Graphical Perception

Nam Wook Kim

Mini-Courses — January @ GSAS
2018

What is graphical perception?

The visual decoding of information encoded on graphs

Why important?

“Graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space” — Edward Tufte

Goal

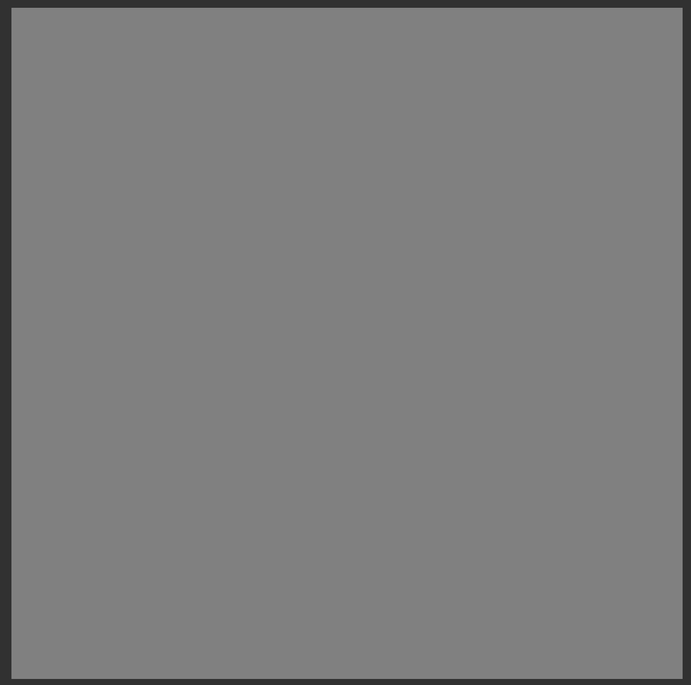
Understand the role of perception in visualization design

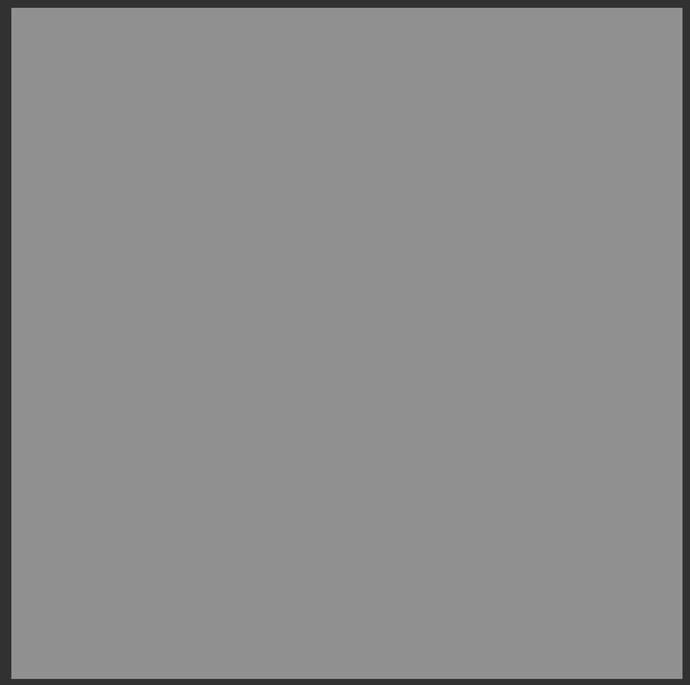
Topics

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

Signal Detection

Detecting Brightness

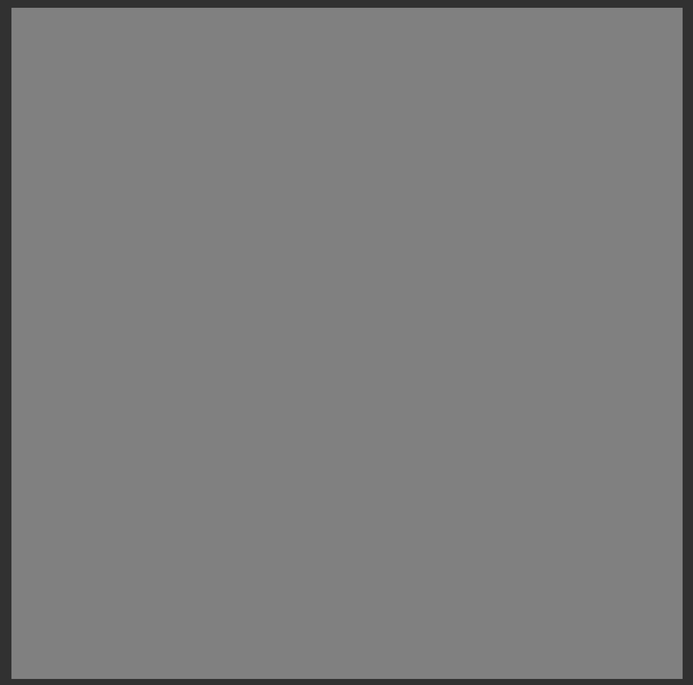




A Which is brighter? B

Detecting Brightness

(128,128,128)

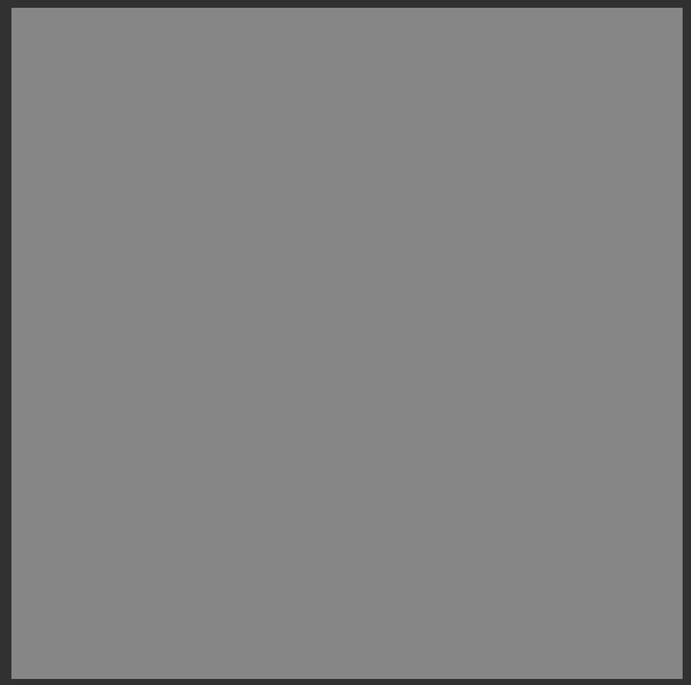


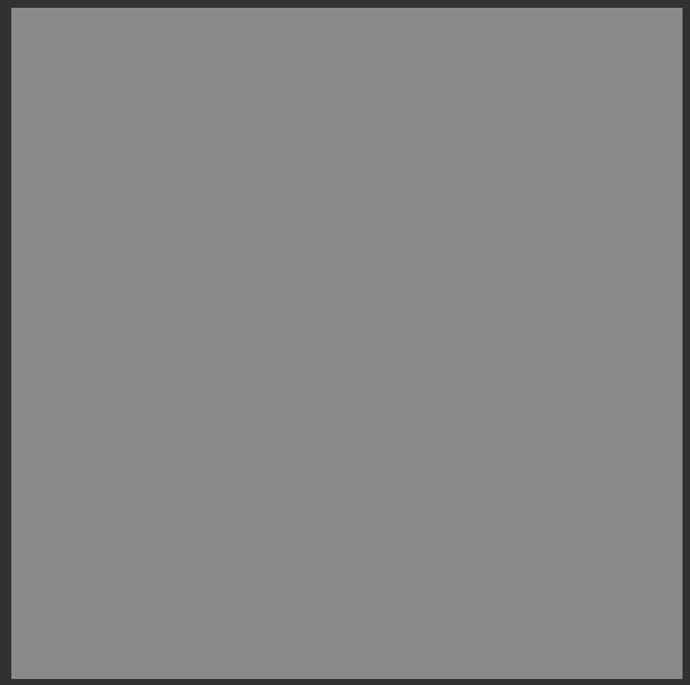
A

(144,144,144)

B

Detecting Brightness

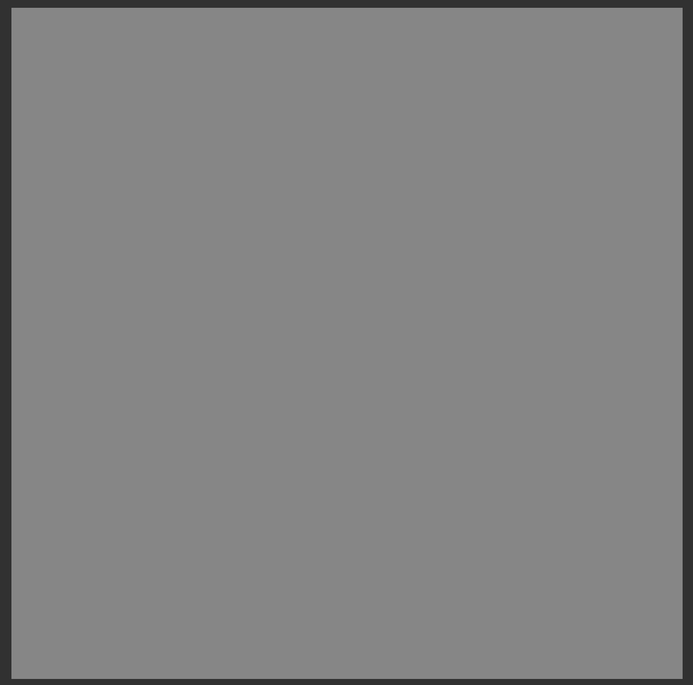




A Which is brighter? B

Detecting Brightness

(134,134,134)



A

(138,138,138)

B

Weber’s Law

Just Noticeable Difference (JND)

$$dp = k \frac{dS}{S}$$

Weber’s Law

Just Noticeable Difference (JND)

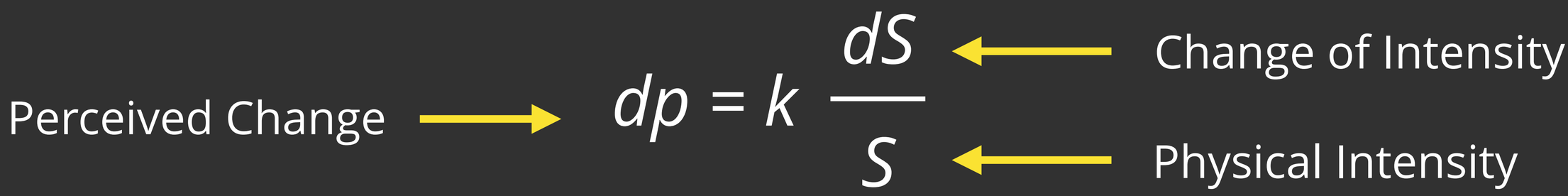
$$dp = k \frac{dS}{S}$$

dS ← Change of Intensity

S ← Physical Intensity

Weber’s Law

Just Noticeable Difference (JND)



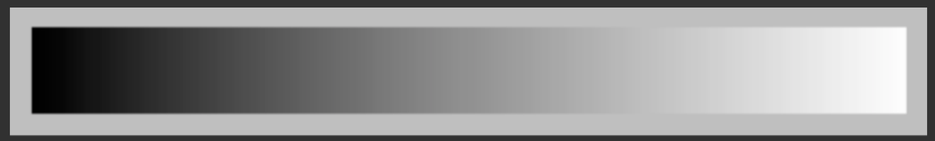
Weber’s Law

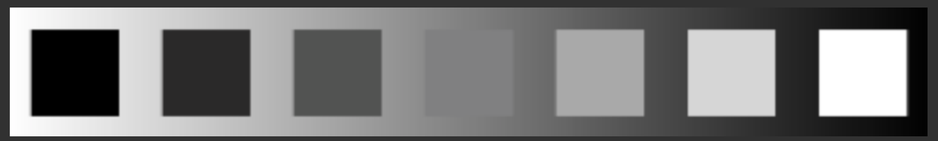
Just Noticeable Difference (JND)

Perceived Change → $dp = k \frac{dS}{S}$ ← Change of Intensity

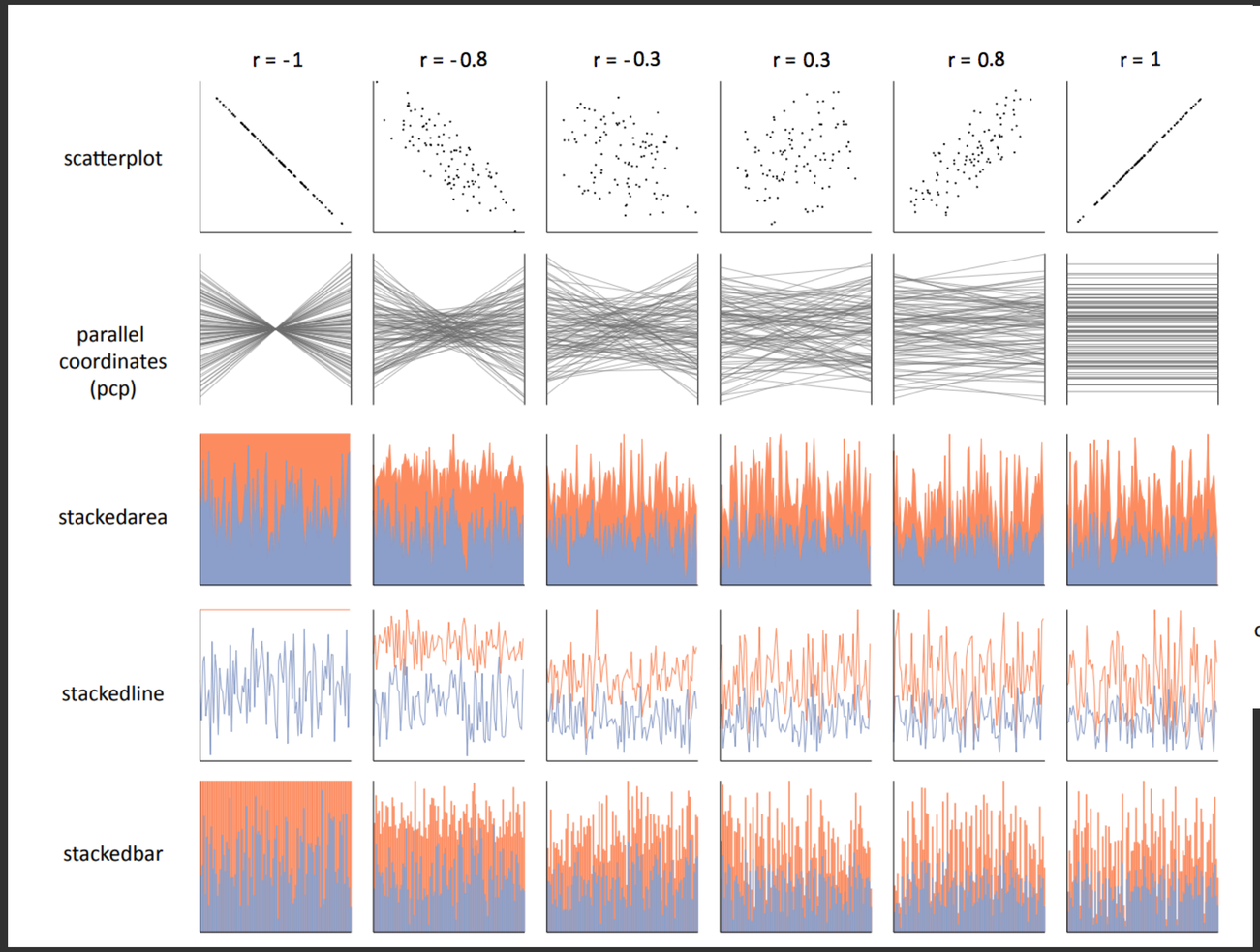
← Physical Intensity

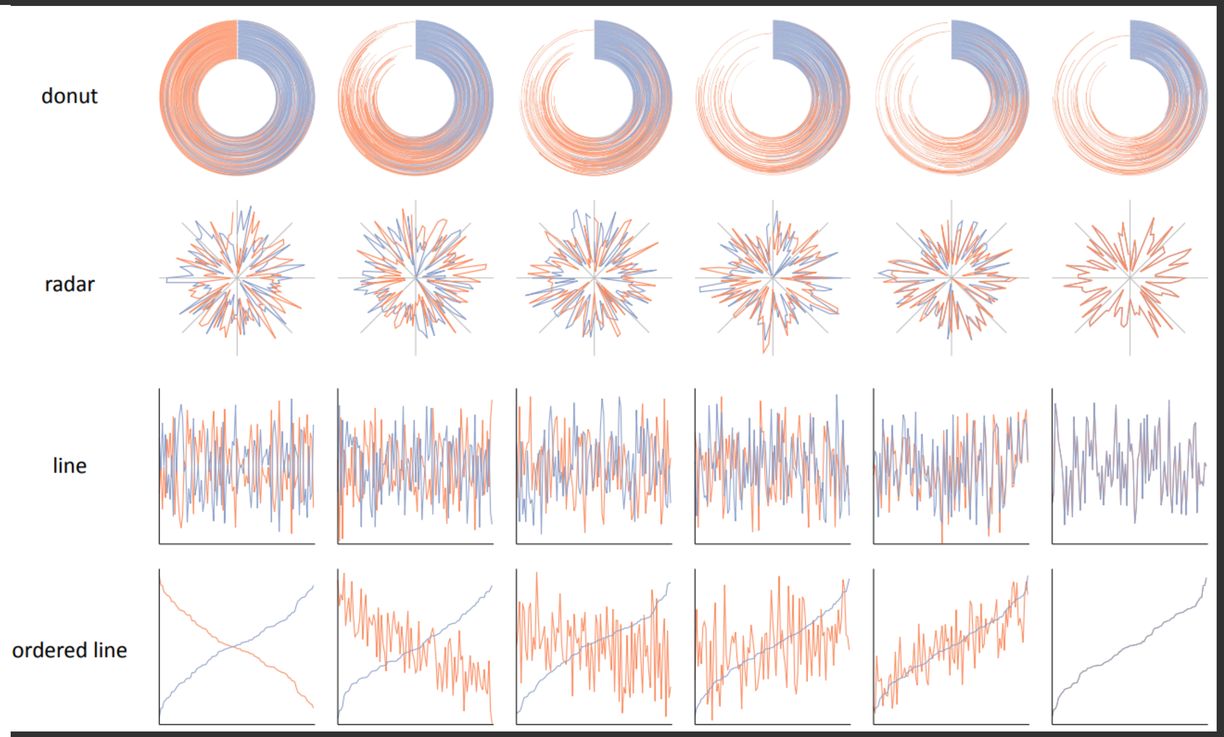
Most continuous variation in stimuli are perceived in discrete steps



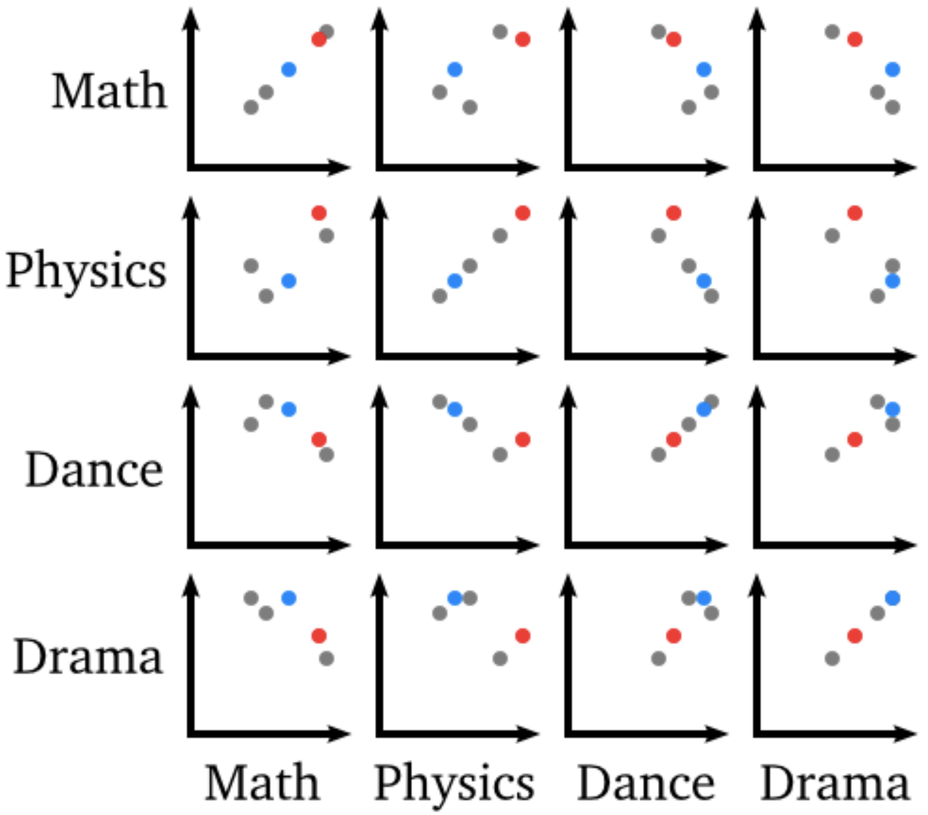


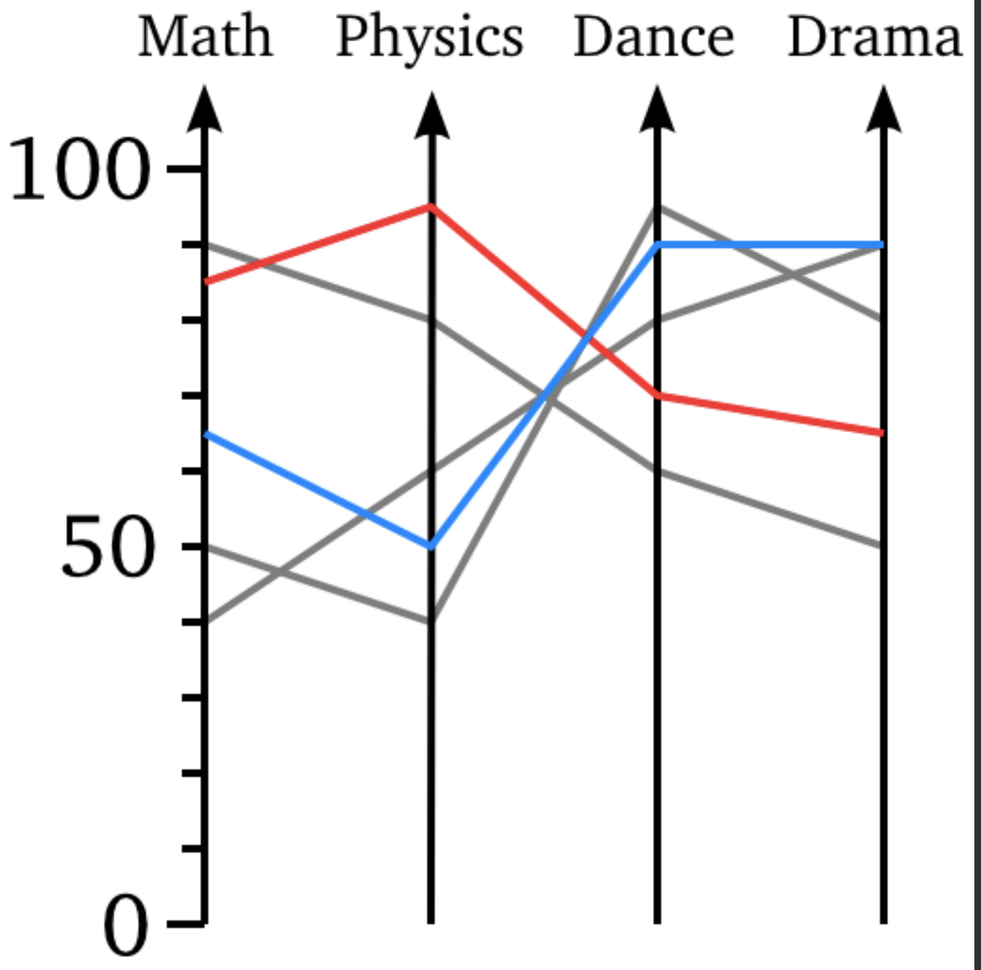
Ranking correlation visualizations





[Harrison et al 2014]

