SCIENTIFIC AND LARGE DATA VISUALIZATION

November 22, 2019

Applied Perception – Part I

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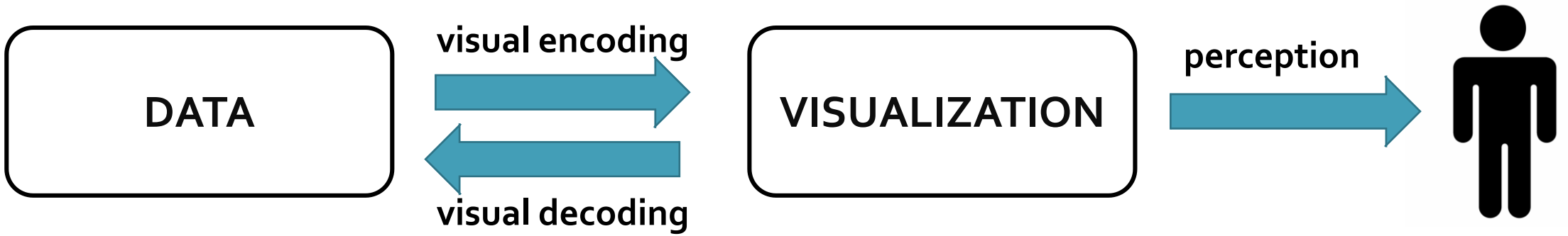
Why studying perception

Why perception

- We have seen that information visualization is about transforming data into a visual representation so that a human can extract useful information out of it



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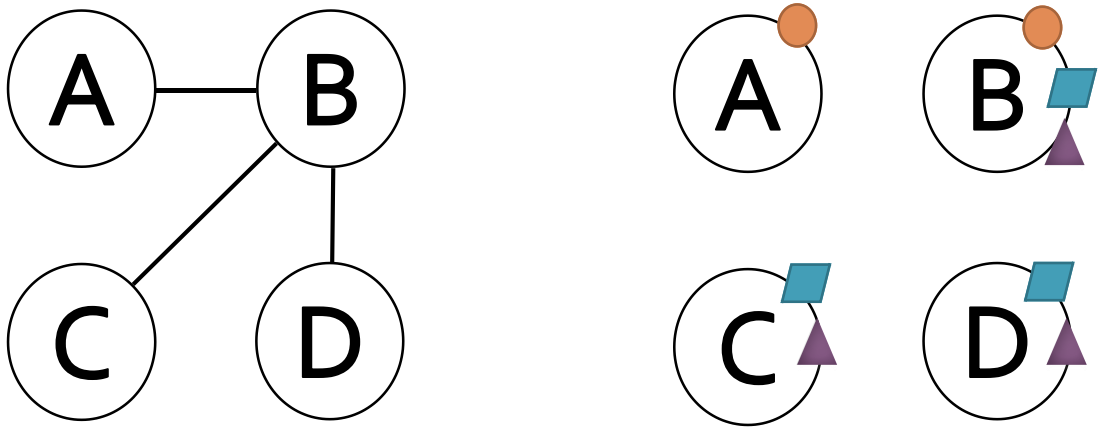
- We have seen that information visualization is about transforming data into a visual representation so that a human can extract useful information out of it
- The *effectiveness* of a visual representation is not arbitrary: it strongly depends on how the brain works



[Redrawn from C. Ware, Information Visualization: Perception for Design (2013)]

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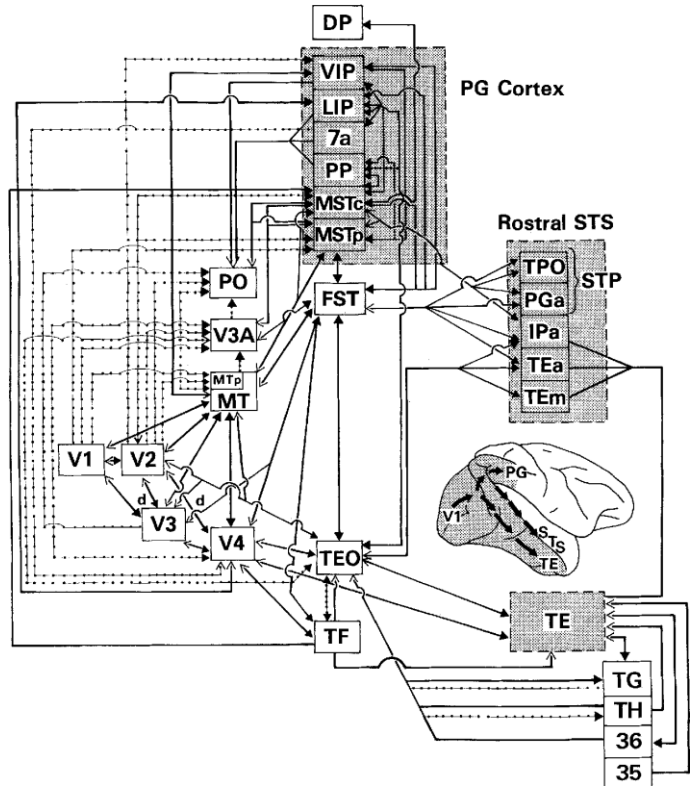

[The major visual pathways of the Macaque monkey, Distler et al. (1993)]

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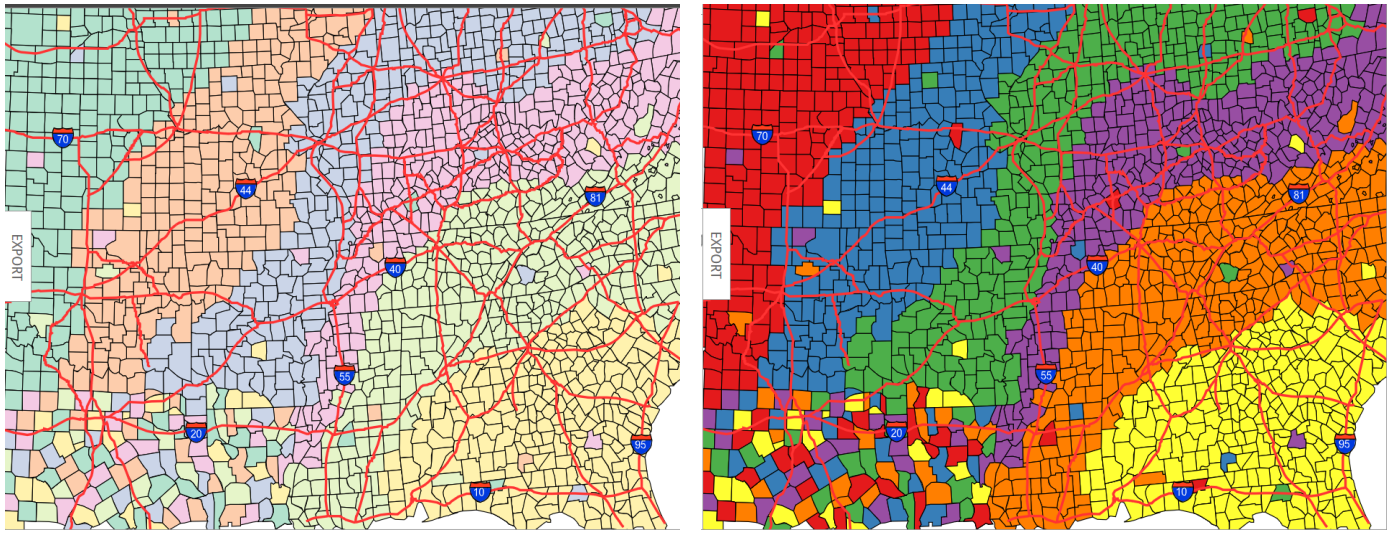

[ColorBrewer2 – Color Advice for Cartography, http://colorbrewer2.org]

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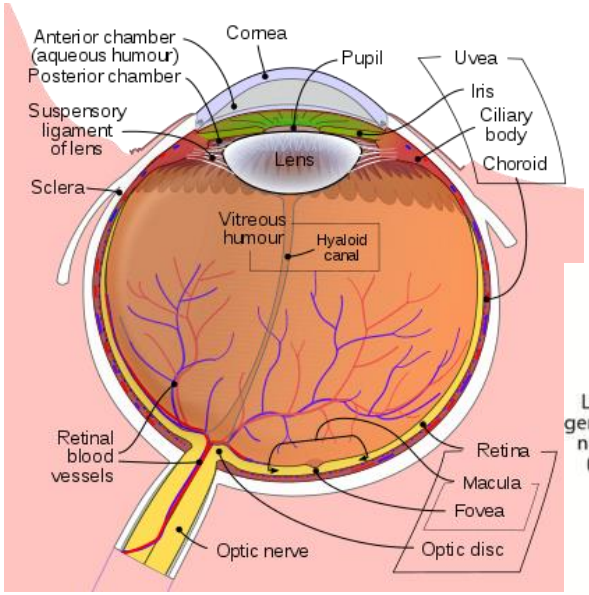
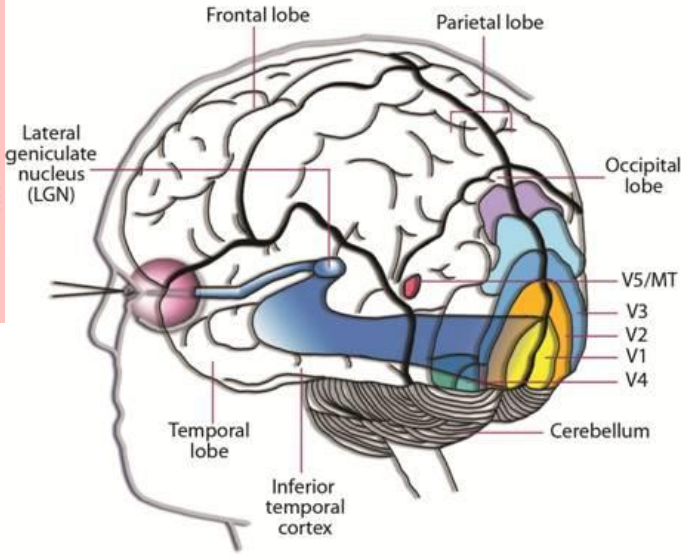
- *«We don't see images with our eyes; we see them with our brain»* (Stephen Few)

The human visual system

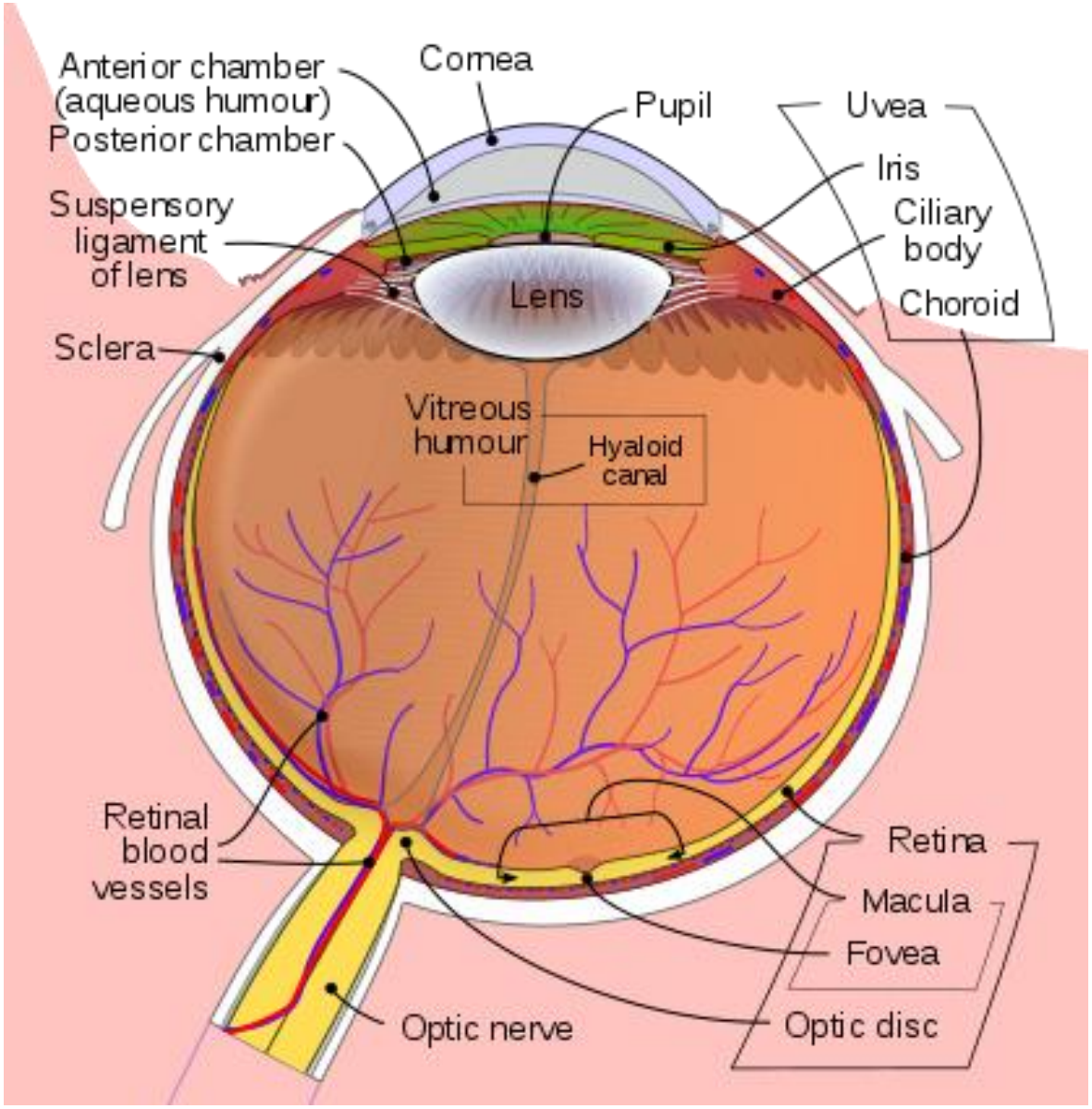
The human visual system

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





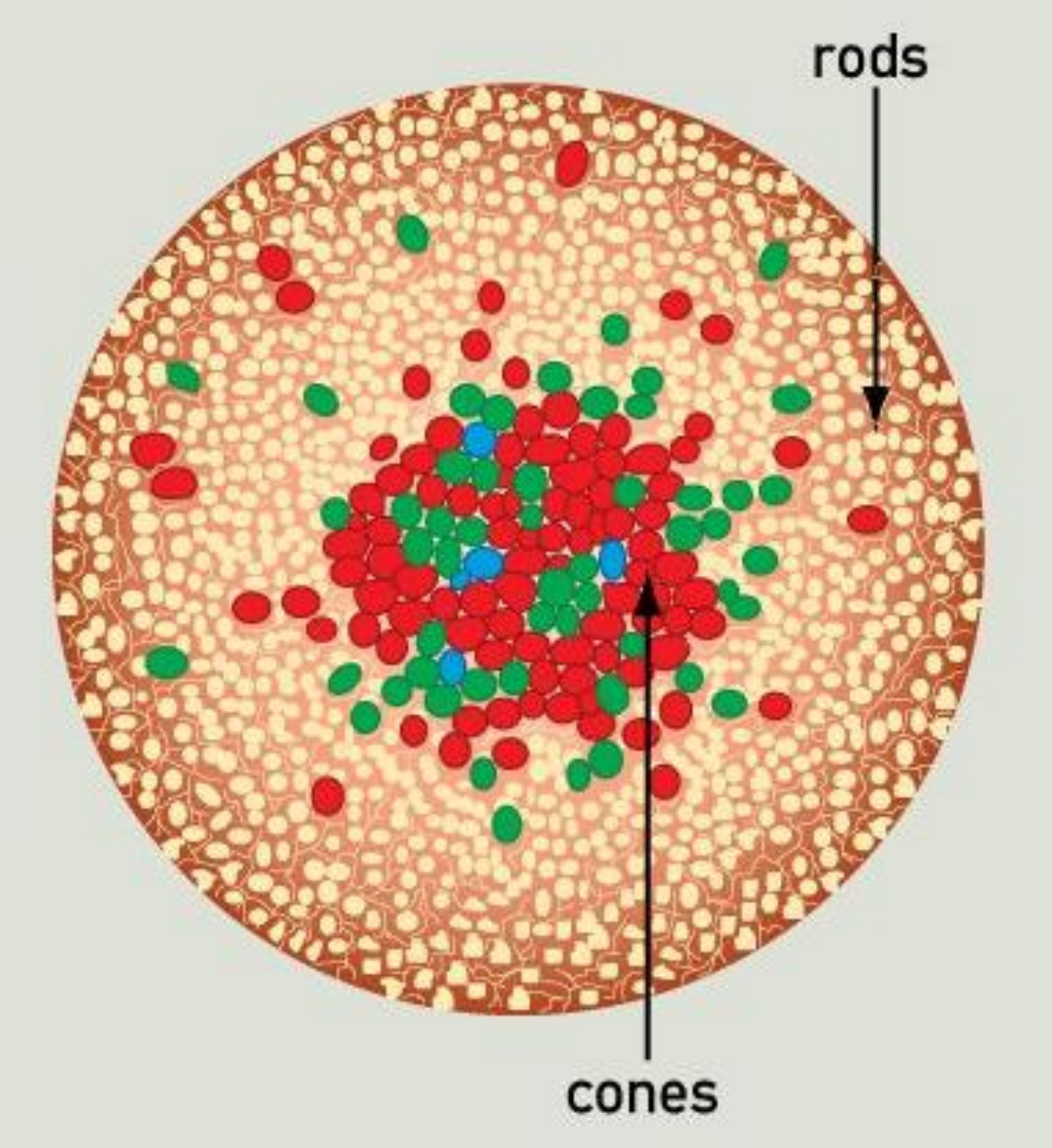
The eye


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

Rods and cones

The retina has a non-uniform distribution of photoreceptors, called *rods* and *cones*, which transform signals from the eye to signals to the brain

