Data Visualization

Graphical Perception

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DVL
Data Visualization Lab

Disclaimer

- These slides can only be used as study material for the Data Visualization class at Sejong University
- The slides cannot be distributed or used for another purpose

Graphical Perception

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

Which best encodes quantities?

- Position
- Length
- Area
- Volume
- Value (Brightness)
- Color Hue
- Orientation (Angle)
- Shape

Mackinlay's ranking of encodings

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

Topics

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

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 (Weber's Law) $\Delta S = k\frac{\Delta I}{I}$
- Ratios more important than magnitude
- Most continuous variation in stimuli perceived in discrete steps

Information in color and value

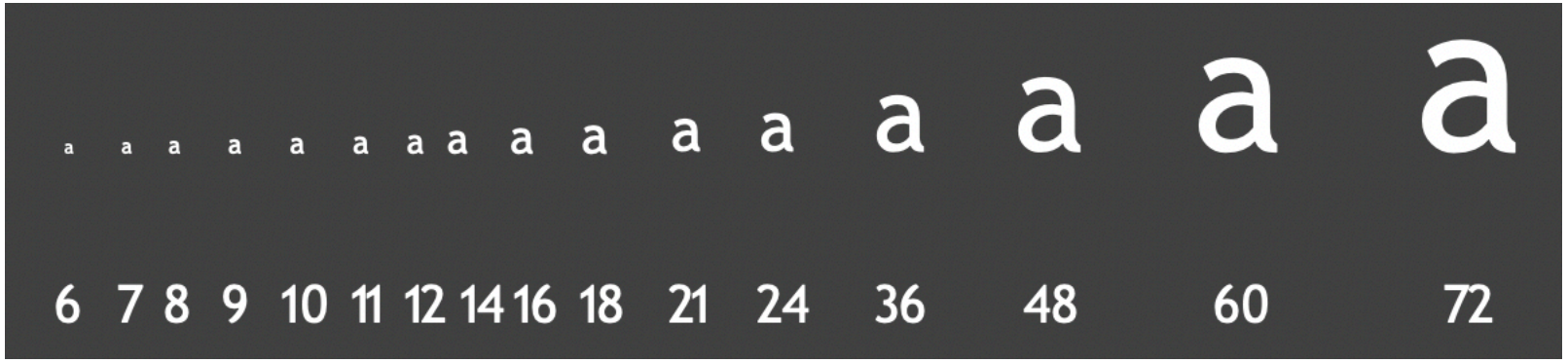
- Value is perceived as ordered
  - Encode ordinal variables (O)

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

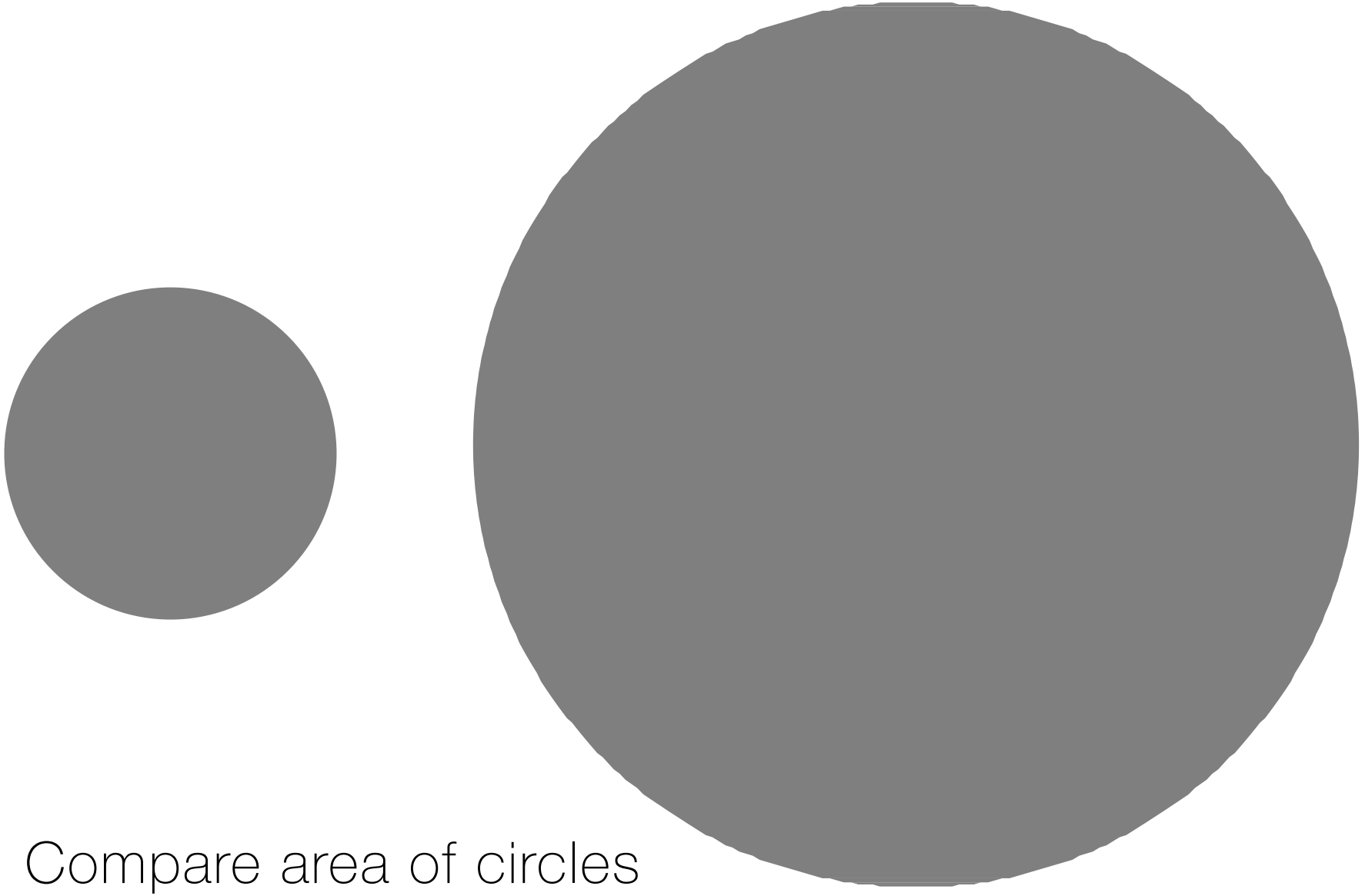
- Hue is normally perceived as unordered
  - Encode nominal variables (N) using color

