# Lecture 3: Principles of Data Visualization

Instructor: Saravanan Thirumuruganathan

# Outline

1. Bertin's Visual Attributes
2. Tufte's Principles
3. Effective Visualization
4. Intro to PsychoPhysics

# In-Class Quizzes

- **URL:** `http://m.socrative.com/`
- **Room Name:** **4f2bb99e**

# Announcements

- One-time attendance recording
- Form teams soon!
- Programming Assignment 1 will be released this weekend (due in 3 weeks)

# Bertin's Visual Attributes

# Introduction to PsychoPhysics

# PsychoPhysics[1]

- "the scientific study of the relation between stimulus and sensation"
- "the analysis of perceptual processes by studying the effect on a subject's experience or behaviour of systematically varying the properties of a stimulus along one or more physical dimensions"

[1] From Wikipedia

# PsychoPhysics[2]

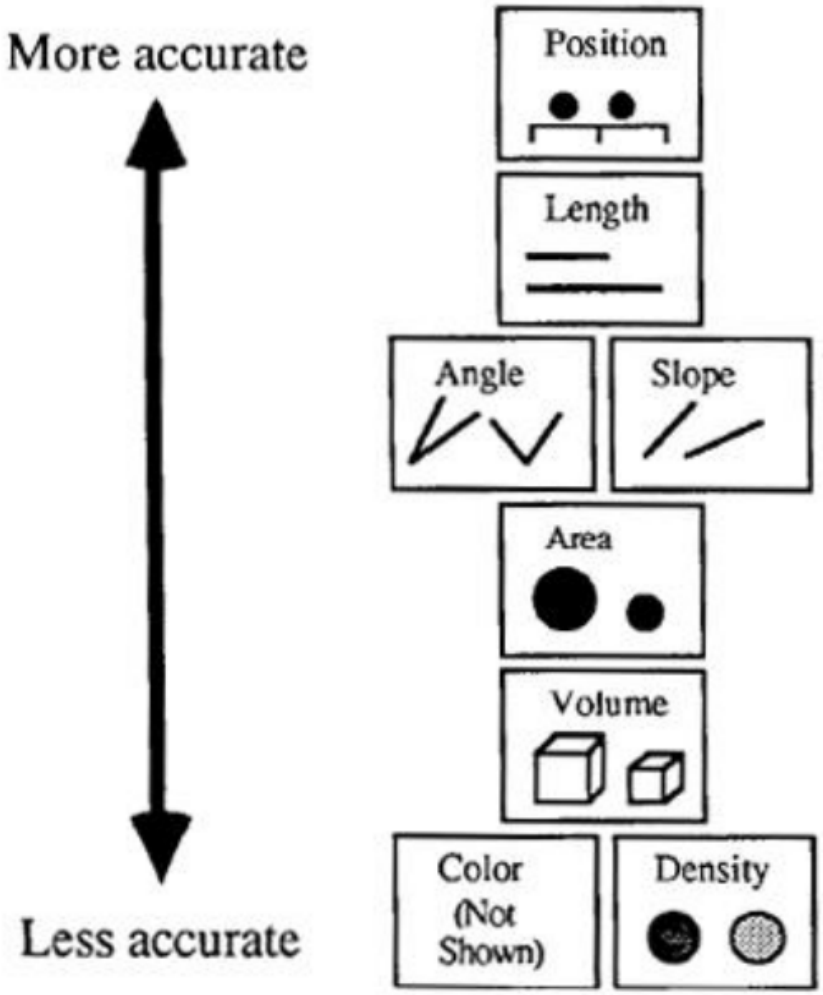
- **Visual Encoding**: the way in which data is mapped into visual structures, upon which we build the images on a screen.
- **Visual Perception:** ability to interpret the surrounding environment by processing information that is contained in visible light.

[2] From Wikipedia

# Effective Visual Encoding

- **Challenge:** Pick the best encoding (or mapping) from many possibilities. Consider:
  - **Importance Ordering**: Encode the most important information in the most perceptually accurate way
  - **Expressiveness**: Depict all the data, and only the data
  - **Consistency**: The properties of the image (visual attributes) should match the properties of the data

# Importance Ordering: Perceptual Properties




Mackinlay, APT (A Presentation Tool), 1986

# Expressiveness

- A length is interpreted as a quantitative value
- Length of bar says something untrue about data

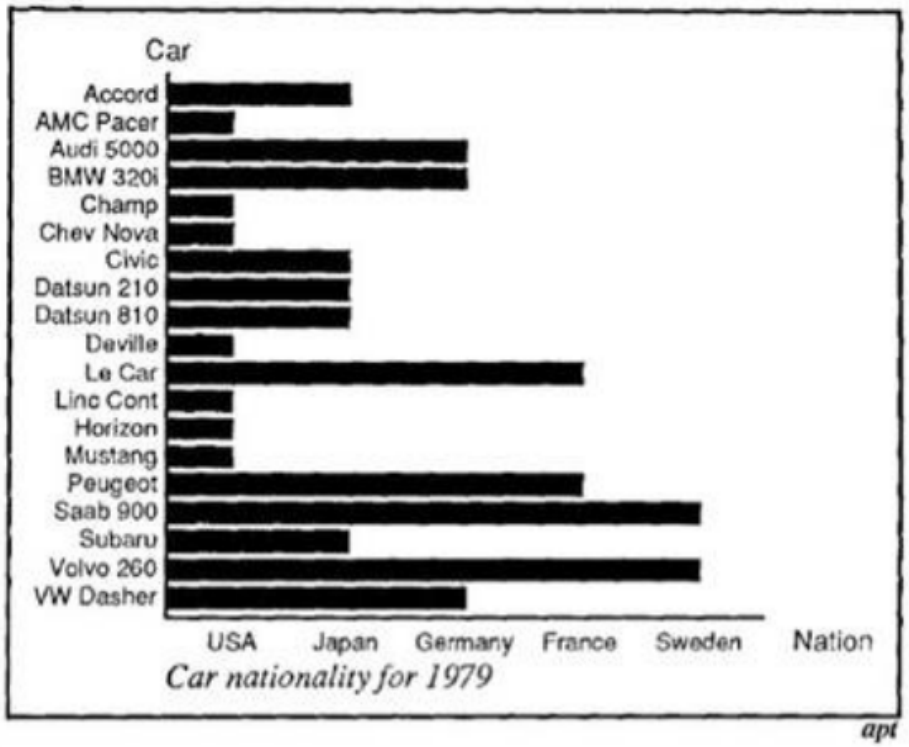
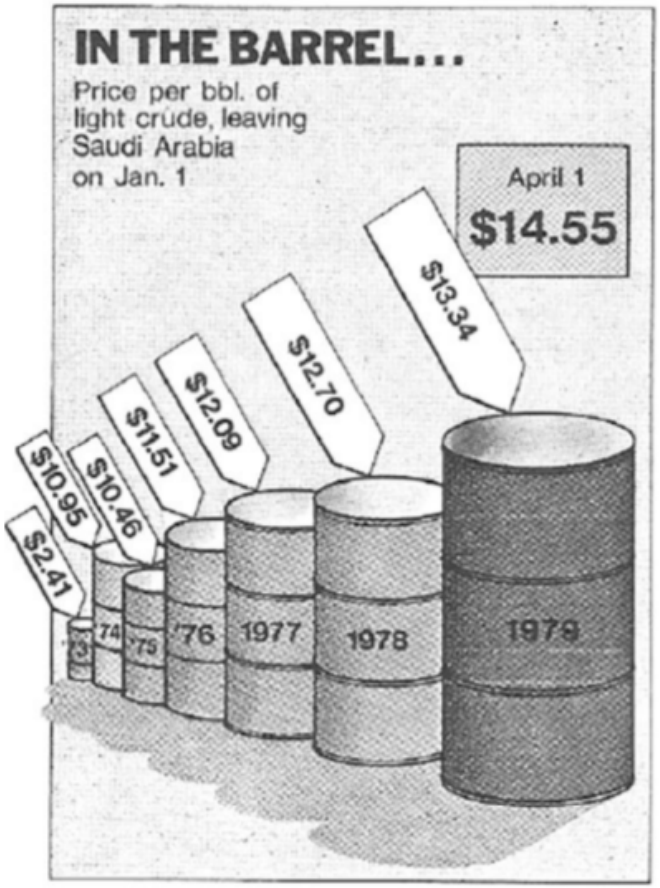



