

COS30045

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# DATA VISUALISATION

TOPIC 05: PSYCHOLOGICAL PRINCIPLES



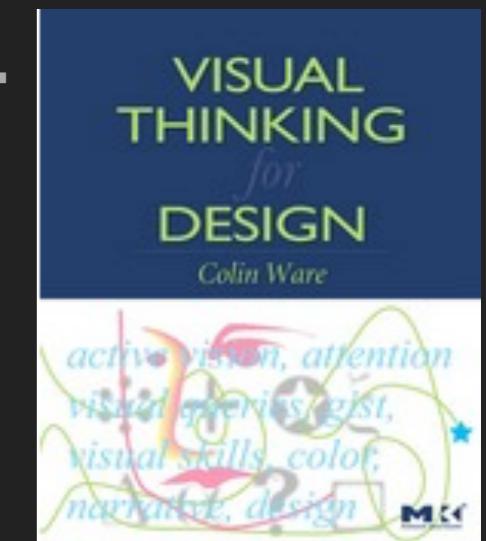
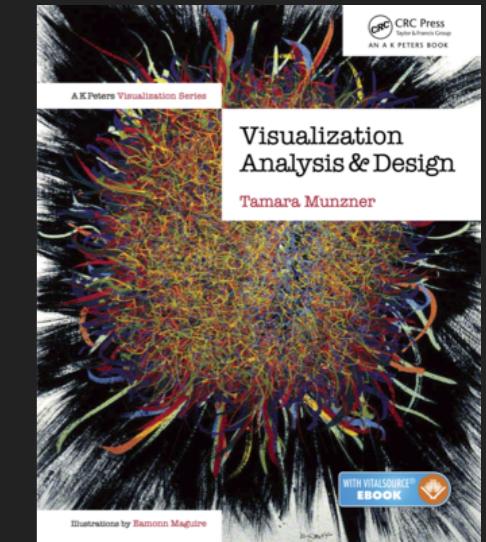
# PERCEPTION, COLOUR AND ATTENTION

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## Lecture Readings

▶ VAD 10.2

▶ VTD Ch 1, 2 and 4





# PERCEPTION AND ATTENTION

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What:

- ▶ models of visual perception and attention

Why:

- ▶ design visualisations that exploit human perceptual and attentional strengths

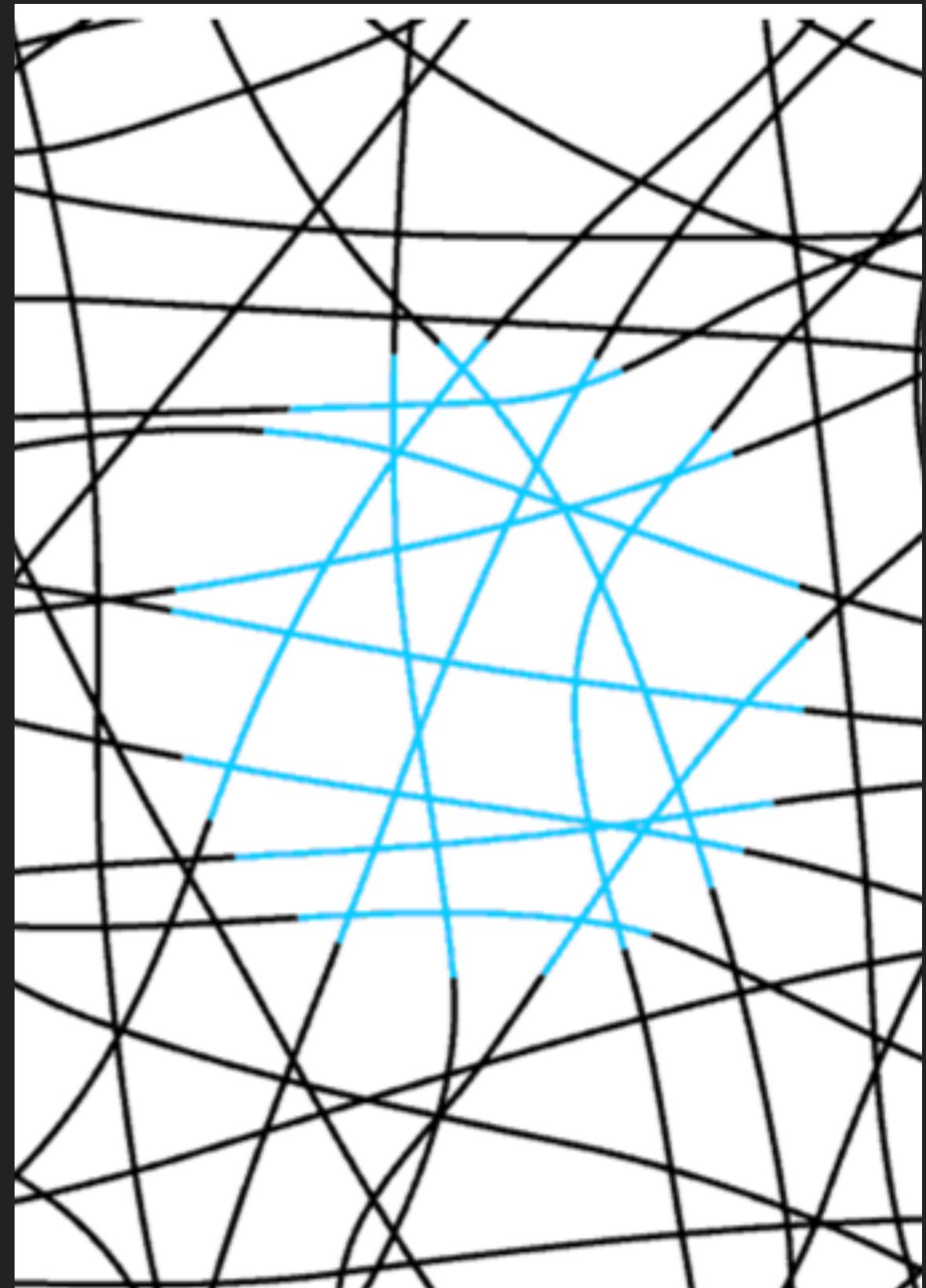
How:

- ▶ understand the capabilities and limitations of human perception and attention

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# OVERVIEW

- ▶ 5.1 Sensation and Perception
- ▶ 5.2 Attention
- ▶ 5.3 Colour
- ▶ 5.4 Gestalt



## 5.1 SENSATION AND PERCEPTION

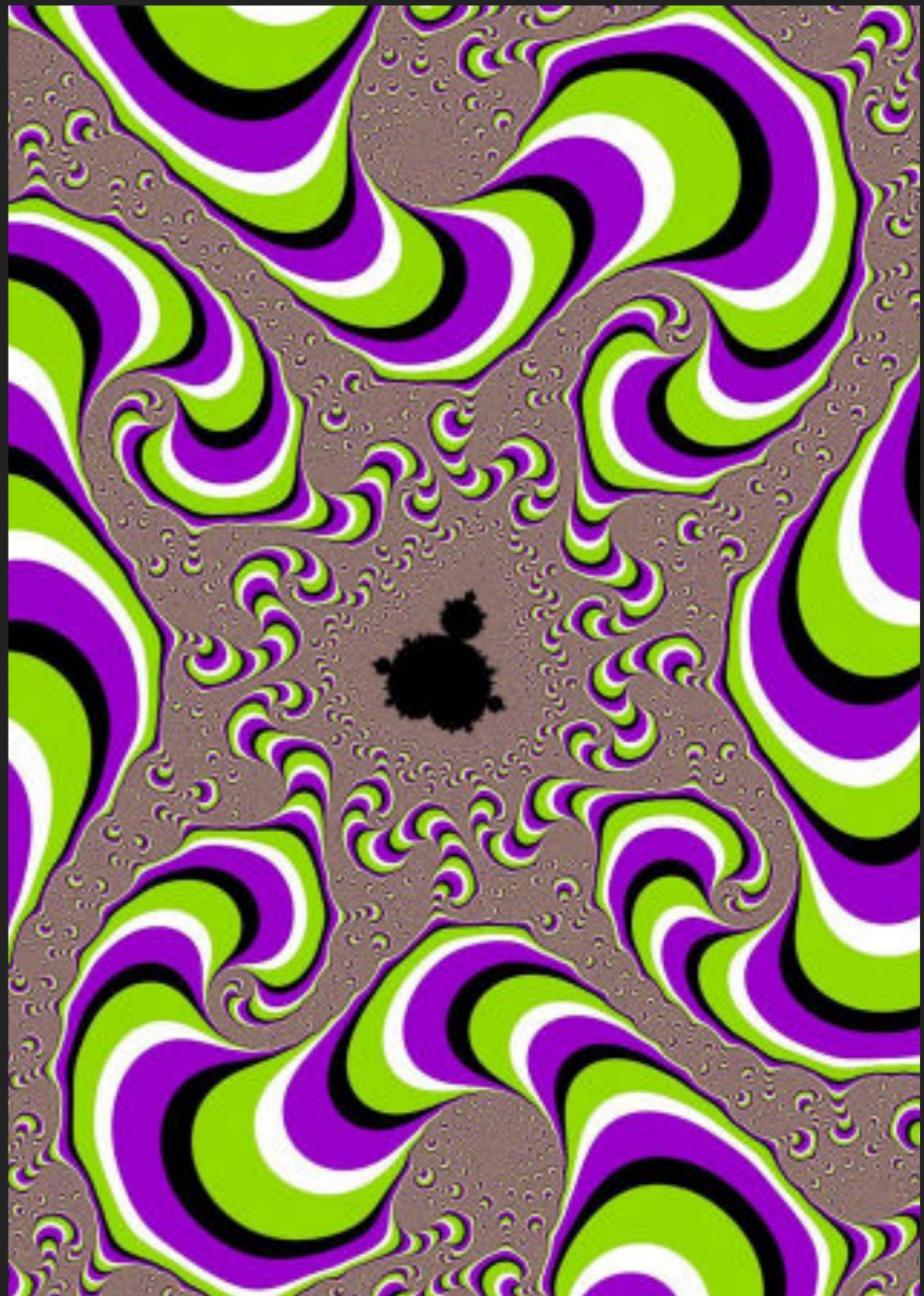
At the end of this topic you should be able to:

- ▶ Understand the difference between sensation and perception
- ▶ Appreciate the effect of context on perception
- ▶ Give some examples of how context influences what is perceived



# SENSATION AND PERCEPTION

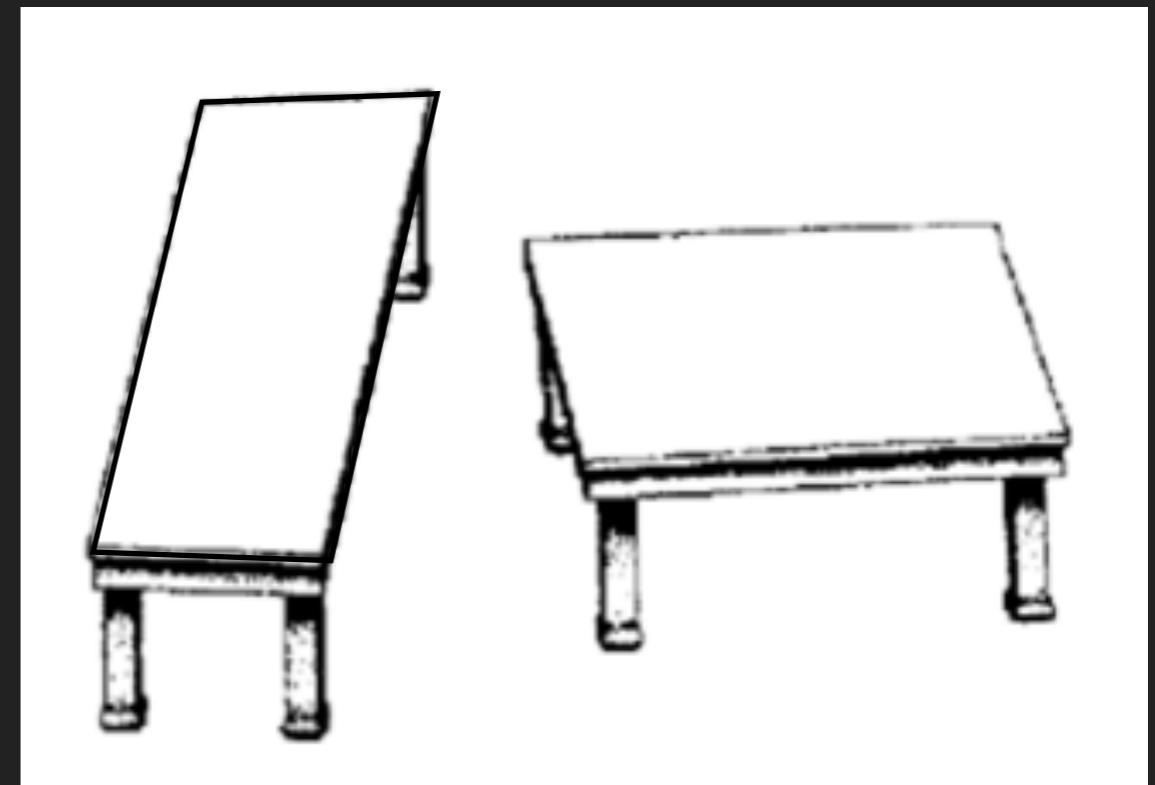
- ▶ Sensation
  - ▶ receiving physical stimulation and encoding it into the nervous system
- ▶ Perception
  - ▶ the process of interpreting and recognising sensory information, the act of understanding what the sensation was

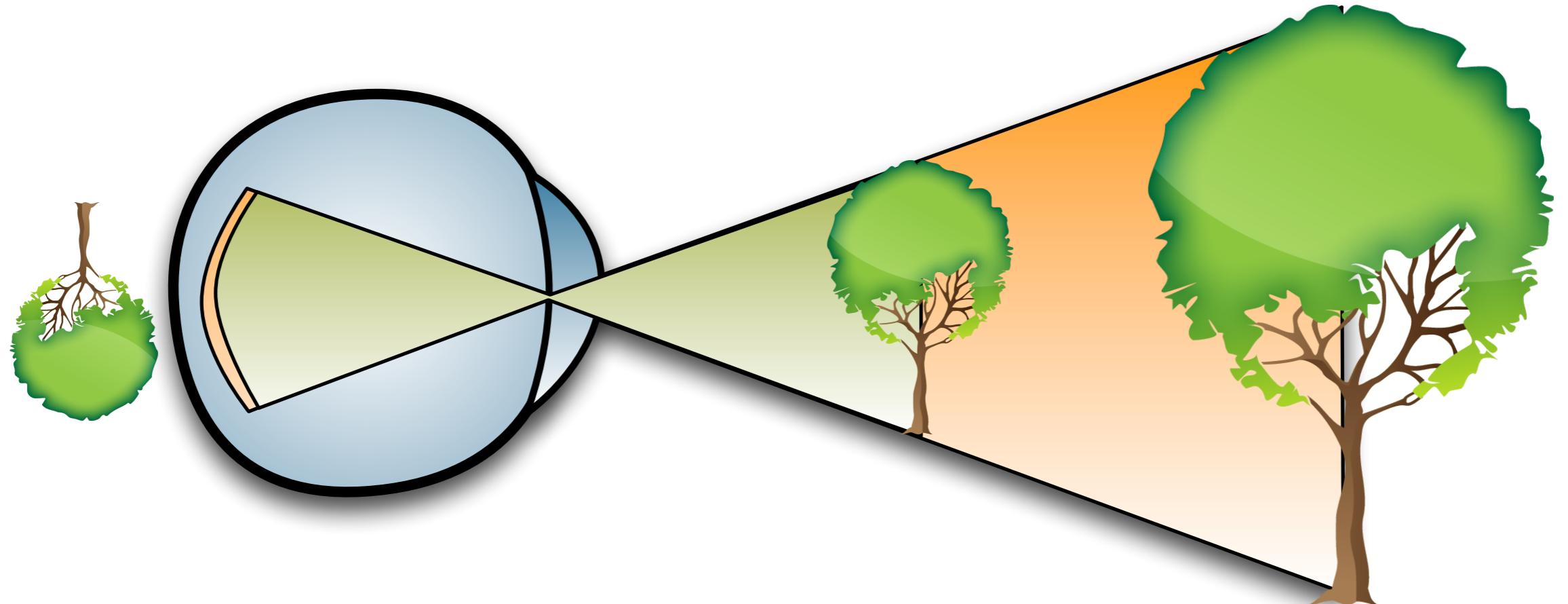


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# PERCEPTION

- ▶ Perception
  - ▶ not a true depiction of the world
  - ▶ biased by
    - ▶ our past experience
    - ▶ the current context
  - ▶ our future goals





small near object and  
large far object cast  
**same** size image on retina

However, we do not perceive  
these objects to be the same  
size...



S I Z E   C O N S T A N C Y



S I Z E   C O N S T A N C Y

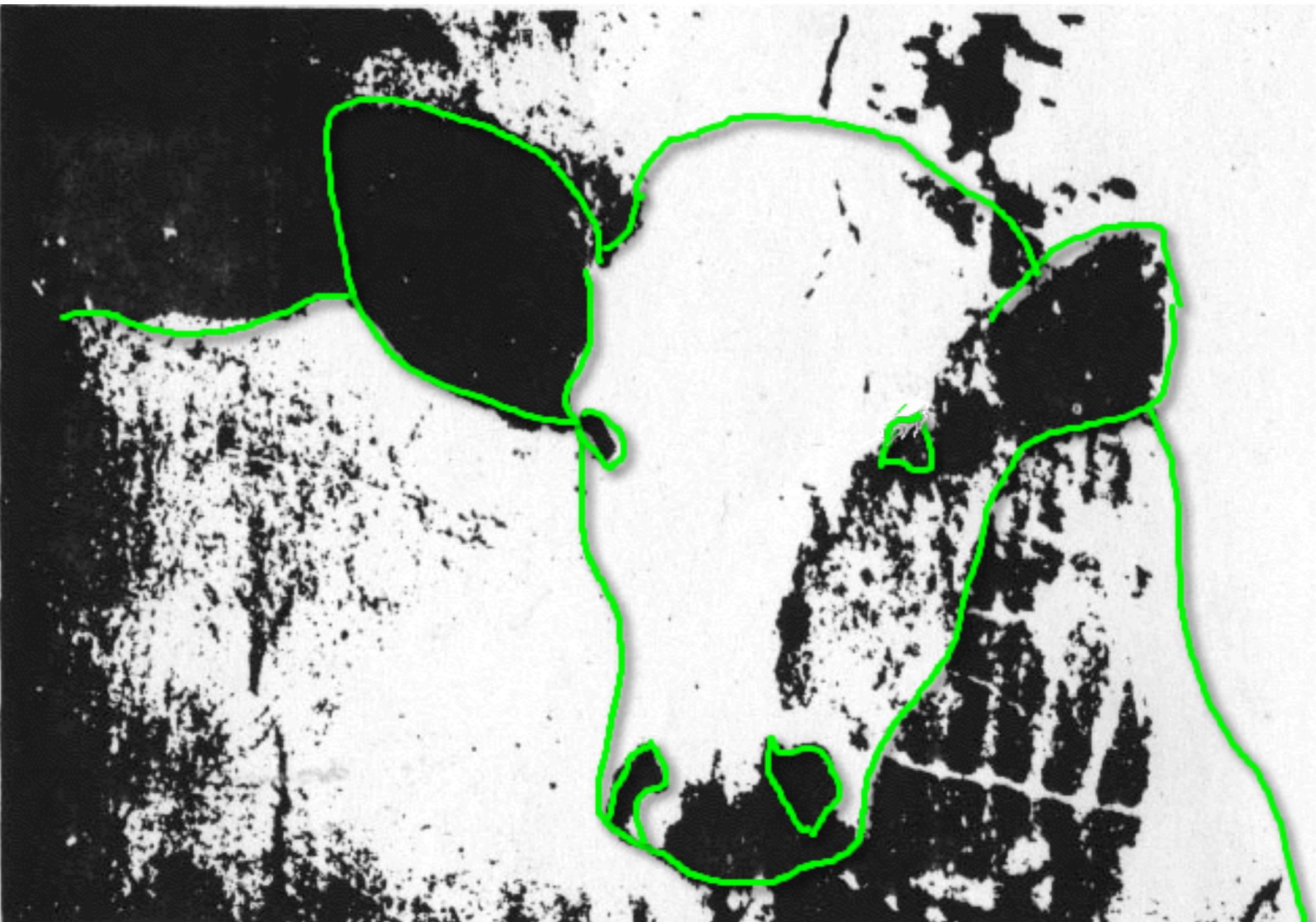
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# SENSORY EXPERIENCE AND PERCEPTION



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# SENSORY EXPERIENCE AND PERCEPTION



## PERCEPTION AND CONTEXT

### ▶ Current context

Fold napkins. *Polish silverware*. Wash dishes.

French napkins. *Polish silverware*. German dishes.

Notice here shows the  
different meaning although  
its the same text.

TAE CAT

REF B

SROT T

FISH H

DEBT

## 5.1 SENSATION AND PERCEPTION

Now you should be able to:

- ▶ Understand the difference between sensation and perception
- ▶ Appreciate the effect of context on perception
- ▶ Give some examples of how context influences what is perceived



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# DATA VISUALISATION

TOPIC 05.2: ATTENTION

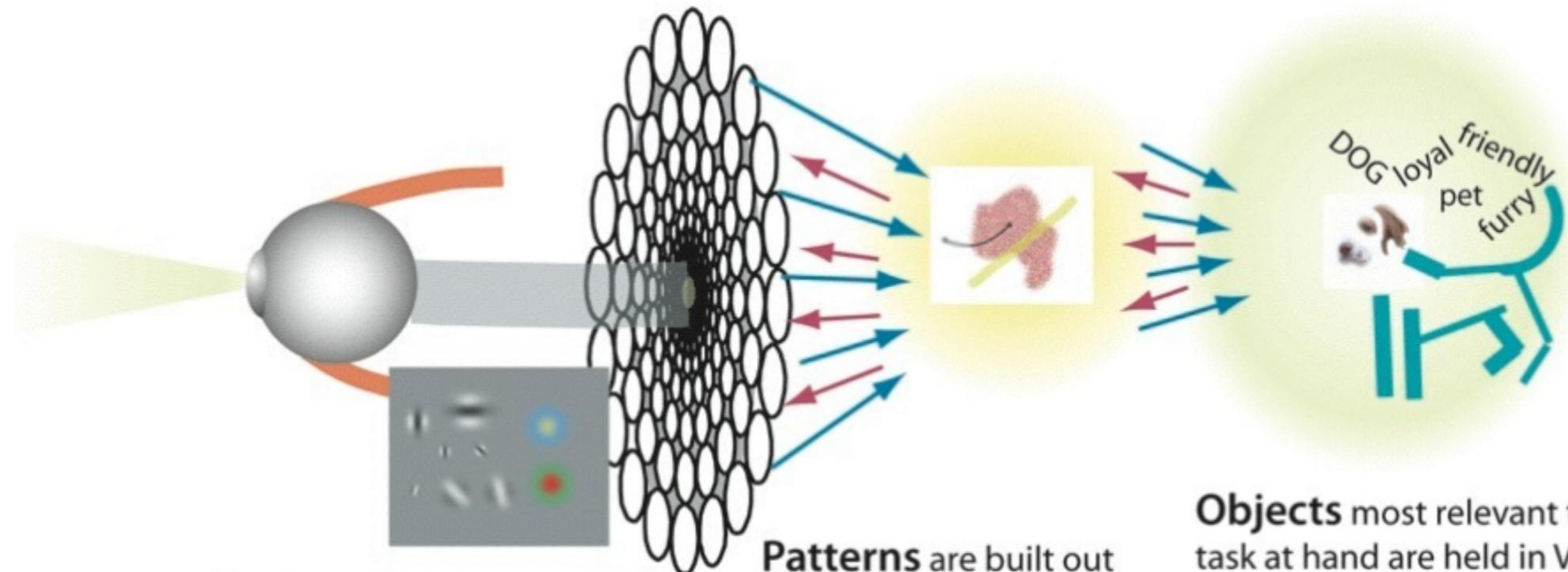
## 5.2 ATTENTION

At the end of this topic you should be able to:

- ▶ Explain the role of attention in perception in terms of Ware's model of perceptual processing
- ▶ List and use a variety of pop-out channels to draw user's attention
- ▶ Identify separable and integral visual channel combinations



# PERCEPTUAL PROCESSING



**Features** are processed in parallel from every part of the visual field. Millions of features are processed simultaneously.

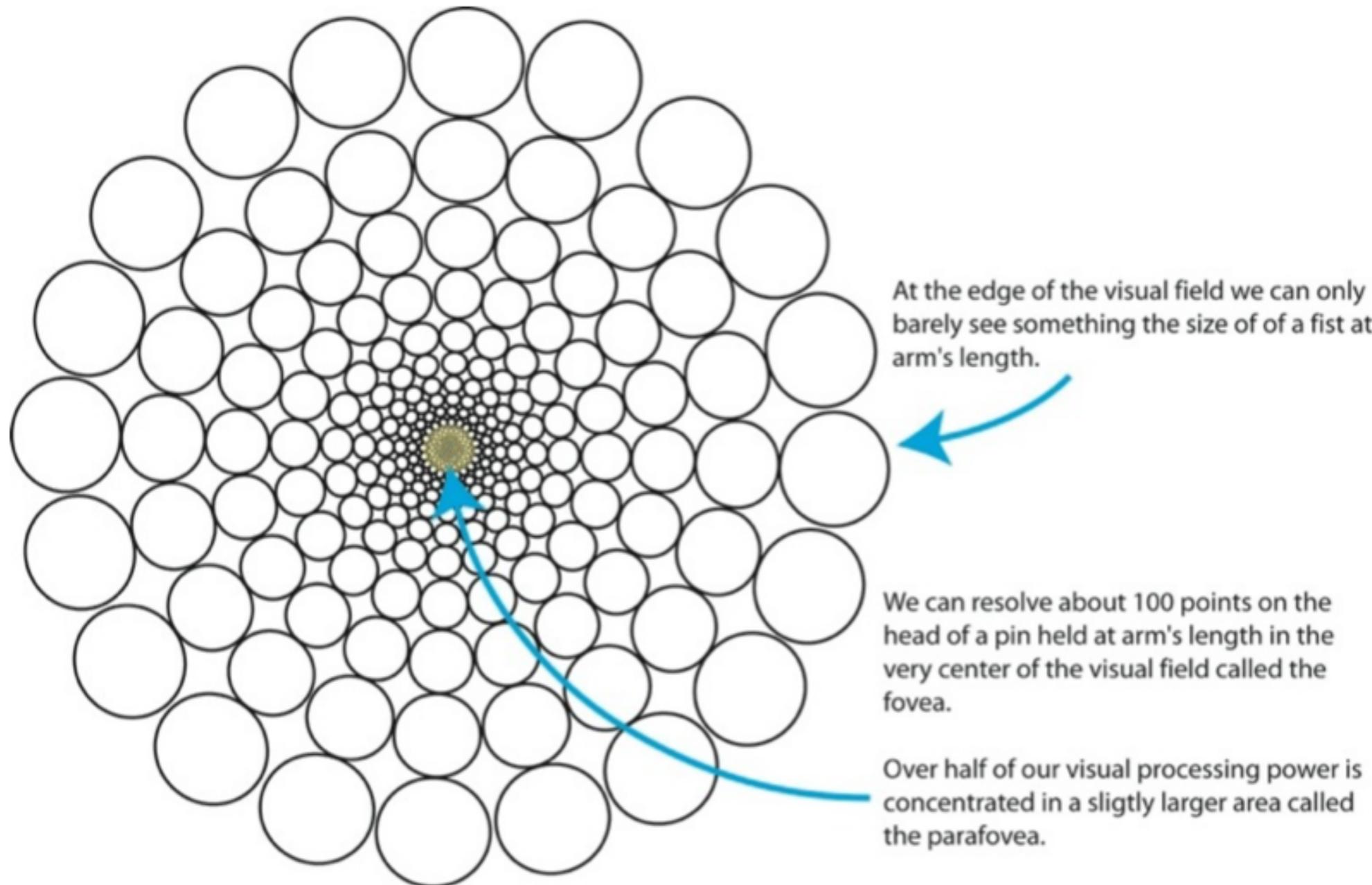
**Patterns** are built out of features depending on attentional demands. Attentional tuning reinforces those most relevant.

**Objects** most relevant to the task at hand are held in Visual Working Memory. Only between one and three are held at any instant. Objects have both non-visual and visual attributes.

**Bottom-up information drives pattern building**

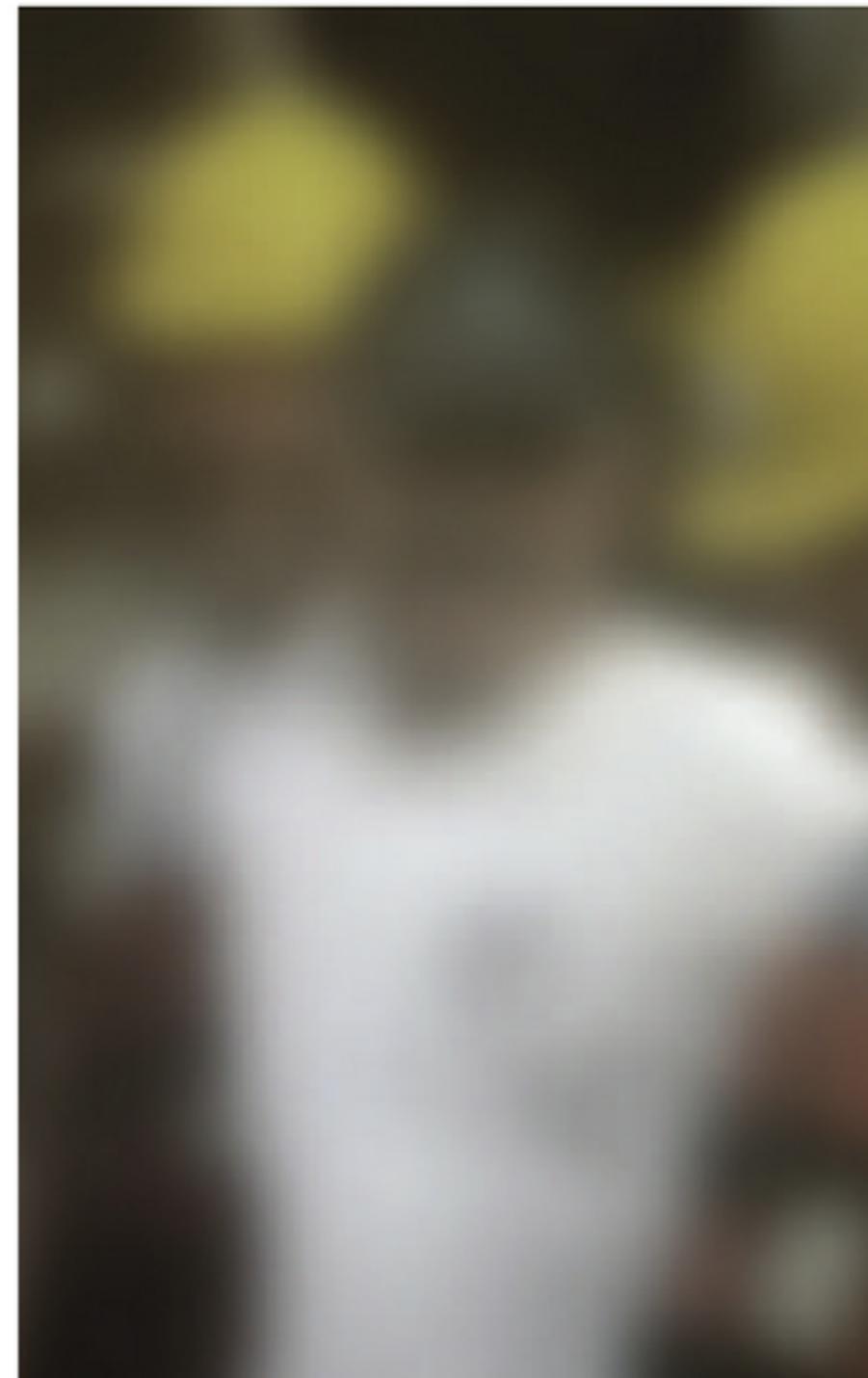
**Top-down attentional processes reinforce relevant information**

# VISUAL PHYSIOLOGY: VISUAL FIELD



# VISUAL PHYSIOLOGY: FOVEA

	2013	2012	2011	2010
1. Total	102,000	86,700	80,000	70,000
2. Direct sales	1,000	1,000	1,000	1,000
3. Indirect sales	101,000	85,700	79,000	69,000
4. Direct sales	101,000	26.8%	25.0%	25.0%
5. Indirect sales	726,112	24.9%	640,56	400
6. Total	23,953	22.7%	63,194	63,194
7. Direct sales	23,853	24.5%	62,944	62,944
8. Indirect sales	106,418	26.7%	416,061	366,061
9. Total	6,278	17.3%	9,250	9,250
10. Direct sales	5,565	19.8%	13,819	13,819
11. Indirect sales	1,093	26.6%	5,431	5,431
12. Total	799	20.0%	19,250	19,250
13. Direct sales	62,000	25.0%	166,000	166,000
14. Indirect sales	75,000	25.0%	98,000	98,000
15. Total	137,000	25.0%	264,000	264,000



Ware (2008)

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# PERCEPTION AND ATTENTION

- ▶ Scanning of visual environment
  - ▶ sequence of **saccades** (rapid (20-200 ms), involuntary eye movement), and
  - ▶ **fixation** points (200-600 ms long)
- ▶ Not like the panning of a camera

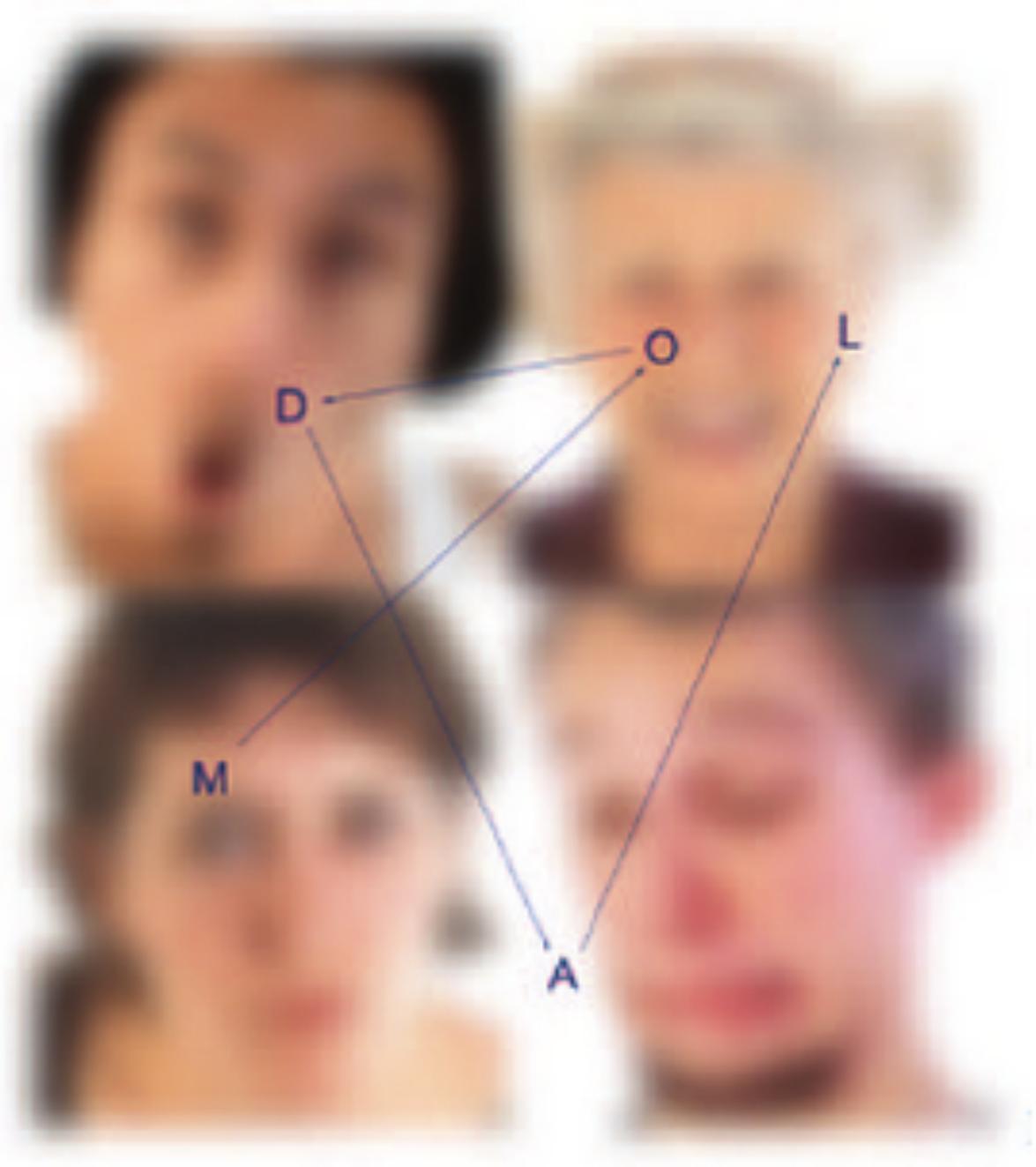
A saccade is a quick, simultaneous movement of both eyes between two or more phases of fixation in the same direction.



