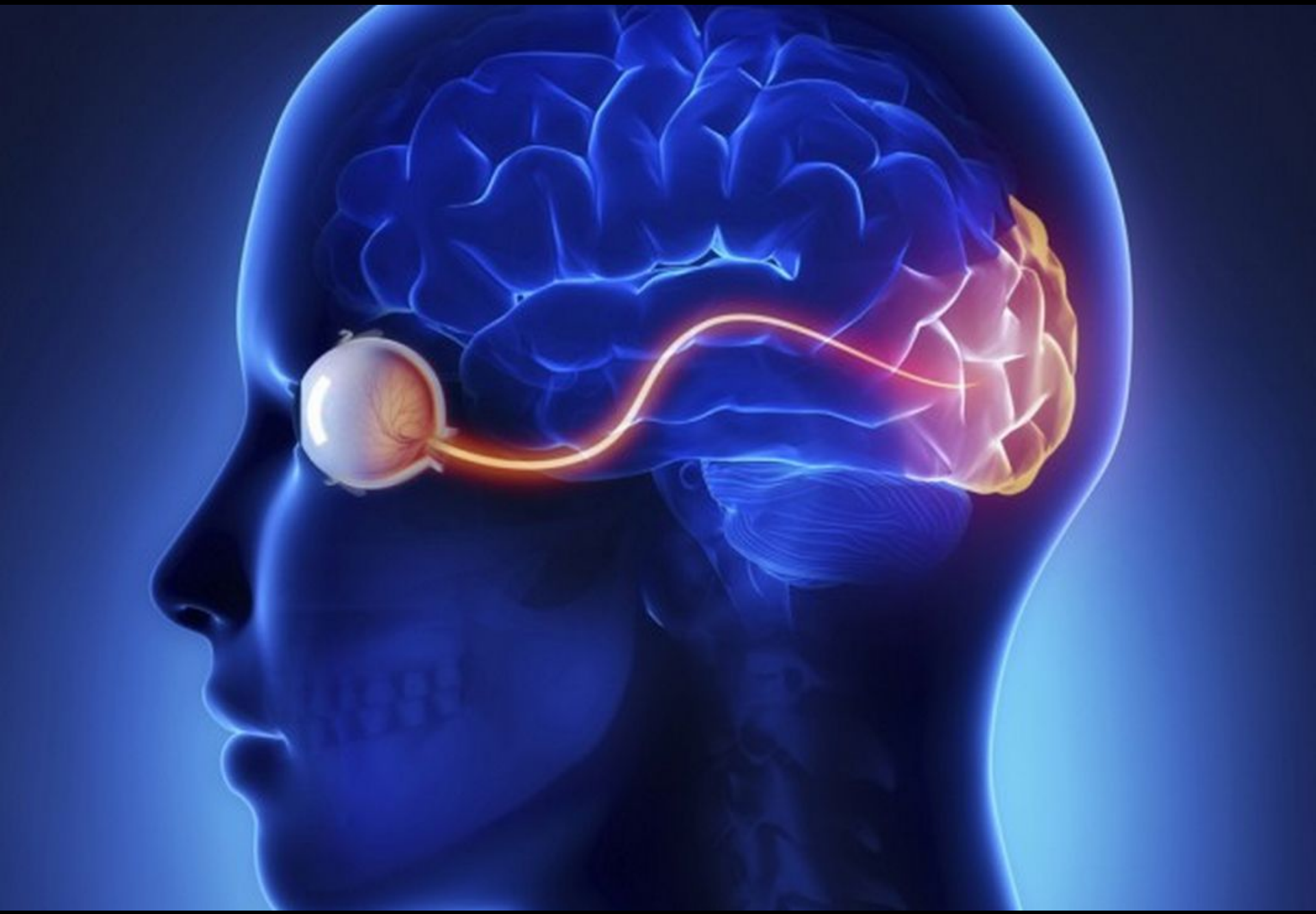
Data Visualization 3: The Visual System

Stat 133 by Gaston Sanchez



Approaching graphing data

With so many chart options, and various software tools, how can you determine what type of graph should you use?

In my opinion, there are a couple of aspects to always keep in mind:

- Data encoding (core idea)
- Common analytical tasks
- **Visual perception basics**
- Effective charts suggestions

Understanding visual perception is fundamental to design better visual displays.

So far ...

> “While graphics technology is moving along at a rapid pace, the human visual system has remained the same.”
>
> William S. Cleveland

About human vision

It is the sense most connected with cognition

Seeing and thinking are extremely related:

How we **see** ← → how we **think**

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

Understanding visual perception is fundamental to design better visual displays.

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

About human vision

Vision dominates our senses

Most powerful channel for receiving information

About half of our brain delas with visual input

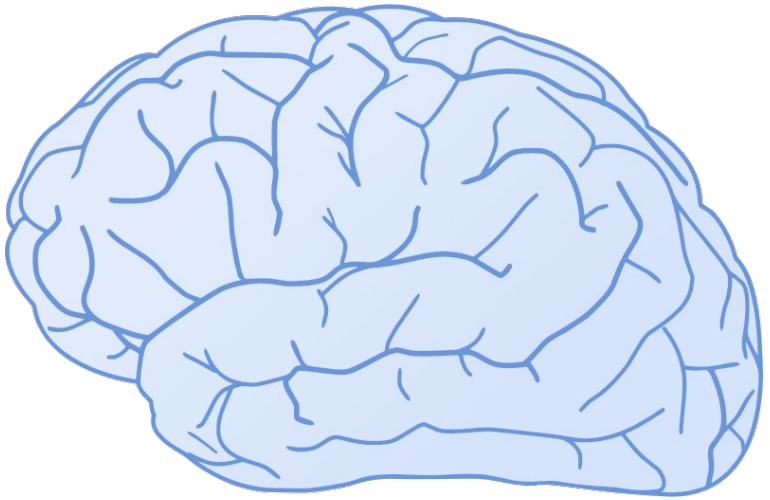
~ 70% of the sense receptors in our bodies are dedicated to vision

Visual System

Seeing and thinking

Eye

+



Brain

Visual System

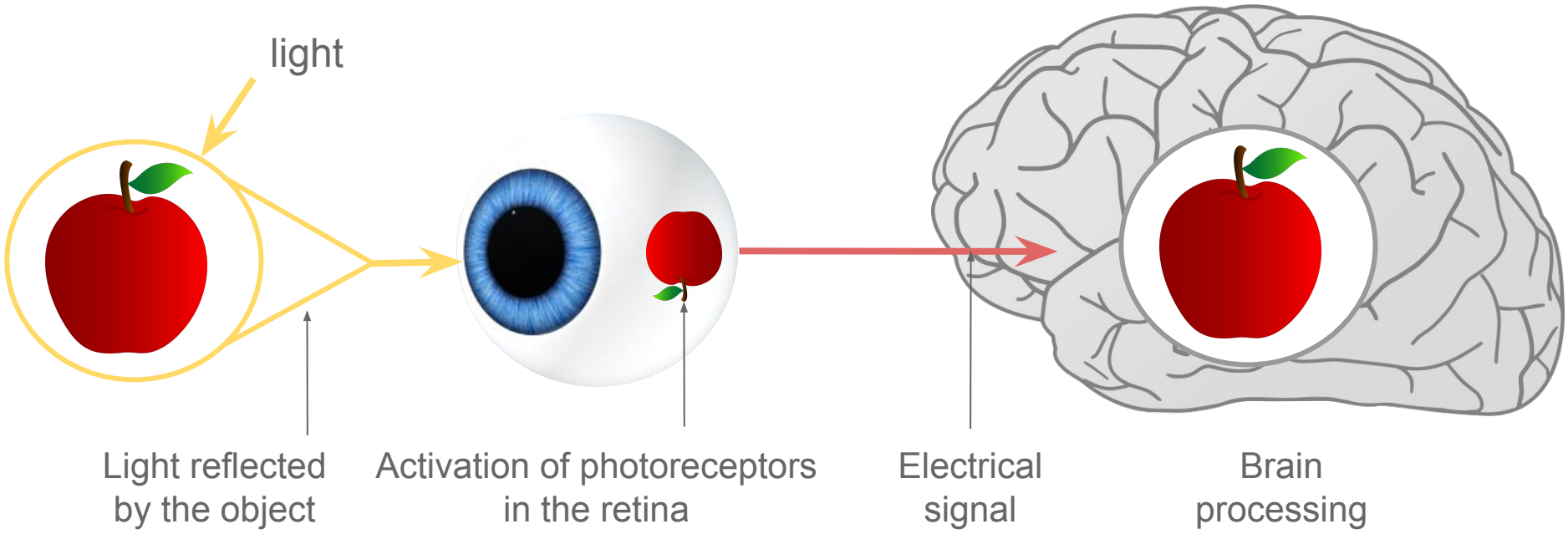
The visual system consists of 2 parts:

- Eyes
- Brain

The **eyes** act as image receptors.

The **brain** acts as an image processing and interpretation unit.

How we see



based on Alberto Cairo's diagram p. 98

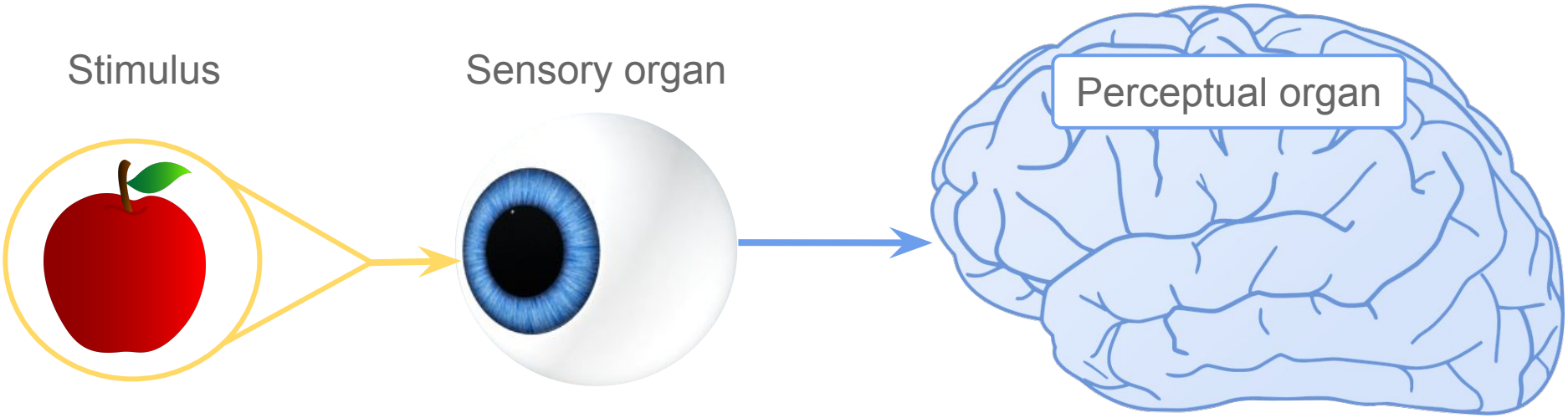
Seeing

What our eyes get is not (really) 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

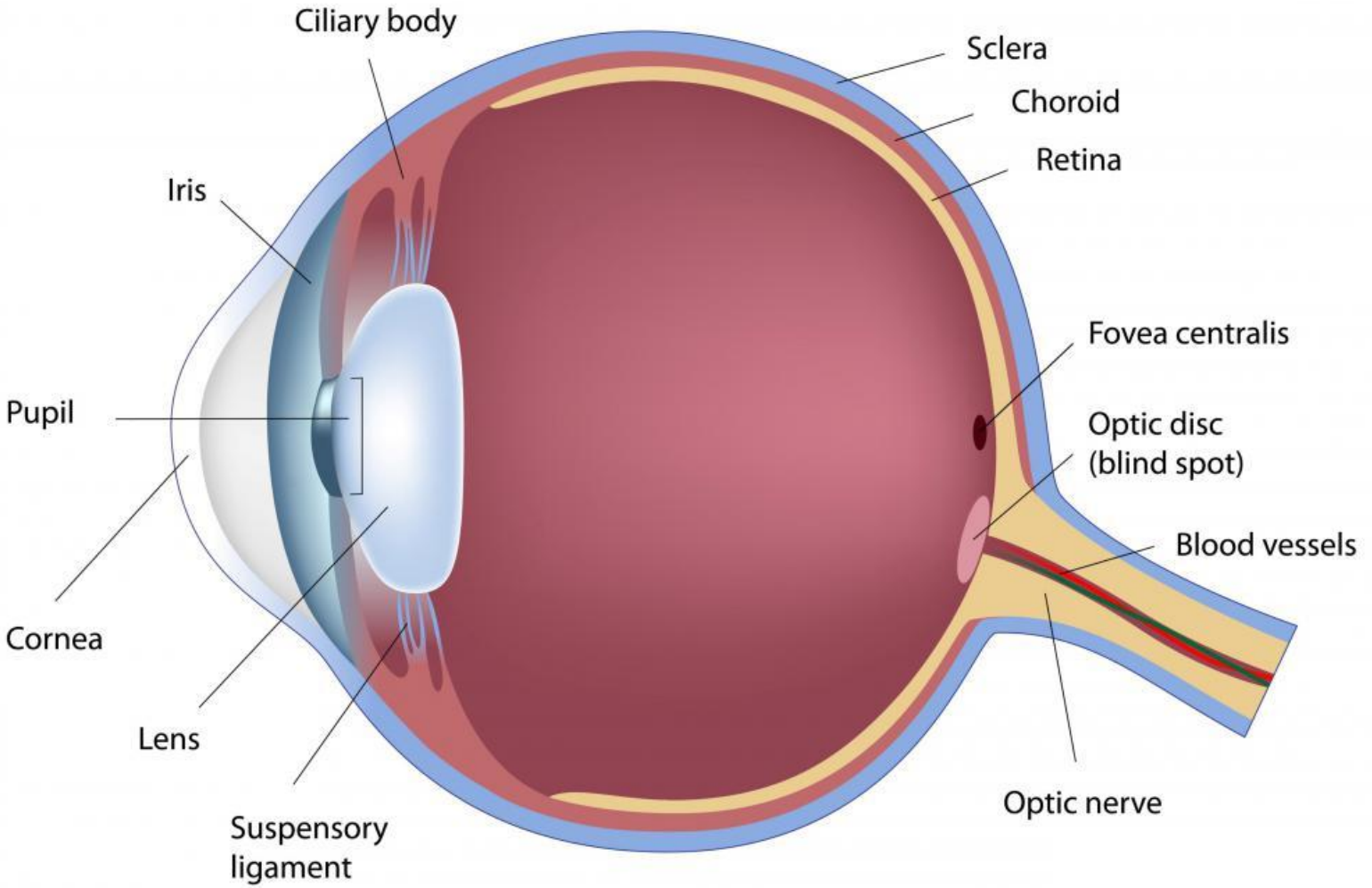
Psycho-Physical System



Sensation
(mechanical/physical)

