

# CSC 544

# Data Visualization

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# Lecture 06

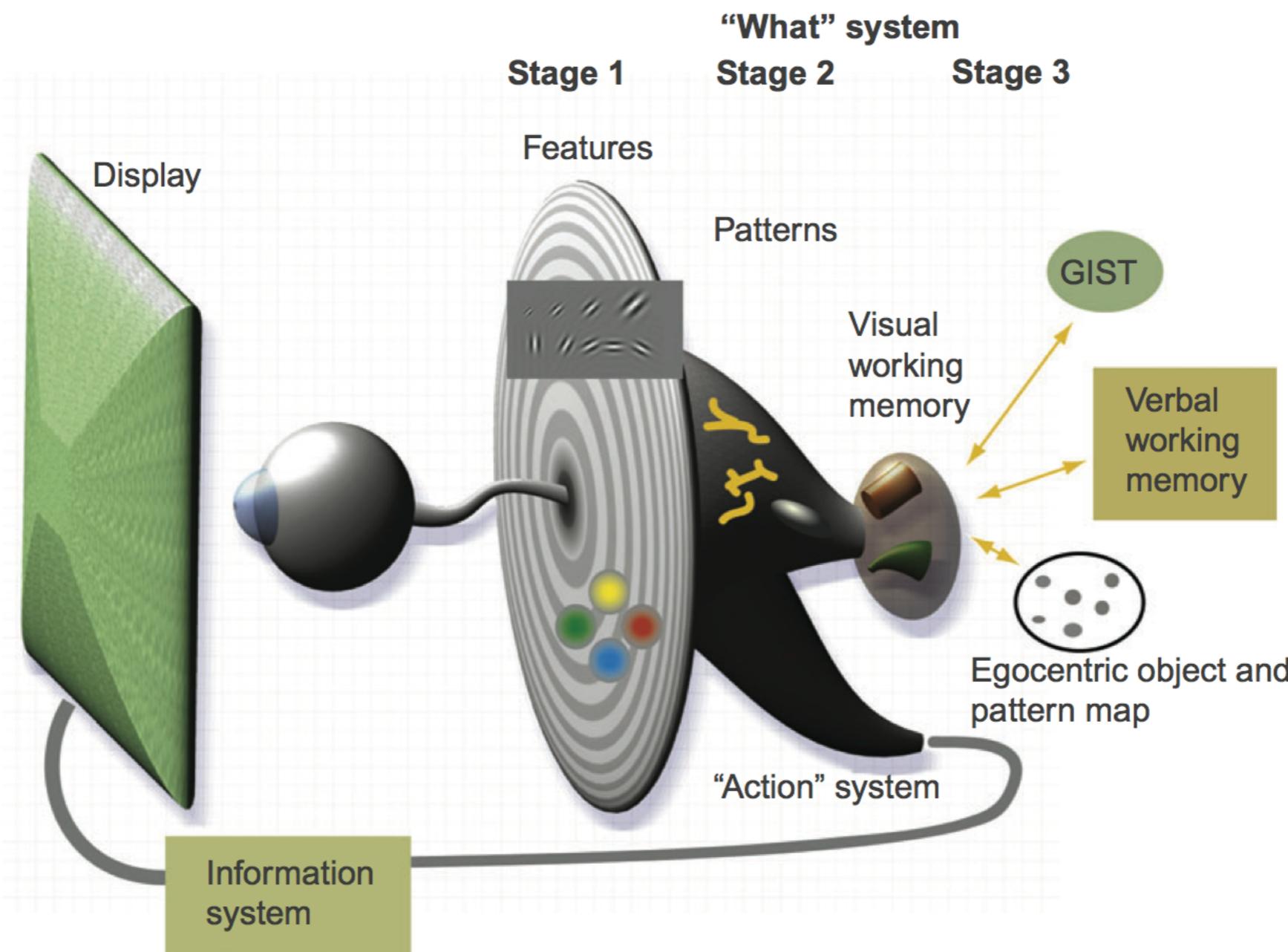
# Perception

Feb. 1, 2023

# Today's Agenda

- Reminders:
  - A01, P01 posted, questions?
  - Note: First “round” of DC’s aren’t due until next week!
- Goals for today:
  - Introduce the human perception system and its effects on visualization

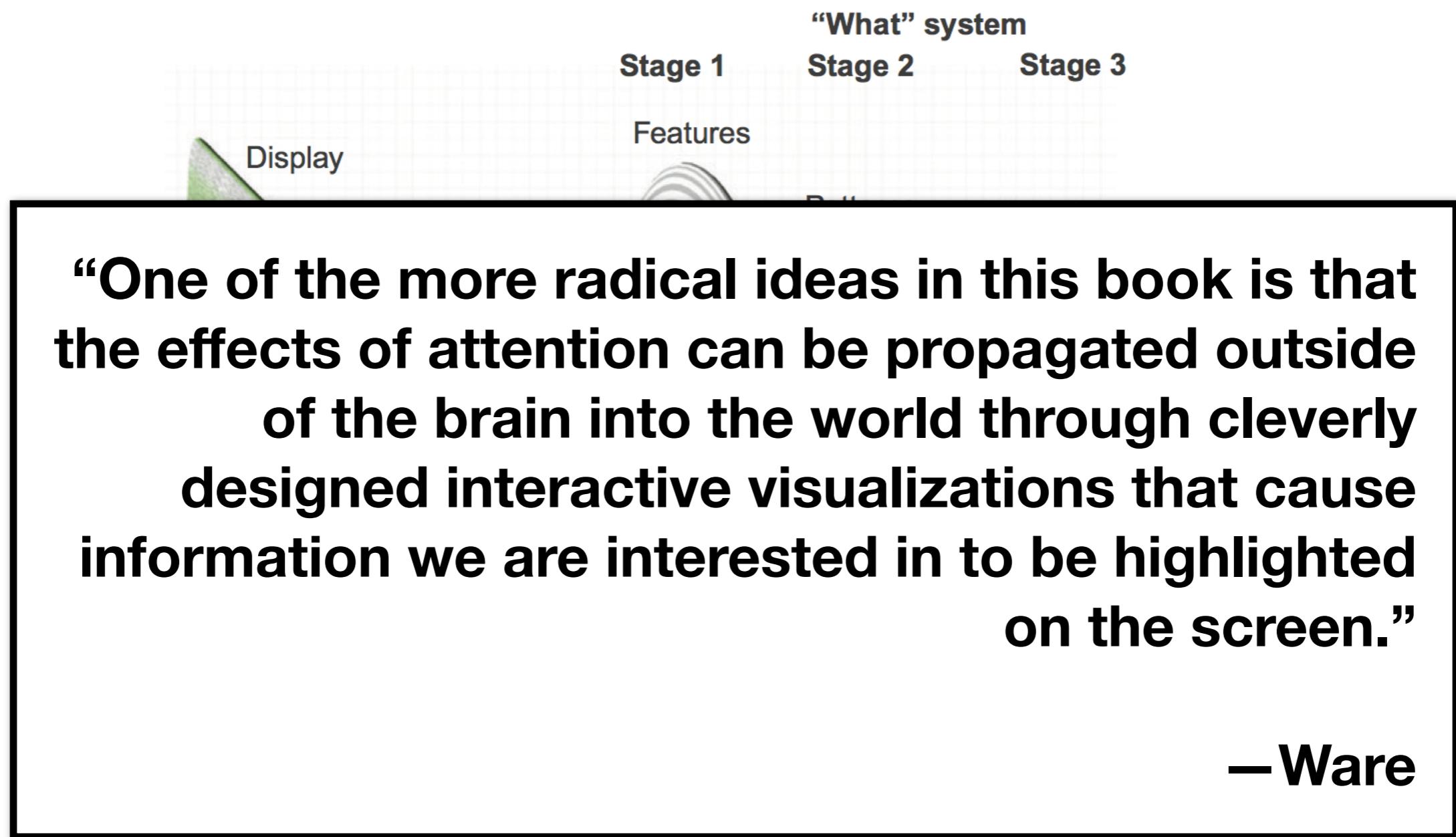
# **The Process of Perception**



**Figure 1.11** A three-stage model of visual information processing.

**Identification of Patterns**

**Attention & Visual Query**



**Figure 1.11** A three-stage model of visual information processing.

**Identification of Patterns**



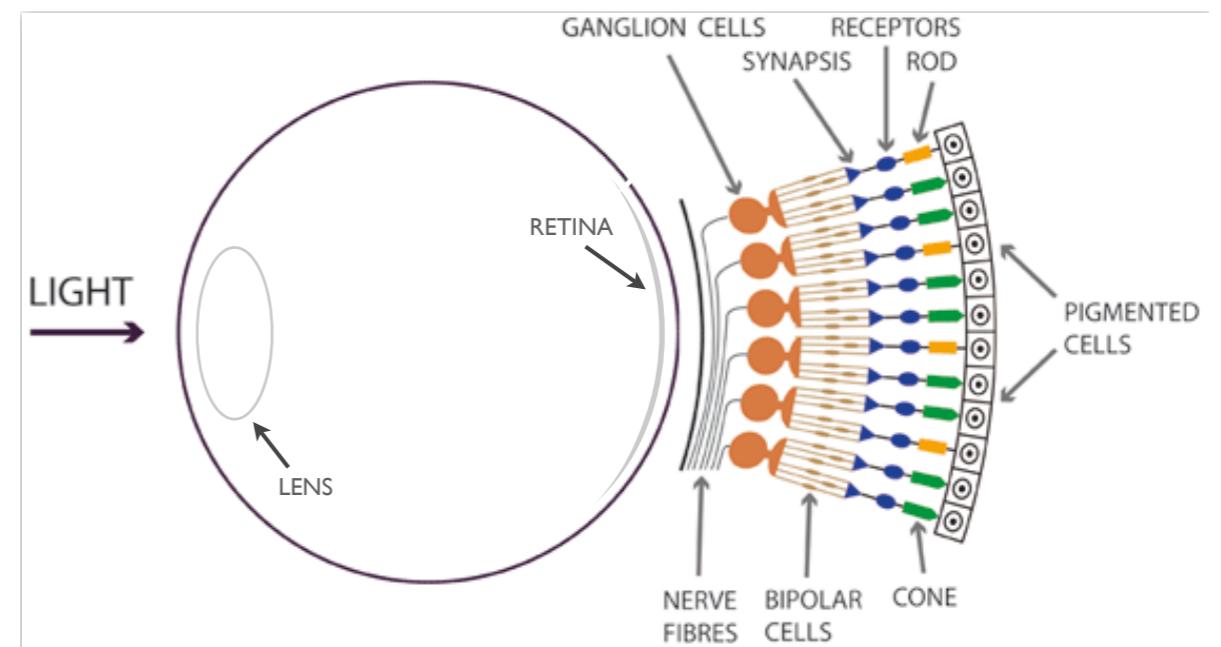
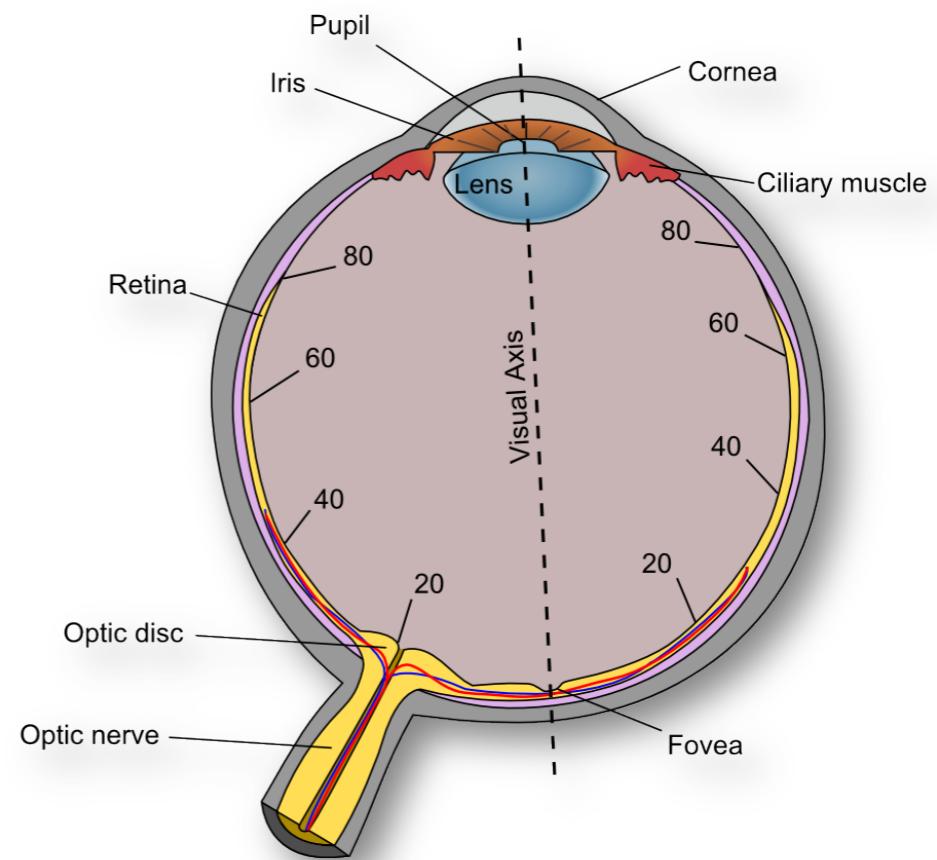
**Attention & Visual Query**



# **Physiology of the Eye**

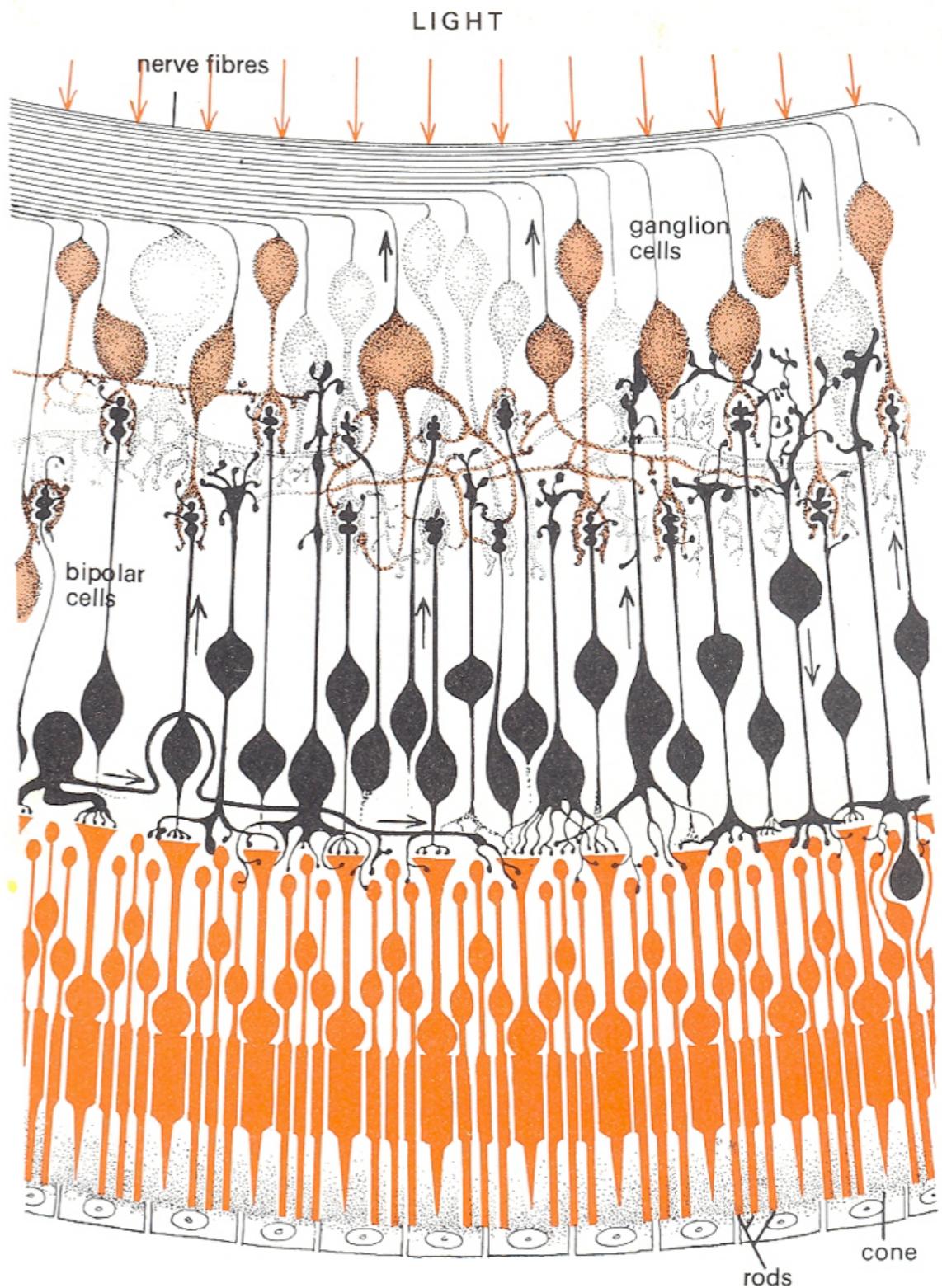
# Human Optics

- In human vision, the **cornea** acts as a protective lens that roughly focuses incoming light
- Iris controls the amount of light that enters the eye
- The **lens** sharply focuses incoming light onto the retina
  - Absorbs both infrared and ultraviolet light which can damage the lens
  - The **retina** is covered by **photoreceptors** (light sensors) which measure light

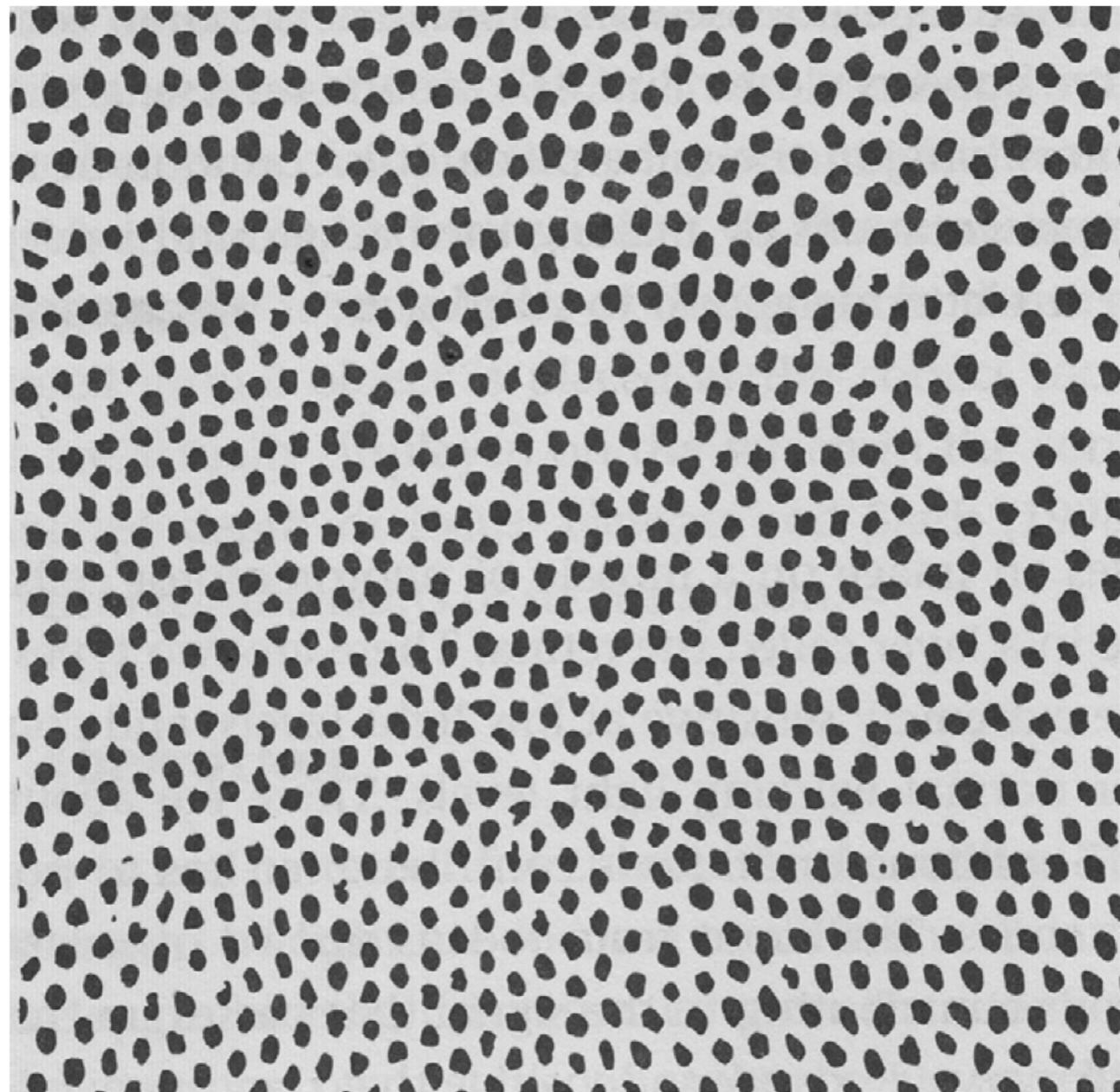


# Photoreceptors

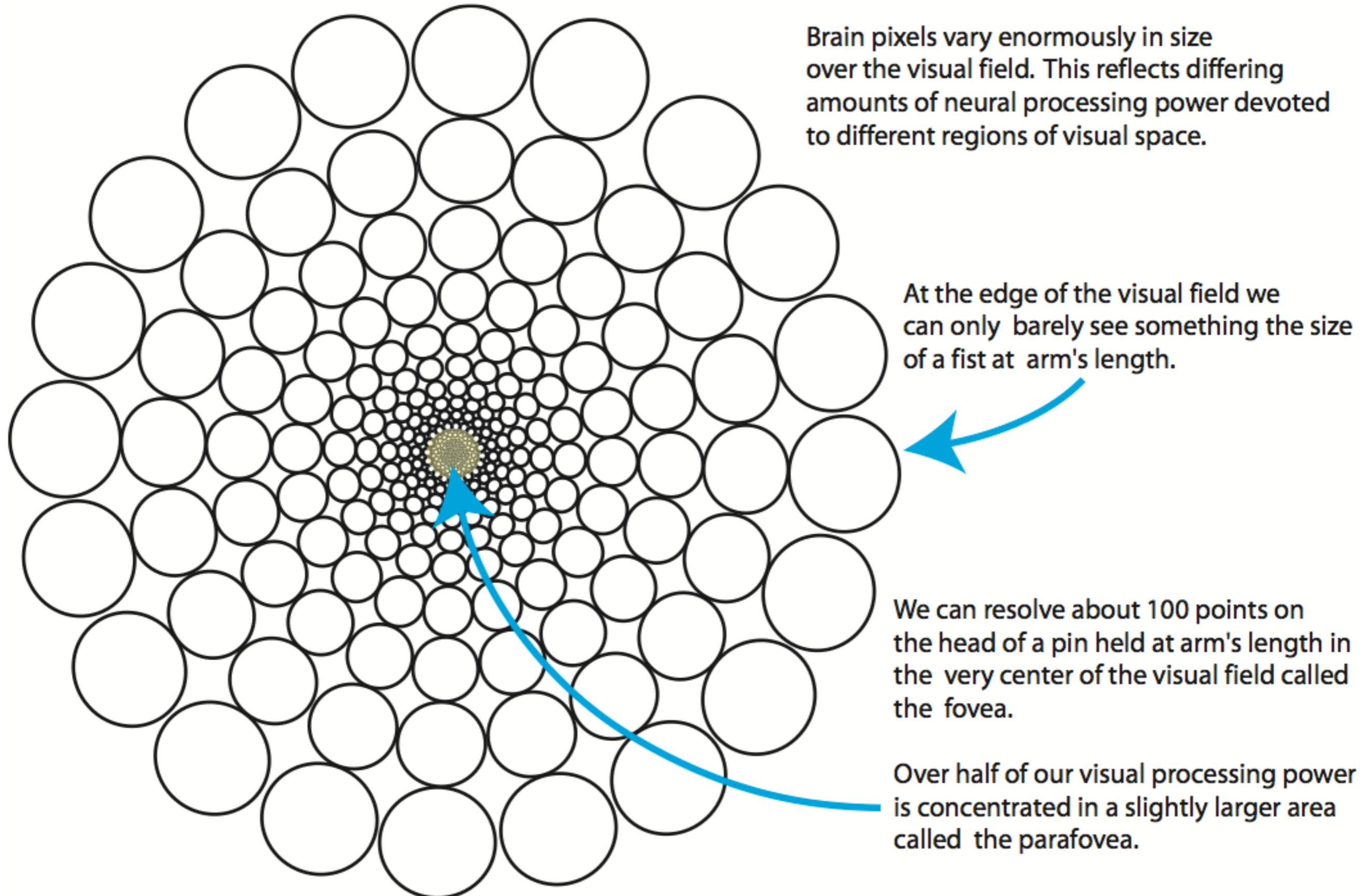
- **Rods** (detect low-light / scotopic vision)
  - Approximately 100-150 million rods  
(Non-uniformly distributed across the retina)
- **Cones** (detect day-light / photopic vision)
  - Approximately 6-7 million cones.
  - Detects color with 3 different kinds:
    - Red (L cone): 65% of all cones
    - Green (M cone): 30% of all cones
    - Blue (S cone): 5% of all cones



# Photoreceptors Are Arranged as Irregular “Brain Pixels”



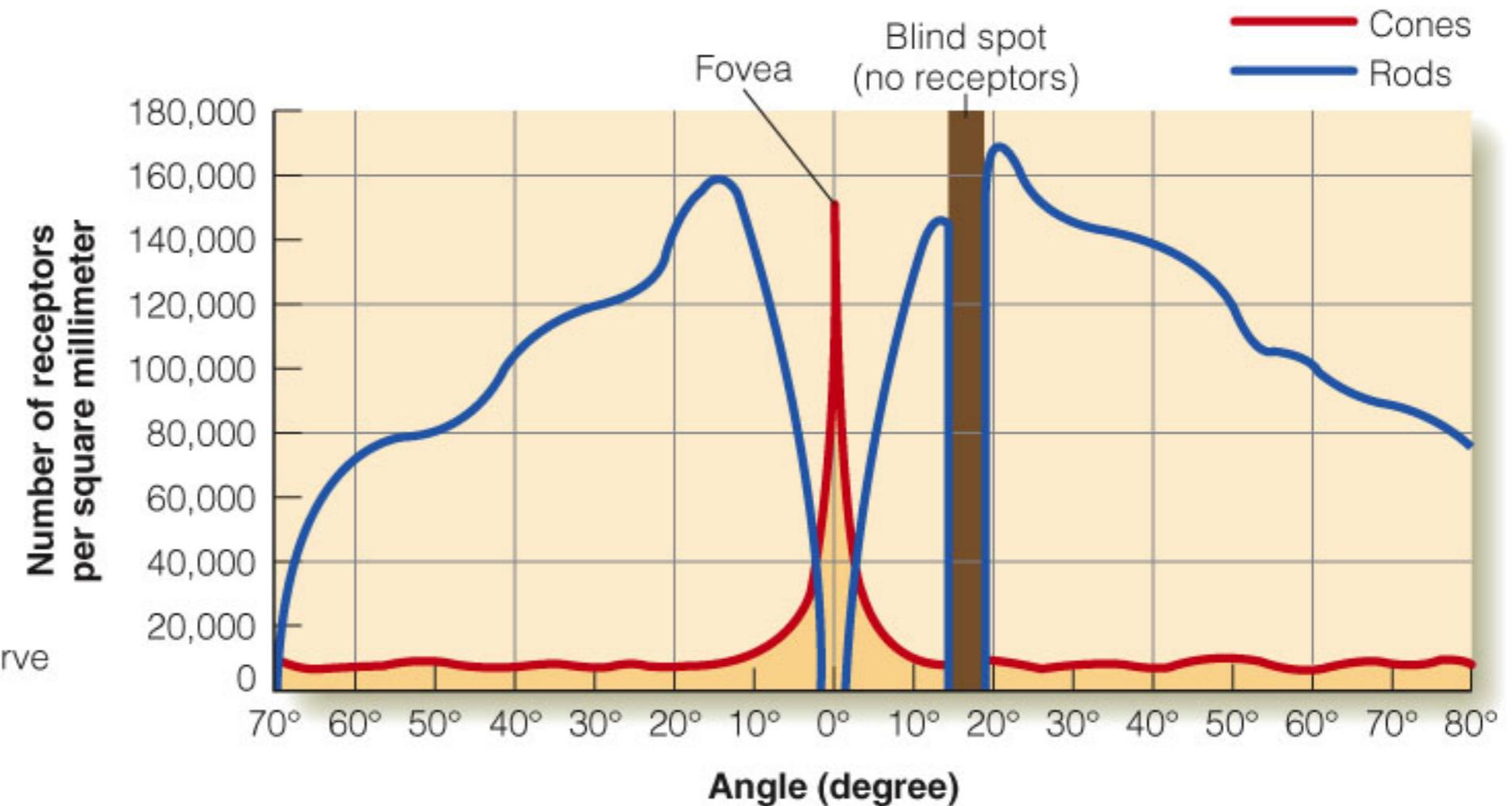
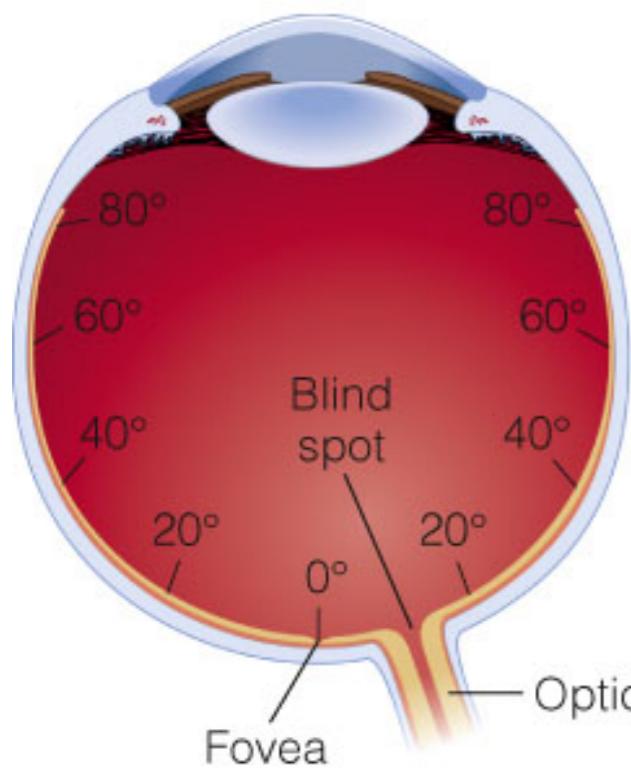
**Figure 2.16** The receptor mosaic in the fovea.