Steps in font size

- Sizes standardized in 16th century



Estimating Magnitude

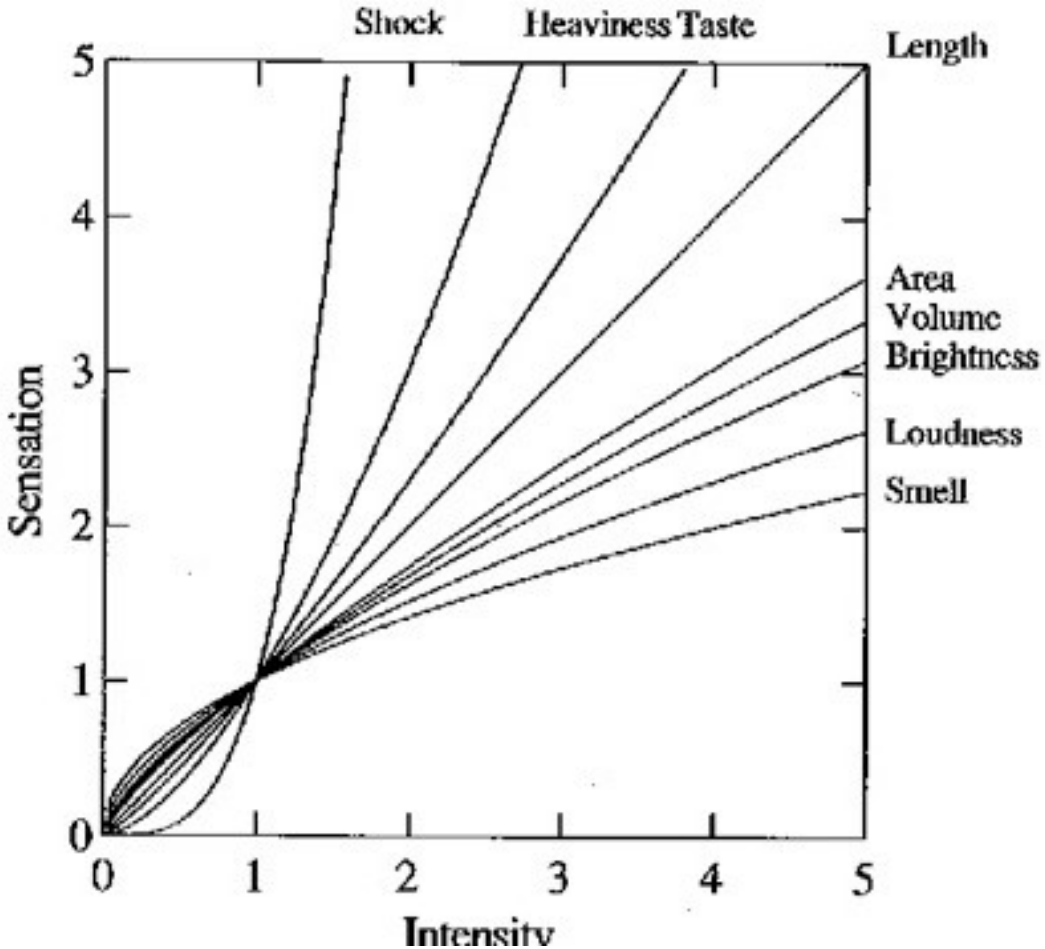


Compare area of circles

Compare length of bars

Steven's Power Law

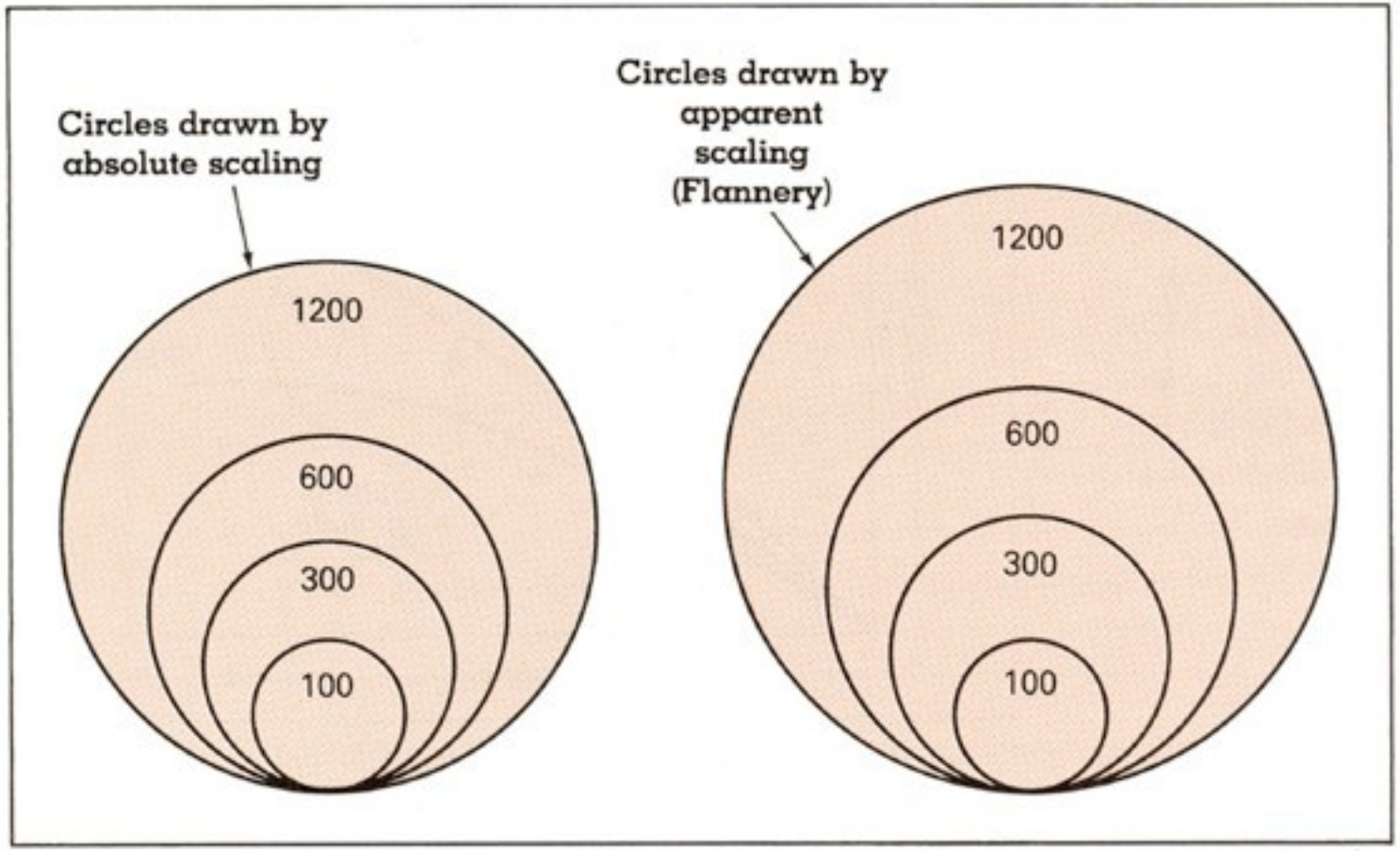
$$S = I^p$$



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

Apparent magnitude scaling

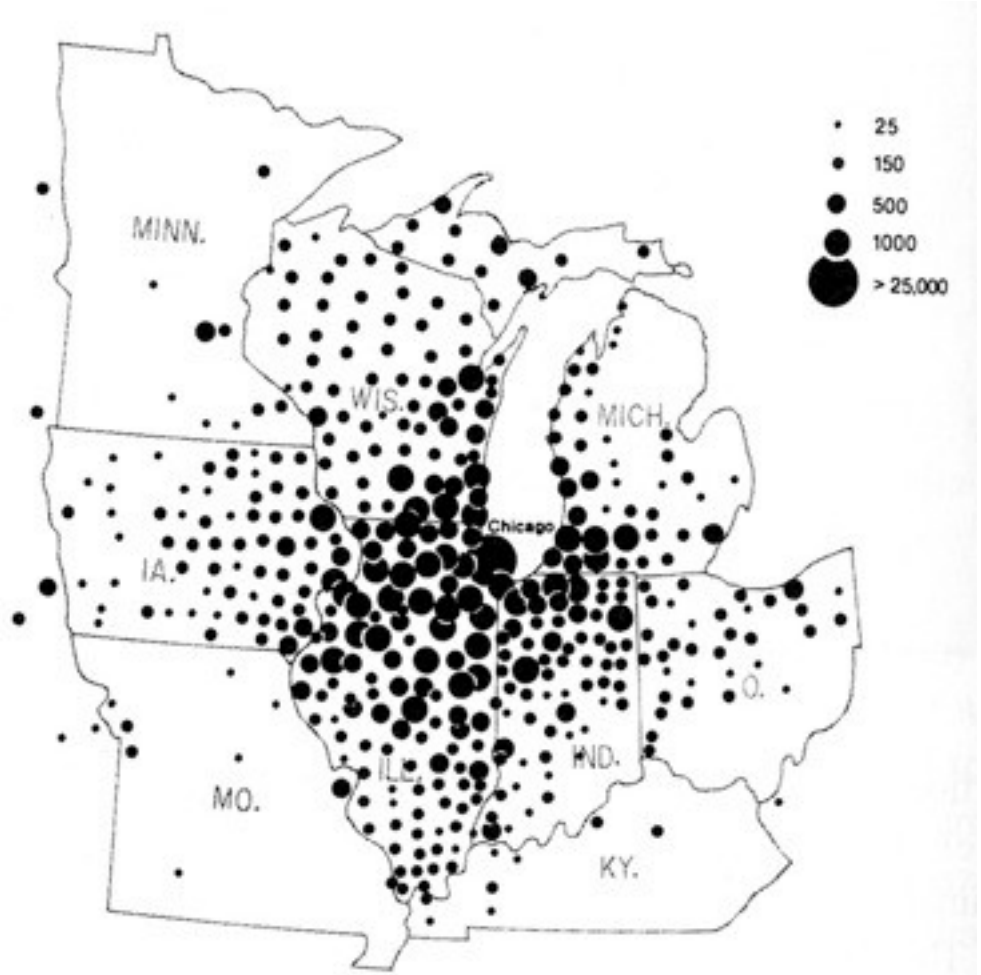


[Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96]

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

Proportional symbol map

Newspaper Circulation



[Cartography: Thematic Map Design, Figure 8.8, p. 172, Dent, 96]

Graduated sphere map

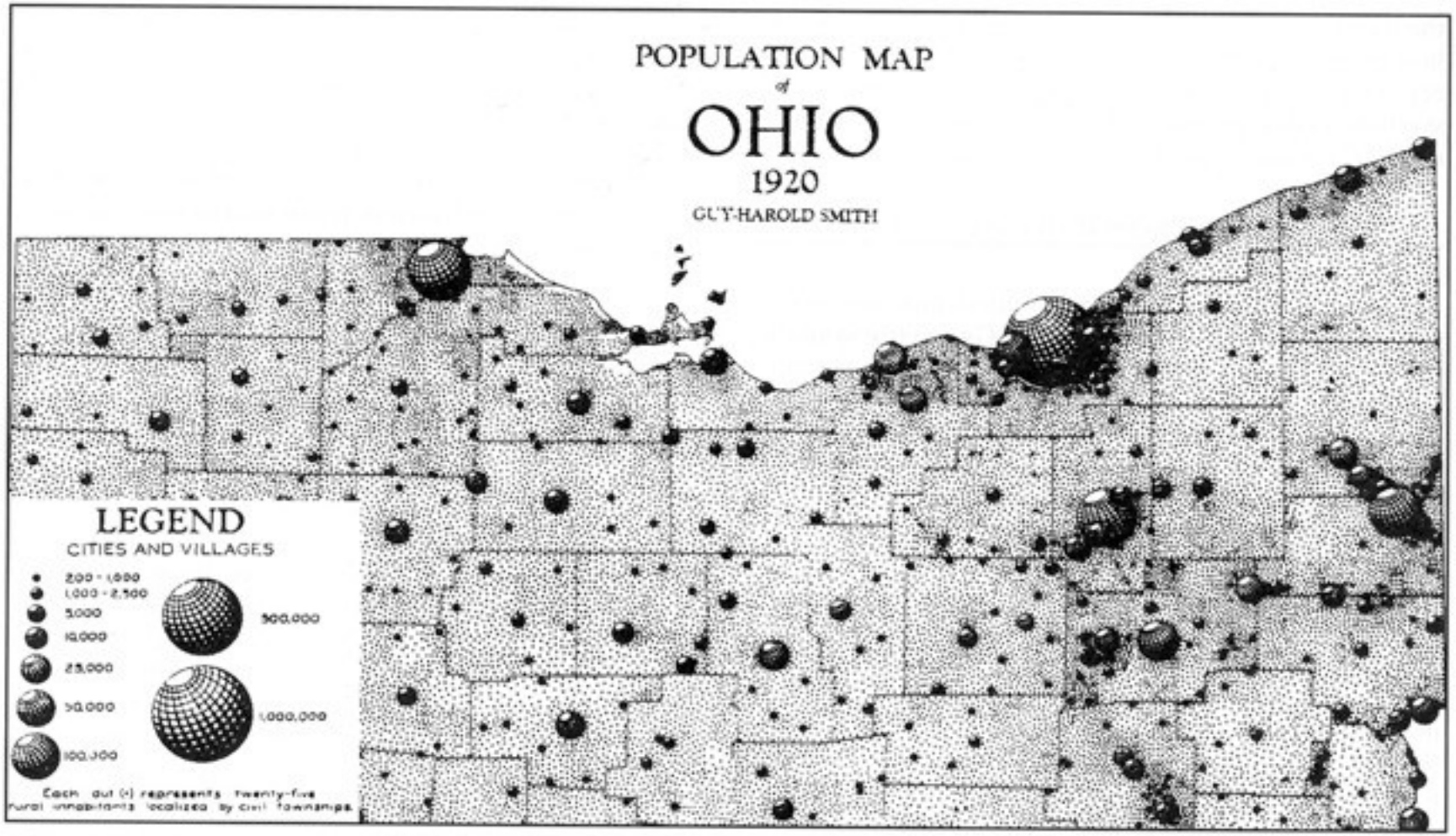


FIGURE 7.4. An eye-catching map created using three-dimensional geometric symbols. (After Smith, 1928. First published in *The Geographical Review,* 18(3), plate 4. Reprinted with permission of the American Geographical Society.)

Cleveland & McGill

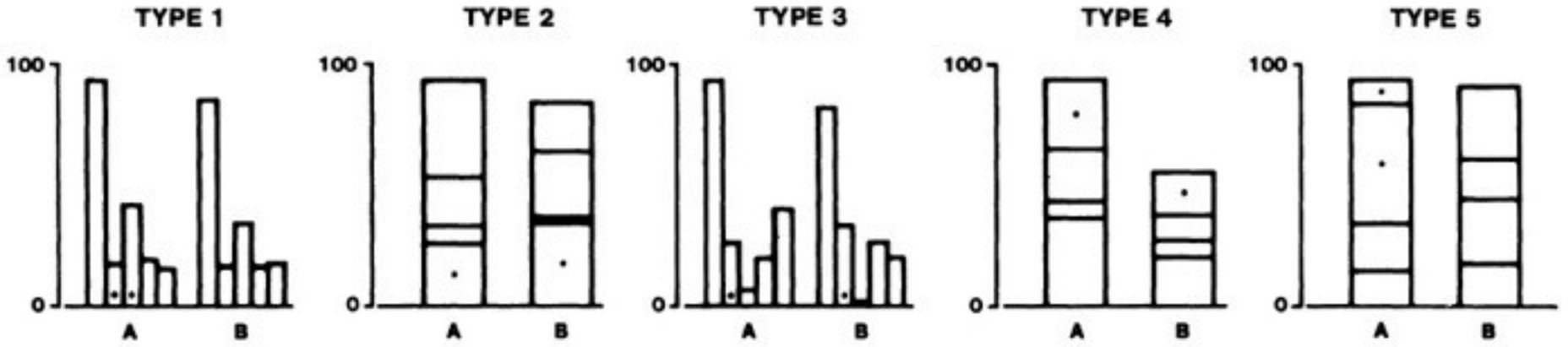


Figure 4. Graphs from position–length experiment.

[Cleveland and McGill 84]

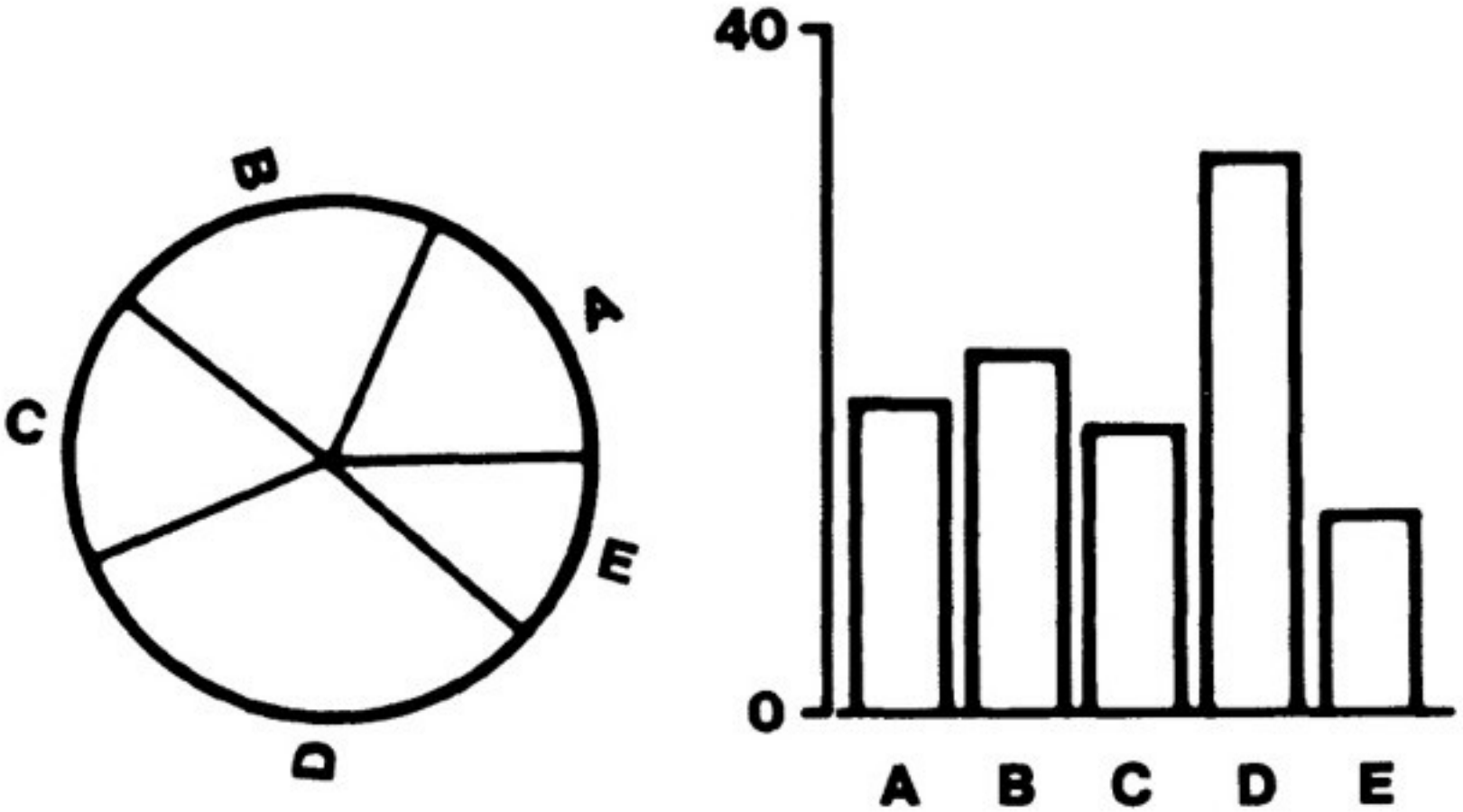


Figure 3. Graphs from position–angle experiment.

