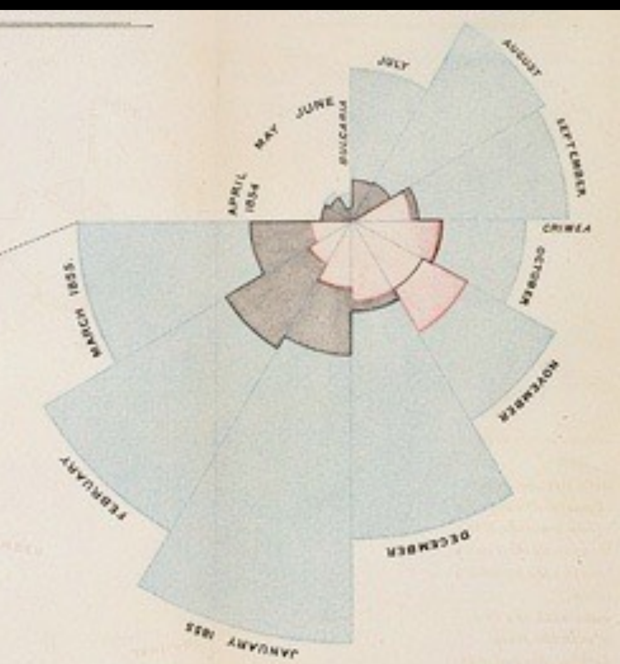
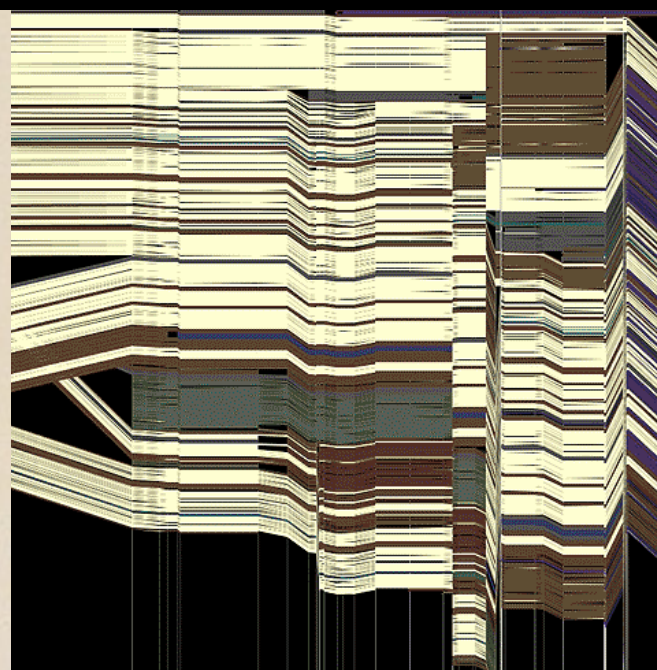
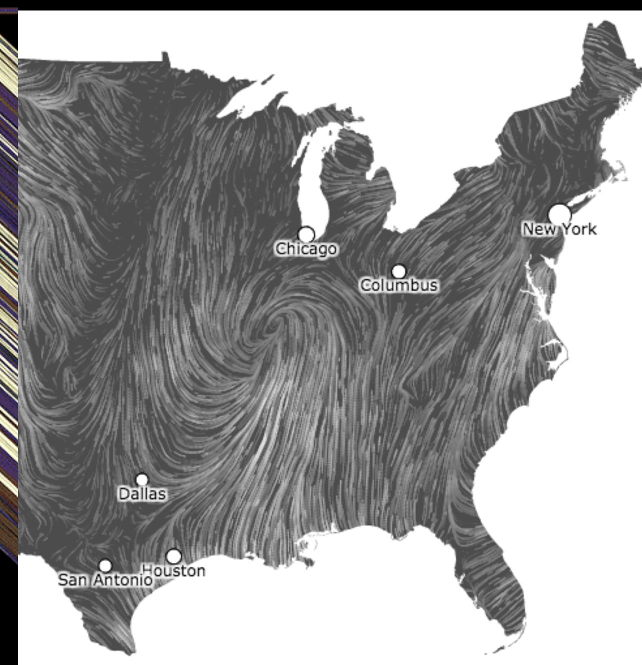
CSE 442 - Data Visualization

Graphical Perception







Jeffrey Heer University of Washington

Design Principles [Mackinlay 86]

Expressiveness
A set of facts is *expressible* in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

Effectiveness
A visualization is more *effective* than another visualization if the information conveyed by one visualization is more readily perceived than the information in the other visualization.

Design Principles *Translated*

Tell the truth and nothing but the truth
(don’t lie, and don’t lie by omission)

Use encodings that people decode better
(where better = faster and/or more accurate)

Effectiveness Rankings [Mackinlay 86]

QUANTITATIVE	ORDINAL	NOMINAL
Position	Position	Position
Length	Density (Value)	Color Hue
Angle	Color Sat	Texture
Slope	Color Hue	Connection
Area (Size)	Texture	Containment
Volume	Connection	Density (Value)
Density (Value)	Containment	Color Sat
Color Sat	Length	Shape
Color Hue	Angle	Length
Texture	Slope	Angle
Connection	Area (Size)	Slope
Containment	Volume	Area
Shape	Shape	Volume

Graphical Perception

The ability of viewers to interpret visual (graphical) encodings of information and thereby decode information in graphs.

Topics

Signal Detection
Magnitude Estimation
Using Multiple Visual Encodings
Pre-Attentive Processing
Gestalt Grouping
Change Blindness

Signal Detection

Detecting Brightness

Which is brighter?

Detecting Brightness

(128, 128, 128)

(144, 144, 144)

Which is brighter?

Detecting Brightness

Which is brighter?

Detecting Brightness

(134, 134, 134) (128, 128, 128)

Which is brighter?

Just Noticeable Difference (JND)

JND (Weber’s Law)

Scale Factor
(Empirically Determined)

Perceived Change → $$\Delta S = k\frac{\Delta I}{I}$$

← Change of Intensity

← Physical Intensity

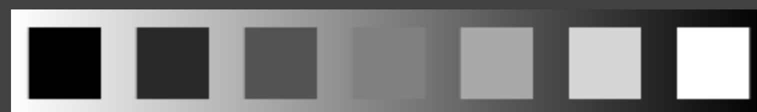
Ratios more important than magnitude

Most continuous variation in stimuli are perceived in discrete steps

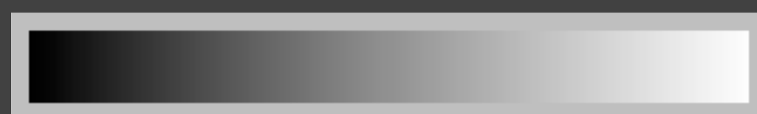
Encoding Data with Color

Value is perceived as ordered

∴ Encode ordinal variables (O)



∴ Encode continuous variables (Q) [not as well]



Hue is normally perceived as unordered

∴ Encode nominal variables (N) using color

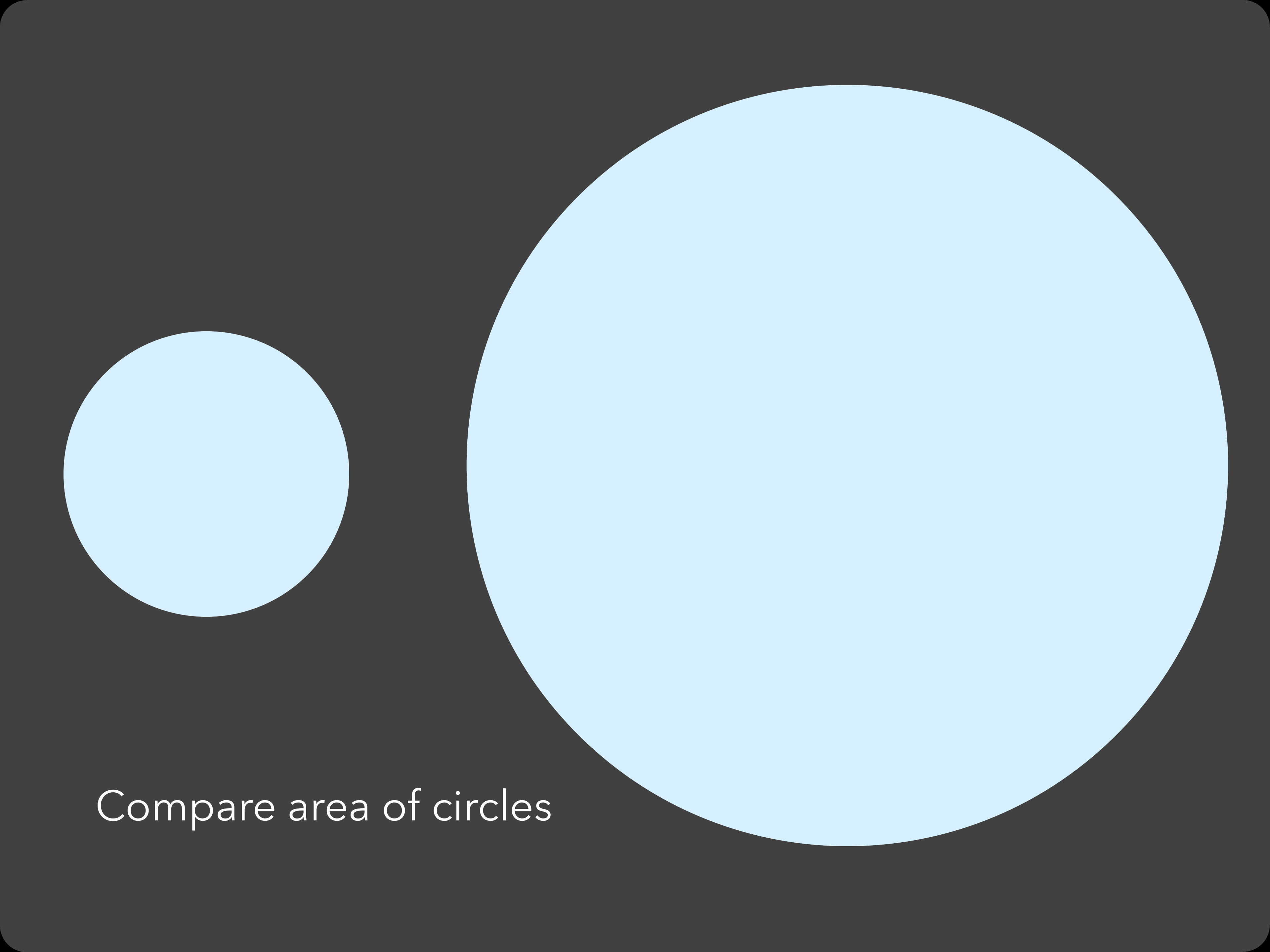
Steps in Font Size

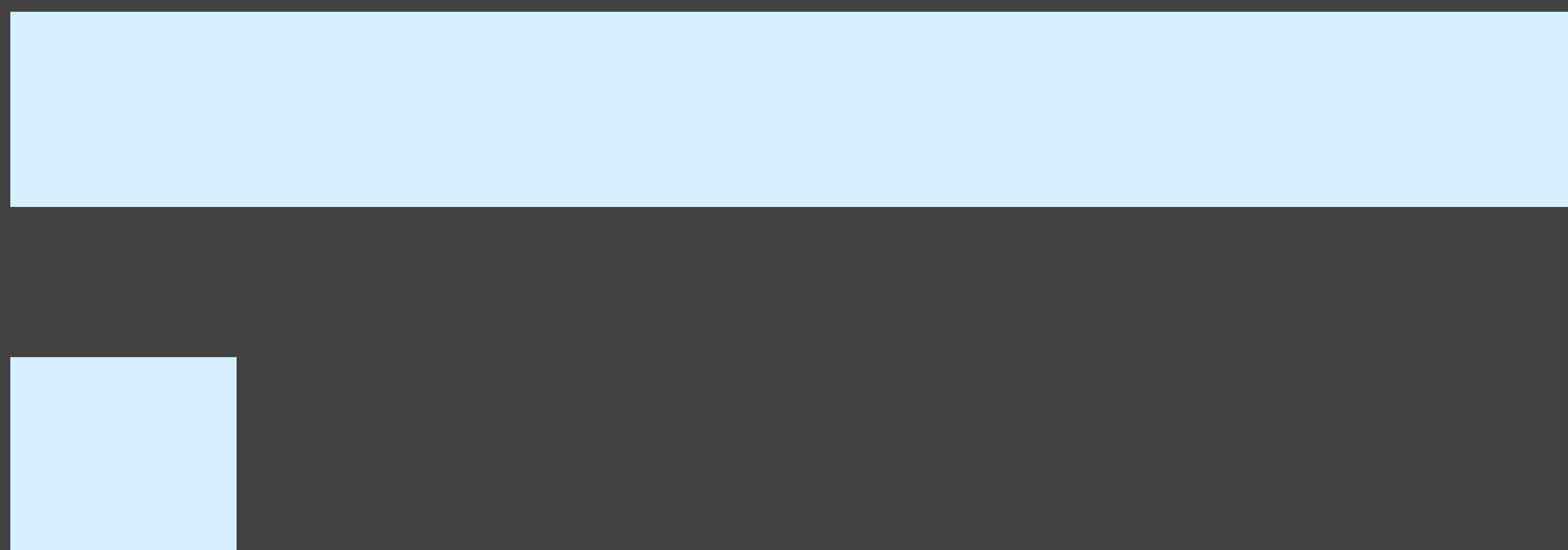
Sizes standardized in 16th century

a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
6	7	8	9	10	11	12	14	16	18	21	24	36	48	60	72

