Data Visualization

VISUAL PERCEPTION

Outline

Motivation

Attention and memory

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

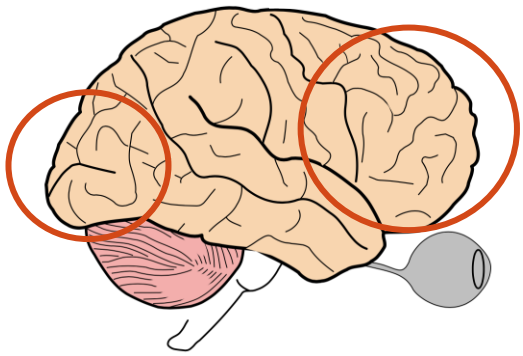
Visual order

Motivation

Why does visualization work?

Perception vs. cognition

Seeing (visual perception) is extremely fast and efficient



Thinking (cognition) is much slower and less efficient

Data visualization is effective because it shifts the balance between cognition and perception to take fuller advantage of the brain's abilities

http://civicmedia.info/resources/stephen-few-data-visualization-for-human-perception

Understanding 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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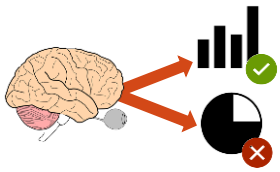
Understanding visual perception

Understanding visual perception enables to make informed decisions about visualization design



The space of possibilities is huge – you need something to guide you in the choices you make

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Next, two examples …

7

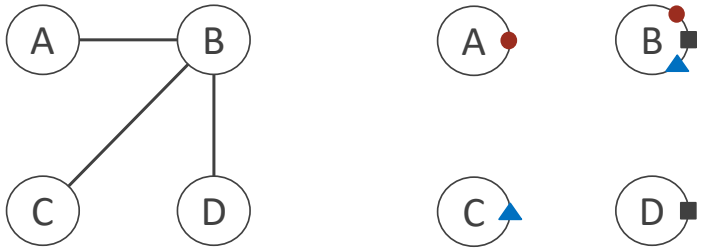
And you will read this last

You will read this first

And then you will read this

Then this one

Which is easier to understand?



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Attention and memory

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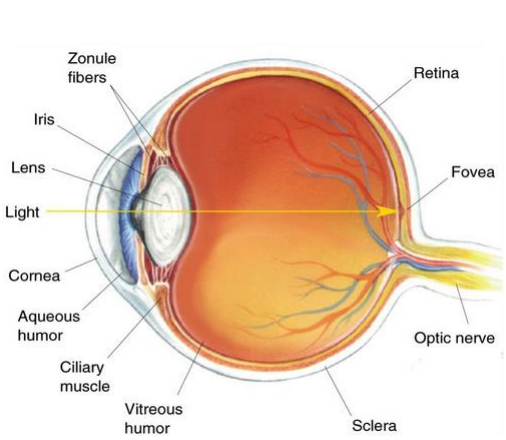
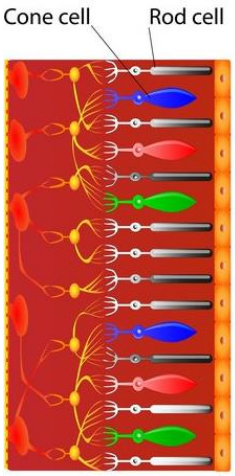
Human eye anatomy

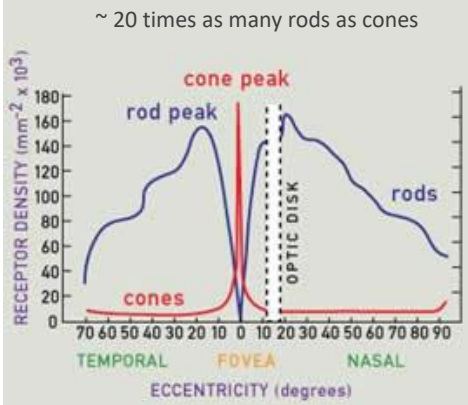


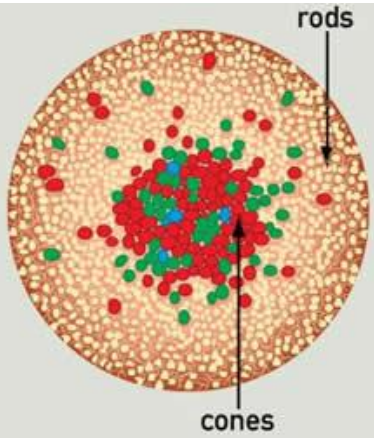


https://www.webrn-maculardegeneration.com/rods-and-cones.html 11

Rods and cones (photoreceptors)

~ 20 times as many rods as cones





http://www.webexhibits.org/causesofcolor/1G.html 12

Blind spot

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Filling in the blanks

We don't see images with our eyes, we see them with our brains.

Stephen Few

The eye is not a camera

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Filling in the blanks

https://en.wikipedia.org/wiki/File:FoveatedLandscape.png 15

Filling in the blanks

Saccadic eye movement

- Fast eye movement to sample the area around the focus of attention
- Eyes in continual motion (series of fixations of connected by saccades – about 3 per second)

What we perceive is the sum of the input that has been received in the last few fixations (things don't disappear when we blink)

https://en.wikipedia.org/wiki/File:This_shows_a_recording_of_the_eye_movements_of_a_participant_looking_freely_at_a_picture.webm 16

Filling in the blanks

https://petapixel.com/2019/07/31/this-black-and-white-photo-uses-color-grid-lines-to-trick-your-brain/

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Attention

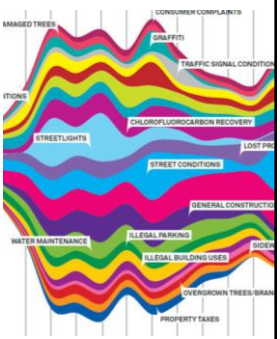
Visual perception is driven by our attention