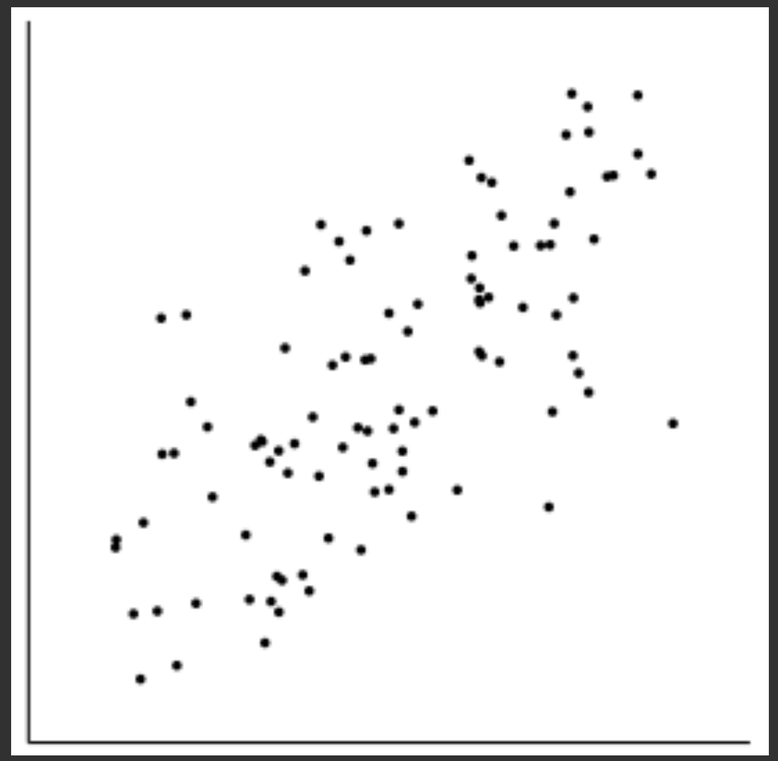




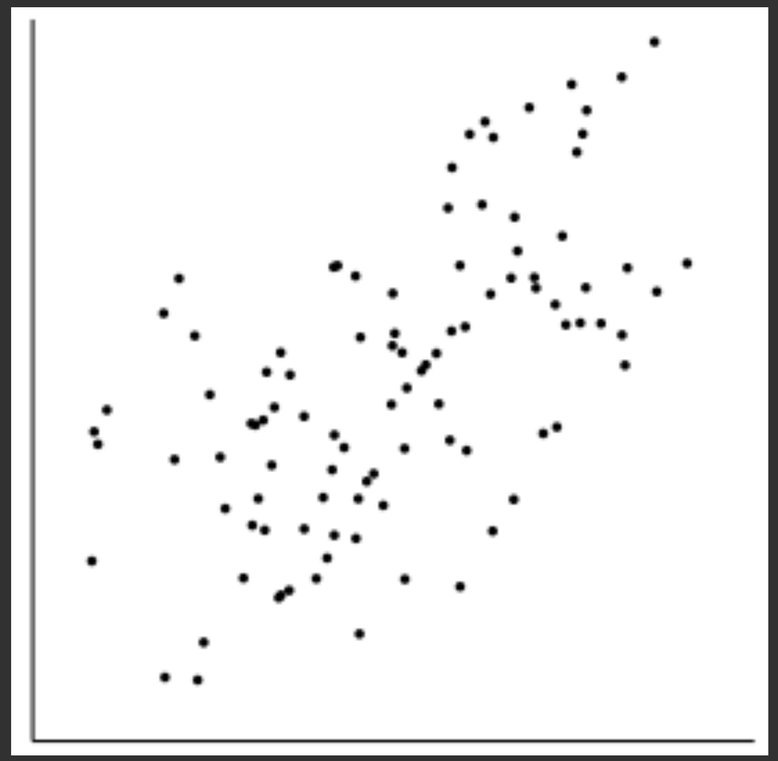
Math	Physics	Dance	Drama
85	95	70	65
90	80	60	50
65	50	90	90
50	40	95	80
40	60	80	90

Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



A

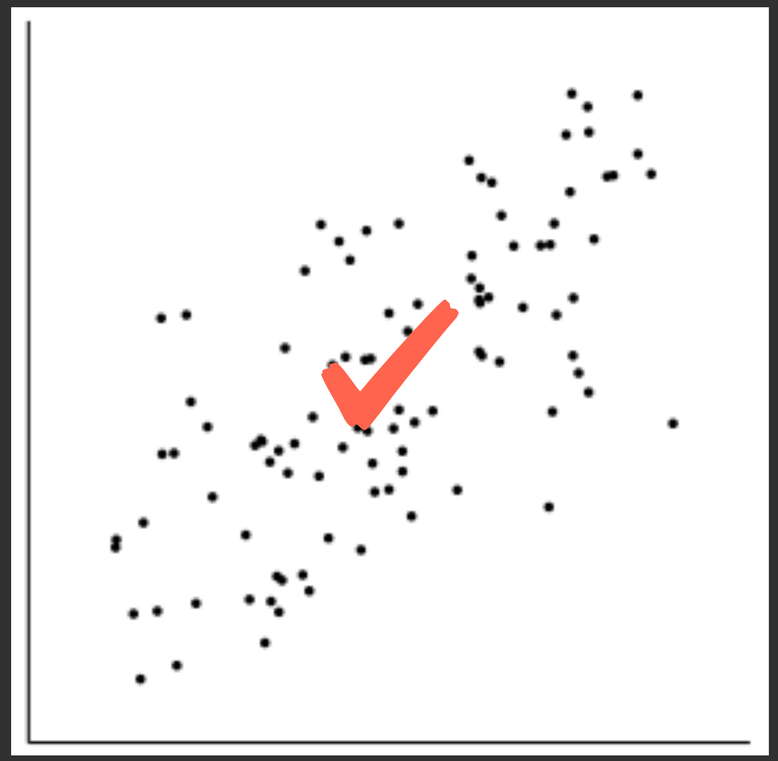


B

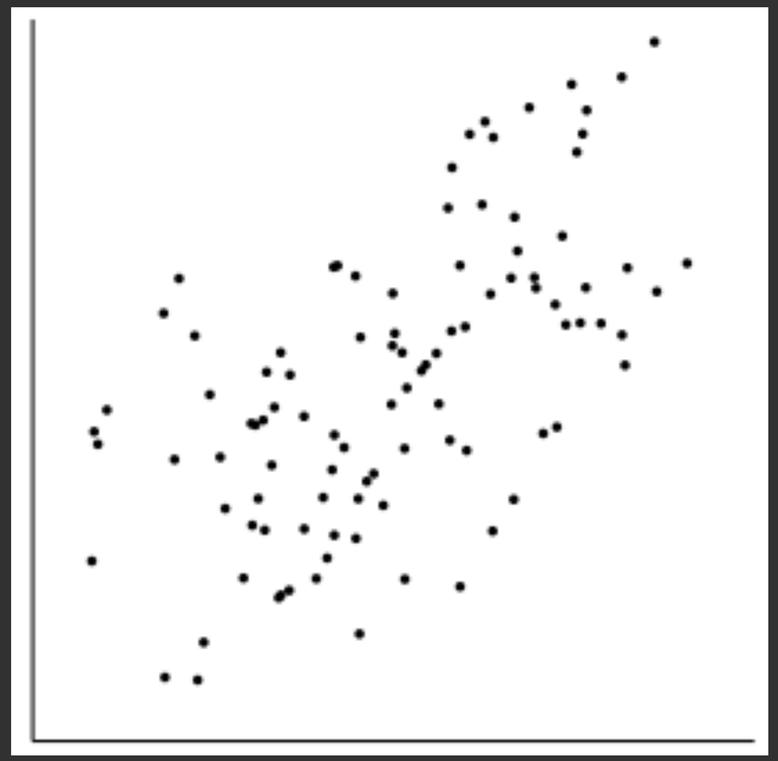
[Harrison et al 2014]

Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



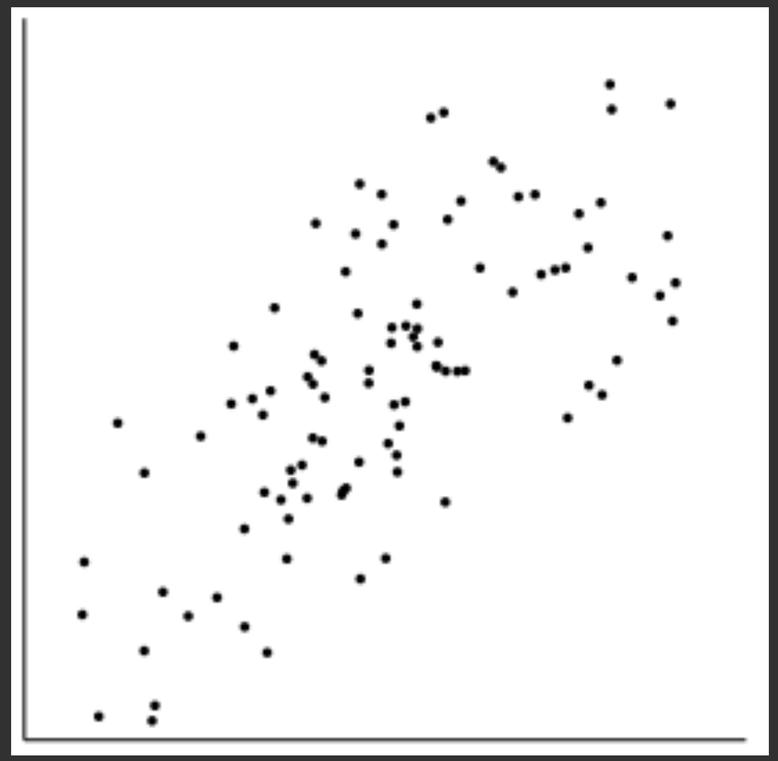
r = 0.7



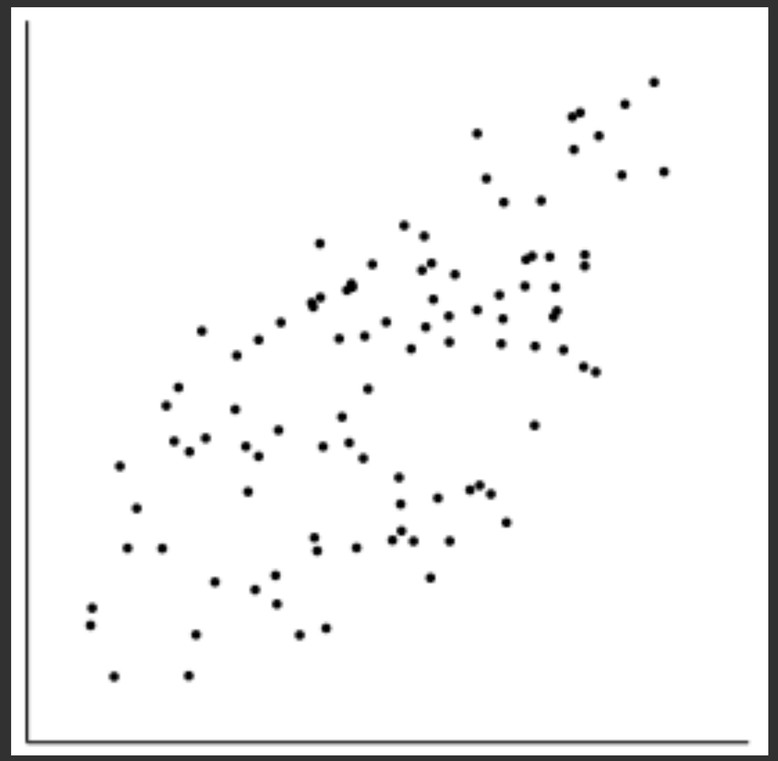
r = 0.6

Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



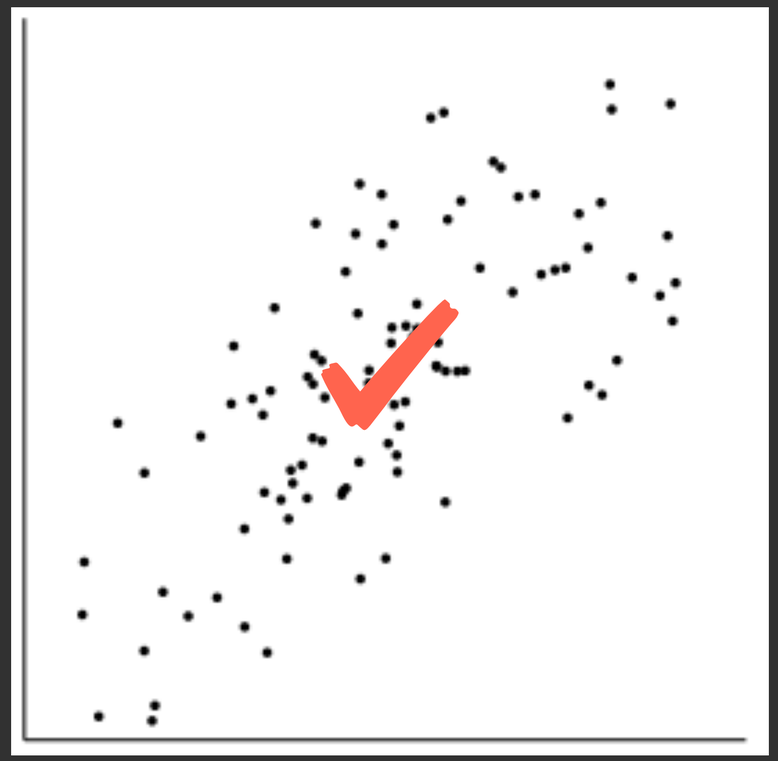
A



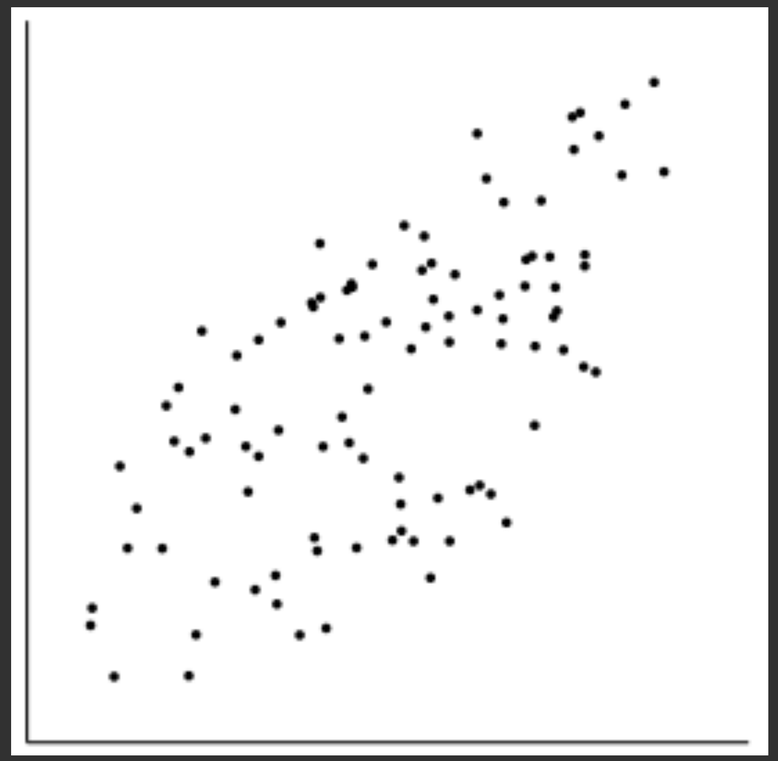
B

Ranking correlation visualizations

Which of the two appeared to be more highly correlated?

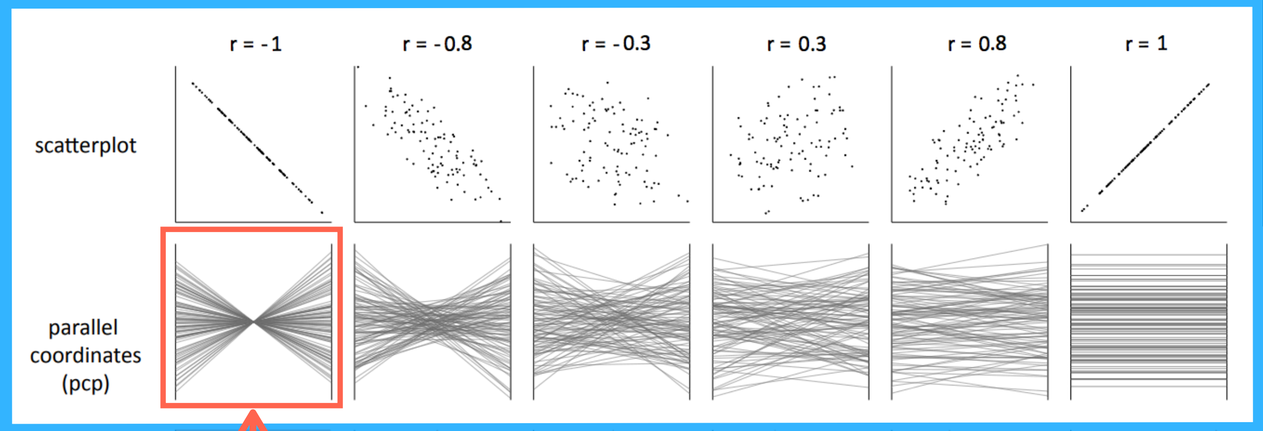


r = 0.7



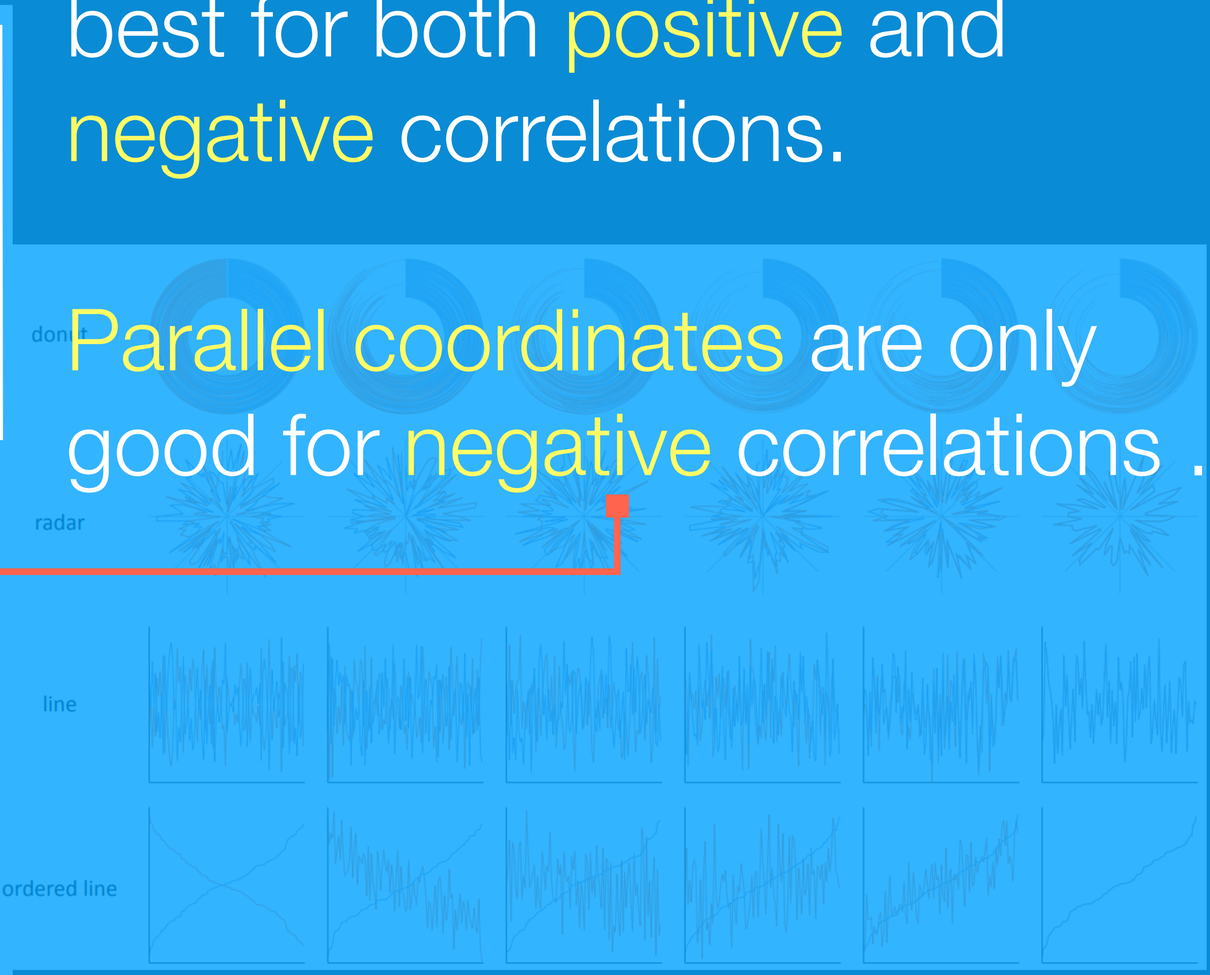
r = 0.65

Ranking visualizations for depicting correlation



Overall, scatterplots are the best for both positive and negative correlations.

