Data Visualization

VISUAL PERCEPTION (1)

Outline

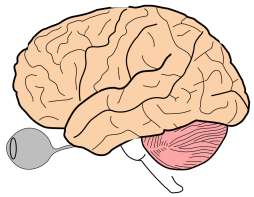
- Motivation
- Memory
- Visual encoding
  - Channel accuracy
  - Channel discriminability
  - Channel salience (pop-out)
  - Channel separability
  - Grouping
- Color
  - Color perception
  - Color specification

Motivation

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

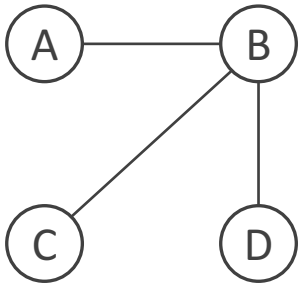


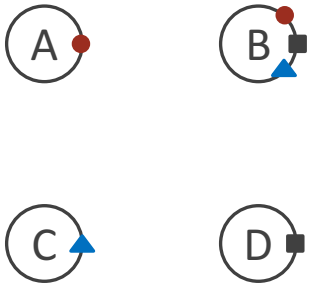
You will read this first

And then you will read this

Then this one

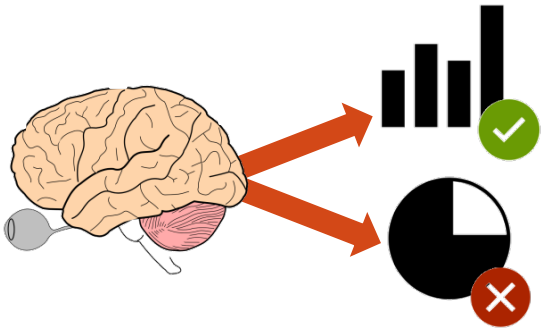
Which is easier to grasp?





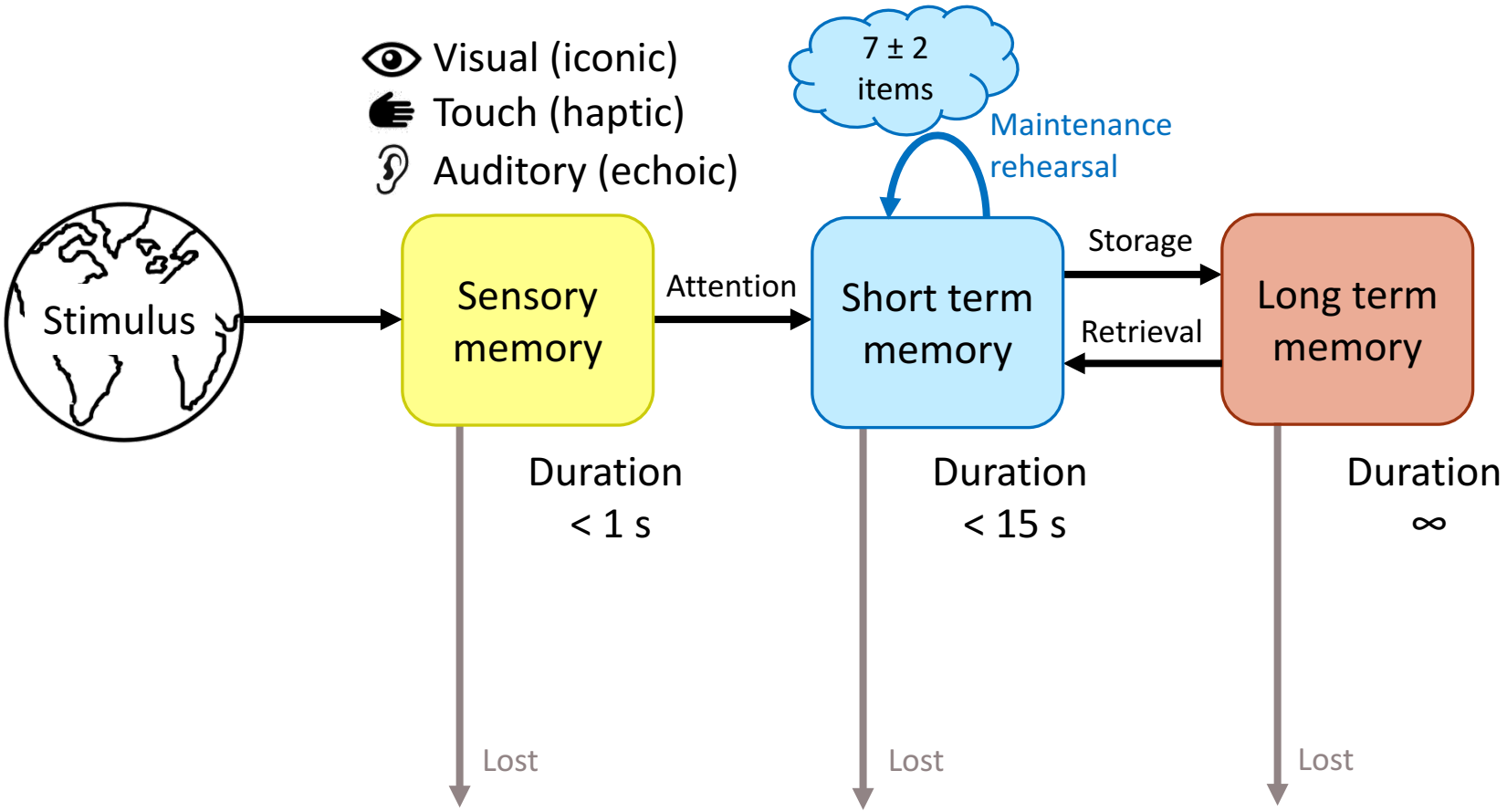
Why study visual perception?

Understanding visual perception enables to make informed decisions about visualization design



Memory

Memory

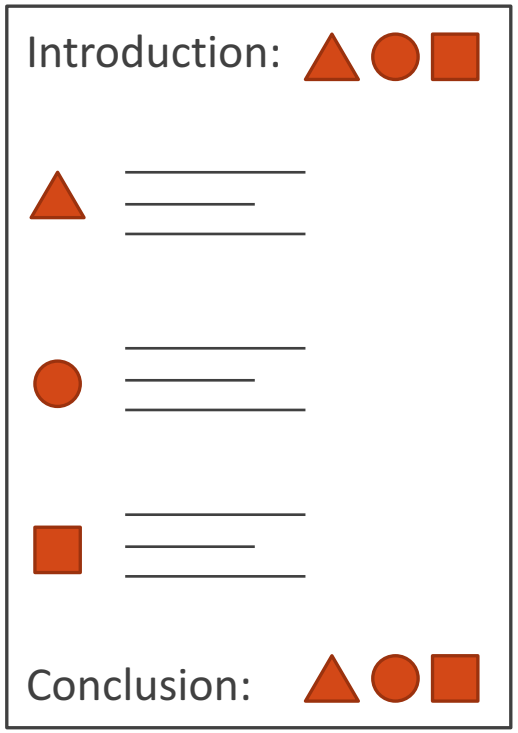

Visual (iconic)
Touch (haptic)
Auditory (echoic)
7 ± 2 items
Maintenance rehearsal
Stimulus
Sensory memory
Attention
Short term memory
Storage
Retrieval
Long term memory
Duration < 1 s
Duration < 15 s
Duration ∞
Lost
Lost
Lost

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)



