

Visualization and accessibility: The state of the art, 2025



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Visualization and accessibility: The state of the art, 2025



I'm on the job market!

Frank Elavsky, PhD Candidate



Human-
Computer
Interaction
Institute



hcii.cmu.edu, axle-lab.com, dig.cmu.edu

2024: SotA in tech + innovation

2025: SotA in *techniques, too!*

2025: SotA in *techniques*, too!



(Many of these are based on my professional experience!)

Identifying access barriers

Chartability to evaluate accessibility



F. Elavsky, C. Bennett, and D. Moritz, "How accessible is my visualization? Evaluating visualization accessibility with *Chartability*," Computer Graphics Forum, 2022.

Bokeh’s ~200 page open source, open access, accessibility audit

Elavsky et al “Bokeh accessibility audit,” 2025.

Bokeh Accessibility Audit

Plot toolsPlotting interfaceAnnotations

Q Search

⌕+K

🔊

Bokeh Accessibility Audit Summary

[Date of latest draft: February 2025]

Introduction

Previously, no large-scale audits or evaluations of the accessibility of a data visualization library have been made publicly available.

Thanks to [CZI Essential Open Source Software \(EOSS\)](#) Cycle 6 grant “Accessible interactive data visualizations in Python with Bokeh,” we have have conducted a thorough, ecosystem-wide audit of the accessibility capabilities of the Python data visualization library, [Bokeh](#).

We present our audit’s [Findings](#) and [Suggestions](#) in this summary document. There are a total of 76 documents that contain evidence of different accessibility barriers in Bokeh’s ecosystem.

Findings: To make sense of this volume of information, the first section of this summary ([Findings](#)) focuses on providing an overview of problems and themes present in all of the evidence we gathered from Bokeh’s [plotting interface](#) (+30 tests with evidence of failure), [plot tools](#) (+20), and [annotations](#) (+26) artifacts.

Themes: The subsections of [Findings](#) below each represent higher level themes that emerged across the evidence we have gathered. Each theme’s subsection contains an explanation of that theme, evidence of that theme (with links), and an example demonstration of what an accessibility barrier related to that theme looks like.

Evidence citations: Each of the evidence documents are cited using a prefix, A-, PI-, or PT- referring each to the abbreviations for “Annotations,” “Plotting Interface,” and “Plot Tools.” We conducted full, systematic audits for each of these subsystems within Bokeh’s ecosystem, as they are each responsible for different aspects of Bokeh’s capabilities. A given evidence document then also has a suffix, which is the number corresponding to the listed number of failures within that subsystem. So in our audit of Bokeh’s annotations subsystem, evidence “[A-2](#)” would correspond to the second test type that contained an error.

Evidence documents: Each citation to evidence links to a document of that evidence. Each evidence document contains

☰ On this page

Introduction

Methodolody

Credits

Overview of findings: problems and themes

1. Finding: Lacks *foundational* accessibility

2. Finding: Perceivability and understandability have barriers

3. Finding: System is fragile

Suggested directions for remediation

Focus on text experiences: explanations, descriptions, and labels

Use better building materials

Build a flexible system

Help developers succeed

[Edit on GitHub](#)

Dev Support

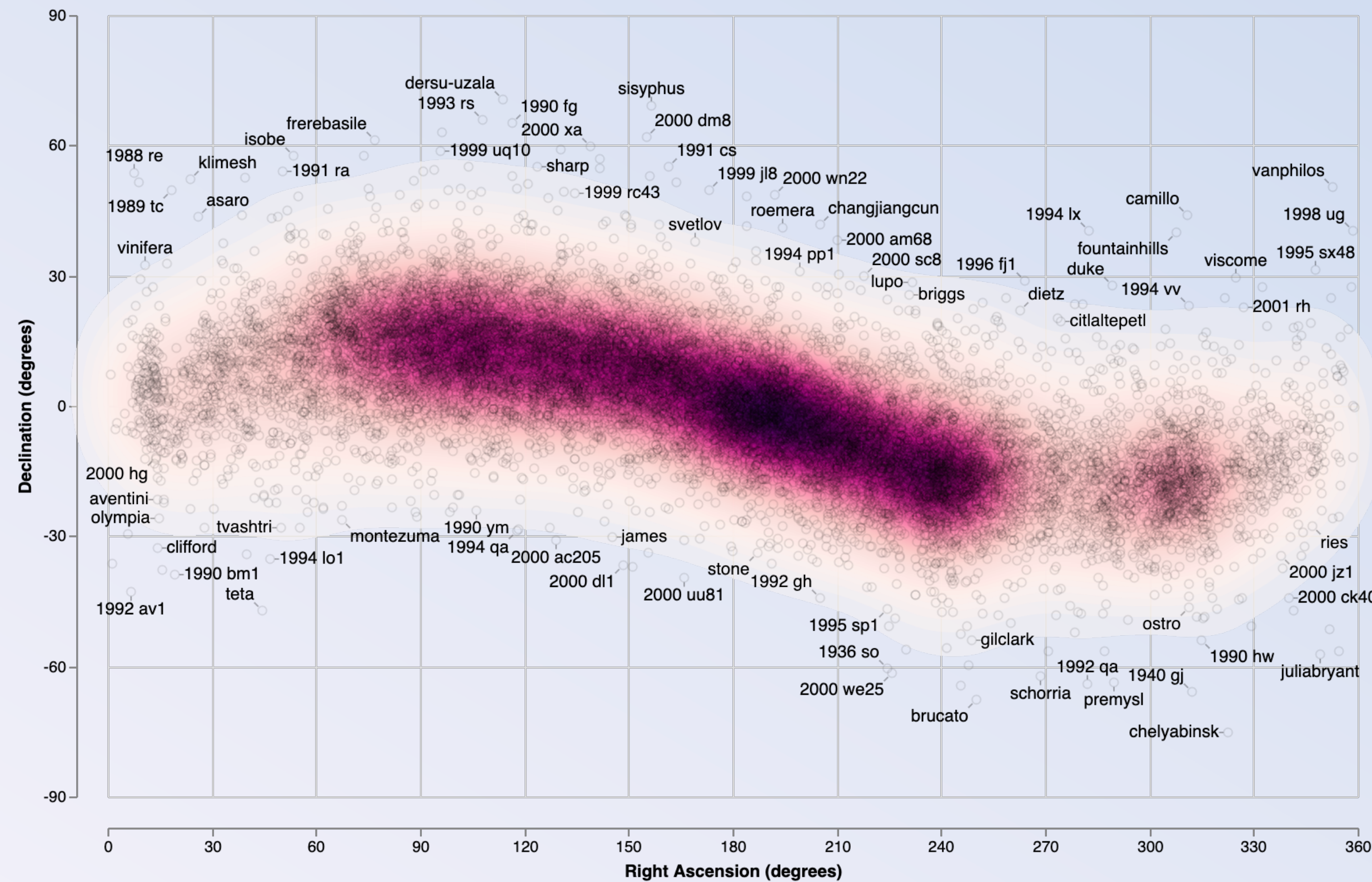
Automatic accessibility validation

Source: Visa Chart Components, Frank Elavsky (2017-2019)

▸	bar-chart-1 has strong accessibility recommendations	bar-chart.entry.js:49478
▼	bar-chart-2 has accessibility warnings and other messages	bar-chart.entry.js:49497
⚠	▸ longDescription: Either accessibility.longDescription or accessibility.contextExplanation is required	bar-chart.entry.js:49499
⚠	▸ executiveSummary: Either accessibility.purpose or accessibility.executiveSummary is required	bar-chart.entry.js:49499
⚠	▸ elementsAreInterface: elementsAreInterface must be a `boolean` type, but the final value was: `null`. If "null" is intended as an empty value be sure to mark the schema as `.nullable()`	bar-chart.entry.js:49499
	longDescription: Either accessibility.longDescription or accessibility.contextExplanation should have minimum 40 characters and a combined length between 40 and 500 characters	bar-chart.entry.js:49481
	executiveSummary: Either accessibility.purpose or accessibility.executiveSummary should have minimum 40 characters and a combined length between 40 and 250 characters	bar-chart.entry.js:49481
	statisticalNotes: accessibility.statisticalNotes should have length between 40 and 250 characters	bar-chart.entry.js:49481
	structureNotes: accessibility.structureNotes should have length between 40 and 250 characters	bar-chart.entry.js:49481

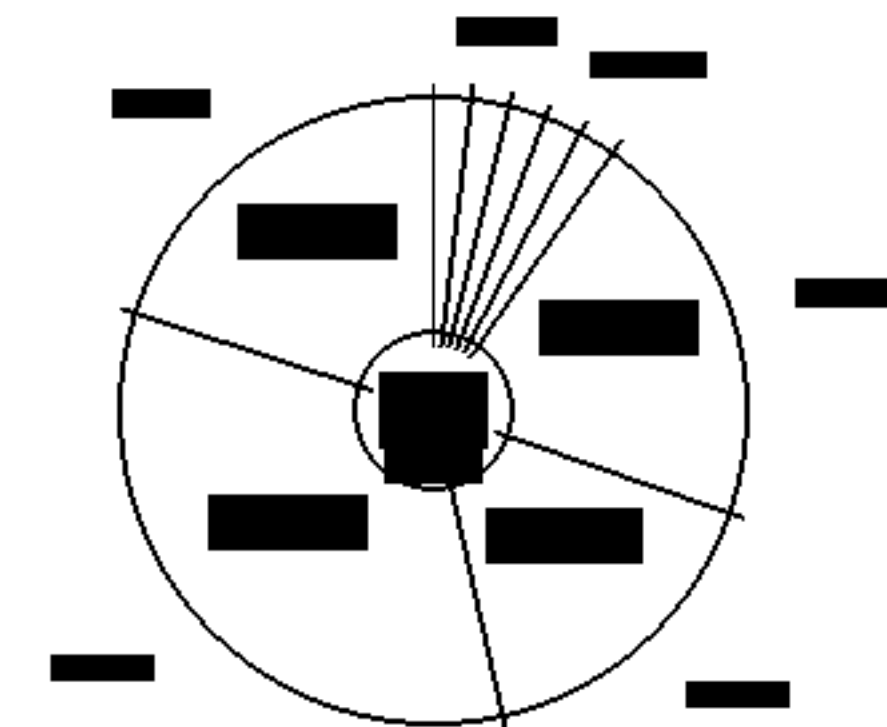
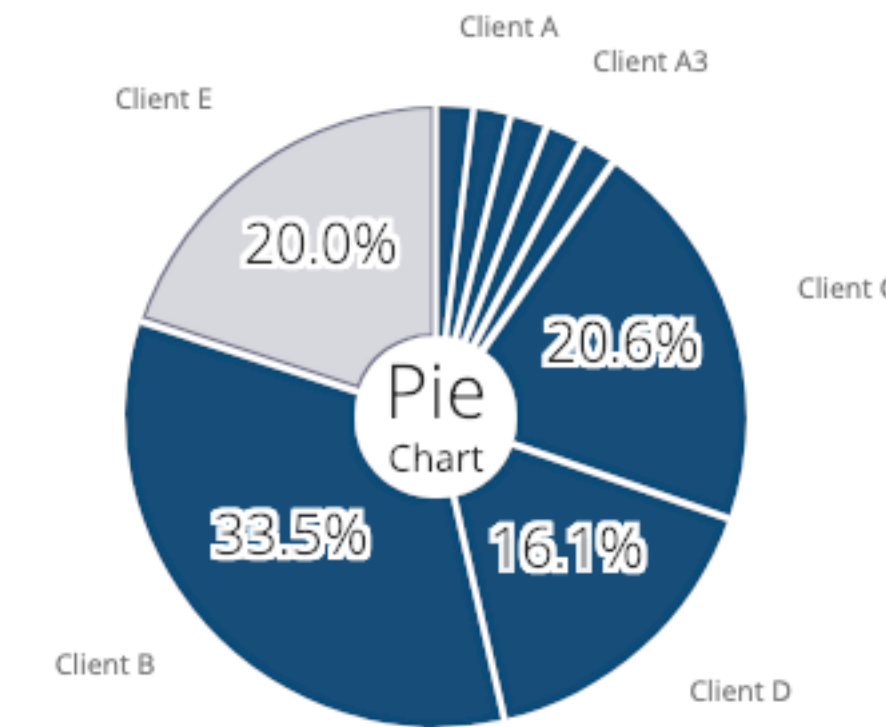
Text Treatment

Source: Moritz et al., Vega-label (2018-2020)



Label Collision

VCC leverages Vega-Label's Occupancy Bitmap approach to handle label overlapping issues.



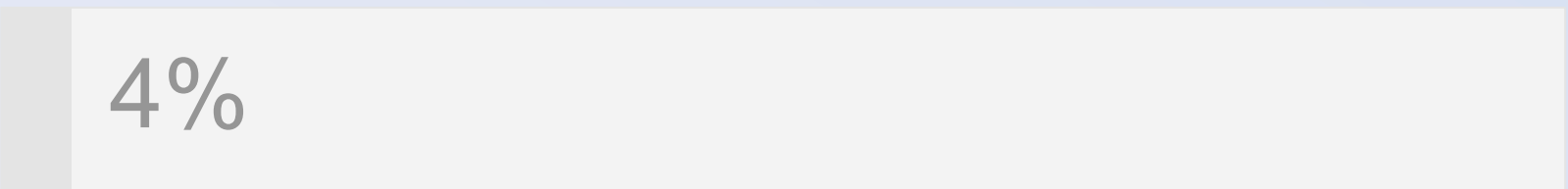
Color and Contrast

Understanding contrast

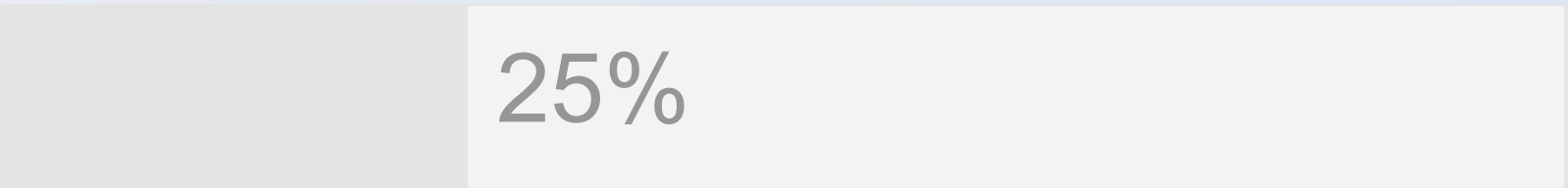
Based on web standards and simple, deterministic algorithms

Colorblindness Disproportionately Overrepresented in A11y Resources

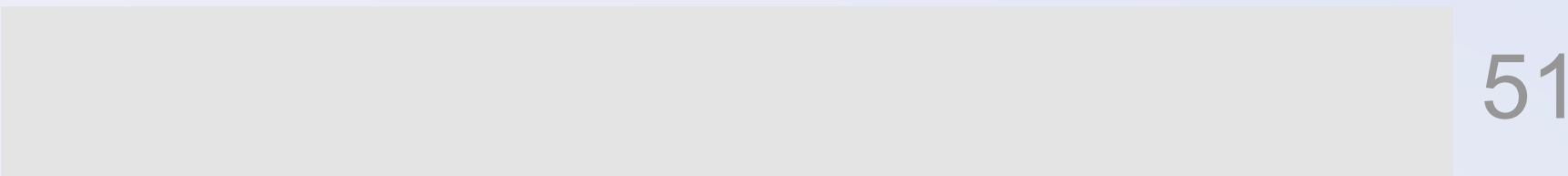
Colorblindness: % of People



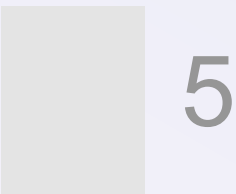
Low Vision: % of People



Colorblindness: # of Resources

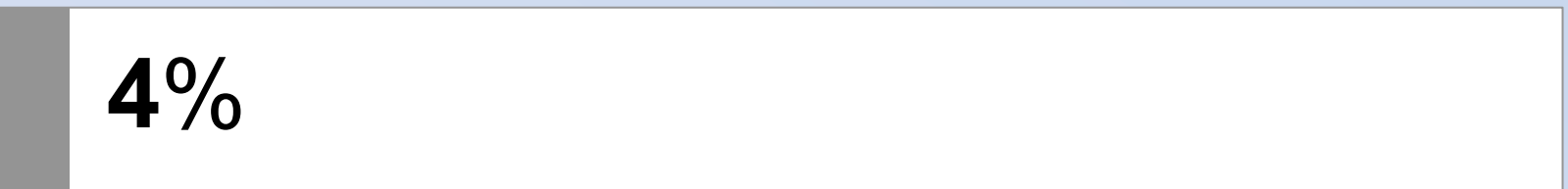


Low Vision: # of Resources



Colorblindness Disproportionately Overrepresented in A11y Resources

Colorblindness: % of People



Low Vision: % of People



Colorblindness: # of Resources

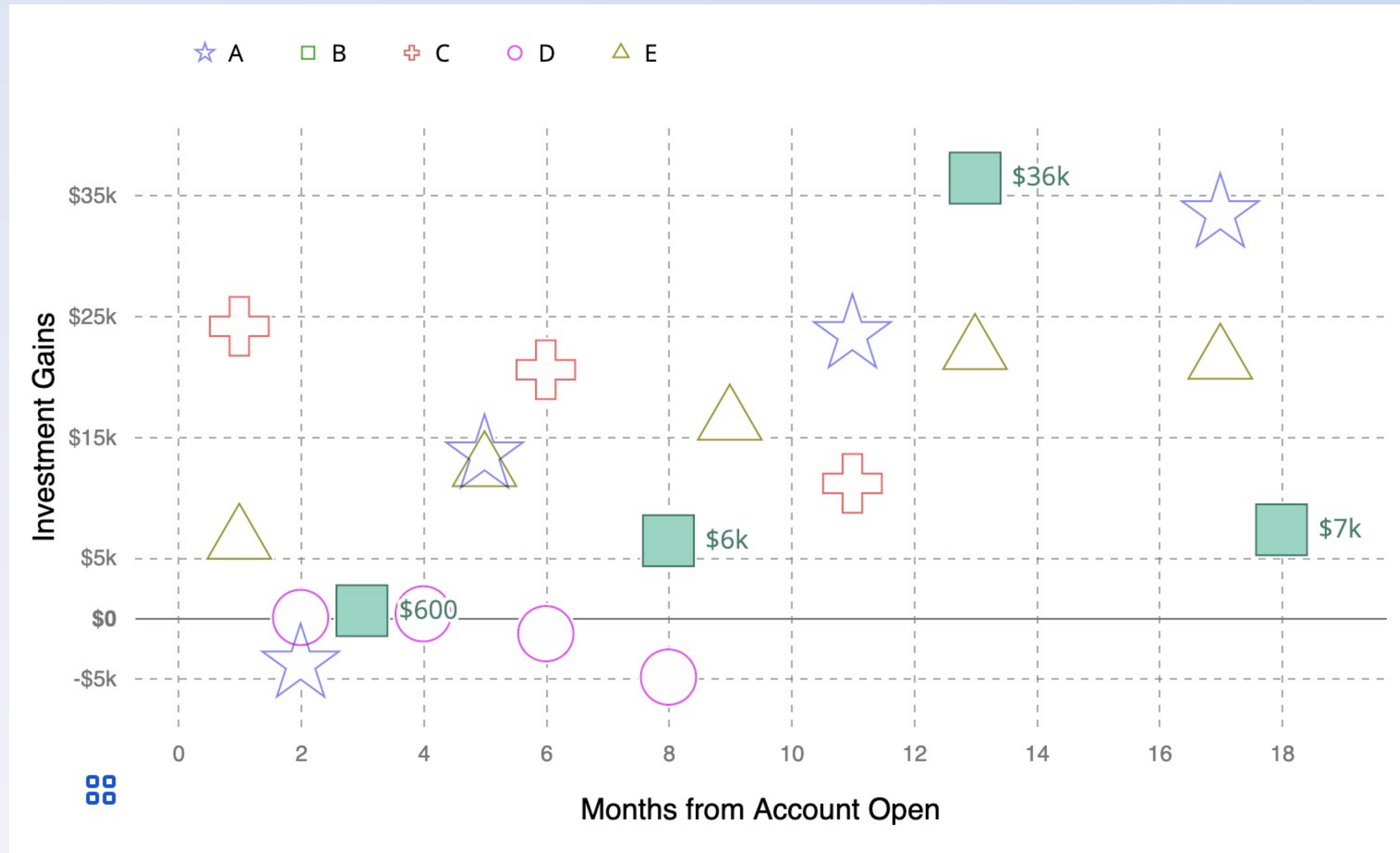


Low Vision: # of Resources



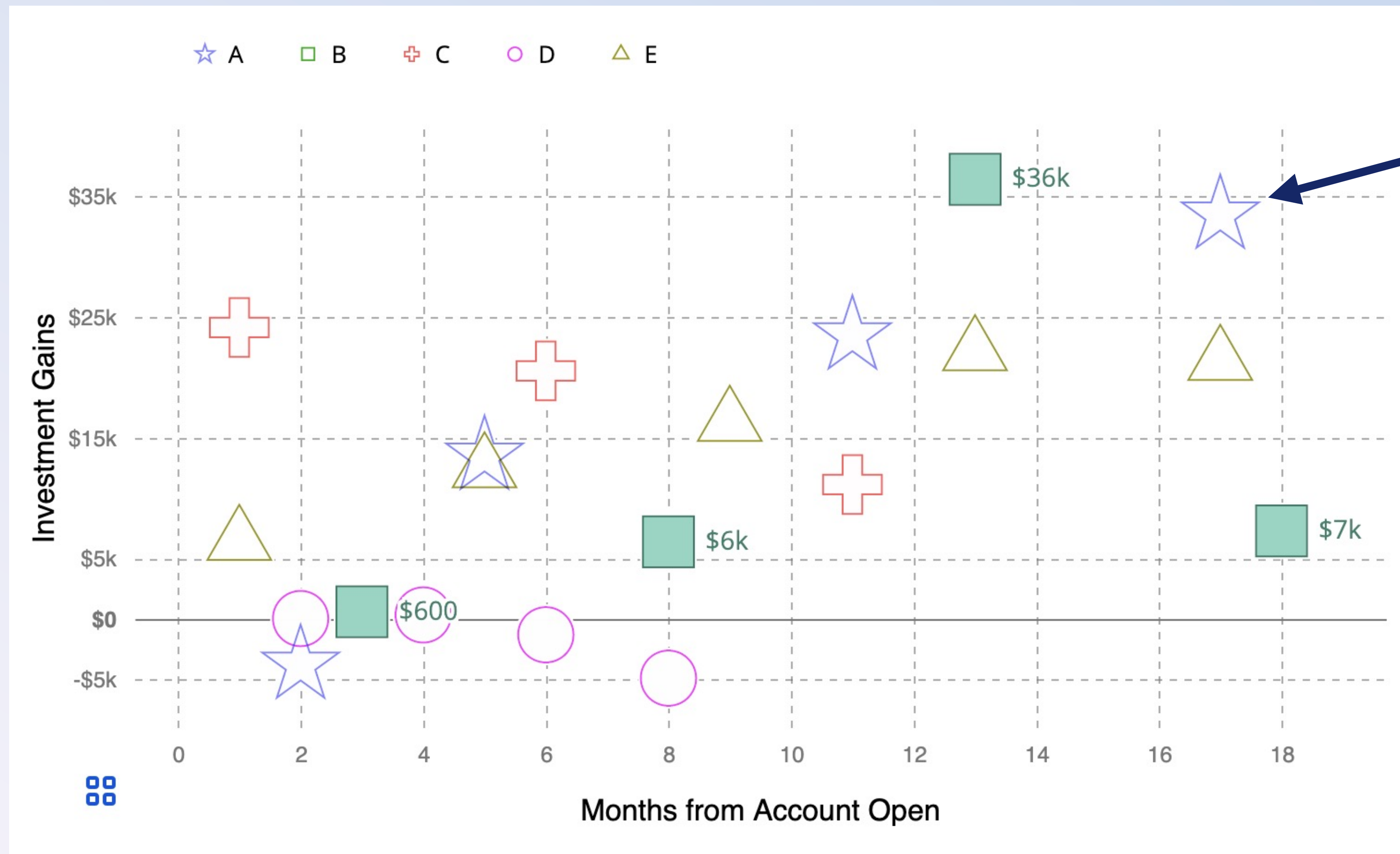
Automatic contrast adjustment

Source: Visa Chart Components, Frank Elavsky (2017-2019)

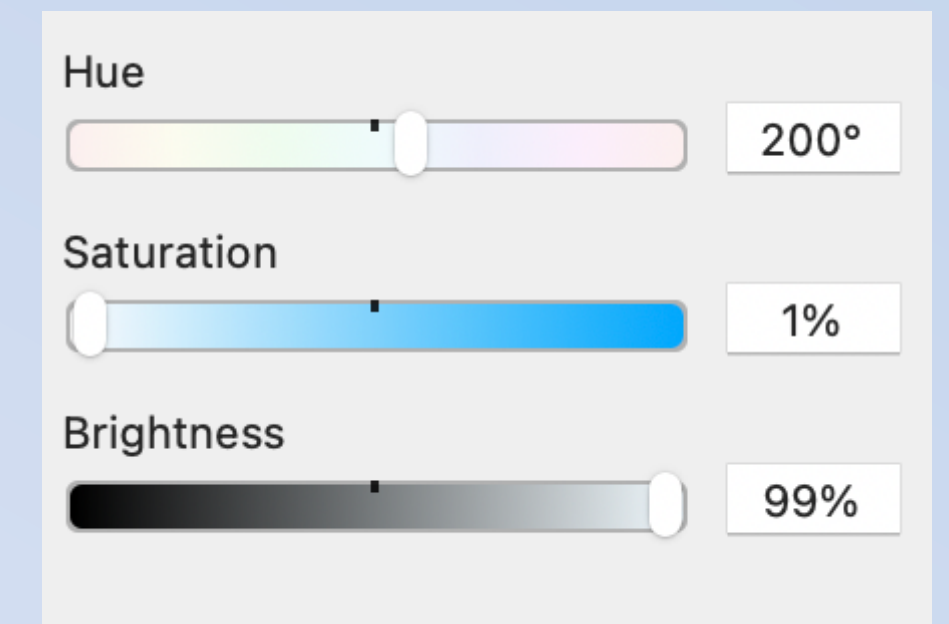


Automatic contrast adjustment

Source: Visa Chart Components, Frank Elavsky (2017-2019)

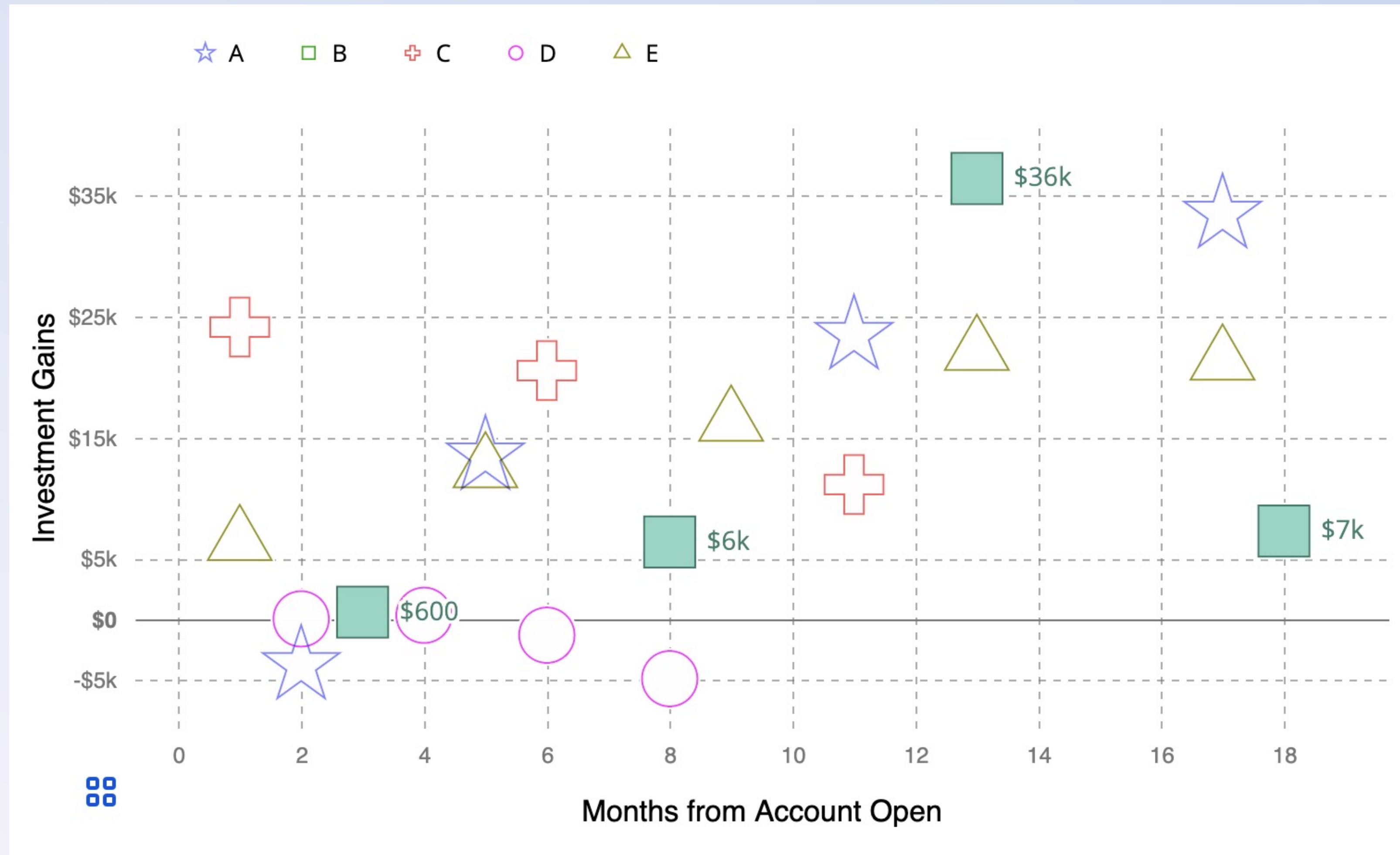


Input color: nearly white, but slightly more blue



Automatic contrast adjustment

Source: Visa Chart Components, Frank Elavsky (2017-2019)