Parallel coordinates are only good for negative correlations .



[Harrison et al 20

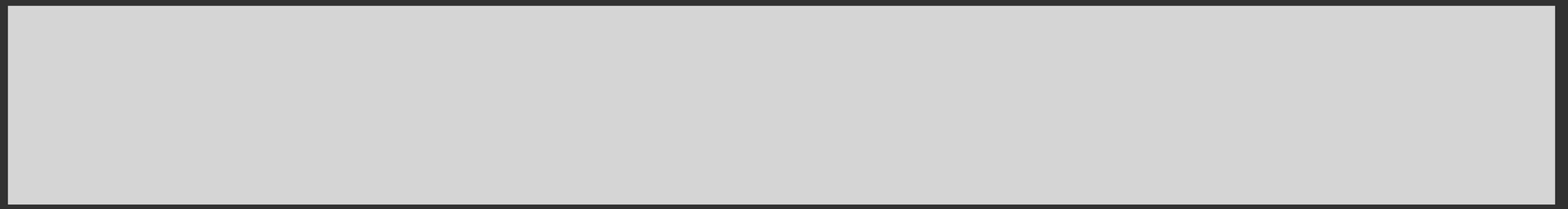
Magnitude Estimation

A Quick Experiment...

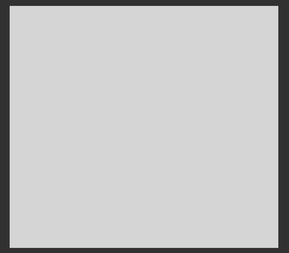
A

B

B

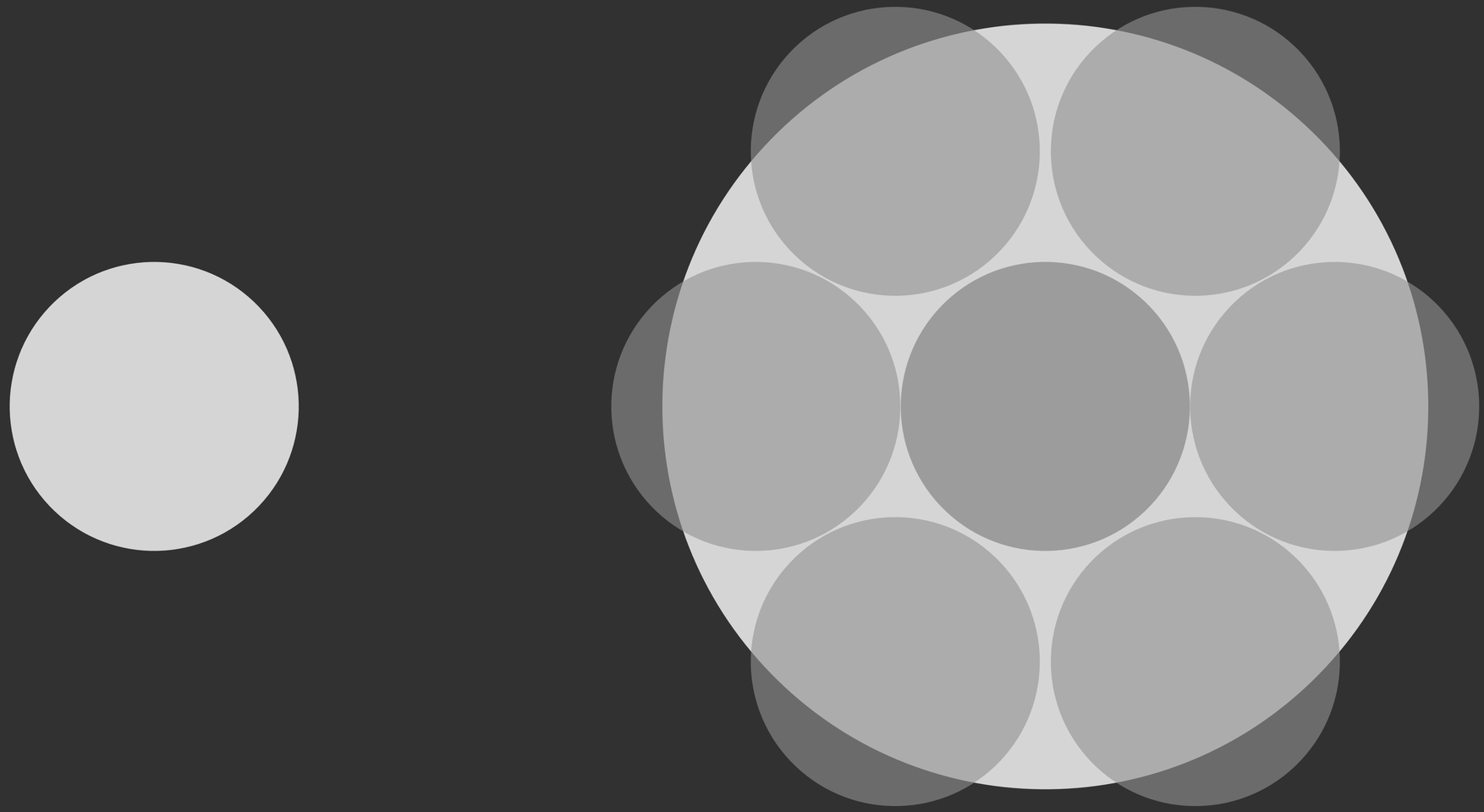


A



A

B



Area


B
A
Length

[Graph from T. Munzner 2014]

Steven's Power Law

Models the **relationship** between the **magnitude** of a physical stimulus and its perceived intensity.

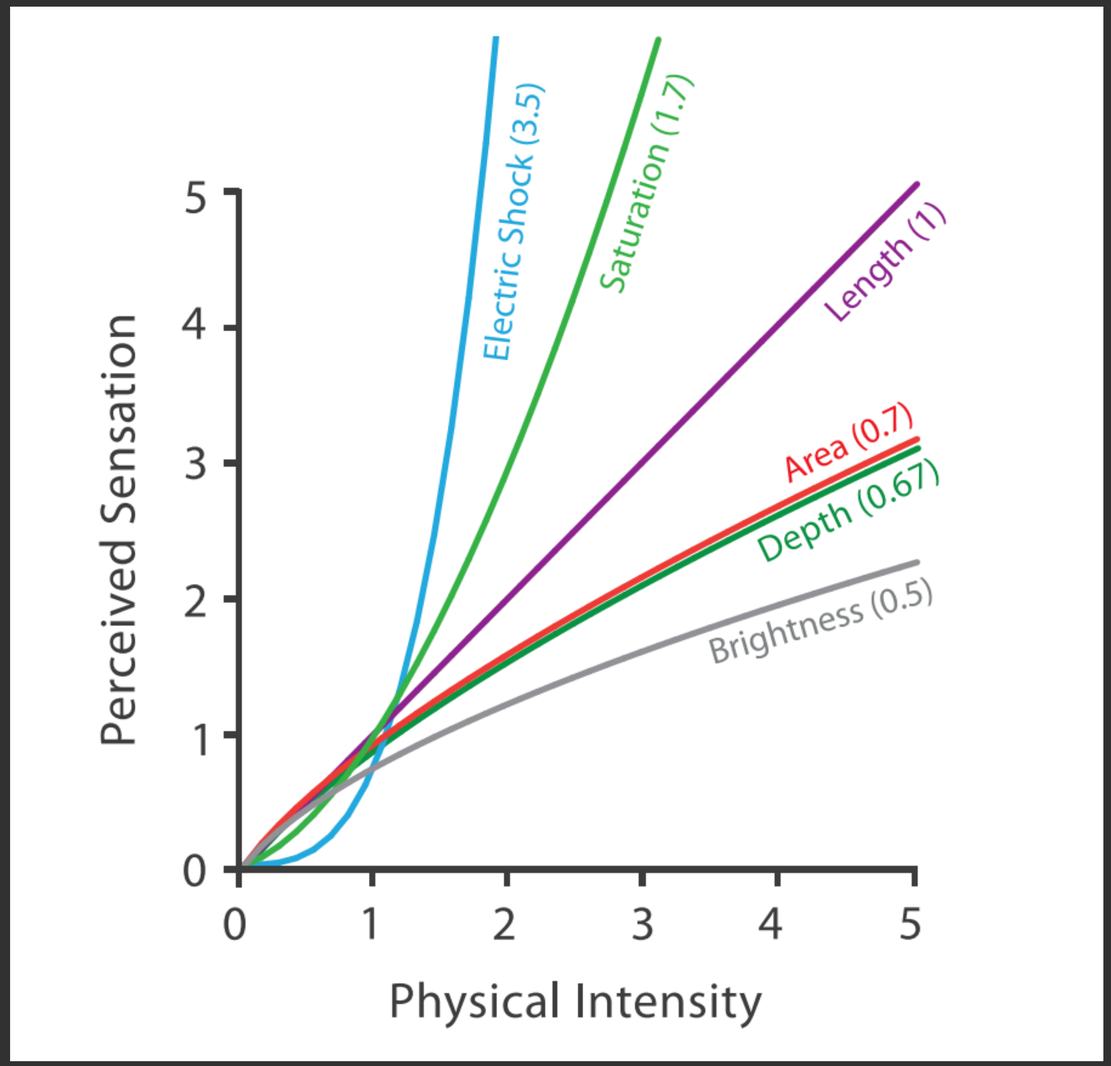
Exponent
(Empirically Determined)

$$S = I^{p}$$

Perceived Sensation

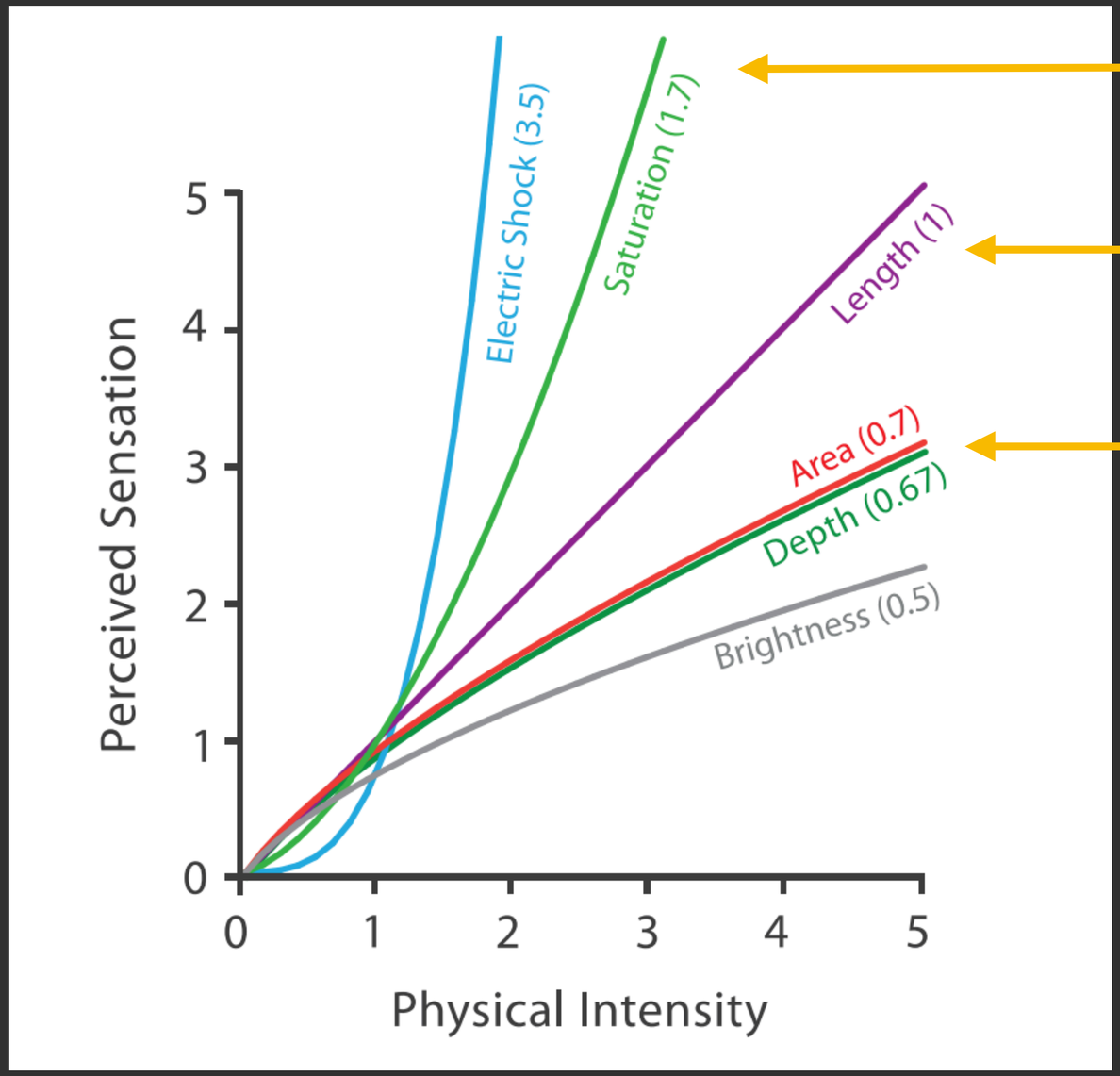
Physical Intensity

Predicts bias, not necessarily accuracy!



[Graph from T. Munzner 2014]

Steven's Power Law



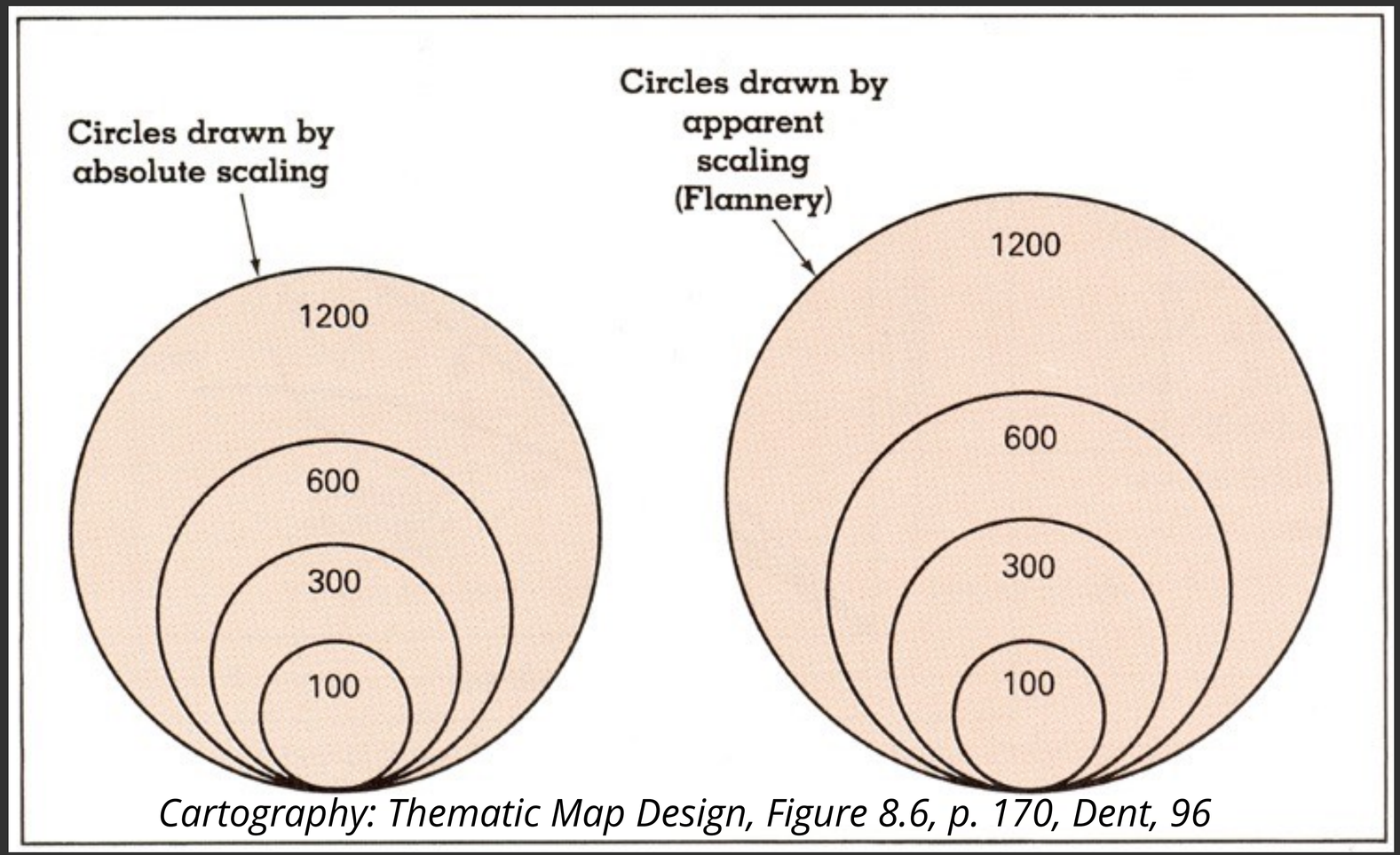
Overestimate

Unbiased

Underestimate

Apparent Magnitude Scaling

To compensate for human error in interpreting scale because people tend to underestimate area

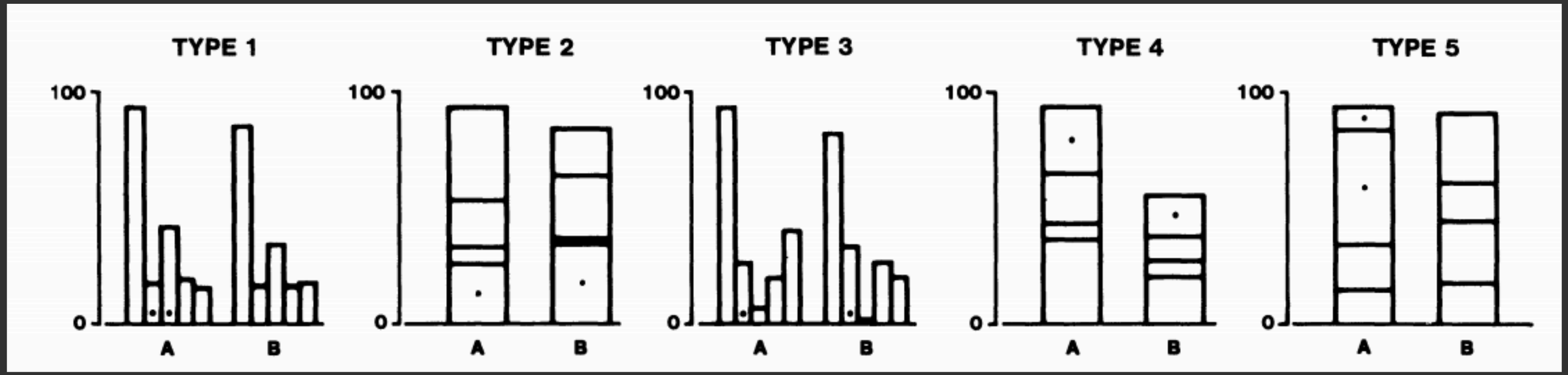


Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96

$$\times \frac{1}{0.7}$$

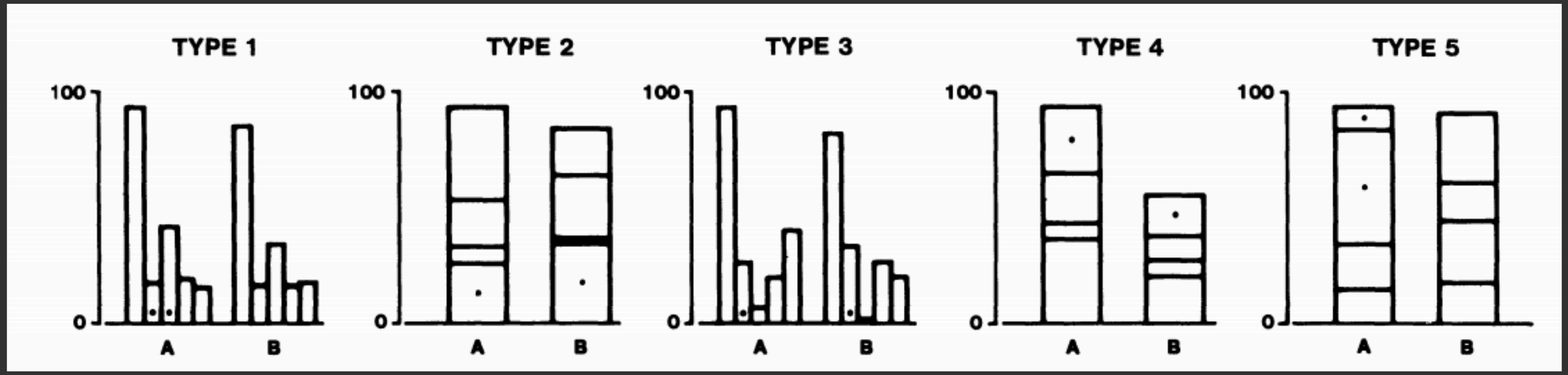
Graphical Perception [Cleveland & McGill 84]

What percentage of the smaller was of the larger?



