

Data Visualization

VISUAL PERCEPTION (1)

Tea Tušar, Data Science and Scientific Computing

Outline

Motivation

Memory

Visual encoding

- Channel accuracy
- Channel discriminability
- Channel salience (pop-out)
- Channel separability
- Grouping

Color

- Color perception
- Color specification

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Motivation

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Why study visual perception?

One might think that the quality of a visualization is a matter of **subjective taste**

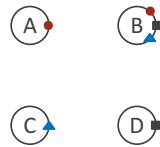
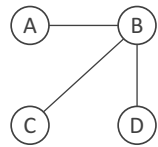


But visual perception follows specific rules derived from **how the brain works**

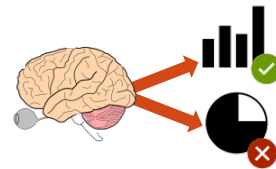


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Why study visual perception?



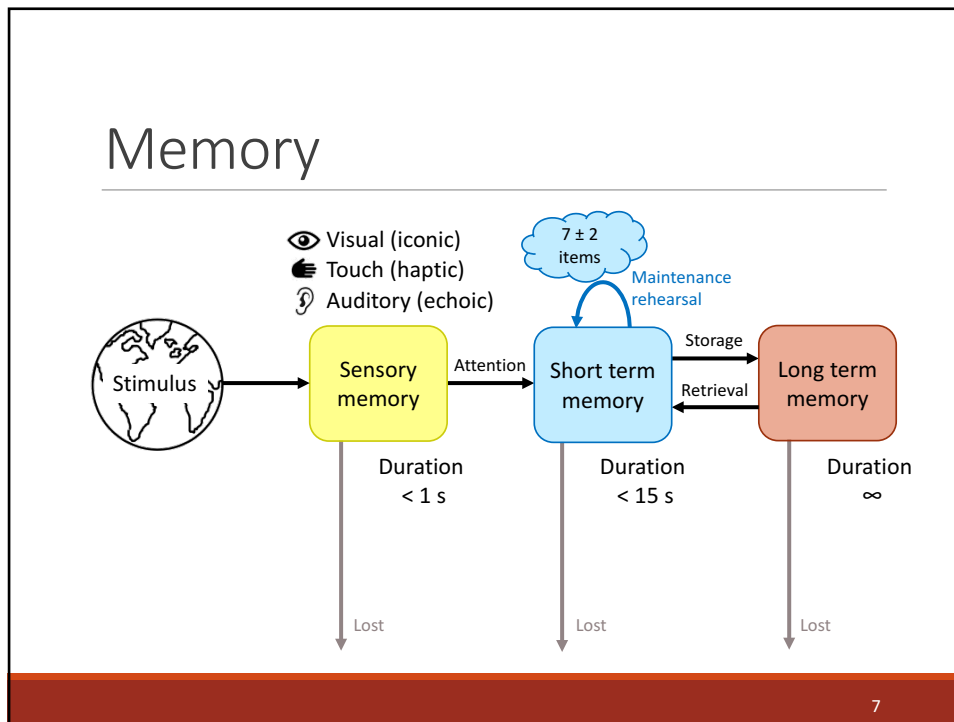
Understanding visual perception enables to make **informed decisions** about visualization design



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Memory

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Memory: Implications for design/presentation

Do not display more than 7 ± 2 items/categories

The power of repetition: **Bing, Bang, Bongo**

- Introduce what you are going to tell the audience (**Bing**)
- Tell the audience (**Bang**)
- Summarize what you just told them (**Bongo**)

Introduction: ▲ ● ■

▲ _____

● _____

■ _____

Conclusion: ▲ ● ■

C. Nussbaumer Knaflic. *Storytelling with data*. Wiley, 2015

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Visual encoding

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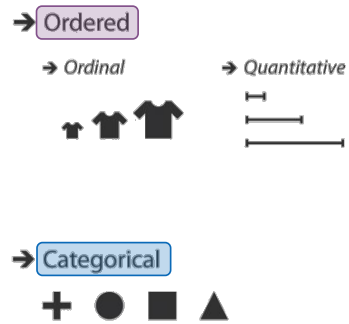
Visual encoding

