03

Human Perception and Information Processing

Notice

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Bibliography

- **Many examples are extracted and adapted from**
  - **Interactive Data Visualization: Foundations, Techniques, and Applications,**

    Matthew O. Ward, Georges Grinstein, Daniel Keim, 2015
  - **Visualization Analysis & Design,**

    Tamara Munzner, 2015

Practical information

Teams: lets check the actual situation

- **Teams registration**

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Teams: lets check the actual situation

- **Not in any team !**

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Shared folder on Google Drive

- **You will received access to a shared folder:**
  - **VID-19-20-GNN**
    - Where GNN is your group ID
    - If not please let me know
- **Proposed organization for your folder**
  - **Data and Workbooks**
  - **Papers and PDFs**
  - **Project Paper**
    - Name the files like VID-GNN-2020.MM.DD-Paper.pdf
  - **You may use overleaf to work on the paper**
  - **Goggle Docs to share drafts**

Project Important dates

- **Team registration - Mars 26th (W03)**
- **Select datasets for your project - April 16th (W06) ; Final validation - April 23th (W07)**
  - **Evaluate de selected datasets**
  - **Discuss in the lab sessions the viability**
  - **Define and get an approval of your research questions**
- **Paper - May 14th (W10)**
- **Project delivery - June 14 th**
- **Oral - June 17 - June 24**

Project Important dates

- **T1: 28 April, 16h (Wednesday)**
- **T2: 12 June, 9h (Saturday)**

- **Paper - May 14th (W10)**

- **Project delivery - June 14 th**
- **Oral - June 17 - June 24**

Never Forget !

What is the Goal of Data Visualization?

The (ultimate) goal of DV

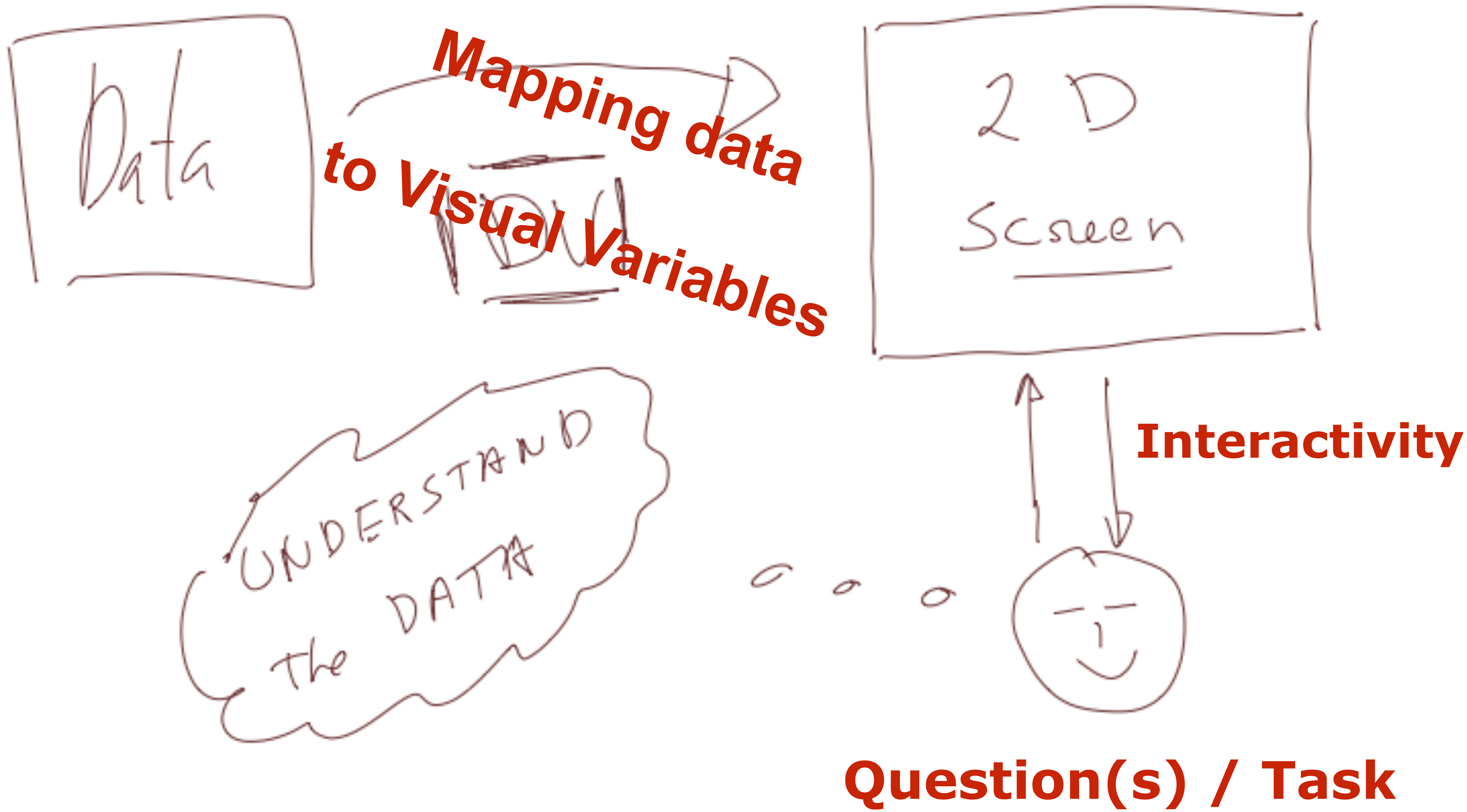
"Data visualization is not just about seeing data !

Is about UNDERSTANDING data,

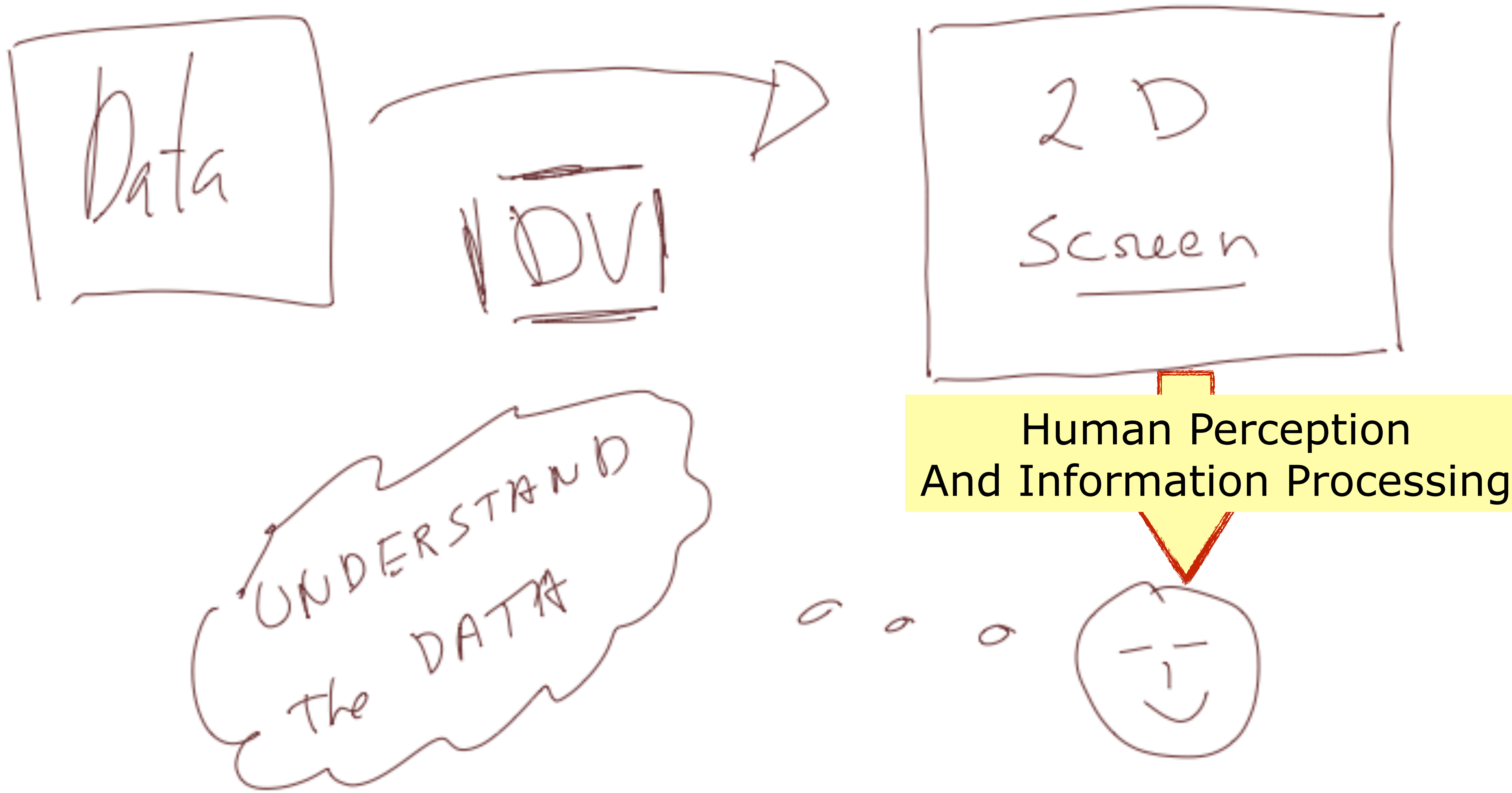
and being able to make decisions based on the data"

by John C. Hart

What is the core idea of Interactive Data Visualization?



What is the core idea of Interactive Data Visualization?



Question(s) / Task

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- **What Is Perception?**
- **Physiology**
- **Perceptual Processing**
- **Perception in Visualization**
- **Metrics**
- **Cognition**

Table of Contents

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What Is Perception?

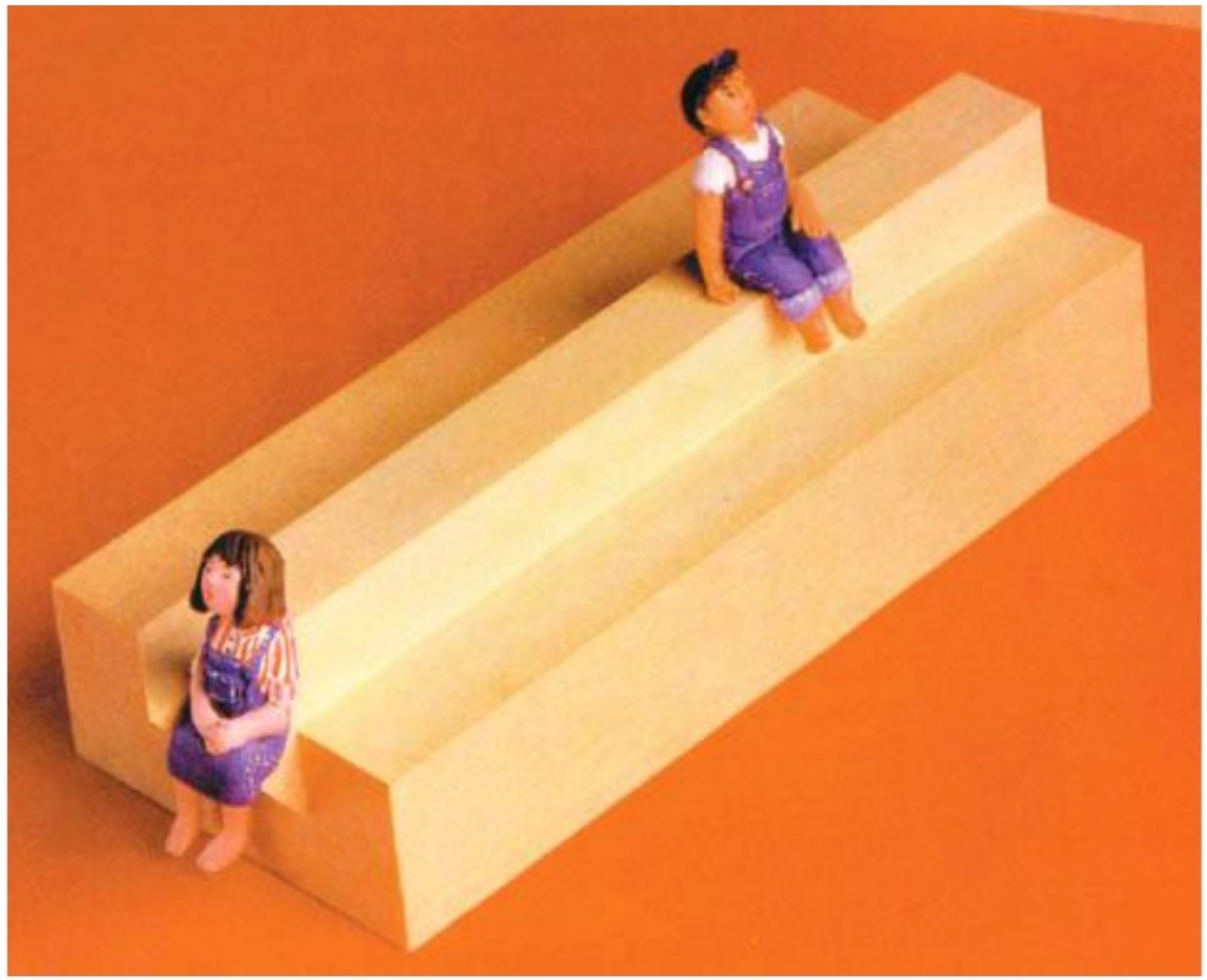
What is perception?

- **Most define perception as the process of:**
  - **recognizing (being aware of);**
  - **organizing (gathering and storing);**
  - **and interpreting (binding to knowledge) sensory information.**

- **Perception is the process by which we interpret the world around us, forming a mental representation of the environment.**

- **The brain makes assumptions about the world to overcome the inherent ambiguity in all sensory data, and in response to the task at hand.**

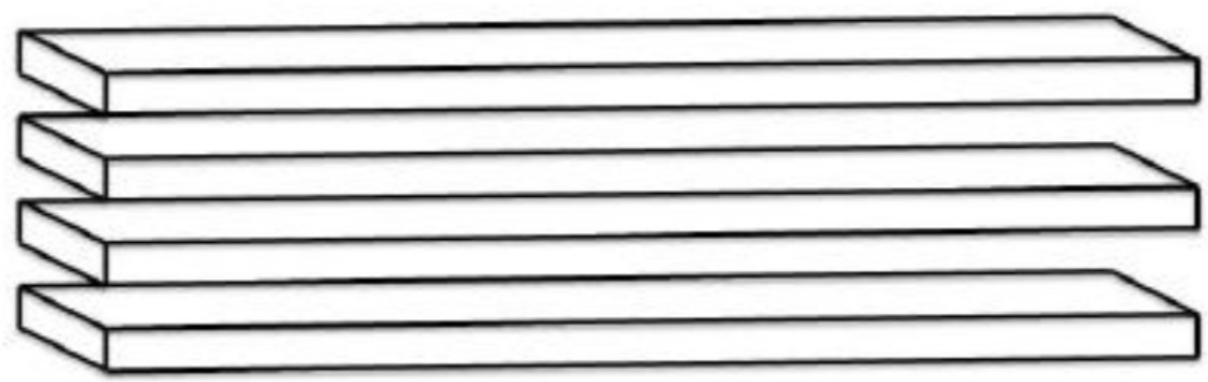
The brain makes assumptions !



Two seated figures, making sense at a higher, more abstract level, but still disturbing. On closer inspection, these seats are not realizable. (Image courtesy N. Yoshigahara.)

Figure 3.1 (Matthew Ward, et. all)

The brain makes assumptions !



Four $\neq$ three. As in Figure 3.1, this object would have a problem being built (there are four boards on the left and three on the right).

Figure 3.2 (Matthew Ward, et. all)

The brain makes assumptions !

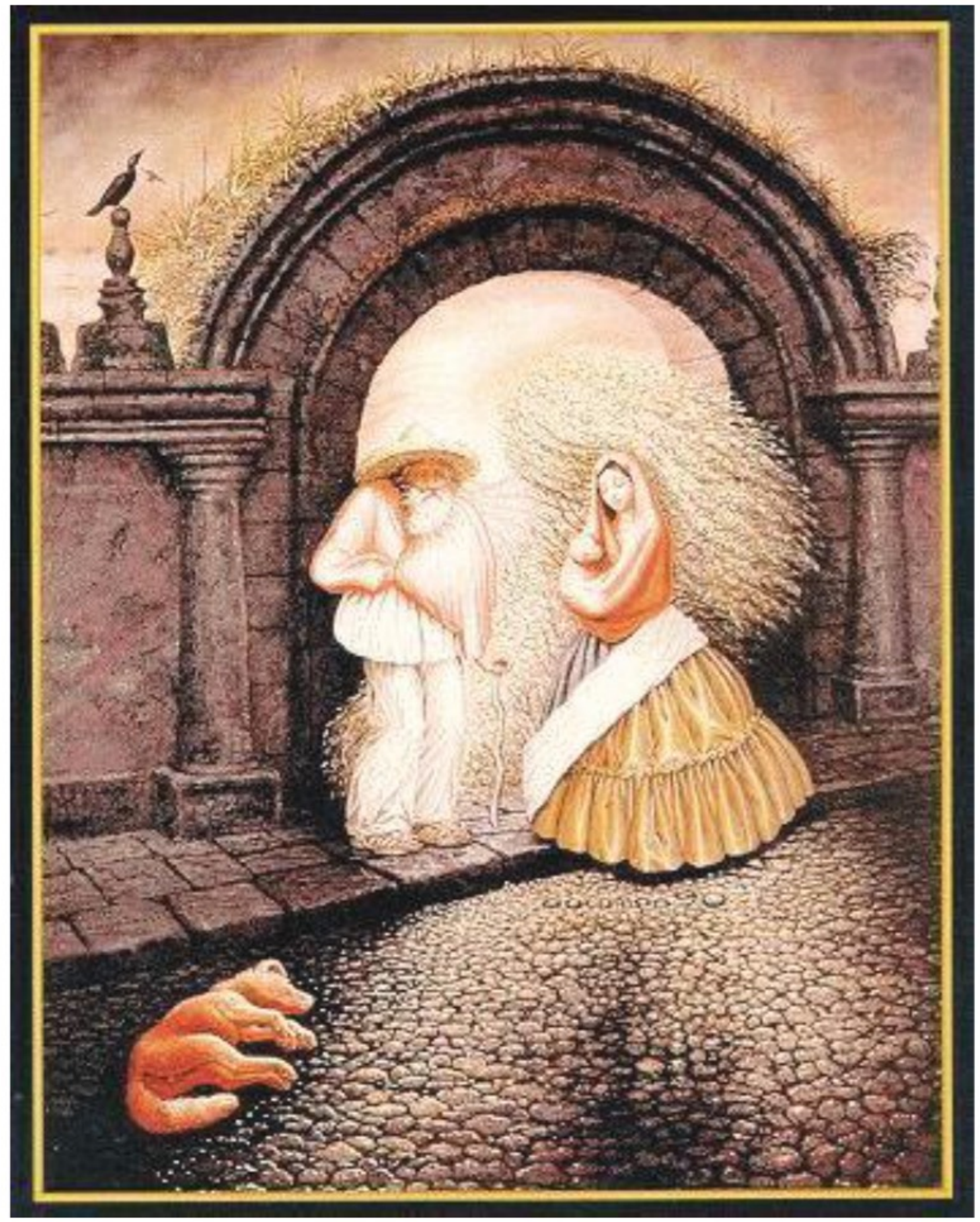


Figure 3.3 (Matthew Ward, et. all)

A more complex illusion: there are two people drawn as part of the face.