## Experiment:

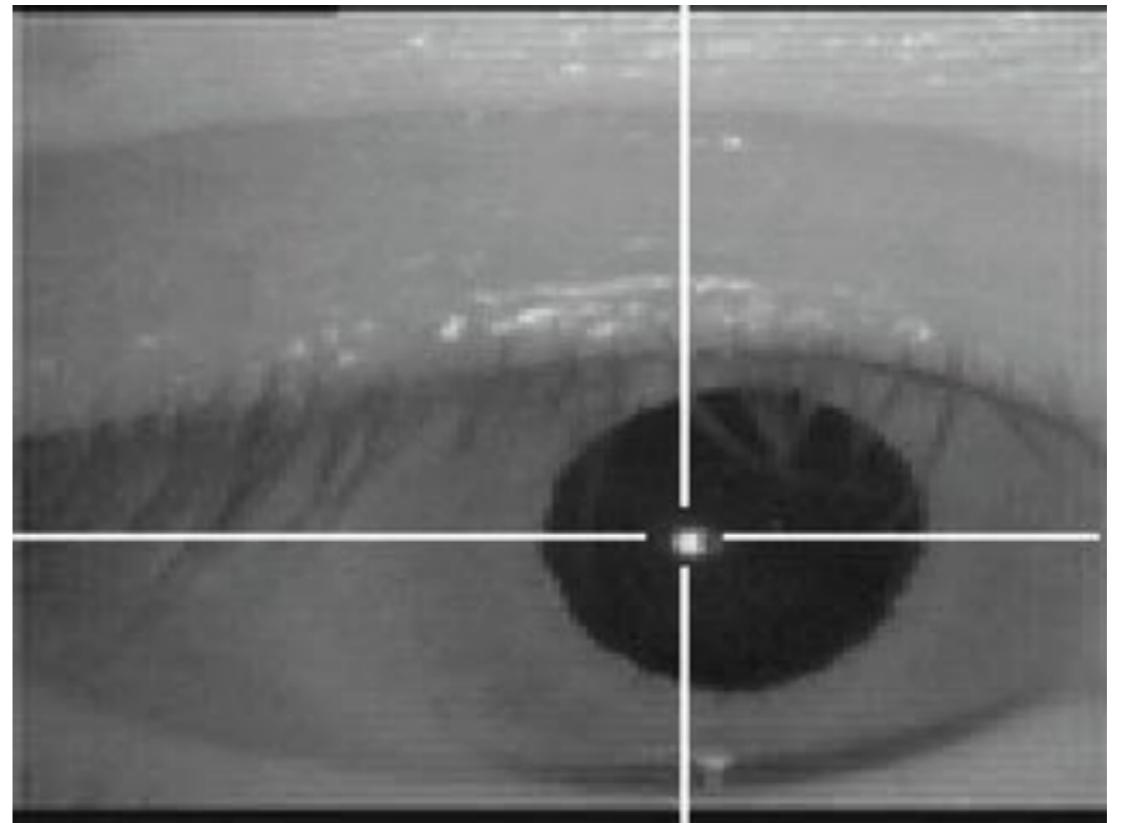
1. Look directly ahead
2. Hold out both arms sideways
3. Wiggle fingers  
(can you see your hands now?)

# Fovea vs. Periphery



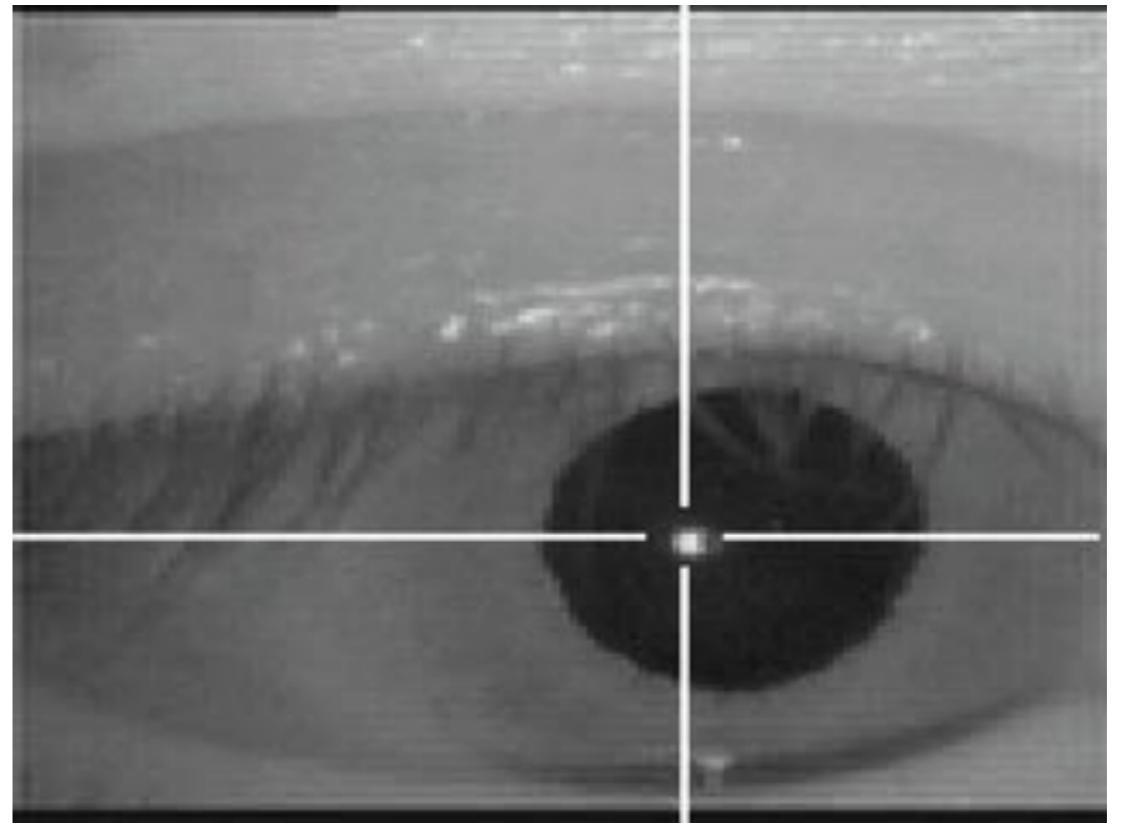
# Saccades

- Rapid involuntary eye movements
- Moving: 20-100 ms
- Fixations: 200-600 ms



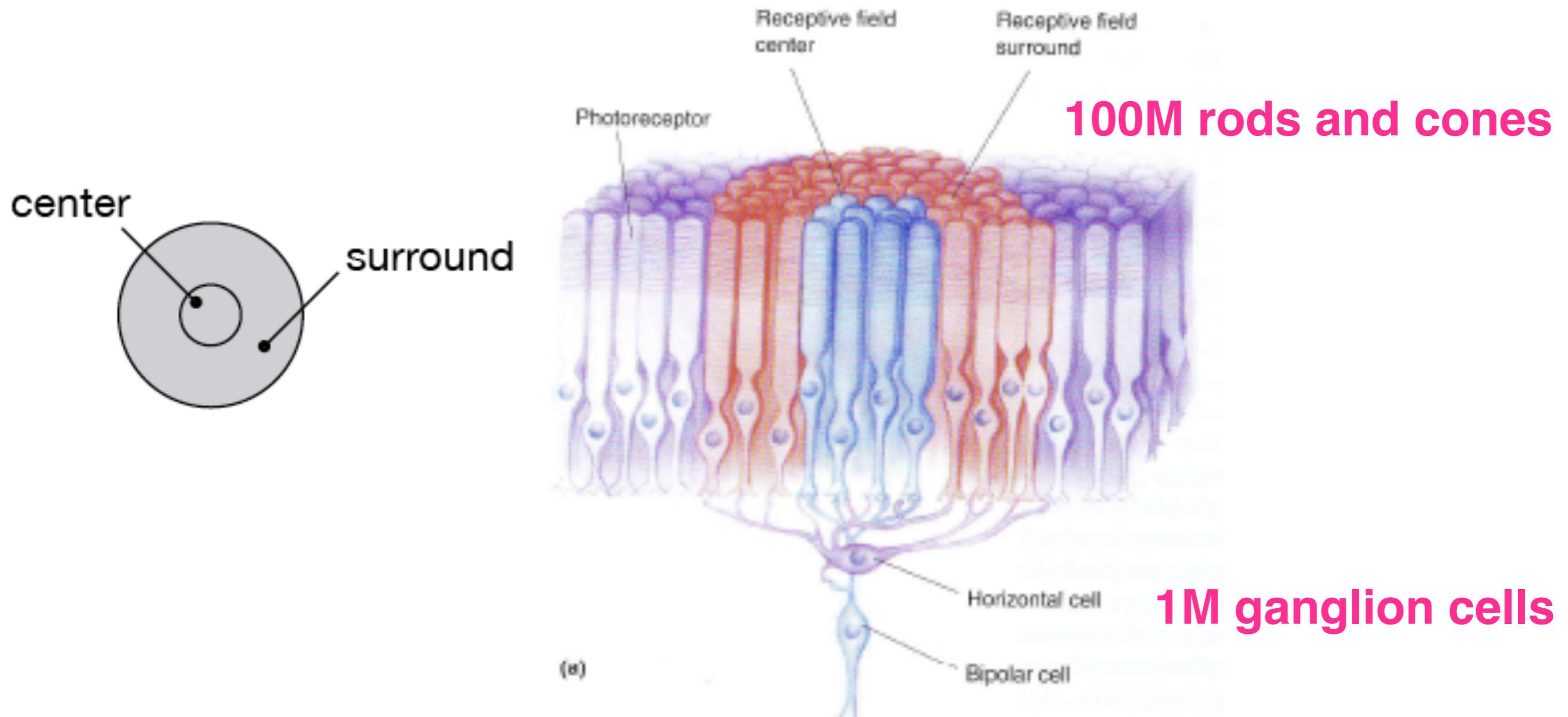
# Saccades

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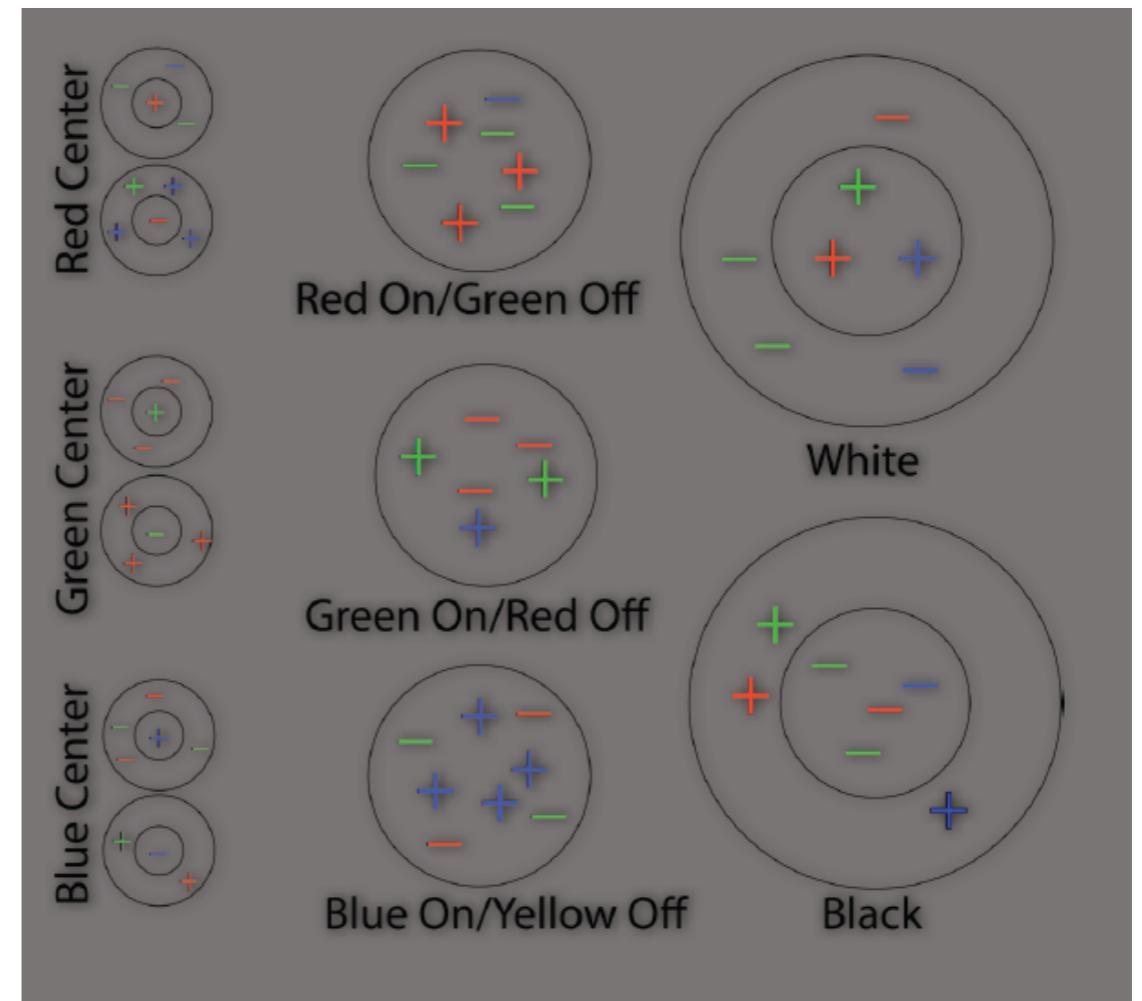
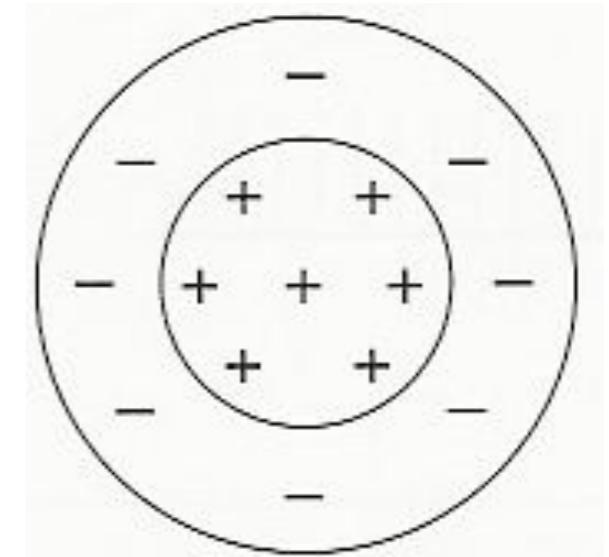
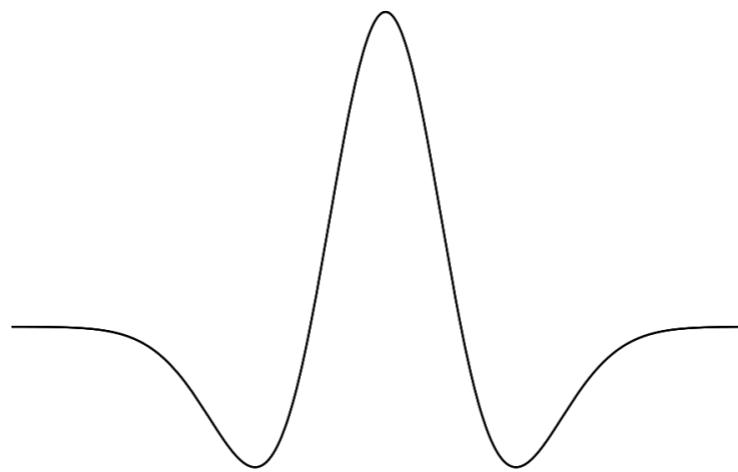
# The Effects of Edges

# Receptive Fields



# Brightness Illusions

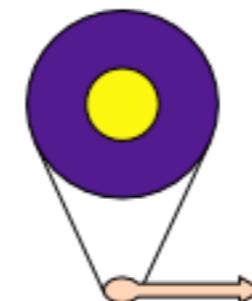
- Primary cause: the Retinal Ganglion Response
- Triggered by light in the center, suppressed by light in the surround
- Causes selective sensitivities to discontinuities in color as well.



# Two Types of Retinal Ganglion Cells

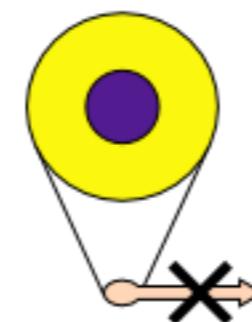
on-center off-center

Light on center only



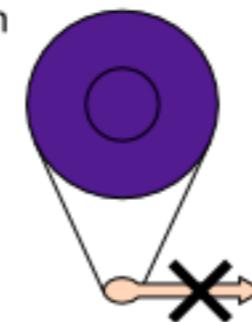
Ganglion cell fires rapidly

Light on surround only



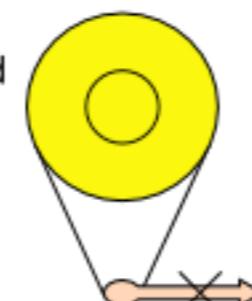
Cell does not fire

No light on center or surround

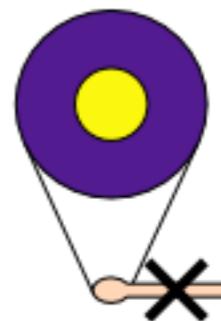


Cell does not fire

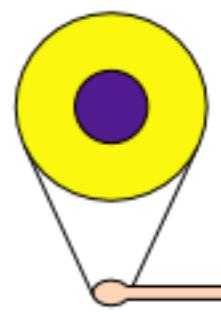
Light on center and surround



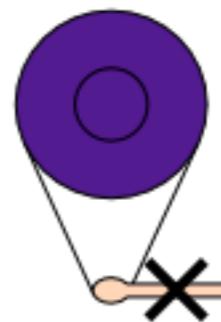
Weak response  
(low frequency firing)



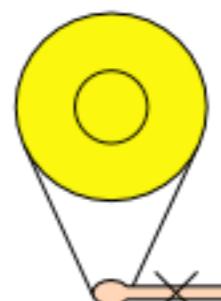
Ganglion cell does not fire



Cell fires rapidly



Cell does not fire



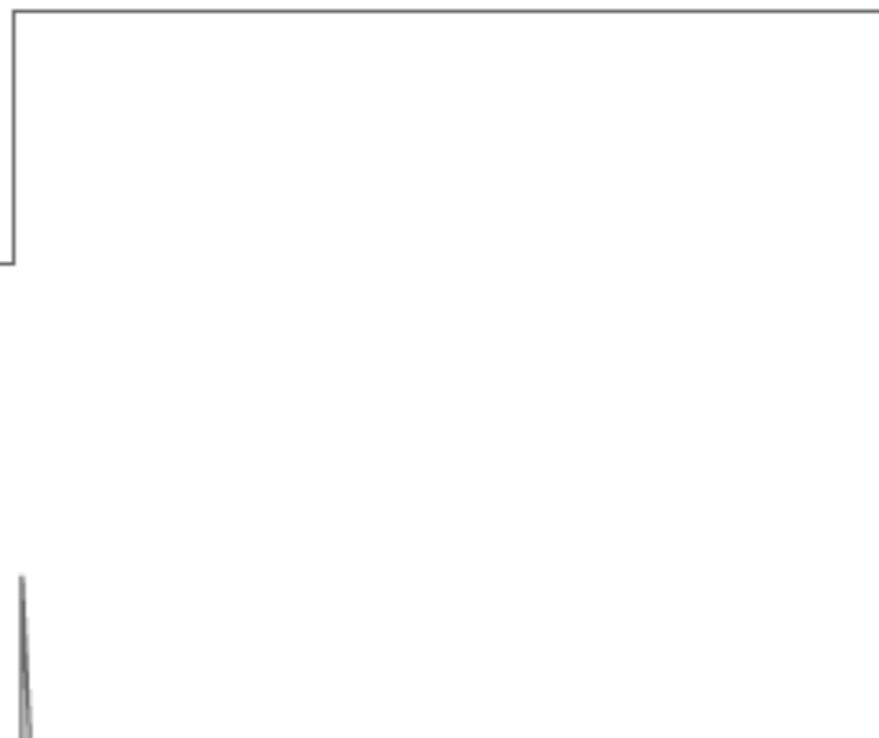
Weak response  
(low frequency firing)