[Cleveland and McGill 84]

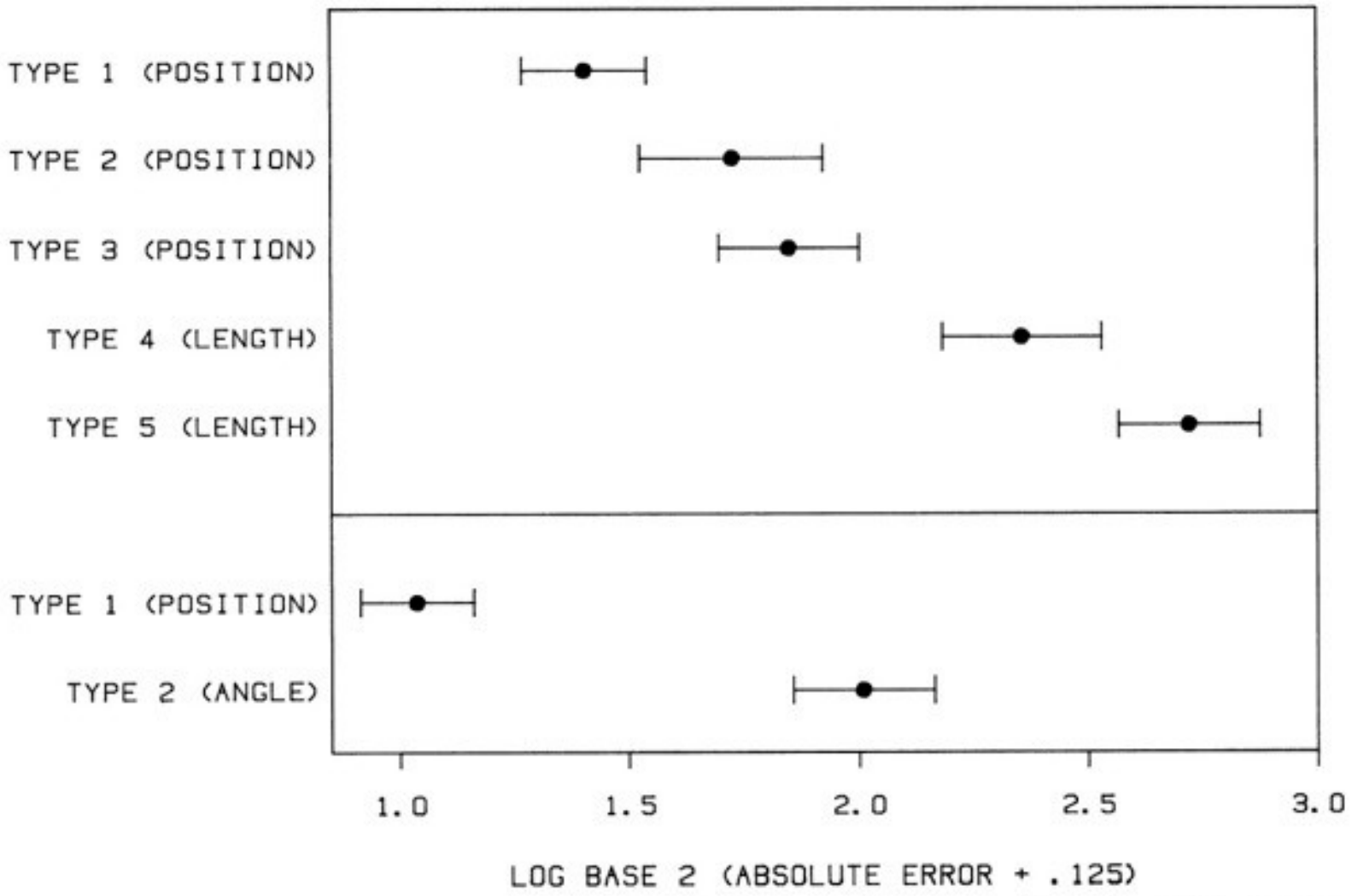
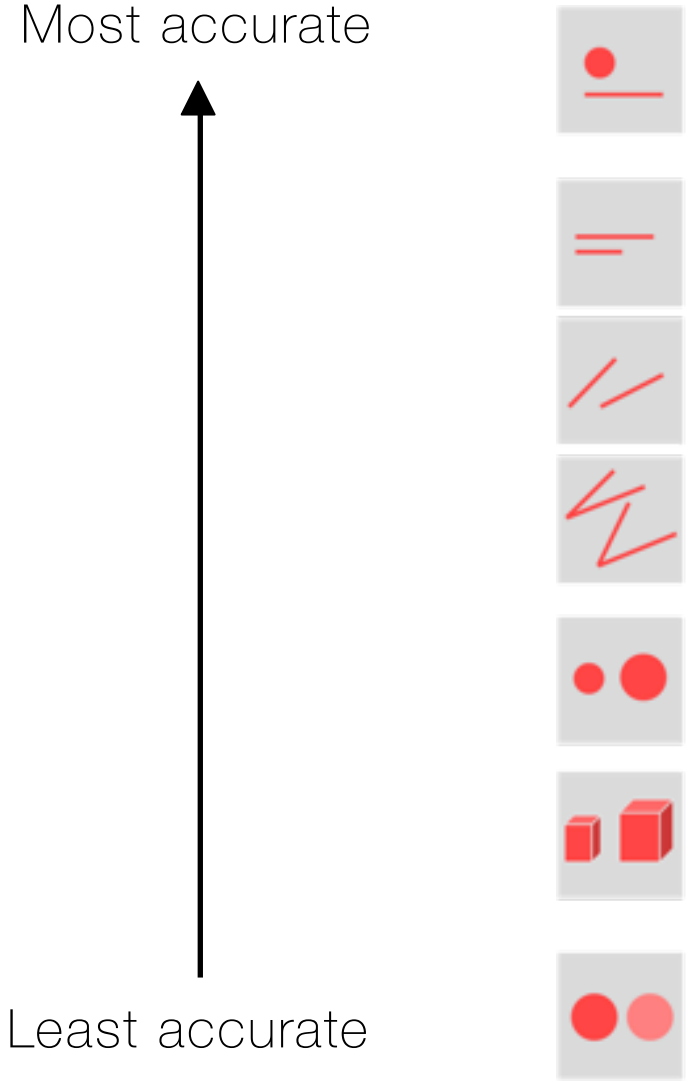


Figure 16. Log absolute error means and 95% confidence intervals for judgment types in position–length experiment (top) and position–angle experiment (bottom).

[Cleveland and McGill 84]

Relative magnitude estimation



Position (common) scale

Position (non-aligned) scale

Length

Slope

Angle

Area

Volume

Color hue-saturation-density

Pre-attentive vs. Attentive Visual Processing

How many 3's

12817687561389765469845069856049828267623

98098584582245098564589450984509809435853

90910302099059595957725646750506789045673

88457898098216776548763649085609129496863

[based on slide from Stasko]

How many 3's

1281768756138976546984506985604982826762

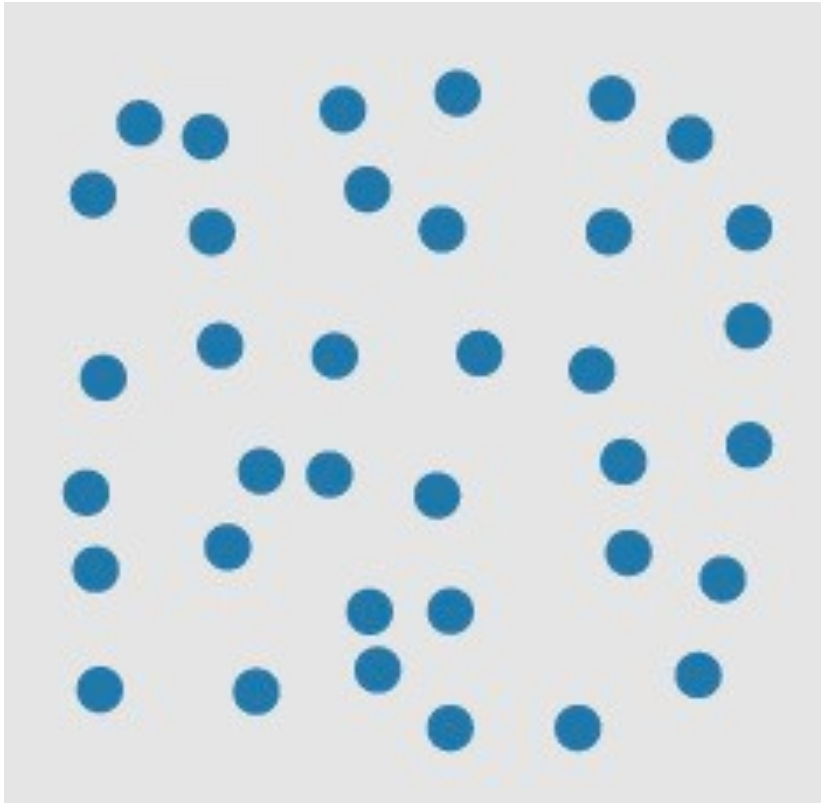
9809858458224509856458945098450980943585

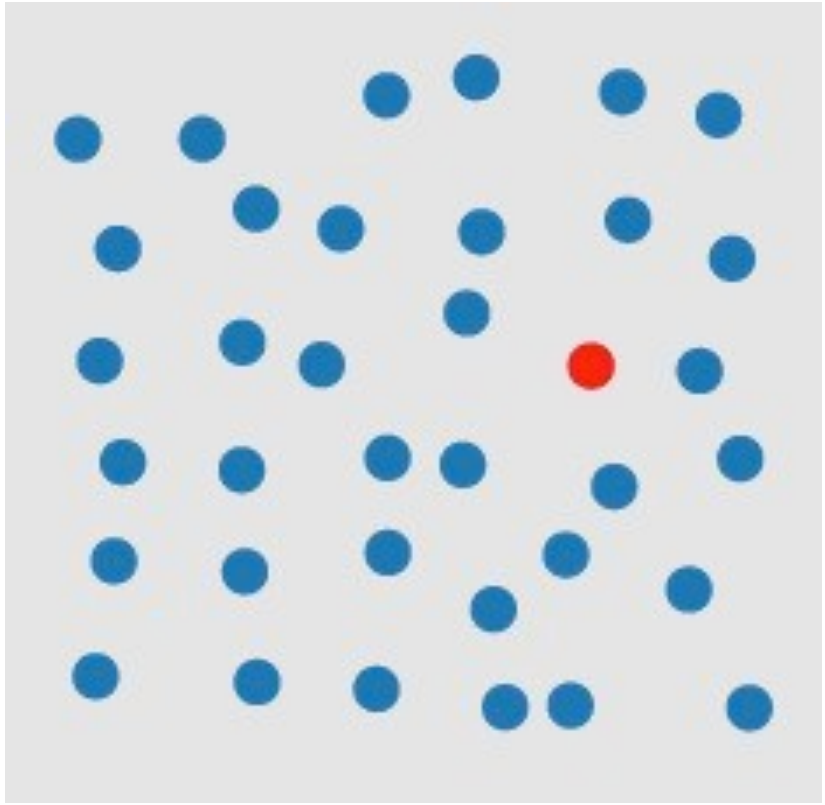
9091030209905959595772564675050678904567

8845789809821677654876364908560912949686

[based on slide from Stasko]