Inattentional blindness

- We are blind to the things we do not pay attention to

Implications for design

- Guide the attention of the viewer in a way that is useful for achieving the goal
- Be aware of how your design choices affect the attention of the user
- You don't want to inadvertently attract attention to unimportant information



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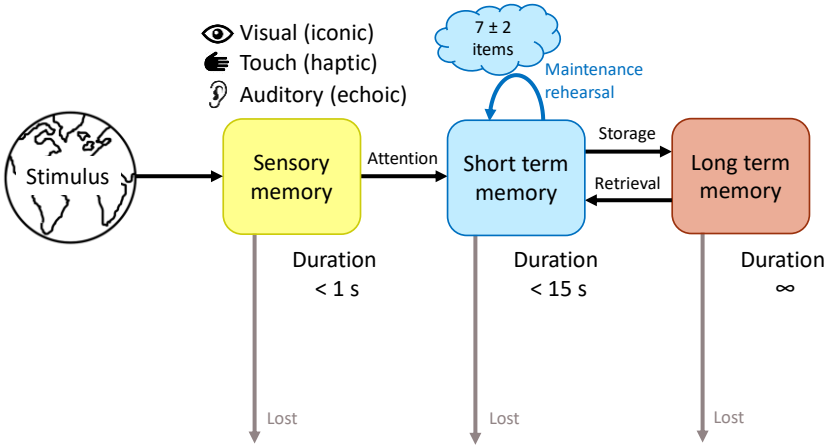
Memory



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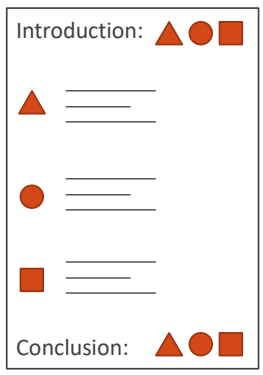
Memory: Implications for design/presentation

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)

Be consistent (for example, always follow the same order)



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

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Visual encoding

Visual encoding

Mapping between data properties and graphical properties

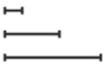
Data attributes ➡ Visual channels

Data attributes

→ Ordered

→ *Ordinal*

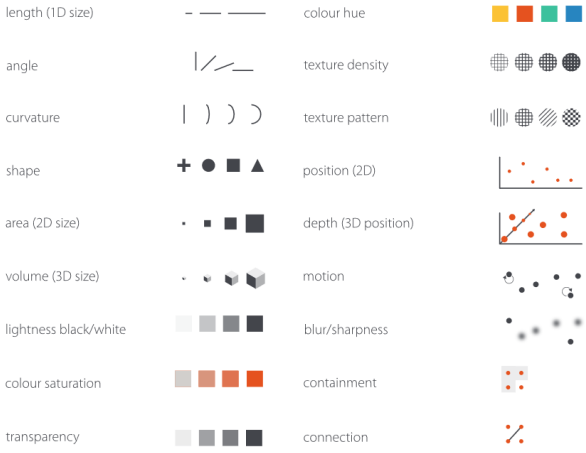
→ *Quantitative*



→ Categorical

T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014 23

Visual channels



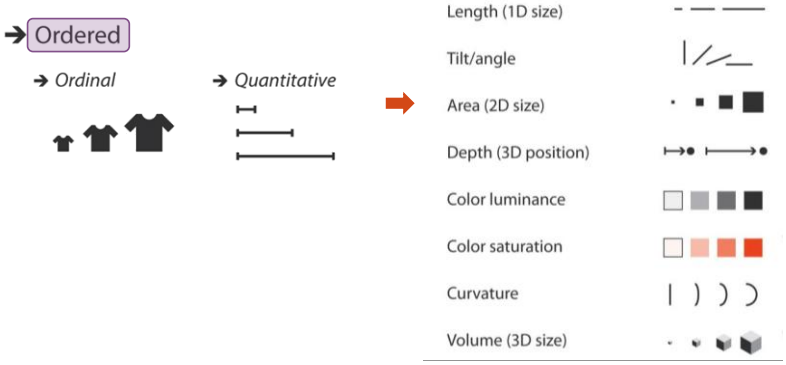
E. J. Maguire. *Systematising Glyph Design for Visualization*, PhD Thesis, University of Oxford, 2014. 24

Visual channels

Channel properties

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

Channels that can express order (magnitude channels)



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

Channels that can express categories (identity channels)

T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014 27

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)

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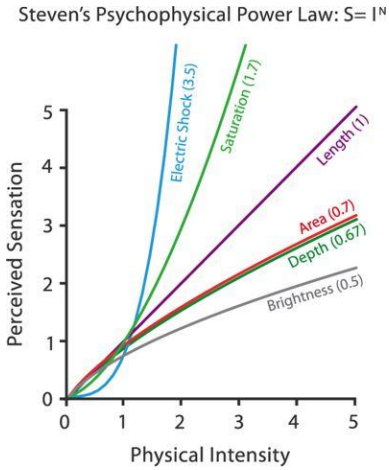
Channel accuracy

Channel accuracy

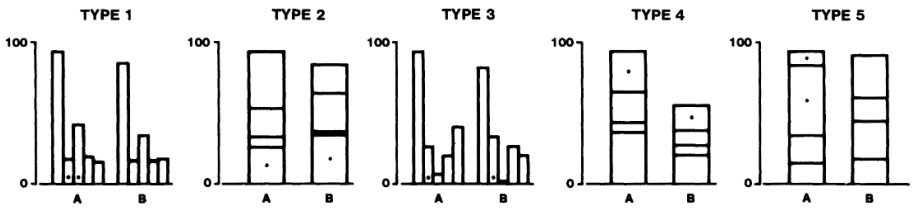


Published in 1957

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

Channel accuracy

Experiments in graphical perception by Cleveland and McGill in 1983

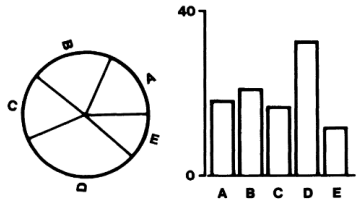


Which is smaller?
How much smaller is it?

