

# Using Visual Perception

to find patterns in data and drive insight  
help others

Alex Gurvich, Ph.D.  
NASA Scientific Visualization Studio  
R Gov. & Public Sector, Oct. 29, 2024

# Using **Visual Perception**

to **find patterns** in data and **drive insight**  
help others

**a.k.a. a book report evangelizing the  
work of Northwestern professor  
Steve Franconeri's**



**Visual Thinking  
Lab**



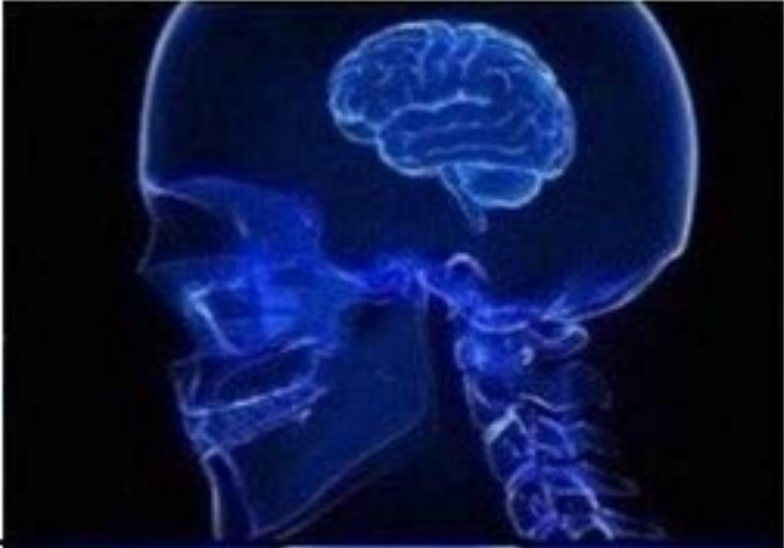
We study visual thinking: how it works, and how  
education + design can make it work better.

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NASA Scientific Visualization Studio  
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When I was in grad school I attended a workshop and saw one of Steve's presentations and it inspired me to become a data visualizer.

BEFORE  
STEVE'S TALK AT  
NU IDEAS FSS  
2017 VIZ WORKSHOP



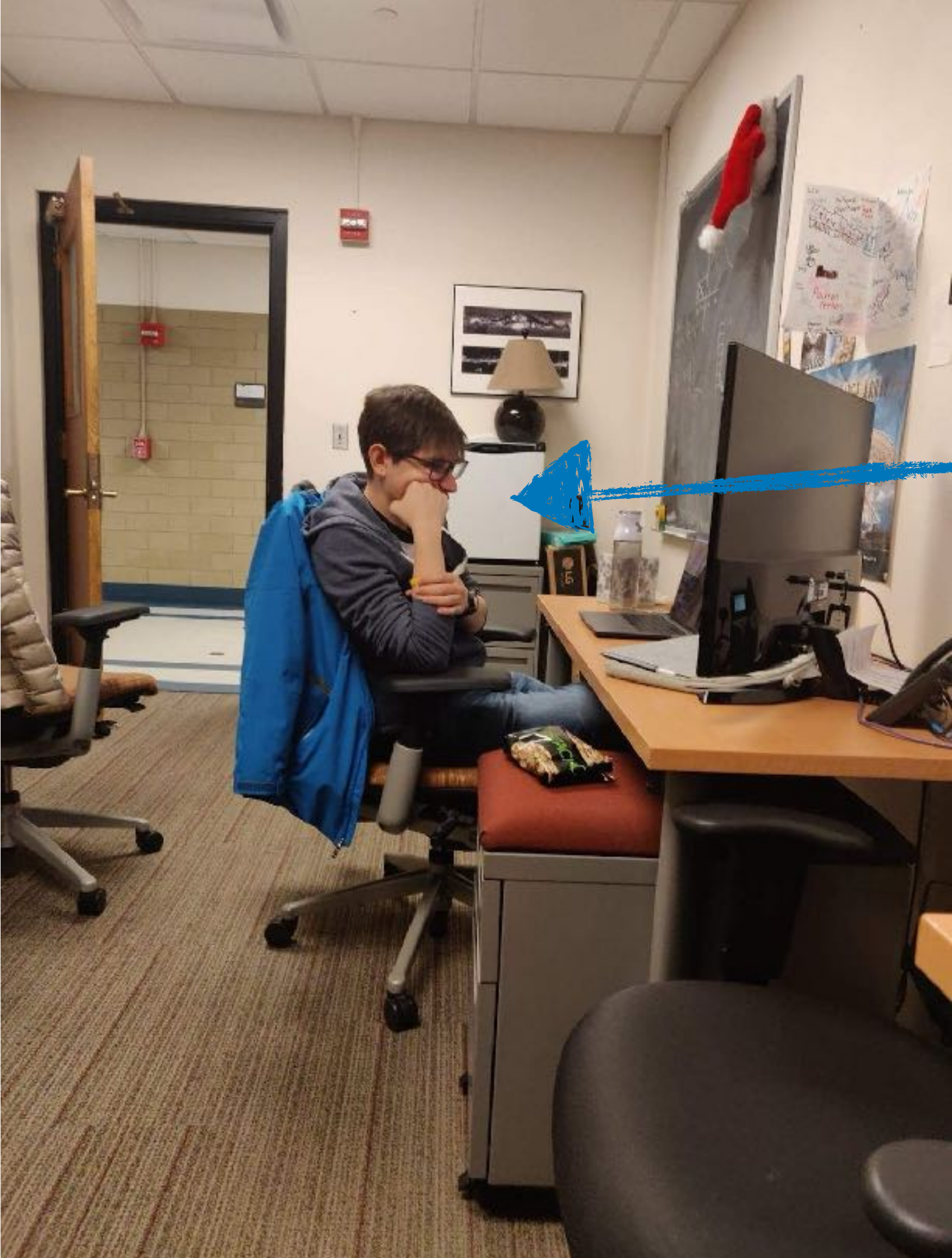
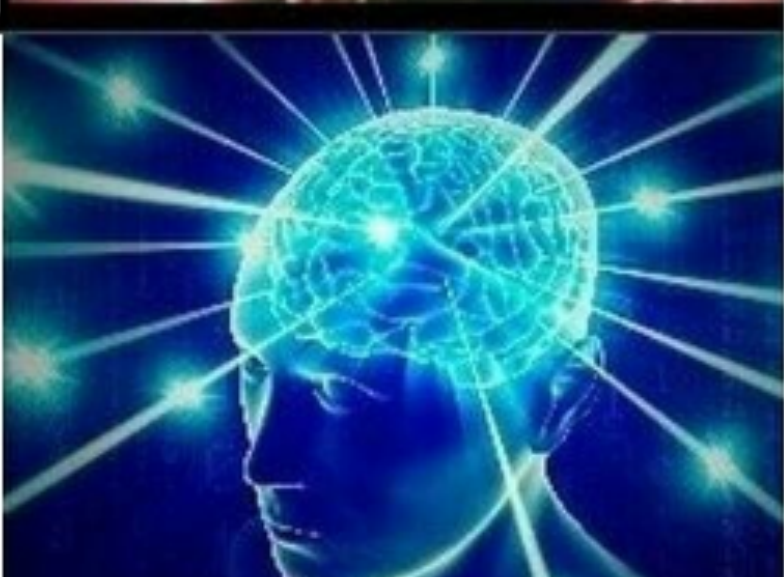
AFTER STEVE'S  
TALK AT NU  
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AFTER  
STEVE'S TALK  
AT OUTLIER 2024



AFTER  
PREPARING THIS  
PRESENTATION



me in grad school  
@ NU on my way  
to deciding to  
become a  
data visualizer



Humans are **hardwired** to quickly process visual information for **aggregate stats**, as visualizers we want to take advantage of this.

**without even having to focus, your brain has turned on a powerful **parallel processing engine** to analyze the photo on the right.**





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without even having to focus, your brain has turned on a powerful **parallel processing engine** to analyze the photo on the right.

**you can quickly and automatically identify clusters, relative sizes, and the overall number of objects.**



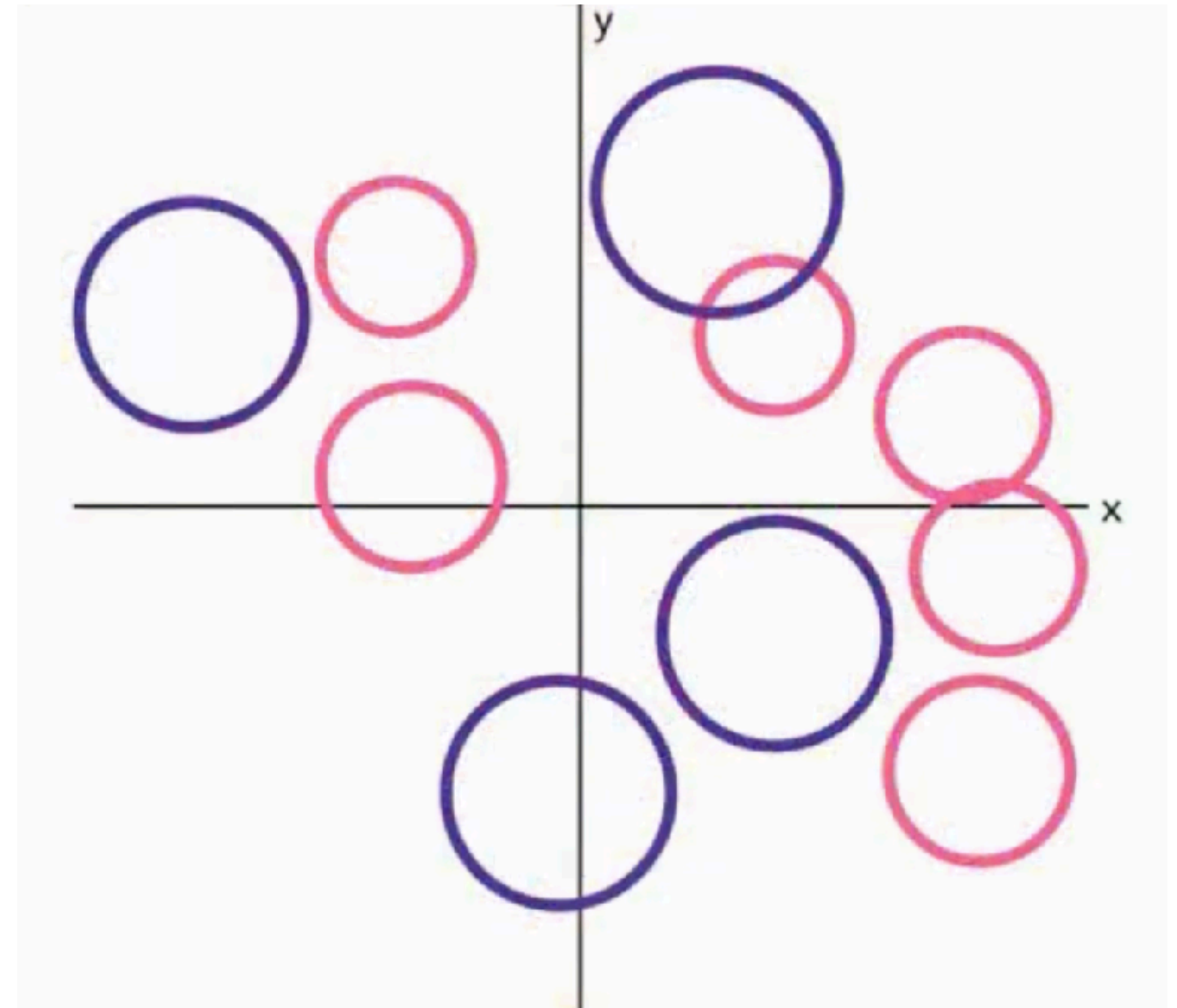


Humans are **hardwired** to quickly process visual information for **aggregate stats**, as visualizers we want to take advantage of this.