Mapping between data properties and graphical properties

Data attributes → Visual channels

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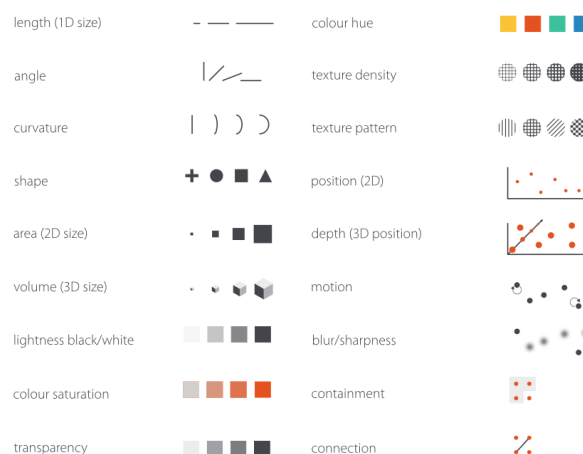
Data attributes



T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014

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Visual channels



E. J. Maguire. *Systematising Glyph Design for Visualization*, PhD Thesis, University of Oxford, 2014. 12

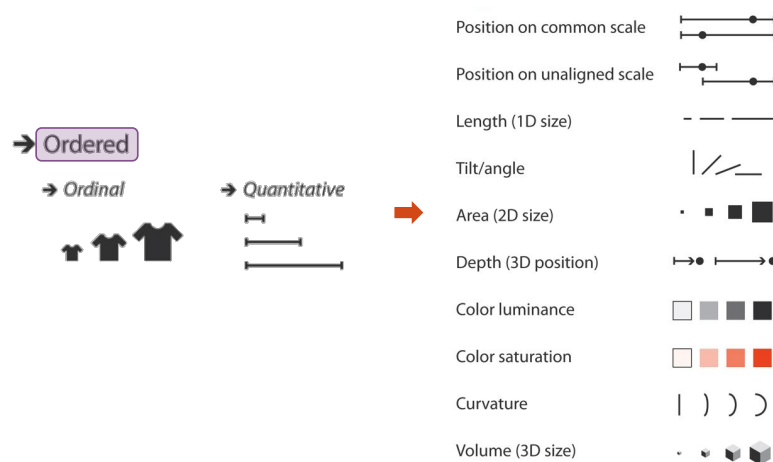
Visual channels

Channel properties

- **Expressiveness** – what can be expressed with a channel
- **Effectiveness** – how well it can be expressed

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Channels that can express order



T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014

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Channels that can express categories



Channel effectiveness

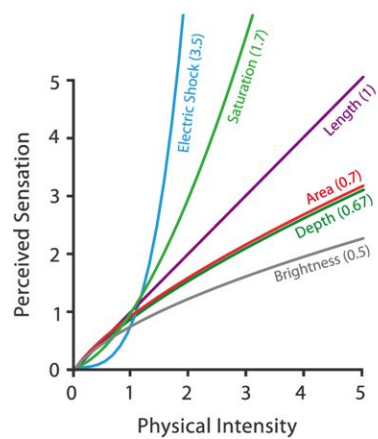
- Single channel
 - Accuracy (estimating magnitude)
 - Discriminability (number of values that can be distinguished)
- Multiple channels
 - Salience or pop-out (attracting attention)
 - Separability (interference between channels)
 - Grouping (pattern formation)