Rods are active in low light conditions, cones in normal light conditions

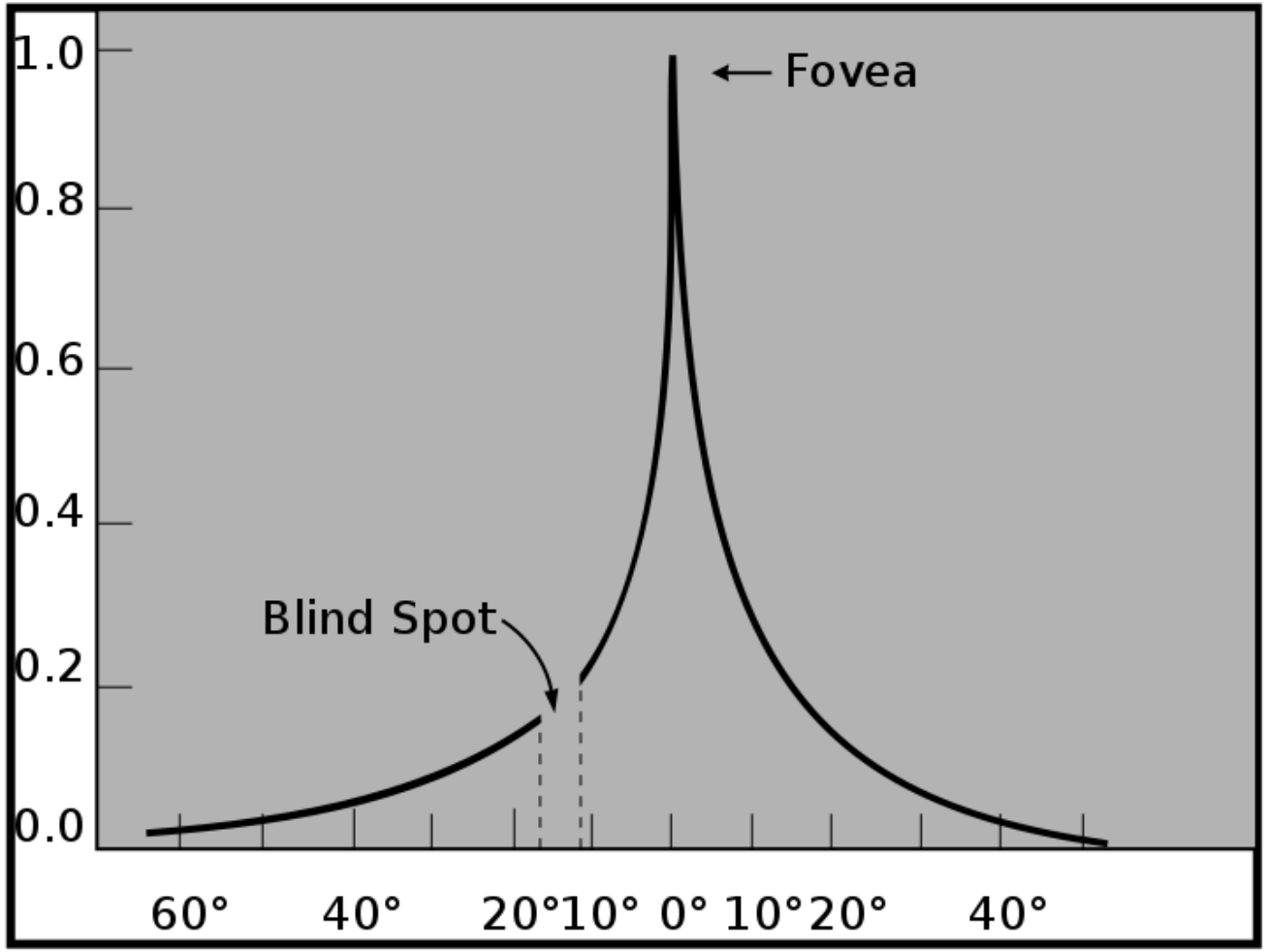


The fovea

The resolution changes according to the location in the retina

Rods and cones are concentrated in a region of the retina called *fovea*

The fovea has a very high resolution



[Figure by Vanessa Ezekowitz under CC-SA-BY 3.0]

The brain

LGN (Lateral Geniculate Nucleus) forwards pulses to V1. It is also connected with V2 and V3

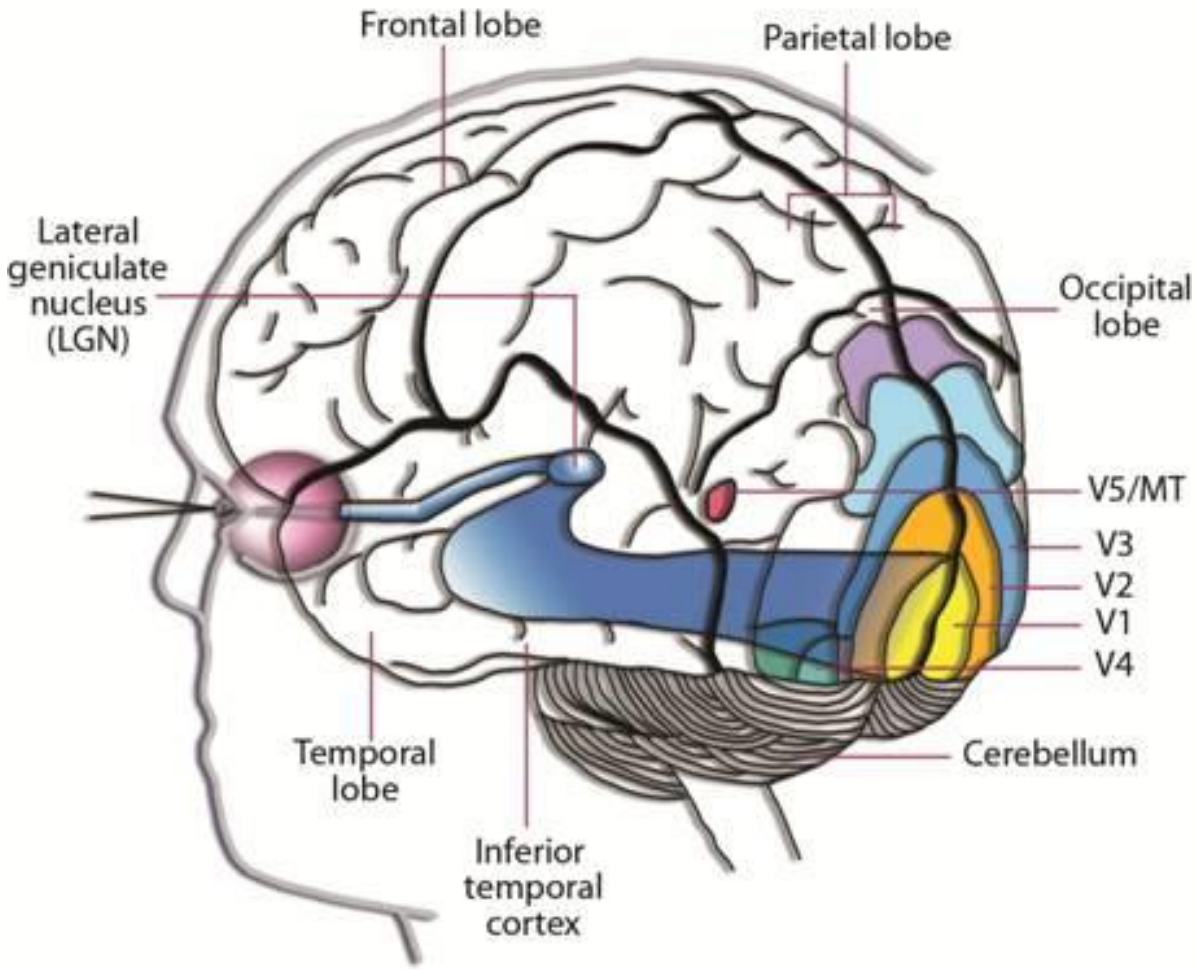
V1 is the *primary visual cortex*. It performs edge detection and global organization (inputs from V2, V3)

V2 handles depth, foreground, illusory contours

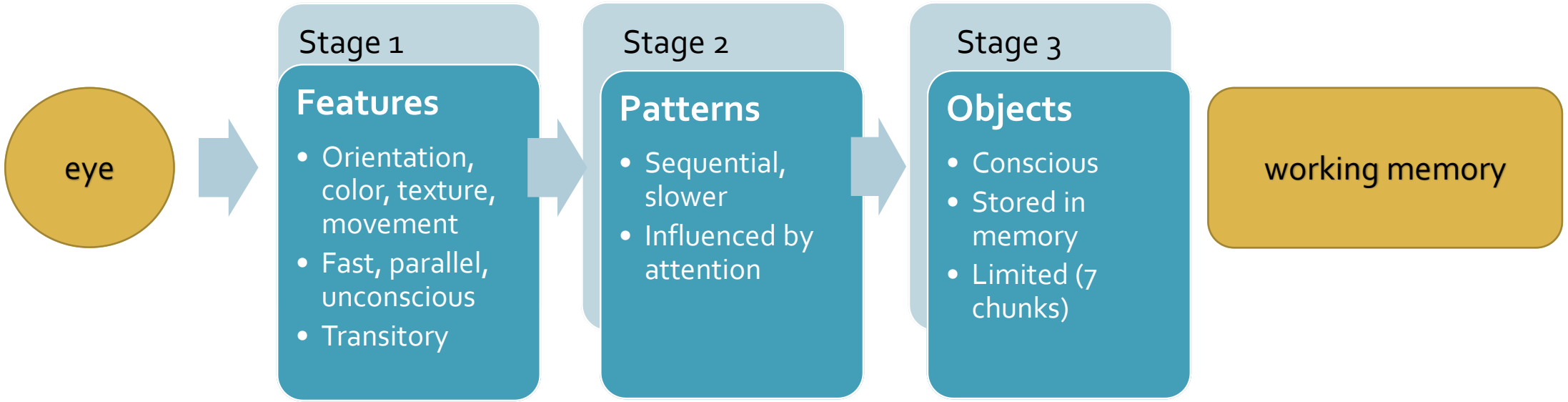
V3 supports global motion understanding

V4 recognizes simple geometric shape

V5/MT: motion perception integration and eye movements guidance



A lossy (idealized) process



Only a small fraction of the information that is entering our eyes is actually stored in our memories.

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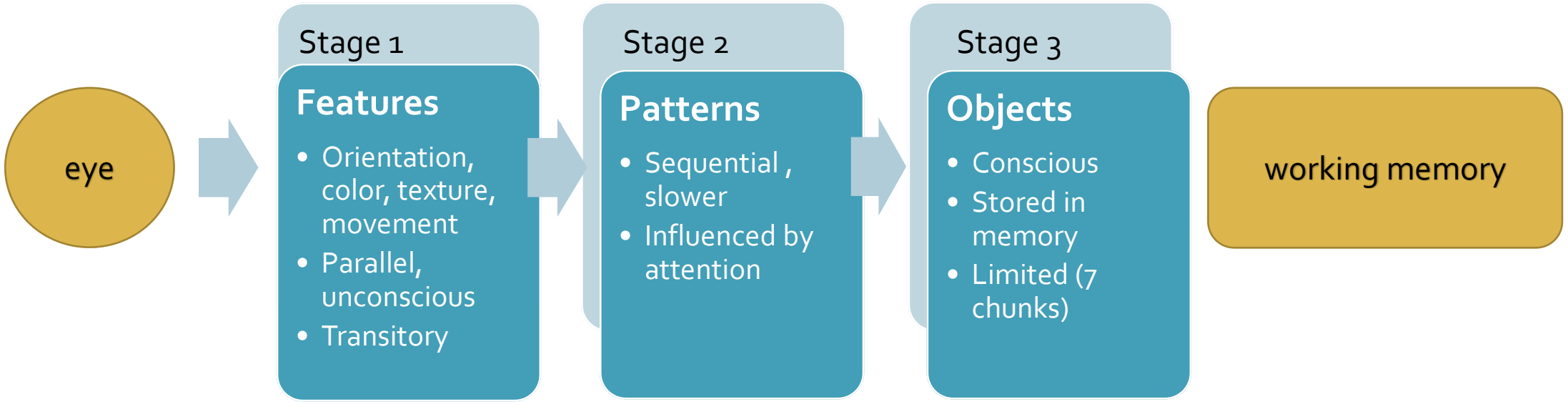


Only a small fraction of the information that is entering our eyes is actually stored in our memories.

Behind this, there are the concepts of *saccadic eye movements* and *visual attention*.

Saccading eye movements

Saccades take 20-180 ms. Both eyes move in the same direction. The movement may not be a simple linear trajectory

A fixation is composed of slower and fine movements (microsaccades, tremor and drift) that help the eye align with the target. A fixation takes 50-600 ms

Visual attention and intentional blindness

What is retained in our memory highly depends on what we are attending to (and on our task)

It is easy to be blind to (even big) changes if we do not pay attention to the visual information that changes

[https://www.smithsonianmag.com/science-nature/but-did-you-see-the-gorilla-the-problem-with-inattentional-blindness-17339778/]

Quick recap

- The study of the HVS helps one to figure out how to design effective visual representations
- With saccadic movements we detect information from different regions, and glue it together to sense the world
- The HVS discards a lot of the information coming from the eyes, and retains what is needed to accomplish a task

Perception and visual effectiveness

Effectiveness parameters

- Remember that *visual channels* are the visual properties that encode data attributes (position, size, angle, color, shape, texture…)
- The effectiveness of a visual channel can be measured in terms of different parameters:
  - accuracy
  - discriminability
  - salience
  - separability
  - grouping

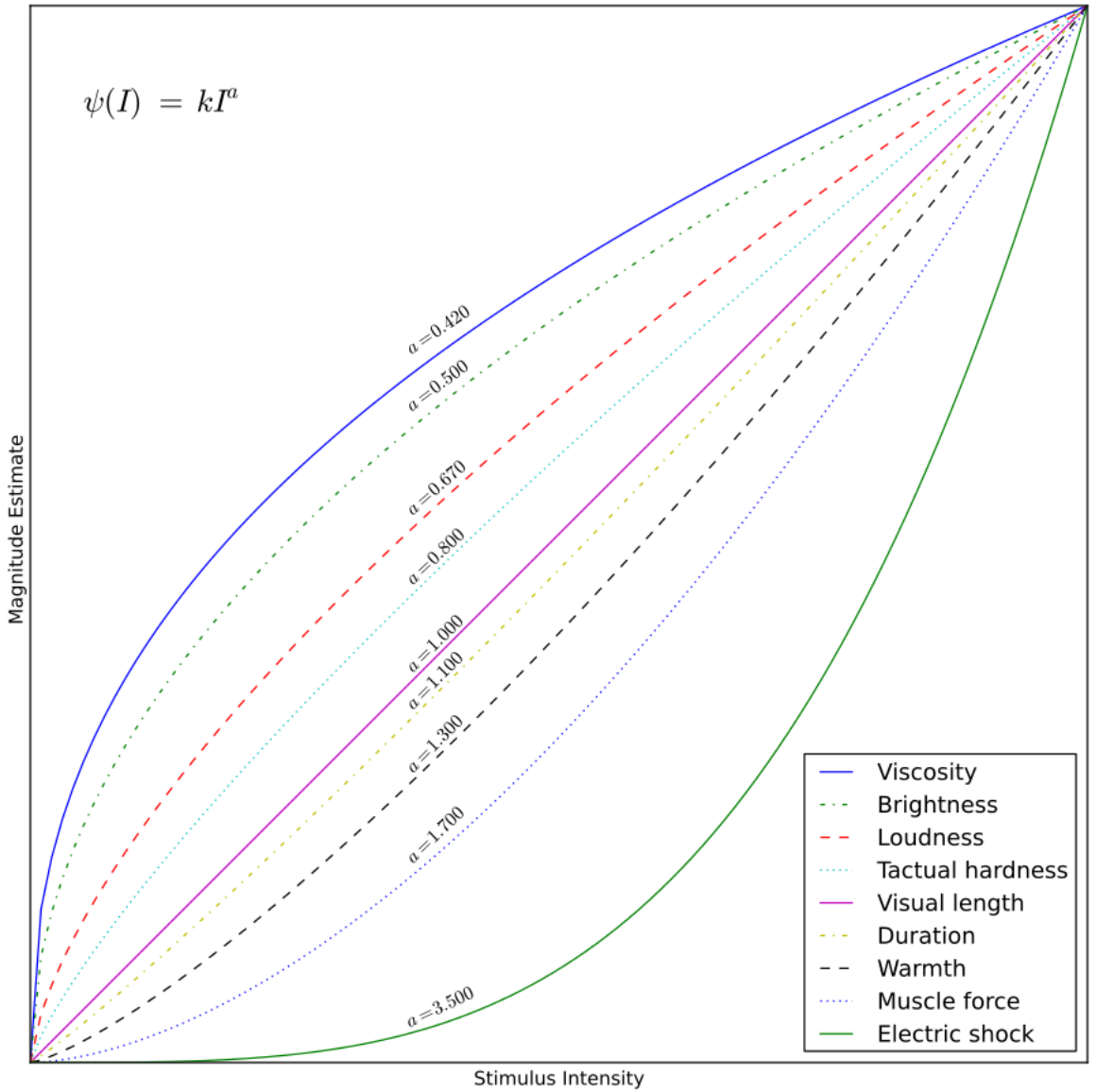
Effectiveness parameters

- Remember that *visual channels* are the visual properties that encode data attributes (position, size, angle, color, shape, texture…)
- The effectiveness of a visual channel can be measured in terms of different parameters:
  - **accuracy: how precisely a channel represents an attribute (e.g., quantitative)**
  - discriminability
  - salience
  - separability
  - grouping

Accuracy

Psychophysics studies the relationship between the physical intensity of a signal and the perceived sensation

The relationship was experimentally found to follow the power law



[https://commons.wikimedia.org/wiki/File:Power_exponents_and_Steven%27s_Power_Law.svg]