The brain makes assumptions !

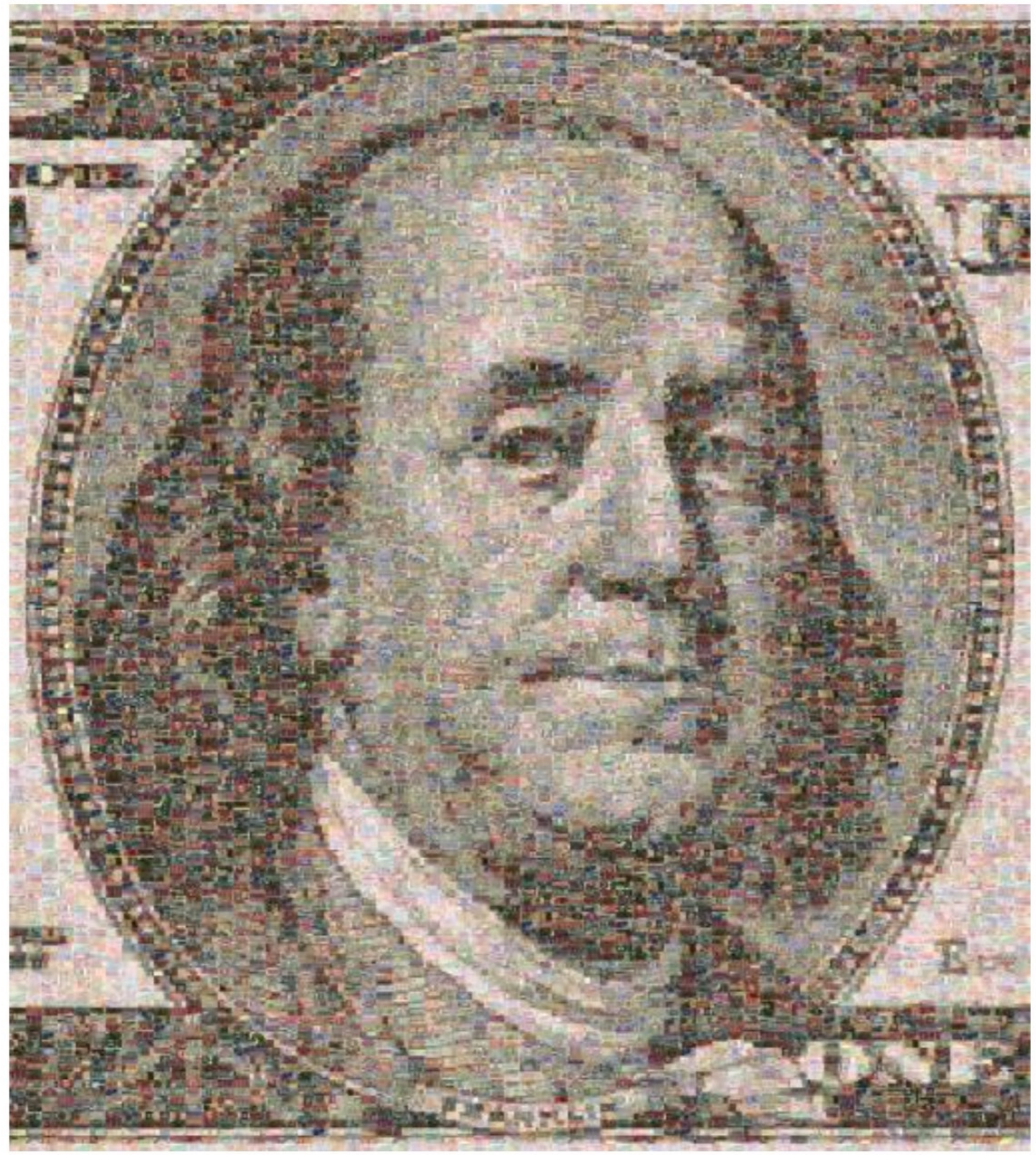


Figure 3.4
(Matthew Ward, et. all)

Photomosaic of Benjamin Franklin using images of international paper money or bank notes. (Photomosaic® by Robert Silvers, http://www.photomosaic.com.)

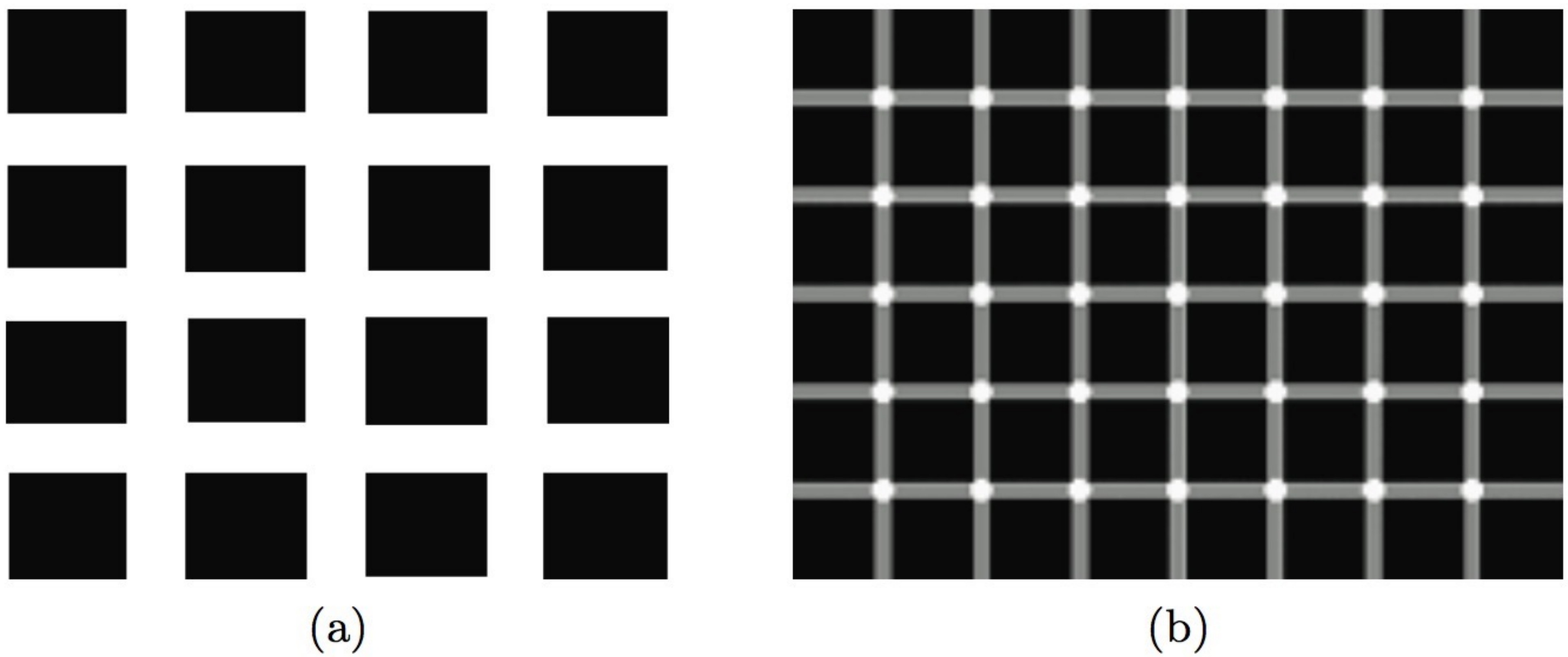
The brain makes assumptions !

Figure 3.5
(Matthew Ward, et. all)

Close-up view of the eye in Figure 3.4. (Photomosaic® by Robert Silvers, http://www.photomosaic.com.)

The brain makes assumptions !

- **Our vision system is, foremost, not static, and secondly, often not under our full control.**



The Hermann grid illusion: (a) illusionary black squares appear over the complete image as you gaze at it; (b) similar to (a) but even more dynamic and engaging.

Figure 3.6 (Matthew Ward, et. all)

The brain makes assumptions !

- **When we visualize data, we need to make sure that no such interferences are present that would impede the understanding of what we are trying to convey in the visualizations.**

The study of perception

- **The study of perception is to identify the whole process of perception, from sensation to knowledge.**

The study of perception

- **The study of perception is to identify the whole process of perception, from sensation to knowledge. What is causing the lines not to appear perfectly straight?**

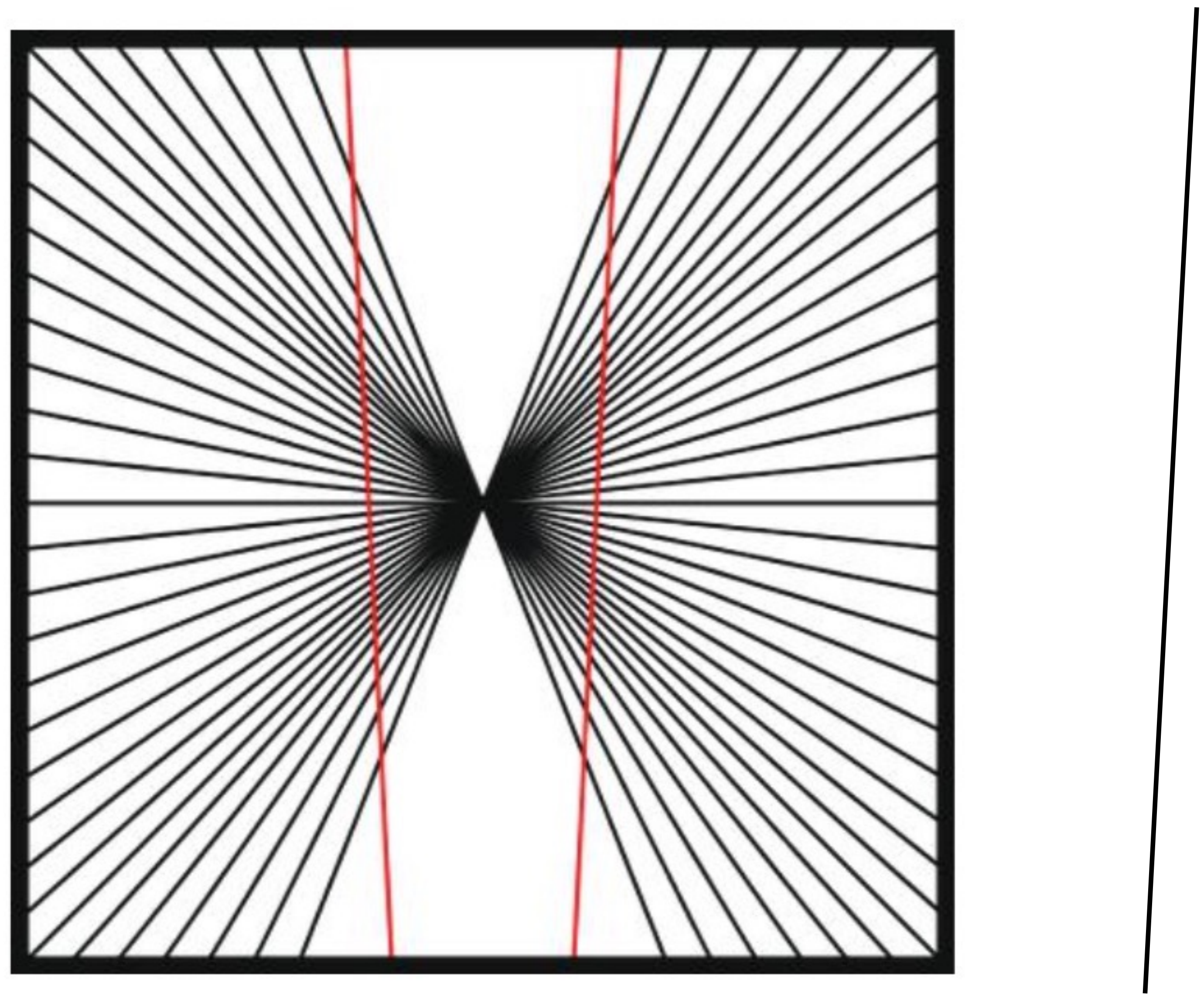


Figure 3.7
(Matthew Ward, et. all)

The study of perception

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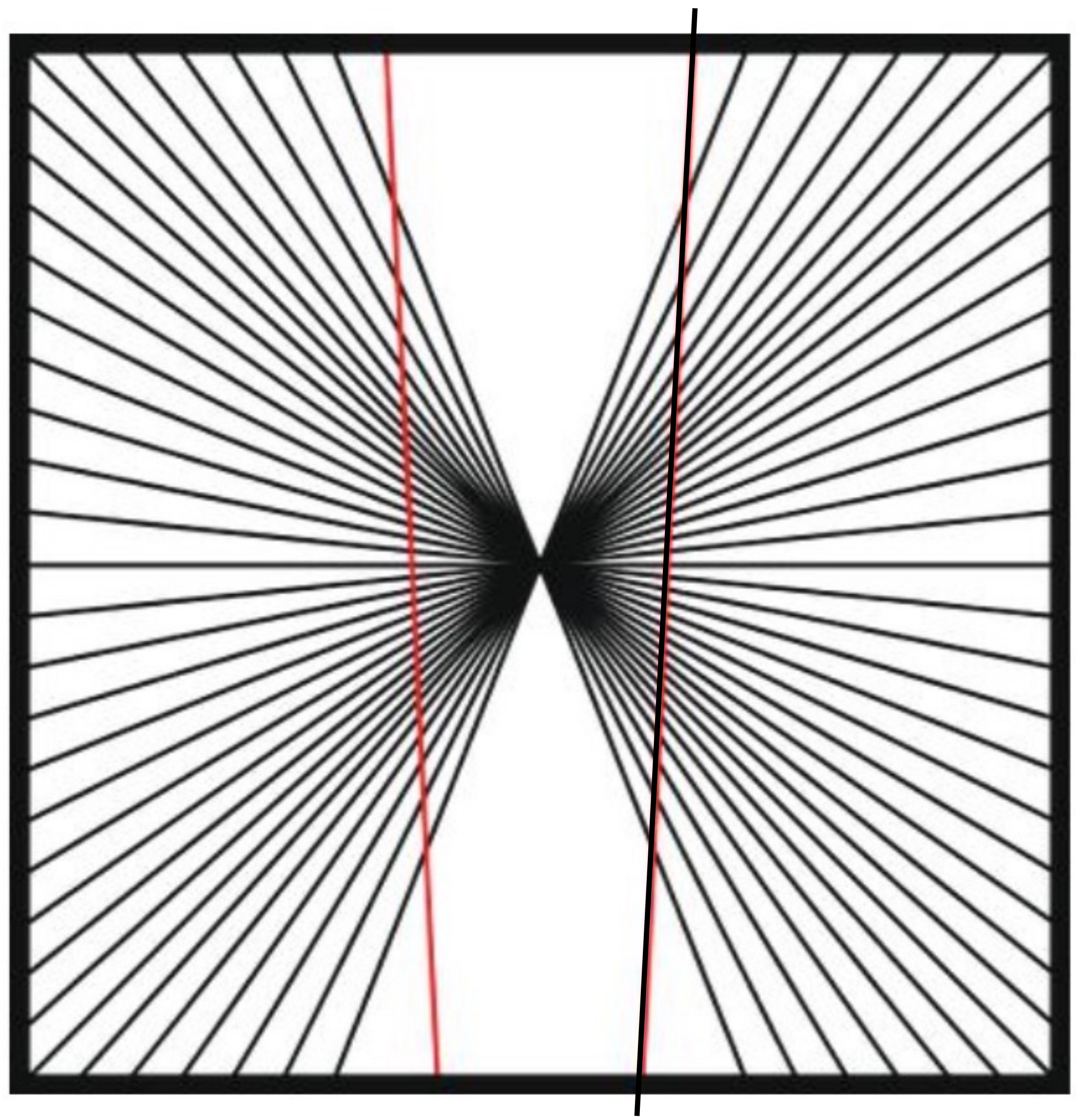