Visual encoding

Visual encoding

Mapping between data properties and graphical properties

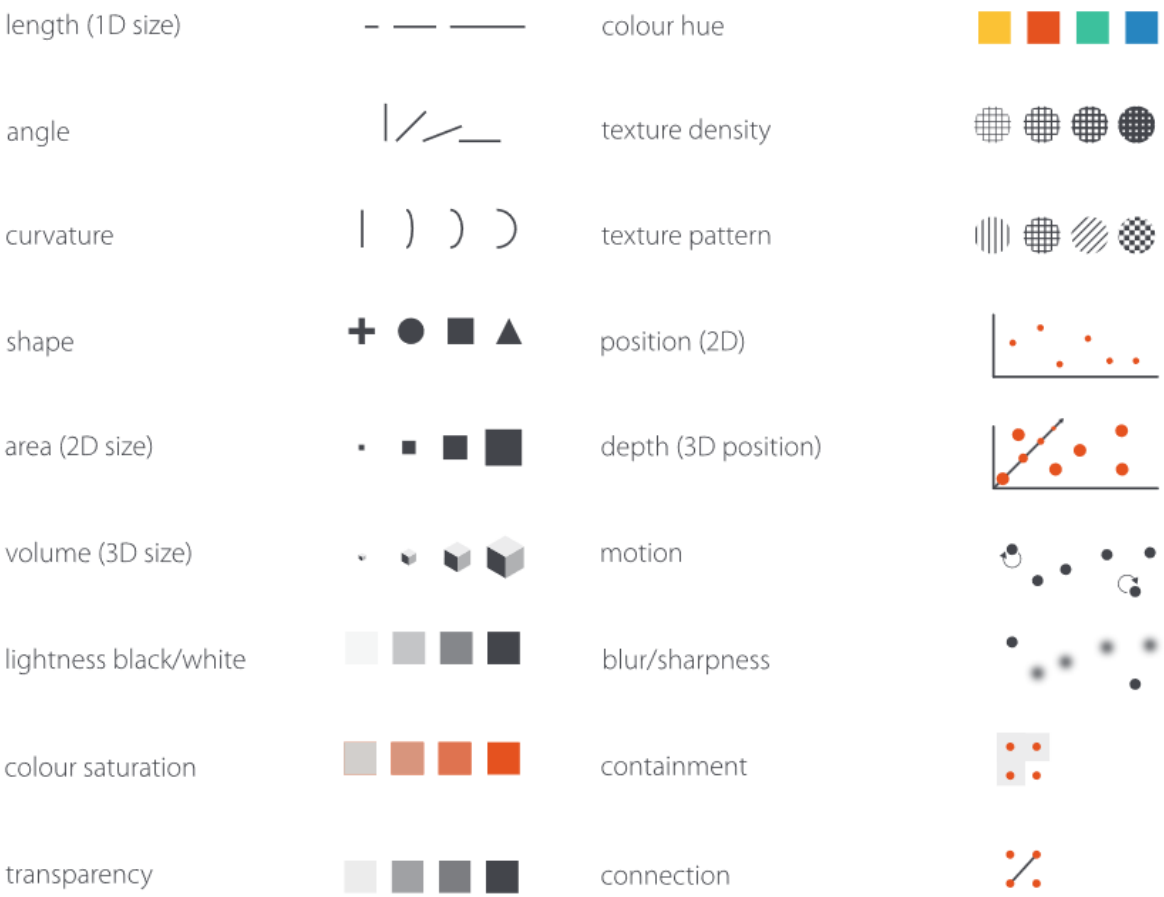
Data attributes ➡ Visual channels

Data attributes

- Ordered
  - *Ordinal*
  - *Quantitative*

- Categorical

Visual channels

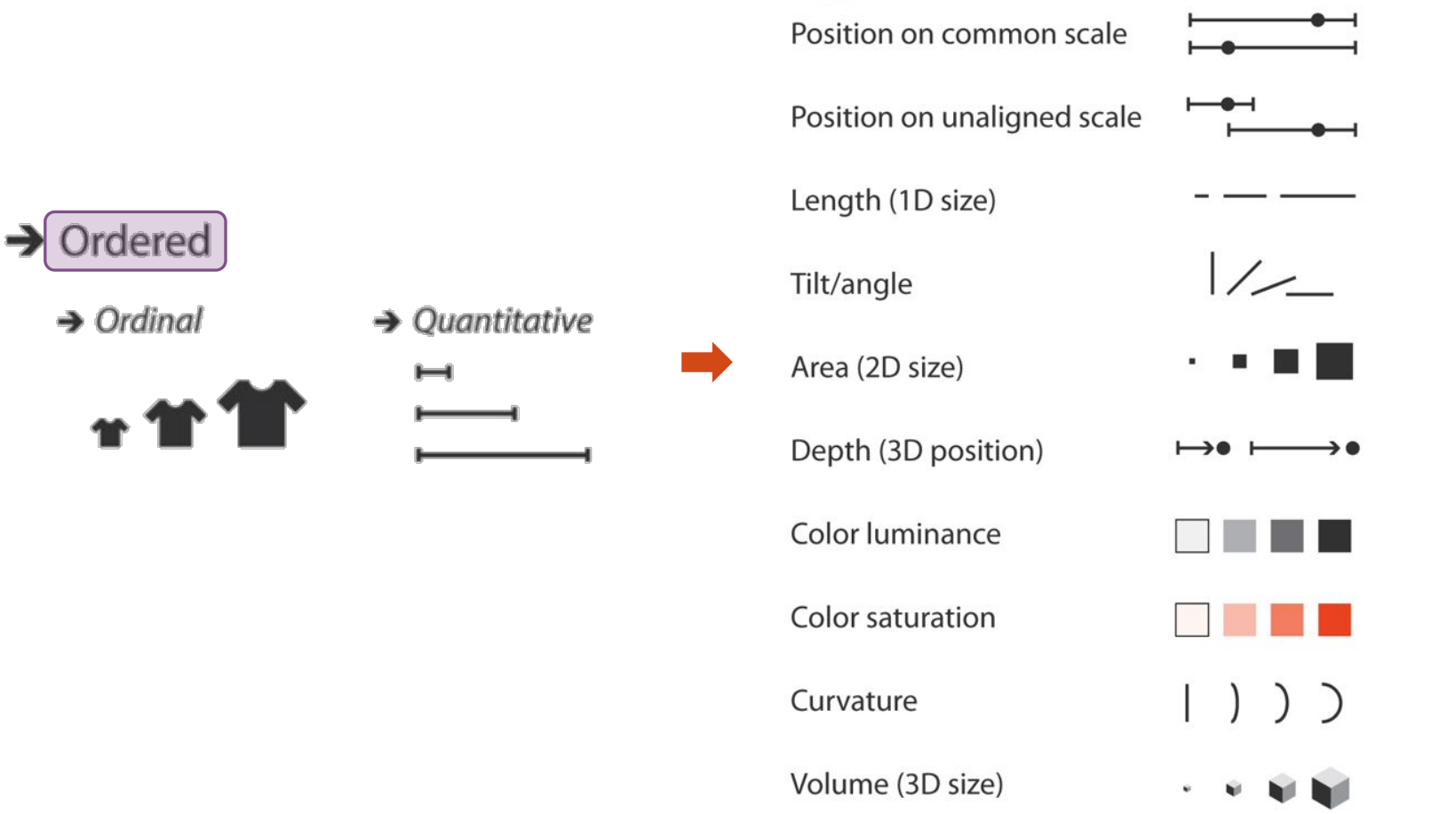


Visual channels

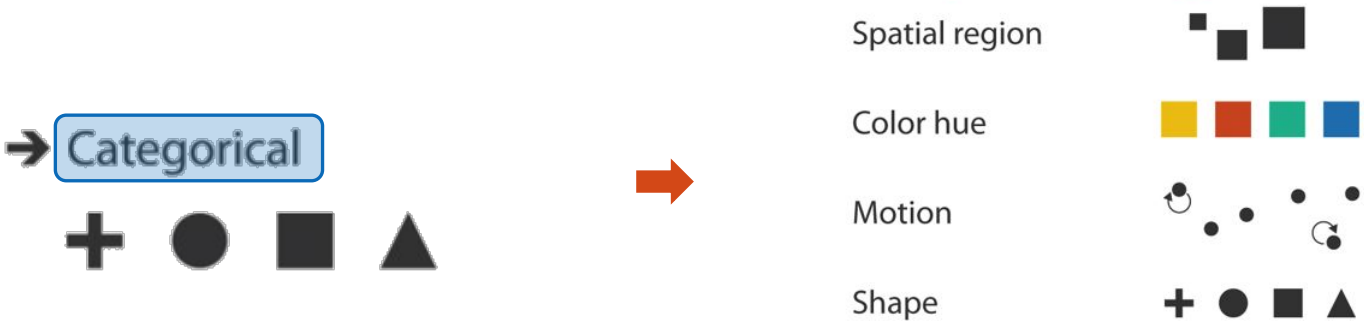
Channel properties

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

Channels that can express order



Channels that can express categories



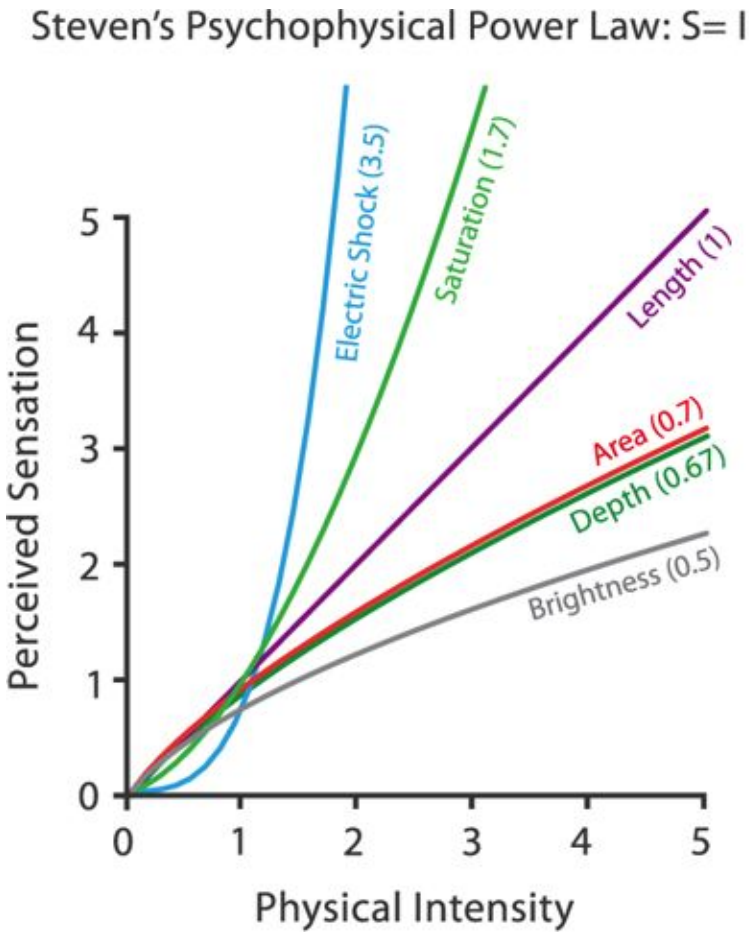
Channel effectiveness

- 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

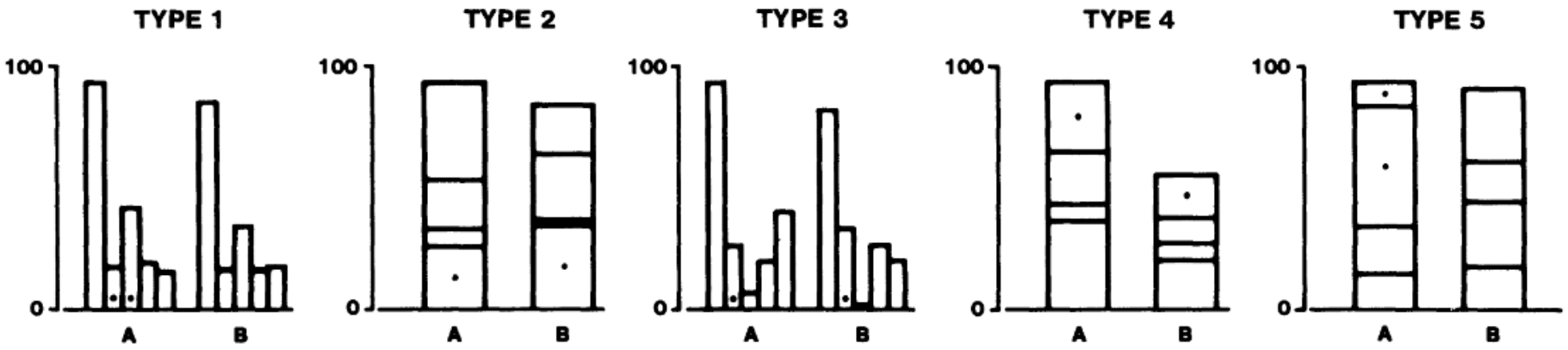
Channel accuracy



Published in 1957

Channel accuracy

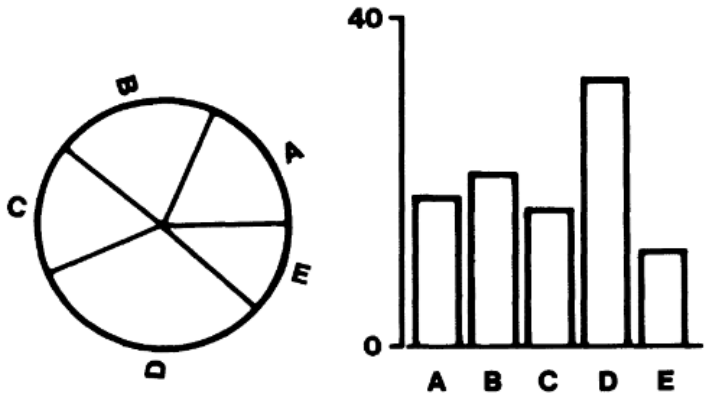
Experiments in graphical perception by Cleveland and McGill in 1983



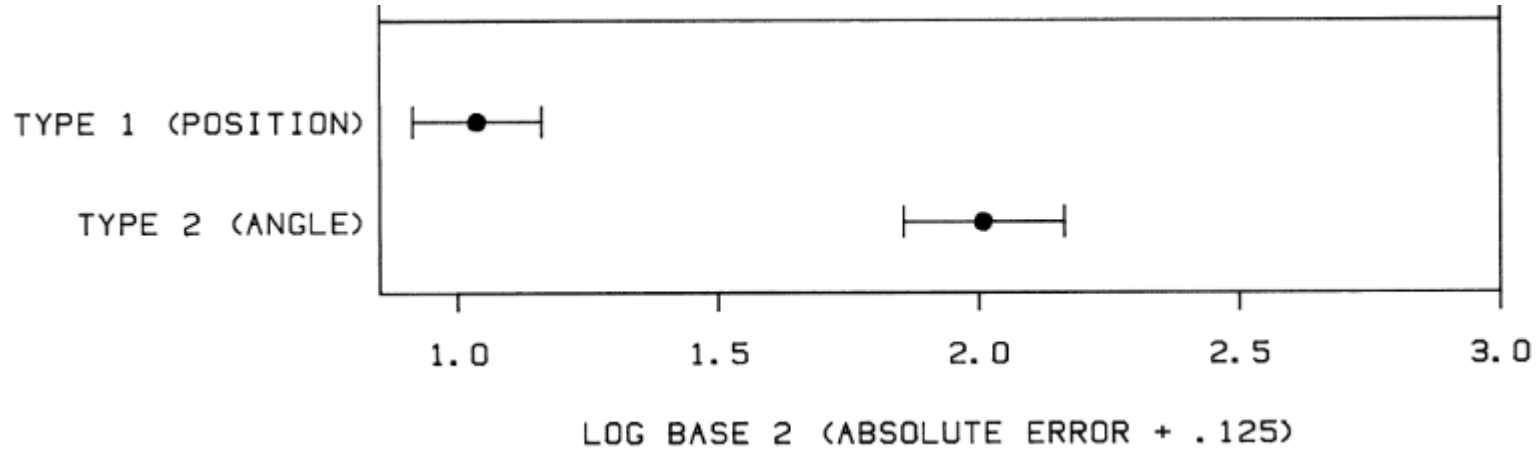
Which is smaller?
How much smaller is it?

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

Channel accuracy

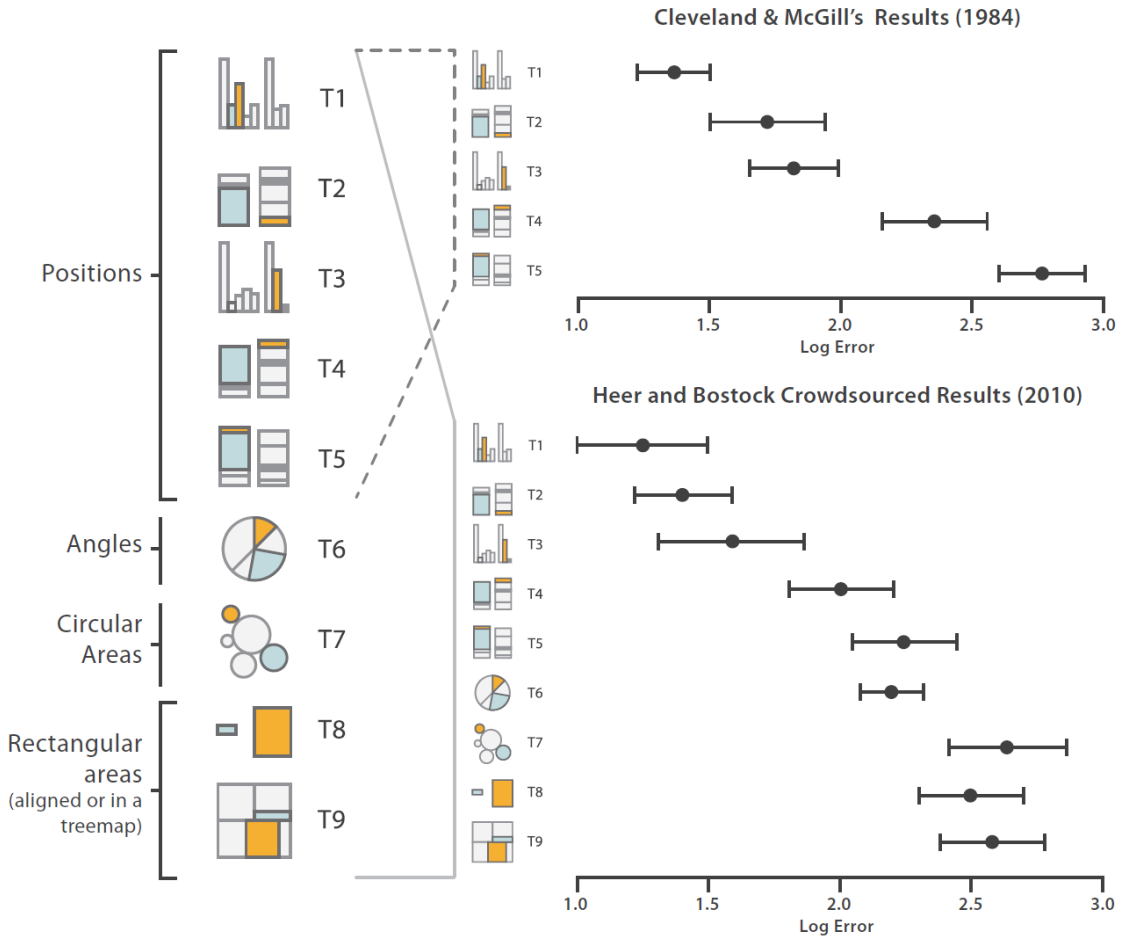


How much bigger is A compared to B?



