



ĐẠI HỌC BÁCH KHOA HÀ NỘI  
VIỆN CÔNG NGHỆ THÔNG TIN VÀ TRUYỀN THÔNG

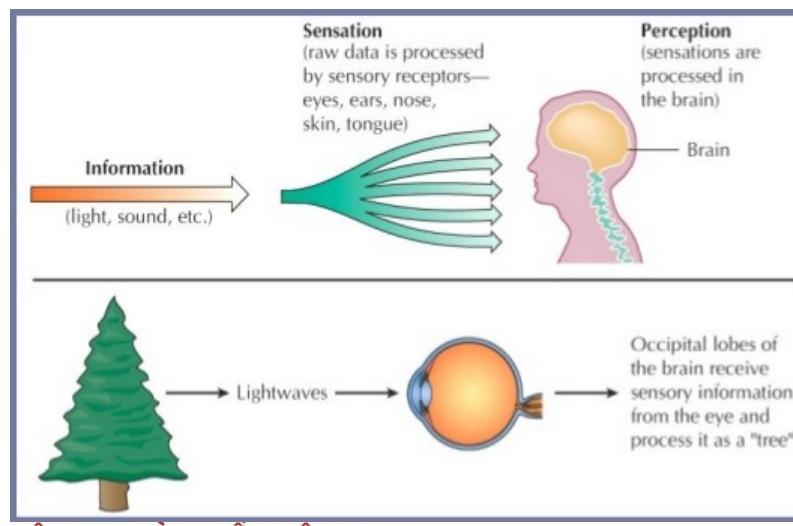
# Graphical Perception

# 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.”

The brain receives input from the sensory organs.

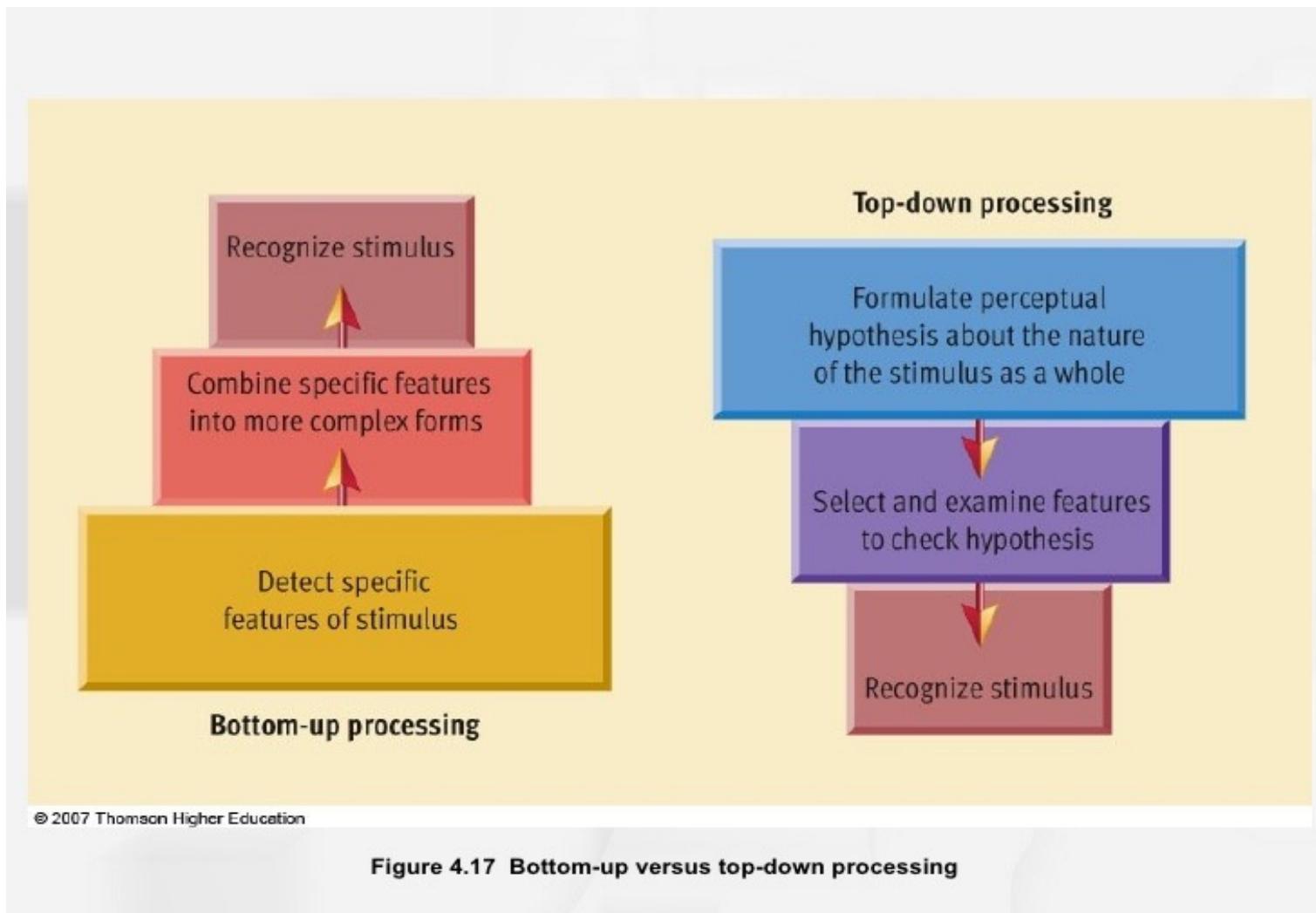
## Perception

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

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

# 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



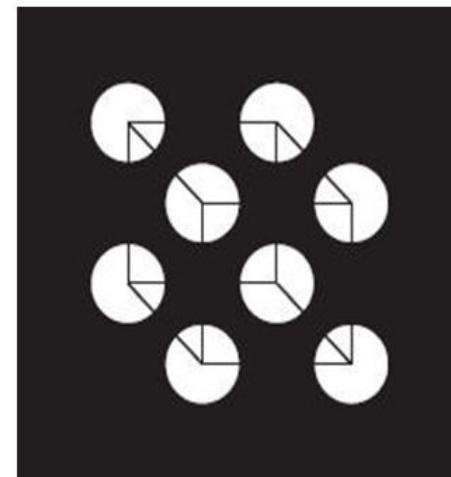
## Bottom Up and Top Down Processing

- 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

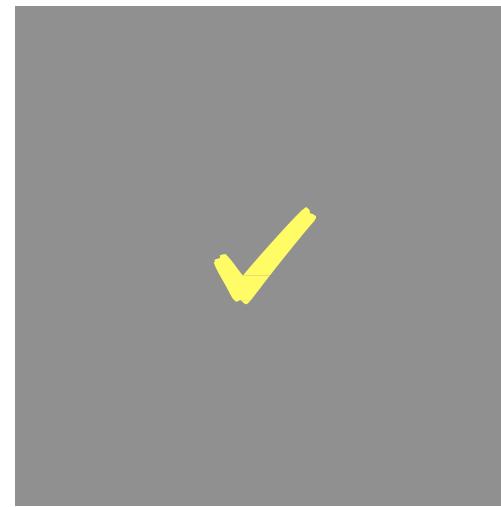
# Detecting Brightness

(128,128,128)



A

(144,144,144)



B

# Detecting Brightness



A

Which is brighter?

B

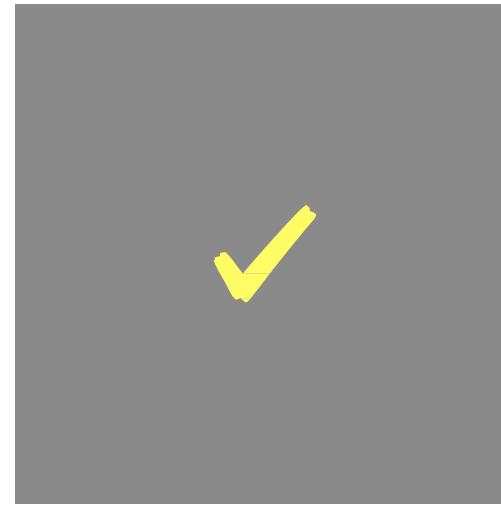


# Detecting Brightness

(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.

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

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← Change of Intensity

← 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.

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

Change of Intensity

Physical Intensity

# Weber's Law: Just Noticeable Difference ( JND)

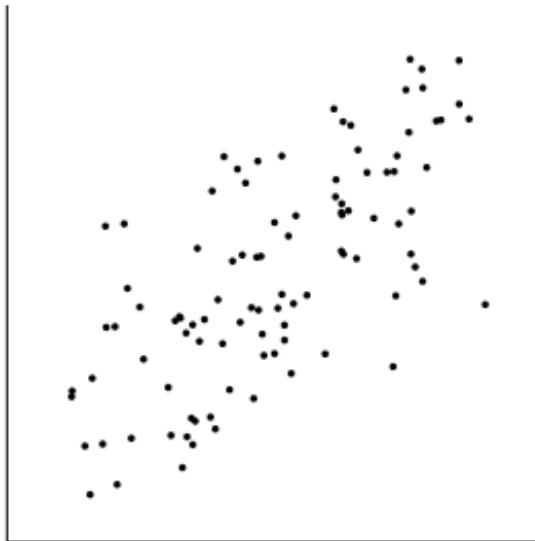
Perceived Change →  $dp = k \frac{dS}{S}$  ← Change of Intensity  
Physical Intensity

Most continuous variation in stimuli are perceived in discrete steps

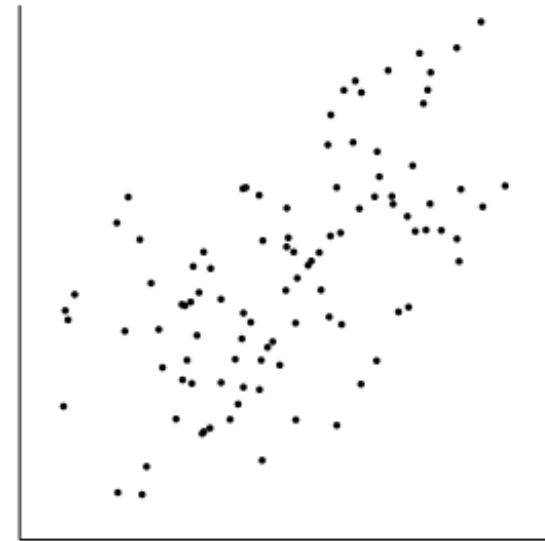


# Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



A

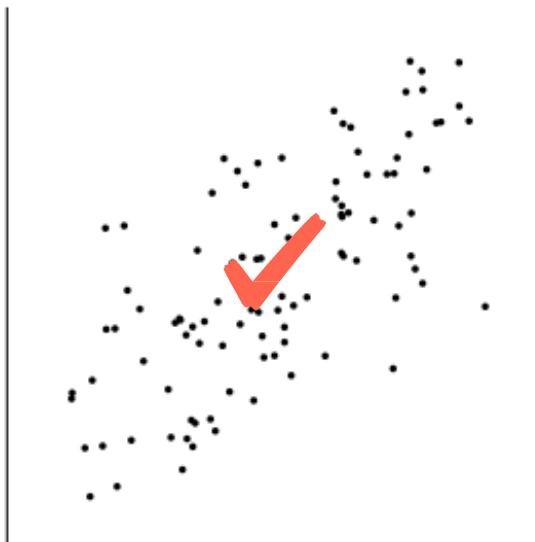


B

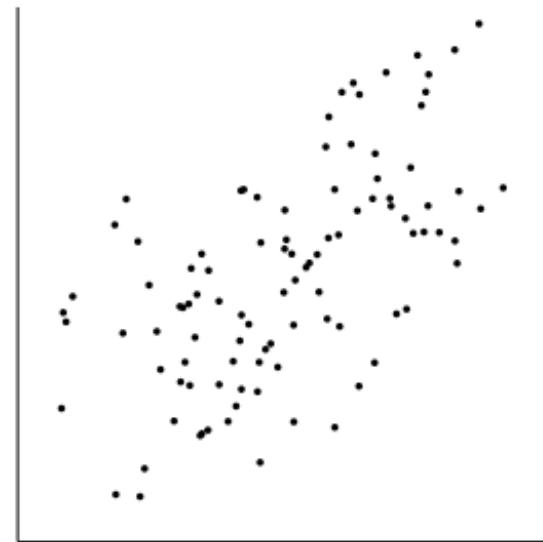
[Harrison et al 2014]

# Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



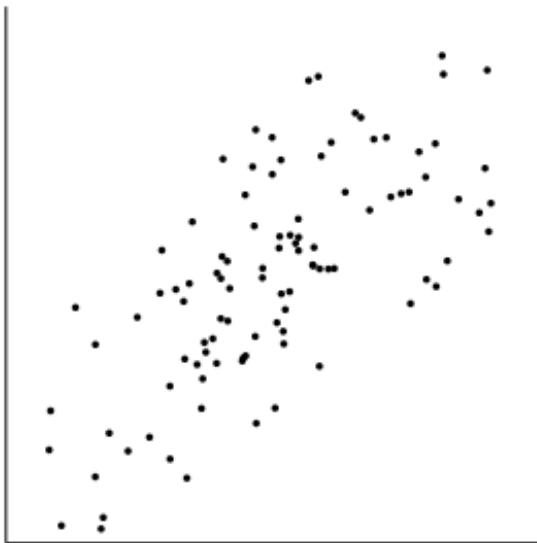
$$r = 0.7$$



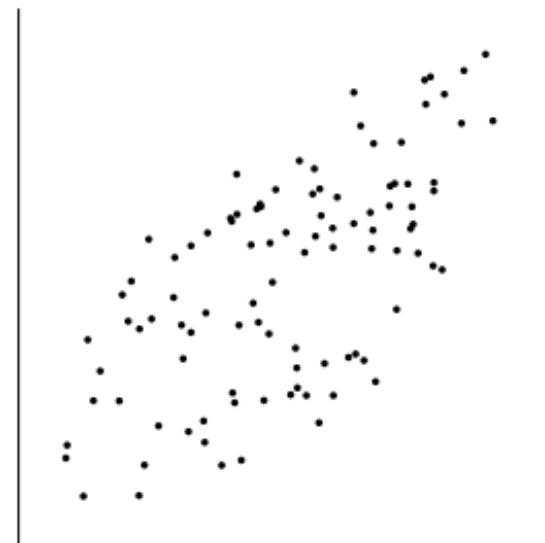
$$r = 0.6$$

# Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



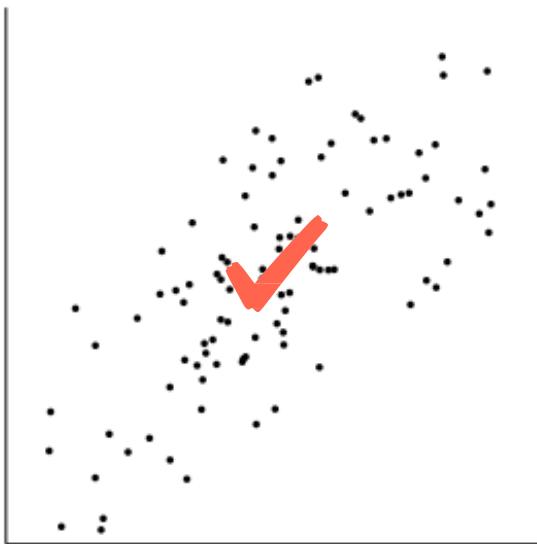
A



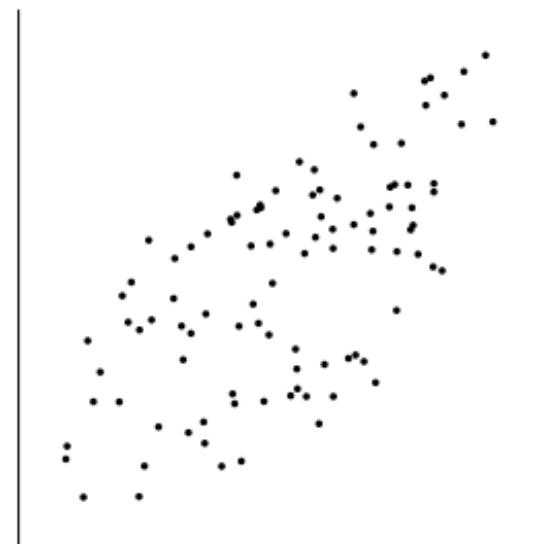
B

# Ranking correlation visualizations

Which of the two appeared to be more highly correlated?



$$r = 0.7$$

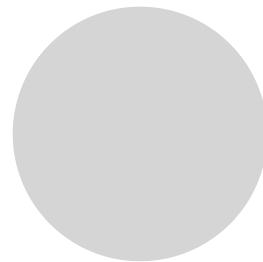


$$r = 0.65$$

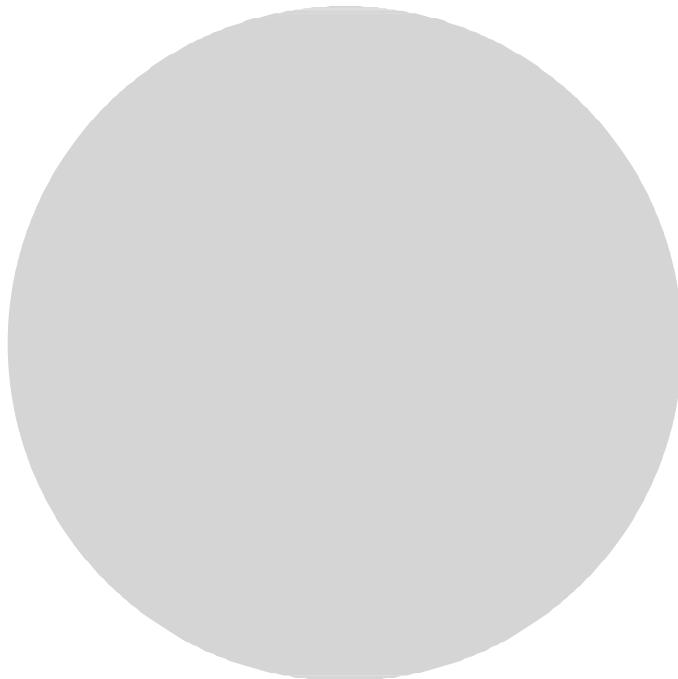
# Magnitude Estimation

# A Quick Experiment...

A



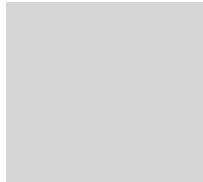
B



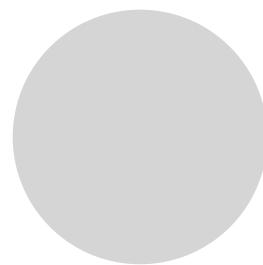
B



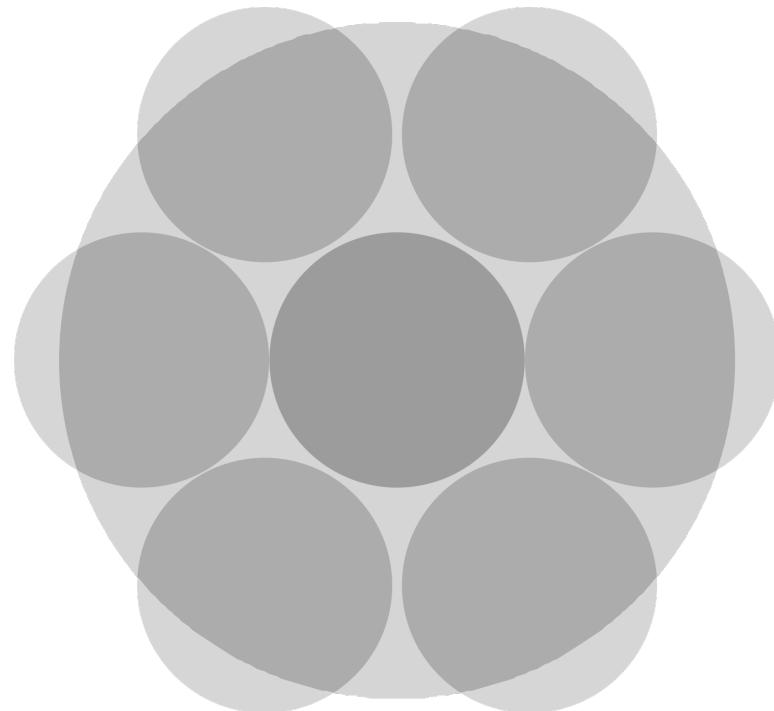
A



A

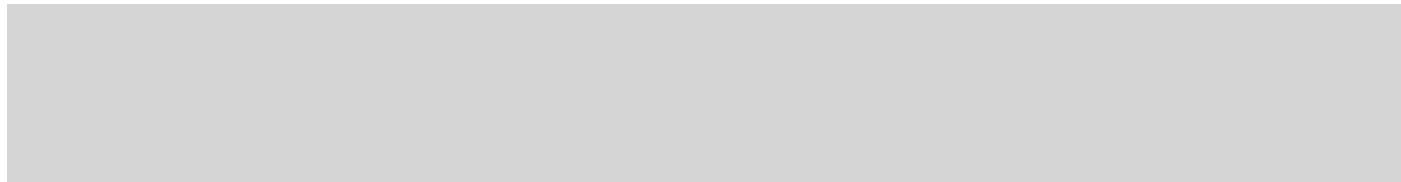


B

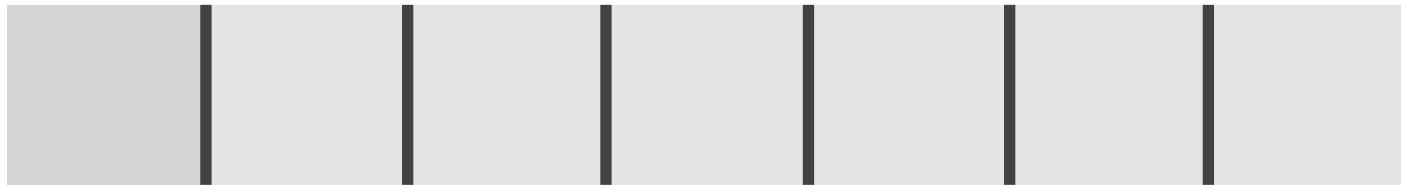


Area

B



A



Length

# Steven's Power Law

[Graph from T. Munzner 2014]

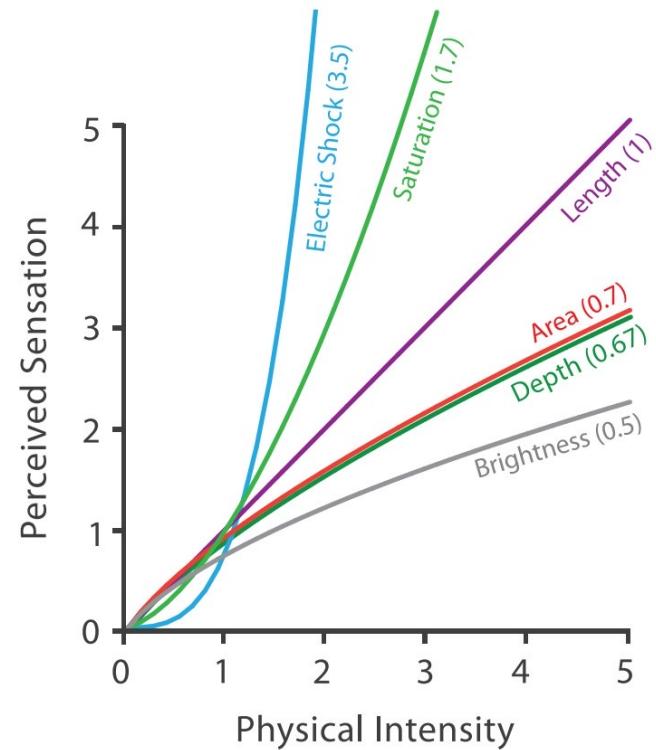
Models the **relationship** between the **magnitude** of a physical stimulus and its perceived intensity.