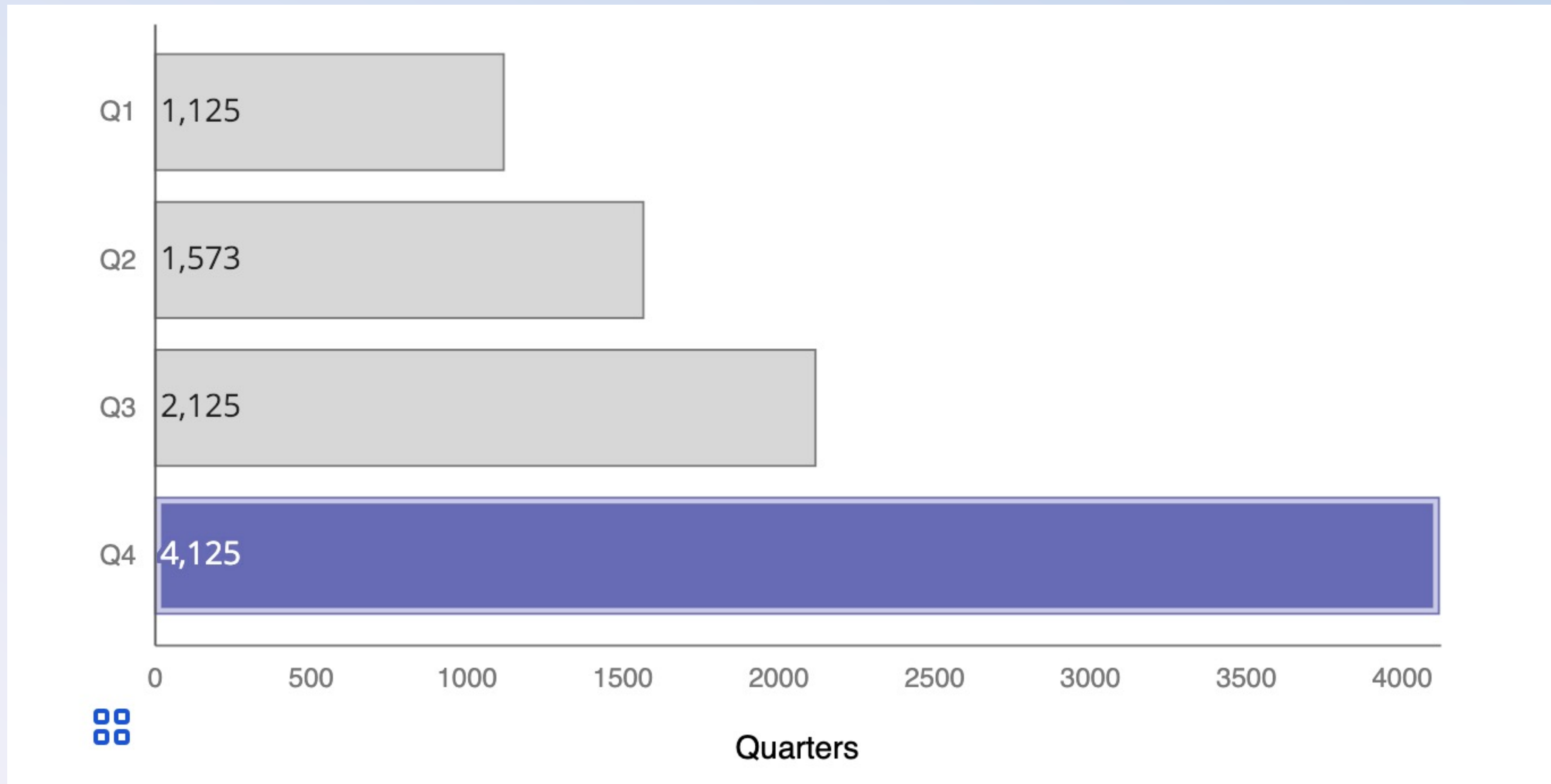
Input color: nearly white, but slightly more blue



Border added via HSL transform (retain H, but darken L until passing)

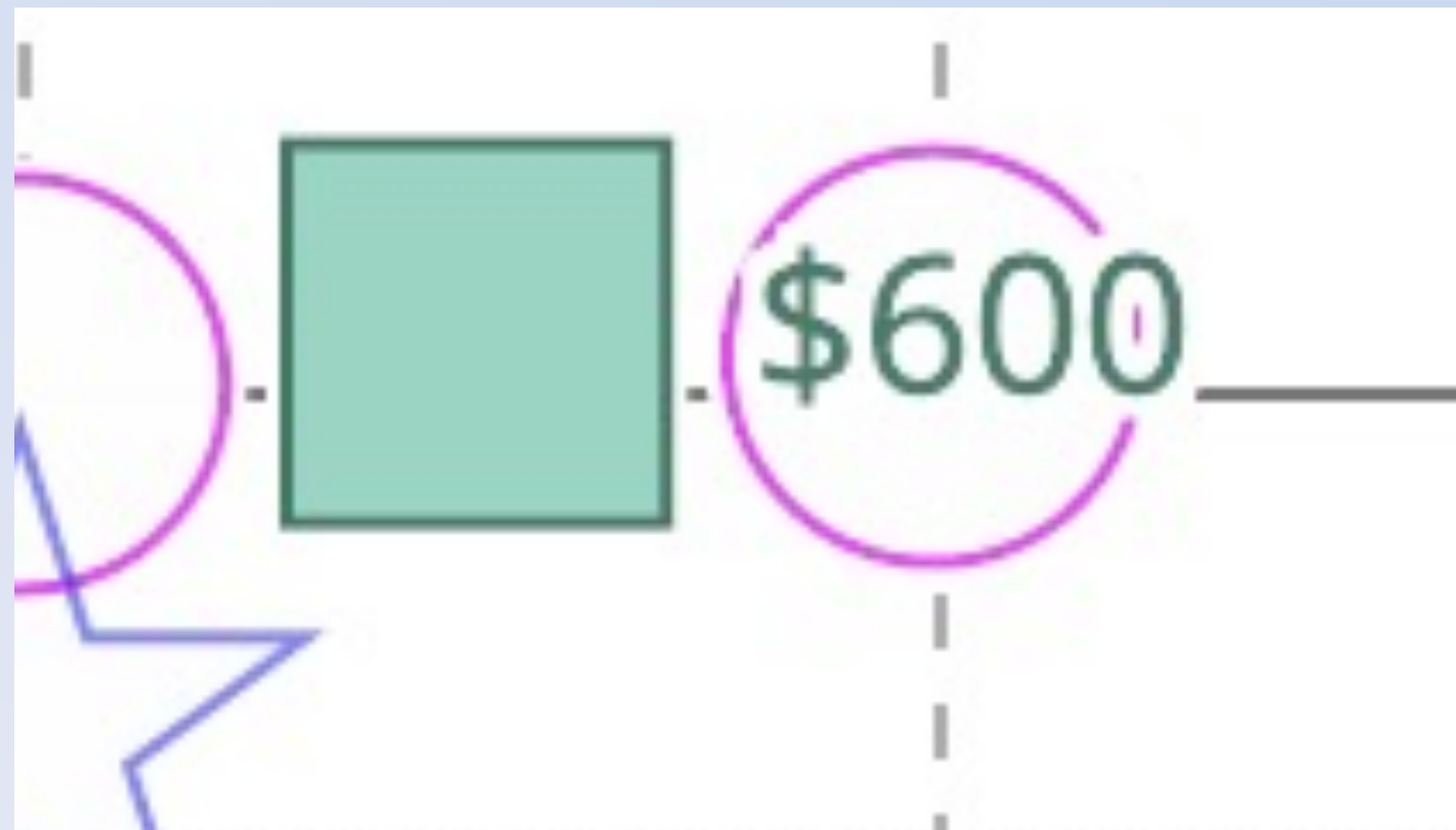
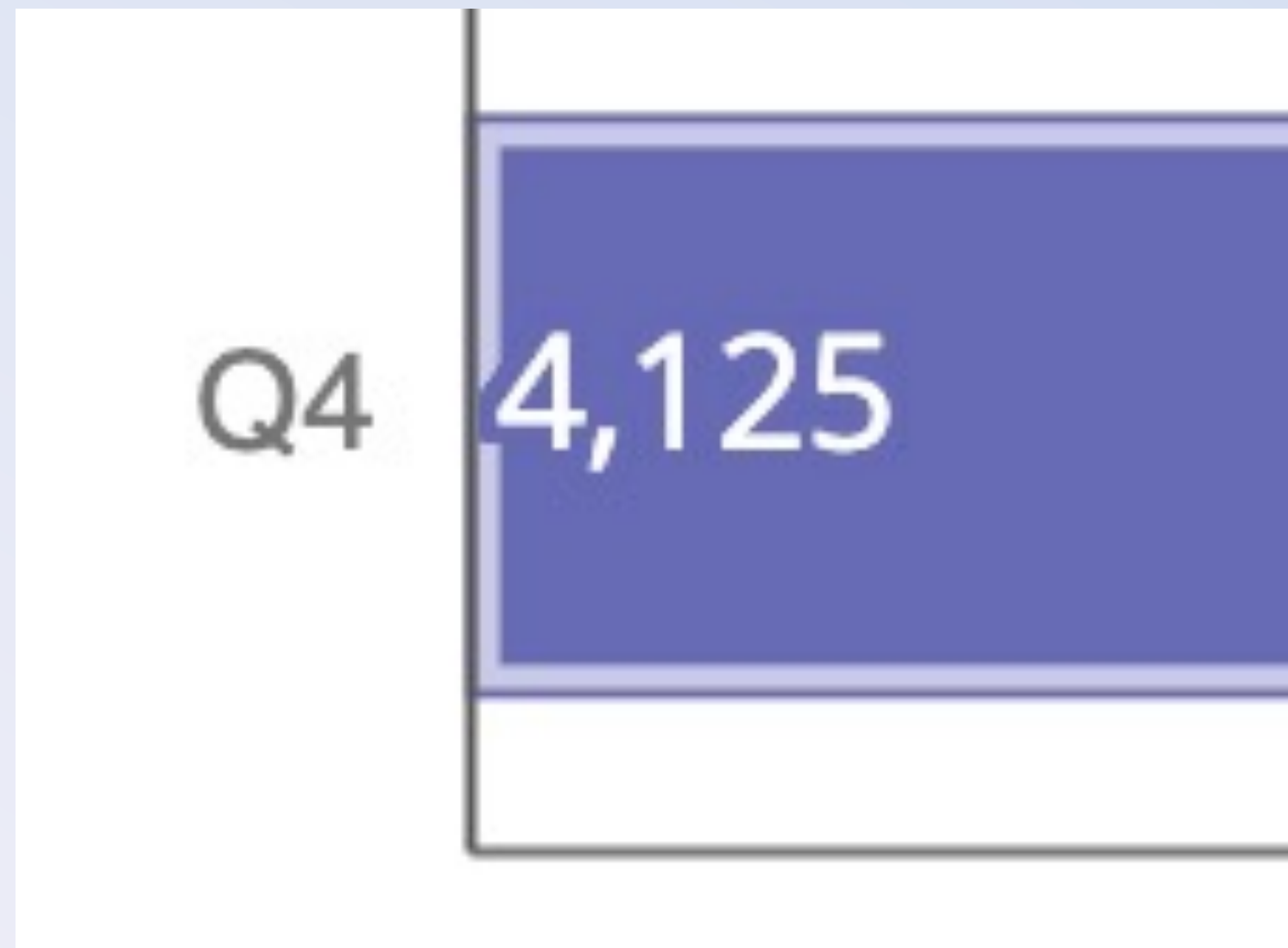
Automatic text color

Source: Visa Chart Components, Frank Elavsky (2017-2019)



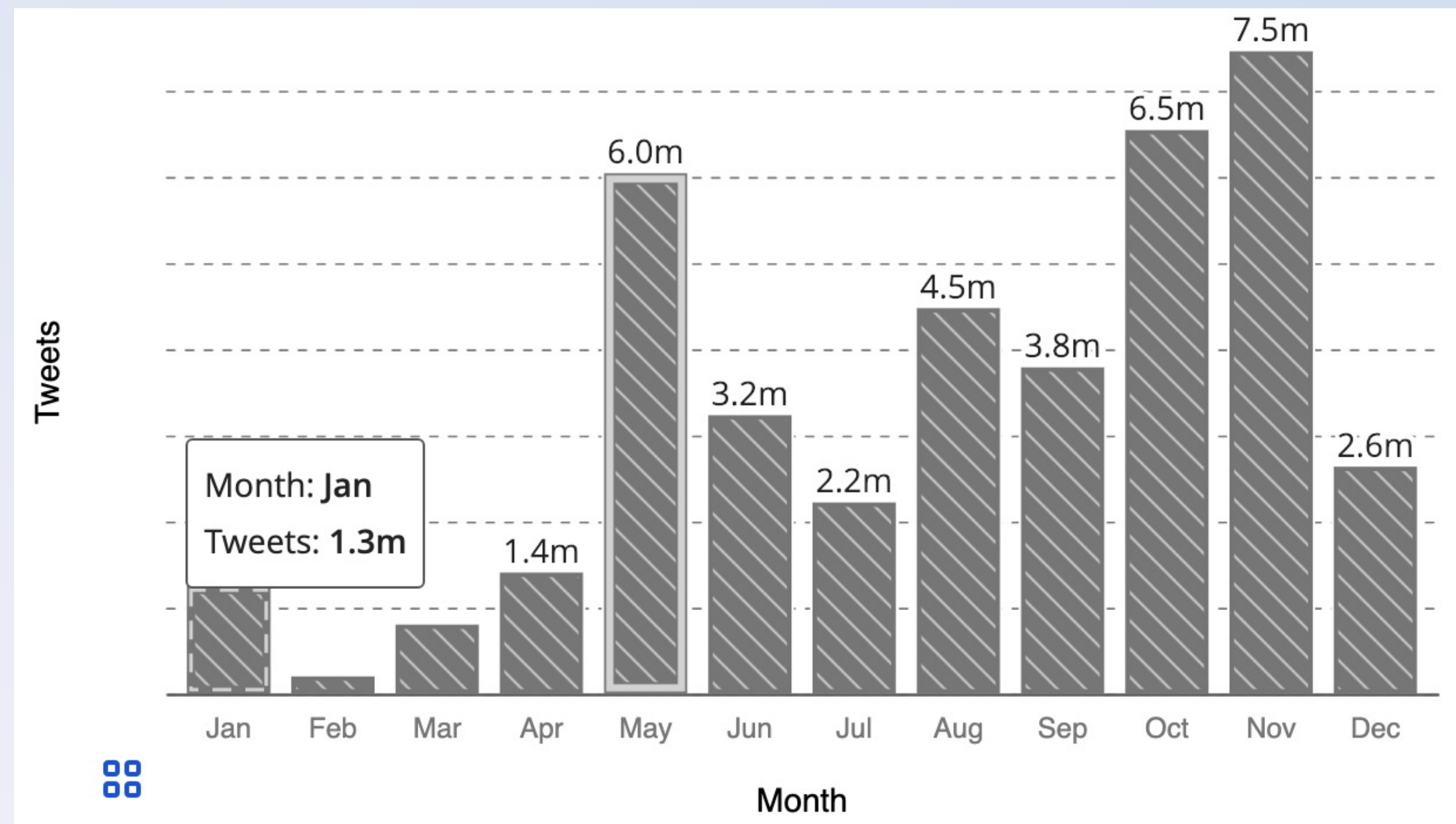
Automatic text outlines

Source: Visa Chart Components, Frank Elavsky (2017-2019)



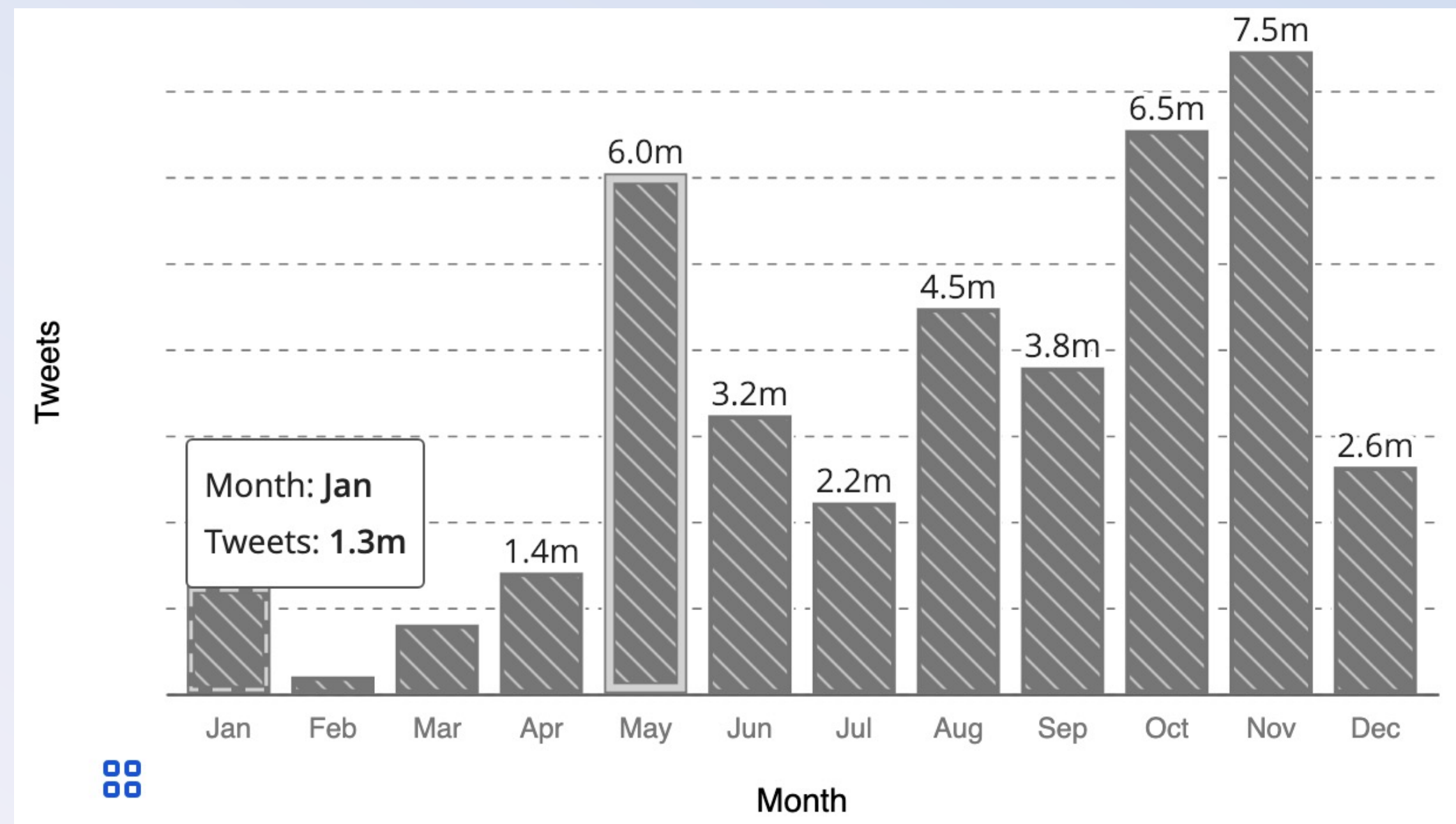
Stroke interaction states

Source: Visa Chart Components, Frank Elavsky (2017-2019)



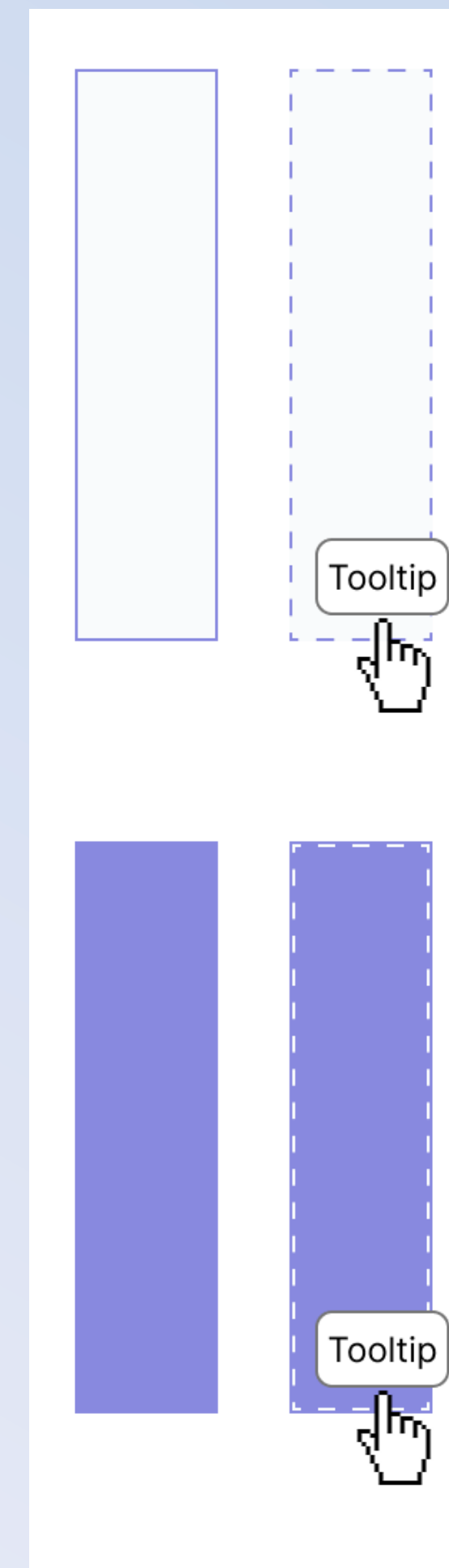
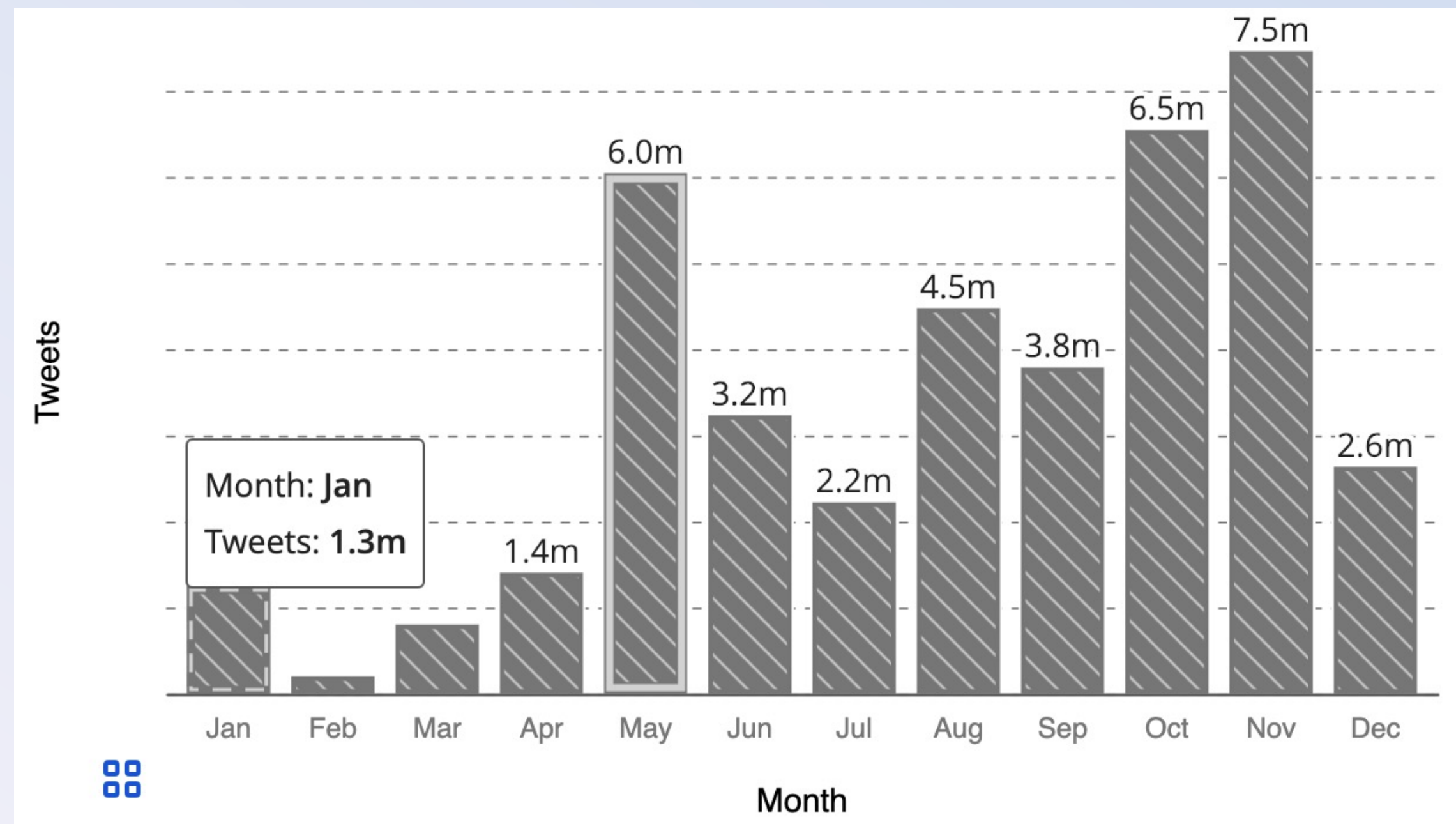
Stroke interaction states

Source: Visa Chart Components, Frank Elavsky (2017-2019)



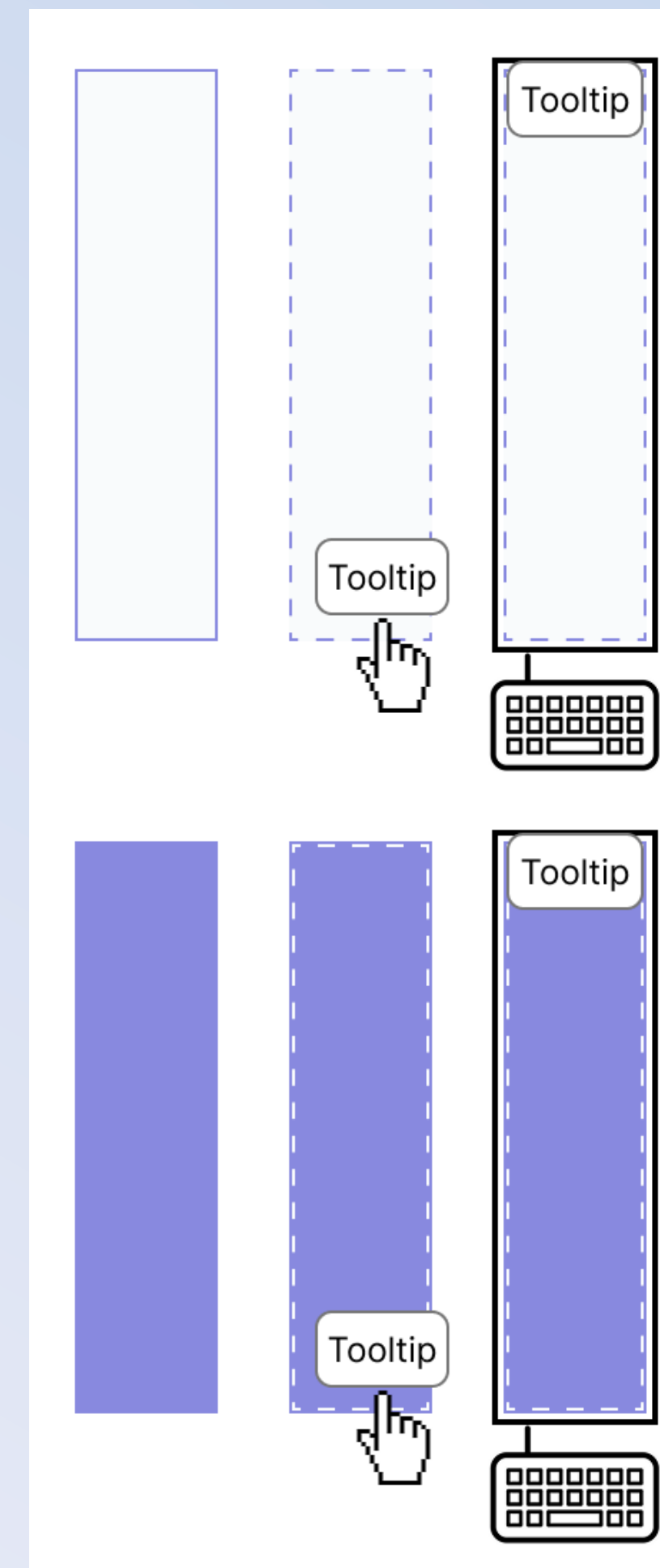
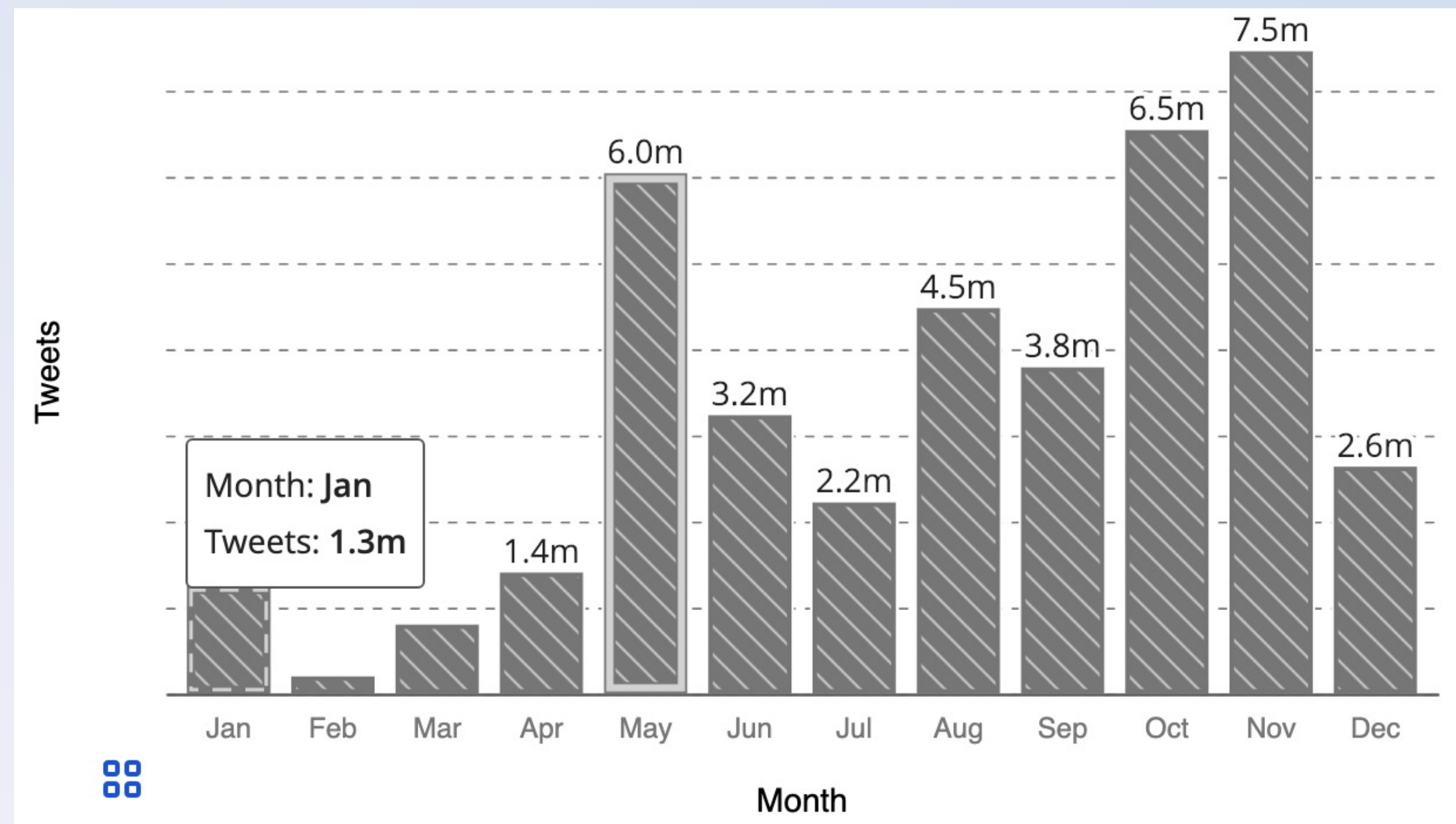
Stroke interaction states

