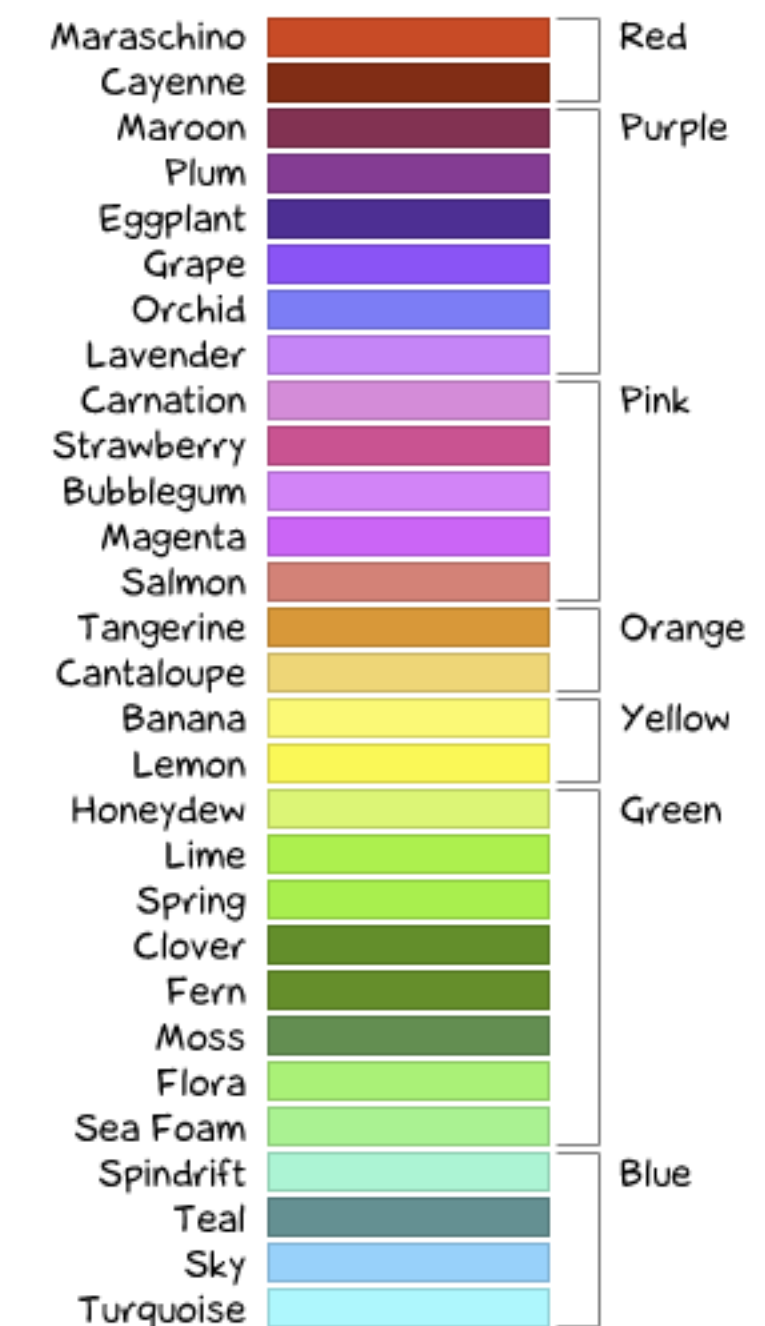


# CS171 Visualization

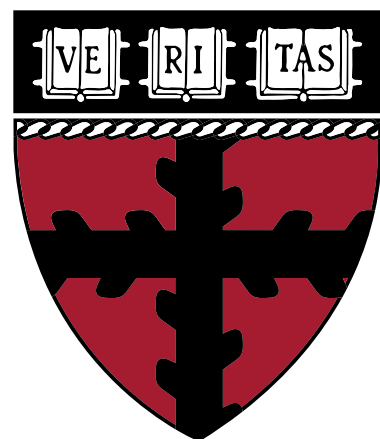
Alexander Lex  
[alex@seas.harvard.edu](mailto:alex@seas.harvard.edu)

Perception,  
Cognition,  
Color

Color names if  
you're a girl...



Color names if  
you're a guy...



**HARVARD**  
School of Engineering  
and Applied Sciences

Doghouse Diaries  
"We take no as an answer."

[Doghouse Diaries]

# 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

Looking vs. Seeing



perceptual hysteresis





we rely on priors

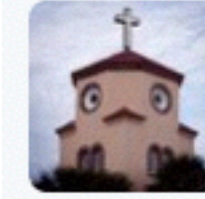






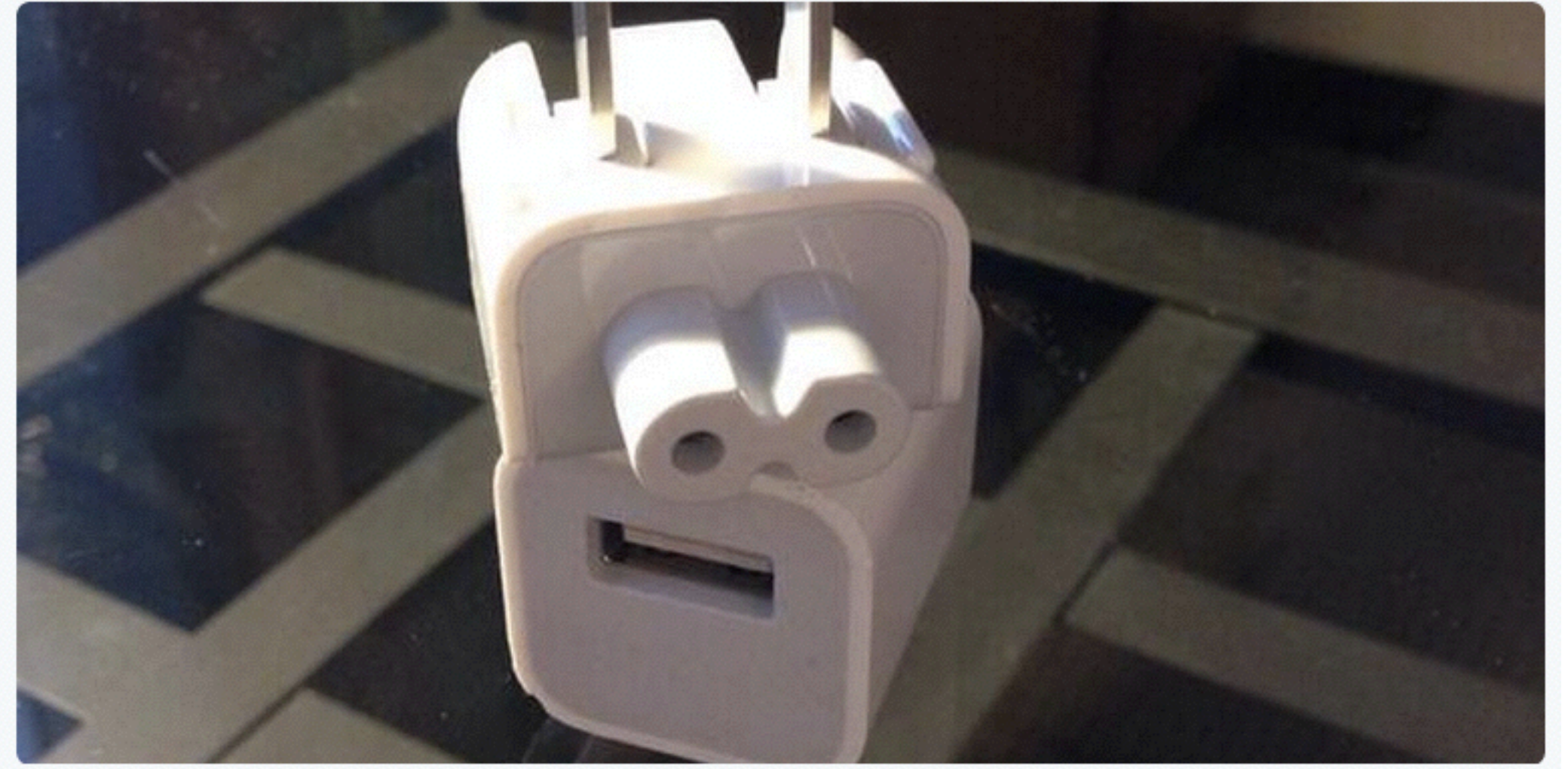
**Faces in Things** @FacesPics · Mar 9

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



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

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



**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 10

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



# Take Home Point

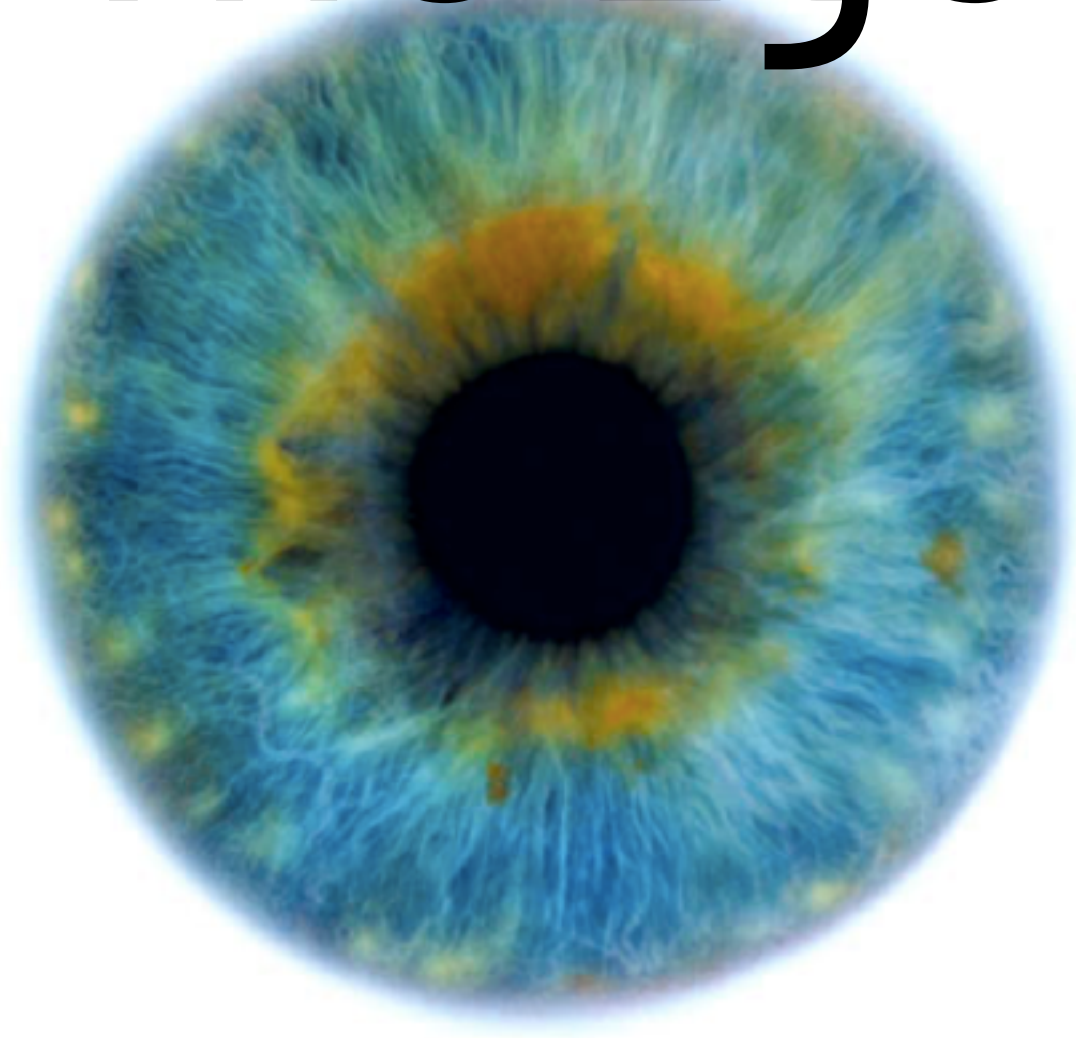
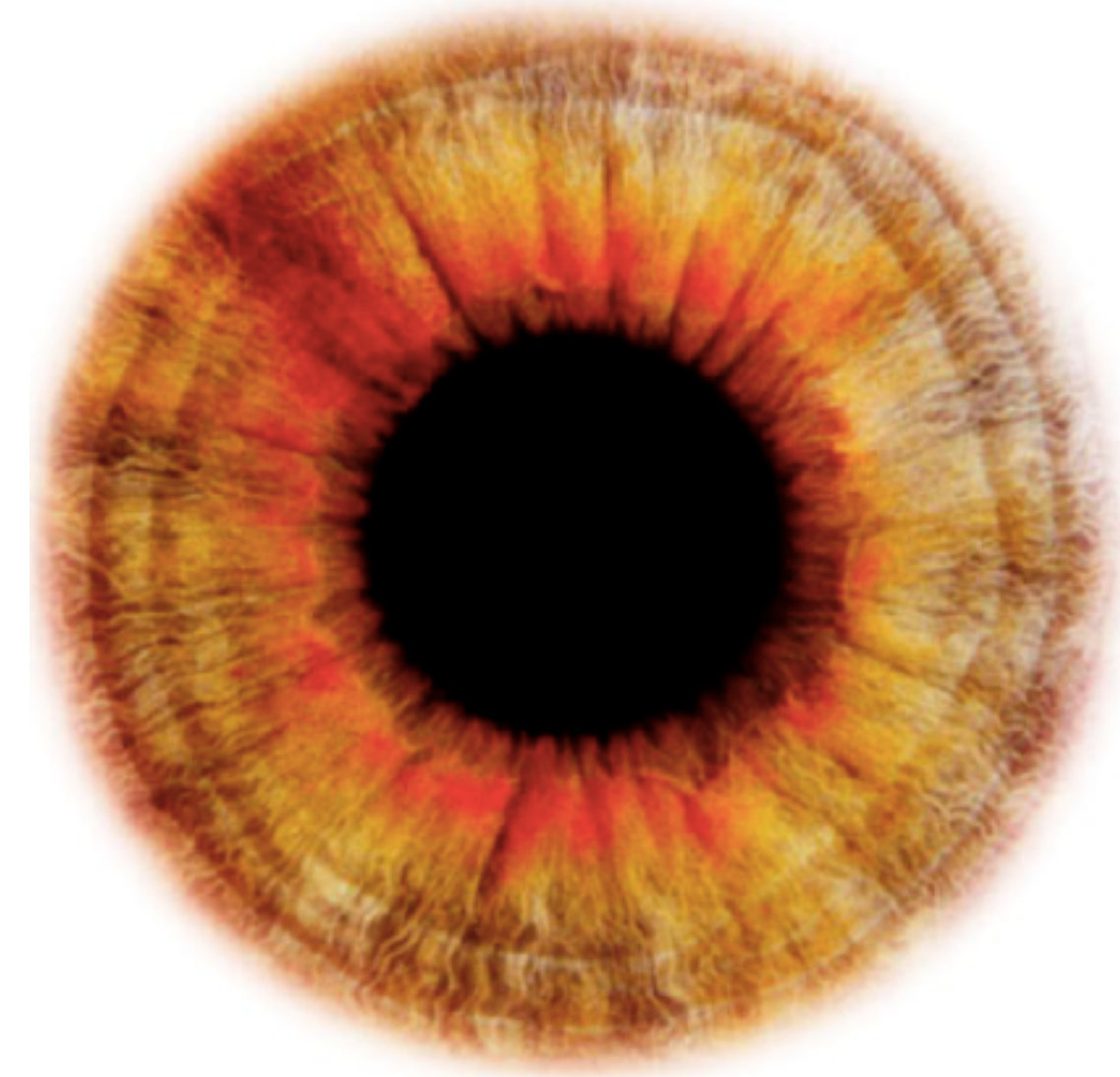
Vision is “constructed” top down from the input

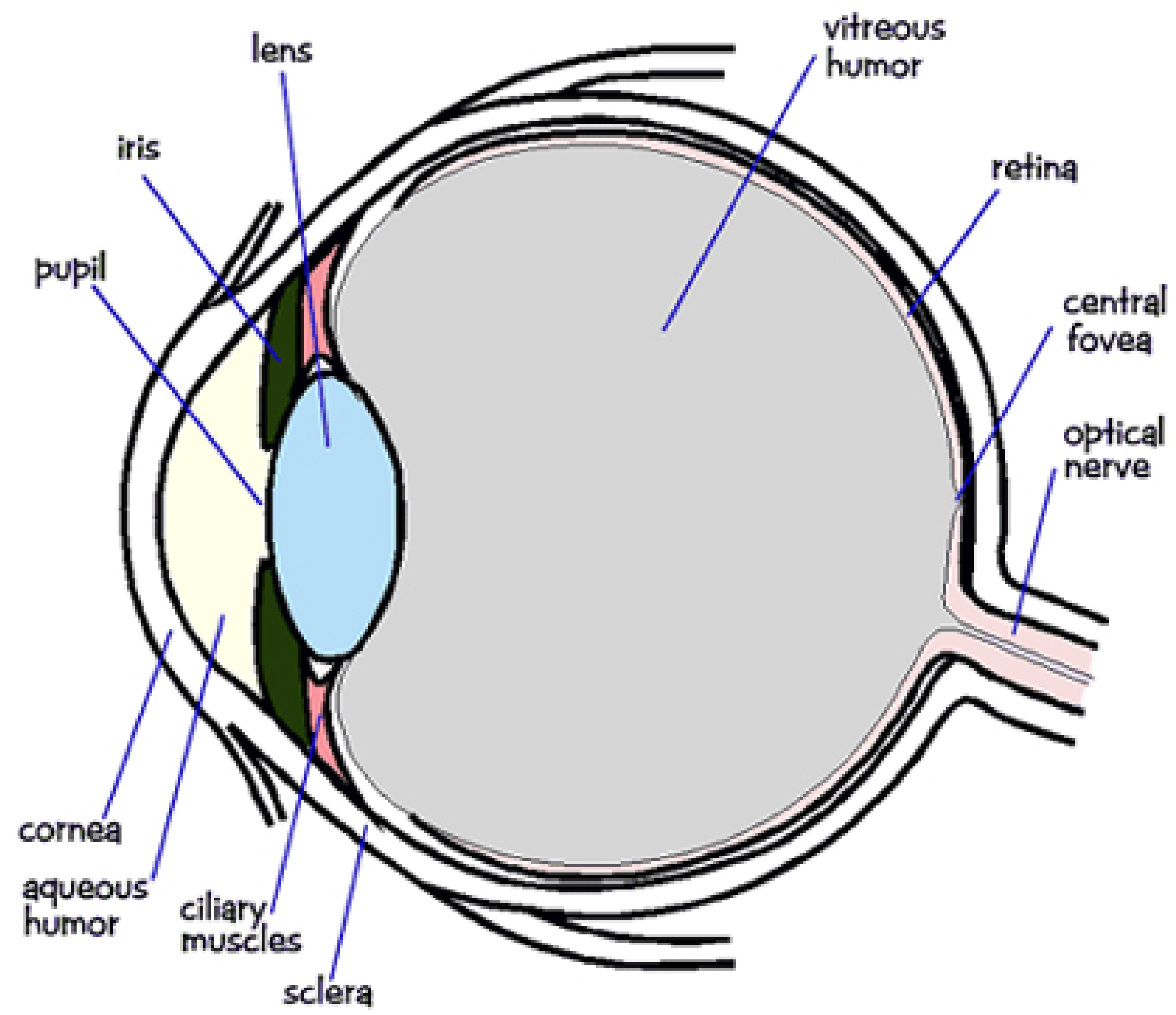
*“What you see when you see a thing depends on what the thing is. What you see the thing as depends on what you know about what you are seeing.”*

Zenon Pylyshyn  
Canadian Cognitive Scientist  
and Philosopher

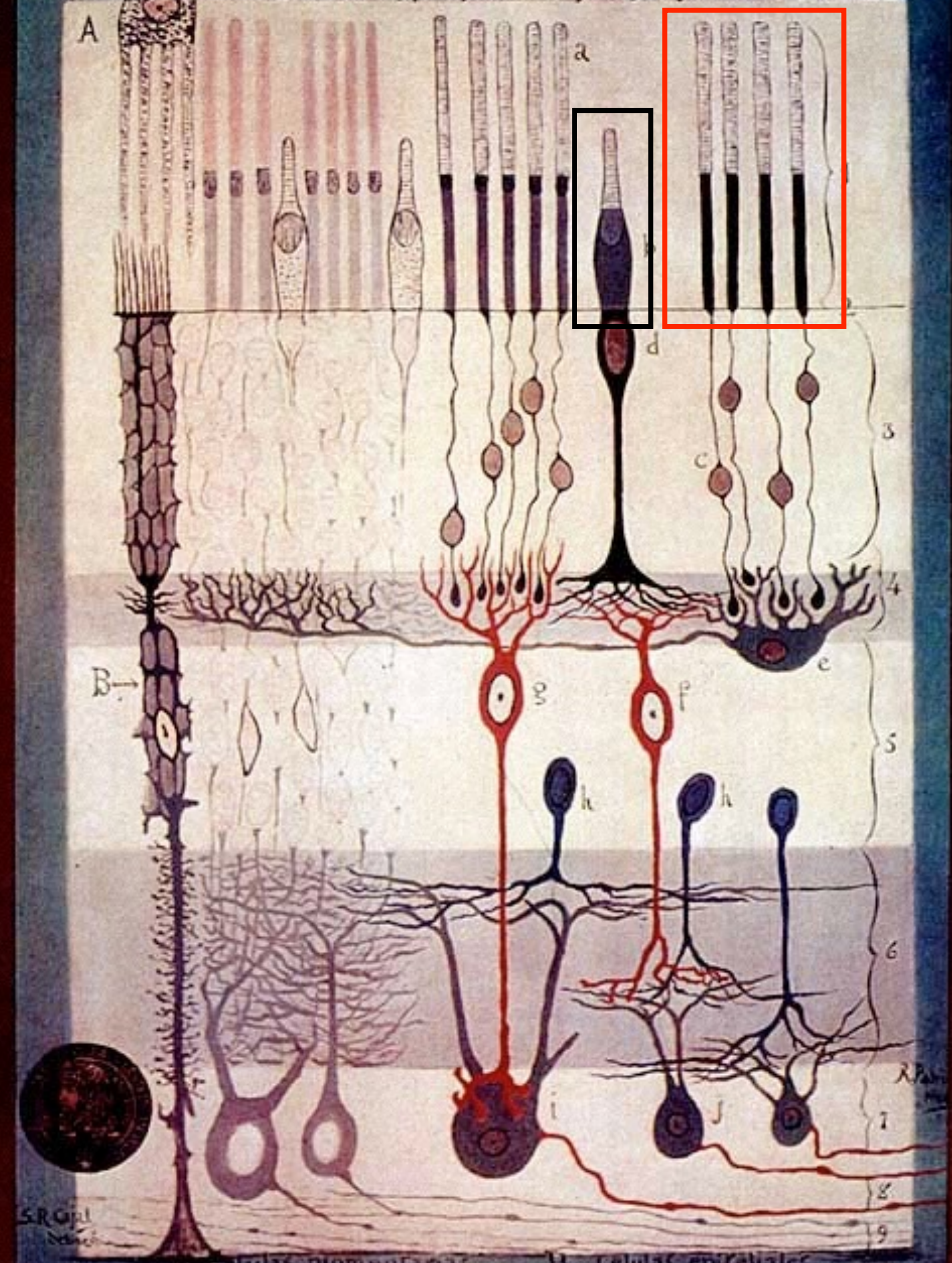


# The Eye





1. Capa de los conos y bastones. 2. Capa limitante externa. 3. Capa de los granos externos. 4. Capa plexiforme externa. 5. Capa de los granos internos. 6. Capa plexiforme interna. 7. Capa de las células ganglionares. 8. Capa de las fibras del nervio óptico. 9. Capa limitante interna.



Rods

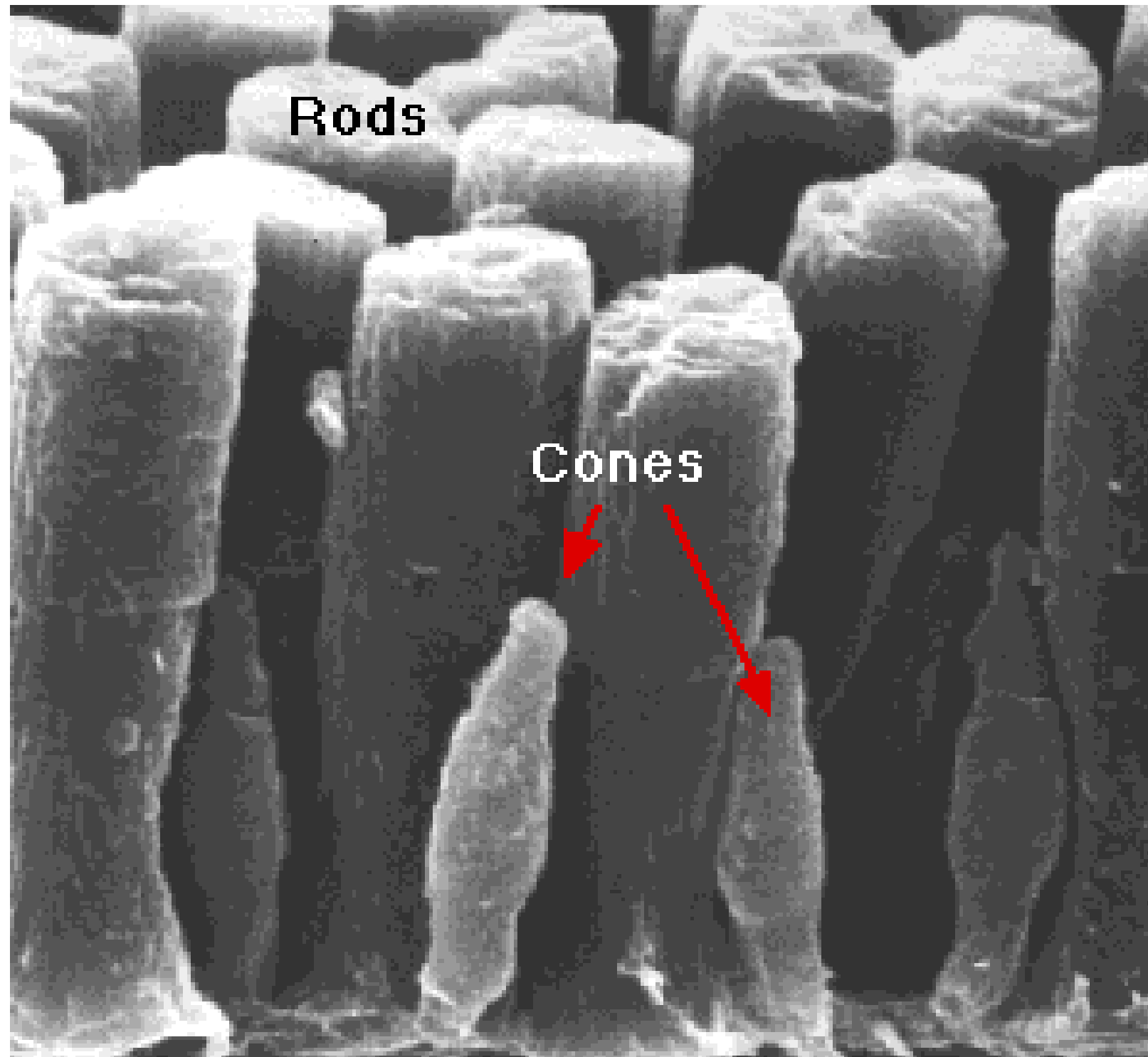
Cones

Ganglion Cells

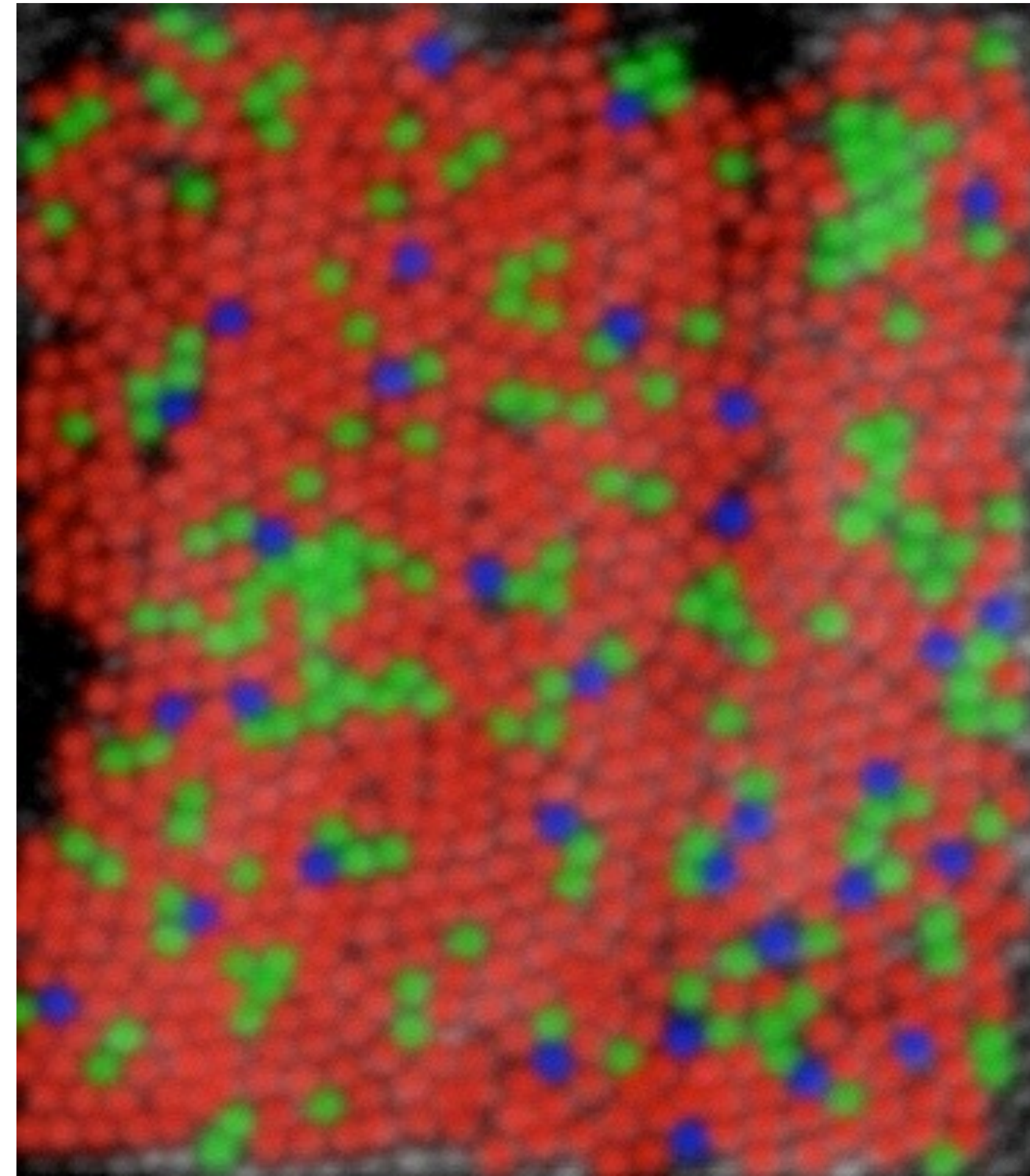
A. células pigmentarias. B. células epiteliales. a. bastones. b. conos. c. núcleo de los bastones. d. núcleo de los conos. e. célula horizontal grande. f. bipolar relacionada con los conos. g. bipolar relacionada con los bastones.

Auto Cajal. CSIC. Madrid.

"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%

Wandell, "Foundations of Vision" (left)  
David R. Williams, Univ. of Rochester (right)

# Human Visual System

6.5 mio cones

color vision

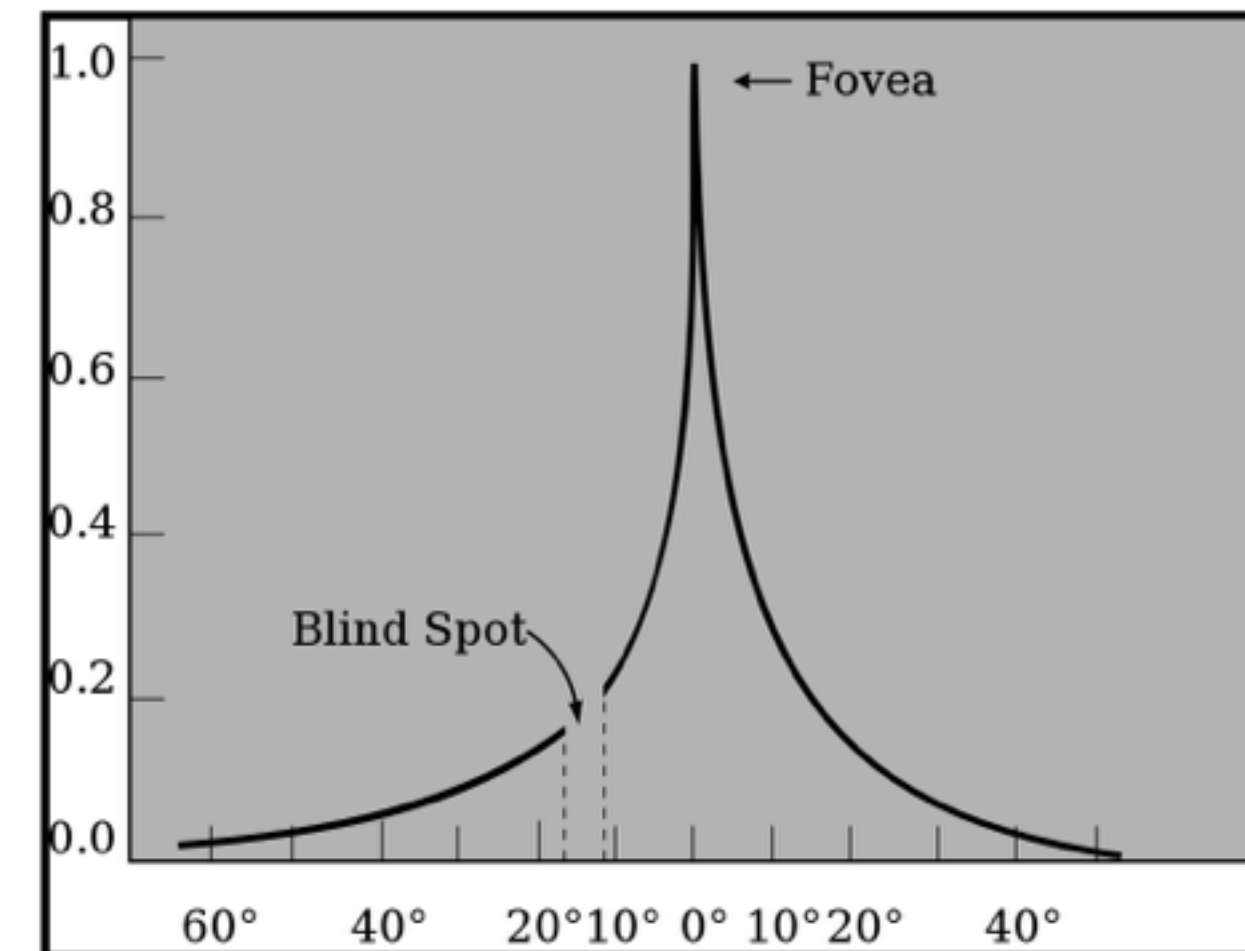
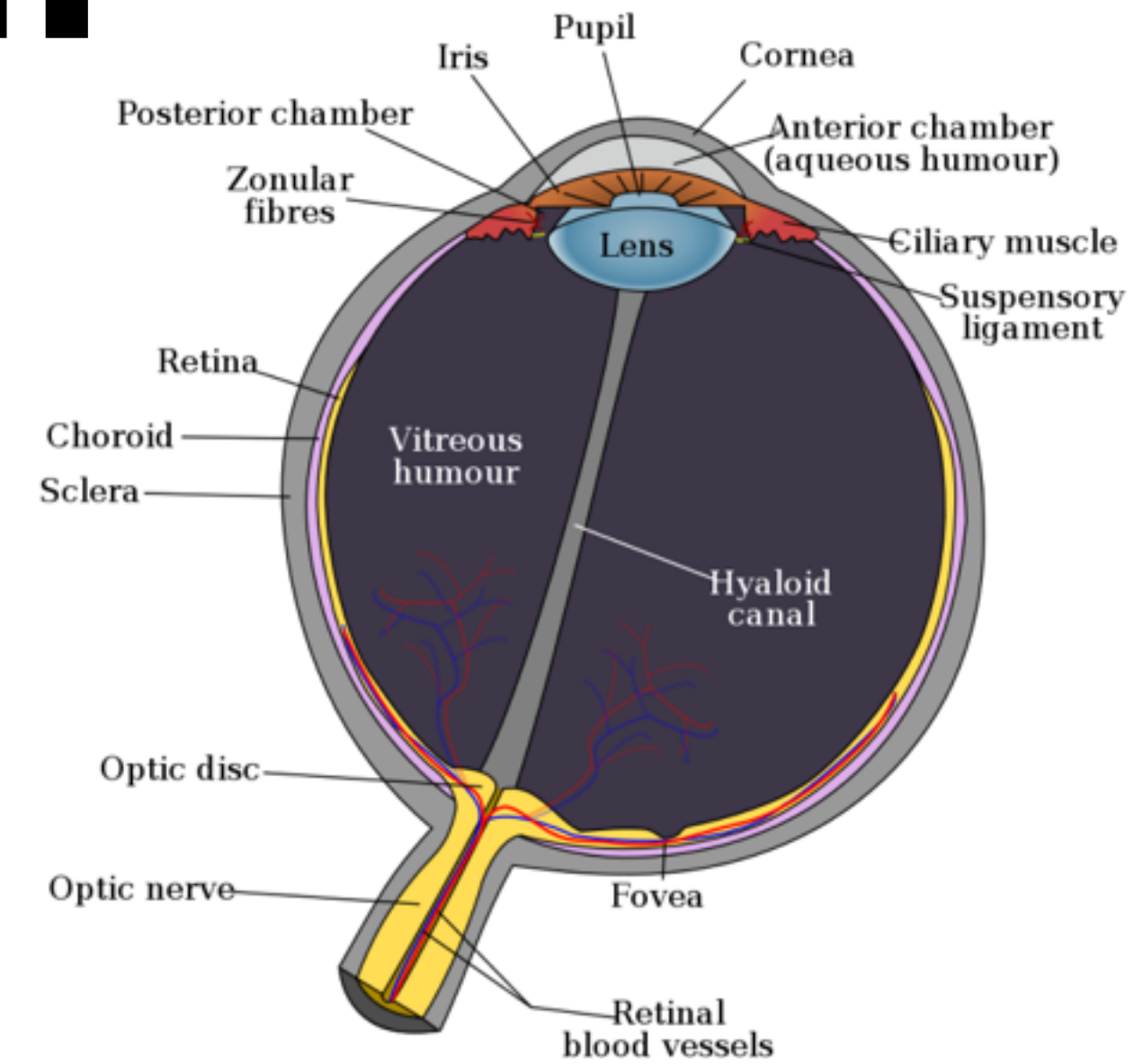
dense in the center

**Fovea:** 27 times the density

responsible for sharp central vision

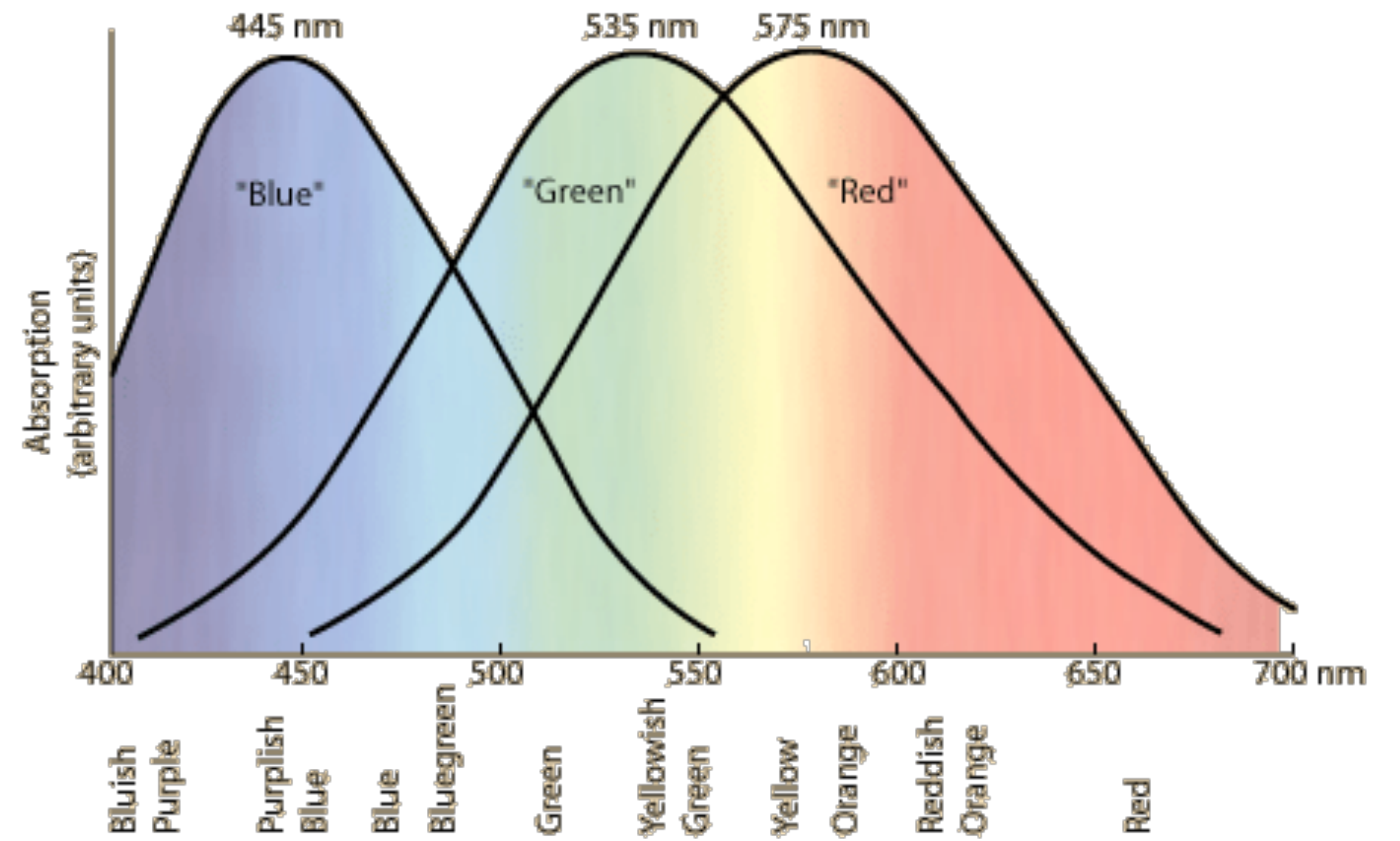
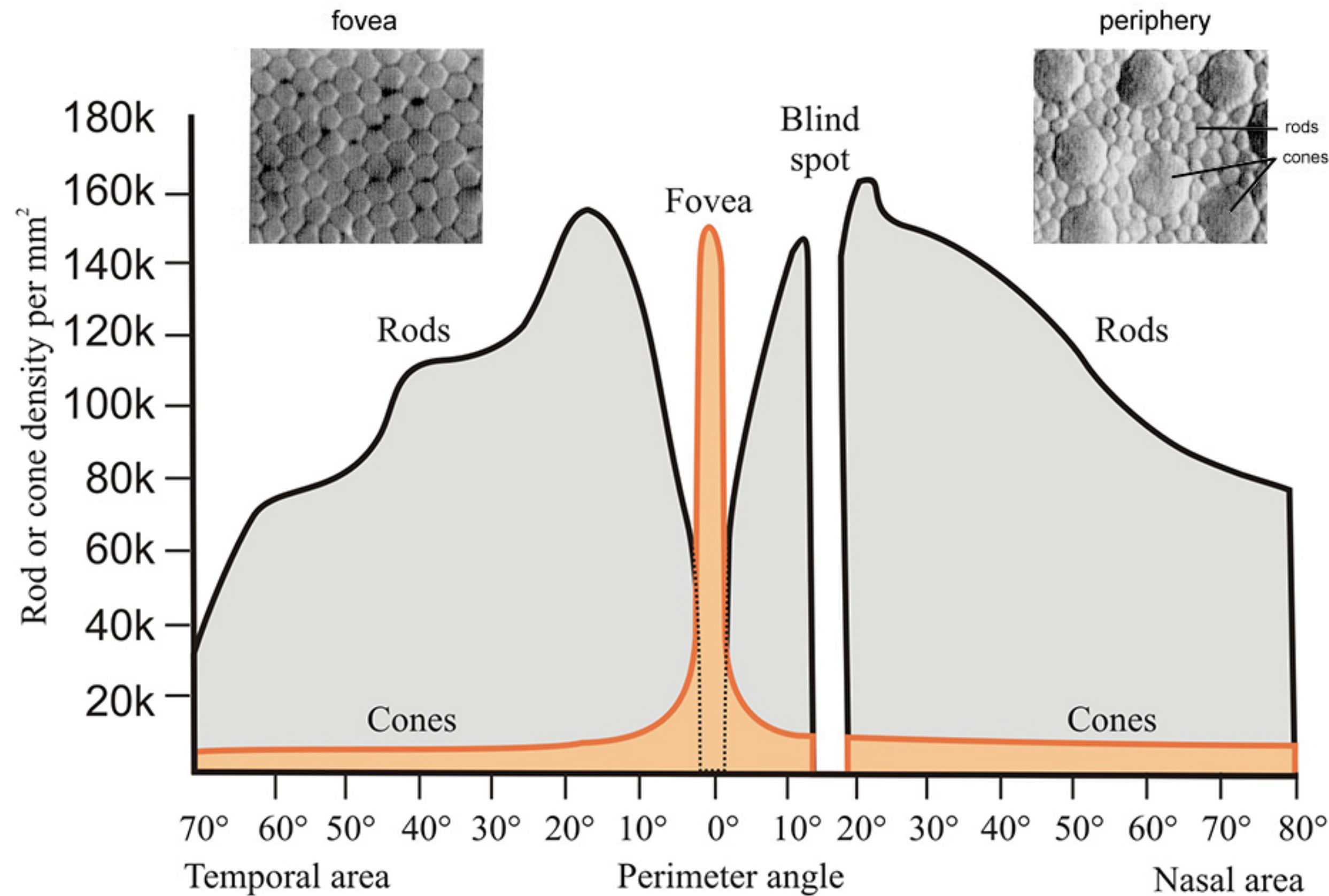
118.5 mio rods

black/white





# Cone Response





# Human Visual System

VIDEO!

