Data Visualization
-
Perception

Dr. Claudius Zelenka

Kiel University

cze@informatik.uni-kiel.de

Encoding: designer

1 Data
What is my data?
Which data type?
Ordinal / numerical / categorical?

2 Visual Mapping
What is my visual representation?
Which visual variables am I using?
How am I encoding my data?

3 Rendering
What is my medium?
monoscopic/stereoscopic?
Tangiblity?
Print / digical?

View

Decoding: user

6 Comprehending
What does it mean for me?
What shall I do now?
Is this all true?
What do I learn?

5 Interpreting
What does it mean?
What does color mean?
Wha does 'up 'mean?
What do these patterns show?

4 Perceiving
What does it show?
Where is big, medium, small?
How do things compare?
What relationships exist?

Problem:
How to choose avisual mapping without knowing about perception?

Solution:
Learn about perception

Why consider perception?

GOOD

EVIL

How many 3 in π?

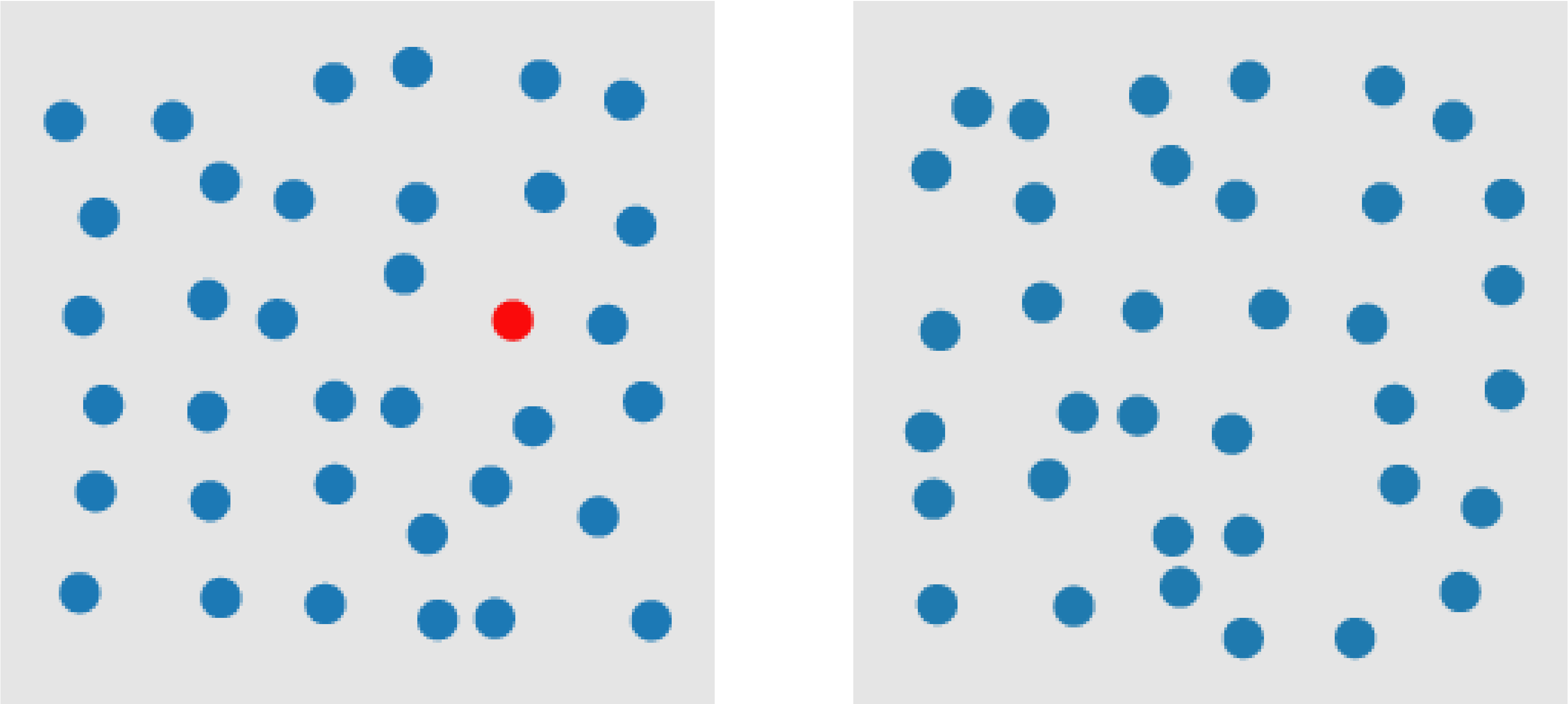
3.
1415926535 8979323846 2643383279 5028841971 6939937510
5820974944 5923078164 0628620899 8628034825 3421170679
8214808651 3282306647 0938446095 5058223172 5359408128
4811174502 8410270193 8521105559 6446229489 5493038196

Count all 3

1	*3.*
8	*1415926535 8979323846 2643383279 5028841971 6939937510*
3	*5820974944 5923078164 0628620899 8628034825 3421170679*
5	*8214808651 3282306647 0938446095 5058223172 5359408128*
3	*4811174502 8410270193 8521105559 6446229489 5493038196*
19	

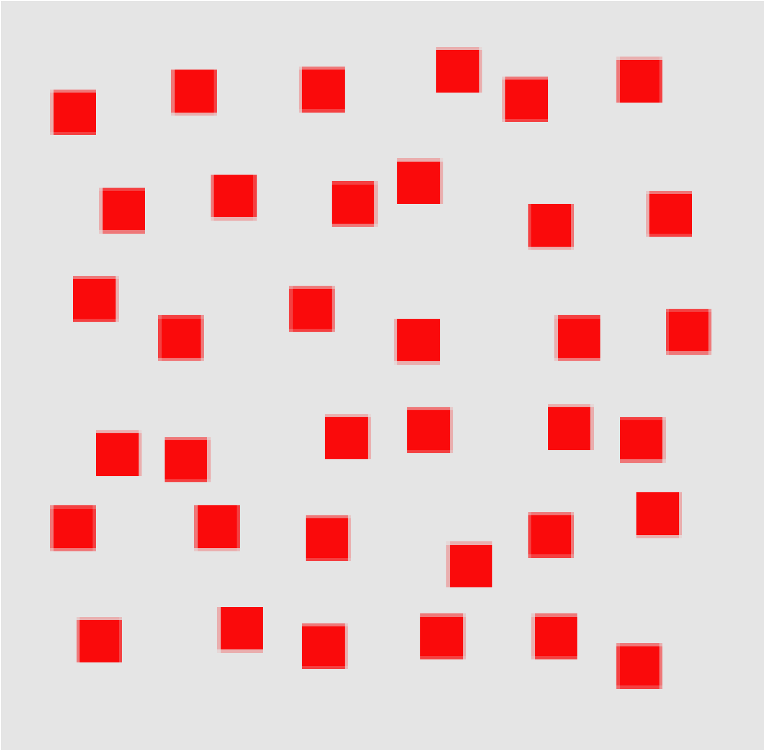
There are 19 !

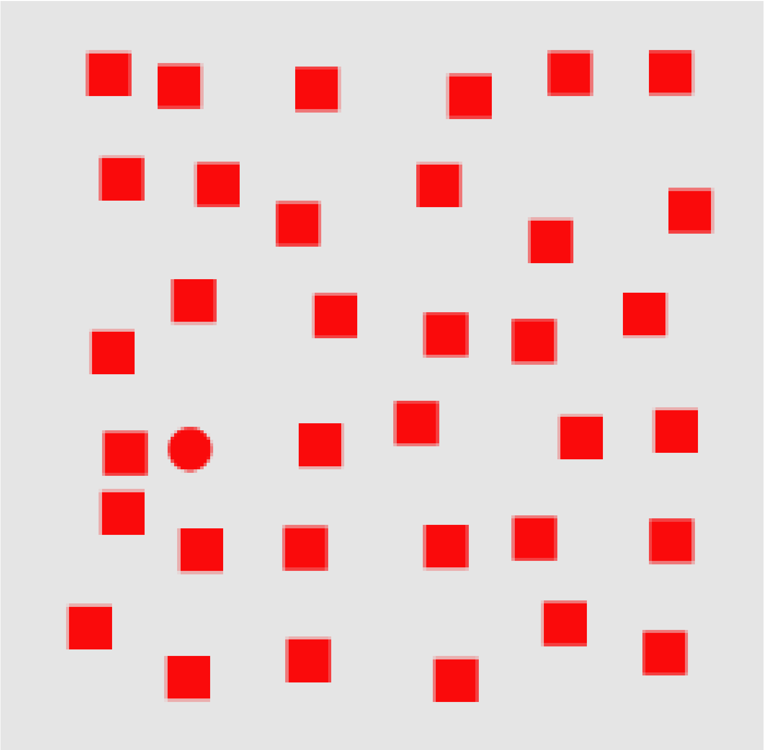
Same or different?



https://www.csc2.ncsu.edu/faculty/healey/PP/index.html#jscript_search

Same or different?





https://www.csc2.ncsu.edu/faculty/healey/PP/index.html#jscript_search

The eye is not a camera

- **Cameras**
  - Good optics
  - Single focus, white balance, exposure
  - “Full image capture“
- **Eyes**
  - Relatively poor optics
  - Constantly scanning (saccades)
  - Constantly adjusting focus
  - Constantly adapting
  - Mental reconstruction of image

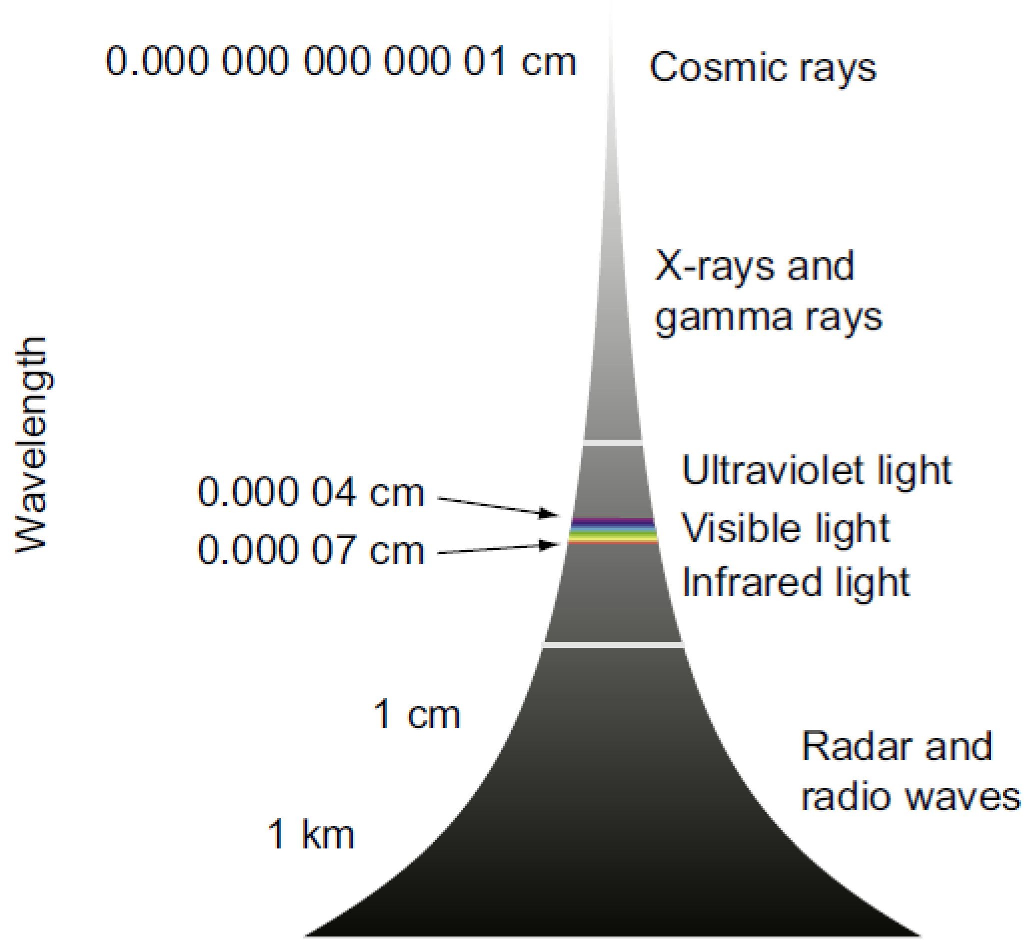


Figure 2.1 The visible light spectrum is a tiny part of a much larger spectrum of electromagnetic radiation.

Anatomy of the human eye

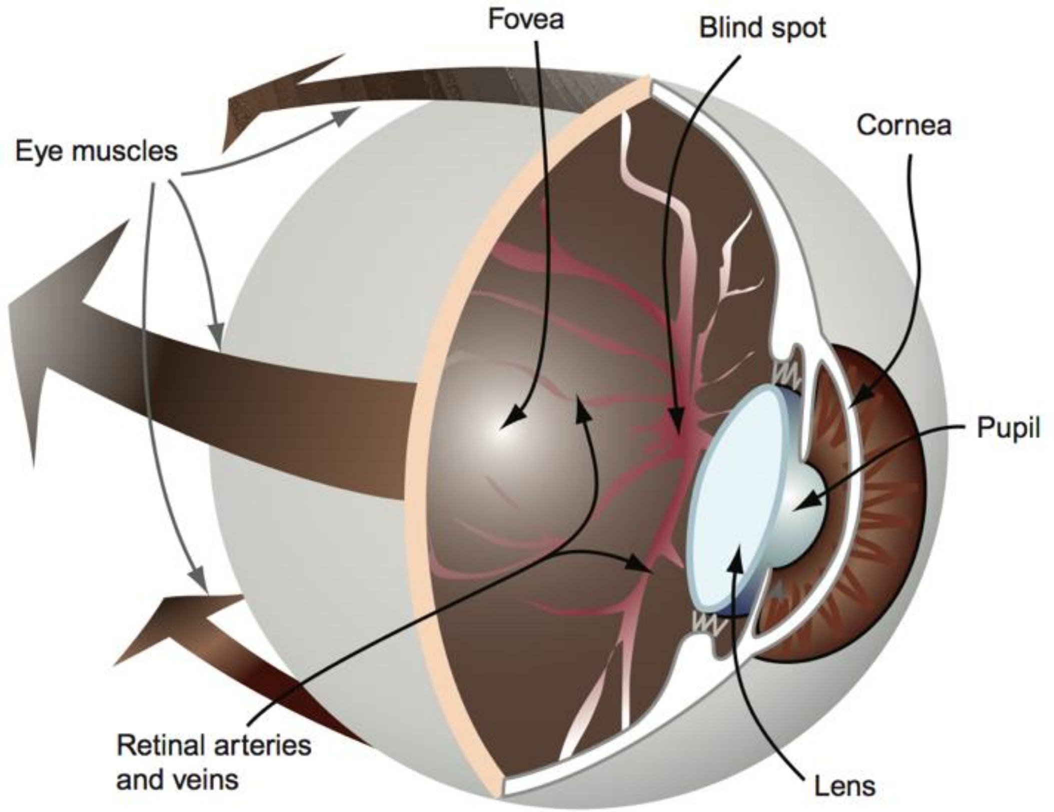


Figure 2.10 The human eye. Important features include the fovea, where vision is sharpest; the pupil, a round aperture through which light enters the eye; the two principal optical elements, the lens and the cornea; and the large eye muscles that control eye movements. This blind spot is caused by the absence of receptors where the retinal arteries enter the eyeball.

Colin Ware, Information Visualization: Perception for Design

Visual system

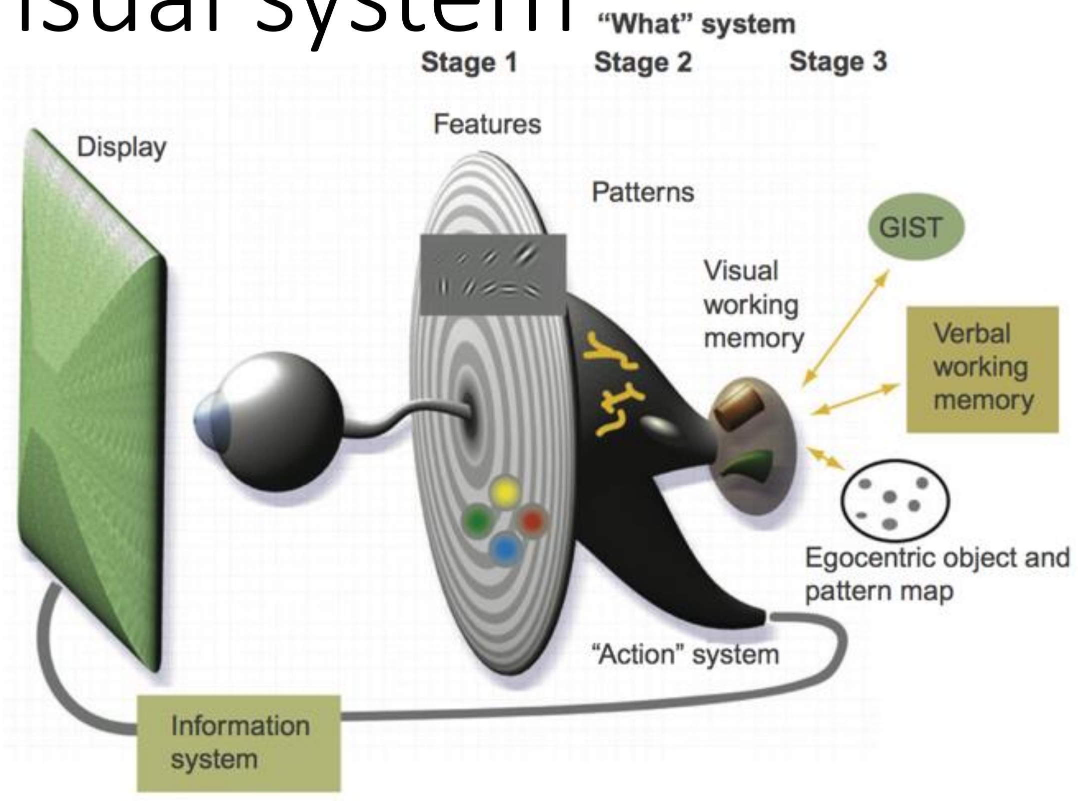


Figure 1.11 A three-stage model of visual information processing.

Identification of Patterns

Attention & Visual Query

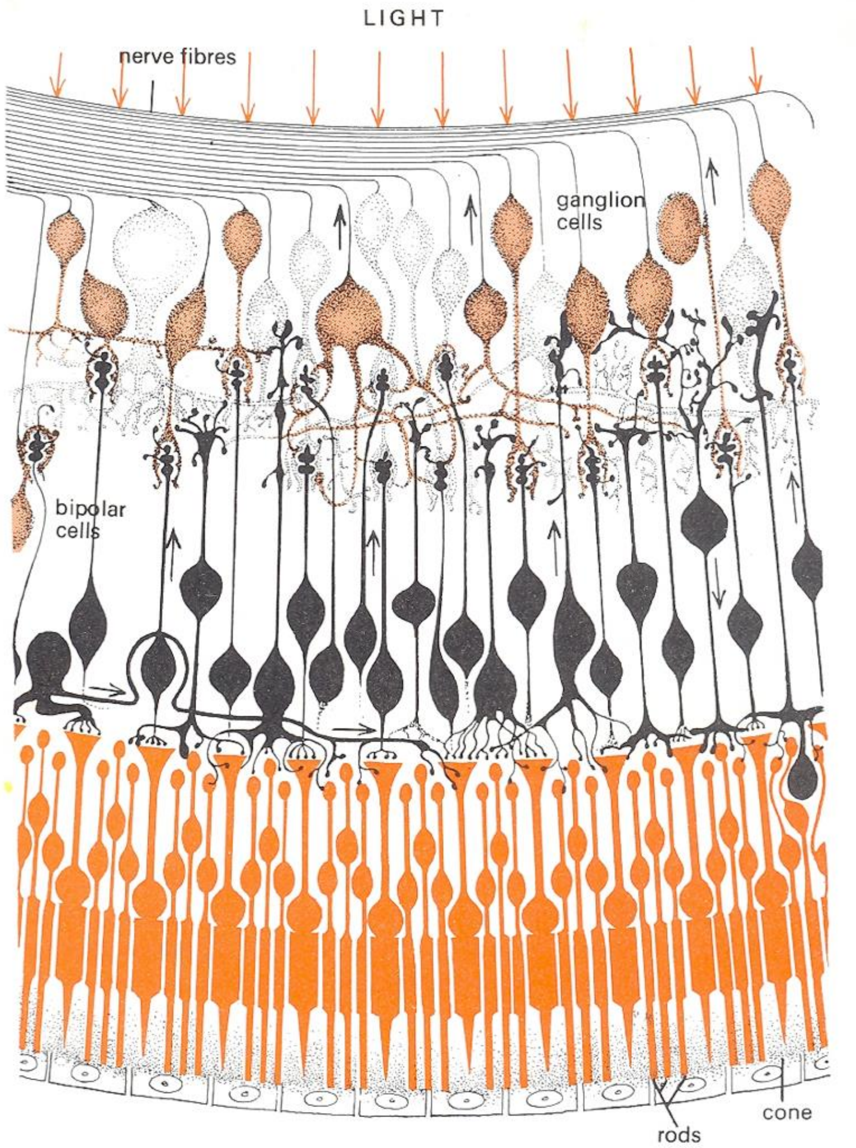
"One of the more radical ideas in this book is that the effects of attention can be propagated outside of the brain into the world through cleverly designed interactive visualizations that cause information we are interested in to be highlighted on the screen."