Figure 3.7
(Matthew Ward, et. all)

The study of perception

- **The study of perception is to identify the whole process of perception, from sensation to knowledge. What is causing the triangle to stand out?**

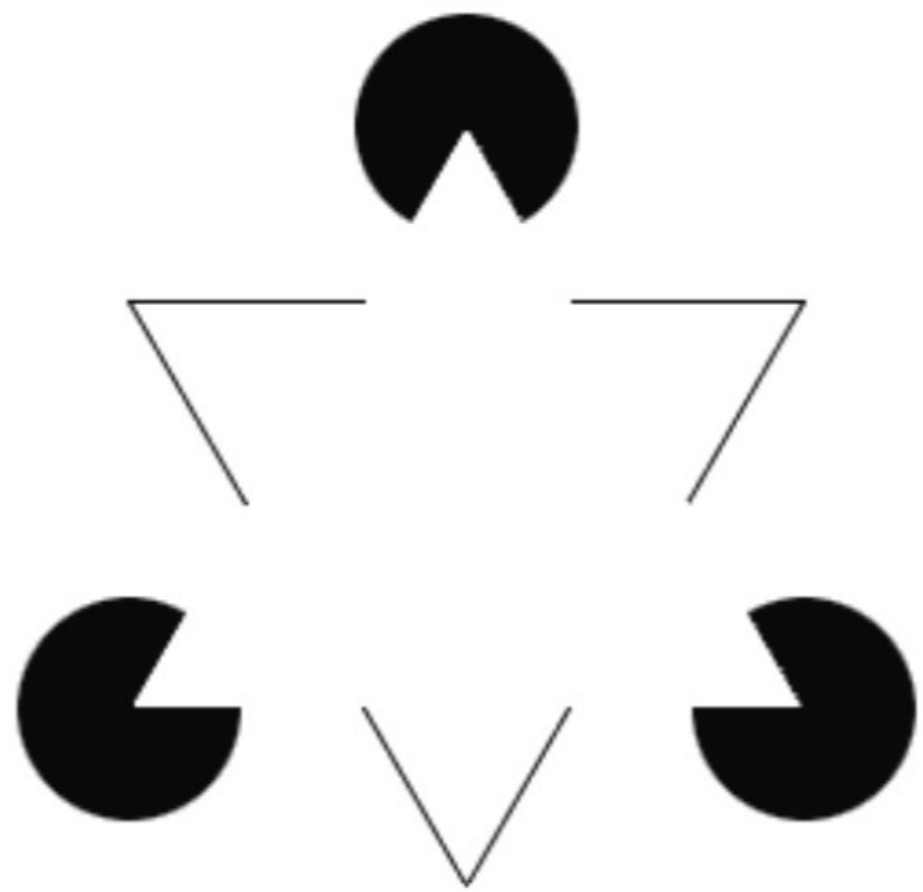


Figure 3.7
(Matthew Ward, et. all)

The study of perception

- **Two main approaches to the study of perception: One deals with measures, and the other with models. Both are linked.**
  - **Measurements can help in the development of a model, and in turn, a model should help predict future outcomes, which can then be measured to validate the model.**
  - **We can measure low-level sensory perception (which line is longer) or higher level perception (can you recognize the bird in this scene?).**

Summary

Q&A

What you should know

- **What is perception.**
  - Process the sensorial information of the world around us, forming a mental representation of the environment
- **The notion that the brain makes a lot of assumption in the process.**
  - Why it seems reasonable and necessary. Examples.
- **The role of measurements and theories in the study of perception.**

Q&A

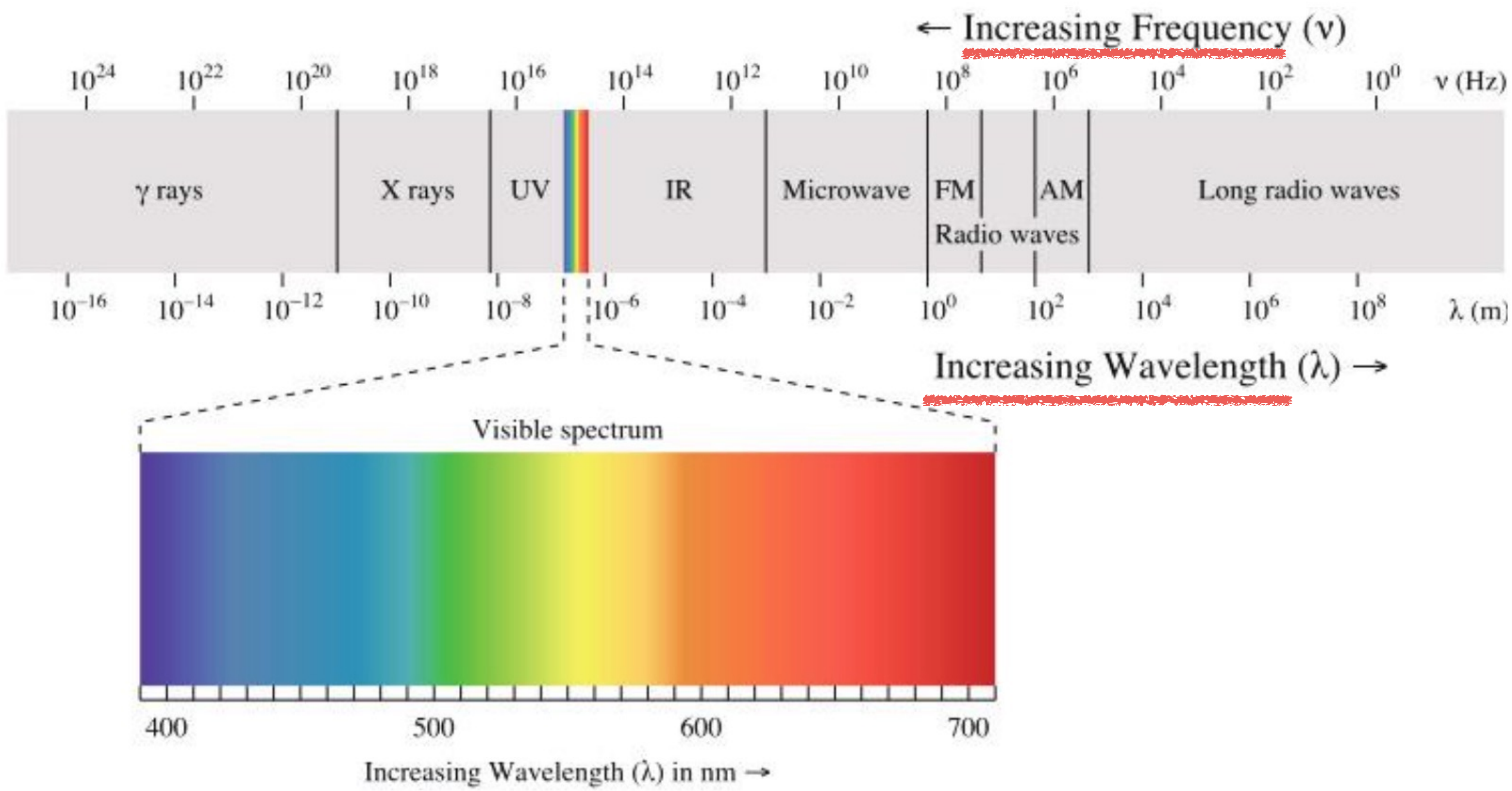
Physiology

Physiology

- **Visible Spectrum**
- **Anatomy of the Visual System**
- **Visual Processing**
- **Eye Movement**

Visible Spectrum

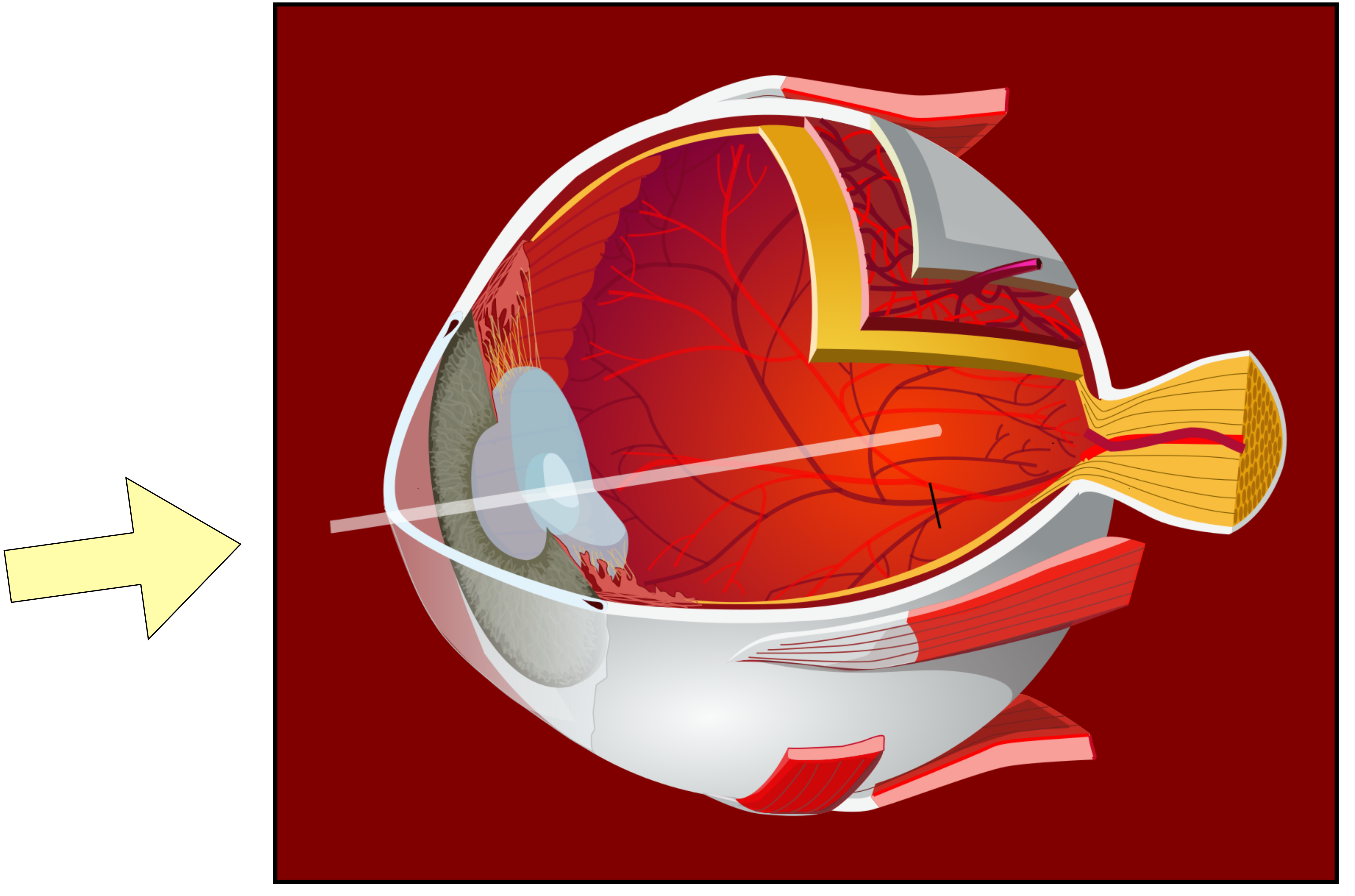
- **The range is very much dependent on the individual.**



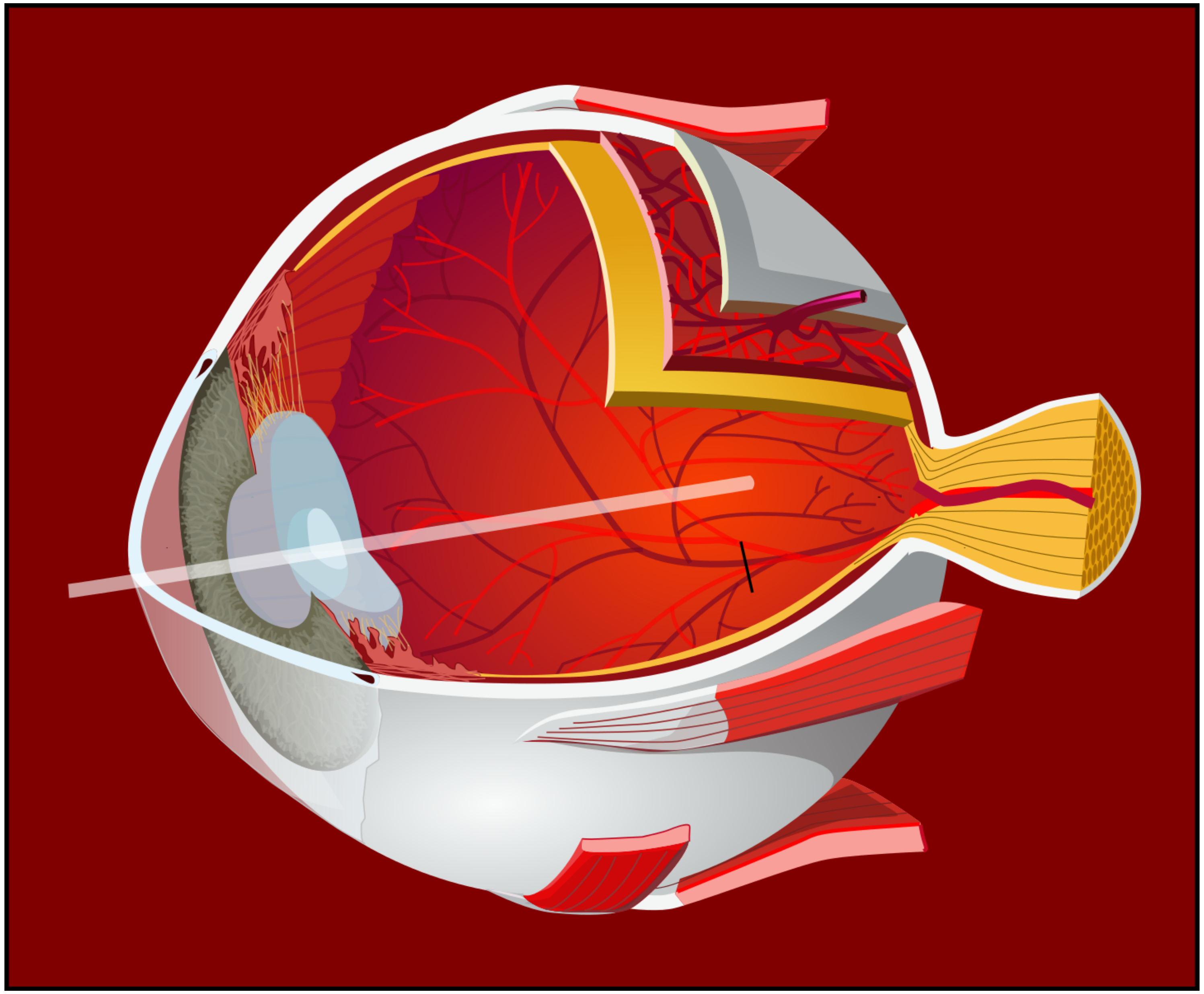
- **Color blindness and total blindness in humans are the result of an individual not responding to certain wavelengths.**

Figure 3.8 - (Matthew Ward, et. all)

Anatomy of the Visual System



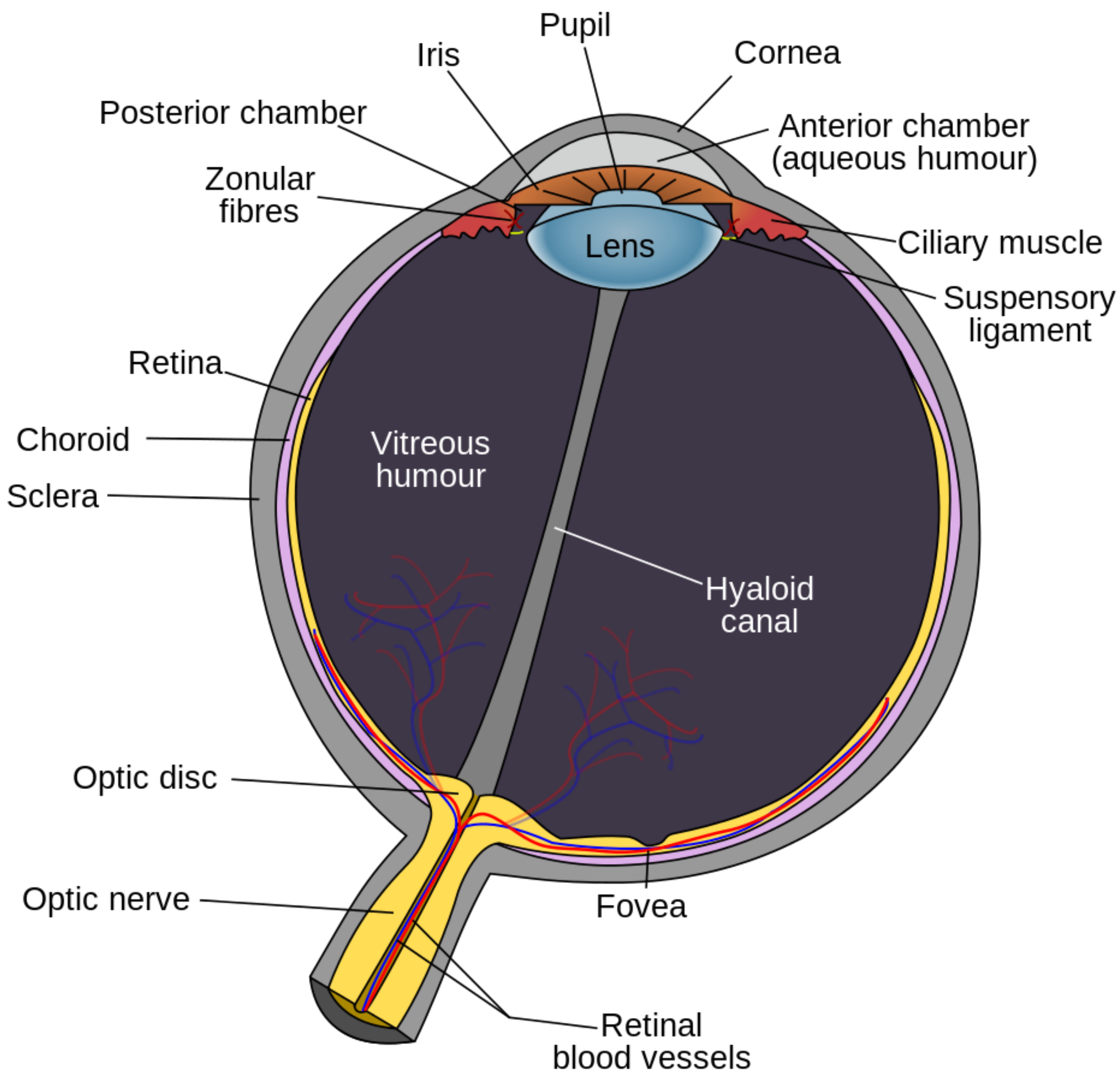
Anatomy of the Visual System



Connected to the head and brain by **six motion control muscles** and **one optic nerve**.

