

# 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

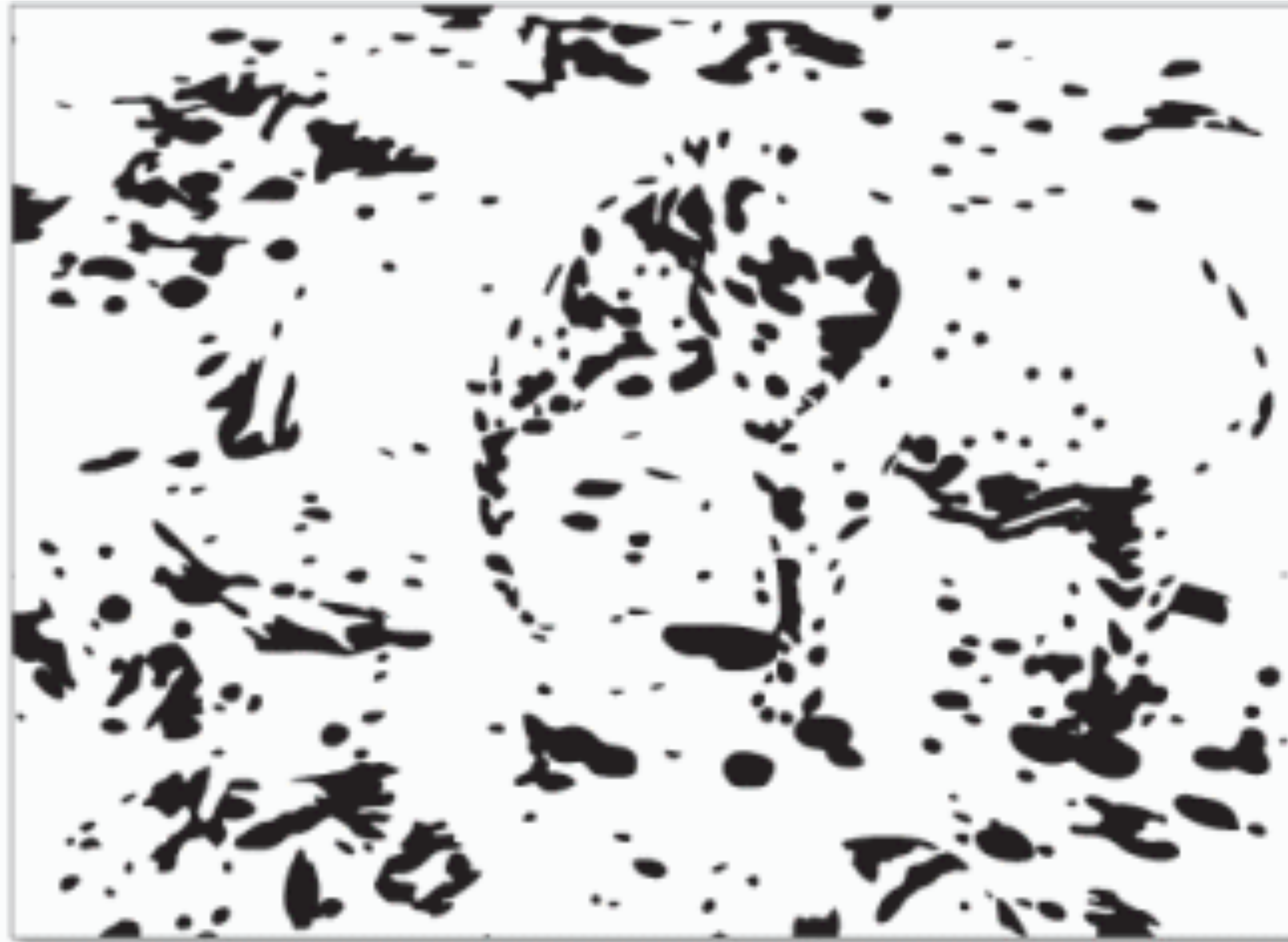
BLUE

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

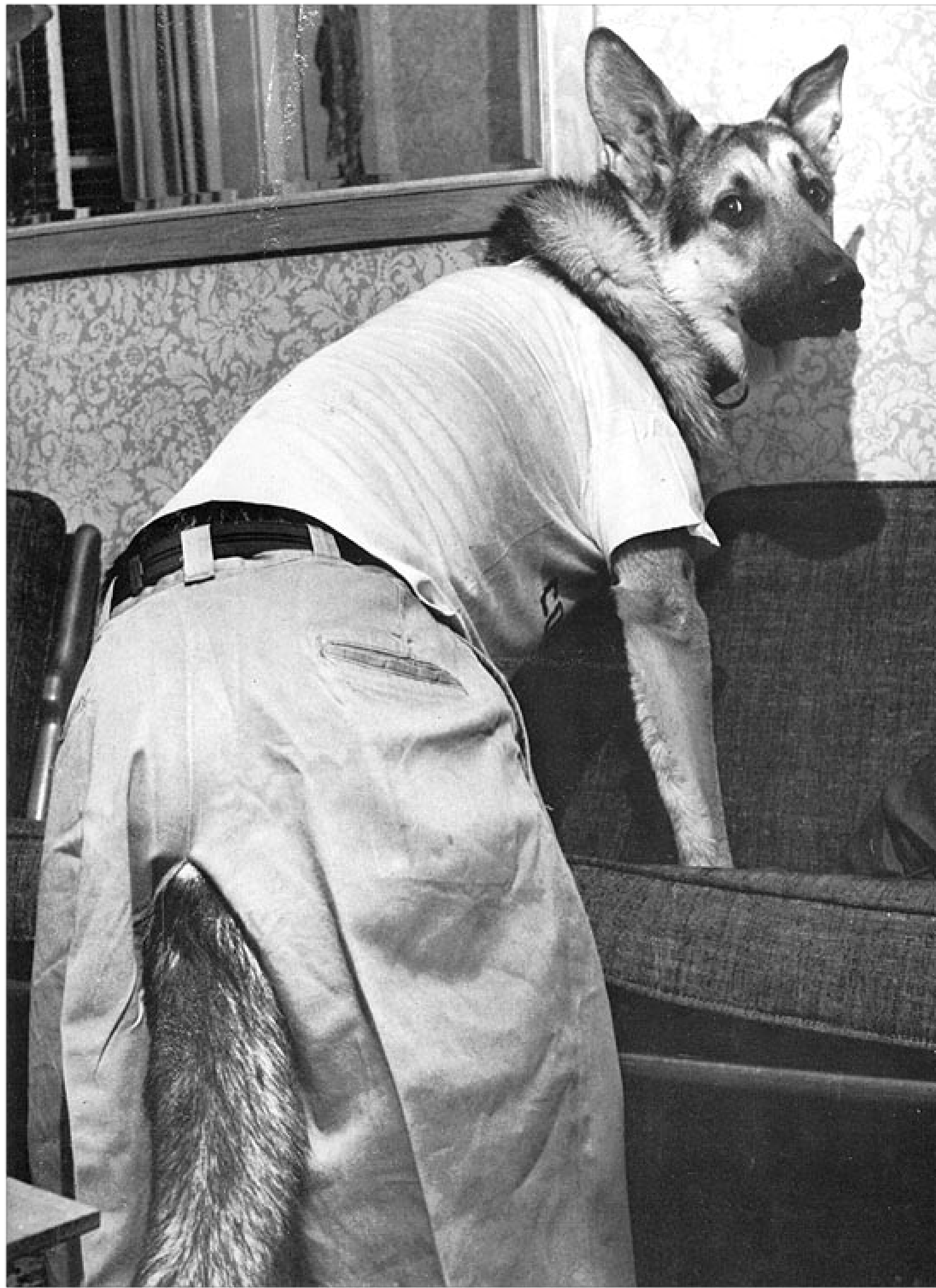
We try to fit what we see into this model.







we rely on priors



# Pareidolia



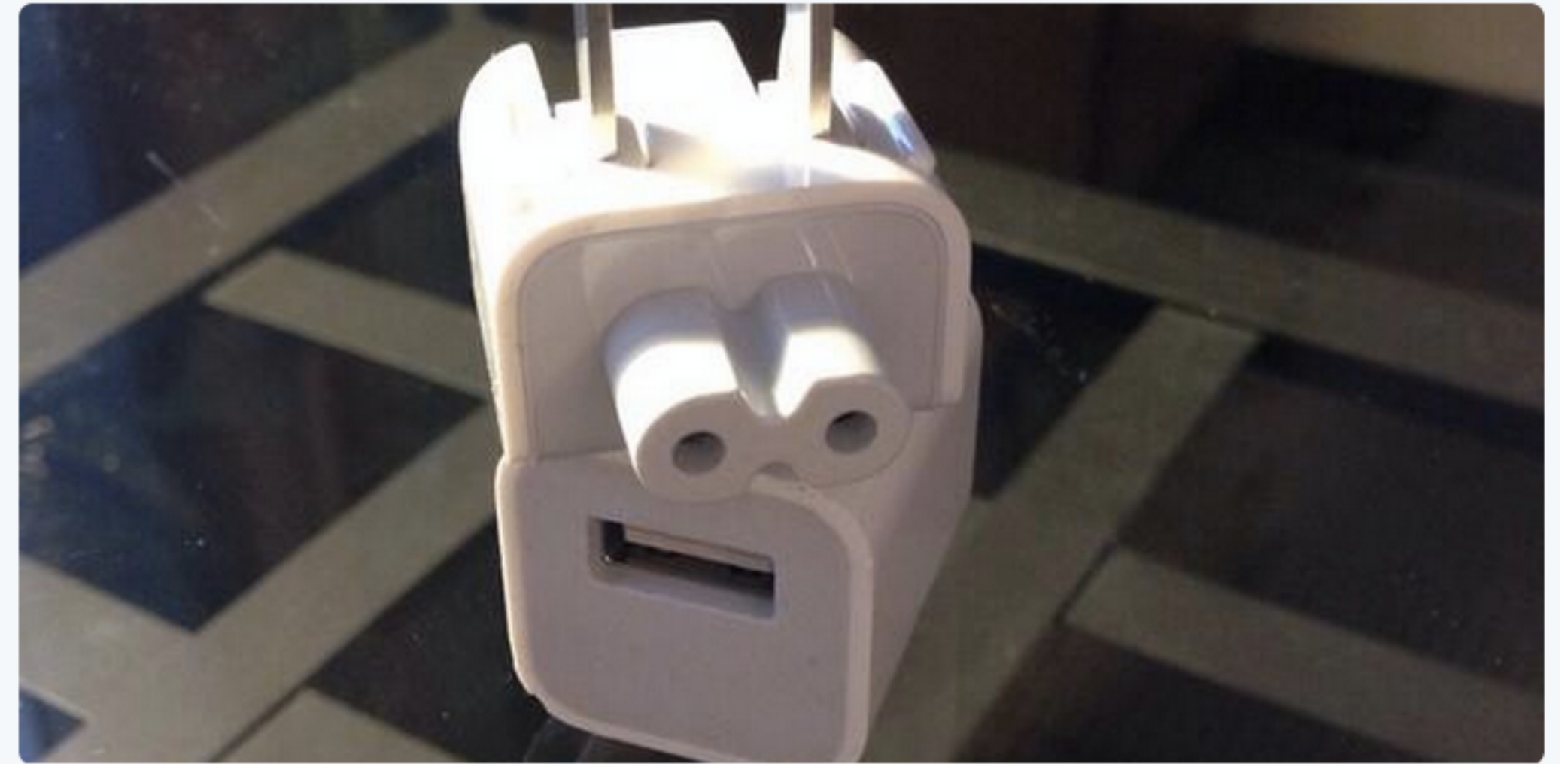
**Faces in Things @FacesPics · Mar 9**  
These chairs have seen some terrible things [pic.twitter.com/Gjlc9wuP47](https://pic.twitter.com/Gjlc9wuP47)



**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

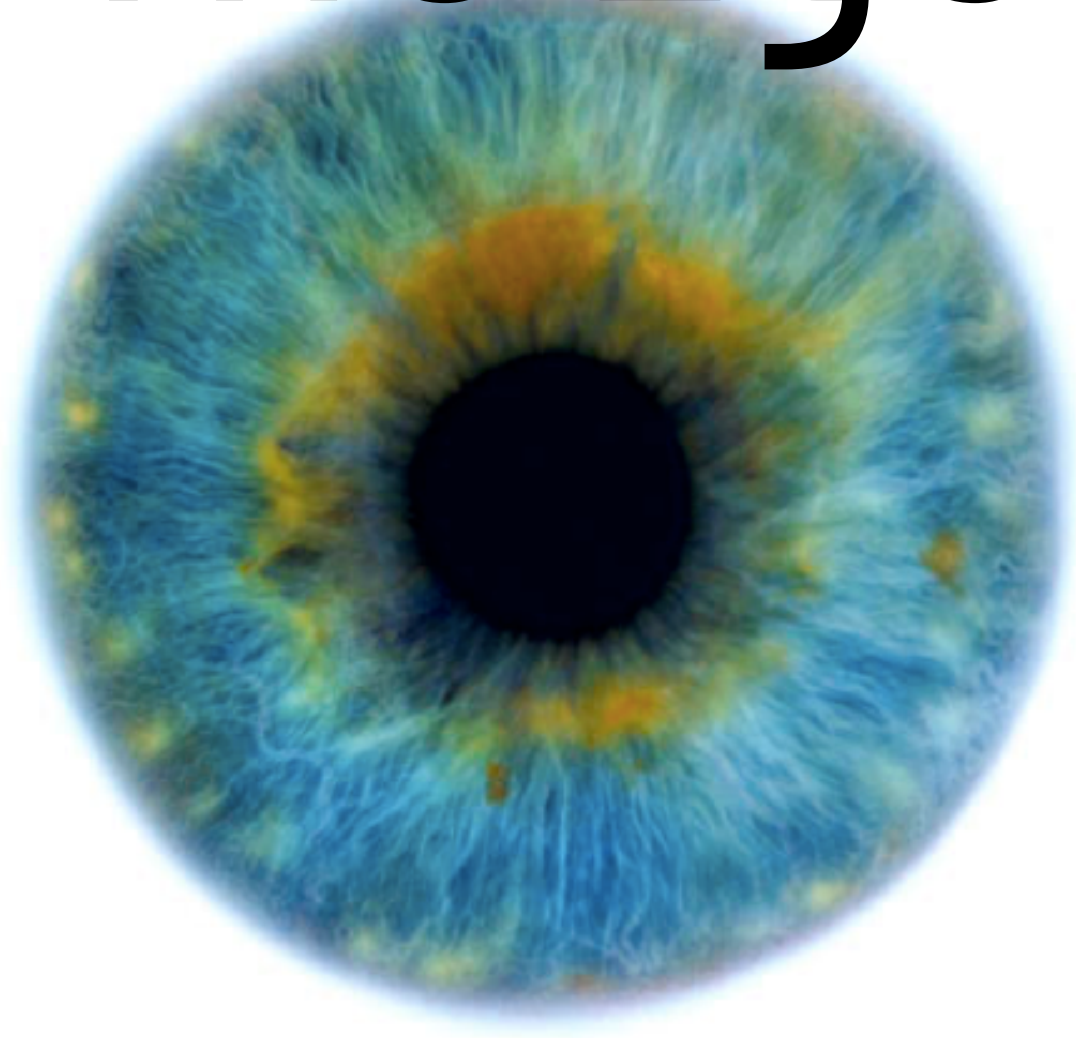
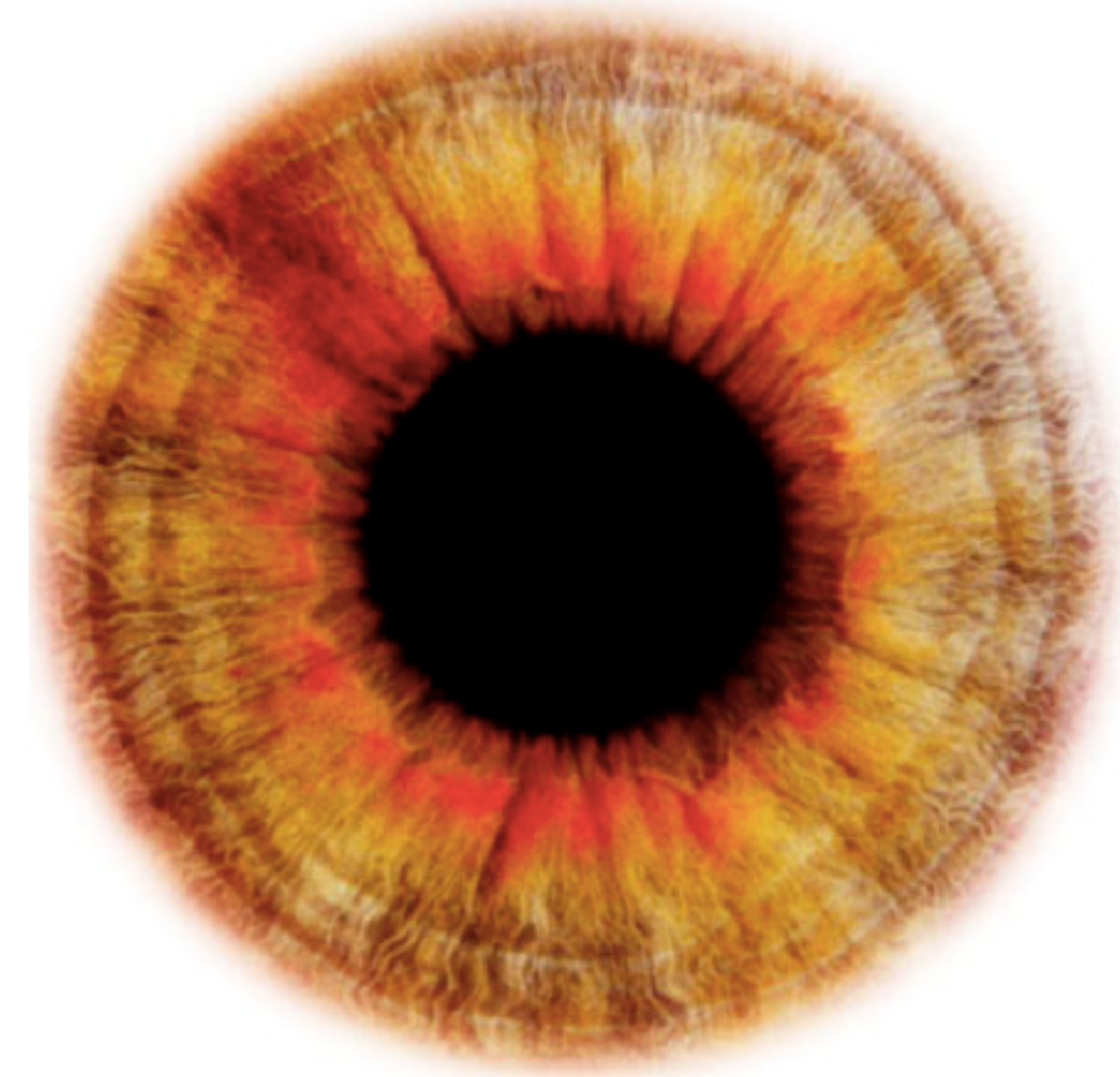
Vision is “constructed” top down from the input

*“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 (COnes for COlor)

dense in the center

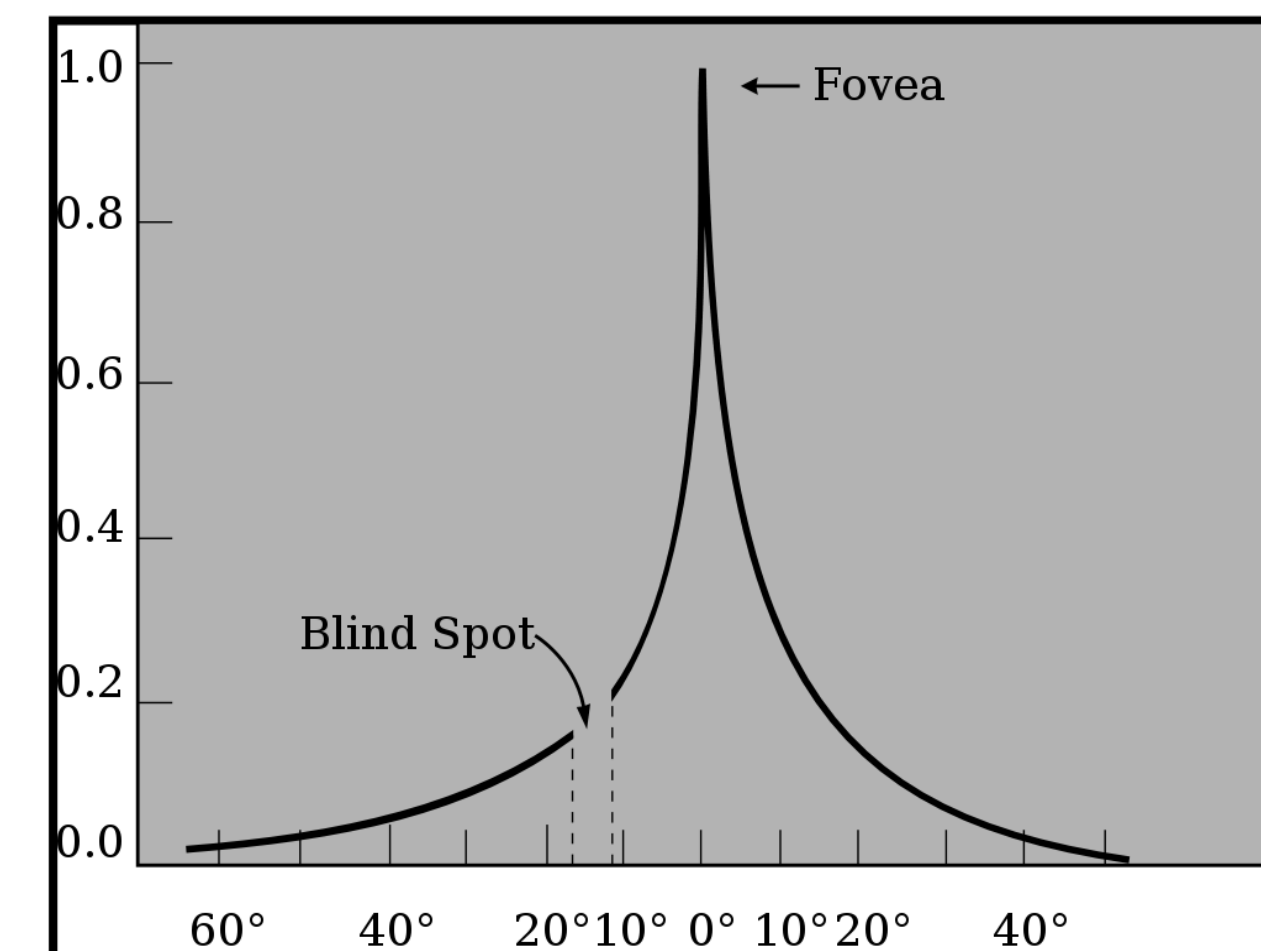
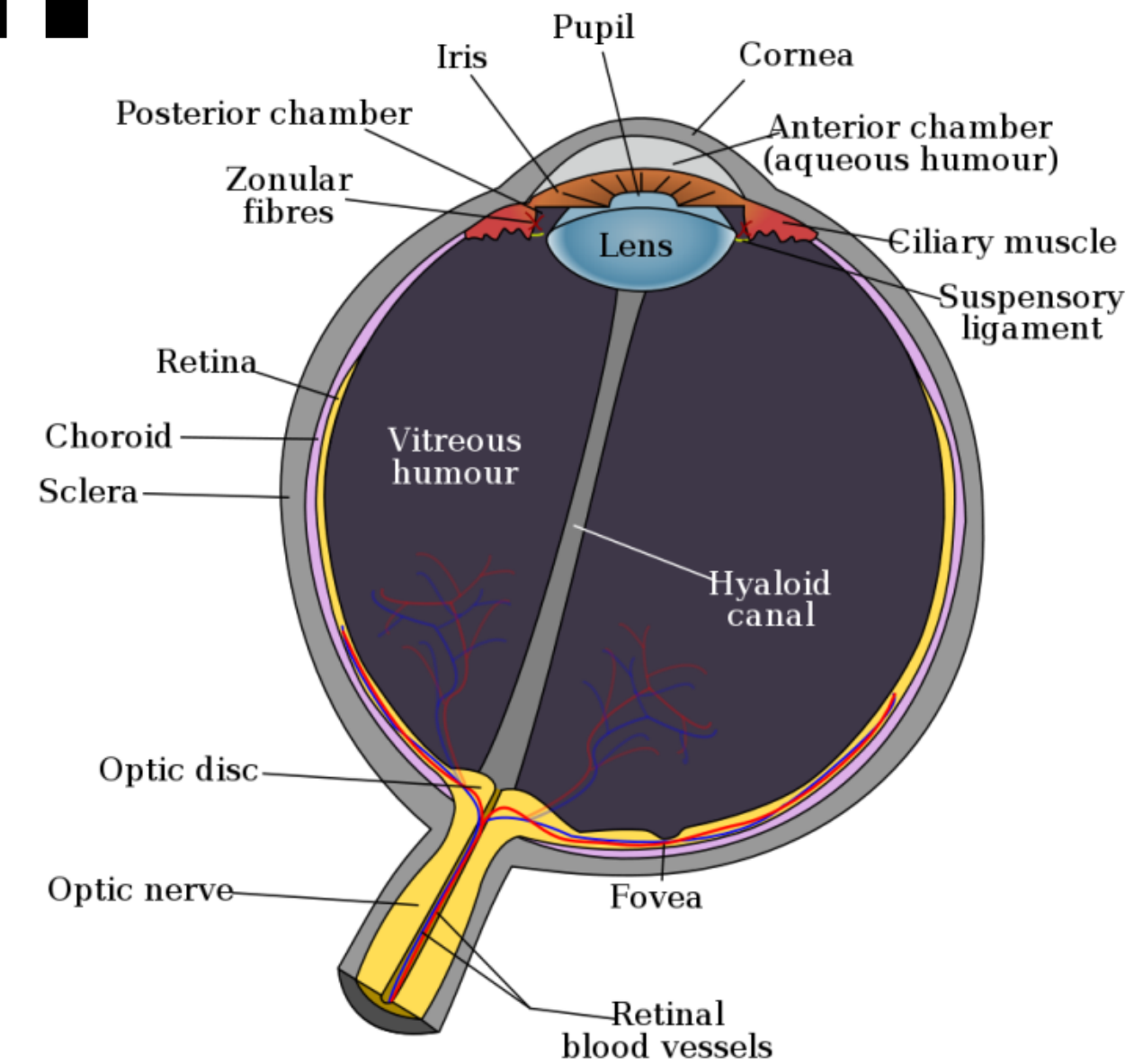
**Fovea:** 27 times the density

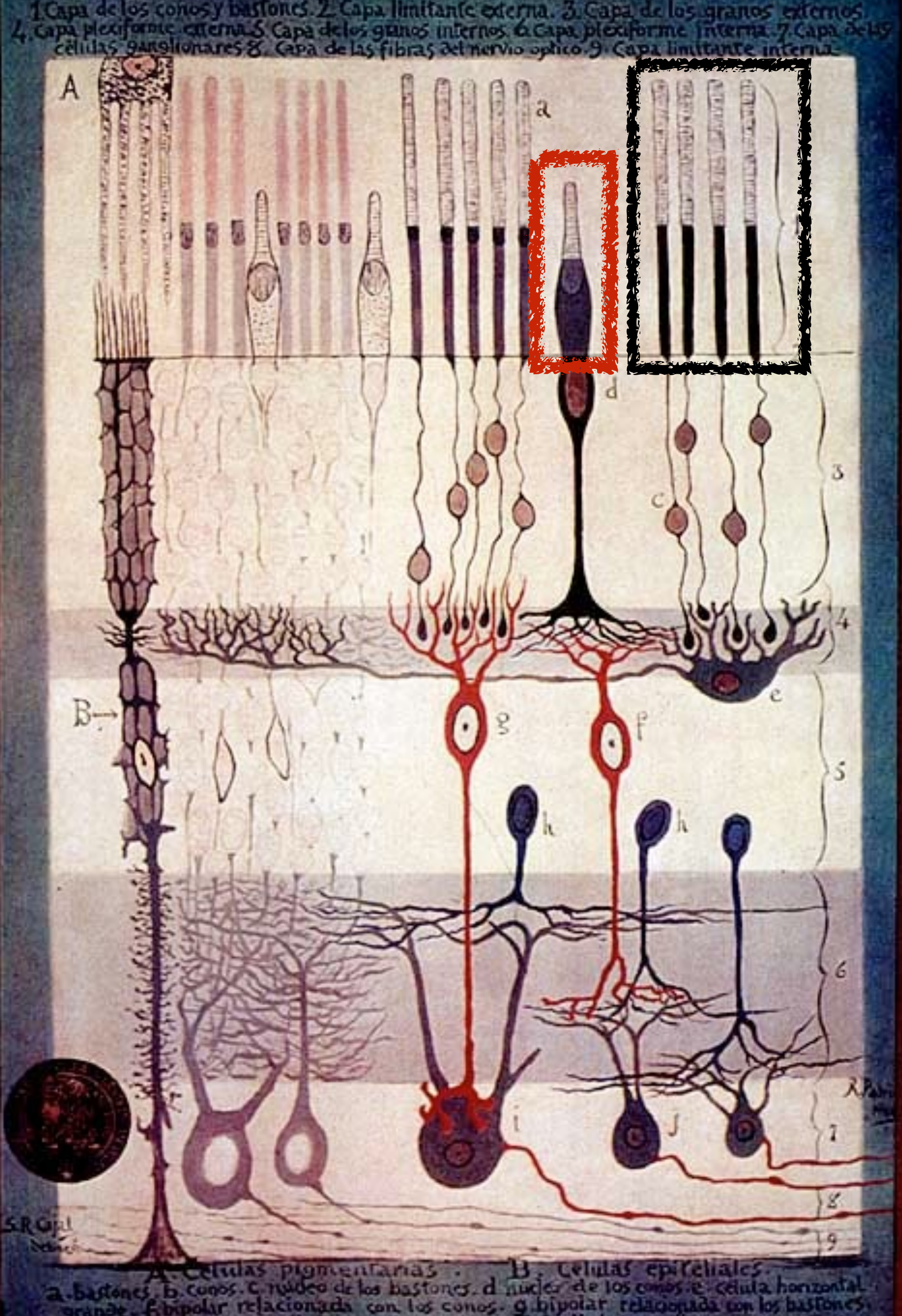
responsible for sharp central vision

only cone cells

~120 mio rods

black/white





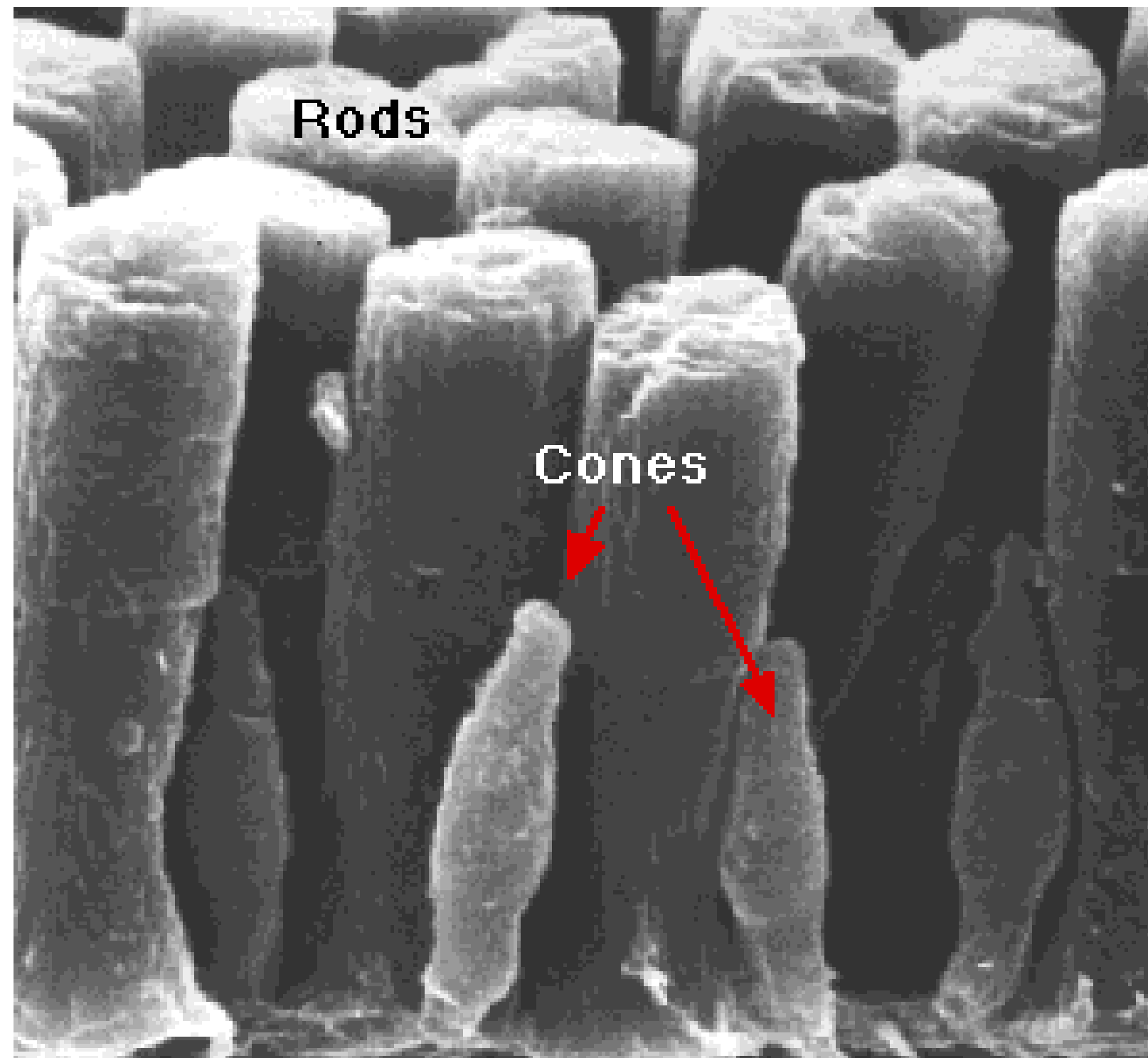
Rods - sensitive black and white

Cones - color vision

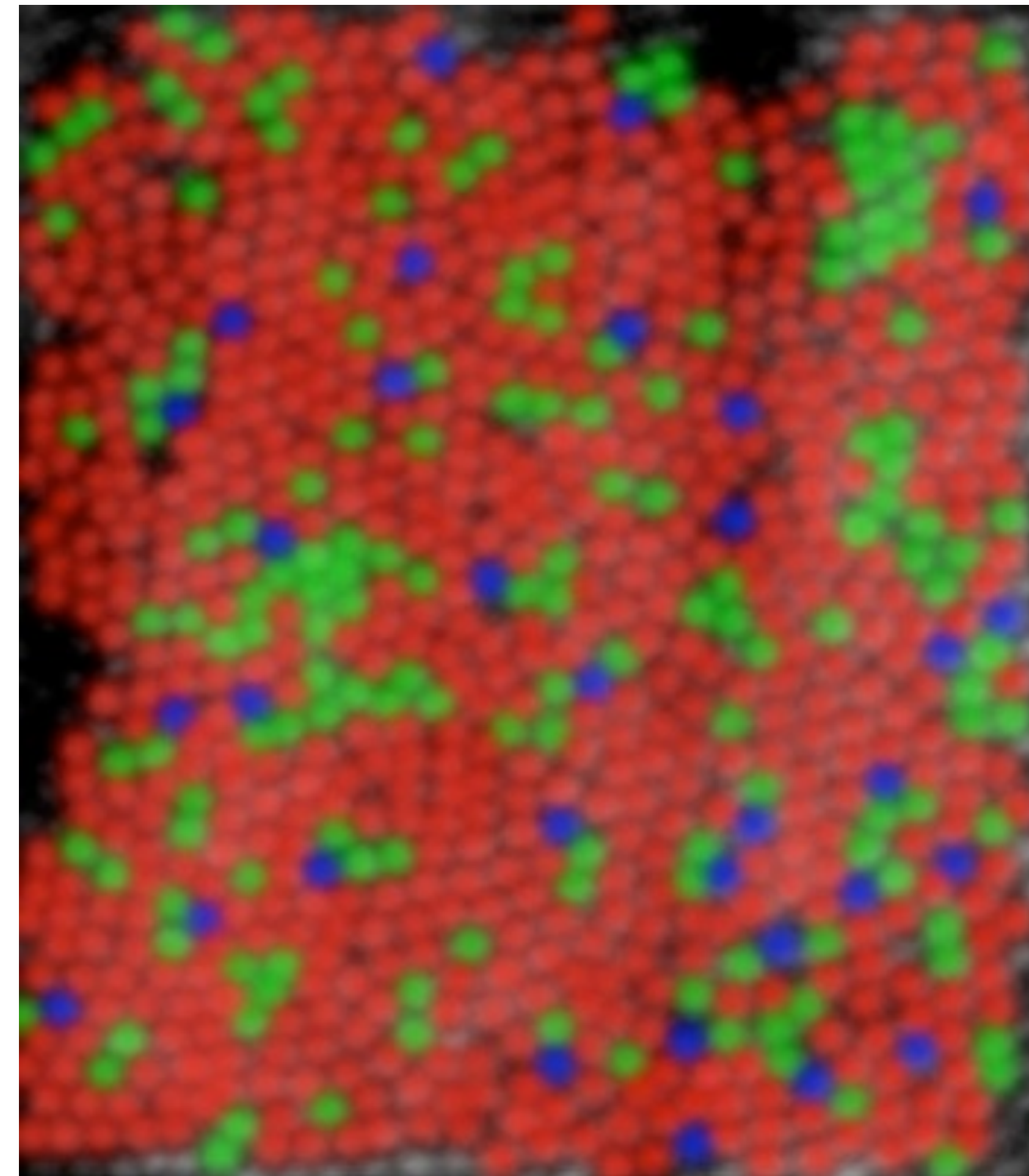
Ganglion Cells

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



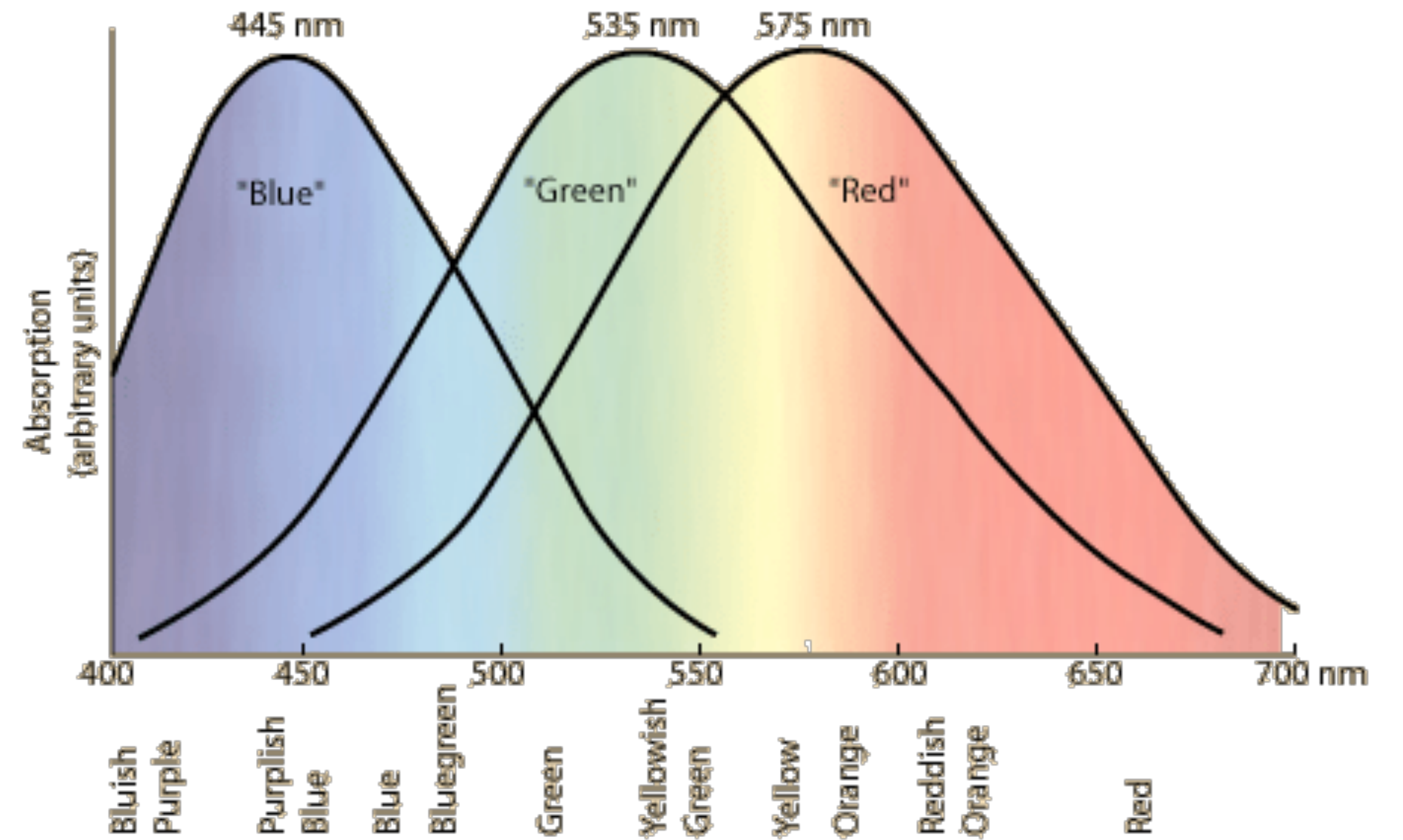
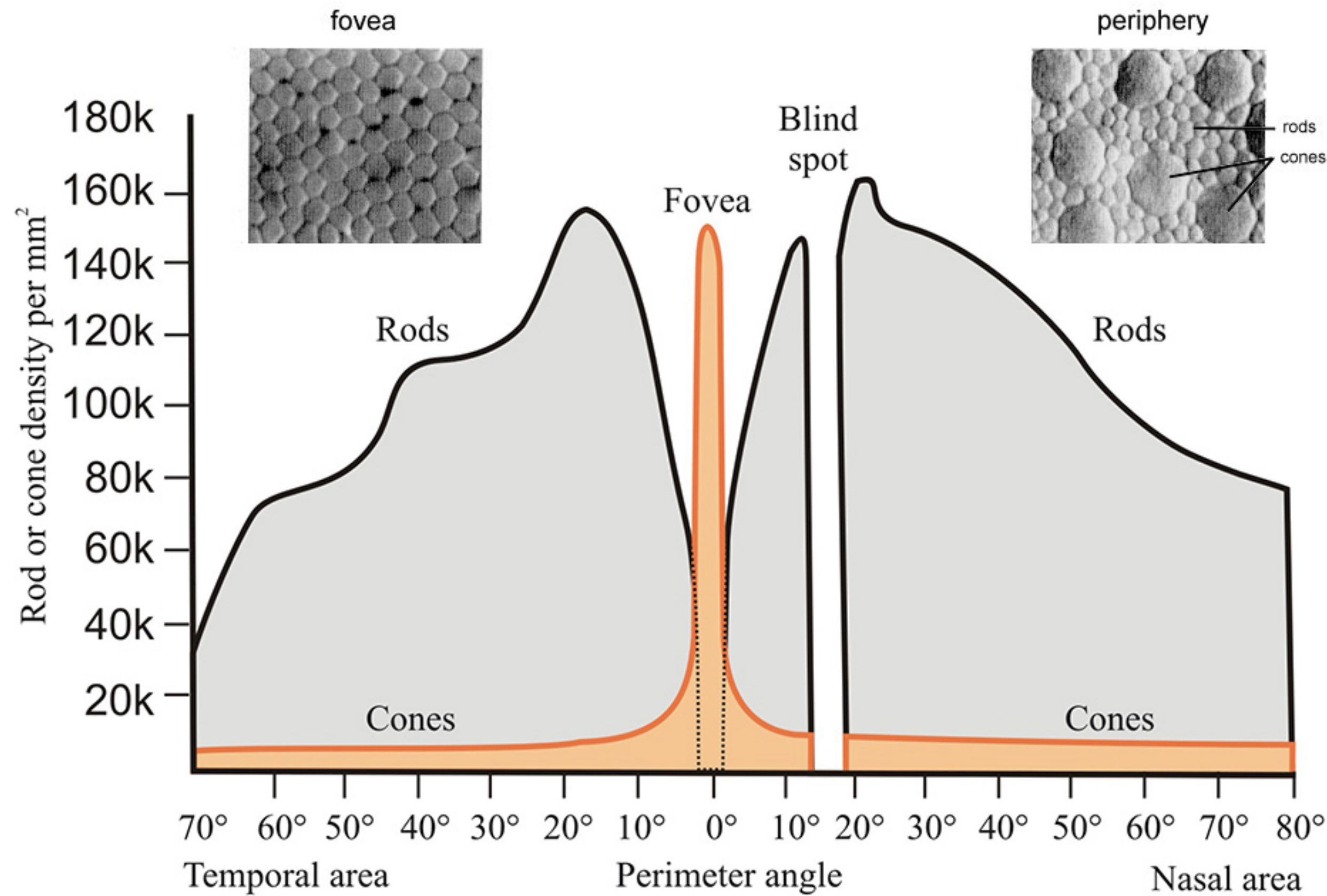


~120 million rods  
~5-6 million cones



R 63% - G 31% - B 6%

# Cone Response



Category	Value	Percentage	Value	Value
	10,000	10.0%	10,000	10,000
	20,000	20.0%	20,000	20,000
	30,000	30.0%	30,000	30,000
	40,000	40.0%	40,000	40,000
	50,000	50.0%	50,000	50,000
	60,000	60.0%	60,000	60,000
	70,000	70.0%	70,000	70,000
	80,000	80.0%	80,000	80,000
	90,000	90.0%	90,000	90,000
	100,000	100.0%	100,000	100,000

# 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





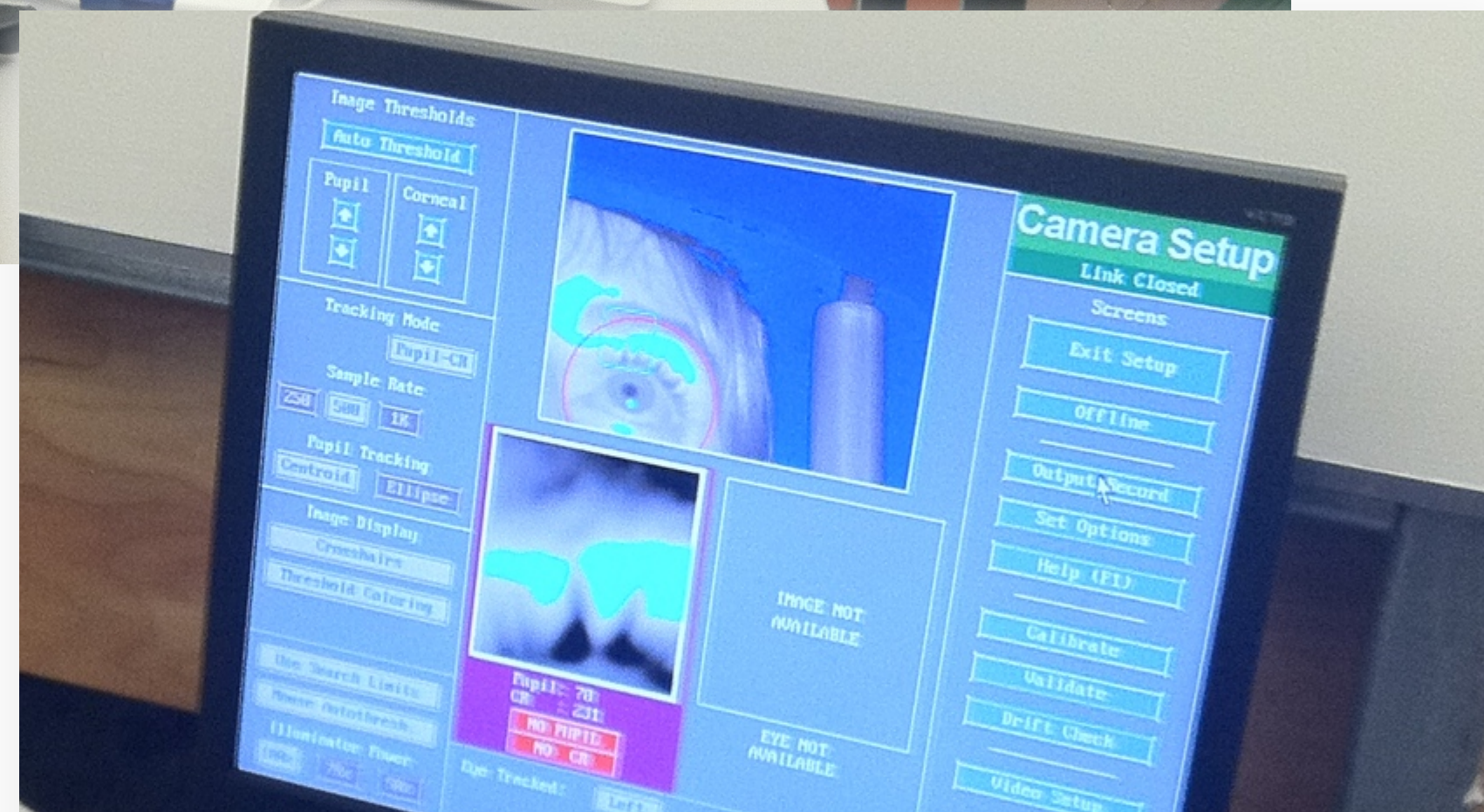
# Eye-Tracking Experiment

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

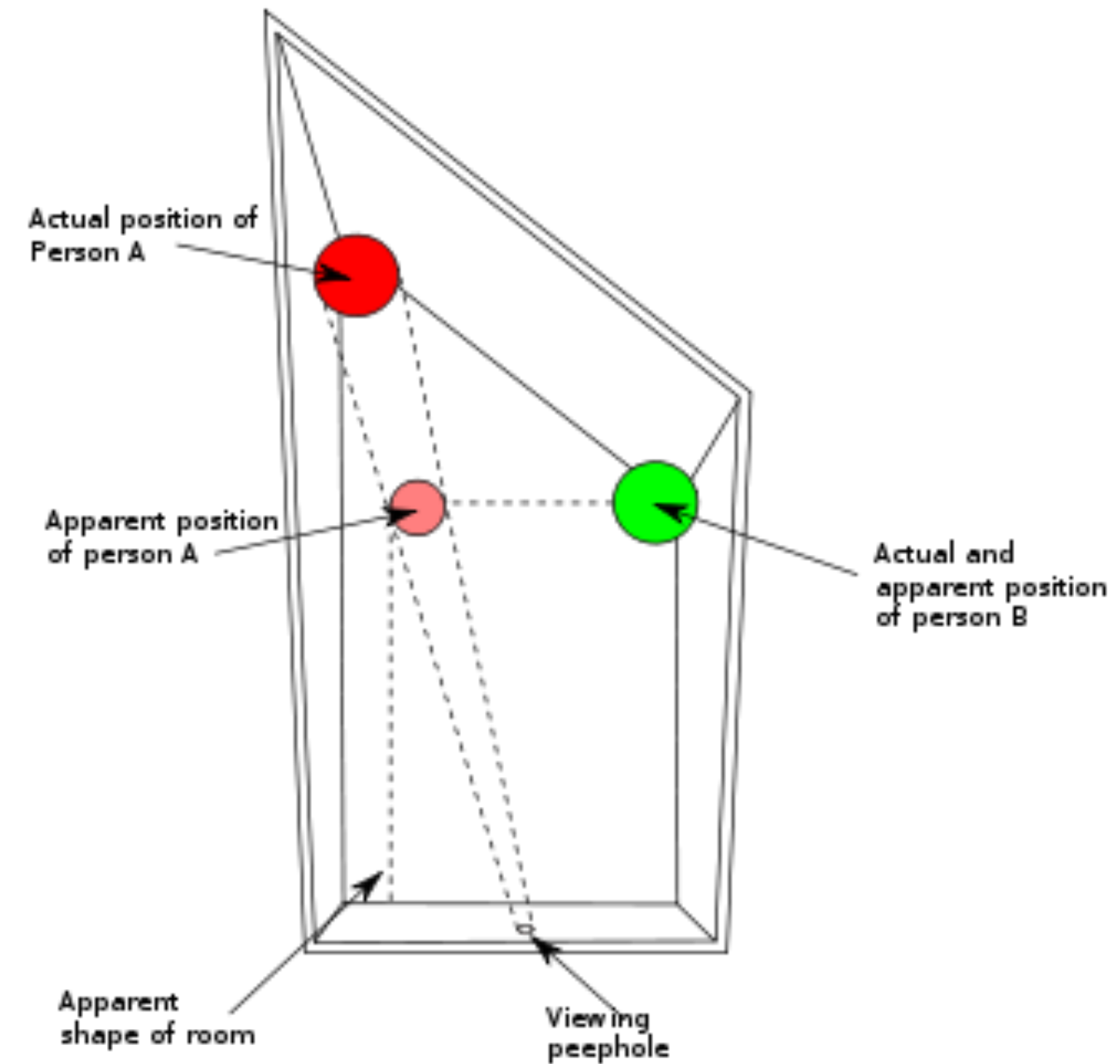
What we see depends on our goals and expectations