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

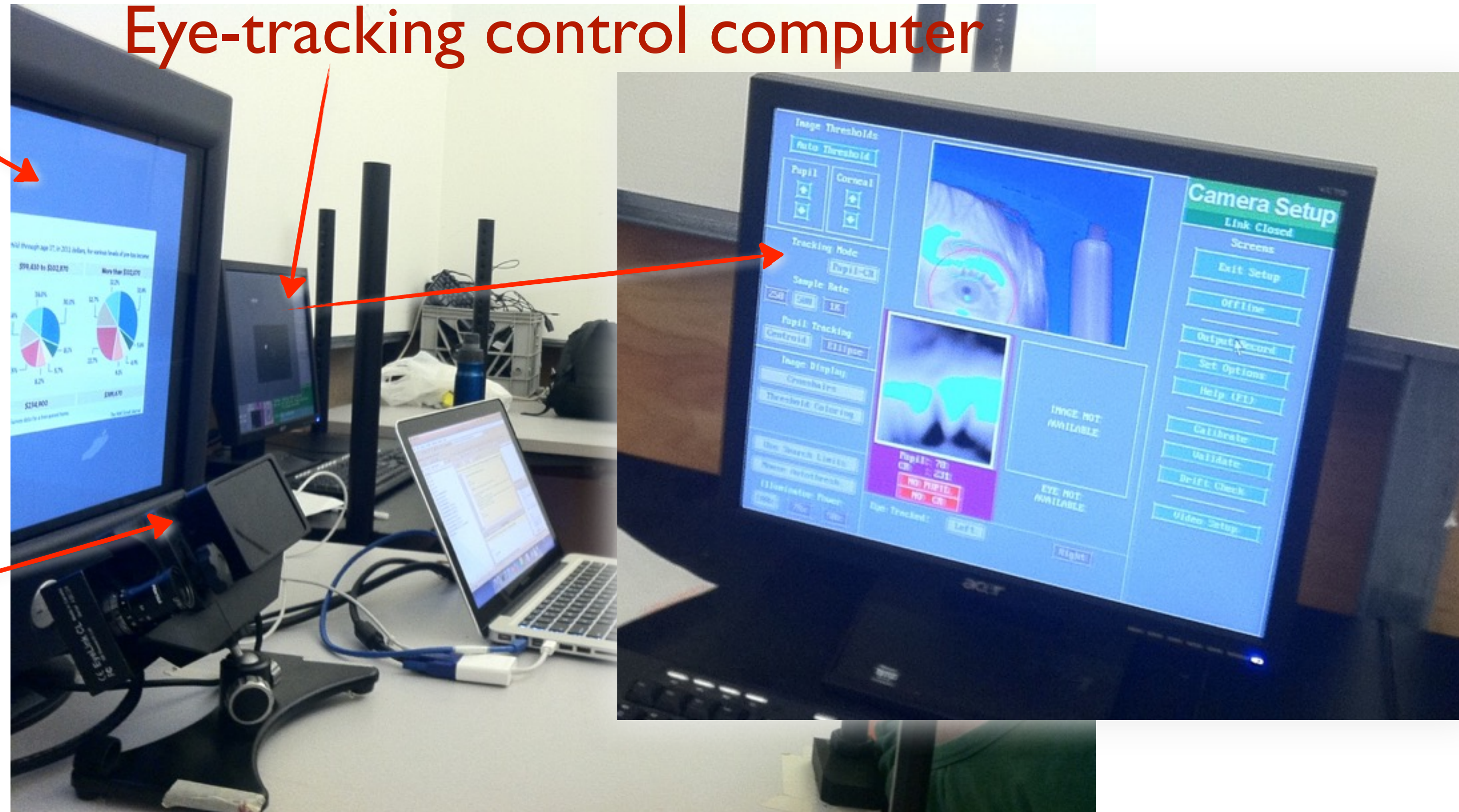


# Eye-Tracking Experiment

Visualization display

Eye-tracking control computer

Infrared camera



Video!

# Human Visual System

VIDEO!

No general purpose vision

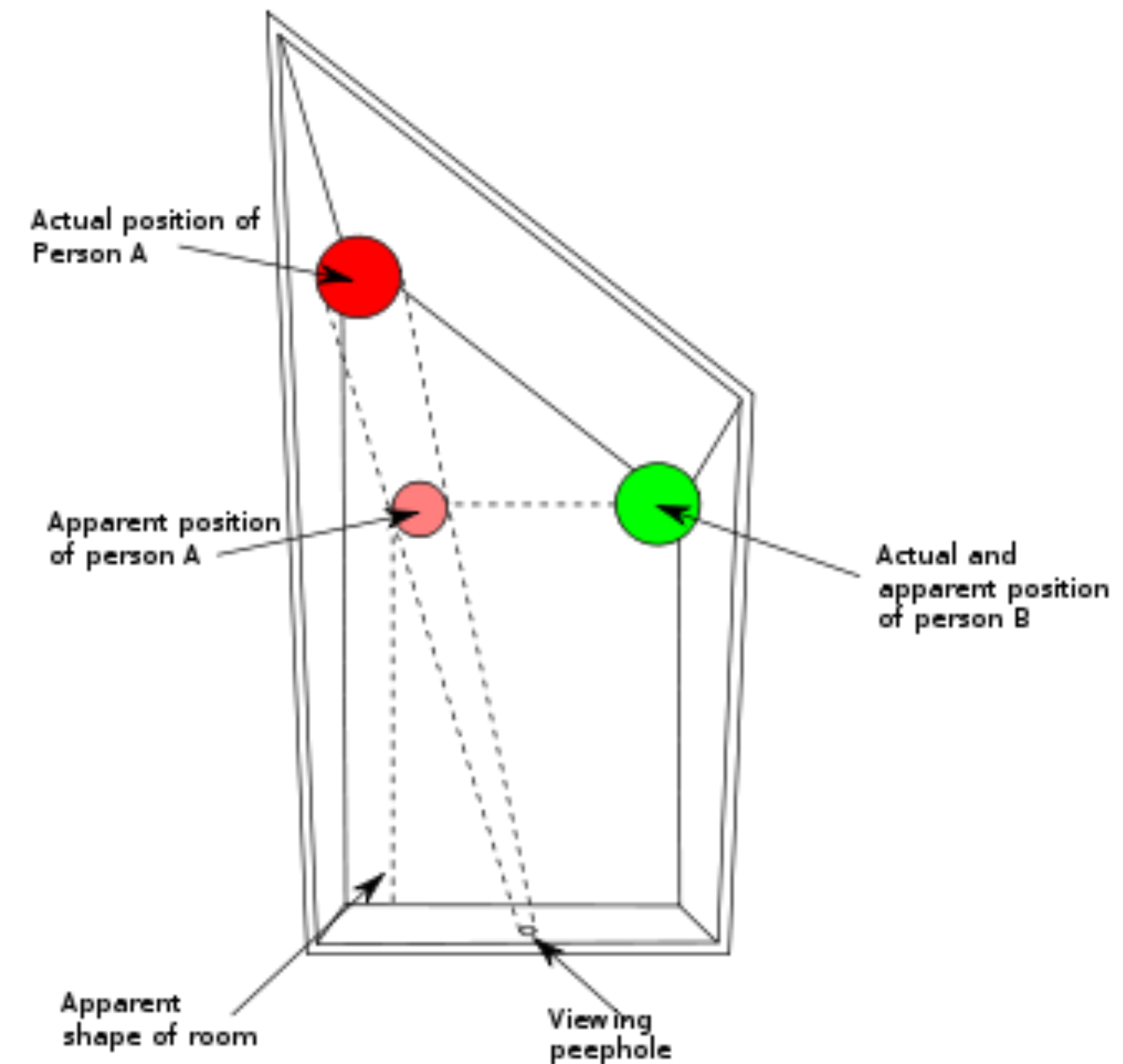
What we see depends on our goals and expectations

Relative judgments: strong

Absolute judgments: weak



Ames Room



Color

# Color Basics

Visible part of the electromagnetic spectrum

390-750 nm

Spectral colors

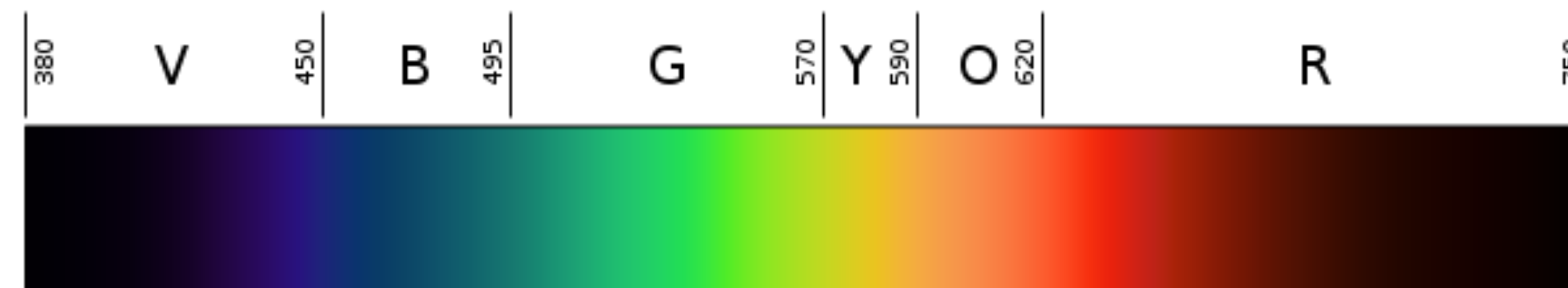
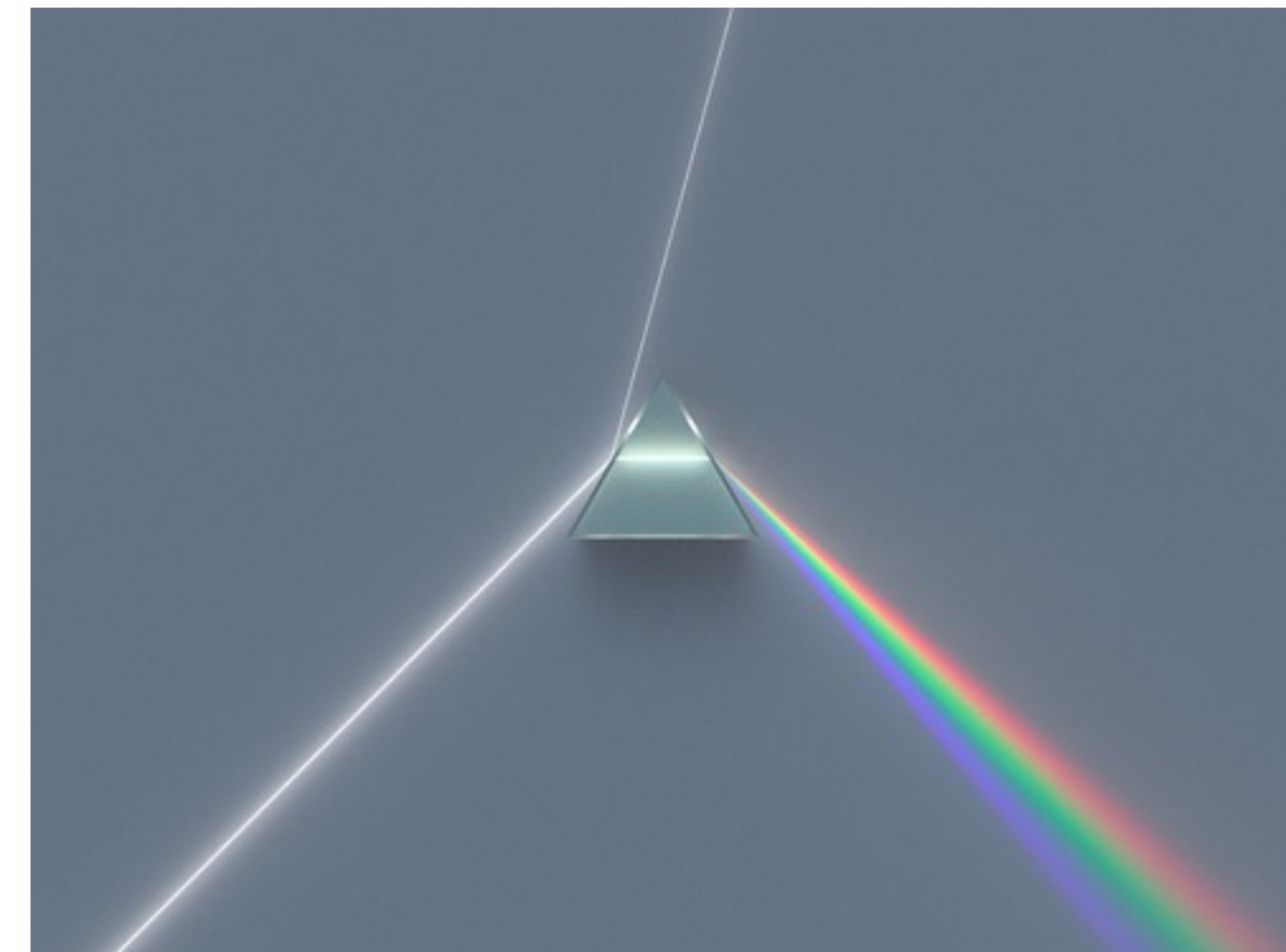
evoked by a single wavelength

Other colors: unsaturated colors

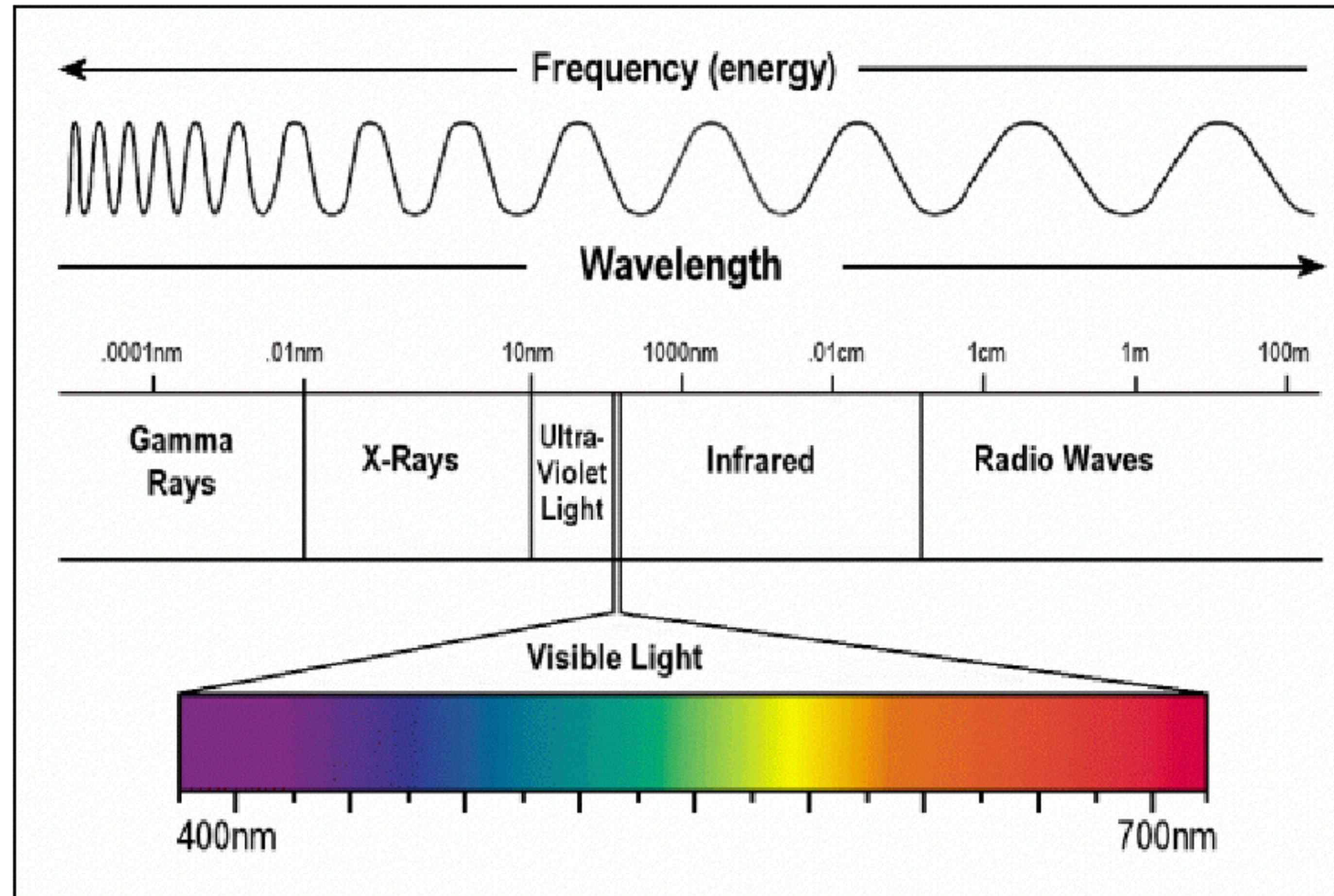
Gray scale (achromatic colors)

Mix of multiple wavelengths

e.g. purple, magenta



# Visible Spectrum





# Dimensions of Color

Hue



Saturation

The purity of a color

Value (Luminance, Brightness)

lightness or darkness of a color

high saturation colors have medium values



Different Saturation, medium Value



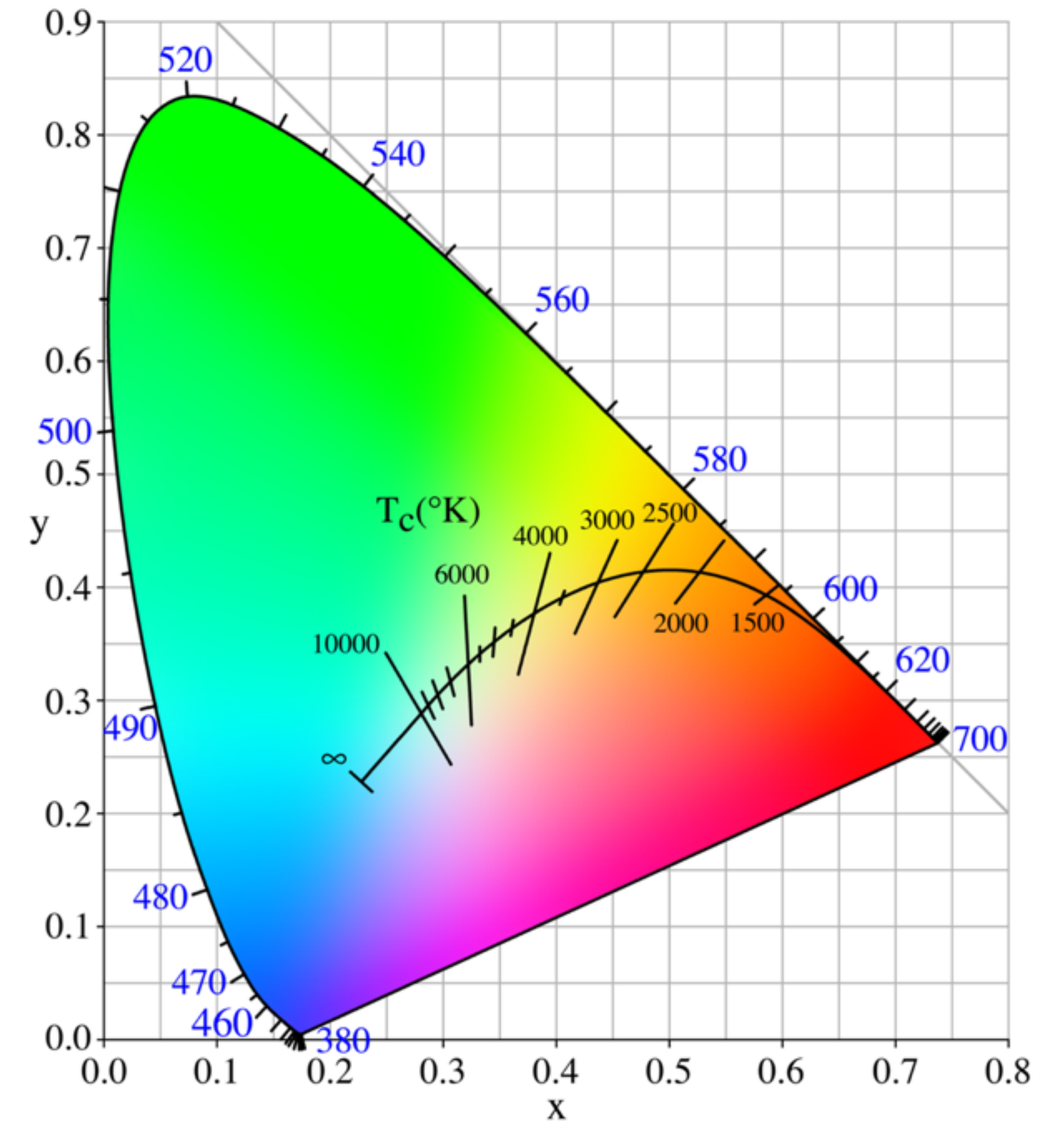
Different Values, low Saturation

# CIE Color Model

## Chromaticity Diagram

Specifies color by hue and saturation

Pure colors of visible spectrum along the curve (wavelength)

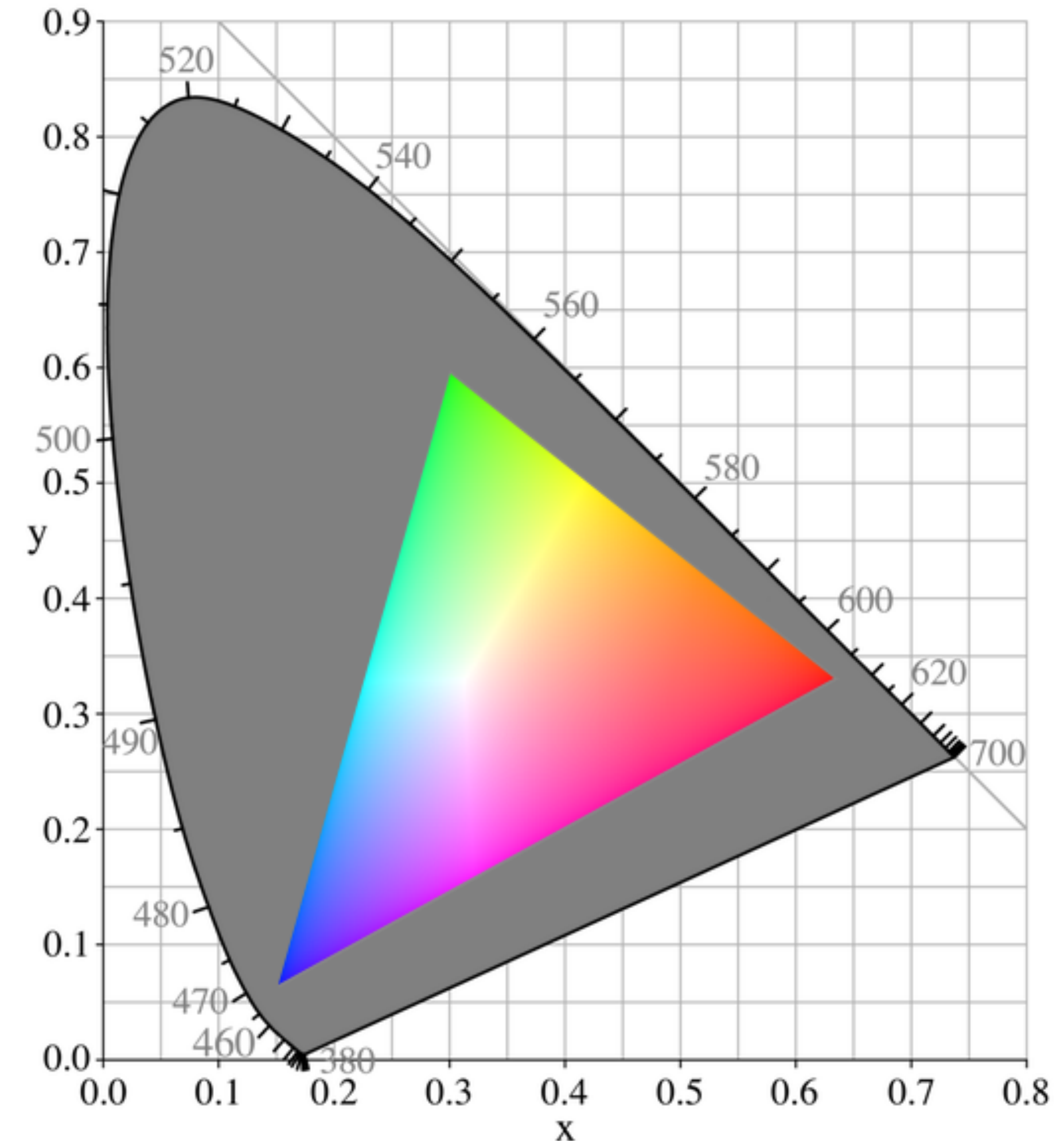
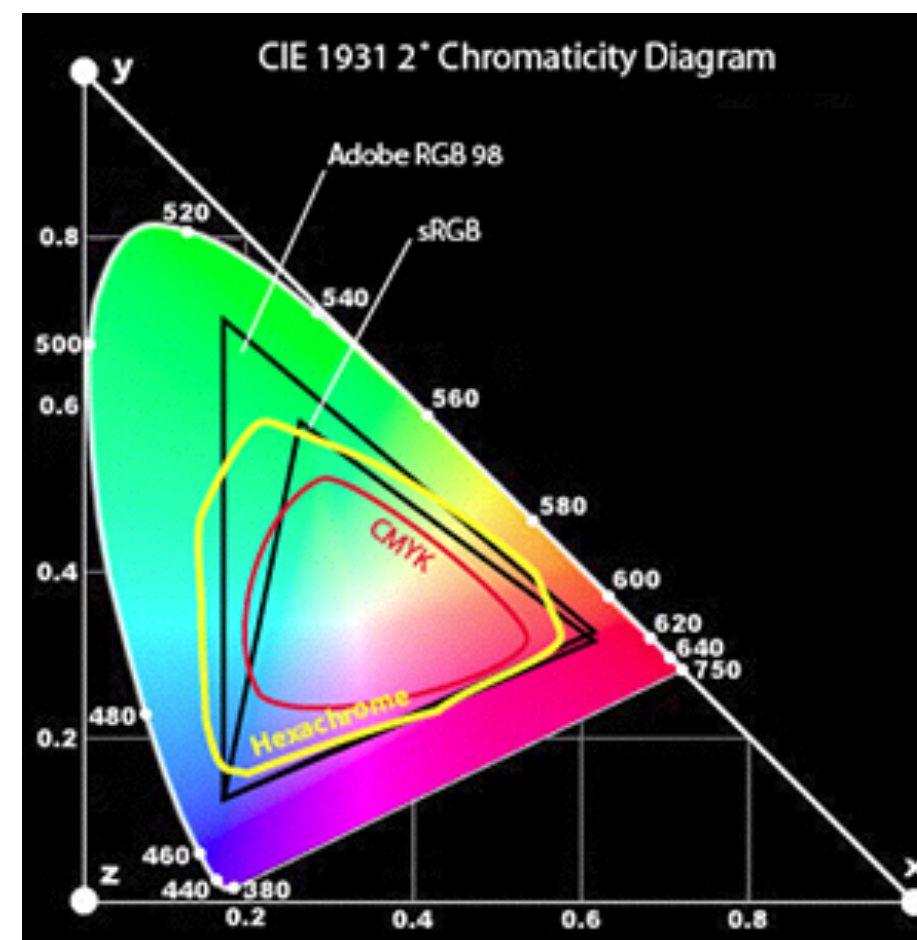


# Gamut

Set of all colors that can be produced by a device

Area between the primary colors used can be shown

Primaries are arbitrary



# Color Composition

## Additive (e.g., RGB)

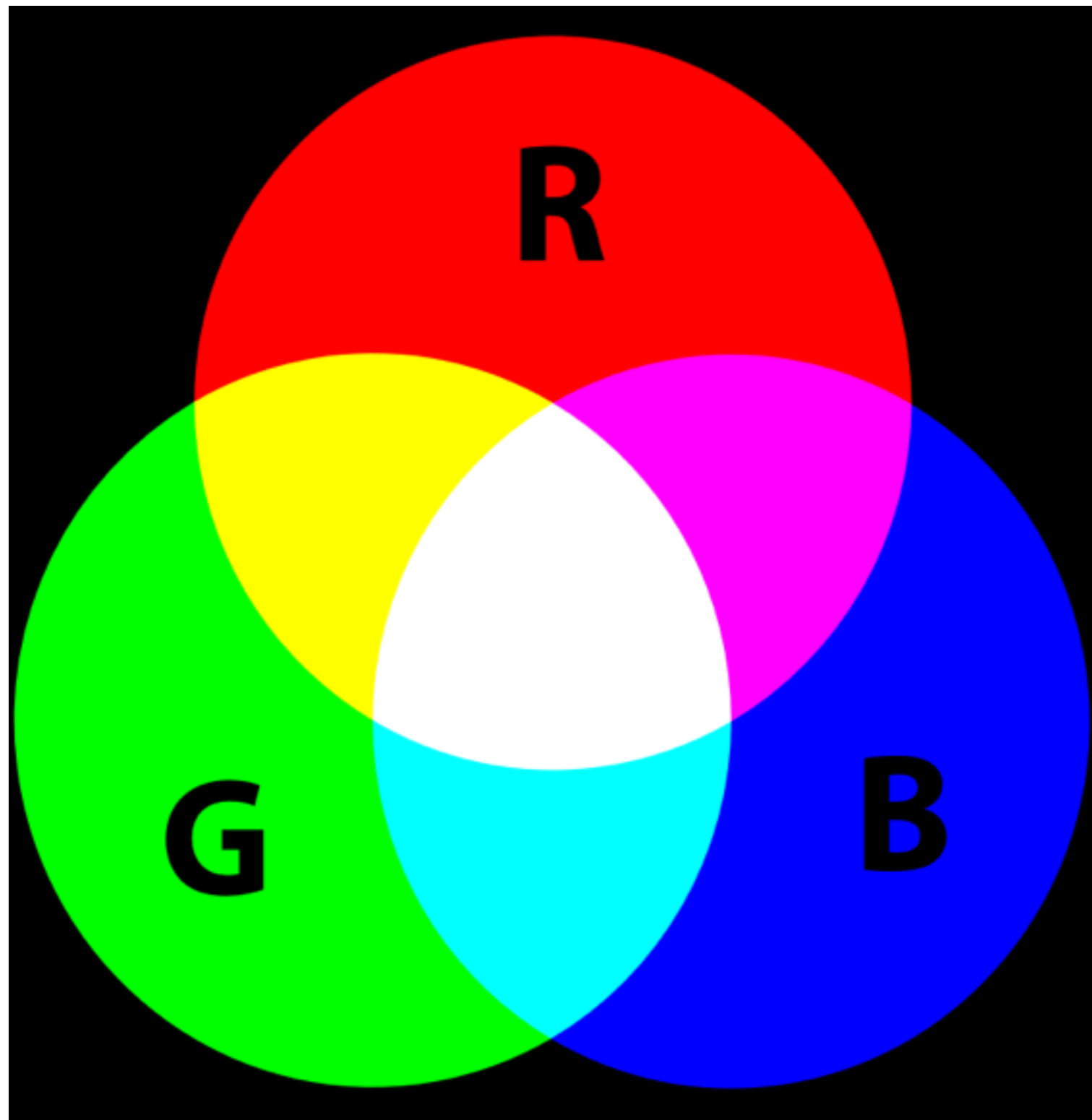
light

white: all three cones stimulated  
with same intensity,  
at high brightness

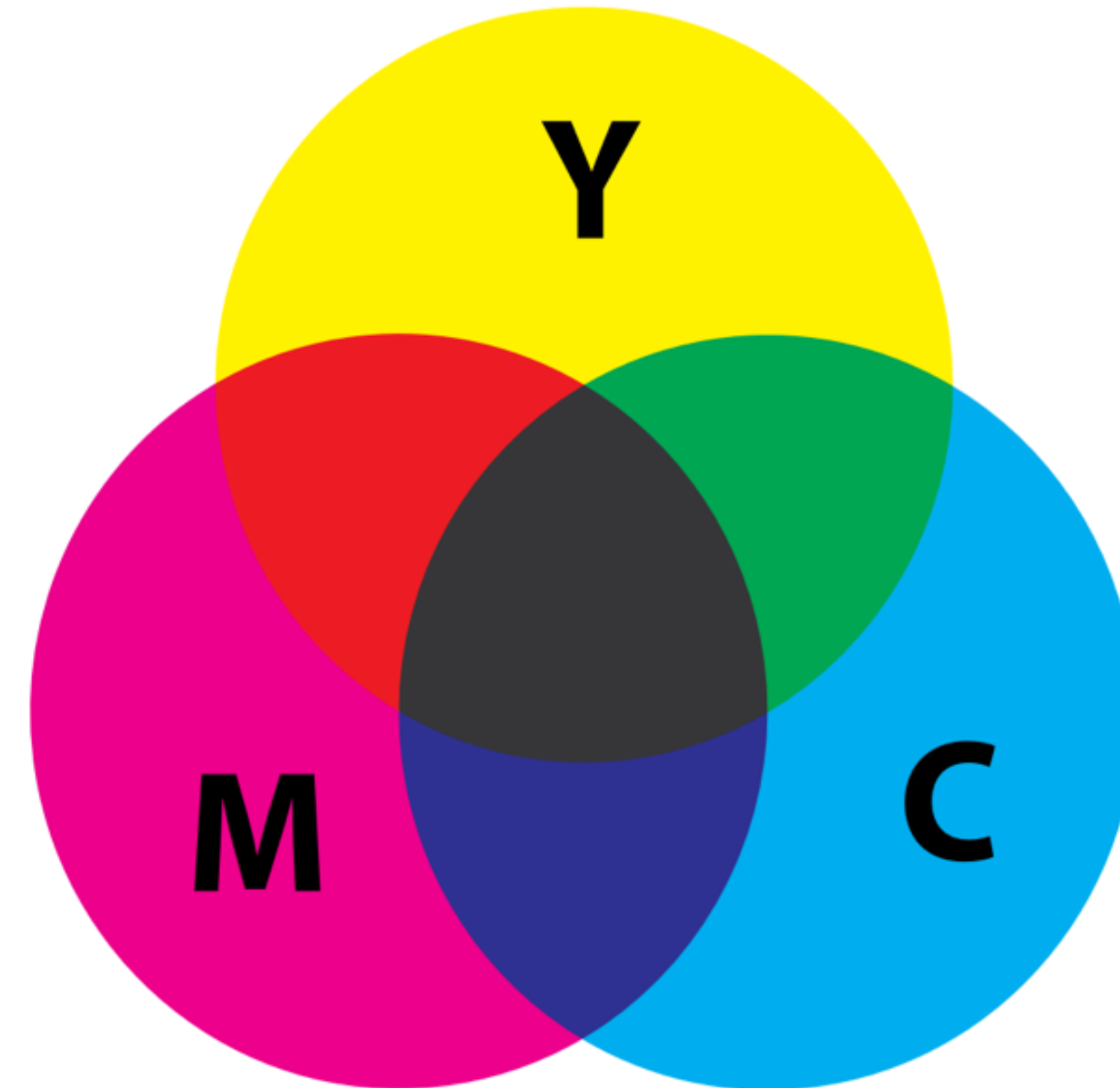
## Subtractive

pigment (e.g., CMYK)

# Additive / Subtractive Color

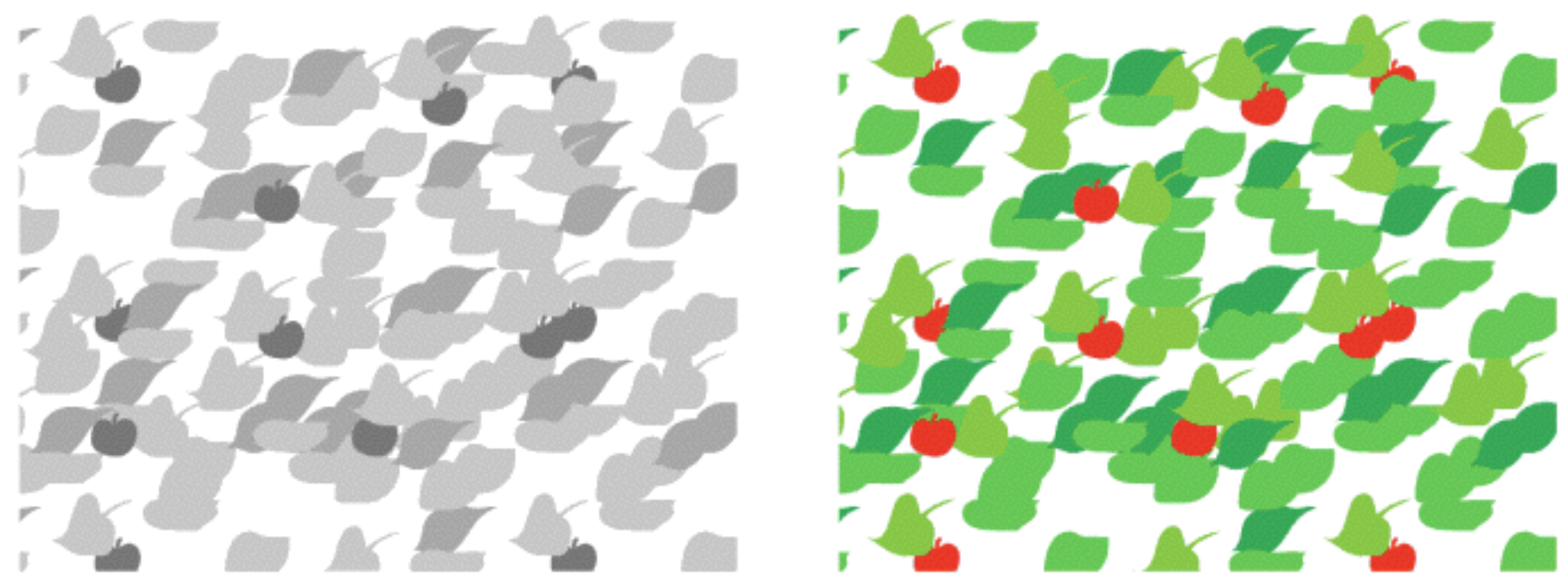


Add colors by adding light of certain wavelength



Subtract colors using pigments, inks by absorbing light

# 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

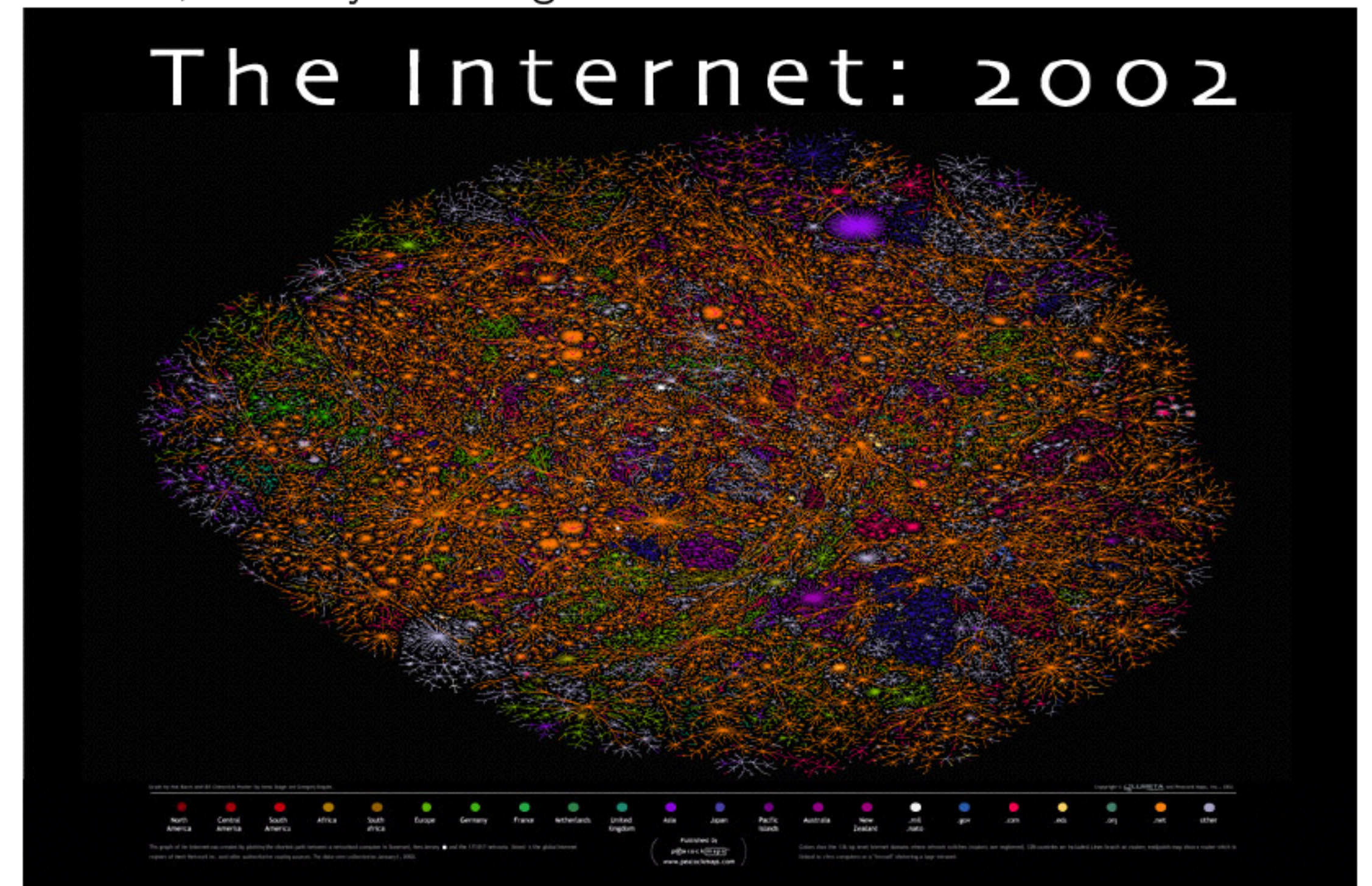
Tells about material properties (judging quality of food)