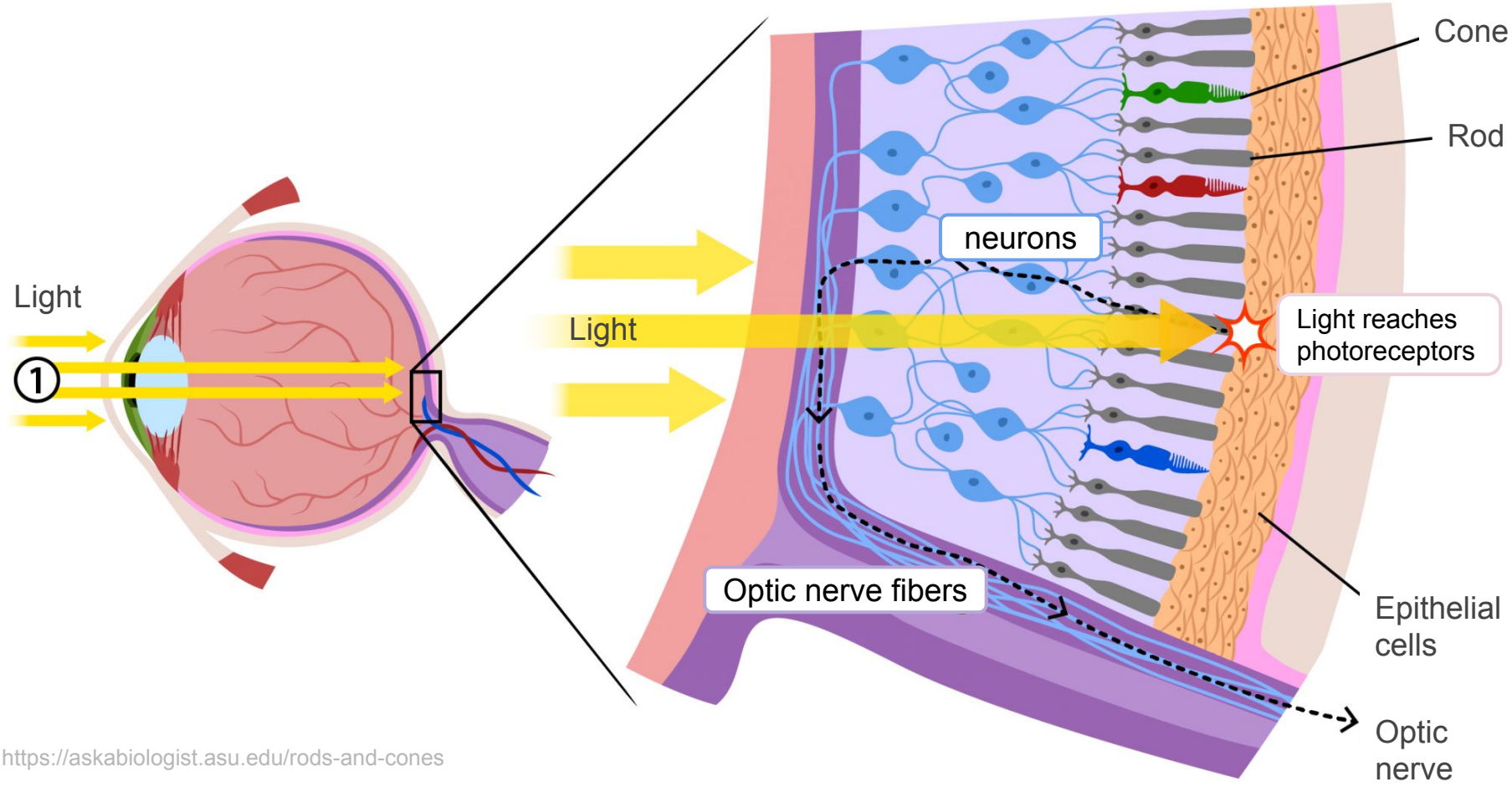
Perception
(cognitive /psychological)

Human Eye Anatomy



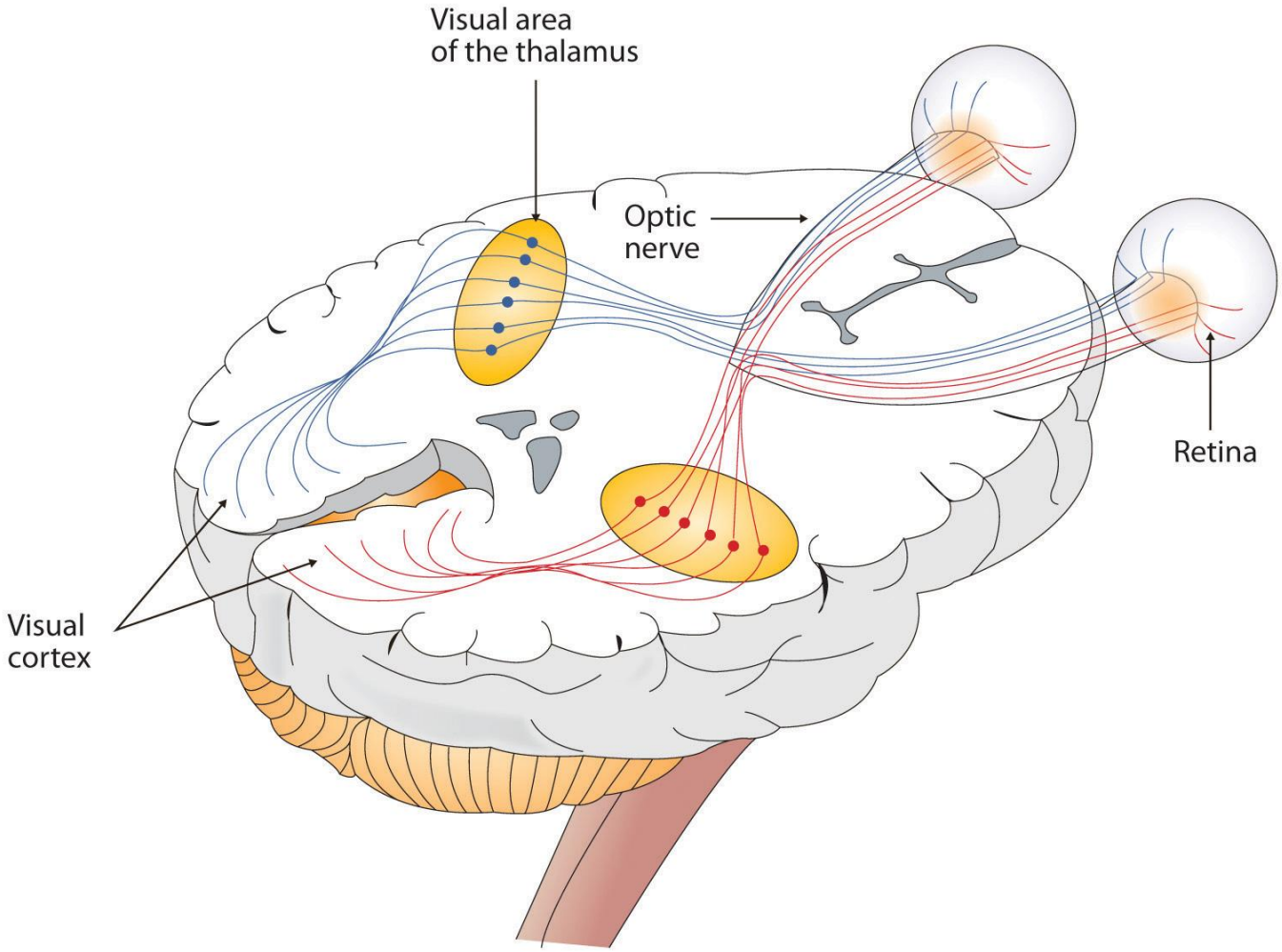
http://www.gridgit.com/postpic/2010/02/human-eye-anatomy-diagram_602620.jpg

