Lecture 8
Graphical Perception

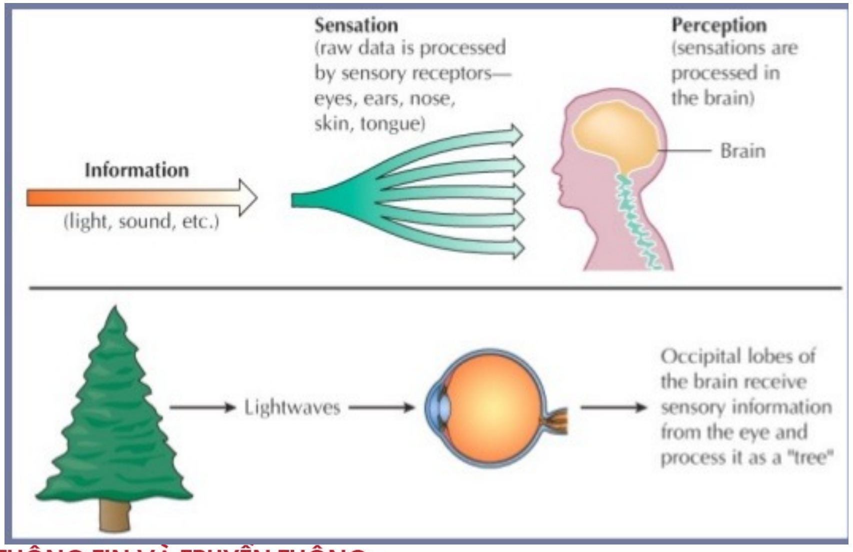
What is graphical perception?

- The human capacity for visually interpreting information on graphs and charts
- The visual decoding of information encoded on graphs

Sensation vs. perception

- Sensation
  - The process by which our sensory receptors and nervous system receive stimulus from the environment

- Perception
  - The process of organizing and interpreting sensory information, enabling us to recognize meaningful objects and events



Sensation

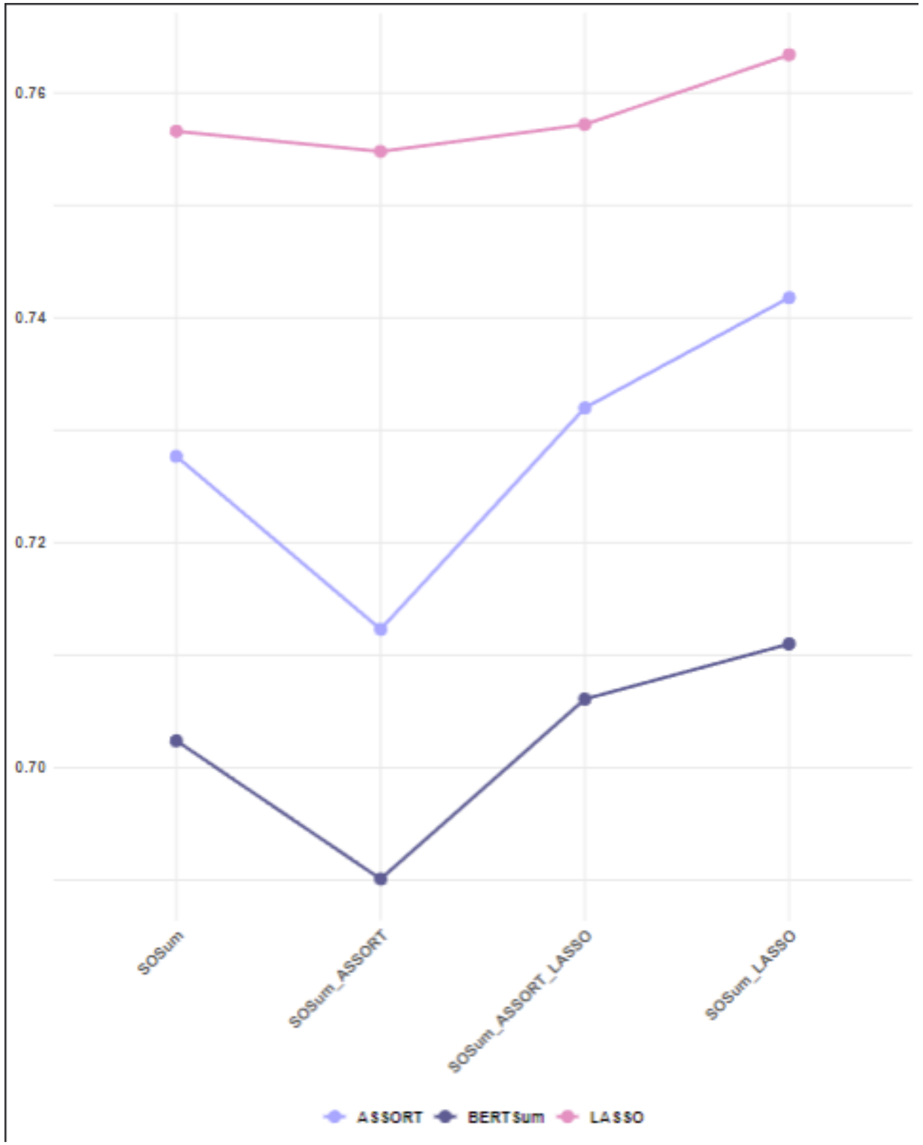
"The process by which our sensory receptors and nervous system receive and represent stimulus energies from our environment."

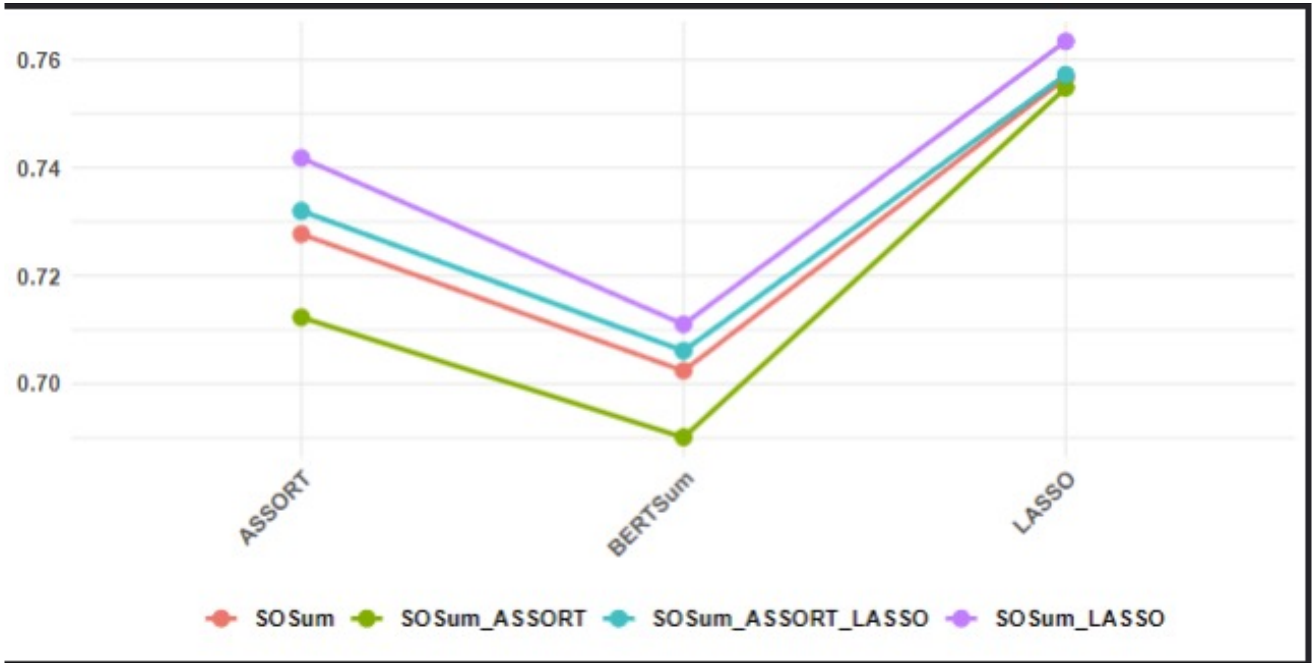
Perception

"The process of organizing and interpreting sensory information, enabling us to recognize meaningful objects and events."

The brain receives input from the sensory organs.

The brain makes sense out of the input from sensory organs.


0.76
0.74
0.72
0.70
SOSum
SOSum_ASSORT
SOSum_ASSORT_LASSO
SOSum_LASSO
ASSORT
BERTSum
LASSO


0.76
0.74
0.72
0.70
ASSORT
BERTSum
LASSO
SOSum
SOSum_ASSORT
SOSum_ASSORT_LASSO
SOSum_LASSO

Example

- Bottom-Up Processing
  - Analysis that begins with the sense receptors and works up to the brain's integration of sensory information
    - Example: piecing lines together to recognize a number
    - SENSATION

- Top-Down Processing
  - Information processing guided by higher-level mental processes
  - constructing perceptions by drawing on our experiences and expectations
    - Example: Thinking you know someone and as they get closer, you realize that you don’t
    - PERCEPTION

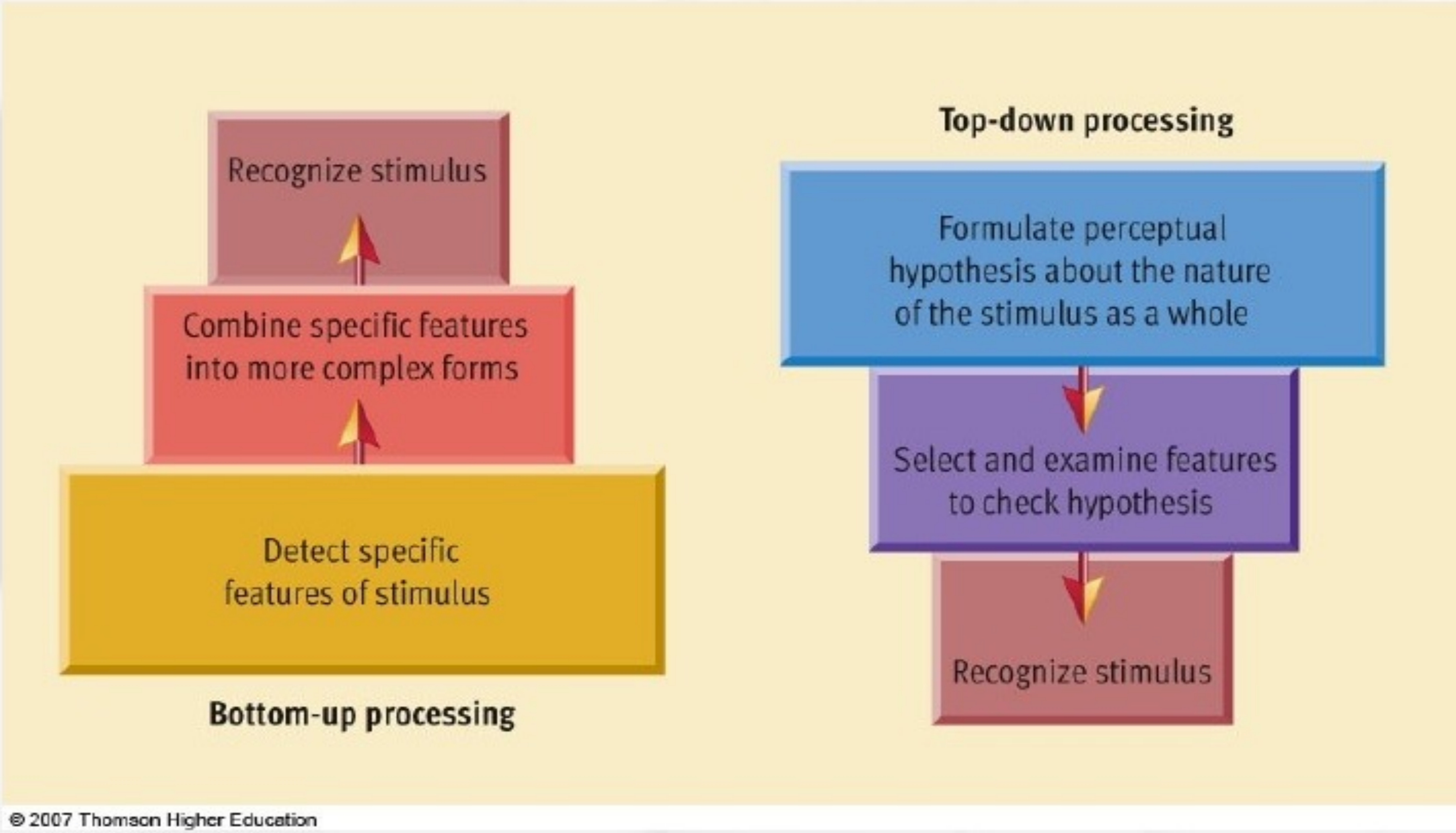


Figure 4.17 Bottom-up versus top-down processing

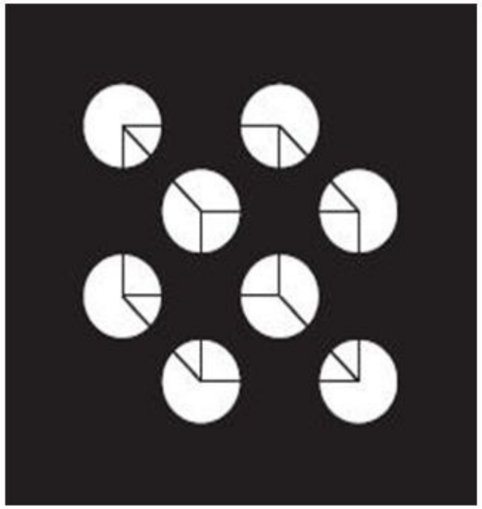
Bottom Up and Top Down Processing

- Bottom up processing – processing of current stimulation influences what is perceived
- Top down processing – person's background knowledge, learning and expectations influence what is perceived.