# Qualitative Data Vis

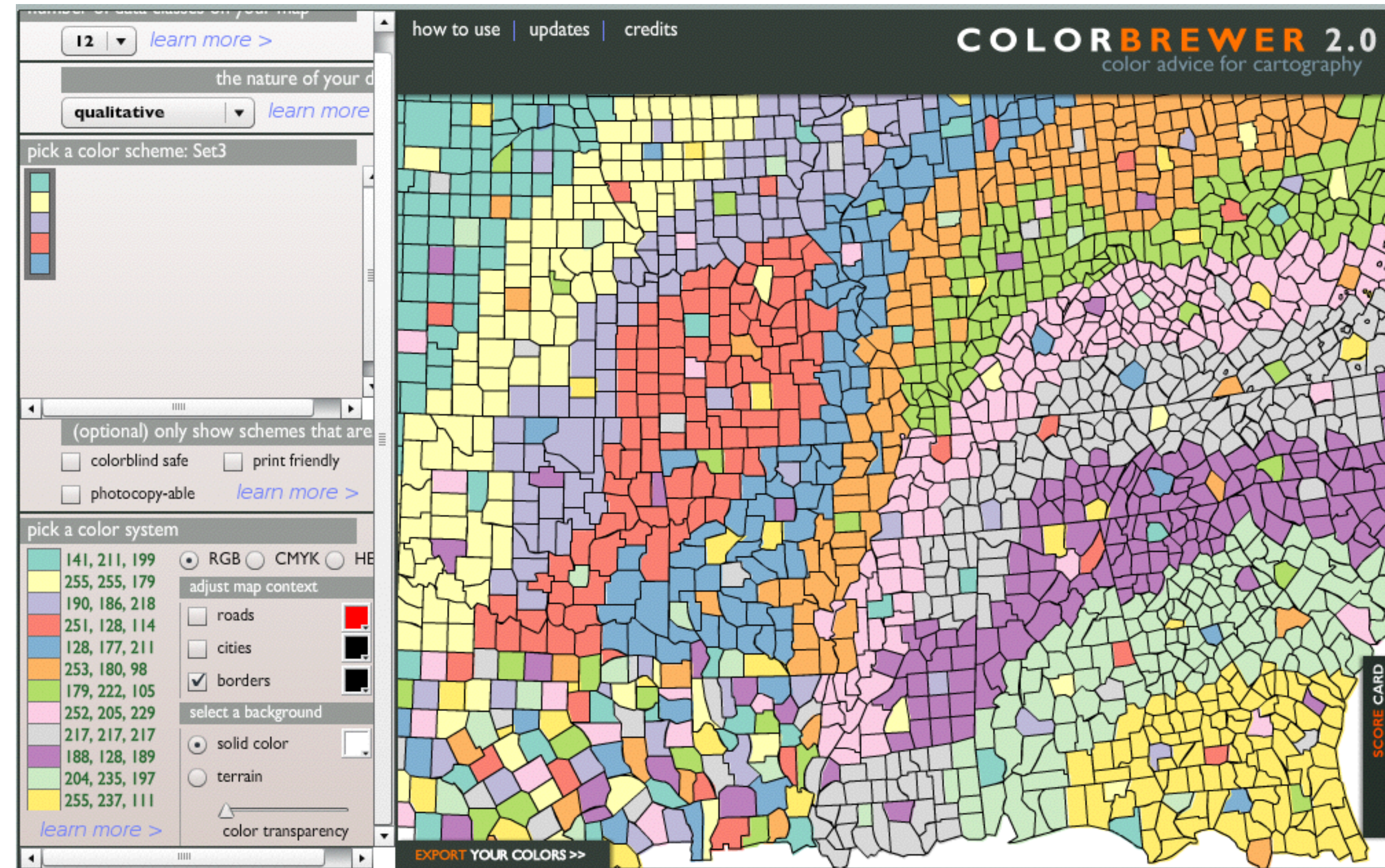
## Color labeling (nominal information coding)

recommended: about 6, no more than 10

22 colors, but only 8 distinguishable



# Application: Labeling



Carefully designed color scheme for 12 colors [colorbrewer]



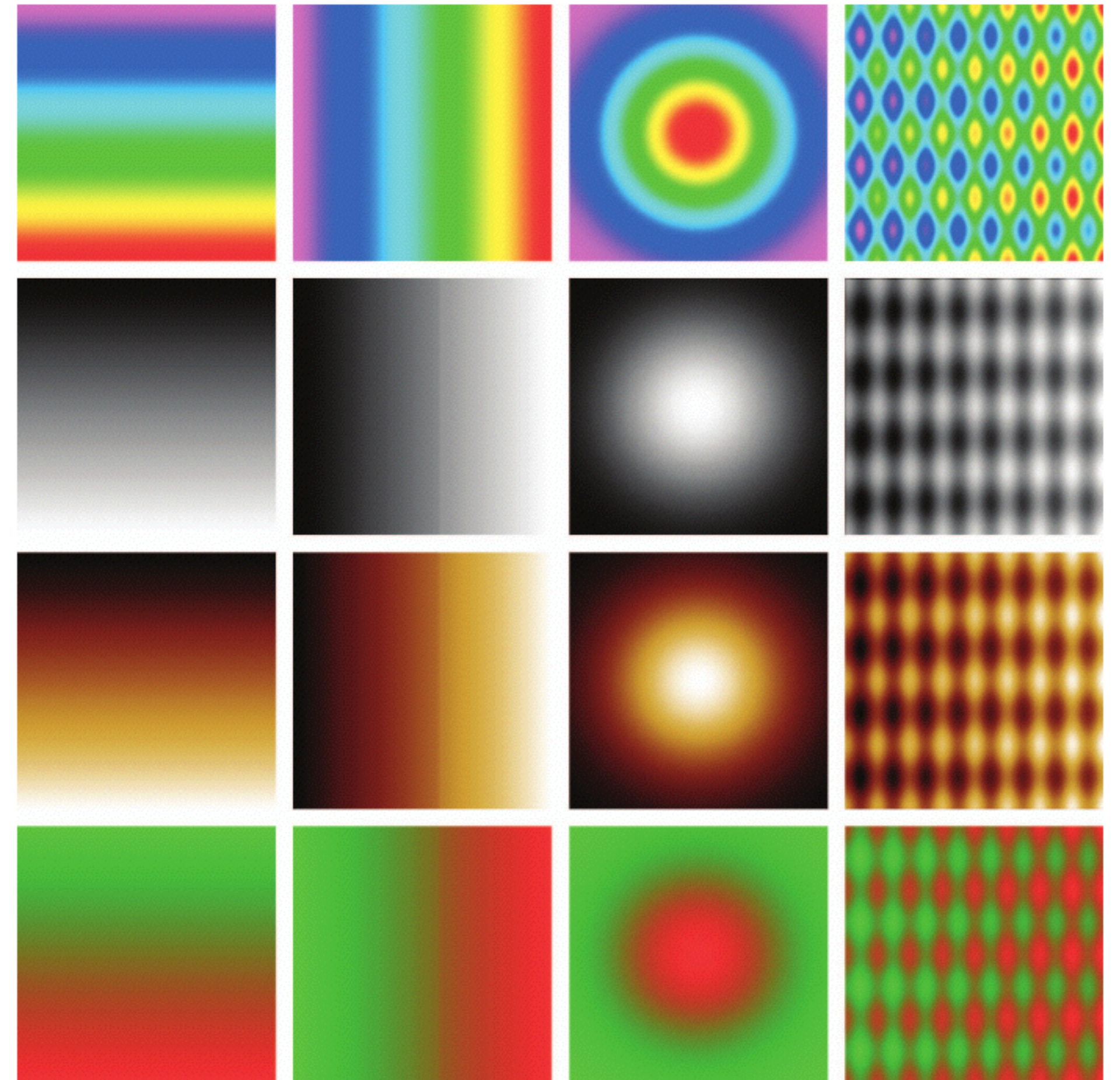
# Quantitative Data Vis

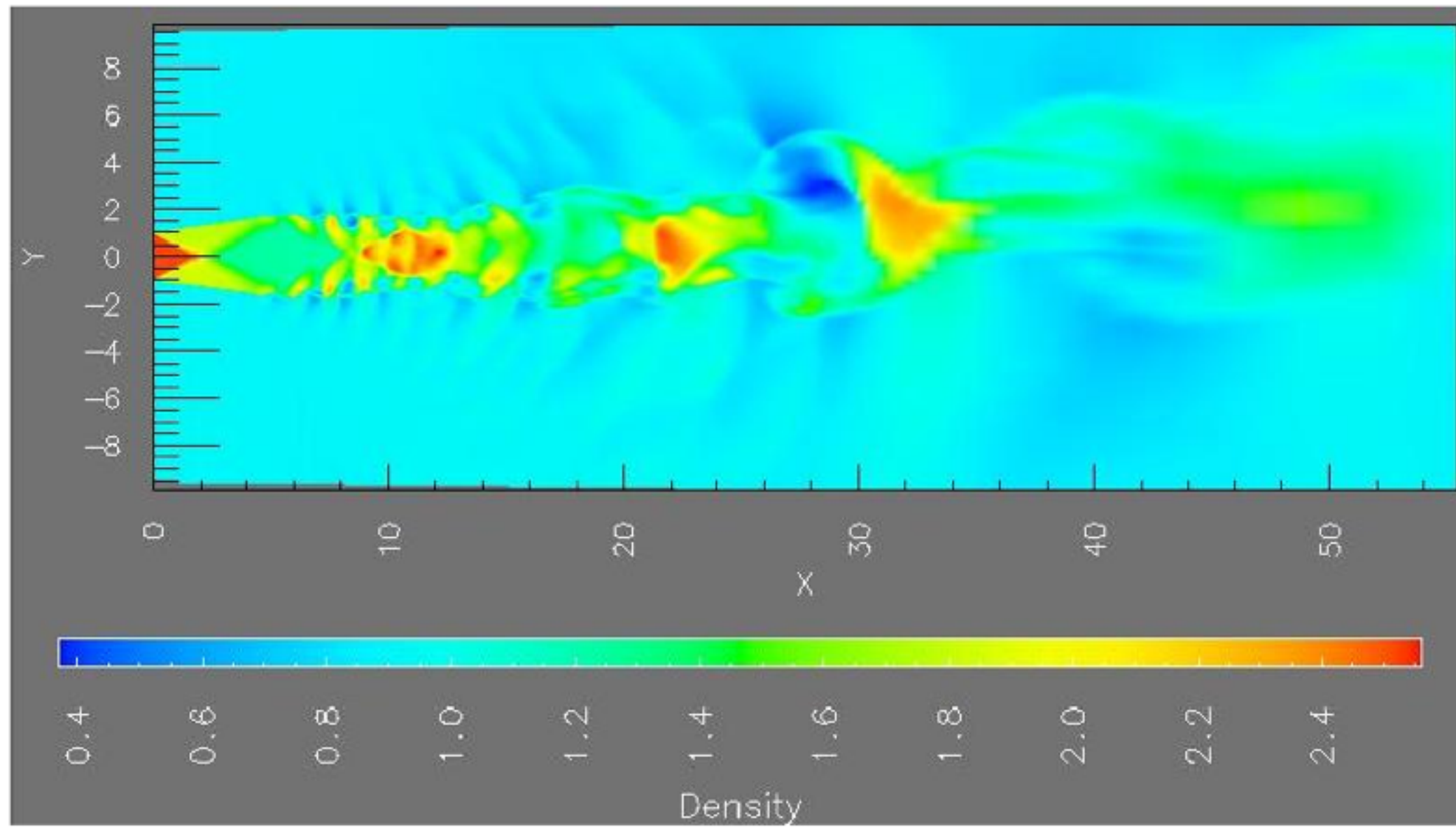
use value

saturation works but not as good

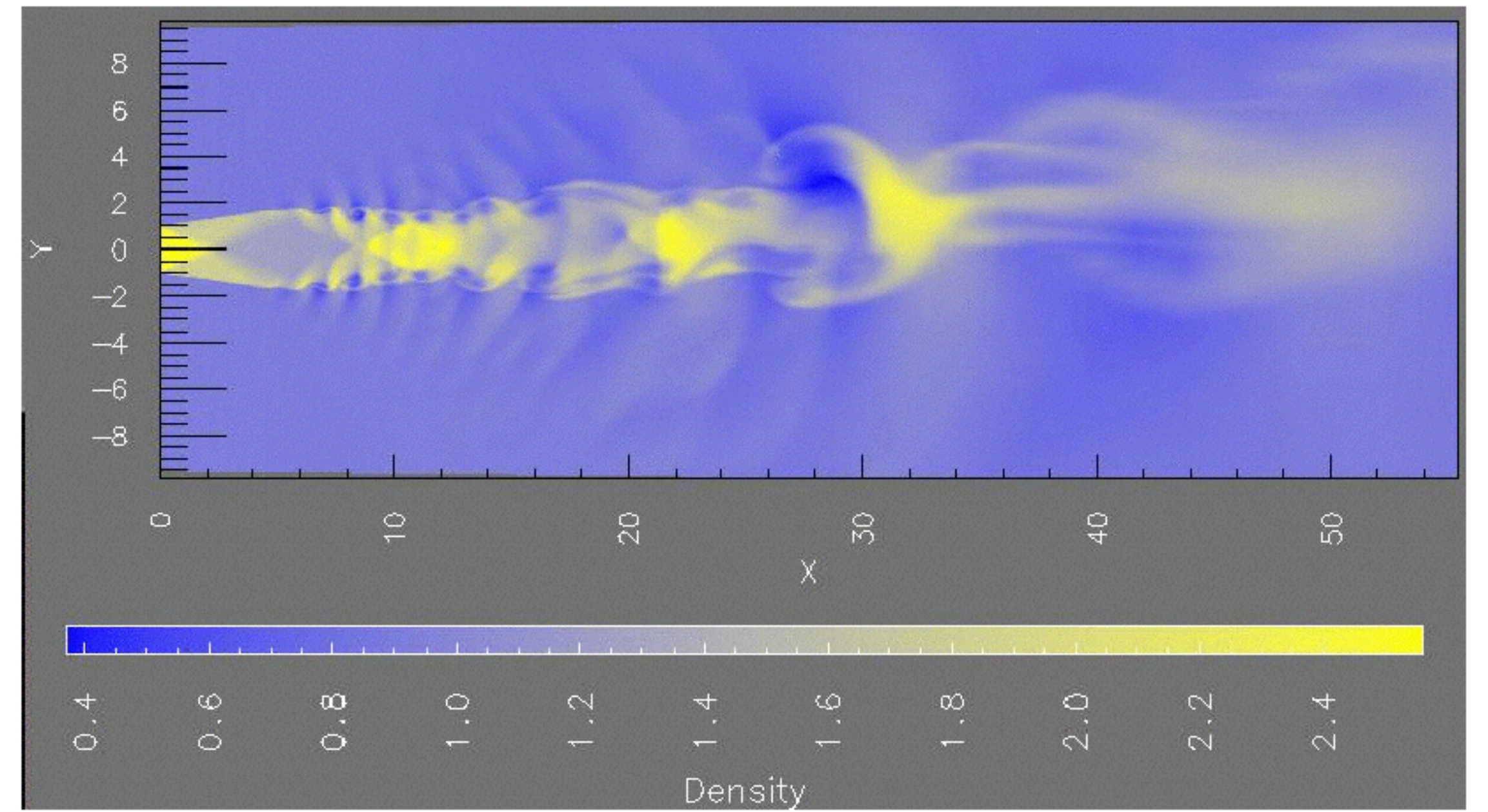
don't use hue!

Danger: rainbow color map



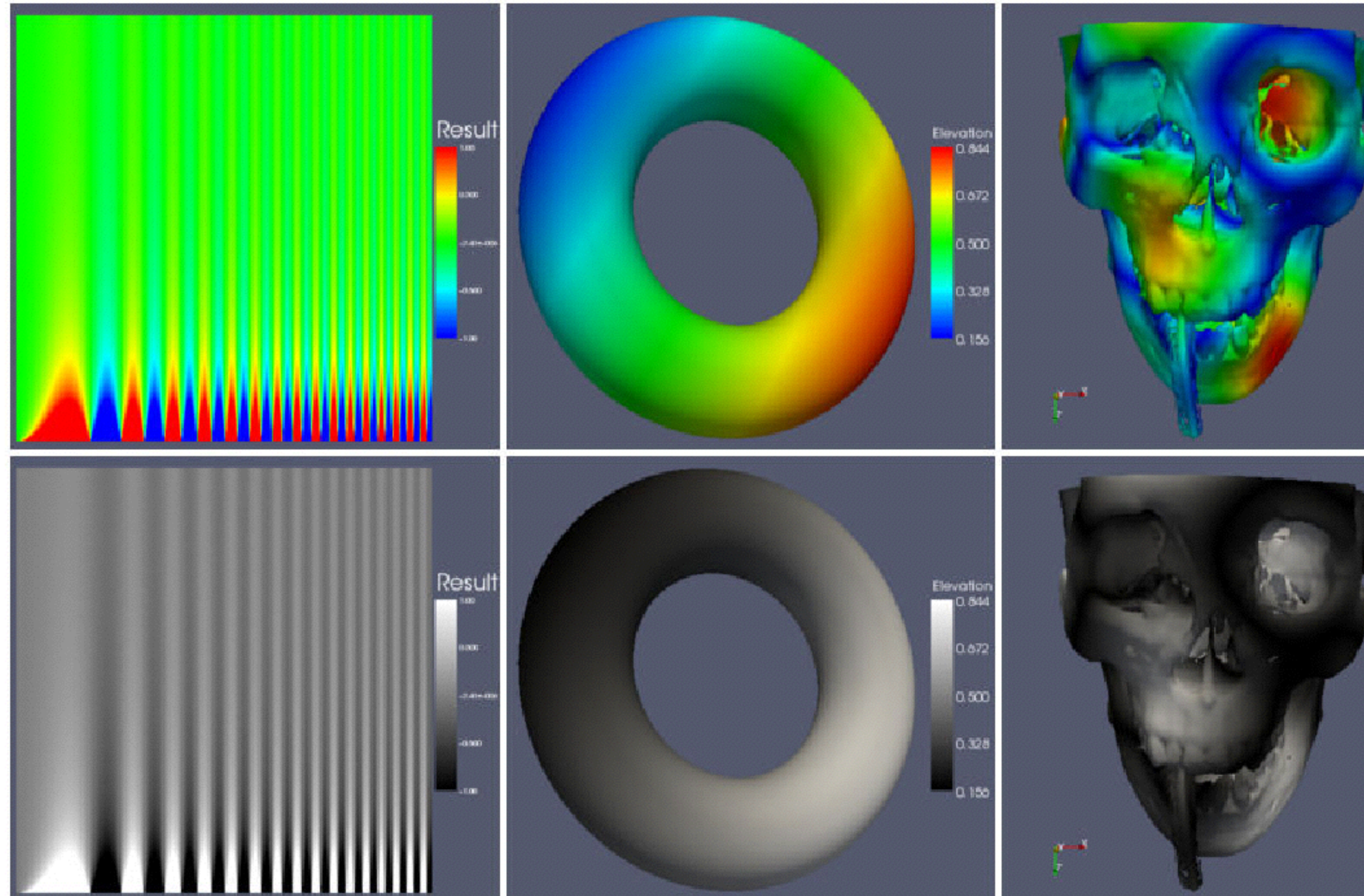


[Rogowitz and Treinish, Why Should Engineers and Scientists Be Worried About Color? <http://www.research.ibm.com/people/l/lloyd/color/color.HTM>]

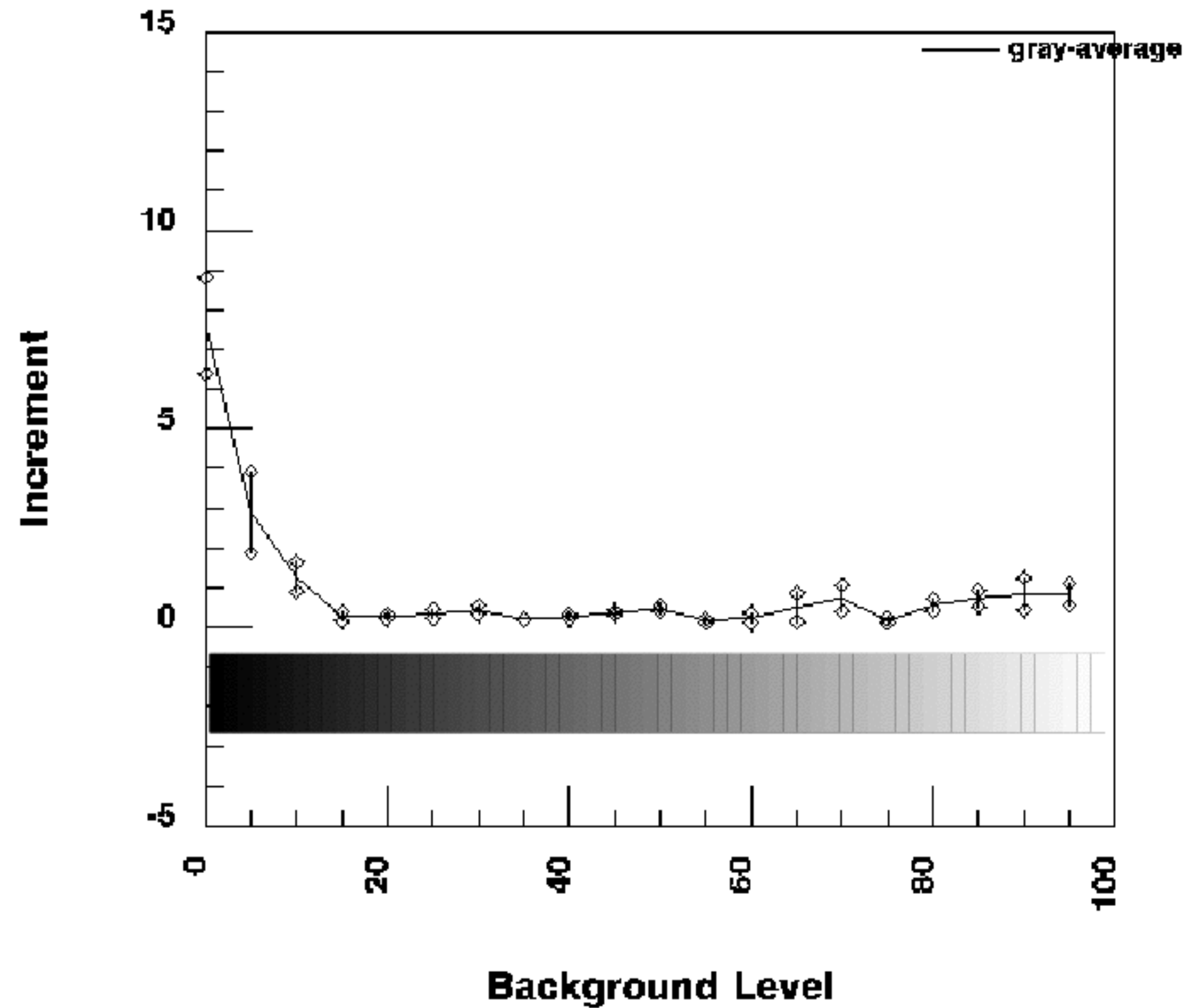
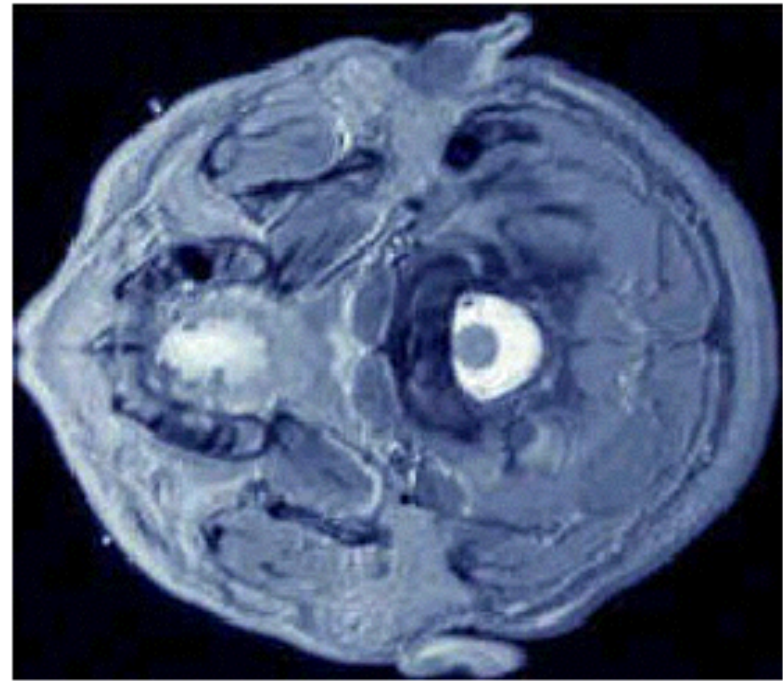


[Rogowitz and Treinish, How NOT to Lie with Visualization, [www.research.ibm.com/dx/proceedings/pravda/truevis.htm](http://www.research.ibm.com/dx/proceedings/pravda/truevis.htm)]

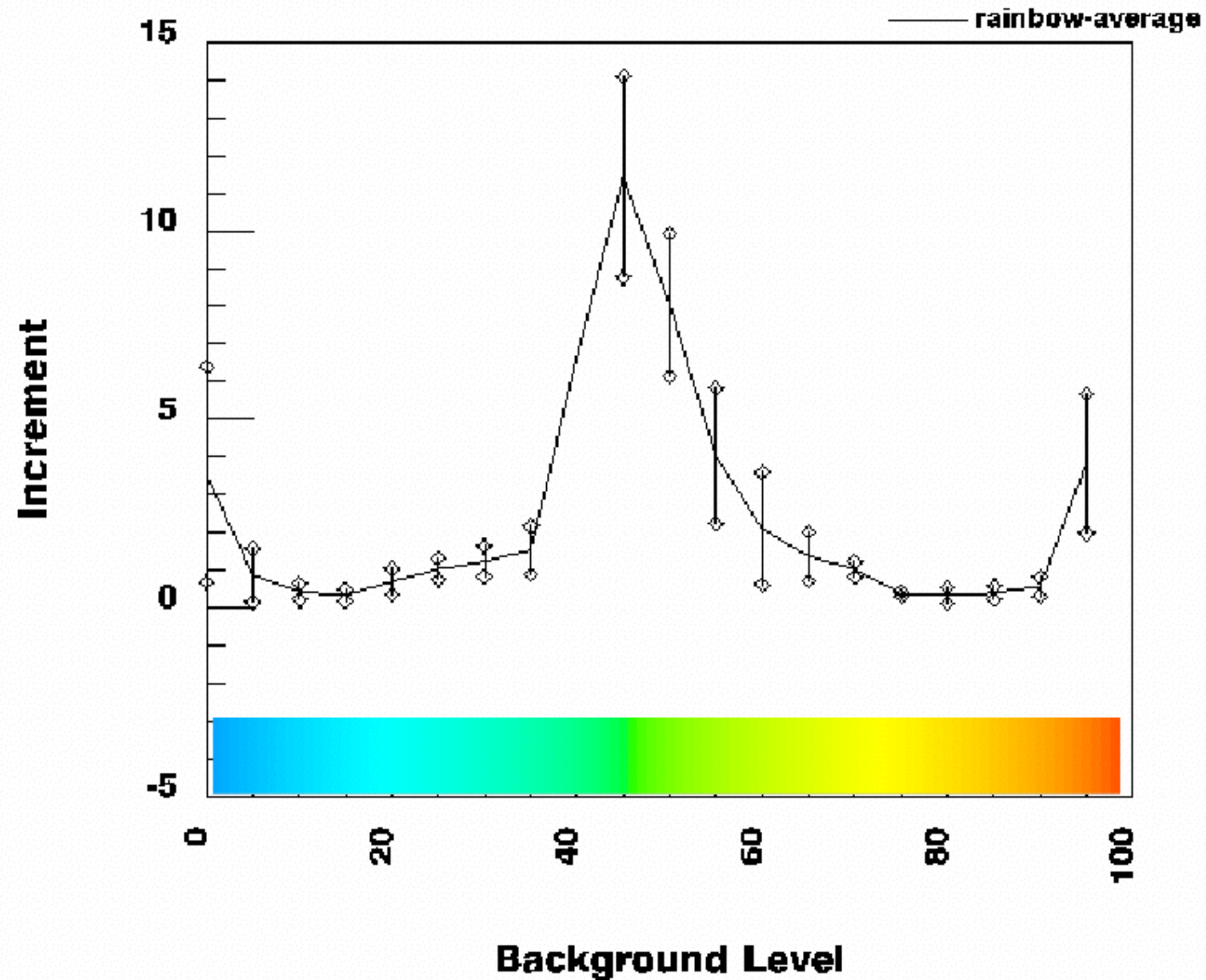
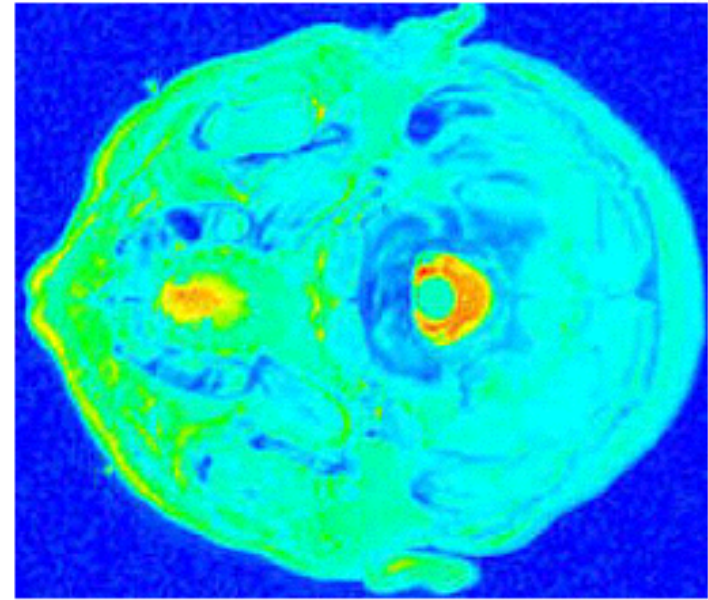
# Rainbow vs. Value Color map



# Increment Threshold Experiment: Luminance



# Increment Threshold Experiment: Rainbow Color Scale



# 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

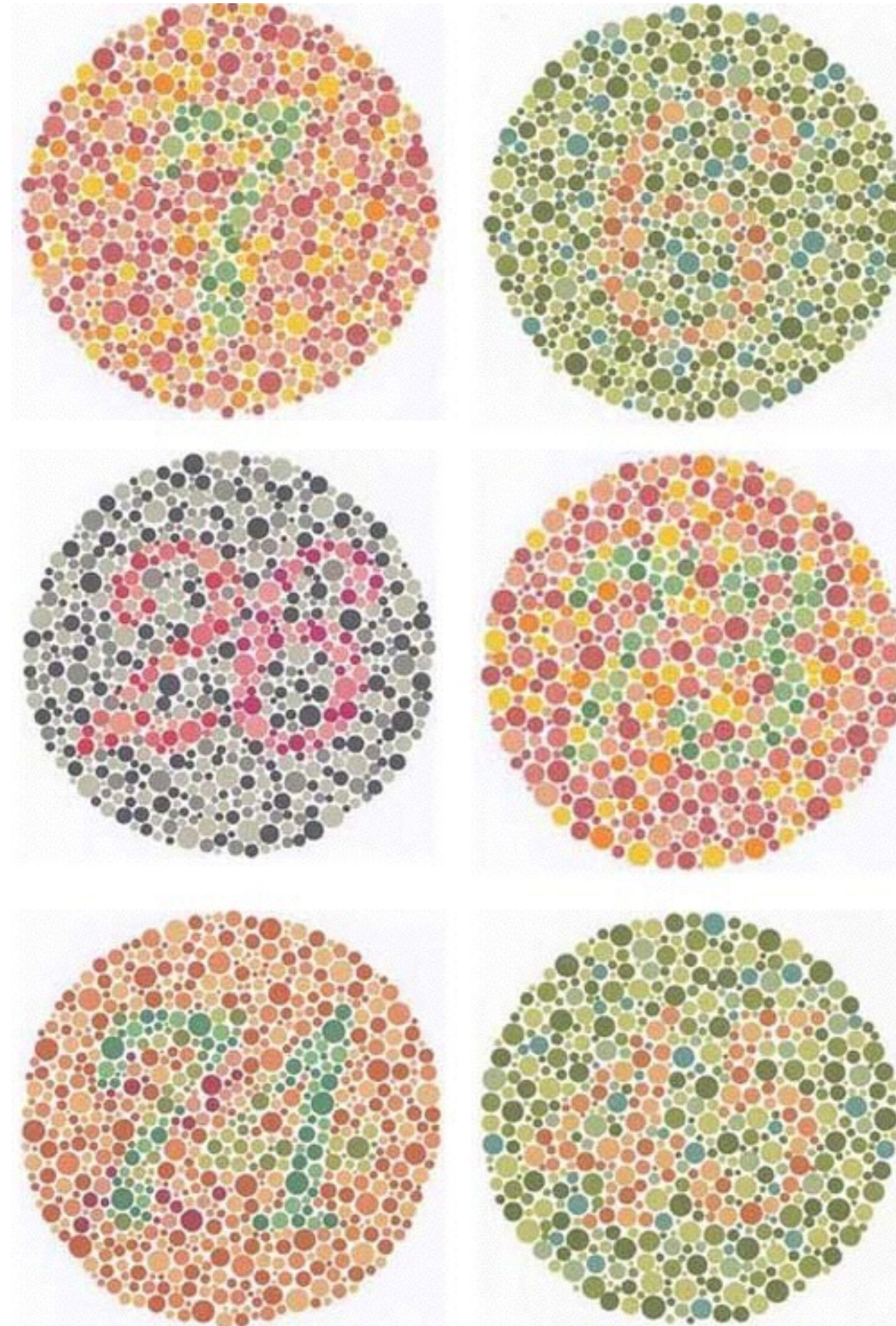


Deuteranopia (no green receptors)

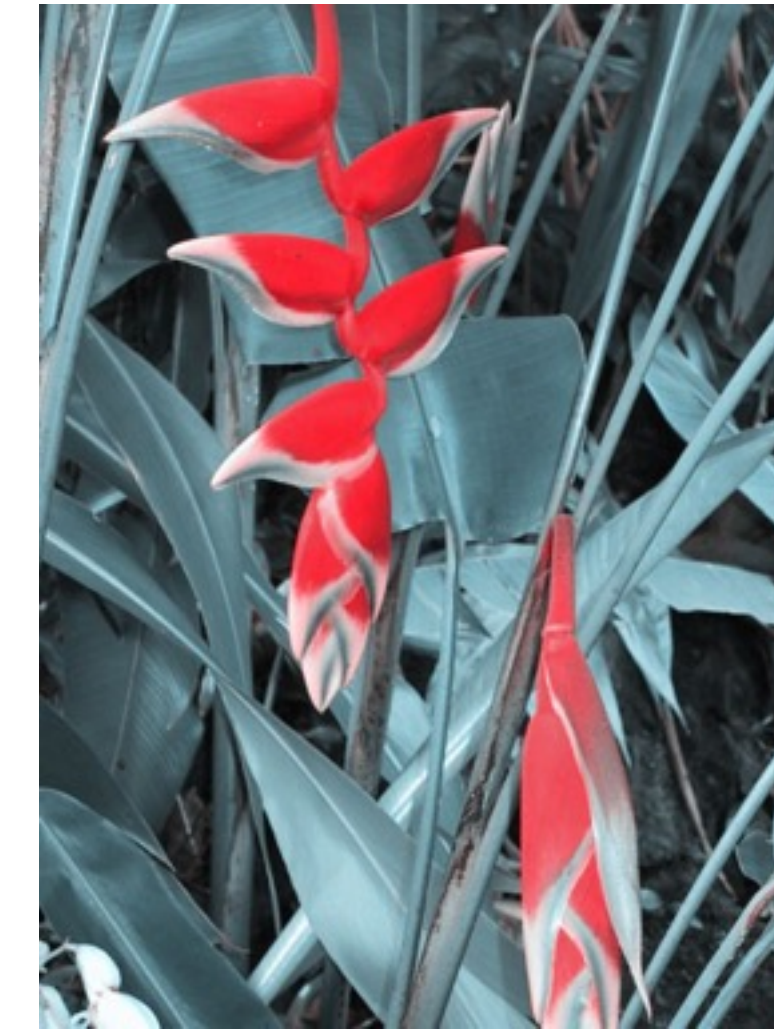


Protanopia (no red receptors)

# Color Blindness Tests



# Color Blindness



Protanope

Deuteranope

Tritanope

No L cones

No M cones

No S cones

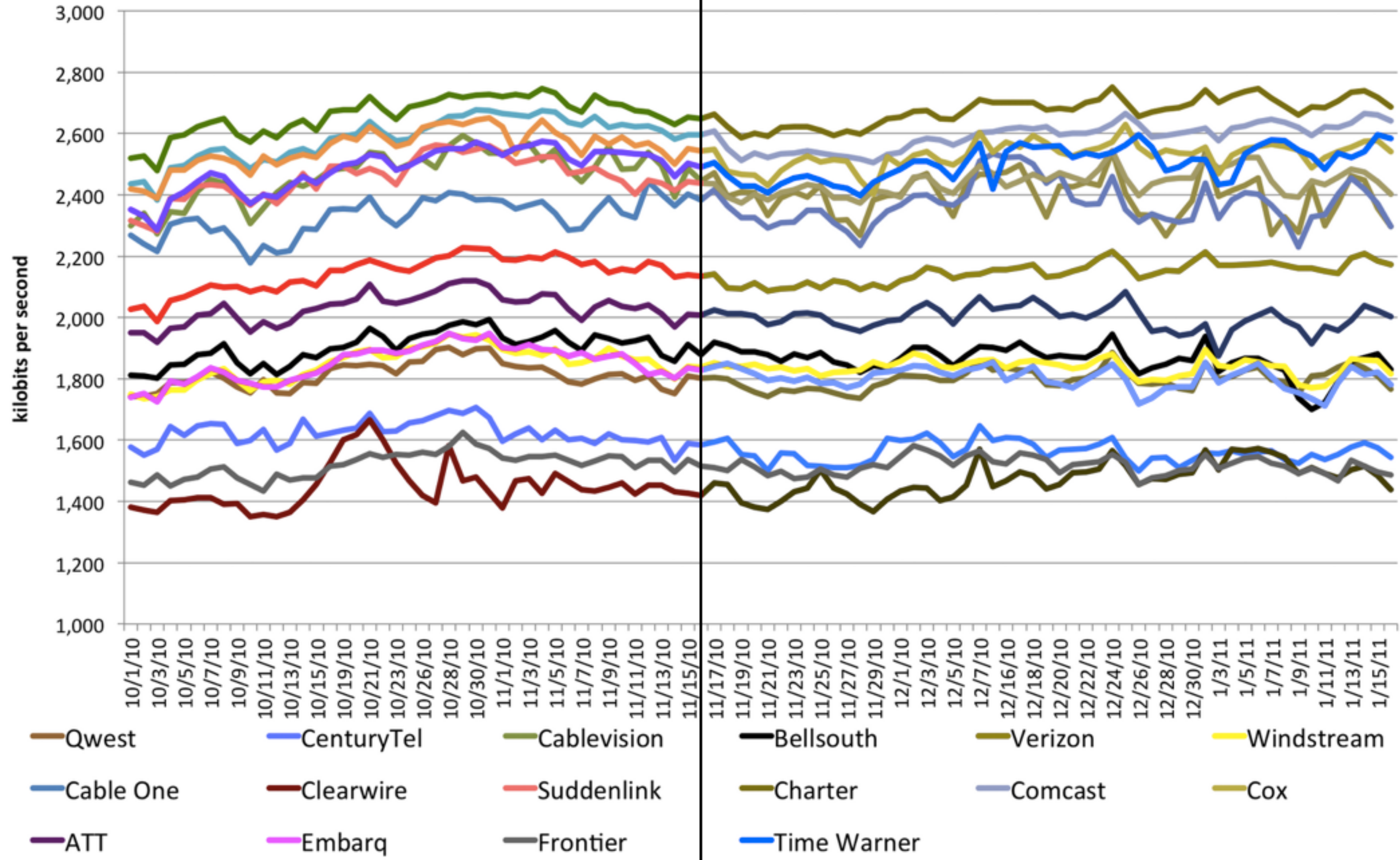
Red / green  
deficiencies

Blue / Yellow  
deficiency



# Normal Vision

# Red-Green Colorblind



All Spending | Types of Spending | Changes | Department Totals

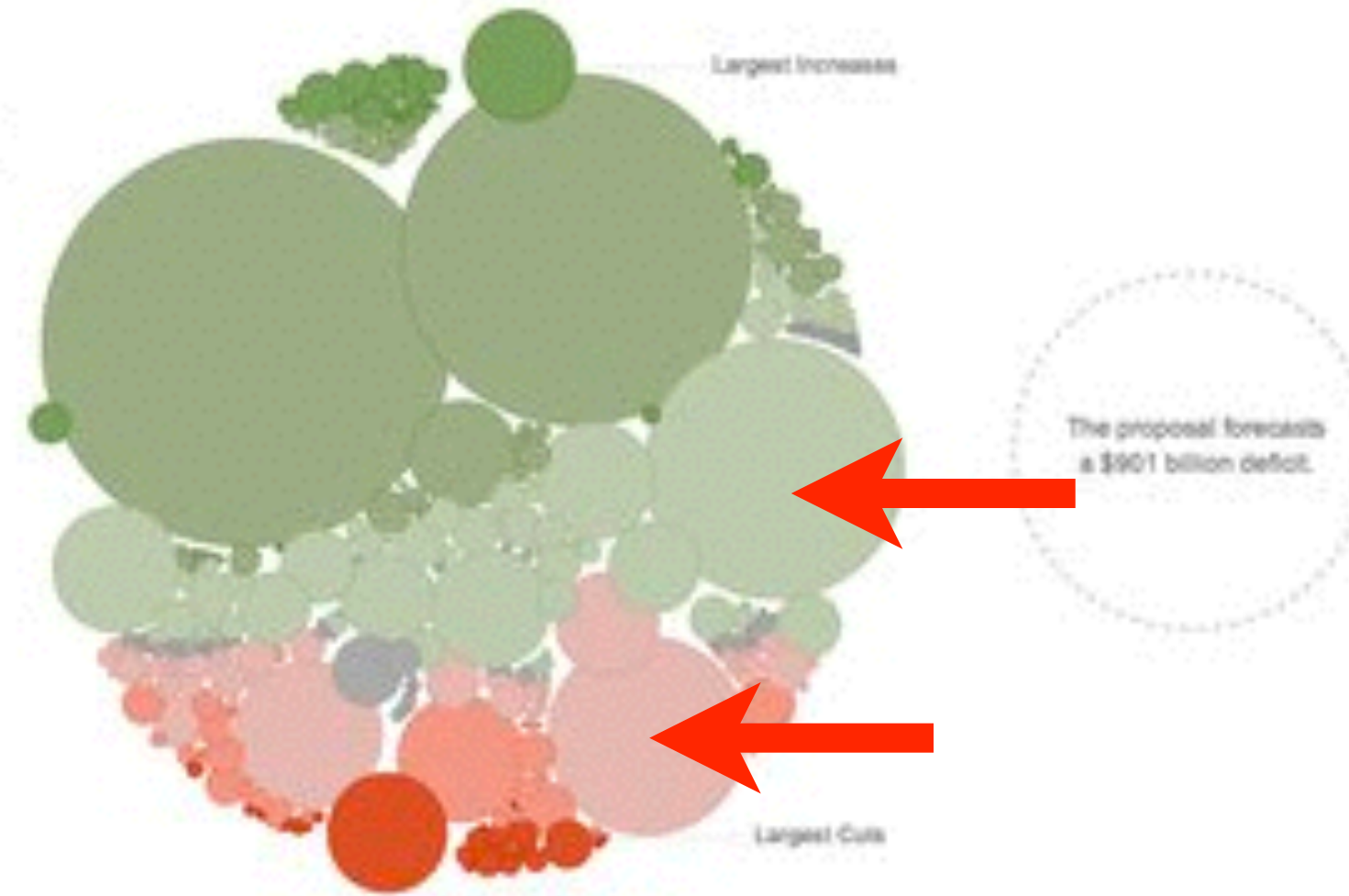
### How \$3.7 Trillion Is Spent

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

Circles are sized according to the proposed spending.



Color shows amount of cut or increase from 2012.



