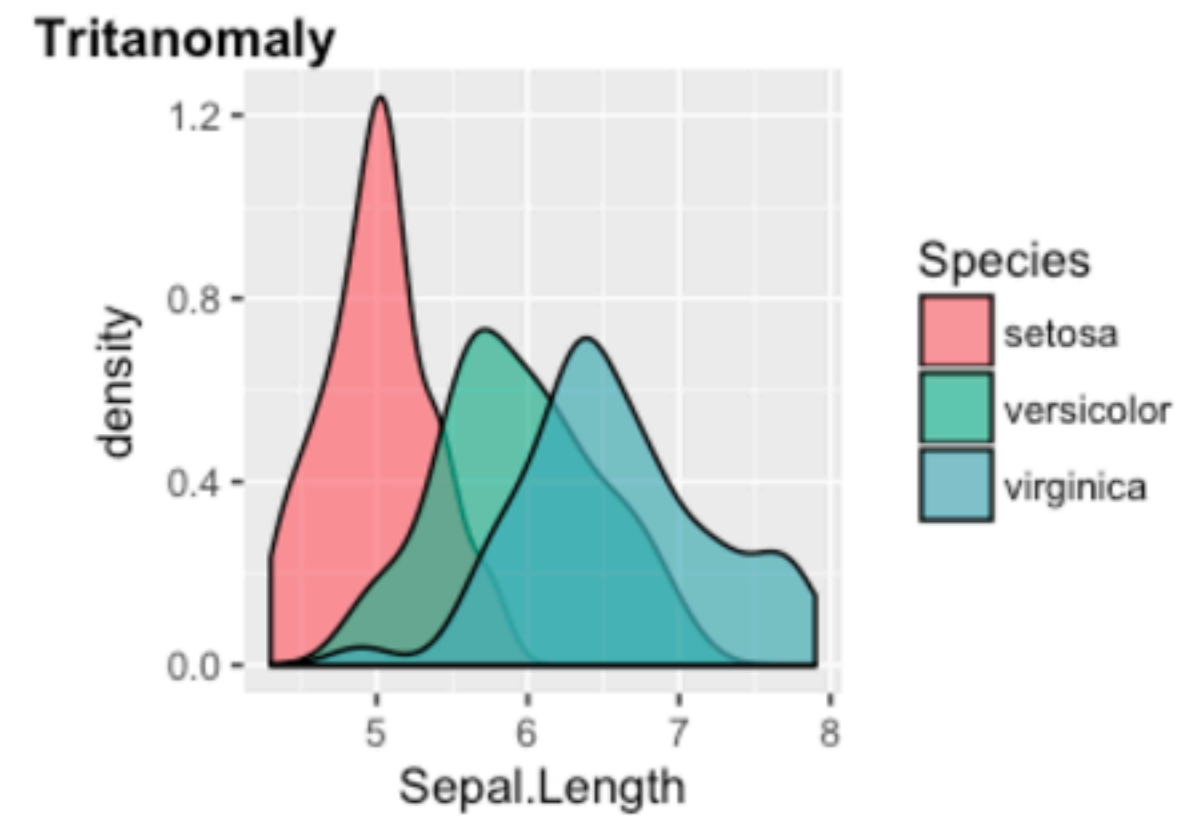
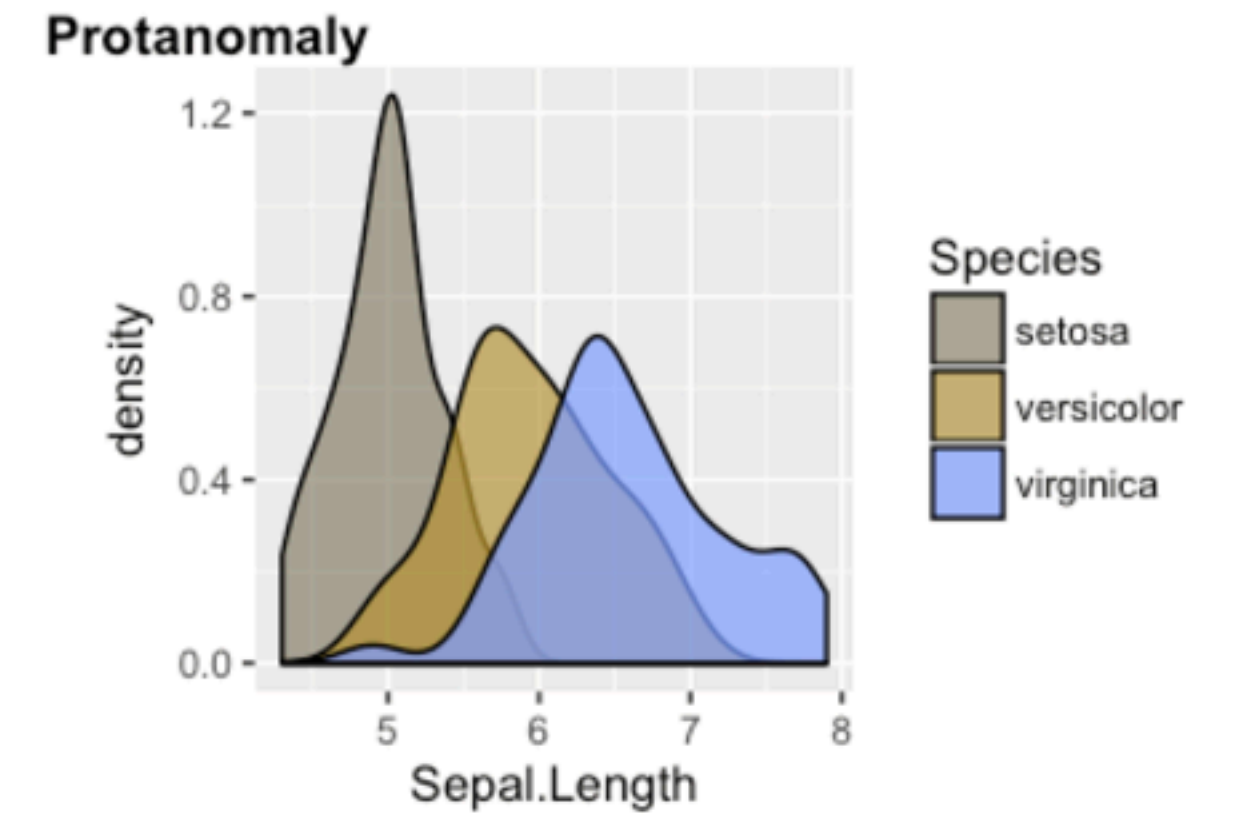
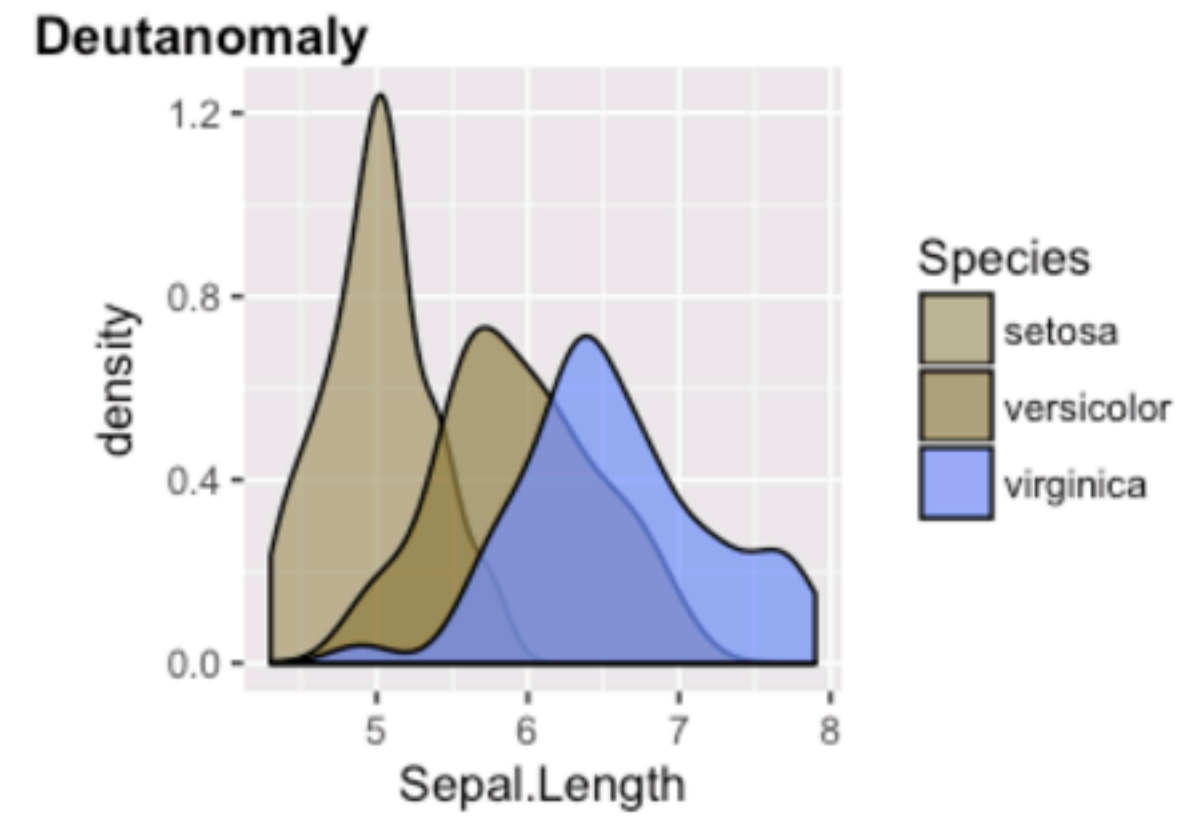
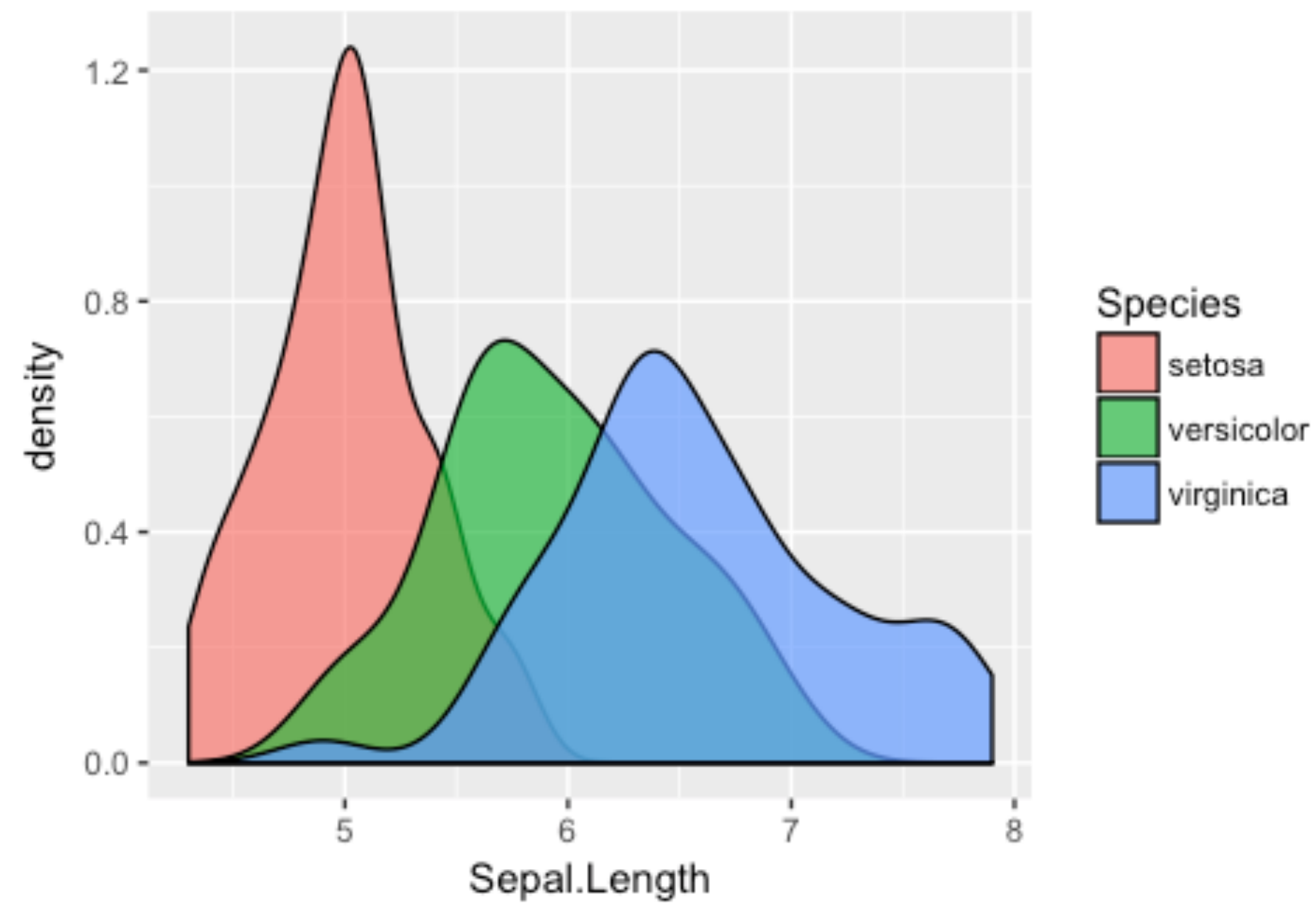


San Jose, Calif. 94%

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



# Simulate in R

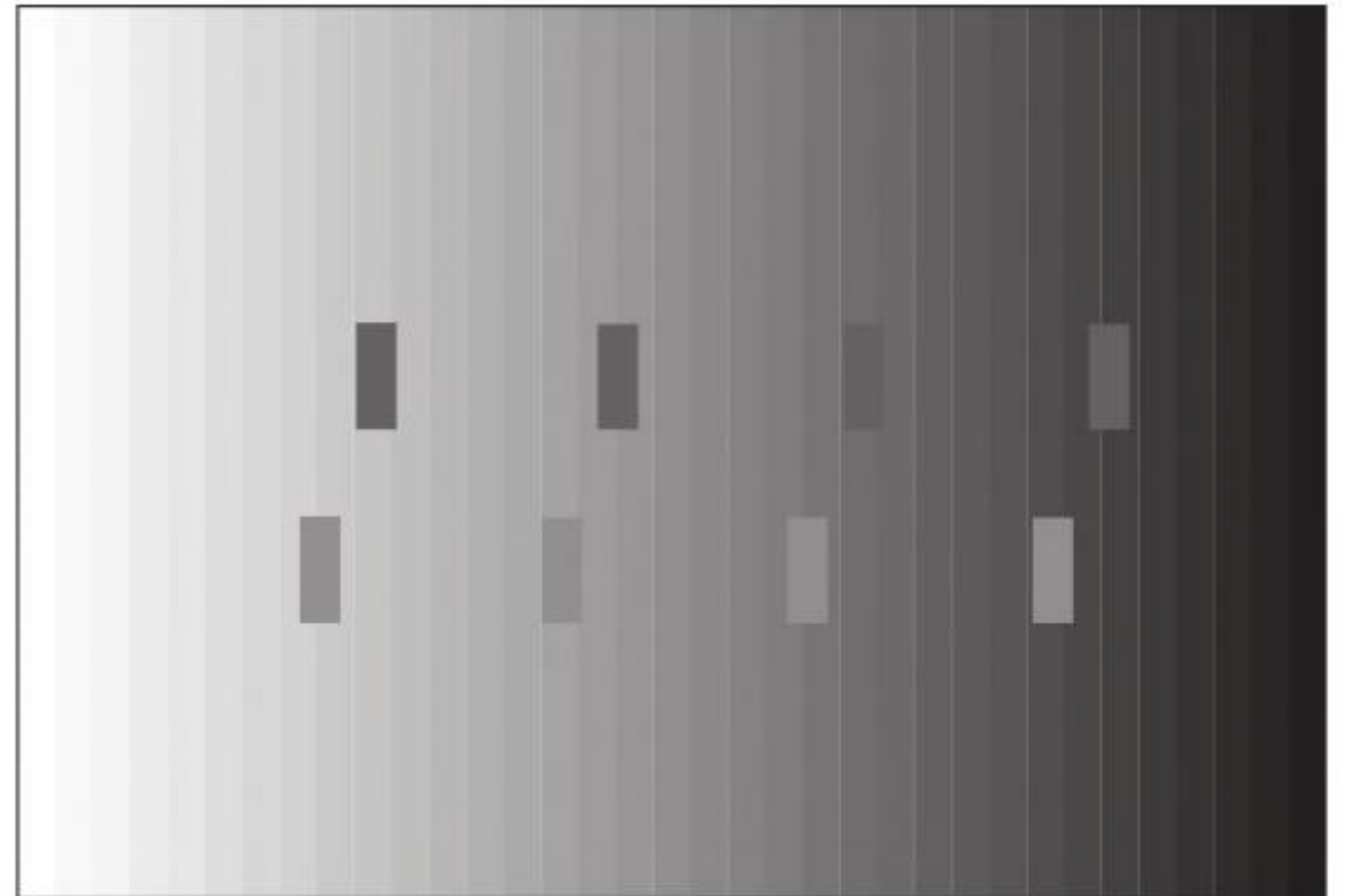


Color / Brightness is  
Relative!

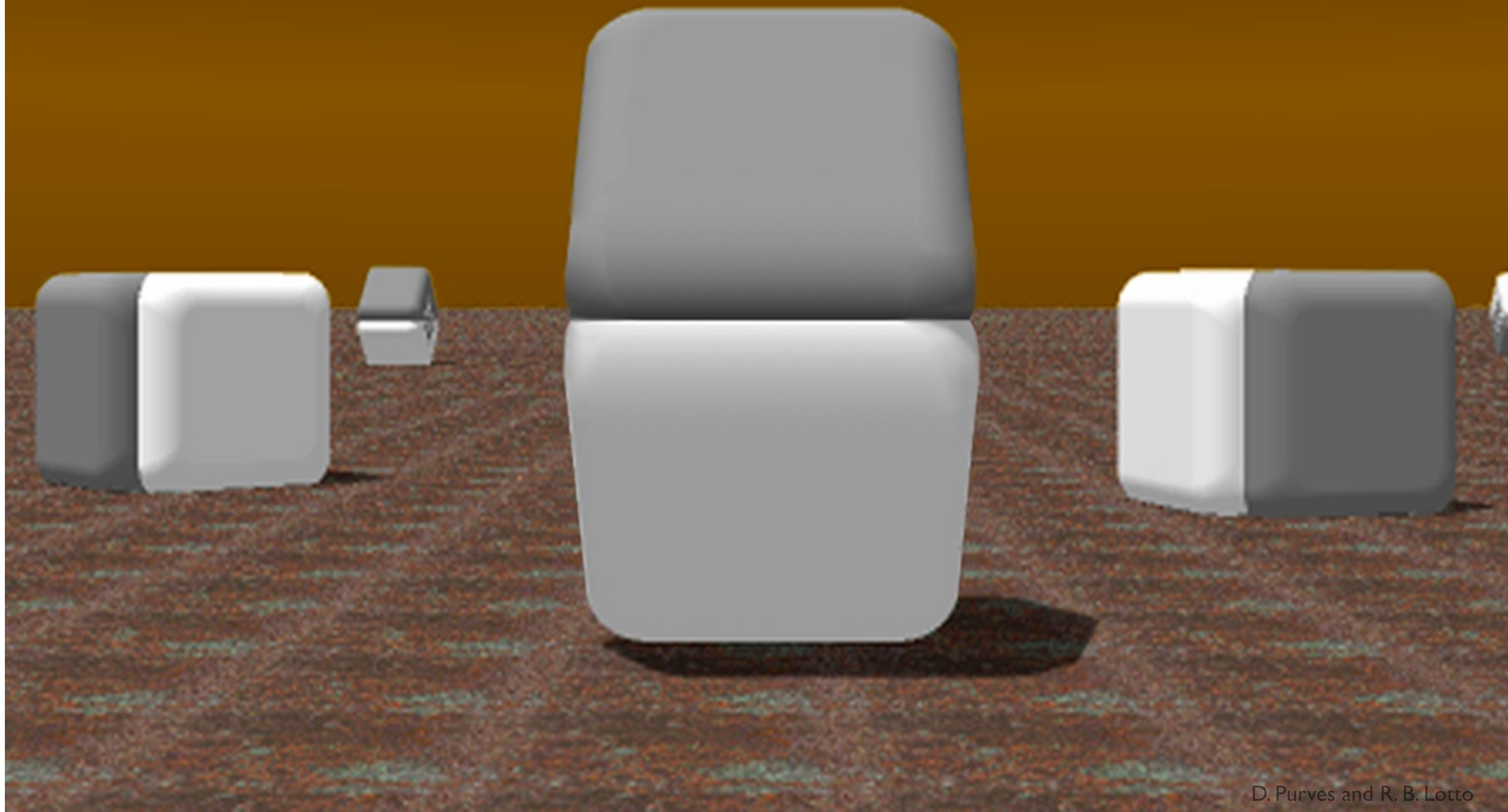


# Simultaneous Brightness Contrast

The perceived brightness of an object is relative to its background

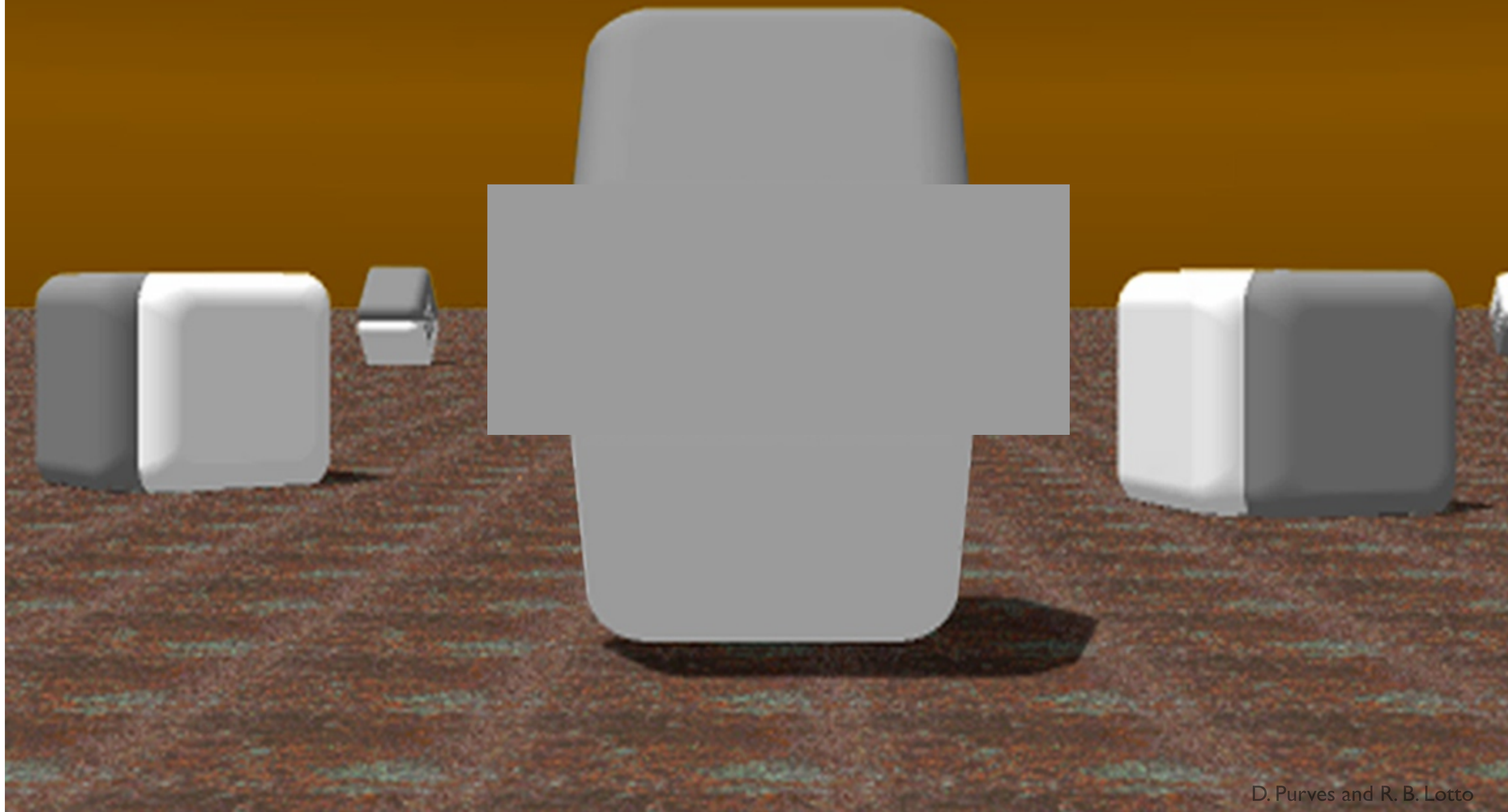


# Cornsweet Illusion





# Cornsweet Illusion



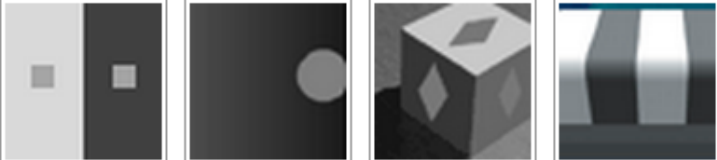
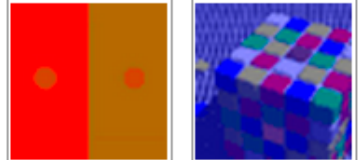
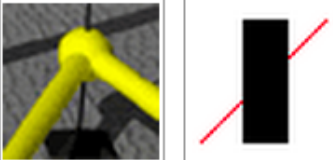

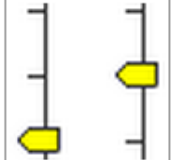

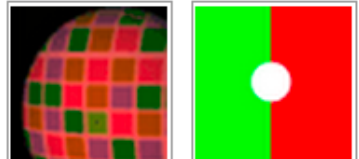

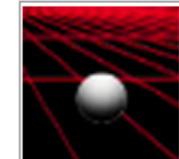


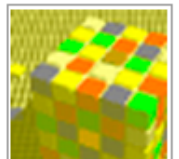
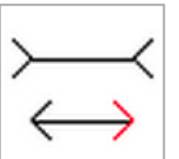


# Demo

<http://purveslab.net/see-for-yourself/>

**purves-lab**

Laboratory of Dale Purves, M.D. Center for Cognitive Neuroscience Duke University

MAINNEWSPEOPLERESEARCHPUBLICATIONSRESOURCESSEE FOR YOURSELFCONTACT

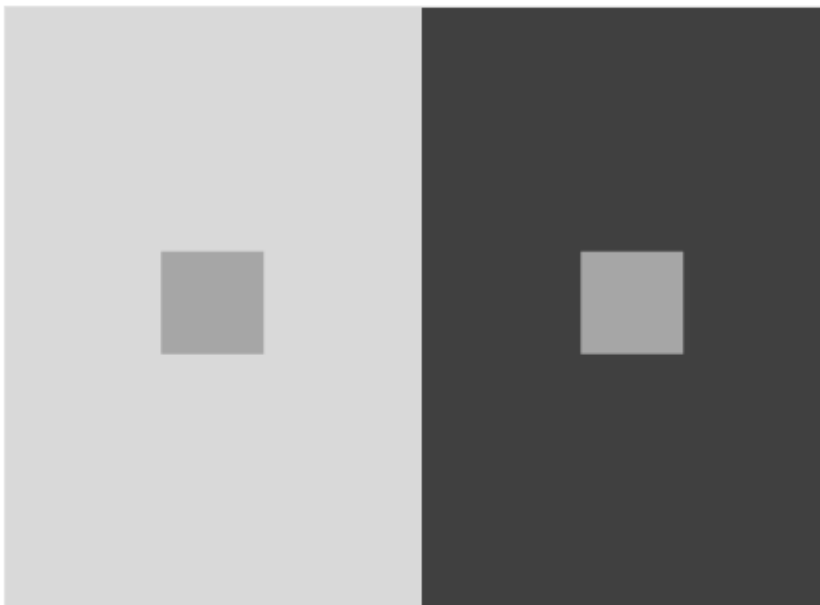
| Lightness/Brightness  | Color   | Lines and Angles  | Motion  | Sound and Music   |
|---|---|---|---|---|
|   |   |   |   |   |
|  |  |  |  |  |
|  |  |  |  |  |


**Brightness contrast: standard**

In viewing this stimulus, people invariably perceive the square on the brighter surround (left) to be darker than the square on the darker surround (right). Click on the "Play" button to convince yourself that the squares are equiluminant or click on the "Move mask" button to manually position the mask over the squares.

[» Read the empirical explanation](#)

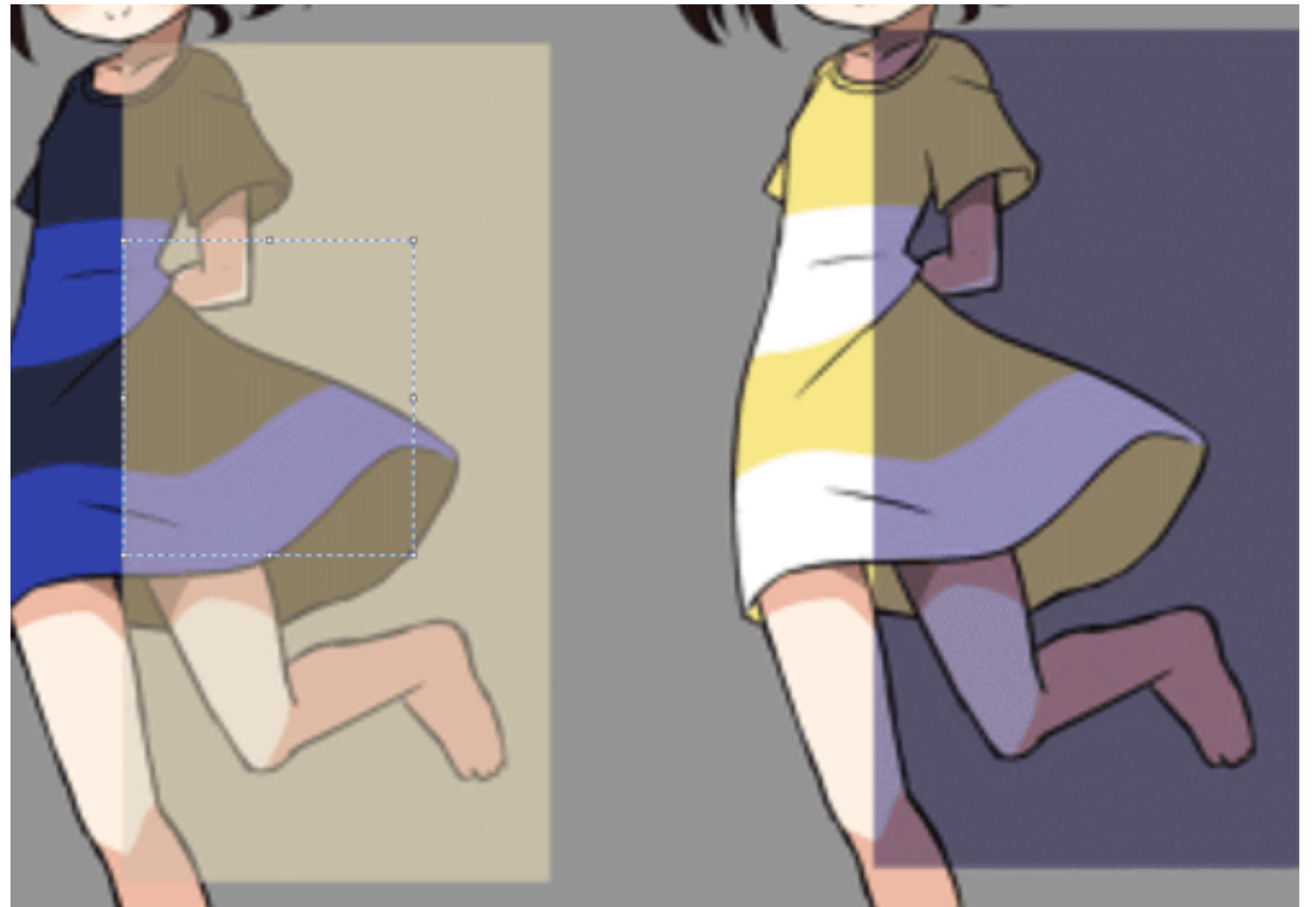
[» Download high resolution images](#)







# The Dress Meme

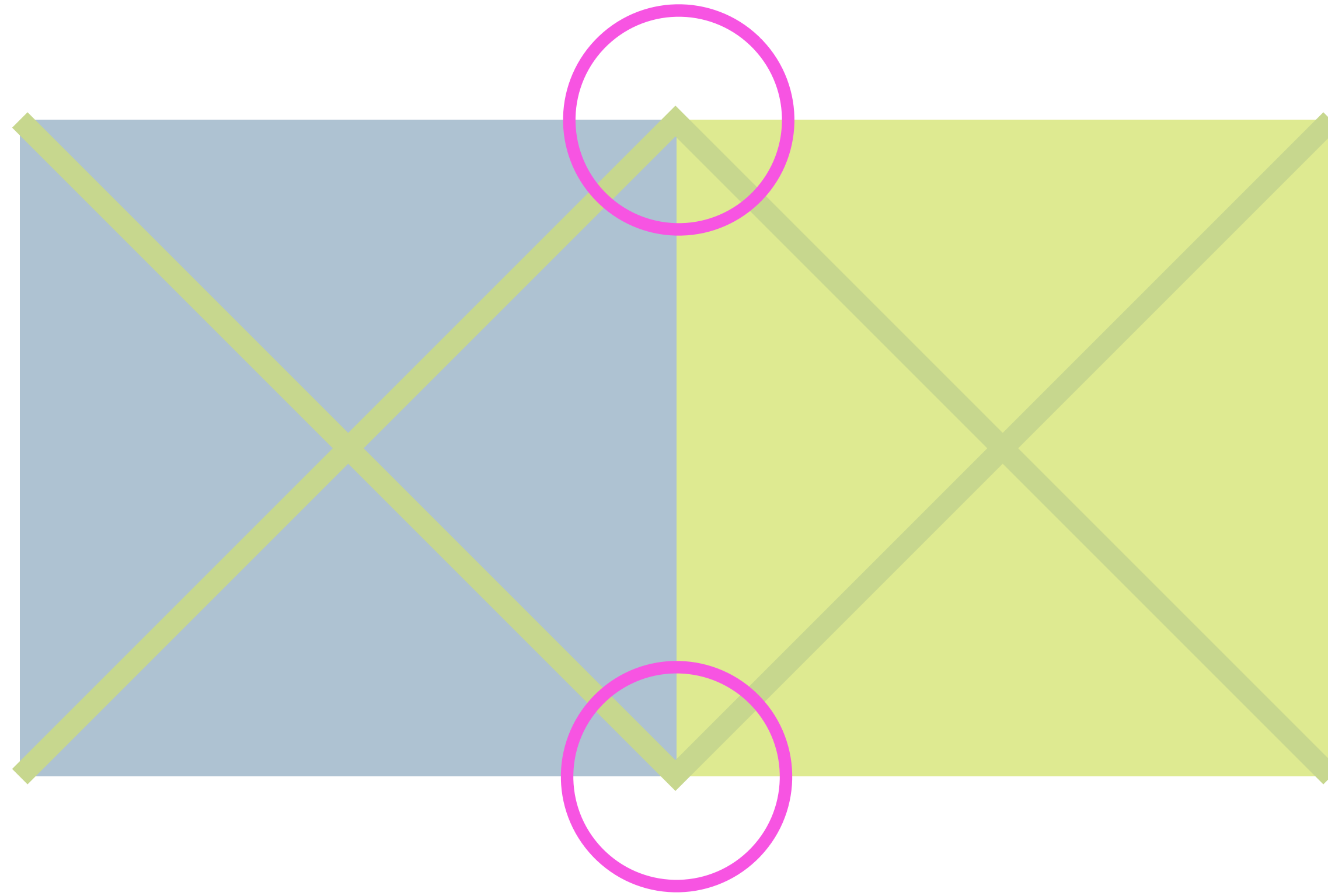


black and blue or white and gold?