Colin Ware, Information Visualization: Perception for Design

The visual system

- 70% of body's sense receptors reside in our eyes
- The eye and the visual cortex of the brain form a massively parallel processor that provides the highest-bandwidth channel into human cognitive centers."—*Colin Ware, Information Visualization, 2004*
- Important to understand how visual perception works in order to effectively design visualizations

Photoreceptors



Rods

- Approximately 100-150 million rods.
- Non-uniform distribution across the retina
- Sensitive to low-light levels (scotopic vision)

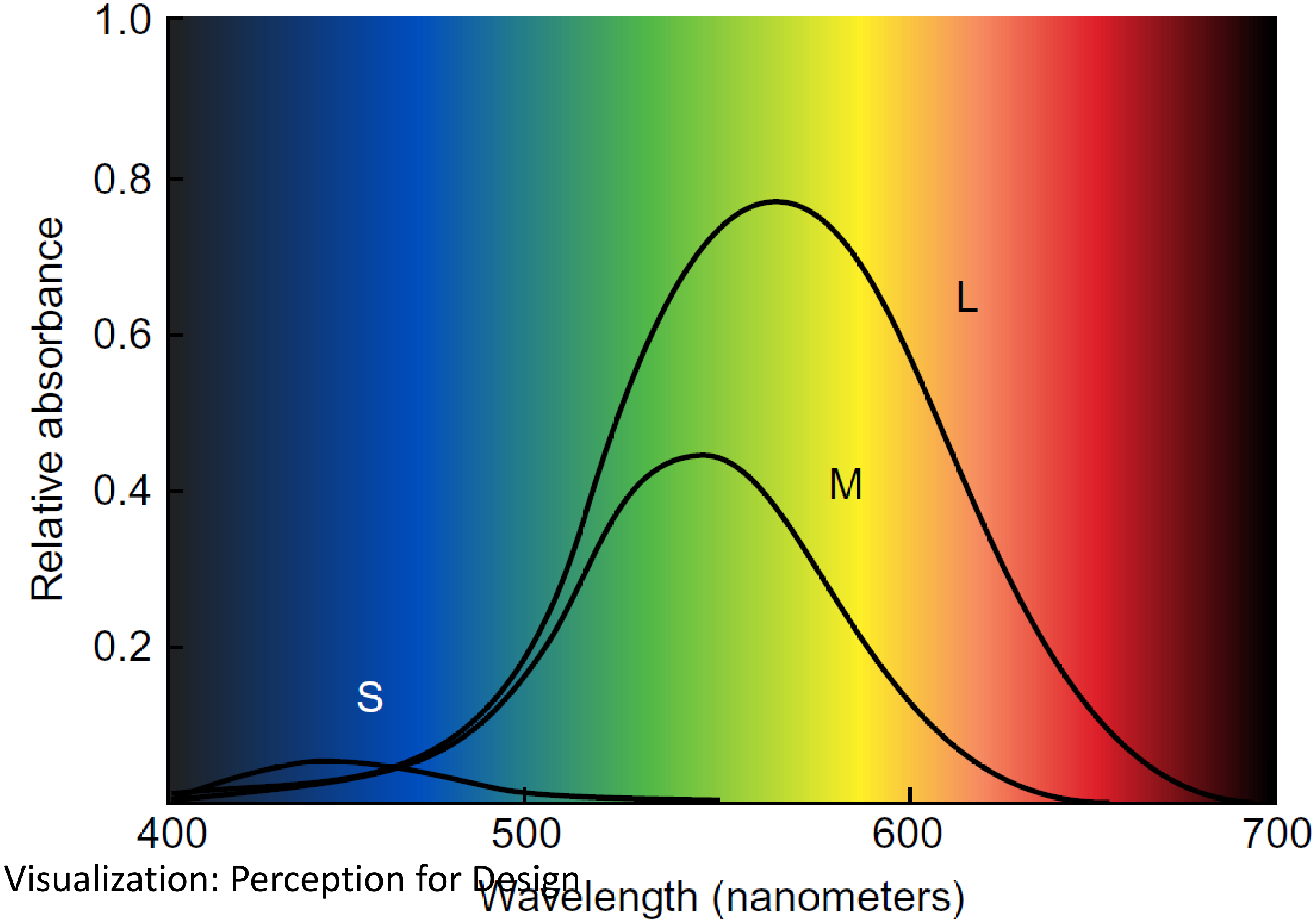
Cones

- Approximately 6-7 million cones.
- Sensitive to daytime-light levels (photopic vision)
- Detect color by the use of 3 different kinds:
- Red (L cone) : 564-580nm wavelengths (65% of all cones)
- Green (M cone) : 534-545nm (30% of all cones)
- Blue (S cone) : 420-440nm (5% of all cones)

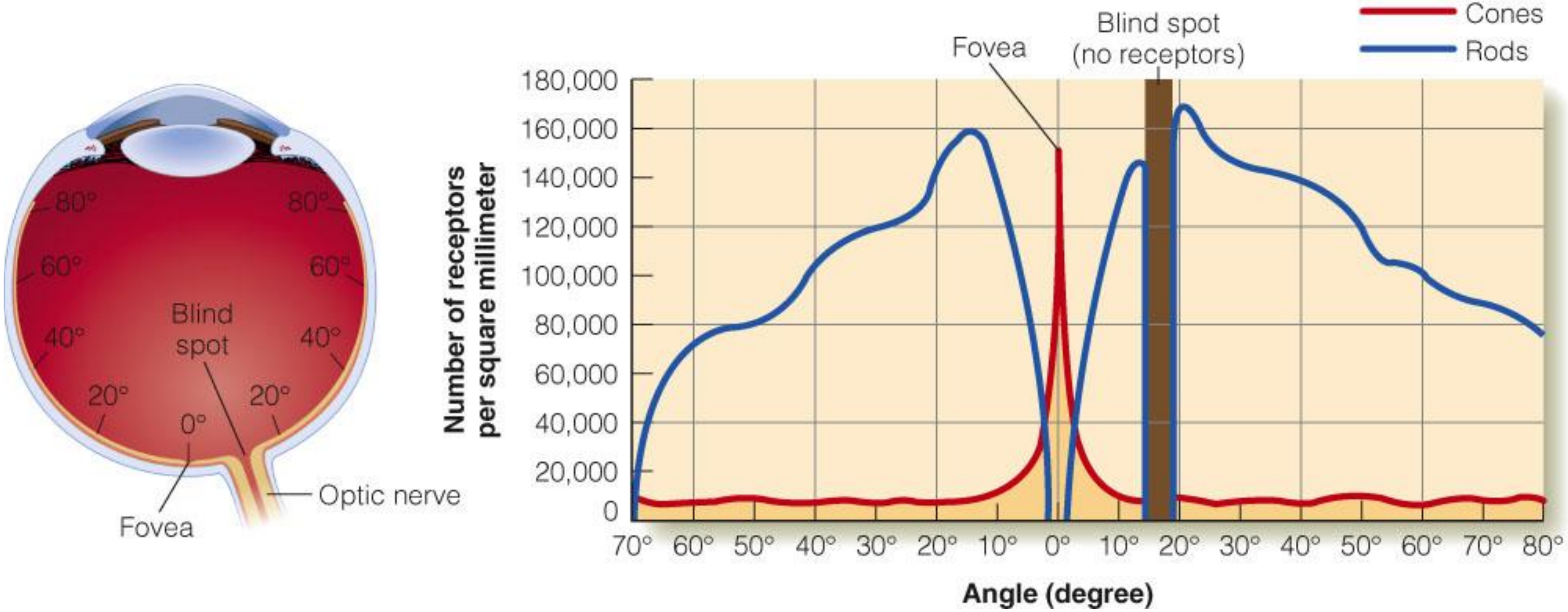
Colin Ware, Information Visualization: Perception for Design

Cones (SML)

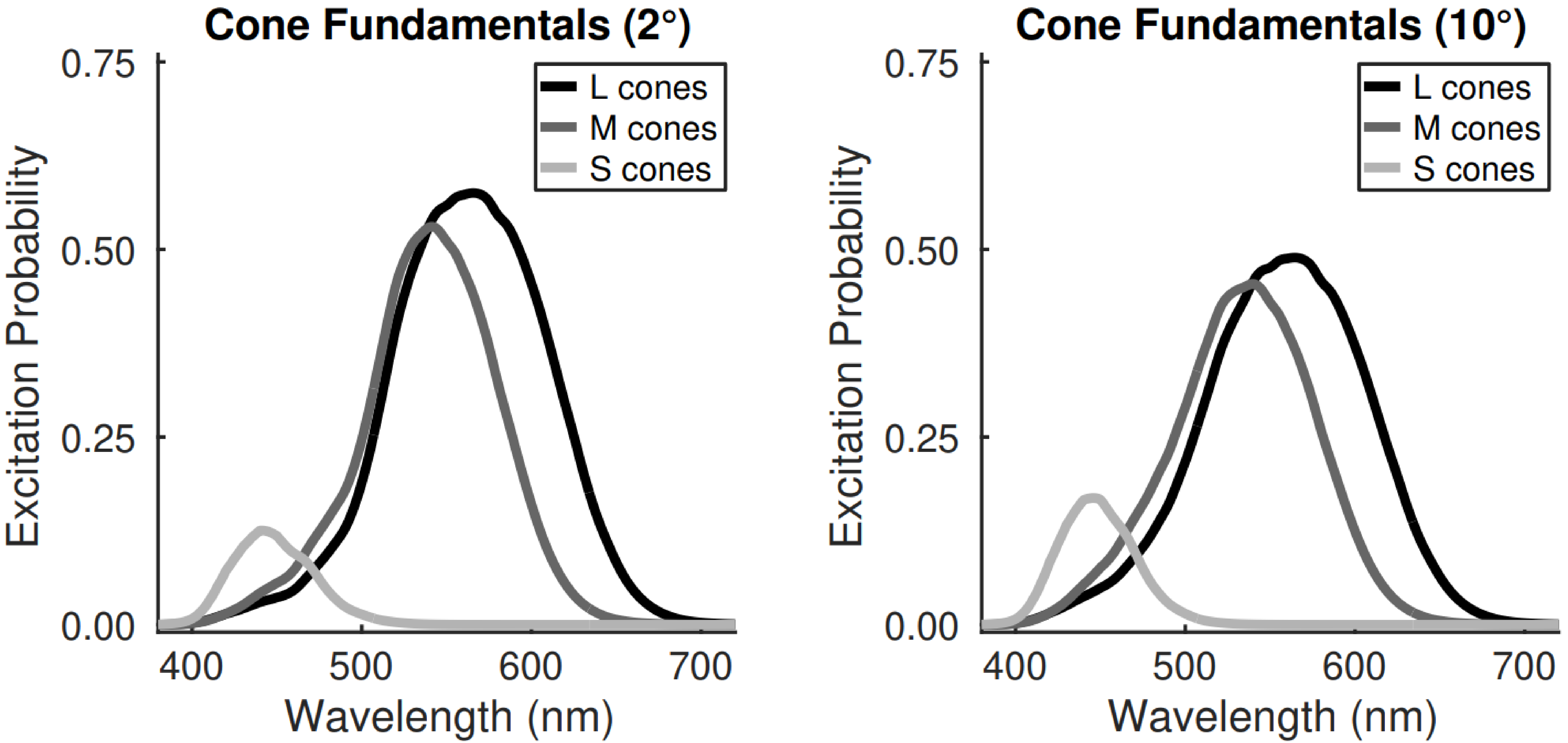
(short, medium, long)



Colin Ware, Information Visualization: Perception for Design



E. B. Goldstein "Sensation and Perception" (Adapted from Lindsay & Norman, 1977)


Cone Fundamentals (2°)
0.75
0.50
0.25
0.00
Excitation Probability
400
500
600
700
Wavelength (nm)
L cones
M cones
S cones
Cone Fundamentals (10°)
0.75
0.50
0.25
0.00
Excitation Probability
400
500
600
700
Wavelength (nm)
L cones
M cones
S cones

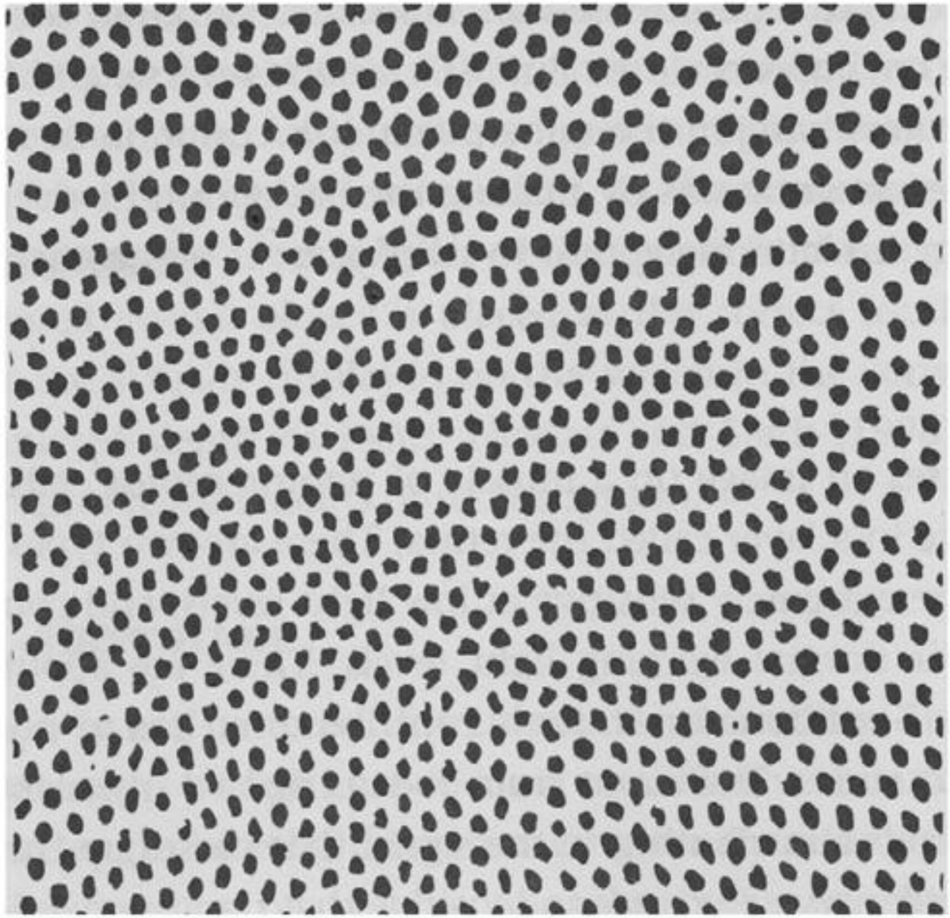
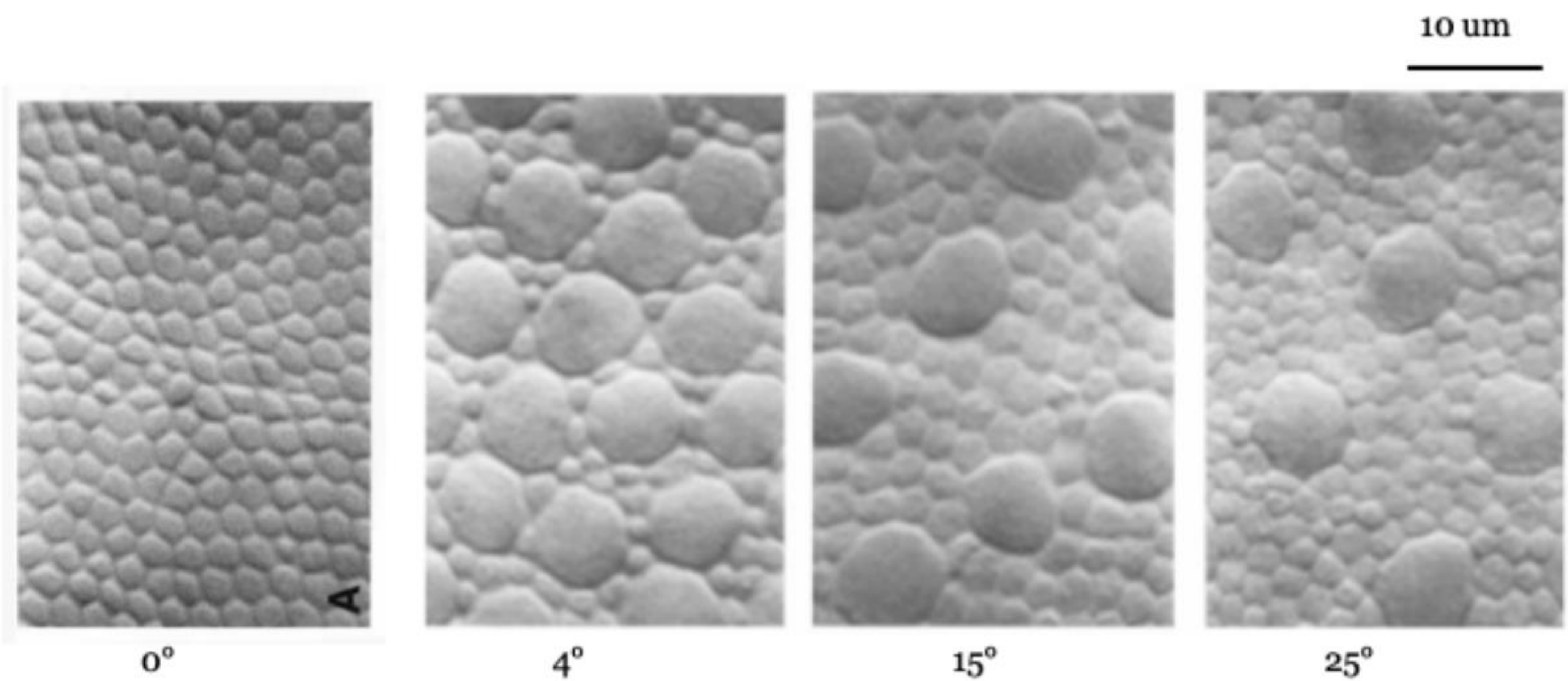
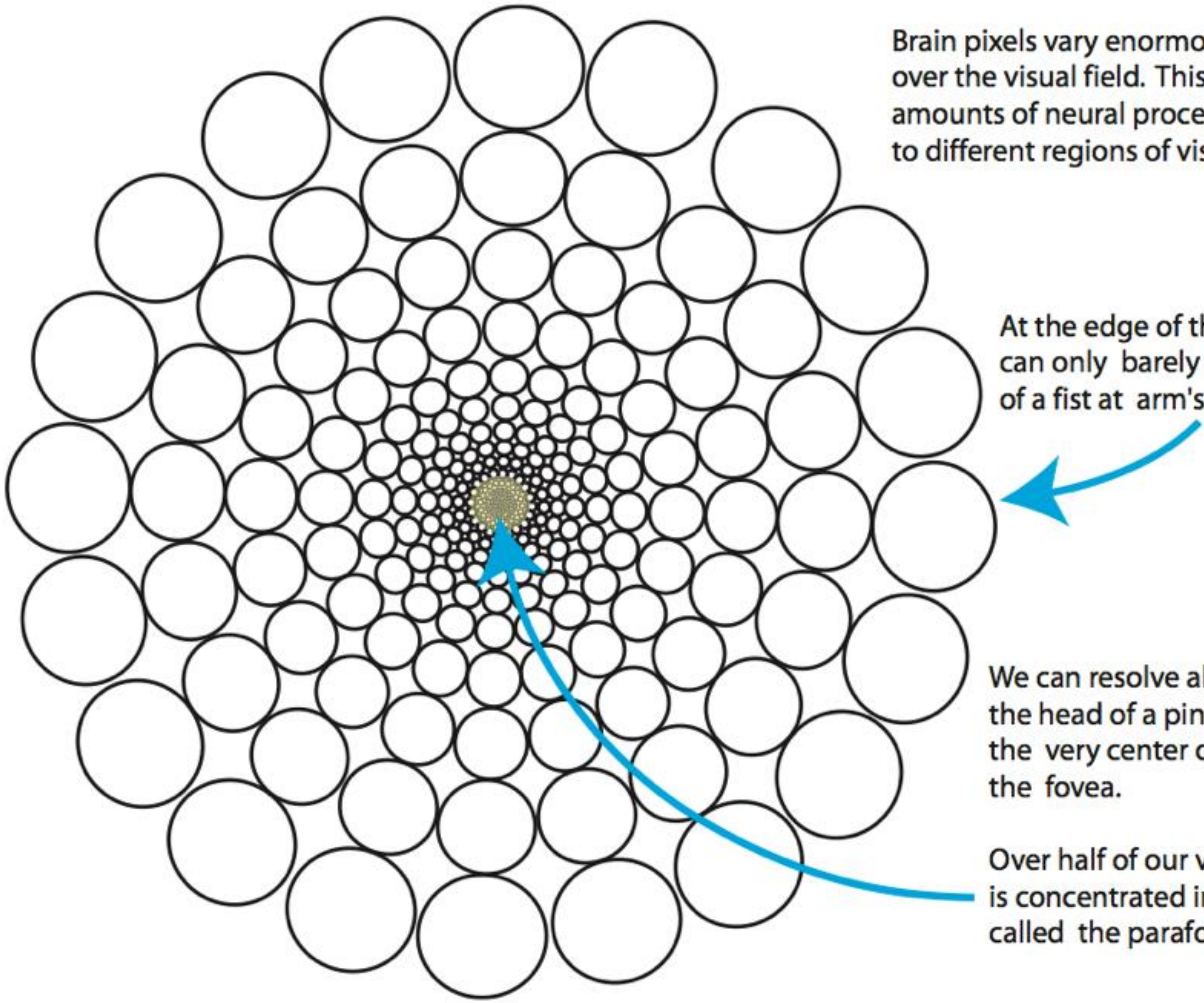


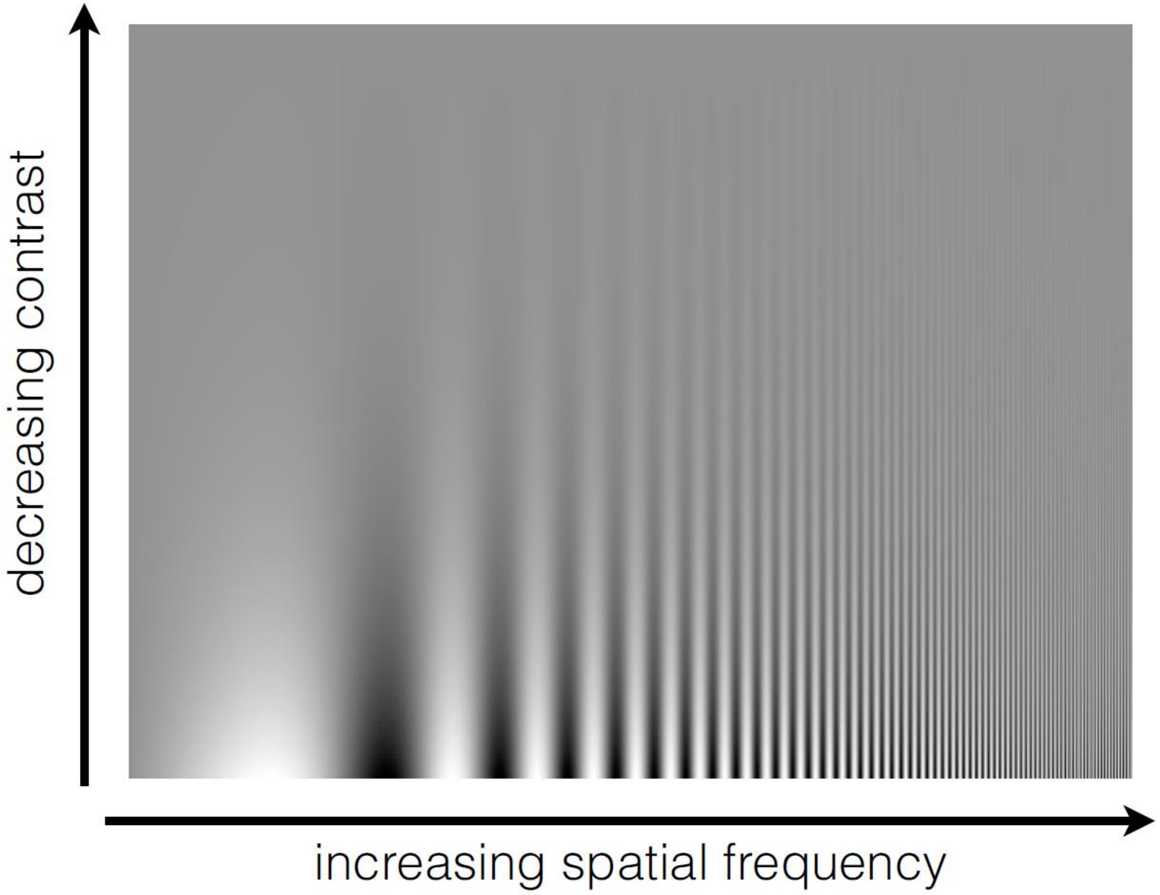
Figure 2.16 The receptor mosaic in the fovea.