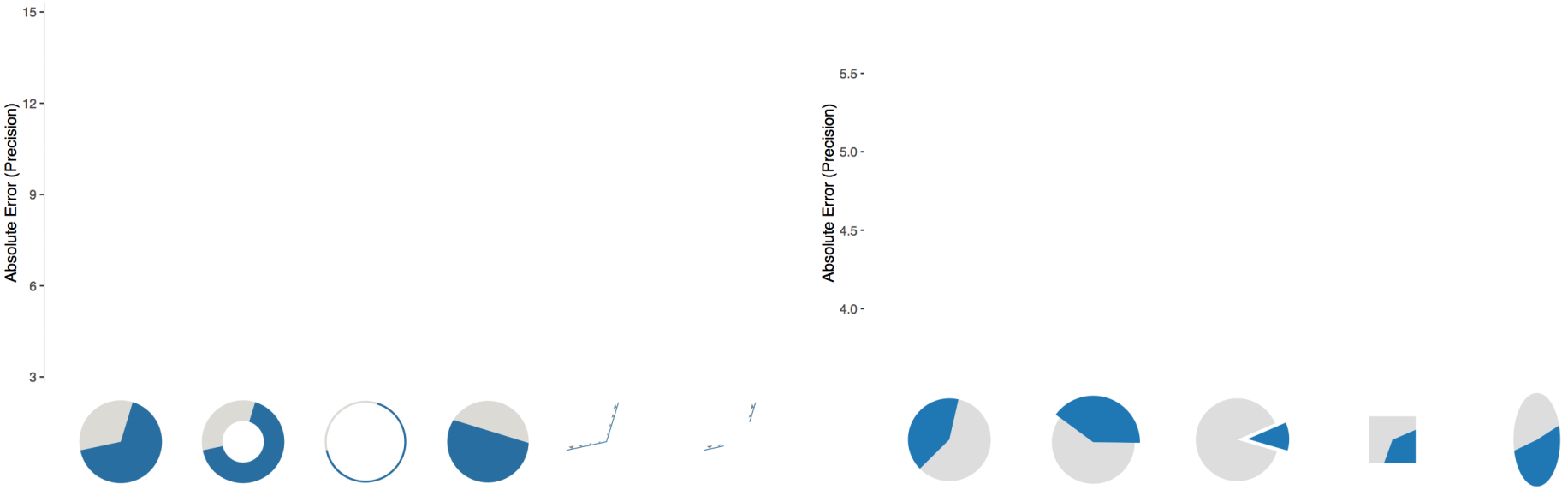
W. S. Cleveland, R. McGill. Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Journal of the American Statistical Association, 1984

Channel accuracy

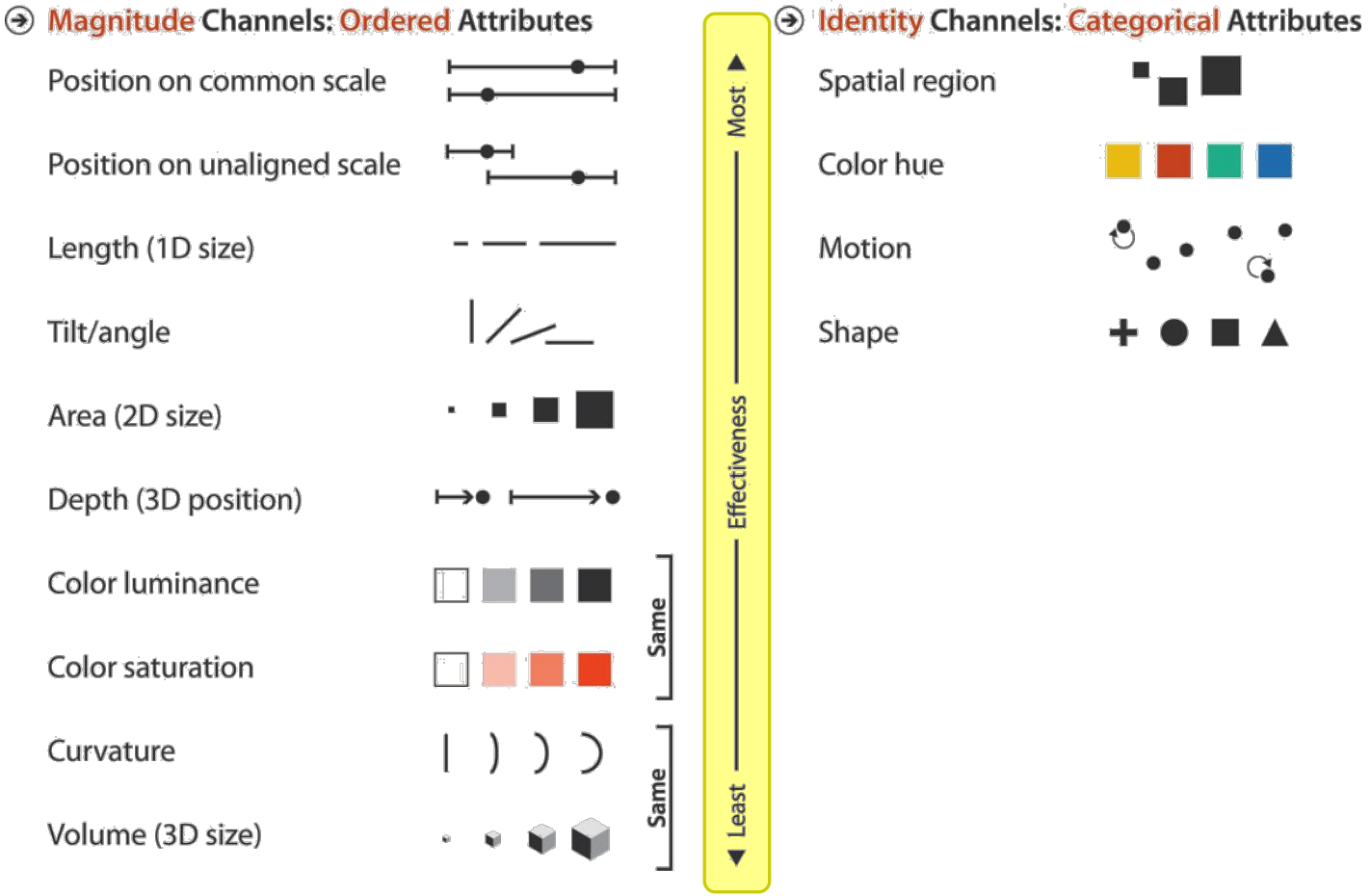


Channel accuracy

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



Channel accuracy: Implications for design

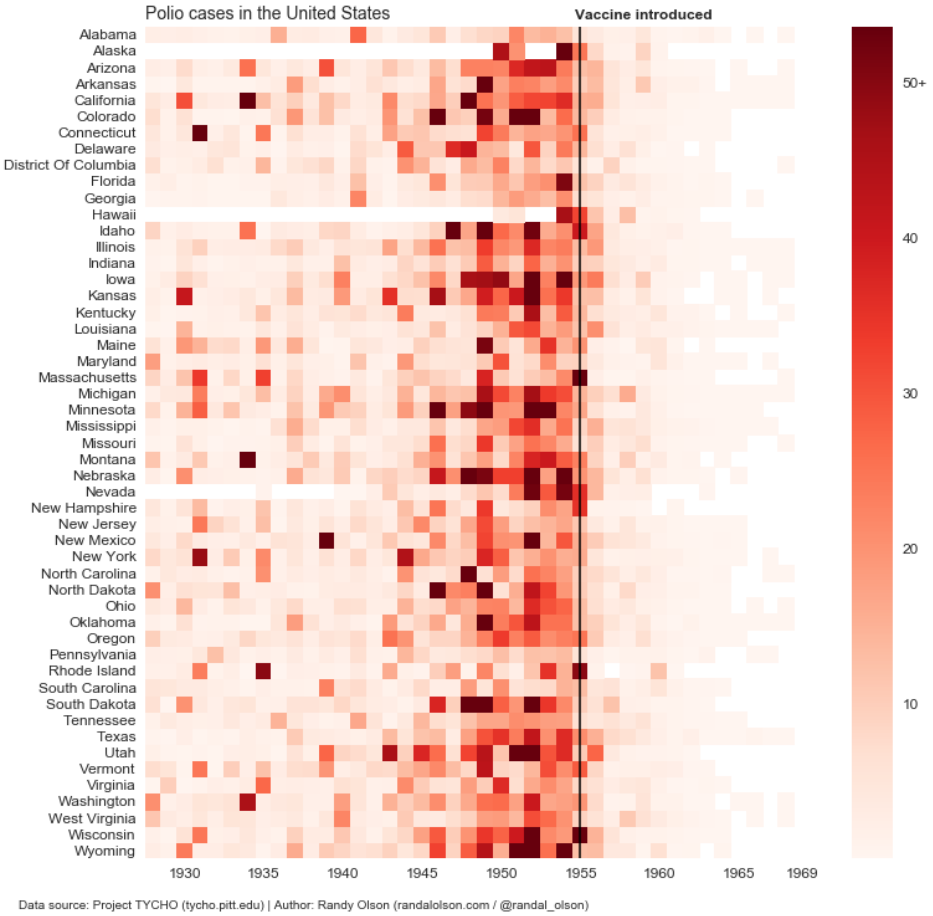


Channel accuracy: Limitations

Specific to comparing and estimating magnitudes – not everything in data visualization is about magnitudes

Trade accuracy for something else, for example, scalability

Polio cases in the US



http://www.randalolson.com/2016/03/04/revisiting-the-vaccine-visualizations/

Channel discriminability

Channel discriminability

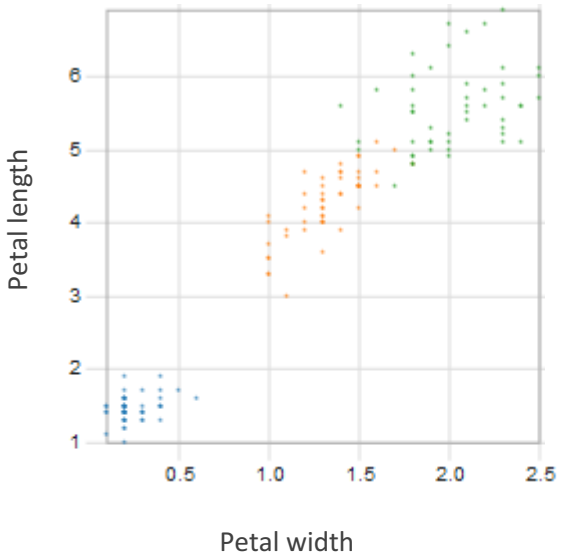
How many distinct values can be distinguished within a channel

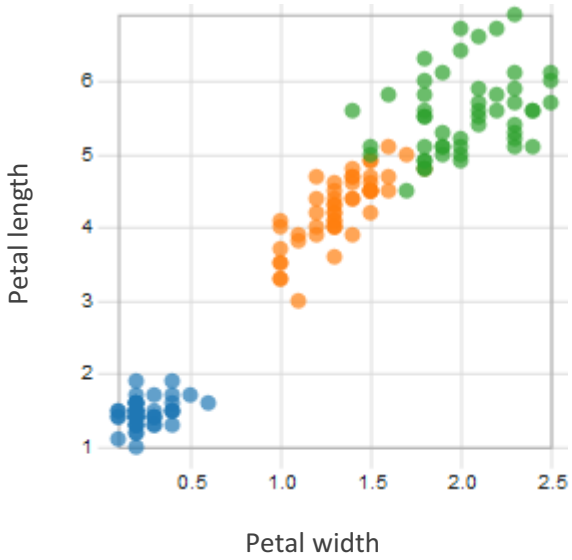
Discriminability depends on

- Channel properties (similar to accuracy)
- Size
- Spatial arrangement
- Cardinality