Exponent  
(Empirically Determined)

$$S = I^p$$

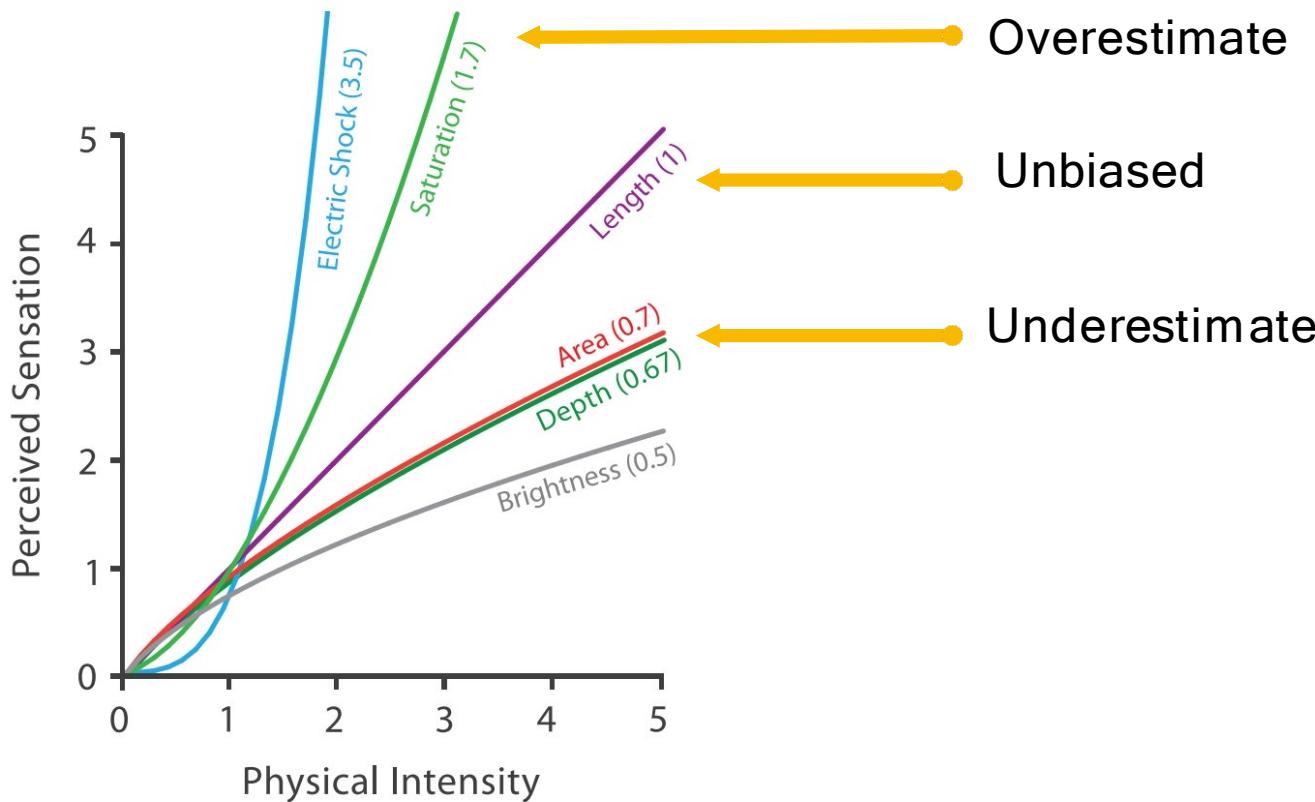
Perceived Sensation      Physical Intensity

Predicts bias, not necessarily accuracy!



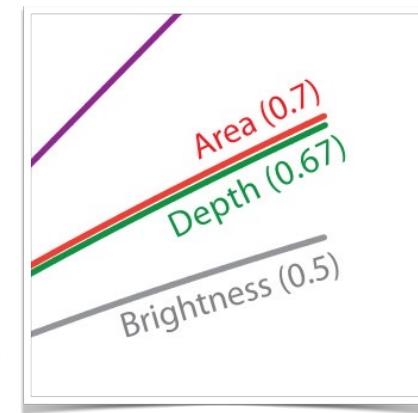
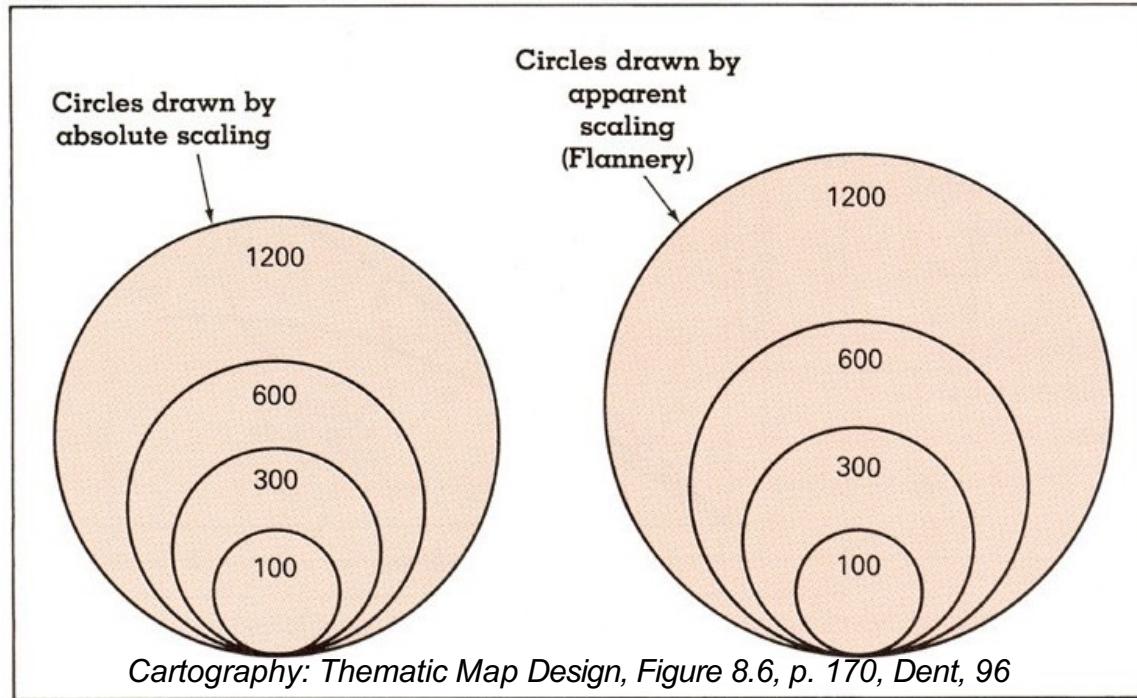
# Steven's Power Law

[Graph from T. Munzner 2014]



# Apparent Magnitude Scaling

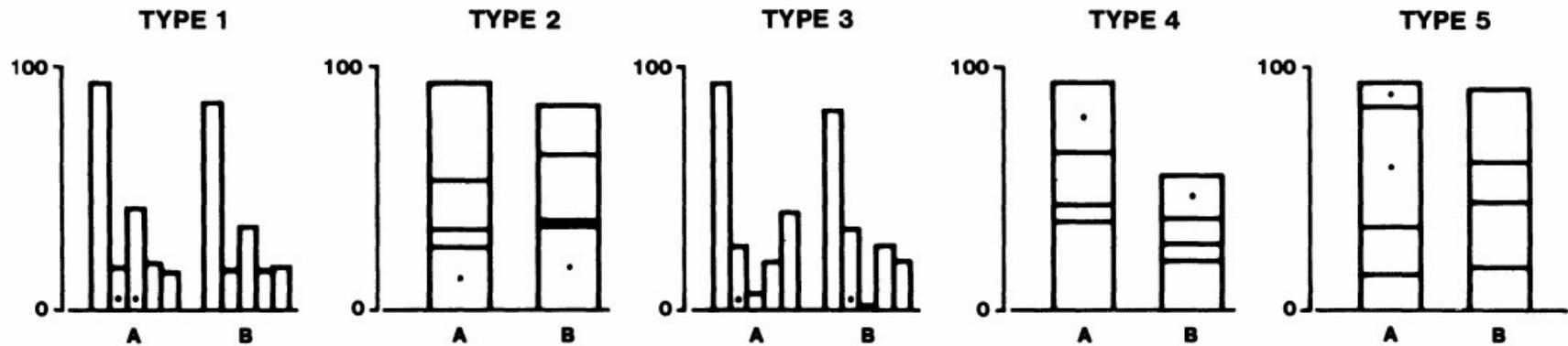
- To compensate for human error in interpreting scale because people tend to underestimate area



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

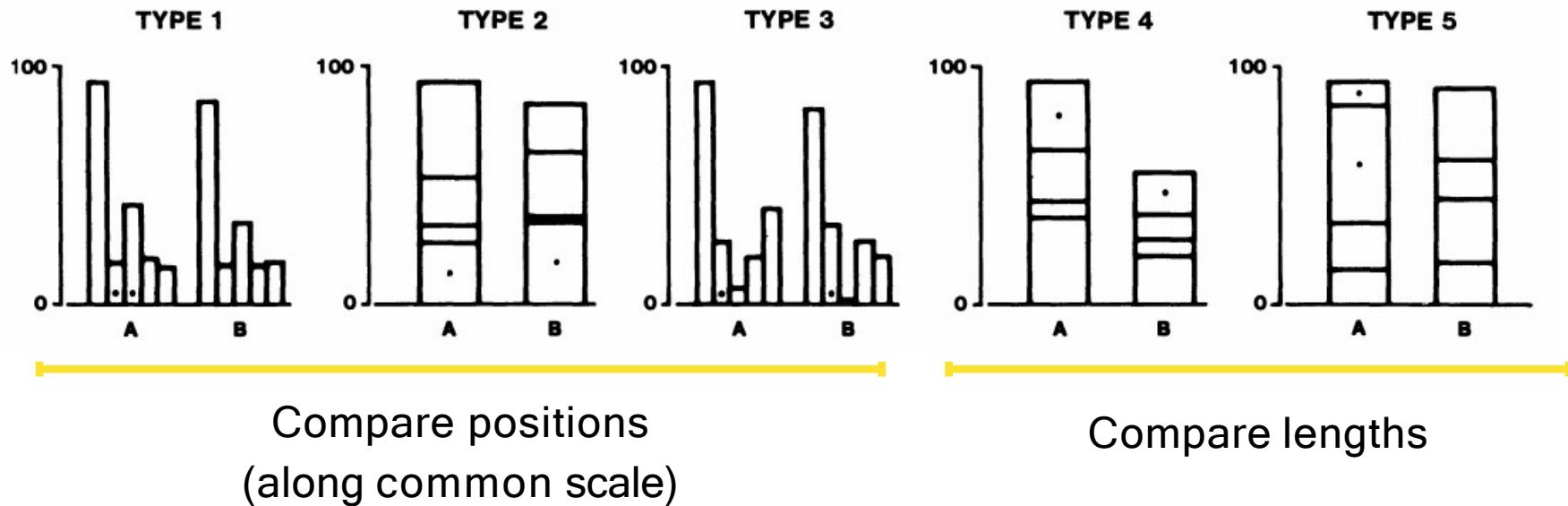
# Graphical Perception [Cleveland & McGill 84]