All Spending | Types of Spending | Changes | Department Totals

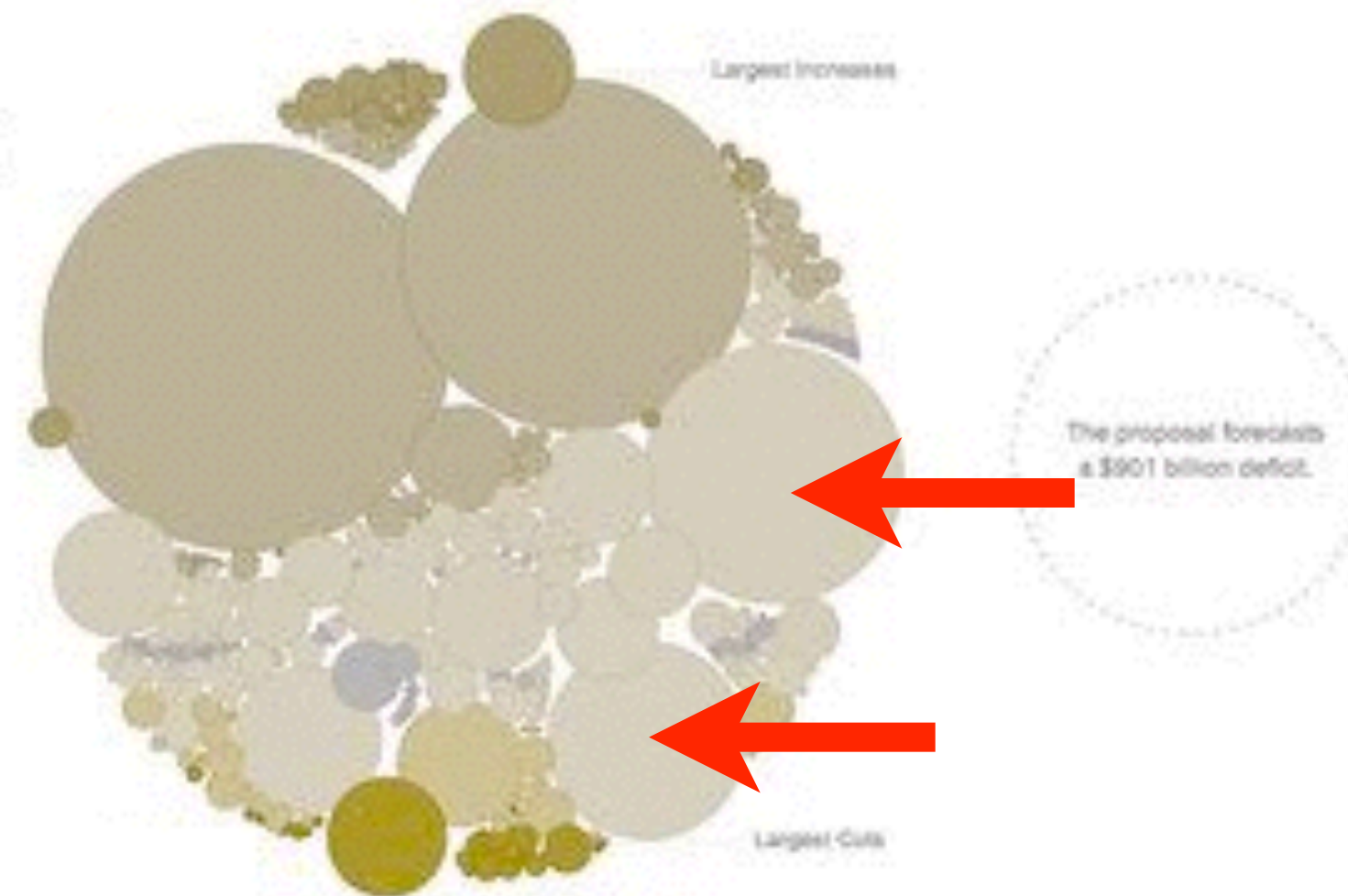
### How \$3.7 Trillion Is Spent

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Circles are sized according to the proposed spending.



Color shows amount of cut or increase from 2012.



# www.vischeck.com

## Try Vischeck on a Webpage

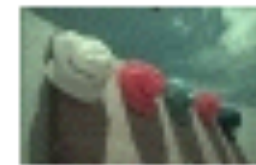
Select the type of color vision to simulate:



Deuteranope (a form of red/green color deficit)



Protanope (another form of red/green color deficit)



Tritanope (a blue/yellow deficit- very rare)

Enter the URL of any webpage- eg. [www.google.com](http://www.google.com).

URL:

Run Vischeck!

# Luminance, Brightness, Lightness

## Luminance

measured amount of light (luminous intensity per area)

## Brightness

perceived amount of light

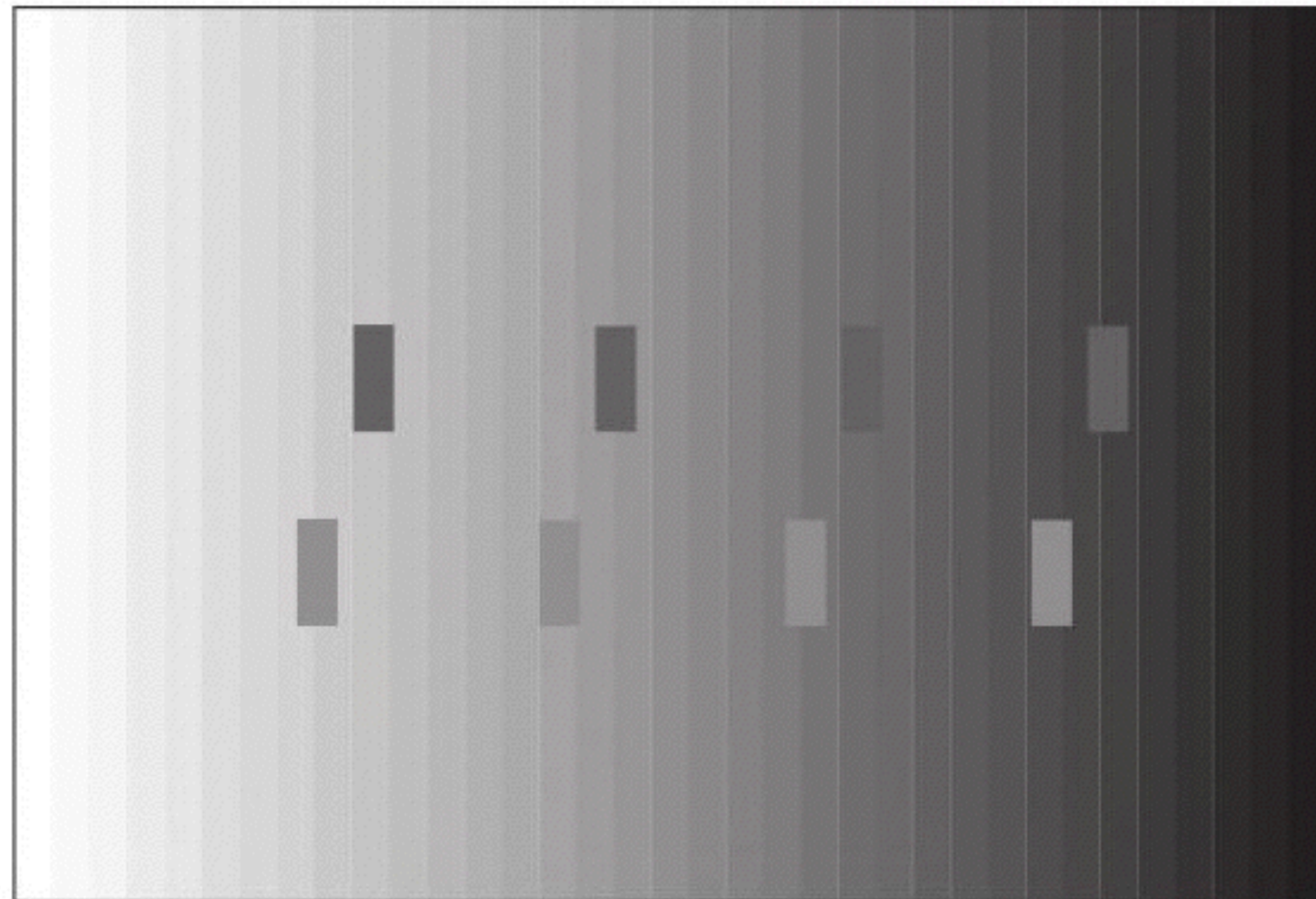
## Lightness

perceived reflectance of a surface

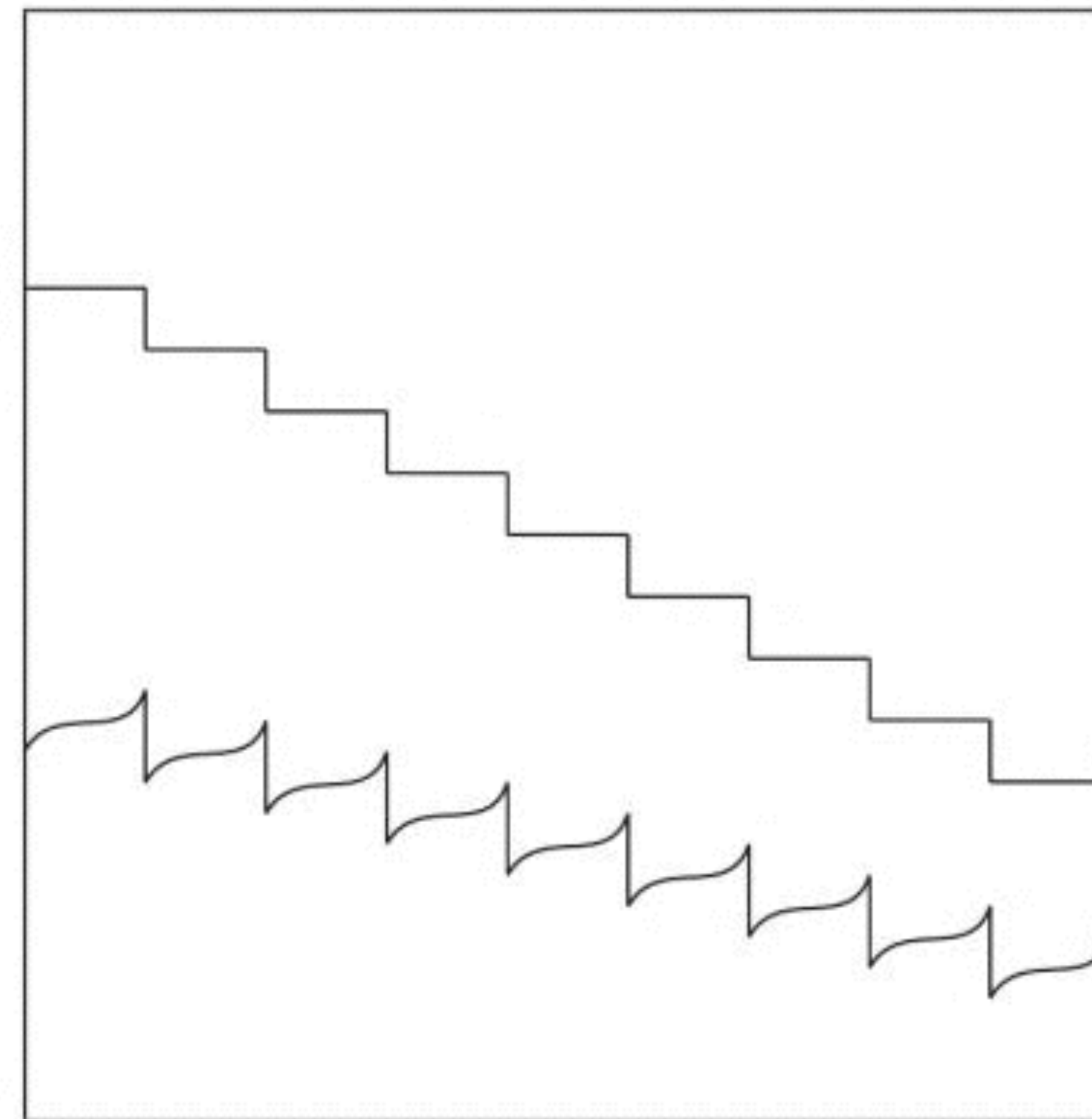
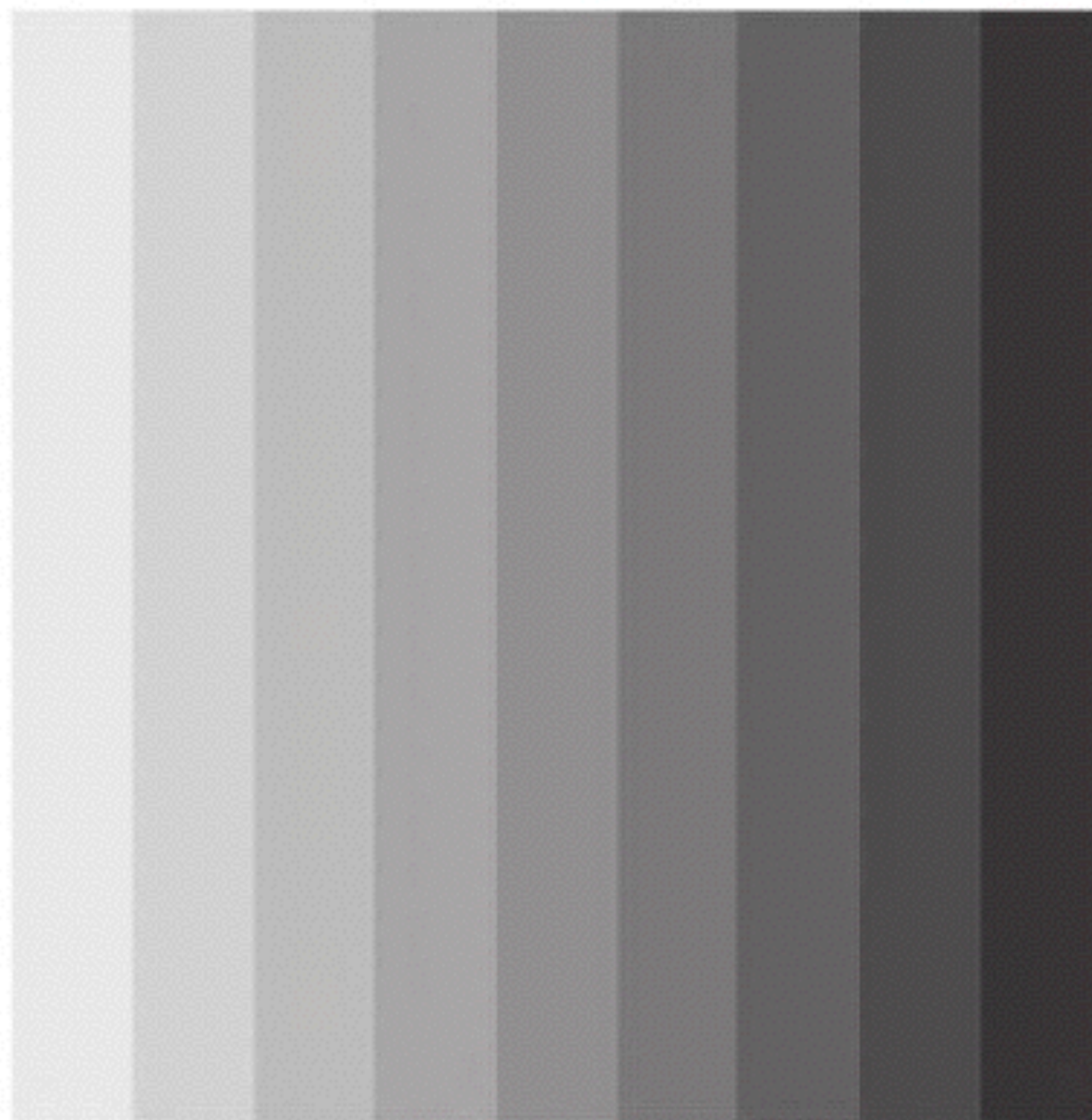
lightness of a color

# Simultaneous Brightness Contrast

The perceived brightness of an object is relative to its background



# Chevreul Illusion



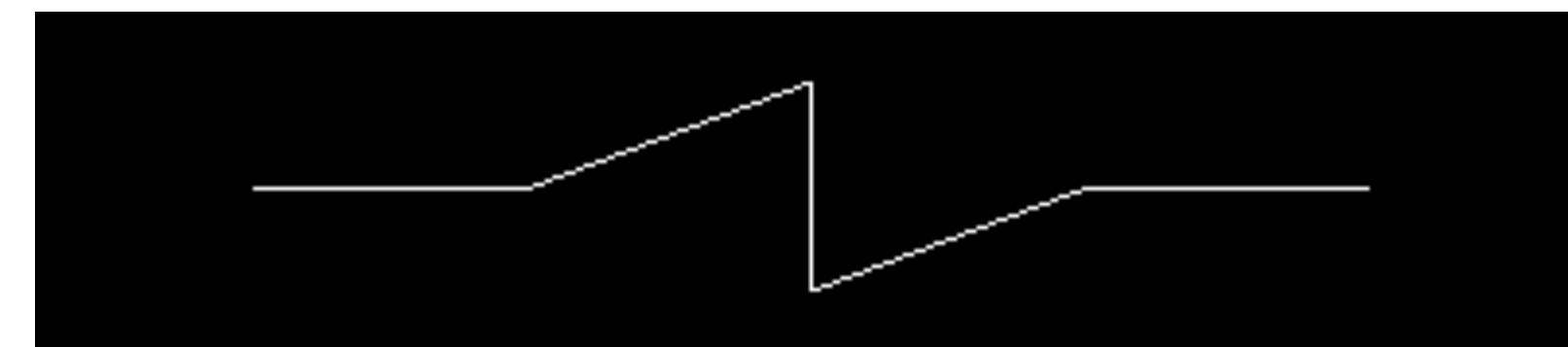
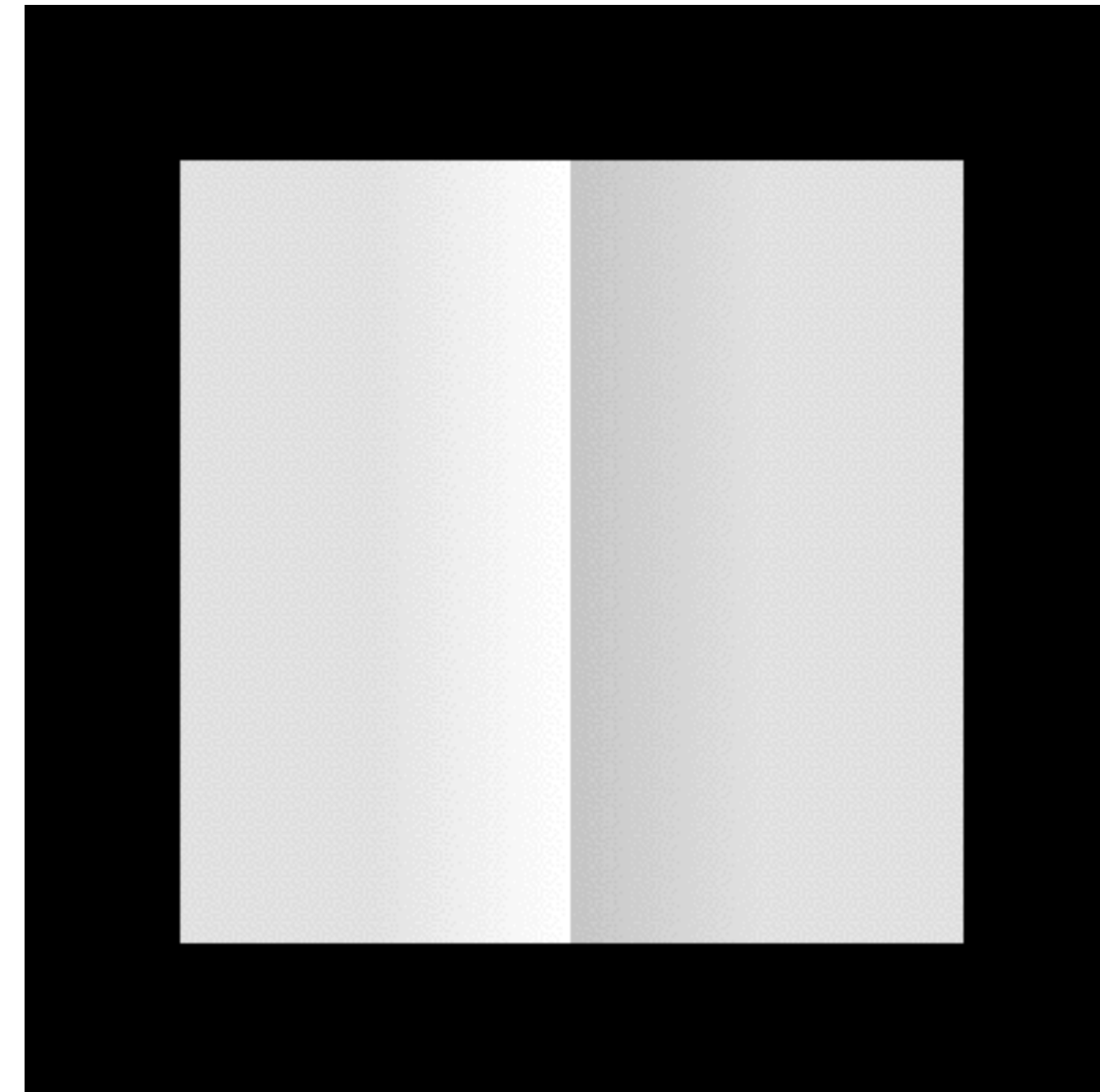
# Edge Enhancement

Cornsweet effect

Make objects more distinct



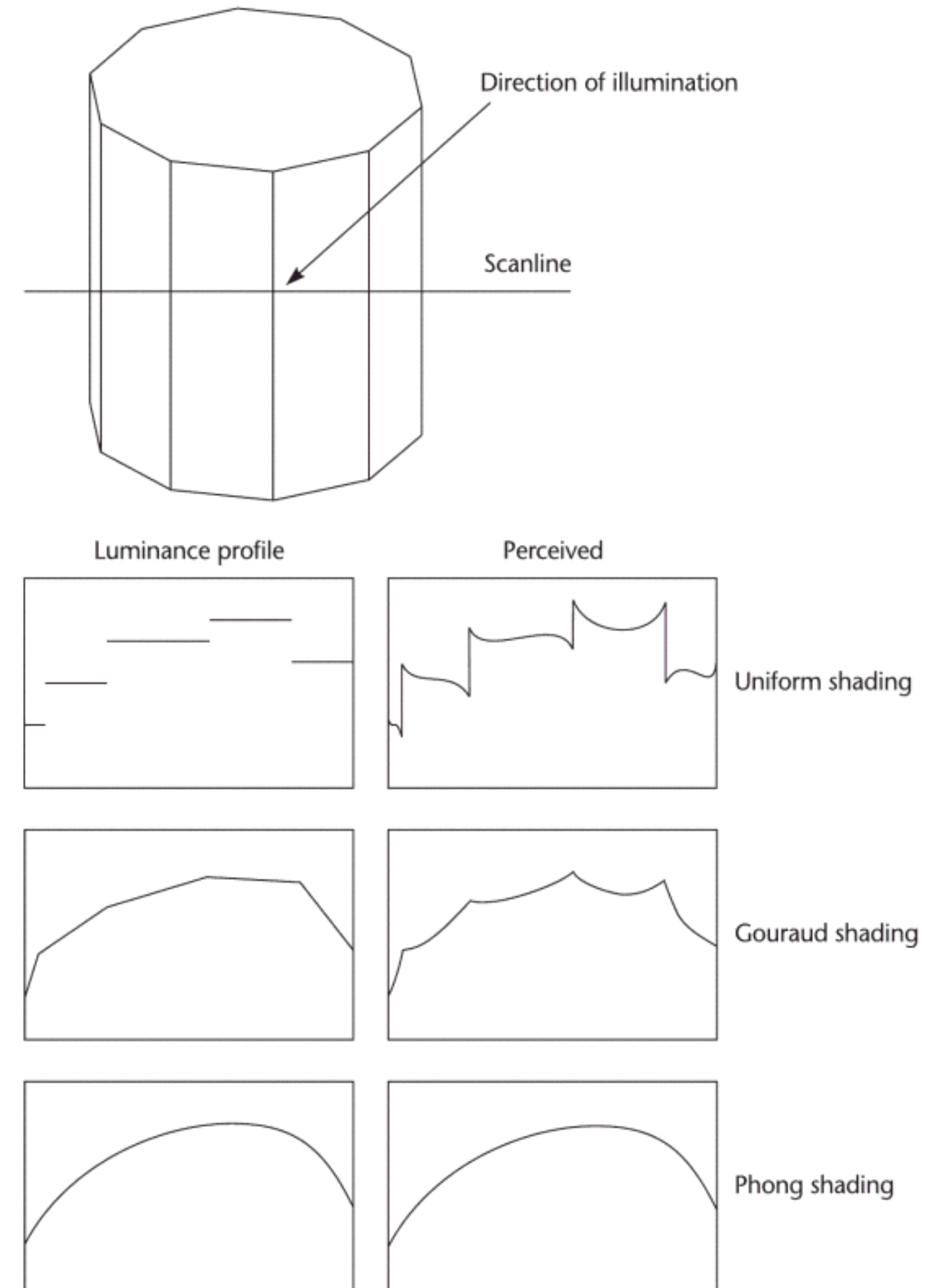
Seurat's Bathers



# Why is this an issue?

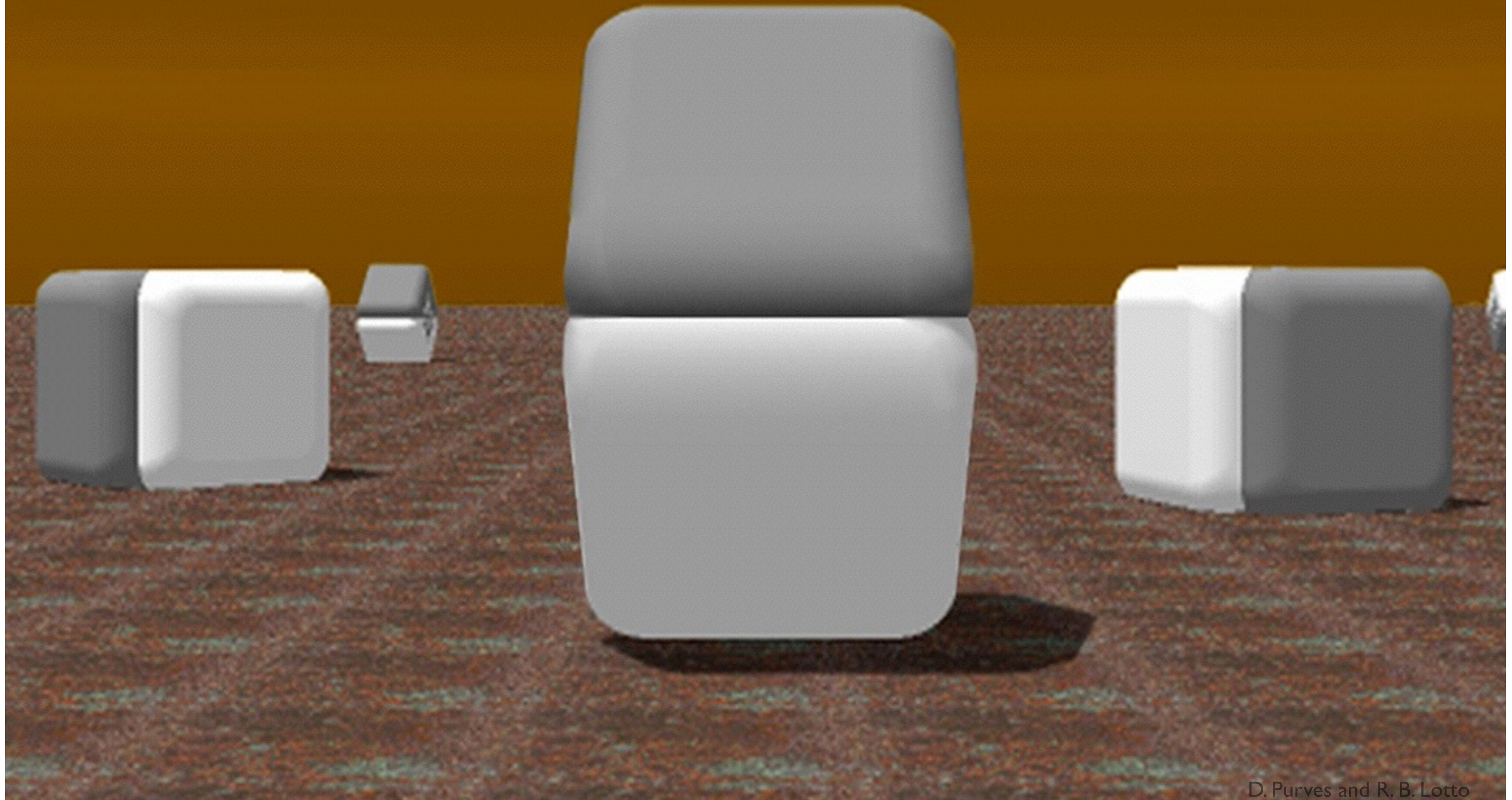
Can result in large errors of judgment

Amplifies artifacts in computer graphics shading

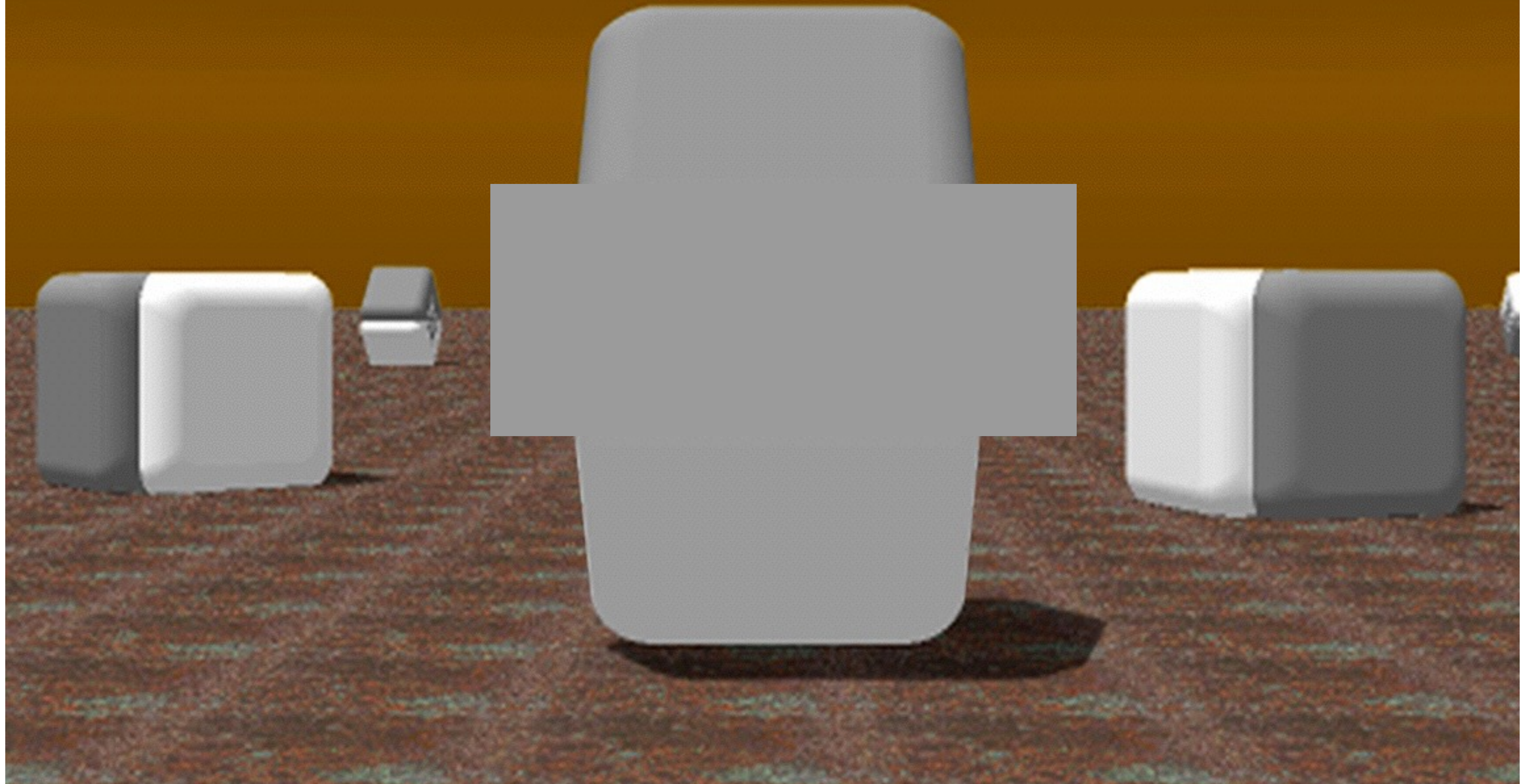




# Cornsweet Illusion



# Cornsweet Illusion

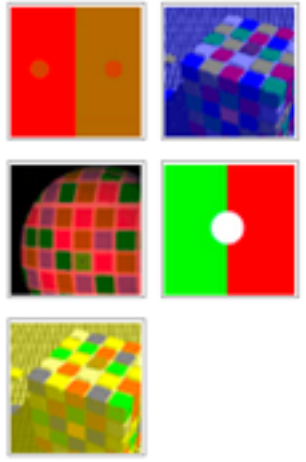
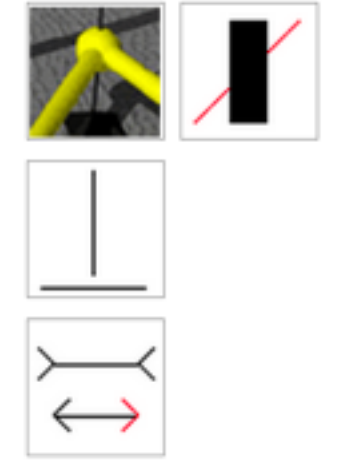
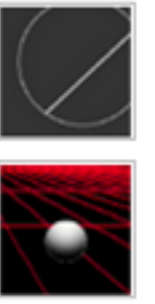



# Demo

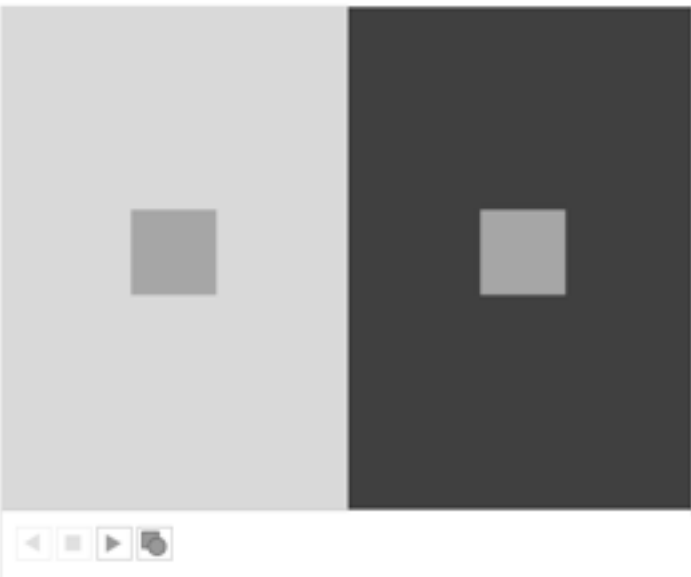
[http://www.purveslab.net/seeforyourself/index.html?0.00'](http://www.purveslab.net/seeforyourself/index.html?0.00)

**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](#)



# Preattentive Processing

# Preattentive Processing

Properties detected by the low-level visual system

very rapid - 200-250 milliseconds

very accurate

processed in parallel

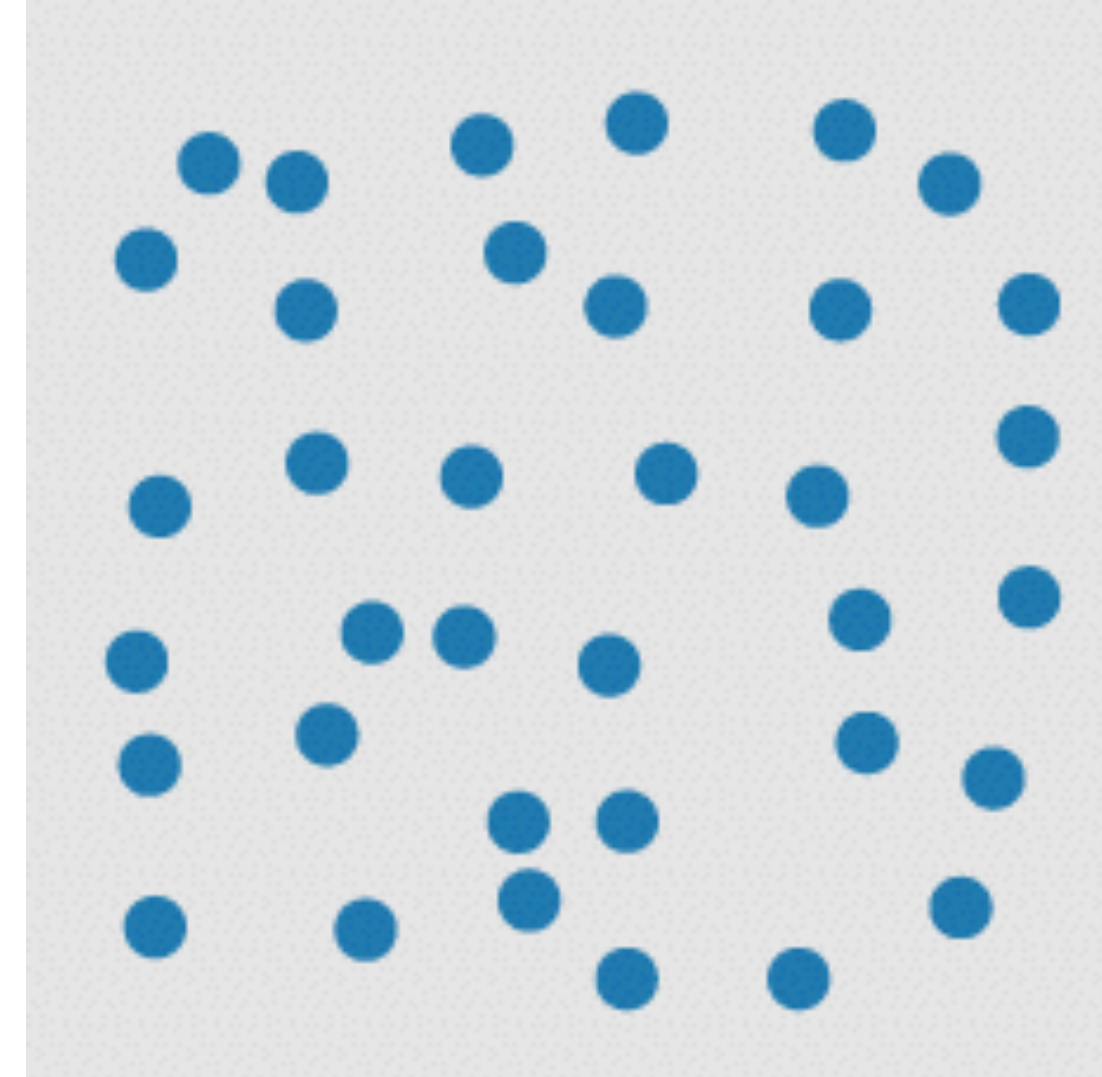
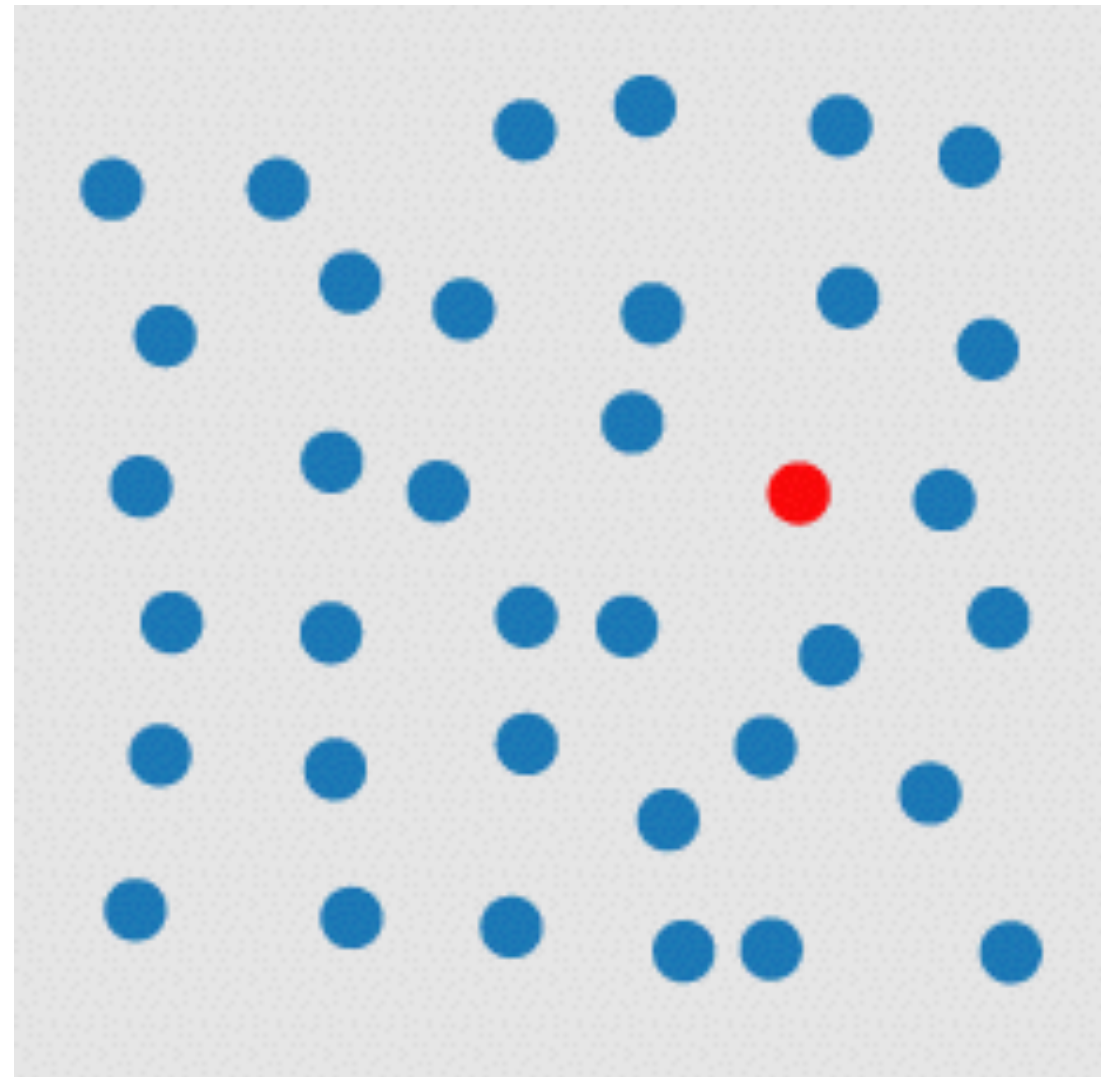
happens before focused attention -> „pre“attentive

attention is very important for cognition

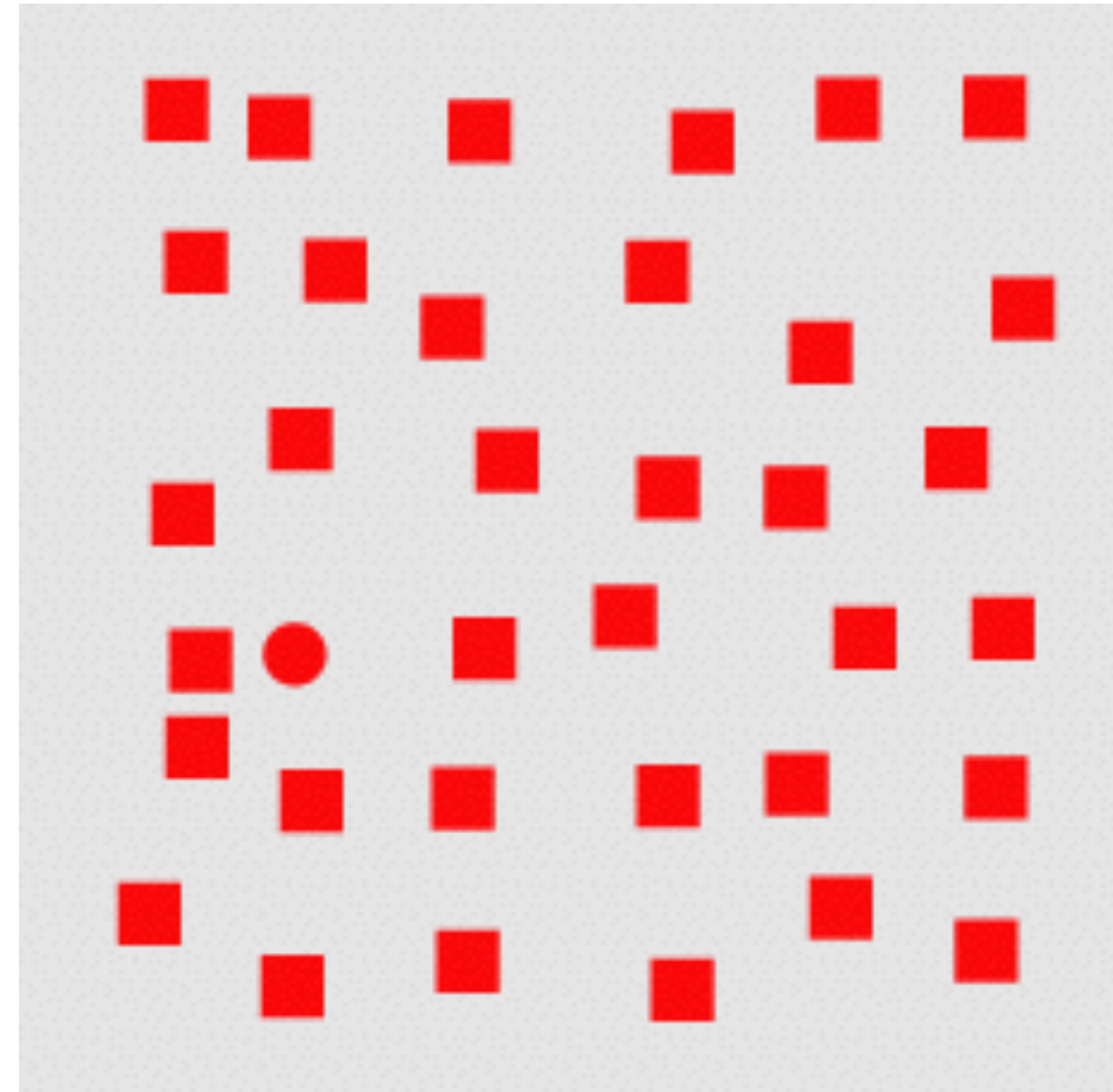
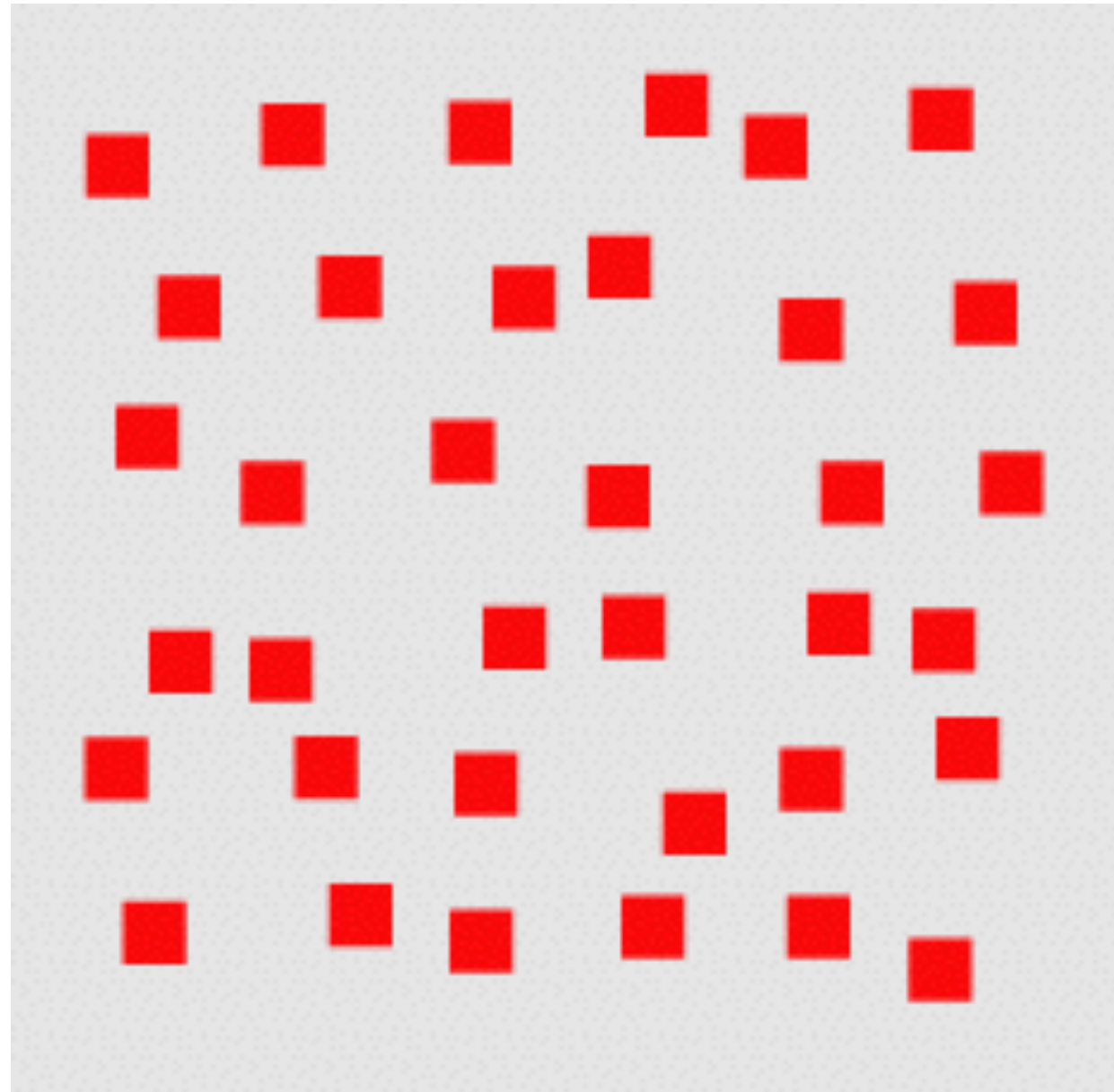
Independent of the number of distractors!