Accuracy

Experiments in graphical perception

Position and length

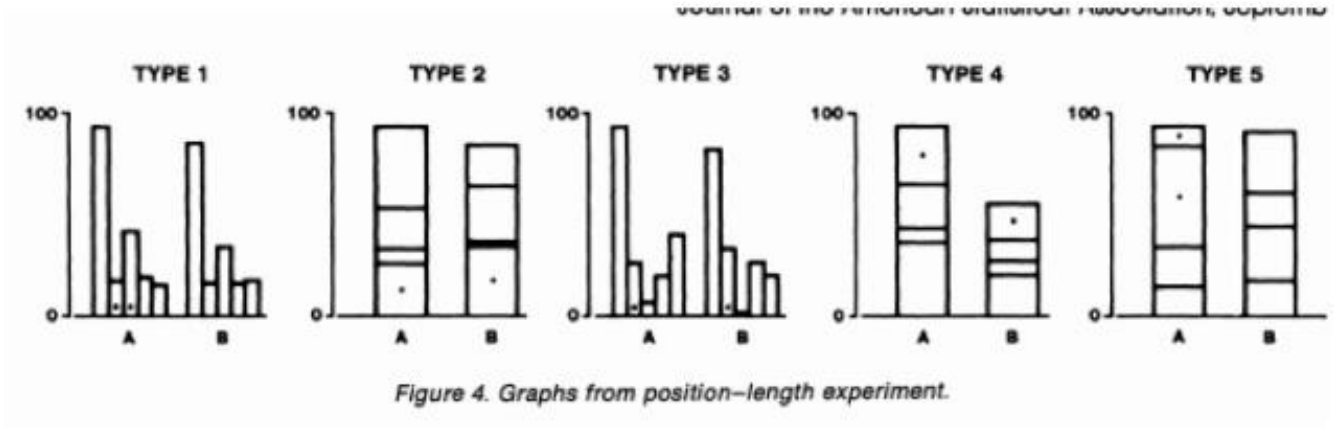
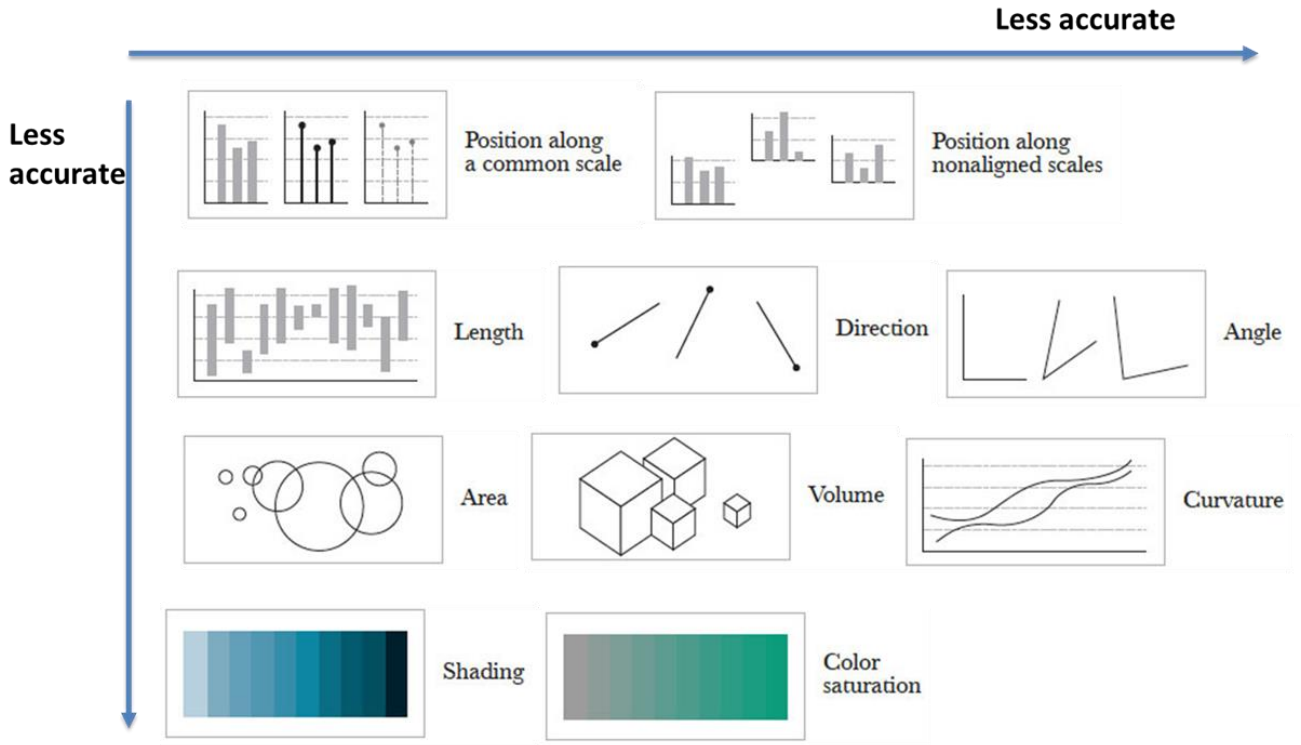


Figure 4. Graphs from position–length experiment.

Cleveland W and McGill R. Graphical Perception: Theory, experimentation and applications to the development of graphical methods. JASA 79 (387): 531-554; 1984.

Accuracy

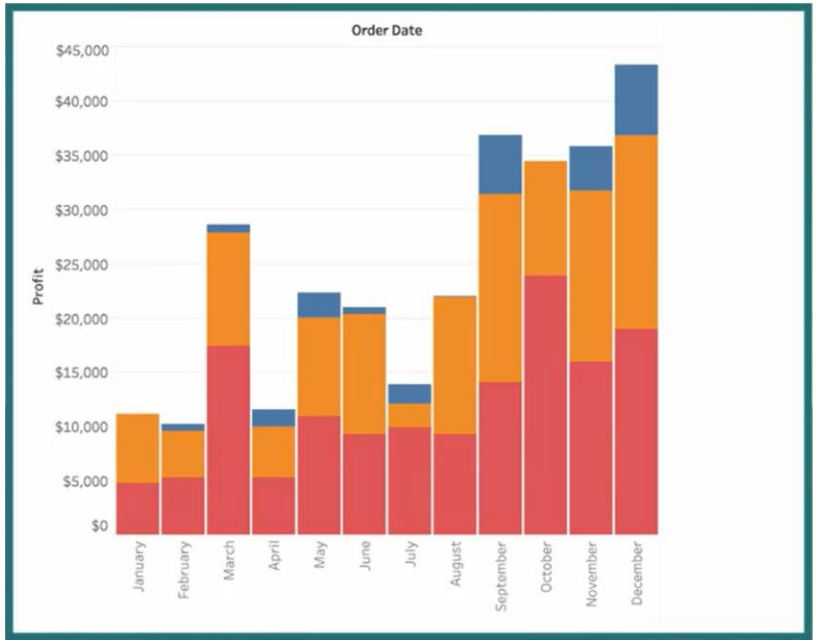
Experiments in graphical perception



[Cleveland nd McGill, 1984 – Adapted from A. Cairo, The functional art]

Accuracy

- Implications for visualization design: prioritize high-ranking channels



[Coursera, Data Visualization course]

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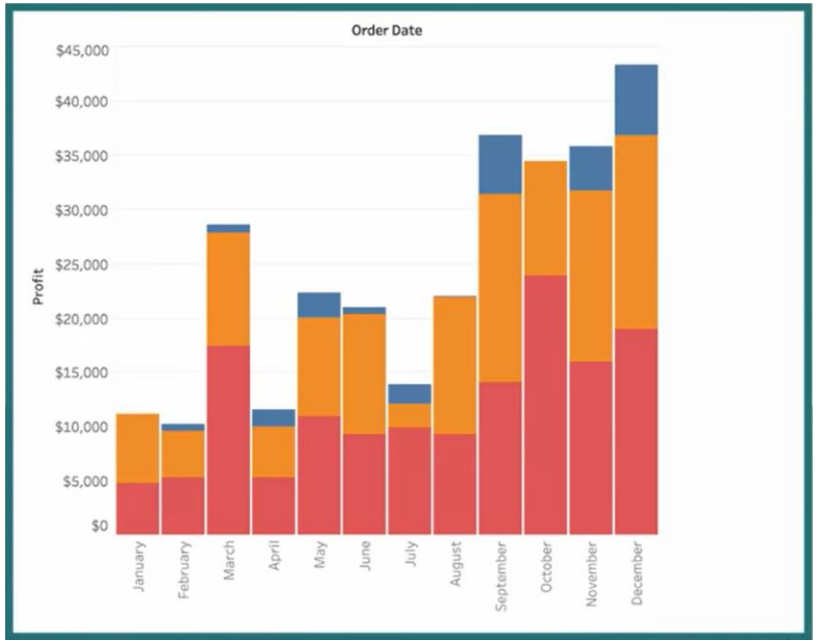

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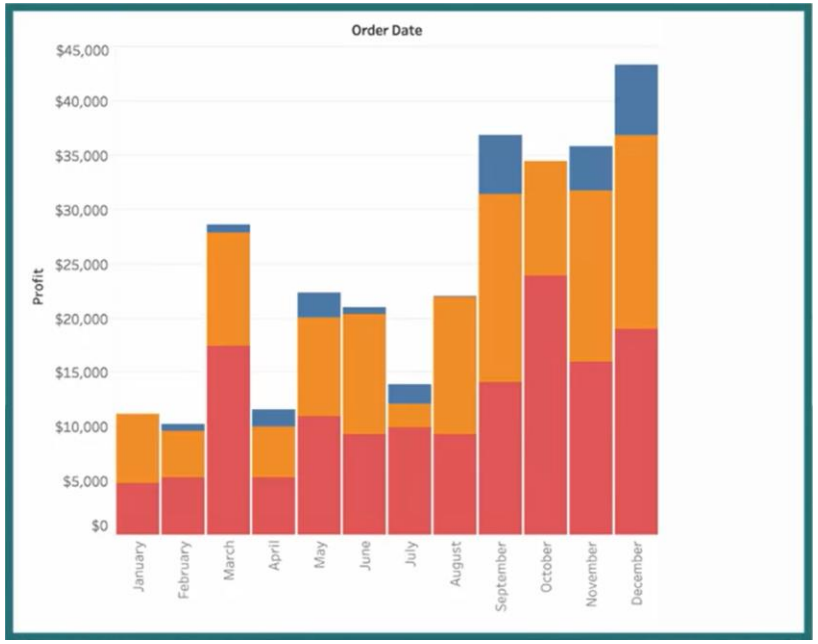

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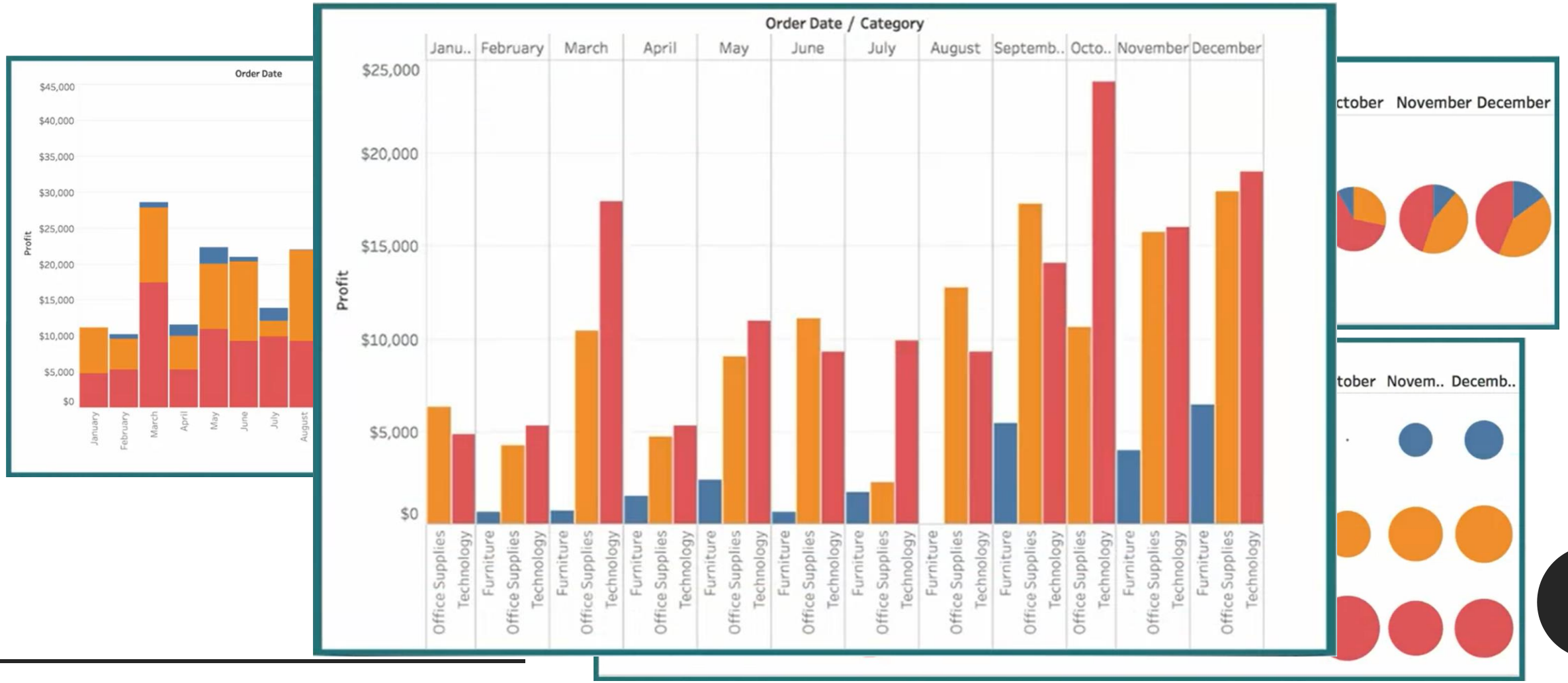

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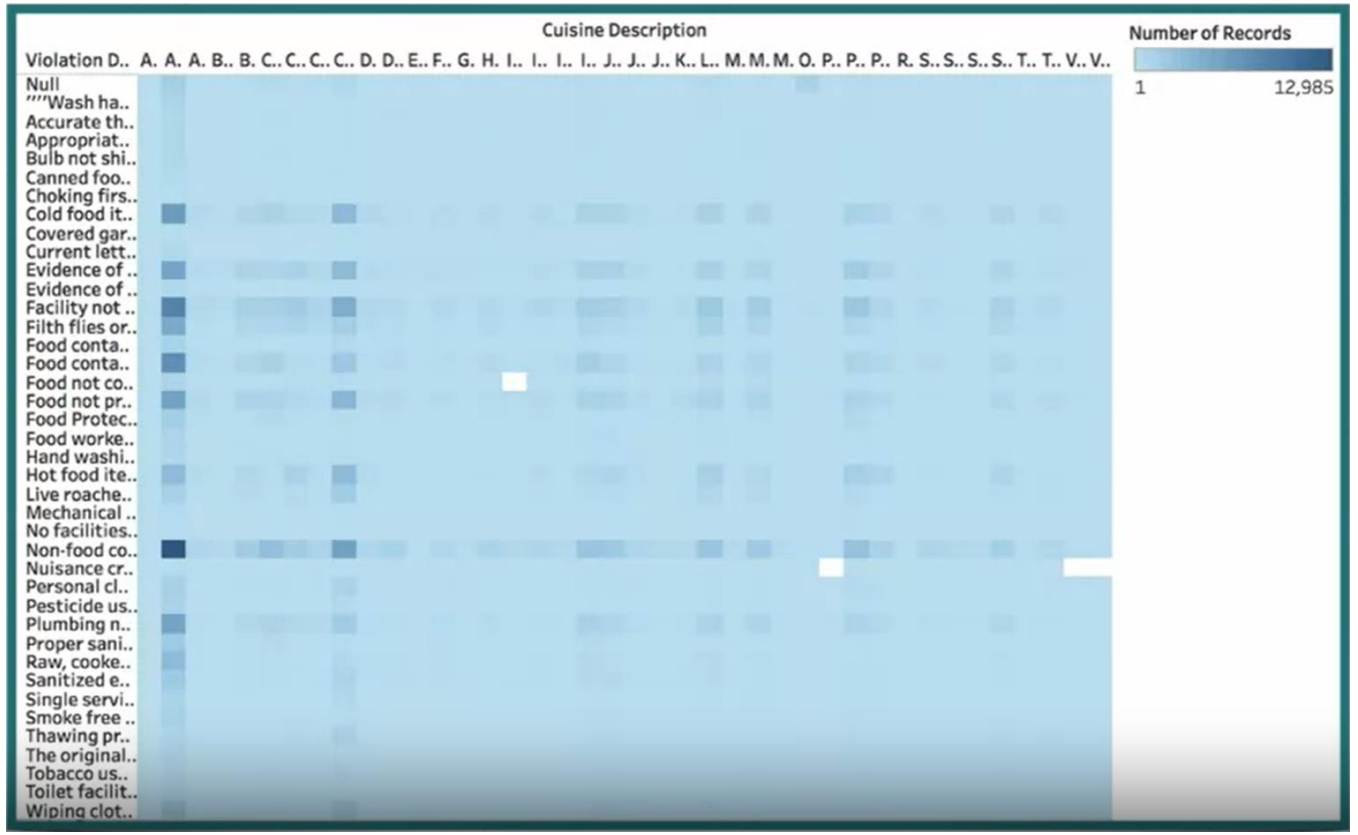
Accuracy

Implications for visualization design

- Take-home message: prioritize high-ranking channels
- …but pay attention to scalability

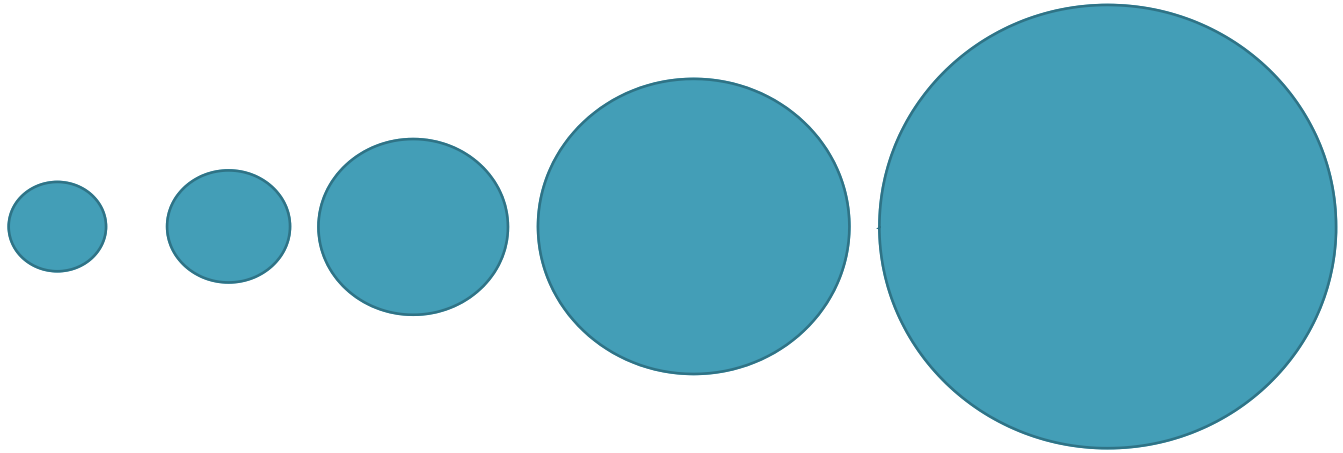


[Coursera, Data Visualization course]

