

Data Visualization

VISUAL PERCEPTION

Tea Tušar, Data Science and Scientific Computing, Information retrieval and data visualization

Outline

Motivation

Attention and memory

Visual encoding

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

Visual order

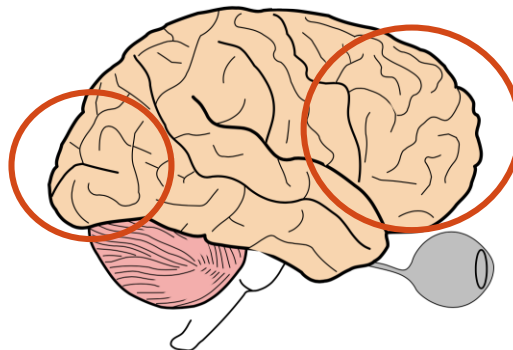
Motivation

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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>

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Understanding visual perception

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



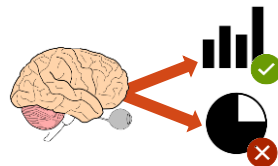
But visual perception follows specific rules derived from **how the brain works**



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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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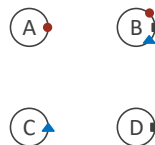
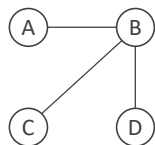
And you will read this last

You will read this first

And then you will read this

Then this one

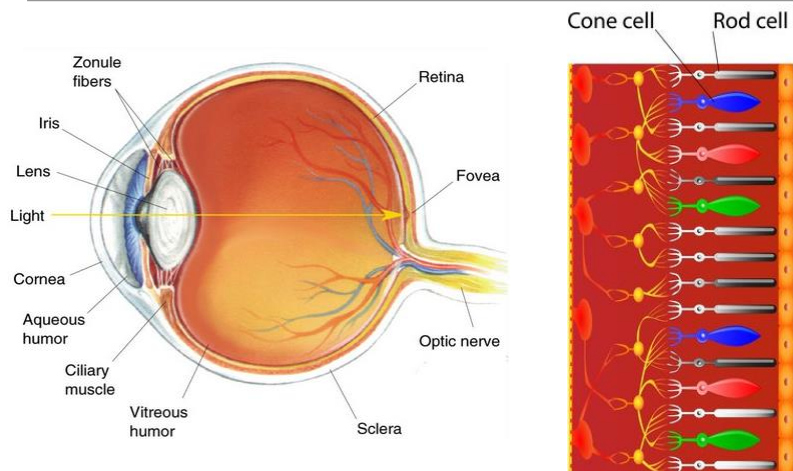
Which is easier to understand?



Attention and memory

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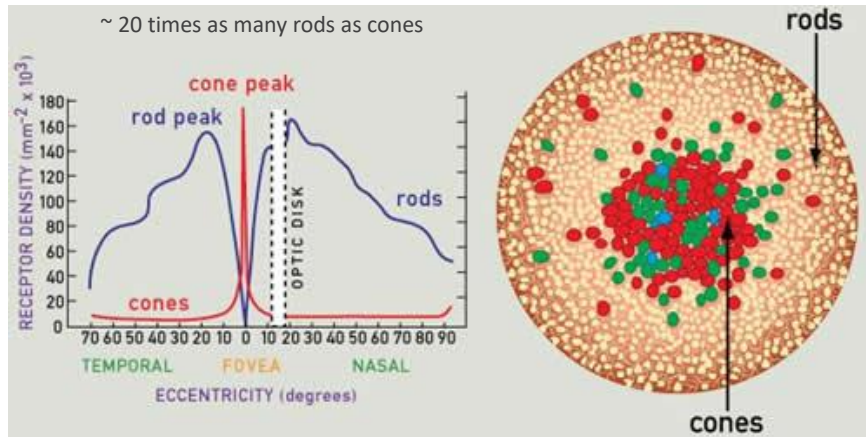
Human eye anatomy



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

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Rods and cones (photoreceptors)



<http://www.webexhibits.org/causesofcolor/1G.html>

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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>

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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

15

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

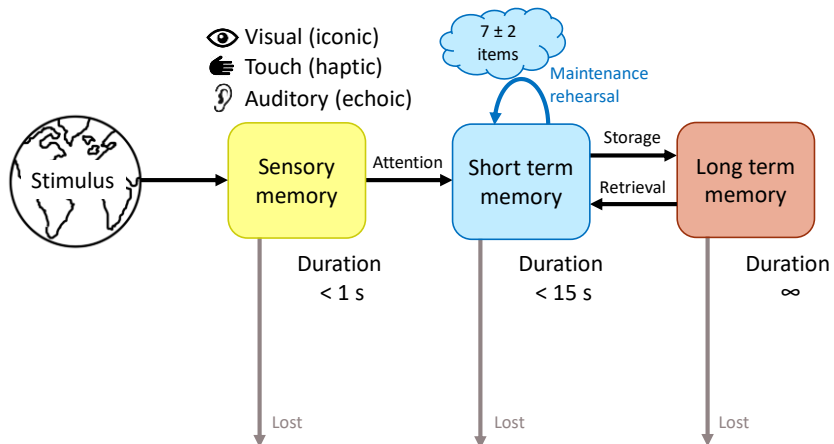
- We are blind to the things we do not pay attention to