Channel accuracy

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Channel accuracy

Steven's Psychophysical Power Law: $S = I^n$



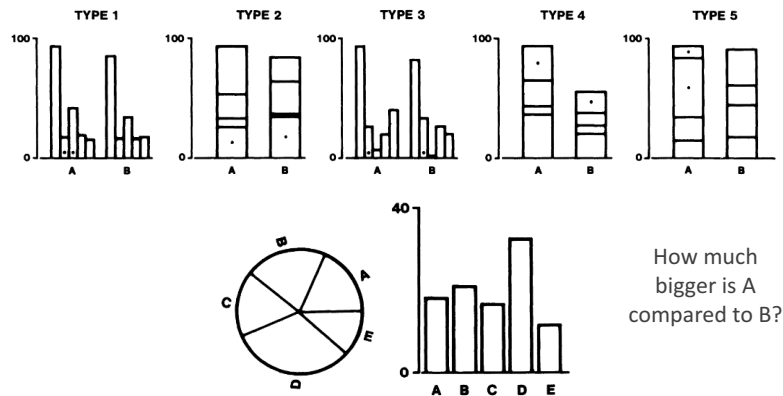
Published
in 1957

T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014

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Channel accuracy

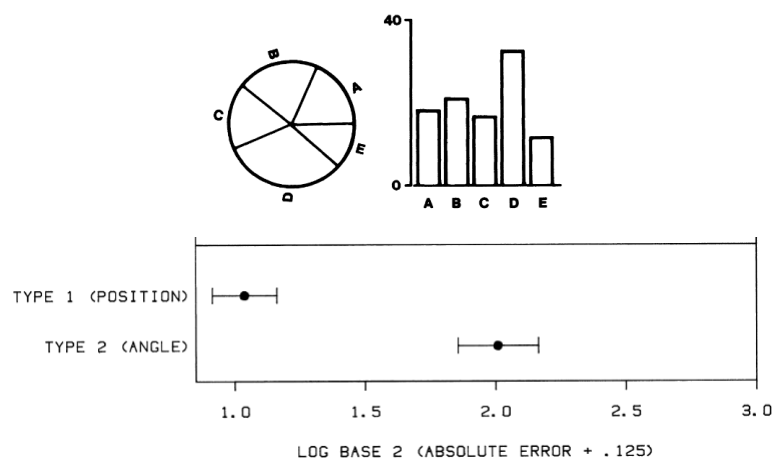
Experiments by Cleveland and McGill in 1983



W. S. Cleveland, R. McGill. Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. *Journal of the American Statistical Association*, 1984

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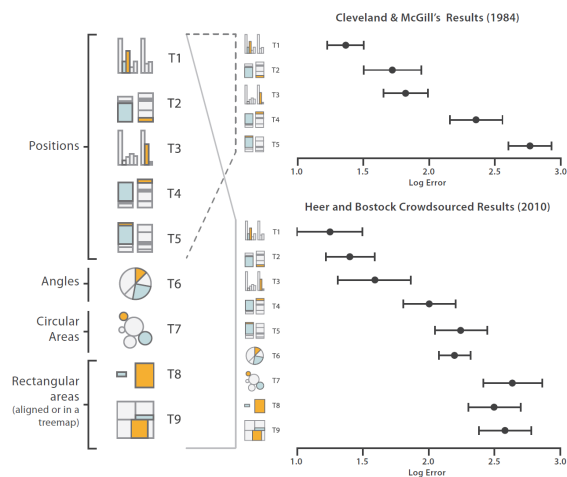
Channel accuracy



W. S. Cleveland, R. McGill. Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. *Journal of the American Statistical Association*, 1984

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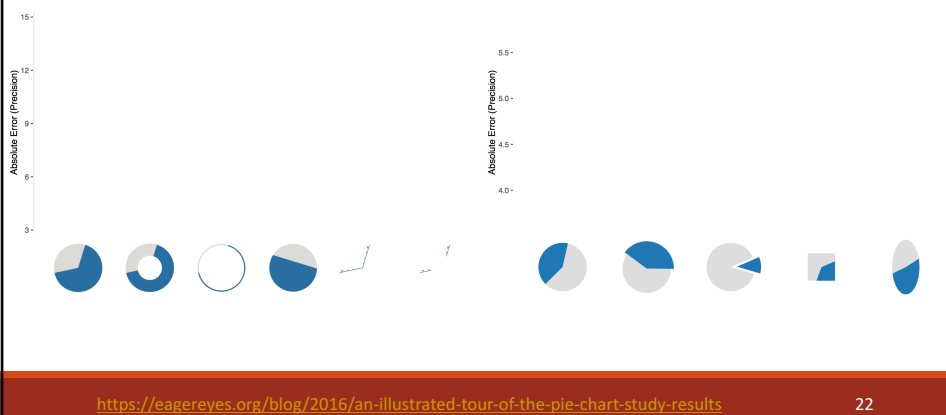
Channel accuracy



