Scientific and Large Data Visualization
8 November 2017
Visual Perception

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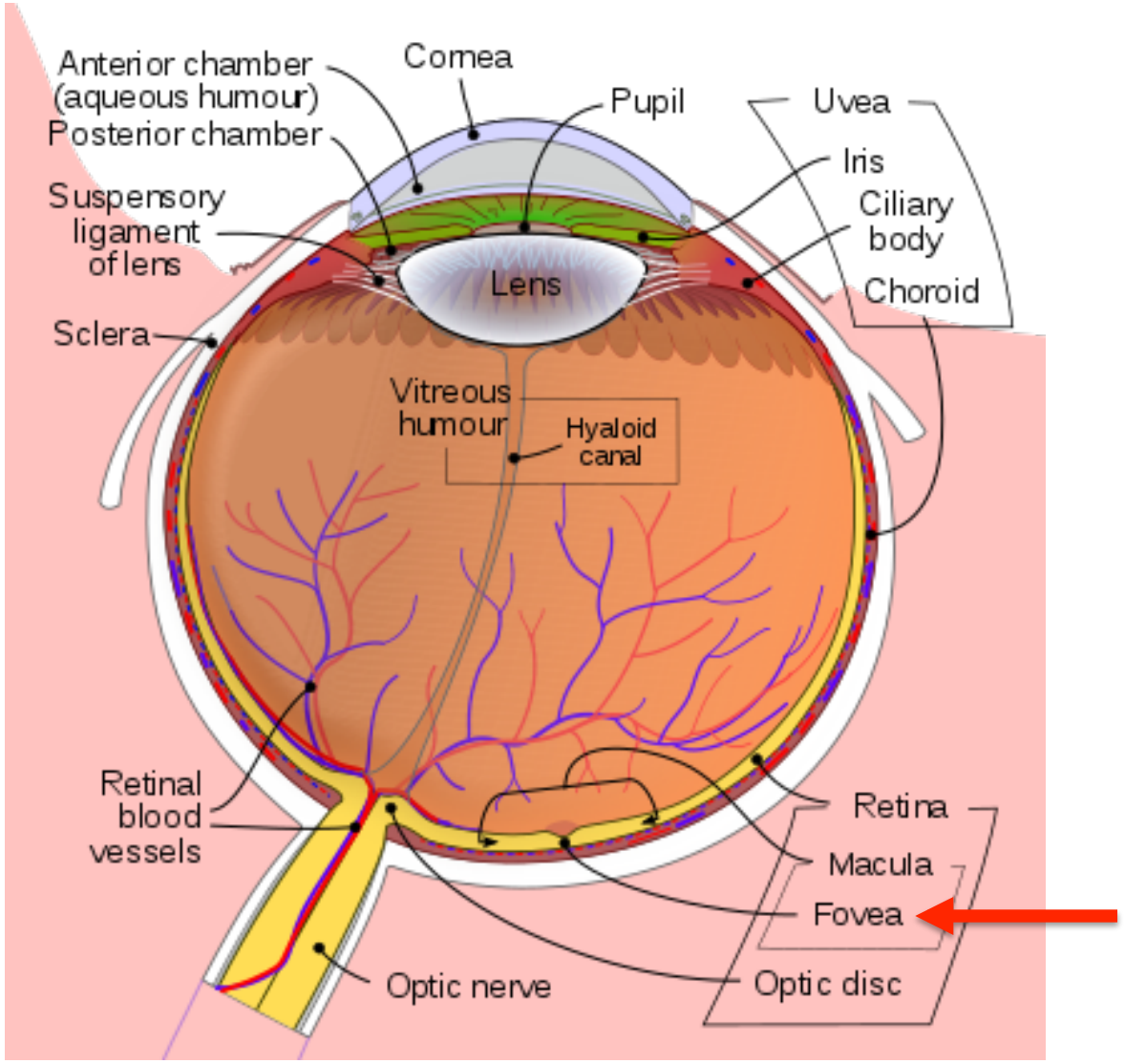
Overview

- **Intro**
- **Our Eye**
- **Receptive Field Model, CSF, Mach Bending, Cornsweet effect..**
- **What we really see**
- **Preattentive Process**
- **Gestalt Laws**
- **Perception of lines and areas**

Human Visual System (HVS)

- The Human Visual System (HVS) is subdivided into two parts:
  - Optical part → our eye.
  - Visual Perception → our brain (visual cortex).

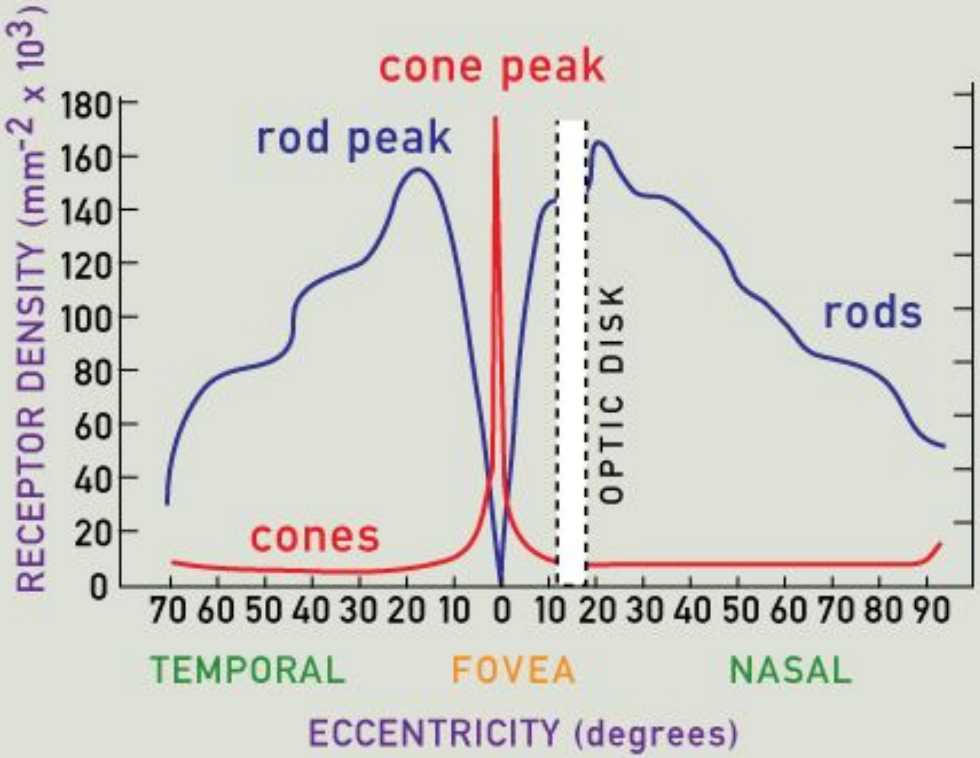
Our Eye

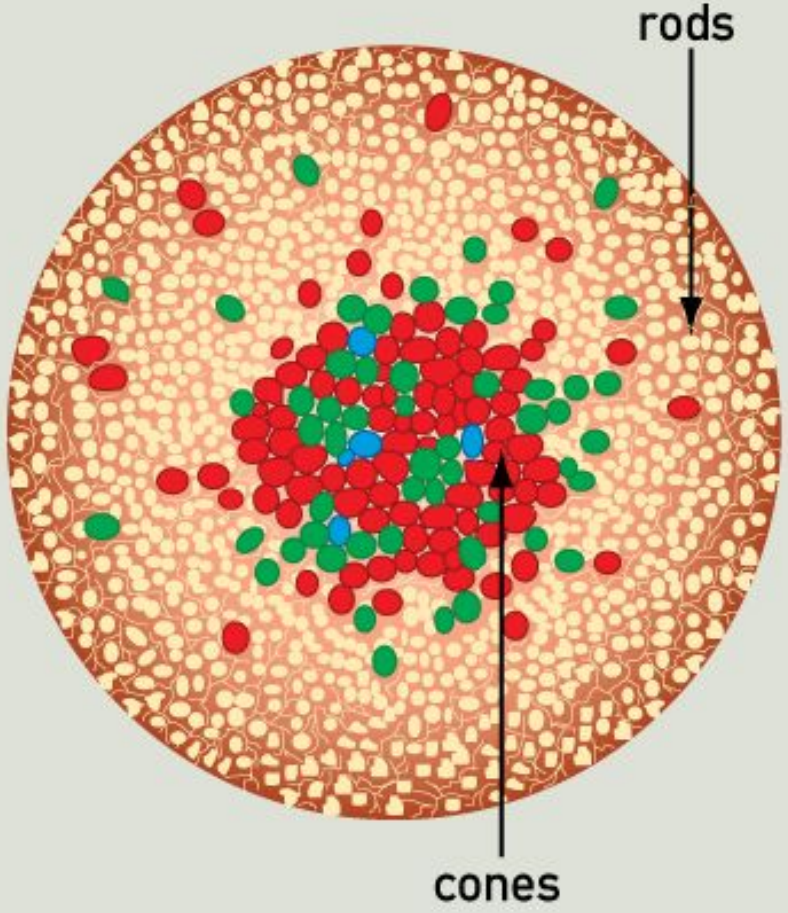

Anterior chamber
(aqueous humour)
Posterior chamber
Cornea
Pupil
Uvea
Iris
Ciliary
body
Suspensory
ligament
of lens
Lens
Choroid
Sclera
Vitreous
humour
Hyaloid
canal
Retinal
blood
vessels
Retina
Macula
Fovea
Optic nerve
Optic disc

The Retina

- The *retina* is composed by a large number of *photoreceptors* (rods and cones).
- 100 millions of rods, 6 millions of cones.
- Cones are concentrated in the *fovea* (1.5-2 degrees).
- Retinal ganglion cells send information, through the optic nerve, to the brain.

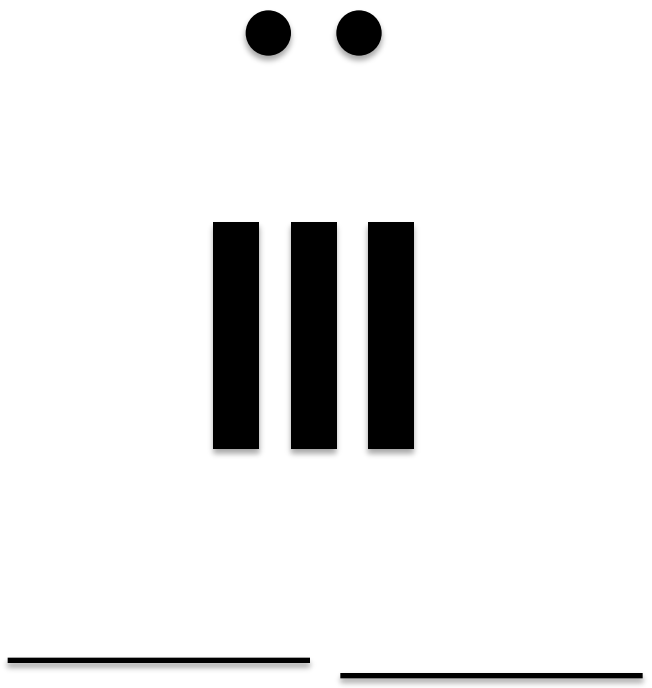
Rods and Cones Distribution





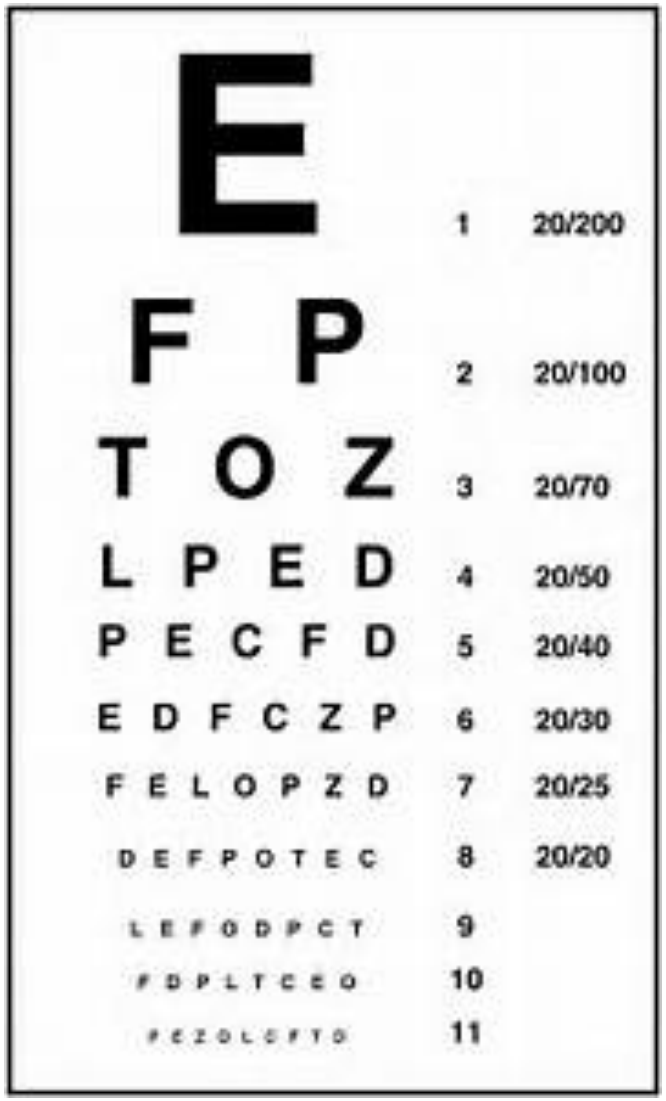
Visual Acuity

- Points – 1 minute of arc.
- Gratings – 1-2 minutes of arc.
- Letter – 5 minutes of arc.
- *Vernier acuity* (the ability to see if two segments are colinear) – 10 seconds of arc.

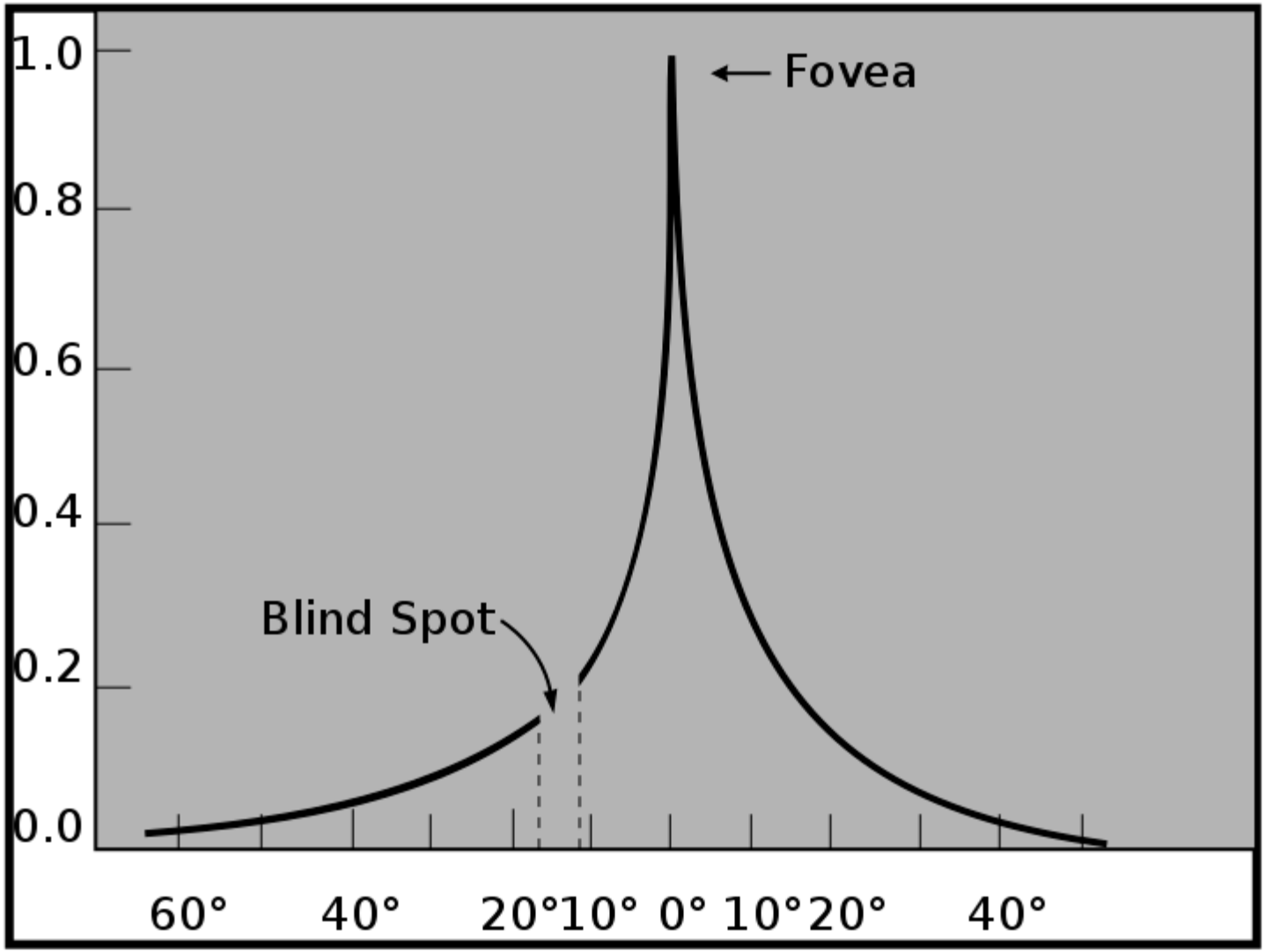


Visual Acuity

Snellen Chart



Visual Acuity



Contrast Sensitivity Function (CSF)

- Our perception is sensitive to pattern contrast, frequency and orientation.
- Also color influences the CSF.