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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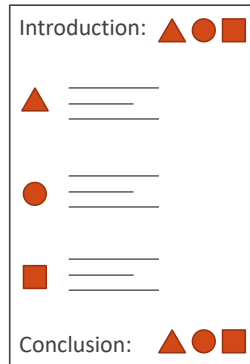
Memory: Implications for design/presentation

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) ▲●■



Visual encoding

Visual encoding

Mapping between data properties and graphical properties

Data attributes → Visual channels

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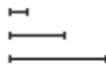
Data attributes

→ Ordered

→ Ordinal



→ Quantitative



→ Categorical



Visual channels

length (1D size)		colour hue	
angle		texture density	
curvature		texture pattern	
shape		position (2D)	
area (2D size)		depth (3D position)	
volume (3D size)		motion	
lightness black/white		blur/sharpness	
colour saturation		containment	
transparency		connection	

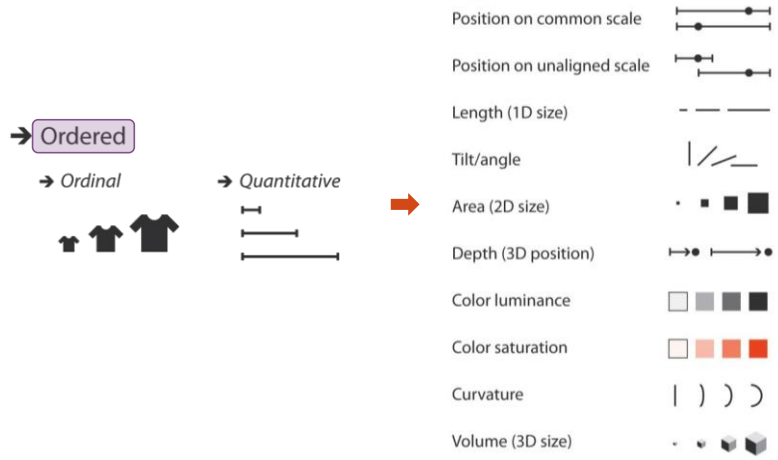
E. J. Maguire. *Systematising Glyph Design for Visualization*, PhD Thesis, University of Oxford, 2014. 23

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)



Channels that can express categories (identity channels)



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)

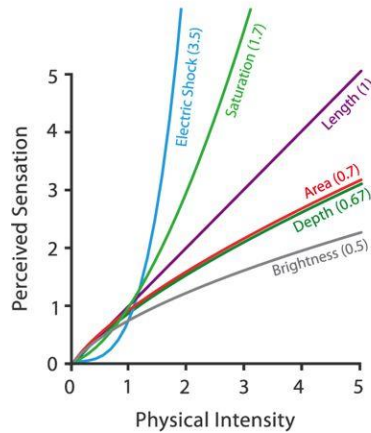
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Channel accuracy

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Channel accuracy

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



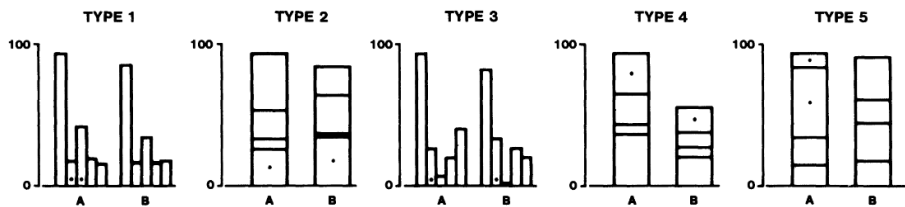
Published
in 1957

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

29

Channel accuracy

Experiments in graphical perception by Cleveland and McGill in 1983

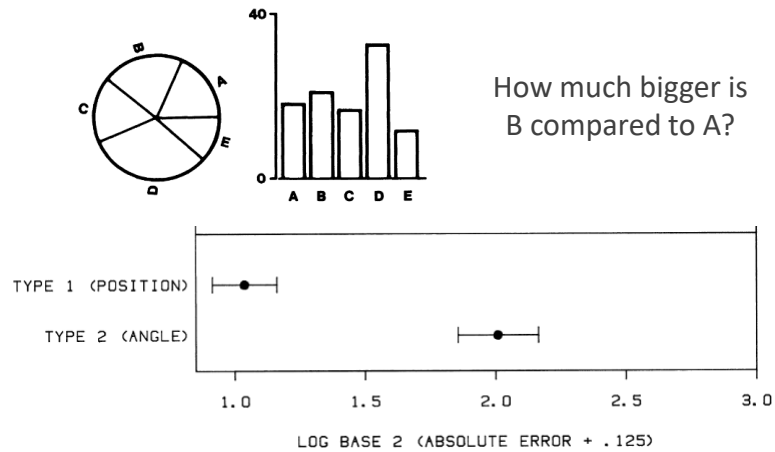


Which is smaller?
How much smaller is it?