Source: Visa Chart Components, Frank Elavsky (2017-2019)



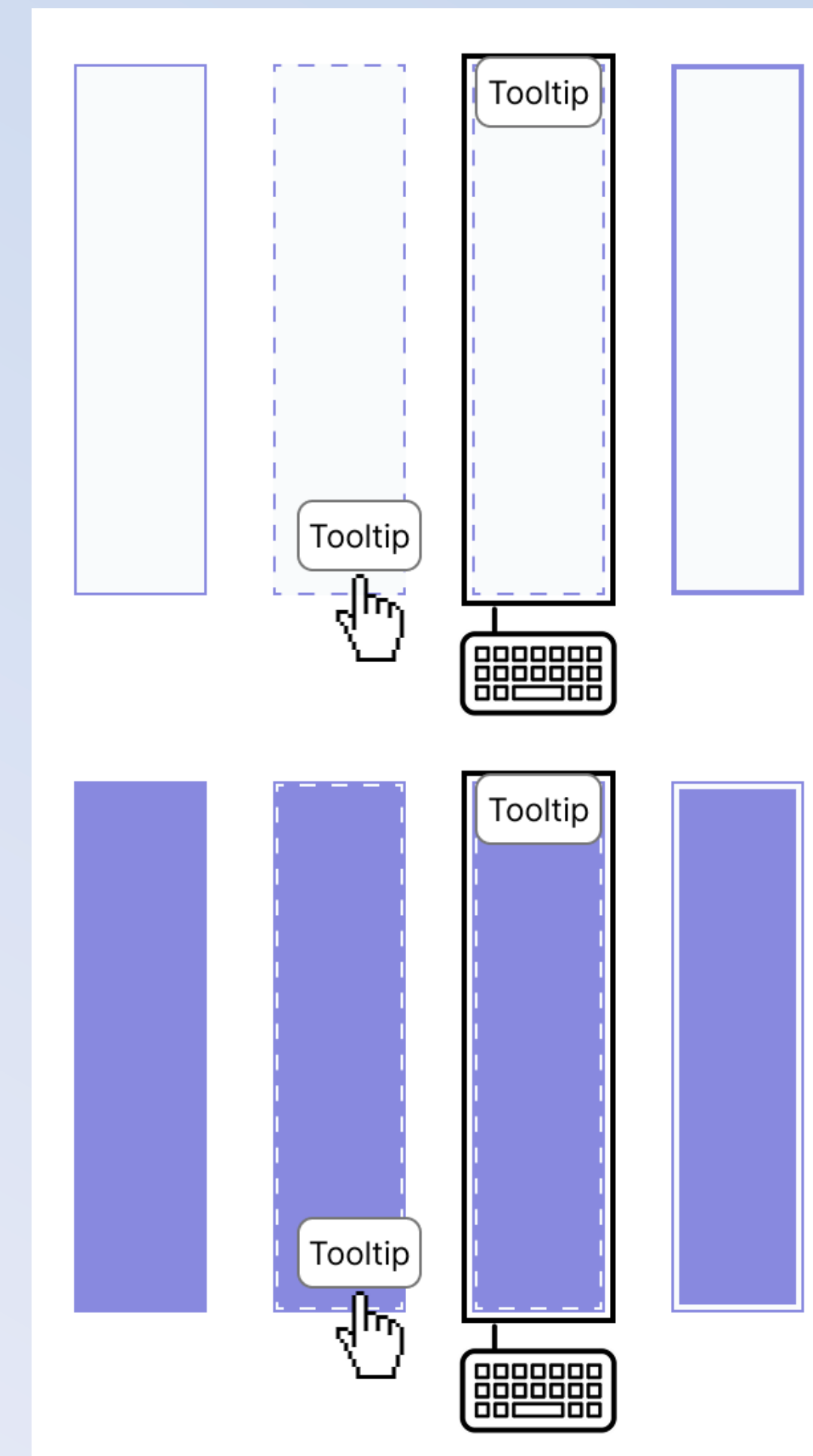
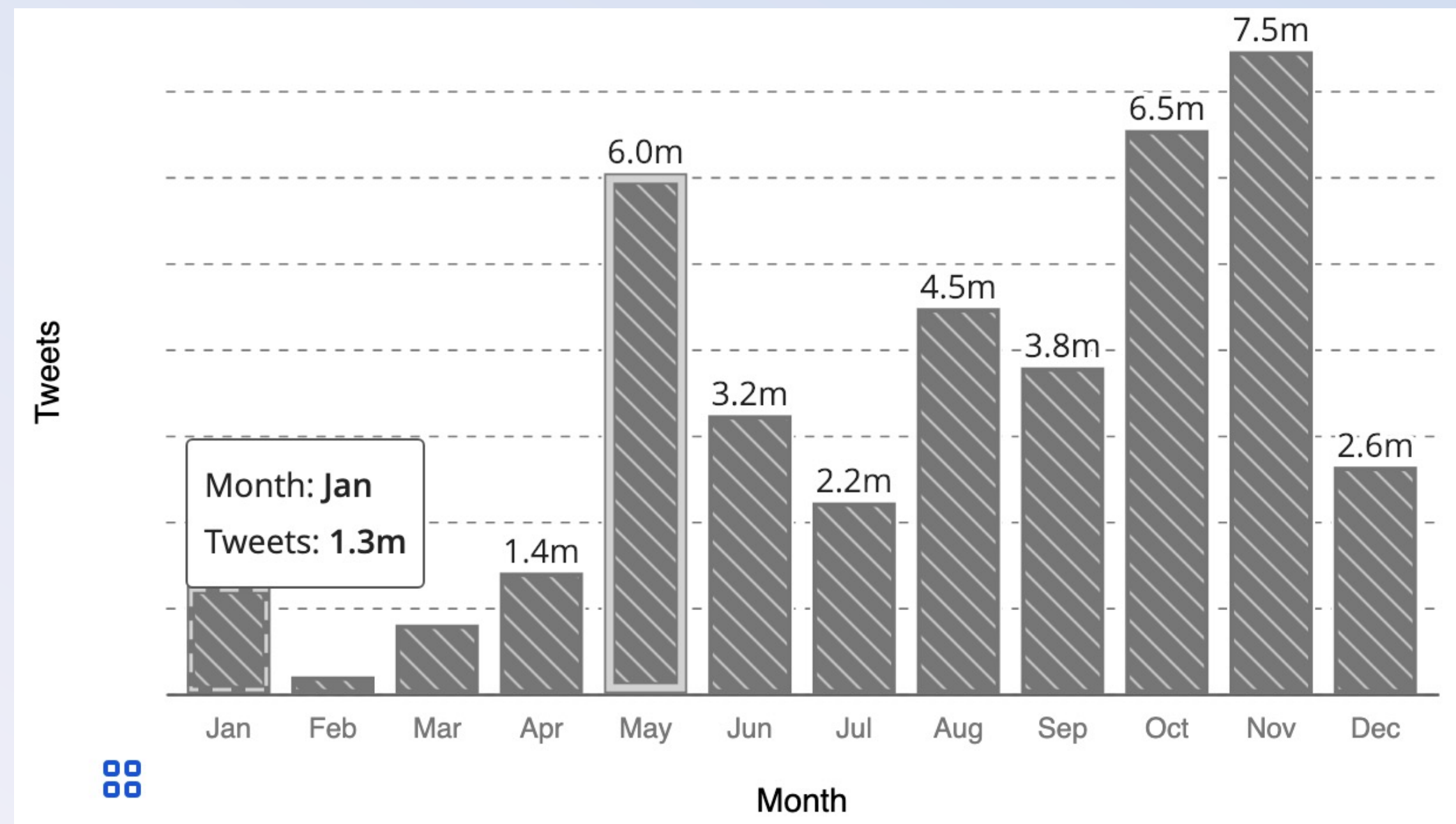
Stroke interaction states

Source: Visa Chart Components, Frank Elavsky (2017-2019)



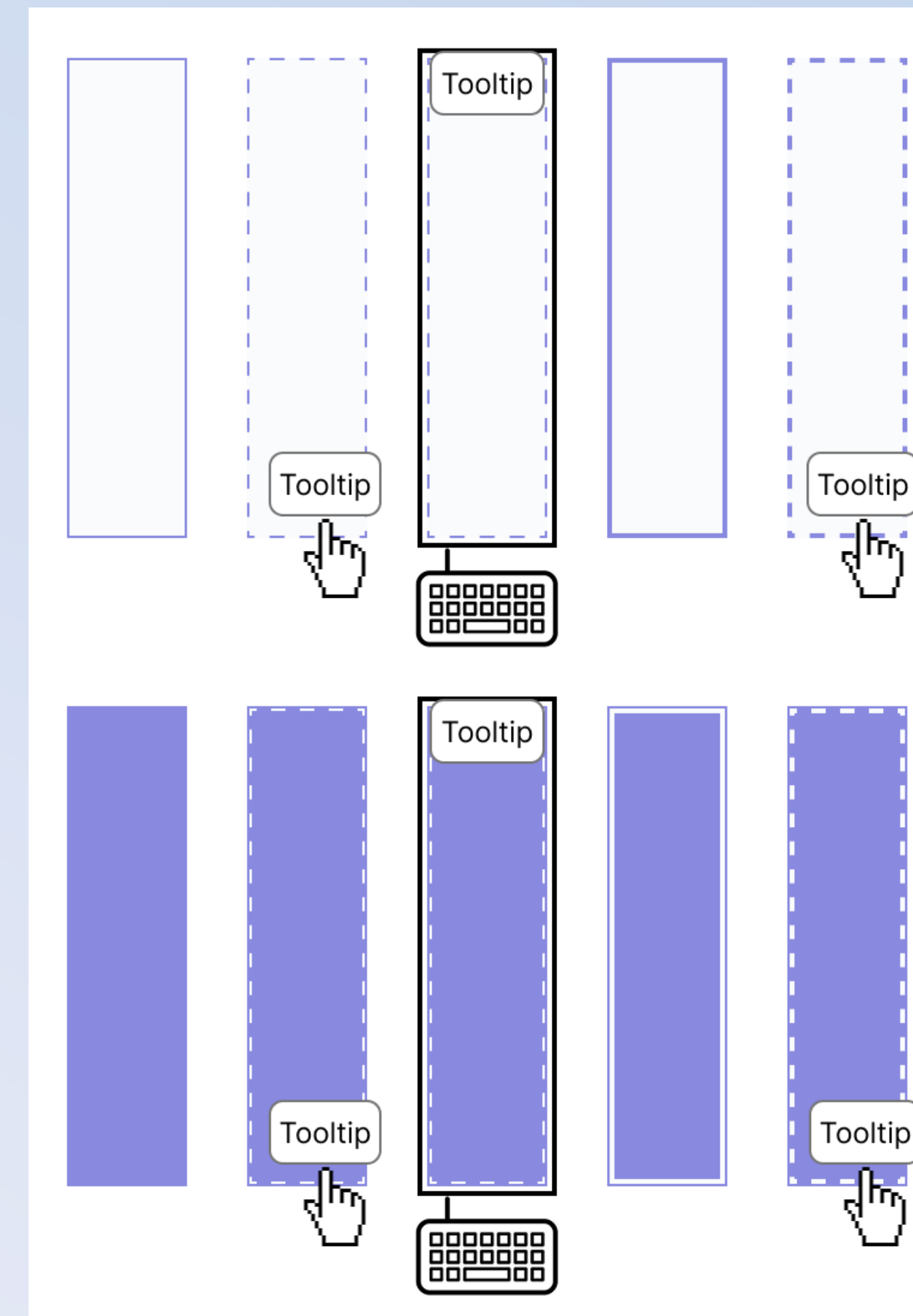
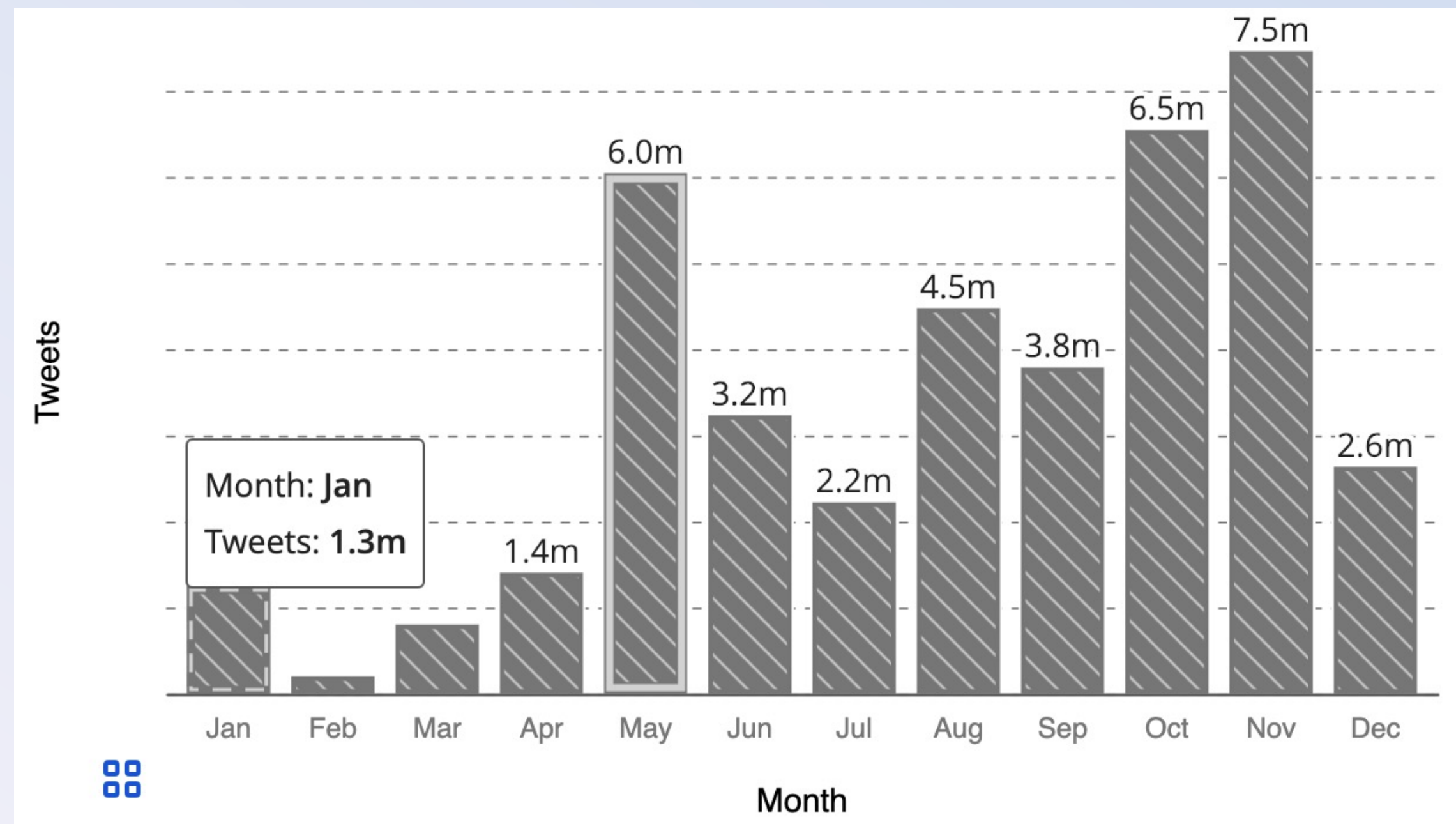
Stroke interaction states

Source: Visa Chart Components, Frank Elavsky (2017-2019)



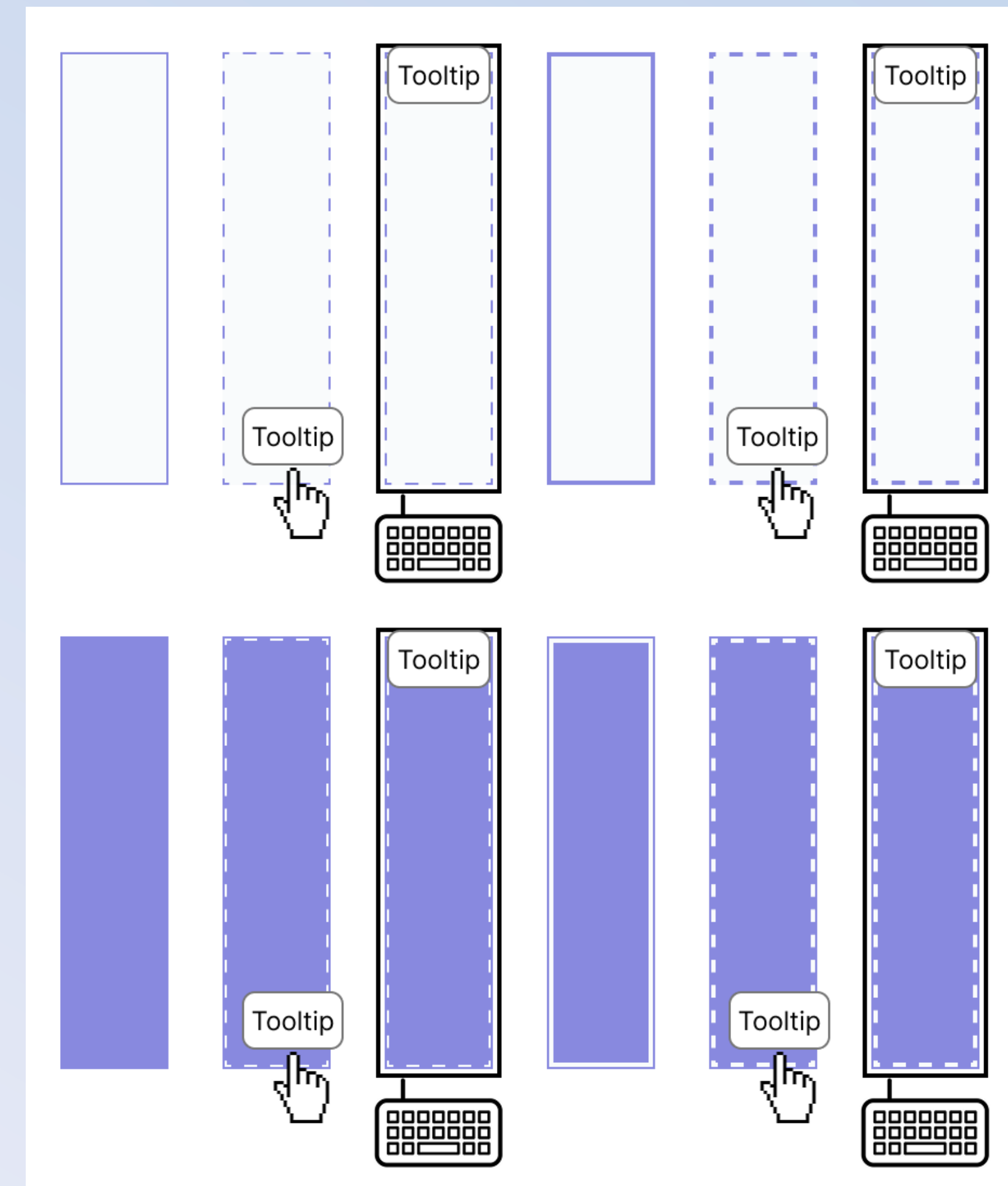
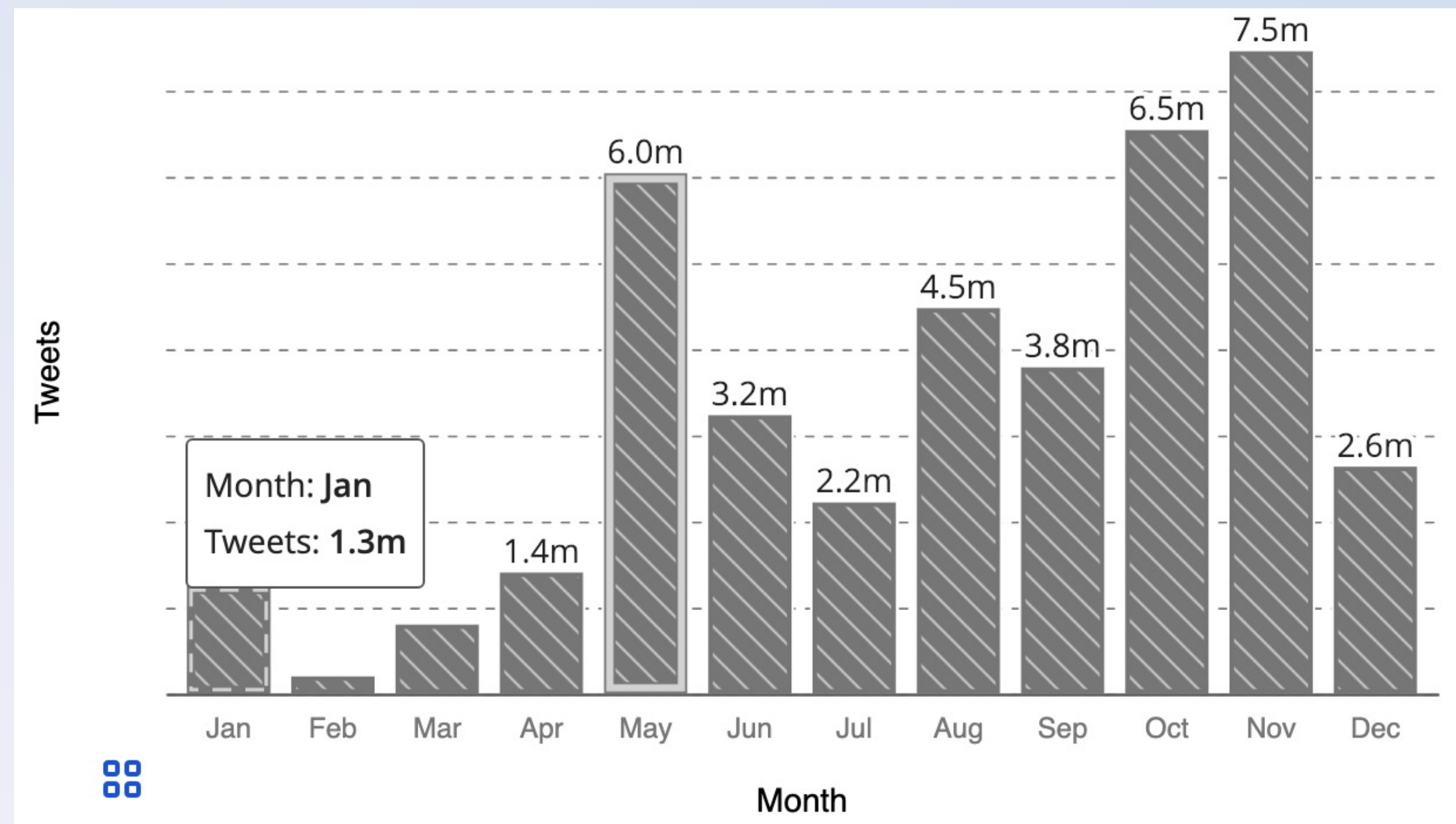
Stroke interaction states

Source: Visa Chart Components, Frank Elavsky (2017-2019)



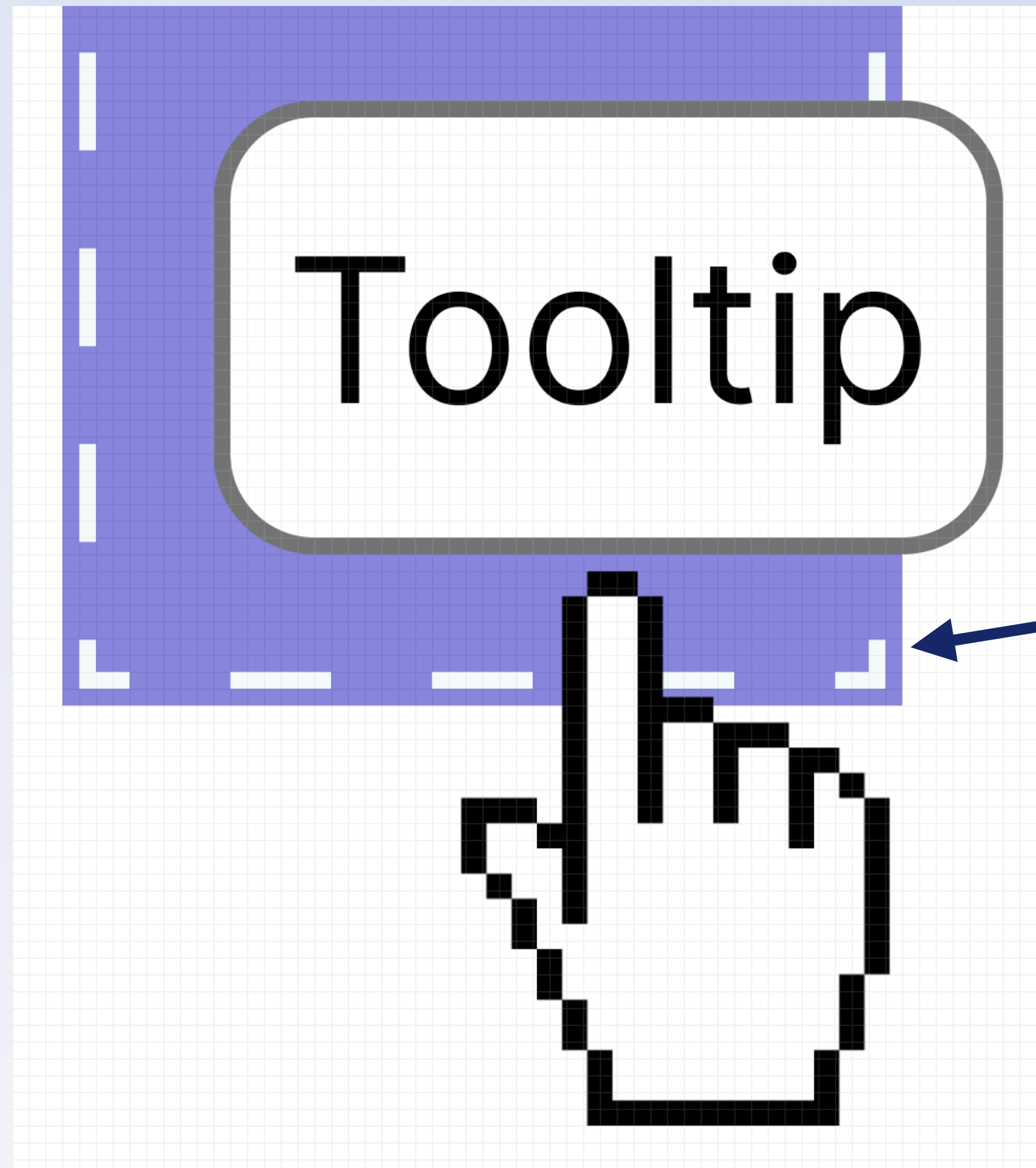
Stroke interaction states

Source: Visa Chart Components, Frank Elavsky (2017-2019)



Stroke interaction states

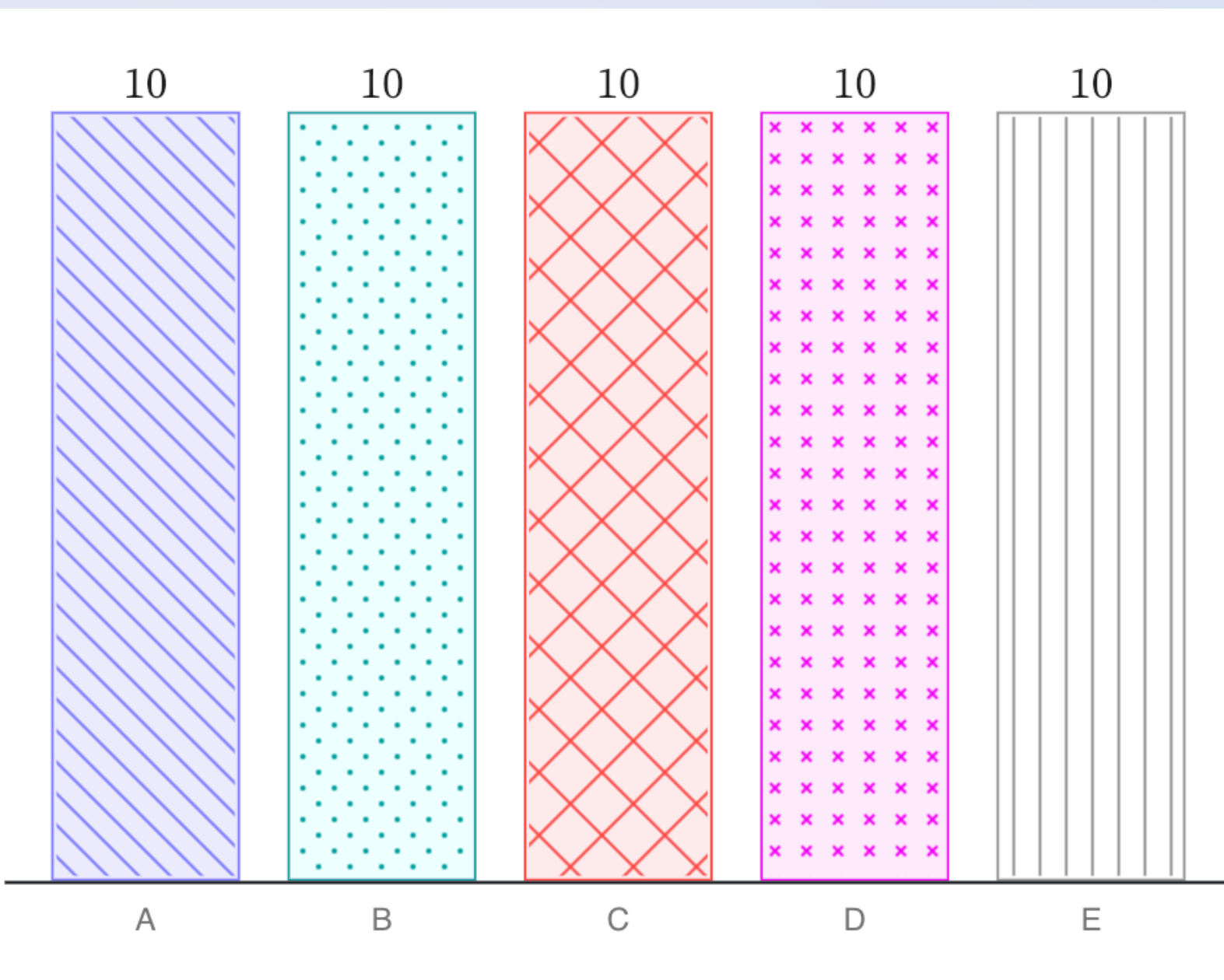
Source: Visa Chart Components, Frank Elavsky (2017-2019)



I spent weeks on
this border design!!