without even having to focus, your brain has turned on a powerful **parallel processing engine** to analyze the photo on the right.

you can quickly and **automatically** identify **clusters**, **relative sizes**, and the **overall number** of objects.

we want to **hijack the visual system**, which evolved to avoid predators and forage for food, to instead identify **abstract relationships in complex data**





The **language center** of our brain isn't as fast as the visual processing center and presents a **bottleneck** to data interpretation.

**Identifying a **pattern** in a **table of numbers** is difficult on its own, and requires the **language processing center** of the brain, which is slower than the **visual processing center**.**

75	50	64	24	23	47	48	80
64	82	61	26	49	64	81	33
34	31	78	41	56	83	42	33
63	37	59	76	82	55	30	63
55	48	49	81	79	56	66	61
48	21	79	34	45	84	57	50
21	83	54	23	28	20	79	24
80	37	50	64	54	31	38	76



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applying **conditional formatting** makes the **pattern** immediately **jump out**.

75	50	64	24	23	47	48	80
64	82	61	26	49	64	81	33
34	31	78	41	56	83	42	33
63	37	59	76	82	55	30	63
55	48	49	81	79	56	66	61
48	21	79	34	45	84	57	50
21	83	54	23	28	20	79	24
80	37	50	64	54	31	38	76



Fast visual processing happens at the intersection of preattentive processing and the Gestalt Principles.

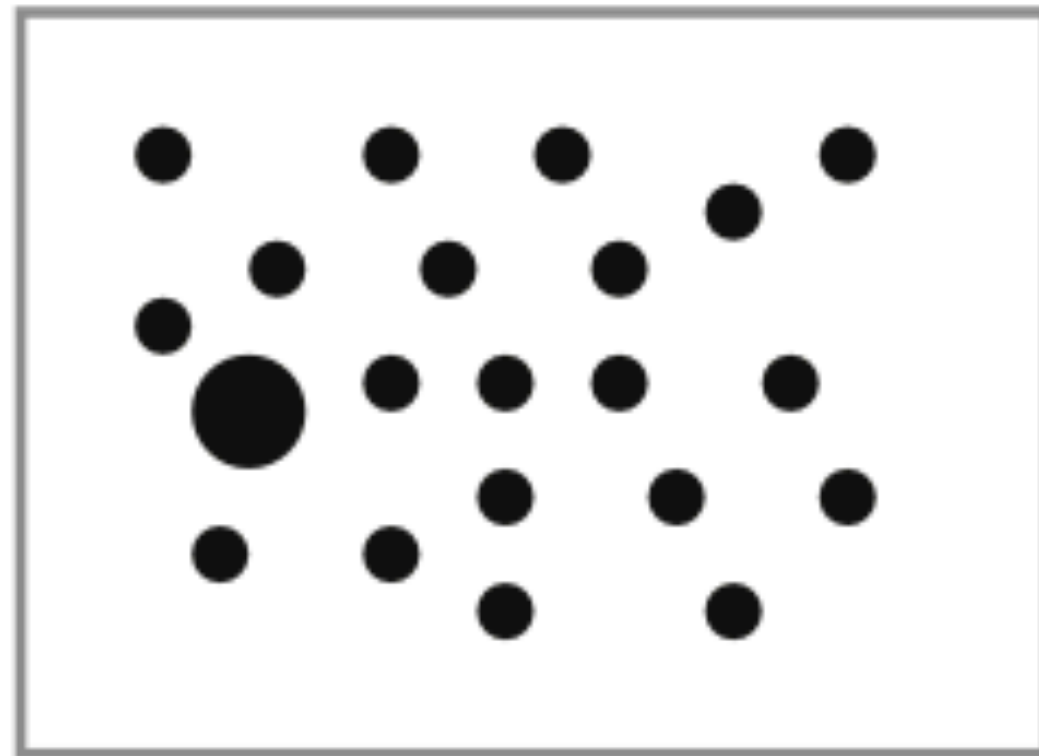
**Preattentive  
Processing**

**Gestalt  
Principles**

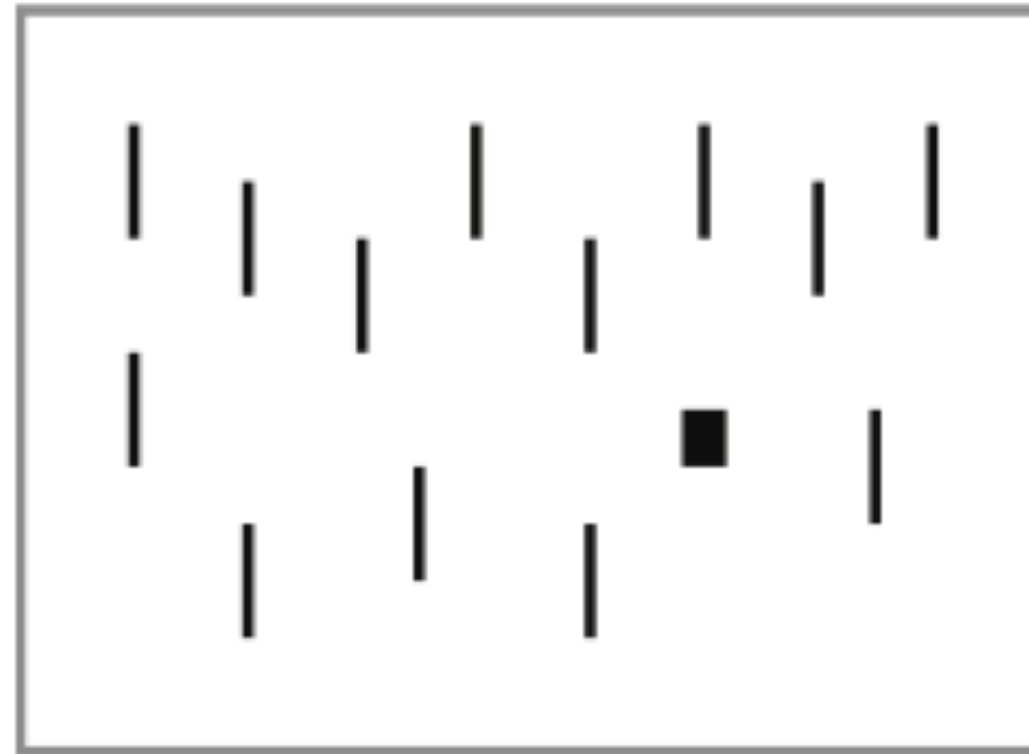


Preattentive processing is the **set of filters** we apply to our visual input **before** we pass it to our brain to **interpret**.