Opposite: sequential search (processed serially)

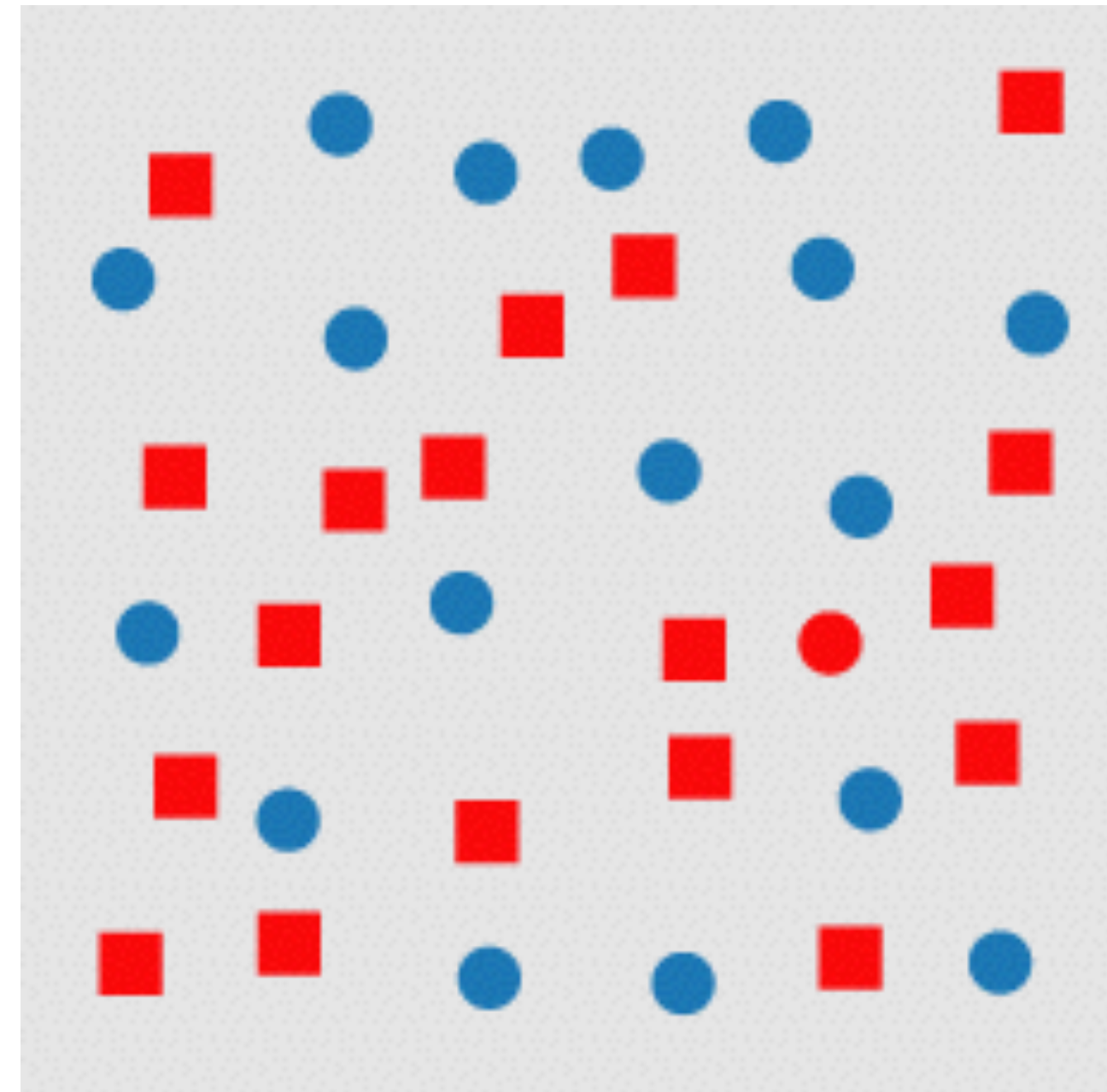
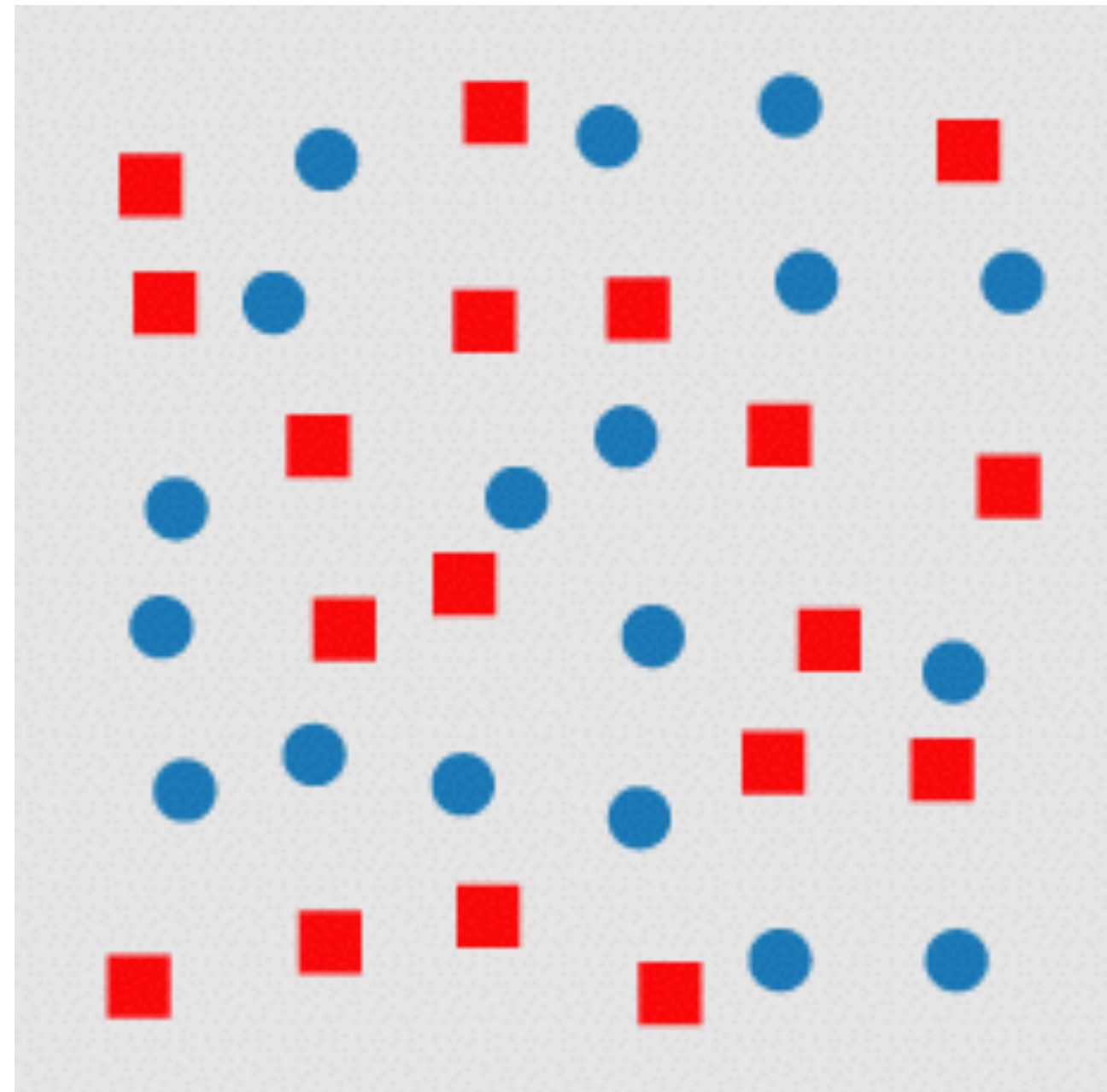
# Difference in Hue



# Difference in Curvature / Form



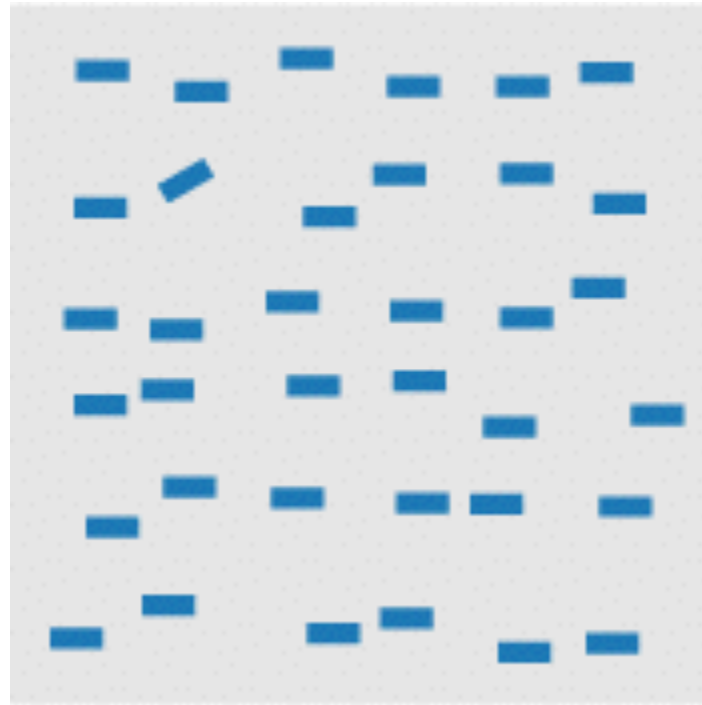
# Not Valid for Combinations



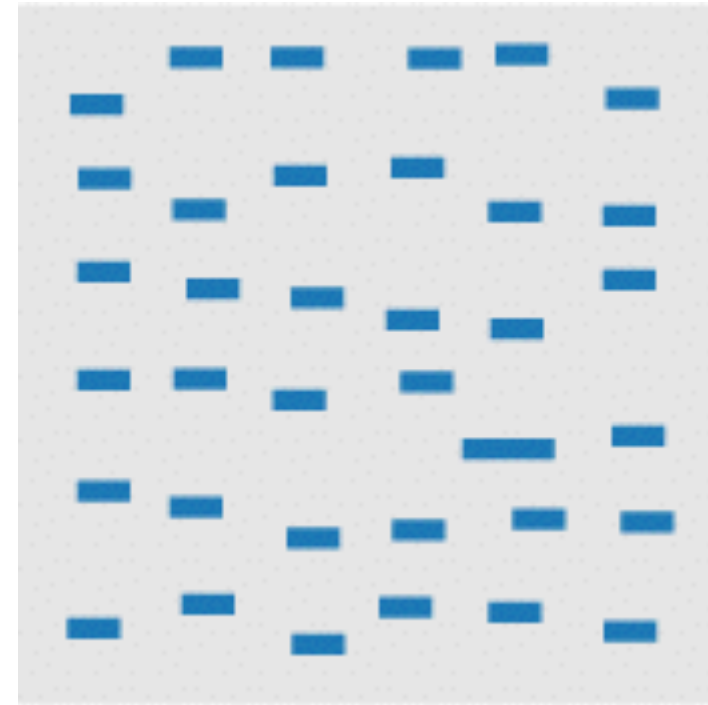
Conjunction Targets – no unique visual property  
target: red, circle  
distractor objects have both properties



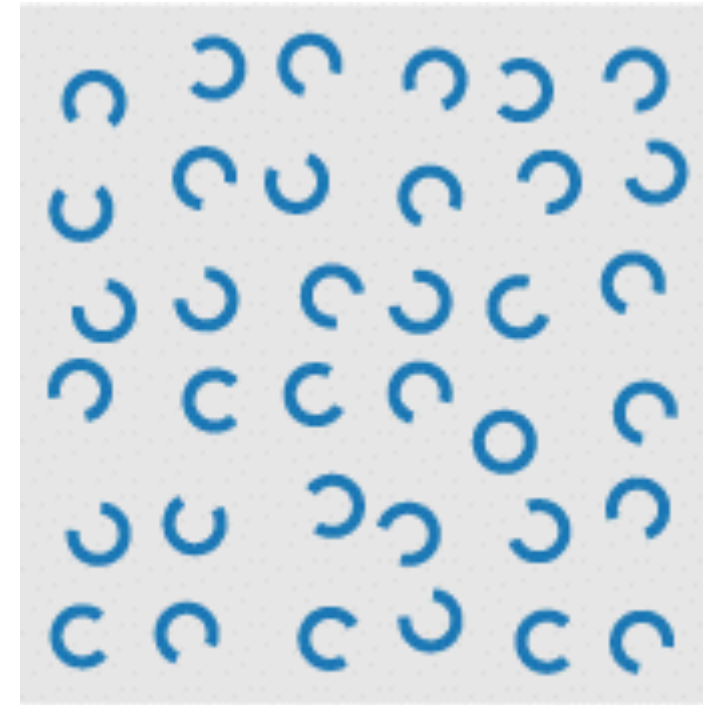
# Some Preattentive Properties



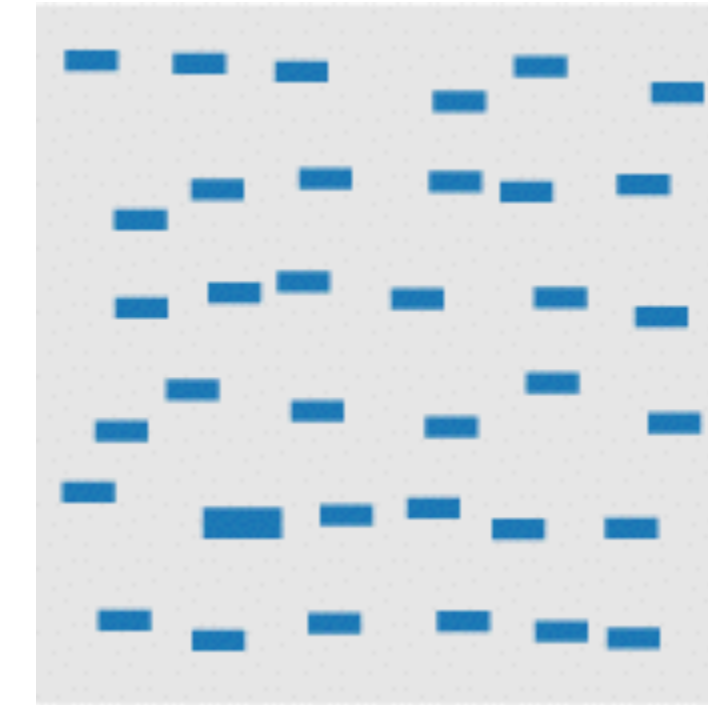
orientation



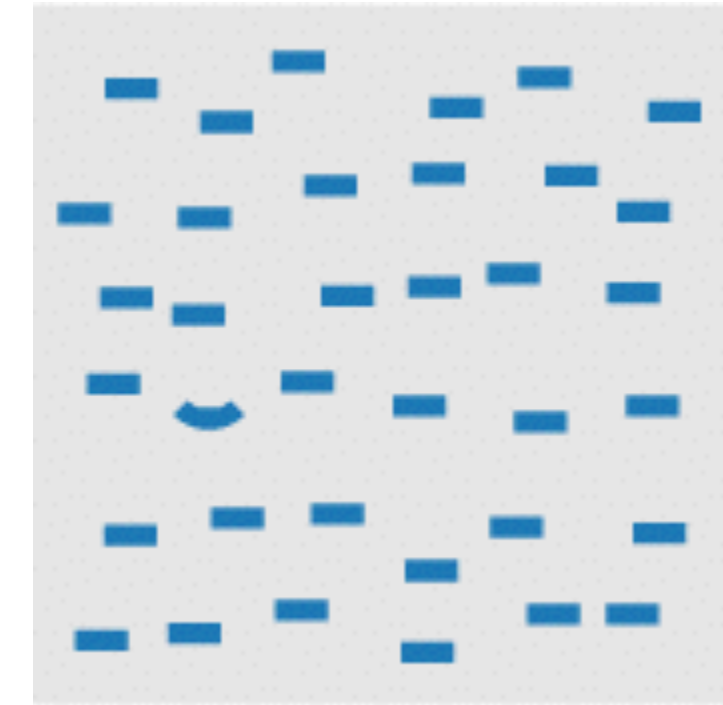
length



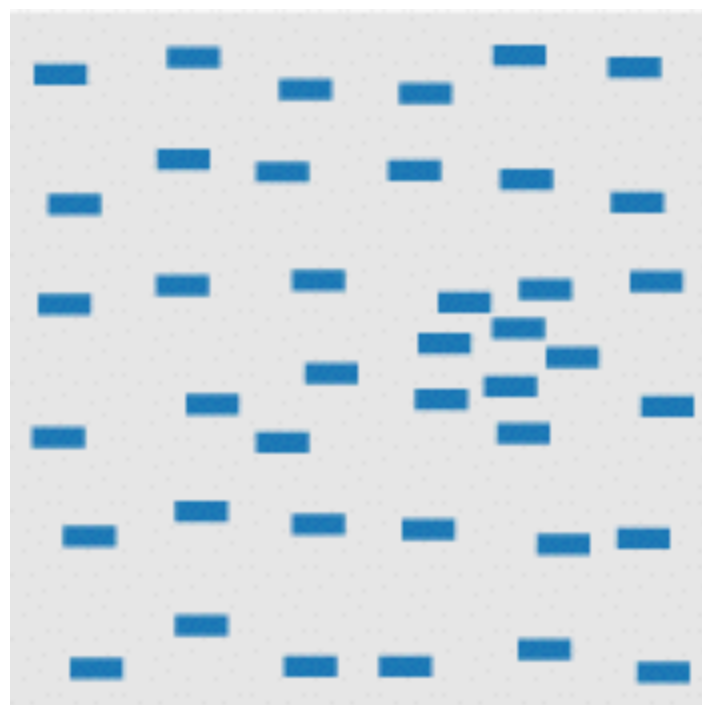
closure



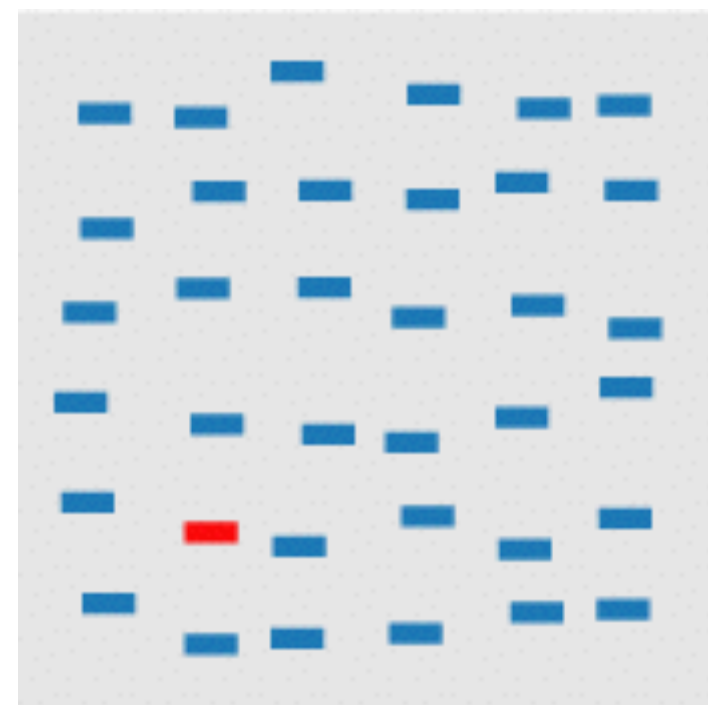
size



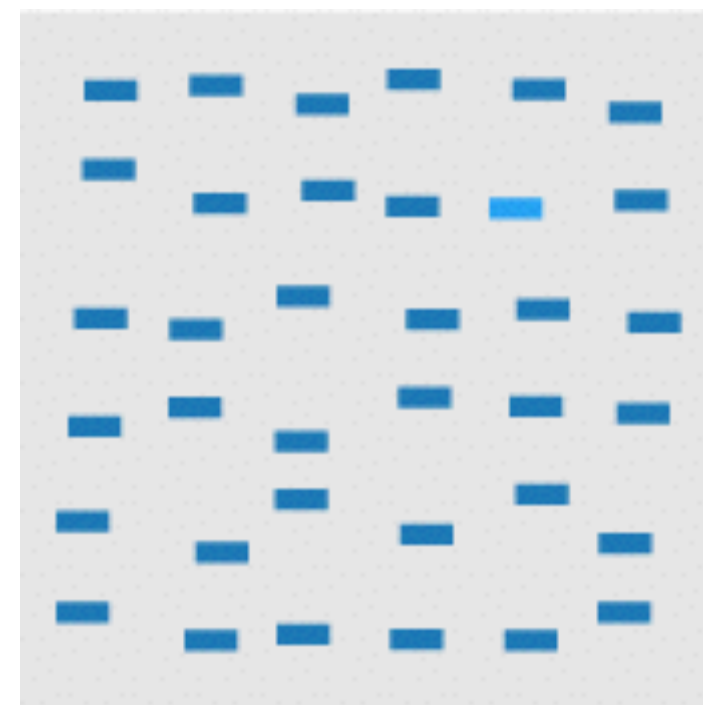
curvature



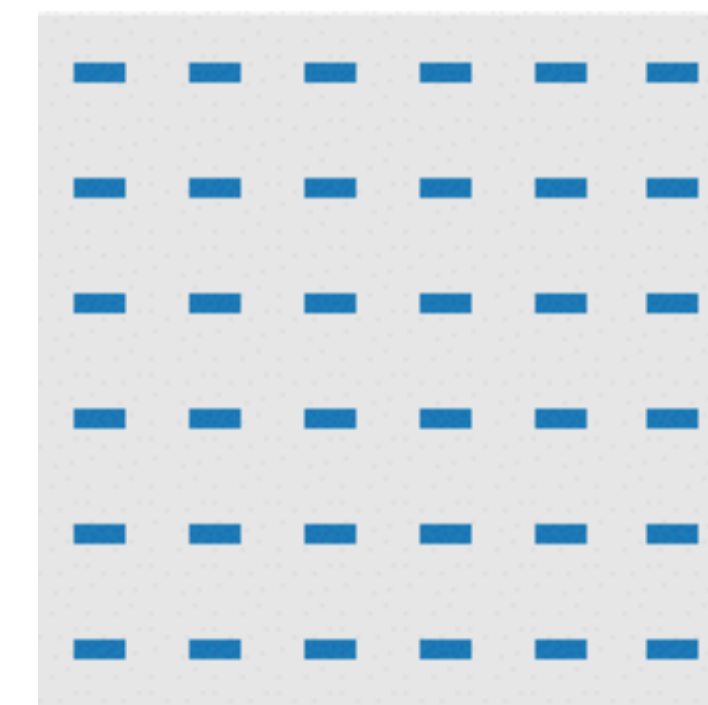
density



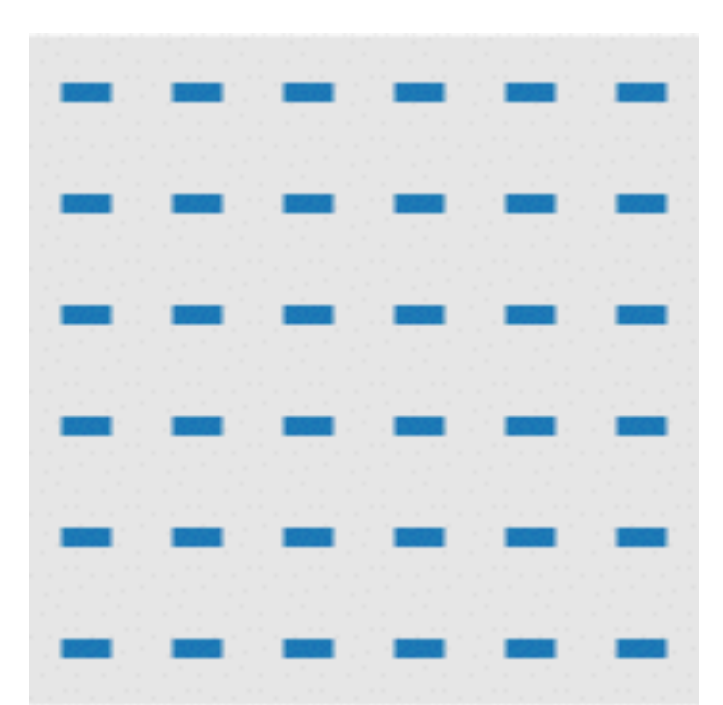
hue



hue



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

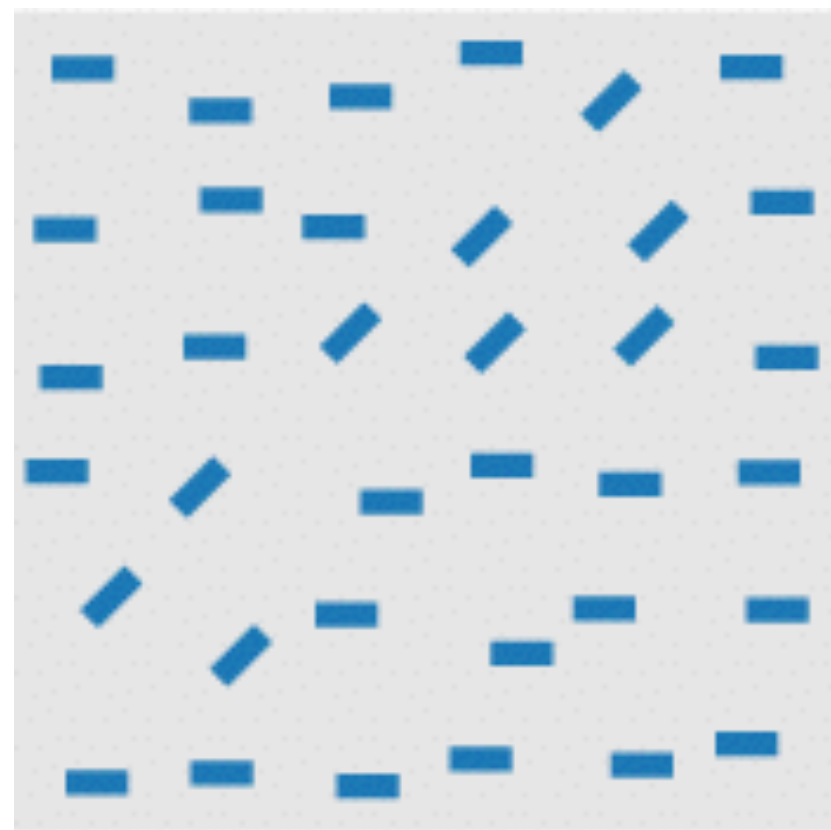
track one or more elements with a unique visual feature as they move in time and space

## counting and estimation

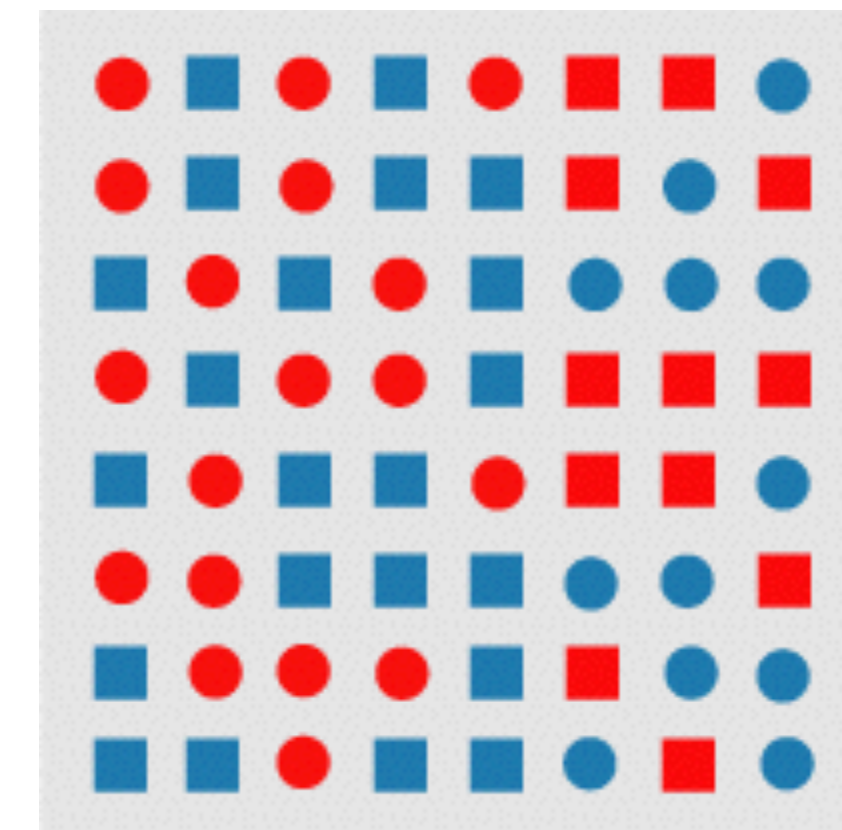
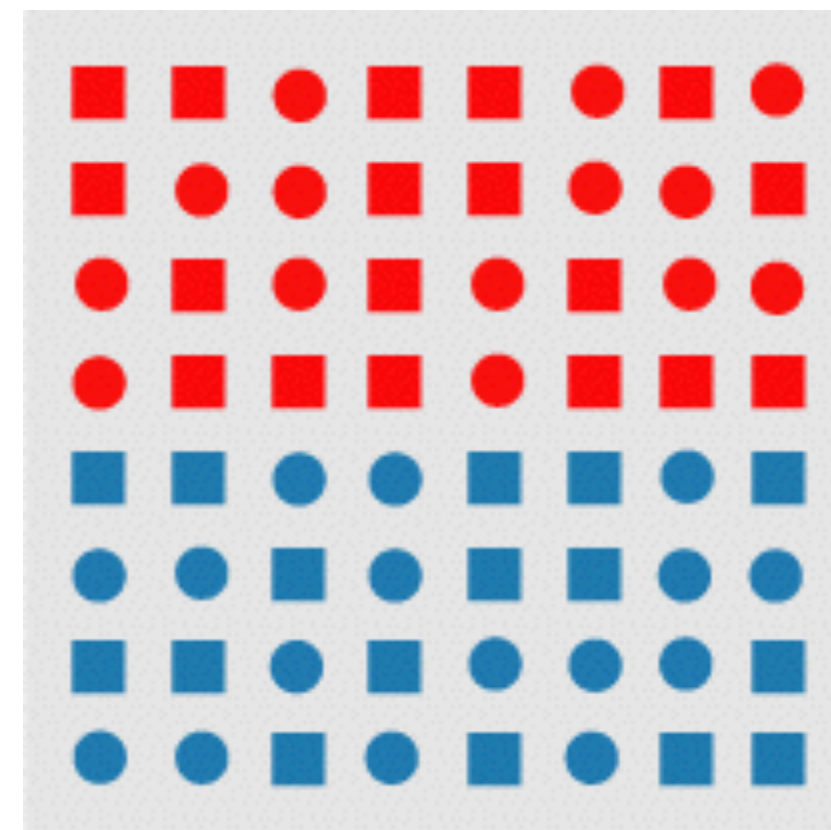
users count or estimate the number of elements with a unique visual feature.

# Tasks

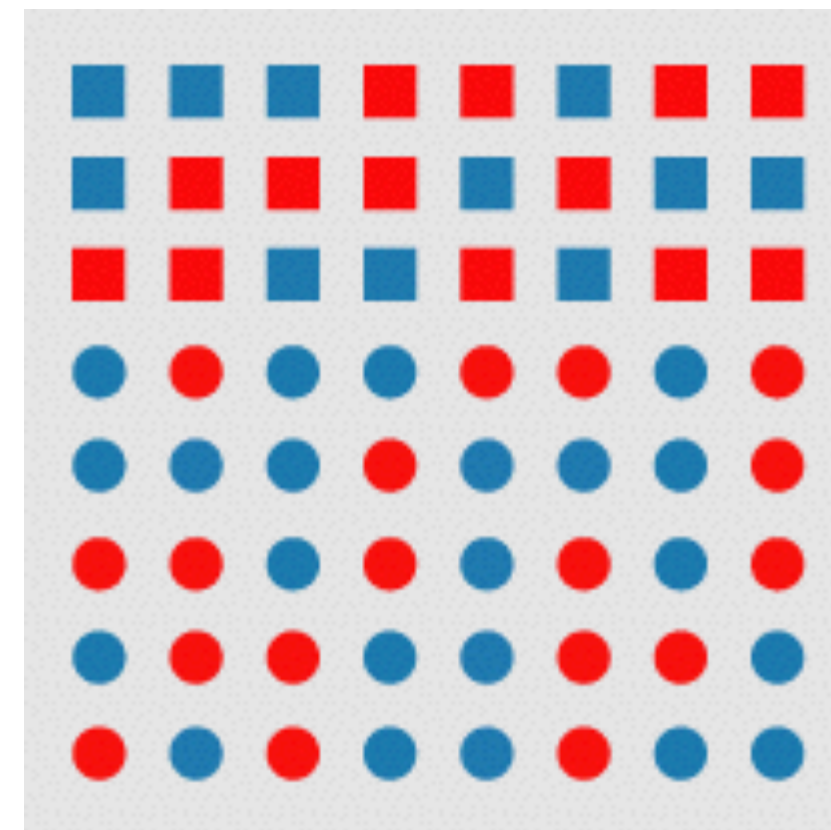
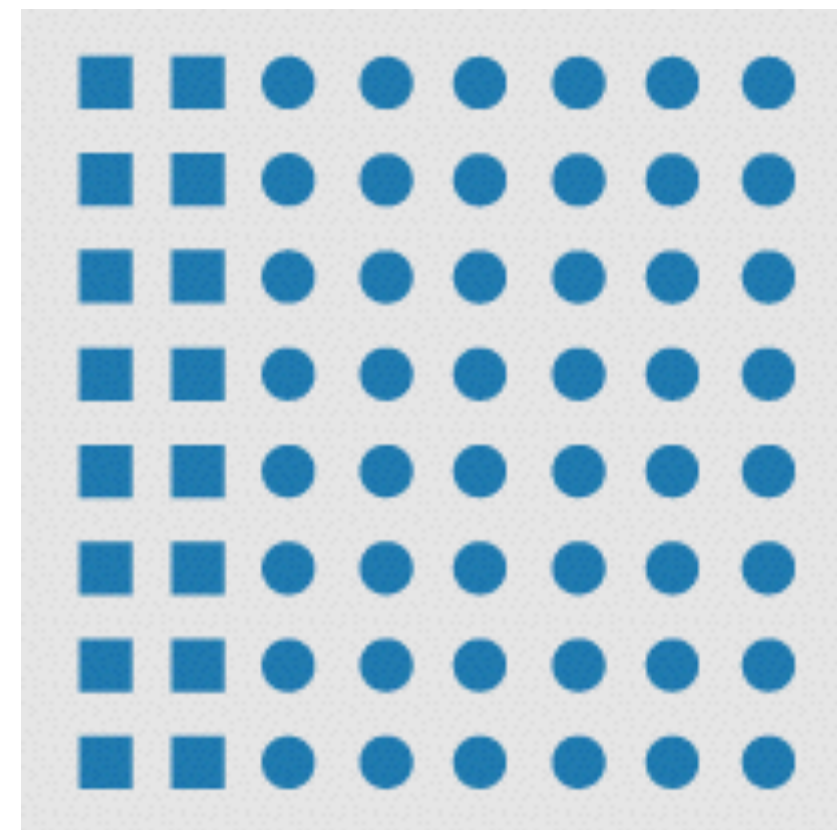
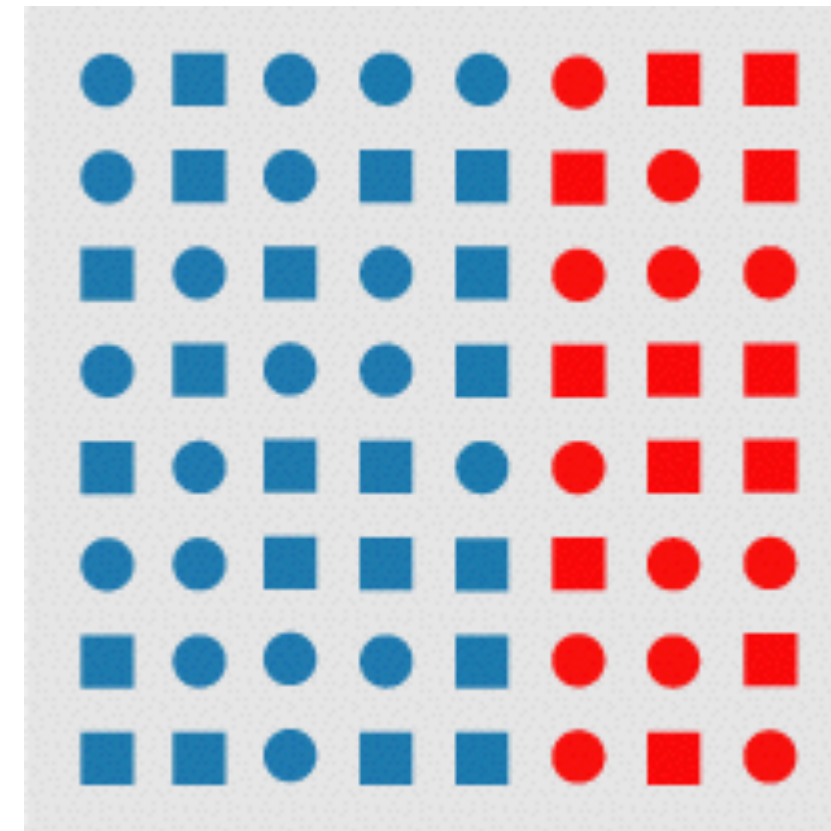
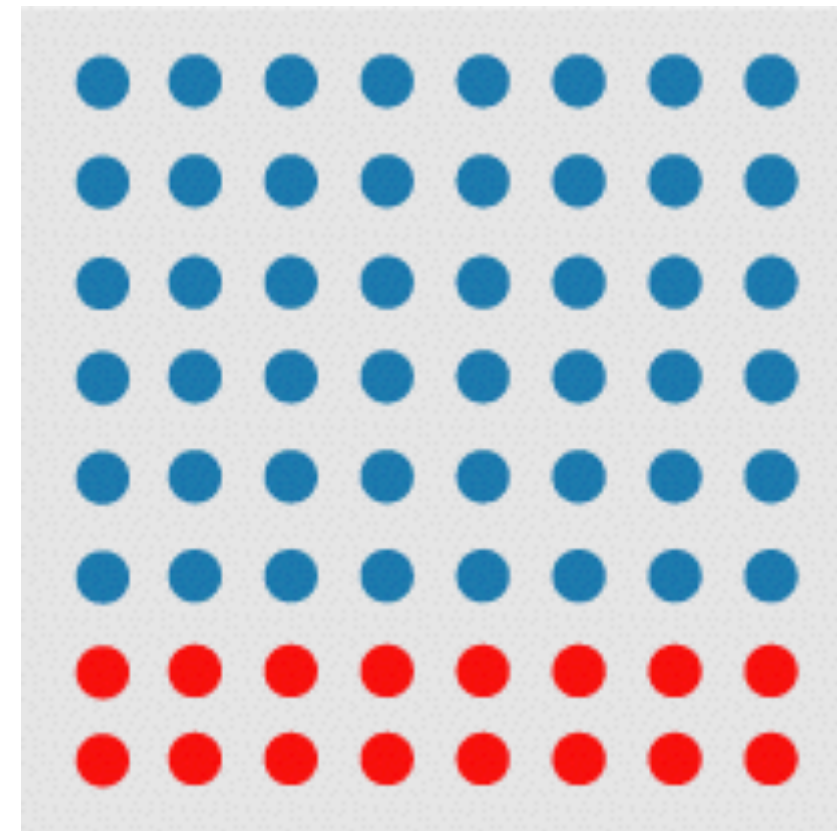
Number Estimation



Boundary Detection



# Hierarchy of Preattentive Features



Examples online!