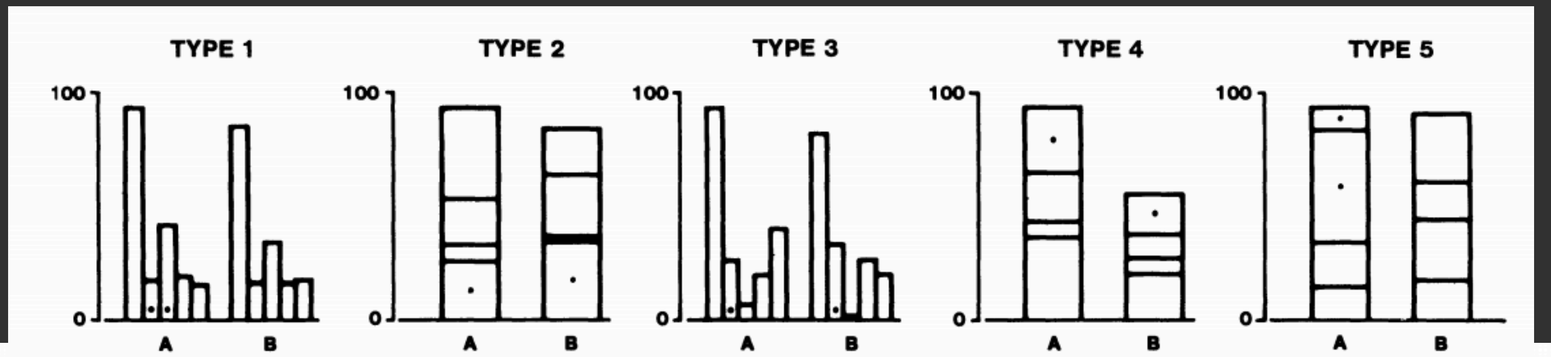
Graphical Perception [Cleveland & McGill 84]

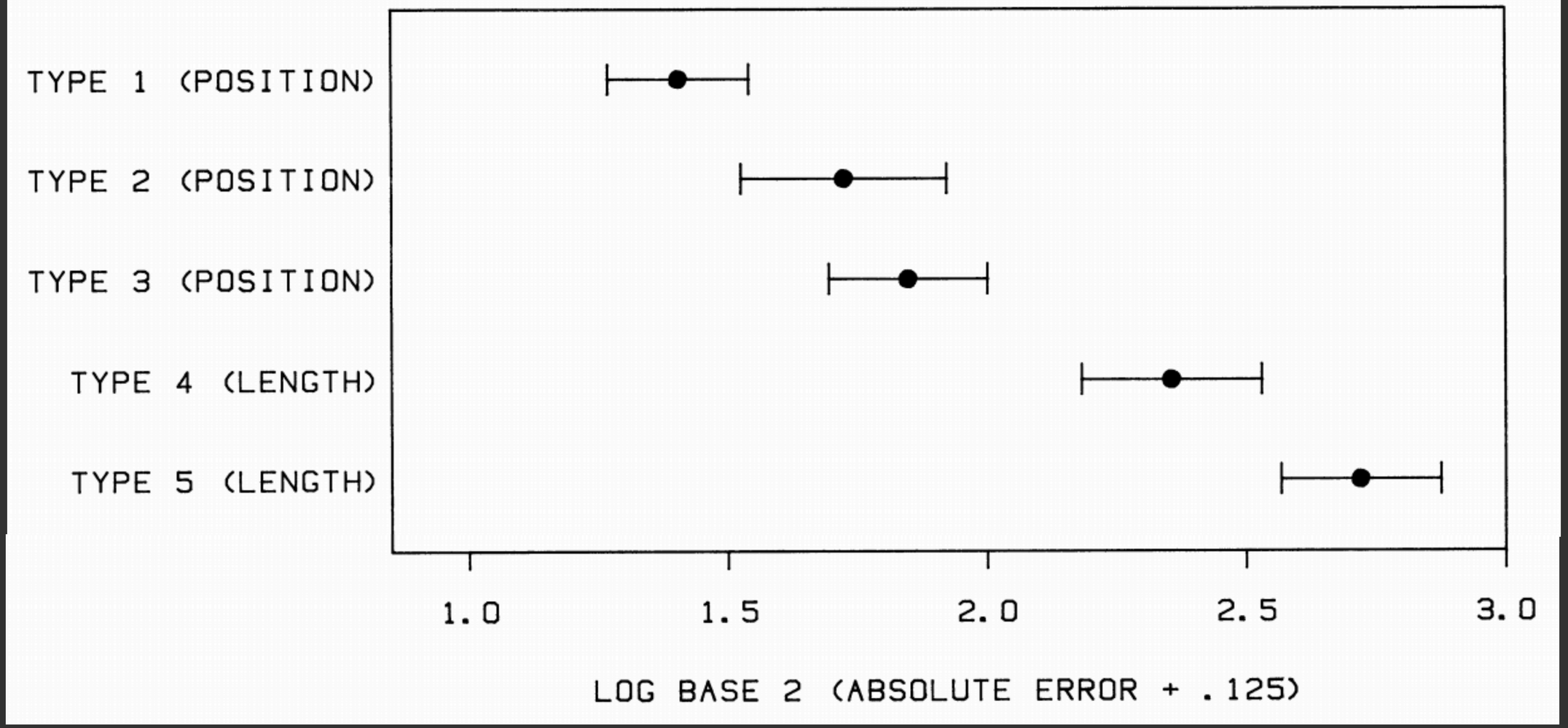
What percentage of the smaller was of the larger?



Compare positions
(along common scale)

Compare lengths


TYPE 1
TYPE 2
TYPE 3
TYPE 4
TYPE 5
100
0
A
B


TYPE 1 (POSITION)
TYPE 2 (POSITION)
TYPE 3 (POSITION)
TYPE 4 (LENGTH)
TYPE 5 (LENGTH)
1.0
1.5
2.0
2.5
3.0
LOG BASE 2 (ABSOLUTE ERROR + .125)

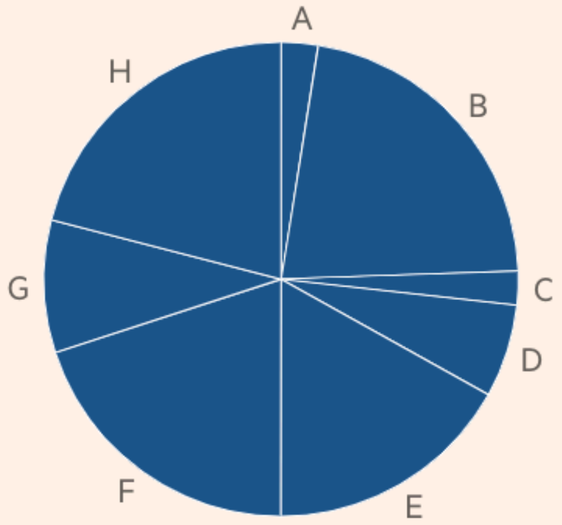
FINANCIAL TIMES

The Chart Doctor

The science behind good charts

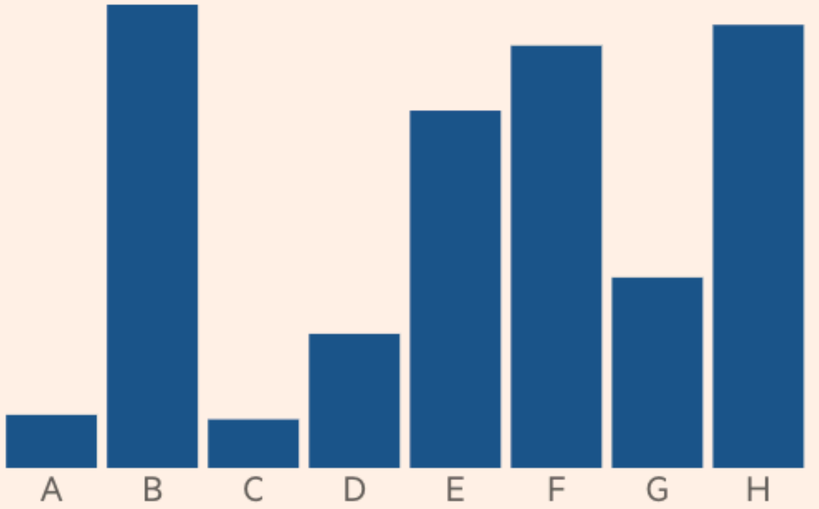
Take part in our interactive experiment to boost your chart-making confidence

https://ig.ft.com/science-of-charts/



Which is the third largest segment in the pie chart?

E	**F**
G	**H**

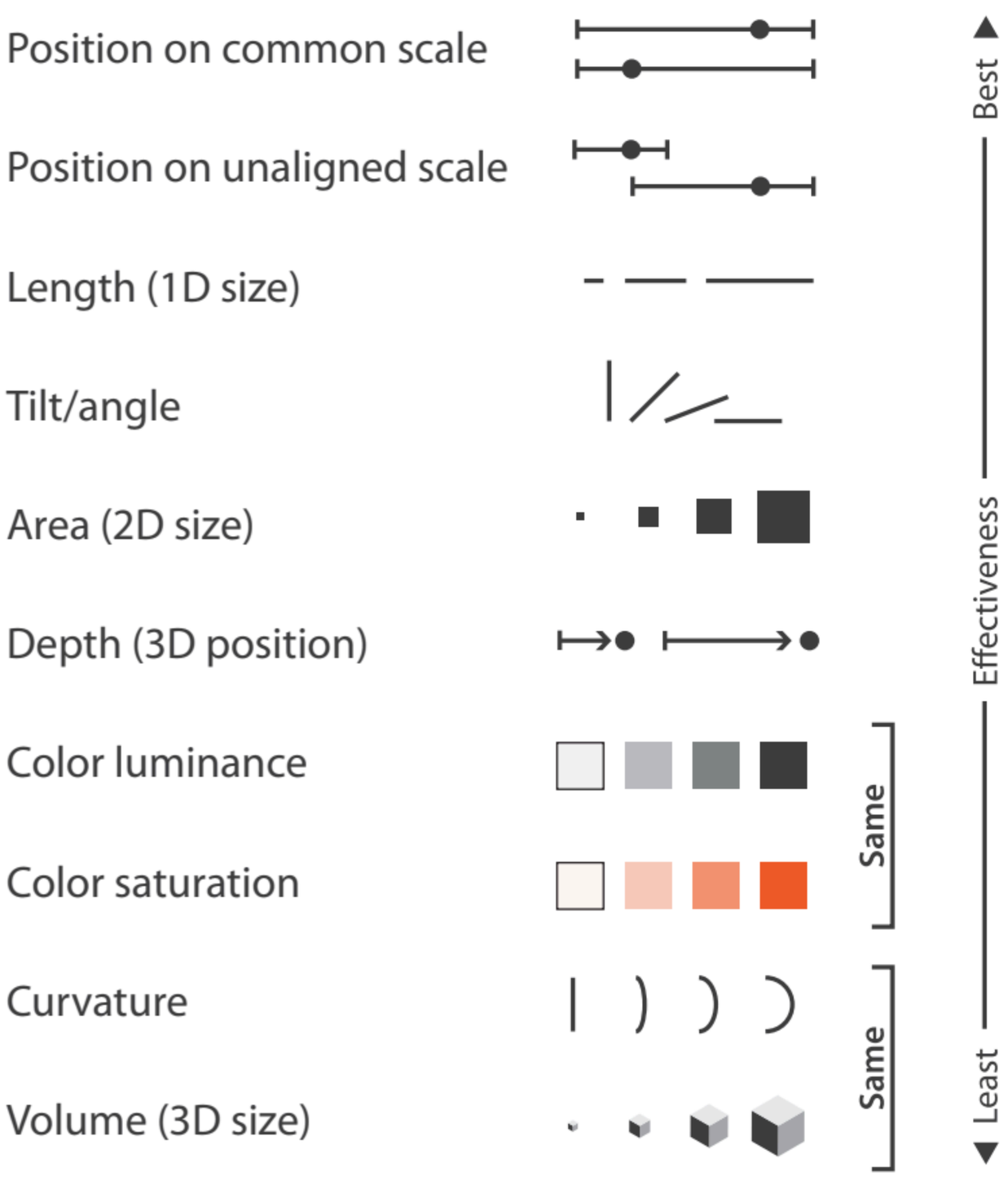


Which is the 3rd largest bar?

E	**F**
G	**H**

Effectiveness Ranking of Visual Encoding Variables

for comparing numerical quantities



[T. Munzer 2014]

Pre-Attentive Processing

How Many 3’s?

12817687561389765469845069856049828267629809858458224509856458945098450980943585909103020990595959577256467505067890456788457898098216776548763649085609129496 86

[based on a slide from J. Stasko]

How Many 3’s?

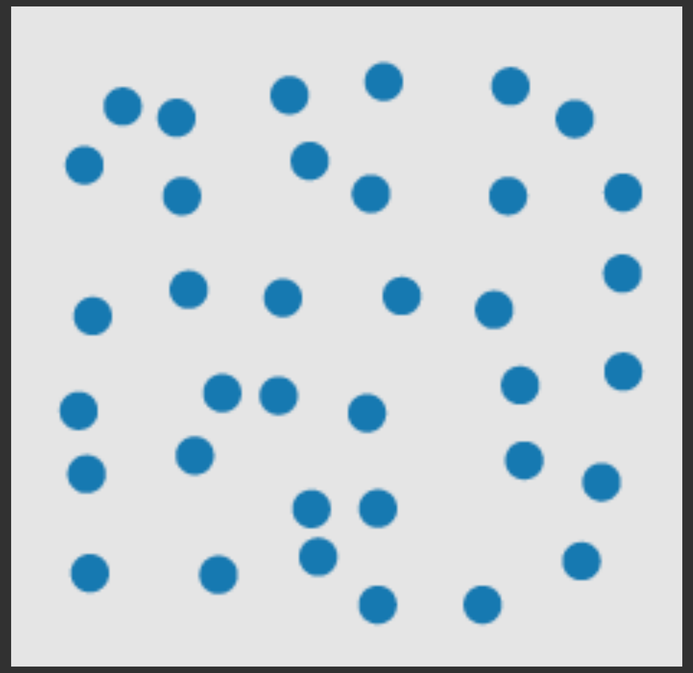
1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

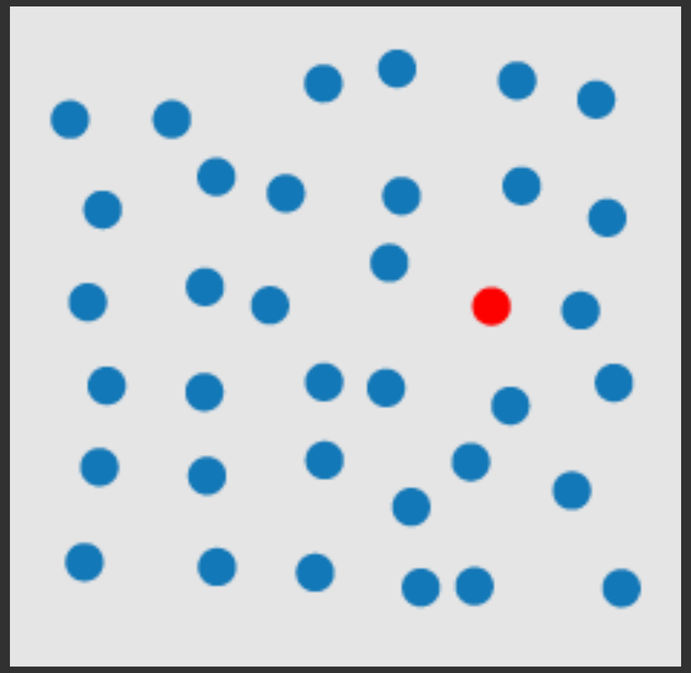
[based on a slide from J. Stasko]

Pre-attentive processing

The ability of the low-level human visual system to effortlessly identify certain basic visual properties.

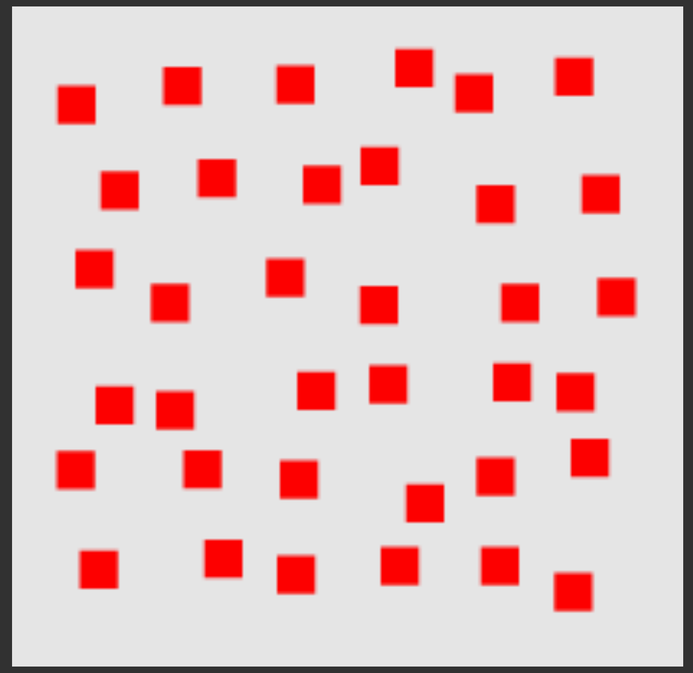
Visual Pop-Out: Color

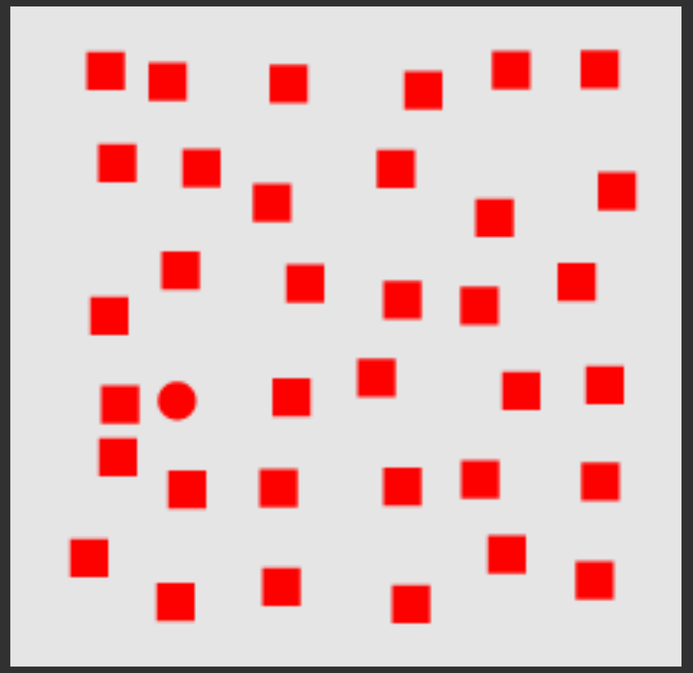




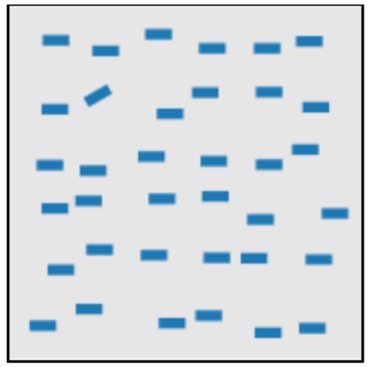
Christopher Healey, https://www.csc.ncsu.edu/faculty/healey/PP/index.html

Visual Pop-Out: Shape

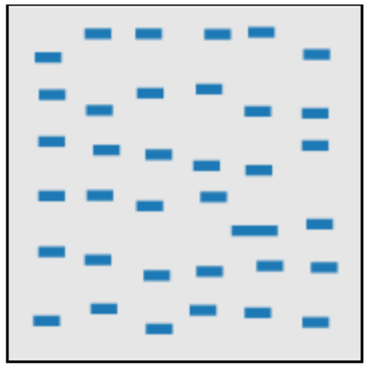




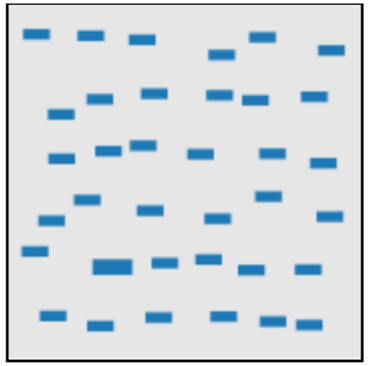
Christopher Healey, https://www.csc.ncsu.edu/faculty/healey/PP/index.html



