Human Perception and Information Processing

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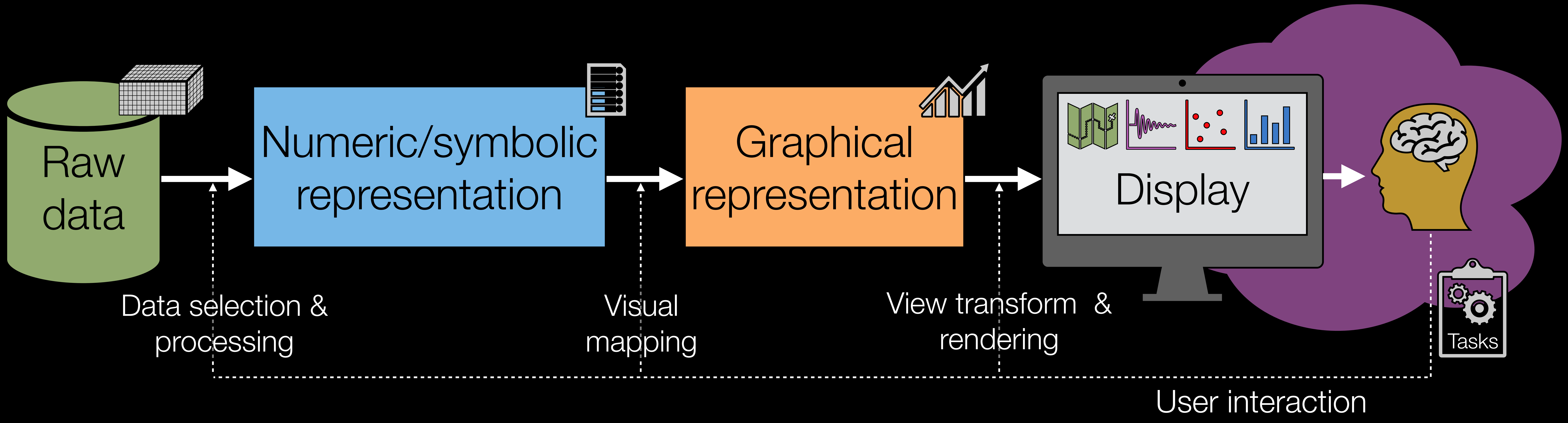
Overview

1. What is Perception?
2. Visual Processing
3. Perceptual Processing
4. Perception in Visualization

Where are we in the Visualization Pipeline?

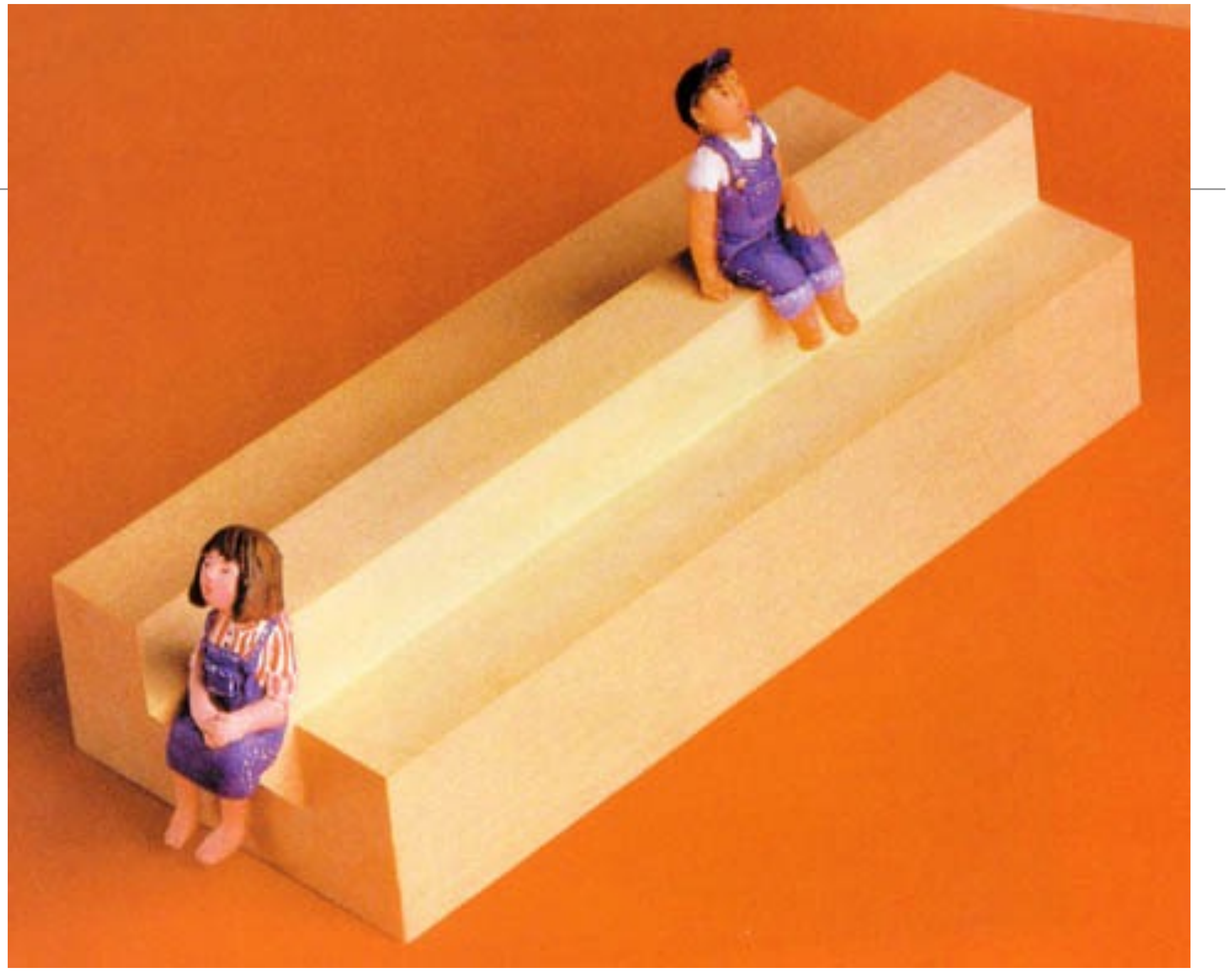


- Data preprocessing and transformation
  - Selection of information and mapping to fundamental computer data types
  - Data cleaning, interpolation, sampling, filtering, aggregation, partitioning
- Mapping for visualization
  - Specific visual representation (geometry, color)
  - Embedding in Euclidean 2D/3D space
- Rendering transformations
  - Final image synthesis by 2D imaging and 3D graphics technology
  - Interactive data and view selection

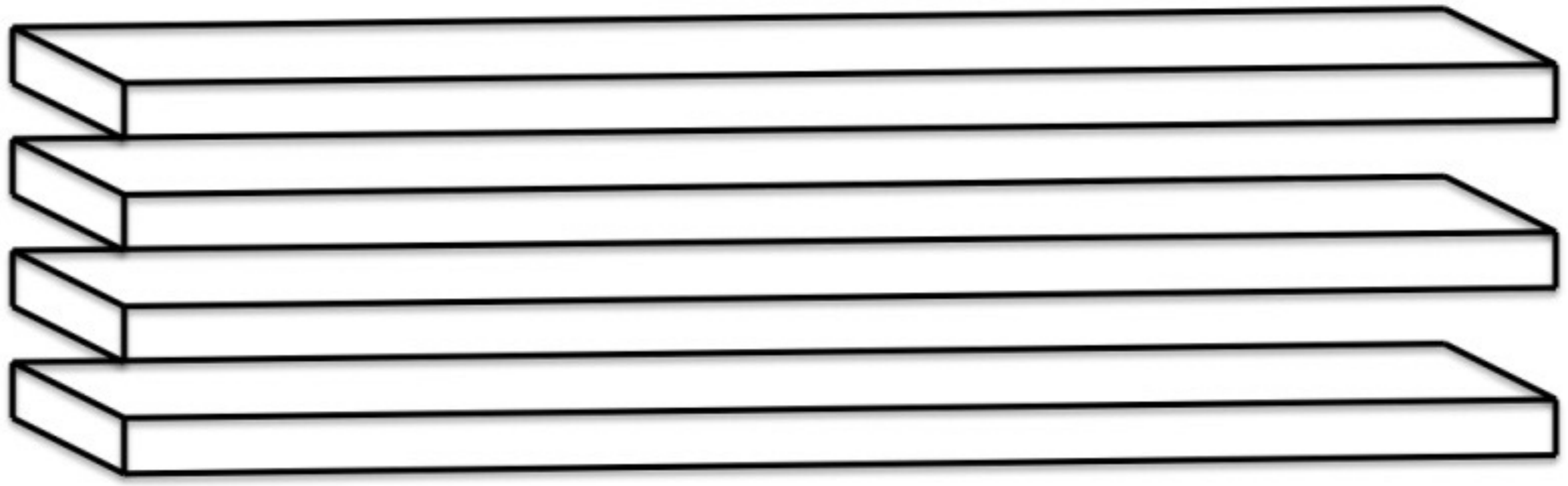
What Is Perception?

