

Visual System

Intro to Data Visualization

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Vision



Why should we talk about human vision?

Why

Data visualization, in the form of graphics, is mostly visual.

Ultimate goal

Understanding visual perception is fundamental to design better visual displays.



Vision

Vision, of our all senses, is the most powerful and efficient **channel for receiving information** from the physical world.

Importance of Vision

- ▶ Vision dominates our senses
- ▶ Most powerful channel for receiving information
- ▶ About half of the human brain deals with visual input
- ▶ $\sim 70\%$ of the sense receptors in our bodies are dedicated to vision
- ▶ It is the sense most connected with cognition
- ▶ Seeing and thinking are extremely related:
how we see \Leftrightarrow how we think

Vision

So many ways to see ...

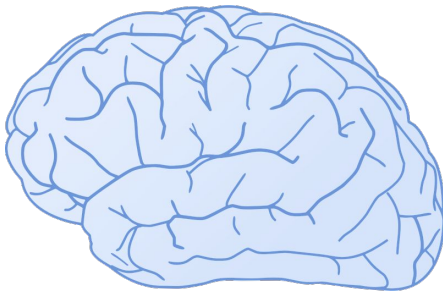
“There are so many ways for speakers of English to see the world. We can glimpse, glance, visualize, view, look, spy, or ogle. Stare, gawk, or gape. Peek, watch, or scrutinize. Each word suggests some subtly different quality: looking implies volition; spying suggests furtiveness; gawking carries an element of social judgment and a sense of surprise.”

Joshua Foer (Utopian for Beginners)

Seeing and Thinking



Eye



Brain

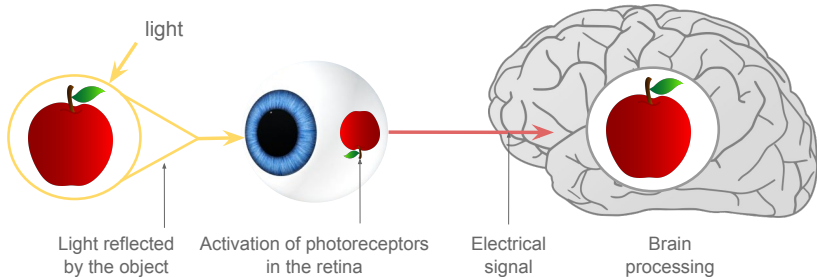
Seeing

What our eyes get is not what our brain perceives

What we commonly call “seeing” is not a single phenomenon but a group of at least 3 operations:

- ▶ Sight
- ▶ Perception
- ▶ Cognition

How we see



based on Alberto Cairo's diagram p. 98

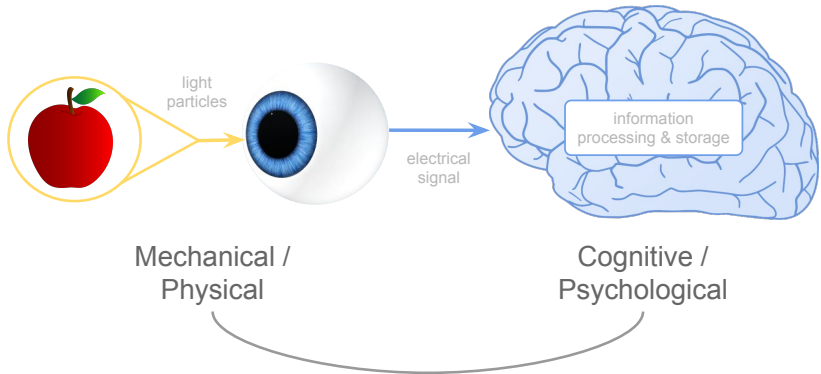
Visual Perception

Making sense of what our eyes see

“We don’t see with our eyes; we see with our brains. Our eyes are the sensory mechanisms through which light enters and is translated by neurons into electrical impulses that are passed on to and around in our brains, but our brains are where perception actually occurs.”