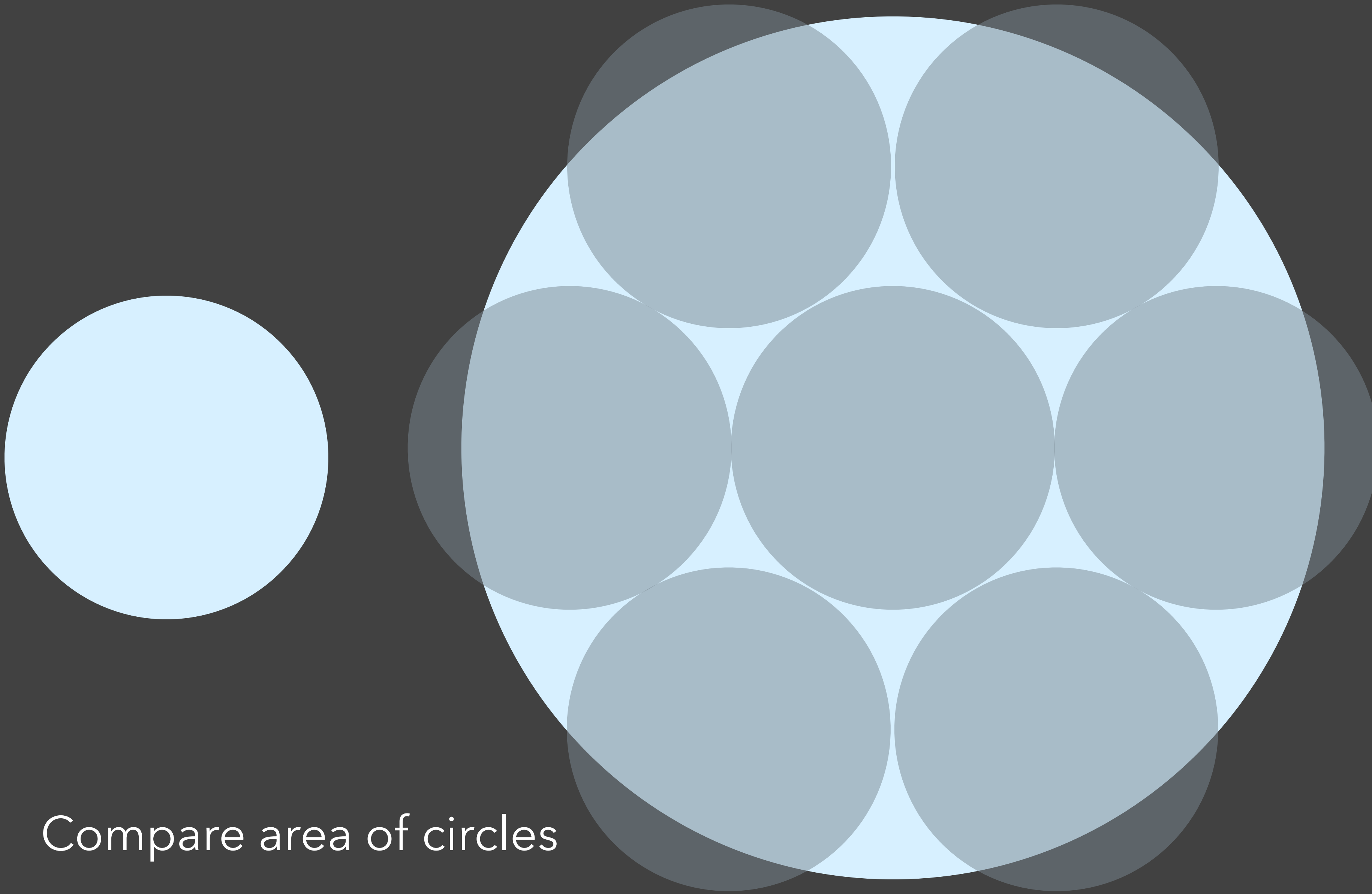
Magnitude Estimation

A Quick Experiment…

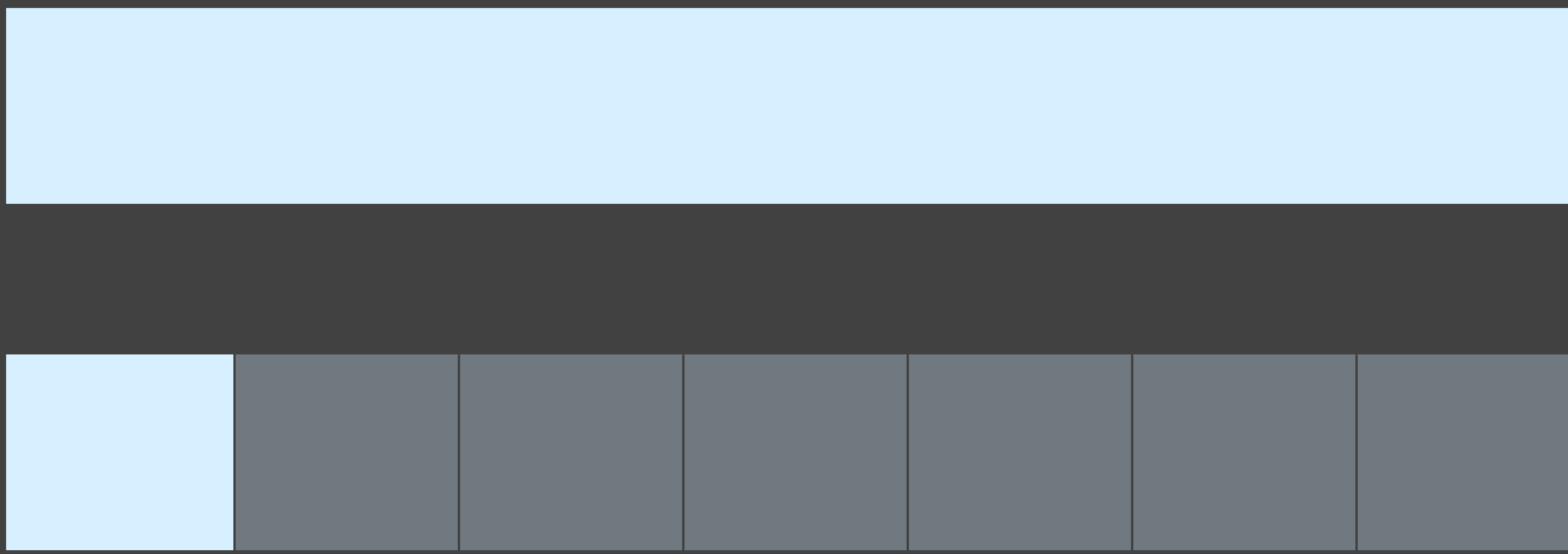

Compare area of circles



Compare length of bars



Compare area of circles



Compare length of bars

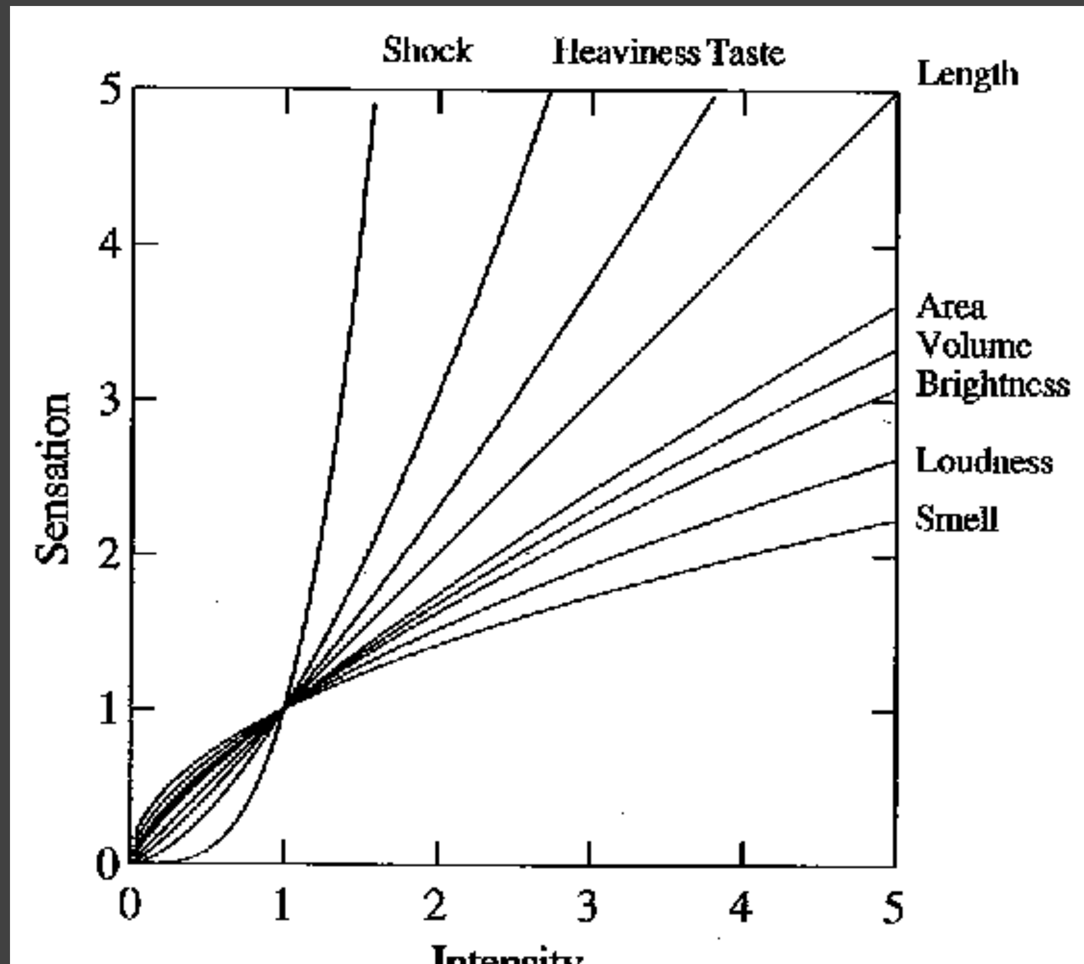
Steven’s Power Law

Exponent
(Empirically Determined)

$$S = I^p$$

Perceived Sensation — Physical Intensity

Predicts bias, not necessarily accuracy!



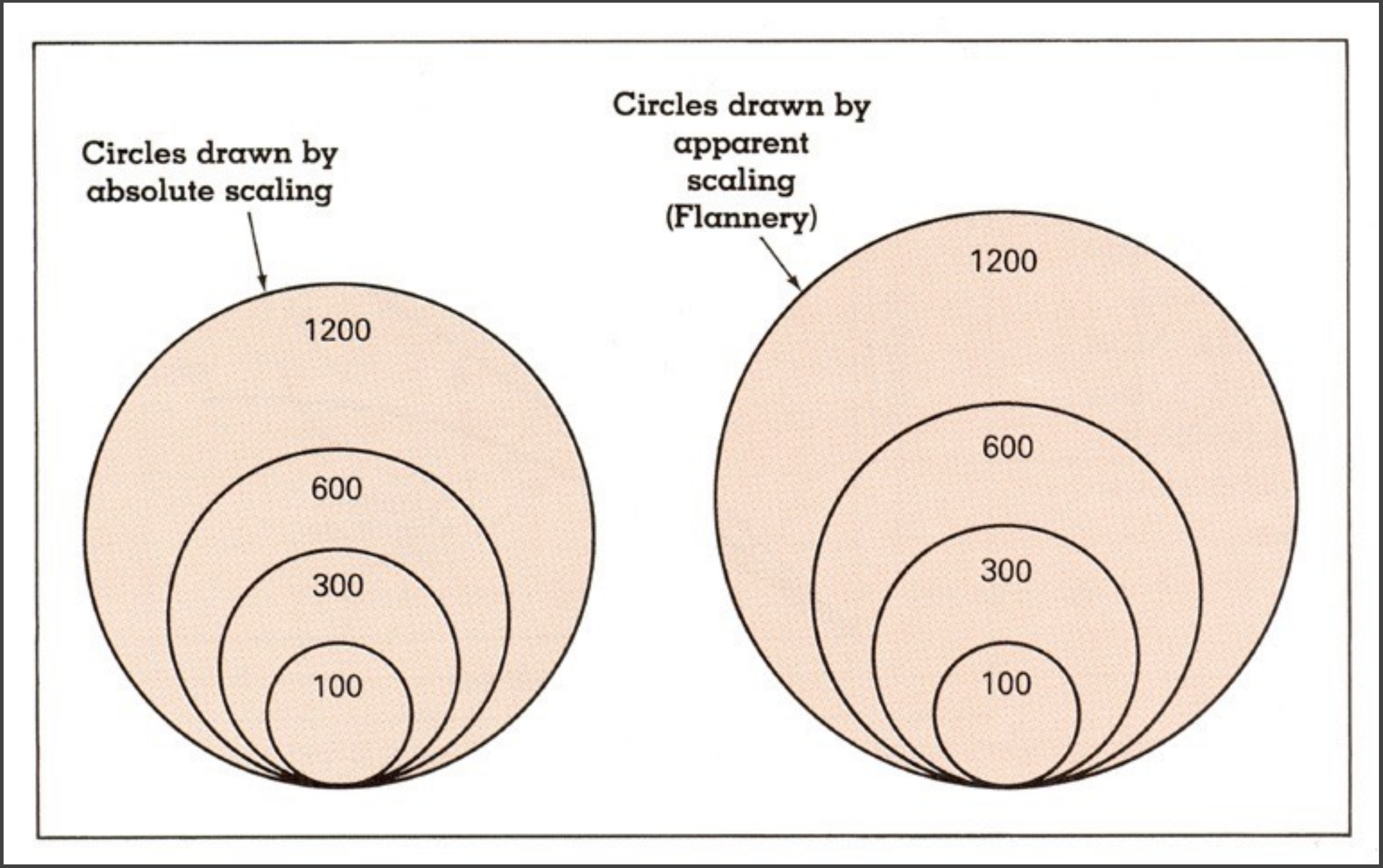
[Graph from Wilkinson ’99, based on Stevens ’61]

Exponents of Power Law

Sensation	Exponent
Loudness	0.6
Brightness	0.33
Smell	0.55 (Coffee) - 0.6 (Heptane)
Taste	0.6 (Saccharine) -1.3 (Salt)
Temperature	1.0 (Cold) – 1.6 (Warm)
Vibration	0.6 (250 Hz) – 0.95 (60 Hz)
Duration	1.1
Pressure	1.1
Heaviness	1.45
Electic Shock	3.5

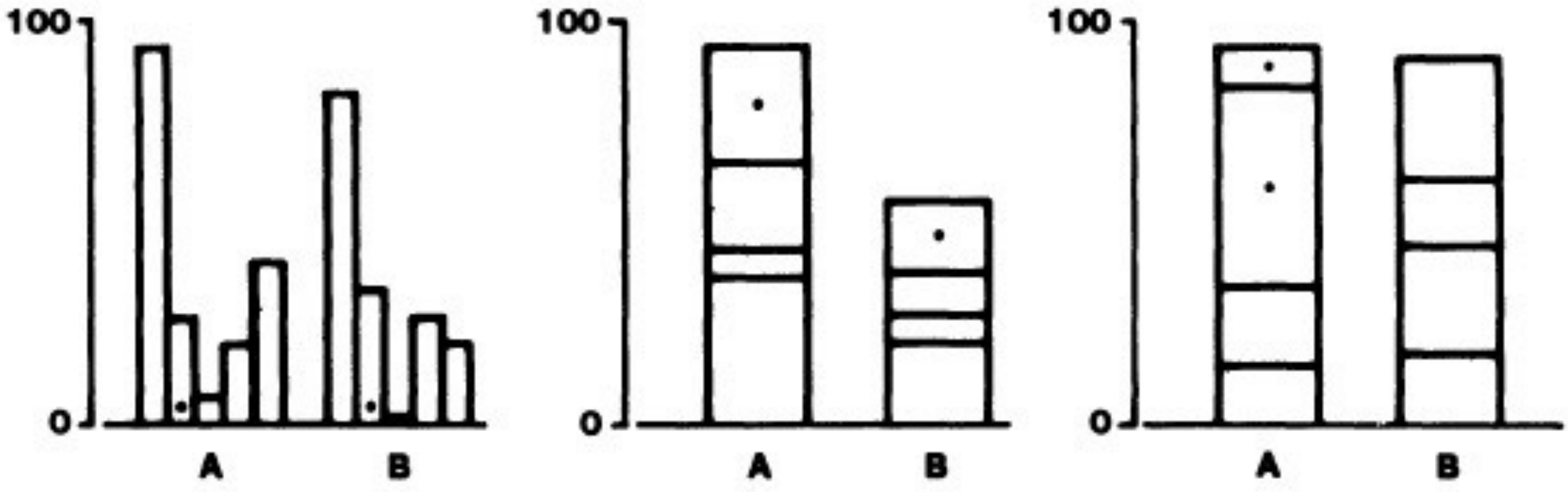
[Psychophysics of Sensory Function, Stevens '61]

Apparent Magnitude Scaling



[Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, '96]

$S = 0.98A^{0.87}$ [from Flannery '71]



Graphical Perception [Cleveland & McGill 84]