- Process of recognizing, organizing and interpreting sensory information
  - Being aware of, gathering and storing, and binding to knowledge
- Human sensory system generates signals, e.g. from visual input
  - Vision and audition being the most well understood
- Perception is the process by which we interpret the world around us, forming a mental representation of the environment
  - Mental form not isomorphic to the real world
  - Brain making assumptions to overcome the ambiguity in all sensory data and the task at hand

Misinterpreting Visual Representations



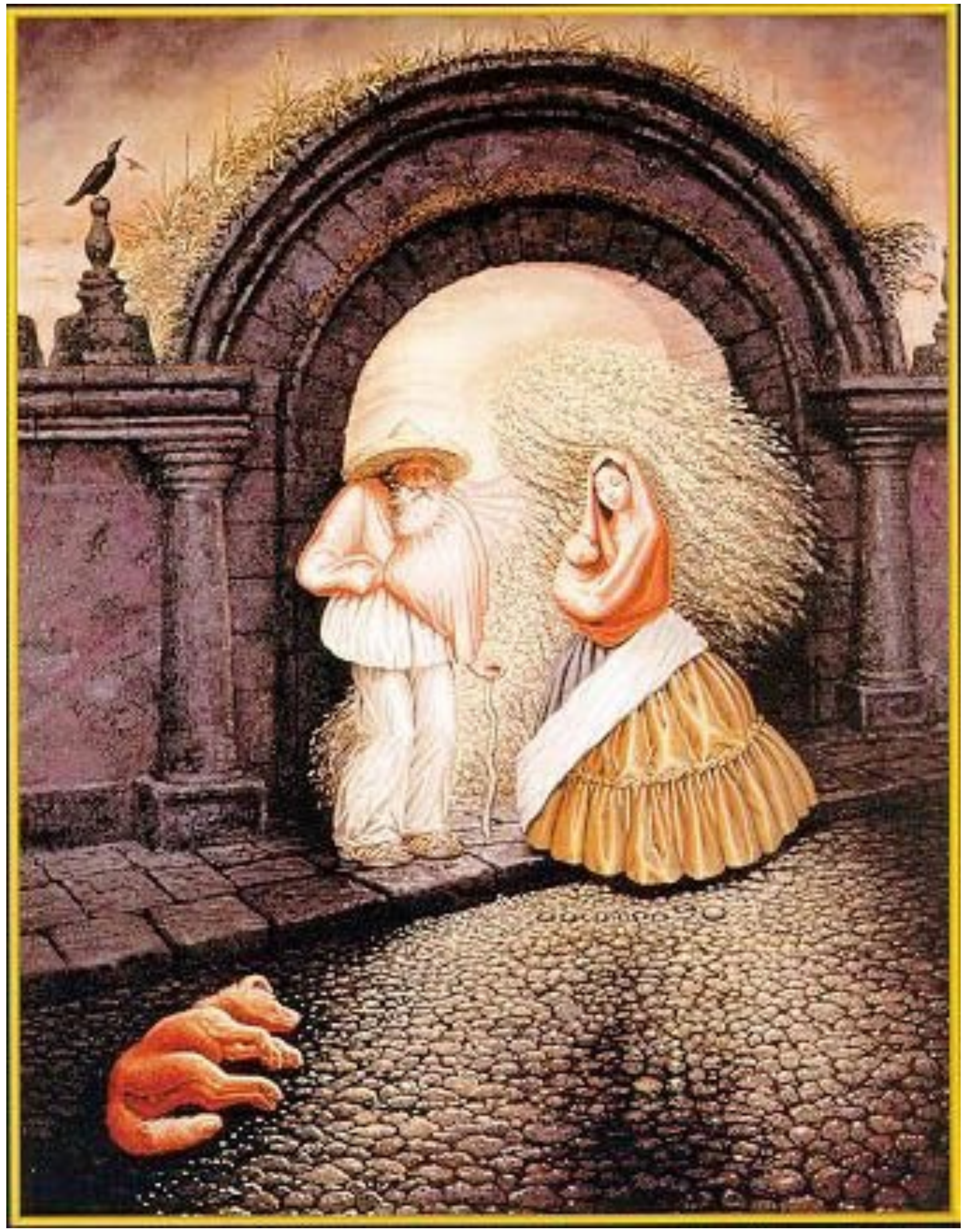
N. Yoshigahara



- Visual representations of objects can often be misinterpreted
  - Not matching our perceptual system
- Illusions as primary source of misinterpretations
  - Two seated figures, making sense at a higher, more abstract level, but still disturbing
    - seats are not realizable
  - Four ≠ three
    - object cannot be built (there are four boards on the left and three on the right)

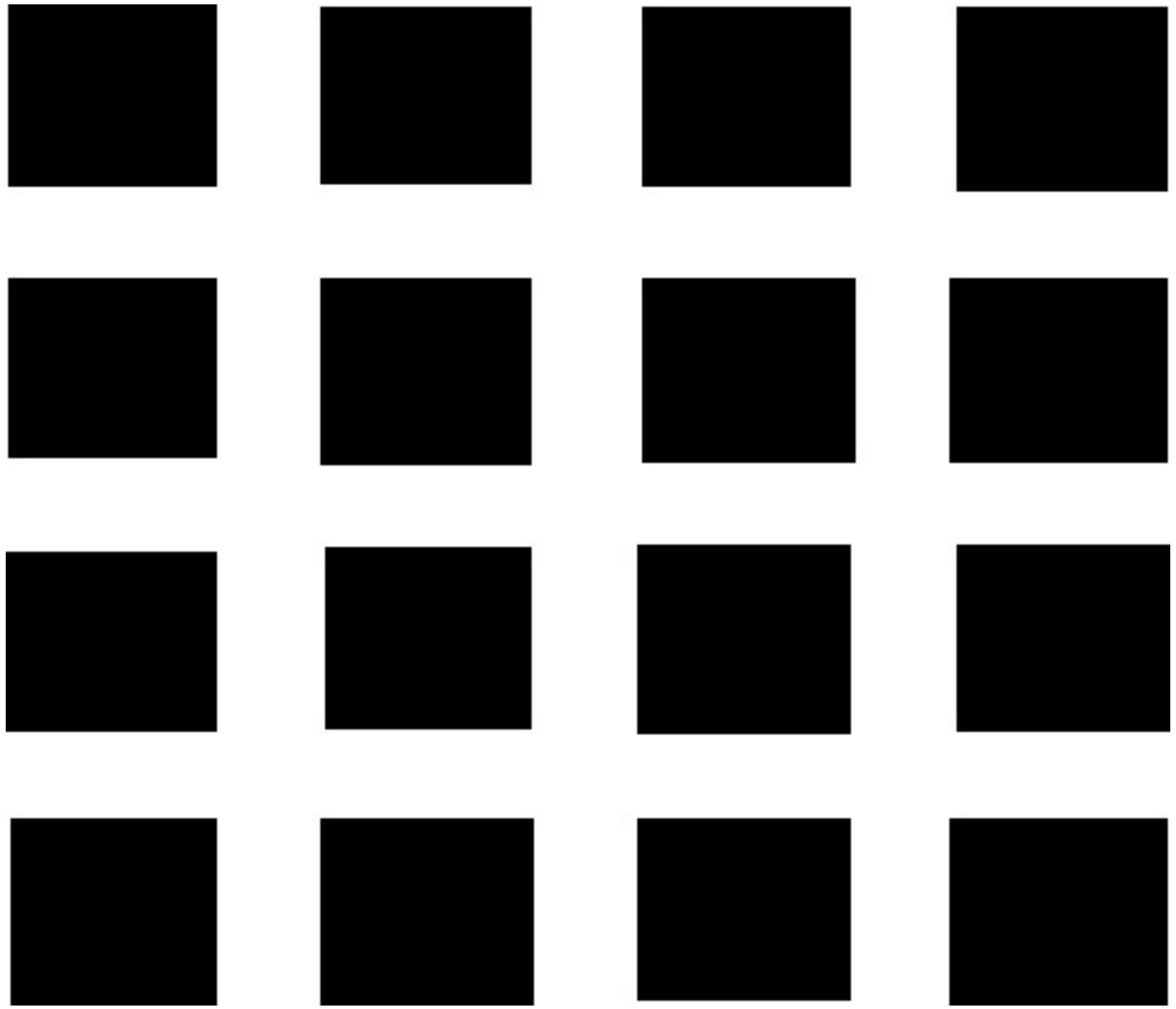
A More Complex Illusion

- An image may represent a primary object more easily than another secondary object which requires more effort or time to recognize
  - Easy to generate, also tools for doing this automatically
- Thus an image can hide or reveal information on purpose or by accident
  - Care must be taken for data to be represented by images