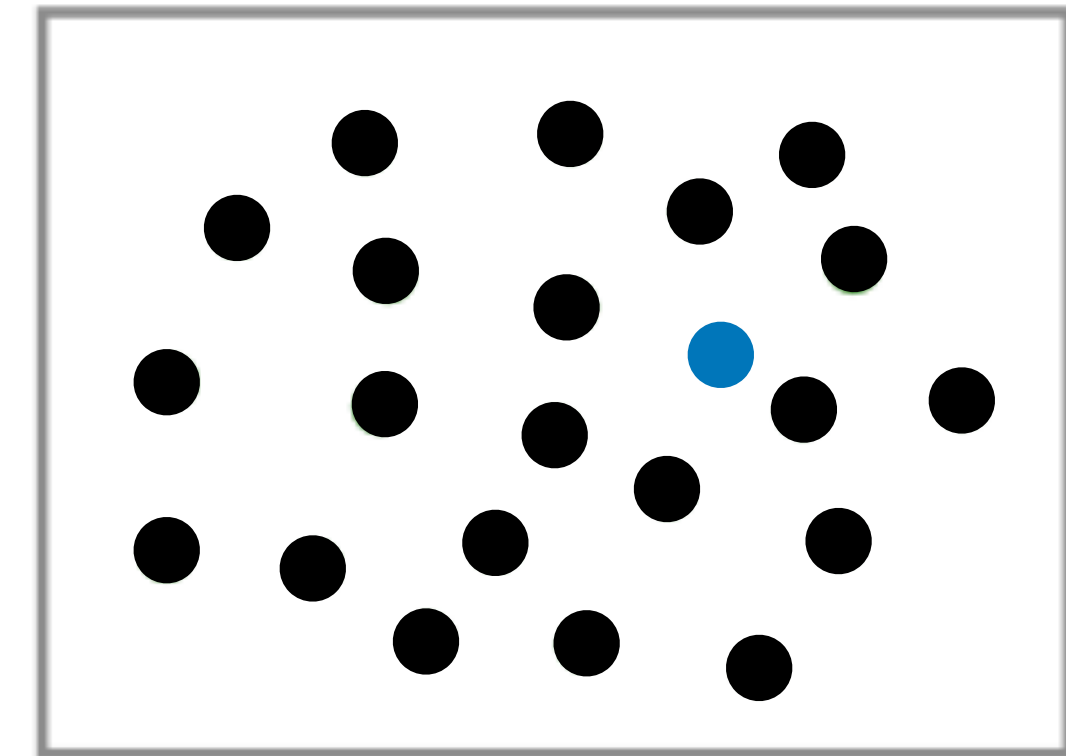
**Area**



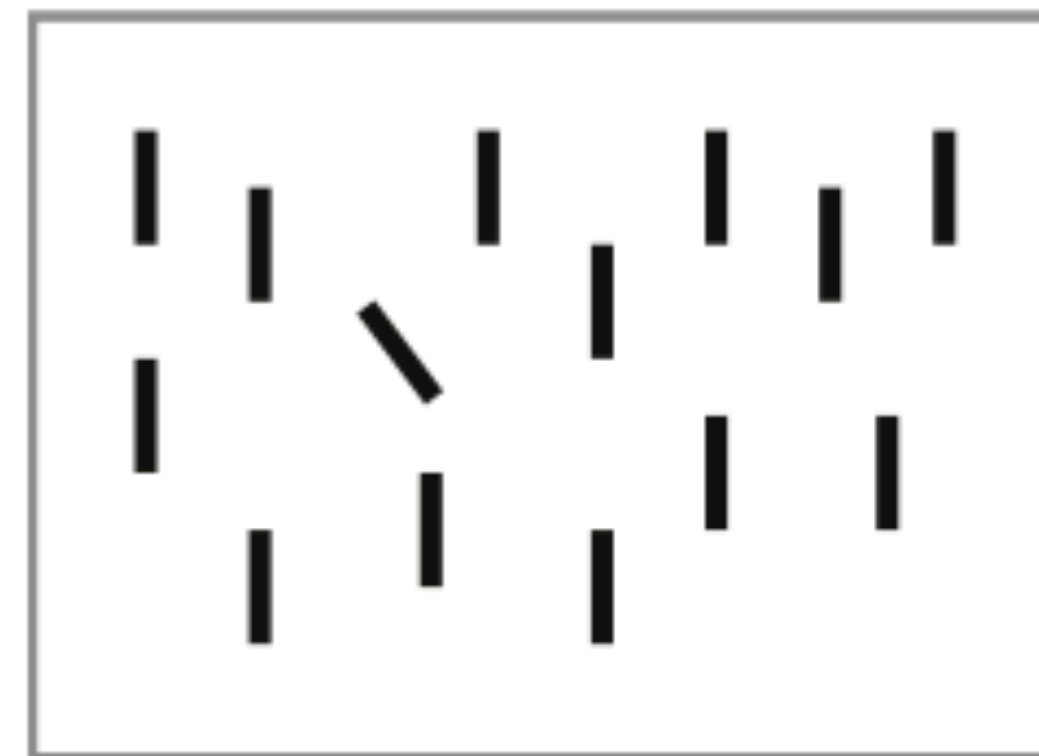
**Shape**



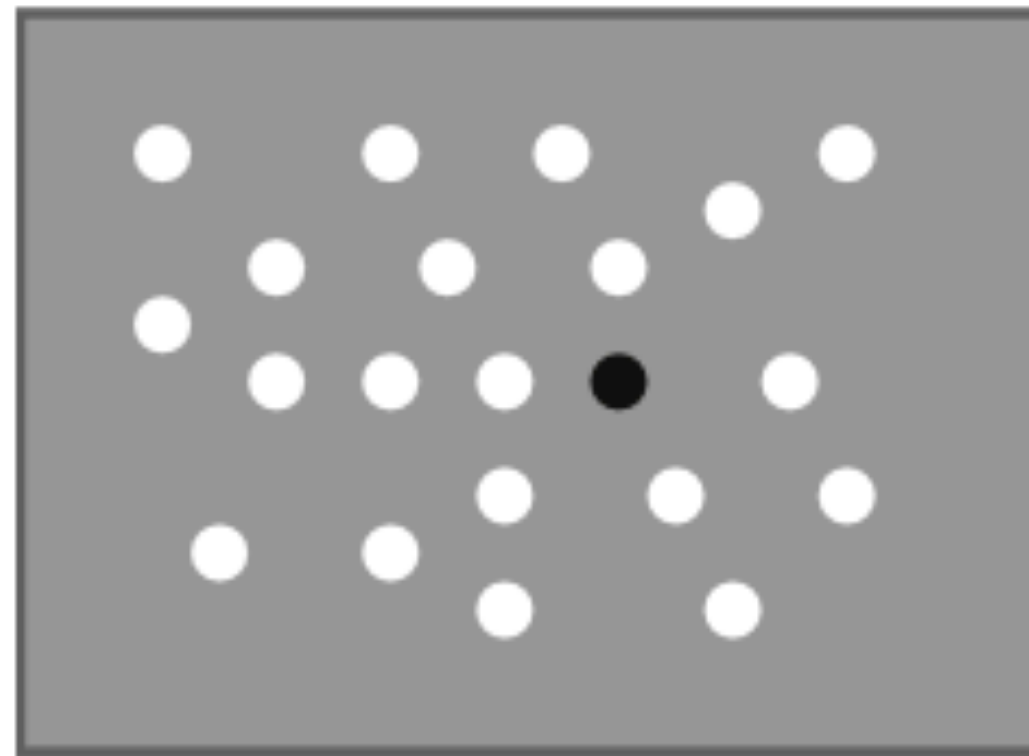
**Color**



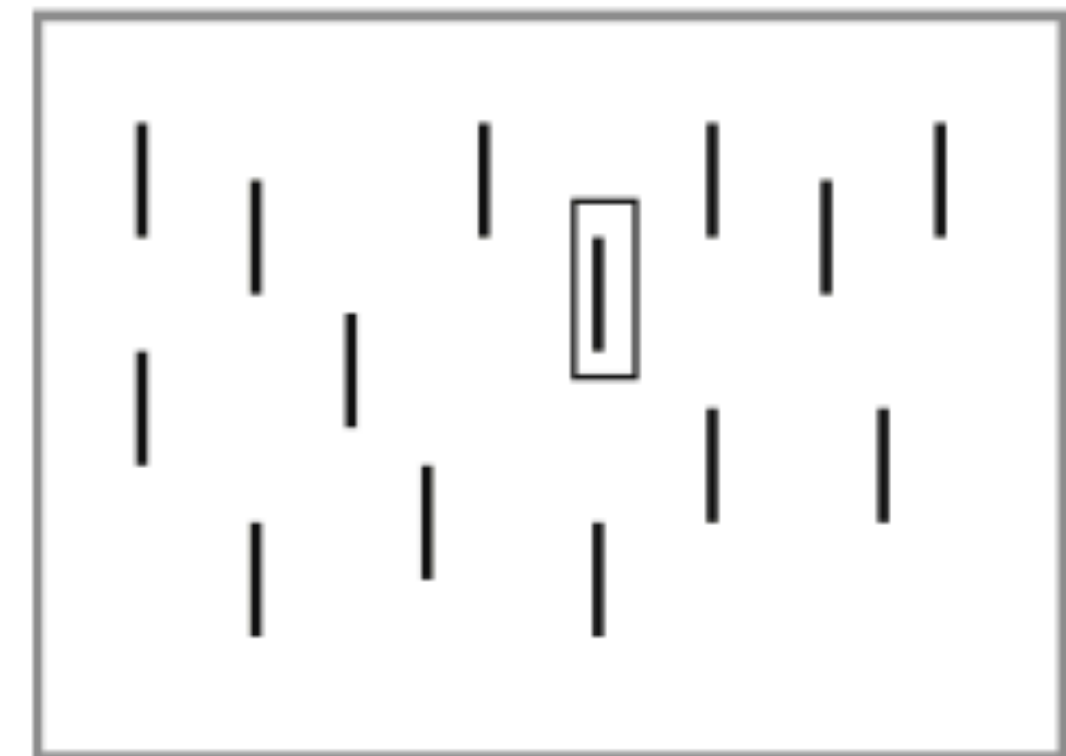
**Angle**



**Intensity**



**Addition**





The Gestalt Principles codify how we **reduce cognitive effort** by perceiving an **organized whole** rather than a **collection of parts**.

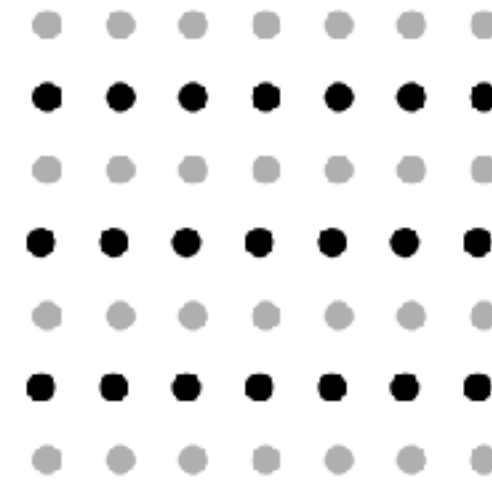
### Proximity

elements that are close together are perceived as part of the same group.



### Similarity

elements that look similar (in color, shape, size, etc.) are seen as related or belonging together.



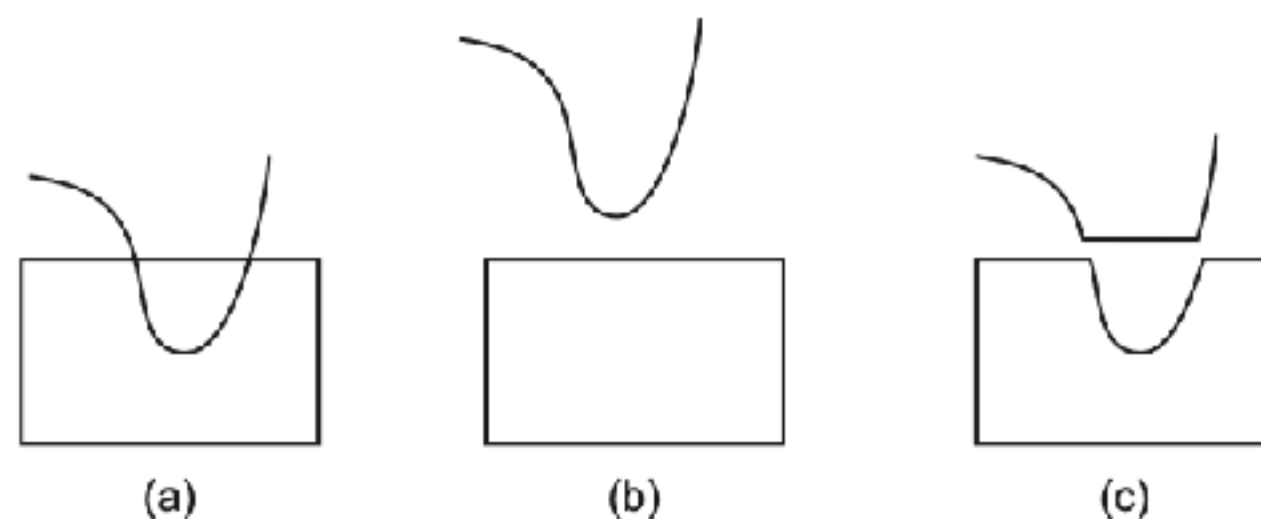
### Connectedness

elements that are literally connected overpower other implicit groupings



### Continuity

our eyes naturally follow lines and paths, so elements aligned in a direction tend to be grouped.



### Closure

our brains fill in missing parts to see a complete, enclosed shape, so elements that suggest a closed contour are grouped.