Effectiveness parameters

- Remember that *visual channels* are the visual properties that encode data attributes (position, size, angle, color, shape, texture…)
- The effectiveness of a visual channel can be measured in terms of different parameters:
  - accuracy
  - **discriminability: it relates to how many distinct values a user can perceive within a channel**
  - salience
  - separability
  - grouping

Discriminability



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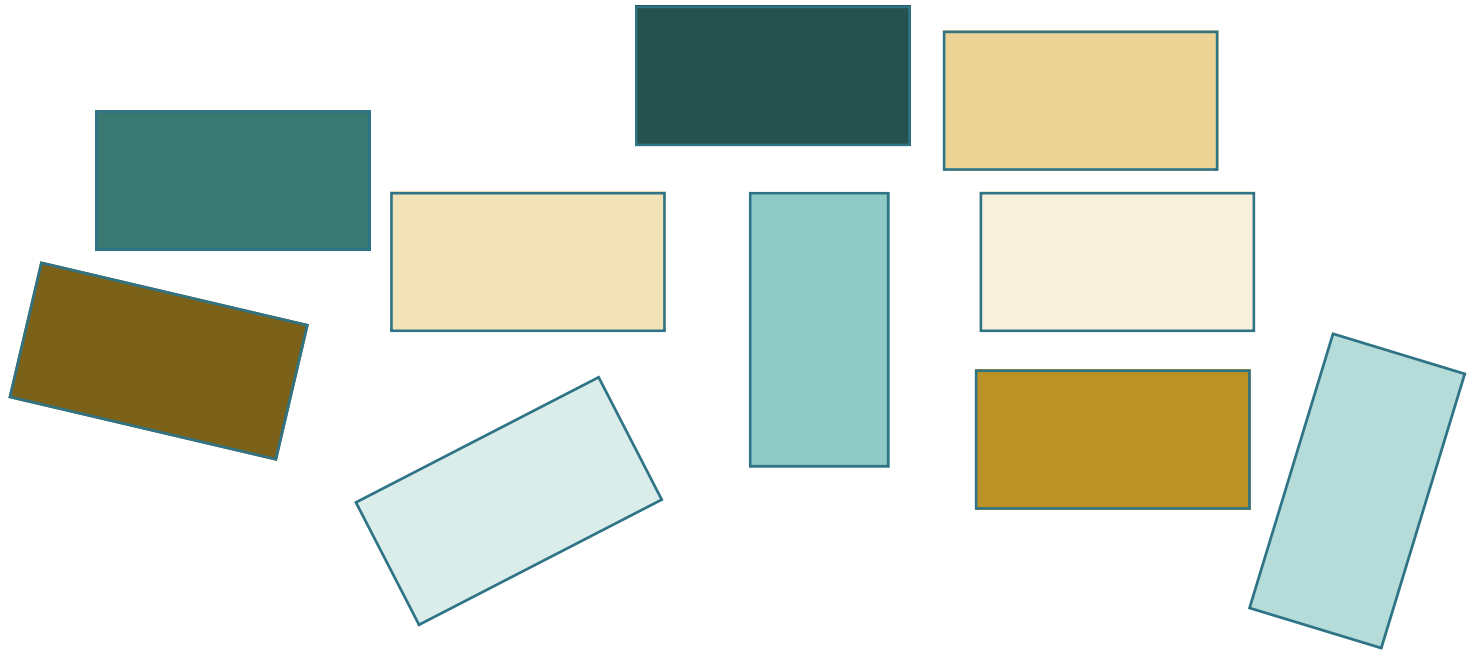

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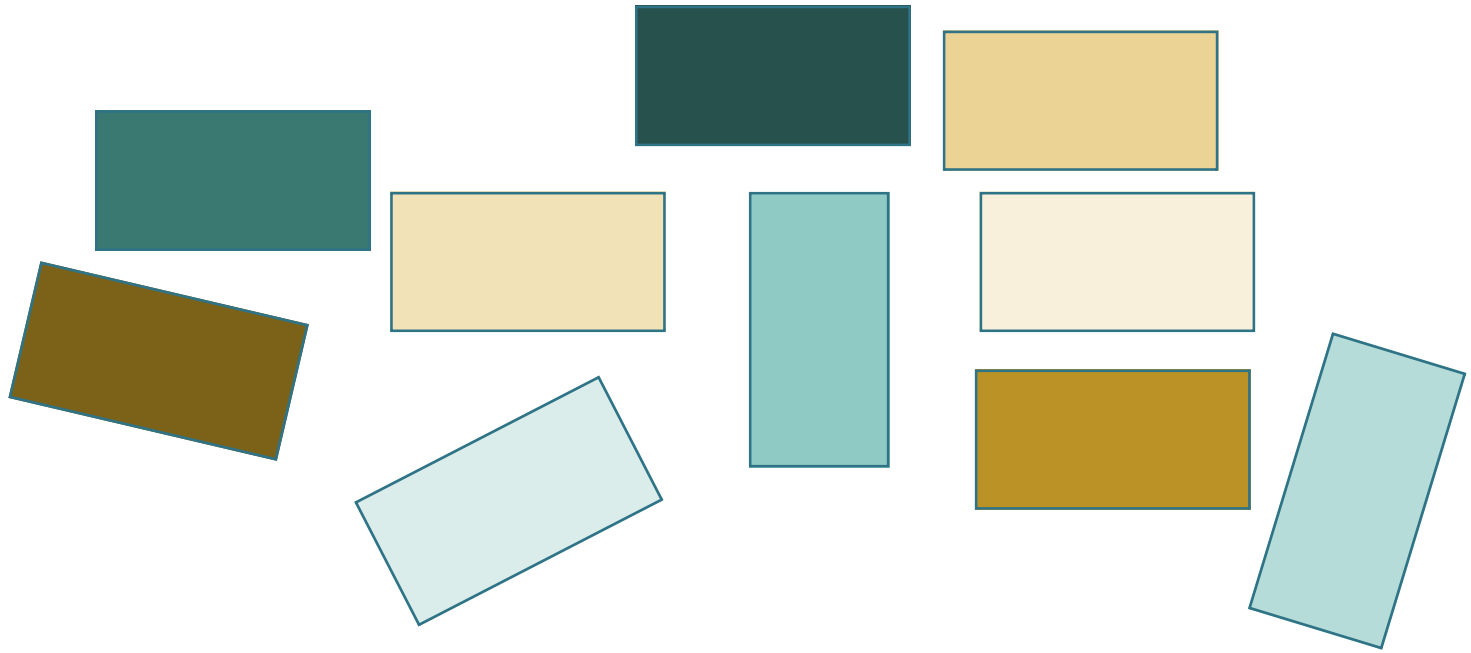
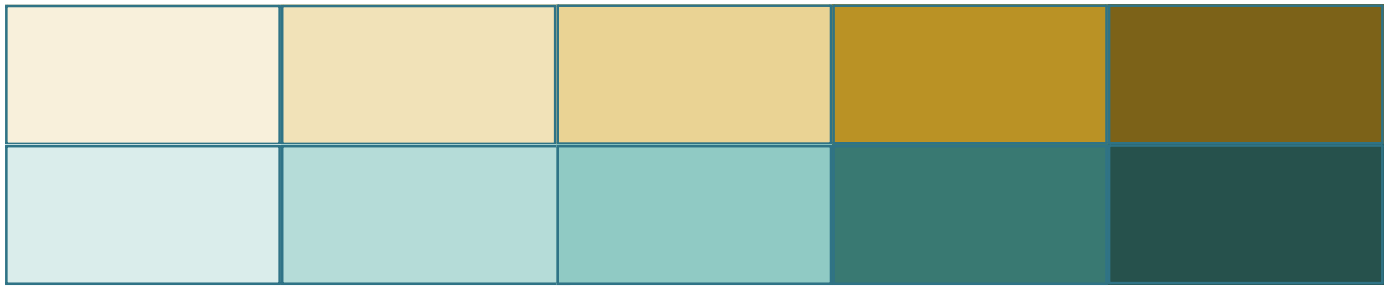




Discriminability

Implications for visualization design

- Take-home message: do not overestimate the number of distinct values that one can perceive in your visualization
- Alternatives: filtering, grouping, faceting

Effectiveness parameters

- Remember that *visual channels* are the visual properties that encode data attributes (position, size, angle, color, shape, texture…)
- The effectiveness of a visual channel can be measured in terms of different parameters:
  - accuracy
  - discriminability
  - **salience: the ability to stand out from the rest**
  - separability
  - grouping

Salience

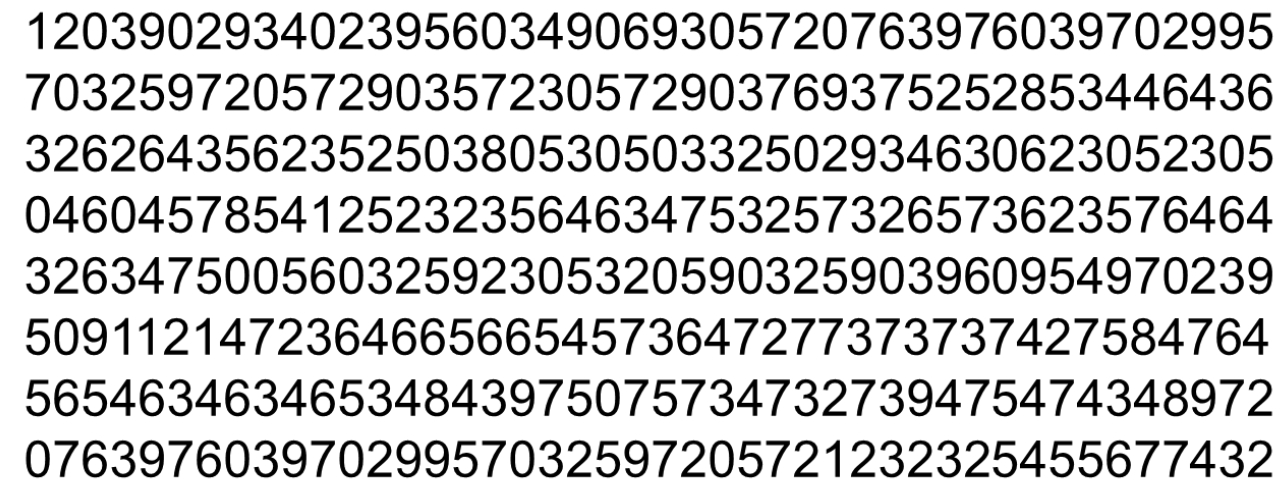
Where is Waldo?

Pre-attentive processing

Some features (visual stimuli) "pop up" from their surroundings very fast (less than 250 milliseconds)

Initially, researchers thinked that they happened before attention (erroneous).

Attention is a part of the process



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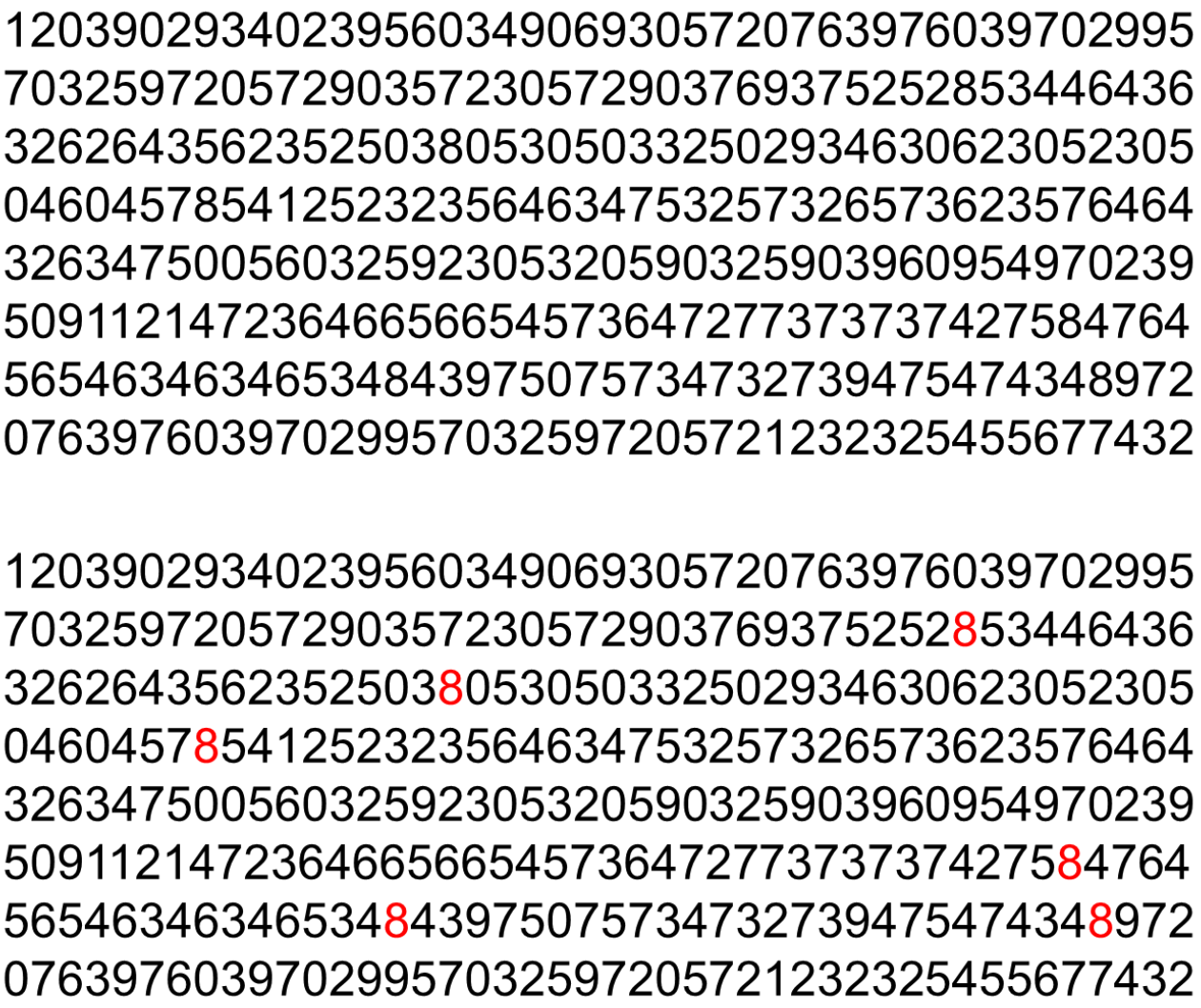

Pre-attentive features

Visual features that are preattentively processed:

Orientation, Curvature, Shape, Size, Color, Light/Dark, Enclosure, Concavity/Convexity, Addition

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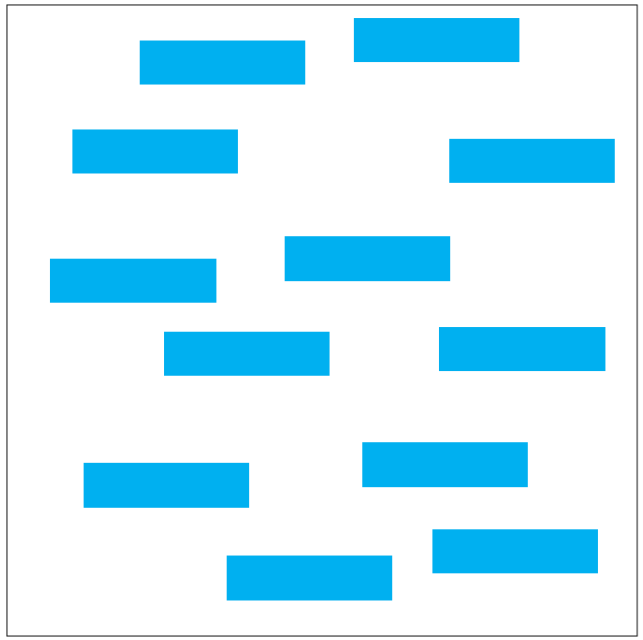

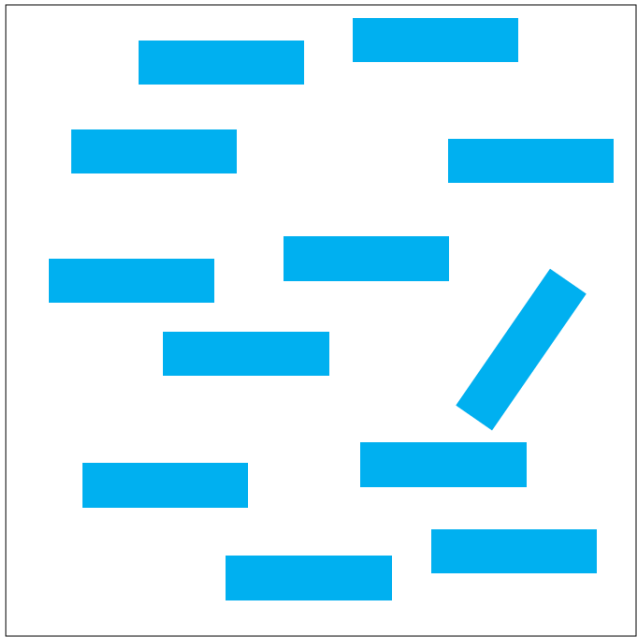

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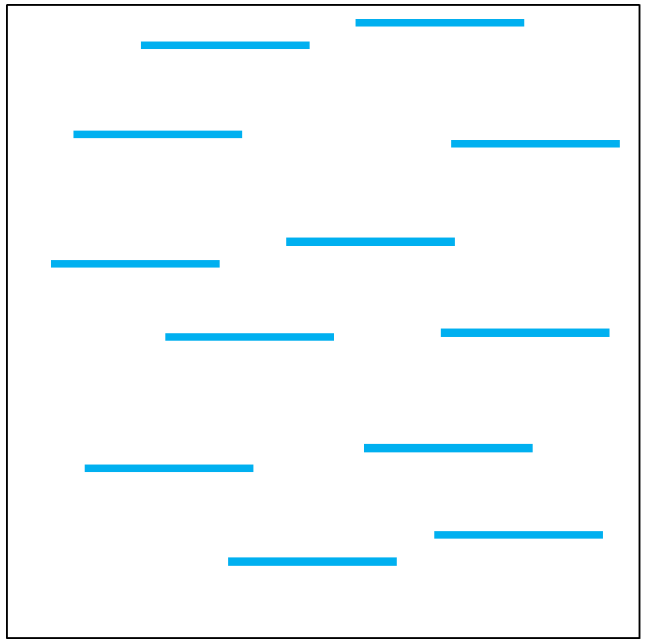