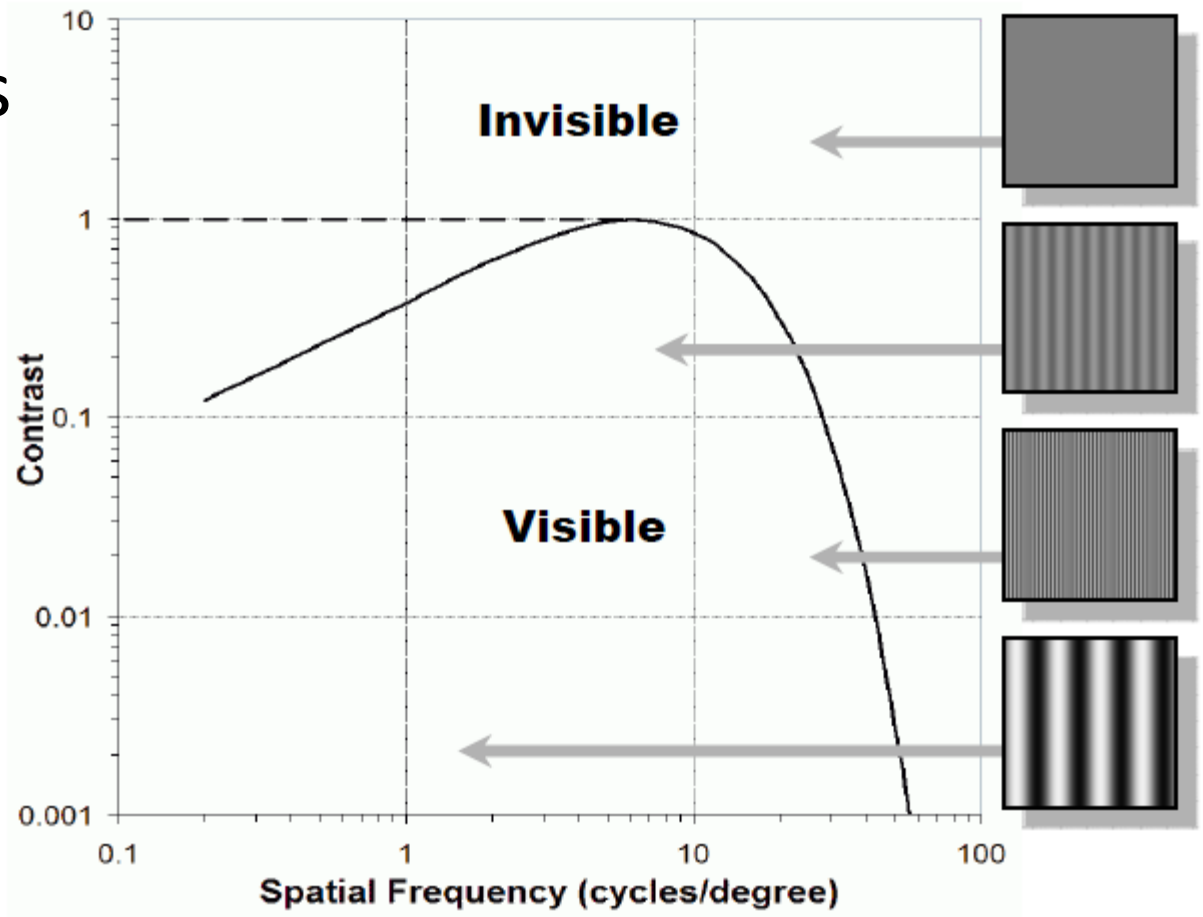
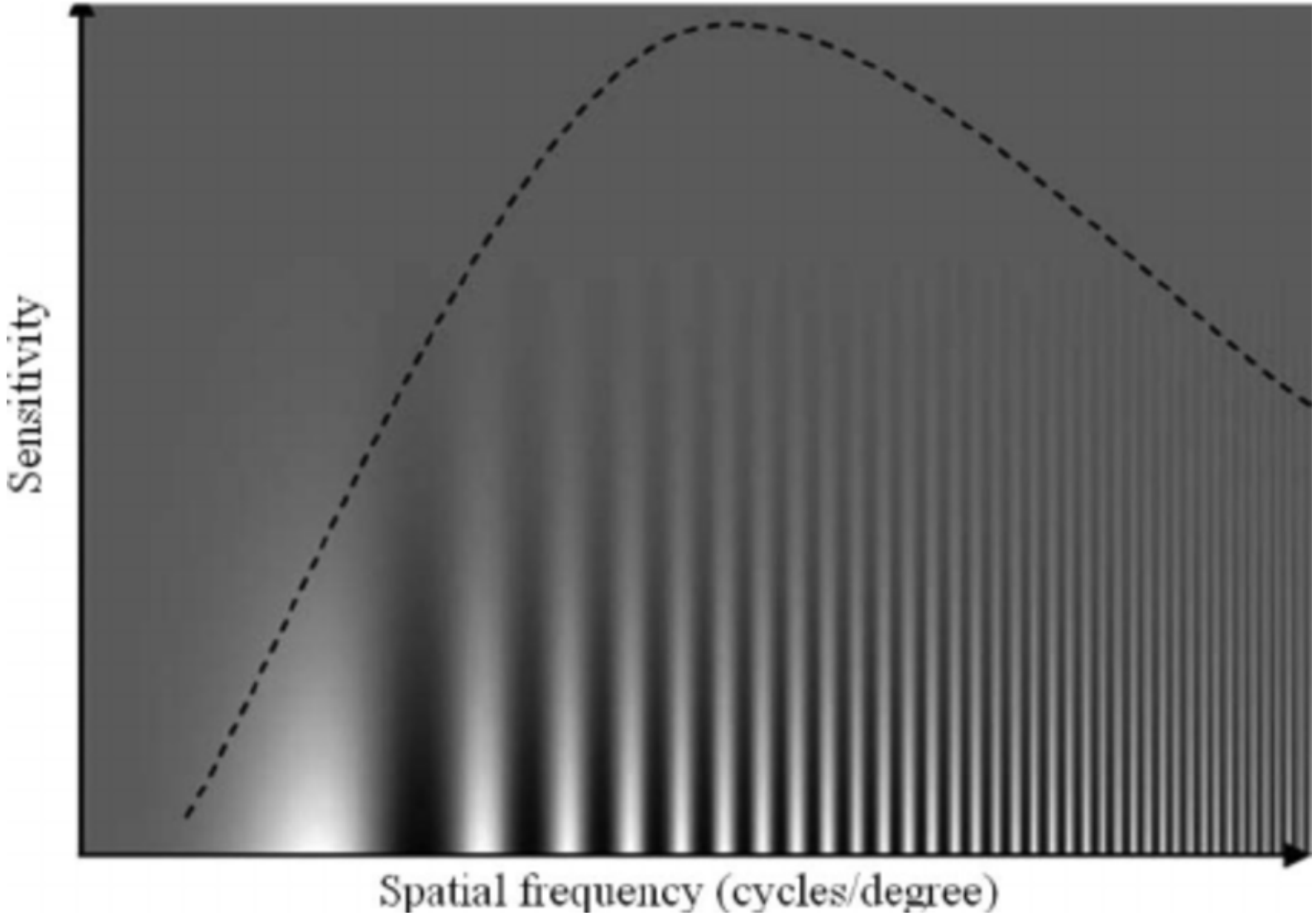
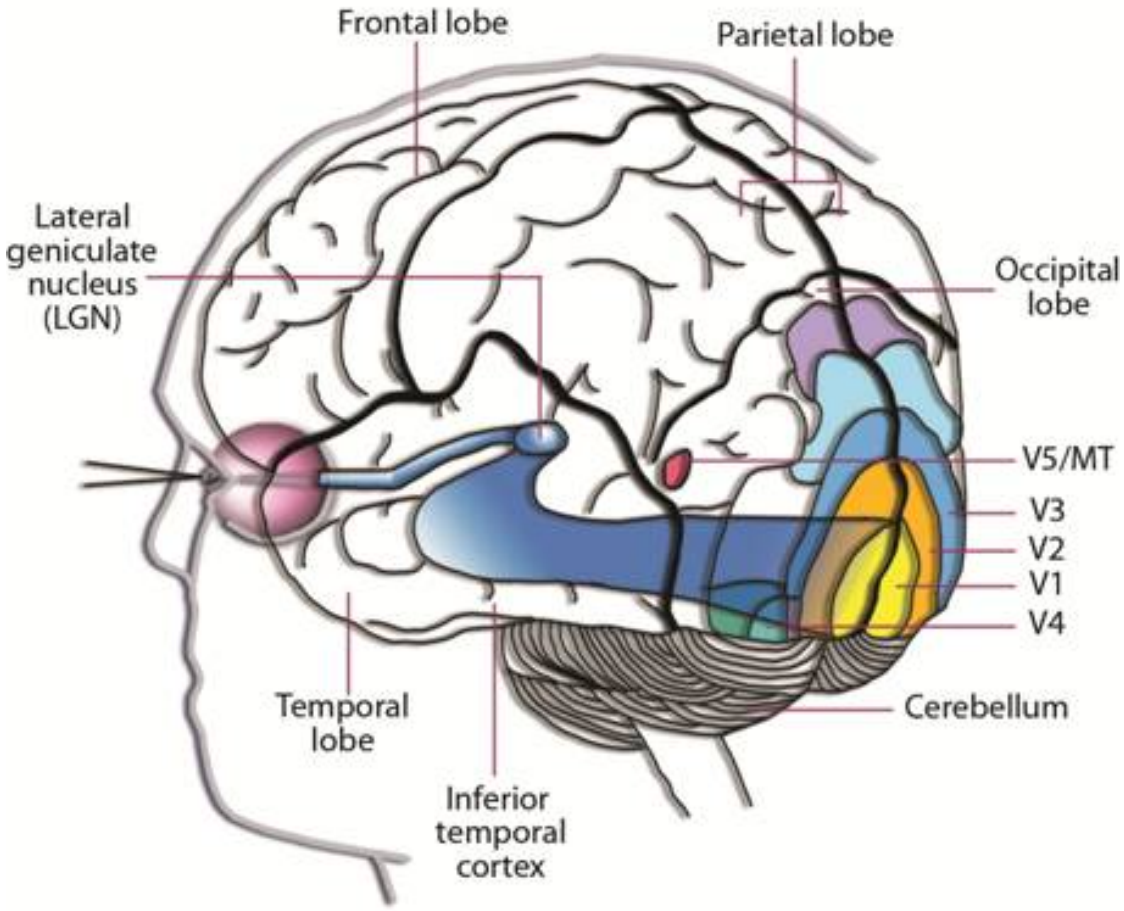


Figure by Martin Reddy.

Contrast Sensitivity Function (CSF)

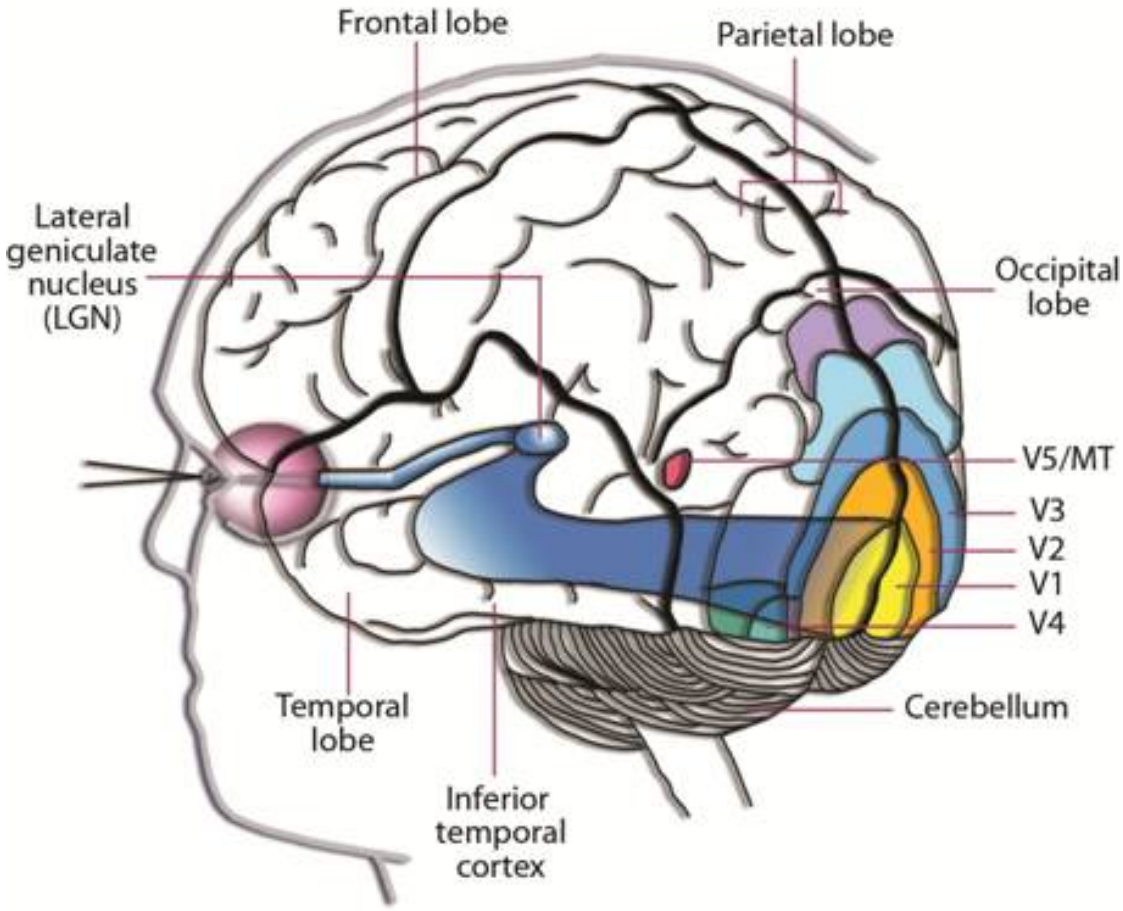


Visual Cortex



- *LGN (Lateral Geniculate Nucleus)* forwards pulses to V1. It is also connected with V2 and V3.
- *V1* is the *primary visual cortex*. It performs edge detection and global organization (inputs from V2, V3).

Visual Cortex

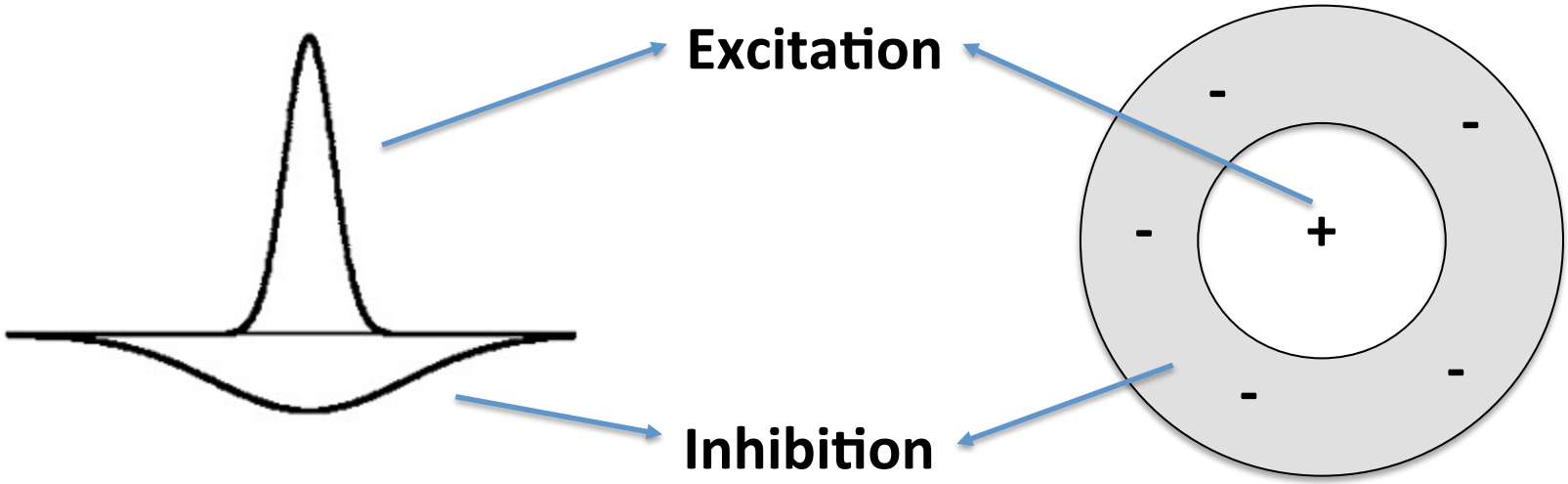


- V2 handles depth, foreground, illusory contours.
- V3 supports global motion understanding.
- V4 recognizes simple geometric shape.
- V5/MT: motion perception integration and eye movements guidance.

Receptive Field (in the retina)

- The *receptive field* of a cell is the visual area over which a cell responds to light.
- Retinal ganglion cells are organized with circular receptive fields.
- Stimulated on-center they are excited, stimulated off-center they are inhibited.

Receptive Field (in the retina)



A good mathematical model is the Difference of Gaussians (DoG):

$$f(x) = k_1 e^{\left(-\frac{x}{\sigma_1}\right)^2} - k_2 e^{\left(-\frac{x}{\sigma_2}\right)^2}$$

Difference of Gaussians (DoG)

Difference of Gaussians (DoG)

Stimulus for sigma = 5 pixels

Difference of Gaussians (DoG)

Stimulus for sigma = 10 pixels

Difference of Gaussians (DoG)

$$\mathbf{I} * \mathbf{G_2} - \mathbf{I} * \mathbf{G_1}$$

Simultaneous Brightness Contrast

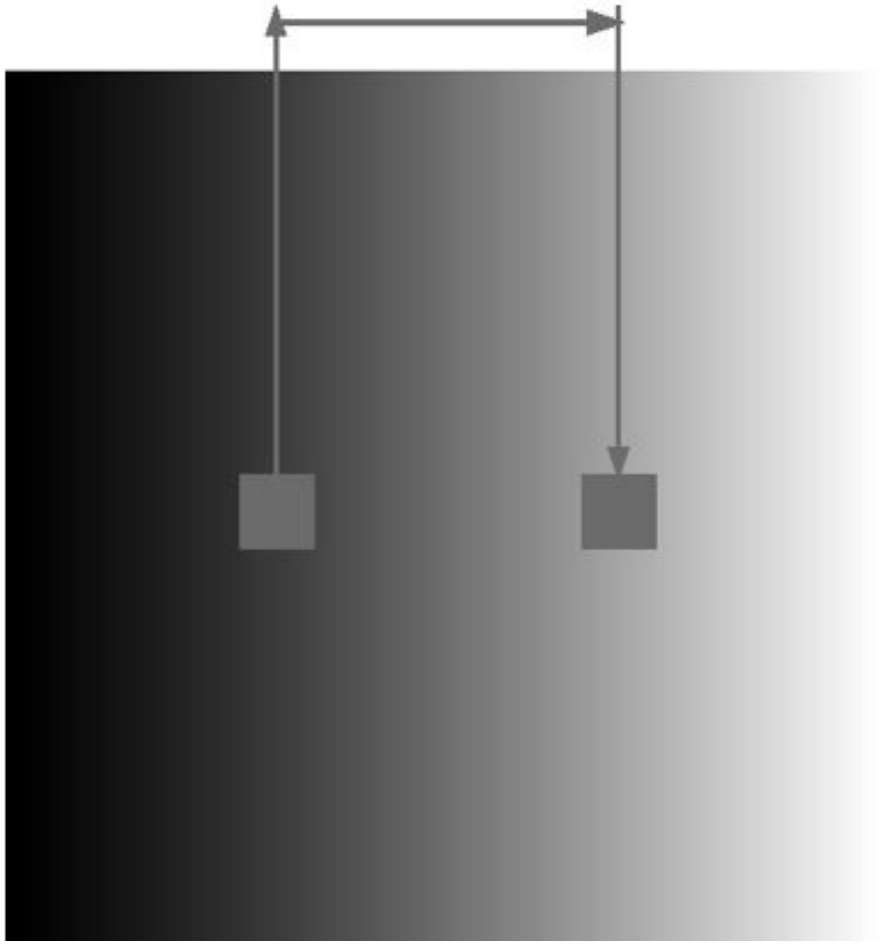
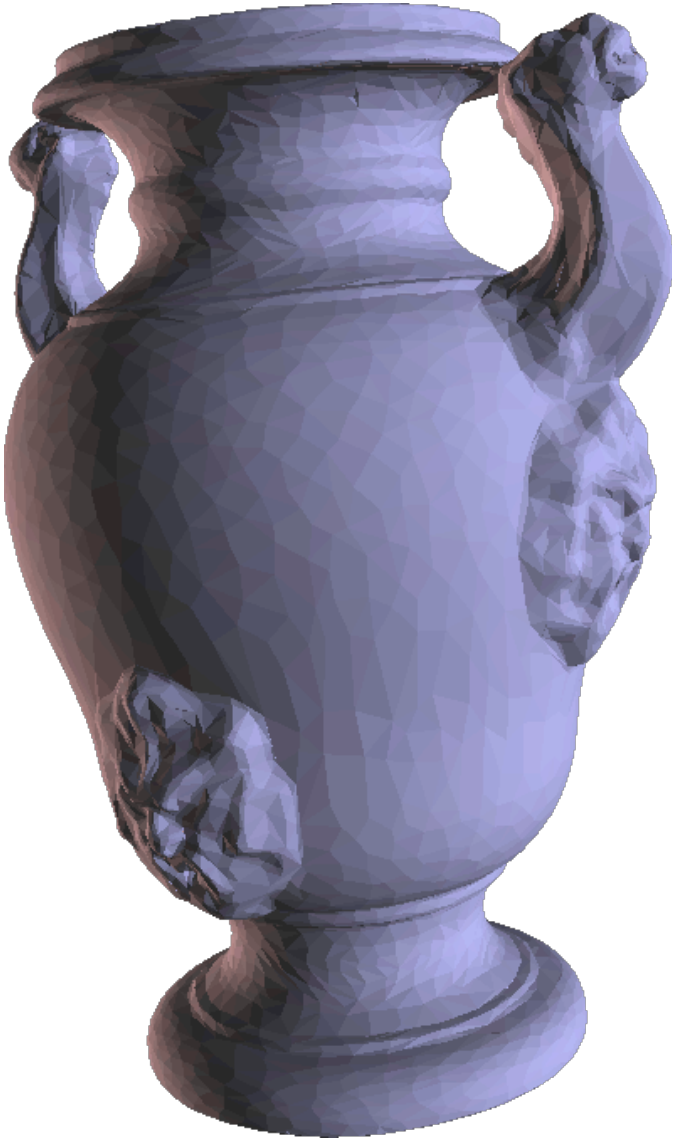


Figure from the *Perception* course by Prof. David Heeger.

