Perception

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CS 558: Visualization
Winter 2005

Lecture adapted from Hanrahan 2004

Topics

Just-noticeable differences
Estimating magnitude
Preattentive features and serial search
Discriminating multiple visual attributes
The principles of Gestalt
Layering and small multiples

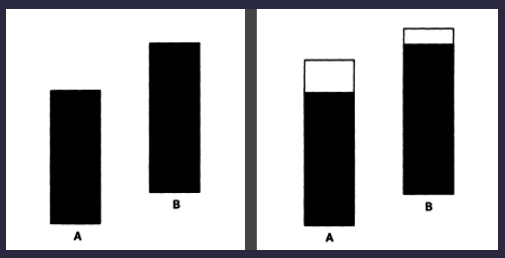
Detection

Just noticeable difference

JND (Weber's Law)

$$\Delta S = k\frac{\Delta I}{I}$$

Ratios more important than magnitude

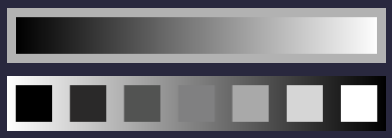


Frames directly show ratio, thereby increase accuracy [Cleveland 84]

Steps

Often continuous variations in values are perceived in discrete steps or levels

Steps in value



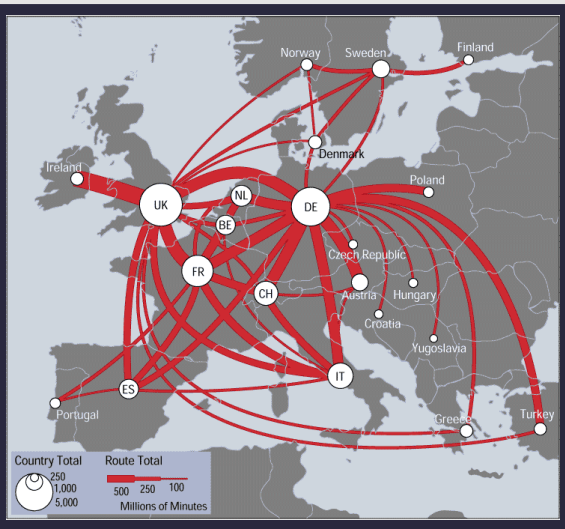
Steps in size and orientation

- Orientation columns roughly 30 deg
- Receptive fields increase by roughly a factor of 2

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

Steps in line width



http://mappa.mundi.net/maps/maps_014/telegeography.html

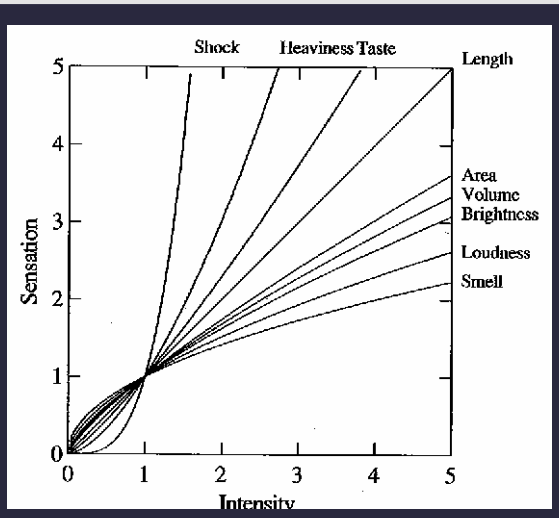
[based on slide from Munzner]

Estimating Magnitude

Steven's power law

$$S = I^p$$

p < 1 : underestimate
p > 1 : overestimate



[graph from Wilkinson 99, based on Stevens 61]

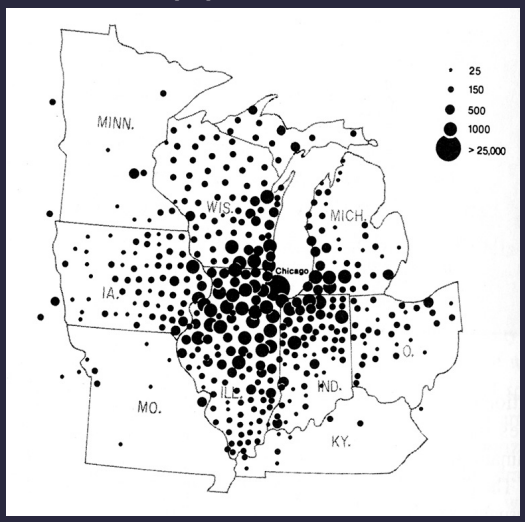
Exponents of power law

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]

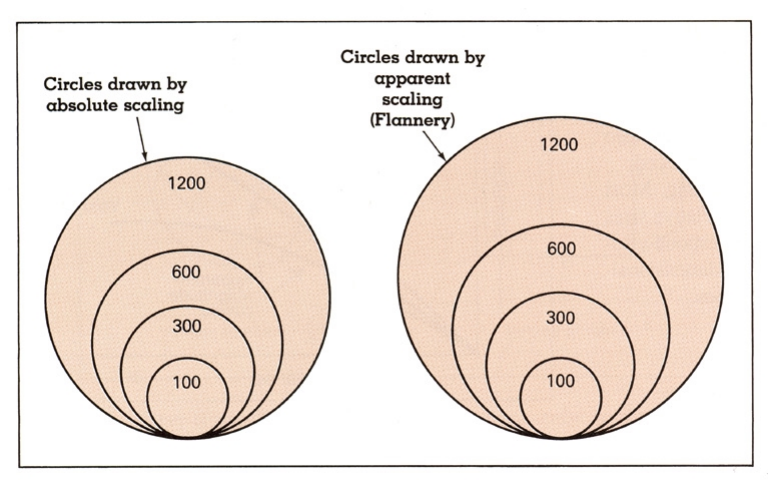
Proportional symbol map

Newspaper Circulation



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

Apparent magnitude scaling



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

Graduated sphere map

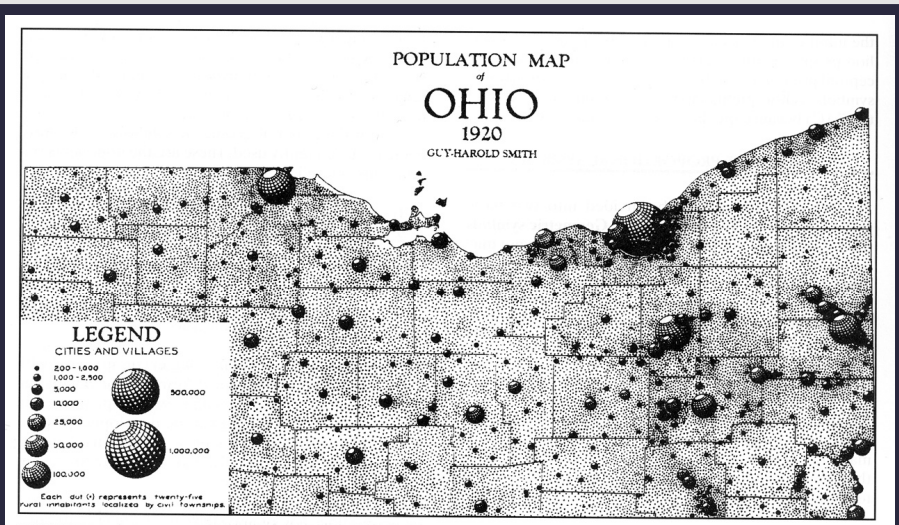


FIGURE 7.4. An eye-catching map created using three-dimensional geometric symbols. (After Smith, 1928. First published in *The Geographical Review,* 18(3), plate 4. Reprinted with permission of the American Geographical Society.)