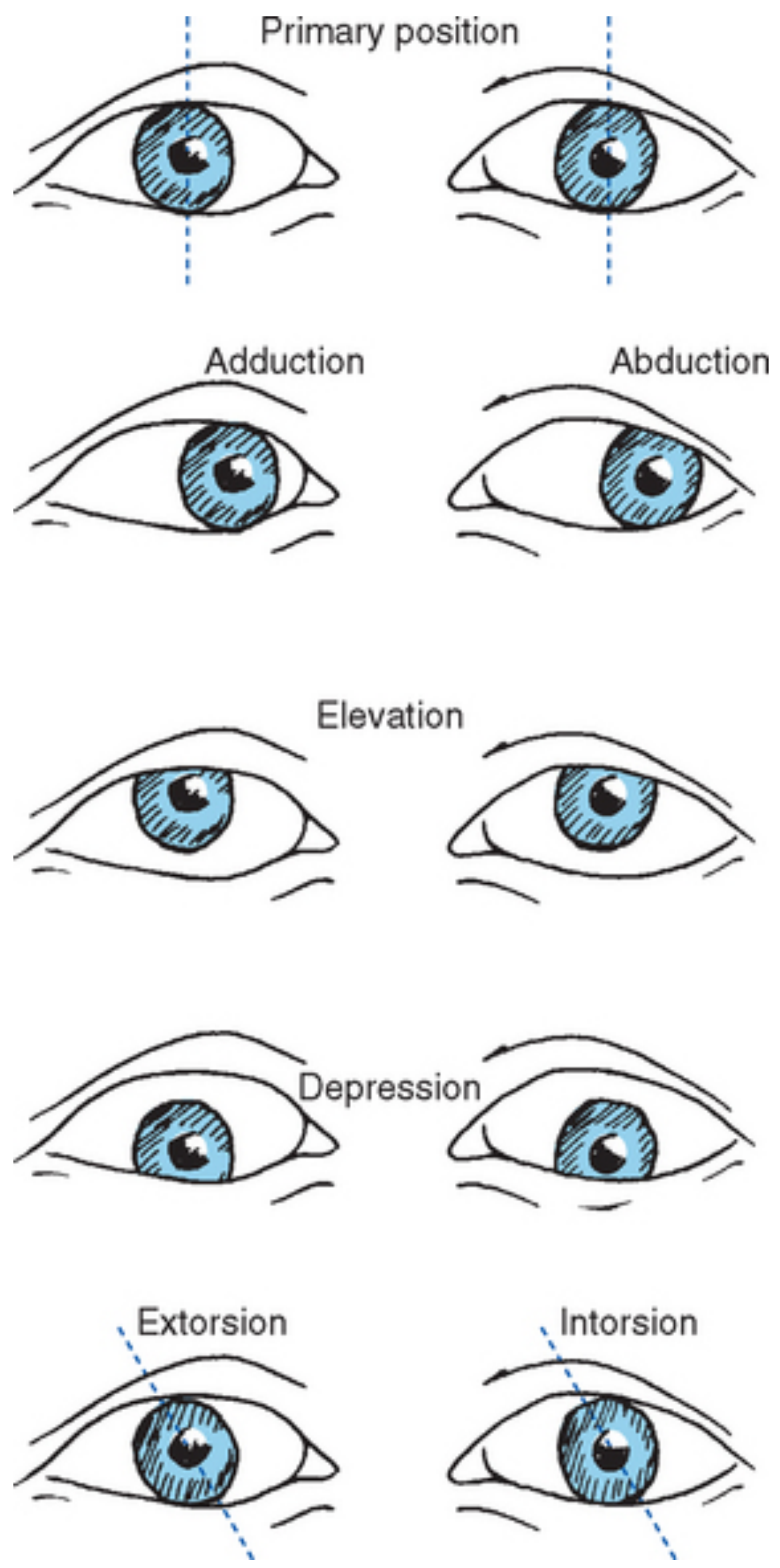
Dynamic Vision System

- The human visual system performs partly unexpected automatic computations
- Vision system is not static and not under our full control
  - Saccadic eye movements cannot easily be overcome
- Visualizations should avoid such interferences
  - Otherwise may impede understanding of data



Eye Movement

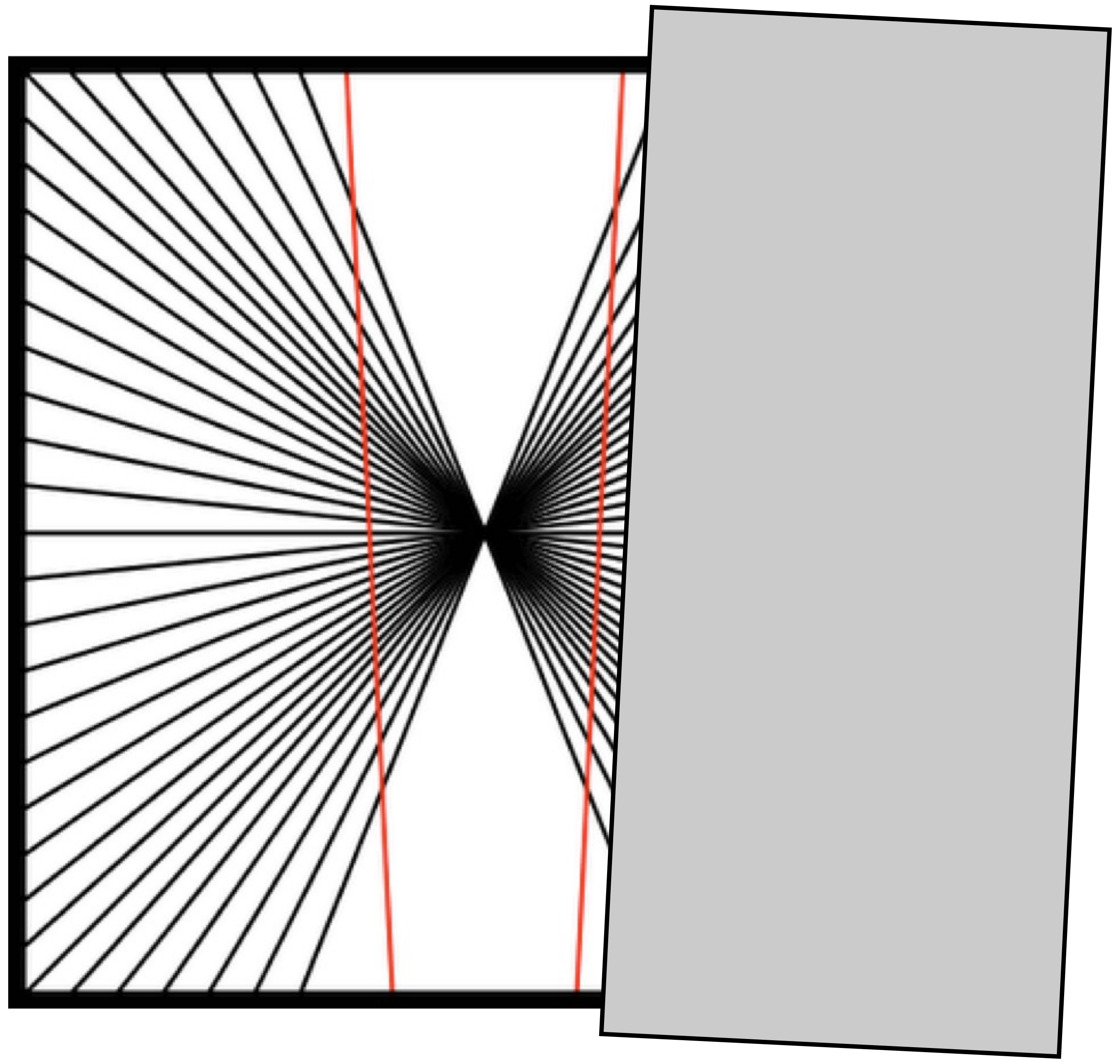
- Eye movements very important for the understanding of scenes and images
- Smooth pursuit movements
  - Conjugate or coordinated movements pursuing a focus point, e.g. following an object
- Vergence eye movements
  - Nonconjugate eye movements for changing depth convergence
- Saccadic eye movements
  - Possibly unconscious focusing on multiple targets by quick eye movements
- Saccadic masking
  - Visual information between saccadic views is suppressed



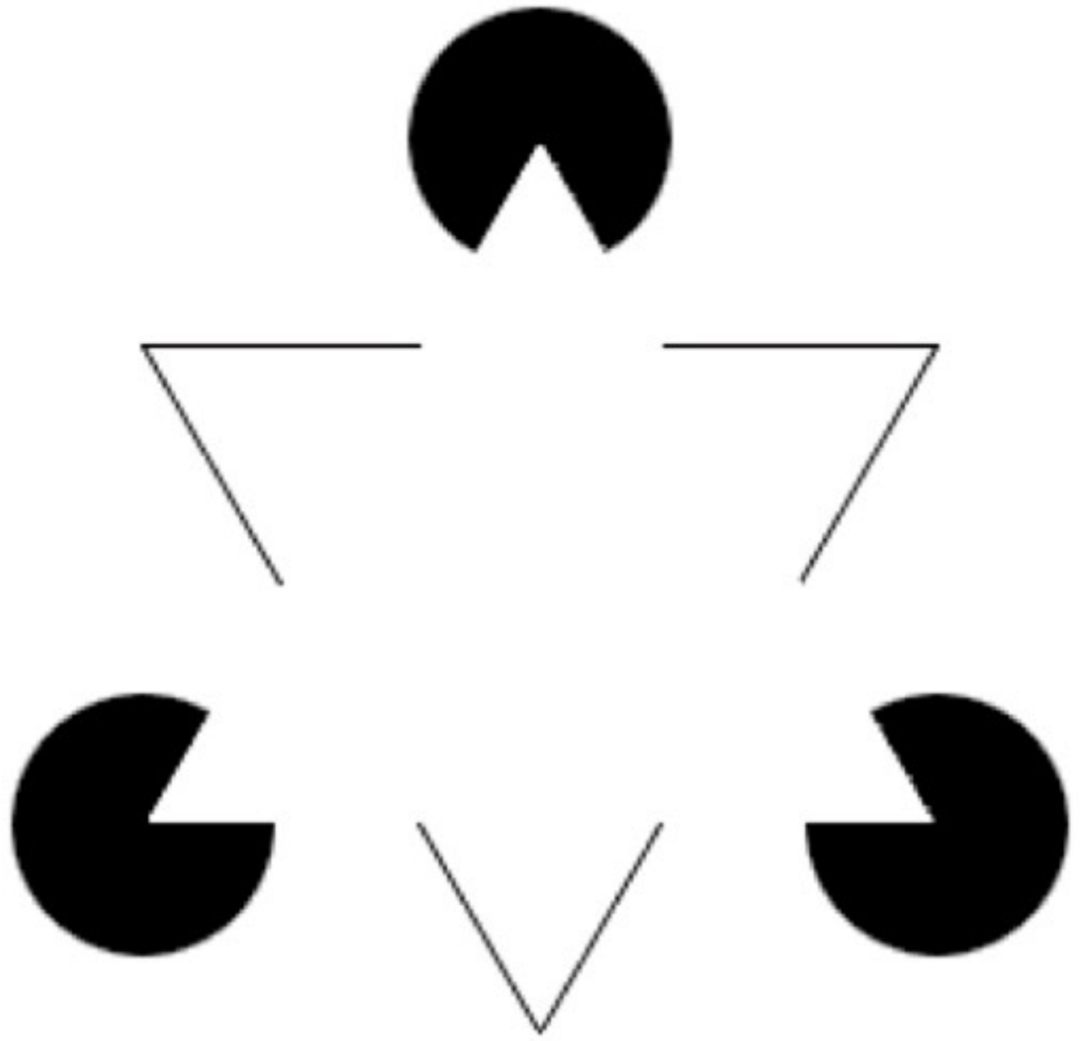
https://neupsykey.com/control-of-eye-movements/