Mach Banding

- Do you remember the problem of costant shading?
- This perceptual effect is called *Mach Banding*.
- Abrupt changes are strongly perceived.



Mach Banding

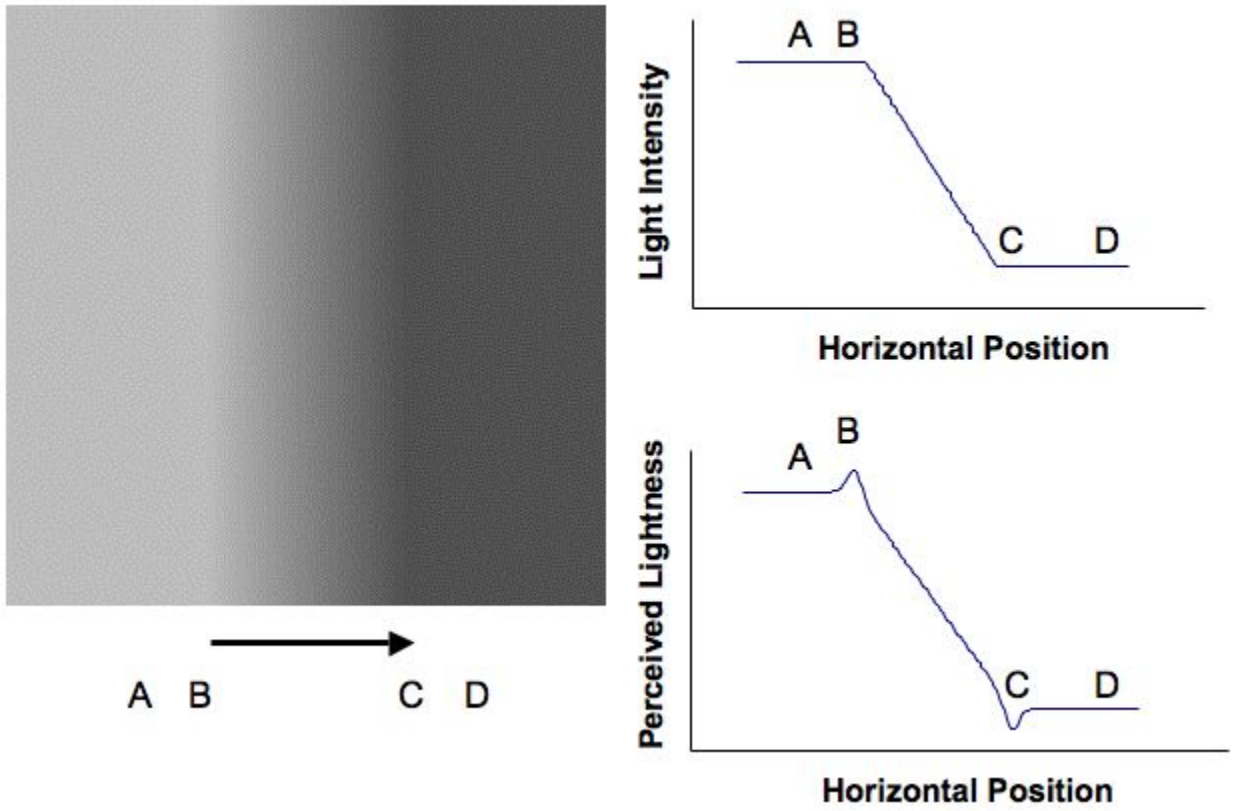
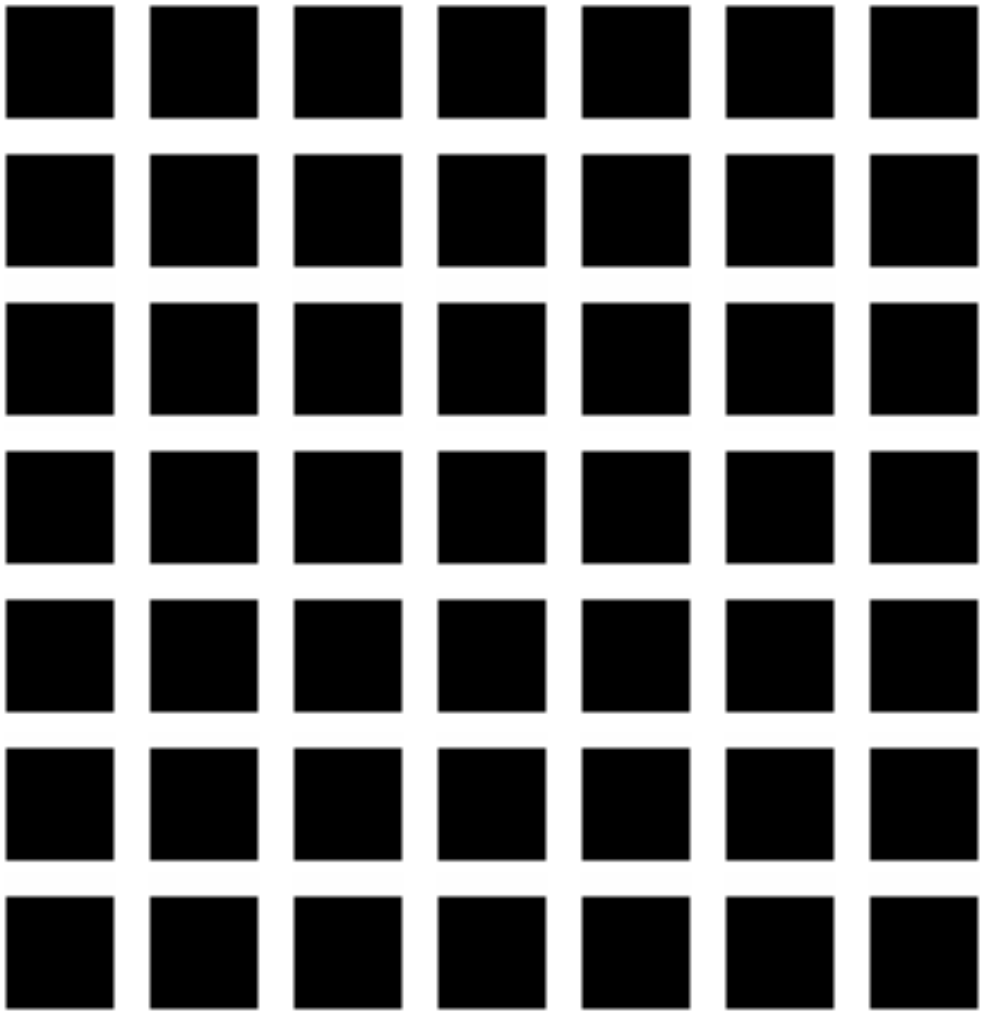
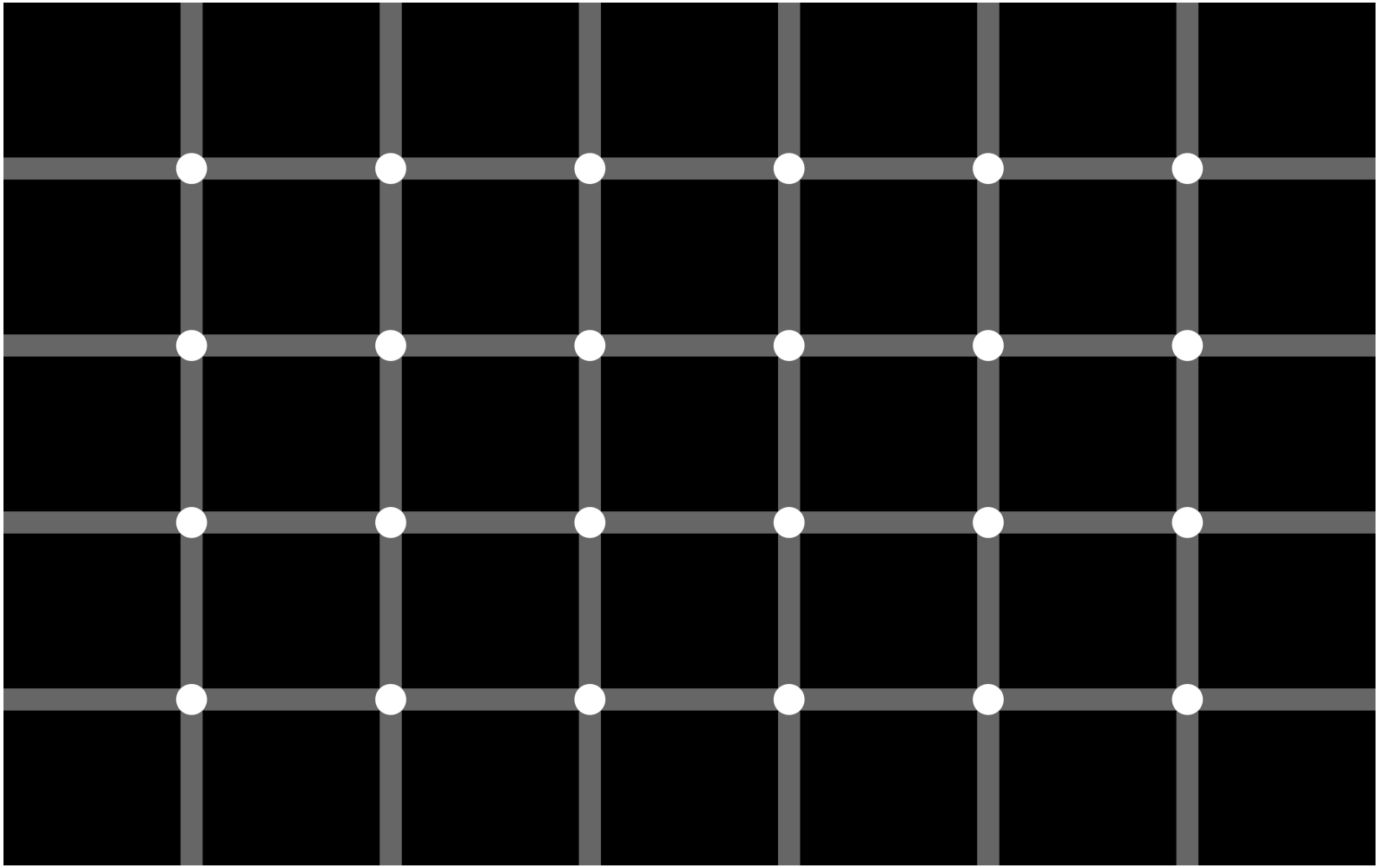


Figure from *Perception* course by Prof. David Heeger.

Hermann Grid Illusion

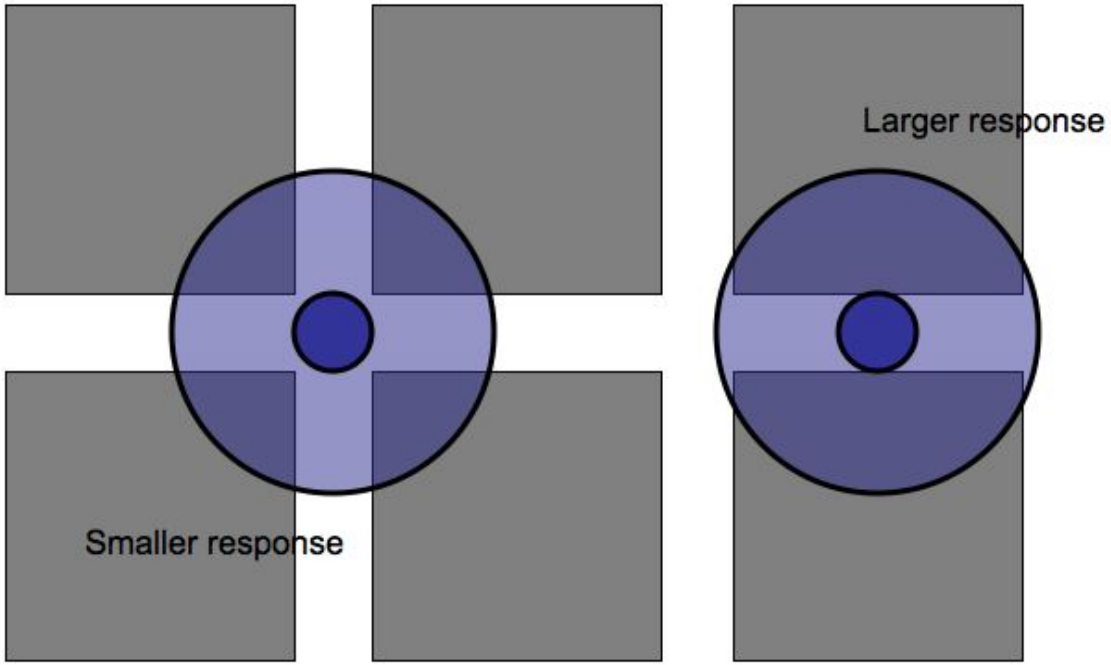


Hermann Grid (stronger stimulus)



Hermann Grid Illusions

- Classical explanations:



- Other experiments demonstrate that this theory is insufficient.
- An alternative theory is that the illusion is due to the S1 type simple cells.

The Chevreul Illusion

- One a sequence of uniform bands is shown, such bands appear darker at one edge.

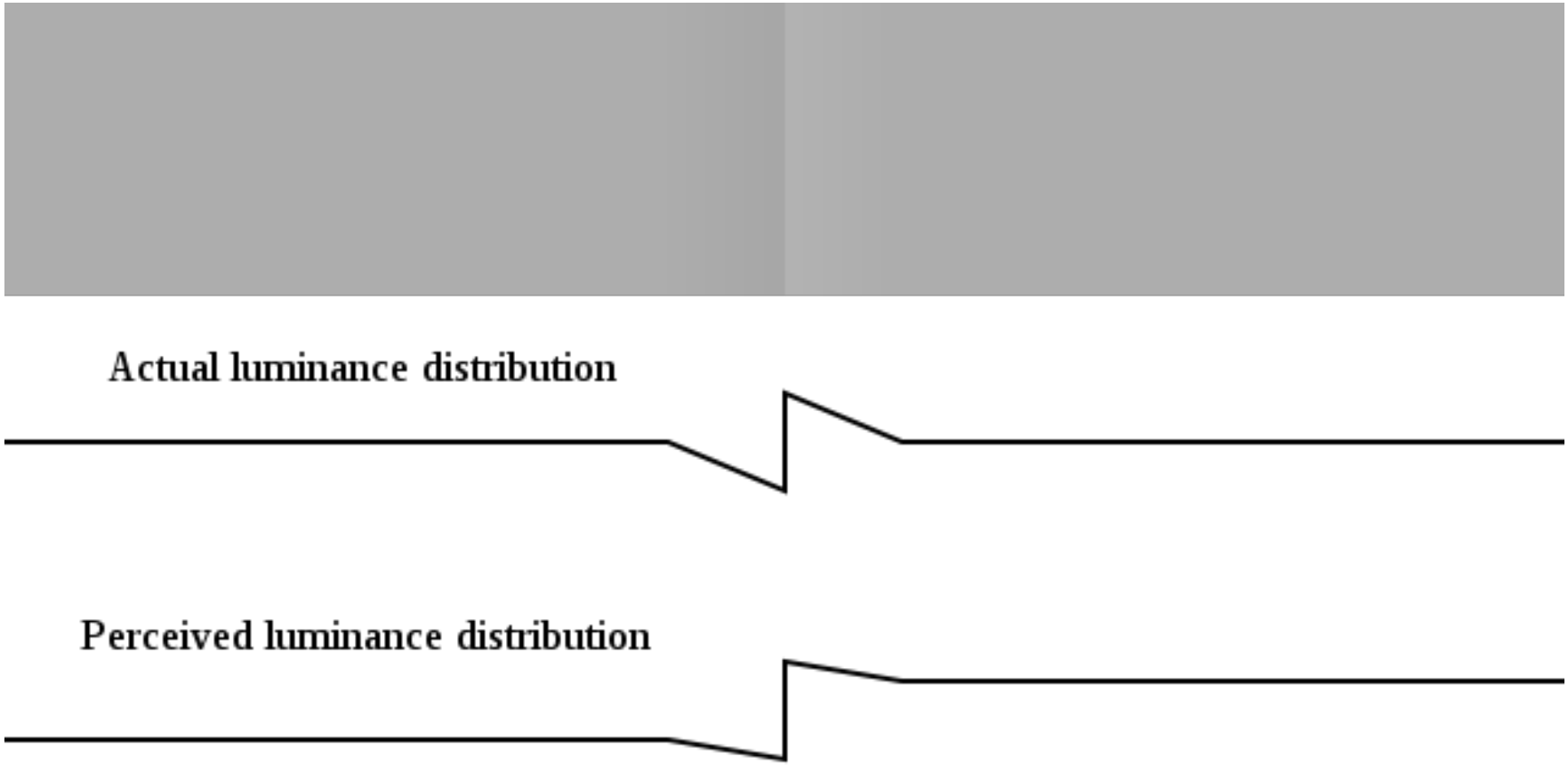
Greyscale Maps

- These visual effects can result in large errors when reading quantitative information map displayed using a greyscale map.
- Use greyscale maps to represent few values (!)

Cornsweet Illusion

- Lateral inhibition can be considered part of an edge detection process in a scene under viewing.
- Pseudo-edges can be seen depending on the stimulus.
- The brain does perceptual interpolation so that regions affected by such edges can appear lighter or darker. This is called Cornsweet illusion (also known as the *Craik–O'Brien–Cornsweet illusion*).

The Cornsweet Effect



Cornsweet Effect

- The Cornsweet effect can be used to highlight bounded regions.

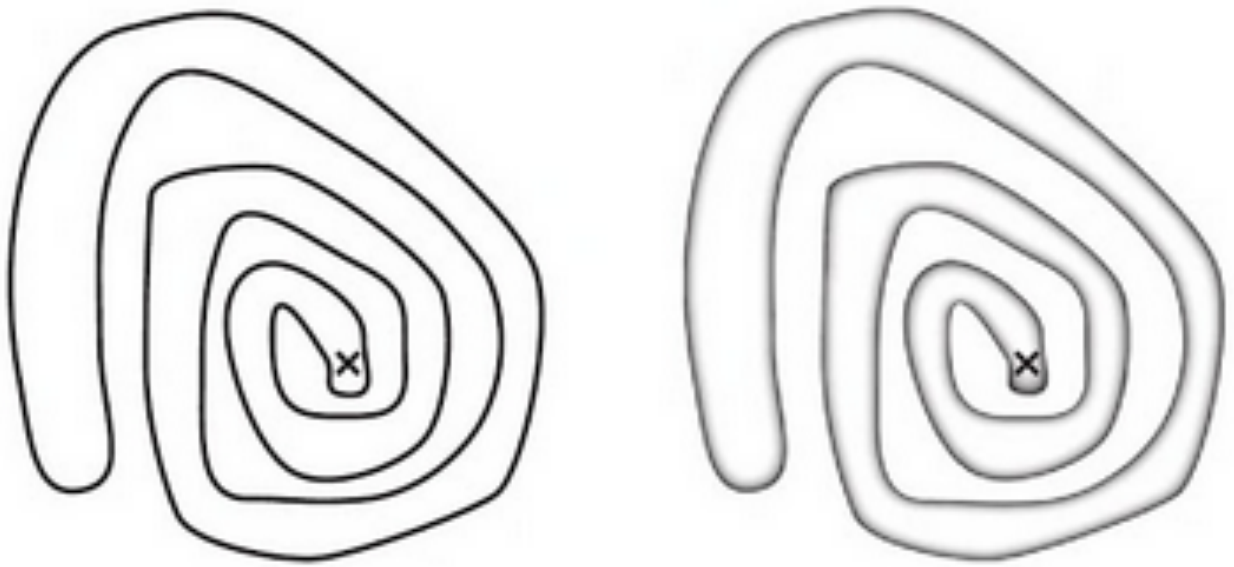


Figure from *Information Visualization – Perception for Design* by Colin Ware.