The en face images show the photoreceptor inner segments, where light enters the cones, at four retinal eccentricities. In the central region, all of the receptors are cones. At 4 deg and beyond, the large apertures are the cones and the smaller apertures are the rods. The cone sampling density and cone aperture sizes differ substantially between the central fovea and other visual eccentricities. The reduced sampling density limits the spatial resolving power of the eye. The larger cone apertures increase the rate of photon excitations per cone. Scale bar is 10 um. Recomposited from figures in Curcio et al. (1990).

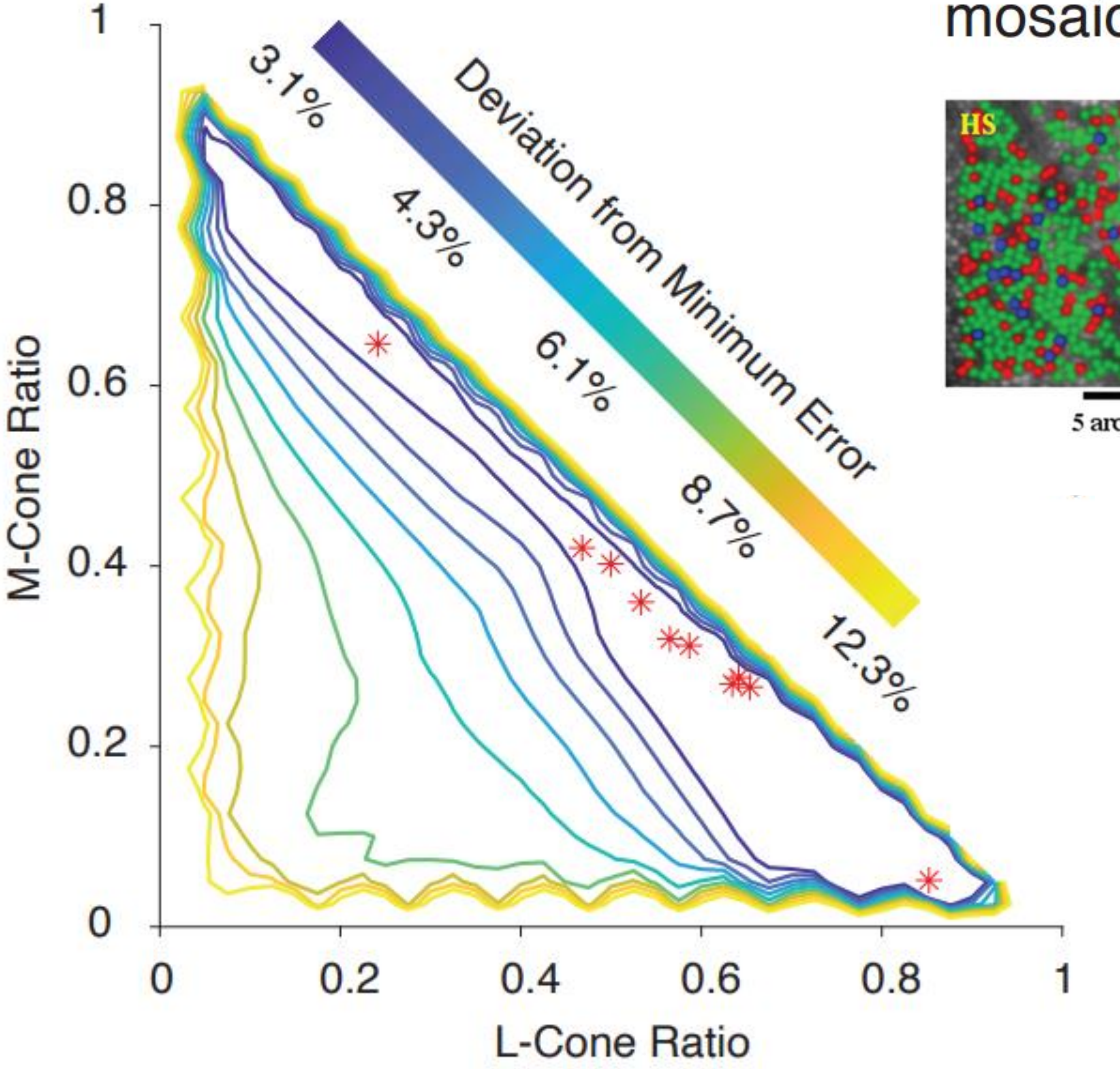

Brain pixels vary enormously in size over the visual field. This reflects differing amounts of neural processing power devoted to different regions of visual space.
At the edge of the visual field we can only barely see something the size of a fist at arm's length.
We can resolve about 100 points on the head of a pin held at arm's length in the very center of the visual field called the fovea.
Over half of our visual processing power is concentrated in a slightly larger area called the parafovea.

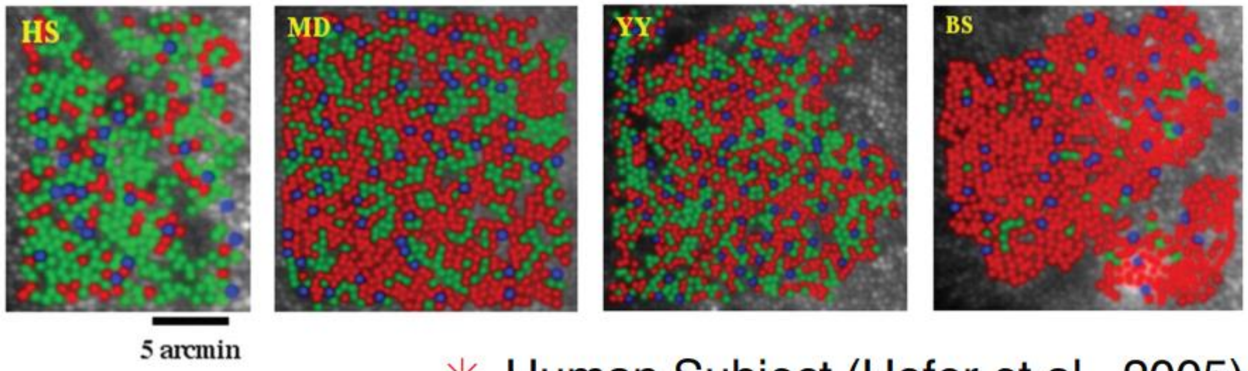
Campbell-Robson Chart



Ability to distinguish frequencies and contrast depends on the individual

How do the characteristics of different cone mosaics impact reconstruction performance?



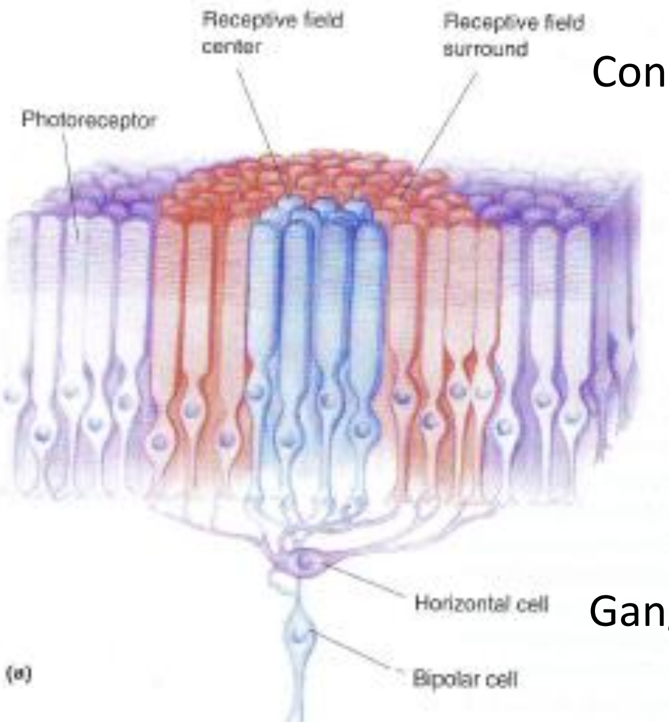


✳ Human Subject (Hofer et al., 2005)

Hofer, H., Carroll, J., Neitz, J., Neitz, M., & Williams, D. R. (2005). Organization of the human trichromatic cone mosaic. *The Journal of neuroscience : the official journal of the Society for Neuroscience*, *25*(42), 9669–9679. https://doi.org/10.1523/JNEUROSCI.2414-05.2005

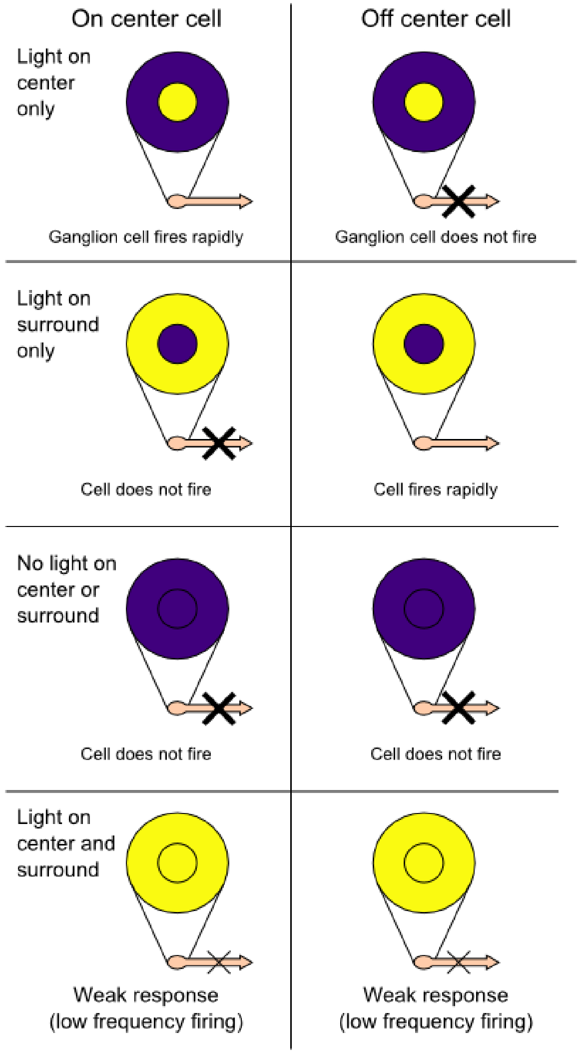
Q Zhang, *Z Kadkhodaie*, *EP Simoncelli* and *DH Brainard*. Image reconstruction from cone excitations using the implicit prior in a denoiser, *Annual Meeting, Vision Sciences Society*, vol.22 May 2022.

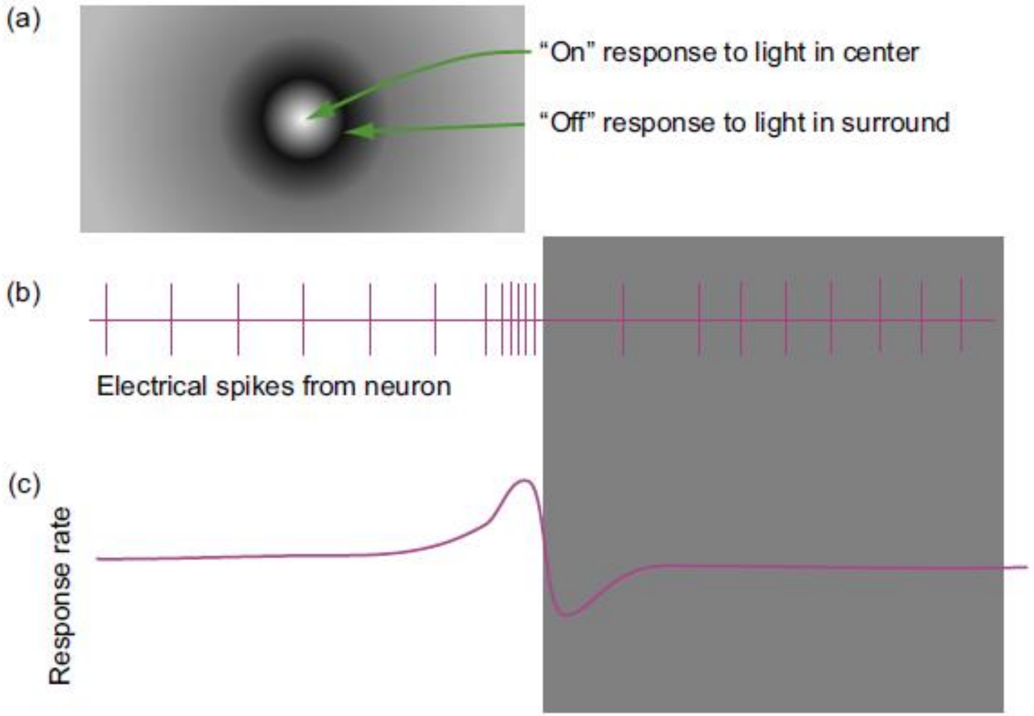
Ganglion cells

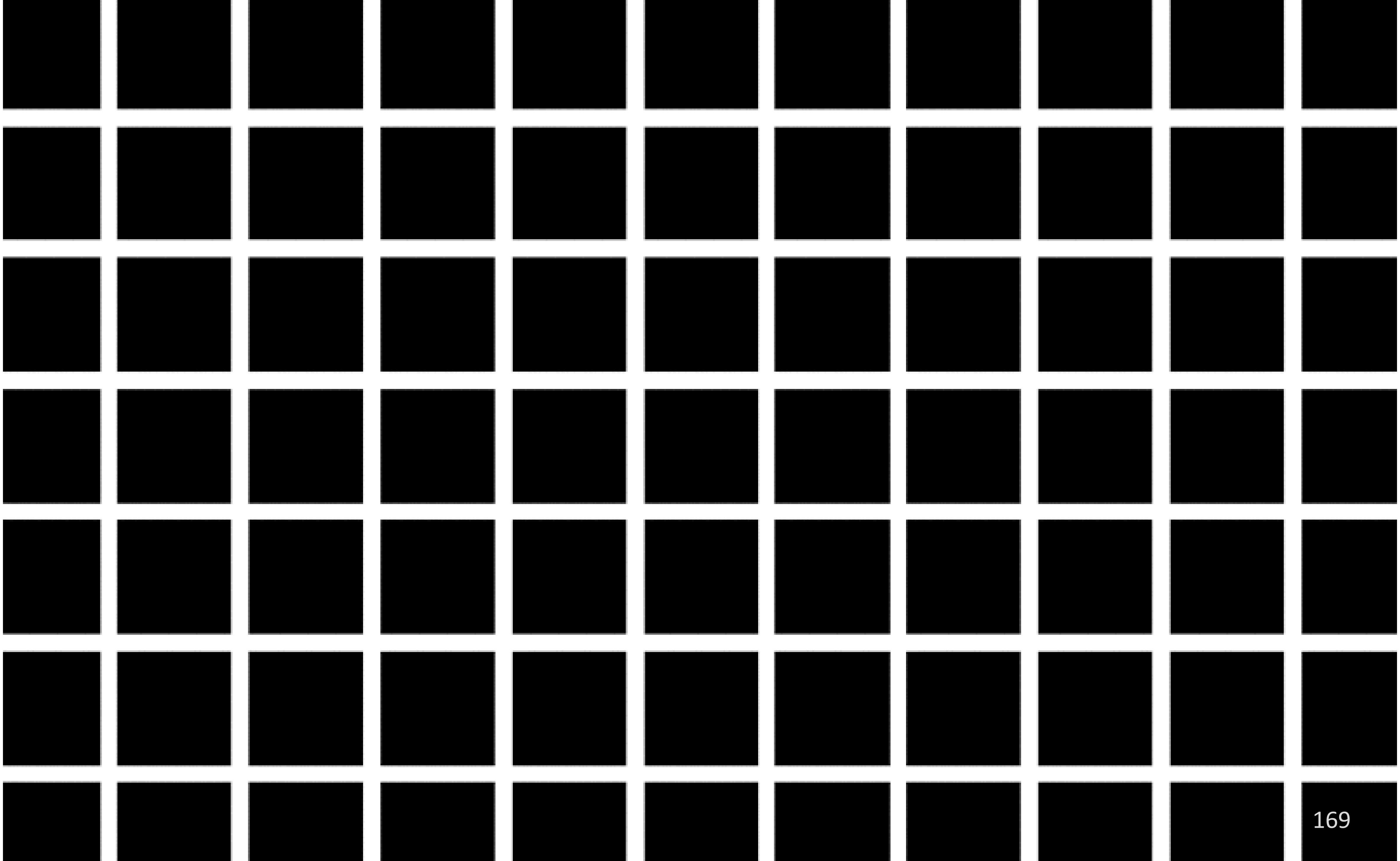


Cones/Rods

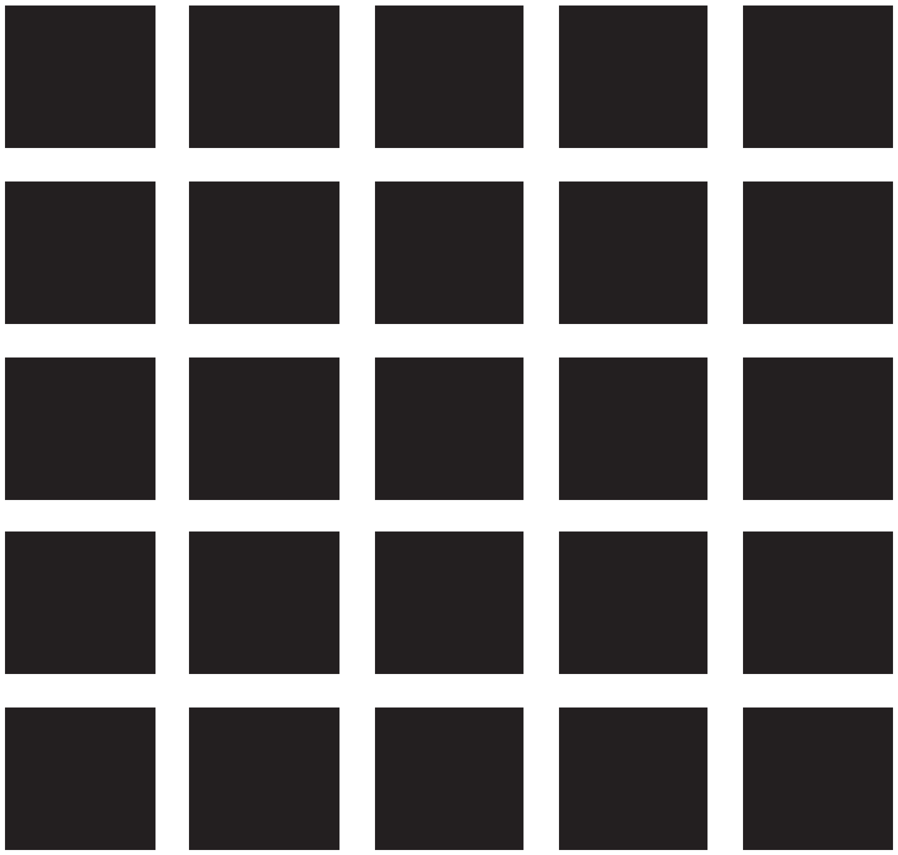
Ganglion cells







Hermann grid effect



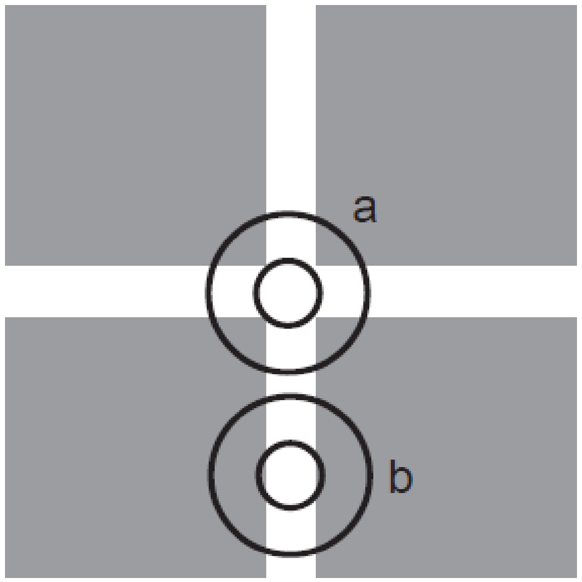
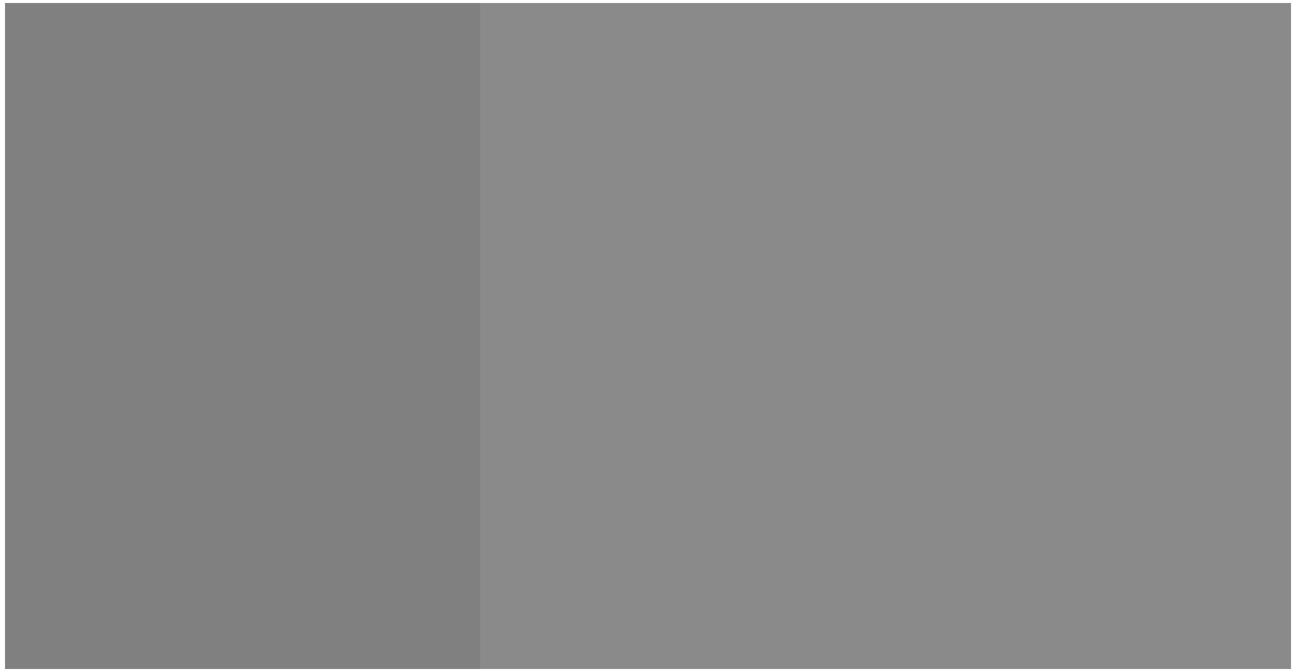