Photoreceptors: Rods and Cones



https://askabiologist.asu.edu/rods-and-cones

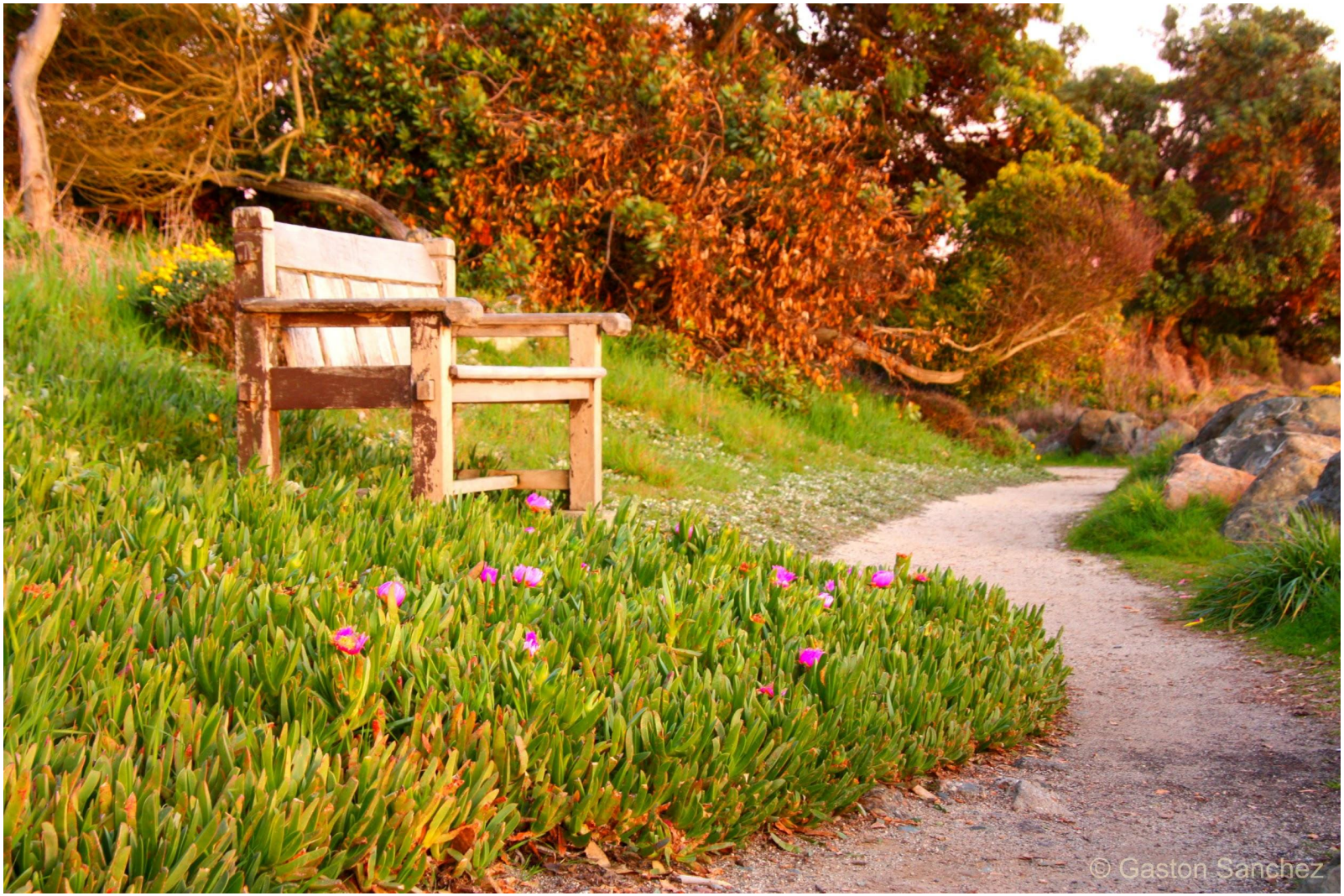
Visual pathways



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

Foveal and Peripheral Vision

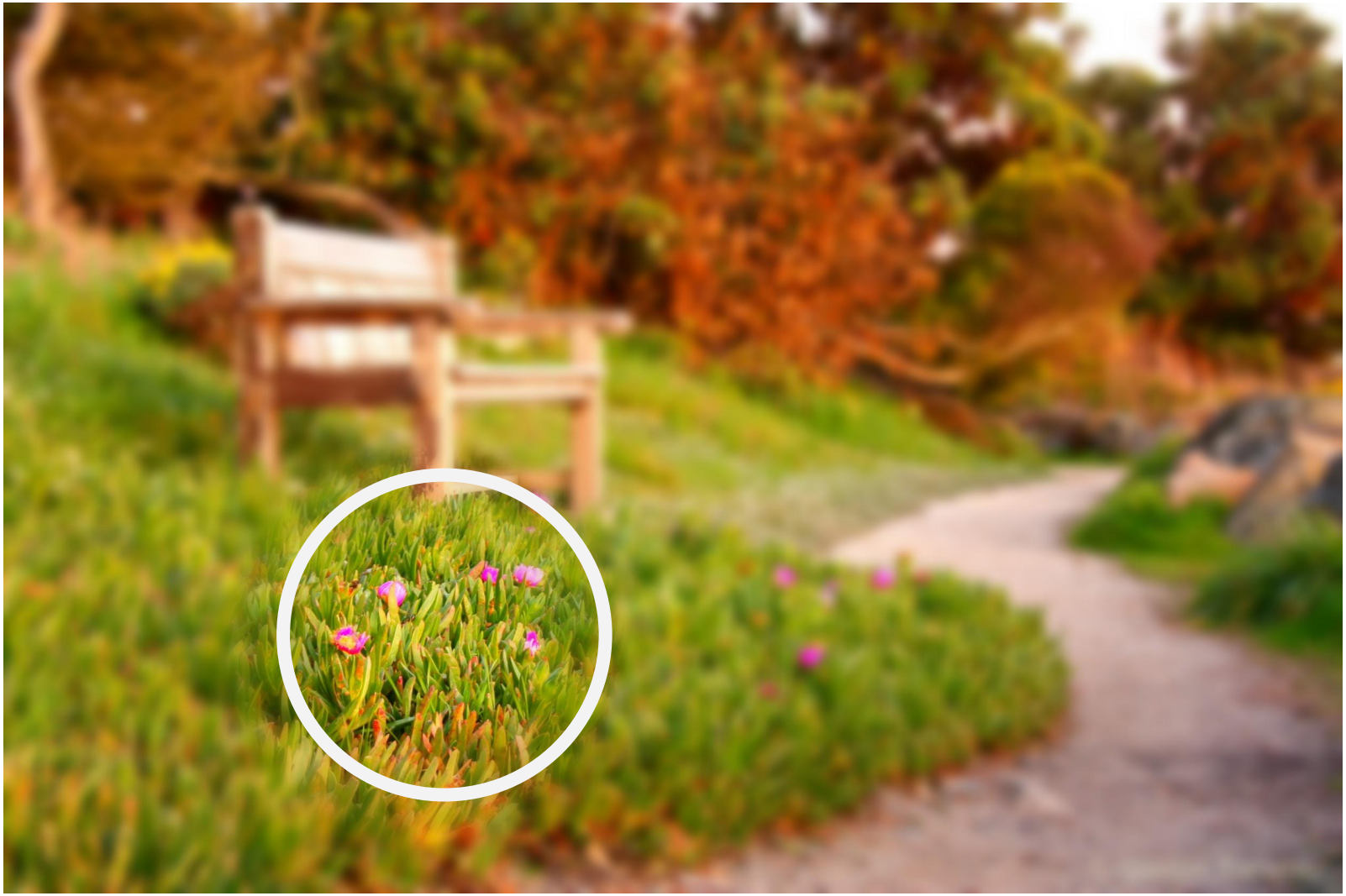
What your brain thinks you are seeing



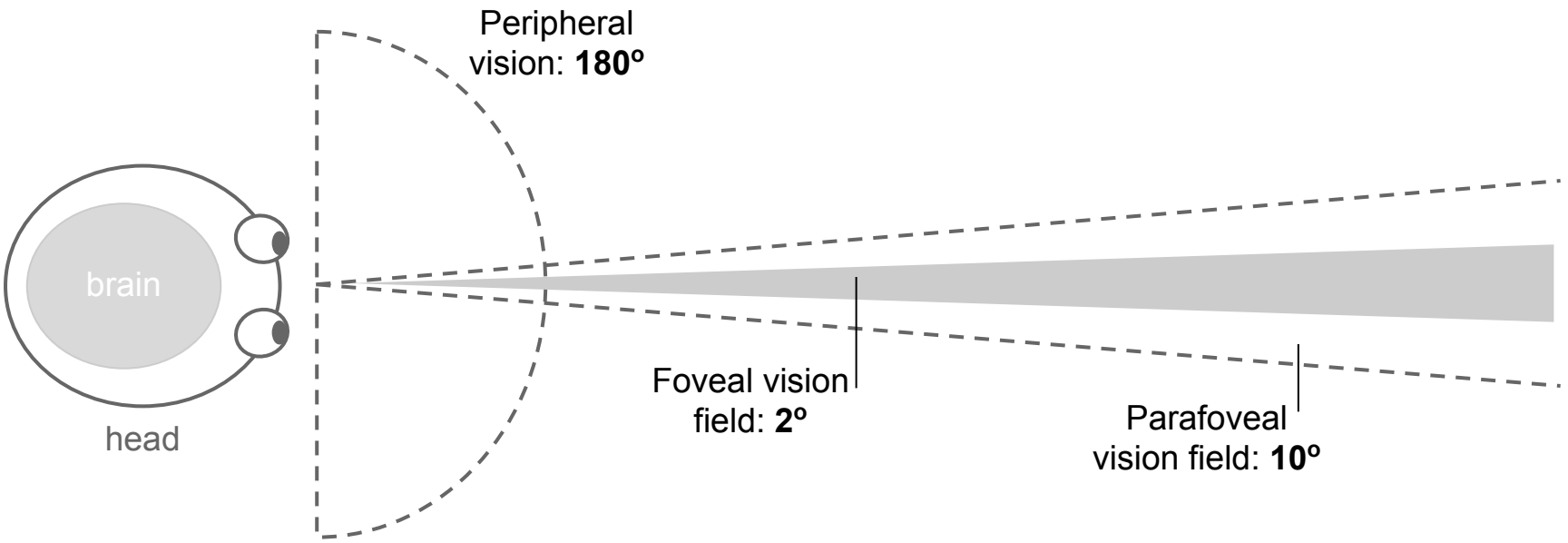
What your eyes are really getting

What your eyes are really getting

What your eyes are really getting



Vision Fields



based on Alberto Cairo's diagram p. 102

Foveal and Peripheral Viison

Most visual information falls in the peripheral areas of the retina.

There's 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.

Foveal and Peripheral Viison

Our eyes repeteadly 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.

Attention and Memory

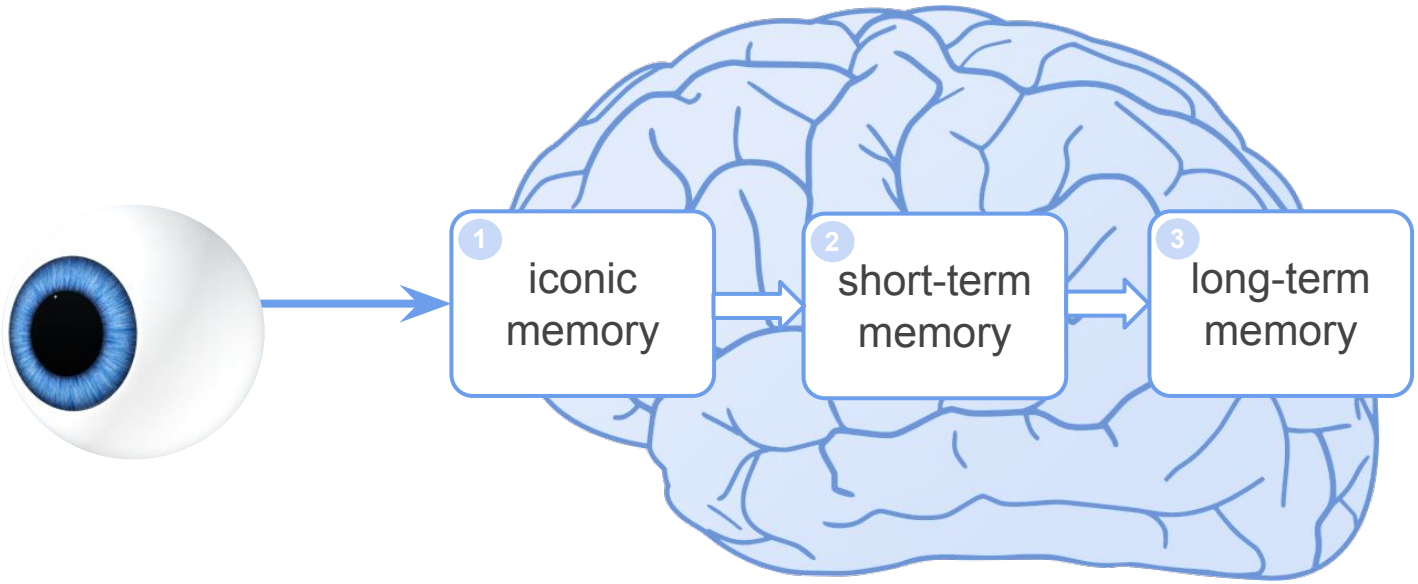
Visual perception

Visual perception is a cognitive process.

Neuroscientists and psychologists have developed an extensive theoretical body of how we process information.

I'll provide a somewhat simplified version of such theories. This requires thinking about the Brain as a computer.

Information Processing and Memory

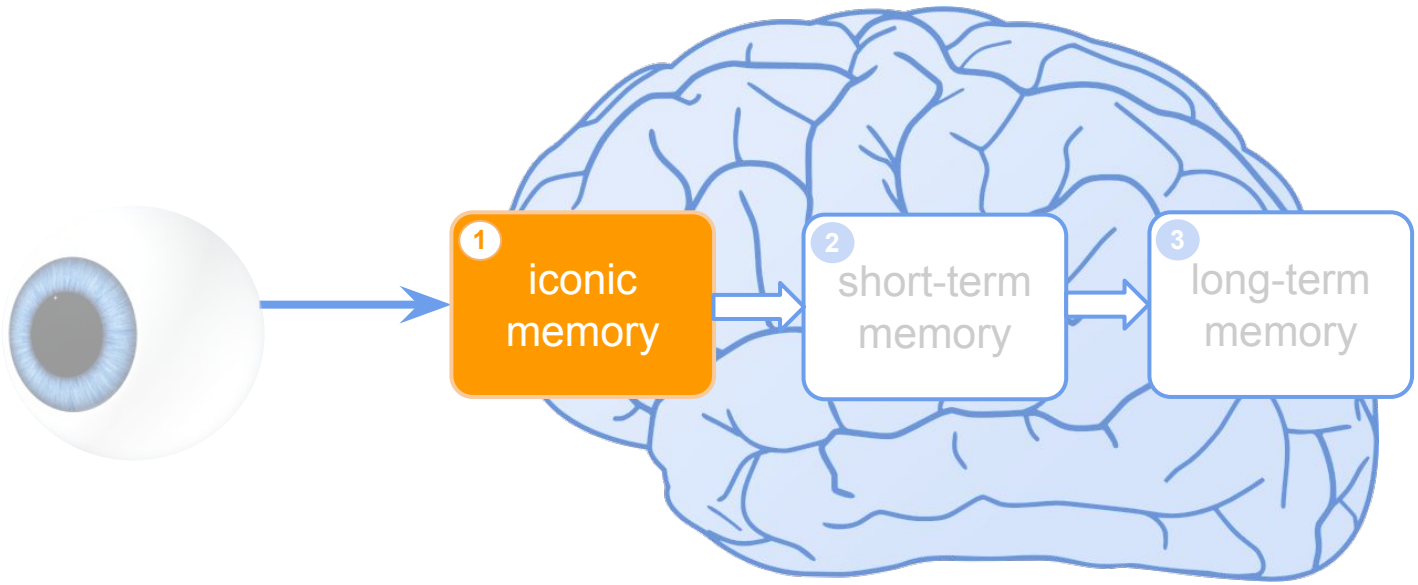


Brain as a computer

Types of memory for processing visual information:

- **Iconic** memory (visual sensory register)
  like the buffer or temporary
- **Short-term** memory (working memory)
  like the random access memory (RAM)
- **Long-term** memory ("permanent" storage)
  like the hard disk

Iconic Memory



Iconic Memory

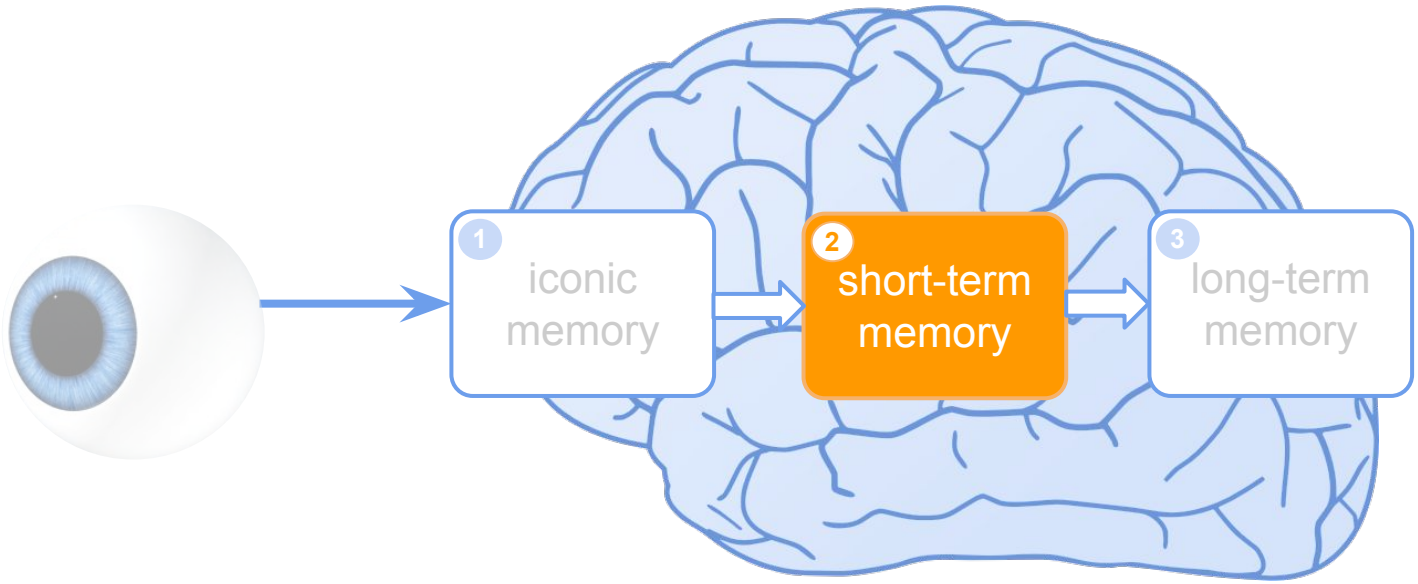
The iconic memory is a sort of waiting room where each snapshot of input waits to be passed on to short-term memory.