Six muscles are generally considered as motion controllers, providing the **ability to look at objects** in the scene. Tend to maintain the **eye-level with the horizon** when the head is not perfectly vertical and in **stabilization of images**.

Anatomy of the Visual System



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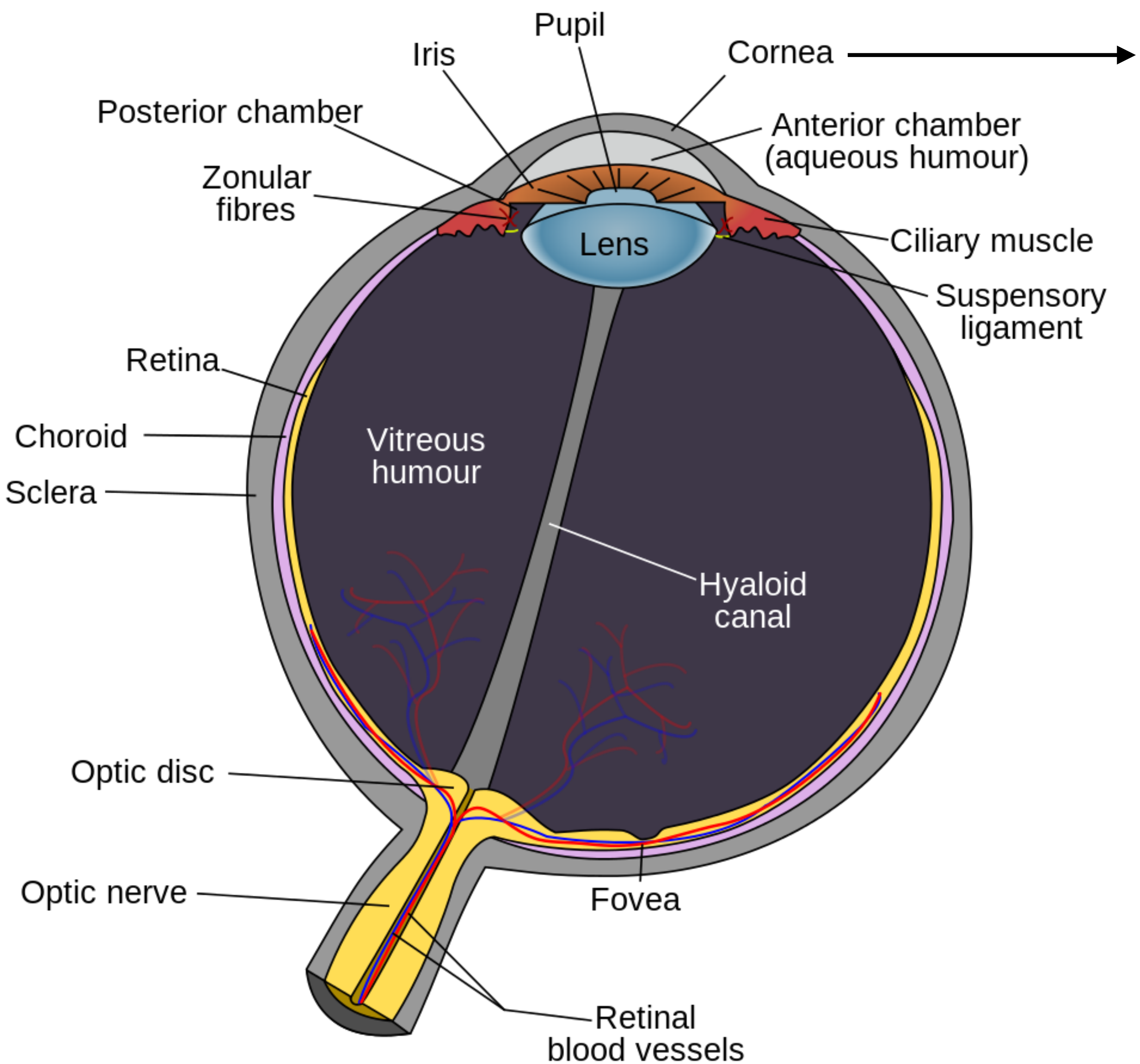
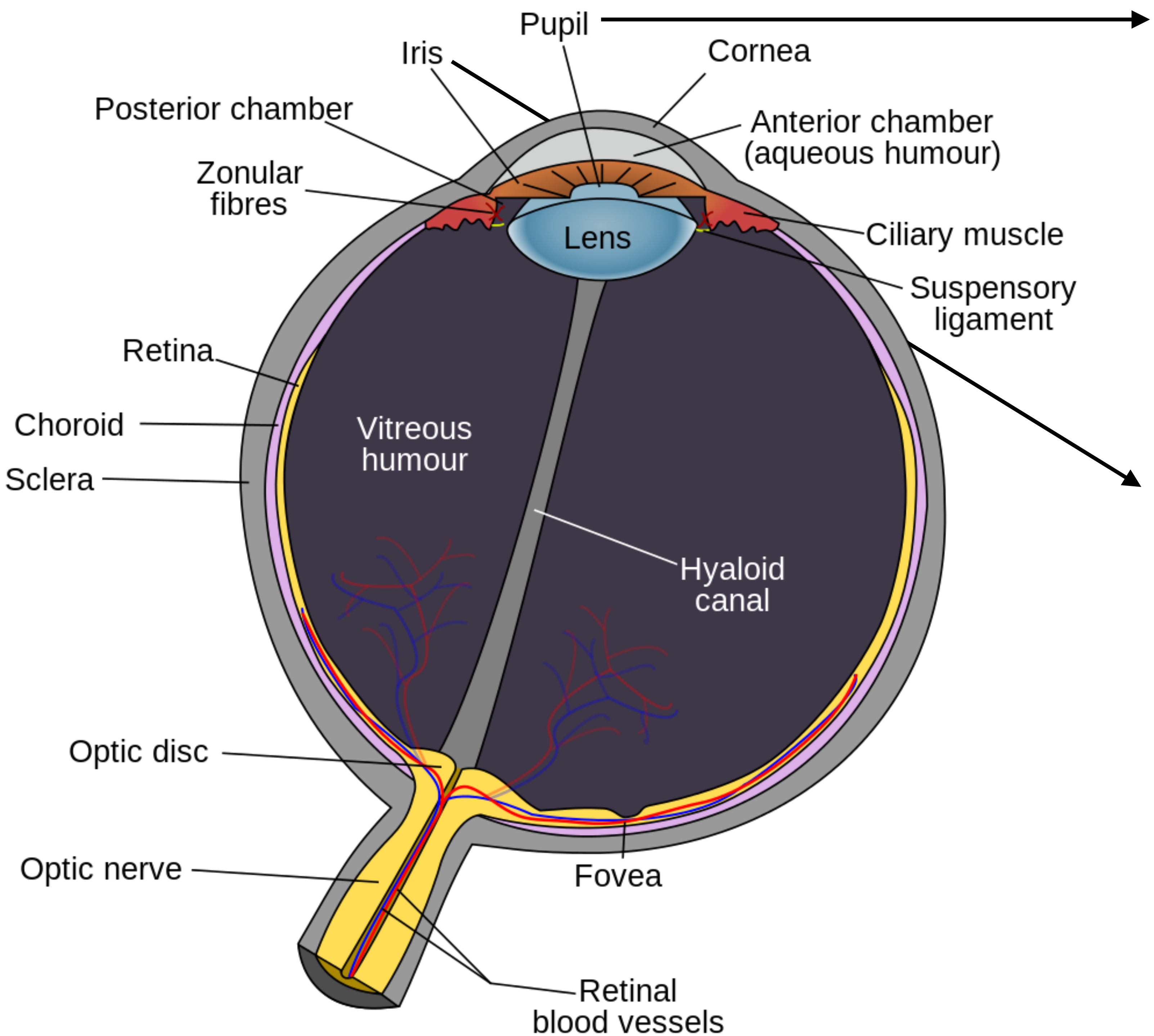
Anatomy of the Visual System



the **exterior cover** of the front of the eye:

- acting as a **protective mechanism** against physical damage to the internal structure
- it also serves as **one lens focusing the light from the surrounding scene** onto the main lens

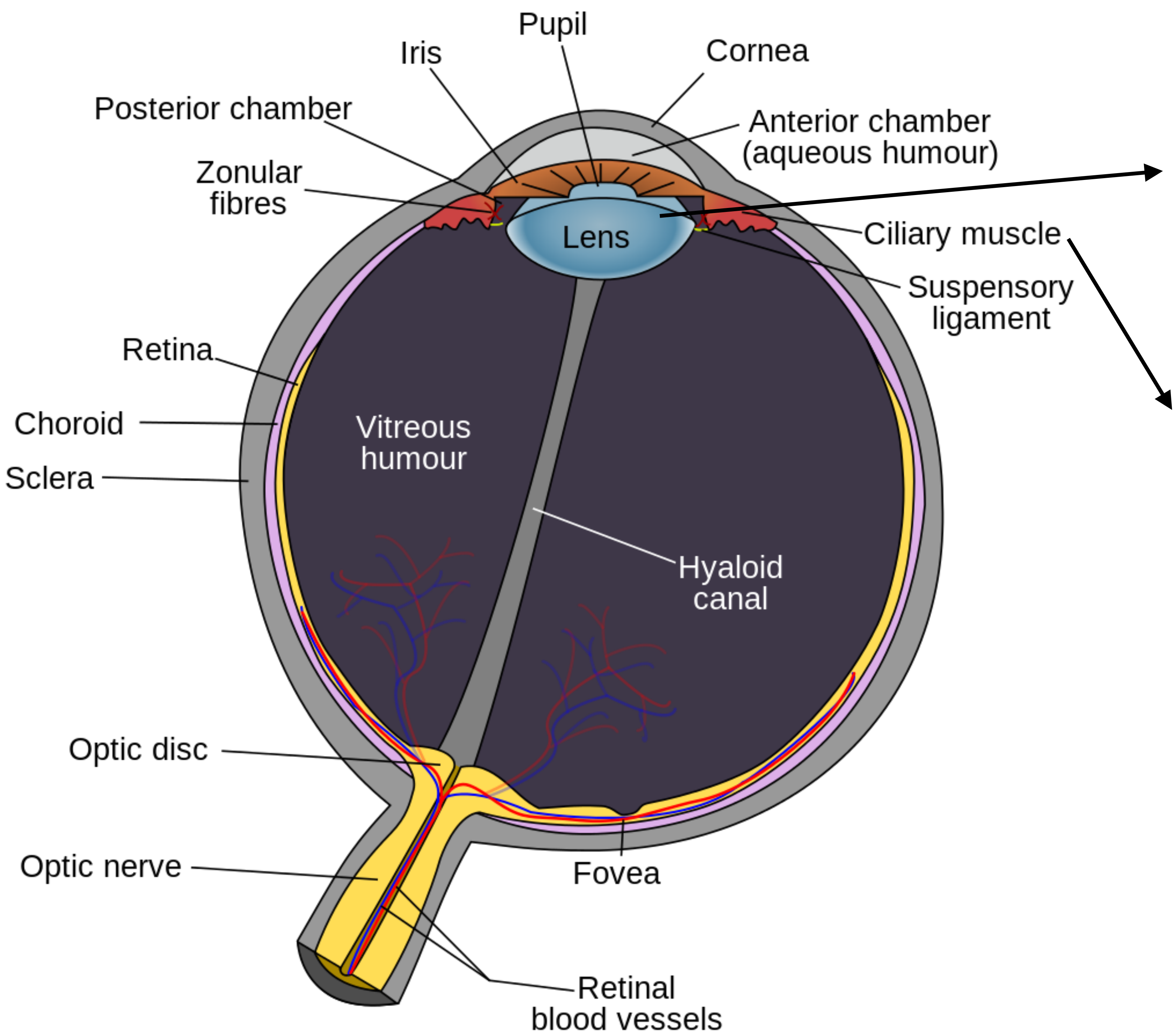
Anatomy of the Visual System



a **circular hole in the iris**, similar in function to an aperture stop on a photographic camera

The **iris** is a colored annulus containing **radial muscles for changing the size of the pupil opening**

Anatomy of the Visual System

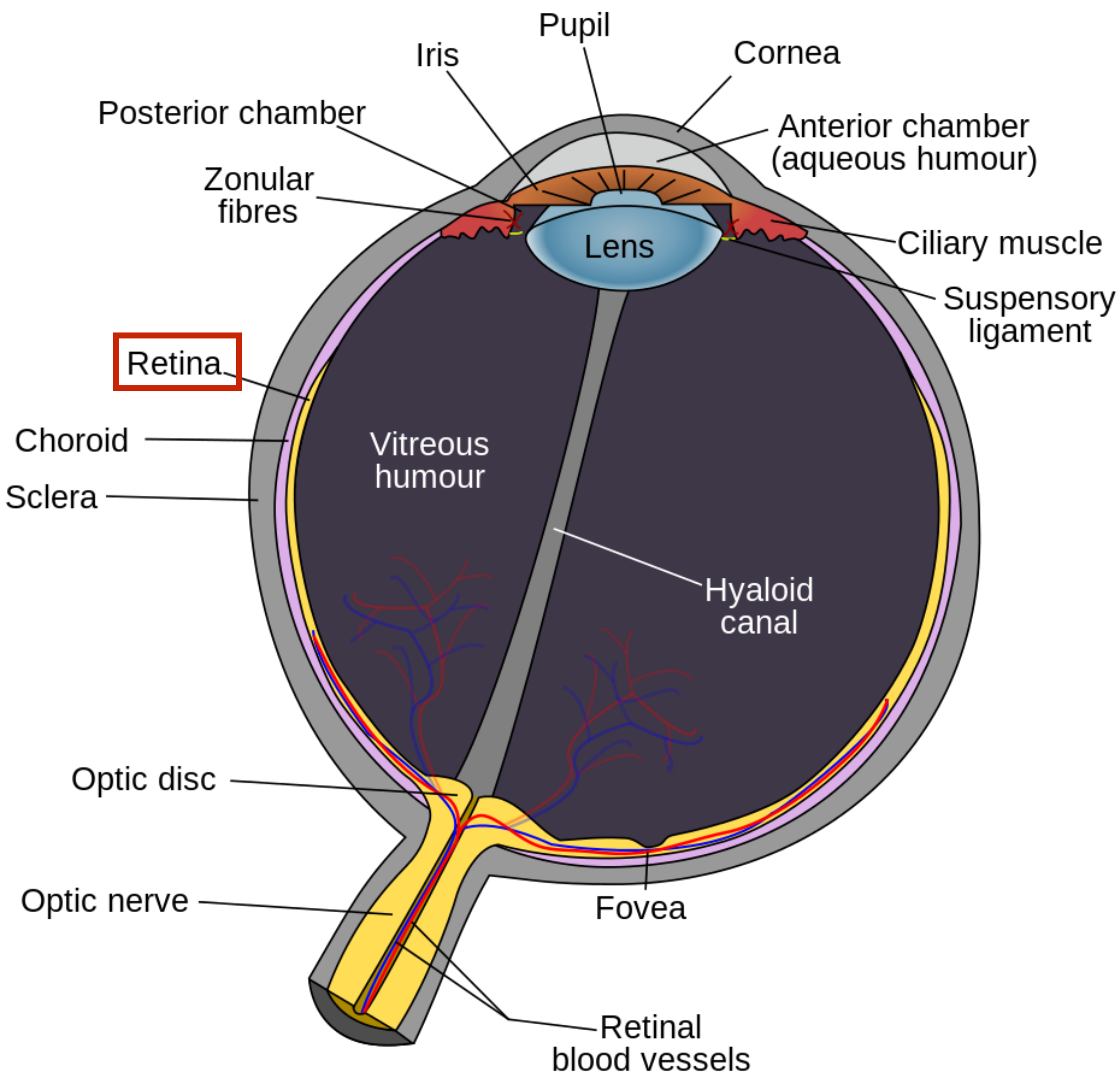


The third major component is the **lens**, whose **crystalline** structure is similar to onion skin.

Surrounded by the **ciliary body, a set of muscles**, the lens can be stretched and compressed, changing the thickness and curvature of the lens and consequently **adjusting the focal length of the optical system**.