Channel discriminability

The effect of size

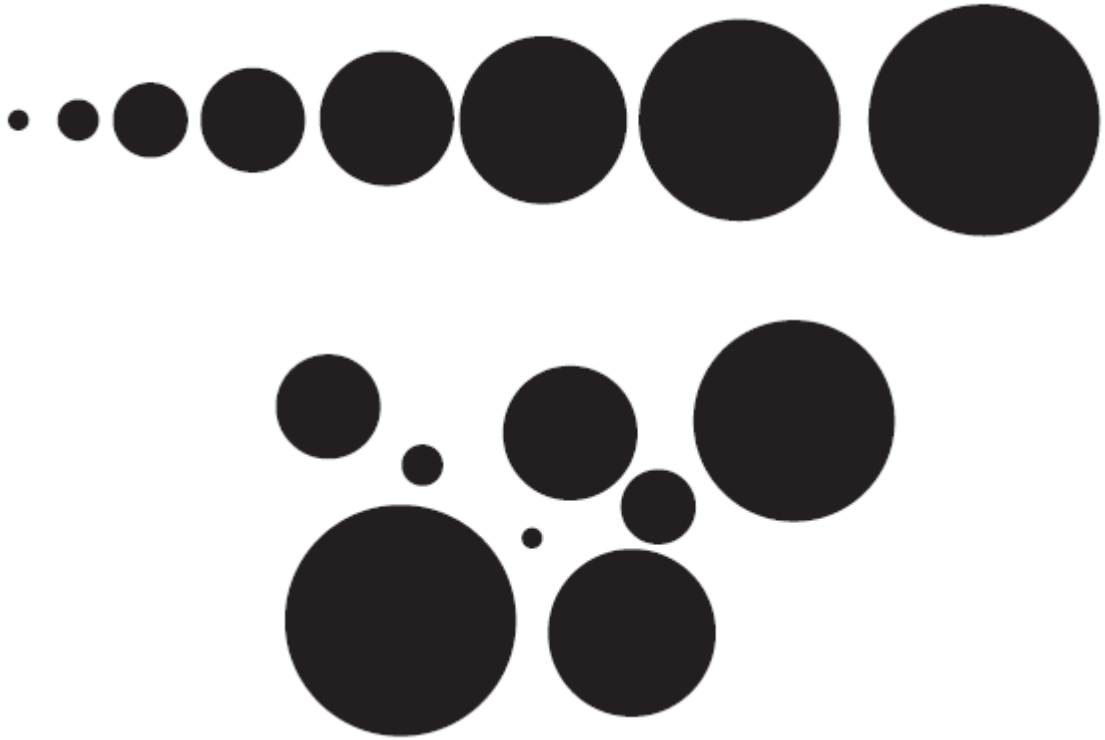




https://beta.observablehq.com/@mbostock/d3-scatterplot-matrix

Channel discriminability

The effect of spatial arrangement



Channel discriminability

The effect of cardinality

Channel discriminability: Implications for design

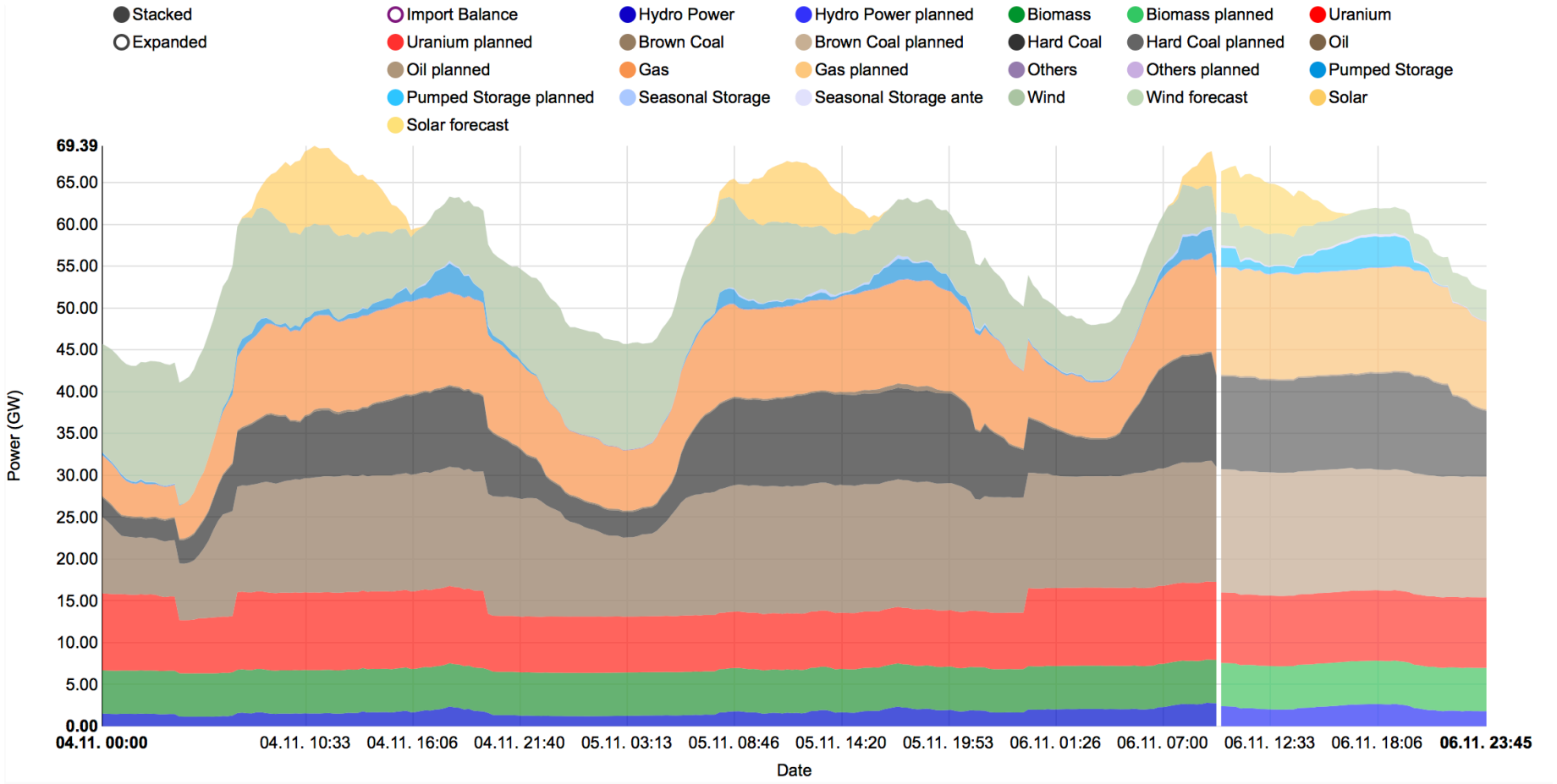
Do not overestimate the number of values viewers can perceive/discriminate

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

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

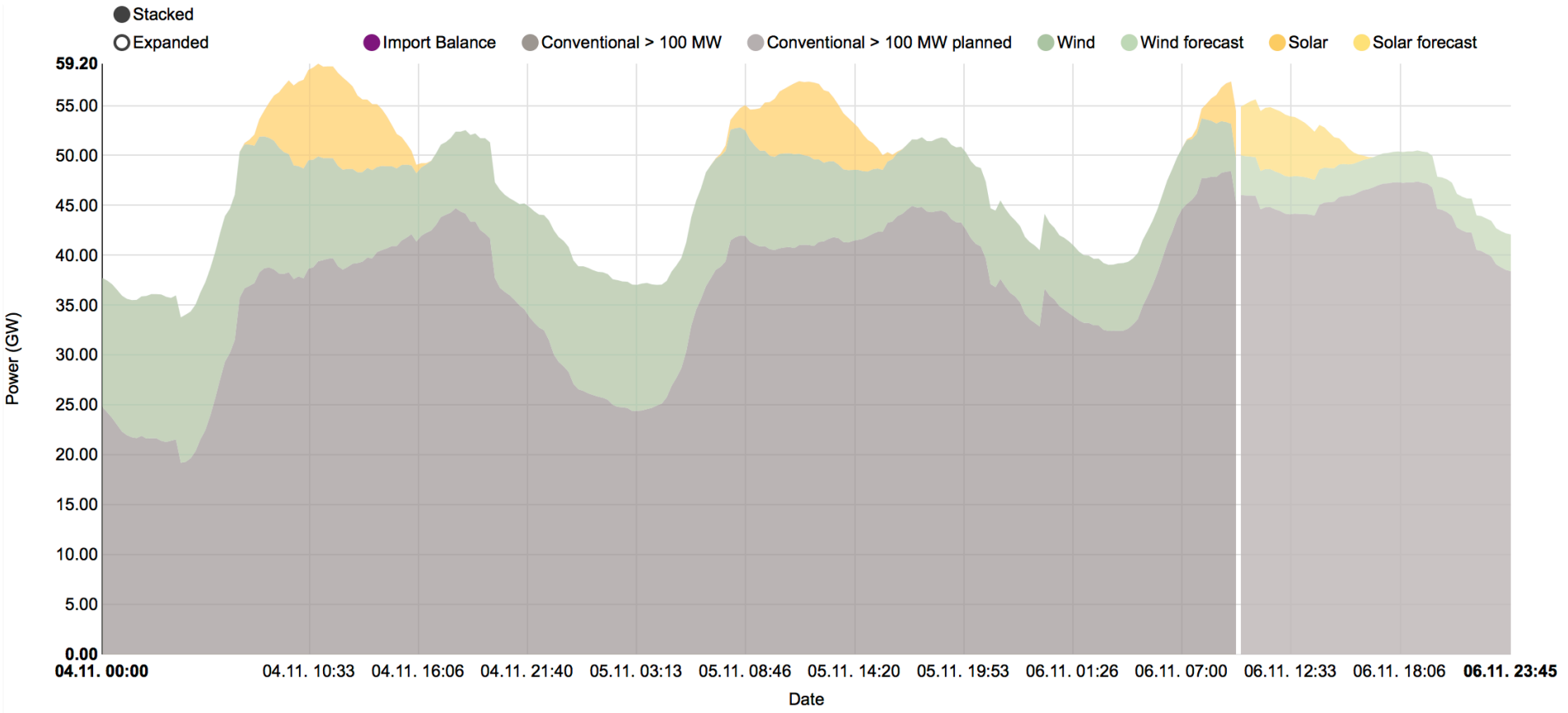
- Grouping (show groups of categories)
- Filtering (show only selected few)
- Faceting (use small multiples)

Electricity production in Germany – all sources



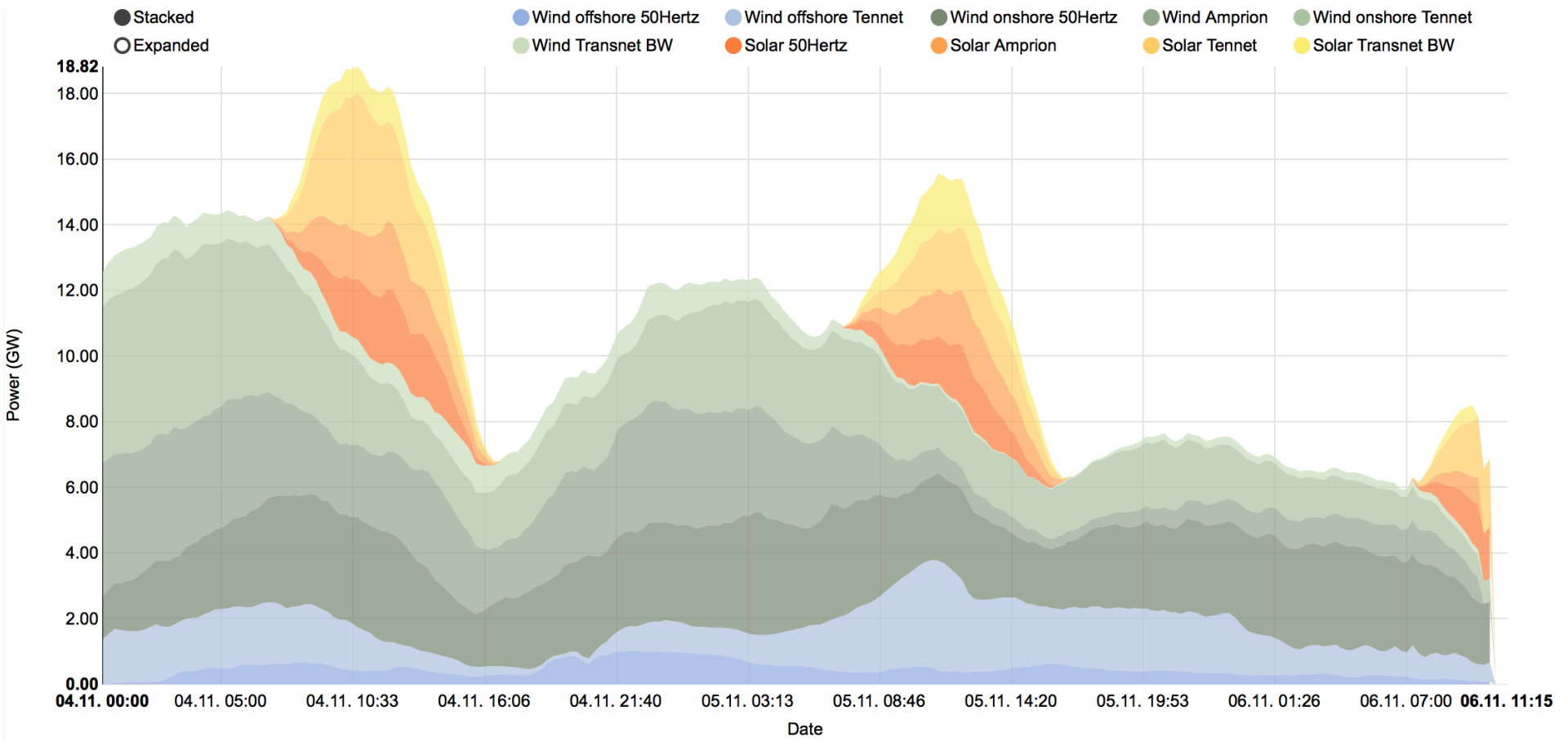
https://energy-charts.de/power.htm?source=all-sources&year=2019&week=45