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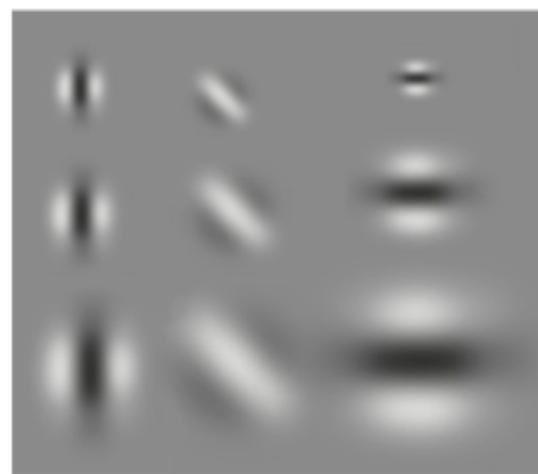
# PERCEPTION AND ATTENTION

- ▶ attentional focus
  - ▶ bottom-up  
(perception of shapes and colours to identify patterns)
  - ▶ top-down (looking for specific features)



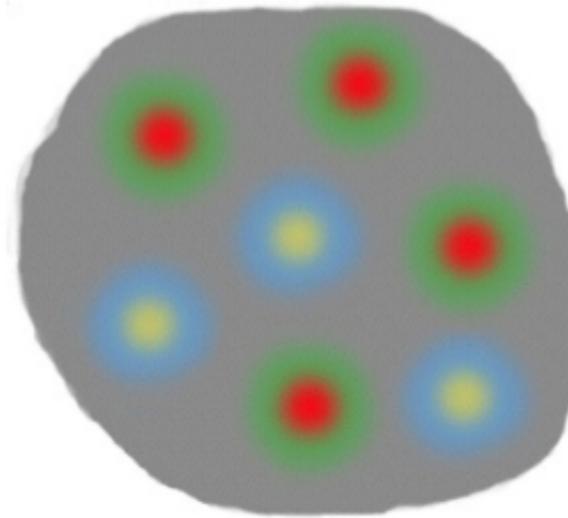
# BOTTOM-UP PROCESSING

- ▶ feature detection
- ▶ pattern recognition
- ▶ object recognition



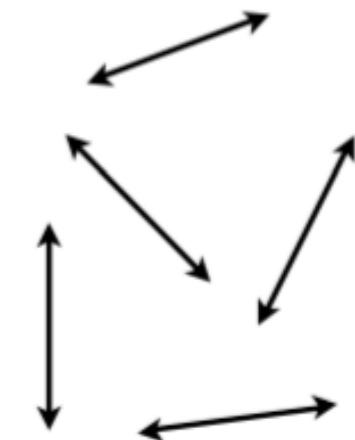
Orientation

some sensitivity to colour



Colour

R/G and Y/B channels



Movement

insensitive to colour

# TOP-DOWN PROCESSING



How affluent?

= Rich or wealthy?



What are their ages?

Ware (2008)

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## POP-OUT EFFECT - ATTENTIONAL TUNING

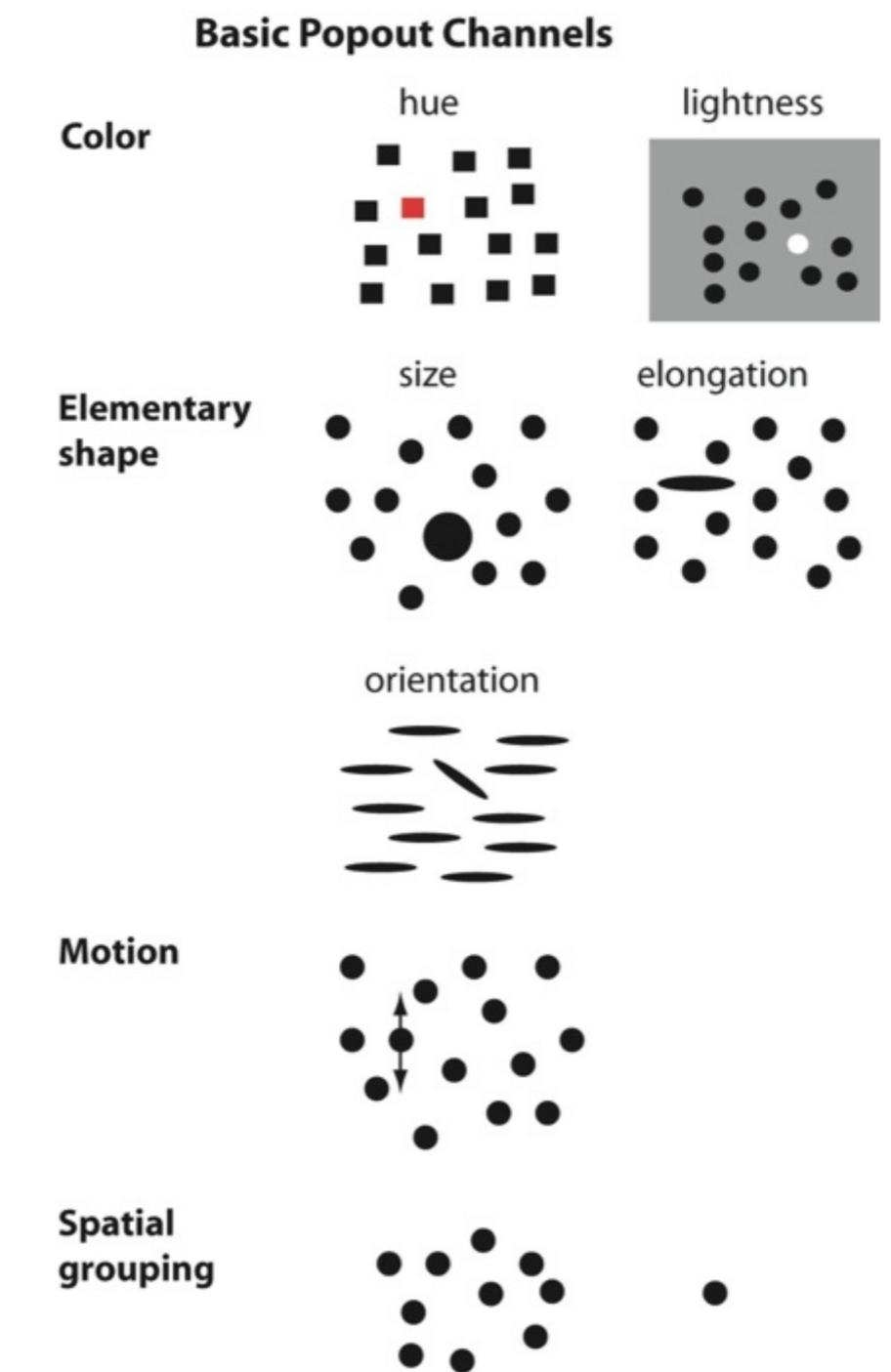
- ▶ Very fast < 200-250 ms
- ▶ Targets processed in parallel
- ▶ Picks up on contrast between features
- ▶ Independent of number of distractors

1269548523612356987458245  
0124036985702069568312781  
2439862012478136982173256

126954852**3**612**3**56987458245  
01240**3**6985702069568**3**12781  
24**3**98620124781**3**69821**7****3**256

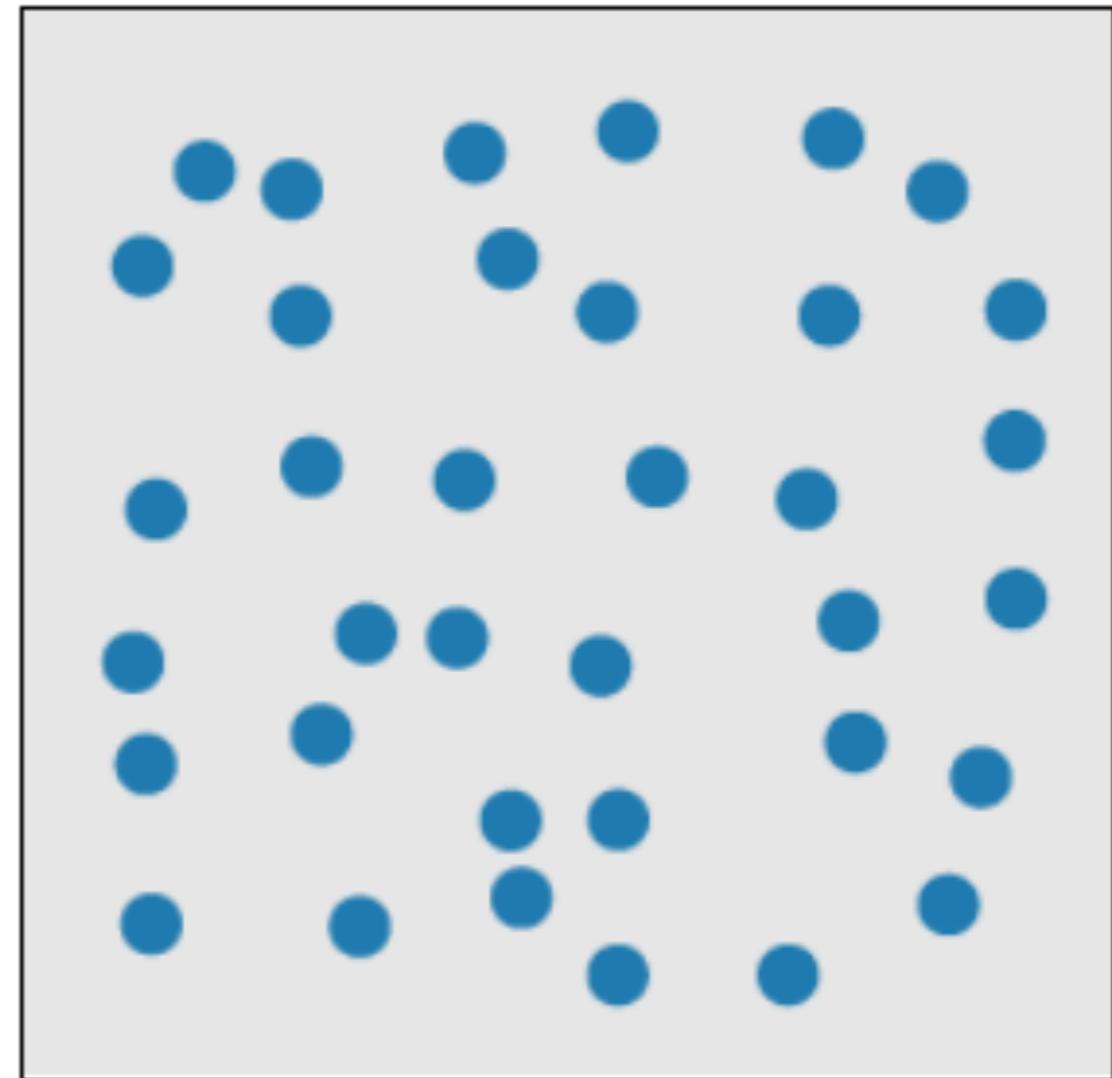
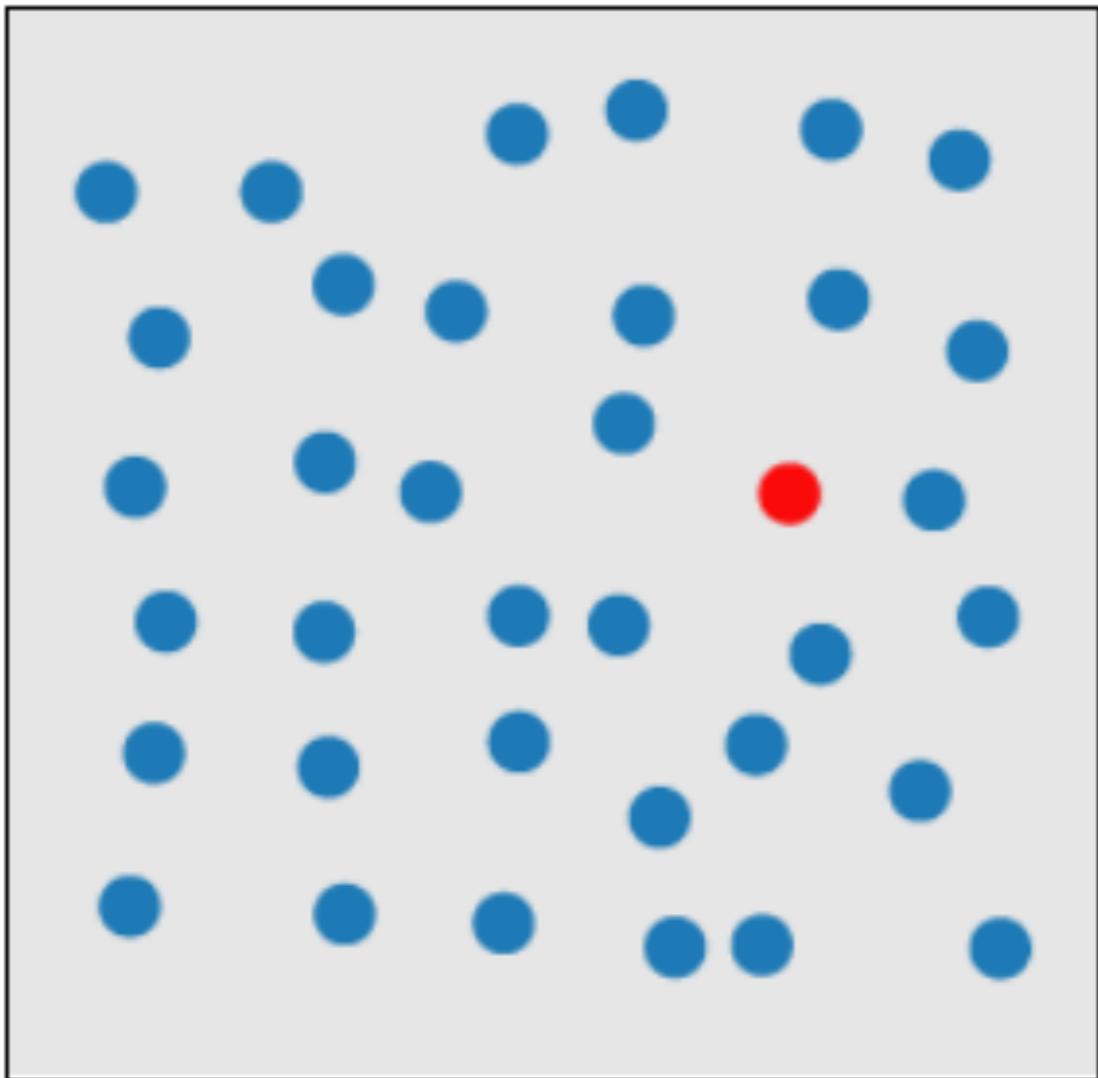
# POP-OUT CHANNELS

- ▶ Colour
- ▶ Shape
- ▶ Orientation
- ▶ Motion
- ▶ Spatial grouping
- ▶ Limits: conjunction, separability and integral



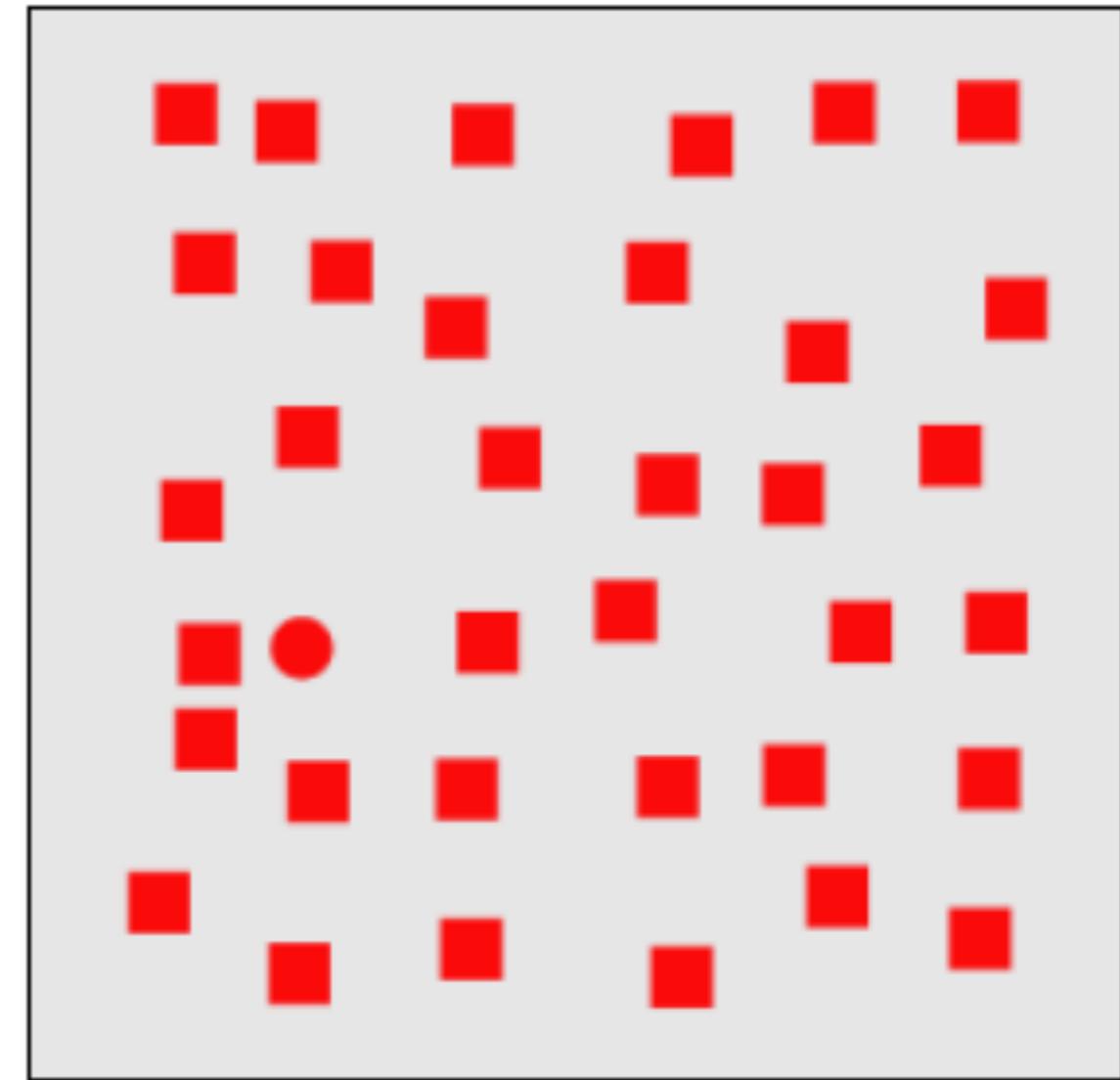
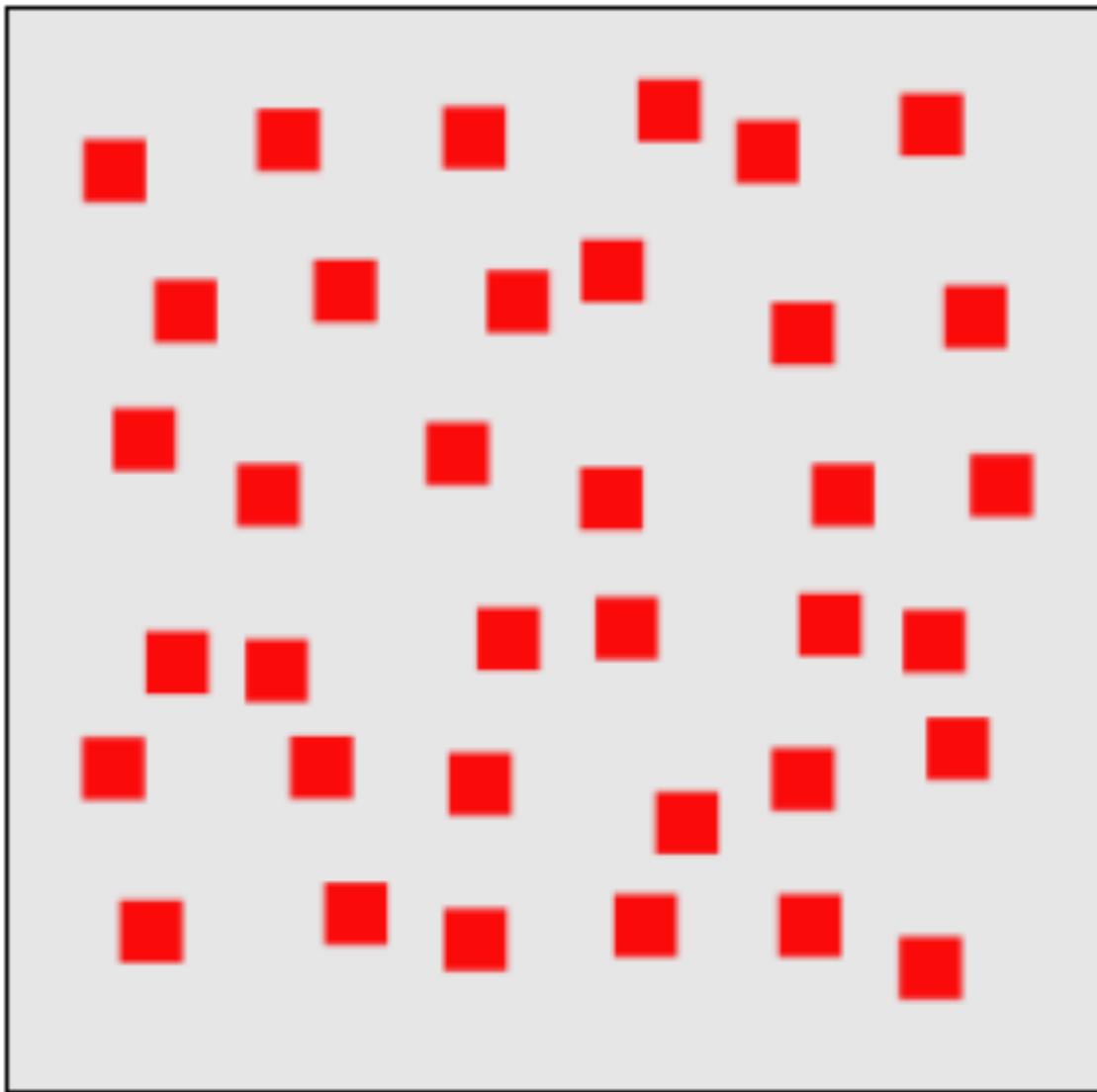
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## POP-OUT: COLOUR

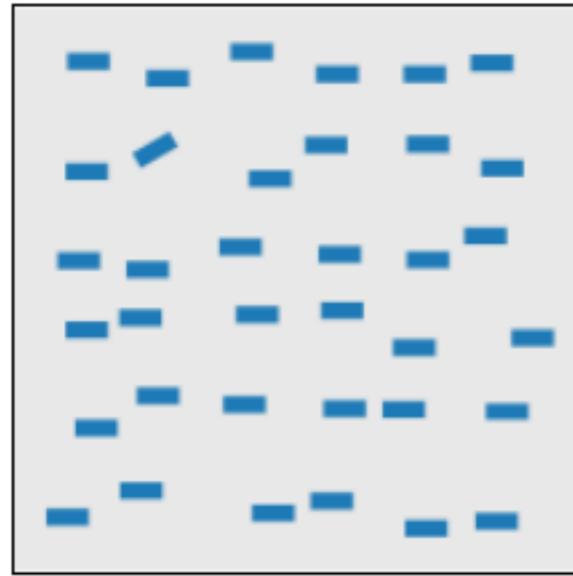


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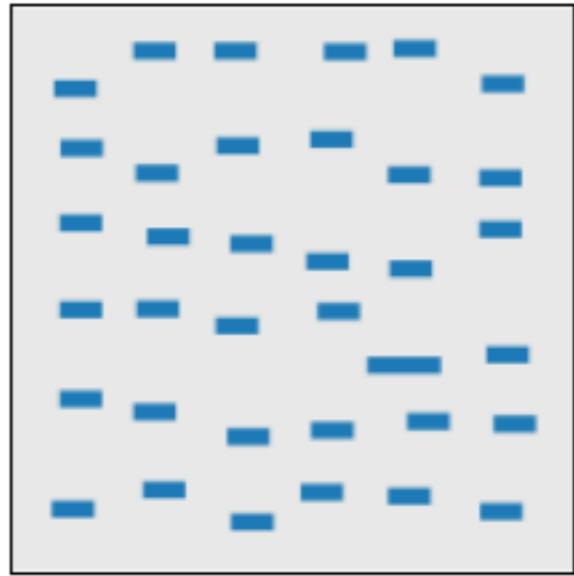
## POP-OUT: SHAPE



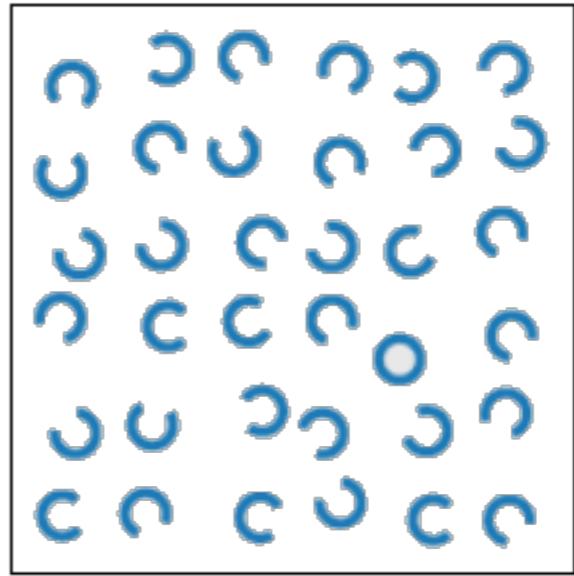
## MORE POP-OUT FEATURE COMBINATIONS...



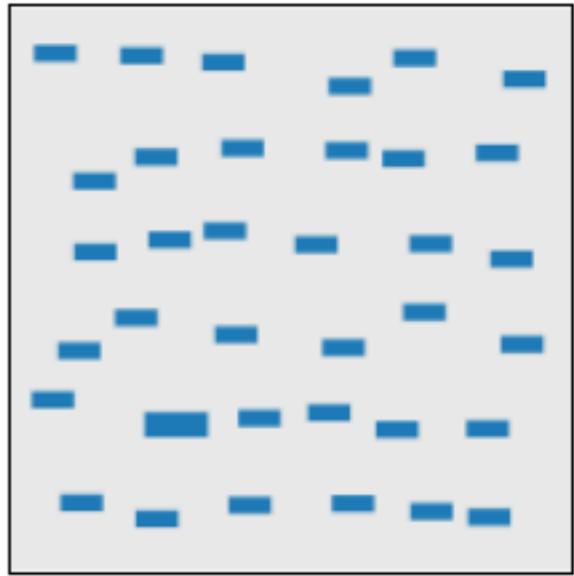
line (blob) orientation



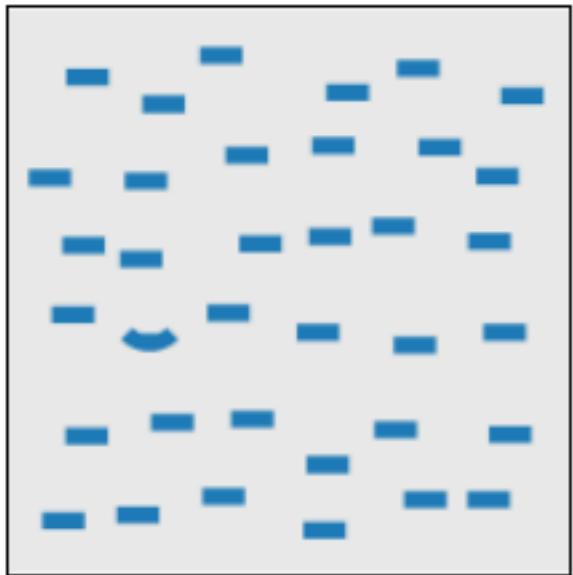
length, width



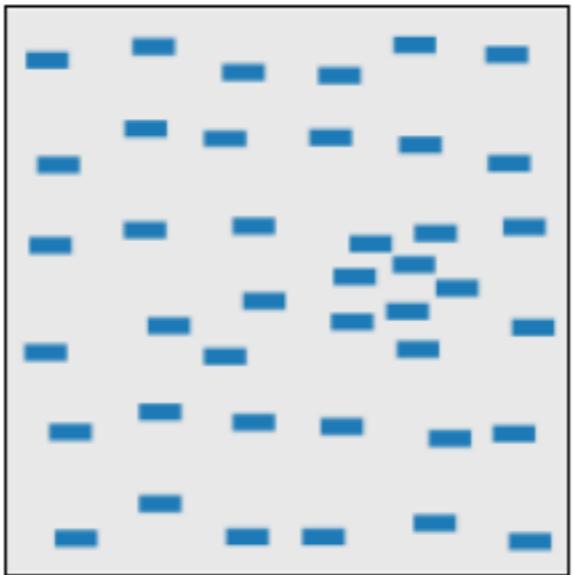
closure



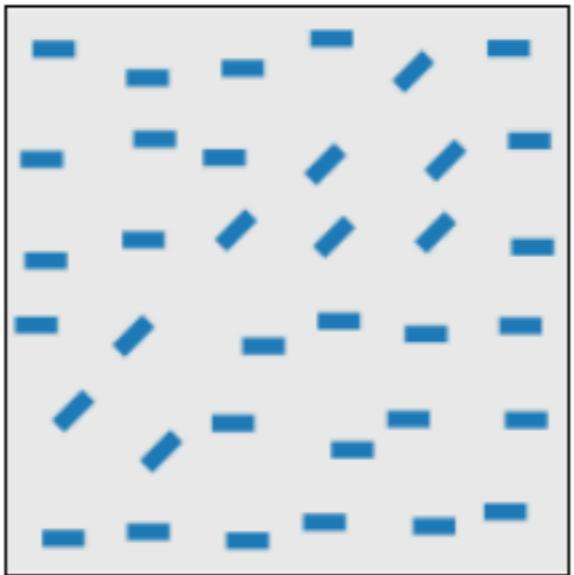
size



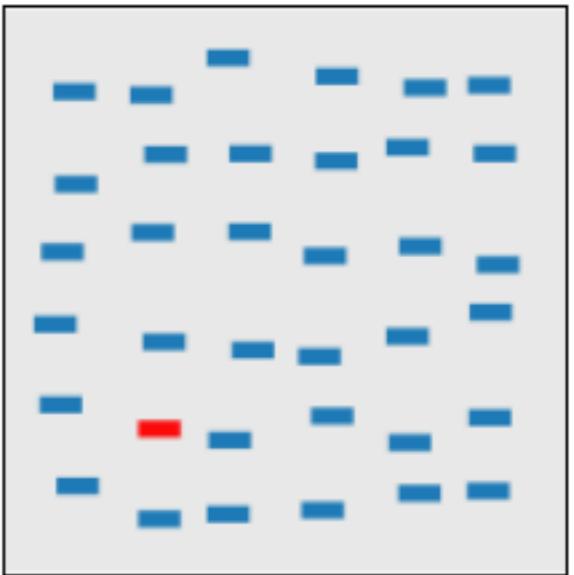
curvature



density, contrast

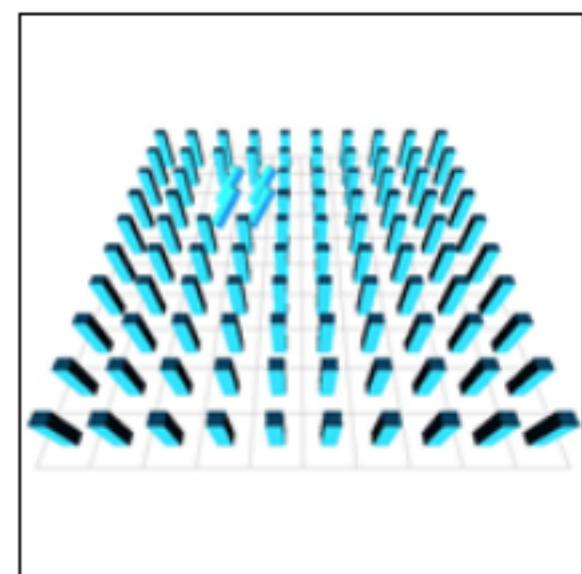
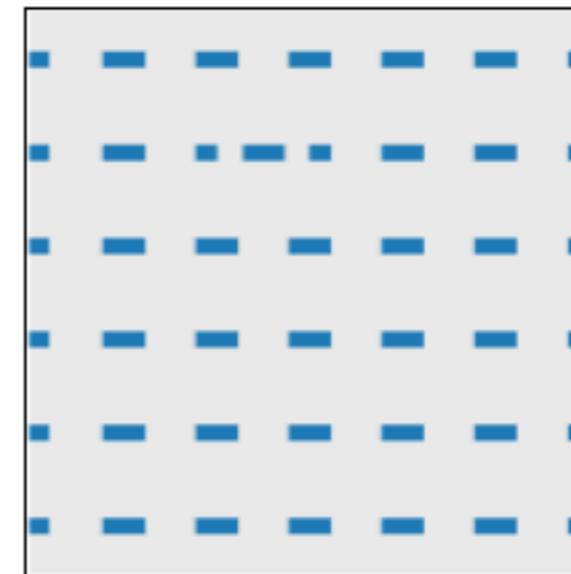
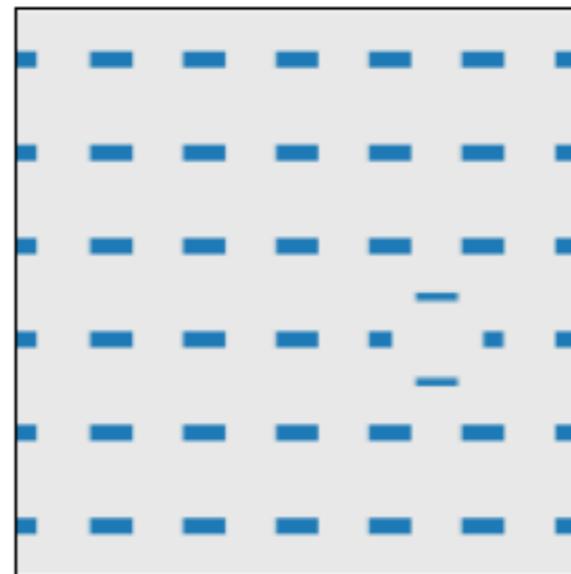
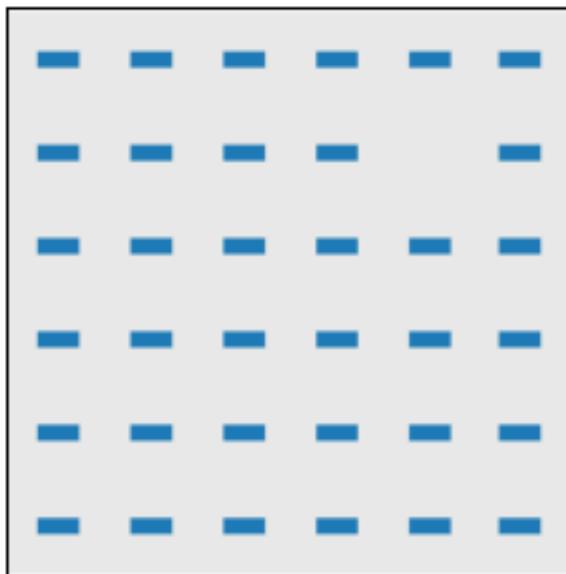
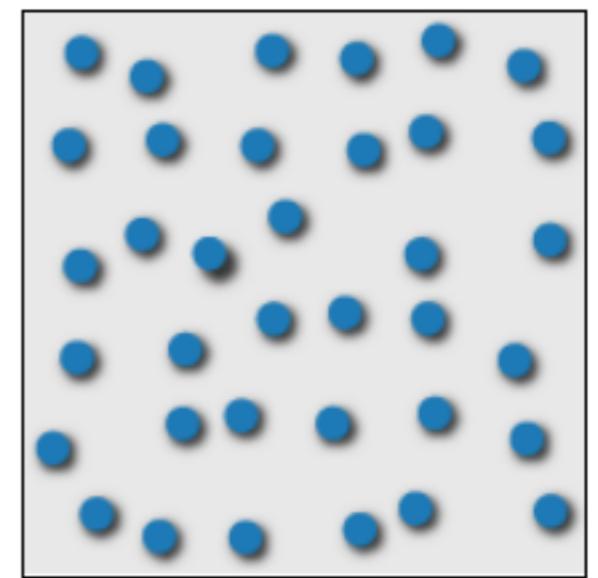
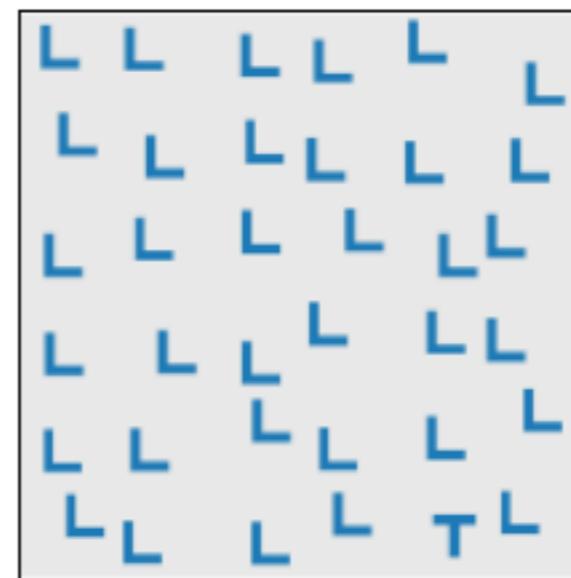
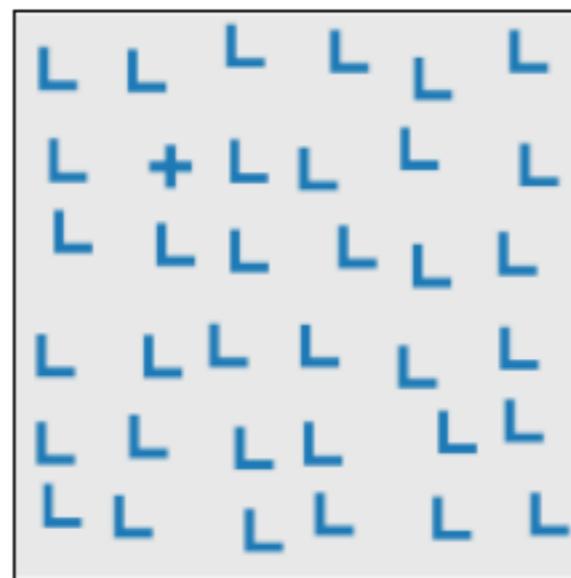
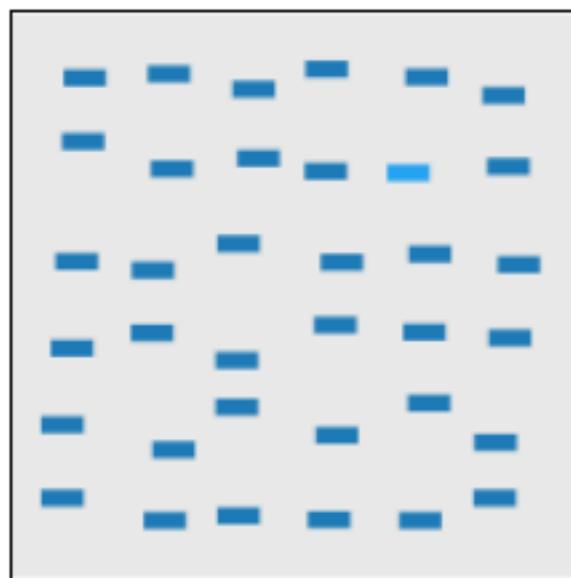


number, estimation



colour (hue)