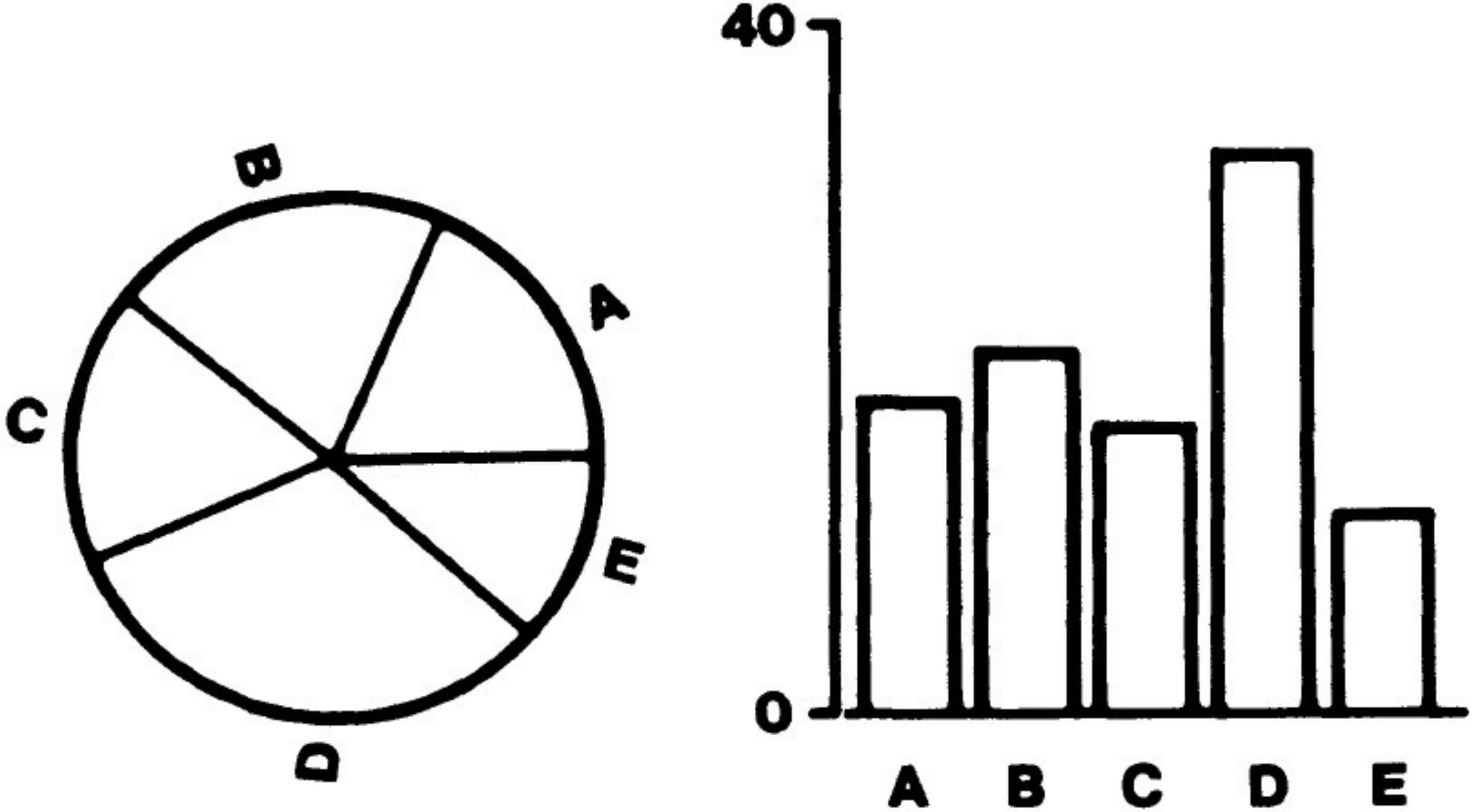
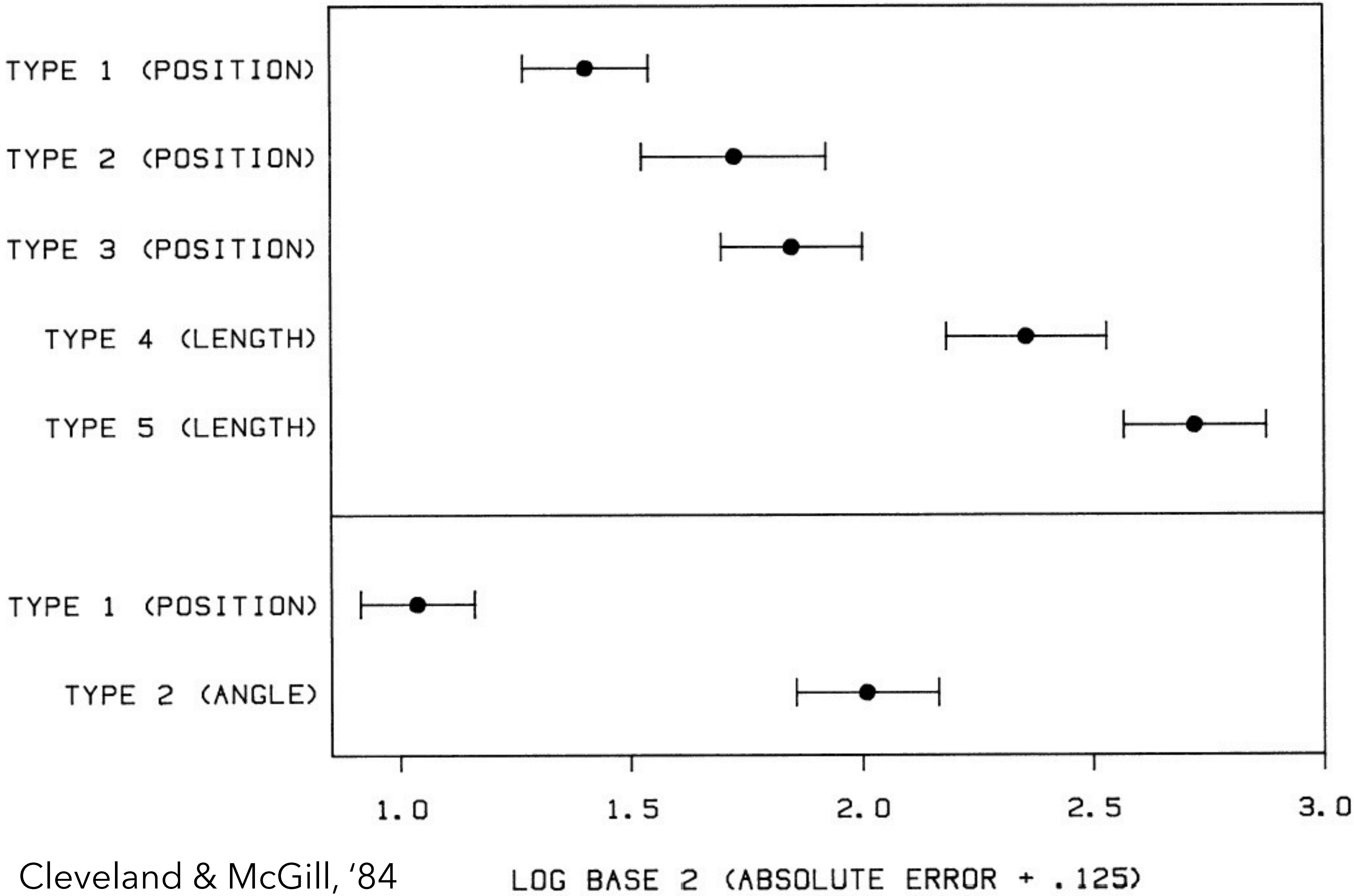
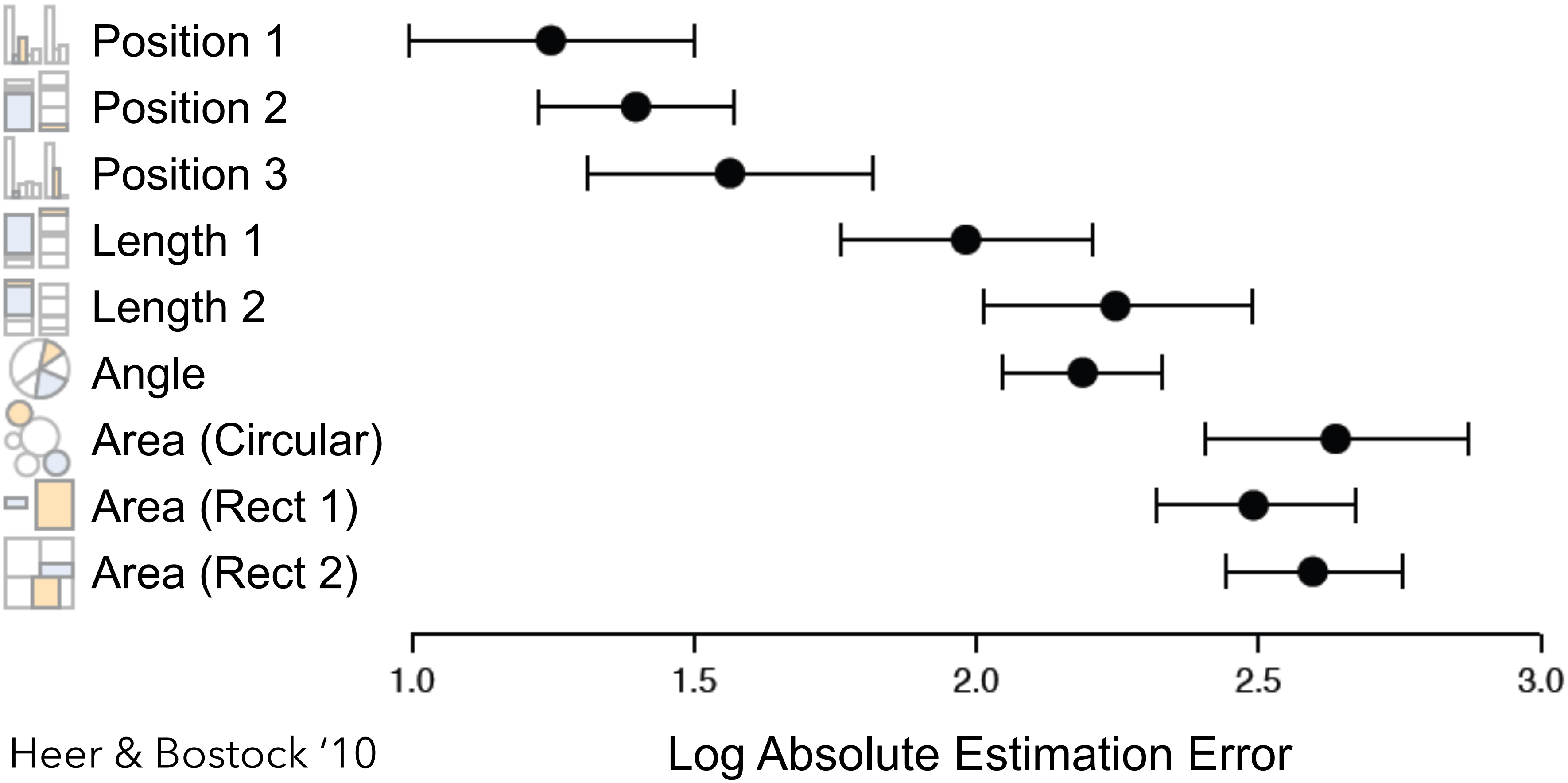


Figure 3. Graphs from position–angle experiment.



Cleveland & McGill, '84

Figure 16. Log absolute error means and 95% confidence intervals for judgment types in position–length experiment (top) and position–angle experiment (bottom).



Heer & Bostock '10

Graphical Perception Experiments

Empirical estimates of encoding effectiveness

Relative Magnitude Comparison

Most accurate

Position (common) scale

Position (non-aligned) scale

Length

Slope

Angle

Area

Volume

Color hue-saturation-density

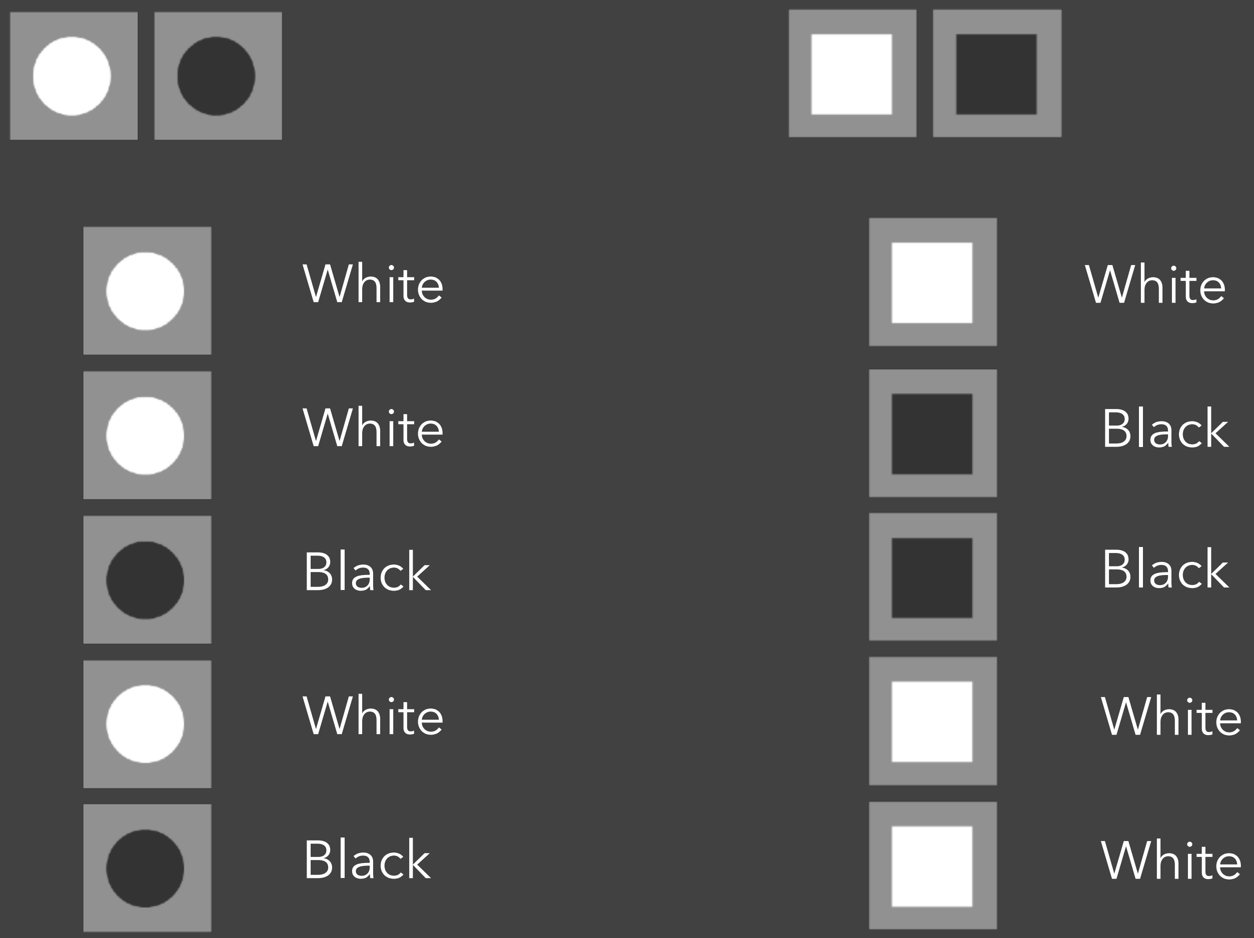
Least accurate

Effectiveness Rankings [Mackinlay 86]

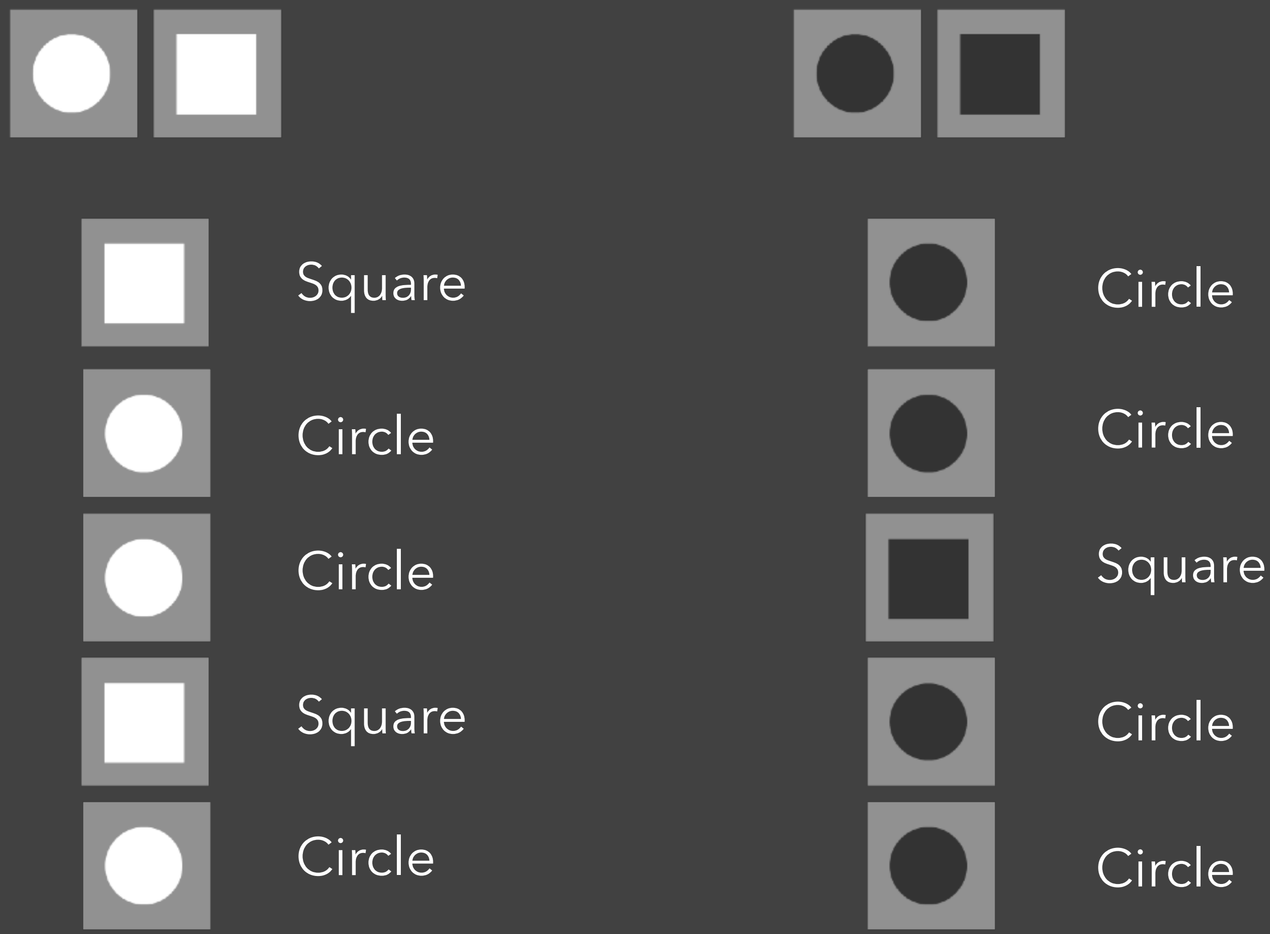
QUANTITATIVE	ORDINAL	NOMINAL
Position	Position	Position
Length	Density (Value)	Color Hue
Angle	Color Sat	Texture
Slope	Color Hue	Connection
Area (Size)	Texture	Containment
Volume	Connection	Density (Value)
Density (Value)	Containment	Color Sat
Color Sat	Length	Shape
Color Hue	Angle	Length
Texture	Slope	Angle
Connection	Area (Size)	Slope
Containment	Volume	Area
Shape	Shape	Volume