Forced Interpretation

- Human visual system performs automatic computations and interpretations
  - Based on experience and assumptions
- Not paying attention to perception may lead to problems in data visualizations



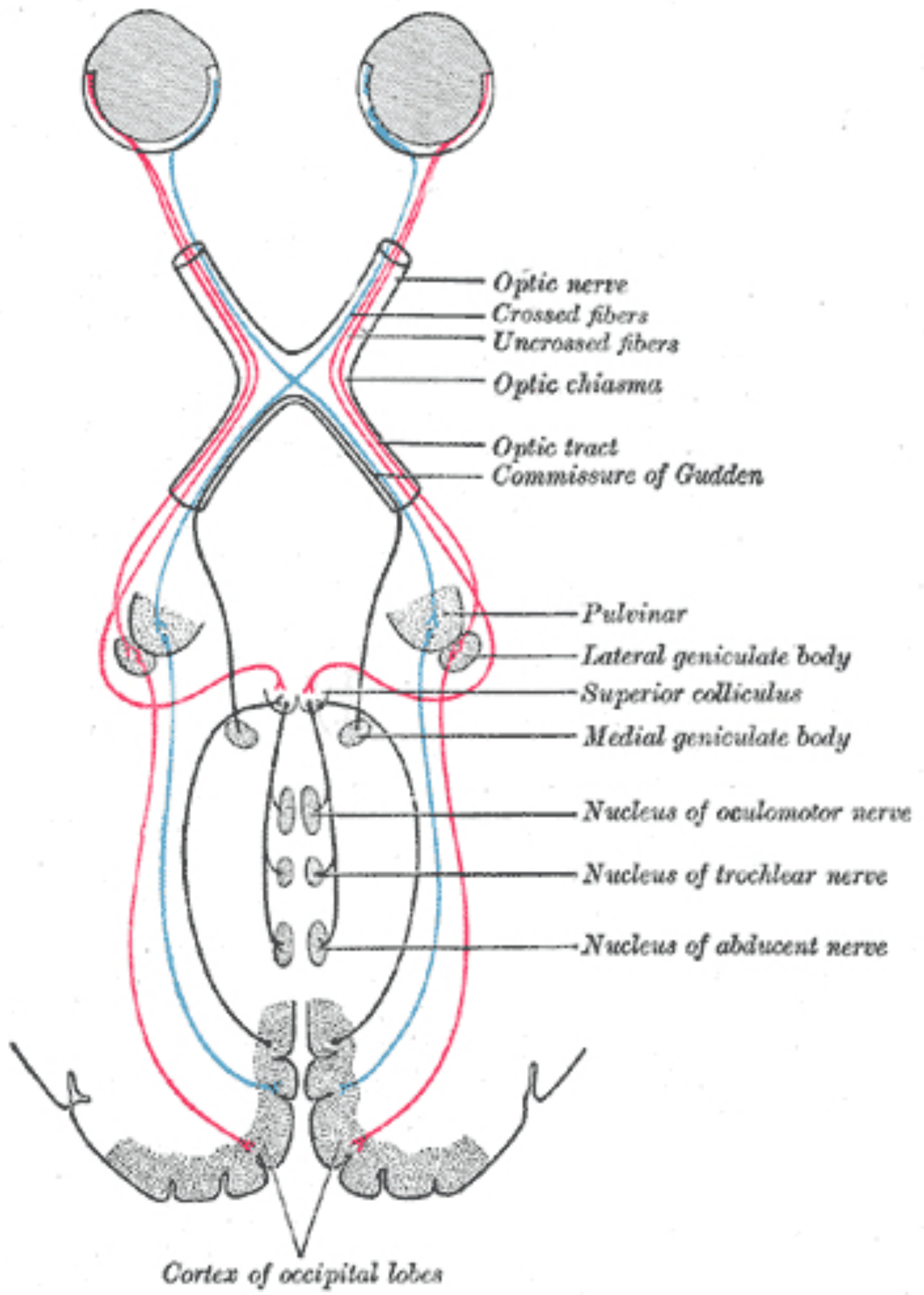
Hering illusion



Kanizsa illusion

Visual Processing

- Signal processing in humans performed by neurons
  - Elementary biological components making the nervous system
  - Complex network of interconnected neurons
- Retina does not just record light intensities but performs automatic initial image processing
  - Four neuron layers process stimulations from the individual photoreceptors
- Some kind of compression and segmentation of the visual signal is taking place
  - Optical nerve information channel of only about one million fibers
  - 100 times less than actual rods and cones
- Left/right crossing of half of the optical nerves in the *optic chasma* to the left/right brain hemispheres



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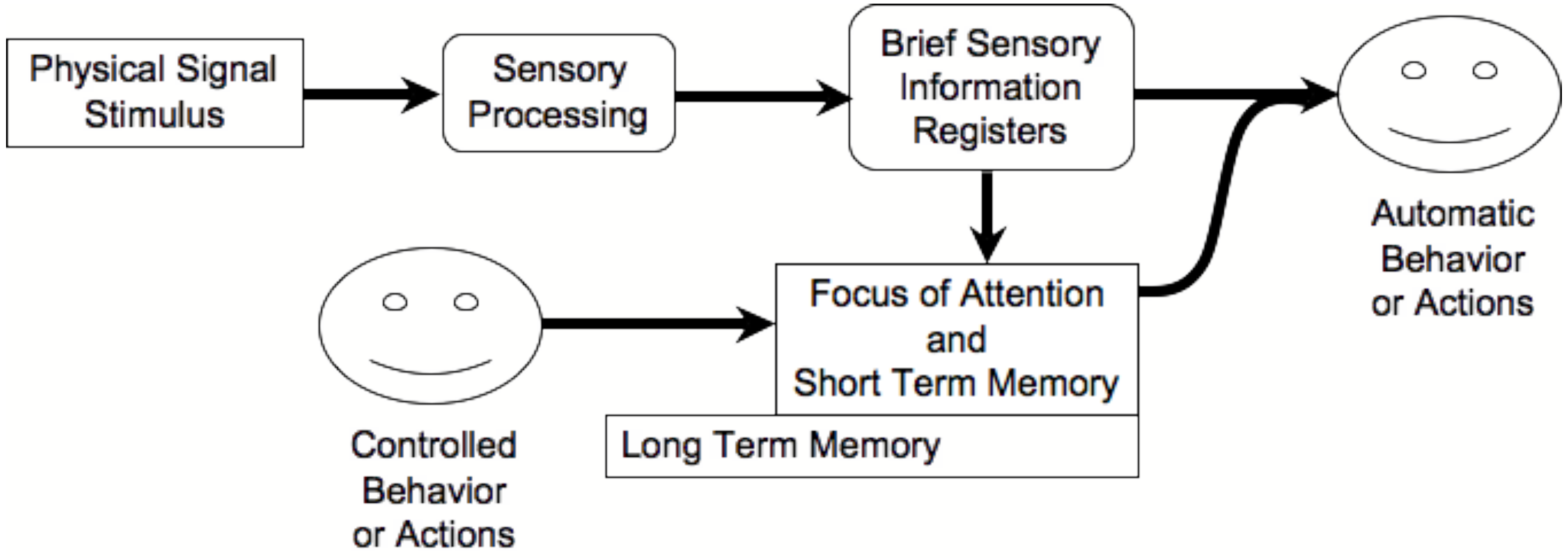
Perceptual Processing

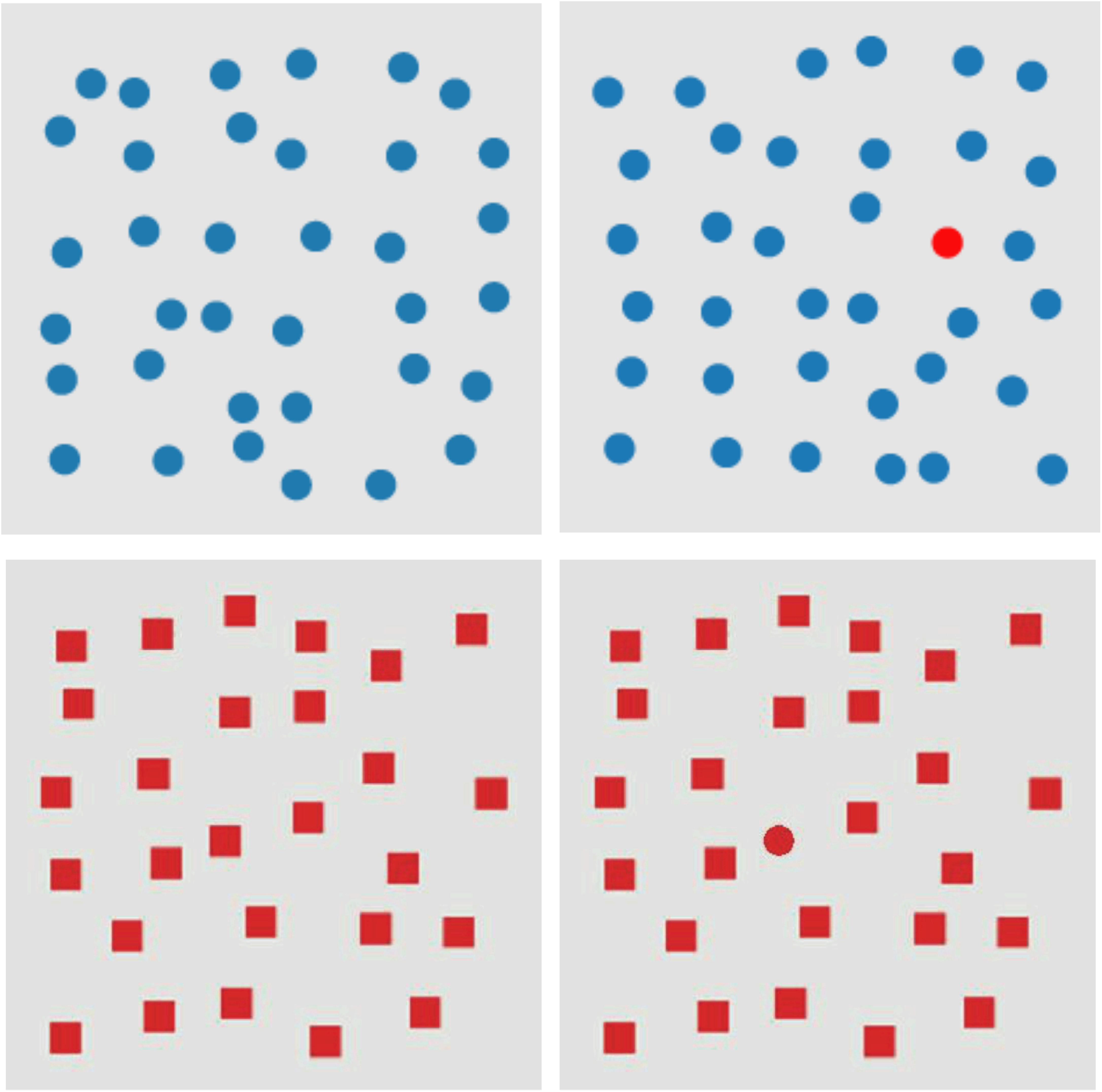
- Visual information processing model, from lower pre-attentive to higher cognition levels