Rapid processing: almost automatic, parallel, and unconcious

Also called preattentive processing.

Processes primitive visual features.

Short-term Memory



Short-term Memory

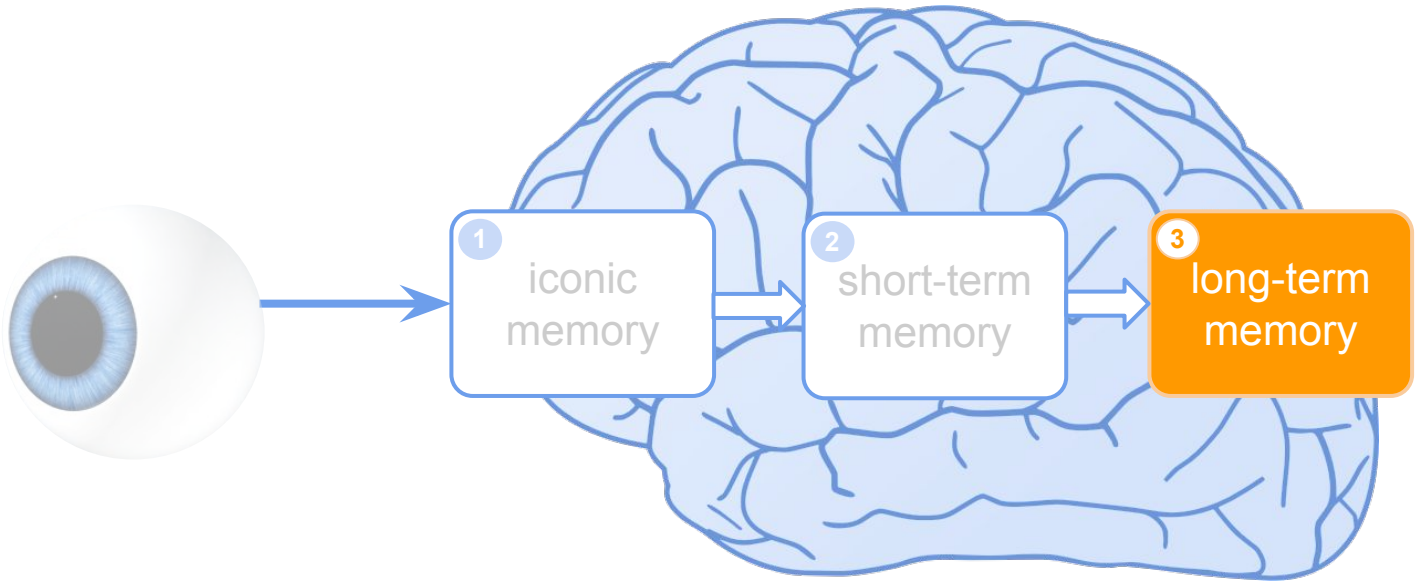
The short-term memory is a sort of RAM.

This is where concious mental work is performed to support cognition, and information is combined into meaningful visual chunks.

This memory is temporary and has limited storage capacity.

Where the attentive process of perception occurs.

Long-term Memory



Long-term Memory

The long-term memory is a sort of hard disk.

It's a dynamic structure that retains everything we know.

Involves an intricate network of links and cross-references that help us find information.

Holds our ability to recognize images and detect meaningful patterns.

Early Vision and Preattentive Vision

Note

Researchers have discovered a limited set of individual properties that are detected very rapidly and accurately by the *early* (low-level) visual system. These properties were initially called **preattentive**. We now know that attention does play a critical role in what we see.

Iconic memory is related with the Early Vision, aka preattentive vision.

Preattentive Processing

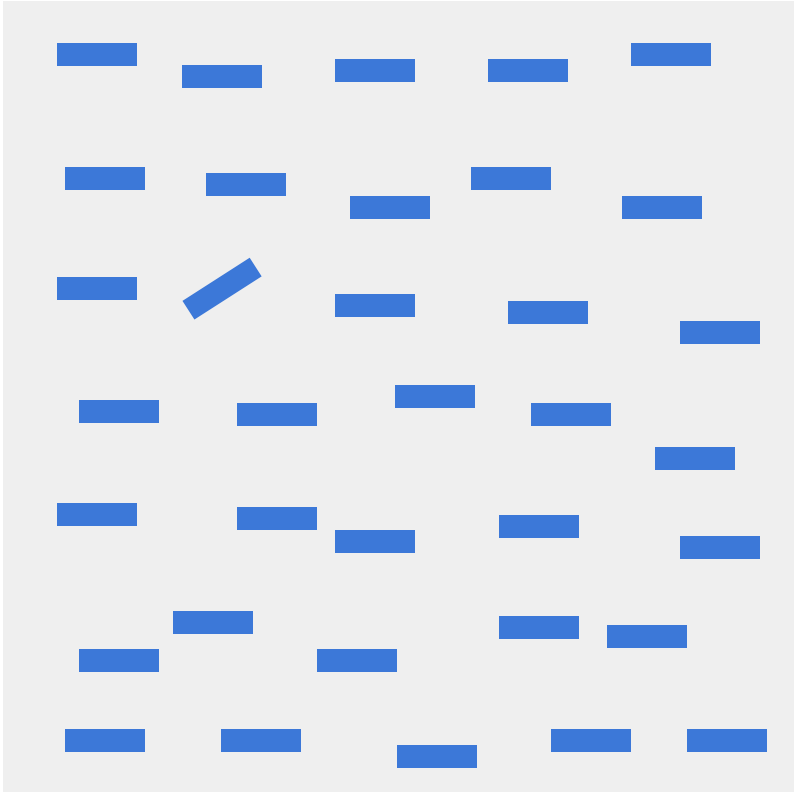
Arrays on neurons work in parallel.

Requires attention despite the name.

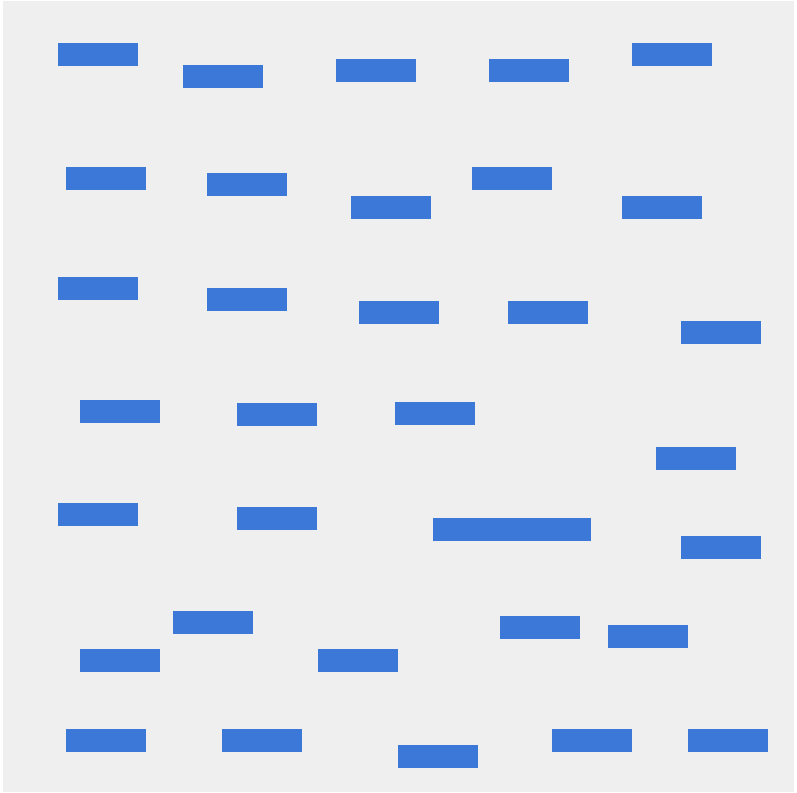
Occurs almost automatically.

What matters most is the contrast between features.