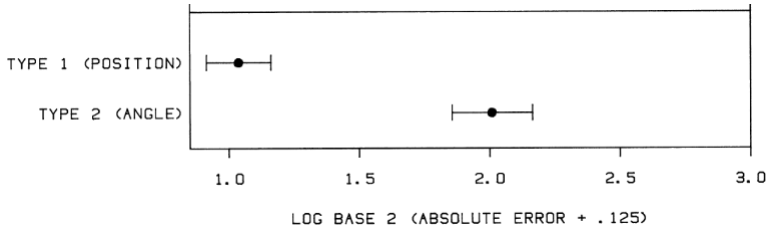
W. S. Cleveland, R. McGill. Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. *Journal of the American Statistical Association*, 1984

31

Channel accuracy



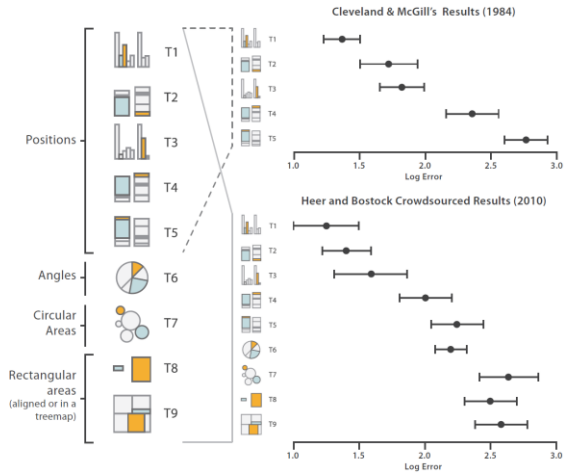
How much bigger is B compared to A?



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

32

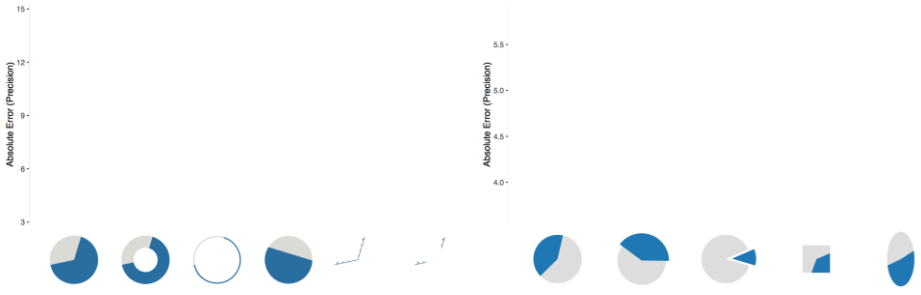
Channel accuracy



E. J. Maguire. Systematising Glyph Design for Visualization, PhD Thesis, University of Oxford, 2014. 33

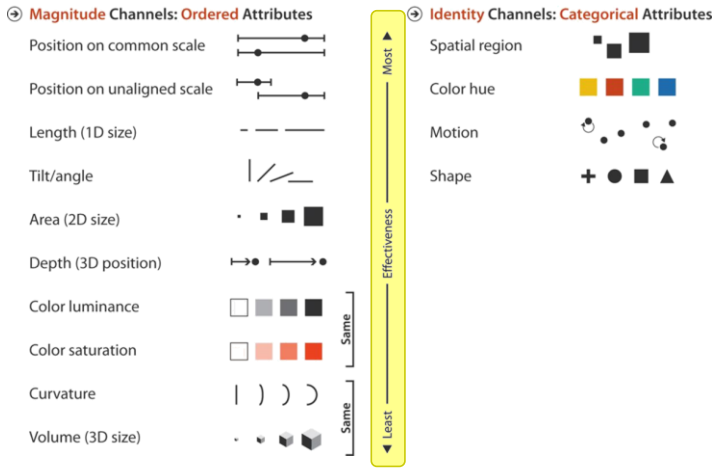
Channel accuracy

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



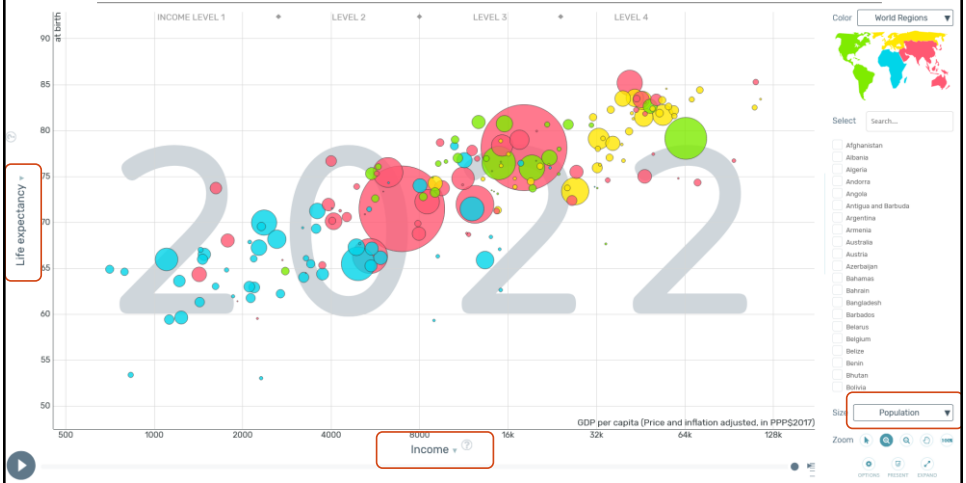
https://eagereyes.org/blog/2016/an-illustrated-tour-of-the-pie-chart-study-results 34