Bottom up processing is data driven.

Top down processing is theory-driven, knowledge-driven, and context-driven.

Example of top down processing:
Your knowledge of rectilinear solids informs your perception.



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) (144,144,144)

A B

Detecting Brightness

A Which is brighter? B

Detecting Brightness

(134,134,134) (138,138,138)

A B

Weber’s Law: Just Noticeable Difference (JND)

- also known as the difference threshold, is the minimum level of stimulation that a person can detect 50 percent of the time.

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

Weber's Law: Just Noticeable Difference (JND)

- also known as the difference threshold, is the minimum level of stimulation that a person can detect 50 percent of the time.

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

dS ← Change of Intensity

S ← Physical Intensity

Weber's Law: Just Noticeable Difference (JND)

- also known as the difference threshold, is the minimum level of stimulation that a person can detect 50 percent of the time.

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

dS ← Change of Intensity

S ← Physical Intensity

Weber's Law: Just Noticeable Difference (JND)

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

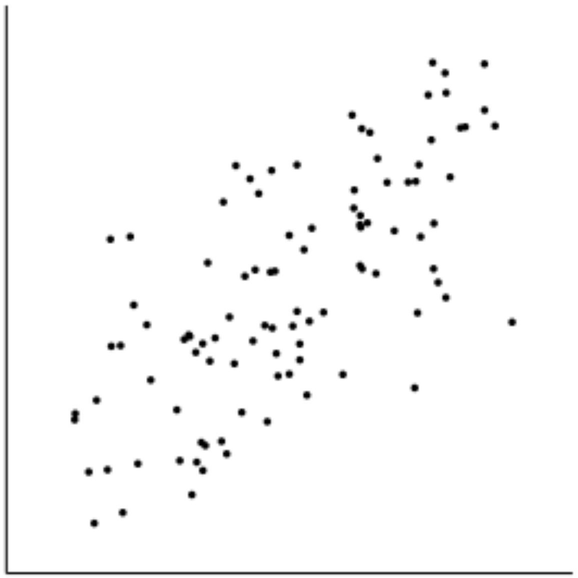
dS ← Change of Intensity

S ← Physical Intensity

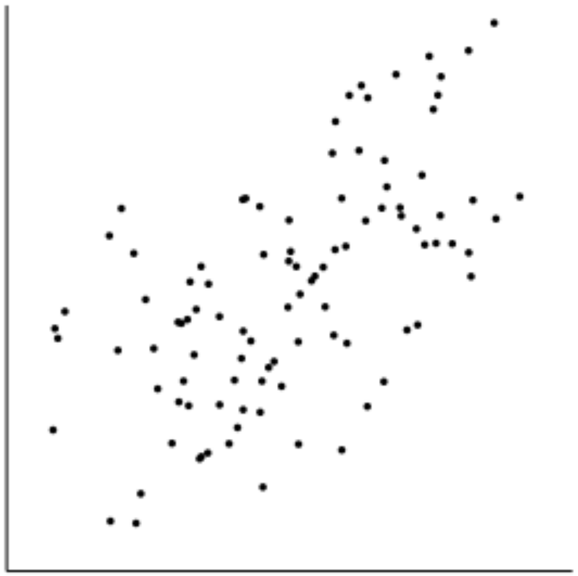
Most continuous variation in stimuli are perceived in discrete steps

Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



A

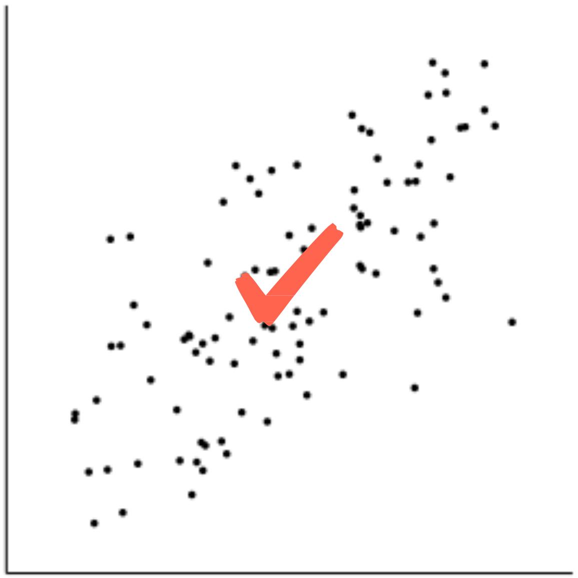


B

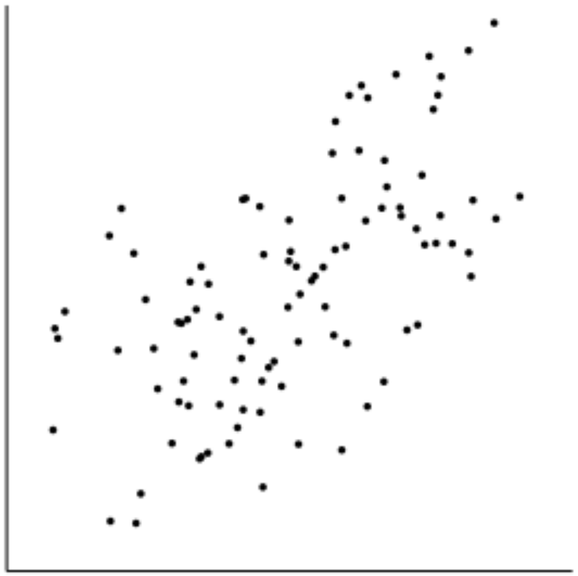
[Harrison et al 2014]

Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



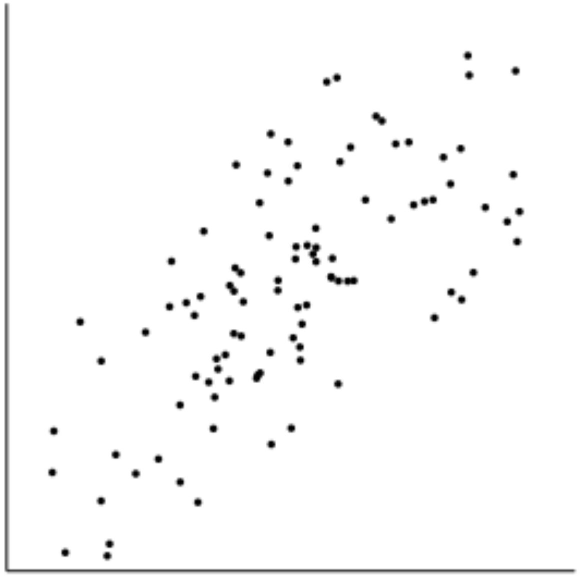
r = 0.7



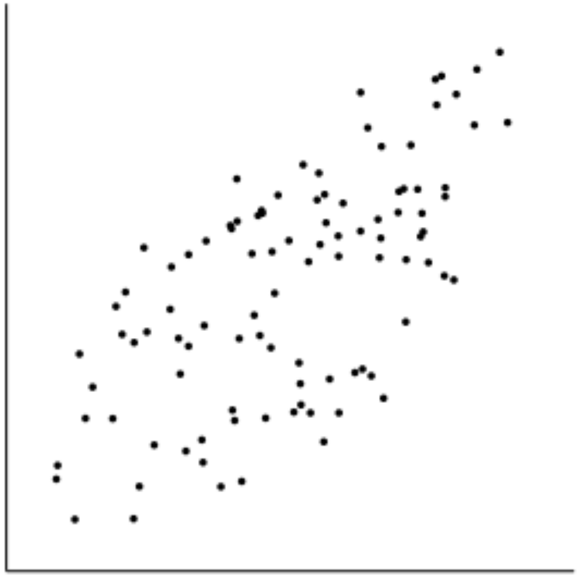
r = 0.6

Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



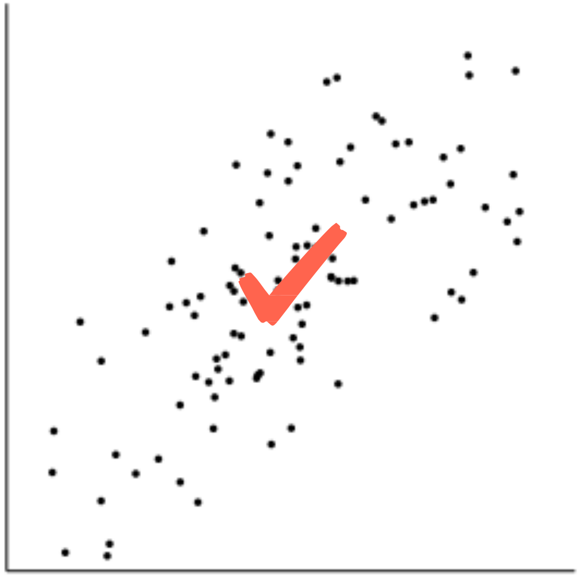
A



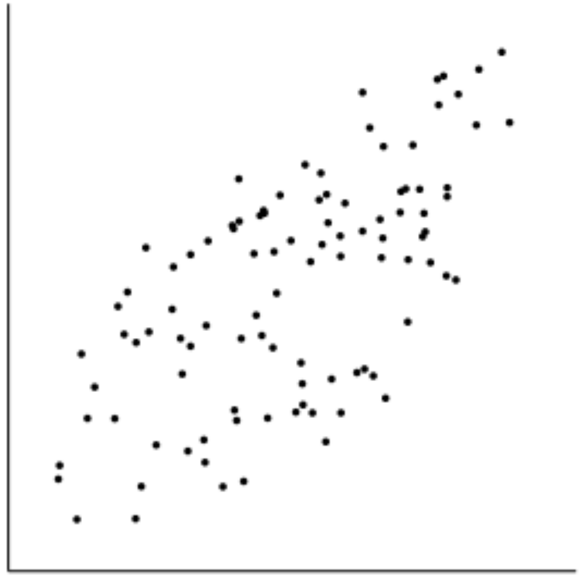
B

Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



r = 0.7

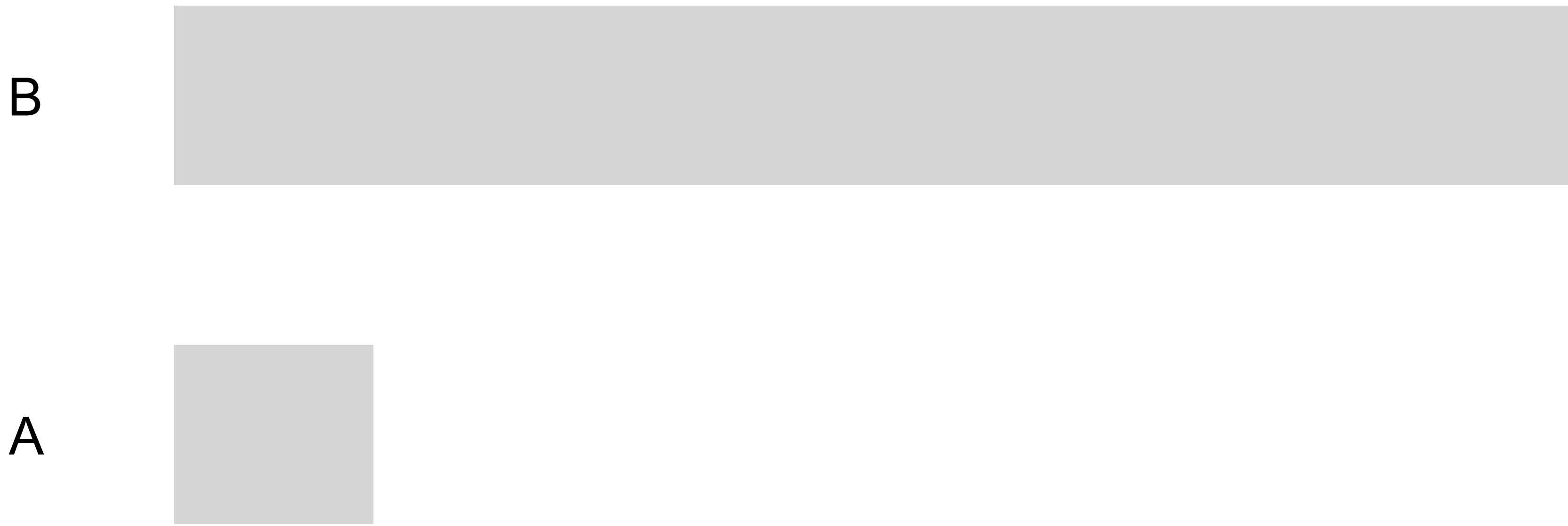


r = 0.65

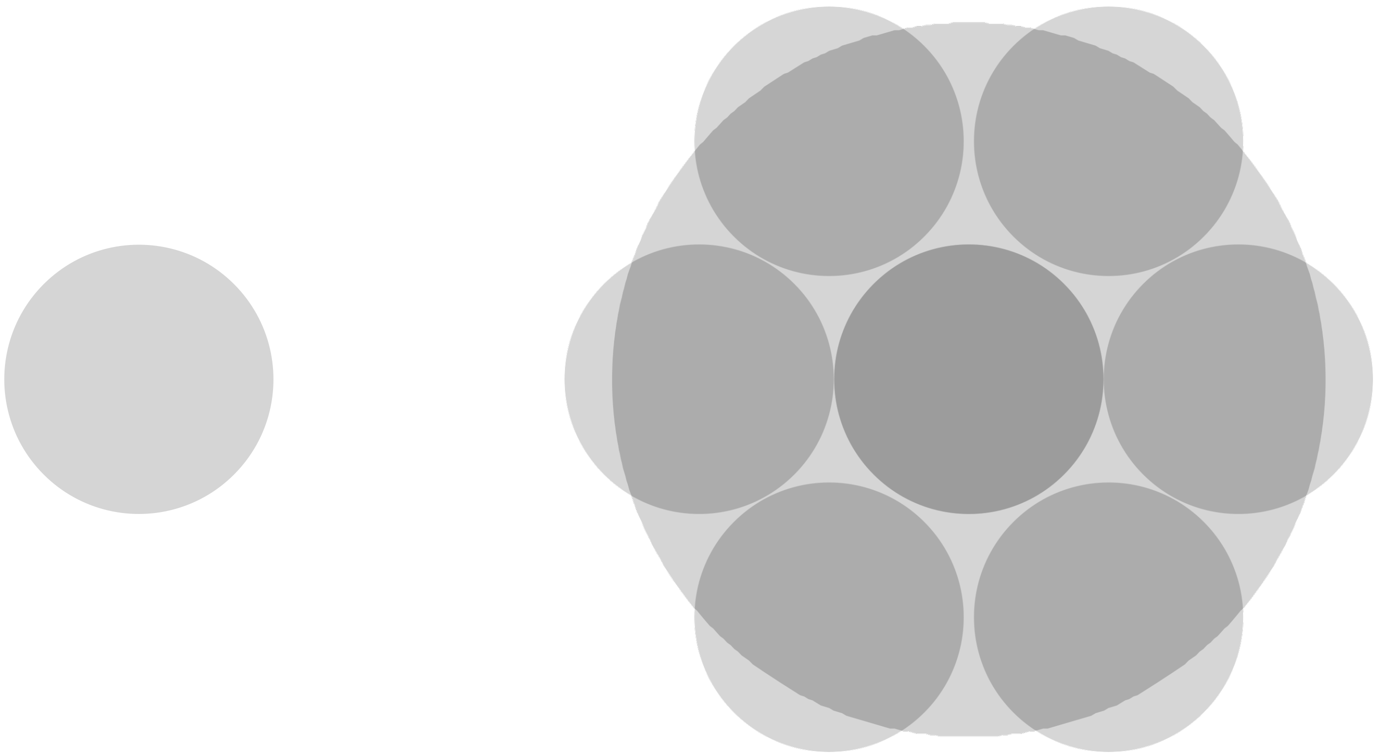
Magnitude Estimation

A Quick Experiment…

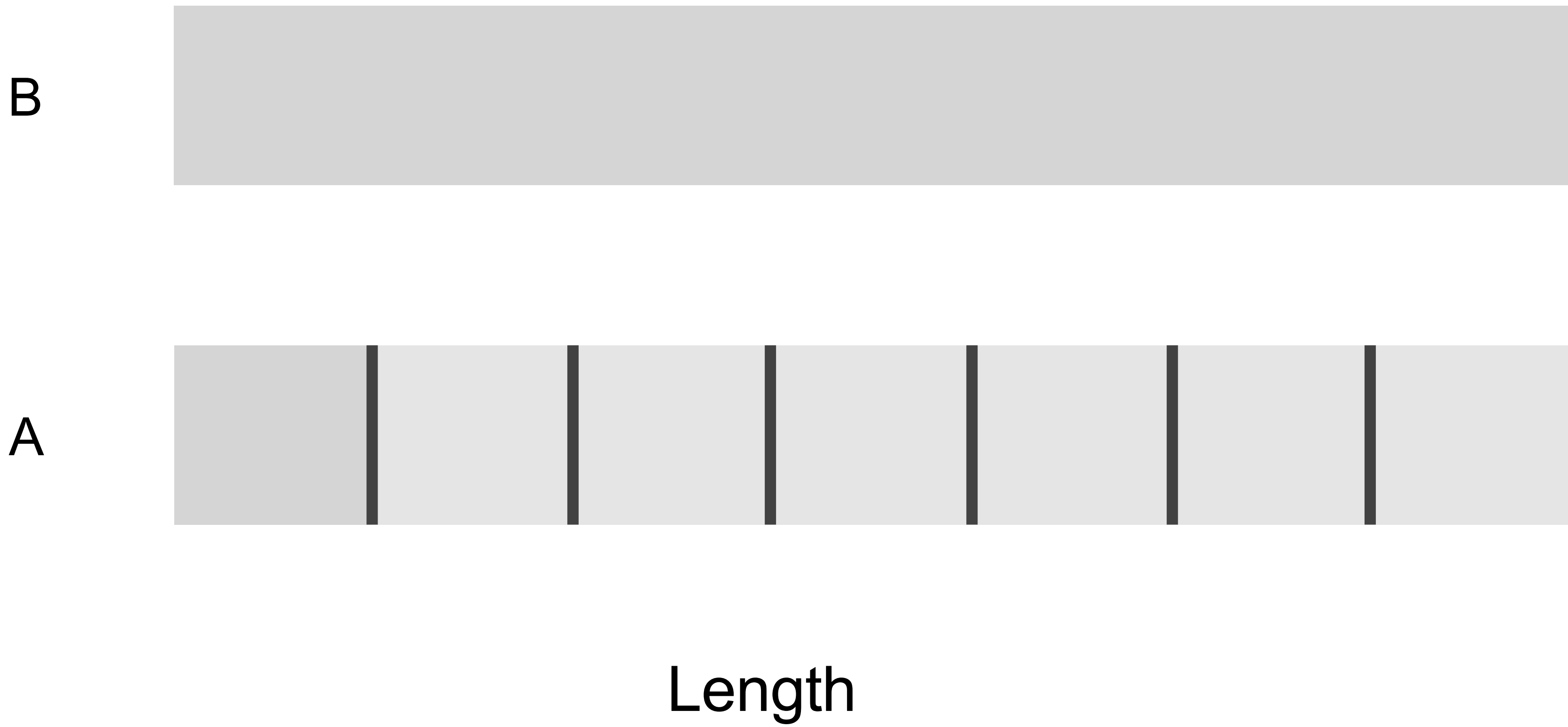
A B


B
A

A B



Area


B
A
Length

Steven's Power Law

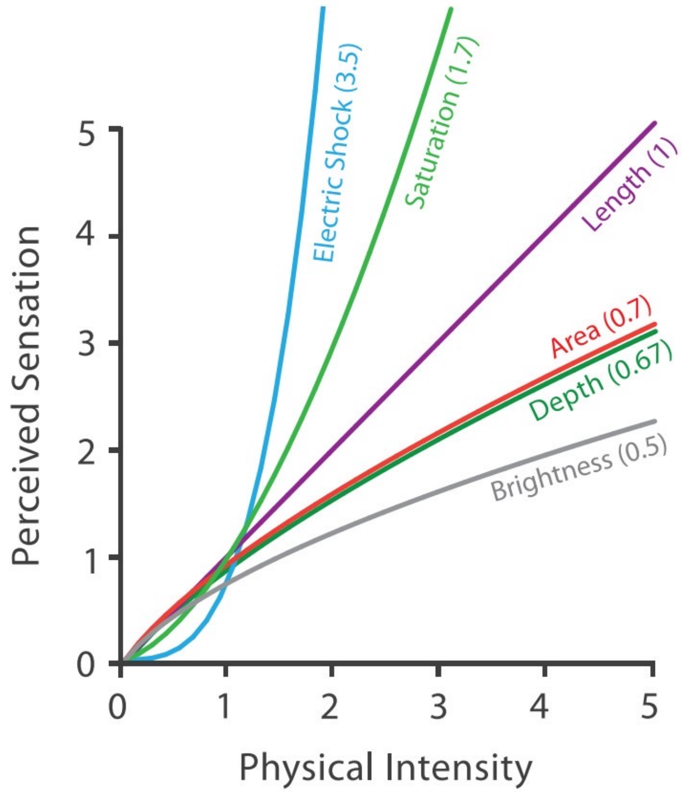
[Graph from T. Munzner 2014]

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

Exponent
(Empirically Determined)

$$S = I^{p}$$

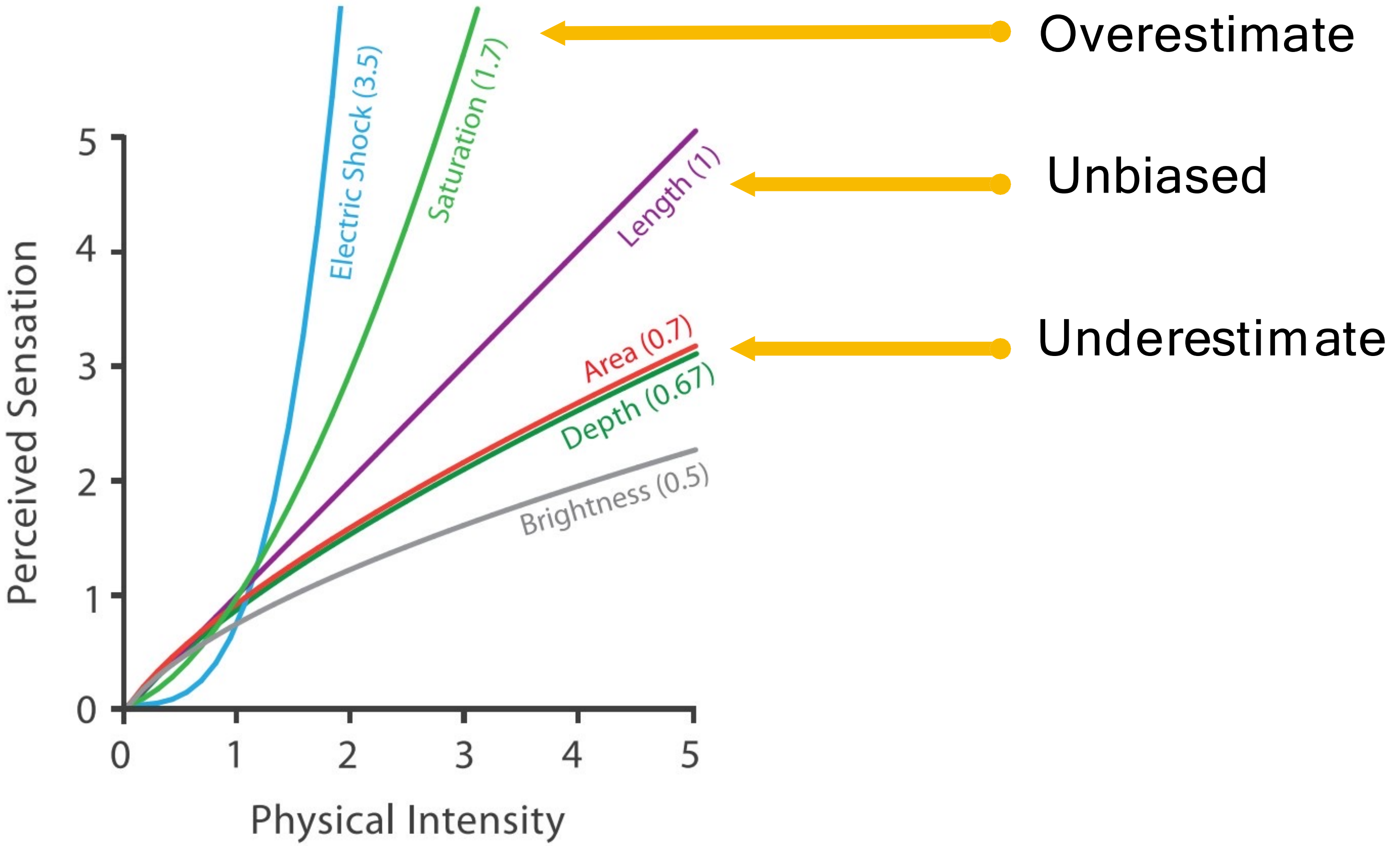
Perceived Sensation   Physical Intensity



Predicts bias, not necessarily accuracy!