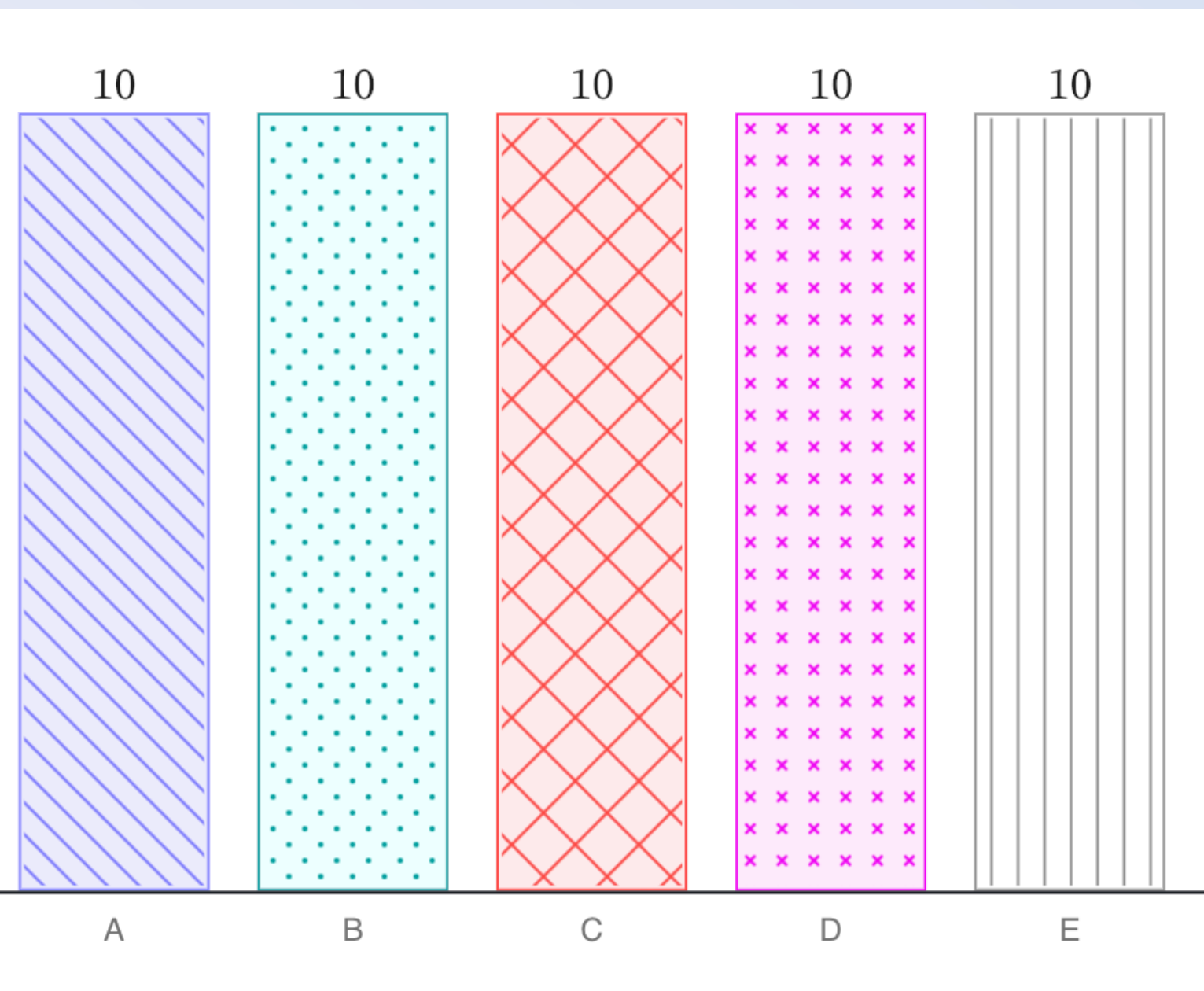
Textures, patterns, and fills: categorical

Source: Visa Chart Components, Frank Elavsky (2017-2019)



Textures, patterns, and fills: categorical

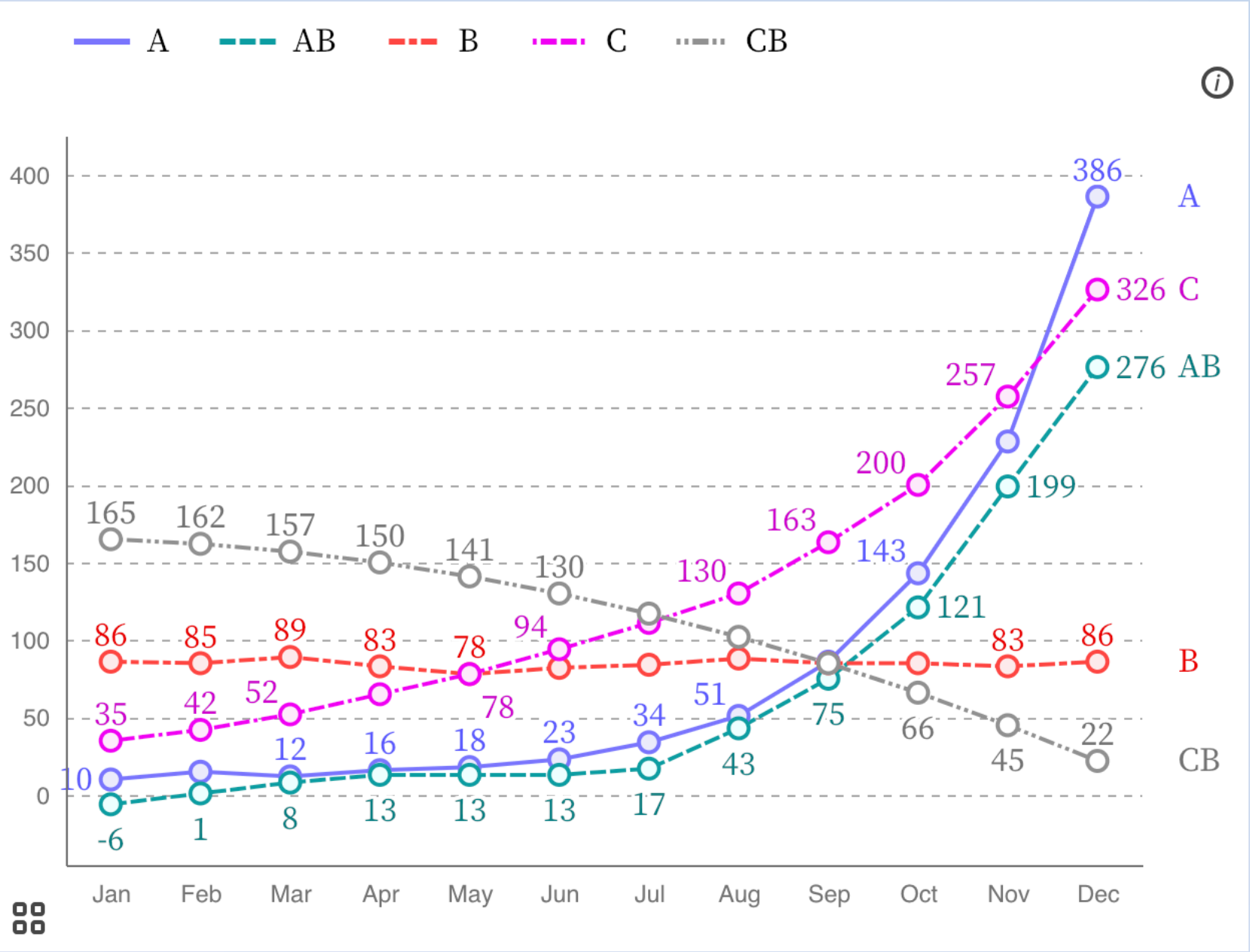
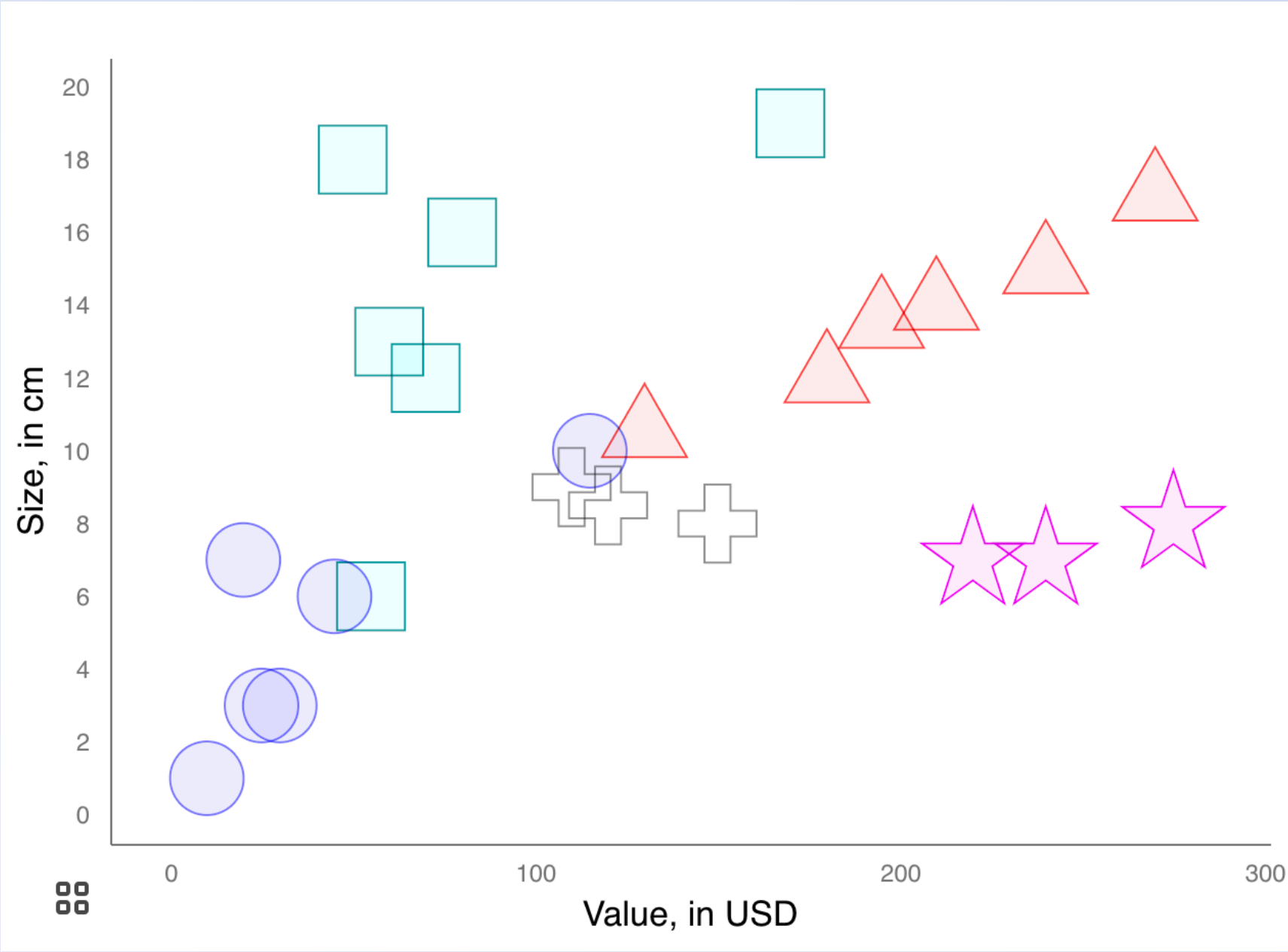
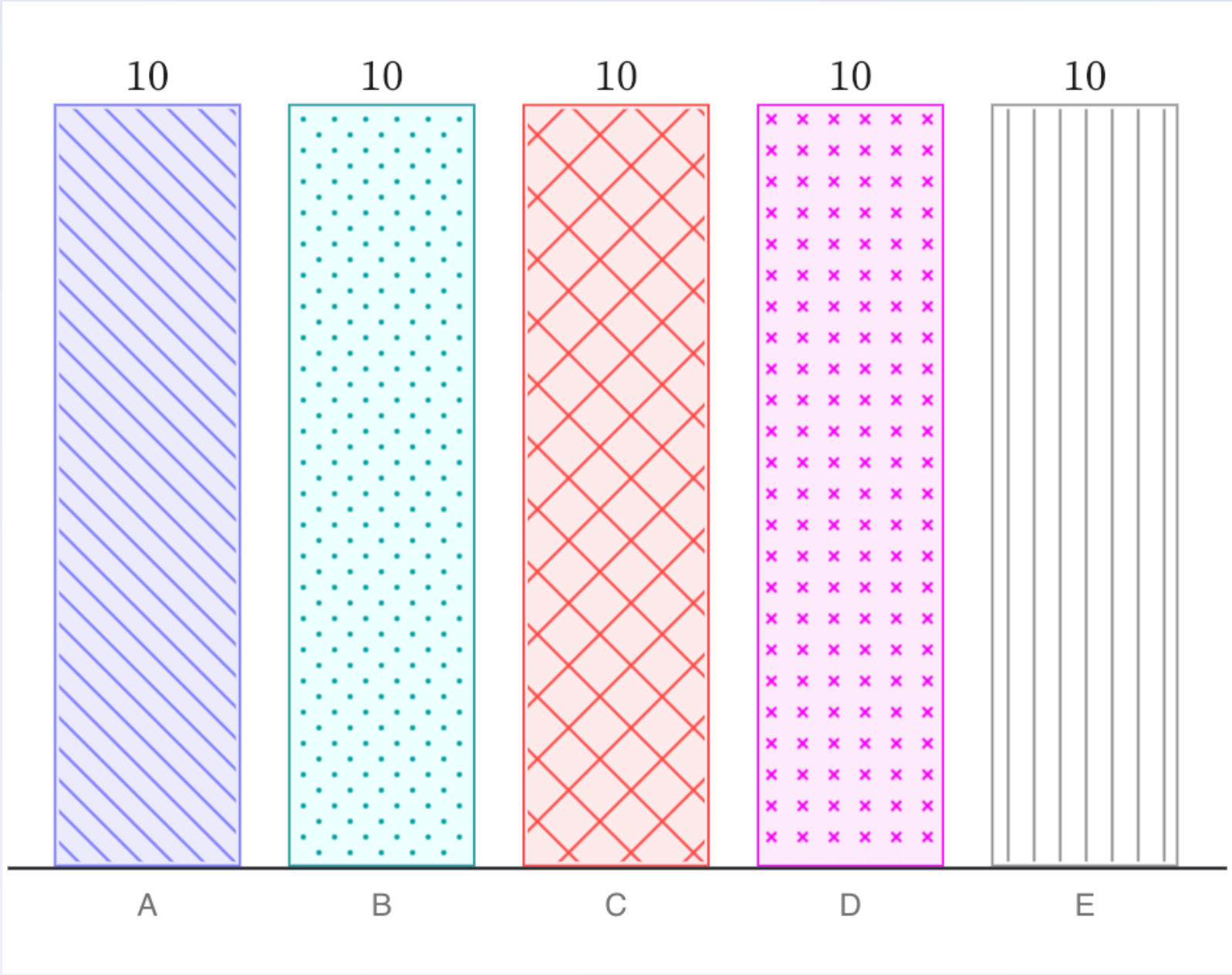
Source: Visa Chart Components, Frank Elavsky (2017-2019)



I also spent weeks on the border spacing in our texture design!!

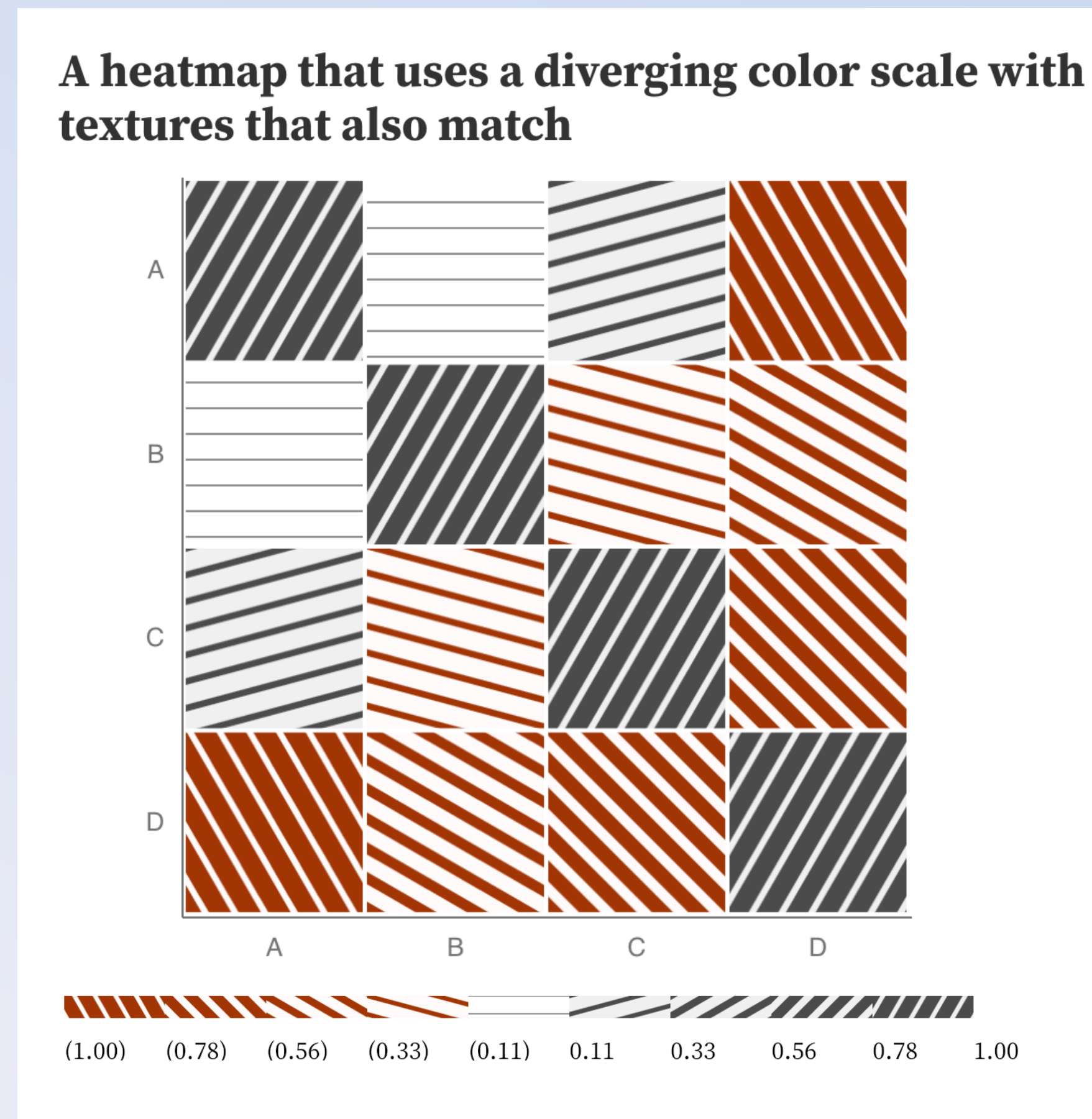
Textures, patterns, and fills: categorical

Source: Visa Chart Components, Frank Elavsky (2017-2019)



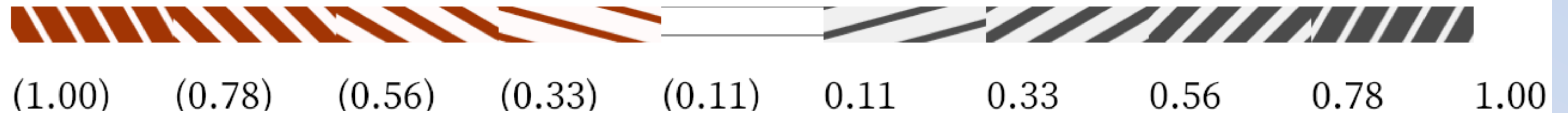
Textures, patterns, and fills: numerical?

Source: Visa Chart Components, Frank Elavsky (2020)



Textures, patterns, and fills: numerical?

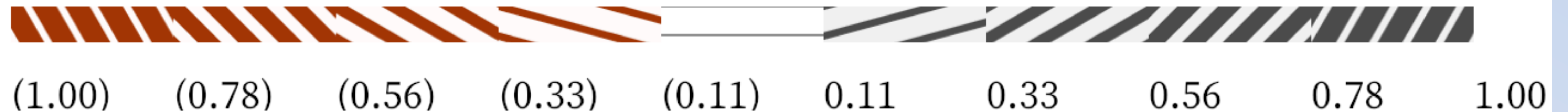
Source: Visa Chart Components, Frank Elavsky (2017-2019)



Textures, patterns, and fills: numerical?

Source: Visa Chart Components, Frank Elavsky (2017-2019)

(Probably not useful, but
was a fun experiment)



Selecting colors for CVD and contrast

Source: Chroma.js by Gregor Aisch, circa 2011-2013ish?

Chroma.js Color Palette Helper

This [chroma.js](#)-powered tool is here to help us [mastering multi-hued, multi-stops color scales](#).

1

What kind of palette do you want to create?

Palette type:

sequentialdiverging

Number of colors:

9

2

Select and arrange input colors

00429d96ffeaffffe0

3

Check and configure the resulting palette

☒ correct lightness☒ bezier interpolation

simulate:

normaldeut.prot.trit.

✓ This palette is colorblind-safe.

lightness

saturation

hue

35

Selecting colors for CVD and contrast

Source: Chroma.js by Gregor Aisch, circa 2011-2013ish?

Chroma.js Color Palette Helper

This [chroma.js](#)-powered tool is here to help us [mastering multi-hued, multi-stops color scales](#).

1 What kind of palette do you want to create?

Palette type: sequential diverging

Number of colors: 9

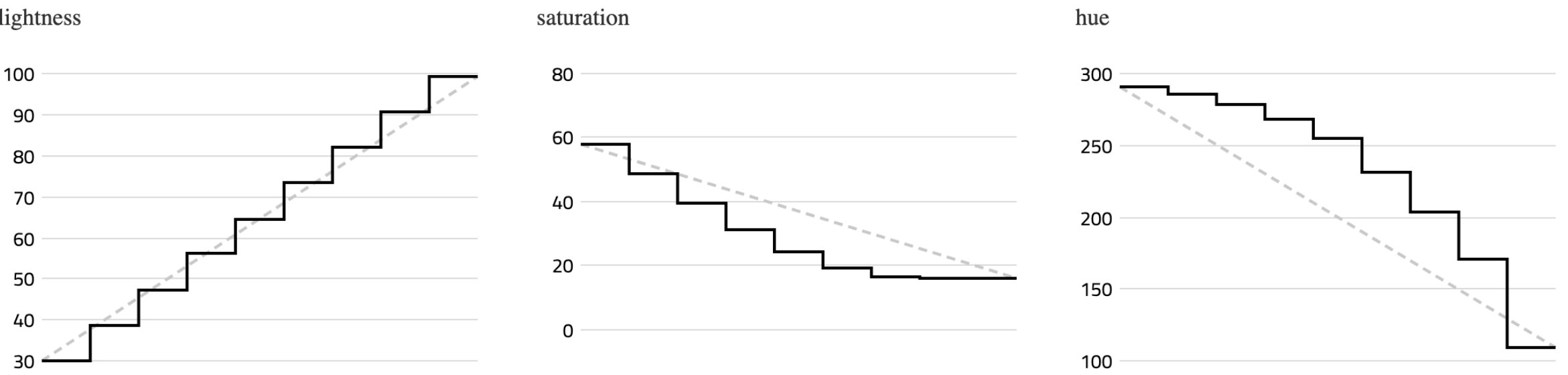
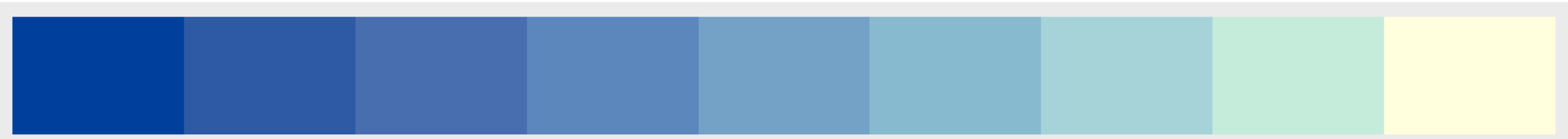
2 Select and arrange input colors

00429d 96ffea ffffe0

3 Check and configure the resulting palette

☒ correct lightness ☒ bezier interpolation

✓ This palette is colorblind-safe.
simulate: normal deut. prot. trit.



Chroma.js Color Palette Helper

This [chroma.js](#)-powered tool is here to help us [mastering multi-hued, multi-stops color scales](#).

1 What kind of palette do you want to create?

Palette type: sequential diverging

Number of colors: 4

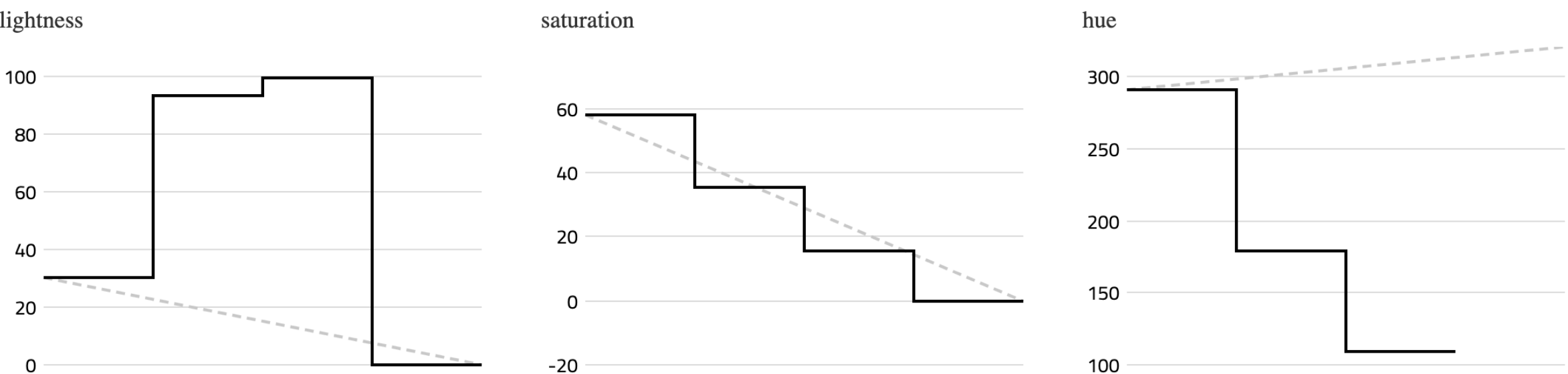
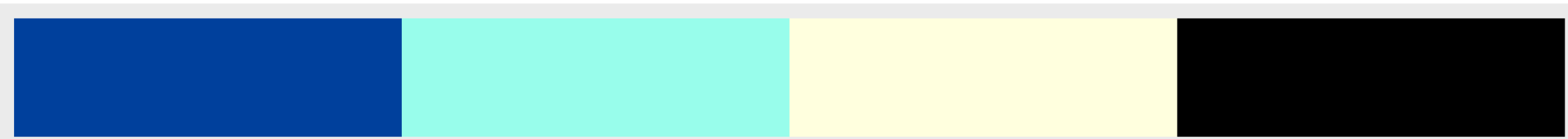
2 Select and arrange input colors

00429d 96ffea ffffe0 000000

3 Check and configure the resulting palette

☐ correct lightness ☐ bezier interpolation

✓ This palette is colorblind-safe.
simulate: normal deut. prot. trit.



Source: Susie Lu + Elijah Meeks, circa 2017ish?