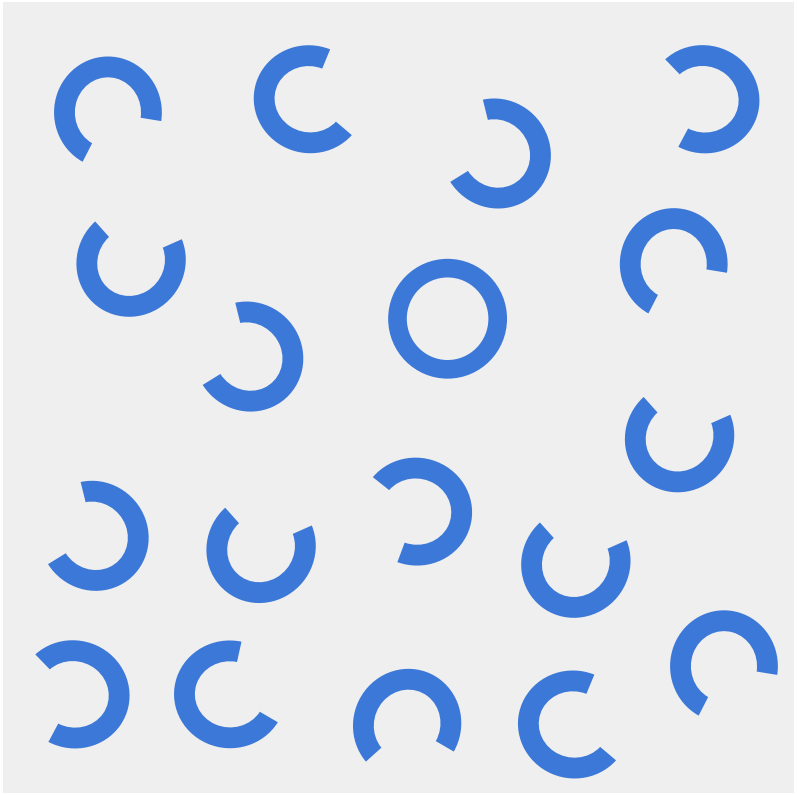
Orientation



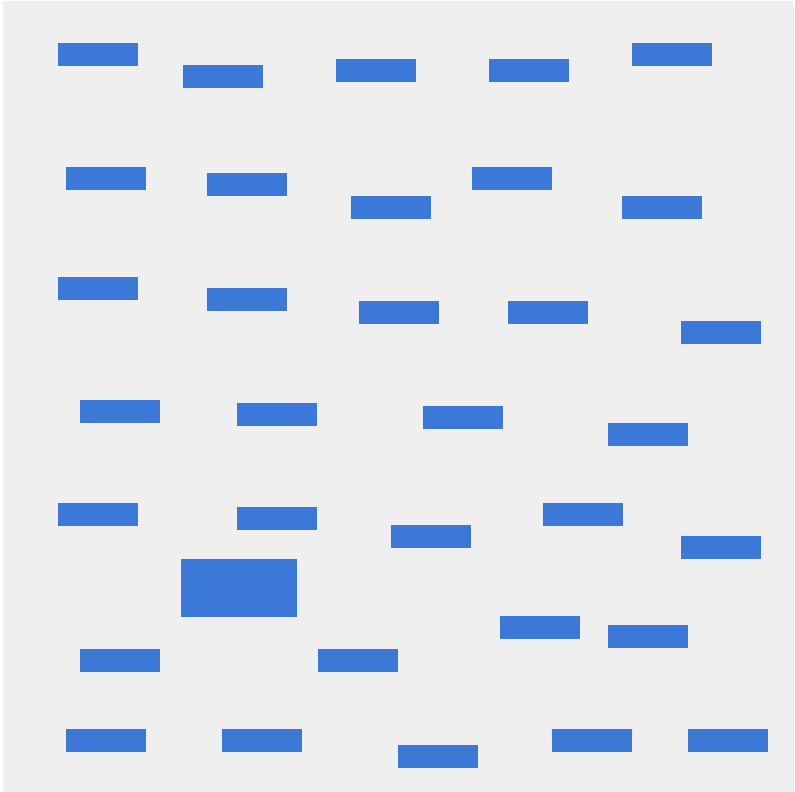
Length



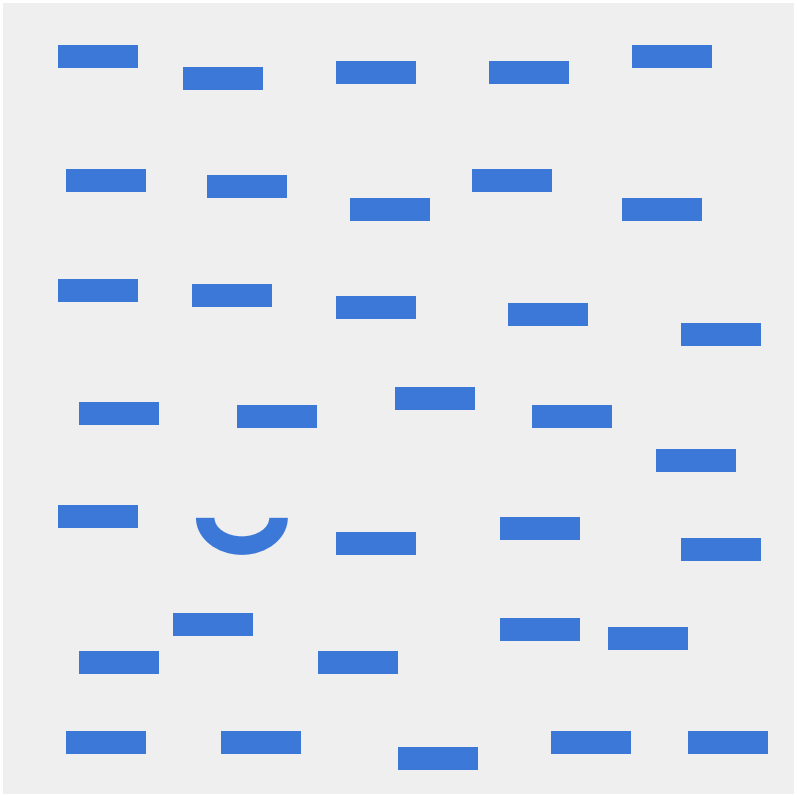
Closure



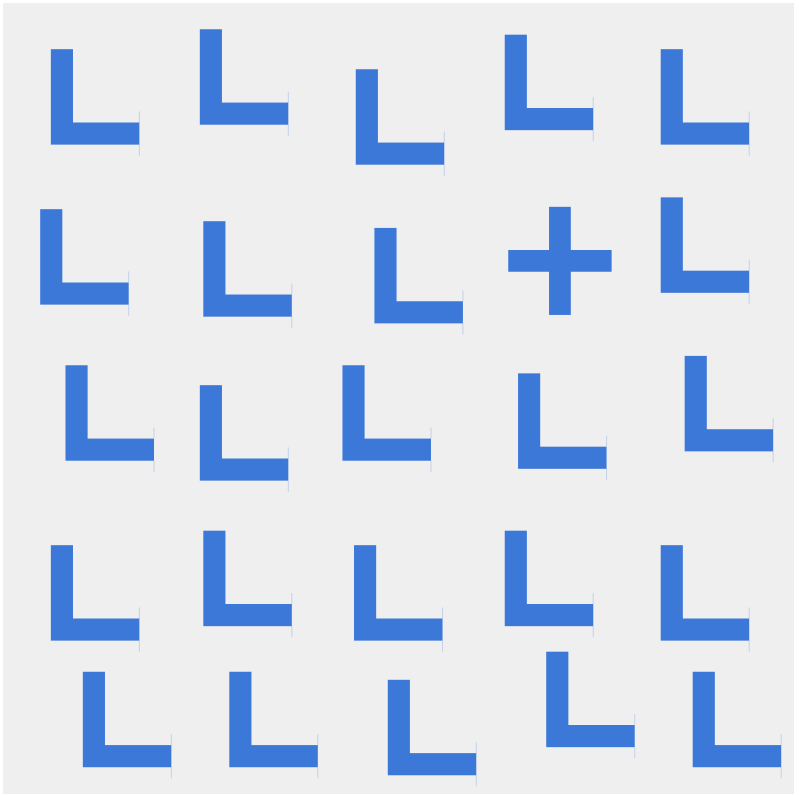
Size



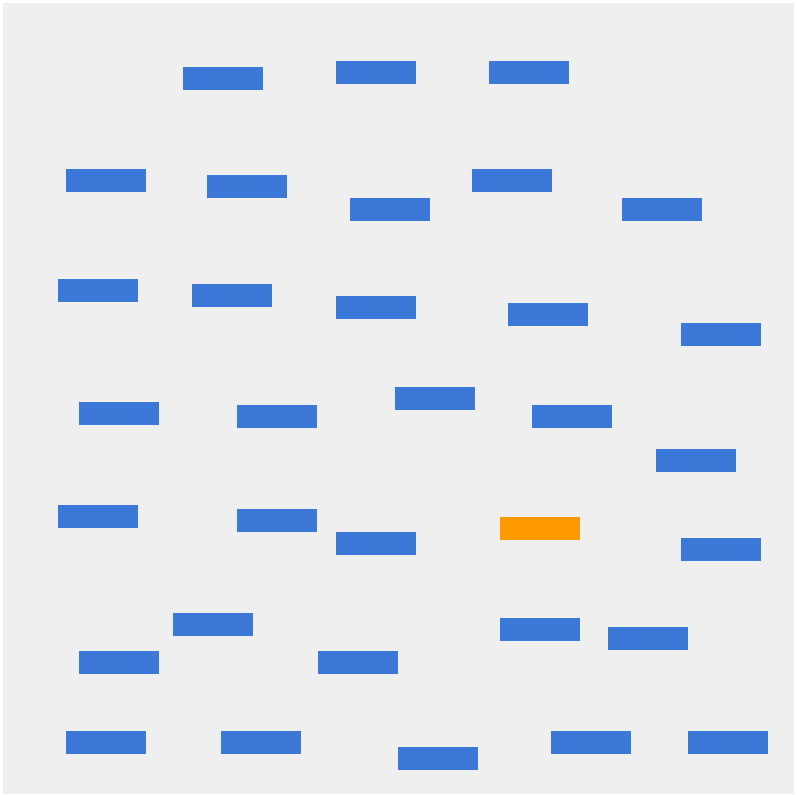
Curvature



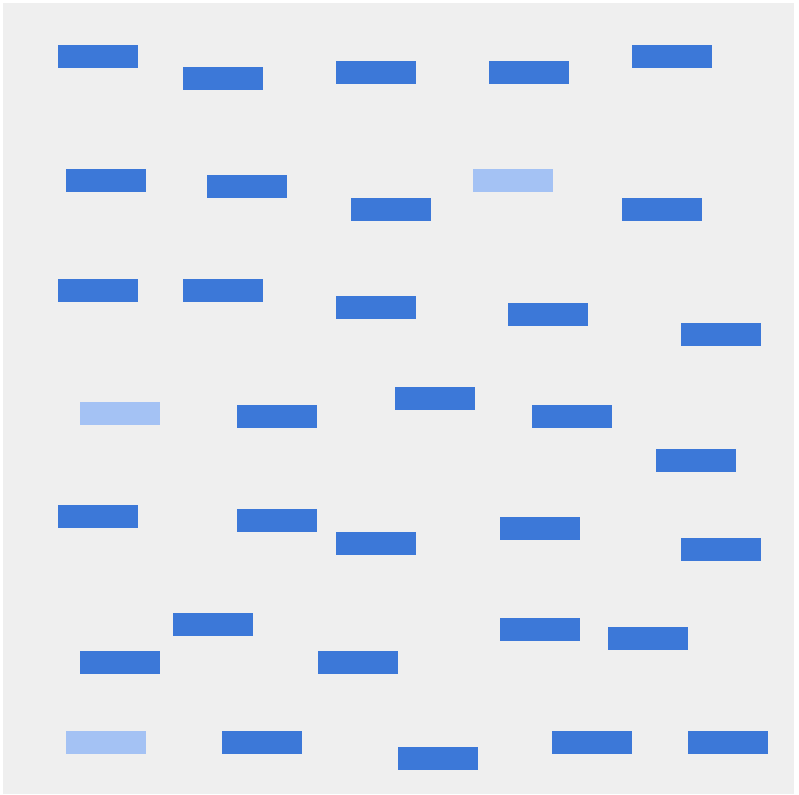
Intersection



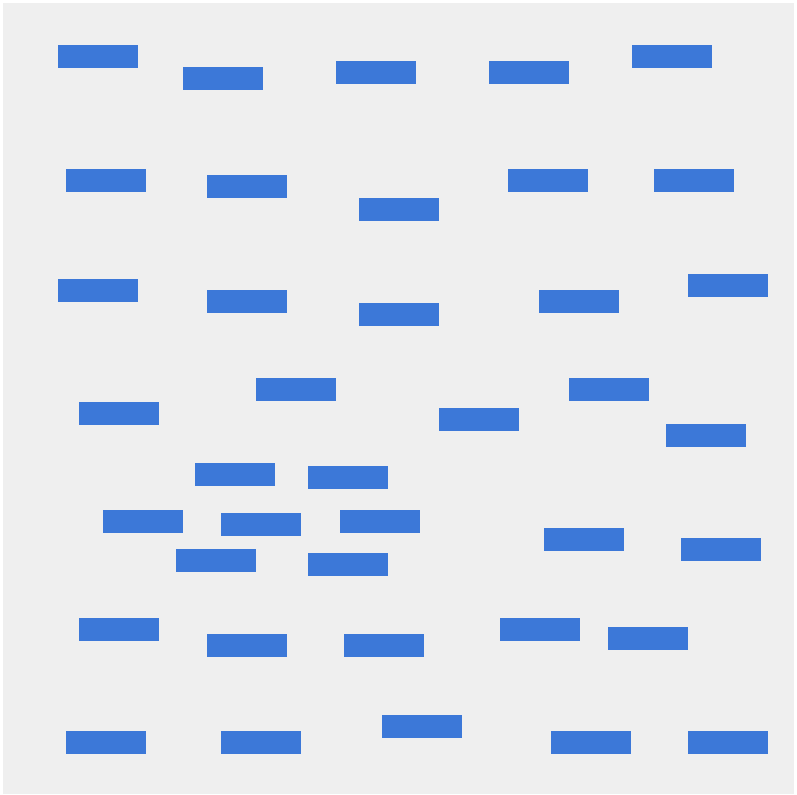
Hue



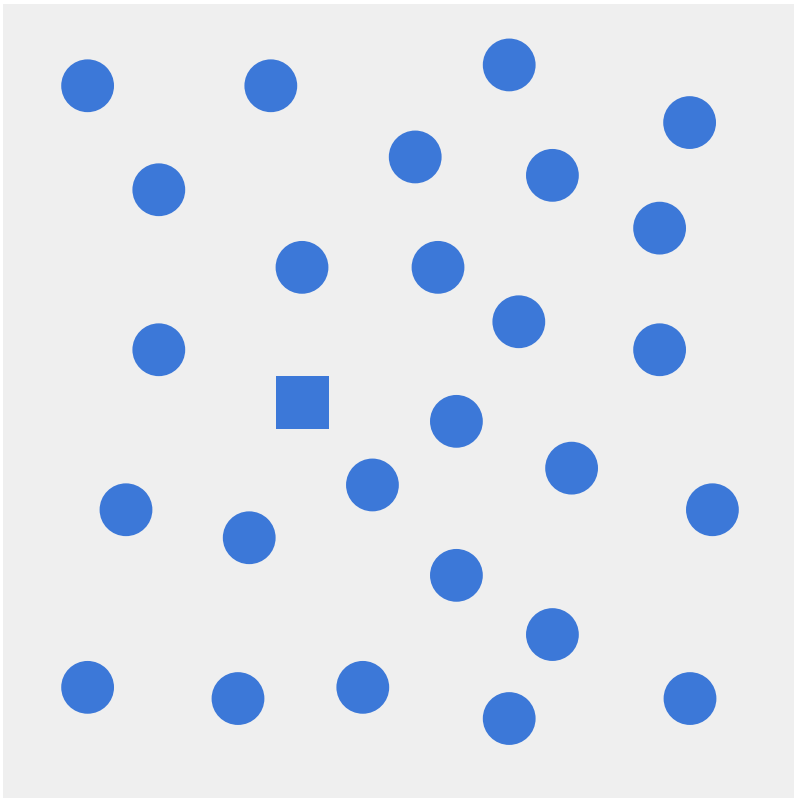
Intensity



Density



Shape



Later Vision and Postattentive Vision

Short-term and Long-term memories are related with the Later Vision, aka postattentive vision.

Postattentive Processing

Slow serial processing.