Recap – Use Grayscale Wisely

- Does not use for maps or to compare many values.
- Use to highlights:
  - Bounded regions
  - Important items (by reduce luminance contrast of unimportant items)
  - Adjust background luminance to obtain better readability

Eye Movements

- *Saccadic* movements: ballistic movements of the eyes that change the point of fixation. They can be voluntary or stimulus-elicited.
- *Smooth-pursuit* movements: slow tracking movements of the eyes to keep a moving stimulus on the fovea.
- *Vergence* movements: align the fovea of each eye to a target according to its distance.
- *Vestibulo-ocular* movements: stabilize the eyes compensating for head movements.

Saccadic Movements and Fixations

Saccadic Movements and Fixations

- Saccade takes 20-180 ms.
- Both eyes move in the same direction.
- The movement may be not a simple linear trajectory.
- A fixation is composed of slower and fine movements (microsaccades, tremor and drift) that help the eye align with the target.
- A fixation varies between 50-600 ms.
- Typical movements during reading: 2 degrees.
- Typical movements (in general): 2-5 degrees.
- > 20 degrees → head movement is required.

Eye Tracking System

Tobii Pro 2

Tobii Lab

Preattentive Processes

Count the number of 8s

1203902934023956034906930572076397603970299570325972057290357230572903769375252853446436326264356235250380530503325029346306230523050460457854125232356463475325732657362357646432634750056032592305320590325903960954970239509112147236466566545736472773737427584764565463463465348439750757347327394754743489720763976039702995703259720572903572305729037693752528534464363262643562352503805305033250293463062305230504604578541252323564634753257326573623576464326347500560325923053205903259039609549702395091121472364665665457364727737373742758476456546346346534843975075734732739475474348972076397603970299570325972057212323254556774328

Preattentive Processes

Count the number of 8s ☺

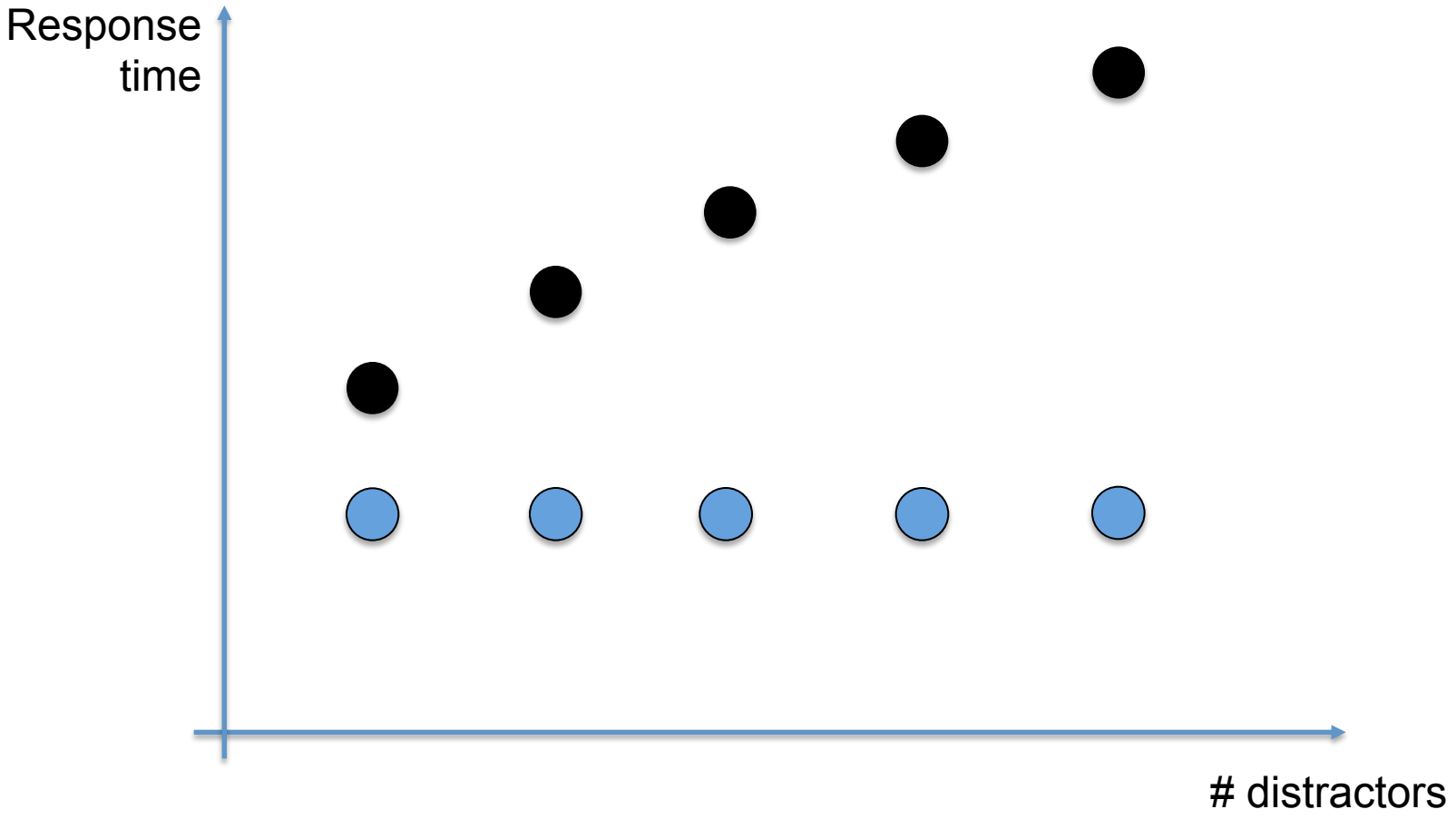
1203902934023956034906930572076397603970299570325972057290357230572903769375252853446436326264356235250380530503325029346306230523050460457854125232356463475325732657362357646432634750056032592305320590325903960954970239509112147236466566545736472773737427584764565463463465348439750757347327394754743489720763976039702995703259720572903572305729037693752528534464363262643562352503805305033250293463062305230504604578541252323564634753257326573623576464326347500560325923053205903259039609549702395091121472364665665457364727737373742758476456546346346534843975075734732739475474348972076397603970299570325972057212323254556774328

Preattentive Processes

- Some visual stimulus “pop up” from their surroundings.
- Initially, researchers thinked that they happened before attention (erroneous).
- Attention is a part of the process.

Preattentive Processes

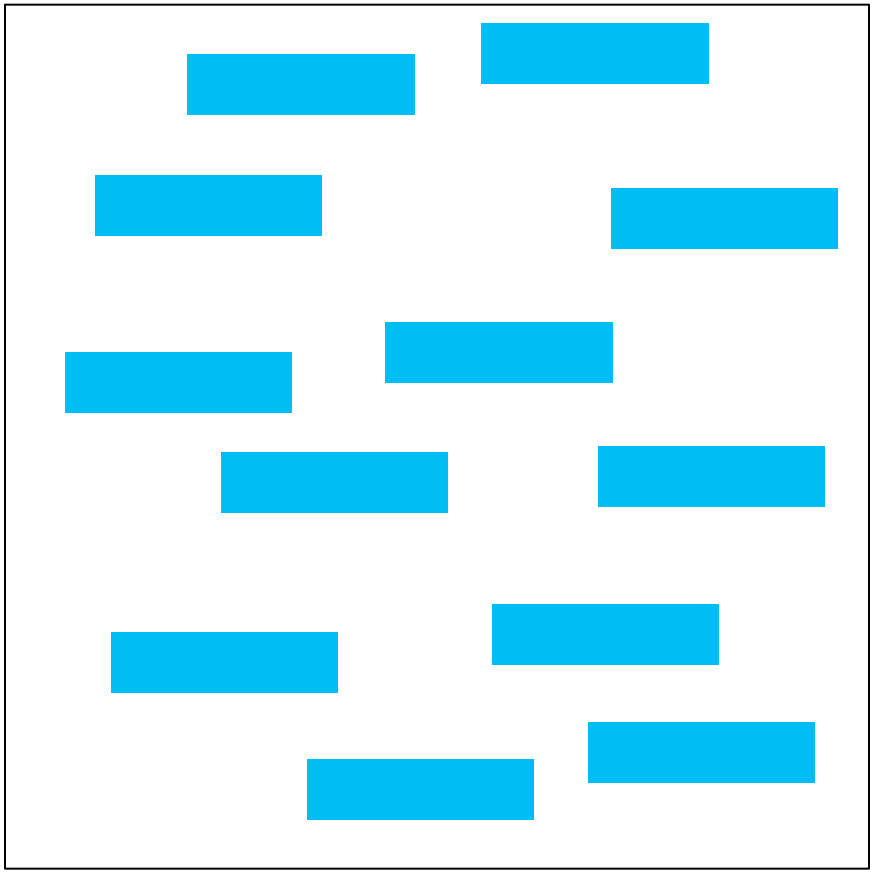
- When a visual stimulus is preattentive ?

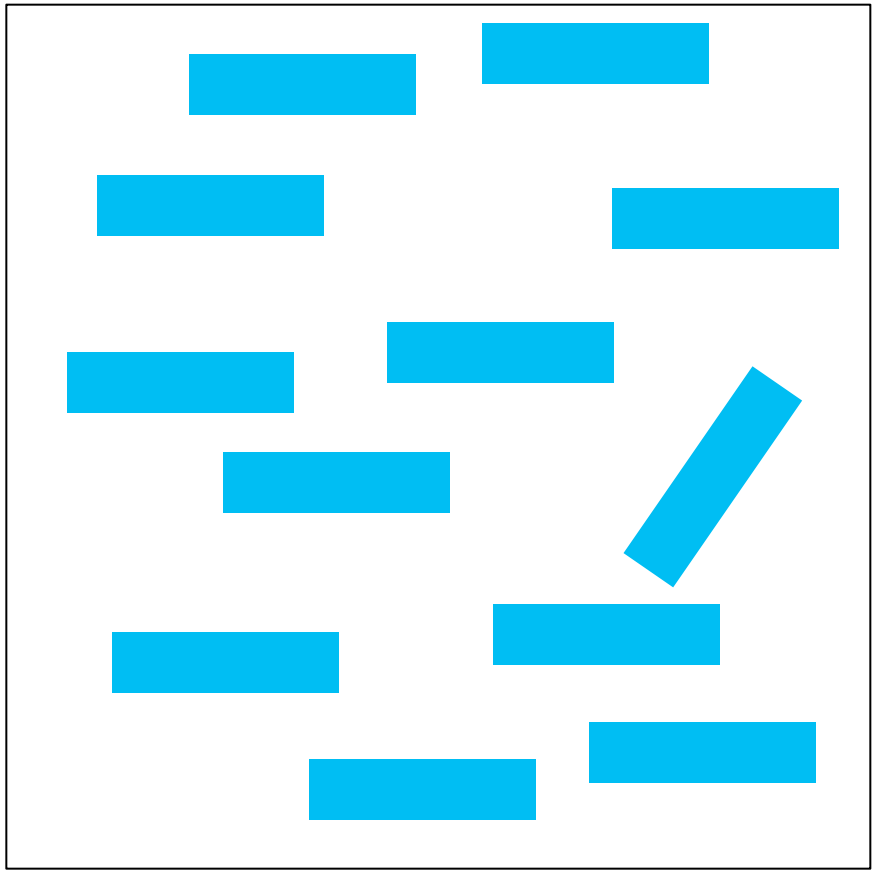


Preattentive Processes

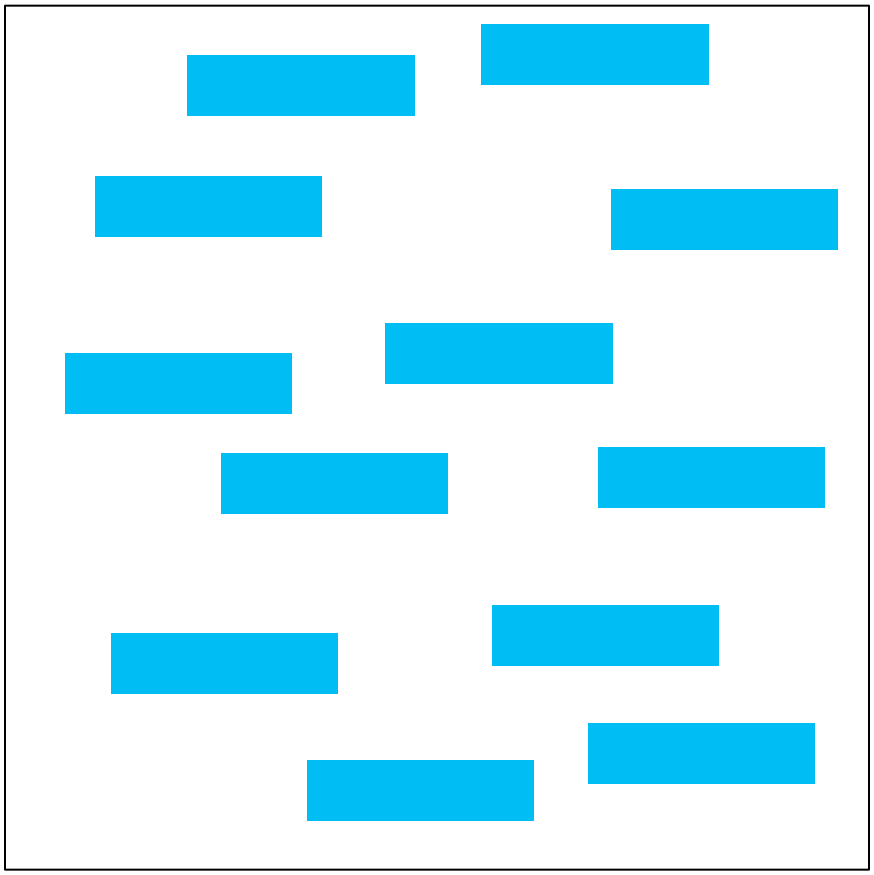
- Visual features that are preattentively processed:
  - Orientation ; Curvature ; Shape ; Size ; Color ; Light/Dark ; Enclosure ; Concavity/Convexity ; Addition
- Some of them are not symmetric.
- Visual features that are not preattentively processed:
  - Juncture ; Parallelism