Relative judgments: strong

Absolute judgments: weak



Ames Room







Color

# Color Basics

Visible part of the electromagnetic spectrum

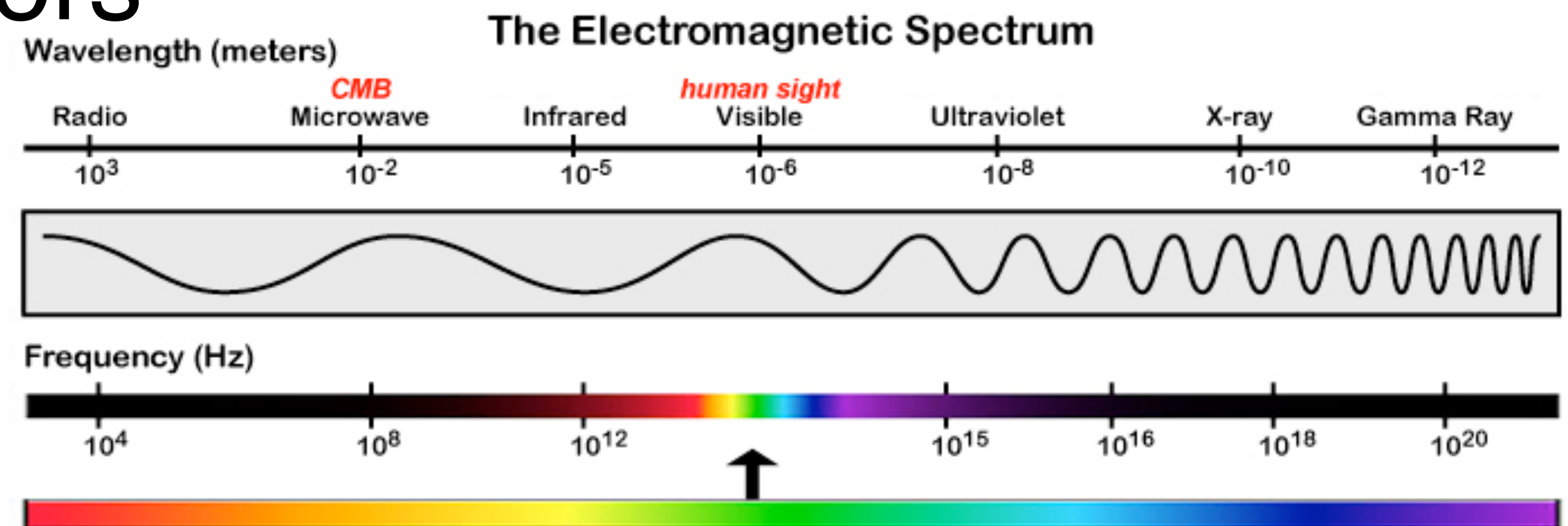
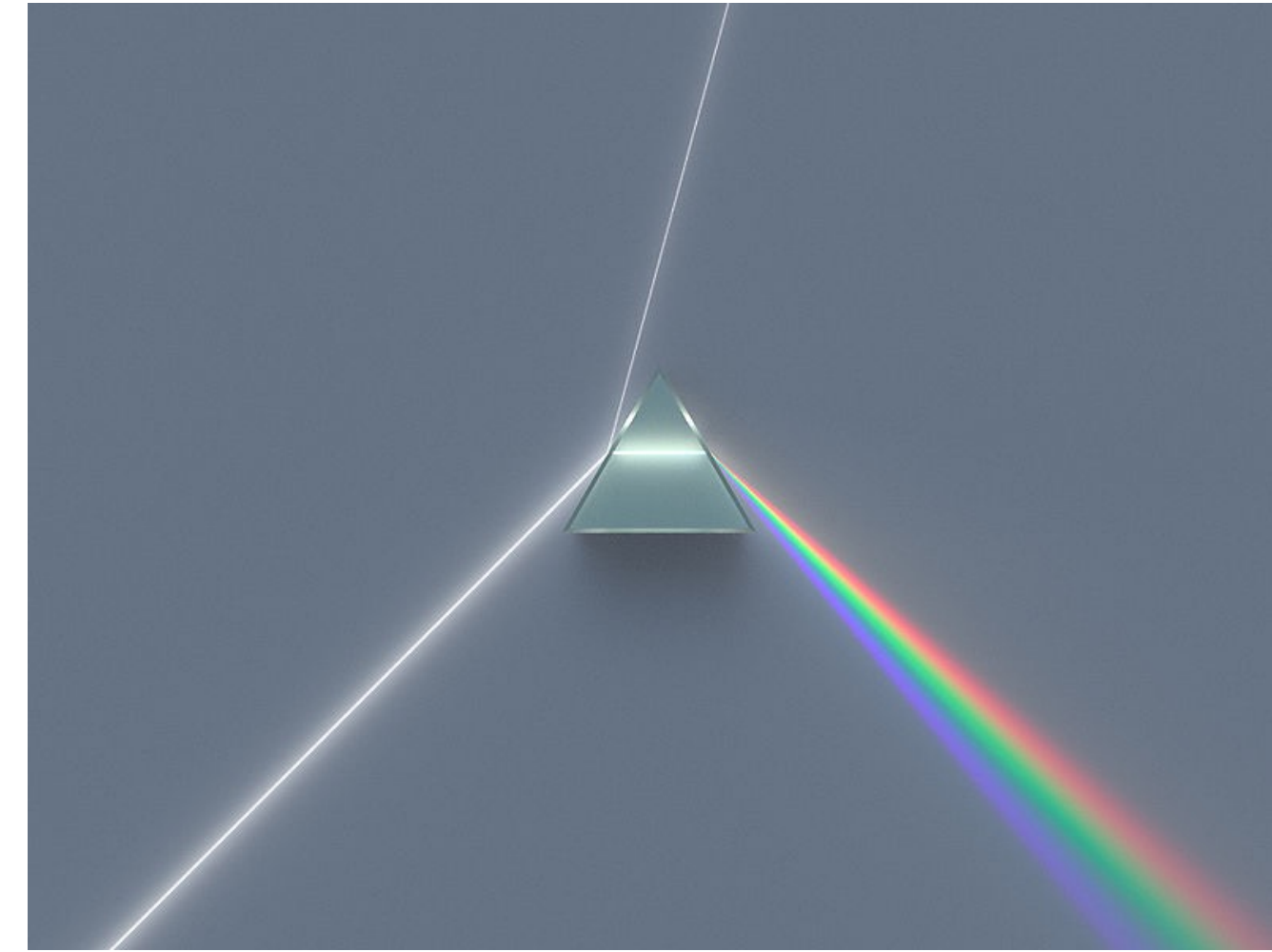
390-750 nm

## Spectral colors

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

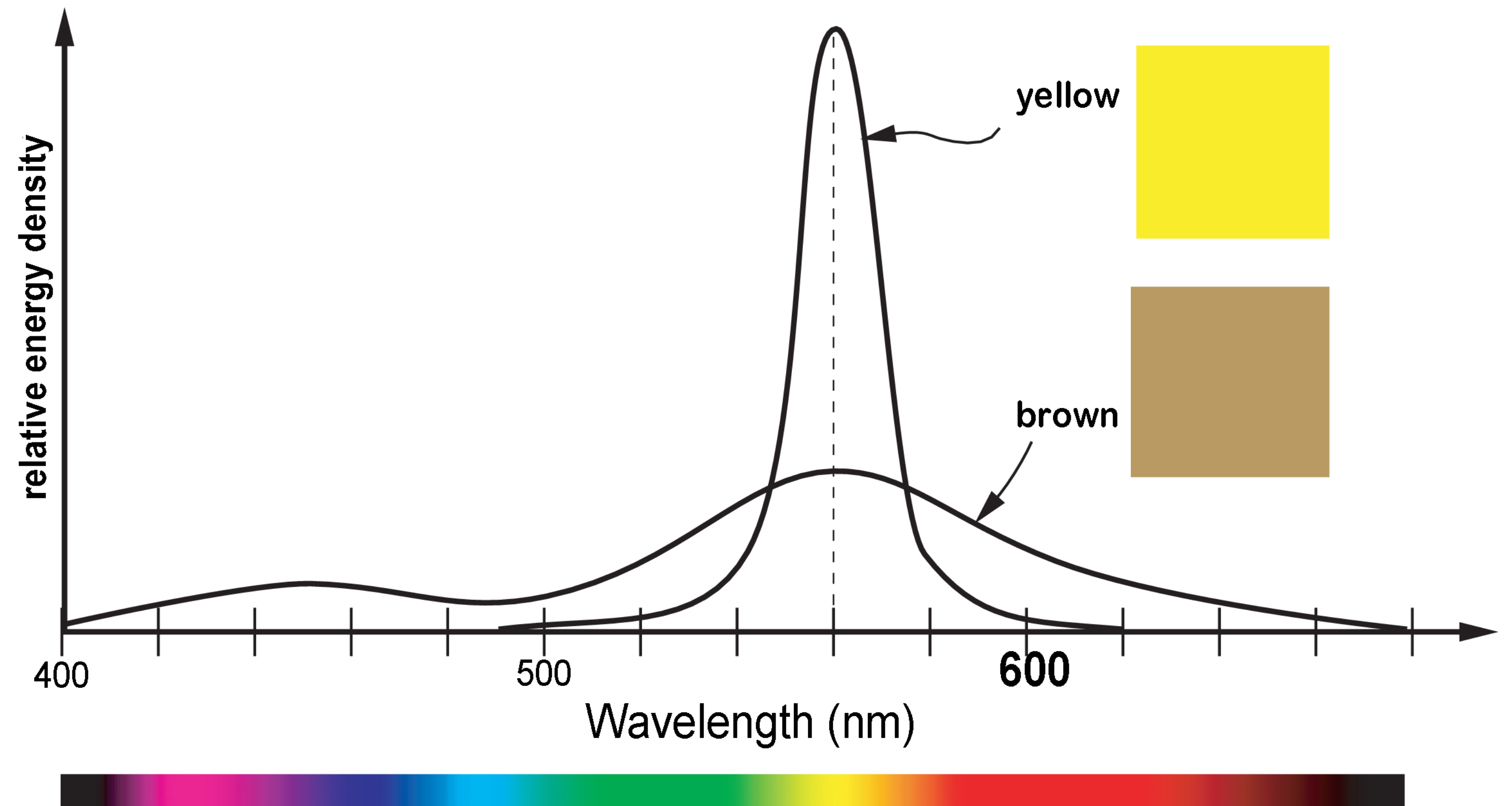
## Other colors: unsaturated colors

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

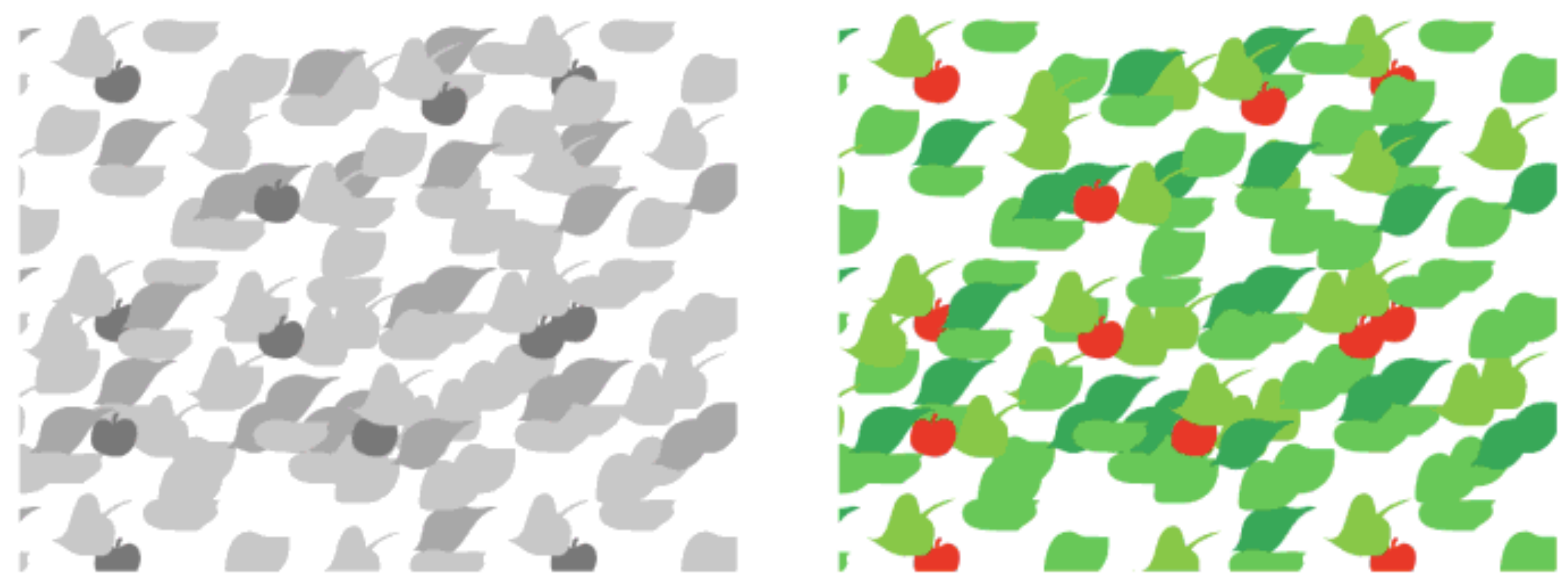


# color $\neq$ wavelength

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

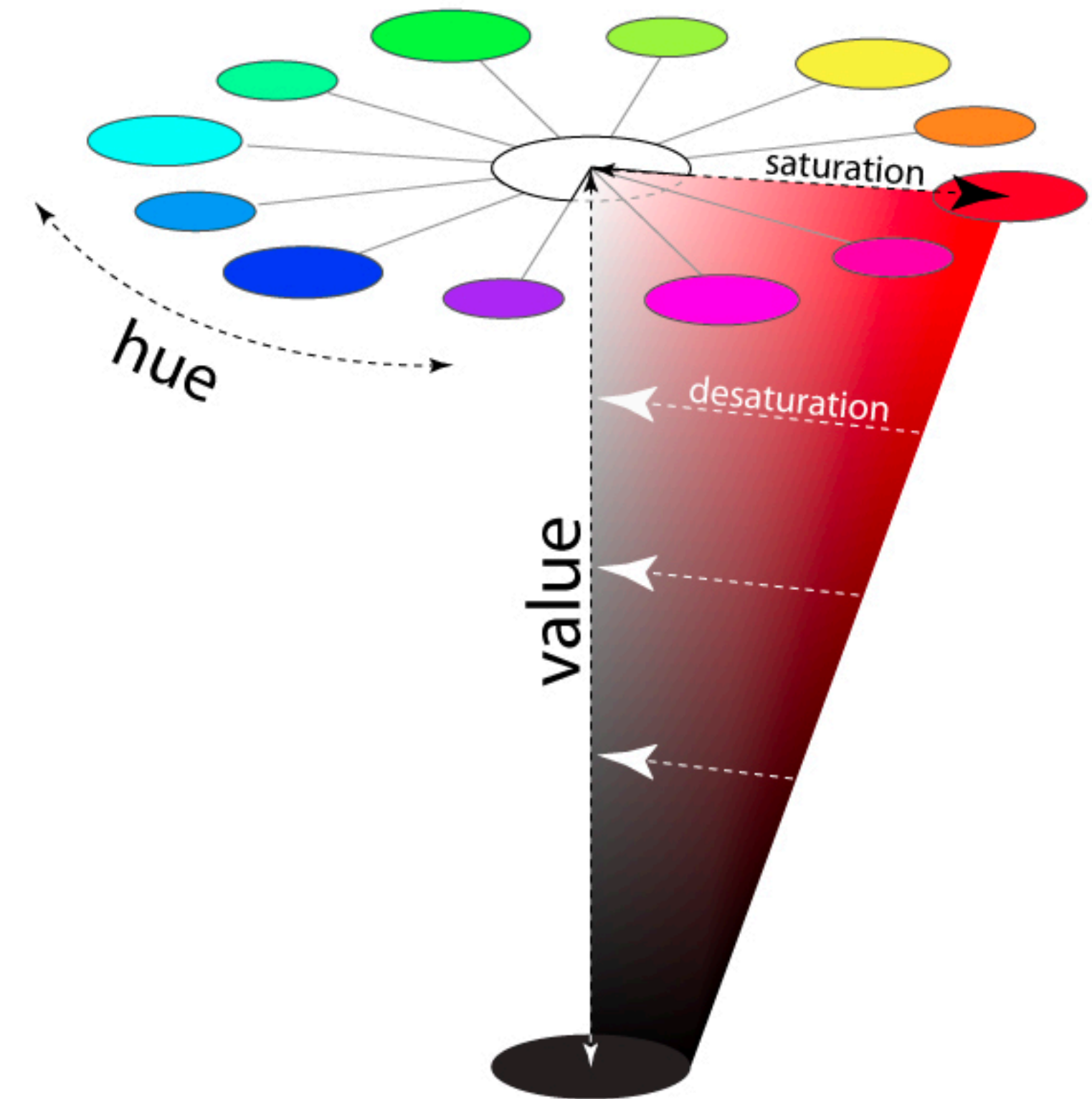
The purity of a color

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)

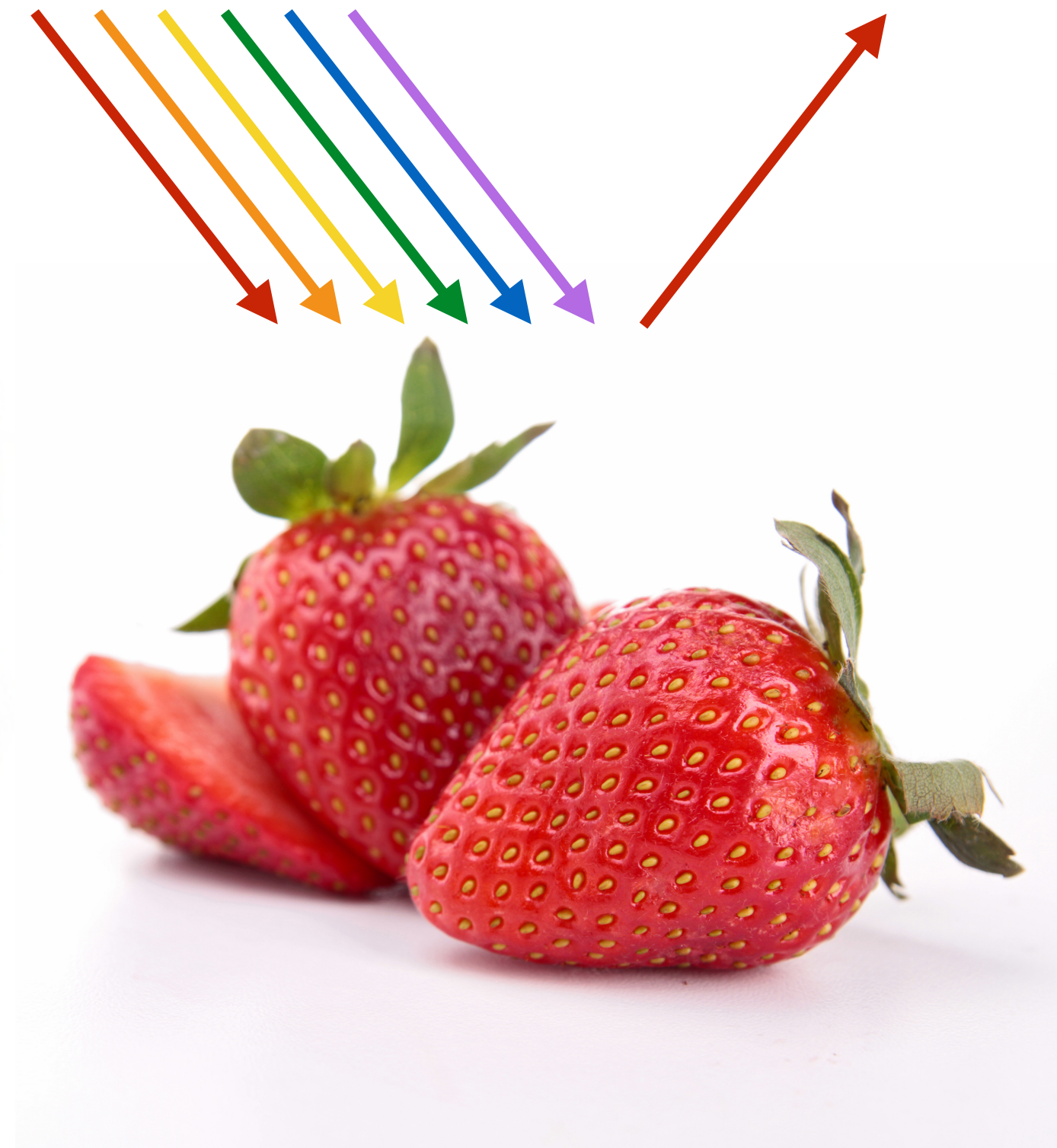
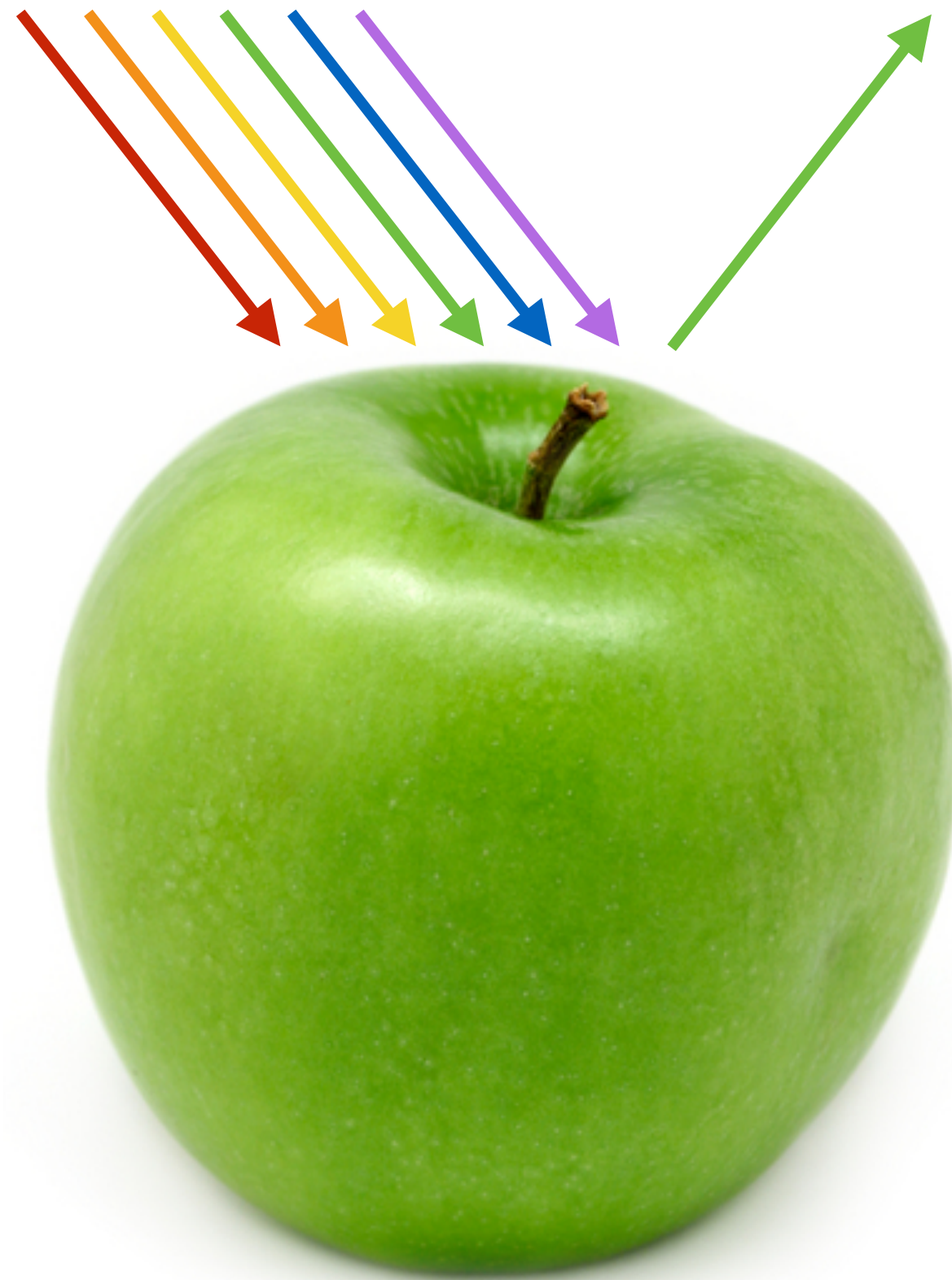
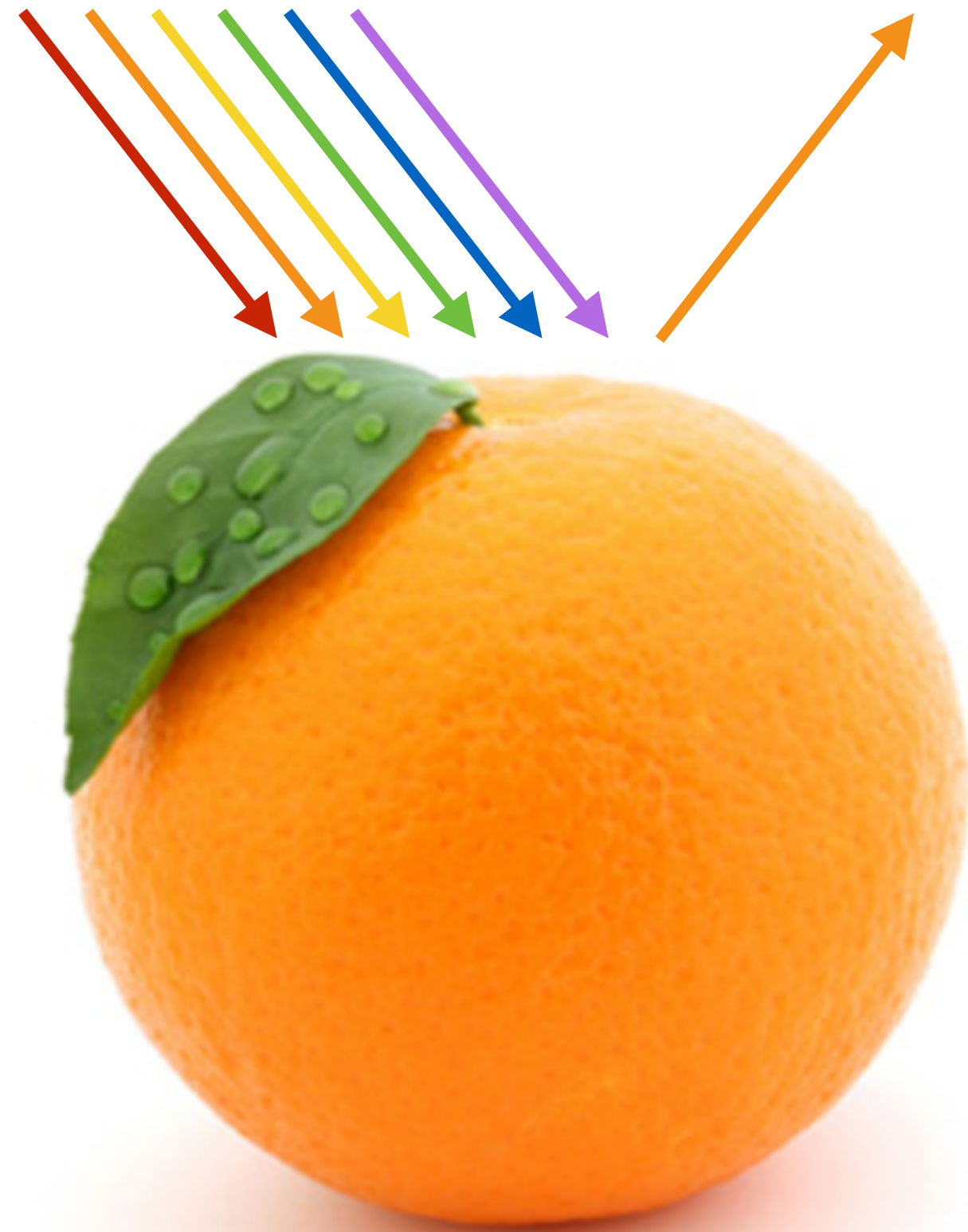
lightness or darkness of a color, i.e., the overall intensity of light



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/

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# RADIOLAB

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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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### The Most

Viewed | Listened | Commented

- ▶ If You're Born In The Sky, What's Your Nationality? An Airplane Puzzler
- ▶ Cities
- ▶ Hello
- ▶ Roadways You Can Install Like Throw Rugs
- ▶ 9-Volt Nirvana

<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

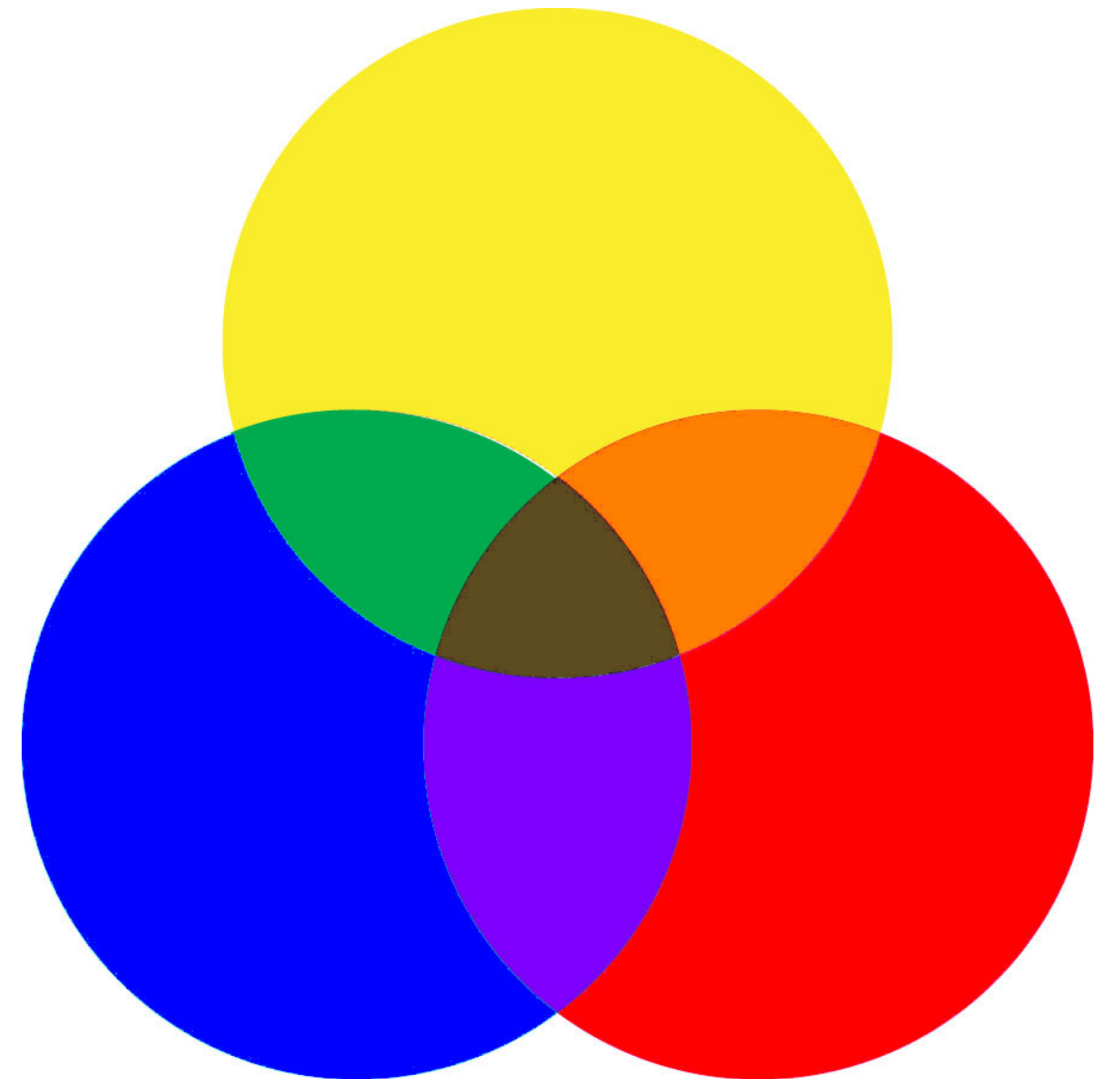
# Paint mixing

physical mixing of opaque paints

primary: Red, Yellow, Blue

secondary (mixed): Green, Orange,  
Purple

subtractive



# Ink mixing

subtractive mix of transparent inks

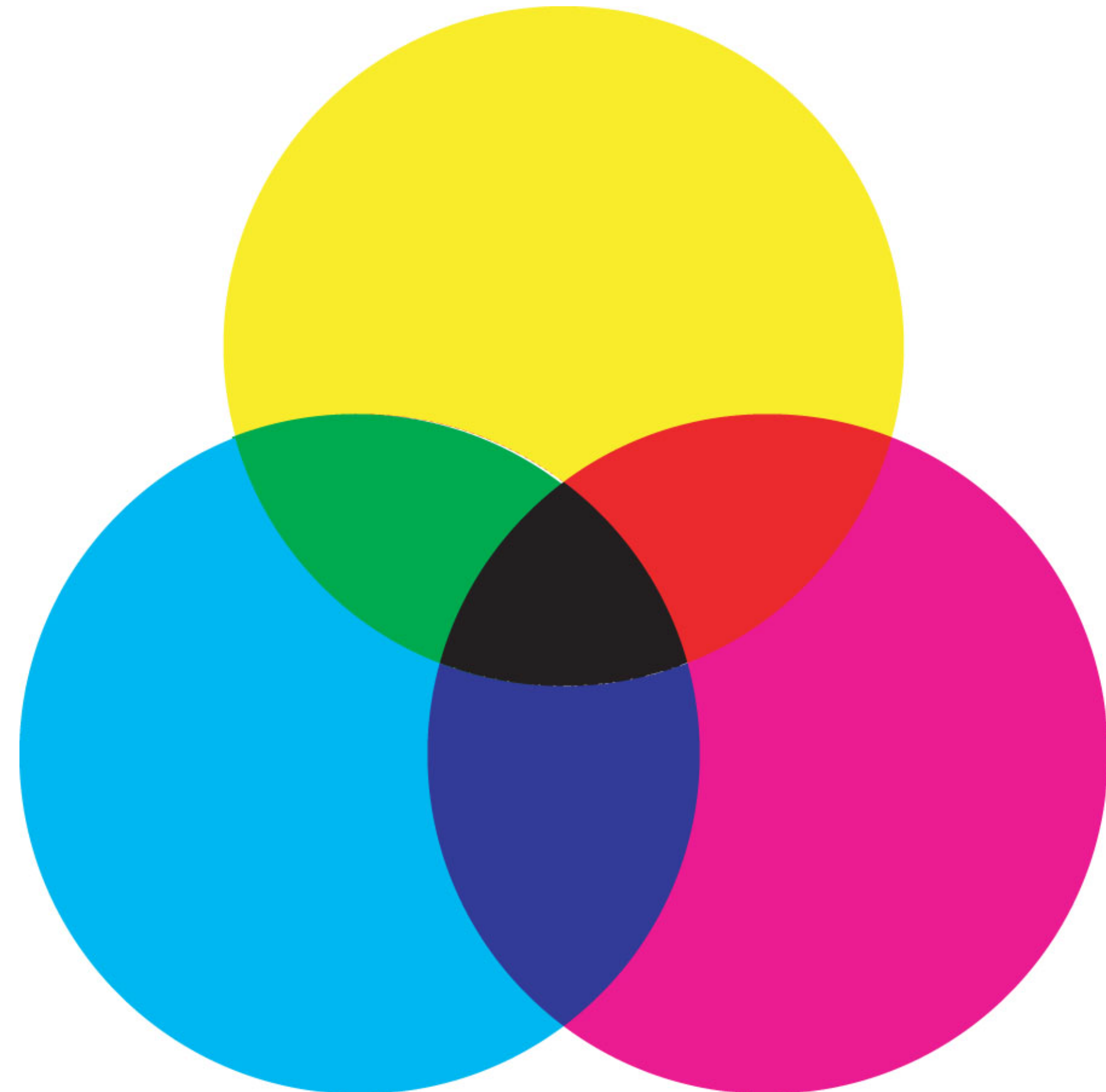
primary: Cyan, Magenta, Yellow

secondary: RGB

approx. black = C+M+Y

true black = C+M+Y+K

subtractive



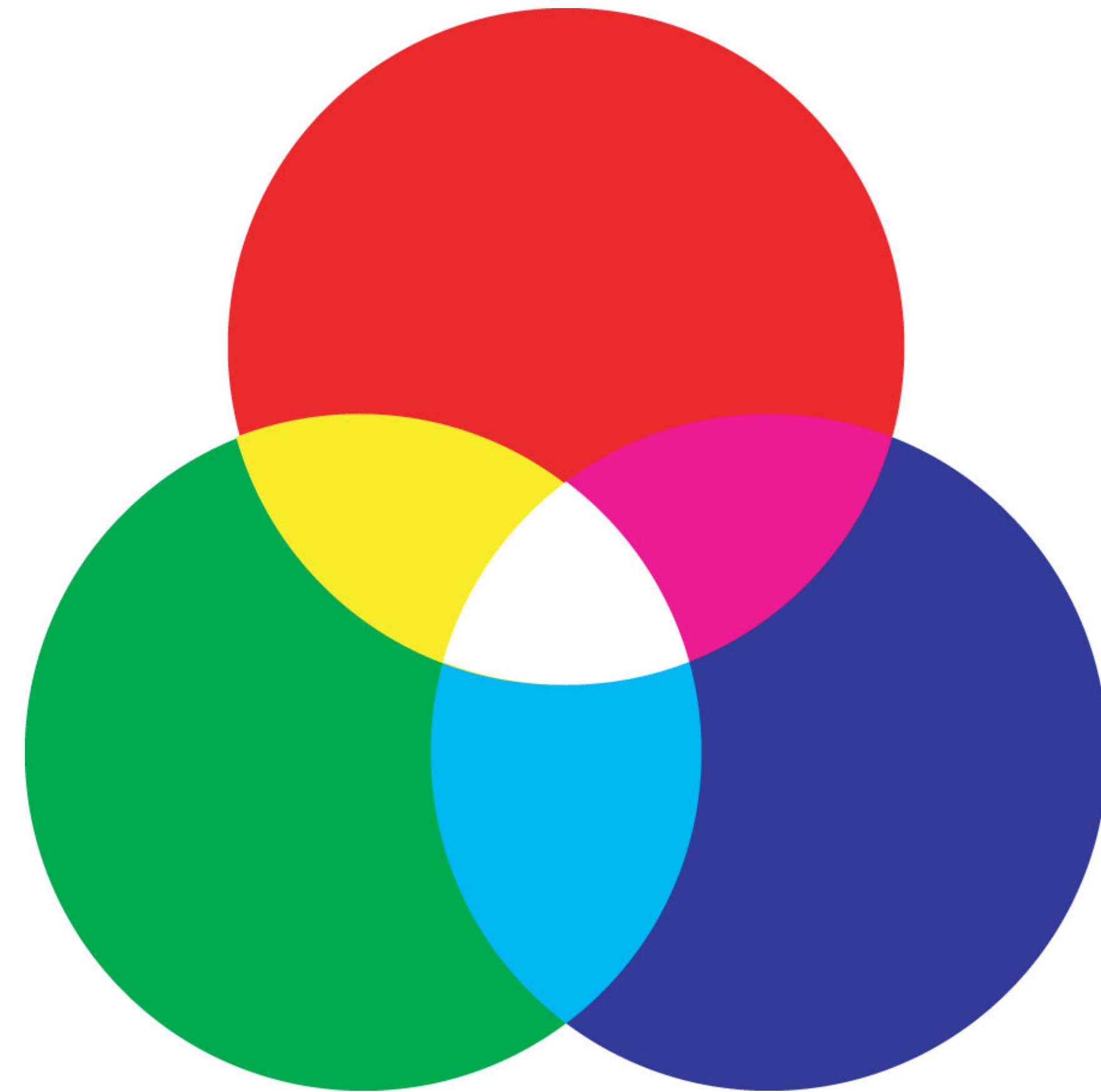
# Light mixing

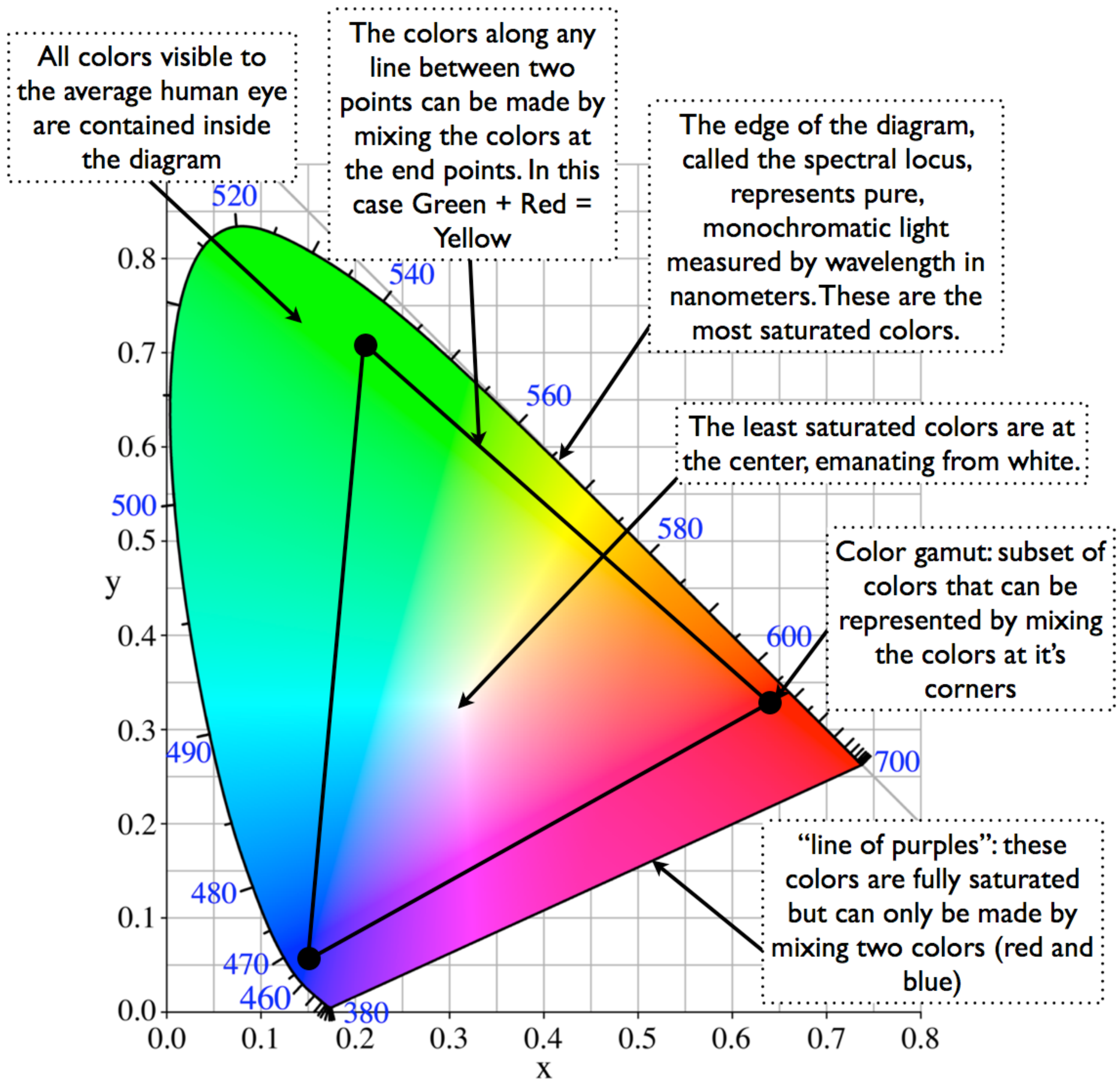
additive mix of colored lights

primary: Red, Green, Blue

secondary: Cyan, Magenta, Yellow

additive





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

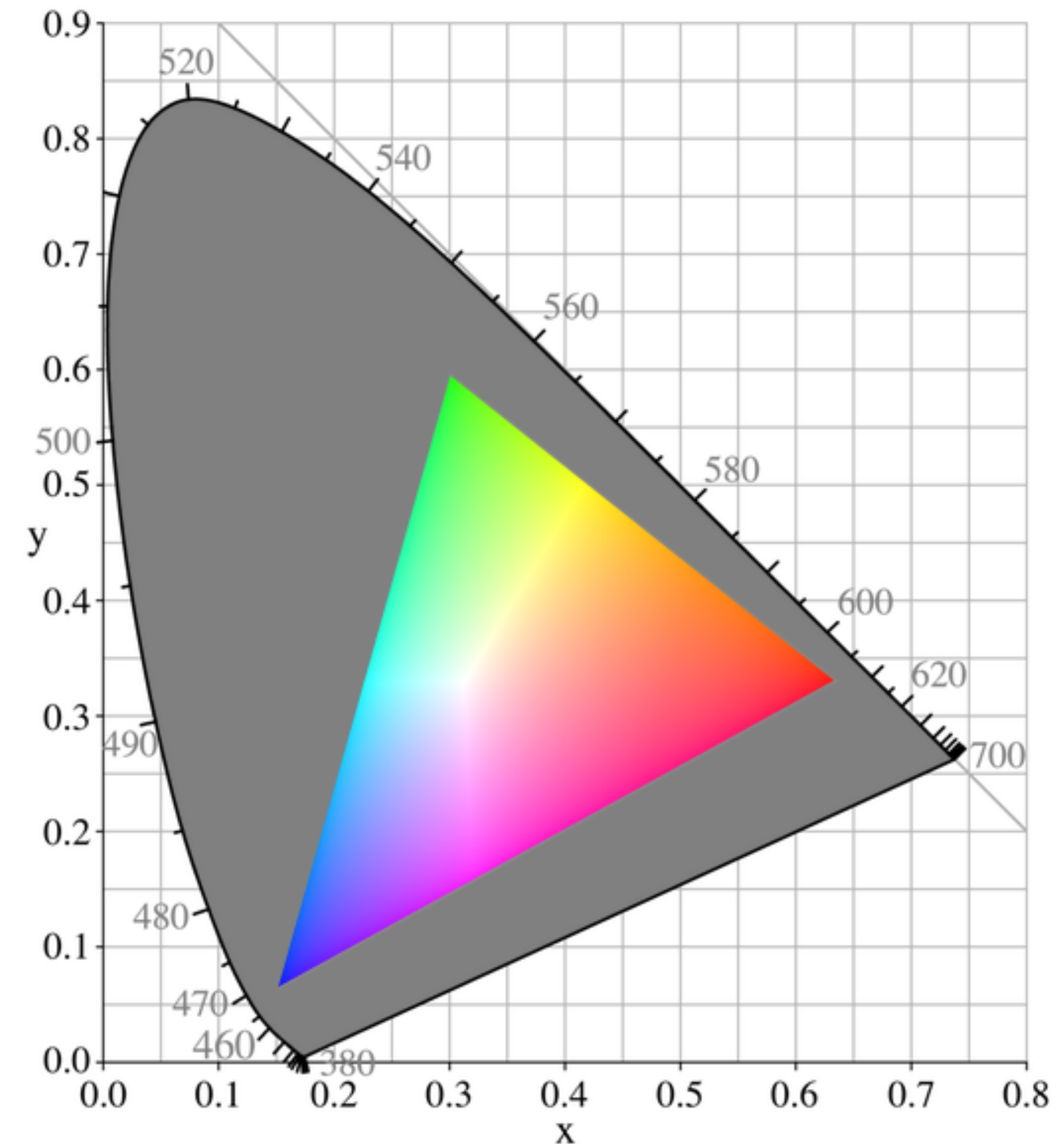
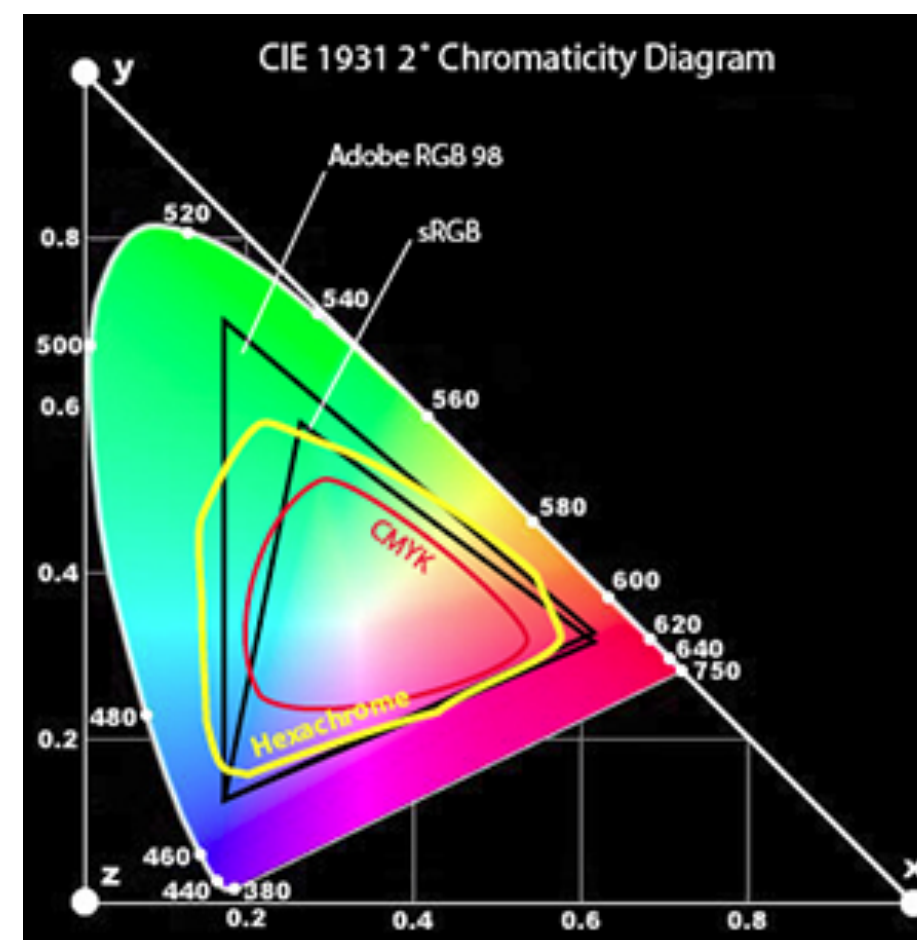
Anatomy of a CIE Chromaticity Diagram