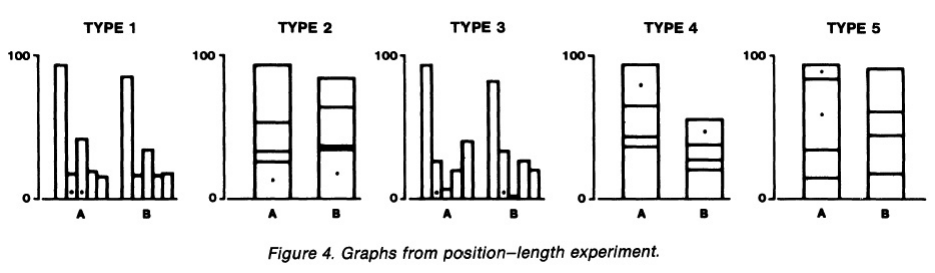


Figure 4. Graphs from position–length experiment.

[Cleveland and McGill 84]

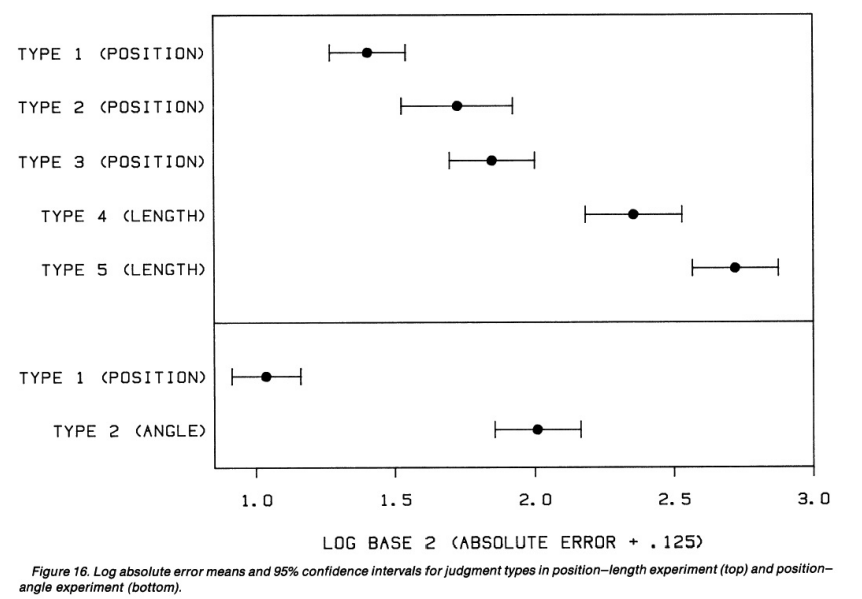


Figure 16. Log absolute error means and 95% confidence intervals for judgment types in position–length experiment (top) and position–angle experiment (bottom).

[Cleveland and McGill 84]

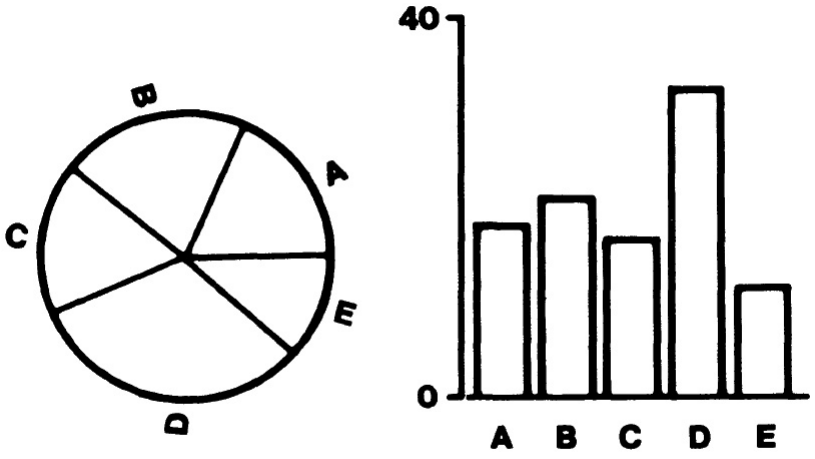


Figure 3. Graphs from position–angle experiment.

[Cleveland and McGill 84]

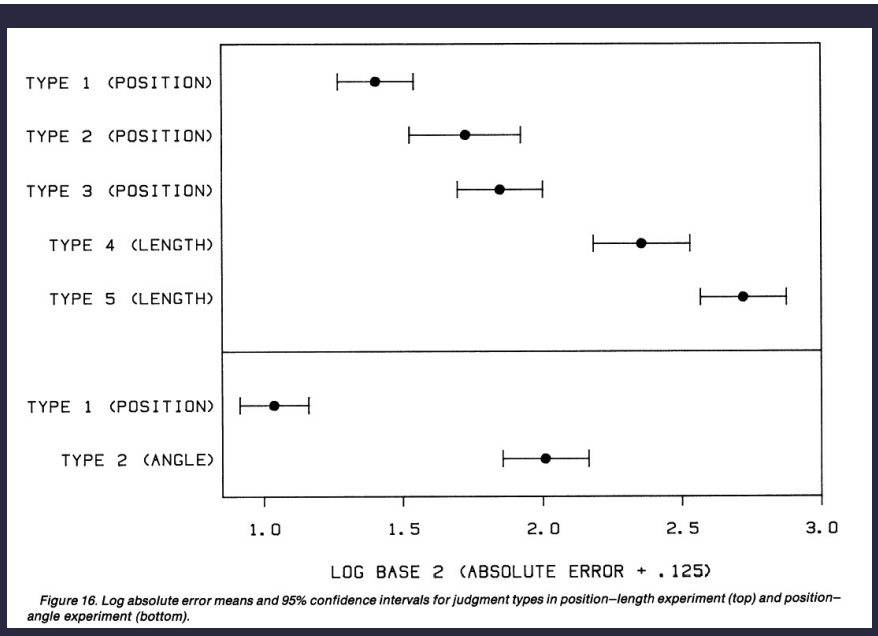


Figure 16. Log absolute error means and 95% confidence intervals for judgment types in position–length experiment (top) and position–angle experiment (bottom).