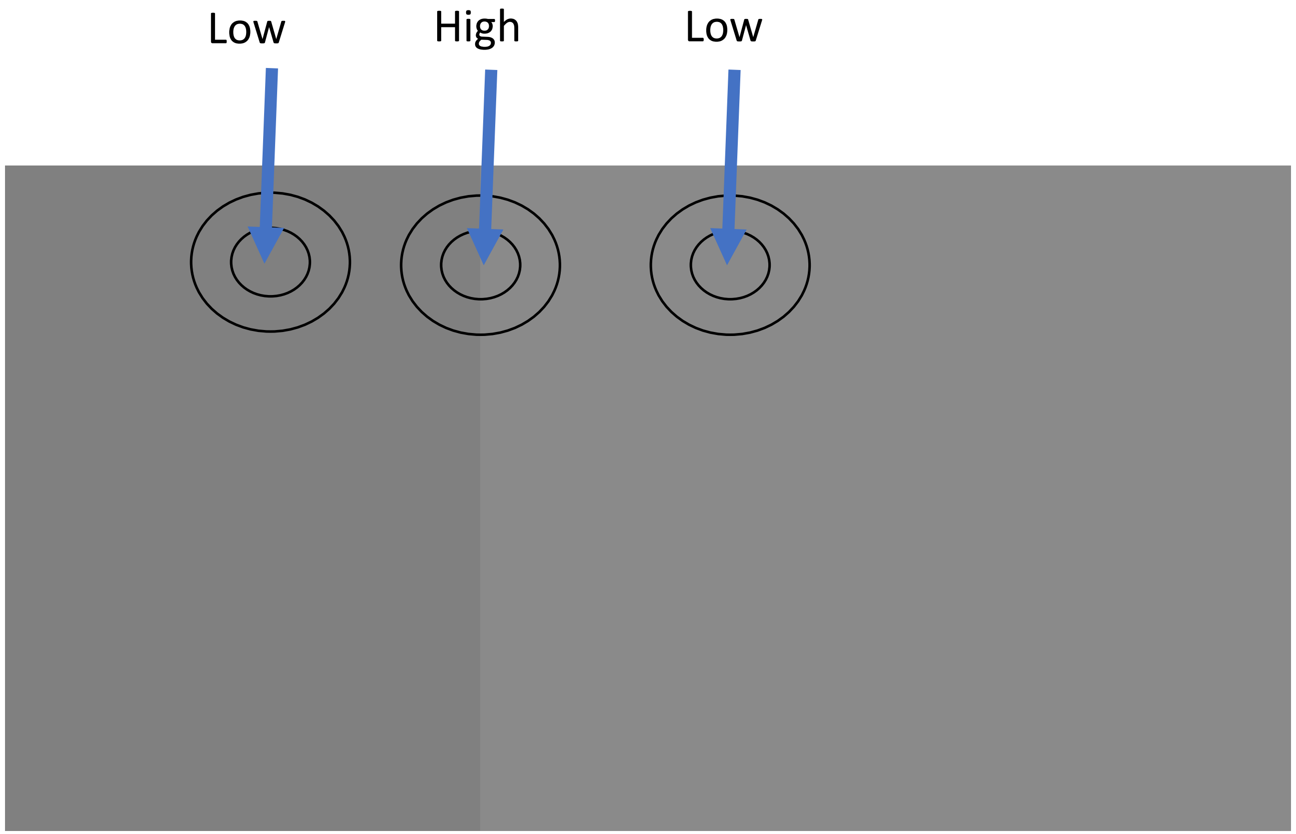
Figure 3.4 Hermann grid illusion. The black spots that are seen at the intersections of the lines are thought to result from the fact that there is more inhibition from the light in the periphery of the receptive field at position (a) than at position (b).

Brightness

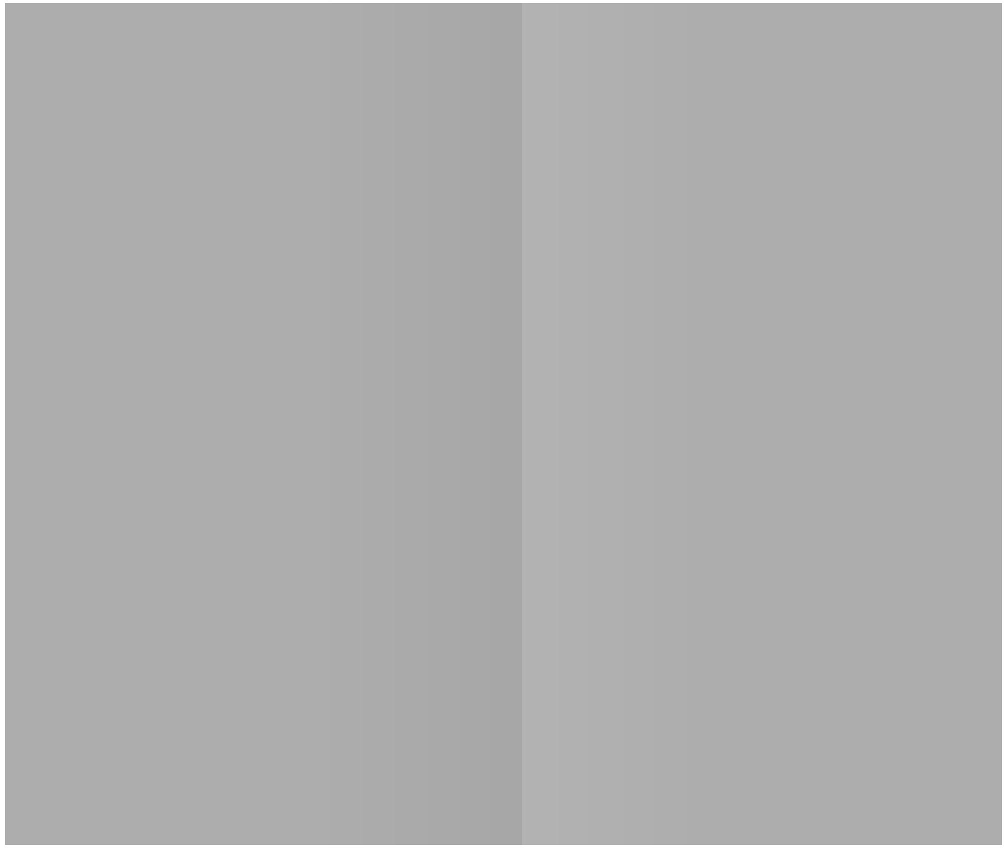
Brightness – Ganglion response



Brightness – Ganglion response

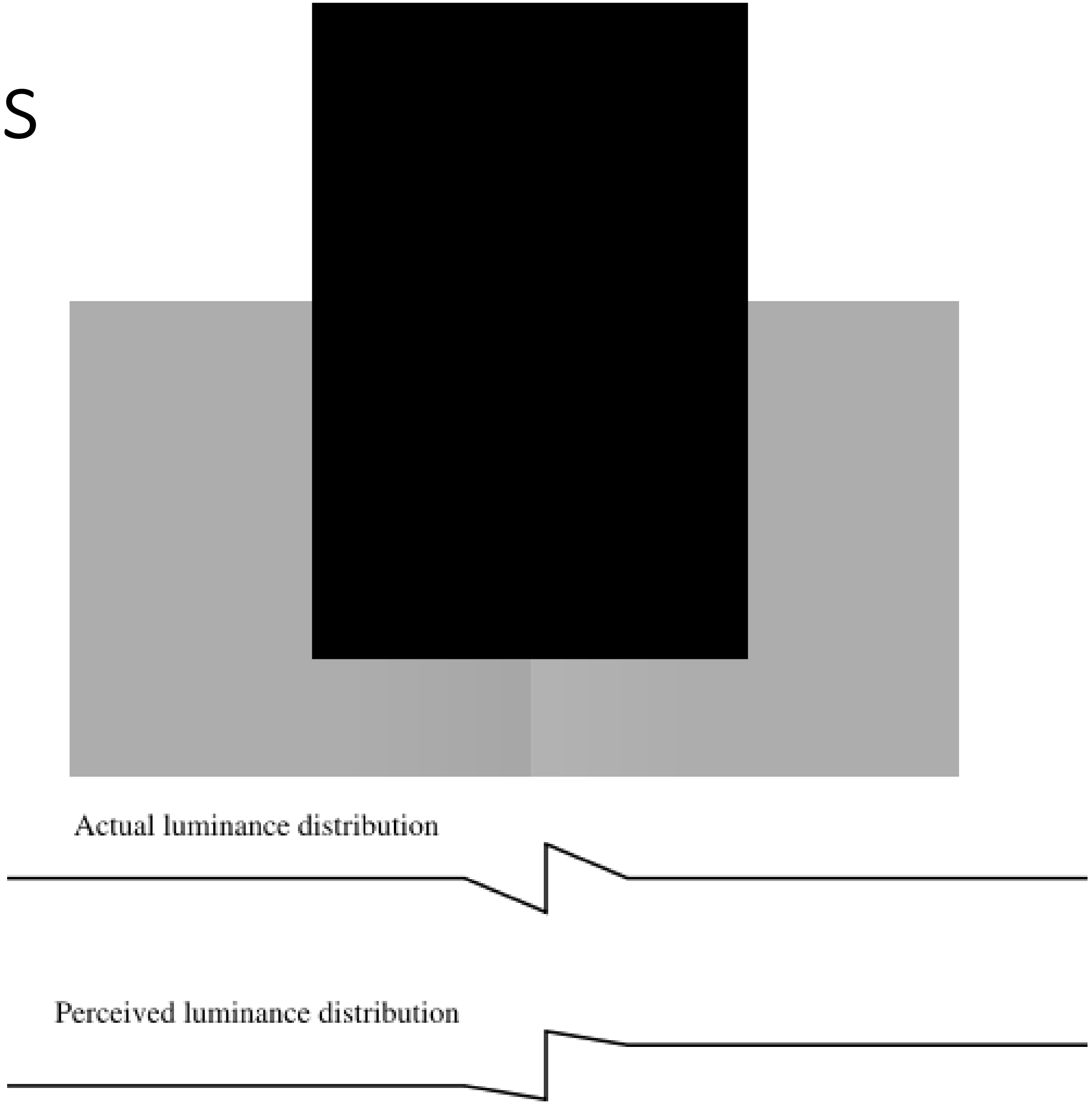


Edges



Edges - Cornsweet Illusion

Edges


Actual luminance distribution
Perceived luminance distribution

Local contrast can be used to enhance edges

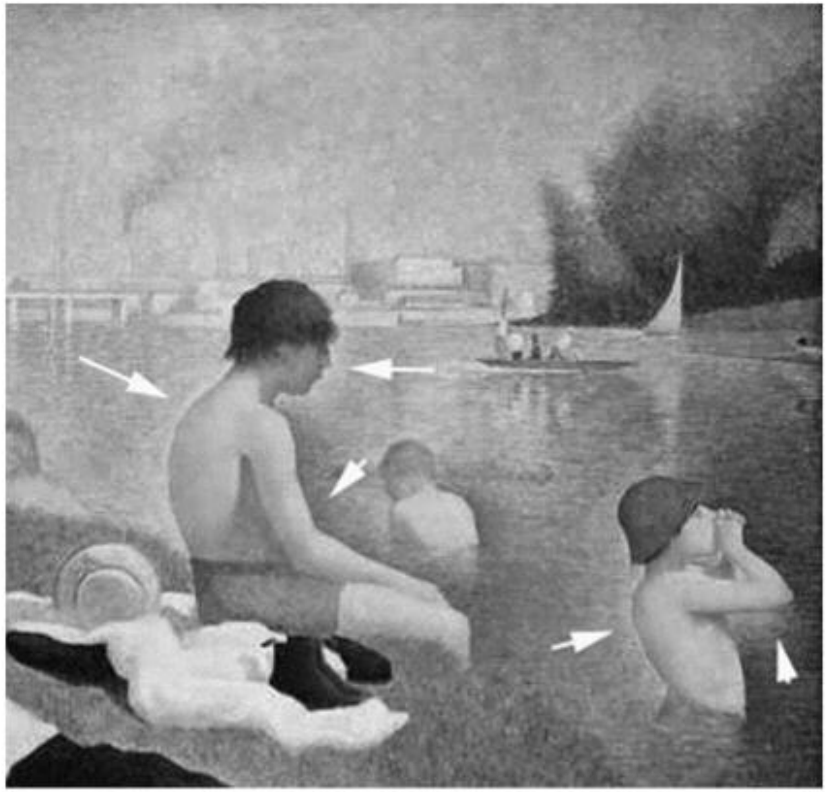


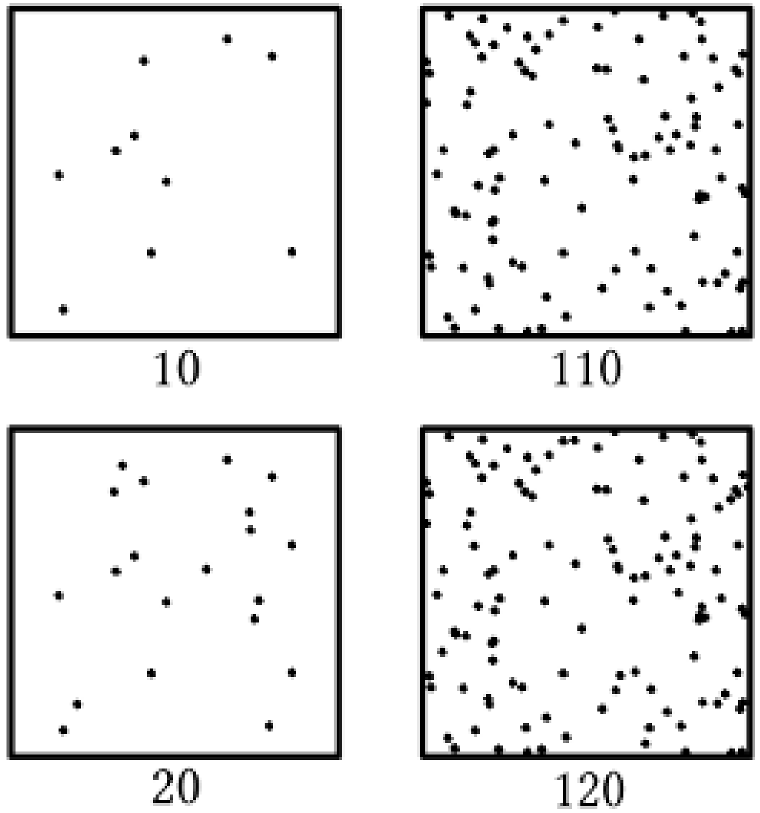
Figure 3.12 Seurat deliberately enhanced edge contrast to make his figures stand out.

Colin Ware, Information Visualization: Perception for Design

Edge detection

- Our visual system sees differences, not absolute values, and is attracted to edges.
- Maximize the contrast with the background if the outlines of shapes are important.
- Our visual system constructs surface colour based largely on edge contrast information.
- We have higher contrast sensitivity in the luminance than in the chrominance channel.

Weber’s law



- We judge based on relative, not absolute, differences

- Weber’s law of JND (Just notable difference) - dS , Reference Stimulus S ,

$$dS = K \cdot S$$

- Fechner's law - S-physical intensity, k constant, p perceived brightness)

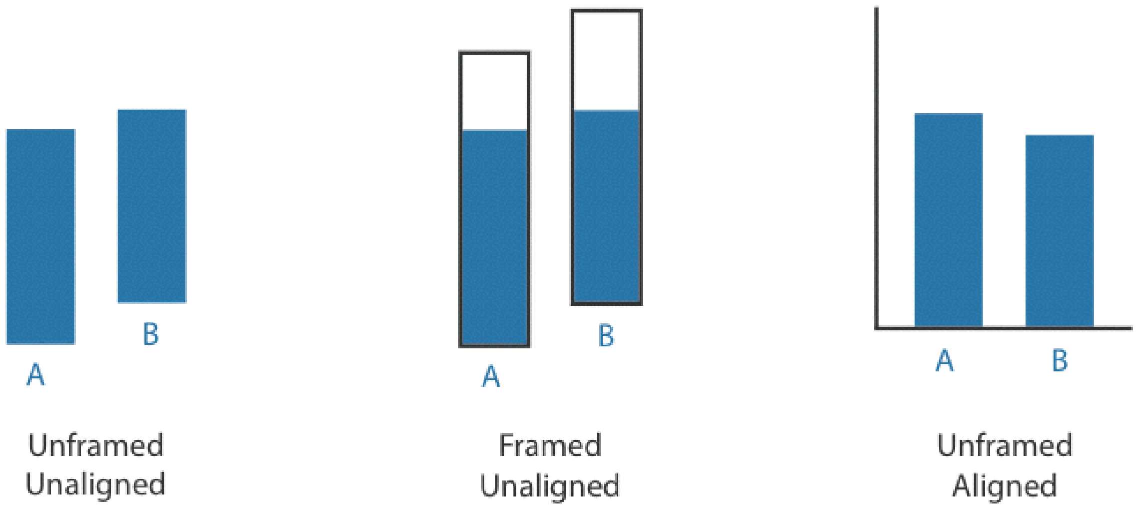
$$p = k \ln \frac{S}{S_0}$$

https://en.wikipedia.org/wiki/Weber–Fechner_law

- According to this law, human perceptions of sight and sound work as follows: Perceived loudness/brightness is proportional to logarithm of the actual intensity measured with an accurate nonhuman instrument

Weber’s law

- We judge based on relative, not absolute, differences



Stroop effect

Red Green Red Blue Green Blue Red Blue Green

Red Green Red Blue Green Blue Red Blue Green

Stroop effect

- What is happening?

- recognizing colors is not an “automatic process" there is hesitancy to respond; whereas, the brain automatically understands the meaning of words as a result of habitual reading

Visual system

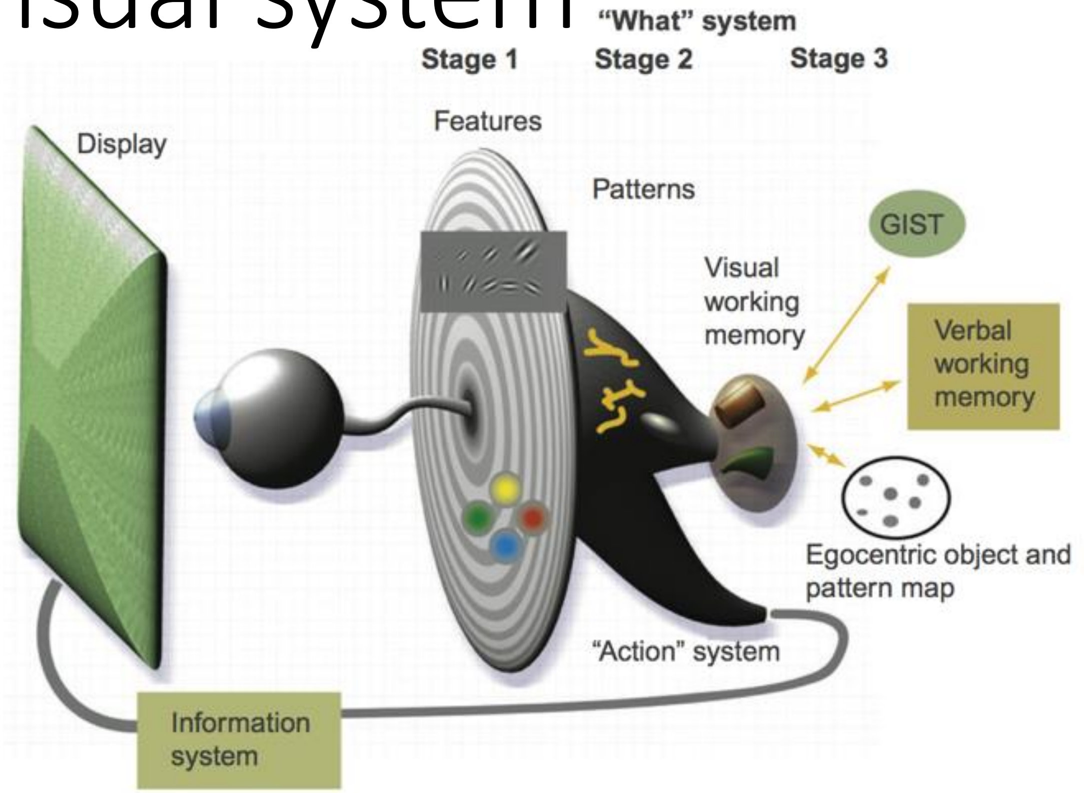


Figure 1.11 A three-stage model of visual information processing.