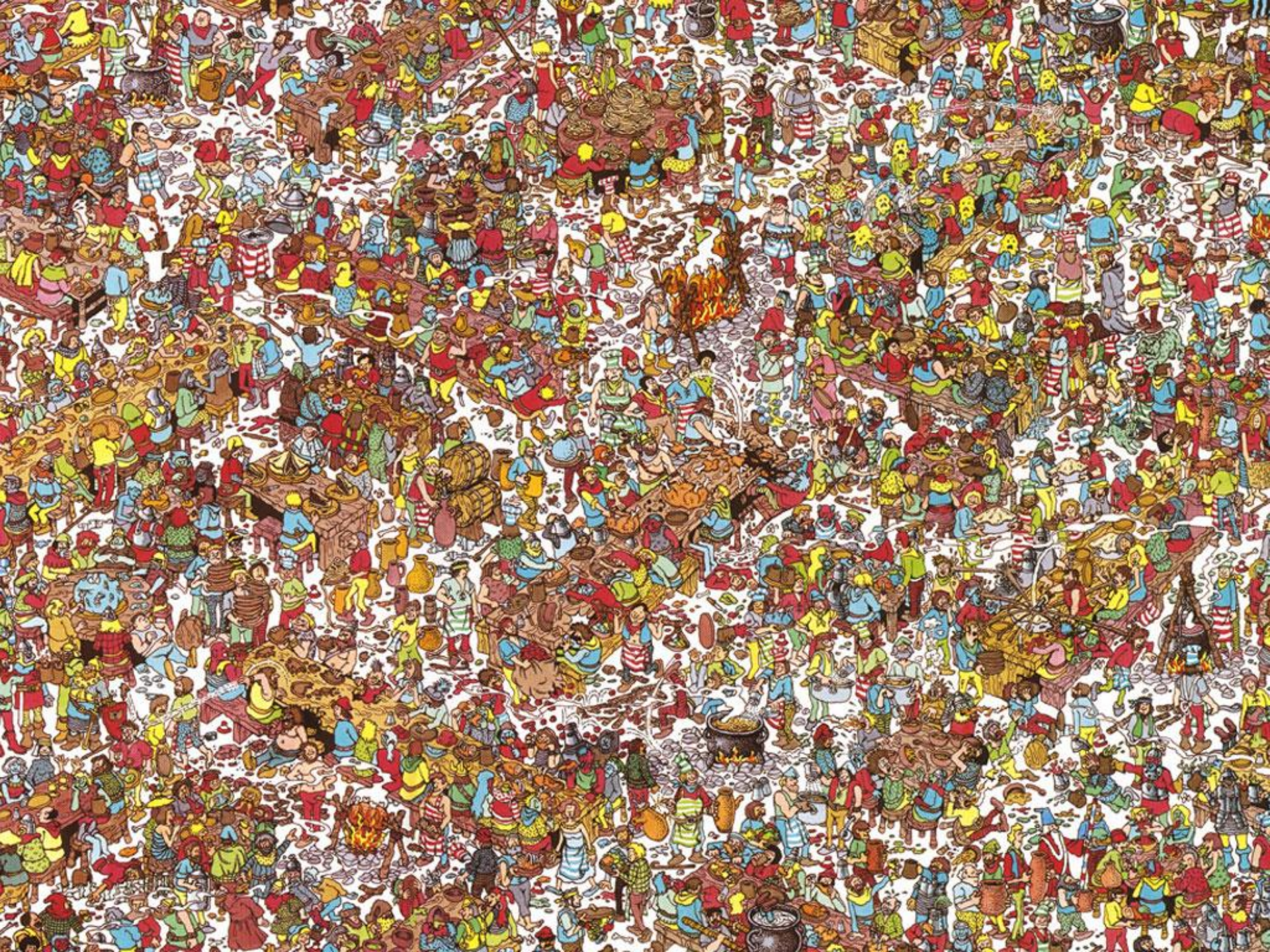
Involves working and long-term memory.

Different pathways for object recognition and visually guided motion.

Ron Rensink's examples

Ron Rensink's examples

Ron Rensink's examples



Postattentive: How many sixes?

```
4 3 6 7 9 8 1 2 5 5 1 1 5 6 1 1 5 8 1 3 4 1 5 9 1 5

1 5 3 4 5 1 1 5 2 5 1 3 1 9 2 5 1 2 1 8 9 1 4 1 1 6

5 2 1 6 1 1 6 1 2 4 1 8 1 6 1 5 8 2 4 1 4 1 5 1 9 1

1 4 1 8 1 9 5 2 1 8 1 9 1 1 5 1 1 5 1 6 1 8 2 6 1 2
```

Preattentive: How many sixes?

4 3 6 7 9 8 1 2 5 5 1 1 5 6 1 1 5 8 1 3 4 1 5 9 1 5

1 5 3 4 5 1 1 5 2 5 1 3 1 9 2 5 1 2 1 8 9 1 4 1 1 6

5 2 1 6 1 1 6 1 2 4 1 8 1 6 1 5 8 2 4 1 4 1 5 1 9 1

1 4 1 8 1 9 5 2 1 8 1 9 1 1 5 1 1 5 1 6 1 8 2 6 1 2

Perceptual Tasks

Recall that ...

Data Visualization is simply **mapping data** to **geometric objects** and their **visual attributes**

Geometric Objects and Visual Attributes

Objects

- Points
- Lines
- Bars
- 2D areas & Polygons

Attributes

- Position
- Color
- Size
- Shape
- Fill pattern
- Border
- Line style

Not all object attributes are equally-effectively perceived

Perceptual Tasks

- 1984 paper by W.S. Cleveland and R. McGill
- Statisticians working at AT&T labs
- Identified a list of 10 elementary perceptual tasks.
- Tasks required to decode information in a graph.
- Ran experiments to determine the accuracy in which we perform those tasks.
- Proposed basic guidelines to encode data.

Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods

WILLIAM S. CLEVELAND and ROBERT McGILL*

Journal of the American Statistical Association, September 1984

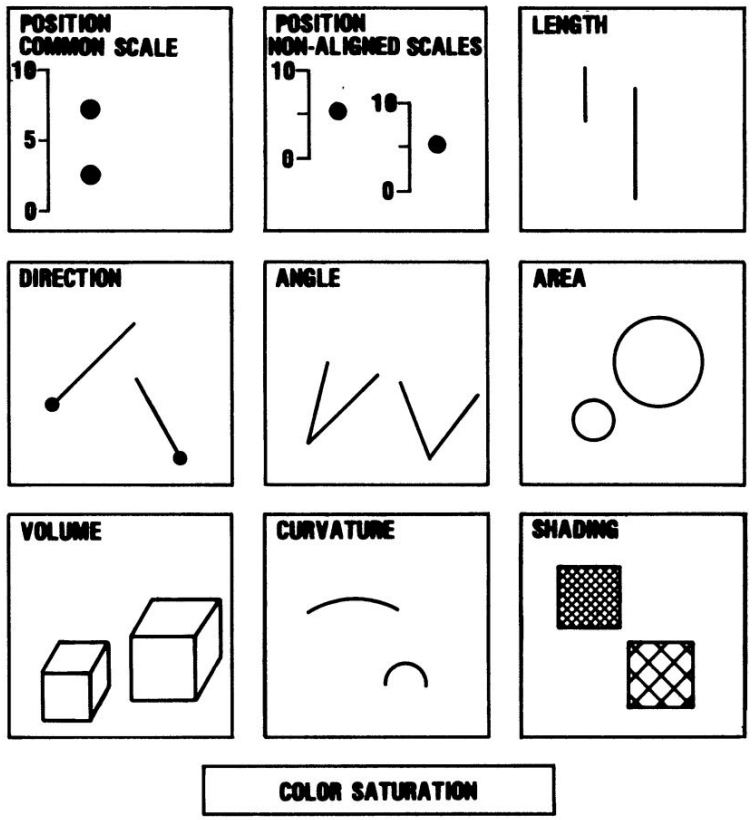


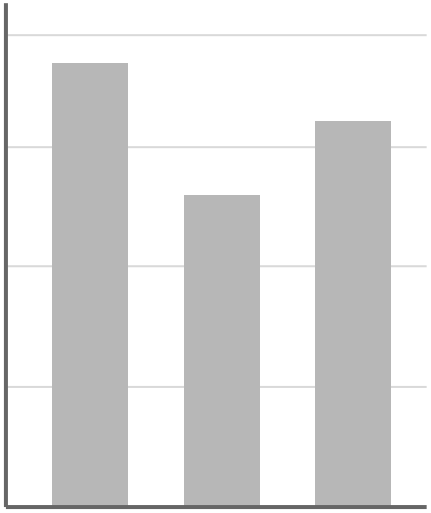
Figure 1. Elementary perceptual tasks.

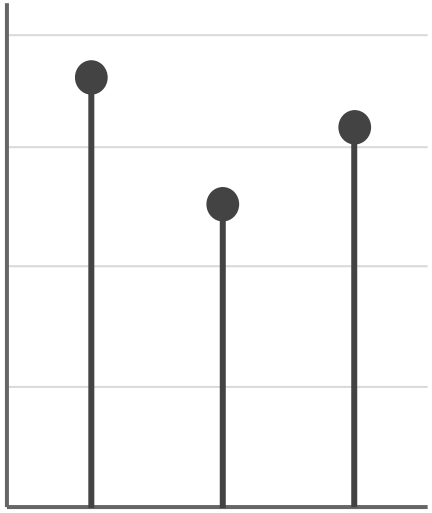
Rank of Perceptual Tasks

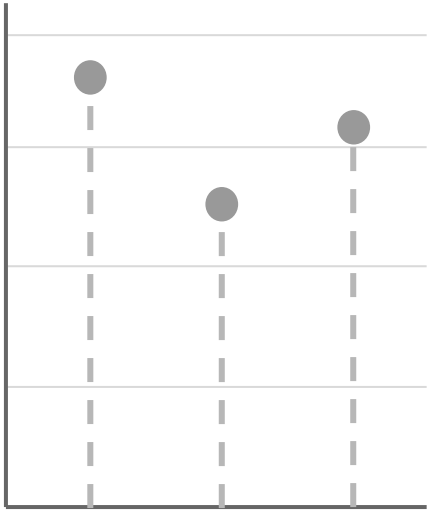
1. Position along a common scale
2. Position along identical, nonaligned scales
3. Length-Direction
4. Angle-Slope
5. Area
6. Volume and Curvature
7. Shading and color saturation

Keep in mind: there are nuances and exceptions to the kind of perceptual task depending on context.