[Cleveland and McGill 84]

Relative magnitude estimation

Most accurate

Least accurate

Position (common) scale
Position (non-aligned) scale
Length
Slope
Angle
Area
Volume
Color hue-saturation-density

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

Conjectured *effectiveness* of visual encodings

Preattentive vs. Attentive

How many 3’s

12817687561389765469845069856049828267629809858458224509856458945098450980943585909103020990595959577256467505067890456788457898098216776548763649085609129496 86

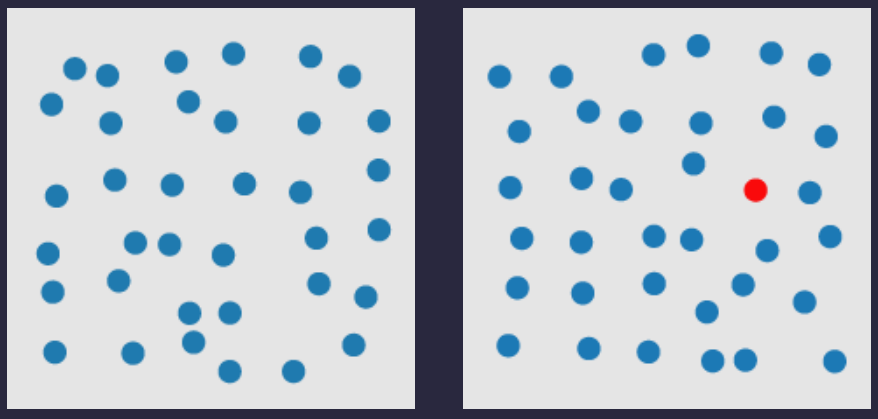
[based on slide from Stasko]

How many 3's

128176875613897654698450698560498282676 2
980985845822450985645894509845098094 3585
909103 0209905959595772564675050678904567
884578980982167765487636490856091294968 6

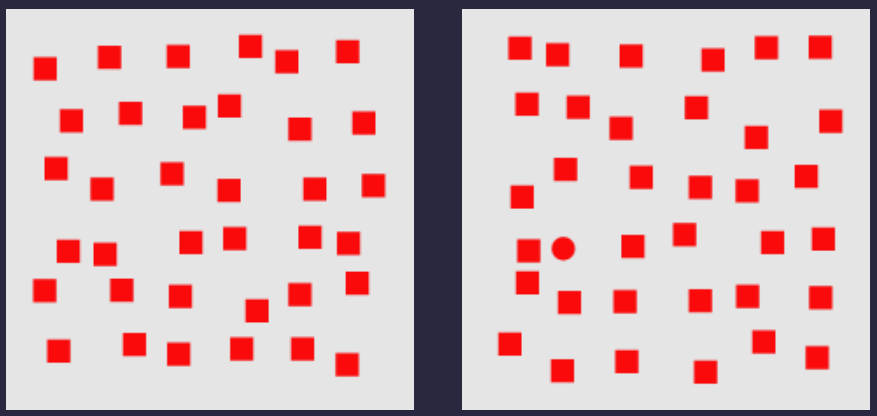
[based on slide from Stasko]

Visual pop-out: Color



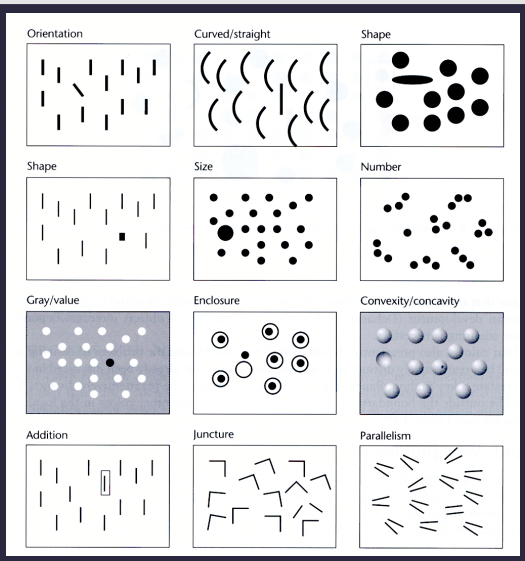
http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Visual pop-out: Form



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

Preattentive features



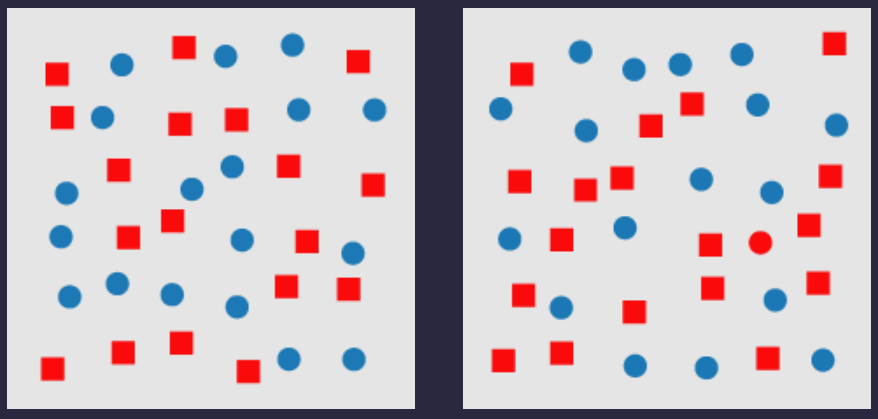
[Information Visualization. Figure 5. 5 Ware 04]

More preattentive 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	Enns [1986]; Triesman & Souther [1985]
Colour (hue)	Nagy & Sanchez [1990, 1992]; D'Zmura [1991]; 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 lustre	Wolfe & Franzel [1988]
Stereoscopic depth	Nakayama & Silverman [1986]
3-D depth cues	Enns [1990]
Lighting direction	Enns [1990]

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

Feature conjunctions



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

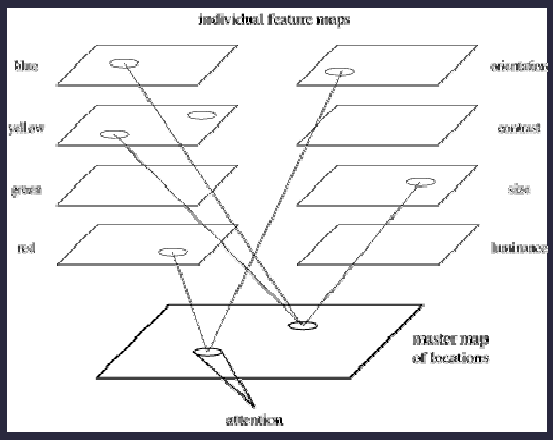
Preattentive conjunctions

Spatial conjunctions are often preattentive

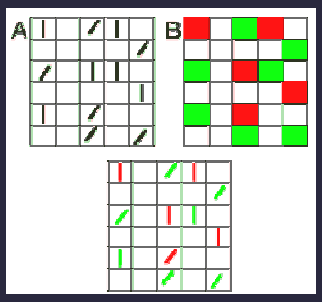
- Motion and disparity
- Motion and color
- Motion and shape
- Disparity and color
- Disparity and shape

Most conjunctions are not preattentive

Feature-integration theory



Treisman's feature integration model [Healey04]



Feature maps for orientation & color [Green]