# 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

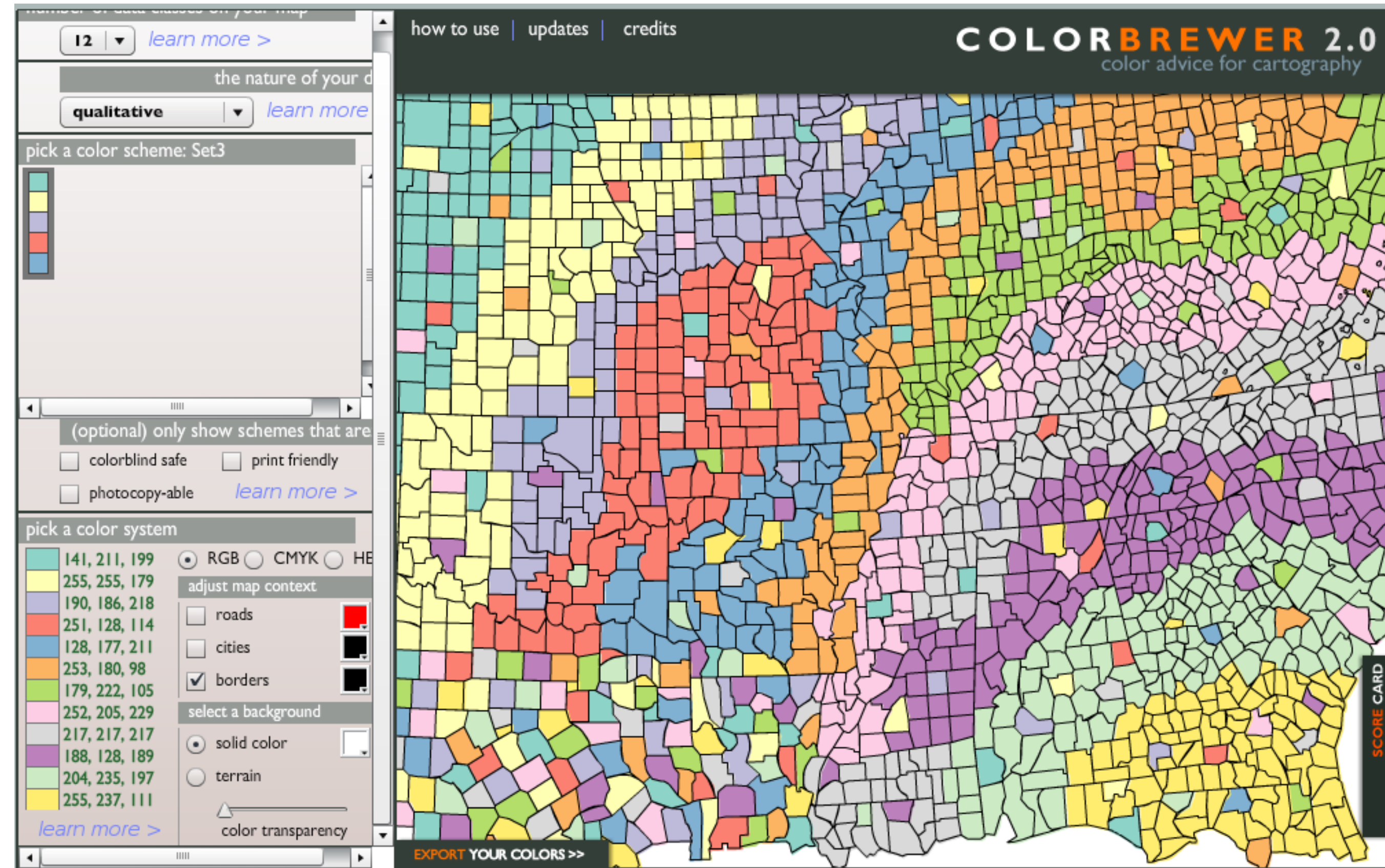
univariate vs bivariate

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

[0,8] →



# Application: Labeling



Carefully designed color scheme for 12 colors [colorbrewer]

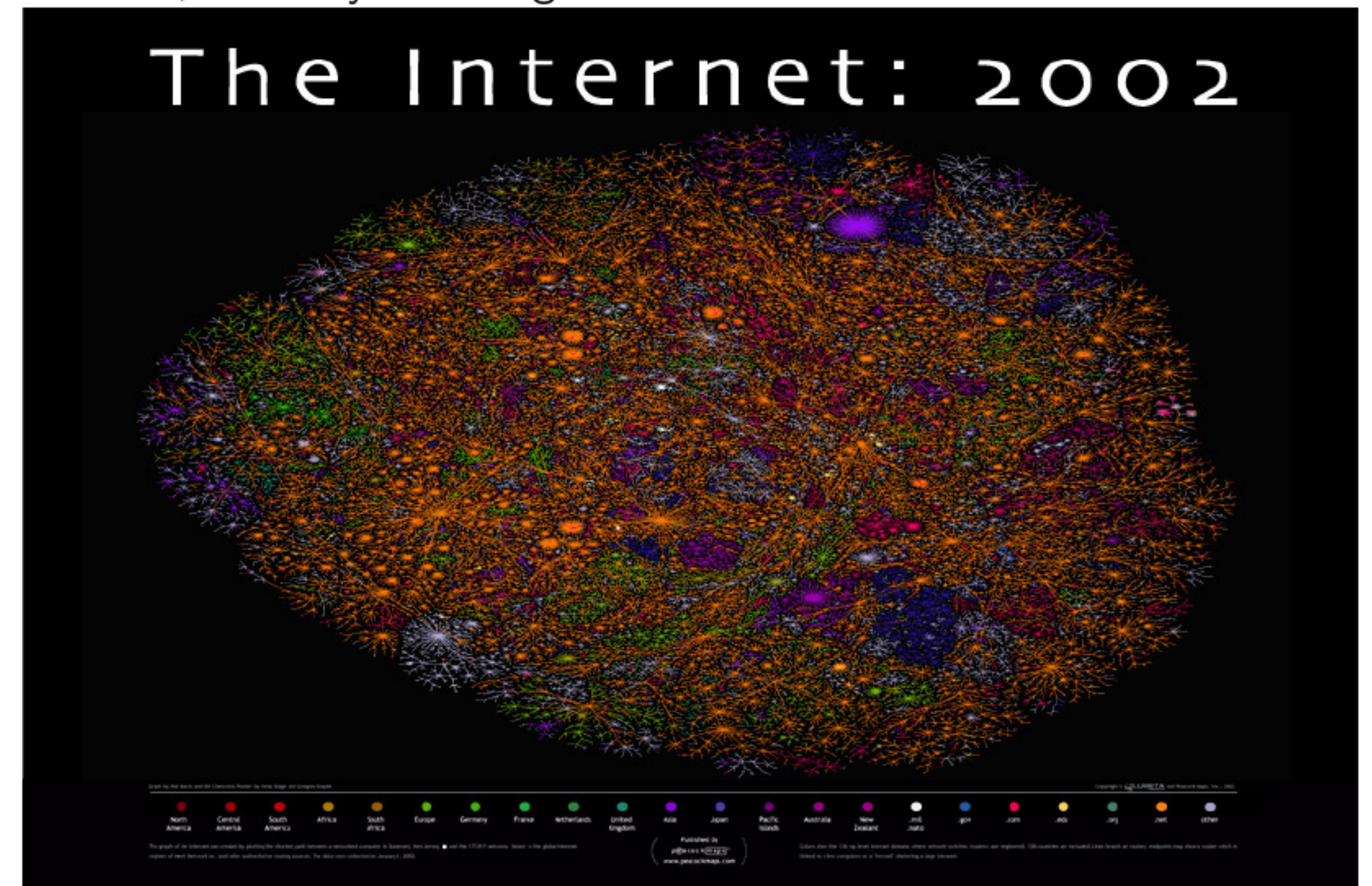


# Color for qualitative data

## Color labeling (nominal information coding)

recommended: about 6, no more than 10

22 colors, but only 8 distinguishable



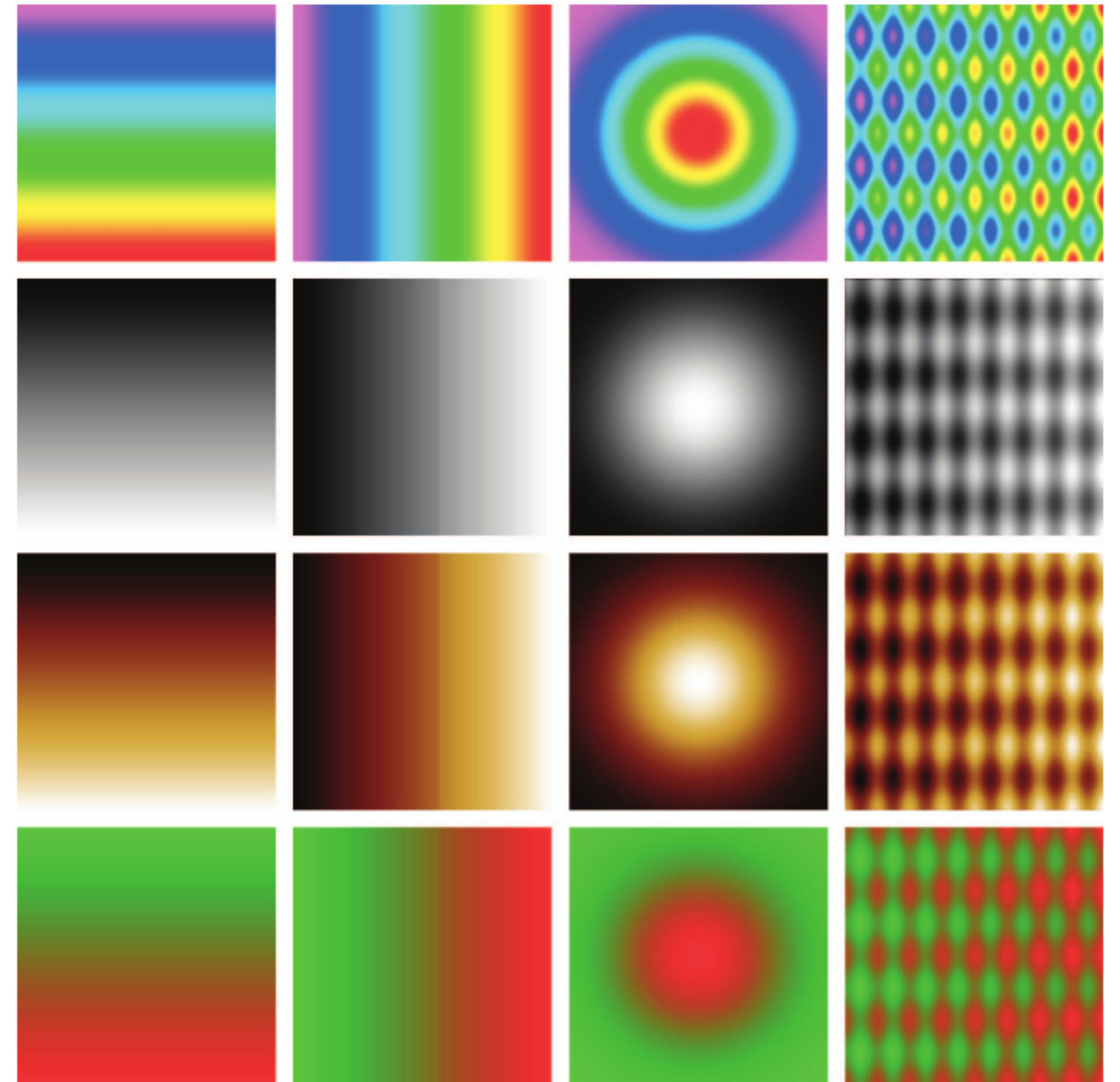
# Color for quantitative data

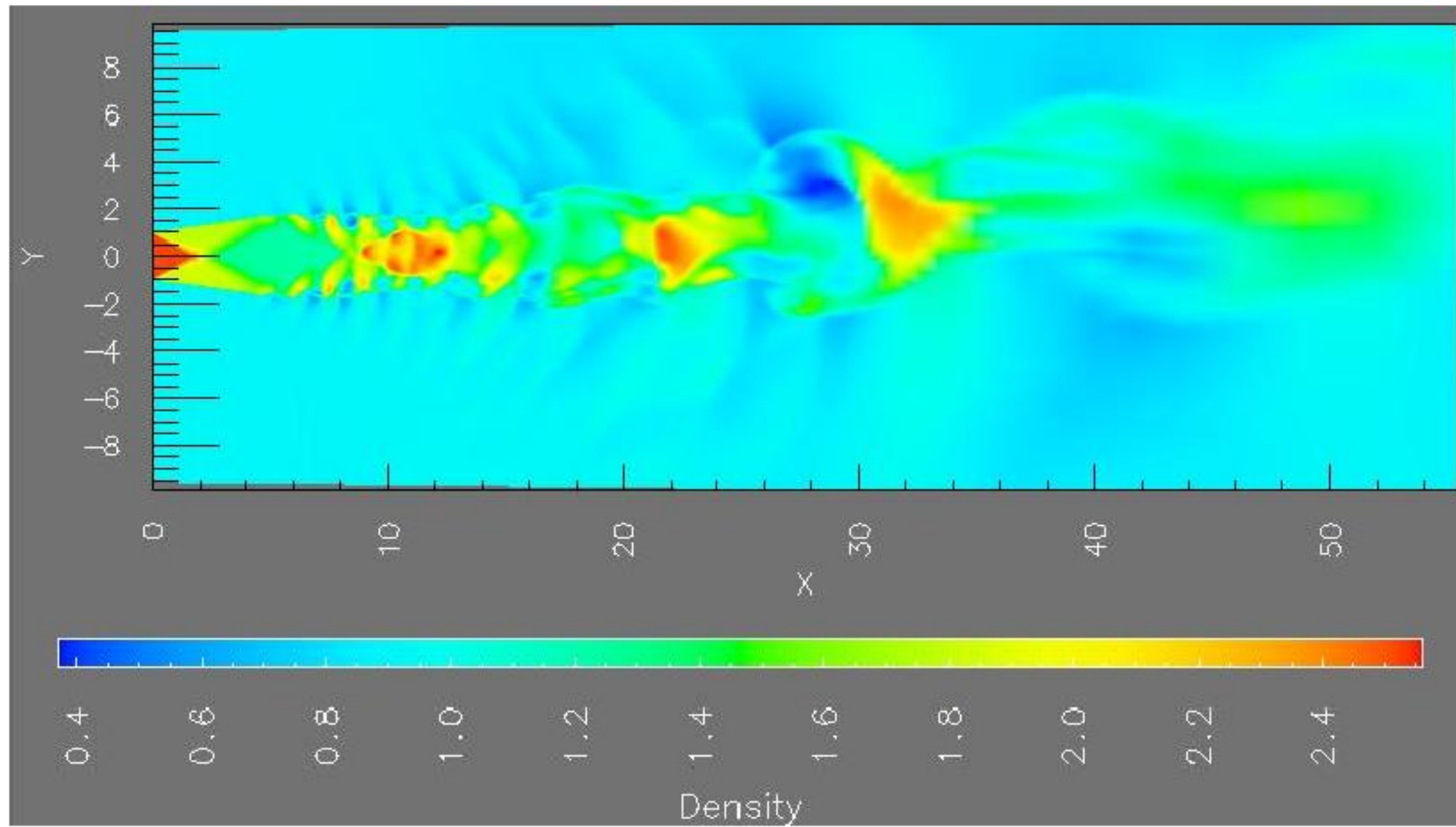
use value

saturation works but not as good

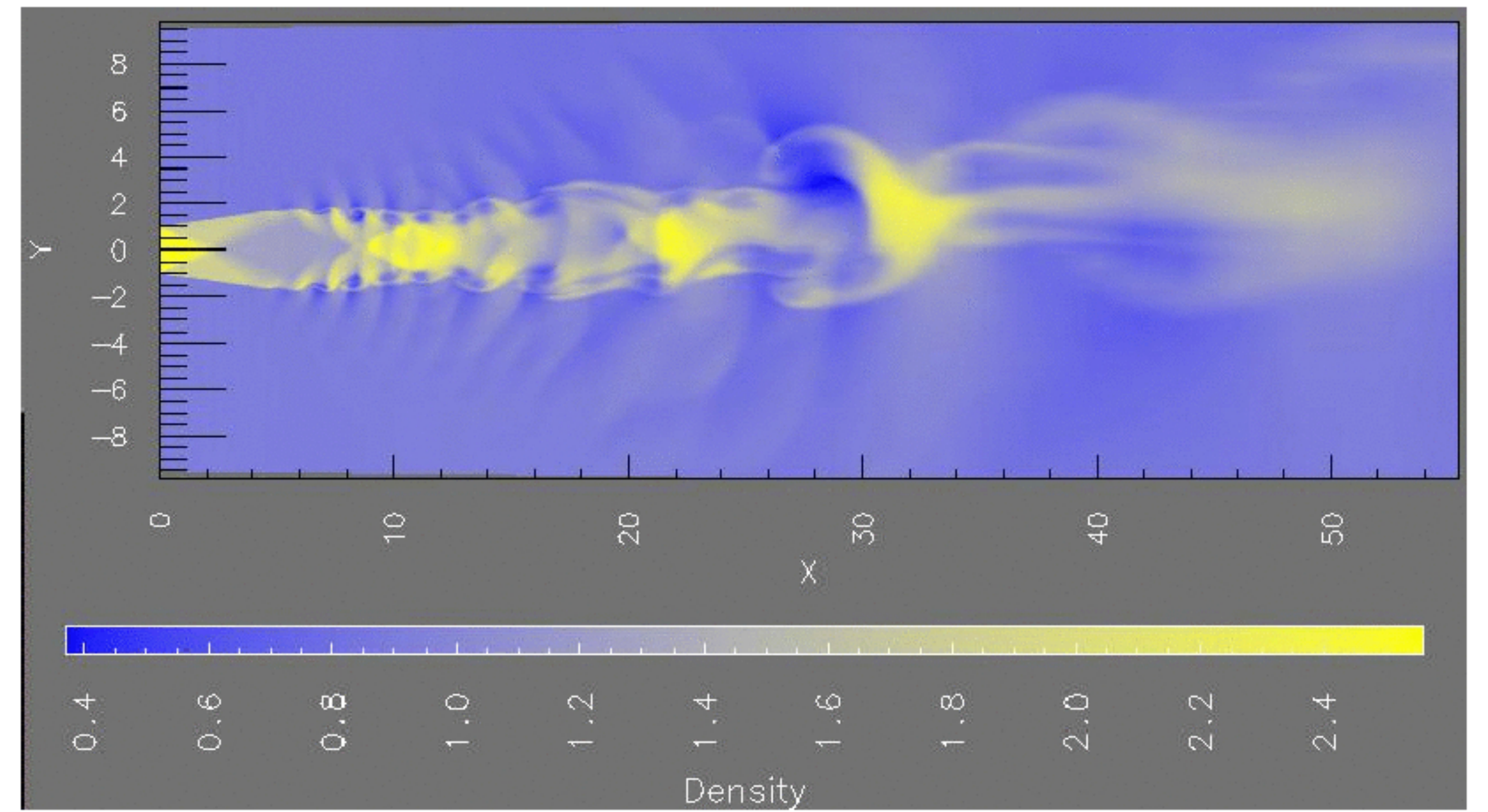
don't use hue!

Danger: rainbow color map





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

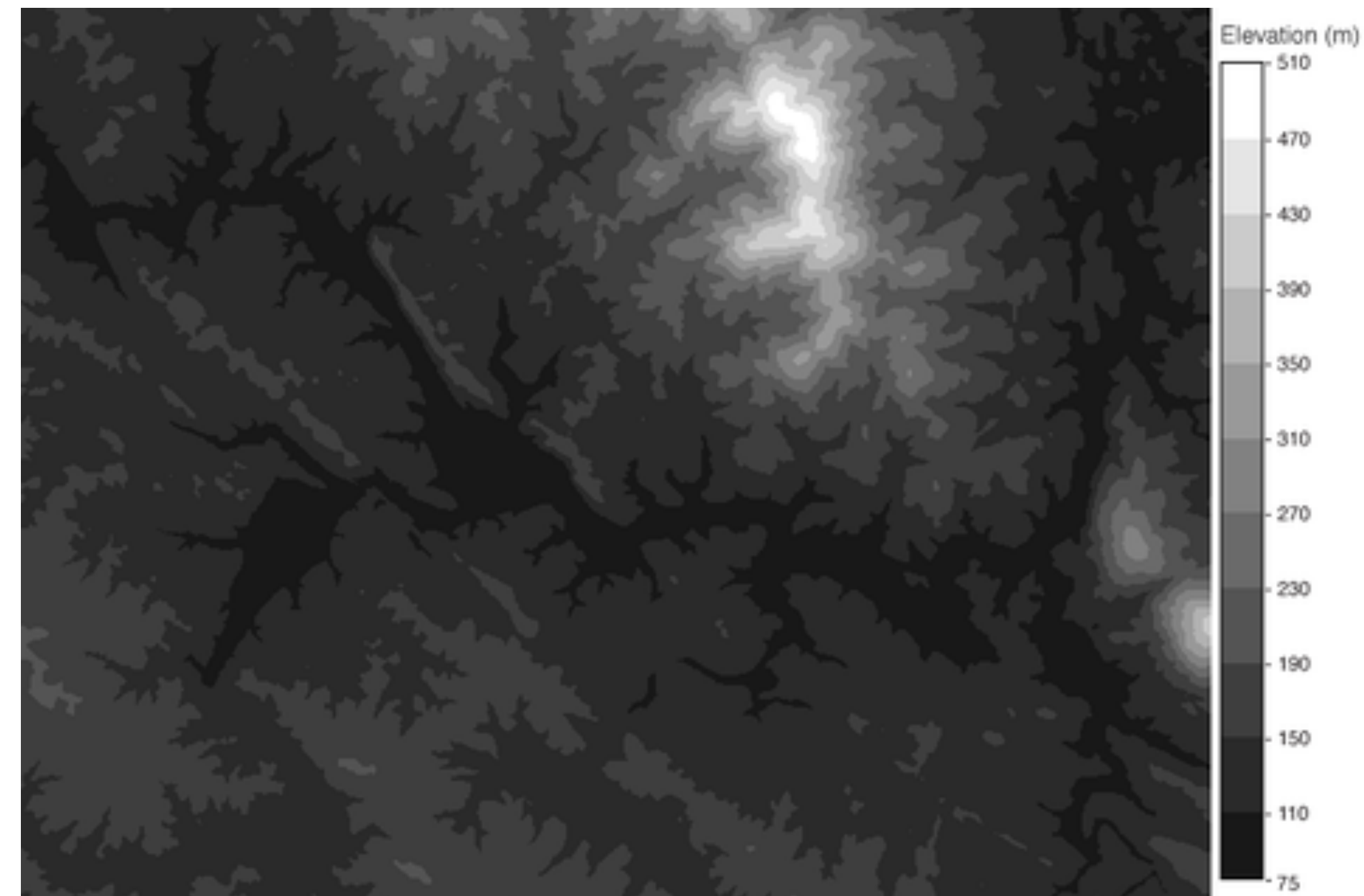
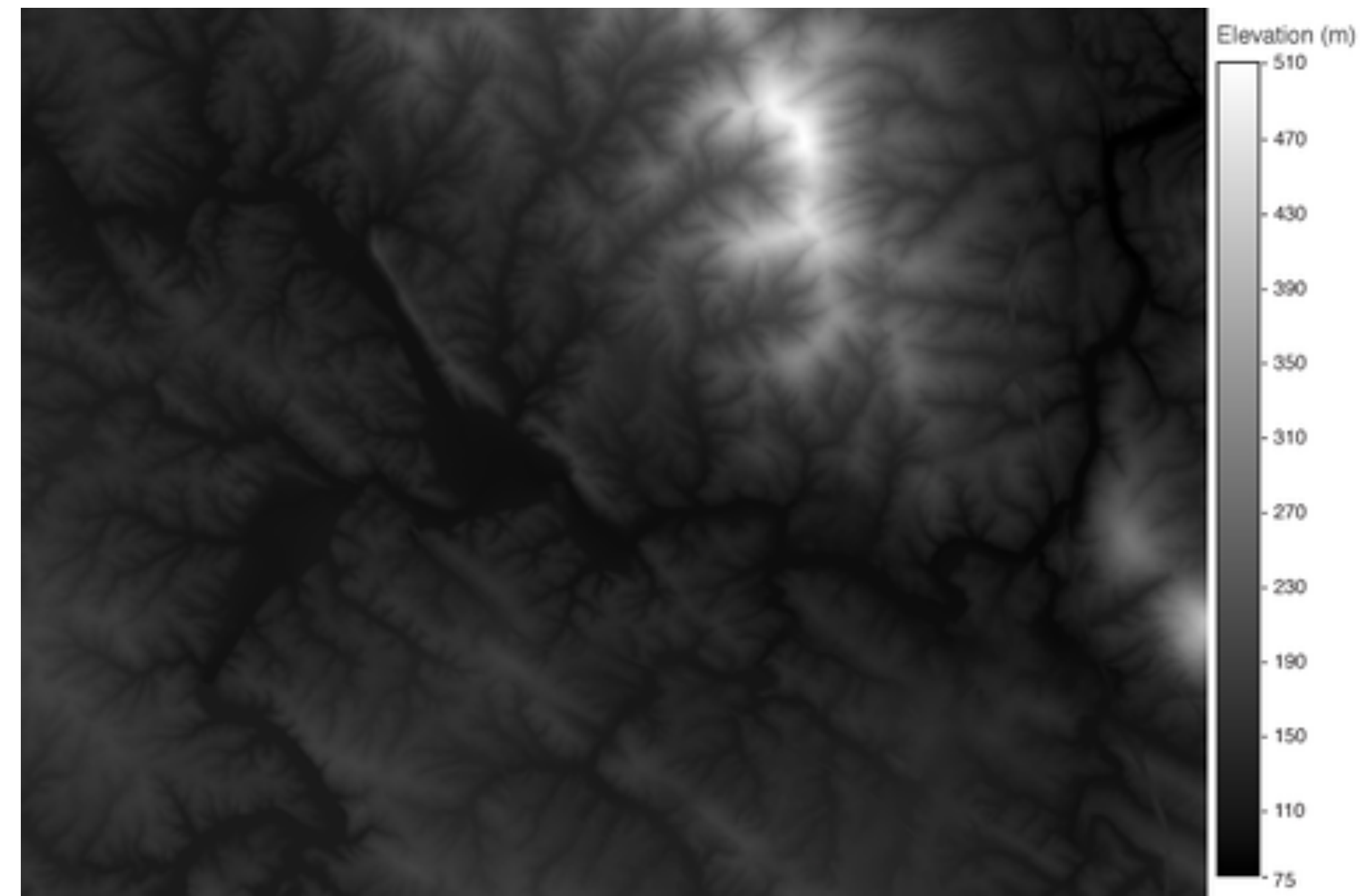
# To bin or not to bin?

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

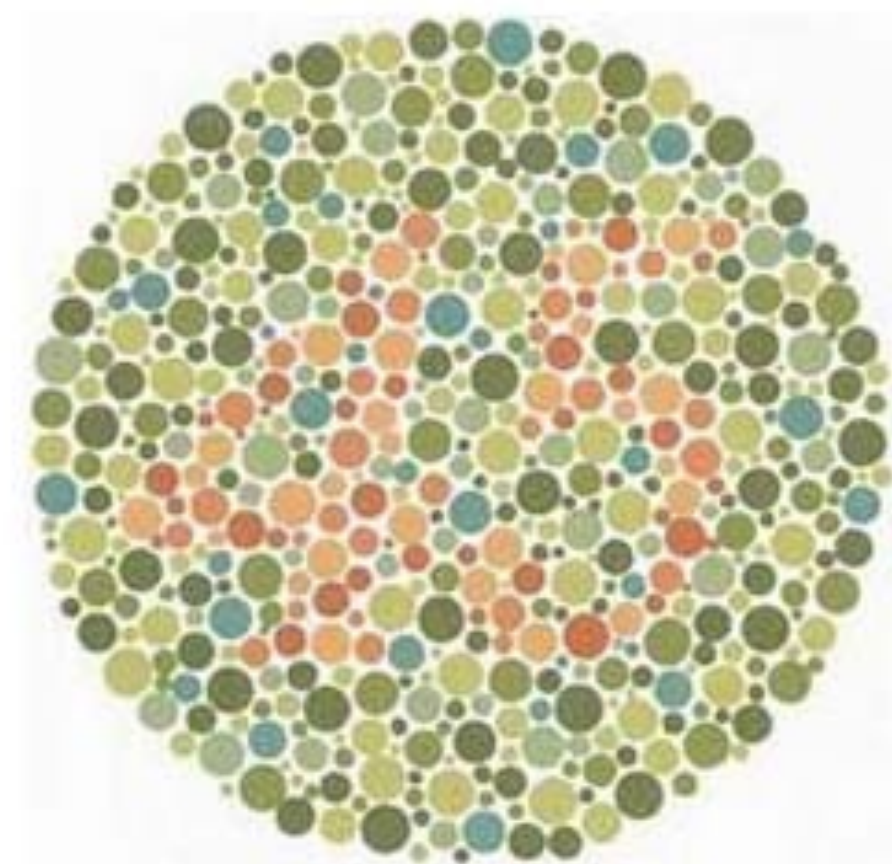
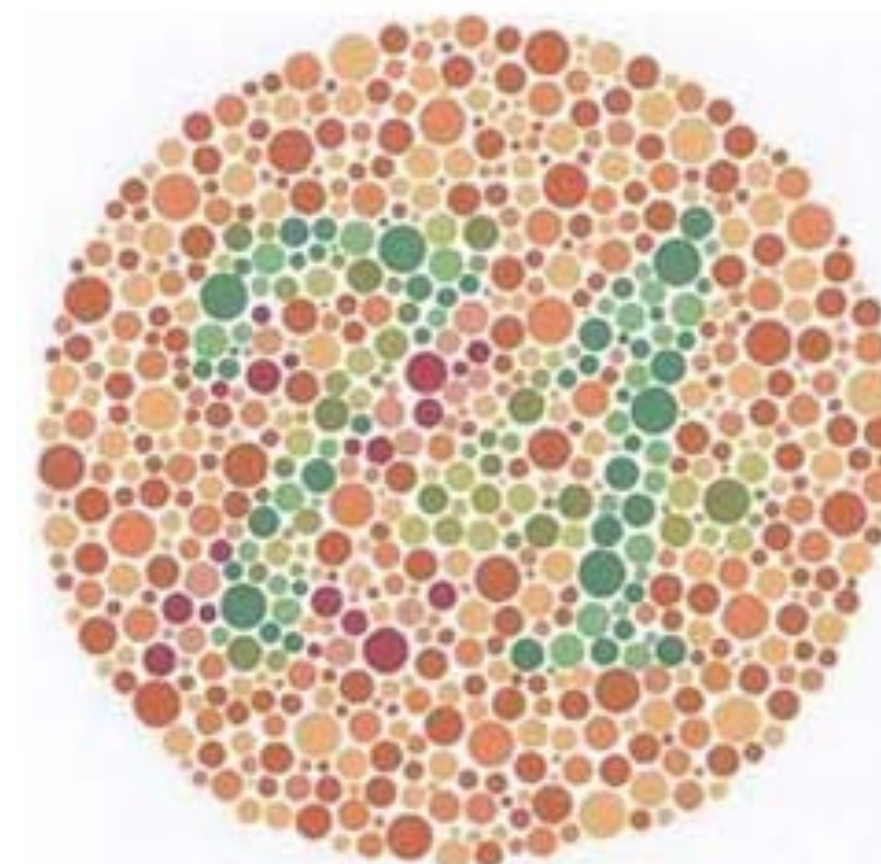
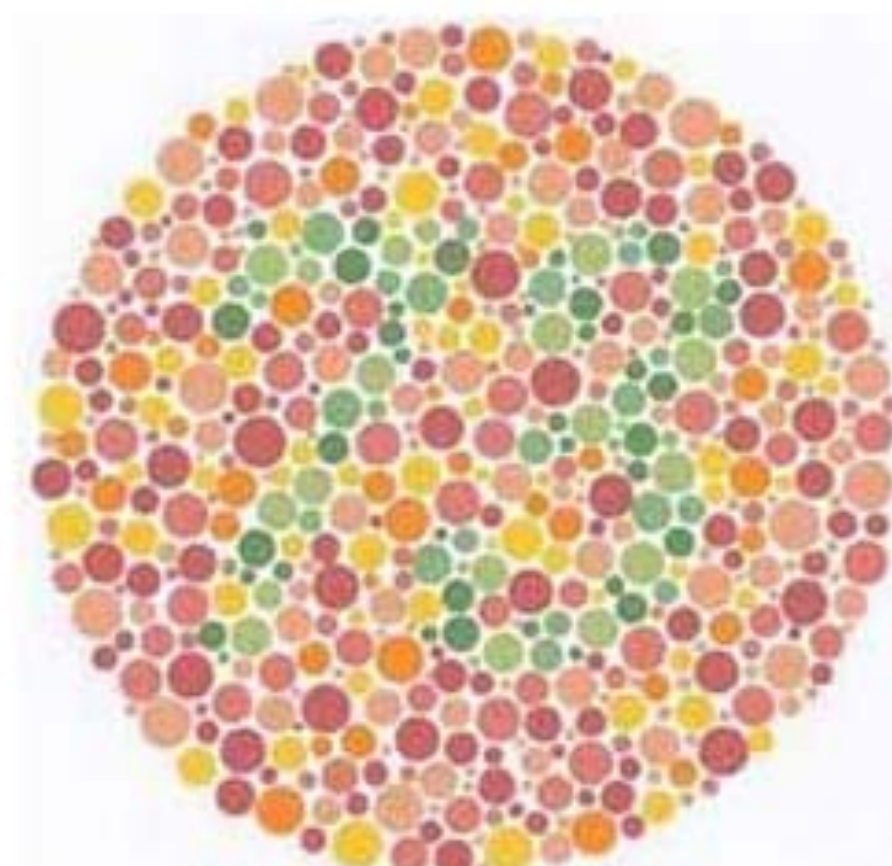
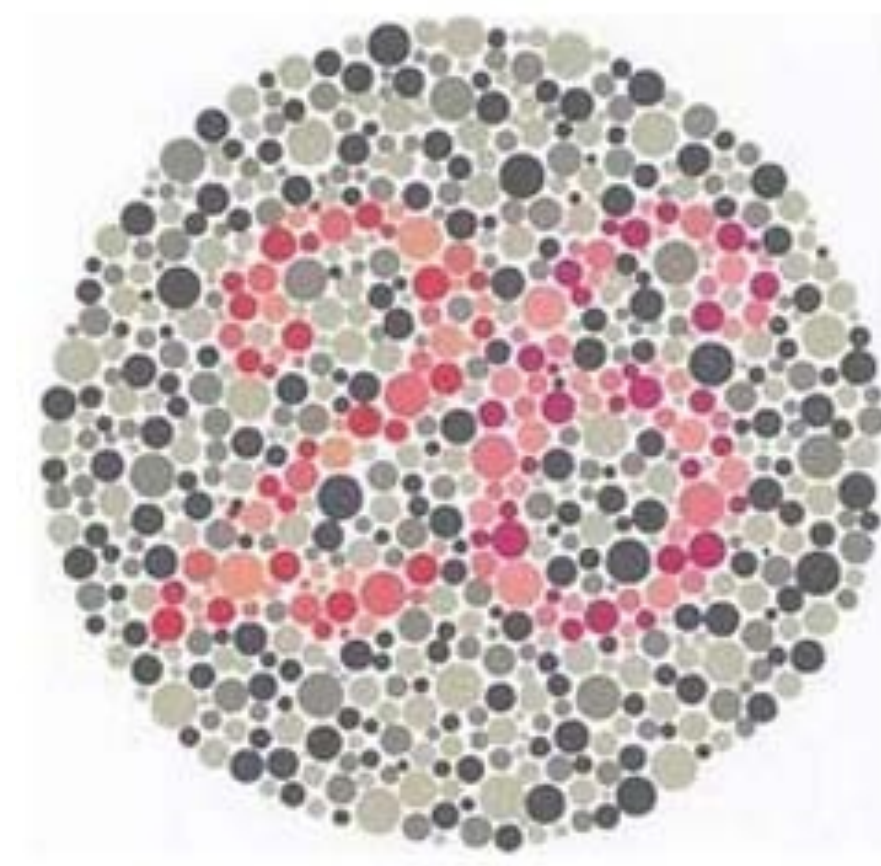
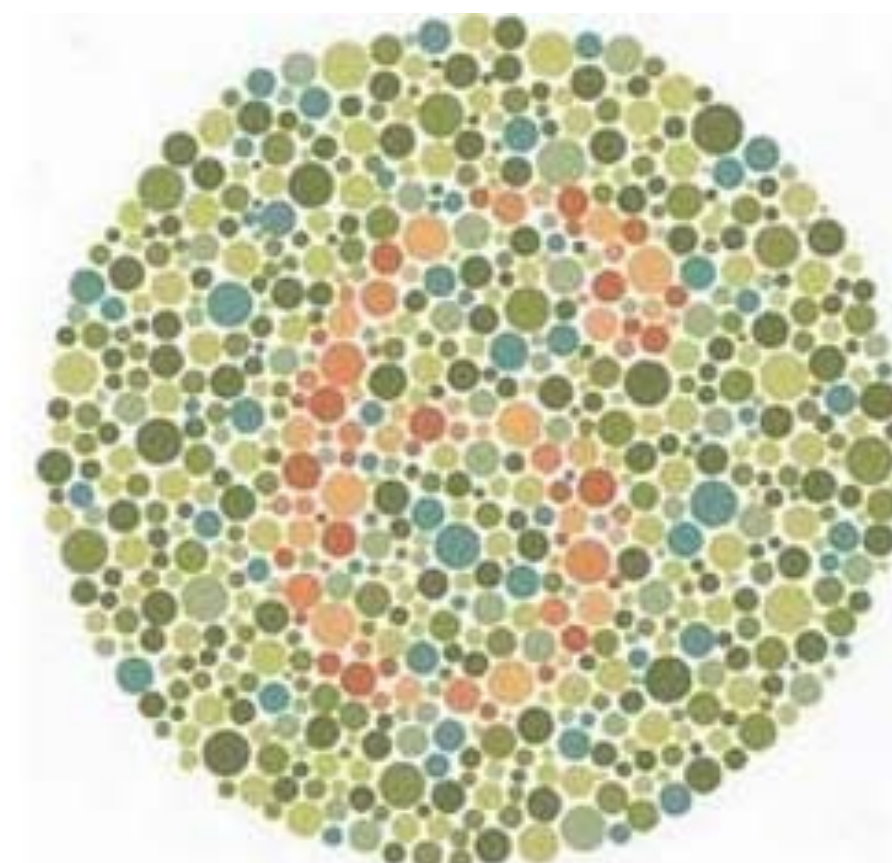
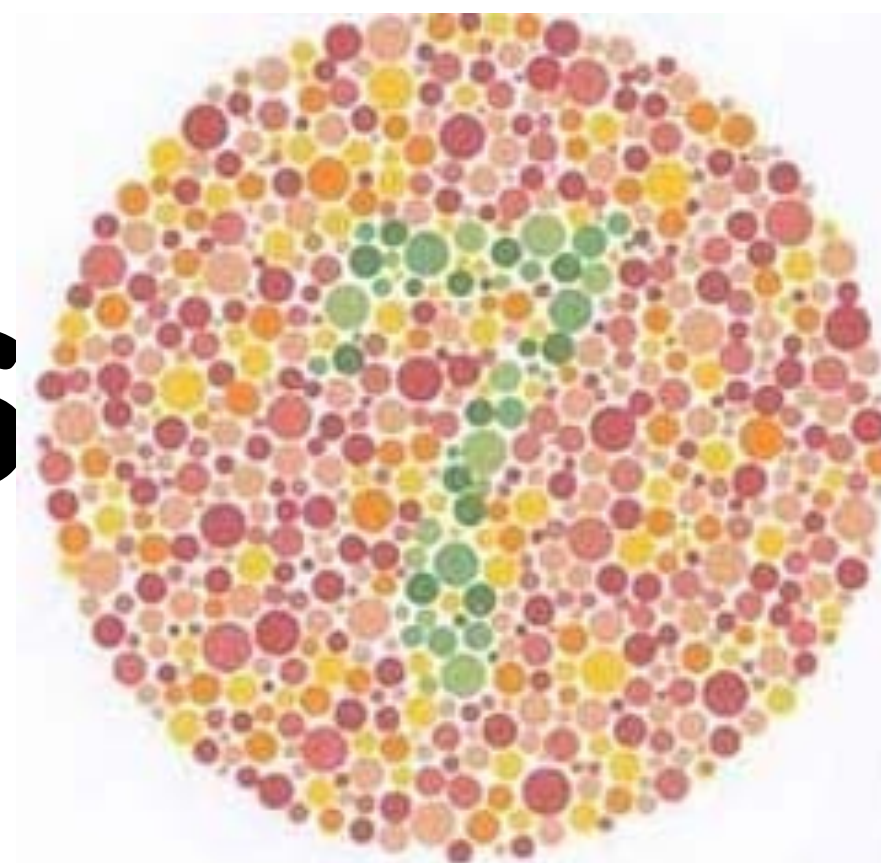
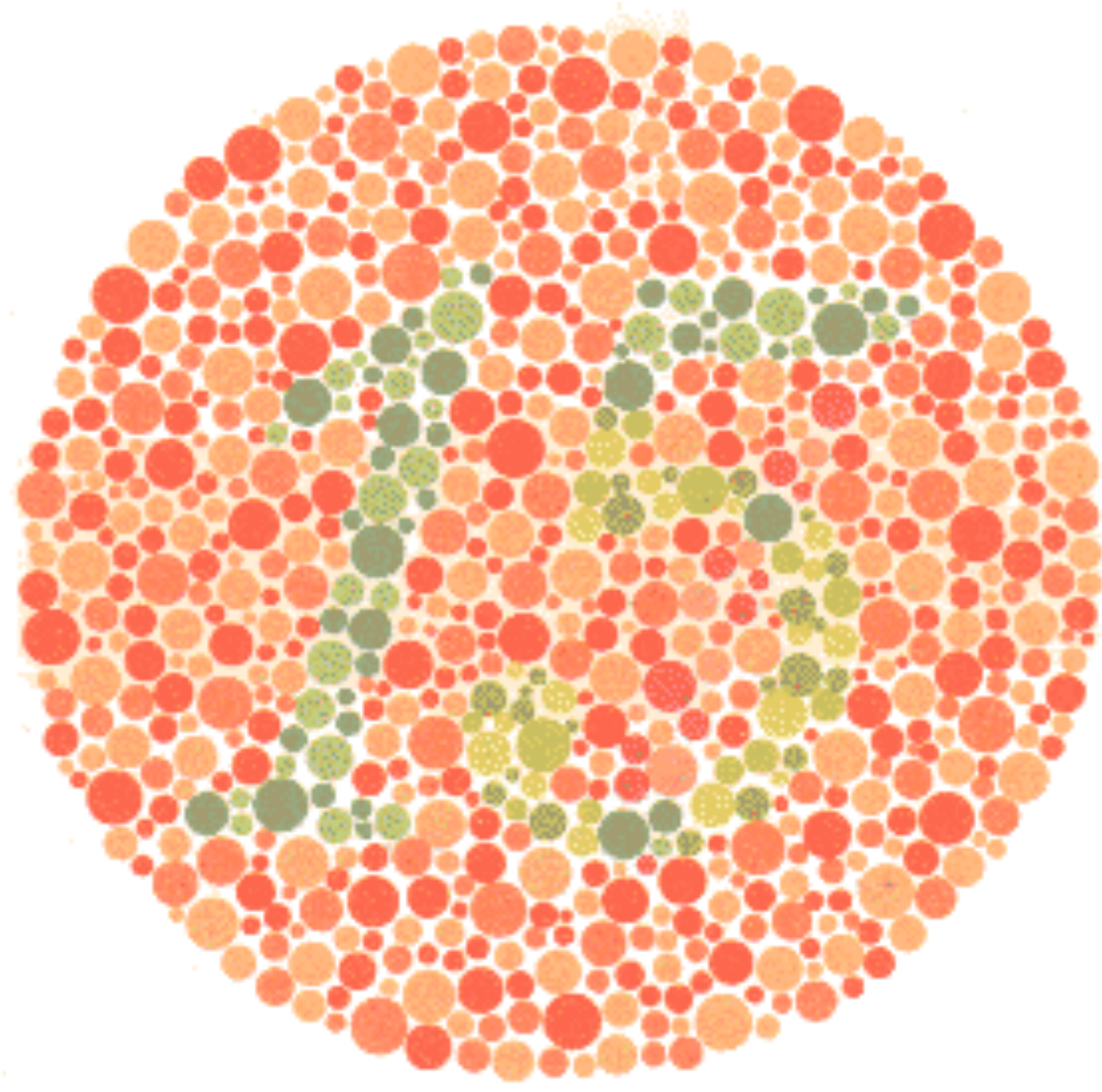
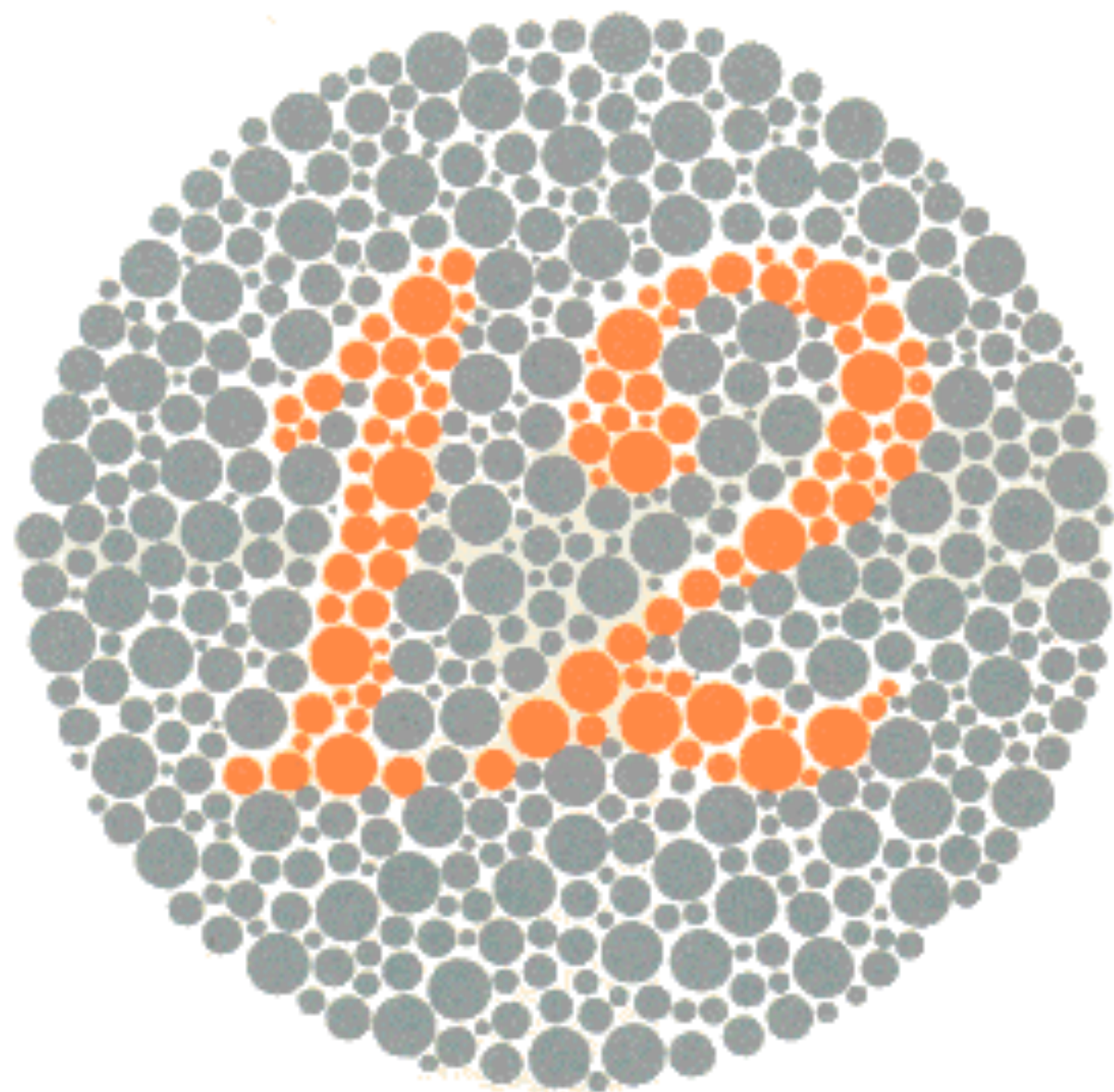


Deuteranopia (no green receptors)

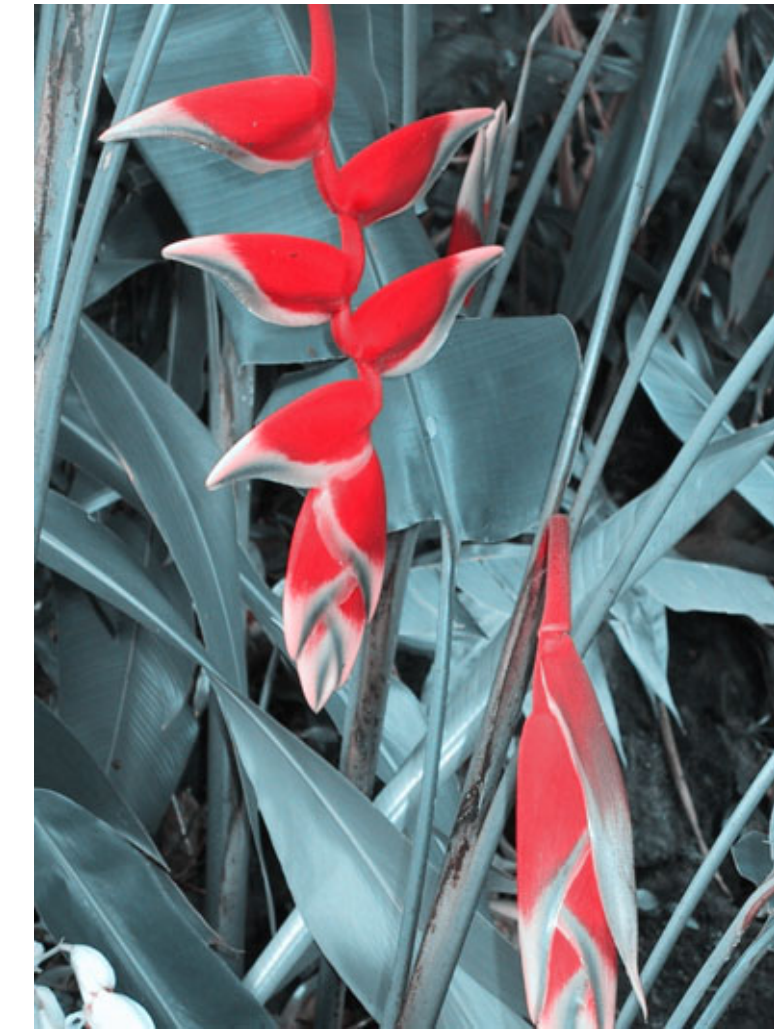


Protanopia (no red receptors)