Channel accuracy: Implications for design



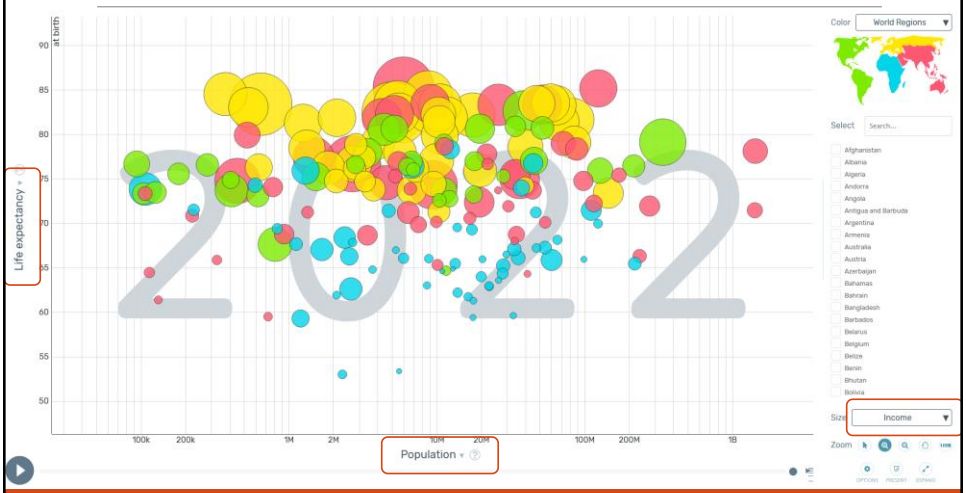
T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014 35

Channel accuracy: Implications for design



https://www.gapminder.org/tools 36

Channel accuracy: Implications for design



https://www.gapminder.org/tools

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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

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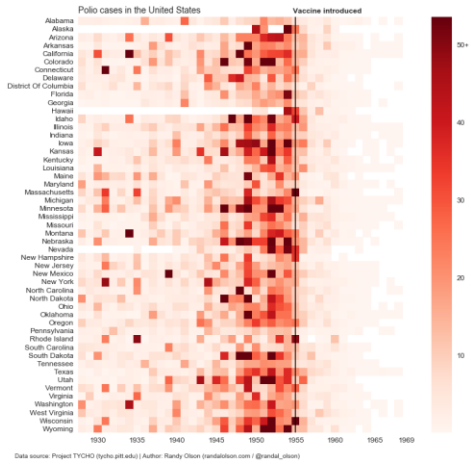
Polio cases in the US



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

Channel discriminability

Channel discriminability

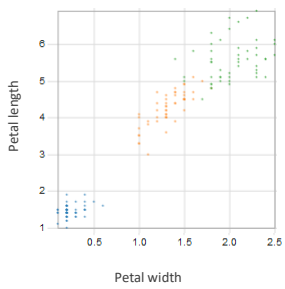
How many distinct values can be distinguished within a channel

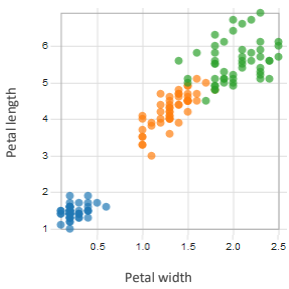
Discriminability depends on

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

Channel discriminability

The effect of size

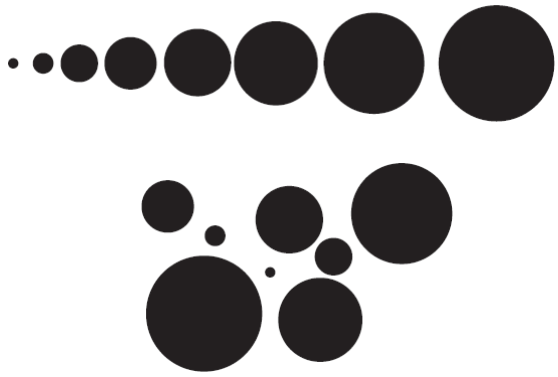




https://beta.observablehq.com/@mbostock/d3-scatterplot-matrix

Channel discriminability

The effect of spatial arrangement



E. J. Maguire. Systematising Glyph Design for Visualization, PhD Thesis, University of Oxford, 2014. 43

Channel discriminability

The effect of cardinality

E. J. Maguire. Systematising Glyph Design for Visualization, PhD Thesis, University of Oxford, 2014. 44

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)

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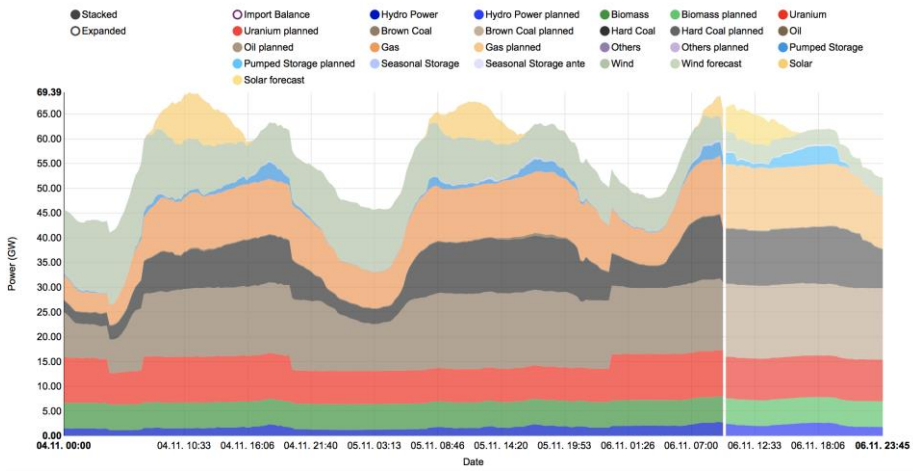
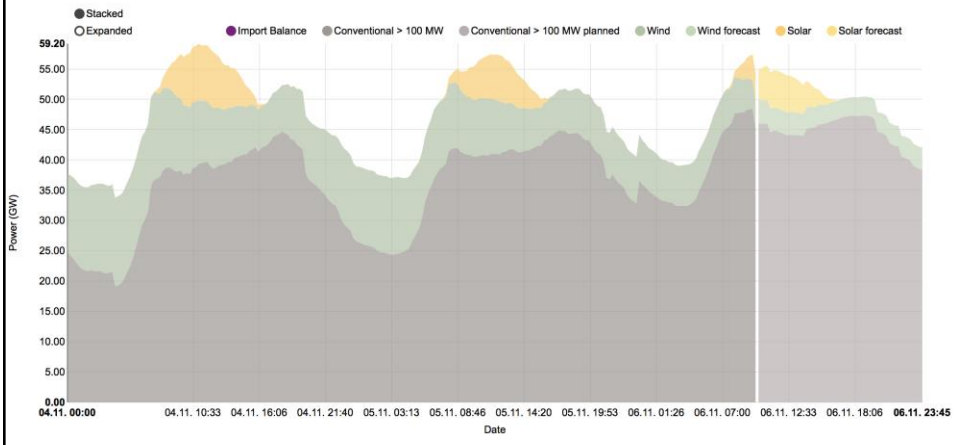
Electricity production in Germany – all sources