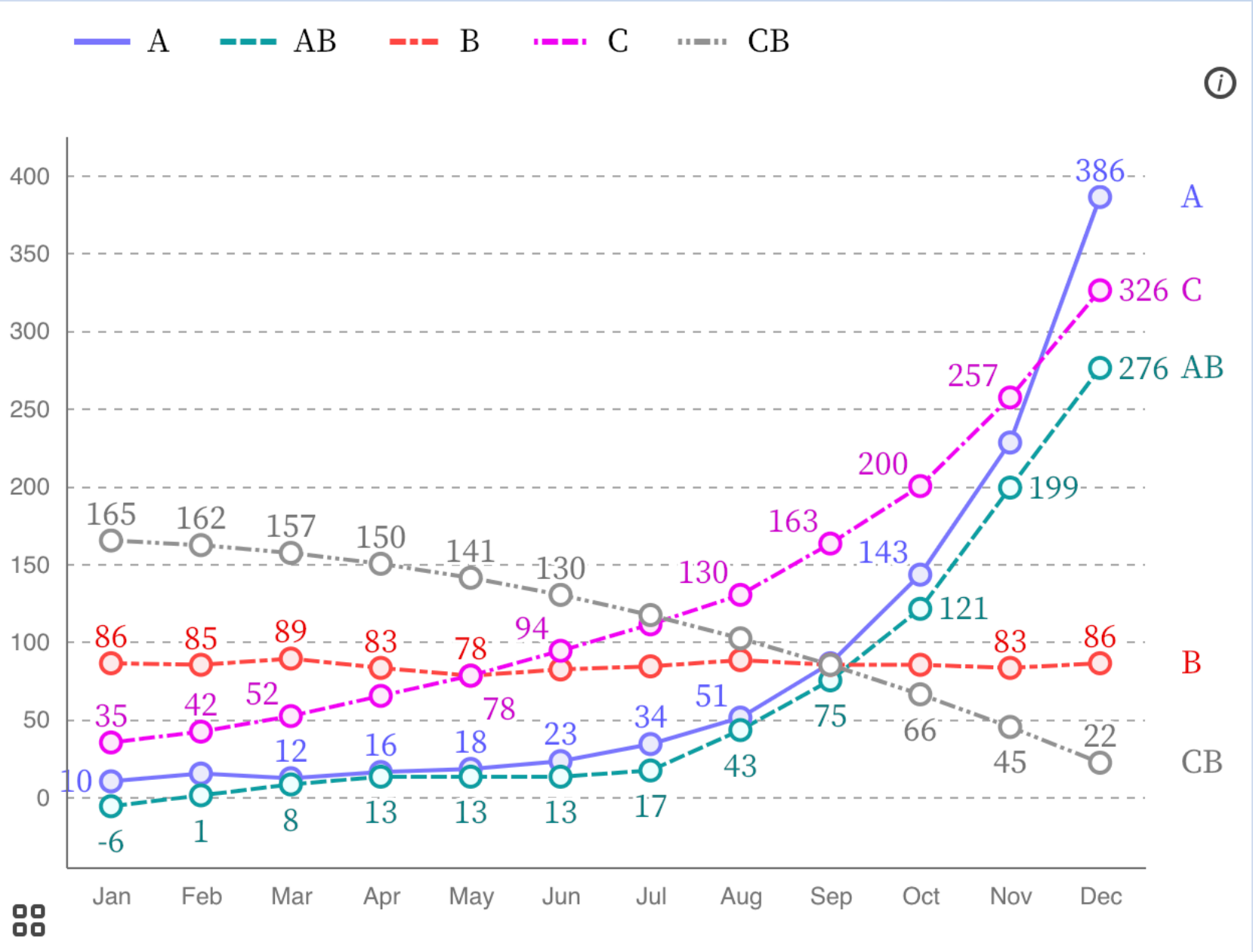
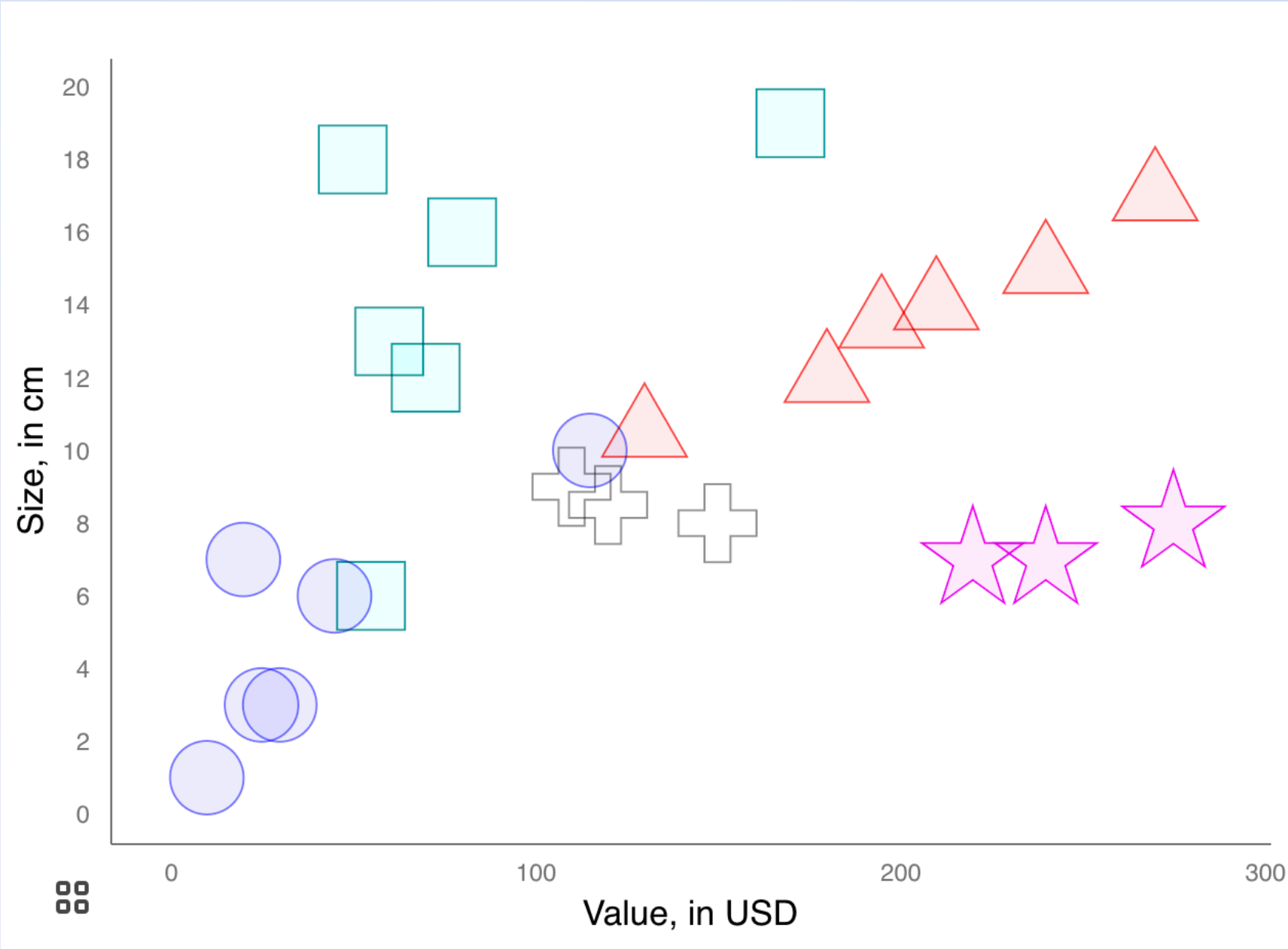
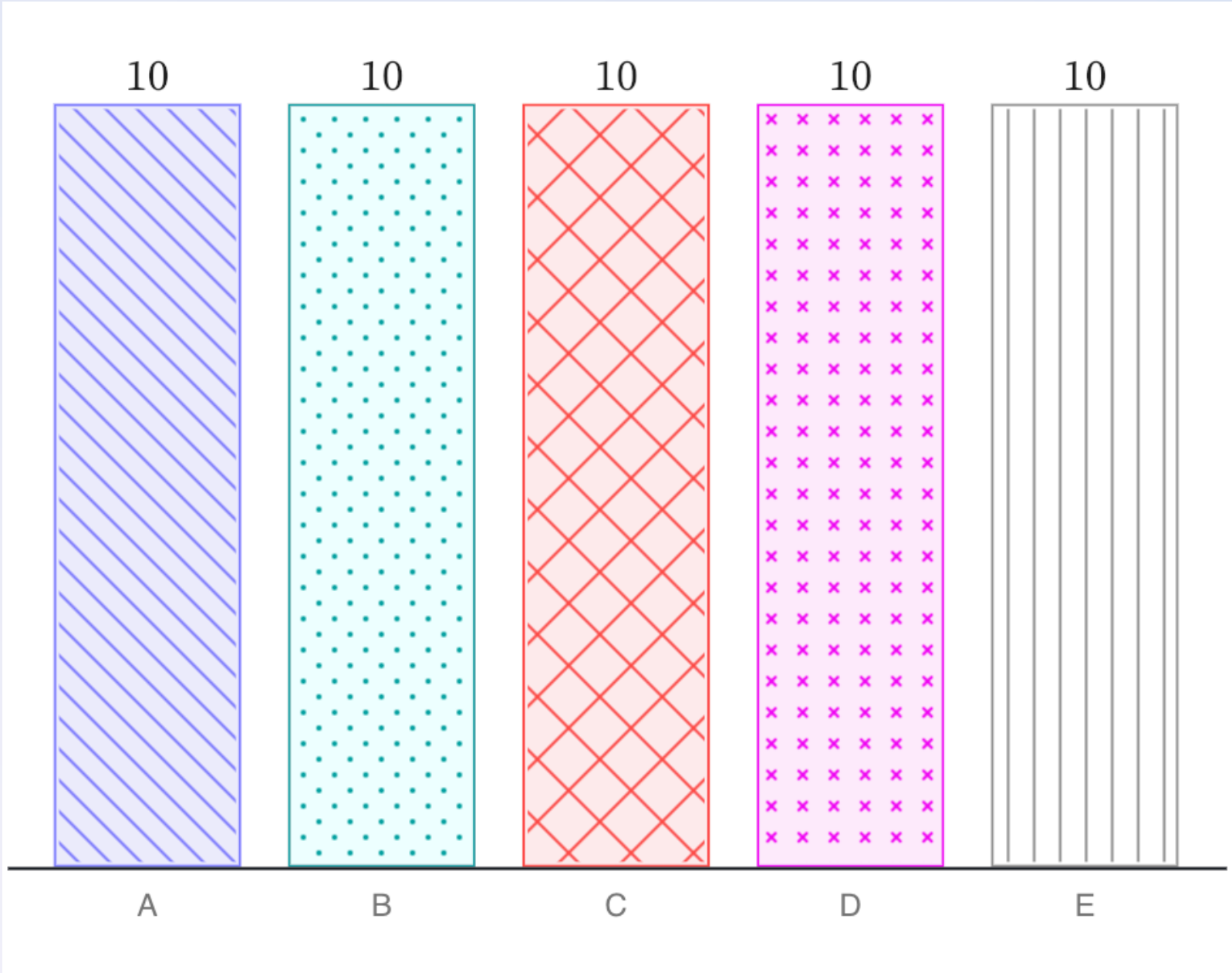


Source: Susie Lu + Elijah Meeks, circa 2017ish?

38

Selecting *textures* for semantic distinguishability

Source: Visa Chart Components, Frank Elavsky (2017-2019)



Selecting colors for JND

Source: Susie Lu + Elijah Meeks, circa 2017ish?

VIZ PALETTE

By: Elijah Meeks & Susie Lu

PICK

Use Chroma.js

Use Colorgical

Use ColorBrewer

Add

Replace

EDIT

7 Colors

Add

#hex

rgb

hsl

#ffd700

#ffb14e

#fa8775

#ea5f94

#cd34b5

#9d02d7

#0000ff

✕

✕

✕

✕

✕

✕

✕

GET

#hex

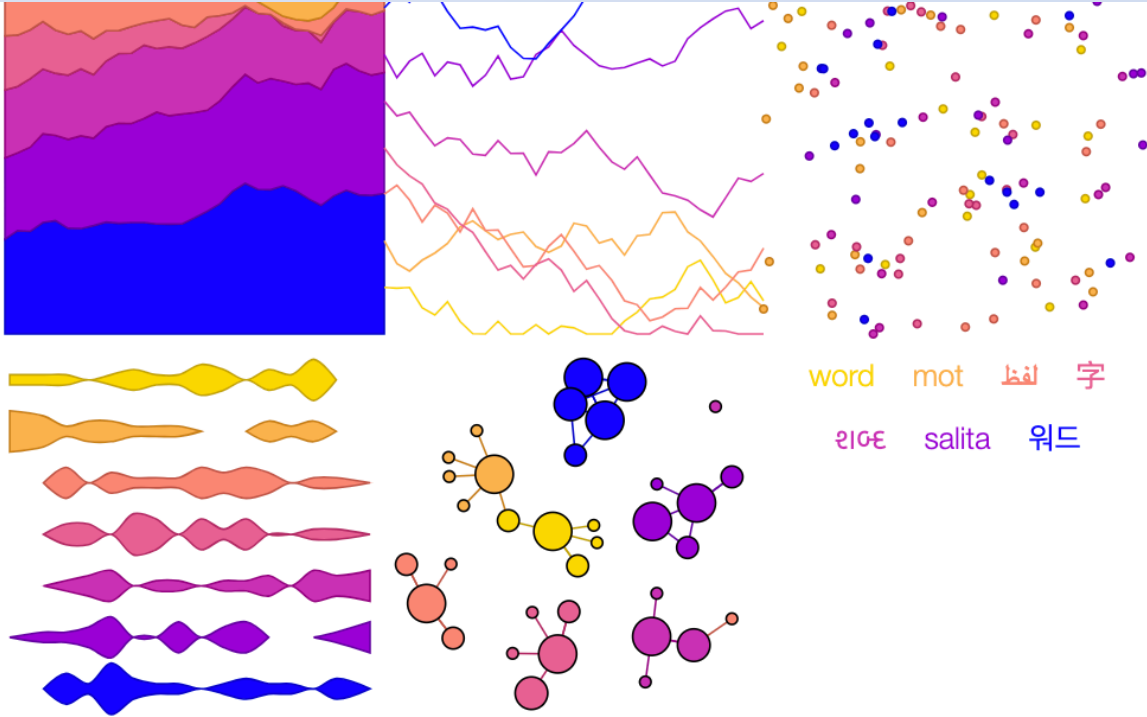
rgb

hsl

☒String quotes

☐Object with metadata

["#ffd700", "#ffb14e", "#fa8775", "#ea5f94", "#cd34b5", "#9d02d7", "#0000ff"]



COLOR REPORT

Arcs link colors difficult to tell apart as:

- Lines or small points
- Medium areas
- Large areas

#ea5f94	pink	• Minimize name conflicts for categorical palettes
#fa8775	light orange	
#ffb14e	orange	
#ffd700	gold	
#0000ff	indigo	
#cd34b5	magenta •	
#9d02d7	magenta •	

COLOR REPORT

Arcs link colors difficult to tell apart as:

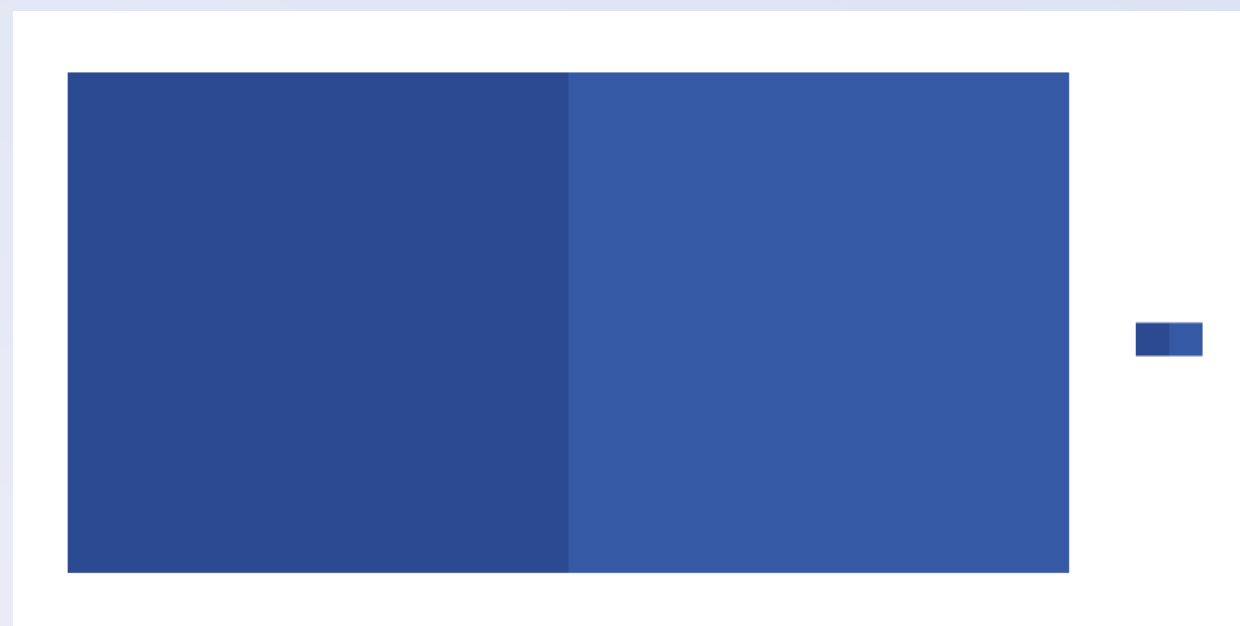
- Lines or small points
- Medium areas
- Large areas

#ea5f94	pink	• Minimize name conflicts for categorical palettes
#fa8775	light orange	
#ffb14e	orange	
#ffd700	gold	
#0000ff	indigo	
#cd34b5	magenta •	
#9d02d7	magenta •	

40

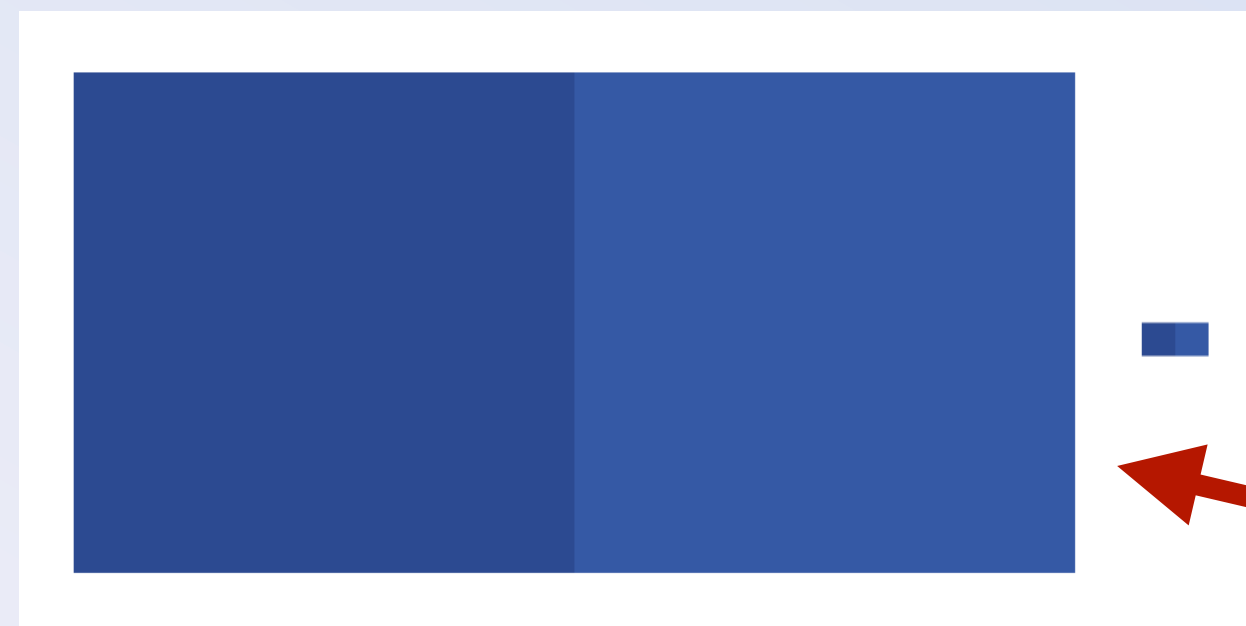
What is JND? (+ why does this matter for visualization accessibility in 2025?)

Source: Connor Gramazio, circa 2016ish?



What is JND? (+ why does this matter for visualization accessibility in 2025?)

Source: Connor Gramazio, circa 2016ish?



These both have the same contrast score! Yikes!

Contrast Checker

[Home](#) > [Resources](#) > Contrast Checker

Foreground		Background	
Hex Value		Hex Value	
#374E90		#415AA4	
Color Picker	Alpha	Color Picker	
<input type="color" value="#374E90"/>	1	<input type="color" value="#415AA4"/>	
Lightness		Lightness	
<input type="range" value="50%"/>		<input type="range" value="50%"/>	

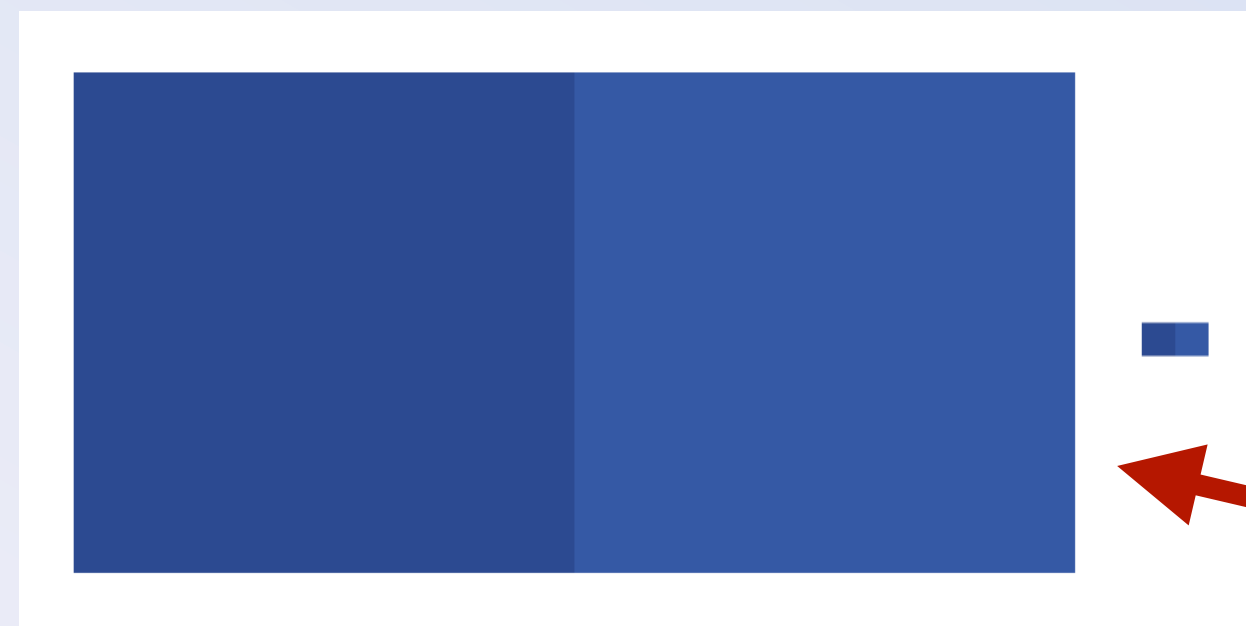
Contrast Ratio

1.21:1

[permalink](#)

What is JND? (+ why does this matter for visualization accessibility in 2025?)

Source: Connor Gramazio, circa 2016ish?



**Seriously: these standards
affect accessibility policy
for ~55% of the world**

Contrast Checker

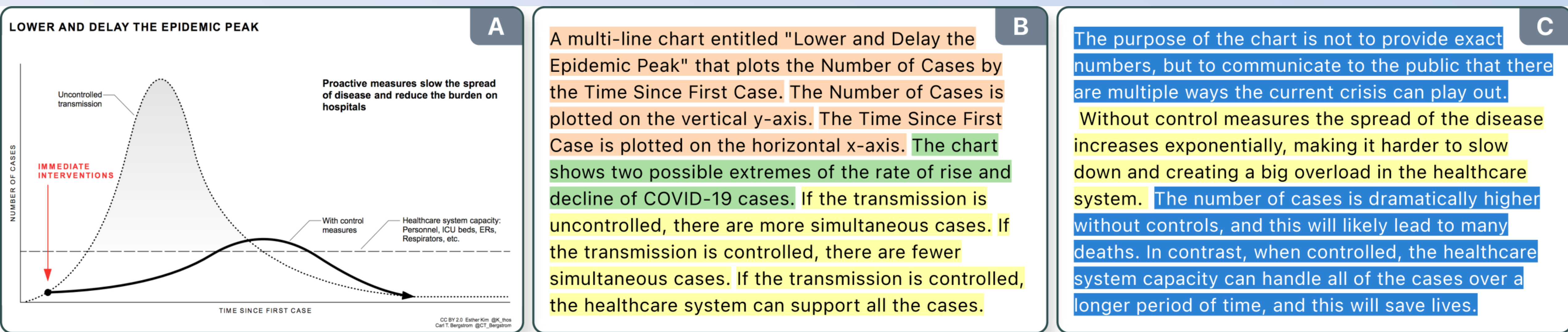
[Home](#) > [Resources](#) > Contrast Checker

Foreground	Background
Hex Value #374E90	Hex Value #415AA4
Color Picker 	Color Picker
Alpha 1	
Lightness 	Lightness
Contrast Ratio 1.21:1	
permalink	

Describing things

Chart descriptions with multi-layered semantics

Lundgard et al's *Semantic Levels* (2021)

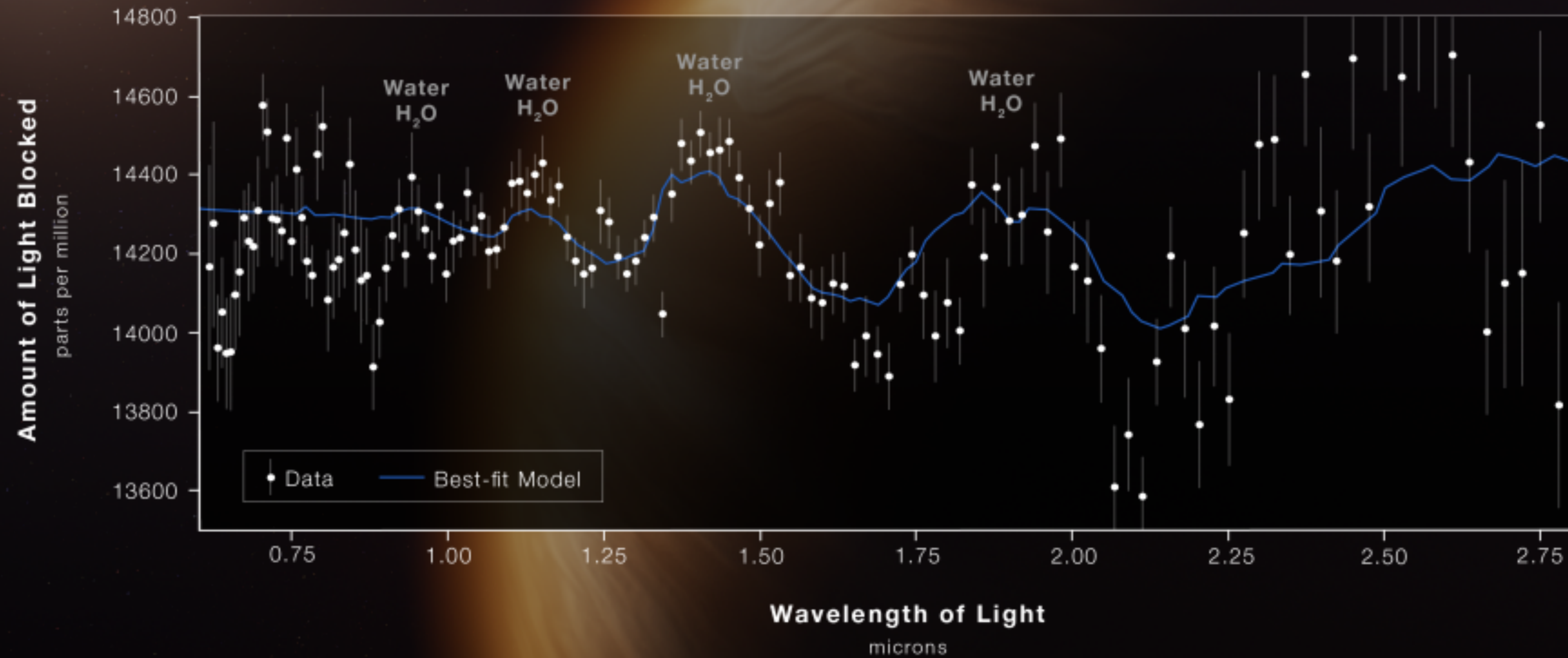




HOT GAS GIANT EXOPLANET WASP-96 b

ATMOSPHERE COMPOSITION

NIRISS | Single-Object Slitless Spectroscopy



Exoplanet WASP-96 b (NIRISS Transmission Spectrum)

Extended Description

Graphic titled "Hot Gas Giant Exoplanet WASP-96 b Atmosphere Composition, NIRISS Single-Object Slitless Spectroscopy."

The graphic shows a transmission spectrum in the form of a graph of the Amount of Light Blocked by the planet's atmosphere in parts per million on the vertical *y*-axis versus Wavelength of Light in microns on the horizontal *x*-axis.

Graph

Axes

The *y*-axis ranges from 13,500 parts per million (less light blocked) at the bottom to 14,800 parts per million (more light blocked) at the top, with labeled tick marks are labeled every 200 parts per million, starting at 13,600.

The *x*-axis ranges from 0.6 microns on the left to 2.8 microns on the right, with labeled tick marks every 0.25 microns, starting at 0.75 microns.

Key

The graph includes a key showing that the solid white circles centered on gray vertical lines represent data points, and a blue solid line represents a best-fit model.

Data and Model

The graph consists of 141 data points, each with a gray error bar. The points range in value from 13,589 to 14,883 parts per million. The data points are not connected. They follow a jagged trend from left to right, with a number of broad peaks and valleys. The lengths of the error bars vary from a minimum of plus or minus 43 to a maximum of plus or minus 314. The error bars are smallest between about 1 and 1.3 microns, generally increasing in length toward the left from 1 to 0.6 microns, and toward the right from about 1.3 to 2.8 microns.