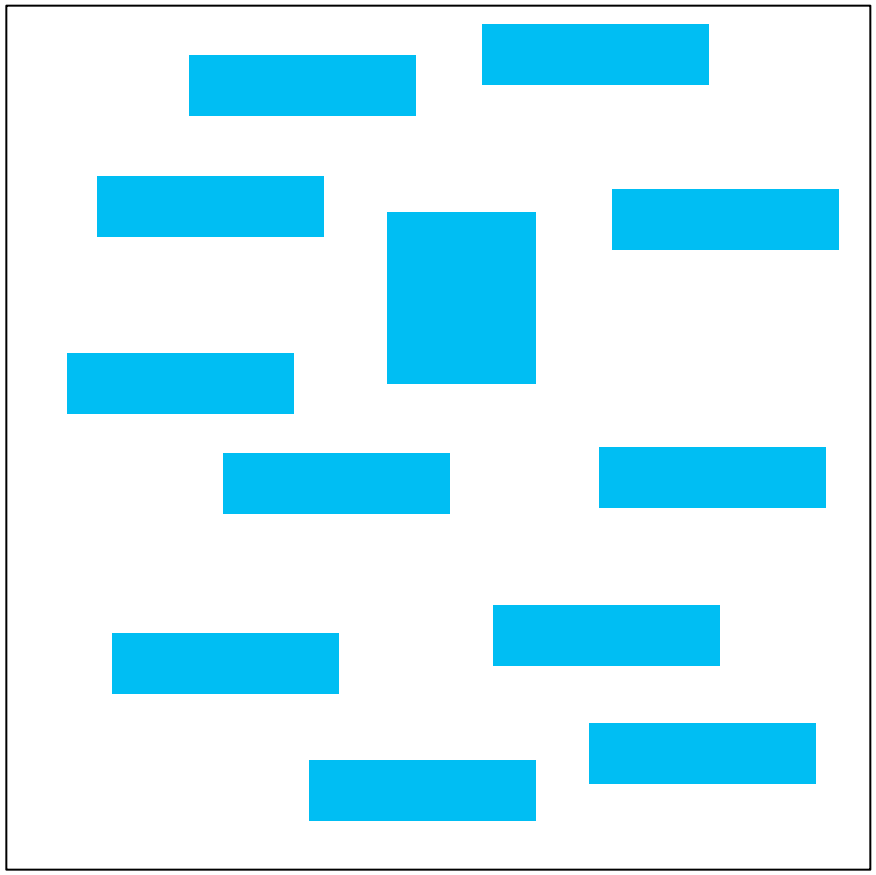
Preattentive Features – Orientation



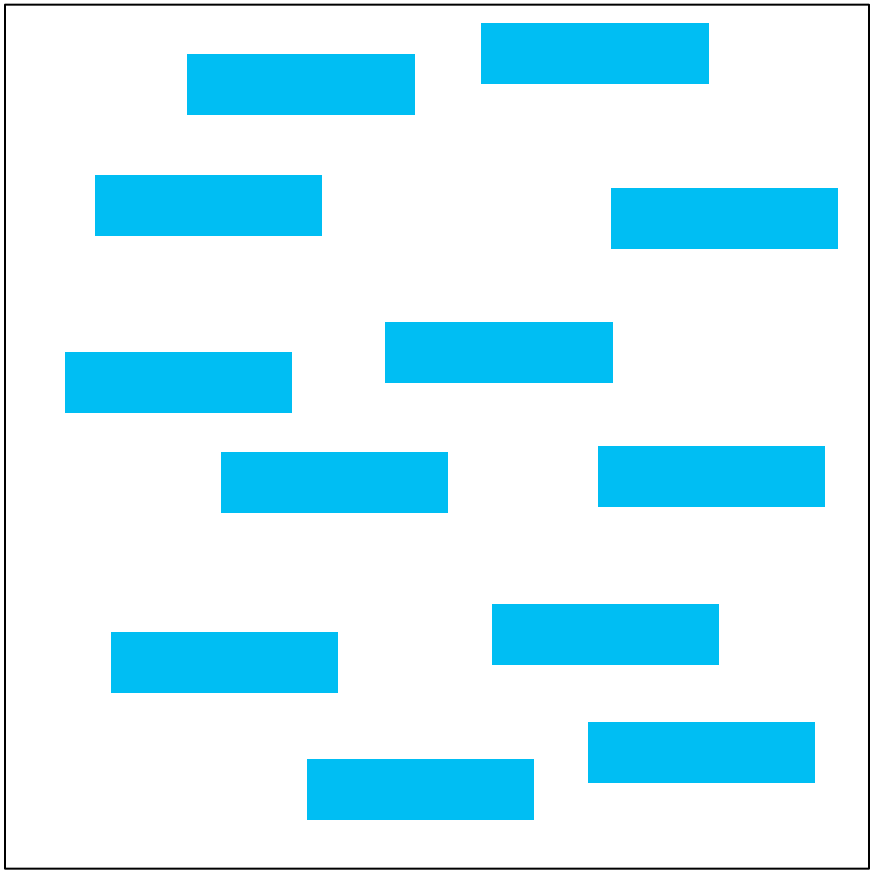


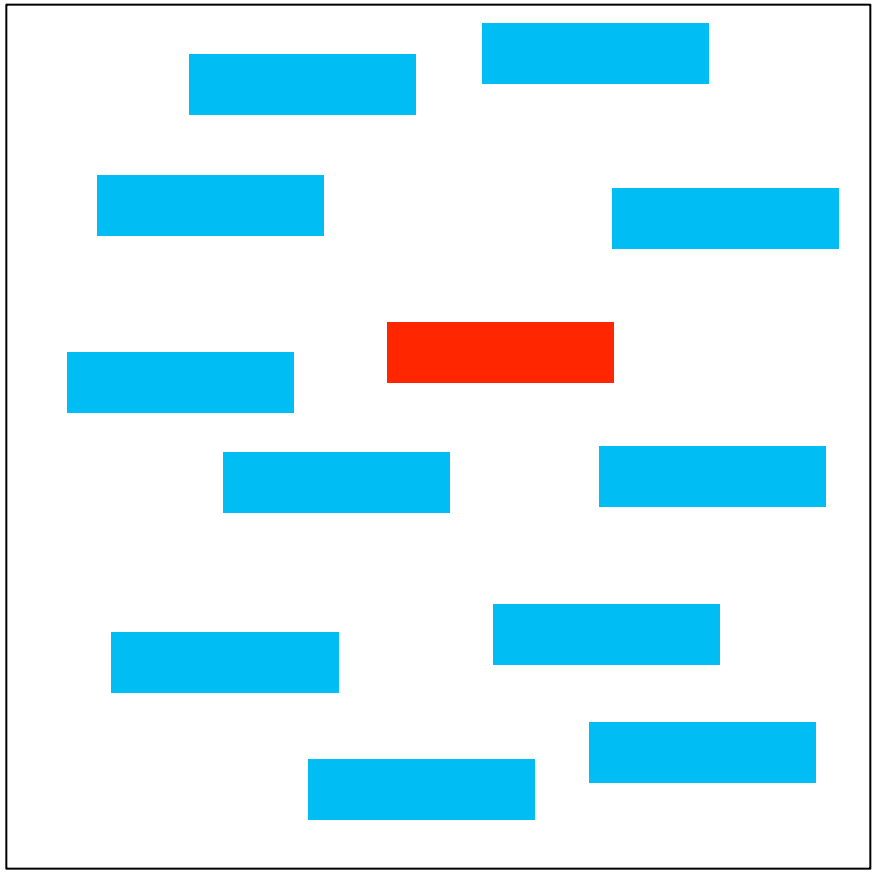
Preattentive Features – Shape



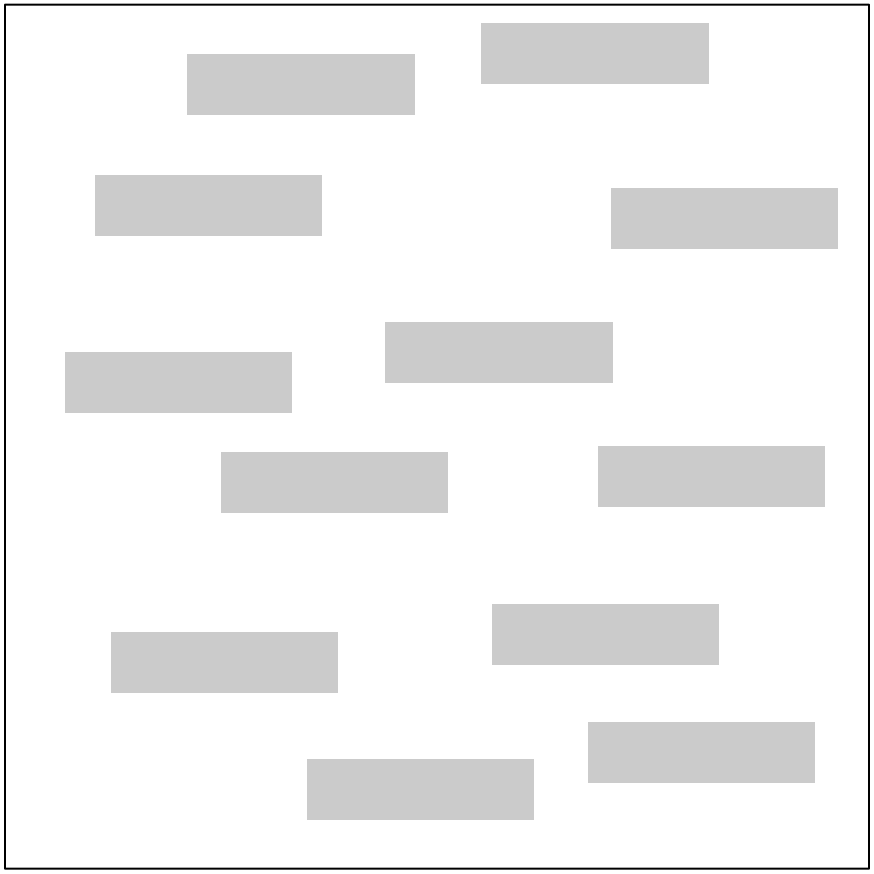


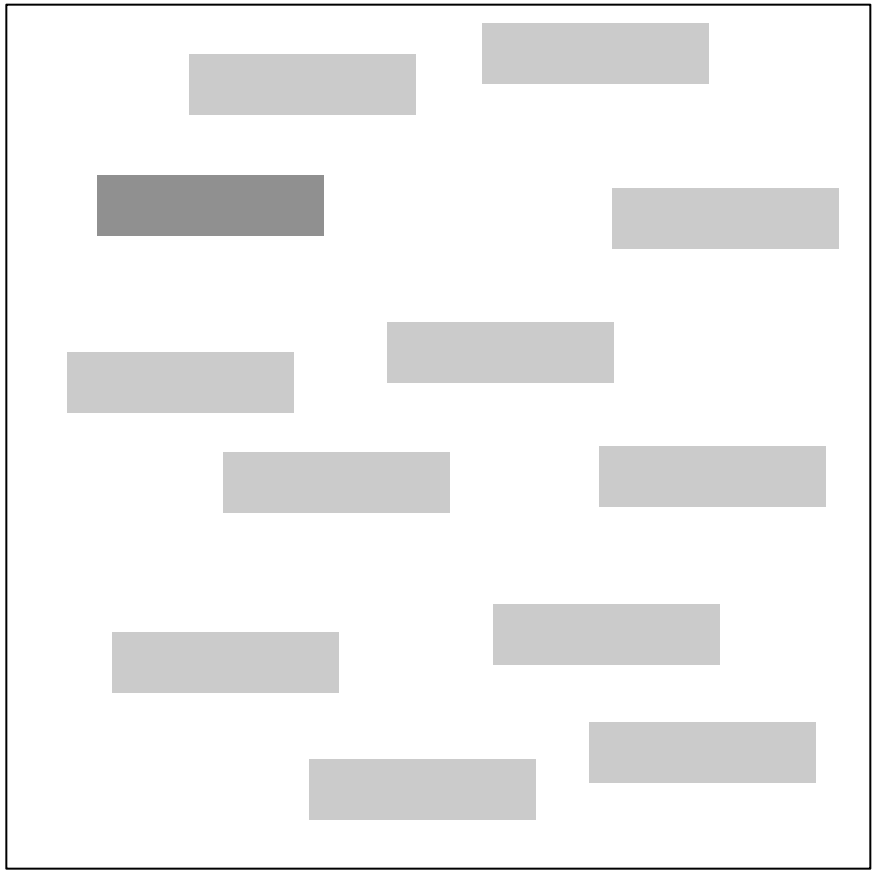
Preattentive Features – Color



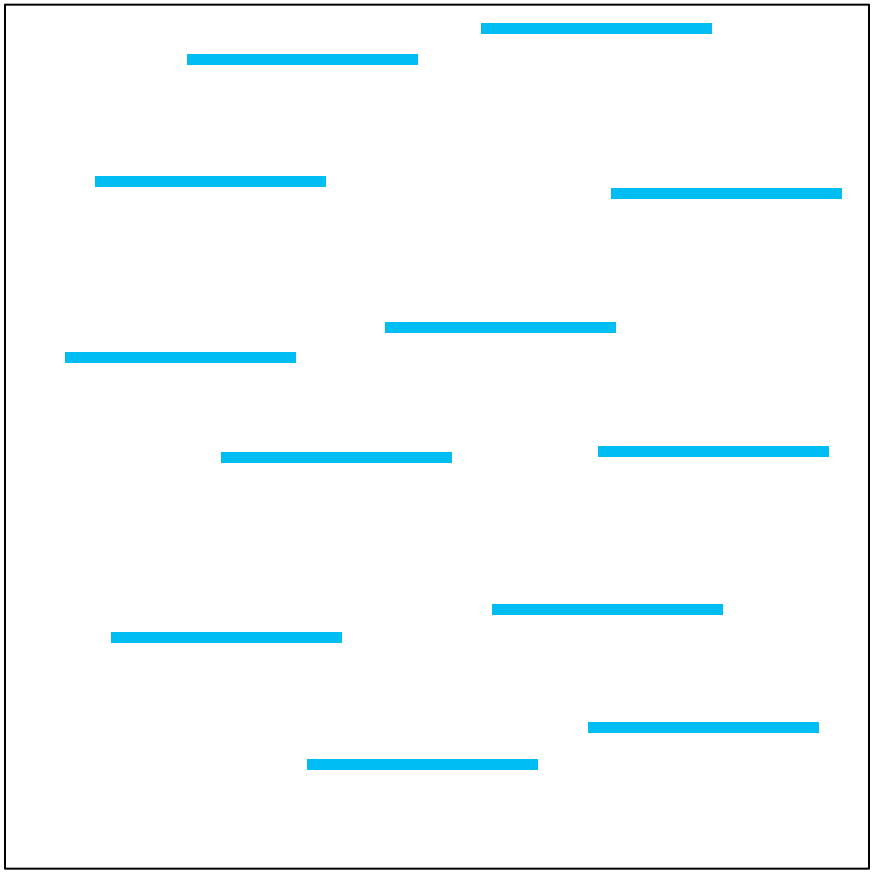


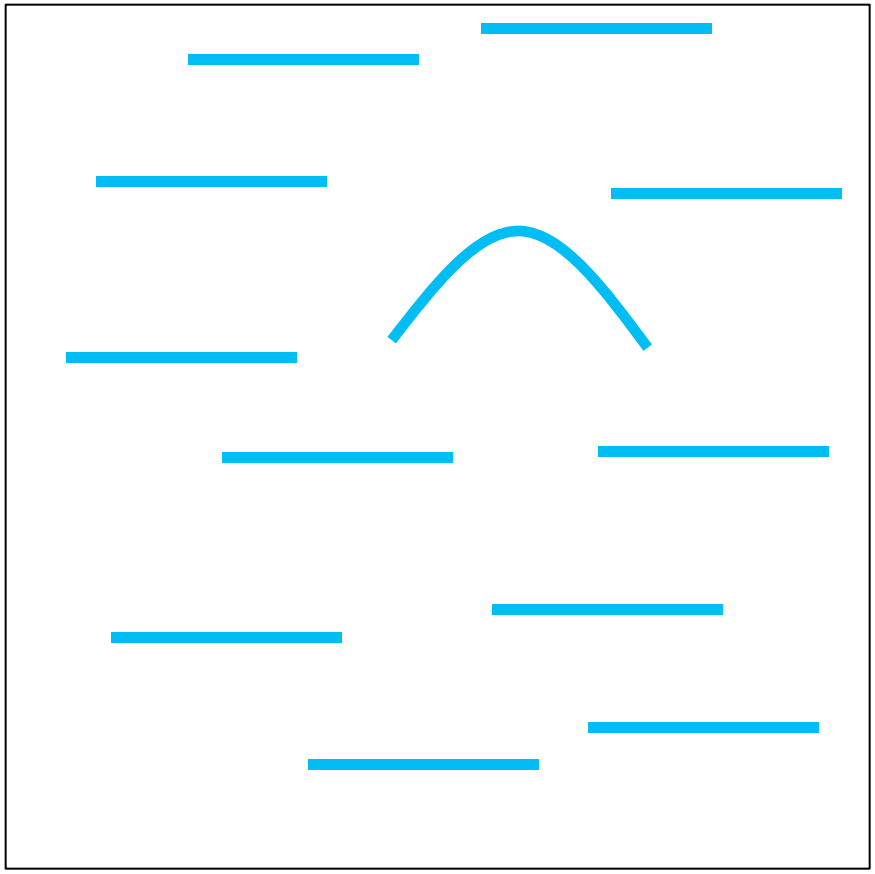
Preattentive Features – Light/Dark



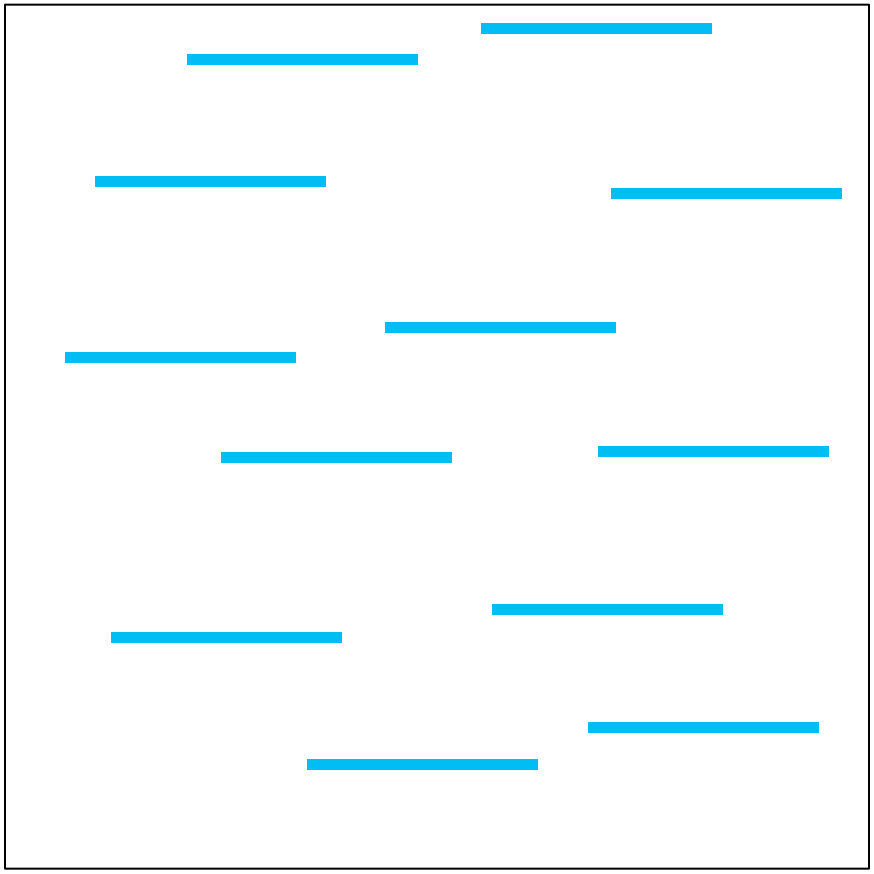


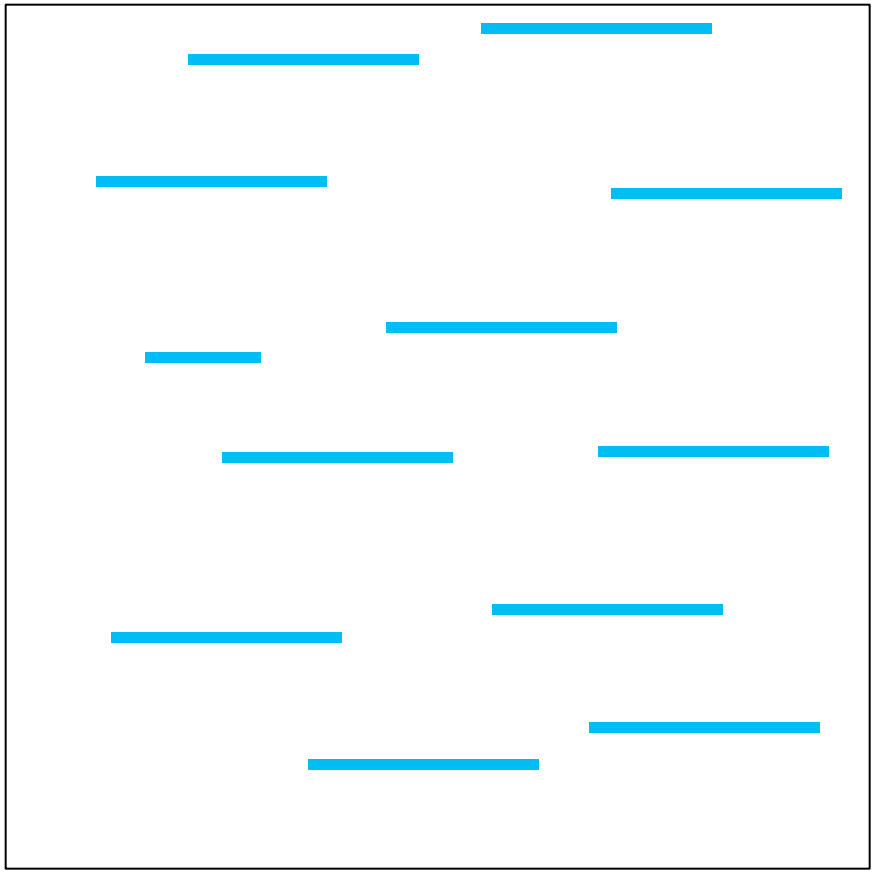
Preattentive Features – Curvature





Preattentive Features – Length

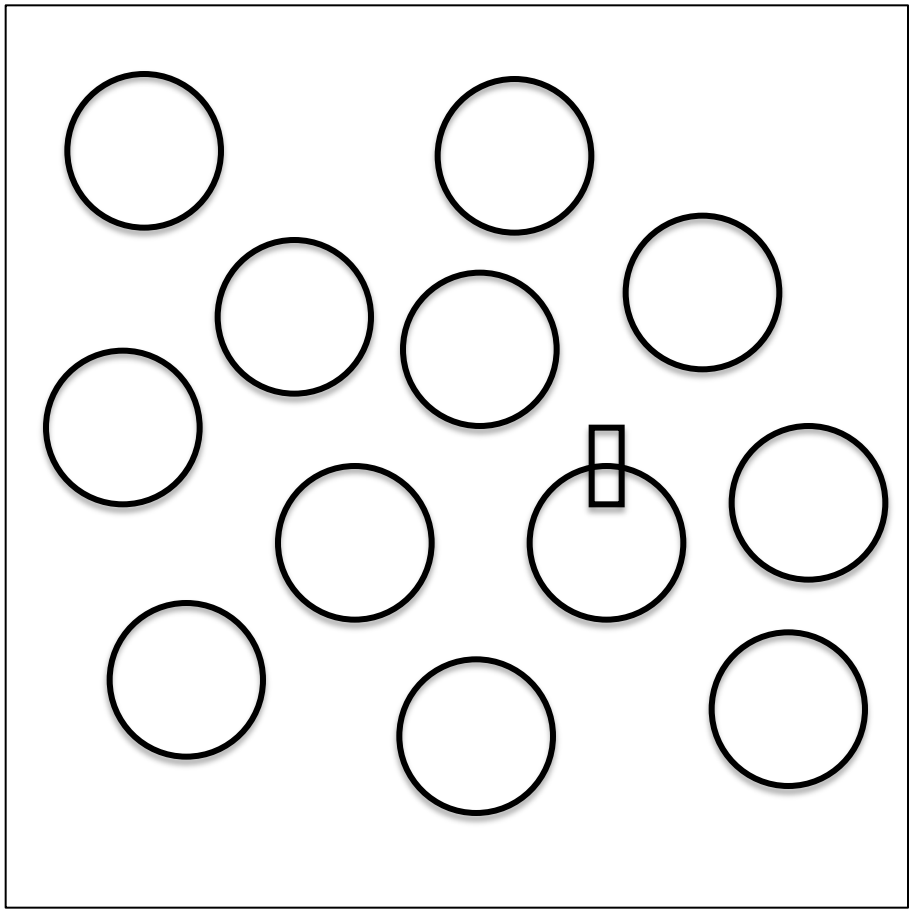


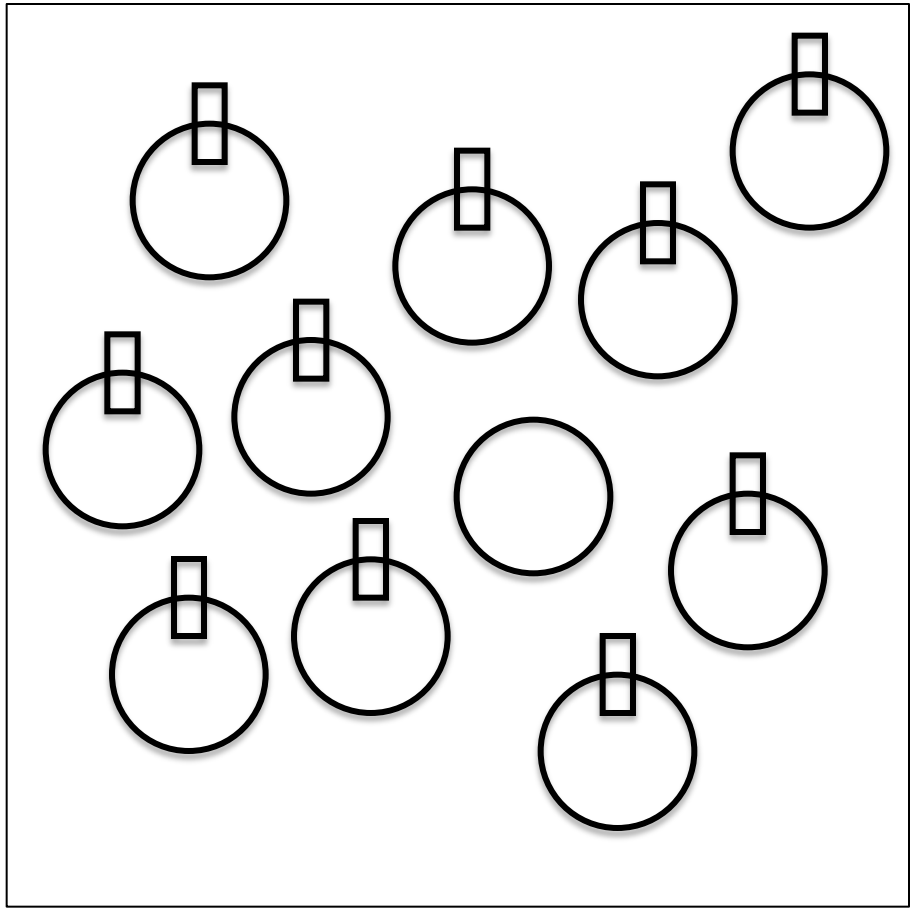


Preattentive Process – Asymmetry

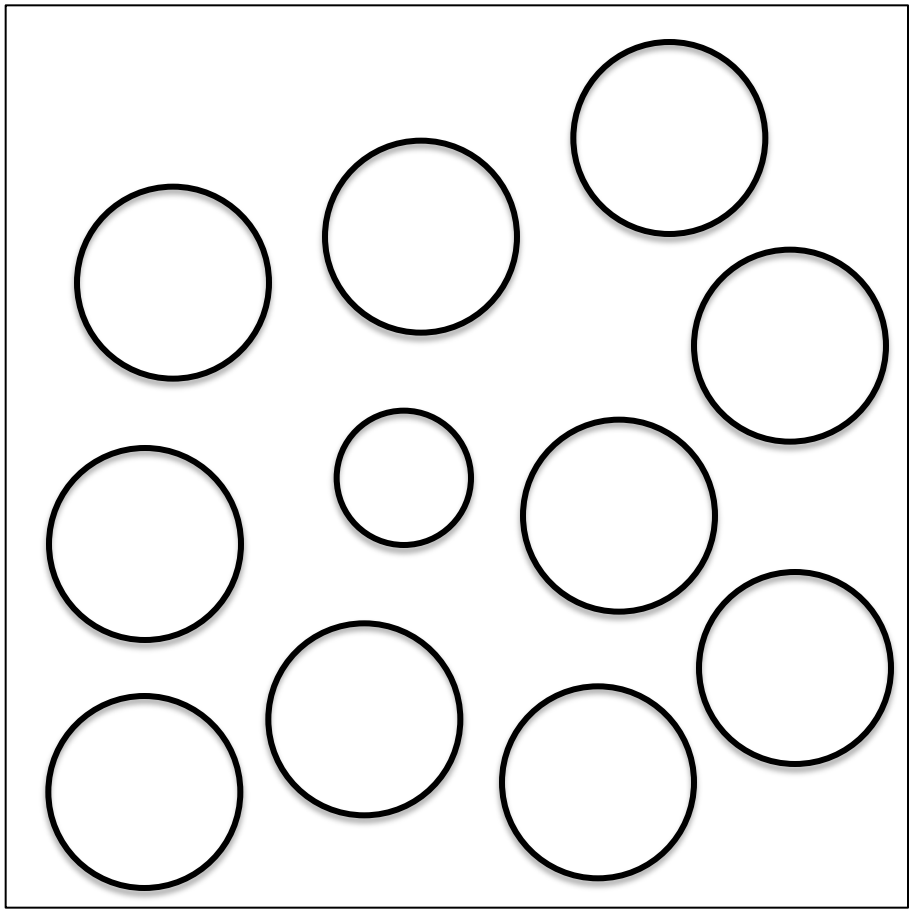
- Some preattentive process are not simmetric:
  - Adding marks is more efficient than removing marks.
  - Increase sharpness is more efficients than decrease sharpness.