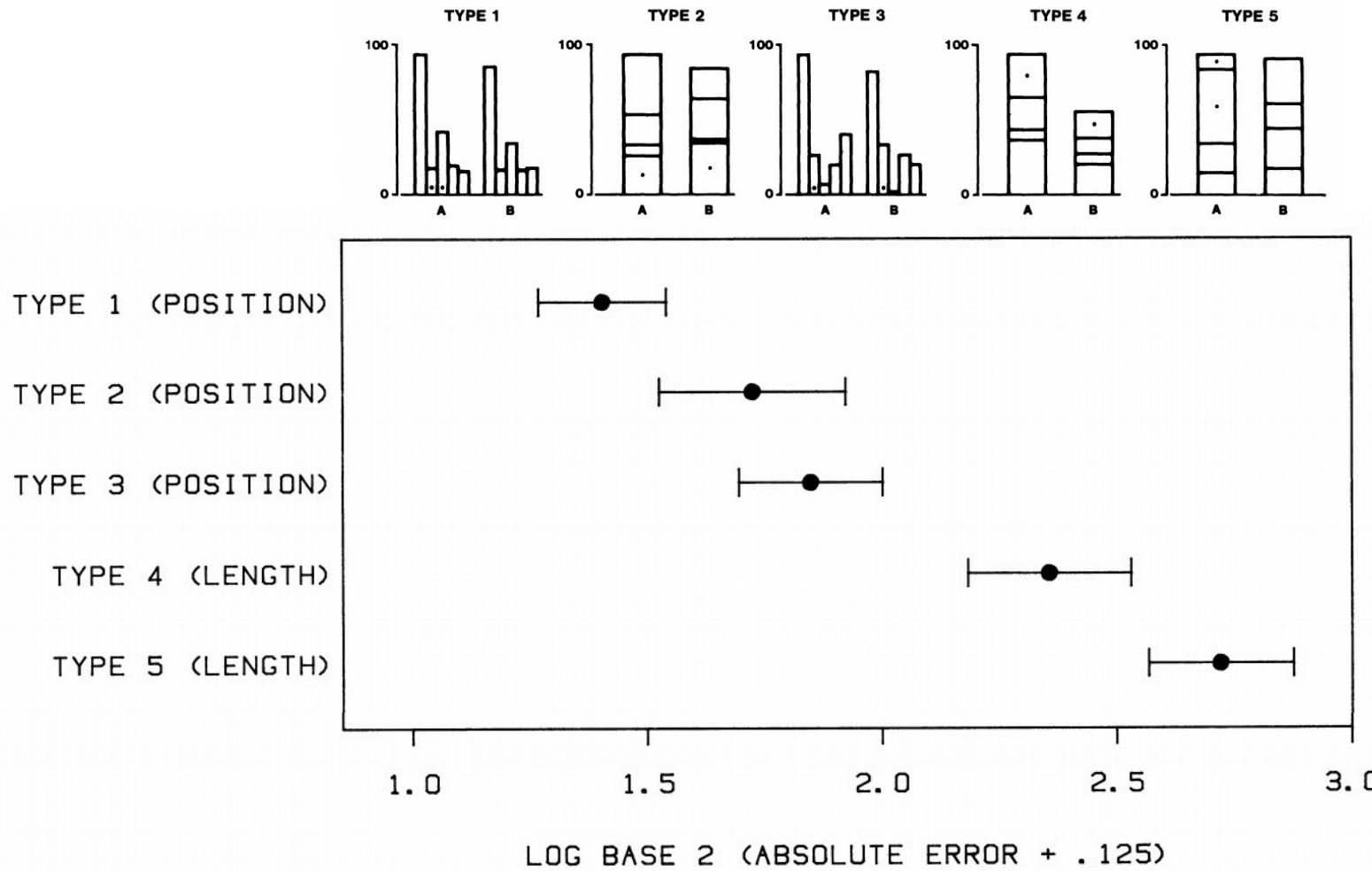
- What percentage of the smaller was of the larger?

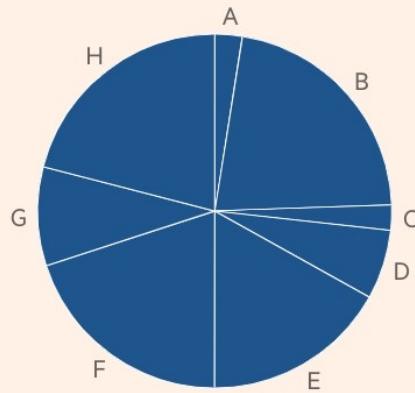


# Graphical Perception [Cleveland & McGill 84]

- What percentage of the smaller was of the larger?

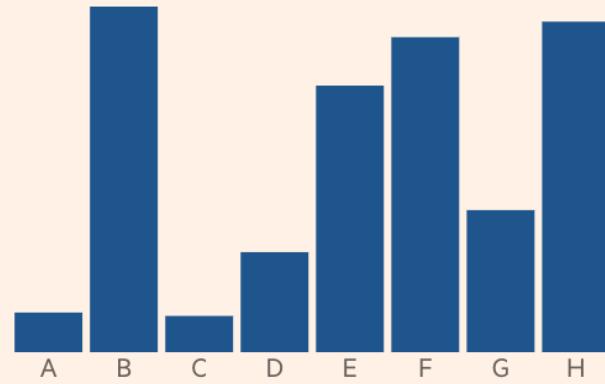






Which is the third largest segment in the pie chart?

E	F
G	H

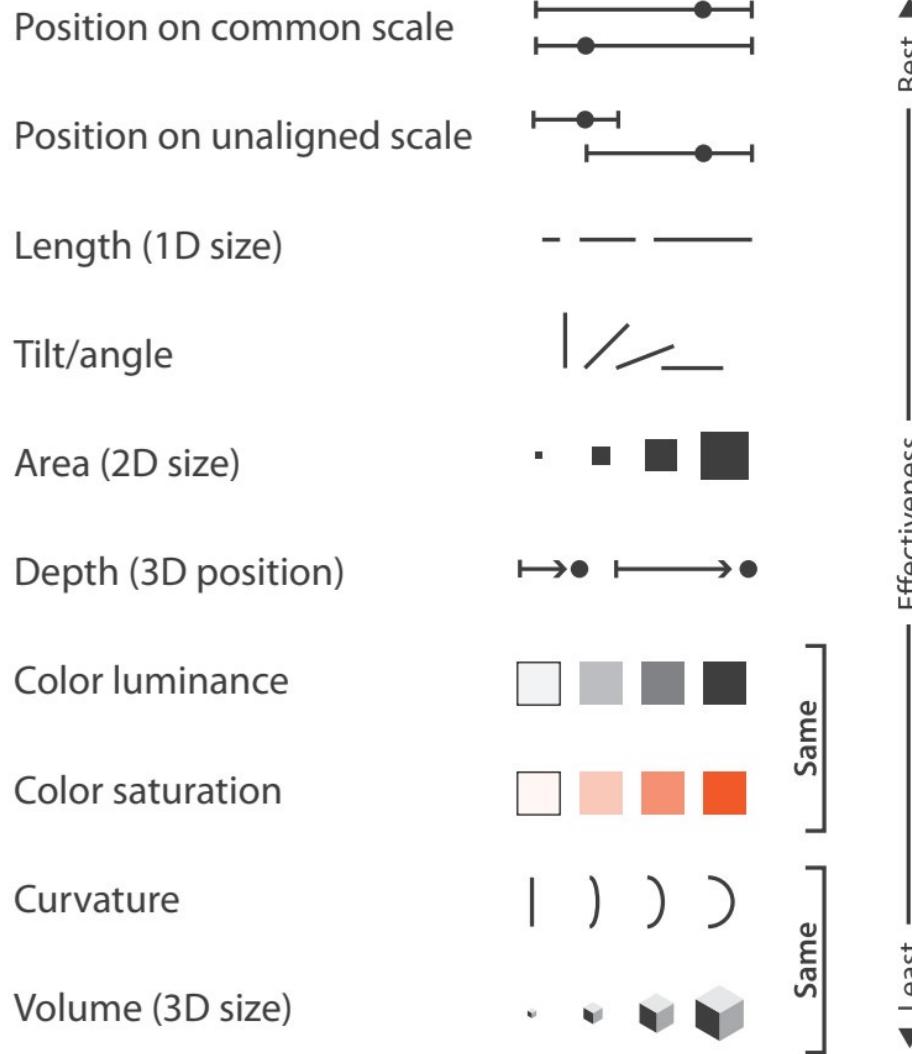


Which is the 3rd largest bar?

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?

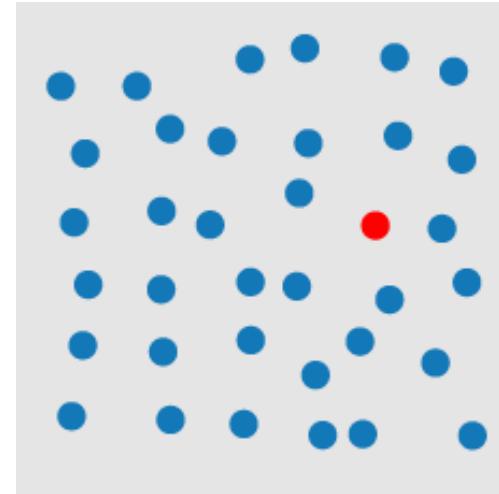
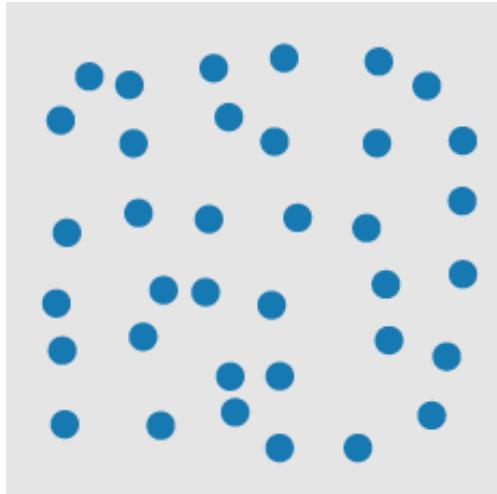
12817687561**3**8976546984506985604982826762  
980985845822450985645894509845098094**3**585  
90910**3**0209905959595772564675050678904567  
8845789809821677654876**3**64908560912949686