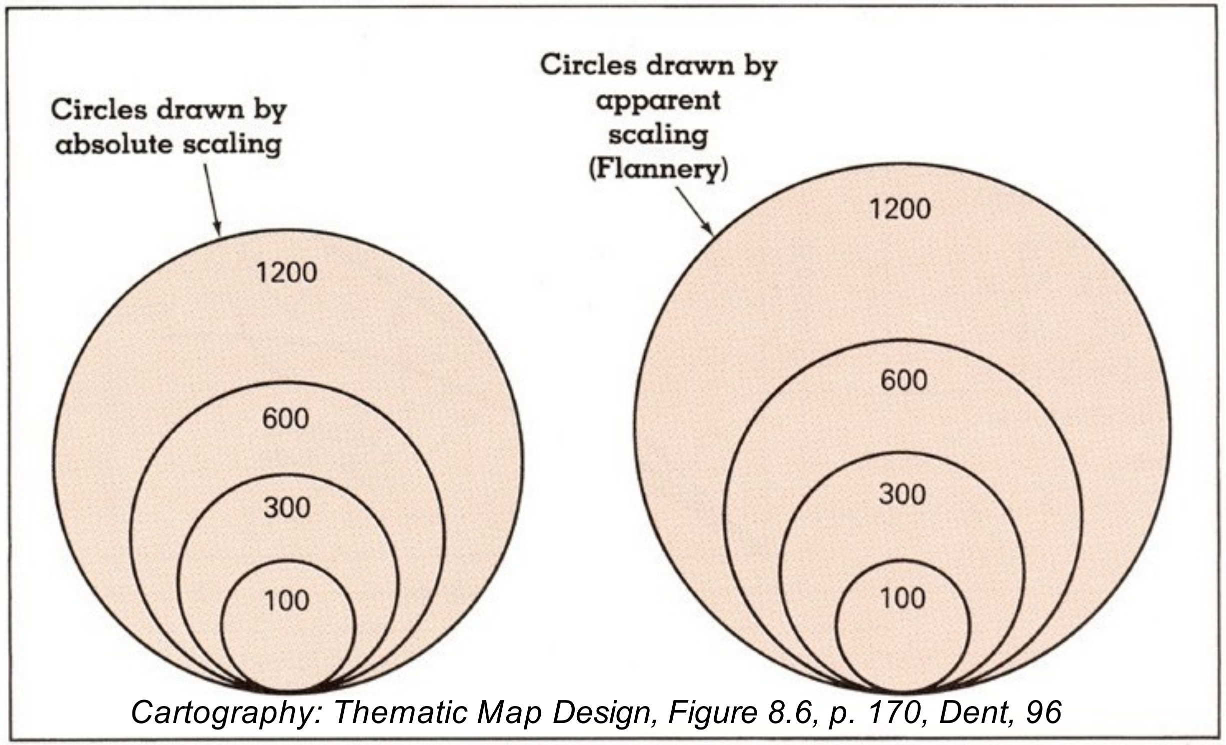
Steven's Power Law

[Graph from T. Munzner 2014]

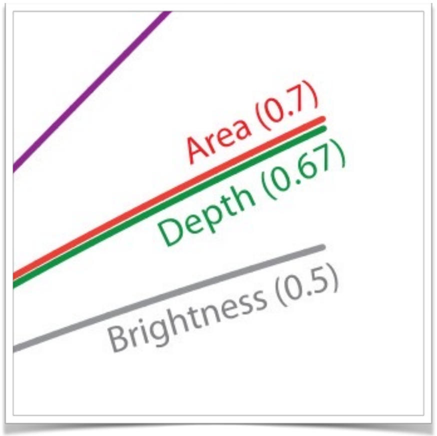


Apparent Magnitude Scaling

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



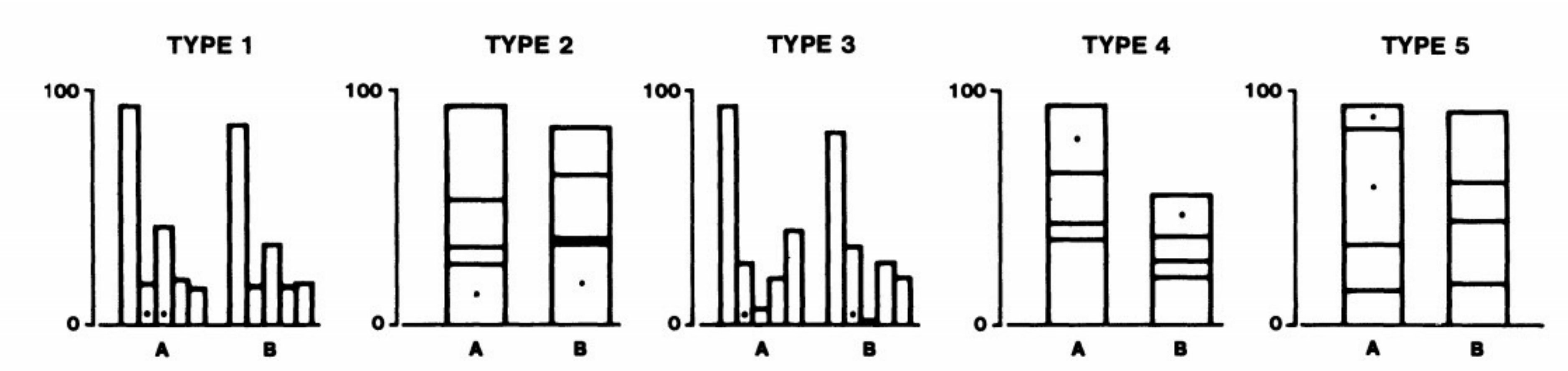
Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96



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

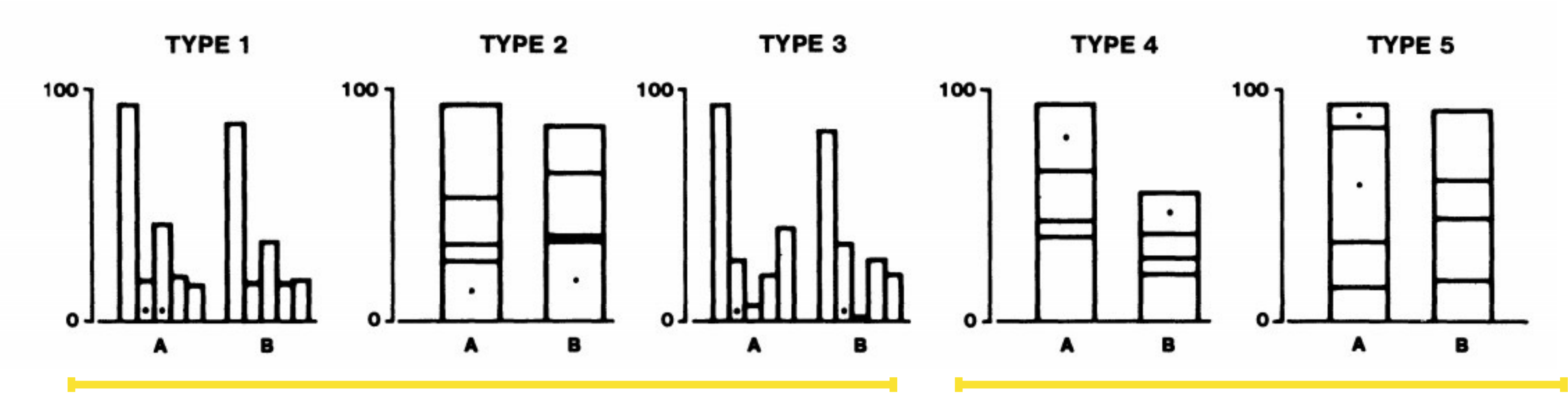
Graphical Perception [Cleveland & McGill 84]

- What percentage of the smaller was of the larger?



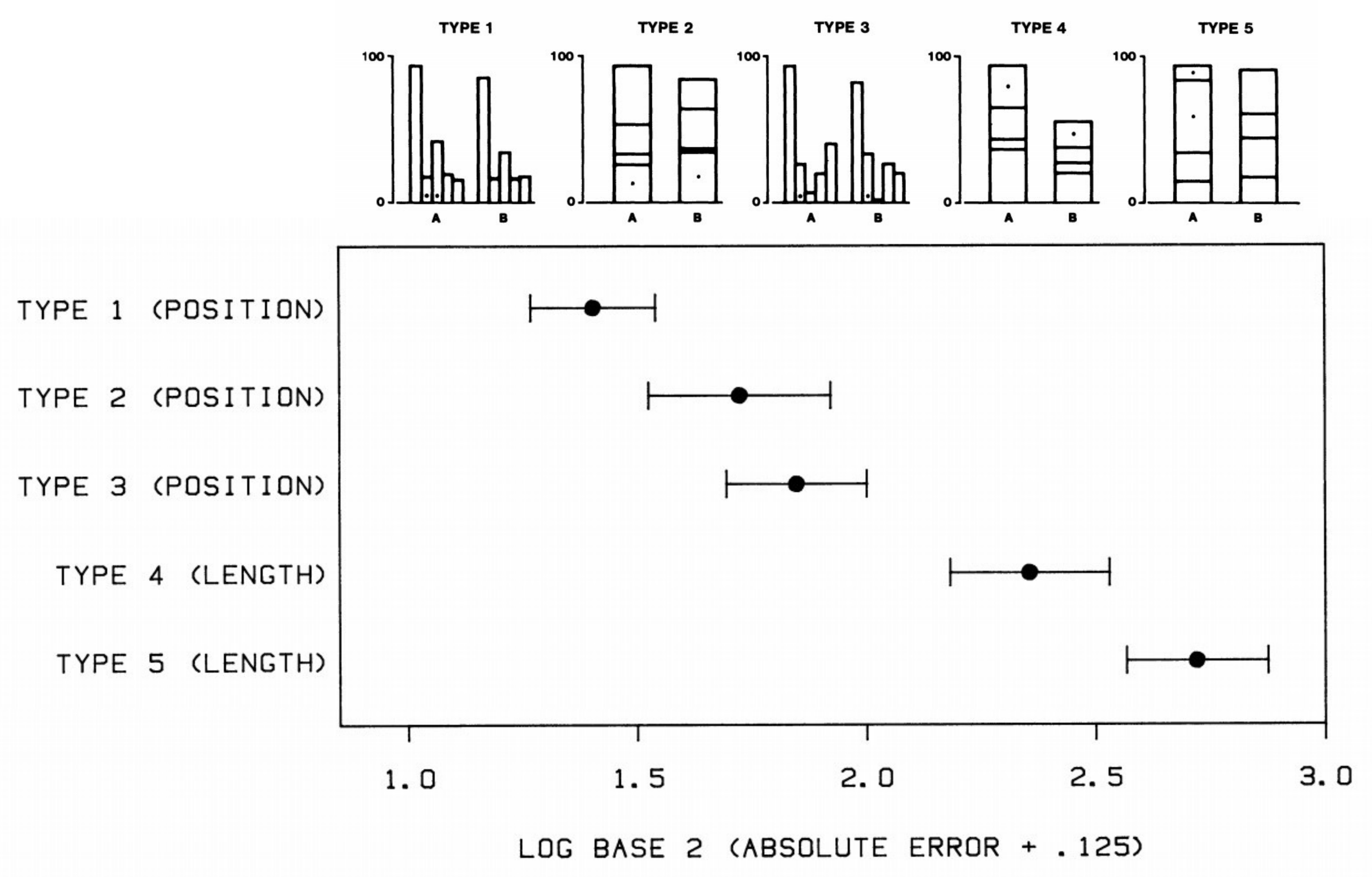
Graphical Perception [Cleveland & McGill 84]

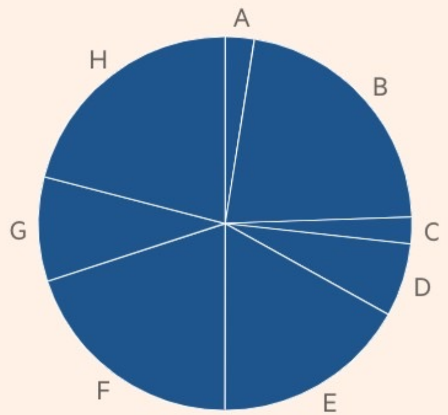
- What percentage of the smaller was of the larger?