Multiple Attributes

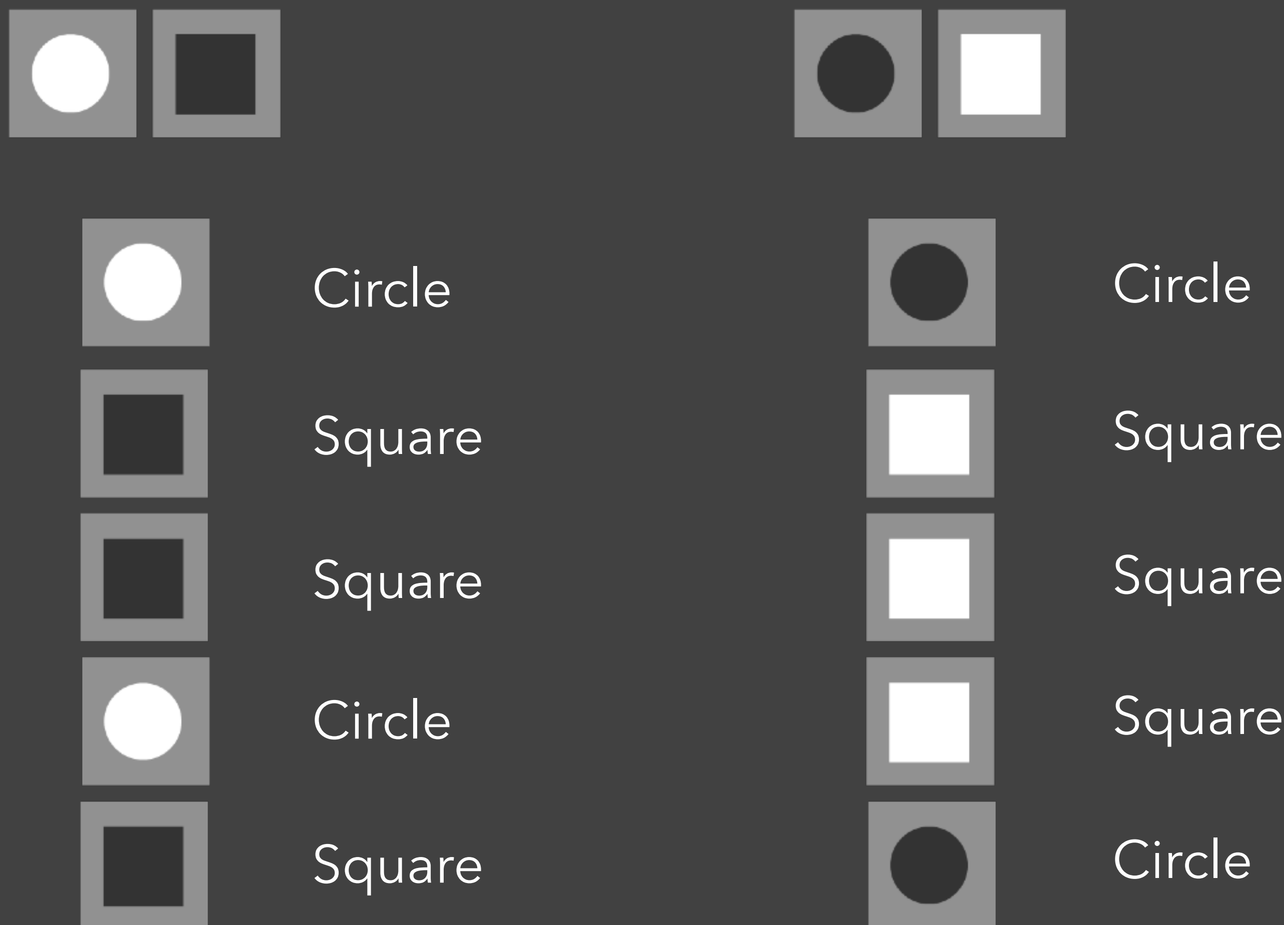
One-Dimensional: Lightness



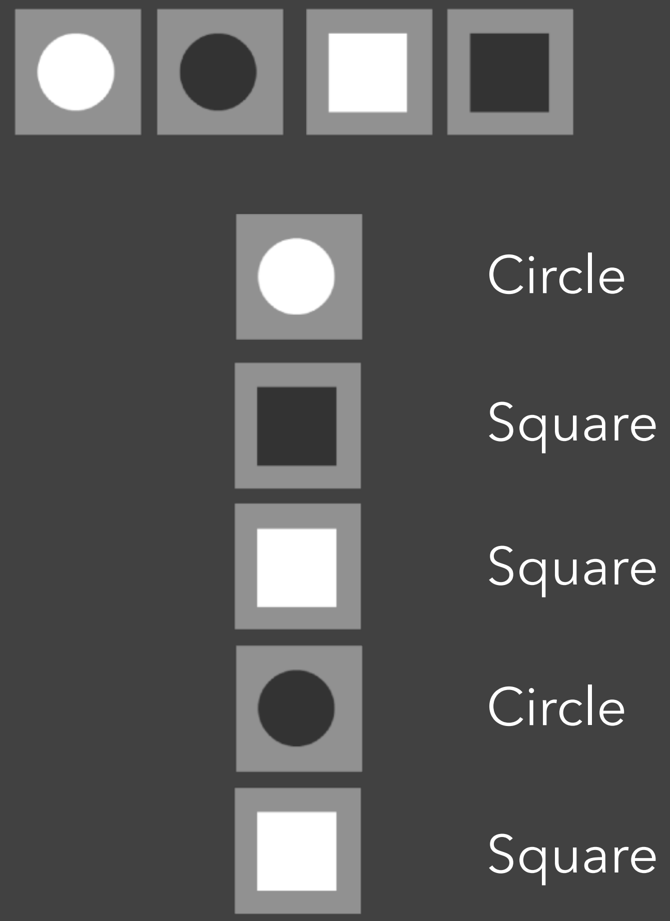
One-Dimensional: Shape



Redundant: Shape & Lightness



Orthogonal: Shape & Lightness



Speeded Classification

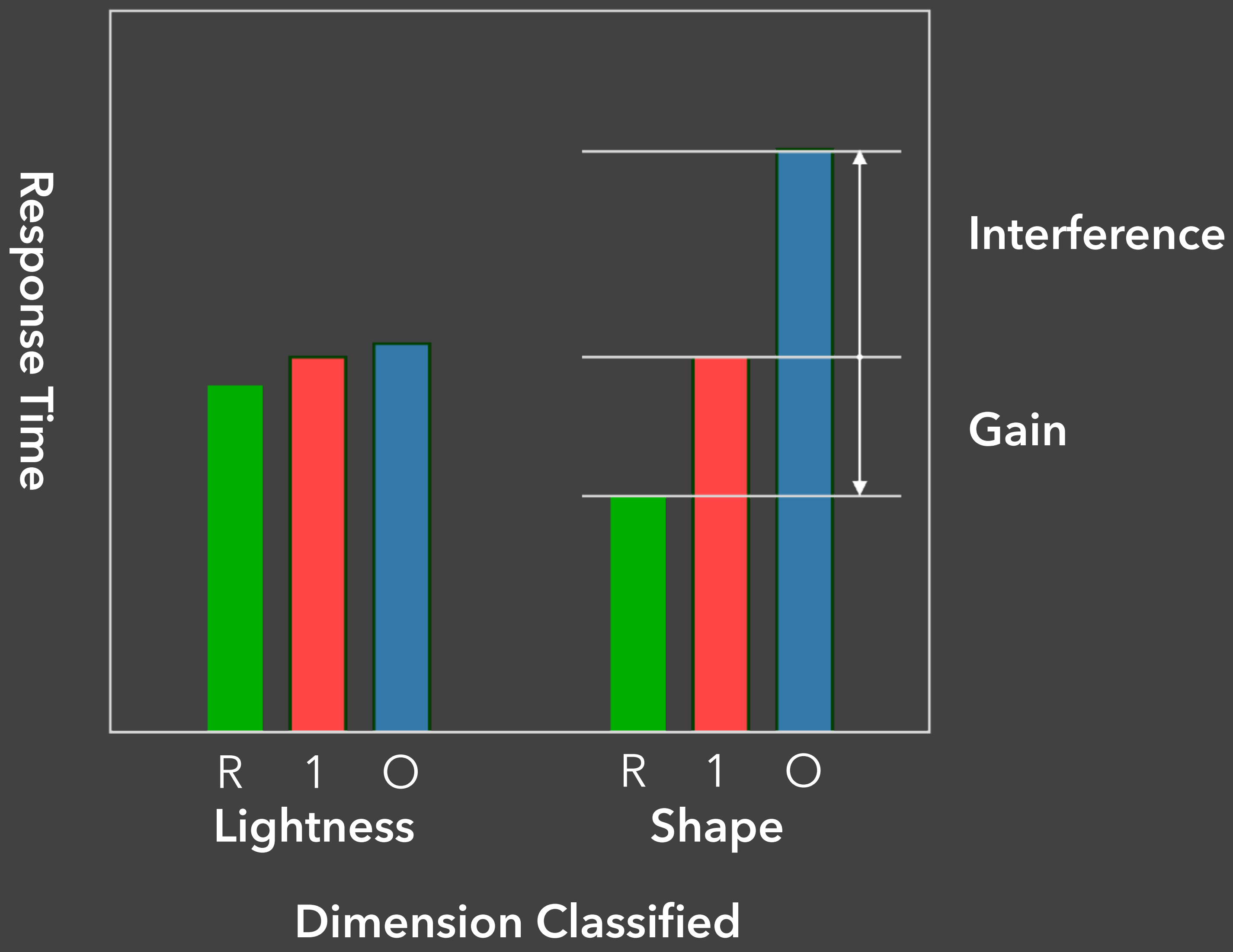
Redundancy Gain

Facilitation in reading one dimension when the other provides redundant information

Filtering Interference

Difficulty in ignoring one dimension while attending to the other

Speeded Classification



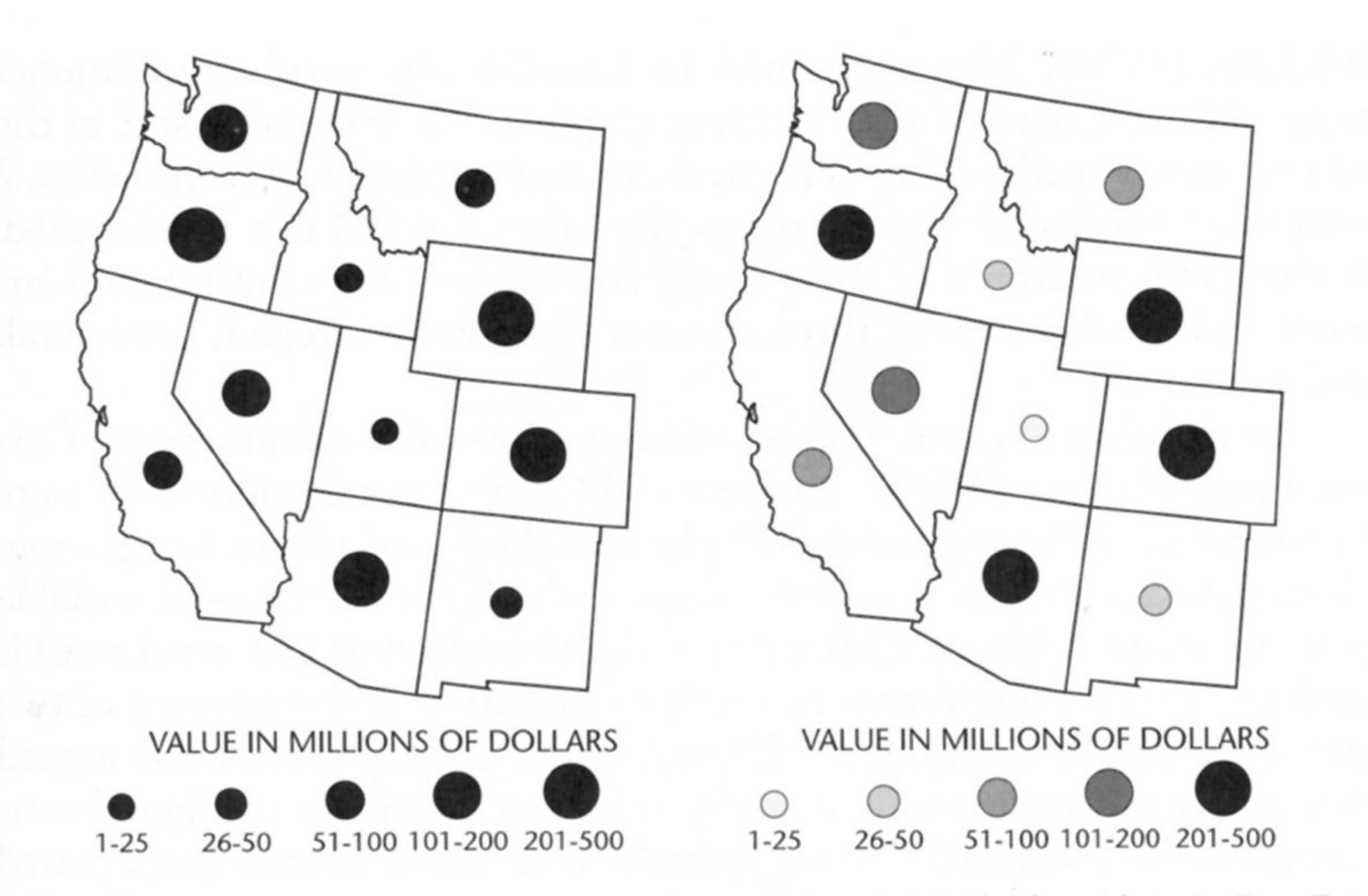
Types of Perceptual Dimensions

Integral
Filtering interference and redundancy gain

Separable
No interference or gain

Asymmetric
One dim separable from other, not vice versa

Size and Brightness



W. S. Dobson, Visual information processing and cartographic communication: The role of redundant stimulus dimensions, 1983 (reprinted in MacEachren, 1995)

Orientation & Size

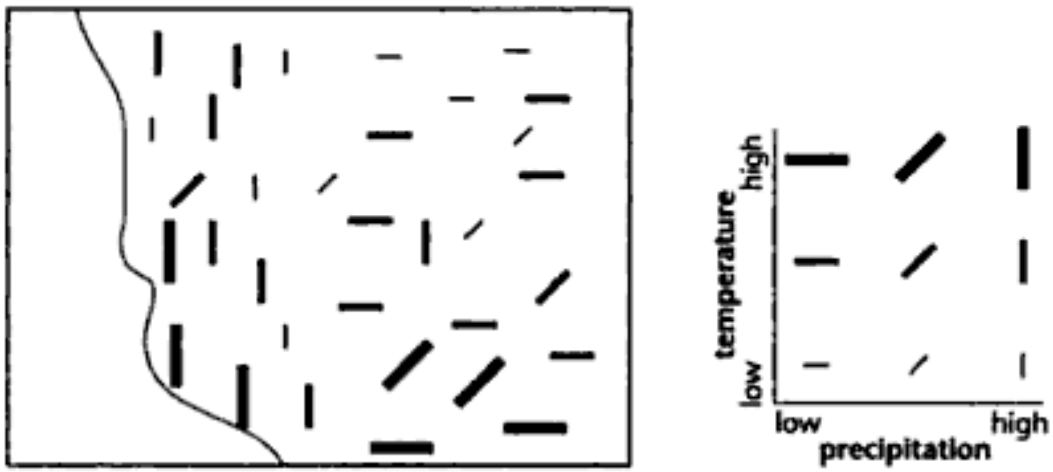


FIGURE 3.36. A map of temperature and precipitation using symbol size and orientation to represent data values on the two variables.

How well can you see temperature or precipitation?

Is there a correlation between the two?

[MacEachren 95]

Length & Length

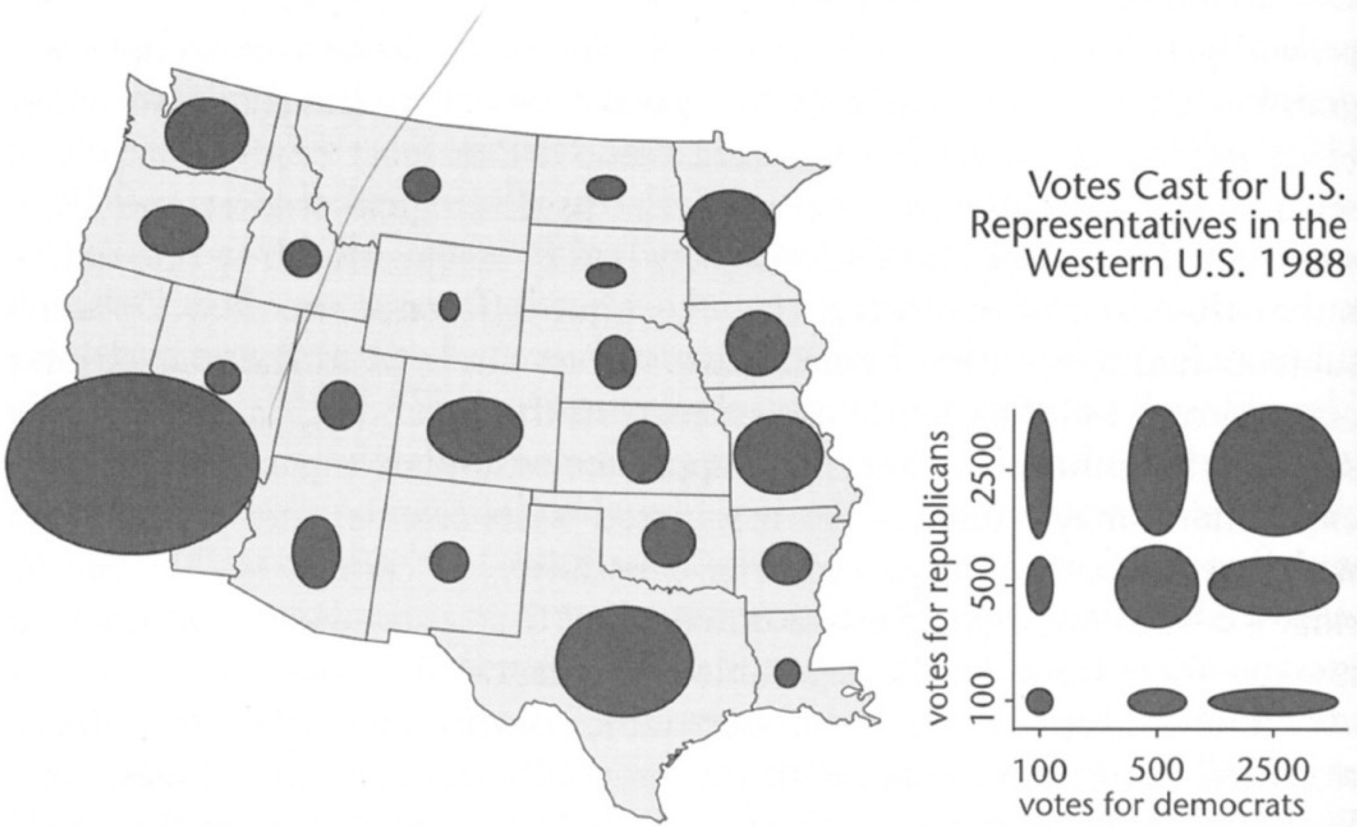


FIGURE 3.38. An example of the use of an ellipse as a map symbol in which the horizontal and vertical axes represent different (but presumably related) variables.