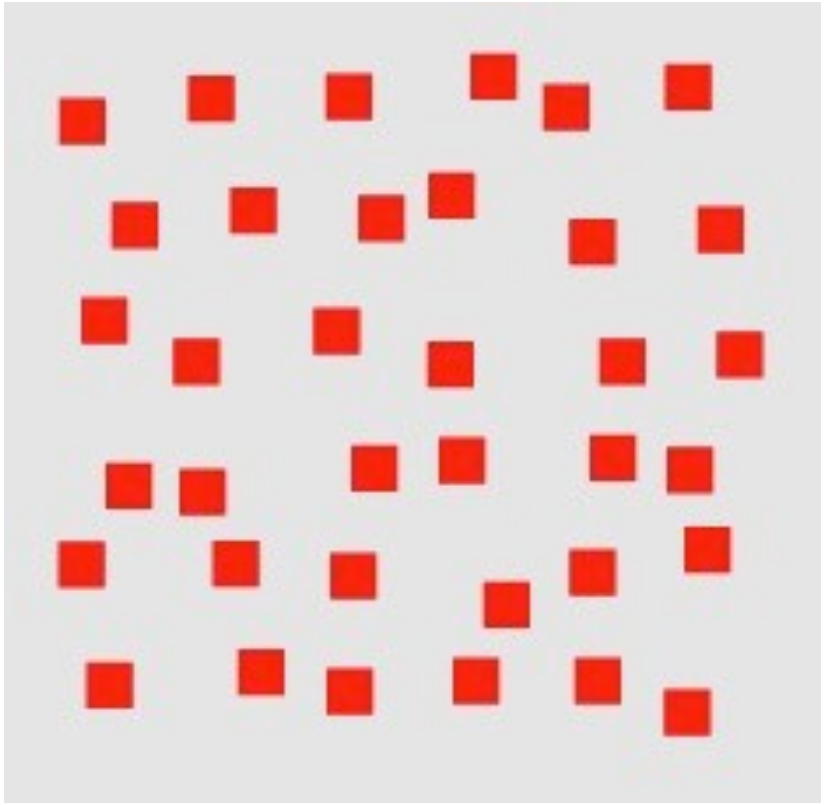
Visual pop-out: Color

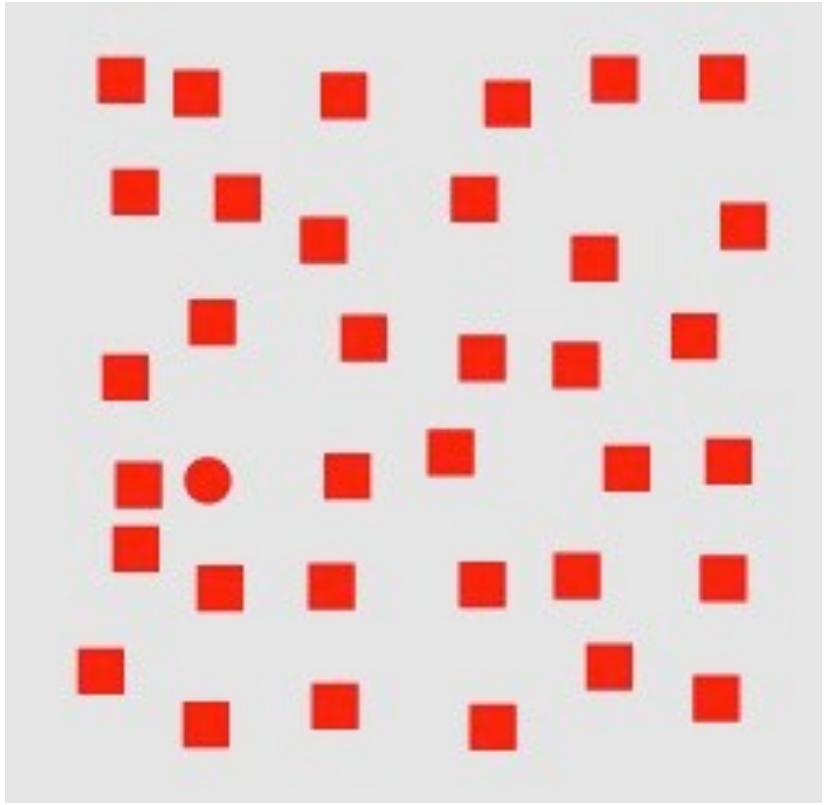




http://www.csc.ncsu.edu/faculty/healey/PP/index.html

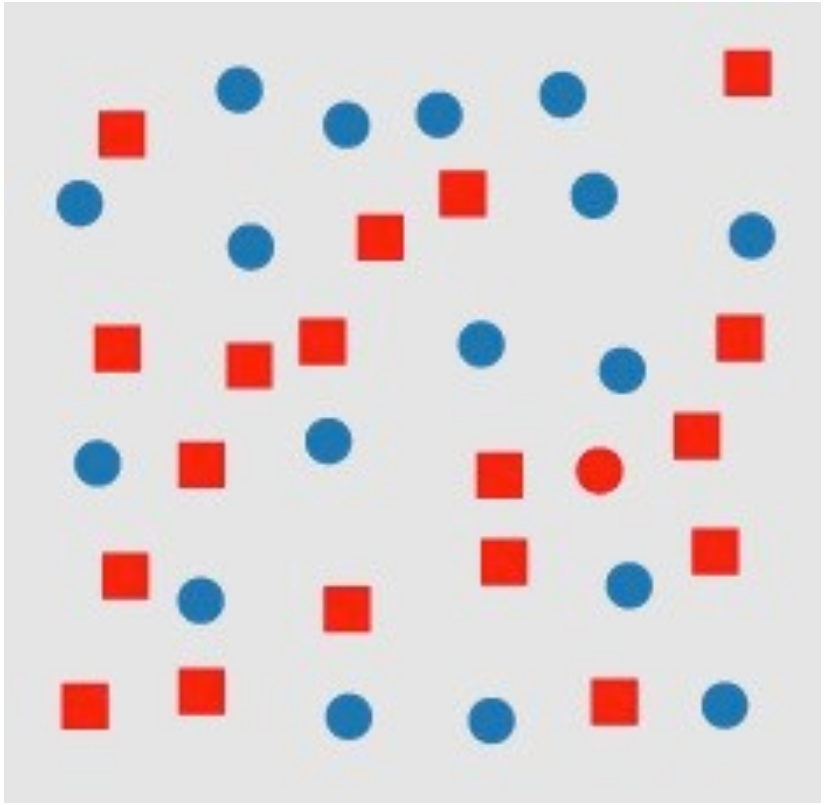
Visual pop-out: Shape

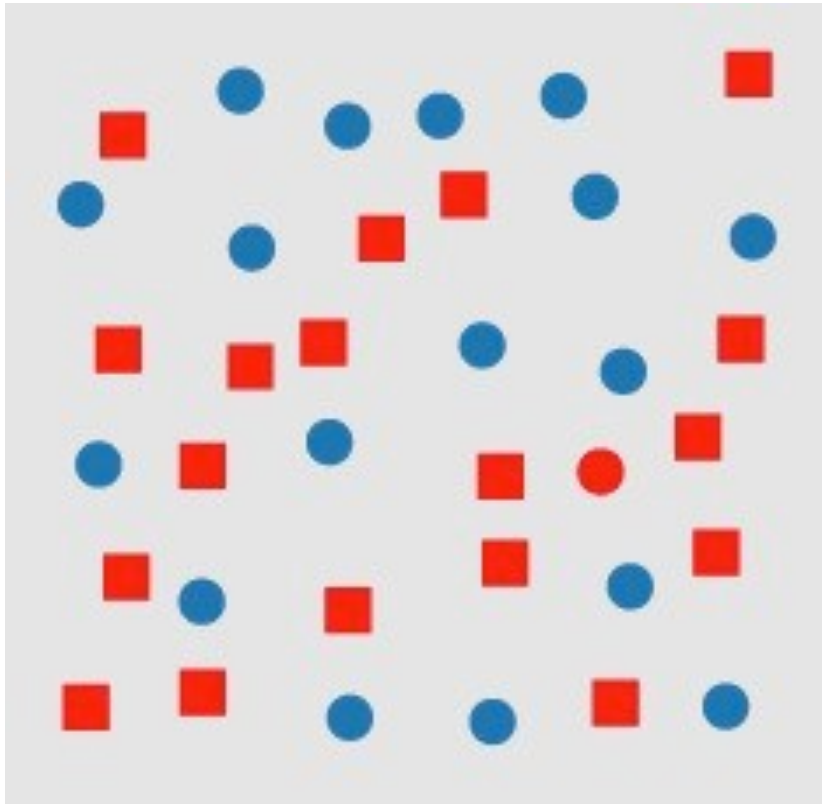




http://www.csc.ncsu.edu/faculty/healey/PP/index.html

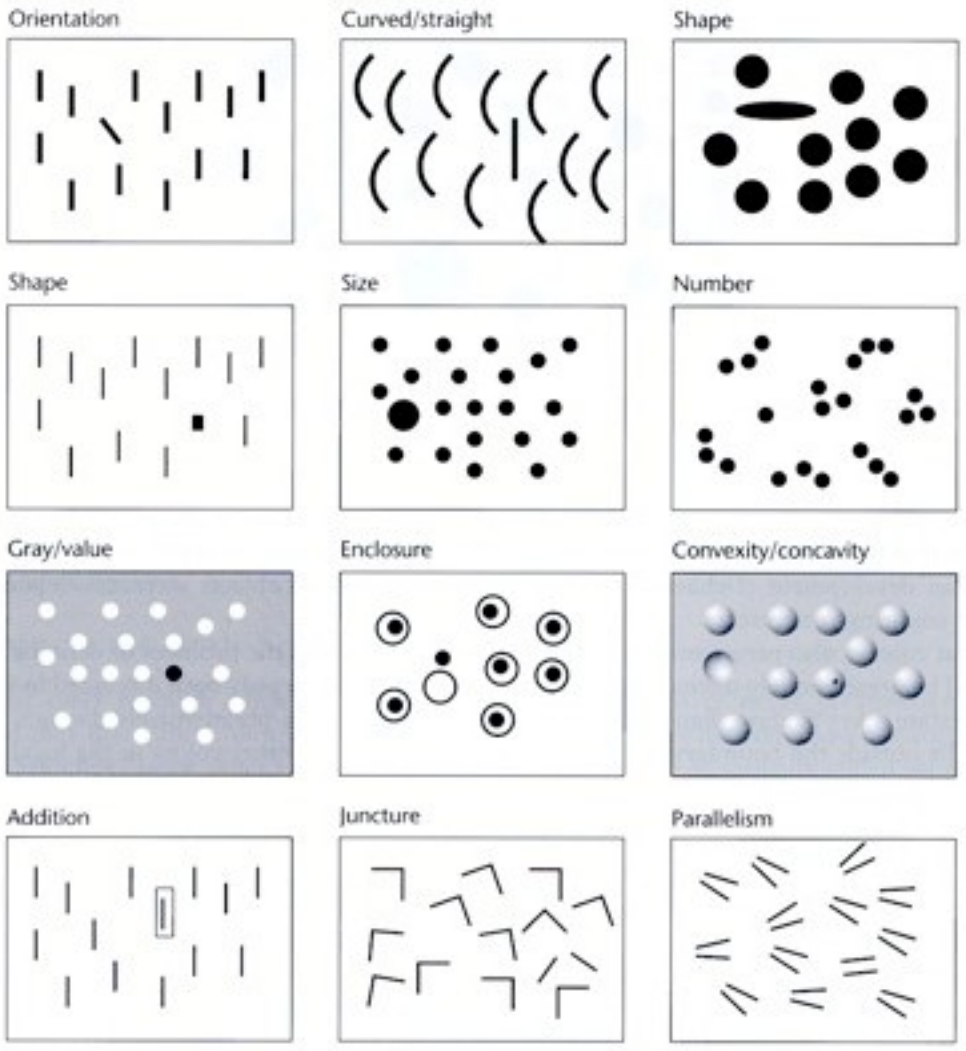
Feature Conjunctions





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

Pre-Attentive features



[Information Visualization. Figure 5. 5 Ware 04]

More Pre-attentive Features

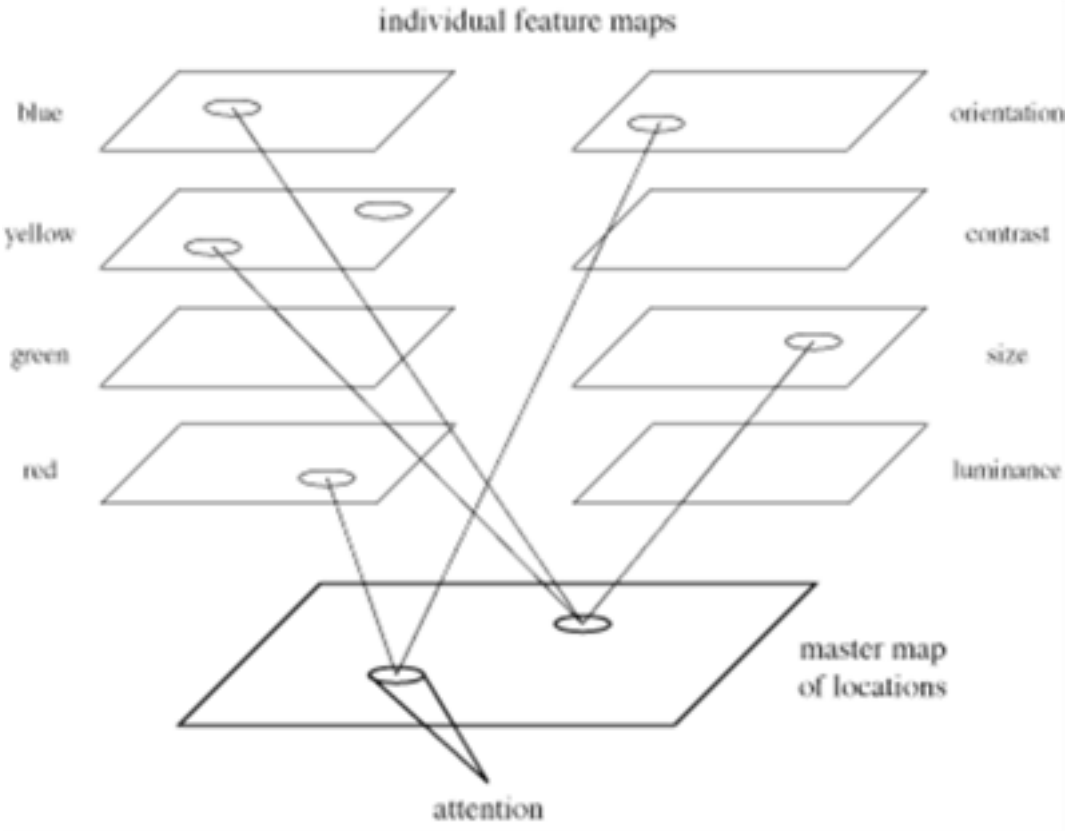
Line (blob) orientation	Julesz & Bergen [1983]; Wolfe et al. [1992]
Length	Triesman & Gormican [1988]
Width	Julesz [1985]
Size	Triesman & Gelade [1980]
Curvature	Triesman & Gormican [1988]
Number	Julesz [1985]; Trick & Pylyshyn [1994]
Terminators	Julesz & Bergen [1983]
Intersection	Julesz & Bergen [1983]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

Pre-attentive conjunctions

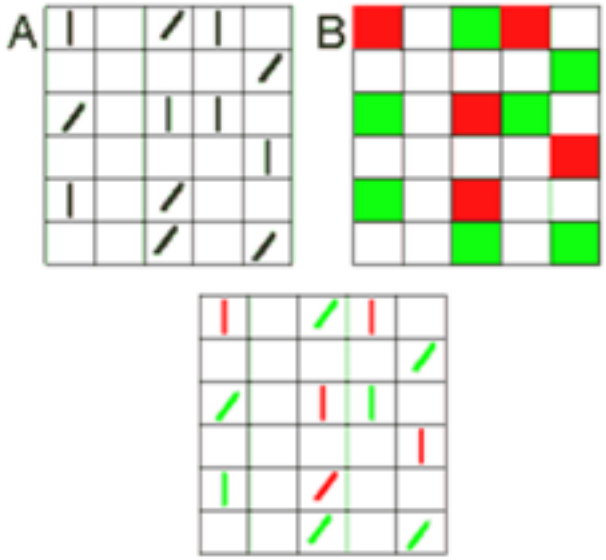
- Spatial conjunctions are often pre-attentive
  - Motion and 3D disparity
  - Motion and color
  - Motion and shape
  - 3D disparity and color
  - 3D disparity and shape

- Most conjunctions are not pre-attentive

Feature-integration theory



Treisman's feature integration model [Healey 04]



Feature maps for
orientation & color [Green]