<https://imgur.com/hxJjUQB>

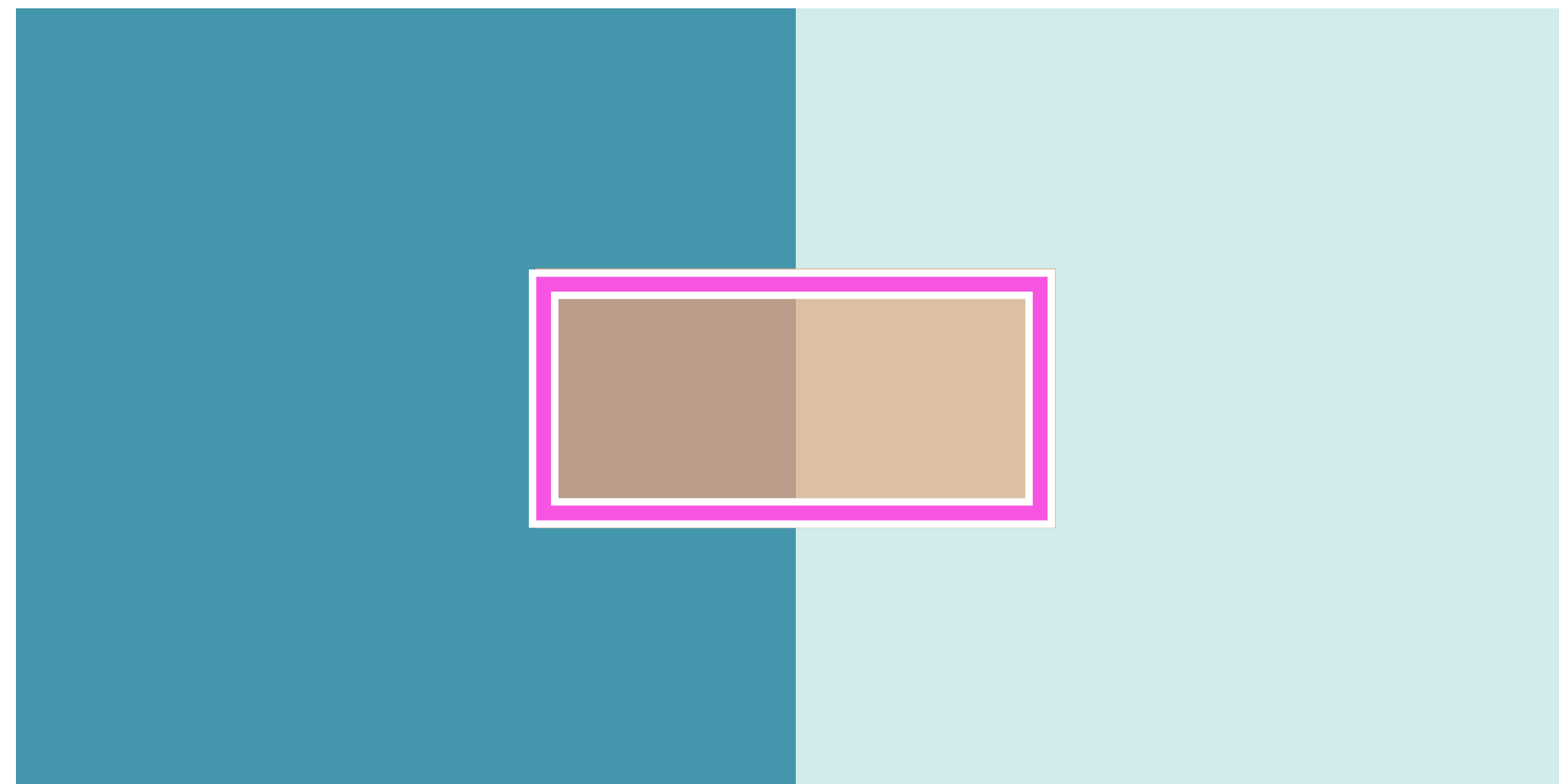
[https://en.wikipedia.org/wiki/The\\_dress](https://en.wikipedia.org/wiki/The_dress)

# INTERACTION OF COLOR





# INTERACTION OF COLOR



# INTERACTION OF COLOR

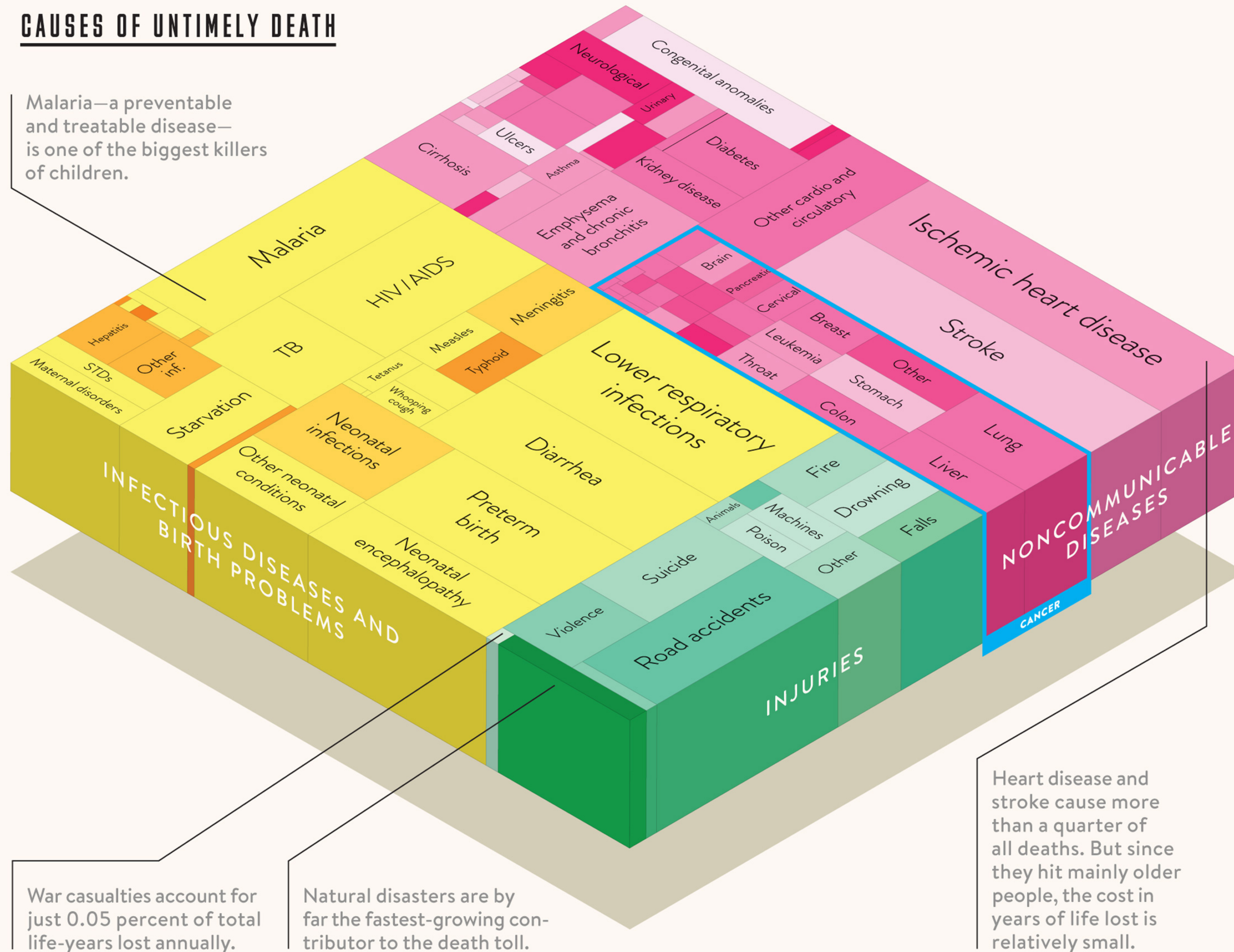




# Design Critique

# CAUSES OF UNTIMELY DEATH

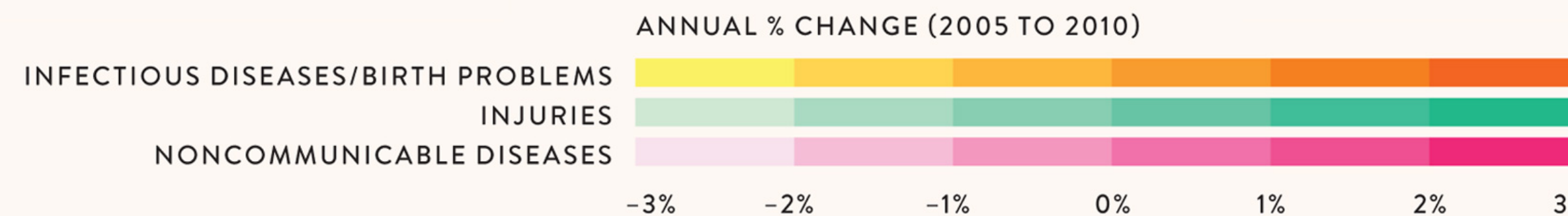
Malaria—a preventable and treatable disease—is one of the biggest killers of children.



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.





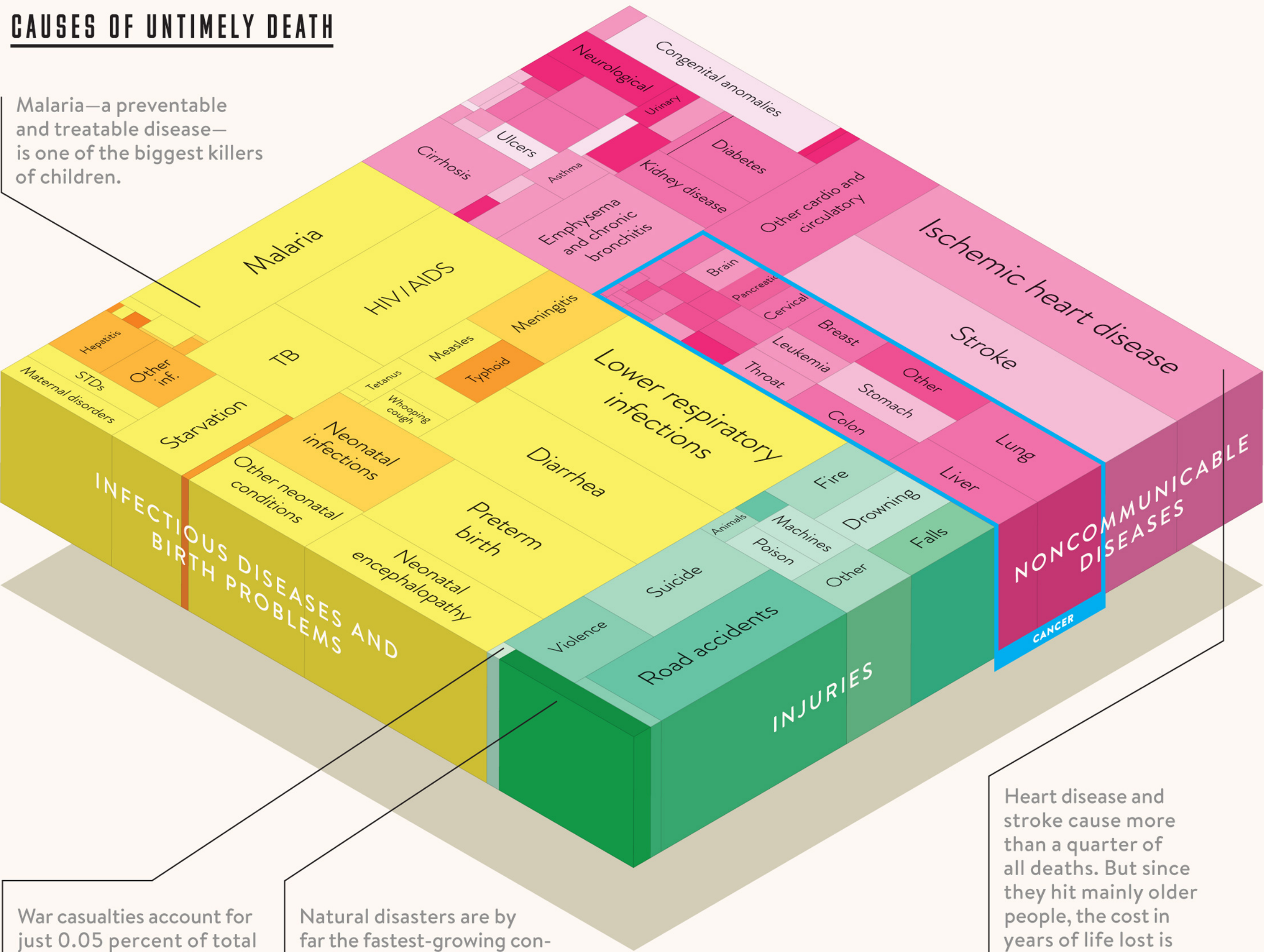
# Graph of the Year?

"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

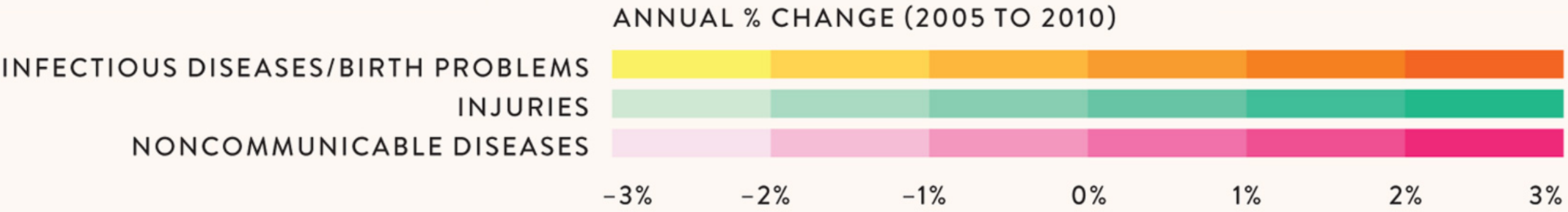
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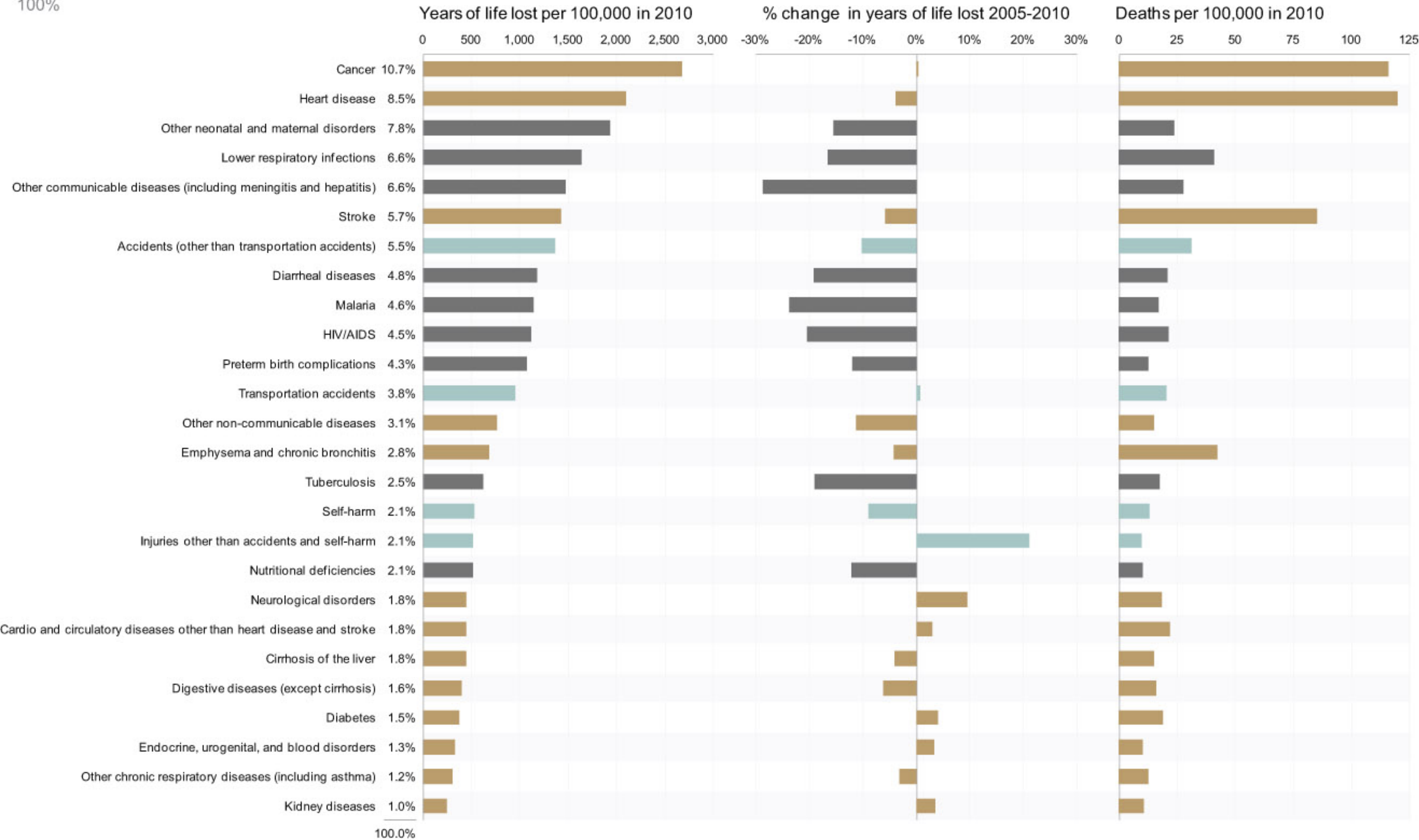




# Global Causes of Lost Life

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

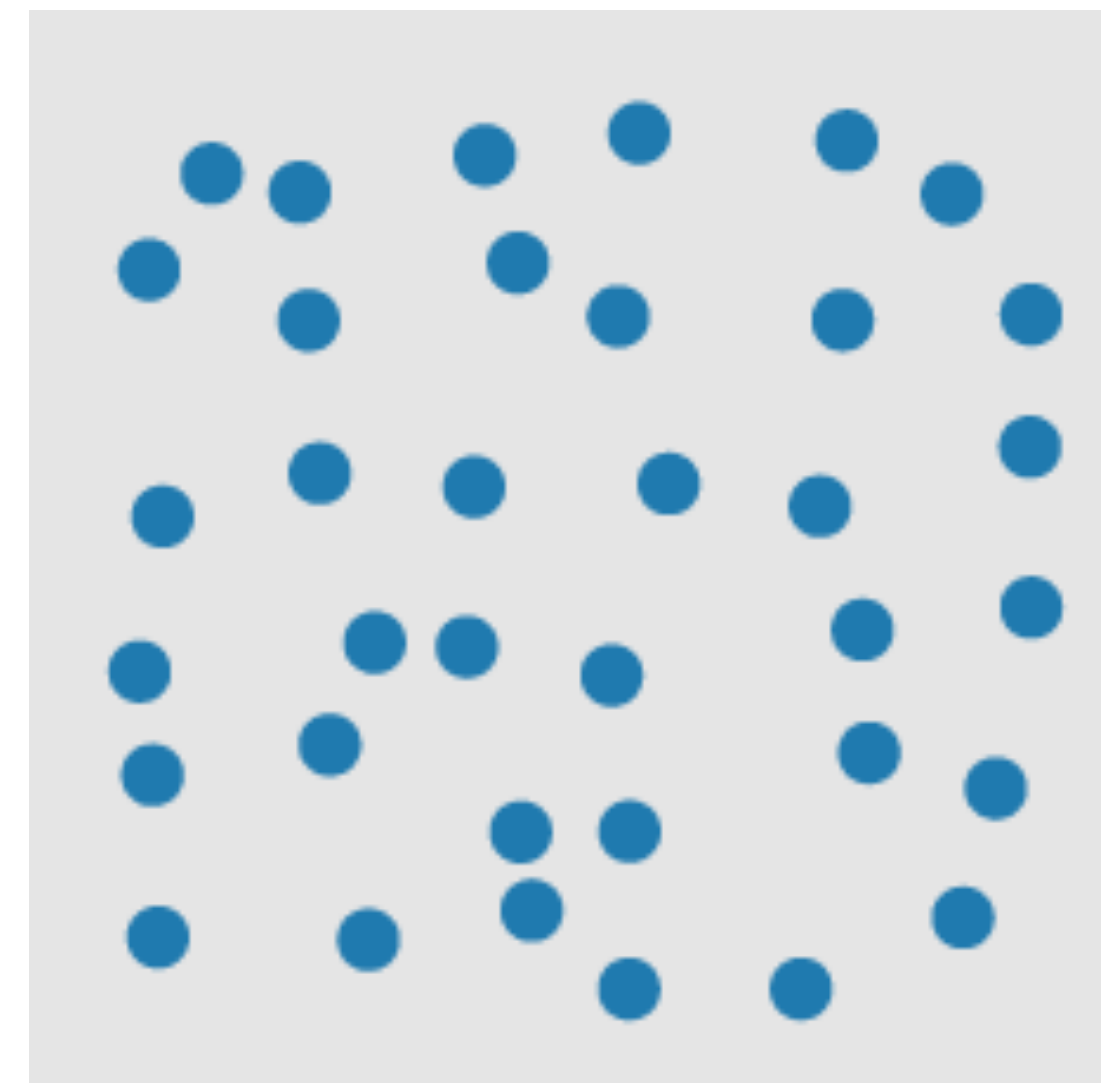
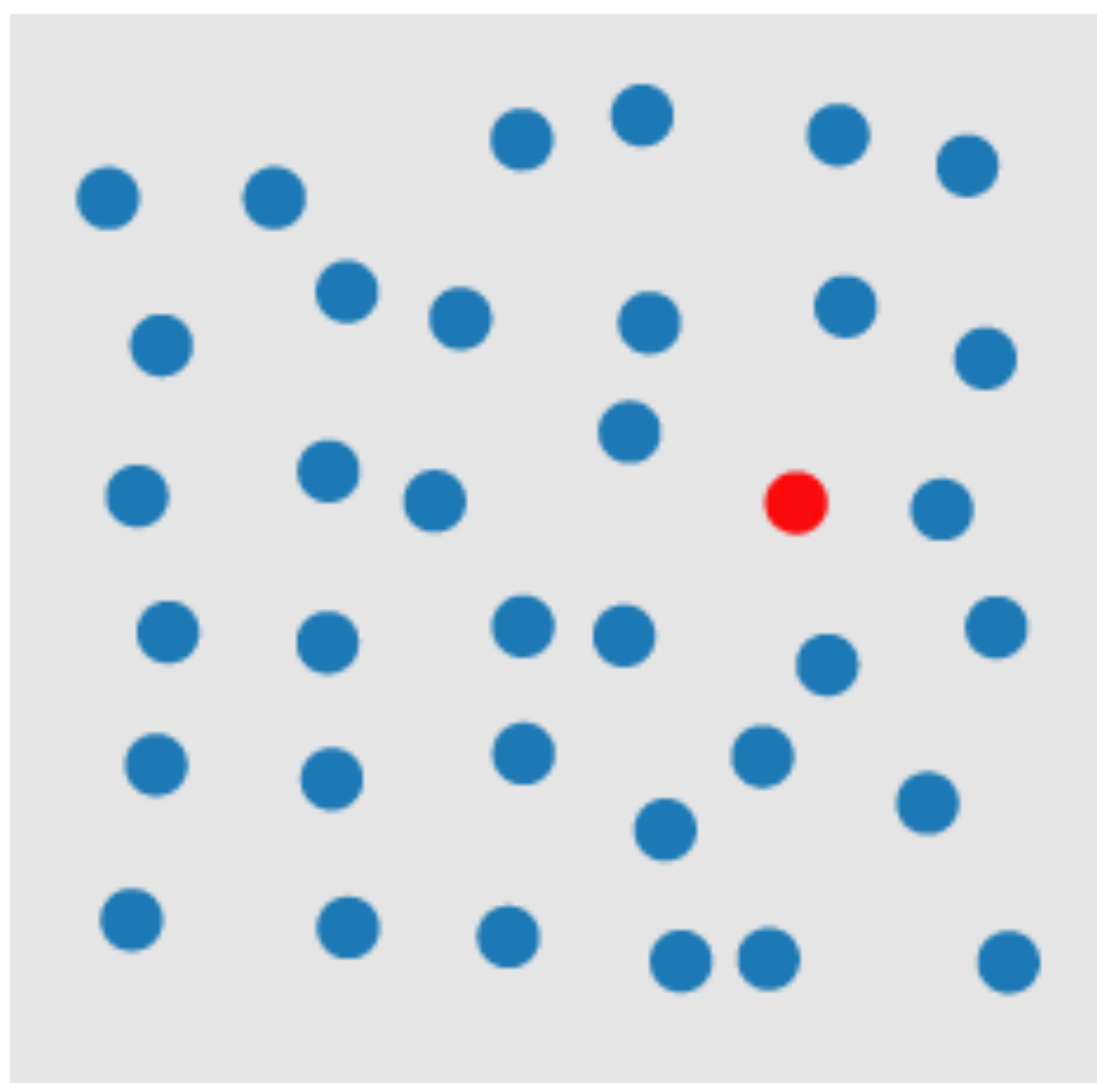
happens before focused attention -> „pre“attentive

attention is very important for cognition

Independent of the number of distractors!