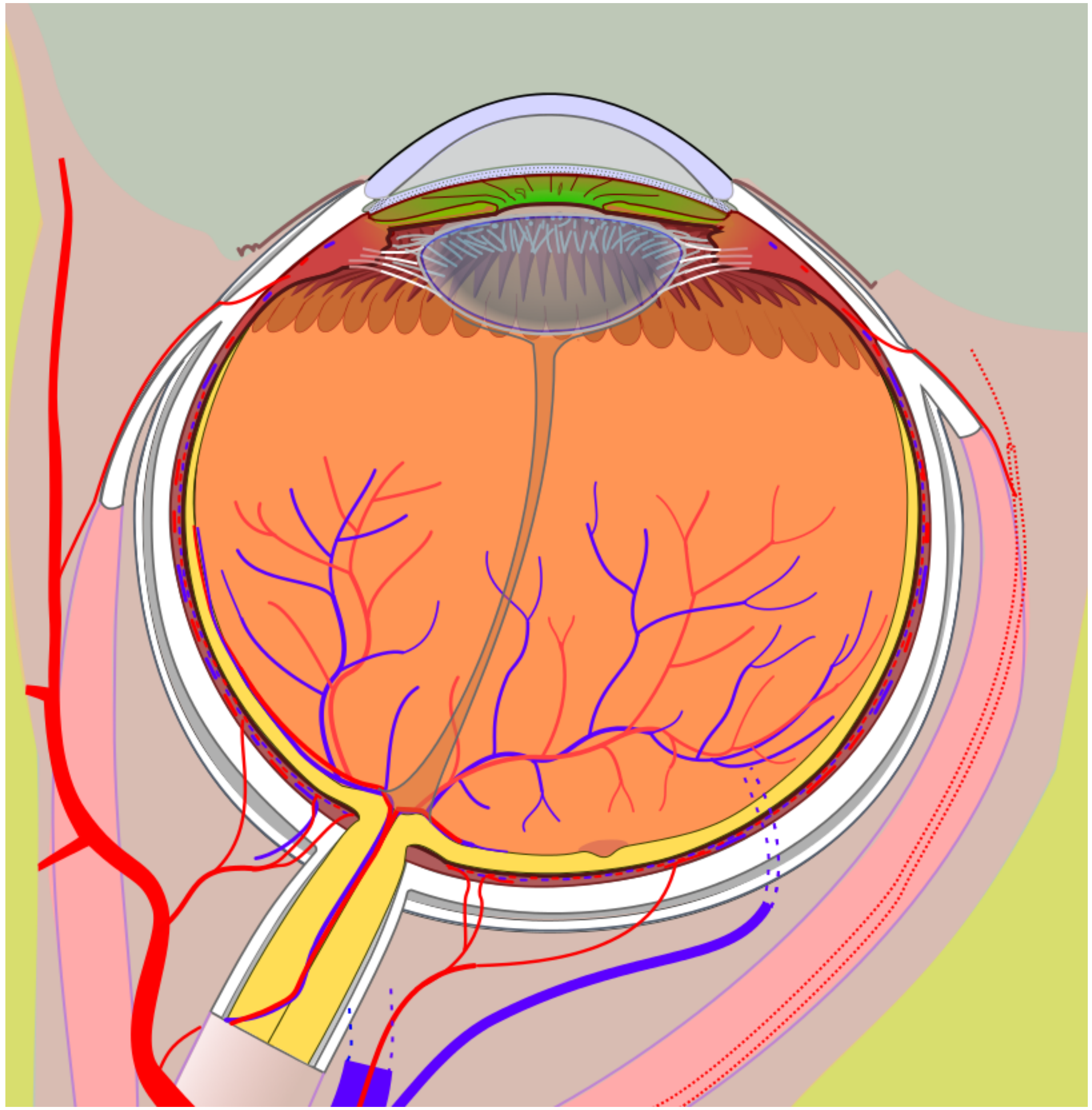
The **elasticity of the lens** determines the range of shape changes possible, which **is lost as one ages**, leaving the lens in a slightly stretched state

Anatomy of the Visual System



Once the light has passed through this lens system, the final light rays are projected onto the **photoreceptive layer**, called the **retina**.

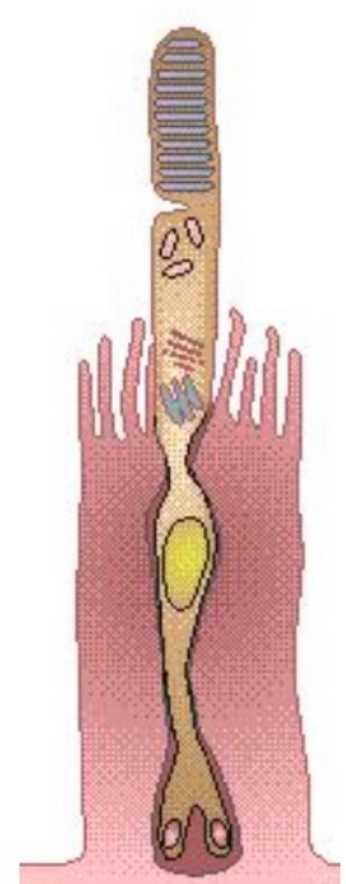
Anatomy of the Visual System: Retina



Anatomy of the Visual System: Retina

- **Two types of photosensitive cells: rods and cones**
  - **Rods are primarily responsible for intensity perception. They are associated with scotopic vision, night vision, operating in clusters for increased sensitivity in very low light conditions.**

Rods

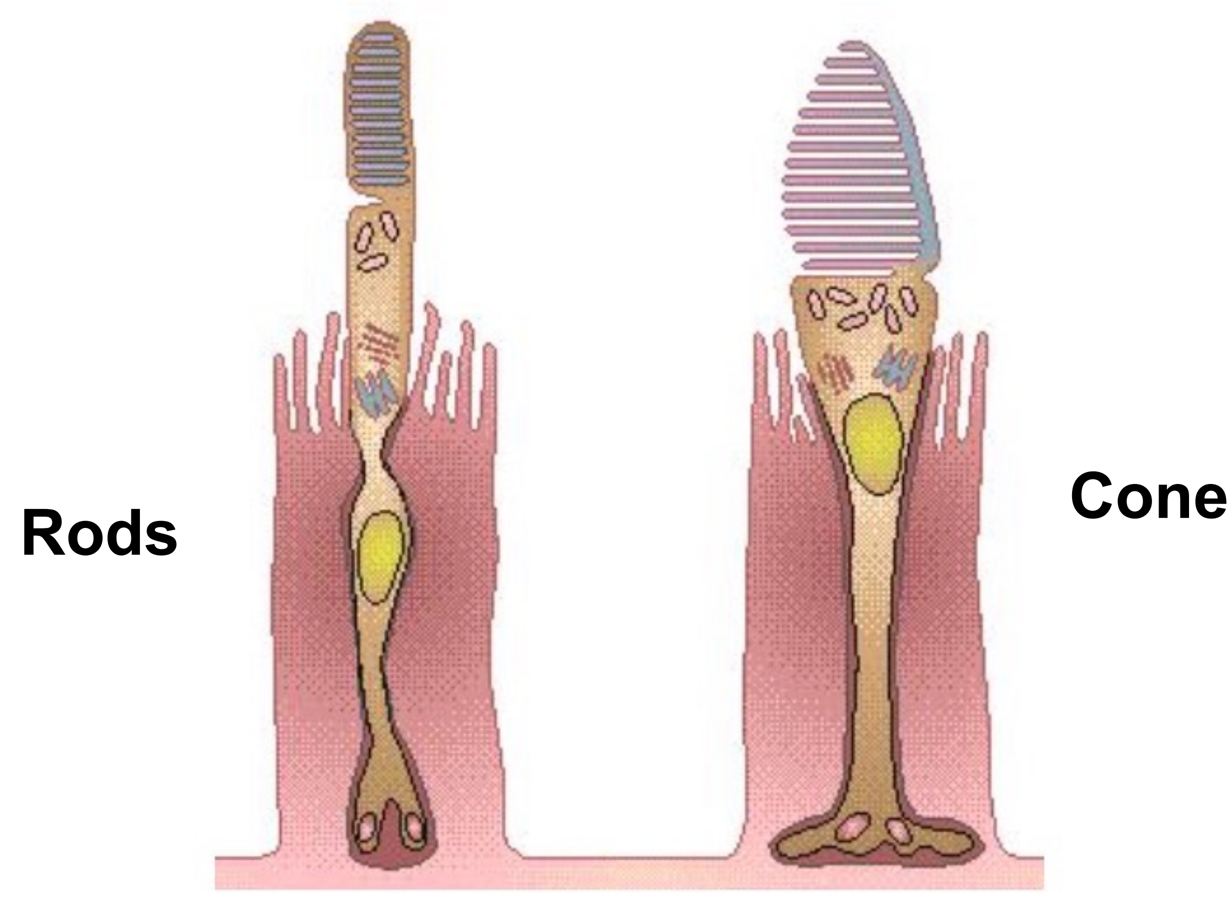


Human rod (left) and cone (right).

Anatomy of the Visual System: Retina

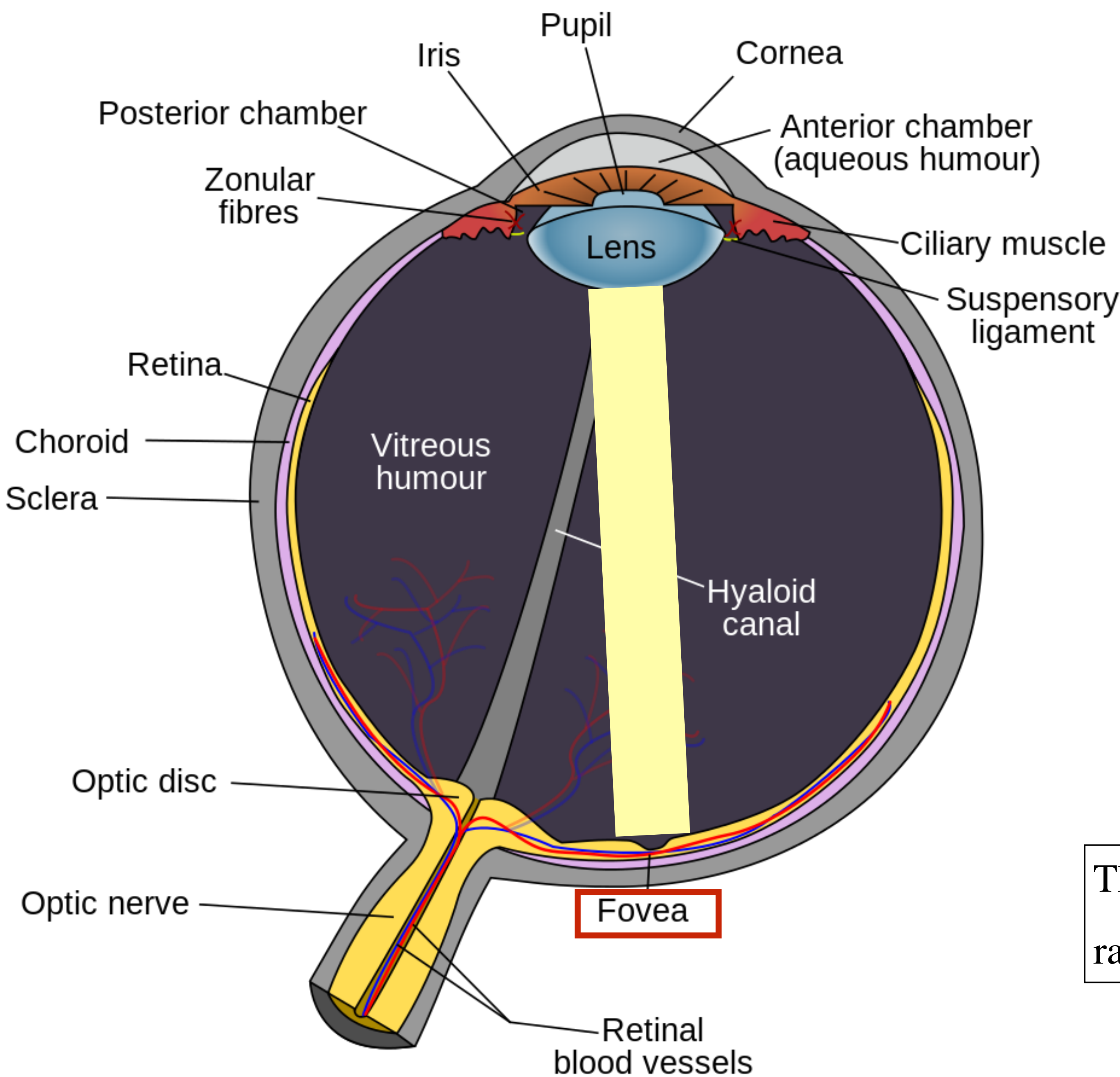
- **Two types of photosensitive cells: rods and cones**
  - **Rods are primarily responsible for intensity perception. They are associated with scotopic vision, night vision, operating in clusters for increased sensitivity in very low light conditions.**
  - **Cones for color perception**

- **Rods are typically ten times more sensitive to light than cones**



Human rod (left) and cone (right). (Image © Colour4Free.)

Anatomy of the Visual System: Retina



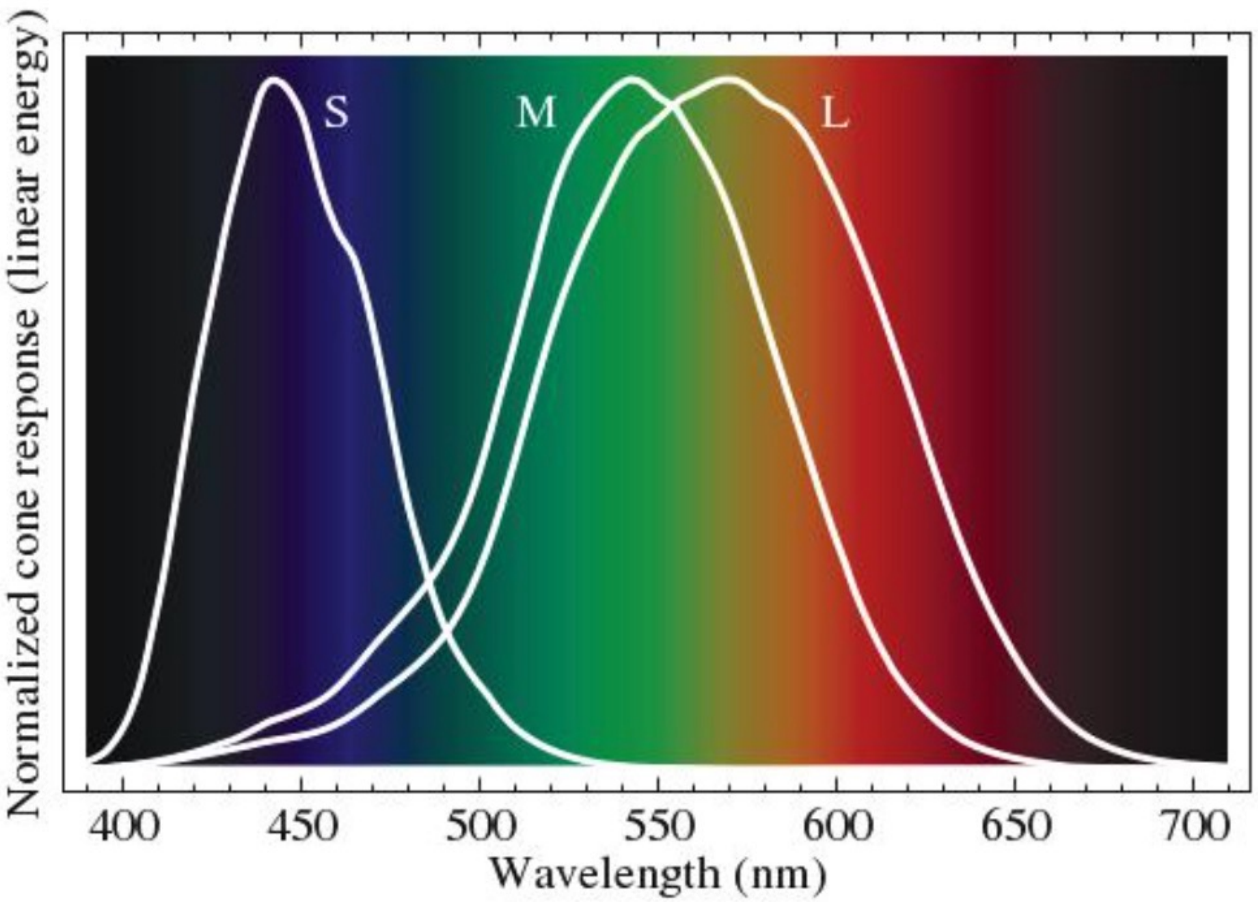
The structure of the retina is roughly radially symmetric around the **fovea**.