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Three stage model

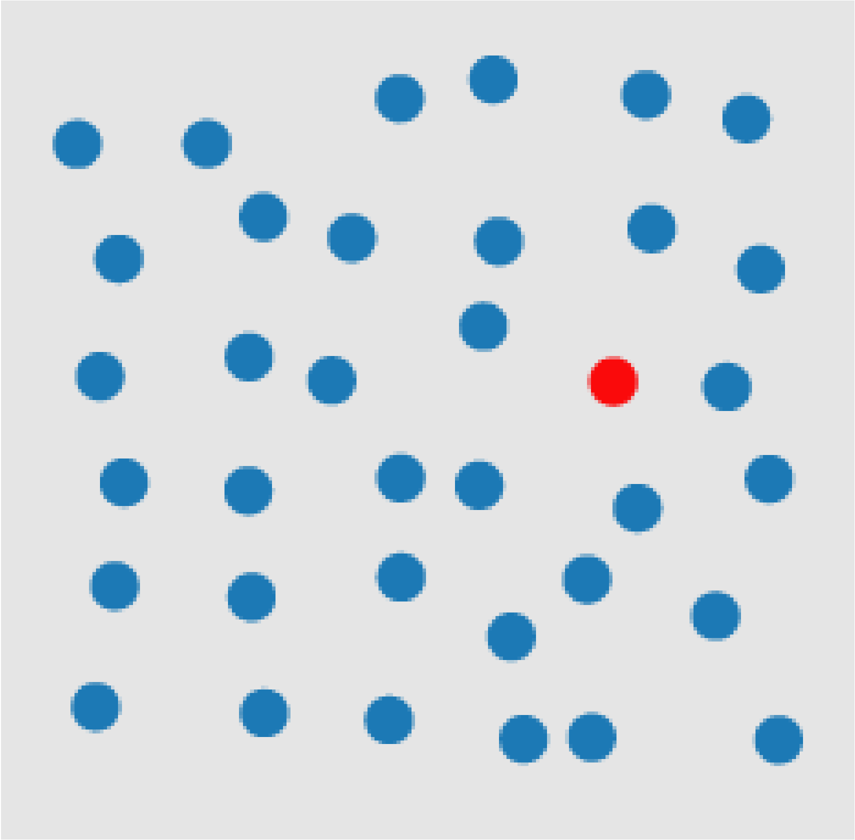
- Stage 1 – rapid parallel processing to extract lowlevel properties of a visual scene
  - preattentive processing
- Stage 2 – pull out structures via pattern perception
  - Object recognition, continuous contours
- Stage 3 – sequential goal-directed processing
  - Attention driven
  - Few objects, verbal linguistic connection
  - Visual working memory

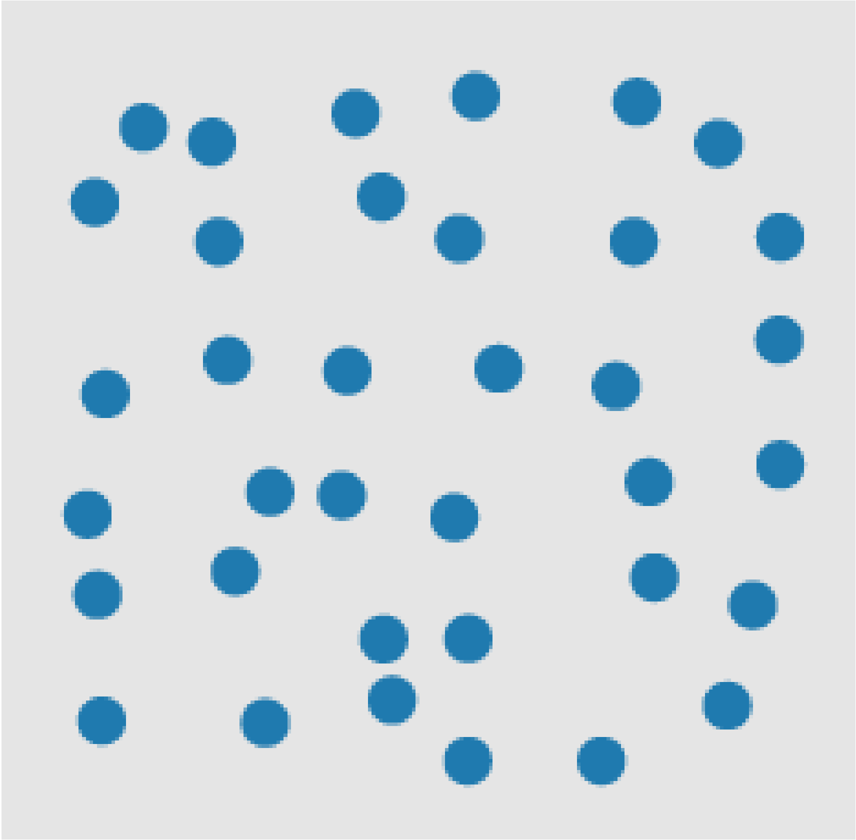
Colin Ware via– Andreas Butz, LMU

Preattentive feature

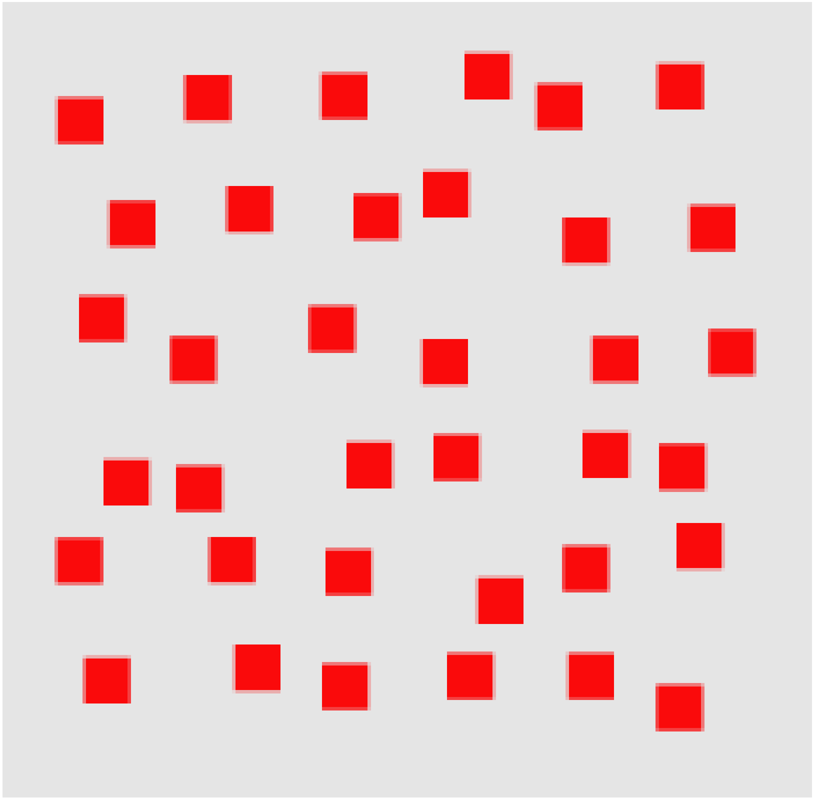
- A limited set of basic visual properties are processed preattentively
  - Information that “pops out”
- Parallel processing by the low-level visual system (Stage 1 in the model)
- Occurs prior to conscious attention
- Important for designing effective visualizations
  - What features can be perceived rapidly?
  - Which properties are good discriminators?
  - What can mislead viewers?
  - How to design information such that it pops out?

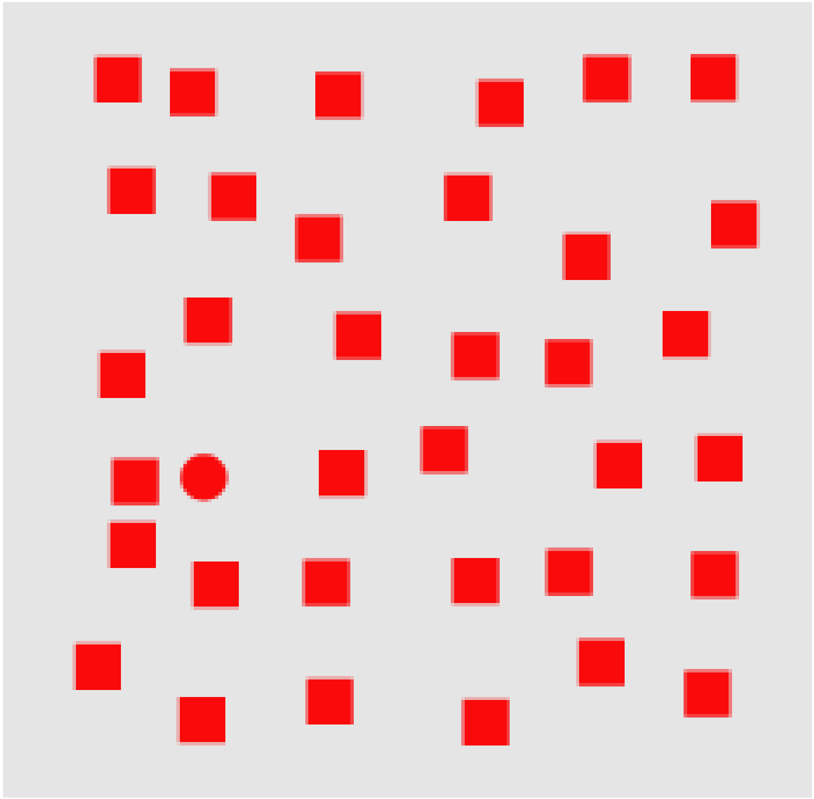
Same of different?



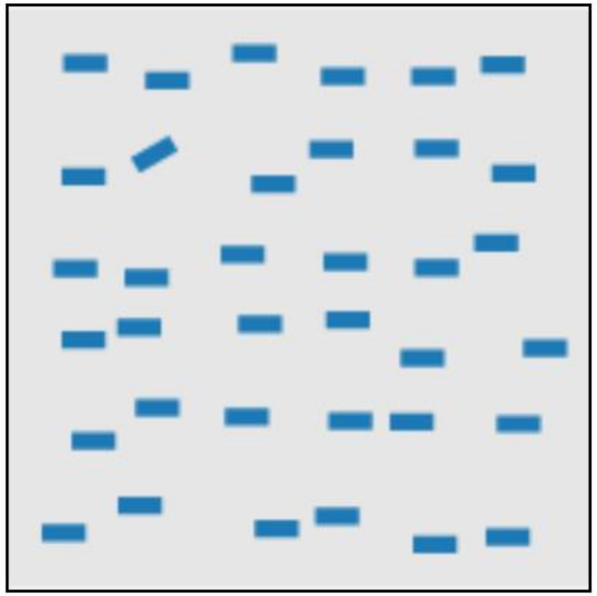


Same or different?

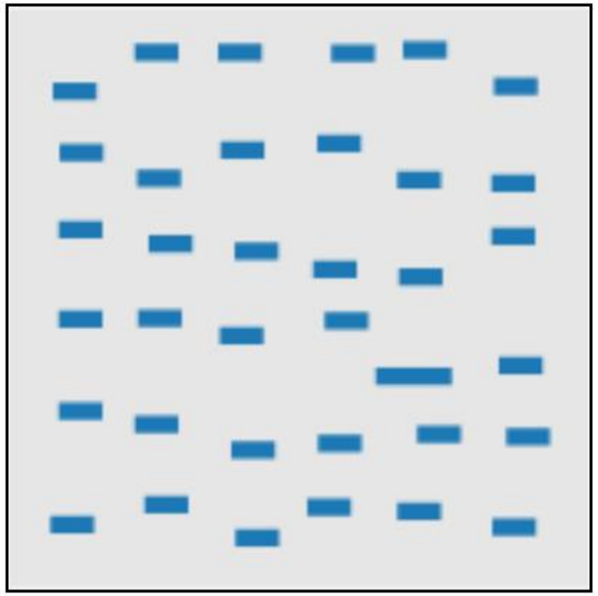




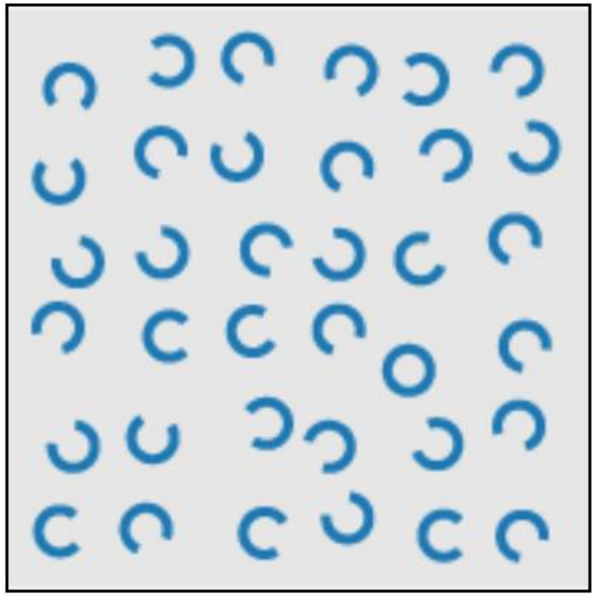
Preattentive features



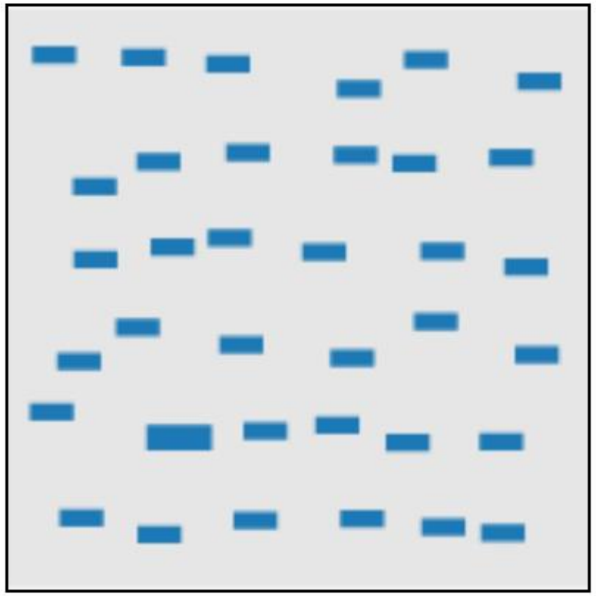
line (blob) orientation
Julész & Bergen 83; Sagi & Julész 85a, Wolfe et al. 92; Weigle et al. 2000



length, width
Sagi & Julész 85b; Treisman & Gormican 88



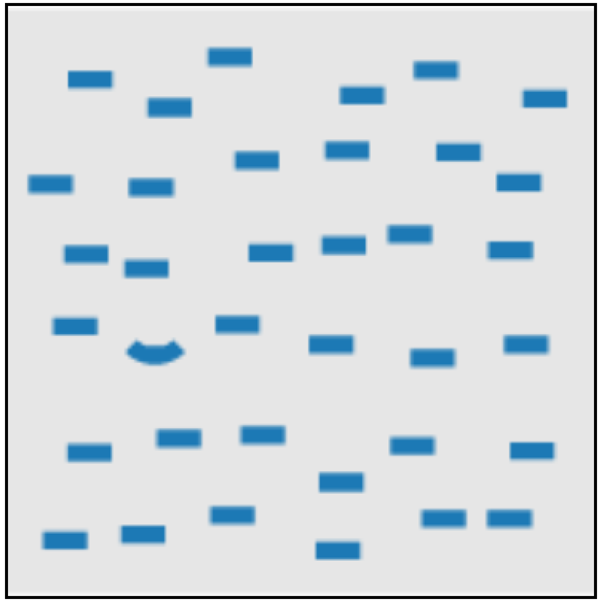
closure
Julész & Bergen 83



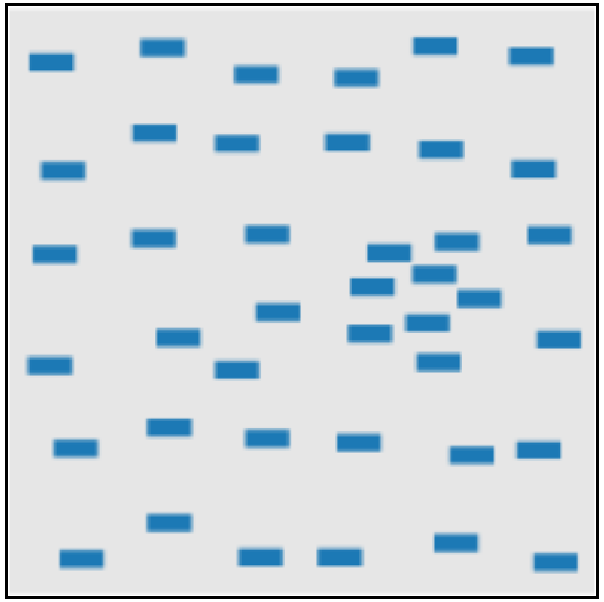
size
Treisman & Gelade 80; Healey & Enns 98; Healey & Enns 99

https://www.csc2.ncsu.edu/faculty/healey/PP/index.html#jscript_search

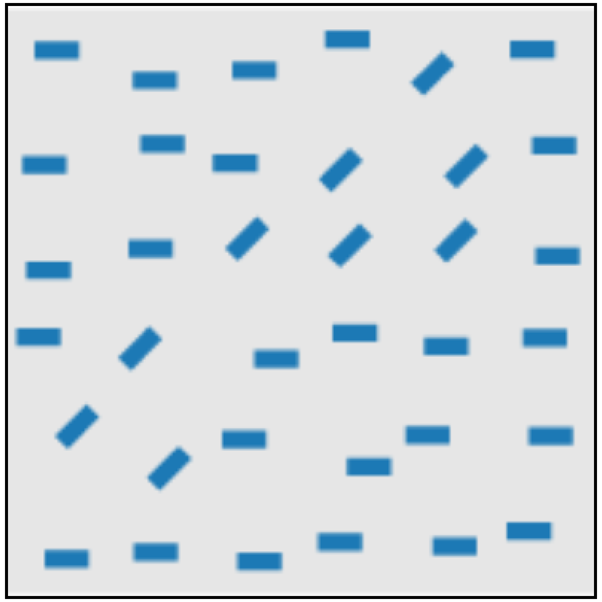
Preattentive features



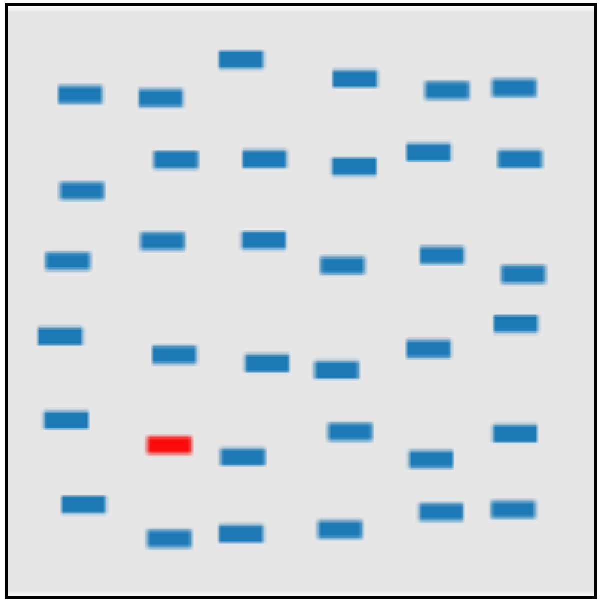
curvature
Treisman & Gormican 88



density, contrast
Healey & Enns 98; Healey & Enns 99

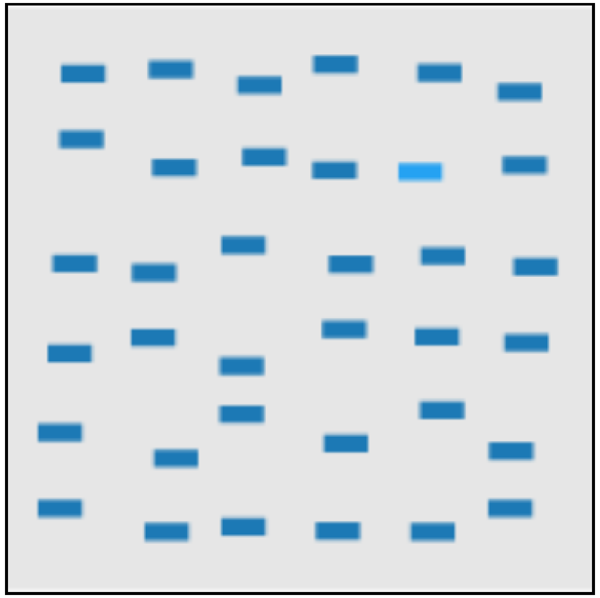


number, estimation
Sagi & Julész 85b; Healey et al. 93; Trick & Pylyshyn 94

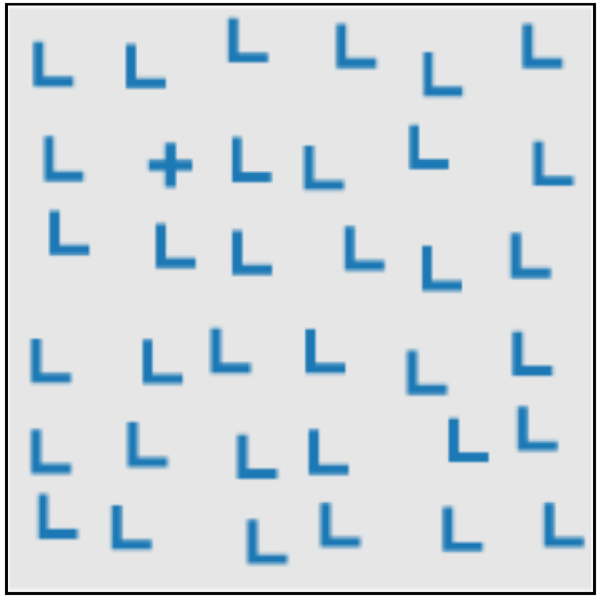


colour (hue)
Nagy & Sanchez 90; Nagy et al. 90; D'Zmura 91; Kawai et al. 95; Bauer et al. 96; Healey 96; Bauer et al. 98; Healey & Enns 99