  - A big object surrounded by small objects is more efficient than a small object surrounded by big objects.

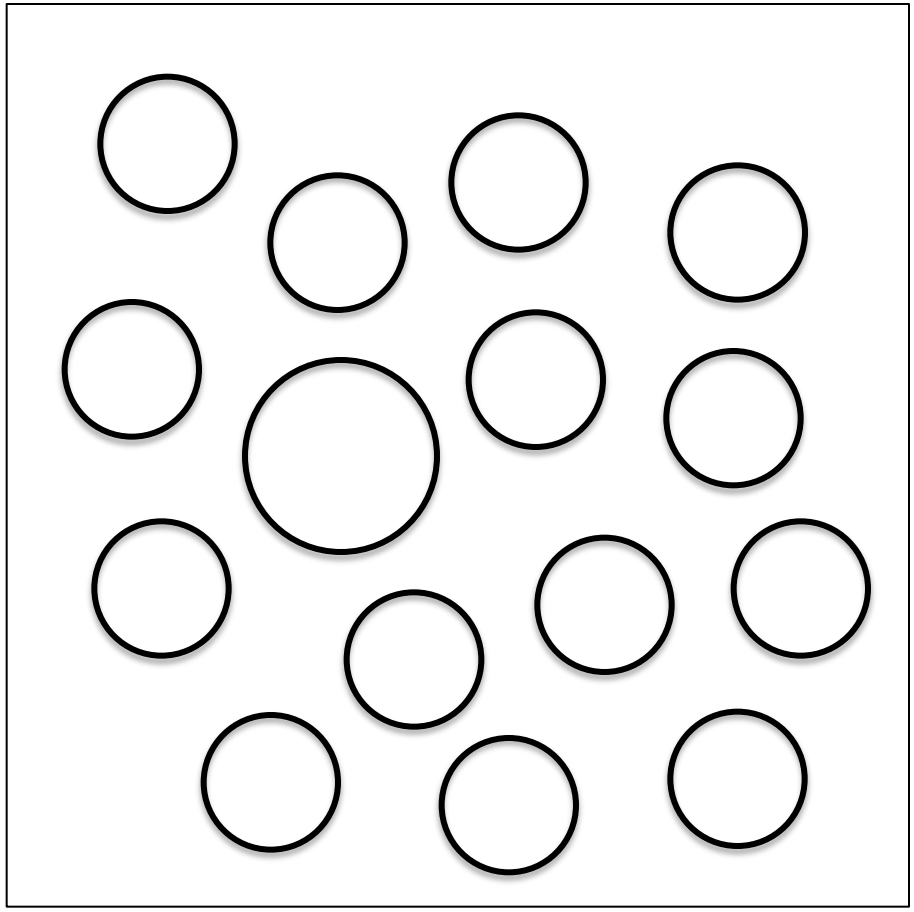
Asymmetric Processes – Marks



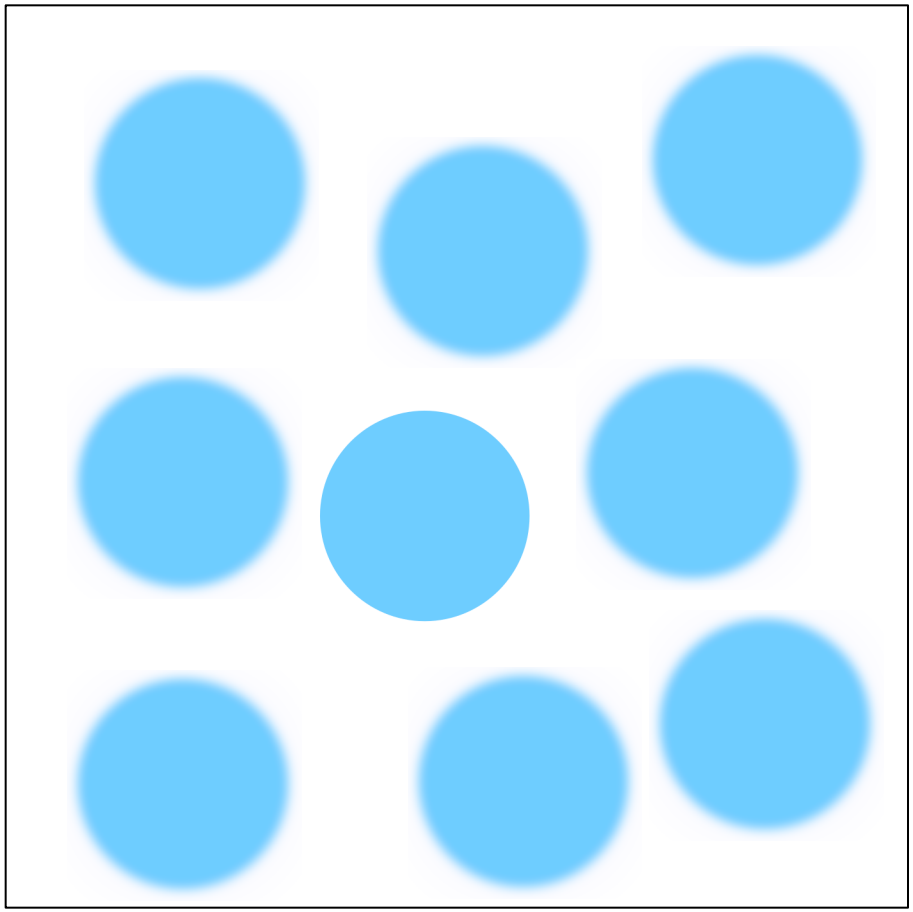


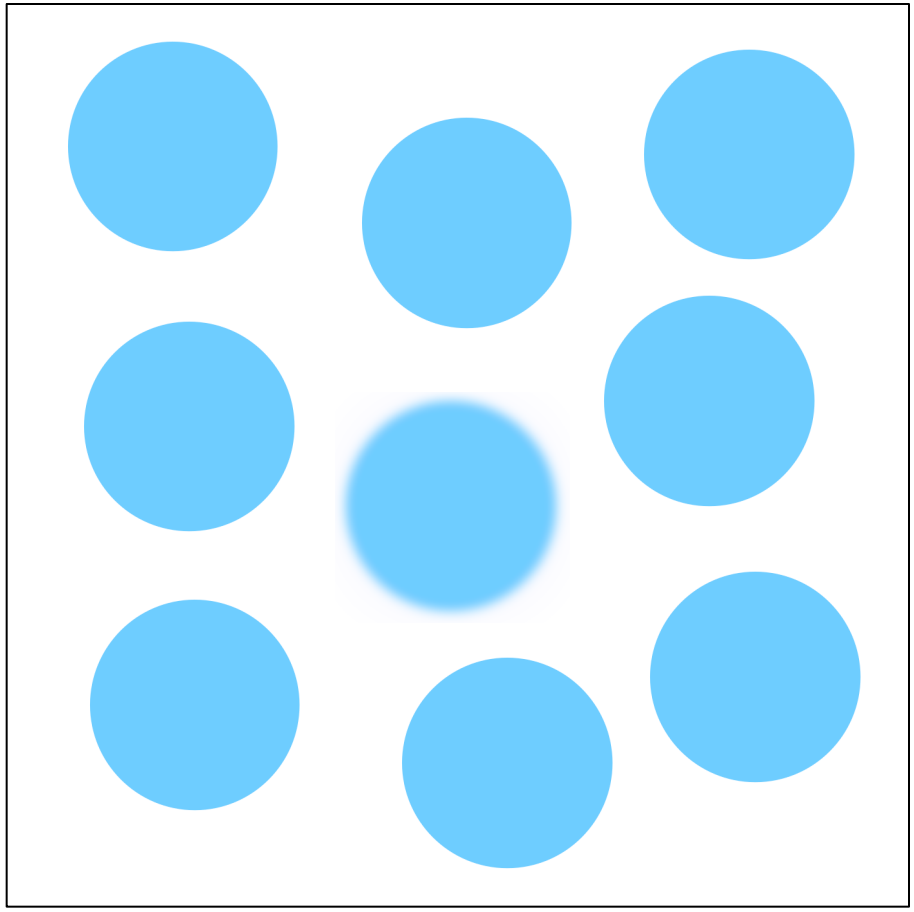
Asymmetric Processes – Size Ratio





Asymmetric Processes – Sharpness





Combination of Preattentive Features

- Note that the combinations of preattentive visual features may not be preattentive.
- Examples:
  - Shape + Color
  - Size + Color
  - Shape + Motion

Combination of Preattentive Features

Where is the red circle ?

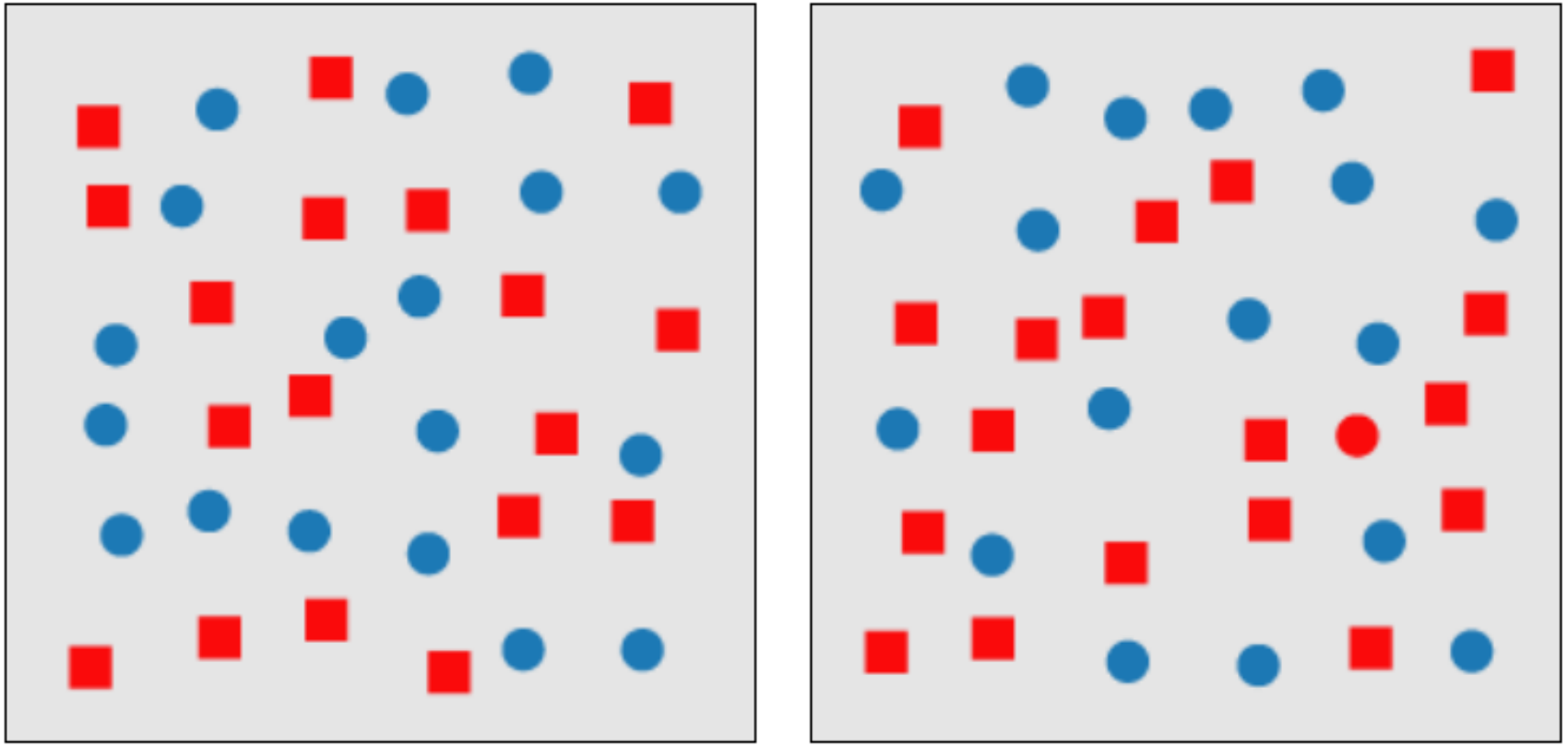


Figure from *Perception in Visualization* by Christopher G. Healey, North Carolina State University.

Combination of Preattentive Features

Where is the red circle ?

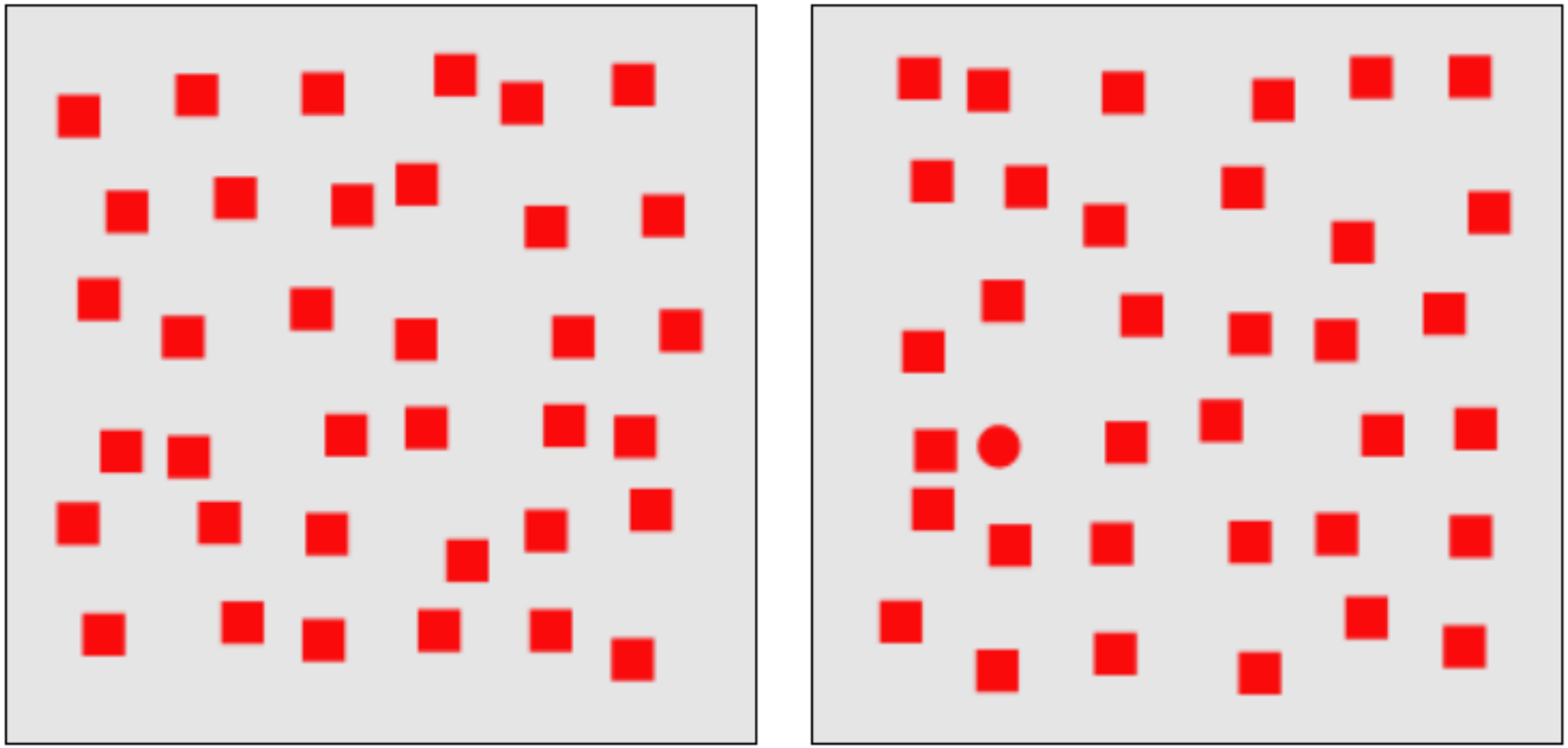


Figure from *Perception in Visualization* by Christopher G. Healey, North Carolina State University.