Effective data visualization is **focused, intentional,**  
and has **high signal-to-noise** for communicating concepts.

**“...induce the viewer to think about the **substance** rather than about the methodology, graphic design, the technology of graphic production, or **something else**”**

- Edward Tufte, *The Visual Display of Quantitative Information*

**“A visualization that is **designed to guide viewers** to make the **“right” visual comparisons** can lead those viewers to make [more] **meaningful insights** than they would make on their own.”**

- Franconeri+21







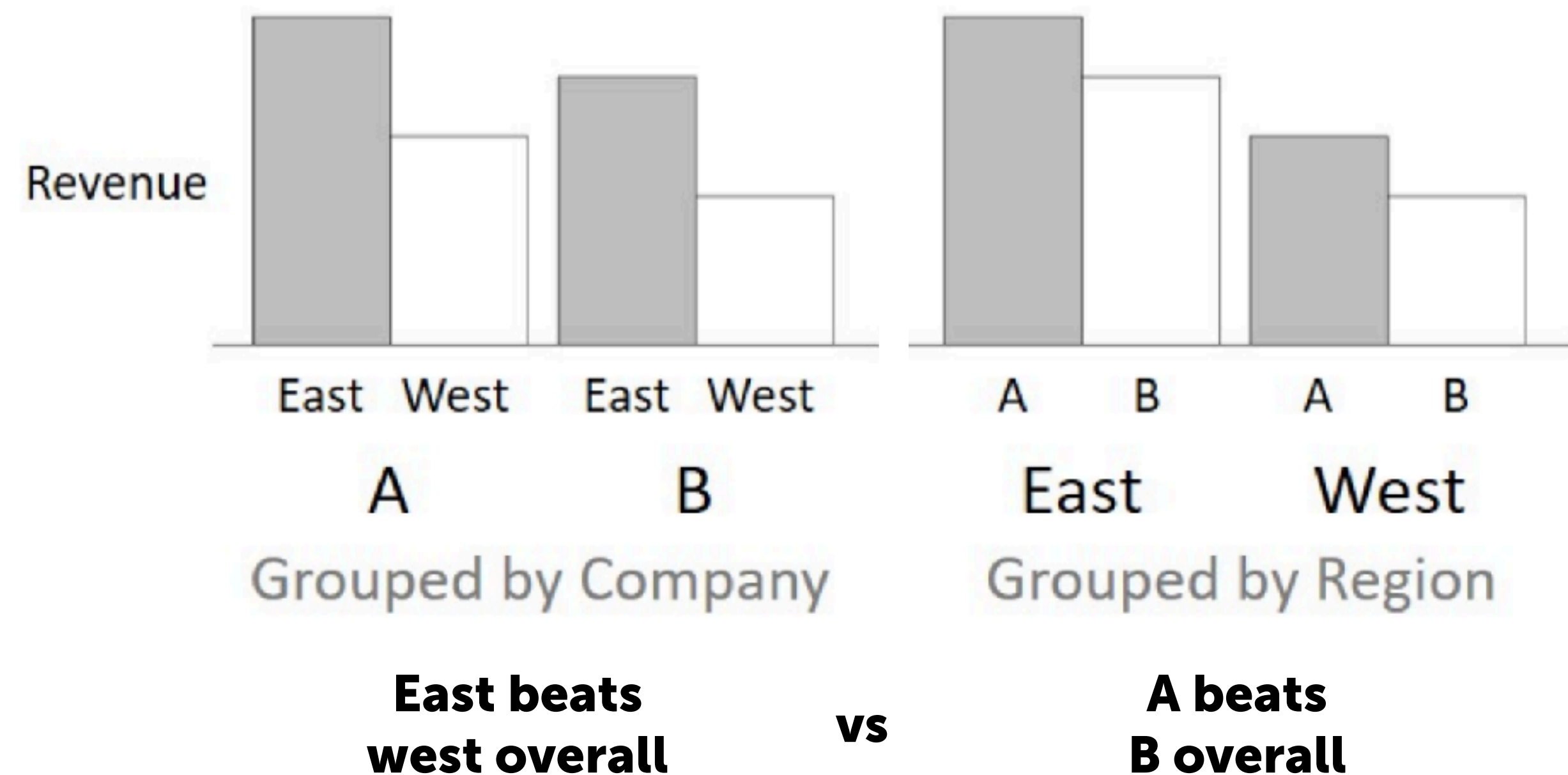




# Takeaway messages can be influenced by choice of visualization and grouping.

What Does the Chart Say? Grouping Cues Guide Viewer Comparisons and Conclusions in Bar Charts  
Cindy Xiong Bearfield, Chase Stokes, Andrew Lovett, and Steven Franconeri  
arxiv:2310.02076

## choice of comparison grouping

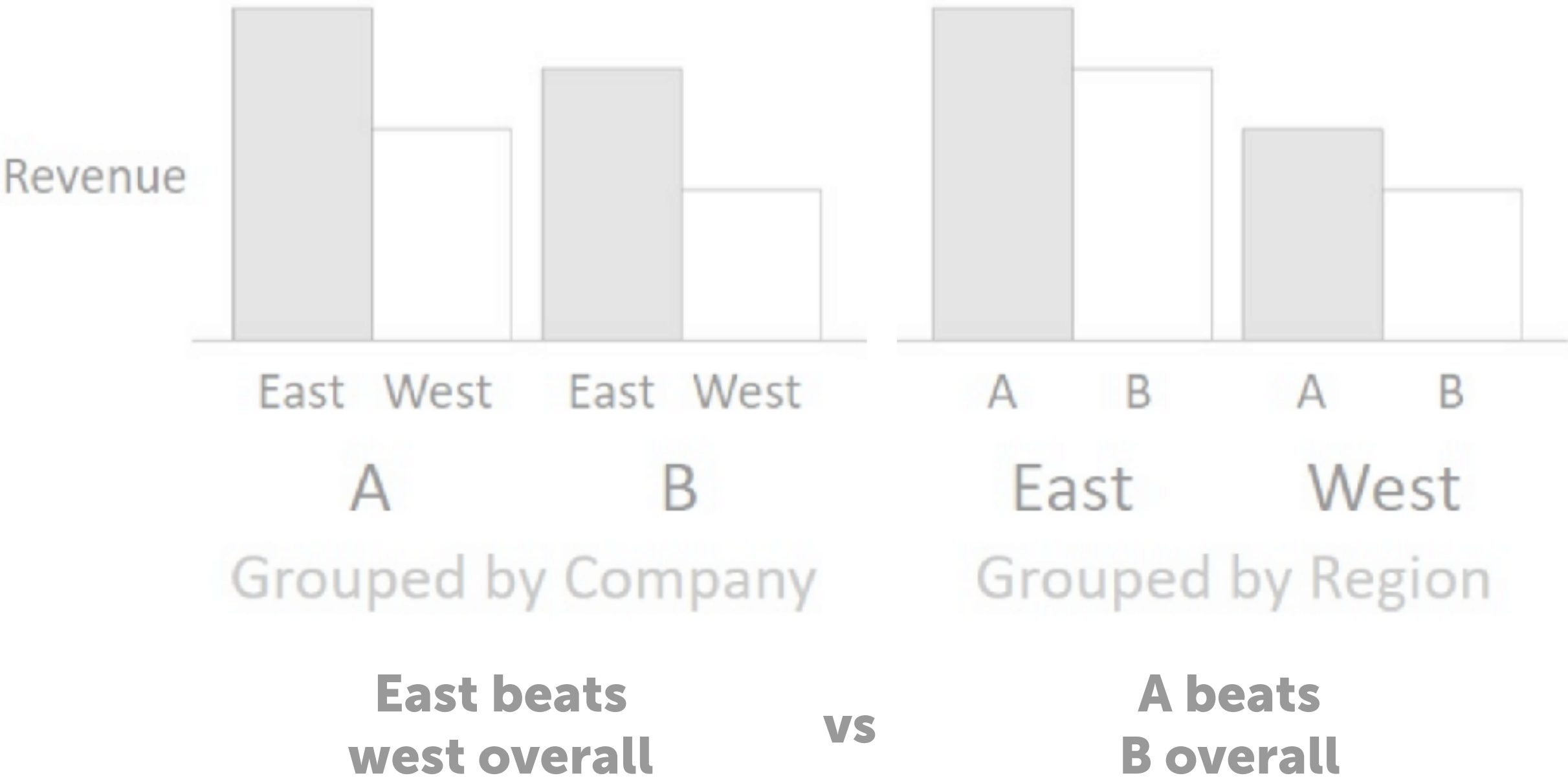


Bearfield+23, Fig. 3

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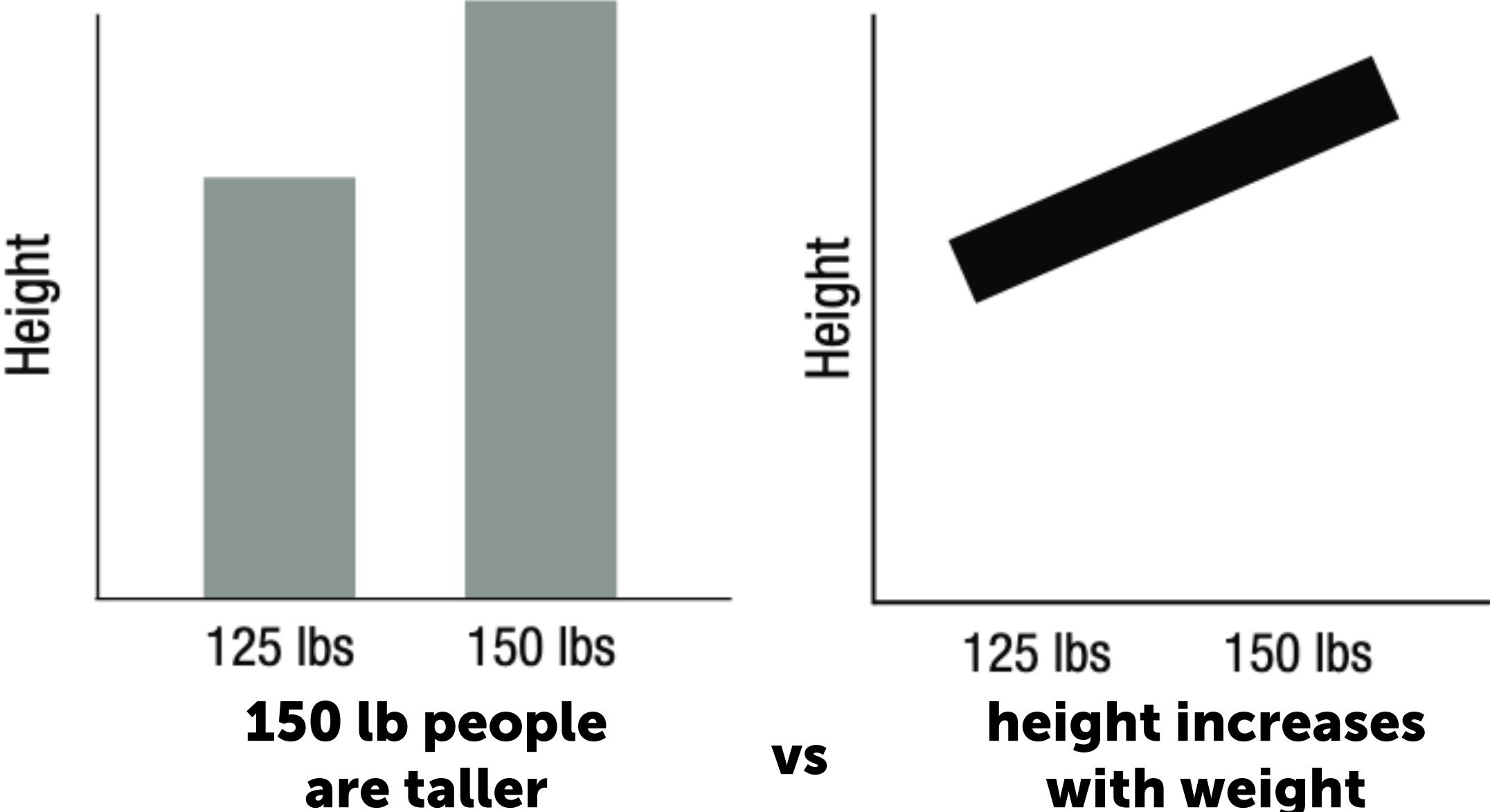
What Does the Chart Say? Grouping Cues Guide Viewer  
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## choice of comparison grouping