Electricity production in Germany – grouped sources



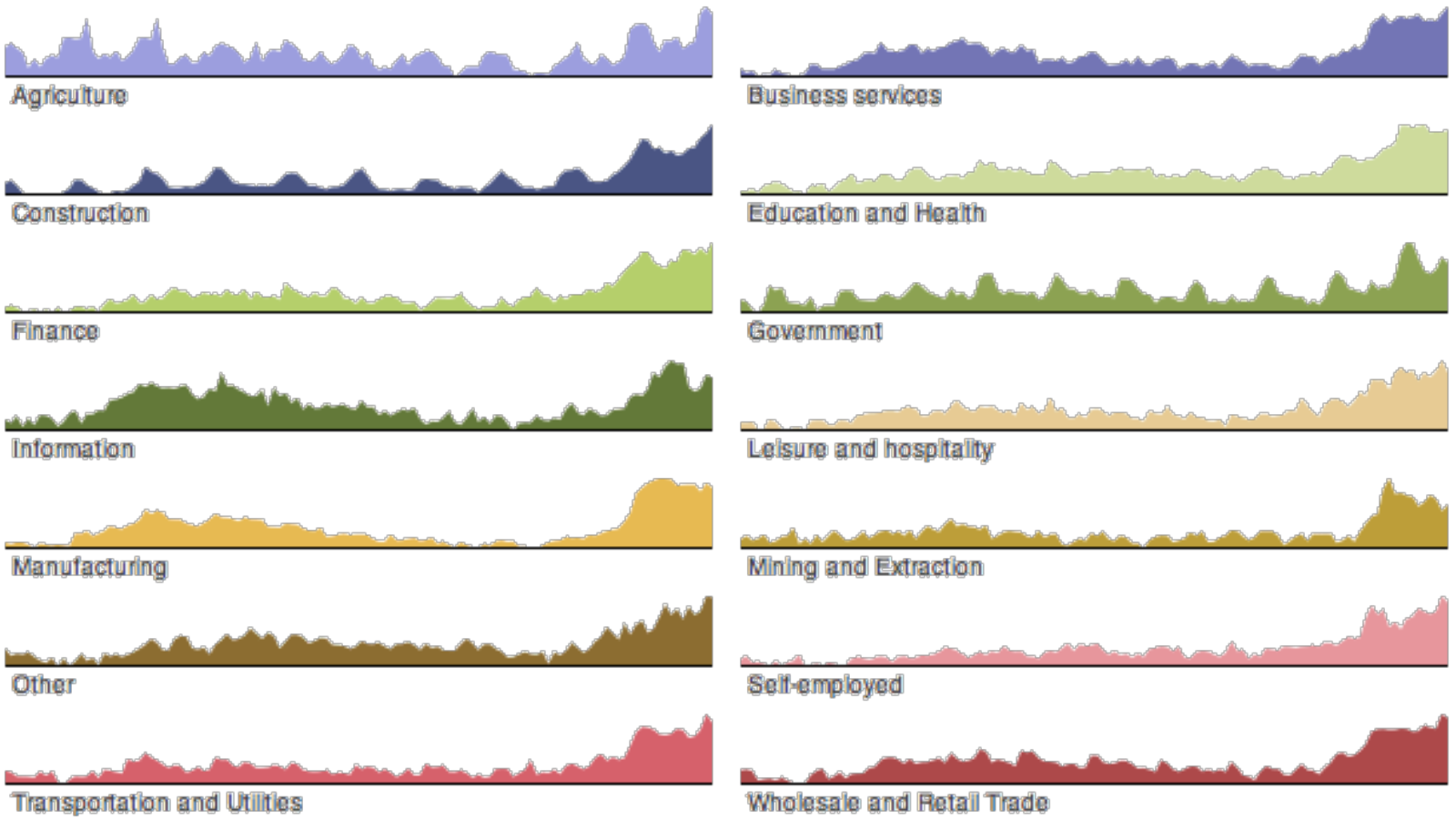
https://energy-charts.de/power.htm?source=all-sources&year=2019&week=45

Electricity production in Germany – filtered sources



https://energy-charts.de/power.htm?source=all-sources&year=2019&week=45

Small multiples



https://homes.cs.washington.edu/~jheer//files/zoo/

Channel salience

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

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

An example

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

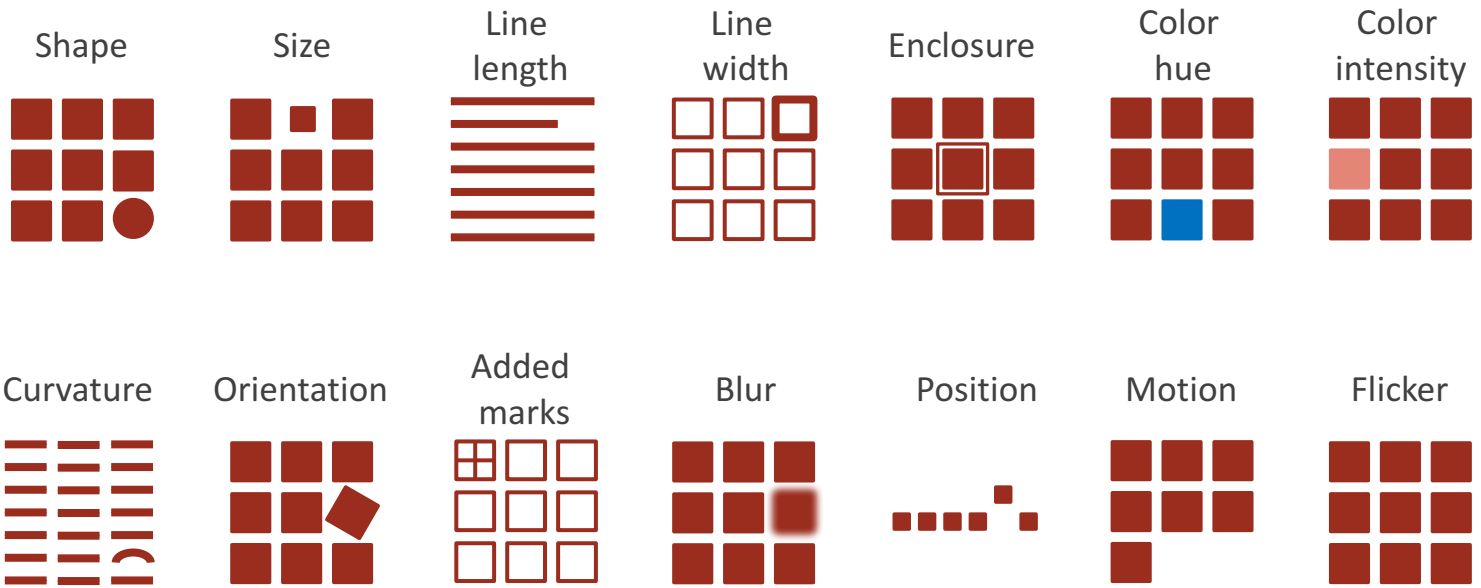
9 0 6 8 2 4 7 4 8 3 8 7 4 3

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

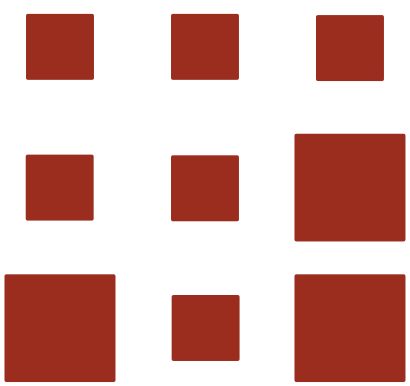
7 2 4 6 1 7 5 9 7 3 2 4 9 1

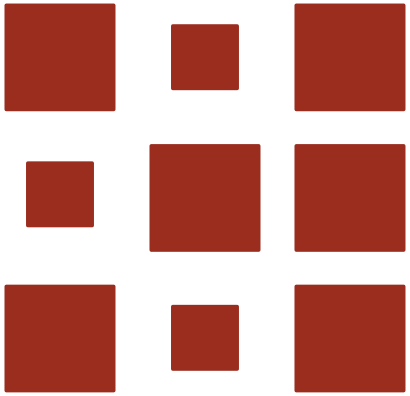
Preattentive attributes



Preattentive attributes

Many attributes are asymmetric

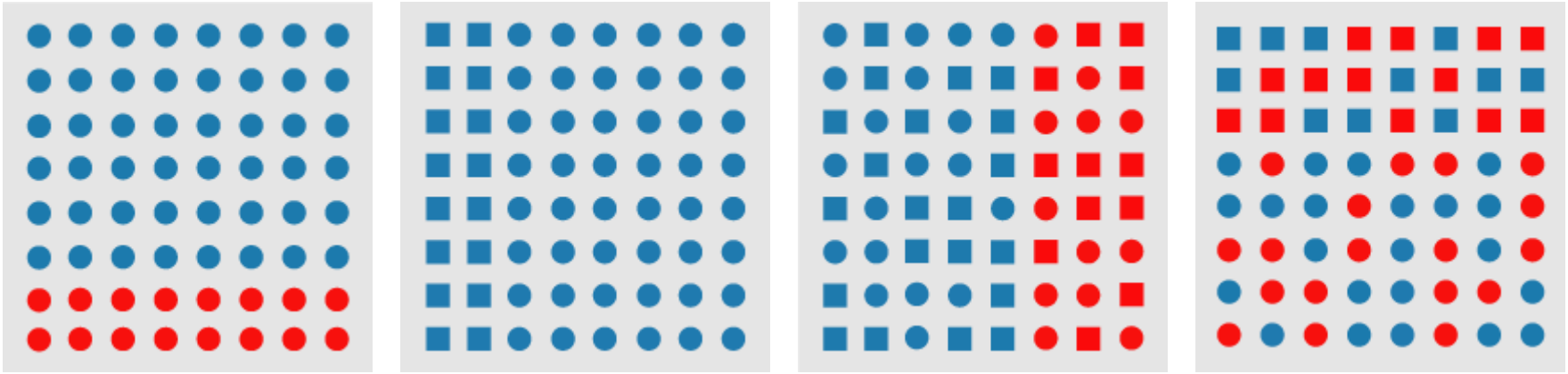




Preattentive attributes

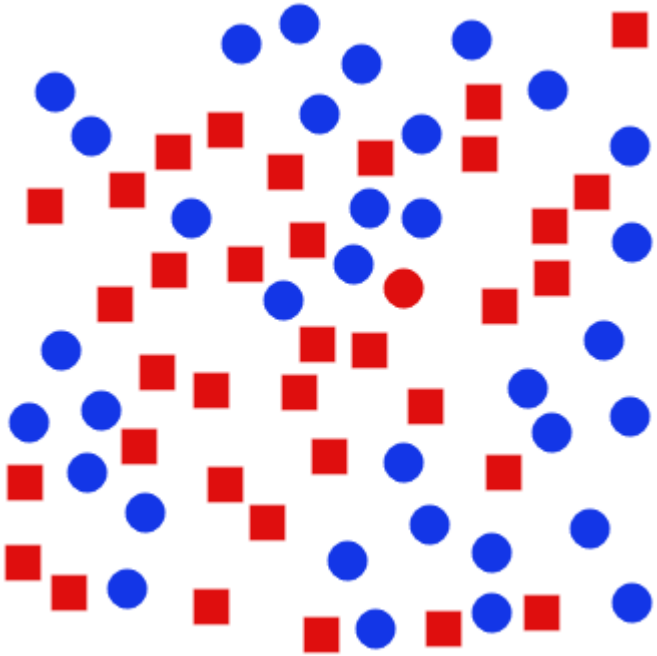
Some attributes are stronger than others