- Automatic uncontrolled (pre-attentive) perception is performed in parallel
  - Certain effects pop out in preconscious visual processes
- Controlled (attentive) processing transform initial vision effects into structures and objects
  - Selective and aggregative of visual scene content

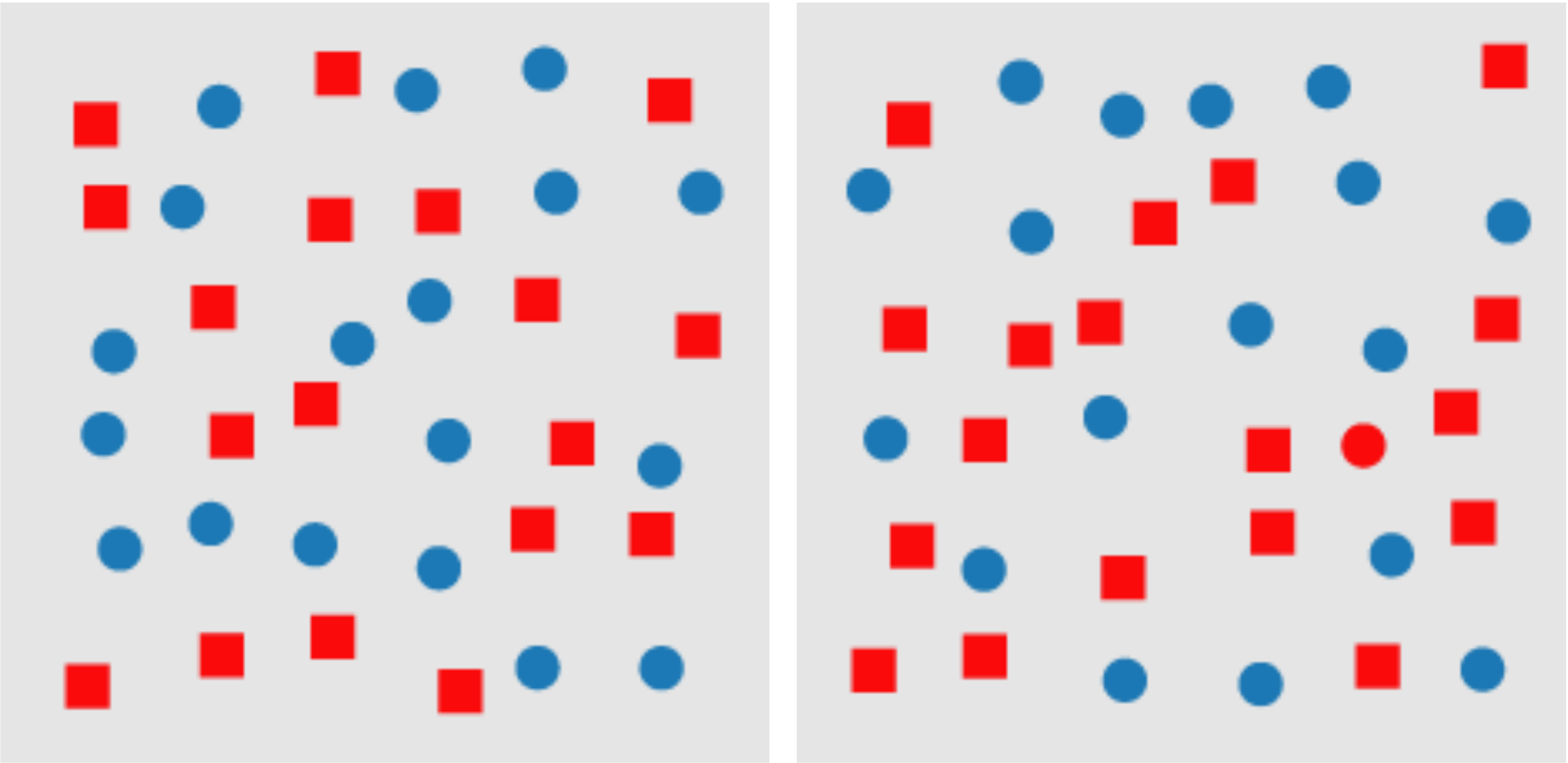
Preattentive Processing

- Rapid and accurate detection of visual properties
  - More rapidly than controlled eye movements could
- Basic task completion parallelized in low-level visual system
- Color hue is a pre-attentive property
  - Not the only property



Preattentive Processing

- Rapid and accurate detection of visual properties
  - More rapidly than controlled eye movements could
- Basic task completion parallelized in low-level visual system
- Color hue is a pre-attentive property
  - Not the only property
- But combination of features may not be detected pre-attentively
  - No unique visual property to separate elements
  - Requires attentive visual search