Visual pathways

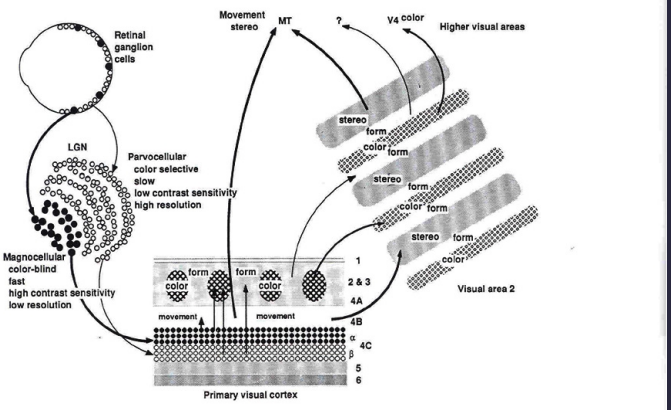
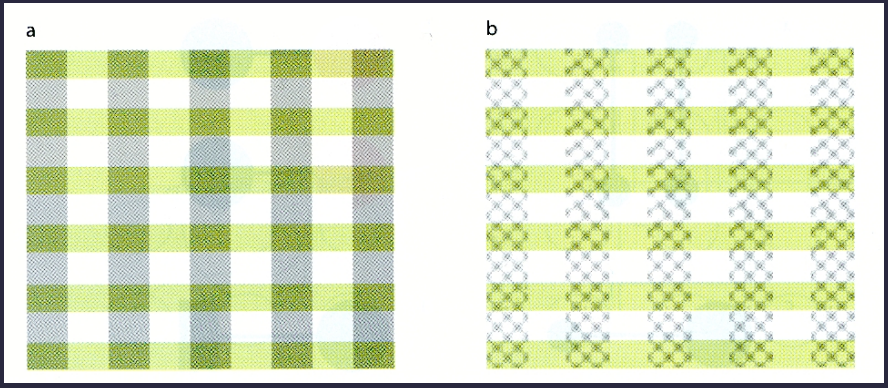


Figure 4.4.1 A theory of separate functional pathways in the primate visual system. Livingstone and Hubel suggested that form, color, motion, and stereo information become increasingly differentiated from retina to extrastriate visual cortex. (LGN = lateral geniculate nucleus; MT = medial temporal lobe; V4 = visual area 4.) (From Livingstone & Hubel, 1988.)

Neuroscientists have found evidence of multiple visual pathways into the brain. They suggest these channels could separately encode color, motion, orientation, size and stereoscopic depth. [from Livingstone and Hubel 88]

Multiple Attributes

Attending to multiple attributes

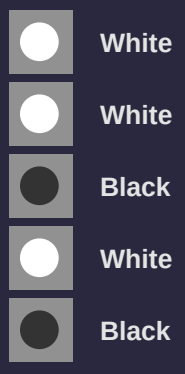


Color & Gray Color & Texture

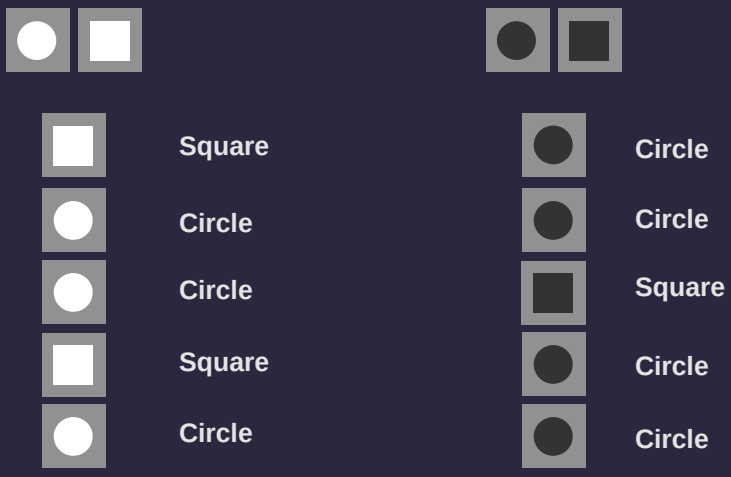
Attending only to rows or columns is more difficult in left image than in right image.

[Information Visualization. Figure 6.5 Ware 04]