# Pre-attentive processing

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

# Visual Pop-Out: Color

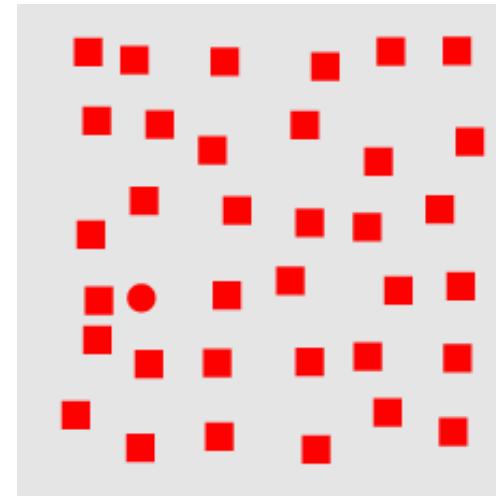
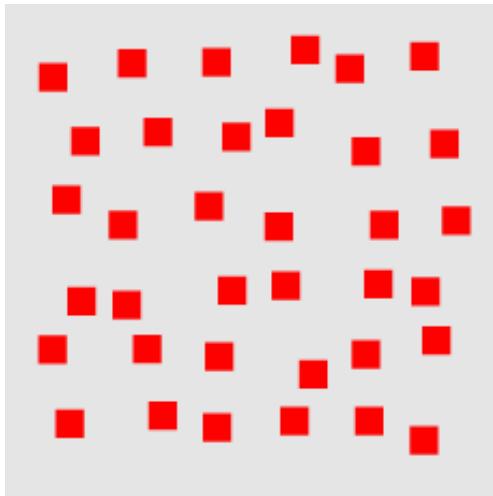
- A unique visual property in the target allows it to "pop out" of a display



[www.csc.ncsu.edu/faculty/healey/PP/index.html](http://www.csc.ncsu.edu/faculty/healey/PP/index.html)

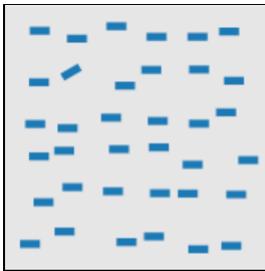
# Visual Pop-Out: Shape

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

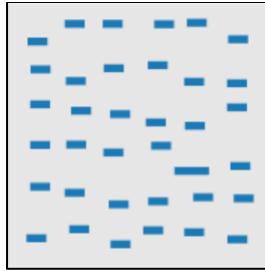


[www.csc.ncsu.edu/faculty/healey/PP/index.html](http://www.csc.ncsu.edu/faculty/healey/PP/index.html)

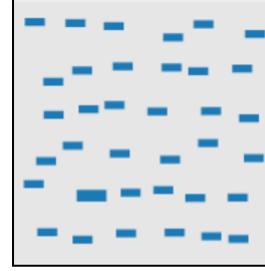
# A partial list of preattentive visual features



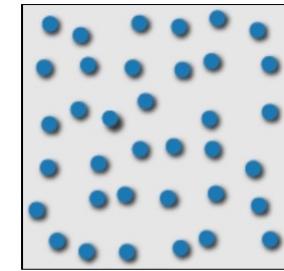
line (blob) orientation  
Julész & Bergen 83; Sagi &  
Julész 85a, Wolfe et al. 92;  
Weigle et al. 2000



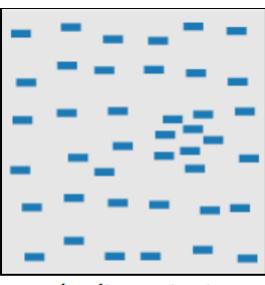
length, width  
Sagi & Julész 85b; Treisman  
& Gormican 88



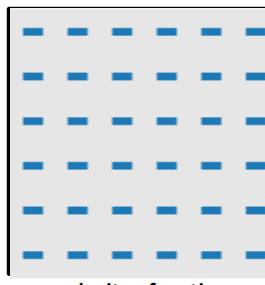
size  
Treisman & Gelade 80;  
Healey & Enns 98; Healey &  
Enns 99



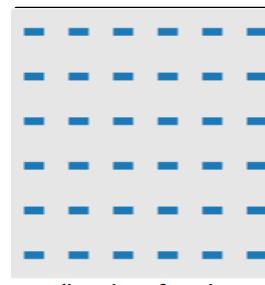
3D depth cues  
Enns 90b; Nakayama & Sil-  
verman 86



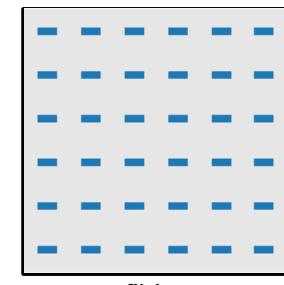
density, contrast  
Healey & Enns 98; Healey &  
Enns 99



velocity of motion  
Tynan & Sekuler 82; Nakaya-  
ma & 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 al. 55; Mowbray &  
Gebhard 55; Brown 65; Julész  
71; Huber & Healey 2005

and many more...

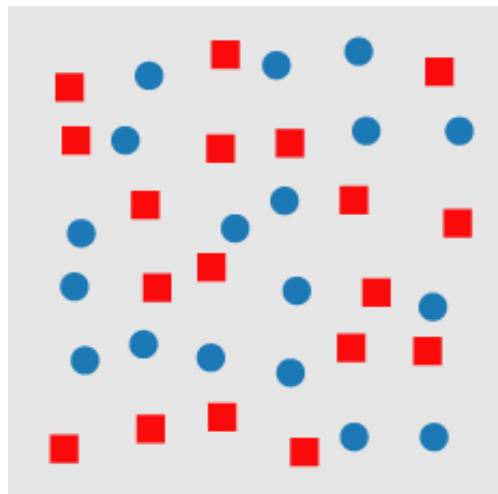
Christopher Healey,  
<https://www.csc.ncsu.edu/faculty/healey/PP/index.html>

# Multiple Attributes

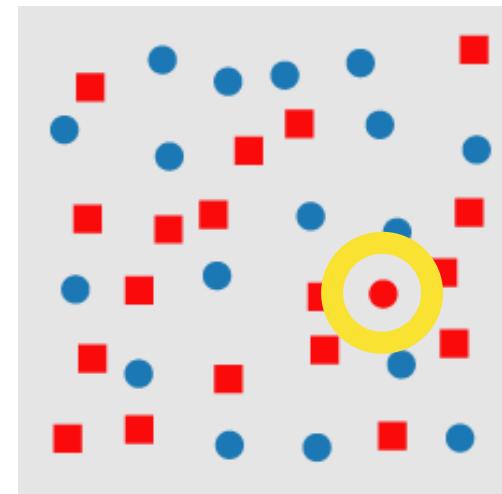
# Feature Conjunctions

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

Consistent



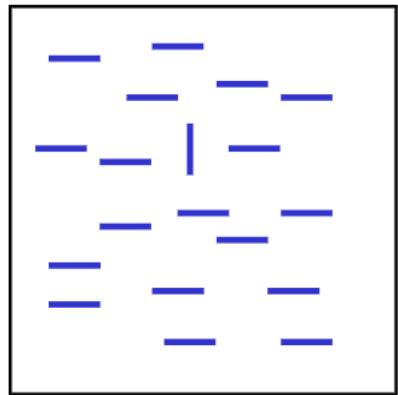
Inconsistent



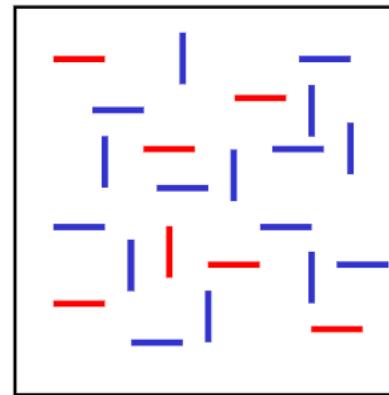
No unique visual property of the target

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

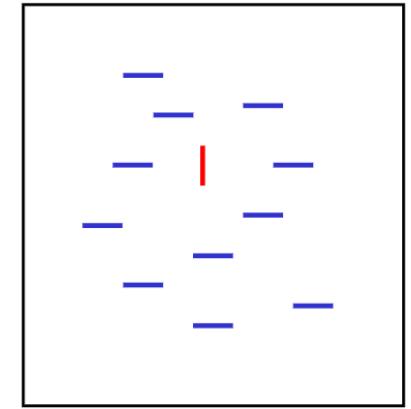
## Feature search



## 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



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?

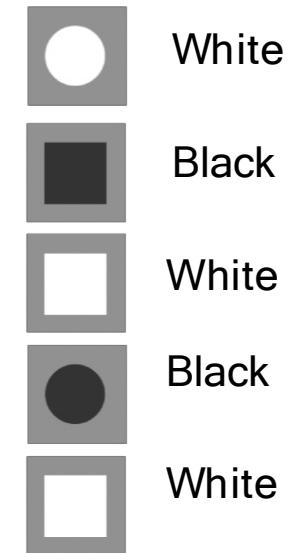
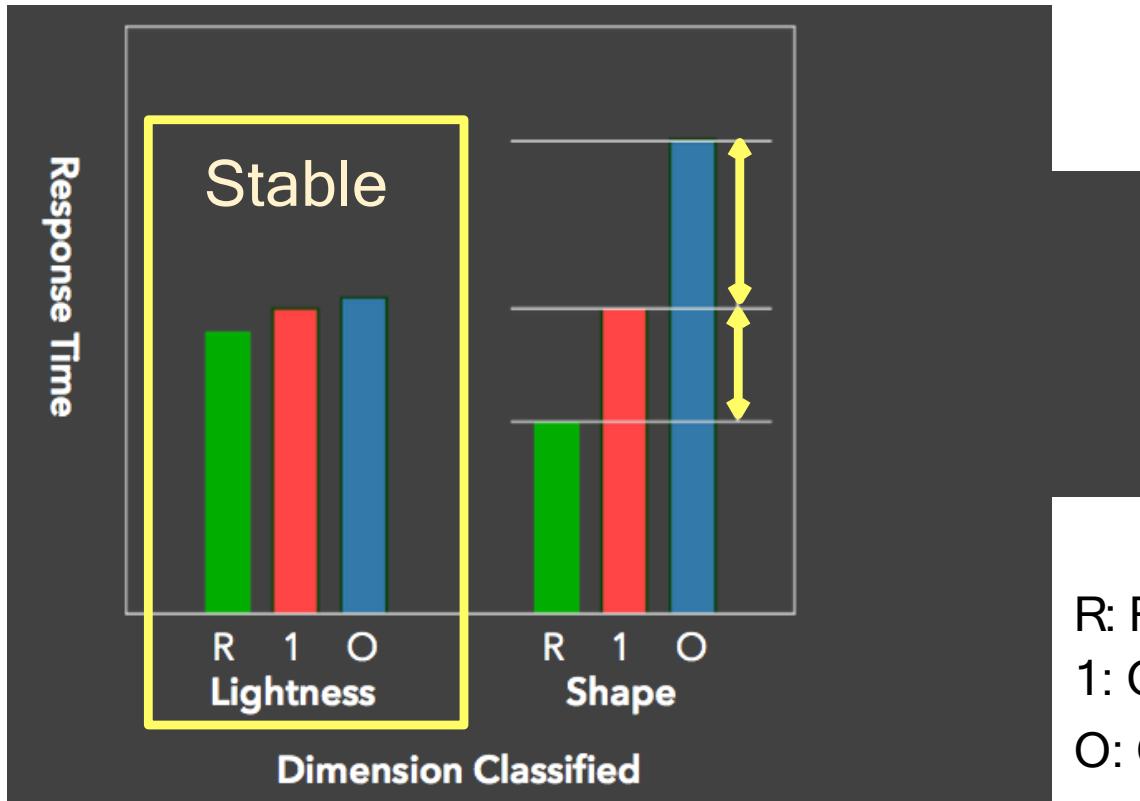