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

30

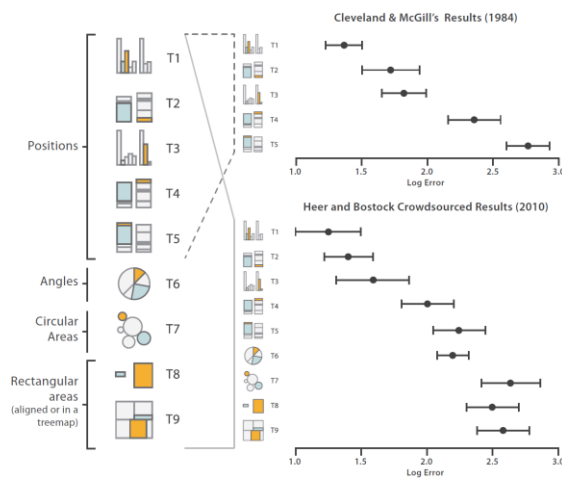
Channel accuracy



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

31

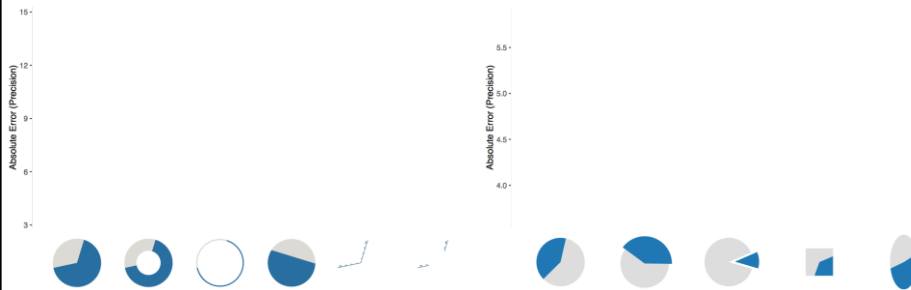
Channel accuracy



E. J. Maguire. Systematising Glyph Design for Visualization, PhD Thesis, University of Oxford, 2014. 32

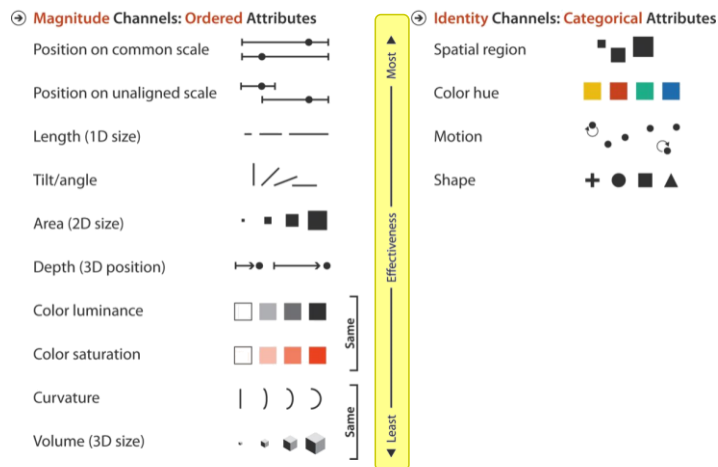
Channel accuracy

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>

Channel accuracy: Implications for design

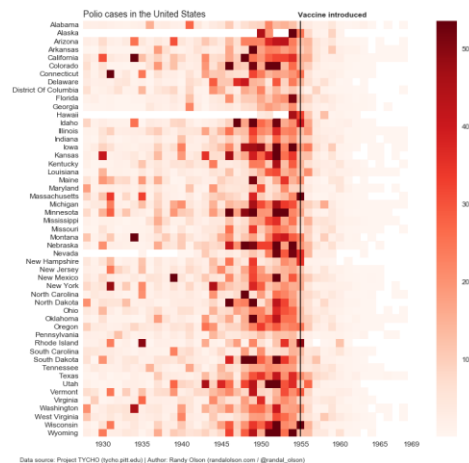


Channel accuracy: Limitations

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



Channel discriminability

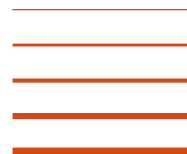
37

Channel discriminability

How many distinct values can be distinguished within a channel

Discriminability depends on

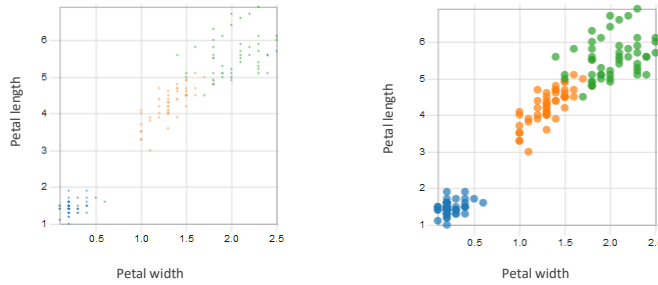
- Channel properties (similar to accuracy)
- Size
- Spatial arrangement
- Cardinality