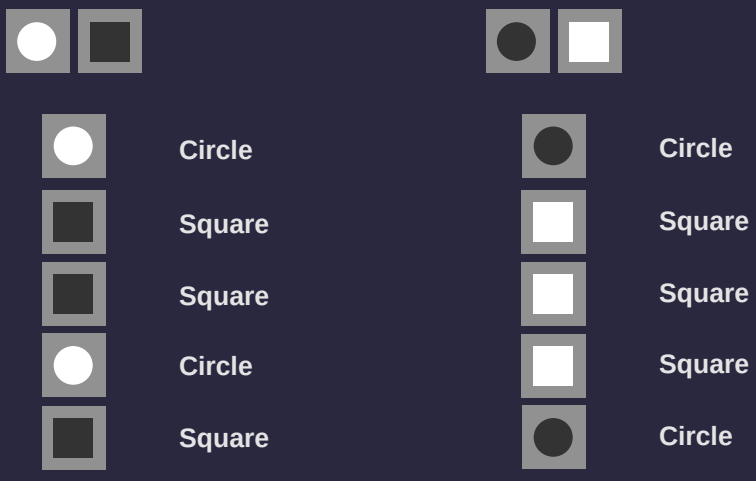
One-dimensional: Lightness



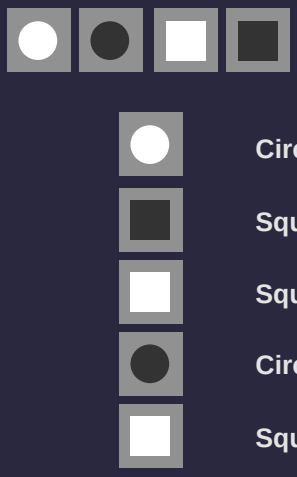
One-dimensional: Shape



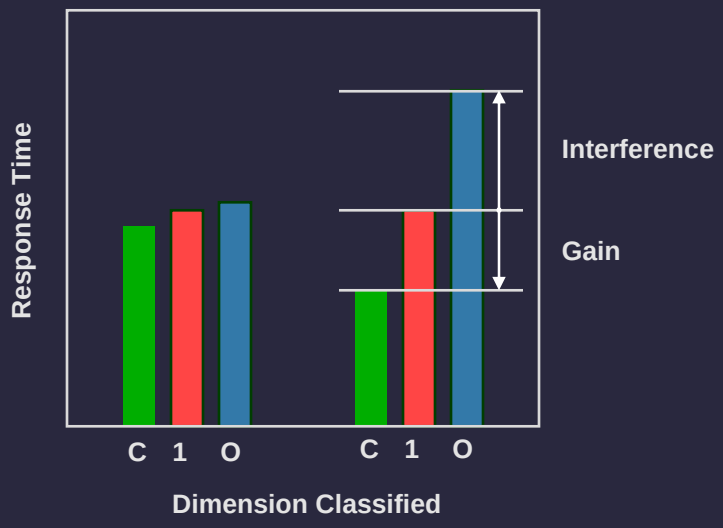
Correlated dims: Shape or lightness



Orthogonal dims: Shape & lightness



Speeded classification



Speeded classification

Filtering interference

- Difficulty in ignoring one dimension while attending to the other

Redundancy gain

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

Types of dimensions

Integral

- Filtering interference and redundancy gain

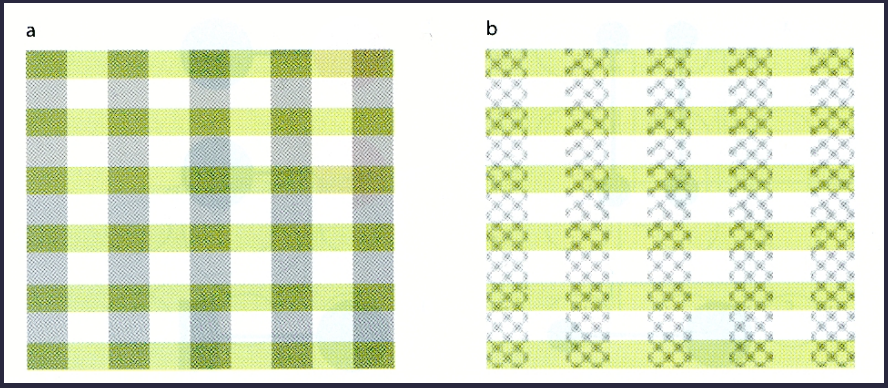
Separable

- No interference or gain

Configural

- Only interference, but no redundancy gain

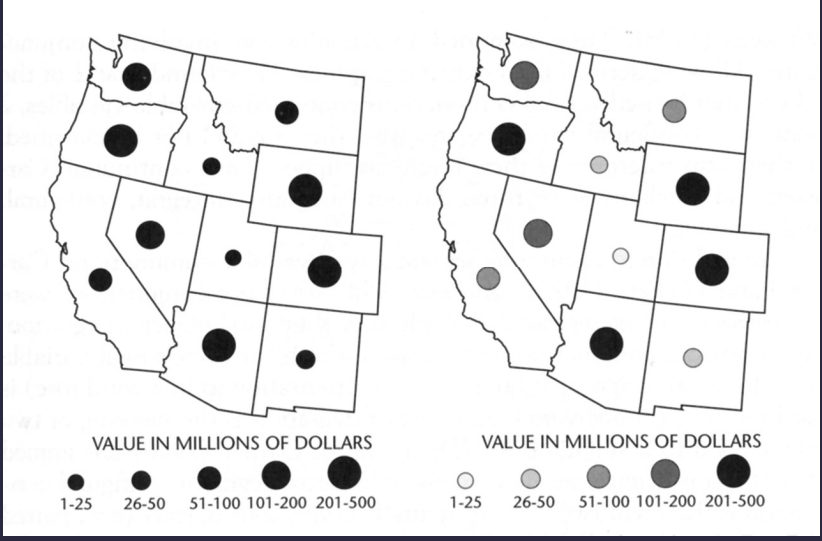
Integral vs. separable



Integral: Color & Gray **Separable: Color & Texture**

[Information Visualization. Figure 6.5 Ware 04]

Correlated dims: Size and value



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

Orthogonal dims: Aspect ratio

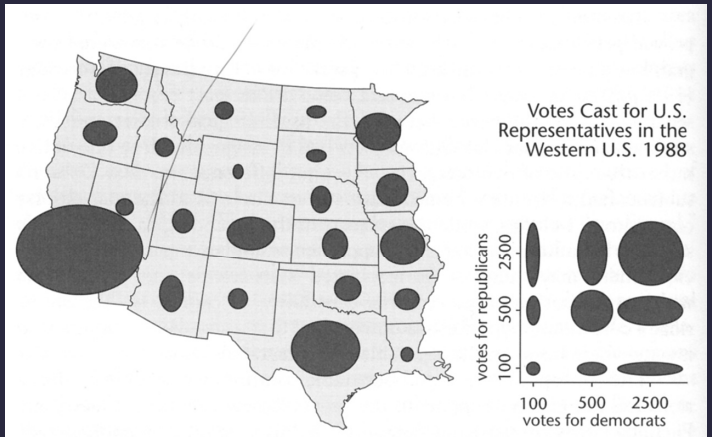
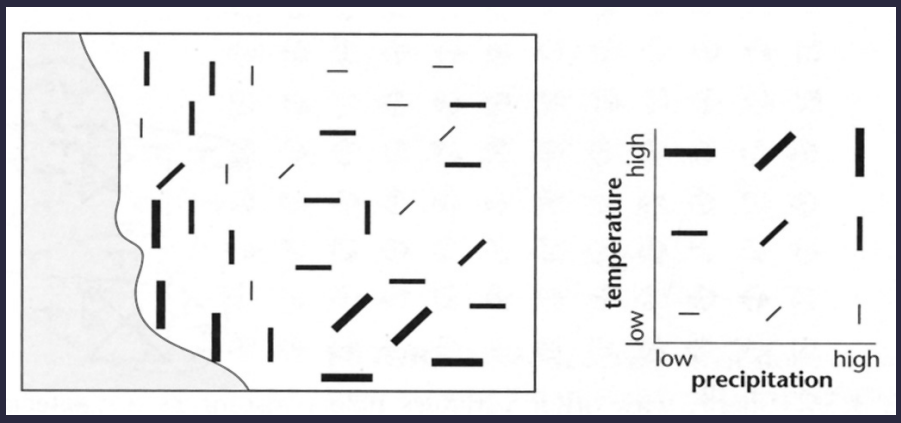


FIGURE 3.38. An example of the use of an ellipse as a map symbol in which the horizontal and vertical axes represent different (but presumably related) variables.

[MacEachren 95]

Orthogonal dims: Size and angle

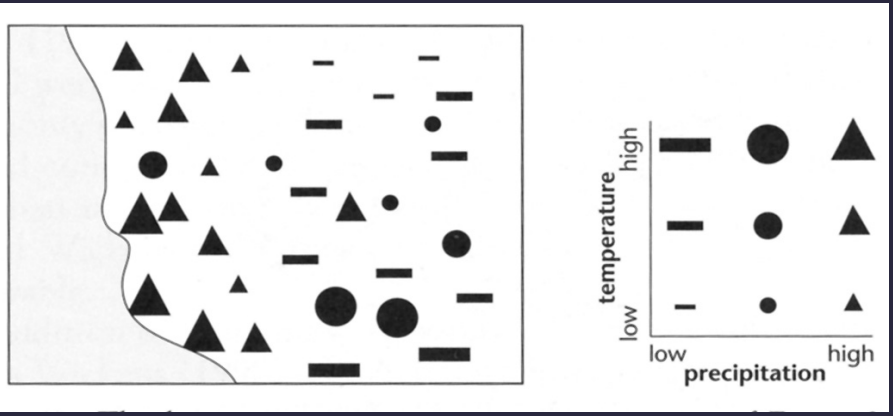
Temperature and precipitation



[Figure 3.36, p. 86 MacEachren 95]

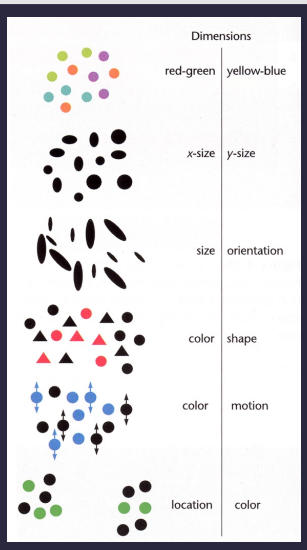
Orthogonal dims: Size and shape

Temperature and precipitation



[Figure 3.40, p. 92 MacEachren 95]