- In boundary detection, color hue is stronger than shape



Preattentive attributes

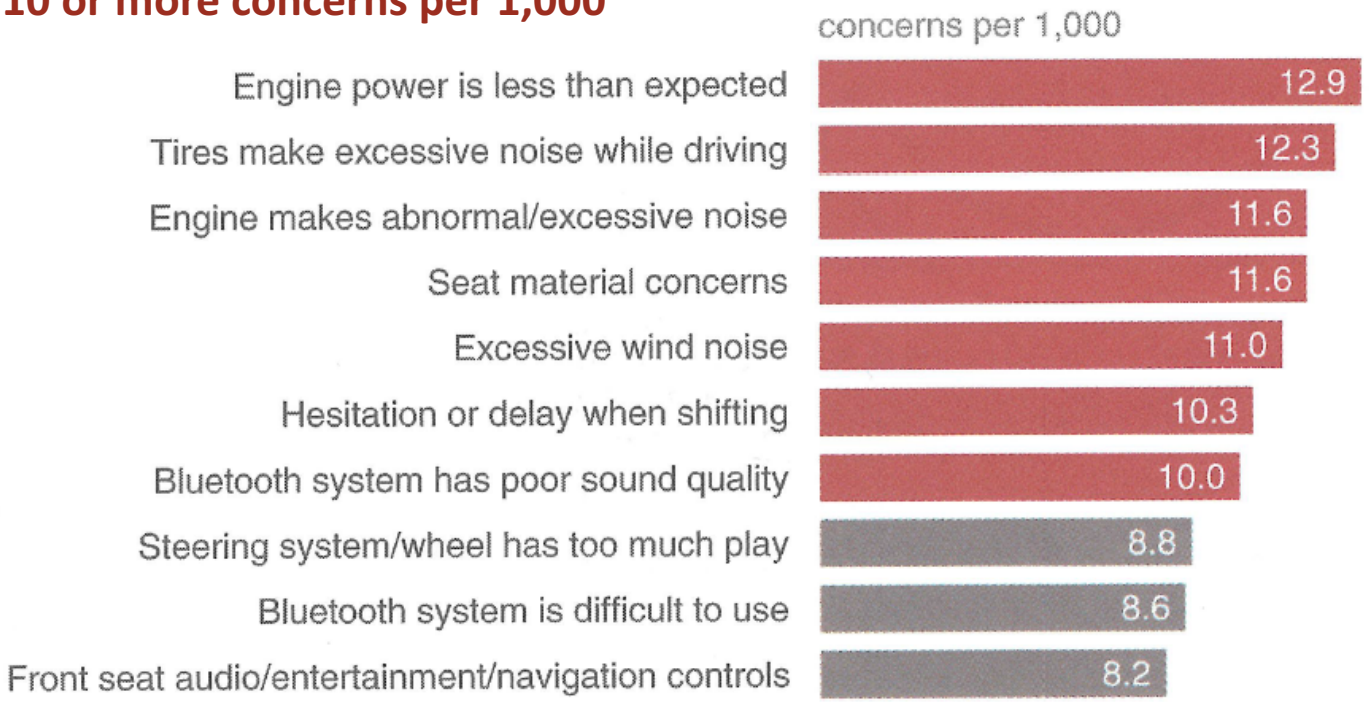
Conjunctions of two attributes often not preattentive



Channel salience: Implications for design

Preattentive attributes can be used to draw attention

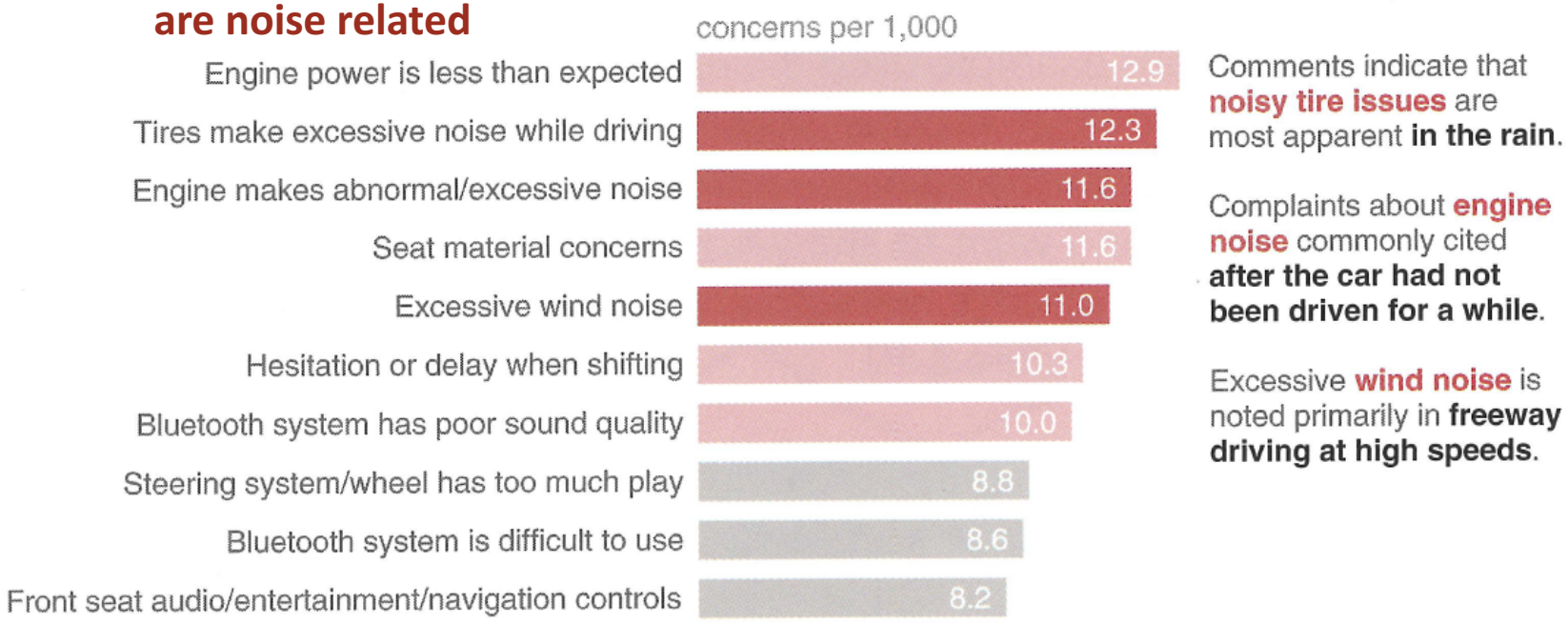
7 of the top 10 complaints have 10 or more concerns per 1,000



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

Use gray for elements that are not that important

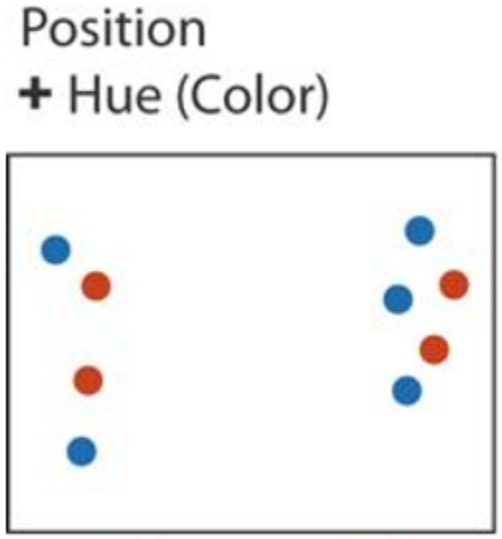
When you highlight one point, you make the other points harder to see

Do not use preattentive attributes in exploratory data analysis

Channel separability

Channel separability

Amount of interference between channels

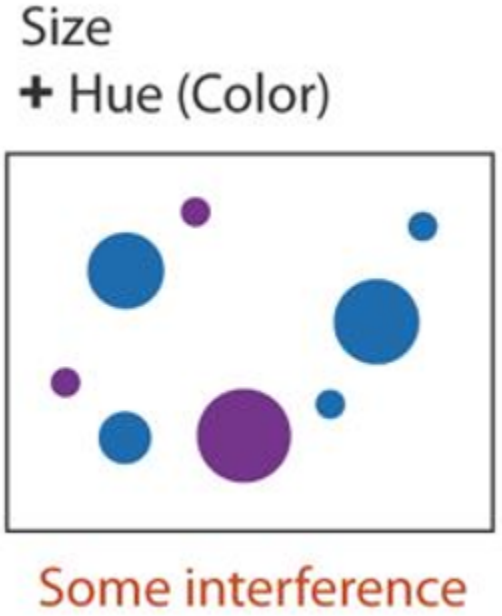


Fully separable

An example of
separable channels

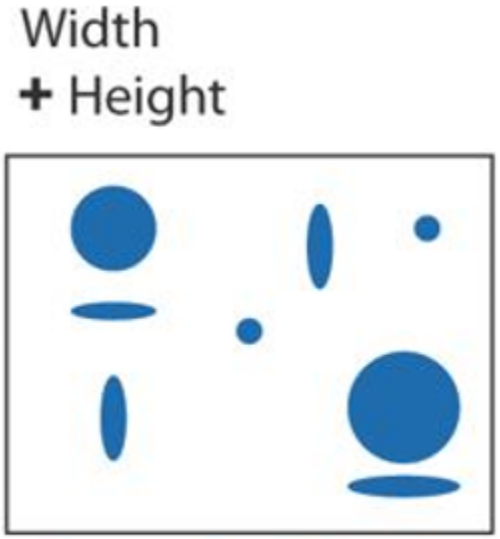
Channel separability

Amount of interference between channels



Channel separability

Amount of interference between channels

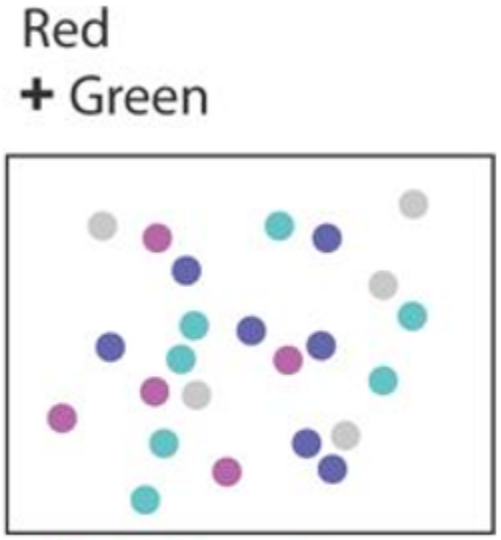


Some/significant interference

An example of integral channels

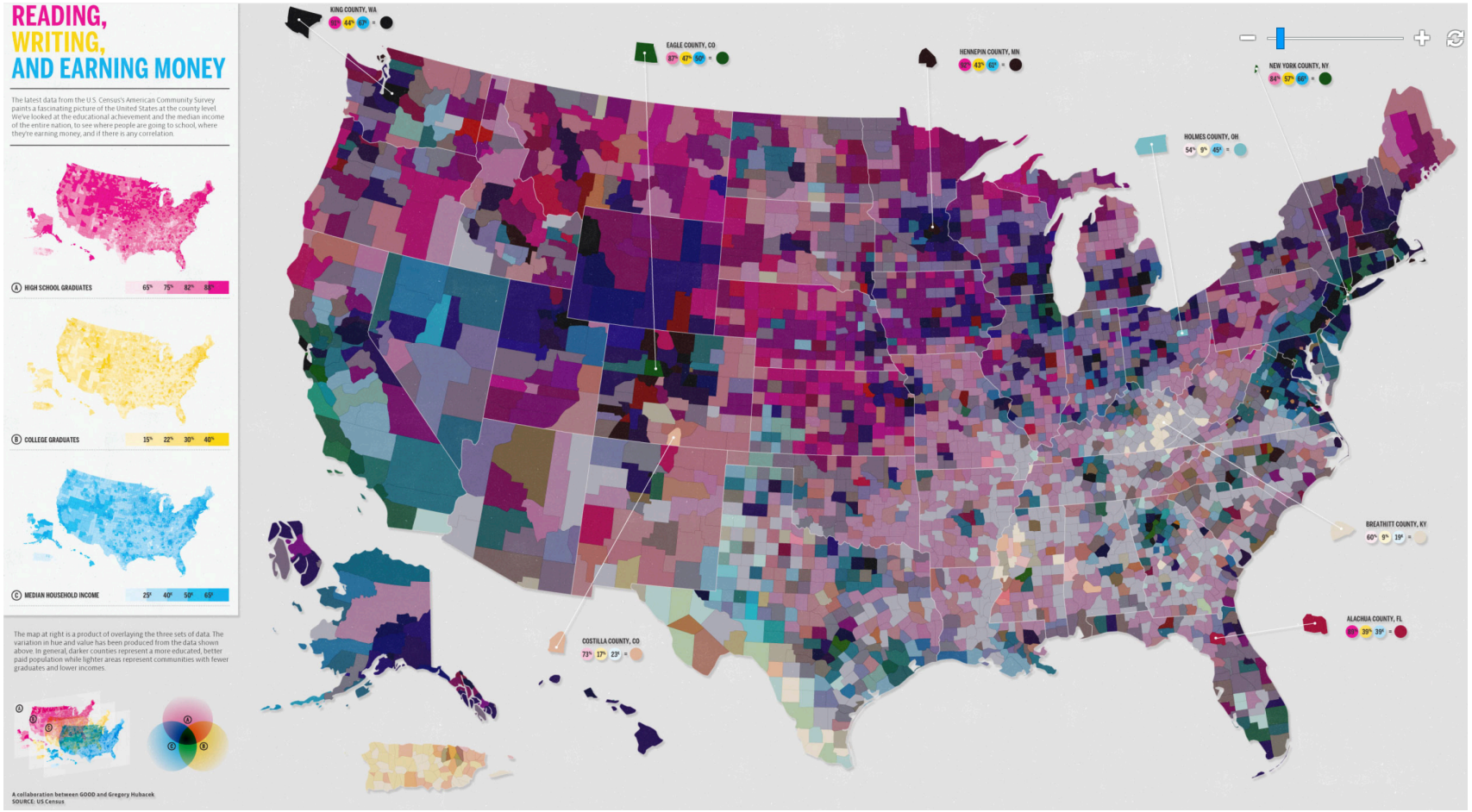
Channel separability

Amount of interference between channels



An example of
integral channels

Are the richest Americans also the best educated?