Bearfield+23, Fig. 3

## choice of visualization type



Franconeri+21, Fig. 18



The translation from **visual** to **verbal** is slow, semantic links from **data** to **meaning** activate the **language center** of the brain.

### Reading a Graph Is Like Reading a Paragraph

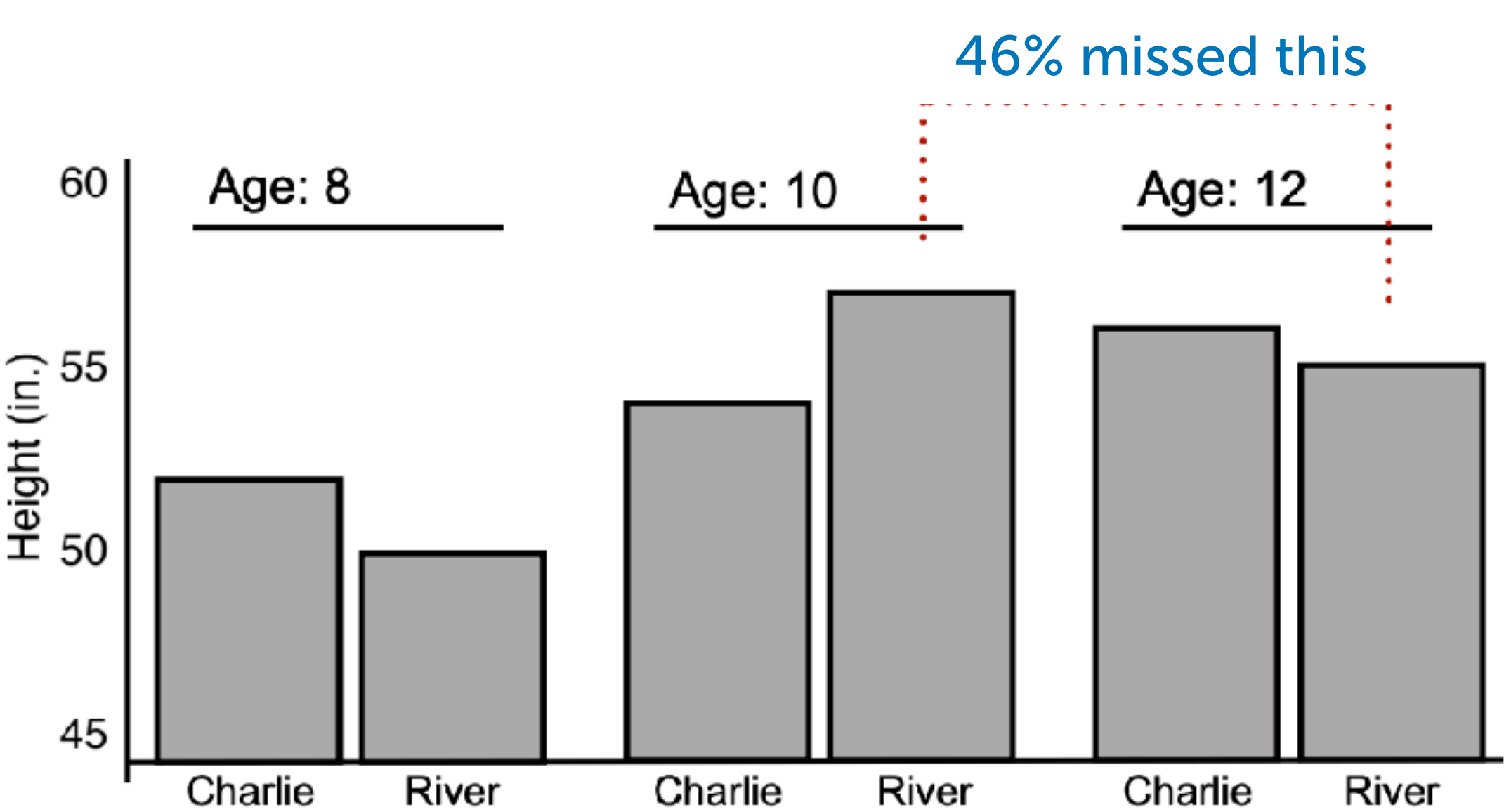
Tal Boger<sup>1</sup> and Steven Franconeri<sup>2</sup>

<sup>1</sup> Department of Psychological & Brain Sciences, Johns Hopkins University

<sup>2</sup> Department of Psychology, Northwestern University

[doi.org/10.1037%2Ffxge0001604](https://doi.org/10.1037/2Ffxge0001604)

### Hides improbable relationship



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### Reading a Graph Is Like Reading a Paragraph

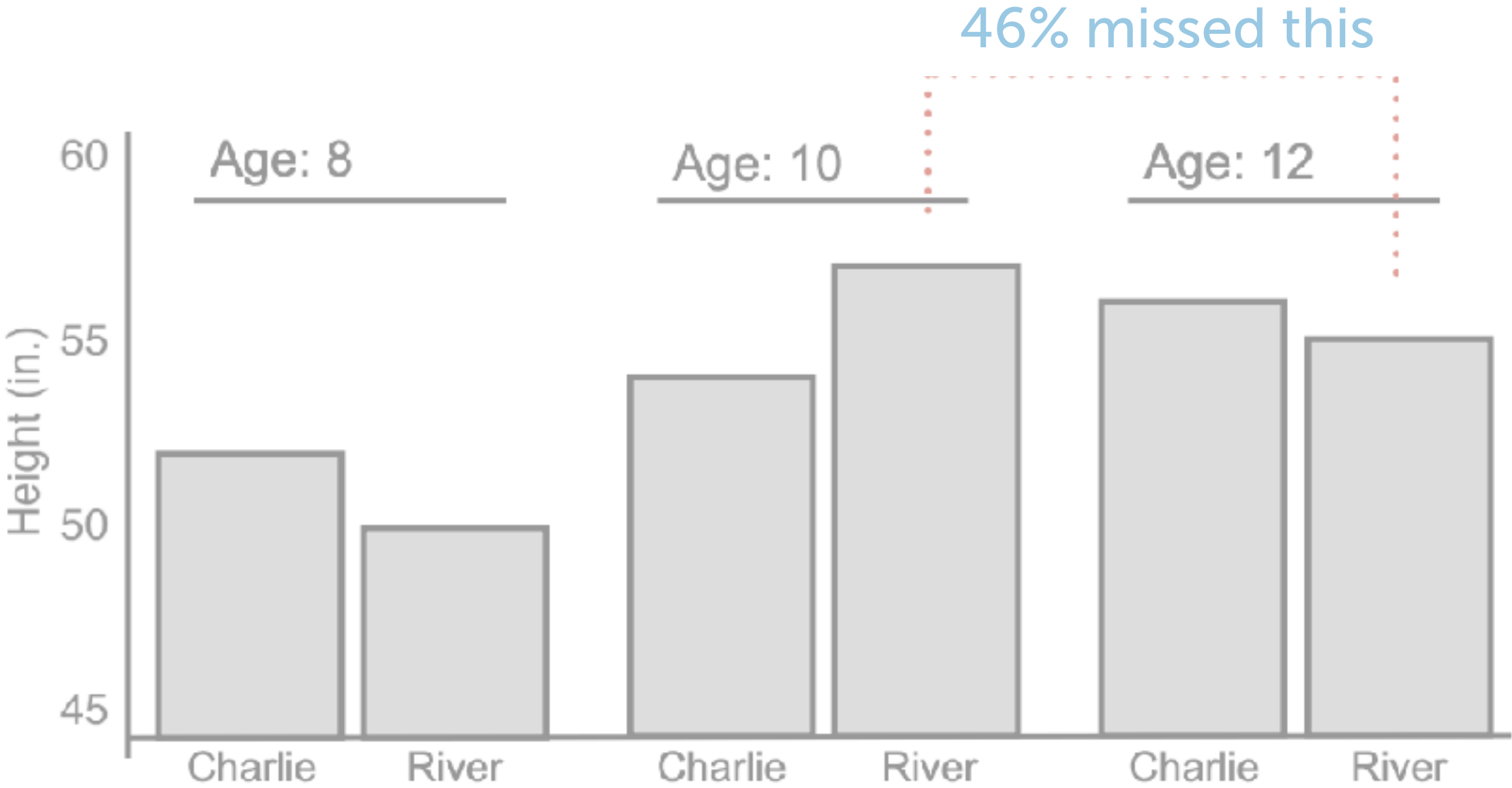
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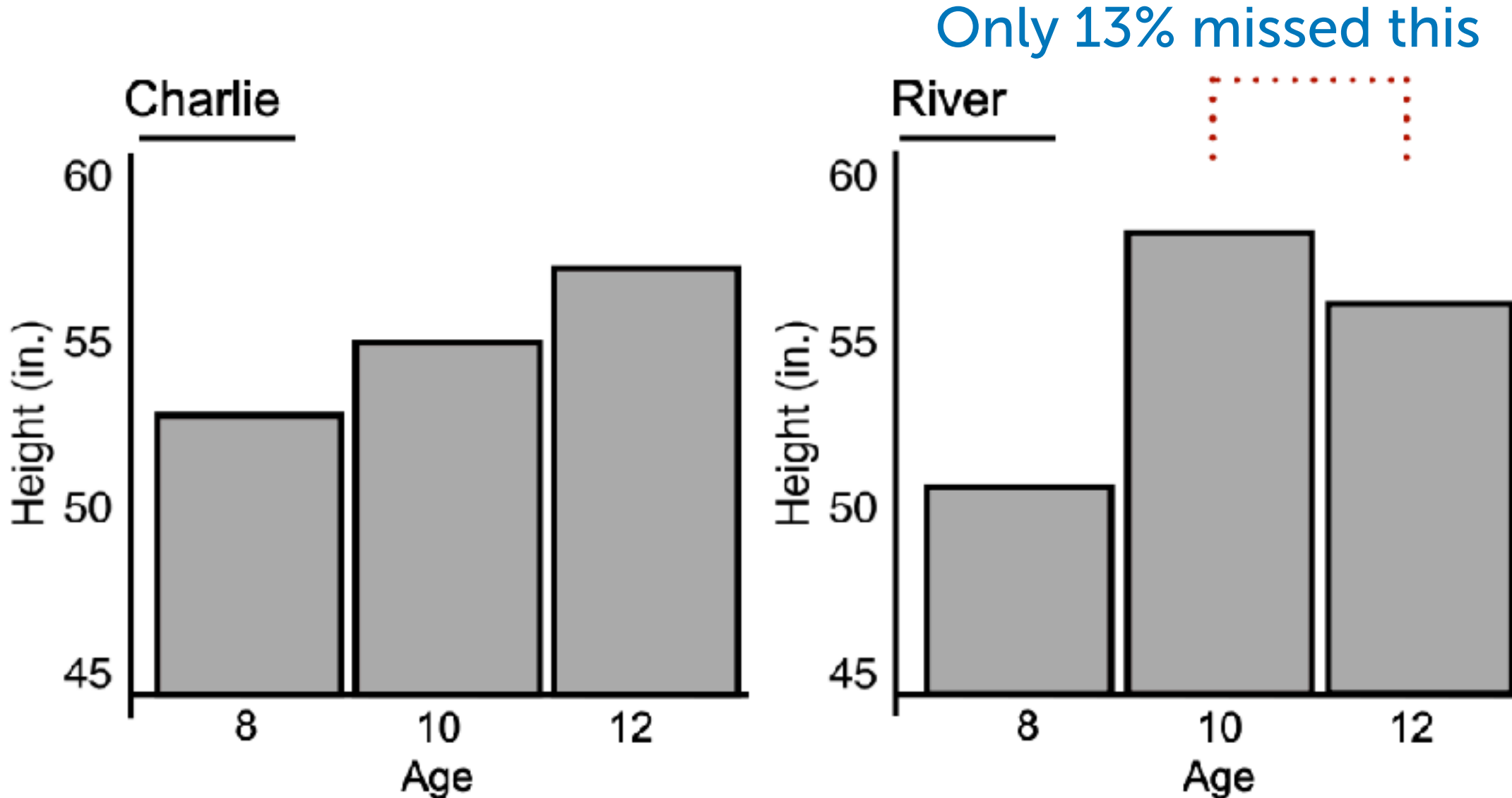
<sup>2</sup> Department of Psychology, Northwestern University