Anatomy of the Visual System: Retina - Rods

- **Rods are the most sensitive type of photoreceptor cells available in the retina.**
- **As these cells are thought to be achromatic, we tend to see objects at night in shades of gray.**
- **Rods do operate, within the visible spectrum between approximately 400 and 700 nm.**
- **It has been noted that during daylight levels of illumination, rods become hyper-polarized, or completely saturated, and thus do not contribute to vision.**

Anatomy of the Visual System: Retina - Cones

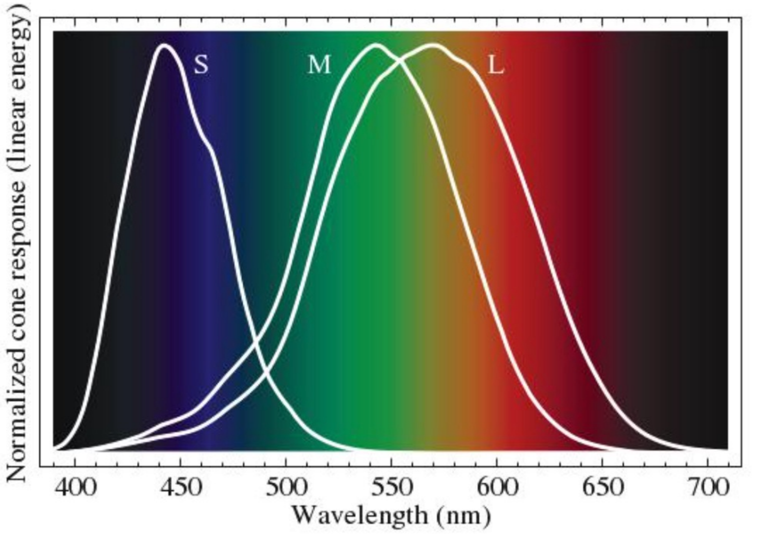
- **Cones provide photopic vision, i.e., are responsible for day vision.**
- **There are three types of cones in the human eye: S (short), M (medium), and L (long) wavelengths.**
- **The three types have been associated with color combinations using R (red), G (green), and B (blue).**



Anatomy of the Visual System: Retina - Cones

- **Three types of cones: S (short), M (medium), and L (long) wavelengths.**
  - **There are considerably fewer S cones, compared to the number of M and L cones**
  - **Humans can visually perceive all the colors within the standard visible spectrum**
- **Cones are not sensitive over a large fixed wavelength range but rather over a small moving-window-based range.**

  Cones tend to adapt to the average wavelength where there is sensitivity above and below their peaks, and a shift in their response curve occurs when the average background wavelength changes.



Anatomy of the Visual System: blind spot

- **Where the optic nerve meets the retina, a blind spot occurs, due to the lack of photoreceptive cells**

Blind spot discovery by identifying disappearance of target.

Figure 3.12 - (Matthew Ward, et. all)

Visual system

- **Because the human eye contains a limited number of rods and cones (about 120 million rods and 6 million cones), it can only manage a certain amount of visual information over a given time frame.**
- **The optic nerve only contains about one million fibers; thus the eye must perform a significant amount of visual processing before transmitting information to the brain.**
- **Additionally, the information transferred from these two types of cells is not equivalent. The eye contains separate systems for encoding spatial properties (e.g., size, location, and orientation), and object properties (e.g., color, shape, and texture).**

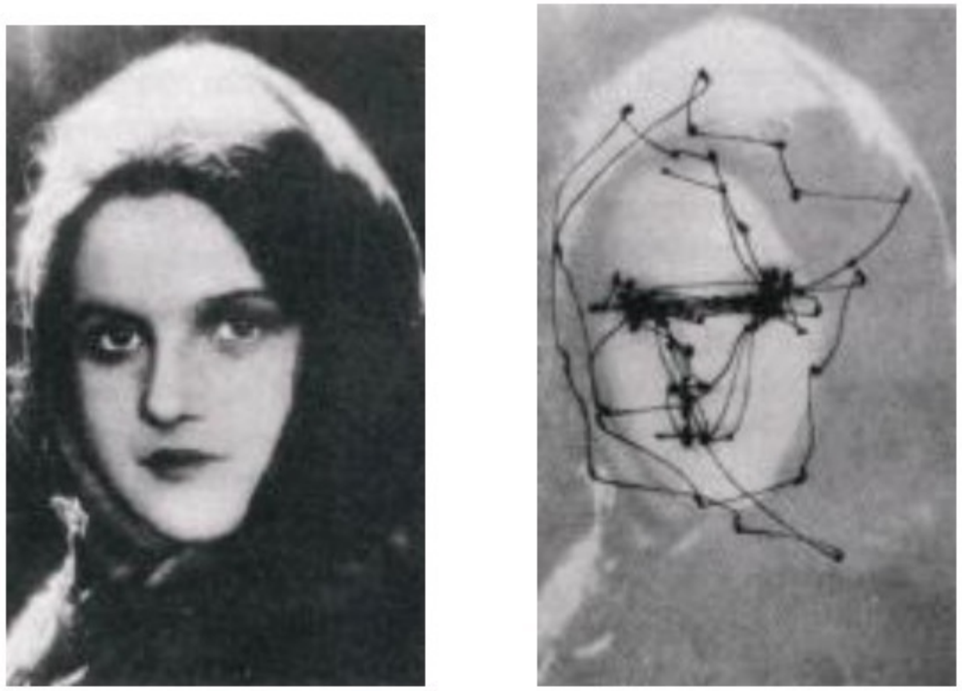
Figure 3.8 - (Matthew Ward, et. all)

Eye Movement

- **There are a variety of eye movements performed for scene interpretation:**
- **Smooth pursuit movements: the eyes move smoothly instead of in jumps.**
  - **The angles from the normal to the face are equal (left and right as well as up and down).**
  - **For example, to make a pursuit movement, look at your forefinger at arms' length and then move your arm left and right while fixating on your fingertip.**
- **Vergence eye movements: moving a finger closer to the face and staring at it will force the eyes inward, resulting in vergence movement. Defocusing to merge depths in illusions is another example.**

Eye Movement

- **Saccadic eye movements: these result from multiple targets of interest (not necessarily conscious).**
- **The eye moves as much as 1000 degrees per second, bringing the gaze on those targets within 25 msec.**
  - **It holds its position once on target.**
  - **Selected targets are determined in the frontal part of the cerebral cortex.**
  - **The selection is discriminatory, dependent on a variety of parameters, and somewhat random.**



(a) (b)

(a) The face used to study eye tracking. (b) The results of the tracking gaze.

Figure 3.15 - (Matthew Ward, et. all)

Eye Movement

- **Saccadic masking** or suppression occurs during two states between saccadic views.
  - The gap produced is ignored (some say blocked).
  - A continuous flow of information is interpreted, one that makes sense.
  - The higher-level visual system filters out the blurred images acquired by the low-level one, and only the two saccadic stop views are seen.

Summary

Q&A

What you should know

- **The visible spectrum, its composition the relation with color and many forms of blindness.**
- **The eye main components and their role in the human vision system**
  - The motion control muscles; cornea, pupil, iris and the crystalline;
  - Retina: Rods and cones; the differences, the roles, the placement, the relative quantities.
- **The eye main components and their role in the human vision system**
  - The optical nerve
  - The information compression from optical system to the brain
- **What is the blind spot. How to detect.**
- **Type of eye movements**

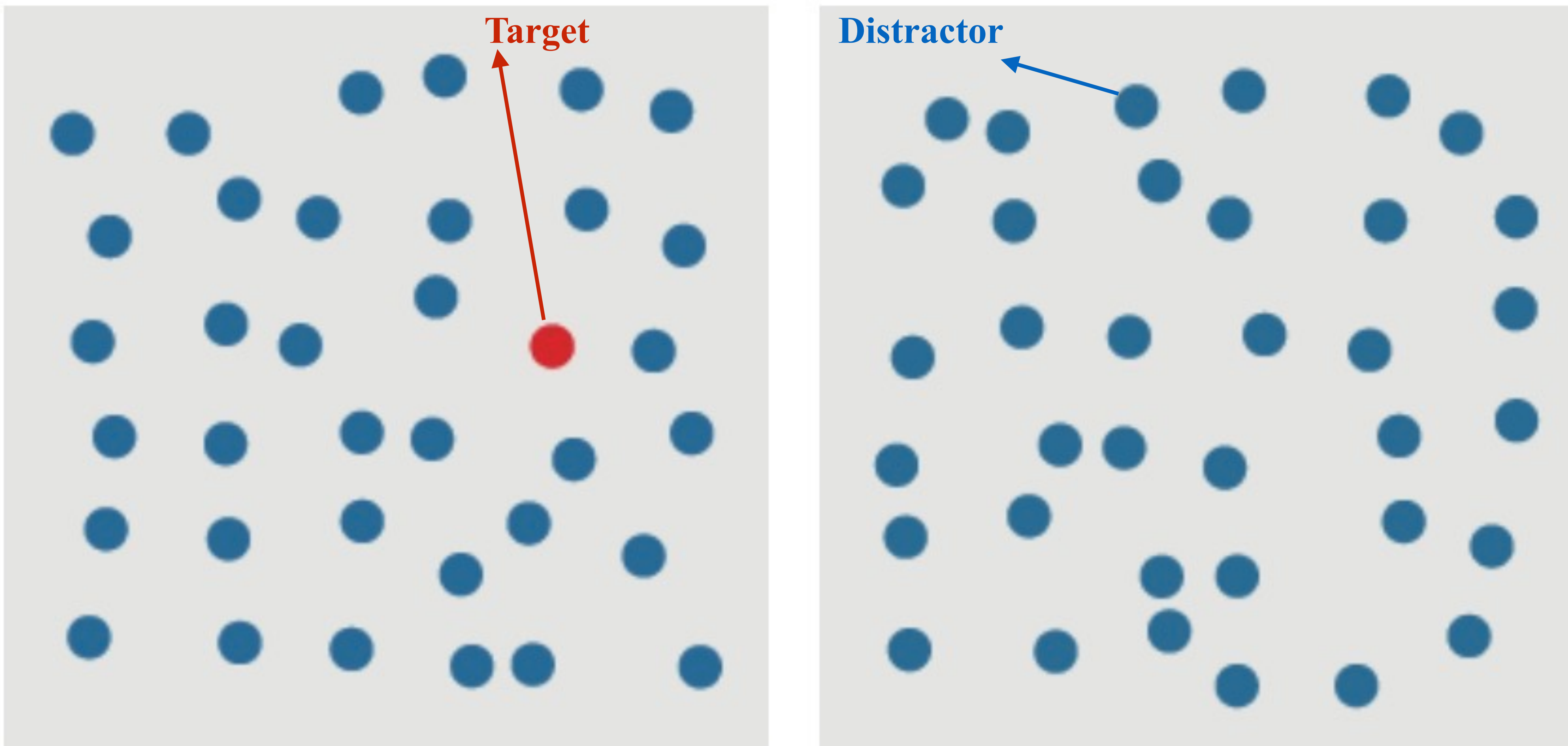
Q&A

Perceptual Processing

Perceptual Processing

- **Preattentive Processing**
- **Theories of Preattentive Processing**
- **Change Blindness**

"Preattentive" properties



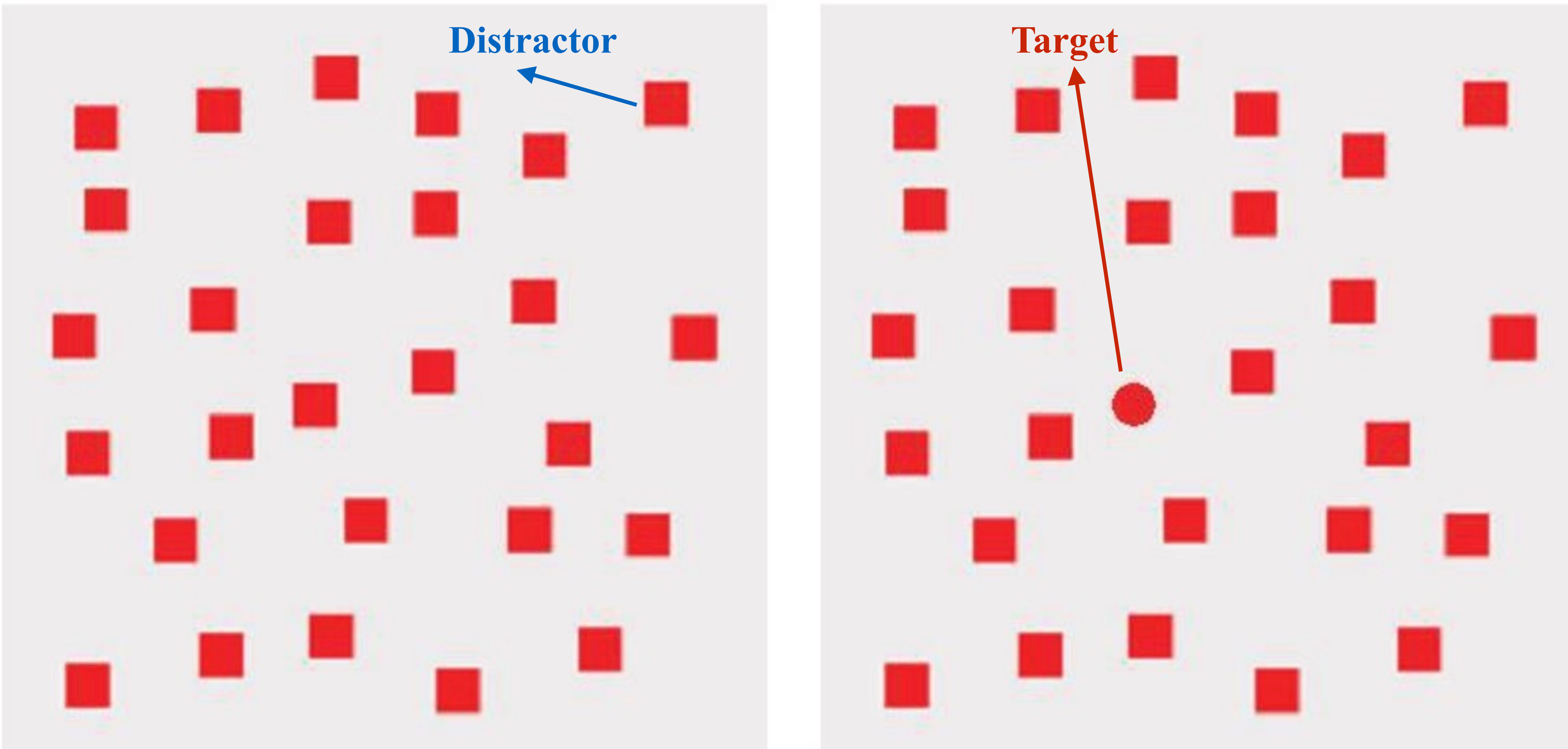
(a) Target is present in a sea of blue circle distractors.

(b) Target is absent.

An example of searching for a target red circle based on a difference in hue.

Figure 3.18 - (Matthew Ward, et. all)

“Preattentive” properties



(a) Target is absent in a sea of red square distractors.

(b) Target is present.

An example of searching for a target red circle based on a difference in curvature.

Figure 3.19 - (Matthew Ward, et. all)

Perceptual Processing: “preattentive” properties

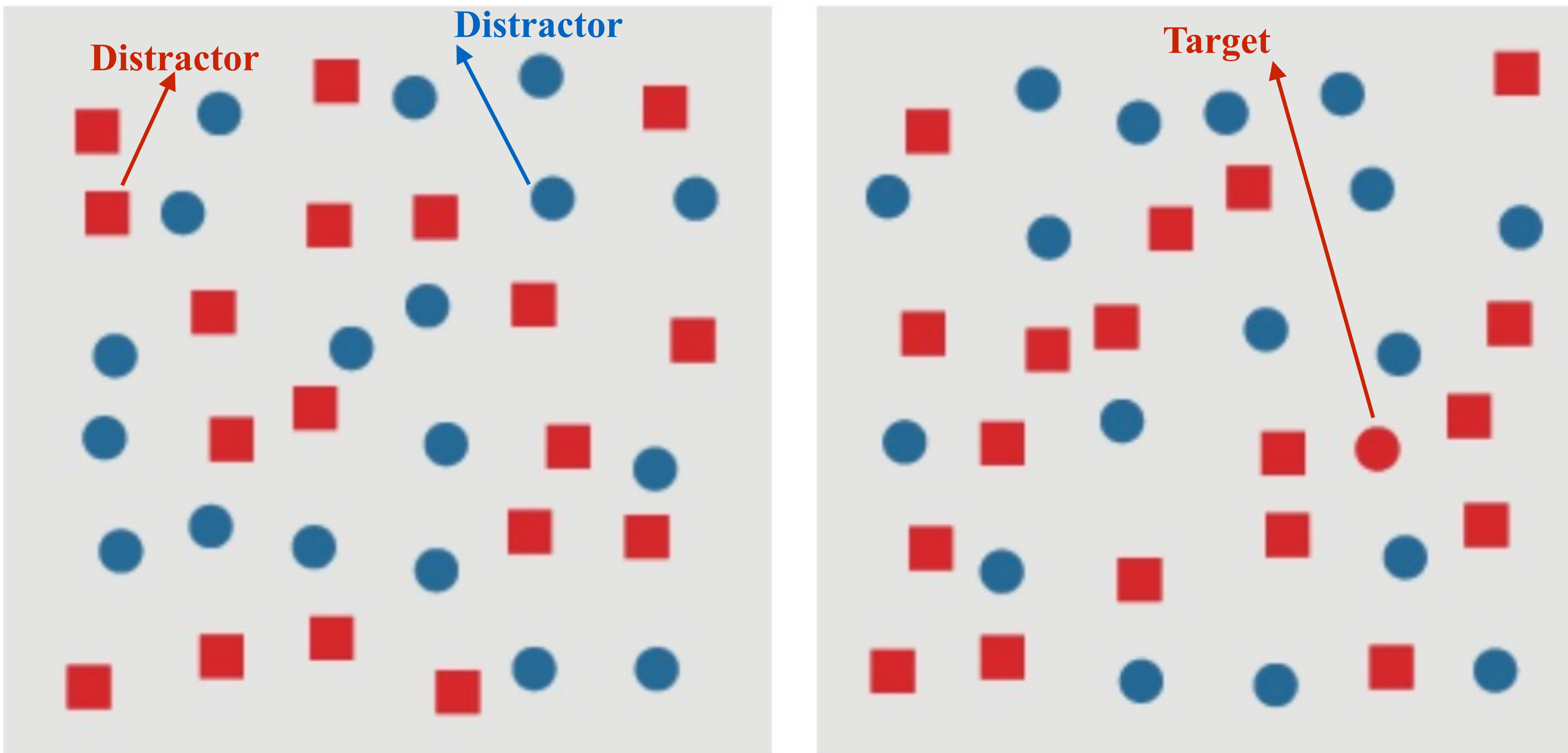
- A limited **set of visual properties** that are **detected very rapidly and accurately** by the **low-level visual system.** These properties were initially called **preattentive**, since their detection seemed to precede focused attention.
  - We now know that **attention plays a critical role** in what we see, even at this early stage of vision.
  - Typically, tasks that can be performed on large multi-element displays in **less than 200 to 250 milliseconds** are considered preattentive.
  - This suggests that **certain information** in the display is **processed in parallel** by the **low-level visual system**.