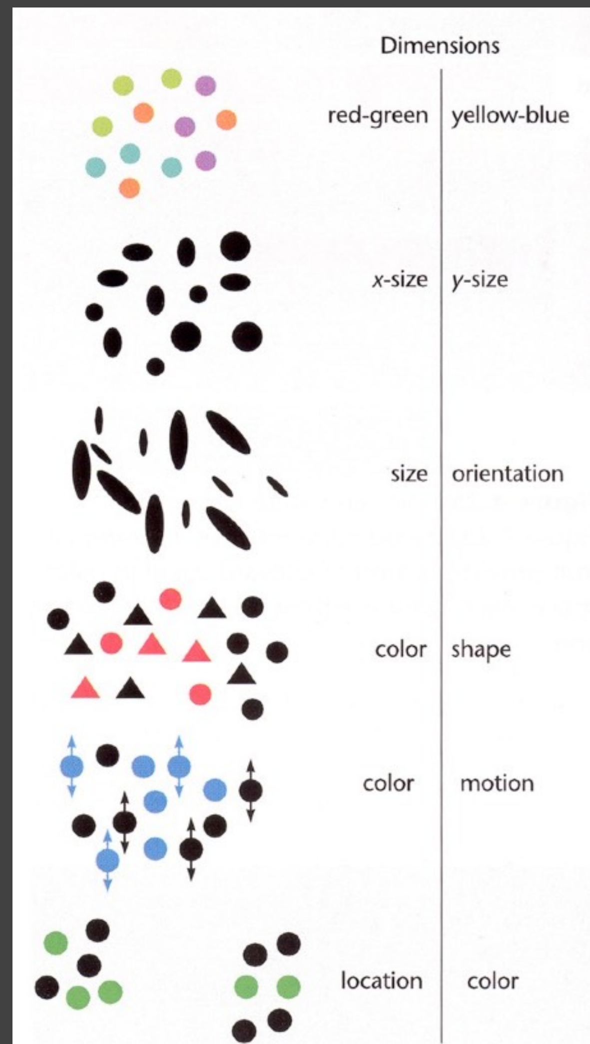
[MacEachren 95]

Angle & Angle

FIGURE 3.39. Bivariate map of NO_3 and SO_4 trends. The original Carr et al. version of this map used a wheel with eight spokes, rather than a simple dot, as the center of each glyph. When large enough, this added feature facilitates judgment of specific values. *After Carr et al. (1992, Fig. 7a, p. 234). Adapted by permission of the American Congress on Surveying and Mapping.*

[MacEachren 95]

Summary of Integral & Separable



Integral

Separable

[Figure 5.25, Color Plate 10, Ware 2000]

Set

Each card has **4 features**:

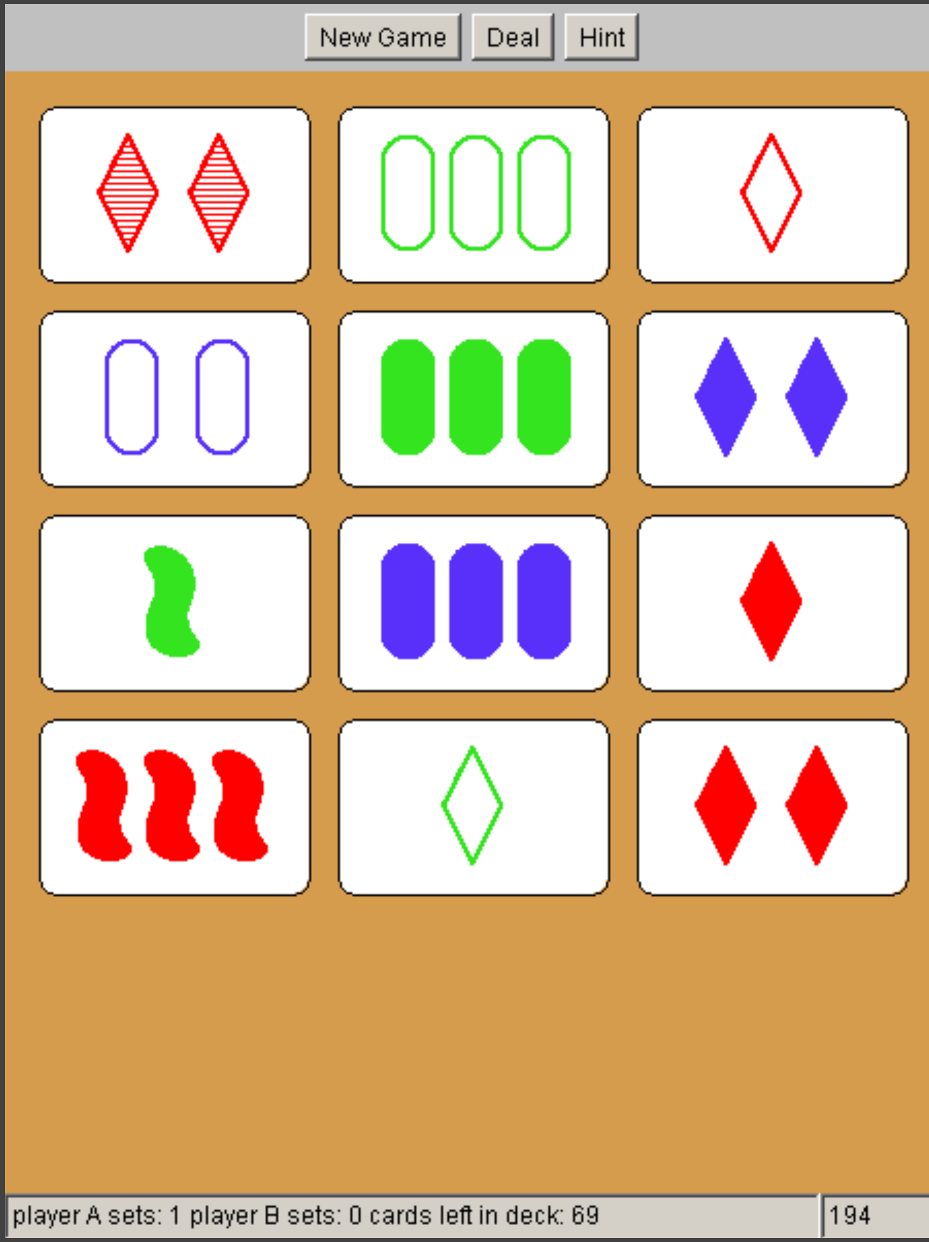
Color

Symbol

Number

Shading/Texture

A set consists of 3 cards in which each feature is the SAME or DIFFERENT on each card.



Pre-Attentive Processing

How Many 3's?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

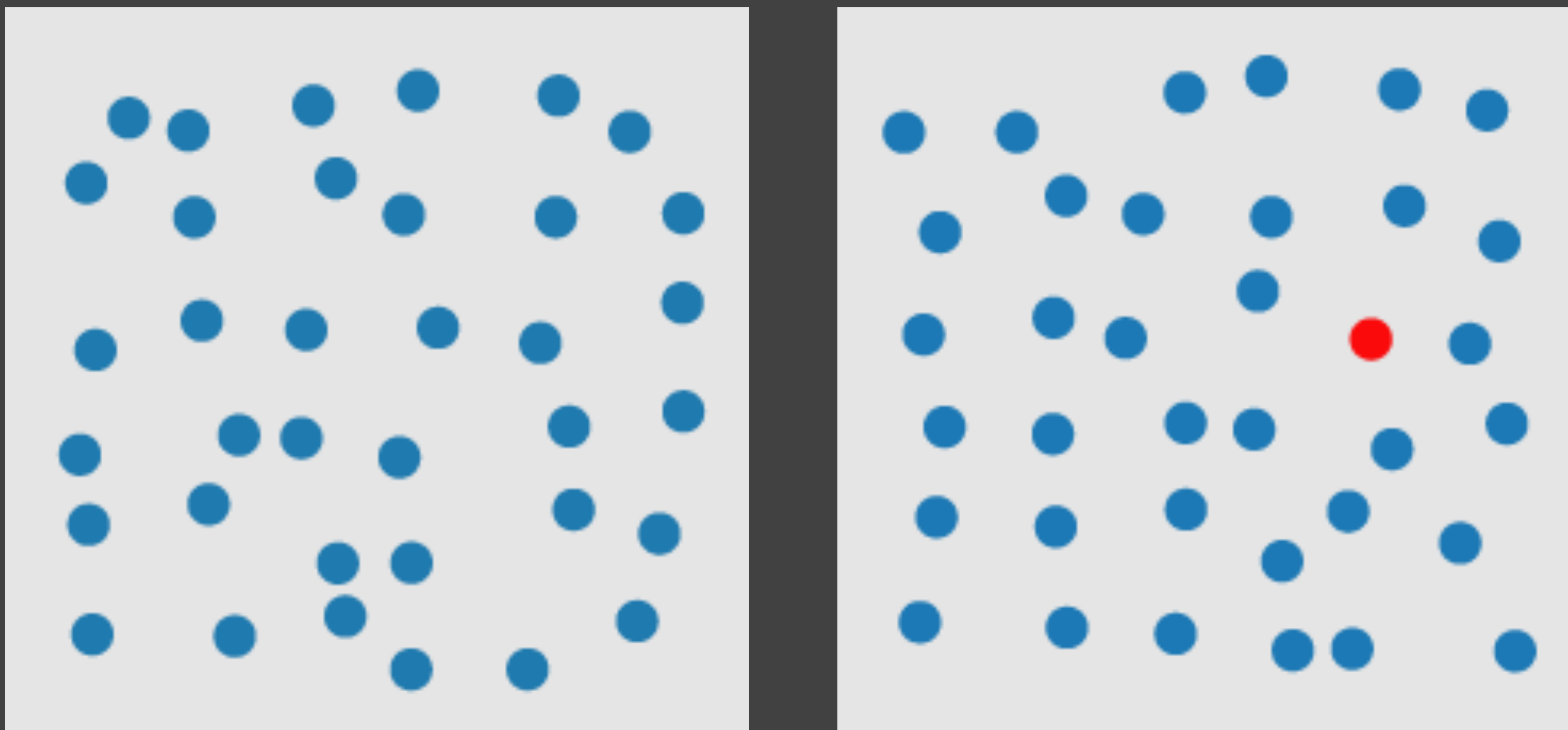
[based on a slide from J. Stasko]

How Many 3's?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

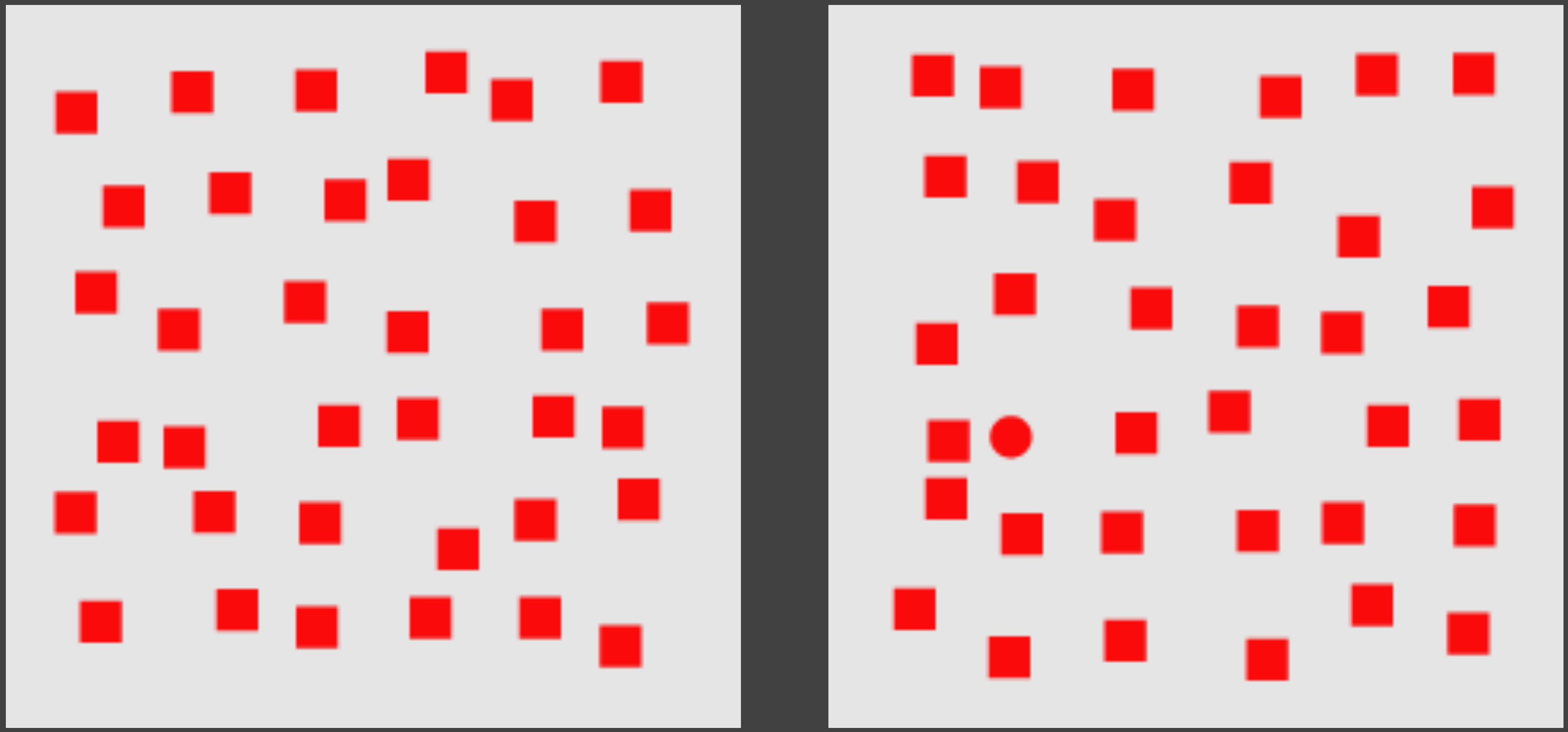
[based on a slide from J. Stasko]

Visual Pop-Out: Color



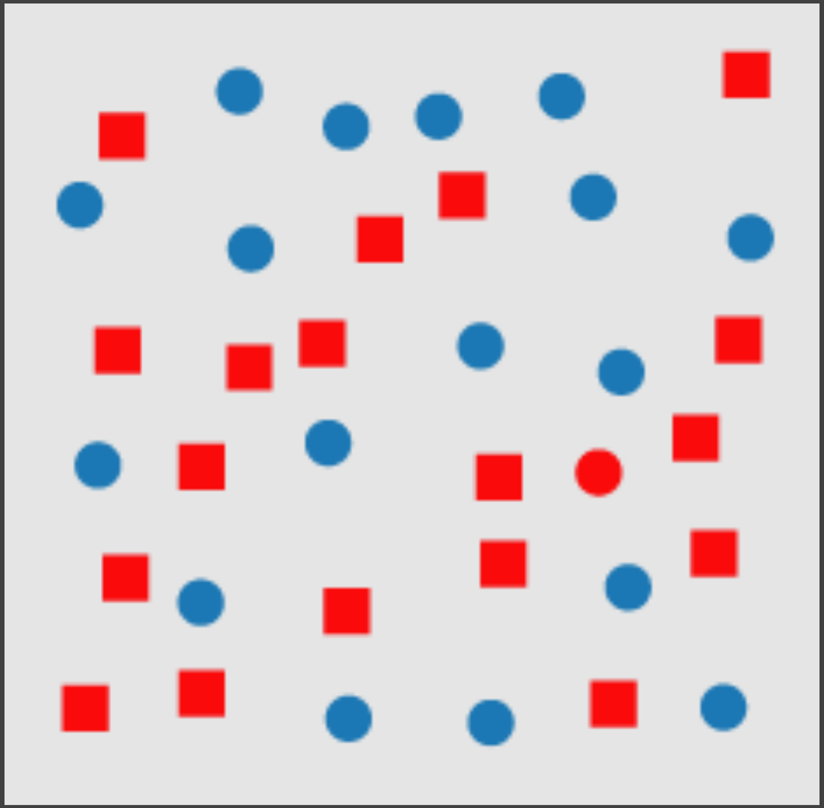
http://www.csc.ncsu.edu/faculty/healey/PP/index.html

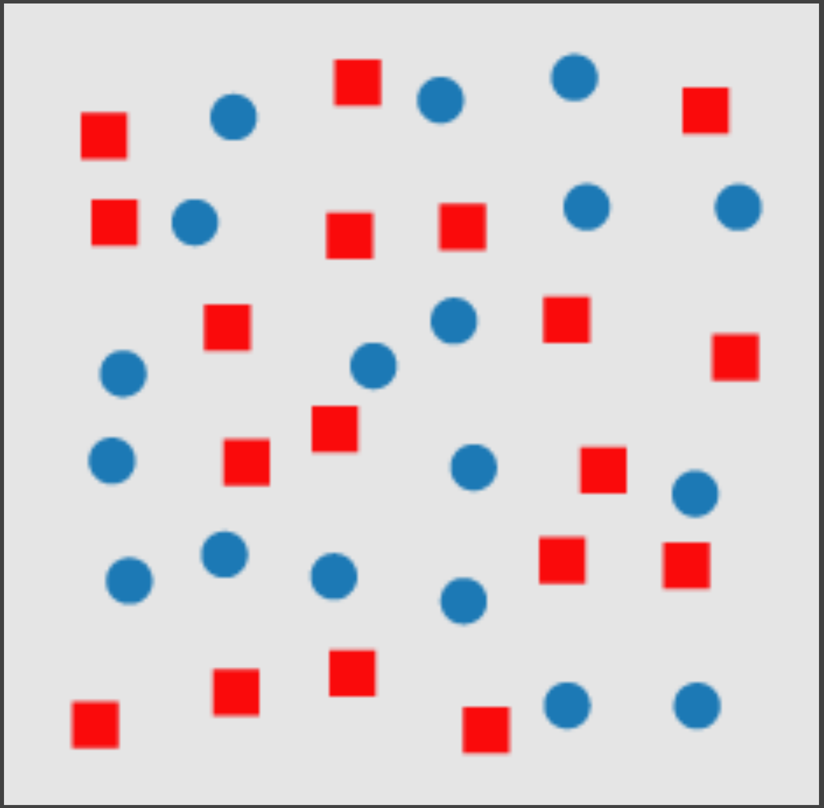
Visual Pop-Out: Shape



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

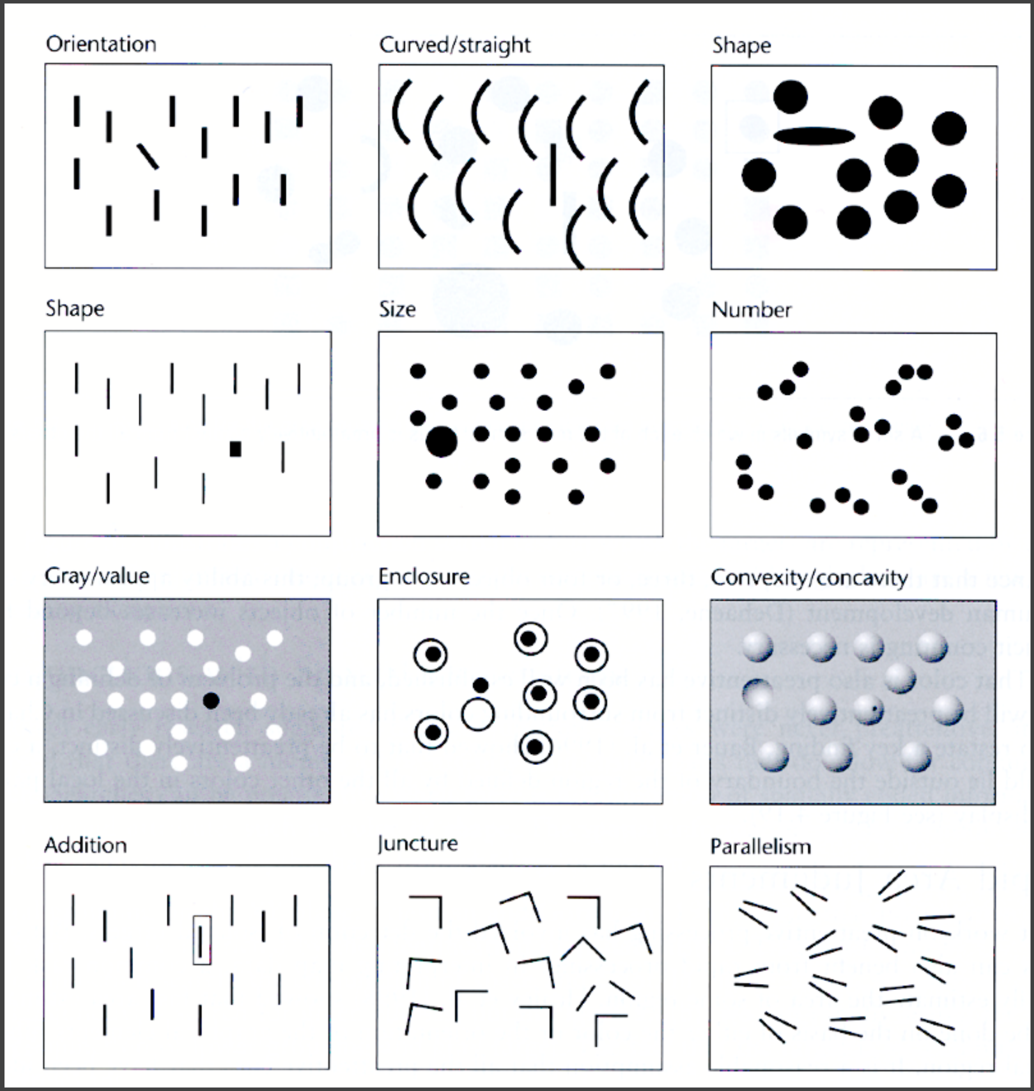
Feature Conjunctions





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

Pre-Attentive Features



[Information Visualization. Figure 5. 5 Ware 04]