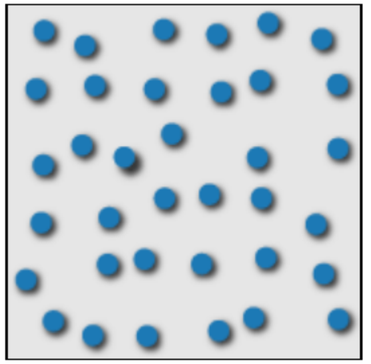
line (blob) orientation
Julész & Bergen 83; Sagi & Julész 85a, Wolfe et al. 92; Weigle et al. 2000



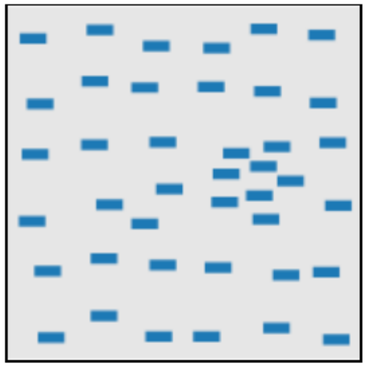
length, width
Sagi & Julész 85b; Treisman & Gormican 88



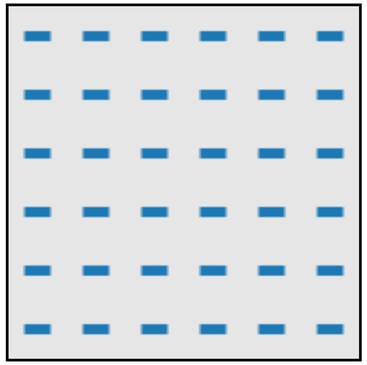
size
Treisman & Gelade 80; Healey & Enns 98; Healey & Enns 99



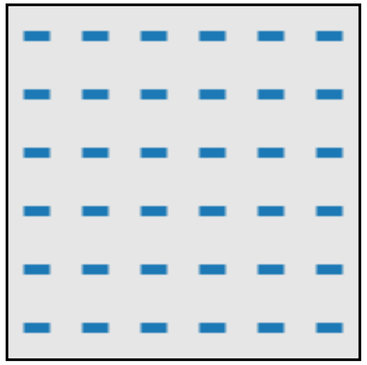
3D depth cues
Enns 90b; Nakayama & Silverman 86



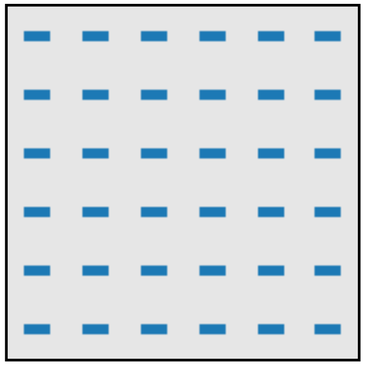
density, contrast
Healey & Enns 98; Healey & Enns 99



velocity of motion
Tynan & Sekuler 82; Nakayama & Silverman 86; Driver & McLeod 92; Hohnsbein & Mateeff 98; Huber & Healey 2005



direction of motion
Nakayama & Silverman 86; Driver & McLeod 92; Huber & Healey 2005



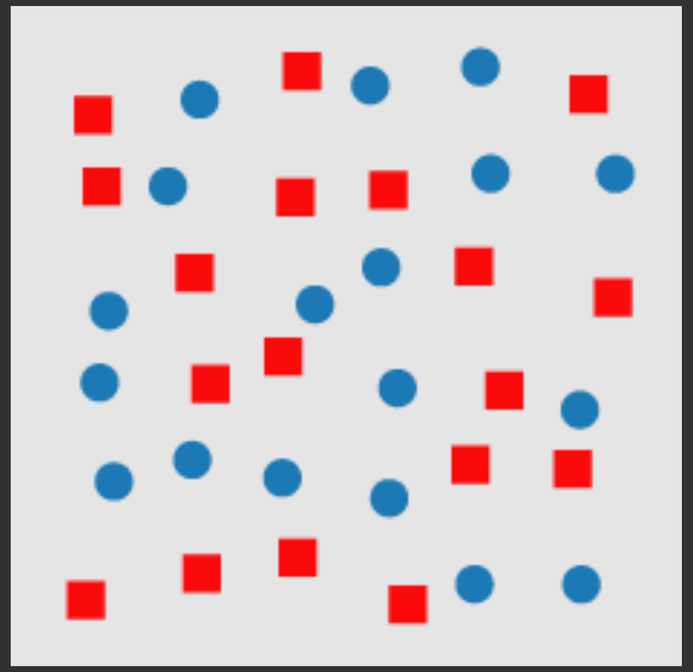
flicker
Gebb et a. 55; Mowbray & Gebhard 55; Brown 65; Julész 71; Huber & Healey 2005

and many more…

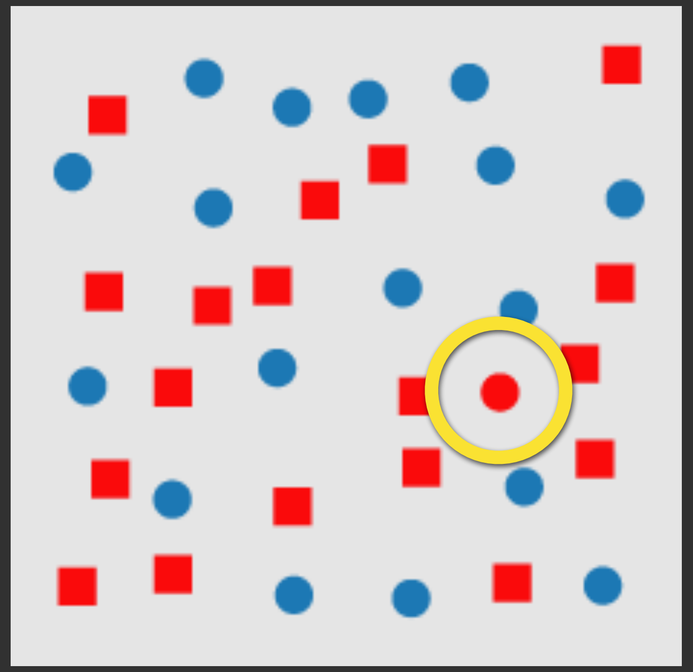
Christopher Healey, https://www.csc.ncsu.edu/faculty/healey/PP/index.html

Feature Conjunctions

Consistent



Inconsistent



No unique visual property of the target

Christopher Healey, https://www.csc.ncsu.edu/faculty/healey/PP/index.html

Pre-attentive Conjunctions

Most conjunctions are not pre-attentive.

Some spatial conjunctions are pre-attentive.

- Motion and color
- Motion and shape
- Motion and 3D disparity
- 3D disparity and color
- 3D disparity and shape

Multiple Attributes

One-Dimensional: Lightness

Classify objects based on lightness

White

White

Black

White

Black

or

White

Black

Black

White

White

One-Dimensional: Shape

Classify objects based on shape

Square

Circle

Circle

Square

Circle

or

Circle

Circle

Square

Circle

Circle

Redundant: Shape & Lightness

Classify objects based on shape. Easier?

Circle

Square

Square

Circle

Square

or

Circle

Square

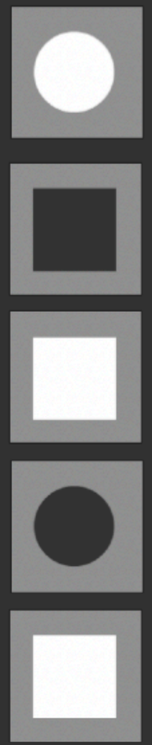
Square

Square

Circle

Orthogonal: Shape & Lightness

Classify objects based on shape. Difficult?



Circle

Square

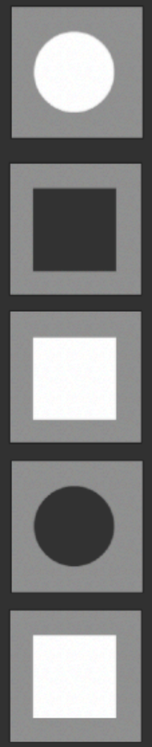
Square

Circle

Circle

Orthogonal: Shape & Lightness

Classify objects based on lightness. Difficult?



Circle

Square

Square

Circle

Circle

Speeded Classification

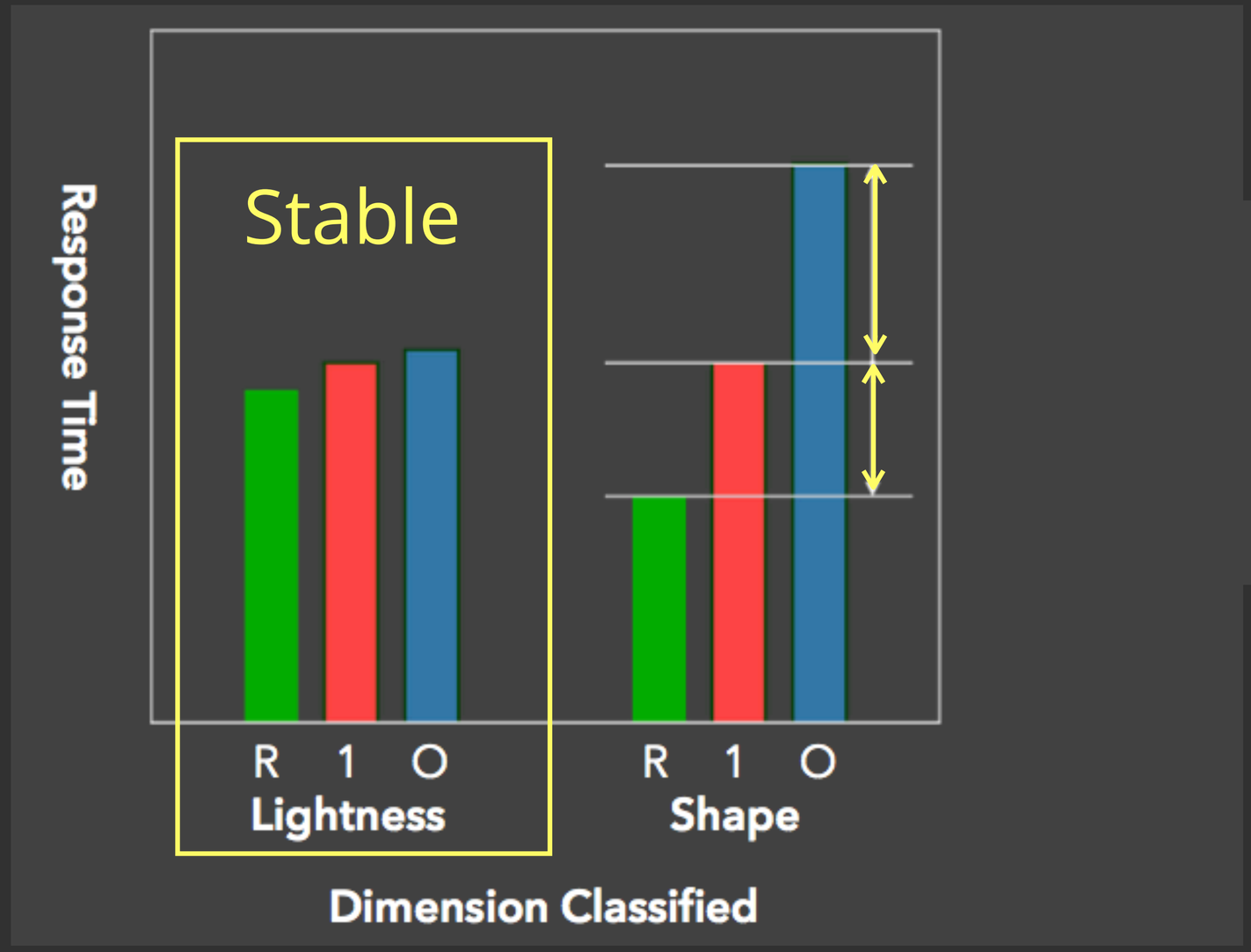
Redundancy Gain

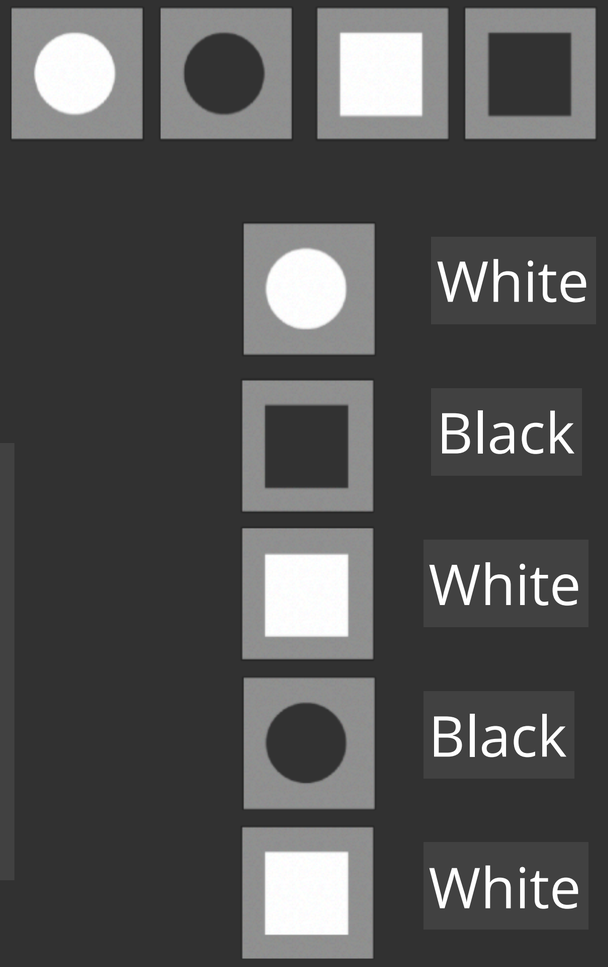
Facilitation in reading one dimension when the other provides redundant information.

Filtering Interference

Difficulty in ignoring one dimension while attending to the other.

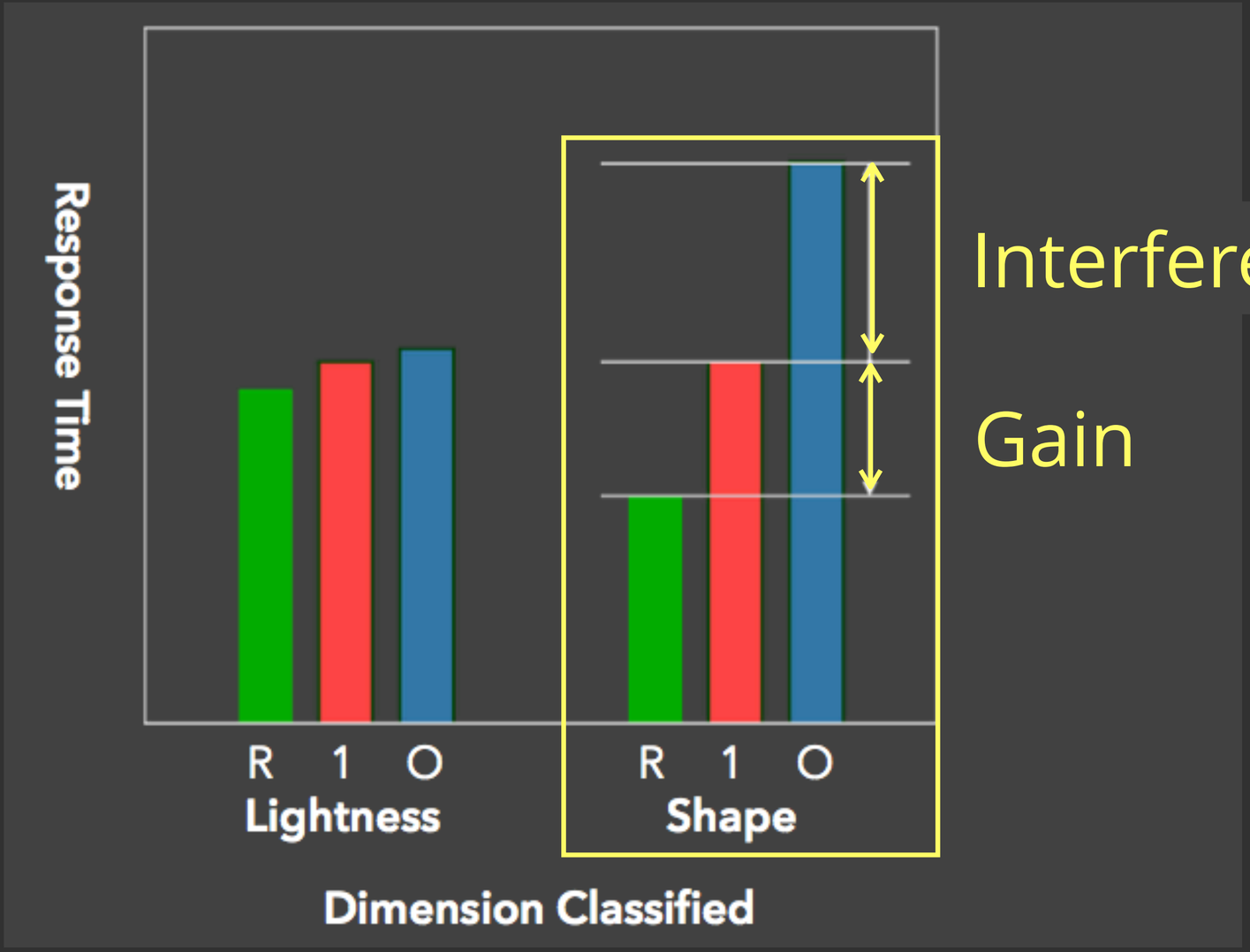
Speeded Classification





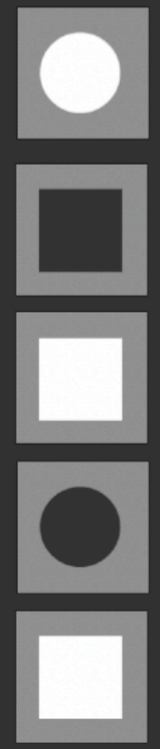
R: Redundant Encoding
1: One-dimensional
O: Orthogonal Encoding

Speeded Classification



Interference

Gain



Circle

Square

Square

Circle

Square

R: Redundant Encoding

1: One-dimensional

O: Orthogonal Encoding

Types of Perceptual Dimensions

Integral

Filtering interference and redundancy gain

Separable

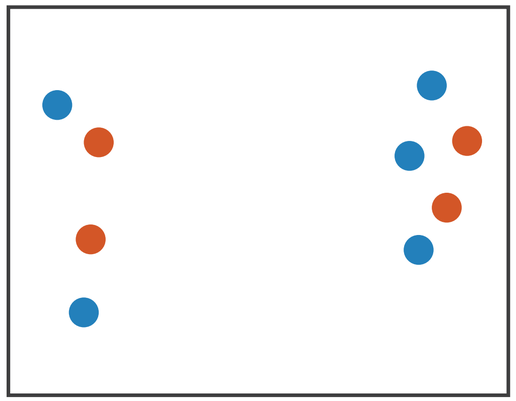
No interference or gain

Asymmetric

One dimension separable from other, not vice versa
e.g., Lightness was not really influenced by shape

Separability vs. Integrality

Position
+ Hue (Color)



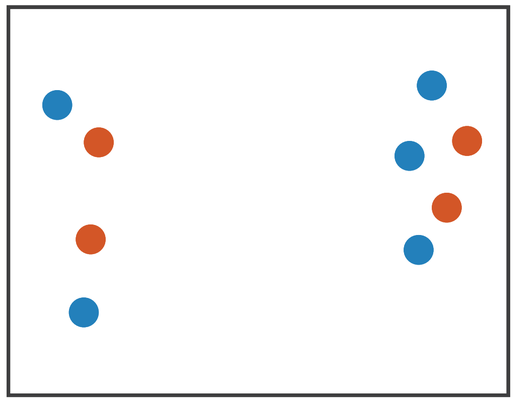
Fully separable

What we perceive:
2 groups each

[Tamara Munzner

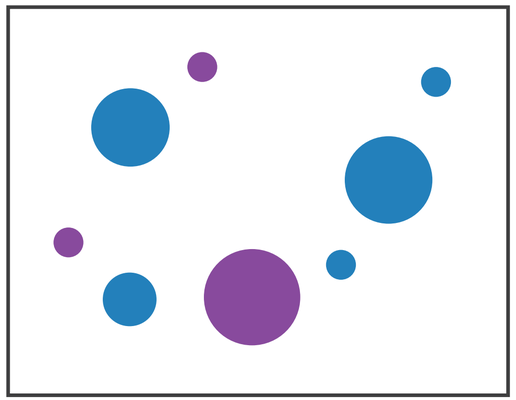
Separability vs. Integrality

Position
+ Hue (Color)



Fully separable

Size
+ Hue (Color)



Some interference

What we perceive:

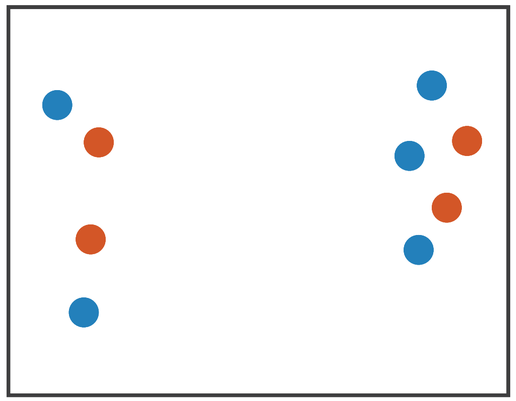
2 groups each

2 groups each

[Tamara Munzner 14]

Separability vs. Integrality

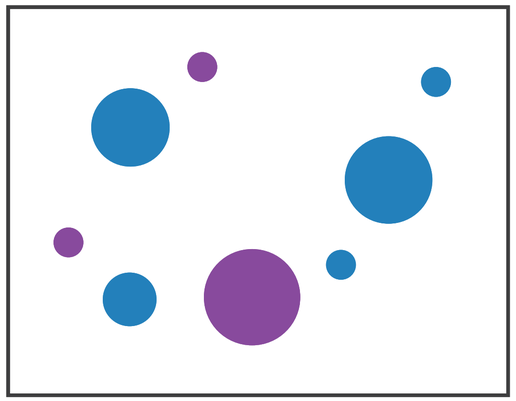
Position
+ Hue (Color)