Fig. 11. Incorrect use of a bar chart for the *Nation* relation. The lengths of the bars suggest an ordering on the vertical axis, as if the USA cars were longer or better than the other cars, which is not true for the *Nation* relation.

Mackinlay, APT (A Presentation Tool), 1986

# Consistency

- The properties of the image (visual attributes) should match the properties of the data
- E.g. don't map one-dimensional data to two-or three- dimensional representations!




[Tufte, Edward R (1983), *The Visual Display of Quantitative Information,* Graphics Press, from *Time Magazine*, April 9, 1979, p. 57.]

# Visual Perception

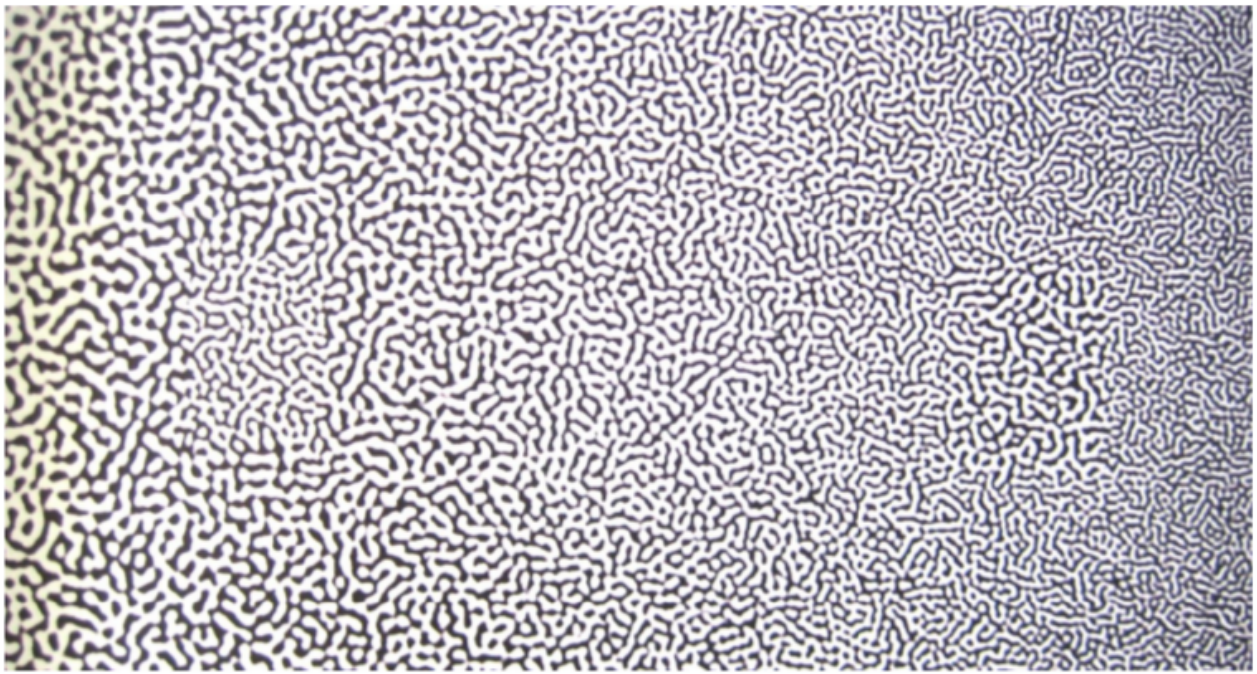
- 70% of body's sense receptors reside in our eyes
- "The eye and the visual cortex of the brain form a massively parallel processor that provides the highest-bandwidth channel into human cognitive centers." Colin Ware, Information Visualization, 2004
- Important to understand how visual perception works in order to effectively design visualizations

# How the Eye Works

- The eye is not a camera!
- Better metaphor for vision: "dynamic and ongoing construction project" - Healey, 95
- Attention is selective (filtering)

# How to Use Perceptual Properties

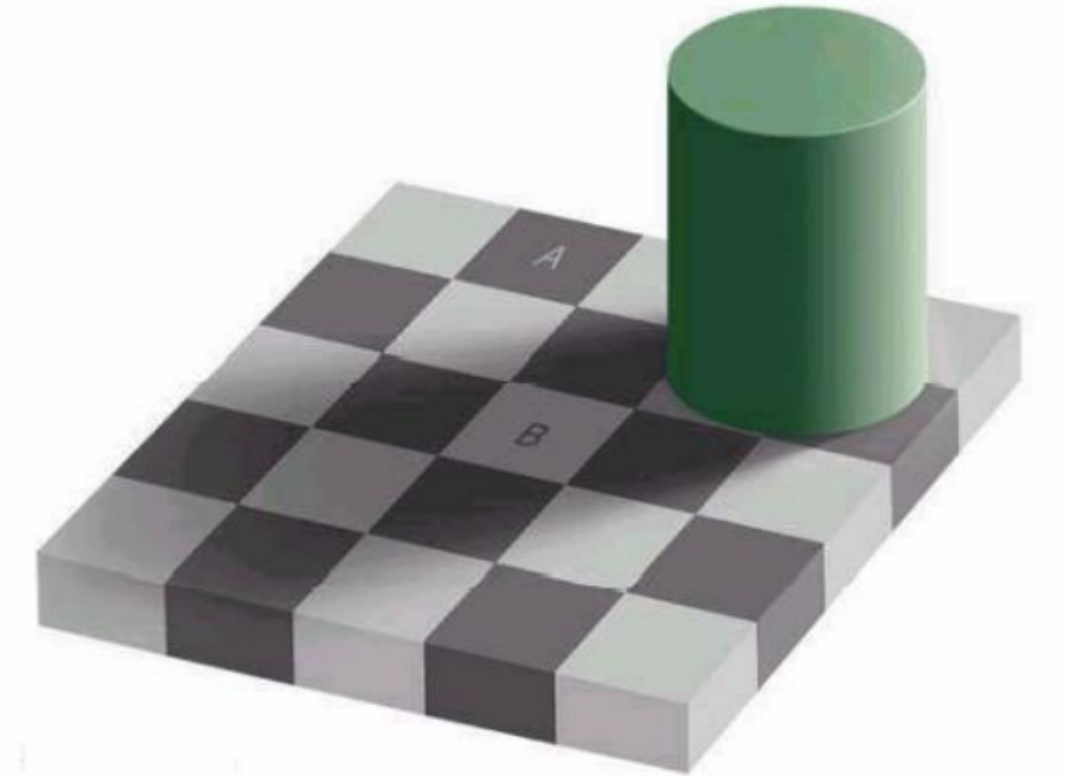
- Information visualization should cause what is meaningful to stand out