More Pre-Attentive Features

Line (blob) orientation	Julesz & Bergen [1983]; Wolfe et al. [1992]
Length	Treisman & Gormican [1988]
Width	Julesz [1985]
Size	Treisman & Gelade [1980]
Curvature	Treisman & Gormican [1988]
Number	Julesz [1985]; Trick & Pylyshyn [1994]
Terminators	Julesz & Bergen [1983]
Intersection	Julesz & Bergen [1983]
Closure	Enns [1986]; Treisman & Souther [1985]
Colour (hue)	Nagy & Sanchez [1990, 1992]; D'Zmura [1991]; Kawai et al. [1995]; Bauer et al. [1996]
Intensity	Beck et al. [1983]; Treisman & Gormican [1988]
Flicker	Julesz [1971]
Direction of motion	Nakayama & Silverman [1986]; Driver & McLeod [1992]
Binocular lustre	Wolfe & Franzel [1988]
Stereoscopic depth	Nakayama & Silverman [1986]
3-D depth cues	Enns [1990]
Lighting direction	Enns [1990]

Pre-Attentive Conjunctions

Spatial conjunctions are often pre-attentive

Motion and 3D disparity

Motion and color

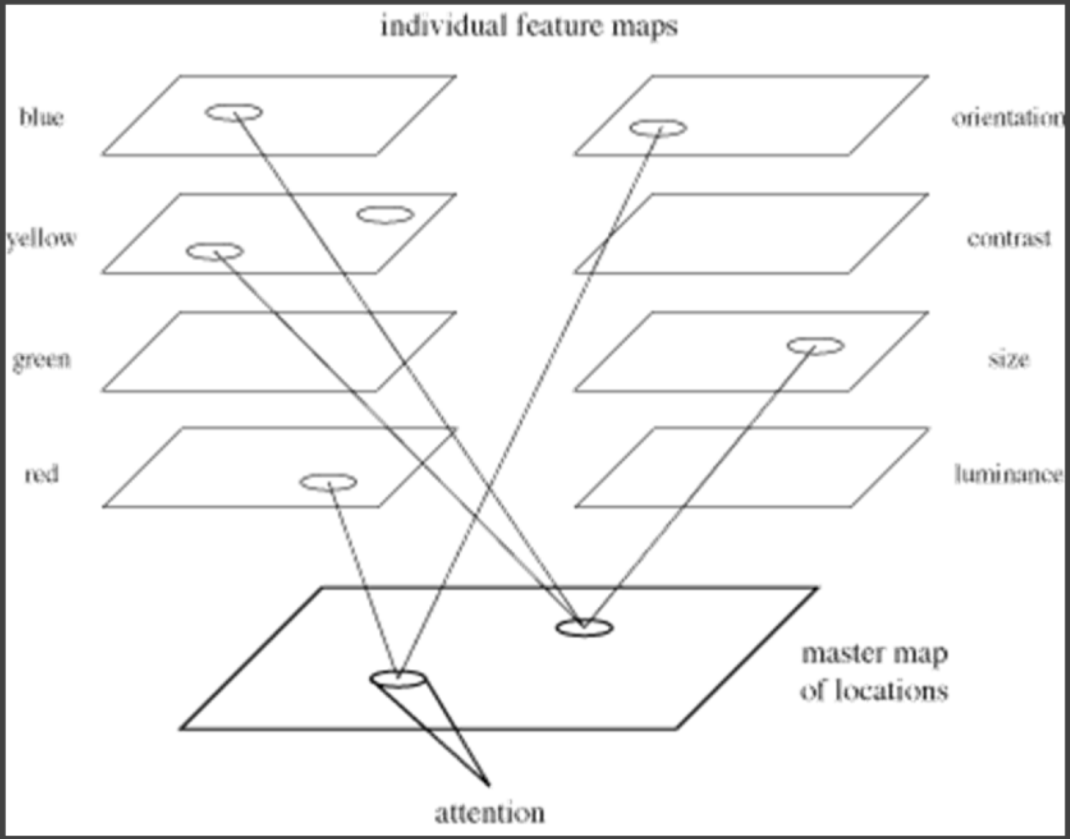
Motion and shape

3D disparity and color

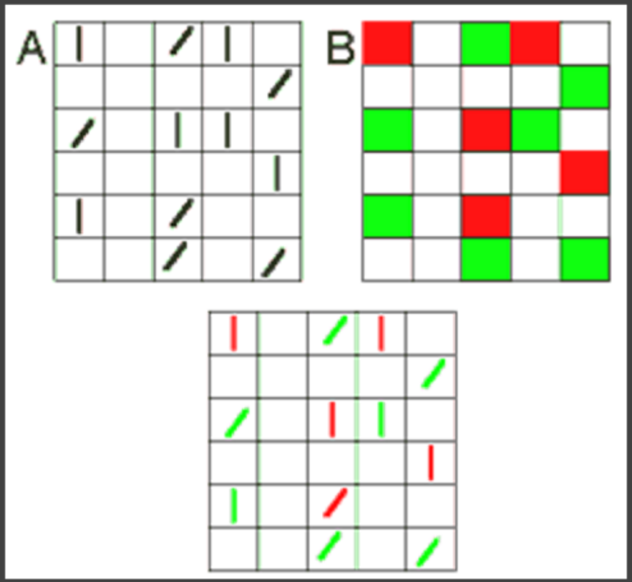
3D disparity and shape

But most conjunctions are NOT pre-attentive

Feature Integration Theory



Treisman's feature integration model [Healey 04]



Feature maps for
orientation & color [Green]

Administrivia

Final Project

Final Project

Produce an **explorable visual explanation**

Initial **prototype** and **design review**

Final deliverables and **video presentation**

Submit and **publish online** (GitHub)

Projects from **previous classes** have been:

- Published as research papers
- Shared widely (some in the New York Times!)
- Released as successful open source projects

Final Project Theme

Explorable Explanations

Goal: produce an interactive web page that explains a complex subject to the reader.

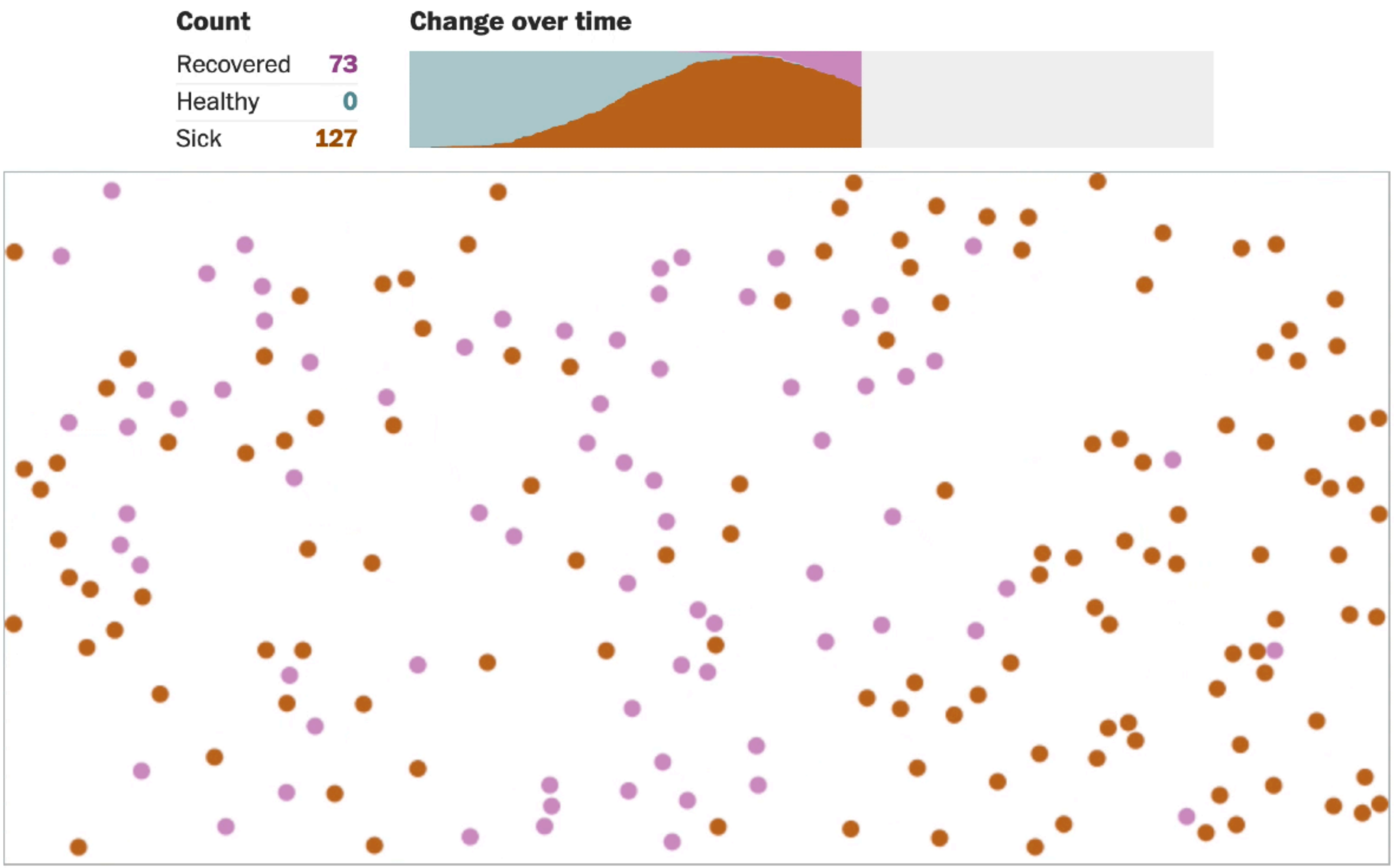
The topic could be a scientific phenomenon, a computer science algorithm, a mathematical concept, a sociological theory, or another topic that you're passionate about.

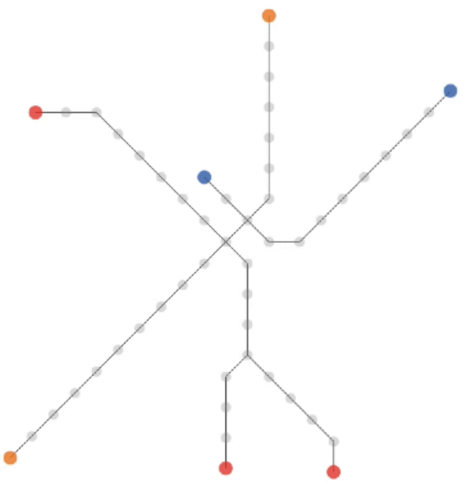
Focus on creating one or more interactive diagrams interlinked with explanatory text or annotations. We urge you to focus on a highly visual or interactive experience. Do not expect a viewer to read large amounts of article text.

Inspiration…

Why outbreaks like coronavirus spread exponentially, and how to "flatten the curve"

Harry Stevens, Washington Post 2020

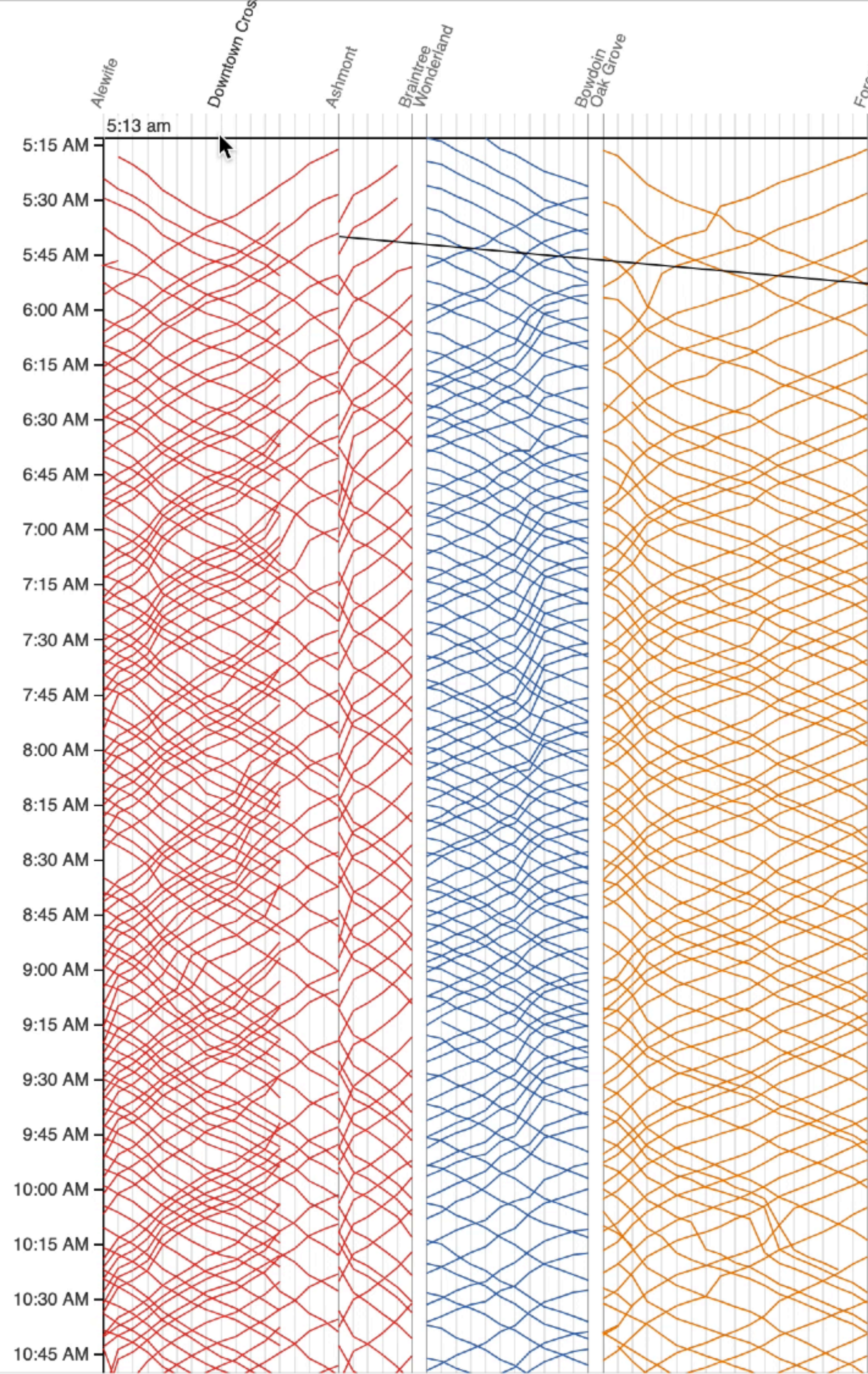




Locations of each train on the red, blue, and orange lines at 5:13 am. Hover over the diagram to the right to display trains at a different time.

Trains are on the right side of the track relative to the direction they are moving.

See the morning rush-hour, midday lull, afternoon rush-hour, and the evening lull.



Service starts at 5AM on Monday morning. Each line represents the path of one train. Time continues downward, so steeper lines indicate slower trains.

Since the red line splits, we show the Ashmont branch first then the Braintree branch. Trains on the Braintree branch "jump over" the Ashmont branch.

Train frequency increases around 6:30AM as morning rush hour begins.

MBTA Viz

Barry & Card

KEYBOARD WALKING

Passwords with a “keyboard walking” pattern start at an arbitrary key, then move in a direction (usually right or down) while continuing to hit keys. Sometimes this is combined with holding down the SHIFT key, so that some characters are uppercase or symbols to improve complexity.

While the generated password may seem to be random and unhackable, password crackers check for these keyboard patterns and guess them early on.

Many passwords in the leaked passwords dataset have a spatial pattern. Other than the numeric passwords like 123456, common keyboard walking offenders include qwerty and 1qaz@wsx.

Semantic Passwords

Vishal Devireddy (CSE 512, Spring '21)

Final Project Schedule

Proposal	Fri Nov 8
Prototype	Wed Nov 20
Demo Video	Wed Dec 4
Video Showcase	Thu Dec 5 (in class)
Deliverables	Mon Dec 9

Logistics

Final project description posted online

Work in groups of up to 4 people

Start determining your project topic!

Tips for a Successful Project

Choose a **well-scoped topic** to explain.
Be clear about what you want people to learn.