Stephen Few (Information Dashboard Design)

Psycho-Physical System

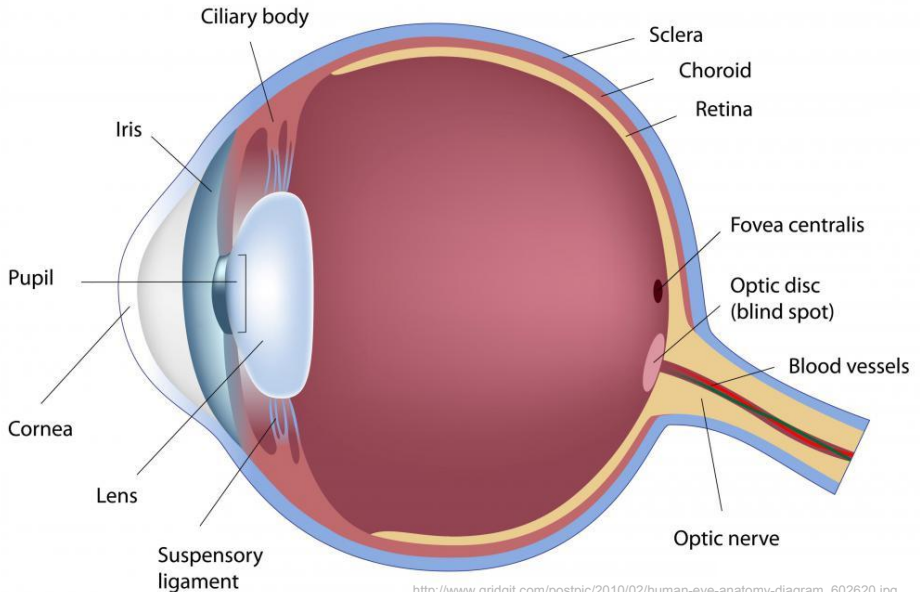


Visual System

- ▶ The visual system consists of 2 parts
 - eyes
 - brain
- ▶ The **eyes** act as image receptors
- ▶ The **brain** acts as an image processing and interpretation unit
- ▶ Understanding how we see requires that we understand both components

Anatomy of the Eye

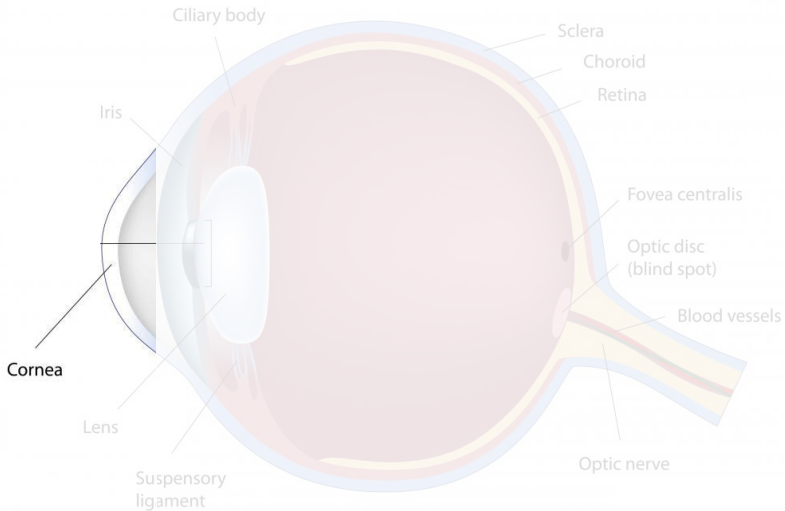
Human Eye Anatomy



Mechanics of eye and sight

- ▶ To better understand how we “see”, we should talk about the eye.
- ▶ Knowing about the physiology of the eye is fundamental to better design visual displays and statistical graphics.

Human Eye Anatomy



Outside layers of the eye

Cornea

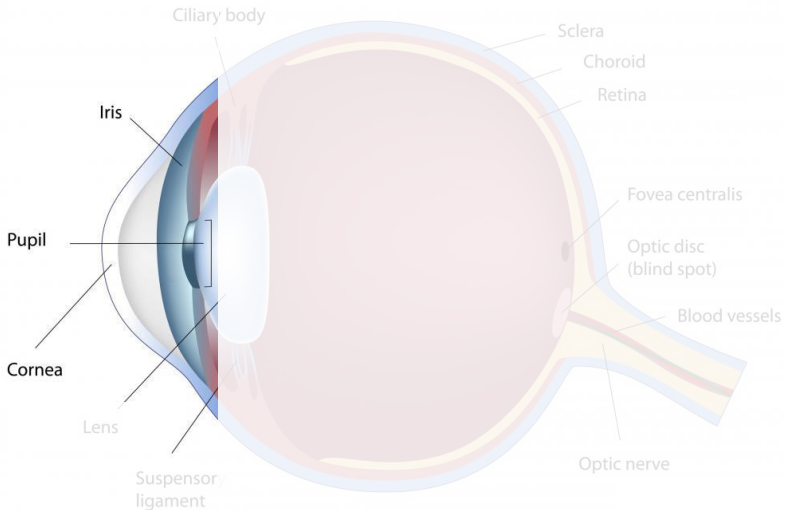
- ▶ The surface of the eye is called the **cornea**.
- ▶ The cornea is a protective covering.
- ▶ It is the transparent, dome-shaped window covering the front of the eye.
- ▶ It is a powerful refracting surface, providing 2/3 of the eye's focusing power.