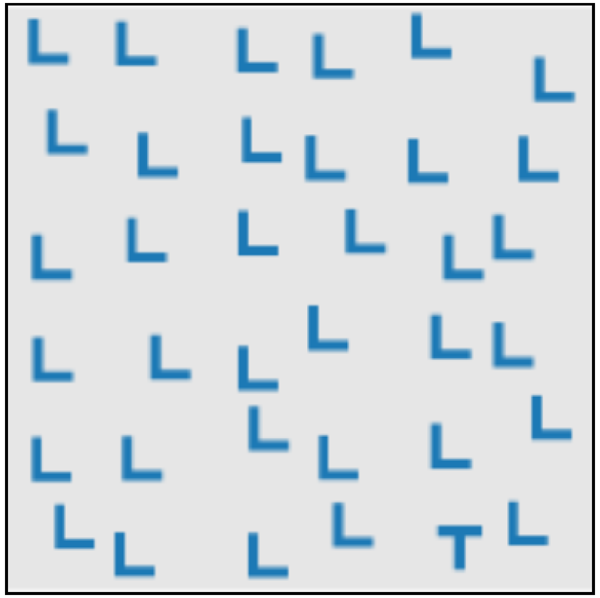
Preattentive features



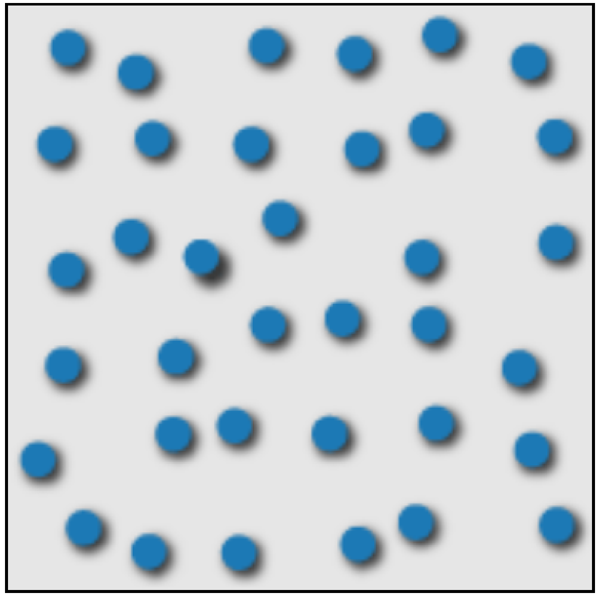
intensity, binocular lustre
Beck et al. 83; Treisman & Gormican 88; Wolfe & Franzel 88



intersection
Julész & Bergen 83

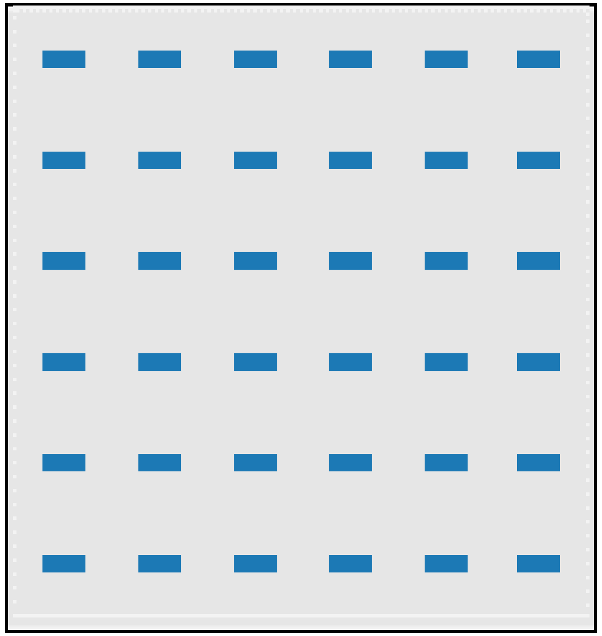


terminators
Julész & Bergen 83

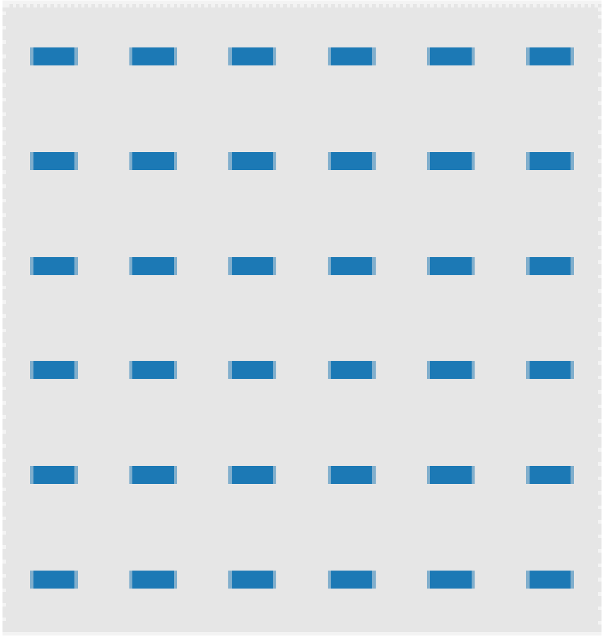


3D depth cues
Enns 90b; Nakayama & Silverman 86

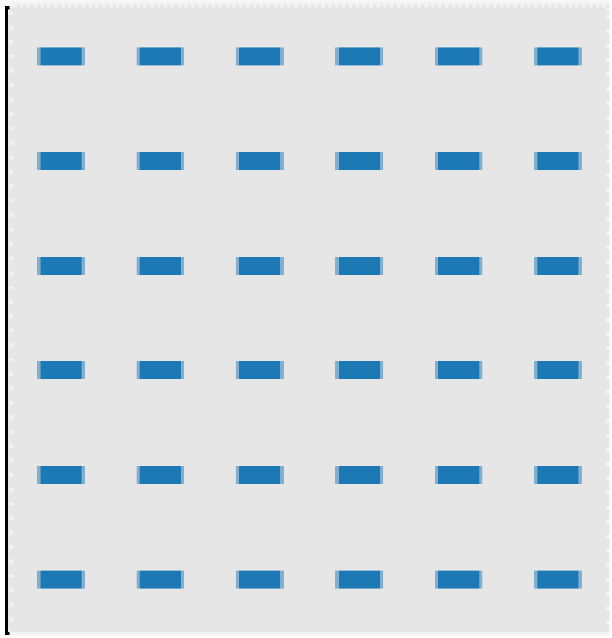
Preattentive features



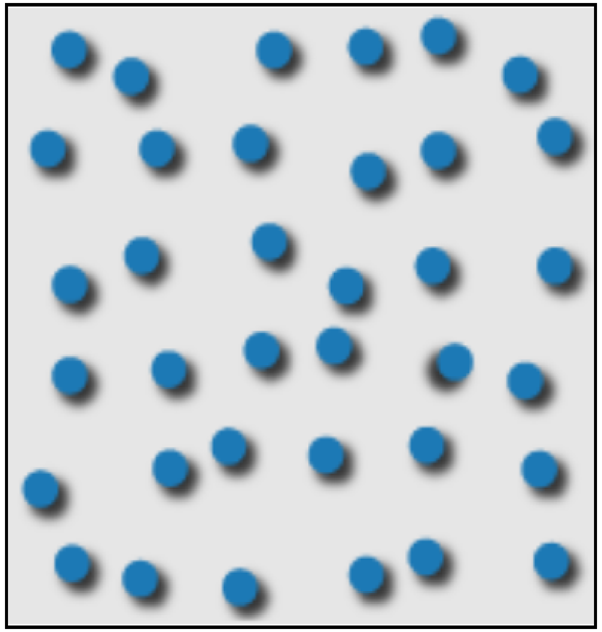
flicker
Gebb et a. 55; Mowbray & Gebhard 55; Brown 65; Julész 71; Huber & Healey 2005



direction of motion
Nakayama & Silverman 86; Driver & McLeod 92; Huber & Healey 2005



velocity of motion
Tynan & Sekuler 82; Nakayama & Silverman 86; Driver & McLeod 92; Hohns-bein & Mateeff 98; Huber & Healey 2005

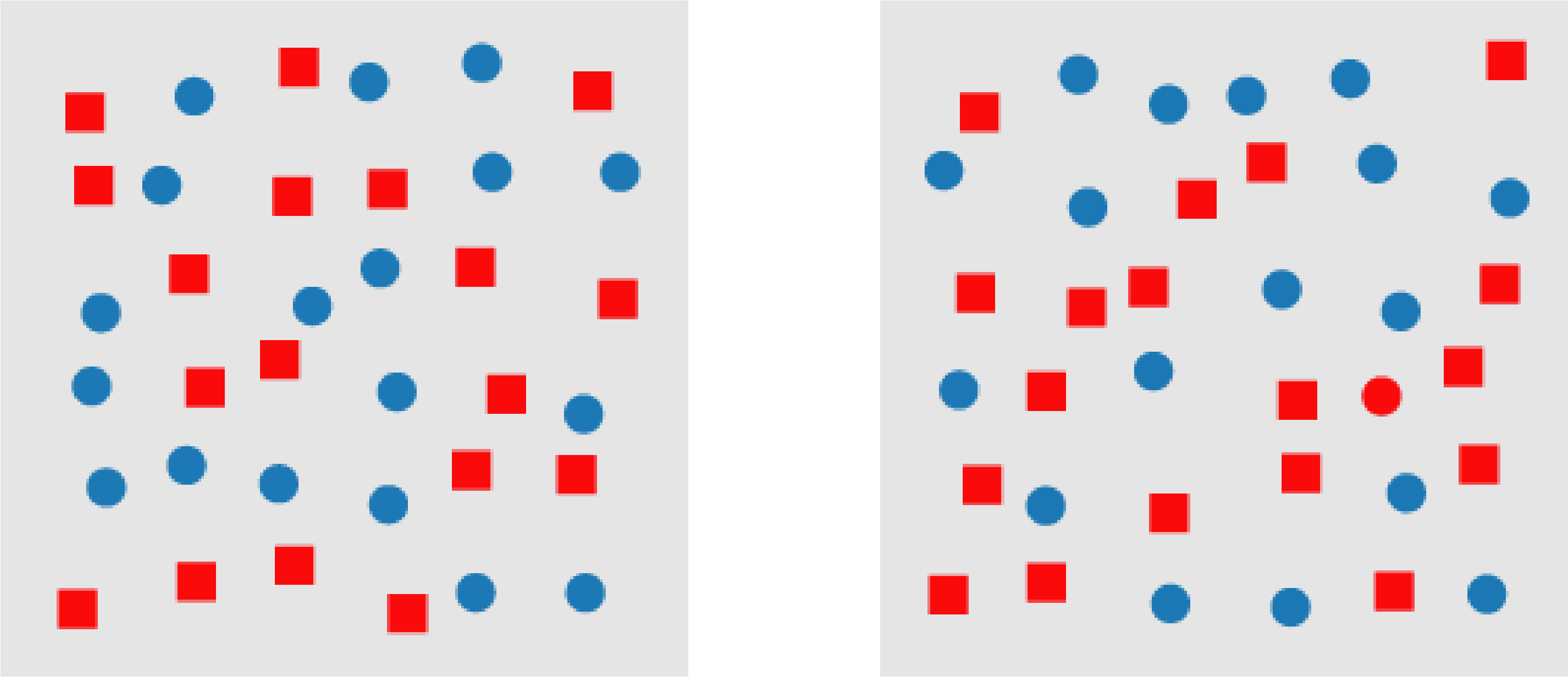


lighting direction
Enns 90a

Live testing

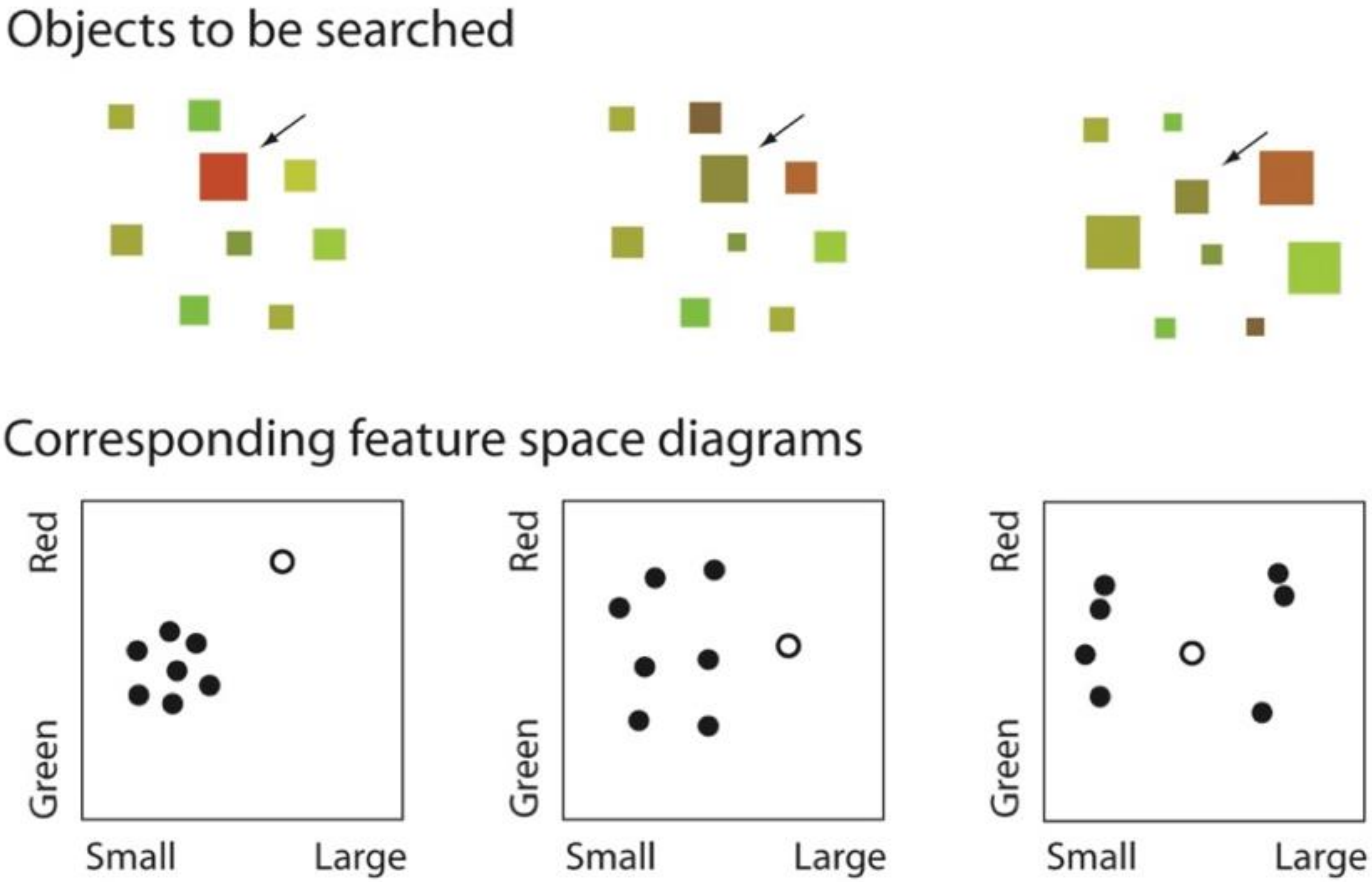
https://www.csc2.ncsu.edu/faculty/healey/PP/index.html#jscript_search

Conjunction - Same or different?

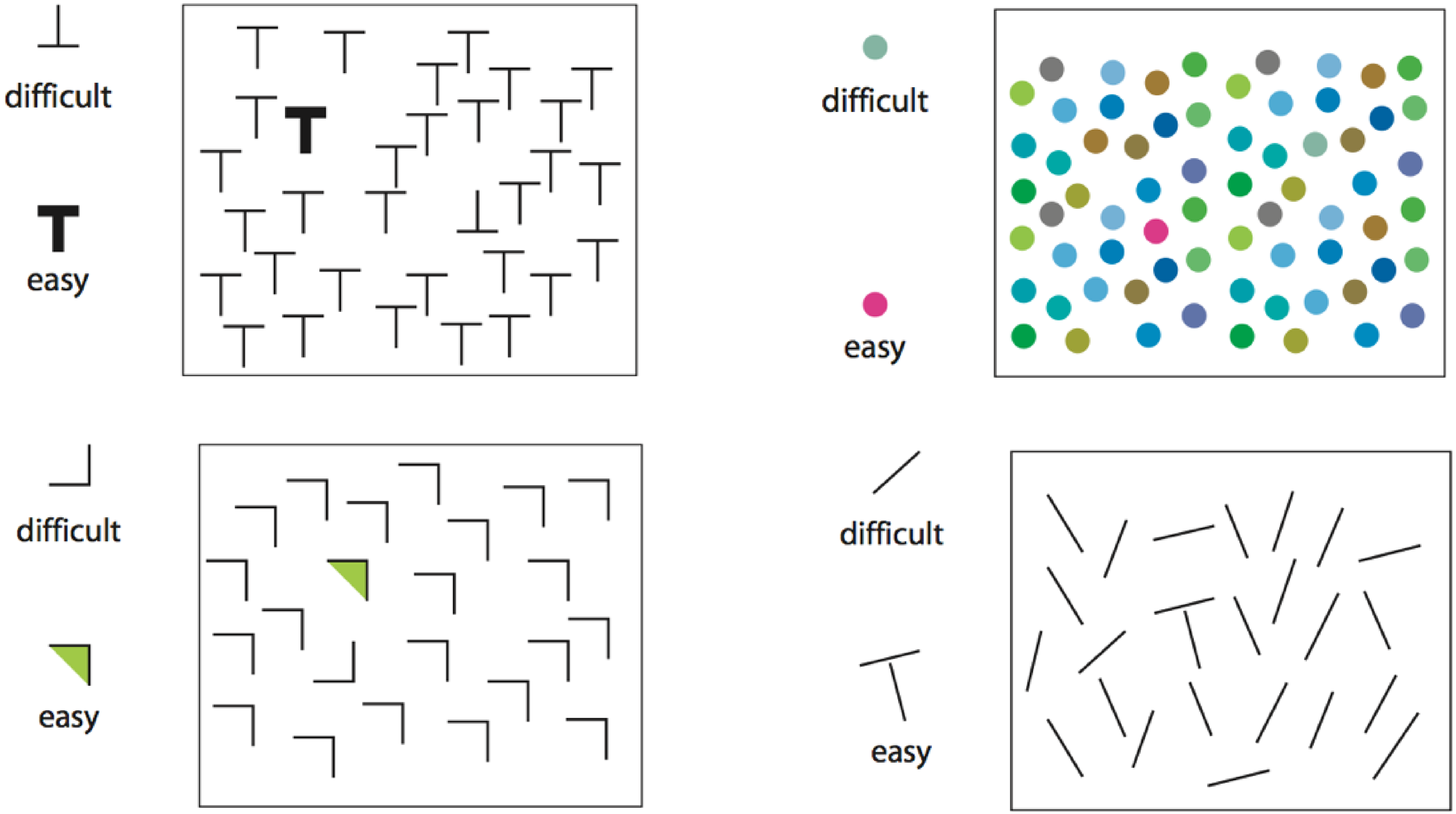


https://www.csc2.ncsu.edu/faculty/healey/PP/index.html#jscript_search

Conjunction



Most conjunctions are **not** pre-attentive



Models of attention

Why are some combinations preattentive?

- Three stage model (earlier slide)[Colin Ware]
- Treisman‘s feature integration model 1980 [Healey 04]
- Guided search theory [Jeremy Wolfe 94]
- Texton theory
- Similarity theory
- Boolean map theory

Foundation: Empirical studies

More detailes in required reading:

[Healey, C., & Enns, J. (2011). Attention and visual memory in visualization and computer graphics. IEEE transactions on visualization and computer graphics, 18(7), 1170-1188.]