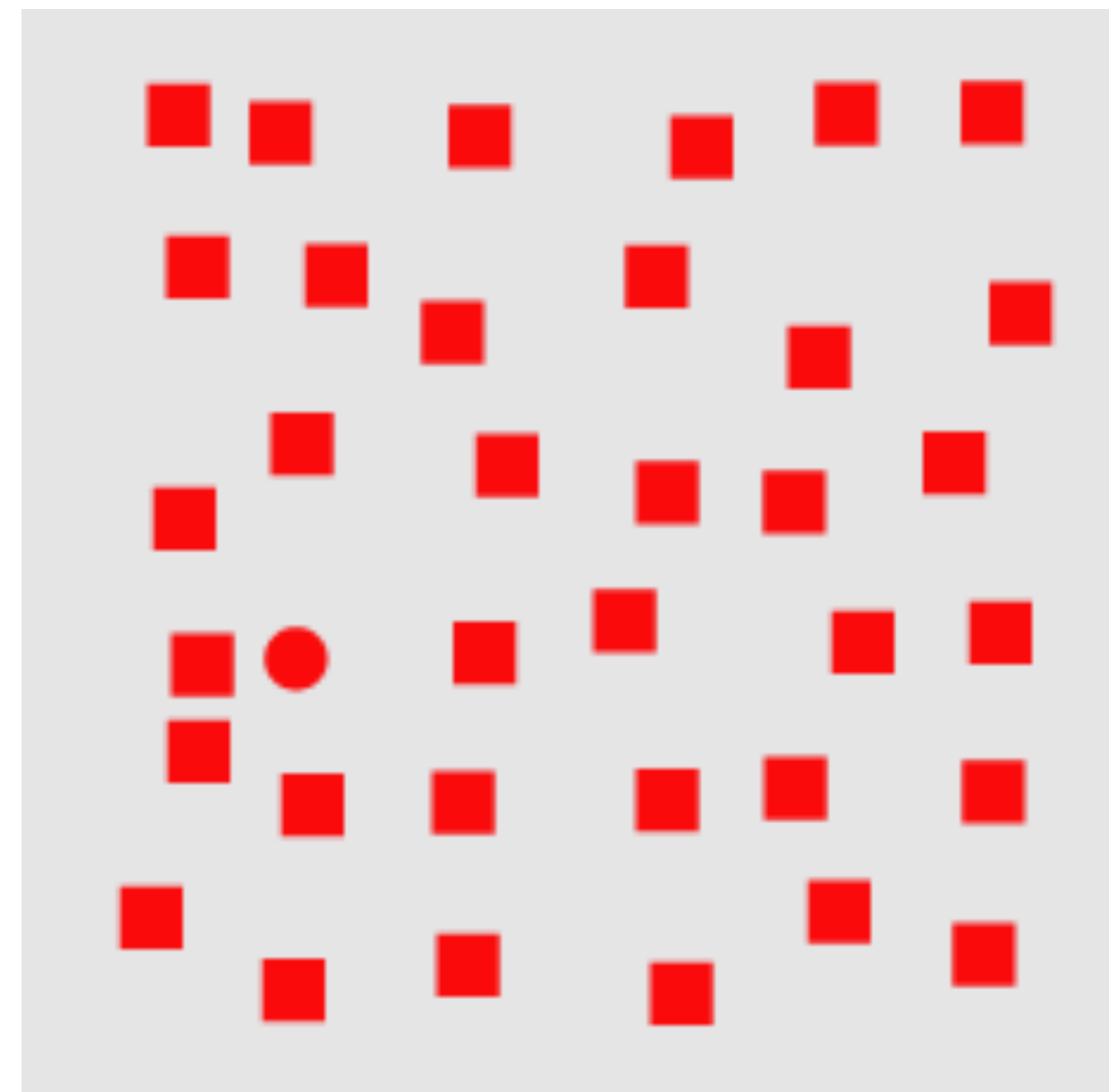
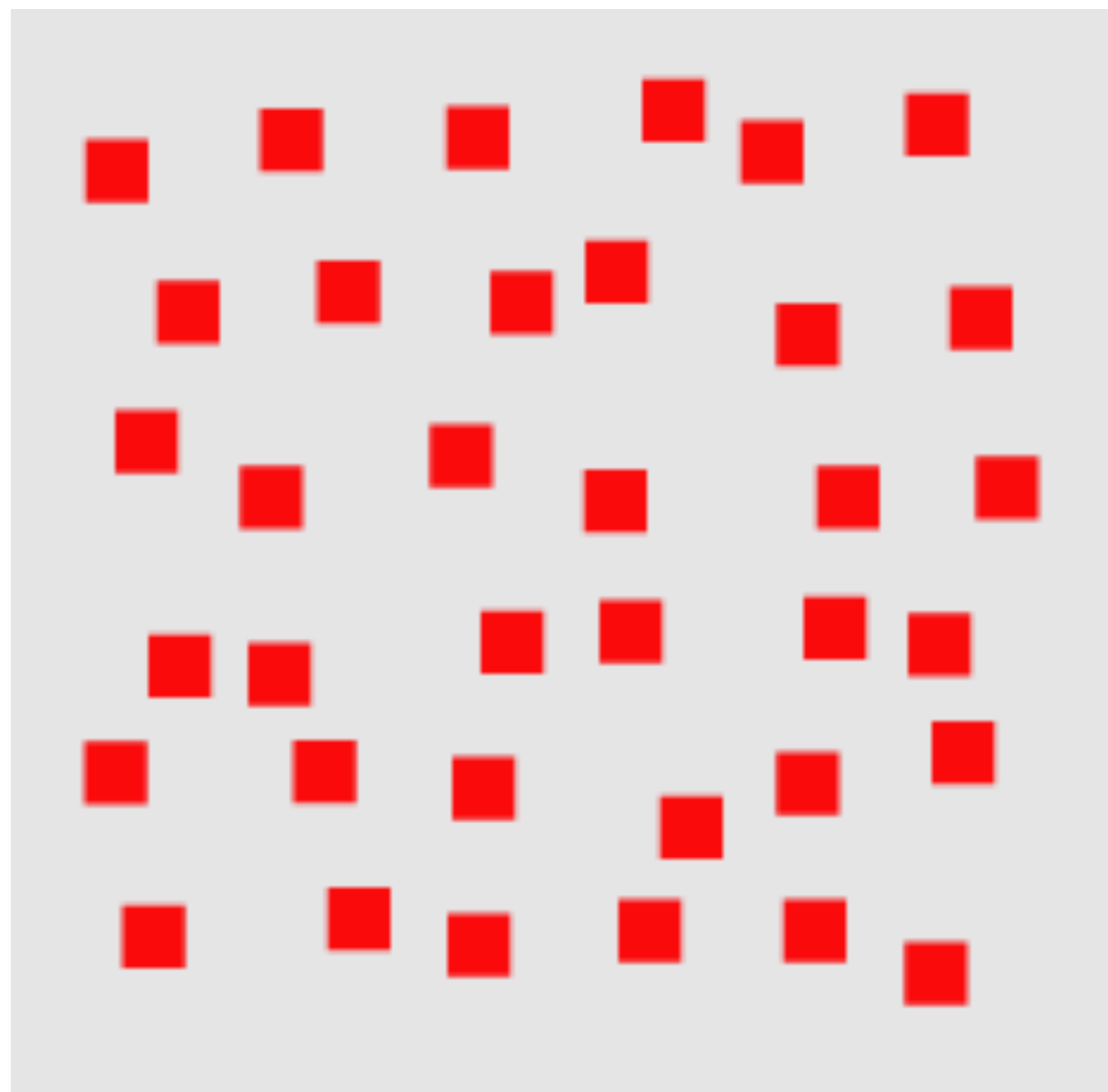
Opposite: sequential search (processed serially)

# Difference in Hue



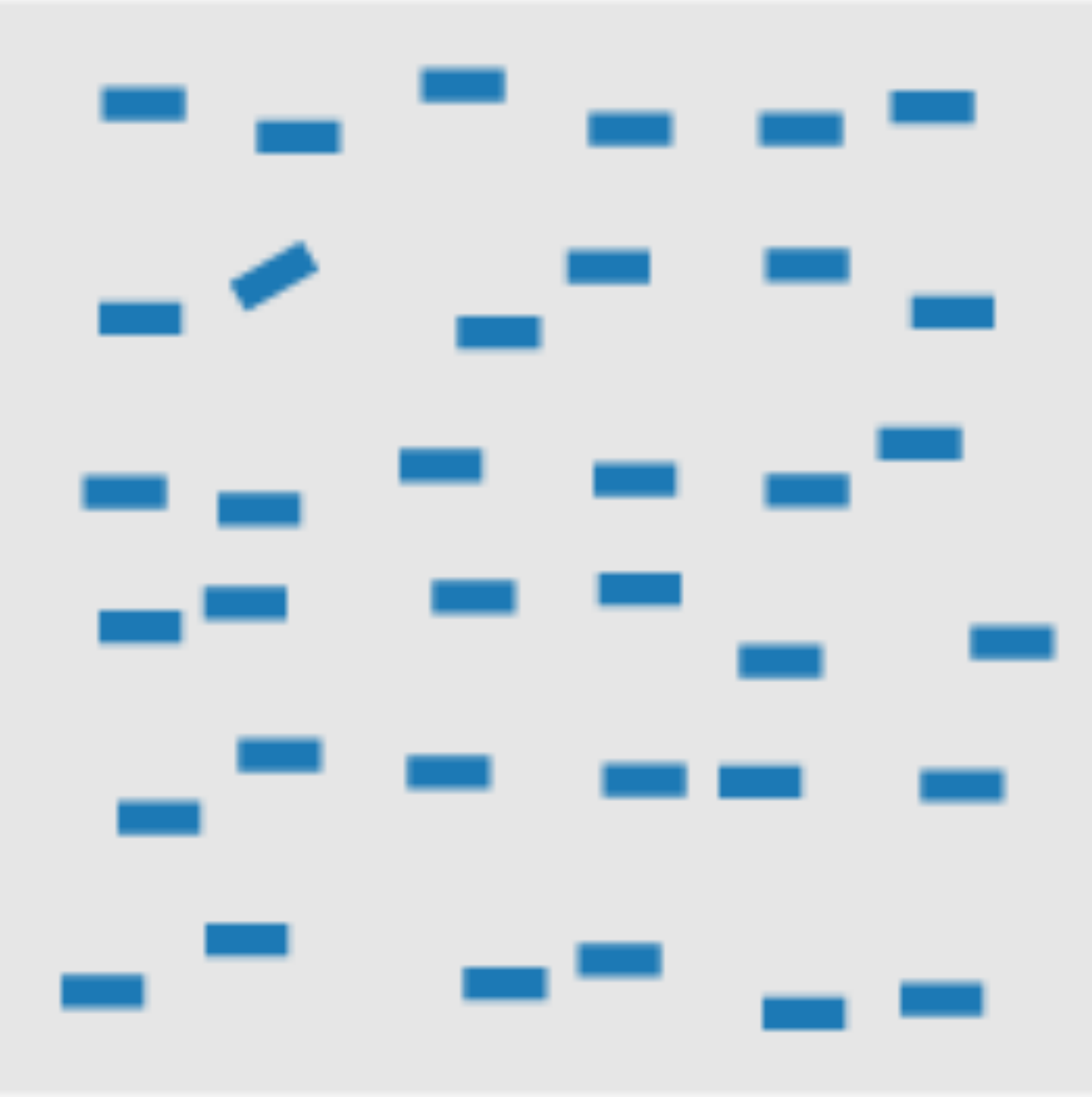


# Difference in Curvature / Form

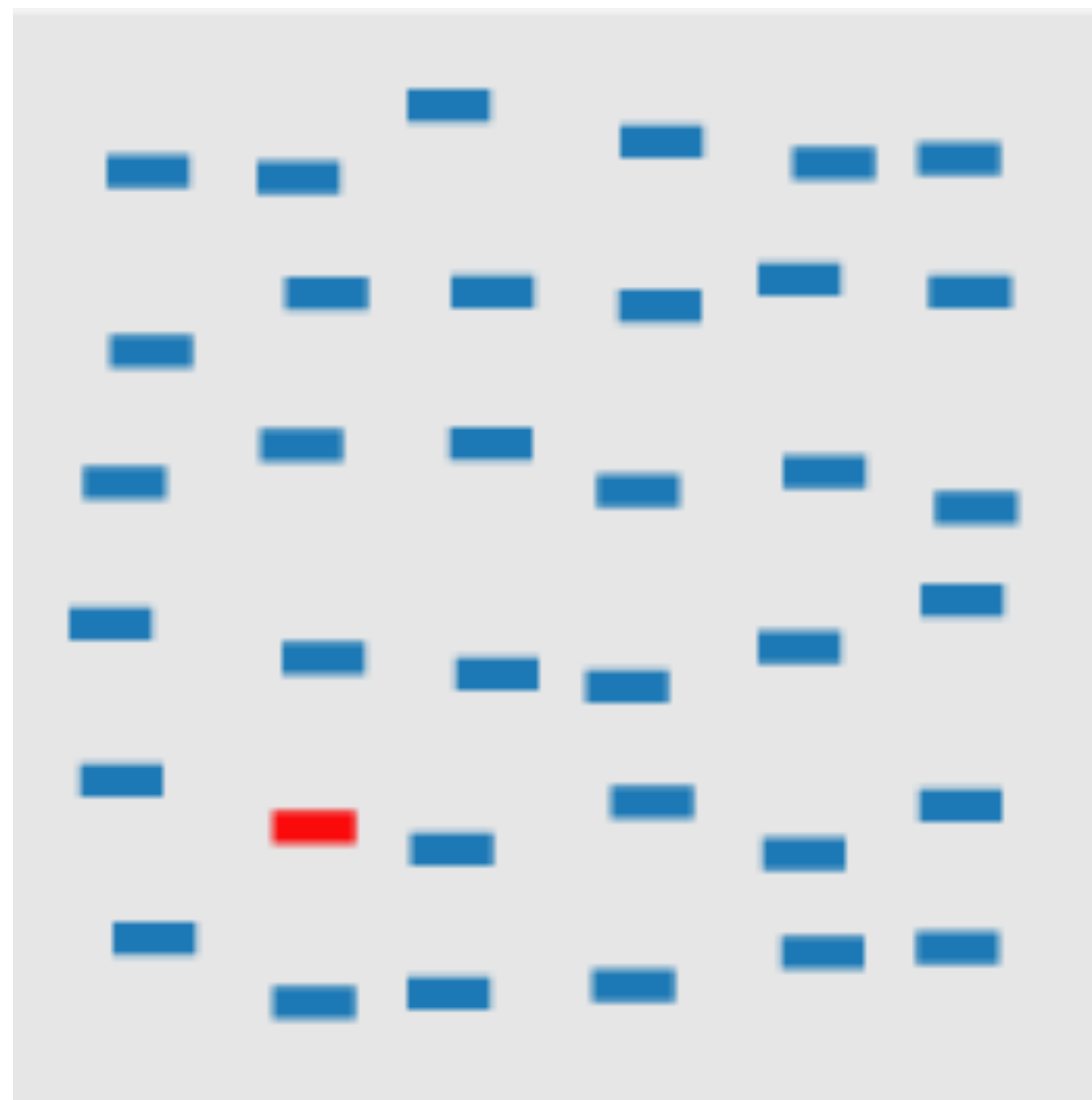


Clap when you spot the  
odd one!





orientation

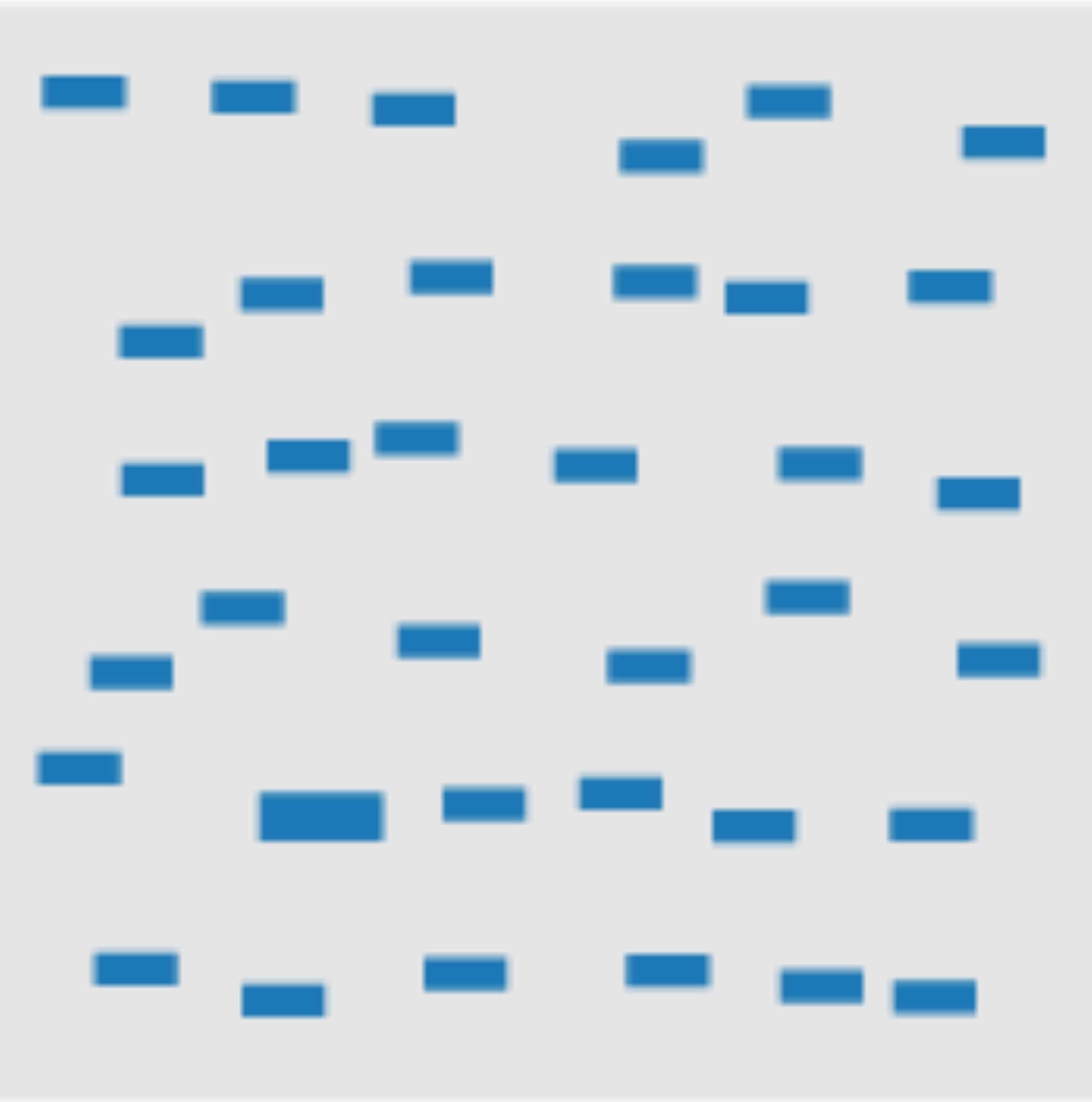


hue



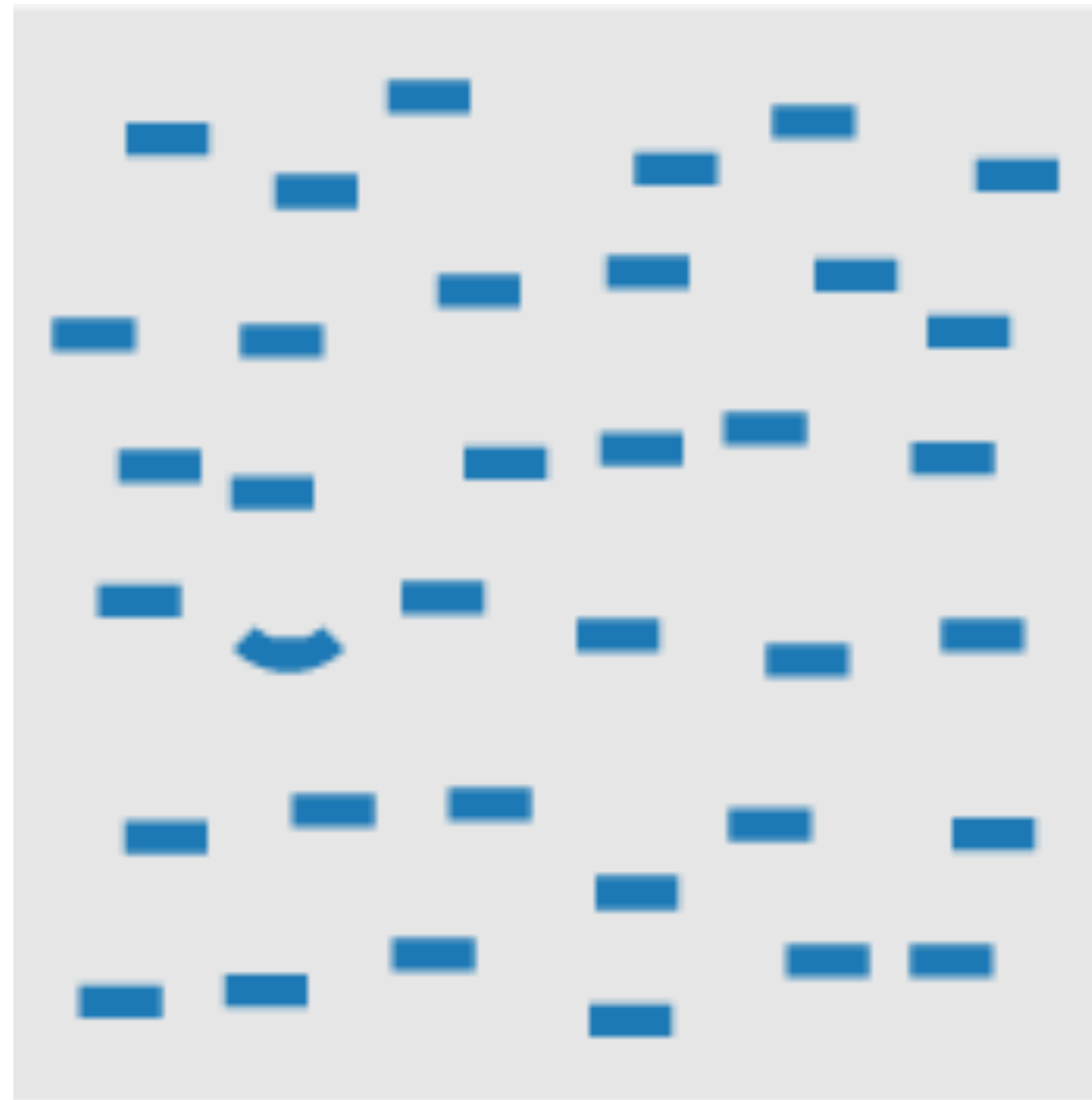


closure

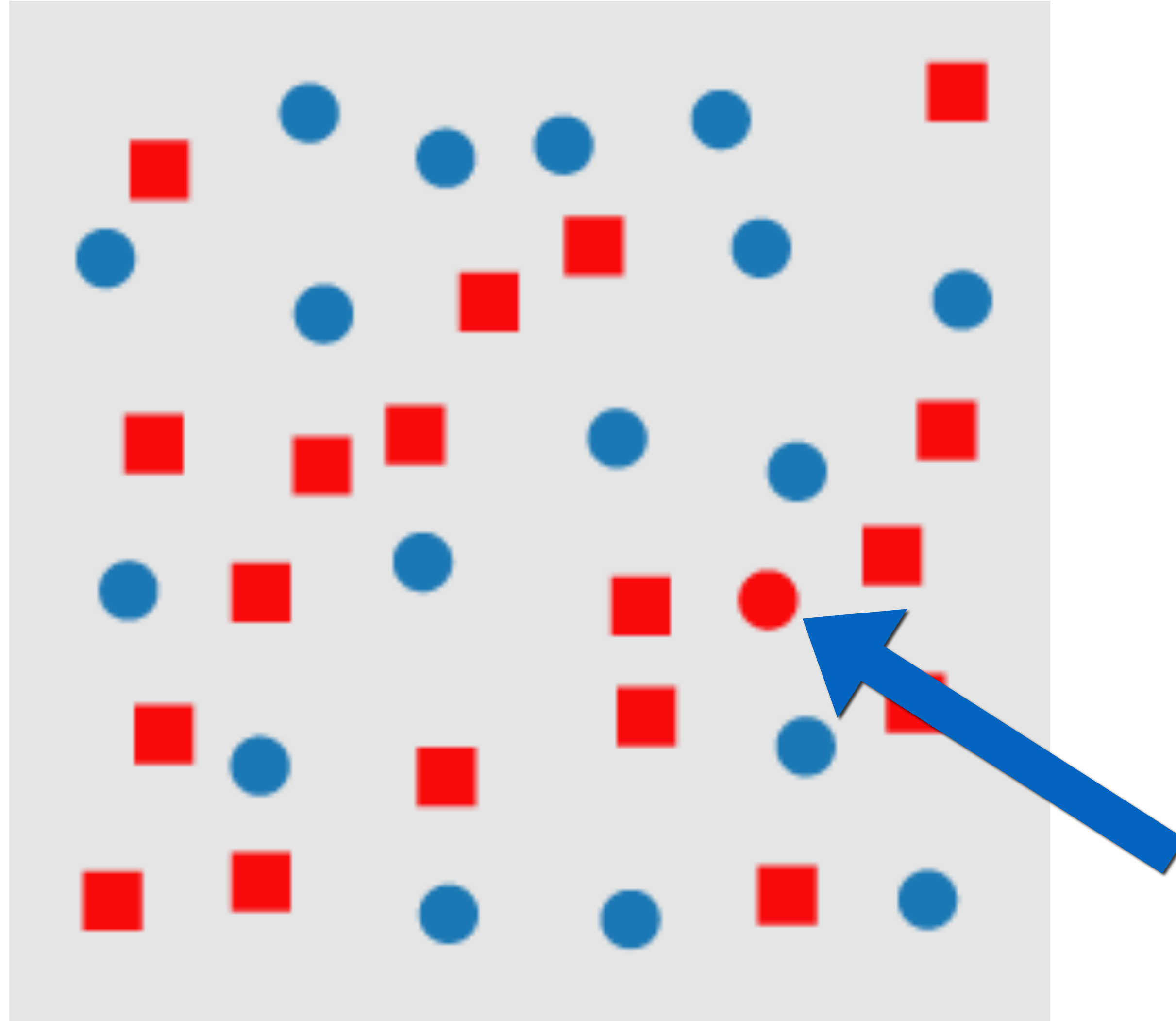


size





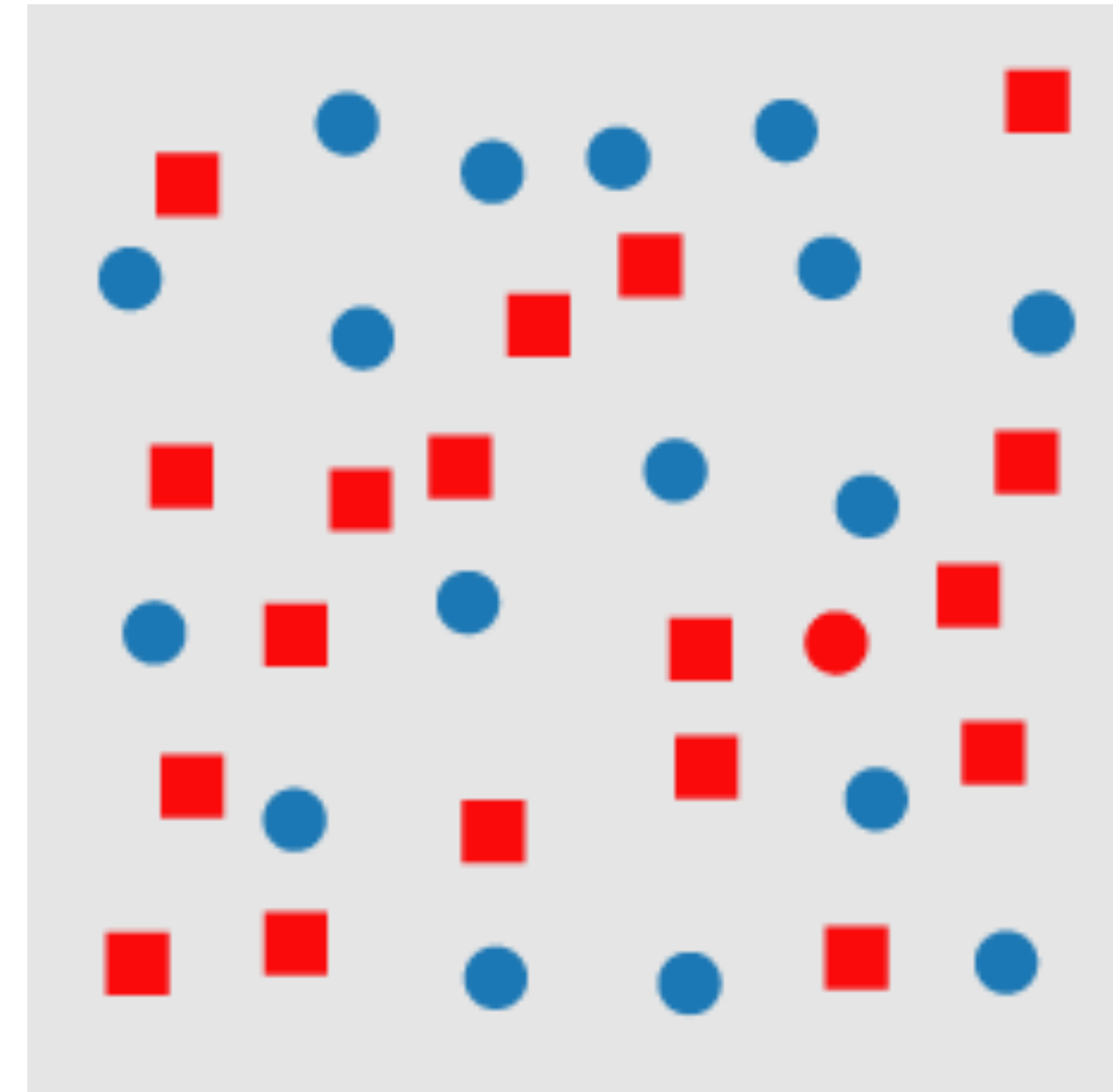
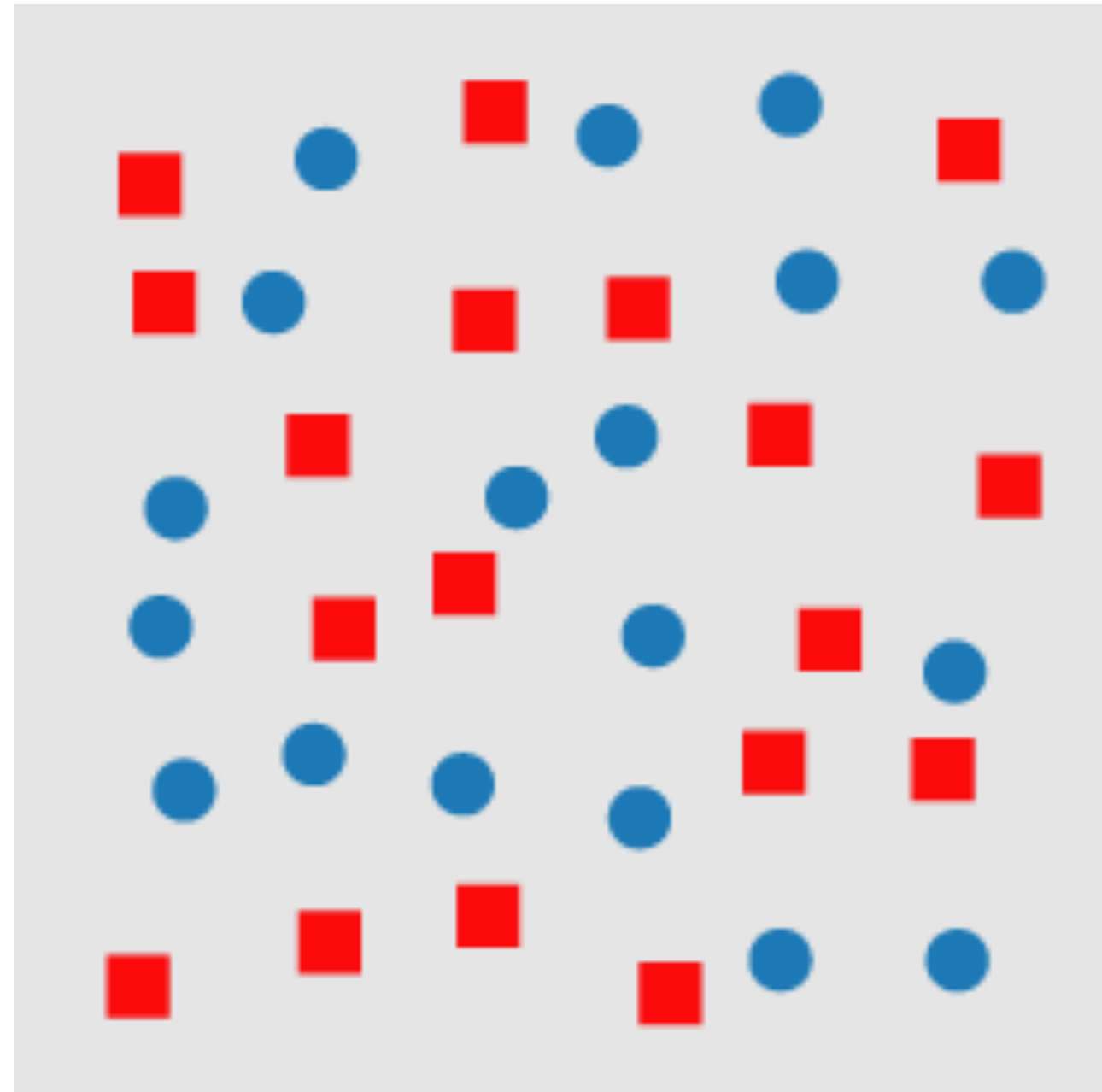
curvature



?