# Color Blindness Tests



# Color Blindness



Protanope

Deuteranope

Tritanope

No L cones

No M cones

No S cones

Red / green  
deficiencies

Blue / Yellow  
deficiency

All Spending | Types of Spending | Changes | Department Totals

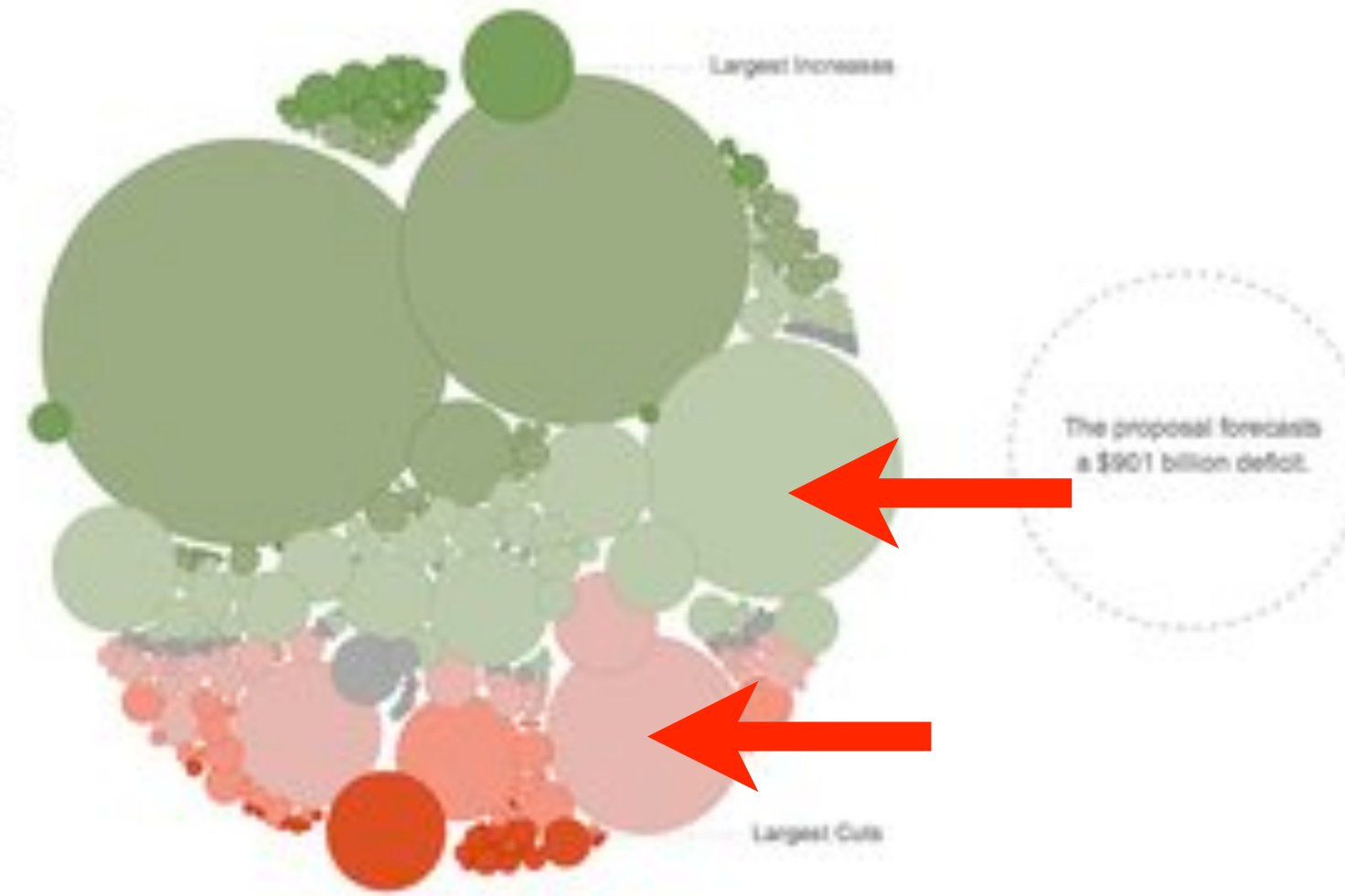
### How \$3.7 Trillion Is Spent

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

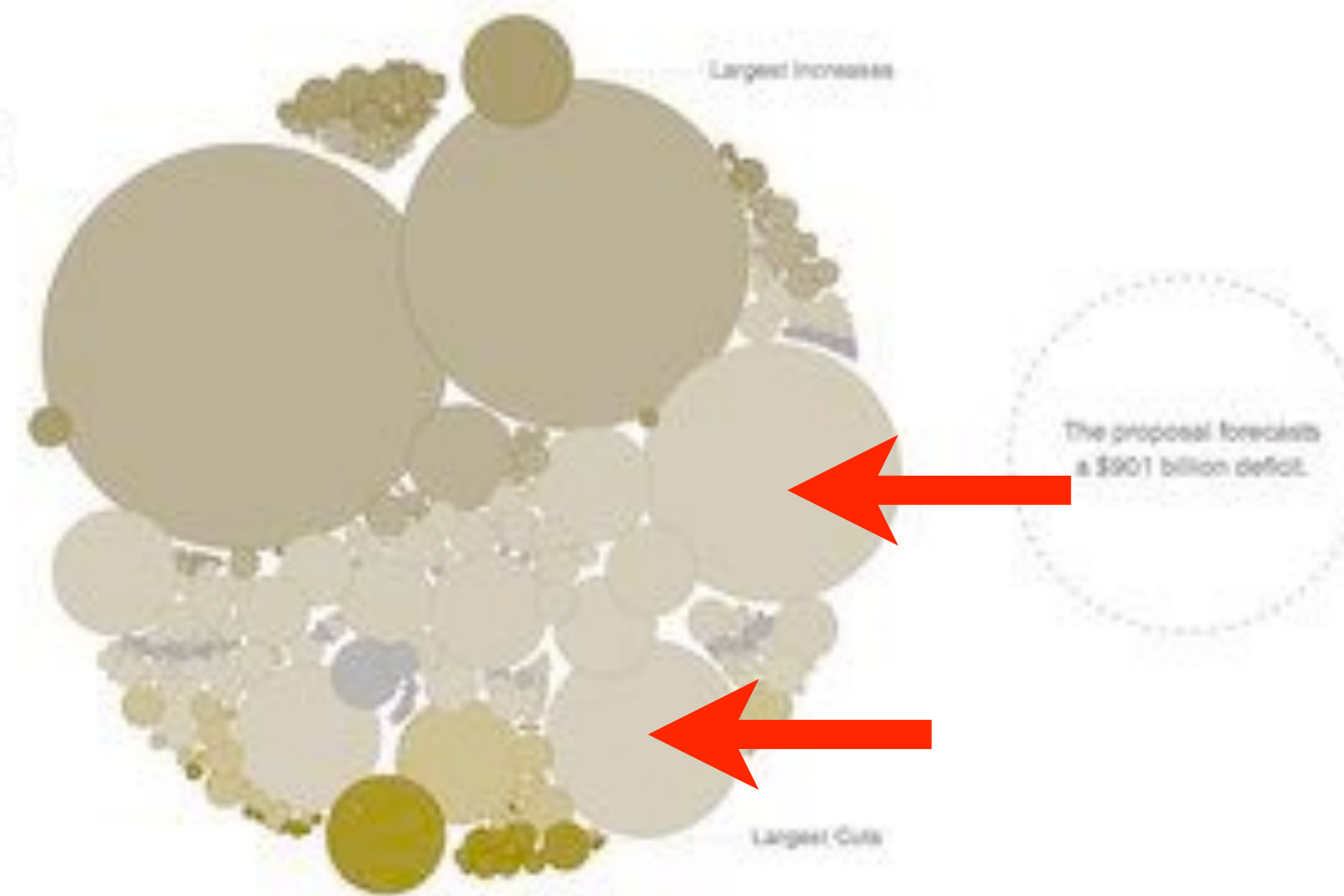
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Circles are sized according to the proposed spending.




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 **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

<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	

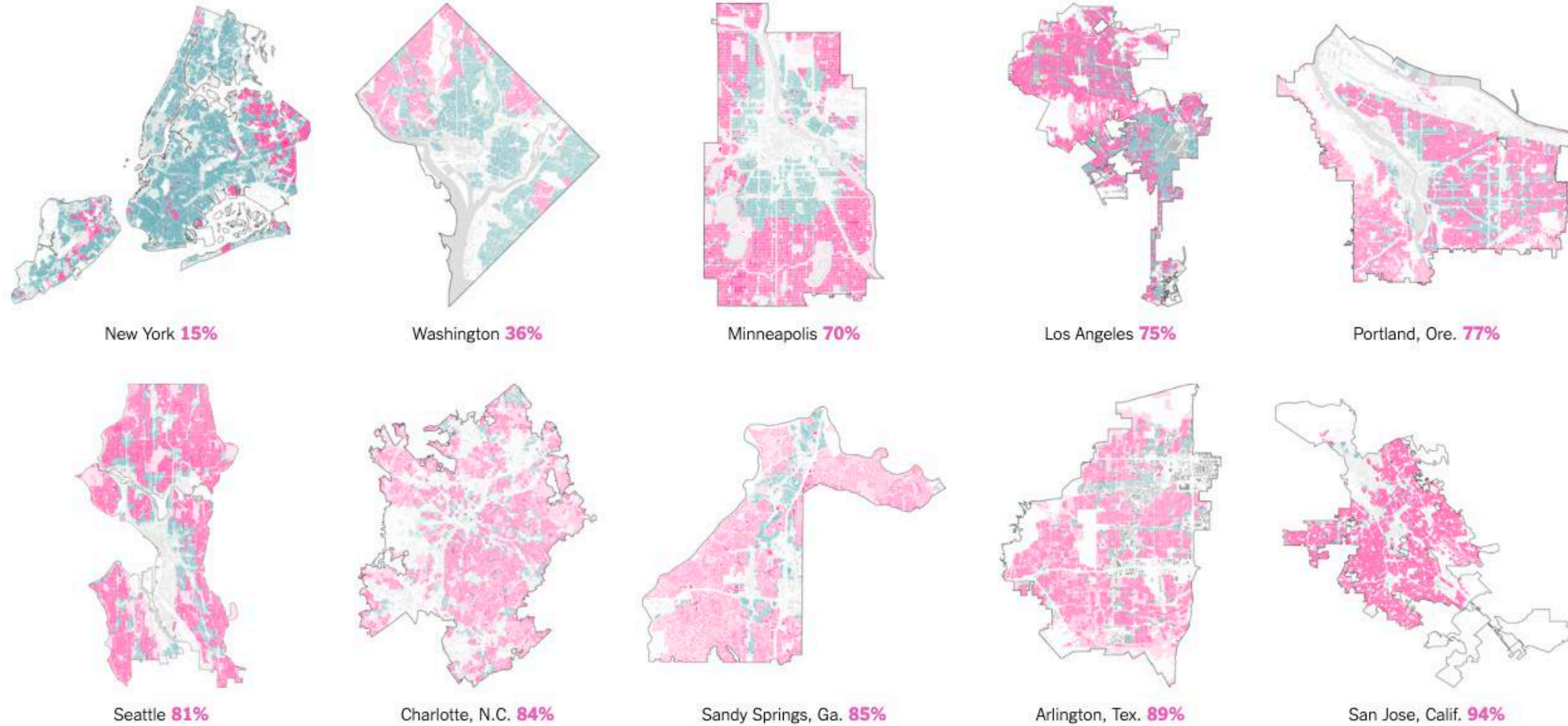
Use lens to compare with normal view:  No Lens  Normal Lens  Inverse Lens

[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:*

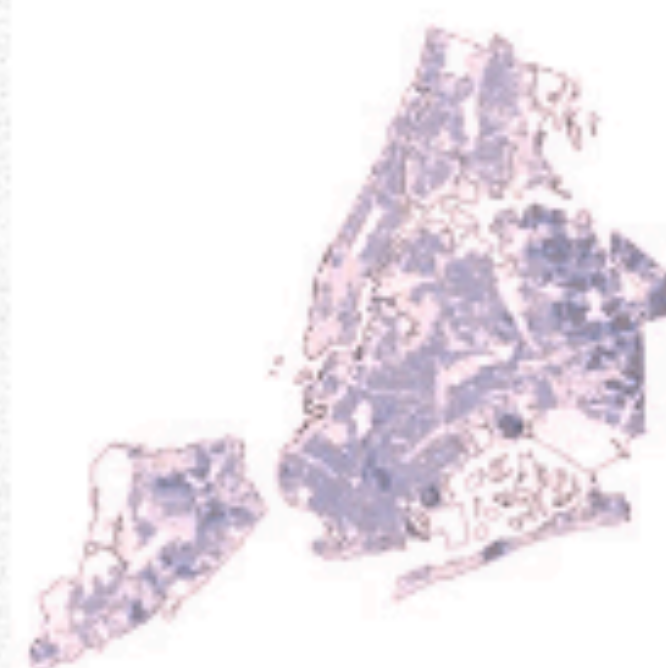
Monochromacy/Achromatopsia

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%



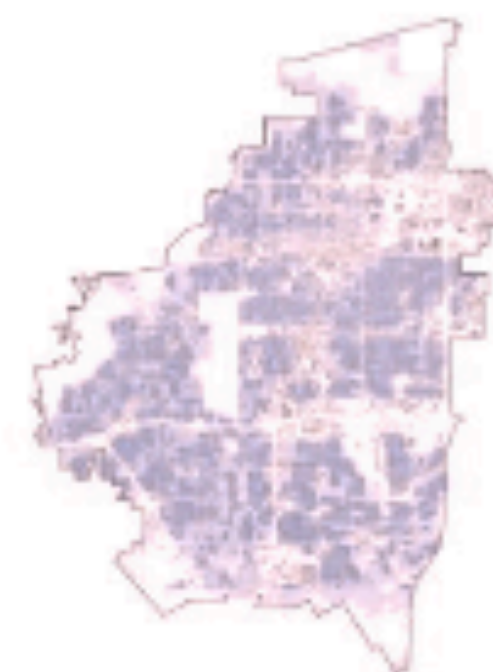
Seattle 81%



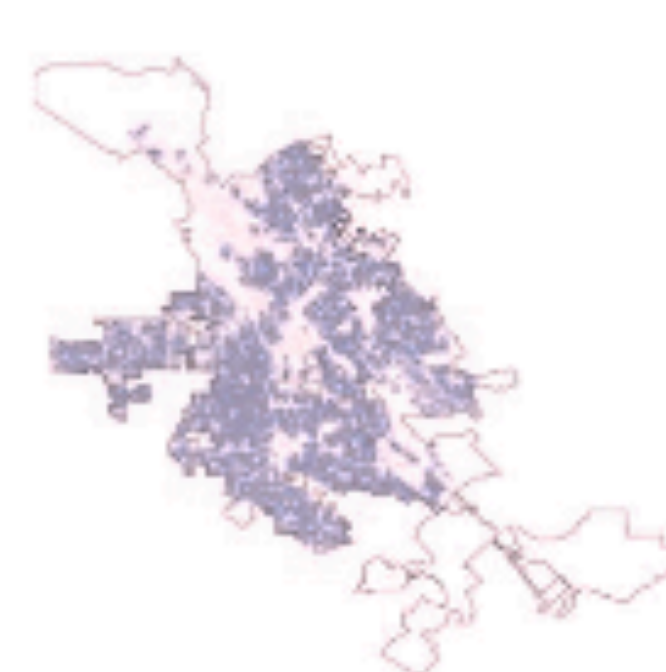
Charlotte, N.C. 84%



Sandy Springs, Ga. 85%



Arlington, Tex. 89%



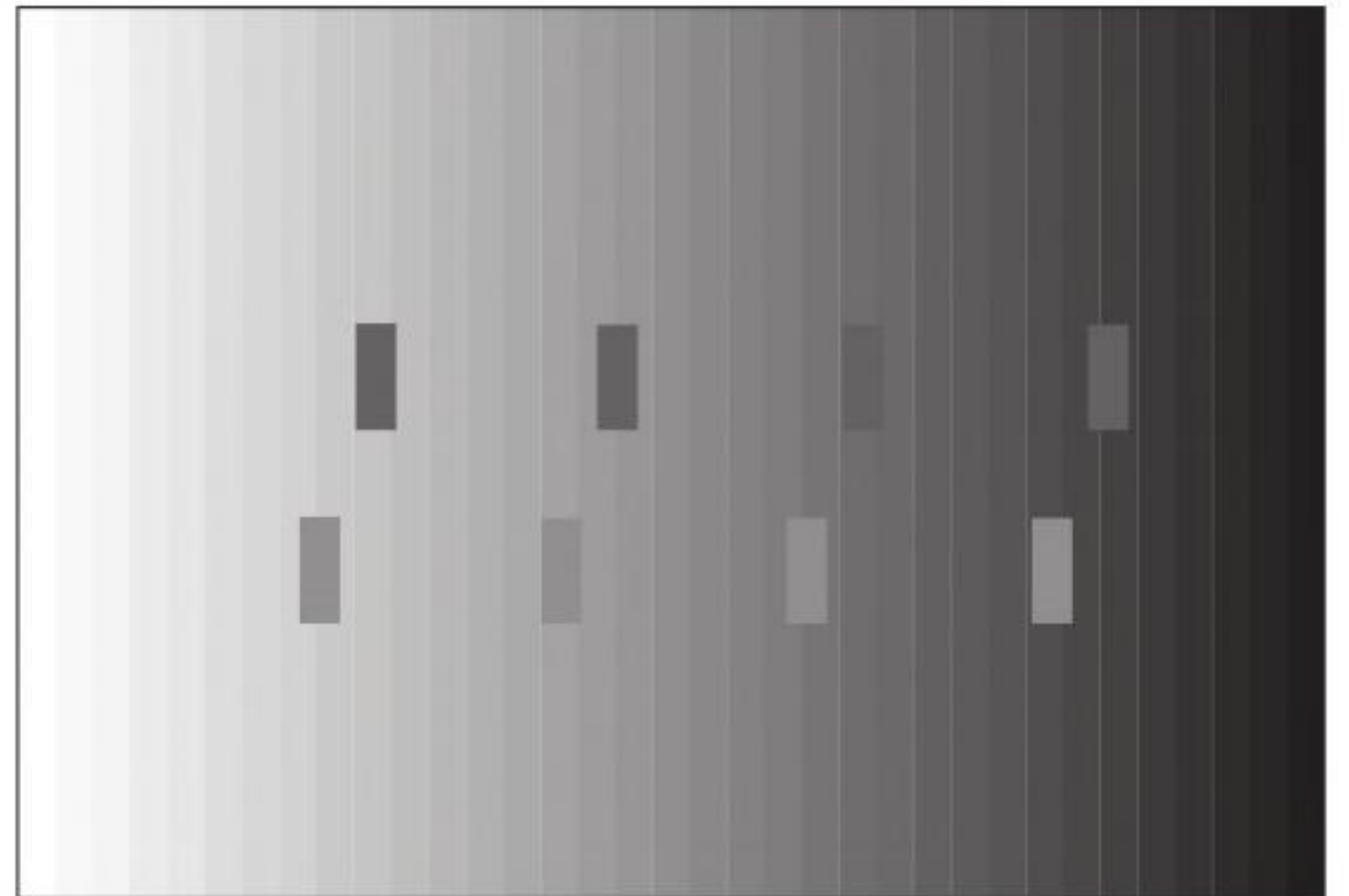
San Jose, Calif. 94%

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

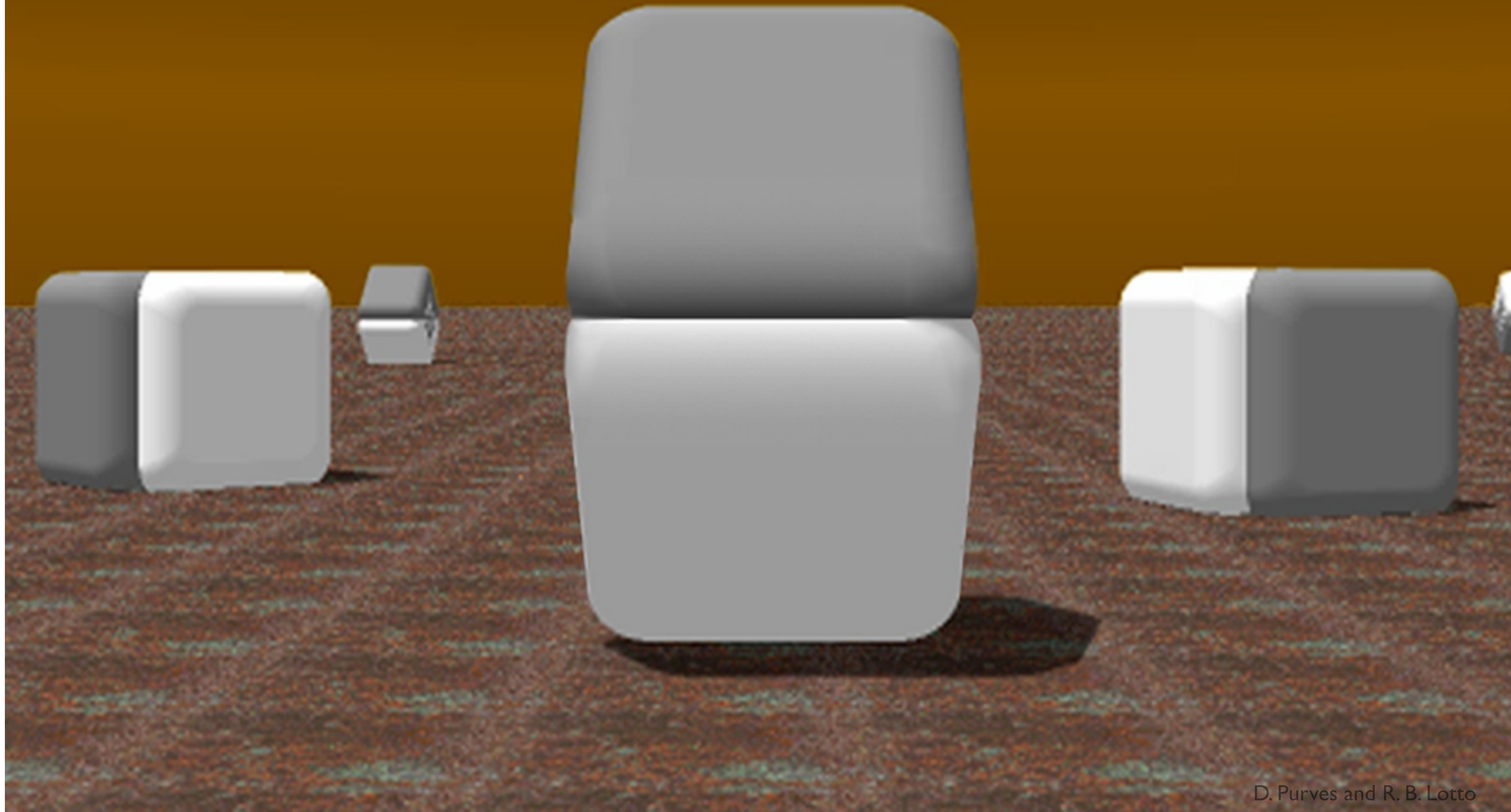
**Color / Brightness is  
Relative!**

# Simultaneous Brightness Contrast

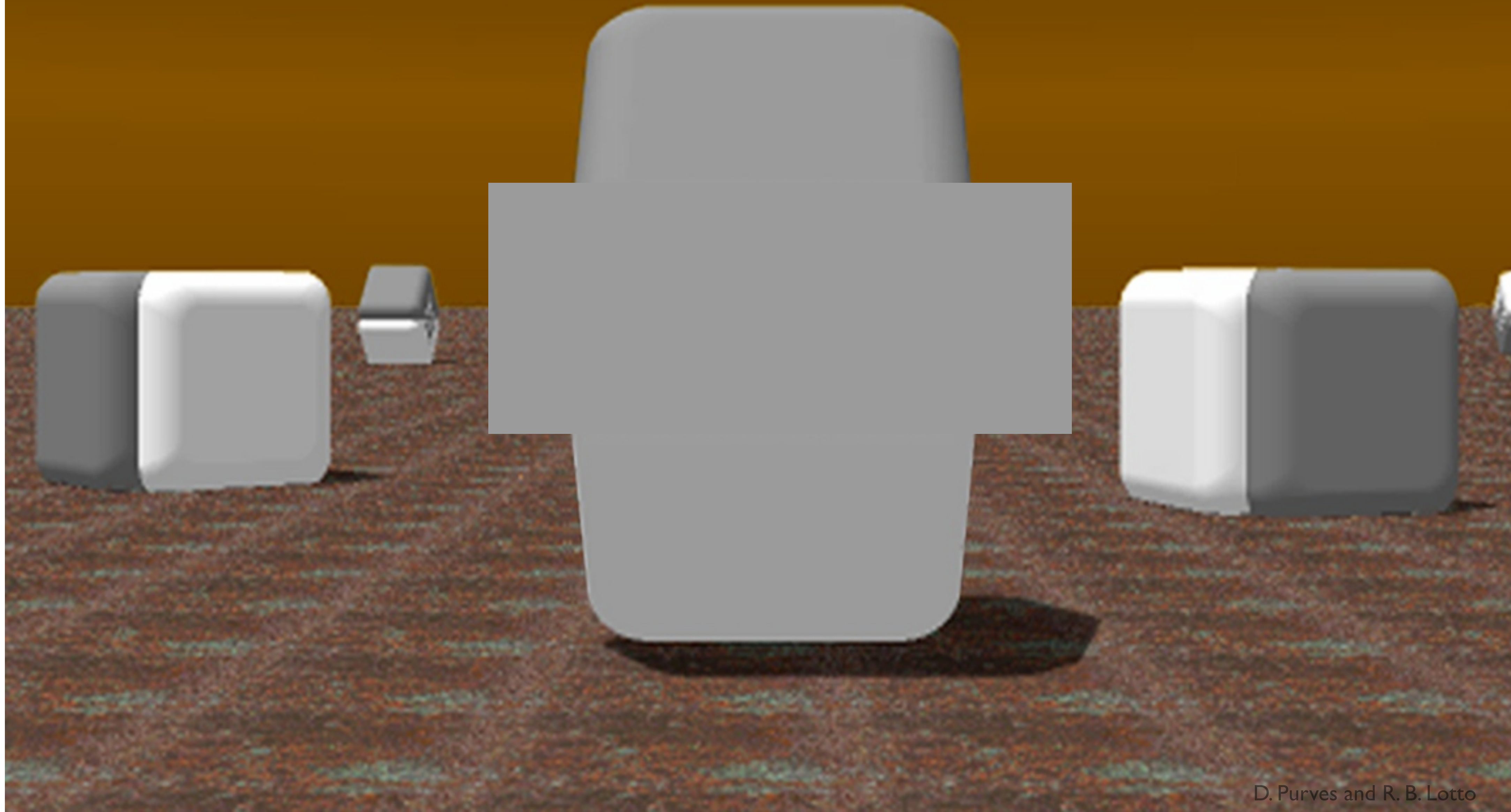
The perceived brightness of an object is relative to its background



# Cornsweet Illusion



# Cornsweet Illusion

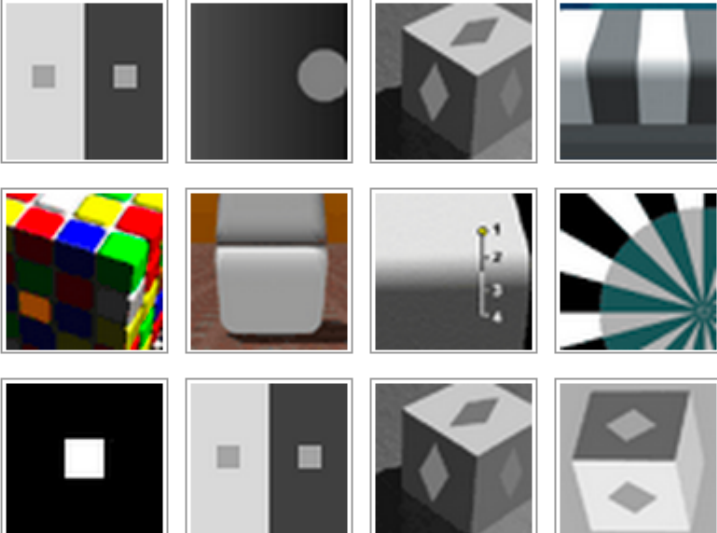
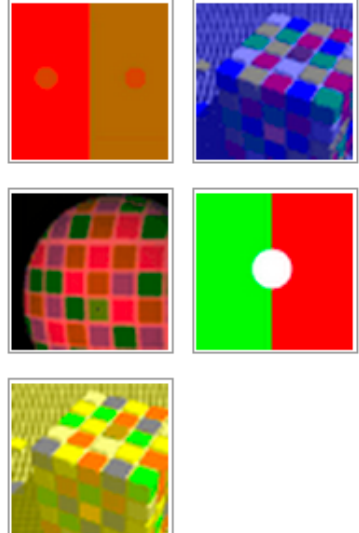
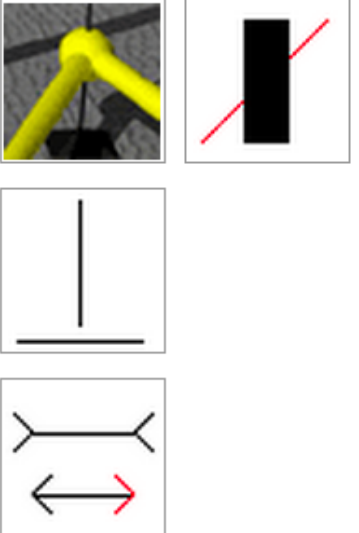
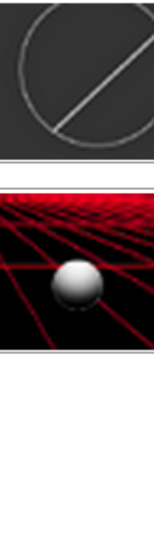



# Demo

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

**purves-lab** Laboratory of Dale Purves, M.D. Center for Cognitive Neuroscience Duke University

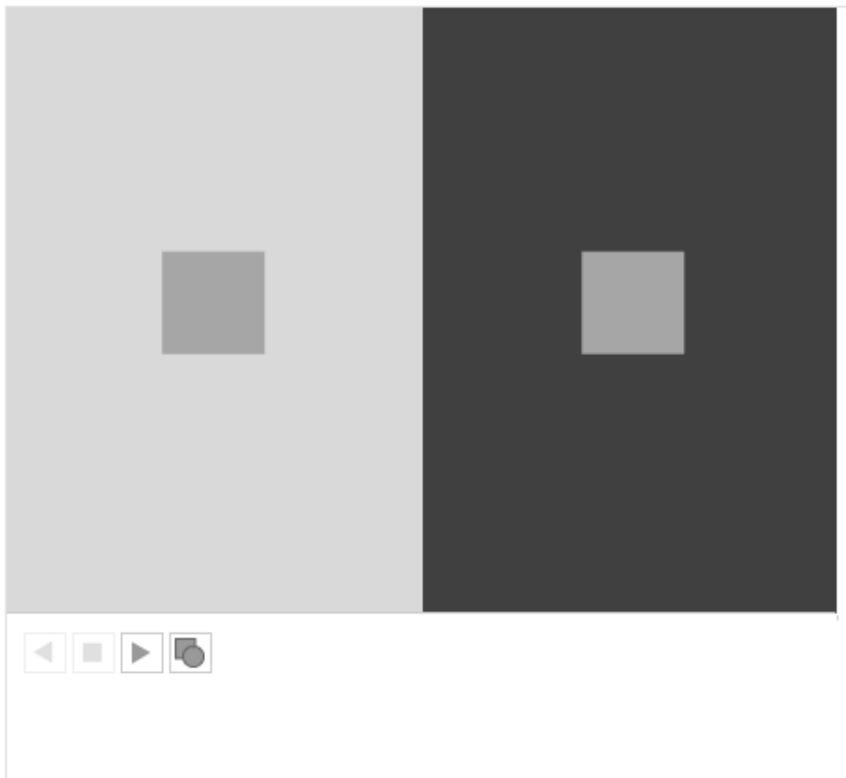
MAIN NEWS PEOPLE RESEARCH PUBLICATIONS RESOURCES [SEE FOR YOURSELF](#) CONTACT

Lightness/Brightness	Color	Lines and Angles	Motion	Sound and Music
				

### Brightness contrast: standard

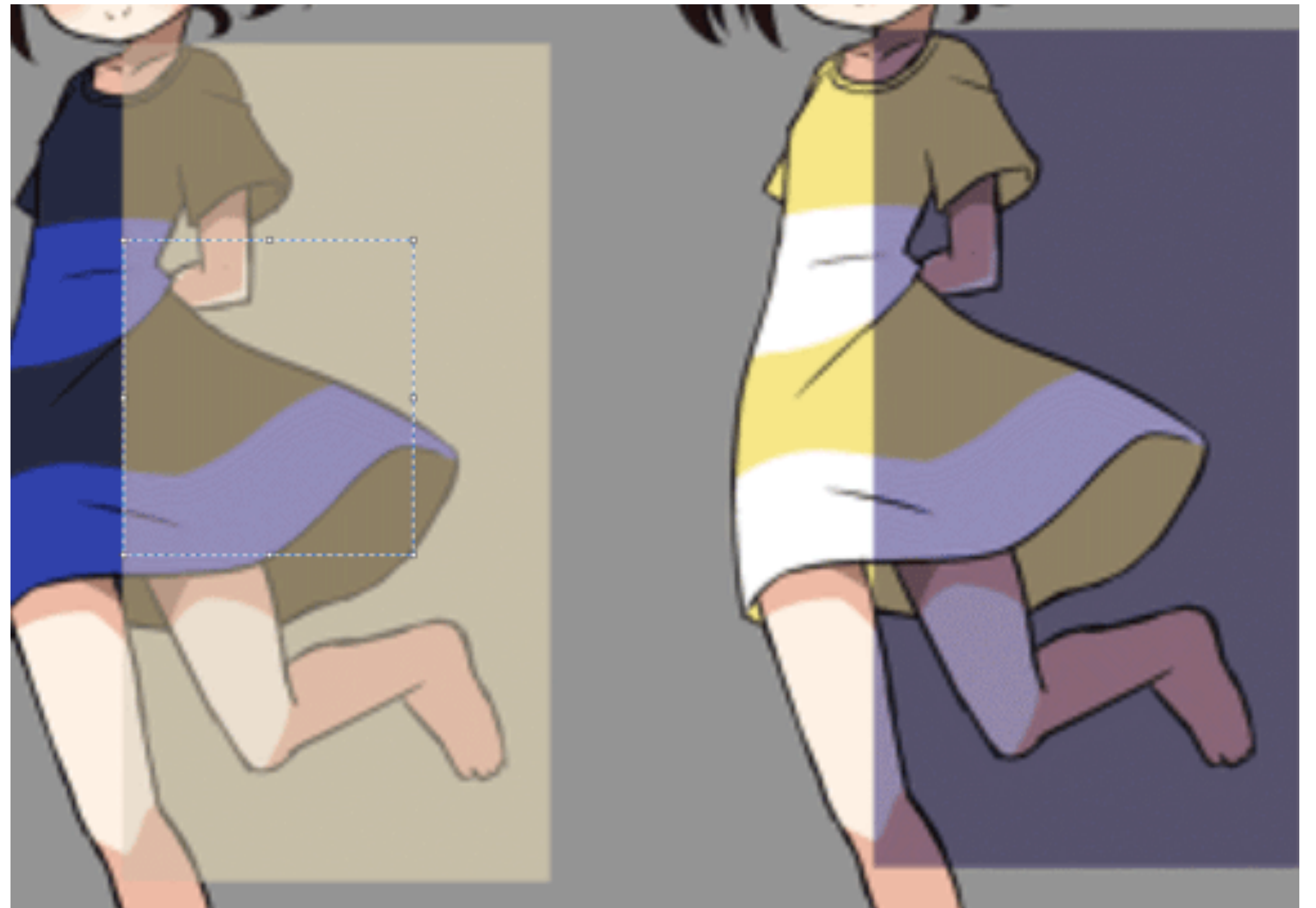
In viewing this stimulus, people invariably perceive the square on the brighter surround (left) to be darker than the square on the darker surround (right). Click on the "Play" button to convince yourself that the squares are equiluminant or click on the "Move mask" button to manually position the mask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

- [» Read the empirical explanation](#)
- [» Download high resolution images](#)





# The Dress Meme

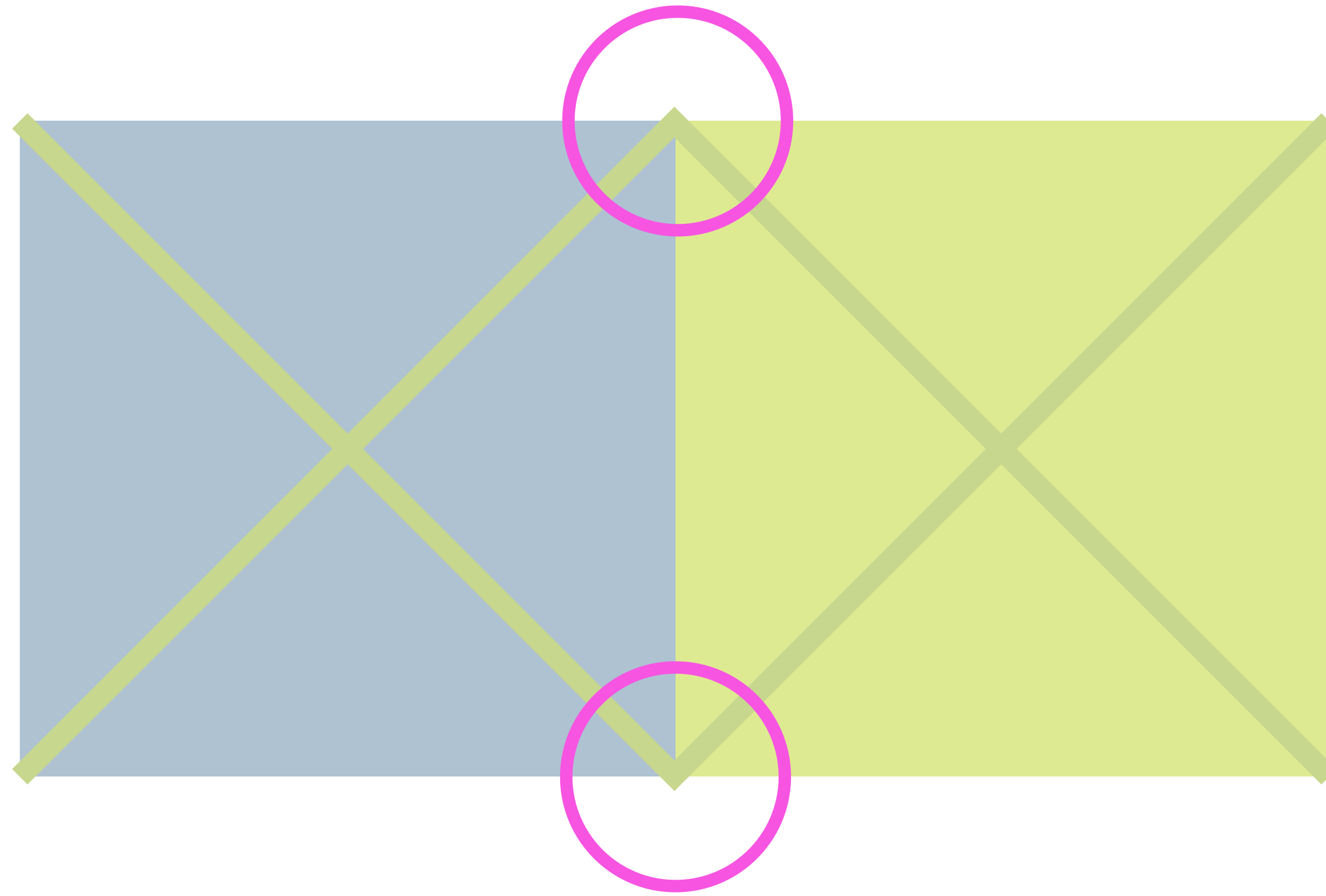


black and blue or white and gold?

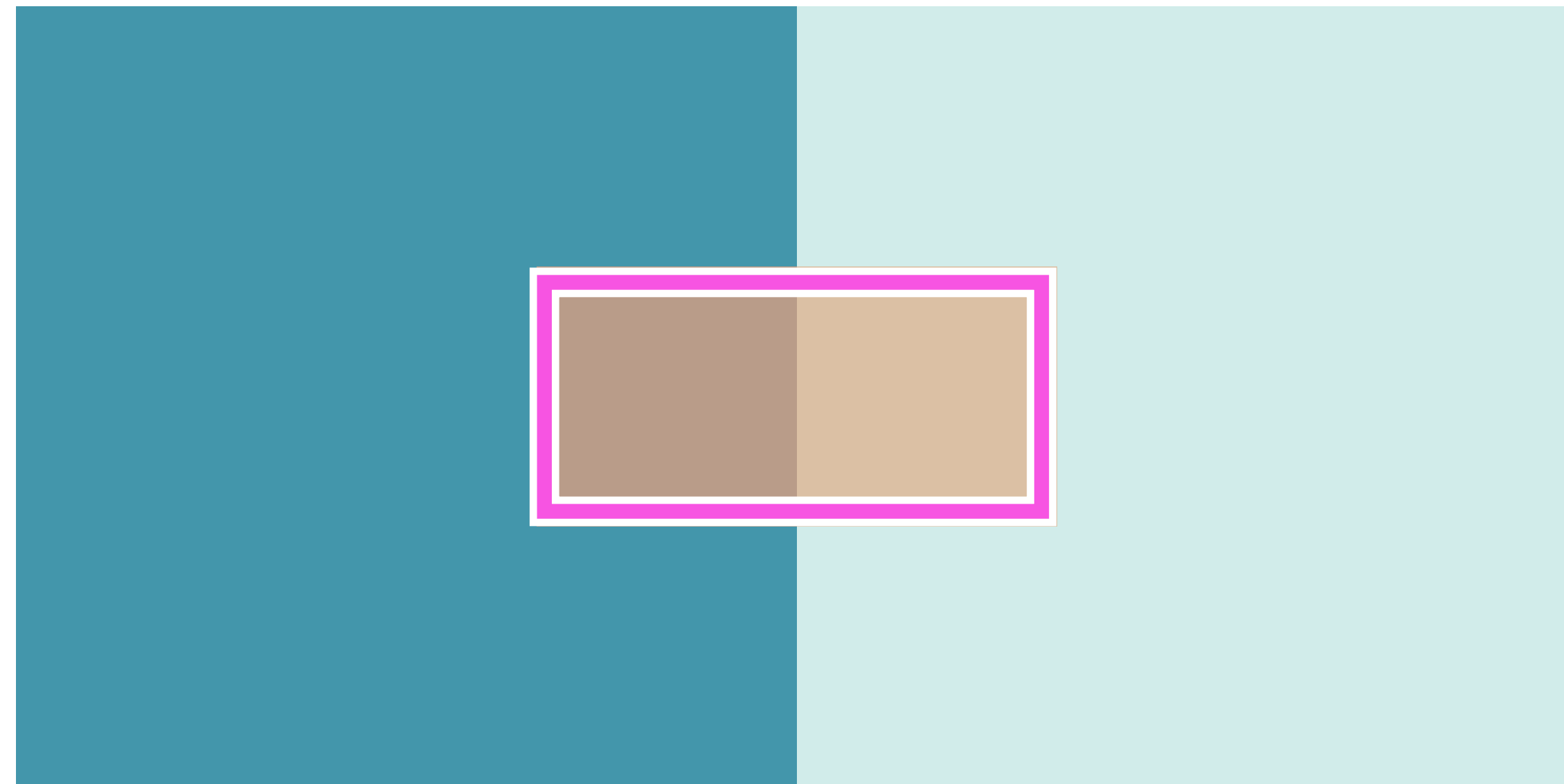
<https://imgur.com/hxJjUQB>

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

# INTERACTION OF COLOR



# INTERACTION OF COLOR



# INTERACTION OF COLOR



Popout

# Popout

## Properties detected by the low-level visual system

very rapid - 200-250 milliseconds

very accurate

processed in parallel

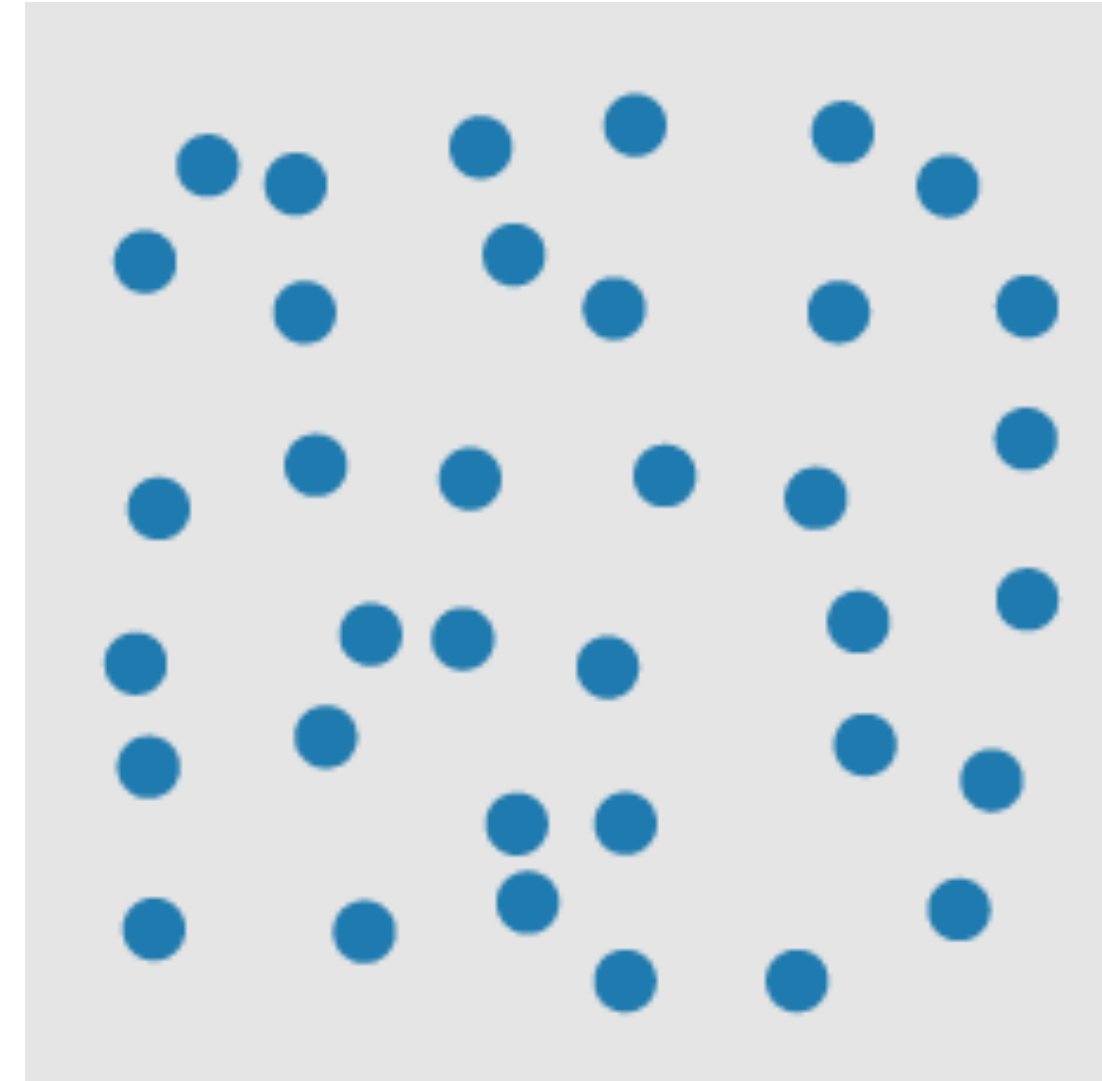
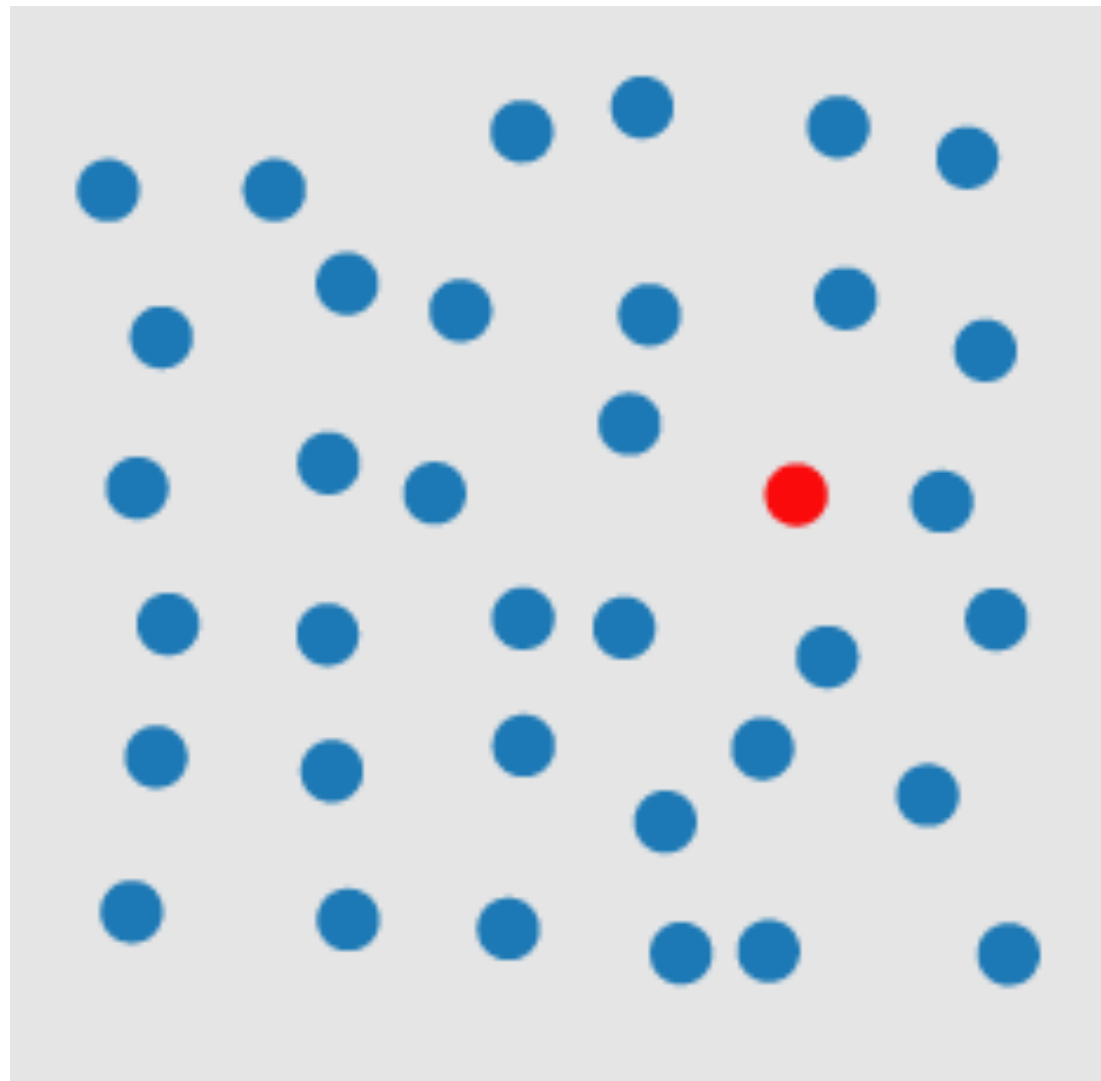
happens before focused attention -> „pre“attentive

attention is very important for cognition

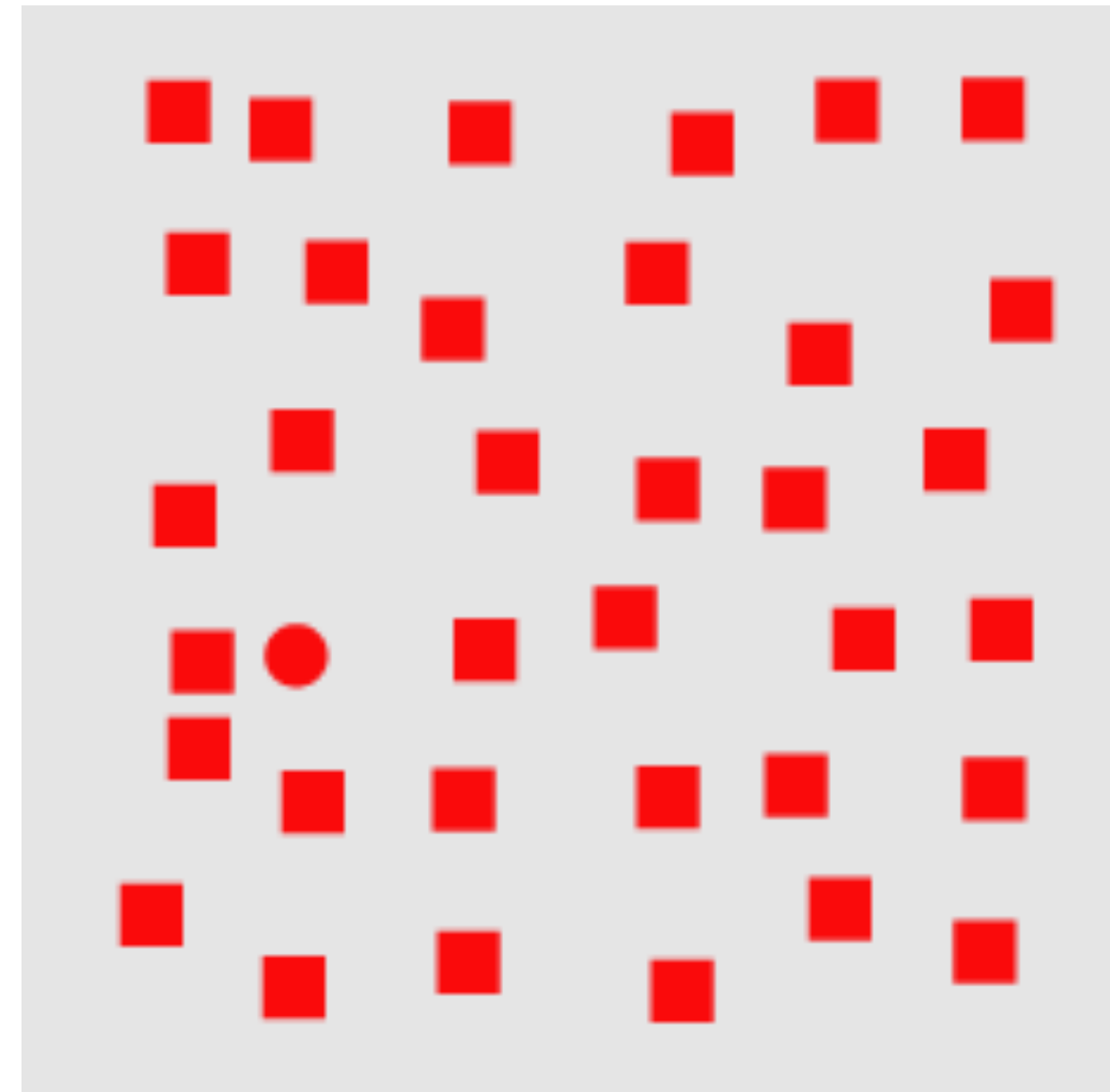
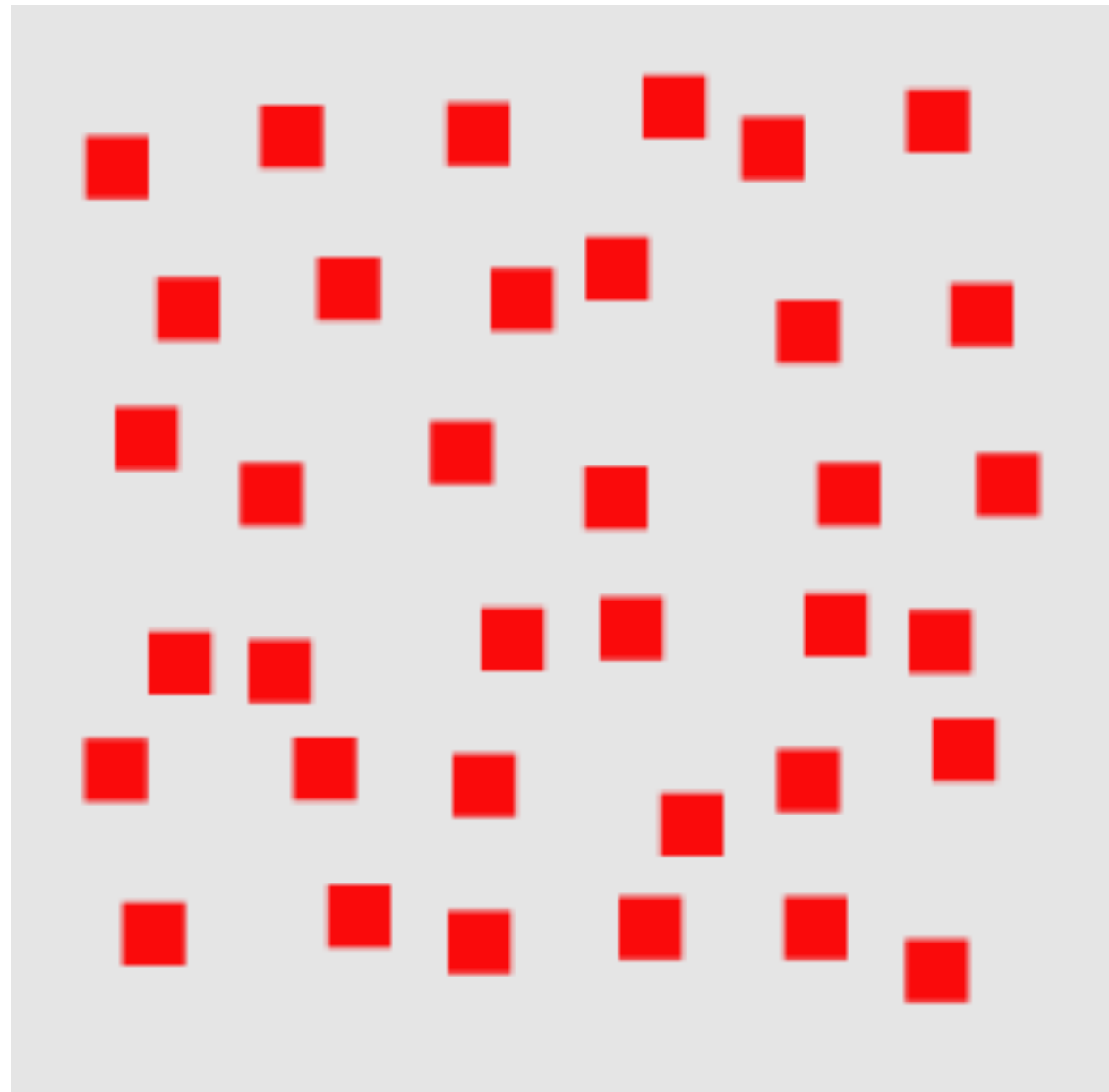
Independent of the number of distractors!