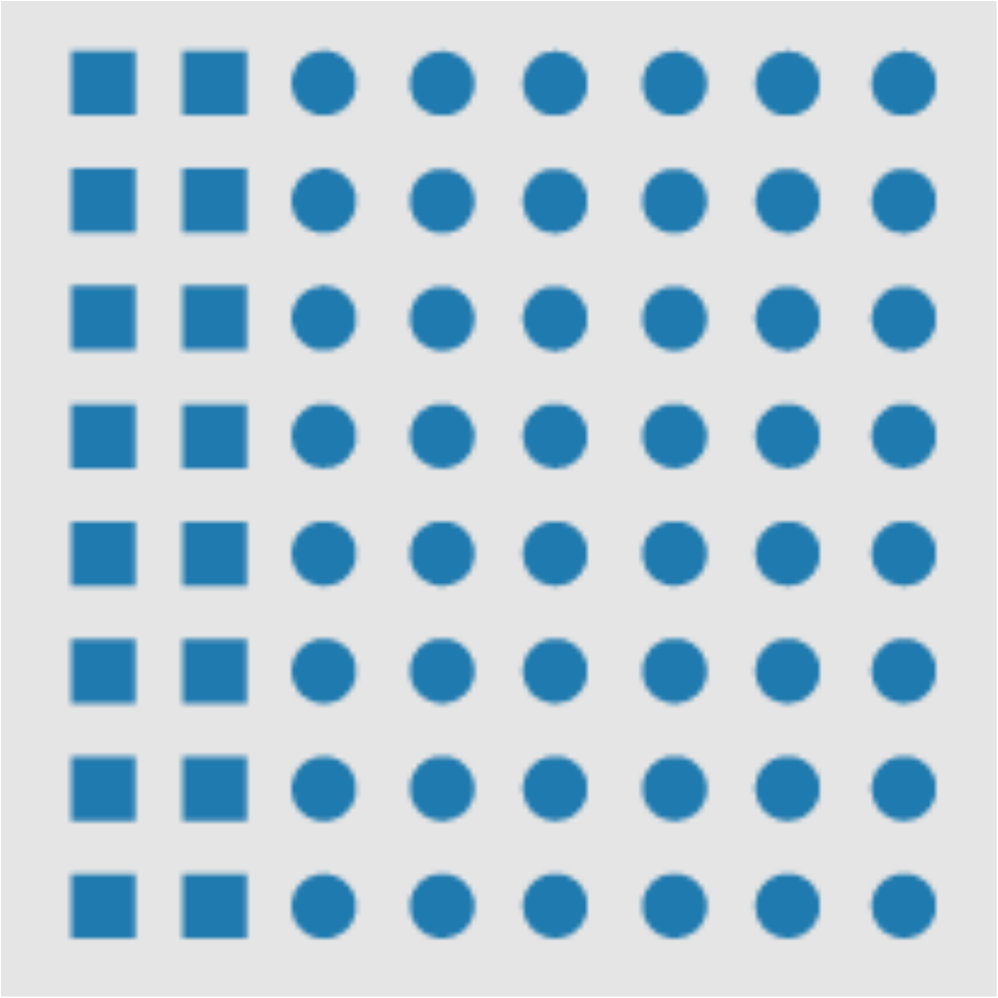


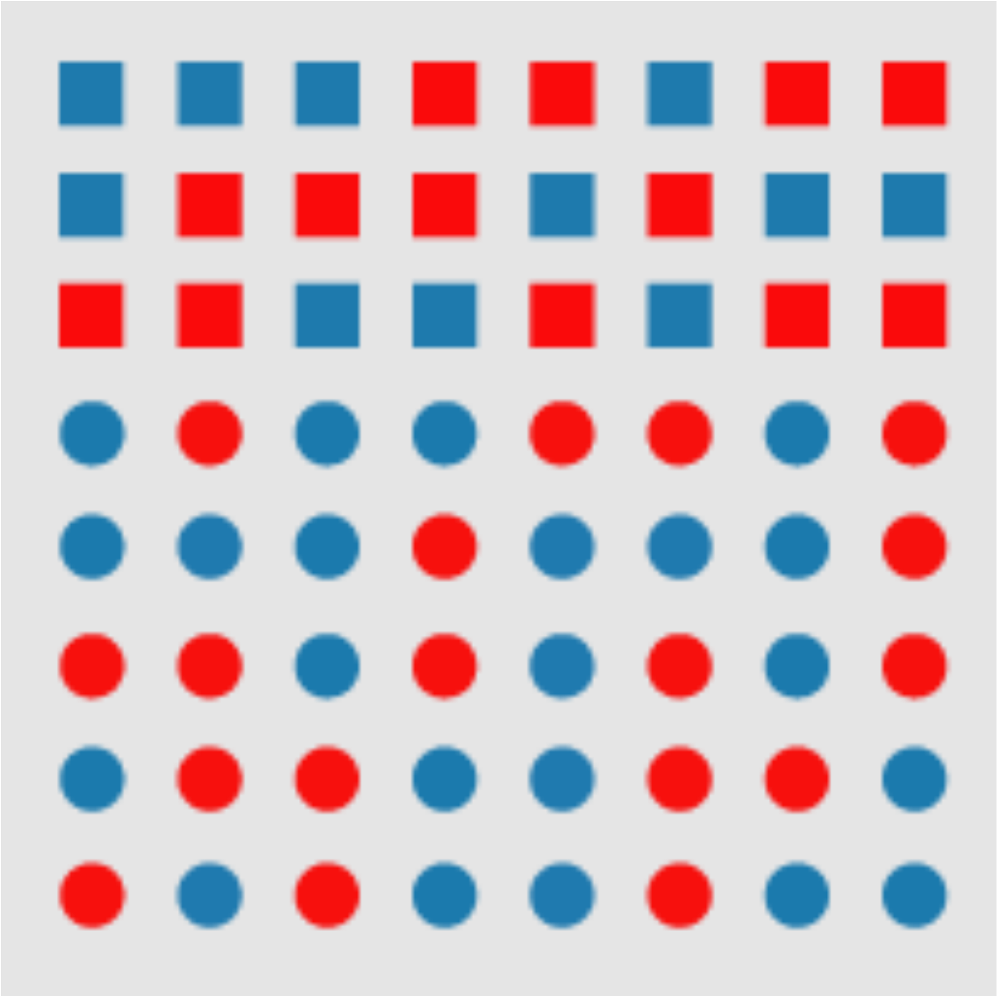
Preattentive Visual Features

- Visual features assigned to different data attributes thus
    - must take advantage of the strength of the visual system
    - must be well suited for the analysis task
    - must not produce visual interference that could mask information
- Example individual preattentive visual features:
    - Length, width, size, curvature, intersection, closure, hue, intensity, flicker, direction
- Luminance/brightness, color, texture and shape as key perceptual attributes
    - Amount of difference affects pre-attentiveness
- Fundamental pre-attentive tasks:
    - Target detection
    - Boundary detection
    - Region tracking
    - Counting and estimation

Feature Hierarchy

- Exploit different preattentive visual features to encode different data attributes
  - Visually explore multiple data values concurrently
- Care has to be taken to avoid interference
  - Interactions between different visual features may hide or mask information
- Hierarchy of visual feature importance exists
  - Variations in color interfere with the detection of shapes and spatial patterns
  - Asymmetric as random shapes do not distract detecting color patterns
    - hue-on-form
    - luminance-on-hue
    - hue-on-texture
- Most important data attributes should be mapped to the most salient visual features