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

46

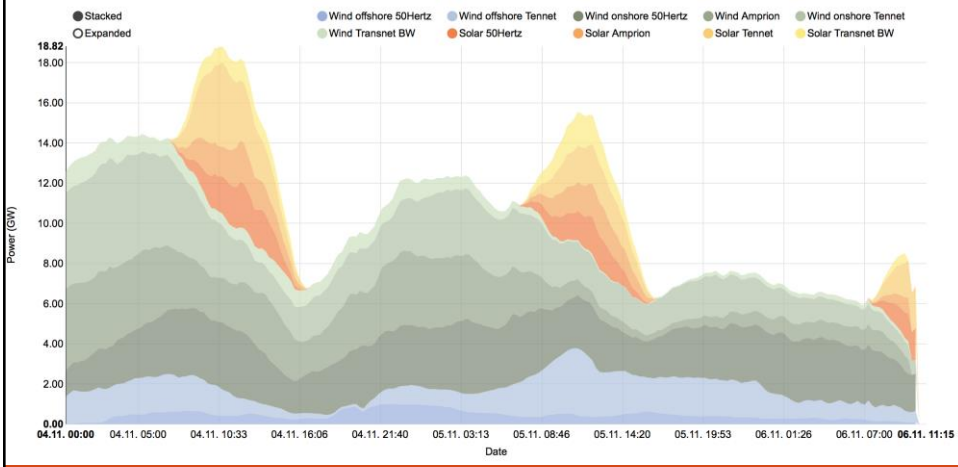
Electricity production in Germany – grouped sources



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

47

Electricity production in Germany – filtered sources



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

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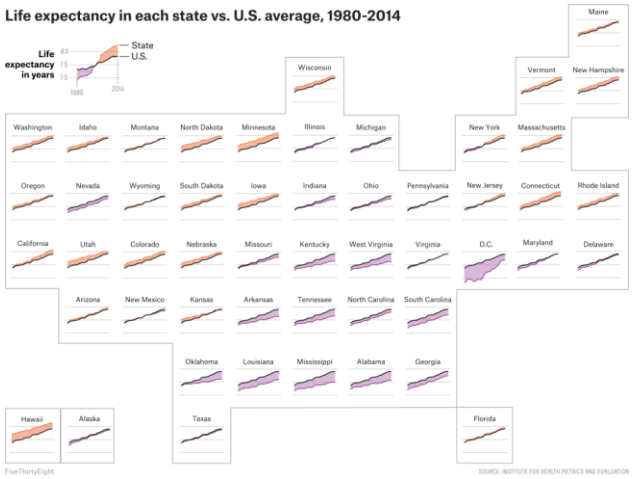
Small multiples



https://fivethirtyeight.com/features/as-u-s-life-expectancies-climb-people-in-a-few-places-are-dying-younger/

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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

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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

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Another example

How many cats do you see?

https://twitter.com/vikkik88/status/1448850783928152074

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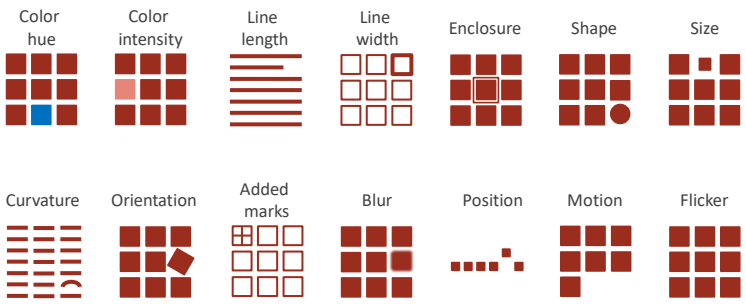
Preattentive attributes



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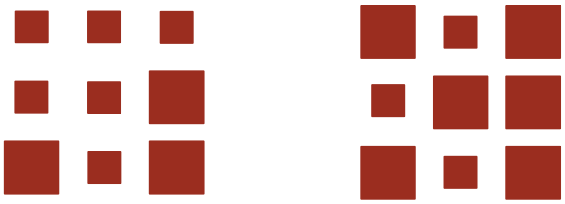
Preattentive attributes

Many attributes are asymmetric



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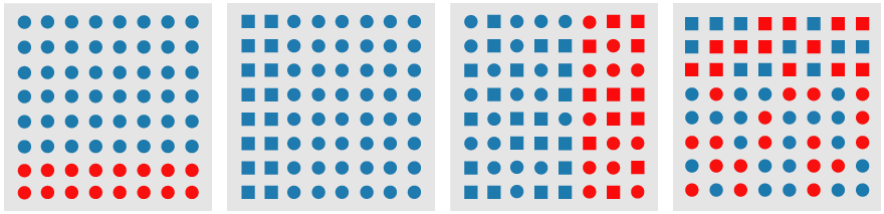
Preattentive attributes

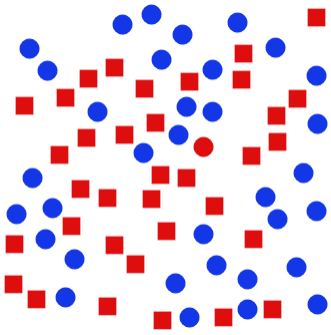
Some attributes are stronger than others