Multiple Attributes

One-dimensional: Lightness

White

White

Black

White

Black

White

Black

Black

White

White

One-dimensional: Shape

Square

Circle

Circle

Square

Circle

Circle

Circle

Square

Circle

Circle

Correlated dims: Shape or lightness

Circle

Square

Square

Circle

Square

Circle

Square

Square

Square

Circle

Orthogonal dims: Shape & lightness

Circle

Square

Square

Circle

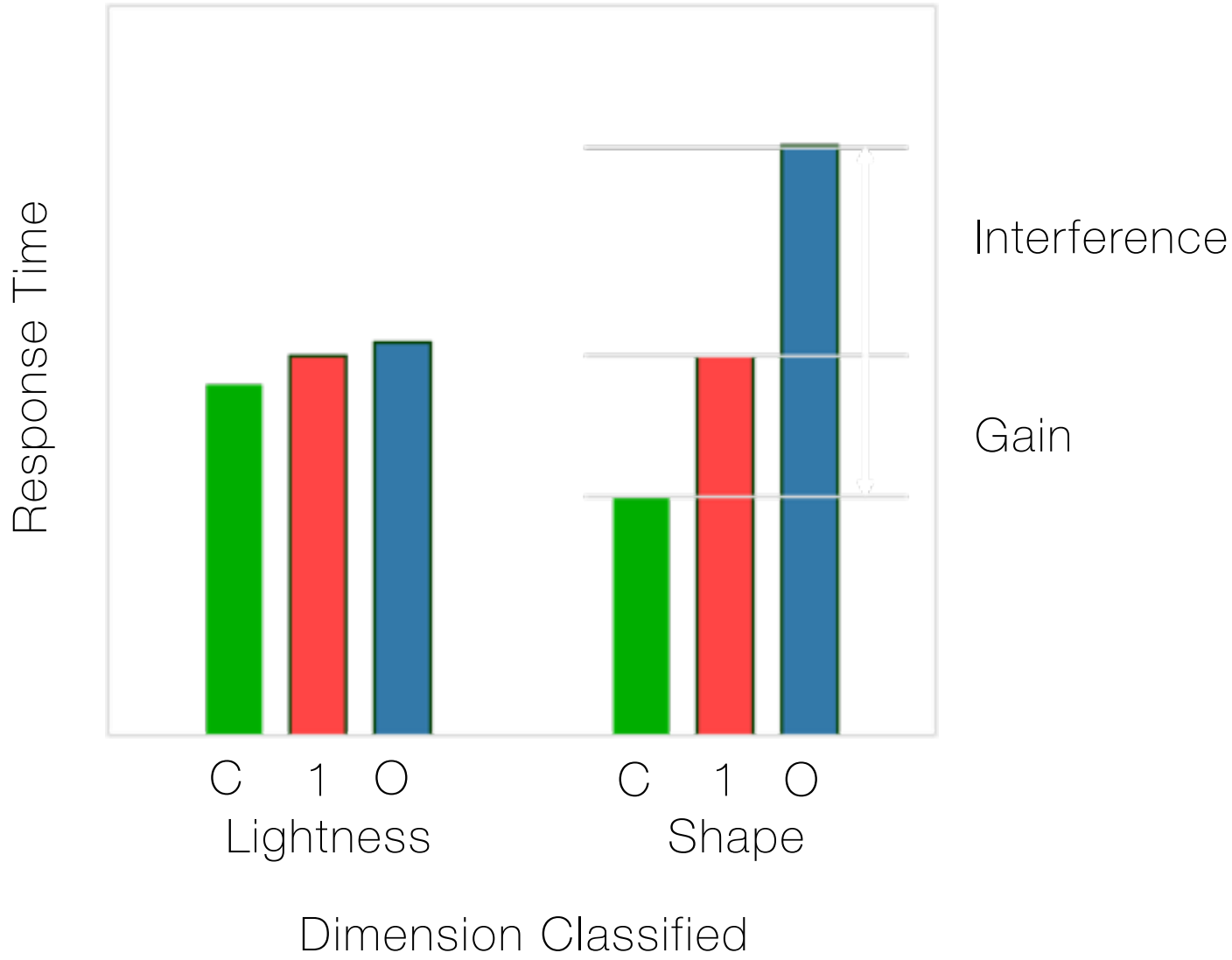
Square

Speeded Classification

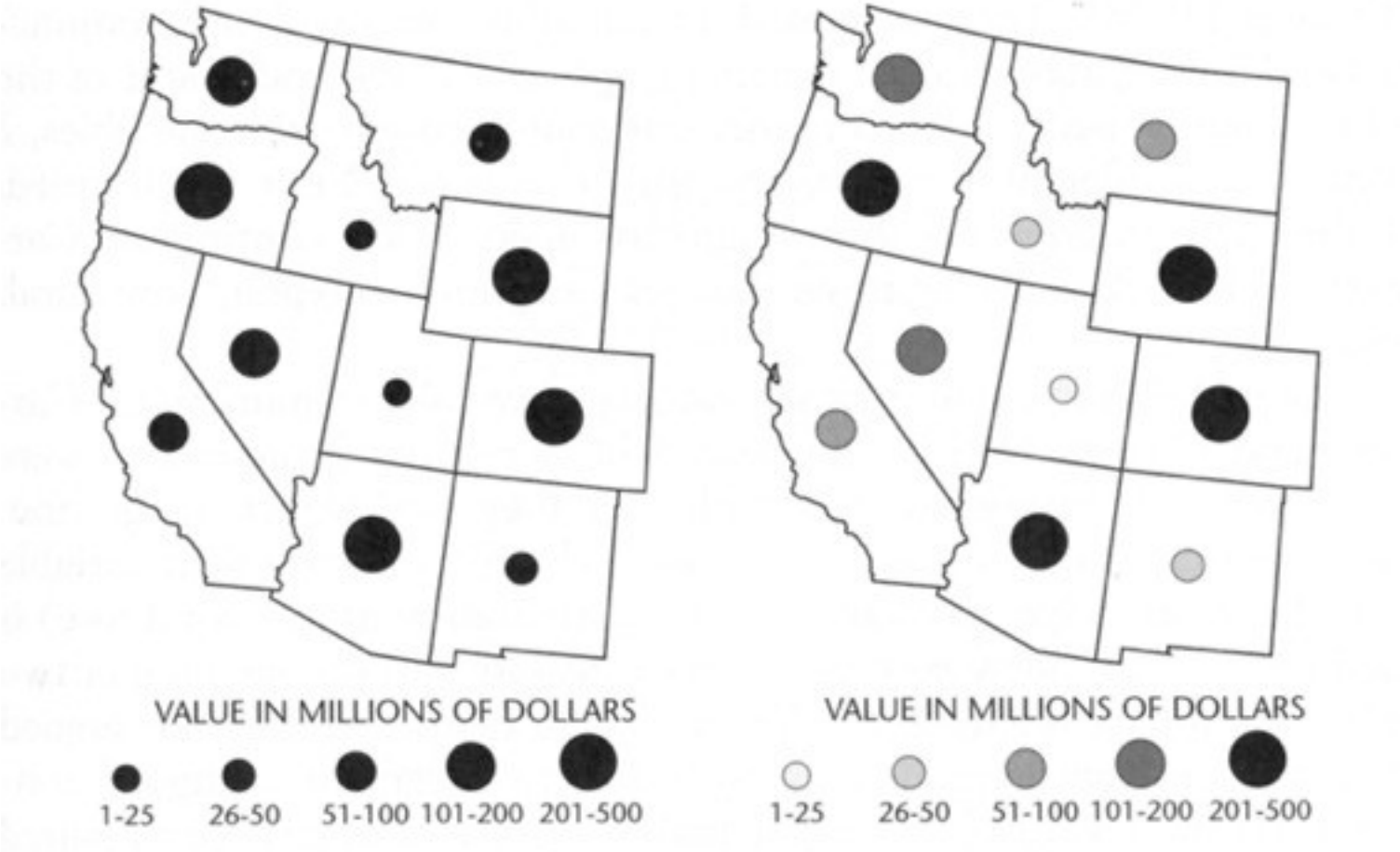
- Redundancy Gain
  - Facilitation in reading one dimension when the other provides redundant information

- Filtering Interference
  - Difficulty in ignoring one dimension while attending to the other

Speeded Classification



Size and Value



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

Orientation and Size (Single Mark)

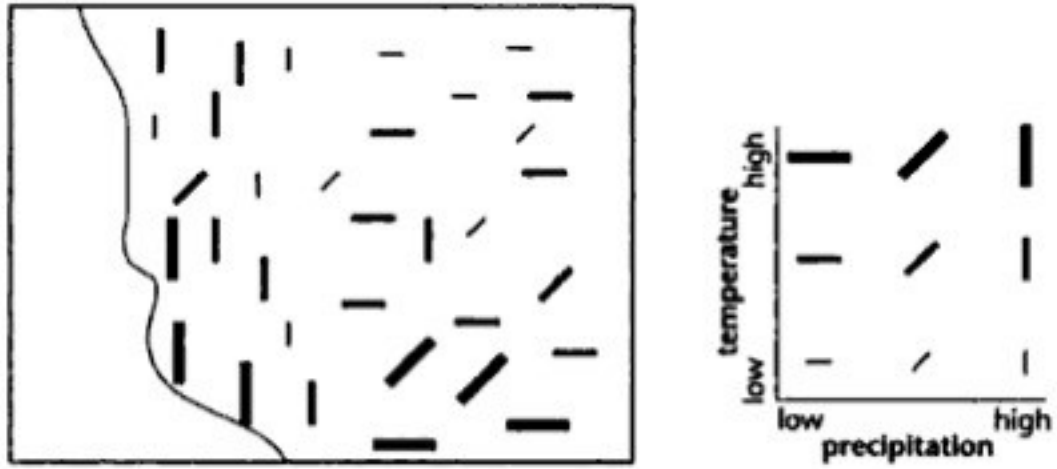


FIGURE 3.36. A map of temperature and precipitation using symbol size and orientation to represent data values on the two variables.

How well can you see temperature or precipitation?

Is there a correlation between the two?

[MacEachren 95]

Shape and Size (Single Mark)

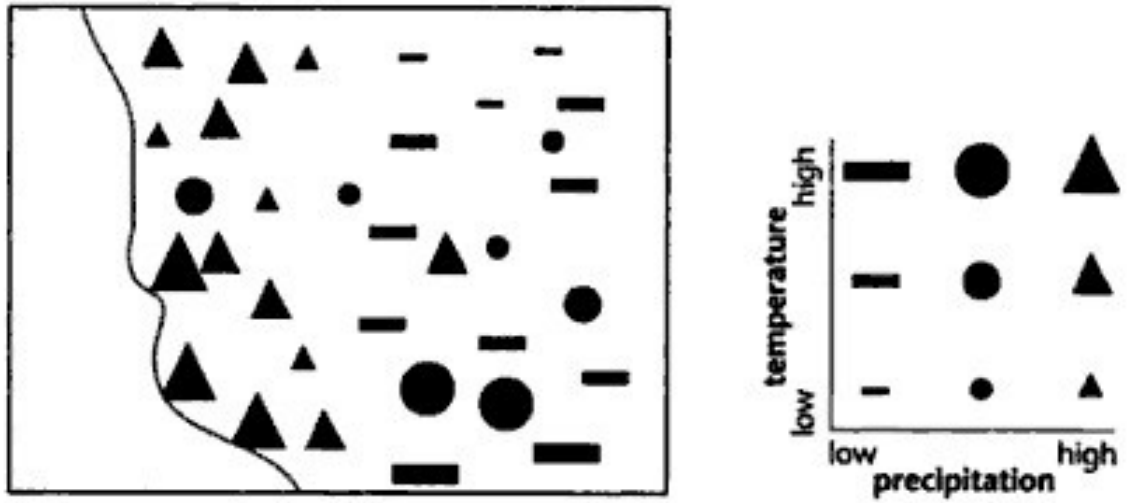


FIGURE 3.40. The bivariate temperature–precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

Easier to see one shape across multiple sizes than one size of across multiple shapes?

[MacEachren 95]

Length and Length (Single Mark)

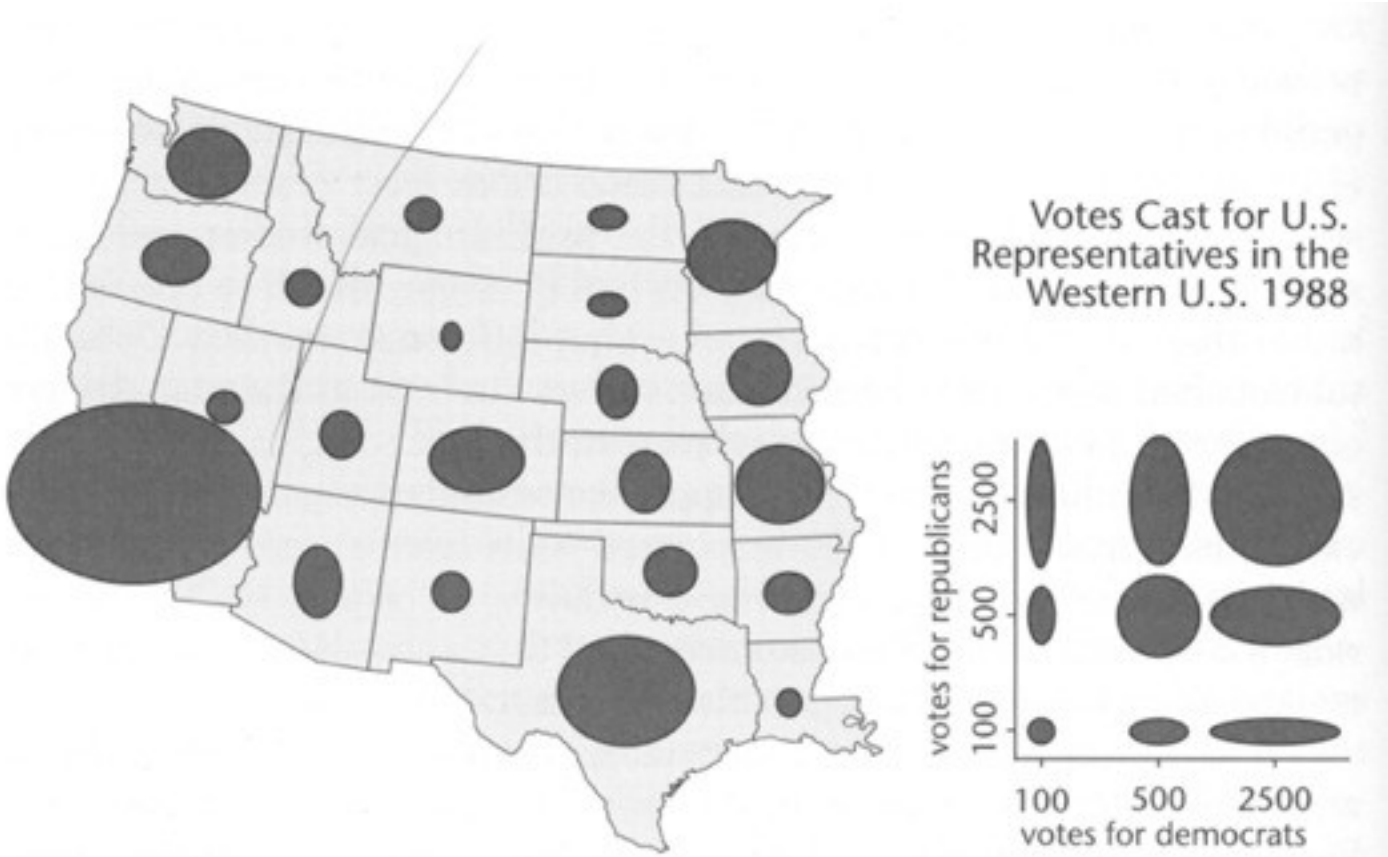


FIGURE 3.38. An example of the use of an ellipse as a map symbol in which the horizontal and vertical axes represent different (but presumably related) variables.