# Edges are regions of rapid change



luminance  $L$

$$\frac{dL}{dx}$$

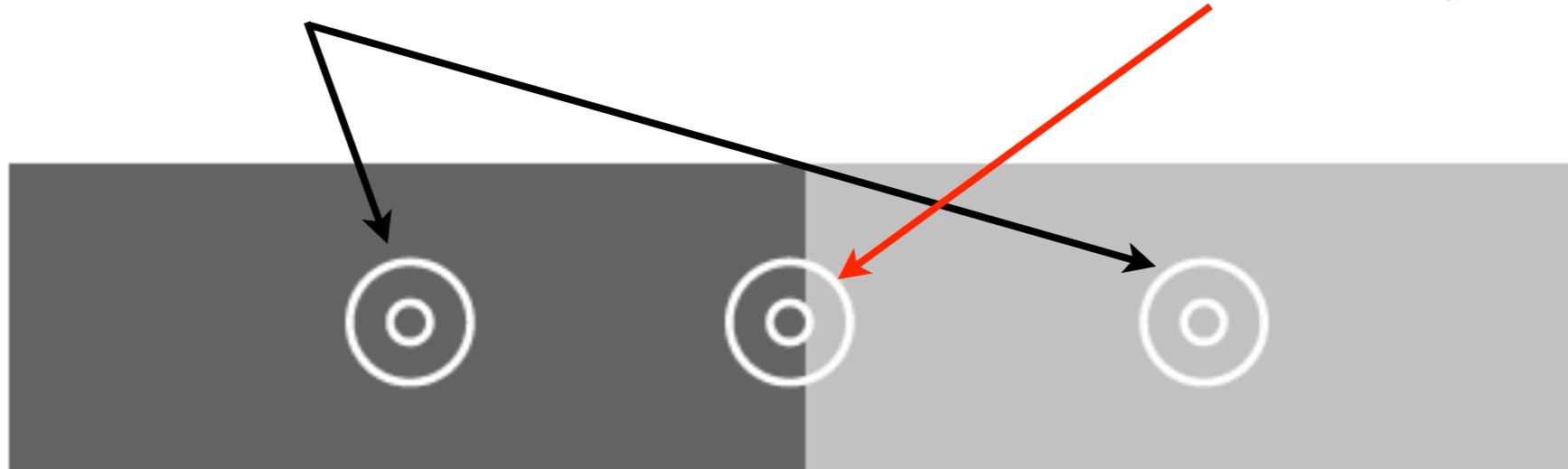


**low activity**

center and surrounds cancel

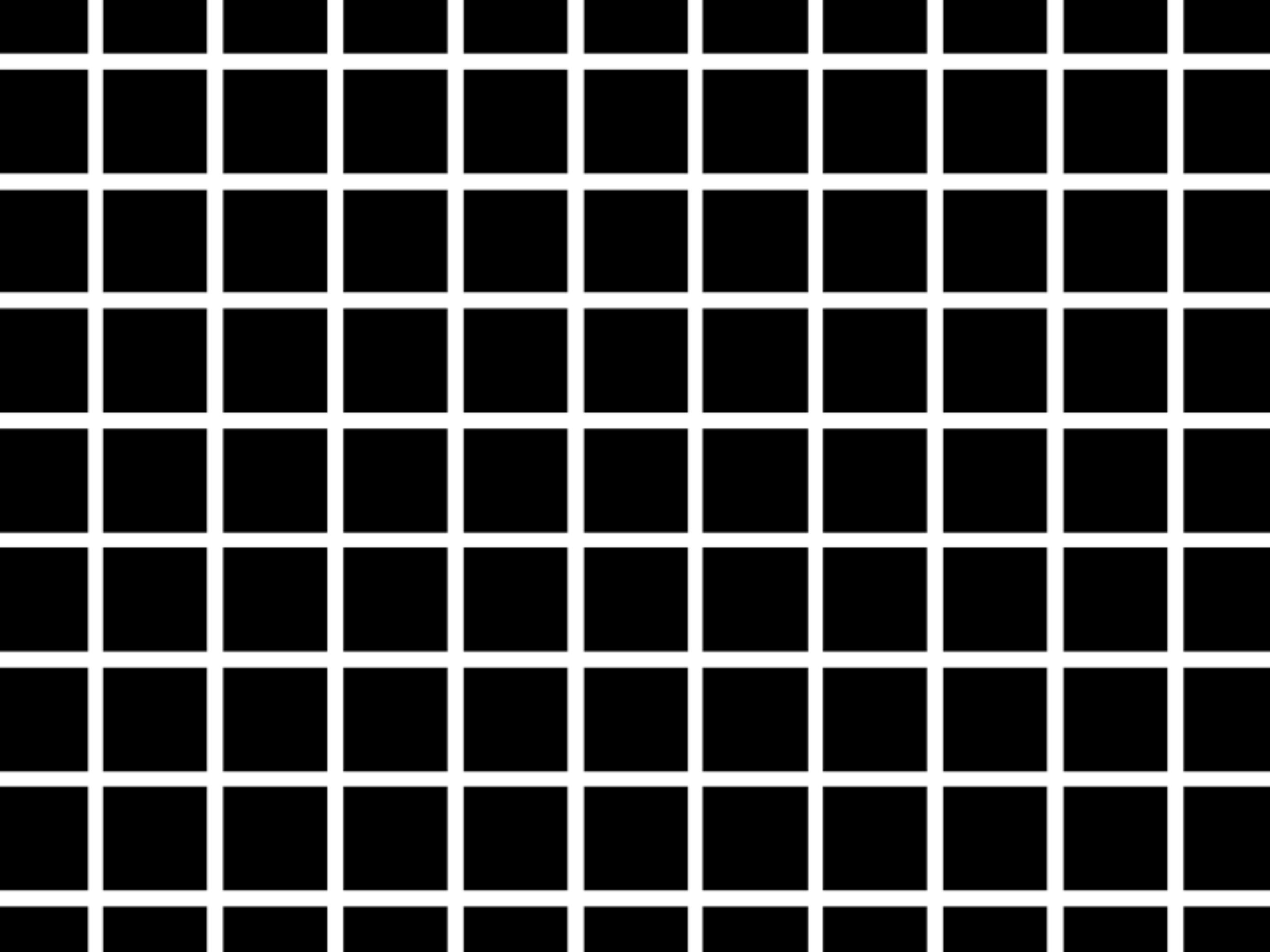
**activity increased**

or decreased at edges

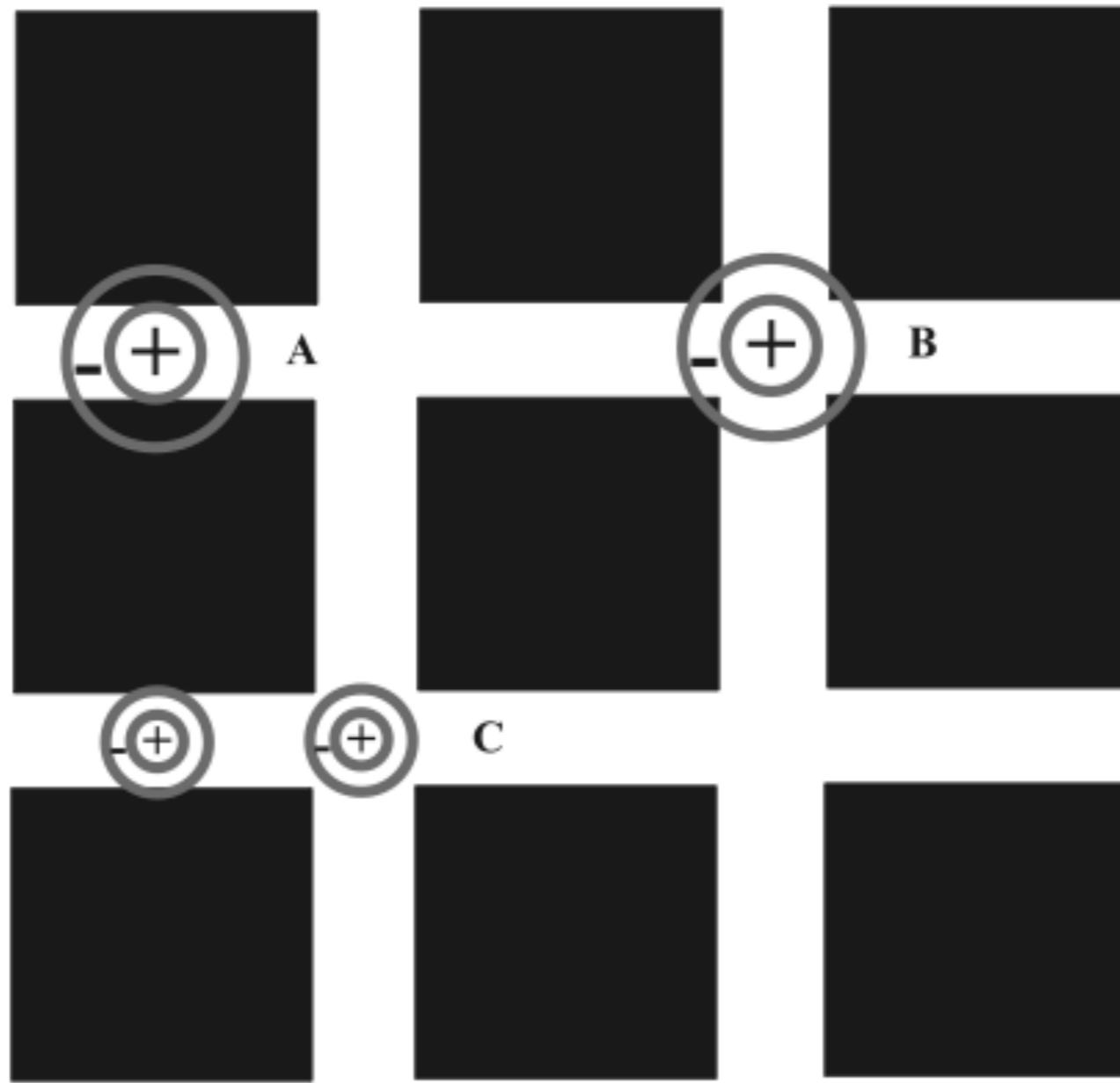


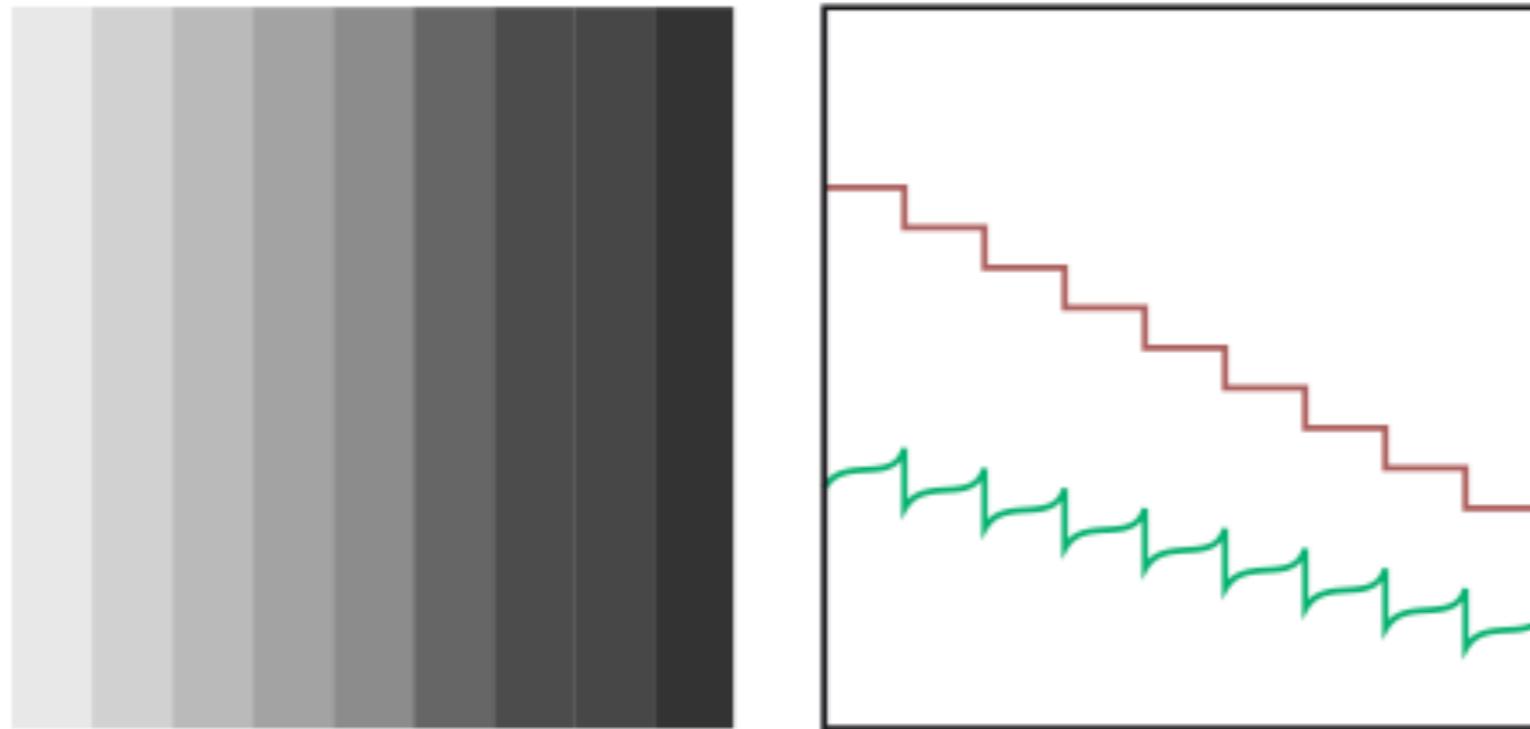
**luminance  $L$**

$$\frac{dL}{dx}$$



# Hermann grid effect (Brightness Adaptation)

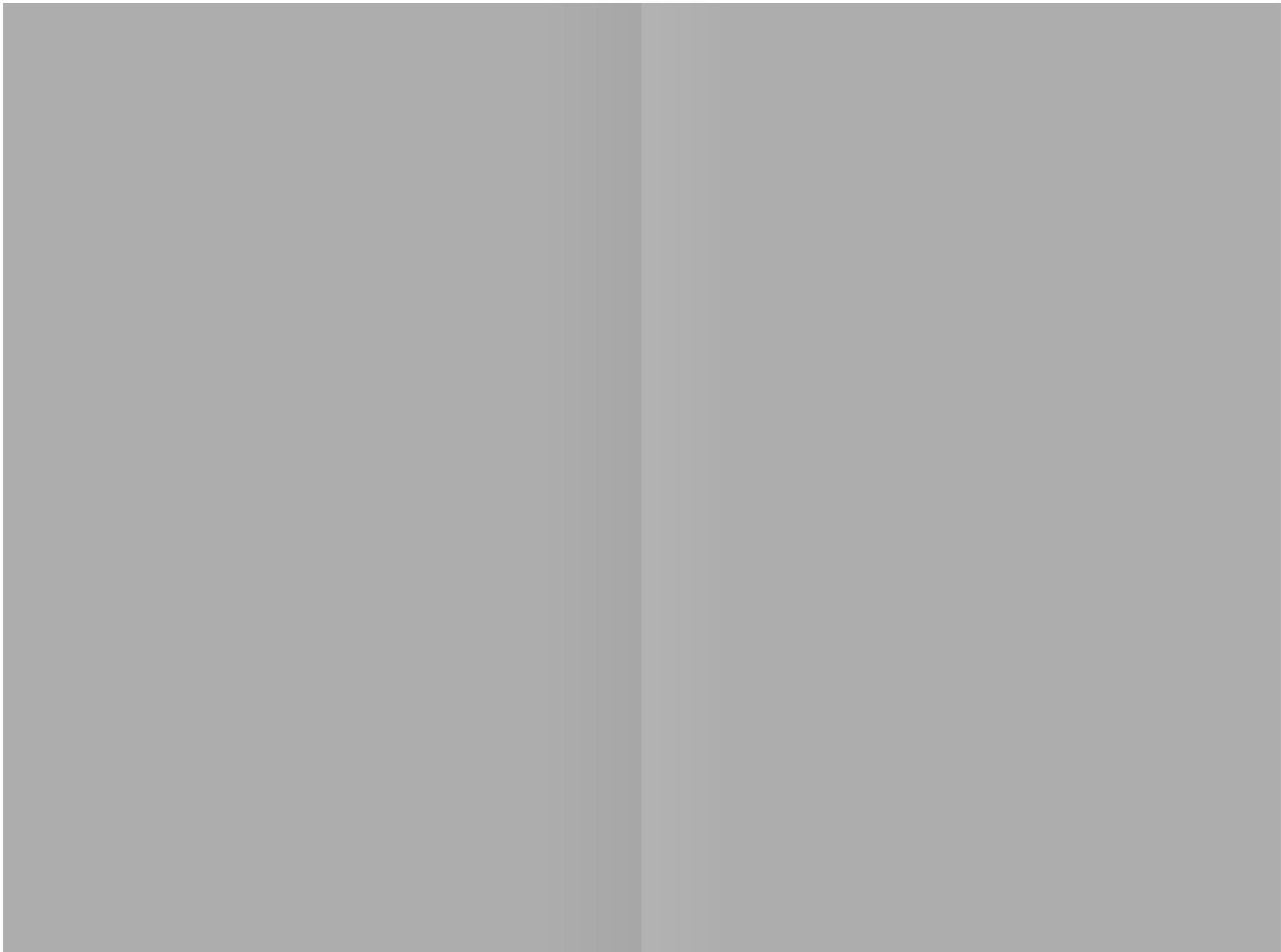




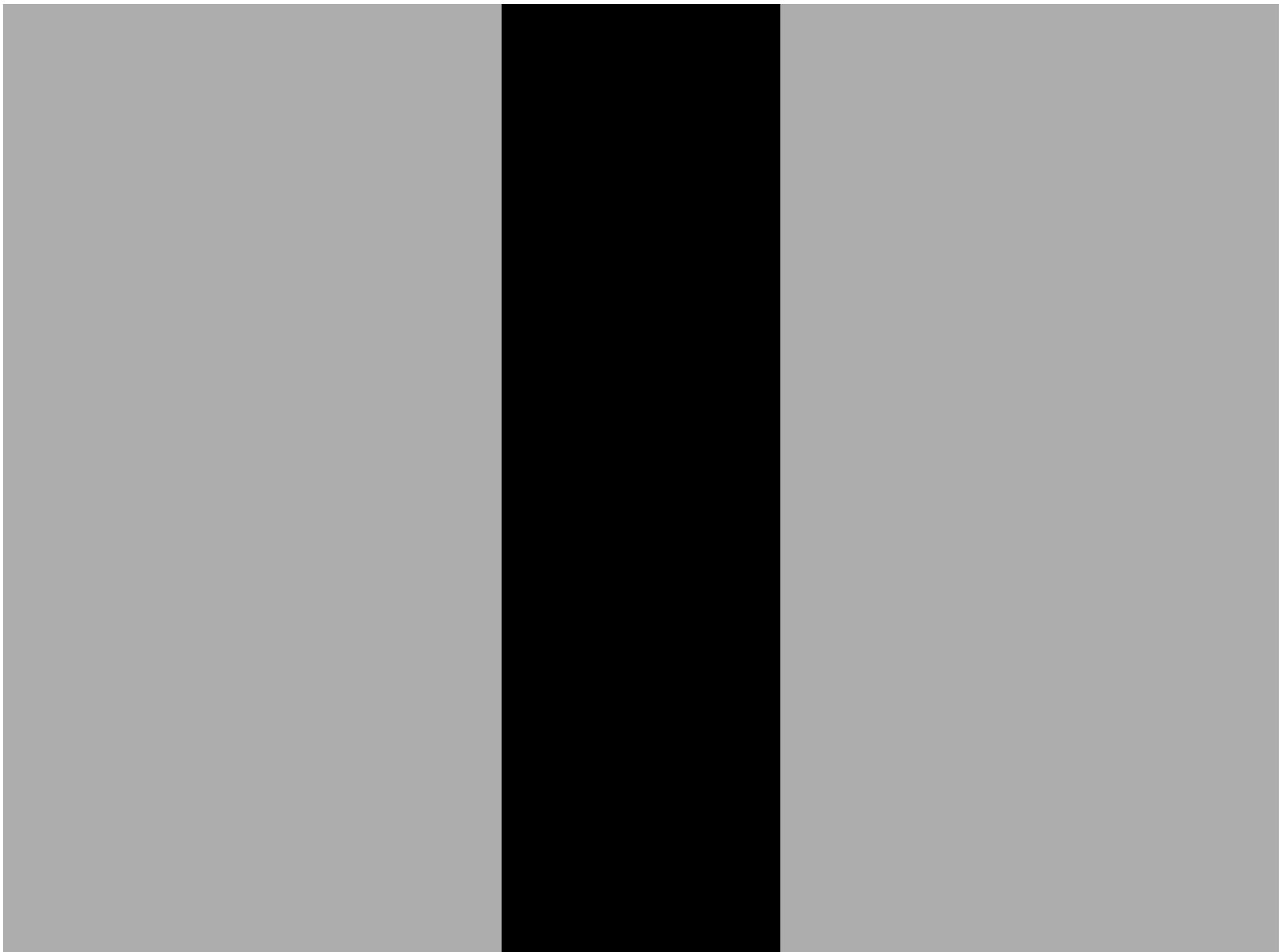
**Figure 3.7** The Chevreul illusion. The measured lightness pattern is shown by the staircase pattern on the right. What is perceived can be closely approximated by a DoG model. The lower plot on the right shows the application of a DoG filter to the staircase pattern shown above.

- The eye rapidly scans across the field of view while coming to momentary rest at each point of particular interest.
- At each of these points the eye adapts to the average brightness
- This phenomena is known as **local brightness adaptation**.
- The eye over-shoots/under-shoots at edges where the brightness changes rapidly. This causes ‘false perception’ of the intensities

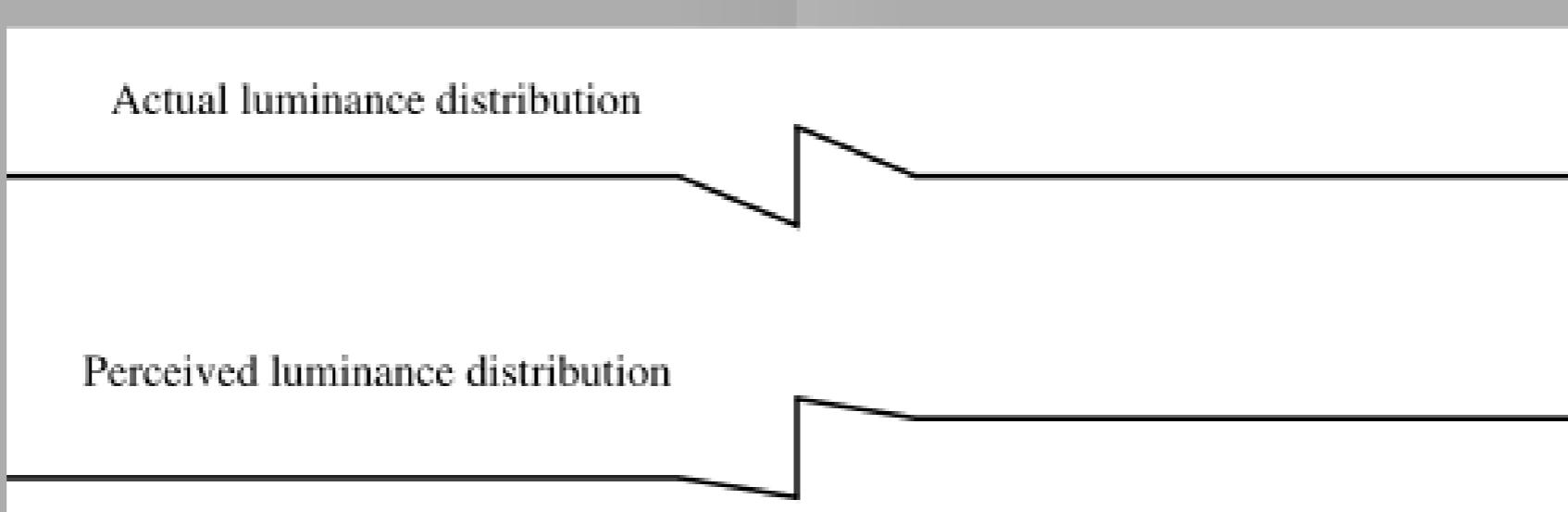
# Cornsweet Illusion



# Cornsweet Illusion



# Cornsweet Illusion



# Cornsweet Can Be Used to Enhance Edges



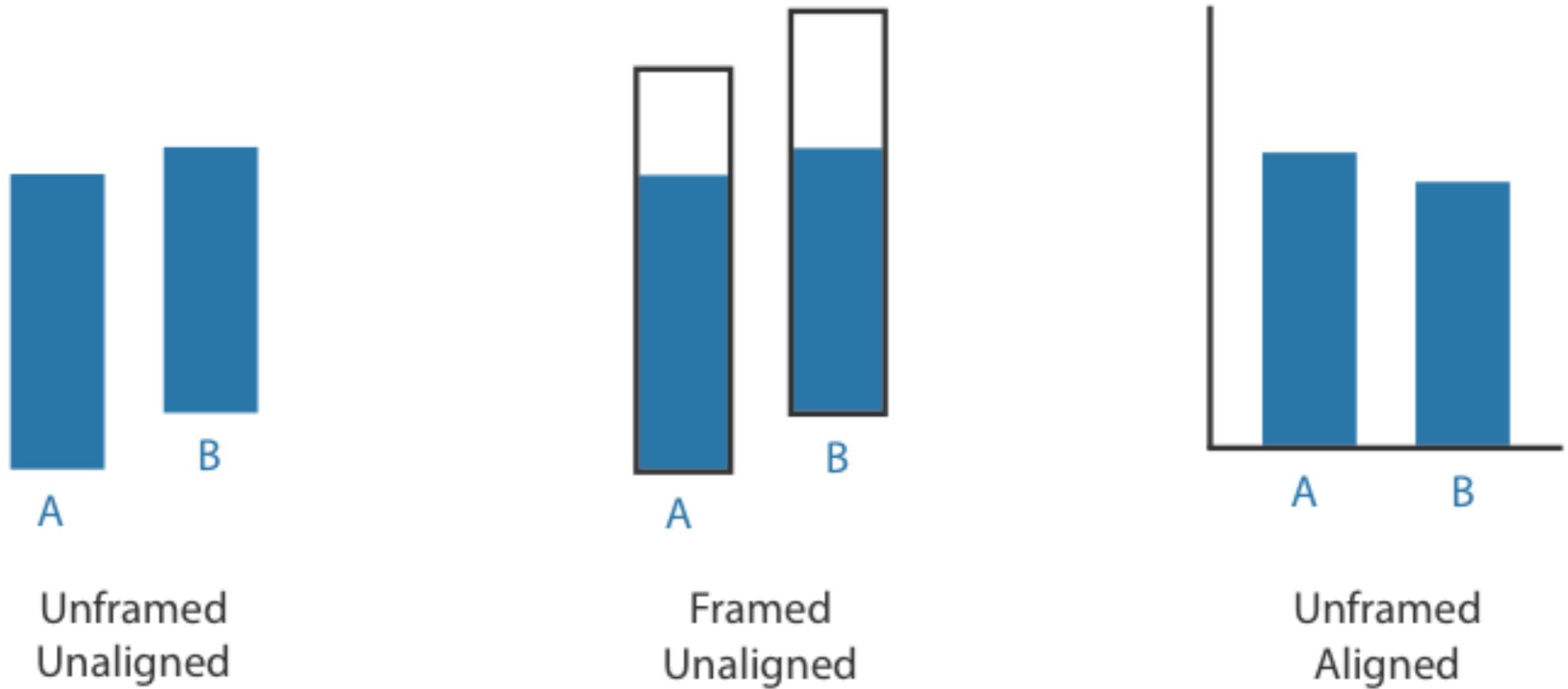
**Figure 3.12** Seurat deliberately enhanced edge contrast to make his figures stand out.

# Takeaways for Visualization

- Our visual system sees differences, not absolute values, and is attracted to **edges** (regions where values change).
  - Maximize the contrast with the background if the outlines of shapes are important.
  - Eyes are mostly sensitive to abrupt changes in luminance.
- Note: color effects edge contrast too, but we have **higher** contrast sensitivity in the luminance than in the chrominance channel.

# **Relativity of Perception**

# Weber's Law



- We judge on relative, not absolute, differences
- Specifically, ratio of intensity increment to background is constant.
- The perceived minimum increment is **just noticeable difference**
- Change the background, change the increment

# Relative Differences



# **Axis of Alignment**

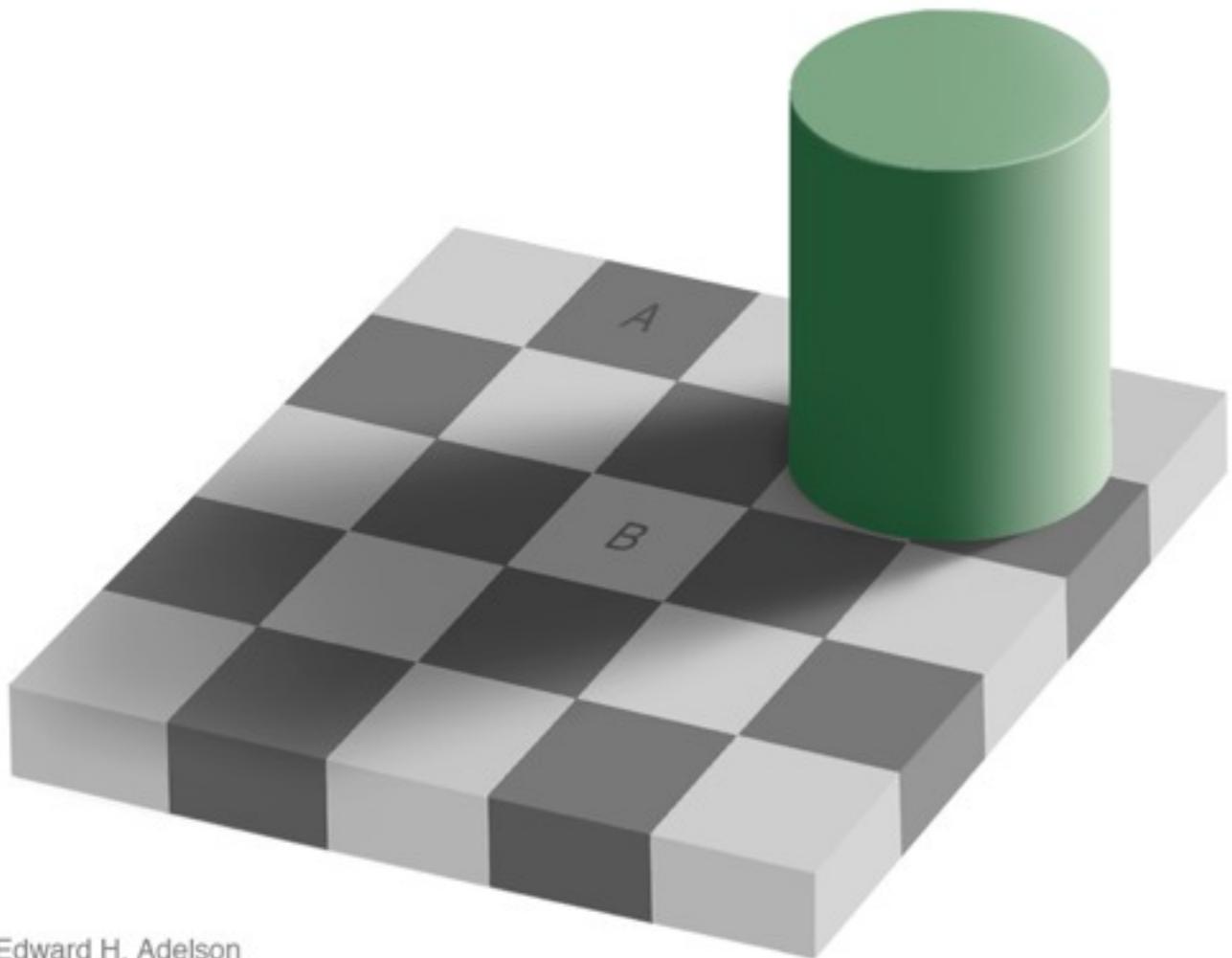
# Axis of Alignment



# Axis of Alignment



# Simultaneous Contrast

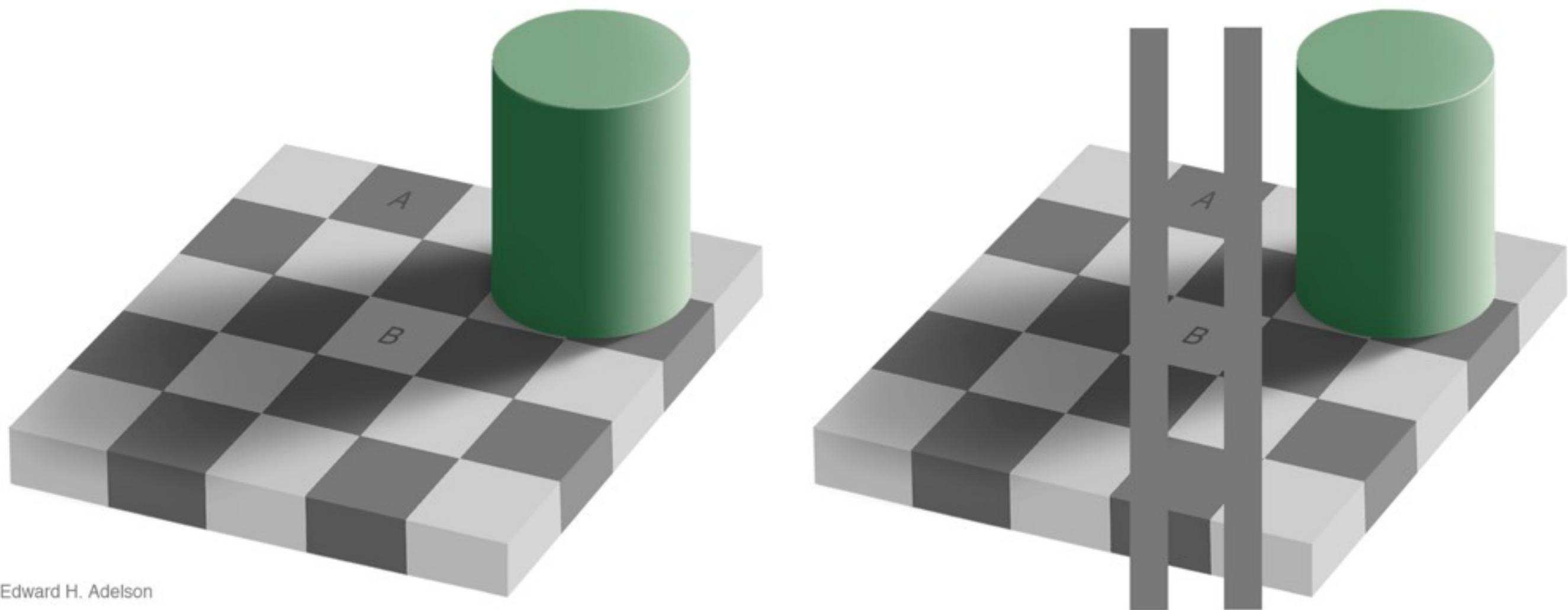


- Perceived color is highly context dependent
- Variable lighting and background conditions affect what we see.