E. J. Maguire. Systematising Glyph Design for Visualization, PhD Thesis, University of Oxford, 2014. 21

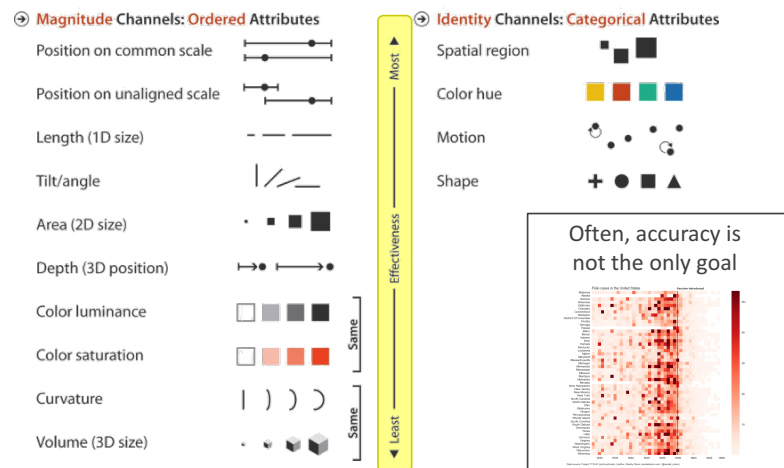
Channel accuracy

Recent experiments by Skau and Kosara show that pie charts are not read by angle



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Channel accuracy: Implications for design



T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014

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Channel discriminability

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Channel discriminability

How many distinct values can be distinguished within a channel

Discriminability depends on

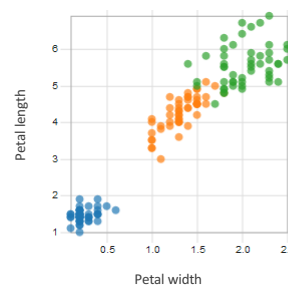
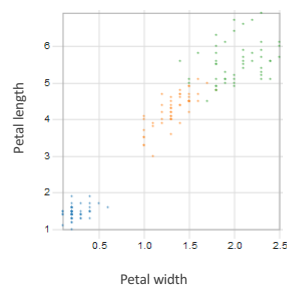
- Channel properties
- Size
- Spatial arrangement
- Cardinality



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Channel discriminability

The effect of size

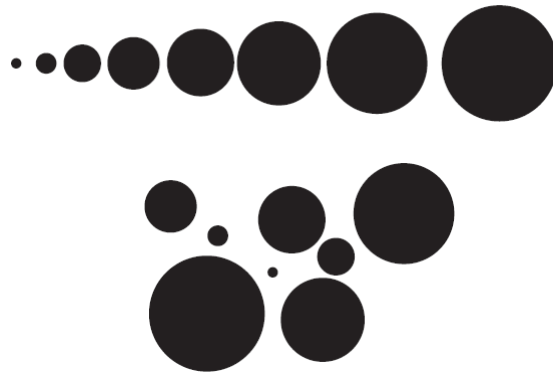


<https://beta.observablehq.com/@mbostock/d3-scatterplot-matrix>

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Channel discriminability

The effect of spatial arrangement



E. J. Maguire. Systematising Glyph Design for Visualization, PhD Thesis, University of Oxford, 2014. 27

Channel discriminability

The effect of cardinality



E. J. Maguire. Systematising Glyph Design for Visualization, PhD Thesis, University of Oxford, 2014. 28

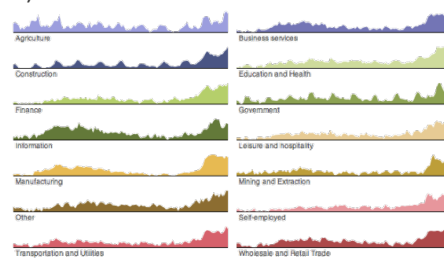
Channel discriminability: Implications for design

Do not overestimate the number of values viewers can perceive/discriminate

Short term memory limitation: 7 ± 2 items (rather 5 than 9)

What to do in case of a large number of categories?