Consider **multiple design alternatives**.
Prototype quickly (use Tableau, R, *etc*…).

Seek feedback (representative users, peers, …).
Even informal usage can provide insights.

Choose **appropriate team roles**.

Start early (and read the suggested paper!)

Gestalt Grouping

Gestalt Principles

Figure/Ground

Proximity

Similarity

Symmetry

Connectedness

Continuity

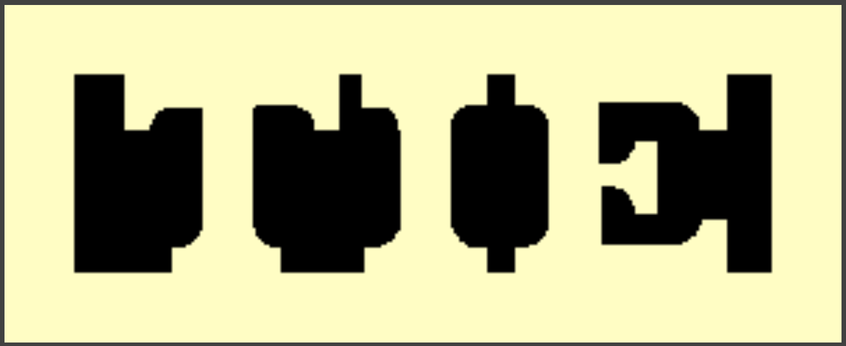
Closure

Common Fate

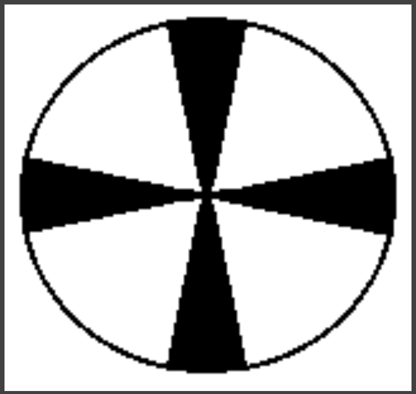
Transparency

Figure/Ground

Ambiguous



Principle of surroundedness

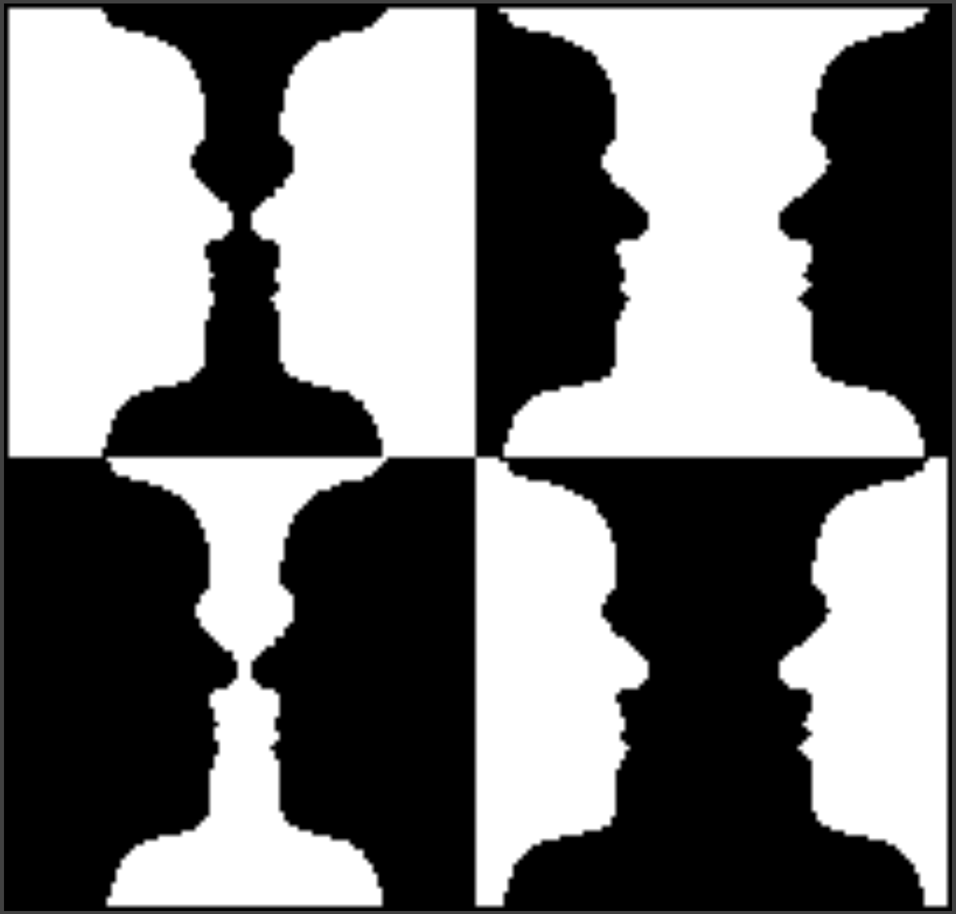


Principle of relative size

http://www.aber.ac.uk/media/Modules/MC10220/visper07.html

Figure/Ground

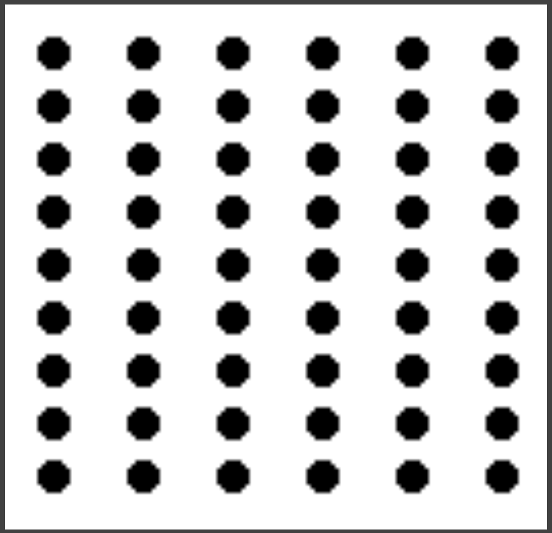
Ambiguous

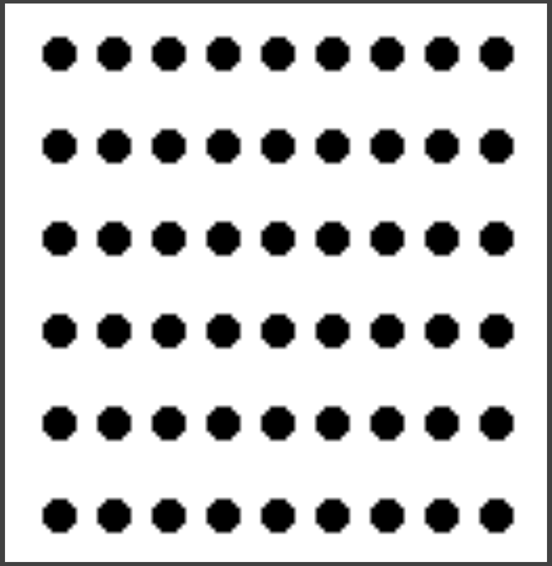


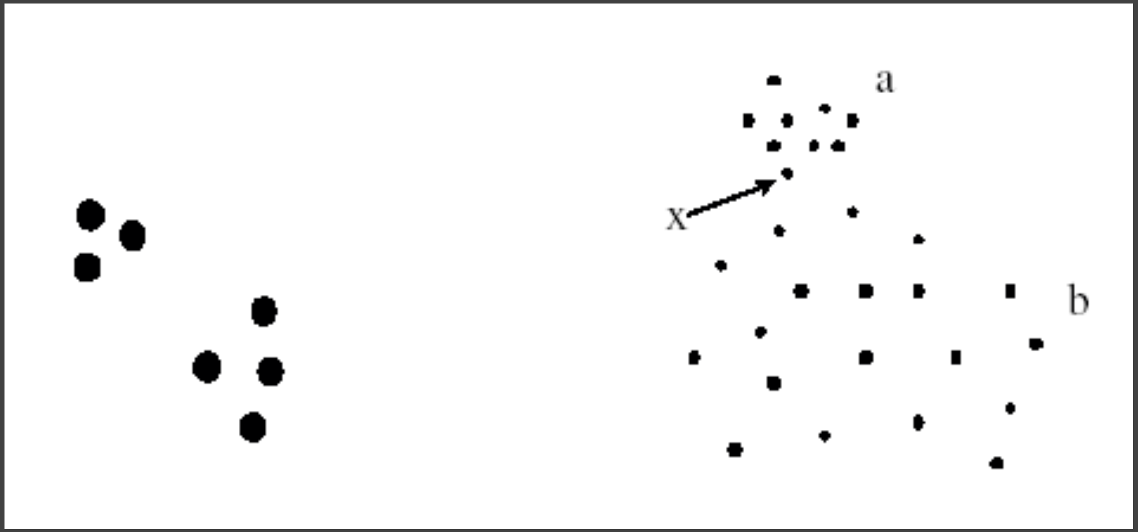
Unambiguous (?)

http://www.aber.ac.uk/media/Modules/MC10220/visper07.html

Proximity

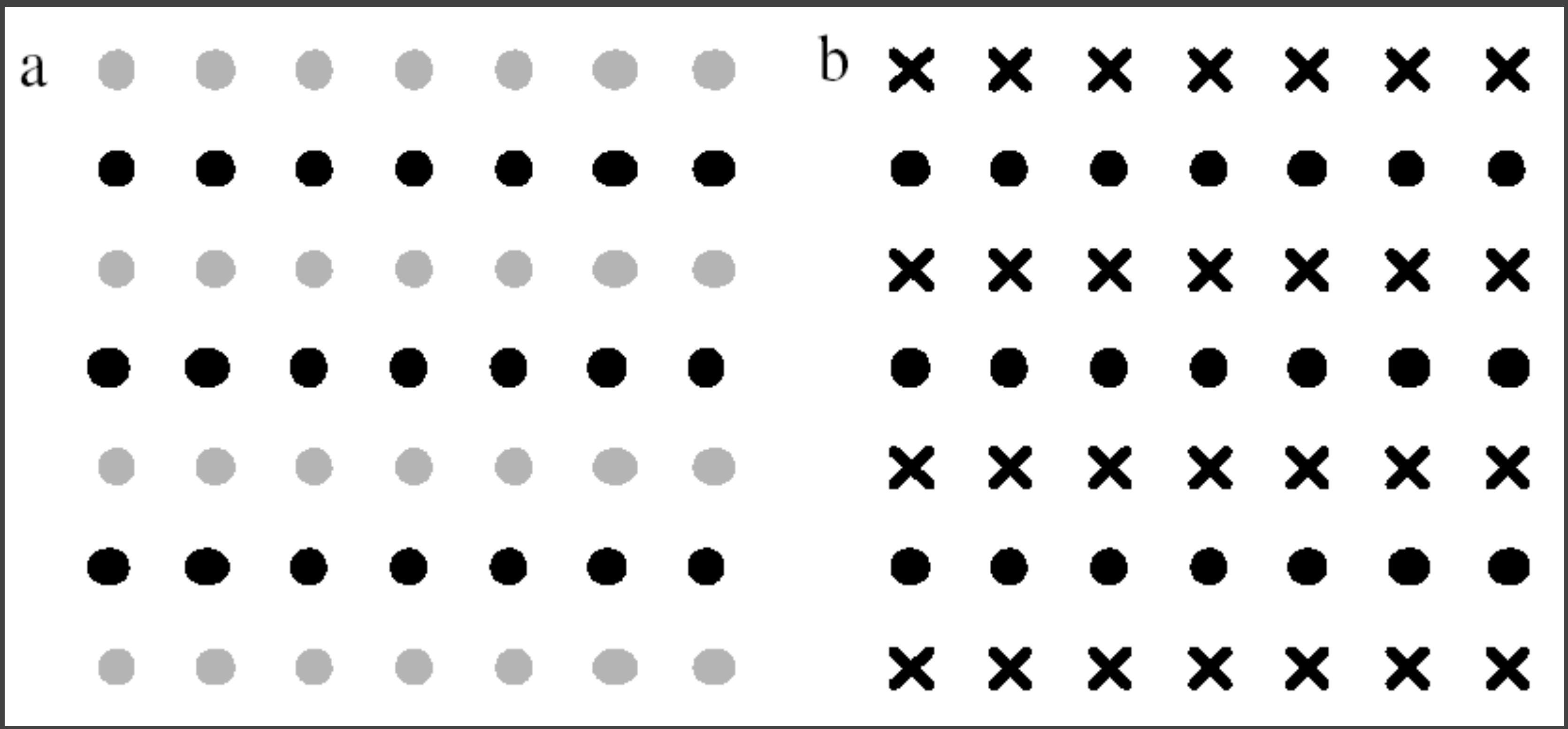






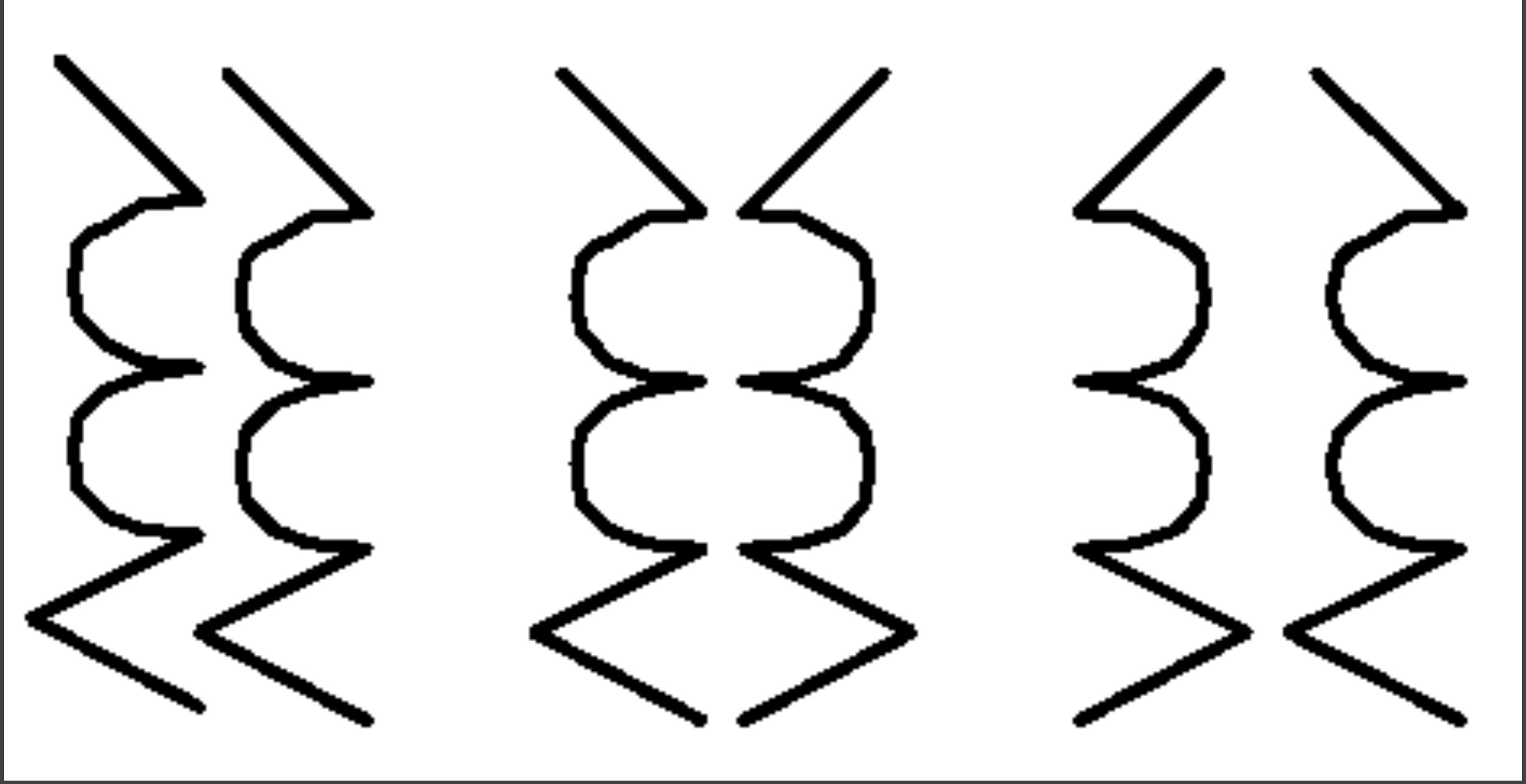
[Ware ’00]

Similarity



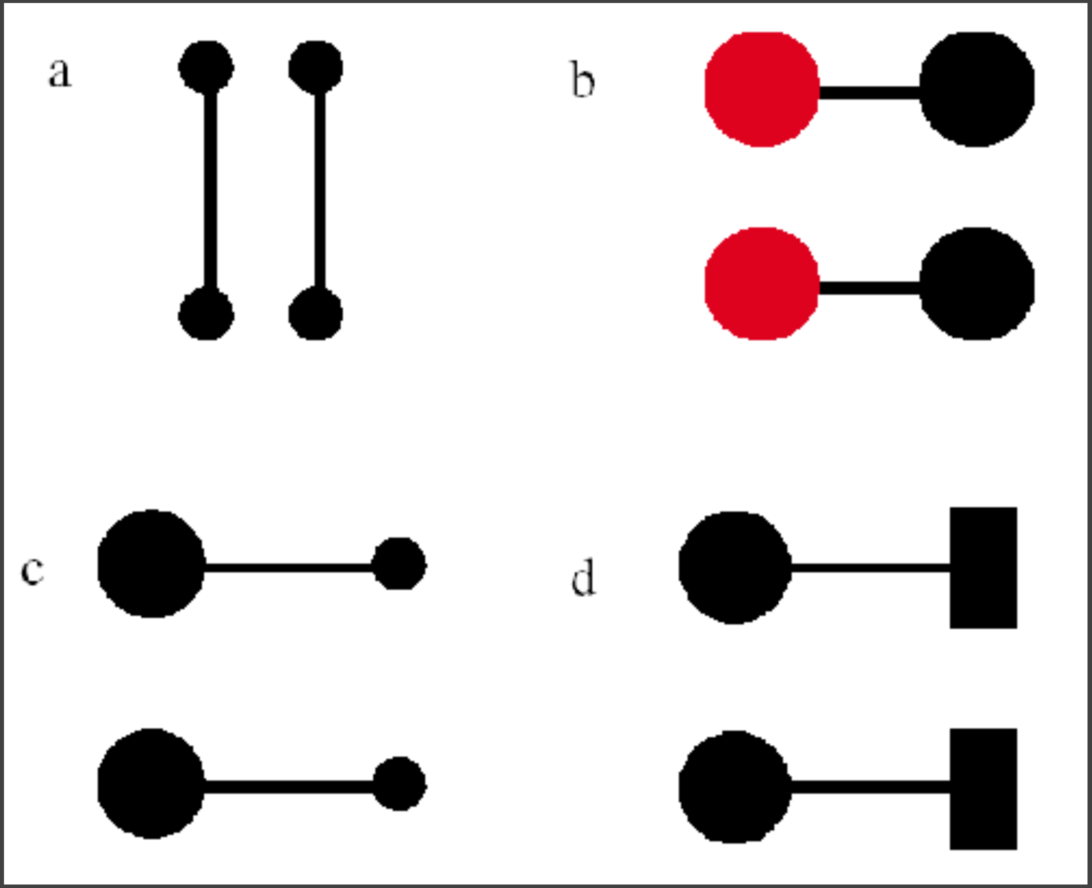
Rows dominate due to similarity [from Ware '04]