Edward H. Adelson

[http://persci.mit.edu/ media/gallery/checkershadow\\_double\\_full.jpg](http://persci.mit.edu/media/gallery/checkershadow_double_full.jpg)

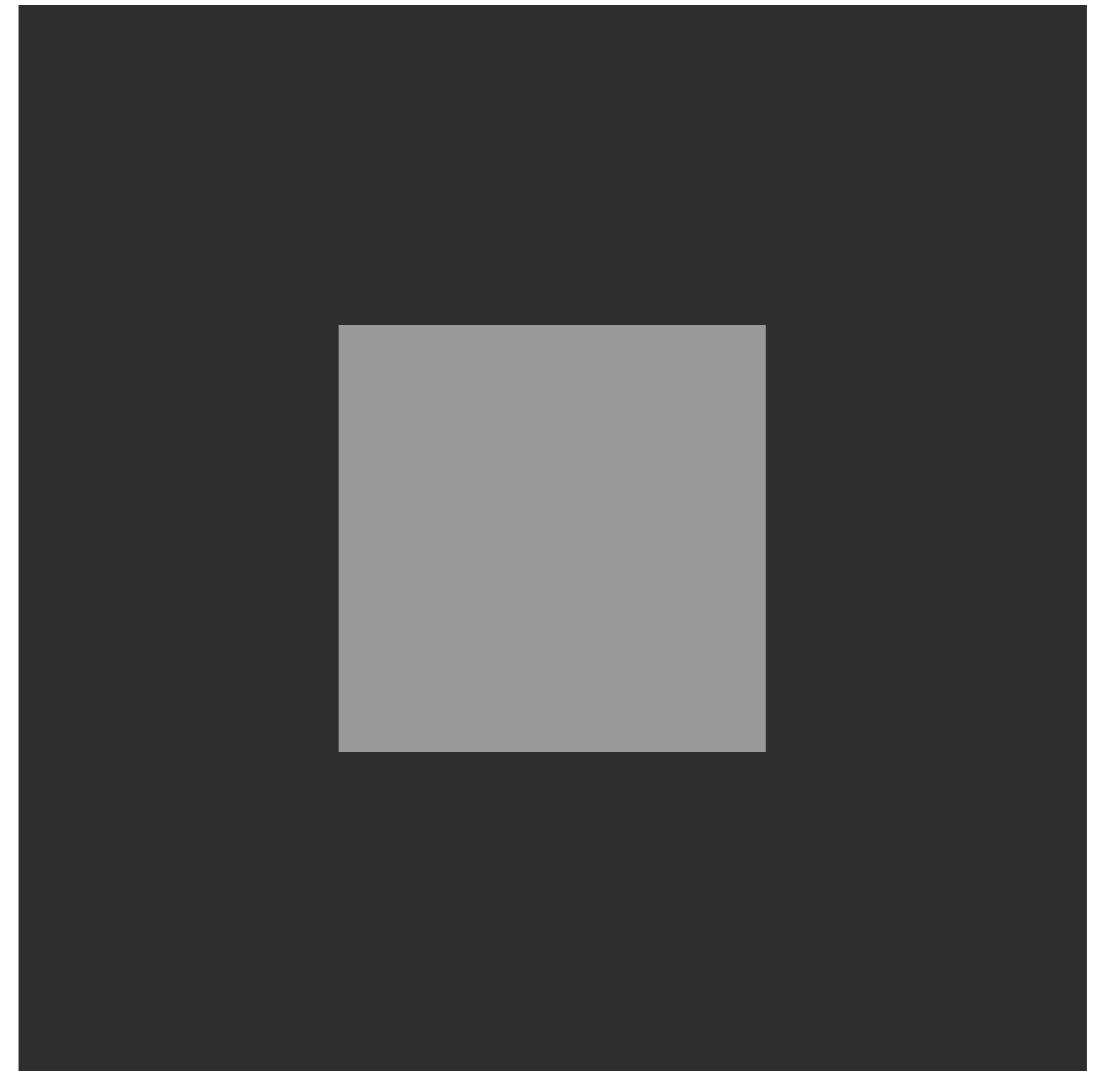
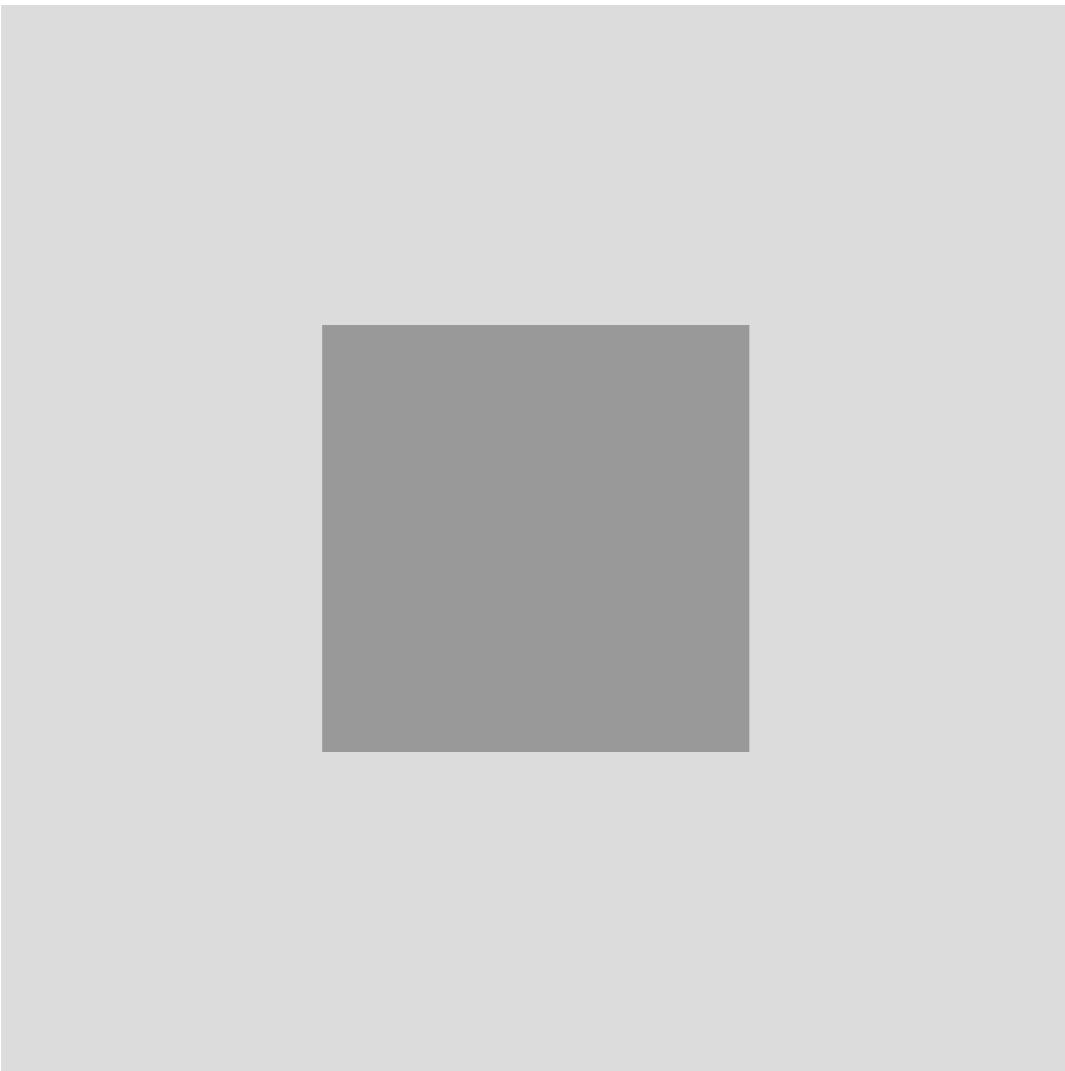
# Simultaneous Contrast



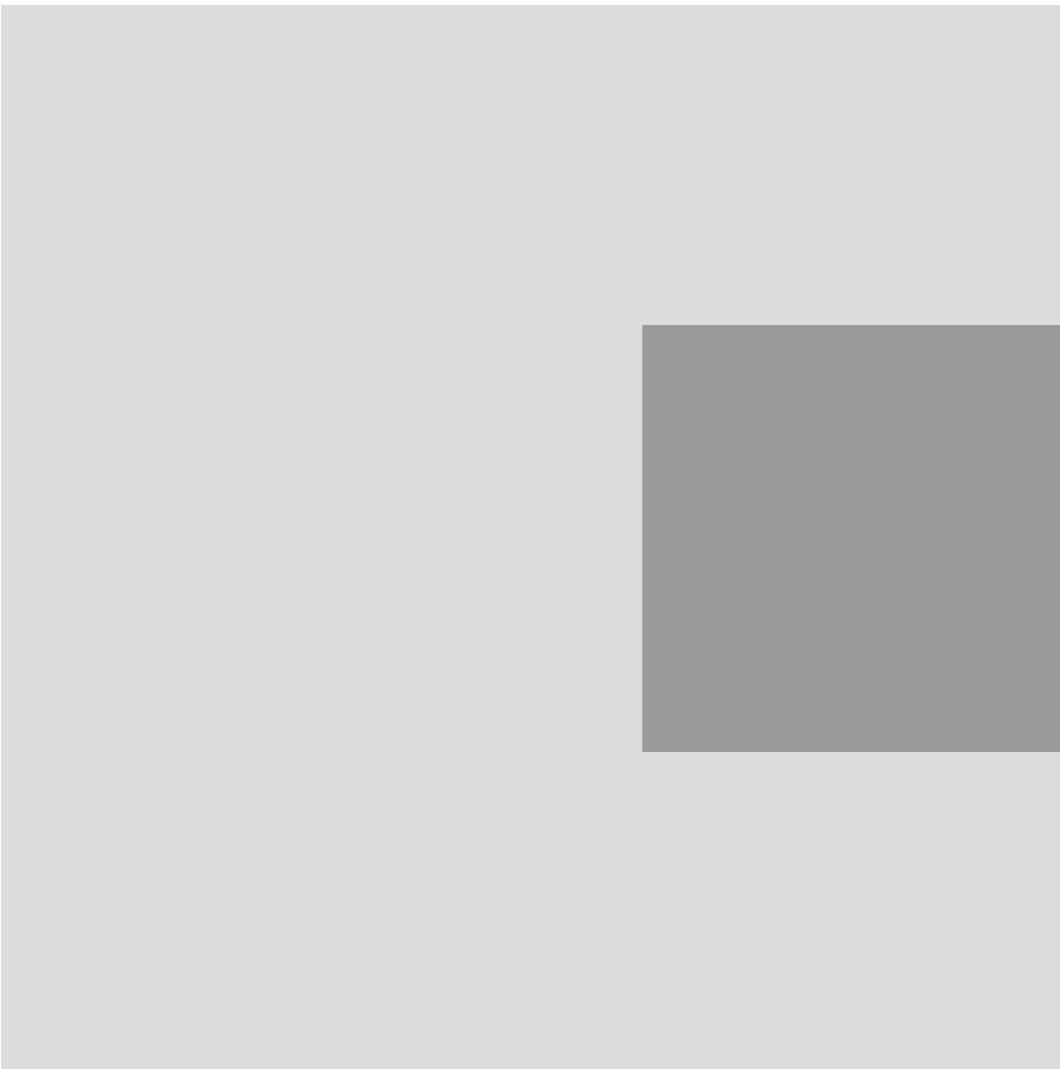
Edward H. Adelson

[http://persci.mit.edu/ media/gallery/checkershadow\\_double\\_full.jpg](http://persci.mit.edu/media/gallery/checkershadow_double_full.jpg)

# Simultaneous Contrast



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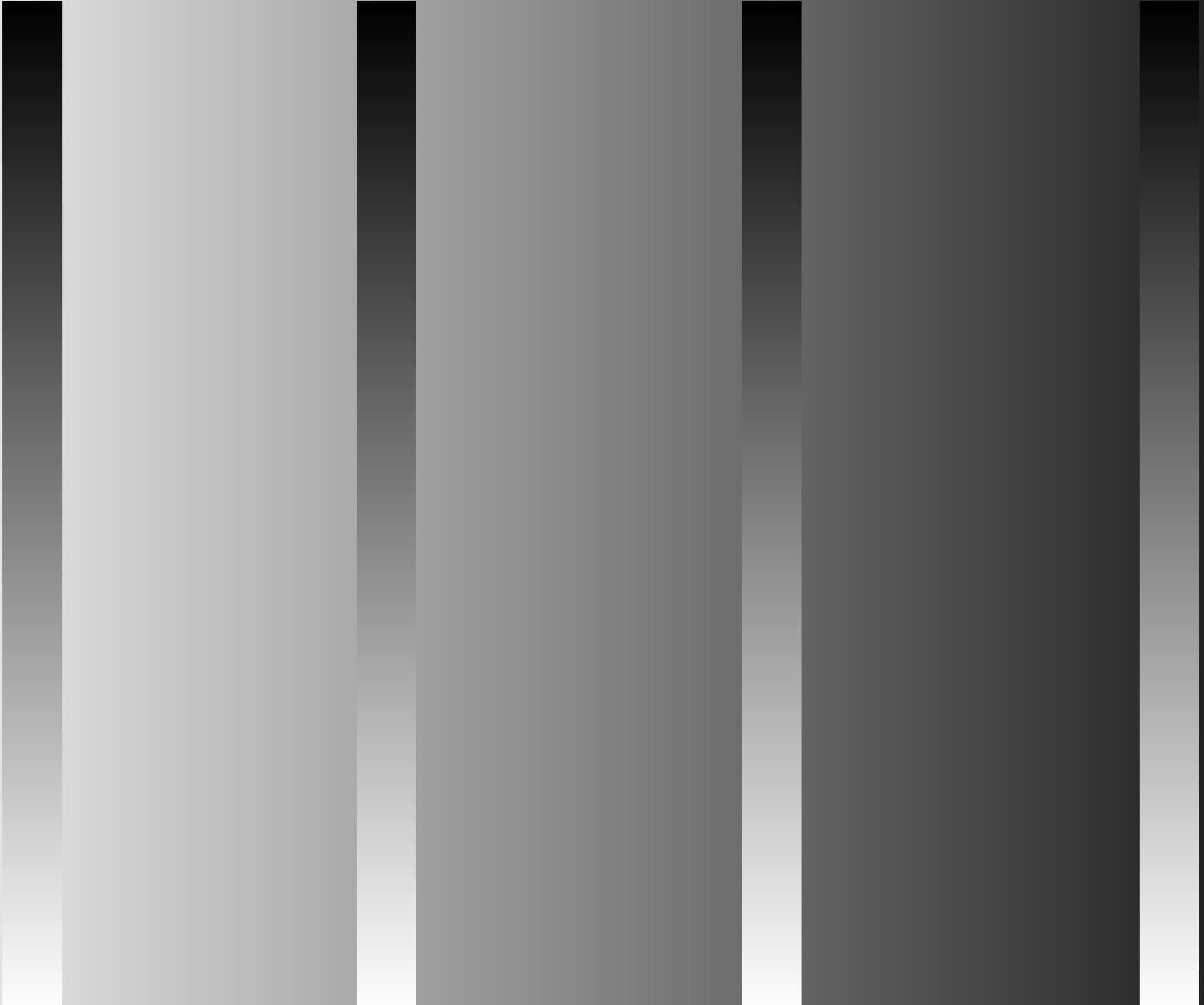
# Simultaneous Contrast



# Crispening

- Perceived differences between grayscale values are enhanced where the values are close to the background gray value





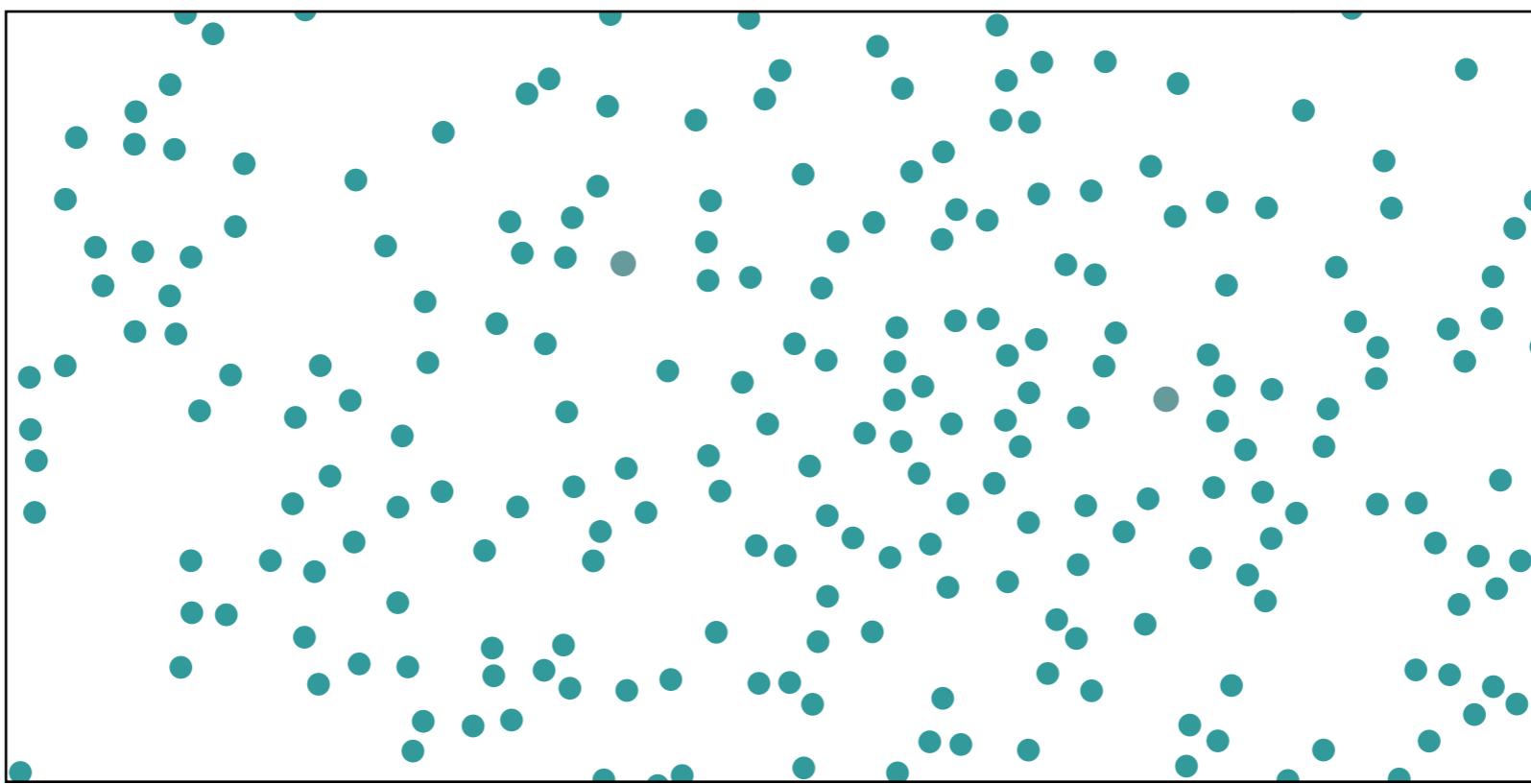


# Takeaways for Visualization

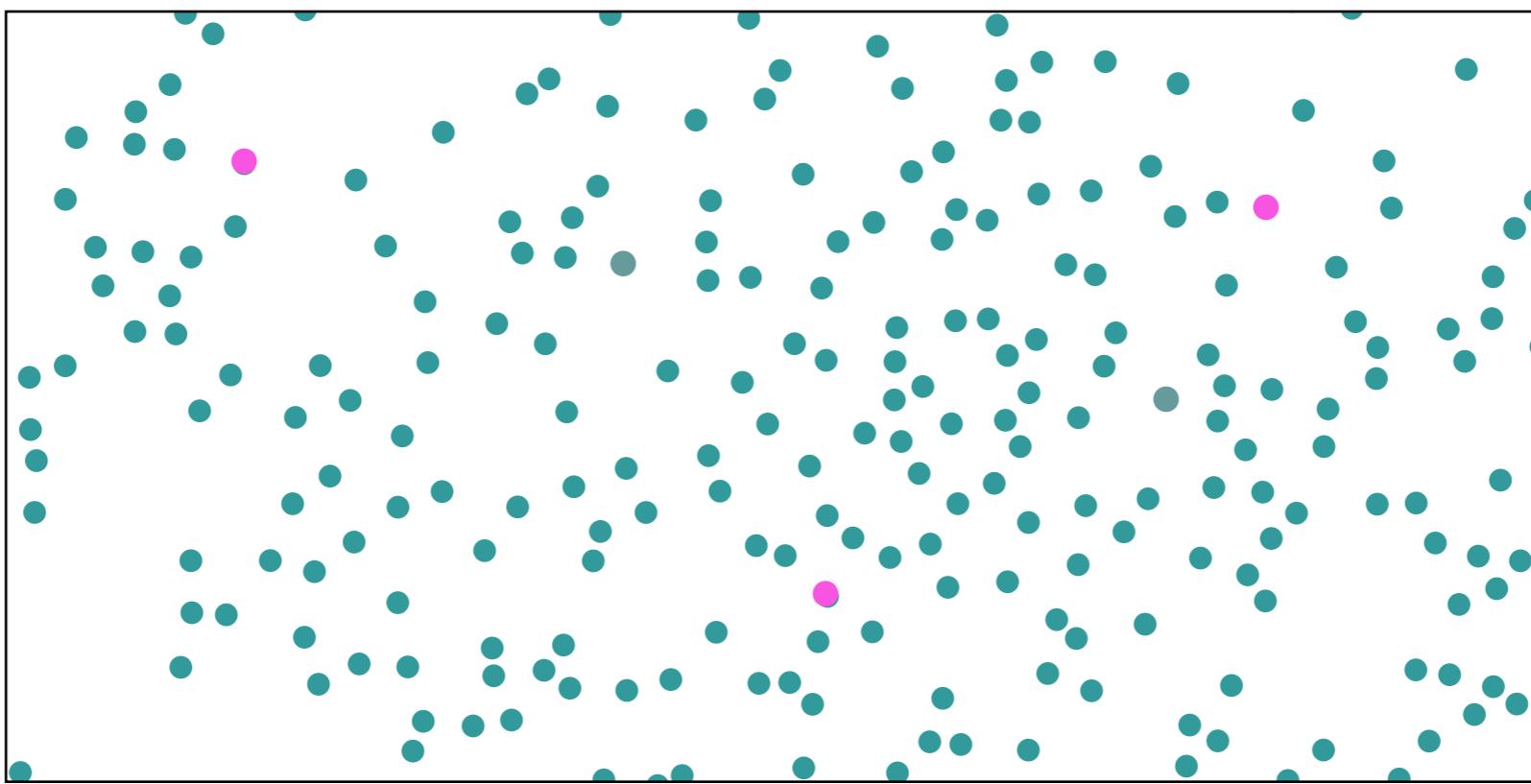
- Our visual system is based on judging relative, not absolute, differences
- When designing a visualization, one needs to take into account both the visualization of the data and the context around the visualization.