A solid blue line with several prominent peaks and valleys represents the best-fit model. The model begins at the far left with a very slight downward slope toward the right with a small peak around 0.95 microns, and another peak at about 1.15 microns. The line then becomes more sinuous, forming a taller, broader peak centered at about 1.4 microns and a slightly shorter broad peak at 1.9 microns. Starting around 2.15 microns, the line trends back upward with a wavy slope of about 30 degrees.

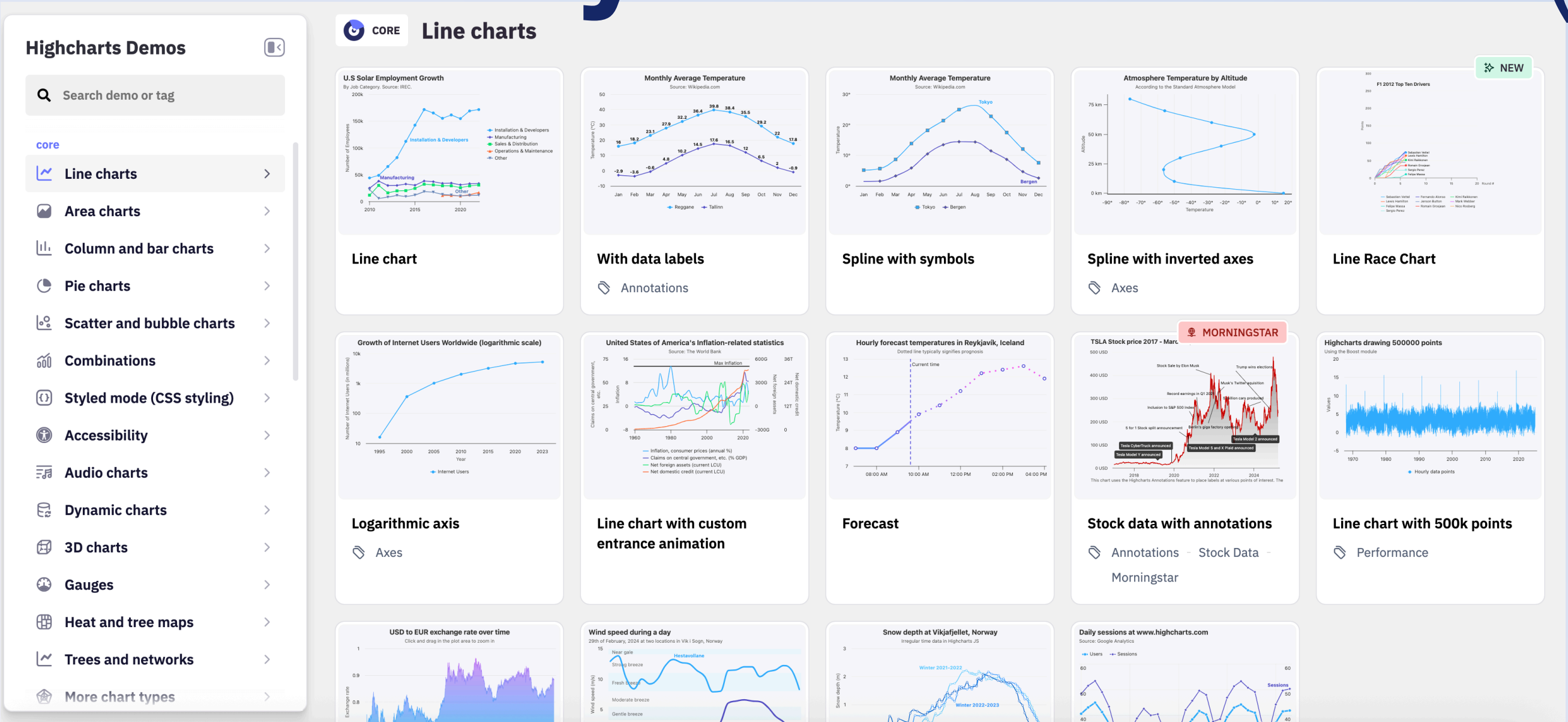
The blue best-fit model line generally follows the trend of the data. It intersects some data points, but does not match the data perfectly. The match between the model and data is clearest between about 0.9 and 1.65 microns.

Zong et al's *Rich Screen Reader Experiences* (2022)



Rich navigation (a short history)

2015: “beyond the table” (highcharts)



Rich navigation (a short history)

2015 (highcharts)

Highcharts Demos

Search demo or tag

core

Line charts

Area charts

Column and bar charts

Pie charts

Scatter and bubble charts

Combinations

Styled mode (CSS styling)

Accessibility

Audio charts

Dynamic charts

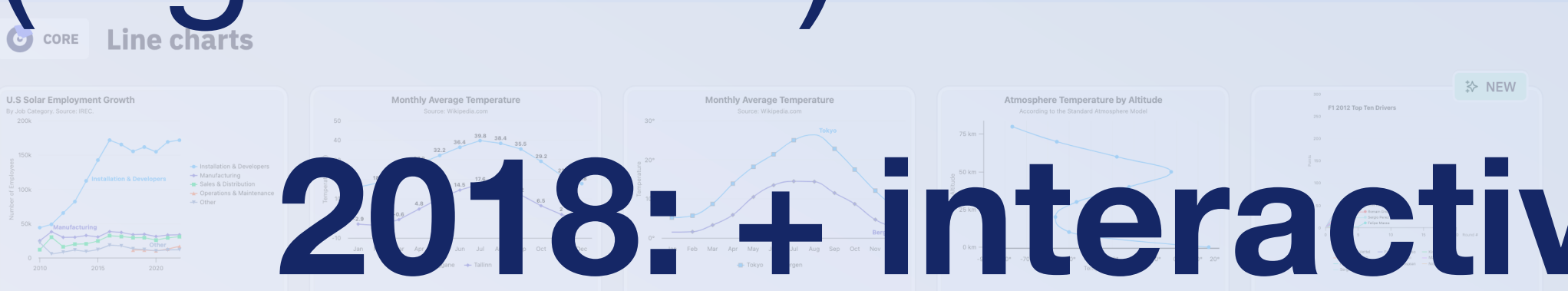
3D charts

Gauges

Heat and tree maps

Trees and networks

More chart types



2018: + interactivity (visa charts)

Visa

Product Design System

About VPDS

What's new

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Contributing

Base elements

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Data visualization

Visa Chart Components

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Data visualization principles

Selecting a chart

Selecting a chart

Learn how to find the right chart for your audience's analysis needs.

Selecting the right chart requires determining the key purpose of the chart and tailoring it to your audience's needs.

Start by understanding the chart types available in our system. Once you're familiar, you can select a chart design from our collection of examples by defining the key insight your chart should provide, and determining the focus elements. Finally, optimize your chart's design to direct attention to the most important information.

Understand the chart types

Chart types refer to the broad categories of visual representations used to display data. Each chart type is best-suited for particular kinds of data analysis or insights. Charts help users understand and interpret data by leveraging simplified visual representations that highlight patterns and relationships.

BAR CHART

LINE CHART

HEAT MAP

SCATTER PLOT

ON THIS PAGE

Understand the chart types

Selecting a chart

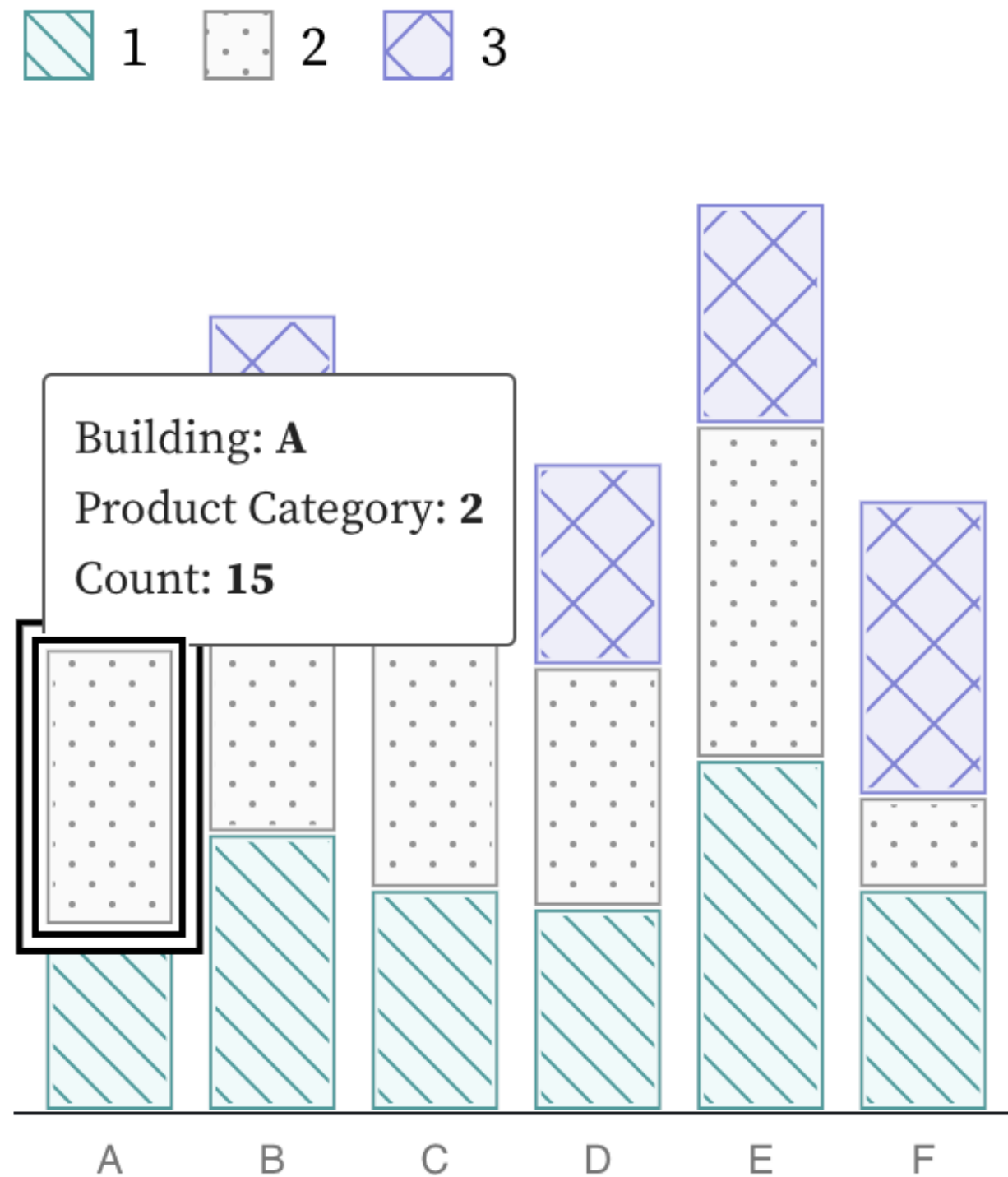
Step 1: Choose a key insight category

Step 2: Determine the focus

Step 3: Refine the chart

Alt text should communicate operability

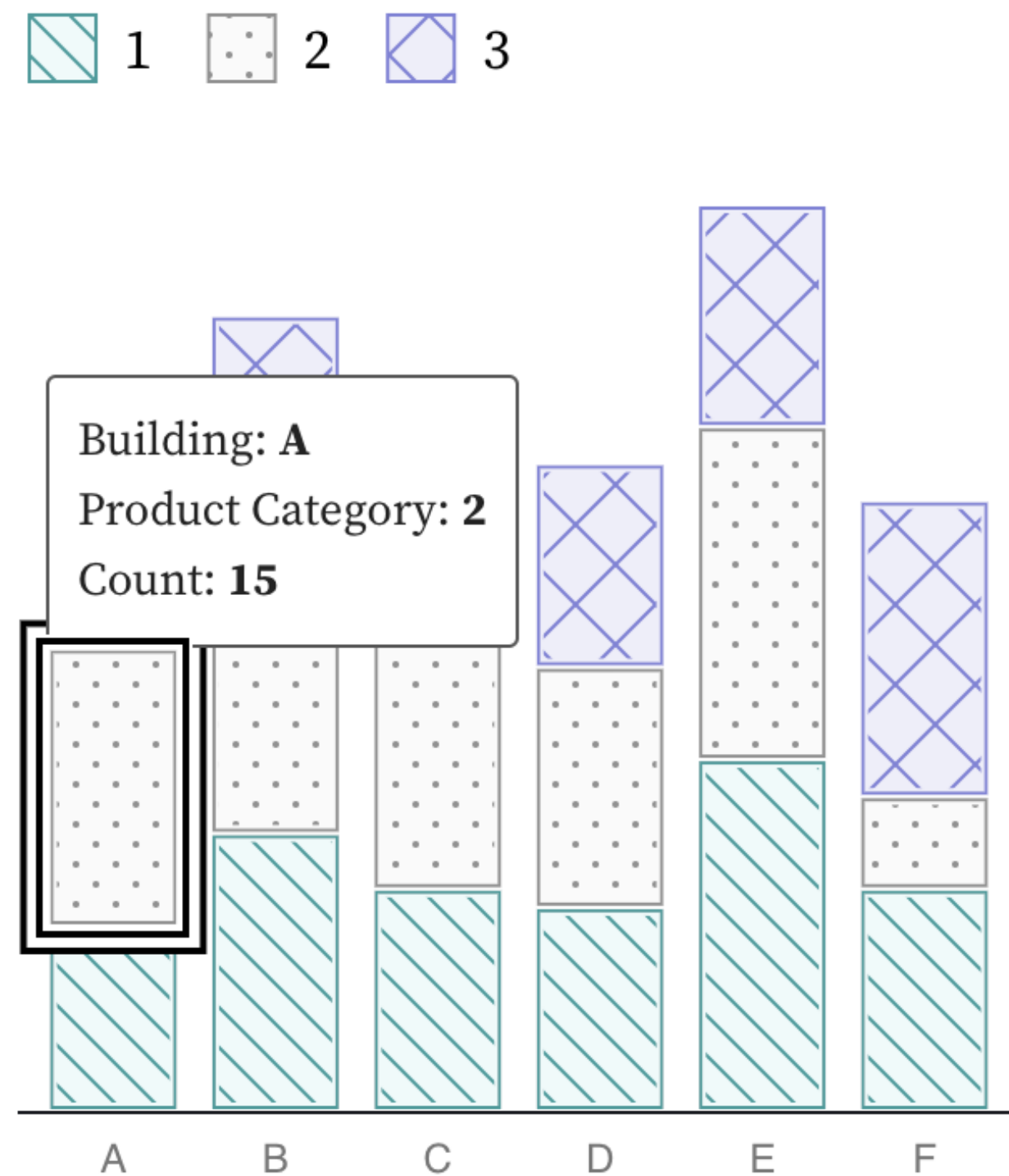
Source: Visa Chart Components, Frank Elavsky (2017-2019)



× Building A. Product Category 2.
Count 15. Bar 2 of 3. Image.

Semantics matter

Source: Visa Chart Components, Frank Elavsky (2017-2019)



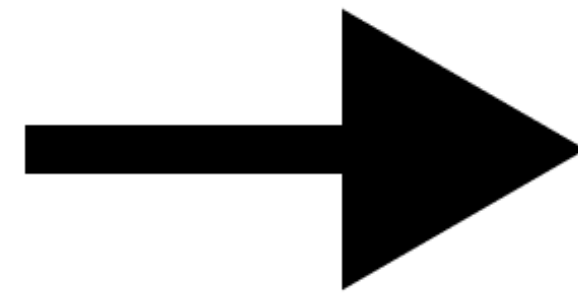
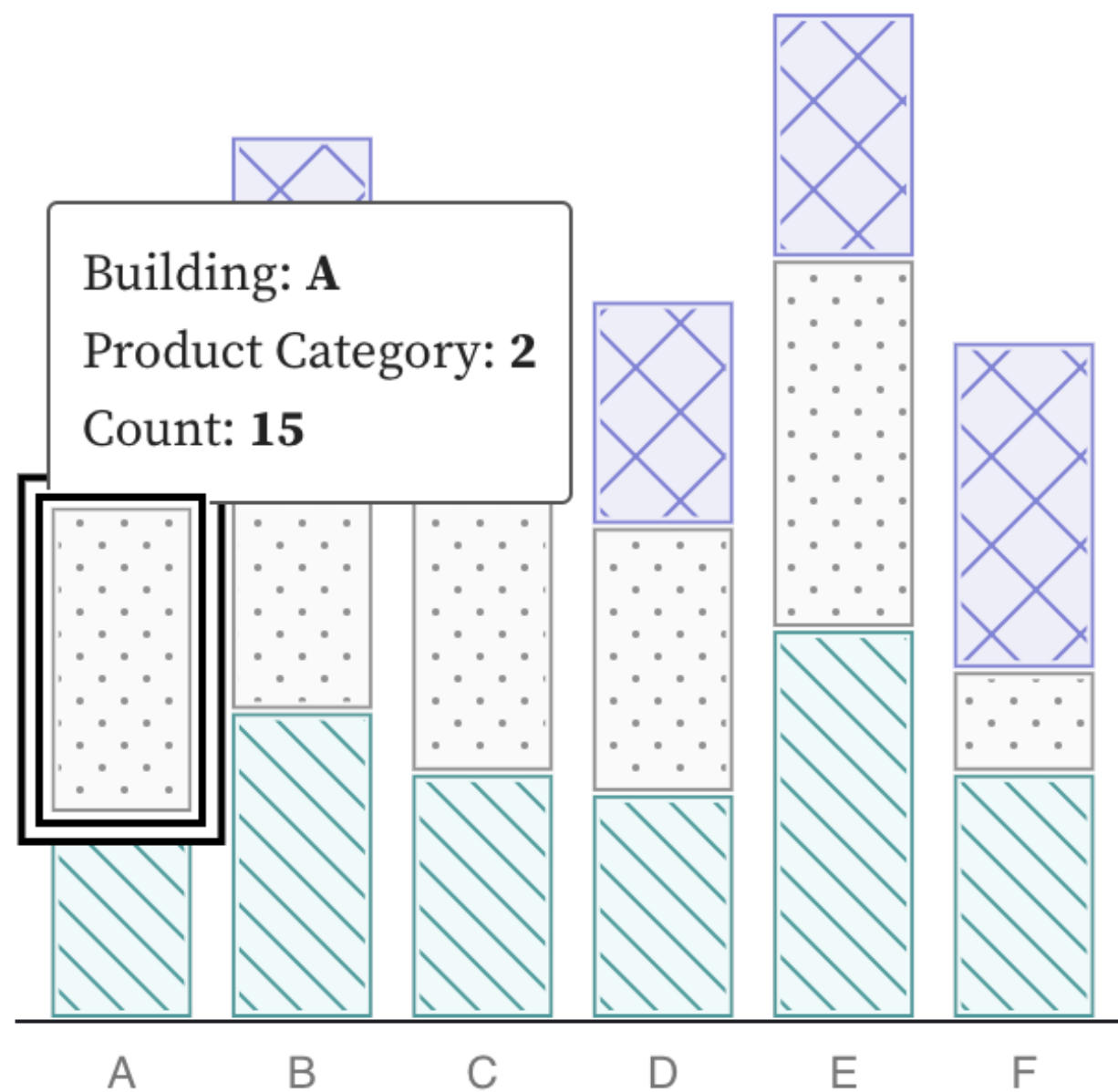
× Building A. Product Category 2.
Count 15. Bar 2 of 3. Image.

“Image” doesn’t signal
interactivity!

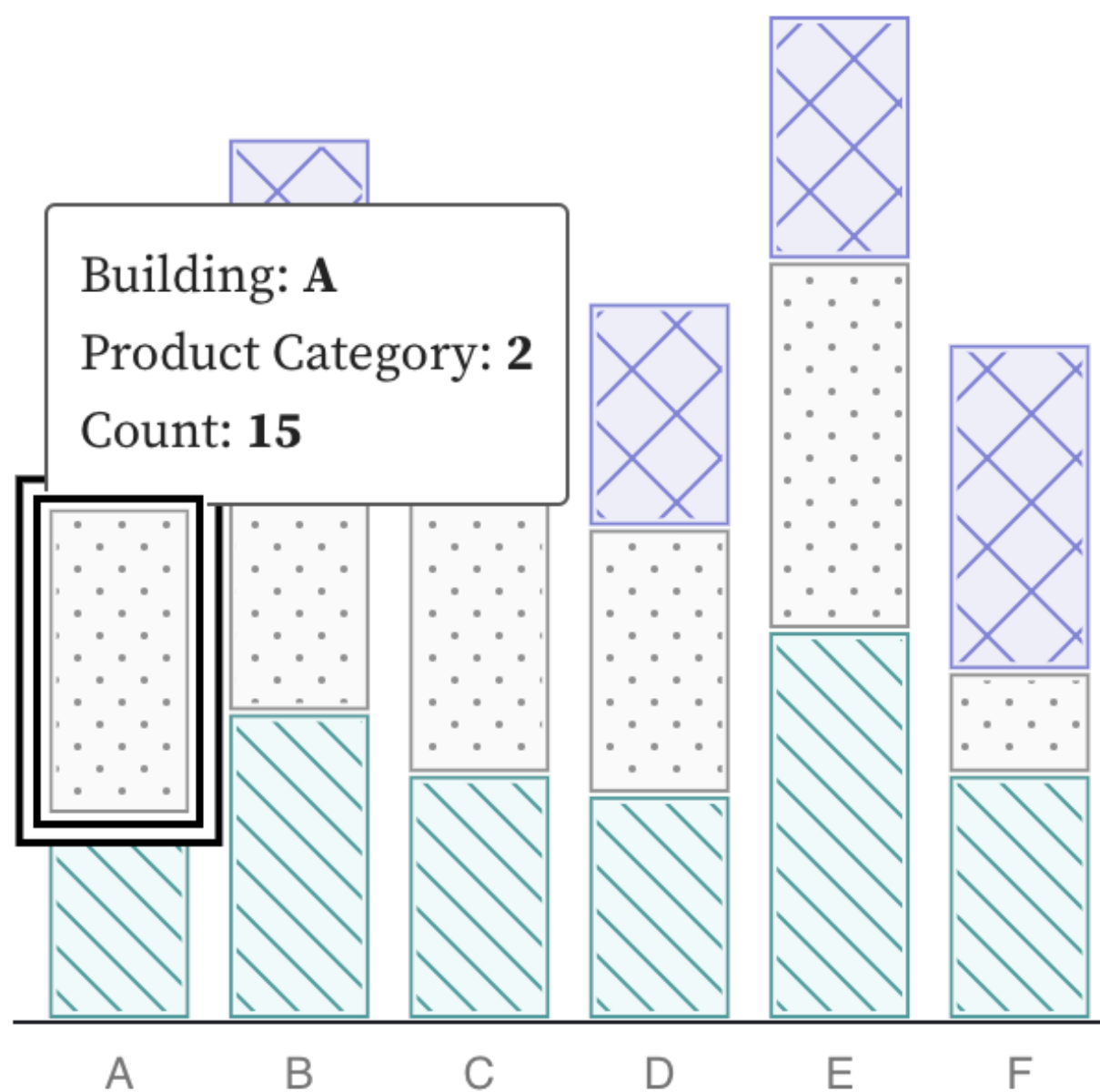
ARIA semantics are standardized

Source: Visa Chart Components, Frank Elavsky (2017-2019)

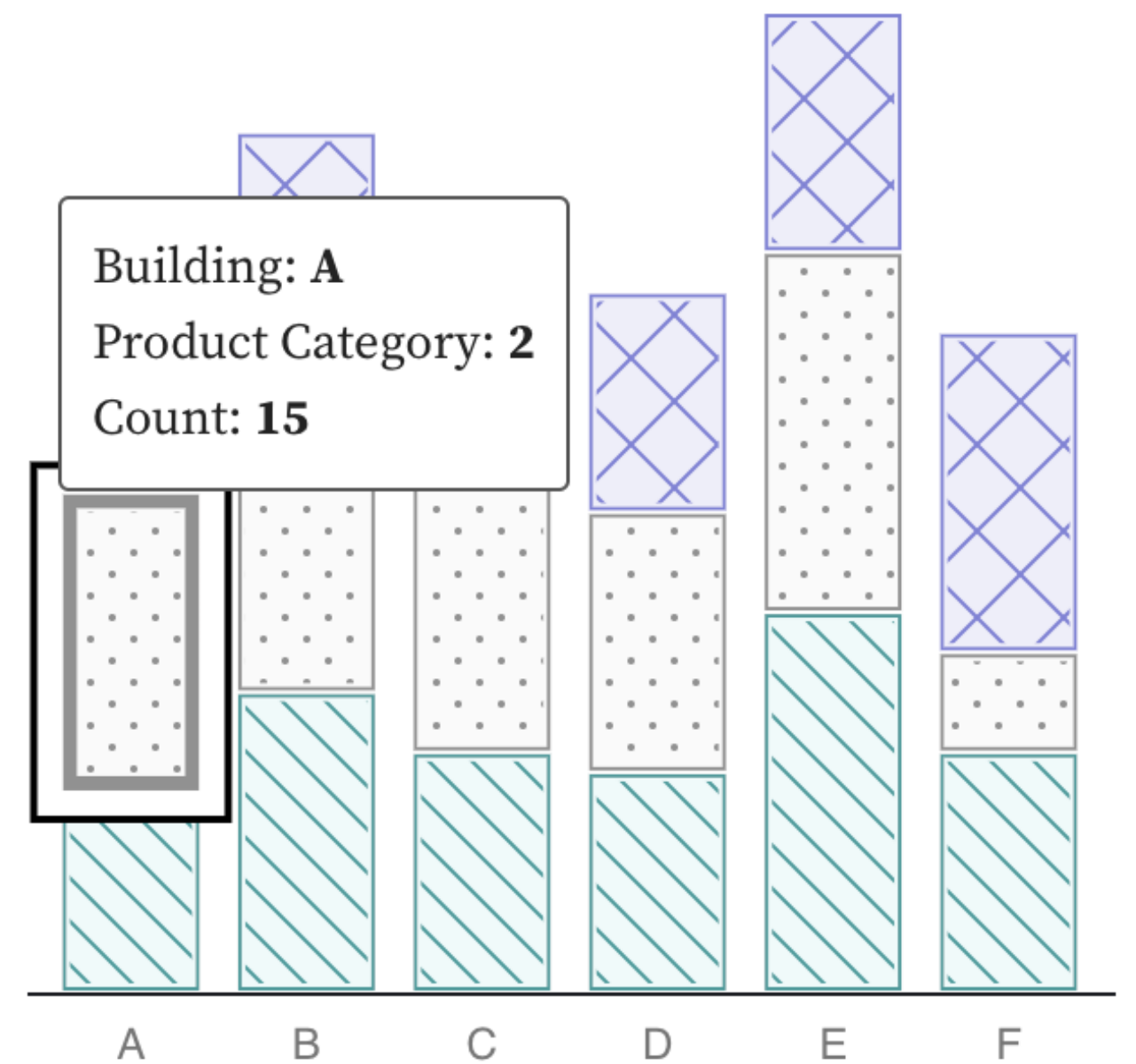
1 2 3



1 2 3



1 2 3



× Building A. Product Category 2.
Count 15. Bar 2 of 3. Image.