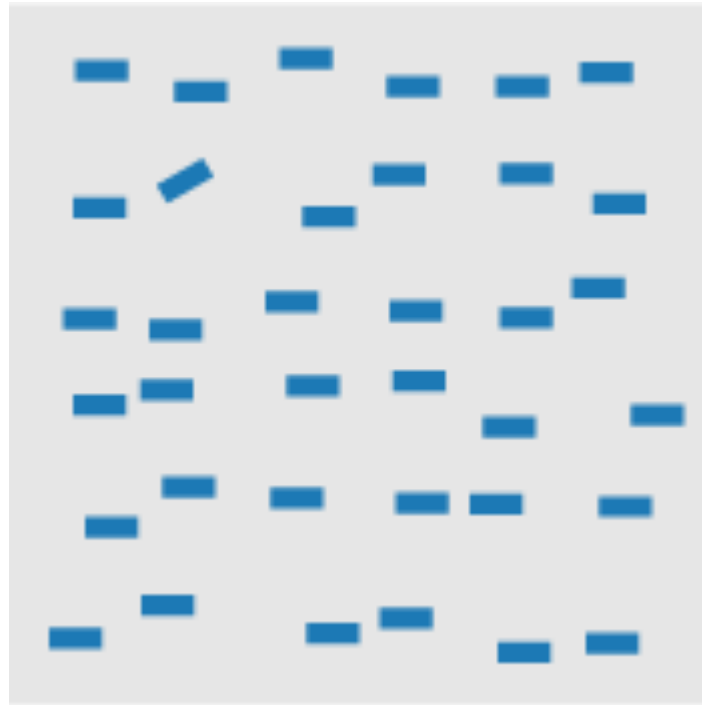


# Not Valid for Combinations

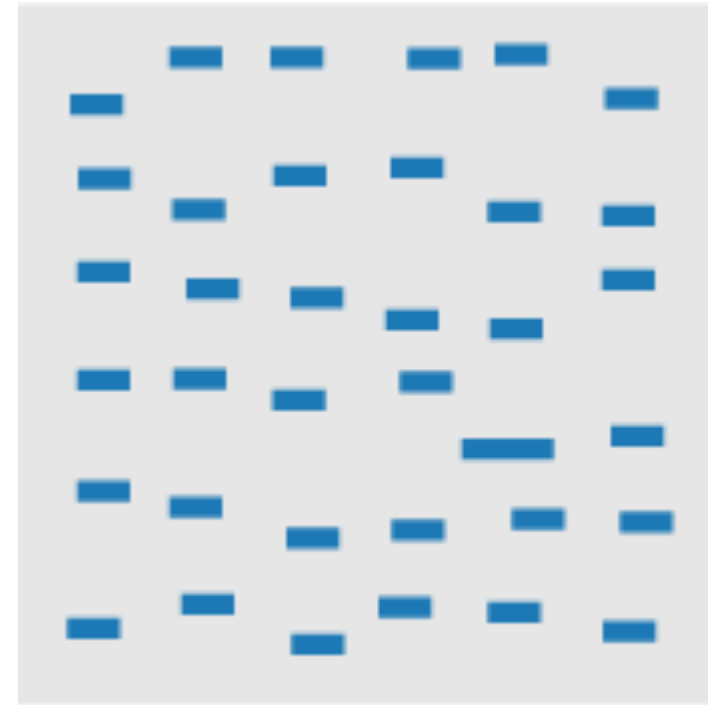


Conjunction Targets – no unique visual property  
target: red, circle  
distractor objects have both properties

# Some Preattentive Properties



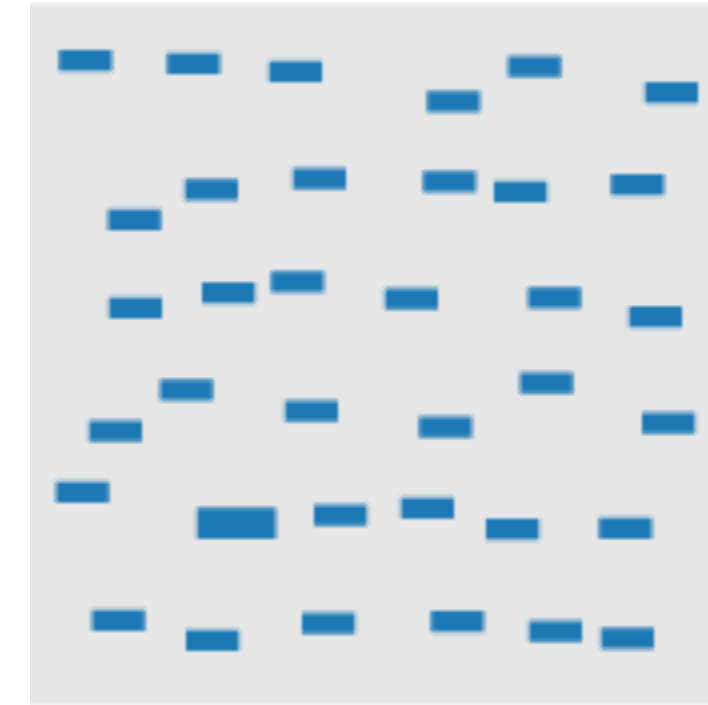
orientation



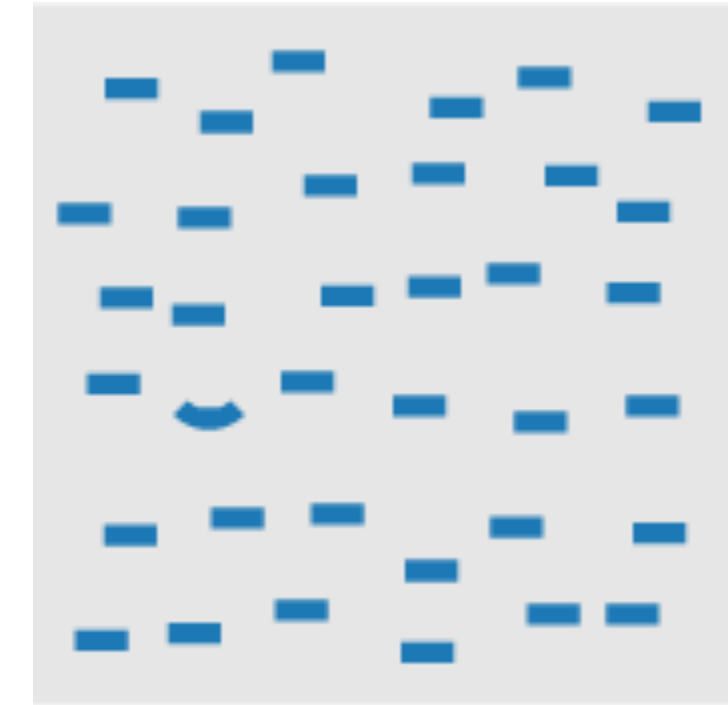
length



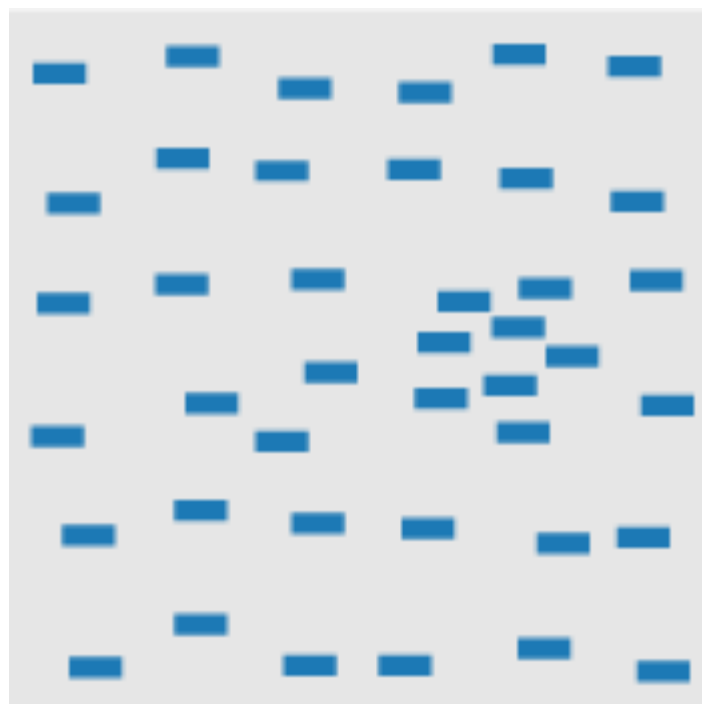
closure



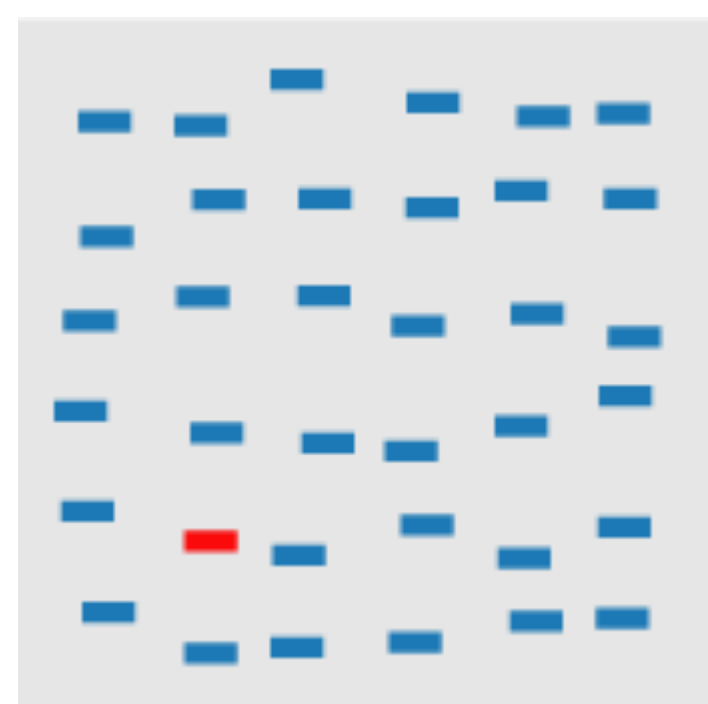
size



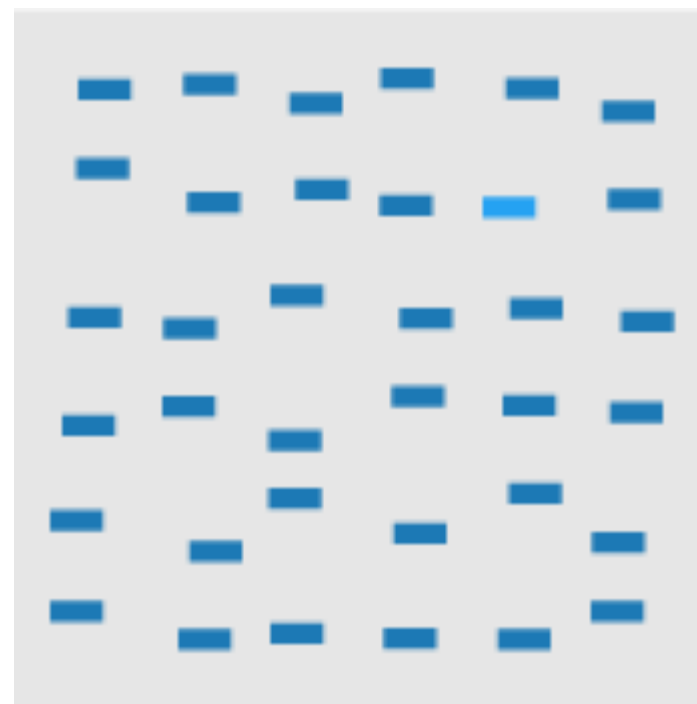
curvature



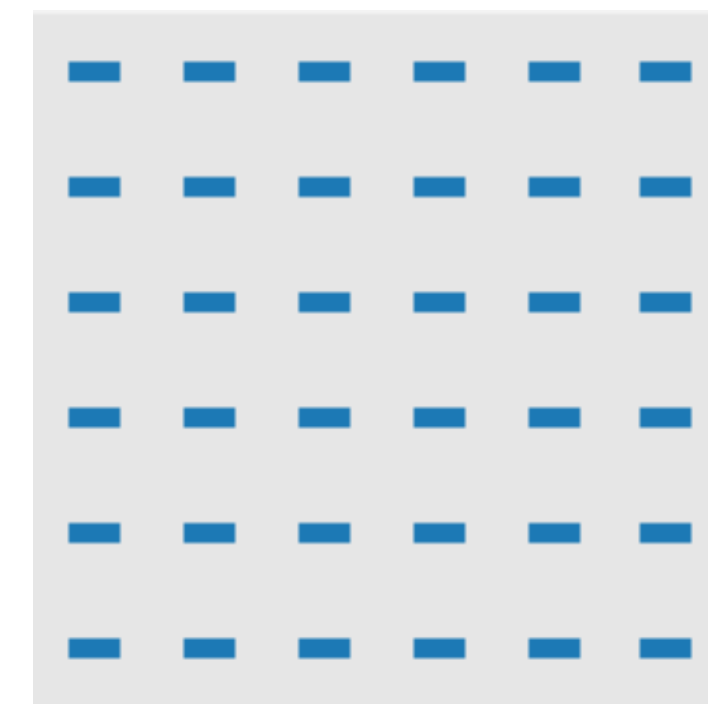
density



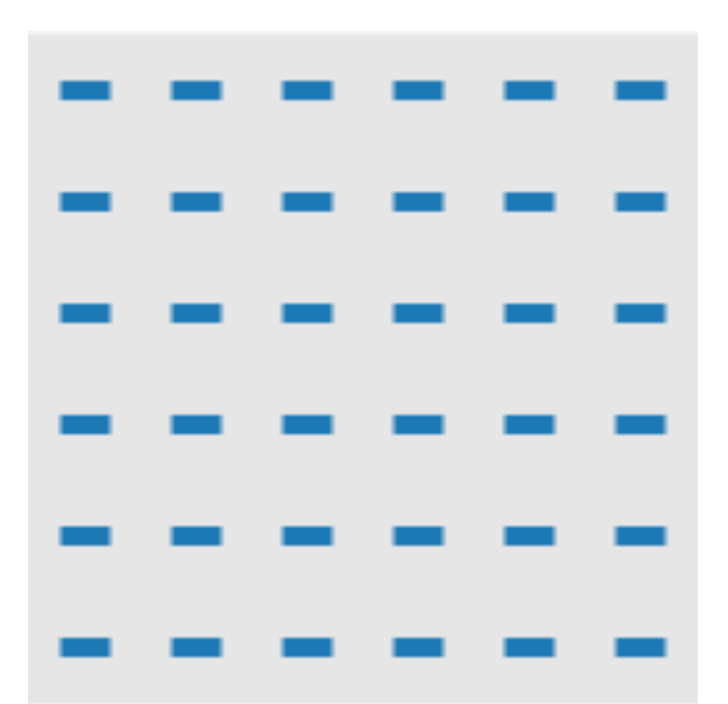
hue



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

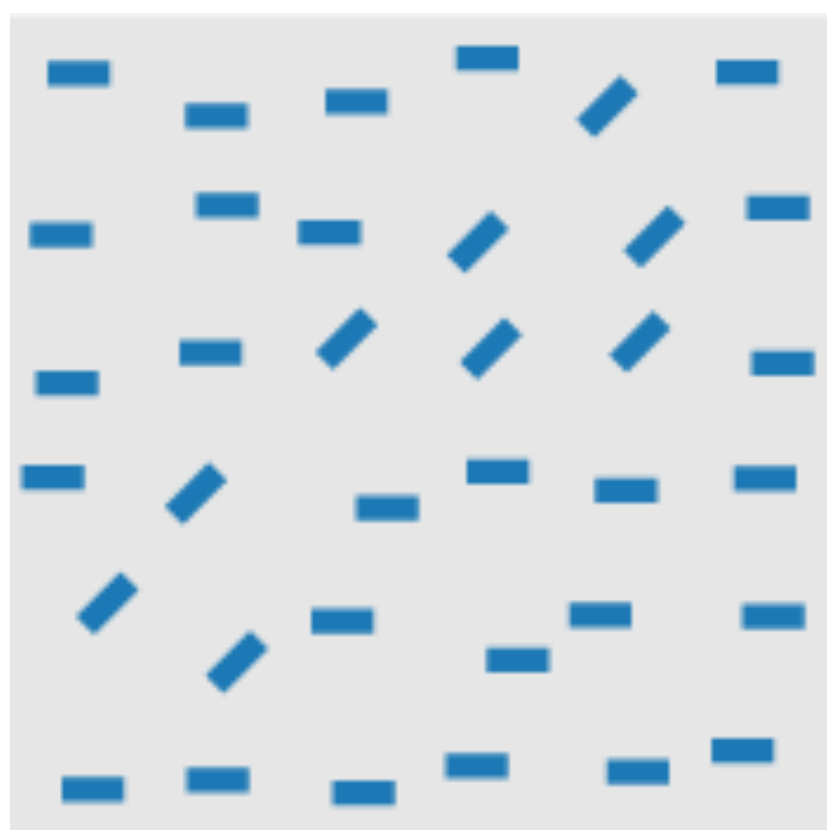
track one or more elements with a unique visual feature as they move in time and space

## counting and estimation

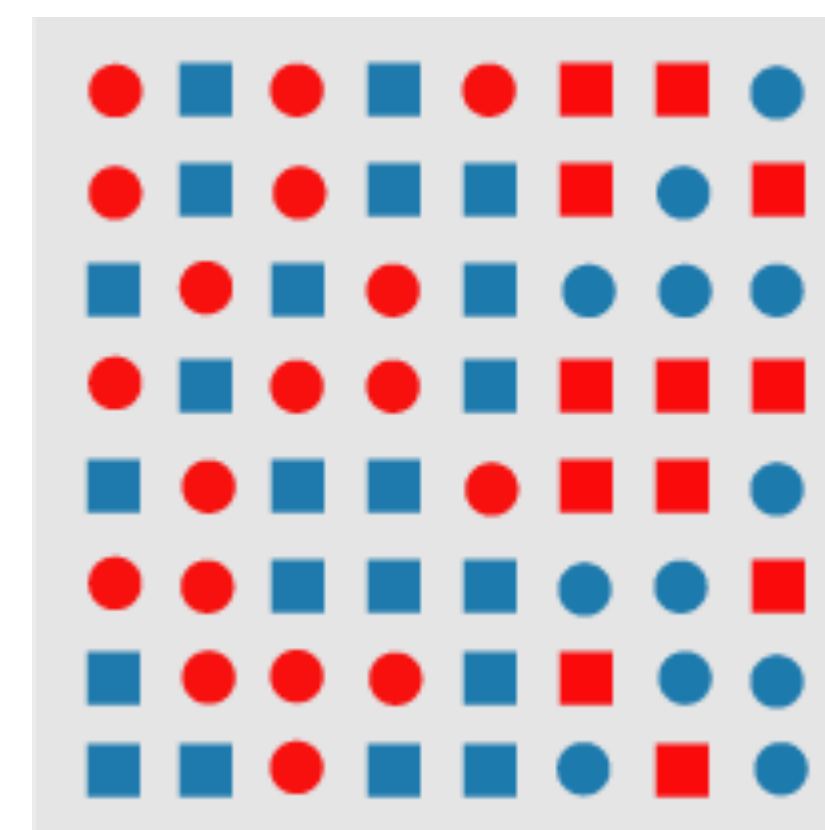
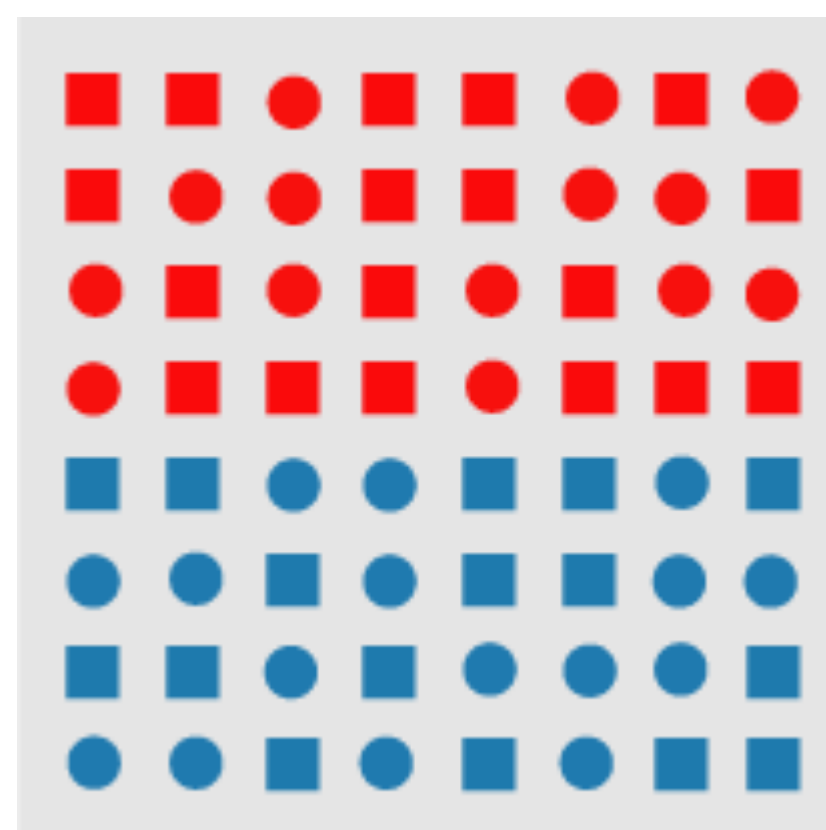
users count or estimate the number of elements with a unique visual feature.

# Tasks

Number Estimation

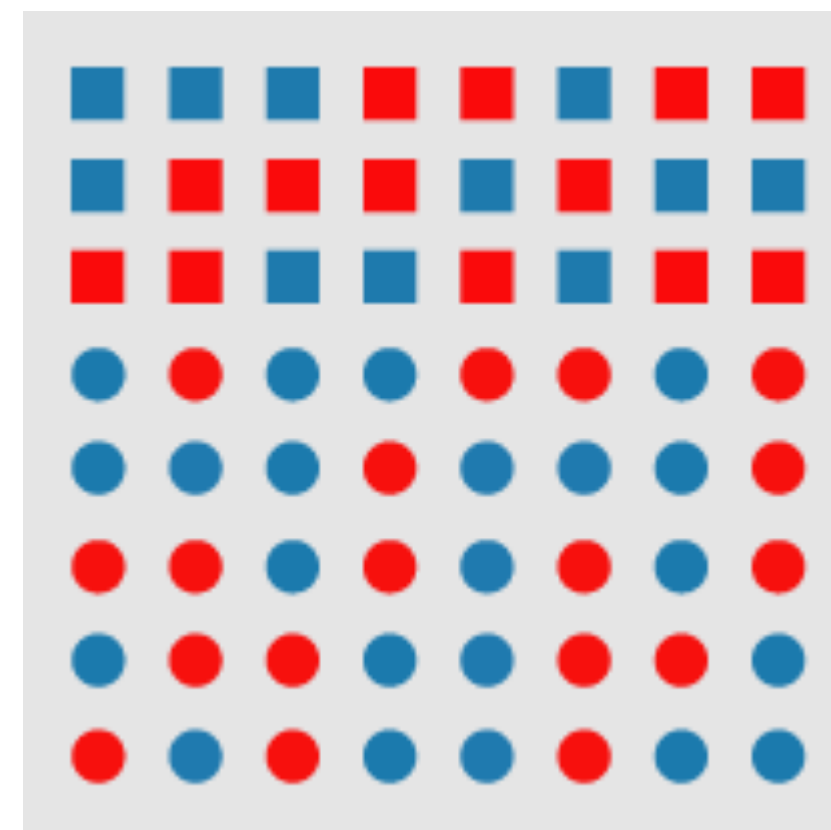
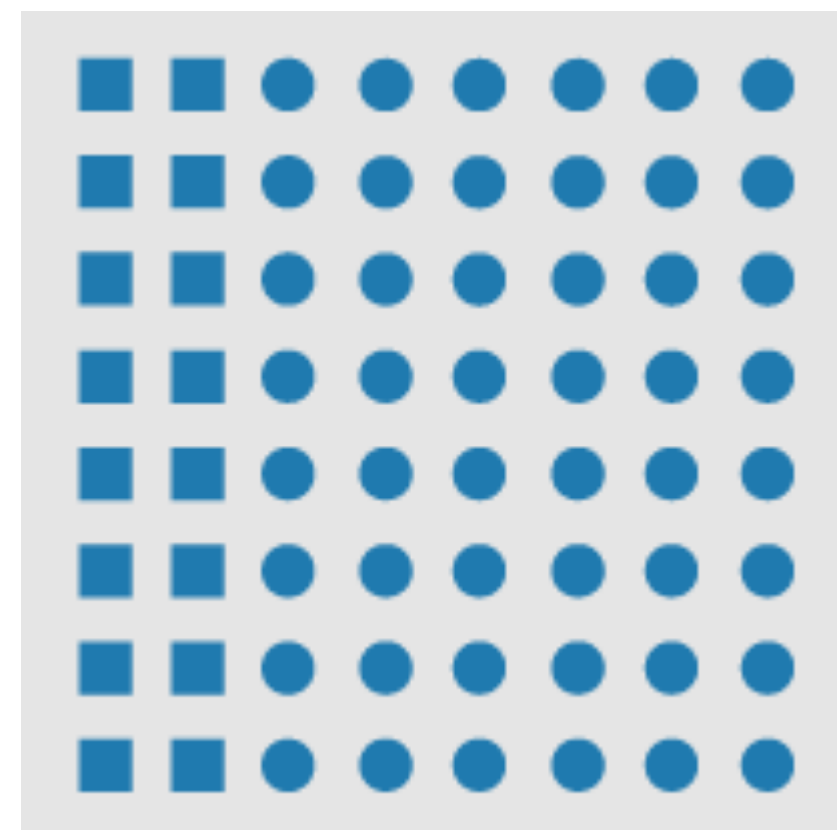
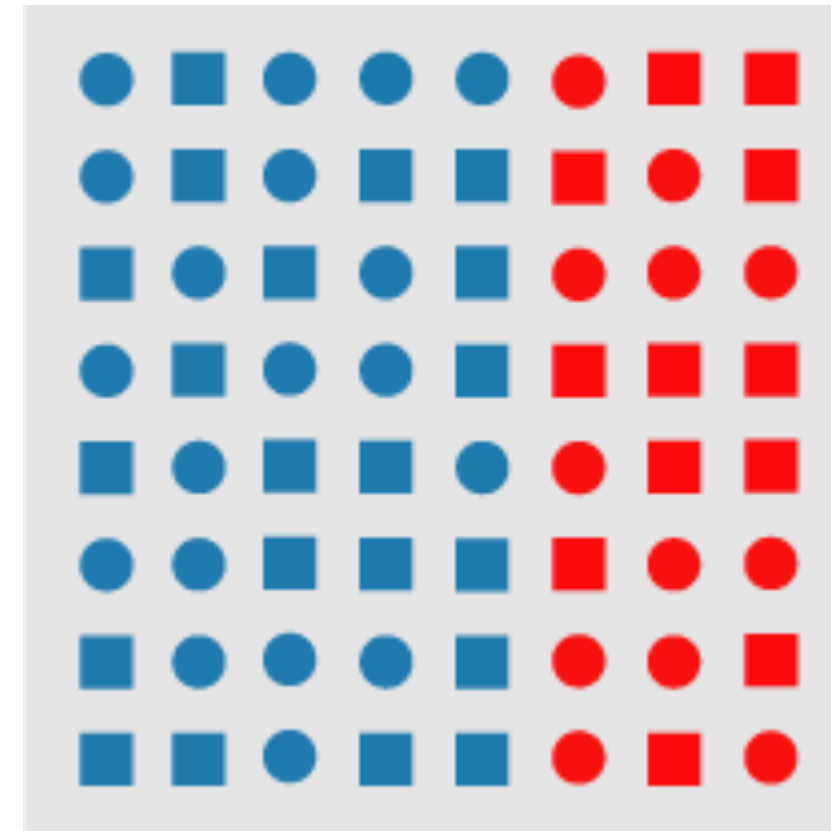
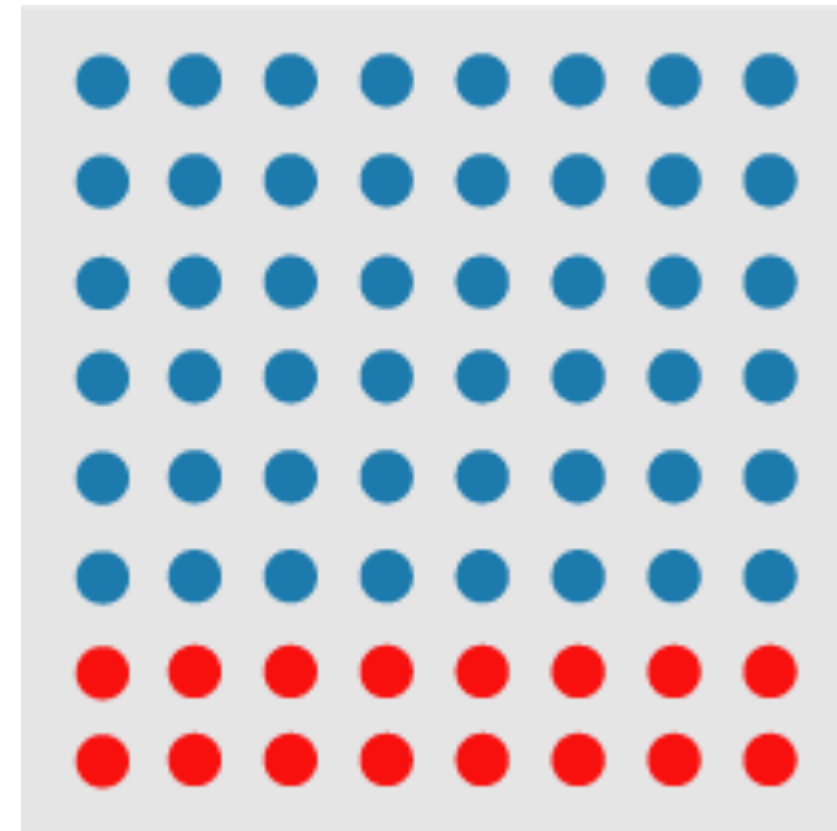


Boundary Detection





# Hierarchy of Preattentive Features



# Theories of Preattentive Processing

Not known for sure how it works

Several theories:

<http://www.csc.ncsu.edu/faculty/healey/PP/index.html>



# Preattentive Processing 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







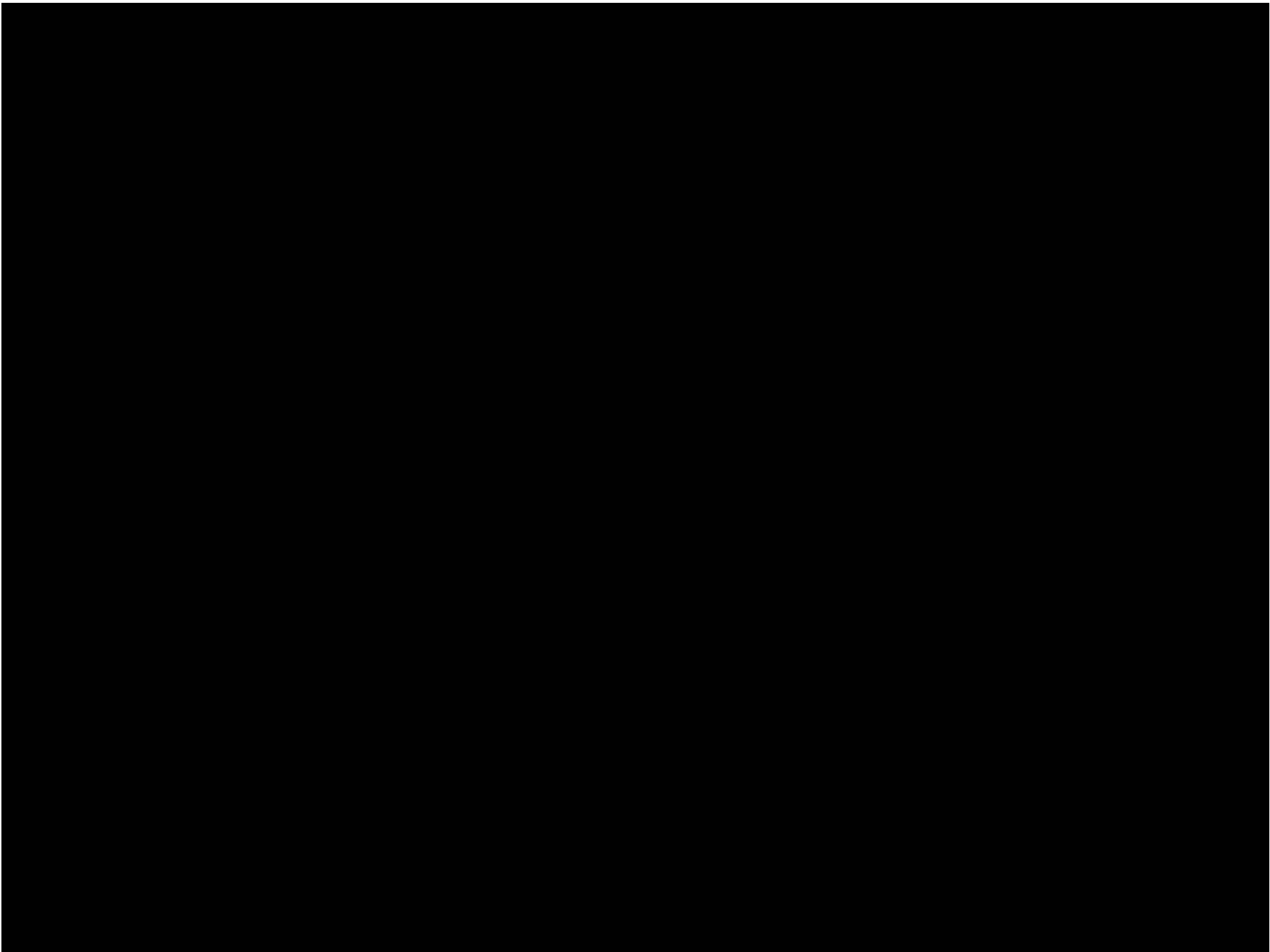




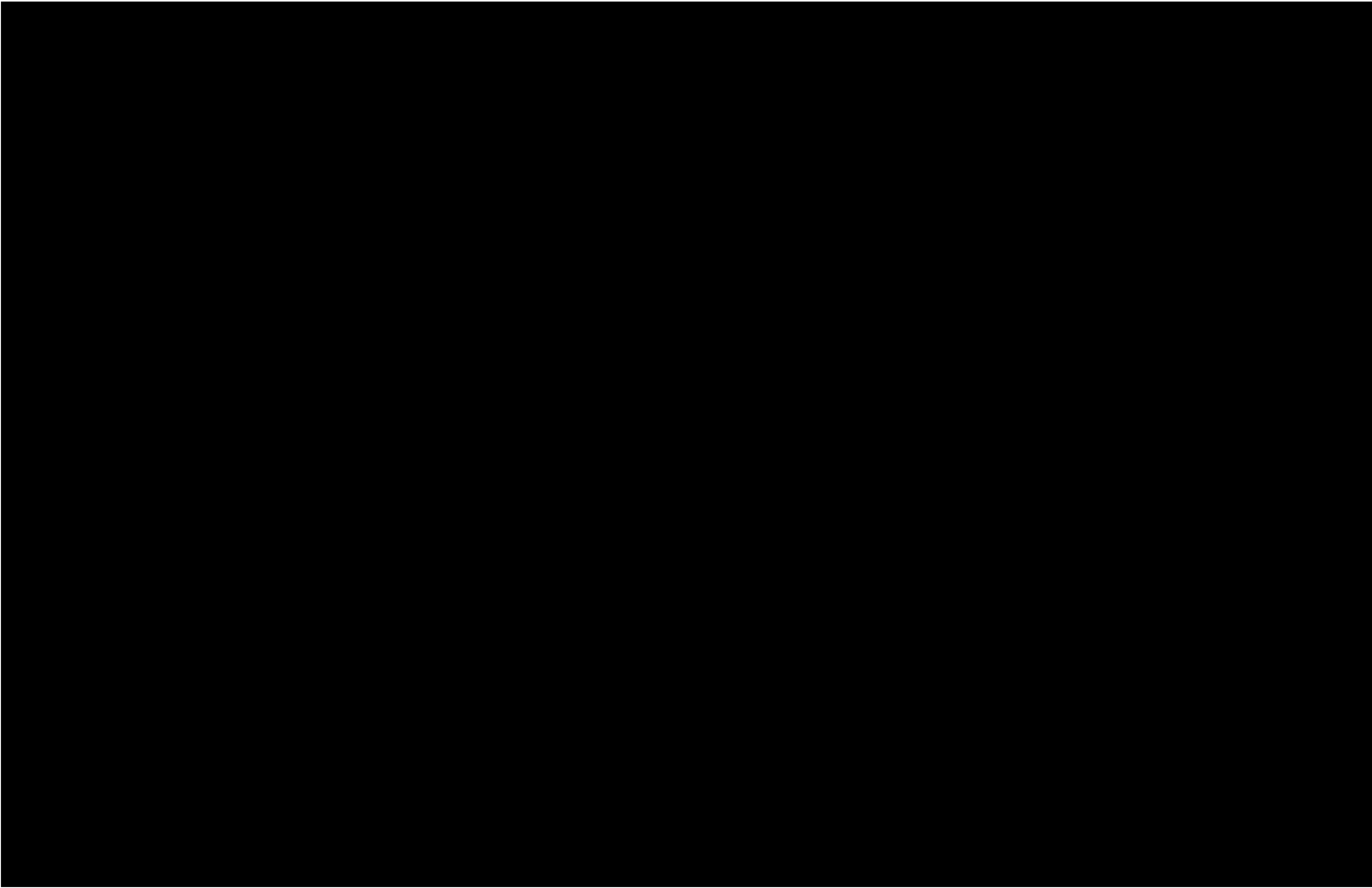




# Attention Blindness













# 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

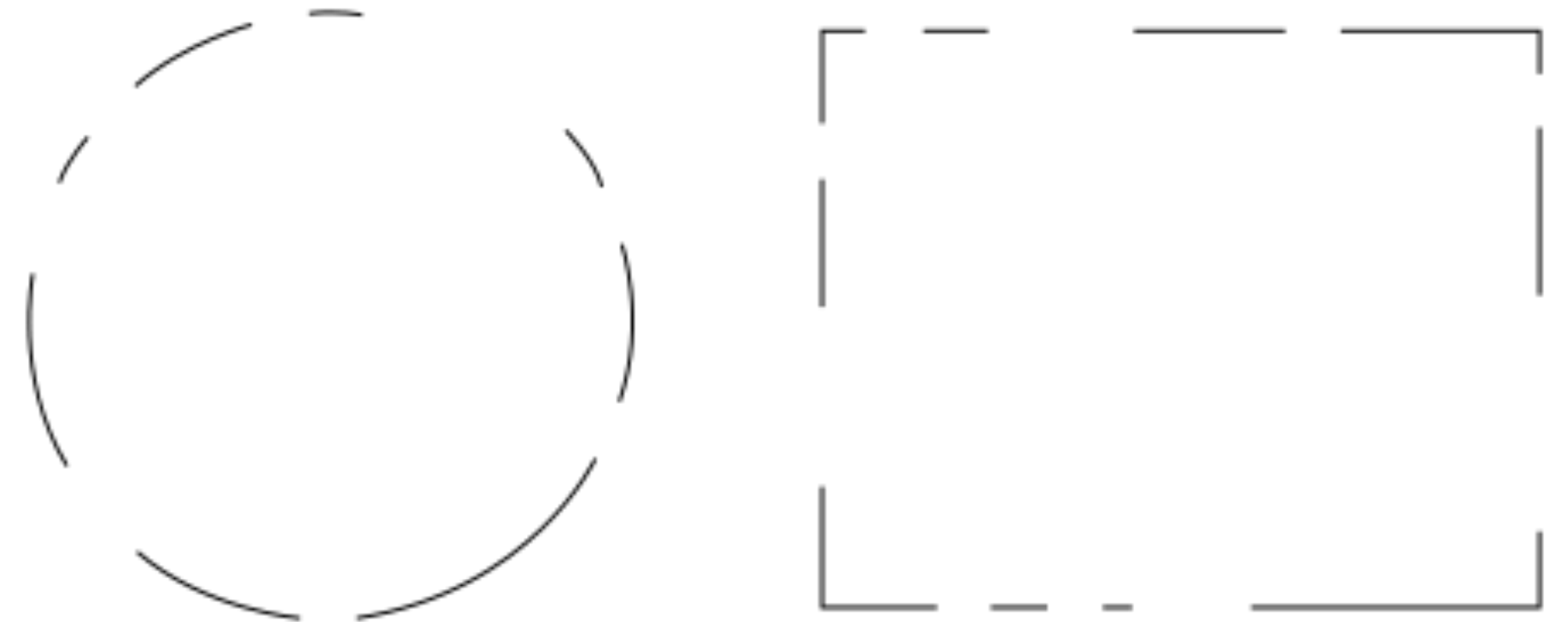
- *Das Ganze ist etwas anderes als die Summe seiner Teile.*
- *The whole is something else than the sum of its parts.*

Kurt Koffka

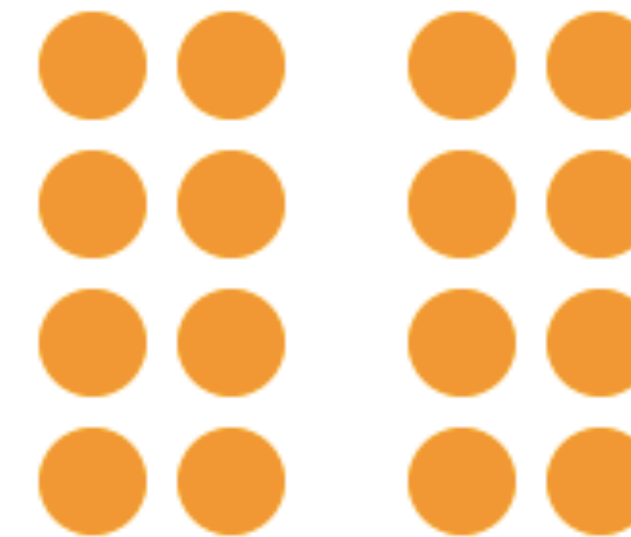
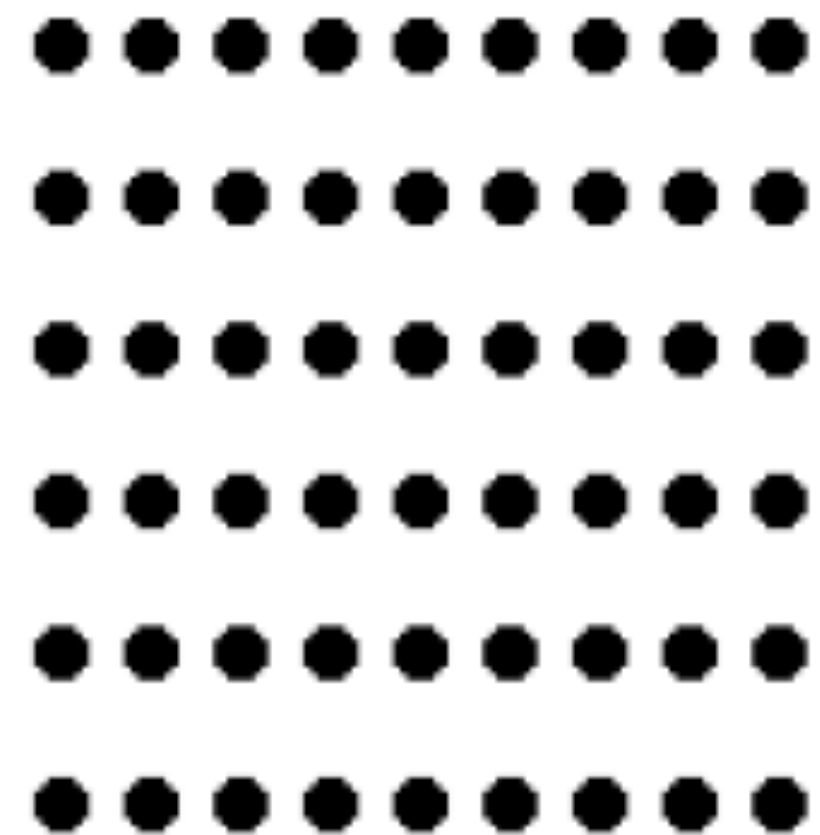
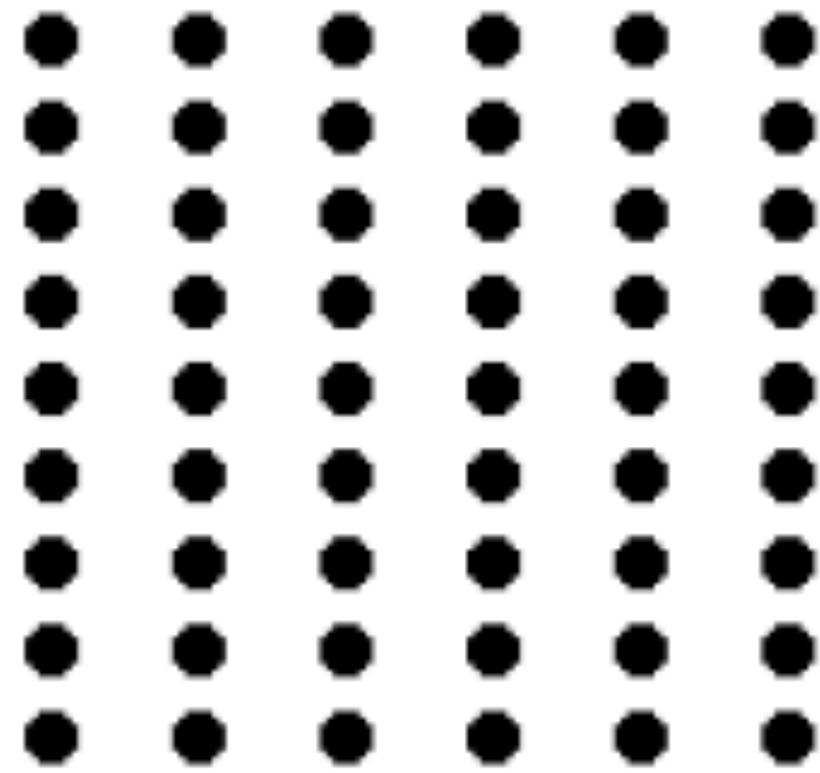
Disagreed with the

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

quote which is attributed to Aristoteles

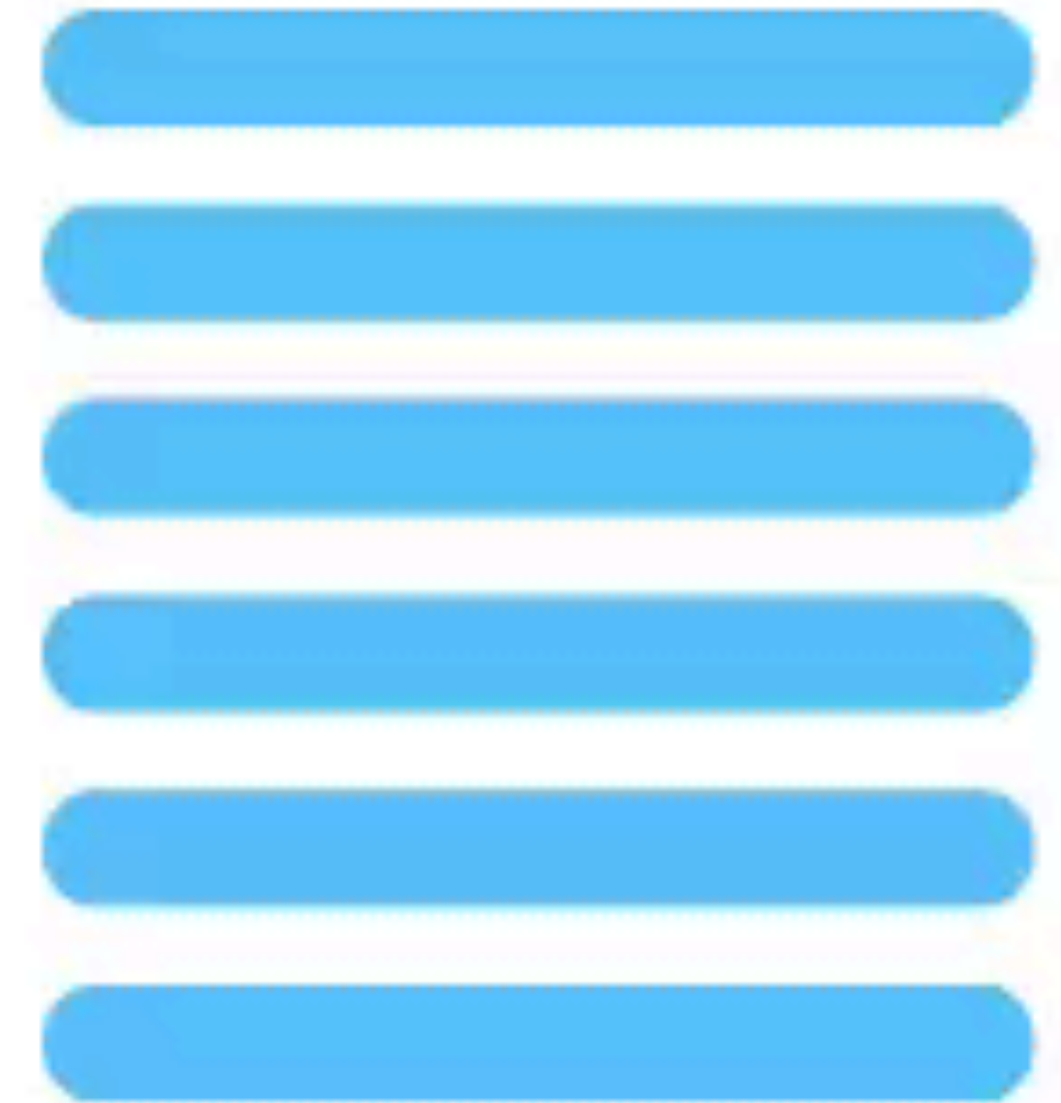
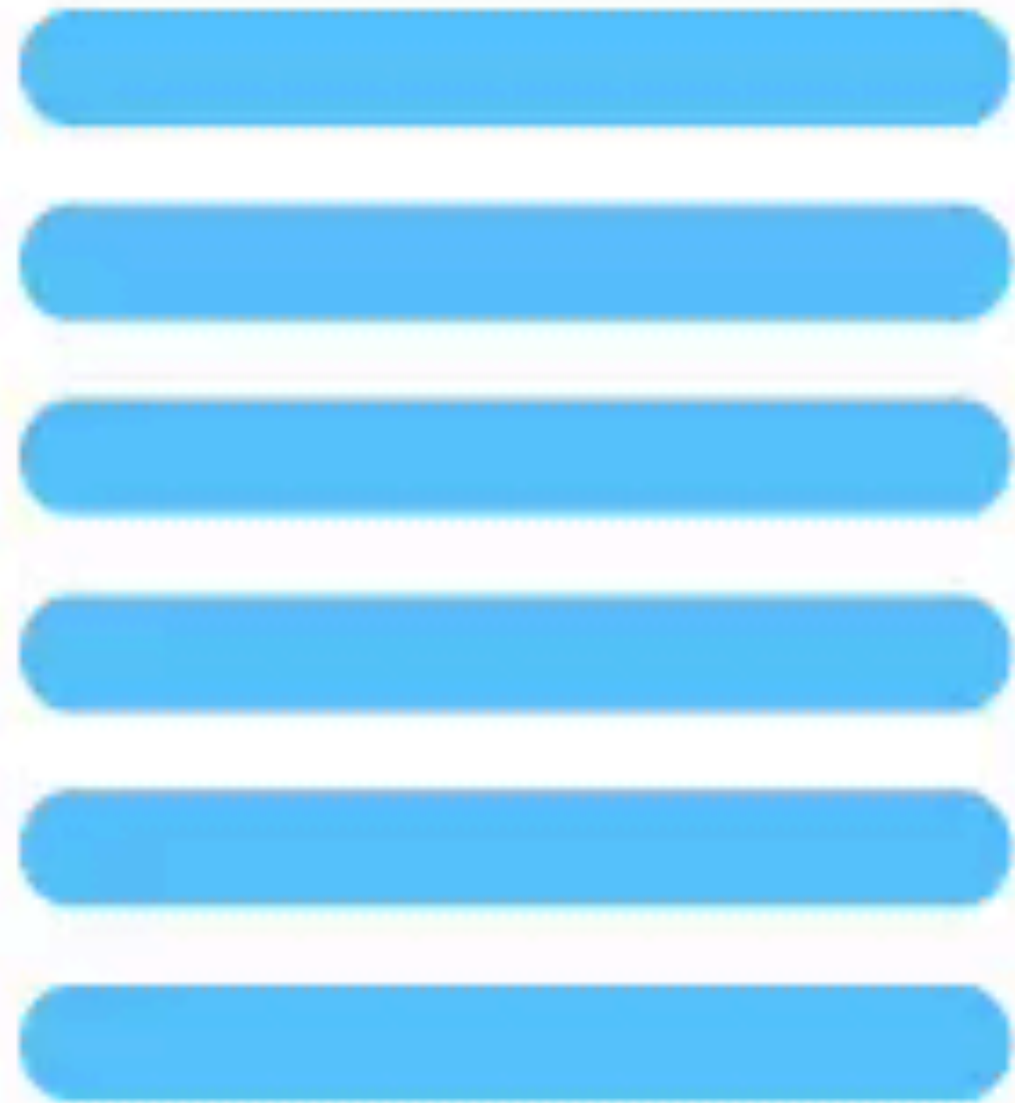


# Proximity





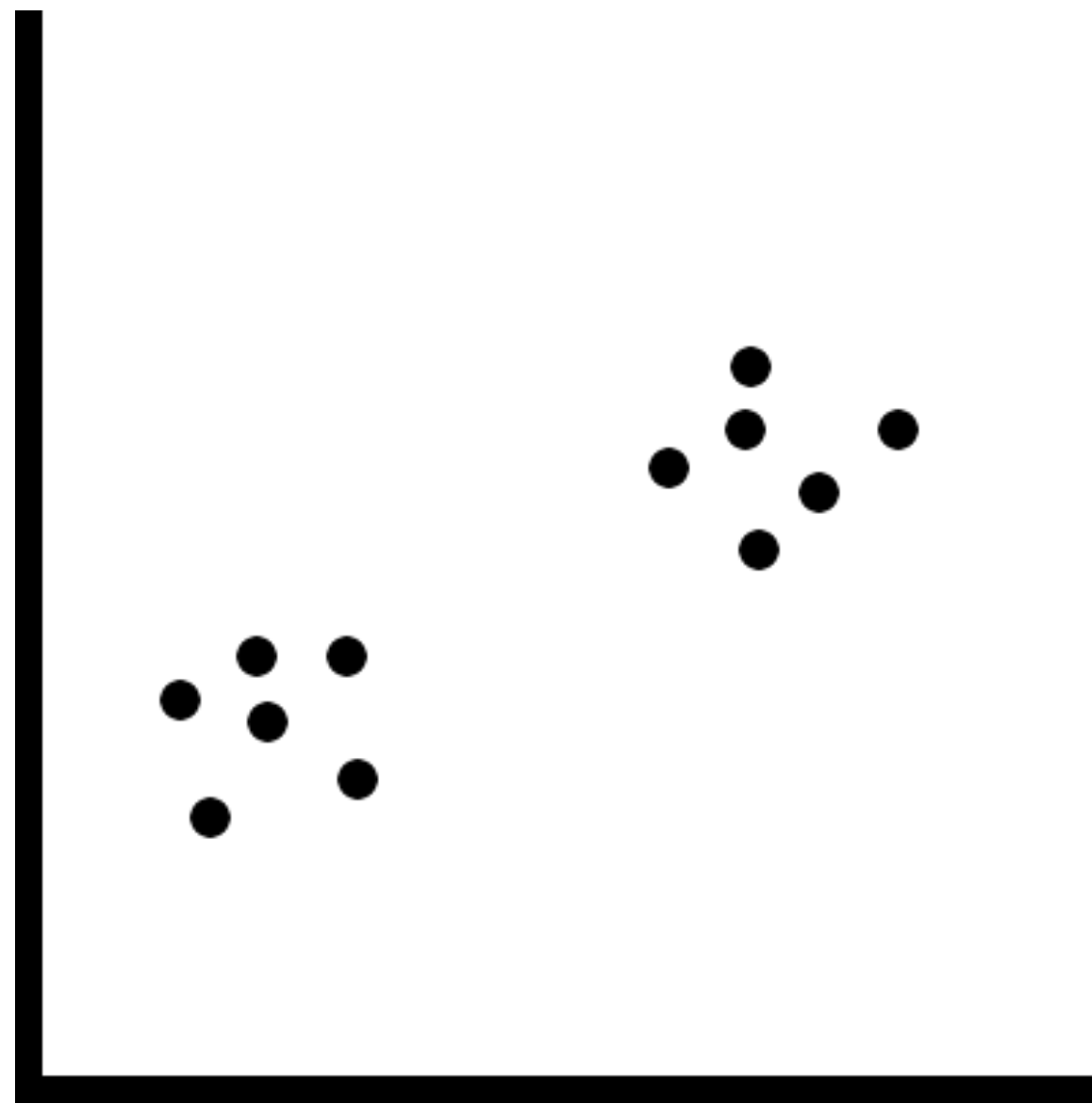
# Law of proximity



4 columns

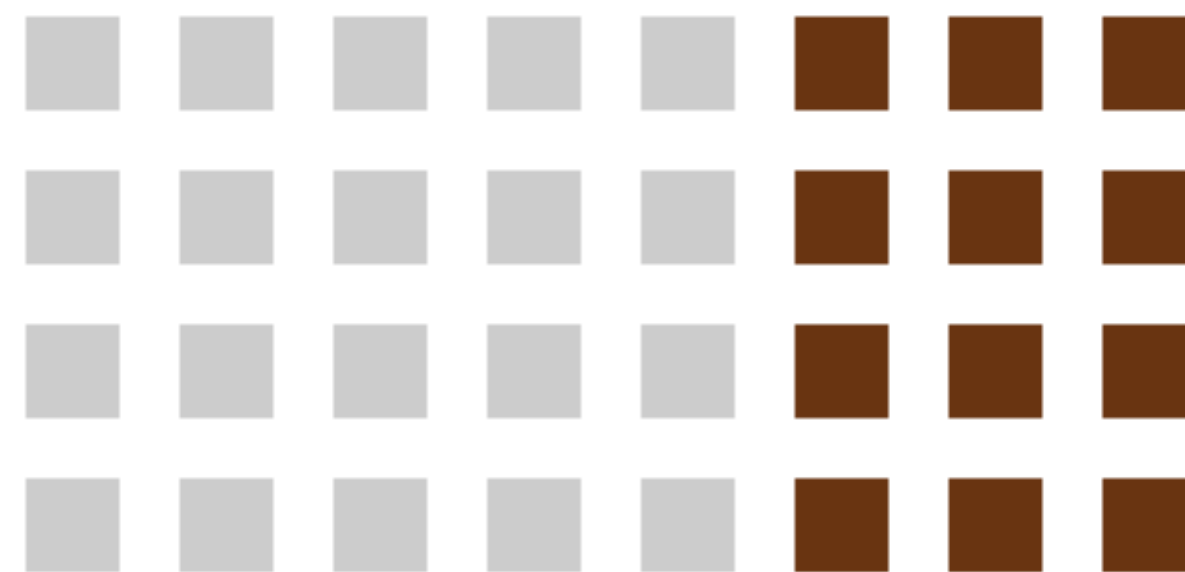
# Proximity

Grouping/linking by placing entities in close proximity

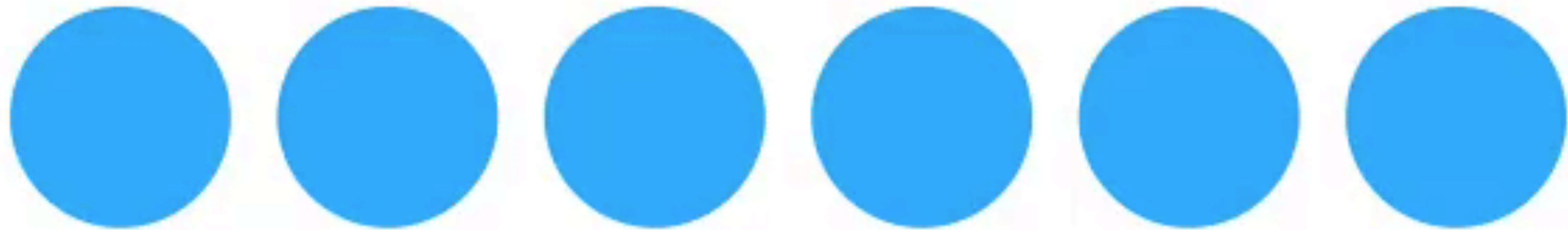




# Similarity



# Similarity Principle



1 group



**Focal Point**



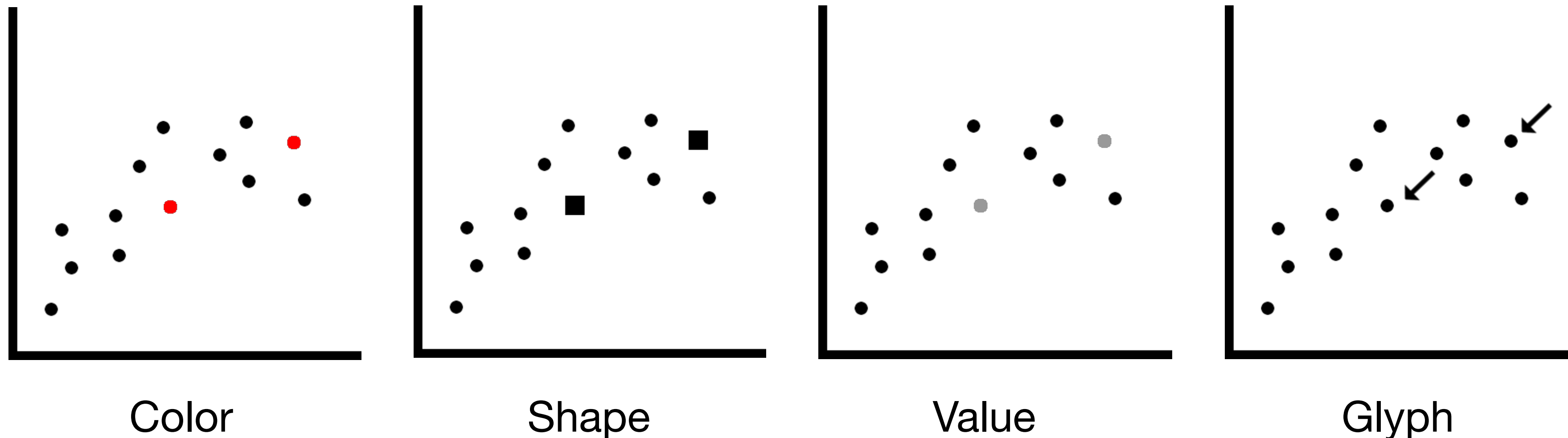
No focus

# Similarity

Co-modulation of a **channel**

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

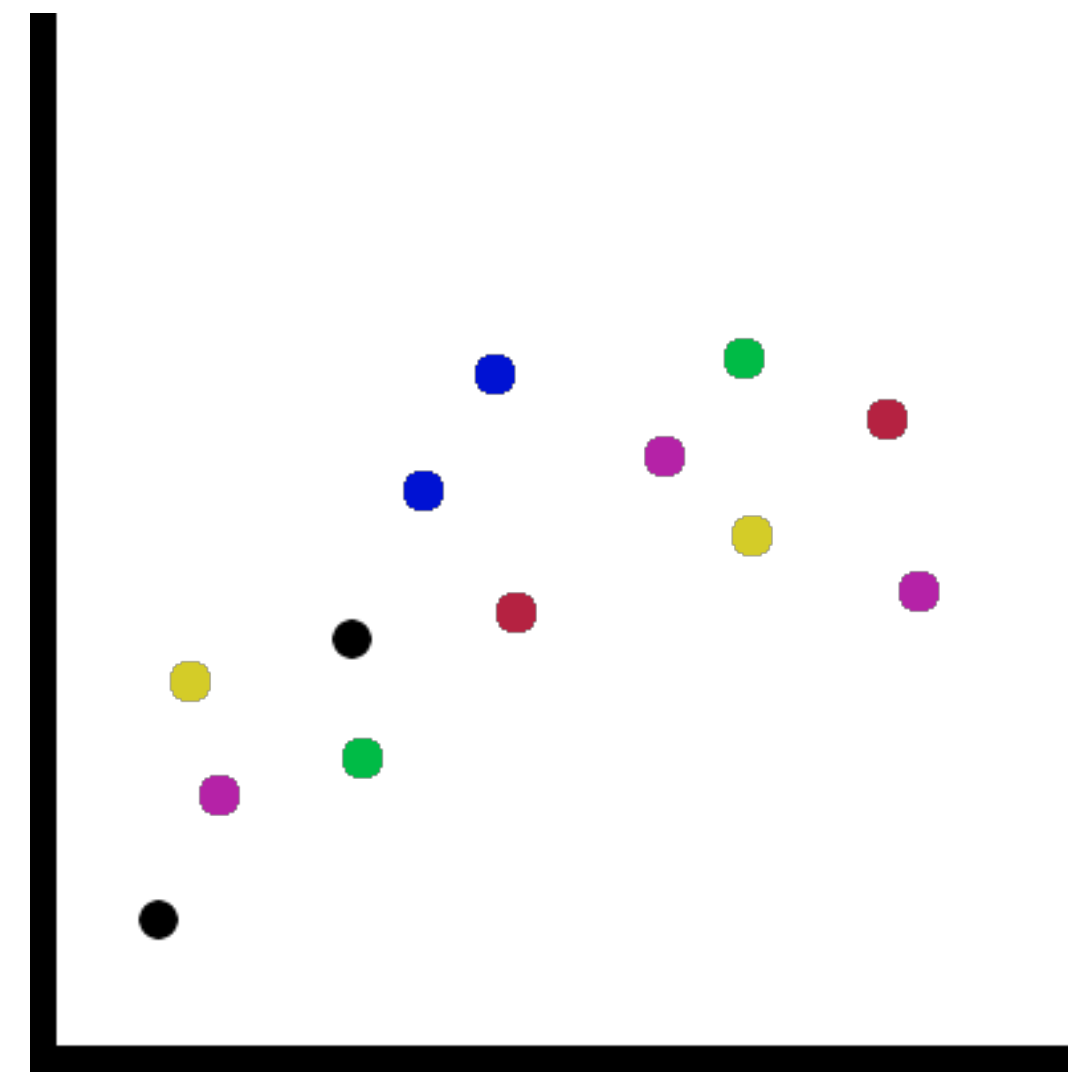
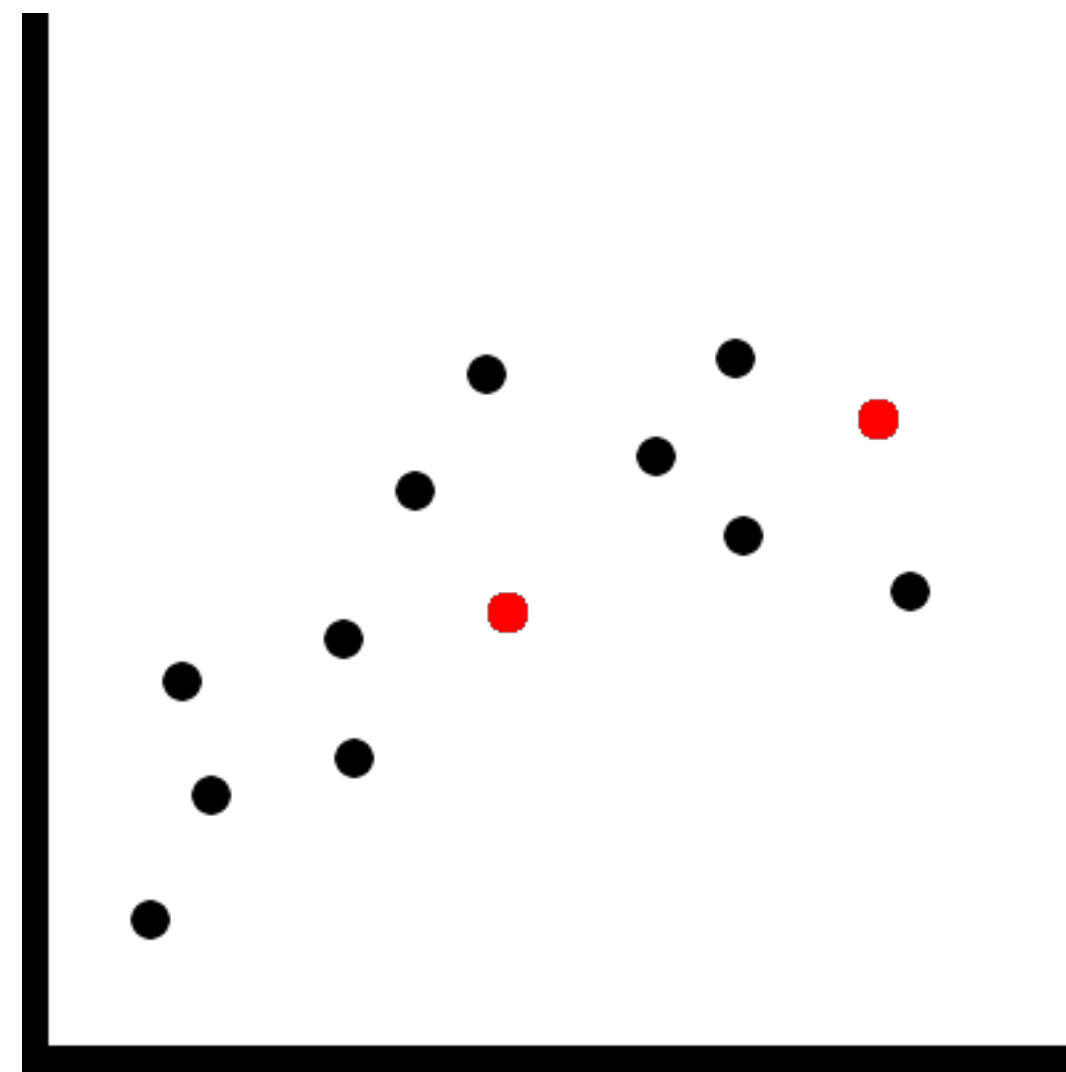
Adding a glyph, label, frame, background