# Enhancing Visual Search

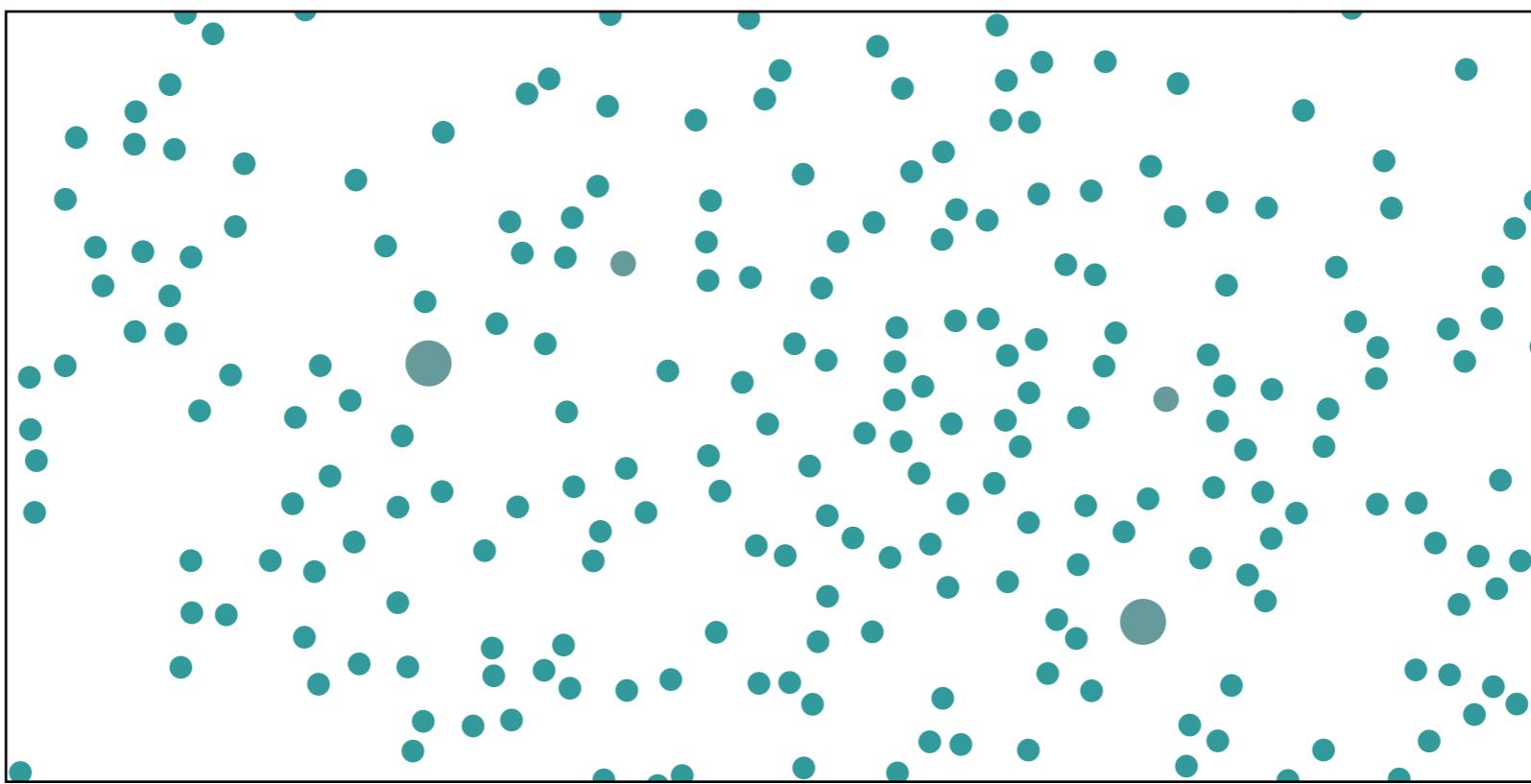
# Popout



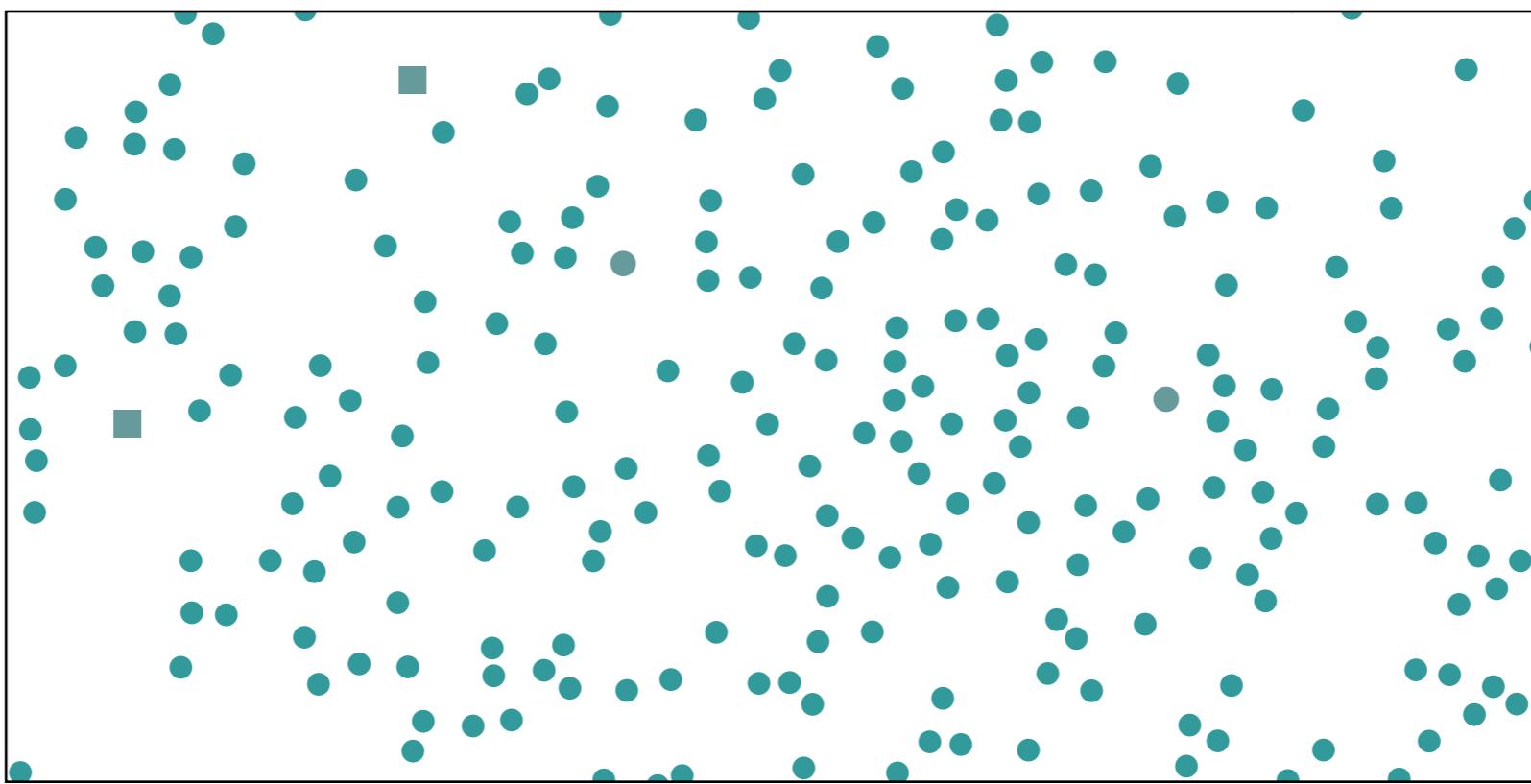
# Popout



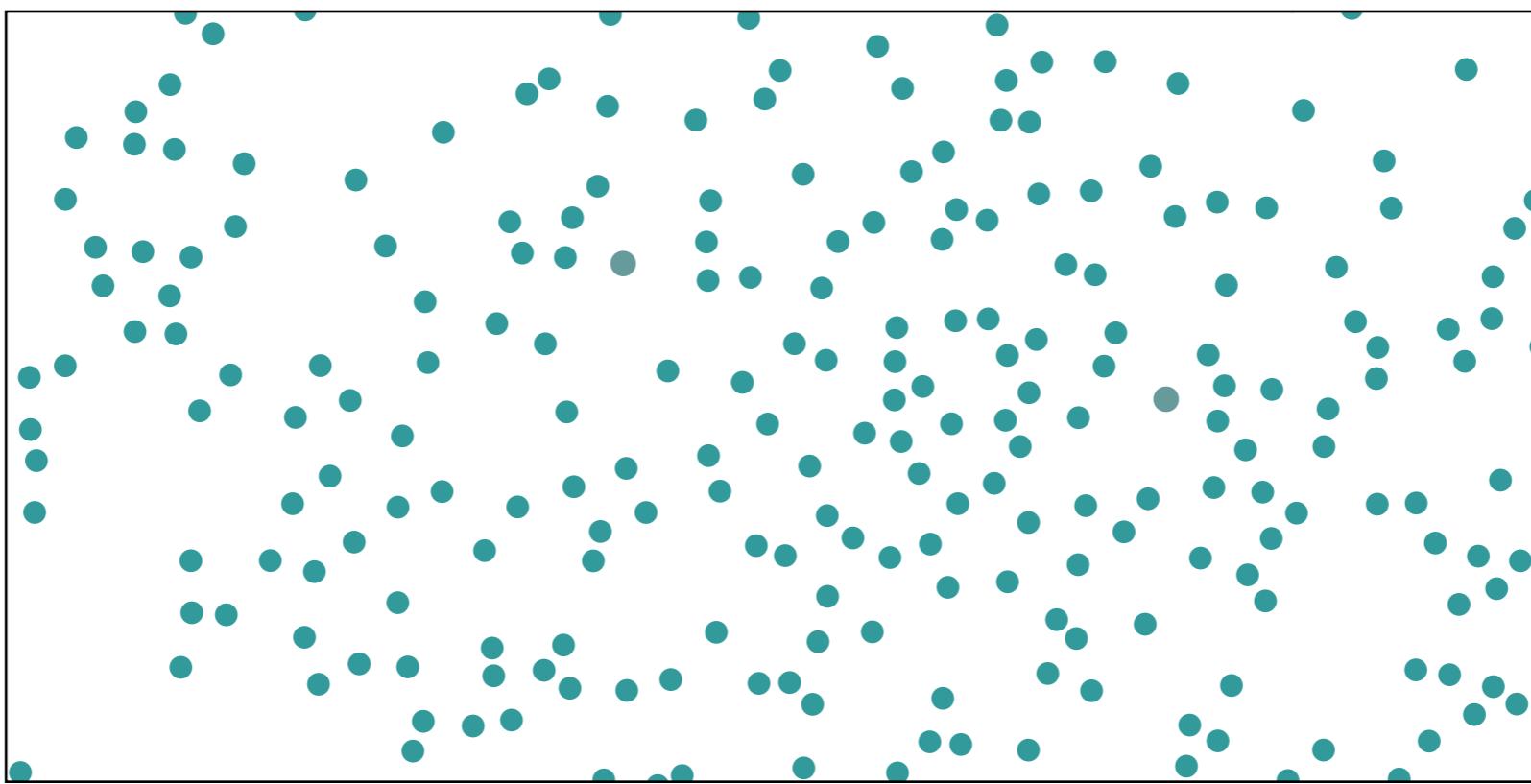
# Popout



# Popout

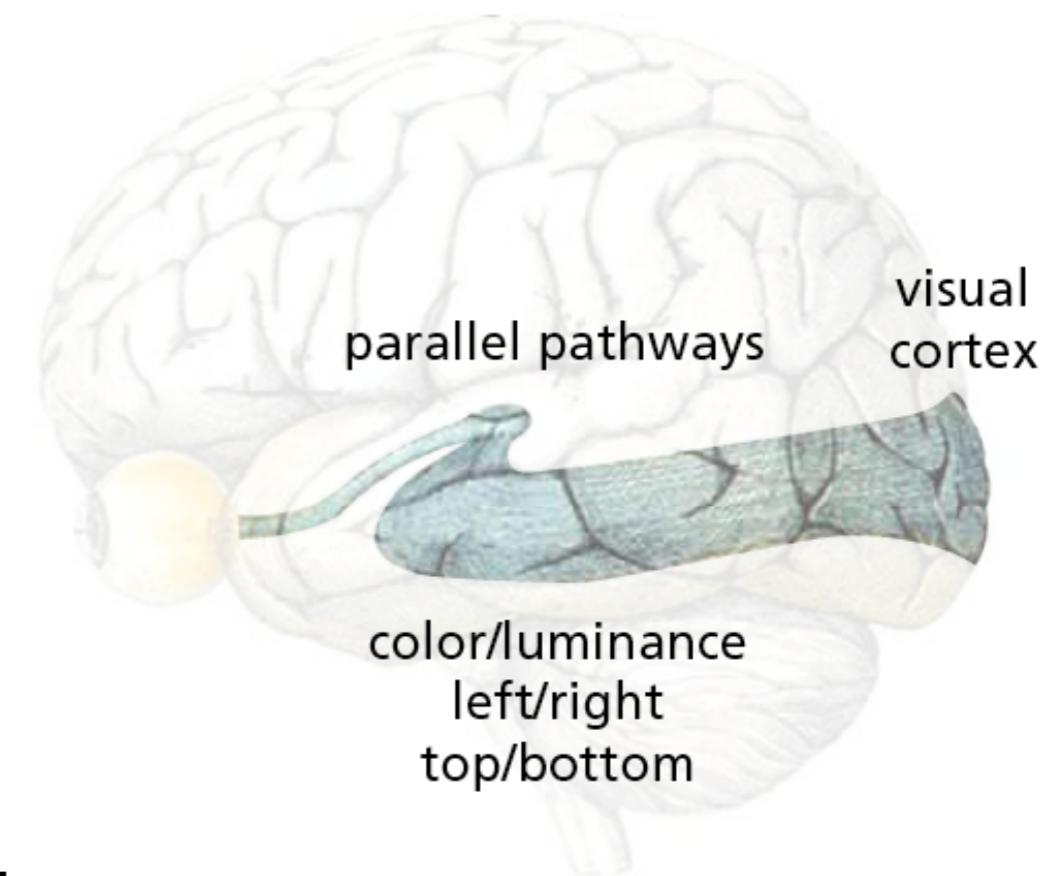


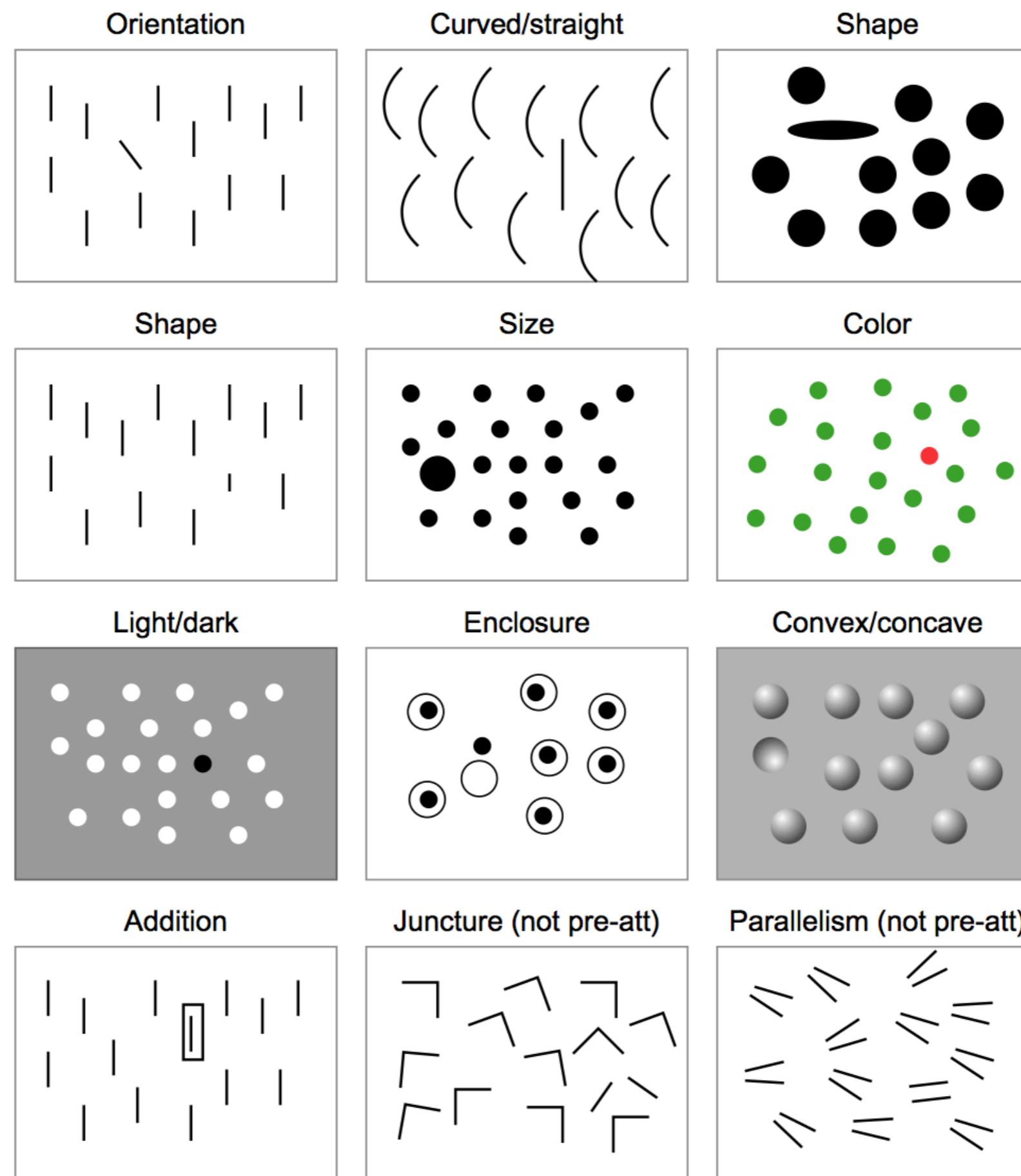
# Popout



# Popout

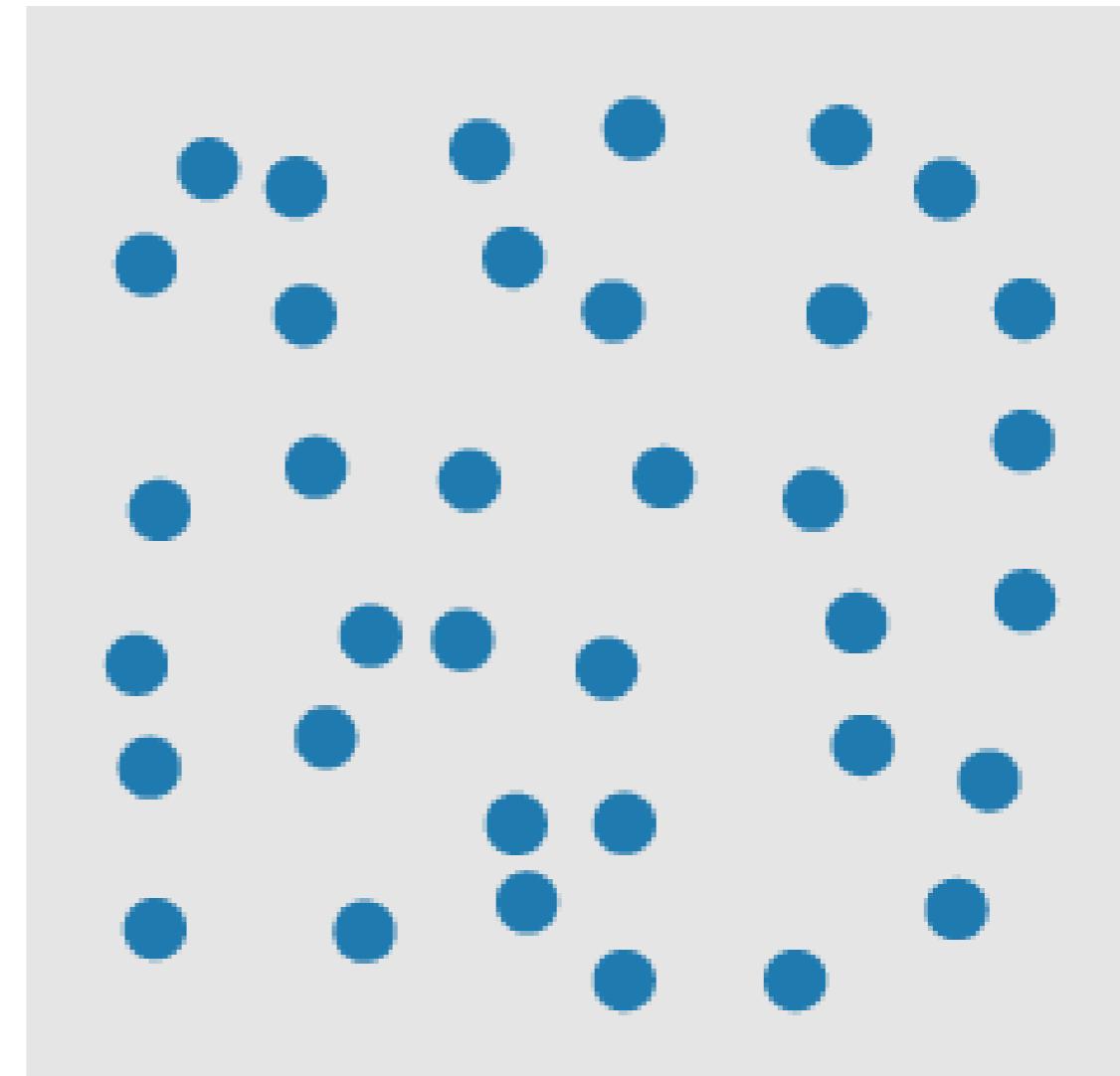
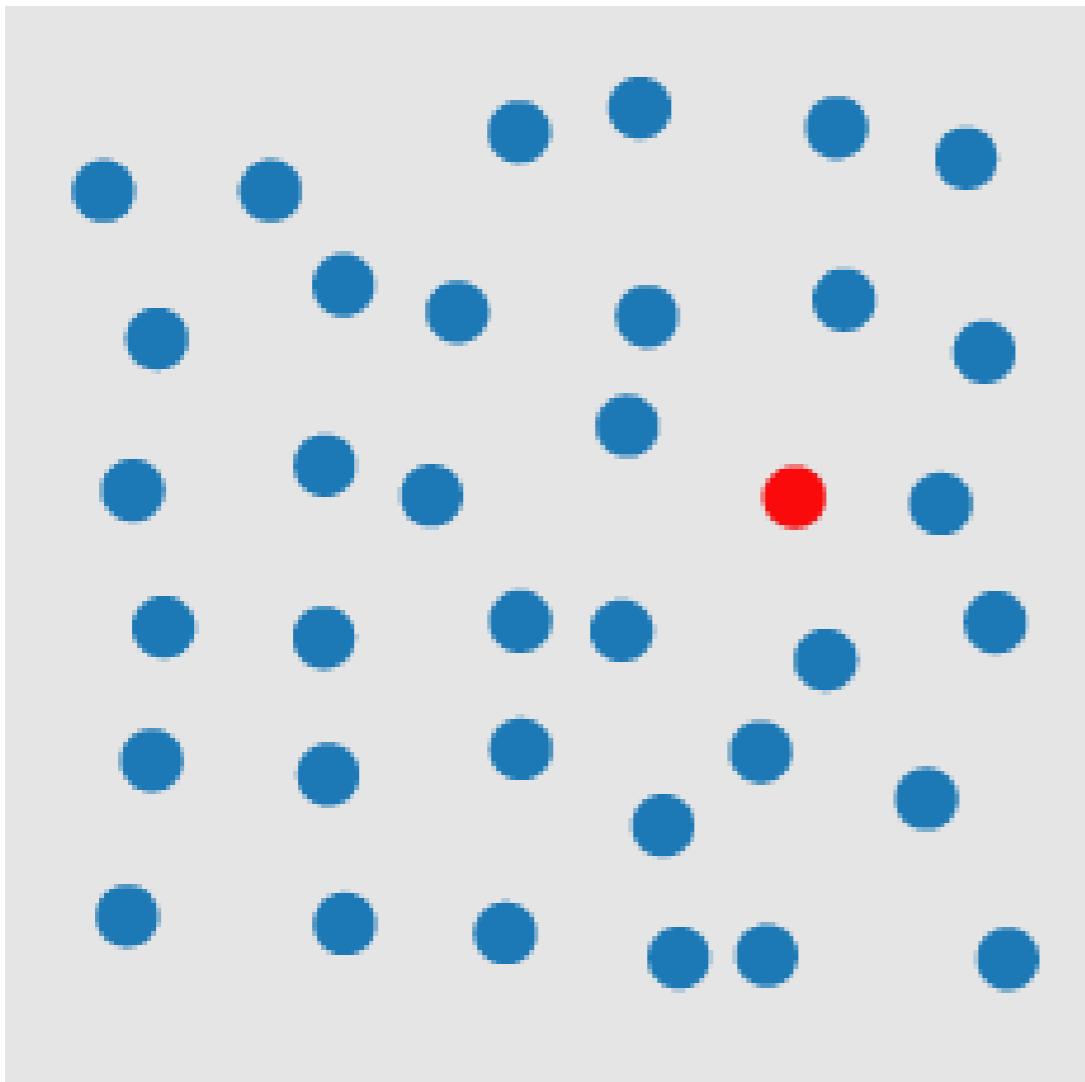
- **Pre-attentive processing** is the unconscious accumulation of information from the environment.
- Requires attention, despite name
- Happens fast: <200 ms -- hence “popout”
- Contrast of visual channels is what matters most.



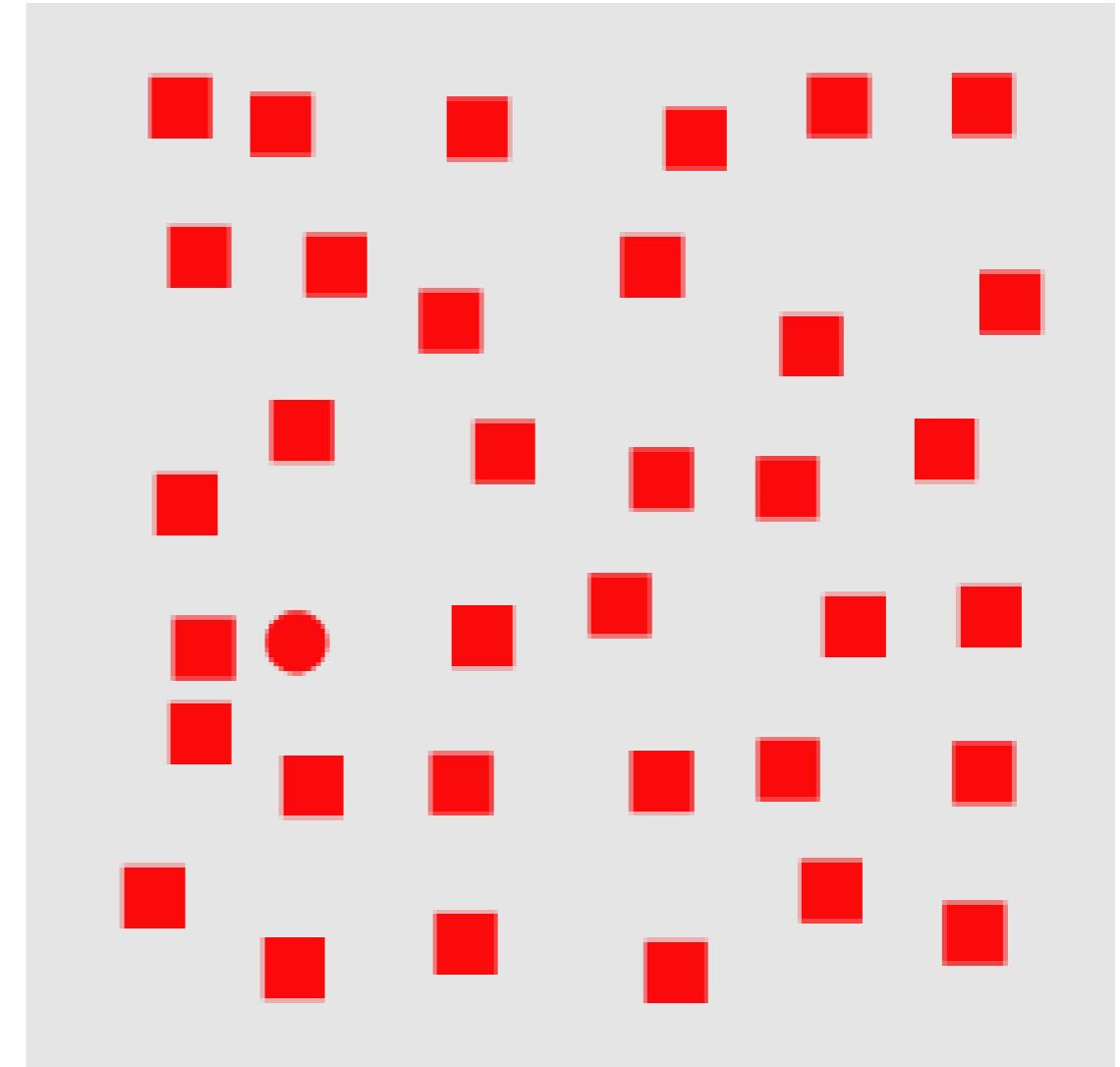
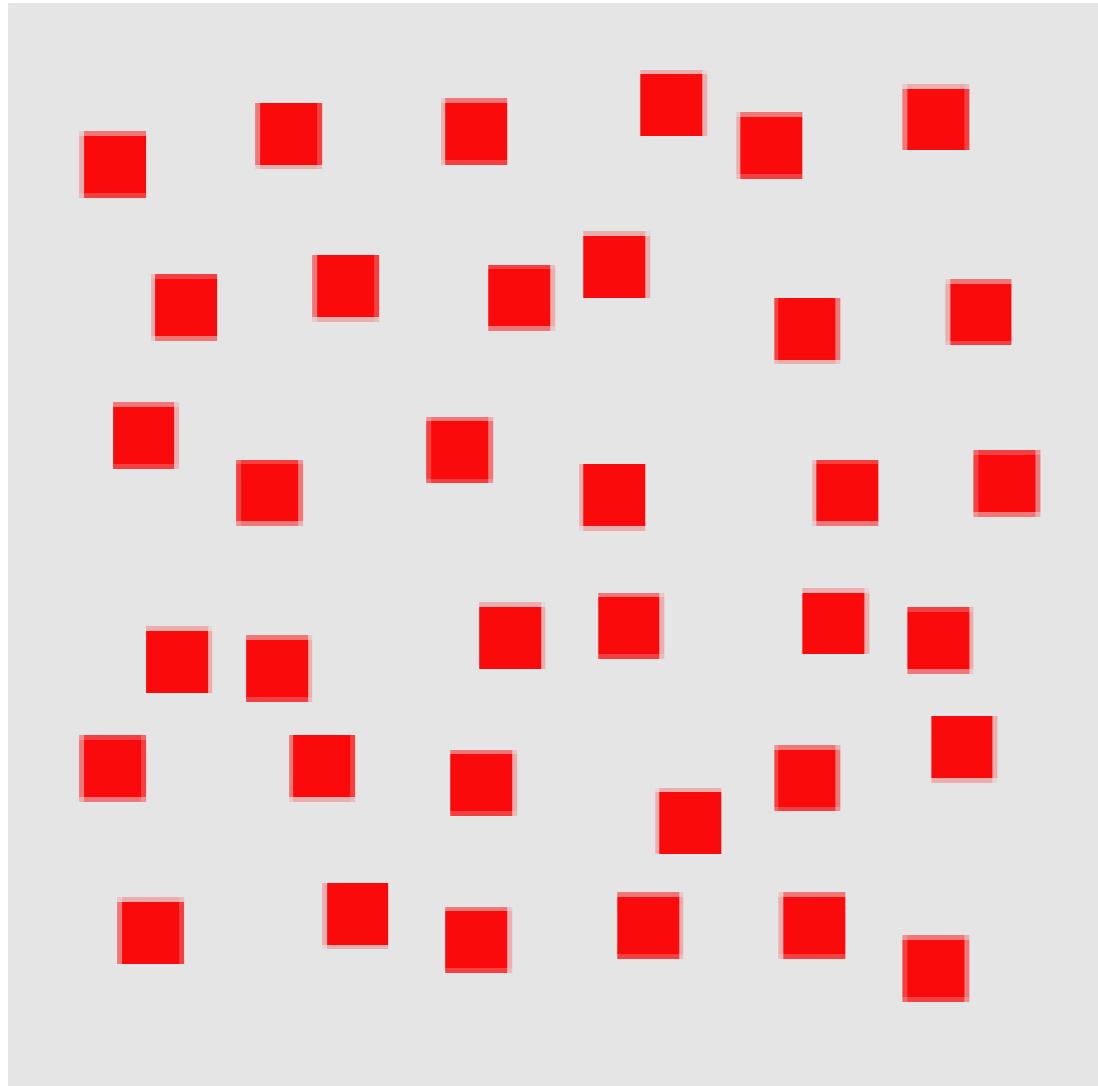