- Grouping (show groups of categories)
- Filtering (show only selected few)
- Faceting (use small multiples)



<https://tableaulearn.wordpress.com/2016/04/20/data-visualization-types/>

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Channel salience

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Channel salience (pop-out)

Ability to stand out in a scene

Highly related to **preattentive processing**

- Uses sensory memory
- Happens automatically
- Tasks performed in less than 250 ms (faster than eye movement initiation)

Neurons in the brain are tuned to specific properties, called **preattentive attributes**

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An example

1 8 2 7 8 6 0 8 3 5 3 1 6 7
9 0 6 8 2 4 7 4 8 3 8 7 4 3
9 3 9 1 0 8 1 9 2 4 8 0 5 1
7 6 0 9 5 2 3 5 1 8 4 0 7 6
7 2 4 6 1 7 5 9 7 3 2 4 9 1

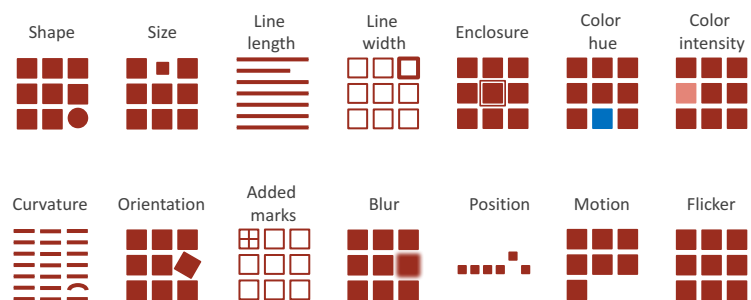
32

An example

1 8 2 7 8 6 0 8 3 5 3 1 6 7
9 0 6 8 2 4 7 4 8 3 8 7 4 3
9 3 9 1 0 8 1 9 2 4 8 0 5 1
7 6 0 9 5 2 3 5 1 8 4 0 7 6
7 2 4 6 1 7 5 9 7 3 2 4 9 1

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Preattentive attributes



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Preattentive attributes

Many attributes are asymmetric

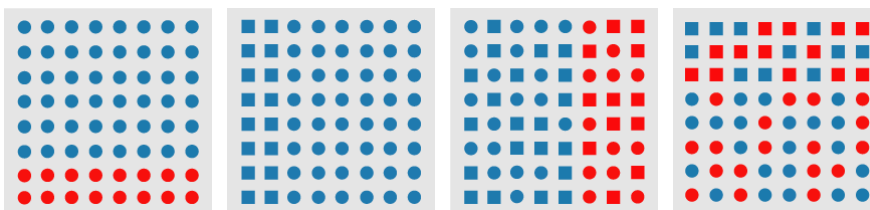


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Preattentive attributes

Some attributes are stronger than others

- In boundary detection, color hue is stronger than shape

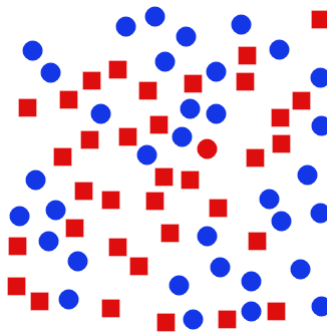


<https://www.csc2.ncsu.edu/faculty/healey/PP/>

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Preattentive attributes

Conjunctions of two attributes often not preattentive



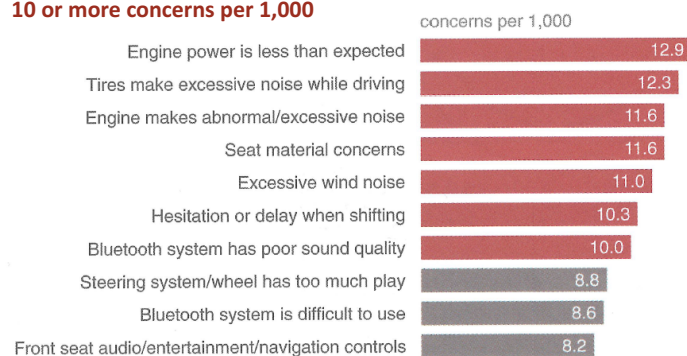
<https://www.csc2.ncsu.edu/faculty/healey/PP/>