Outside layers of the eye

Sclera and conjunctiva

- ▶ The **sclera** is “the white of the eye.” It is the tough, opaque tissue that serves as the eye’s protective outer coat.
- ▶ The **conjunctiva** is the thin, transparent tissue that covers the outer surface of the eye.

Human Eye Anatomy



Outside layers of the eye

Iris and Pupil

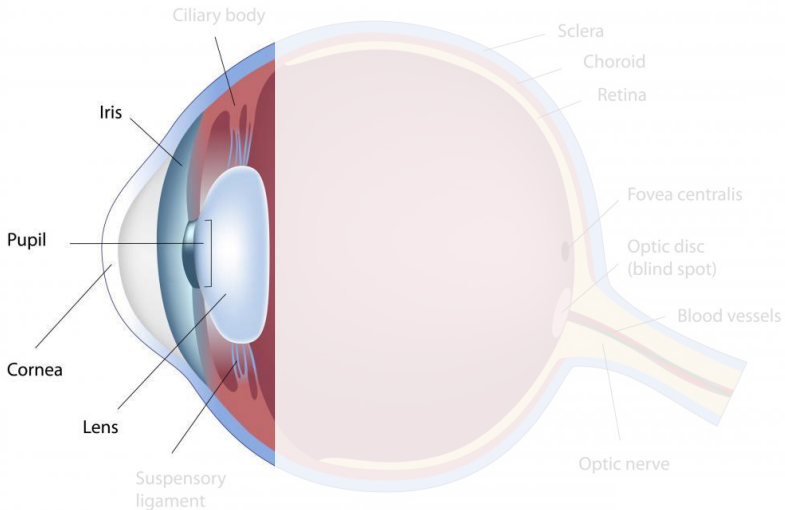
- ▶ Behind the cornea resides the **iris**.
- ▶ The iris is a colored muscle that works like a camera shutter.
- ▶ It covers all but a small opening in the front of the eye.
- ▶ The **pupil** is the opening at the center of the iris.
- ▶ The iris enlarges or decreases the size of the pupil.

Outside layers of the eye

Iris and Pupil

- ▶ The iris controls the amount of light entering the eye.
- ▶ In low-light conditions the pupil dilates to let in more light.
- ▶ In high-light conditions the pupil contracts to let in less light.
- ▶ The size of the pupil is also subject to mood. It dilates when we are happier.

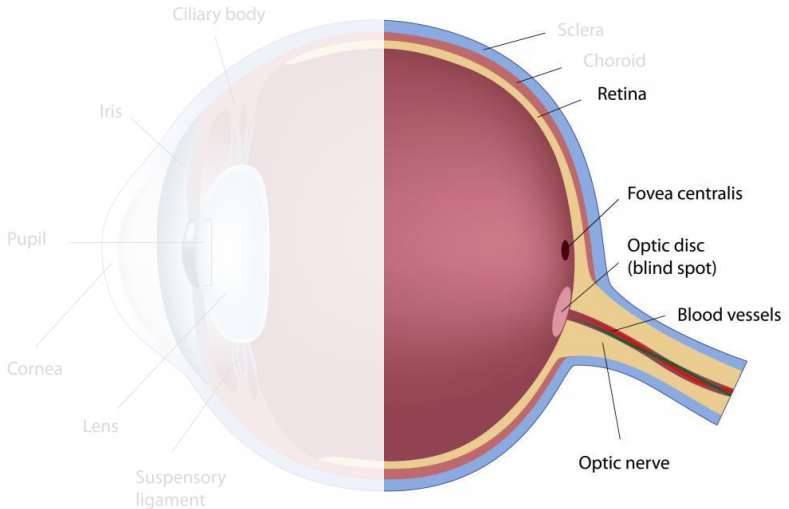
Human Eye Anatomy



Focus Control

- ▶ The cornea and aqueous humour act as a primary lens which performs crude focusing of the incoming light.
- ▶ Behind the iris there is the **lens**, similar to the lens of a camera
- ▶ The **lens** is made of a soft transparent substance. It provides control over the eye's focusing.
- ▶ With age, the lens gradually hardens making it harder for the eye to focus on nearby objects.