[doi.org/10.1037/2Fv0001604](https://doi.org/10.1037/2Fv0001604)

#### Hides improbable relationship



#### Highlights improbable relationship





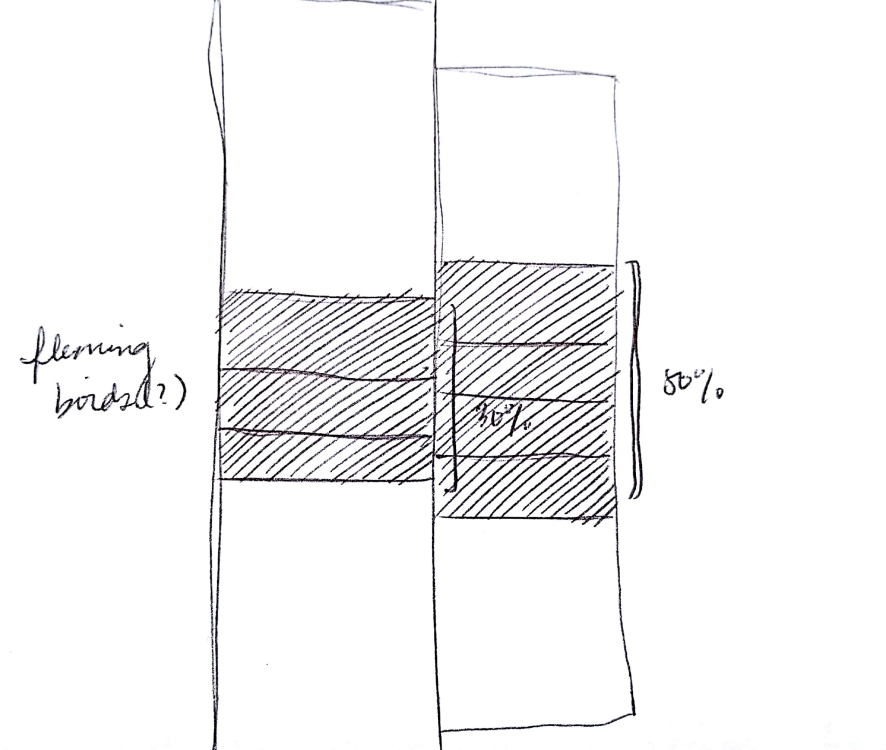
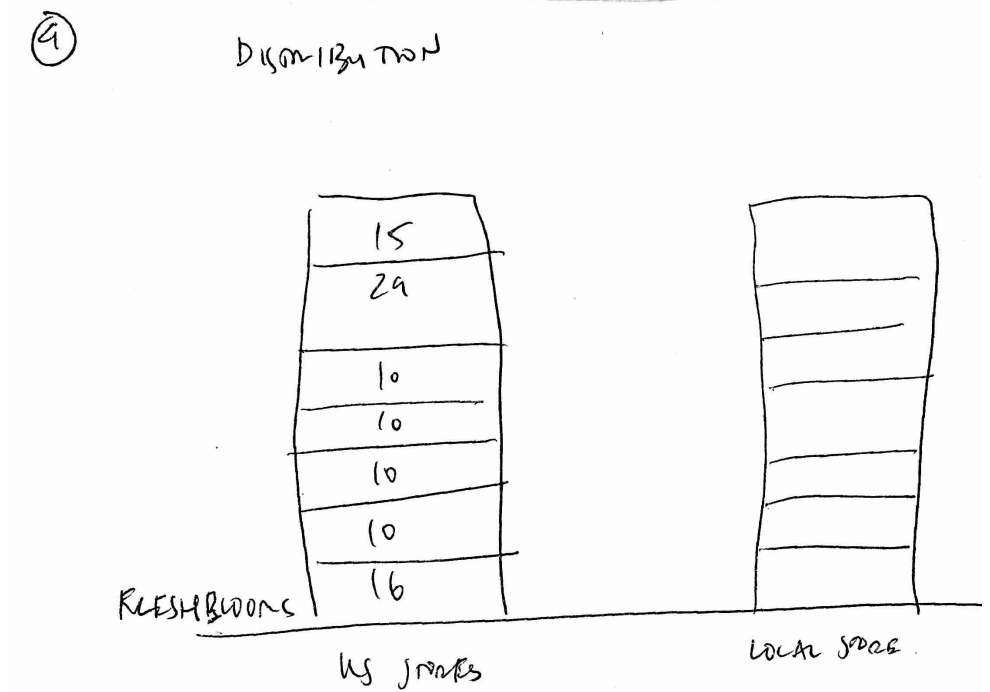
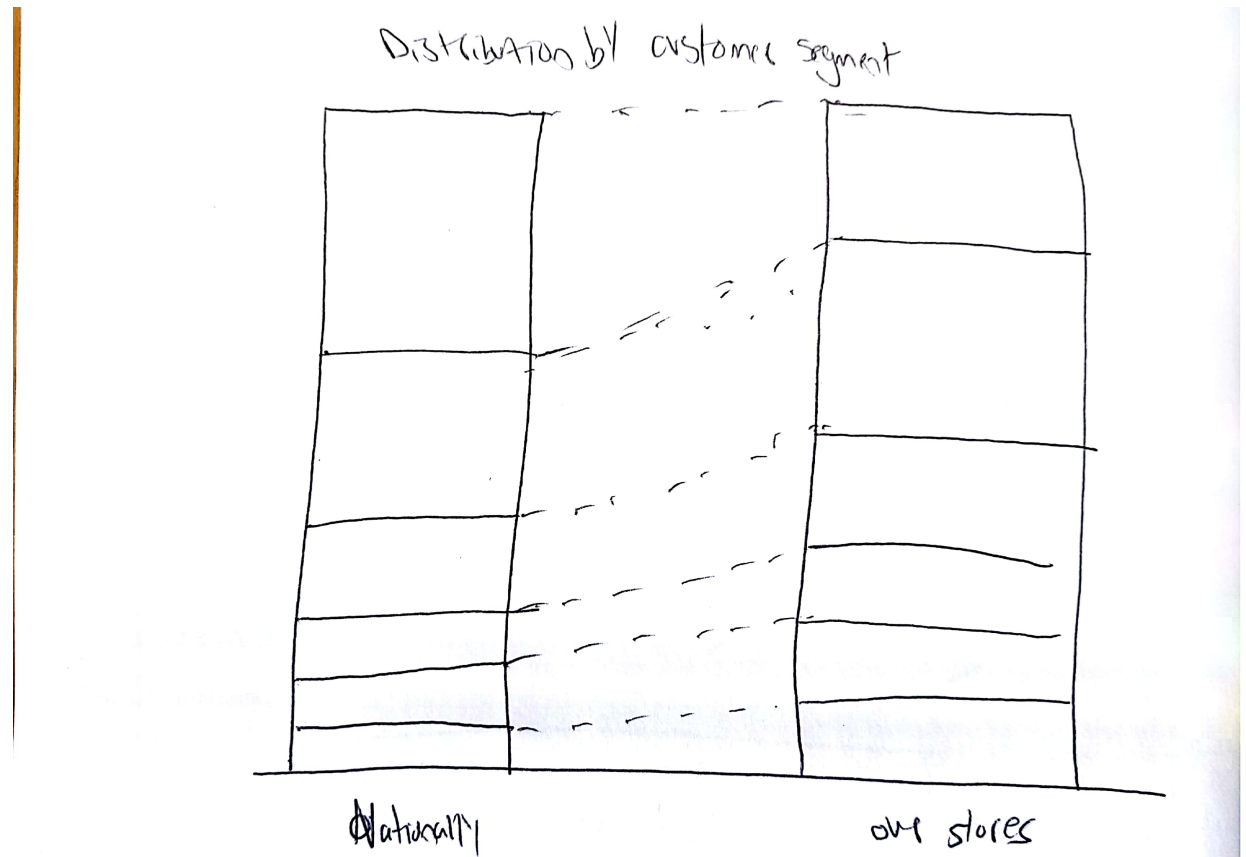