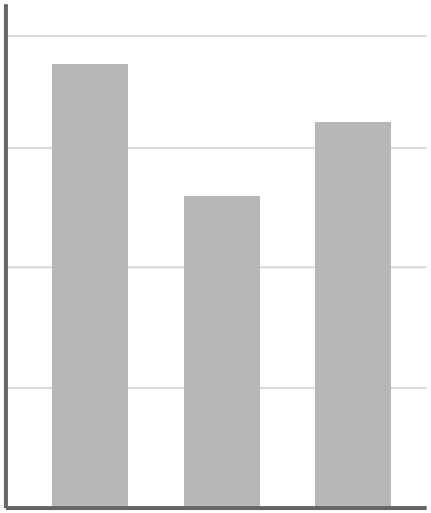
Position along a common scale

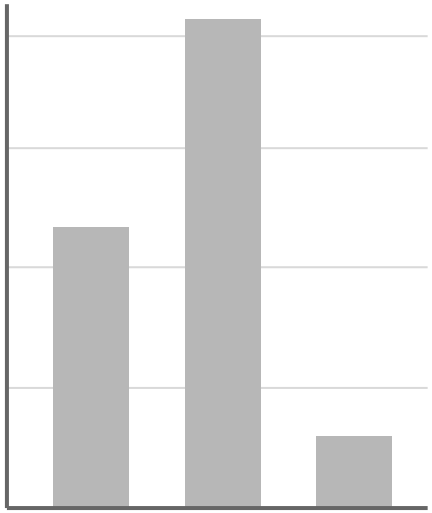


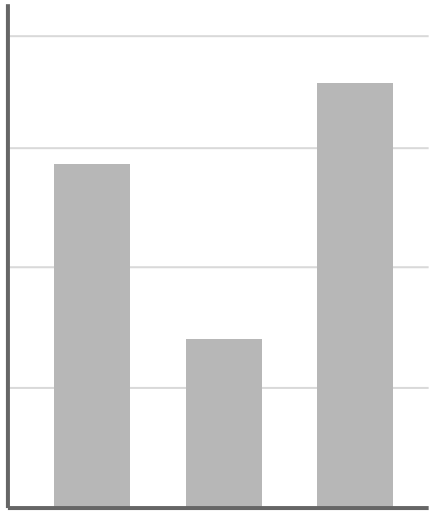




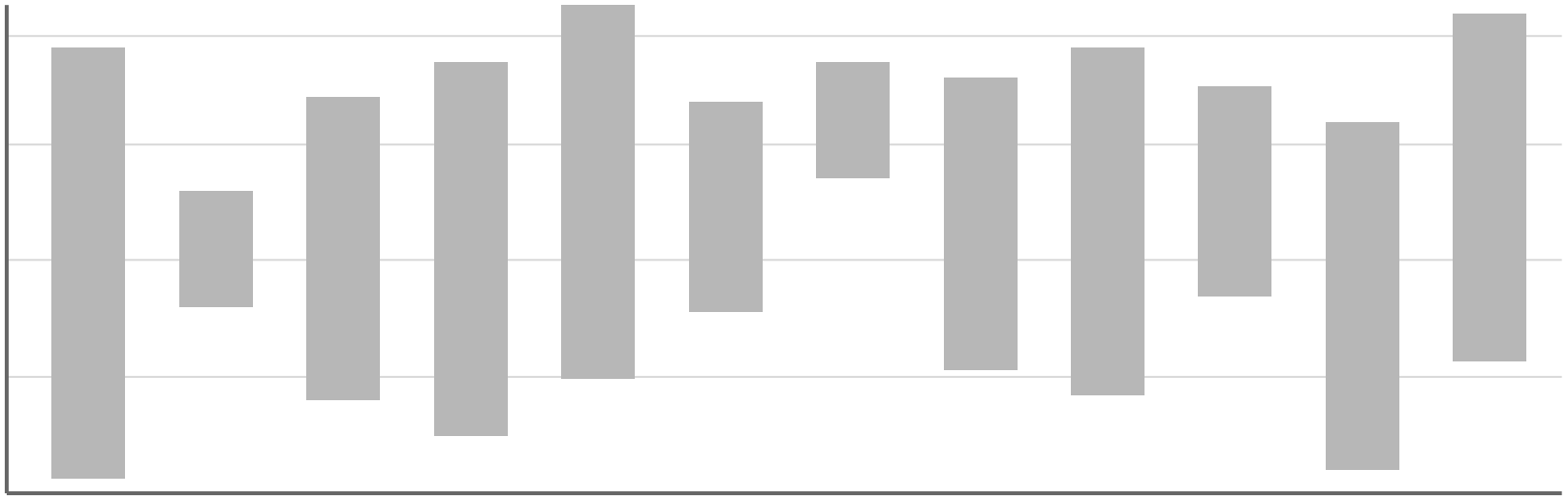
Position along a nonaligned scales





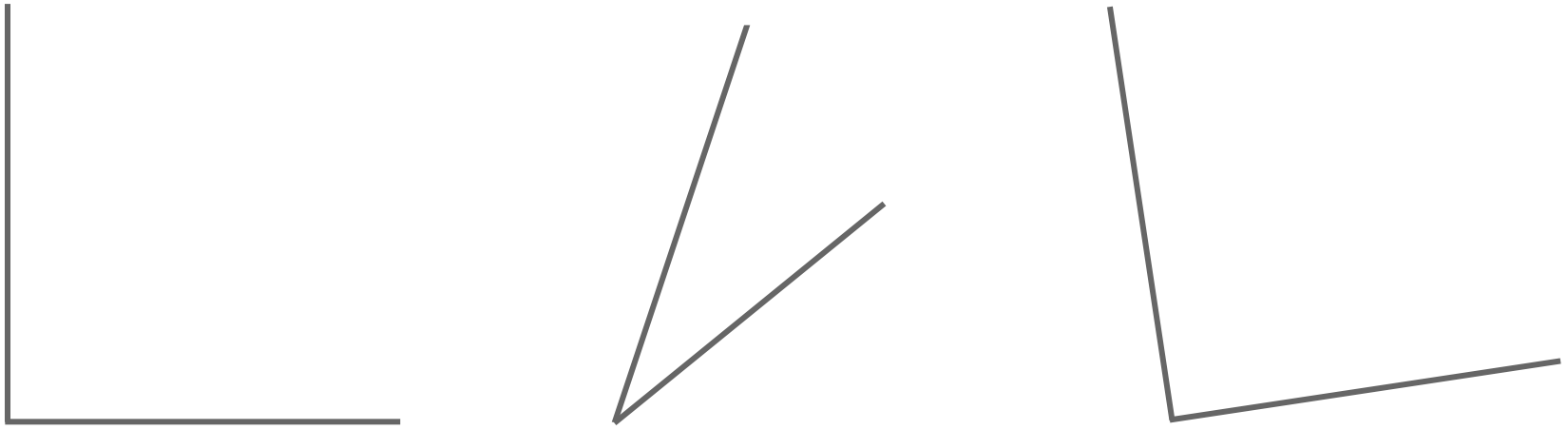


Length

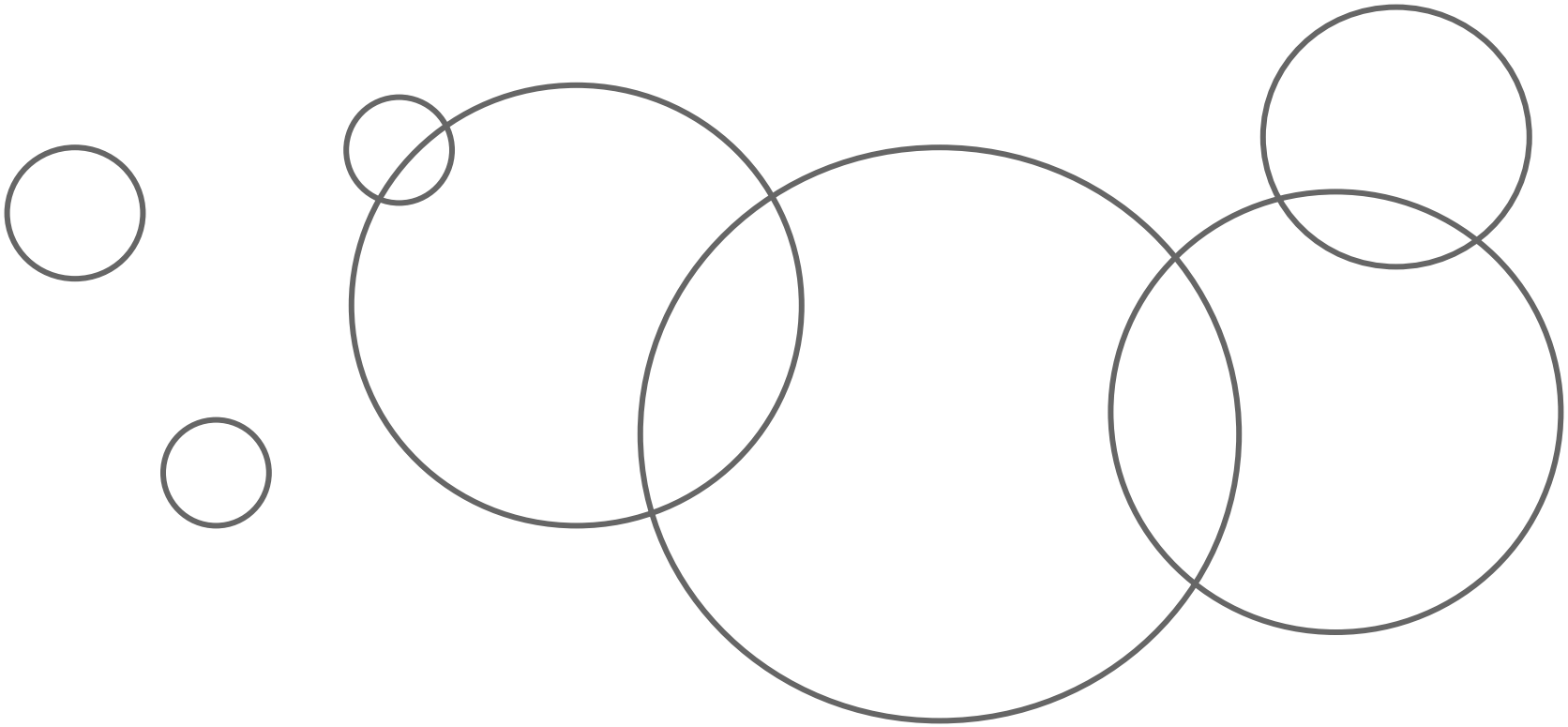


Direction

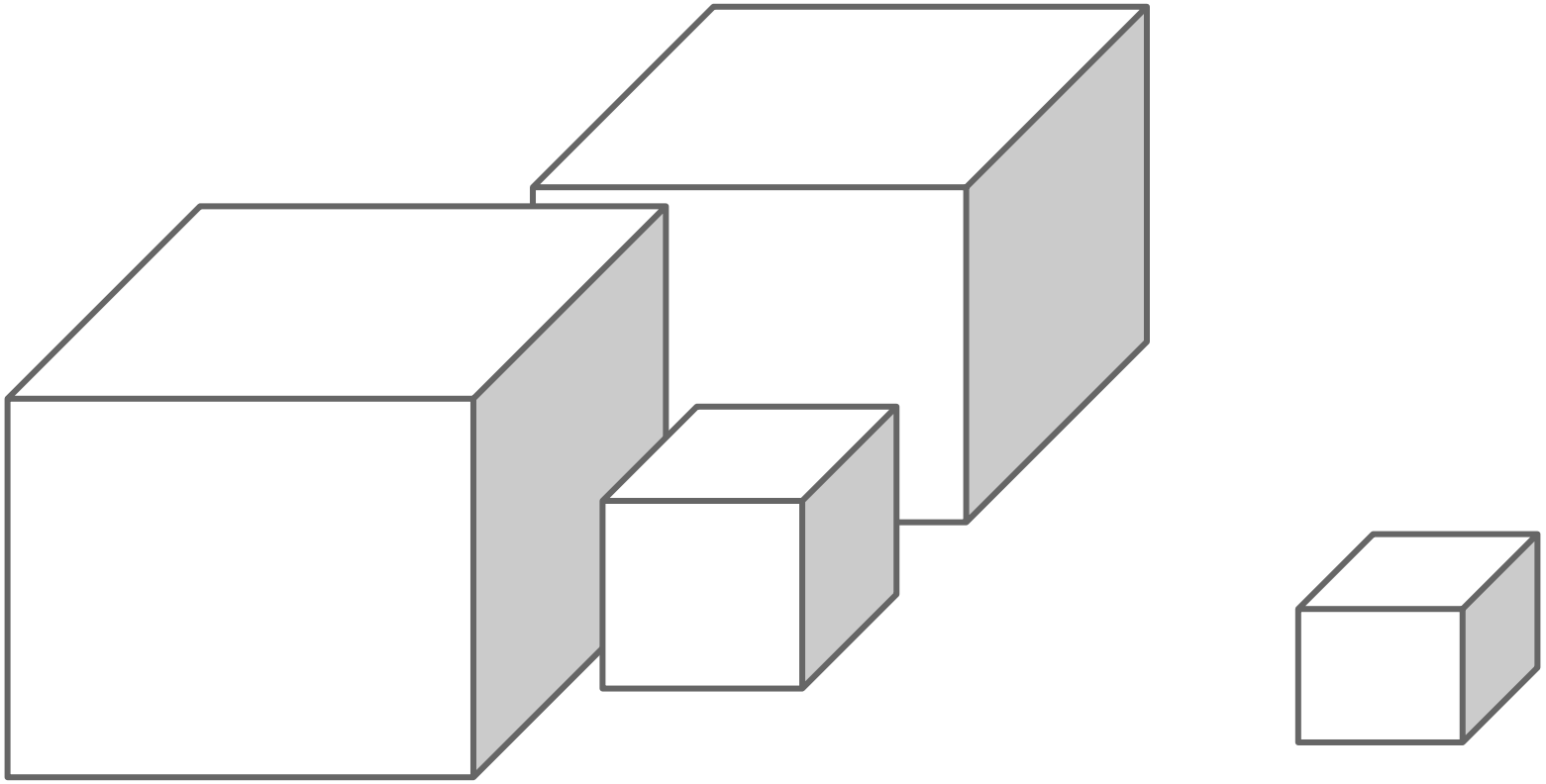
Angle



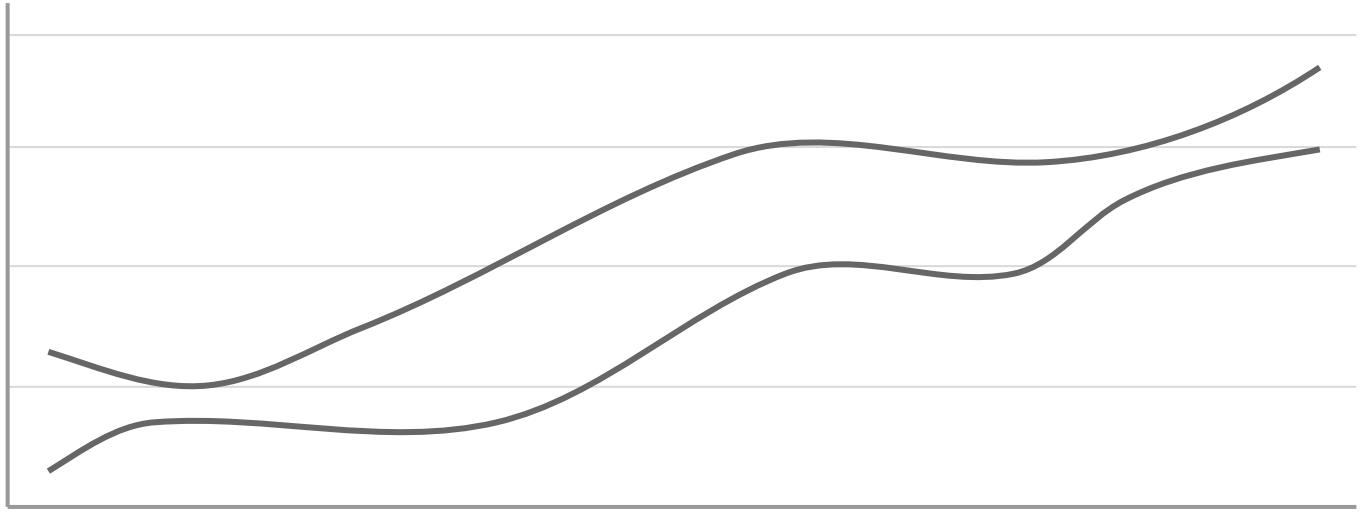
Area



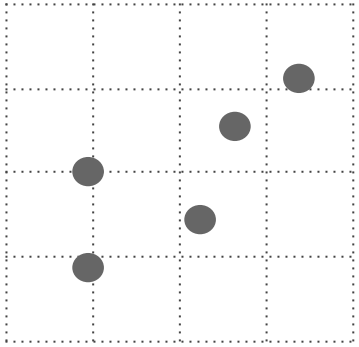
Volume



Curvature

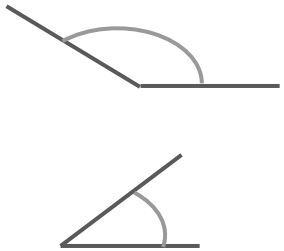


Position

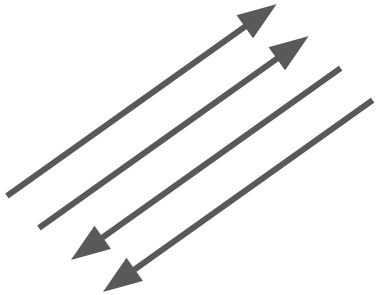


Length

Angle



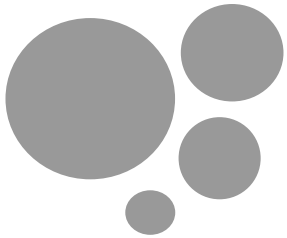
Direction



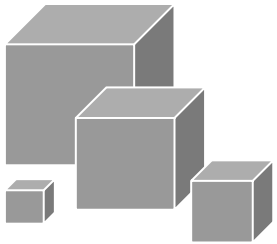
< More accurate

Less accurate >

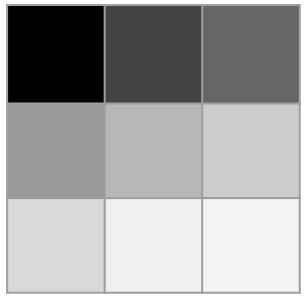
Area



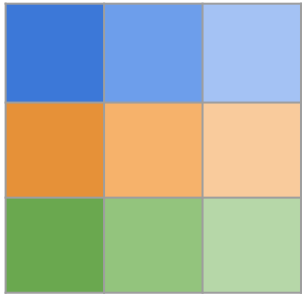
Volume



Saturation



Hue



< More accurate

Less accurate >

Visual cues ranked by Cleveland and McGill

Some Comments

We tend to jundge lengths relatively well.