Fully separable

What we perceive:
2 groups each

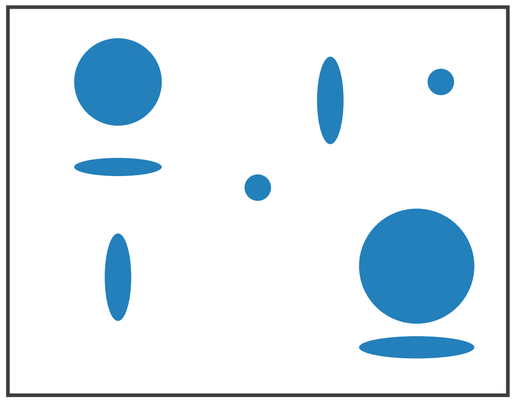
Size
+ Hue (Color)



Some interference

2 groups each

Width
+ Height

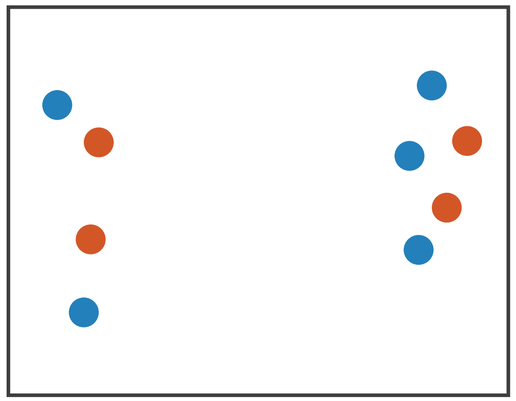
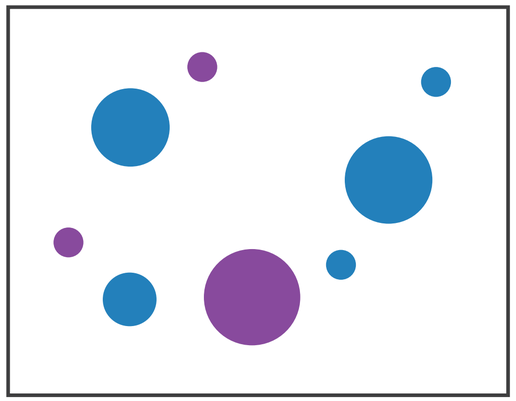
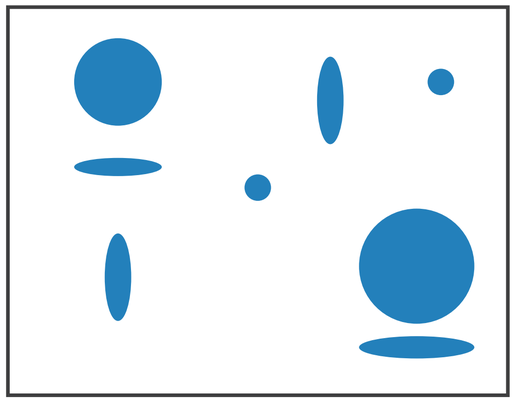
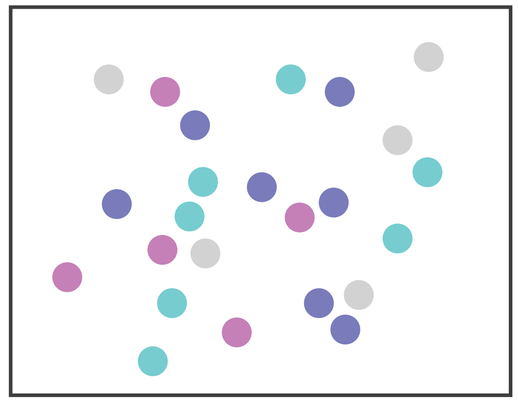


Some/significant interference

3 groups total:
integral area

[Tamara Munzner

Separability vs. Integrality

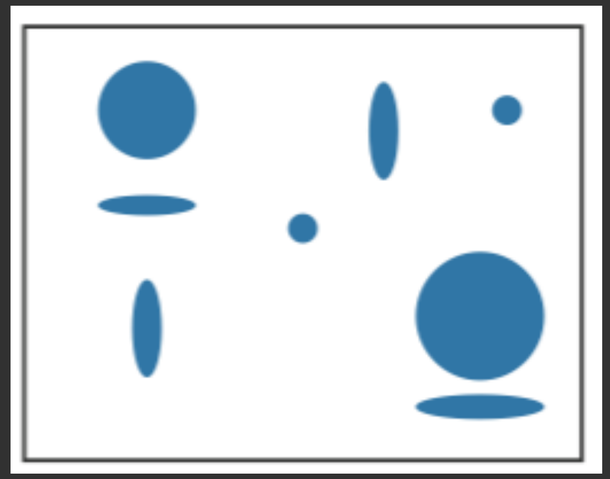
Position + Hue (Color)	Size + Hue (Color)	Width + Height	Red + Green
			
Fully separable	Some interference	Some/significant interference	Major interference
What we perceive: 2 groups each	2 groups each	3 groups total: integral area	4 groups total: integral hue

[Tamara Munzner 14]

Not about good or bad

Match the characteristics of the channels to the information that is encoded.

For a single data attribute with three categories, this may work just fine: small, flattened, and large.



[Tamara Munzner 14]

Gestalt Grouping

Principles of Perceptual Organization

Similarity

Proximity

Uniformed Connectedness

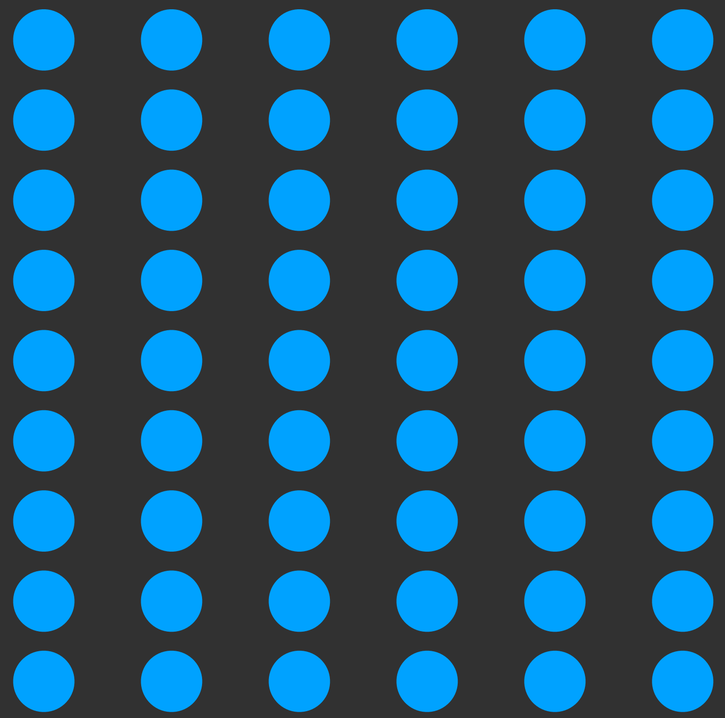
- Connection
- Enclosure

Continuity

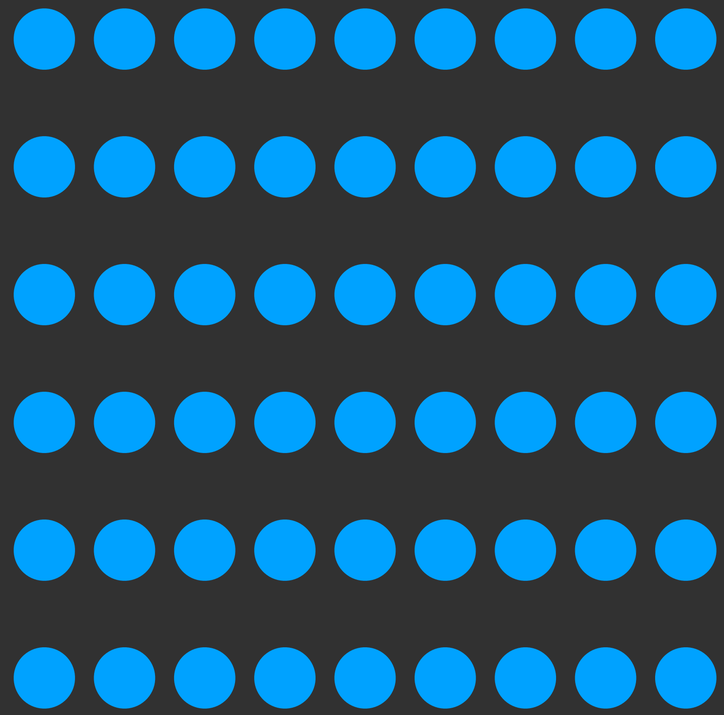
Symmetry

and there are more not covered here...

Proximity

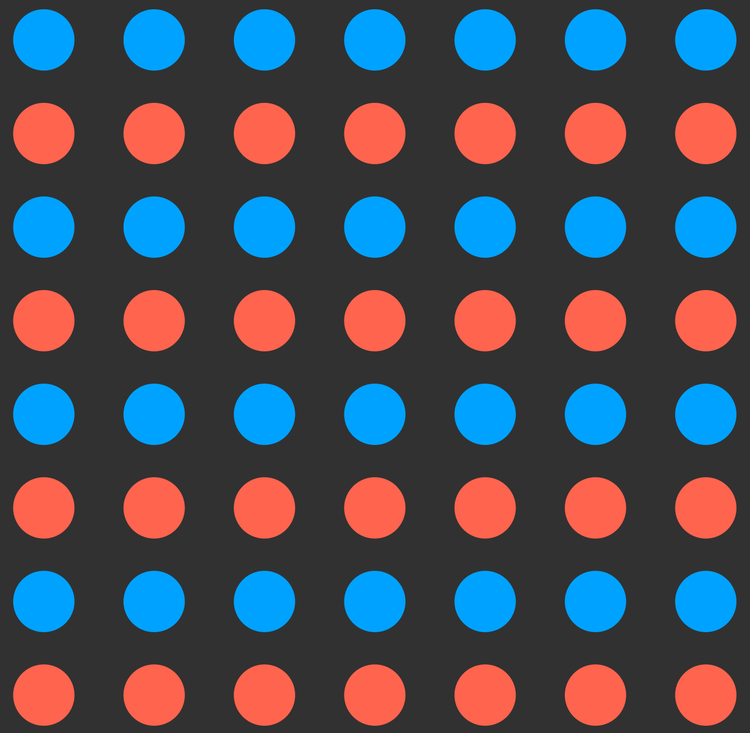


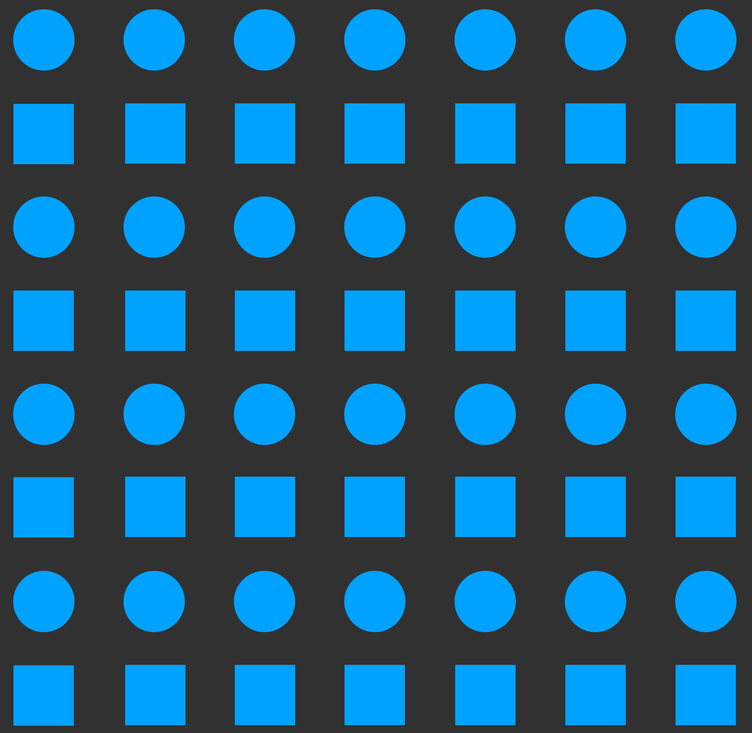
Columns



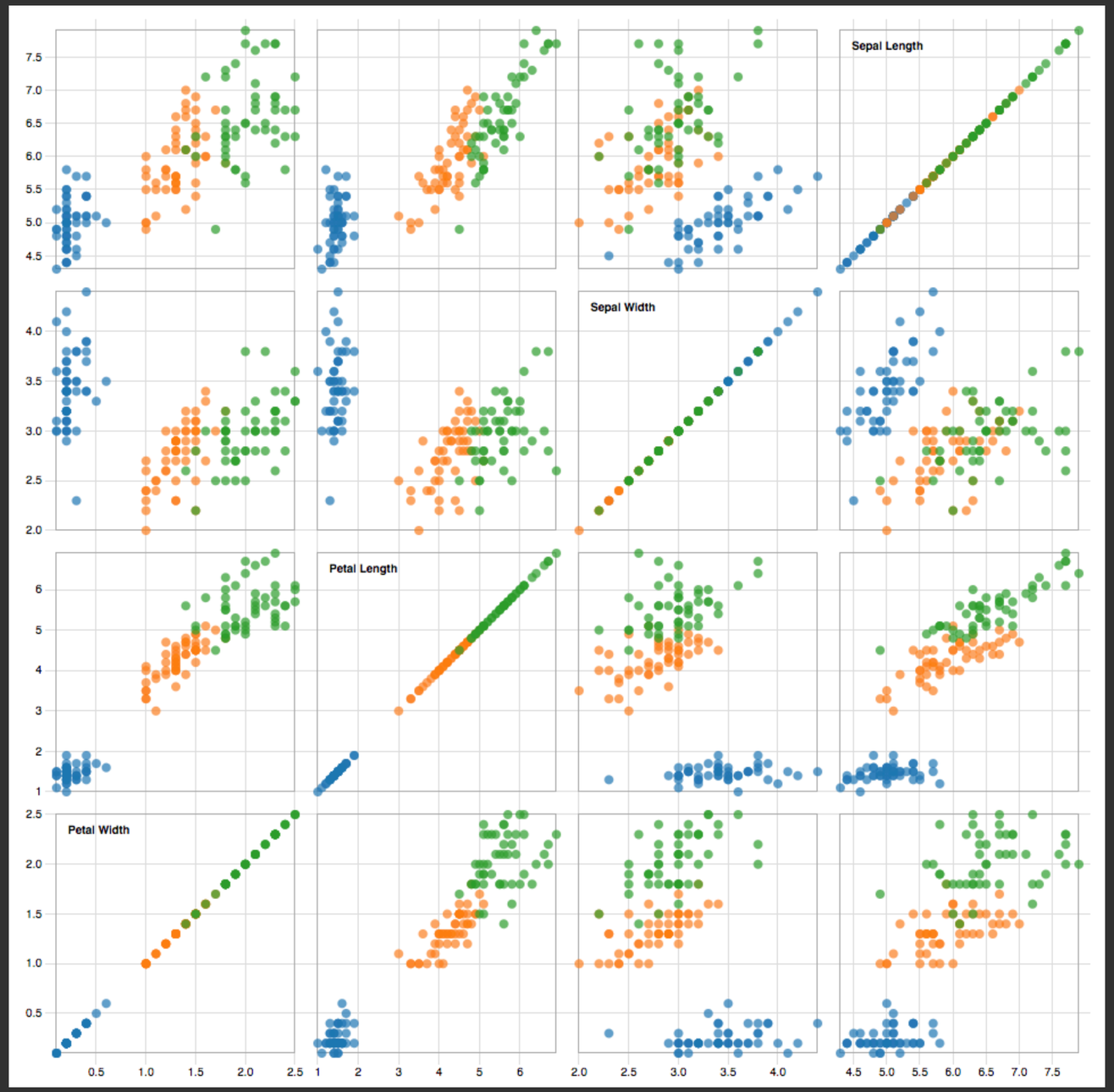
Rows

Similarity





Rows stand out due to similarity.

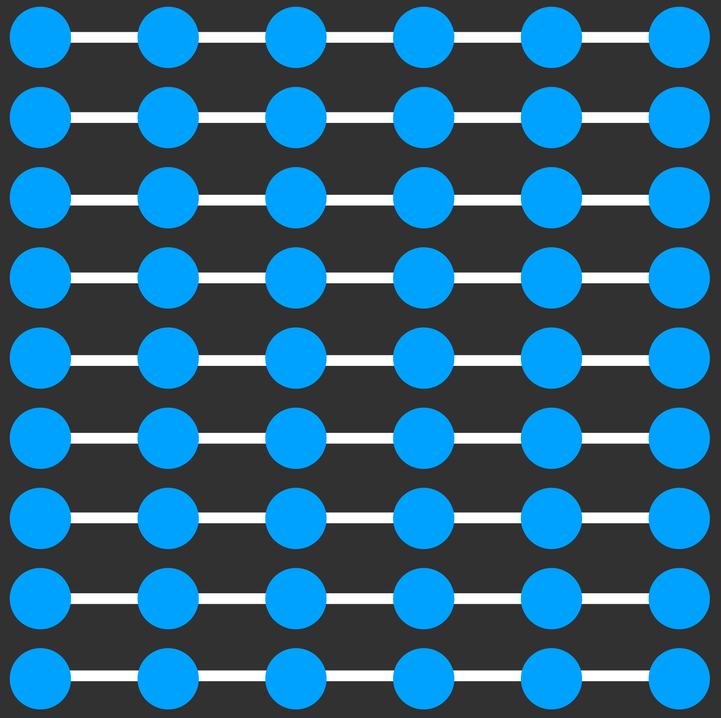


Scatter Plot Matrix

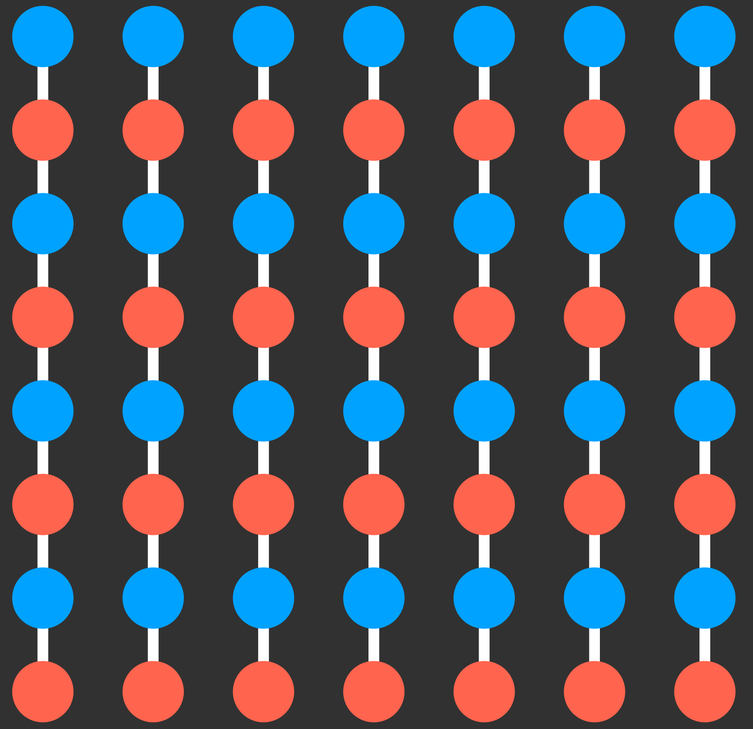
Clusters and outliers

Uniformed Connectedness: Connection

Connectedness dominates proximity and similarity

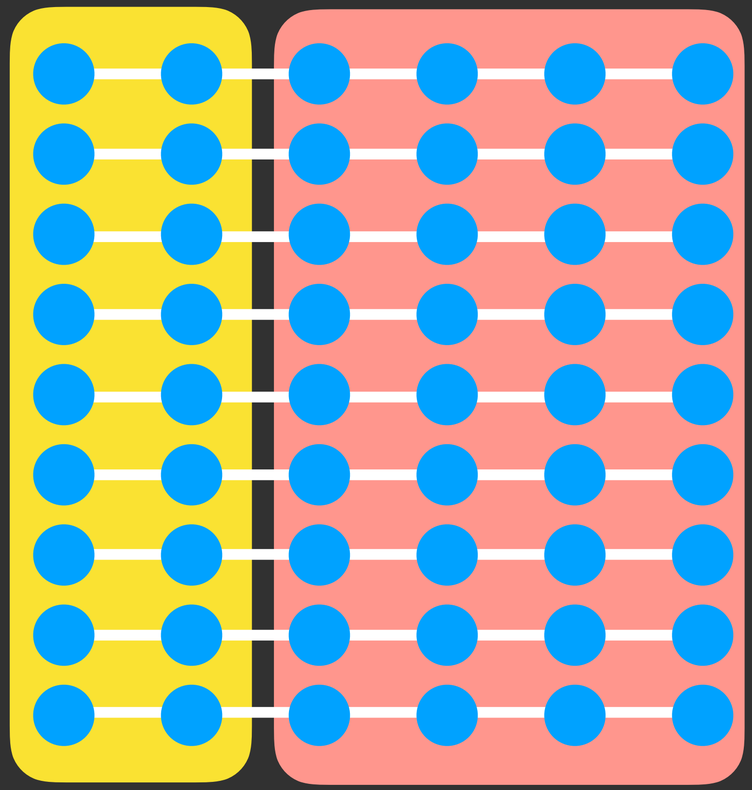


Proximity (column)
vs connection (row)



Similarity (row)
vs connection (column)