- |  |        |
|--|--------|
|  | Circle |
|  | Square |
|  | Square |
|  | Circle |
|  | Circle |

# Speeded Classification

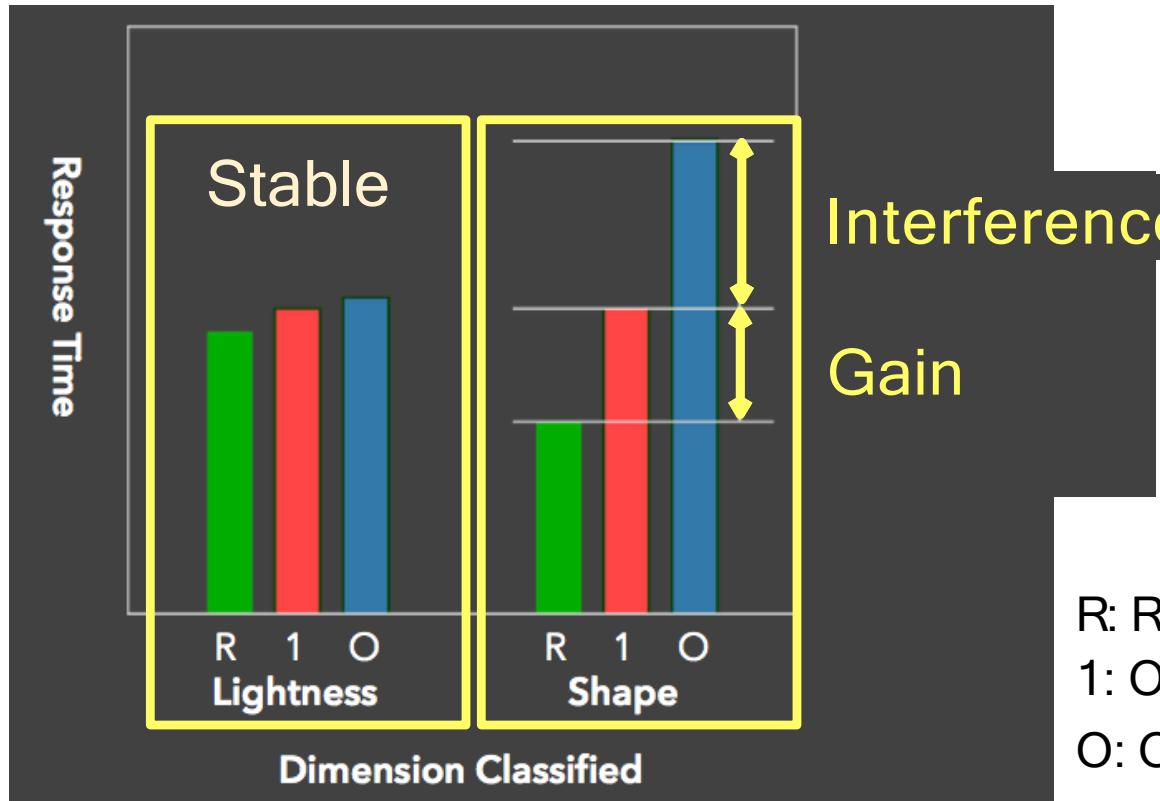
- Redundancy Gain
  - Facilitation in reading one dimension when the other provides redundant information.
- Filtering Interference
  - Difficulty in ignoring one dimension while attending to the other.

# Speeded Classification



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

# Speeded Classification



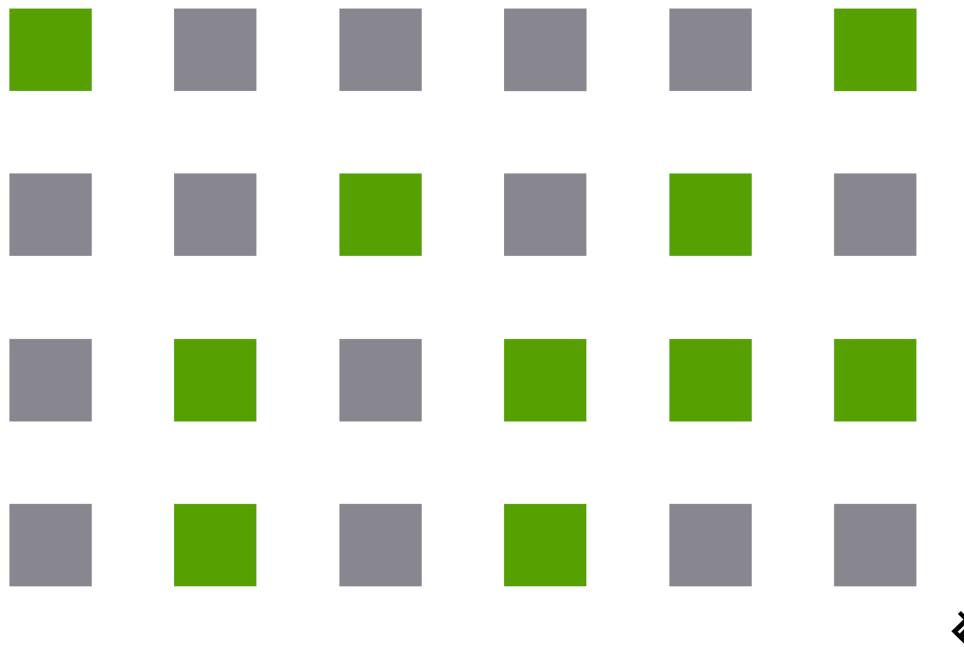
	White
	Black
	White
	Black
	White

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

# Gestalt Grouping

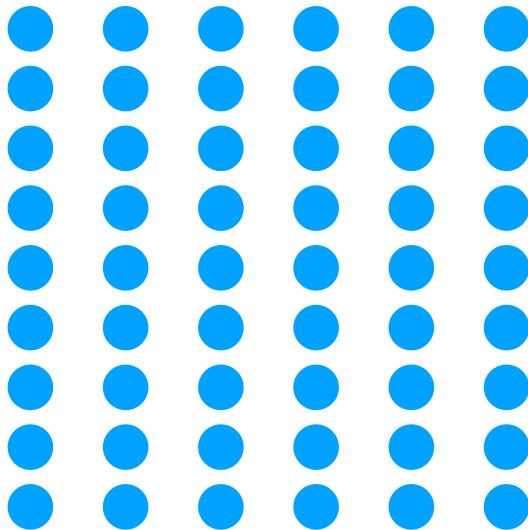
# Gestalt principles of design

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

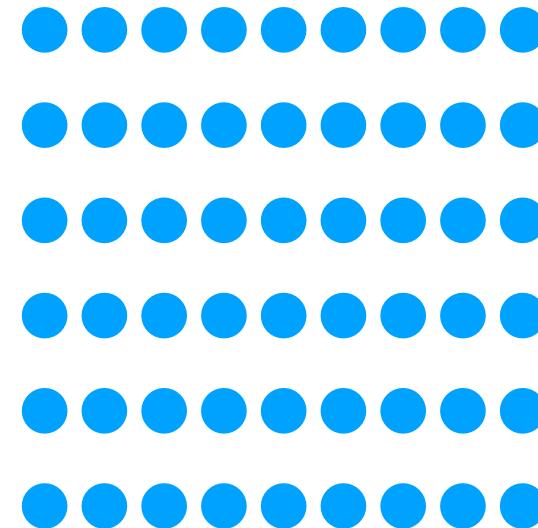


The squares here are all equally spaced and the same size, but we automatically group them by color, even though there's no rhyme or reason to their placement.

# Proximity

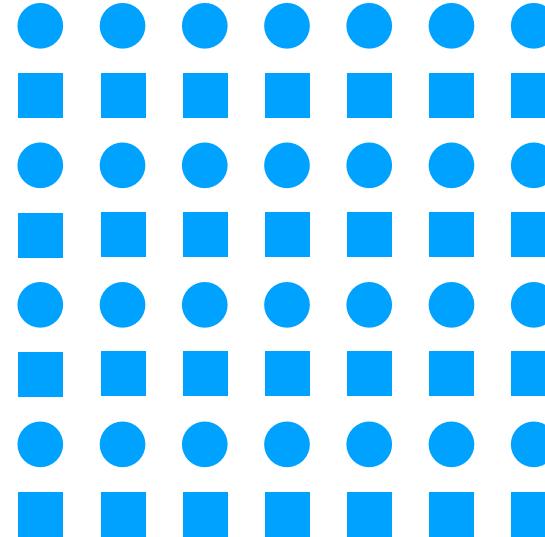
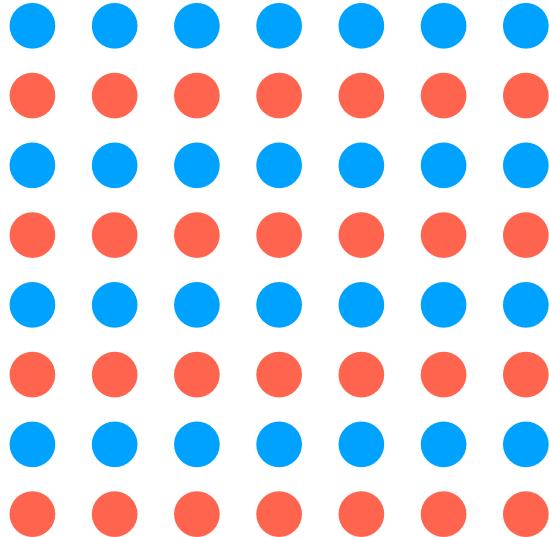


Columns

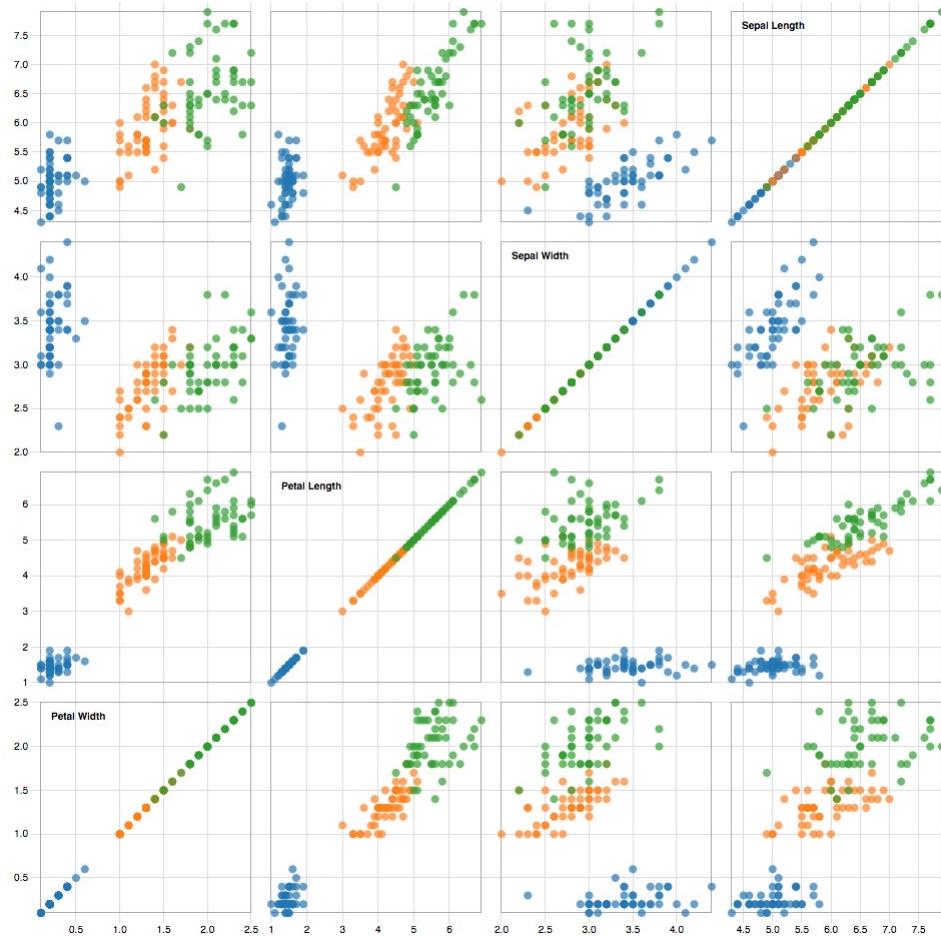


Rows

# Similarity



Rows stand out due to similarity.