## MORE POP-OUT FEATURE COMBINATIONS...



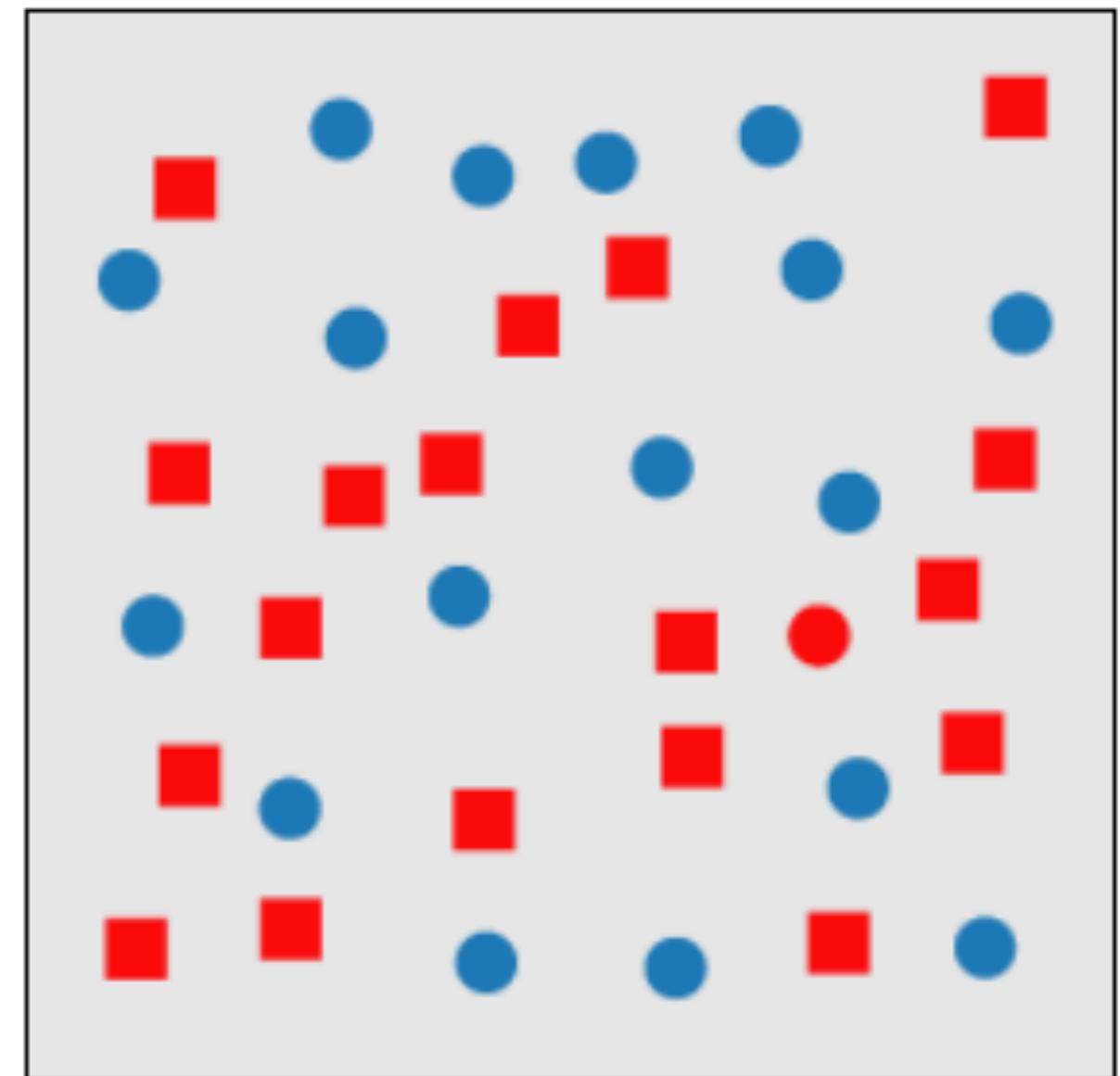
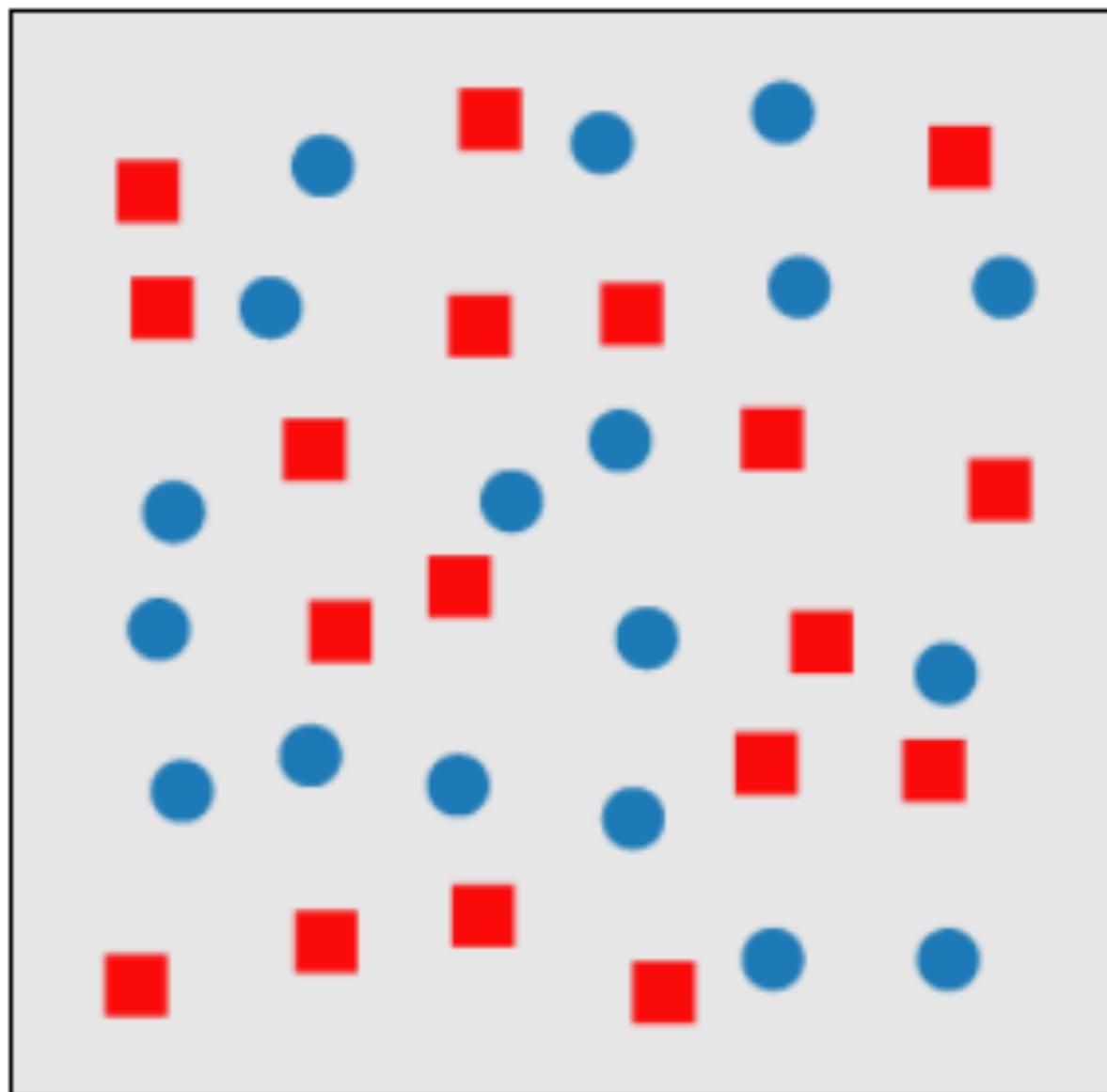
flicker

direction of motion

velocity of motion

3D orientation

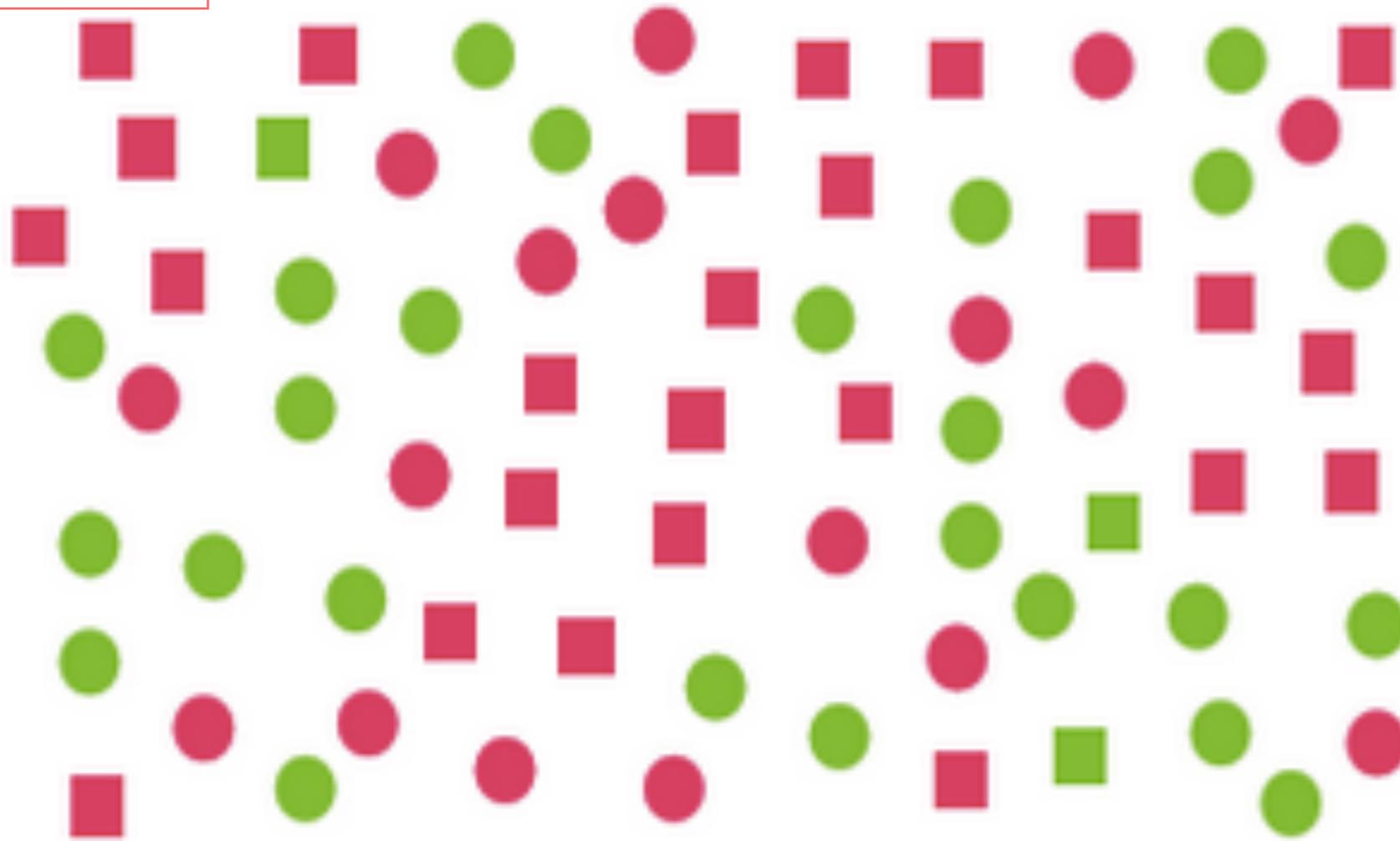
## ~~POD~~-OUT: CONJUNCTION (COMBINATION OF NON-UNIQUE FEATURES)



Red Circle Target - must be search for serially (time consuming)

# POP-OUT: CONJUNCTION (COMBINATION OF NON-UNIQUE FEATURES)

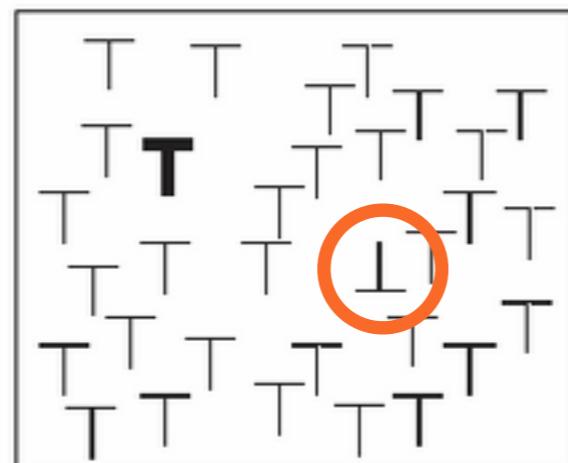
Example of data  
contains  
Green = female  
Red = male



Green Square Target - must be search for serially (time consuming)

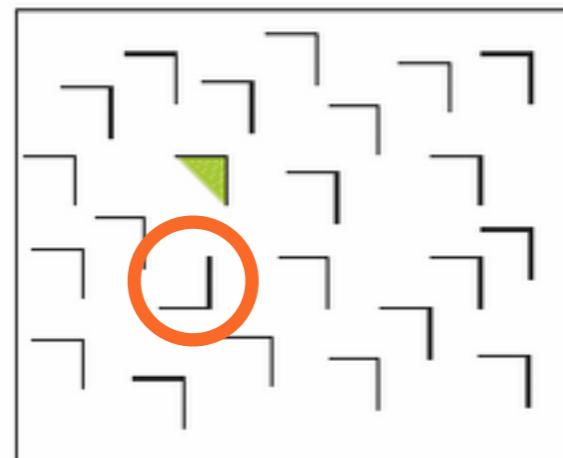
# FEATURE COMBINATIONS – SOME WORK SOME DON'T

⊥  
difficult  
**T**  
easy



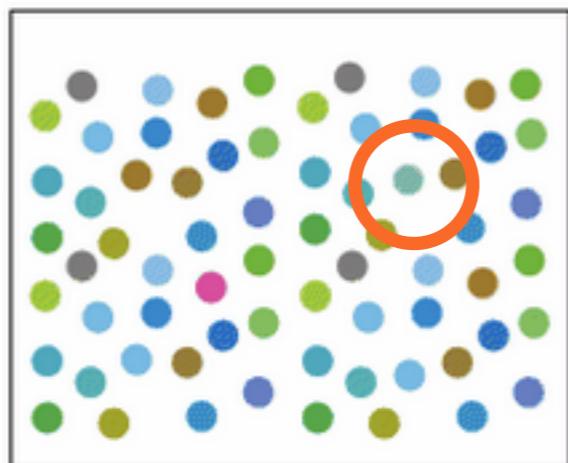
The inverted T has the same feature set as the right-side-up T and is difficult to see. But the bold T does support pop-out and is easy to find.

∟  
difficult  
▽  
easy



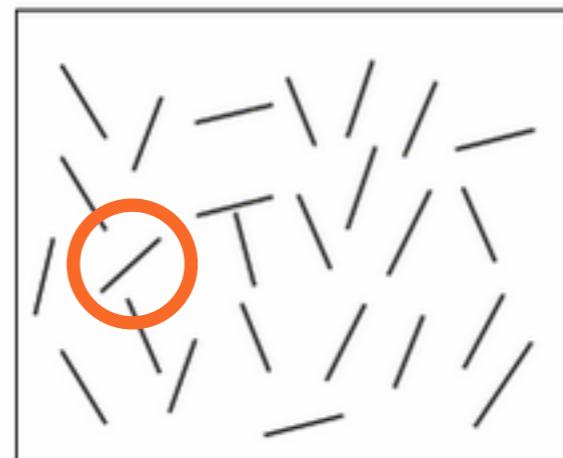
Similarly the backwards L has the same feature set as the other items, making it difficult to find. But the green triangle addition does pop out.

•  
difficult  
●  
easy



A color that is close to many other similarly colored dots cannot be tuned for and is difficult to find.

/  
difficult  
—  
easy



Similarly, if a line is surrounded by other lines of various similar orientations it will not stand out.

# SEPARABLE AND INTEGRAL CHANNEL COMBINATIONS

## ▶ Separable:

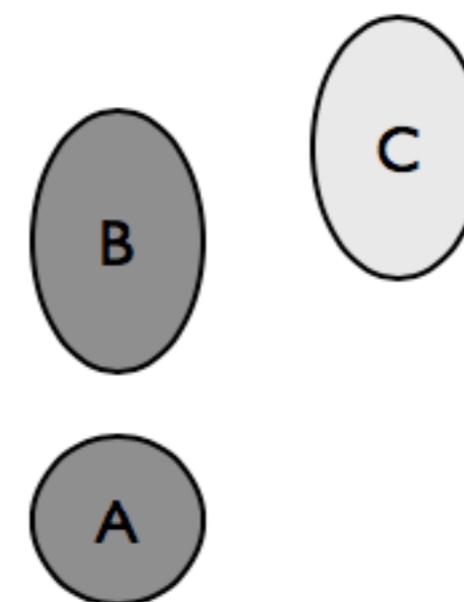
- ▶ Two channels that can be judged independently

## ▶ Integral:

- ▶ Two channels are viewed holistically

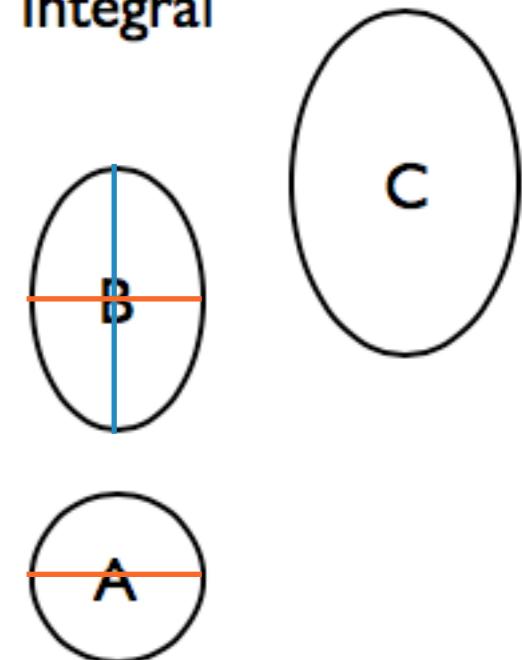
Separable

Dimension 2:Y size



Integral

Dimension 2:Y size



Dimension I: Luminance

Two independent channels

Dimension I: X size

Two 'dependent' channels

relating to or concerned with wholes or with complete system rather than with the analysis of, treatment of, or dissection into parts

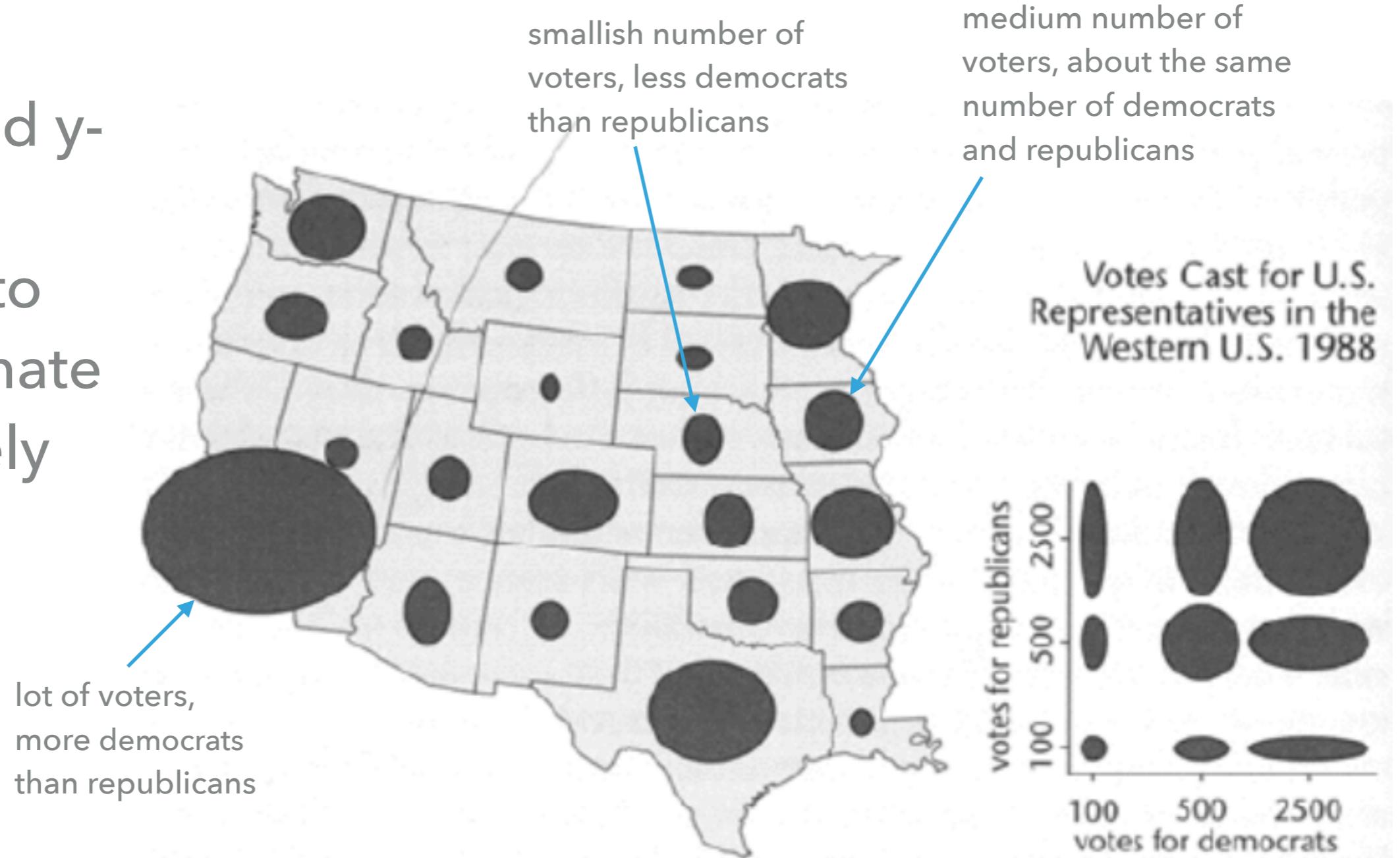
# SEPARABLE CHANNEL COMBINATION

- ▶ size and luminance work together

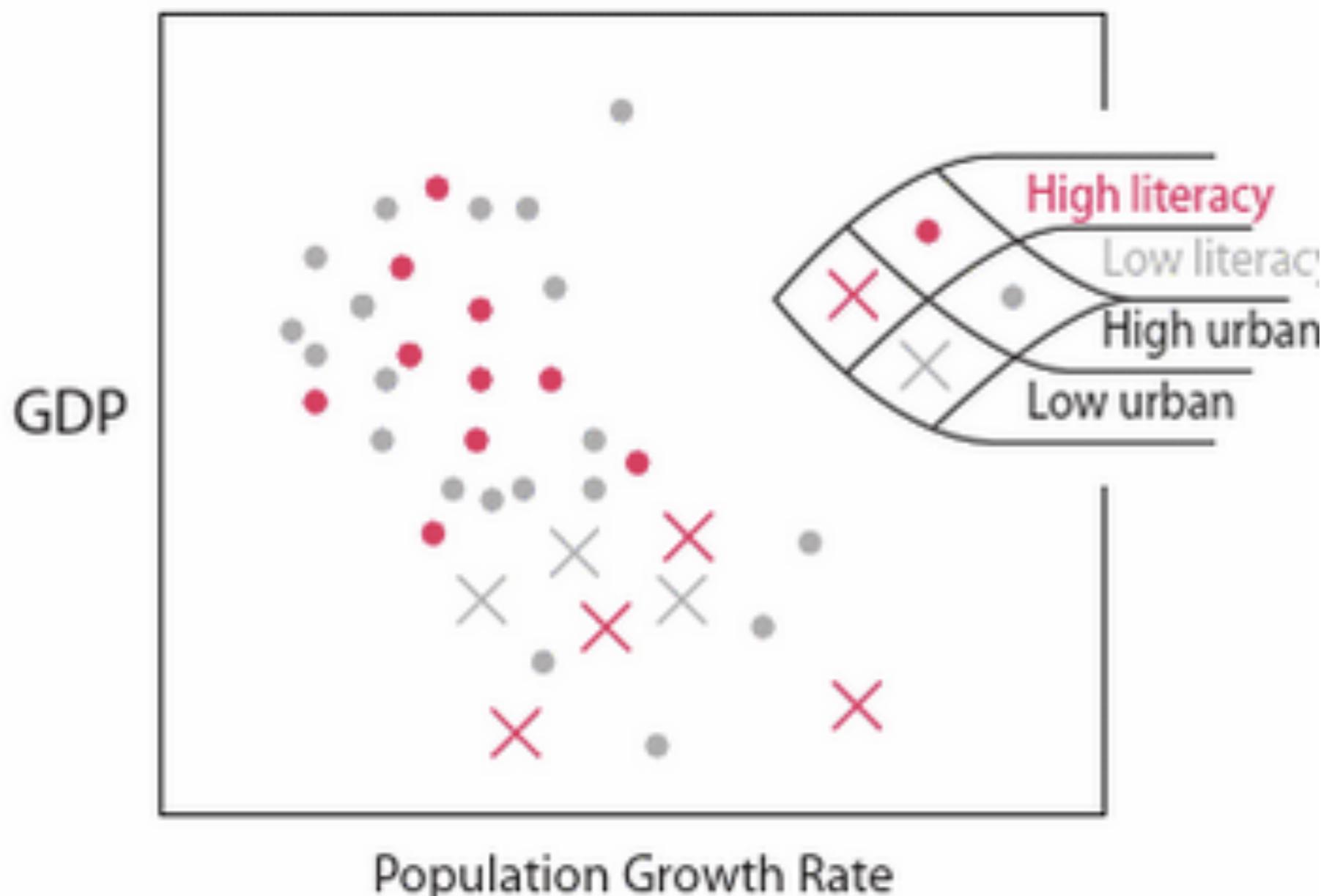


# INTEGRAL CHANNEL COMBINATION

- ▶ x-size and y-size are difficult to discriminate separately



## SEPARABLE CHANNEL COMBINATIONS



# SEPARABLE AND INTEGRAL CHANNEL COMBINATIONS

Separable ← → Integral



colour  
and  
location

colour  
and  
motion

colour  
and  
shape

size  
and  
orientation

x-size  
and  
y-size

red-green  
and  
yellow-blue

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# CHANGE BLINDNESS

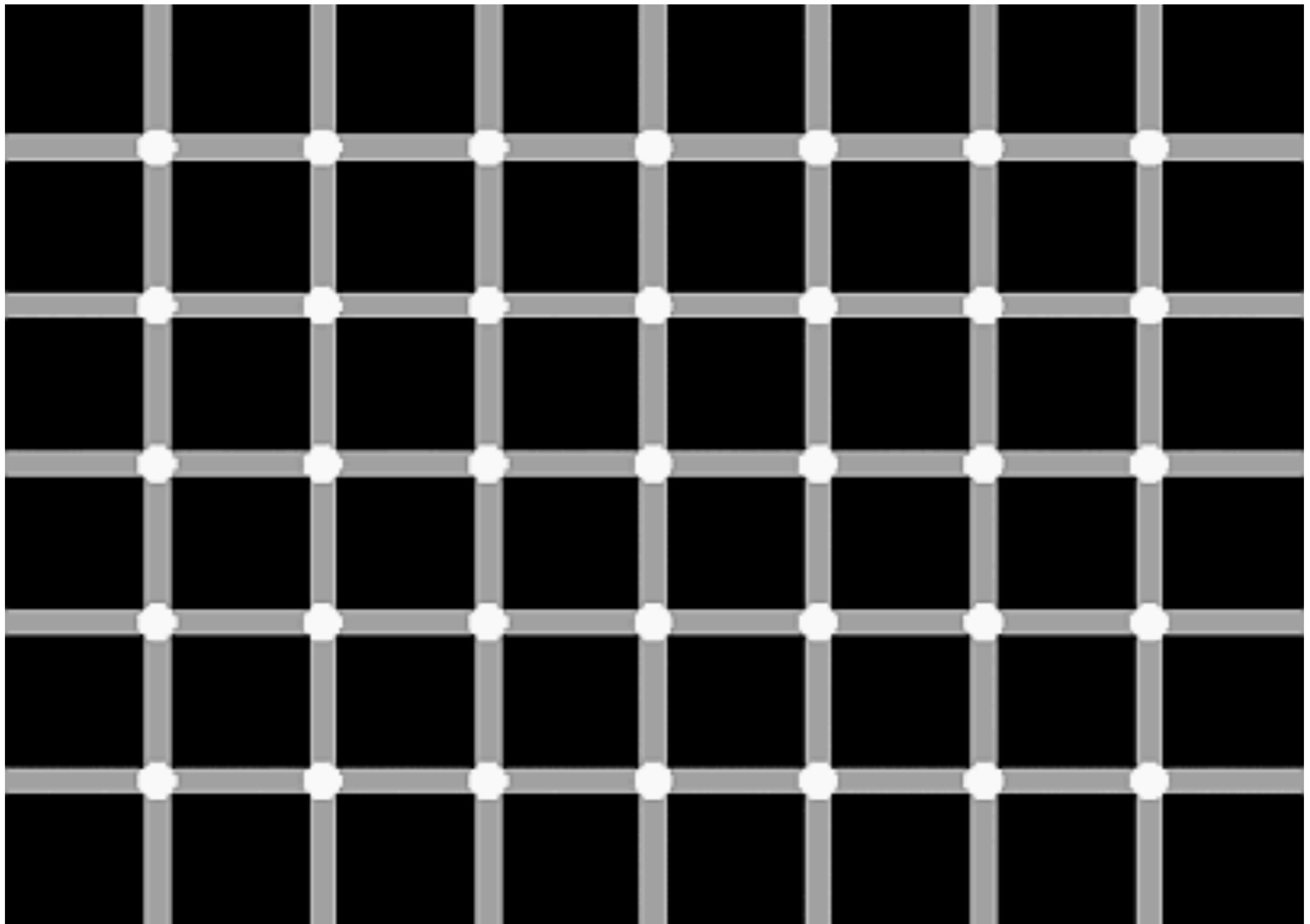
- ▶ Details of an image cannot be remembered across separate scenes
  - ▶ except in areas with focused attention
- ▶ Interruption (e.g. a blink, eye saccade or blank screen) amplifies this effect
- ▶ Not failure of vision system
- ▶ Failure due to inappropriate attentional guidance



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# CHANGE BLINDNESS





Hermann Grid - completion between cells with different receptive fields

## 5.2 ATTENTION

You should now be able to:

- ▶ Explain the role of attention in perception in terms of Ware's model of perceptual processing
- ▶ List and use a variety of pop-out channels to draw user's attention
- ▶ Identify separable and integral visual channel combinations



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# DATA VISUALISATION

TOPIC 05.3: COLOUR

## 5.3 COLOUR

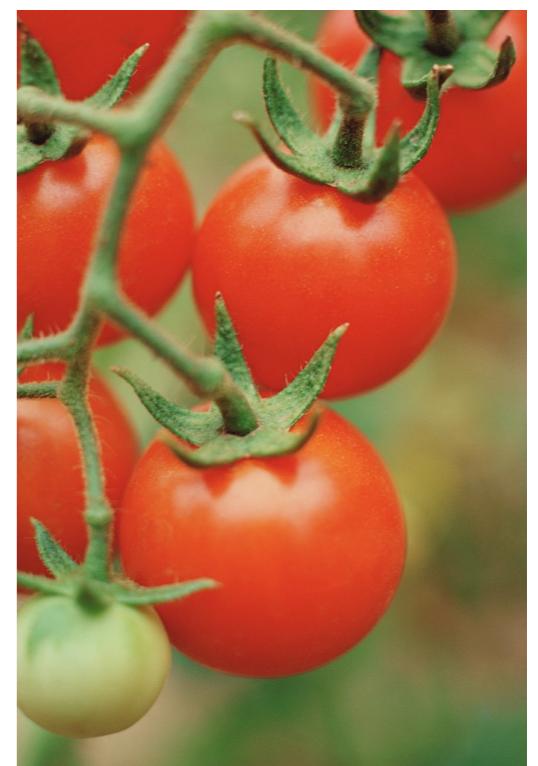
At the end of this topic you should be able to:

- ▶ Be familiar with the anatomy of the human eye and the difference between rod and cone cells
- ▶ Explain the difference between Hue, Saturation and Luminosity
- ▶ Be aware of design guidelines for use of colour
- ▶ Understand the effect of colour blindness on perception of colour and design strategies for colour blind users

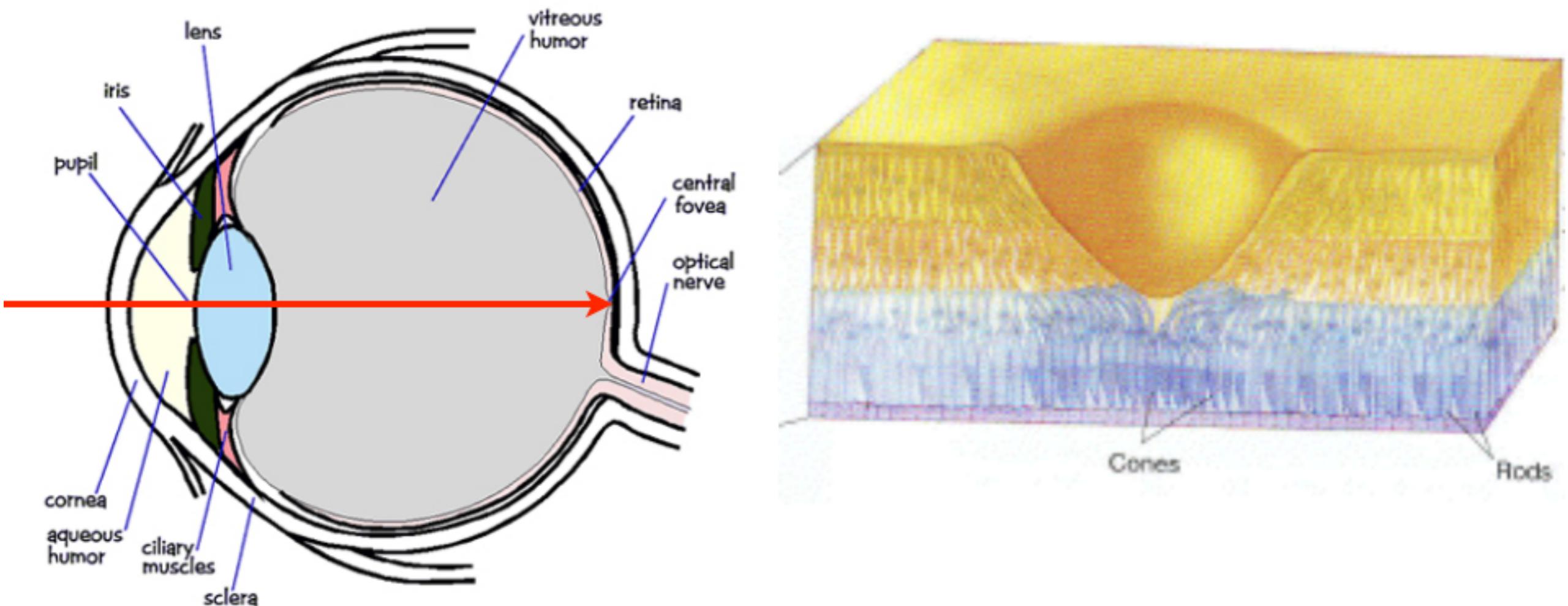


# COLOUR

- ▶ not a big part of normal vision
- ▶ does not help us perceive layout
- ▶ does not show movement or shape
- ▶ helps us pick out elements in our environment (breaks camouflage)