- In boundary detection, color hue is stronger than shape



Preattentive attributes

Conjunctions of two attributes often not preattentive



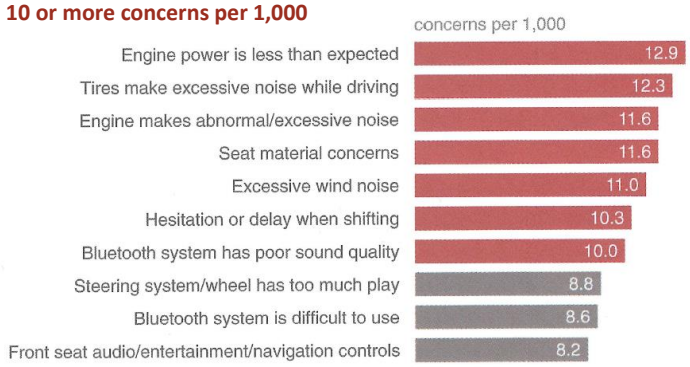
Preattentive conjunctions

- Space and color
- Motion and shape

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

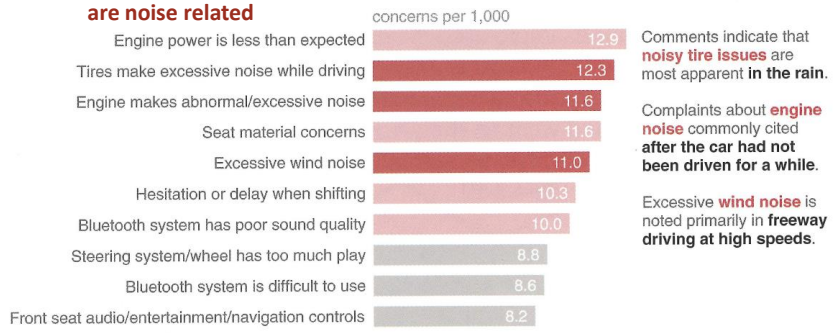


C. Nussbaumer Knaflic. *Storytelling with data*. Wiley, 2015 59

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



C. Nussbaumer Knaflic. *Storytelling with data*. Wiley, 2015 60

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

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Channel separability

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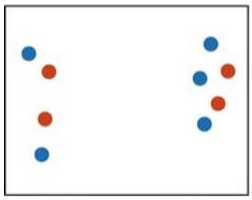
Channel separability

Amount of interference between channels

Position
+ Hue (Color)



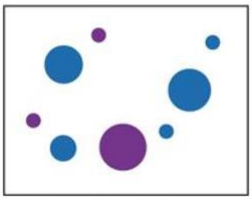
Fully separable

An example of
separable channels

Channel separability

Amount of interference between channels

Size
+ Hue (Color)

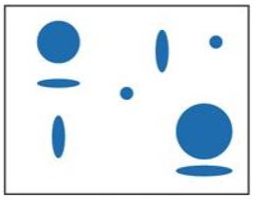


Some interference

Channel separability

Amount of interference between channels

Width
+ Height



Some/significant interference

An example of integral channels

Channel separability

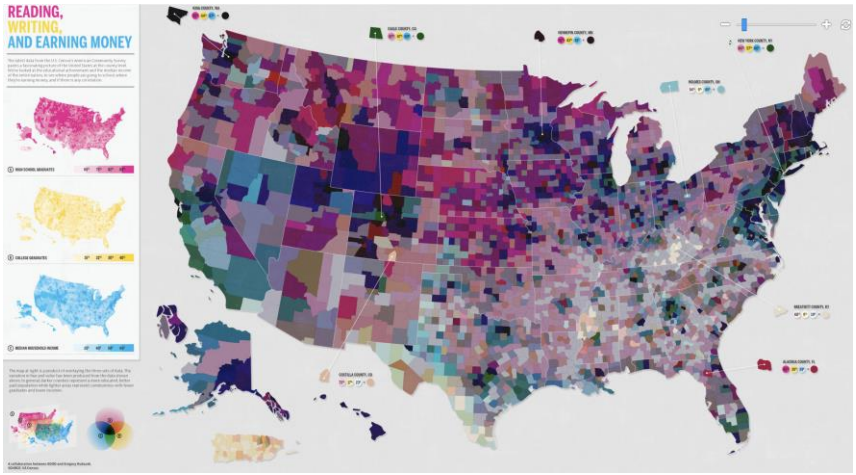
Amount of interference between channels

Red
+ Green

Major interference

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

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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

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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

70

Gestalt laws

Proximity

Similarity

Connection

Enclosure

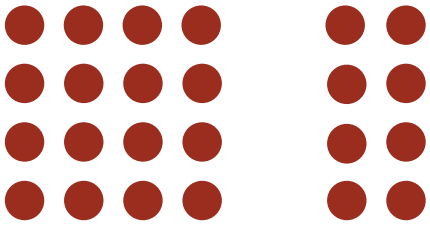
Closure

Figure/Ground

71

Gestalt law of Proximity

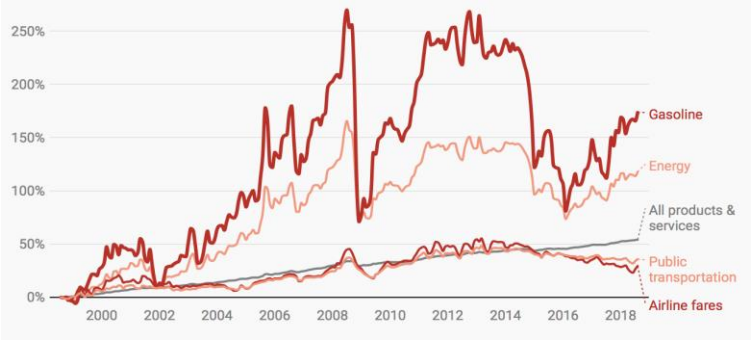
We perceive objects close to each other as belonging to a group