# 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

No failure of vision system, failure based on 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)

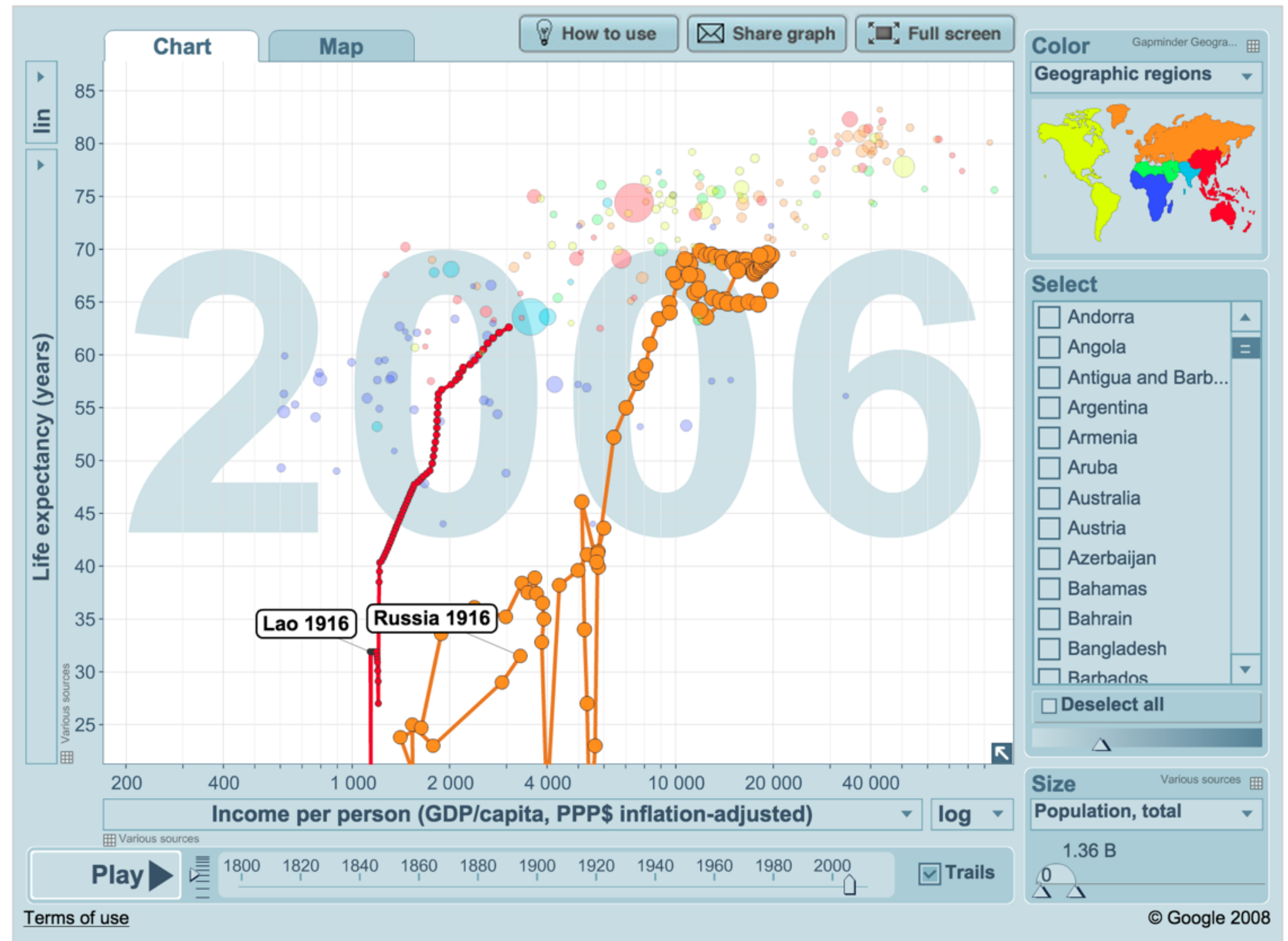
semantic importance of changed object

low level object properties overlooked more easily

# Design Critique

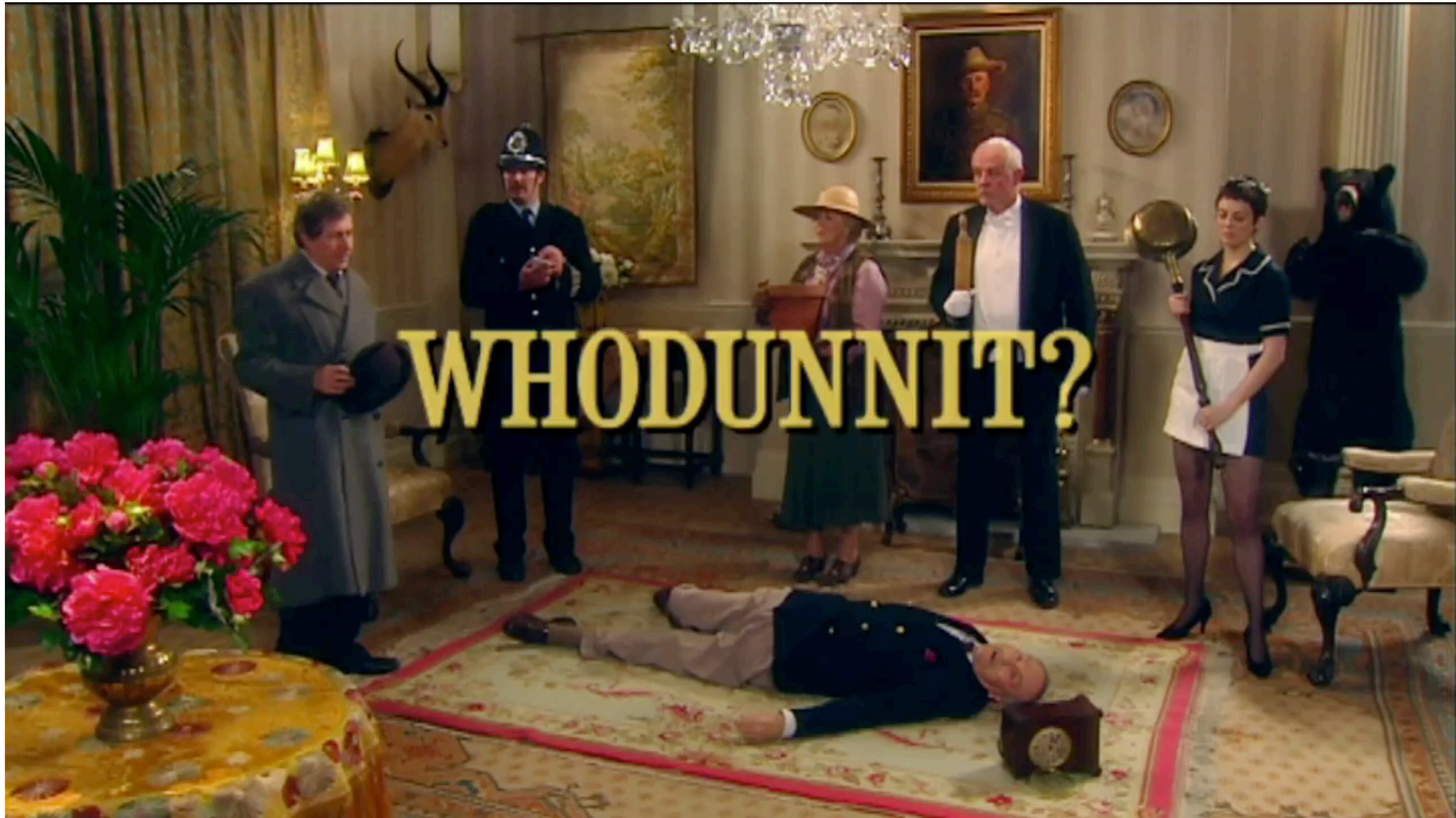
# GapMinder

<http://goo.gl/FqbQ3P>





# Attention Blindness



WHODUNNIT?

Other Videos

# 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)

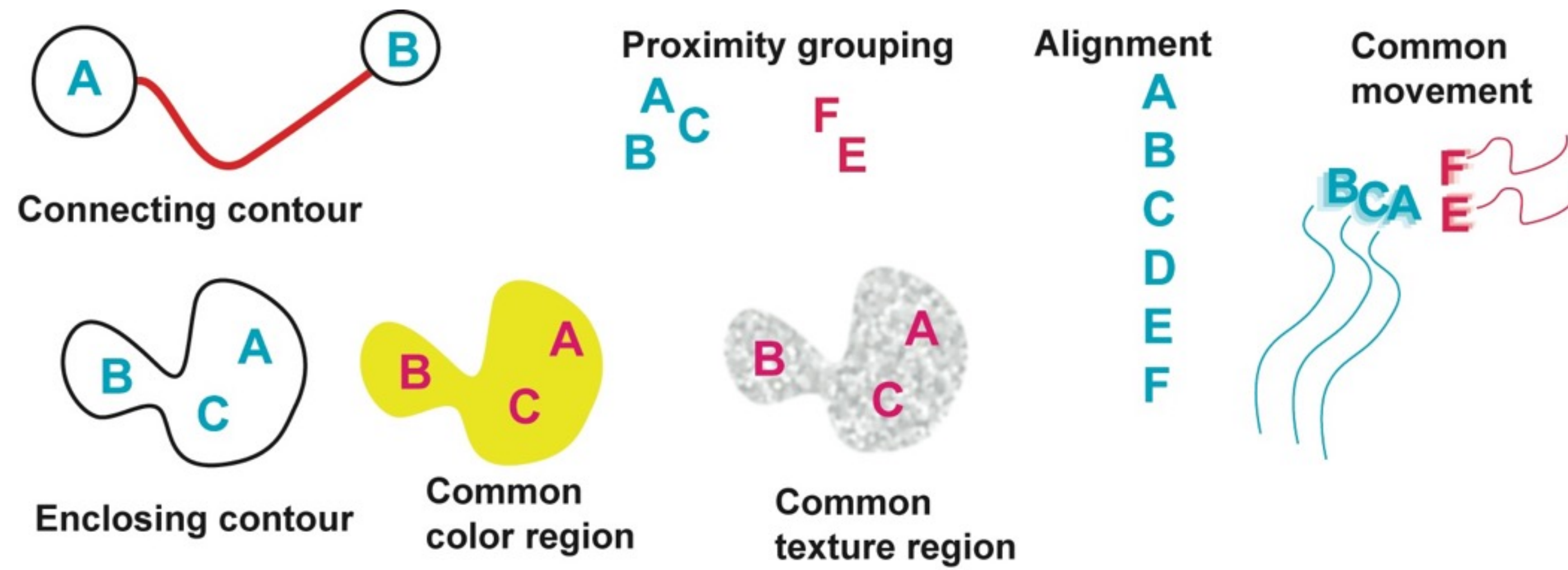
Attention is driven by preexisting knowledge, expectations, and goals stored in long-term memory

# Gestalt Principles

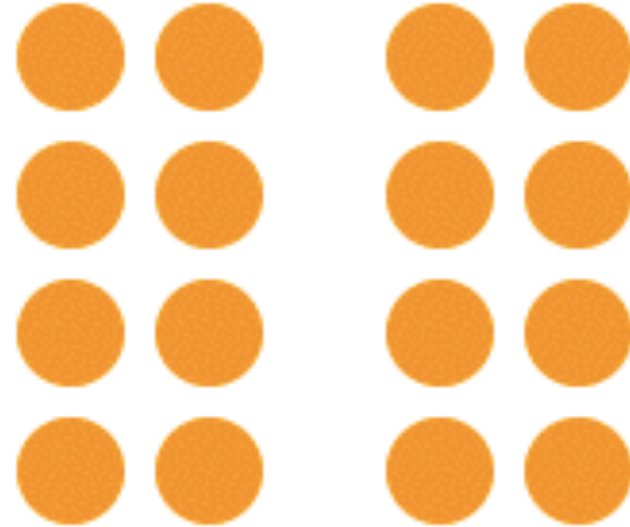
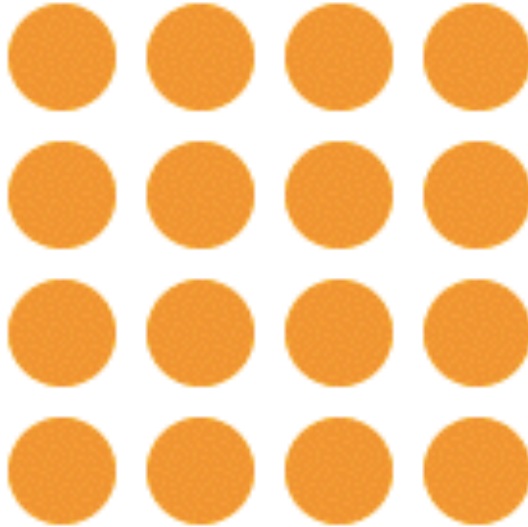
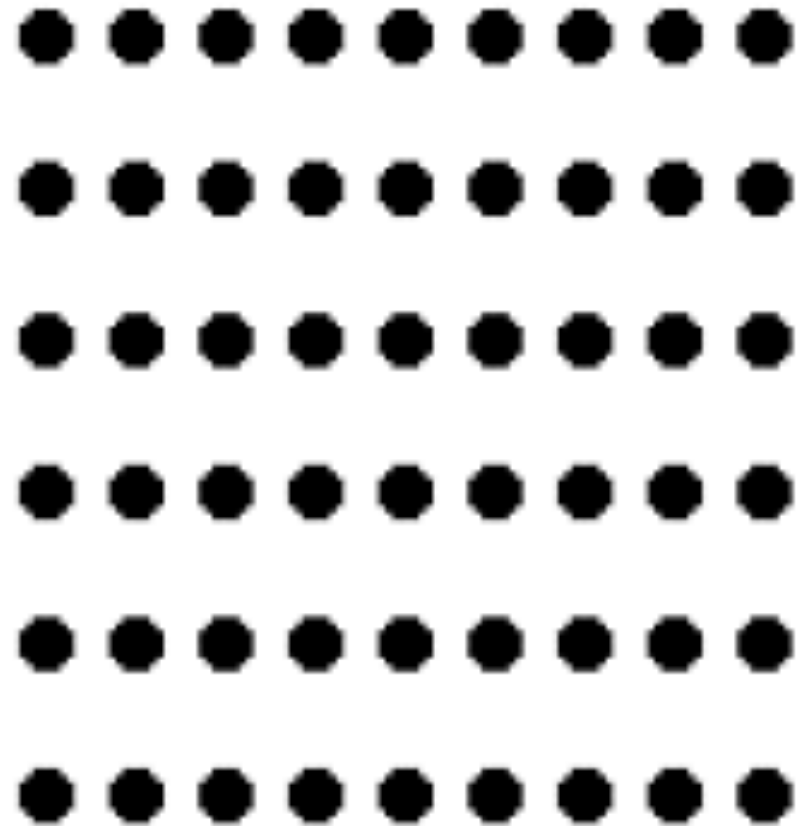
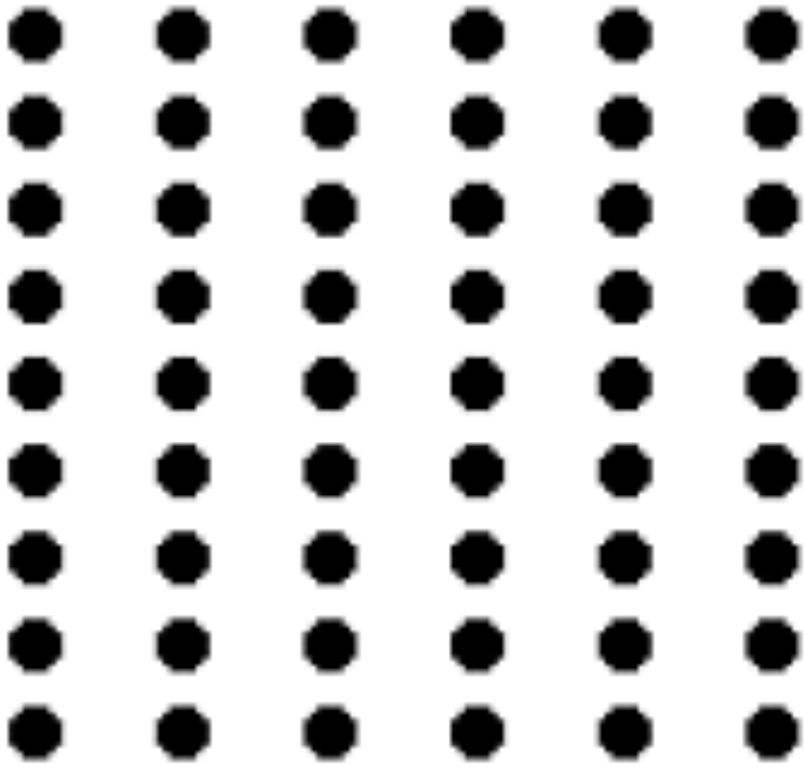
Wertheimer, 1923, and recent extensions

# Gestalt Principles

Patterns that transcend the visual stimuli that produced them

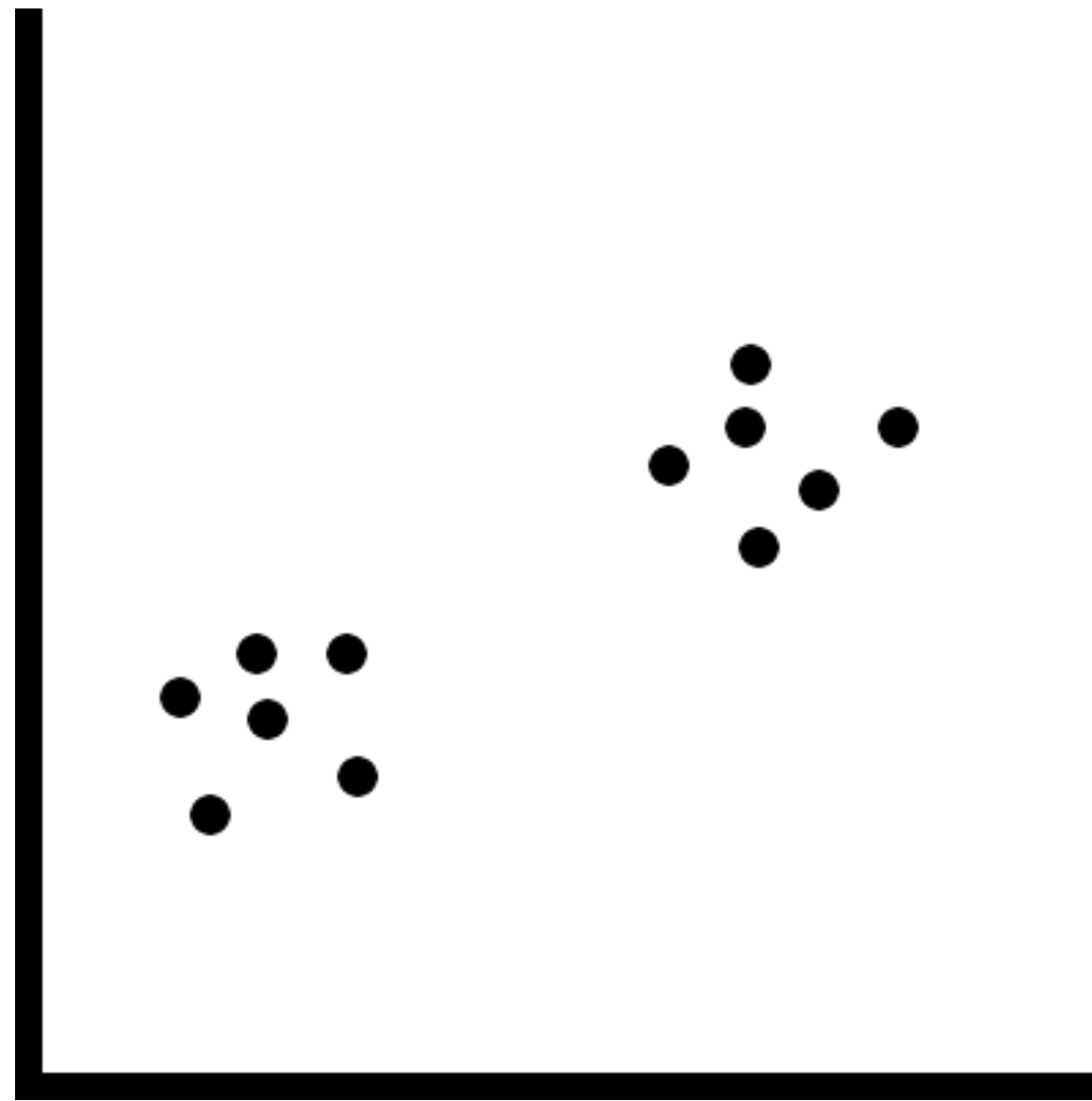


# Proximity



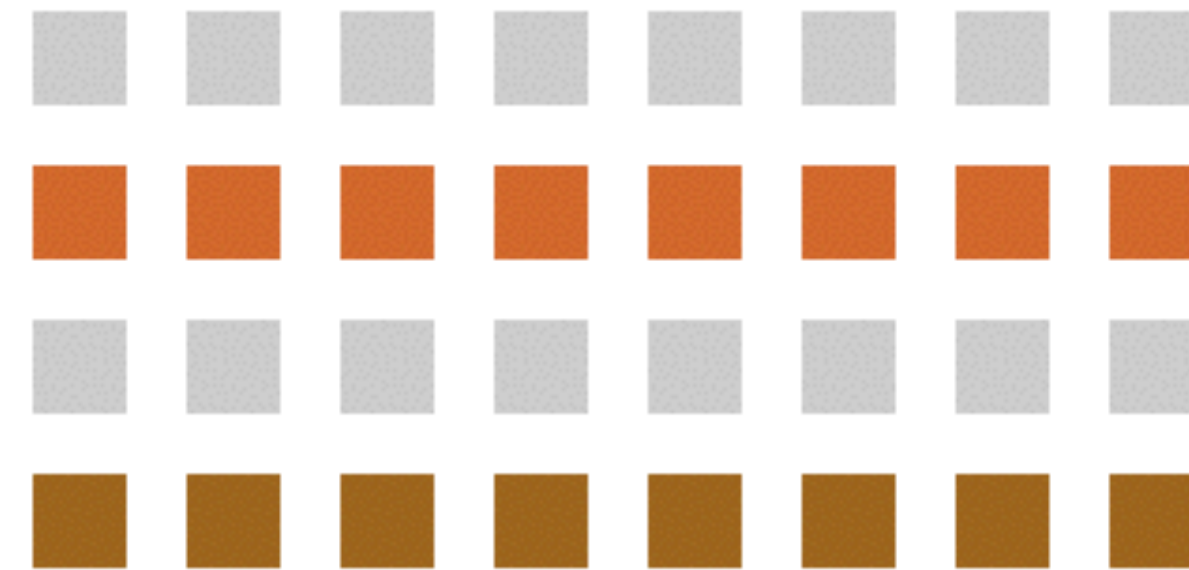
# Proximity

Grouping/linking by placing entities in close proximity





# Similarity

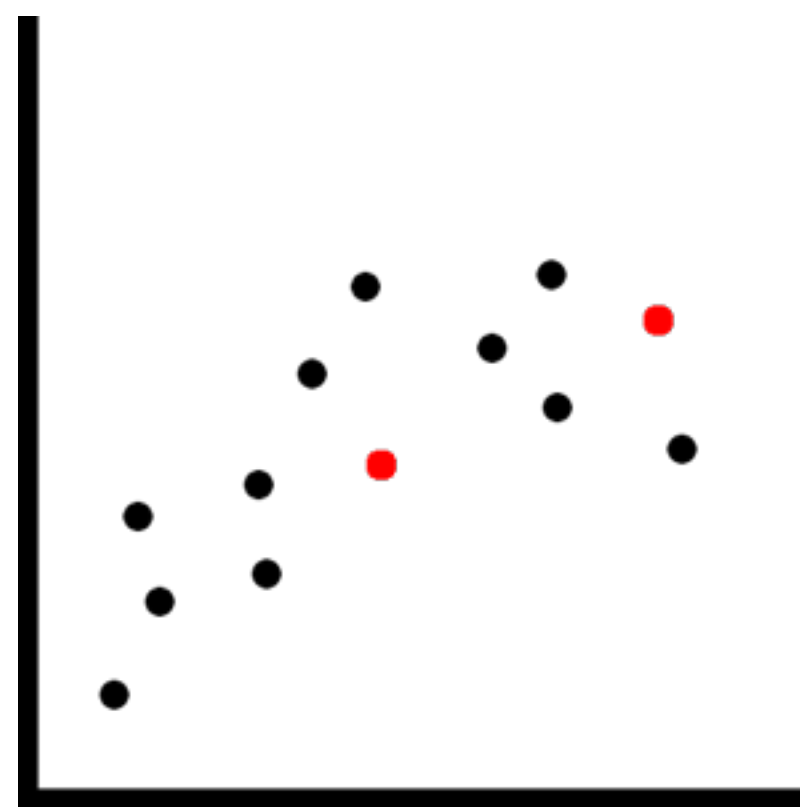


# Similarity

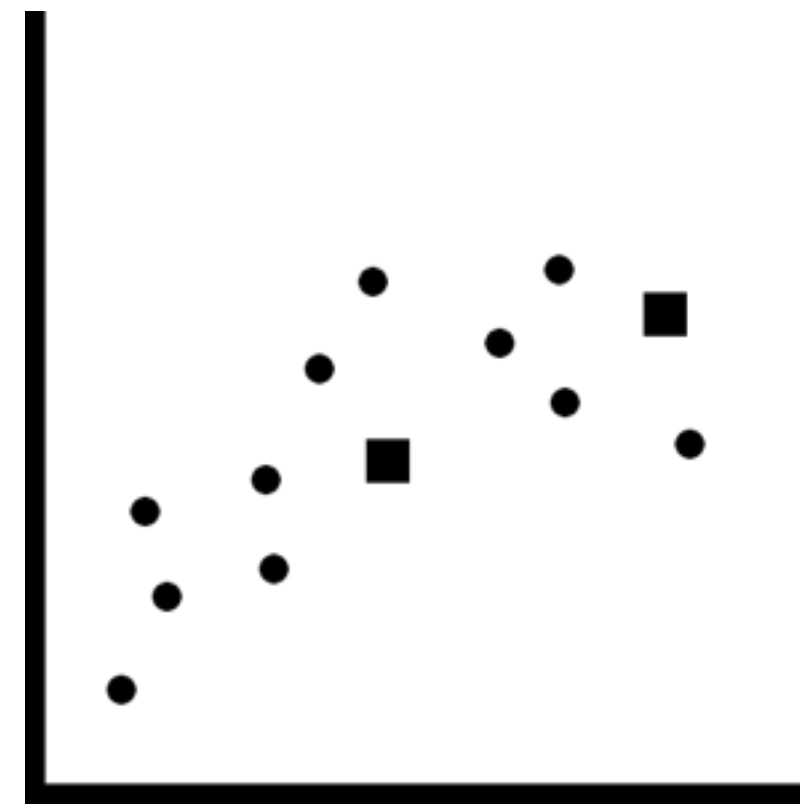
Co-modulation of a **channel**

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

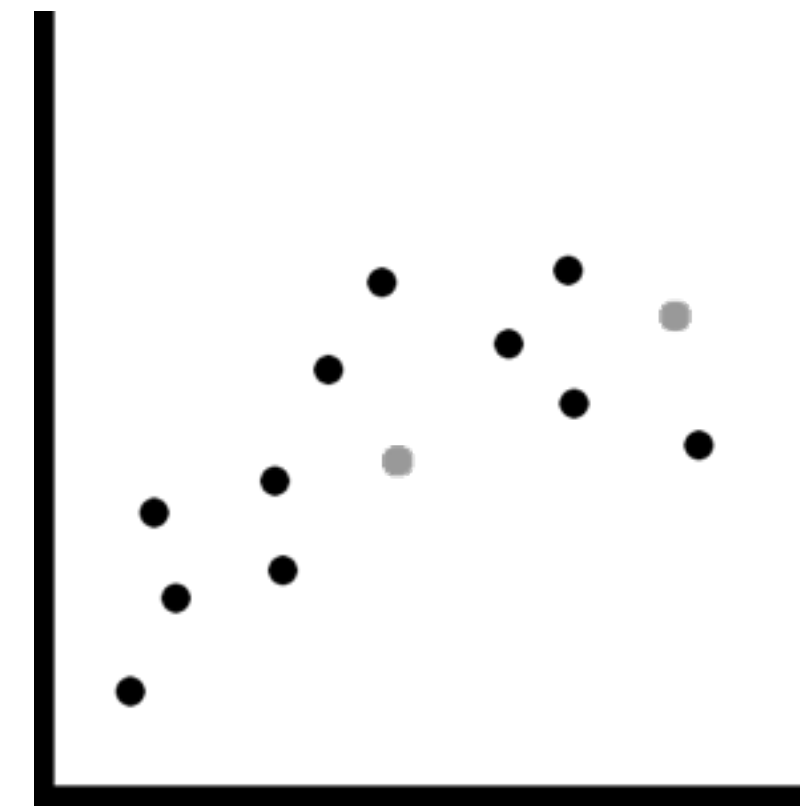
Adding a glyph, label, frame, background



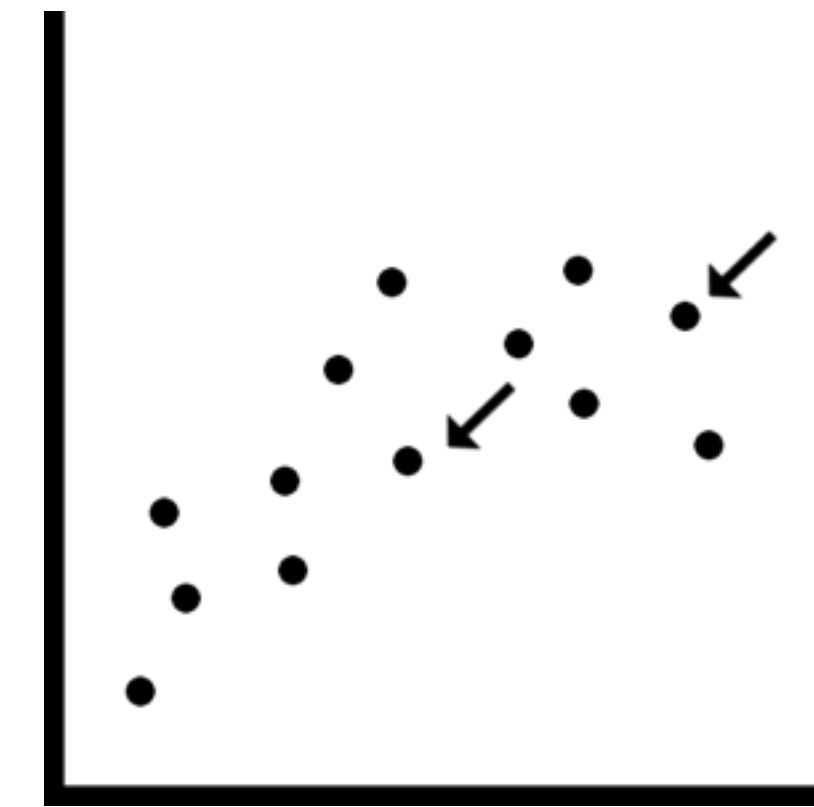
Color



Shape



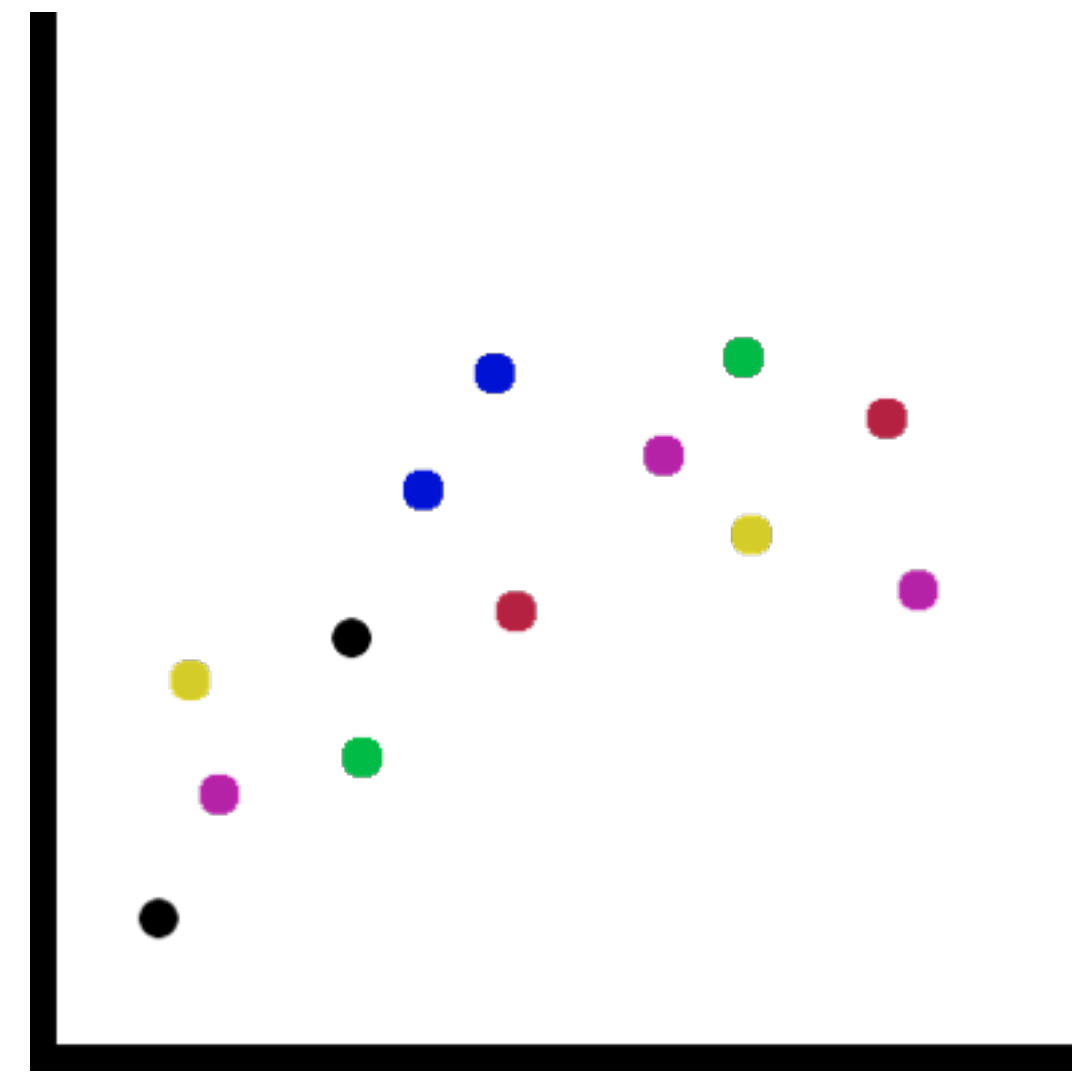
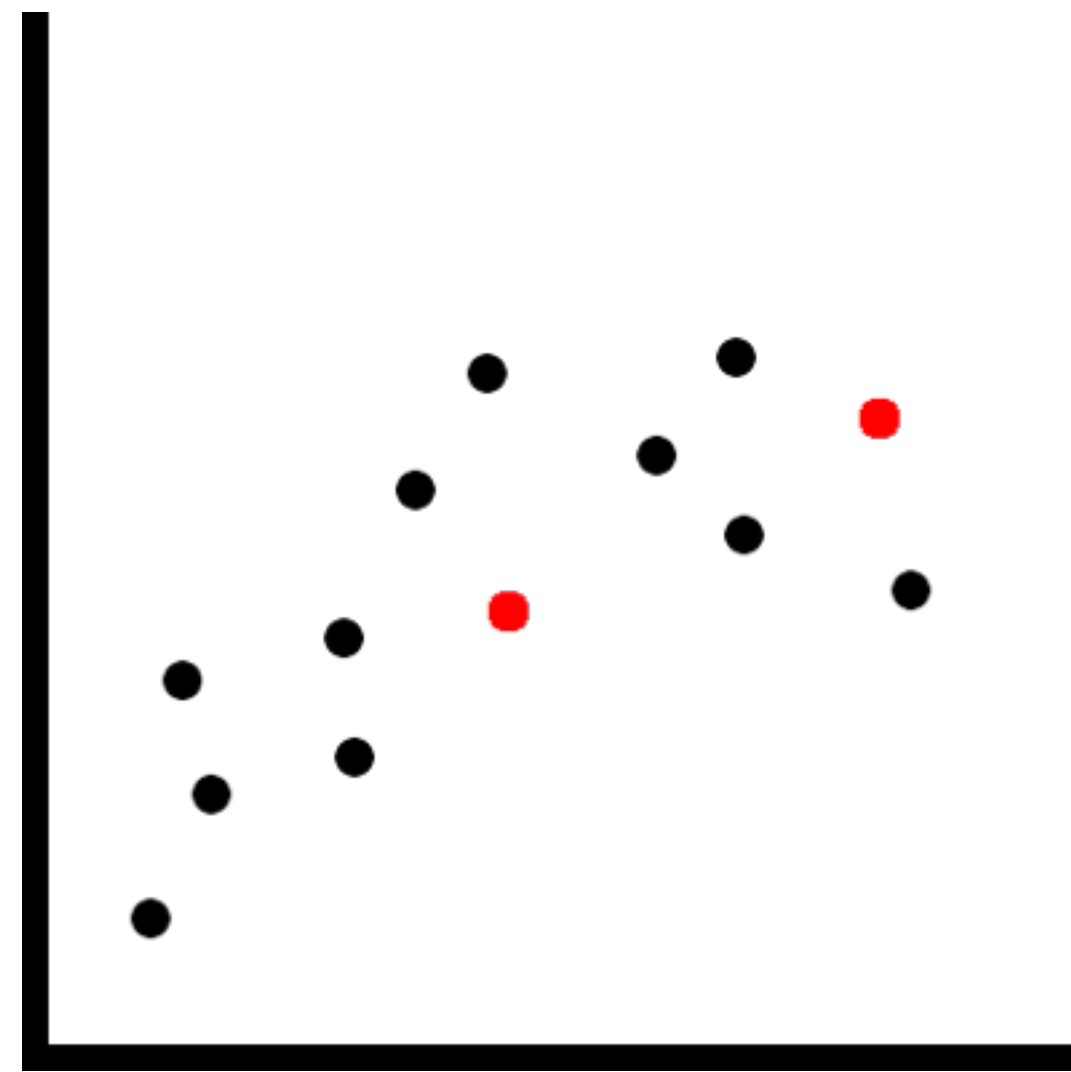
Value



Glyph

# Color – Perception Issues (1/2)

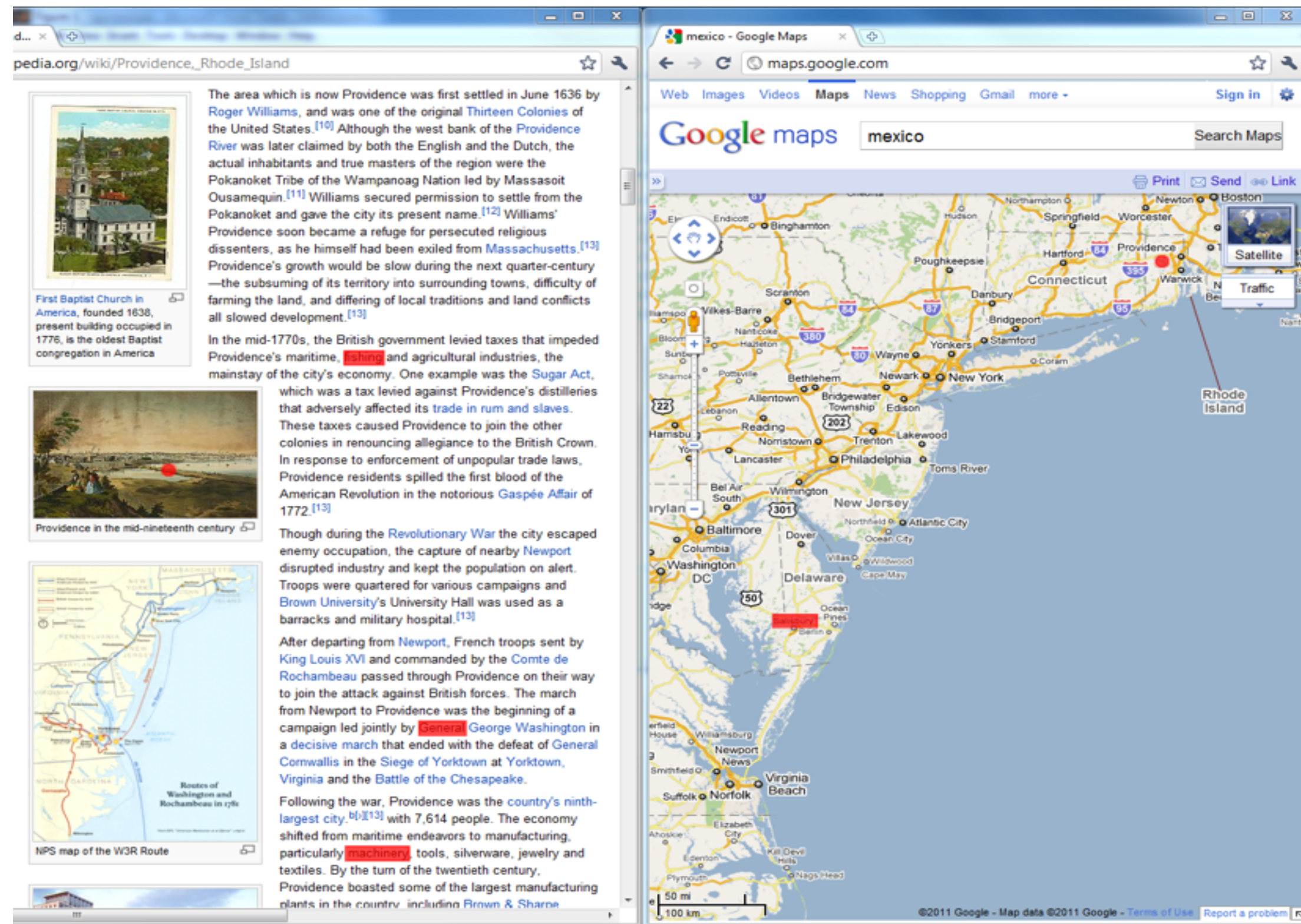
Preattentive properties: Very good for 1-2 simultaneous, serial search for more



# Color – Perception Issues (2/2)

Slower in a cluttered environment

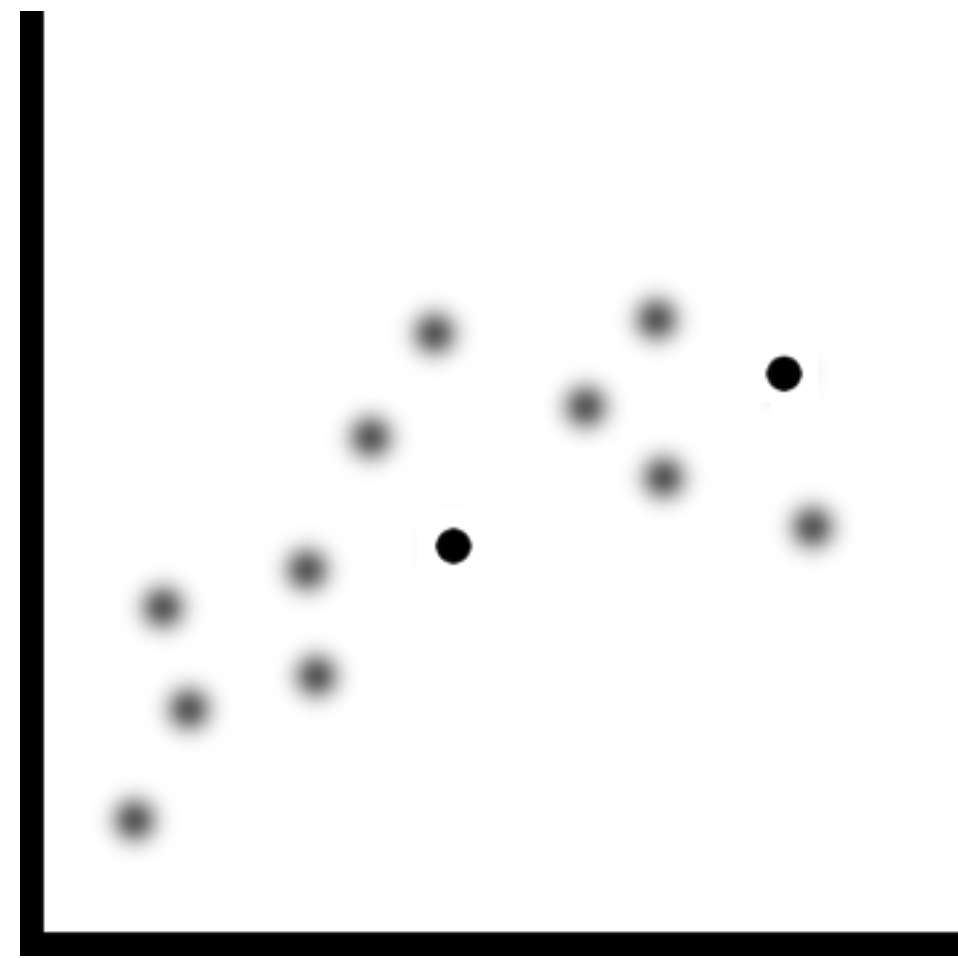
Size of colored object relevant.