Compare positions
(along common scale)

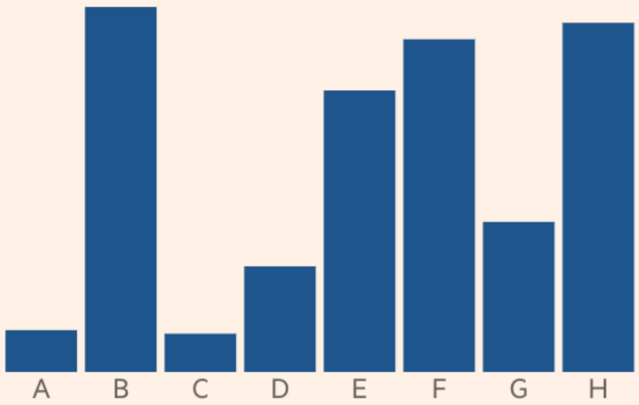
Compare lengths


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)



Which is the third largest segment in the pie chart?

E	F
G	H

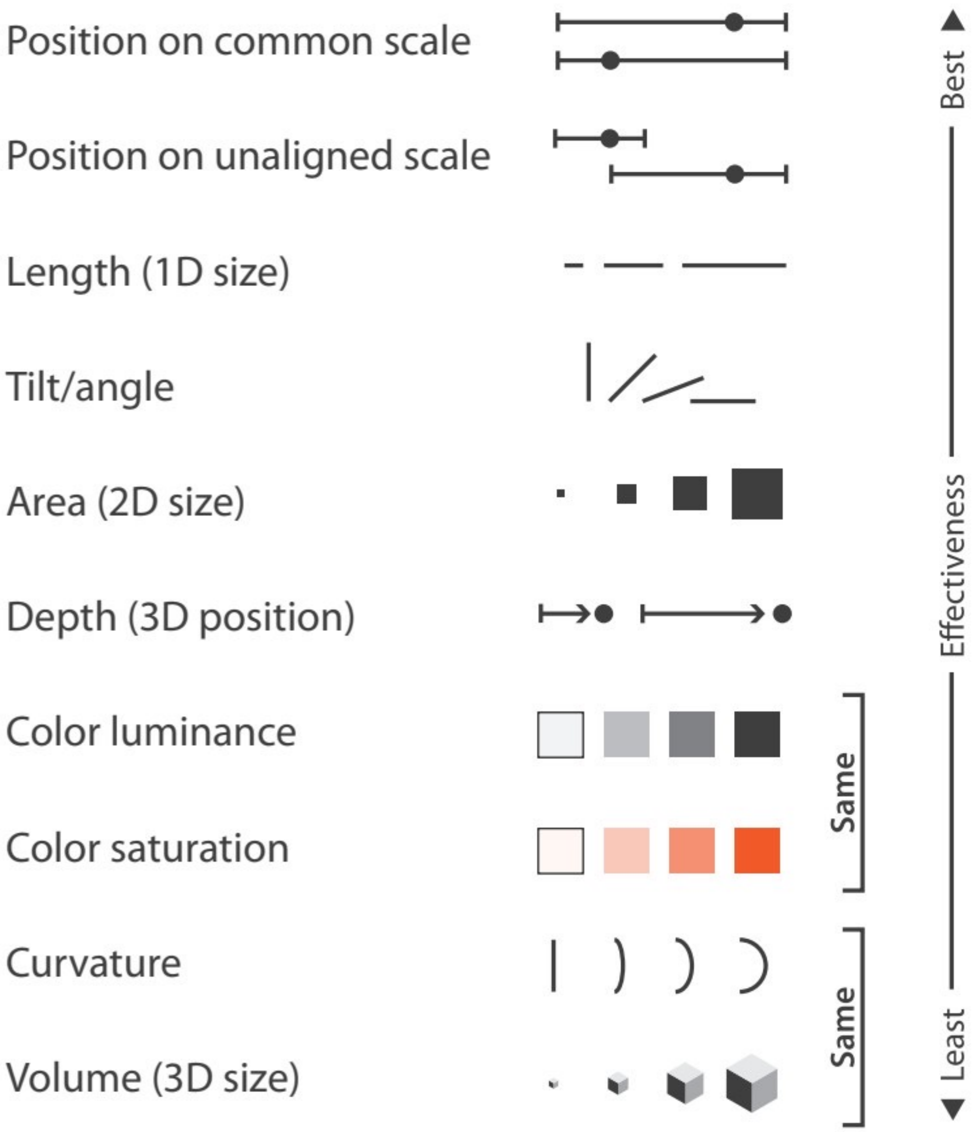


Which is the 3rd largest bar?

E	F
G	H

Effectiveness Ranking of Visual Encoding Variables

for comparing numerical quantities



[T. Munzer 2014]

Pre-Attentive Processing

How Many 3's?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

[based on a slide from J Stasko]

How Many 3's?

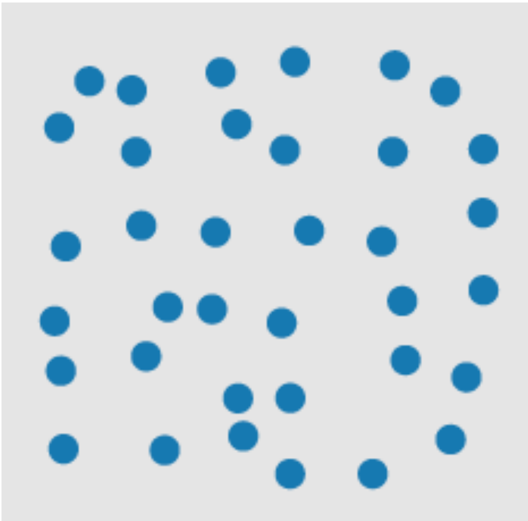
1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

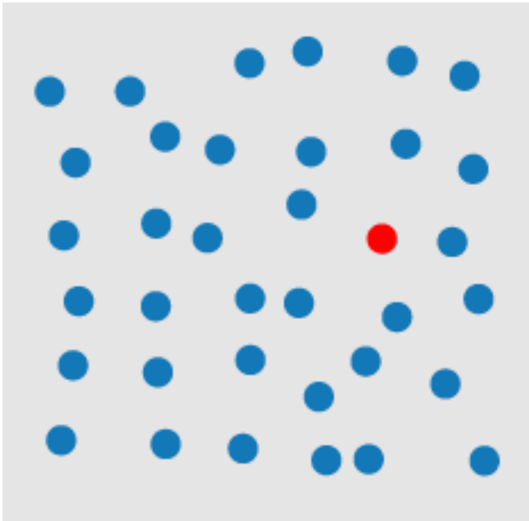
Pre-attentive processing

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

Visual Pop-Out: Color

- A unique visual property in the target allows it to "pop out" of a display

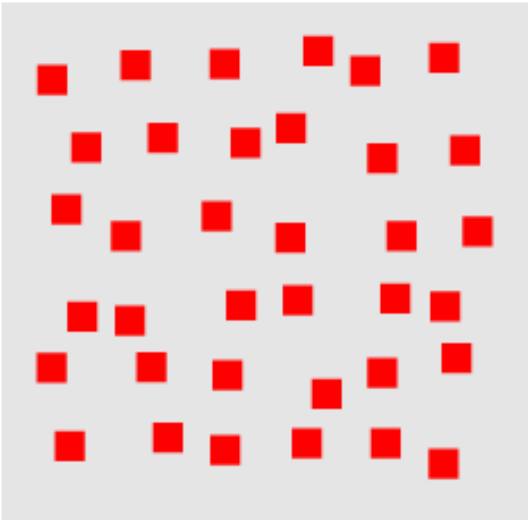


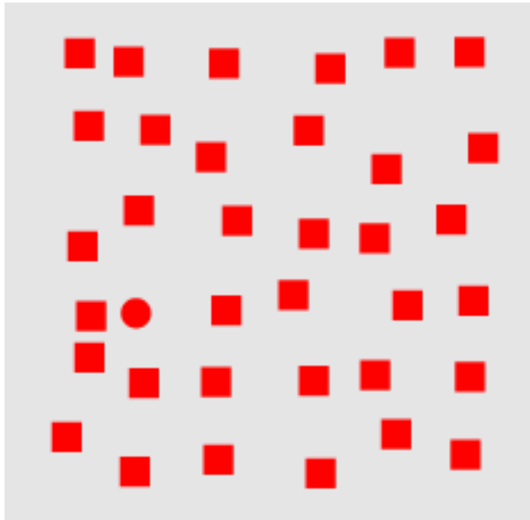


www.csc.ncsu.edu/faculty/healey/PP/index.html

Visual Pop-Out: Shape

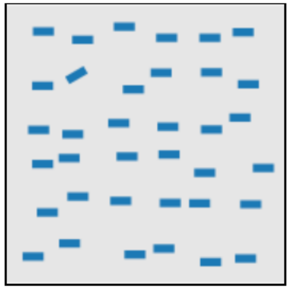
- A unique visual property in the target allows it to "pop out" of a display



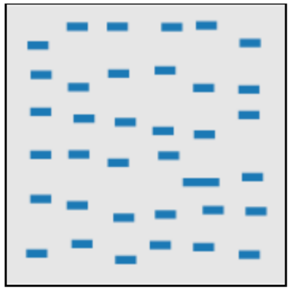


www.csc.ncsu.edu/faculty/healey/PP/index.html

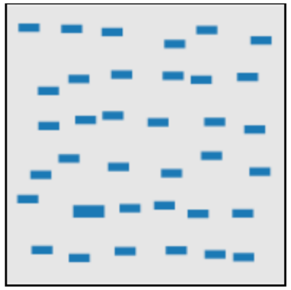
A partial list of preattentive visual features



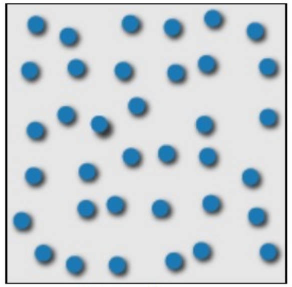
line (blob) orientation
Julész & Bergen 83; Sagi & Julész 85a, Wolfe et al. 92; Weigle et al. 2000



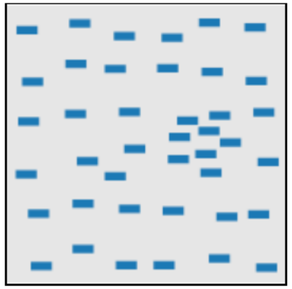
length, width
Sagi & Julész 85b; Treisman & Gormican 88



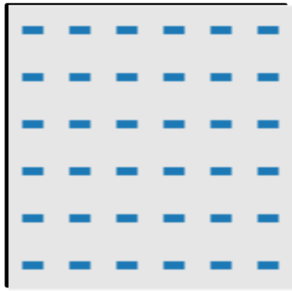
size
Treisman & Gelade 80; Healey & Enns 98; Healey & Enns 99



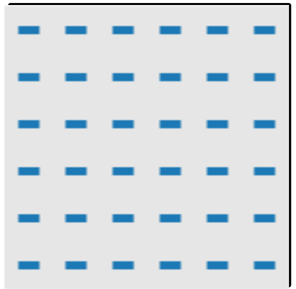
3D depth cues
Enns 90b; Nakayama & Silverman 86



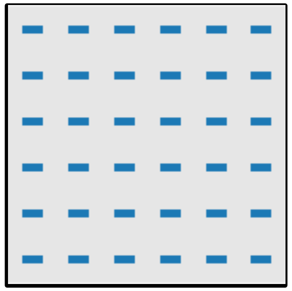
density, contrast
Healey & Enns 98; Healey & Enns 99



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…

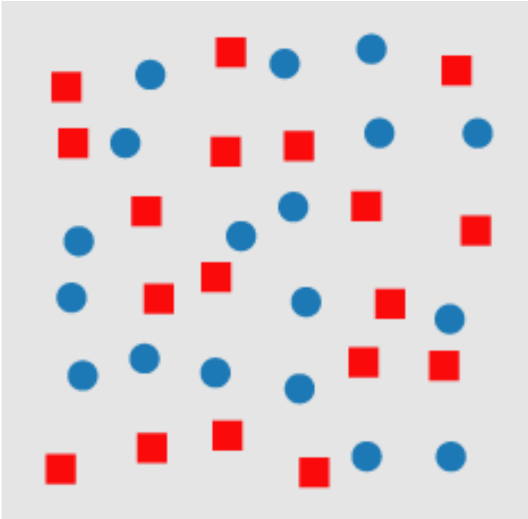
Christopher Healey,
https://www.csc.ncsu.edu/faculty/healey/PP/index.html

Multiple Attributes

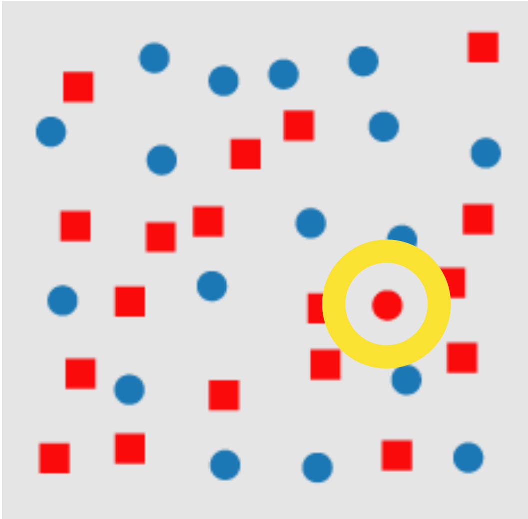
Feature Conjunctions

- A target made up of a combination of non-unique features (a *conjunction* target) normally cannot be detected preattentively
- Where is red circle?