72

Gestalt law of Proximity: Implications for design

Place annotations close to the data

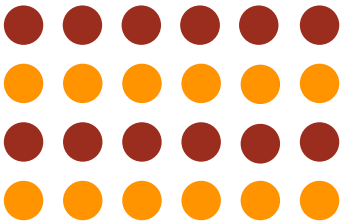


https://blog.datawrapper.de/weekly47-cpi-dollars-for-college/

73

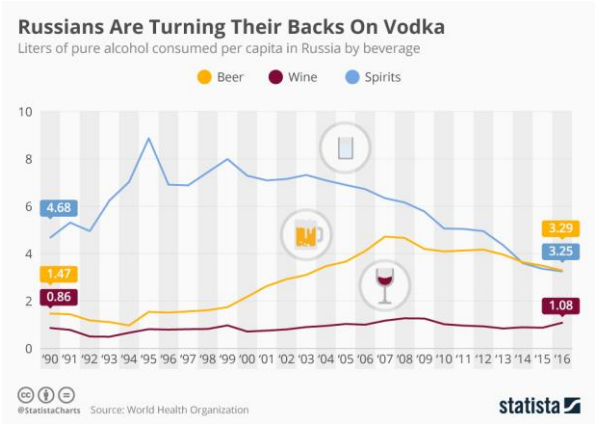
Gestalt law of Similarity

We perceive similar objects as belonging to a group



74

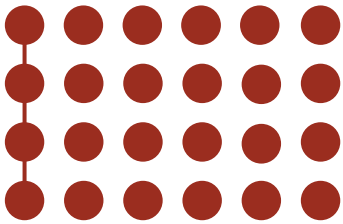
Gestalt law of Similarity: Implications for design



https://www.statista.com/chart/15918/liters-of-pure-alcohol-consumed-per-capita-in-russia/ 75

Gestalt law of Connection

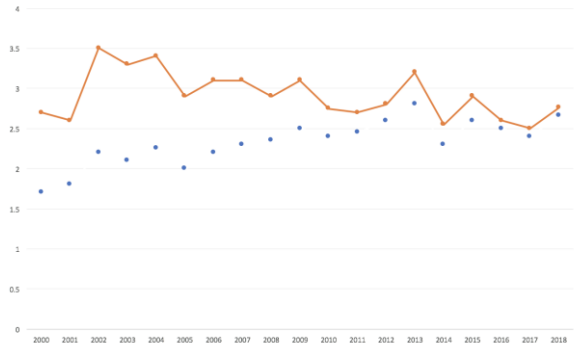
We perceive objects connected to each other as a single group



76

Gestalt law of Connection: Implications for design

Use lines to show the data is in the same group



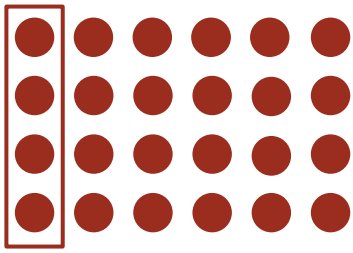
http://daydreamingnumbers.com/concepts/gestalt-laws-data-visualization/ 77

Gestalt law of Connection: Implications for design

https://twitter.com/mikebrondbjerg/status/1011560612055408640 78

Gestalt law of Enclosure

We perceive physically enclosed objects as part of a group



79

Gestalt law of Enclosure: Implications for design

Use enclosures to show groups

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

80

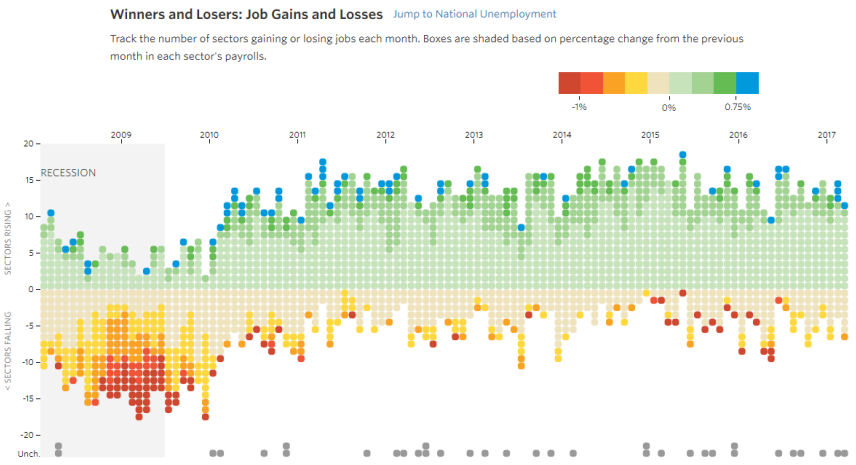
Gestalt law of Enclosure: Implications for design

Bubble sets visualization

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

81

Gestalt law of Enclosure: Implications for design

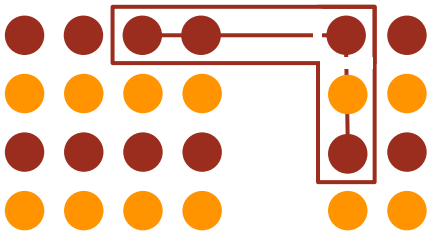


http://graphics.wsj.com/job-market-tracker/

82

Hierarchy within grouping

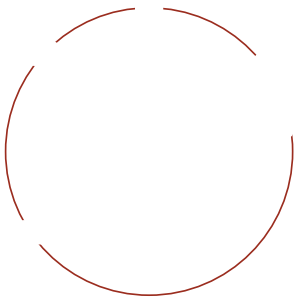
Similarity < Proximity < Connection & Enclosure



83

Gestalt law of Closure

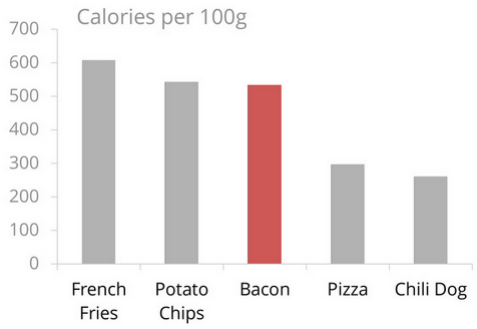
We perceive objects as being whole even when they are not complete