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Channel discriminability

The effect of size

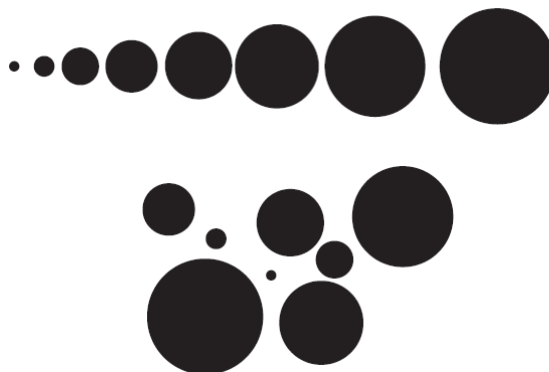


<https://beta.observablehq.com/@mbostock/d3-scatterplot-matrix>

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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. 40

Channel discriminability

The effect of cardinality



E. J. Maguire. Systematising Glyph Design for Visualization, PhD Thesis, University of Oxford, 2014. 41

Channel discriminability: Implications for design

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

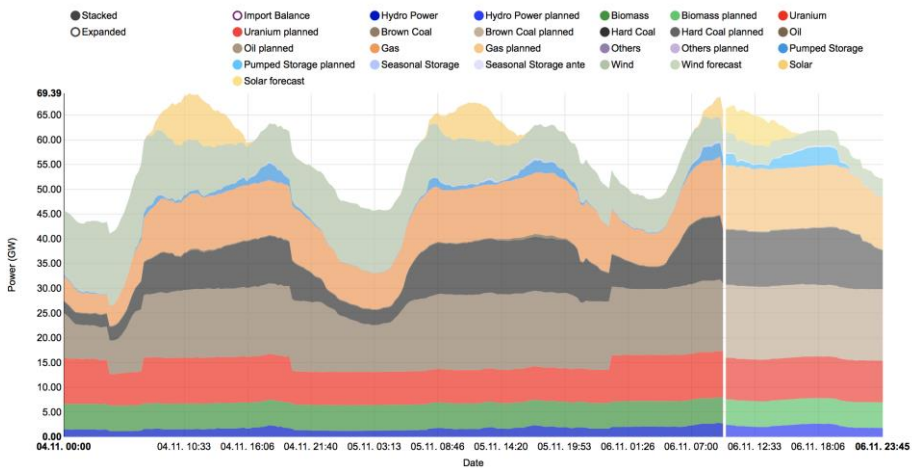
Short term memory limitation: 7 ± 2 items (rather 5 than 9)

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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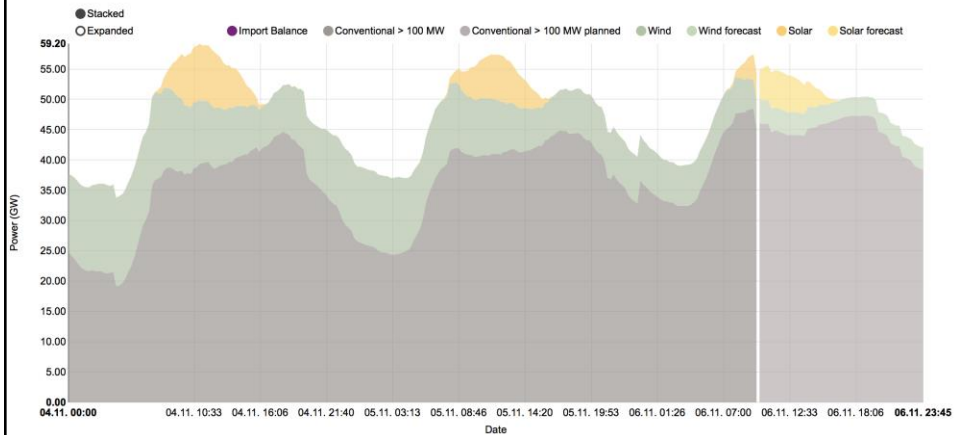
Electricity production in Germany – all sources



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

43

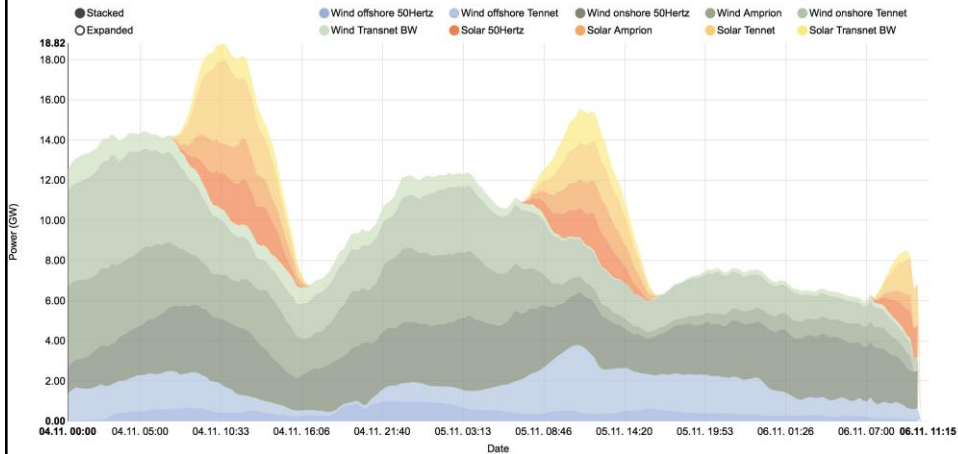
Electricity production in Germany – grouped sources