# Color – Perception Issues (1/2)

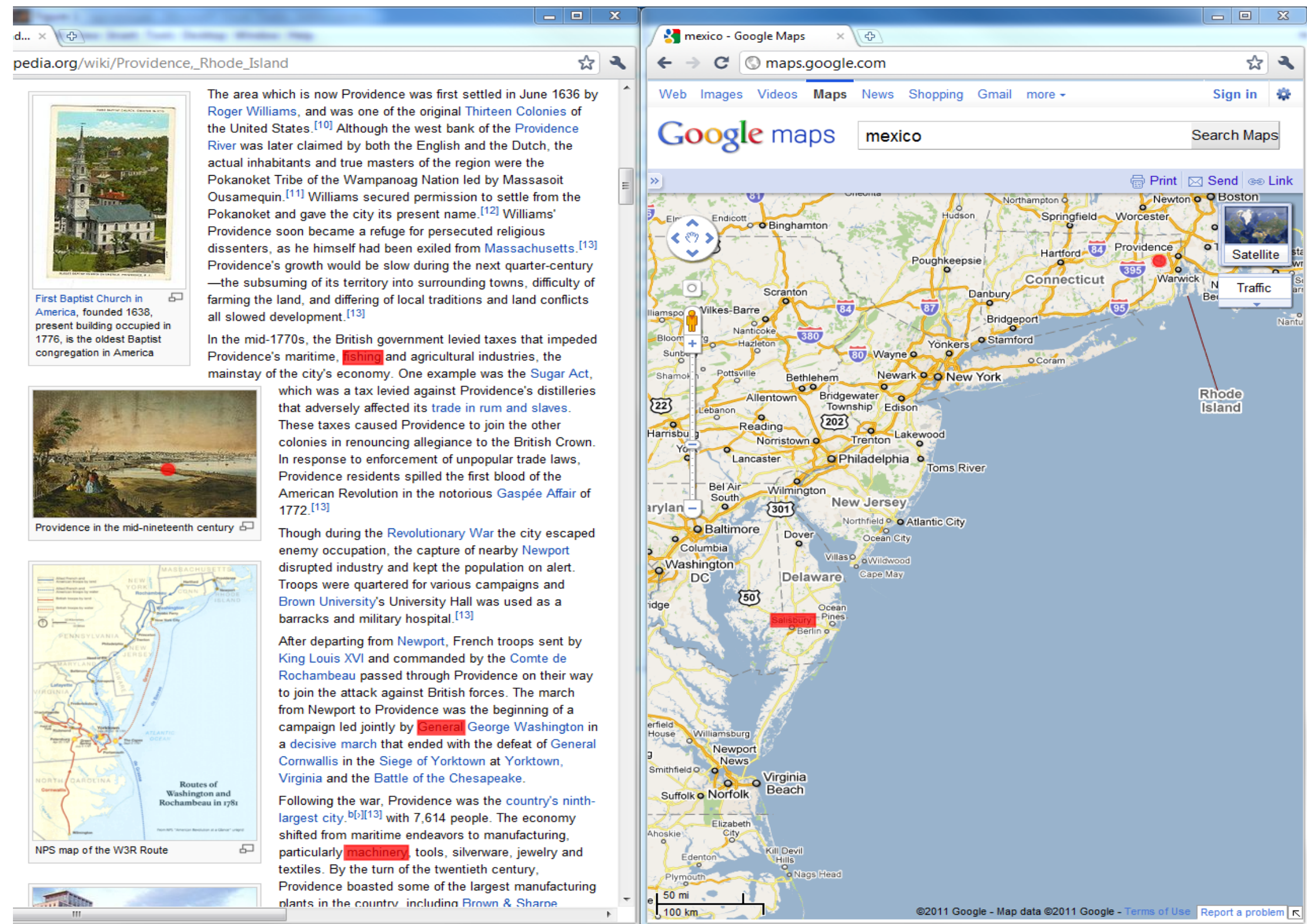
Popout properties: Very good for 1-2 simultaneous, **serial search for more**



# Color – Perception Issues (2/2)

Slower in a cluttered environment

Size of colored object relevant.

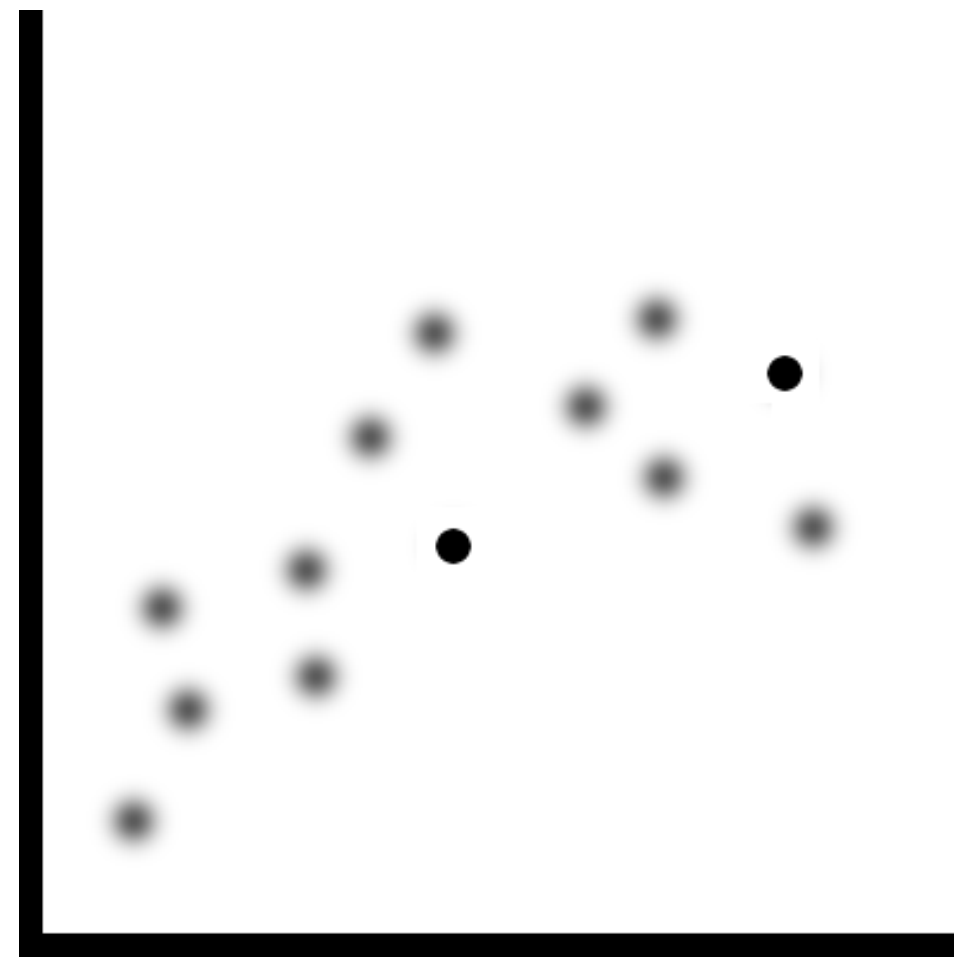




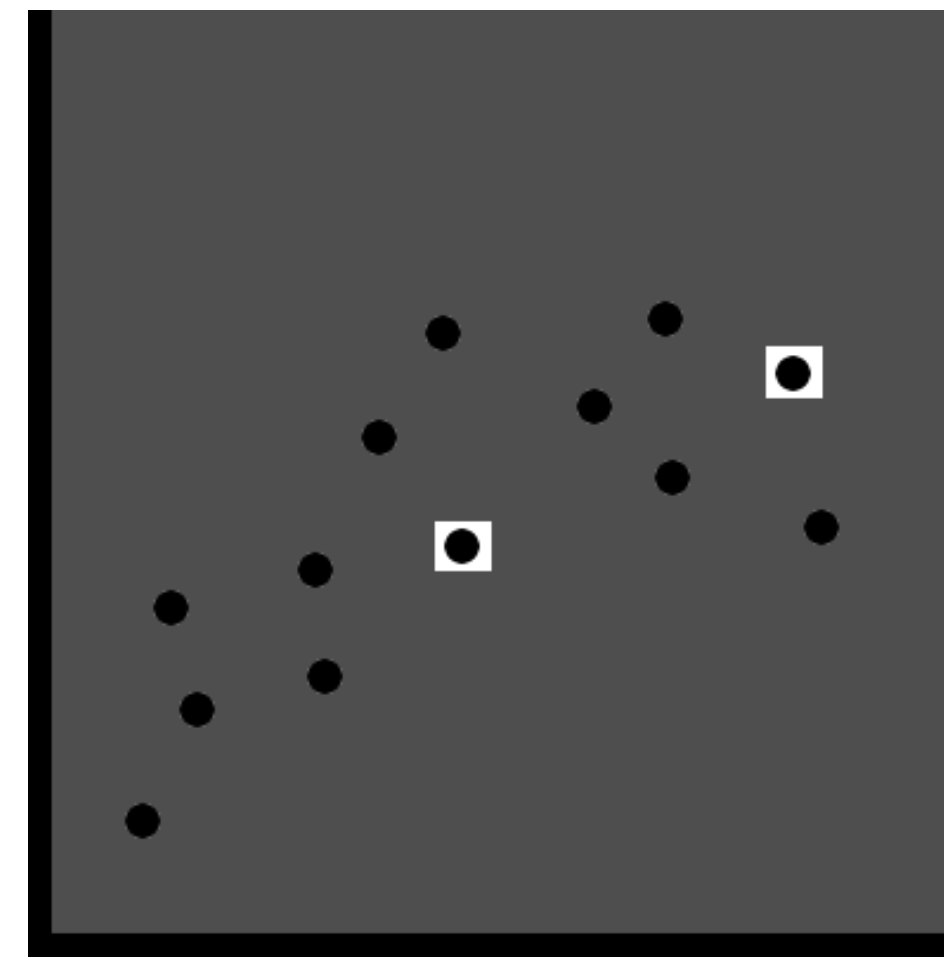
# Similarity

Modulate everything else

Blurring, darkening, desaturating, etc.



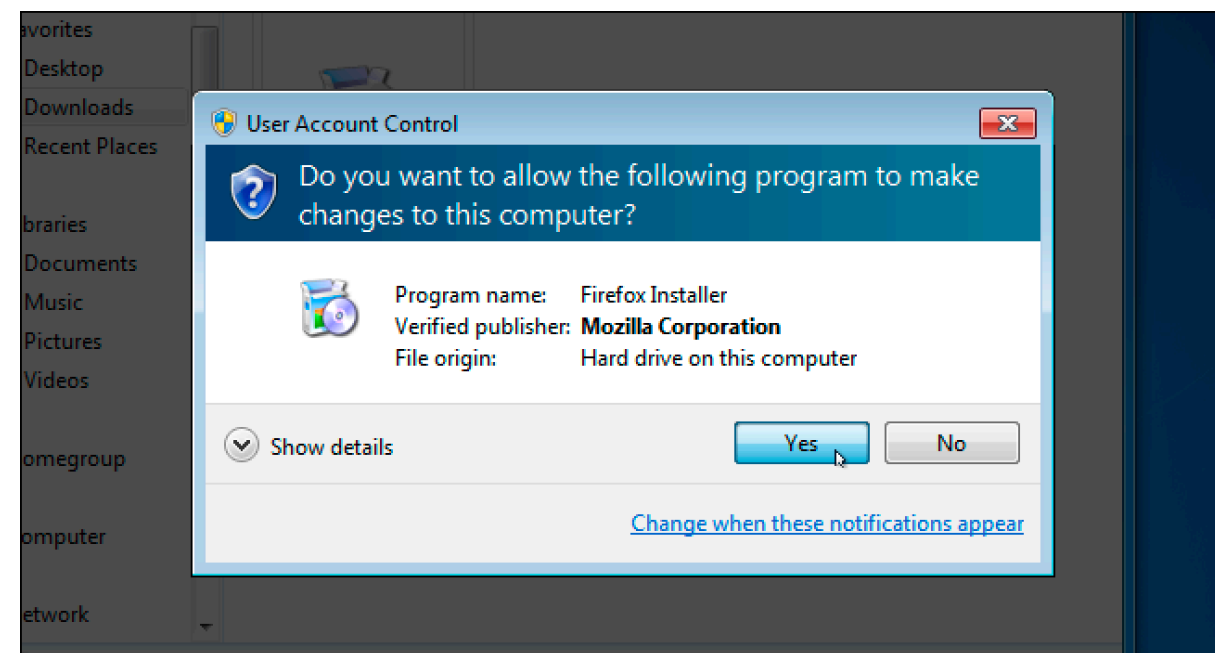
Blur



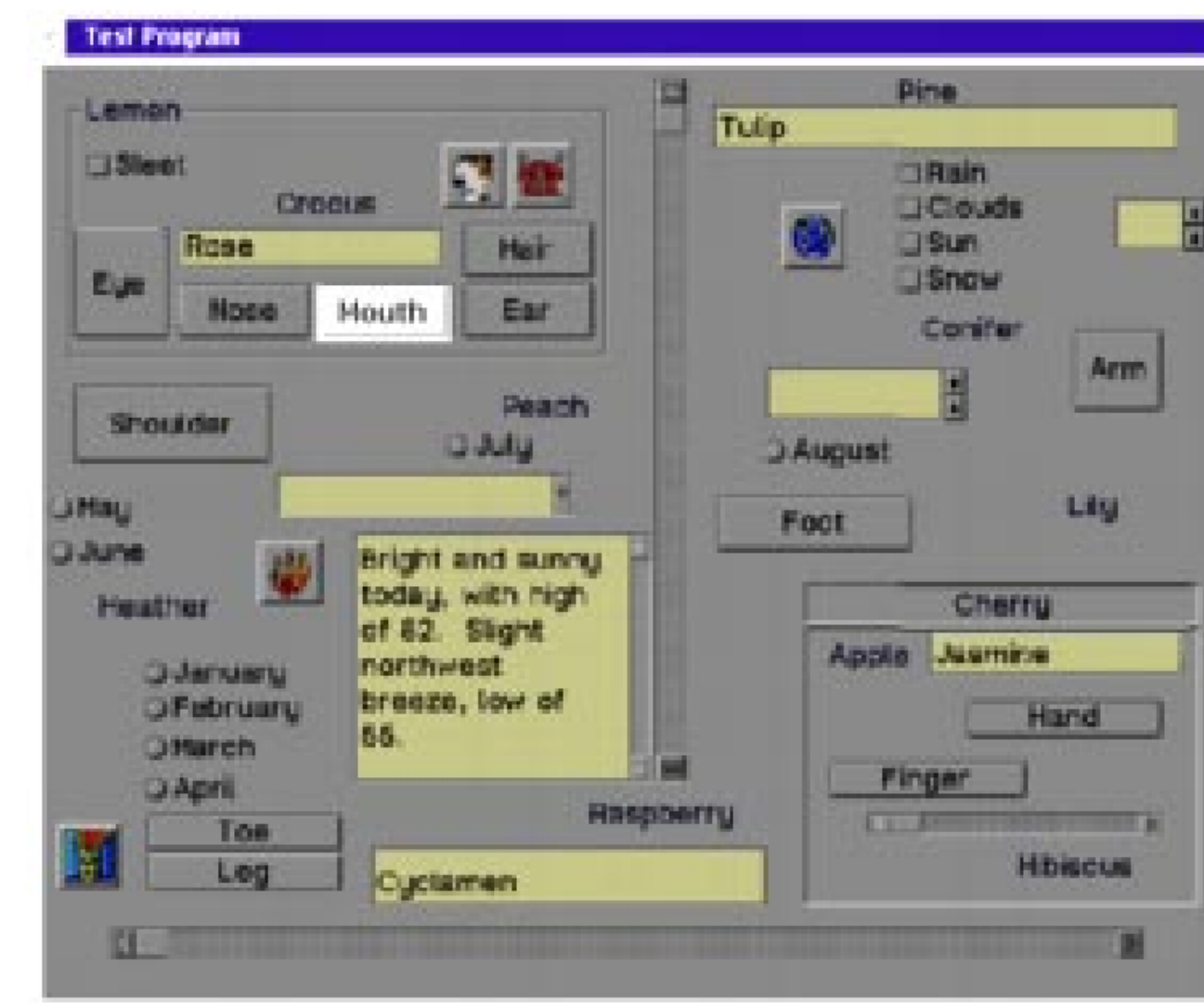
Darkening

# Modulating Everything Else: Recommendation, Example

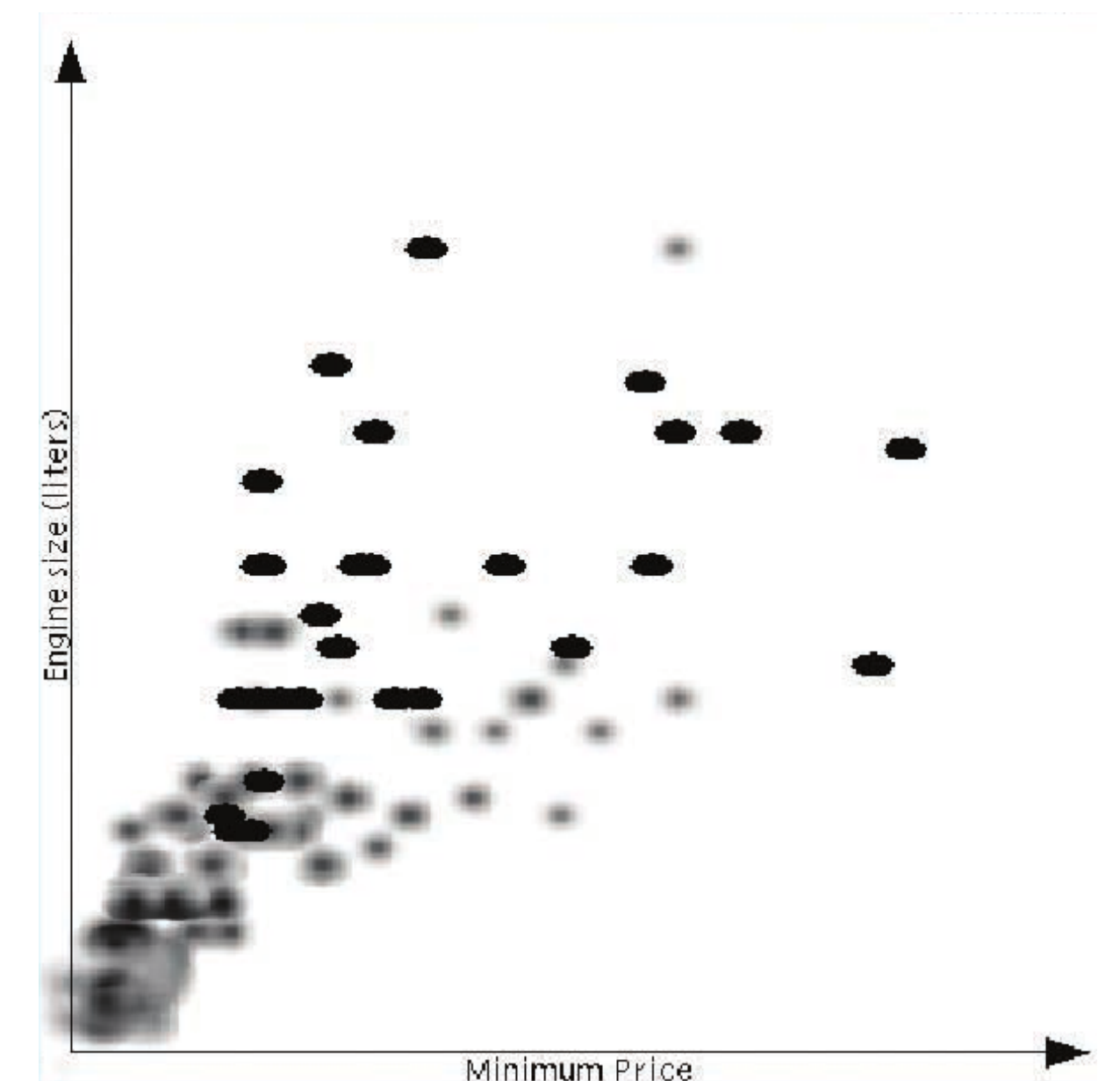
Don't use unless the sole objective is to guide attention toward one (set of) items



[MS Windows  
User Account Control]



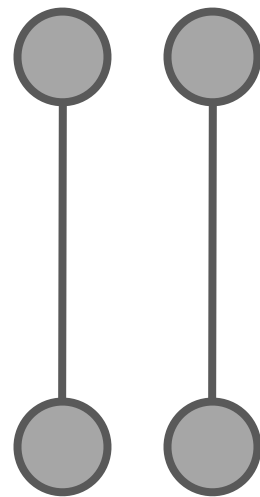
[Zhai et al., 1997]



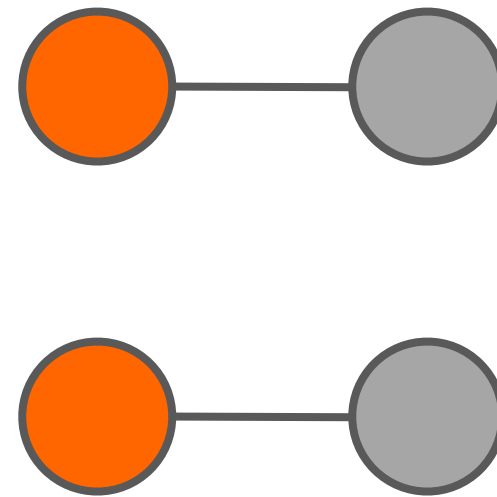
[Kosara et al., 2002]



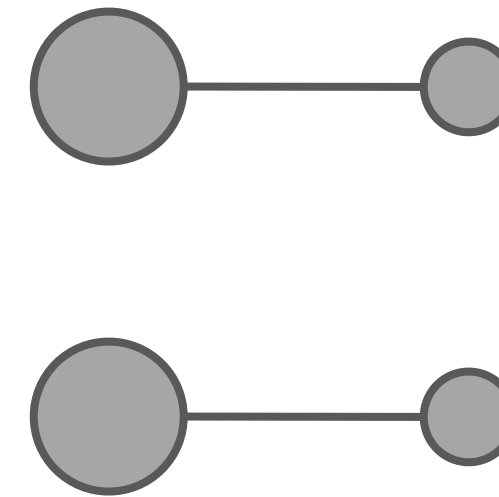
# A Little Experiment...



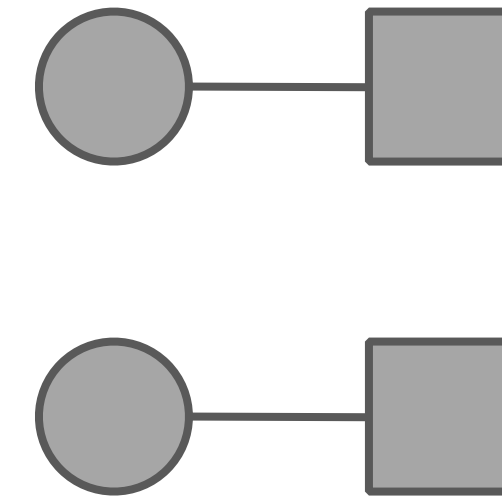
Proximity



Color



Size

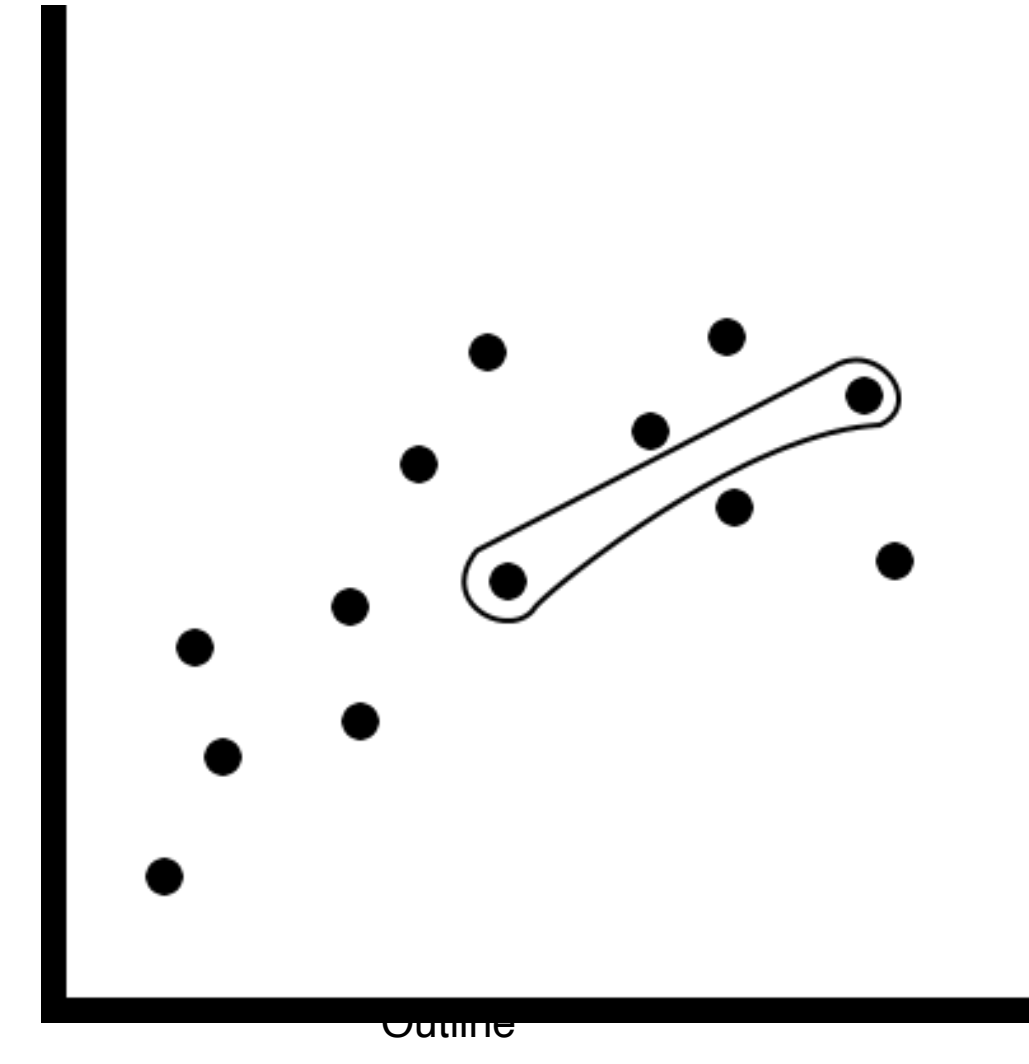
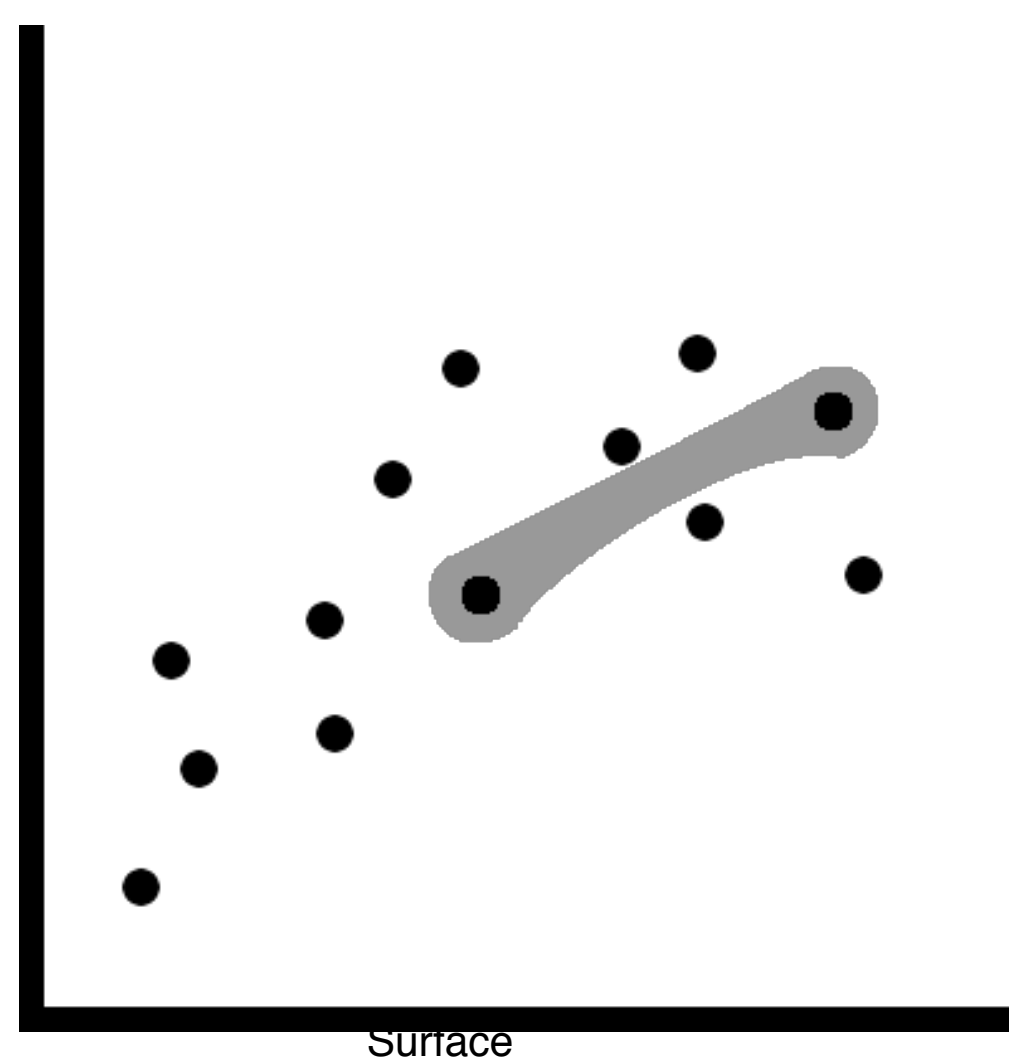
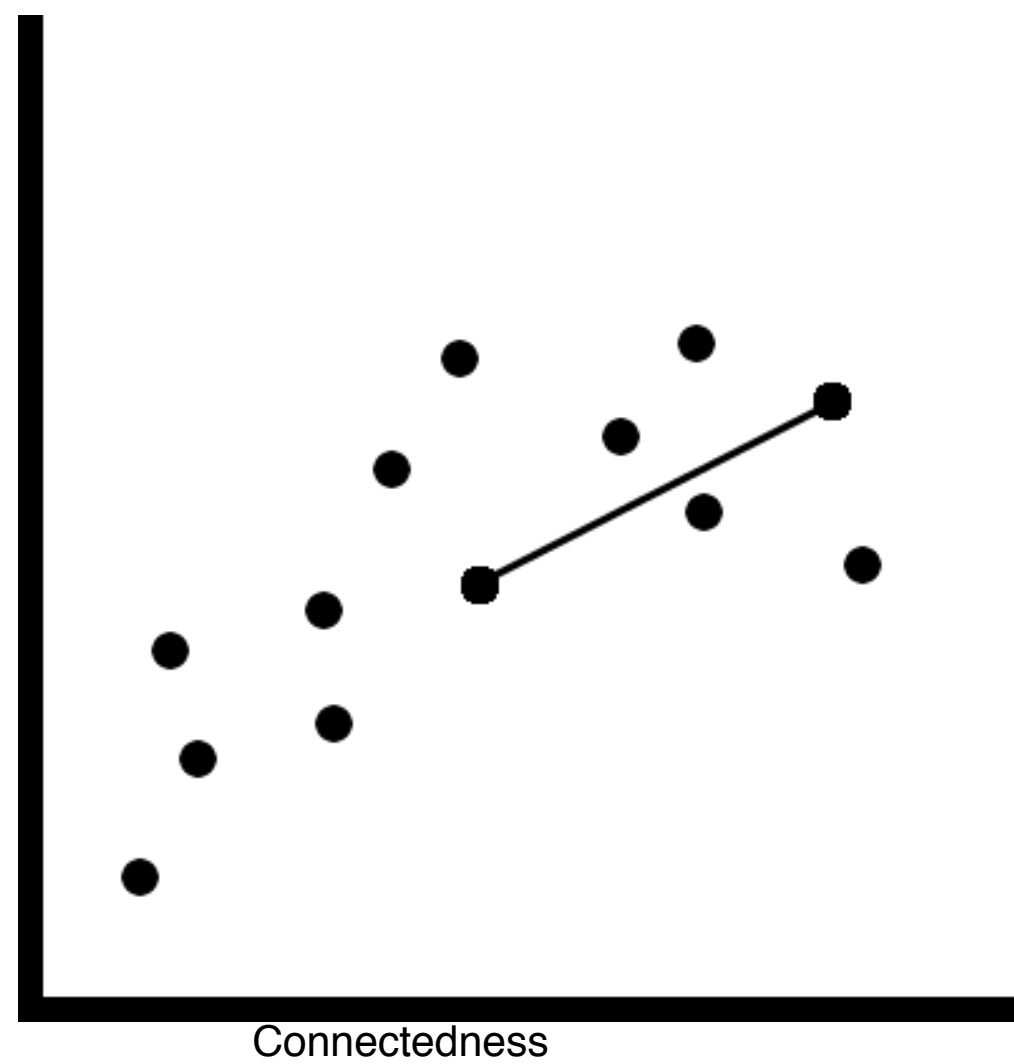