Feature integration theory

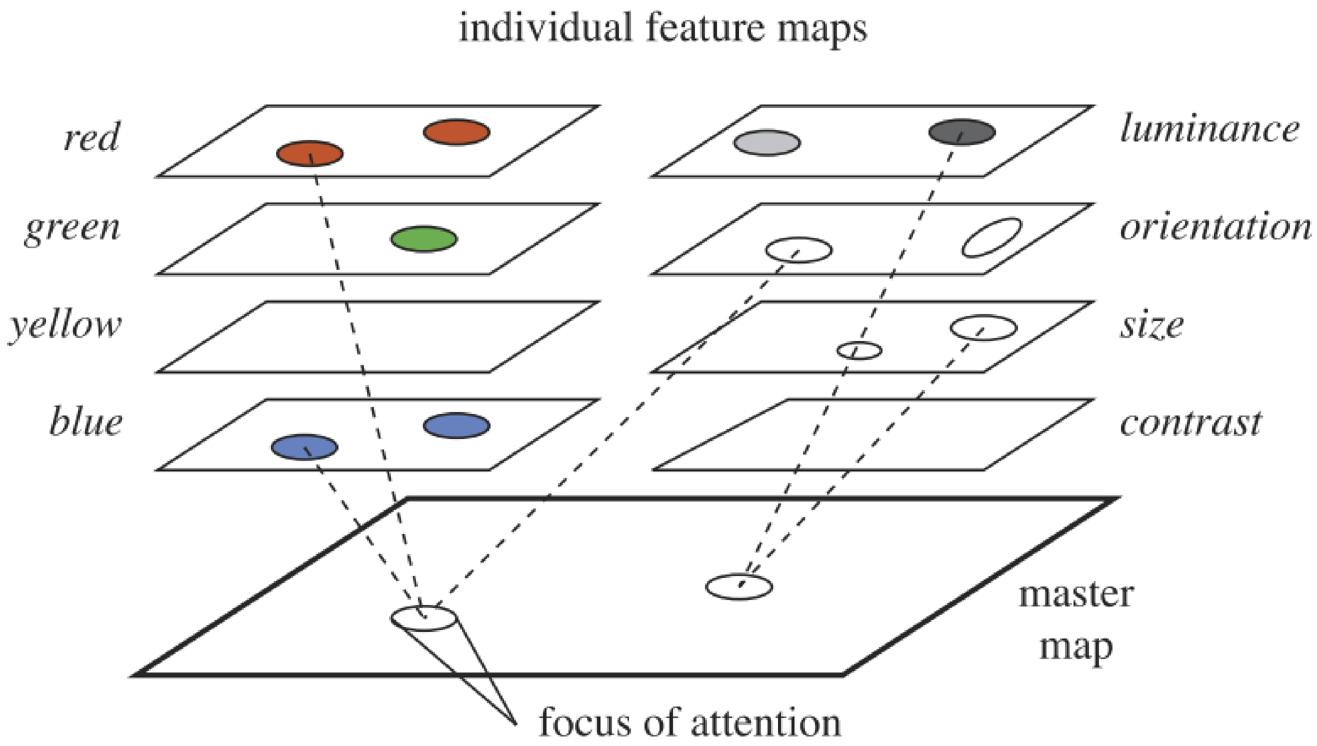


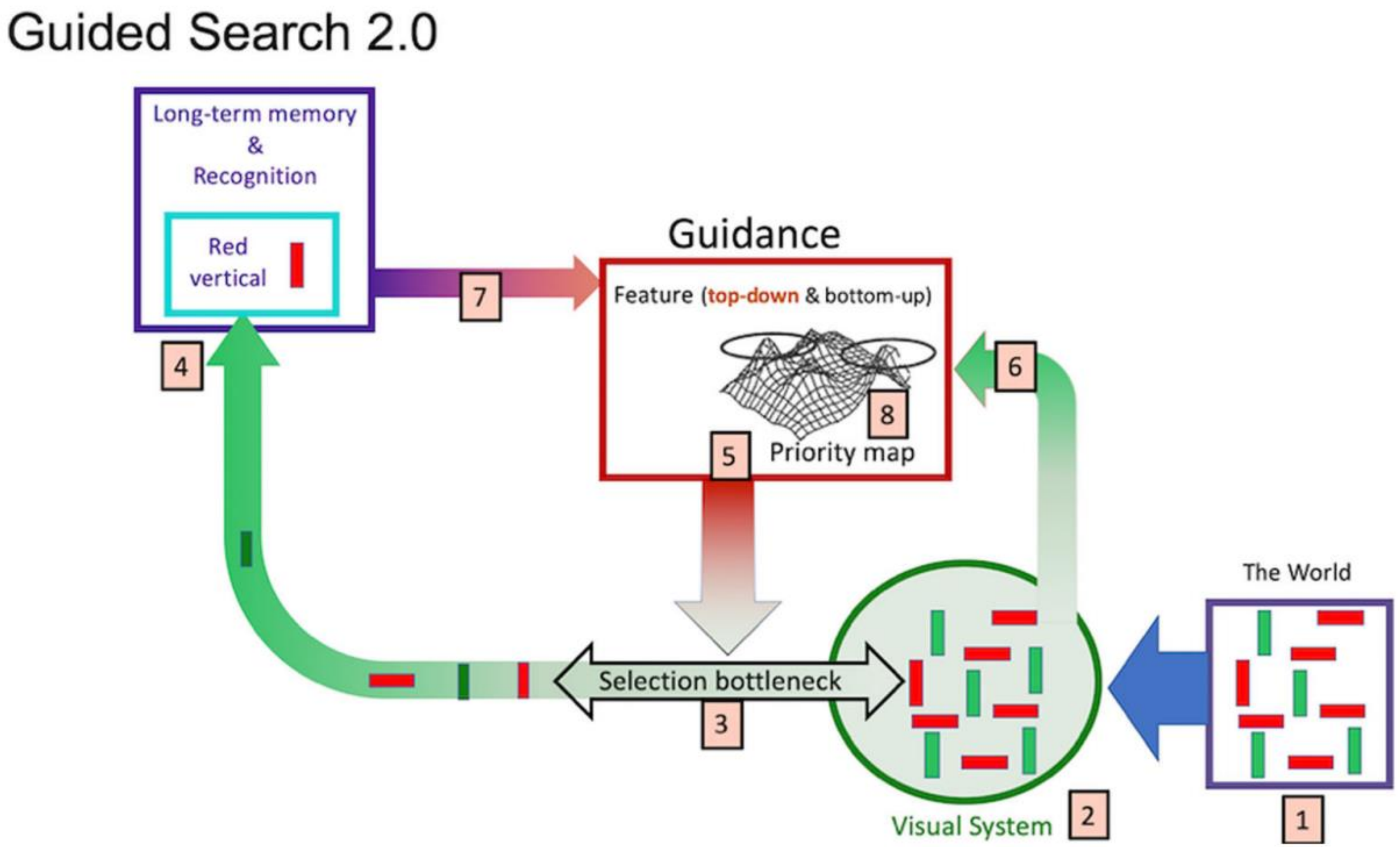
Fig. 3. Treisman's feature integration model of early vision—individual maps can be accessed in parallel to detect feature activity, but focused attention is required to combine features at a common spatial location [22].

Guided search

- we first process multiple basic features such as color, shape, and motion simultaneously across a large field.
- we then look for one specific element or combination of basic features at a time in a smaller area of the visual field.
- Example: we might first scan the sporting event crowd for the color and pattern of our friend's shirt and then focus on the most promising spots in the crowd to find his face.
- Information from the early stage of processing is used to guide attention in the later stage and make our visual search more efficient.

https://www.alleydog.com/glossary/definition.php?term=Guided+Search optional

Guided search



optional

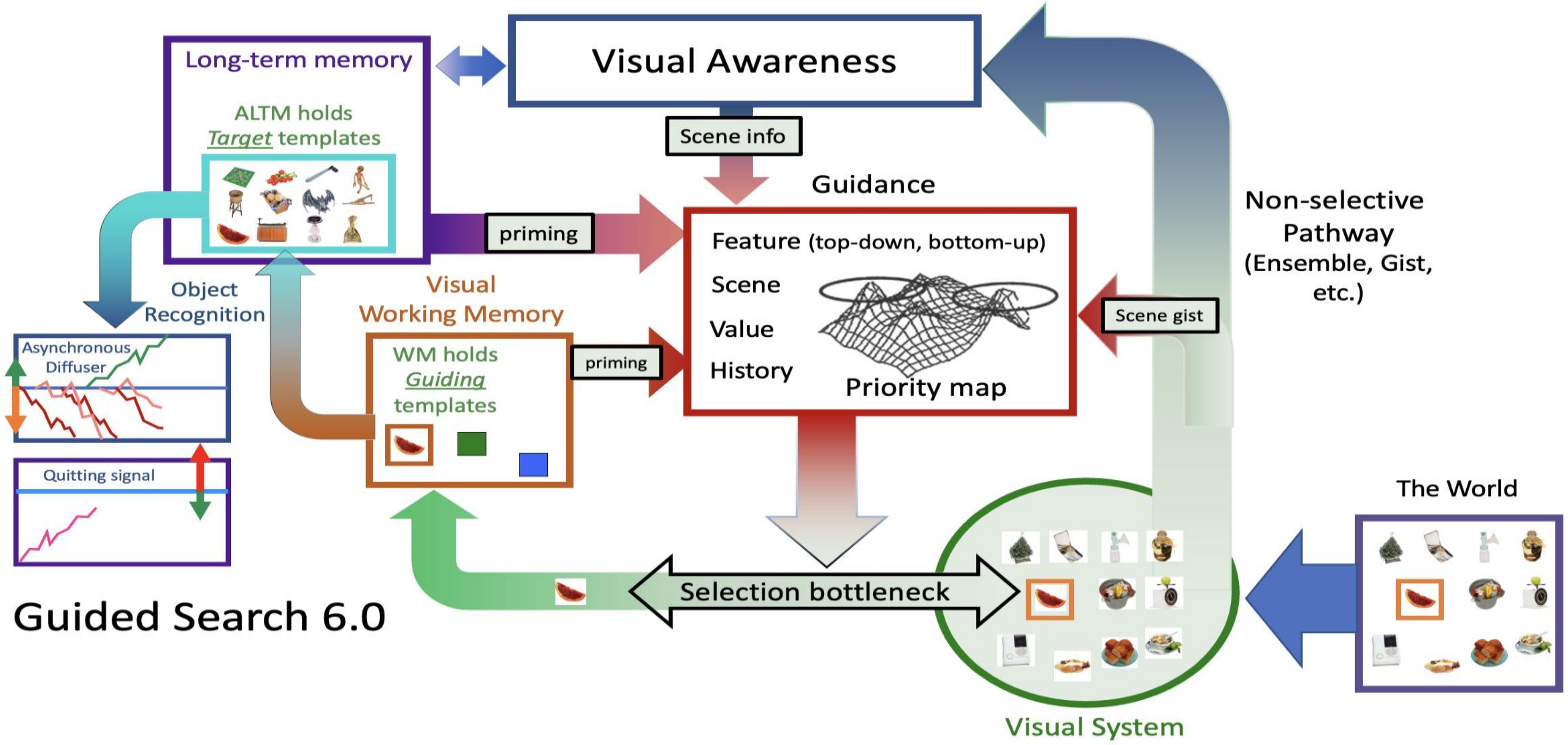
Evoluation Guided search theory

- GS2 (Wolfe, 1994)
- GS3 (Wolfe & Gancarz, 1996). GS3 was an attempt to integrate the covert deployments of visual attention with overt deployments of the eyes.
- Guided Search 4.0 (GS4)(2006)
- Guided Search 6.0 (2021)

https://search.bwh.harvard.edu/new/pubs/GS4chapInGray07.pdf

https://search.bwh.harvard.edu/new/pubs/Wolfe2021_GS6.pdf

Guided search theory

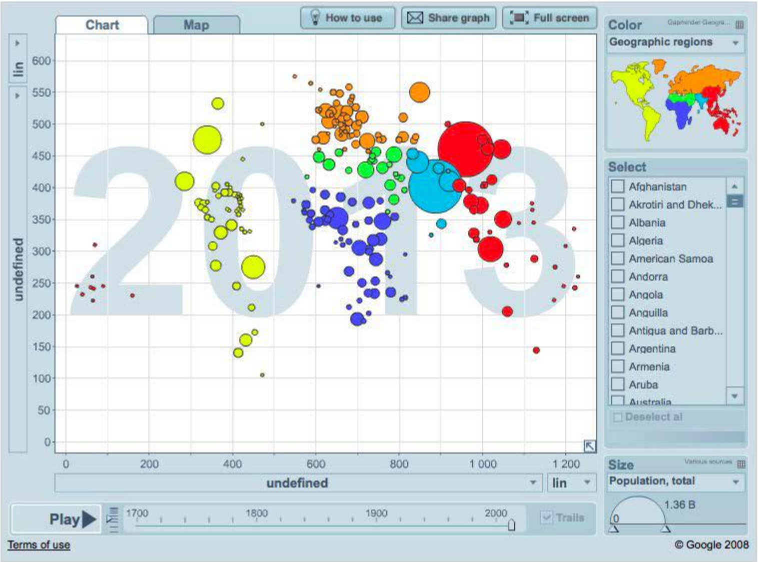


Guided search model 6.0 by Dr. Jeremy Wolfe

https://search.bwh.harvard.edu/new/pubs/Wolfe2021_GS6.pdf

Takeaway for Visualization: Visual encoding

- Certain visual features “pop out” (pre-attentive features)
- Important for any visualization
  - Especially for the design of glyphs
- Data variables should (usually) be mapped to preattentive features (they are processed fast)
- conjunction searches are usually not pre-attentive
- More detail in lecture on visual encoding



Change blindness

https://www.youtube.com/watch?v=EARtANyz98Q

https://www.csc2.ncsu.edu/faculty/healey/PP/index.html

https://www.usertesting.com/resources/topics/gestalt-principles

What is going on? We need an explanation.

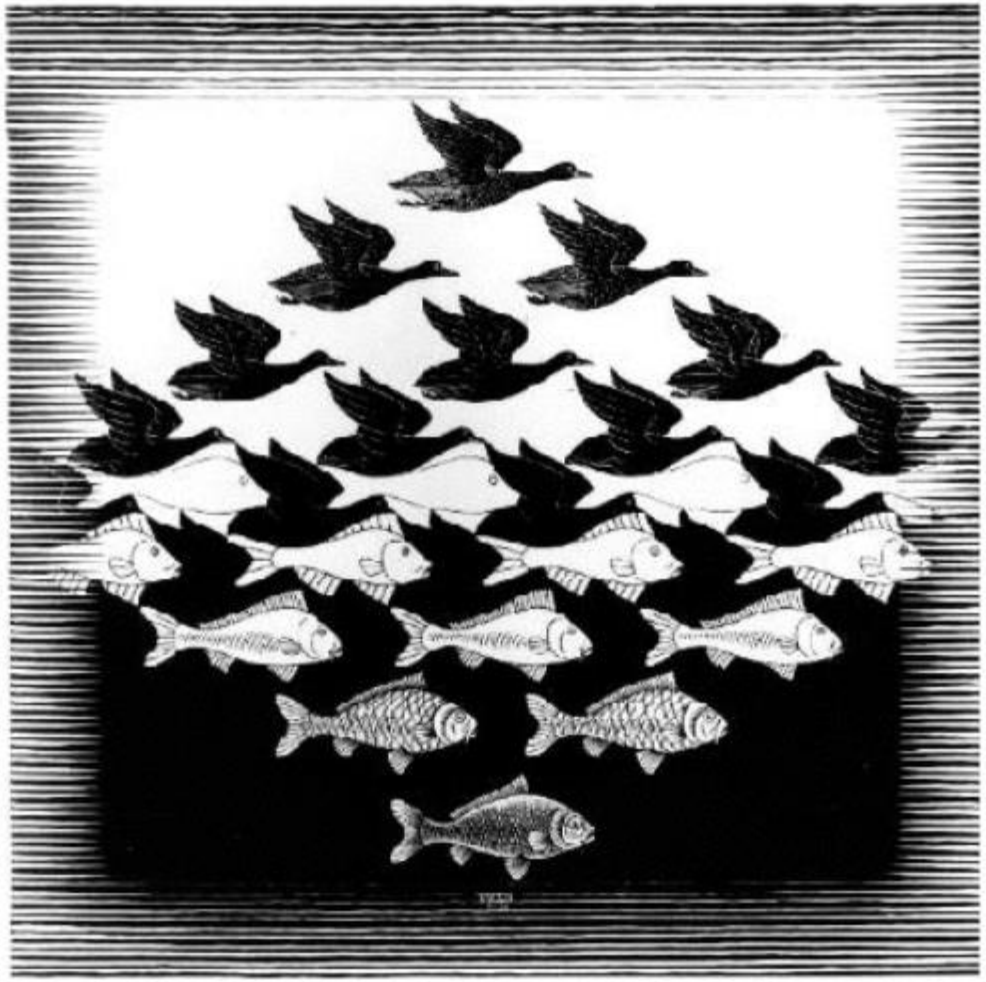
Gestalt theory

- Max Wertheimer, Kurt Koffka and Wolfgang Köhler
- **Holistic** and structured view of perception
  - to explain how people organize visual information
- Gestalt is a German word meaning shape or form.
- The principles describe the various ways we tend to visually asse
  individual objects into groups or 'unified wholes’
- “The whole is 'other' than the sum of its parts.” (Kurt Koffka)
- Symbiosis of viewing and meaning

Max Wertheimer, 1880 - 1943

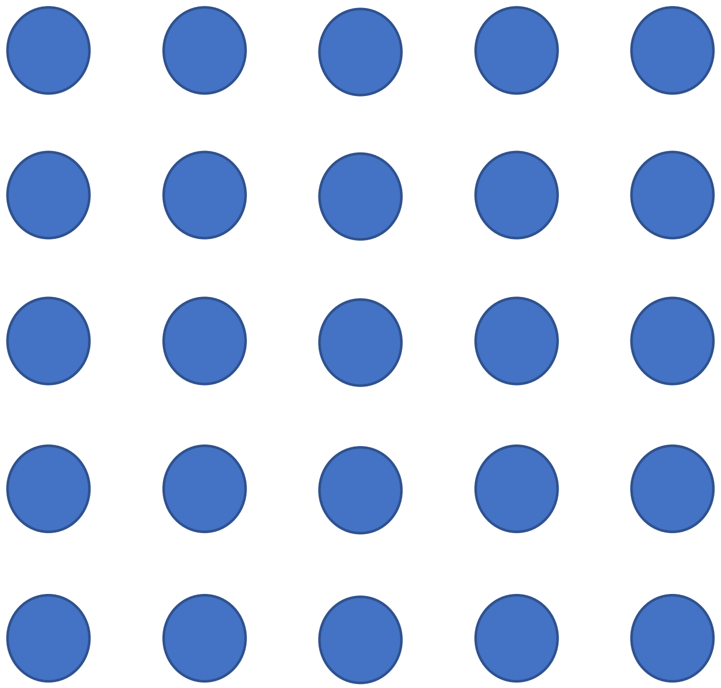
- More detailed history in required reading