Opposite: sequential search (processed serially)

# Difference in Hue

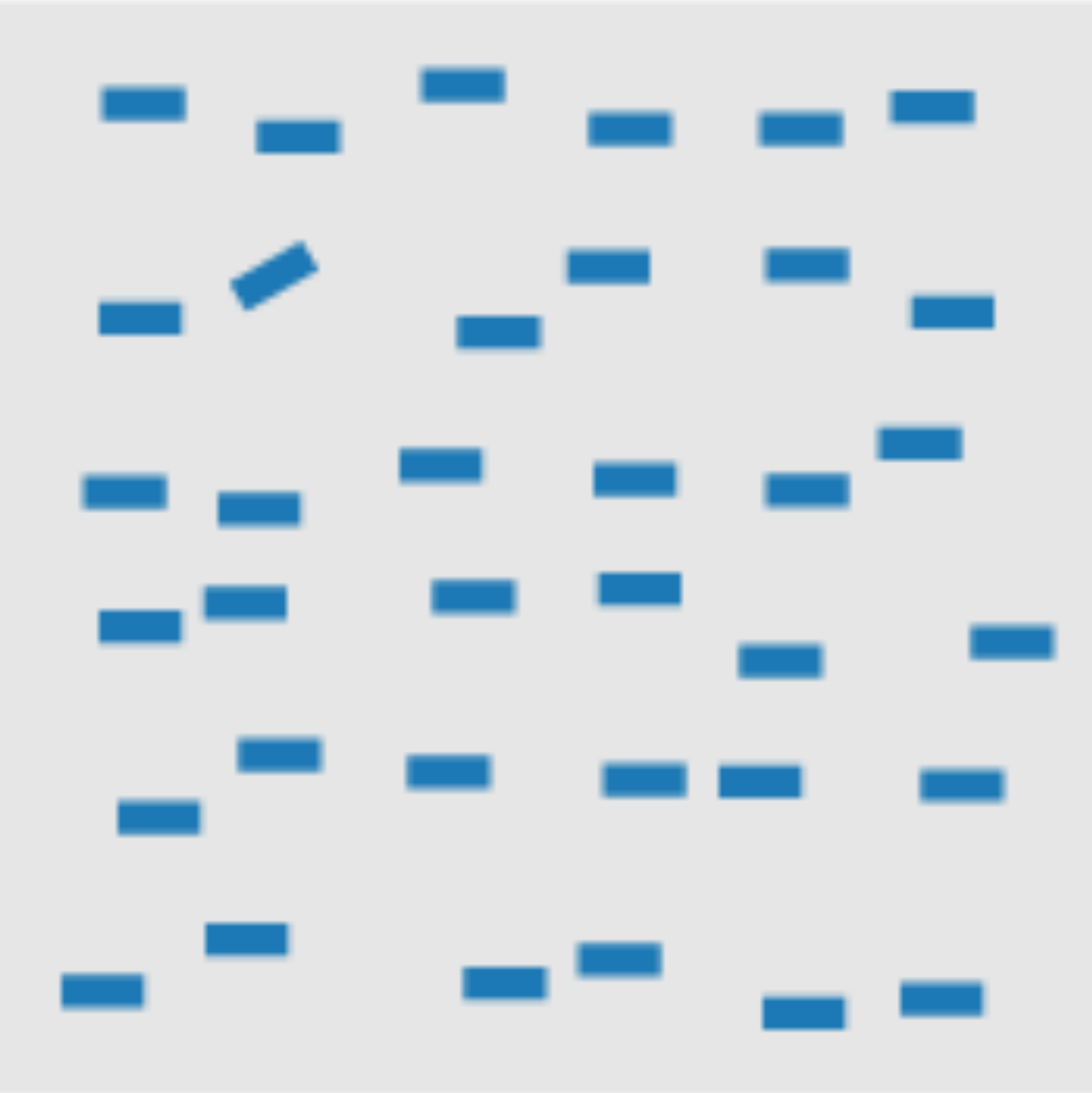


# Difference in Curvature / Form

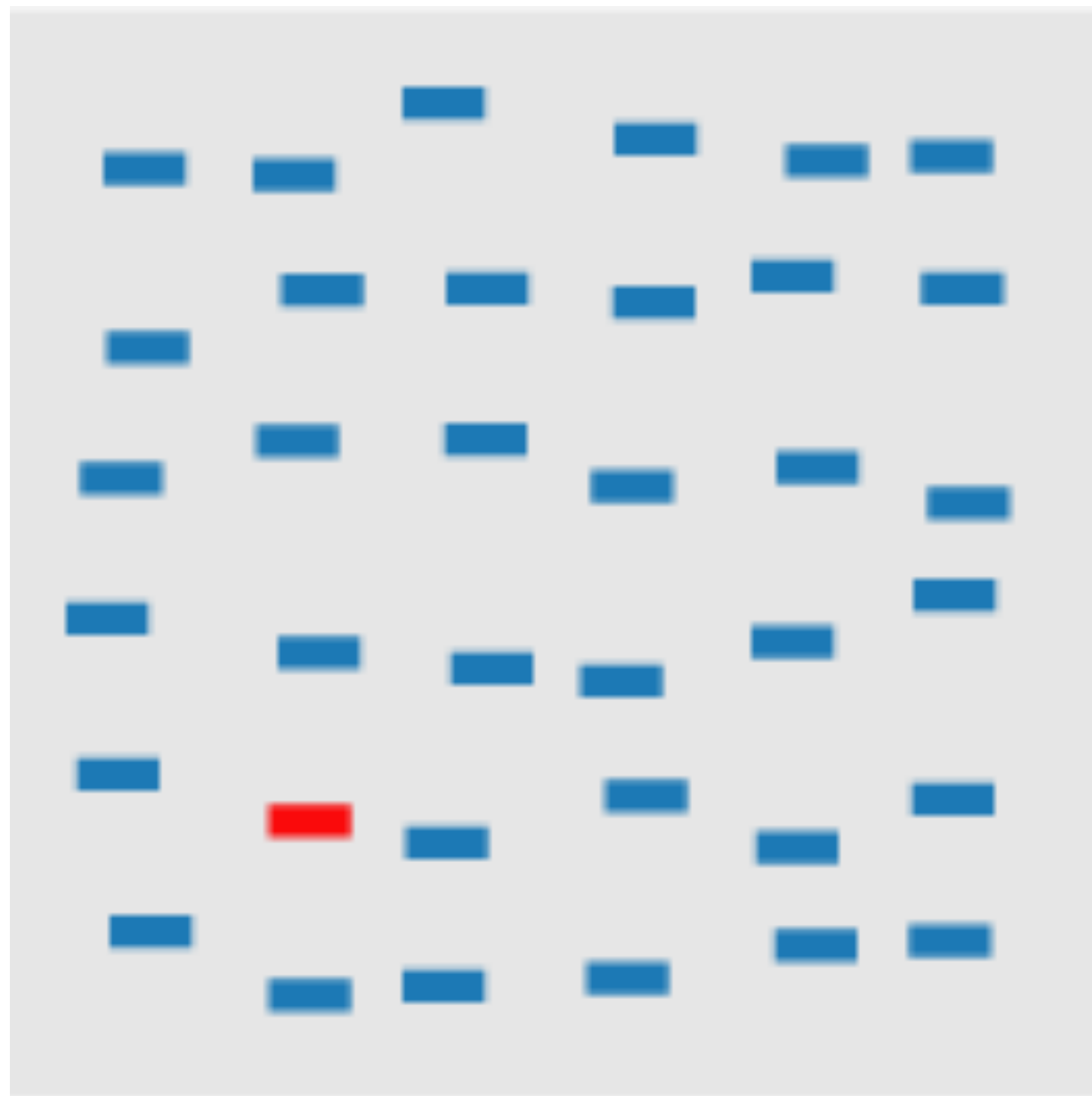




Clap when you spot the  
odd one!



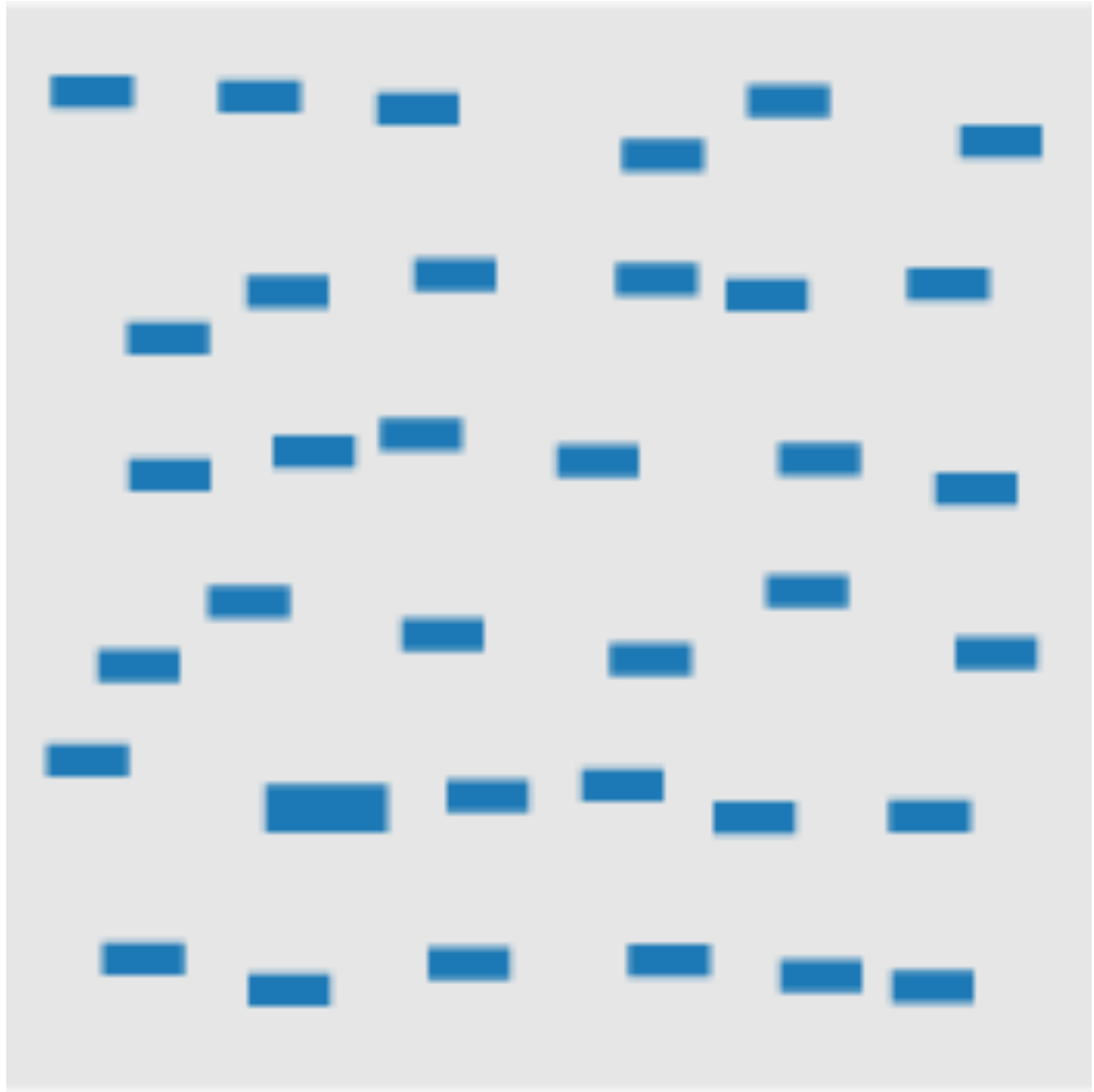
orientation



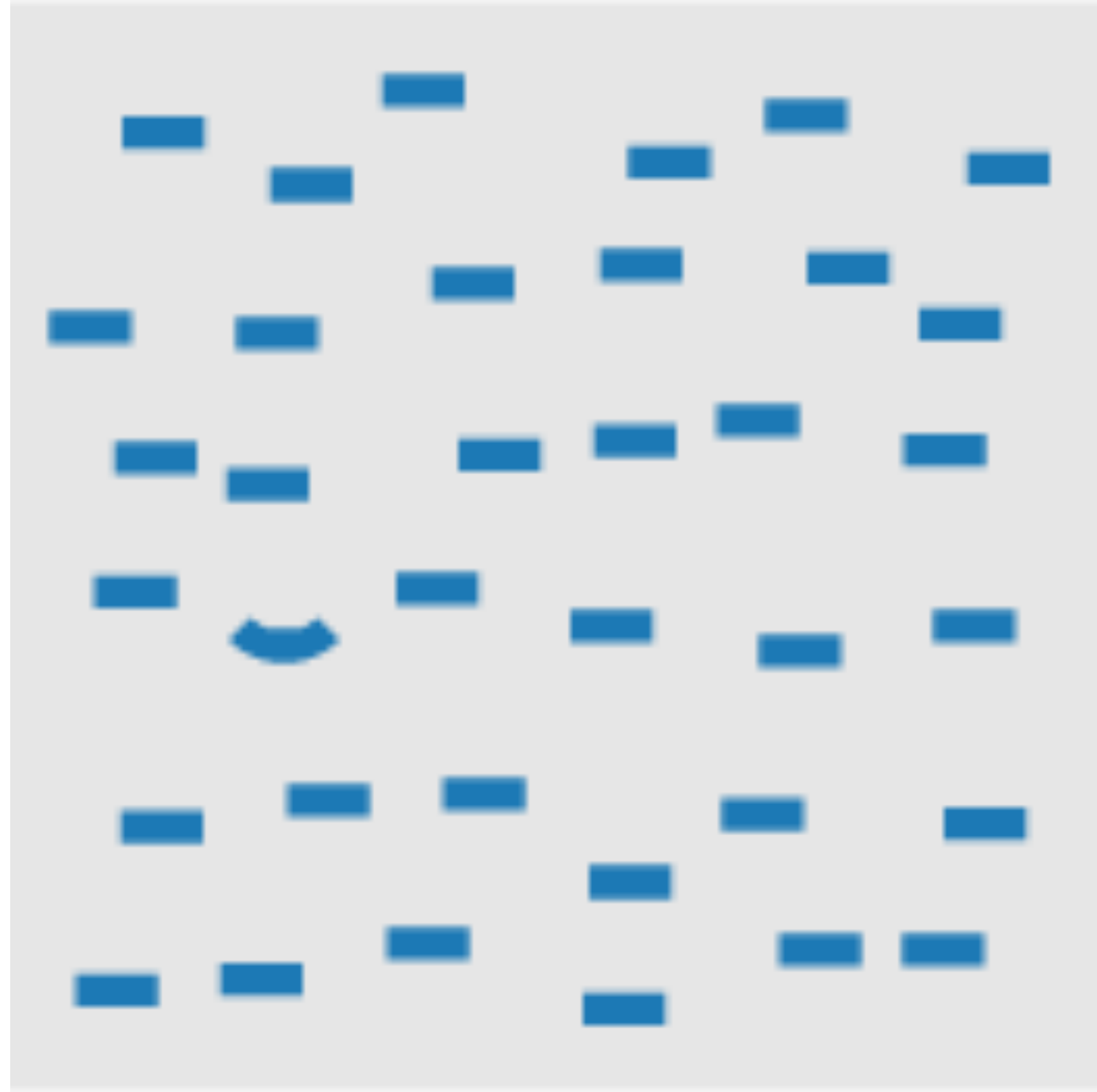
hue



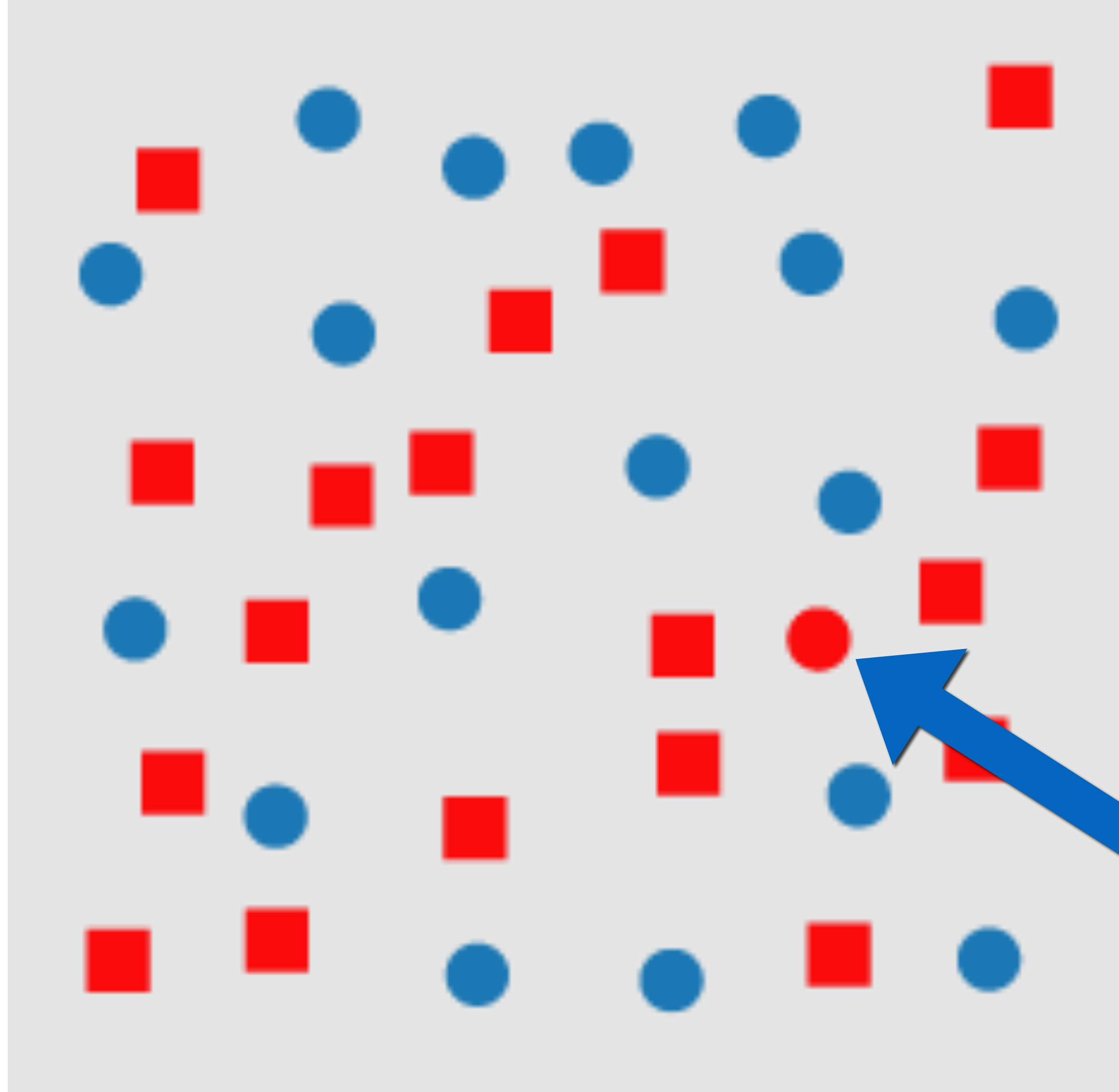
closure



size

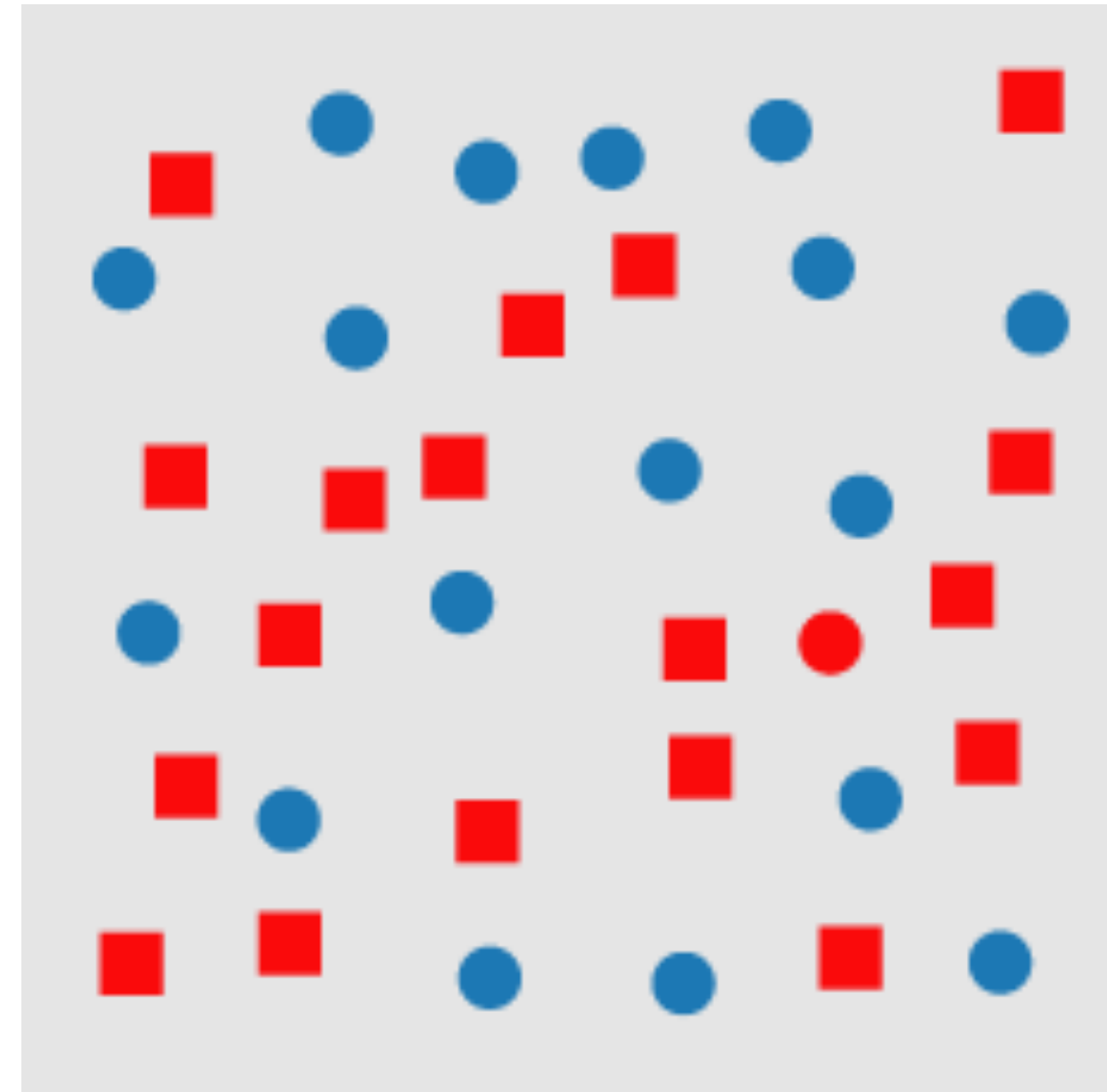
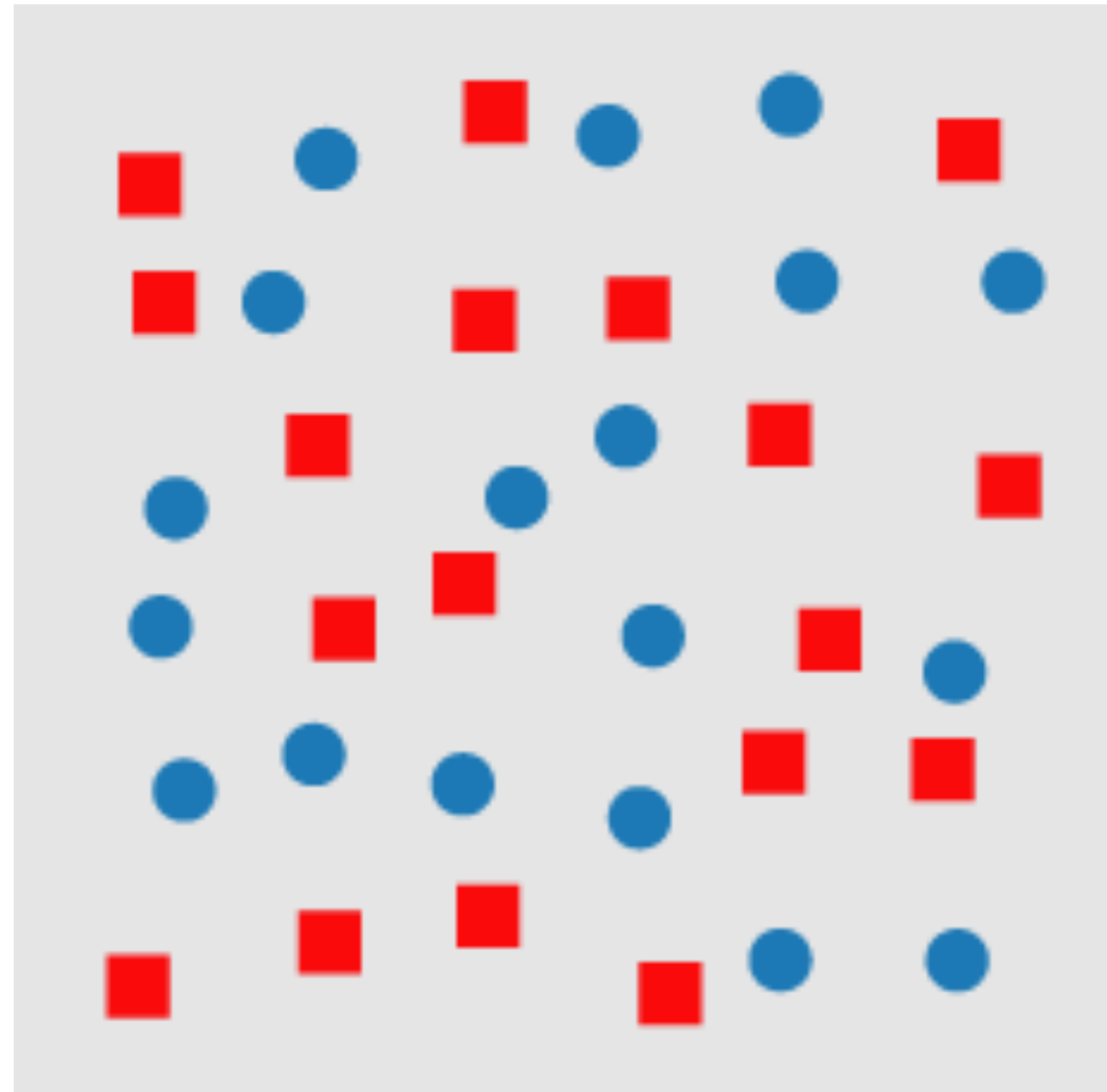


curvature



?

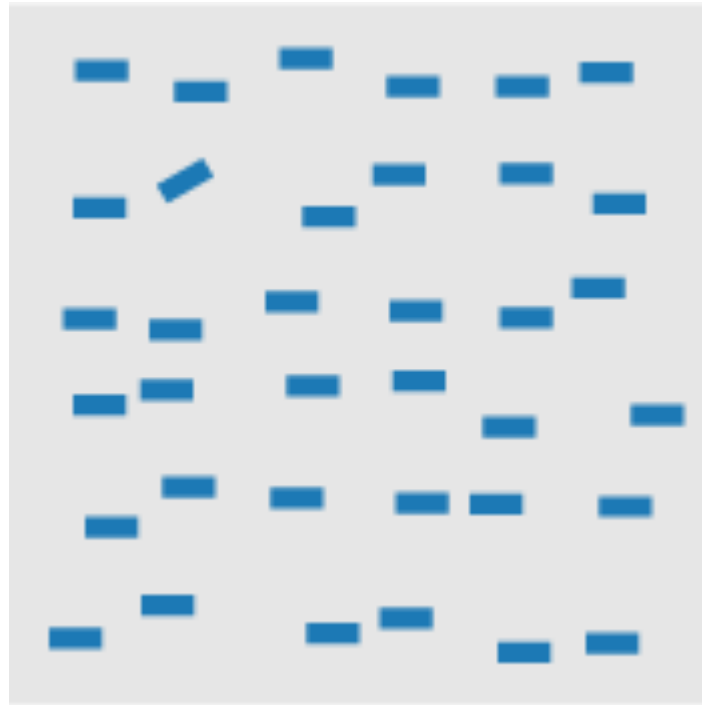
# Not Valid for Combinations



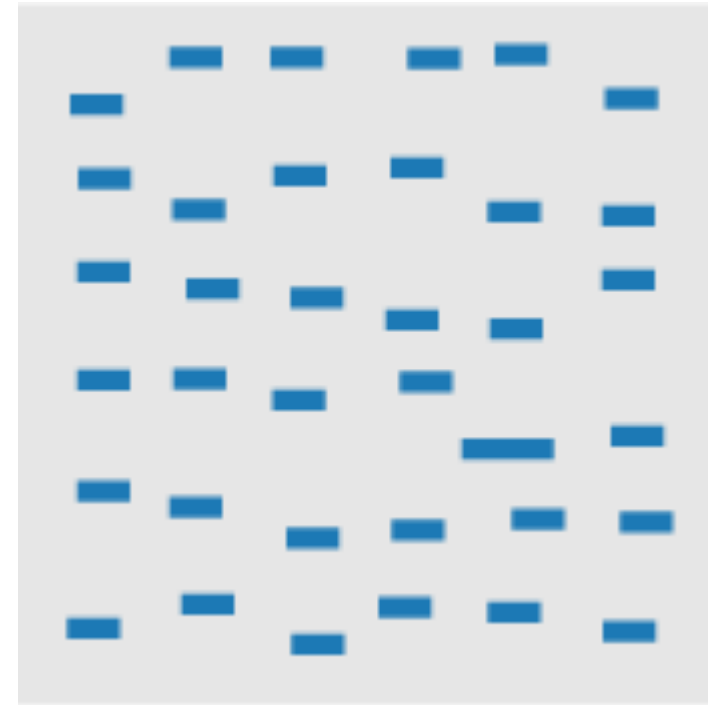
Conjunction Targets – no unique visual property  
target: red, circle  
distractor objects have both properties



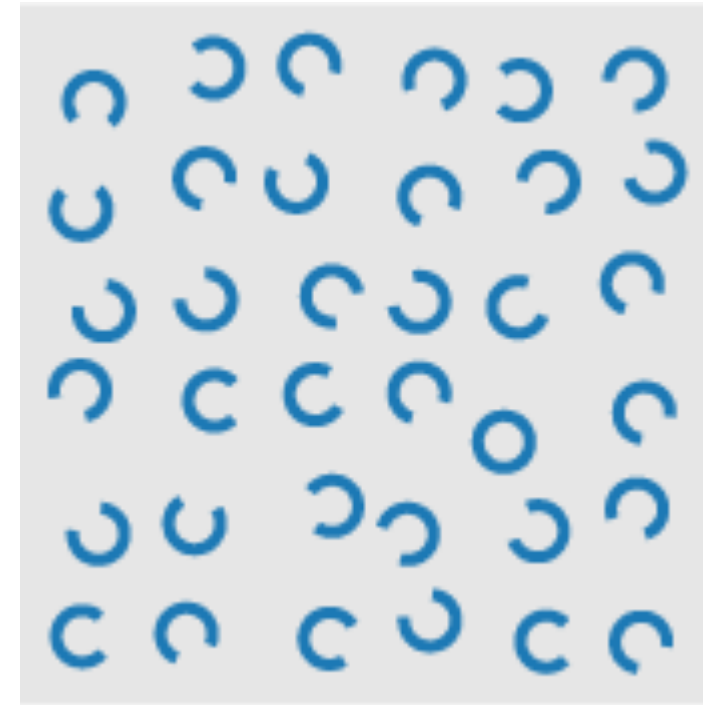
# Some Preattentive Properties



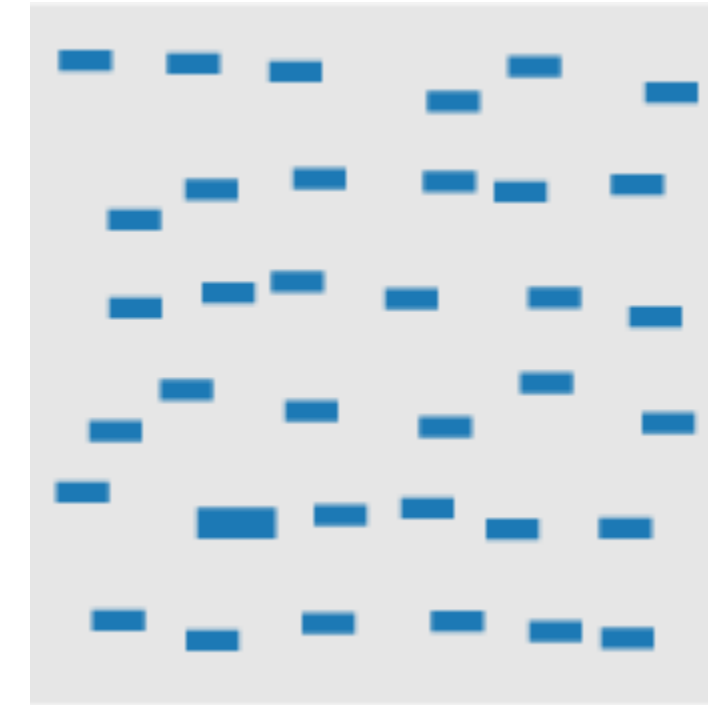
orientation



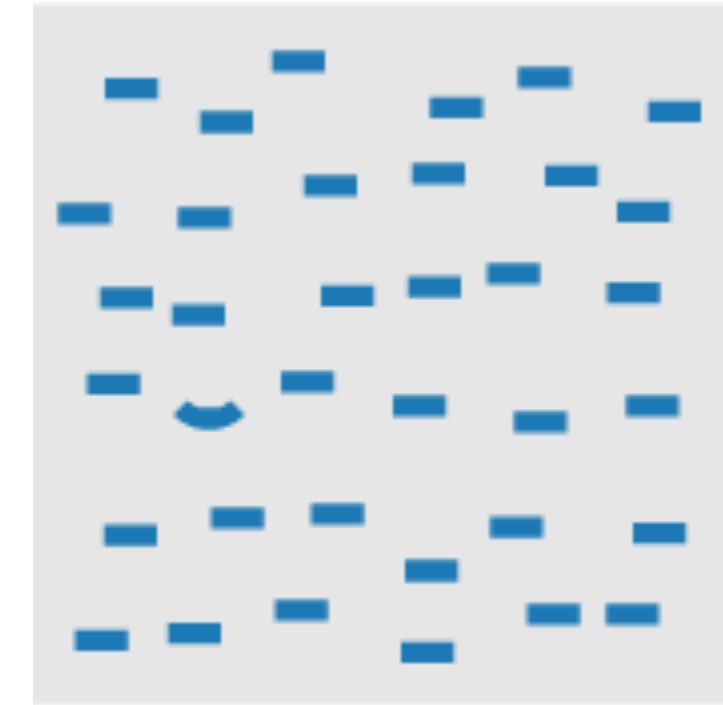
length



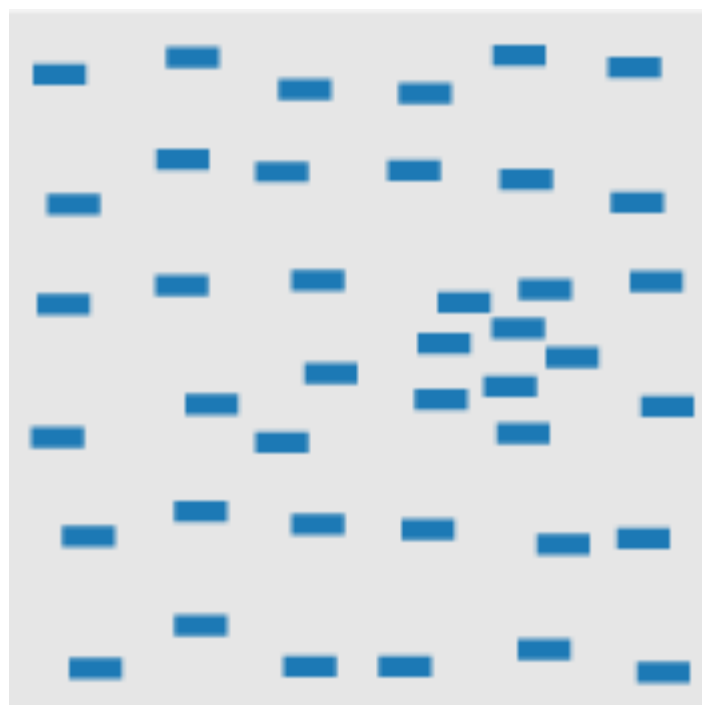
closure



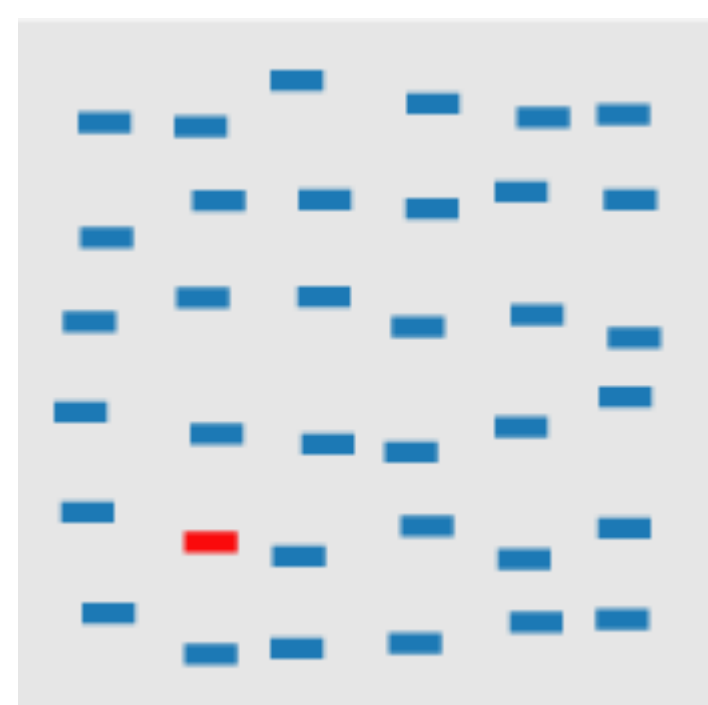
size



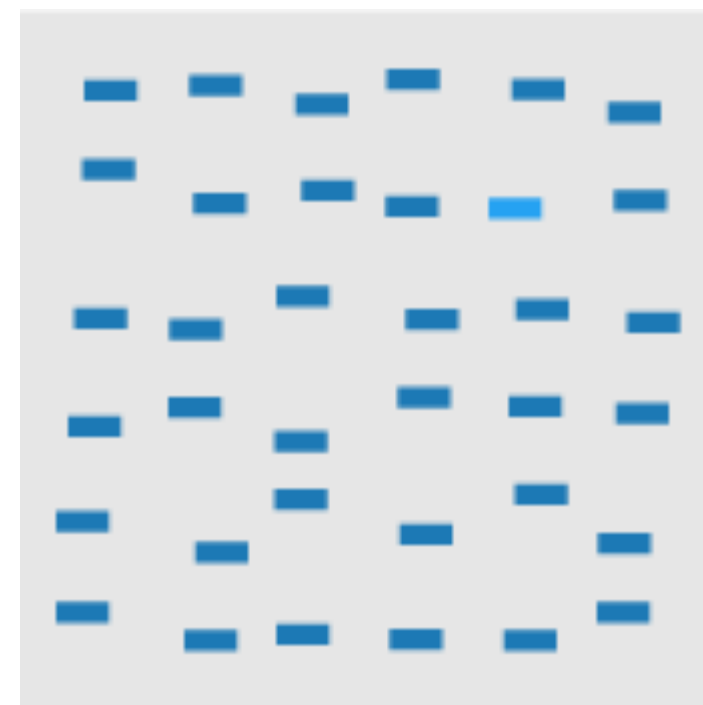
curvature



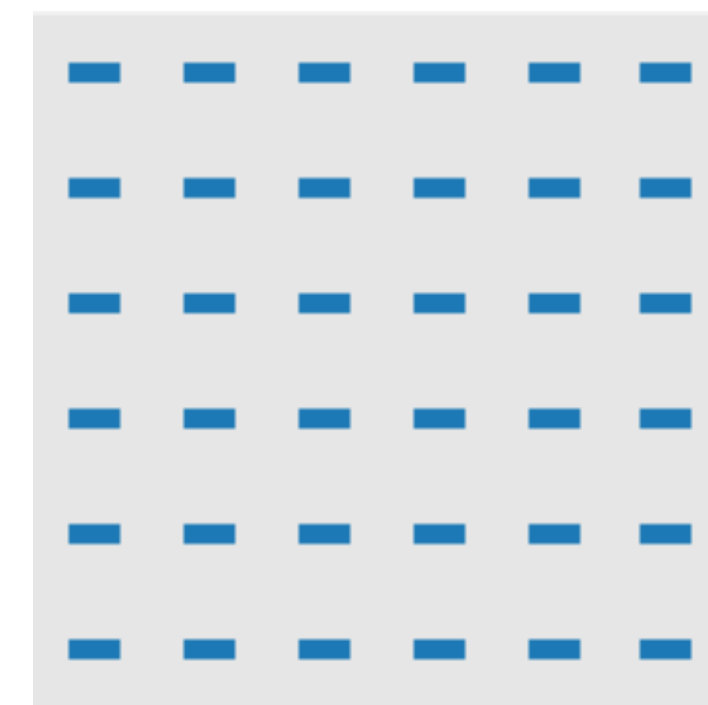
density



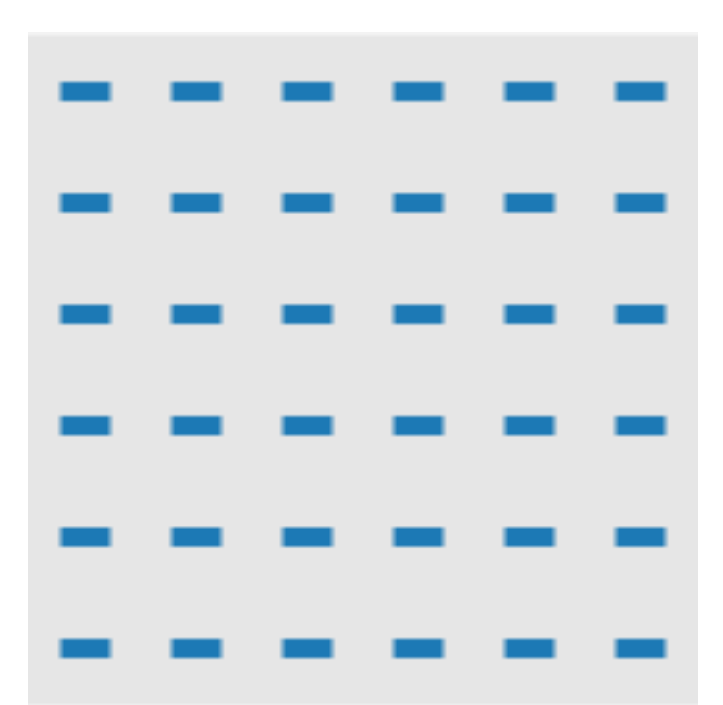
hue



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

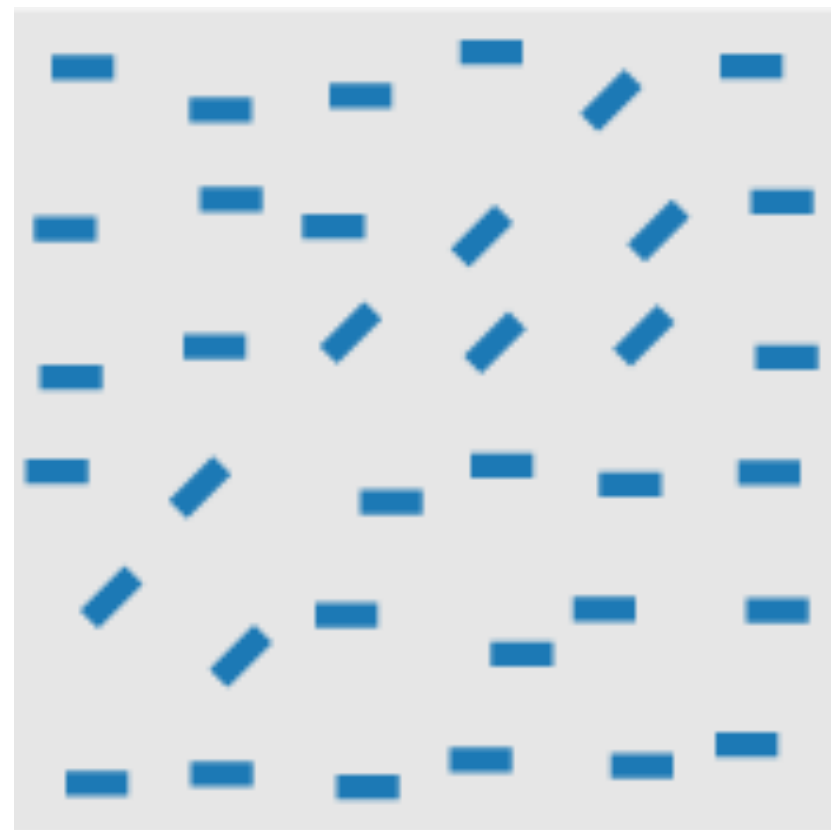
track one or more elements with a unique visual feature as they move in time and space

## counting and estimation

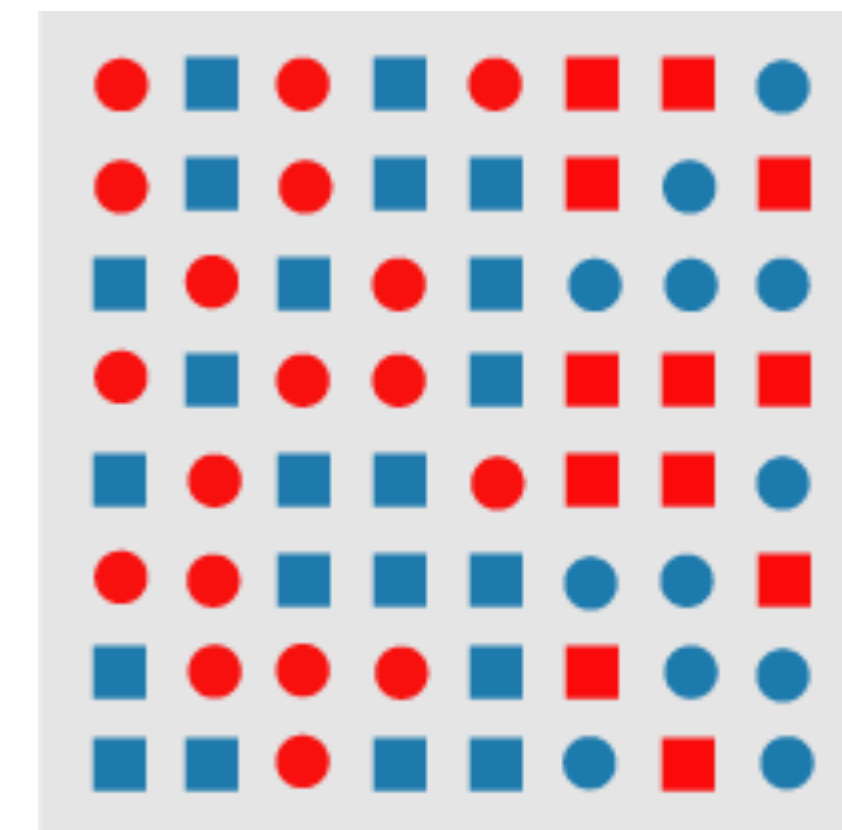
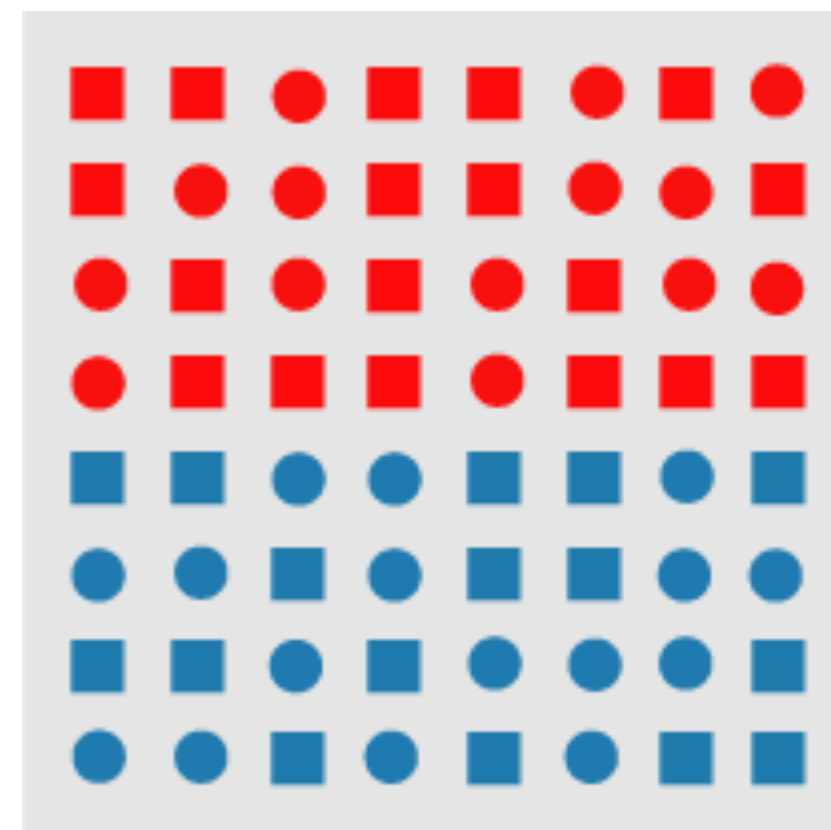
users count or estimate the number of elements with a unique visual feature.