Shape

# Connectedness and Common Region

Connected items with a line or curve

Surround items with a outline, surface, volume

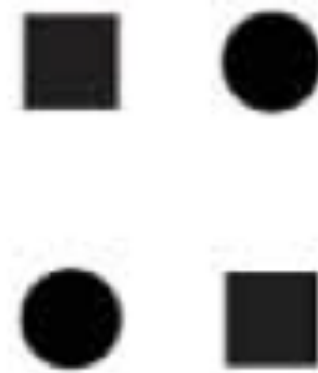


Common Region

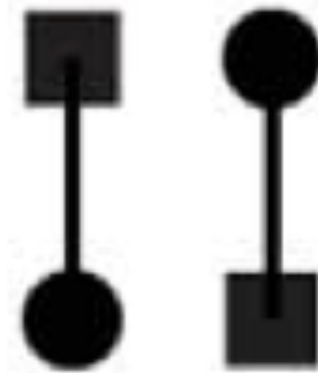


# Enclosure / Common Region

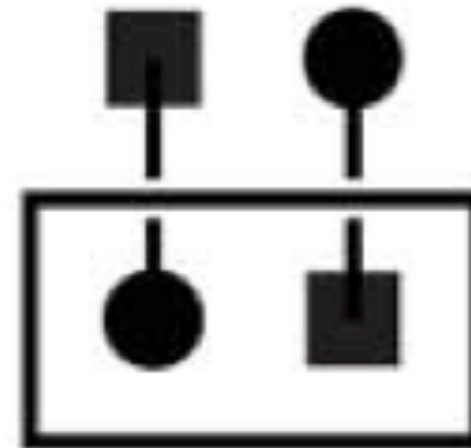
Similarity



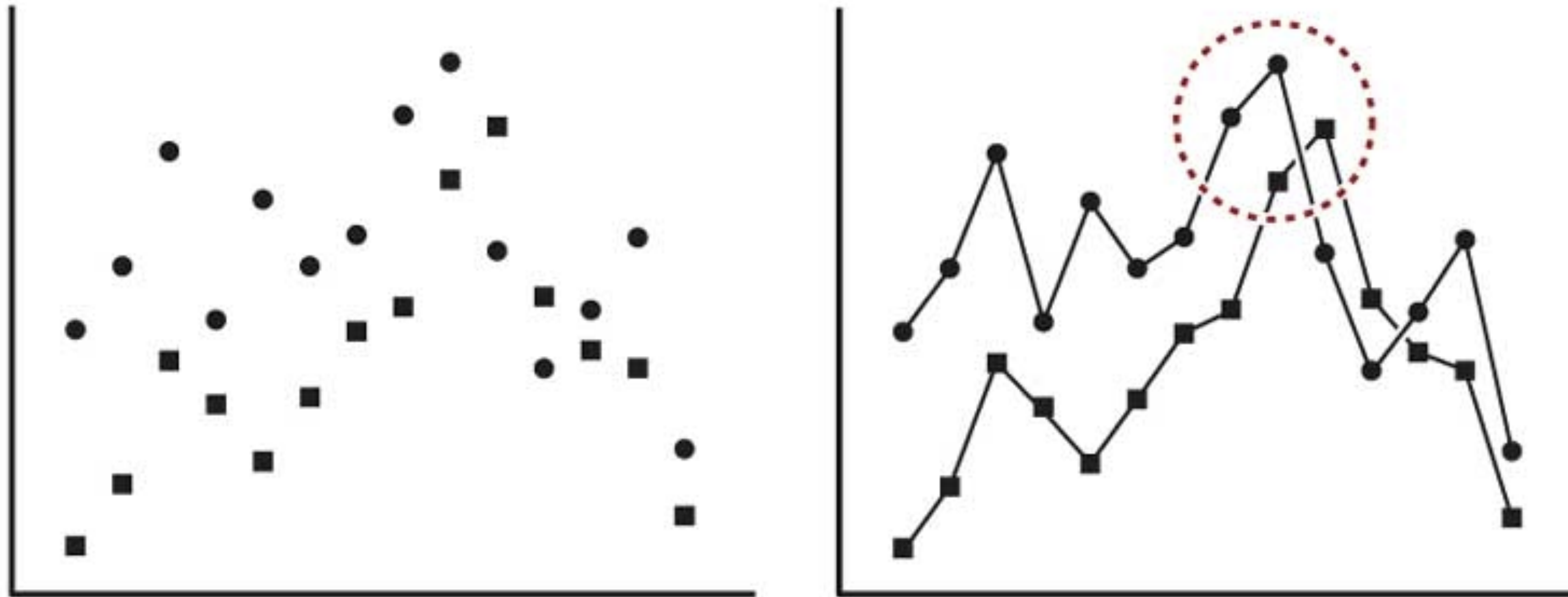
Connection



Enclosure

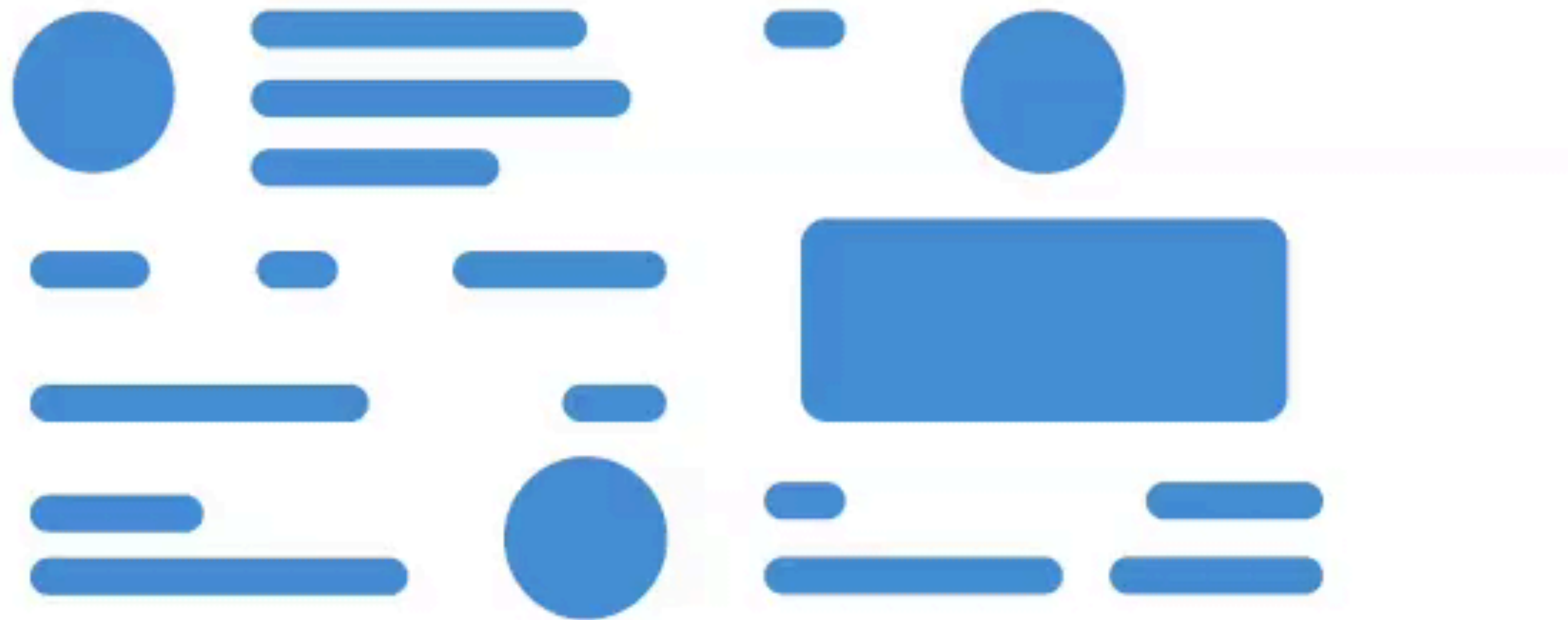


# Connectedness / Enclosure





## Common Region



Scattered elements

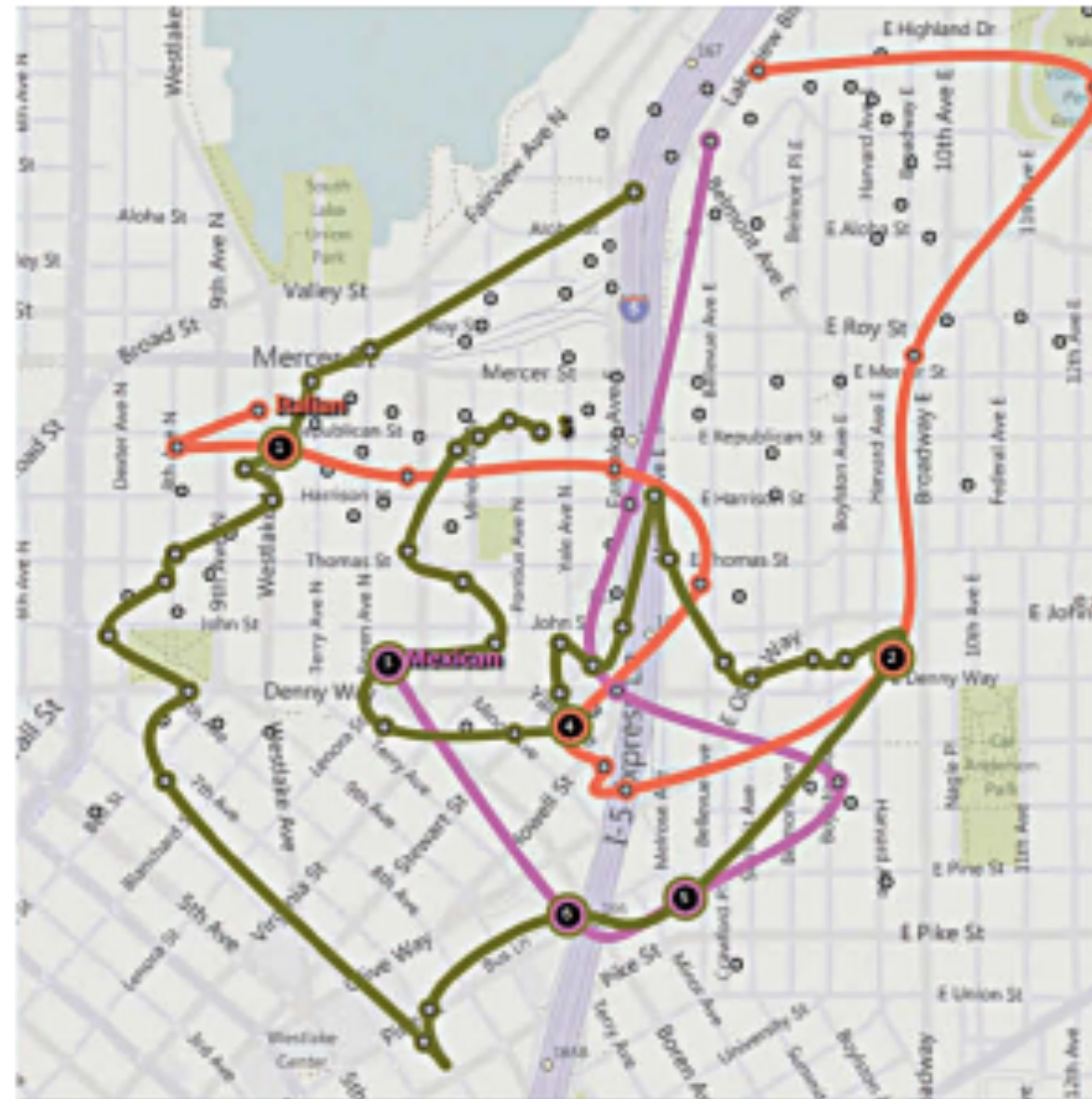


# Connectedness Varieties

Bubble Sets



Line Sets



Kelp Diagrams

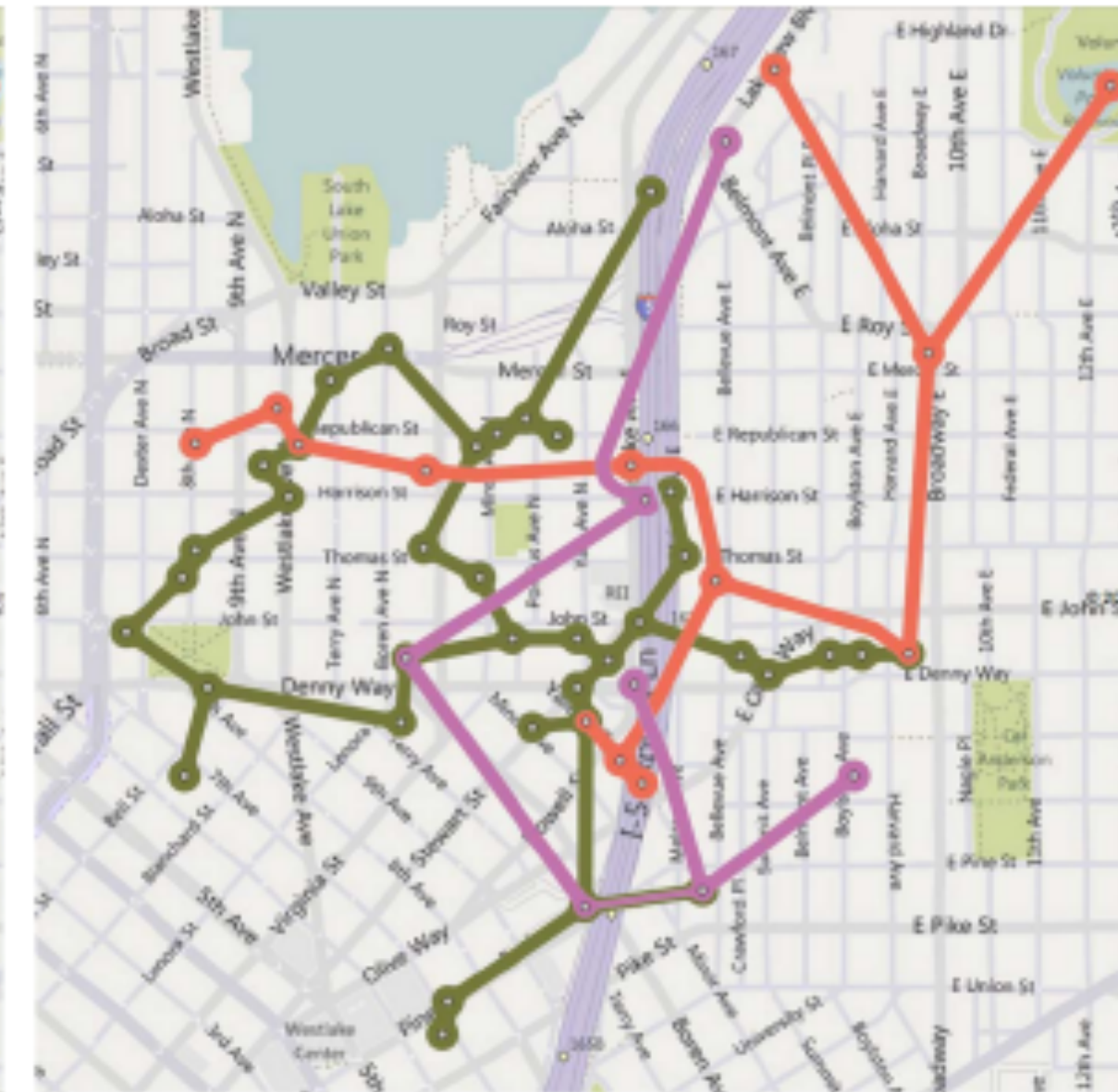


Image by [Dinkla et al., 2011]

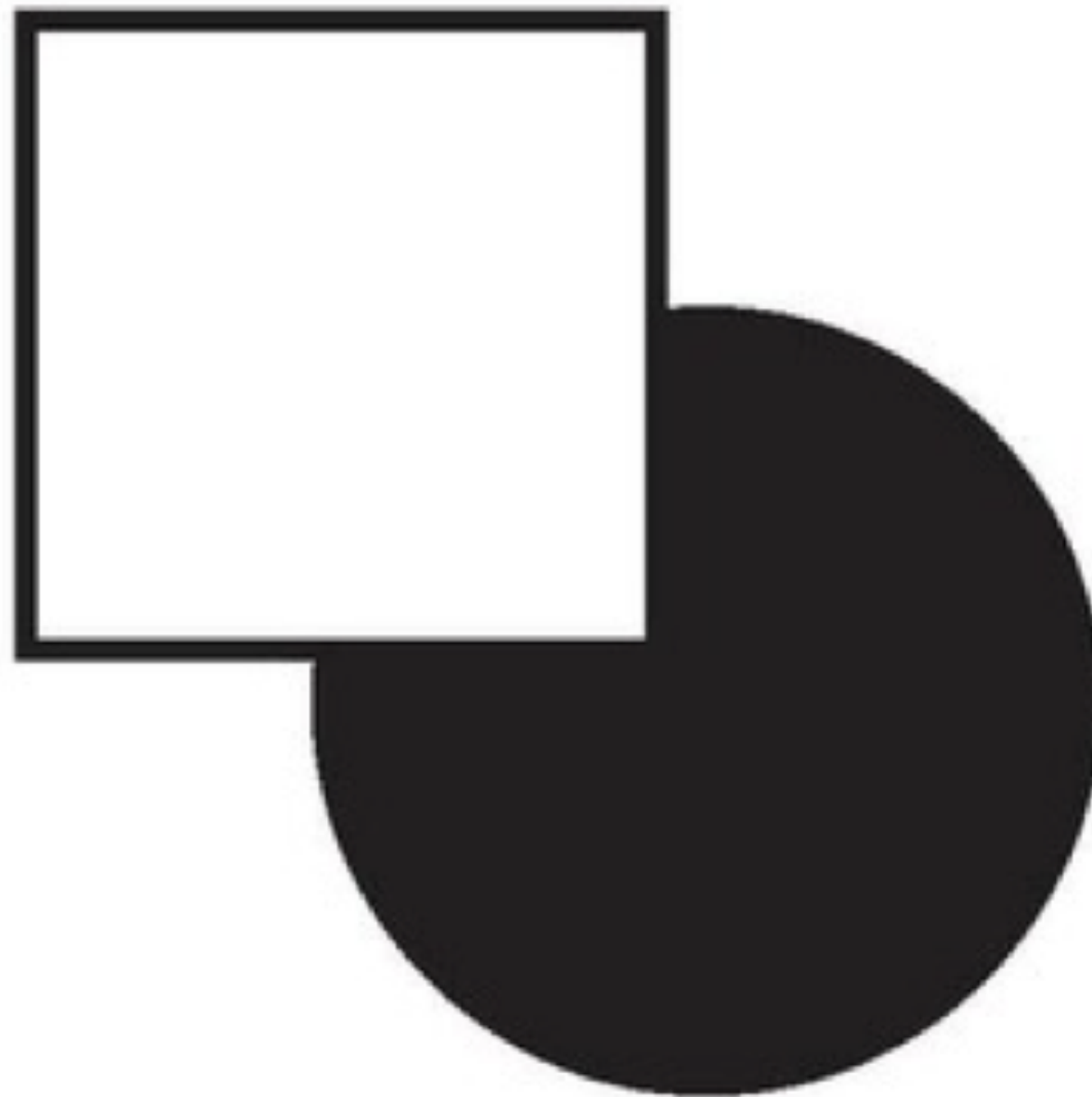
Technique by [Collins et al., 2009]

[Alper et al., 2011]

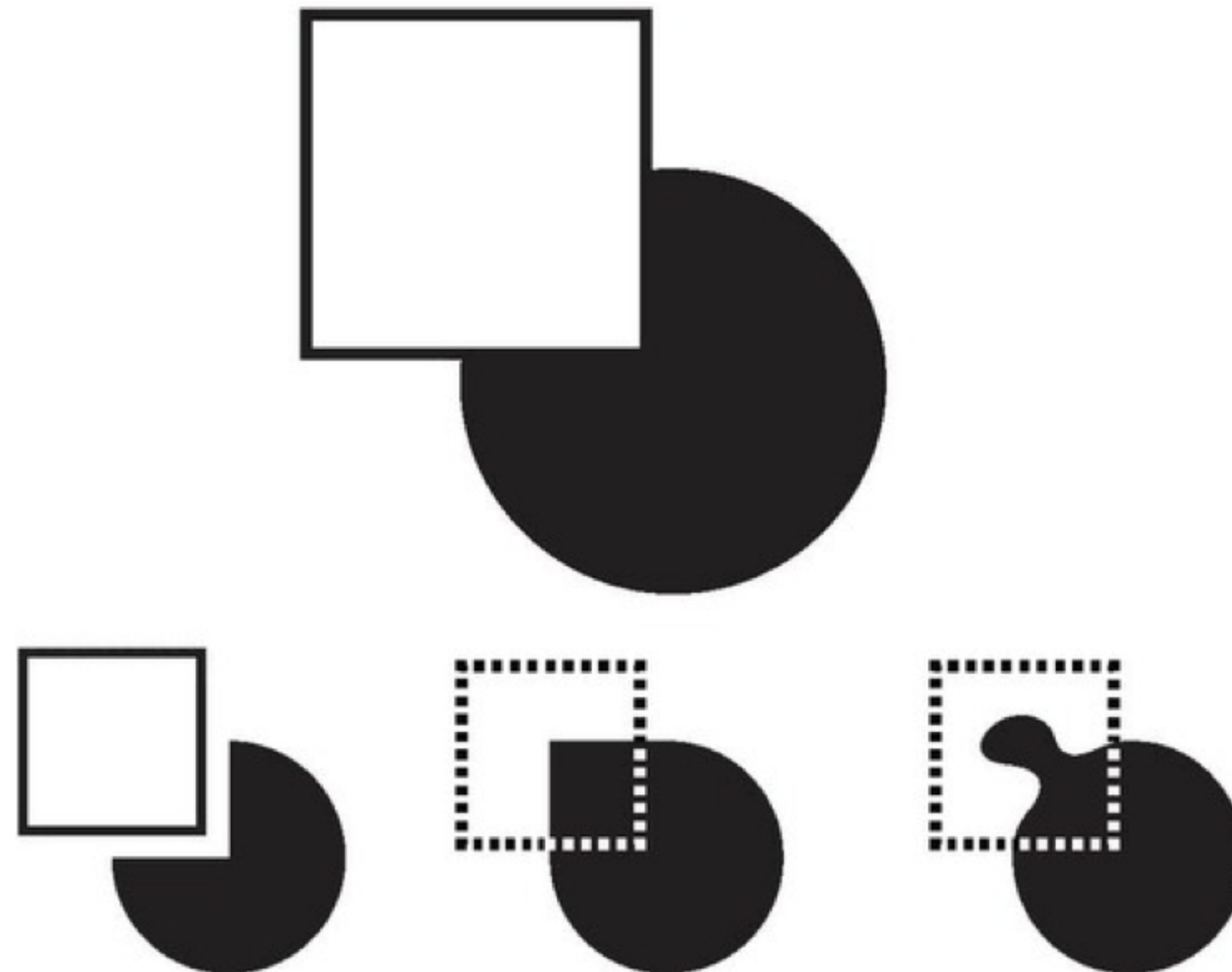
[Dinkla et al., 2012]