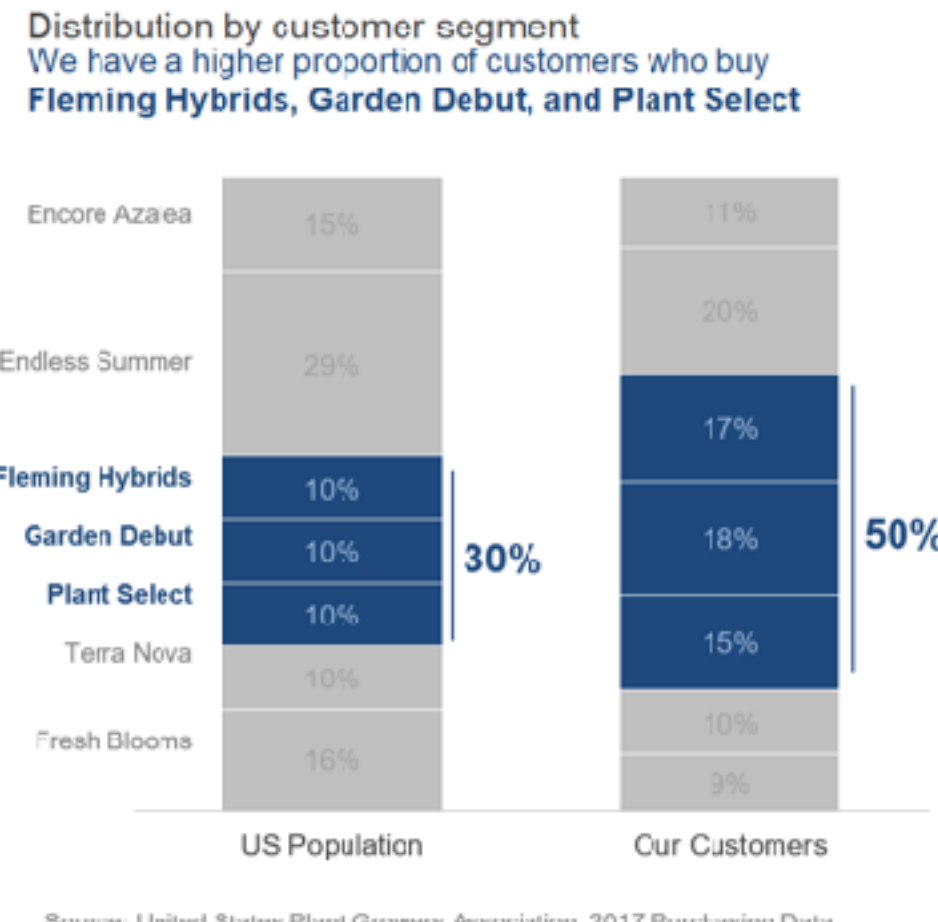
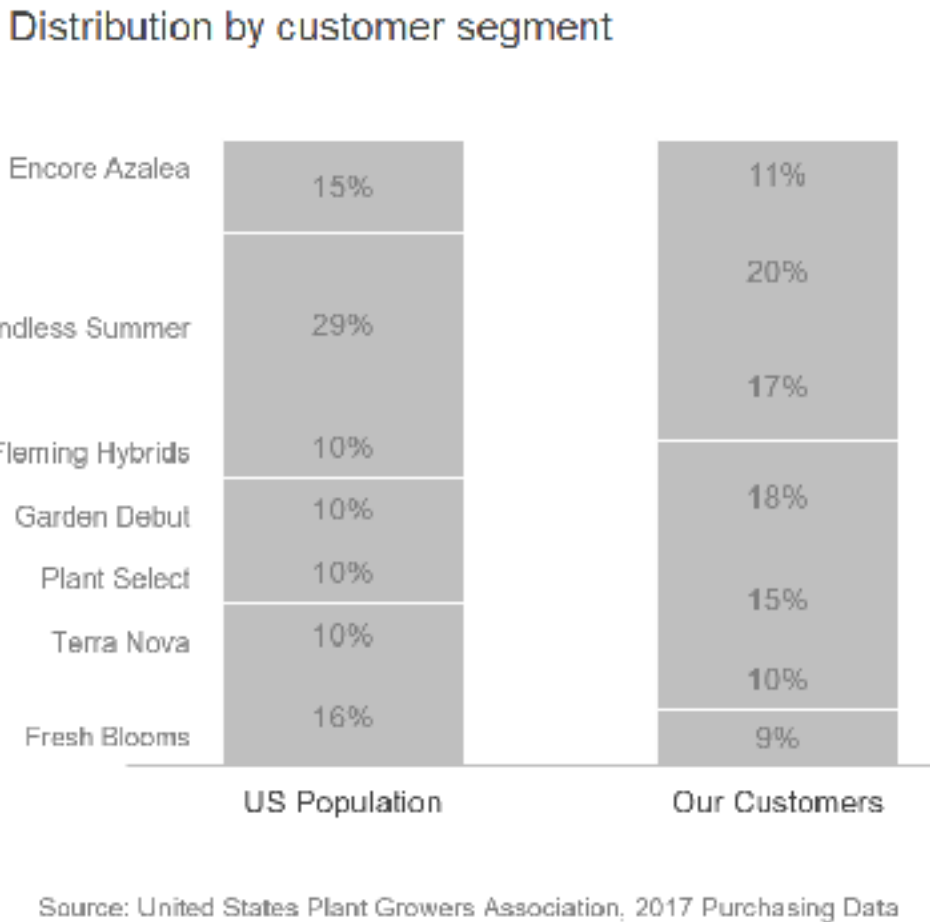
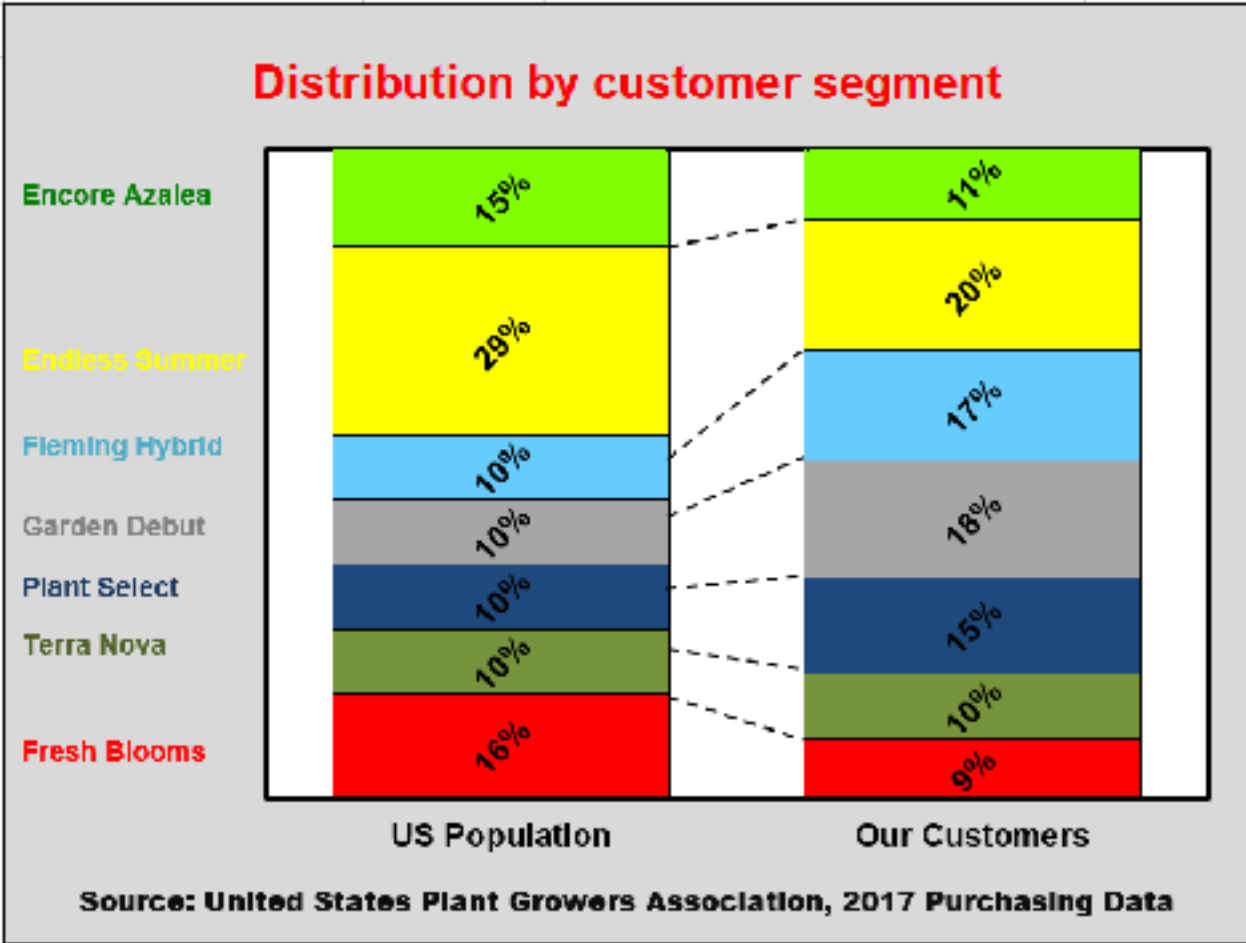
# Focusing with highlighted color, annotations, and a clear takeaway message leads to more effective comprehension and retention.