https://www.good.is/infographics/america-s-richest-counties-and-best-educated-counties#open

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

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

Gestalt laws

Proximity

Similarity

Connection

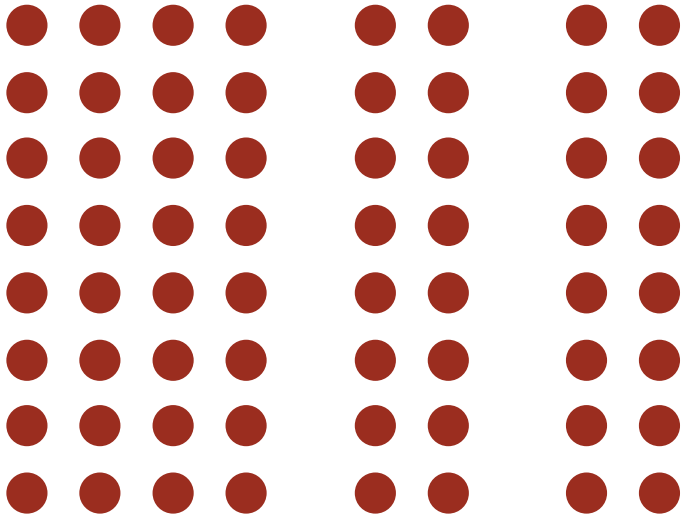
Enclosure

Closure

Figure/Ground

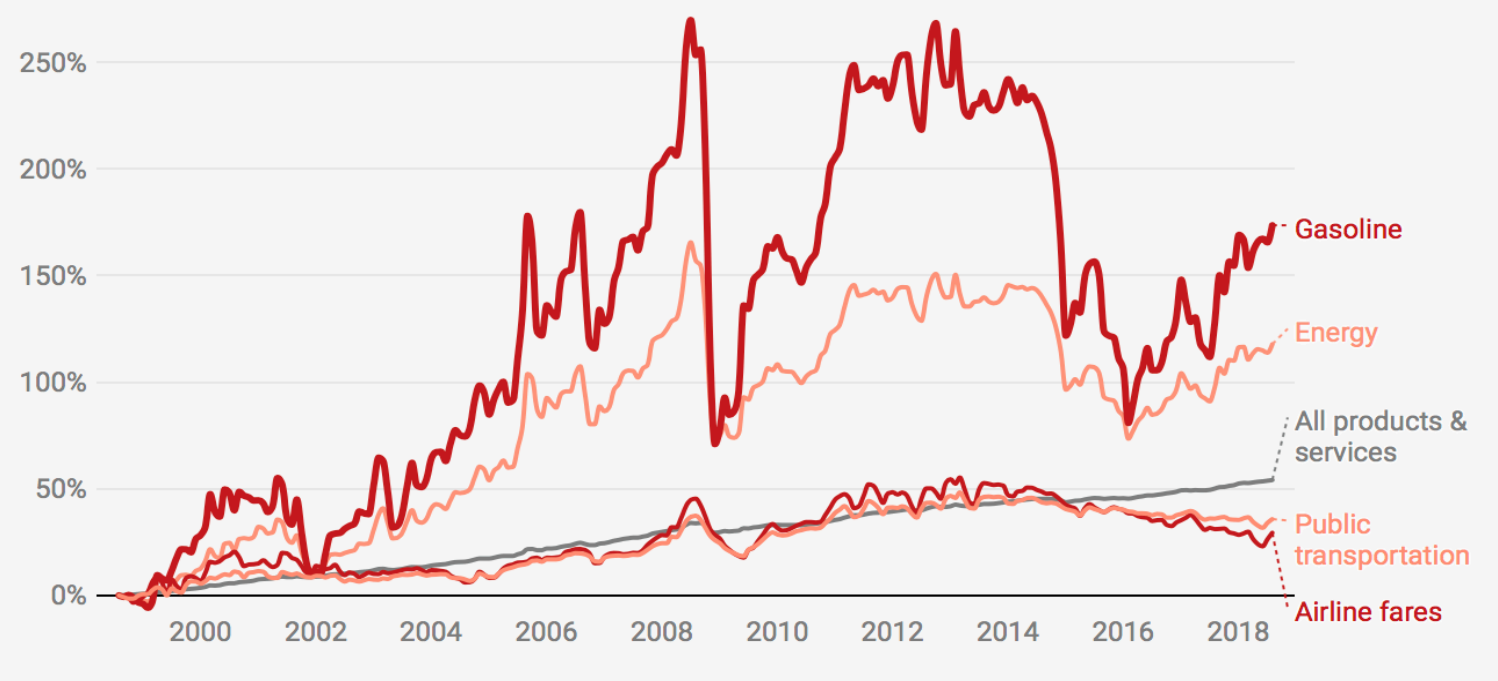
Gestalt law of Proximity

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



Gestalt law of Proximity: Implications for design

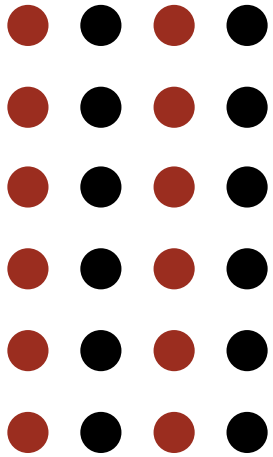
Place annotations close to the data



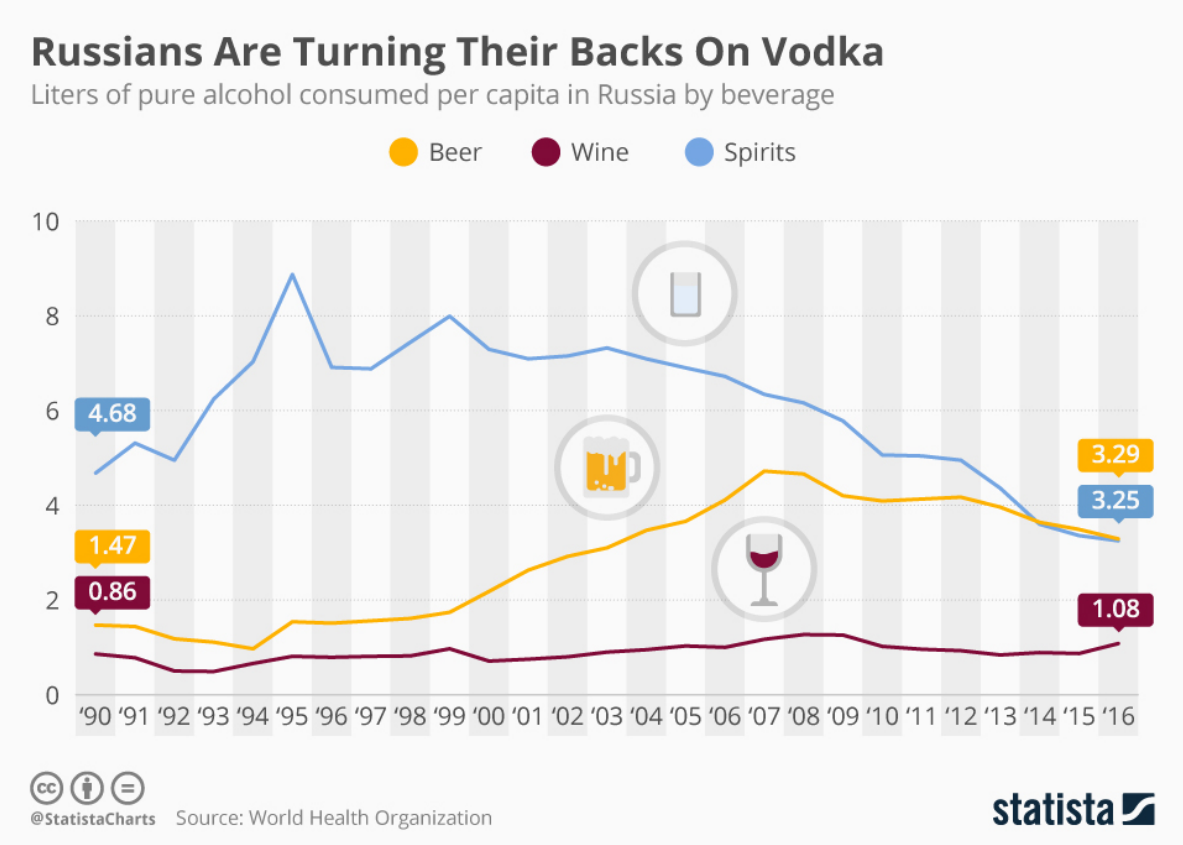
https://blog.datawrapper.de/weekly47-cpi-dollars-for-college/

Gestalt law of Similarity

We perceive similar objects as belonging to a group



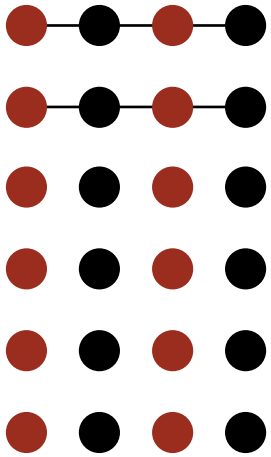
Gestalt law of Similarity: Implications for design



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

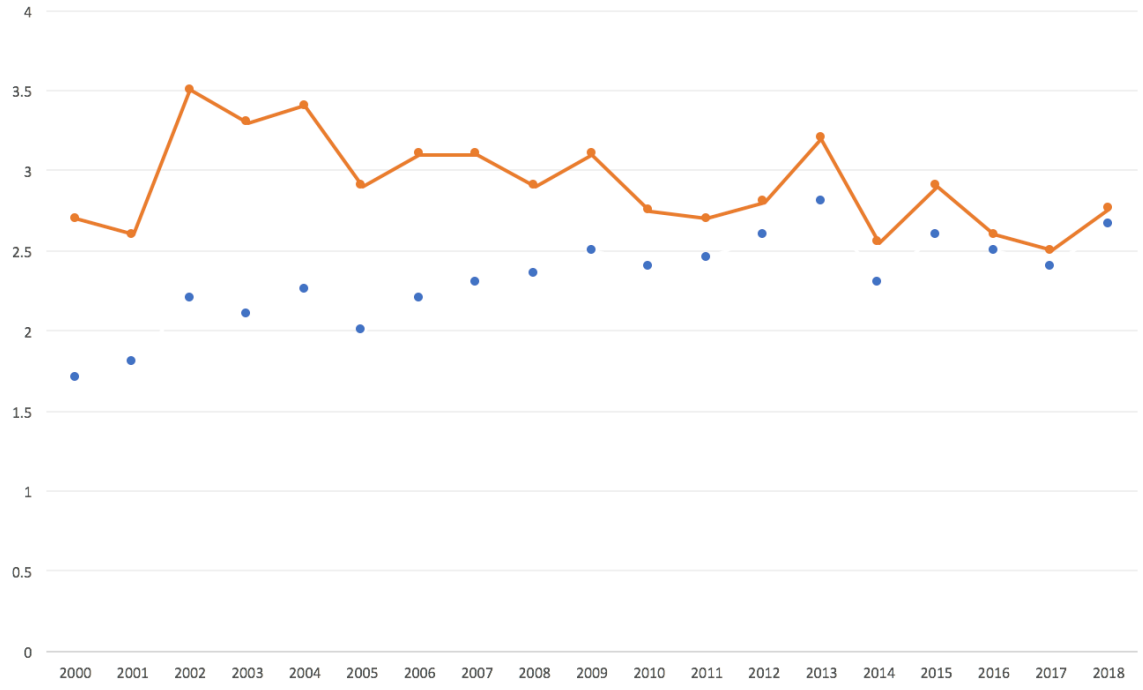
Gestalt law of Connection

We perceive objects connected to each other as a single group



Gestalt law of Connection: Implications for design

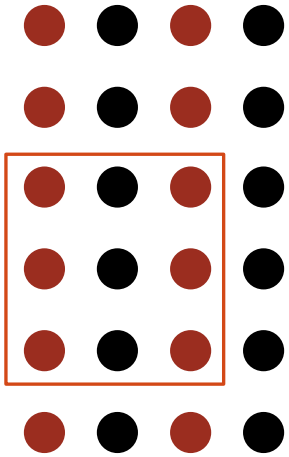
Use lines to show the data is in the same group