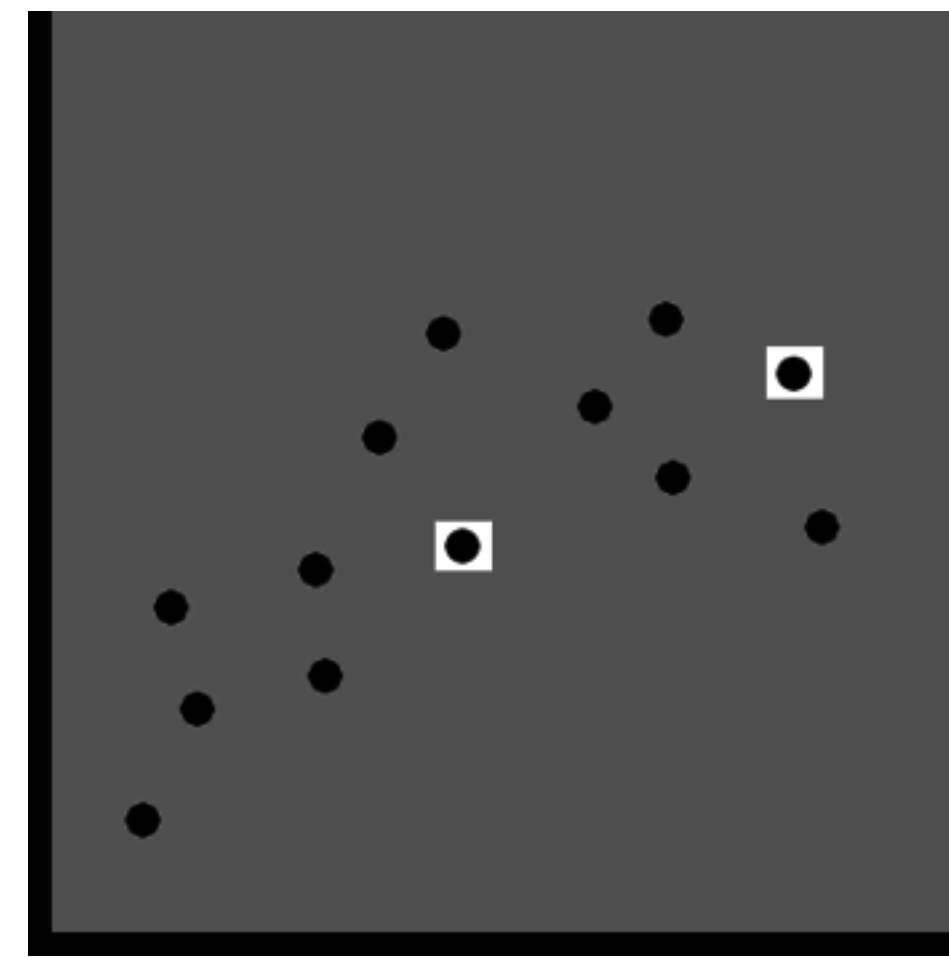
# Similarity

Modulate everything else

Blurring, darkening, desaturating, etc.



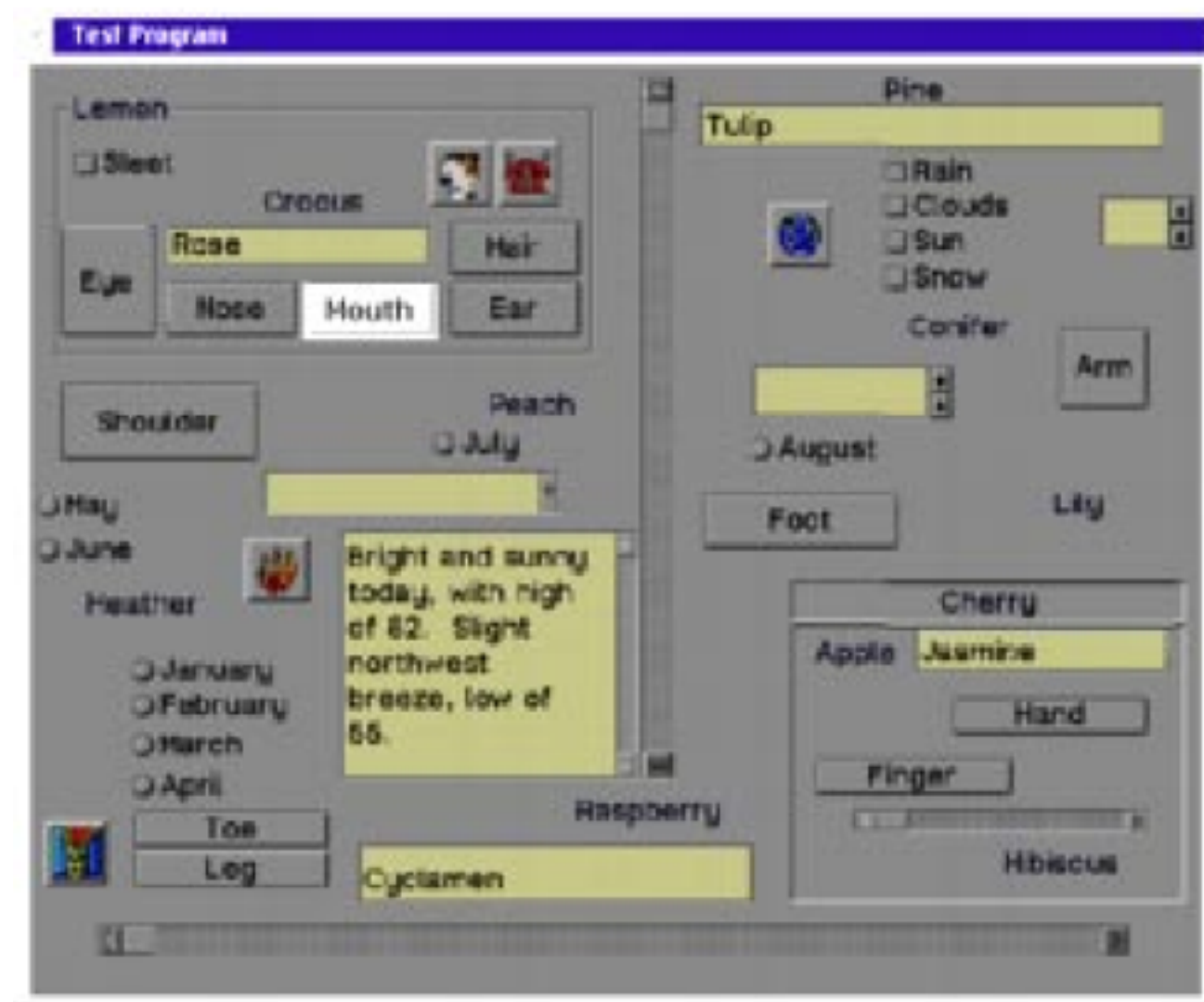
Blur



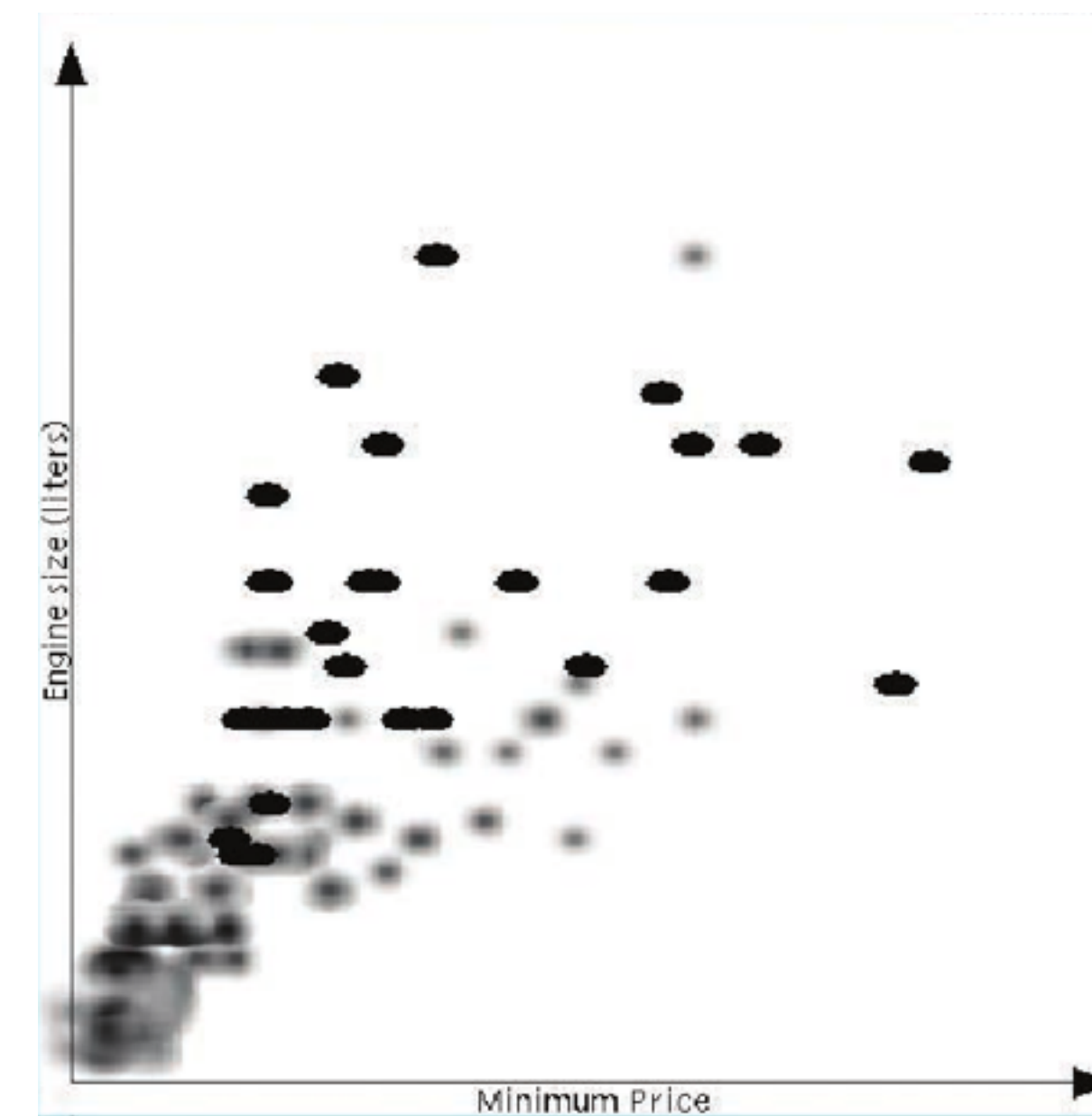
Darkening

# Modulating Everything Else: Recommendation, Example

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

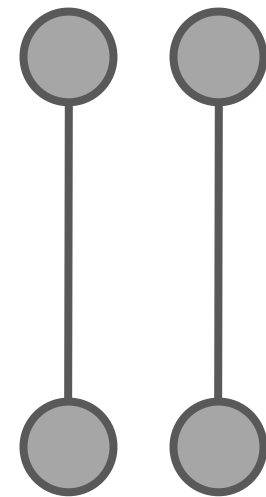


[Zhai et al., 1997]

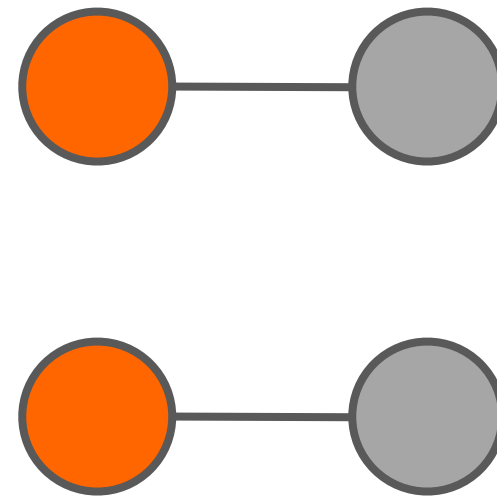


[Kosara et al., 2002]

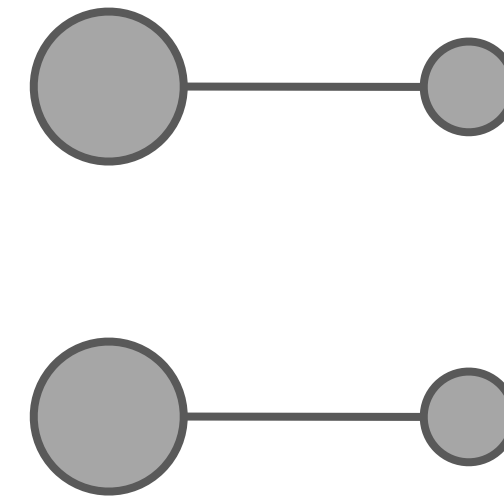
# A Little Experiment...



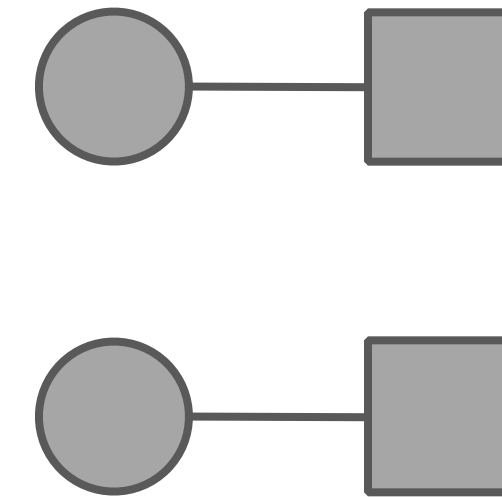
Proximity



Color



Size



Shape

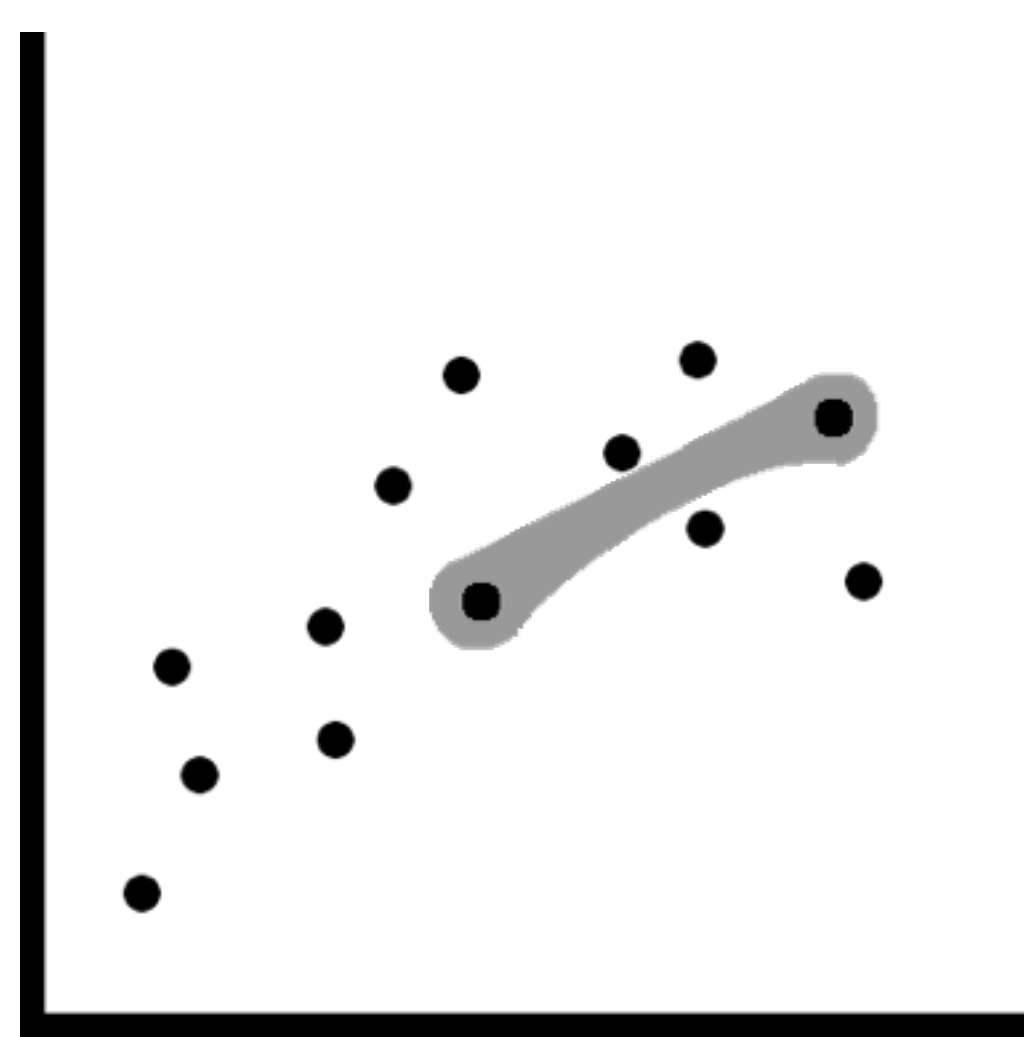
# Connectedness and Common Region

Connected items with a line or curve

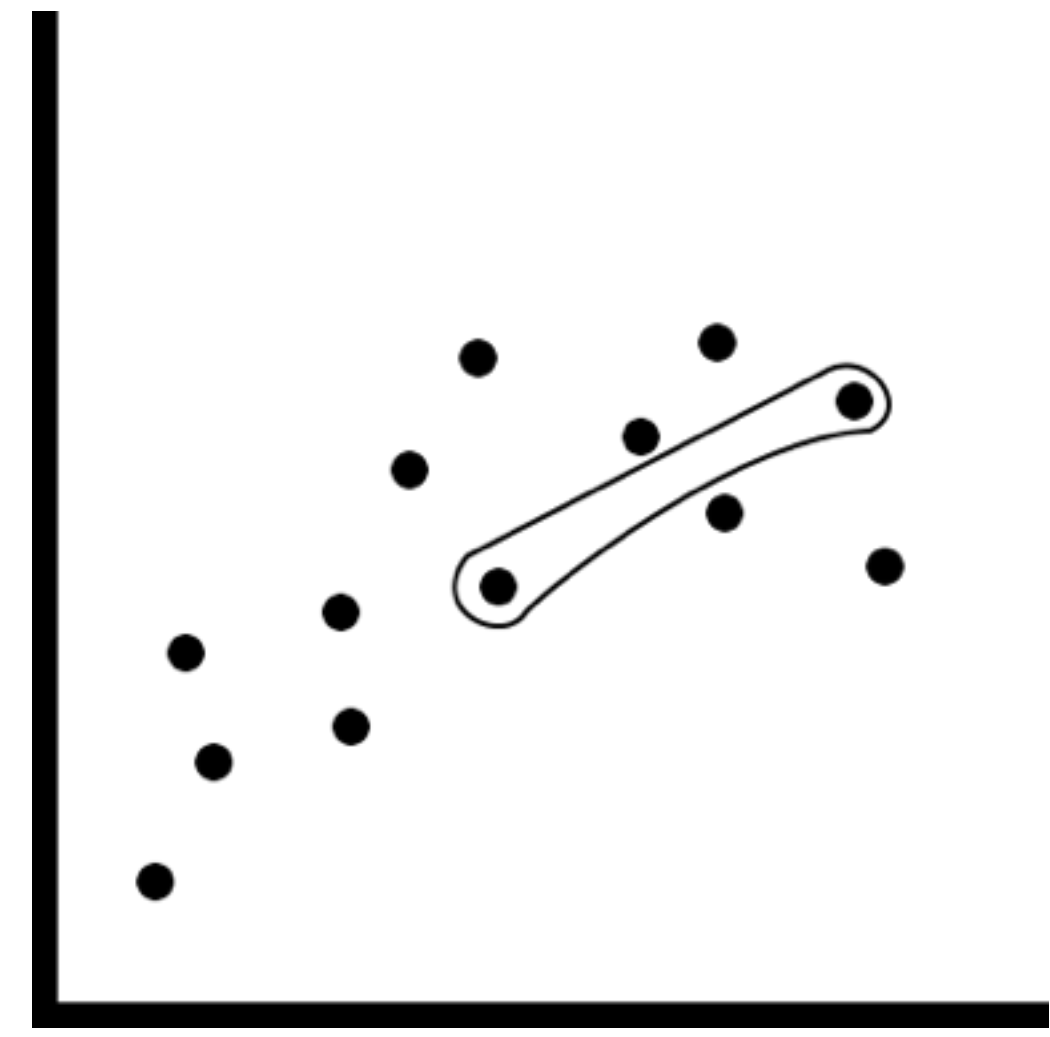
Surround items with a outline, surface, volume



Connectedness



Surface

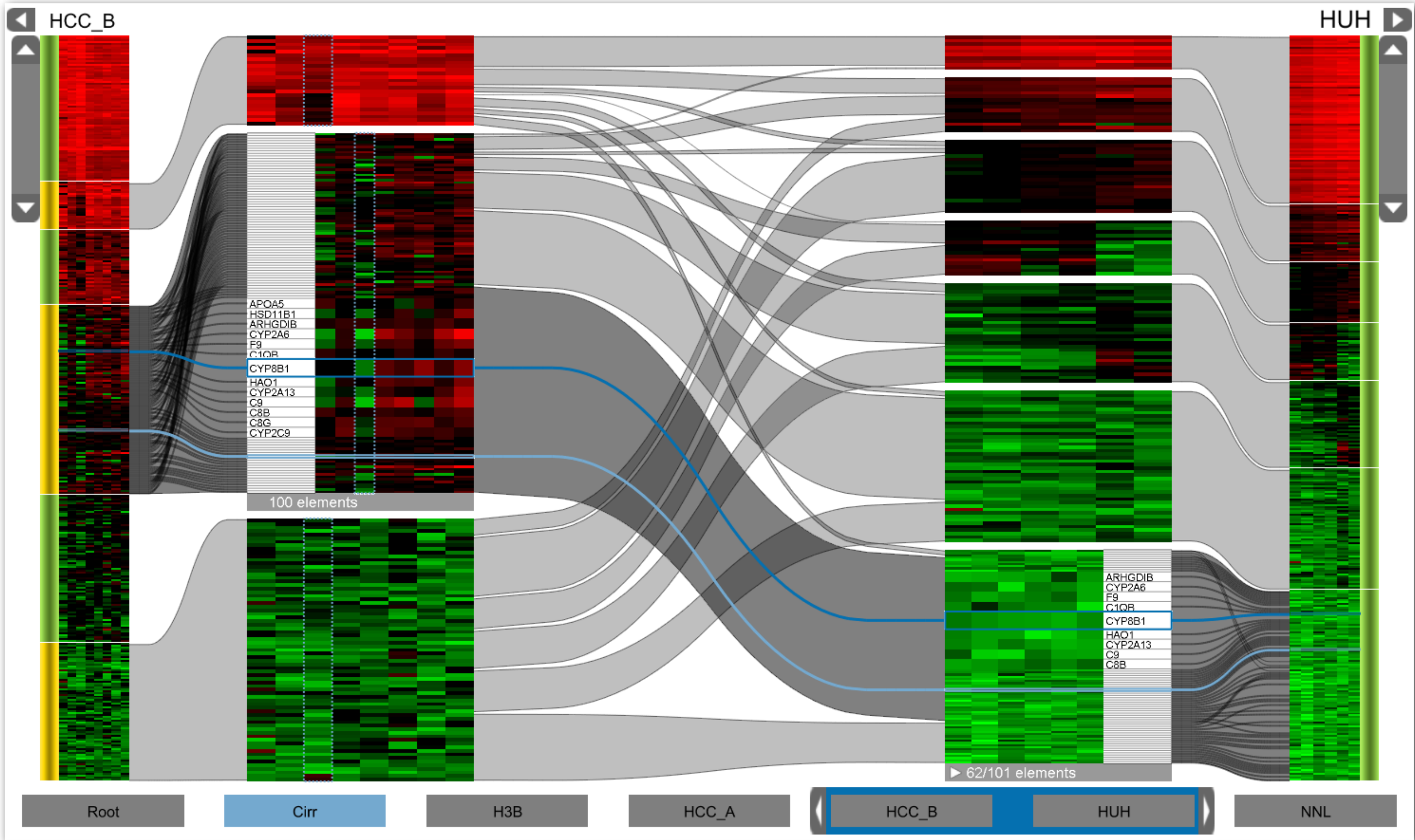


Outline

Common Region

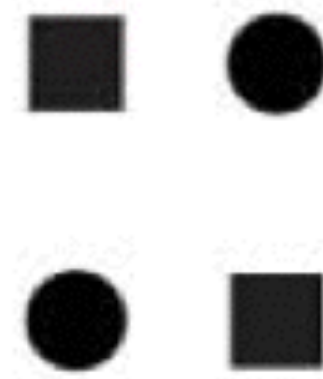


# Connection

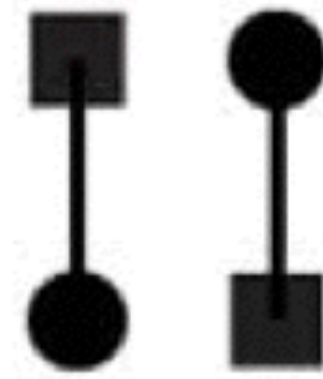


# Enclosure

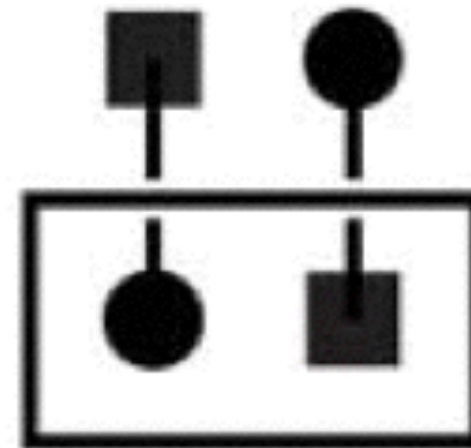
Similarity



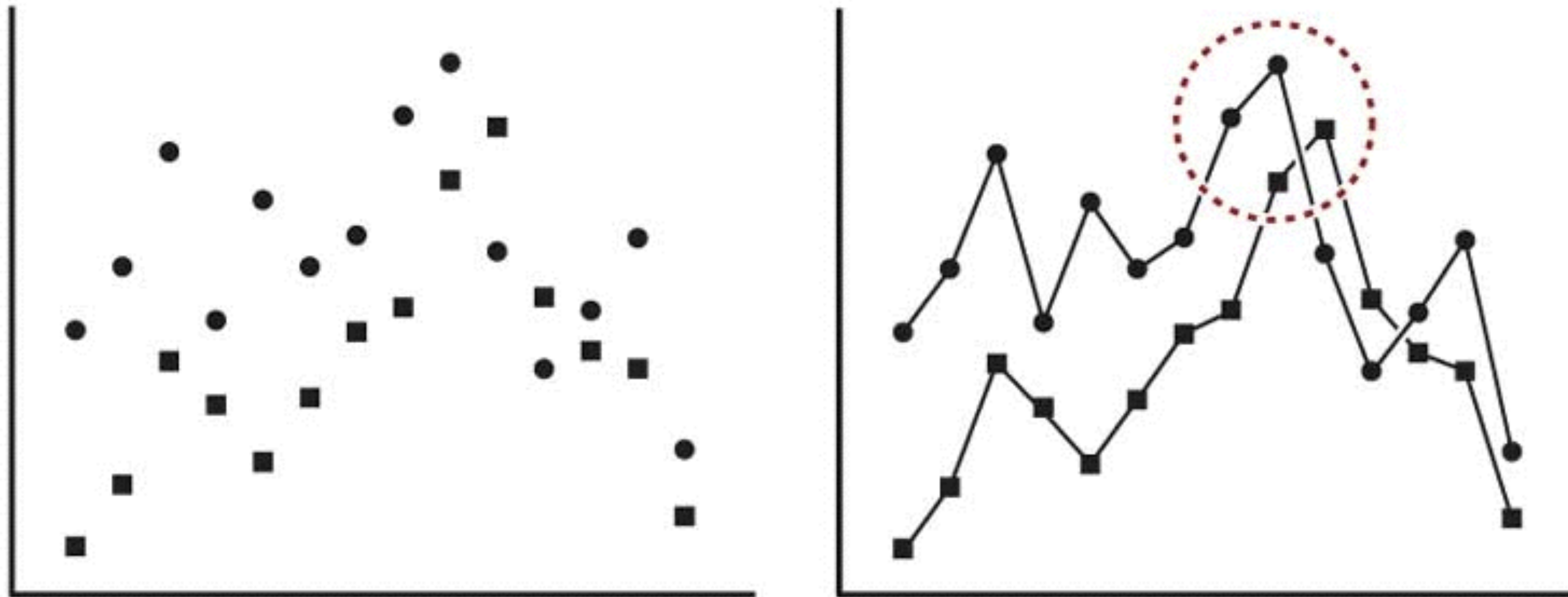
Connection



Enclosure



# Enclosure



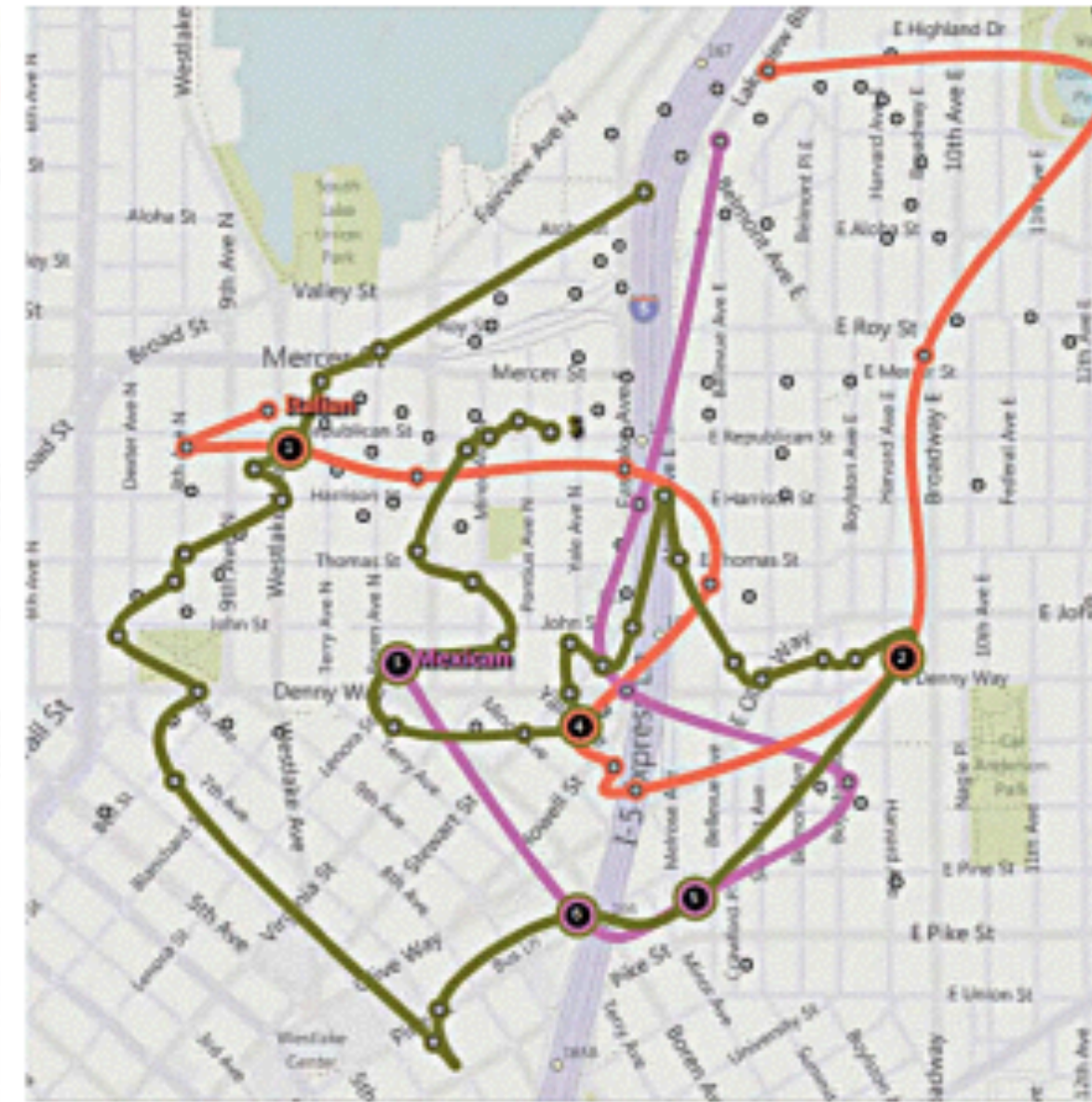
# Connectedness Varieties

Bubble Sets



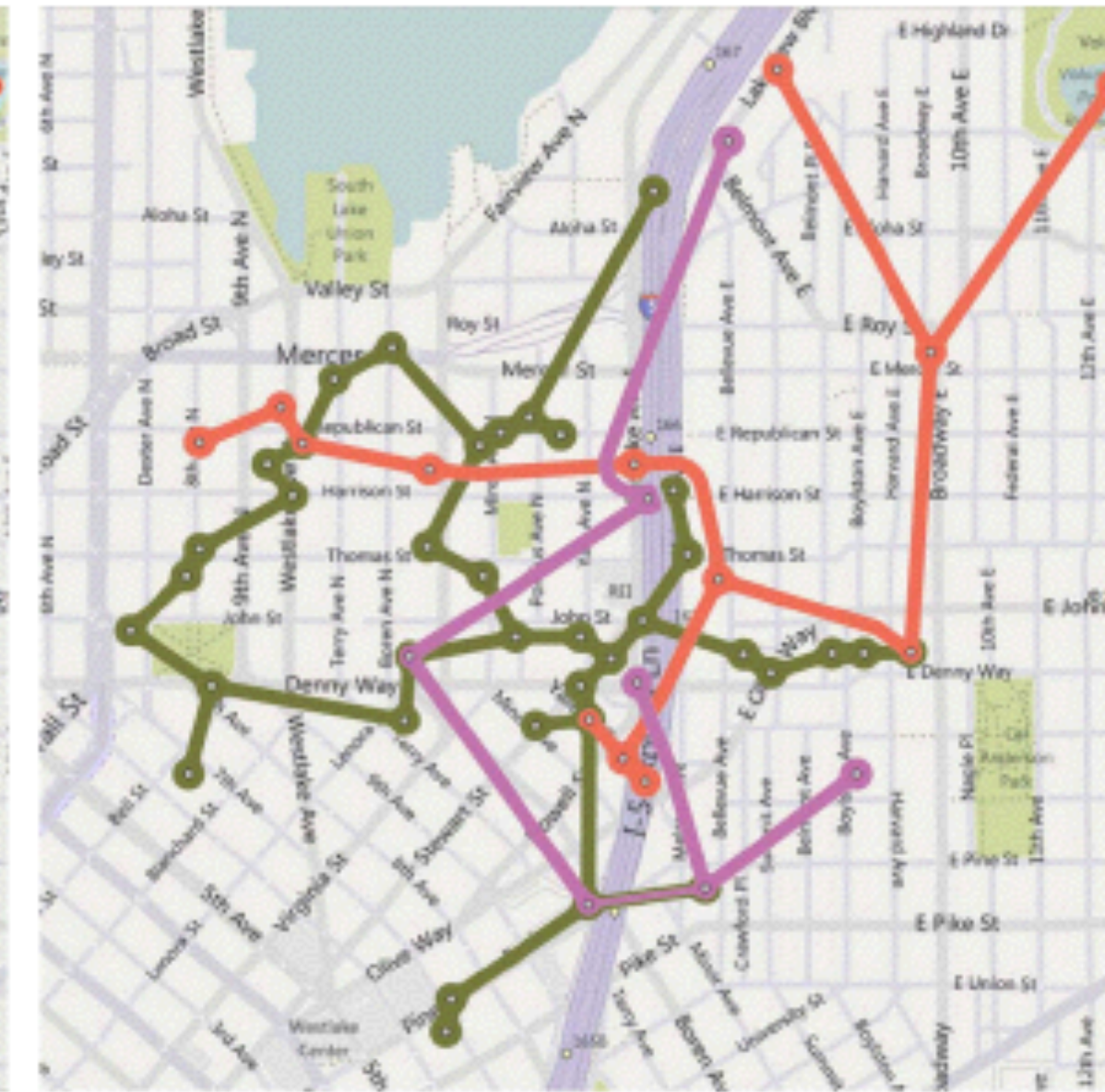
Image by [Dinkla et al., 2011]  
Technique by [Collins et al., 2009]

Line Sets



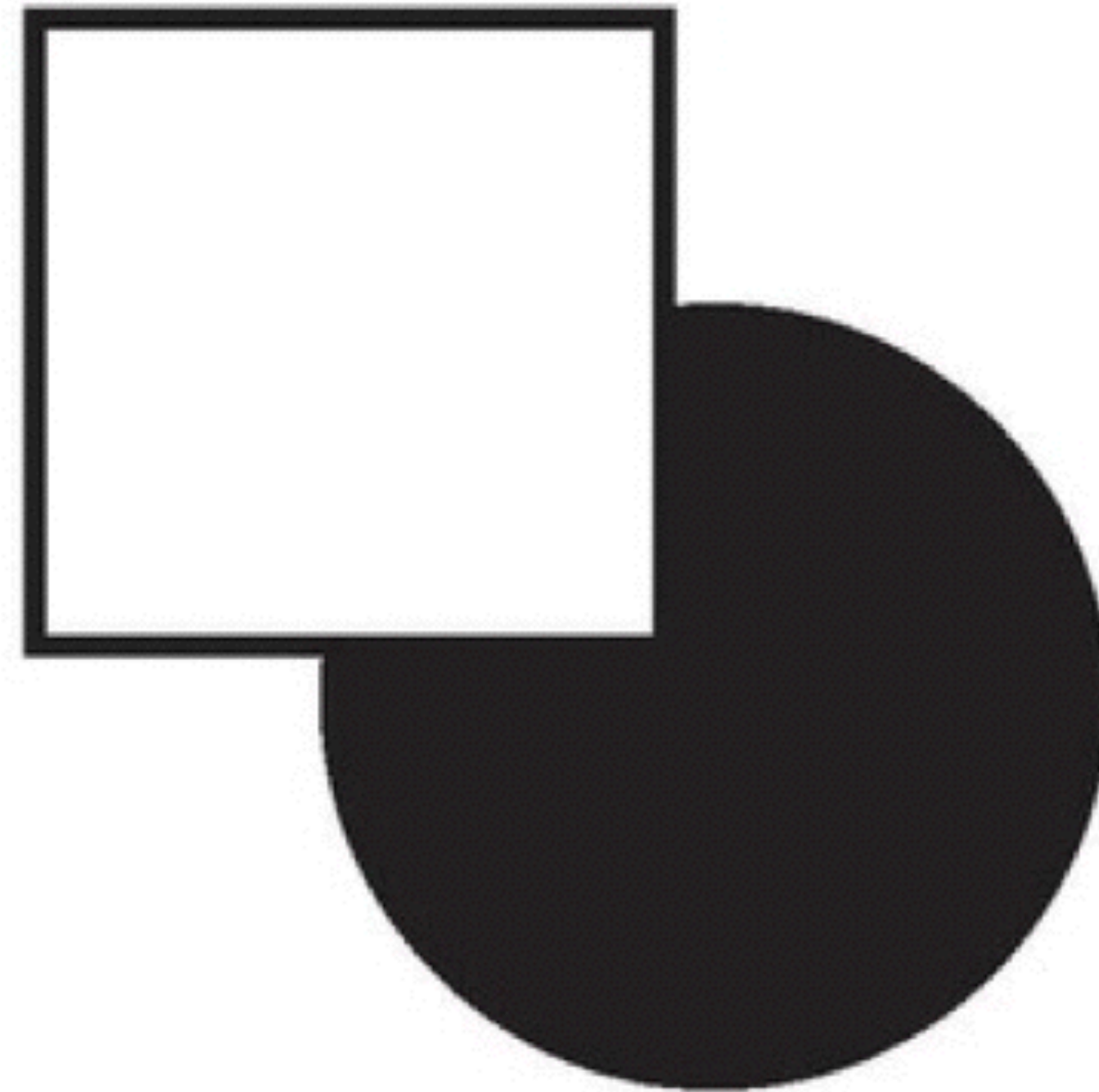
[Alper et al., 2011]

Kelp Diagrams

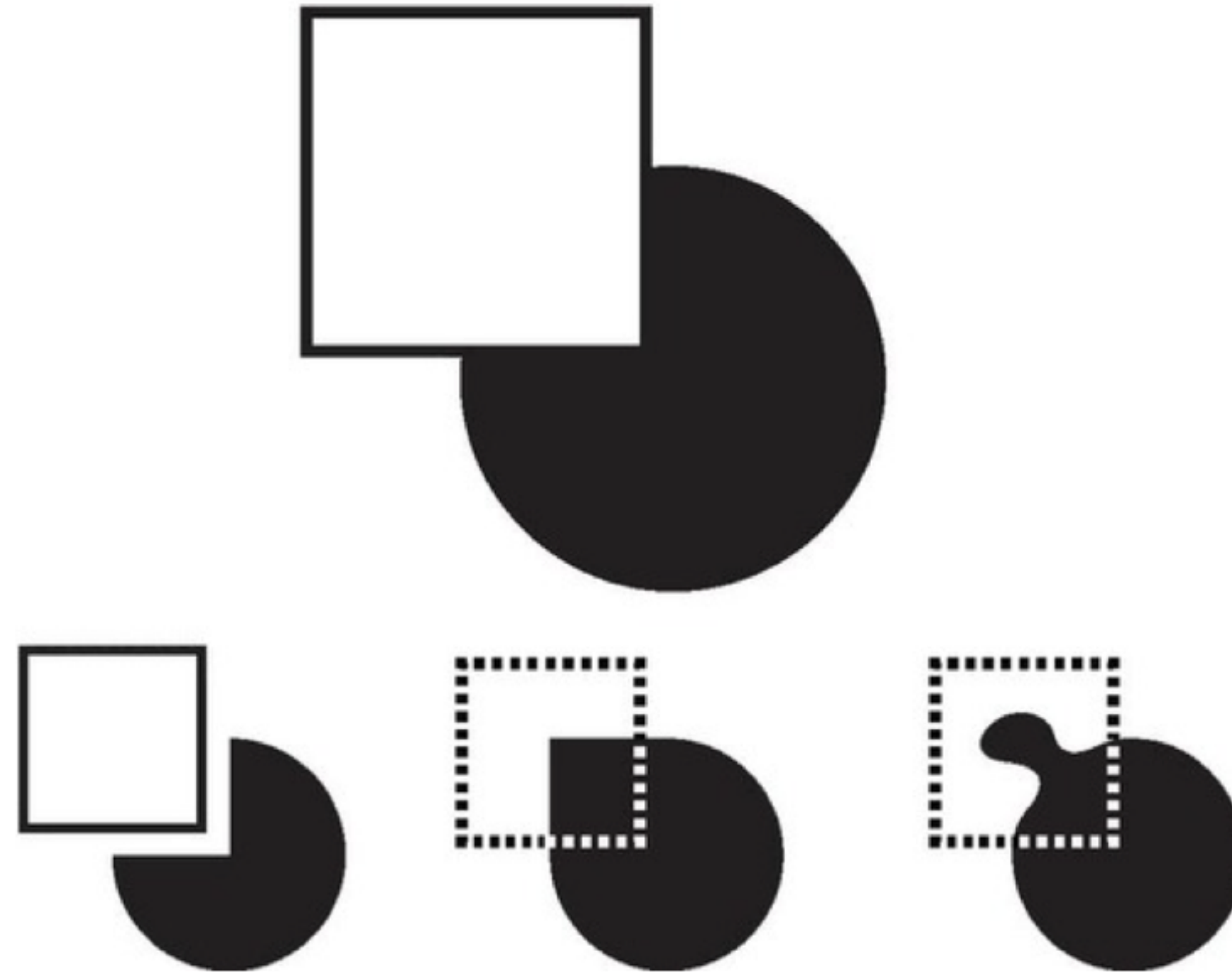


[Dinkla et al., 2012]