× Building A. Product Category
2. Count 15. Bar 2 of 3., toggle
button

× selected, Building A. Product
Category 2. Count 15. Bar 2 of
3., toggle button

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2015 (highcharts)

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CORE

Line charts

U.S. Solar Employment Growth

Monthly Average Temperature

Monthly Average Temperature

Atmosphere Temperature by Altitude

F1 2012 Top Ten Drivers

Line chart

Spline with symbols

Spline with inverted axes

Line Race Chart

2018 (visa charts)

With Product Design System

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Line chart with custom entrance animation

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Wind speed during a day

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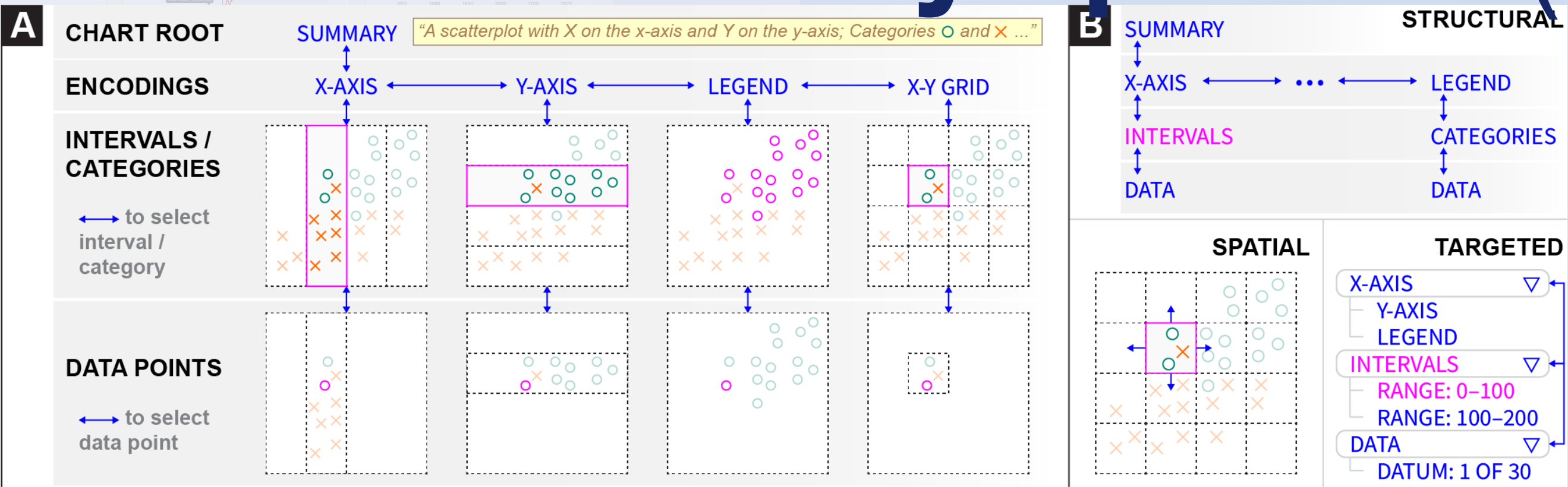
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2022: not library specific (olli)



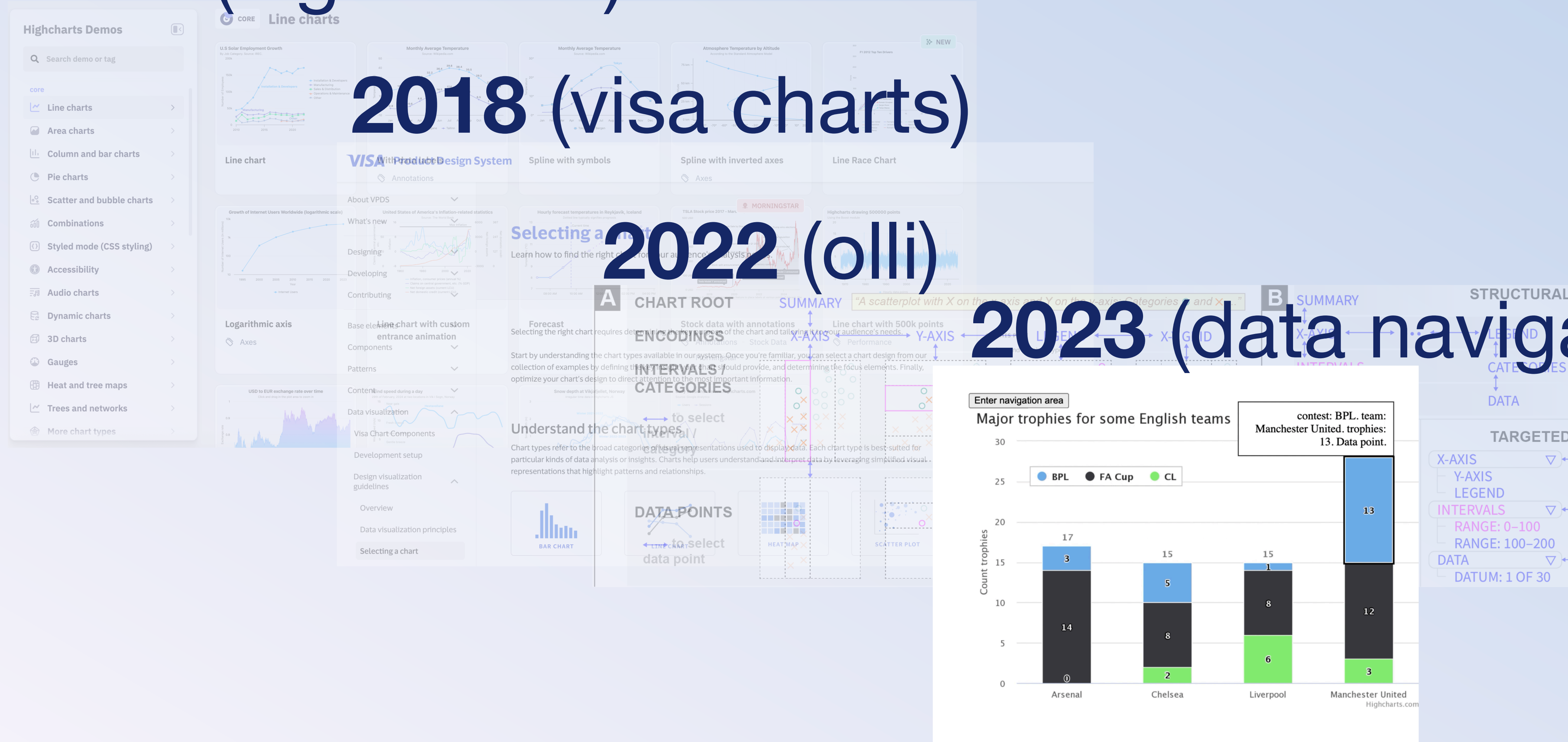
Rich navigation (a short history)

2015 (highcharts)

2018 (visa charts)

2022 (olli)

2023 (data navigator)



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2018 (visa charts)

Growth of Internet Users Worldwide (logarithmic scale)

United States of America's Inflation-related statistics

Hourly forecast temperatures in Reykjavik, Iceland

TSLA Stock price 2017 - March

Highcharts drawing 500000 points

Logarithmic axis

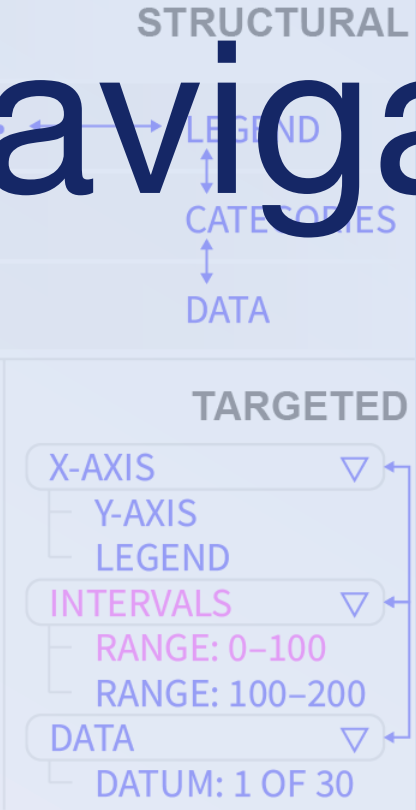
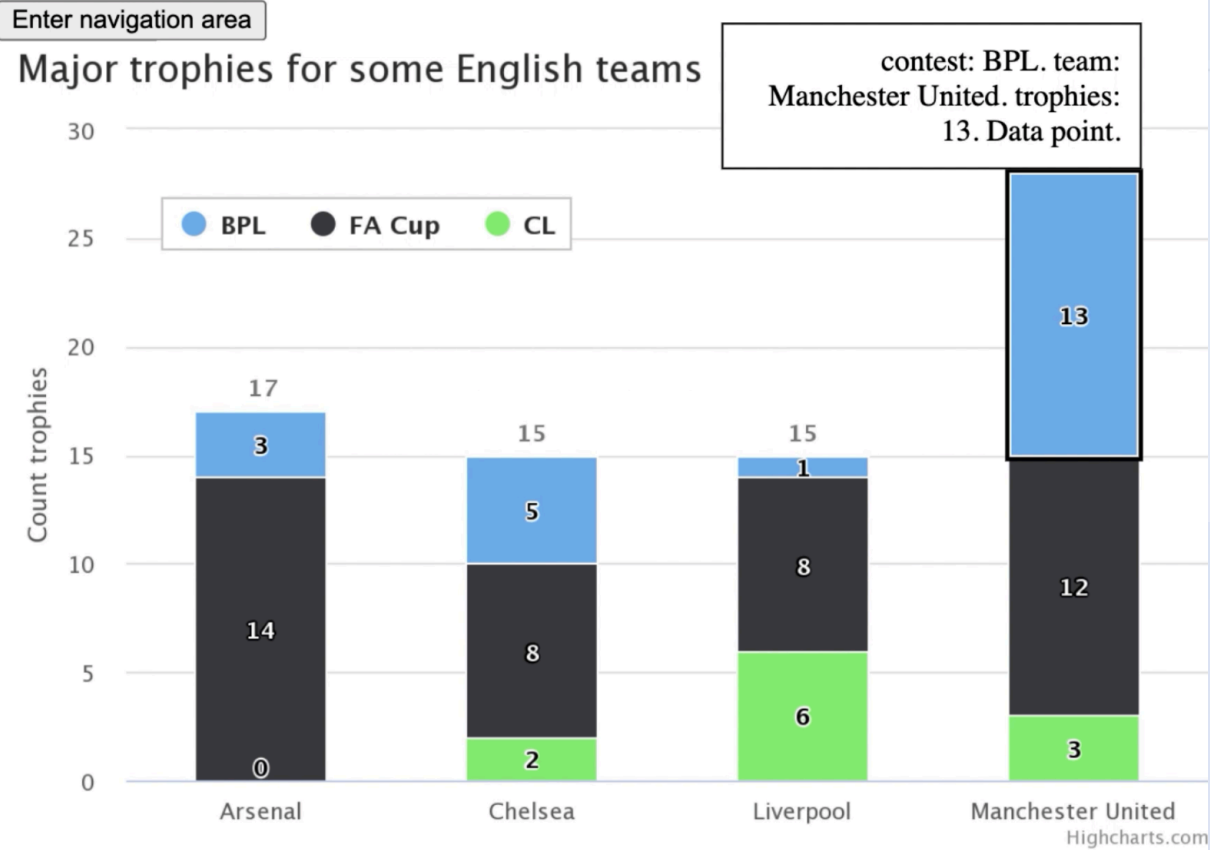
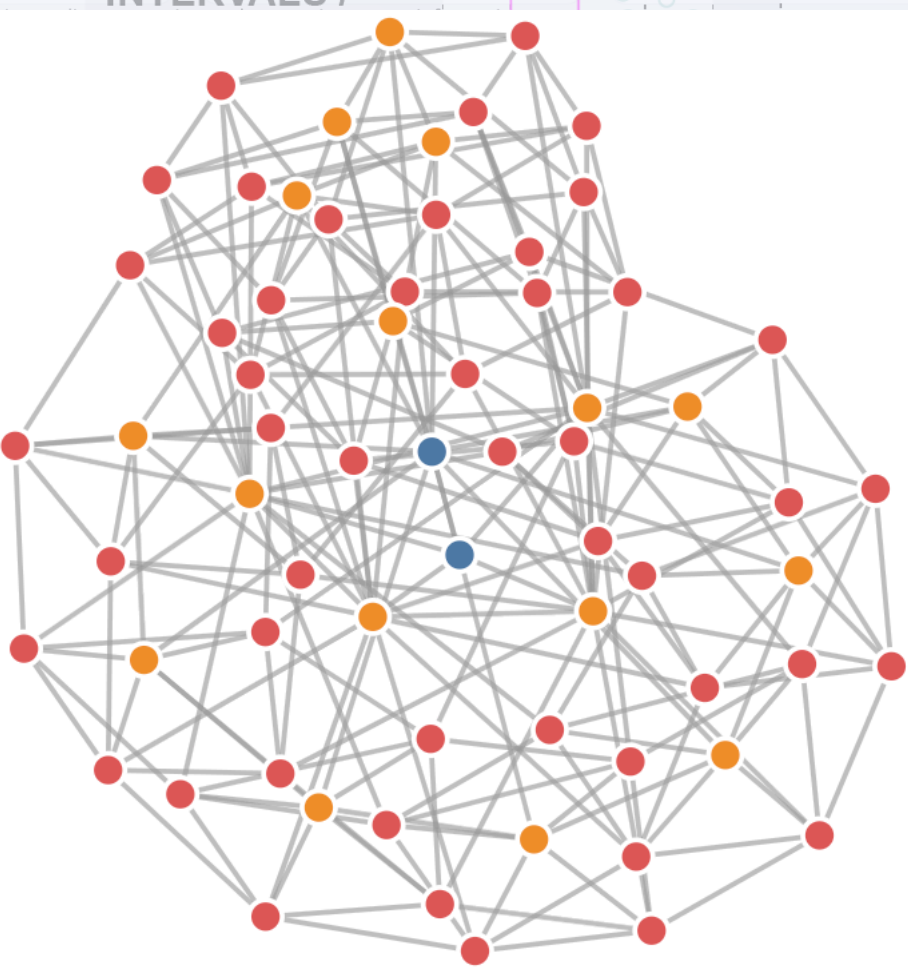
Line chart with custom entrance animation

Forecast

Understanding

2022 (olli)

2023 (data navigator)



Rich navigation (a short history)

2015 (highcharts)

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Search demo or tag

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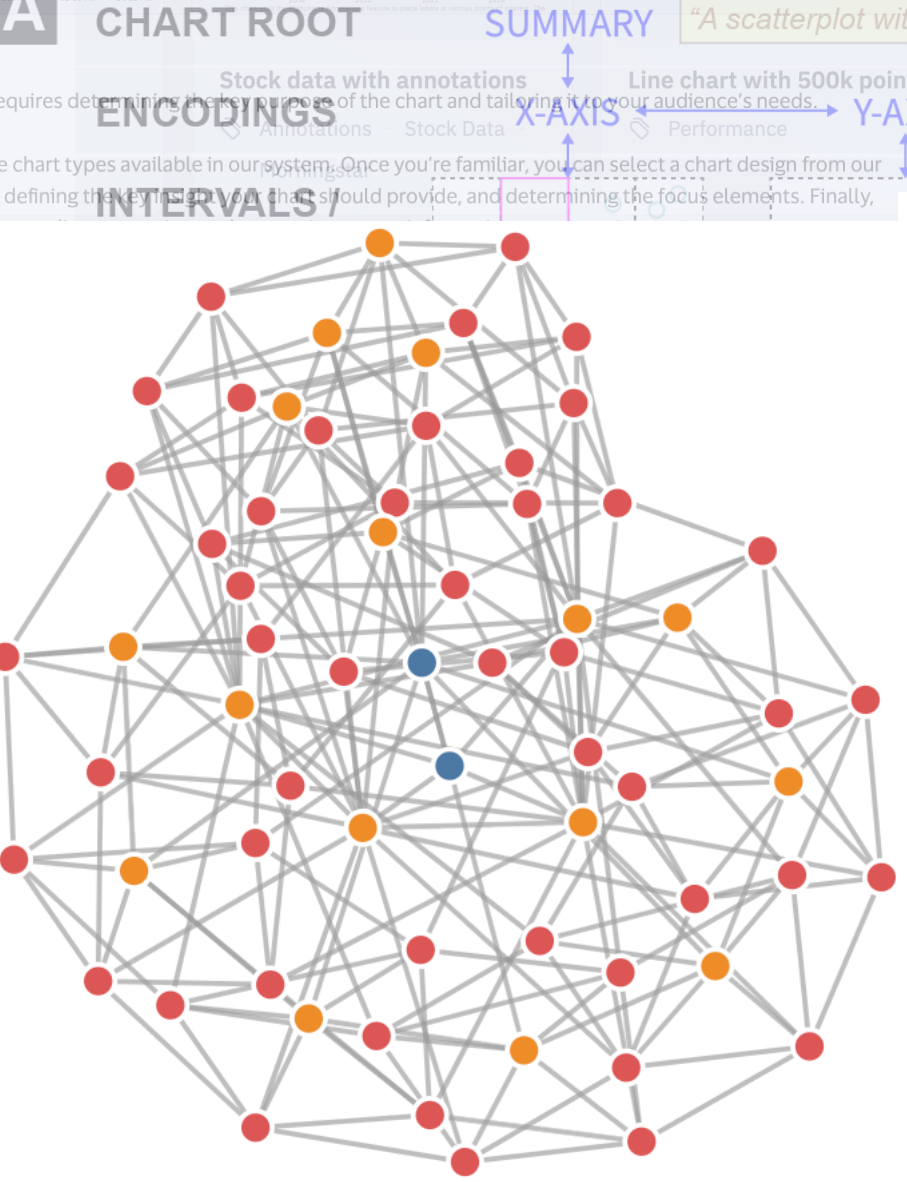
Logarithmic axis

Line chart with custom entrance animation

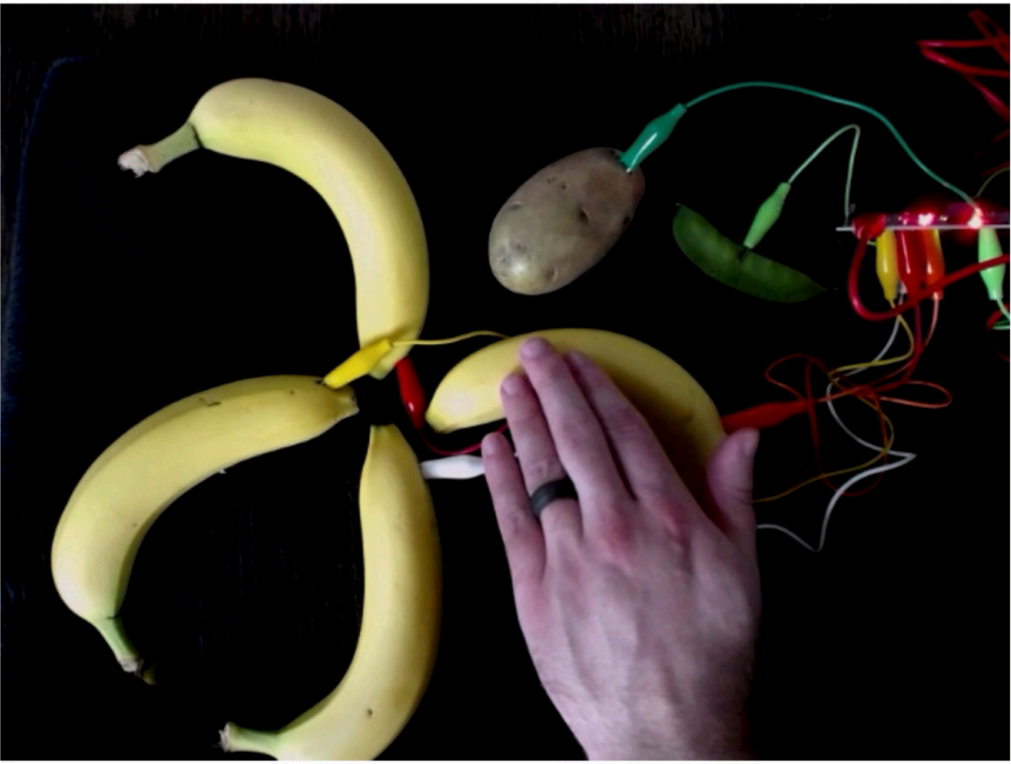
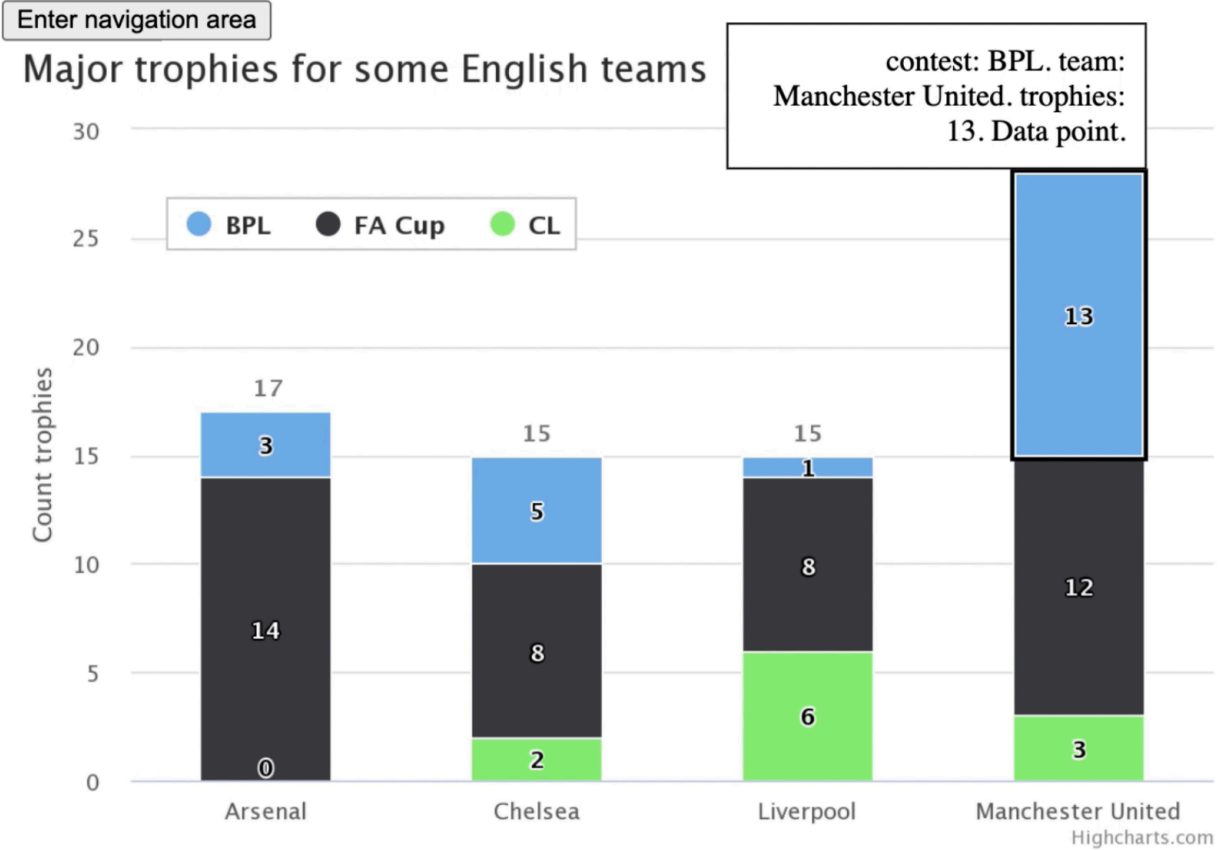
Forecast

Understanding

2022 (olli)



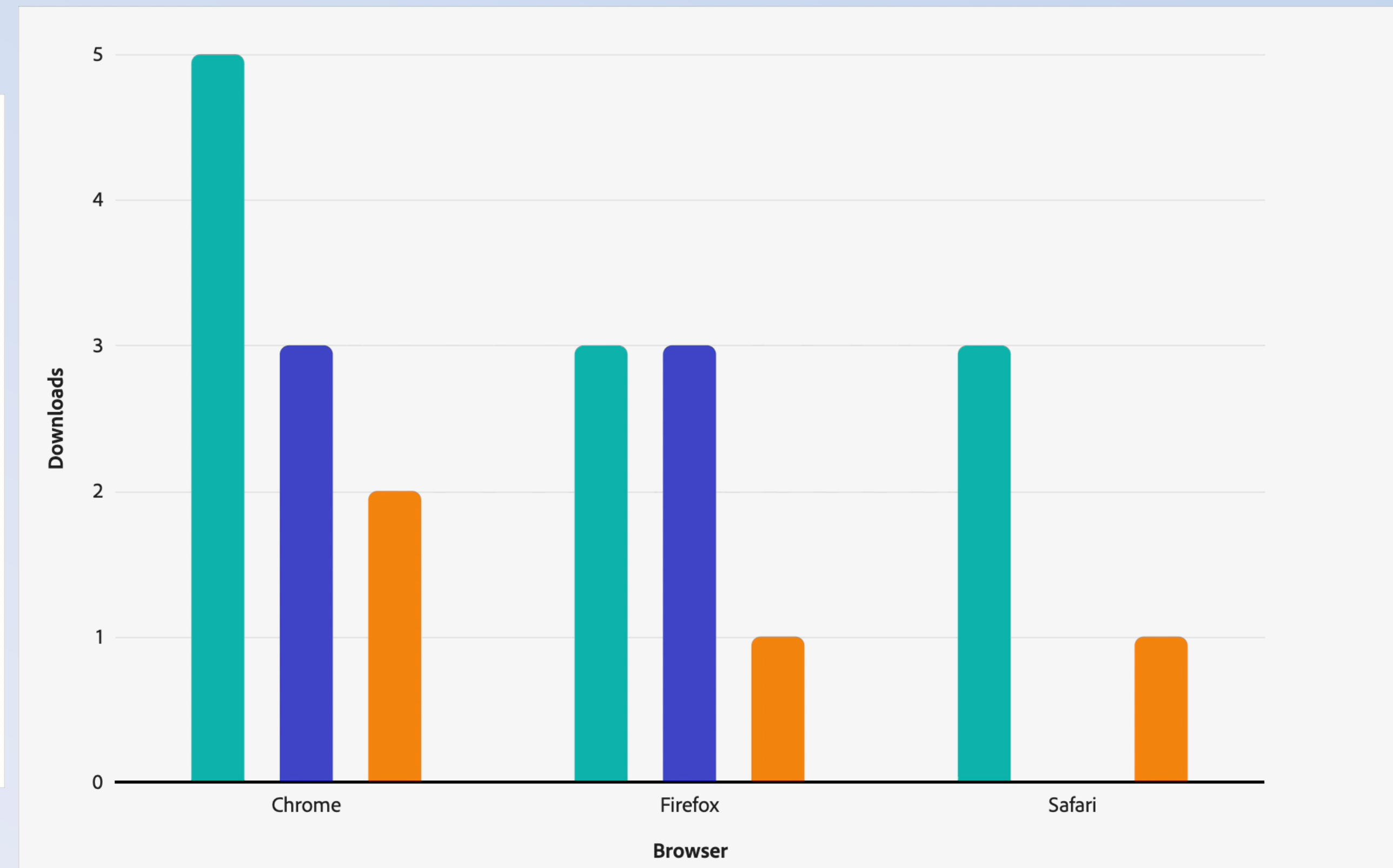
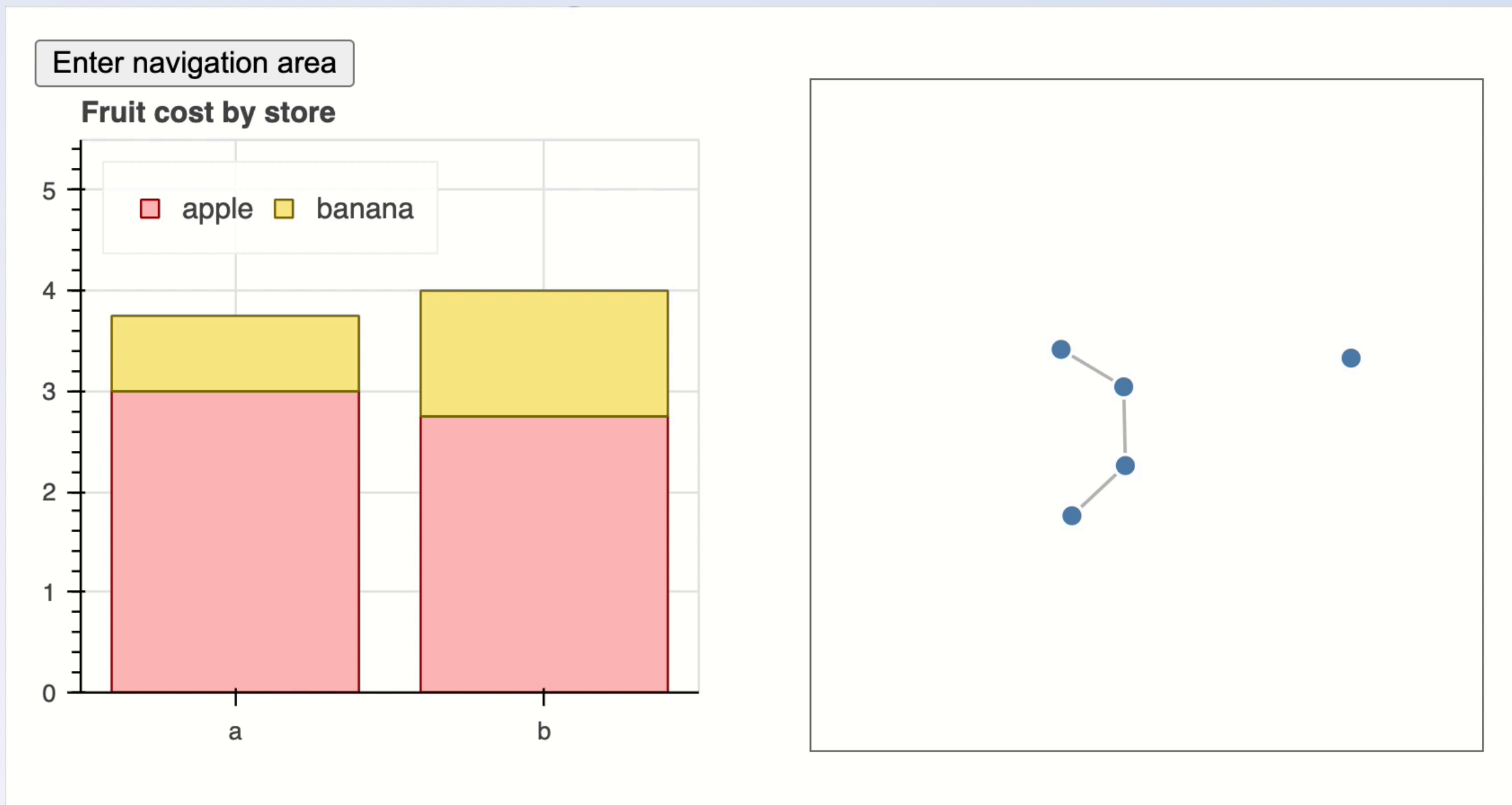
2023 (data navigator)



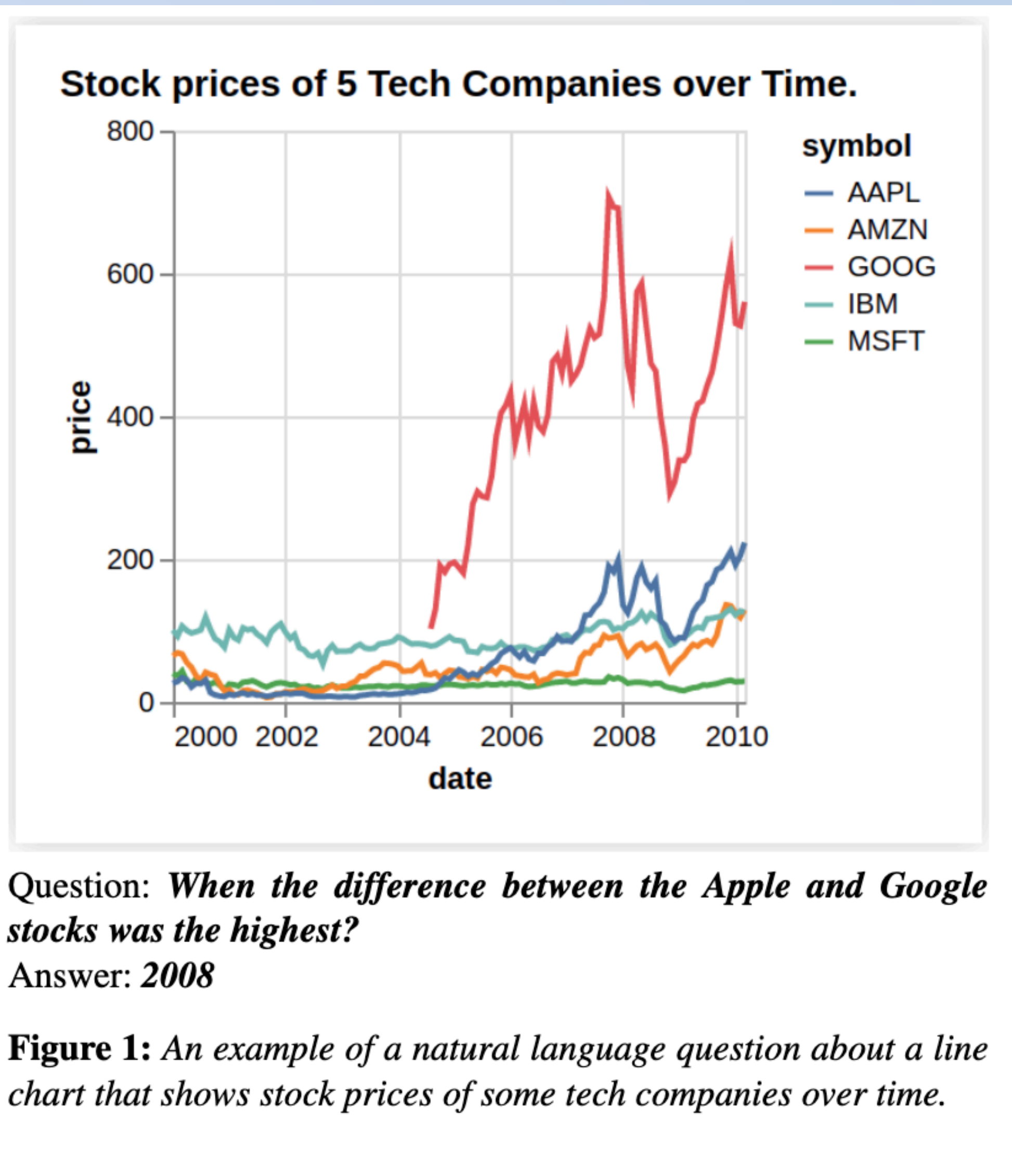
Data Navigator: Empowering practitioners