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

44

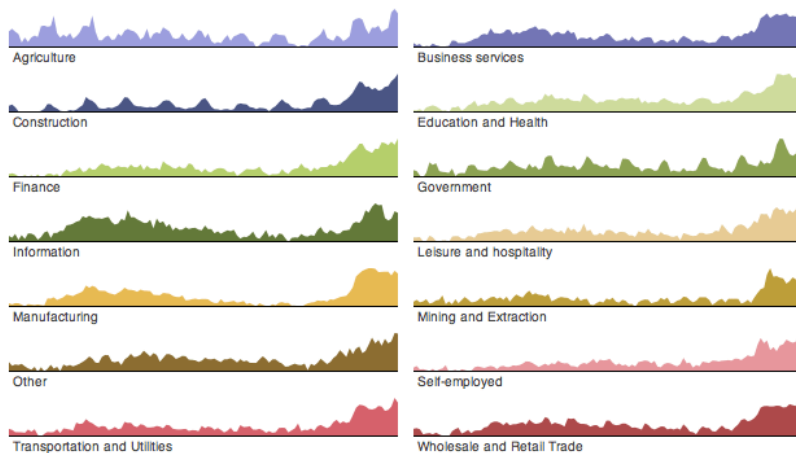
Electricity production in Germany – filtered sources



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

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Small multiples



<https://homes.cs.washington.edu/~iheer/files/zoo/>

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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

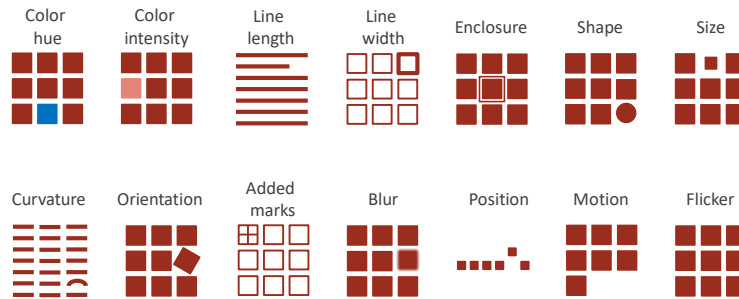
49

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

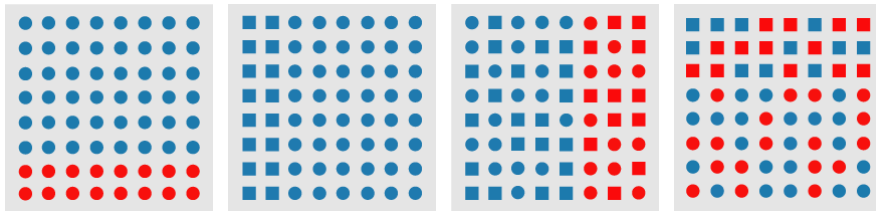


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Preattentive attributes

Some attributes are stronger than others

- In boundary detection, color hue is stronger than shape

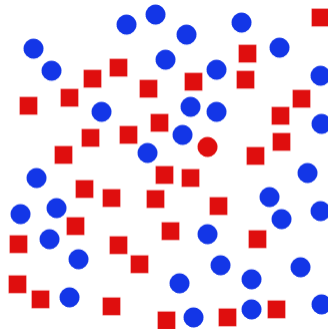


<https://www.csc2.ncsu.edu/faculty/healey/PP/>

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Preattentive attributes

Conjunctions of two attributes often not preattentive



Preattentive conjunctions

- Space and color
- Motion and shape

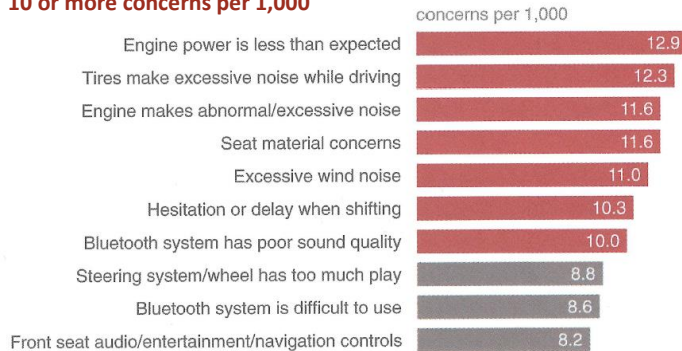
<https://www.csc2.ncsu.edu/faculty/healey/PP/>

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Channel salience: Implications for design