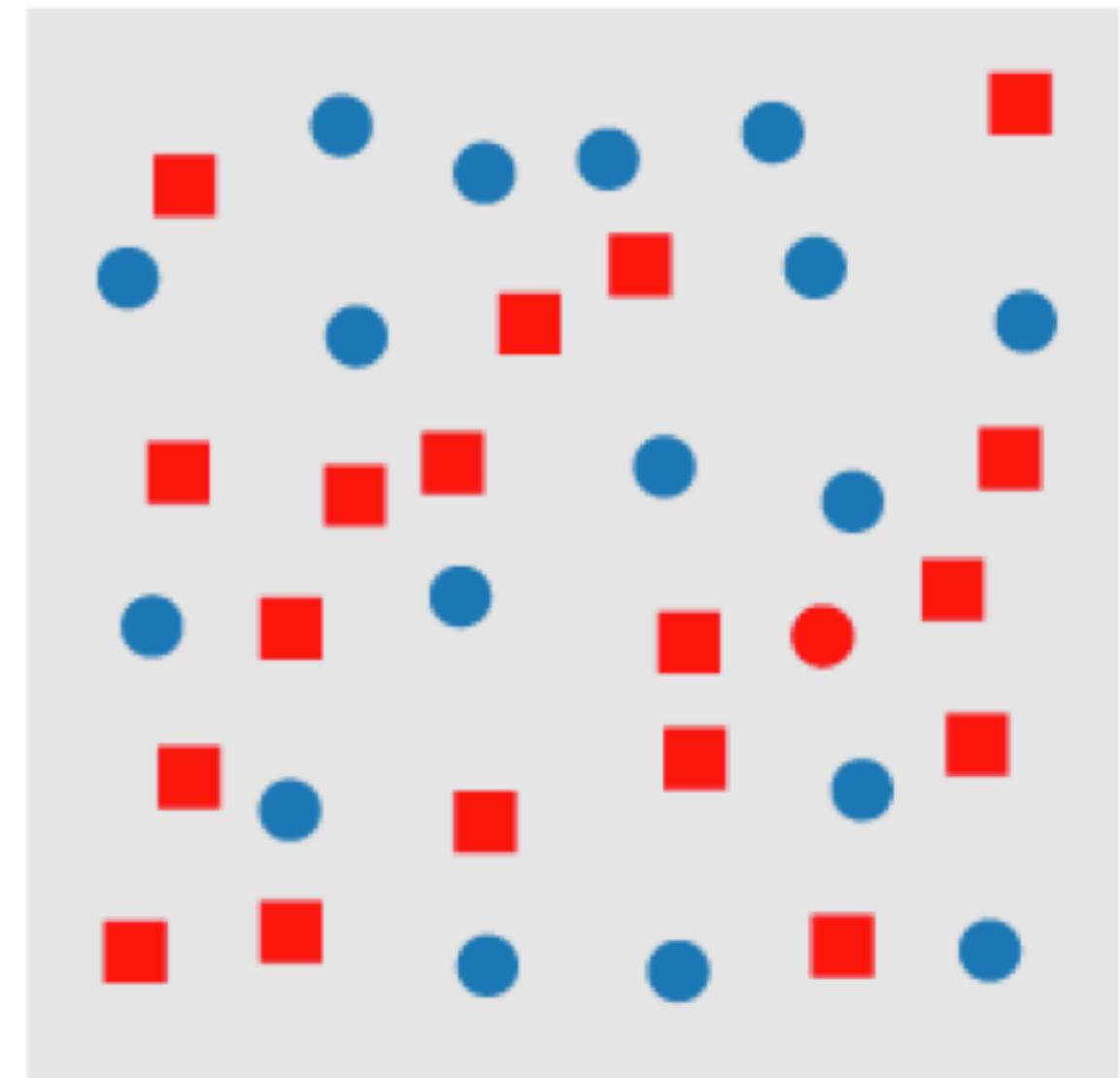
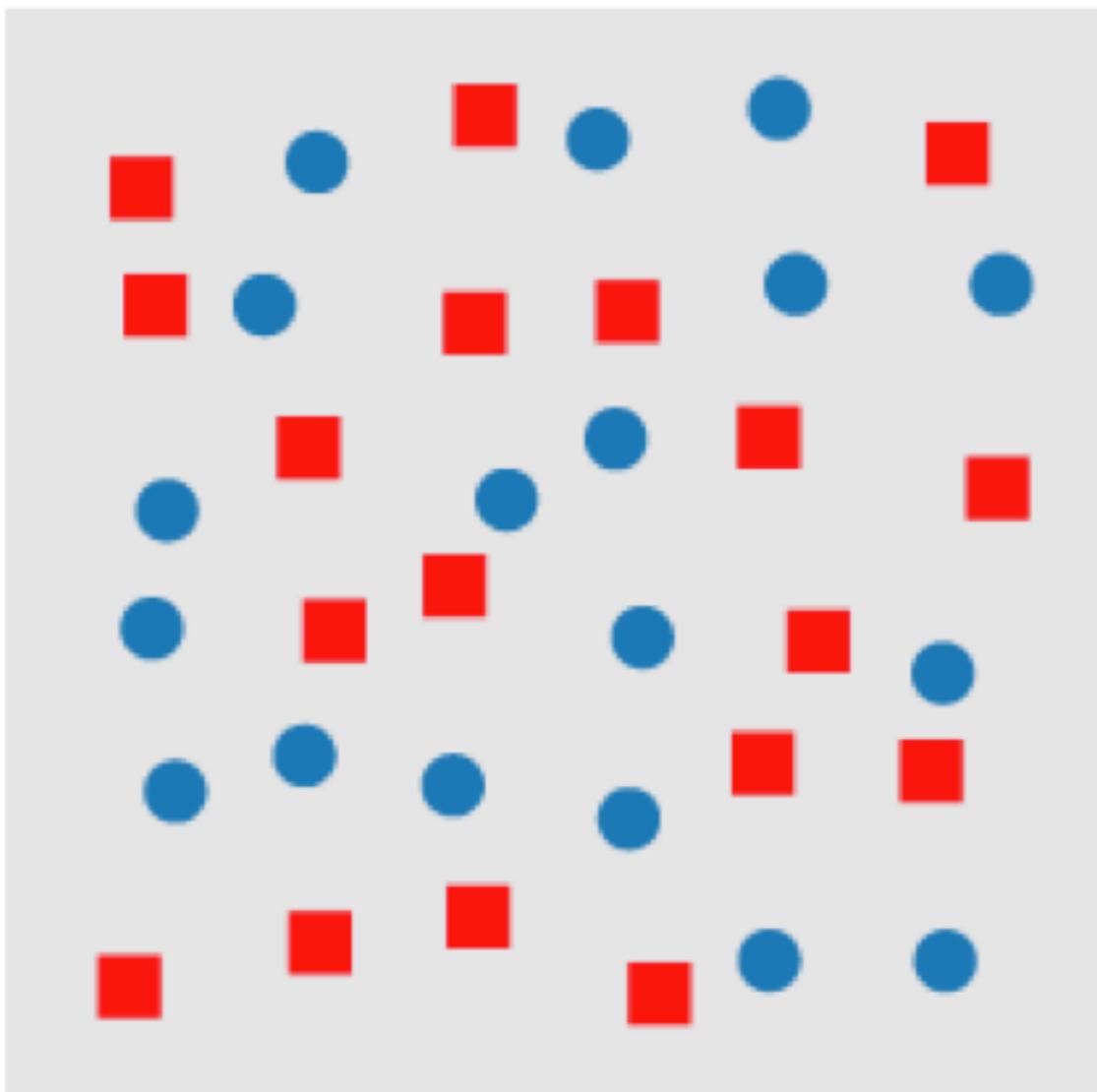
**Figure 5.11** Most of the preattentive examples given here can be accounted for by the processing characteristics of neurons in the primary visual cortex.

**Which Side Has the  
Outlier?**



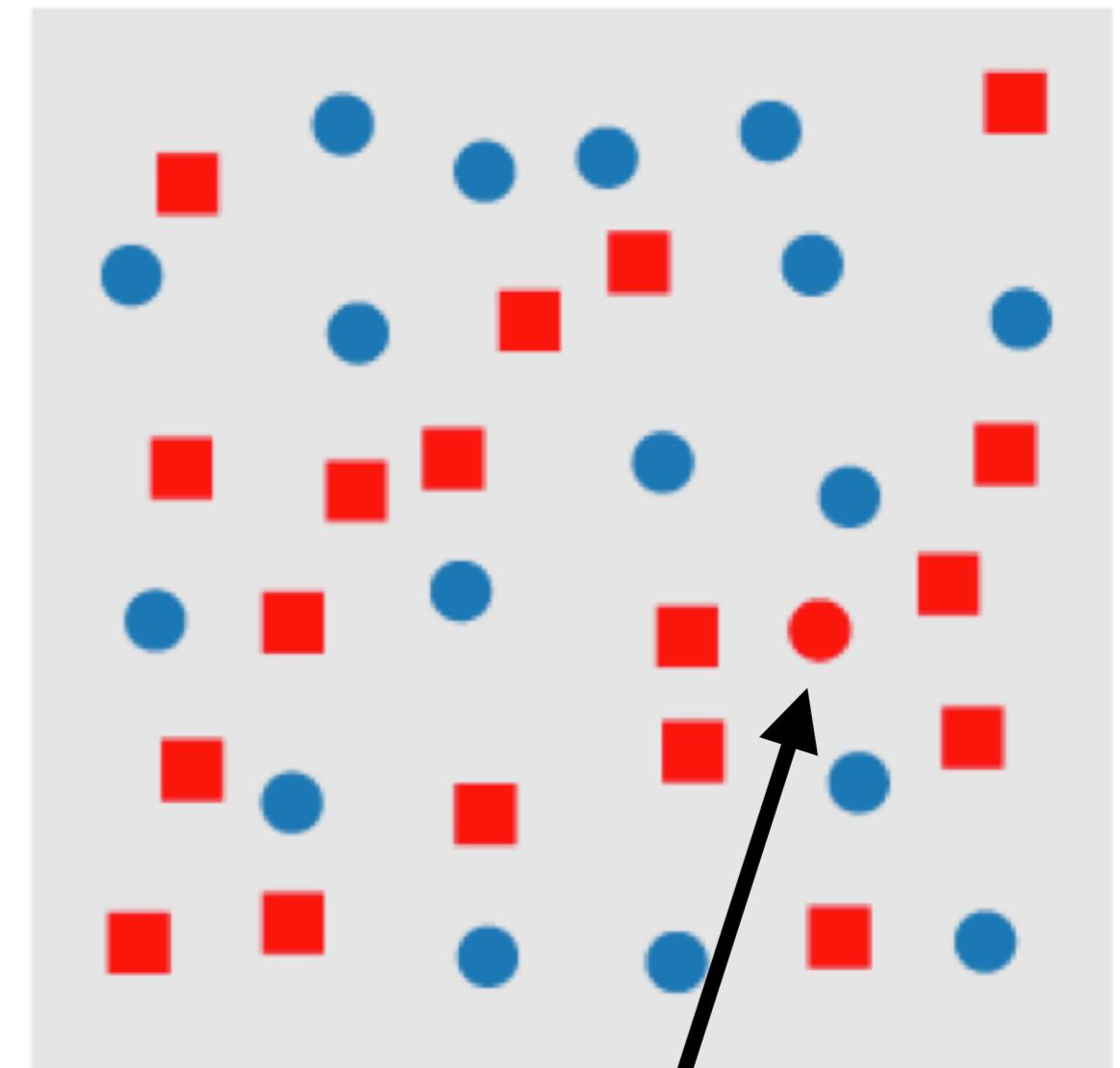
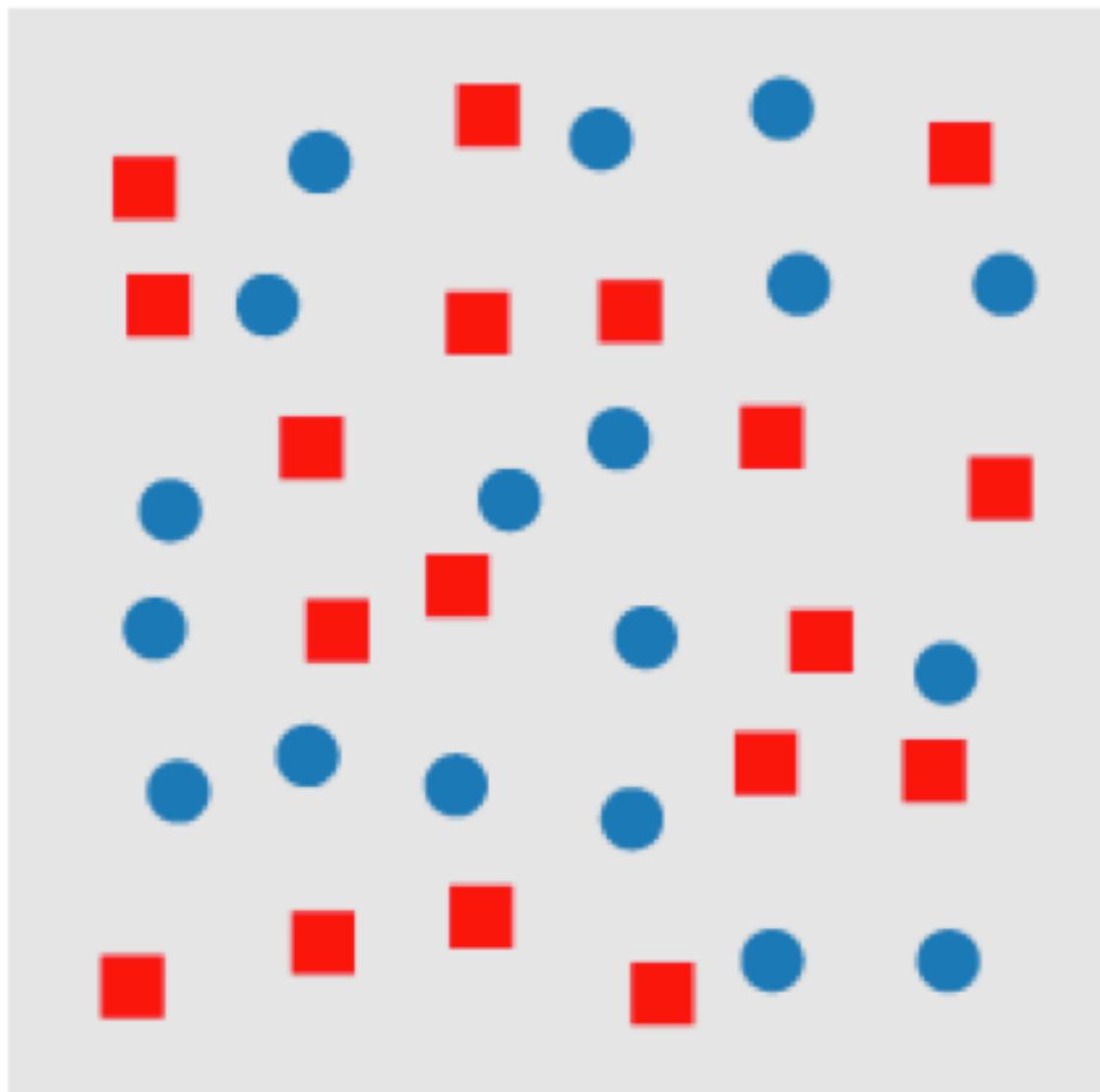
**Healey 2007, <https://www.csc2.ncsu.edu/faculty/healey/PP/>**





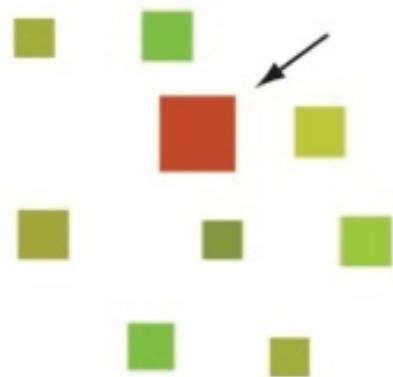
# Conjunction

(or, why to use a single channel at a time)

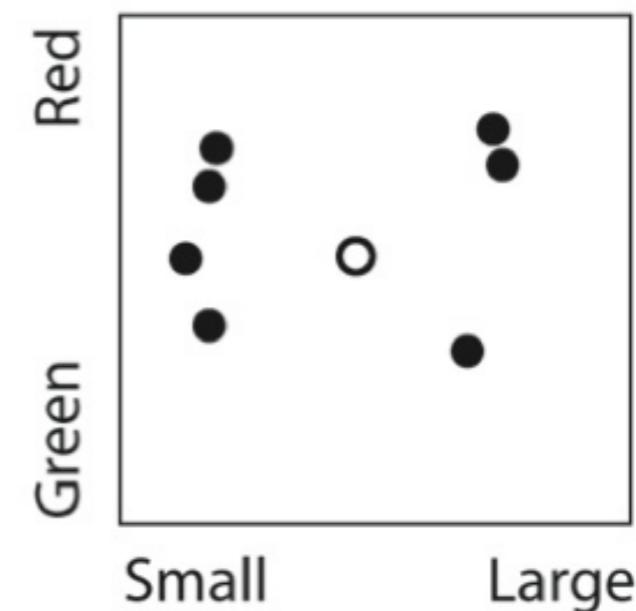
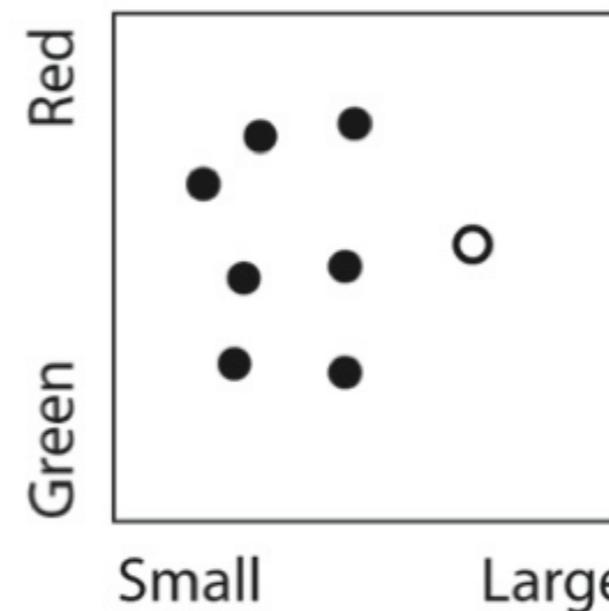
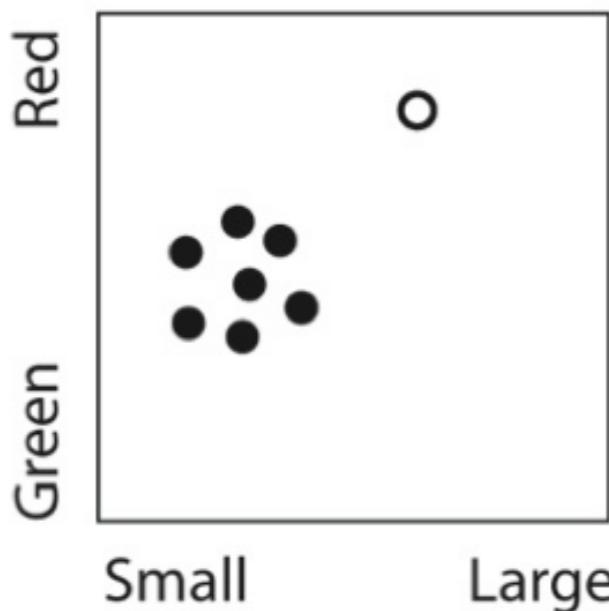


# Conjunction

Objects to be searched



Corresponding feature space diagrams

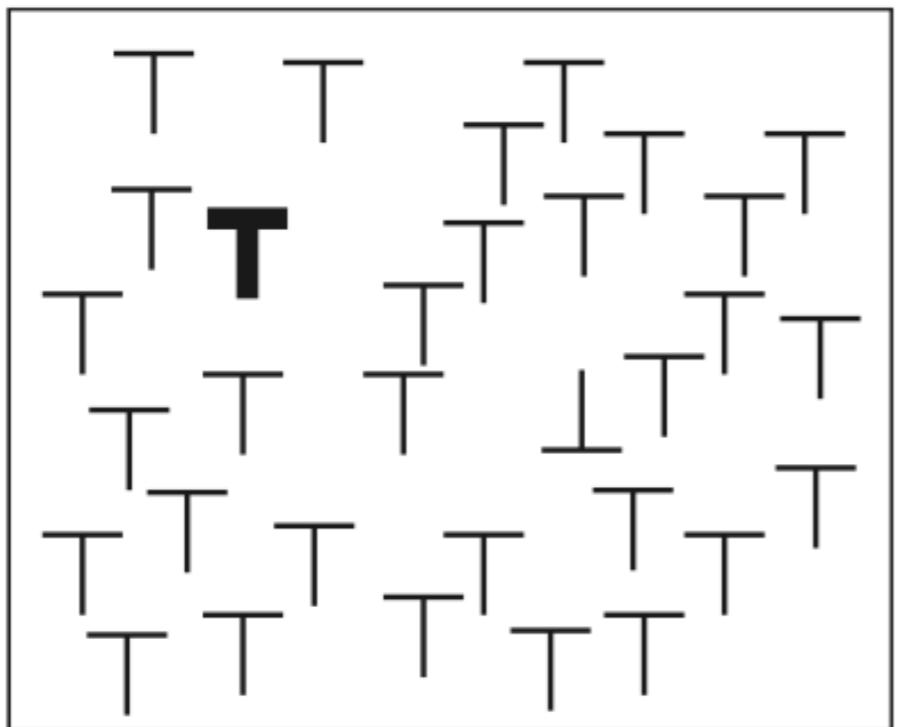


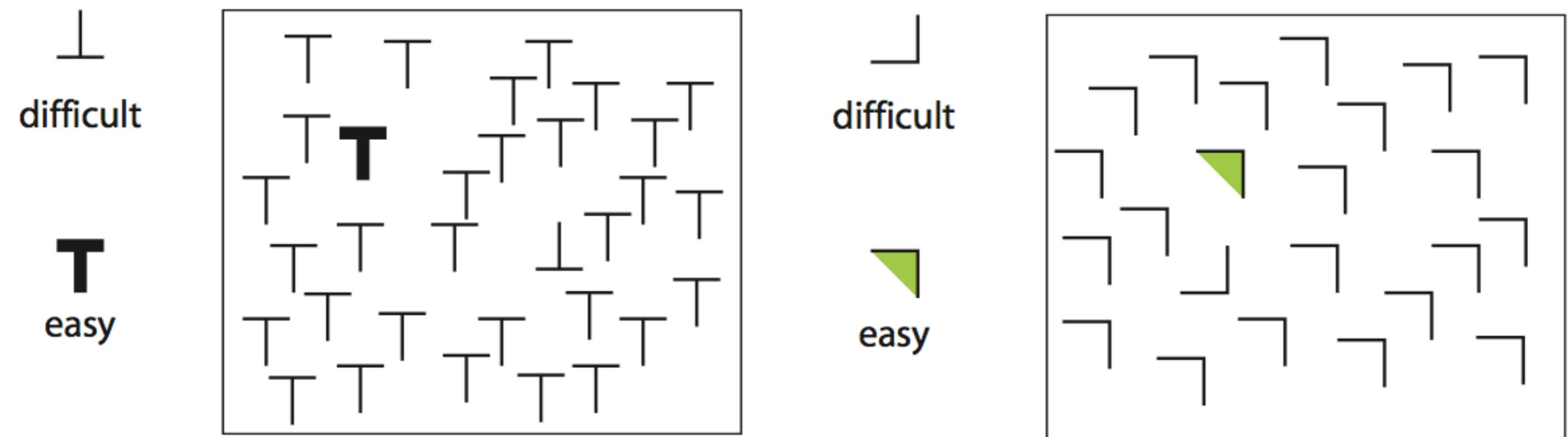
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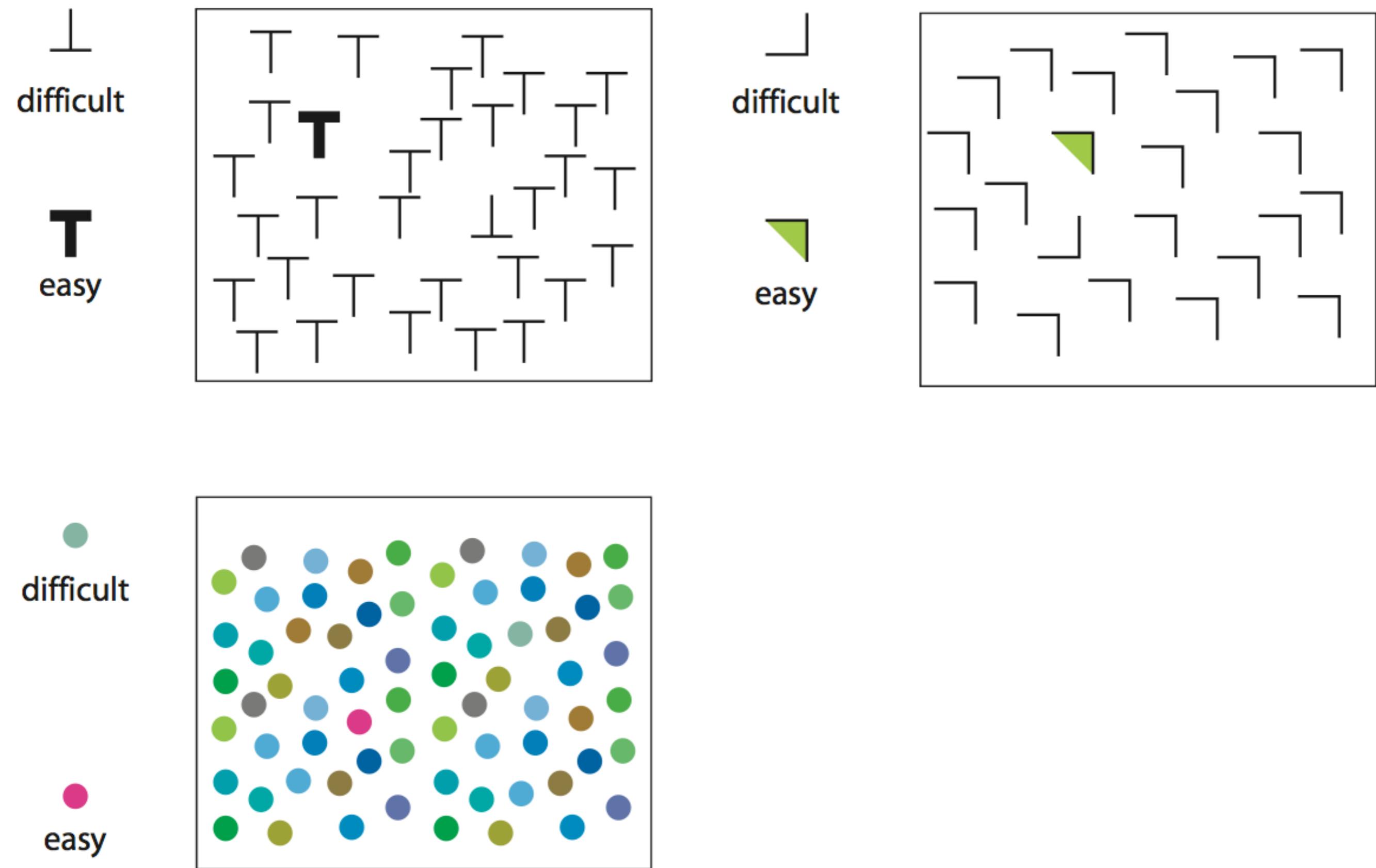
difficult