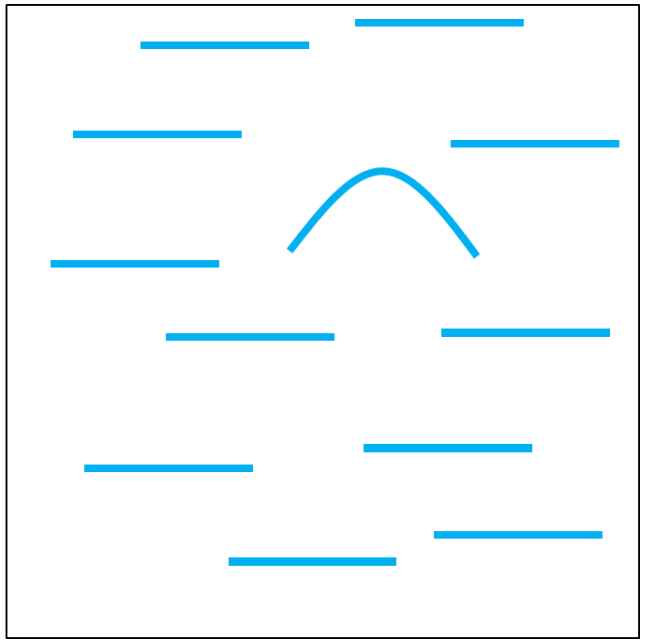

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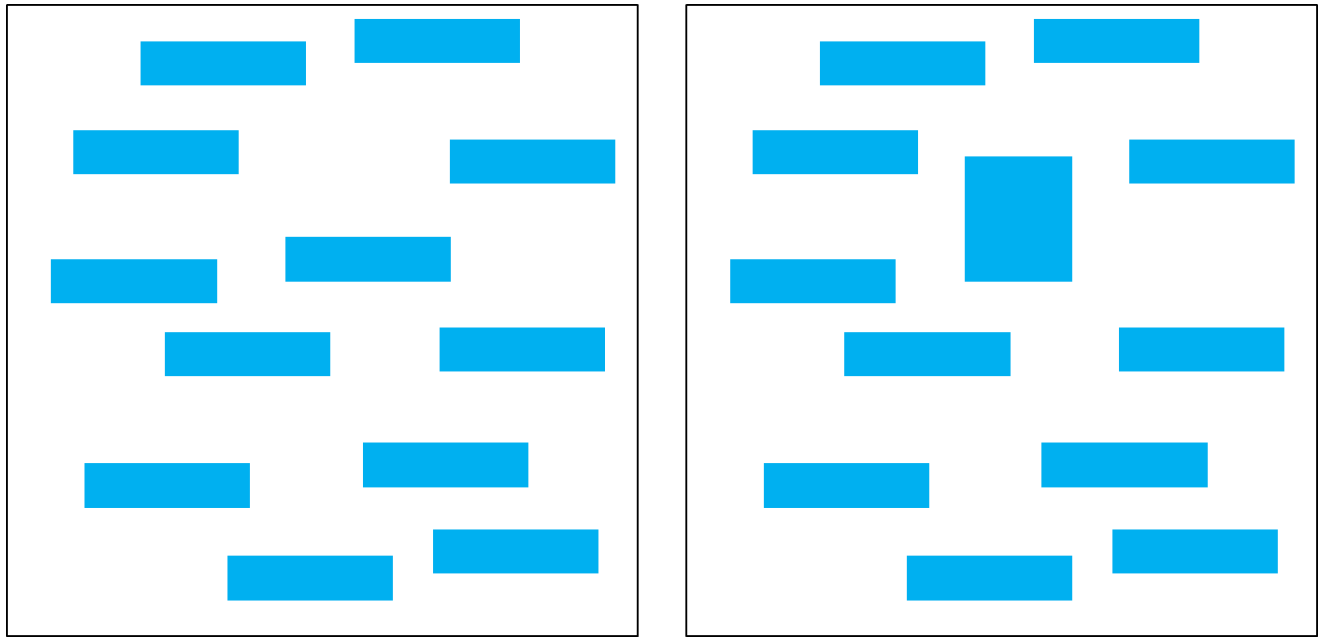

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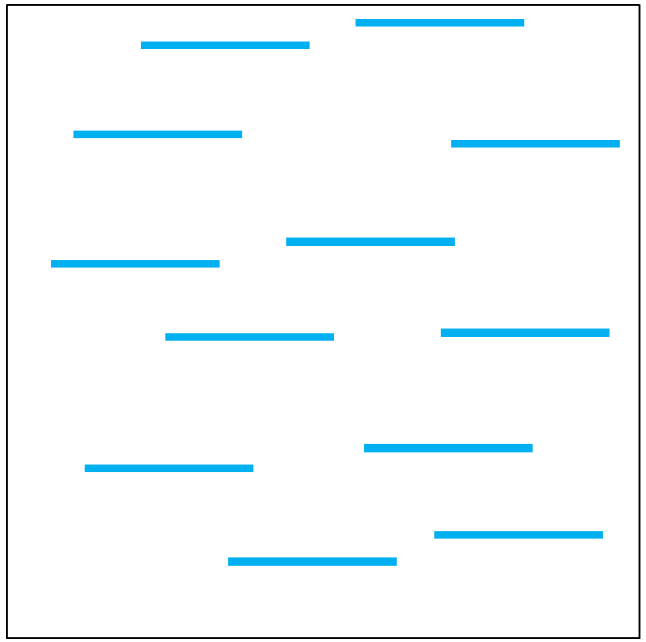

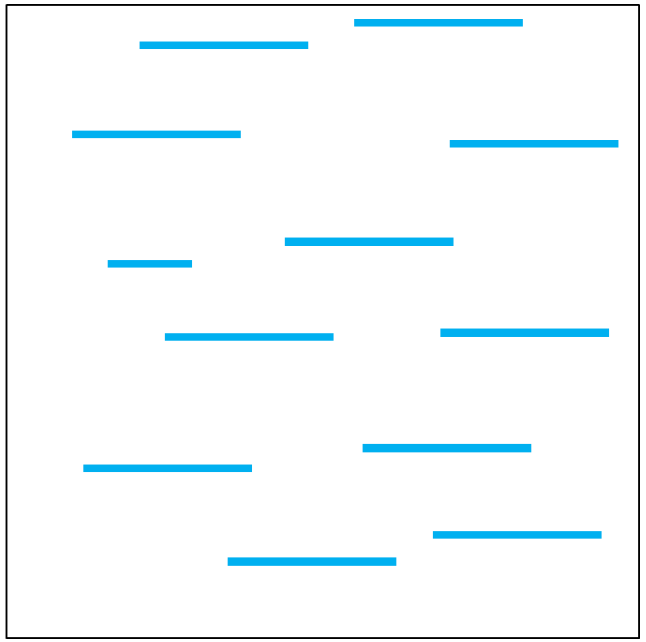

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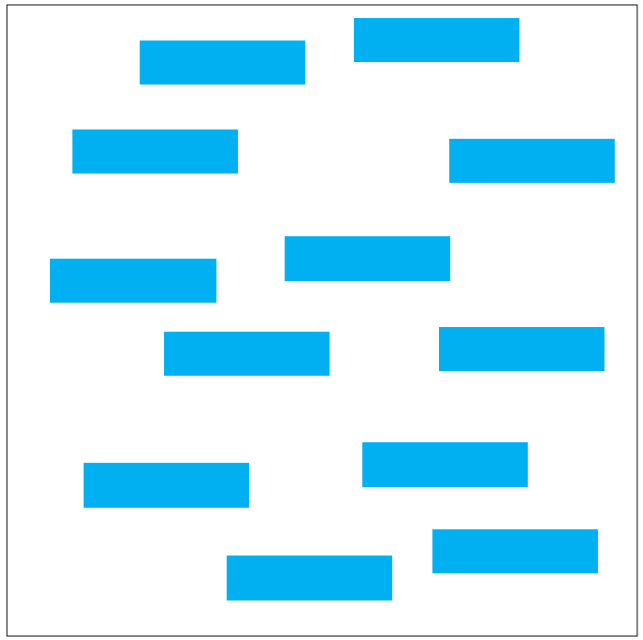

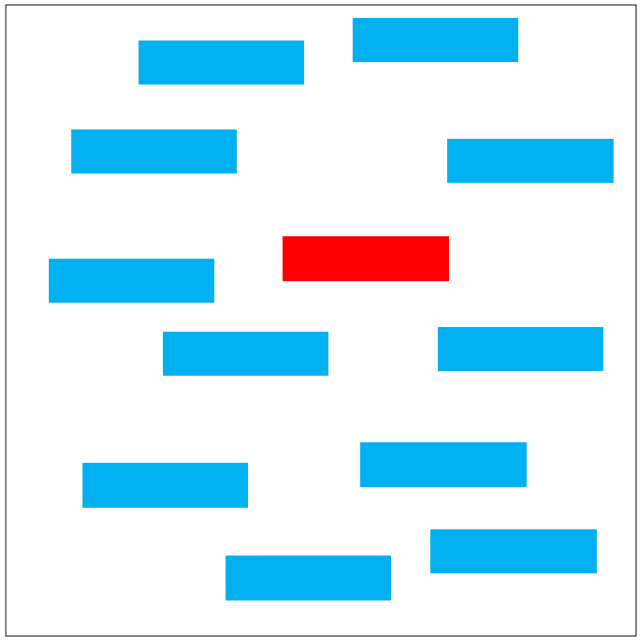

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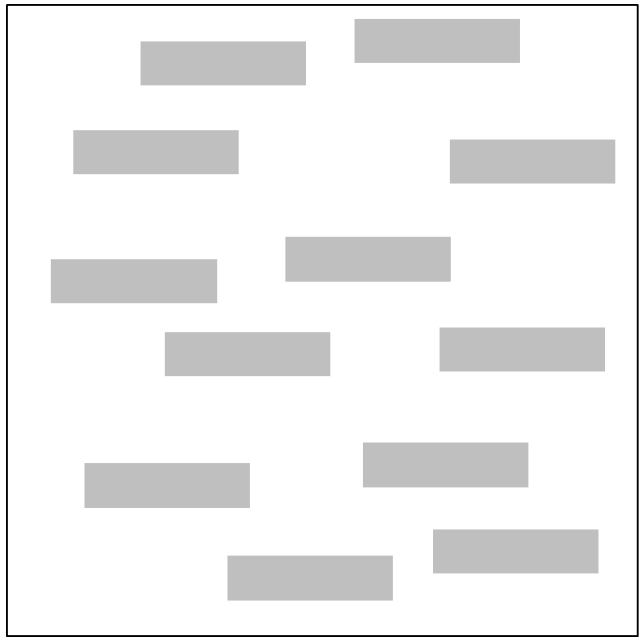
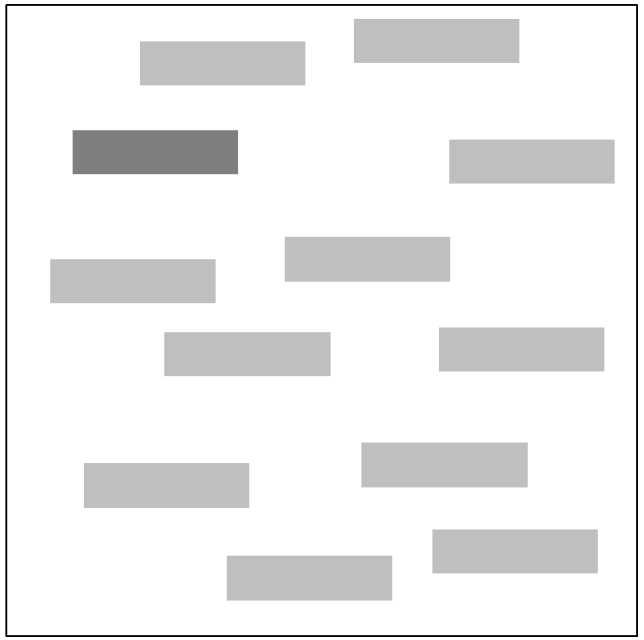
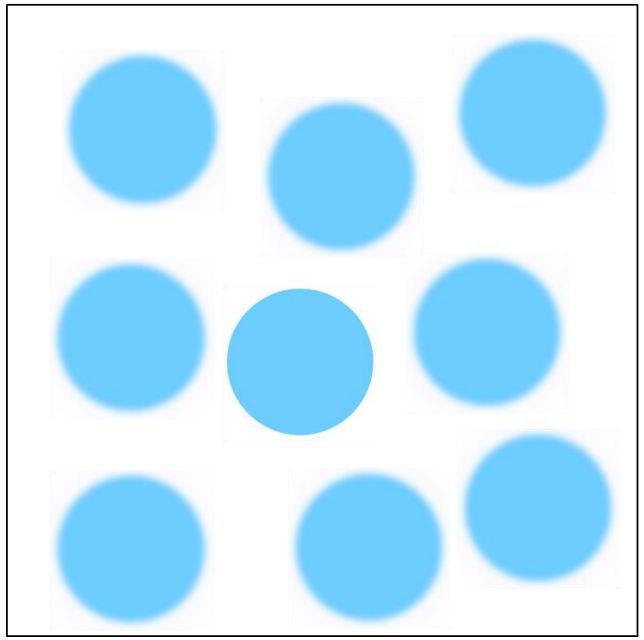
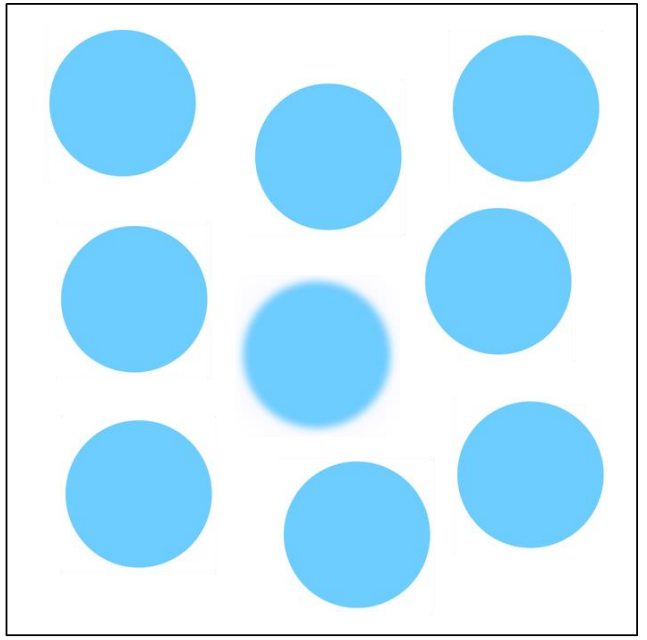




Non-simmetric pre-attentive processes

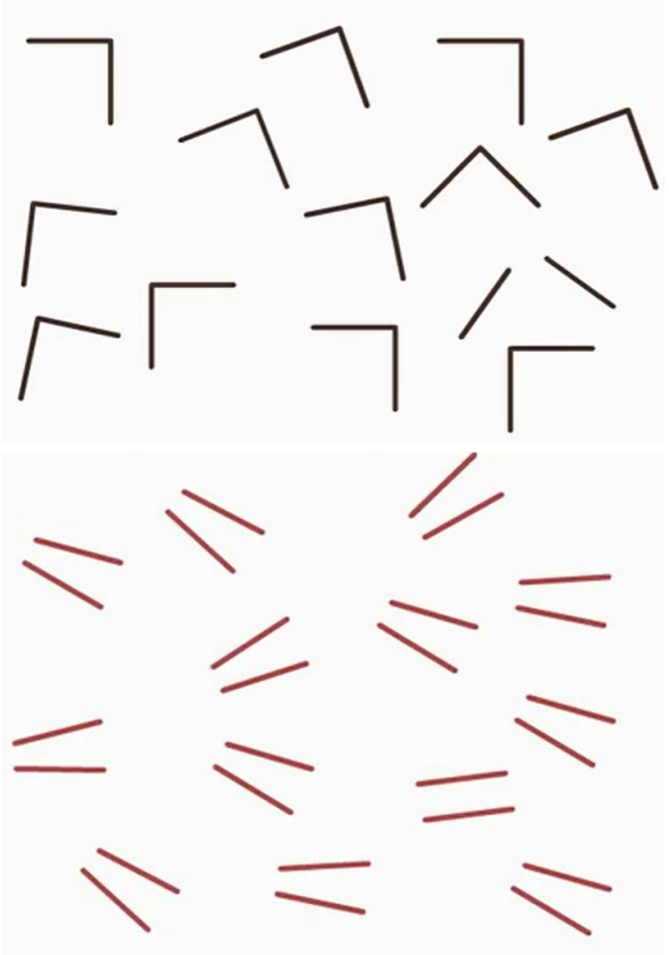
- Some preattentive processes are not simmetric, e.g.:
  - adding marks is more efficient than removing marks;
  - a big object surrounded by small objects is more efficient than a small object surrounded by big objects;
  - increasing sharpness is more efficients than decreasing sharpness.





Non pre-attentive features

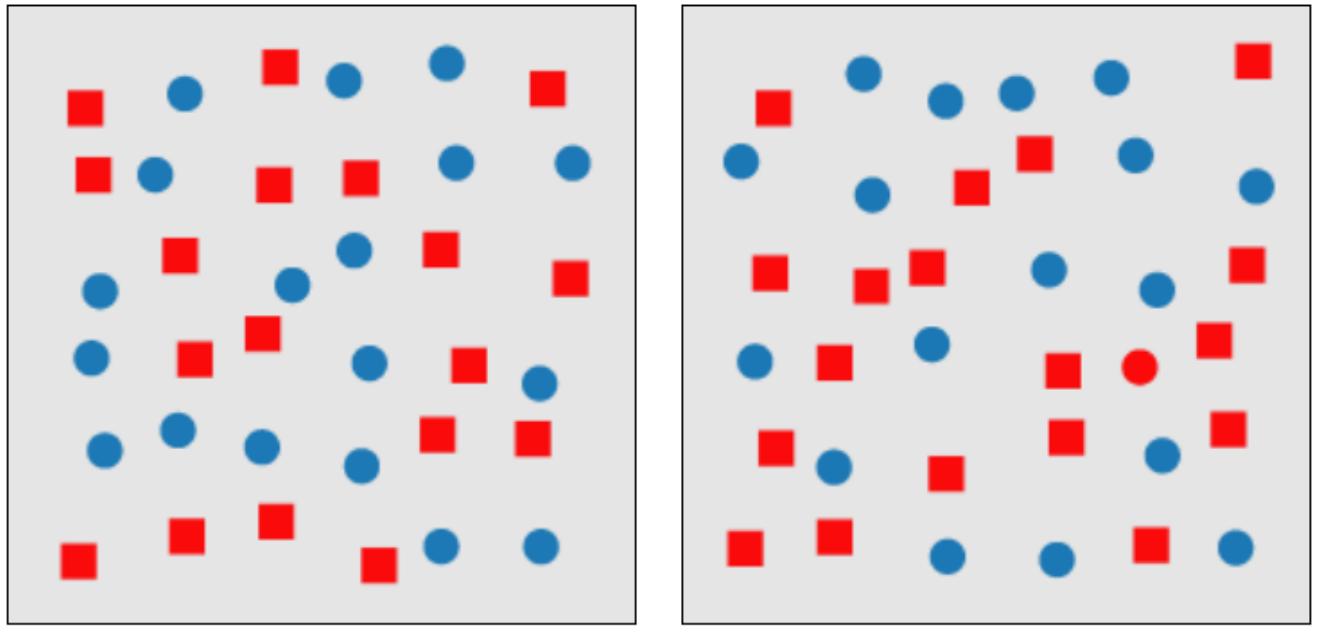
- Visual features that are not preattentively processed are juncture and parallelism



Non pre-attentive features

- The combinations of pre-attentive visual features may not be pre-attentive. Examples:
  - Shape + Color
  - Size + Color
  - Shape + Motion

Where is the red circle?