We underestimate acute angles (< 90º).

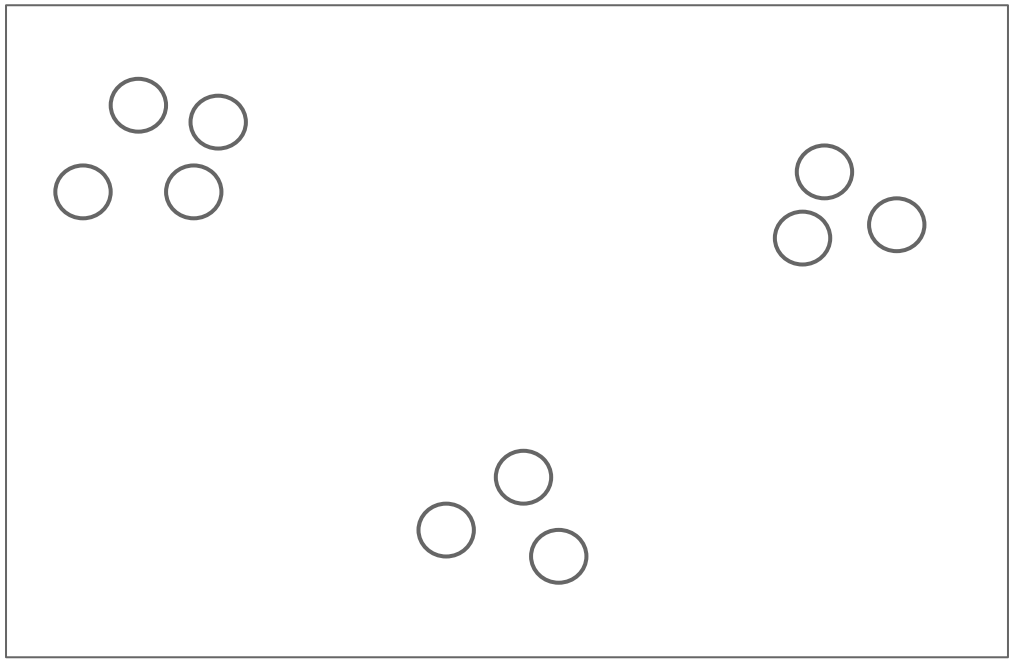
We overestimate obtuse angles (> 90º).

Angles with horizontal bisectors appear larger than those with vertical bisectors.

Area judgements are less accurate than length and position judgements.

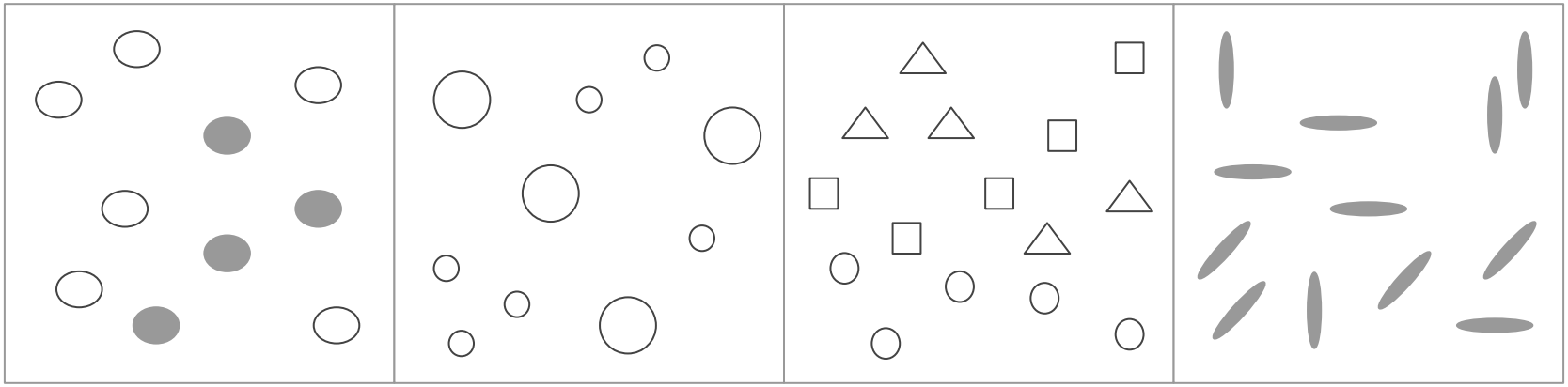
Gestalt Principles

Principle of Proximity



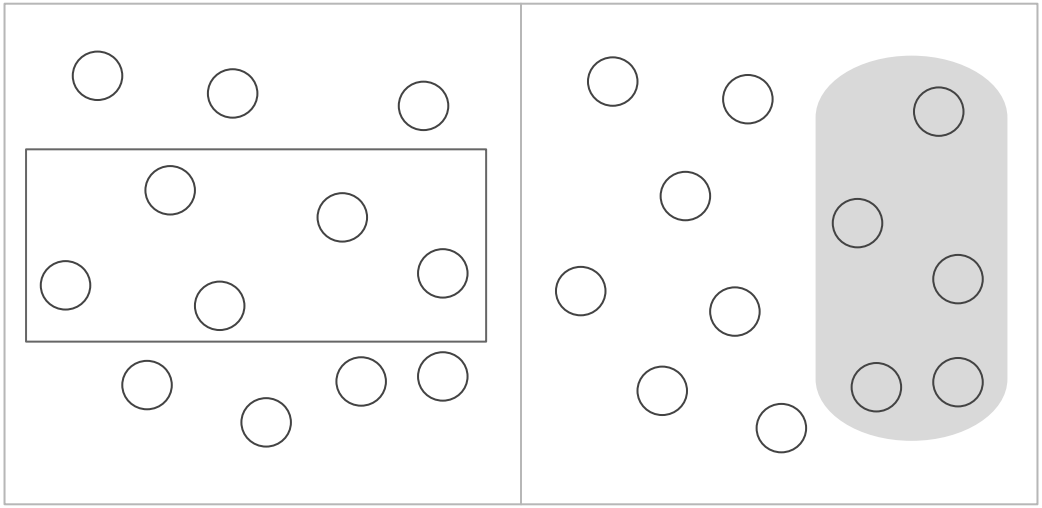
We perceive objects that are closer to each other as belonging to a group.

Principle of Similarity



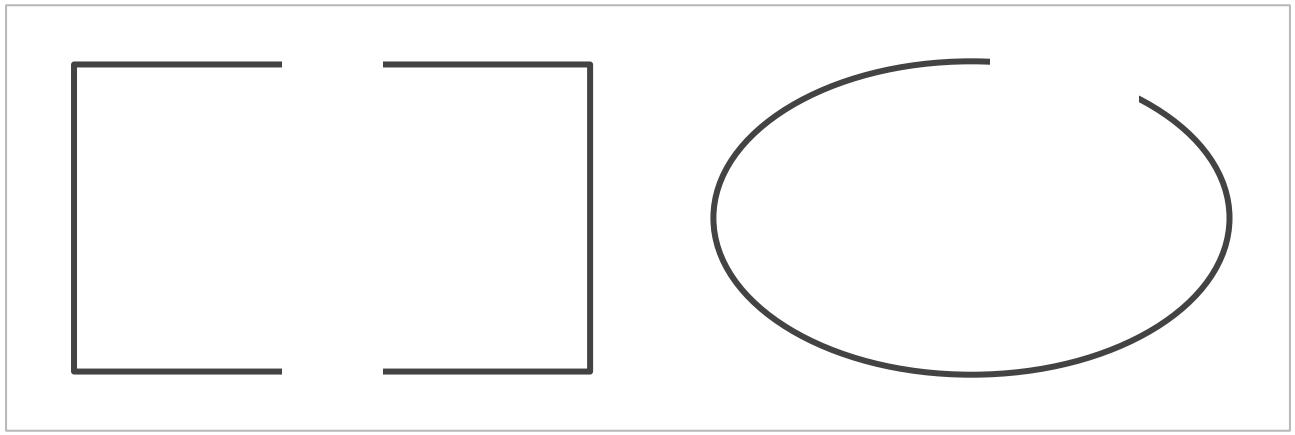
We tend to group together objects that are similar in color, size, shape, and orientation.

Principle of Enclosure



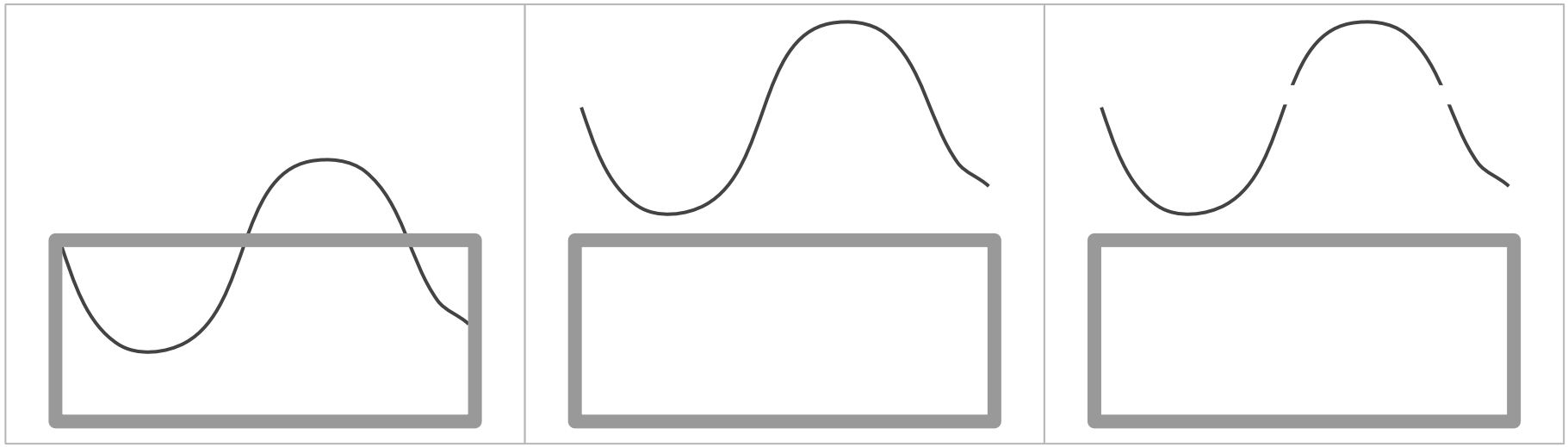
We perceive objects as belonging together when they are enclosed by anything.

Principle of Closure



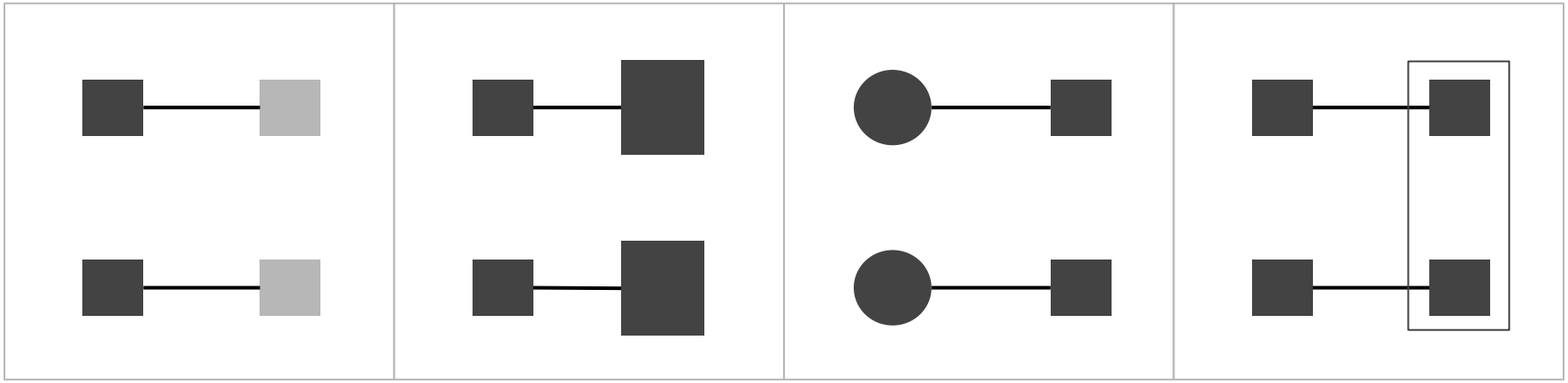
We have a keen dislike for loose ends. We perceive open structures as closed, complete, and regular.

Principle of Continuity



We perceive objects as belonging together, as part of a single whole, if they are aligned with one another or appear to form a continuation of one another.

Principle of Connection



We perceive objects that are connected (e.g. by a line) as part of the same group. Connection exercises greater power over proximity or similarity, but less than enclosure (as you can see in this figure).

In summary ...

2 types of visions

Early Vision

↓

Iconic memory

↓

Preattentive processing

↓

Parallel & Rapid

Later Vision

↓

Short-term memory

↓

Postattentive processing

↓

Serial & Slow

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.

Not all visual attributes are equally perceived.