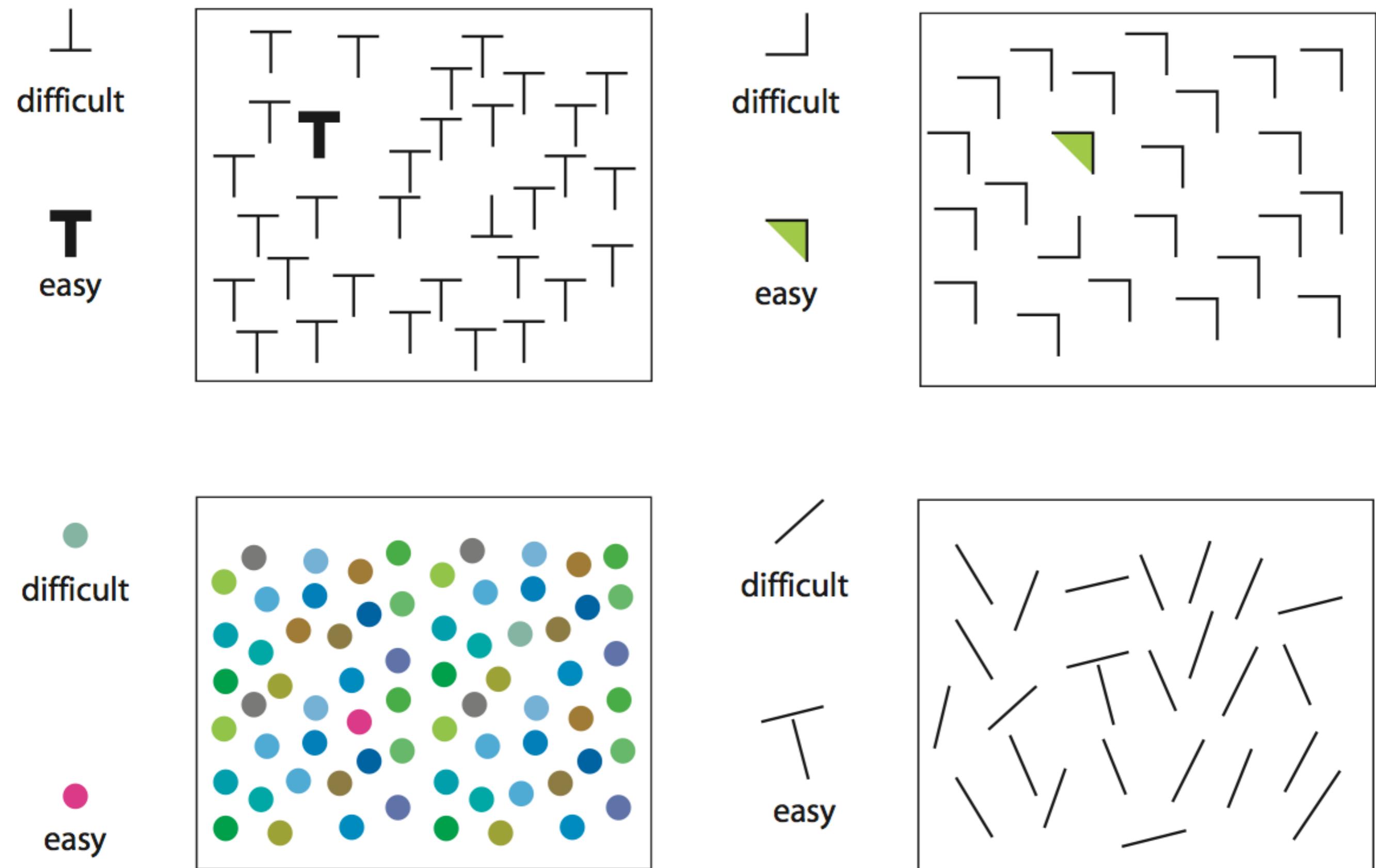
█

easy





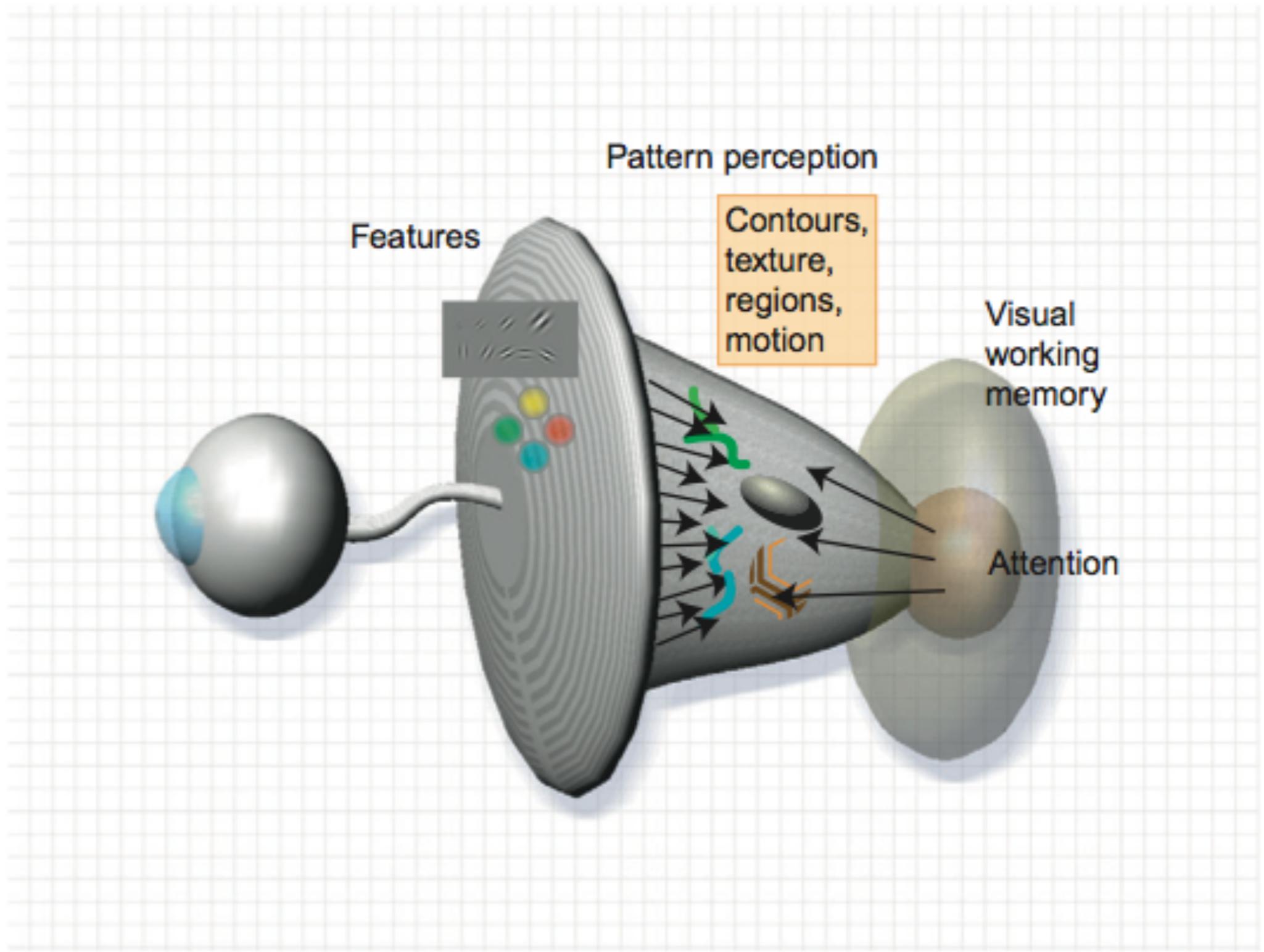




# Takeaways for Visualization

- We can easily see objects that are different in color and shape, or that are in motion.
- Use color and shape sparingly to make the important information pop out.
- Be wary of the effects of conjunction
  - More examples with boundary detection:  
<https://cscheid.net/courses/fal18/csc444/lectures/lecture1/boundary/>

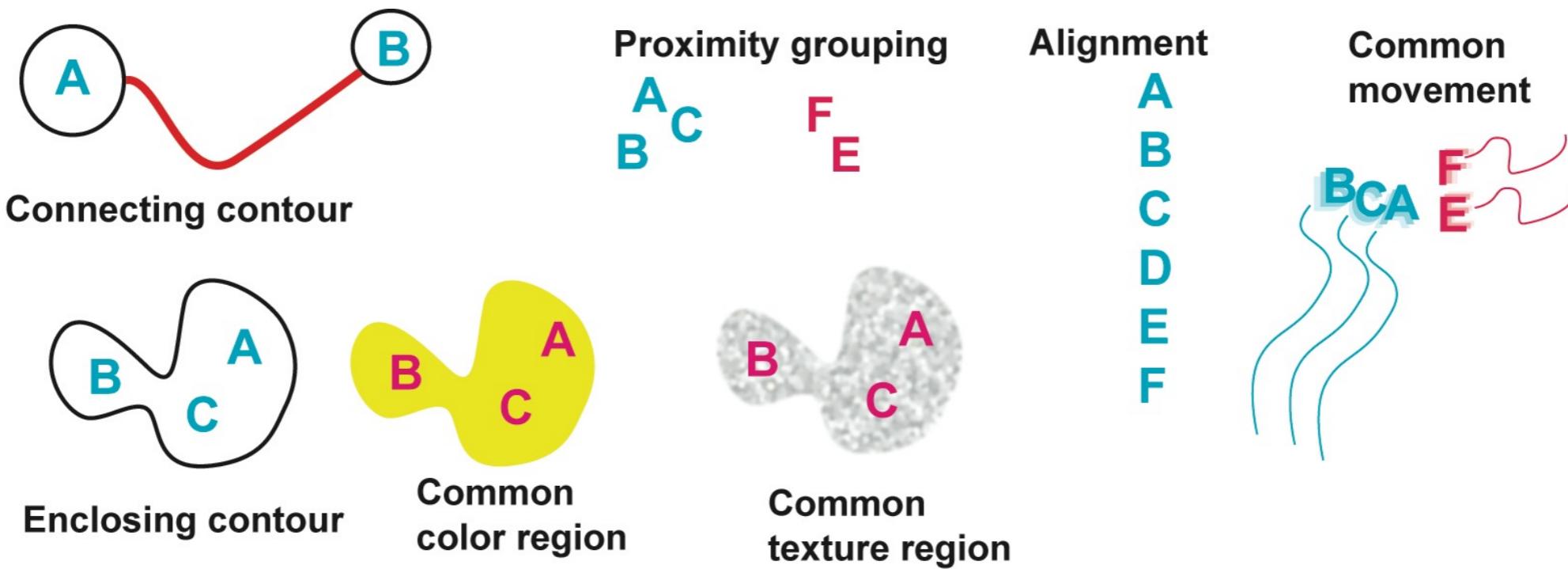
# Utilizing Patterns



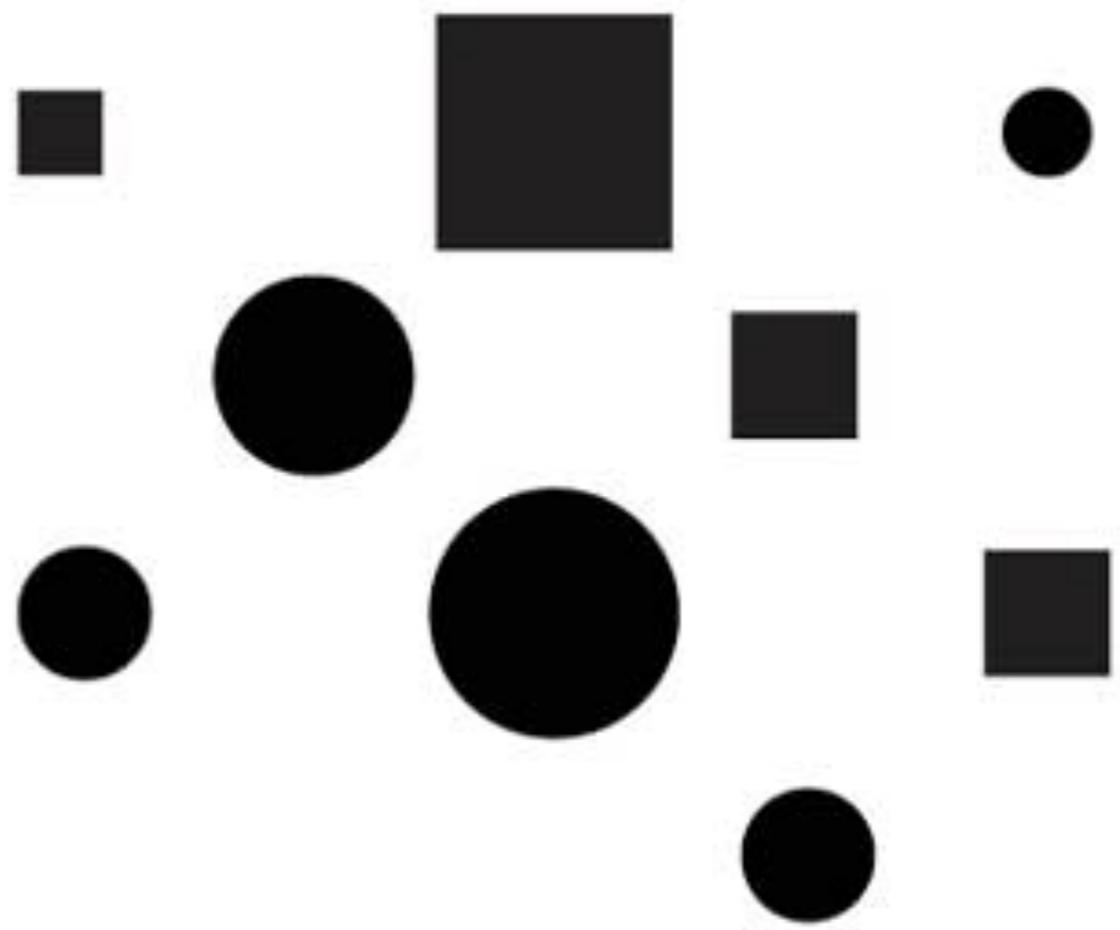
**Figure 6.1** Pattern perception occurs in a middle ground where bottom-up feature processing meets the requirements of top-down active attention.

# Gestalt Principles

- German: “Gestalt” = form
- Patterns that transcend the visual stimuli that produced them
- Translate into useful sets of rules for visual design.

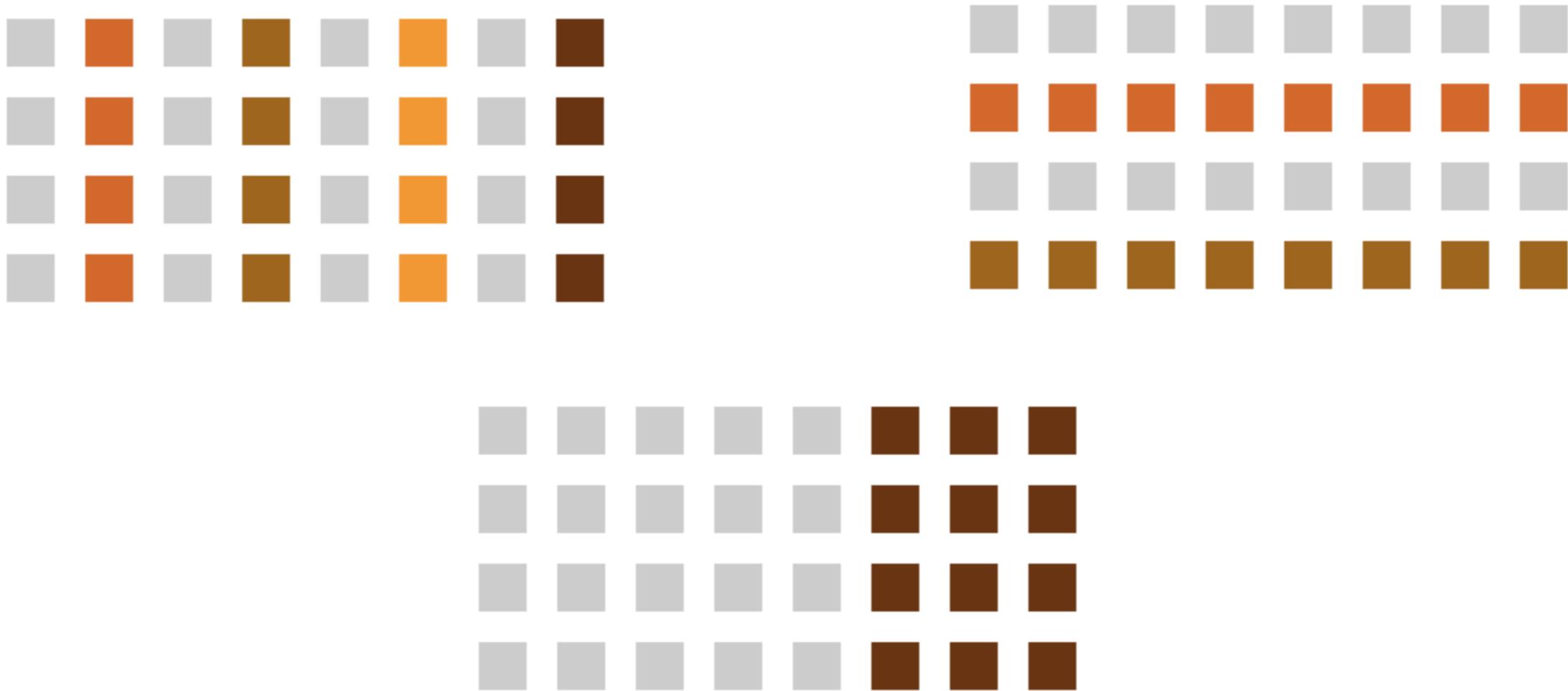


# Similarity



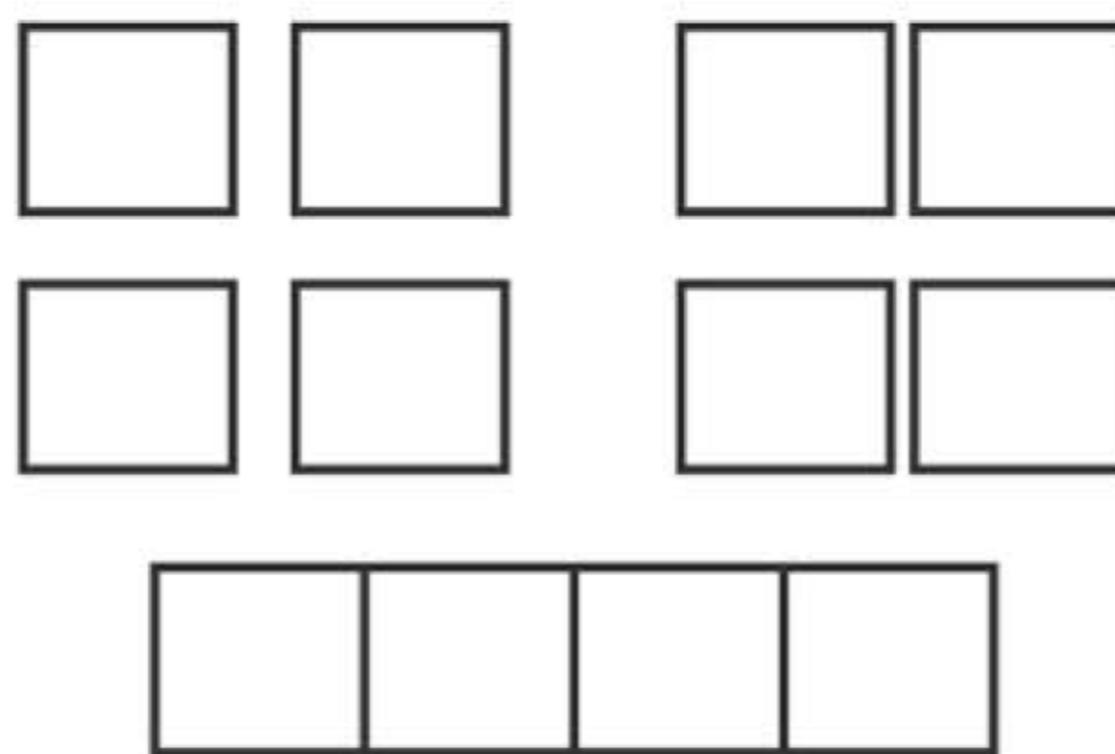
Bang Wong, “Gestalt Principles, 1”, Nature Methods

# Similarity: What Patterns Dominate?



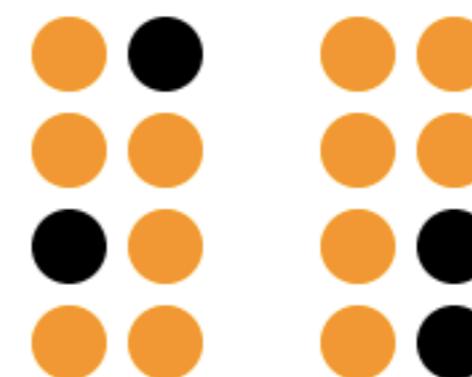
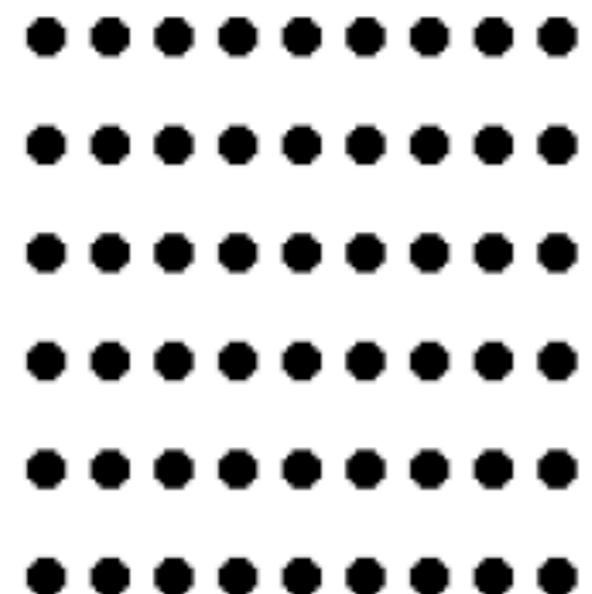
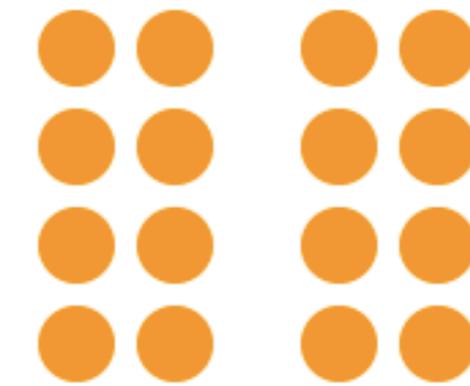
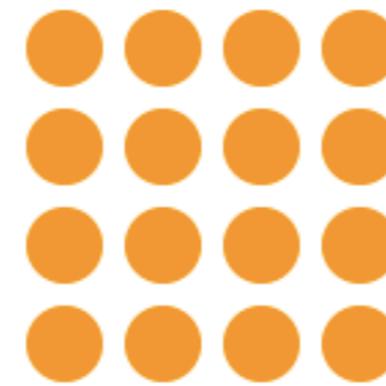
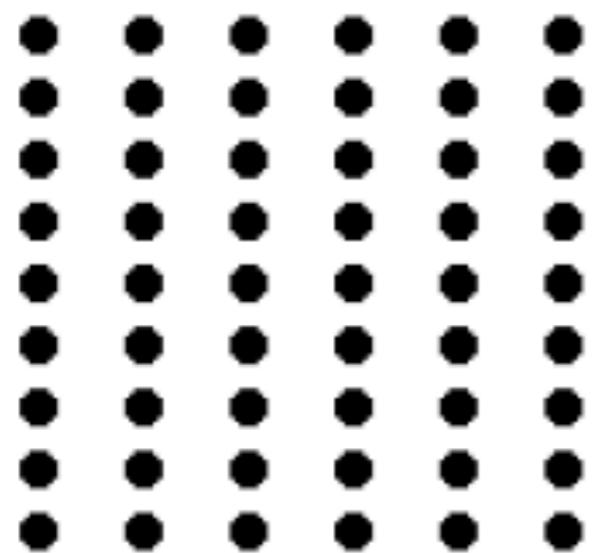
Andy Rutledge, “Gestalt Principles of Perception”  
<https://andyrutledge.com/gestalt-principles-2-similarity.html>

# Proximity



Bang Wong, “Gestalt Principles, 1”, Nature Methods

# Proximity: How is the Data Organized?



Andy Rutledge, “Gestalt Principles of Perception”  
<https://andyrutledge.com/gestalt-principles-3.html>

# Connectedness and Domination of Grouping



(a)



(b)



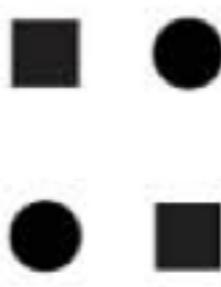
(c)



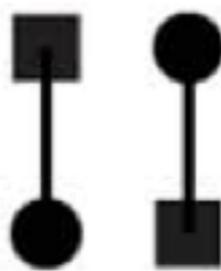
(d)

# Relative Strength of Groupings

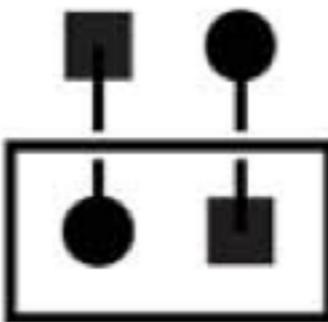
**Similarity**



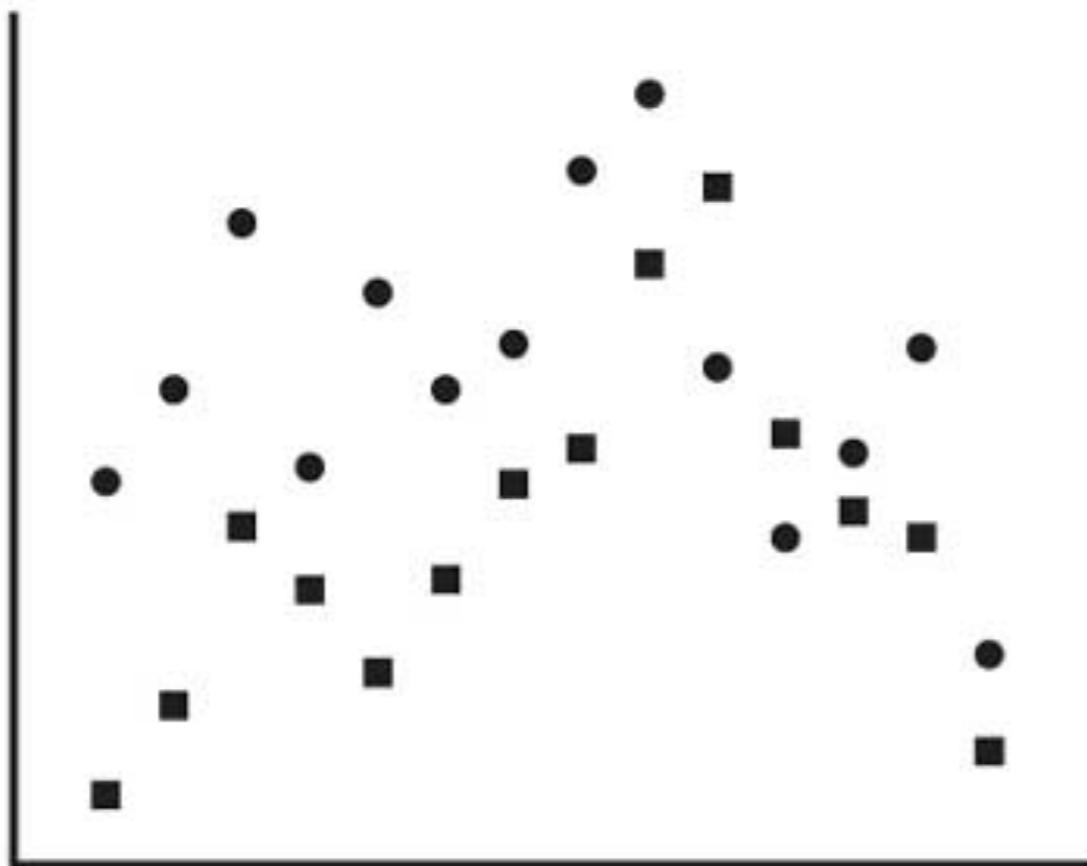
**Connection**



**Enclosure**

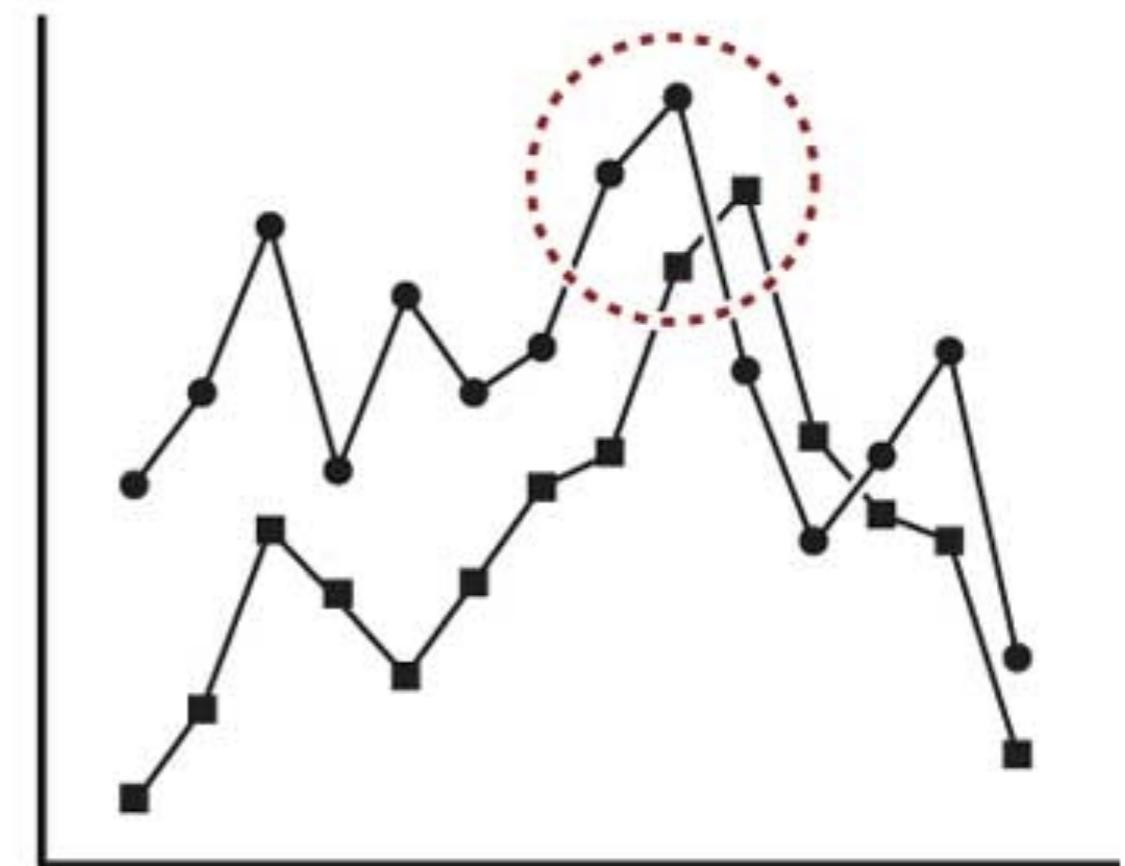
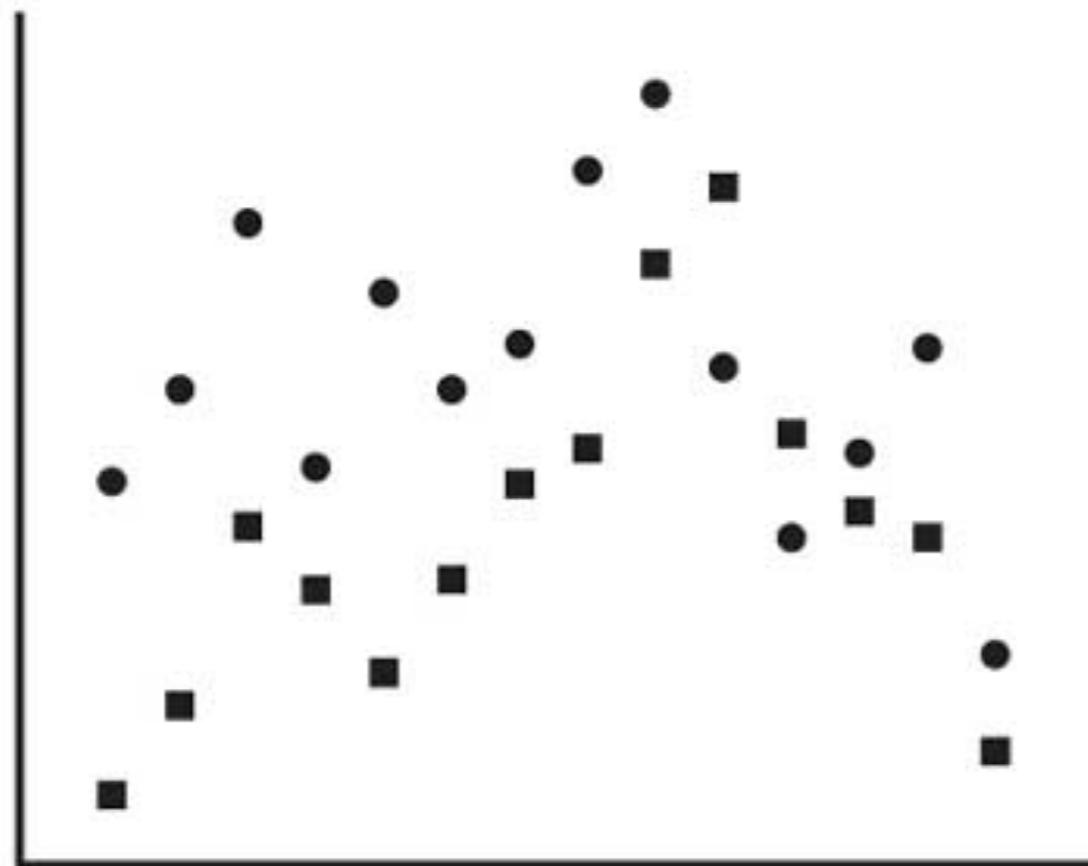