# Eyes vs. Cameras

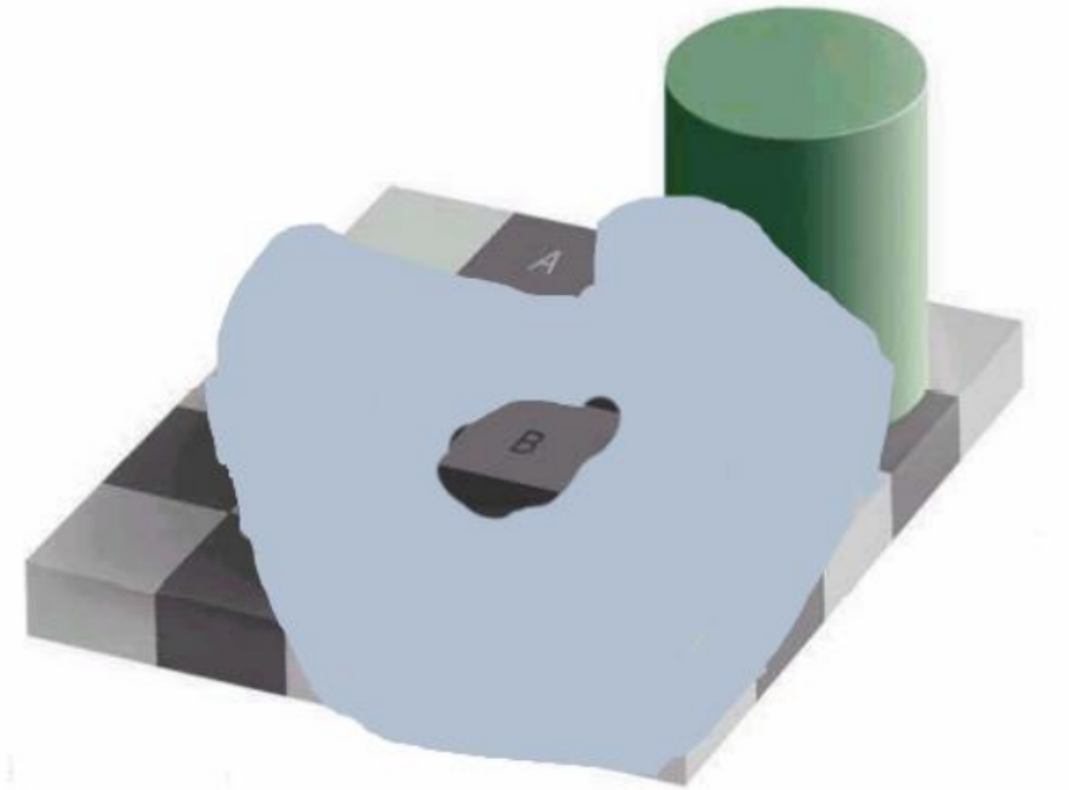
- Cameras
  - Good optics
  - Single focus, white balance, exposure
  - "Full image capture"
- Eyes
  - Relatively poor optics
  - Constantly scanning (saccades)
  - Constantly adjusting focus
  - Constantly adapting (white balance, exposure)
  - Mental reconstruction of image (sort of)

# Visual perception is not just camera work



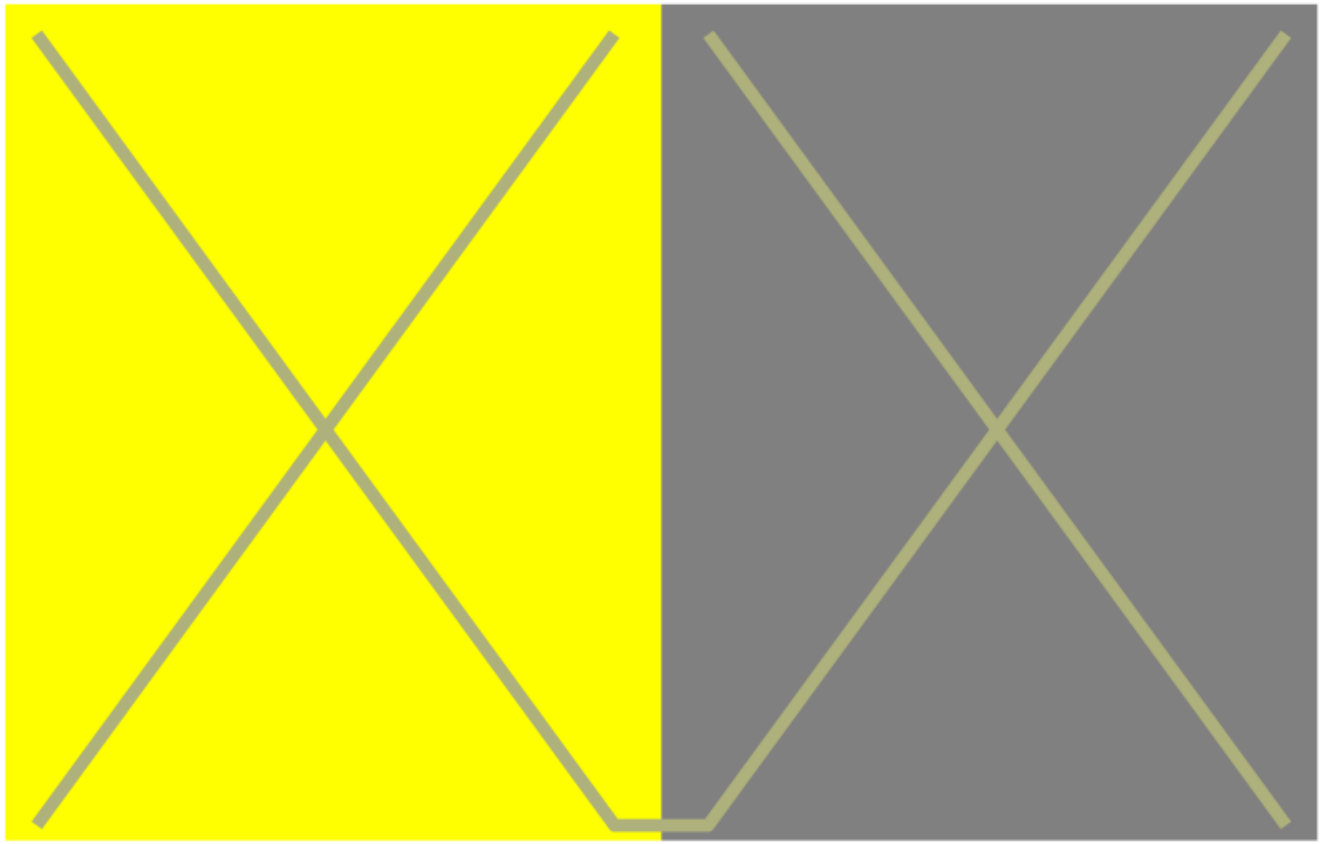

Square A is darker than B, right?