“Preattentive” properties

An example of a conjunction search for a target red circle.

Figure 3.20 - (Matthew Ward, et. all)

"Preattentive" properties



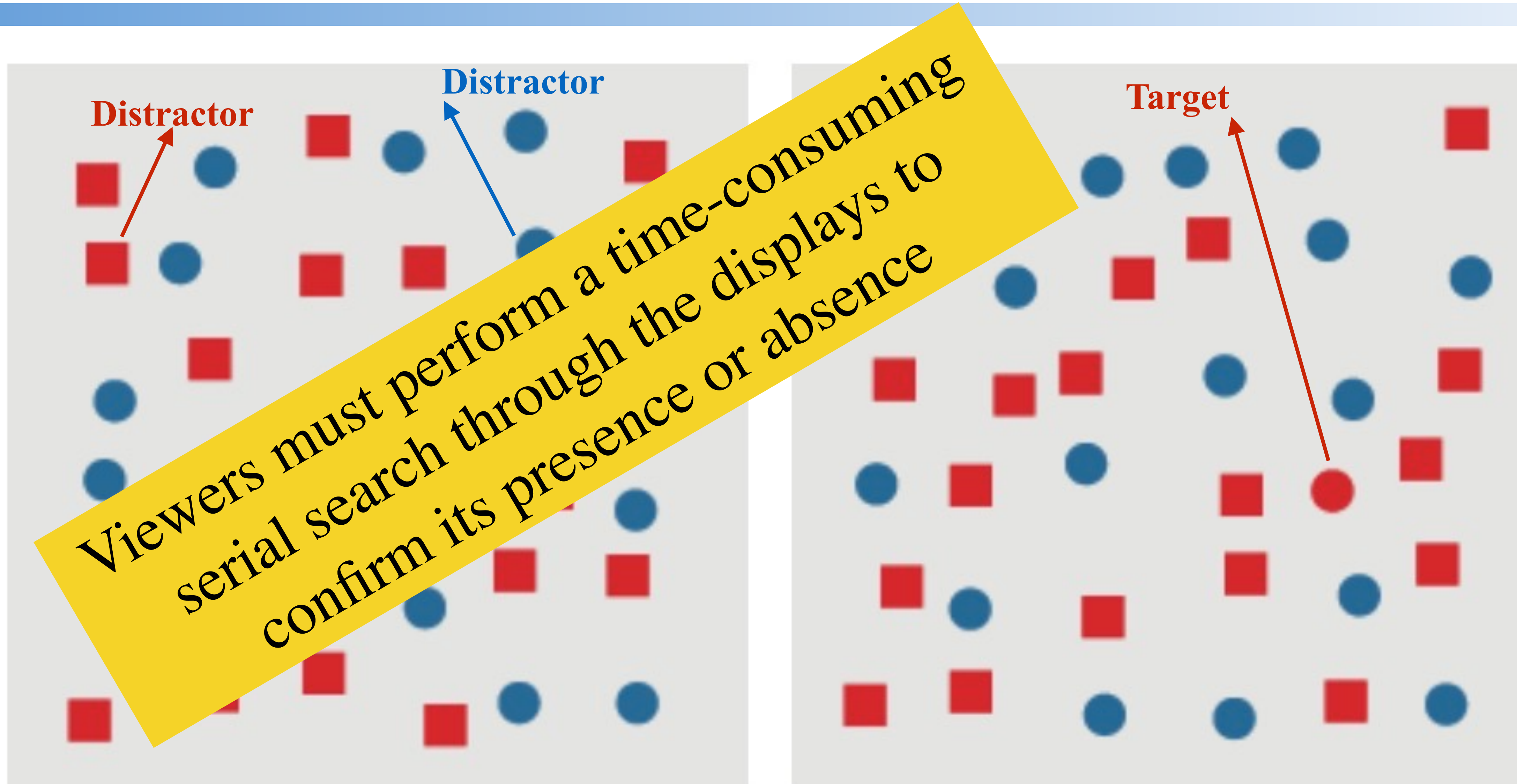
(a) Target is absent in a sea of red square and blue circle distractors.

(b) Target is present.

An example of a conjunction search for a target red circle.

Figure 3.20 - (Matthew Ward, et. all)

“Preattentive” properties



(a) Target is absent in a sea of red square and blue circle distractors.

(b) Target is present.

An example of a conjunction search for a target red circle.

Figure 3.20 - (Matthew Ward, et. all)

“Preattentive” properties

- A **unique visual property** in the target (e.g., a red hue or curved form) allows it to **“pop out”** of a display.

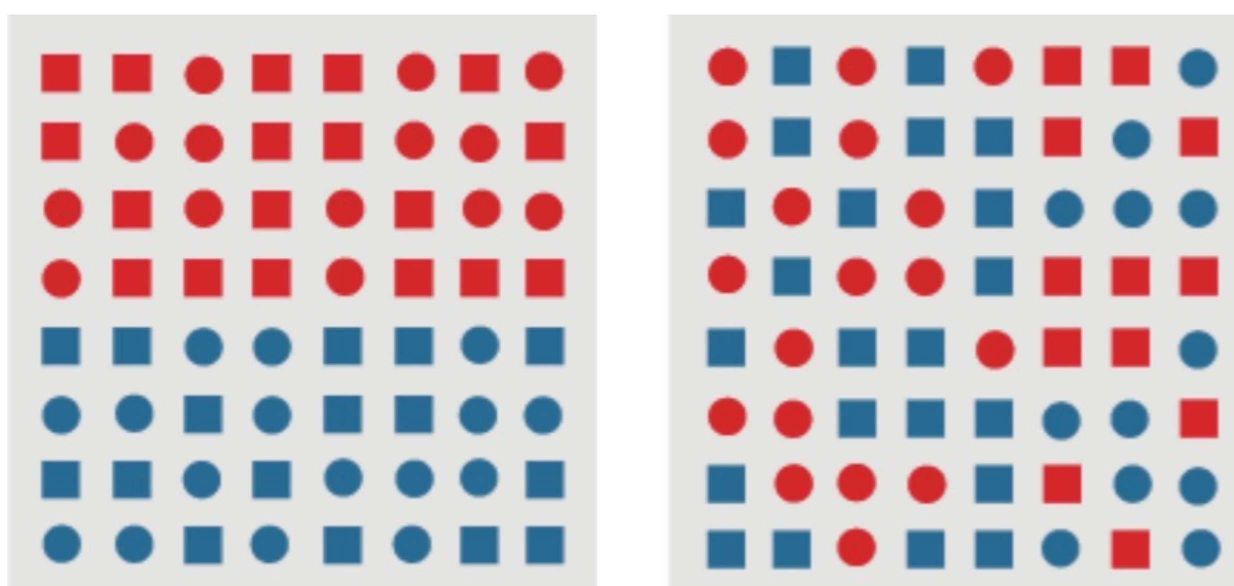
- A target made up of a **combination of non-unique features** (a **conjunction target**) normally cannot be detected preattentively.
  - A **red circle target** is made up of two features: **red** and **circular**.
  - One of these features is present in each of the **distractor** objects (**red squares** and **blue circles**).
  - The visual system has no unique visual property to search for when trying to locate the target. If a viewer searches for red items, the visual system always returns true. Similarly, a search for circular items always sees blue circles.

“Preattentive” properties

- **Visual features that have been identified as preattentive:**
  - **length, width, size, curvature, number, terminators, intersection, closure, hue, intensity, flicker, direction of motion, binocular luster, stereoscopic depth, 3D depth cues, and lighting direction.**
- **The key perceptual attributes associated with the above include luminance and brightness, color, texture, and shape**
  - **Luminance is the measured amount of light coming from some place.**
  - **Brightness is the perceived amount of light coming from a source (is a nonlinear function of the amount of light emitted by the source) [Paper ≠ Screen].**
  - **Texture is the characteristic appearance of an area or surface.**

“Preattentive” visual tasks

- **Target detection.**
  - **Users rapidly and accurately detect the presence or absence of a “target” element with a unique visual feature within a field of distractor elements.**
- **Boundary detection.**
  - **Users rapidly and accurately detect a texture boundary between two groups of elements, where all of the elements in each group have a common visual.**



“Preattentive” visual tasks

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- **Boundary detection.**
  - **Users rapidly and accurately detect a texture boundary between two groups of elements, where all of the elements in each group have a common visual.**
- **Region tracking.**
  - **Users track one or more elements with a unique visual feature as they move in time and space.**
- **Counting and estimation**
  - **Users count or estimate the number of elements with a unique visual feature.**

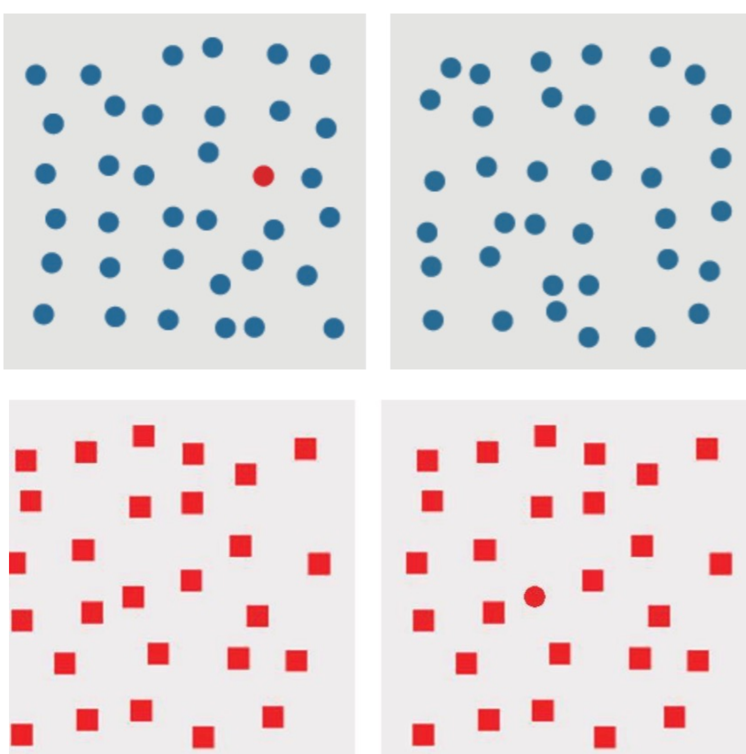
Theories of Preattentive Processing

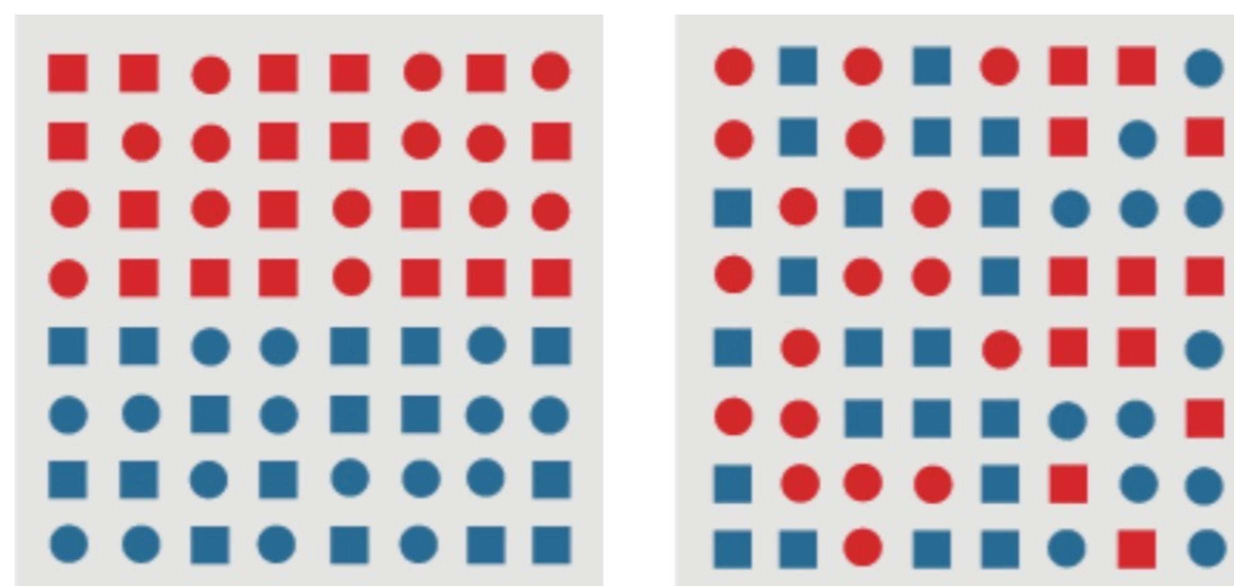
- **Feature Integration Theory (Anne Treisman)**
- **Texton Theory**
- **Similarity Theory**
- **Guided Search Theory**

- **Postattentive Vision**

Feature Integration Theory (Anne Treisman)

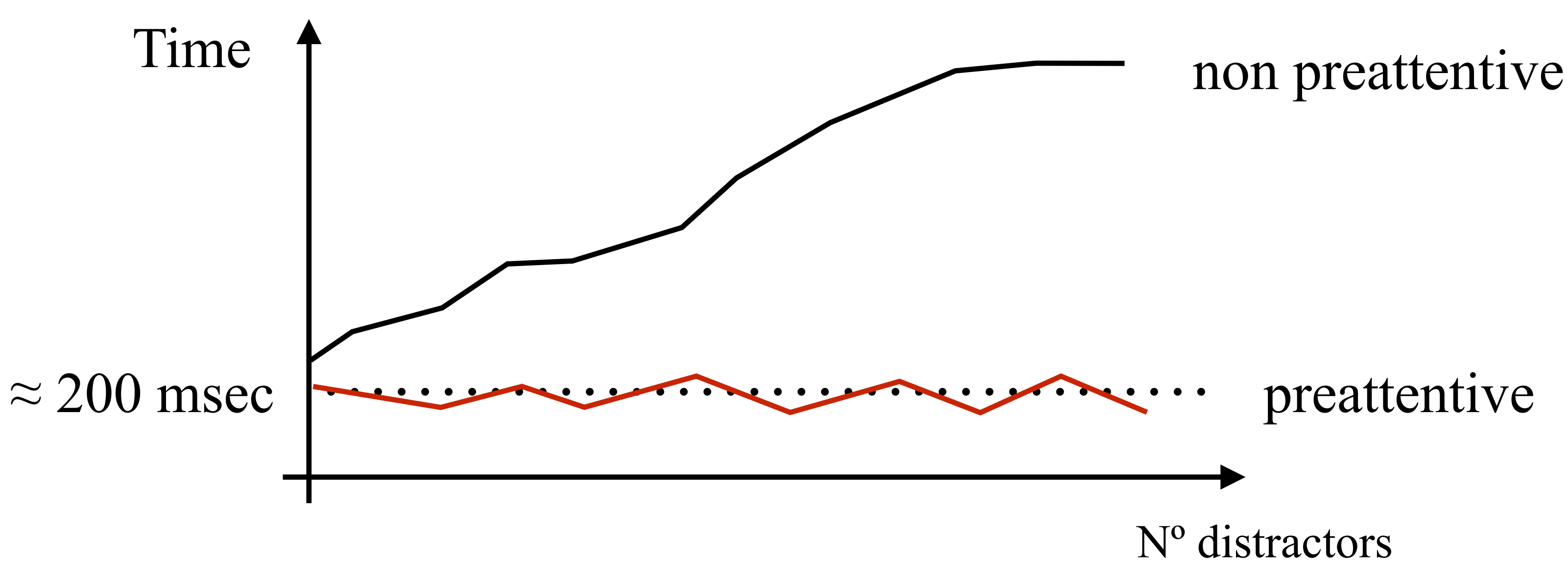
- **She starts by studying two important problems:**
  - **she tried to determine which visual properties are detected preattentively;**
  - **she formulated a hypothesis about how the human visual system performs preattentive processing**
- **Treisman ran experiments using target and boundary detection**