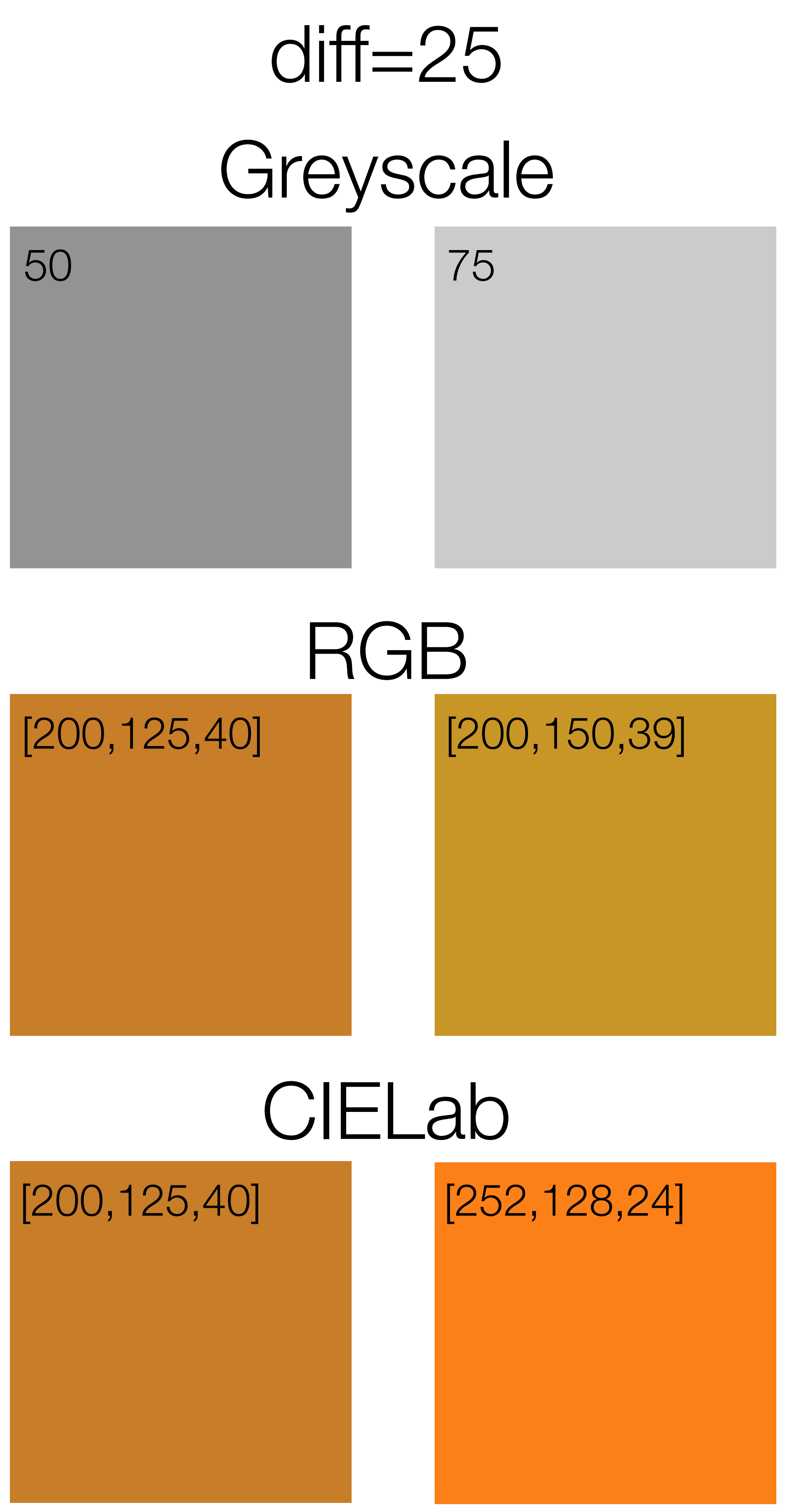




Perception in Visualization

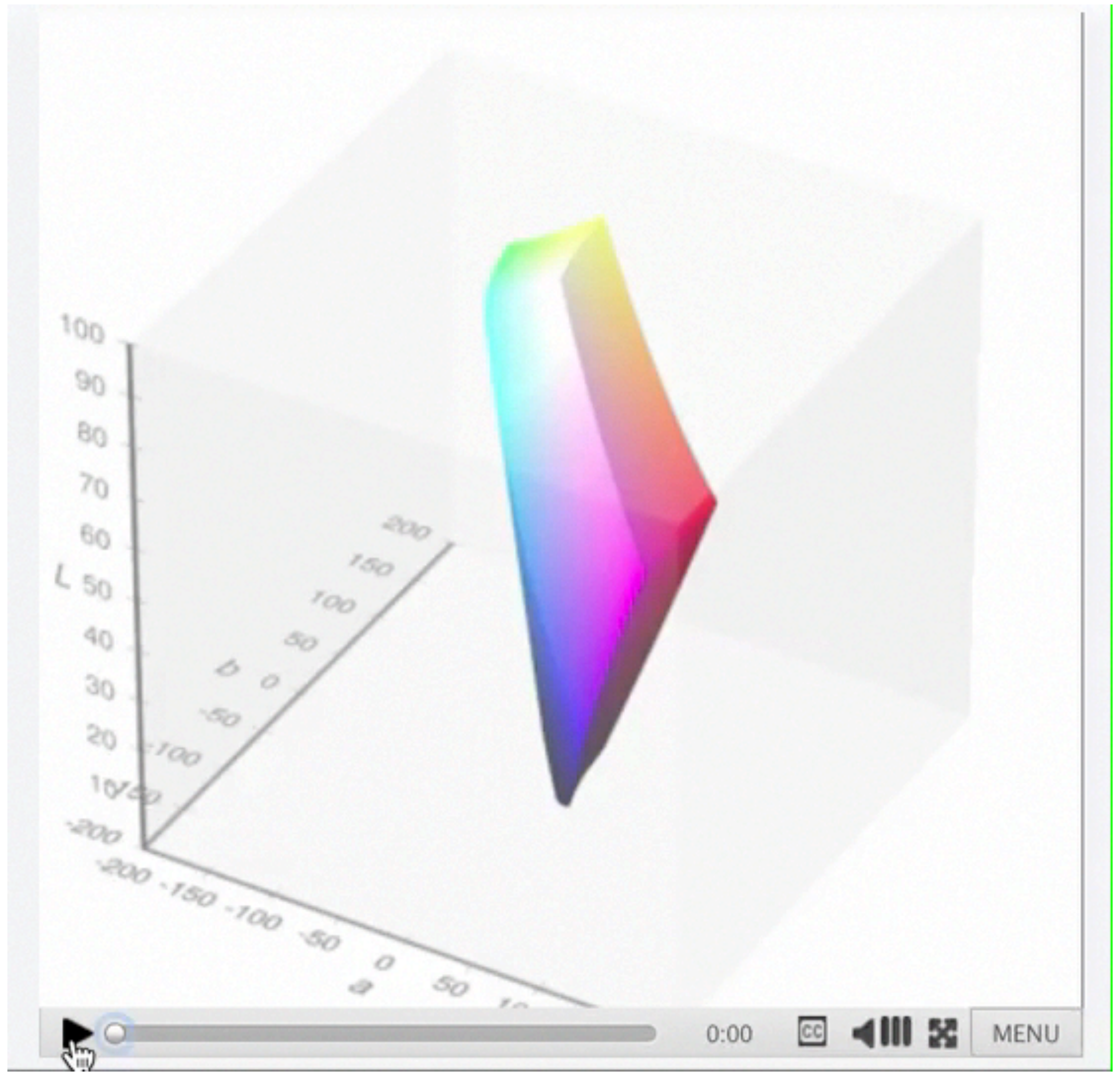
- Choices for visualization methods and parameters should be perceptually motivated
- Specifically the use of visual features such as color, texture and motion

- **Color** is a common and key visual feature to describe data in visualizations
  - Rainbow spectrum, red-blue/red-green or greyscale gradients
- Perceived color differences should match the (numerical) differences in the data
  - *Perceptual balance*: unit step in color space in a perceptual uniform difference in color
  - *Distinguishability*: within a discrete collection of (sufficiently) different colors, every color is equally distinguishable
  - *Flexibility*: colors can be selected from any part of the color space
- CIE Lab, CIE LUV and others support perceptually uniform color balance



Perceptually Uniform Color

- Common RGB, HSV or YUV color models are not perceptually uniform
  - Not even the CIE color space
- The CIELab color model is and can be derived from CIE
  - There are no simple formulas for conversion between RGB values and L*a*b*, because the RGB color model is device-dependent



$$L^\star = 116\, f\left(\frac{Y}{Y_n}\right) - 16$$

$$a^\star = 500\left(f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right)$$

$$b^\star = 200\left(f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right)$$

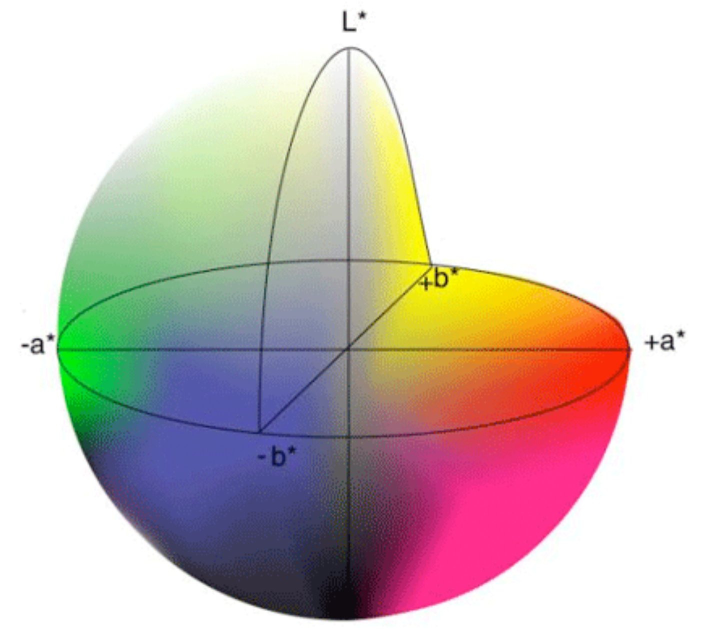
$$f(t) = \begin{cases} \sqrt[3]{t} & \text{if } t > \delta^3 \\ \frac{t}{3\delta^2} + \frac{4}{29} & \text{otherwise} \end{cases}$$

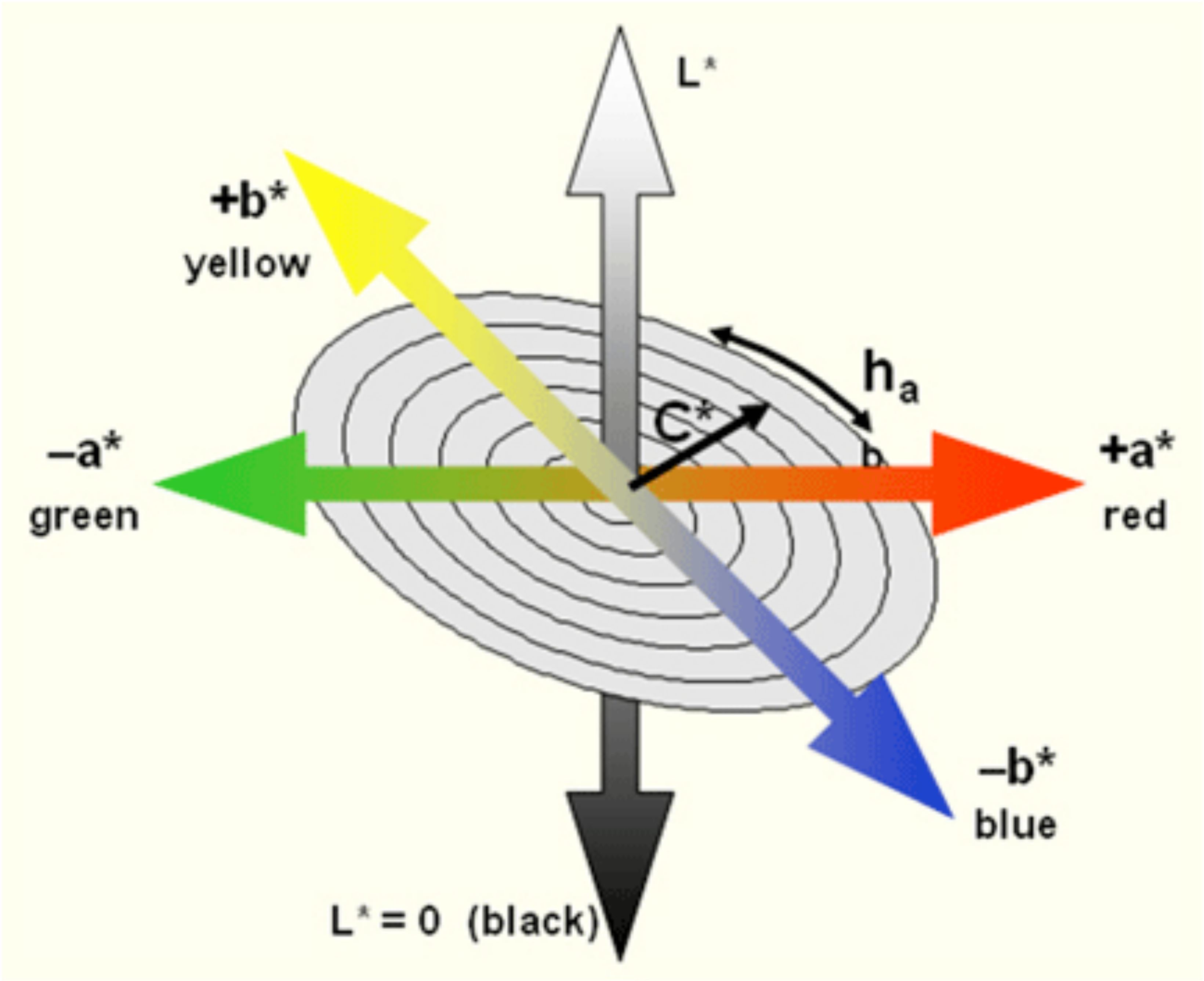
$$\delta = \frac{6}{29}$$

$$X_n = 95.047,\quad Y_n = 100.000,\quad Z_n = 108.883$$

CIELab and CIELCh Perceptually Uniform Color Spaces

- Distortion of the CIE space to be more uniform in terms of perceived color differences
- CIELab is based on the opponent color theory
  - L* (Lightness) provides a scale of neutral color from black to white (0 to 100 L* units)
  - CIE a* is the coordinate for *redness-greenness*
  - CIE b* is the coordinate for *yellowness-blueness*
- CIELCh is identical to CIELab expressed with different coordinates:
  - ***Hue***: angle around vertical color space axis
  - ***Chroma***: intensity, or vividness, of a hue (the higher the value of chroma, the more pure, vivid, or saturated the color is)