# Visual perception is not just camera work




Square A is darker than B, right?

# Color is relative



# How many 5's

385720939823728196837293827
382912358383492730122894839
909020102032893759273091428
938309762965817431869241024

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385720939823728196837293827
382912358383492730122894839
909020102032893759273091428
938309762965817431869241024

# Stroop Effect

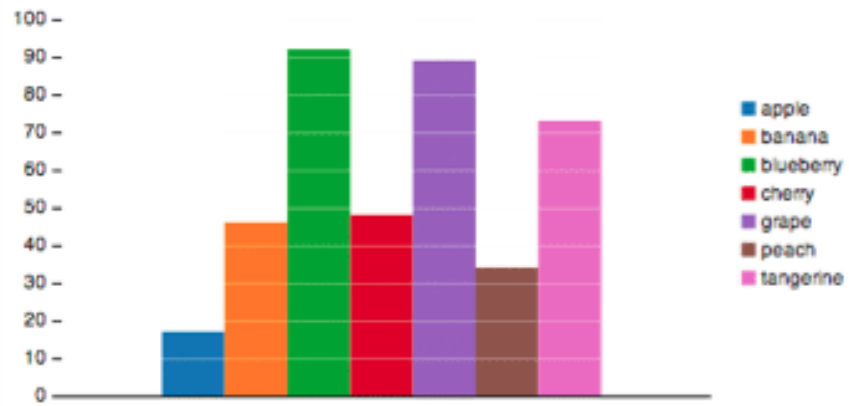
- **Stroop Effect:** interference in the reaction time of a task.
  1. Green Red Blue
     Purple Blue Purple
  2. Blue Purple Red
     Green Purple Green

# Stroop Effect Theories[3]

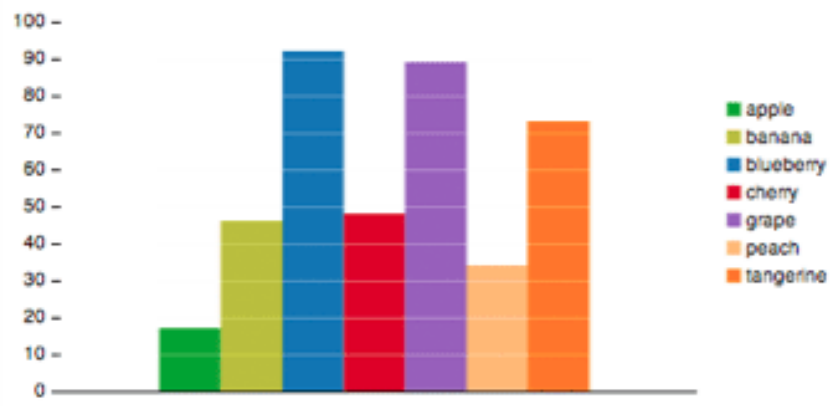
1. brain's ability to recognize the color of the word since the brain reads words faster than it recognizes colors.
2. color recognition as opposed to reading a word, requires more attention.
3. recognizing colors is not an "automatic process" there is hesitancy to respond; whereas, the brain automatically understands the meaning of words as a result of habitual reading.
4. brain analyzes information, different and specific pathways are developed for different tasks. Some pathways, such as reading, are stronger than others

[3] From Wikipedia

# Semantically Resonant Color Assignments




Default color assignment




Semantically resonant color assignment

# Preattentive Processing

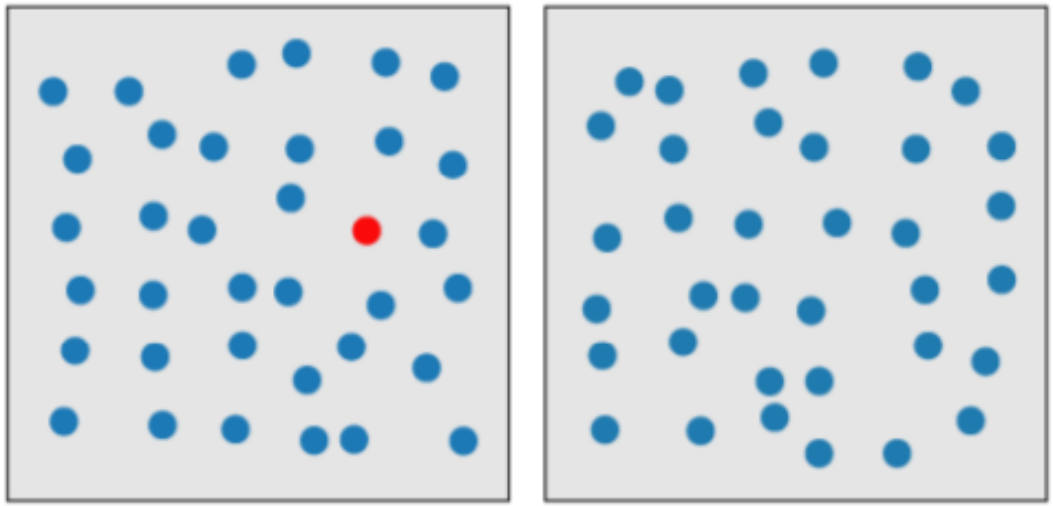
- Certain basic visual properties are detected immediately by low-level visual system
- "Pop-out" vs. serial search
- $<$ 200 - 250ms qualifies as preattentive
  - eye movements take at least 200ms
  - yet certain processing can be done very quickly, implying low-level processing in parallel
- If a decision takes a fixed amount of time regardless of the number of distractors, it is considered to be **preattentive**.

# Preattentive Processing

- A limited set of visual properties are processed preattentively
  - (without need for focusing attention).
- This is important for design of visualizations
  - What can be perceived immediately?
  - Which properties are good discriminators?
  - What can mislead viewers?