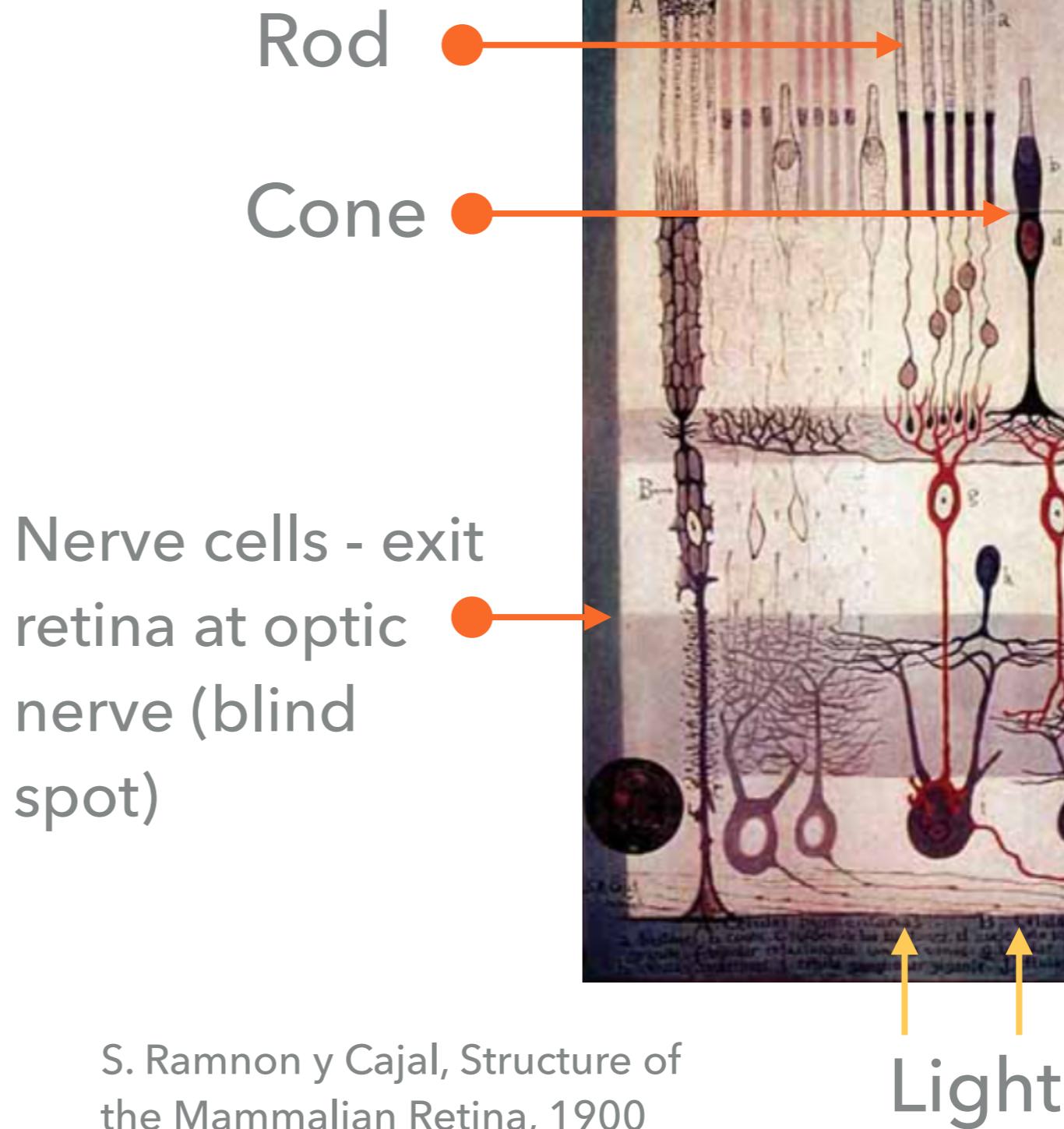
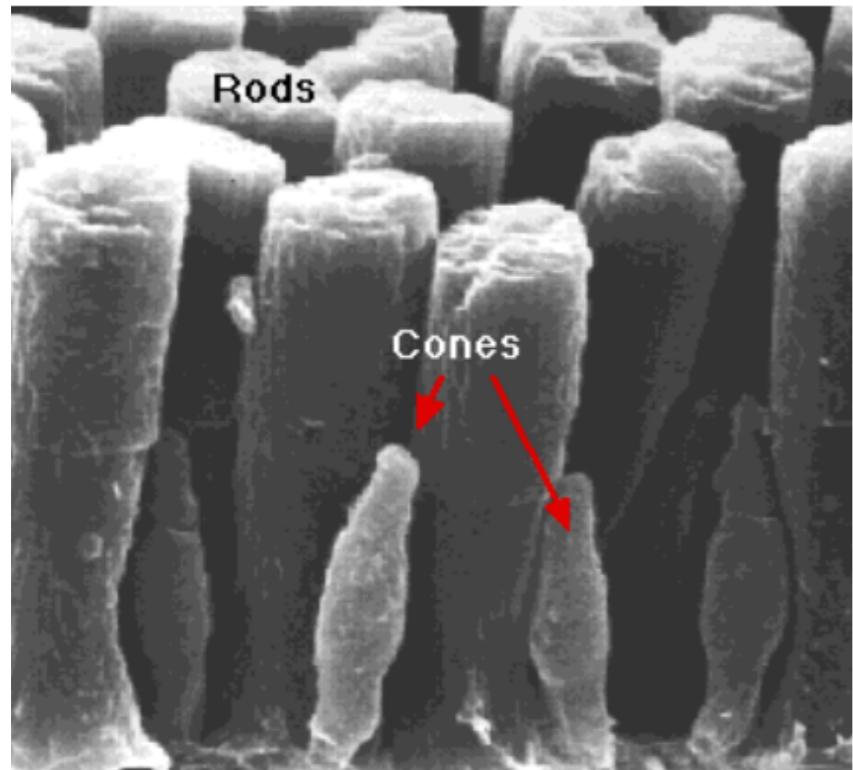
# VISUAL PHYSIOLOGY: FOVEA



- ▶ high cell density (27 times)
- ▶ responsible for sharp, central vision
- ▶ only cone cells -> colour vision

# VISUAL PHYSIOLOGY: STRUCTURE OF RETINA

- ▶ 120 million rods
- ▶ 5-6 million cones

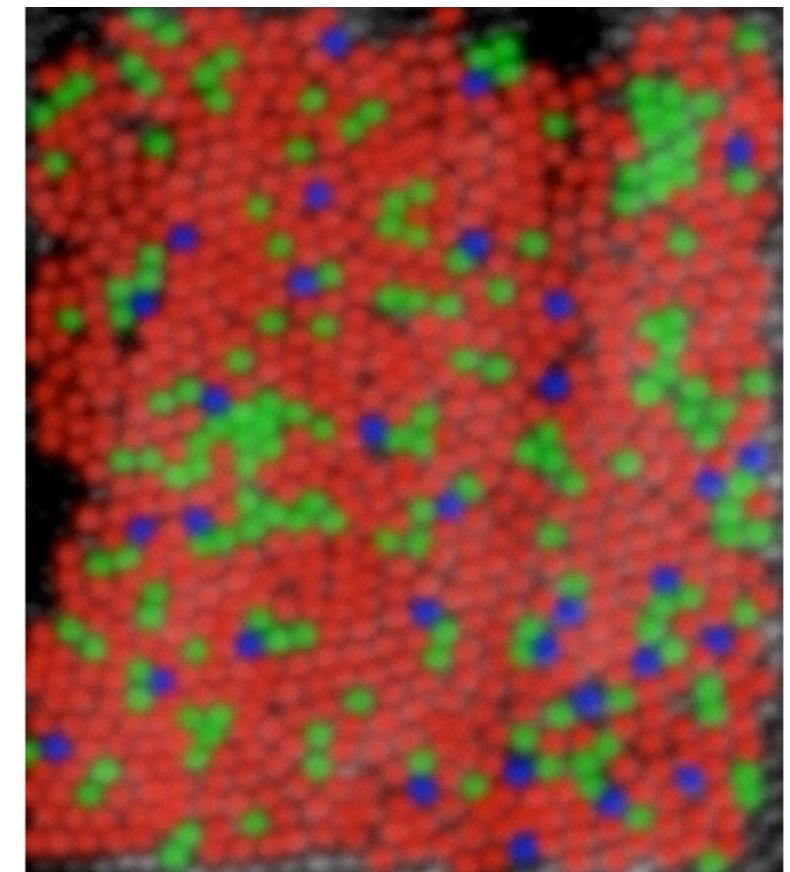


S. Ramón y Cajal, Structure of the Mammalian Retina, 1900

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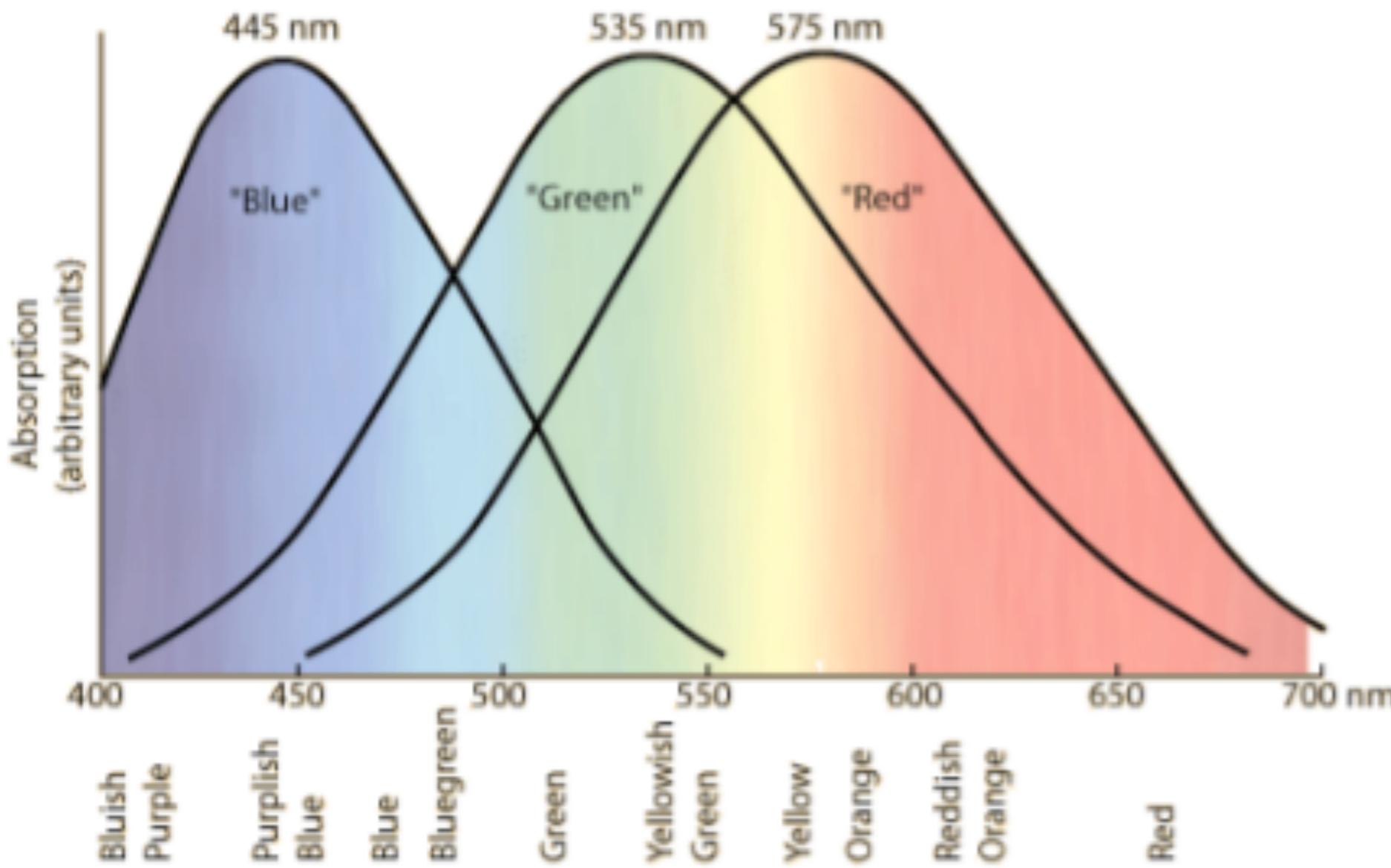
# VISUAL PHYSIOLOGY: CONES

- ▶ Cones
  - ▶ daytime vision
  - ▶ three different kinds
    - ▶ short wavelength (blue) 6%
    - ▶ medium wavelength (green) 31%
    - ▶ long wavelength (red) 63%



Distribution of red, green  
and blue cone cells

# VISUAL PHYSIOLOGY: CONE WAVELENGTH RESPONSE



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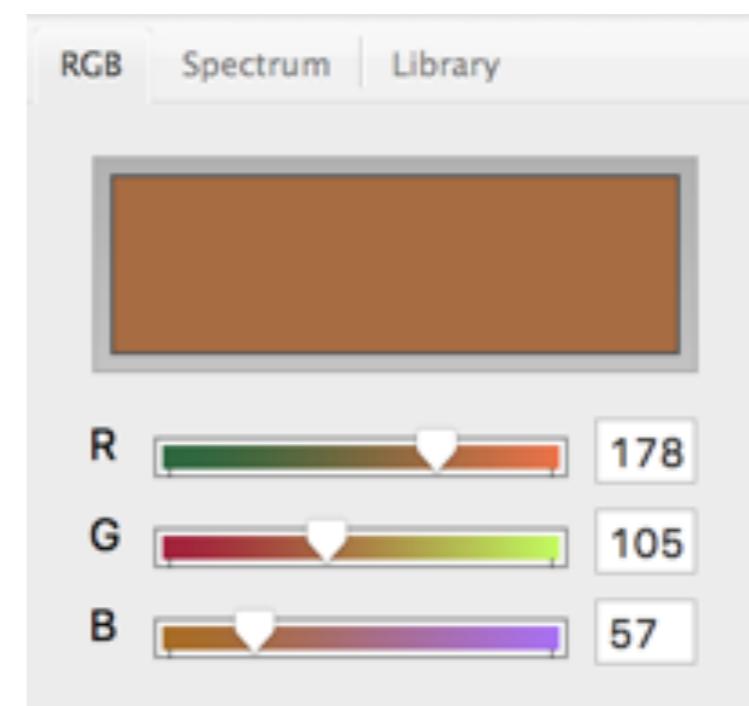
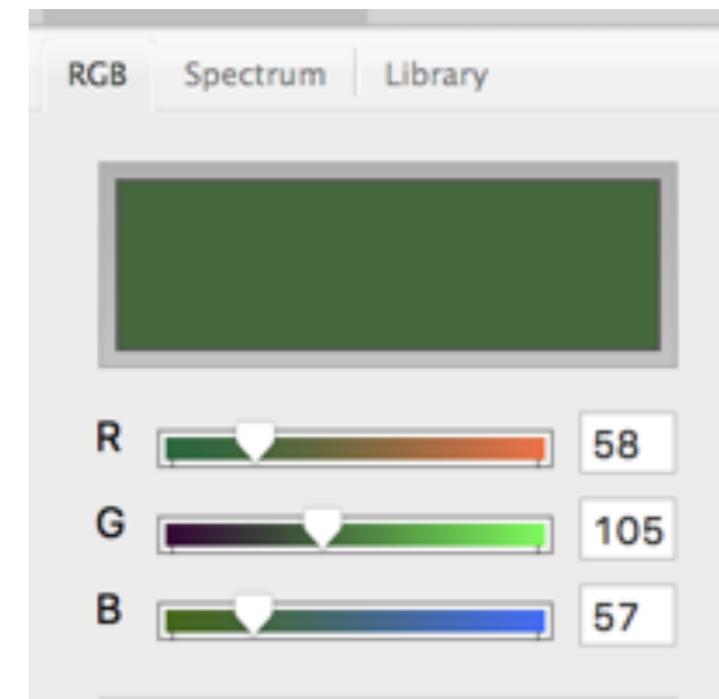
# OPPONENT PROCESS THEORY

- ▶ Receptor cells that respond to one colour are inhibited by another colour (cells can only detect one colour at a time)
- ▶ Opponent process channels
  - ▶ red-green - lower resolution 
  - ▶ blue-yellow - lower resolution 
  - ▶ black-white (luminance) - high resolution edge information 

For example, neurones excited by red are inhibited by green - people never see reddish-green, but do see greenish-blue

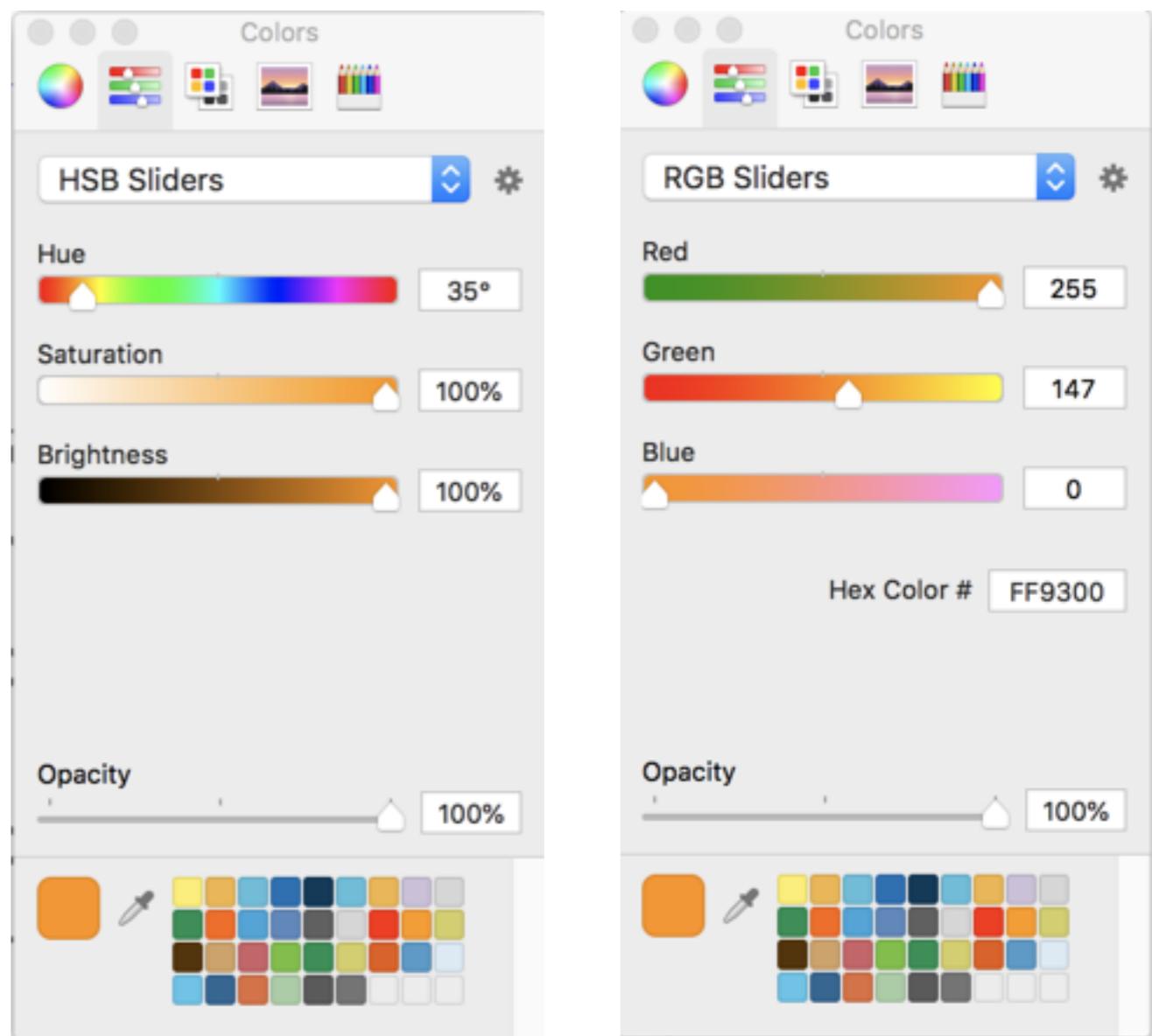
# RGB (RED-GREEN-BLUE)

- ▶ Commonly used in computer displays
- ▶ Alter the 'amount' of red, green and blue to make colour
- ▶ Difficult to make adjustments for lighter/darker or paler/richer (e.g., saturation)

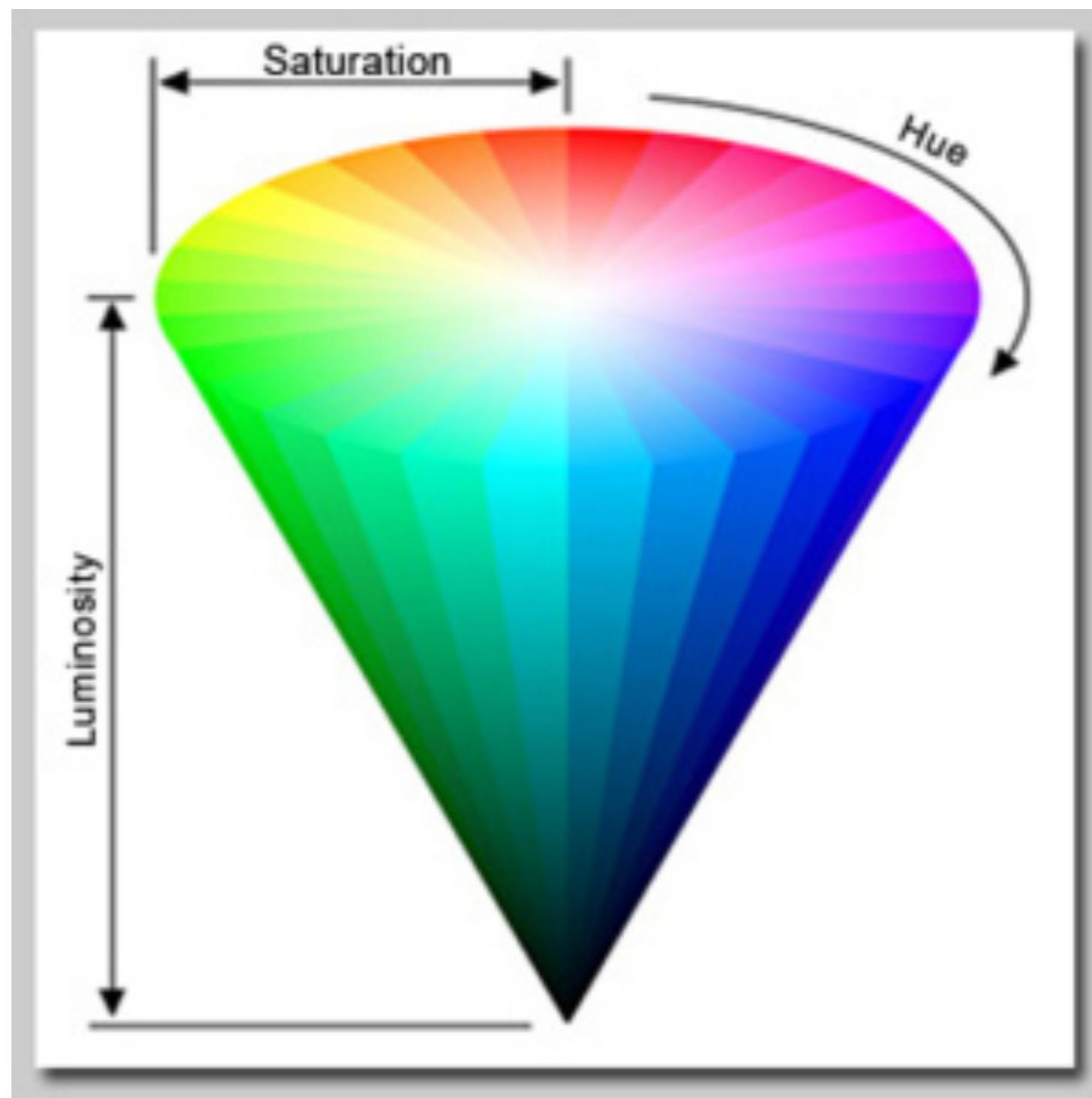


# HSL (HUE-SATURATION-LUMINOSITY)

- ▶ More human friendly way of presented colour
  - ▶ Hue - pure colour
  - ▶ Saturation - amount of white (pale to vivid)
  - ▶ Luminosity (brightness) - amount of black (light to dark)
- ▶ easier to manipulate saturation (key vis channel)

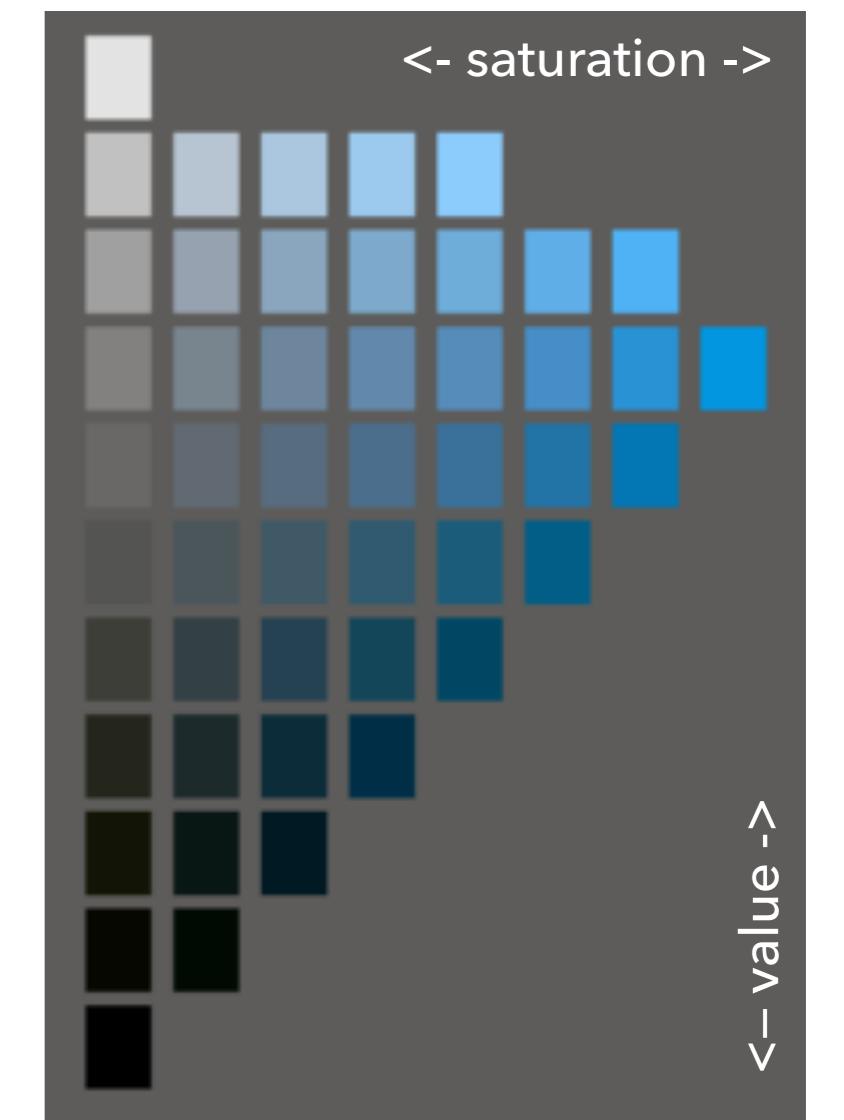


# HSL COLOUR SPACE



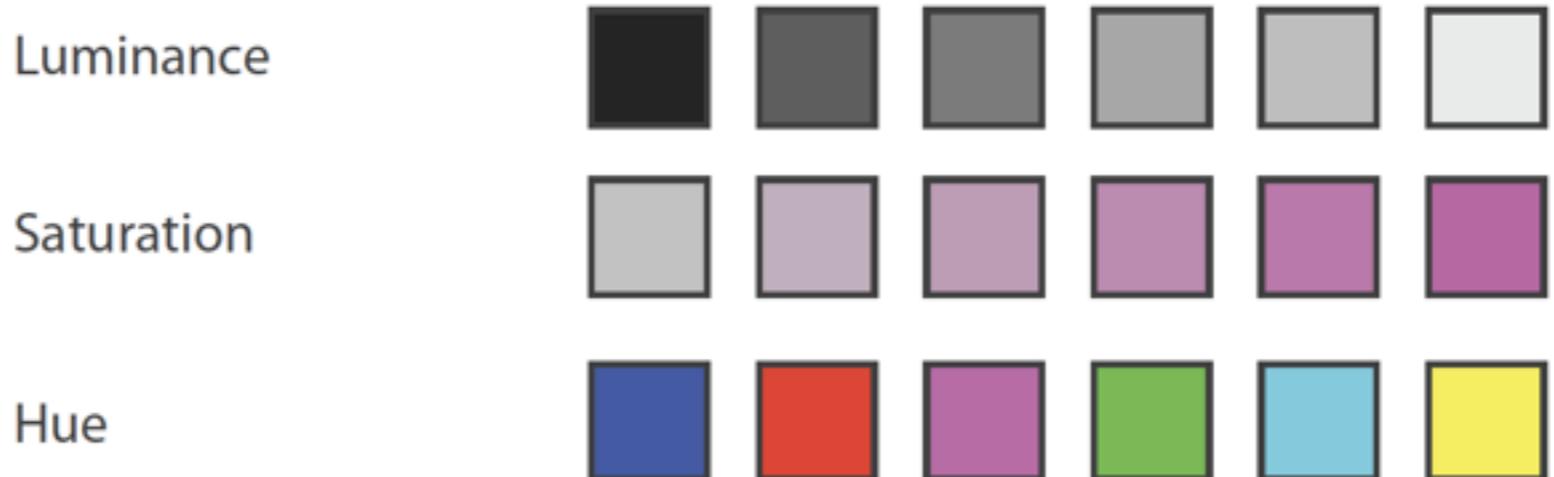
# DIMENSIONS OF COLOUR

- ▶ Hue
  - ▶ what most people call 'colour'
- ▶ Saturation
  - ▶ purity of a colour (pale to vivid)
- ▶ Luminance
  - ▶ lightness of a colour (light to dark)



# CHANNEL DISCRIMINABILITY

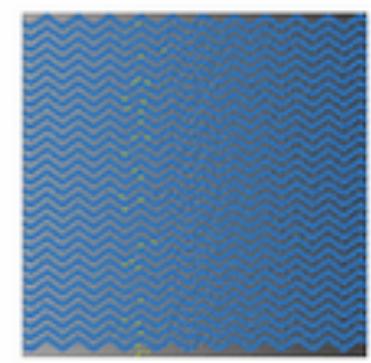
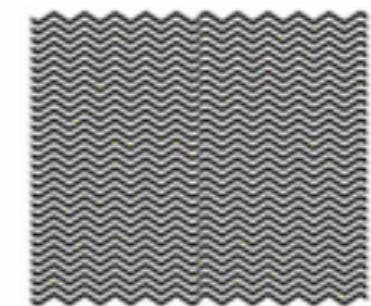
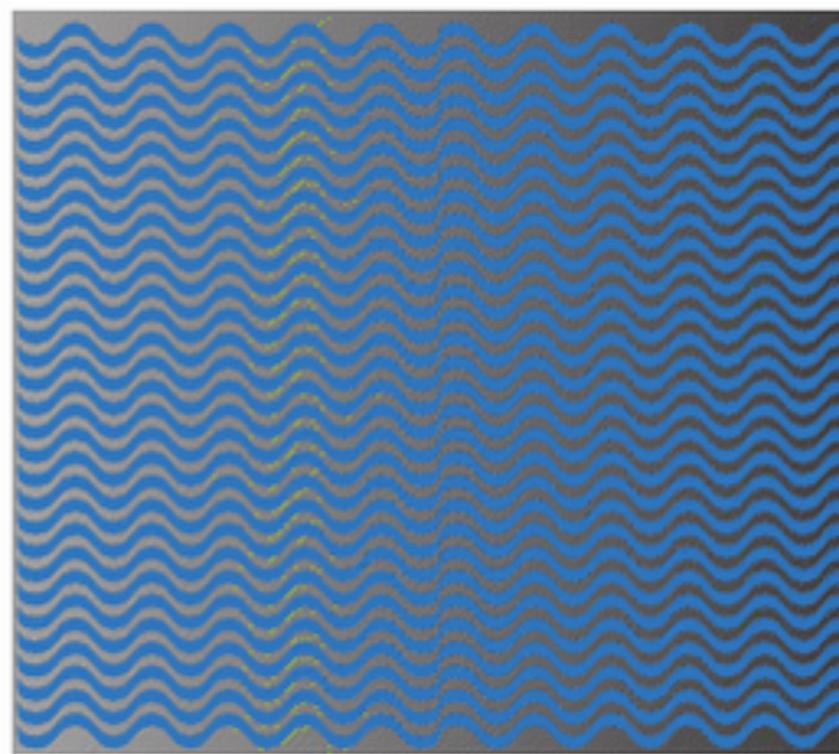
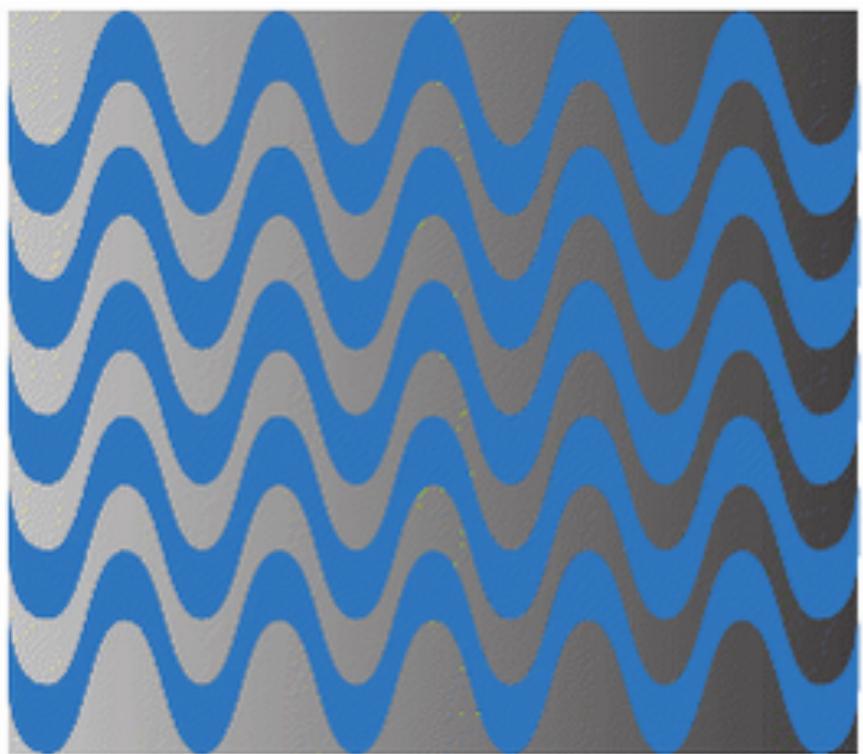
- ▶ Perceptual ordering
  - ▶ luminance - very good
  - ▶ saturation - good
  - ▶ hue - poor



**Figure 10.5.** The luminance and saturation channels are automatically interpreted as ordered by our perceptual system, but the hue channel is not. Munzner

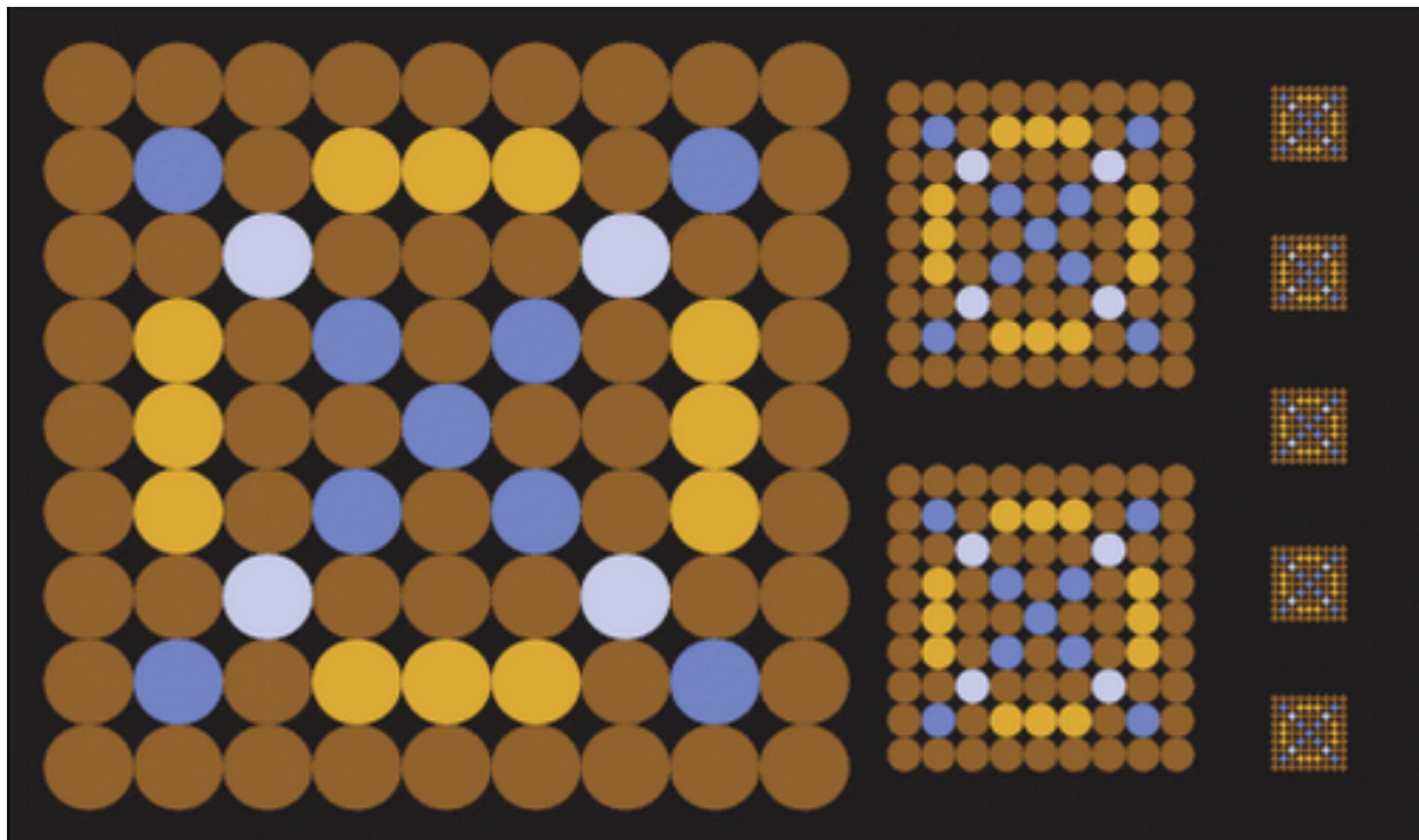
---

## HUE VS LUMINANCE



Ware (2008)