Law of figure and ground

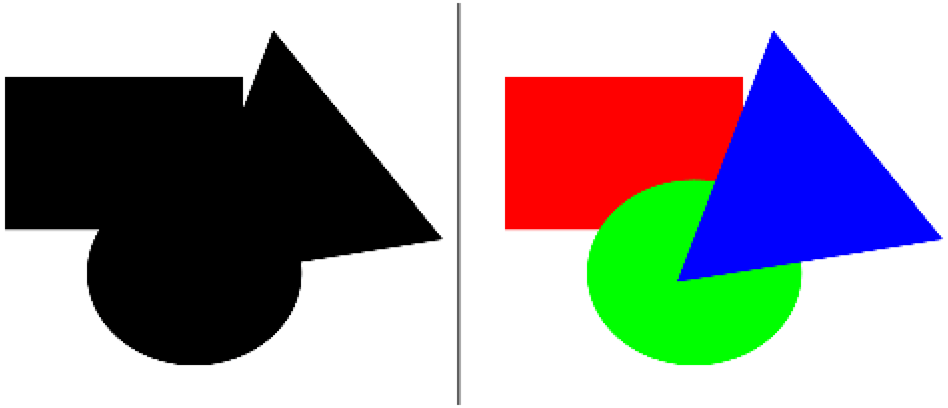


M.C. Escher: *Sky and Water I* 1938 woodcut

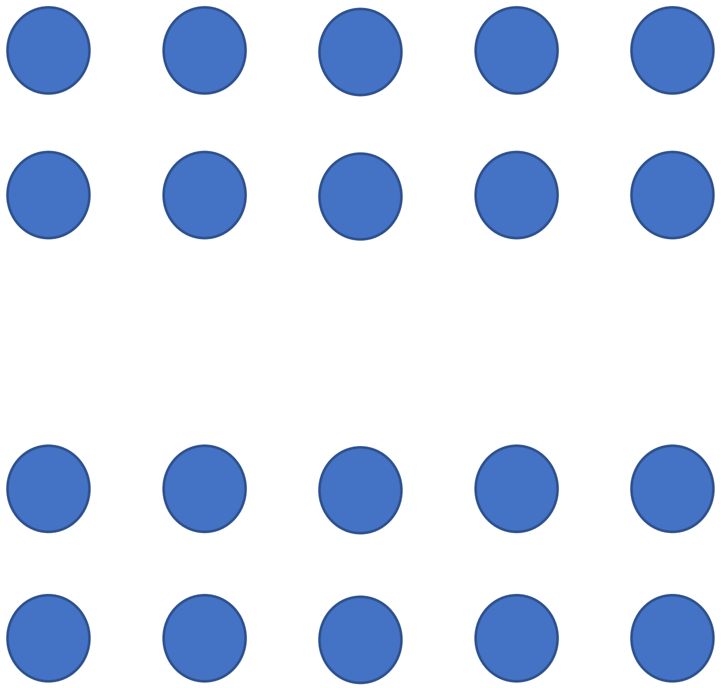
Gestalt laws



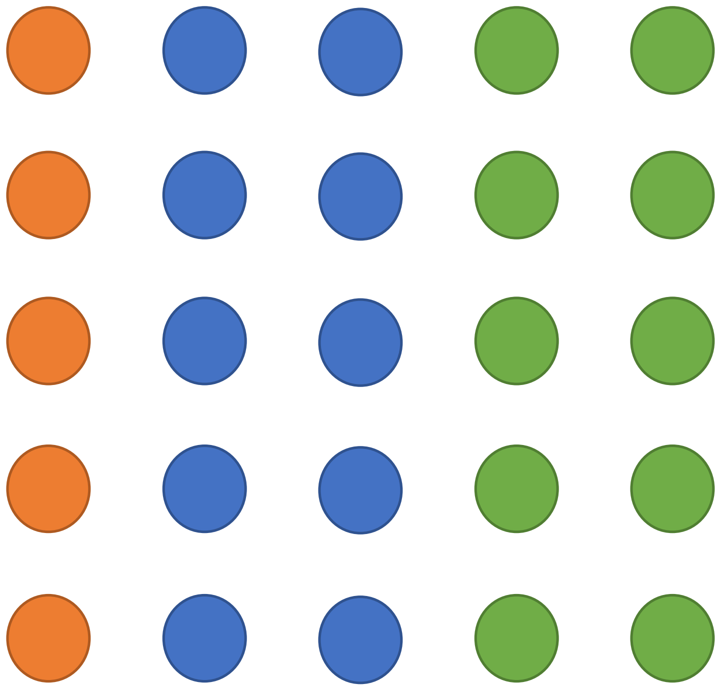
Law of Prägnanz



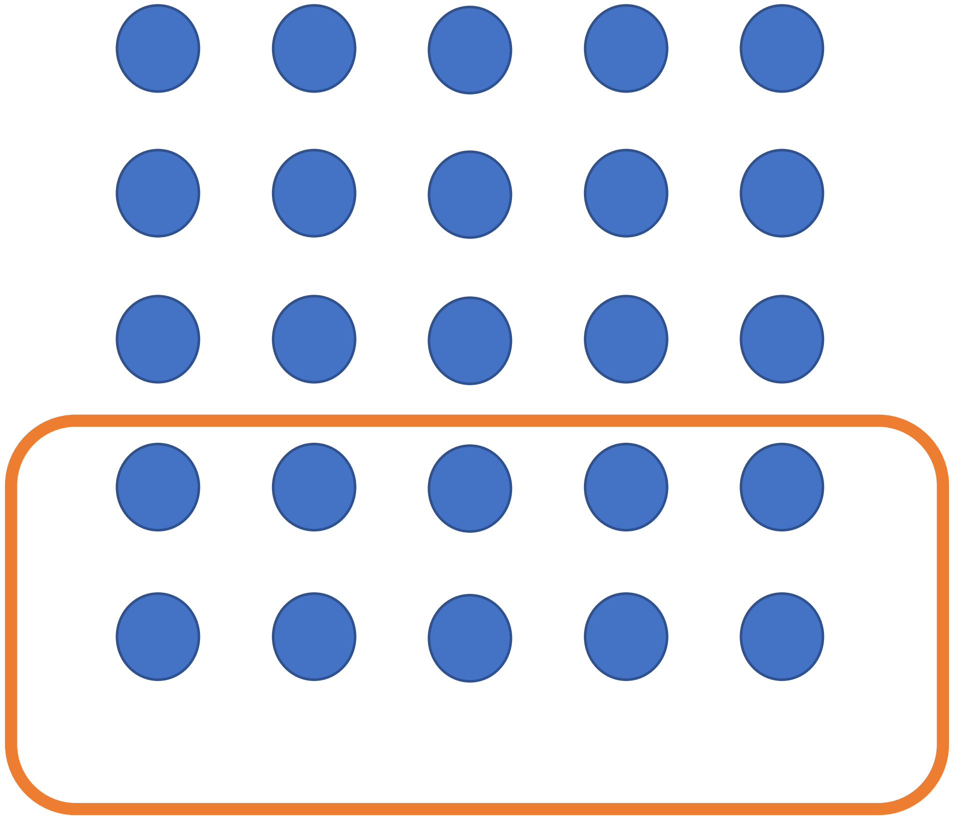
Law of proximity



Law of similarity

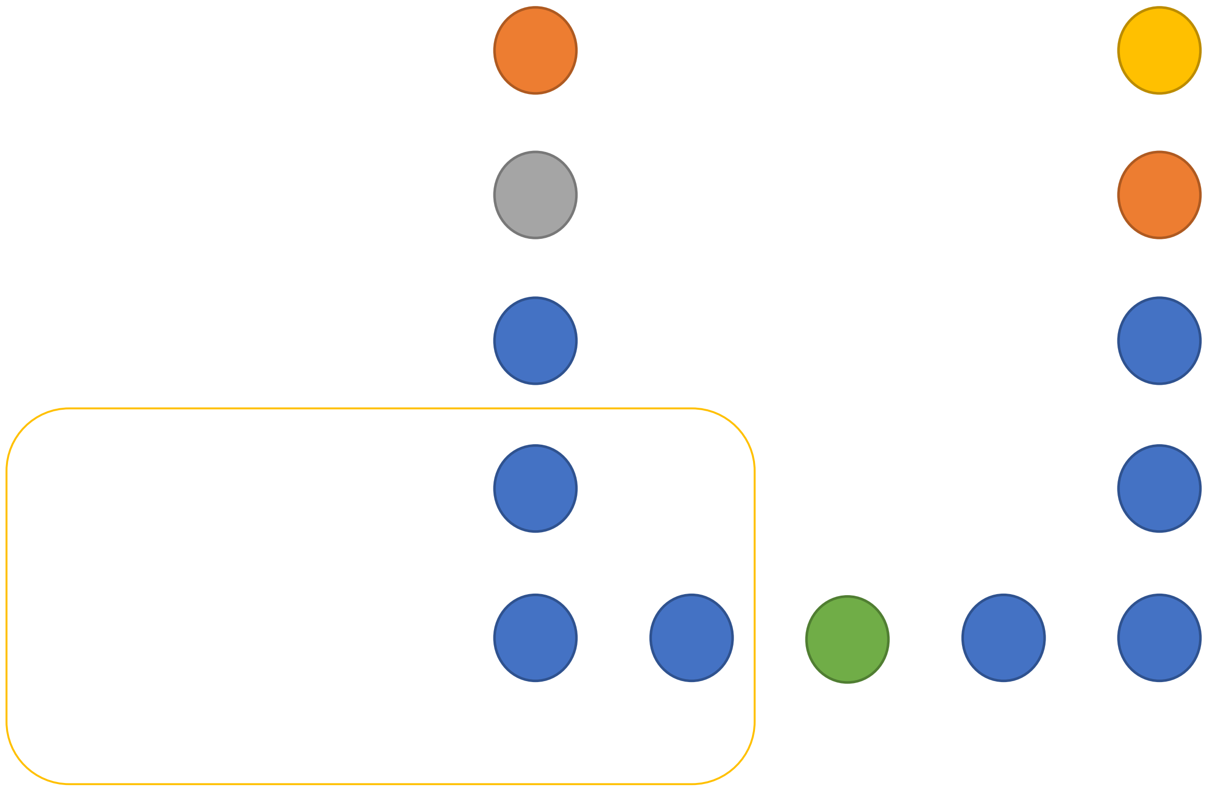


Law of enclosure

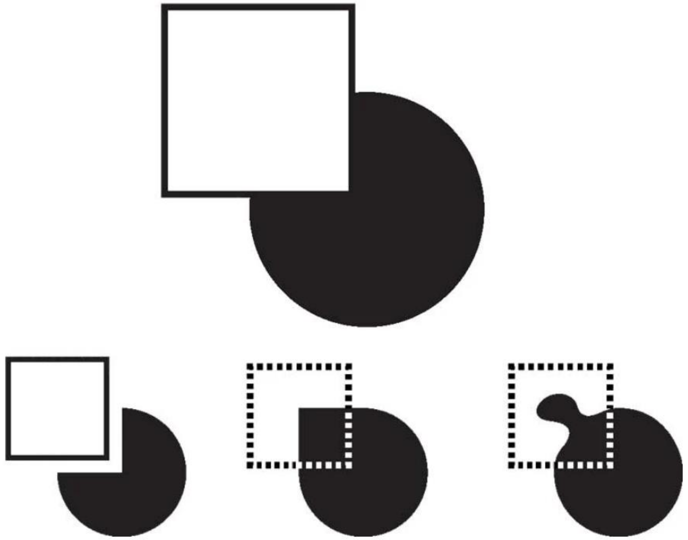


Law of closure

Law of continuity



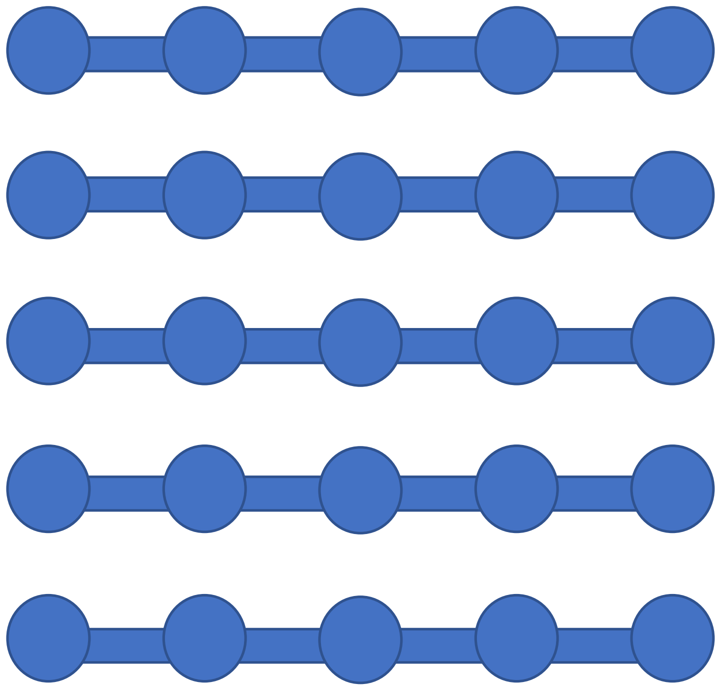
The Kanizsa triangle and illusory contour.



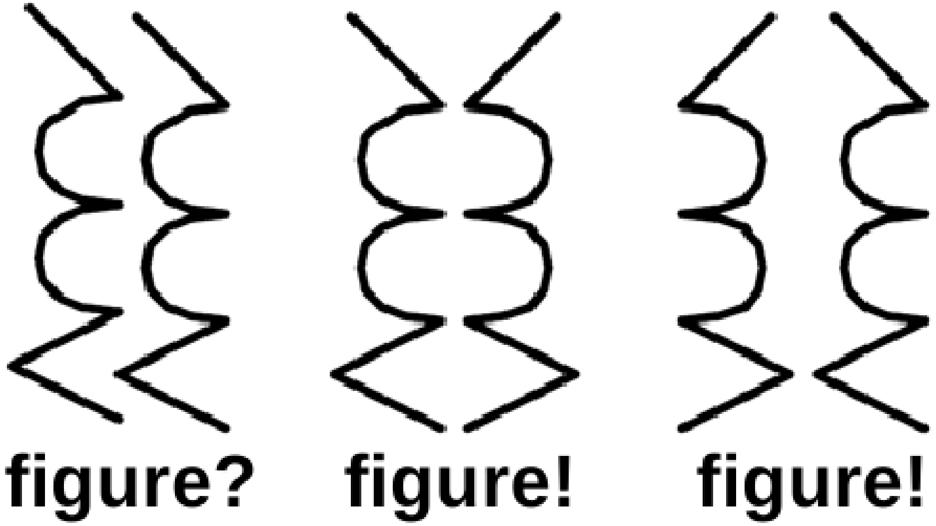
Spontaneous and automatic completion of occluded surfaces as a simple and familiar circle.

Gestalt principles (Part 1)
•Bang Wong
Nature Methods **volume 7**, page863 (2010)

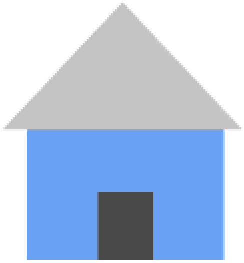
Law of connection

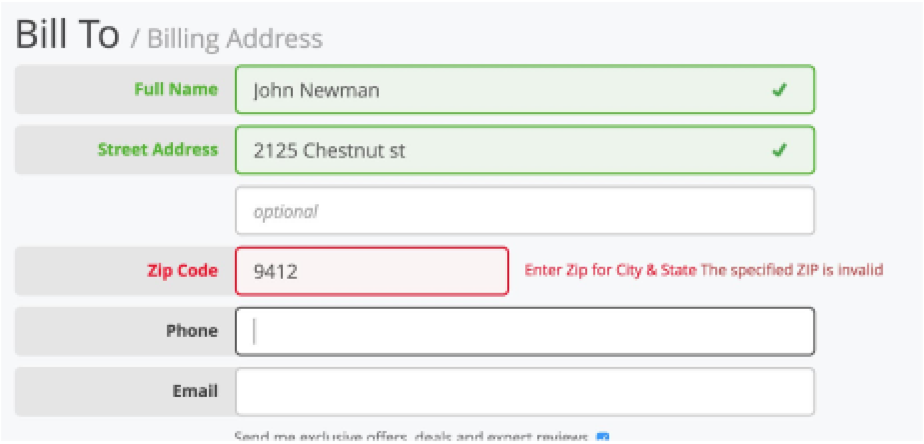


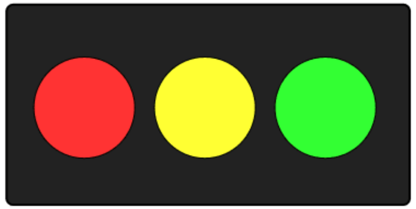
Law of symmetry



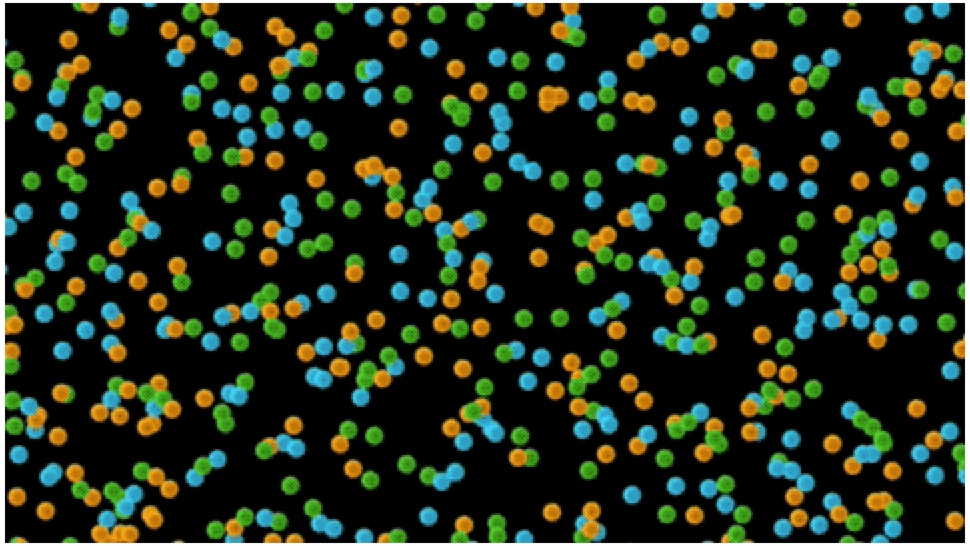
Law of past experience

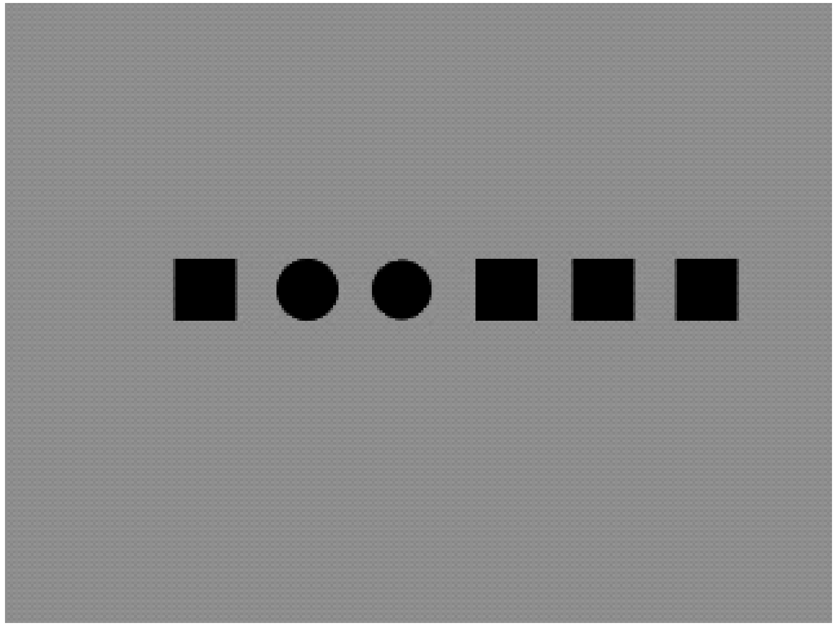




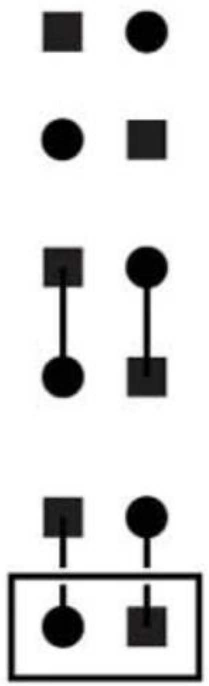


Law of common fate





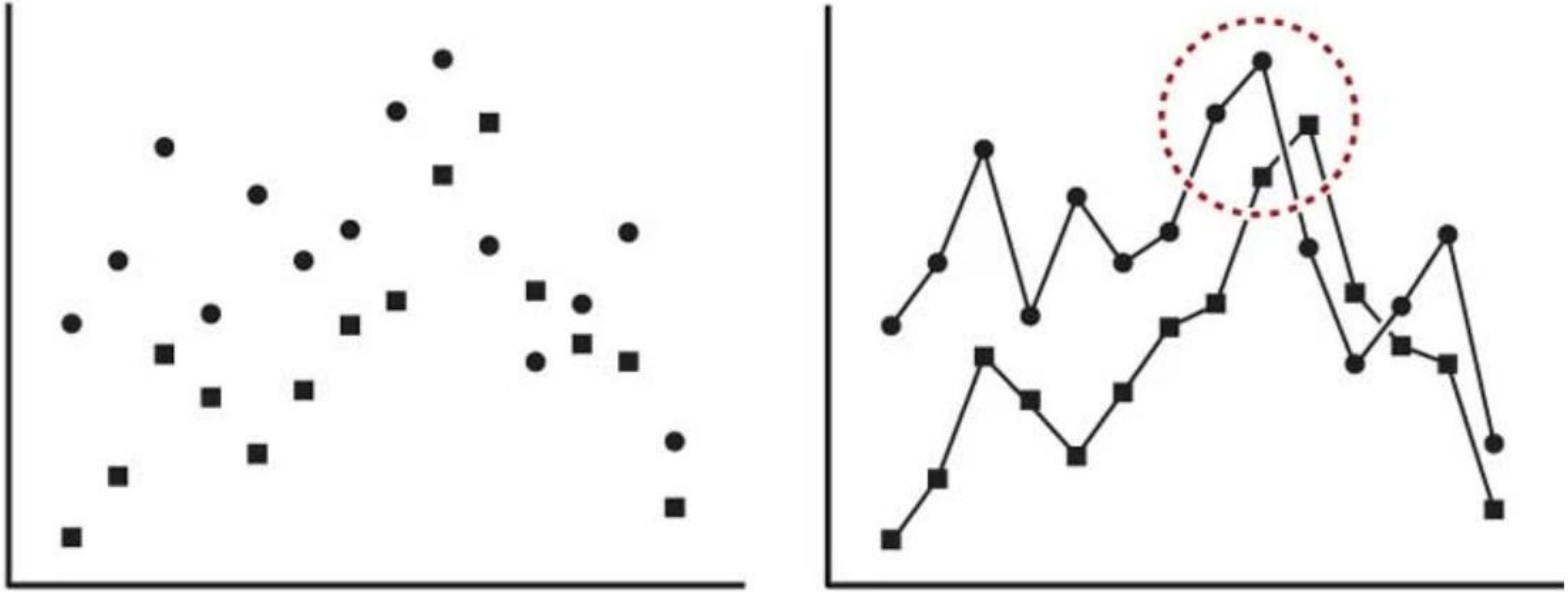
Principles of grouping.



Relative strength of grouping by similarity, proximity, connection and enclosure

Bang Wong Gestalt principles (Part 1)

Principles of grouping.



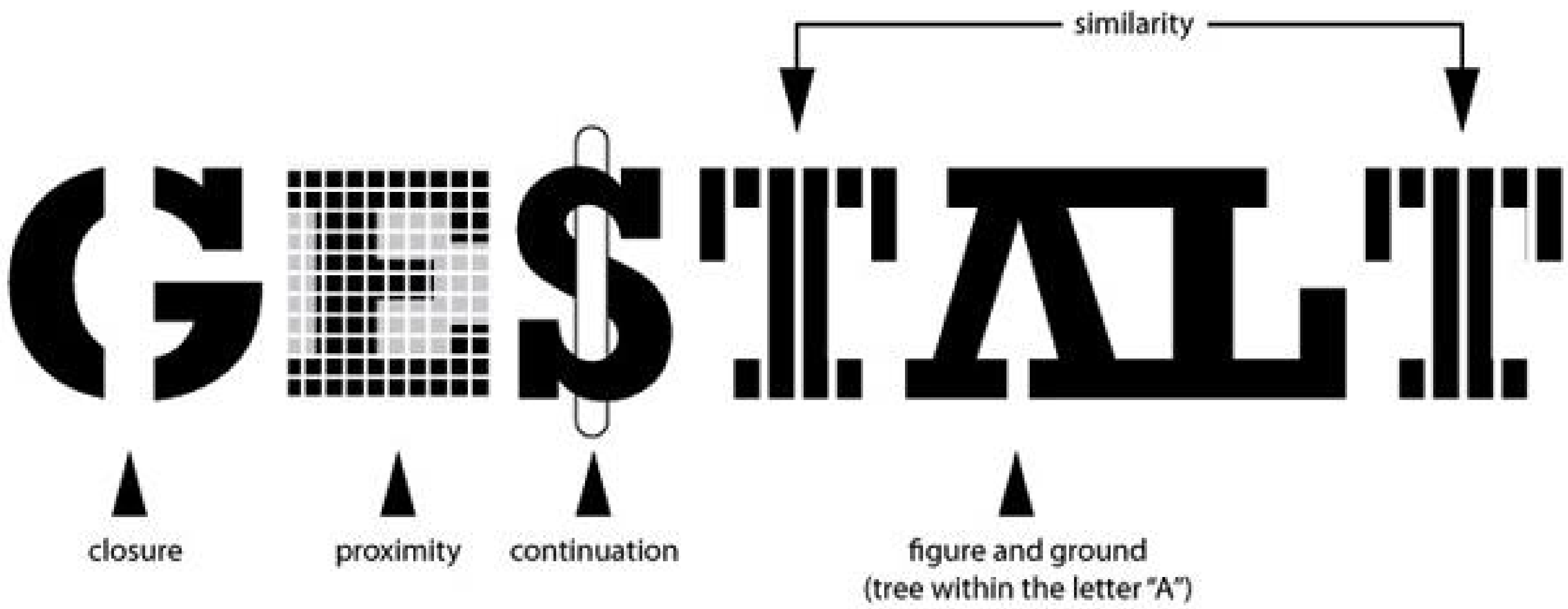
Lines in graphs create clear connection. Enclosure is an effective way to draw attention to a group of objects.

Bang Wong Gestalt principles (Part 1)

Gestalt principles

Miriah meyer

Which laws apply?


similarity
closure
proximity
continuation
figure and ground
(tree within the letter "A")

Gestalt laws

- **Prägnanz (good law):** *“People will perceive and interpret ambiguous or complex images as the simplest form(s) possible.”*
- **Proximity:** things that are visually close to each other are related
- **Similarity:** things that look like each other (size, color, shape) are related
- **Connection:** things that are visually connected are related
- **Closure:** we see incomplete shapes as complete
- **Continuity:** we complete hidden objects into simple, familiar shapes
- **Symmetry**: things are symmetric can be perceived as forming a visual whole
- **Experience**: decipher complex, foreign phenomena with the help of known things interpreted into them
- **Figure / Ground:** elements are perceived as either figures or background
- **Common Fate:** elements with the same moving direction are perceived as a unit

Summary

1. Human Perception
2. Attention
3. Gestalt theory

1. Perception based on physical properties of the eye/nerves
2. Empirical models of perception
3. Holistic model of perception