# Tasks

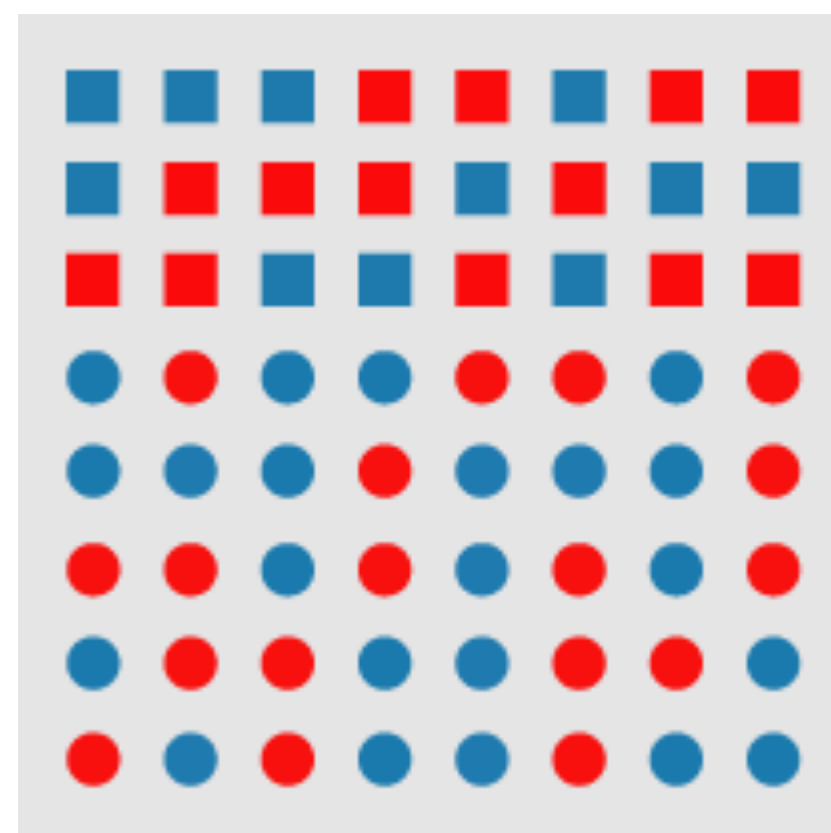
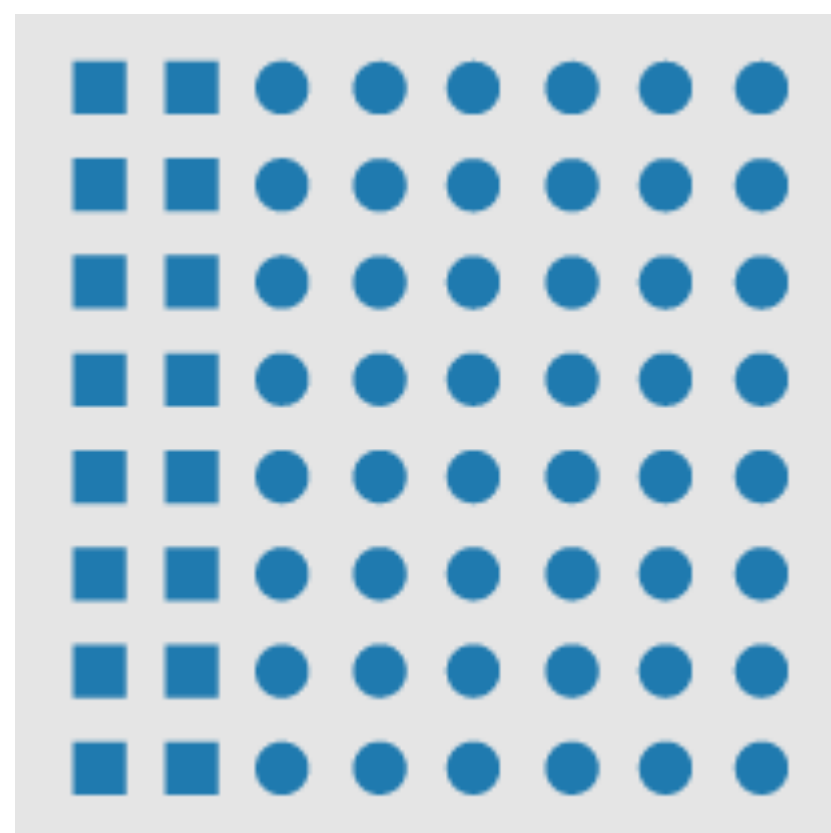
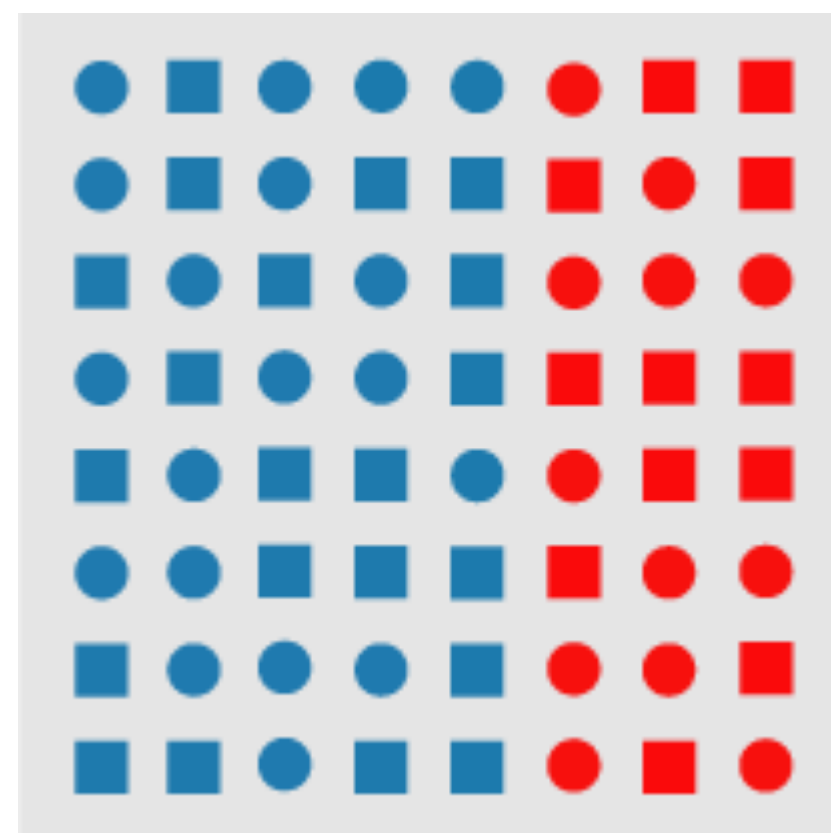
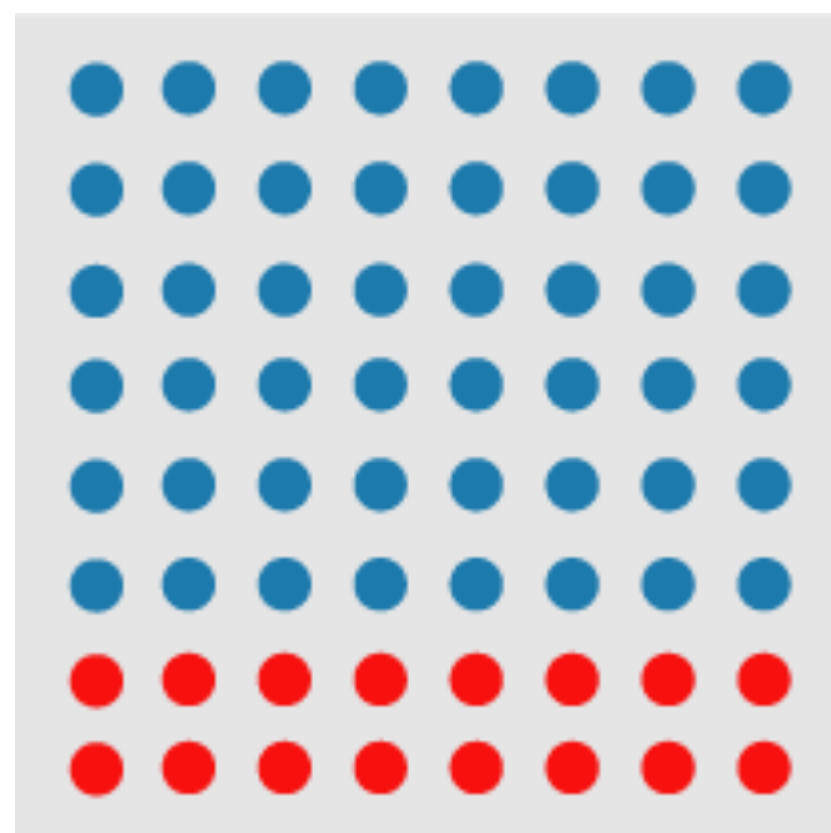
Number Estimation



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









Ron Rensink 2002





# 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

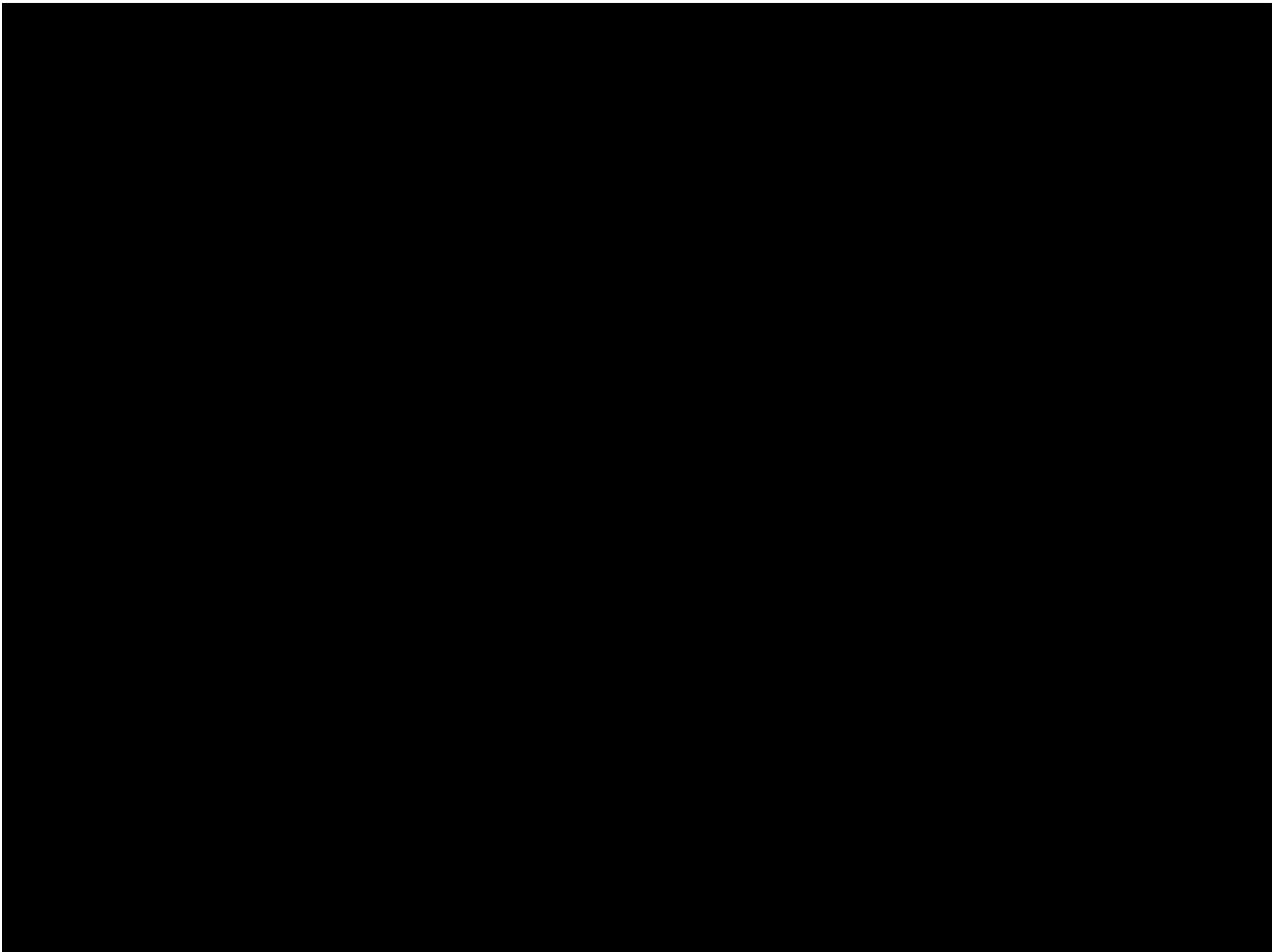


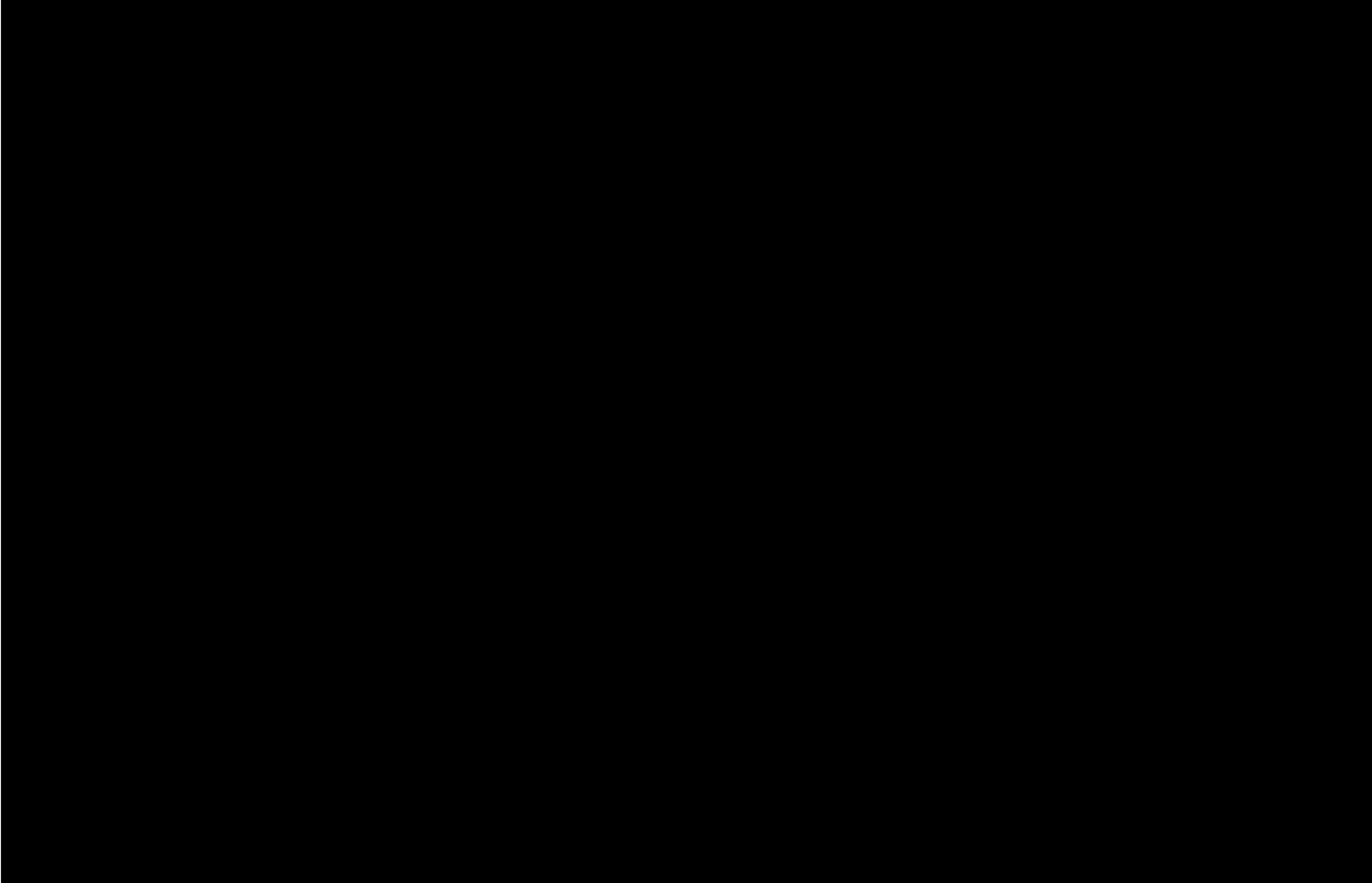


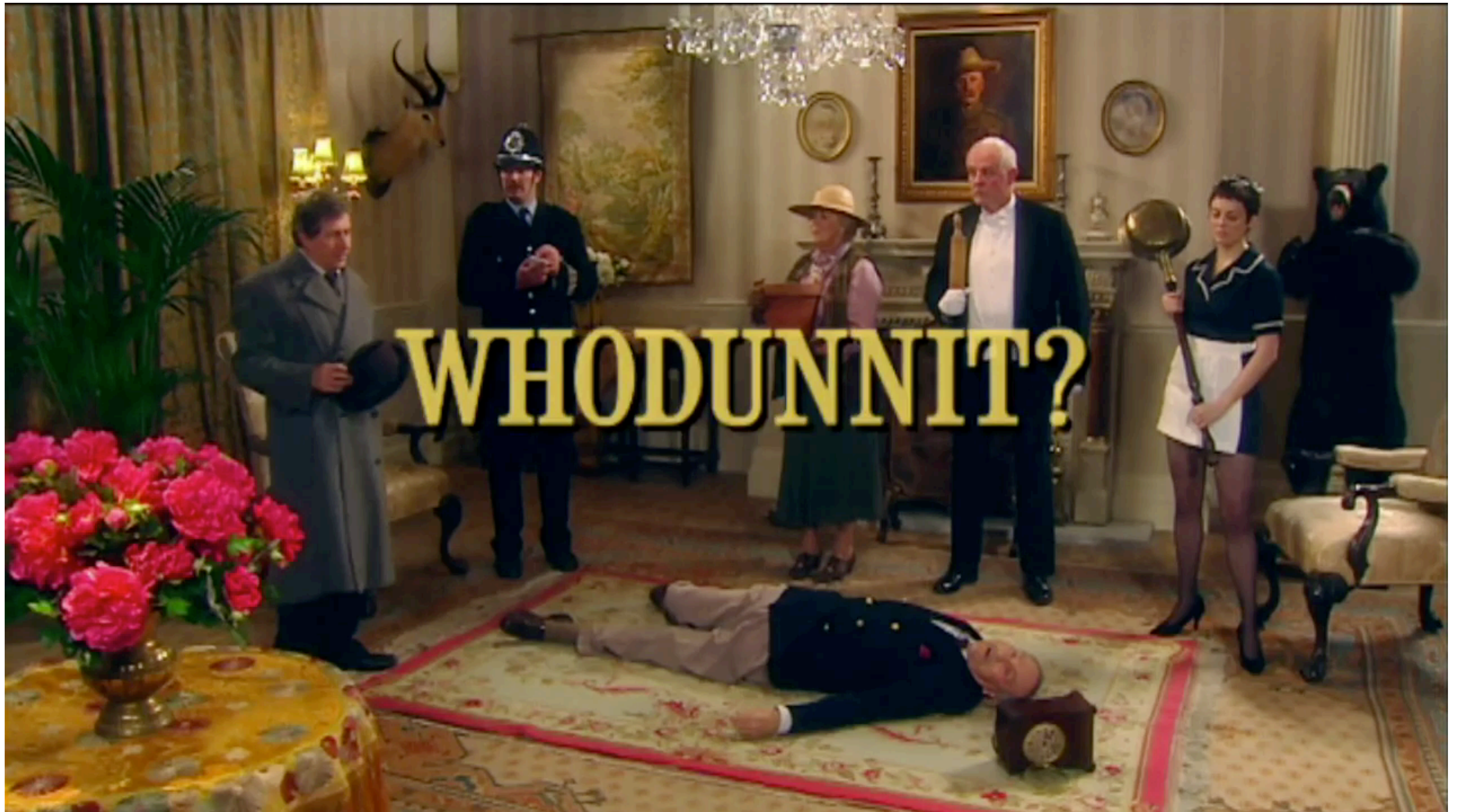




# Attention Blindness







Transport for London

# 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

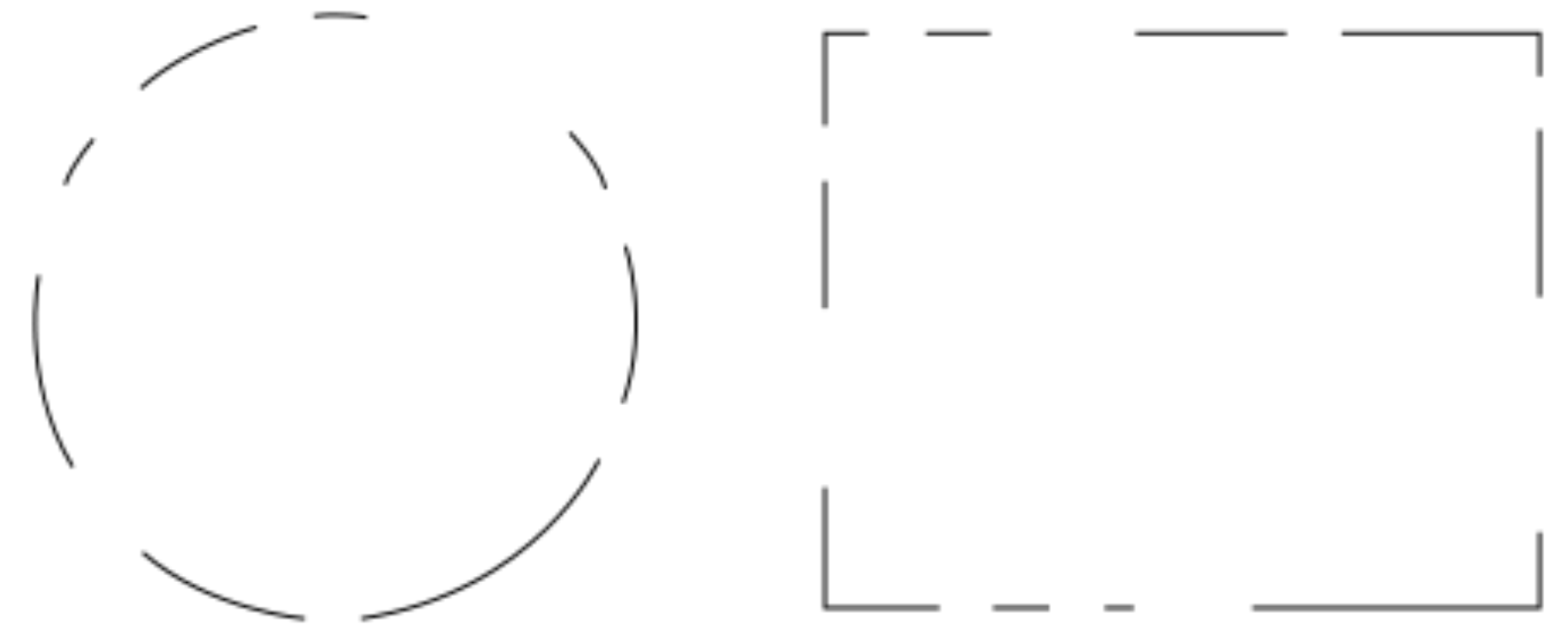
- *Das Ganze ist etwas anderes als die Summe seiner Teile.*
- *The whole is something else than the sum of its parts.*

Kurt Koffka

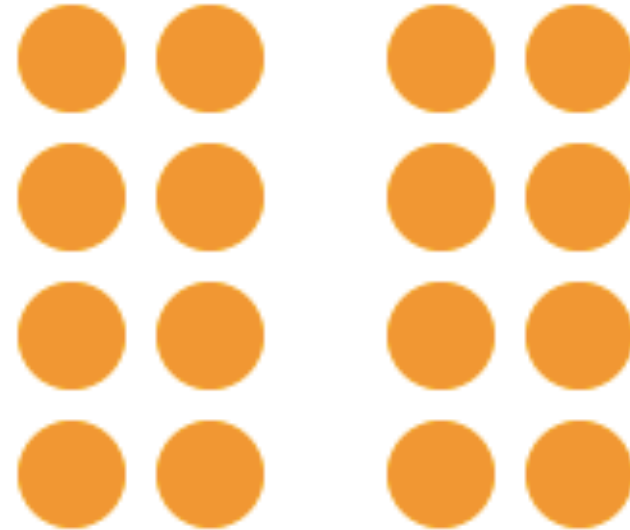
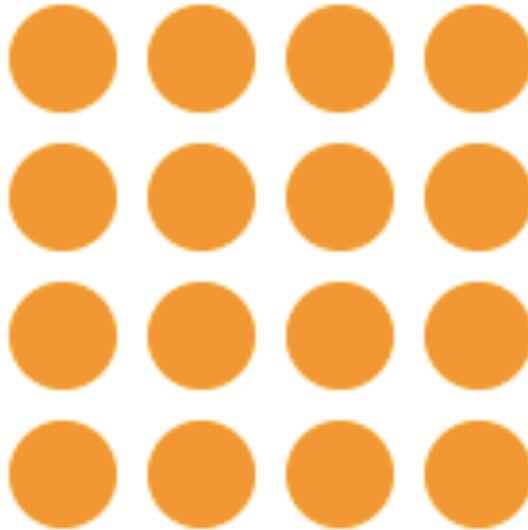
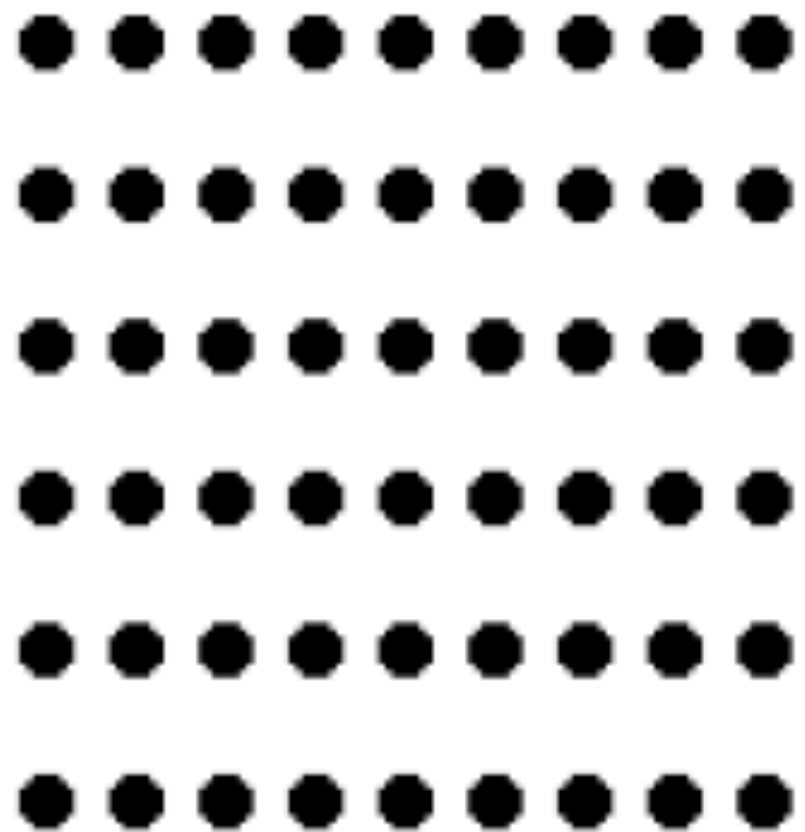
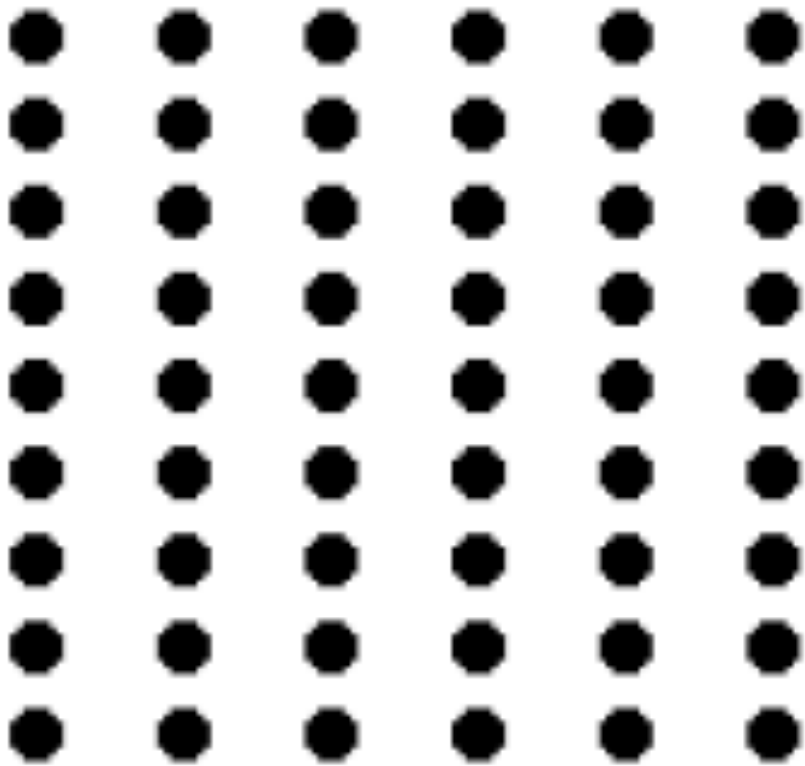
Koffka disagreed with the

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

quote which is attributed to Aristoteles

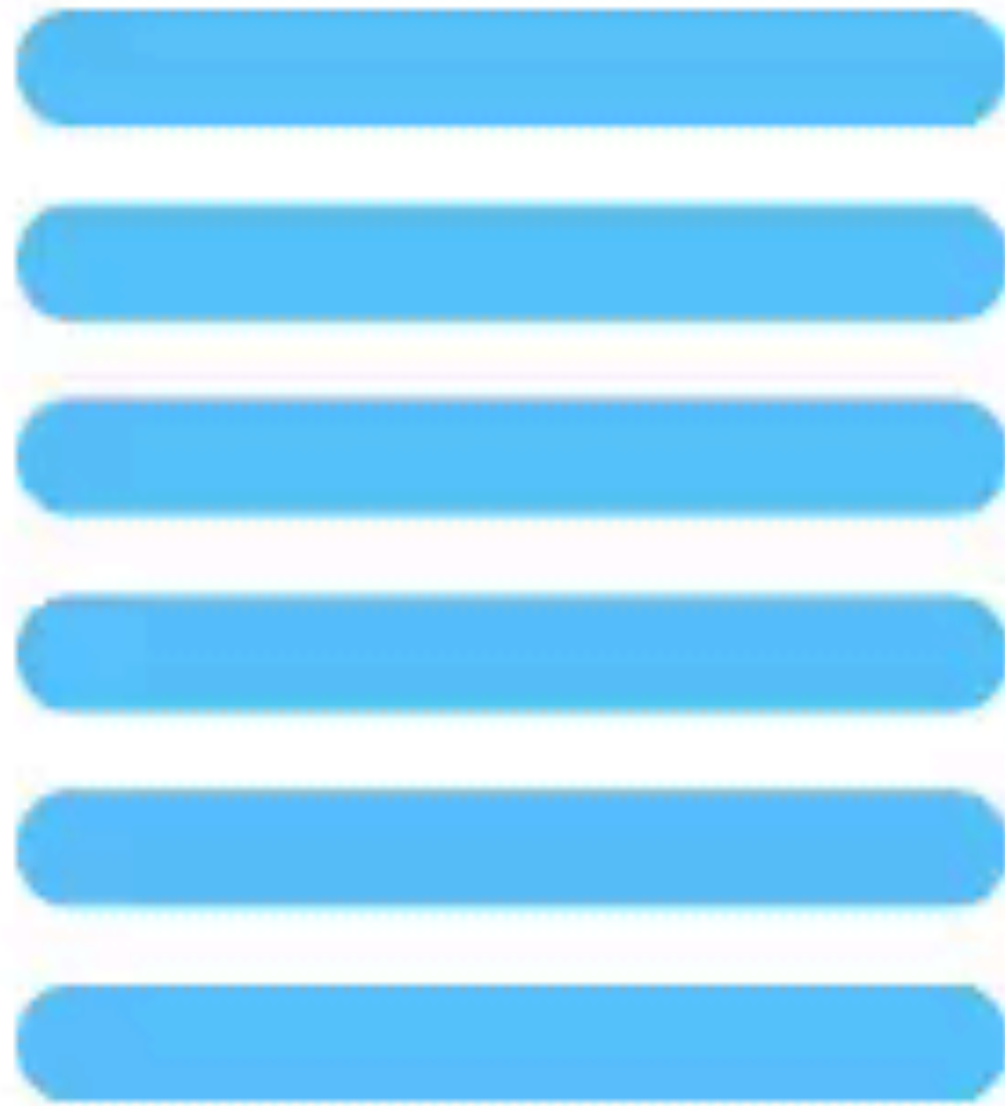


# Proximity





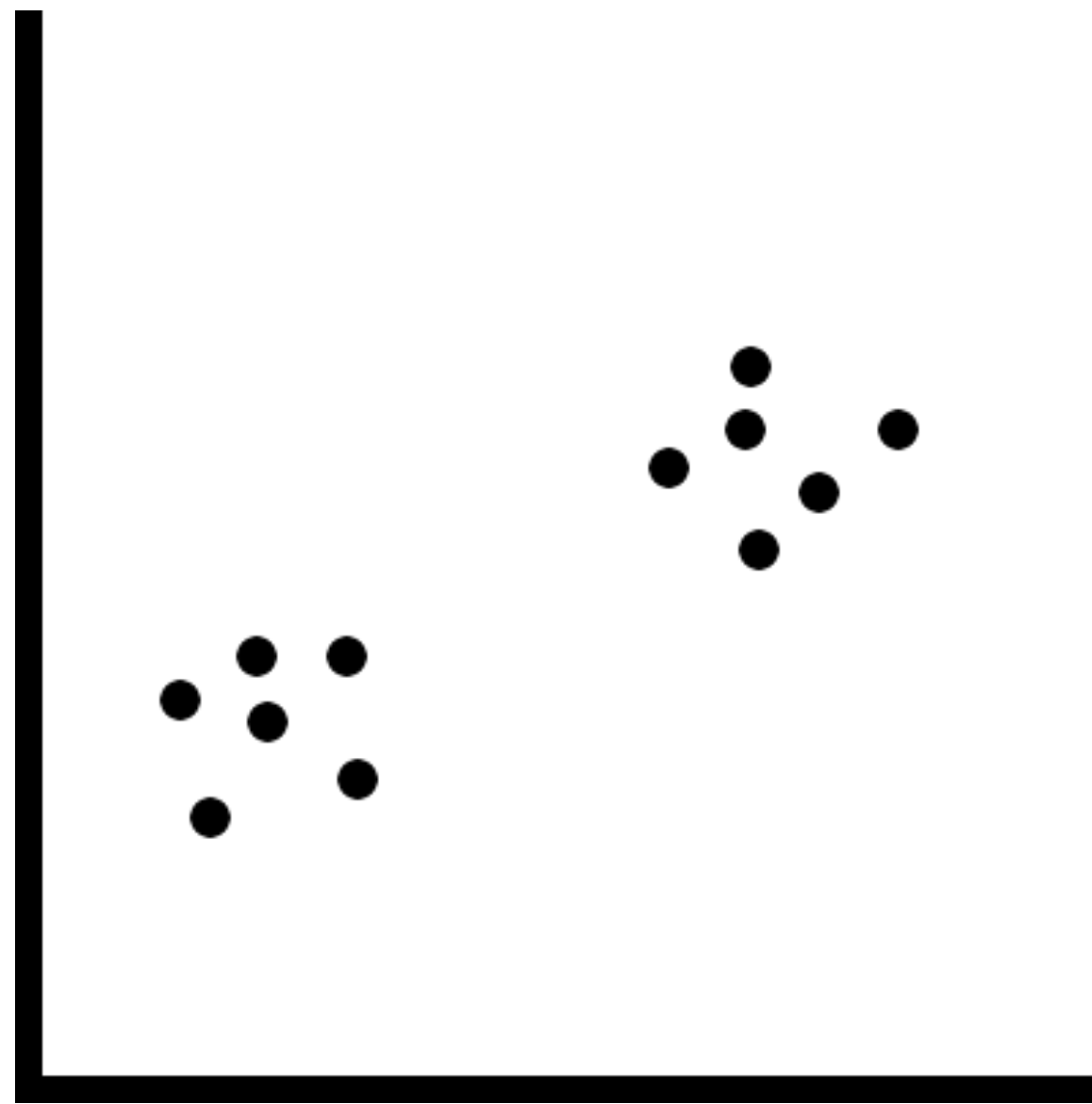
# Law of proximity



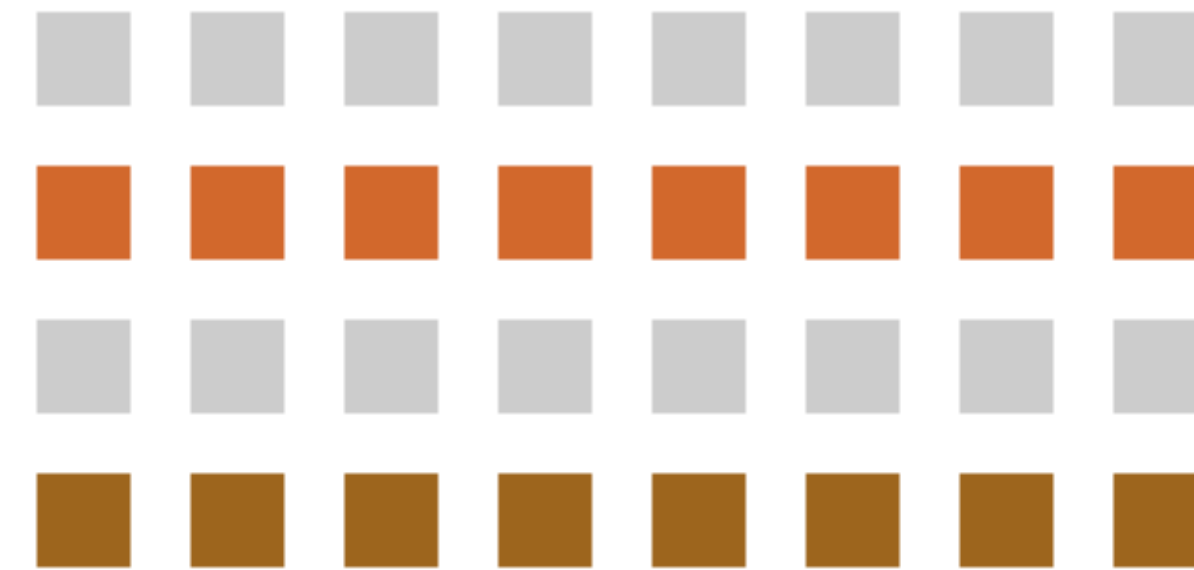
4 columns

# Proximity

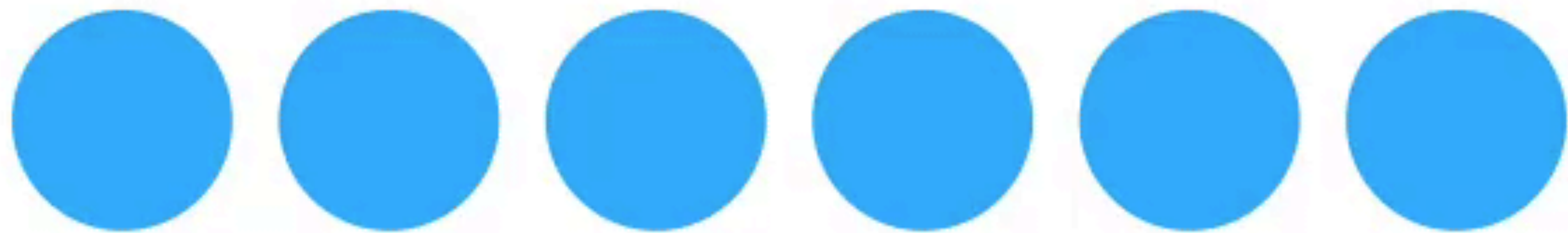
Grouping/linking by placing entities in close proximity



# Similarity

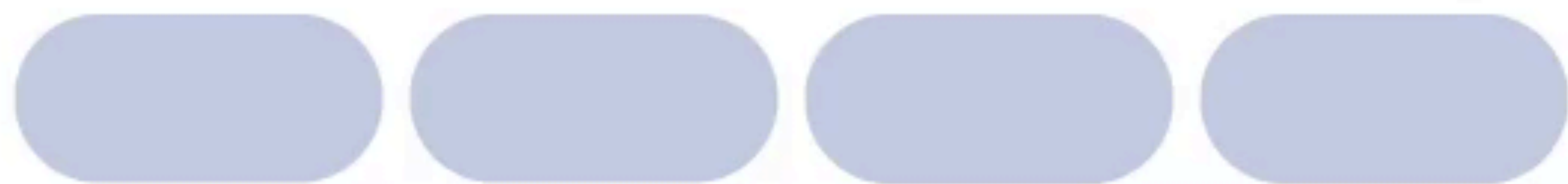


# Similarity Principle



1 group

**Focal Point**



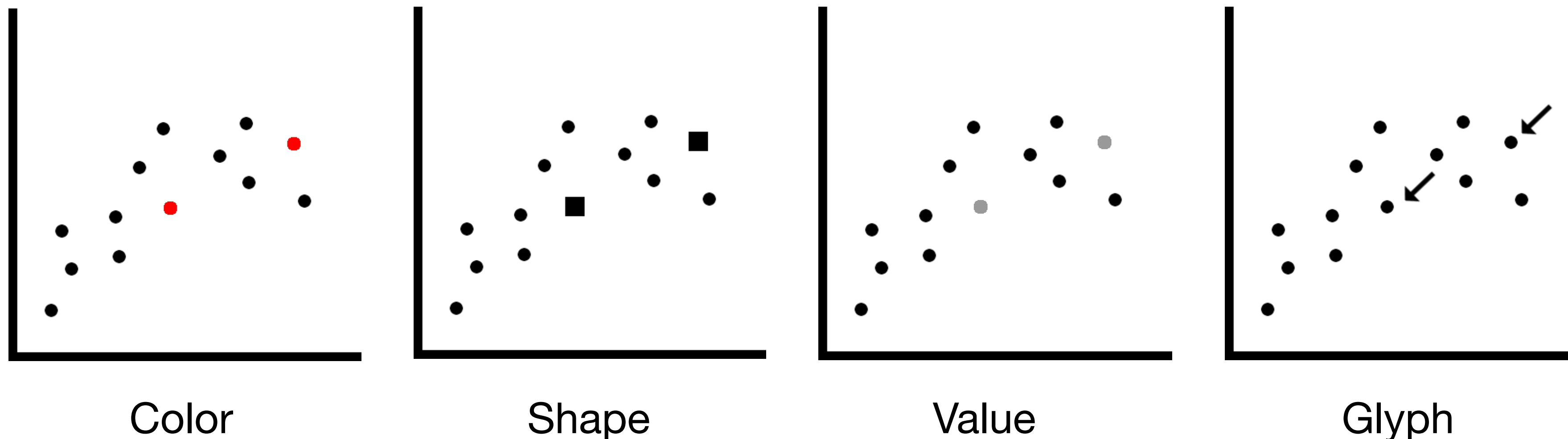
No focus

# Similarity

Co-modulation of a **channel**

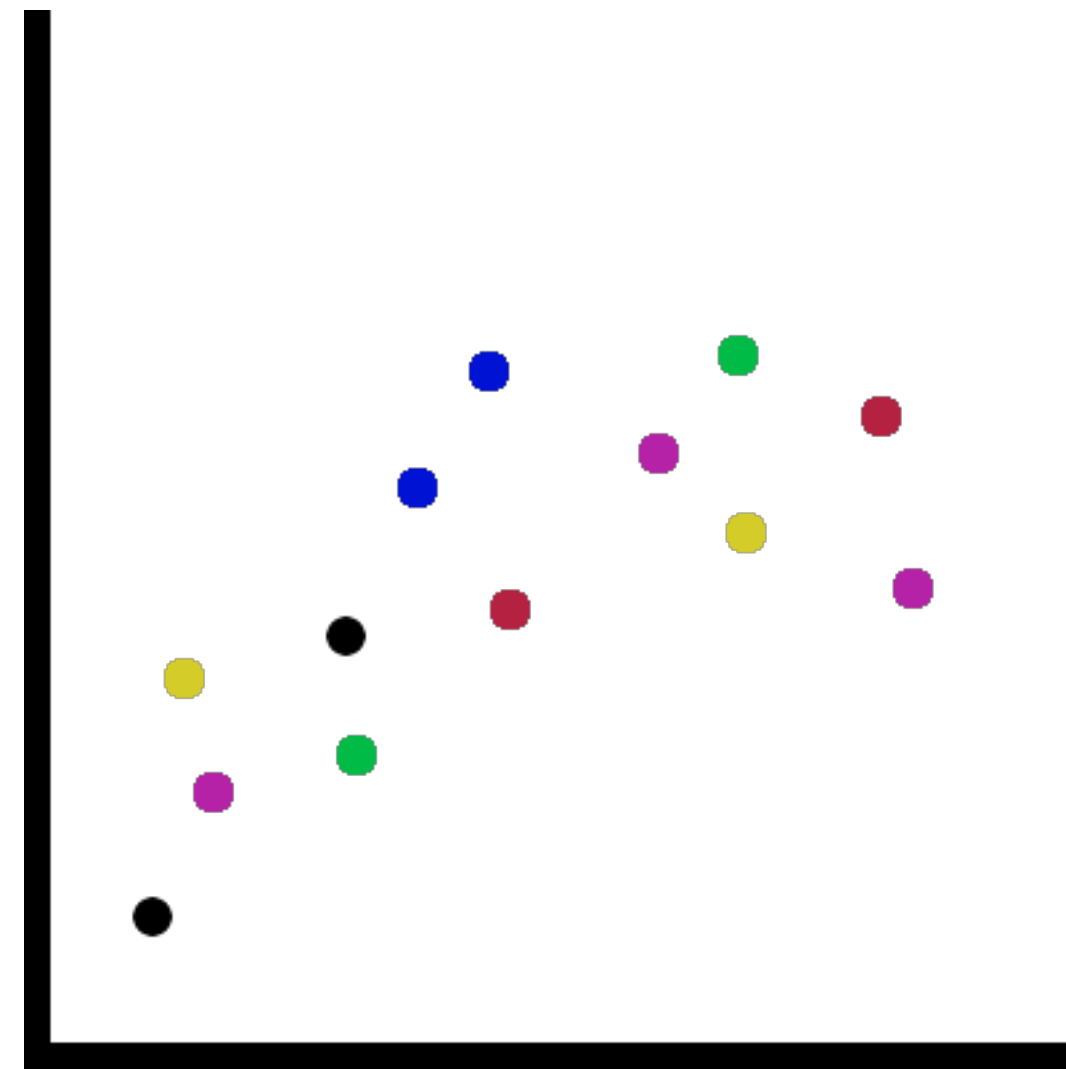
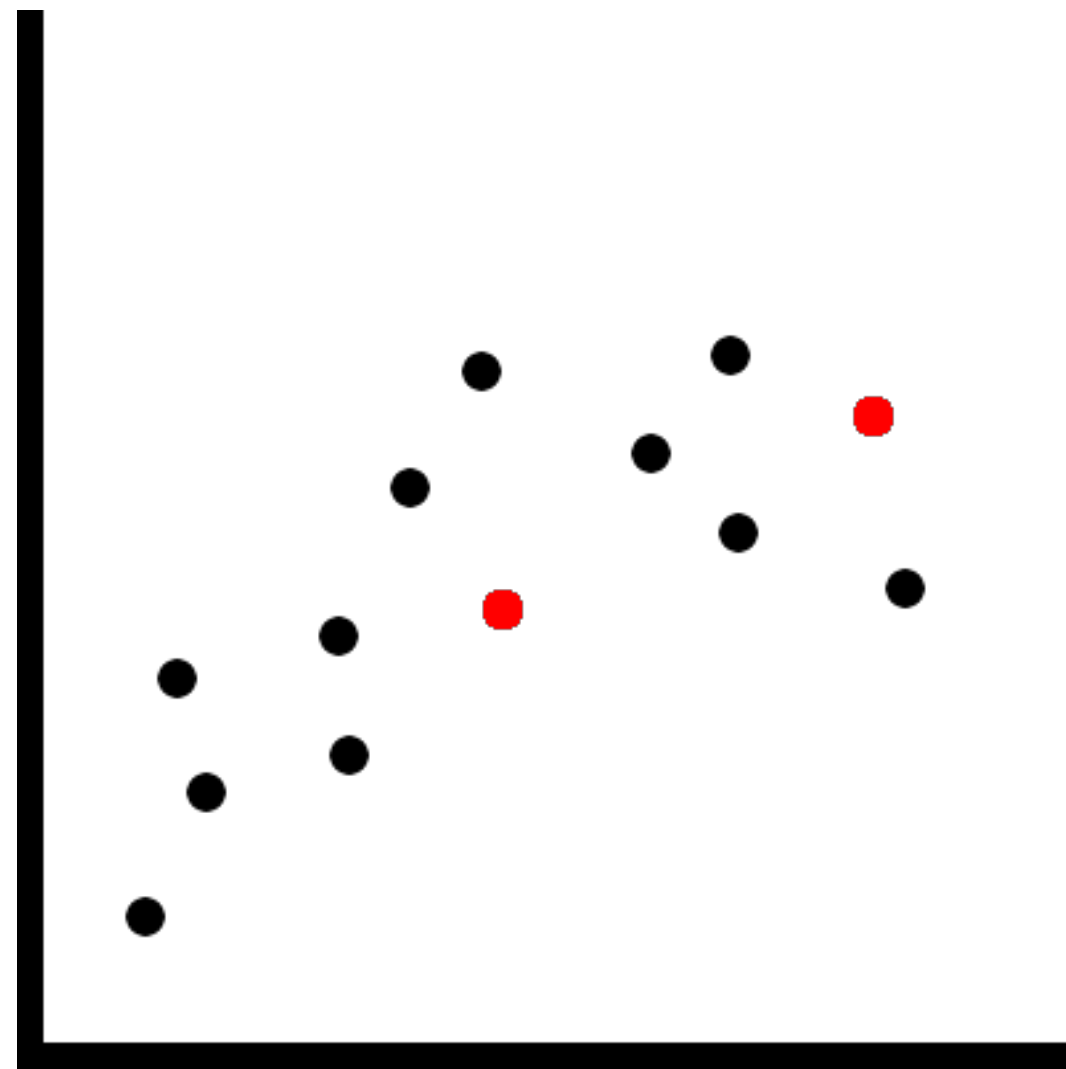
color, shape, size, value, orientation, texture, ...