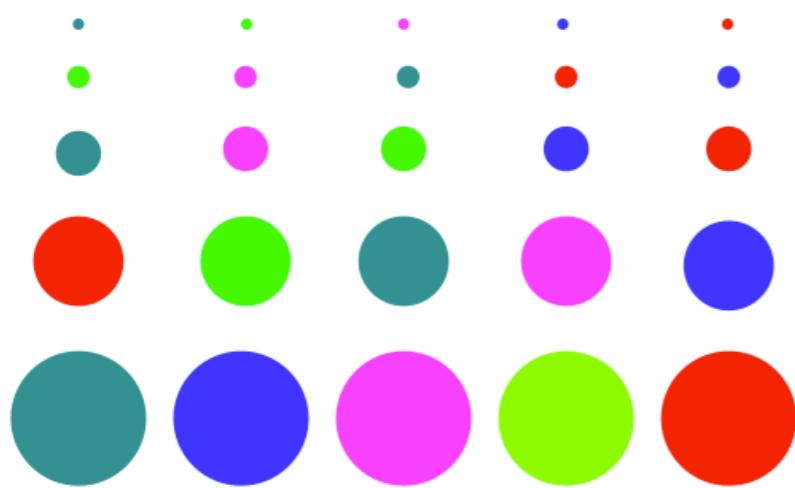
# HUE VS SATURATION



Ware (2008)

# COLOUR GUIDELINES

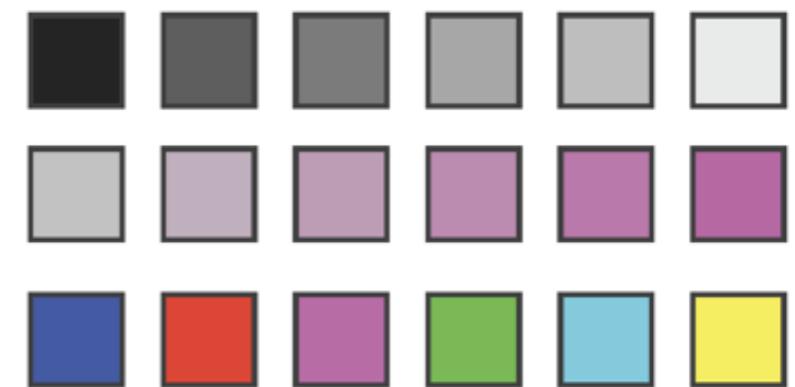
- ▶ Use luminance and saturation for **magnitude** channels
- ▶ Use hue for **categories**
- ▶ Watch out for saturation
- ▶ Harder to see colour on smaller items



Luminance

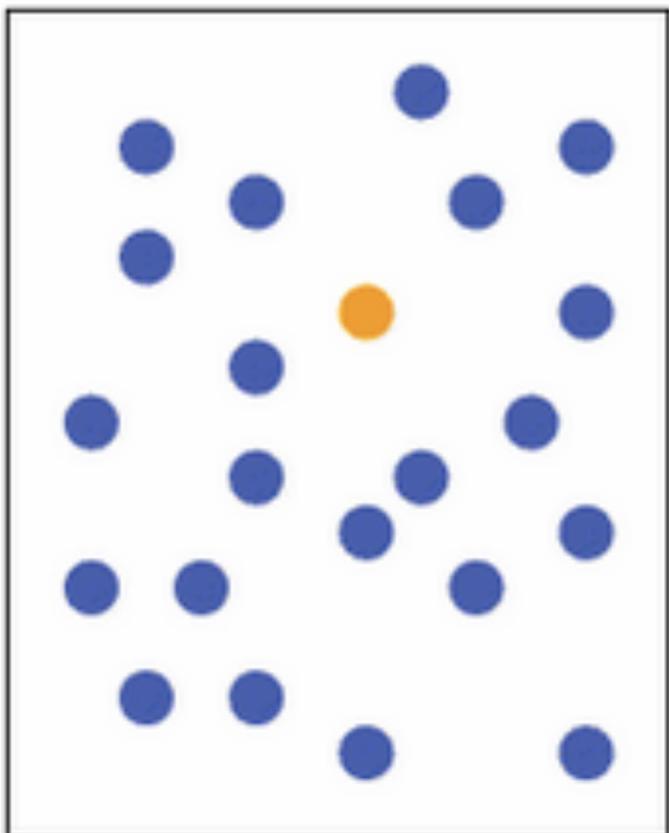
Saturation

Hue

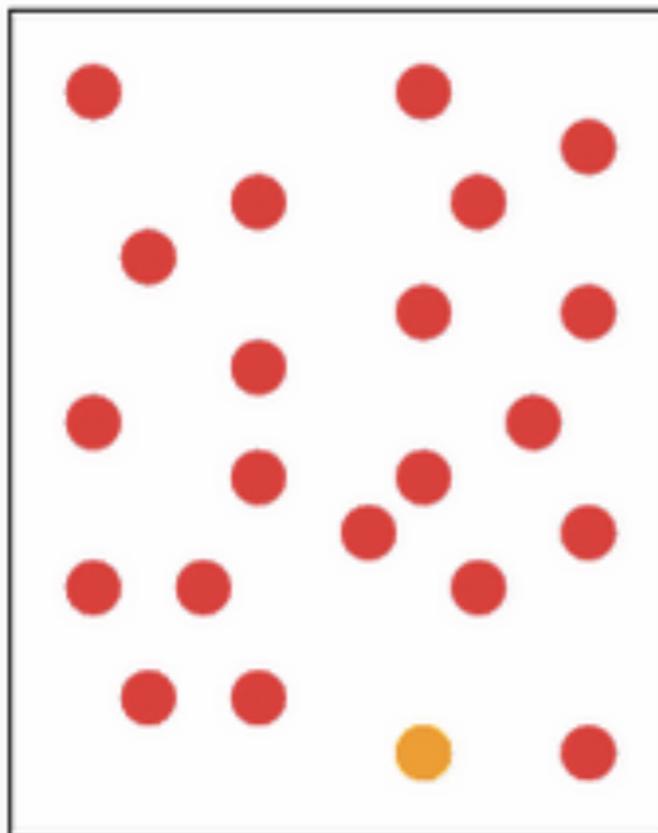


**Figure 10.5.** The luminance and saturation channels are automatically interpreted as ordered by our perceptual system, but the hue channel is not.

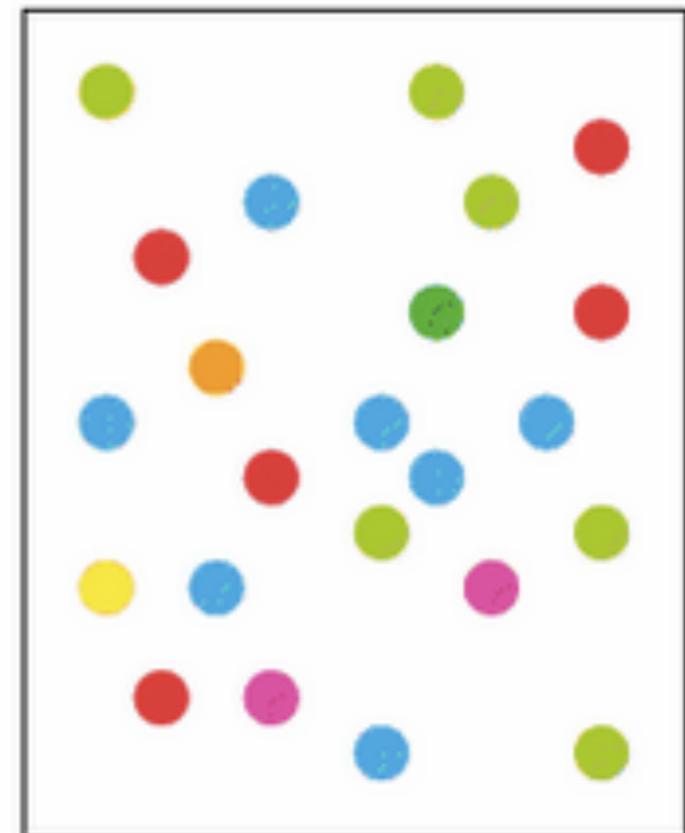
# POP-OUT EFFECT AND COLOUR



The larger the chromatic difference between the target symbol and the other symbols, the easier the search.

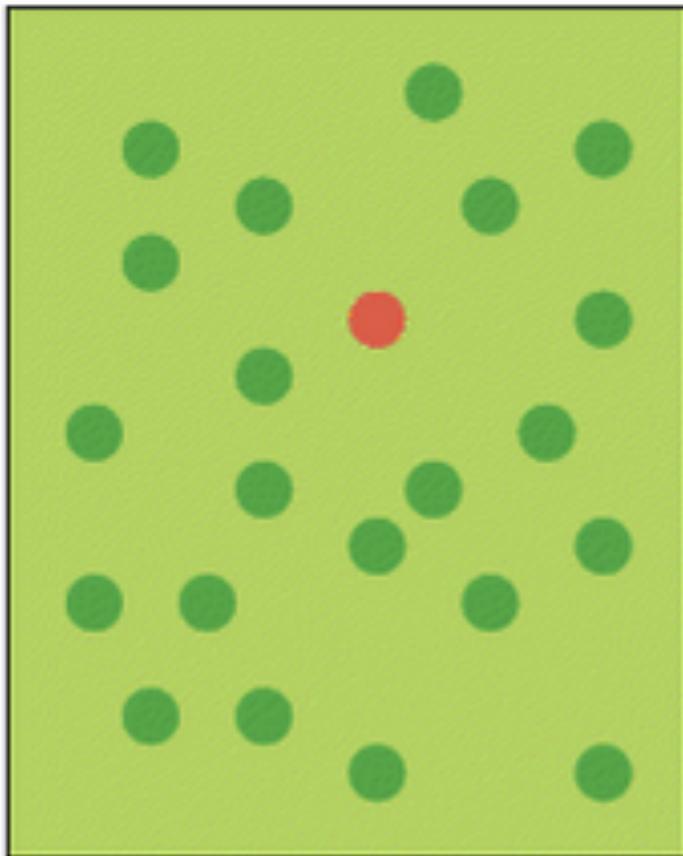


When there is only a small color difference from non-target symbols, the search is difficult.

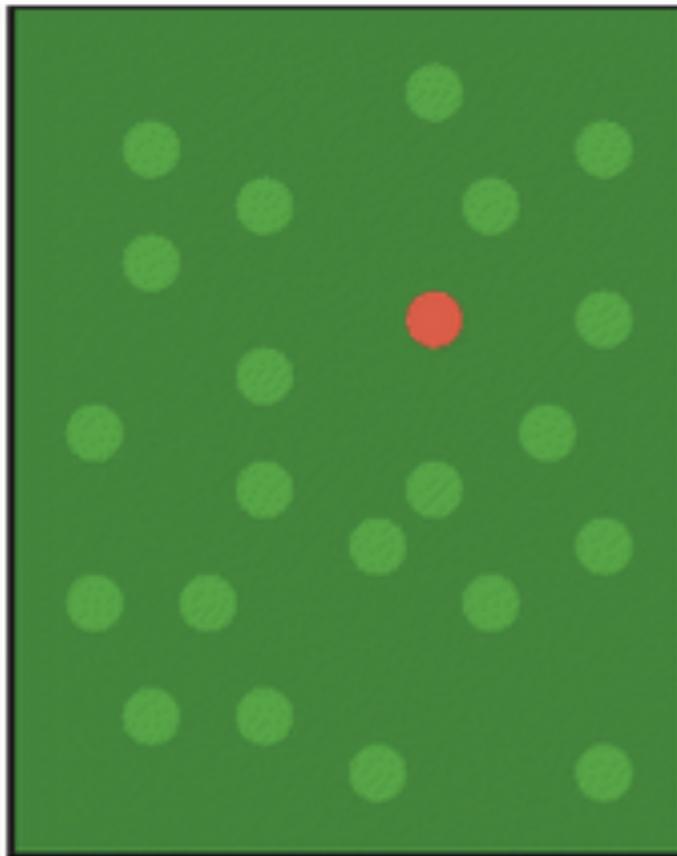


When there are many non-target symbol colors, the search is the most difficult.

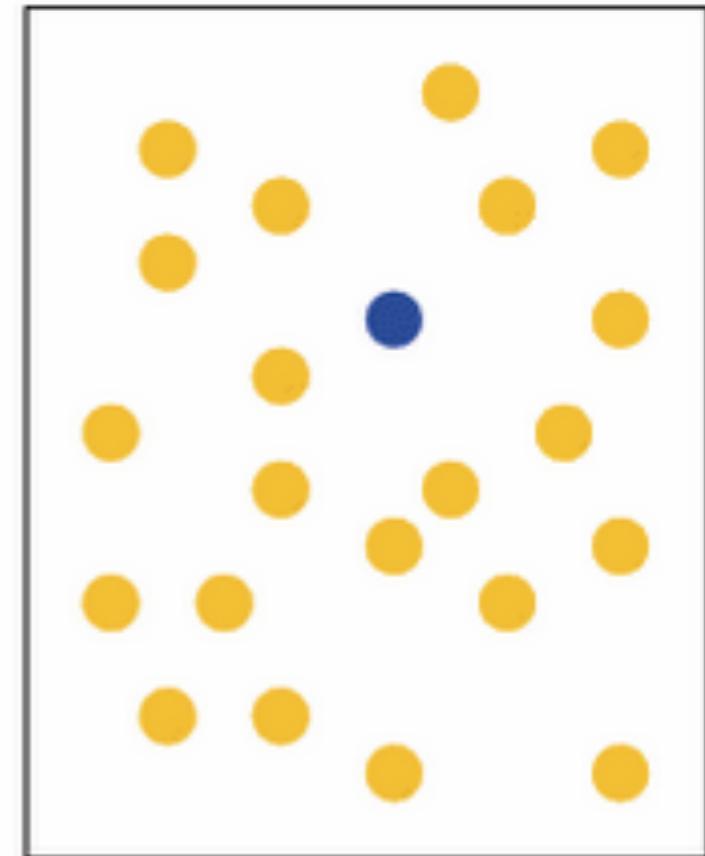
# POP-OUT EFFECT AND COLOUR



● If non-target symbols are similar to the background, they are easy to exclude from the visual search.



● A luminance difference plus a chromatic difference from other symbols and the background leads to the easiest search.

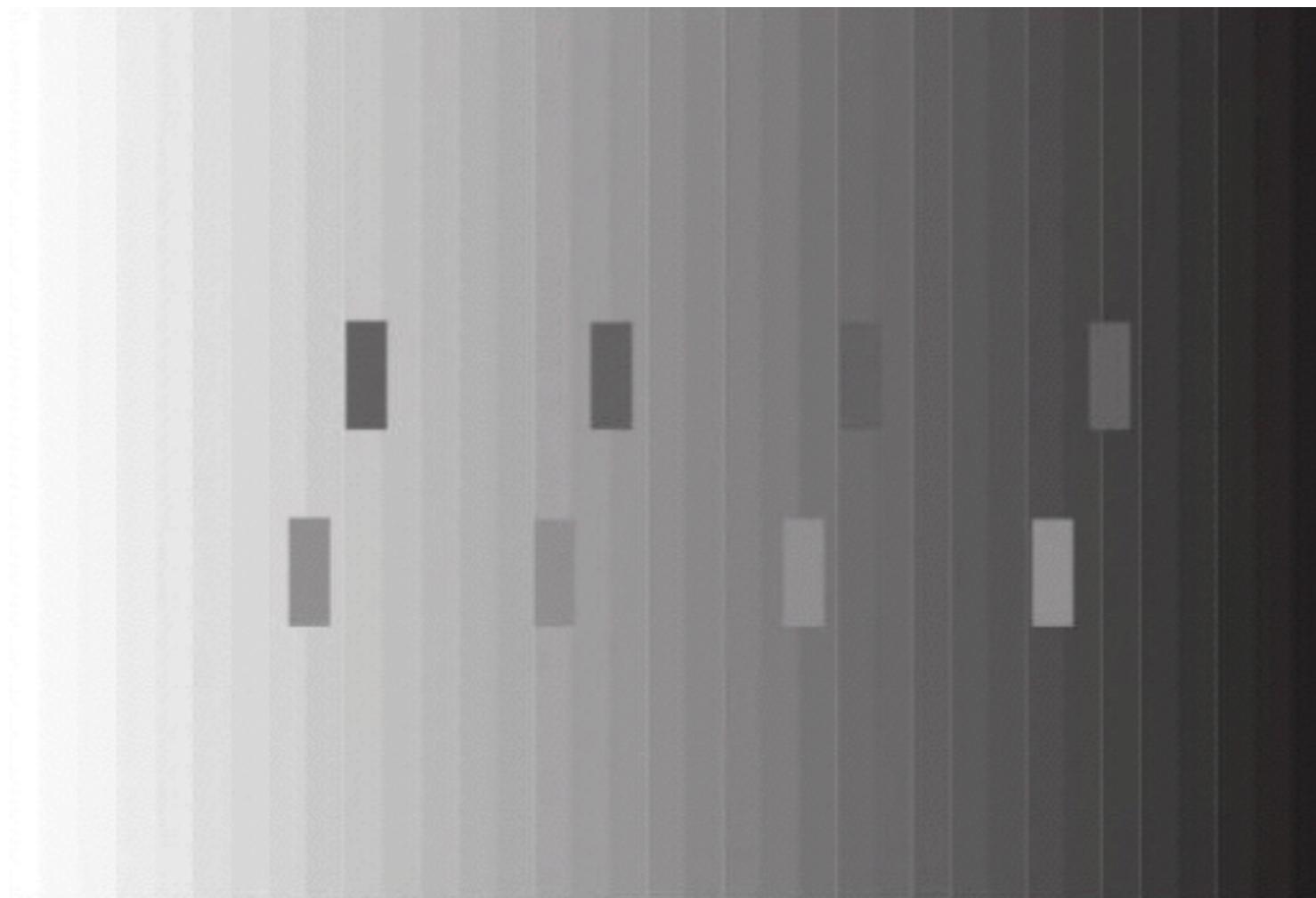


● A dark target on a light background with light non-target symbols can be as effective as the reverse.

---

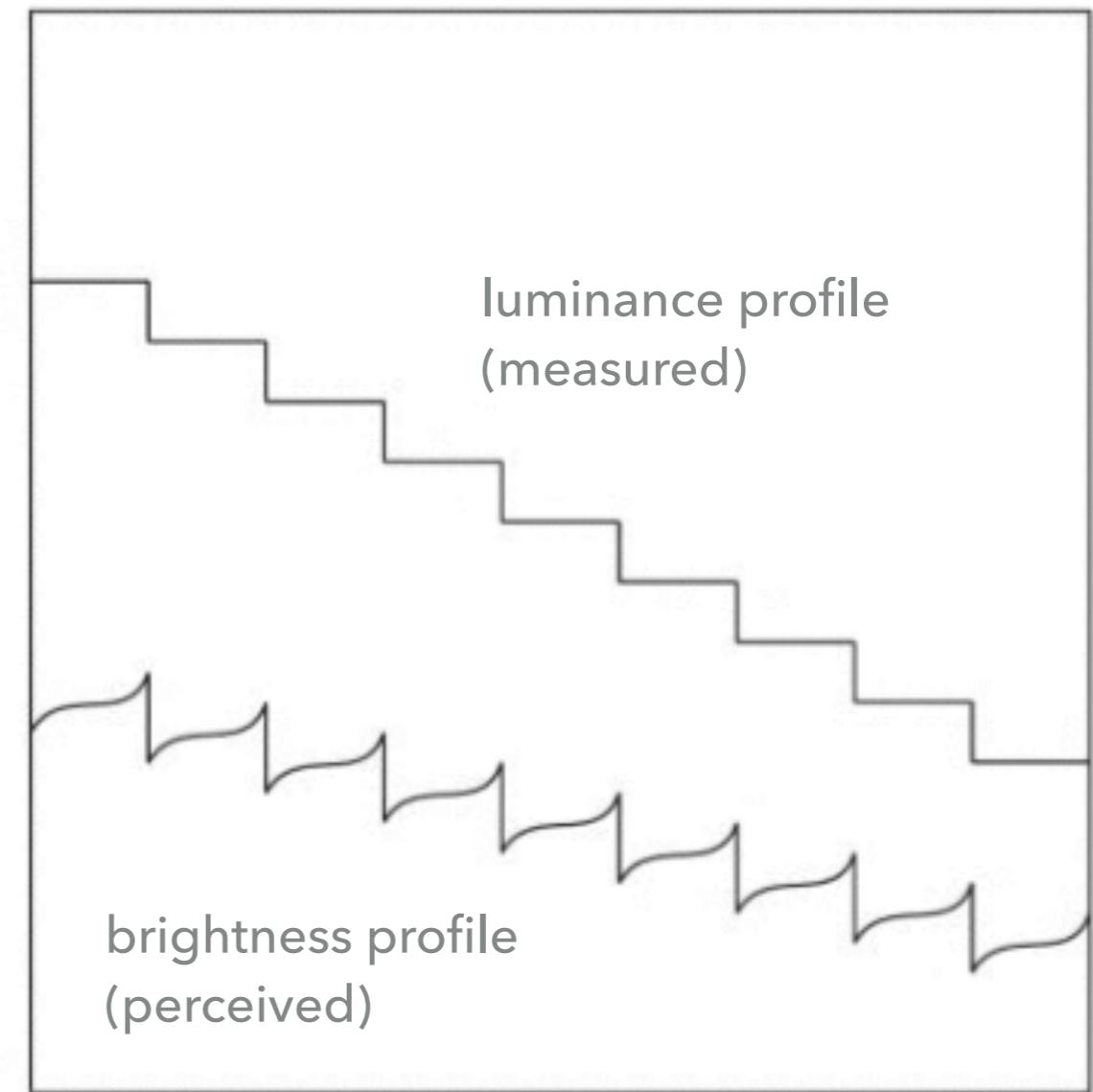
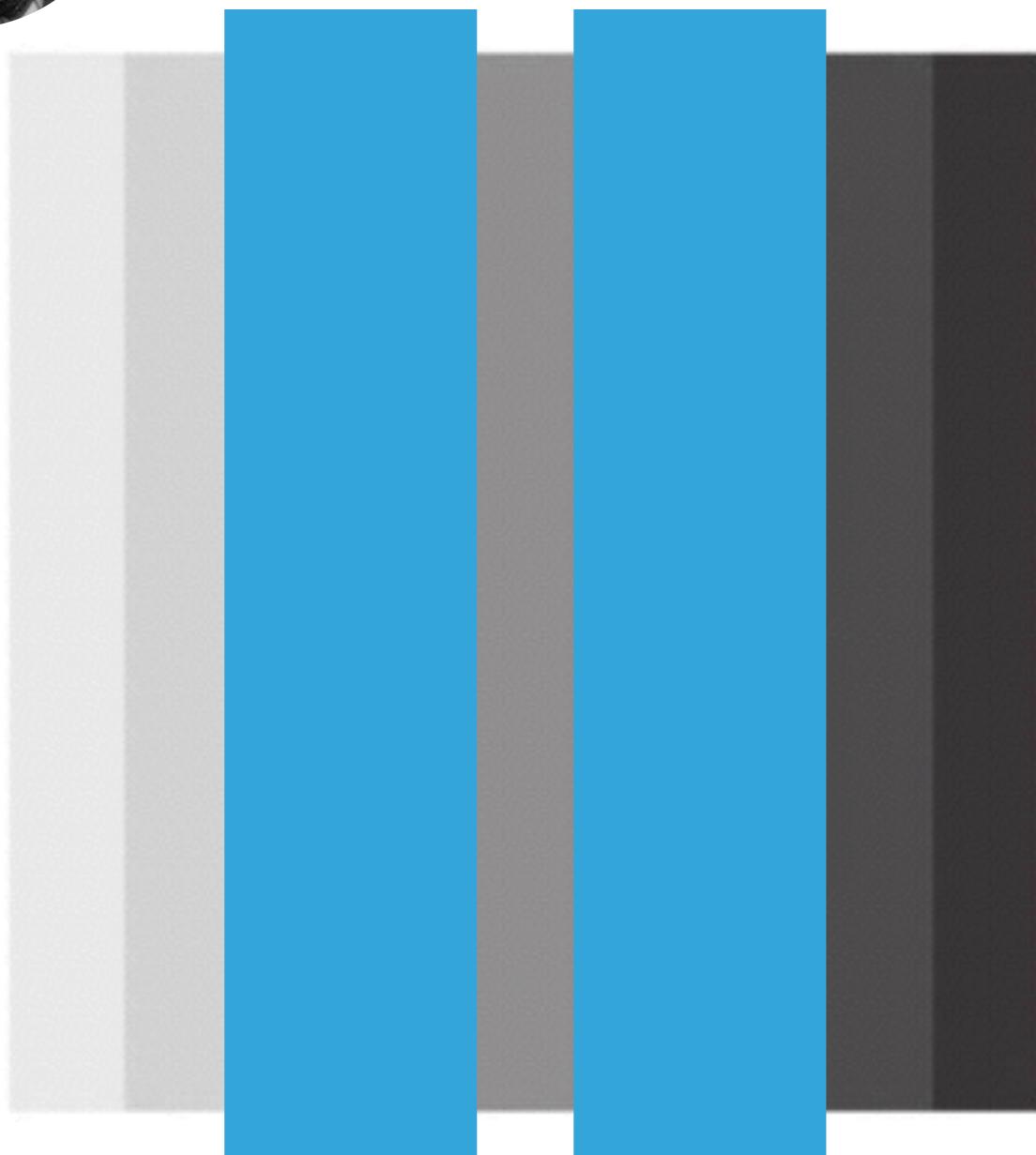
# PERCEIVED BRIGHTNESS

- ▶ Perceived brightness is relative to background





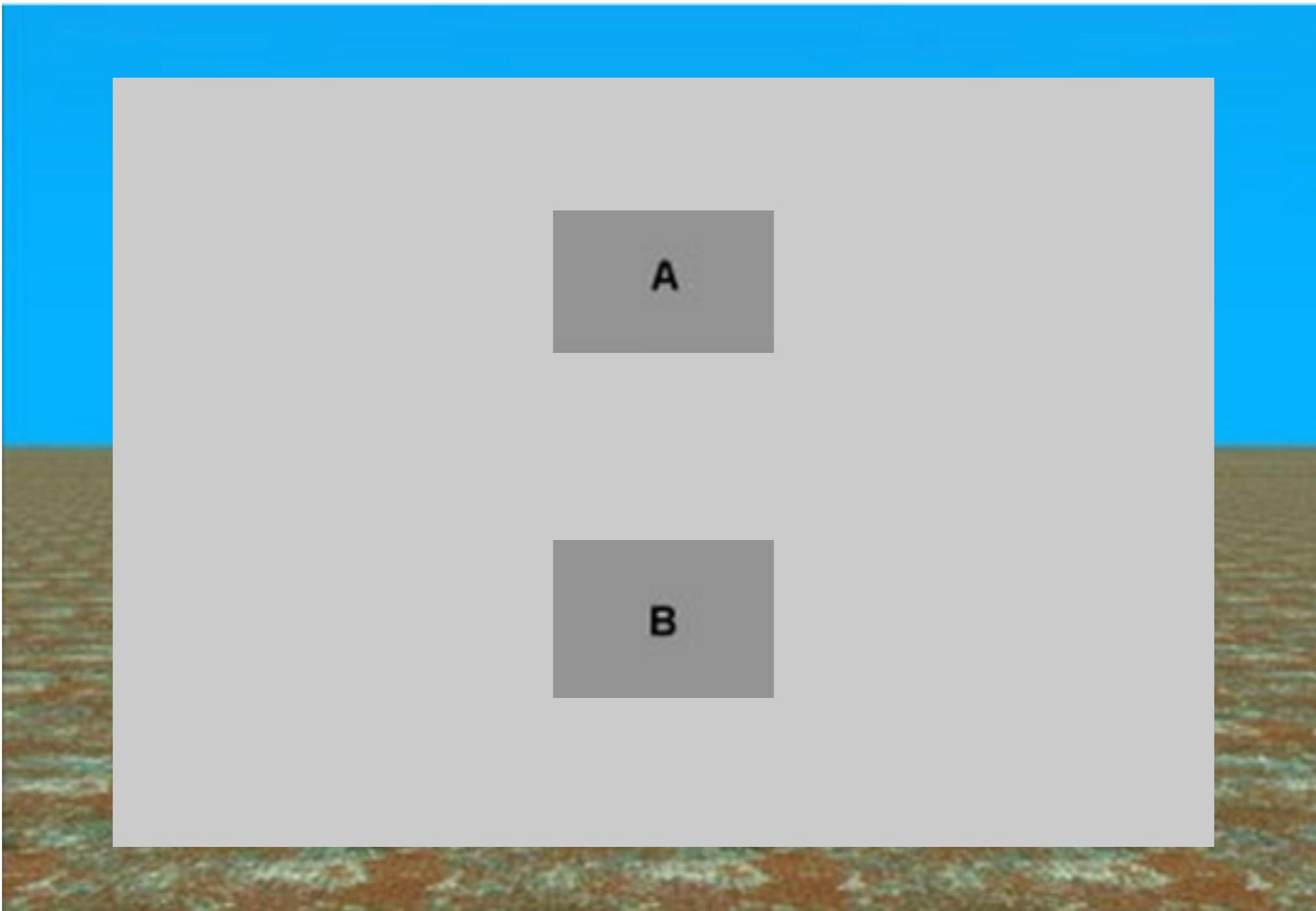
## CHEVREULL ILLUSION



Can result in errors of judgement

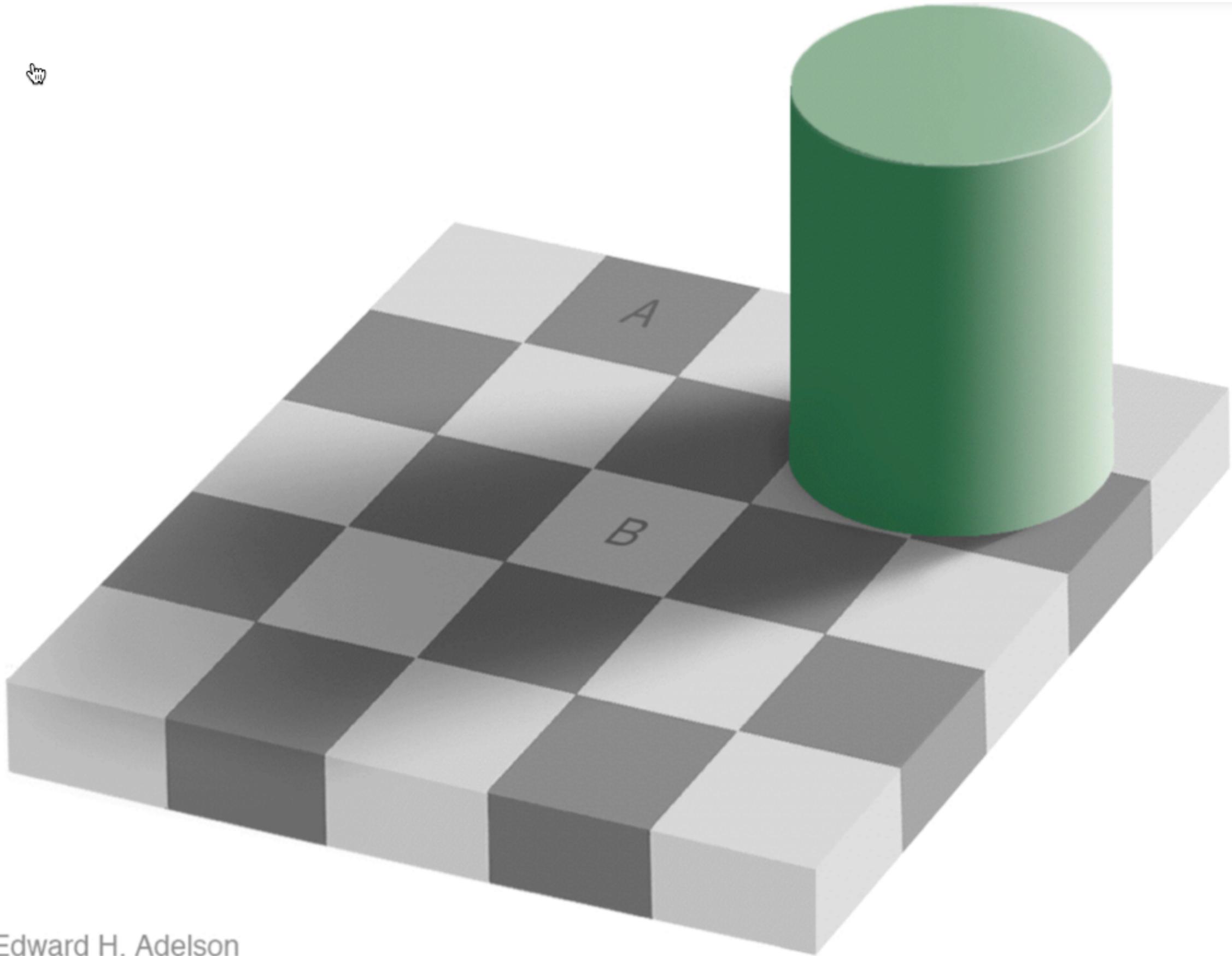
Amplifies artefacts in computer graphic shading

Lex

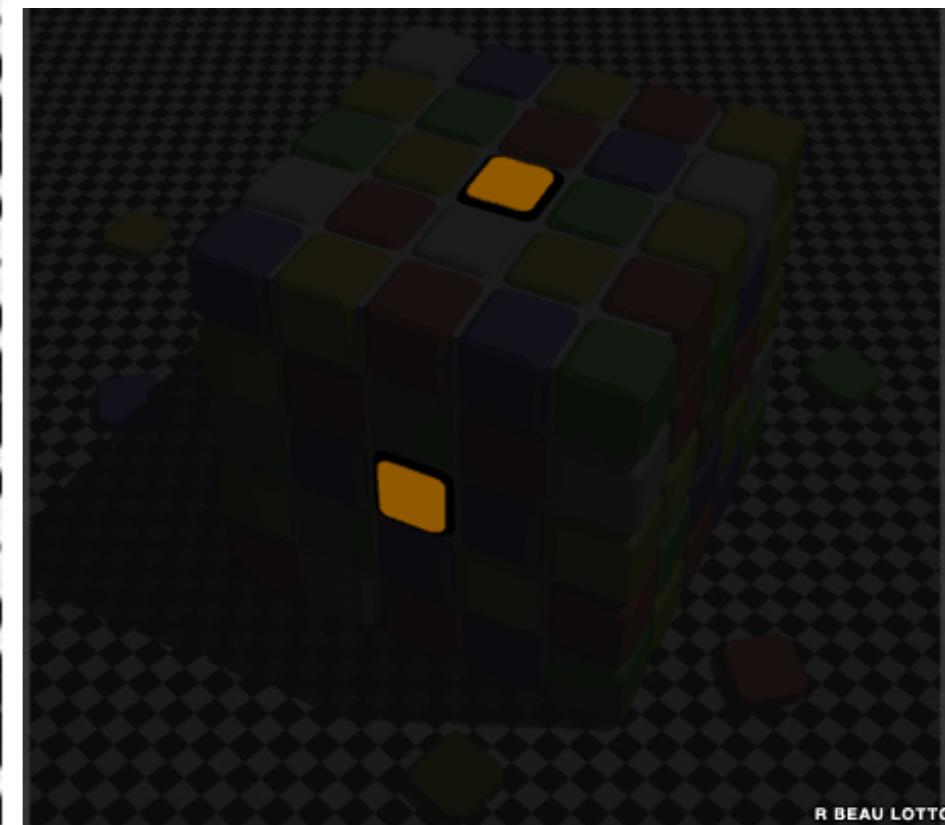
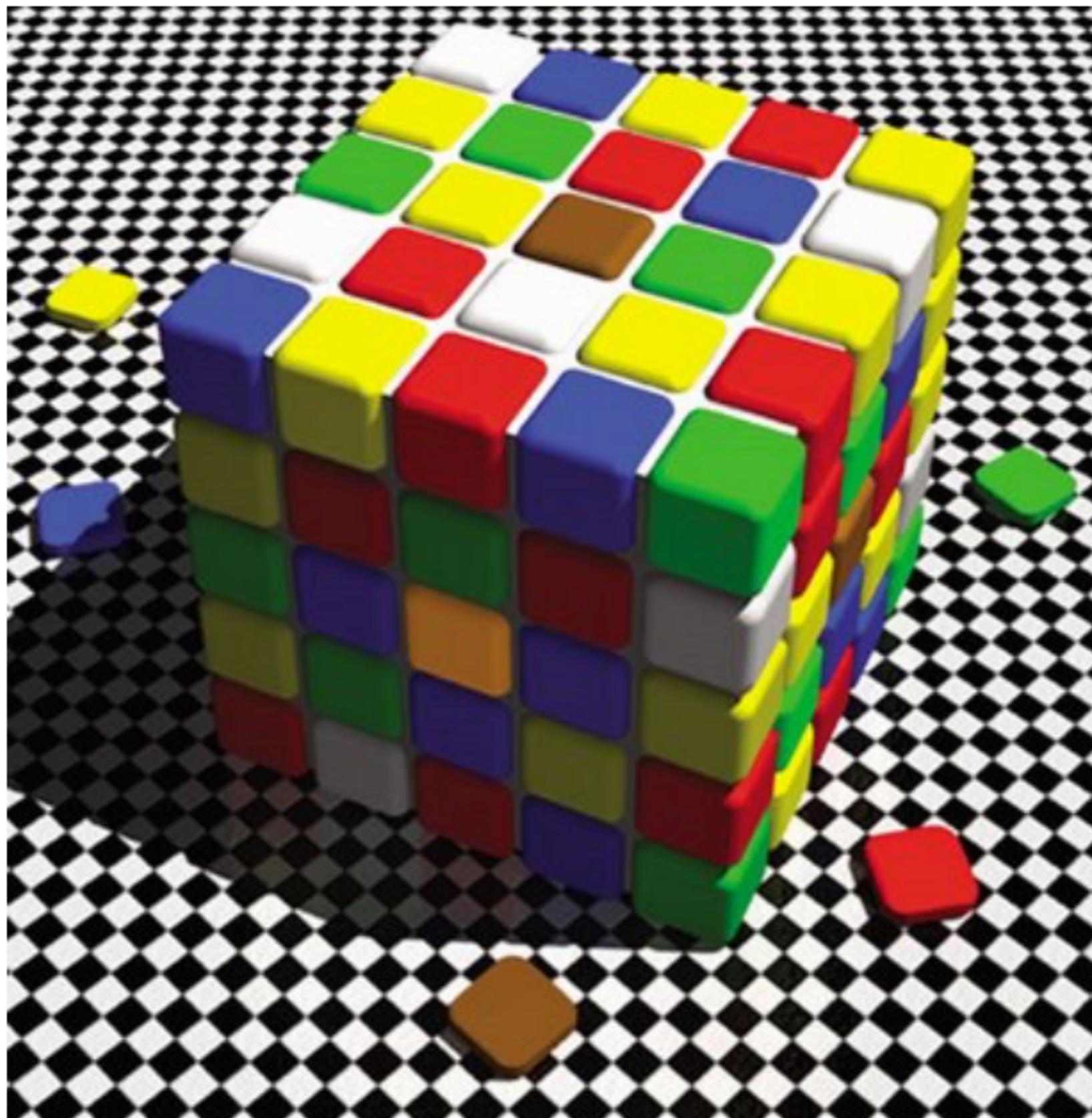