# Continuity

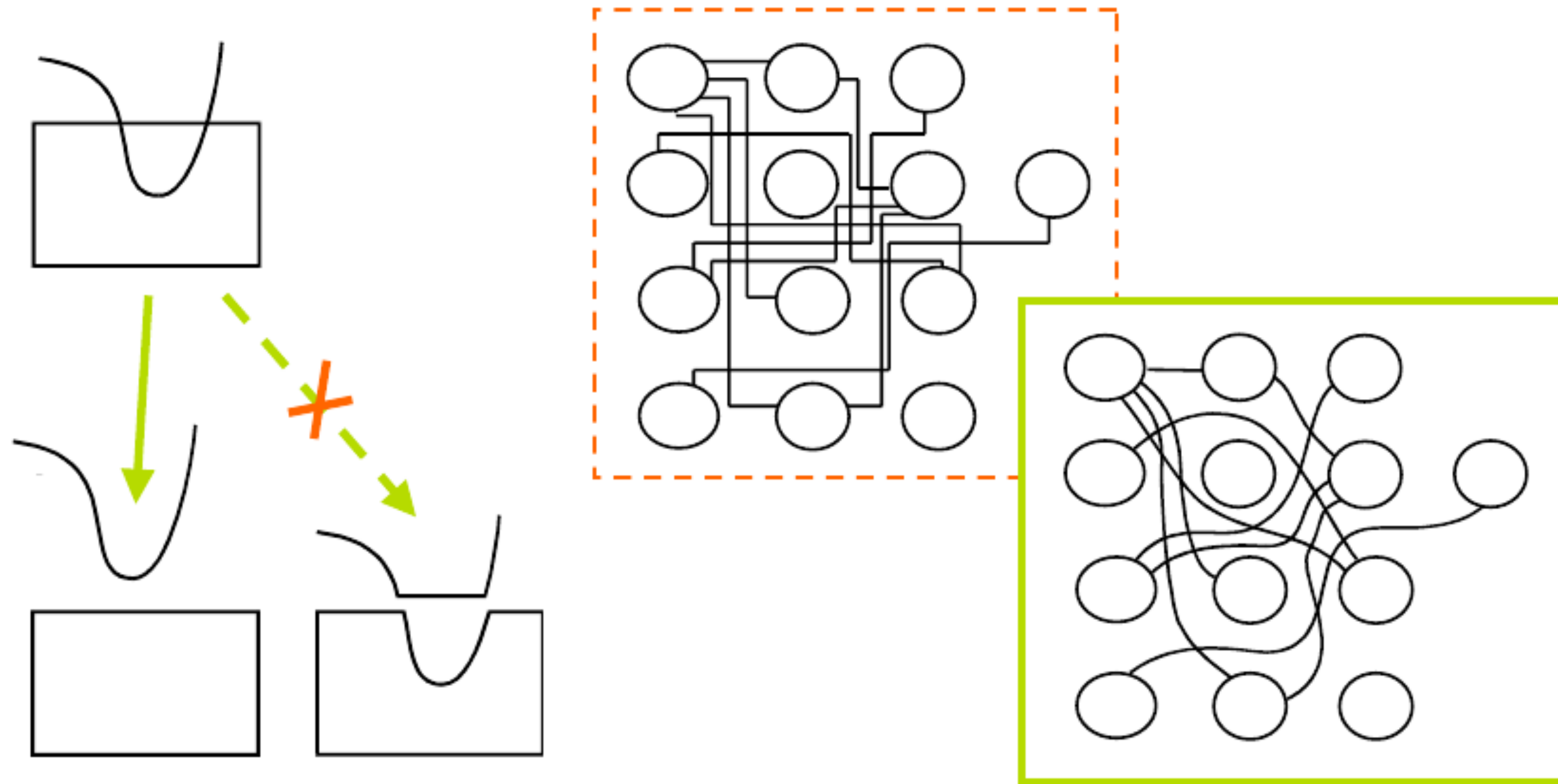


# Continuity

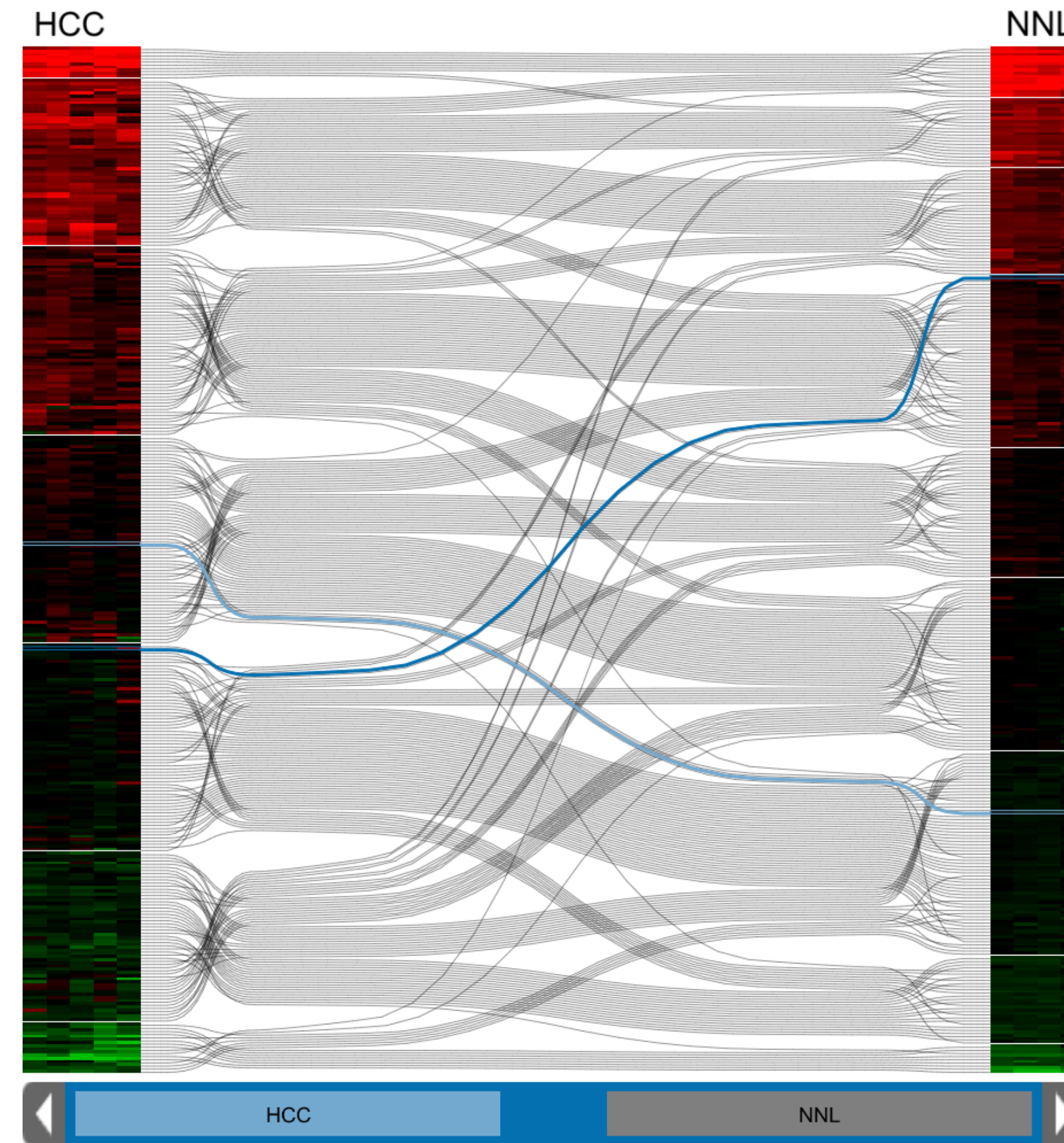
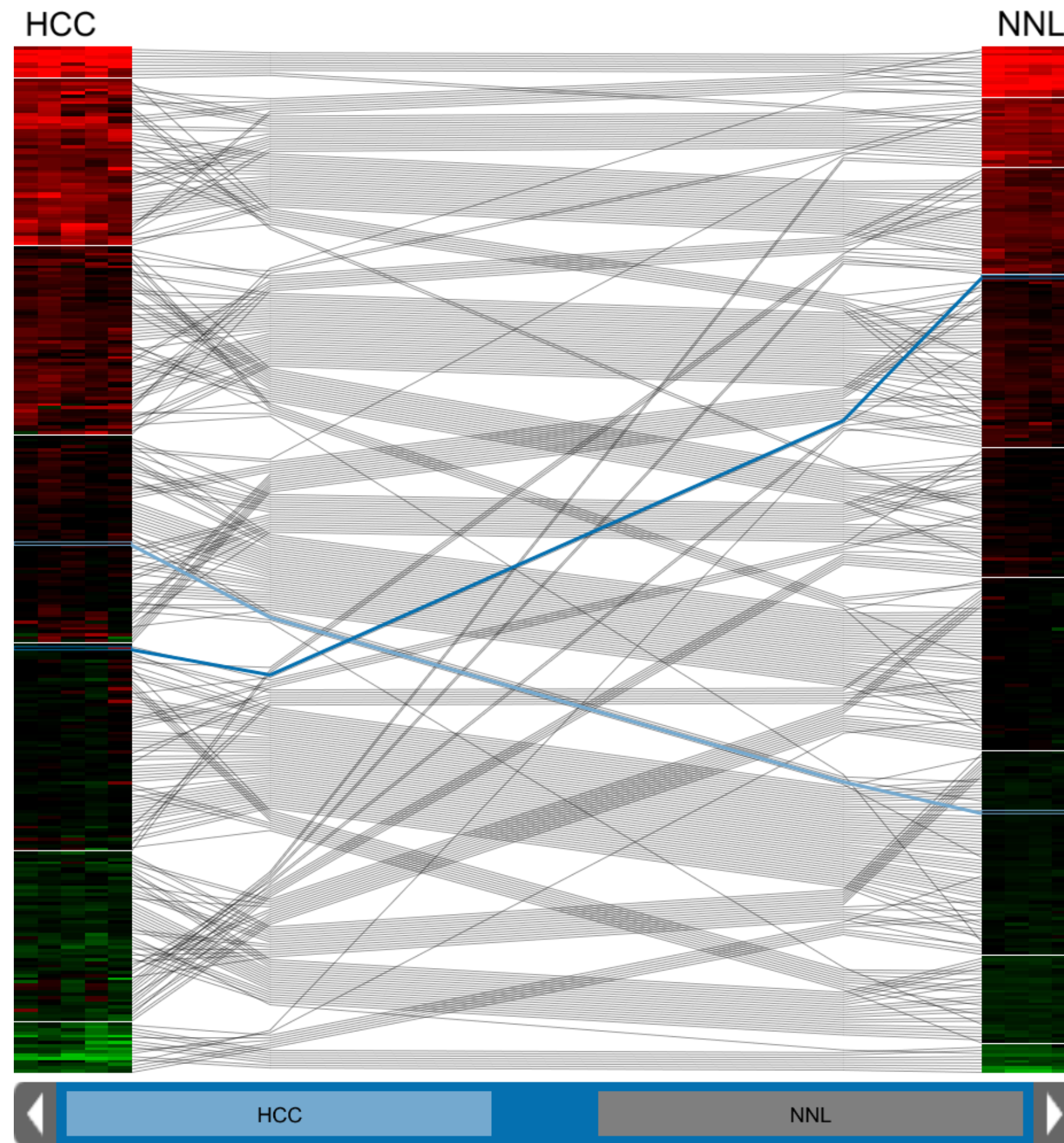


# Continuity

Things: smooth & continuous



# Continuity





# Closure

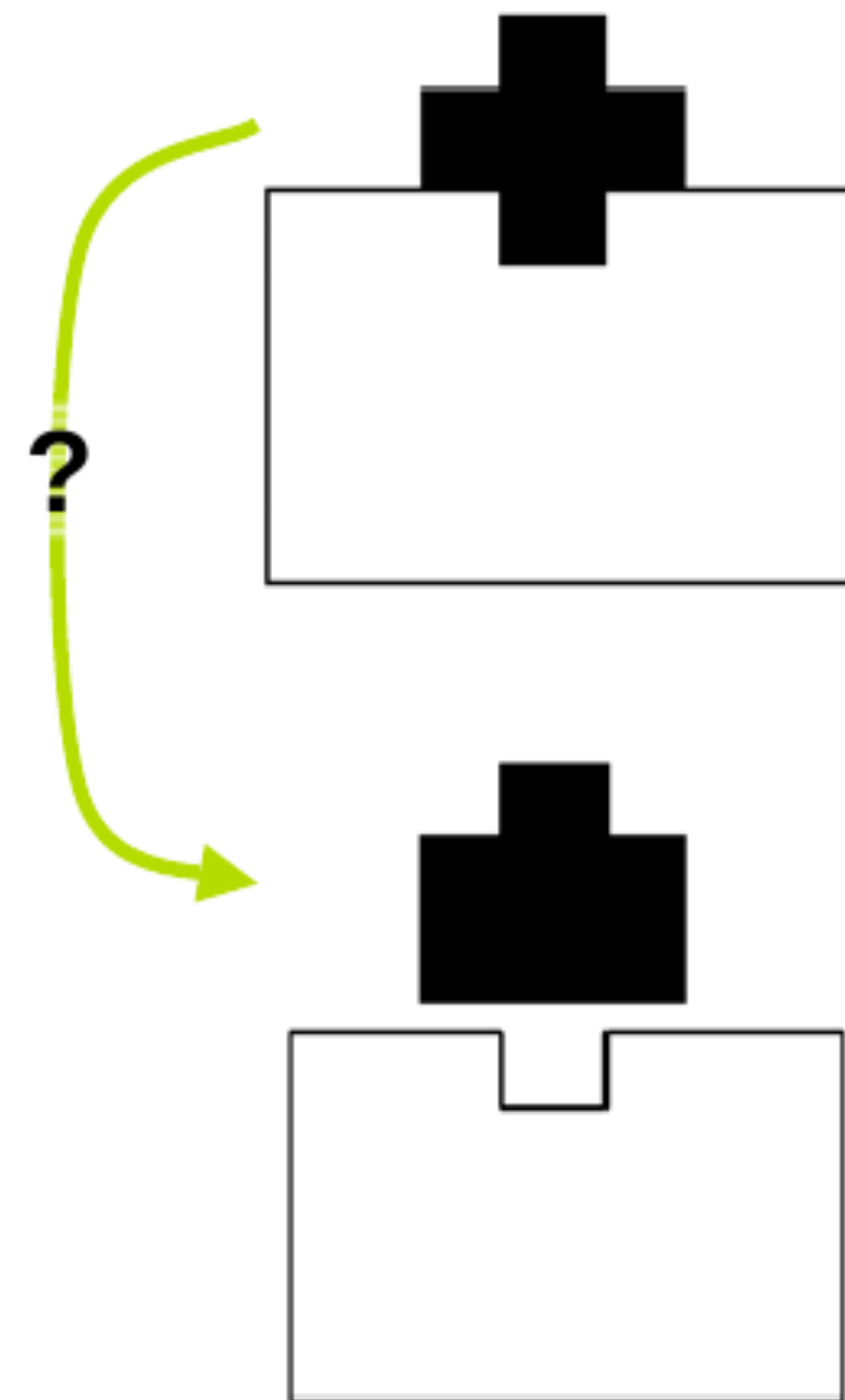
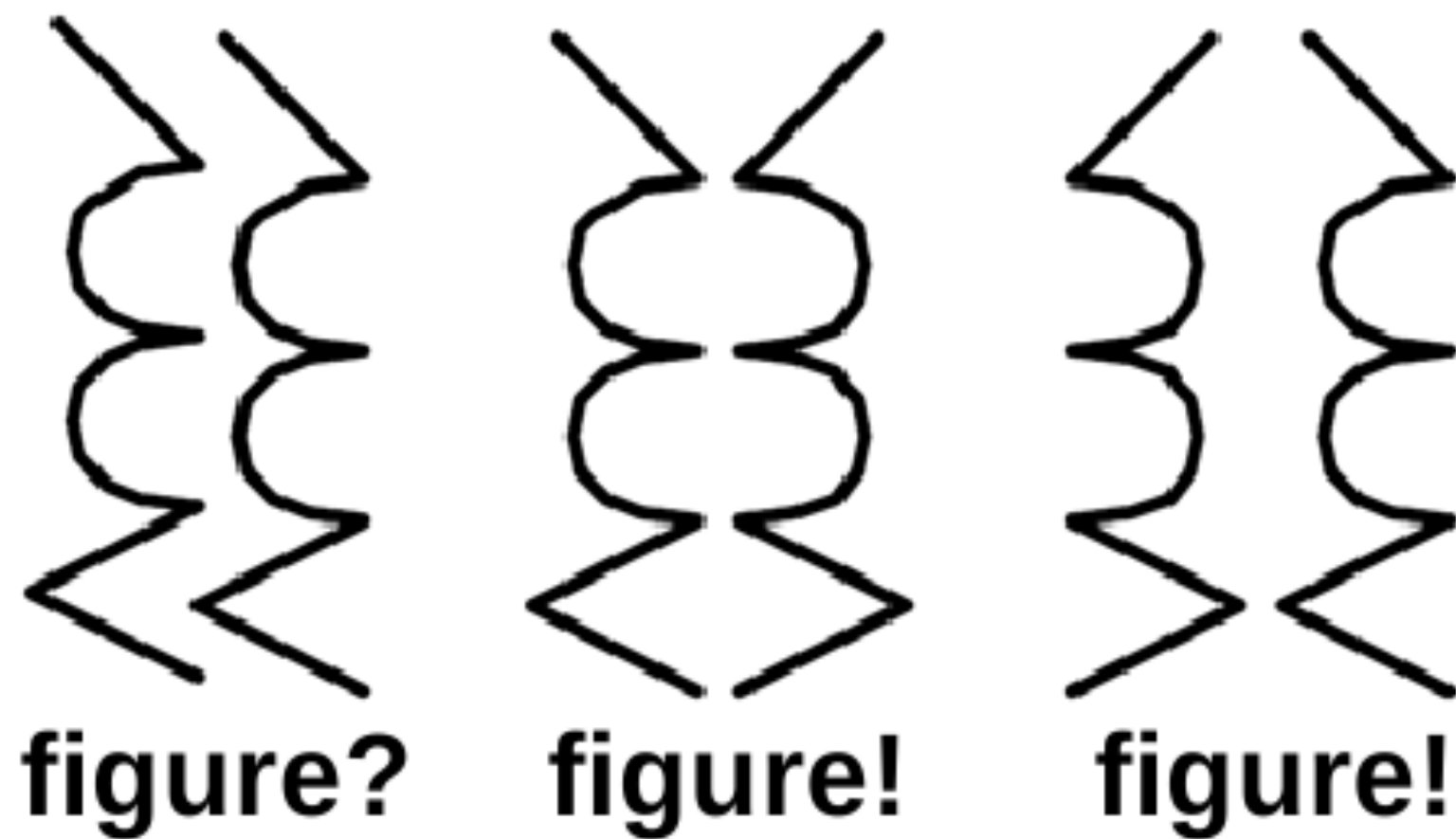


# Closure

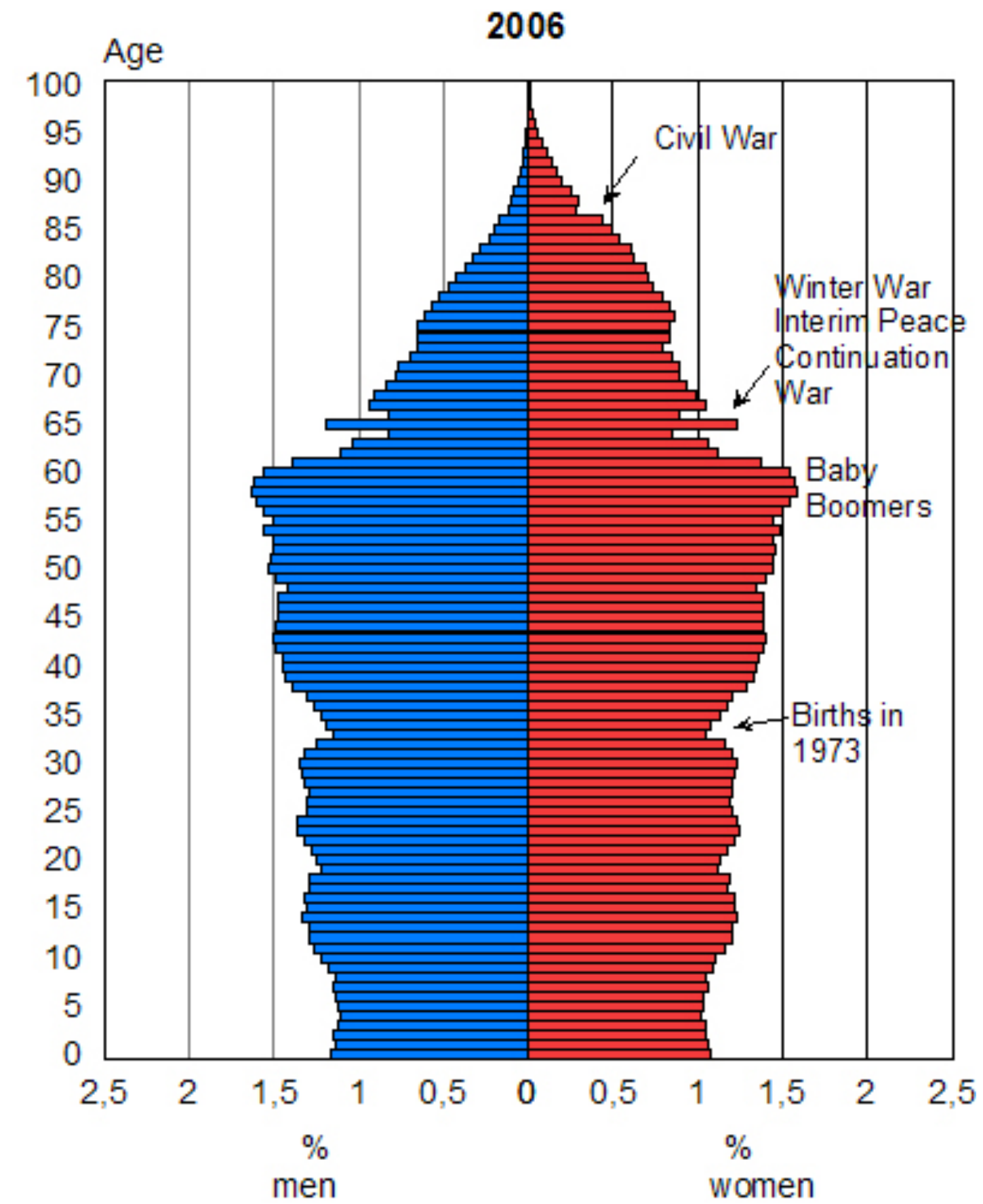
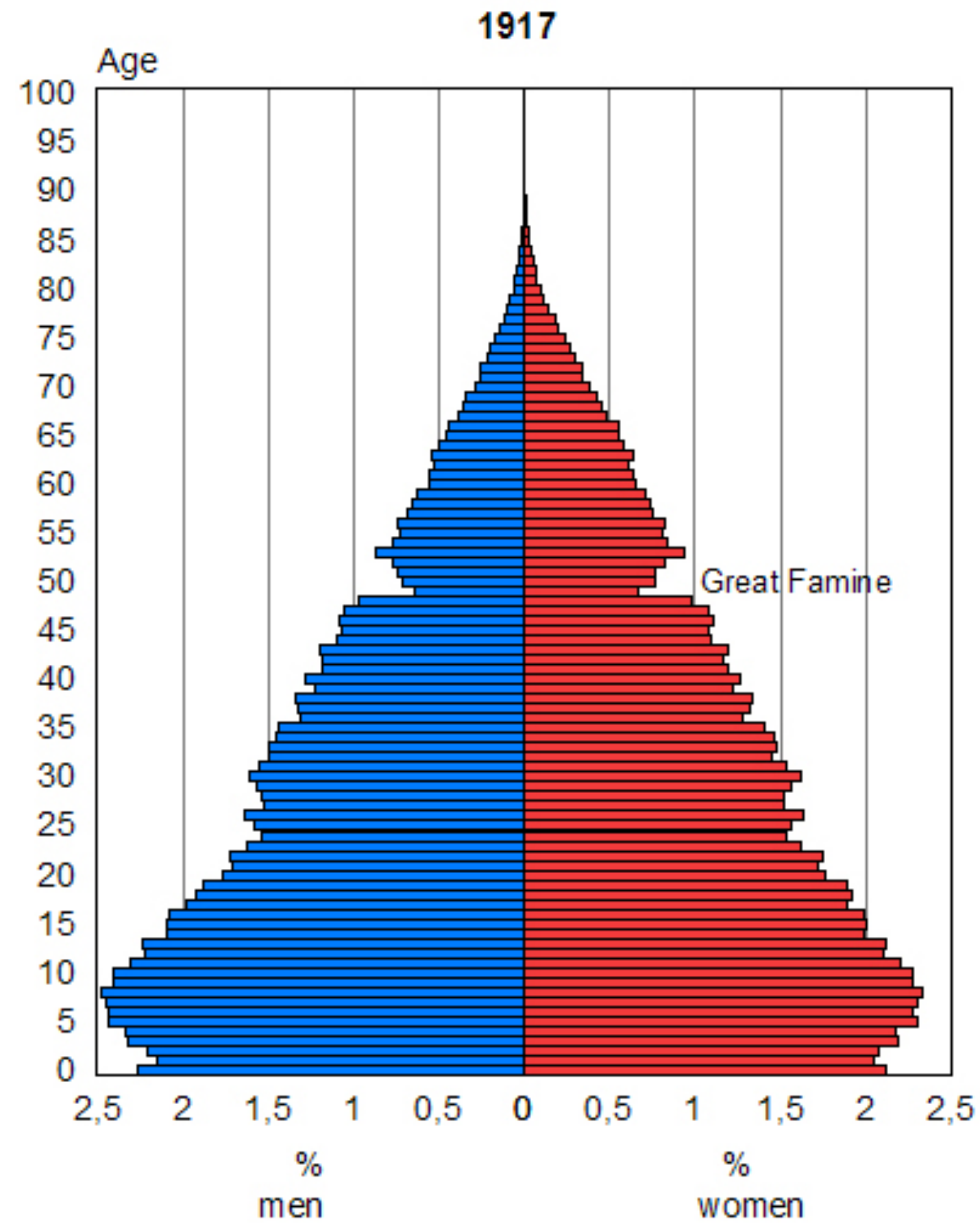


# Symmetry

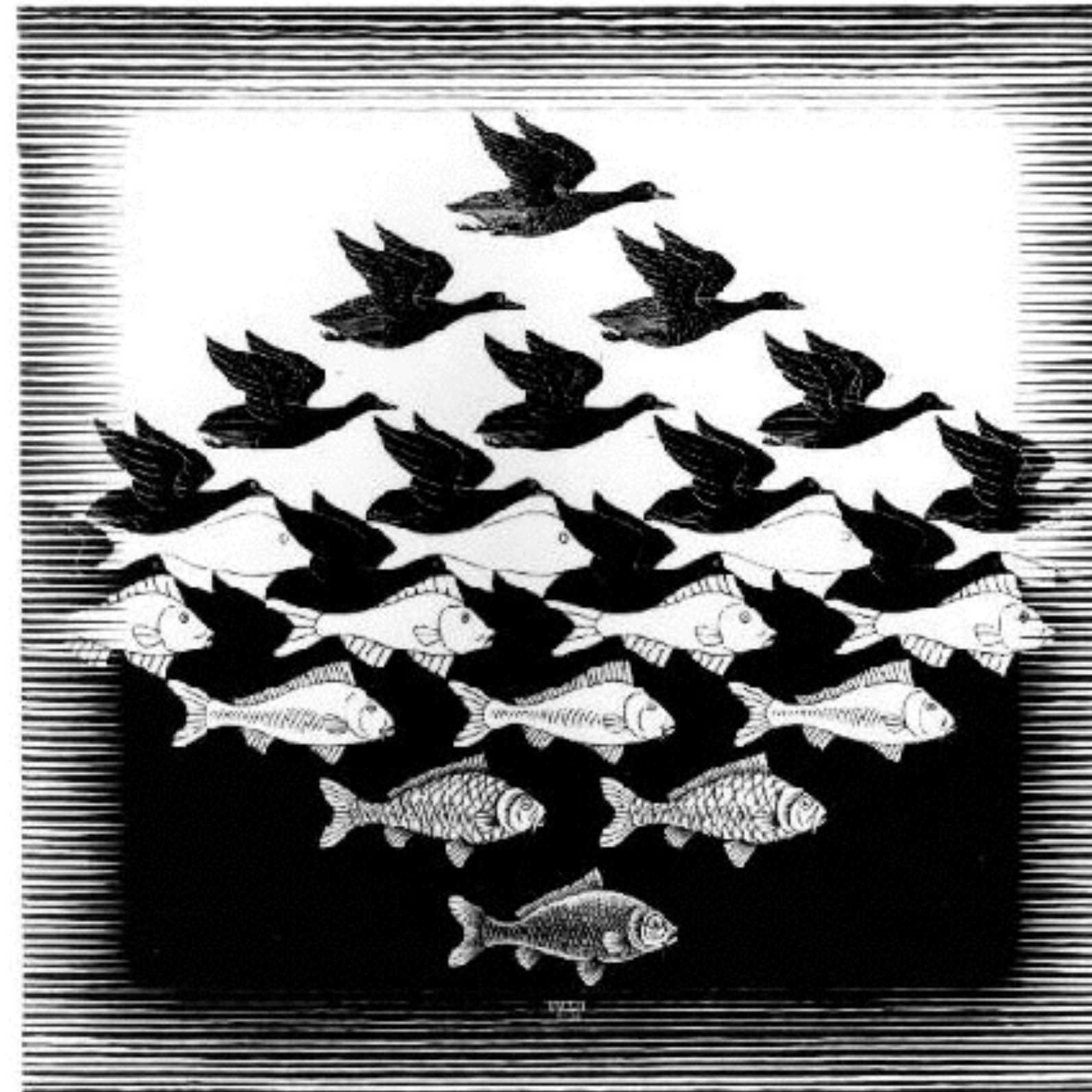
Things: symmetric



# Population Pyramid

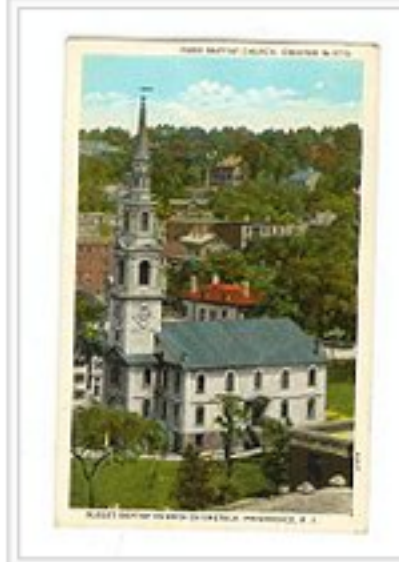


# Figure / Ground



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

Applications in Vis



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

The area which is now Providence was first settled in June 1636 by Roger Williams, and was one of the original Thirteen Colonies of the United States.<sup>[10]</sup> Although the west bank of the Providence River was later claimed by both the English and the Dutch, the actual inhabitants and true masters of the region were the Pokanoket Tribe of the Wampanoag Nation led by Massasoit Ousamequin.<sup>[11]</sup> Williams secured permission to settle from the Pokanoket and gave the city its present name.<sup>[12]</sup> Williams' Providence soon became a refuge for persecuted religious dissenters, as he himself had been exiled from Massachusetts.<sup>[13]</sup> Providence's growth would be slow during the next quarter-century—the subsuming of its territory into surrounding towns, difficulty of farming the land, and differing of local traditions and land conflicts all slowed development.<sup>[13]</sup>

In the mid-1770s, the British government levied taxes that impeded Providence's maritime, fishing and agricultural industries, the mainstay of the city's economy. One example was the Sugar Act,

which was a tax levied against Providence's distilleries that adversely affected its trade in rum and slaves.

These taxes caused Providence to join the other colonies in renouncing allegiance to the British Crown. In response to enforcement of unpopular trade laws, Providence residents spilled the first blood of the American Revolution in the notorious Gaspée Affair of 1772.<sup>[13]</sup>

Though during the Revolutionary War the city escaped enemy occupation, the capture of nearby Newport disrupted industry and kept the population on alert. Troops were quartered for various campaigns and Brown University's University Hall was used as a barracks and military hospital.<sup>[13]</sup>

After departing from Newport, French troops sent by King Louis XVI and commanded by the Comte de Rochambeau passed through Providence on their way to join the attack against British forces. The march from Newport to Providence was the beginning of a campaign led jointly by General George Washington in a decisive march that ended with the defeat of General Cornwallis in the Siege of Yorktown at Yorktown, Virginia and the Battle of the Chesapeake.

Following the war, Providence was the country's ninth-largest city,<sup>b</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





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

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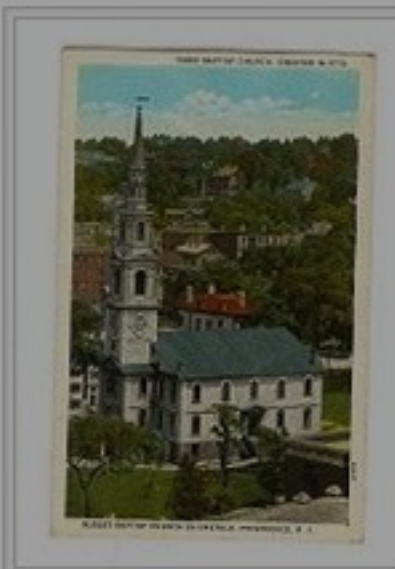
Providence in the mid-nineteenth century



NPS map of the W&R Route







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

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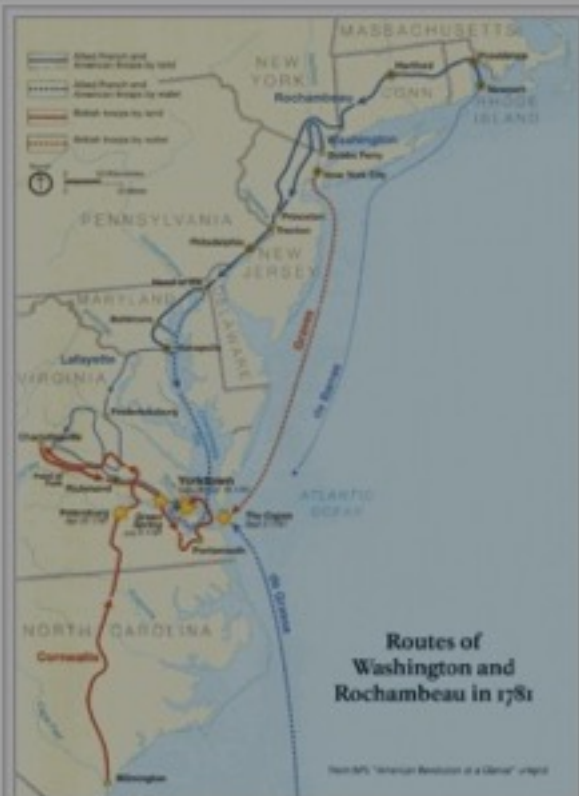
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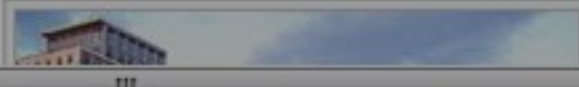
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Providence in the mid-nineteenth century



NPS map of the W3R Route

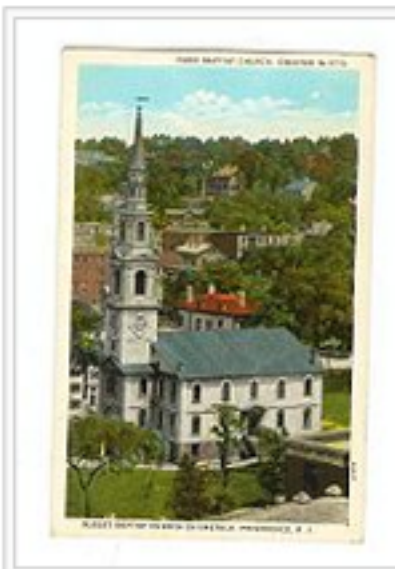


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First Baptist Church in America, founded 1638, present building occupied in 1776, is the oldest Baptist congregation in America

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Providence in the mid-nineteenth century

In the mid-1770s, the British government levied taxes that impeded Providence's maritime, fishing and agricultural industries, the mainstay of the city's economy. One example was the Sugar Act, which was a tax levied against Providence's distilleries that adversely affected its trade in rum and slaves. These taxes caused Providence to join the other colonies in renouncing allegiance to the British Crown. In response to enforcement of unpopular trade laws, Providence residents spilled the first blood of the American Revolution in the notorious Gaspée Affair of 1772.<sup>[13]</sup>



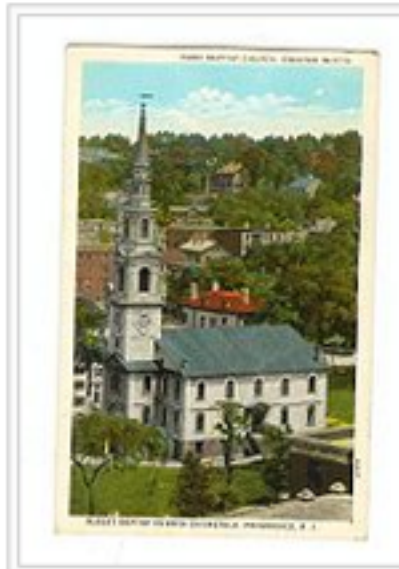
NPS map of the W3R Route

Though during the Revolutionary War the city escaped enemy occupation, the capture of nearby Newport disrupted industry and kept the population on alert. Troops were quartered for various campaigns and Brown University's University Hall was used as a barracks and military hospital.<sup>[13]</sup>

After departing from Newport, French troops sent by King Louis XVI and commanded by the Comte de Rochambeau passed through Providence on their way to join the attack against British forces. The march from Newport to Providence was the beginning of a campaign led jointly by General George Washington in a decisive march that ended with the defeat of General Cornwallis in the Siege of Yorktown at Yorktown, Virginia and the Battle of the Chesapeake.

Following the war, Providence was the country's ninth-largest city.<sup>b</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





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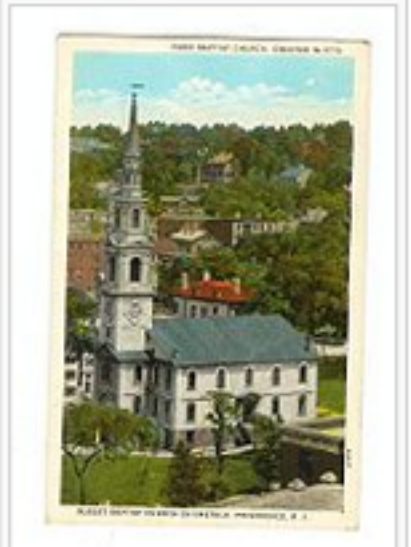
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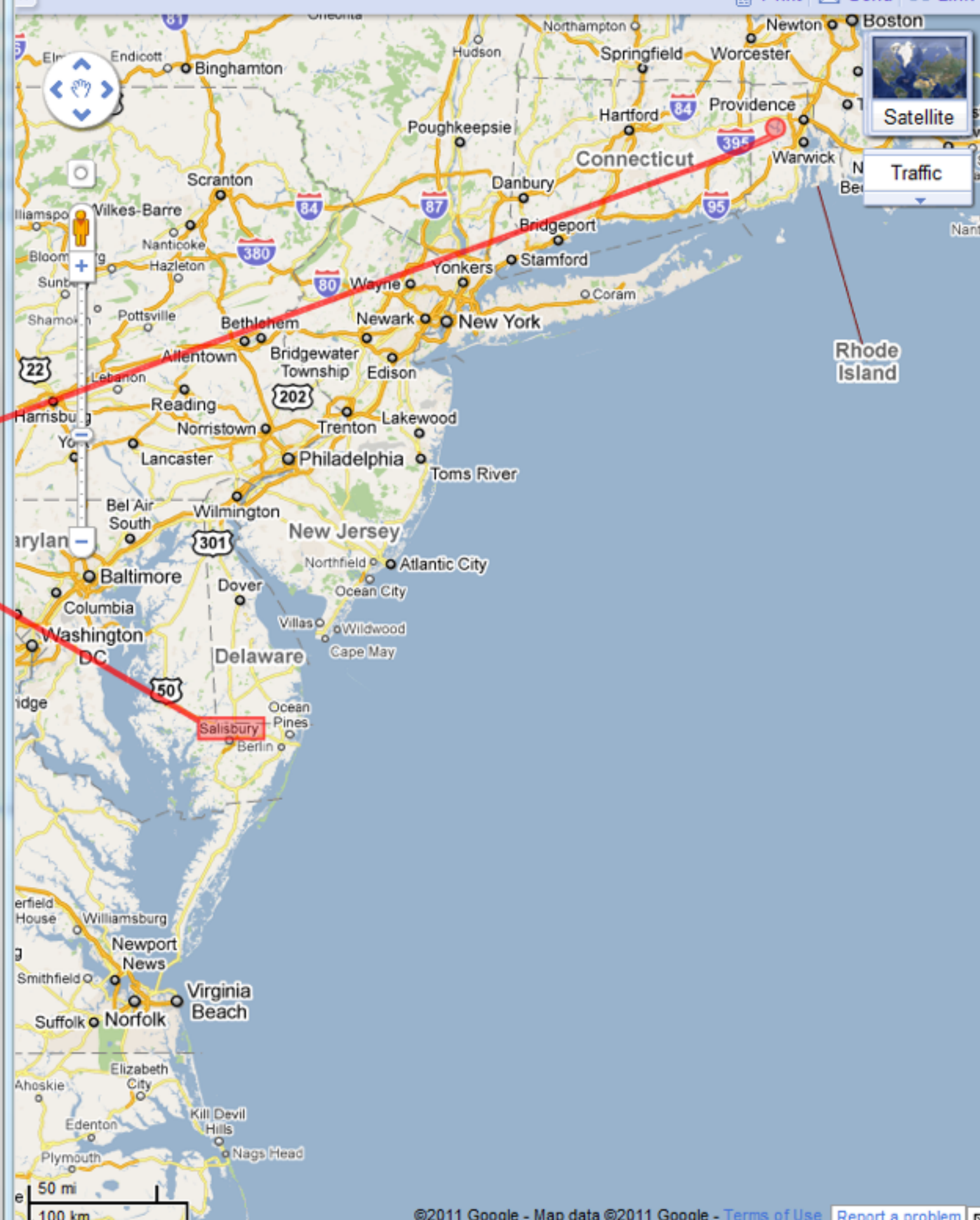
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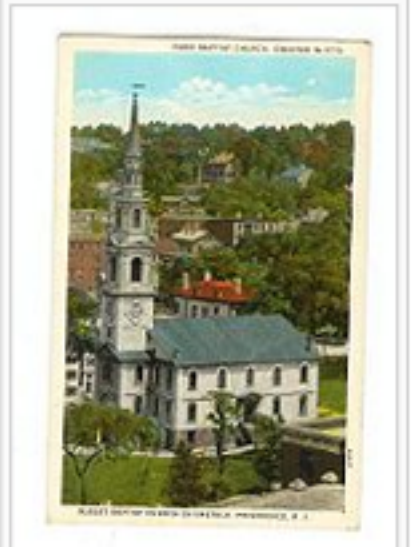
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