# Continuity

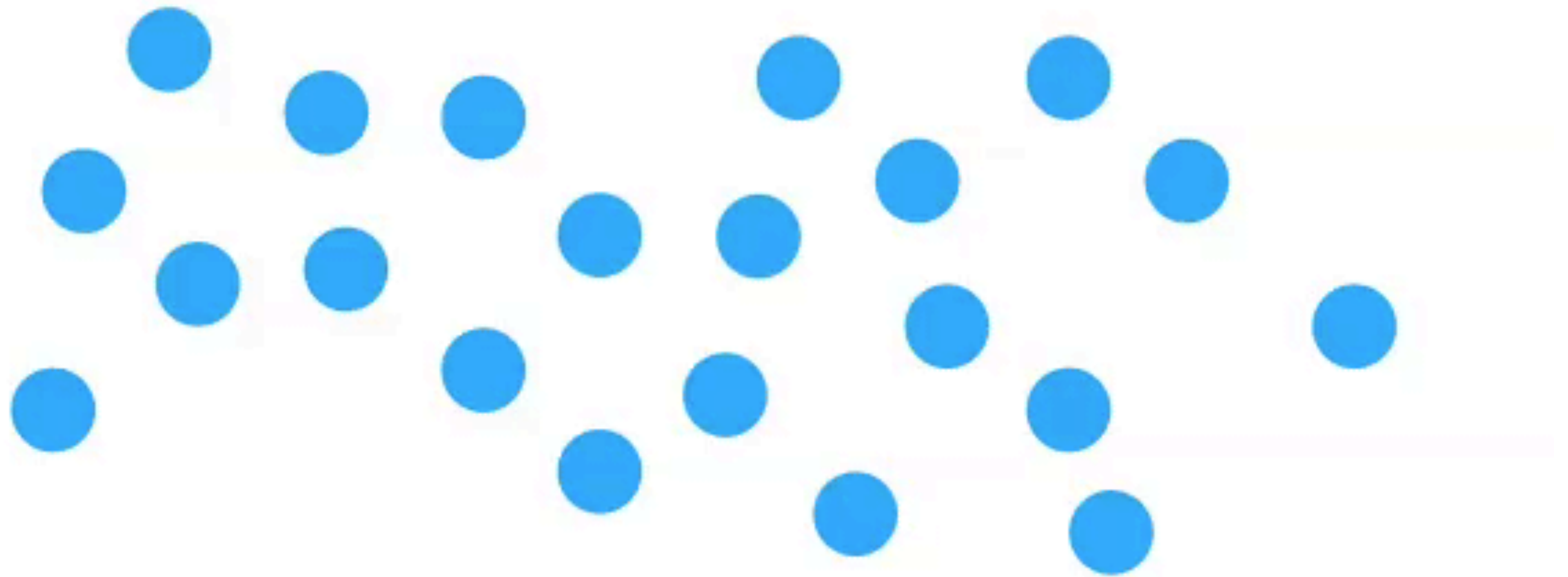


# Continuity





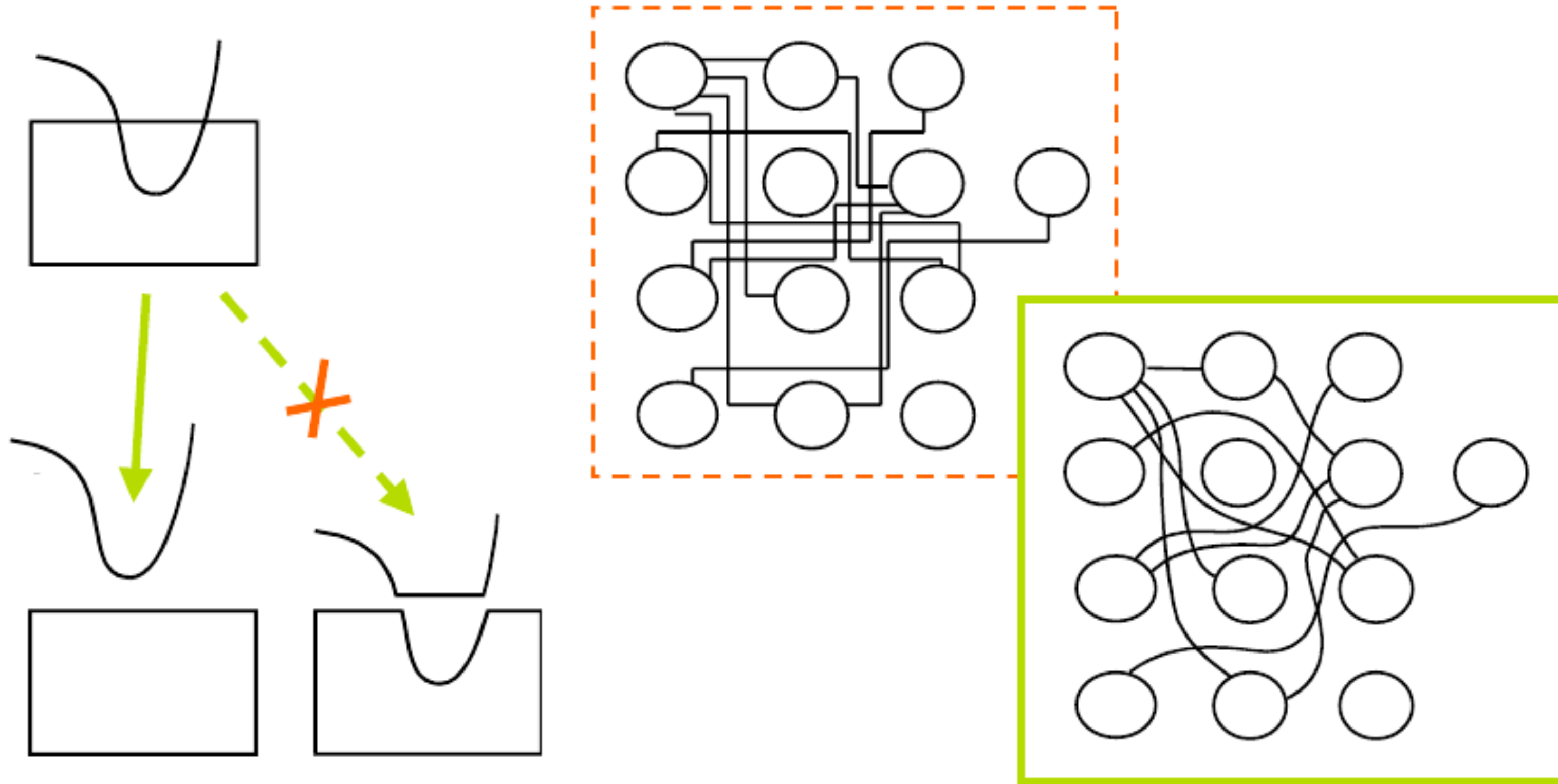
# Continuity Principle



Scattered elements

# Continuity

Things: smooth & continuous





# Closure / Completion



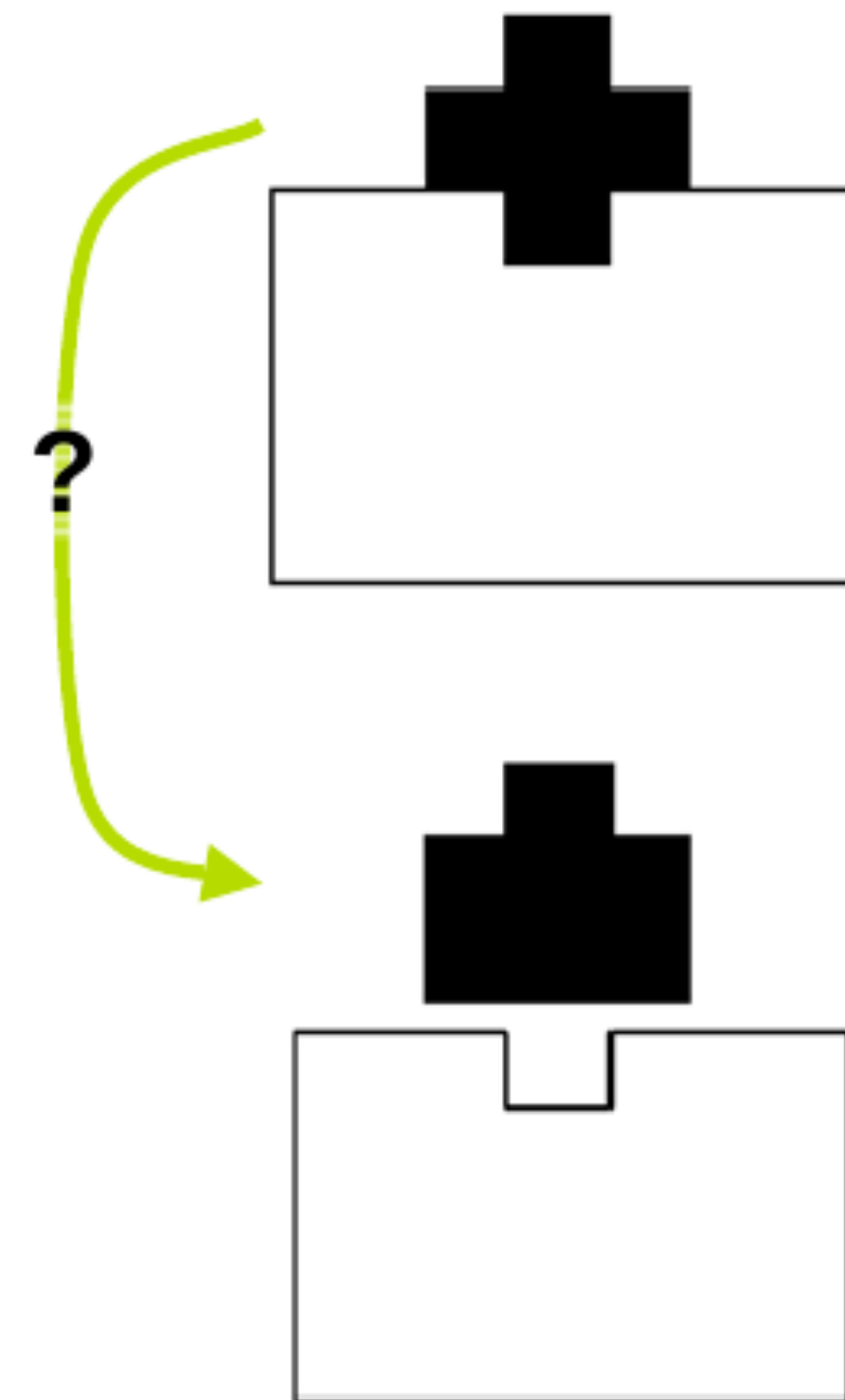
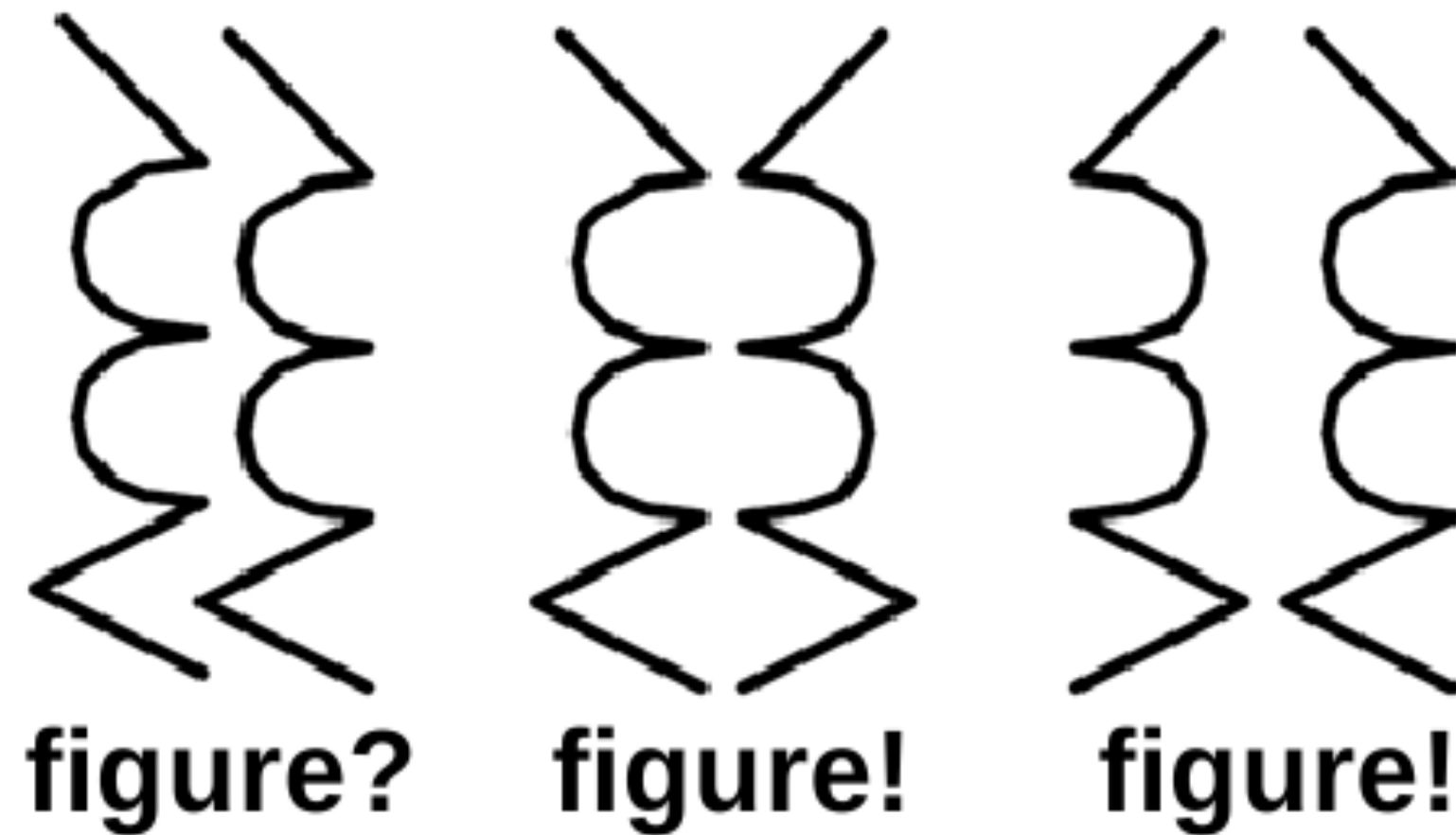
# Closure



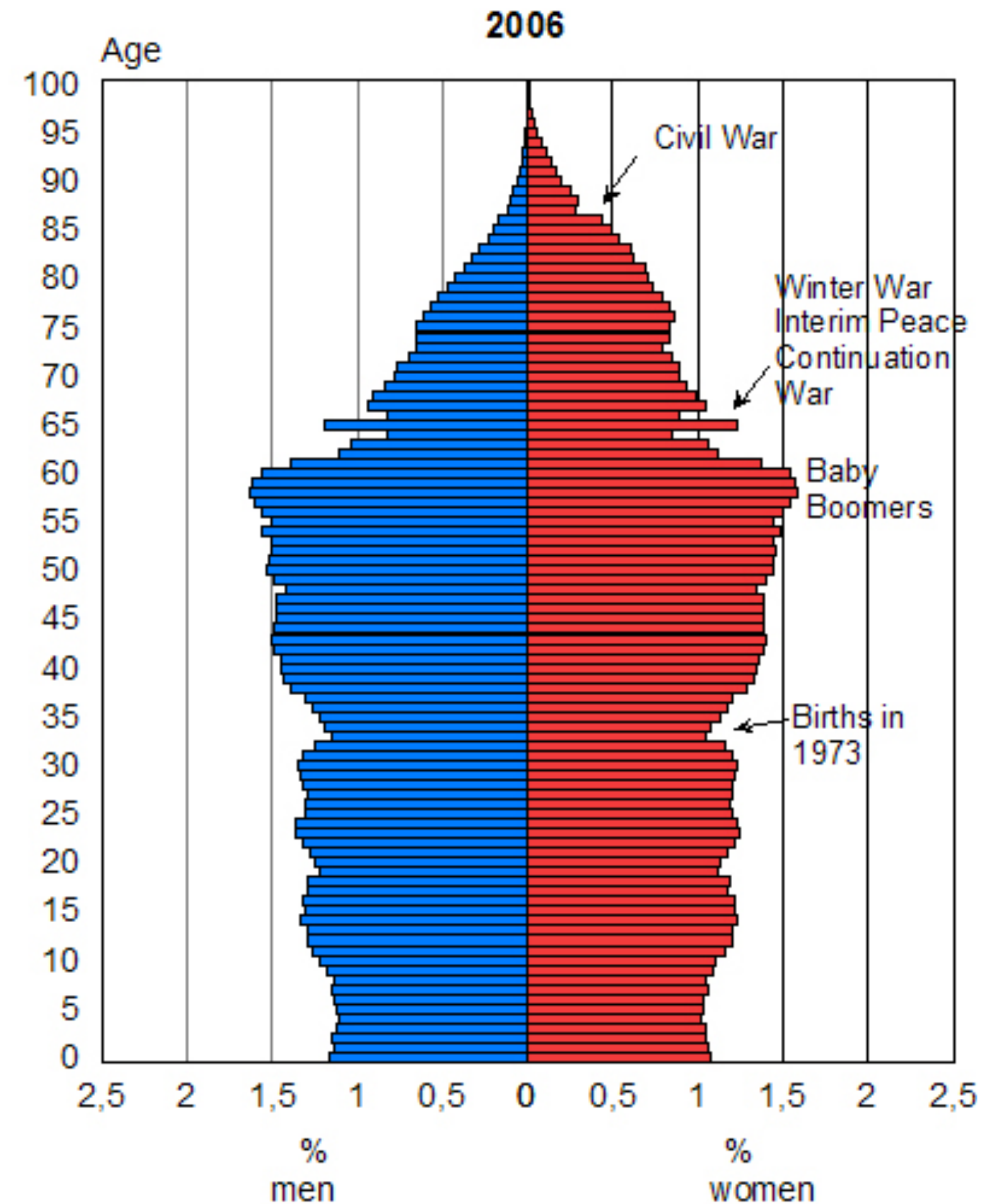
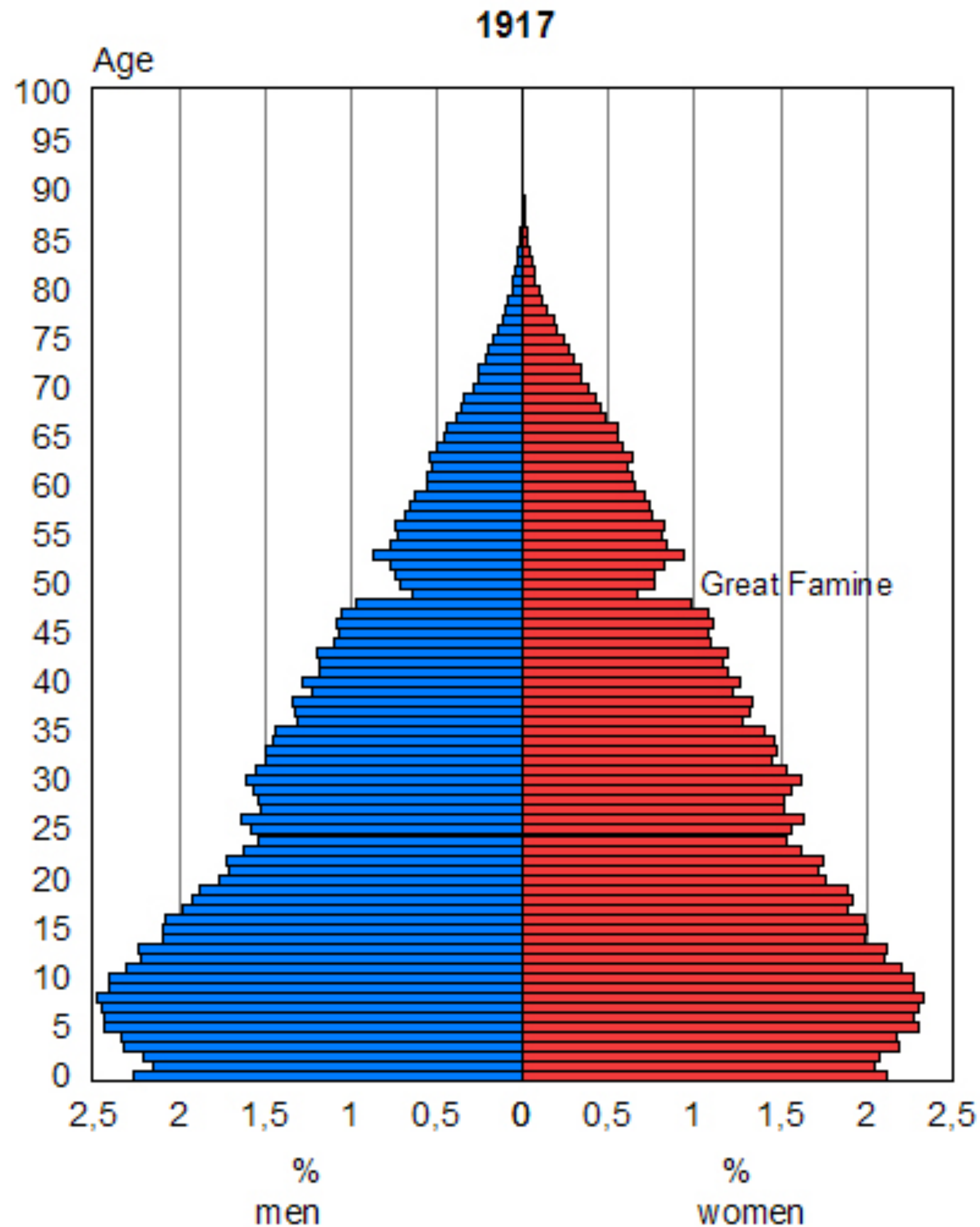


# Symmetry

Things: symmetric

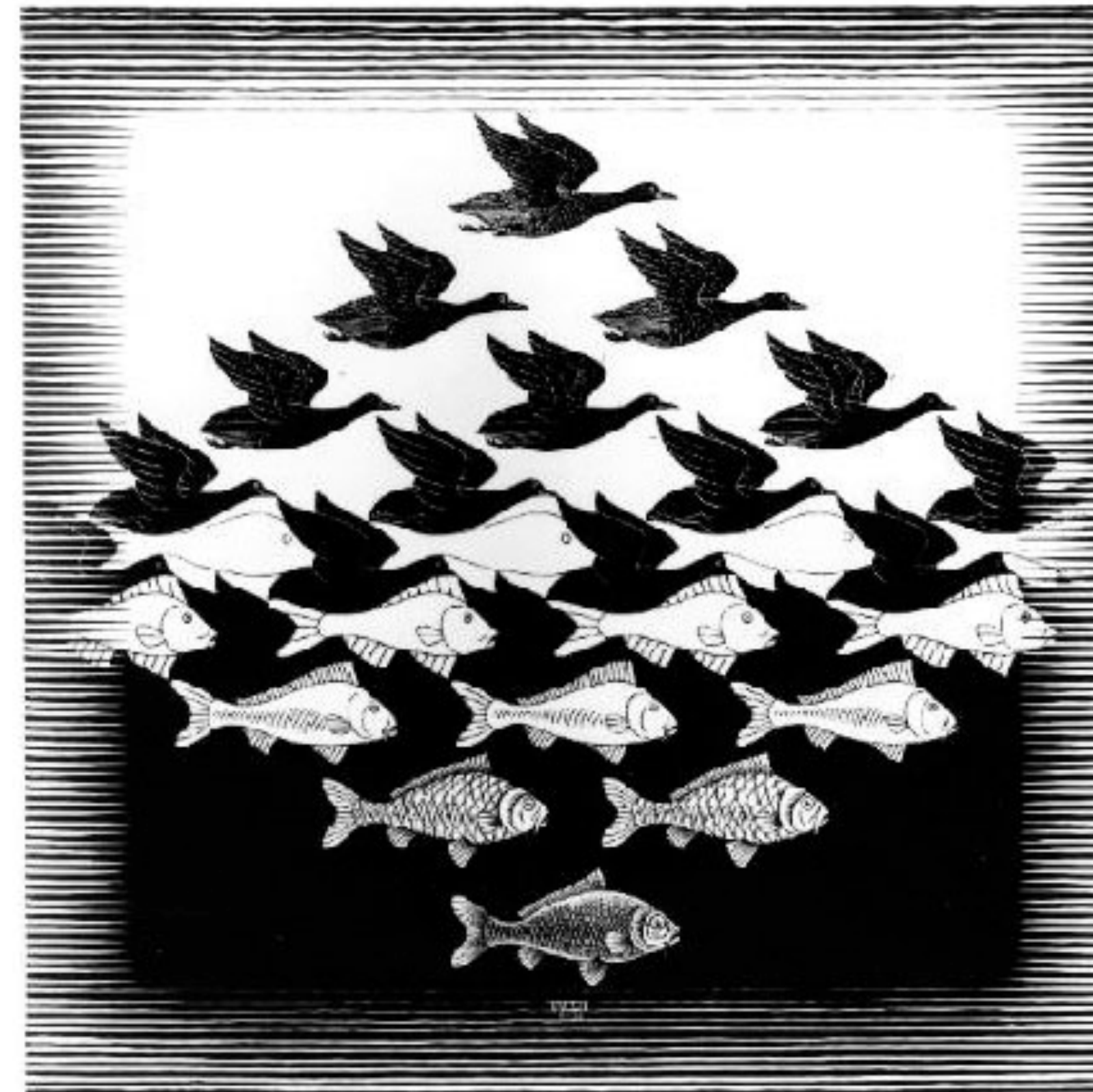


# Population Pyramid



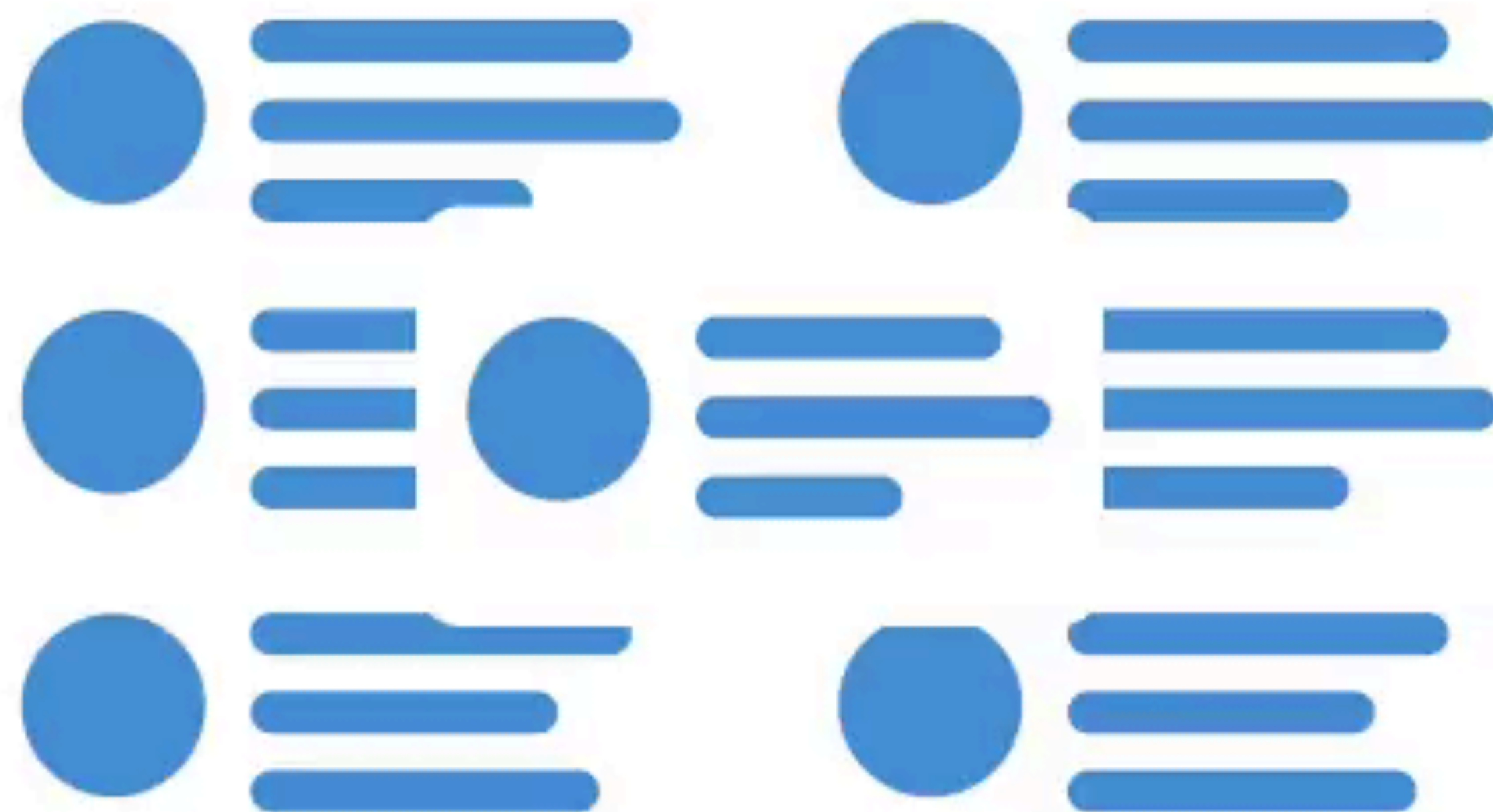


# Figure / Ground



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

## Figure-Ground Articulation



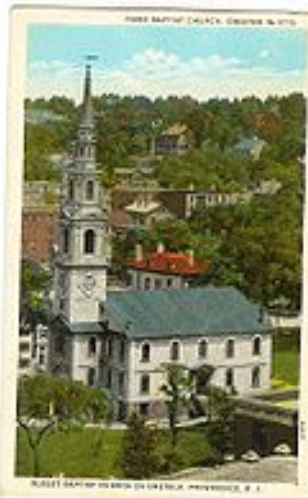
No separation



# Applications in Vis



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First Baptist Church in America, founded 1638, present building occupied in 1776, is the oldest Baptist congregation in America



Providence in the mid-nineteenth century



NPS map of the W3R Route

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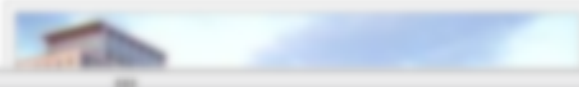
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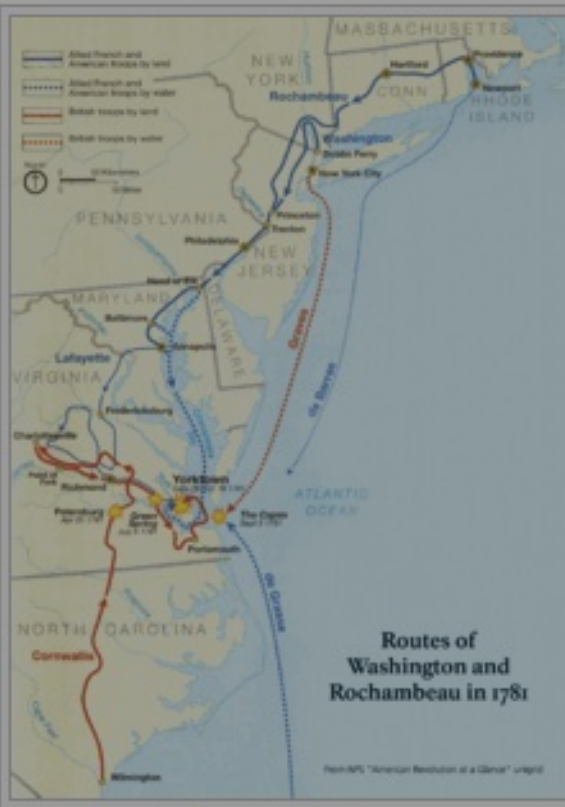
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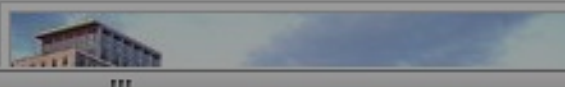
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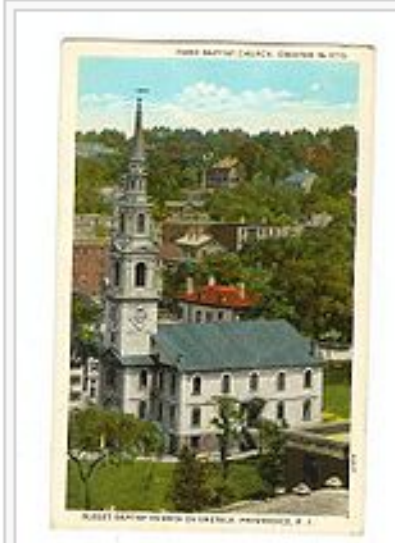
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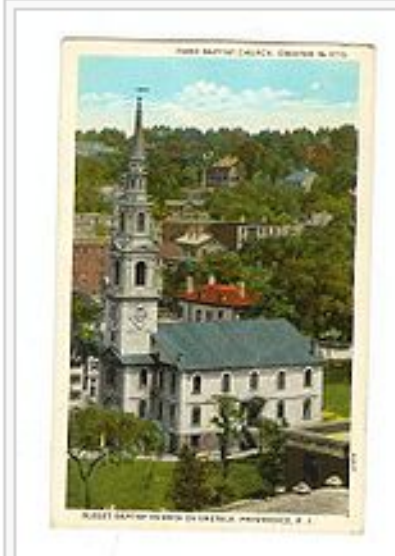
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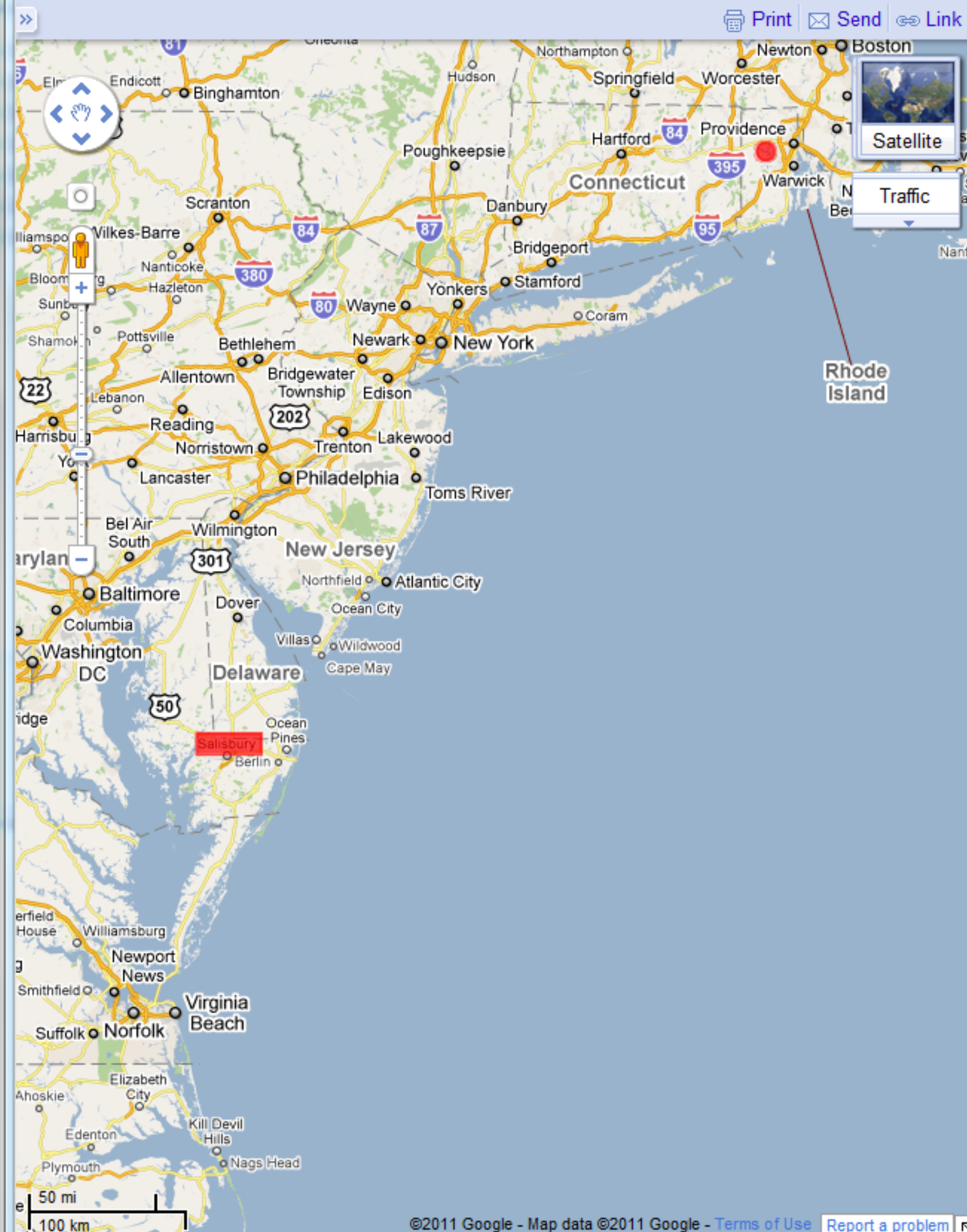
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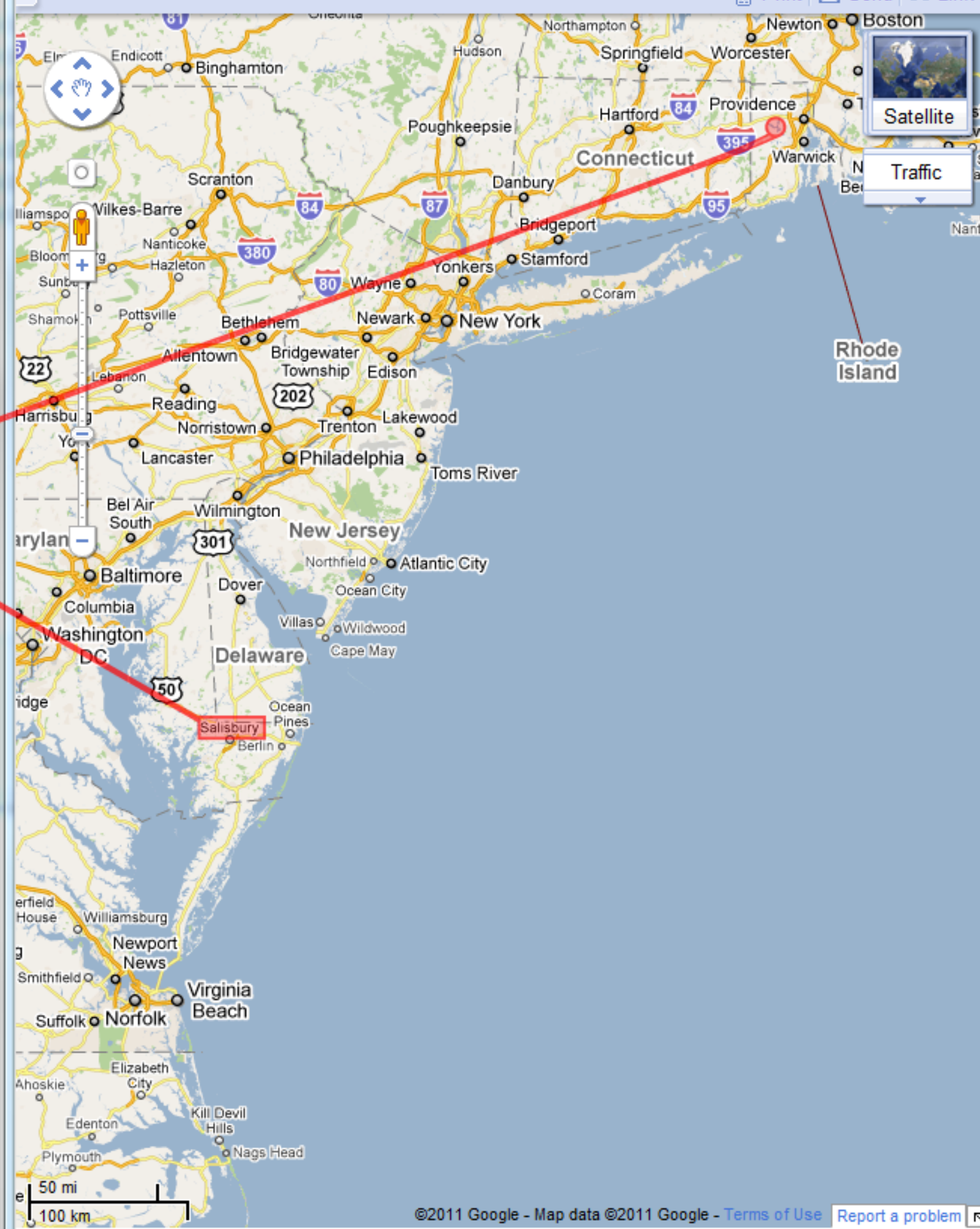
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# Context-Preserving Visual Links



# 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