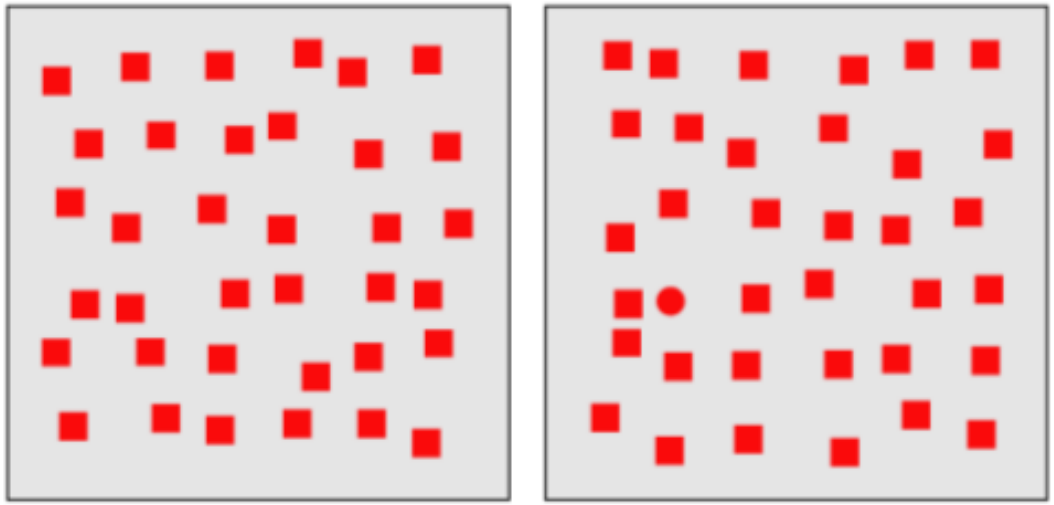
# Color (Hue) is Preattentive

- Detection of red circle in group of blue circles is Preattentive



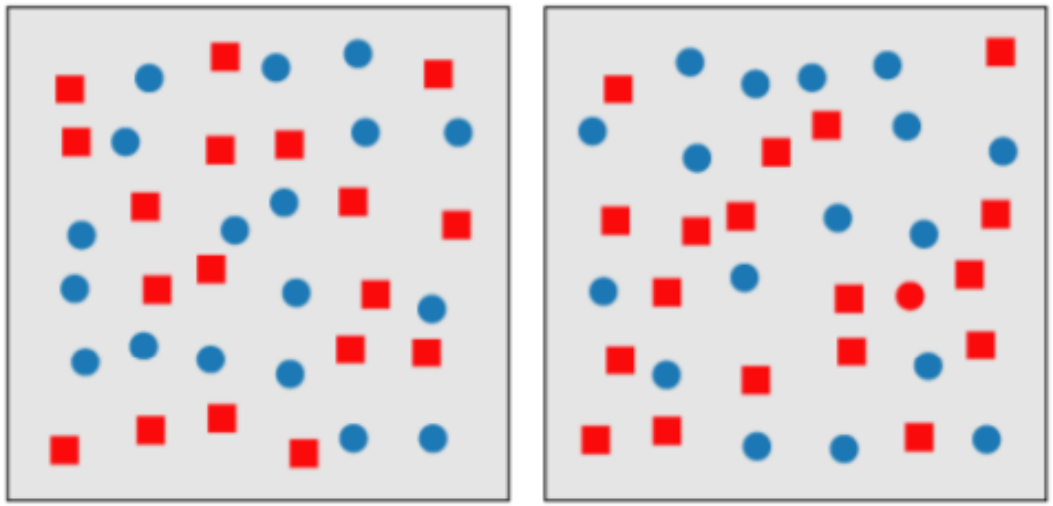
# Form (curvature) is preattentive

- Curved form "pops out" of display

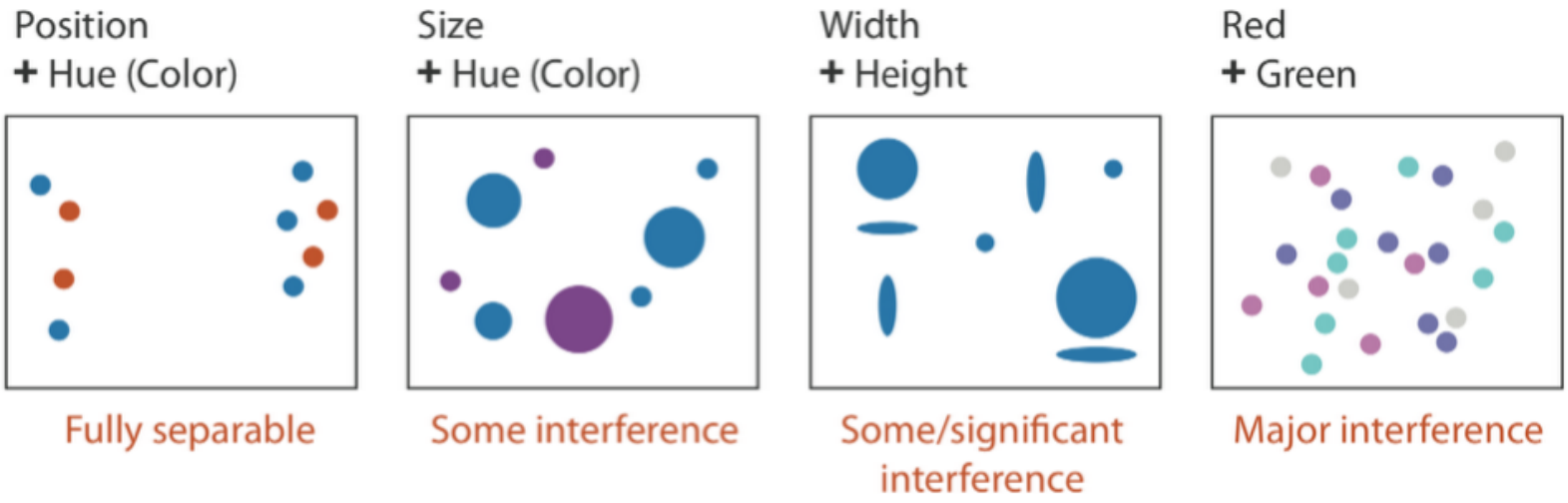


# Conjunction of Attributes

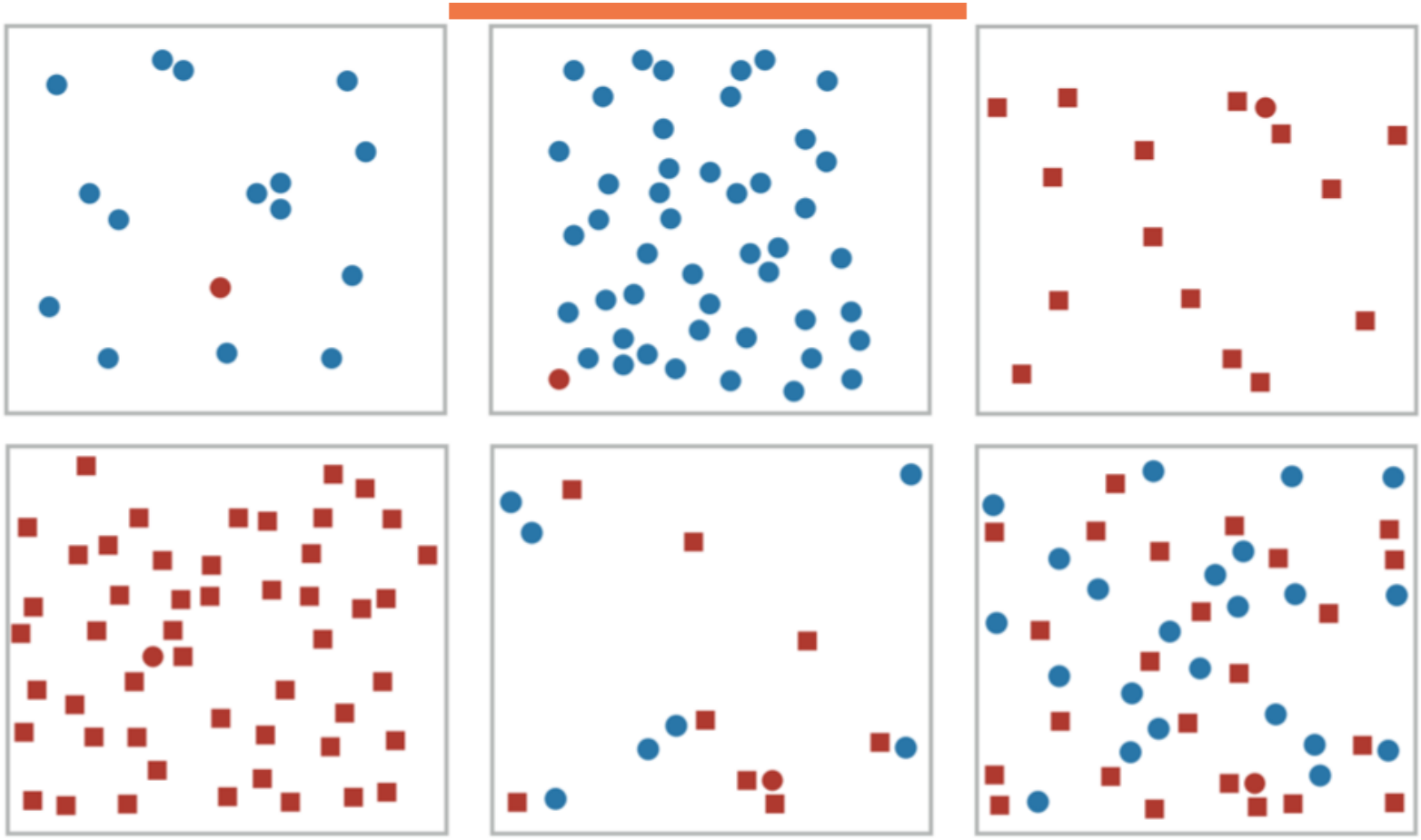
- Conjunction target generally cannot be detected preattentively (red circle in sea of red square and blue circle distractors)