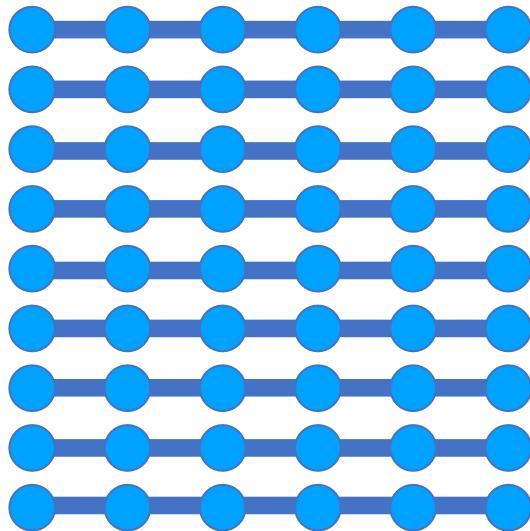


# Scatter Plot Matrix

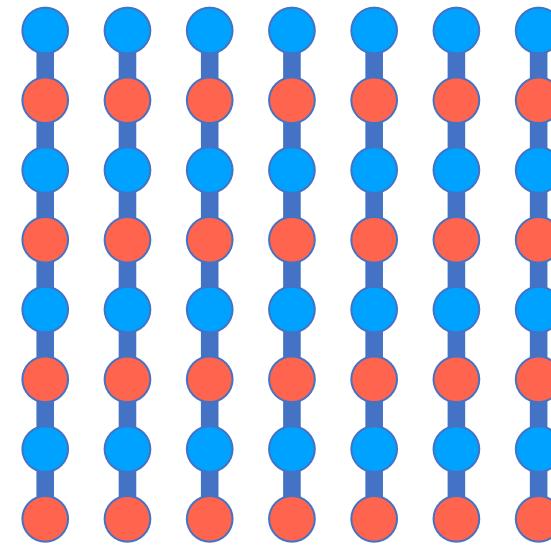
## Clusters and outliers

# Uniformed Connectedness: Connection

- Connectedness dominates proximity and similarity

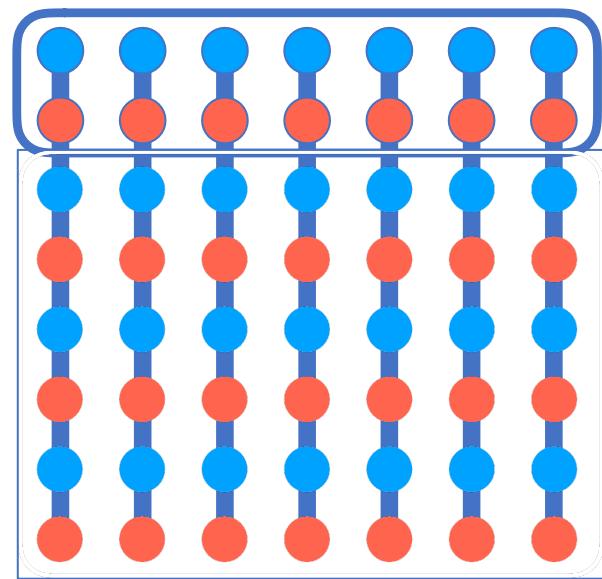
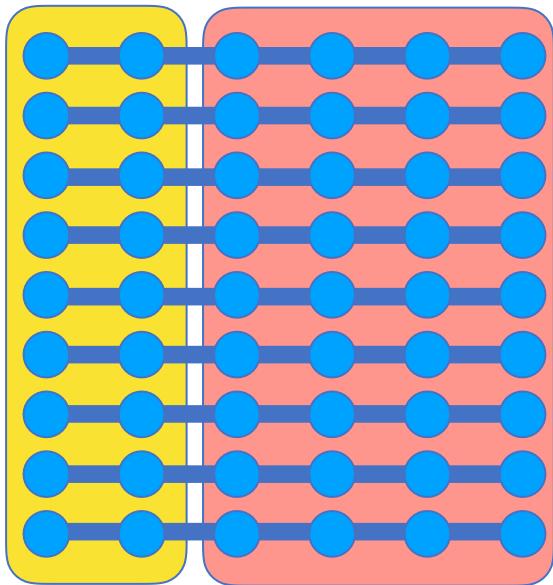


Proximity (column)  
vs connection (row)

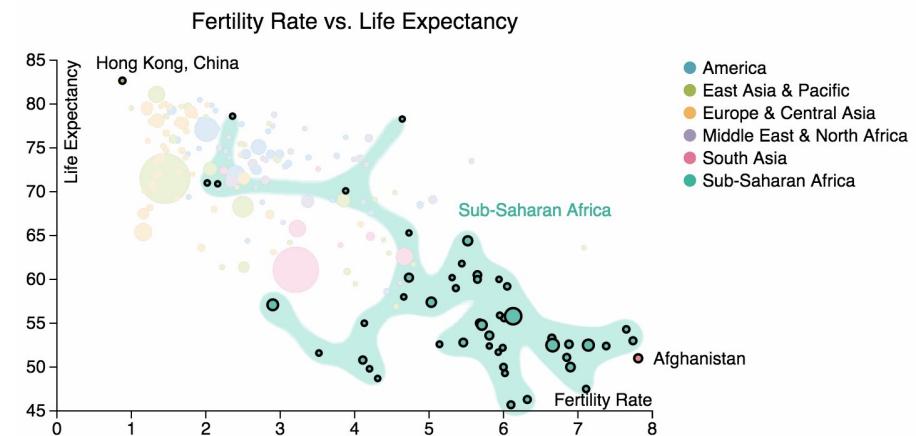
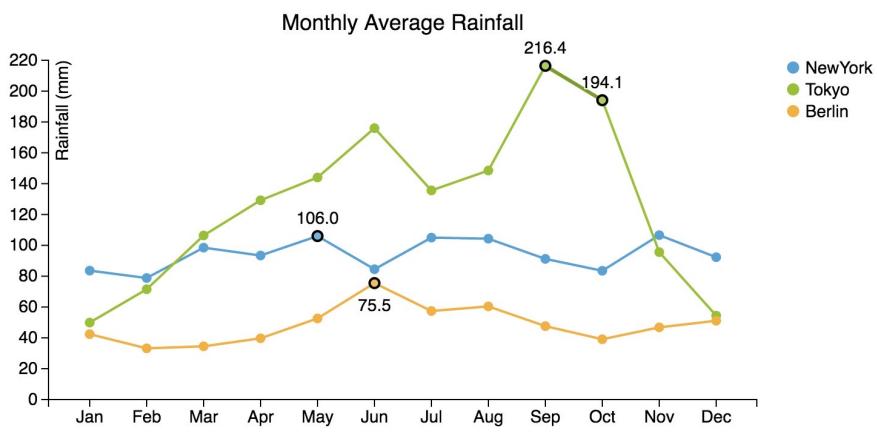


Similarity (row)  
vs connection (column)

# Uniformed Connectedness: Enclosure



# Chart Annotations



# Visualizing Sets

- Visualizing sets is a non-trivial problem due to the large number of possible relations between them.

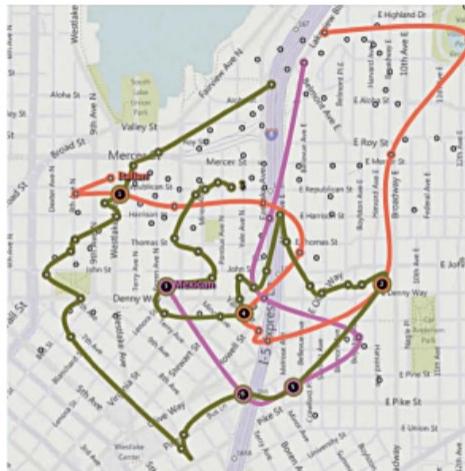
Bubble Sets



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

[https://www.youtube.com/watch?time\\_continue=34&v=Ju2hSThmPWA&feature=emb\\_logo](https://www.youtube.com/watch?time_continue=34&v=Ju2hSThmPWA&feature=emb_logo)

Line Sets



[Alper et al., 2011]

making sure that the traversed path over the elements is relatively short

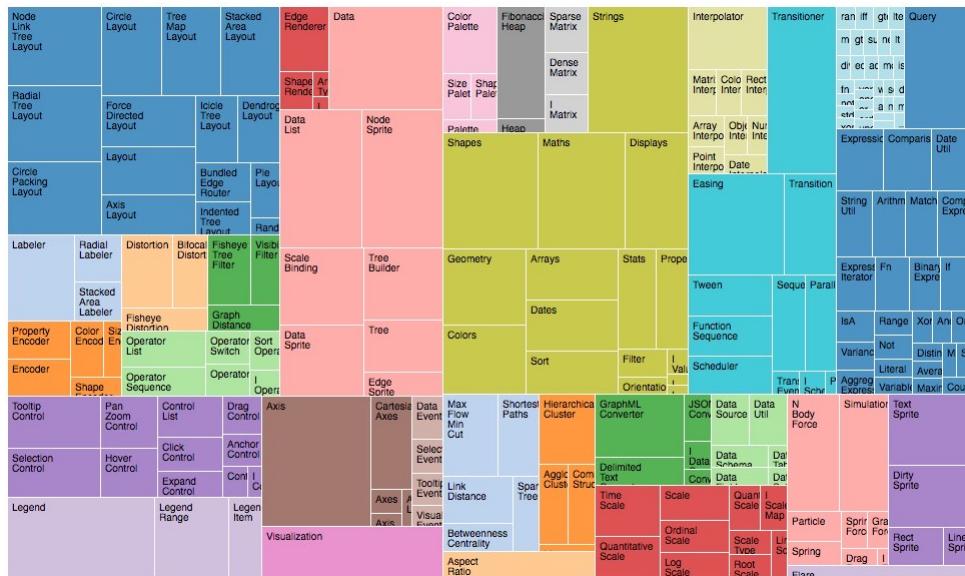
Kelp Diagrams



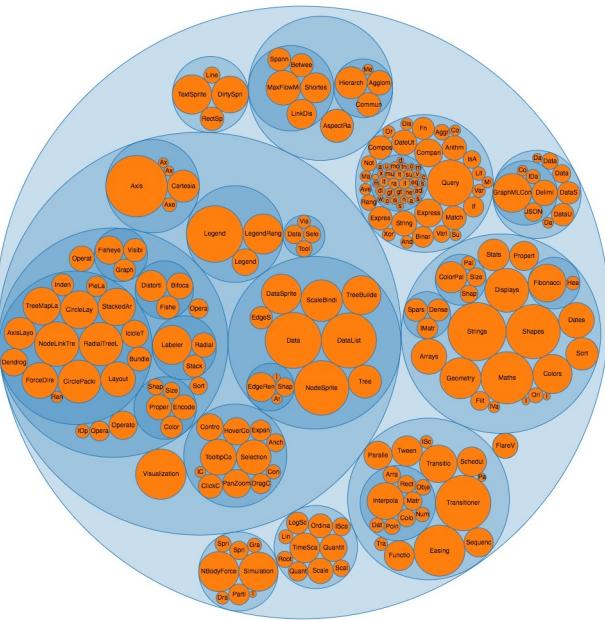
[Dinkla et al., 2012]