Preattentive attributes can be used to draw attention

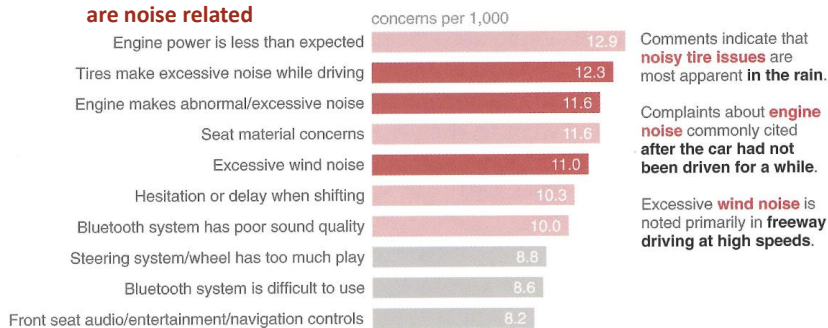
**7 of the top 10 complaints have
10 or more concerns per 1,000**



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

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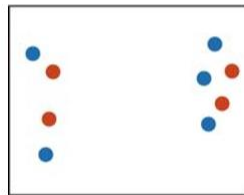
Channel separability

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Channel separability

Amount of interference between channels

Position
+ Hue (Color)



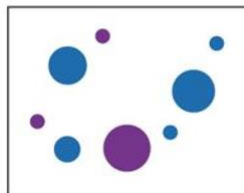
An example of
separable channels

Fully separable

Channel separability

Amount of interference between channels

Size
+ Hue (Color)

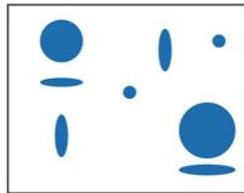


Some interference

Channel separability

Amount of interference between channels

Width
+ Height



An example of
integral channels

Some/significant
interference

Channel separability

Amount of interference between channels

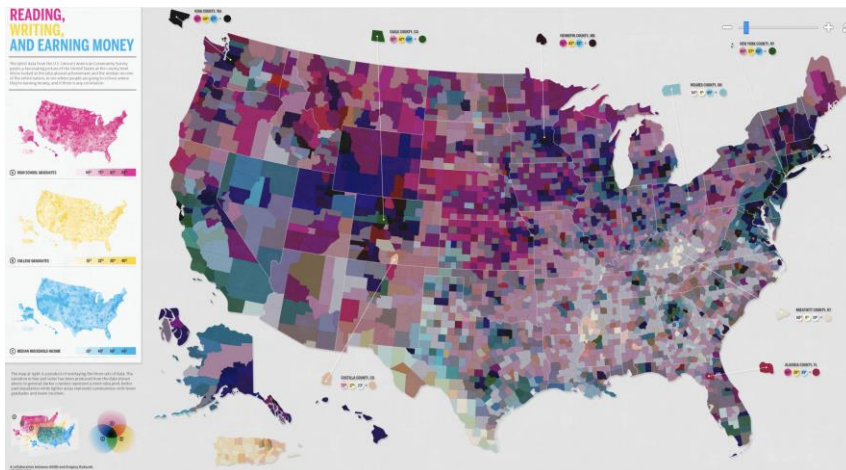
Red
+ Green



An example of
integral channels

Major interference

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

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Gestalt laws

Proximity

Similarity

Connection

Enclosure

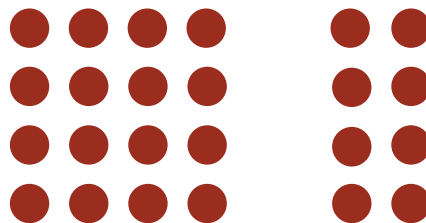
Closure

Figure/Ground

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Gestalt law of Proximity

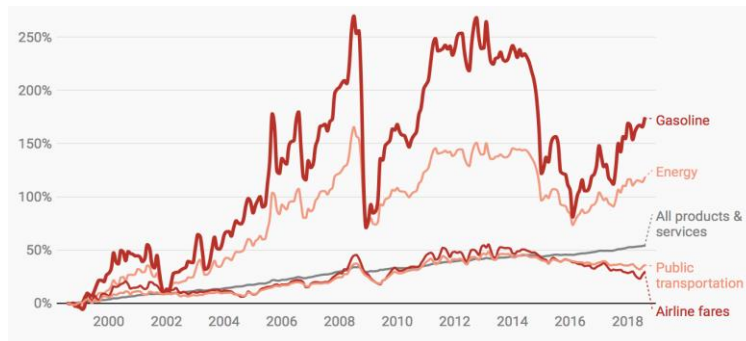
We perceive objects close to each other as belonging to a group



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Gestalt law of Proximity: Implications for design