Uniformed Connectedness: Enclosure



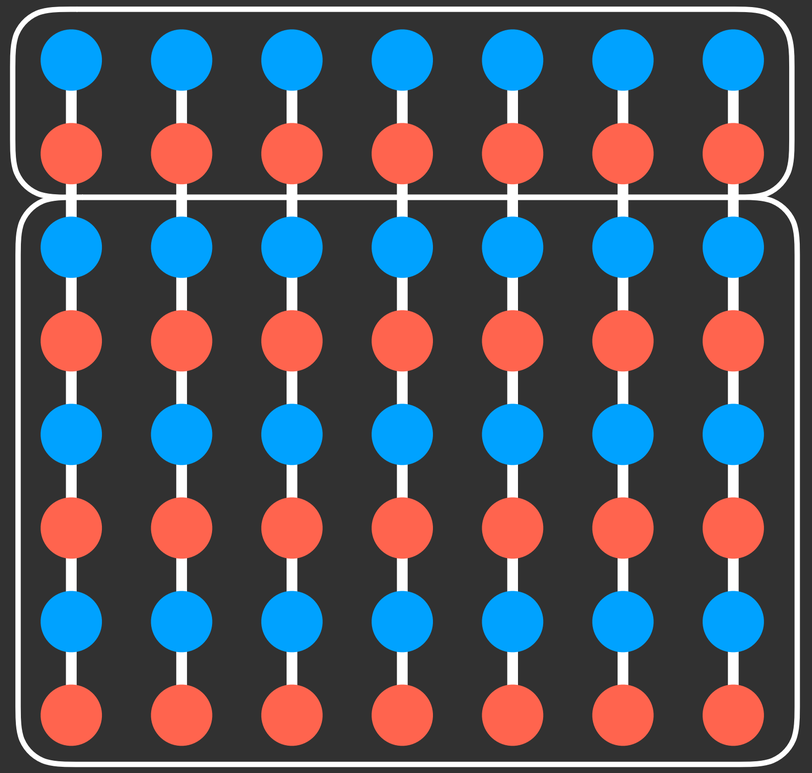
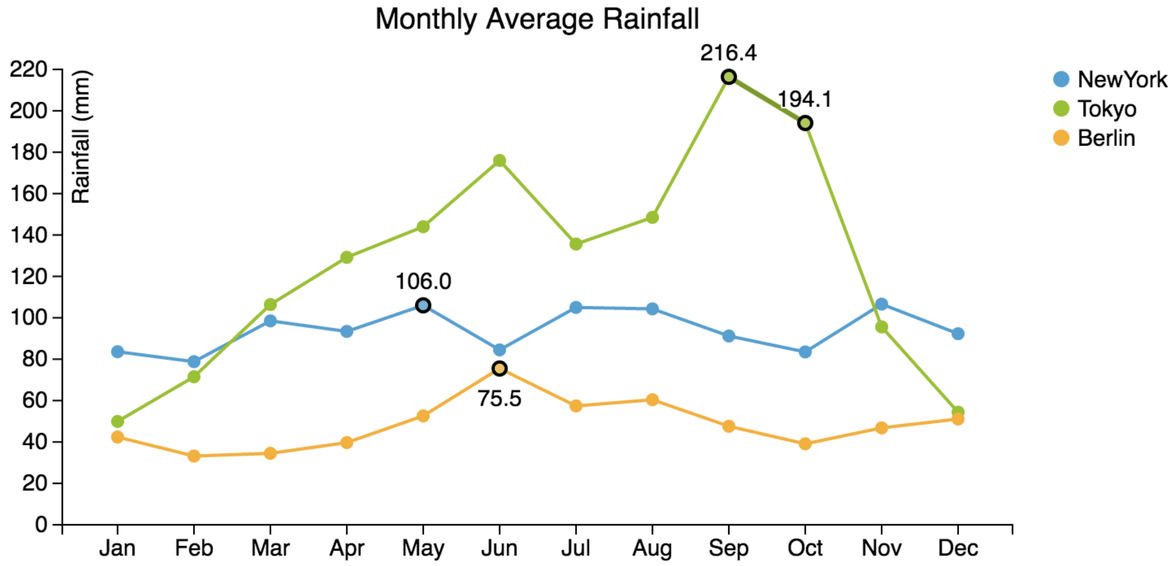
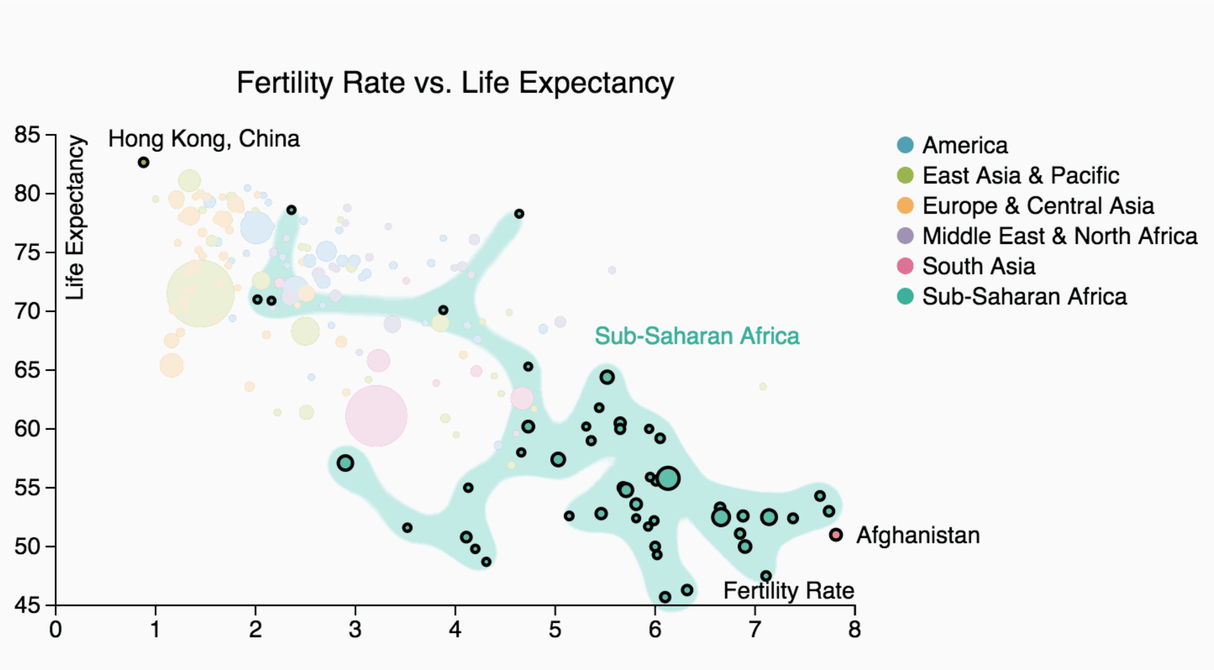


Chart Annotations



Connection



Enclosure

[https://chartaccent.github.io/]

Visualizing Sets

Bubble Sets

Image by [Dinkla et al., 2011]
Technique by [Collins et al.,2009]

Line Sets

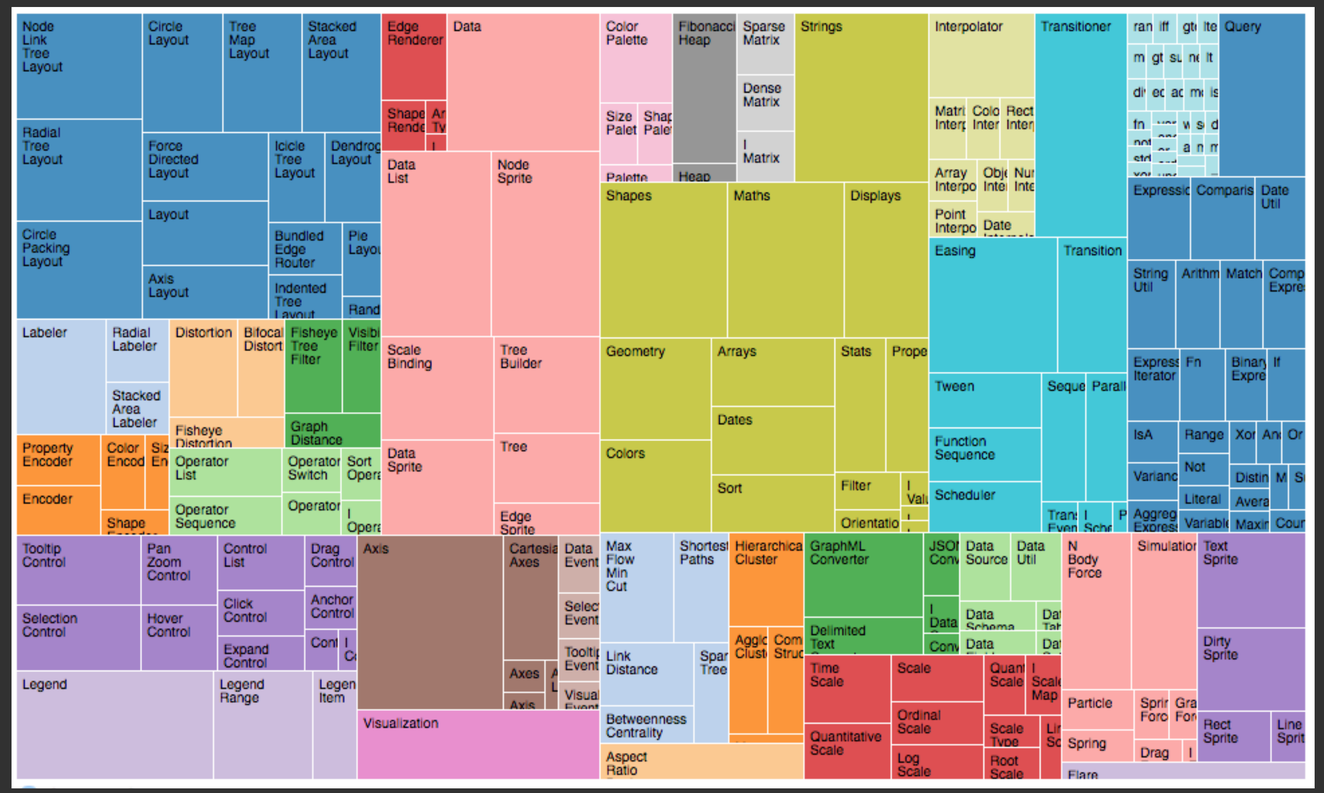
[Alper et al., 2011]

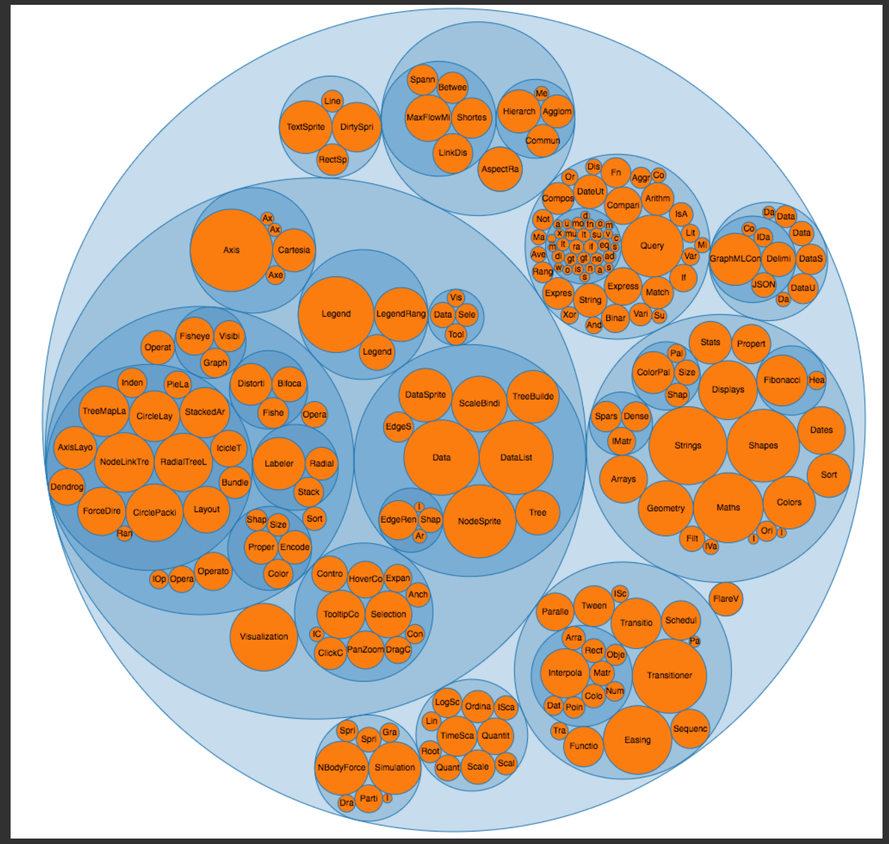
Kelp Diagrams

[Dinkla et al., 2012]

[Slides from A. Lex]

TreeMap and Circle Packing



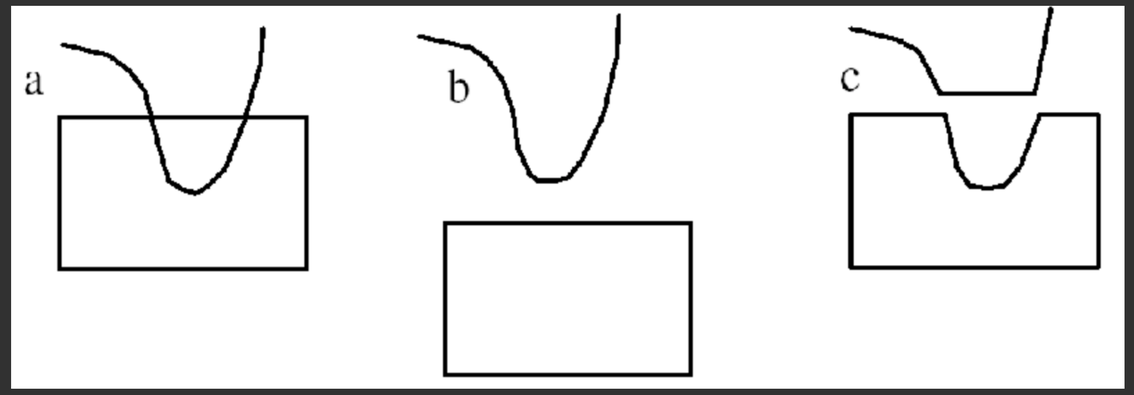


https://bl.ocks.org/mbostock/4063582

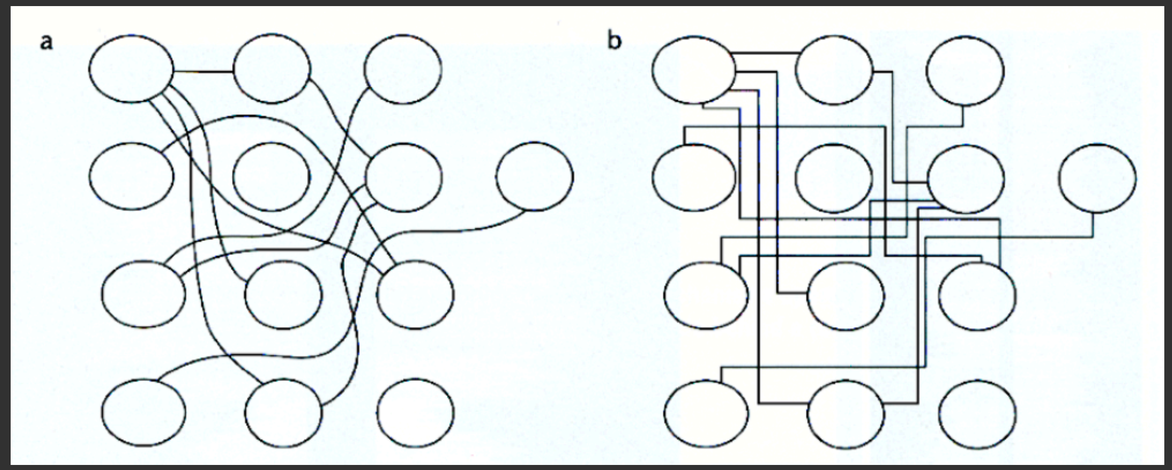
https://bl.ocks.org/mbostock/4063530

Proximity, Similarity, Enclosure

Continuity



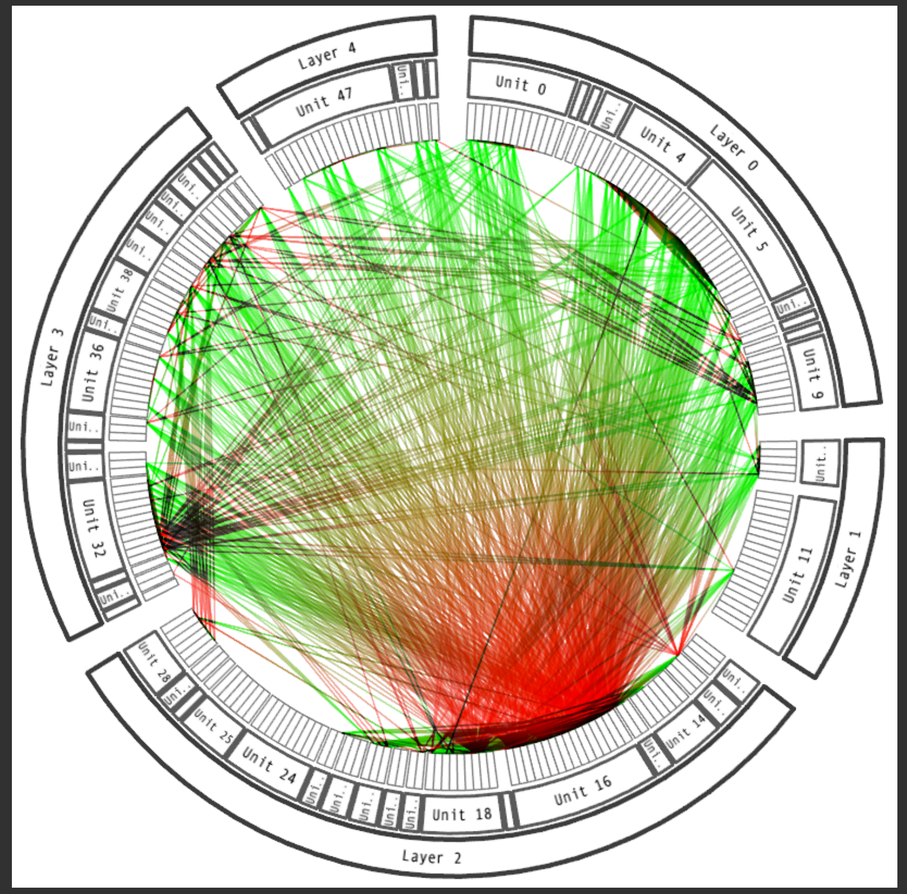
We prefer smooth not abrupt changes

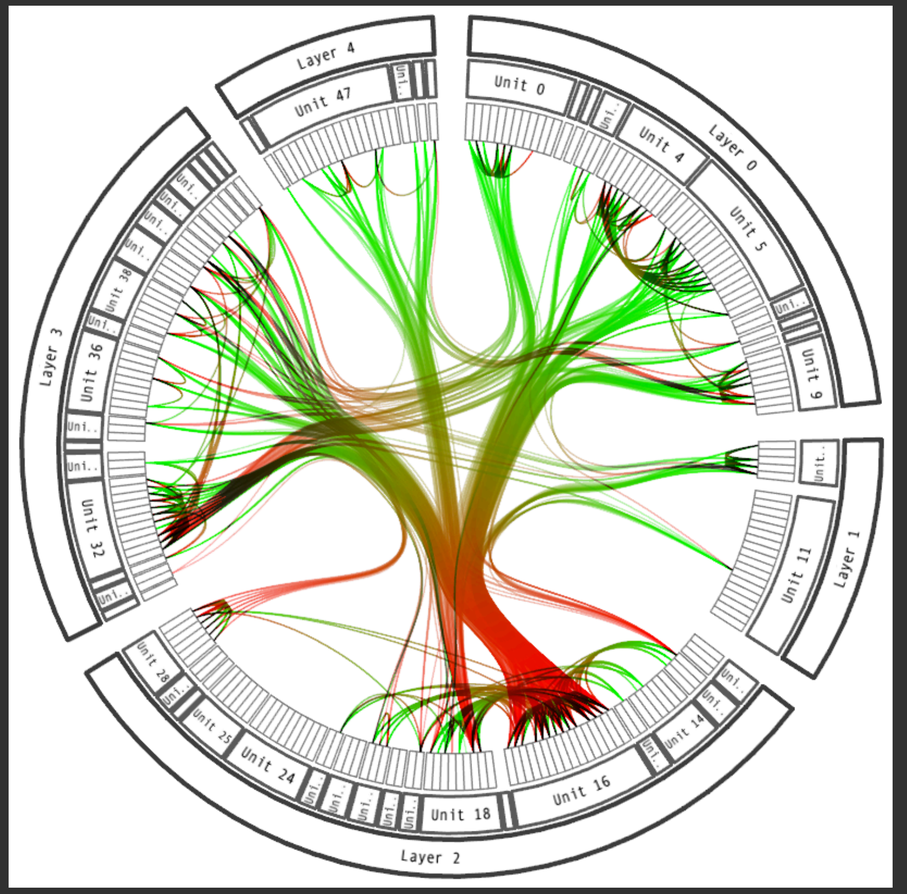


Connections are clearer with smooth contours

[from Ware 04]