Summary of Integral-Separable

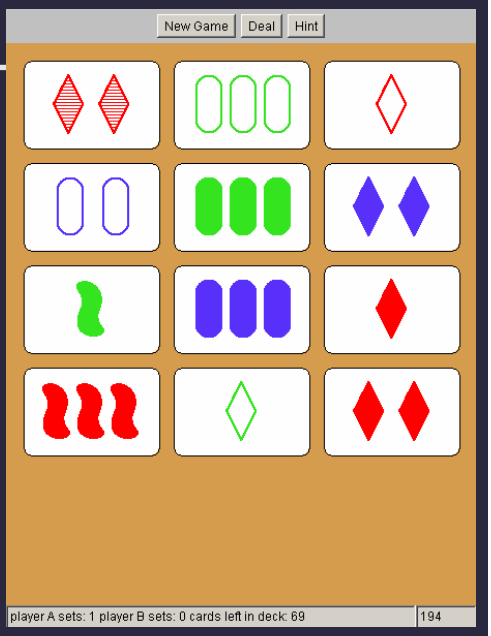


Integral

Separable

[Figure 5.25, Color Plate 10, Ware 00]

Set



Adrien Treuille's applet
http://www.cs.washington.edu/homes/treuille/resc/set

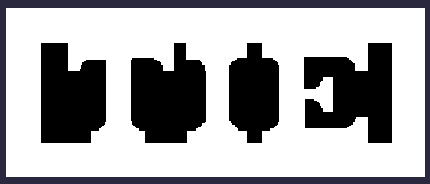
Gestalt

Principles

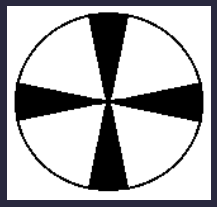
- figure/ground
- proximity
- similarity
- symmetry
- connectedness
- continuity
- closure
- common fate
- transparency

Figure/Ground

Ambiguous



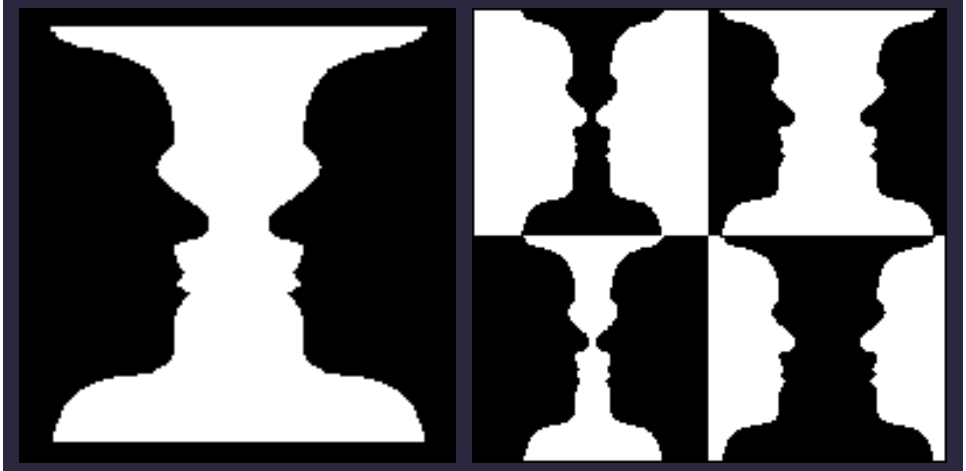
Principle of surroundedness



Principle of relative size

http://www.aber.ac.uk/media/Modules/MC10220/visper06.html

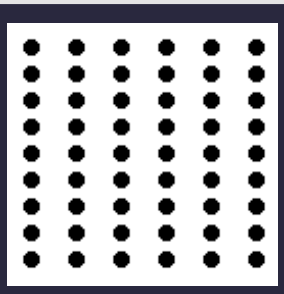
Figure/Ground

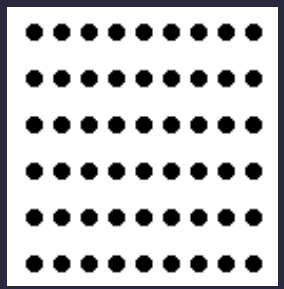


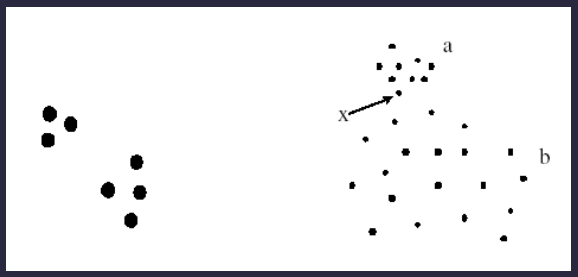
Ambiguous Unambiguous

http://www.aber.ac.uk/media/Modules/MC10220/visper06.html

Proximity

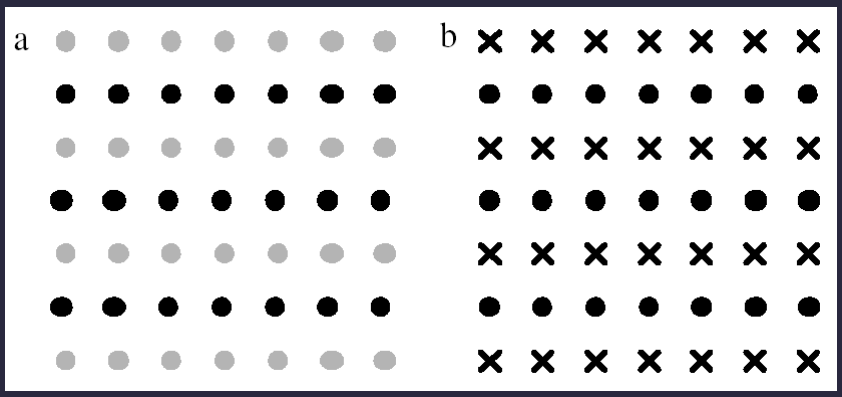






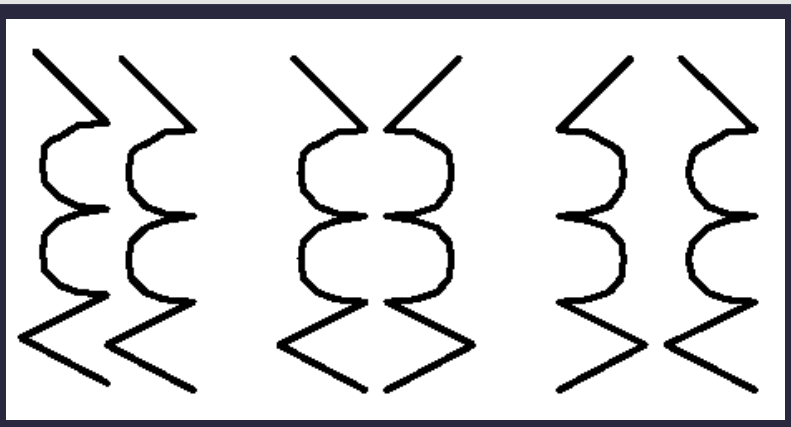
[Ware 00]