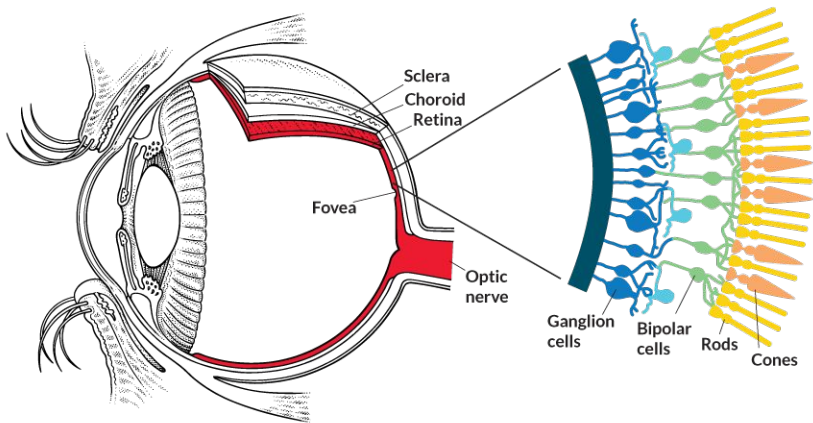
Human Eye Anatomy



Retina

- ▶ The **retina** is a thin sheet of nerve tissue at the back of the eye.
- ▶ The retina is not really part of the eye but part of the brain.
- ▶ It is composed of more than 100 million light-absorbing receptors.
- ▶ Its job is to convert this light energy into electrical impulses for the brain to interpret.

Retina Cell Receptors

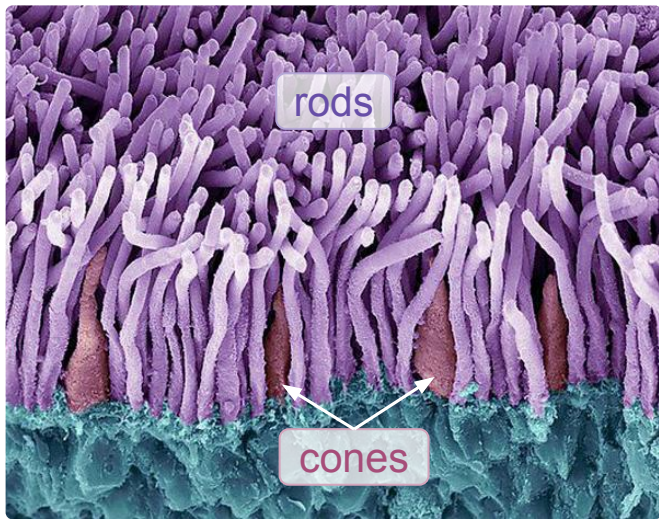


https://www.sciencenews.org/sites/default/files/main/articles/opto_opener.png

Retina Cell Receptors

- ▶ Two kinds of nerve cells live in the retina: rods and cones
- ▶ The retina has about 100 million rods, and 7 million cones
- ▶ Rods control our ability to see in low light
- ▶ Cones control our color and detail vision
- ▶ Photosensitive chemicals in the rods and cones cause an electrical reaction that sends seen images through optic nerves to the brain's cerebral cortex

Photosensitive Cells



Rod cells

- ▶ Rods come in only one type.
- ▶ Most sensitive type of photoreceptor cells.
- ▶ Provide low-light vision (night vision).
- ▶ Provide no color discrimination.
- ▶ Operate within light spectrum between 400 and 700 nm.

Cone cells

Three types of cell cones

- ▶ **S** (short wavelength)
- ▶ **M** (medium wavelength)
- ▶ **L** (long wavelength)
- ▶ The cone types combine to help us see the range of visible color.