Hierarchical Edge Bundling

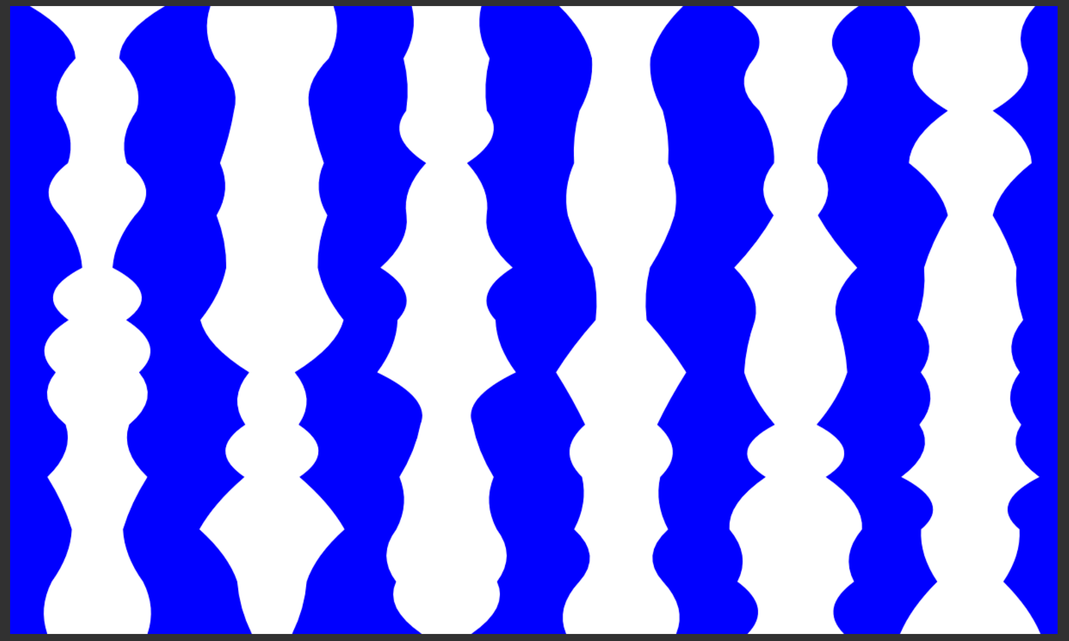


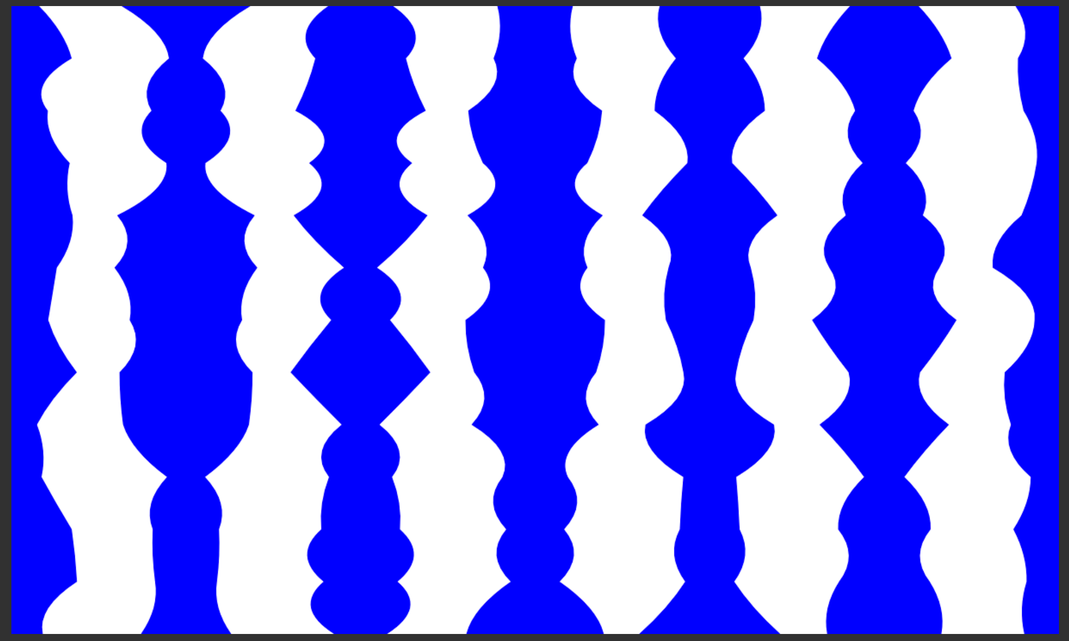


[Holten 06]

Symmetry

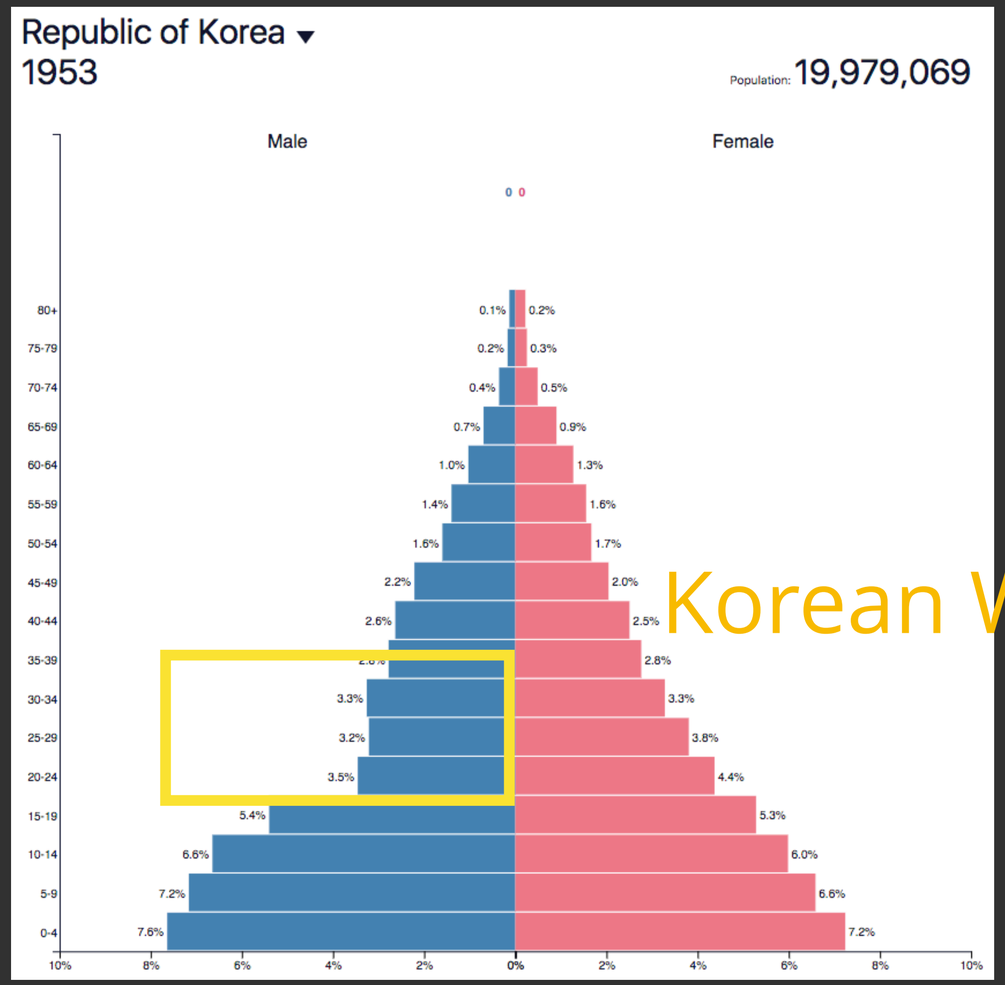
Elements that are symmetrical to each other tend to be grouped together.



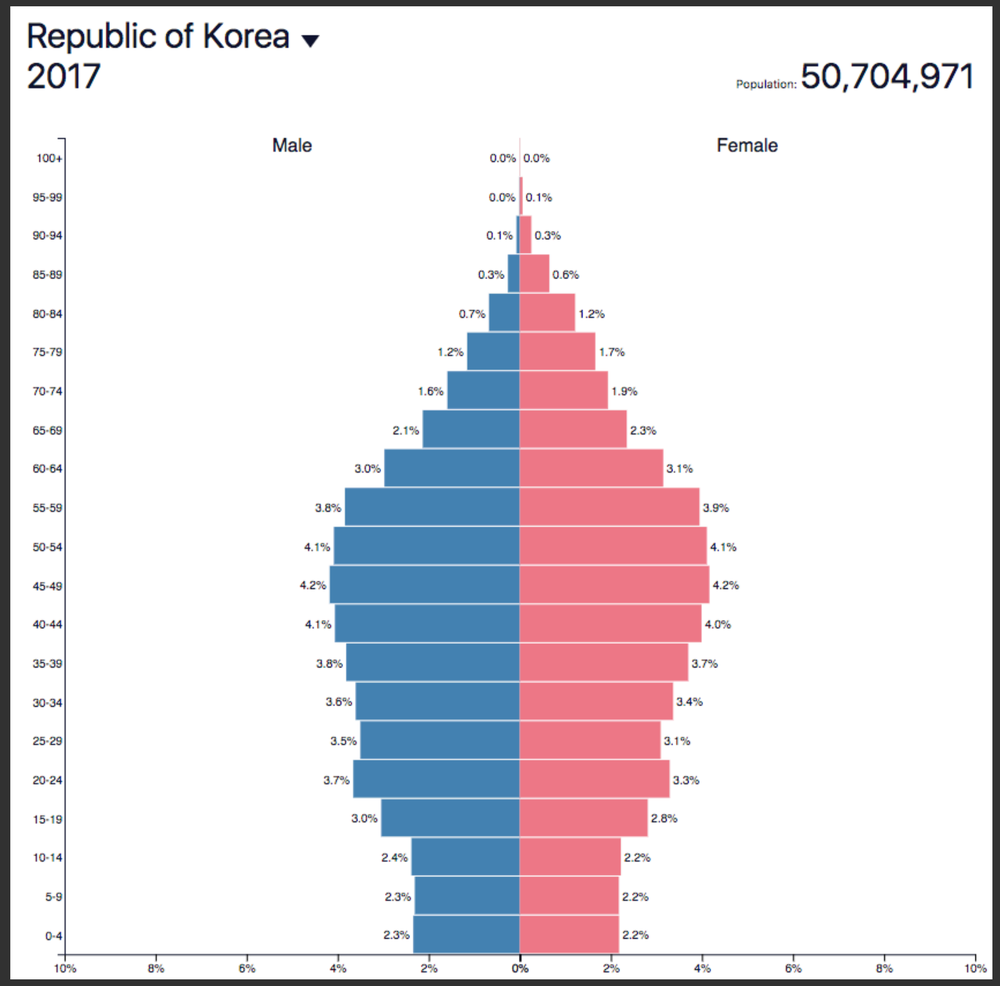


https://www.populationpyramid.net/united-states-of-america/2017/

Population Pyramid (or tornado chart?)



Korean War?



https://www.populationpyramid.net/united-states-of-america/2017/

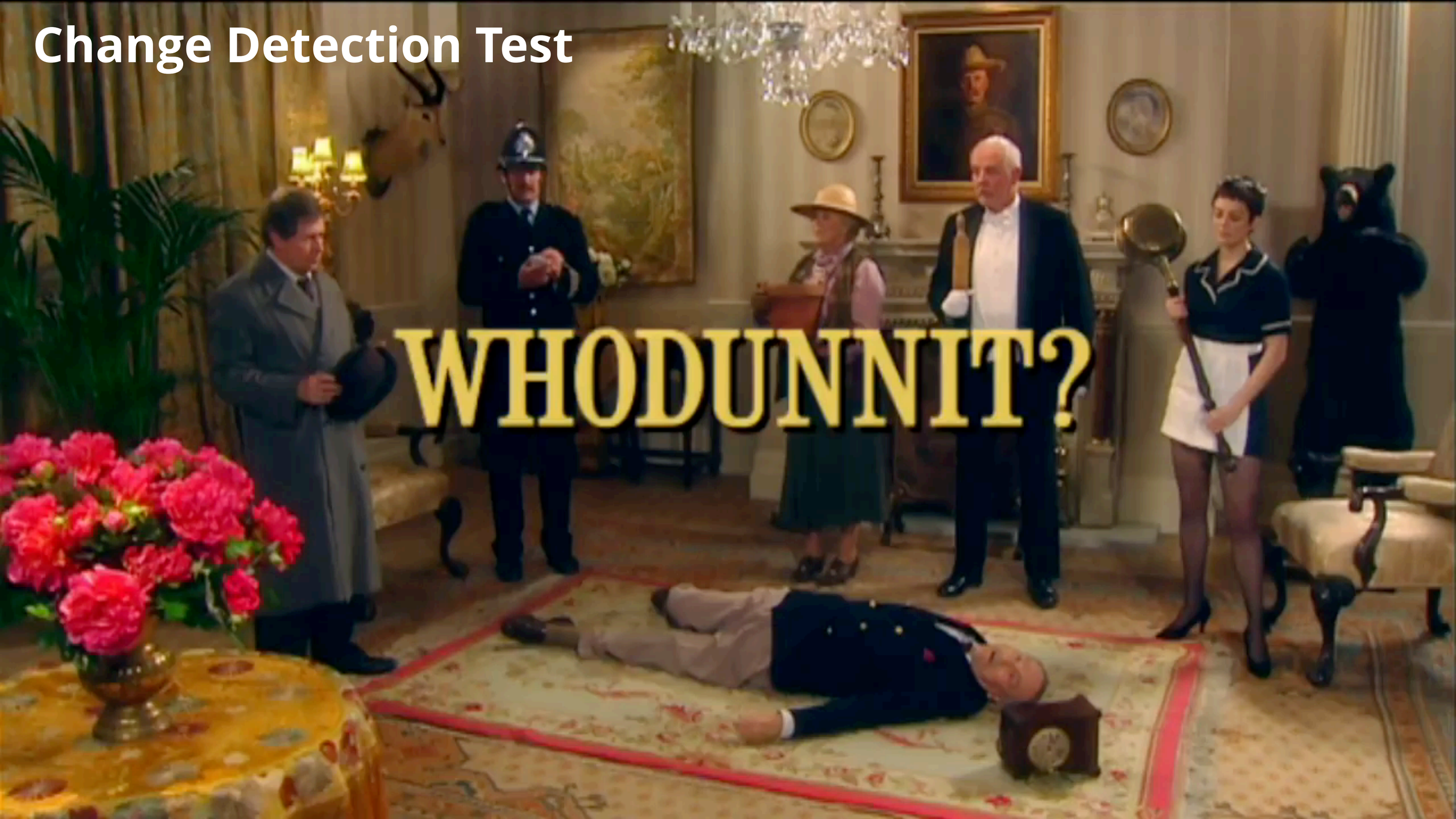
Change Blindness

The phenomenon where even very large changes are not noticed if we are attending to something else.

Change Detection Test

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

Change Detection Test

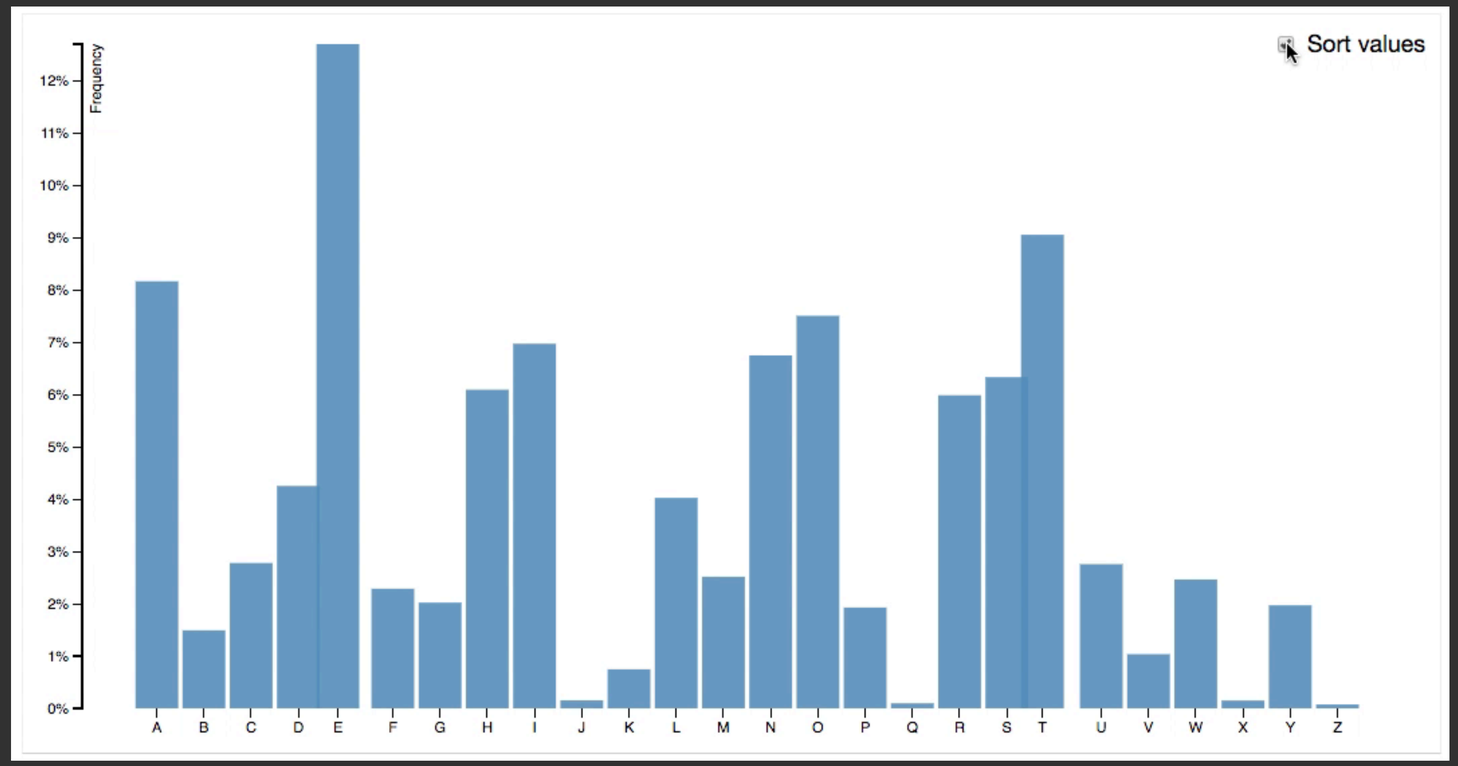


“To see an object change, it is necessary to attend to it.”
— Ronald A. Rensink

Reducing change blindness in visualization

Provide attentional guidance by leveraging pre-attentive features, Gestalt principles, etc.

Example: Ease tracking objects through motion



https://bl.ocks.org/mbostock/3885705

Topics

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

Take away

Knowledge of perception can benefit visualization design

1. Human don’t perceive changes and magnitude at face value.
2. Use pre-attentive visual features for faster target detection.
3. Be aware of interference and redundancy of multiple features.
4. Leverage gestalt principles for high-level grouping.
5. Change blindness in visualization is the failure of design, not because of our vision system.

Today

Fundamental

1. Value of visualization
2. Design principles
3. Graphical perception

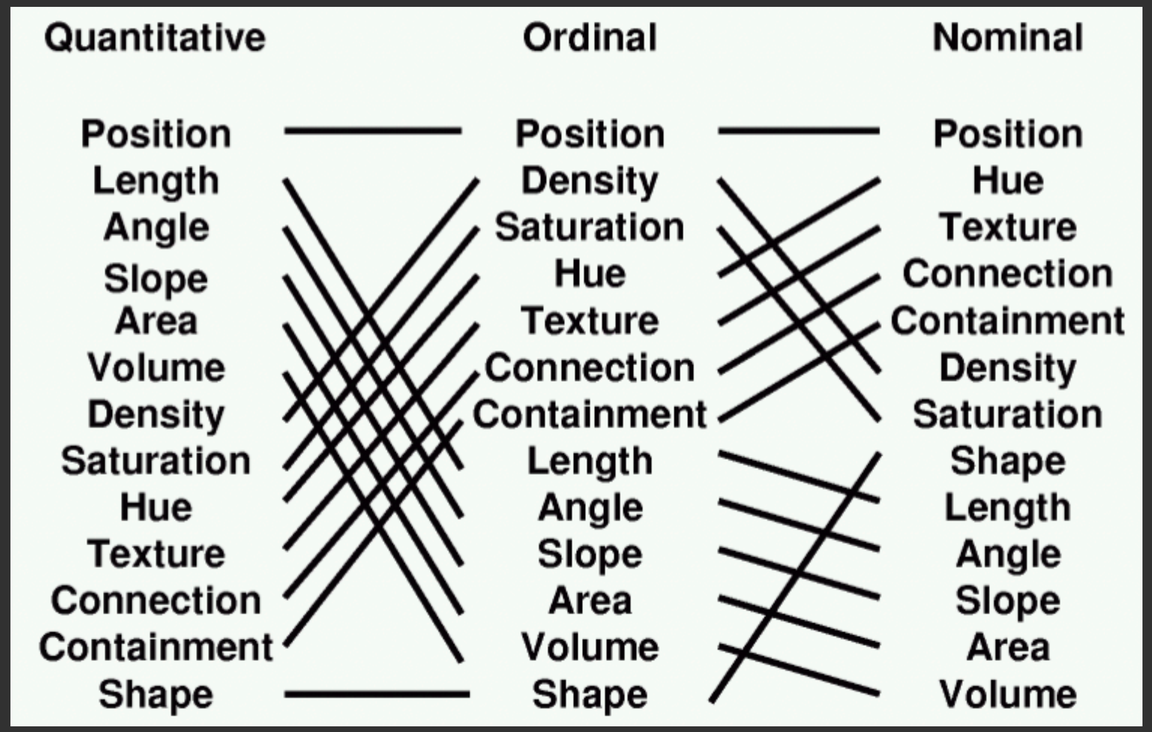
Tomorrow

Practical

1. Data model and visual encoding
2. Exploratory data analysis
3. Storytelling with data
4. Advanced visualizations

Next

Data model
and visual encoding



Rankings of visual variables
for quantitative, ordinal, and normal data

See you tomorrow!