# Grouping Helps Us Organize Data

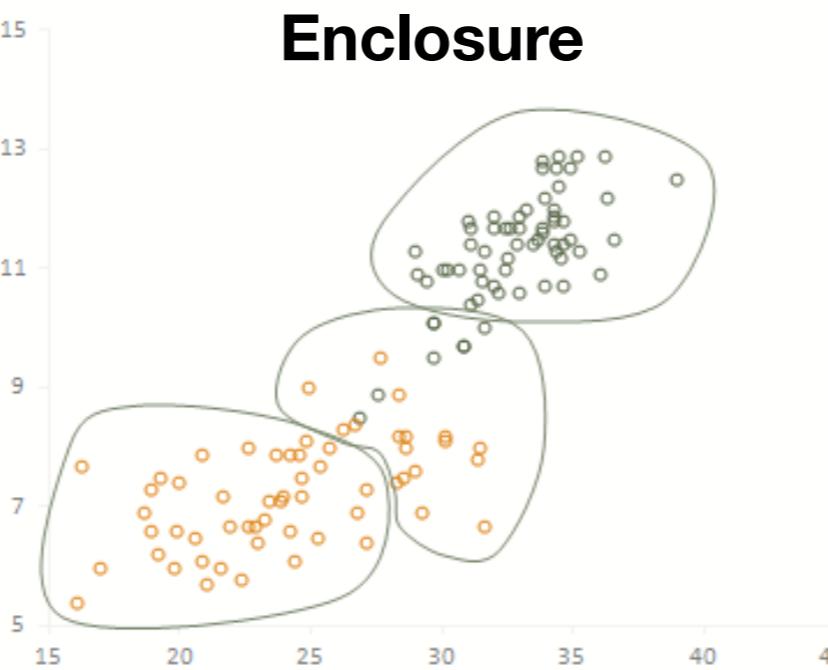
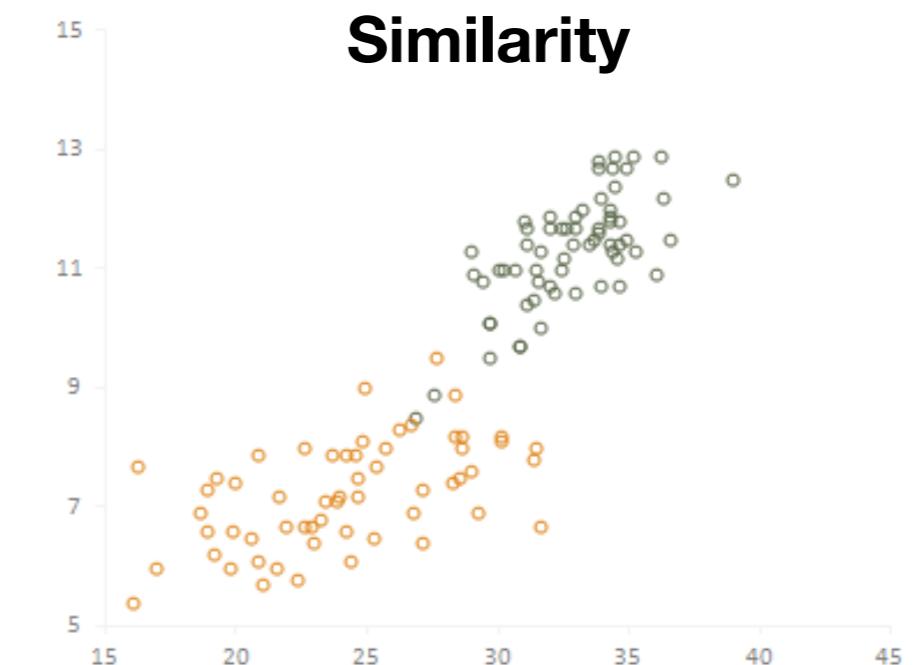
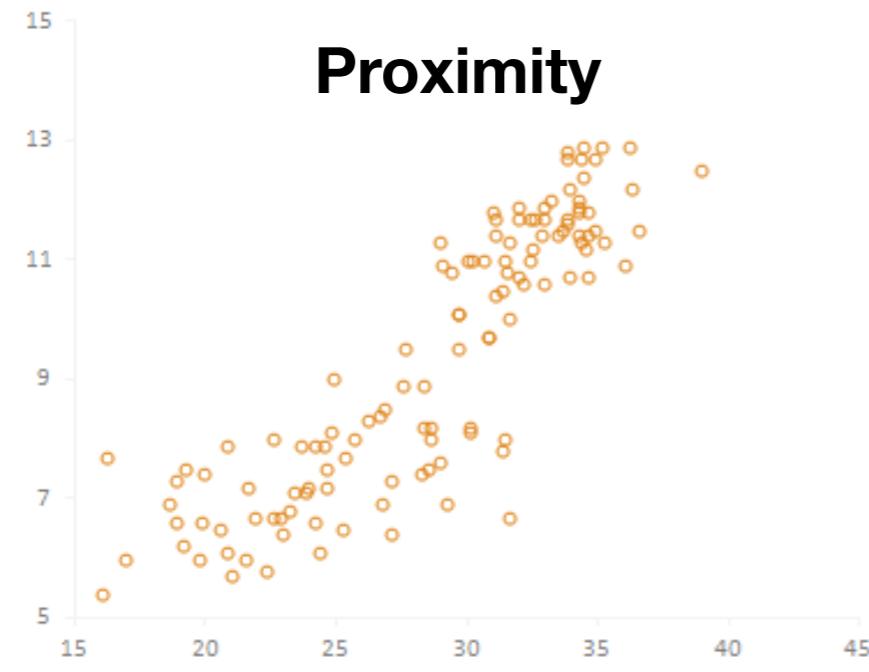


Bang Wong, “Gestalt Principles, 1”, Nature Methods

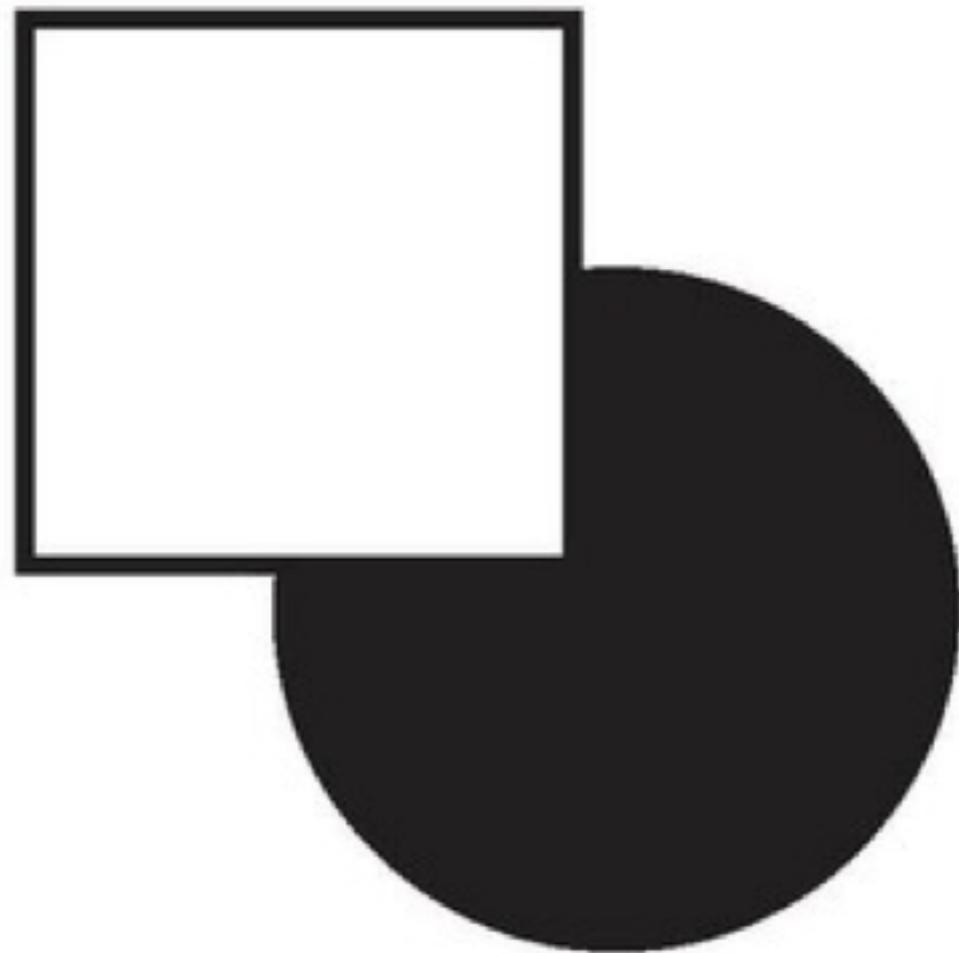
# Grouping Helps Us Organize Data



# Understanding Grouping Helps to Draw Attention to Certain Features

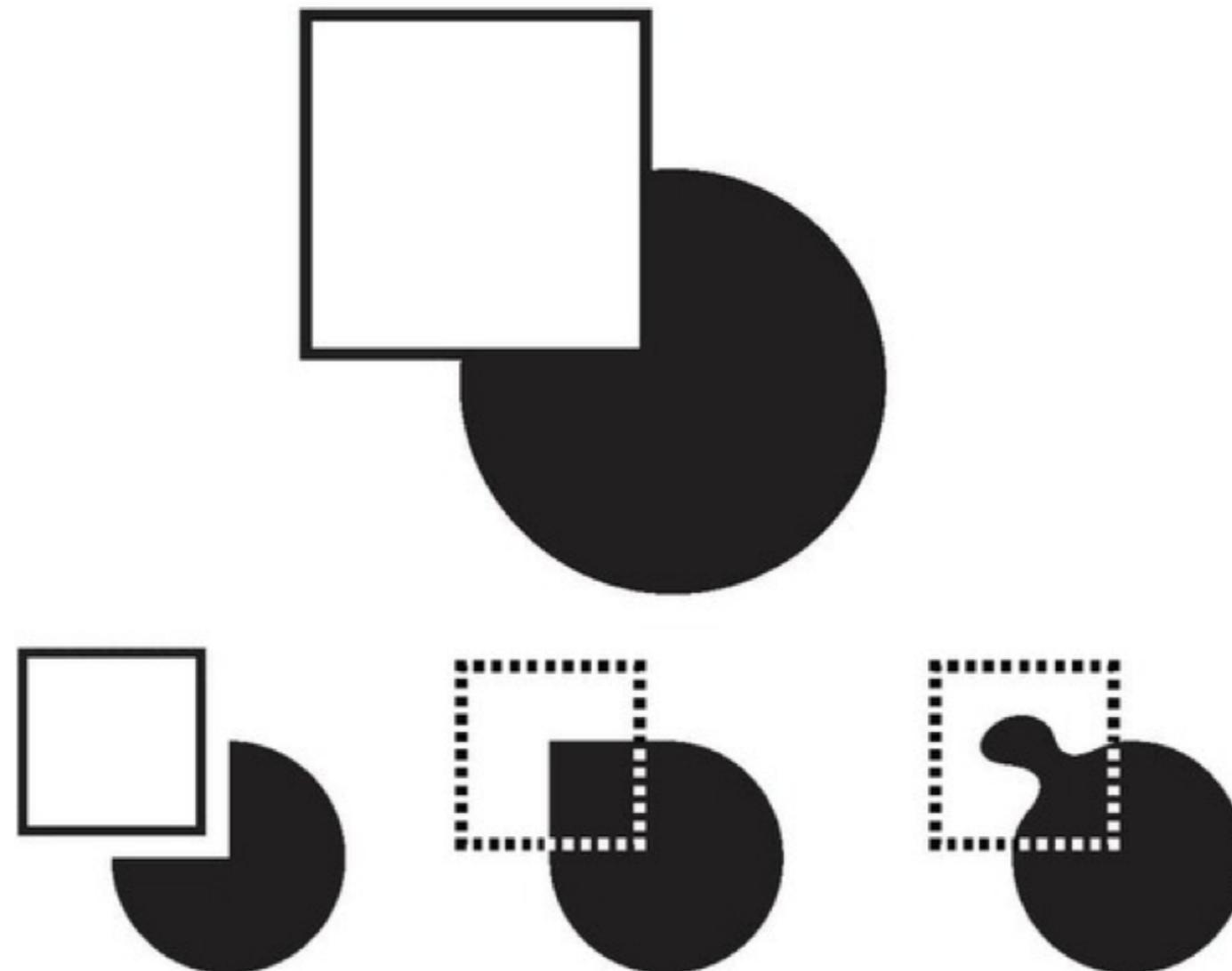


# Continuity



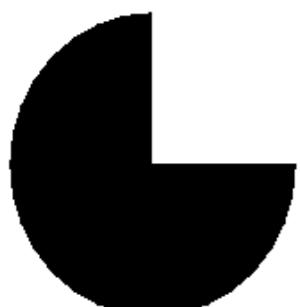
Bang Wong, “Gestalt Principles, 2”, Nature Methods

# Continuity



Bang Wong, “Gestalt Principles, 2”, Nature Methods

# Closure

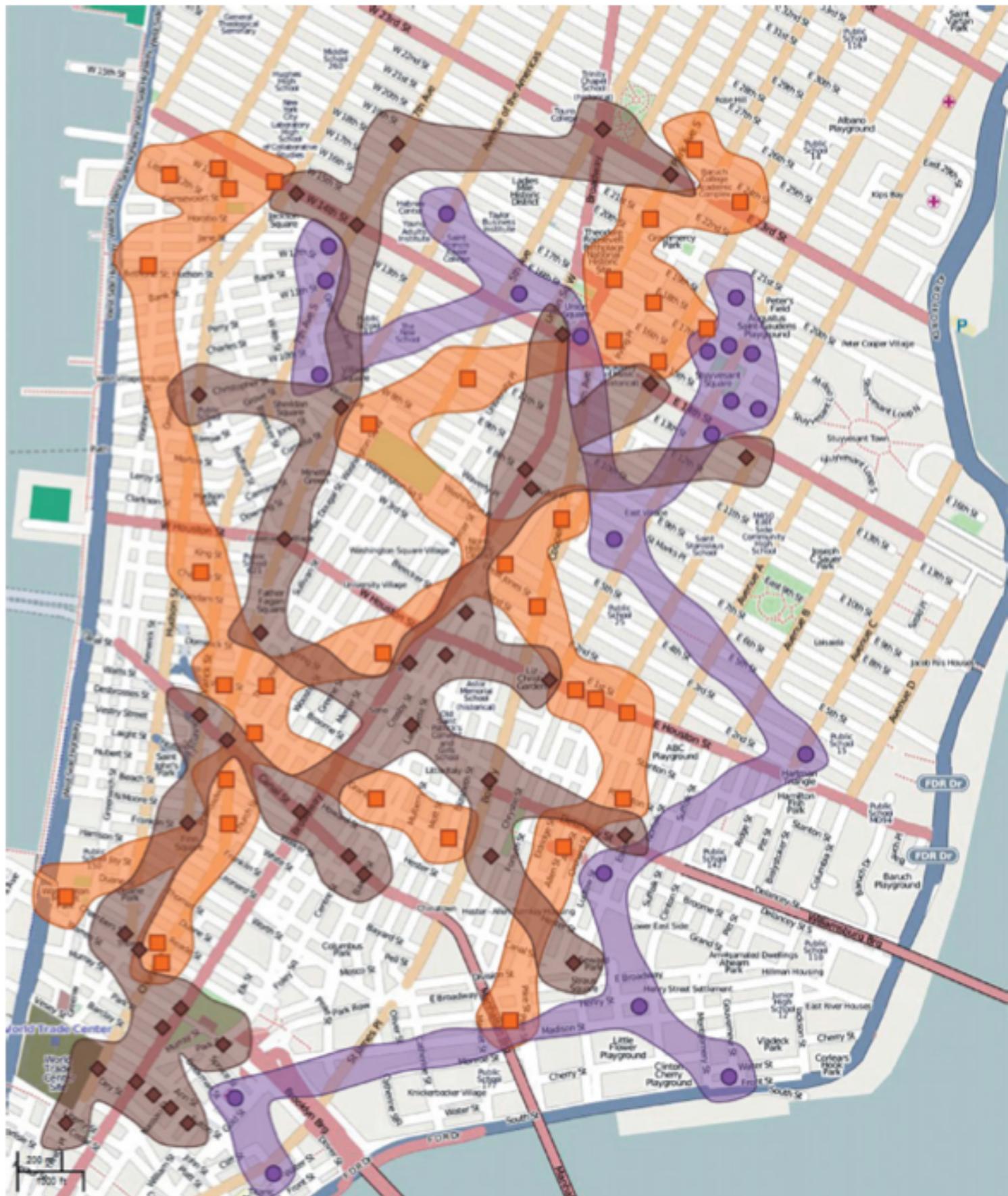


# Closure



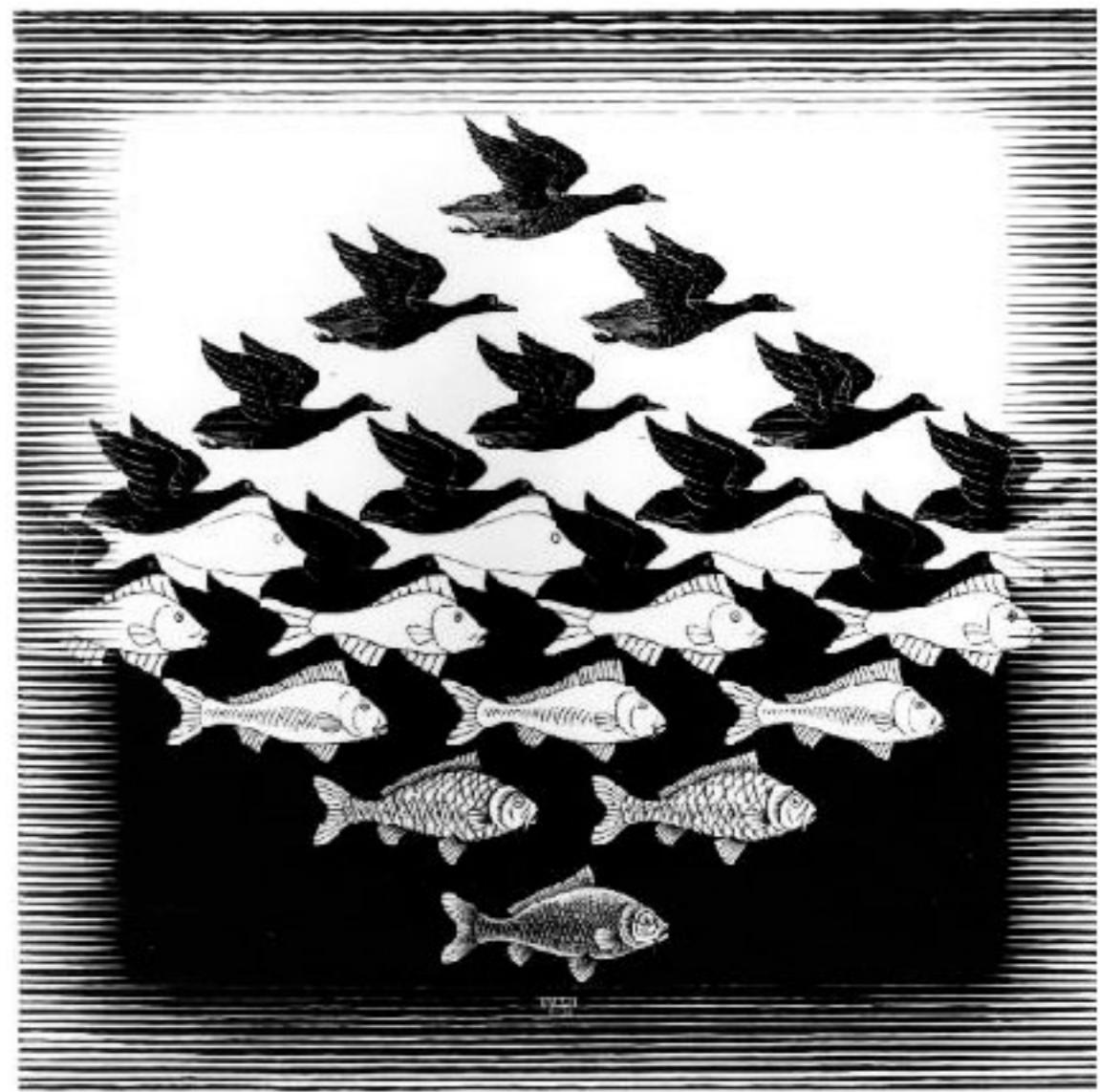
Andy Rutledge, "Gestalt Principles of Perception"  
<https://andyrutledge.com/closure.html>

# Closure, Continuity, and Use of Cornsweet Contours



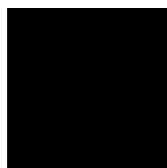
**Figure 6.15** Both contour- and color-defined regions have been added to make clear the distribution of hotels (orange), subway stations (brown), and medical clinics (purple). (From Collins et al. (2009). Reproduced with permission.)

# Figure / Ground

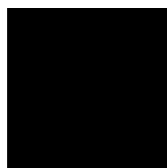


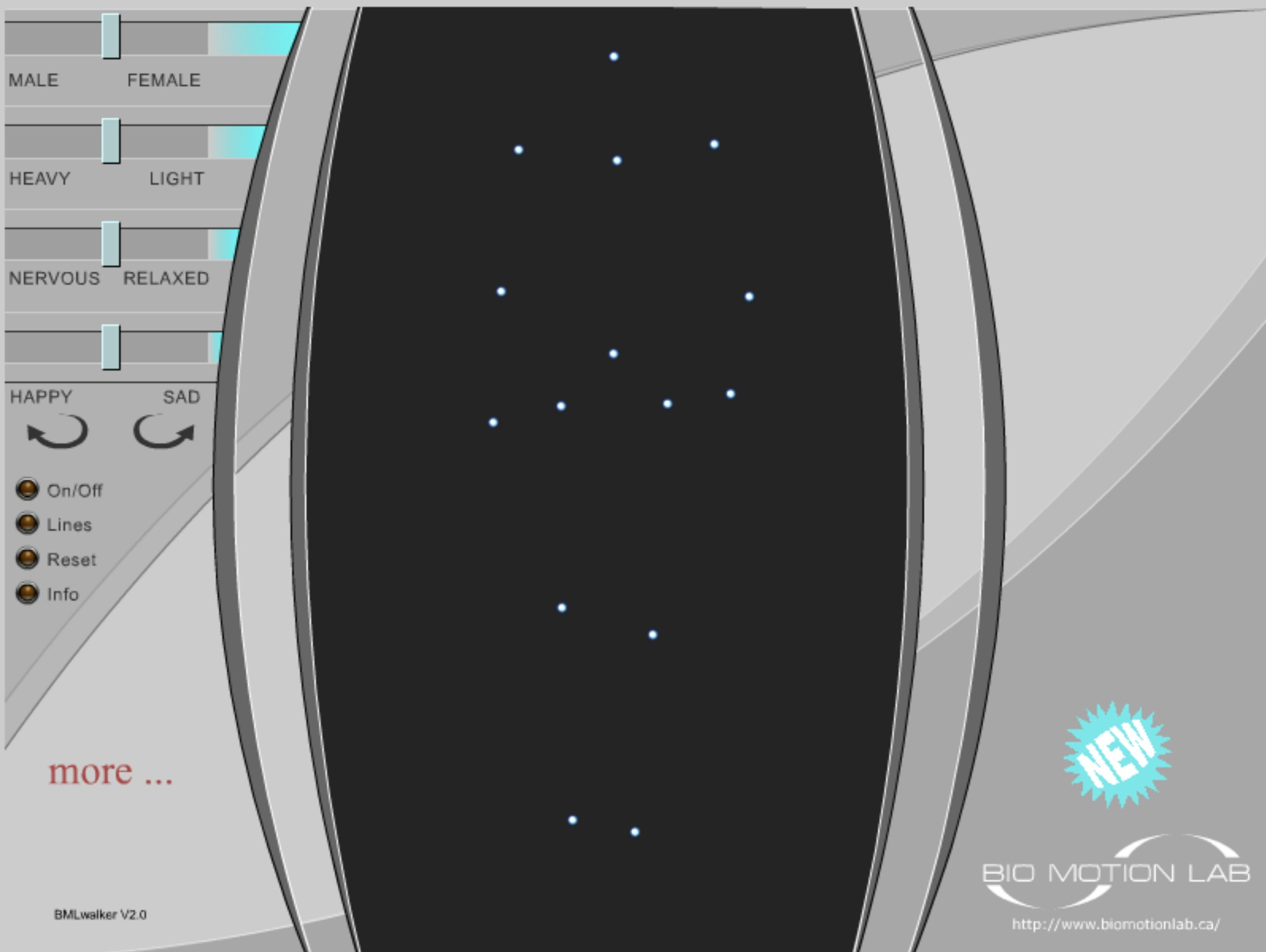
M.C. Escher: *Sky and Water I* 1938 woodcut

# Common Fate



# Common Fate





# Gestalt Principles Summarized

- **Similarity:** things that look like each other (size, color, shape) are related
- **Proximity:** things that are visually close to each other are related
- **Connection:** things that are visually connected are related
- **Continuity:** we complete hidden objects into simple, familiar shapes
- **Closure:** we see incomplete shapes as complete
- **Figure / Ground:** elements are perceived as either figures or background
- **Common Fate:** elements with the same moving direction are perceived as a unit

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# Lec07 Reading

- Munzner, Ch. 2
- S. S. Stevens. On the Theory of Scales of Measurement. *Science*, 103(2684), pp. 677-680, June 1946.

# **Reminder**

# **Assignment 01**

**Assigned: Monday, January 23**

**Due: Monday, February 6, 4:59:59 pm**

# **Reminder**

# **Project Milestone 01**

**Assigned: Monday, January 25**

**Due: Monday, February 22, 4:59:59 pm**