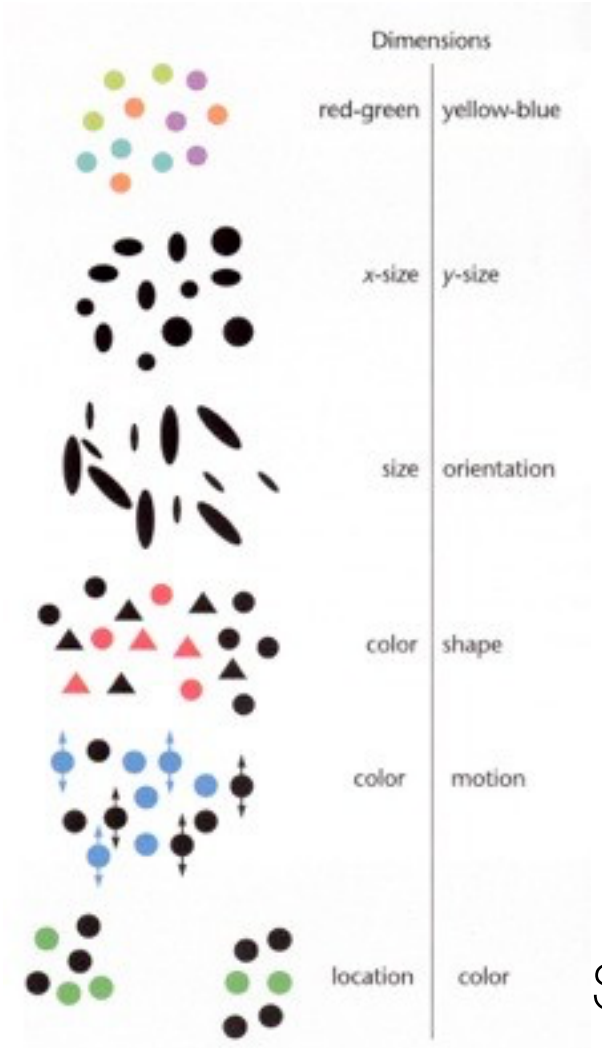
[MacEachren 95]

Angle and Angle (Composed Marks)

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]

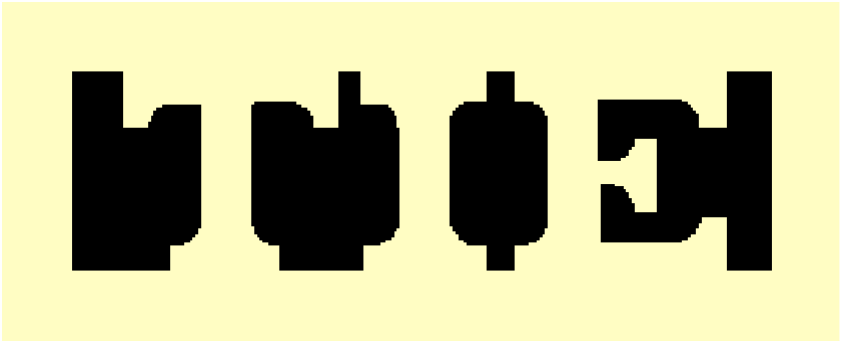
Gestalt Grouping

Principles

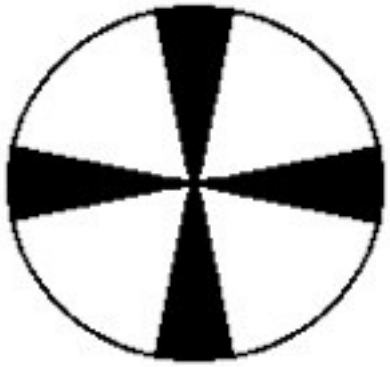
- Figure/Ground
- Proximity
- Similarity
- Symmetry
- Connectedness
- Continuity
- Closure
- Common Fate
- Transparency

Figure/Ground

Ambiguous



Principle of surroundedness

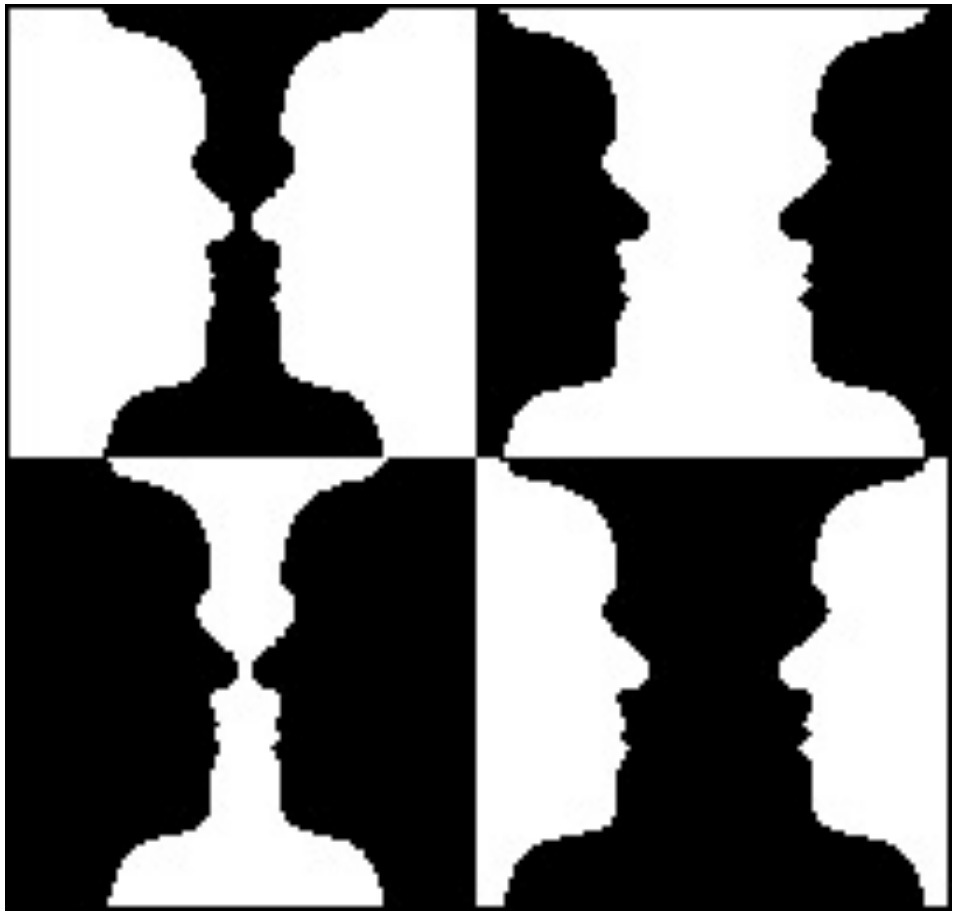


Principle of relative size

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

Figure/Ground

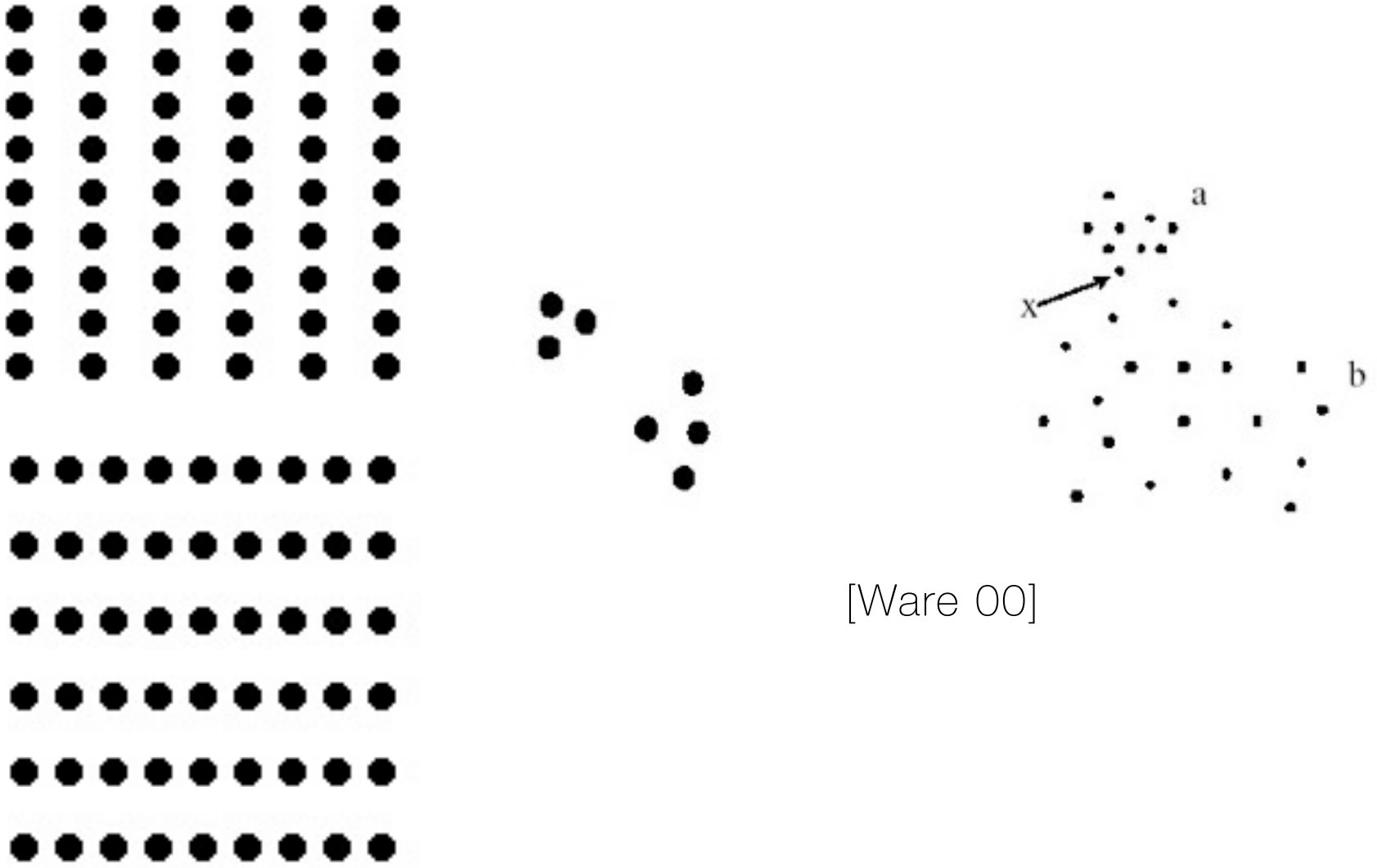
Ambiguous



Unambiguous (?)

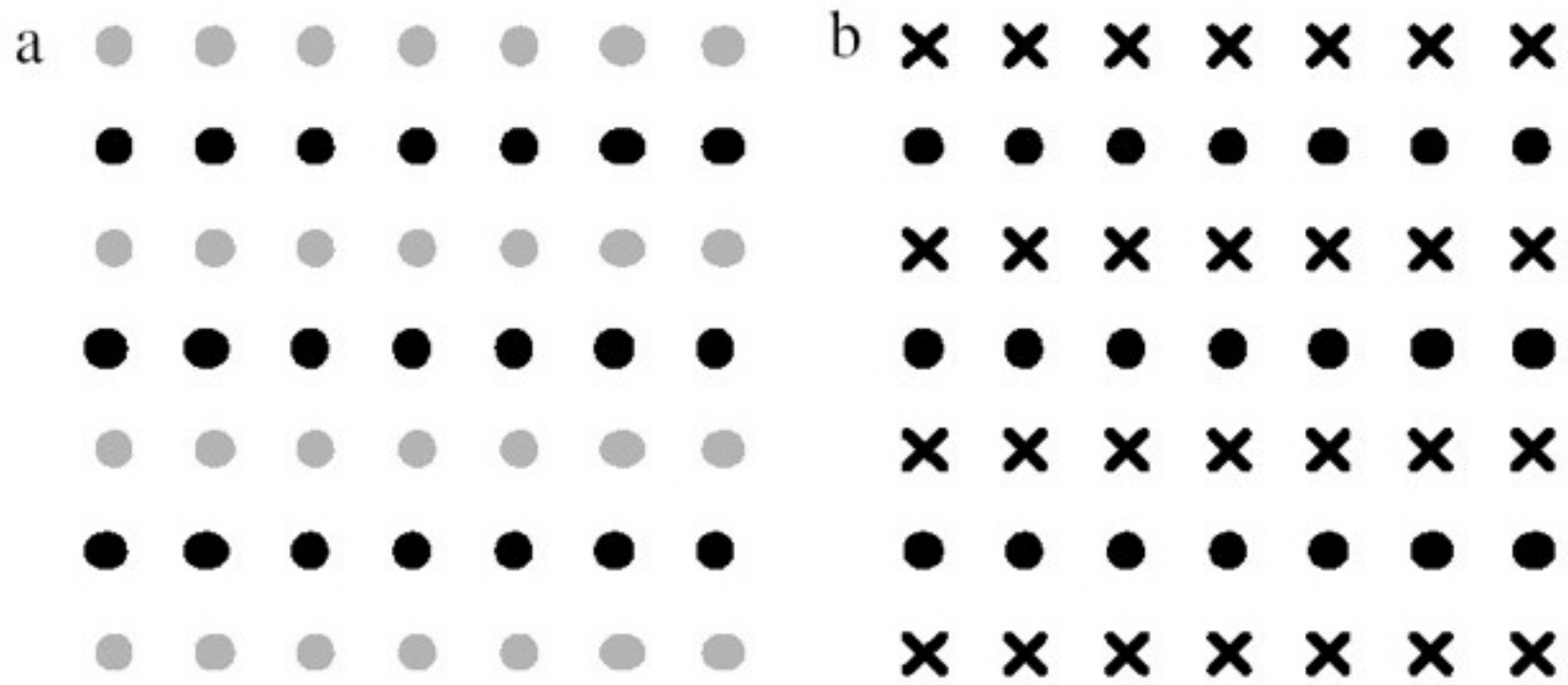
http://www.aber.ac.uk/media/Modules/MC10220/visper07.html