Similarity



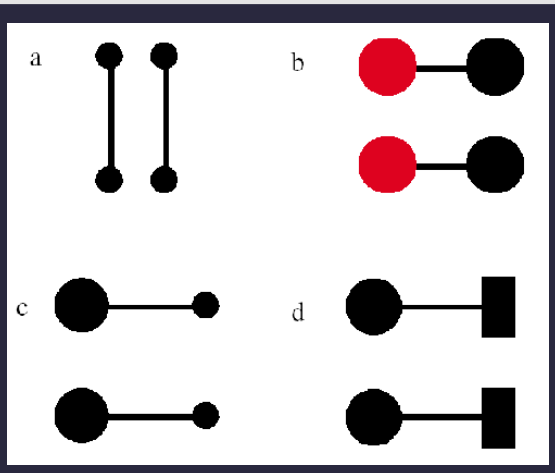
Rows dominate due to similarity [from Ware 04]

Symmetry



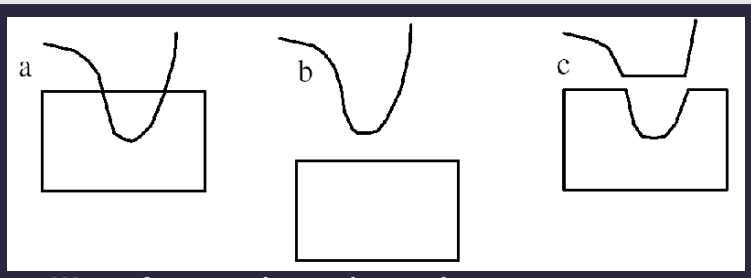
Bilateral symmetry gives strong sense of figure [from Ware 04]

Connectedness

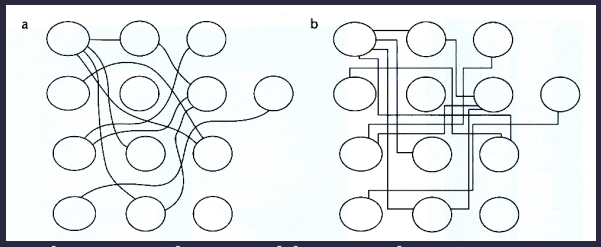


Connectedness overrules proximity, size, color shape [from Ware 04]

Continuity

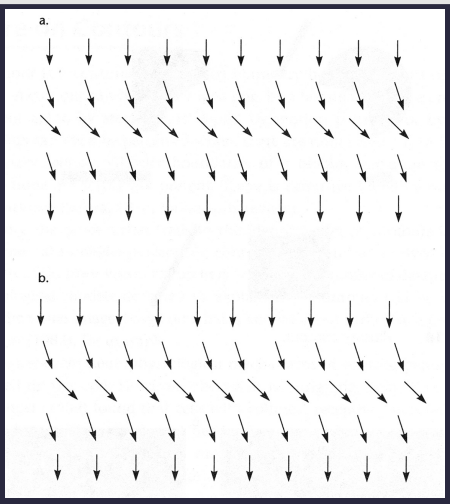


We prefer smooth not abrupt changes [from Ware 04]



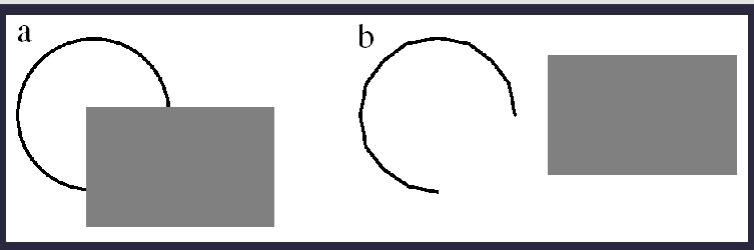
Connections are clearer with smooth contours [from Ware 04]

Continuity: Vector fields

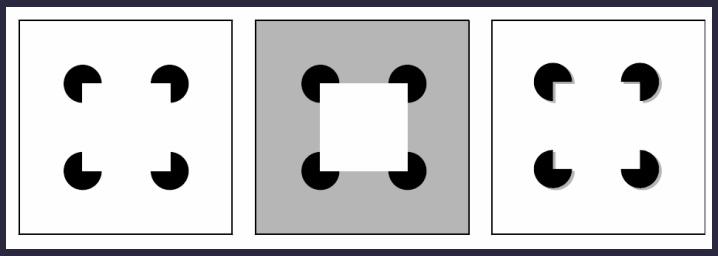


Prefer field that shows smooth continuous contours [from Ware 04]

Closure

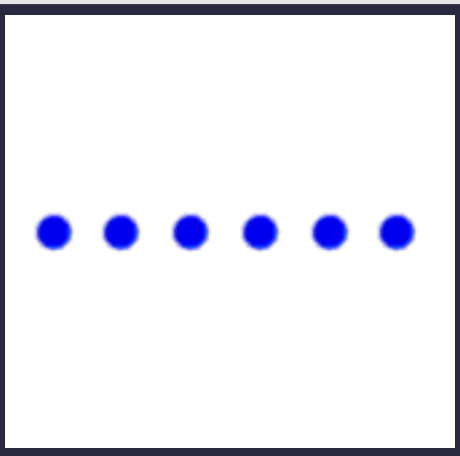


We see a circle behind a rectangle, not a broken circle [from Ware 04]



Illusory contours [from Durand 02]

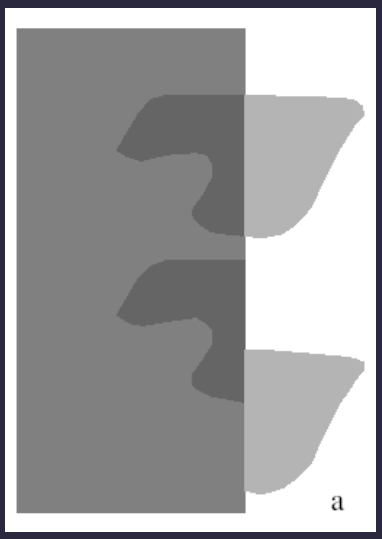
Common fate



Dots moving together are grouped

http://coe.sdsu.edu/eet/articles/visualperc1/start.htm

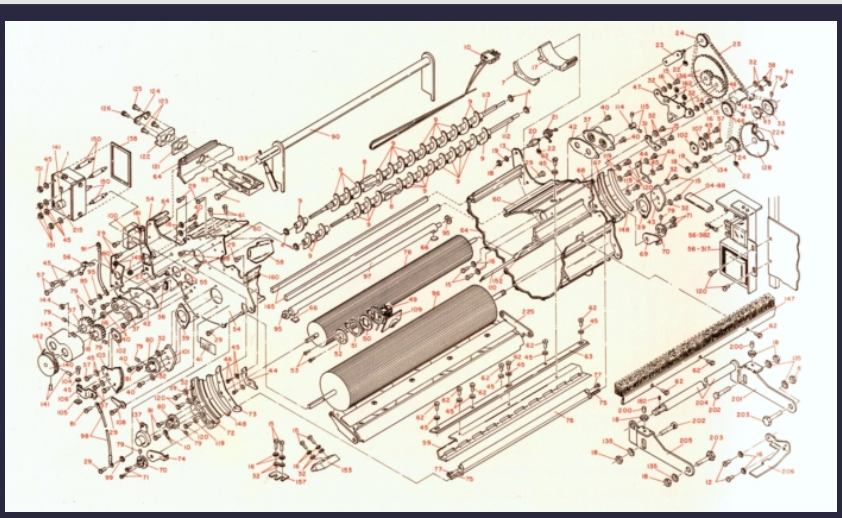
Transparency



Requires continuity and proper color correspondence [from Ware 04]