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Channel salience: Implications for design

Preattentive attributes can be used to draw attention

**7 of the top 10 complaints have
10 or more concerns per 1,000**



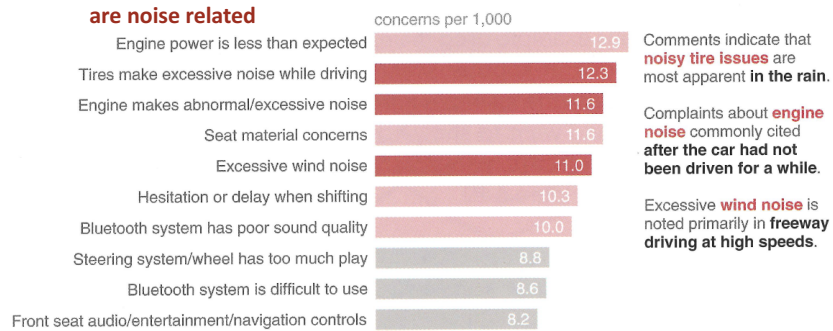
C. Nussbaumer Knaflic. *Storytelling with data*. Wiley, 2015

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Channel salience: Implications for design

Preattentive attributes can be used create a visual hierarchy of information

3 of the top 10 complaints are noise related



Channel salience: Implications for design

Use color sparingly

When you highlight one point, you make the other points harder to see

Do not use preattentive attributes in exploratory data analysis

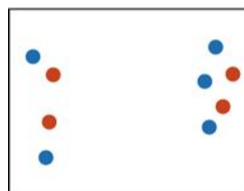
Channel separability

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Channel separability

Amount of interference between channels

Position
+ Hue (Color)



An example of
separable channels

Fully separable

Channel separability

Amount of interference between channels

Size
+ Hue (Color)



Some interference

Channel separability

Amount of interference between channels

Width
+ Height



Some/significant
interference

Channel separability

Amount of interference between channels

Red
+ Green



An example of
integral channels

Major interference

Channel separability: Implications for design

Use **separable channels** when the audience should perceive
one variable at a time

Use **integral channels** when you want a **holistic effect**

Grouping

GESTALT LAWS

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Gestalt laws

Gestalt (German) = shape, form

Gestalt psychology aims to understand how individual visual objects are grouped to form a pattern

The whole is other than the sum of its parts

Kurt Koffka, Gestalt psychologist

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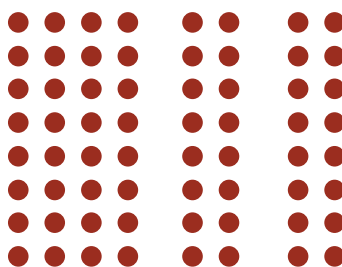
Gestalt laws

Proximity
Similarity
Connection
Enclosure
Closure
Figure/Ground

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Gestalt law of Proximity

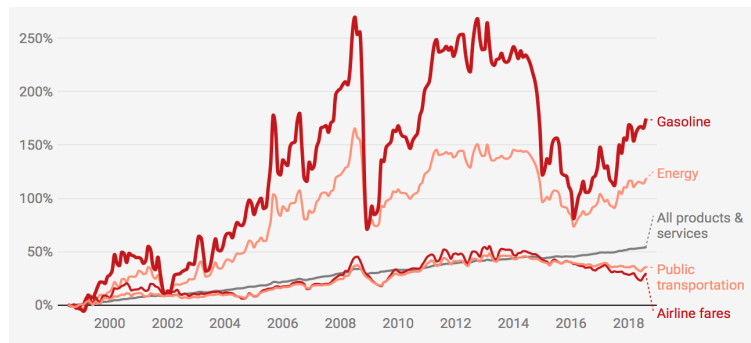
We perceive objects close to each other as belonging to a group