Cornsweet Illusion - A and B are the same colour

Visual system operates on relative differences, not absolute differences



Edward H. Adelson

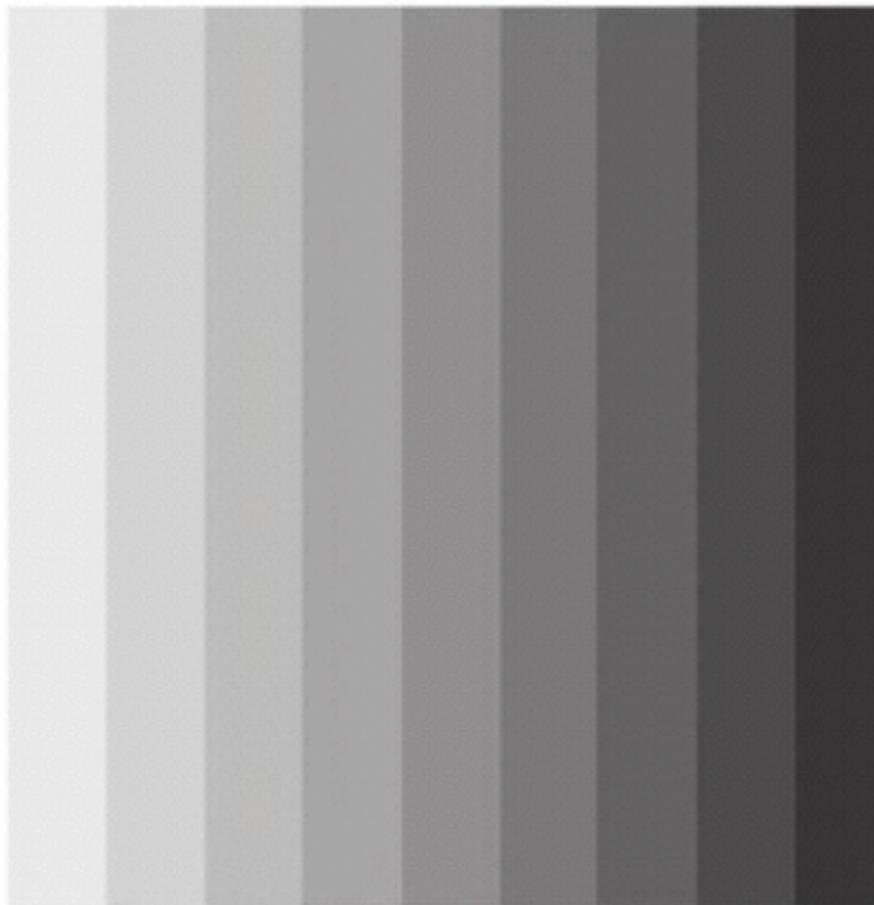


R BEAU LOTTO

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## COLOUR GUIDELINES

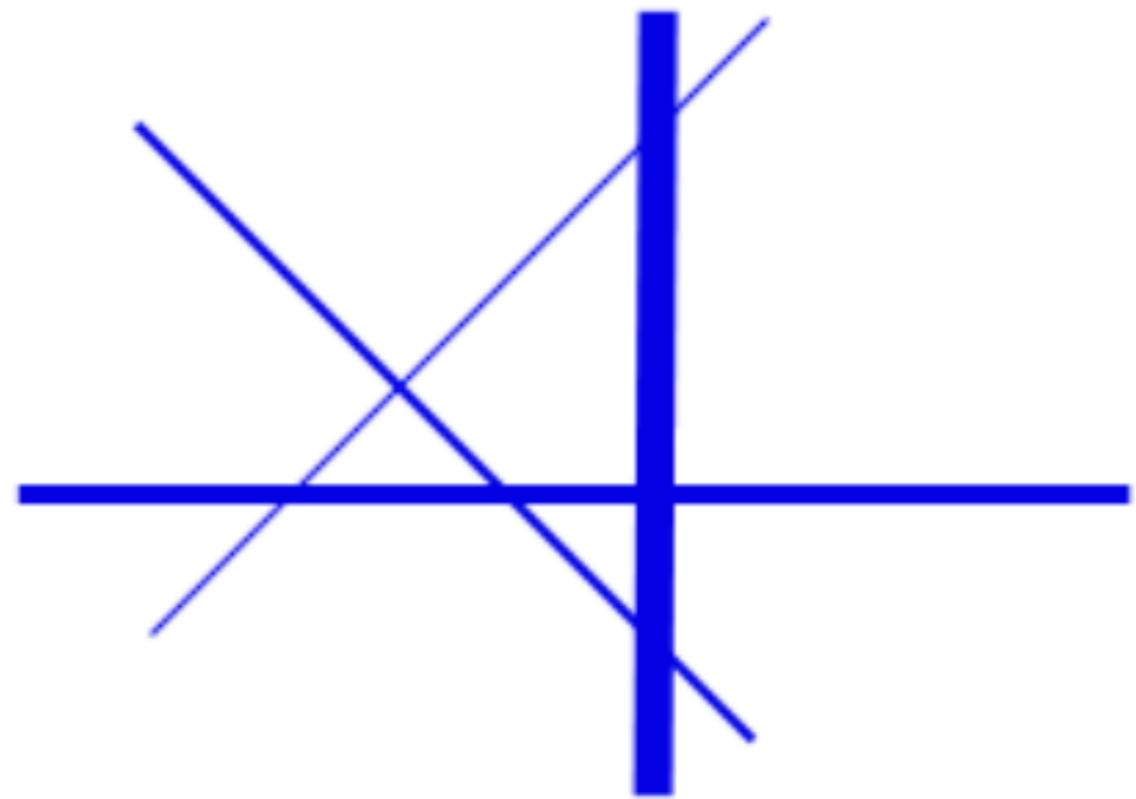
- ▶ Perception of luminance affected by context
- ▶ Avoid grey scale when more than four 'bins' required (Ware)



---

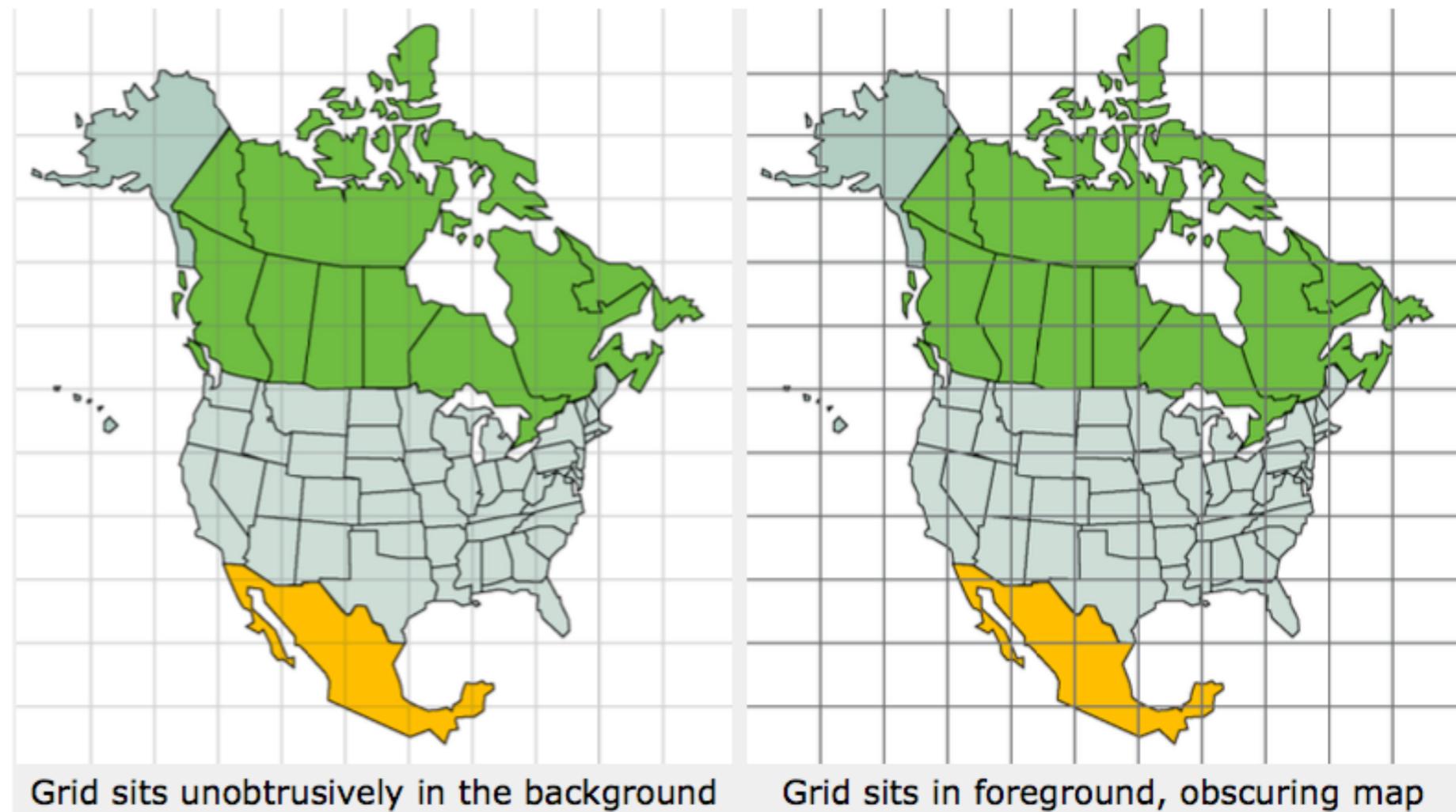
## LINE WEIGHT AND ITEM SIZE

- ▶ Wide lines:
  - ▶ have higher brightness contrast
  - ▶ more salient
  - ▶ line width used a lot in map making



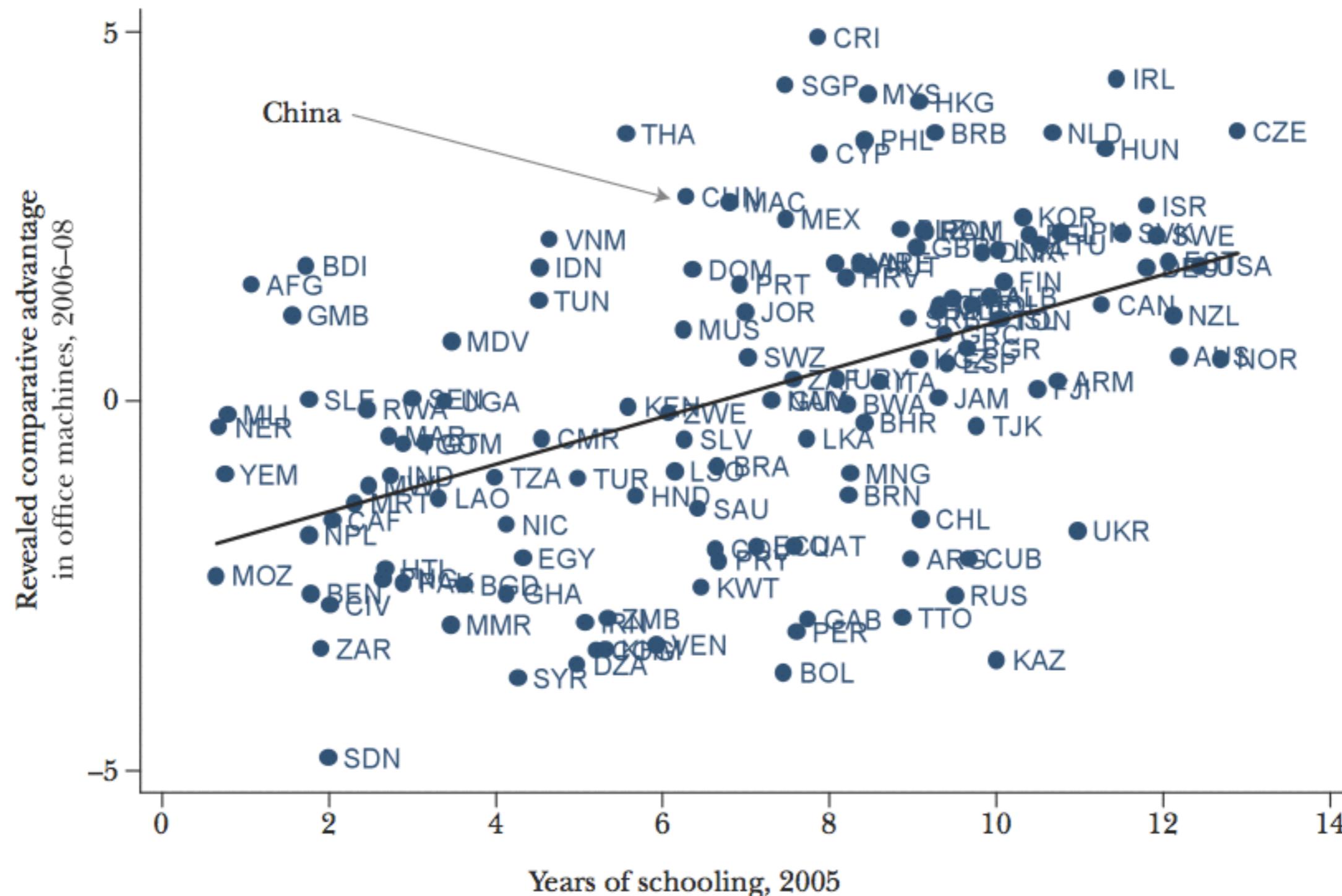
# CONTRAST AND LAYERING

- ▶ differences in luminosity used to give contrast and to layer visual elements

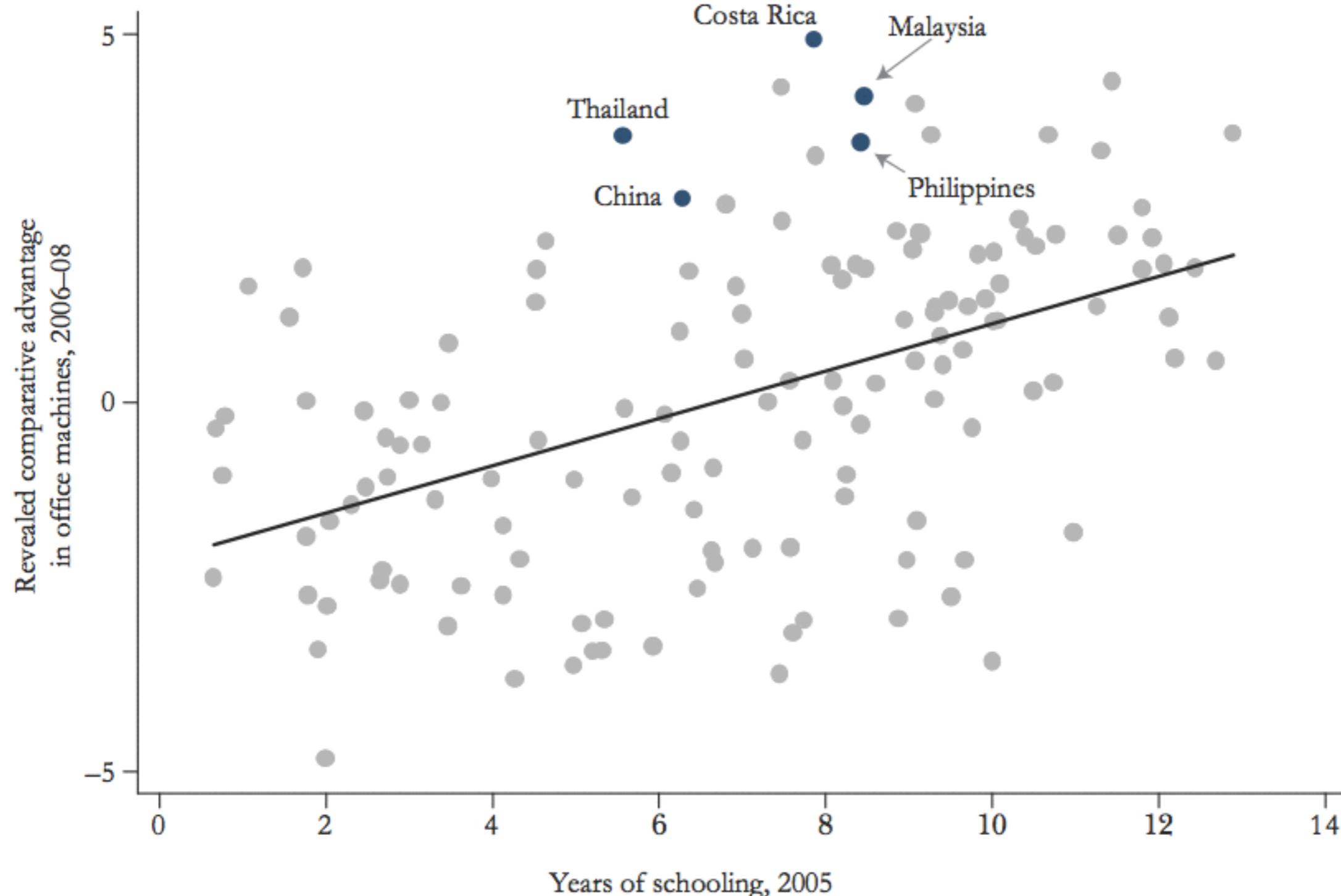


Great Grids: How and Why? (APGV06 and SIGGRAPH poster) Maureen Stone, Lyn Bartram and Diane Gromala

## Education and Exports of Office Machines

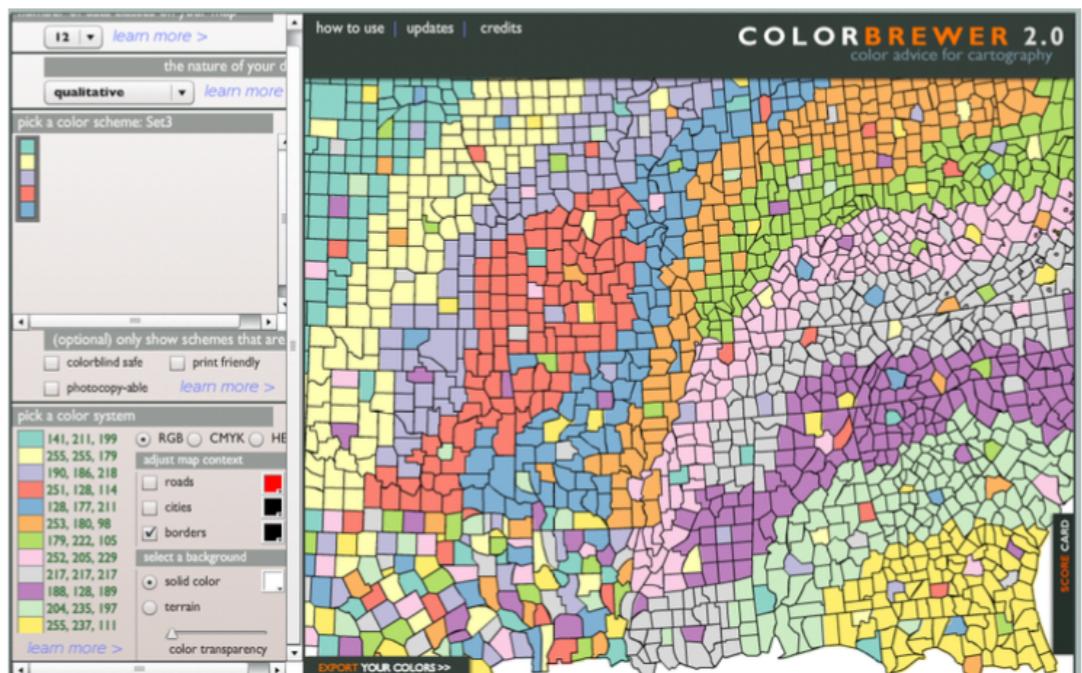
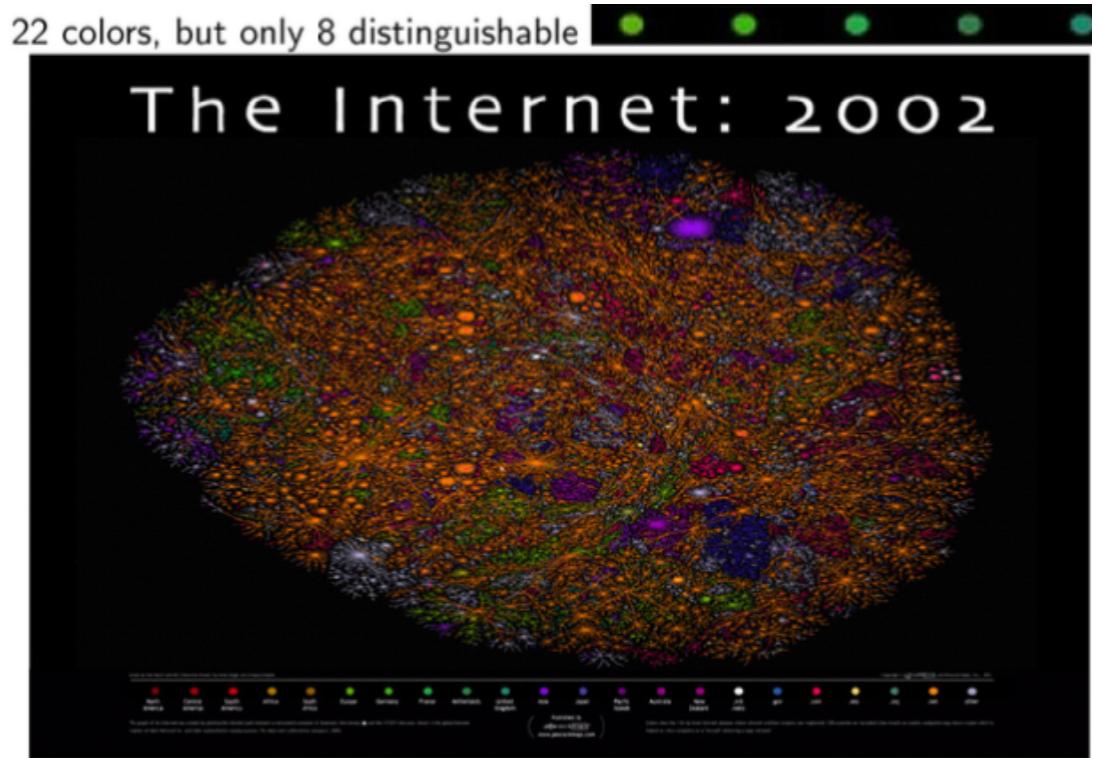


## Education and Exports of Office Machines



# COLOUR GUIDELINES

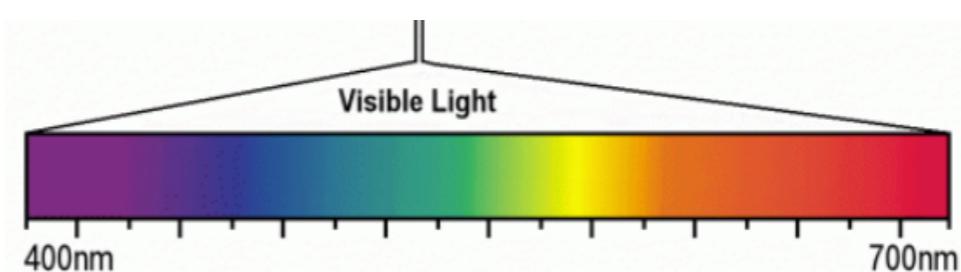
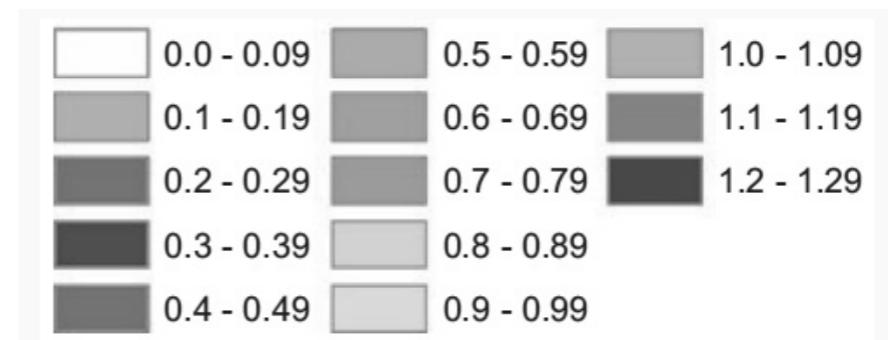
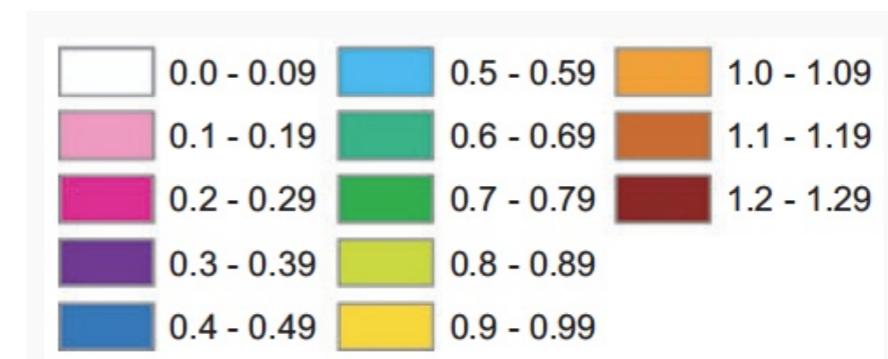
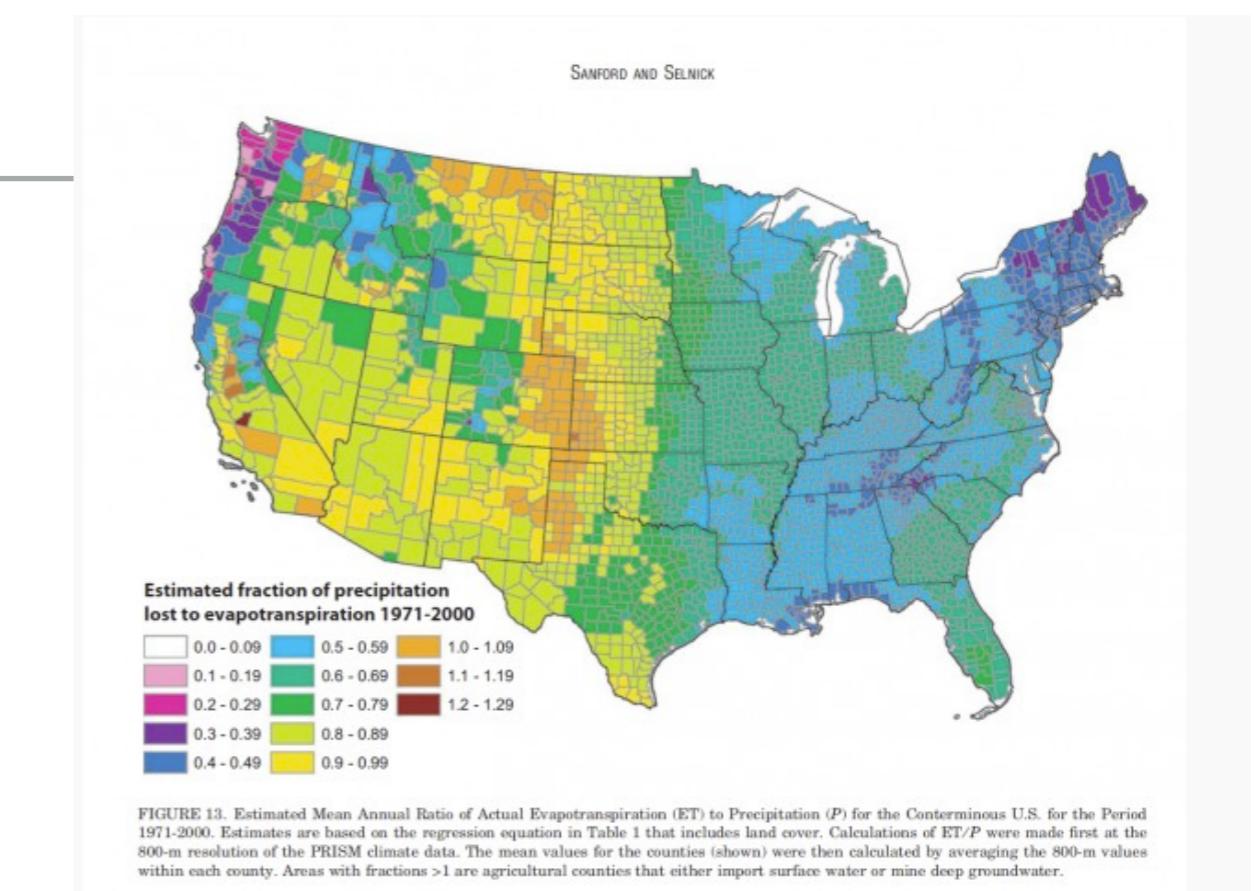
- ▶ Hue
  - ▶ qualitative (nominal) data
  - ▶ around 6 variables (no more than 10)
  - ▶ more becomes difficult to discriminate between colours
  - ▶ although see [colorbrewer](#) for large workable colour schemes



# COLOUR GUIDELINES

## Quantitative data

- ▶ Hue, not good...
- ▶ **avoid** rainbow colour map
- ▶ differences in luminance misleading
- ▶ the steps between hues is not equal



## READING, WRITING, AND EARNING MONEY

The latest data from the U.S. Census's American Community Survey paints a fascinating picture of the United States, at the county level. We've looked at the educational achievement and the median income of the entire nation, to see where people are going to school, where they're earning money, and if there is any correlation.

### High School Graduates



### College Graduates



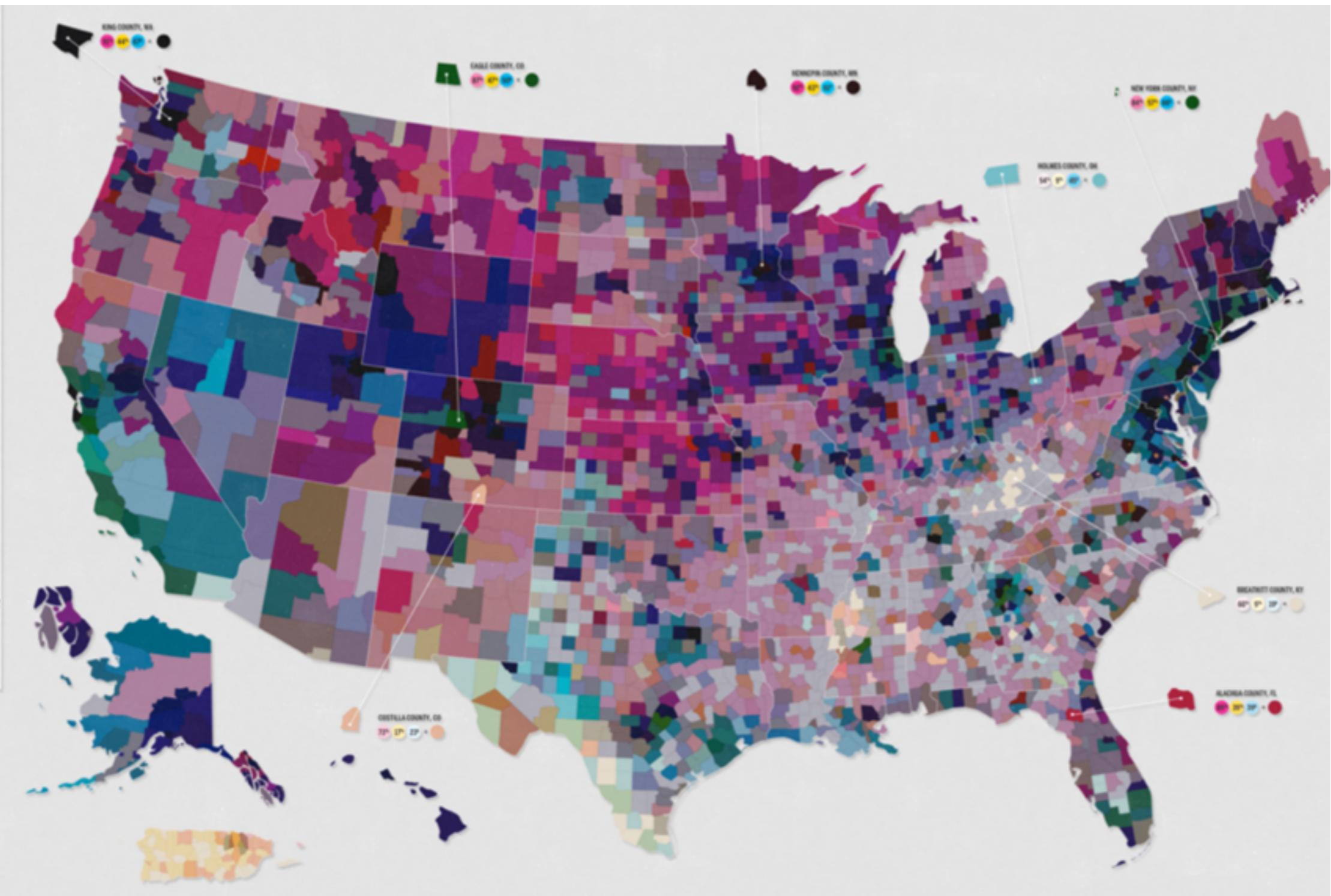
### Median Household Income



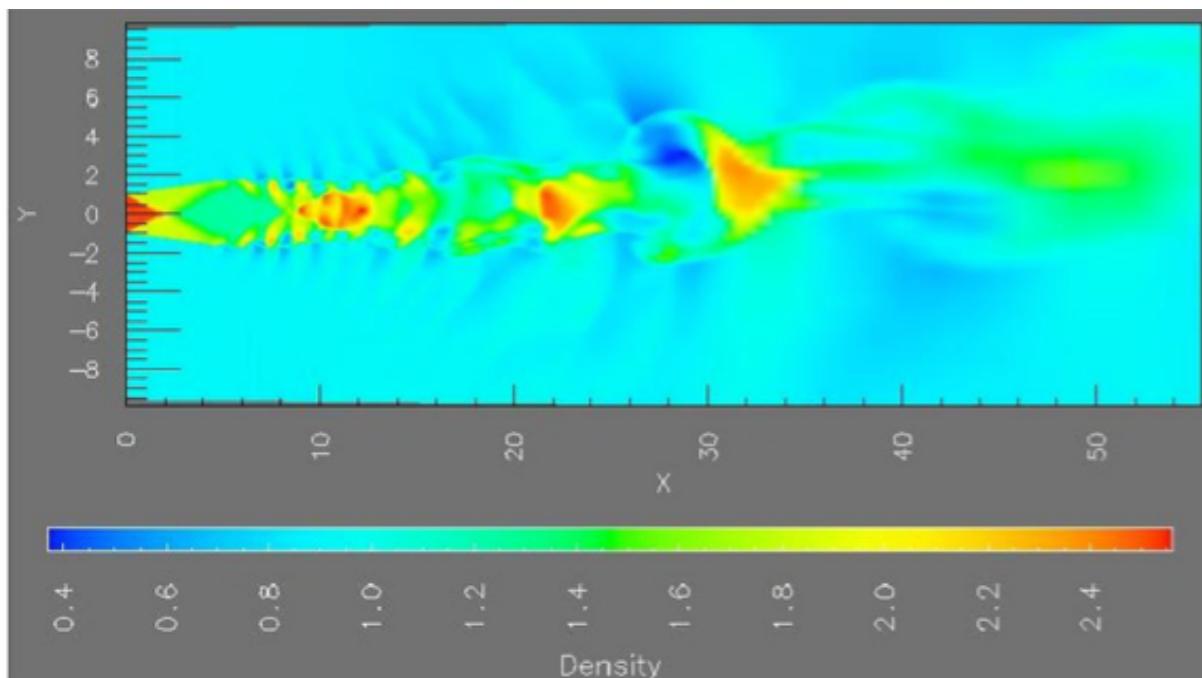
The map at right is a product of overlaying these sets of data. The variation in color and value has been produced from the data shown above. In general, darker counties represent a more educated, better paid population while lighter areas represent communities with fewer graduates and lower incomes.