Consistent



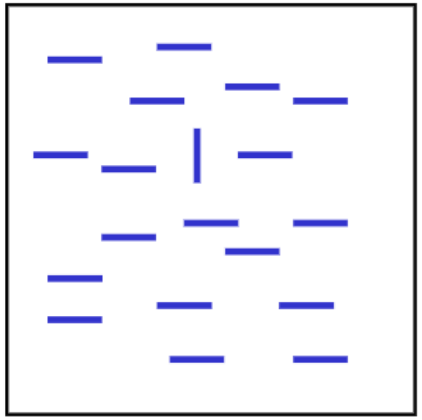
Inconsistent



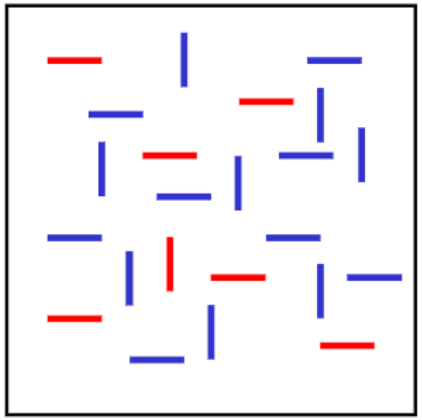
No unique visual property of the target

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

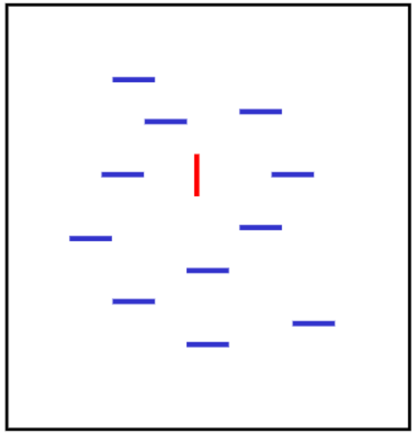
Feature search



Conjunction search



Double feature search

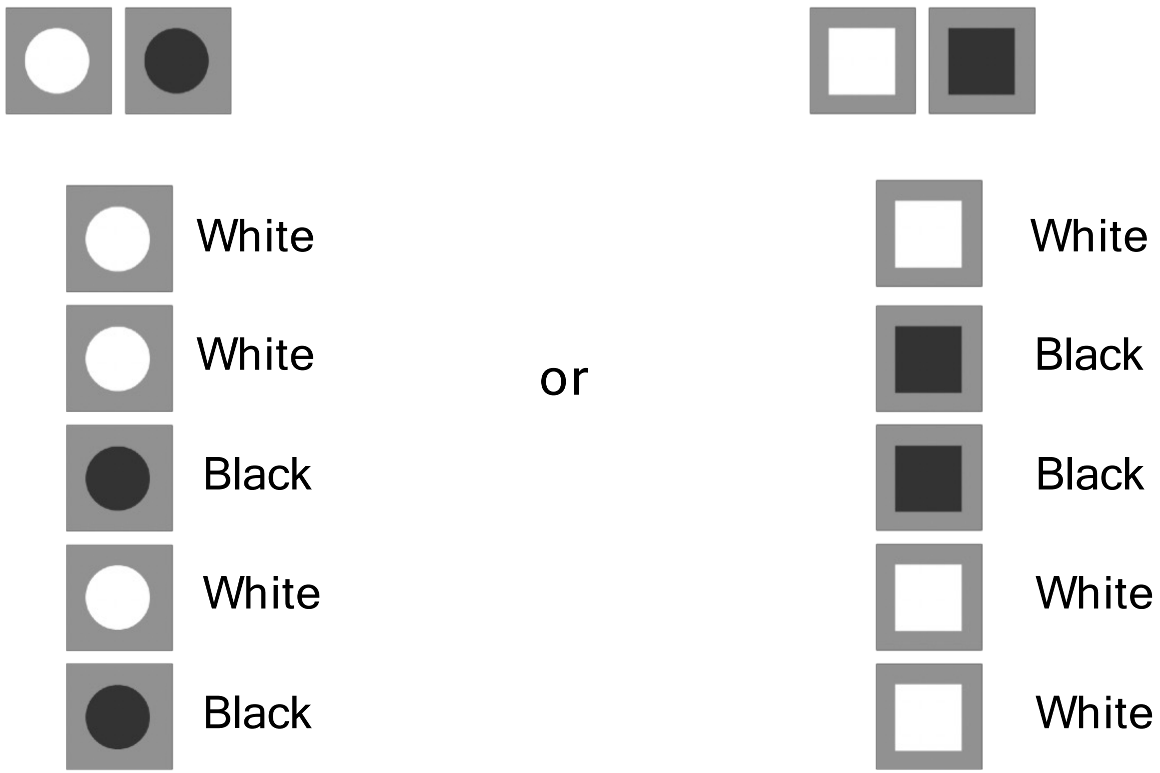


Fast, parallel, pre-attentive, effortless, pops out

Slow, serial, effortful, needs attention, does not pop out

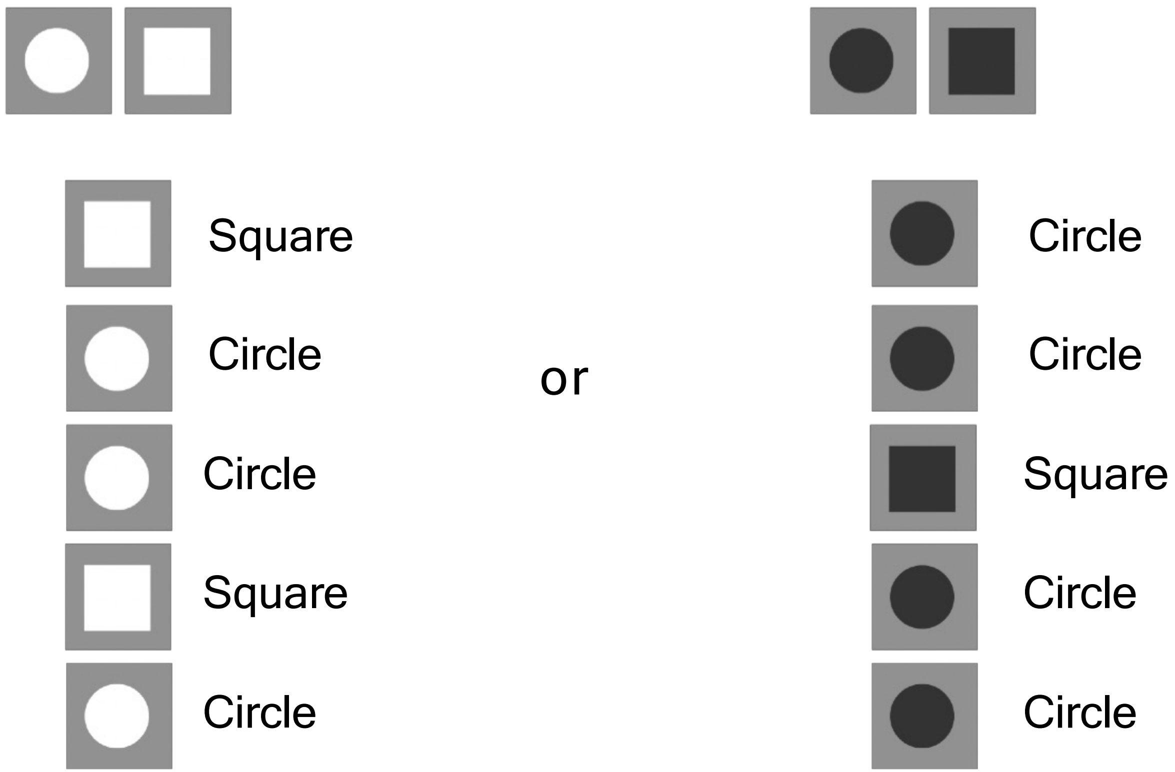
One-Dimensional: Lightness

Classify objects based on lightness



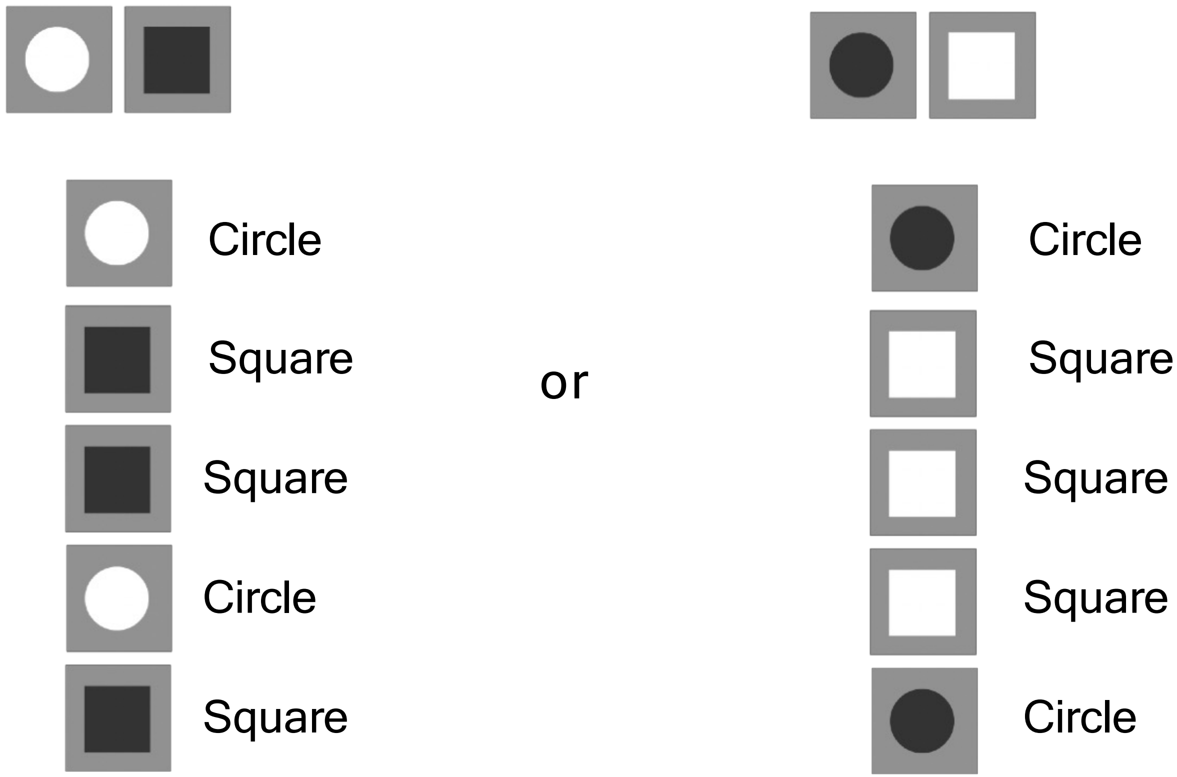
One-Dimensional: Shape

Classify objects based on shape



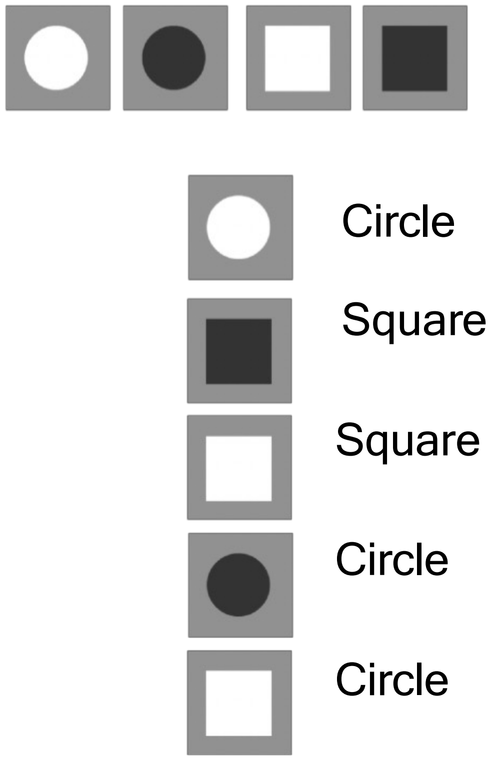
Redundant: Shape & Lightness

Classify objects based on shape. Easier?