84

Gestalt law of Closure: Implications for design

No need to draw chart borders

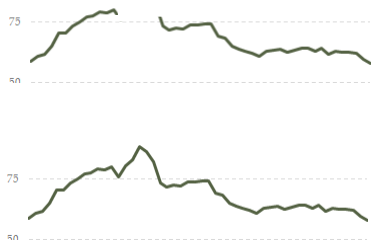


https://www.darkhorseanalytics.com/blog/data-looks-better-naked

85

Gestalt law of Closure: Implications for design

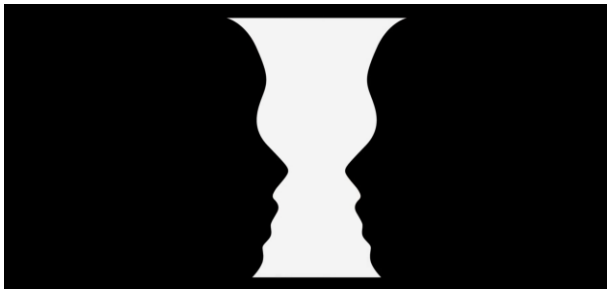
Be careful in case of missing values



86

Gestalt law of Figure/Ground

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



87

Gestalt law of Figure/Ground: Implications for design

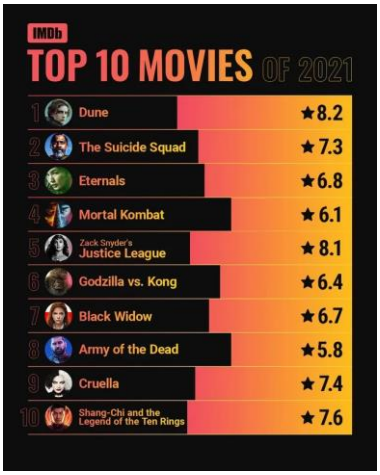
Color contrast and overlays can be used to discern the figure from the background

https://twitter.com/cherdarchuk/status/1408466111465594881

88

Gestalt law of Figure/Ground: Implications for design

Which bar represents the data, the black one or the colored one?



https://twitter.com/IMDb/status/1468600009285320707

89

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

90

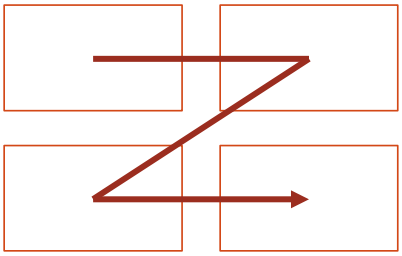
Visual order

Visual order

https://twitter.com/flieldy/status/1384950048086282246

Visual order

The attention of people follows the Z shape



You should place the important things on the top (left) of the display

C. Nussbaumer Knaflic. *Storytelling with data*. Wiley, 2015 93

Visual order

All elements should be aligned – create clean vertical and horizontal 'lines' to establish a sense of unity and cohesion

Do not be afraid of white (empty) space – do not add more data (or stretch the graphics) to get rid of it

C. Nussbaumer Knaflic. *Storytelling with data*. Wiley, 2015 94

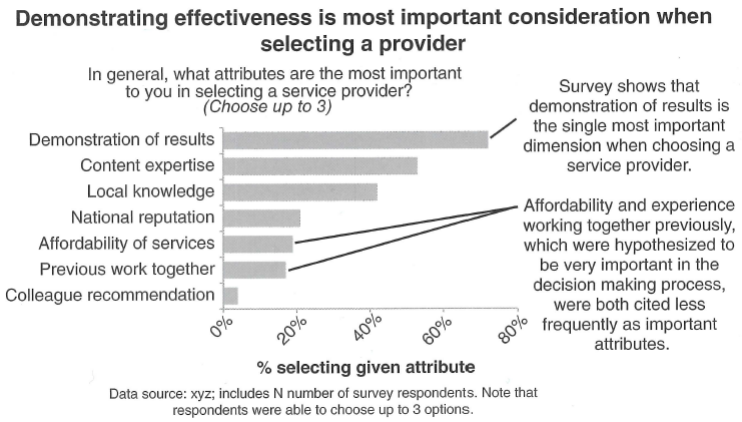
Visual order

Stay away from diagonal components (especially text)

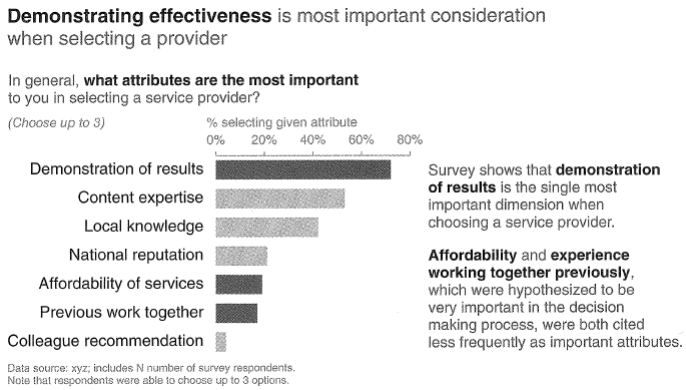
Text rotated by 45 degrees (in either direction) is 52% slower to read than normally oriented text

Text rotated by 90 degrees (in either direction) is 205% slower to read than normally oriented text

Visual order – an example



Visual order – an example



Visual order

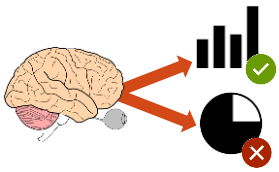
Pay attention to details

Avoid

- Too much centered text
- Diagonal components, especially text
- Vertical text
- Too many things on a single display

Summary

How data visualization works



The quality of visualizations is mostly not subjective

How data visualization works

And you will read this last

You will read this first

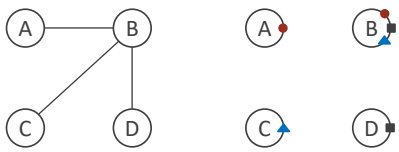
And then you will read this

Then this one

Pop-out and visual order

10
1

How data visualization works



Connection more powerful than similarity

10
2