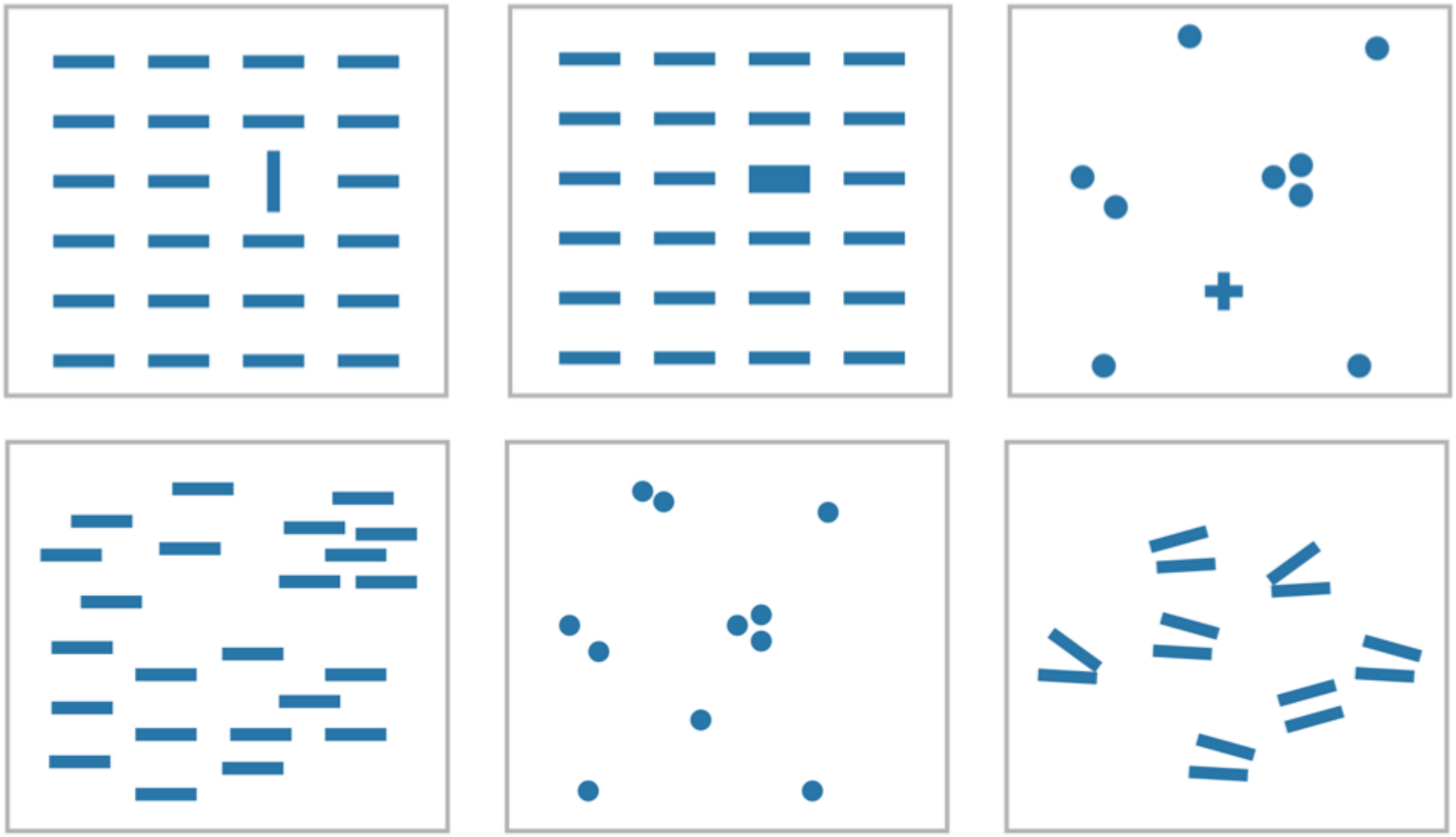
# Separability of Attributes



# Visual Popout (Preattentive Features) - I

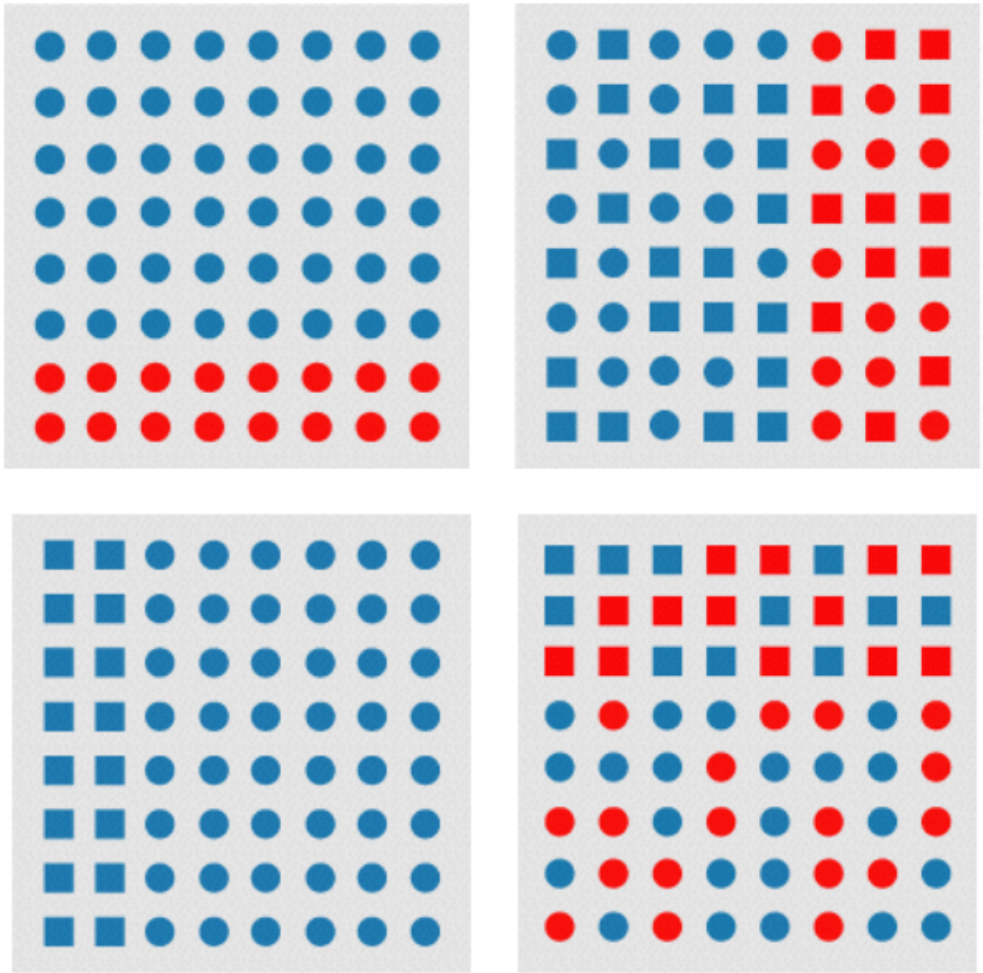


# Visual Popout (Preattentive Features) - II

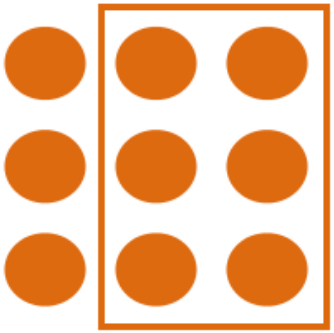


http://www.csc.ncsu.edu/faculty/healey/PP

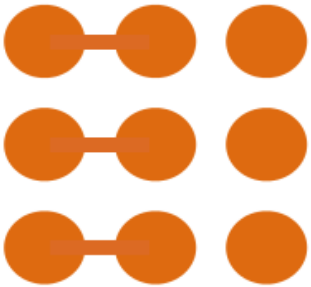
# Feature Hierarchy



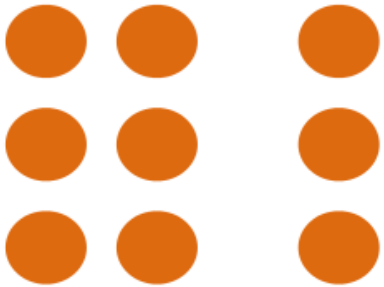