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

Gestalt law of Enclosure

We perceive physically enclosed objects as part of a group



Gestalt law of Enclosure: Implications for design

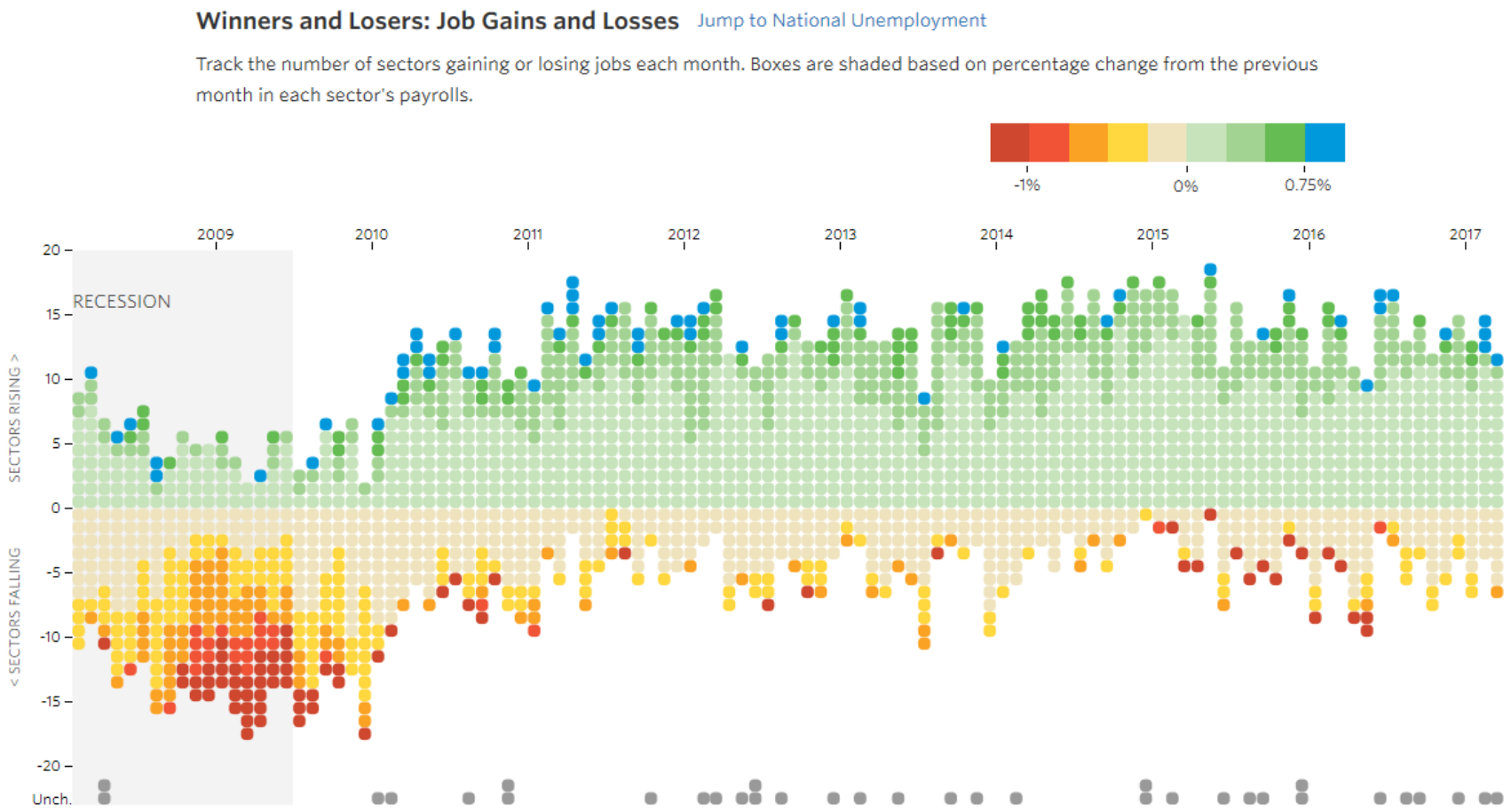
Use enclosures to show groups

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

Gestalt law of Enclosure: Implications for design

Bubble sets visualization

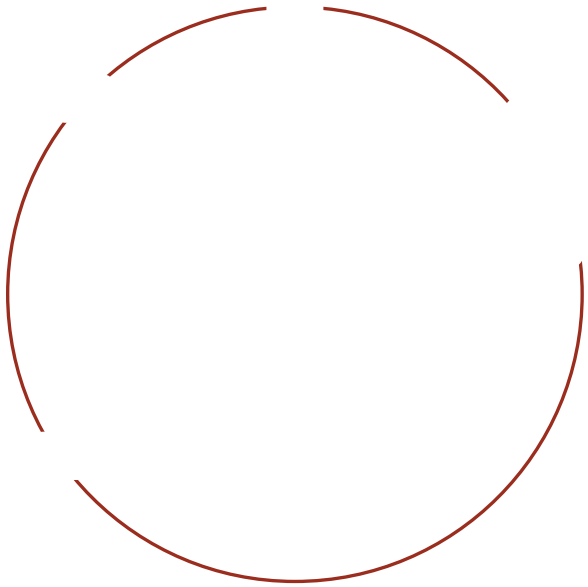
Gestalt law of Enclosure: Implications for design



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

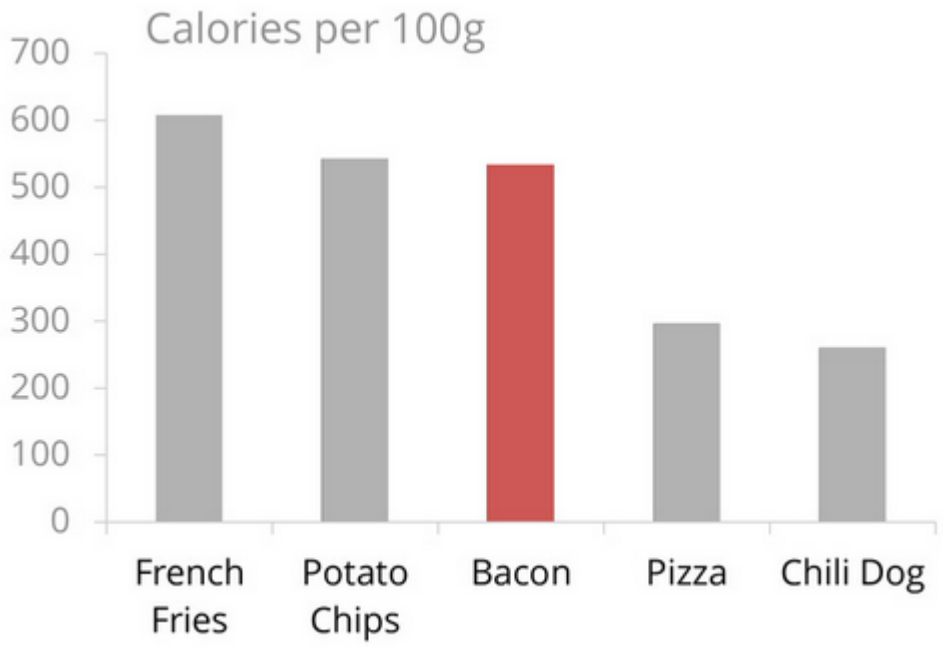
Gestalt law of Closure

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



Gestalt law of Closure: Implications for design

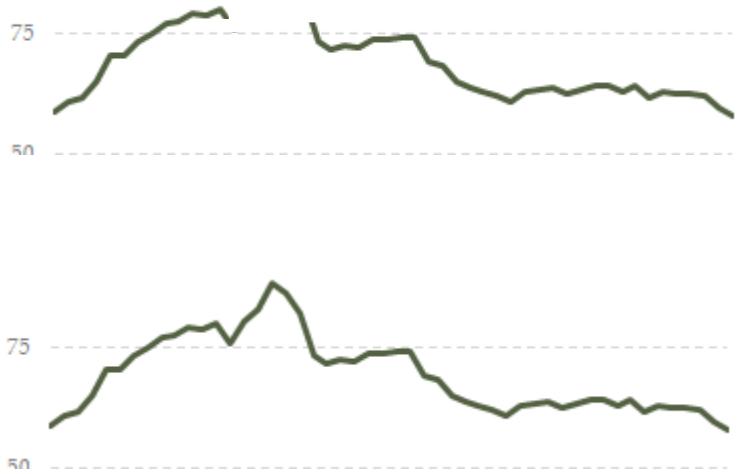
No need to draw chart borders



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

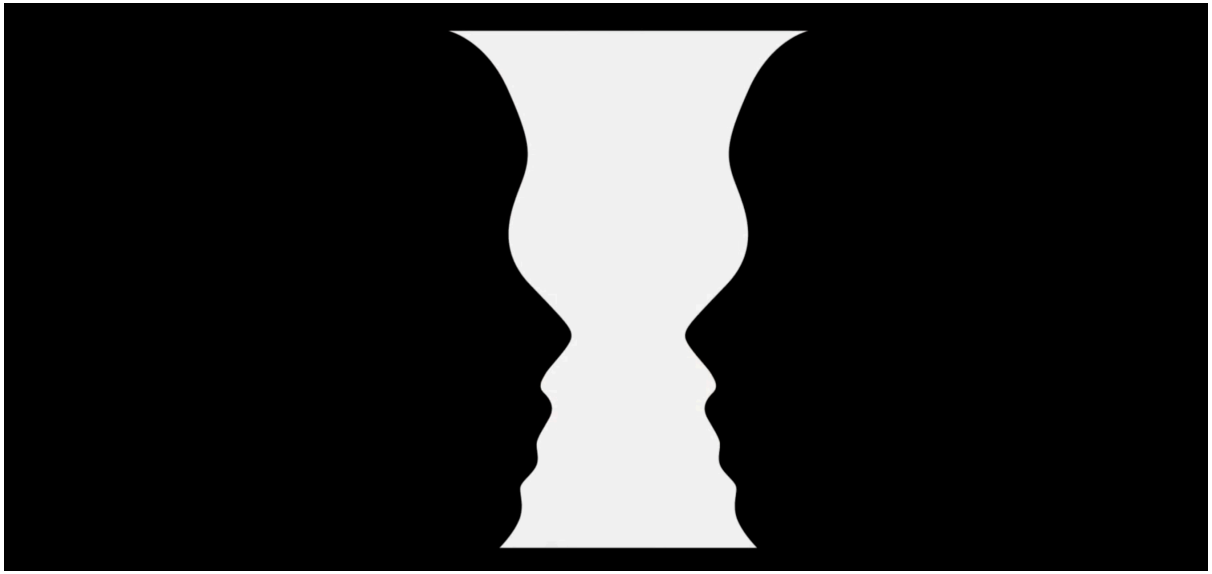
Gestalt law of Closure: Implications for design

Be careful in case of missing values



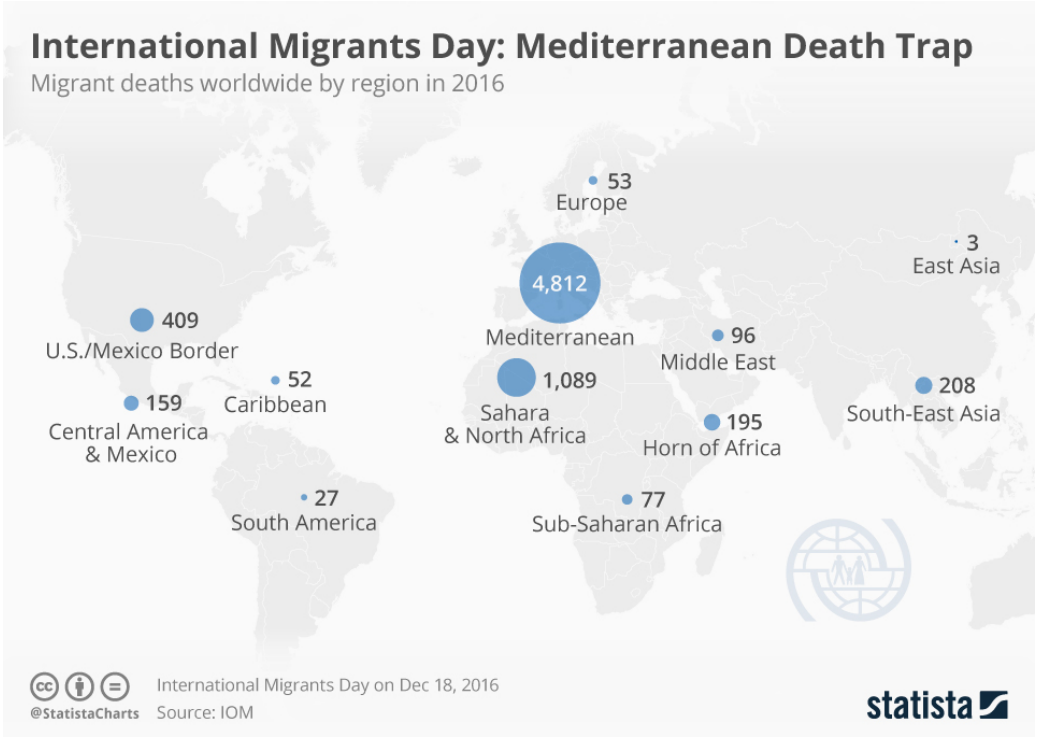
Gestalt law of Figure/Ground

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



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/

Channel efficiency summary

Accuracy
- Prioritize high ranking channels

Discriminability
- Do not use more than 5-7 colors

Salience (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