Cones light sensitivity

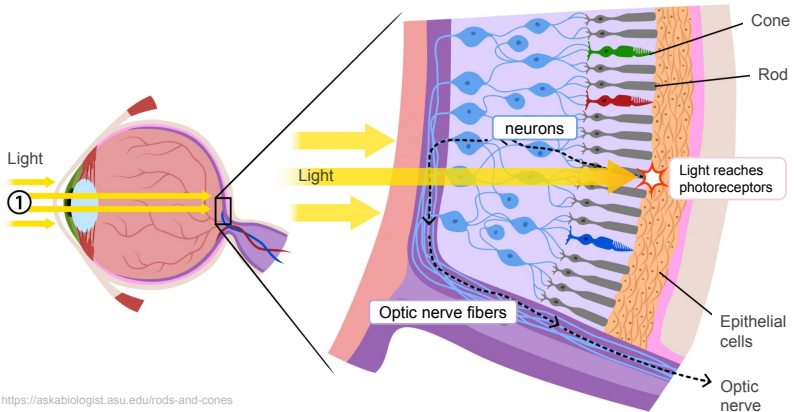
Spectrum Peaks

- ▶ Each cone is most sensitive to light in a different wavelength.
- ▶ **S** cones peak at 420 nm
- ▶ **M** cones peak at 530 nm
- ▶ **L** cones peak at 560 nm

Rods and Cones

- ▶ The distribution of rod and cone cells is not uniform across the retina.
- ▶ The cones are concentrated at the center rear of the retina.
- ▶ The rods are more evenly distributed away from the retina.
- ▶ In very low light or at night we see using only our rods.
- ▶ At night we have a blind spot at the center of our visual field.

Retina Cell Receptors

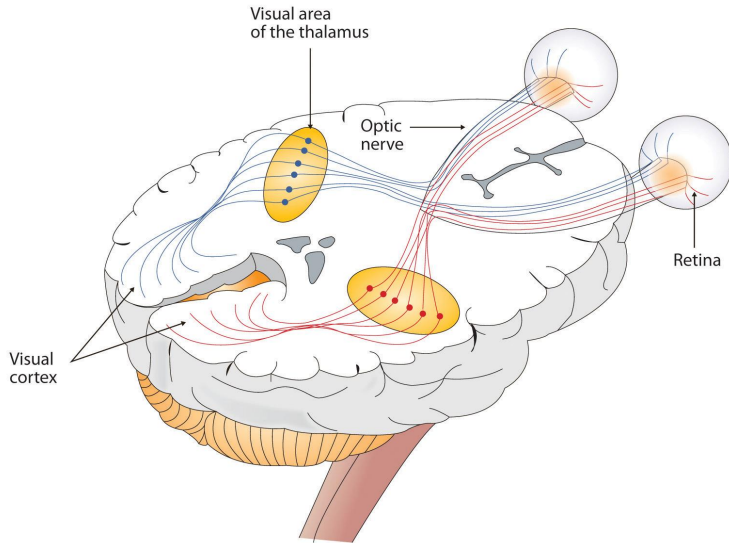


Orientation of Photosensitive Cells

- ▶ Once the light passes through the pupil, it shines on the retina.
- ▶ Layer of cells that makes up the retina is backwards.
- ▶ Light rays must pass through neurons and optic nerve fibers first.
- ▶ Then the rays reach the photosensitive cells.
- ▶ Rods and cones are also facing away from the light source.
- ▶ In summary: the eyes are actually part of the brain.

The Visual Brain

Visual Pathways



<http://open.lib.umn.edu/intropsyc/chapter/4-2-seeing/>

Visual Pathways

- ▶ After light has entered the eye, it is filtered and adjusted
- ▶ Then it reaches the retina (at the back of the eye)
- ▶ The retina contains nerve cells that are sensors designed to absorb light and translate it into neural signals
- ▶ The neural signals are then passed via the optic nerve to our brains
- ▶ They are processed in the region of the brain called the visual cortex

Transmission to the Cortex

- ▶ The visual signal from the retina is transmitted down the optic nerve.
- ▶ There are roughly 1 million nerve fibers in the optic nerve, and around 125 million photoreceptors in the retina.
- ▶ The signal is not transmitted in a one-fiber per receptor fashion.
- ▶ The greatest convergence occurs for the rod cells: the signals from 1000 rods may be carried by the same nerve fiber.
- ▶ This implies that there some “data compression” processing.