## Declutter and Focus: Empirically Evaluating Design Guidelines for Effective Data Communication

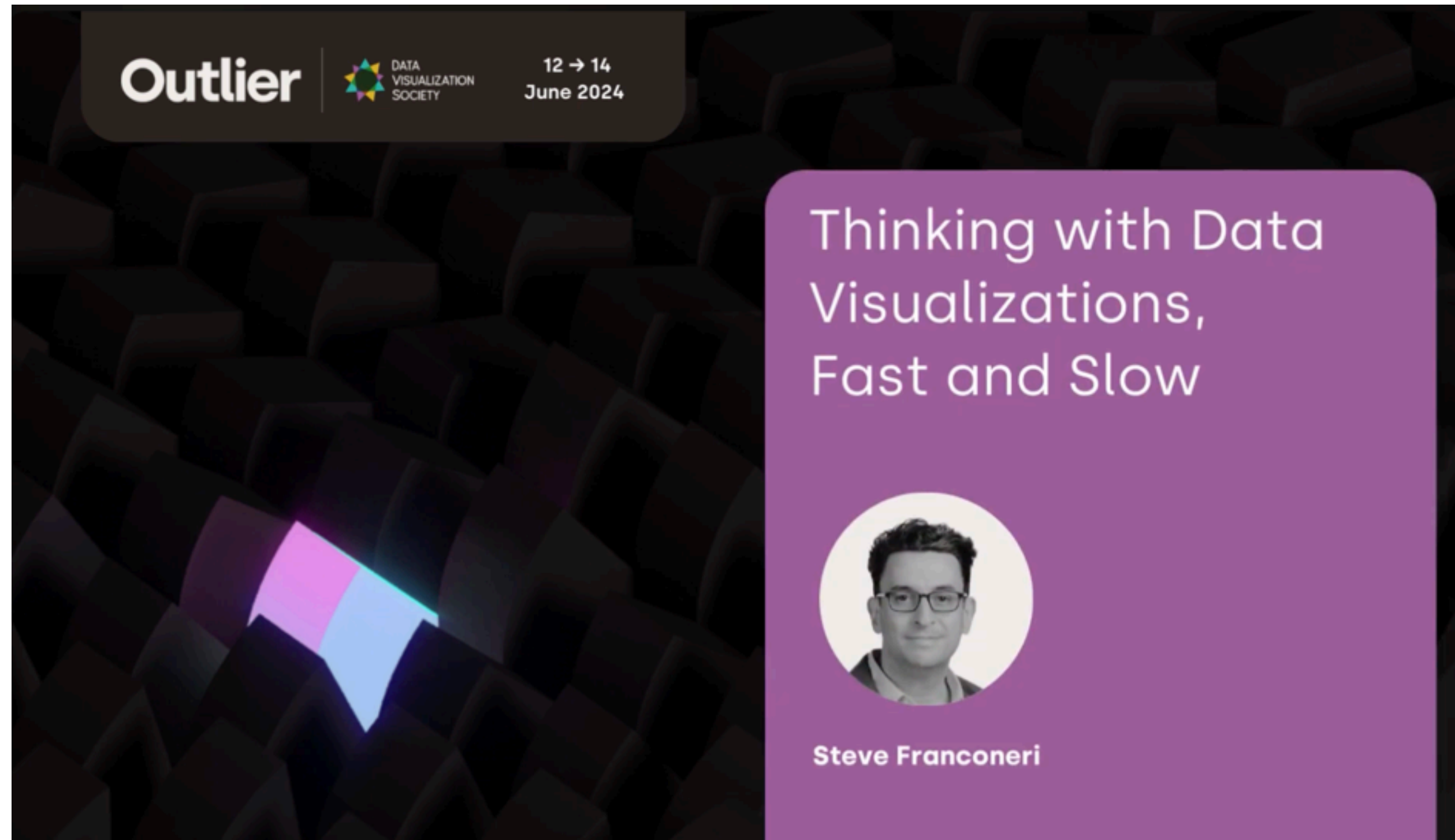
Kiran Ajani, Elsie Lee, Cindy Xiong, Cole Nussbaumer Knaflic, William Kemper, and Steven Franconeri, *Member, IEEE*

[doi.org/10.1109/TVCG.2021.3068337](https://doi.org/10.1109/TVCG.2021.3068337)

a clear headline plus color highlighting led to 3.5x more effective retention



If you enjoyed this talk and want to learn more, go watch [Steve's keynote from Outlier](#) or check out his [2021 review paper](#).



<https://youtu.be/OdHLpZQF-Zs>

aps  
ASSOCIATION FOR  
PSYCHOLOGICAL SCIENCE

## The Science of Visual Data Communication: What Works

Steven L. Franconeri<sup>1</sup>, Lace M. Padilla<sup>2</sup>, Priti Shah<sup>3</sup>,  
Jeffrey M. Zacks<sup>4</sup>, and Jessica Hullman<sup>5</sup>

<sup>1</sup>Department of Psychology, Northwestern University; <sup>2</sup>Department of Cognitive and Information Sciences, University of California, Merced; <sup>3</sup>Department of Psychology, University of Michigan; <sup>4</sup>Department of Psychological & Brain Sciences, Washington University in St. Louis; and <sup>5</sup>Department of Computer Science, Northwestern University

Psychological Science in the  
Public Interest  
2021, Vol. 22(3) 110–161  
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DOI: 10.1177/15291006211051956  
www.psychologicalscience.org/PSP  
SAGE

**“Extracting global statistics is fast, but comparing between subsets of values is slow. Effective graphics avoid taxing working memory, guide attention, and respect familiar conventions.”**

[doi.org/10.1177/15291006211051956](https://doi.org/10.1177/15291006211051956)



You can find [an extended version of these slides](#) (with extra resources) and more at [alexbgurvi.ch](http://alexbgurvi.ch)

Steve's Talk



Steve's Paper



Me



alexbgurvich



alex-b-gurvich



[www.alexbgurvi.ch](http://www.alexbgurvi.ch)

## DO

use **labels** directly on the visualization

add **annotations** to features of the visualization

put a **descriptive title** with takeaway

use **color** to **highlight** points

use **recognizable chart** types unless absolutely necessary or if communicating with experts

## DON'T

use **complicated legends** that require the viewer to **look back and forth**

put lots of **"chartjunk"** on the plot like extraneous axes lines

require viewers to **compare things** that are **far away**

require viewers make **series of comparisons** that use **different perceptual filters**

Other **tools** and **resources** that you may find useful

## Color Palette Generators

<https://colorbrewer2.org/>

<https://python-graph-gallery.com/color-palette-finder/>

<https://vis4.net/labs/multihue/>

<https://colororacle.org/>

## Books

**Cole Nussbaumer Knaflic**

Storytelling with data: A data visualization guide for business professionals

**Alberto Cairo**

The truthful art: Data, charts, and maps for communication.

&

The Art of Insight

**John Schwabish**

Better data visualizations: A guide for scholars, researchers, and wonks.

**Kat Greenbrook**

Data Storytellers Handbook

**Alli Torban**

Chart Spark

**Amanda Makulec**

Big Book of Dashboards (TBD)

**Stephen Few**

Data Storytellers Handbook



# Which Visualization? A Quick Reference

You have the following data (sample):

Discrete Categories,  
Ordered categories,  
and Continuous Metrics

Categories		Ordered Cats		Continuous Metrics			
City	Airline	Class	PriceBracket	Month	Distance	FlightTime	Price
Alphaville	XeroTrip	Coach	\$	1	300	120	250
Betastan	YoloFly	Business	\$\$	2	500	185	1,525
Chicago	ZeusAir	First	\$\$\$	3	650	240	4,023
...	...	...	...	...	...	...	...

Here's how to plot them

Discrete Categories
Ordered Categories
Continuous Metrics

Metric, binned by 1 category

**Bar (Row)**

Rows allow readable labels, while columns awkwardly limit text

**Lollipop**

More focus on the positions of tops. Fun factor +1

**Dot Plot**

A non-zero y-axis base may be less misleading here

**Bar (Column)**

Histogram. Bars help convey the underlying bins

**Bar (Column)**

Time moves horizontally. So use Column, not Row

**Area**

Adds continuity to x-axis.

**Line**

A non-zero y-axis base may be less misleading here

... by 2 categories

**Bar Table X,Y,Z,...**

Compare X to Y to Z. "Small multiples". Please use this more

**Bar Table X,Y, Delta**

Comparisons are slow. Plot critical Deltas explicitly

**Mirror Bar**

Compare X to Y. leverage's human symmetry perception

**2D Heat**

2D Histogram. Similar in spirit to a bar table, but ordered cats + color encoding

**Bar Table**

Compare a metric across an ordered category

**Bar Line Table**

Now one is continuous-er

**Line Table**

Trends visible, but use Lines (below) to compare heights

**Benchmark Bar**

Compare X to a benchmark

**Benchmarks Bar**

Compare X to Y. Fancyer version called a "Bullet graph"

**Interleaved Bar**

Compare X to Y (not recommended)

**Slopegraph**

With two values, slope encodes delta

**Dual Axis**

Use (above) instead. Crossings here are soiled, but meaningless

**Lines**

Compare many. Getting spaghetti? Split into subset or Line-Table (above)

Part-to-Whole, binned by 1 category

**Pie**

Screams "Percentages"

**Stacked Bar (Row)**

More precise and less, but less screaming

**Stacked Bar (Col)**

Now I'm standing

**Waterfall**

Waterfalls are vertical stacked bars that narrate financial values in a (typically) artificially imposed ordering across fantasy-time

**Waterfall**

These lines are identical, with equal Y separation at each X slice, but it doesn't look that way!

**Waterfall**

Beware of an illusion for these: seeing differences (lines), or category values (stacked area) can be difficult and even misleading

... by 2 categories

**MultiPie**

Please don't... (not recommended)

**Stacked Bars (R)**

Stacked bars but now with with X, Y, Z info. Here XYZ might be absolute values of a market. ABC are company % market shares

**[Mar]Mekko**

Horizontal flow implies an ordering

**Stacked Bars (C)**

Horizontal flow implies an ordering

**... with lines**

Added lines suggest continuity, help depict changes

**Stacked area**

Now it's delightfully continuous

... by hierarchies

**Breakout Bar**

Let's zoom in here. Use different colors. Global at top or left.

**Treemap**

Hierarchy. ~3 levels max of better boxes going all inception within other boxes. Size+Color better code different metrics. Typically misused. 95% sure you actually wanted a Bar Table (above)

**Scatter Price**

An elegant graph, from a calibrated eye

**Connected Scatter Price**

A scaffold, connected into a journey over time

**Parallel Coordinates**

Beyond 2 perpendicular Cartesian axes, Parallel format allows more axes

**Map**

Maps and Roslings share the same DNA. Color = Flight Time. Size = Price

**Hans Rosling Scatter Distance**

Watch Rosling's TED talk. Take XY scatter and adds two more metrics (color and size), and then moves in time

**Rosling Comet Distance**

Show two or more X+Y history values for comparison over time

**Look at this number. Just look at it.**

Dot Array

Dot Array %

**43%**

Huge Number

Icon Array (SOOOO)

Icon Array %

Connecting Lines imply continuous data

Some data, ask people. "What do you see?"

USA Dumb

"Such people as to be than Americans"

USA Dumb

"Thoughtful folks as they get more Dumb"

Zacks & Tereky, 1997

**Metrics: relationships to other metrics**

Steve Franconeri