[Figure from Perception in Visualization by Christopher G. Healey]

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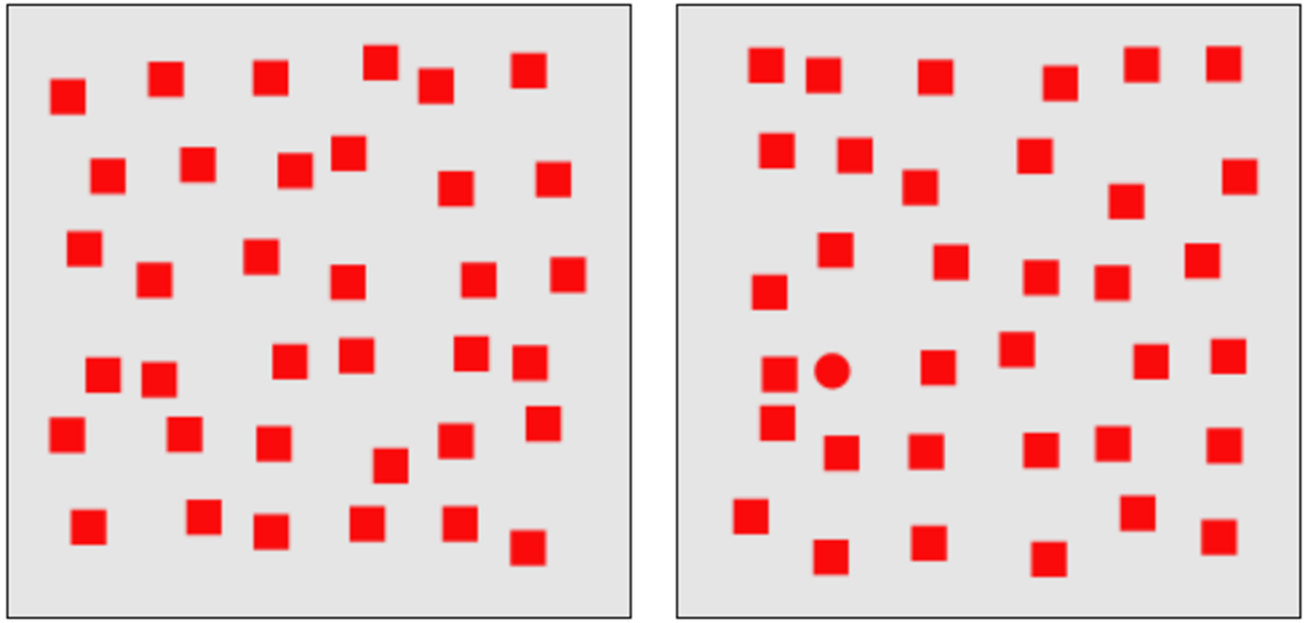
Where is the red circle?



[Figure from Perception in Visualization by Christopher G. Healey]

Saliency

Implications for visualization design

- Take-home message: be careful about what grabs the viewer's attention
  - e.g., use gray shades to attract attention towards colors
- Pre-attentive features may be a good choice

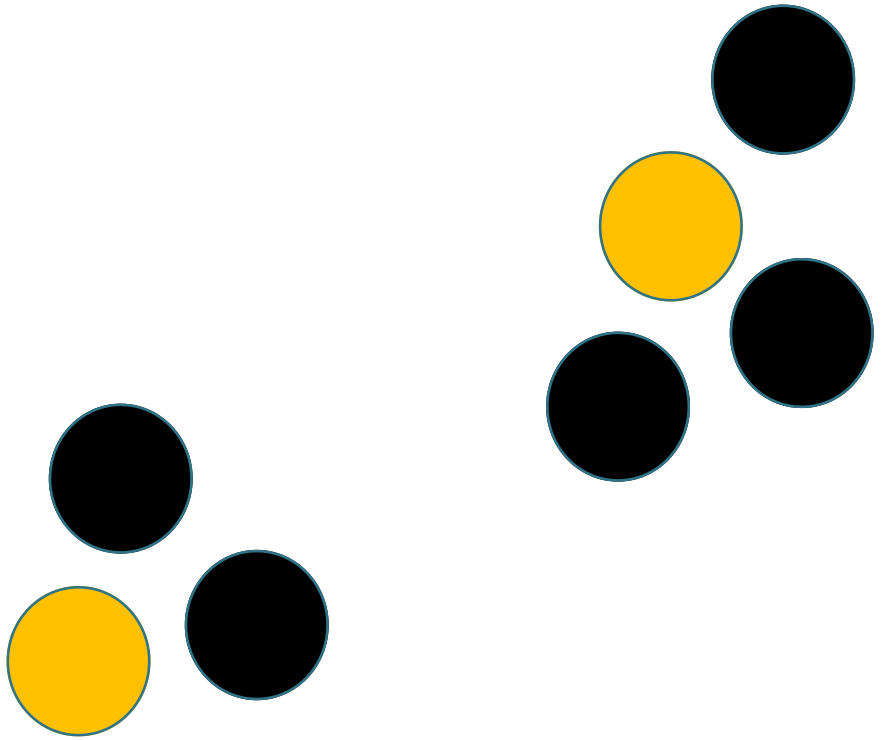
Effectiveness parameters

- Remember that *visual channels* are the visual properties that encode data attributes (position, size, angle, color, shape, texture…)
- The effectiveness of a visual channel can be measured in terms of different parameters:
  - accuracy
  - discriminability
  - salience: the ability to stand out from the rest
  - **separability: it has to do with how easy is it to focus attention on one channel versus the other**
  - grouping

Separability

- Highly separable (position and color)

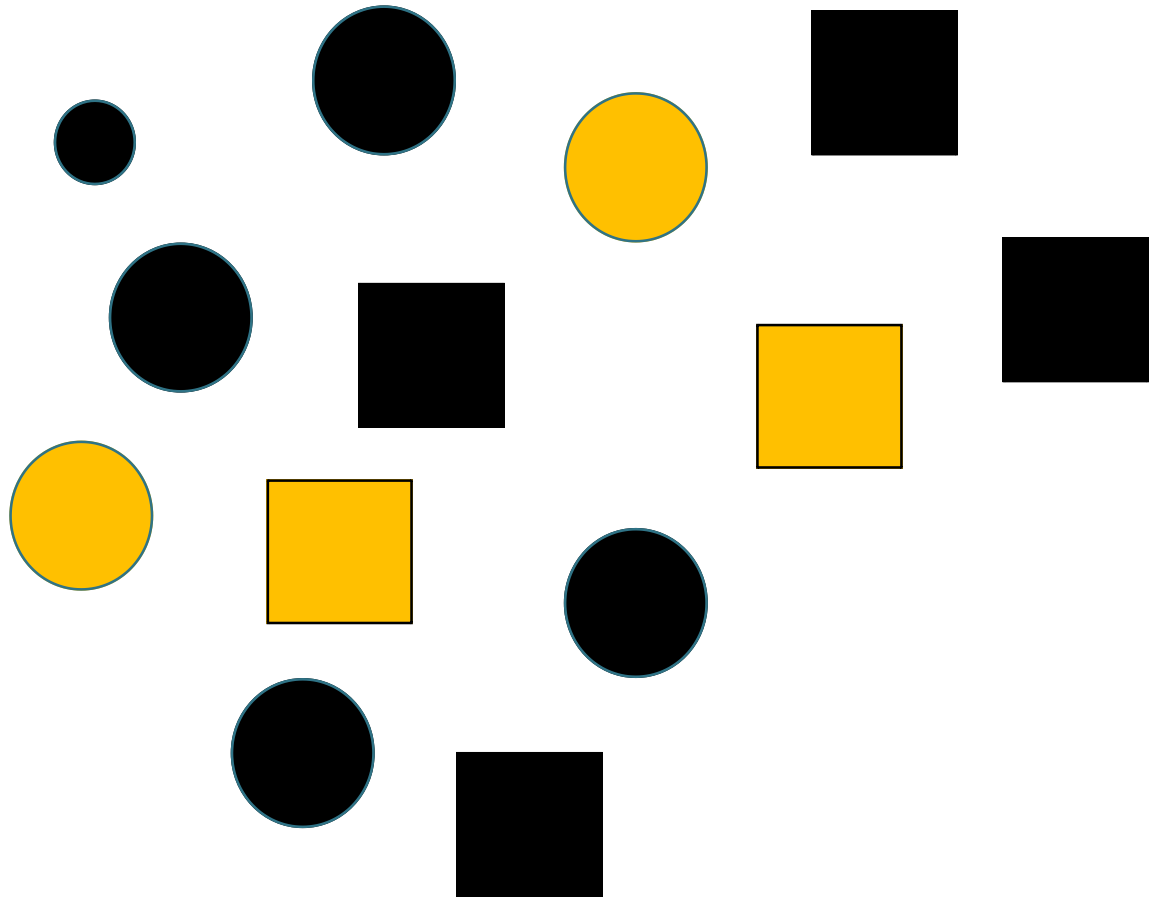
Visual features are separable if it is easy to focus on one feature regardless of the other



Separability

- Partly interacting (color and shape)

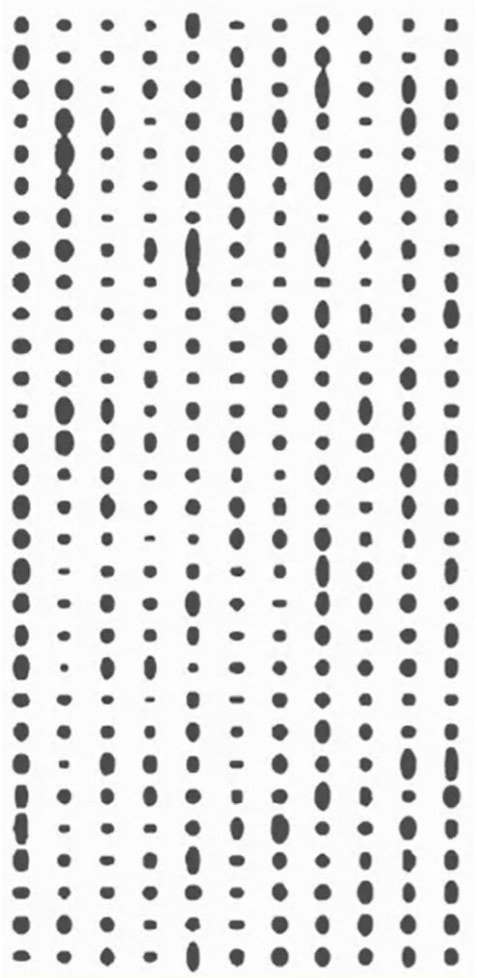
Visual features are separable if it is easy to focus on one feature regardless of the other



Separability

Visual features are separable if it is easy to focus on one feature regardless of the other

- Integral



[Perception of the BMI of 400 people, by mapping height and weight to the axes of the ellipses: from C. Ware, Information Visualization: Perception for Design (2013)]

Effectiveness parameters

- Remember that *visual channels* are the visual properties that encode data attributes (position, size, angle, color, shape, texture…)
- The effectiveness of a visual channel can be measured in terms of different parameters:
  - accuracy
  - discriminability
  - salience
  - separability
  - **grouping: it has to do with how patterns emerge from single elements**

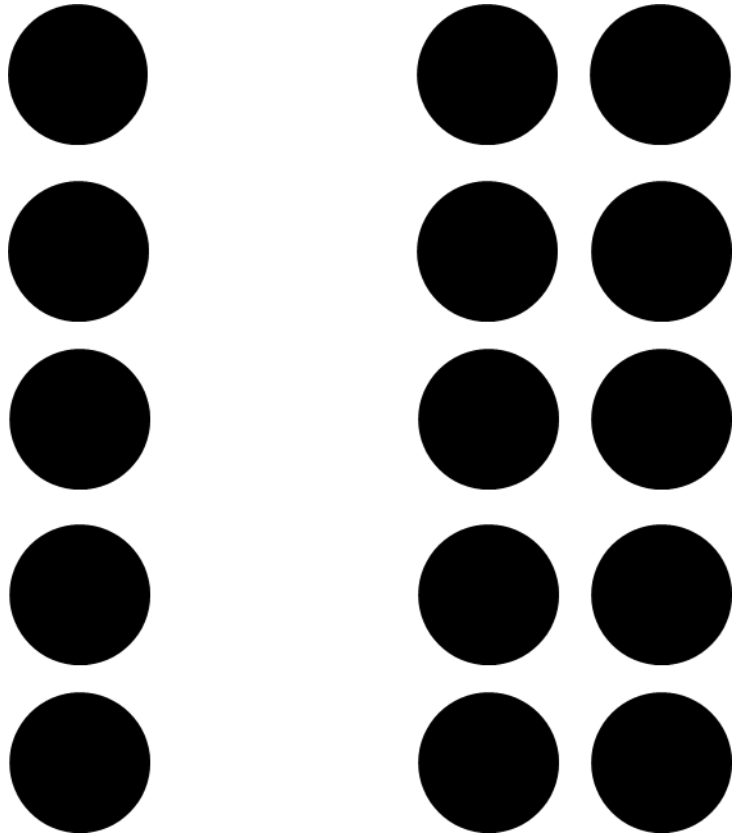
Gestalt laws

Laws that try to explain under what conditions individual visual objects are perceived as a group

- From *Gestalt School of Psychology* (founded in 1912 by Max Westhemer, Kurt Koffka and Wolfgang Koheler)
- The first serious attempt to understand pattern perception
- The neural mechanisms proposed do not pass the test of the time, but the laws have proven to be valid:
  - Proximity
  - Similarity
  - Connectedness
  - Continuity
  - Symmetry
  - Closure
  - Common fate
  - Figure-ground
- Gestalt Laws are powerful allies (to group elements, to show relationships, to make patterns comparison, in an effective way)

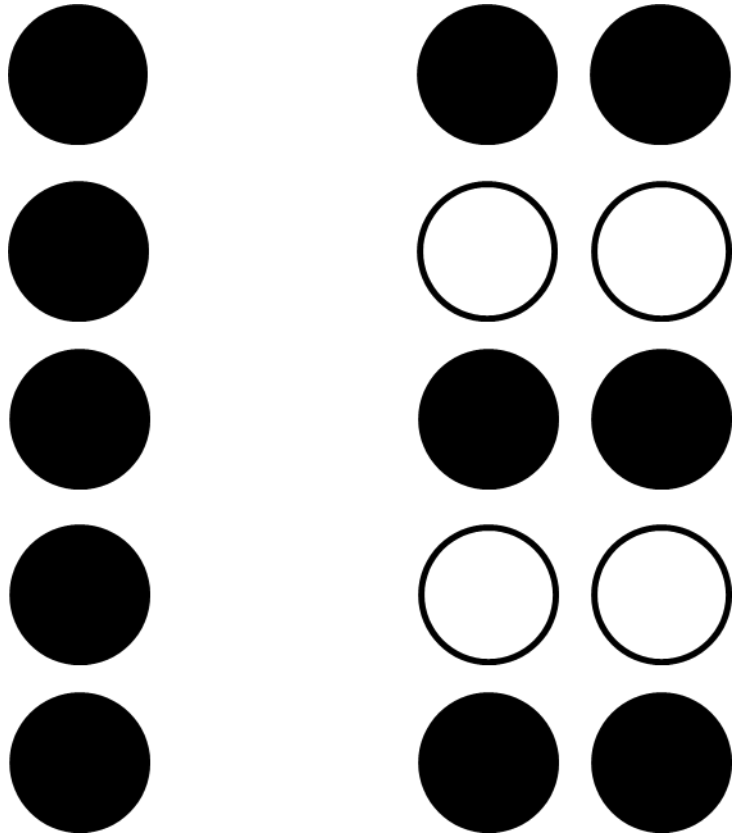
Proximity

Objects close to each other are perceived to form a group



Similarity

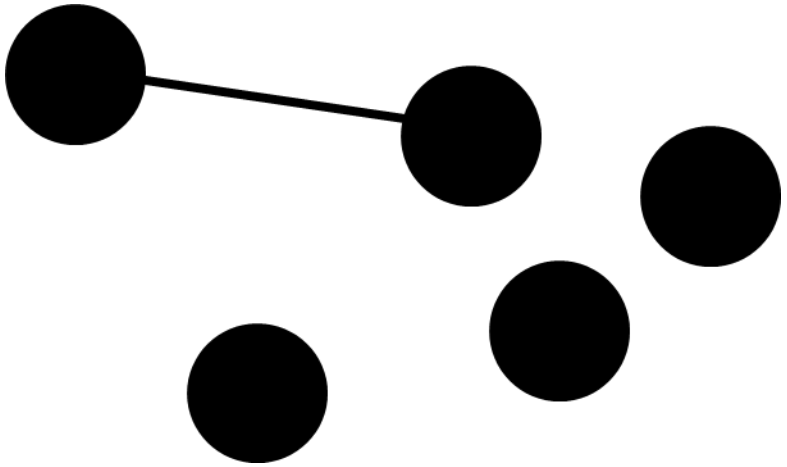
Similar objects are perceived to from a group