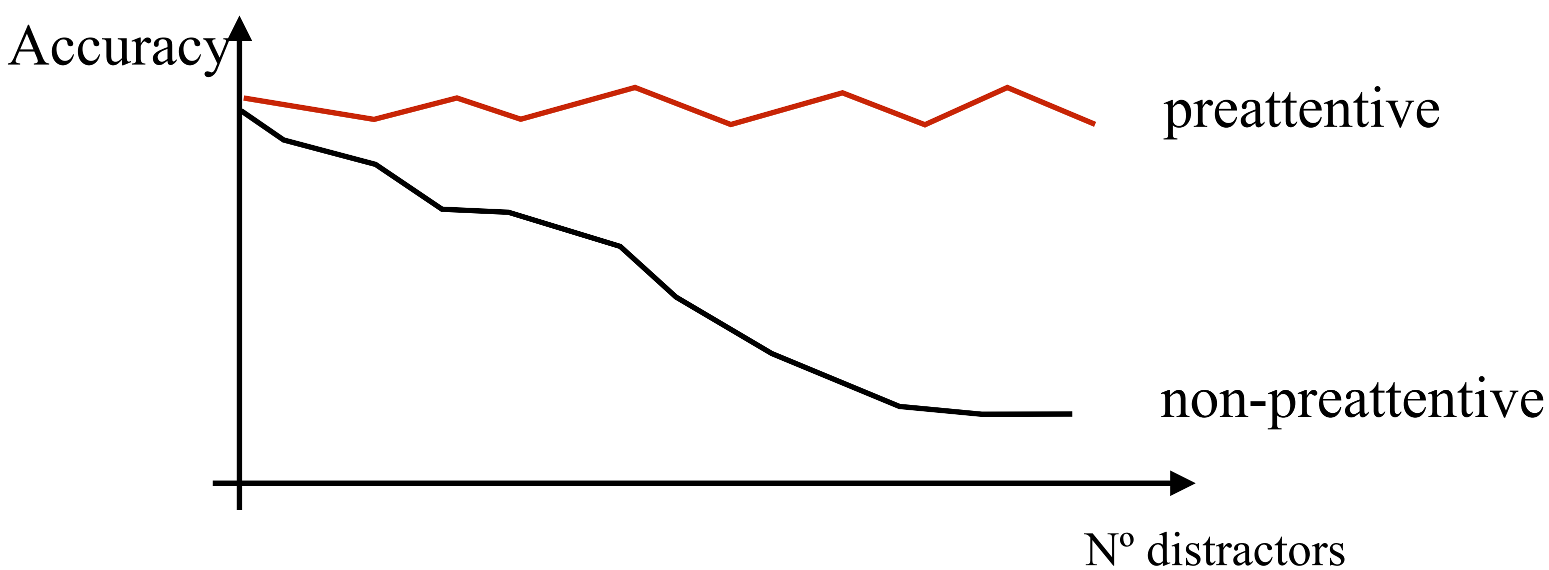
Feature Integration Theory (Anne Treisman)

- **Measuring preattentive task performance:**
  - **response time:**
    - **Viewers are asked to complete the task (e.g., target detection) as quickly as possible while still maintaining a high level of accuracy.**
    - **The number of distractors in a scene is repeatedly increased**
    - **If task completion time is relatively constant and below some chosen threshold, independent of the number of distractors, the task is said to be preattentive.**



Feature Integration Theory (Anne Treisman)

- **Measuring preattentive task performance:**
  - **accuracy:**
    - **the display is shown for a small, fixed exposure duration, then removed from the screen (200 to 250 msec).**
    - **The number of distractors in a scene is repeatedly increased**
    - **If viewers can complete the task accurately, regardless of the number of distractors, the feature used to define the target is assumed to be preattentive**



Feature Integration Theory (Anne Treisman)

- List of visual features that are detected preattentively
  - Some of these features are asymmetric:
    - A sloped line in a sea of vertical lines can be detected preattentively
    - A vertical line in a sea of sloped lines cannot be detected preattentively
  - Different types of background distractors may have a impact on the target feature

- To explain the preattentively features and processing they propose a "Feature Integration Theory"
  - A model of low-level human vision made up of a set of feature maps. Each feature map registers activity in response to a specific visual feature
  - and a master map of locations.

Feature Integration Theory (Anne Treisman)

- **Relaxing the strict dichotomy of features being detected as being either in parallel or in serial**
  - **For example, a long vertical line can be detected immediately among a group of short vertical lines.**
  - **As the length of the target shrinks, the search time increases, because the target is harder to distinguish from its distractors.**
  - **At some point, the target line becomes shorter than the distractors. If the length of the target continues to decrease, search time decreases, because the degree of similarity between the target and the distractors is now decreasing.**

Feature Integration Theory (Anne Treisman)

- **Treisman extended feature integration to explain certain cases where conjunction search is preattentive**
  - **Conjunction search tasks involving motion, depth, color, and orientation have been shown to be preattentive by Nakayama and Silverman !**
  - **Treisman hypothesizes that a significant target-nontarget feature difference would allow individual feature maps to ignore non target information**
    - **Example: green horizontal bar within a set of red horizontal bars and green vertical bars. Wolfe showed that search times are independent of display size!**
    - **If color constituted a significant feature difference, the red color map could inhibit information about red horizontal bars. Thus, the search reduces to finding a green horizontal bar in a sea of green vertical bars.**

Postattentive Vision

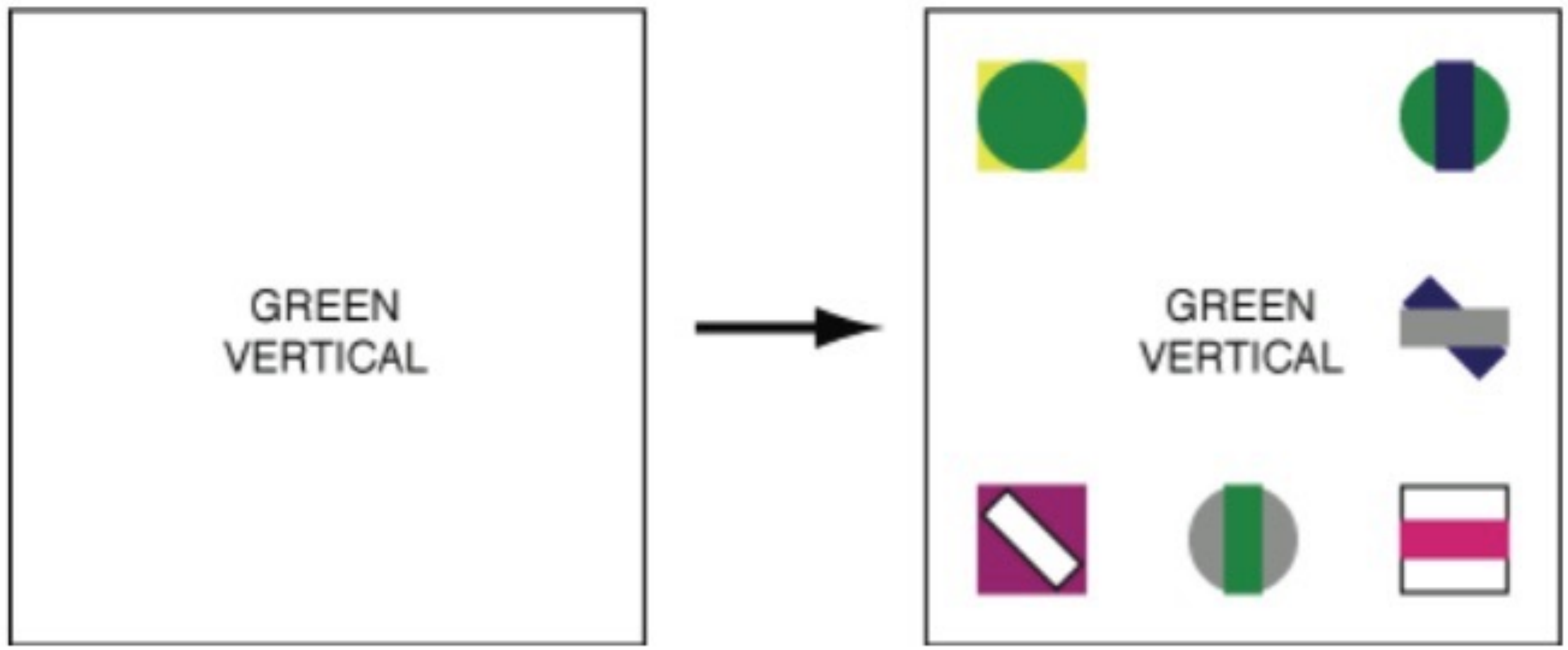
- Preattentive processing asks in part:
  - What visual properties draw our eyes, and therefore our focus of attention, to a particular object in a scene?
- An equally interesting question is:
  - What happens to the visual representation of an object when we stop attending to it and look at something else?
- The intuitive belief that a rich visual representation accumulates as we look at more and more of a scene …
  - Appears not to be true.

Postattentive Vision

- Wolfe designed targets with two critical properties:
  - The targets were formed from a conjunction of features (e.g., they could not be detected preattentively).
  - The targets were arbitrary combinations of colors and shapes (e.g., they were not objects that could be semantically recognized and remembered on the basis of familiarity).
- Wolfe initially tested two search types (response-time search)
  - Traditional search: Text on a blank screen was shown to identify the target. This was followed by a display containing 4, 5, 6, 7, or 8 potential target objects in a 3 × 3 array (formed by combinations of seven colors and five shapes).
  - Postattentive search

Postattentive Vision

- **Traditional search**



Search for color-and-shape conjunction targets:

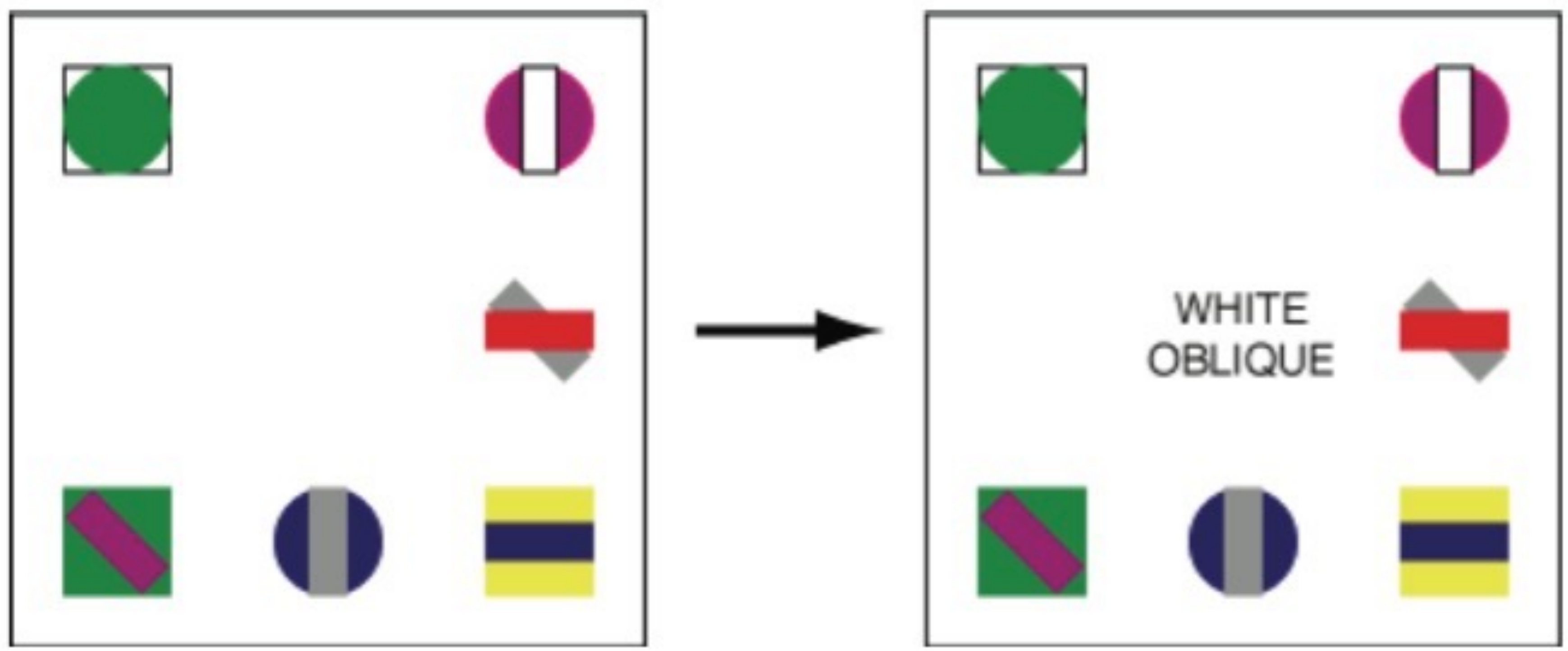
- no preview of the scene is shown (although text identifying the target is shown prior to the search)

- in this case, the green vertical target is present

Figure 3.27 - (Matthew Ward, et. all)

Postattentive Vision

- **Postattentive search**



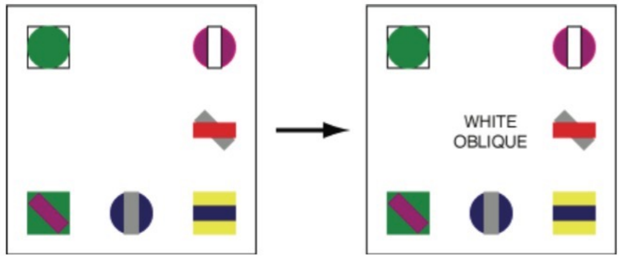
Search for color-and-shape conjunction targets:
- a preview of the scene is shown, followed by text identifying the target;
- in this case, a white oblique target is not present

Figure 3.27 - (Matthew Ward, et. all)

Postattentive Vision

- **Postattentive search**
  - **The display to be searched was shown to the user for a specific duration (up to 300 msec)**
  - **Text identifying the target was then inserted into the scene**
  - **Results showed that the postattentive search was as slow (or slower) than the traditional search, with approximately 25–40 msec per object required for the target present trials.**

- **Previewing the scene provides no advantage to the viewer for finding a conjunction target**



Change Blindness

- **The goal of human vision is not to create a replica or image of the seen world in our heads.**

- **A much better metaphor for vision is that of a dynamic and ongoing construction project, where the products being built are short-lived models of the external world that are specifically designed for the current visually guided tasks of the viewer.**

- **What we "see" when confronted with a new scene depends as much on our goals and expectations as it does on the array of light that enters our eyes.**

Change Blindness

- **New research in psychophysics has shown that an interruption in what is being seen (i.e., a blink, an eye saccade, or a blank screen) renders us "blind" to significant changes that occur in the scene during the interruption**

Figure 3.30 - (Matthew Ward, et. all)

Change Blindness

- **New research in psychophysics has shown that an interruption in what is being seen (i.e., a blink, an eye saccade, or a blank screen) renders us “blind” to significant changes that occur in the scene during the interruption**
- **A list of possible explanations for why change blindness occurs in our VS:**
  - **Overwriting: information that was not abstracted from the first image is lost.**
  - **First Impression: hypothesis that only the initial view of a scene is abstracted.**
  - **Nothing Is Stored: after a scene has been viewed and information has been abstracted, no details are represented internally.**
  - **Everything Is Stored, Nothing Is Compared: only compared is requested**
  - **Feature Combination: details from an initial view might be combined with new features from a second view.**

Summary

Q&A

What you should know

- **The concept of Preattentive Processing.**
  - Why the name Preattentive is not completely correct?
  - Examples of visual properties
  - Examples of tasks (Target detection, Boundary detection, Region tracking, …)
  - Time to performed on large multi-element displays in less than 200 to 250 milliseconds
  - What is the meaning of conjunction target
  - key perceptual attributes: luminance, brightness, color, texture, and shape.
- **How to Measuring preattentive task performance (response time and accuracy)**
- **Some of features that are detected preattentively are asymmetric**
- **Different types of background distractors may have a impact on the target feature**

What you should know

- **Some ideas from main perception theories and models**
  - Some conjunction search tasks have been shown to be preattentive
  - Search time is based on two criteria: T-N similarity and N-N similarity
    - T-N similarity ^ => Ef. v
    - N-N similarity v => Ef. v
- **Postattentive Vision**
  - Previewing a scene provides no advantage to the viewer for finding a conjunction target

    Feature Hierarchy
- **Change Blindness**
  - Nothing Is Stored: after a scene has been viewed and information has been abstracted, no details are represented internally.

Q&A

Further Reading and Summary

Q&A

Further Reading

- **Pag 81 - 117 from Interactive Data Visualization: Foundations, Techniques, and Applications, Matthew O. Ward, Georges Grinstein, Daniel Keim, 2015**

What you should know

- **What is perception.**
  - Process the sensorial information of the world around us, forming a mental representation of the environment
- **The notion that the brain makes a lot of assumption in the process.**
  - Why it seems reasonable and necessary. Examples.
- **The role of measurements and theories in the study of perception.**
- **The visible spectrum, its composition the relation with color and many forms of blindness.**
- **The eye main components and their role in the human vision system**
  - The motion control muscles; cornea, pupil, iris and the crystalline;
  - Retina: Rods and cones; the differences, the roles, the placement, the relative quantities.

What you should know

- **The eye main components and their role in the human vision system**
  - The optical nerve
  - The information compression from optical system to the brain
- **What is the blind spot. How to detect.**
- **Type of eye movements**
- **The concept of Preattentive Processing.**
  - Why the name Preattentive is not completely correct?
  - Examples of visual properties
  - Examples of tasks (Target detection, Boundary detection, Region tracking, …)
  - Time to performed on large multi-element displays in less than 200 to 250 milliseconds
  - What is the meaning of conjunction target
  - key perceptual attributes: luminance, brightness, color, texture, and shape.

What you should know

- **How to Measuring preattentive task performance (response time and accuracy)**
- **Some of features that are detected preattentively are asymmetric**
- **Different types of background distractors may have a impact on the target feature**
- **Some ideas from main perception theories and models**
  - Some conjunction search tasks have been shown to be preattentive
  - Texton Theory (elongated blobs, terminators, crossings). Difference in textons or in their density
  - Search time is based on two criteria: T-N similarity and N-N similarity
    - T-N similarity ^ => Ef. v
    - N-N similarity v => Ef. v

What you should know

- **Postattentive Vision**
  - Previewing a scene provides no advantage to the viewer for finding a conjunction target

    Feature Hierarchy
- **Change Blindness**
  - Nothing Is Stored: after a scene has been viewed and information has been abstracted, no details are represented internally.

Q&A