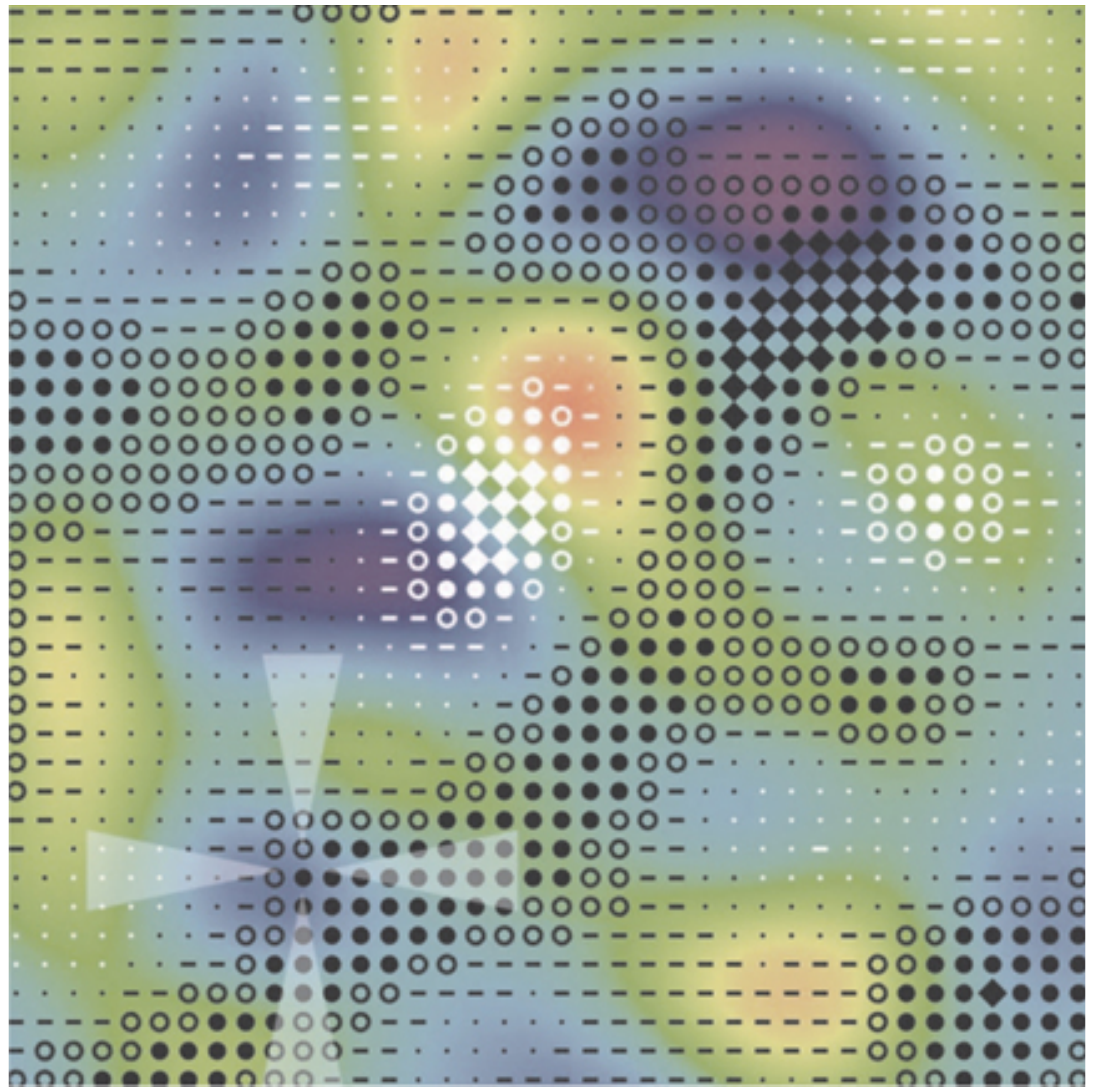




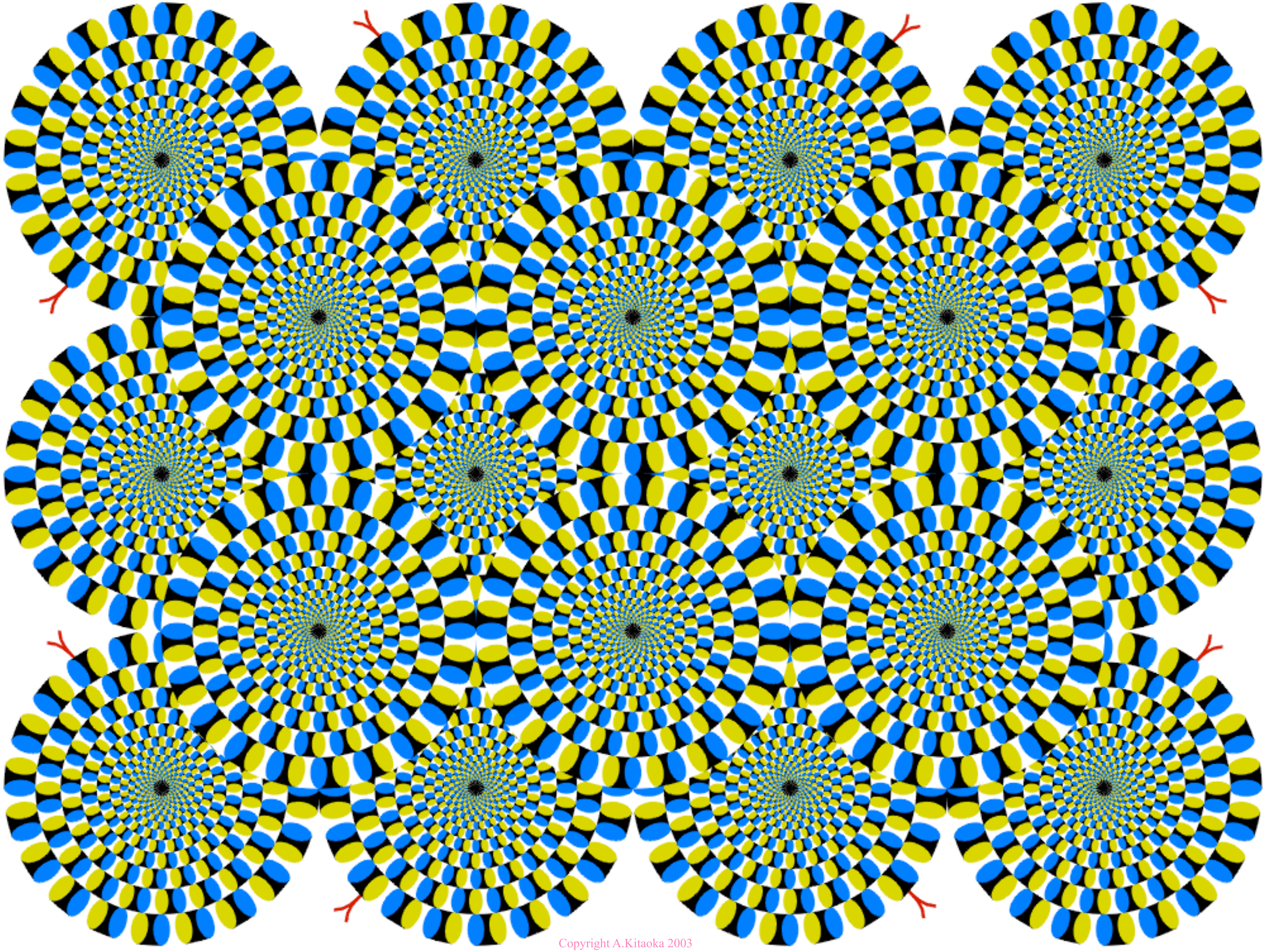
Texture and Motion

- **Texture** often used as a single visual feature
  - But decomposed into fundamental perceptual dimensions
    - regularity, directionality, contrast, size, coarseness
  - Recognized by low-level visual system
- Use perceptual texture dimensions to represent multiple data attributes
  - Changing texture pattern based on the underlying data

- **Motion** can indicate direction and magnitude of vector fields
  - Changes in the data along a specific dimension (e.g. time)
- Perceptual dimensions of motion include flicker, direction, and velocity
  - Distinguishable flicker frequencies vary between central and peripheral view
  - Changes in velocities are faster to detect at higher initial velocities



Colin Ware. Quantitative Texton Sequences for Legible Bivariate Maps. *IEEE Transactions on Visualization and Computer Graphics*, 15(6):1523–1529, 2009.



Memory Issues

- Sensory memory
  - High capacity information storage processing large quantities on information very fast
  - Can be harnessed for repeated actions (e.g. typing and piano playing)
    - preattentive image processing and filtering
- Short-term memory
  - Limited information capacity to analyze sensory input
  - High level of processing with limited time span
  - Harnessed by grouping, repetition and chunking
- Long-term memory
  - Large multi-coded and redundantly stored information
  - Information retrieval is the key problem, access is slow and unreliable

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Recap

- **Visual illusions:** visual system can be fooled, leading to misinterpretations
- **Dynamic vision:** unconscious eye movements, automatic visual ‘computations’, forced interpretations
- **Perceptual visual processing:** automatic unconscious image processing, preattentive visual processing, hierarchy of preattentive visual features
- **Color perception:** perceptually uniform colors, CIE Lab color model, perception of motion and texture

- Required textbook Chapter(s): 3

Related Readings

- **The Magic Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information** [Psychological Review 63:2 (1956), 81–97.]
  - Parts of the section on metrics from the article by George Miller.
- **Graphical Perception** [Chapter in William S. Cleveland, The Elements of Graphing Data CA: Wadsworth, Inc., 1985.].
  - More recent work on graphical perception
- **Kurzweil's The Age of Spiritual Machines** [London: Penguin, 2000.] and **Looks et al., Novamente: An Integrative Architecture for Artificial General Intelligence** [In Proceedings of the AAAI Fall Symposium on Achieving Human-Level Intelligence through Integrated Systems and Research, AAAI Fall Symposium Series, pp. 54–61. Menlo Park, CA: AAAI Press, 2004].
  - Work on AI and cognition