Orthogonal: Shape & Lightness

Classify objects based on shape. Difficult?



Orthogonal: Shape & Lightness

Classify objects based on lightness. Difficult?

Circle

Square

Square

Circle

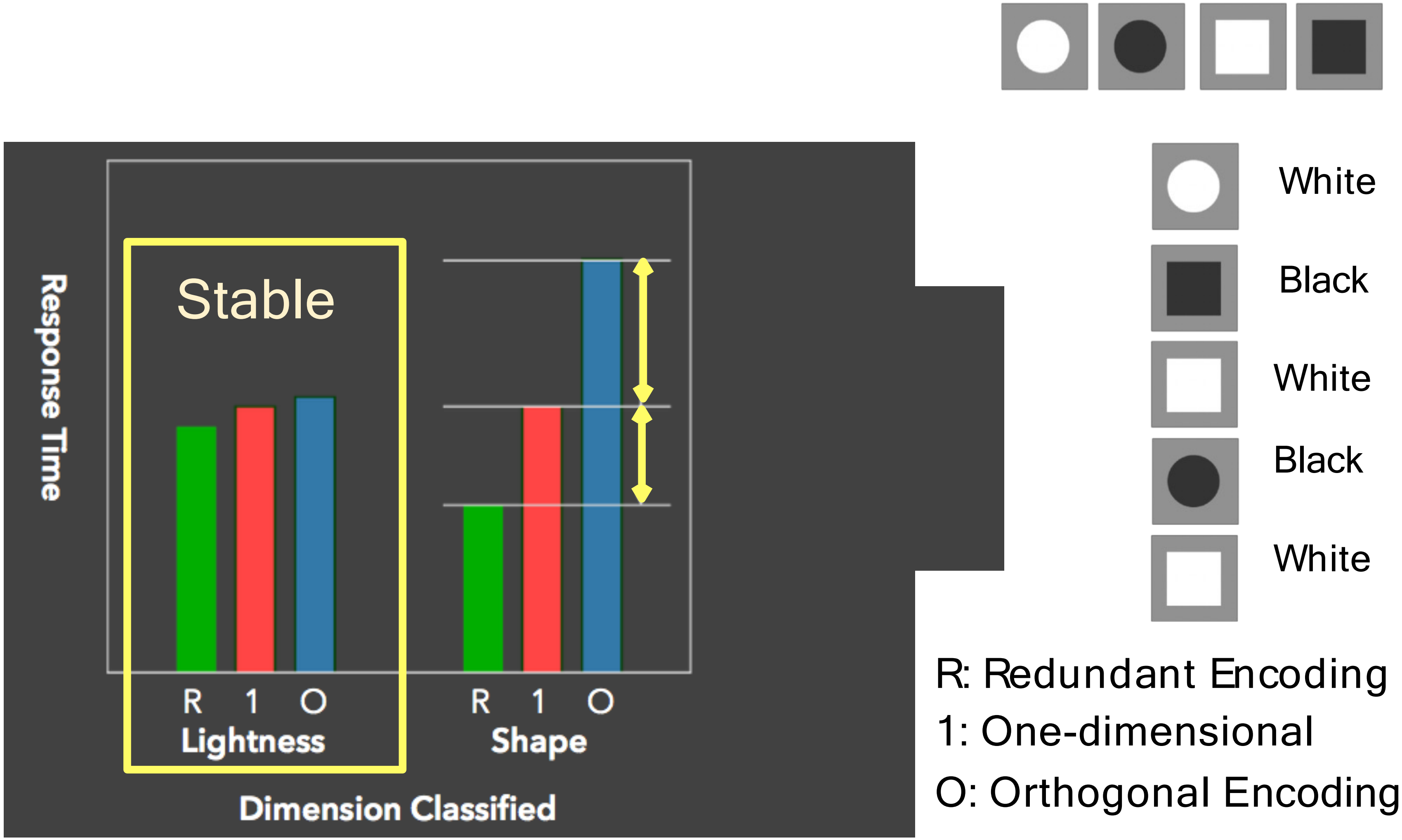
Circle

Speeded Classification

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

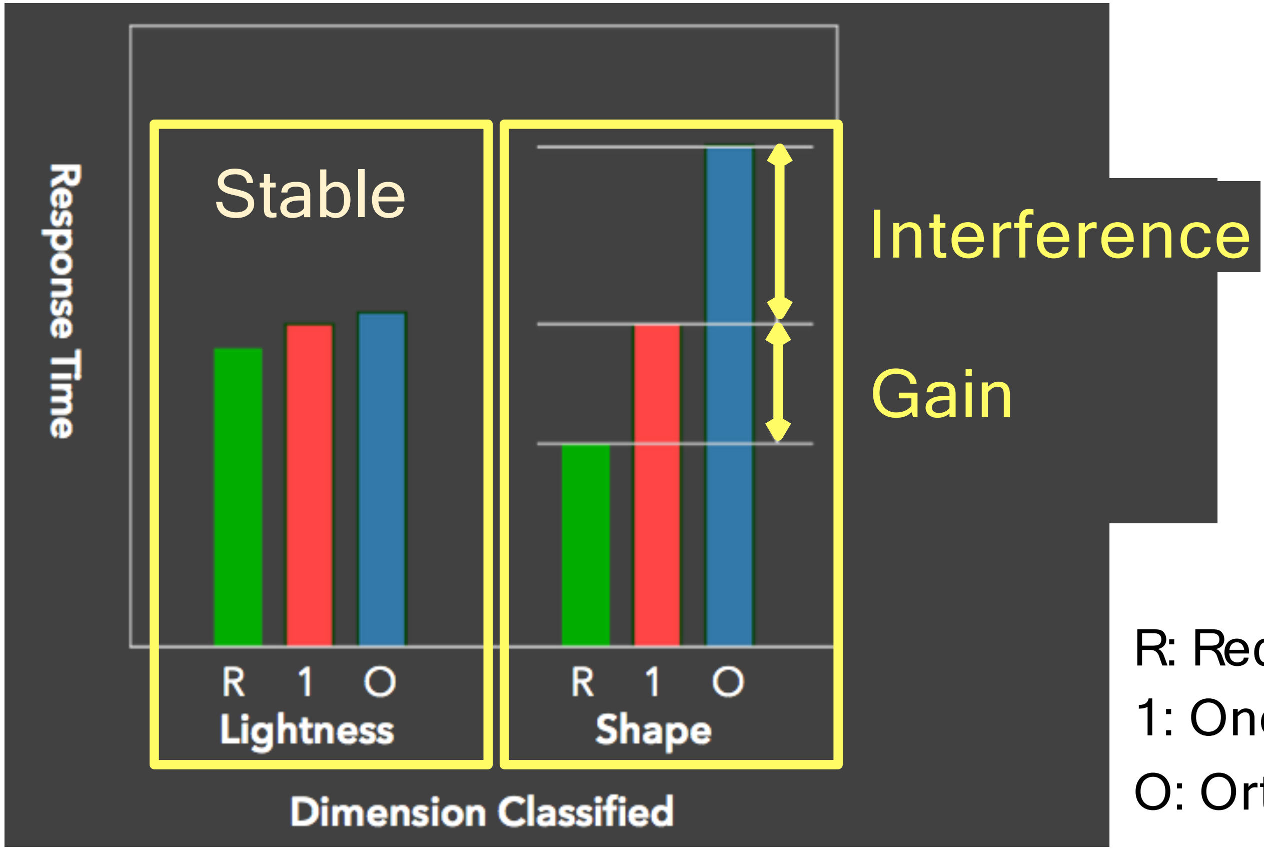
- Filtering Interference
  - Difficulty in ignoring one dimension while attending to the other.

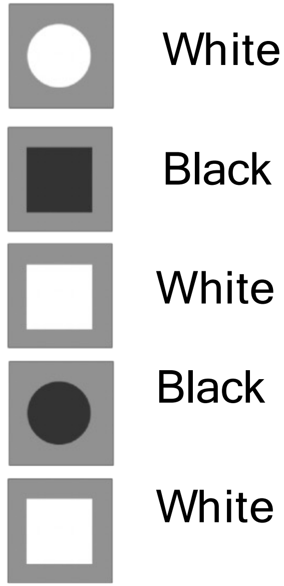
Speeded Classification



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

Speeded Classification





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

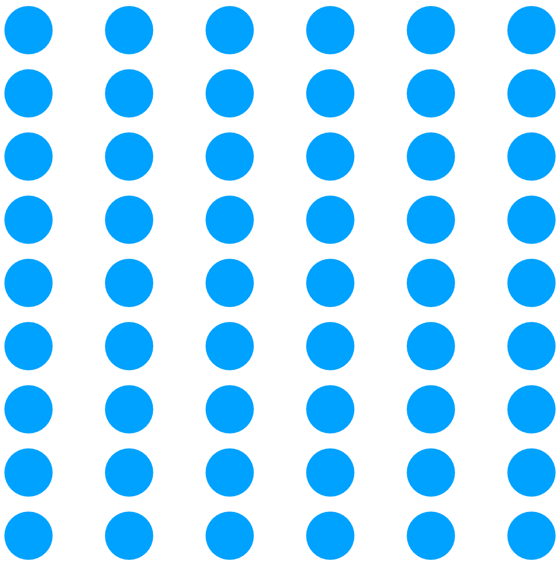
Gestalt Grouping

Gestalt principles of design

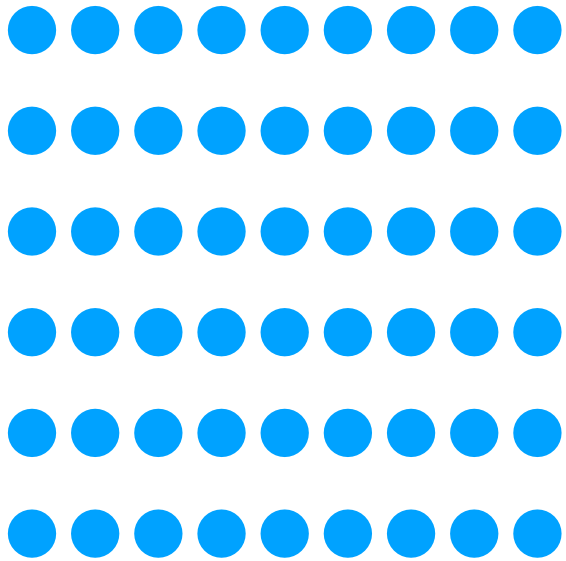
- Similar elements are visually grouped, regardless of their proximity to each other.
  - They can be grouped by color, shape, or size.

The squares here are all equally spaced and the same size, but we automatically group them by color, even though there's no rhyme or reason to their placement.