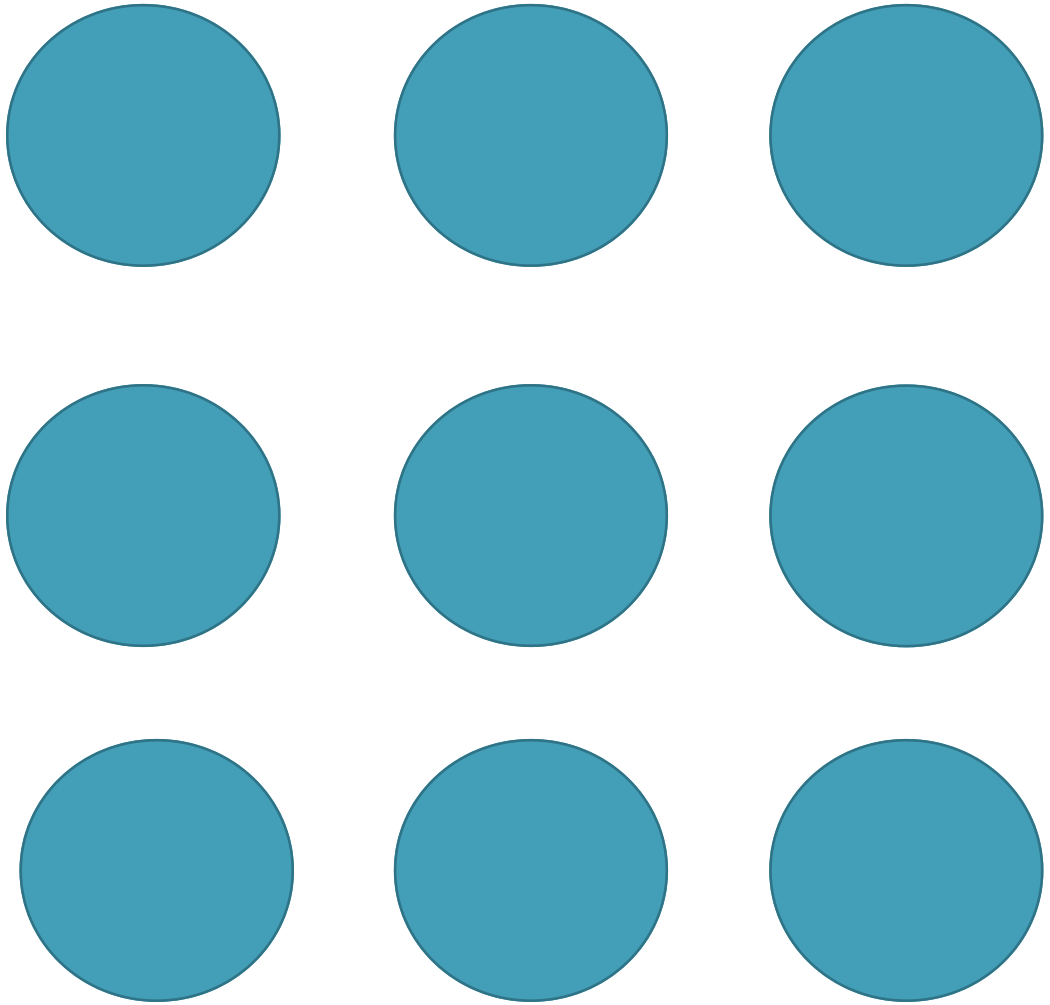


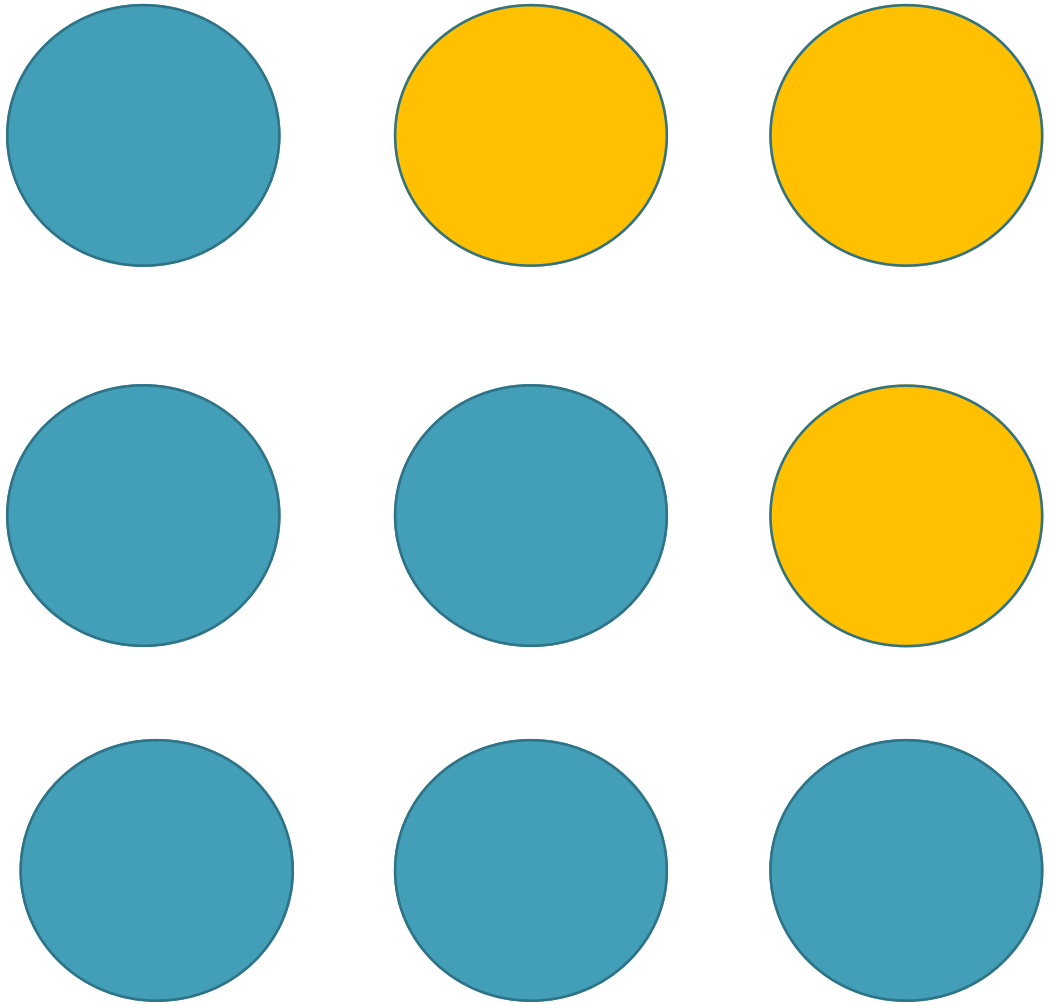
Connectedness

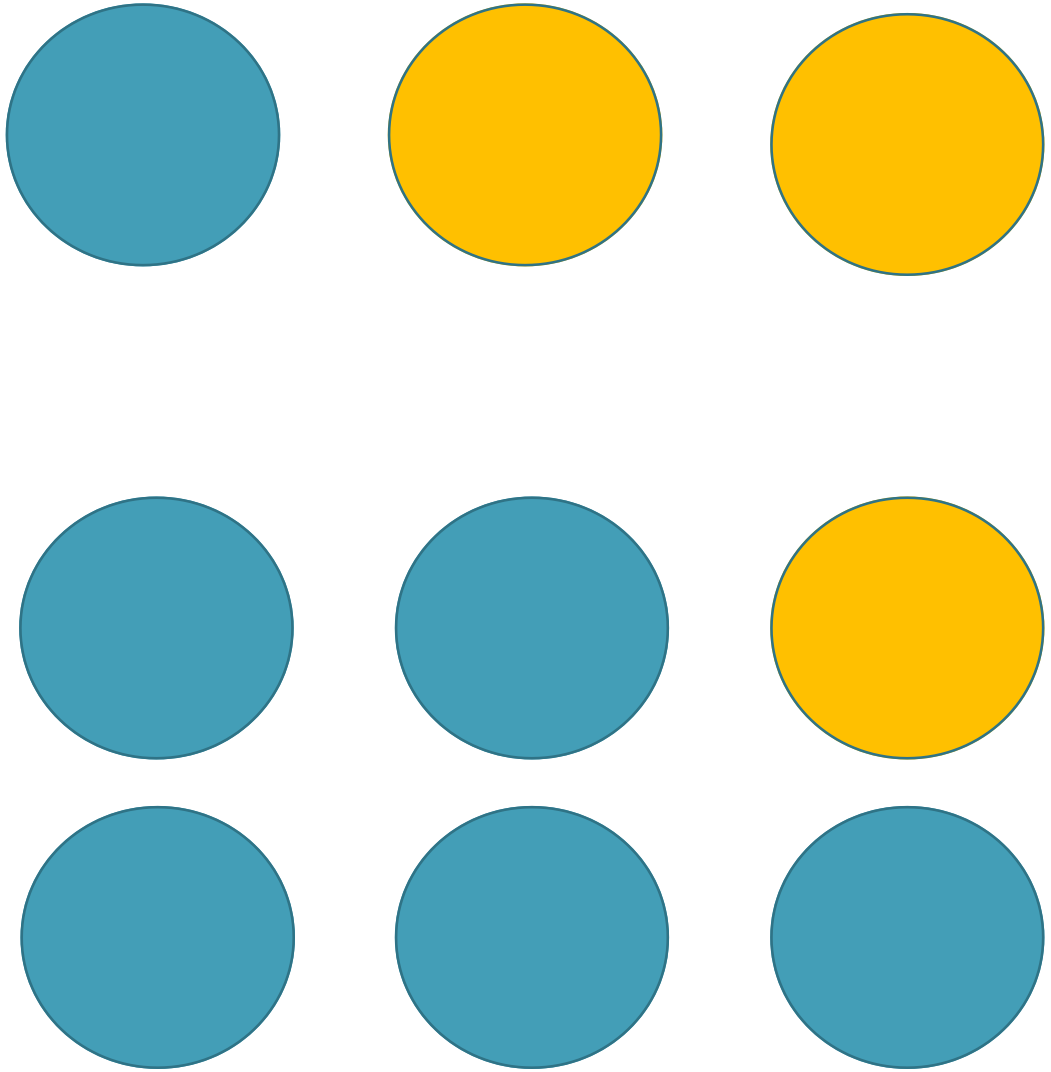
Connected objects are perceived as related.

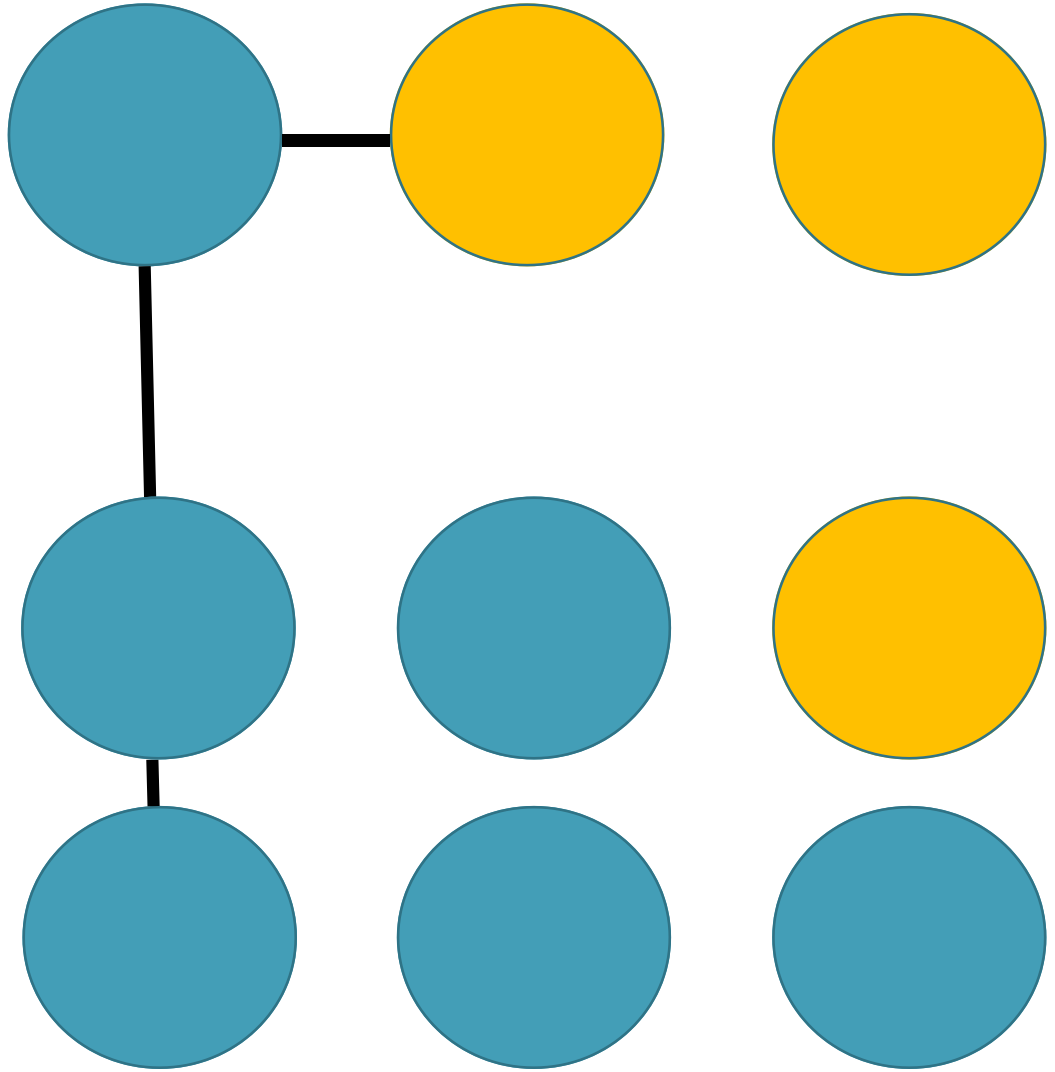
Connecting different objects with a line is a powerful way to express that there is some relationship between them.