Adding a glyph, label, frame, background



# Color – Perception Issues (1/2)

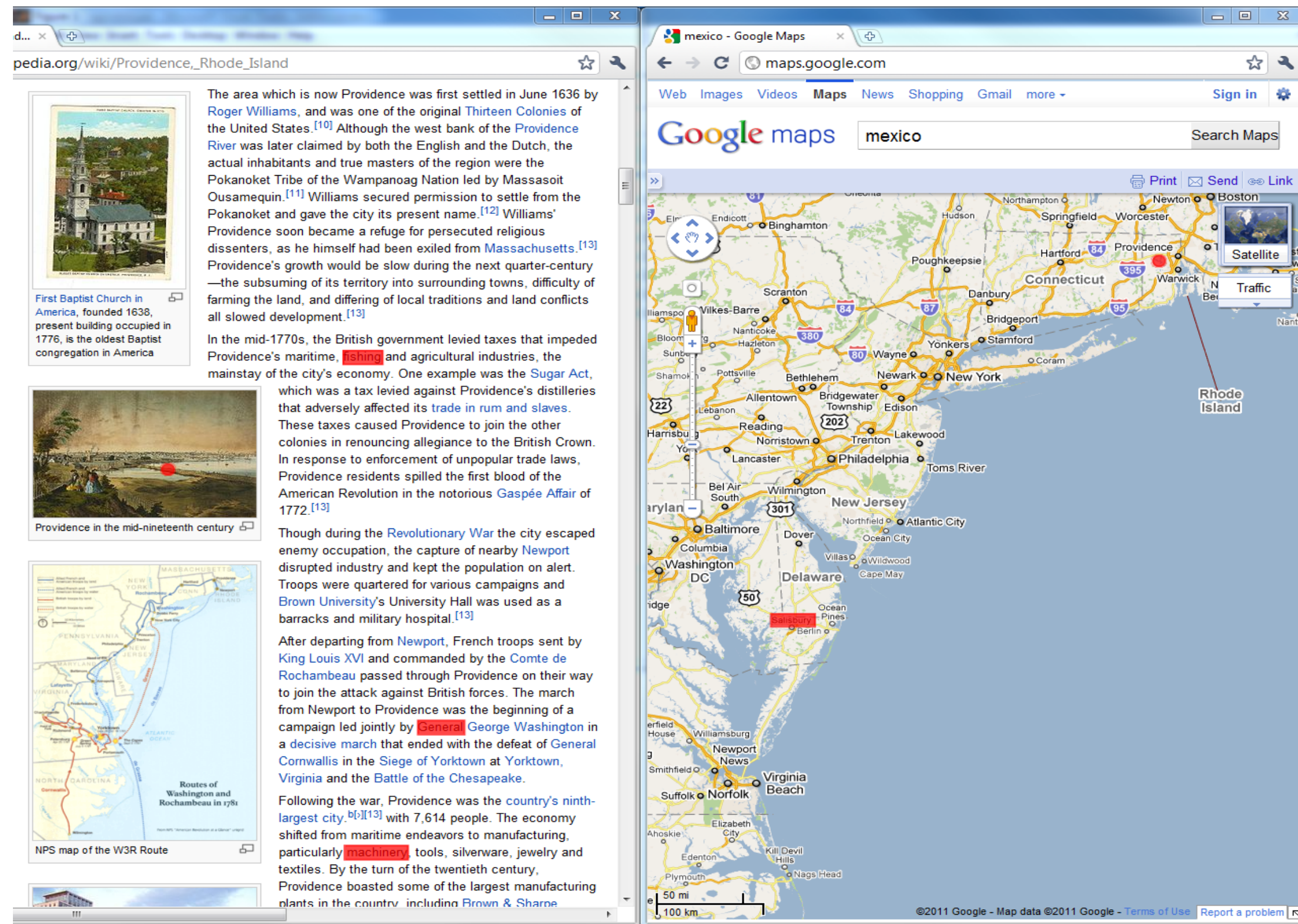
Popout properties: Very good for 1-2 simultaneous, **serial search for more**



# Color – Perception Issues (2/2)

Slower in a cluttered environment

Size of colored object relevant.

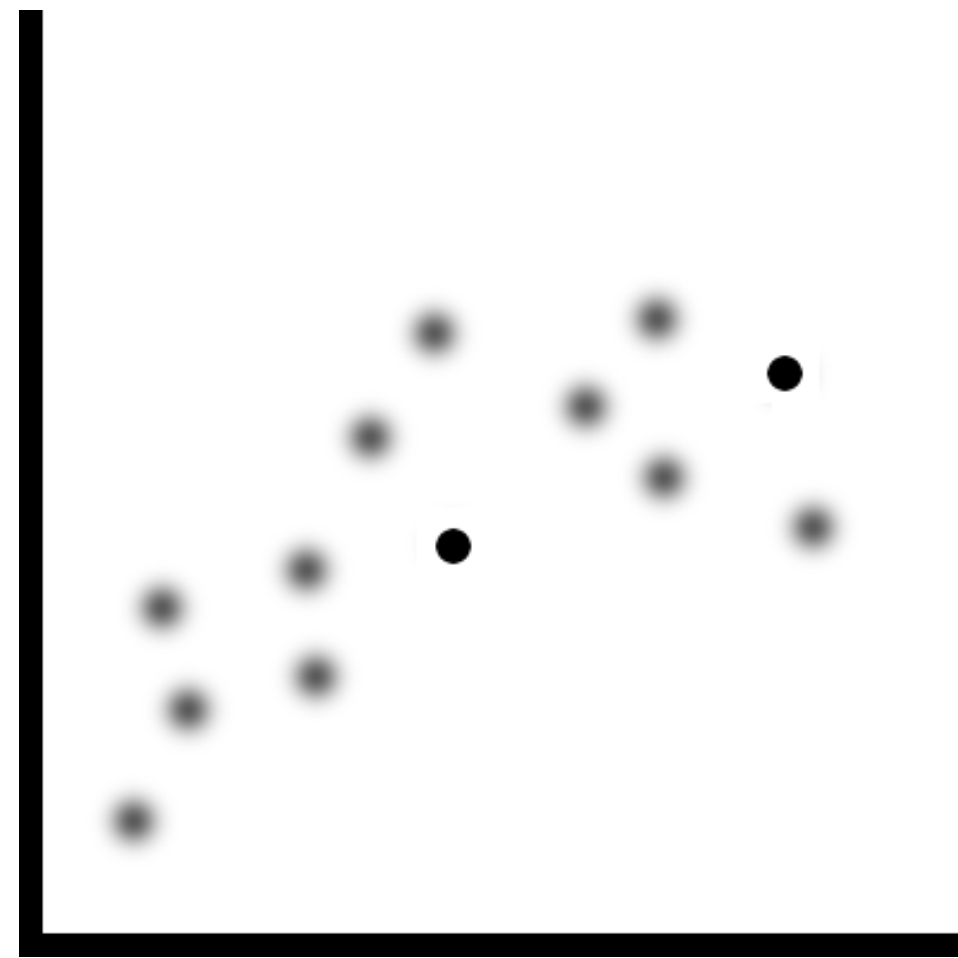




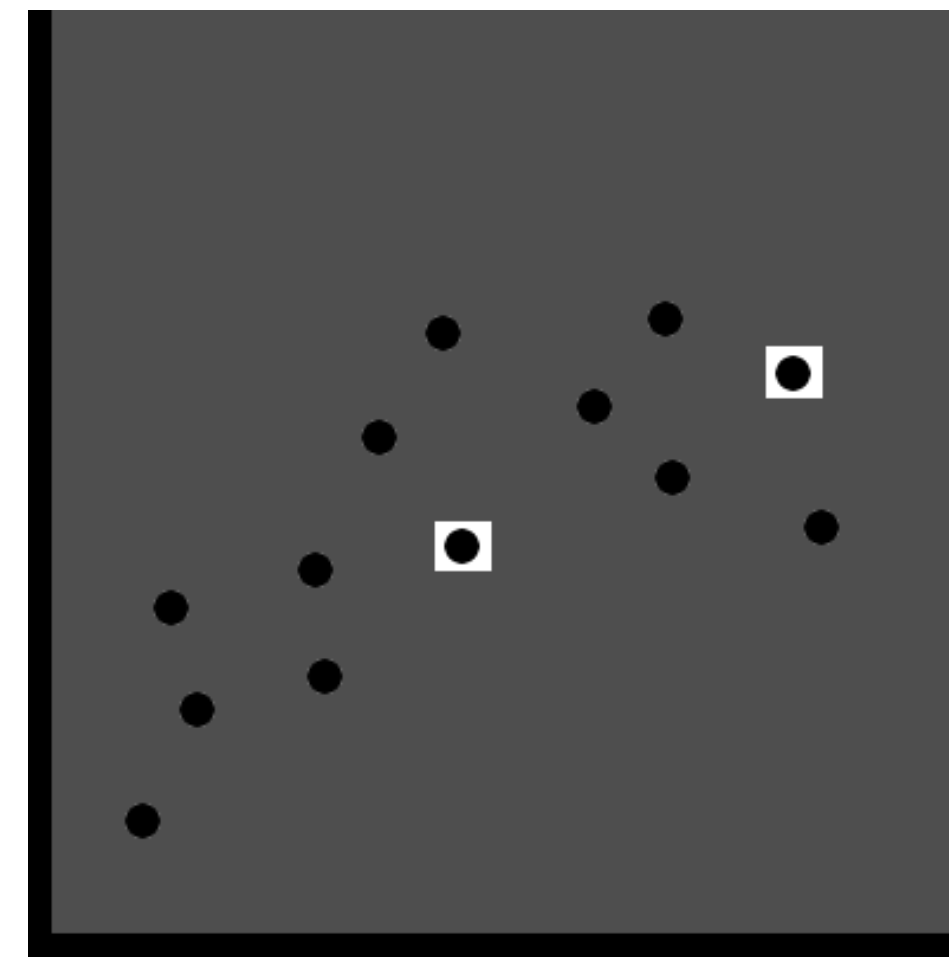
# Similarity

Modulate everything else

Blurring, darkening, desaturating, etc.



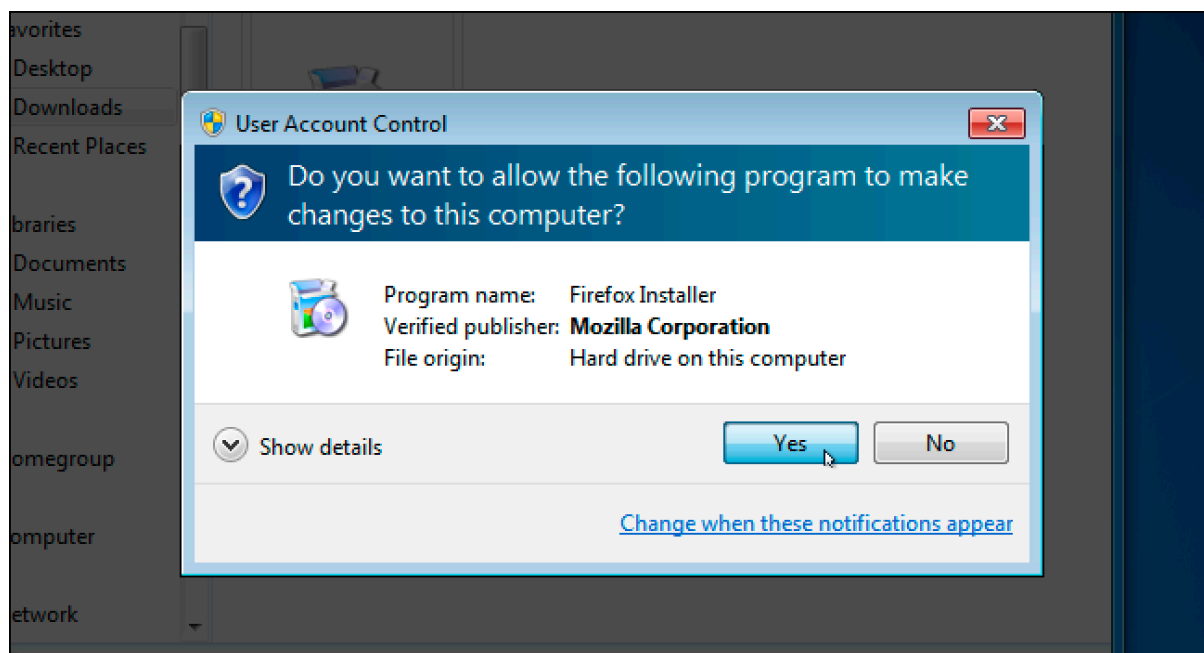
Blur



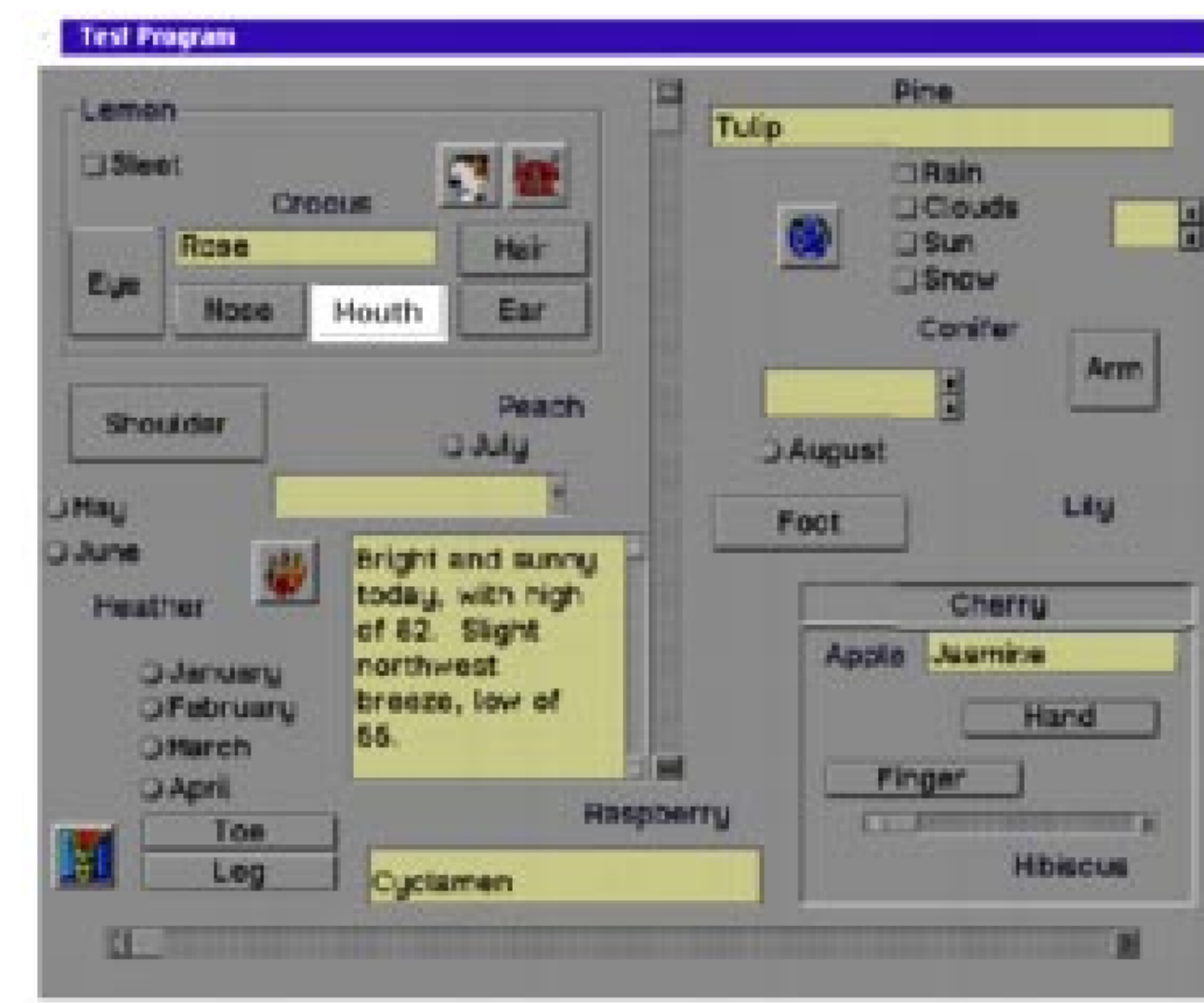
Darkening

# Modulating Everything Else: Recommendation, Example

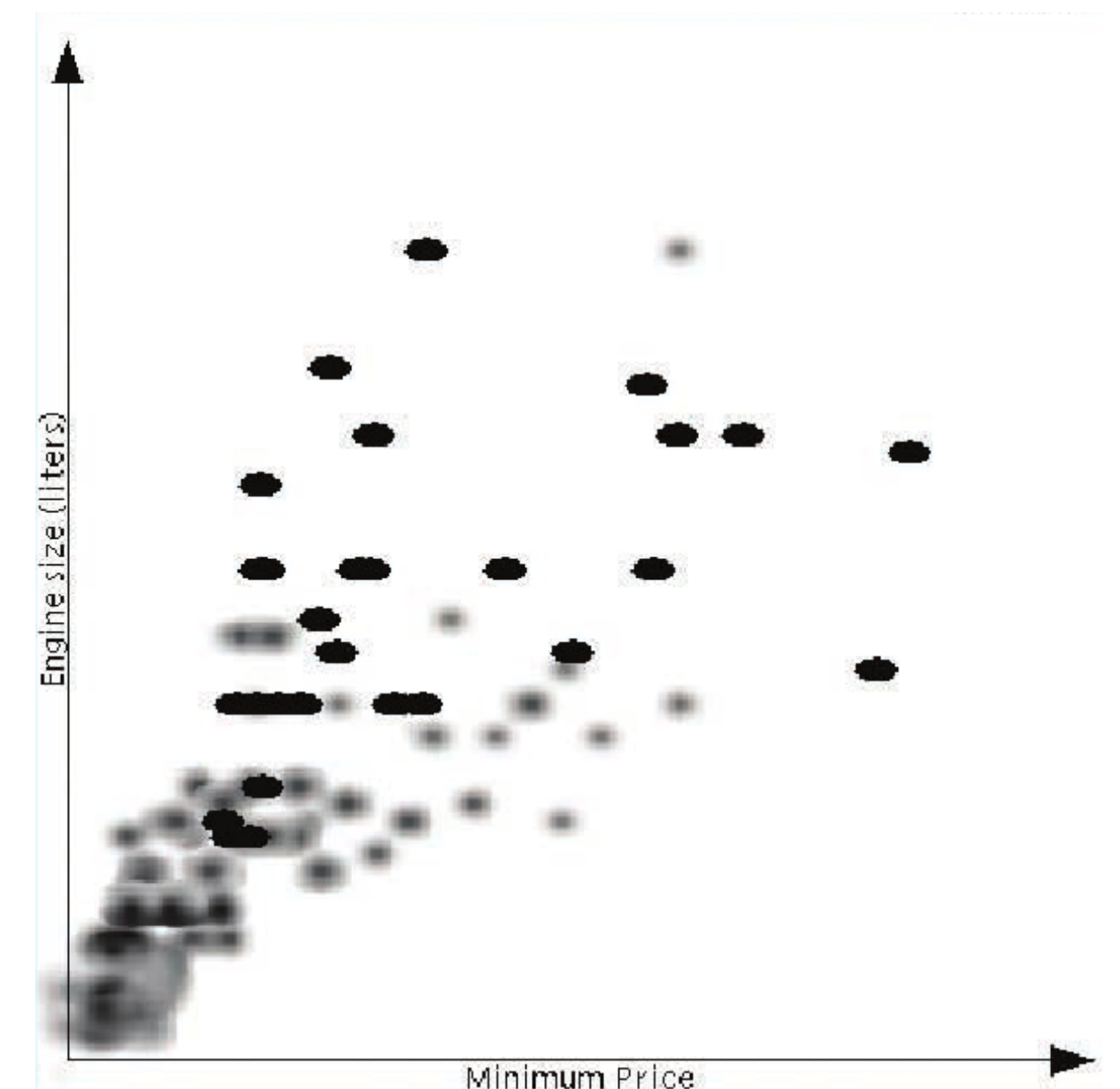
Don't use unless the sole objective is to guide attention toward one (set of) items



[MS Windows User Account Control]

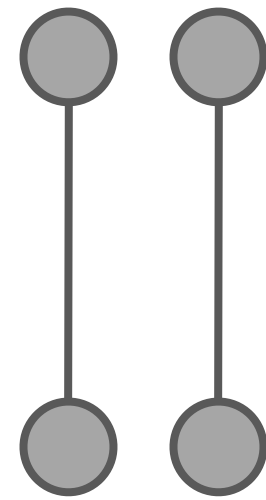


[Zhai et al., 1997]

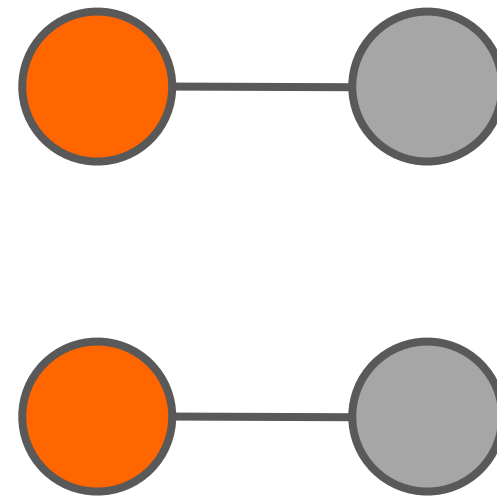


[Kosara et al., 2002]

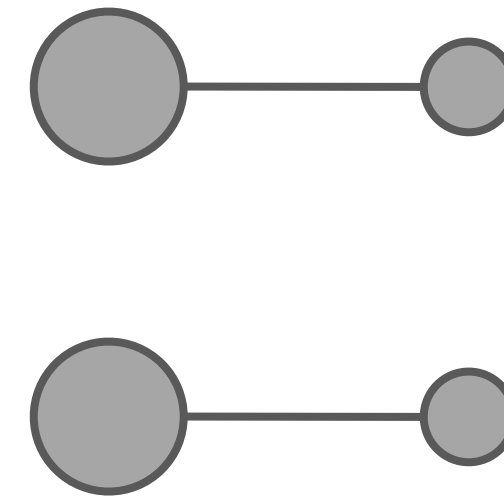
# A Little Experiment...



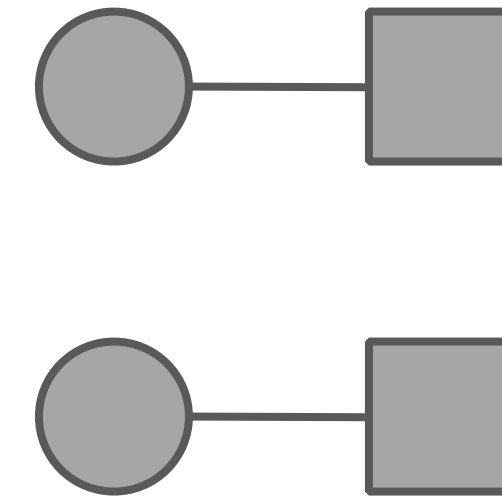
Proximity



Color



Size

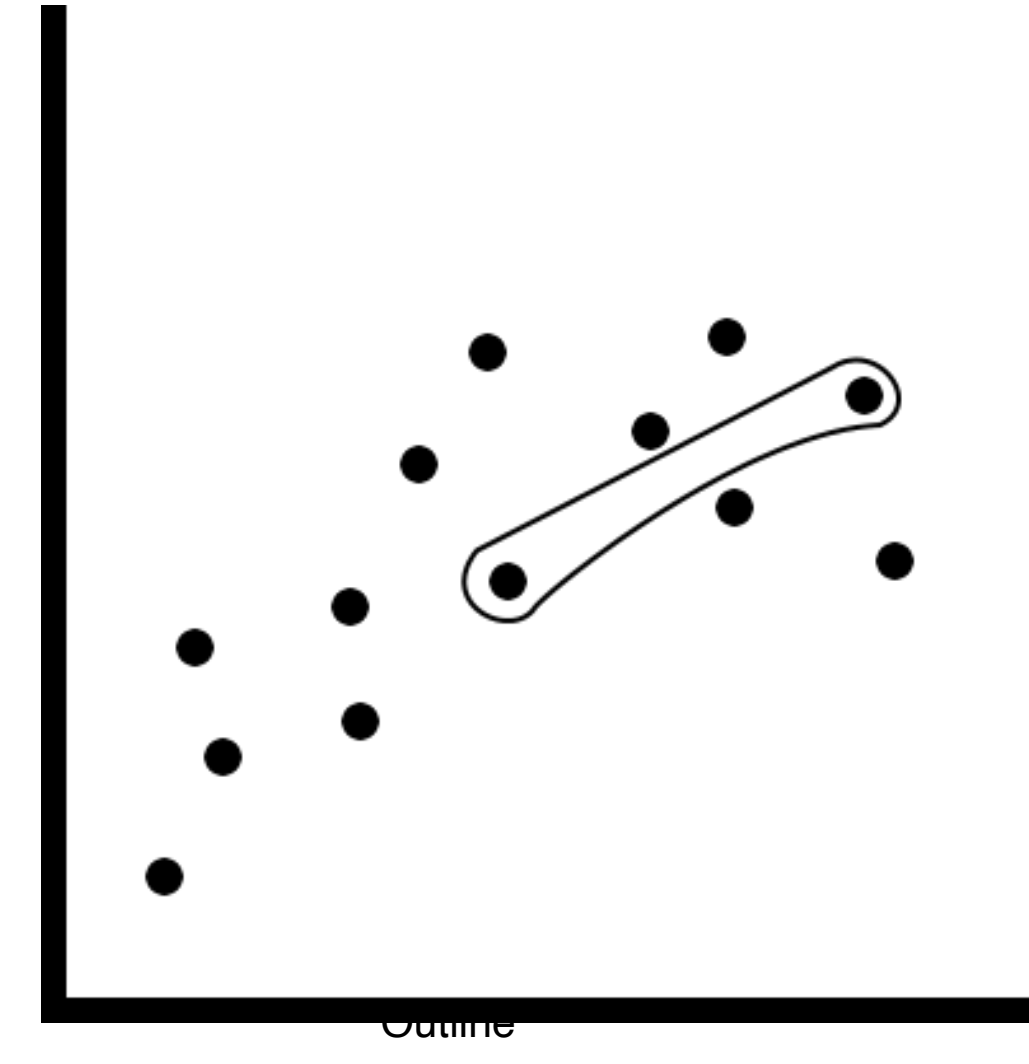
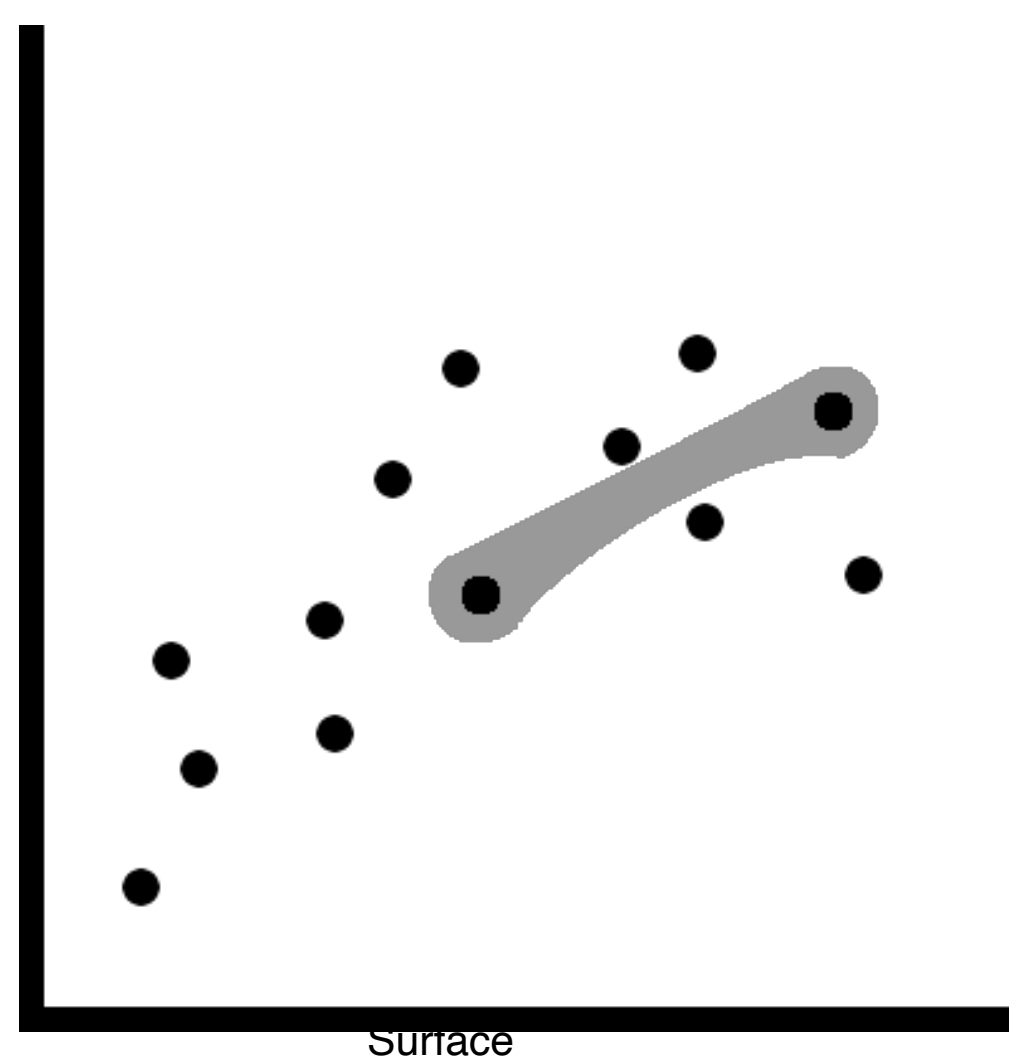
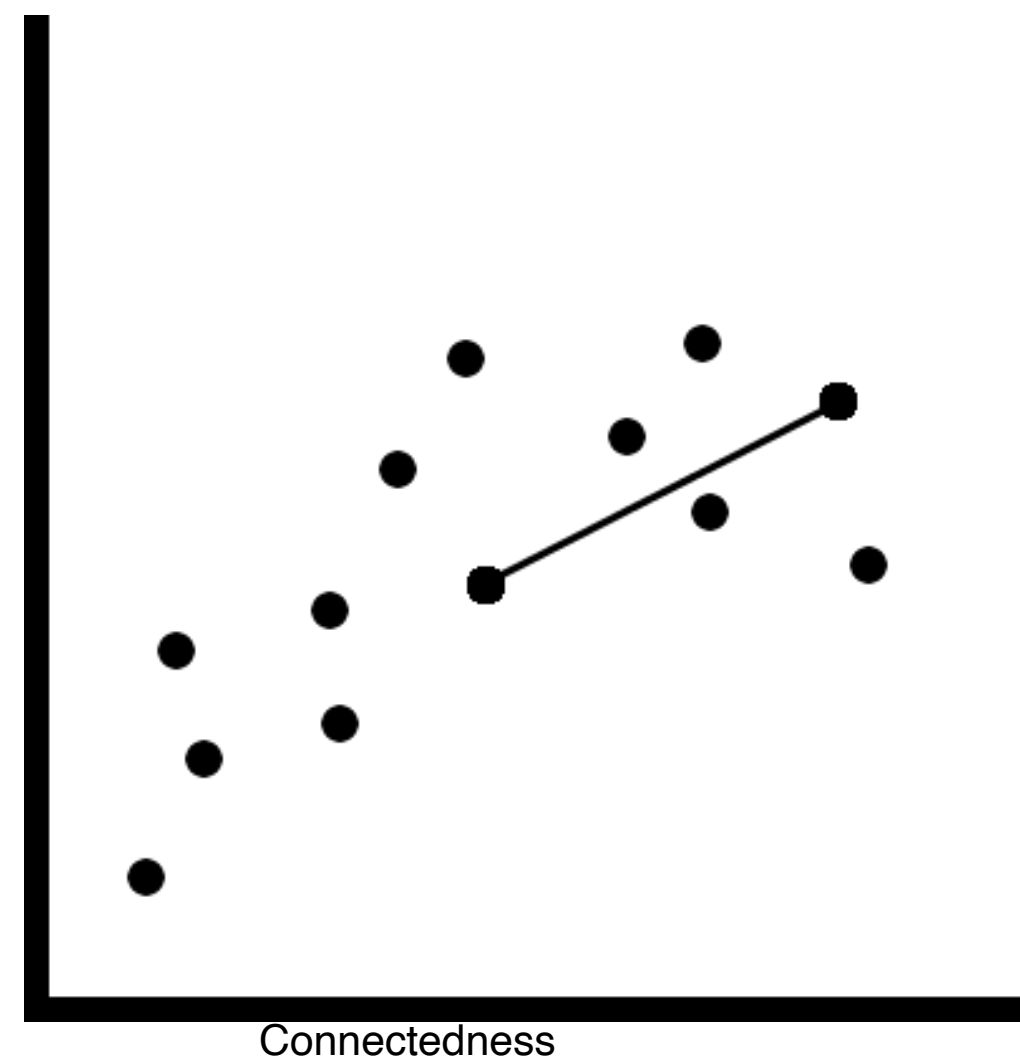


Shape

# Connectedness and Common Region

Connected items with a line or curve

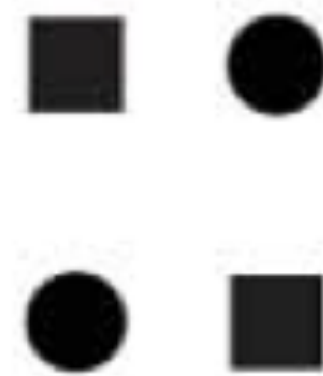
Surround items with a outline, surface, volume



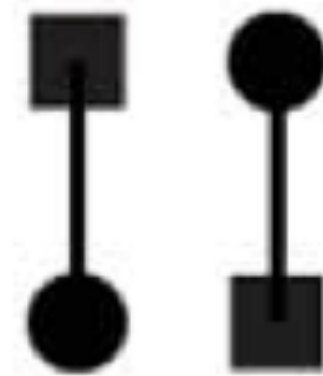
Common Region

# Enclosure / Common Region

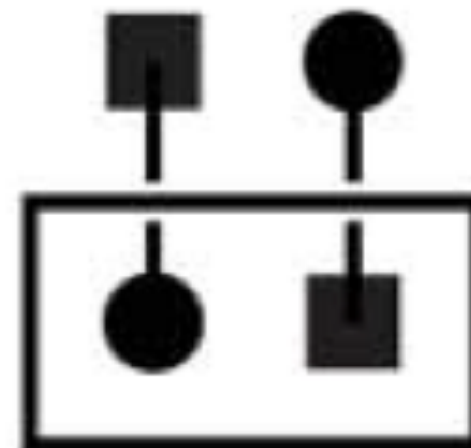
Similarity



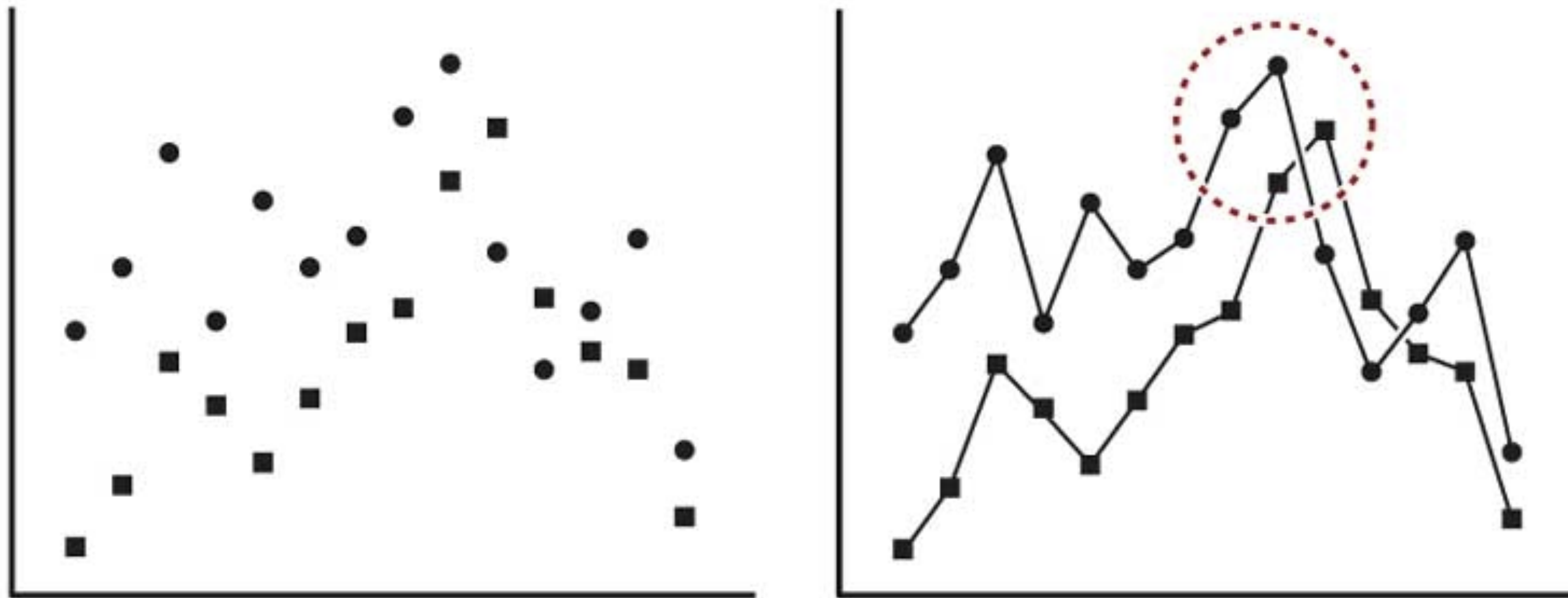
Connection



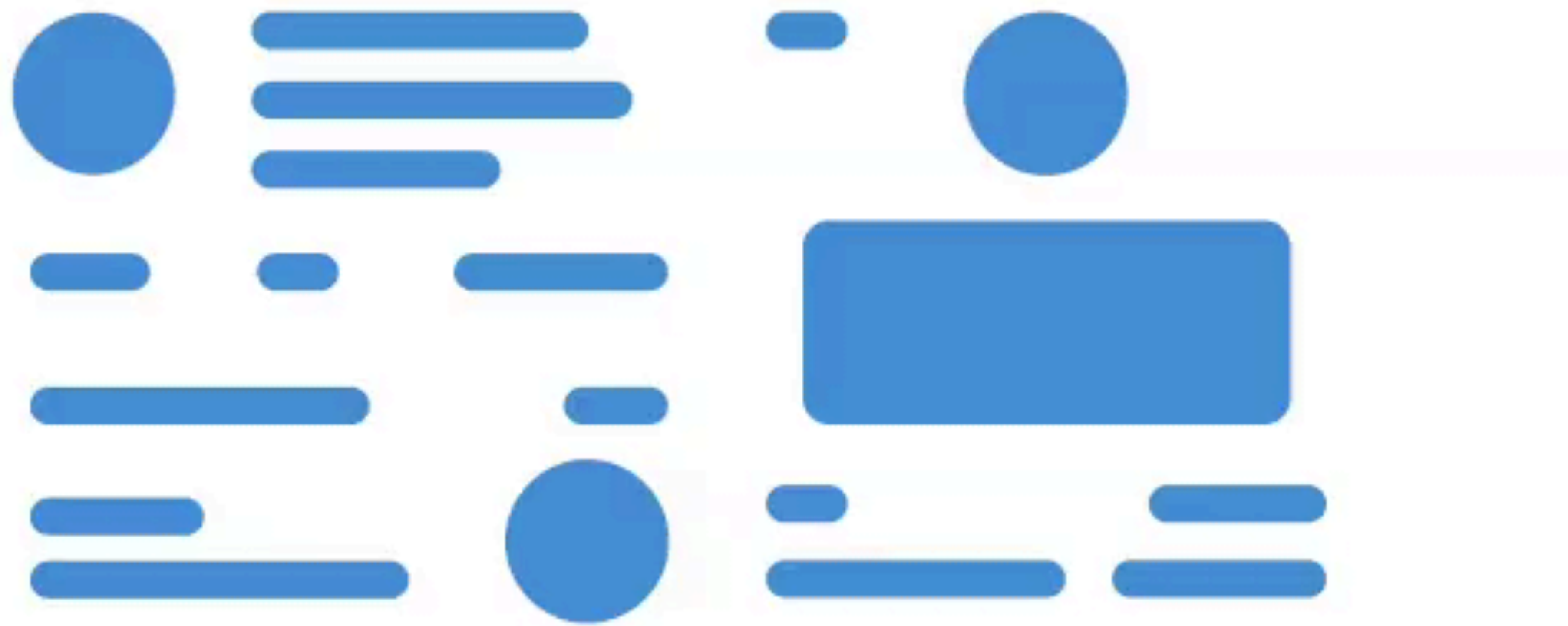
Enclosure



# Connectedness / Enclosure



# Common Region



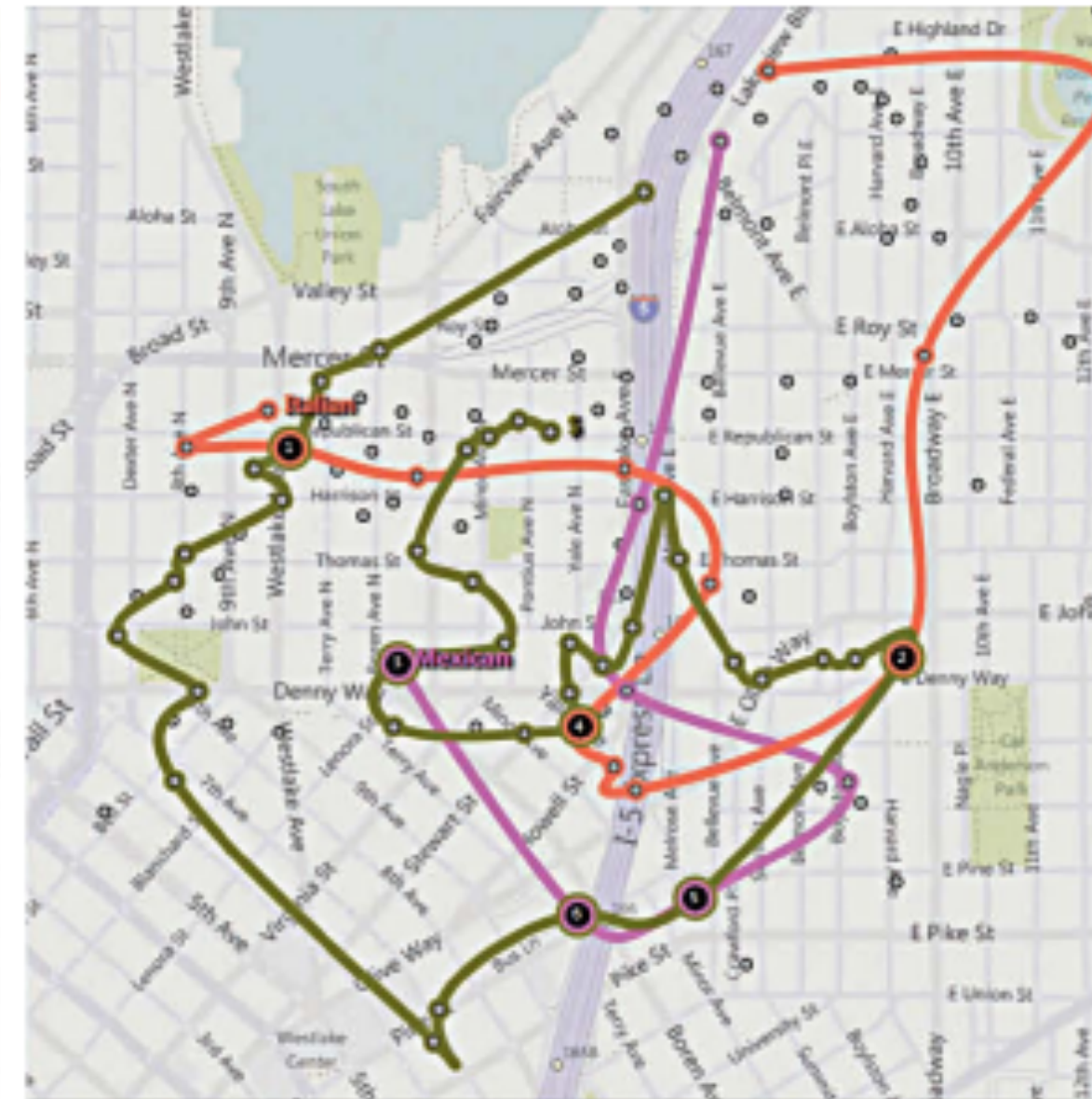
Scattered elements

# Connectedness Varieties

Bubble Sets



Line Sets



Kelp Diagrams

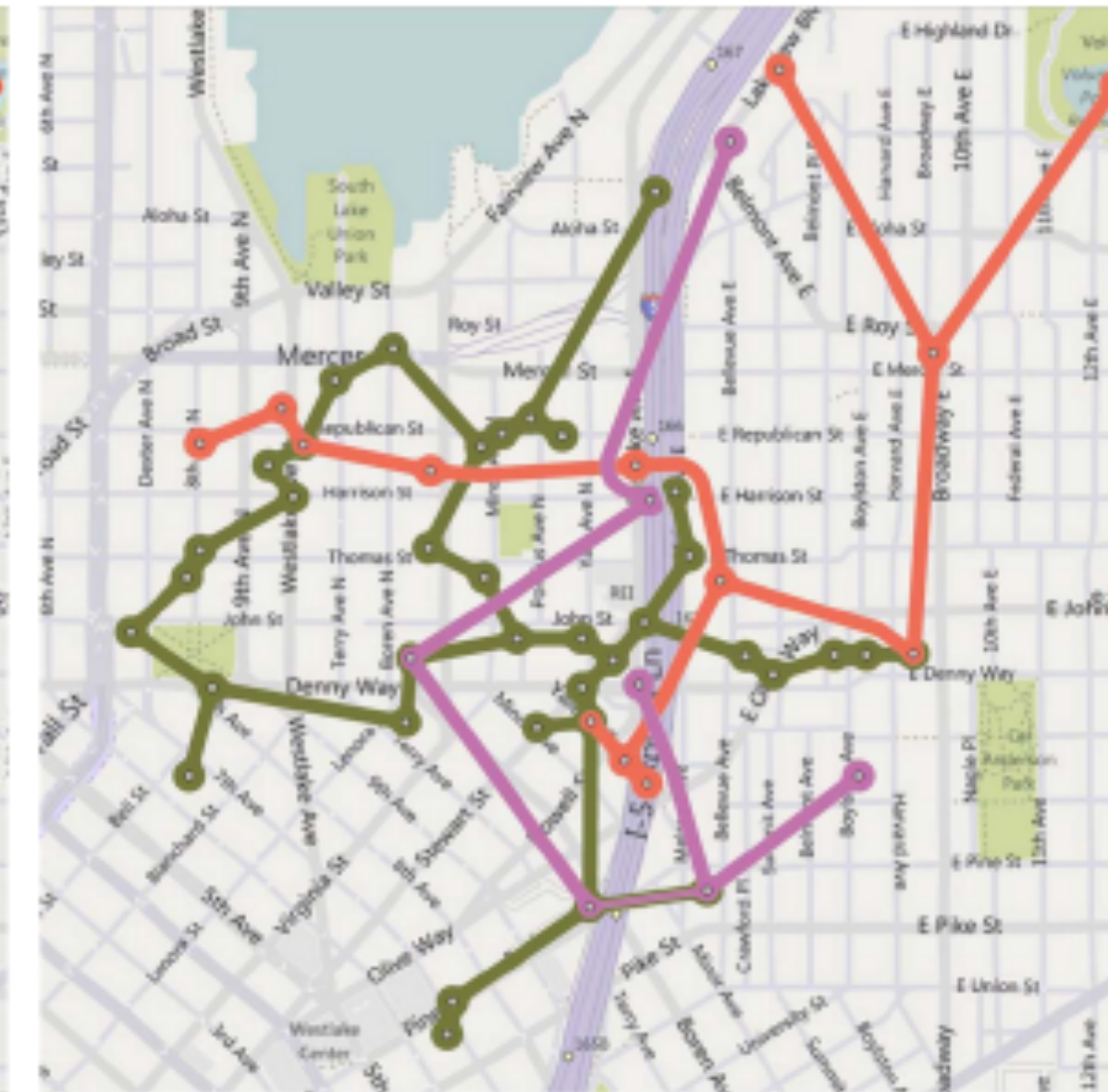


Image by [Dinkla et al., 2011]