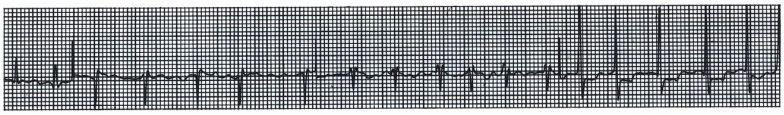
Layering and Small Multiples

Layering: Color and line width

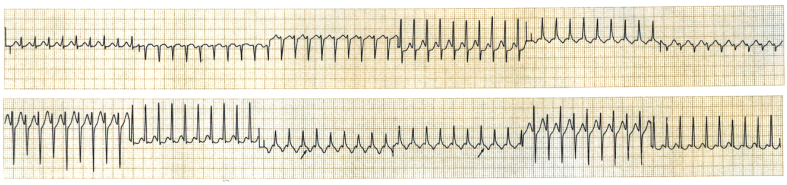


IBM Series III Copier [from Tufte 90]

Layering: Gridlines

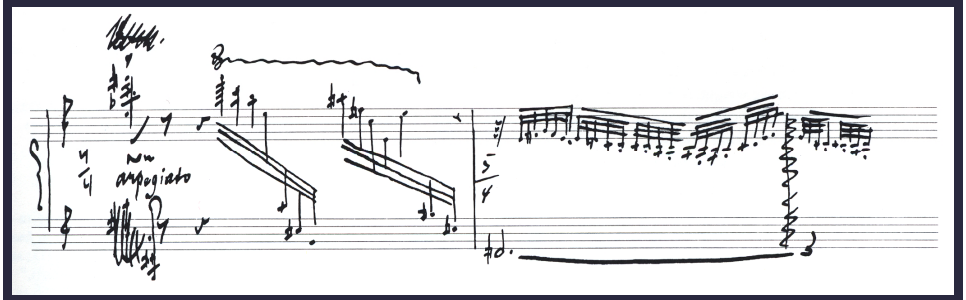


Signal and background compete above, as an electrocardiogram trace-line becomes caught up in a thick grid. Below, the screened-down grid stays behind traces from each of 12 monitoring leads:[4]



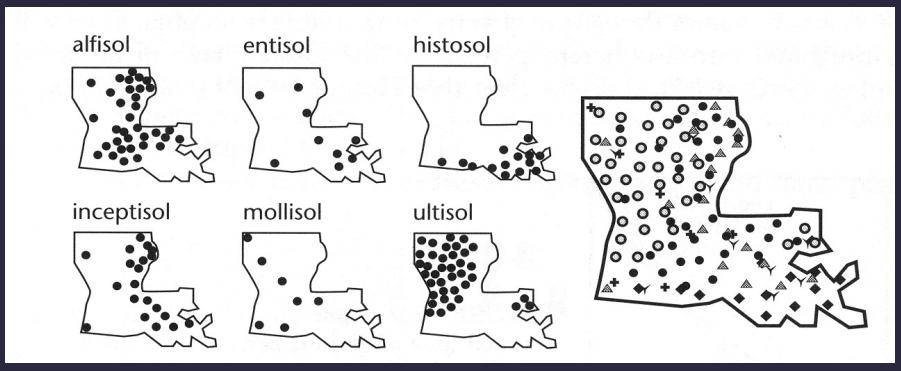
Electrocardiogram tracelines [from Tufte 90]

Layering: Gridlines



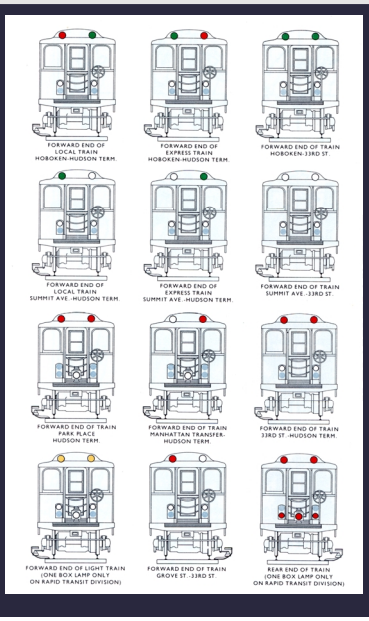
Stravinsky score [from Tufte 90]

Small multiples



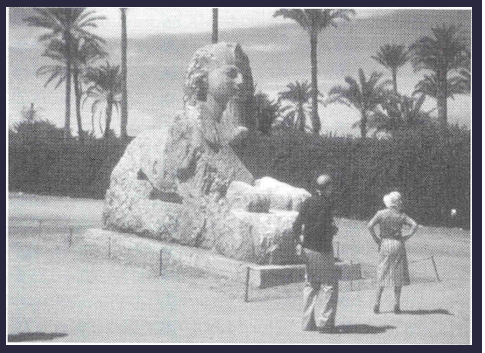
[Figure 2.11, p. 38, MacEachren 95]

Small multiples



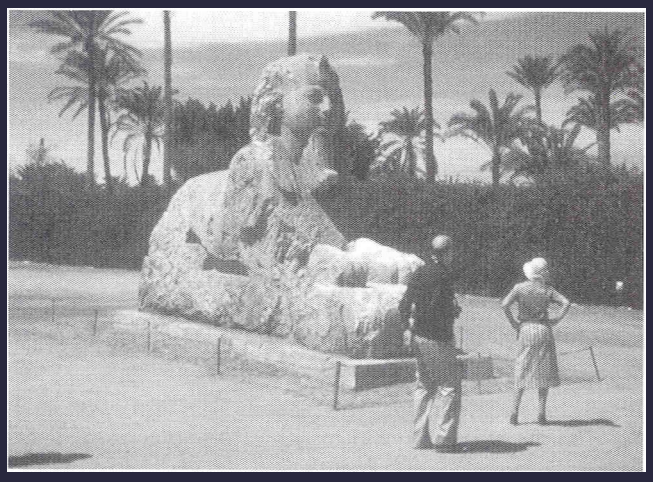
Operating trains. Redrawn by Tufte to emphasize colored lights. [fromTufte 90]

Change blindness

[Example from Palmer 99, originally due to Rock]

Change detection



Change detection

Rensink's demonstration

http://www.usd.edu/psyc301/Rensink.htm

Summary

Choosing effective visual encodings requires knowledge of visual perception

Visual features/attributes

- Individual attributes often preattentive
- Multiple attributes may be separable, often integral

Gestalt principles provide higher level design guidelines

Sometimes we don’t see everything that is there