Proximity

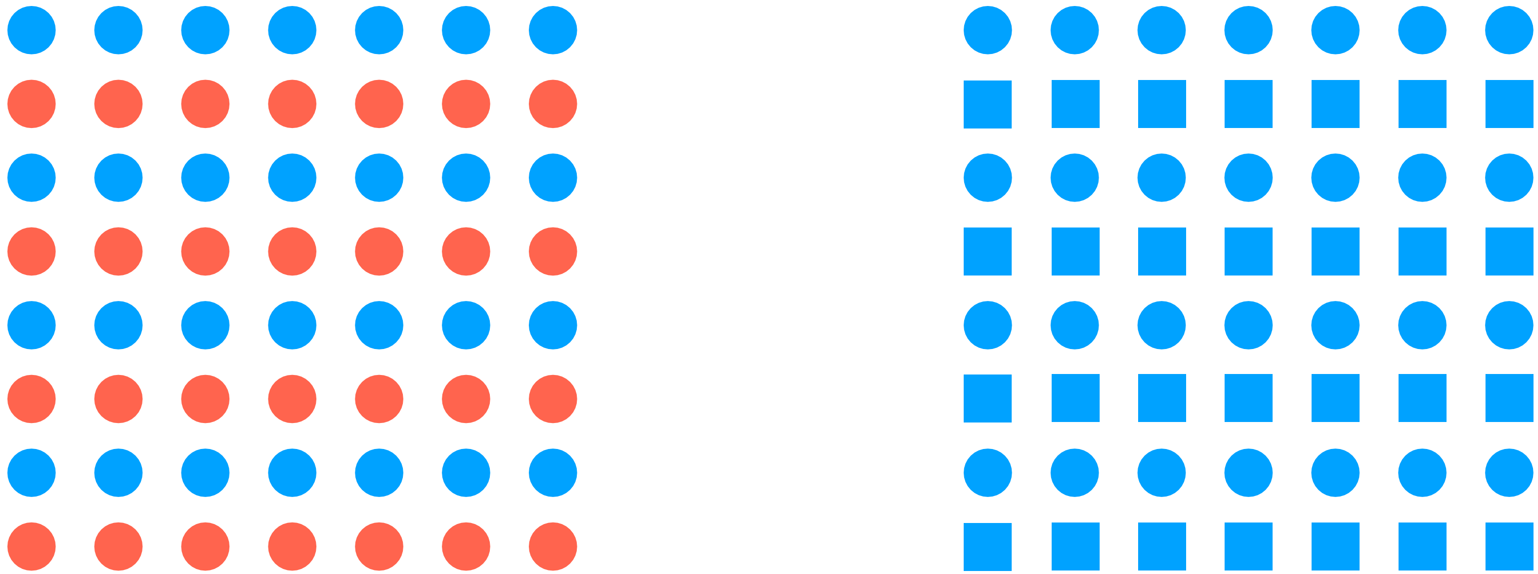


Columns

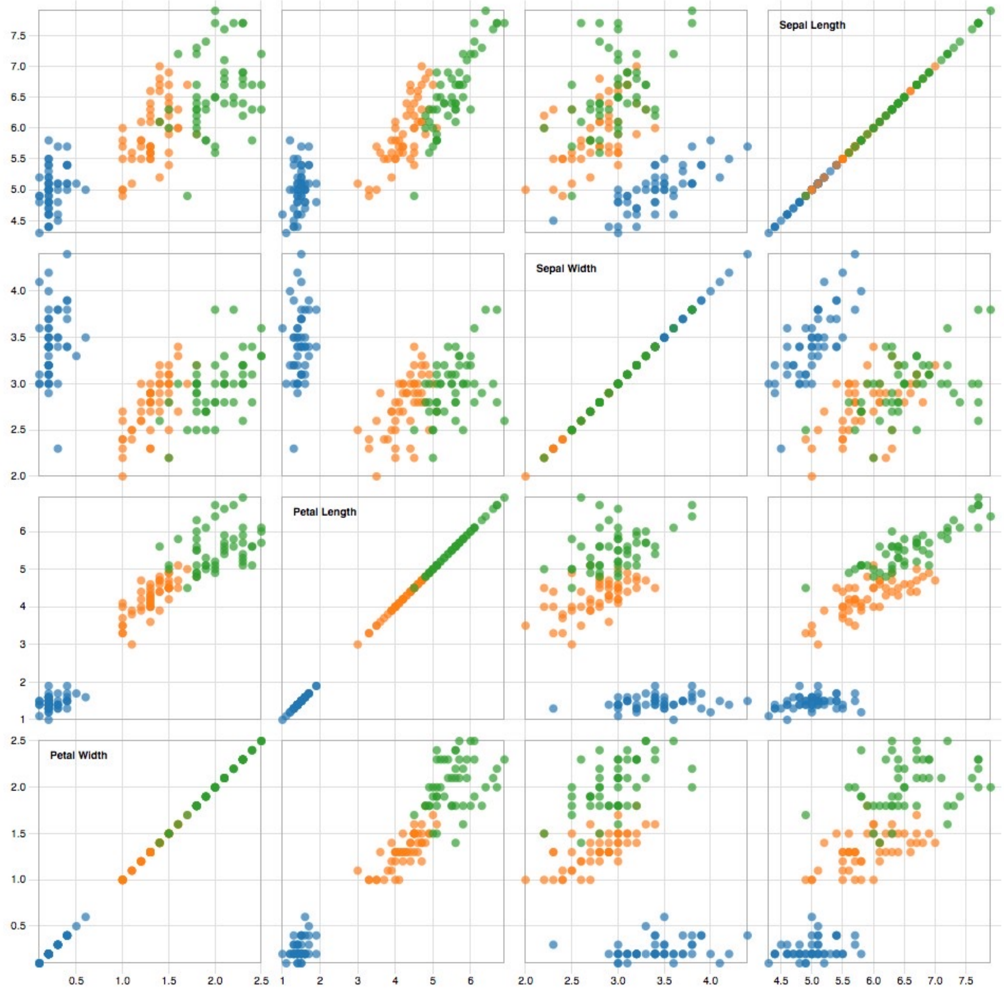


Rows

Similarity



Rows stand out due to similarity.

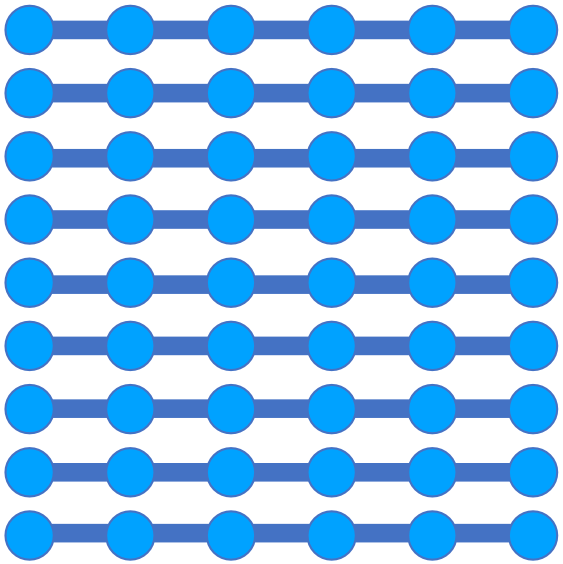


Scatter Plot Matrix

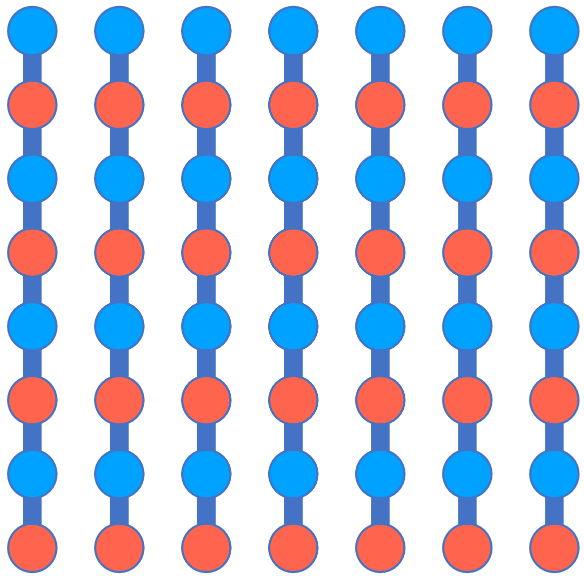
Clusters and outliers

Uniformed Connectedness: Connection

- Connectedness dominates proximity and similarity



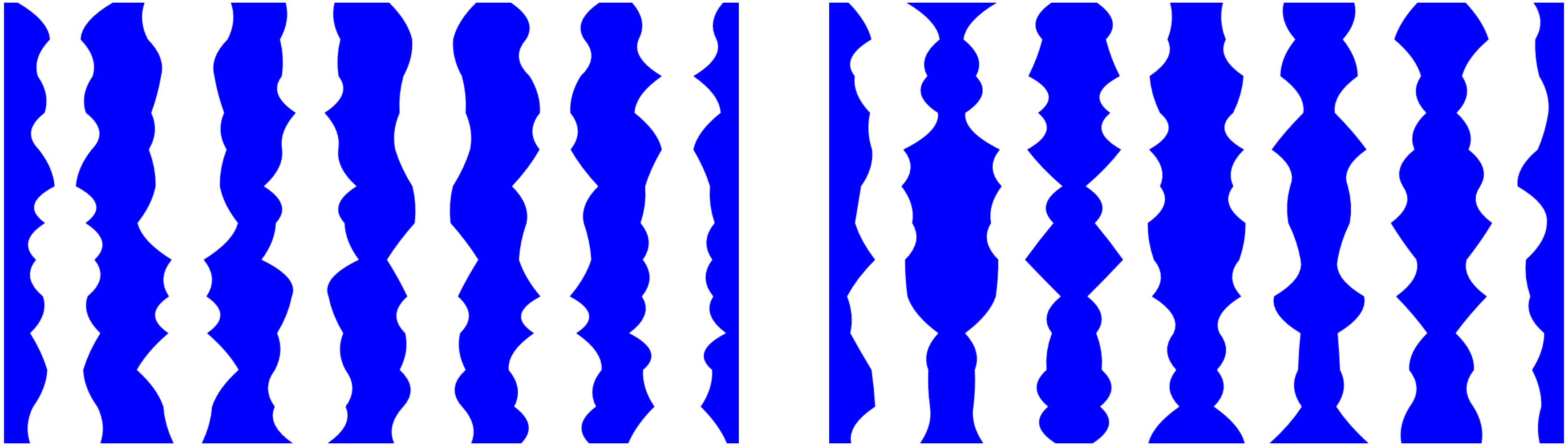
Proximity (column)
vs connection (row)



Similarity (row)
vs connection (column)

Symmetry

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



https://isle.hanover.edu/Ch05Object/Ch05SymmetryLaw_evt.html#:~:text=The%20Law%20of%20Symmetry%20is,perceived%20as%20a%20unified%20group.

Change Blindness

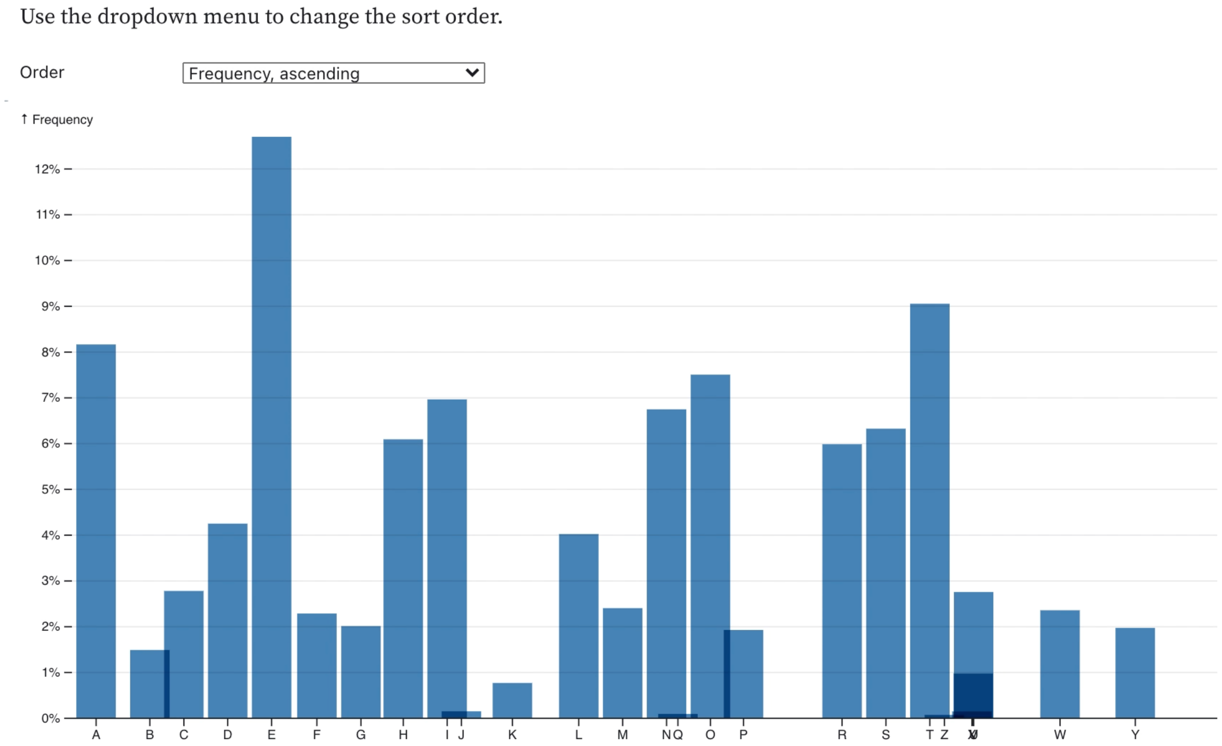
The phenomenon where even very large changes are not noticed if we are attending to something else.

"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.