Place annotations close to the data

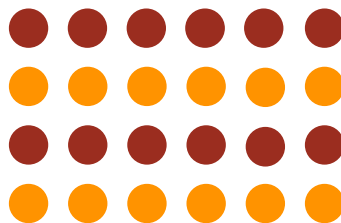


<https://blog.datawrapper.de/weekly47-cpi-dollars-for-college/>

69

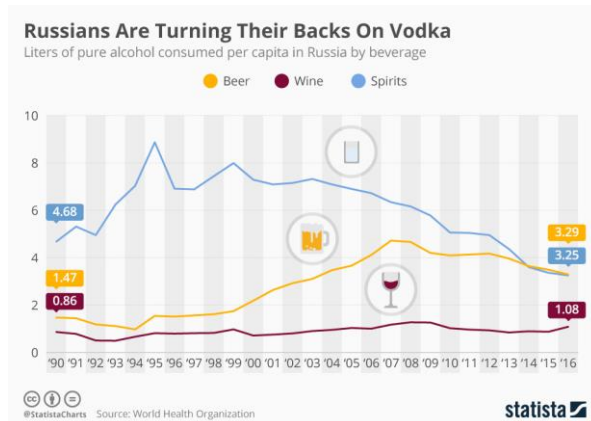
Gestalt law of Similarity

We perceive similar objects as belonging to a group



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Gestalt law of Similarity: Implications for design

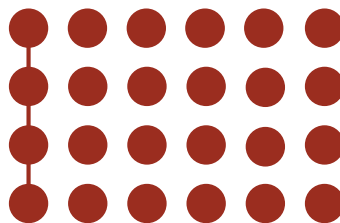


<https://www.statista.com/chart/15918/liters-of-pure-alcohol-consumed-per-capita-in-russia/>

71

Gestalt law of Connection

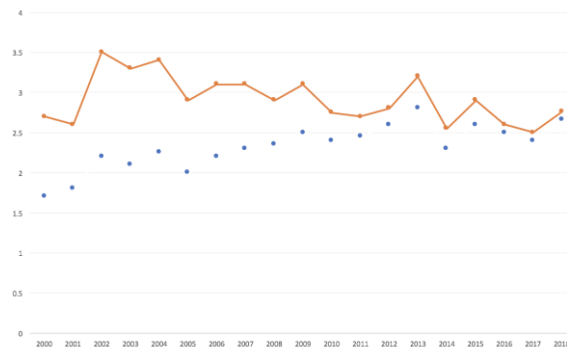
We perceive objects connected to each other as a single group



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Gestalt law of Connection: Implications for design

Use lines to show the data is in the same group

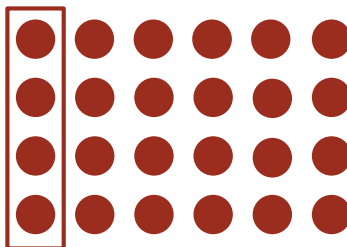


<http://daydreamingnumbers.com/concepts/gestalt-laws-data-visualization/>

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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



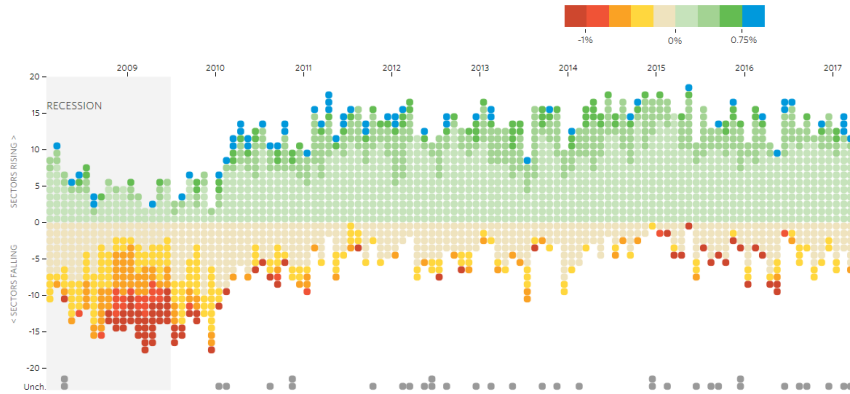
<http://vialab.science.uoit.ca/portfolio/bubblesets>

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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.

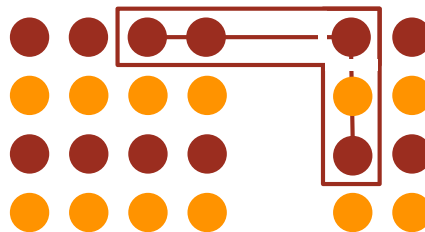


<http://graphics.wsj.com/job-market-tracker/>

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Hierarchy within grouping

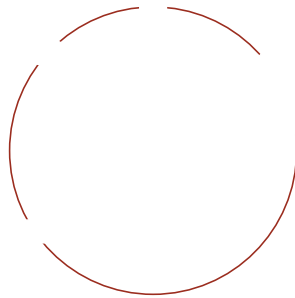
Similarity < Proximity < Connection & Enclosure