Proximity



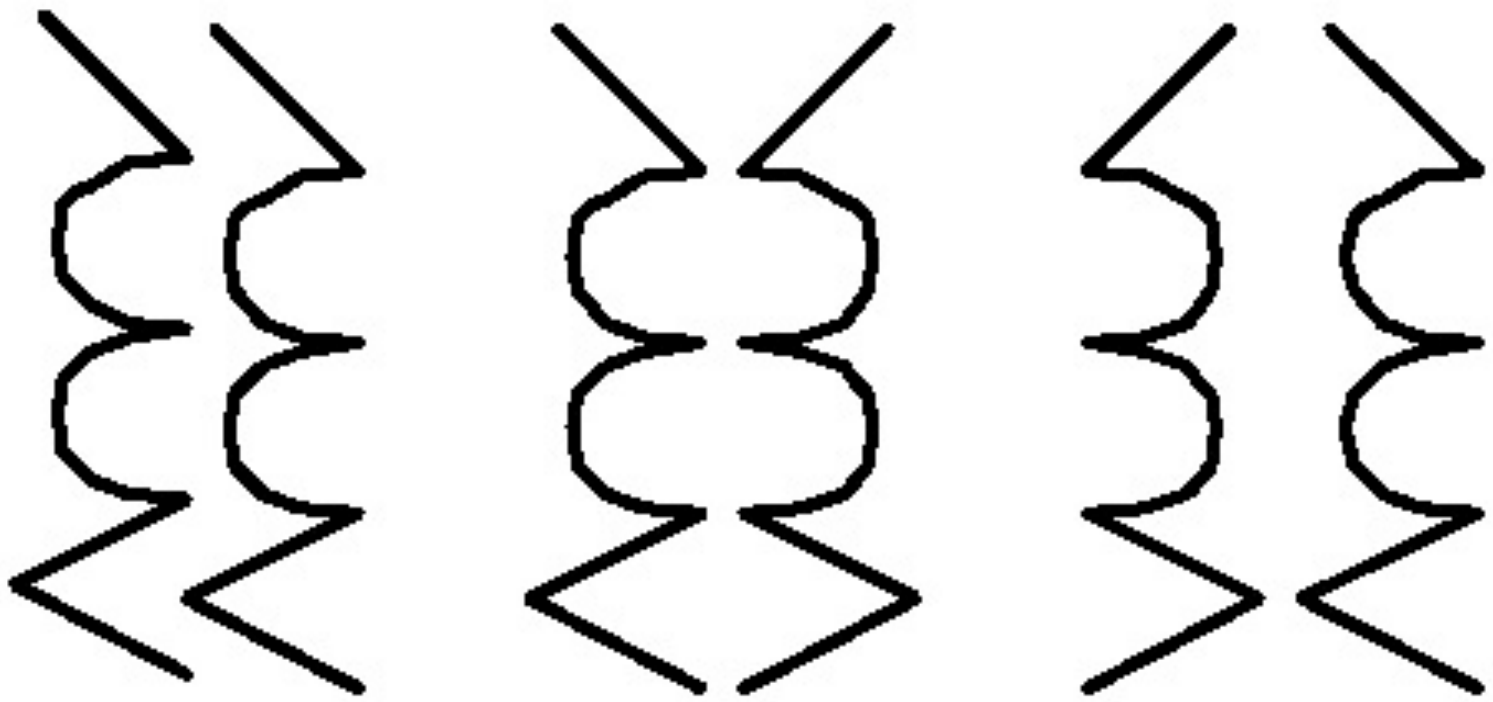
[Ware 00]

Similarity



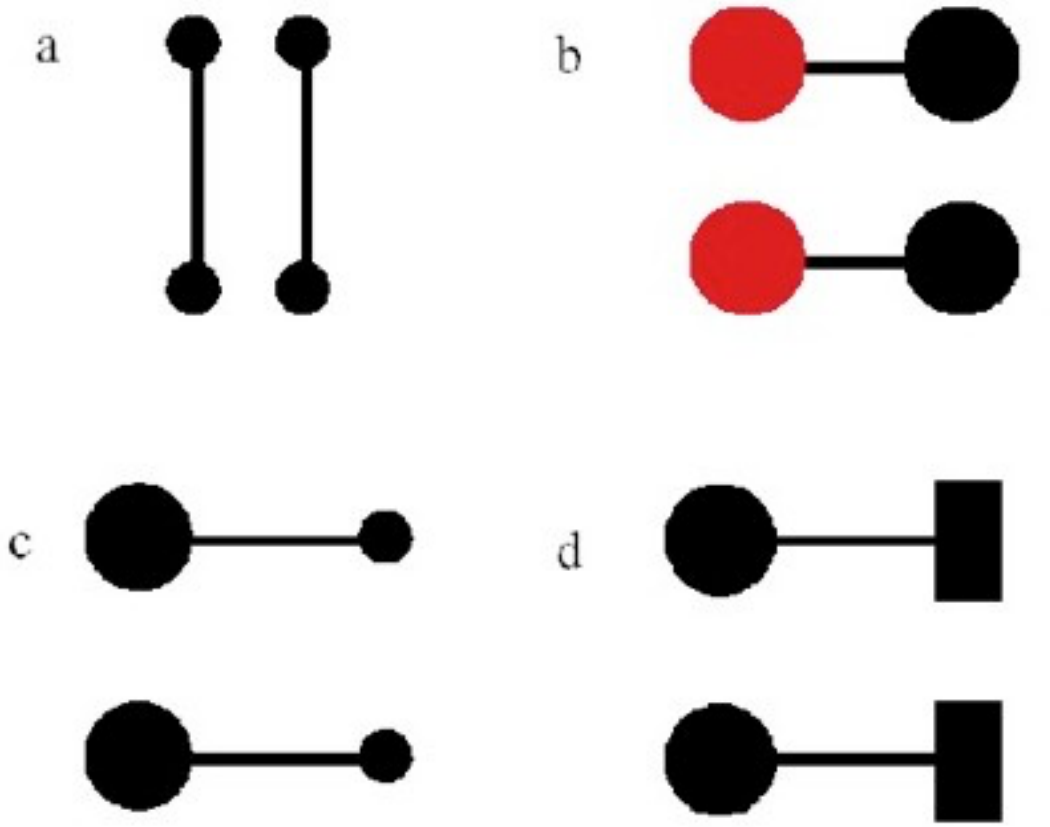
Rows dominate due to similarity [from Ware 04]

Symmetry



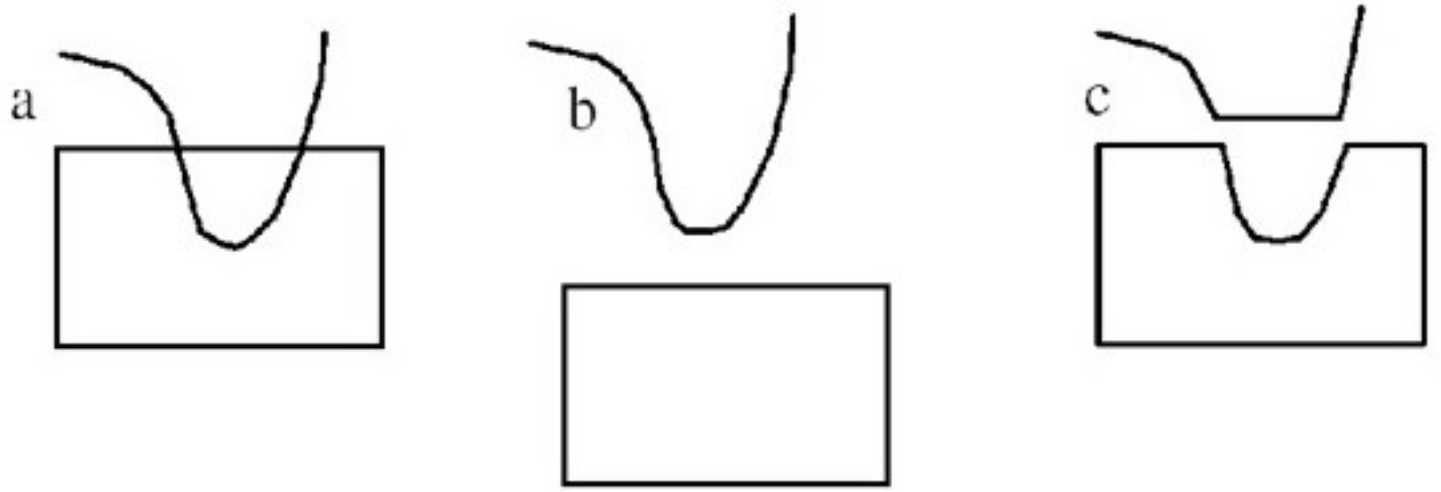
Bilateral symmetry gives strong sense of figure [from Ware 04]

Connectedness

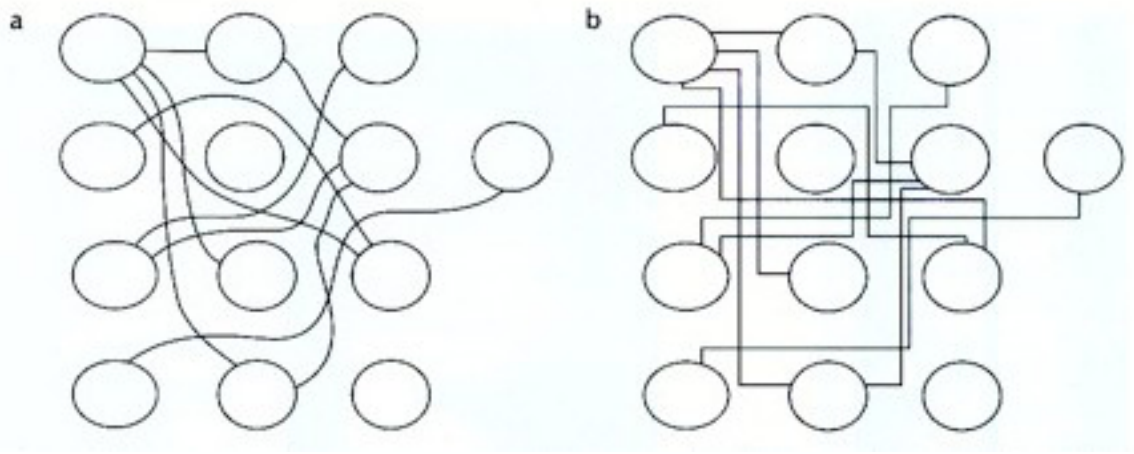


Connectedness overrules proximity, size, color shape [from Ware 04]

Continuity

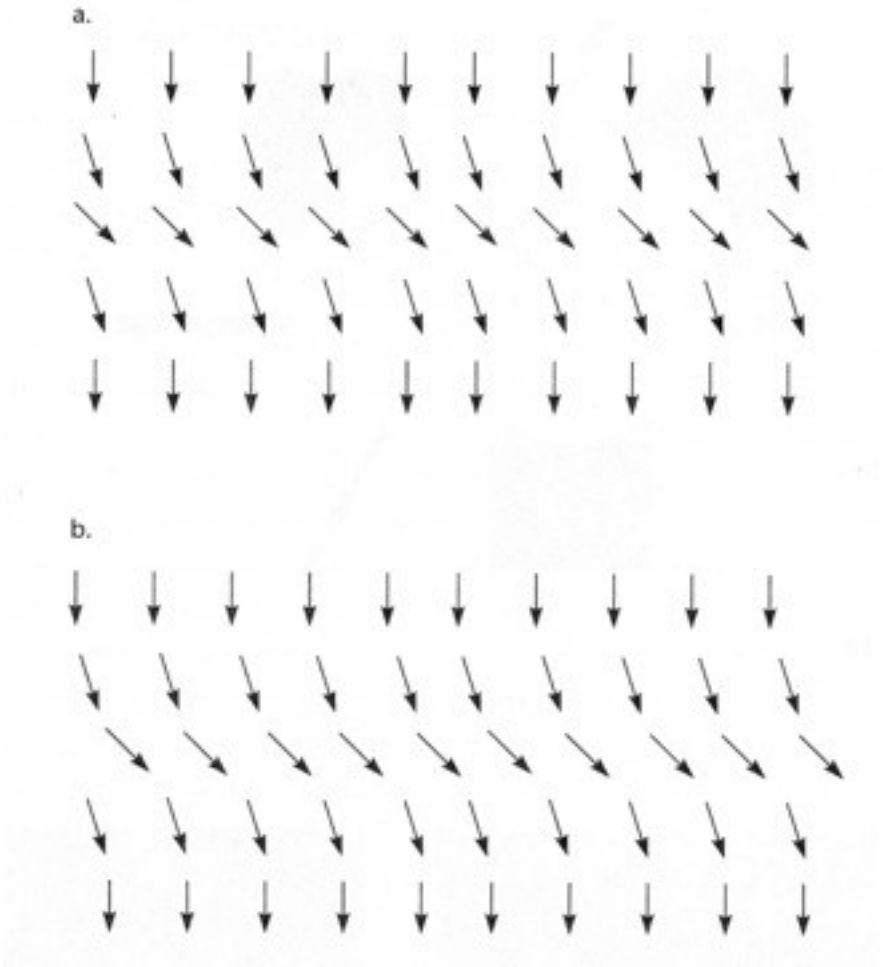


We prefer smooth not abrupt changes [from Ware 04]

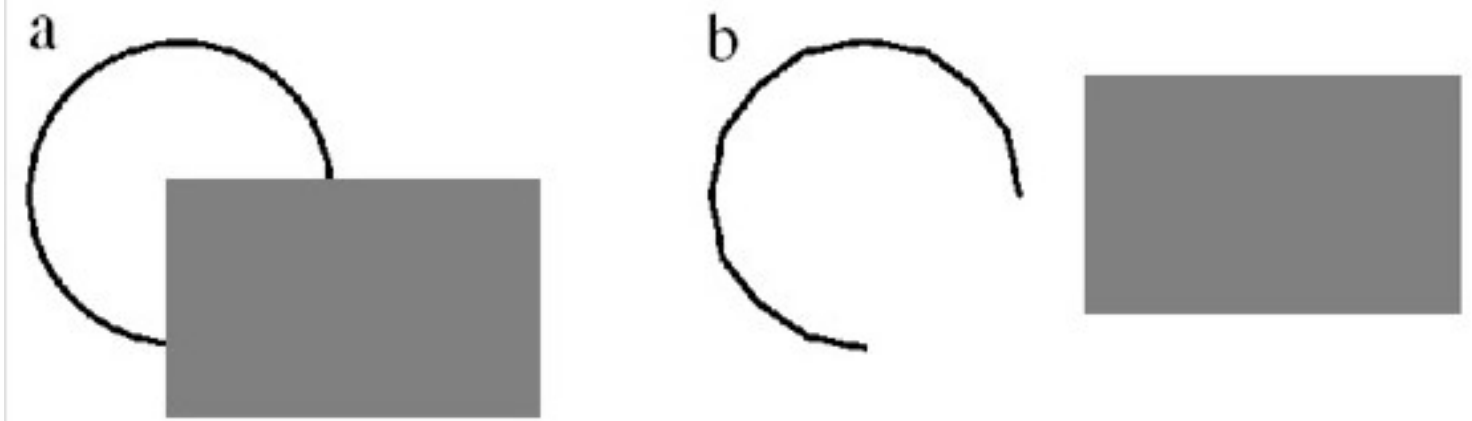


Connections are clearer with smooth contours [from Ware 04]