[Slides from A. Lex]

# TreeMap and Circle Packing



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

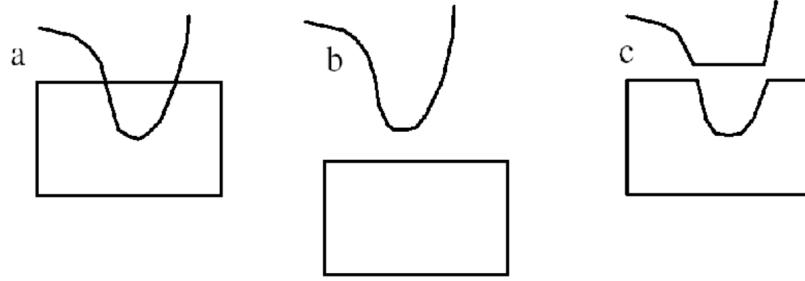


<https://bl.ocks.org/mbostock/4063530>

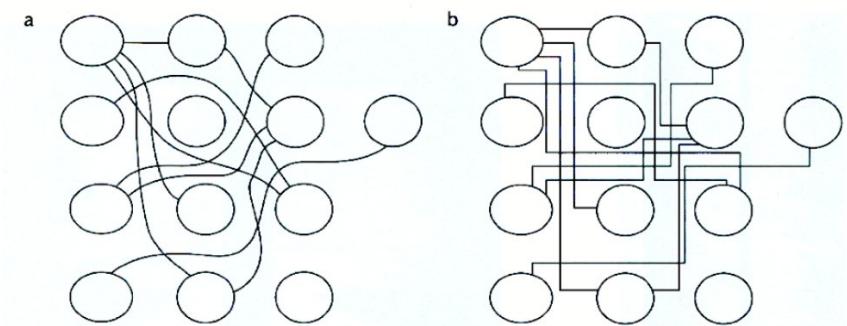
# Proximity, Similarity, Enclosure



# Continuity



We prefer smooth not abrupt changes

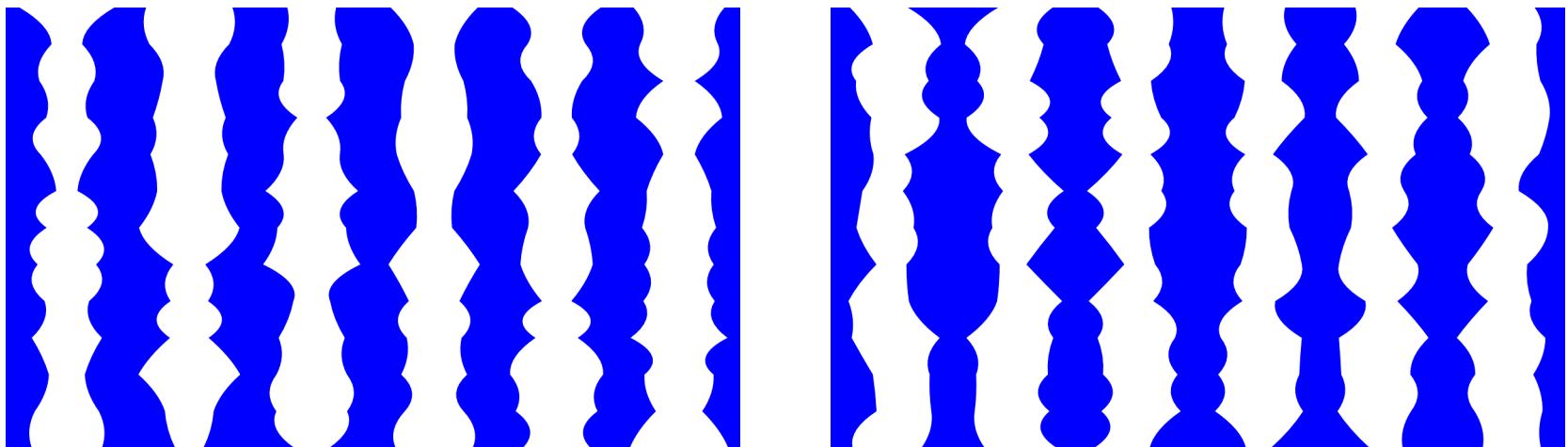


Connections are clearer with smooth contours

[from Ware 04]

# Symmetry

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

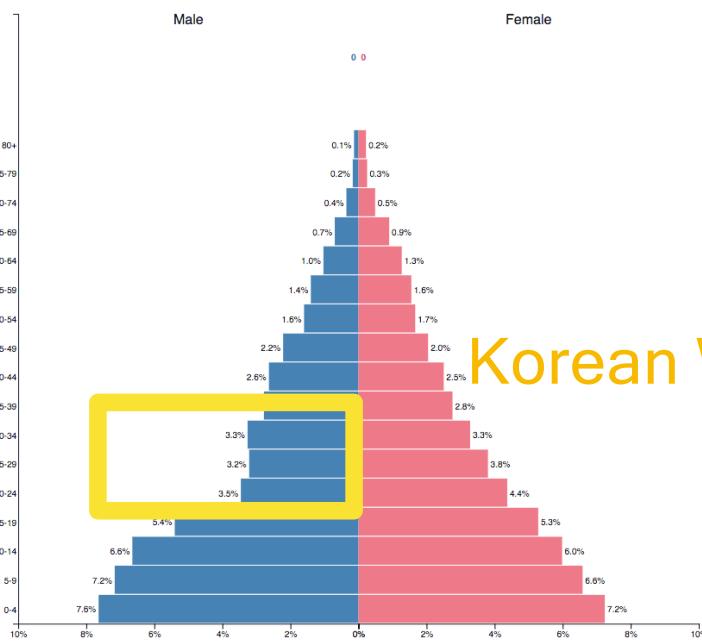


[https://isle.hanover.edu/Ch05Object/Ch05SymmetryLaw\\_evt.html  
#:~:text=The%20Law%20of%20Symmetry%20is,perceived%20as%20a%20unified%20group.](https://isle.hanover.edu/Ch05Object/Ch05SymmetryLaw_evt.html#:~:text=The%20Law%20of%20Symmetry%20is,perceived%20as%20a%20unified%20group.)

# Population Pyramid (or tornado chart)

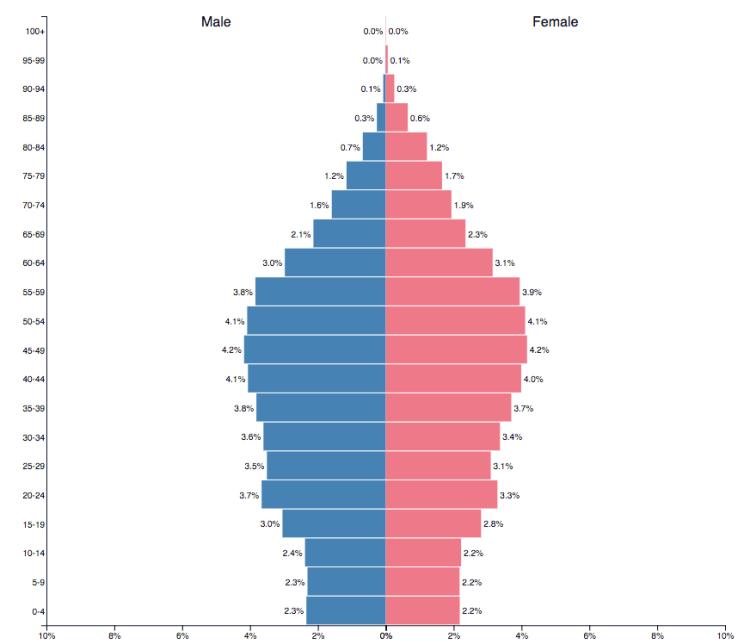
Republic of Korea ▾  
1953

population: 19,979,069



Republic of Korea ▾  
2017

Population: 50,704,971



Korean War?

[www.populationpyramid.net/united-states-of-america/2017/](http://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.









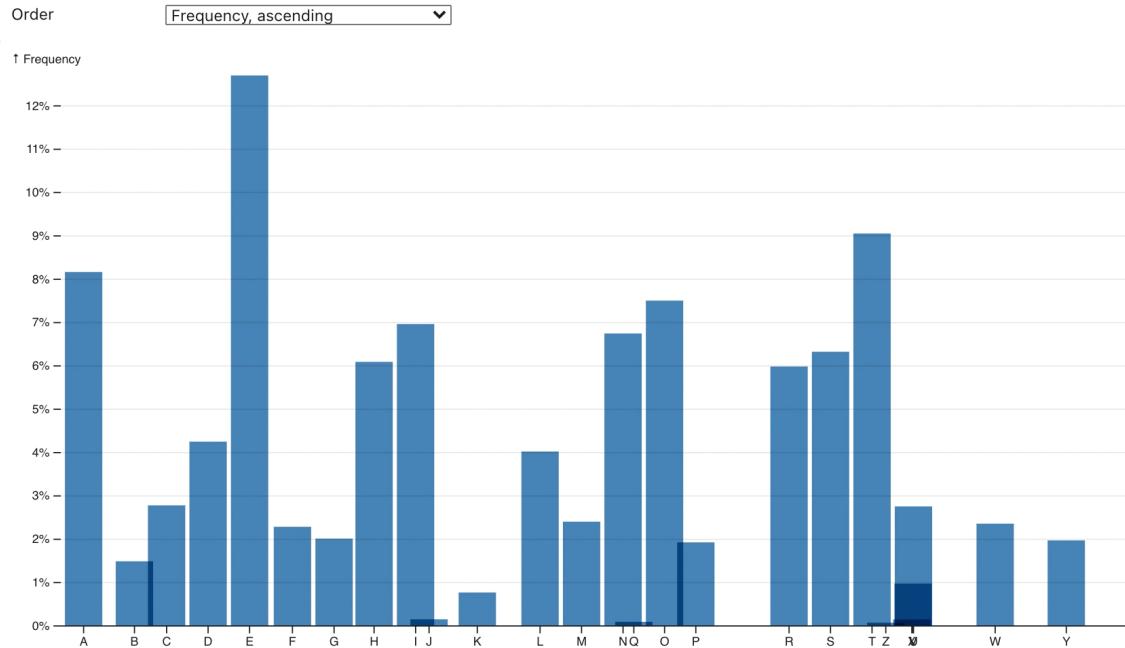
“To see an object change, it is necessary to attend to it.”

– 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

Use the dropdown menu to change the sort order.



# 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.