# Grouping Principles



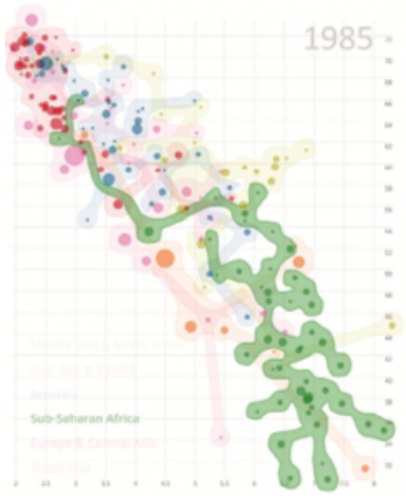
Containment



Connection



Proximity




Collins et al. 2009

D3.js Example

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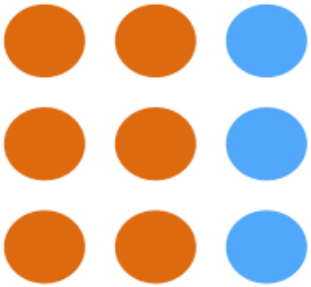
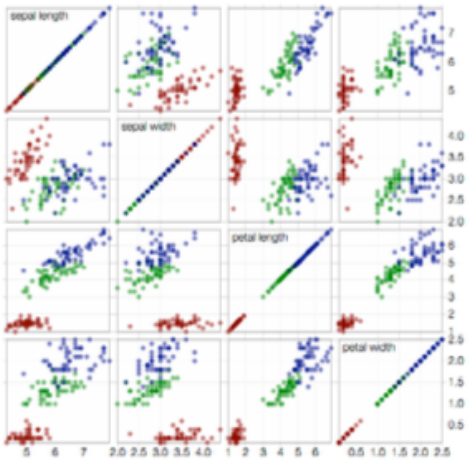
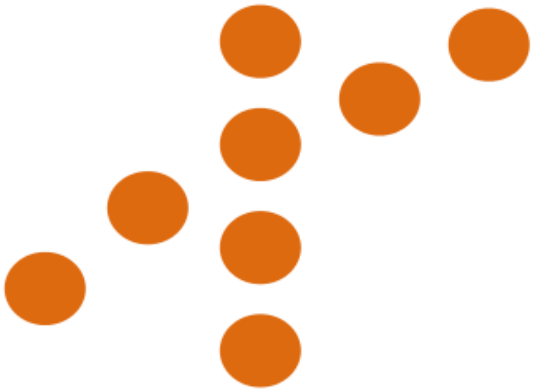
# Grouping Principles