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Gestalt law of Proximity: Implications for design

Place annotations close to the data

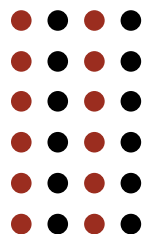


<https://blog.datawrapper.de/weekly47-cpi-dollars-for-college/>

51

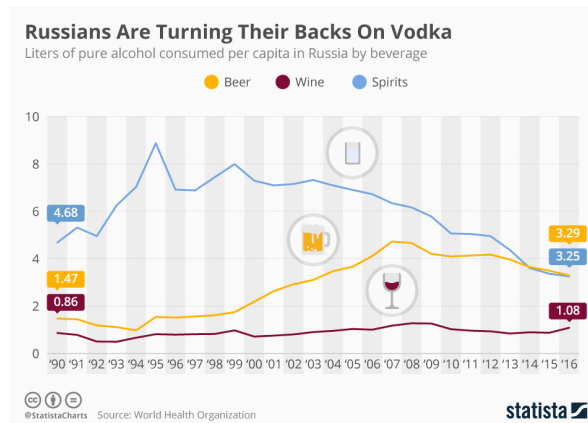
Gestalt law of Similarity

We perceive similar objects as belonging to a group



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Gestalt law of Similarity: Implications for design

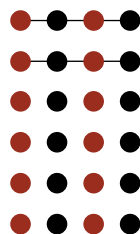


<https://www.statista.com/chart/15918/liters-of-pure-alcohol-consumed-per-capita-in-russia/>

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Gestalt law of Connection

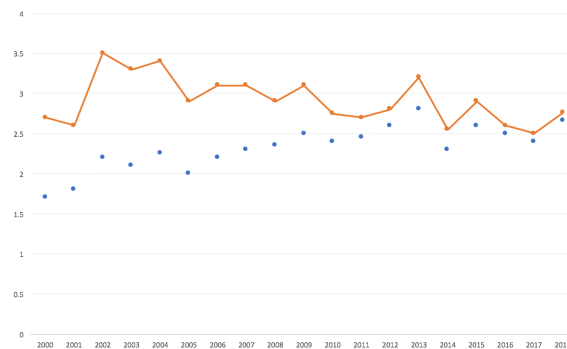
We perceive objects connected to each other as a single group



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Gestalt law of Connection: Implications for design

Use lines to show the data is in the same group

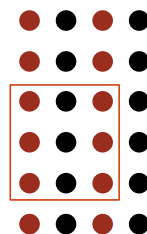


<http://daydreamingnumbers.com/concepts/gestalt-laws-data-visualization/>

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Gestalt law of Enclosure

We perceive physically enclosed objects as part of a group



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Gestalt law of Enclosure: Implications for design

Use enclosures to show groups



<https://logoblink.com/logo-map-major-brands/>

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Gestalt law of Enclosure: Implications for design

Bubble sets visualization



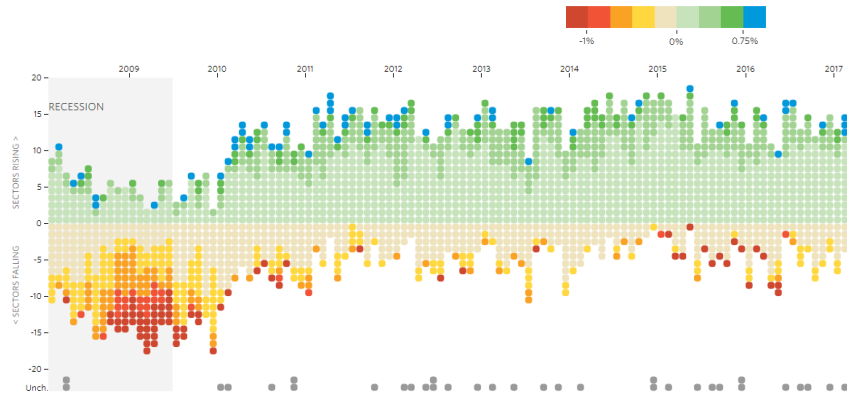
<http://vialab.science.uoit.ca/portfolio/bubblesets>

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Gestalt law of Enclosure: Implications for design

Winners and Losers: Job Gains and Losses [Jump to National Unemployment](#)

Track the number of sectors gaining or losing jobs each month. Boxes are shaded based on percentage change from the previous month in each sector's payrolls.