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Gestalt law of Closure

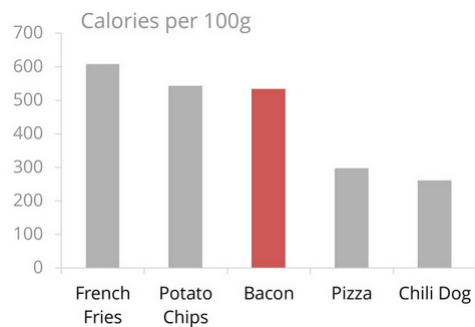
We perceive objects as being whole even when they are not complete



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Gestalt law of Closure: Implications for design

No need to draw chart borders

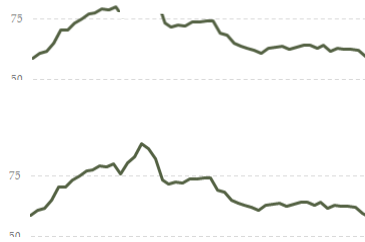


<https://www.darkhorseanalytics.com/blog/data-looks-better-naked>

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Gestalt law of Closure: Implications for design

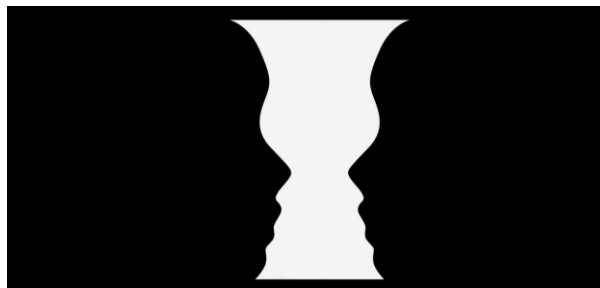
Be careful in case of missing values



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Gestalt law of Figure/Ground

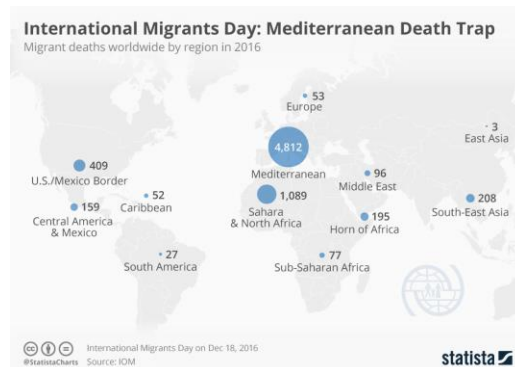
We perceive elements as either figure (element of focus) or ground (background)



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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

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

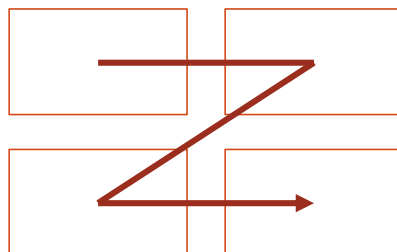
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Visual order

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Visual order

The attention of people follows the Z shape



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

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

Visual order

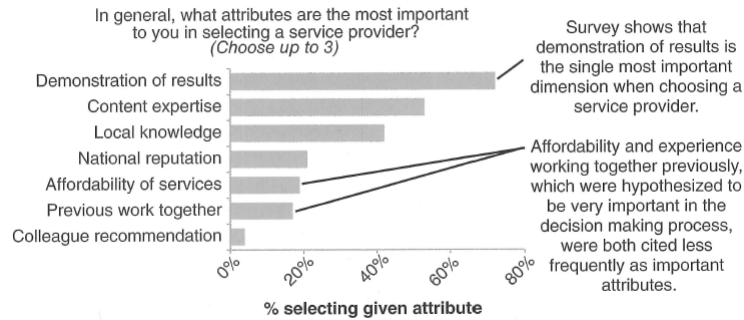
Stay away from diagonal components (especially text)

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

Demonstrating effectiveness is most important consideration when selecting a provider



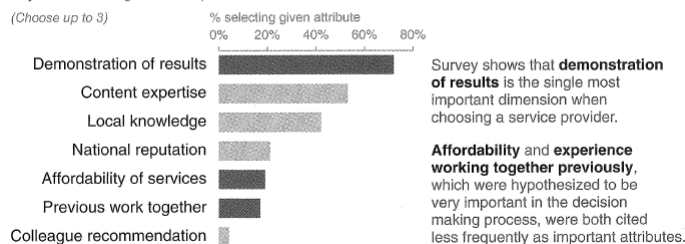
Data source: xyz; includes N number of survey respondents. Note that respondents were able to choose up to 3 options.

Visual order – an example

Demonstrating effectiveness is most important consideration when selecting a provider

In general, **what attributes are the most important** to you in selecting a service provider?

(Choose up to 3)



Data source: xyz; includes N number of survey respondents. Note that respondents were able to choose up to 3 options.

Visual order

Pay attention to details

Avoid

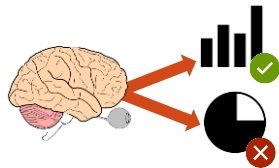
- Too much centered text
- Diagonal components, especially text
- Too many things on a single display

Use the title wisely

- Very important
- It should contain the take-home message

Summary

How data visualization works



The quality of visualizations
is mostly not subjective

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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

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How data visualization works