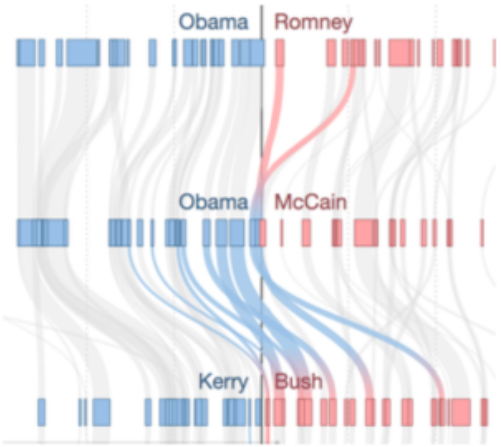
Similarity




D3.js Example



Continuity

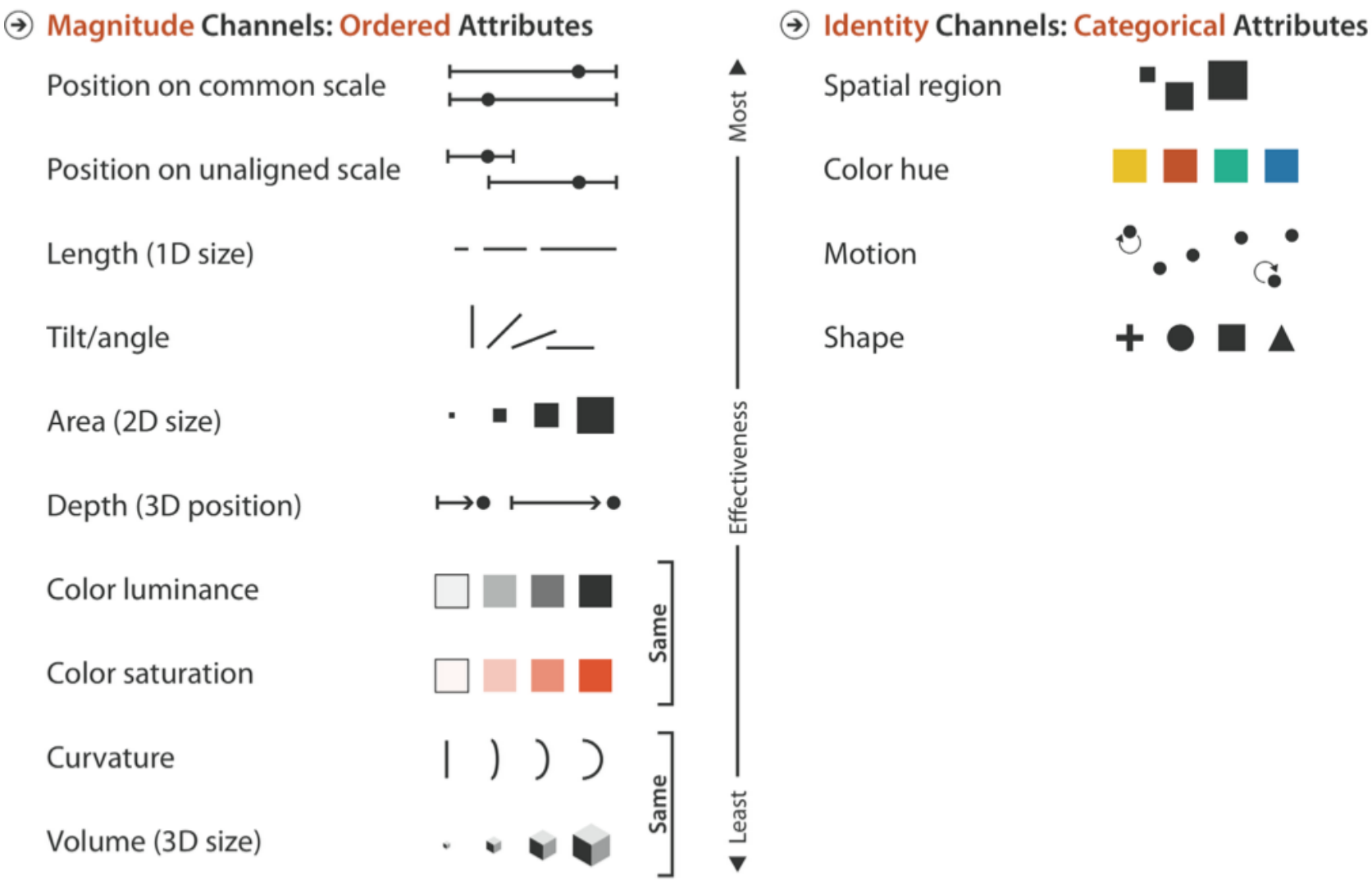



NYT Swing States

Common Fate

Closure

# Munzner Hierarchy




T. Munzner, Visualzation Analysis and Design, 2014

# Preattentive Visual Properties (Healey 97)

| | |
|---|---|
| length | Triesman & Gormican [1988] |
| width | Julesz [1985] |
| size | Triesman & Gelade [1980] |
| curvature | Triesman & Gormican [1988] |
| number | Julesz [1985]; Trick & Pylyshyn [1994] |
| terminators | Julesz & Bergen [1983] |
| intersection | Julesz & Bergen [1983] |
| closure | Enns [1986]; Triesman & Souther [1985] |
| color (hue) | Nagy & Sanchez [1990, 1992]; D'Zmura [1991]<br>Kawai et al. [1995]; Bauer et al. [1996] |
| intensity | Beck et al. [1983]; Triesman & Gormican [1988] |
| flicker | Julesz [1971] |
| direction of motion | Nakayama & Silverman [1986]; Driver & McLeod [1992] |
| binocular luster | Wolfe & Franzel [1988] |
| stereoscopic depth | Nakayama & Silverman [1986] |
| 3-D depth cues | Enns [1990] |
| lighting direction | Enns [1990] |

# Critiquing a Visualization

1. First, consider the purpose of the visualization and who the intended audience is.
2. Then, ascertain your initial reaction.
3. Then, examine the visualization in detail.
4. Then, answer questions like the following.

# Over-Arching Questions

1. Is the design visually appealing/aesthetically pleasing?
2. Is it immediately understandable? If not, is it understandable after a short period of study?
3. Does it provide insight or understanding that was not obtainable with the original representation (text, table, etc)?
4. Does it provide insight or understanding better than some alternative visualization would? Or does it require excessive cognitive effort? What kind of visualization might have been better?

# How Successful is the Visualization?

5. Does the visualization reveal trends, patterns, gaps, and/or outliers? Can the viewer make effective comparisons?
6. Does the visualization successfully highlight important information, while providing context for that information?
7. Does it distort the information? If it transforms it in some way, is this misleading or helpfully simplifying?
8. Does it omit important information?
9. Is it memorable?

# Questions about the Visual Transformation

10. Does it use visual components properly?
    - Does it properly represent the data using lines, color, position, etc?
    - Does it transform nominal, ordinal, and quantitative information properly?
11. Does it use labels and legends appropriately?

# Summary

## Major Concepts:

- Visual Attributes
- Principles of effective visualization
- Visual encoding and perception

# Slide Material References

- Slides from Harvard CS 109 (2013 and 2014)
- Slides by Cecilia Aragon