The Optic Chiasm

- ▶ The optic nerves from the two eyes converge and cross at the structure called the **optic chiasm**.
- ▶ Signals from each eye are mixed at this point.
- ▶ Such combination is necessary for filling-in the blind spot and for comparison leading to the extraction of depth information.

Visual Brain

- ▶ The retina receives electrical patterns and creates several tracks from the patterns
- ▶ Some tracks contain information about shadows, others about movement, and so on
- ▶ As many as 12 tracks of information are then sent to the brain's visual cortex
- ▶ Different regions of the visual cortex respond to and process the information of the tracks.

The Visual Cortex

- ▶ The visual cortex contains a number of neural structures which extract basic information from the visual signal.
- ▶ There are groups of neurons which are dedicated to detecting lines with particular orientation.
- ▶ Other groups are dedicated to detect shapes.
- ▶ The signal is processed at higher and higher levels and eventually passed forward to the higher brain centers.

Retina is part of the brain

- ▶ There is about 120 million rods and 6 million cones.
- ▶ The optic nerve only contains about 1 million fibers.
- ▶ Not all the visual information is transmitted to the brain.
- ▶ The eye performs a significant amount of visual processing.
- ▶ Compressed information is sent via the optic nerve.

Visual Brain

- ▶ What your eyes physically perceive is only one part of the equation.
- ▶ Light delivers images and colors to the brain through nerve cells, in the retina of the eye.
- ▶ What you see isn't what your brain gets. To get to the retina at the back of the eye, images and colors travel through various layers.
- ▶ The images coming to your brain are processed and interpreted
- ▶ It is really your brain that is “seeing”

Foveal and Peripheral Vision

The Blind Spot

- ▶ There are no photoreceptors where the optic nerve reaches the retina.
- ▶ This creates a blind spot in the visual field of each eye.
- ▶ We are usually unaware of our blind spots because information from the other eye is used to fill in the missing part of the visual field.

Finding your blind spot

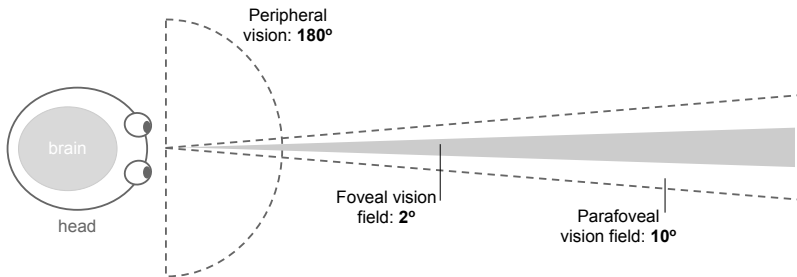
- ▶ Draw a cross and a dot about 8 cm apart as shown below.
- ▶ Close your right eye.
- ▶ Look directly at the cross.
- ▶ Move the page backward and forward until you see the dot disappear.



Foveal and Peripheral Vision

- ▶ Most visual information falls in the peripheral areas of the retina
- ▶ There is one special region in the retina called the fovea
- ▶ It is the place that provides the sharpest vision
- ▶ The fovea allows us to distinguish small objects, detail, and color
- ▶ Our eyes repeatedly move to keep the object of most interest imaged on the fovea

Vision Fields

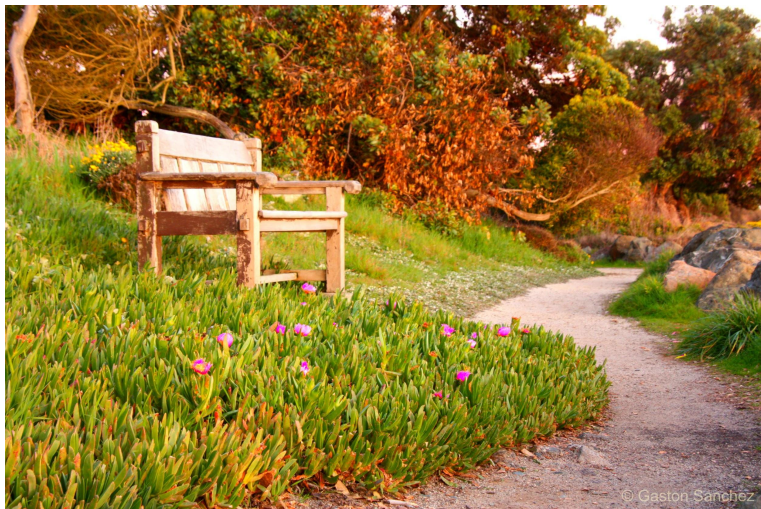


based on Alberto Cairo's diagram p. 102

Foveal and Peripheral Vision

- ▶ Most visual information falls in the peripheral areas of the retina.
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- ▶ It is the place that provides the sharpest vision.
- ▶ The fovea allows us to distinguish small objects, detail, and color.
- ▶ Our eyes repeatedly move to keep the object of most interest imaged on the fovea.
- ▶ The central vision is critical for specific object recognition.
- ▶ Peripheral vision is used for getting the gist of a scene.