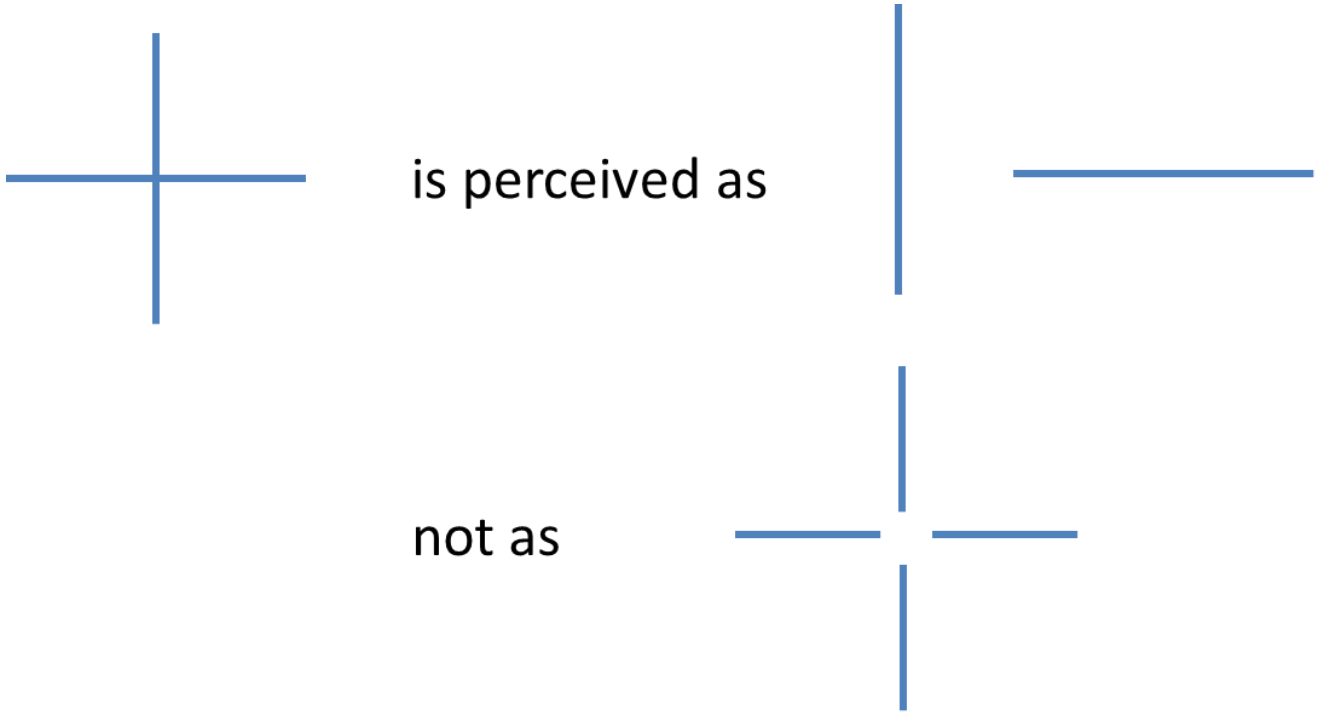






Continuity

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



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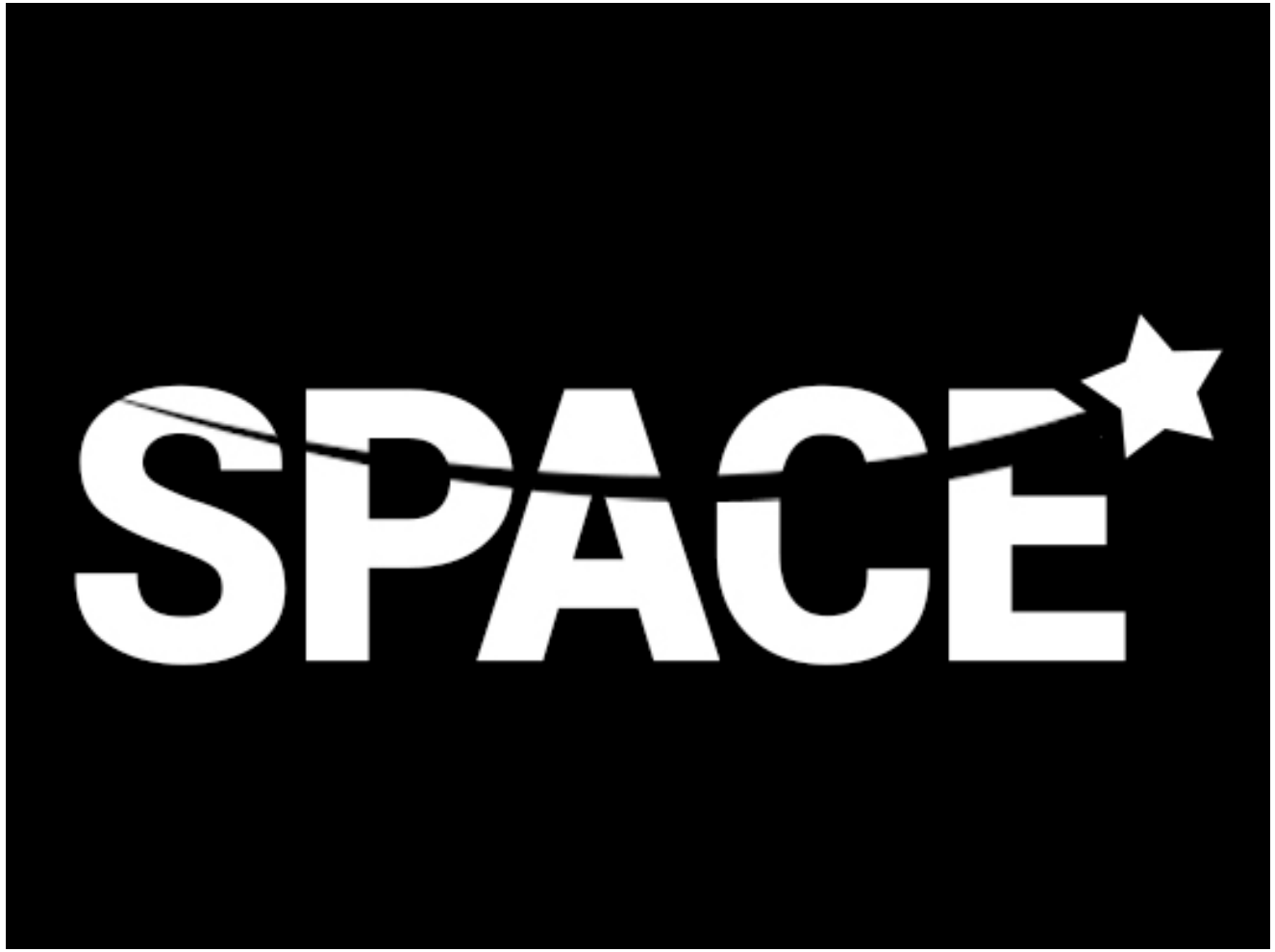
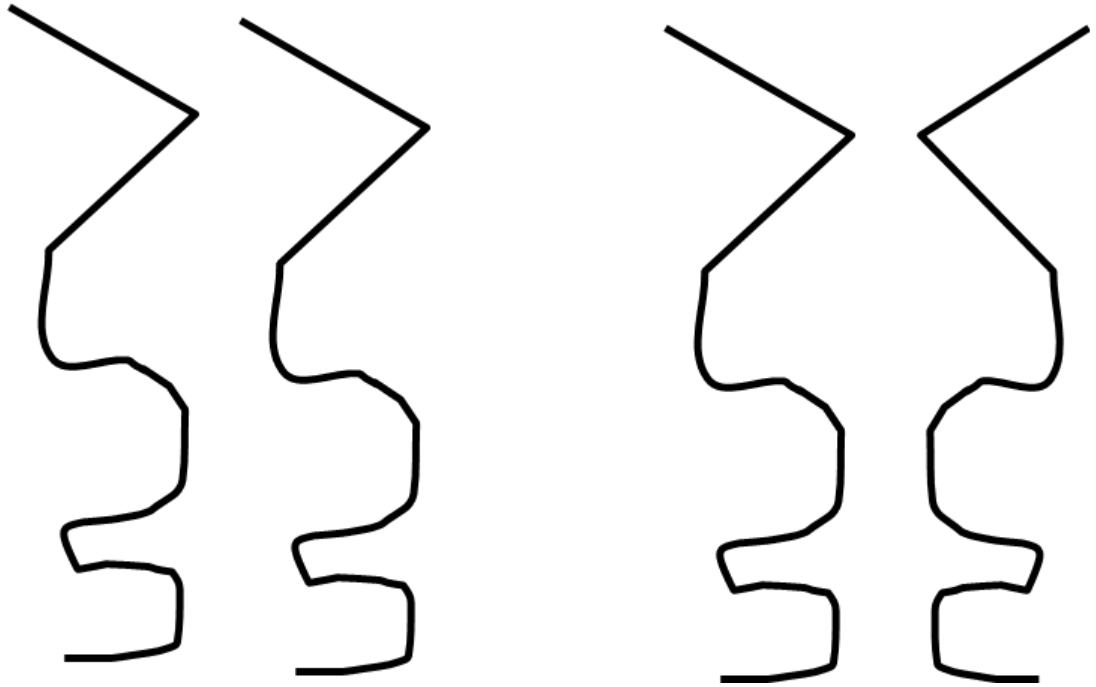


Simmetry

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

Simmetry is best perceived for horizontal and vertical axes



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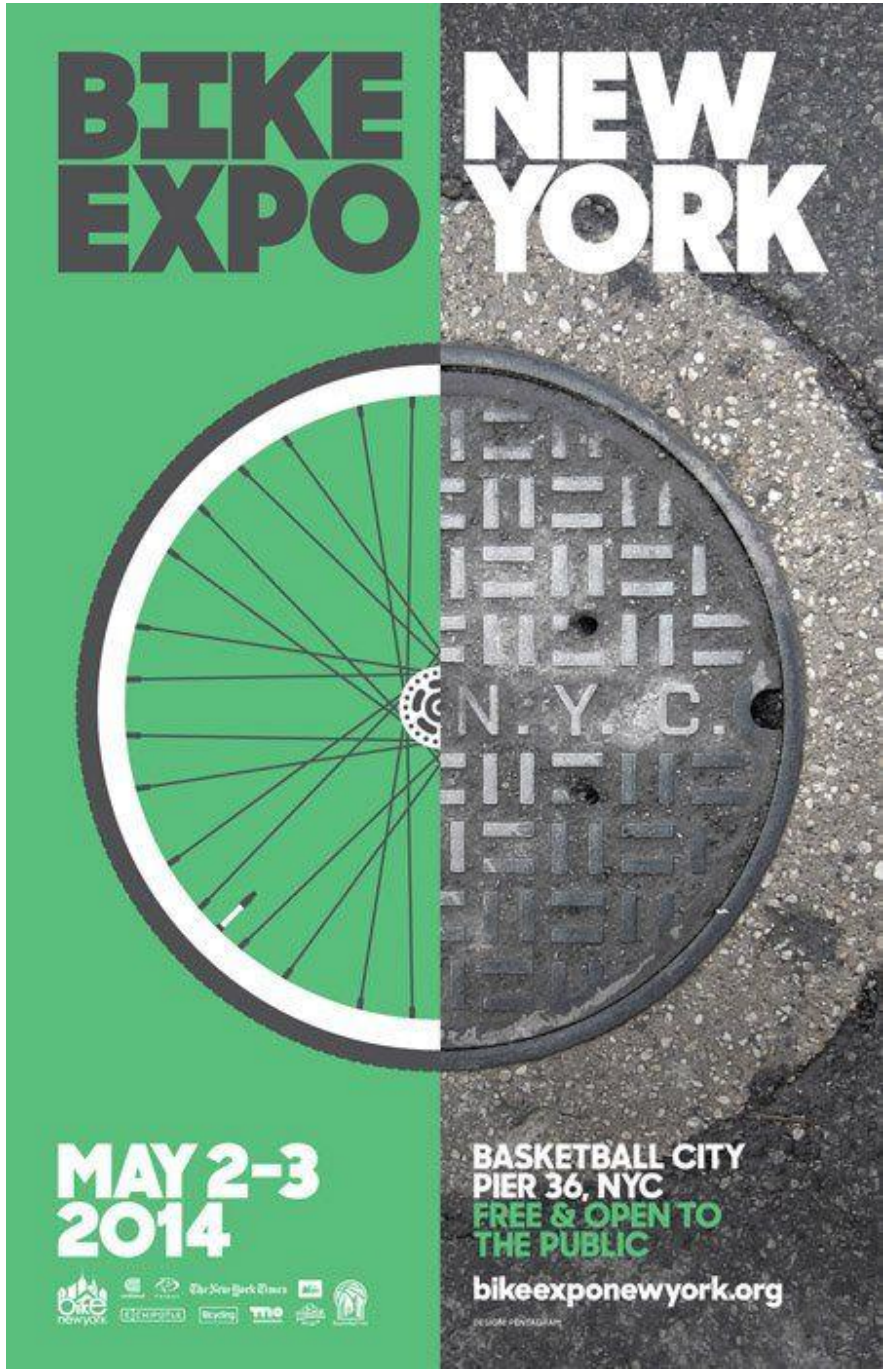


Closure

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

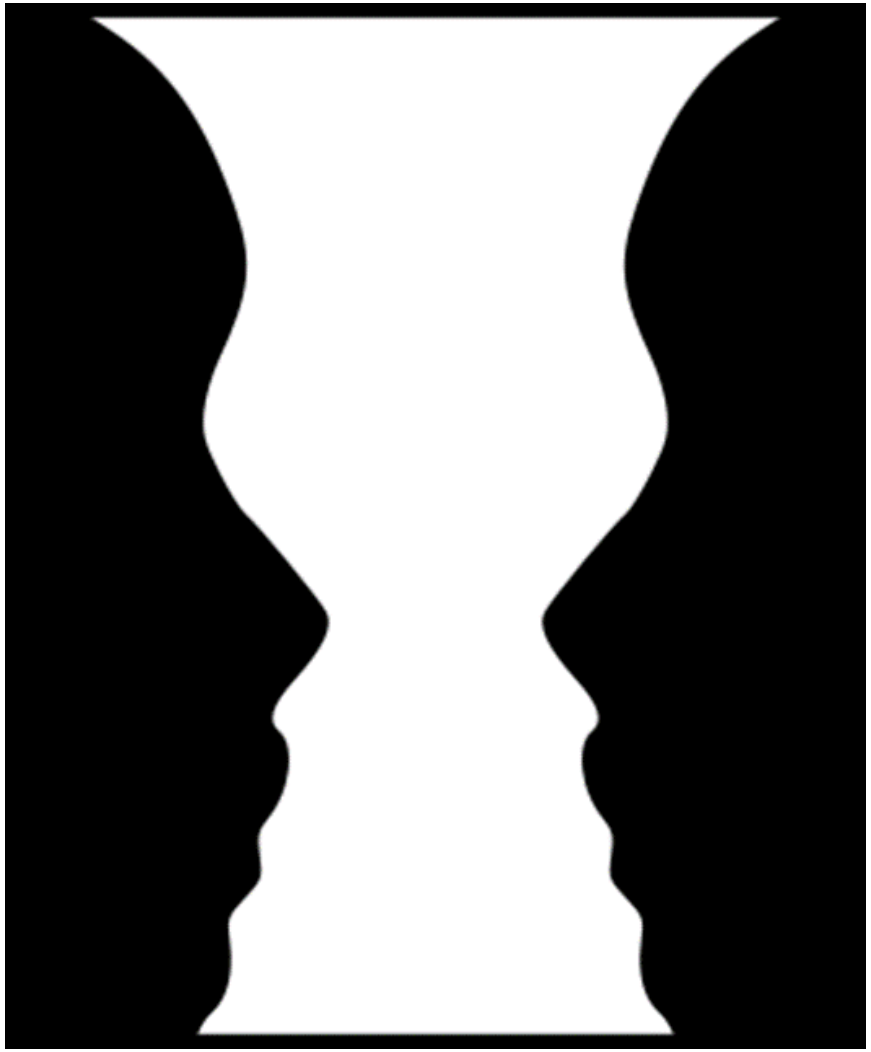
Illusory contour

Common fate

We tend to perceive as a group objects that move in the same direction

Figure-ground

A perceptual effect regarding the formation of a figure from the background



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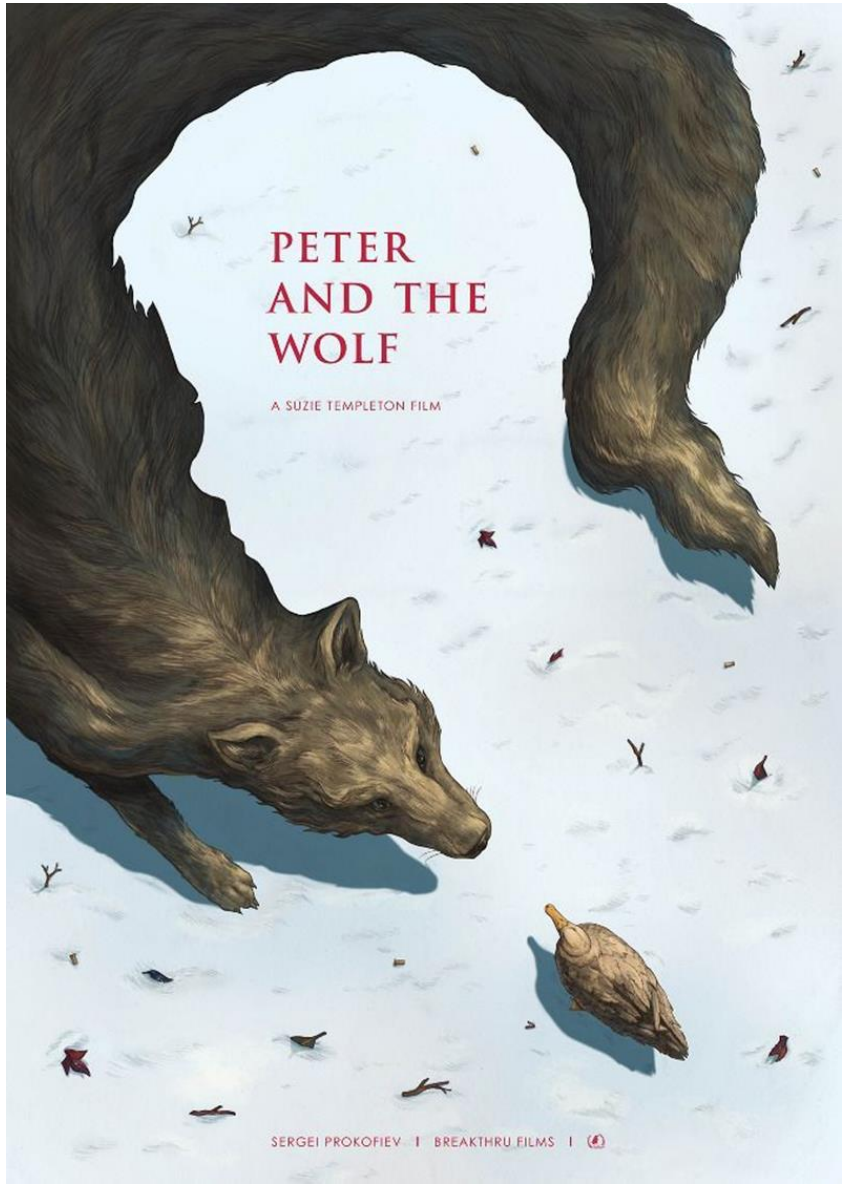

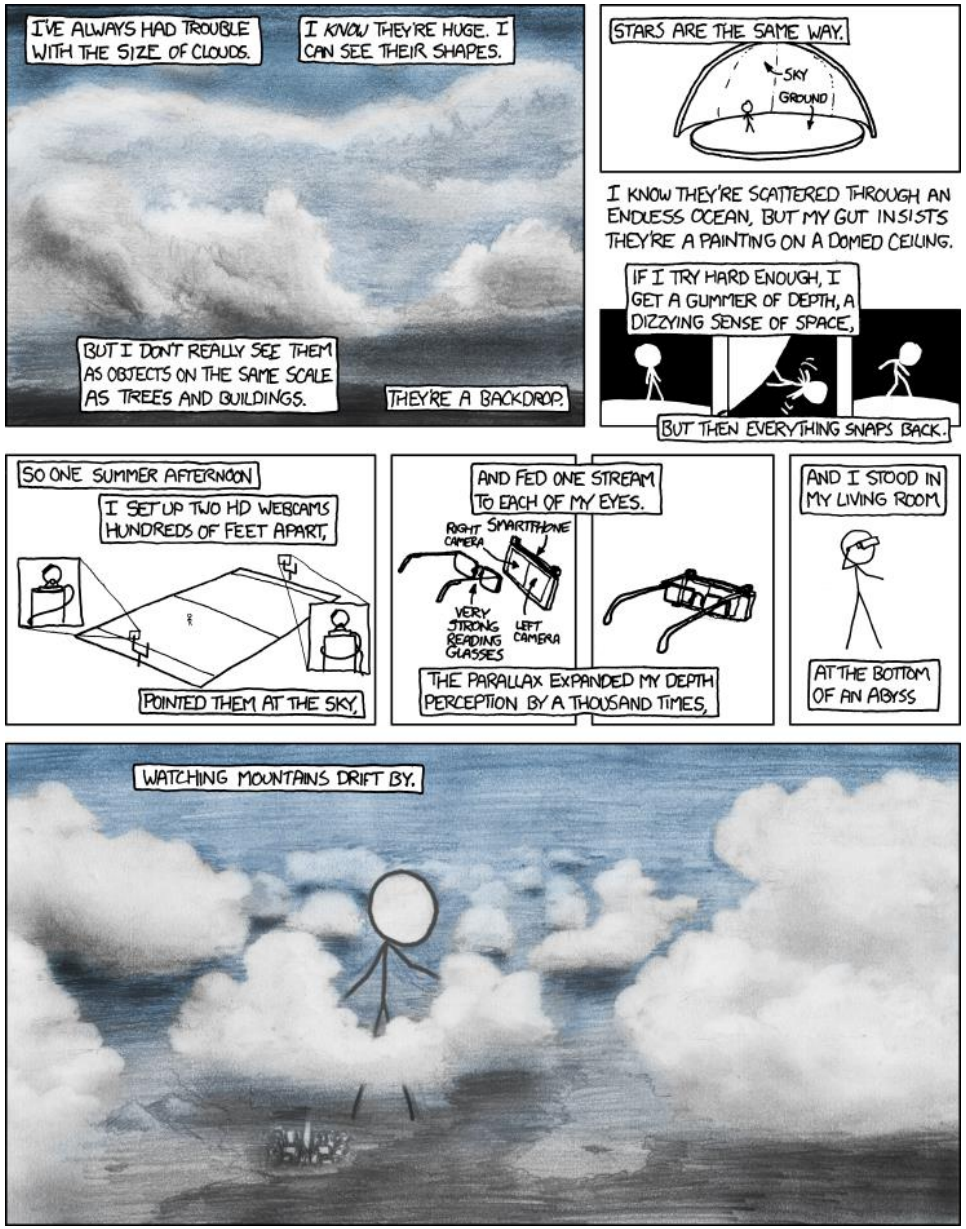

Questions?

[https://xkcd.com/941/]