In collaboration between GOOD and Gregory Wolak.  
© 2011 GOOD.

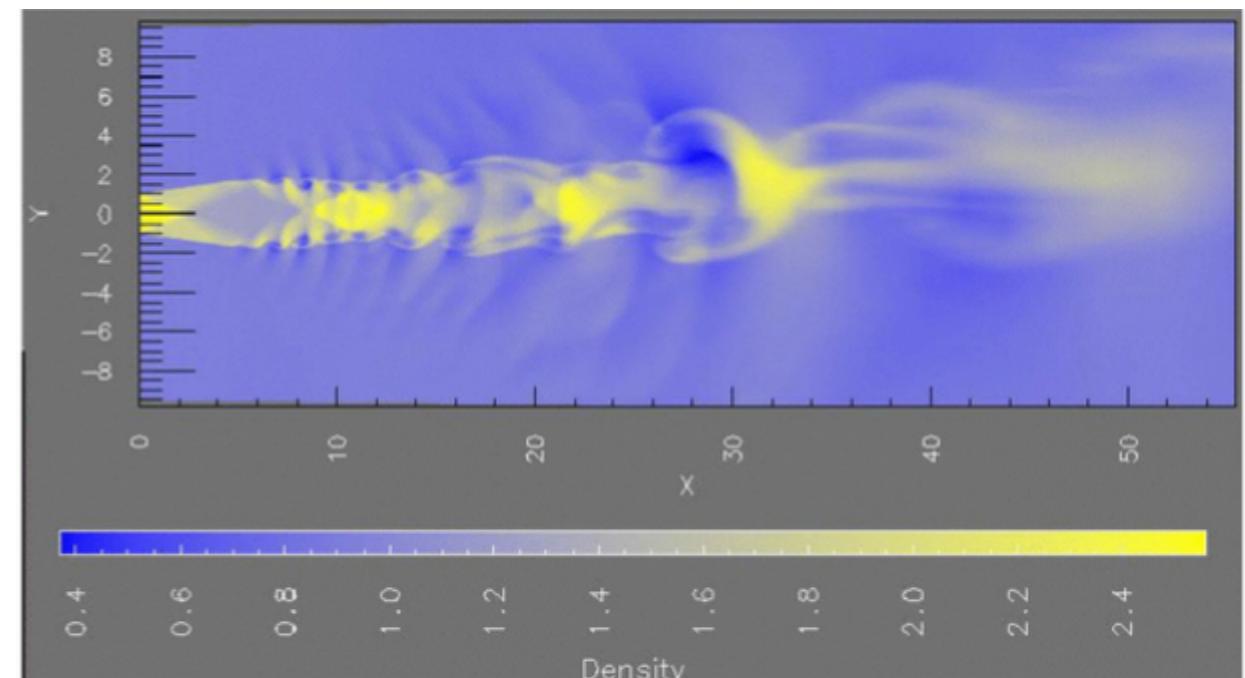


# COLOUR GUIDELINES



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

Hue - Rainbow map  
difficult to see all features of data



[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)]

Saturation - Divergent scale (blue/yellow)  
easier to see features of data

# COLOUR BLINDNESS



Normal

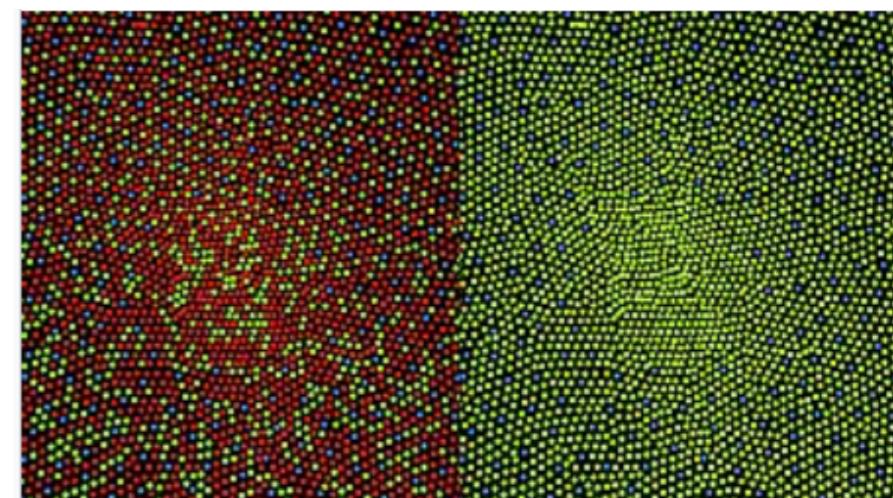


Deutanopia  
no green receptors



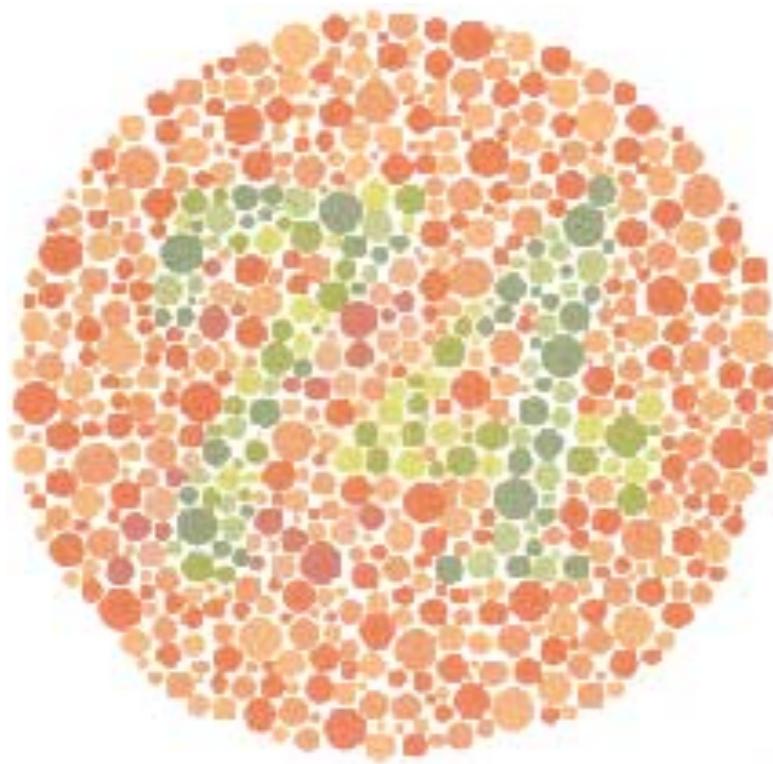
Protanopia  
no red receptors

- ▶ approx. 10% Male (x chromosome recessive)
- ▶ approx. 1% Female
- ▶ red/green (deutanopia) most common

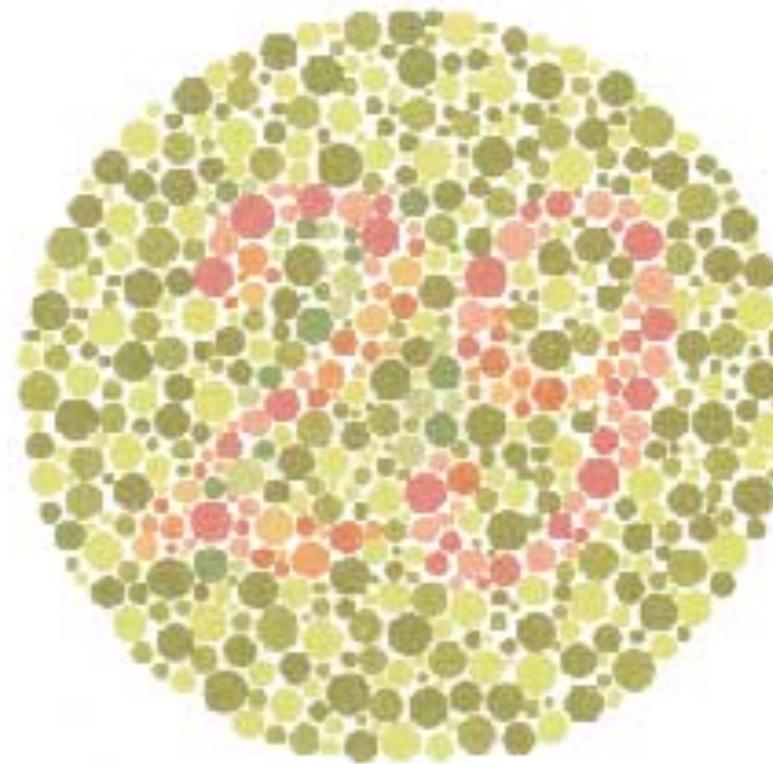


Normal fovea

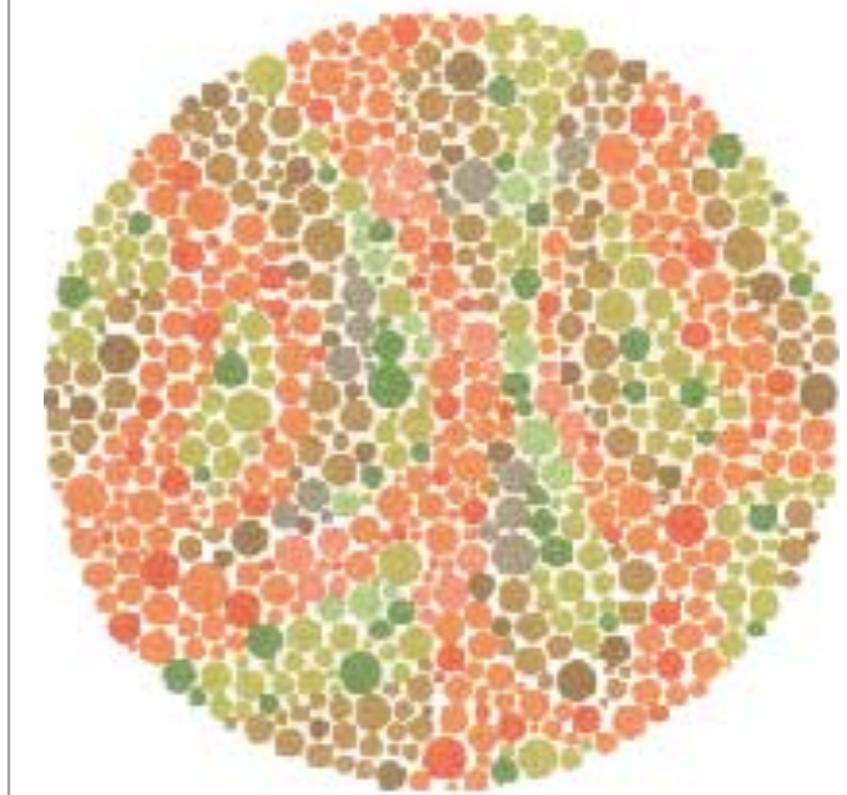
Protanopia



Normal - 74



Normal - 29  
Red-Green - 70



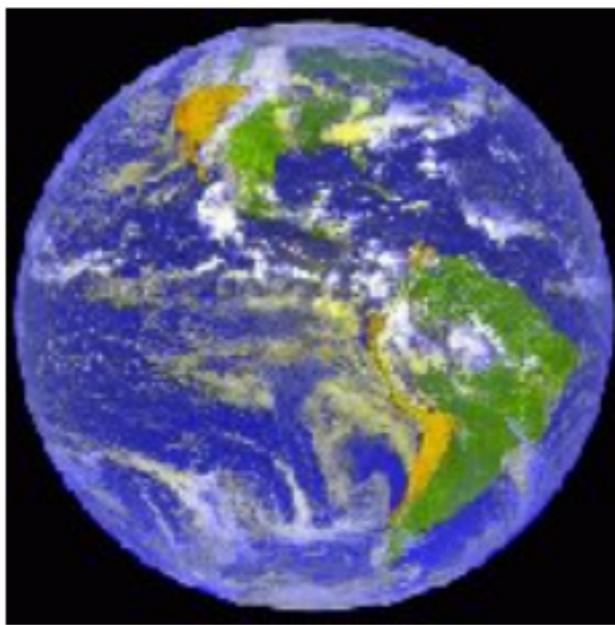
Normal - NA  
Red-Green - 5

Ishihara plates - for diagnosing  
colour blindness

---

# COLOUR BLINDNESS

Normal



Deuteranopia

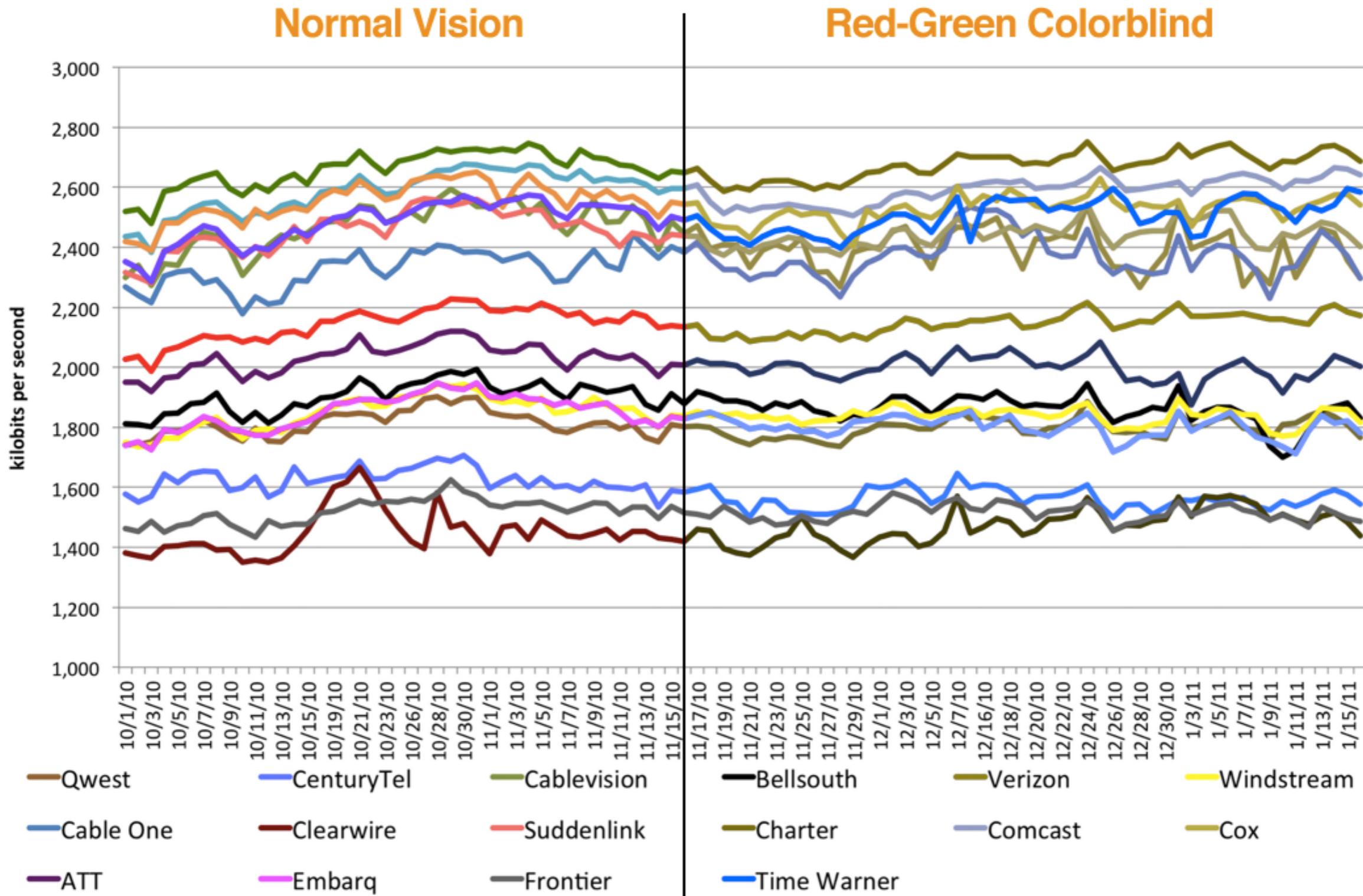


red/green  
colour deficit

Tritanopia



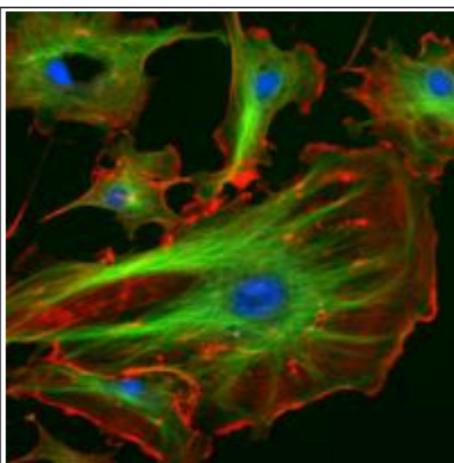
blue/yellow  
colour deficit



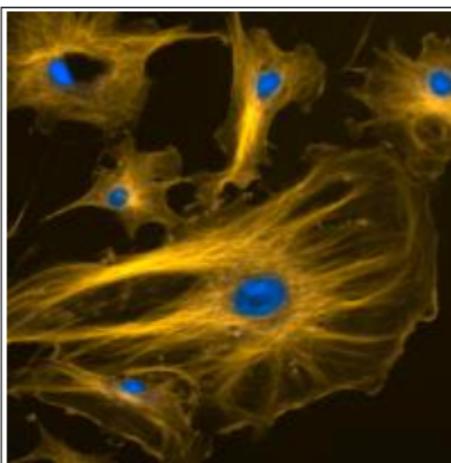
## VALIDATION TOOLS



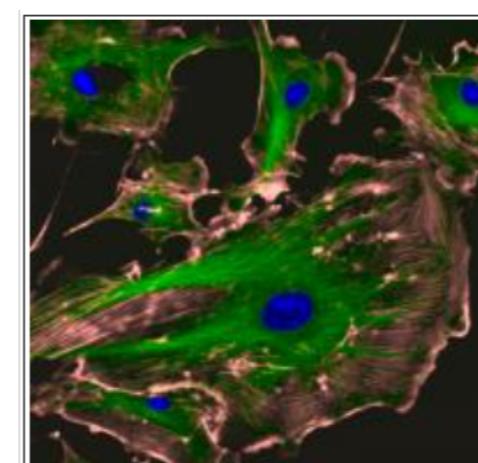
- ▶ Tools for checking what your website or image looks like to colour blind people
- ▶ Where true colour not as important as information conveyed by colour difference -> [Daltonization](#) - map colour variants to colours colourblind people can see



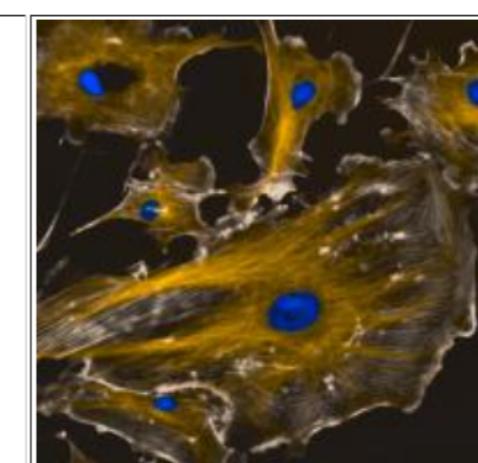
**1) Cells labelled with three types of fluorescent markers to show up three different structures.**



**2) Red/green color blind simulation of fluorescent cell picture.**



**3) Daltonized version of three-color-labelled fluorescent cells.**



**4) Dichromat (red/green color blind) simulation of the Daltonized image.**

## 5.3 COLOUR

You should now be able to:

- ▶ Be familiar with the anatomy of the human eye and the difference between rod and cone cells
- ▶ Describe the difference between Hue, Saturation and Luminosity
- ▶ Be aware of design guidelines for use of colour
- ▶ Understand the effect of colour blindness on perception of colour and design strategies for colour blind users



COS30045

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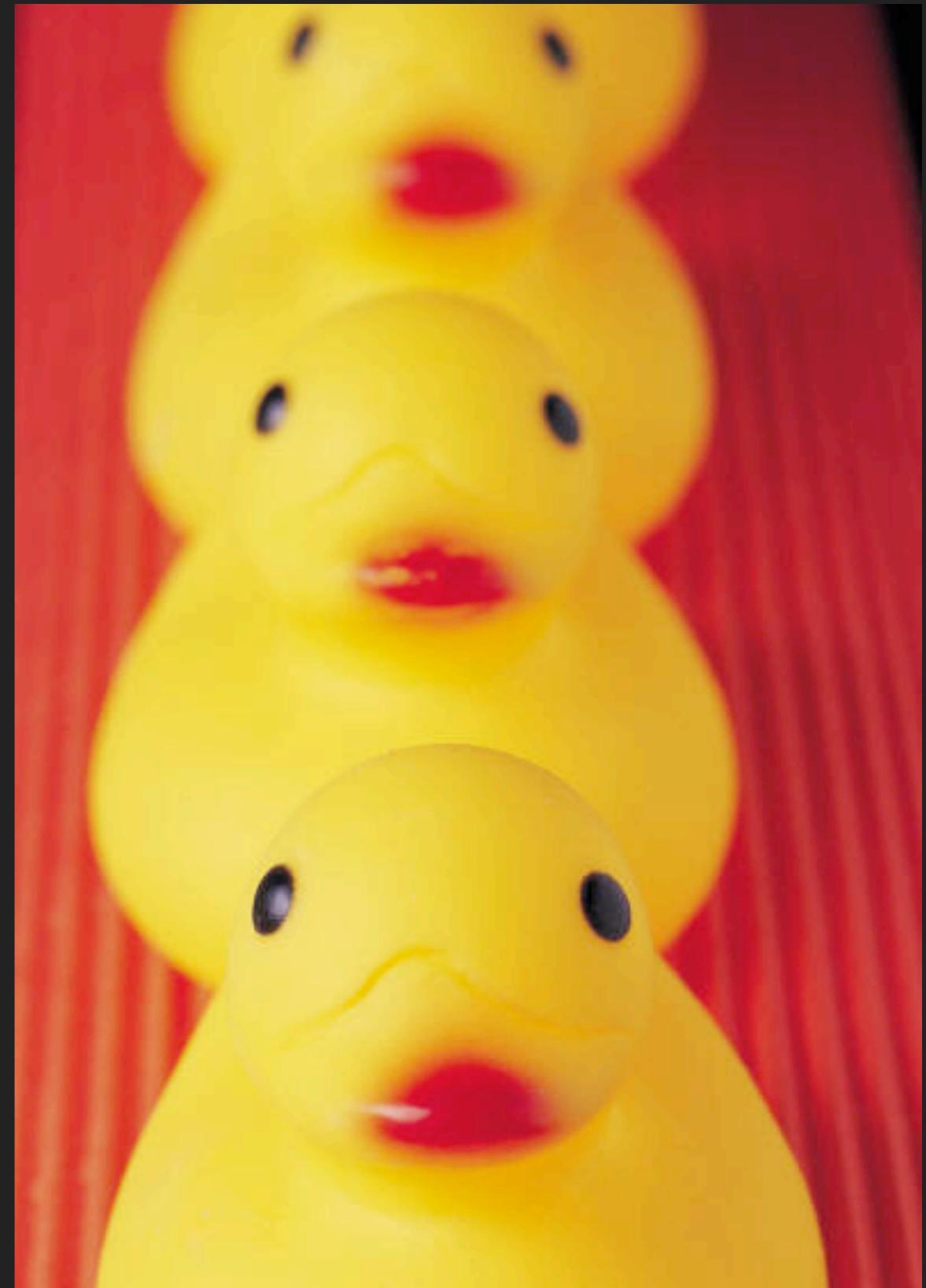
# DATA VISUALISATION

TOPIC 05.4 PSYCHOLOGY - GESTALT

## 5.4 GESTALT

At the end of this topic you should be able to:

- ▶ Identify a range of Gestalt principles
- ▶ Consider how to use gestalt principles to manipulate perception of relationships between objects in your design



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# GESTALT PRINCIPLES

*The whole is **other** than the sum of the parts- Kurt Koffka*

- ▶ Perception is more than the sum of the parts

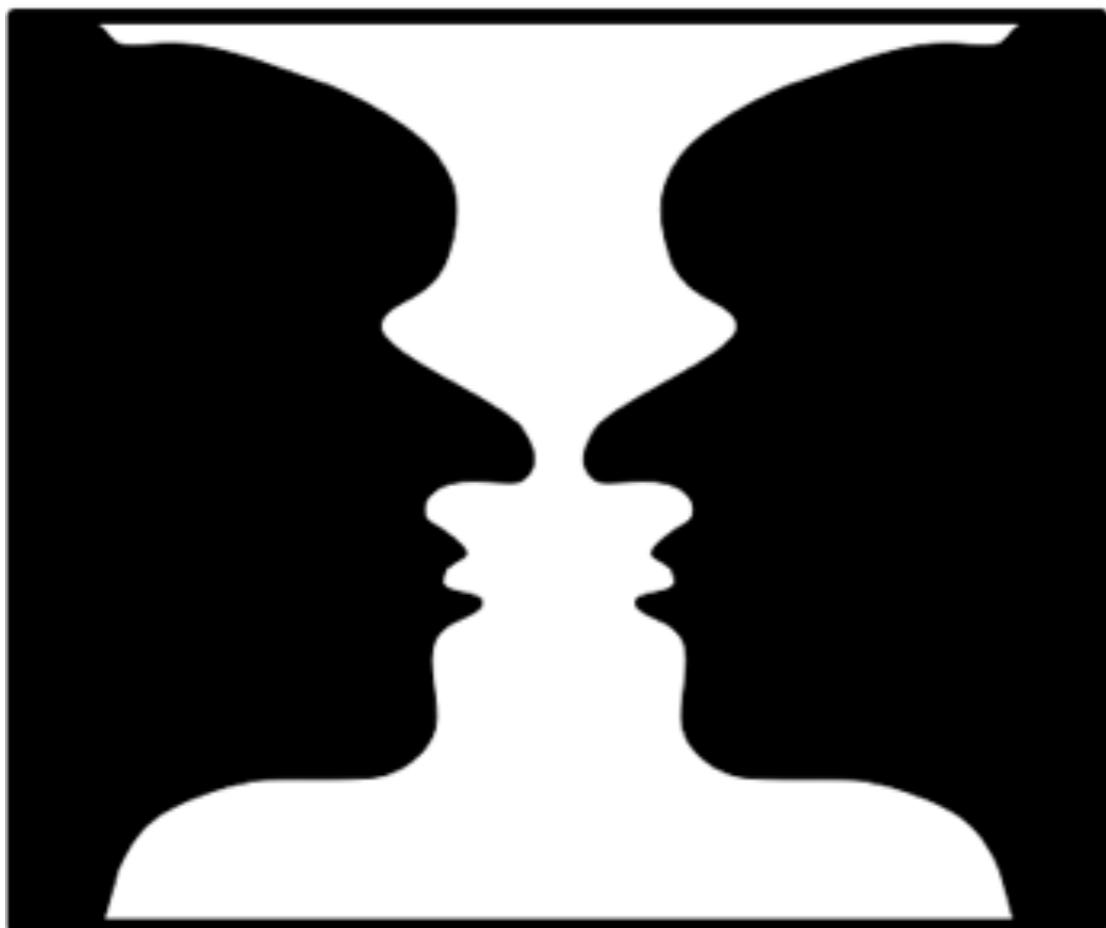


Figure- ground - the object doesn't change, but our perception of it does

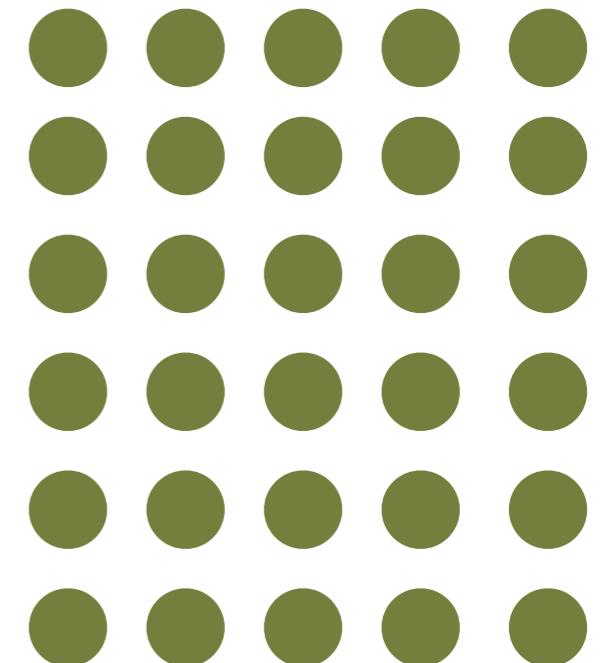
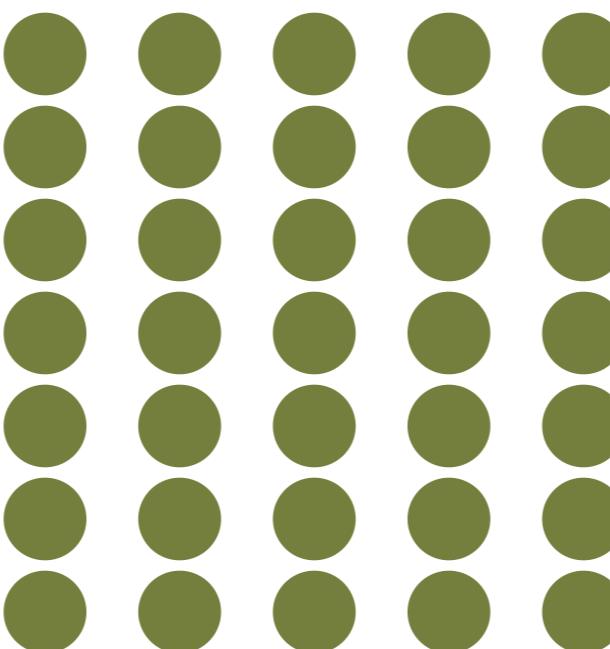
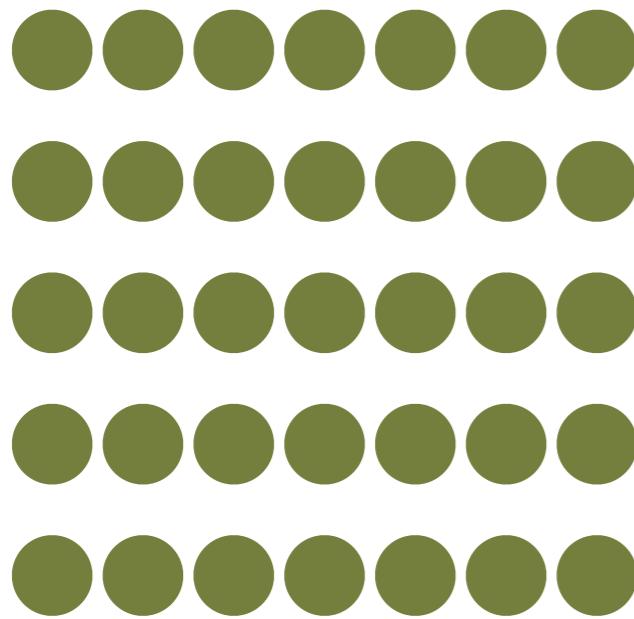


**Kurt Koffka**  
Gestalt Psychologist

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## GESTALT: PROXIMITY

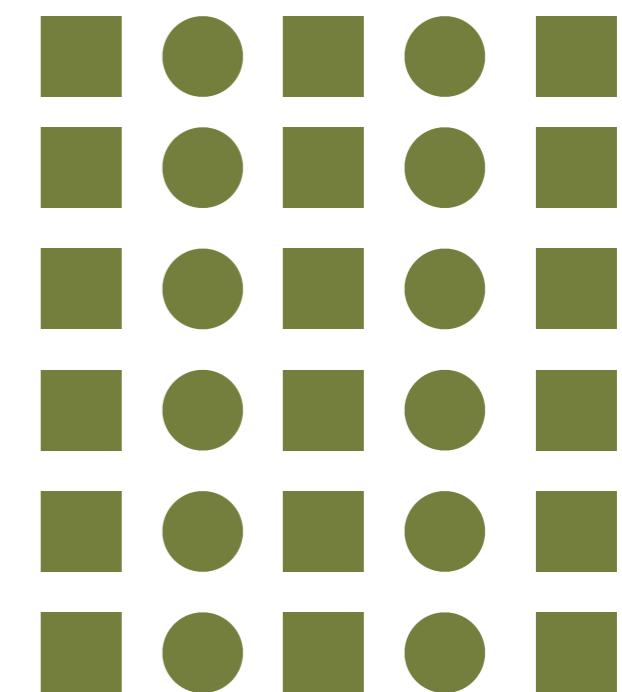
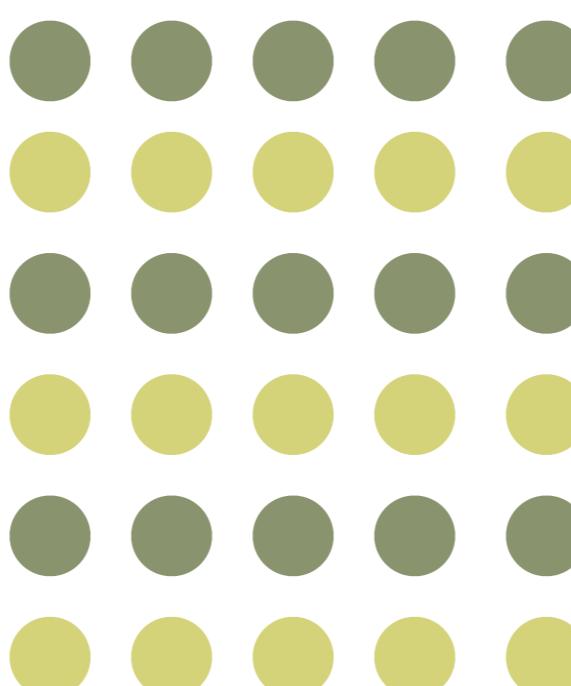
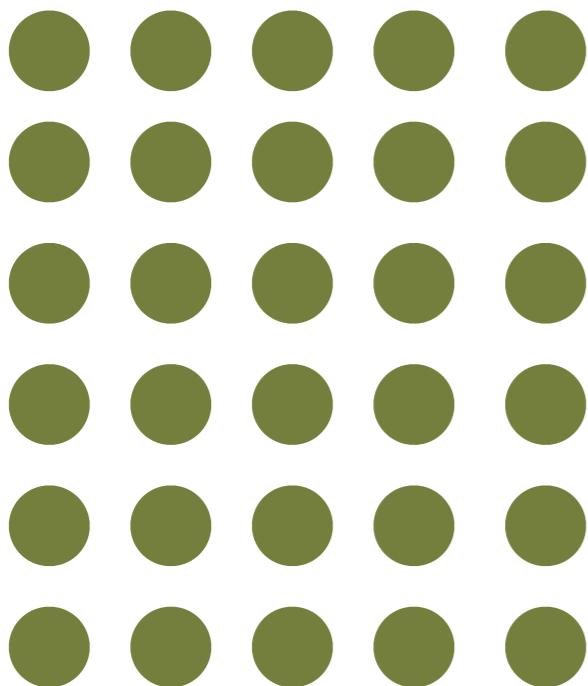
- ▶ Objects that are close together are perceived to be more related than those that are far away



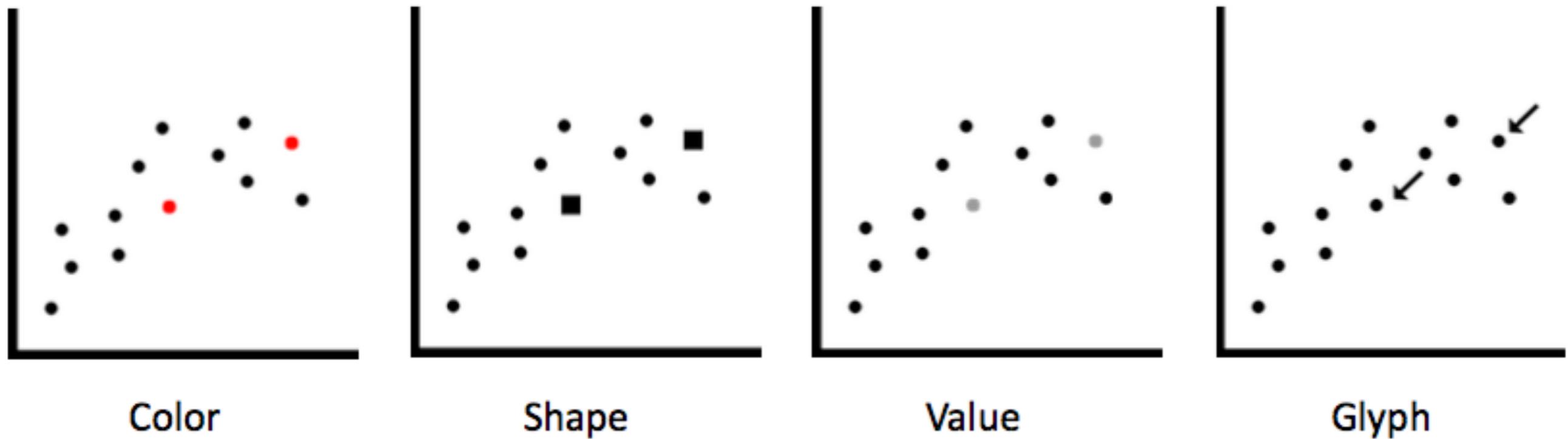
---

## GESTALT: SIMILARITY

- ▶ Objects that share characteristics are perceived to be related than those that don't