What your brain thinks you are seeing



What your eyes are really getting



What your eyes are really getting

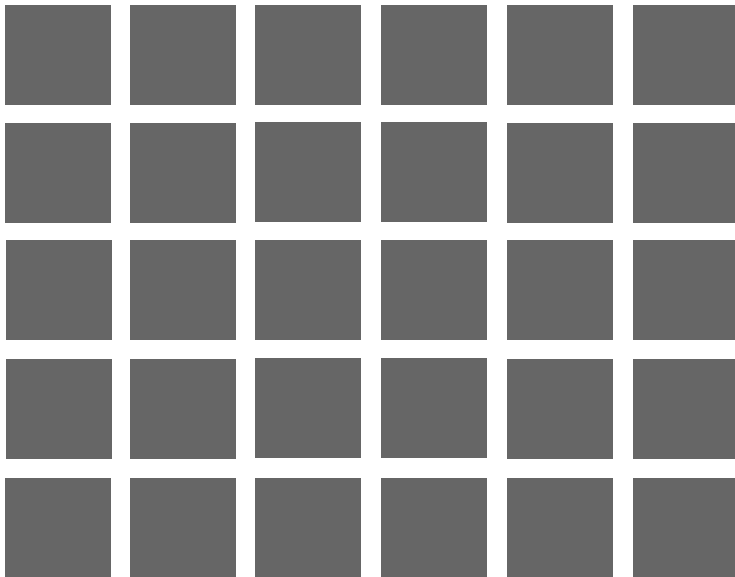


What your eyes are really getting



Foveal and Peripheral Vision

Herman Grid Illusion

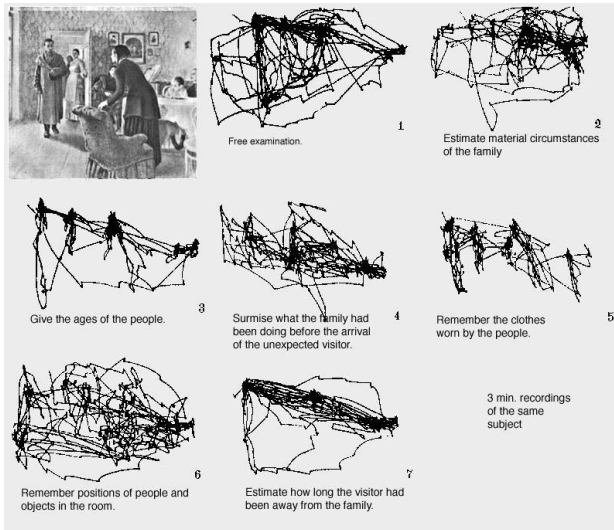


Unexpected Visitors by Ilya Repin (1884-1888)



<https://www.wikiart.org/en/ilya-repin/unexpected-visitors-1888>

Eye tracking experiments by Alfred Yarbus



Wikimedia commons: Yarbus The Visitor

Takeaways

Main takeaways

- ▶ We use both peripheral and central vision when looking at an image.
- ▶ Don't assume people will see something on a graphic just because it's there.
- ▶ Avoid putting important things on the edges, since we tend not to look there.
- ▶ About short-term memory: viewers of graphs can only hold a few chunks of information in their heads at any one time.

References

- ▶ **The Functional Art** (chapter 5) by Alberto Cairo.
- ▶ **Visual Language for Designers** (section 1) by Connie Malamed.
- ▶ **Now You See It** (chapter 3) by Stephen Few.
- ▶ **Show Me the Numbers** (chapter 6) by Stephen Few.
- ▶ **Interactive Data Visualization** (chapter 3) by Ward, Grinstein and Keim.
- ▶ **100 Things Every Designer Needs to Know About People** (chapter 1) by Susan M. Weinschenk.