Gestalt Laws

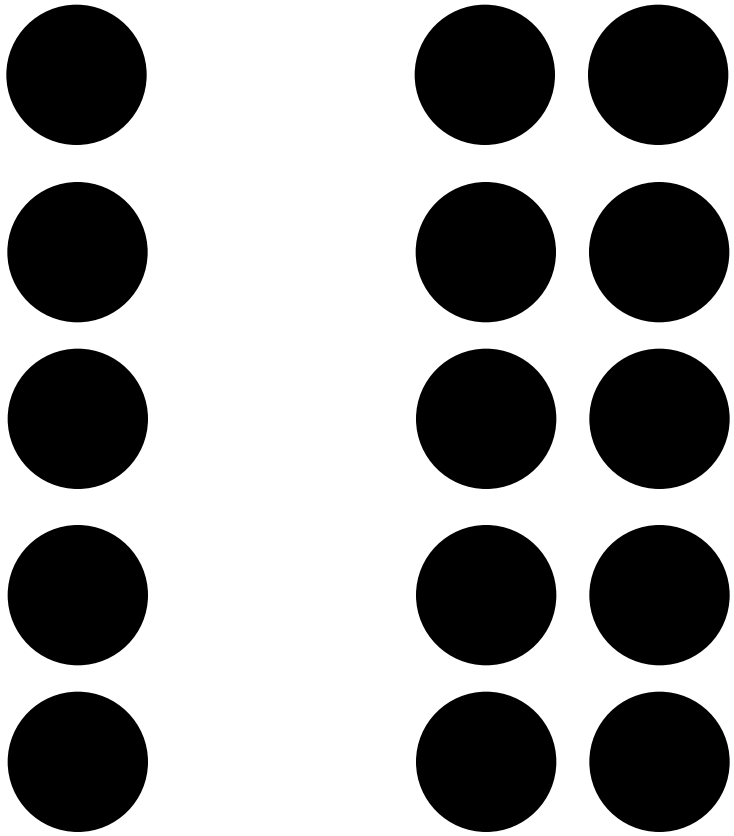
- From *Gestalt School of Psychology* (founded in 1912 by Max Westhemer, Kurt Koffka and Wolfgang Koheler).
- The first serious attempt to understand pattern perception.
- The neural mechanisms proposed do not pass the test of the time..
- .. BUT the laws have proven to be valid.

Gestalt Laws

- Proximity
- Similarity
- Connectedness
- Continuity
- Symmetry
- Closure
- Common fate
- Figure-ground

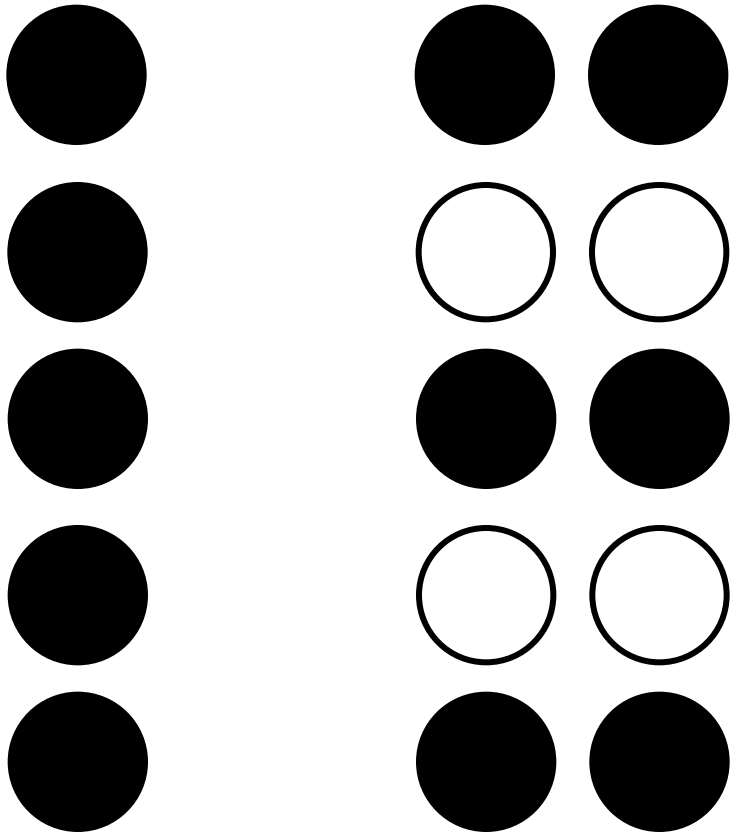
Proximity

- Objects close to each other are perceived to form a group.



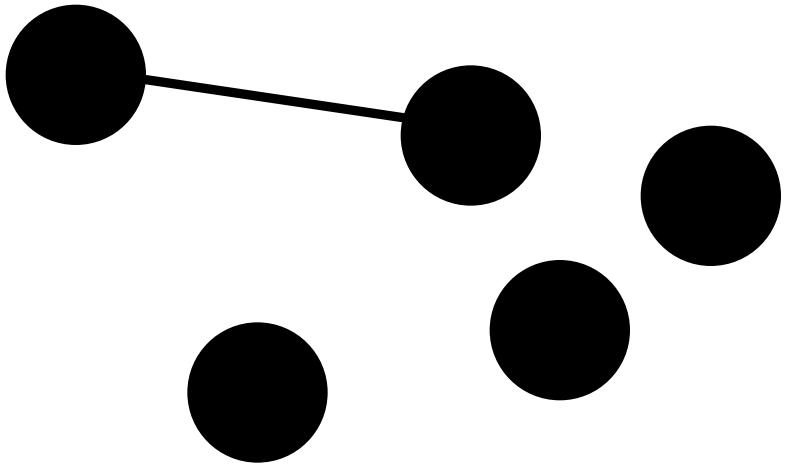
Similarity

- Similar objects are perceived to from a group.



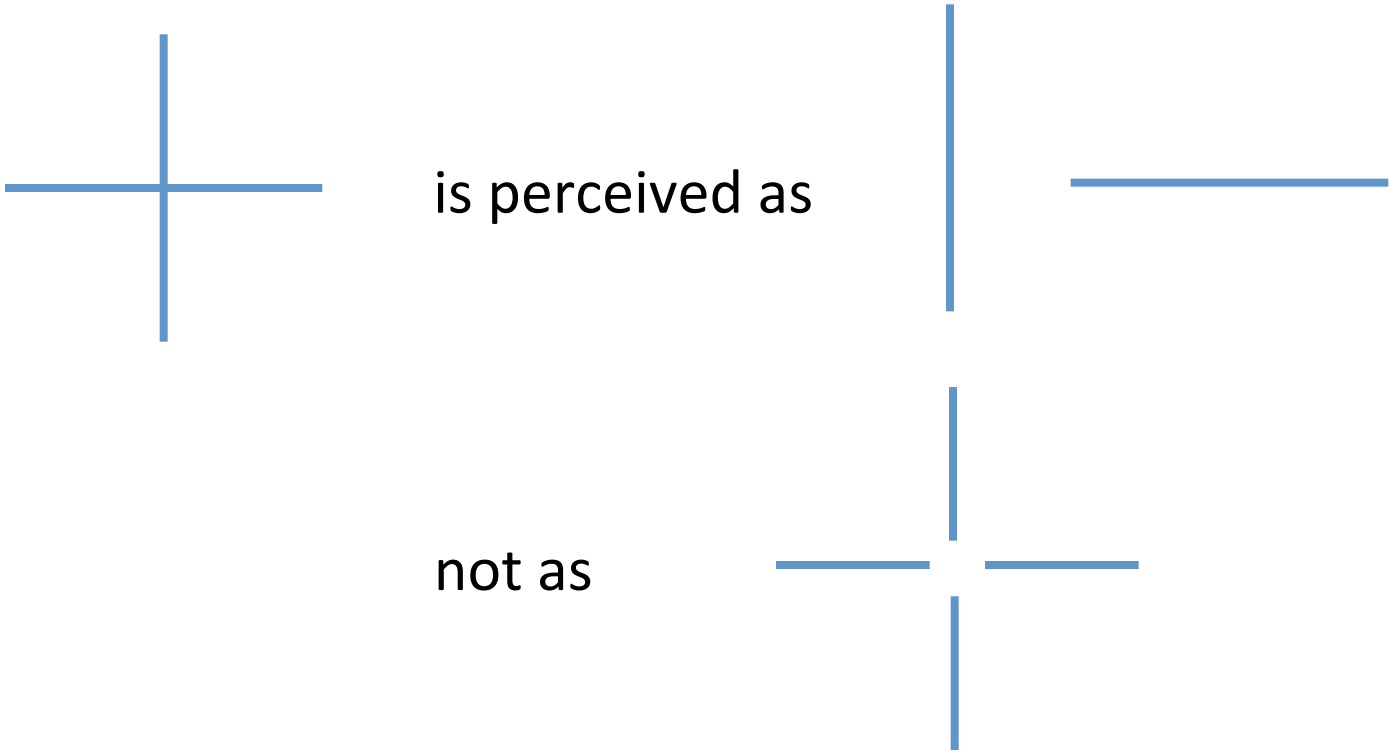
Connectedness

- Connected objects are perceived as related.
- Connecting different objects with a line is a powerful way to express that there is some relationship between them.

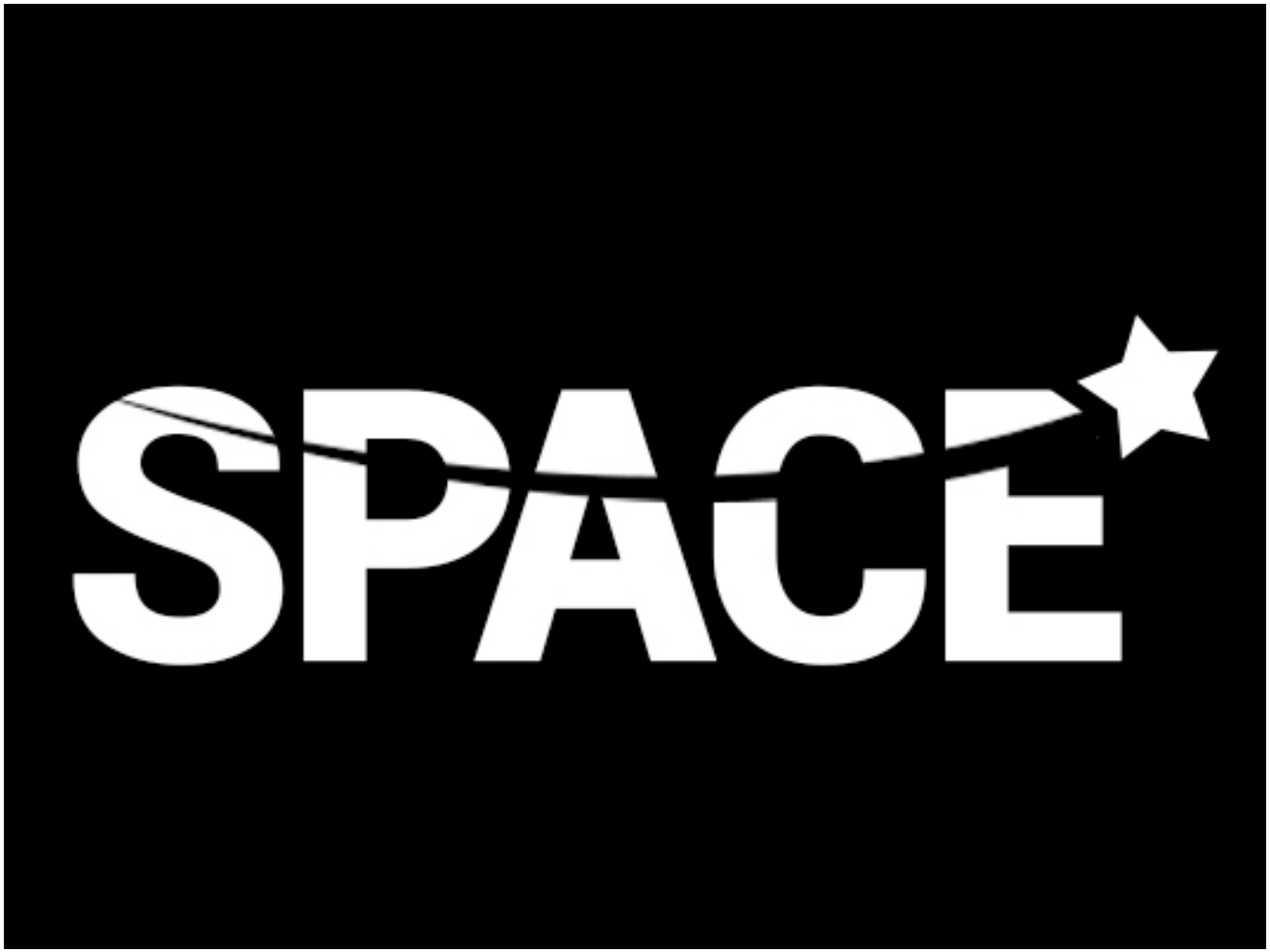


Continuity

- We expect that a line or an edge continue to follow its direction and does not deviate from it.

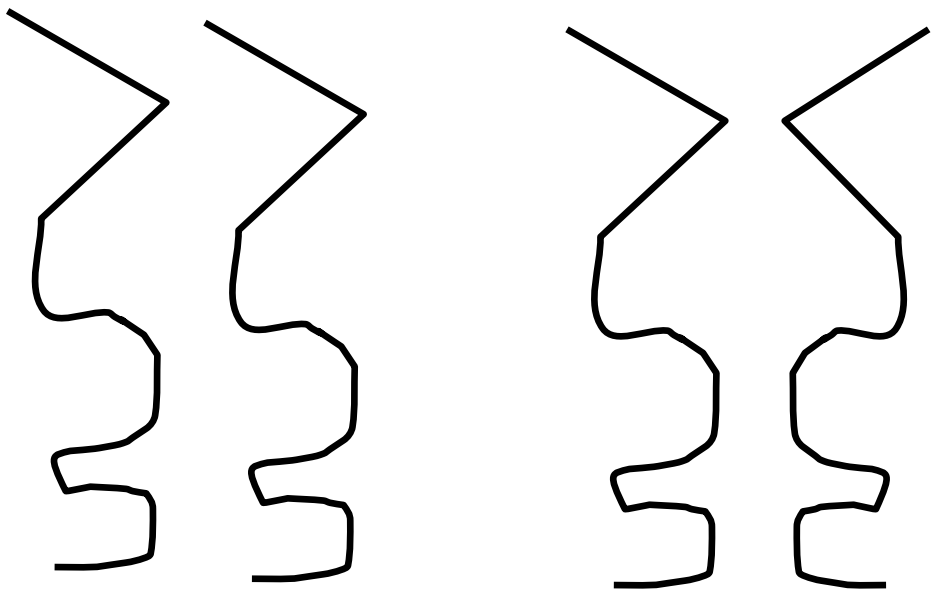


Continuity



Simmetry

- Objects arranged simmetrically are perceived as forming a visual whole instead of being preceived as separated entities.



- Simmetry is best perceived for horizontal and vertical axes.

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Closure

- We tend to perceive the complete appearance of an object. Our brain fills the gap in case of missing parts.

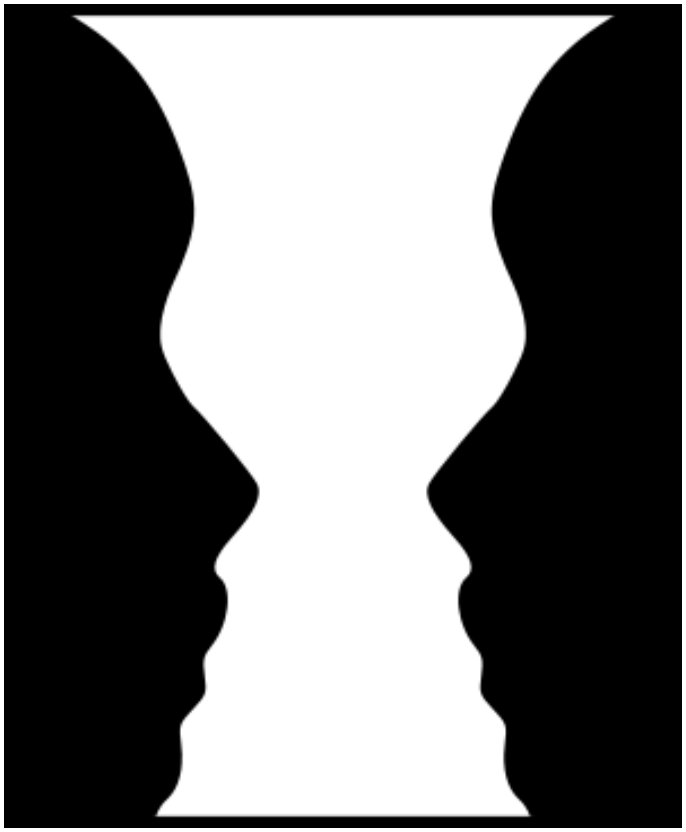
Illusory Contour

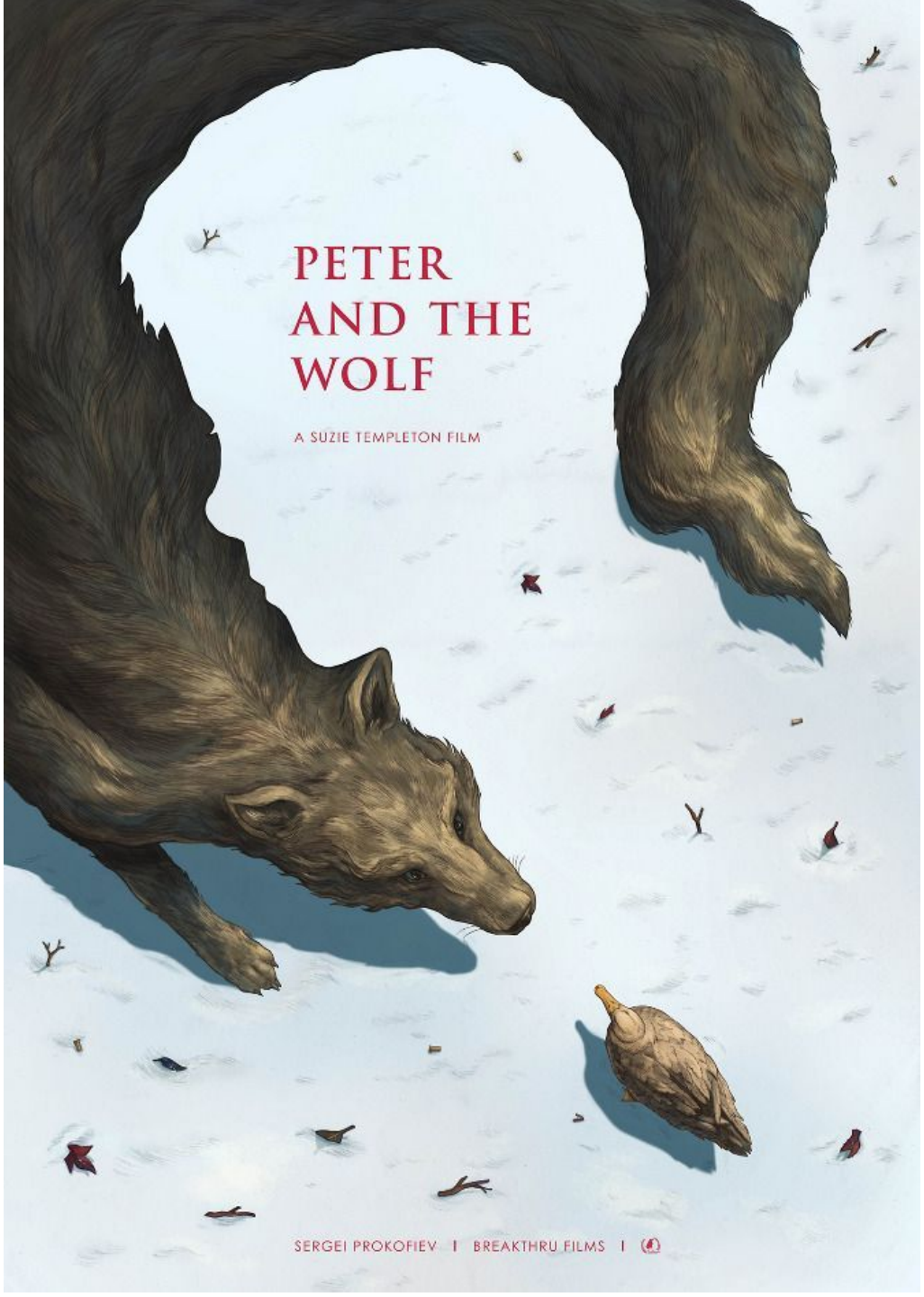
Common Fate

- We tend to perceive as a group objects that moves in the same direction.