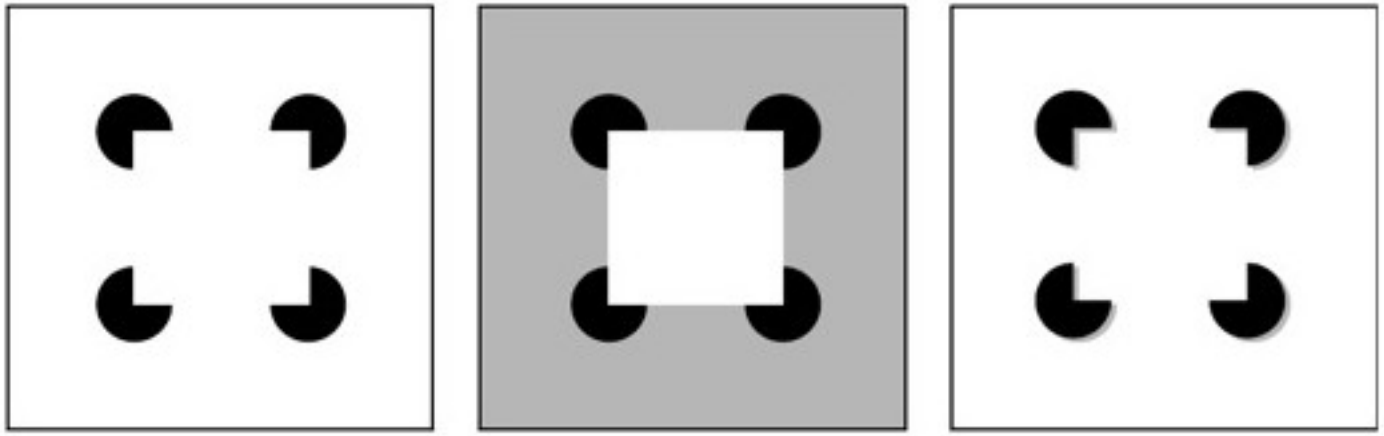
Continuity: Vector fields



Closure



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



Illusory contours [from Durand 02]

Common Fate

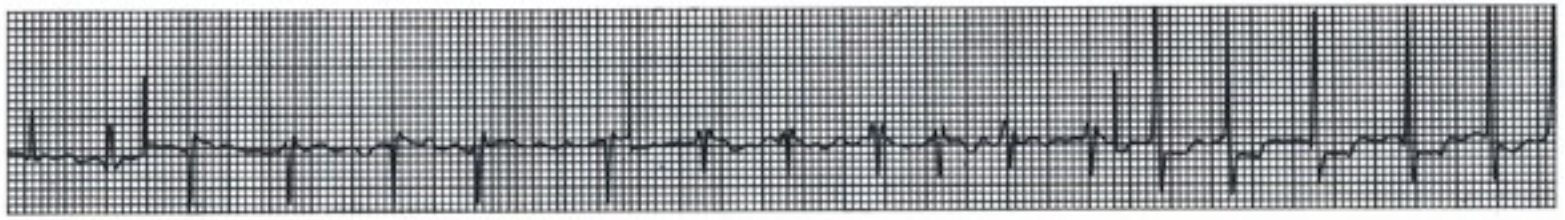
Dots moving together are grouped

Transparency

Requires continuity and proper color correspondence [from Ware 04]

Layering

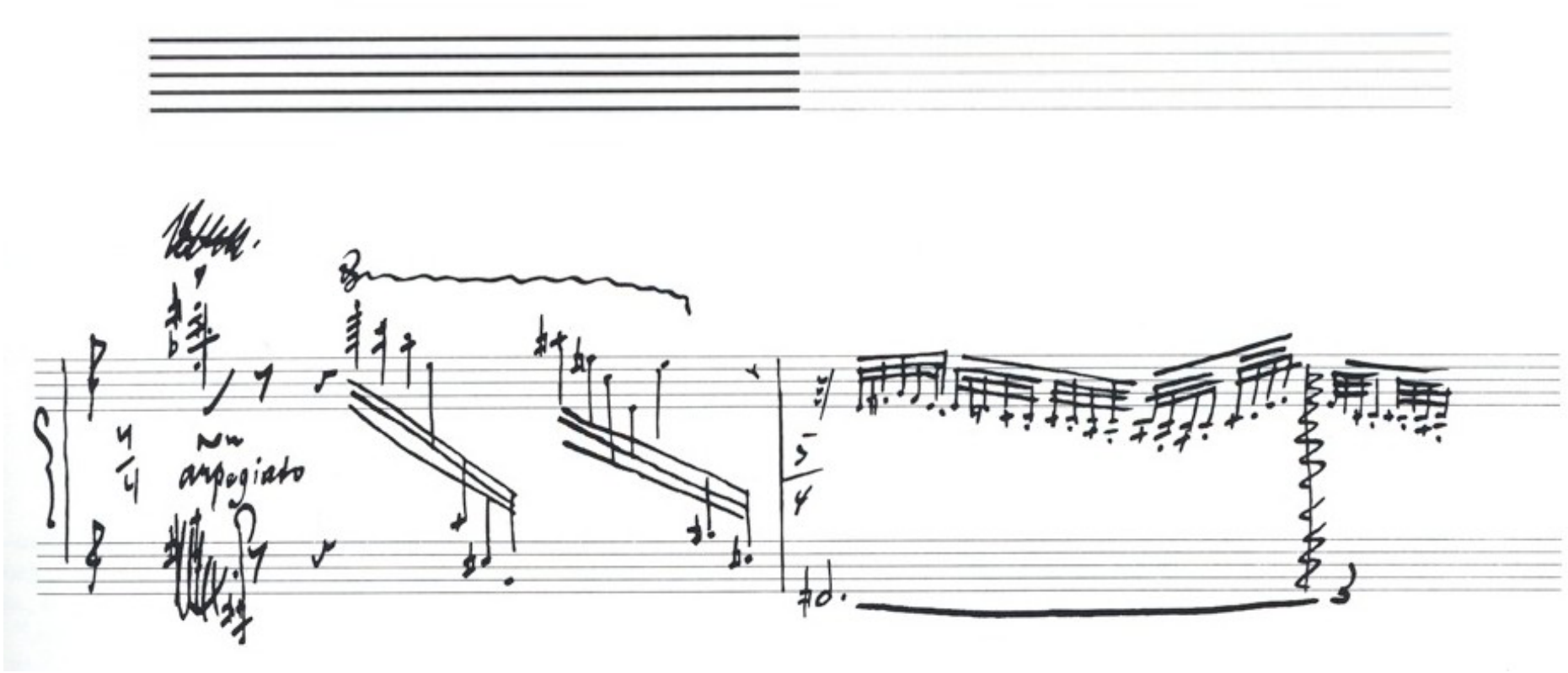
Layering: Gridlines



Signal and background compete above, as an electrocardiogram trace-line becomes caught up in a thick grid. Below, the screened-down grid stays behind traces from each of 12 monitoring leads:[4]

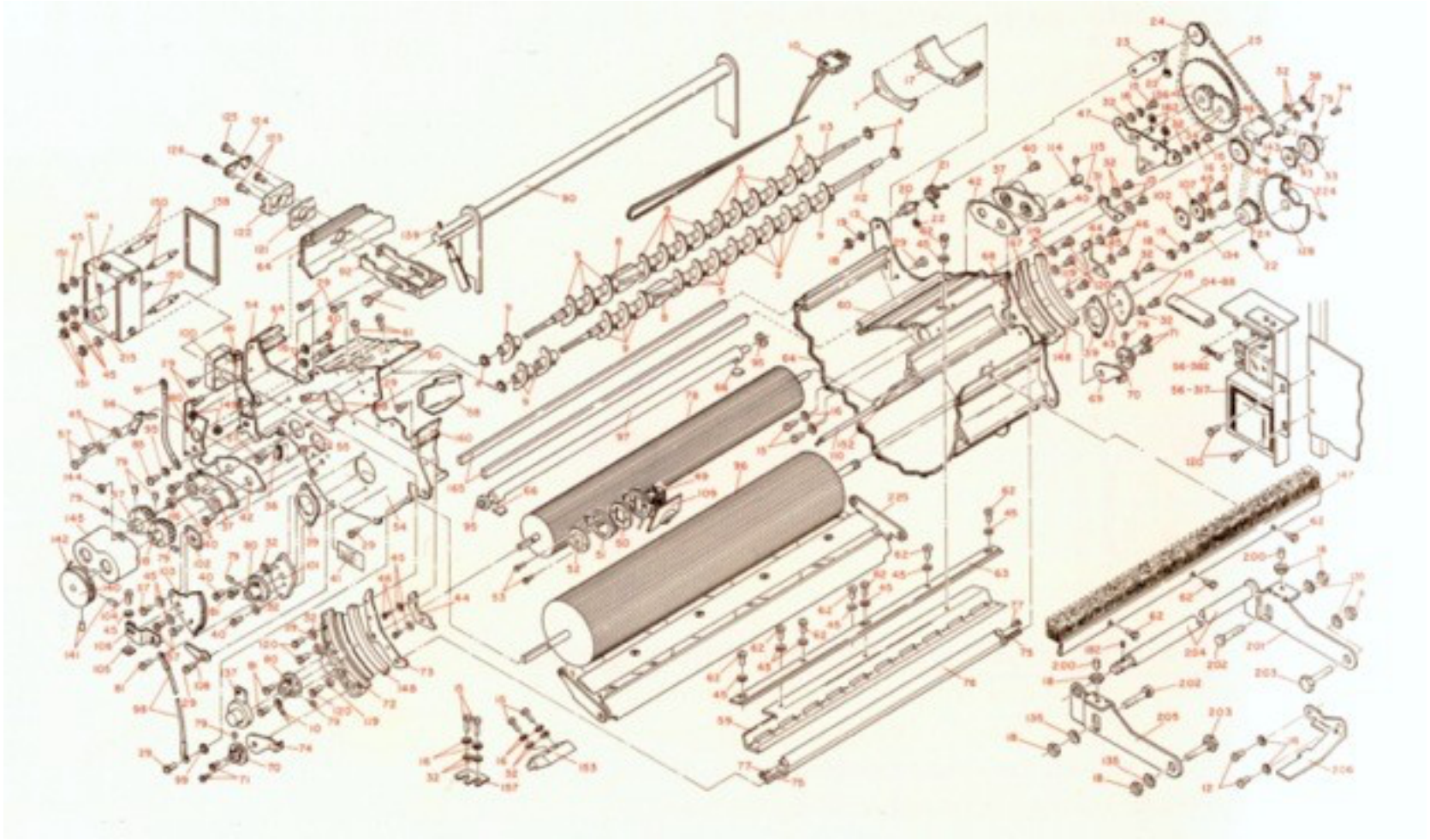
Electrocardiogram tracelines [from Tufte 90]

Layering: Gridlines



Stravinsky score [from Tufte 90]

Layering: color and line width



IBM Series III Copier [from Tufte 90]

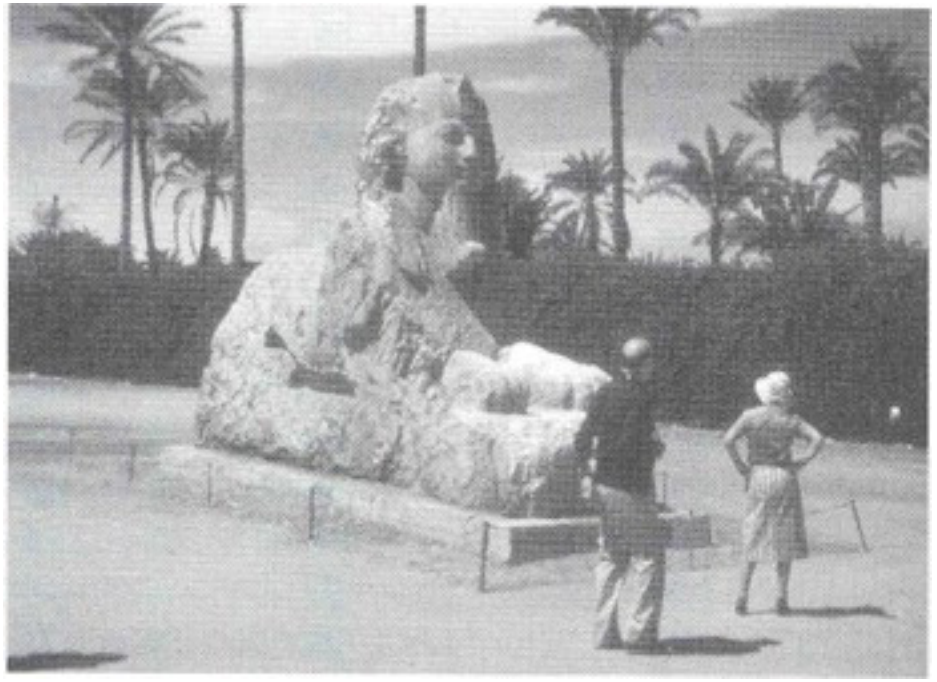
Change Blindness

Change detection

Change detection

Change detection

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, often integral
- Gestalt principles provide high-level guidelines
- We don’t always see everything that is there

Questions?

- Ask now or e-mail later
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