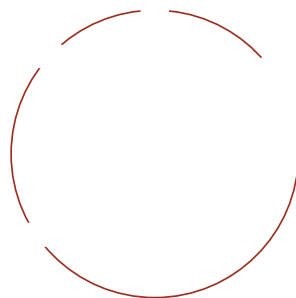


<http://graphics.wsj.com/job-market-tracker/>

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Gestalt law of Closure

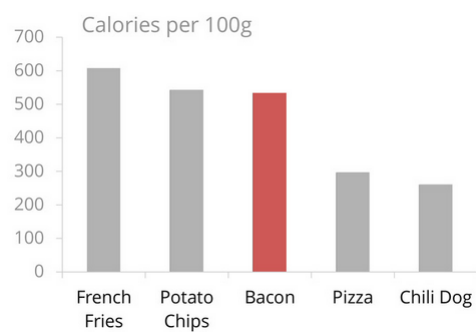
We perceive objects as being whole even when they are not complete



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Gestalt law of Closure: Implications for design

No need to draw chart borders

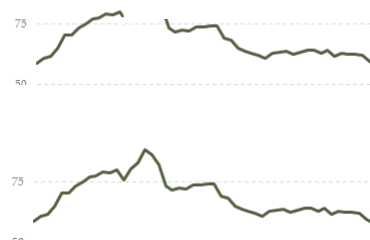


<https://www.darkhorseanalytics.com/blog/data-looks-better-naked>

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Gestalt law of Closure: Implications for design

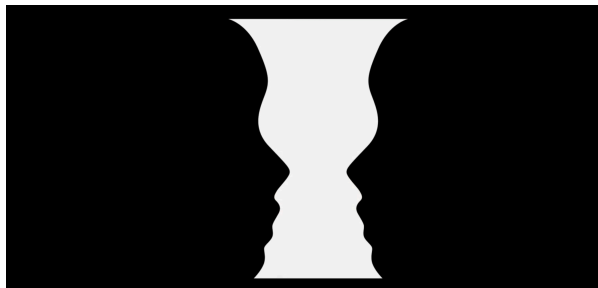
Be careful in case of missing values



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Gestalt law of Figure/Ground

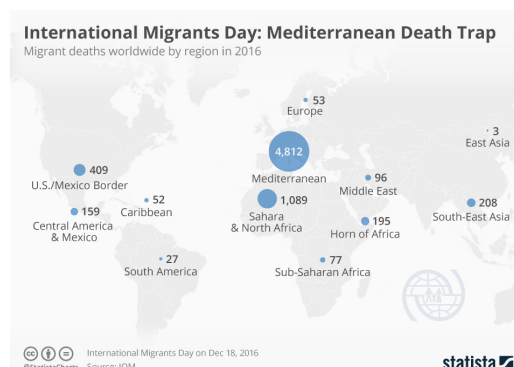
We perceive elements as either figure (element of focus) or ground (background)



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Gestalt law of Figure/Ground: Implications for design

Color contrast and overlays can be used to discern the figure from the background



<https://www.statista.com/chart/7253/number-deaths-migrants-worldwide-2016/>

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Channel efficiency summary

Accuracy

- Prioritize high ranking channels

Discriminability

- Do not use more than 5-7 colors

Saliency (pop-out)

- Be mindful with how you direct attention

Separability

- Use separable channels to perceive one variable at a time
- Use integral channels to obtain a holistic effect

Grouping

- Be mindful of how visual elements form groups