Figure-Ground

- This perceptual effect regards the formation of a figure from the background.

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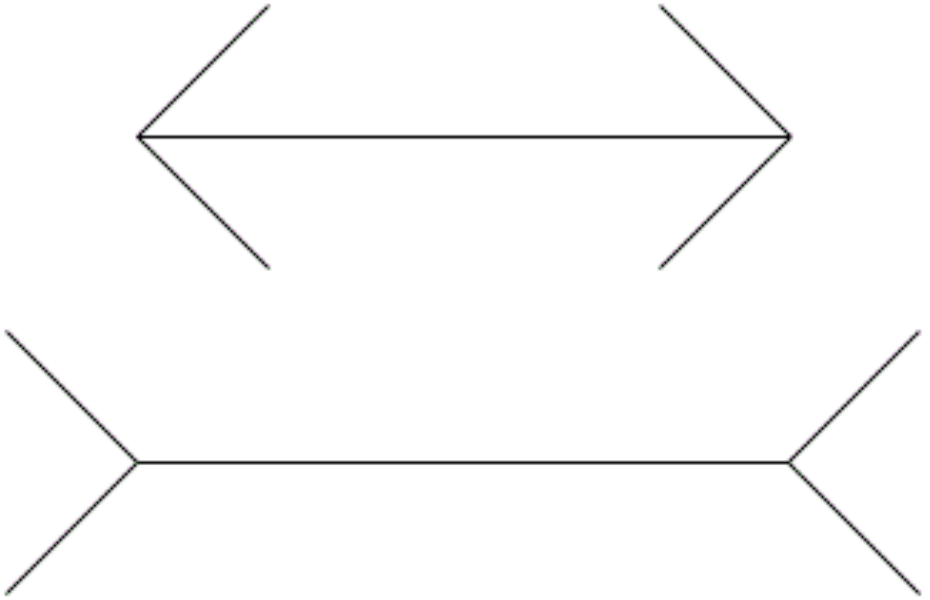
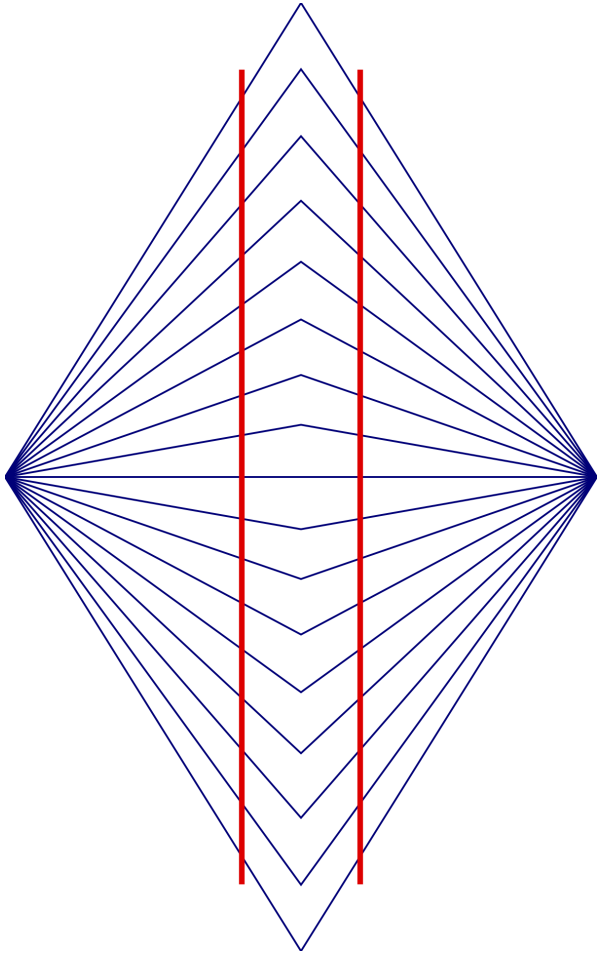
Müller-Lyer Illusion

- These two lines have equal length but we perceive that they have different length.
- Two explanations:
  - Perspective explanation
  - Centroid explanation



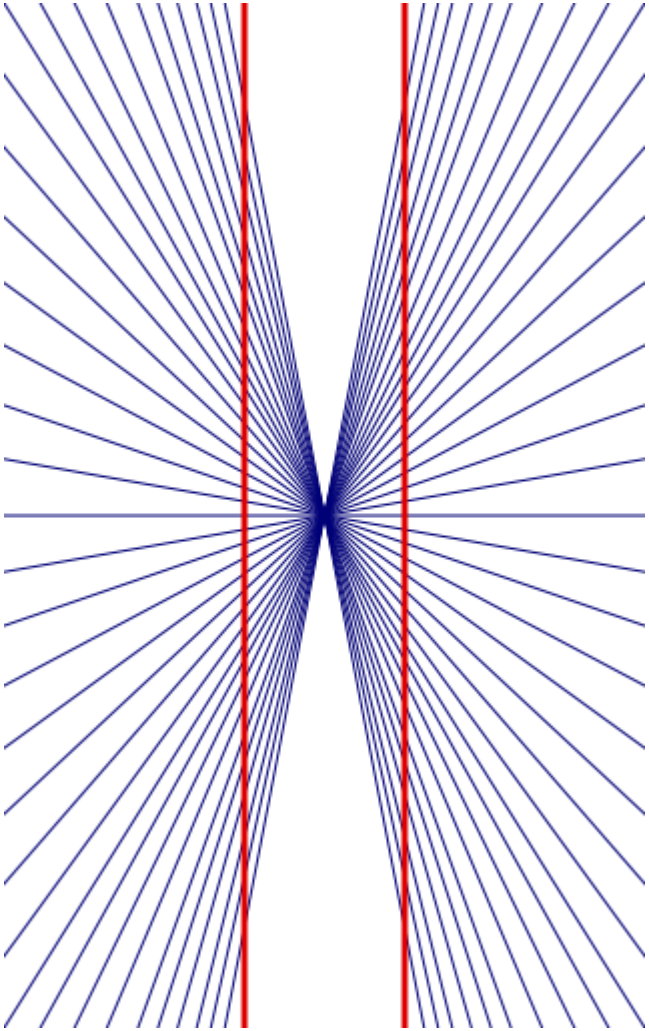
Wundt Illusion

- Wilhelm Wundt (1832-1920) (“father of experimental psychology”).
- Not completely explained.



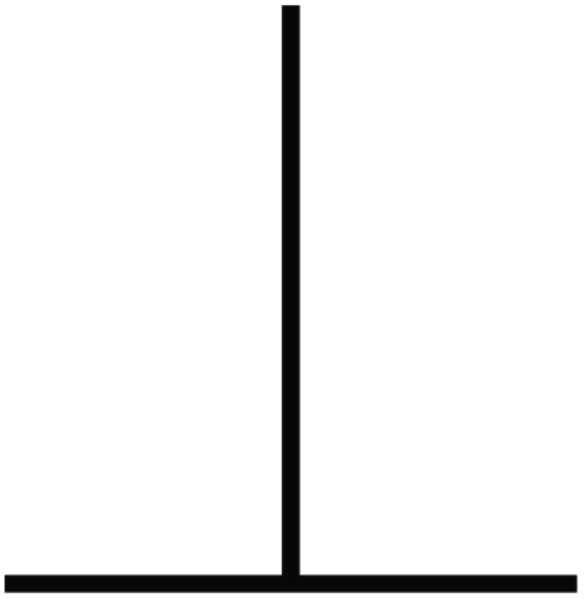
Hering Illusion

- Another similar illusion (inverted effect of Wundt illusion).
- Possible explanations:
  - Lateral inhibition
  - Perspective effect
  - Temporal delays in visual processing



Horizontal–Vertical Illusion

- Another simple illusion discovered by Wundt.
- The vertical line is perceived 30% more length than the horizontal line.
- Cross-cultural (small) differences have been noticed.
- This is true also for intersecting lines.

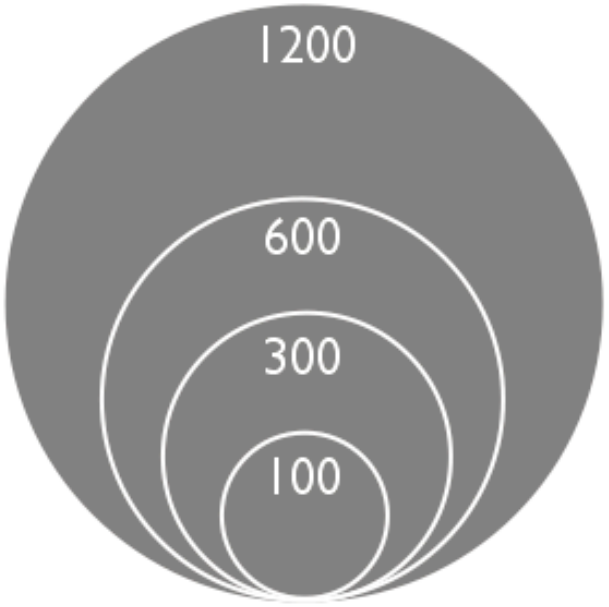


Comparing Area

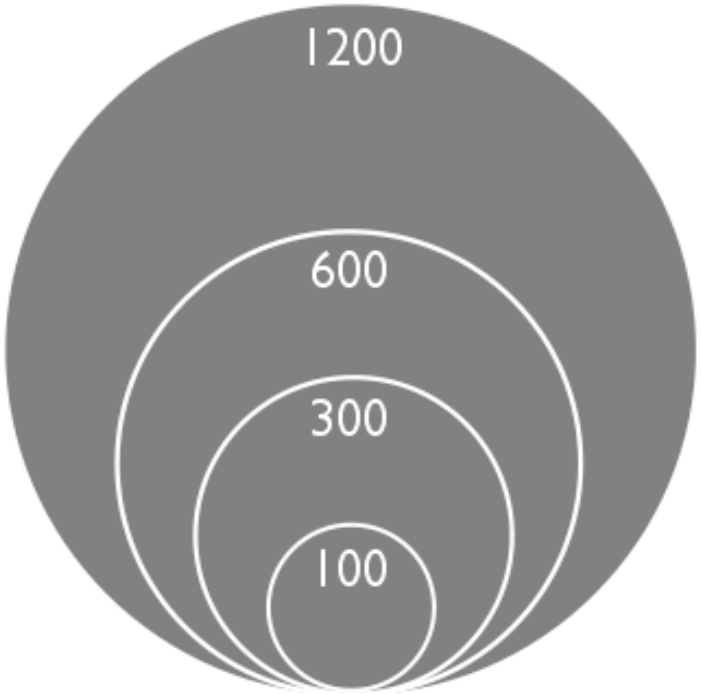
- Comparing area is difficult (remember the area of circles just mentioned).
- When we compare areas the proportions are underestimated (worst for volumes).
- Flannery (1970) proposed to compensate the perception by applying a perceptual scaling factor.
- Tufte, in his famous *The Visual Display of Quantitative Information (2001)*, opposed to anything but absolute scaling, i.e. to excludes compensation for human perceptual failings.

J. J. Flannery, *"The Relative Effectiveness of Some Common Graduated Point Symbols in the Presentation of Quantitative Data*", Symposium on the Influence of Map User on Map Design, 1970.

Flannery's Perceptual Scaling



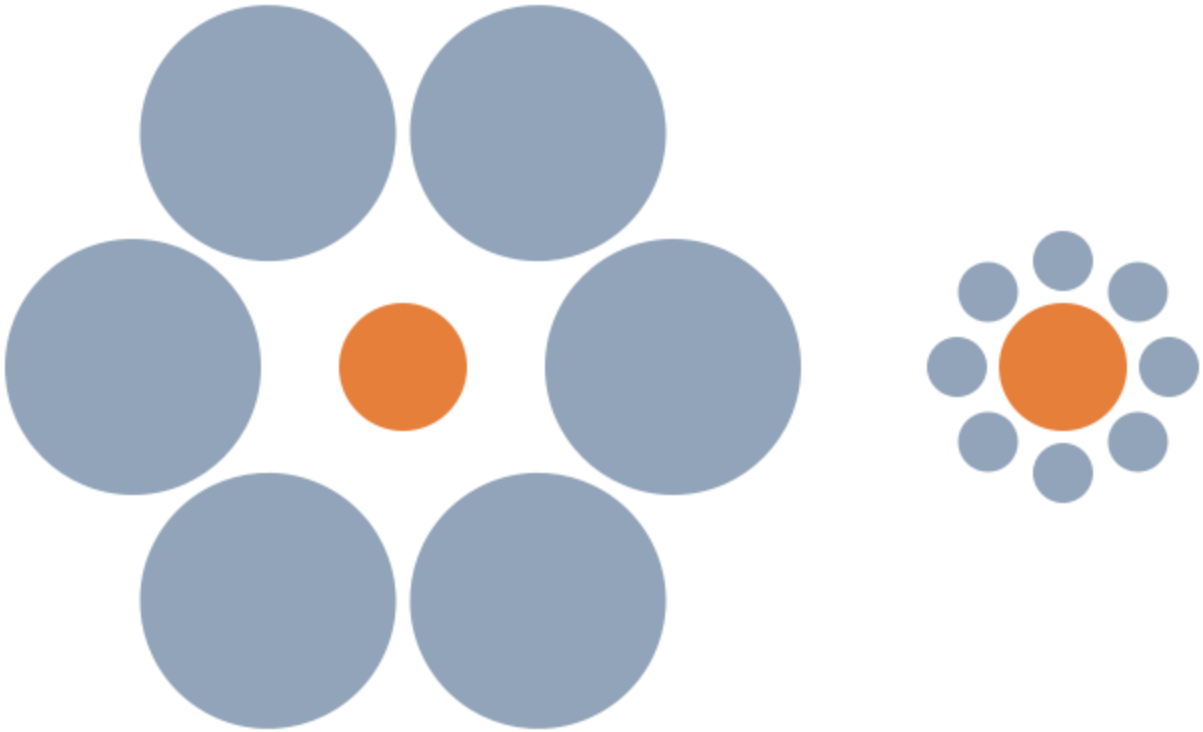
Absolute Scaling



Apparent Scaling
(Flannery's Compensation)

Comparing Area

- Perceptual scaling may be insufficient. Things are more complex from a perceptual point of view → *Heidenberg illusion*.



Weber's Law

- *Ernst Heinrich Weber* (1795–1878) conducted studies on the perception of physical stimulus by human senses (vision, hearing, taste, touch and smell).
- Weber's Law:

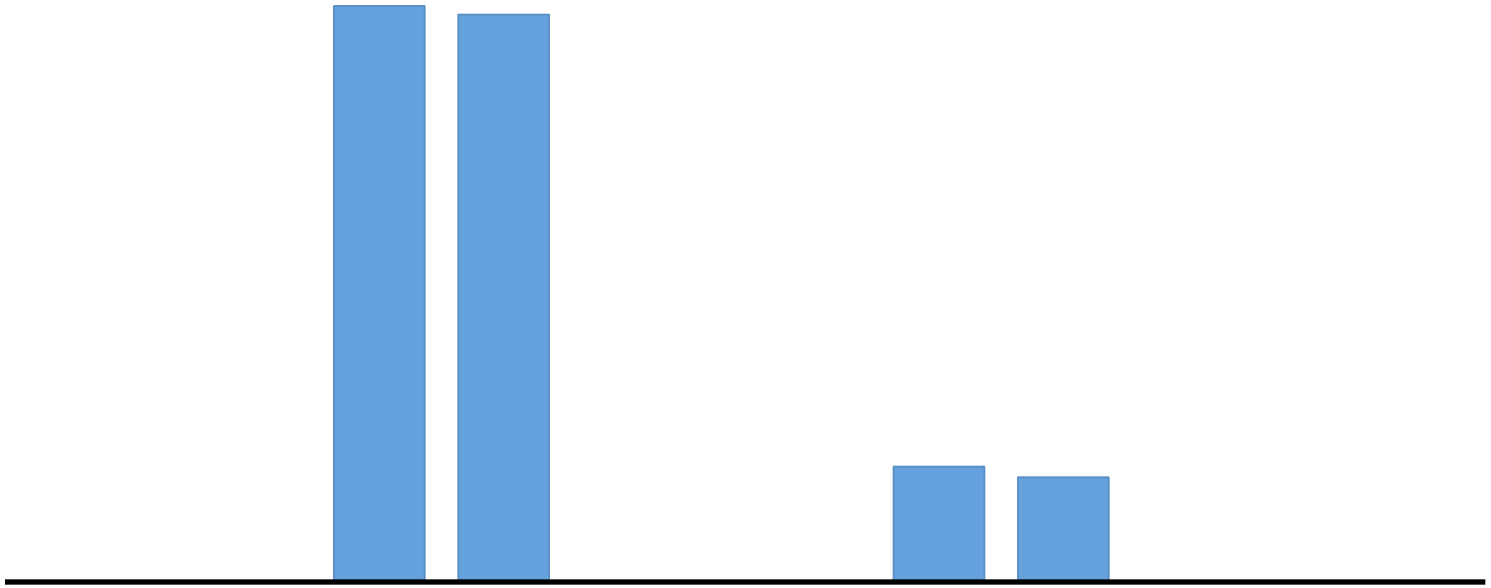
Just Noticeable Difference (JND)

$$\frac{\Delta S}{S} = k$$

Stimulus

Weber's Law

- Perception depends by the initial stimulus.
- Ratios are more important than absolute values.



What about color ?

- We will see something about color in the next lesson...

Summary

- Visual designers take in great consideration visual perception → the same has to be done for data visualization.
- Grayscale should be used wisely.
- Preattentive processes are powerful to drive the attention and to avoid confused visualization.
- Gestalt Laws are powerful allies (to group elements, to show relationships, to make patterns comparison, in an effective way).

Questions ?