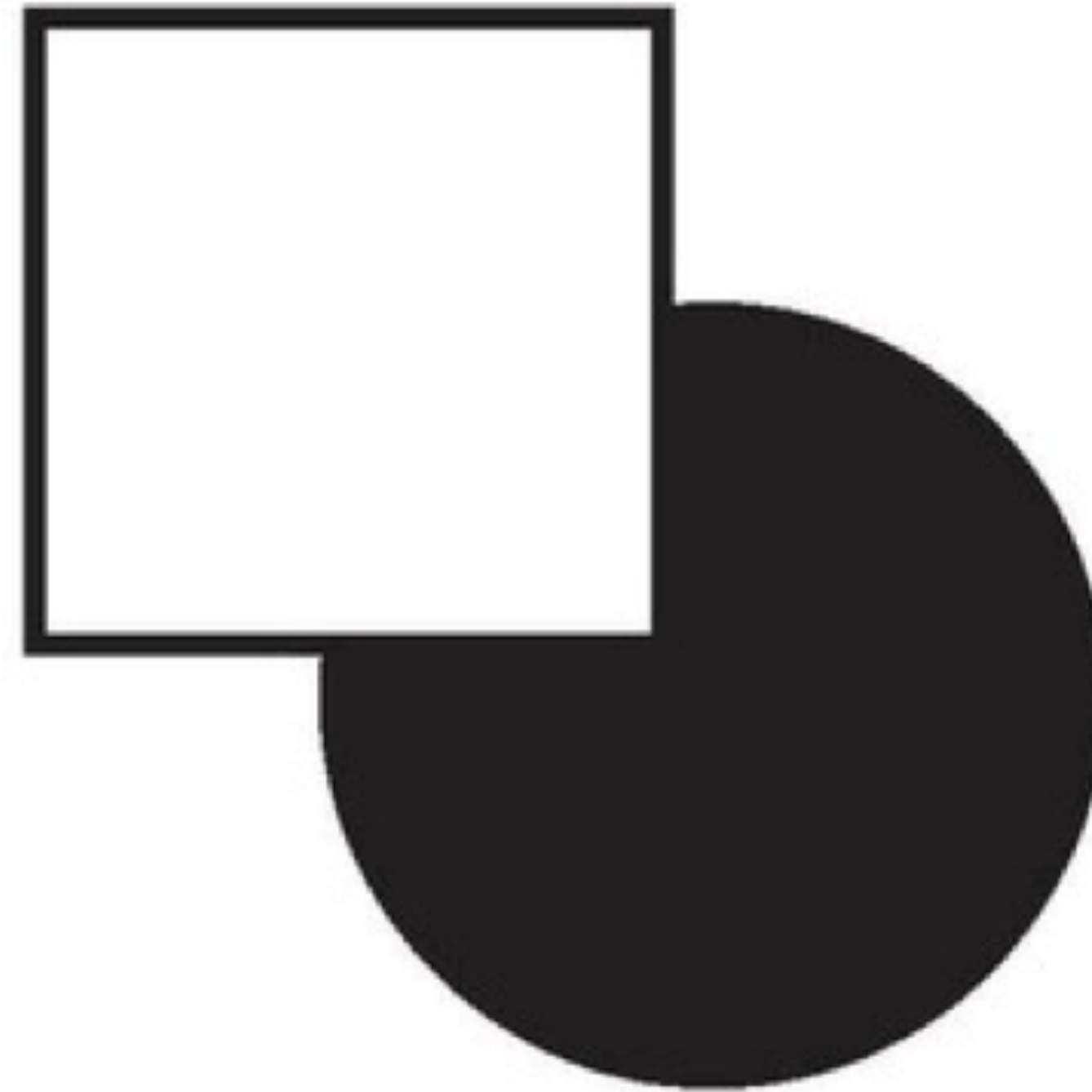
Technique by [Collins et al., 2009]

[Alper et al., 2011]

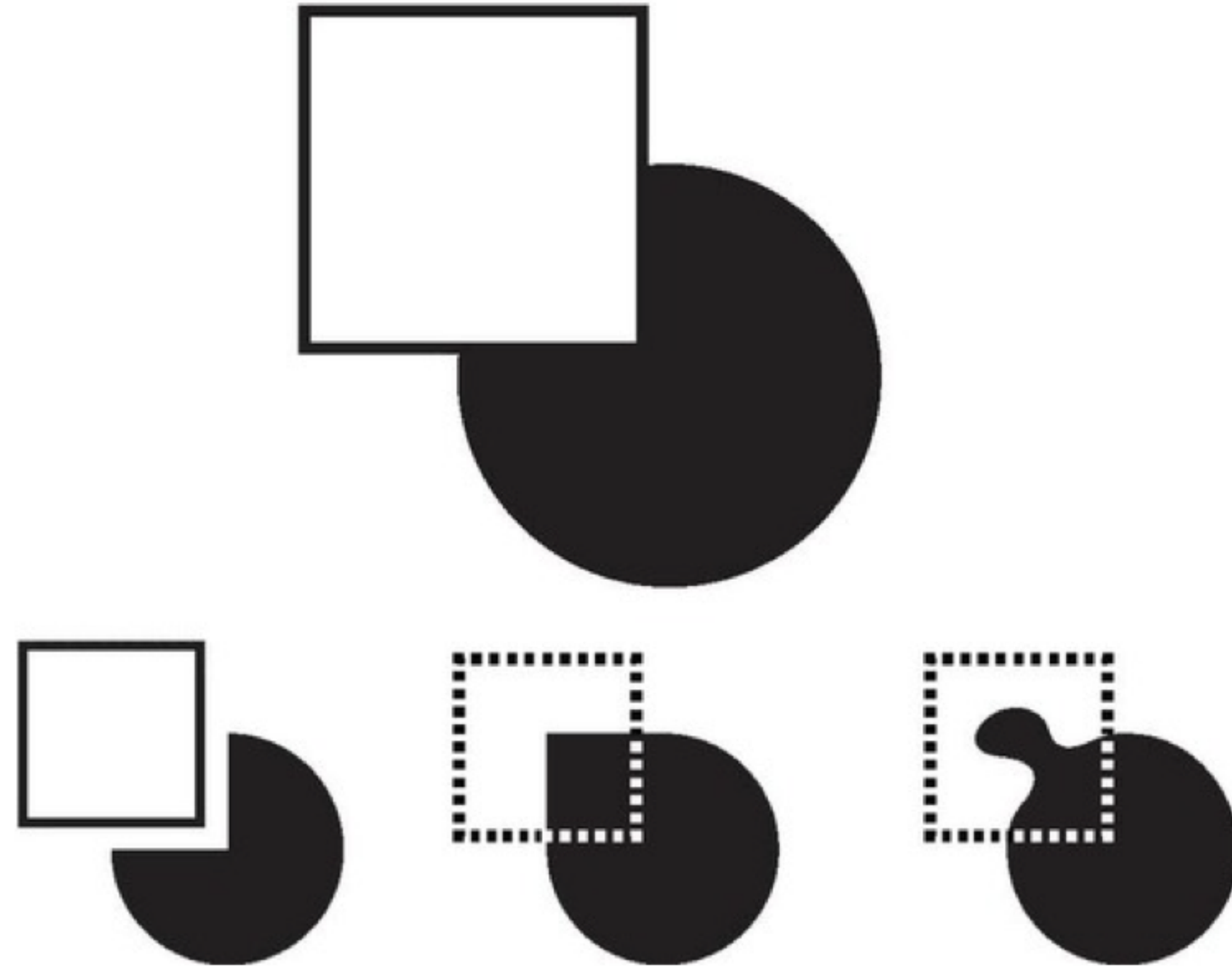
[Dinkla et al., 2012]



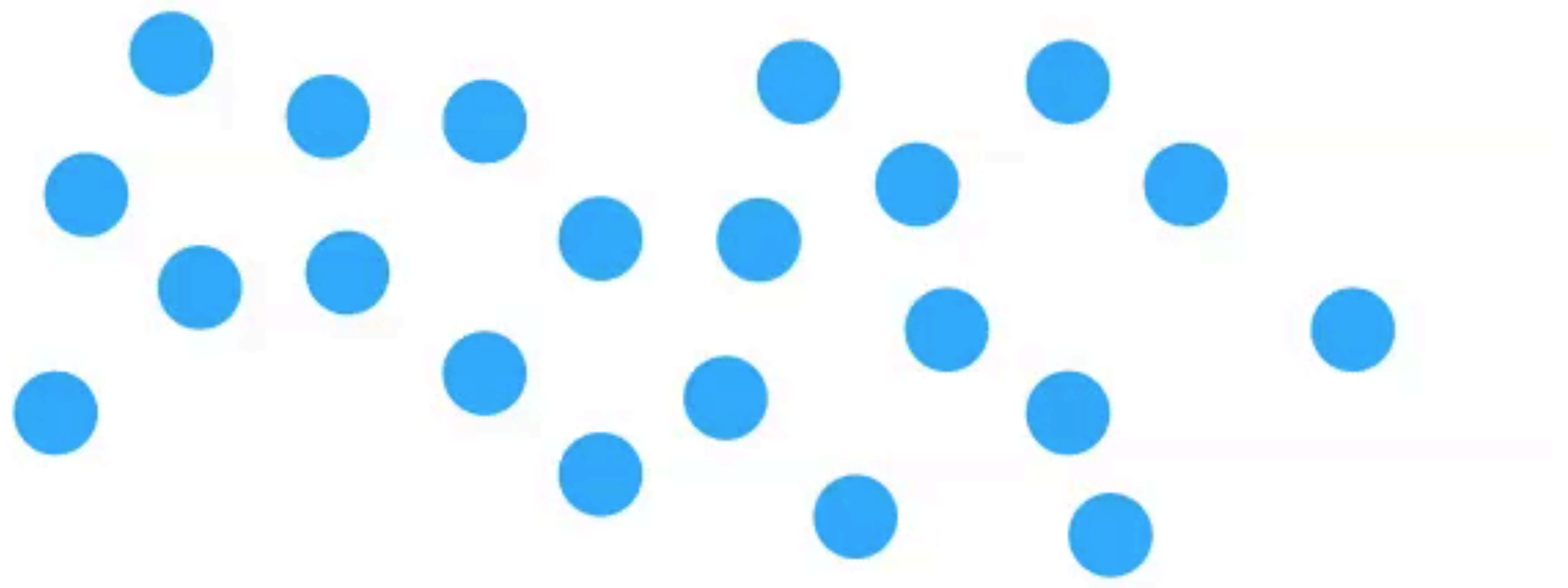
# Continuity



# Continuity



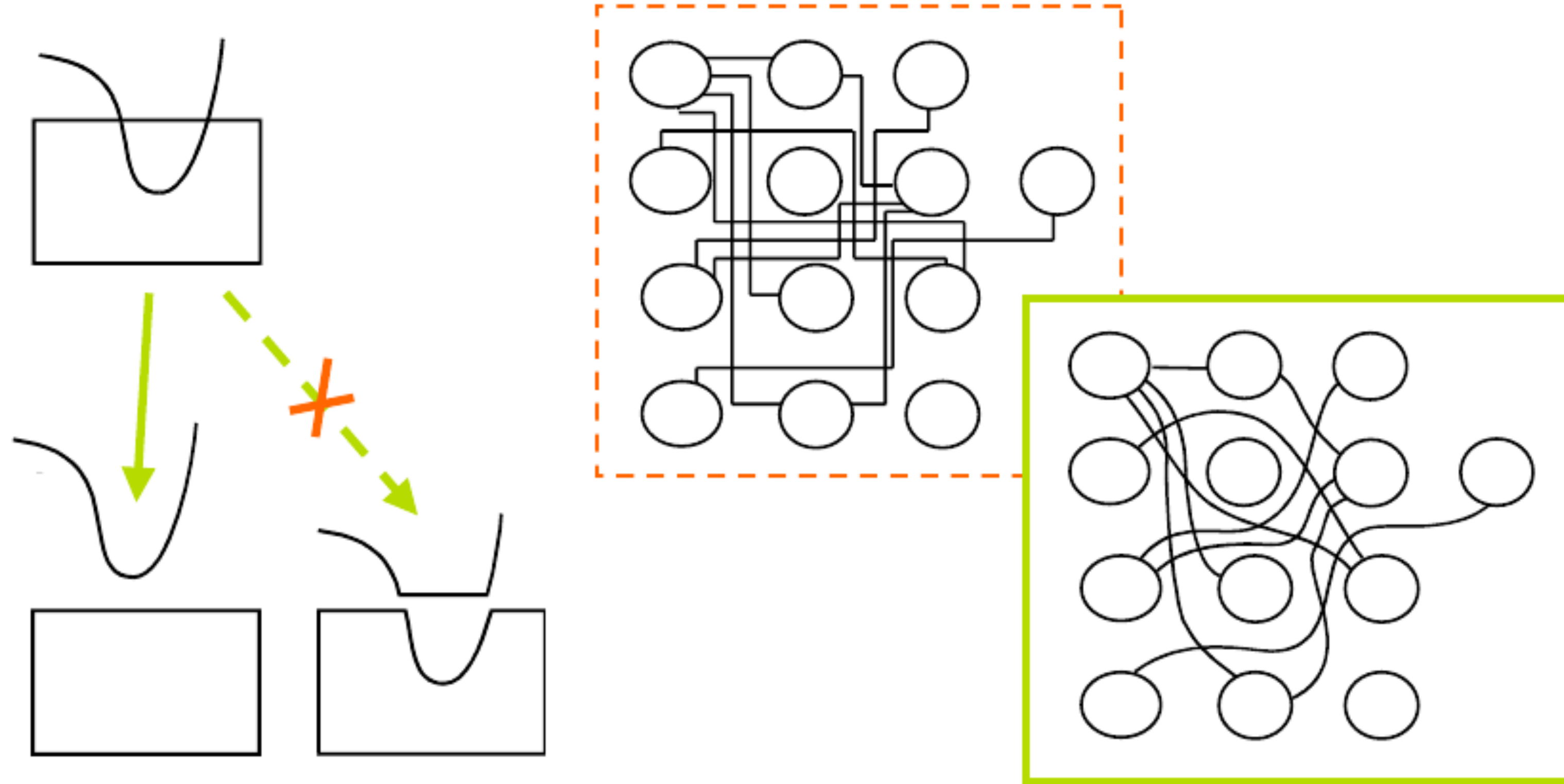
# Continuity Principle



Scattered elements

# Continuity

Things: smooth & continuous



# Closure / Completion

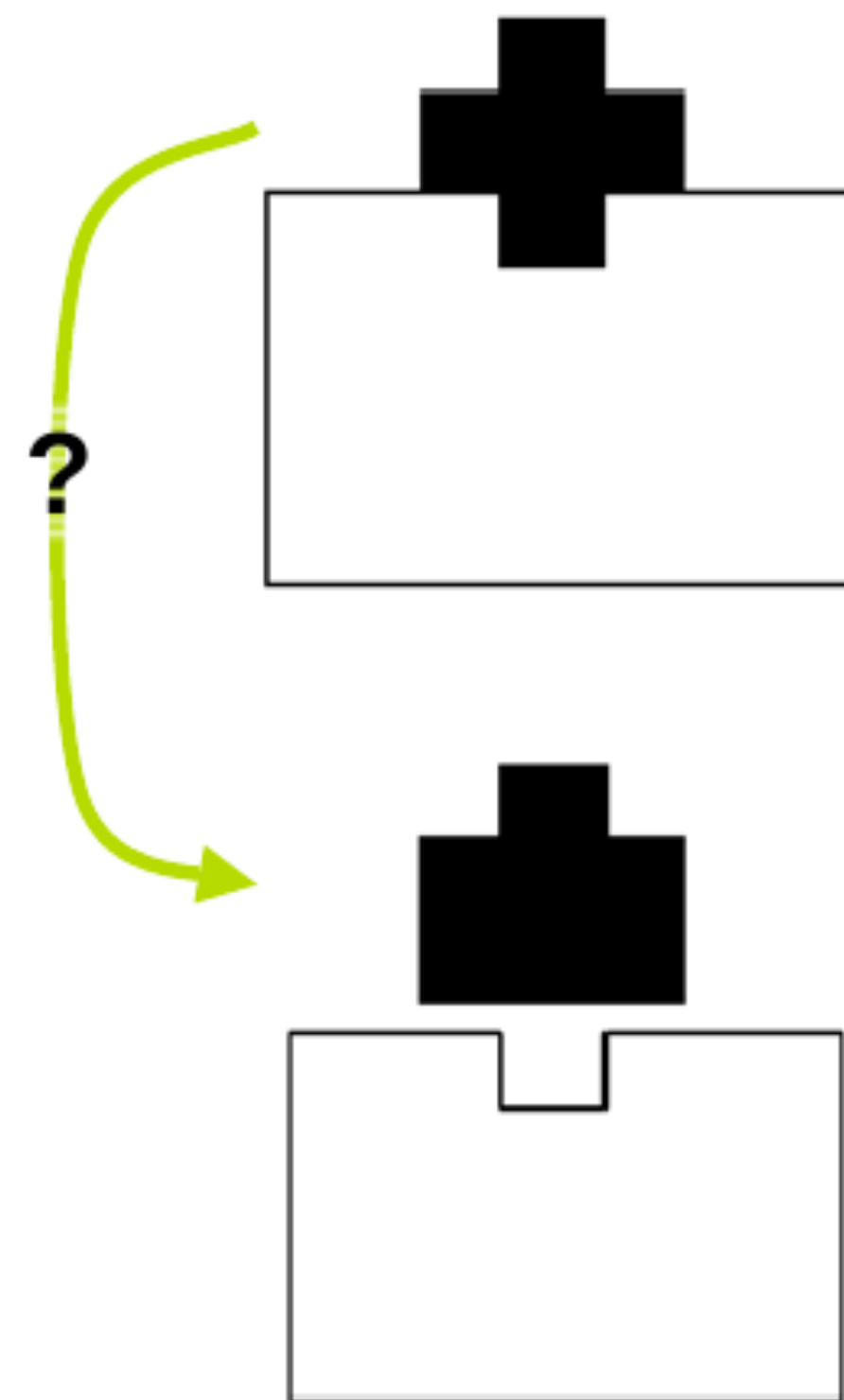
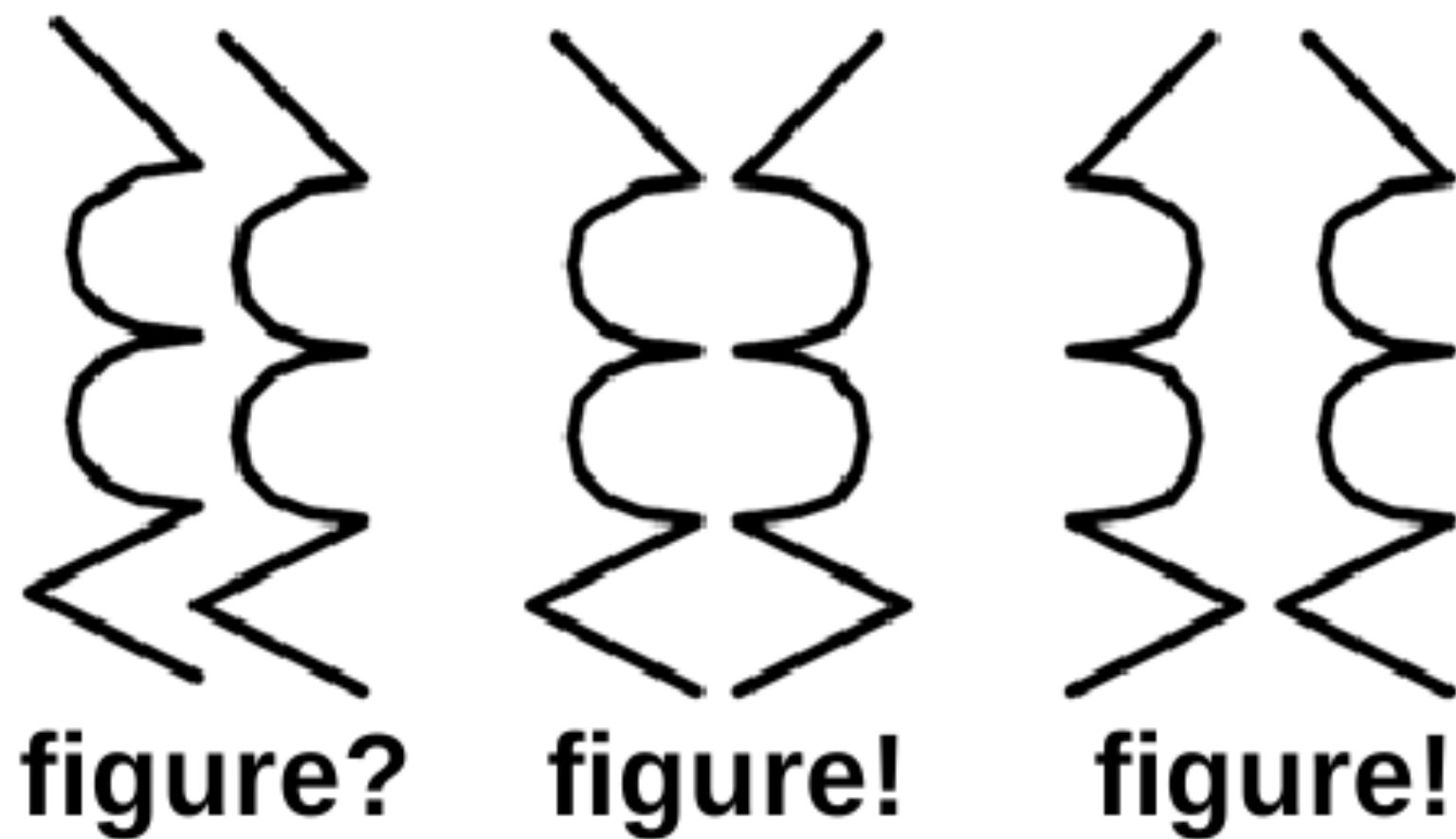


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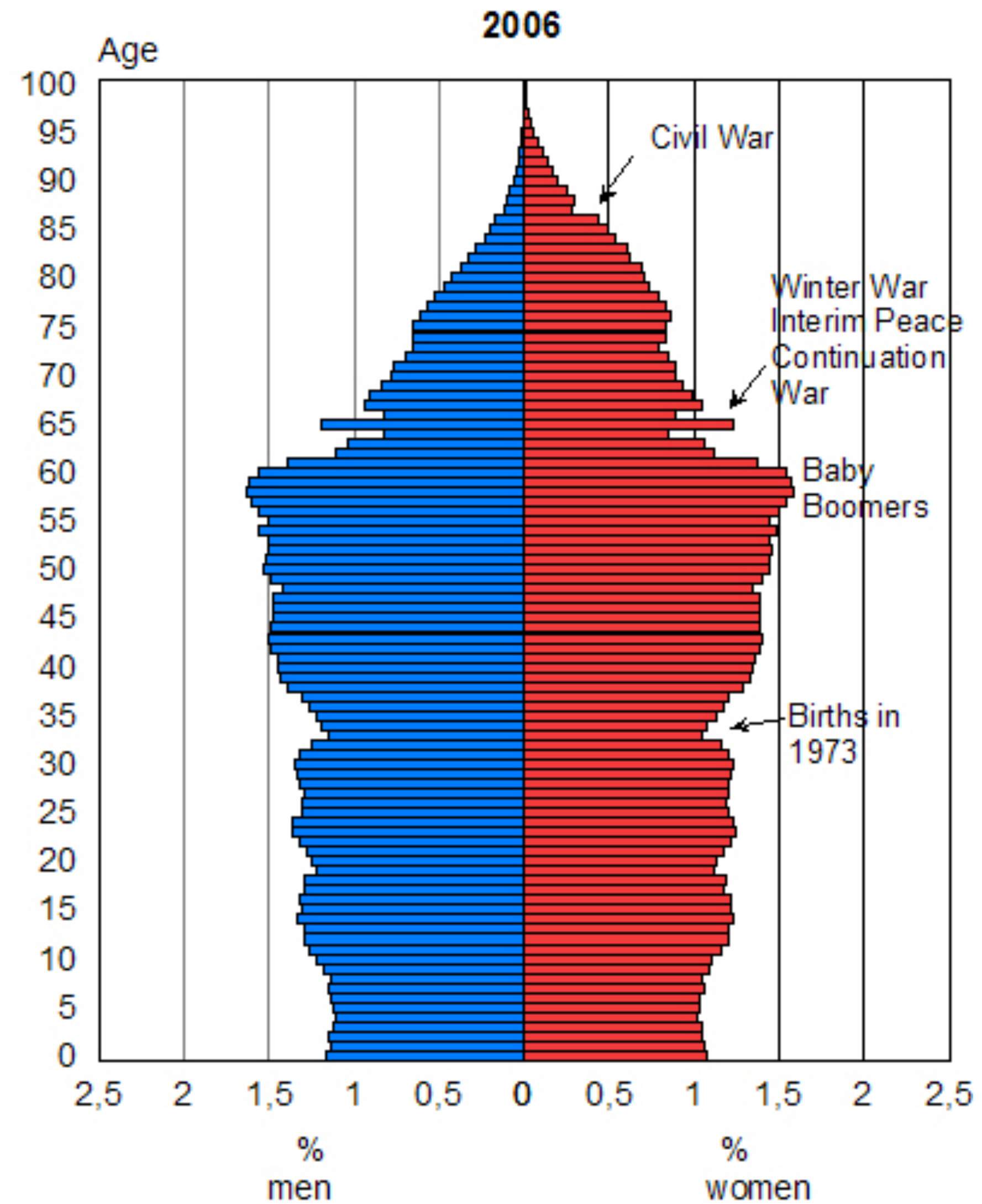
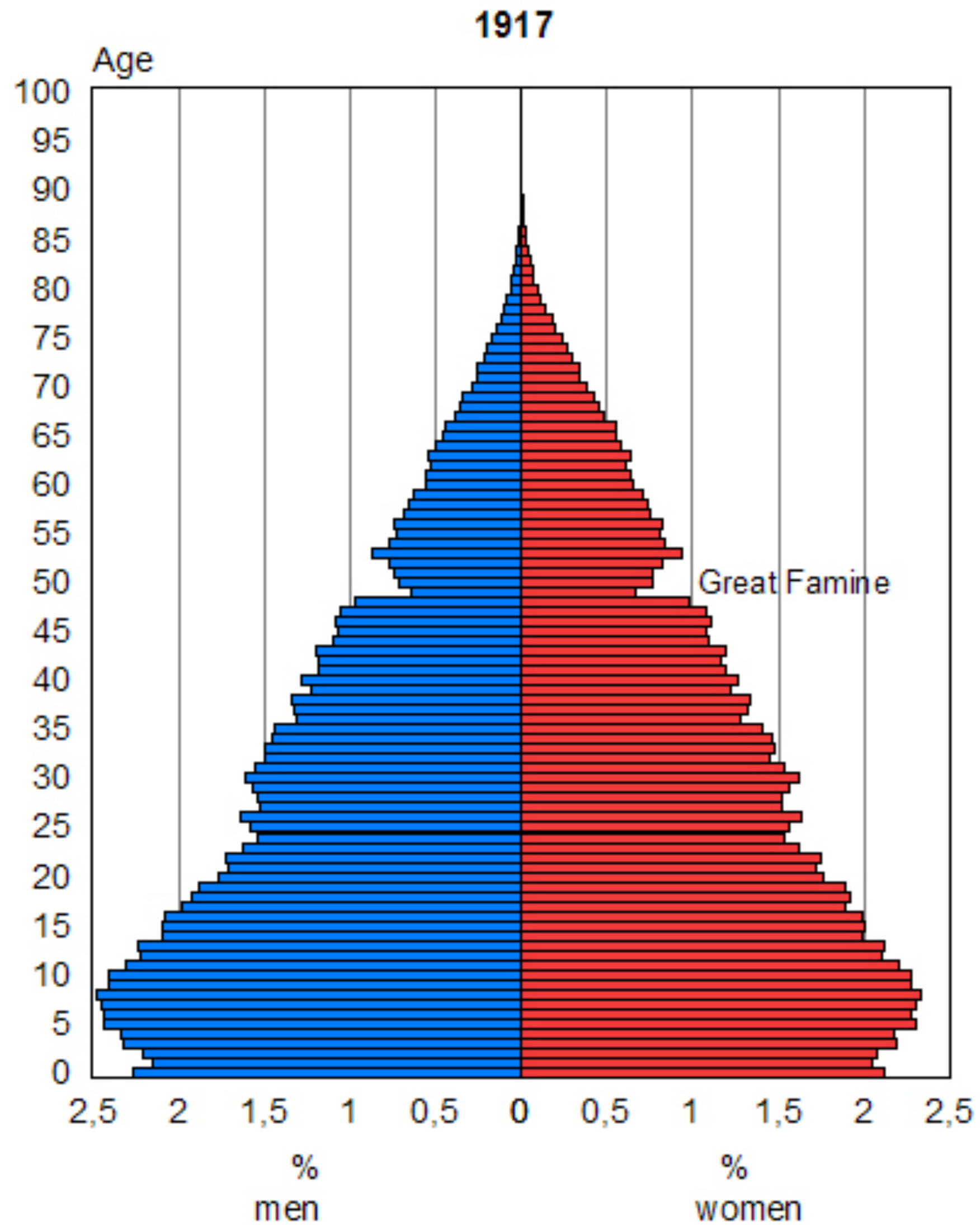


# Symmetry

Things: symmetric

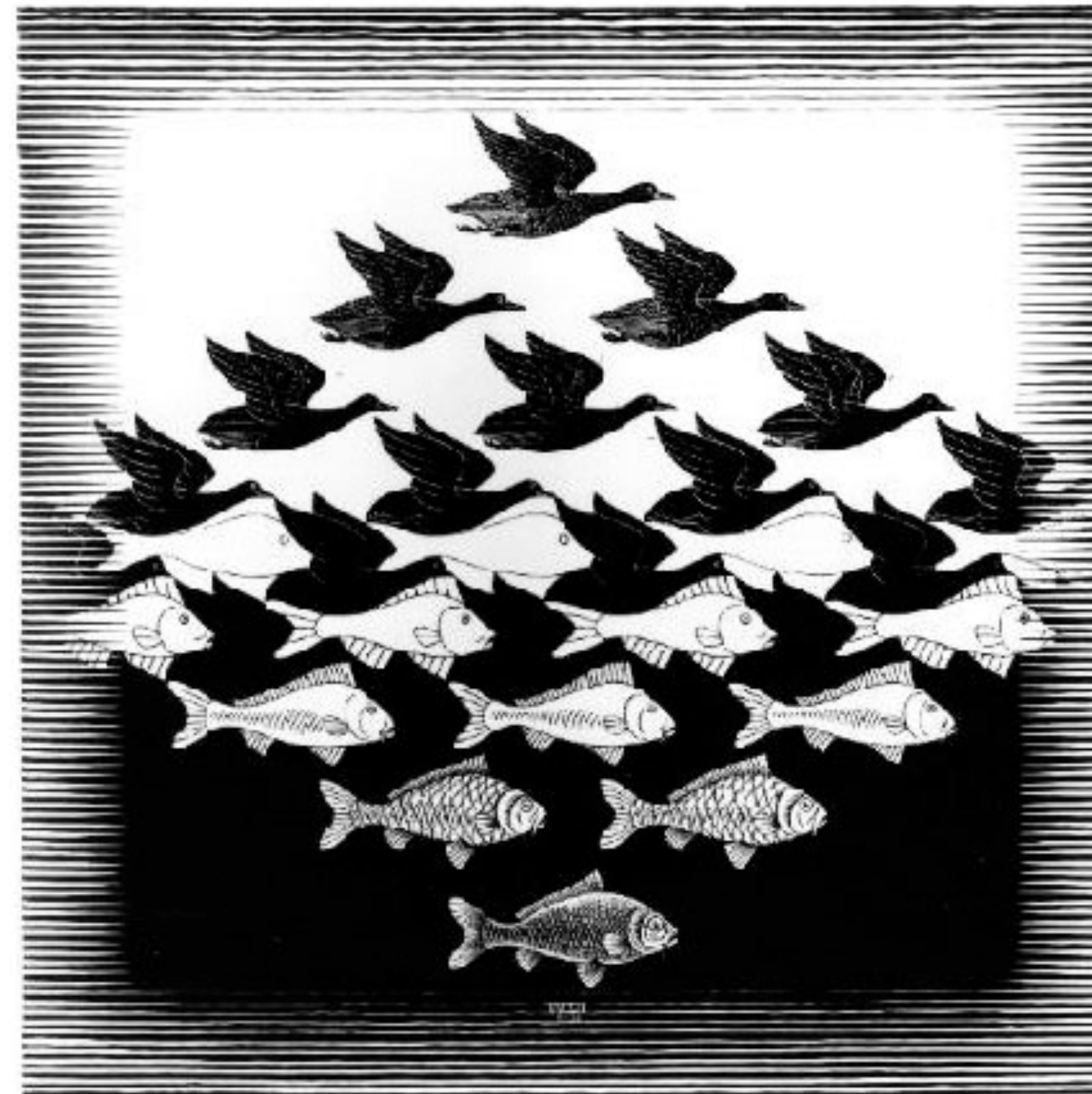


# Population Pyramid



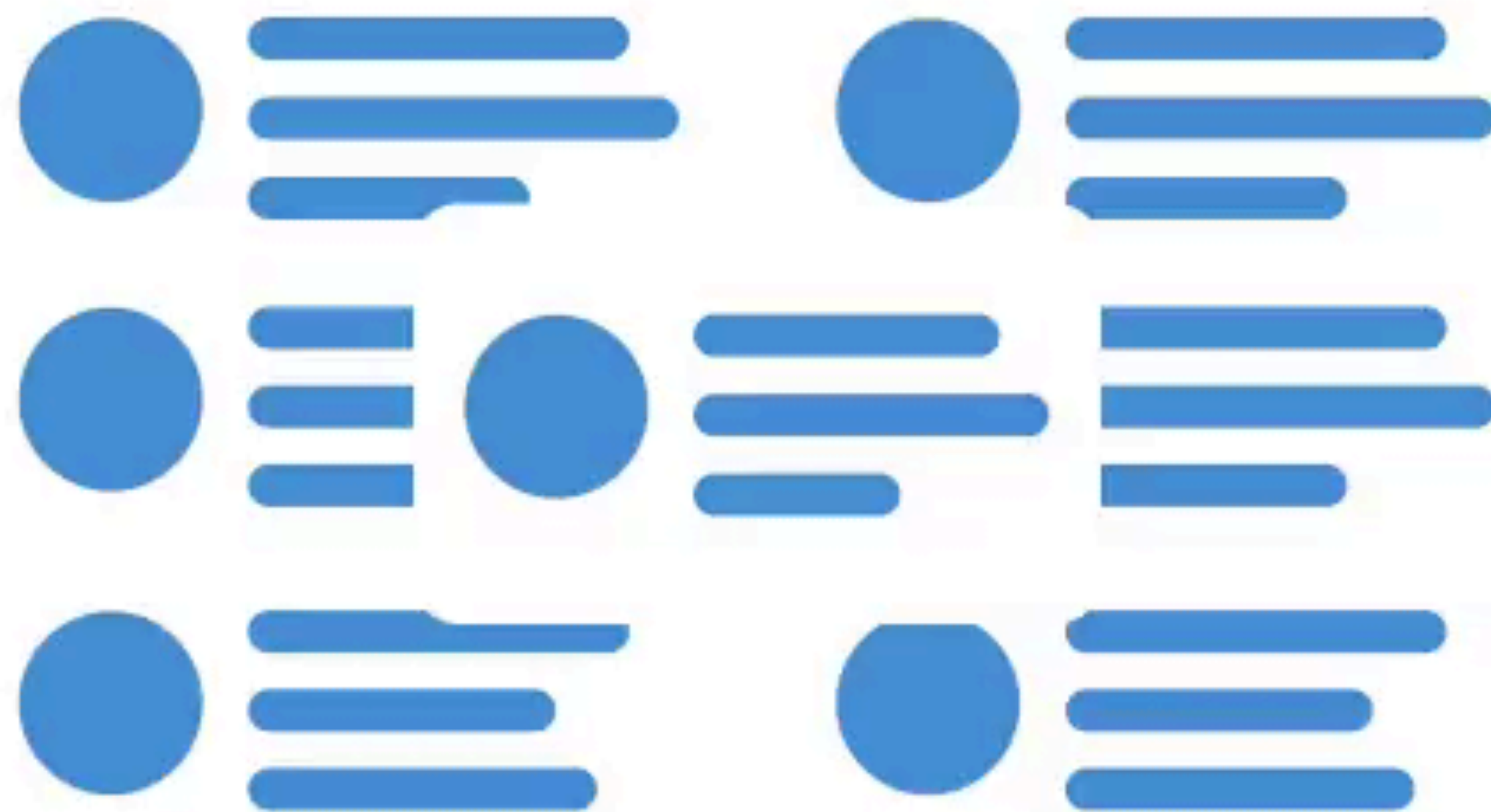


# Figure / Ground



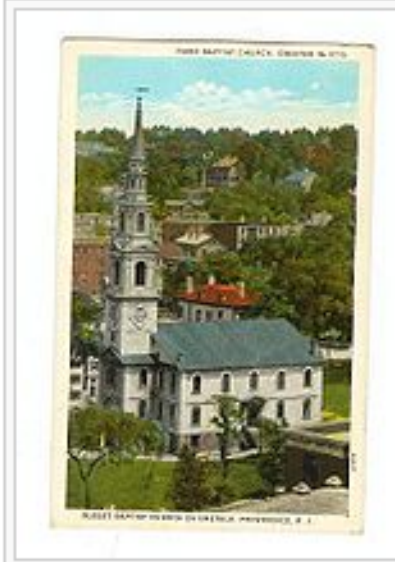
M.C. Escher: *Sky and Water I* 1938 woodcut

## Figure-Ground Articulation



No separation

Applications in Vis



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Following the war, Providence was the country's ninth-largest city,<sup>bj</sup><sup>[13]</sup> with 7,614 people. The economy shifted from maritime endeavors to manufacturing, particularly machinery, tools, silverware, jewelry and textiles. By the turn of the twentieth century, Providence boasted some of the largest manufacturing plants in the country, including Brown & Sharpe



Providence in the mid-nineteenth century



NPS map of the W3R Route





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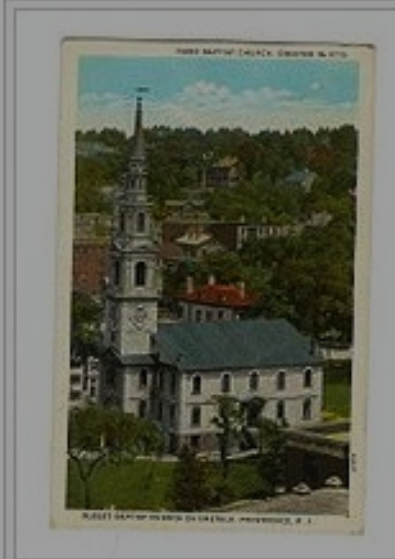
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Google maps Search Maps





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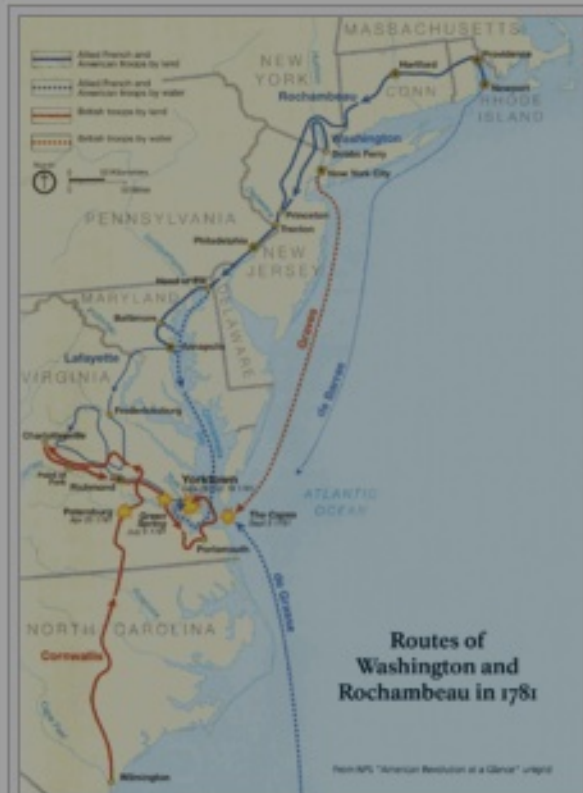
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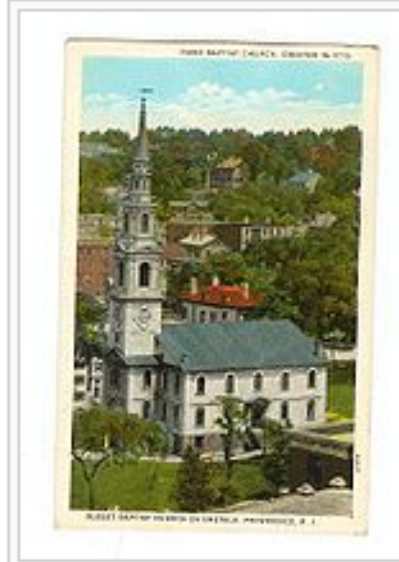


NPS map of the W3R Route

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Google Maps interface showing a map of the Northeastern United States. The search bar contains 'mexico'. The map displays major cities like Boston, New York, Philadelphia, and Washington, D.C., along with state boundaries for Connecticut, New Jersey, Delaware, and Virginia. A scale bar at the bottom indicates 50 miles and 100 kilometers. The footer contains copyright information: ©2011 Google - Map data ©2011 Google - Terms of Use Report a problem



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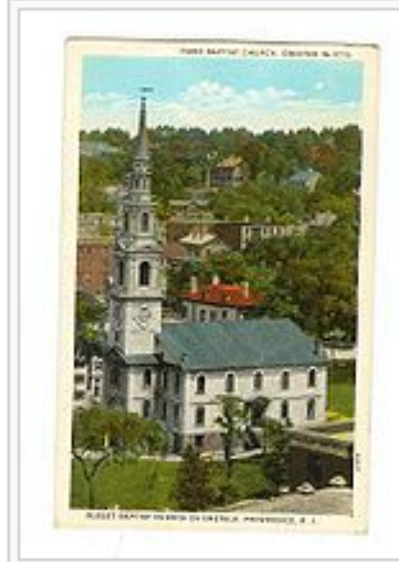


Providence in the mid-nineteenth century



NPS map of the W3R Route





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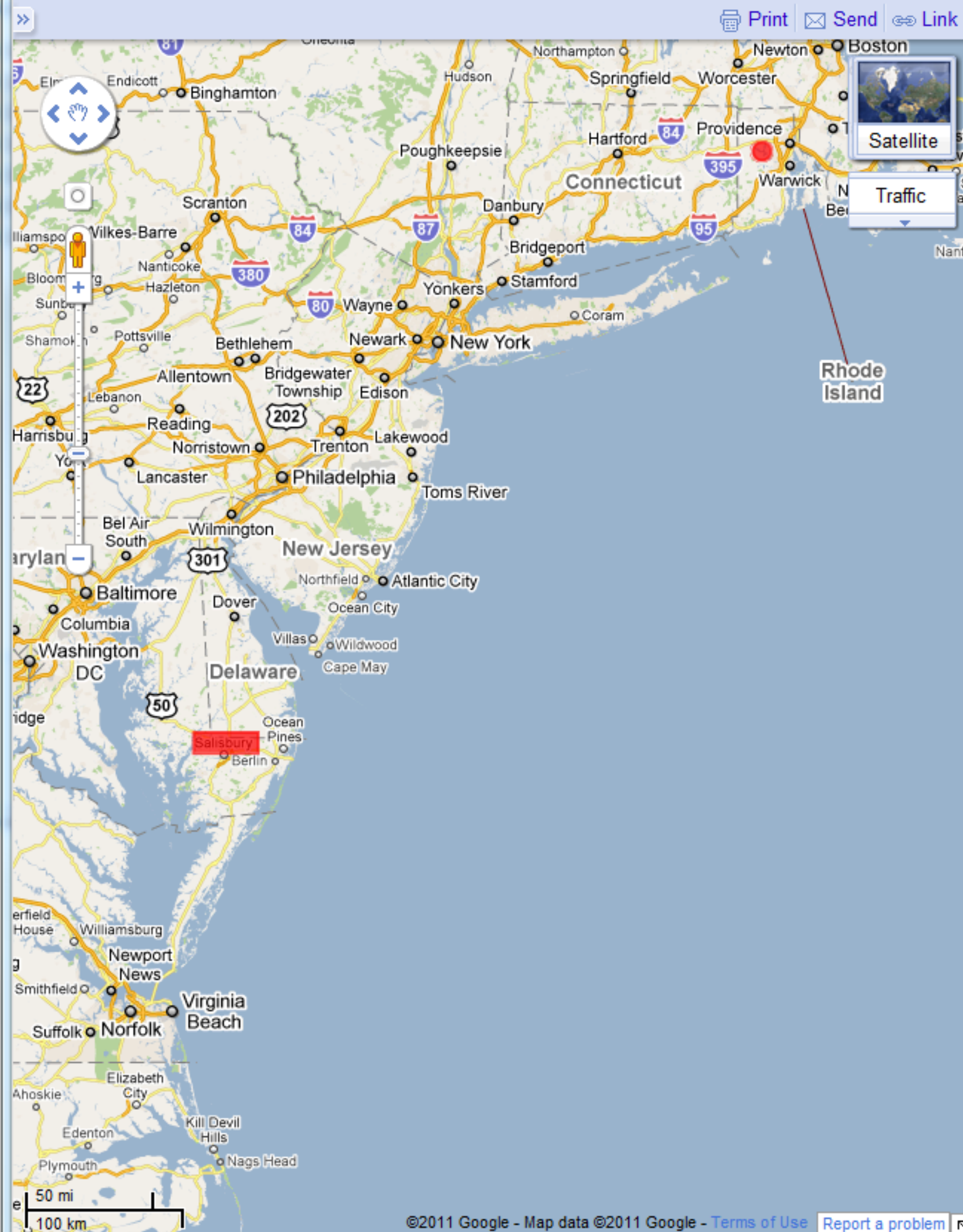
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NPS map of the W3R Route





edia.org/wiki/Providence,\_Rhode\_Island





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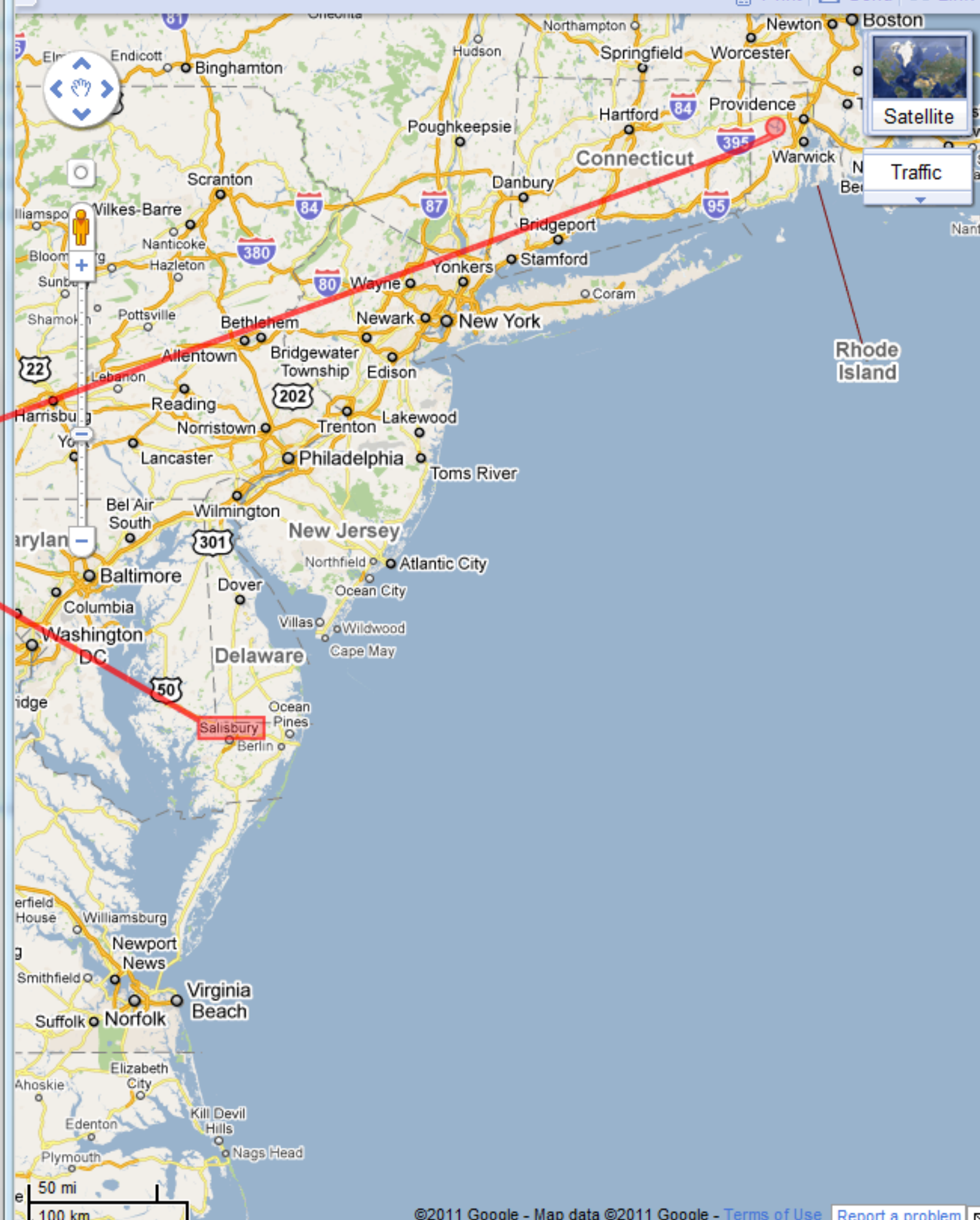
NPS map of the W3R Route

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Rhode Island

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What is the problem?

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**Visual Links:** Red lines connect the text to the map. One line connects "Providence" in the text to the city of Providence on the map. Another line connects "Newport" in the text to Newport, Rhode Island. A third line connects "Yorktown" in the text to Yorktown, Virginia. A fourth line connects "the Chesapeake" in the text to the Chesapeake Bay area. A fifth line connects "the Atlantic Ocean" in the text to the Atlantic Ocean on the map.

# 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