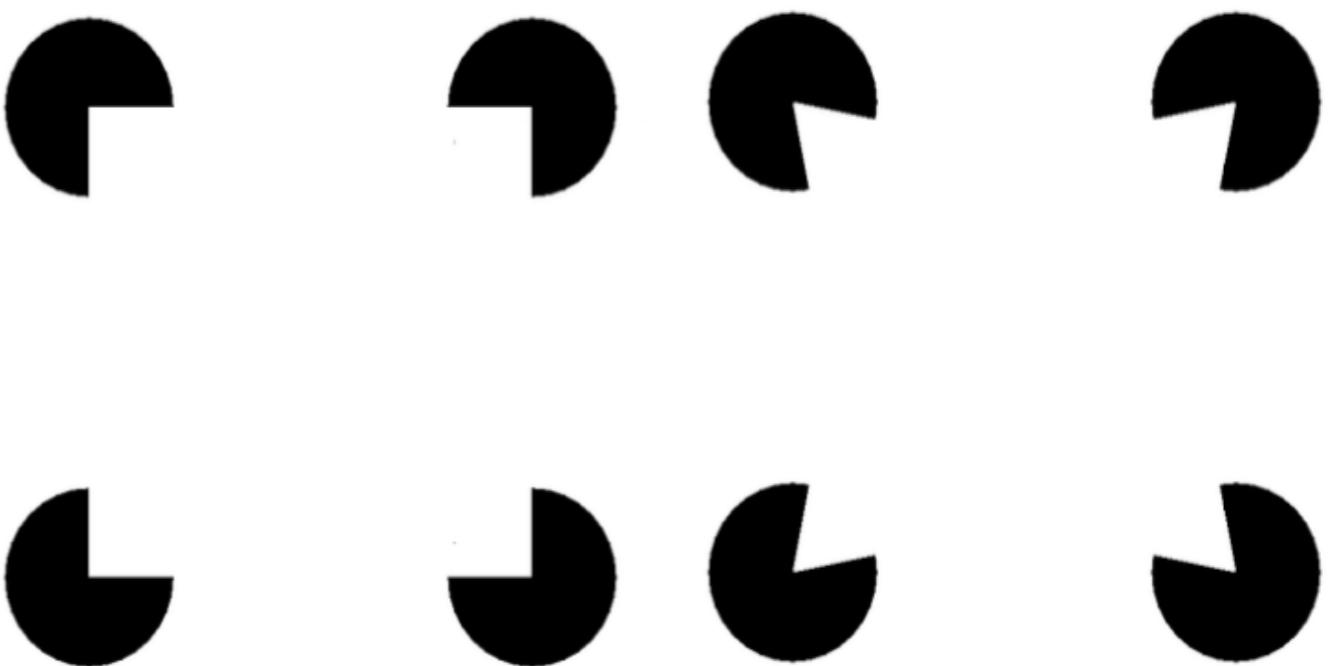
## GESTALT: SIMILARITY



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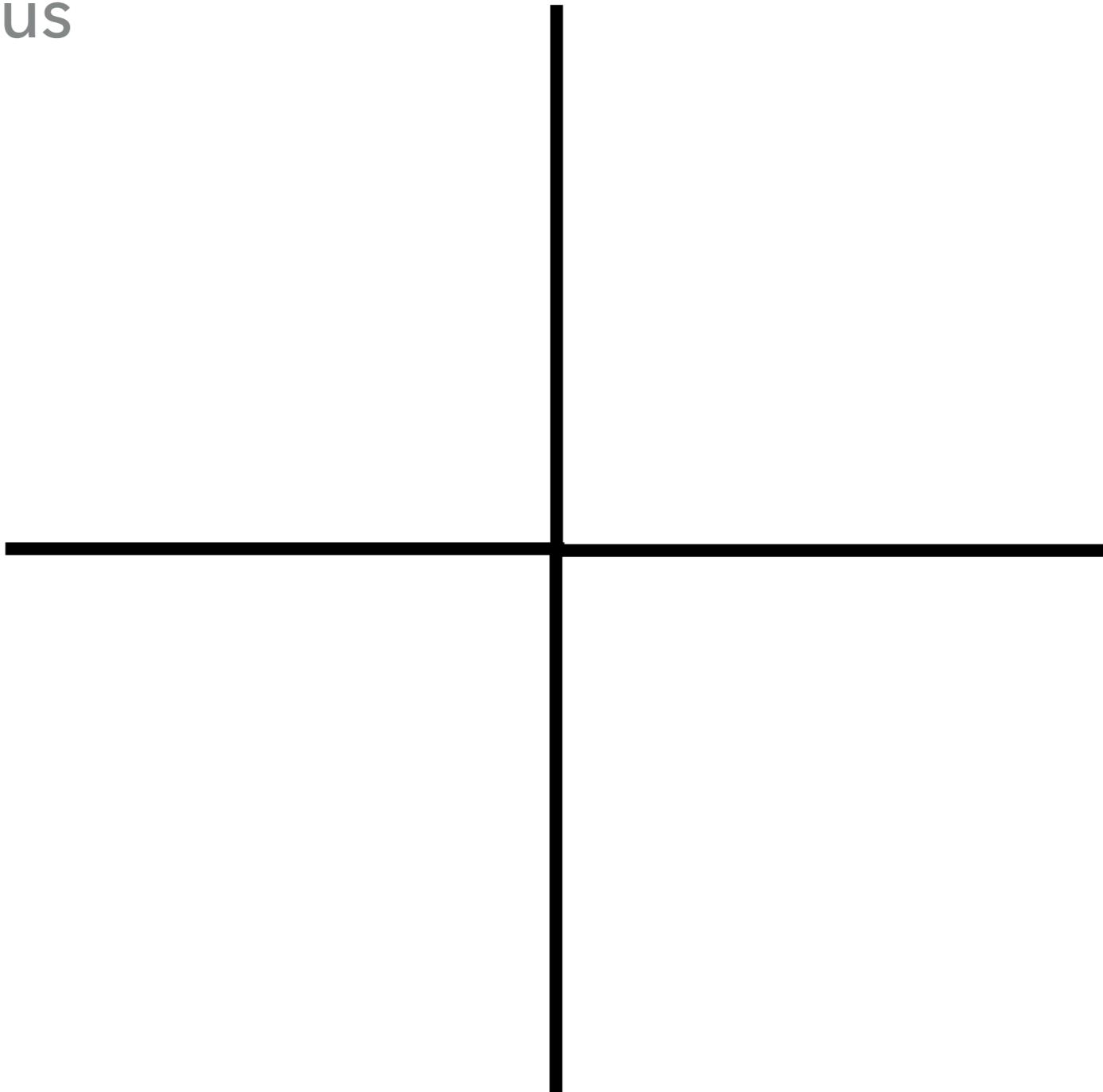
## GESTALT: CLOSURE

- ▶ Closure of gaps to perceive a familiar form



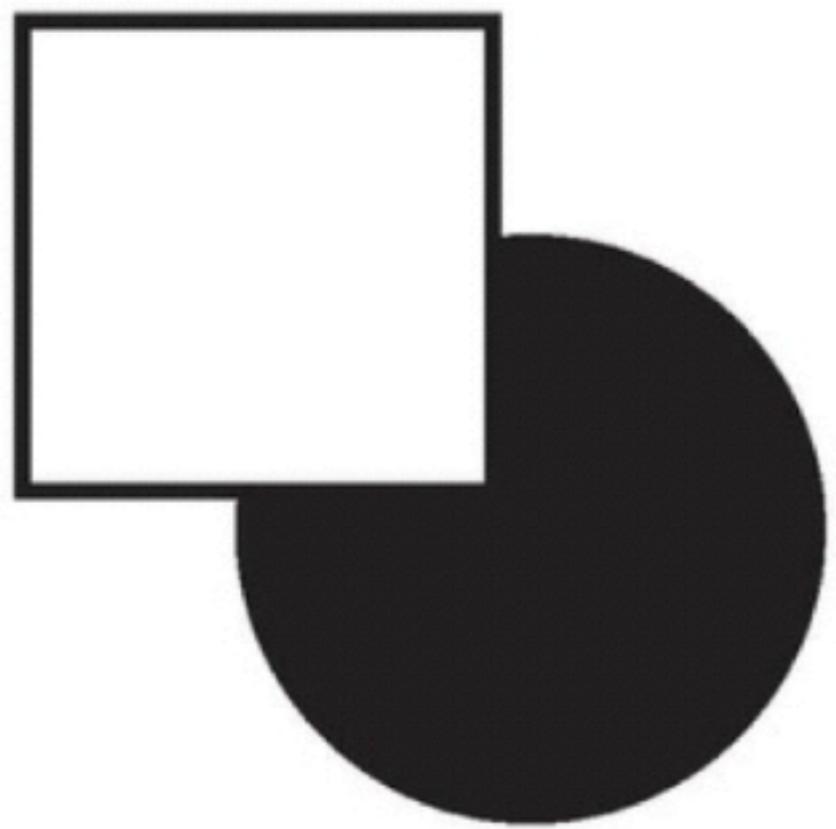
# GESTALT: CONTINUITY

- ▶ Tendency to perceive objects as continuous rather than discontinuous



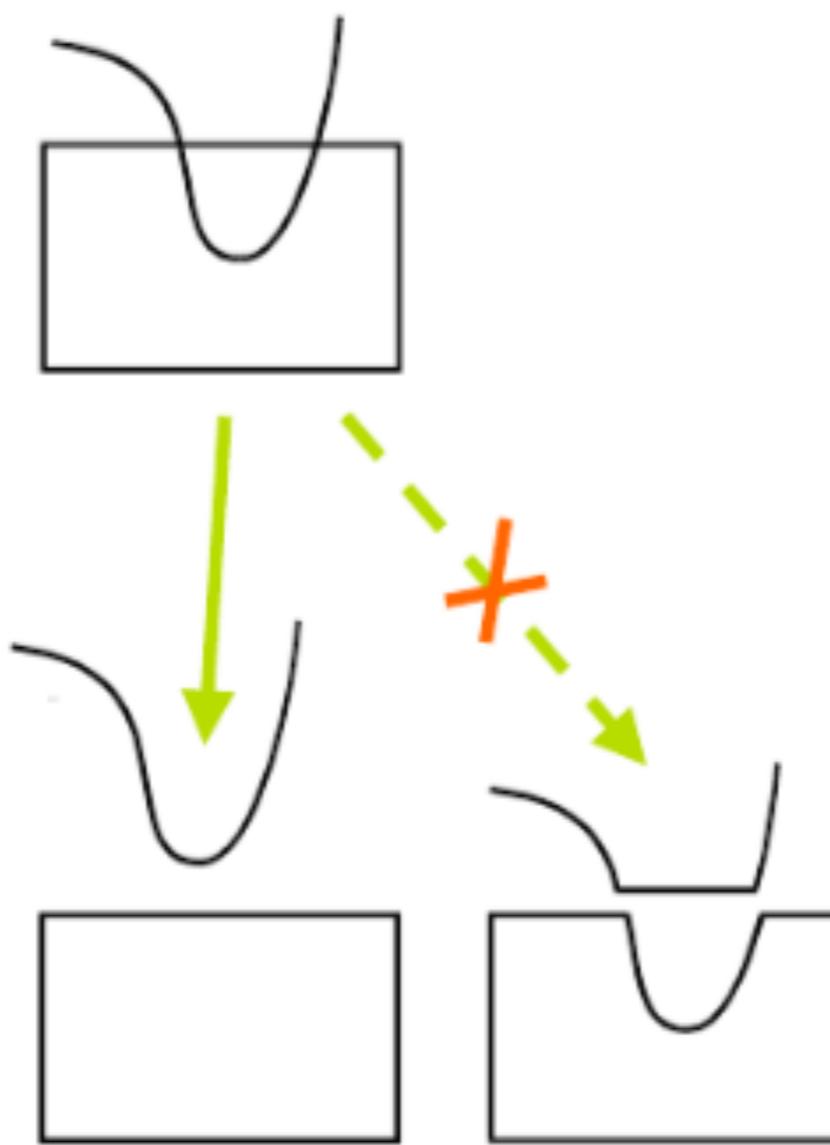
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## GESTALT: CONTINUITY



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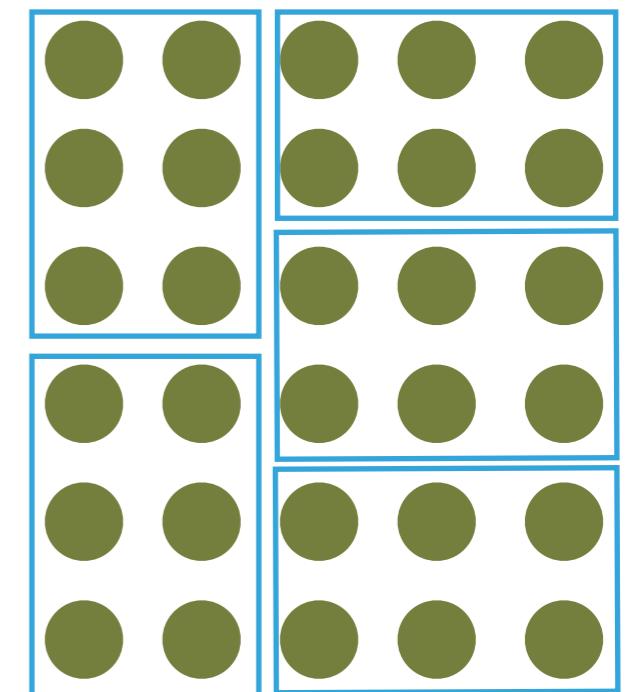
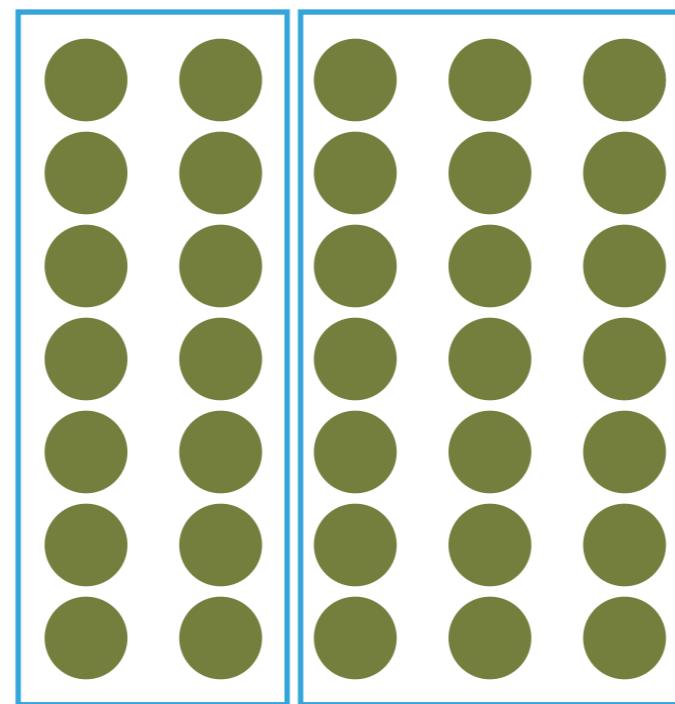
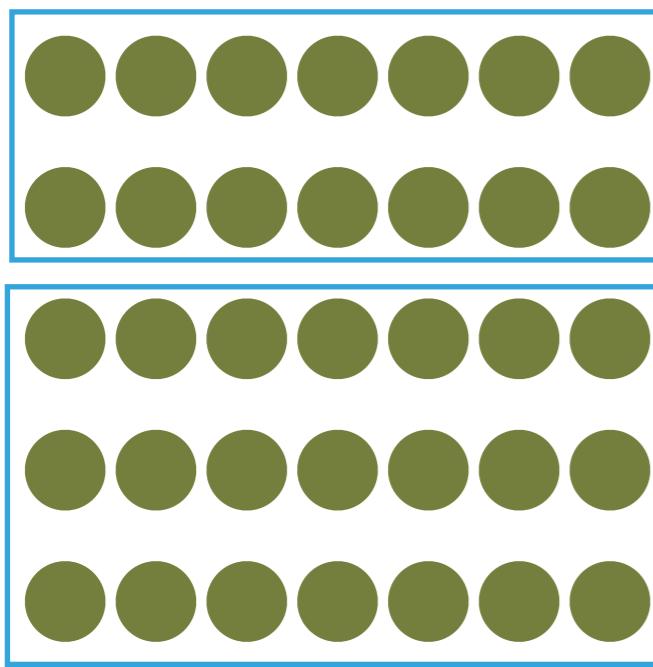
## GESTALT: CONTINUITY



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## GESTALT: ENCLOSURE (COMMON REGION)

- ▶ Objects that are perceived to be in a group if they share an area with a clearly defined boundary

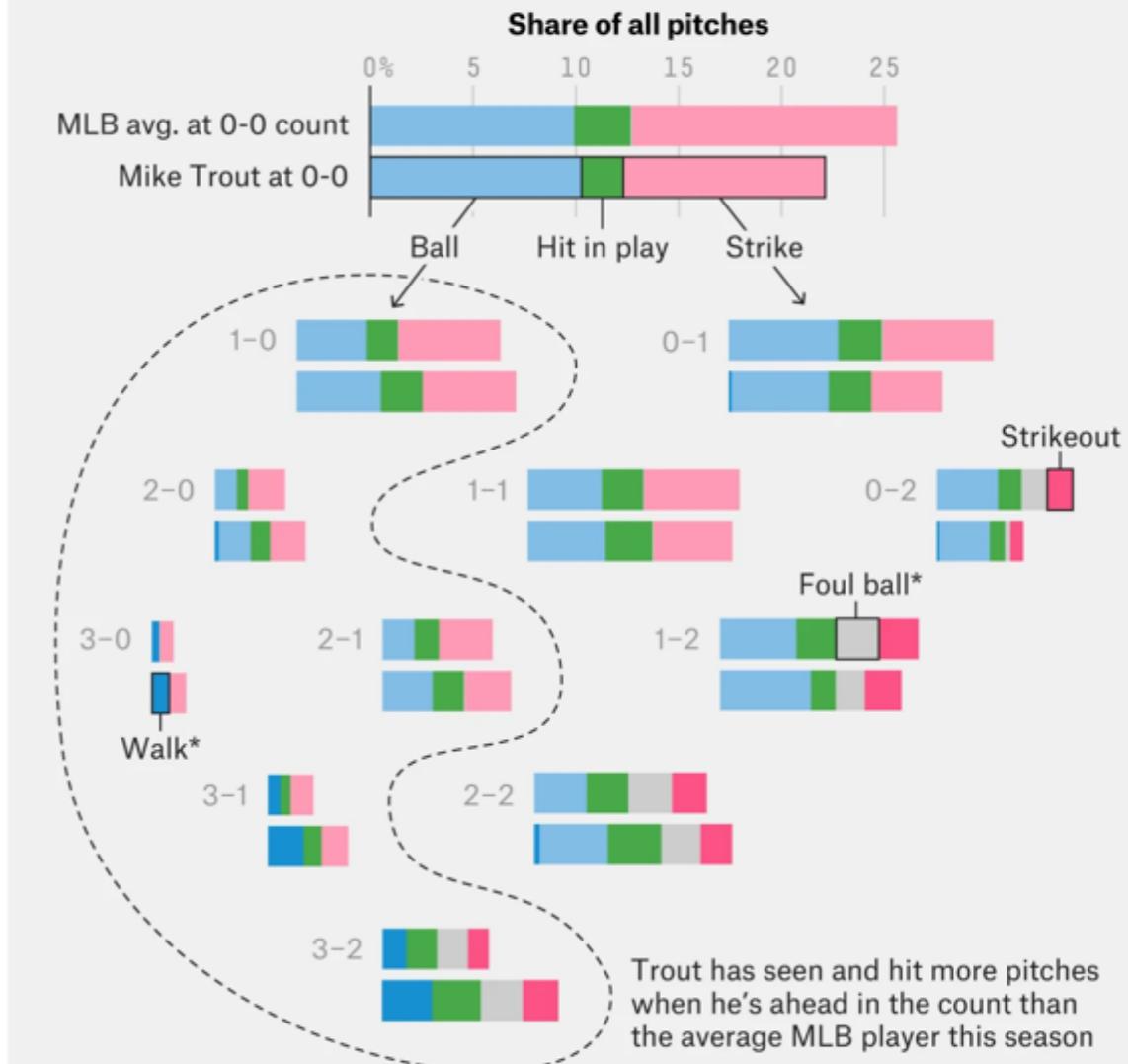


# DESIGN PRINCIPLES IN ACTION



## Mike Trout likes to stay ahead of pitchers

Batting outcomes as a share of all pitches for every count in the 2019 MLB season, through Aug. 6



\*Foul balls shown on two-strike counts only and are included as strikes in earlier counts. Walk totals include batters hit by a pitch on that count.

# DESIGN PRINCIPLES IN ACTION

## How many people might the census miss?

Estimated share of the projected population that would not be counted in the 2020 census if a citizenship question is added, based on five scenarios from researchers

### ① 5.8% undercount of noncitizens

Based on Census Bureau estimates from Aug. 2018



### ② 5.8% undercount of noncitizens and Hispanics

Partially based on Census Bureau estimates from Aug. 2018



### ③ 5.9% undercount of Hispanics and 11.3% undercount of foreign-born non-Latinos

Based on responses in a survey experiment



### ④ Poorly conducted census and a 10% undercount of households with undocumented immigrants

Partially based on the undercount in the 1990 census



### ⑤ Undercount of 6 million Hispanics

Based on questions skipped in a survey experiment



ESTIMATED SHARE OF PROJECTED 2020 POPULATION THAT WOULD GO UNCOUNTED

0% 1 2 3 4 5

2020 population projections were derived by the researchers and vary from scenario to scenario

Scenario 3 is based on a survey experiment that tested how much less likely respondents were to say they would return the census form if the citizenship question was included. Scenario 5 is based on a survey experiment that tested how much less likely respondents were to respond to individual questions on the form if the citizenship question was included.

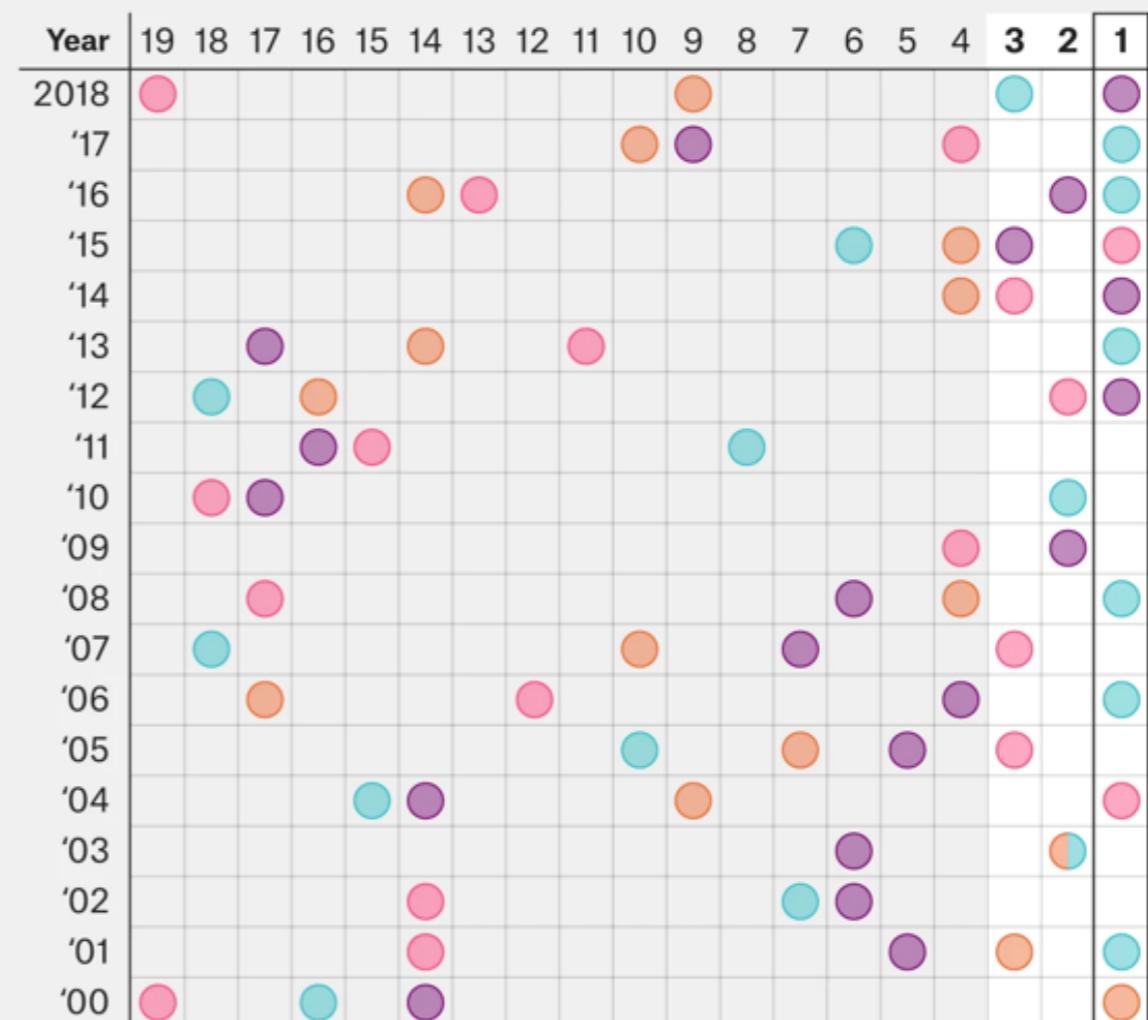
FiveThirtyEight

## The races that pick Derby favorites

Finishing position in the Kentucky Derby of the winner of four major prep races, by year

Arkansas Derby Wood Memorial Florida Derby Santa Anita Derby

### Kentucky Derby finishing position



In 2003, Empire Maker won the Wood Memorial and the Florida Derby

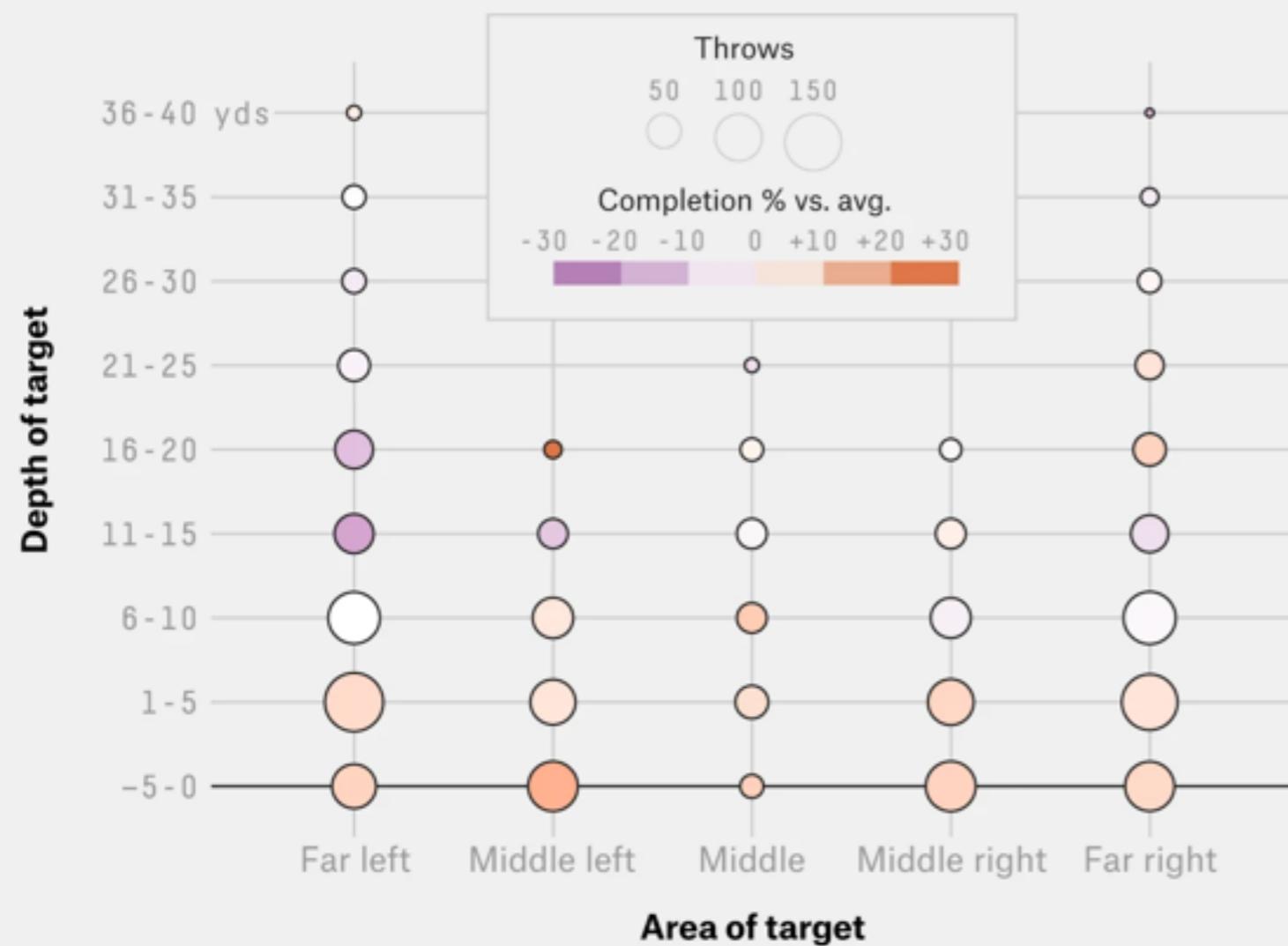
FiveThirtyEight

SOURCE: HORSE RACING NATION

# DESIGN PRINCIPLES IN ACTION

## Rodgers has struggled on intermediate throws

Completion percentage relative to an average NFL quarterback, regular season 2015-18



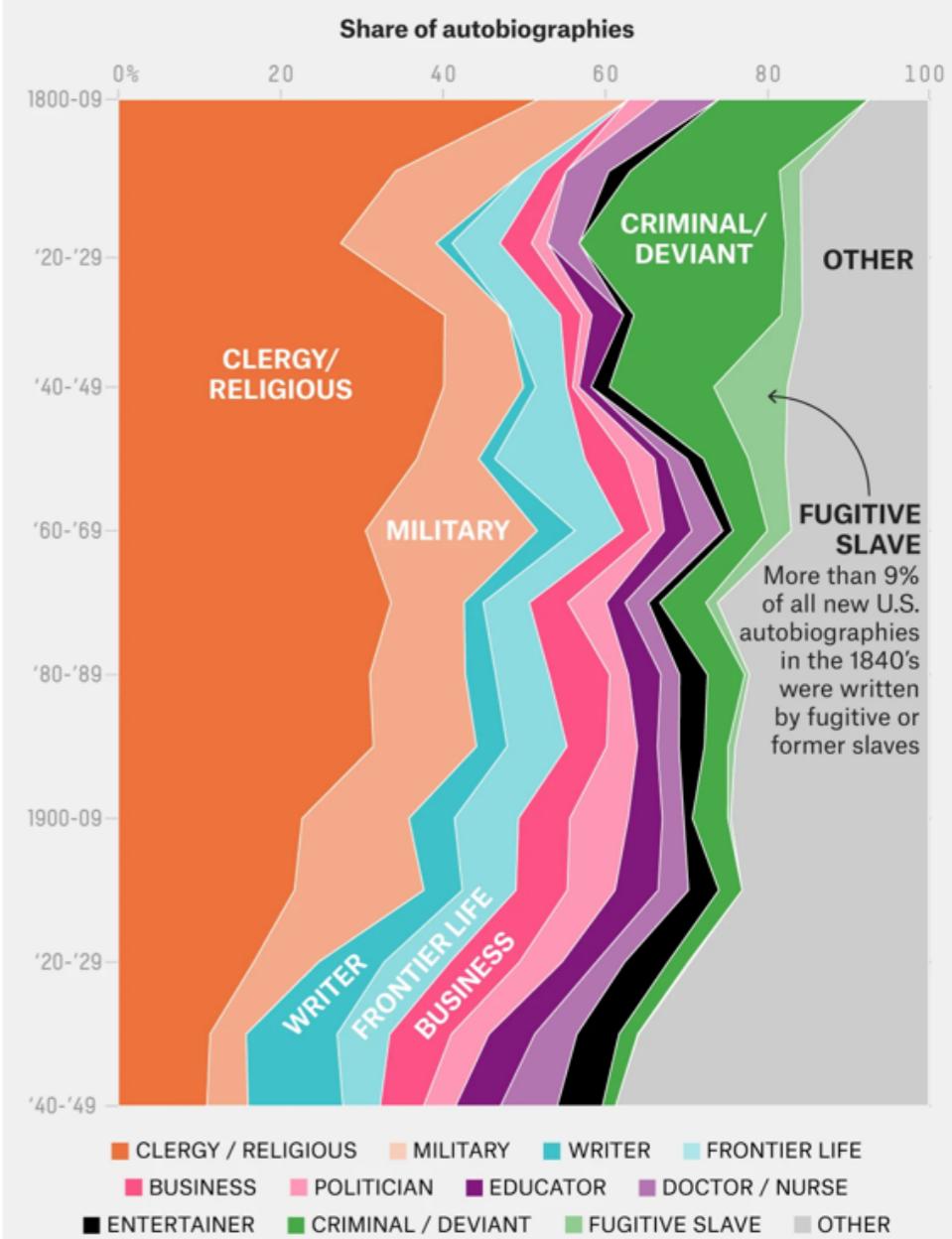
Among area/depth combinations with at least six pass attempts. Only passes with a charted direction are included.

FiveThirtyEight

SOURCE: ESPN STATS & INFORMATION GROUP

## The 150-year evolution of American autobiographies

Share of new autobiographies published per decade in the U.S. by category, between 1800 and 1949, as collected by Louis Kaplan and categorized by Diane Bjorklund



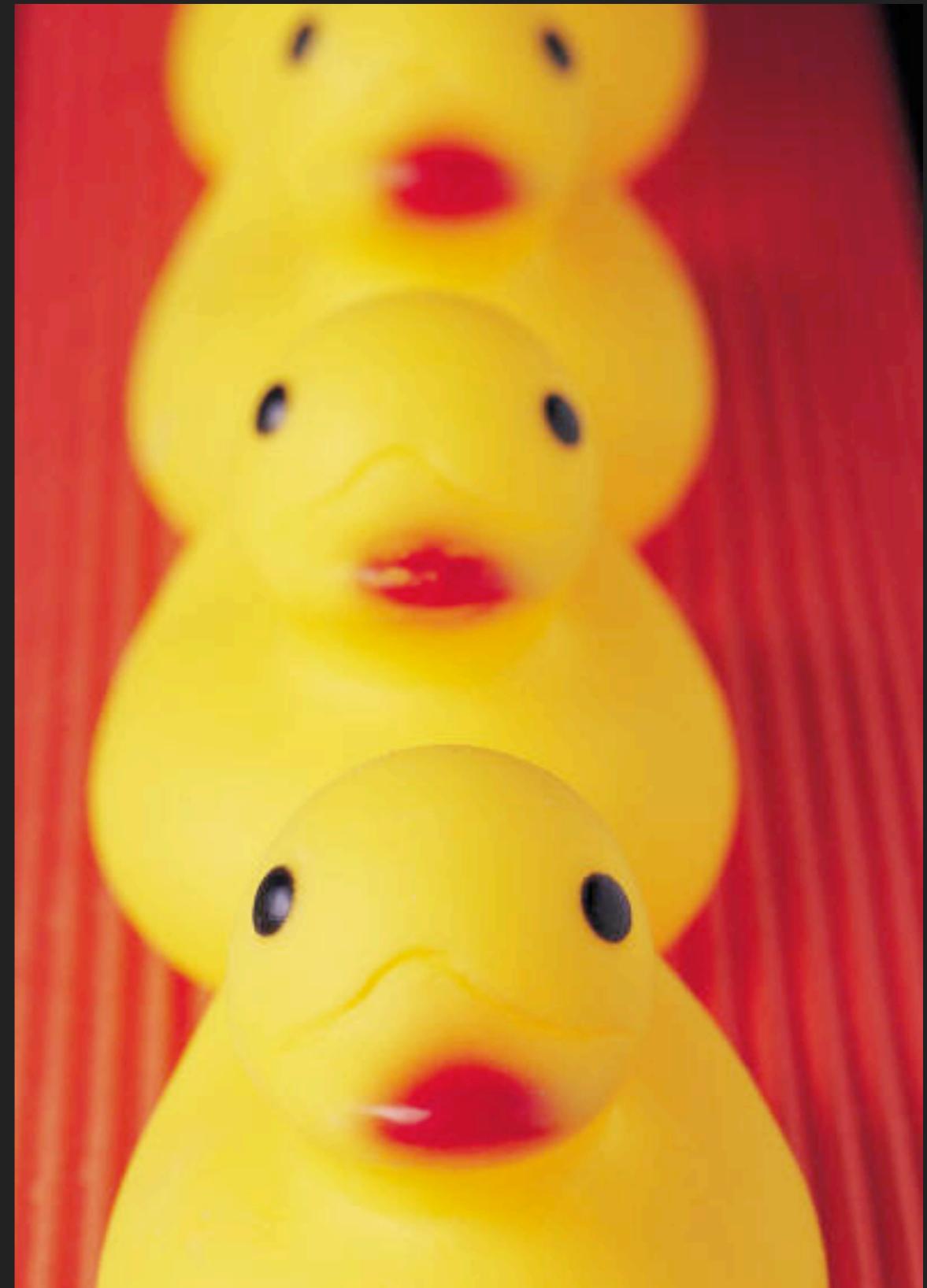
FiveThirtyEight

SOURCES: LOUIS KAPLAN AND DIANE BJORKLUND

## 5.4 GESTALT

You should now be able to:

- ▶ Be aware of a range of Gestalt principles
- ▶ Consider how to use gestalt principles to manipulate perception of relationships between objects in your design



We see what we look for, not  
what we look at.

**Ulrich Neisser**

Cognitive  
Psychologist