Symmetry



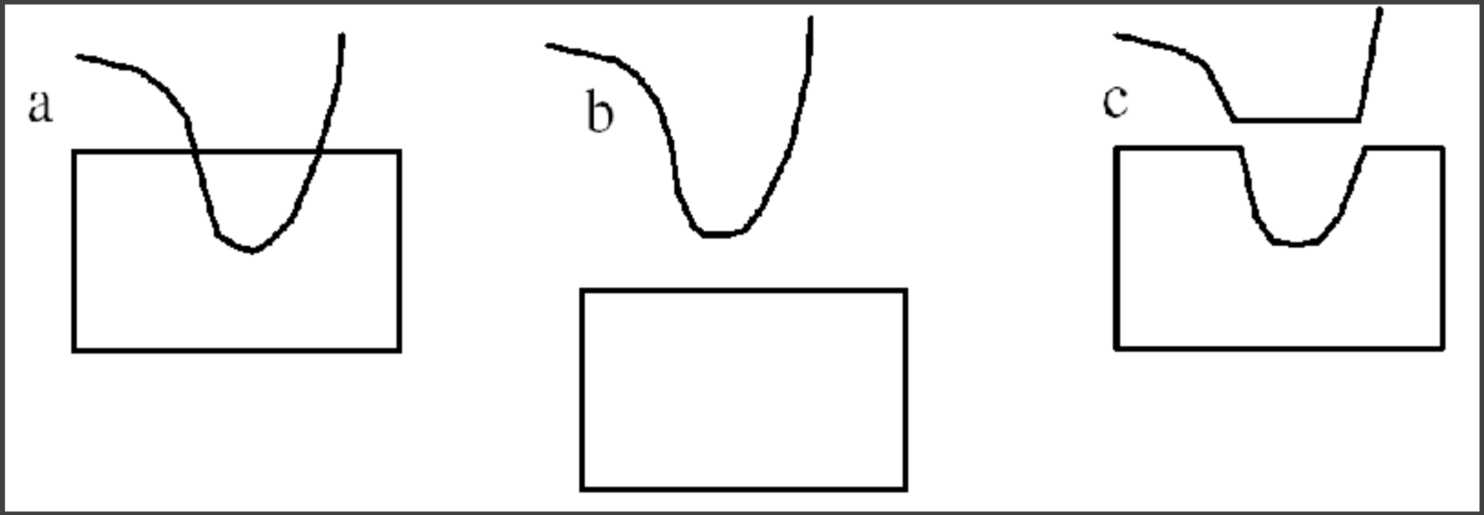
Bilateral symmetry gives strong sense of figure [from Ware '04]

Connectedness

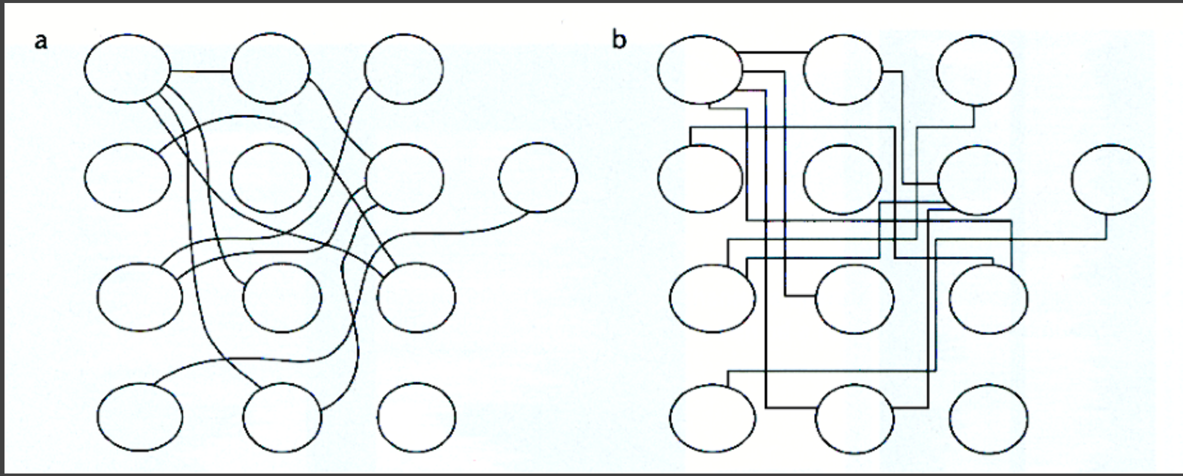


Connectedness overrules proximity, size, color shape [from Ware '04]

Continuity

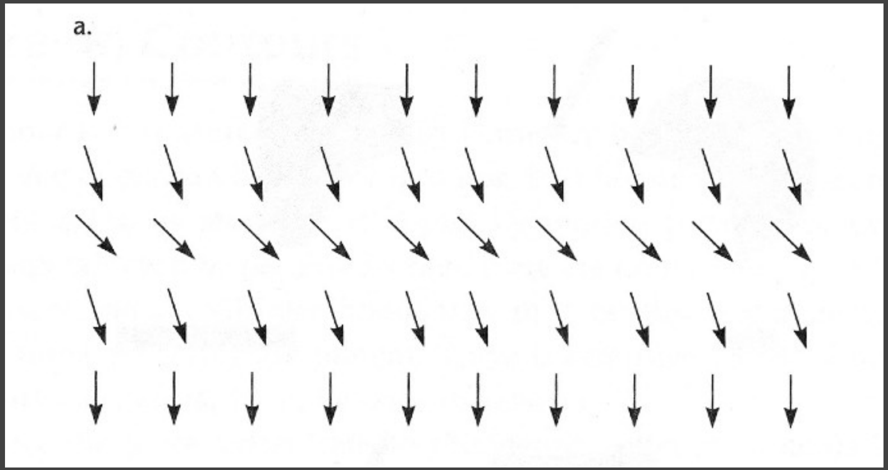


We prefer smooth not abrupt changes [from Ware '04]

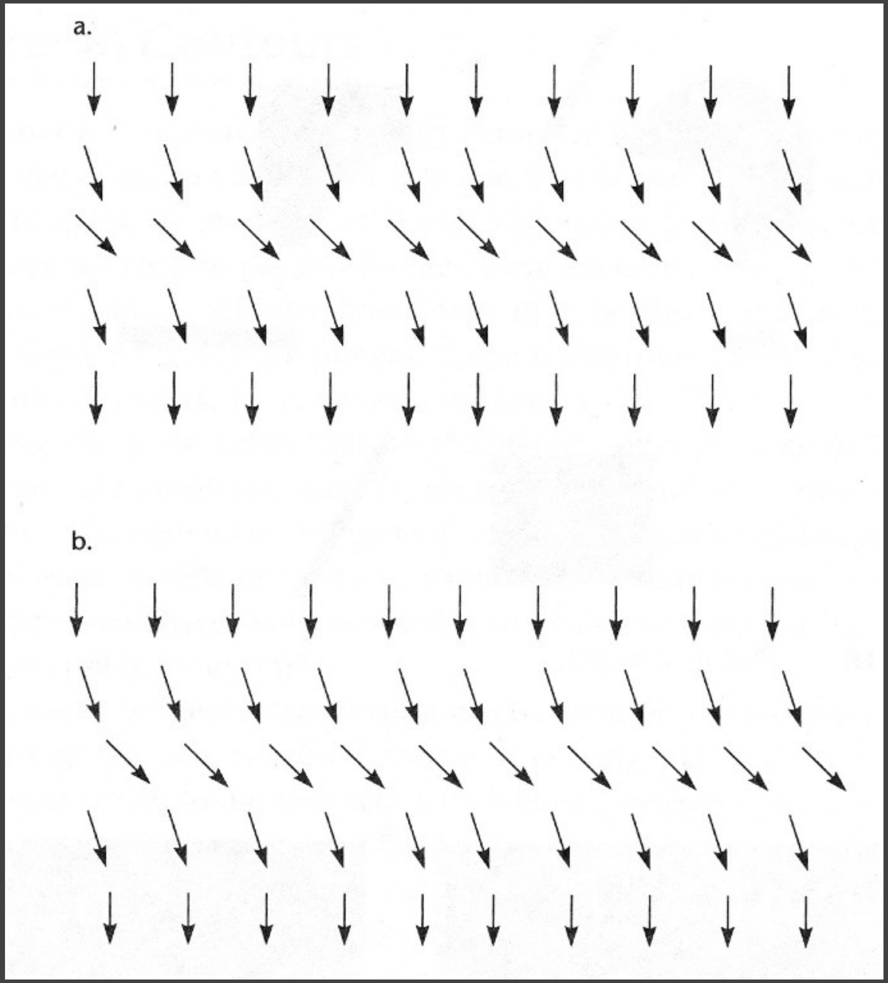


Connections are clearer with smooth contours [from Ware '04]

Continuity: Vector Fields

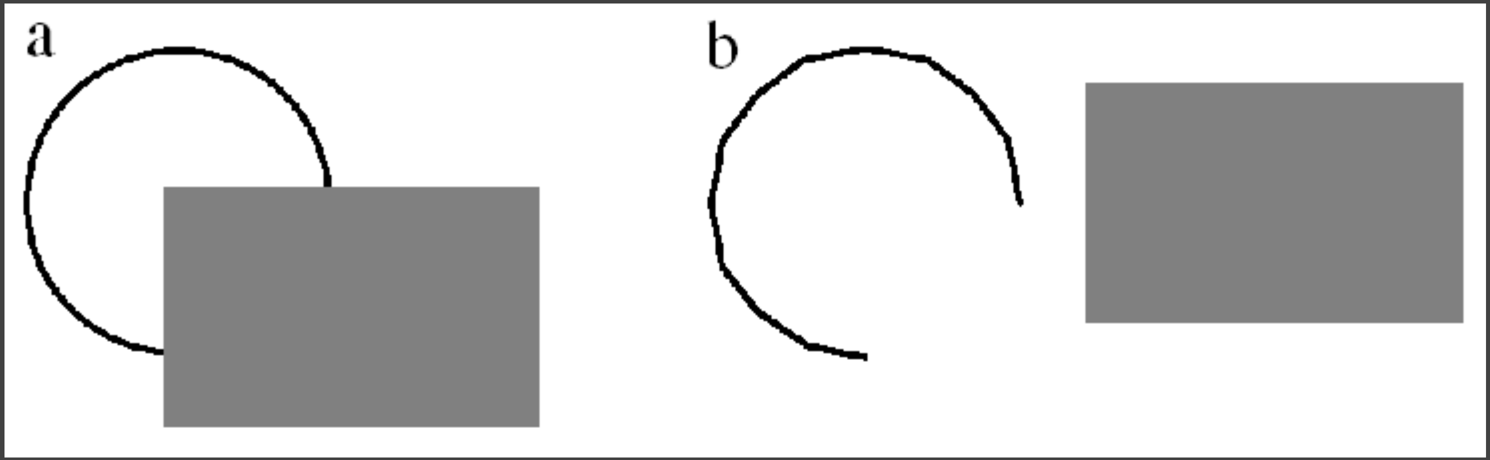


Continuity: Vector Fields

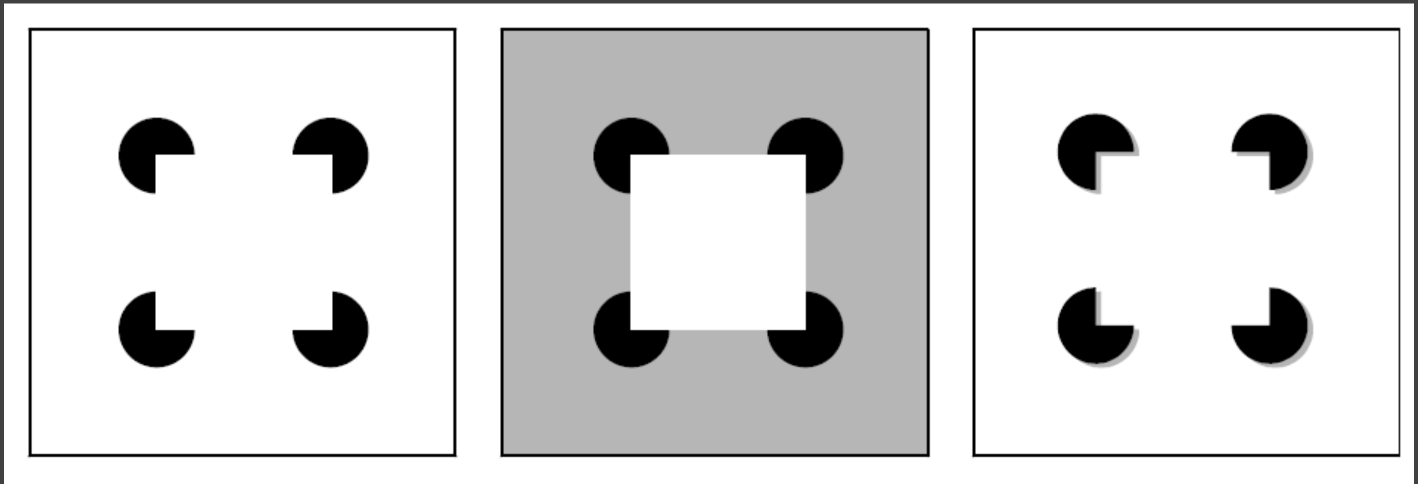


Prefer field that shows smooth continuous contours [from Ware '04]

Closure

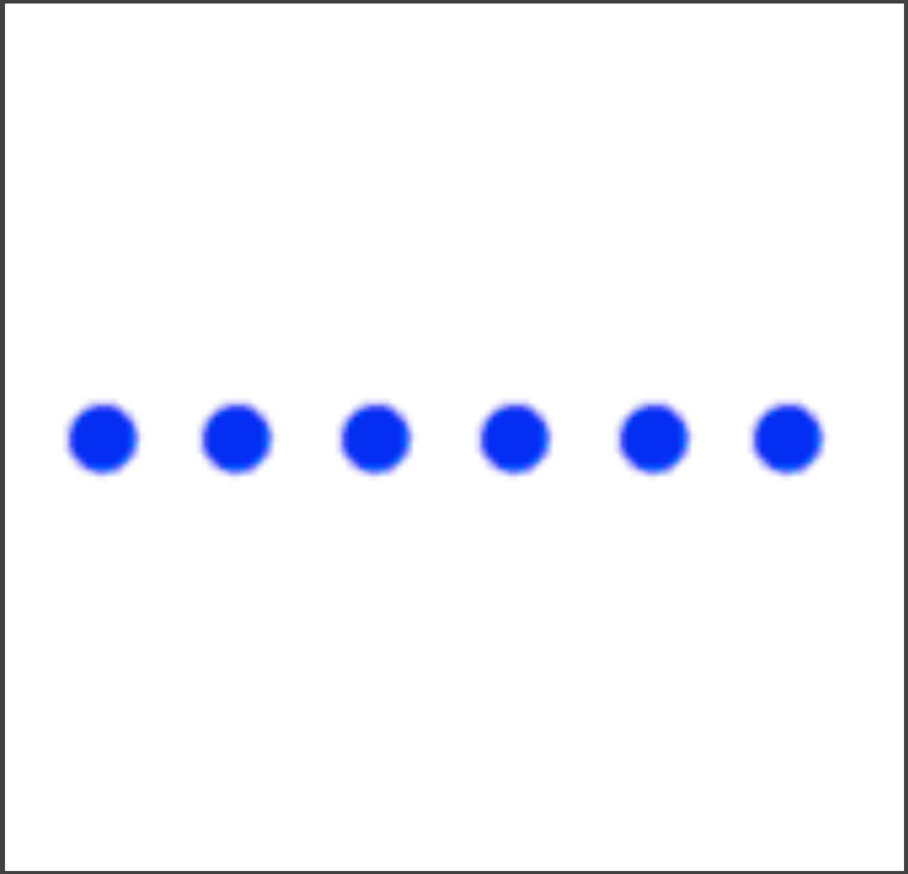


We see a circle behind a rectangle, not a broken circle [from Ware ’04]



Illusory contours [from Durand ’02]

Common Fate



Dots moving together are grouped

Transparency

Requires continuity and proper color correspondence [from Ware '04]

Change Blindness

Change Blindness

Change Blindness

Change Blindness

Change Blindness

Change Blindness

[Example from Palmer 99, originally due to Rock]

Demonstrations

http://www.psych.ubc.ca/~rensink/flicker/download/

http://www.youtube.com/watch?v=Ahg6qcgoay4

Summary

Choosing effective visual encodings requires knowledge of visual perception.

Visual features/attributes
Individual attributes often pre-attentive
Multiple attributes may be separable or integral

Gestalt principles provide high-level guidelines

We don't always see everything that is there!