Bokeh, a python visualization library, and

React Spectrum Charts, Adobe's visualization design system



I have yet to see
conversational
visualizations in
the wild, but the
research is there!
VoxLens, VizAbility, “Blind
question answering,” etc



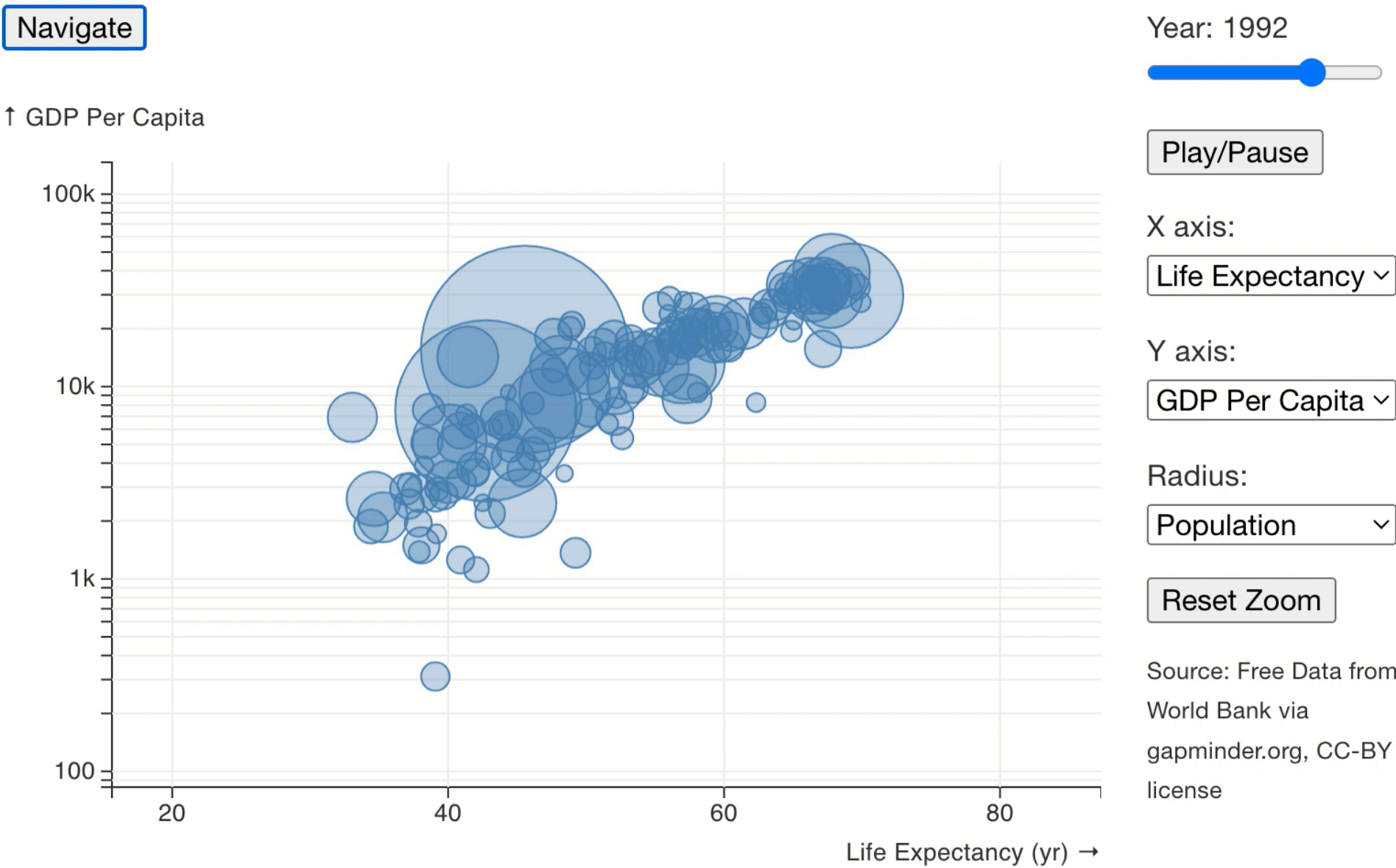
Counterpoint: navigating animations

Sivaraman's *Counterpoint* (2024)



Example: Accessible Gapminder Chart

Below is a responsive, screen-reader-navigable version of the chart shown on the [homepage](#). Press Navigate to enter keyboard navigation. Or, change your “prefers reduced motion” system setting to see fade animations instead of motion.



Opt-out of visualization scrollytelling

Amaka, Thomas, + Elavsky (2021)

The Pudding

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Story by
[Ofunne Amaka](#)
Data & Code by
[Amber Thomas](#)
March 2021

HOW THE
NAMES OF
6,816
COMPLEXION
PRODUCTS
CAN REVEAL
BIAS IN
BEAUTY

First Place. Lead Role. Number One. When things are arranged in a sequence, we have a mild obsession with being the “first.” You want the blue ribbon. To be on the

NUDE & NATURAL

As a siloed event, there is absolutely nothing wrong with describing the color of a foundation shade as “nude” or “natural”. After all, a foundation is meant to mimic the color of your skin. But problems can arise if these words aren’t used to name shades consistently across the color spectrum.

The next graphics in this story will utilize scroll-driven animations. Use this toggle to disable this and view static graphics instead.

Animations are

on off

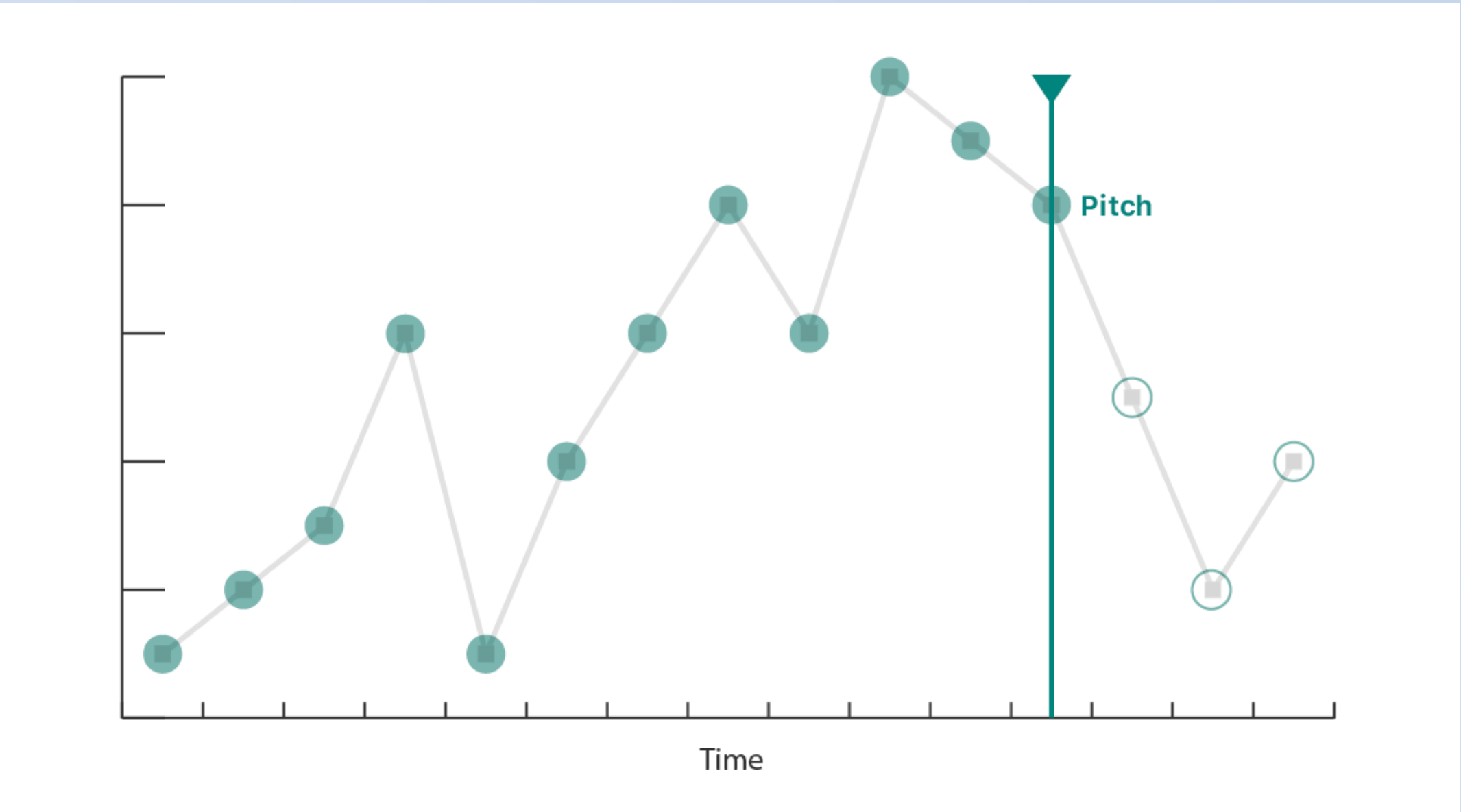
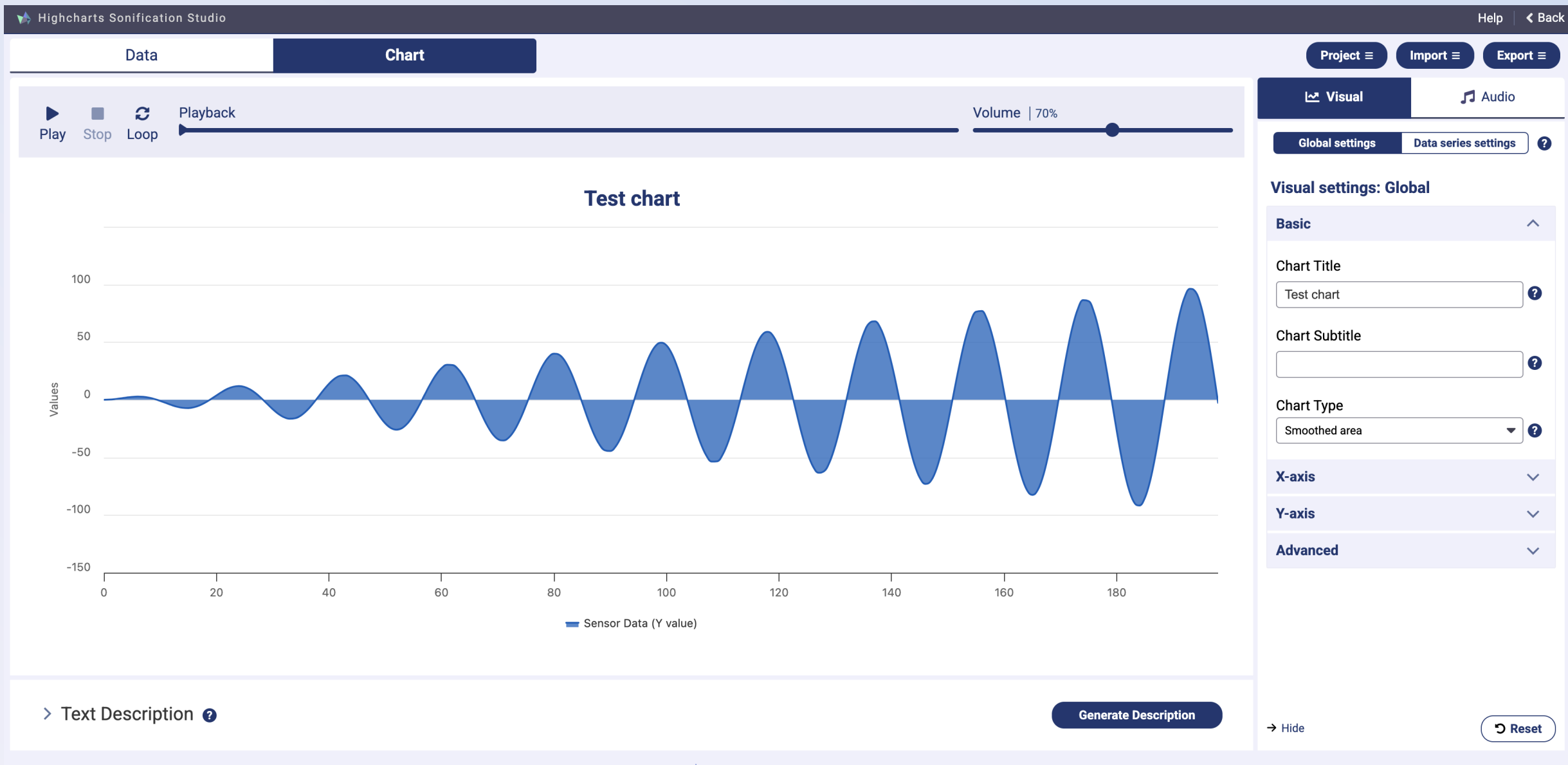
We identified 110 shades from 73 products that contained the word “nude” in the name.

110 shades with "nude" in the name

Non-visual, non-text modalities

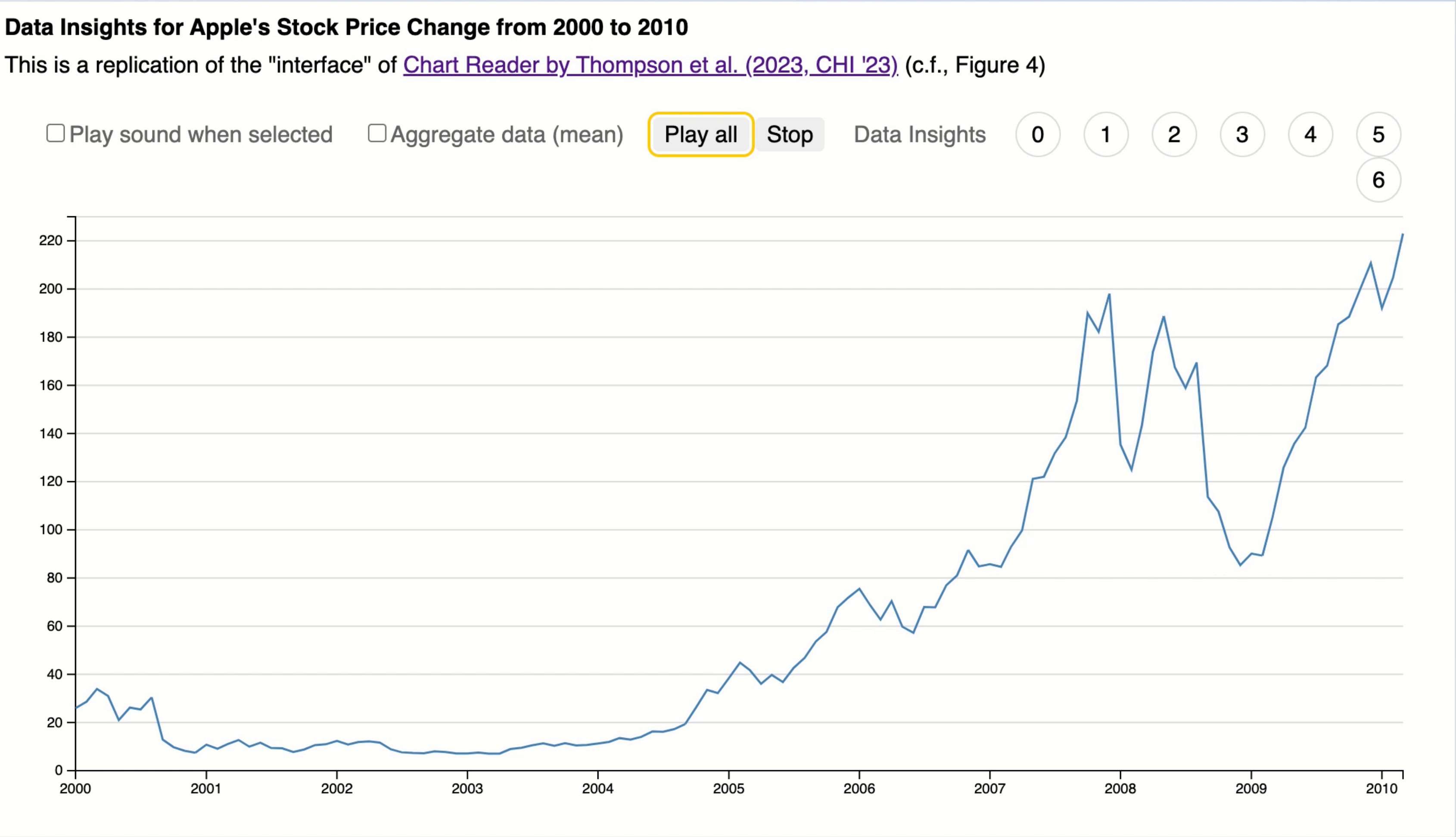
Sonification at scale

Highcharts (2018ish), Apple (WWDC 2021)



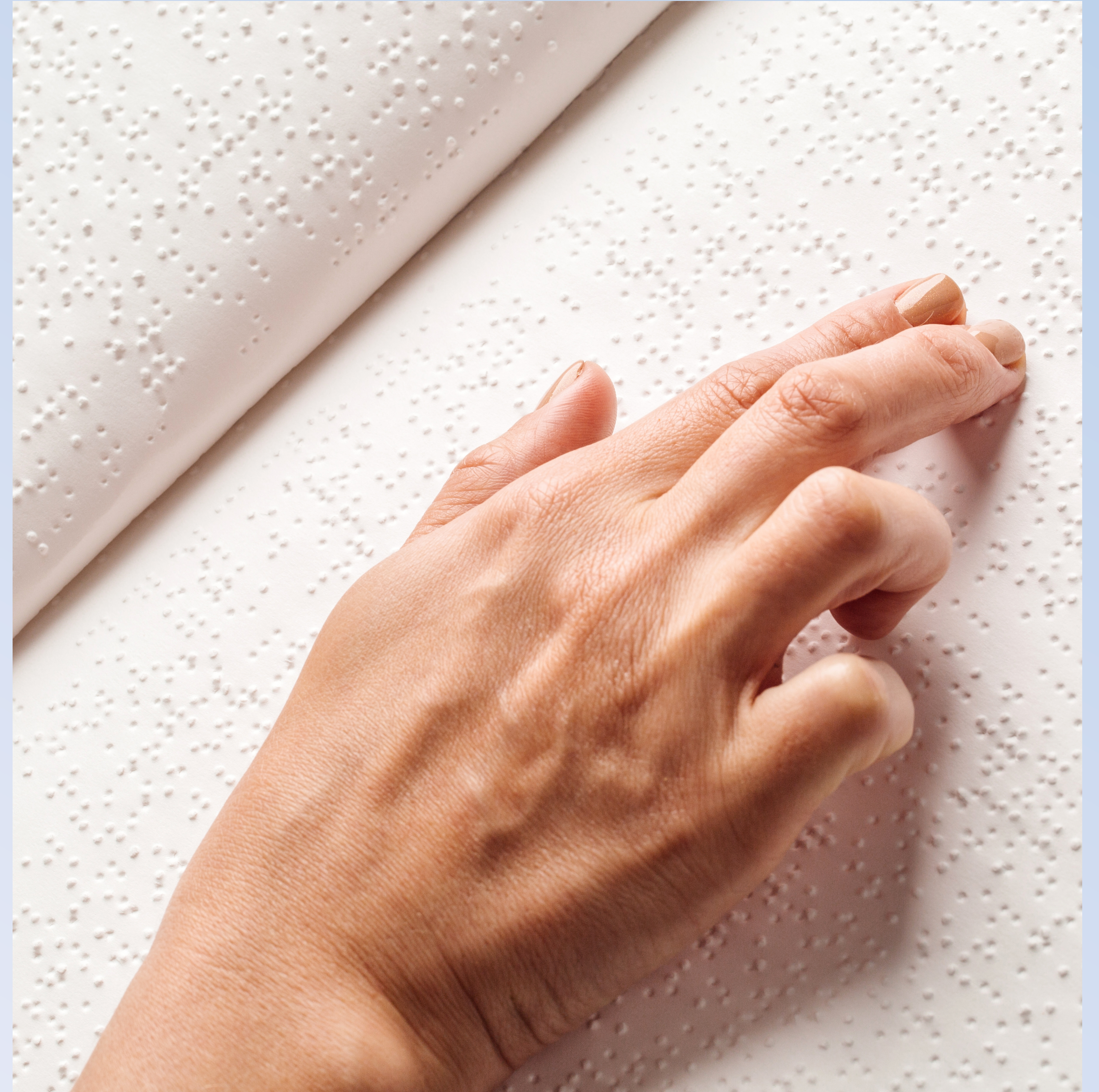
Sonification for *any* web visualization library

Kim et al's *Erie* (2024)



Embossing visualizations on paper

Still one of the best
technologies out there!



Refreshable tactile displays

Great work by Holloway,
also: Reinders, Butler,
Marriott, and crew



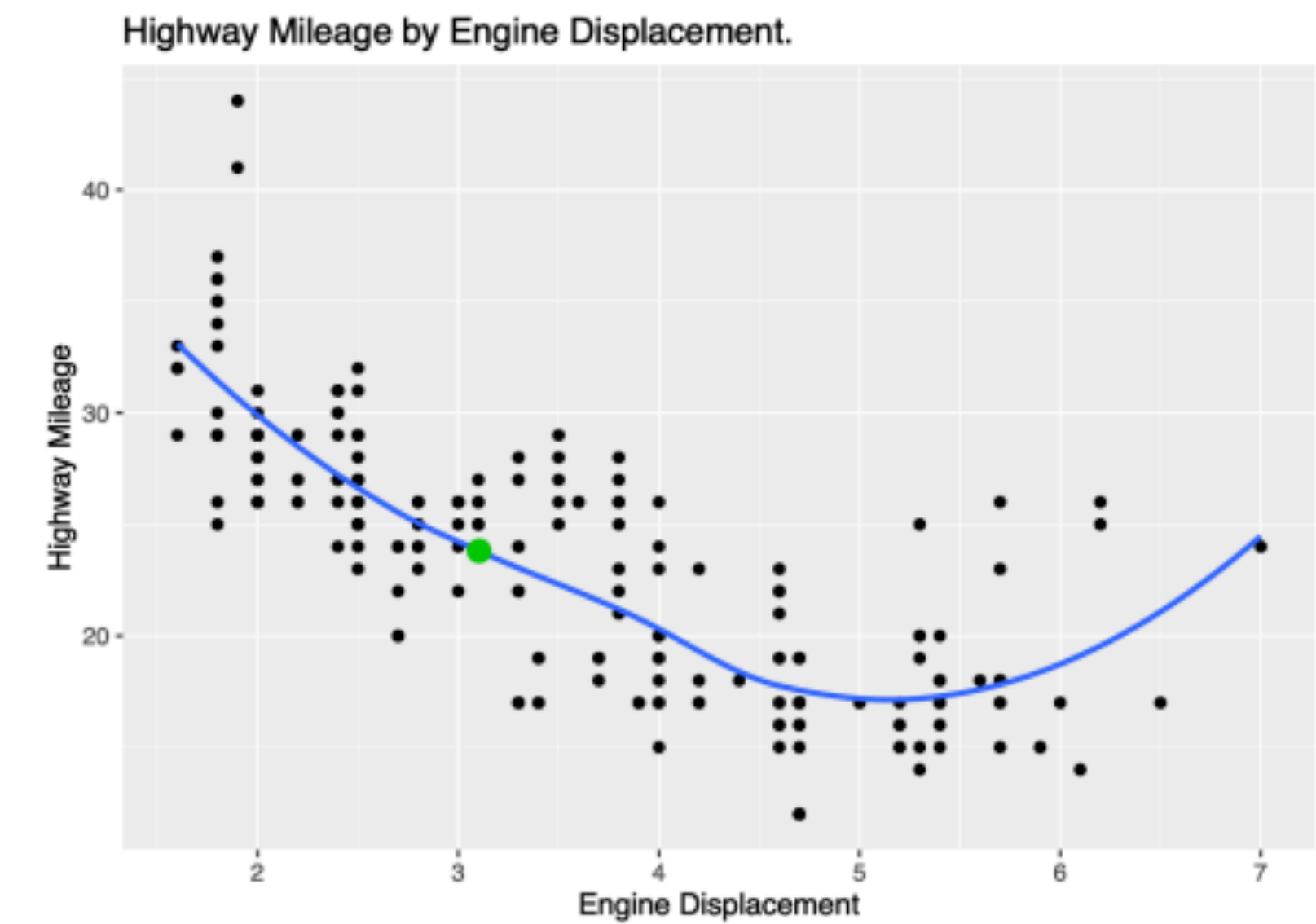
20,000 USD???

Refreshable tactile displays

**Great work by Holloway,
also: Reinders, Butler,
Marriot, and crew**



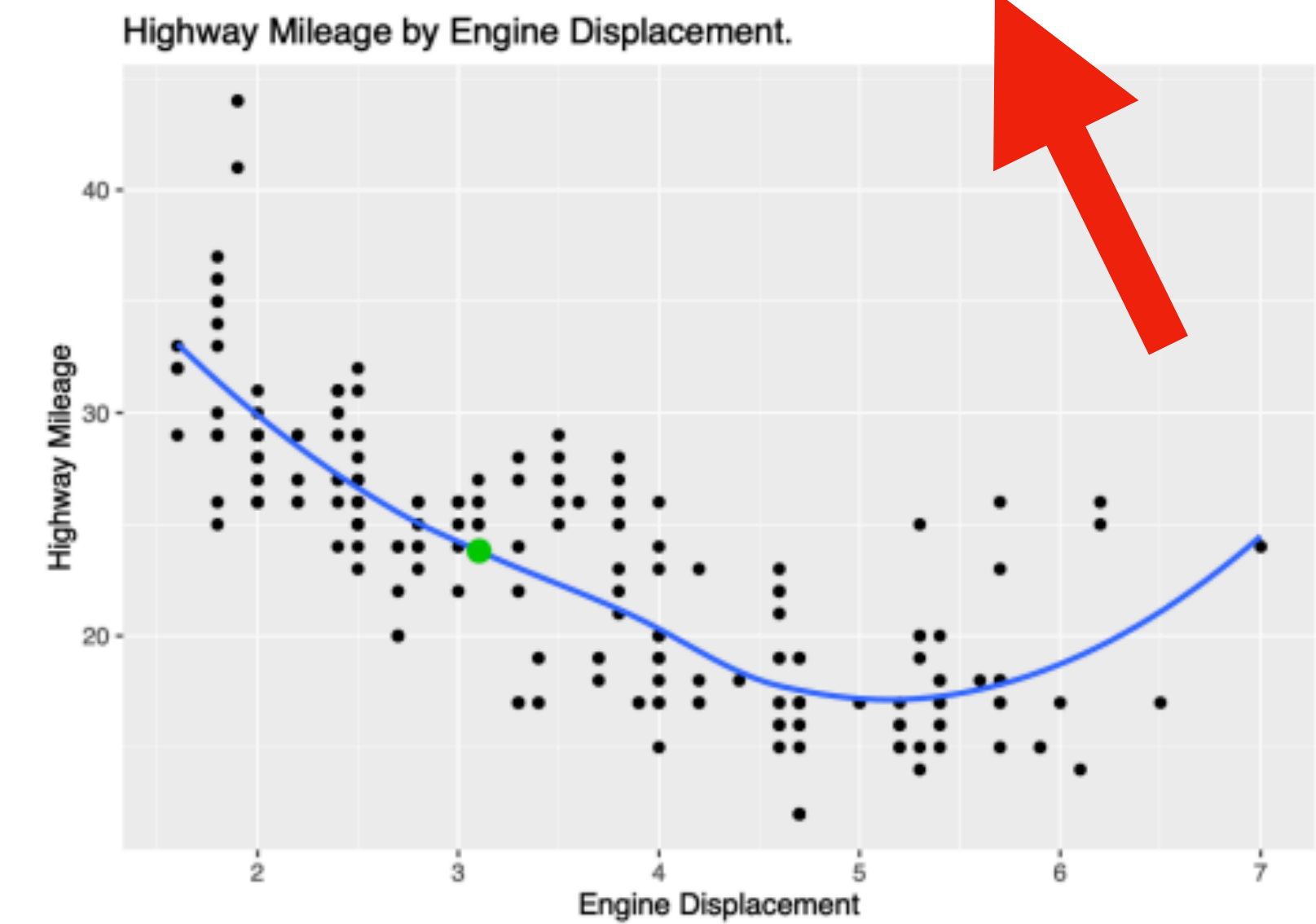
Micro-tactiles (MAIDR, SparkBraille, etc)



Engine Displacement 3.1038, Highway Mileage 23.8055

(d) Scatter plot

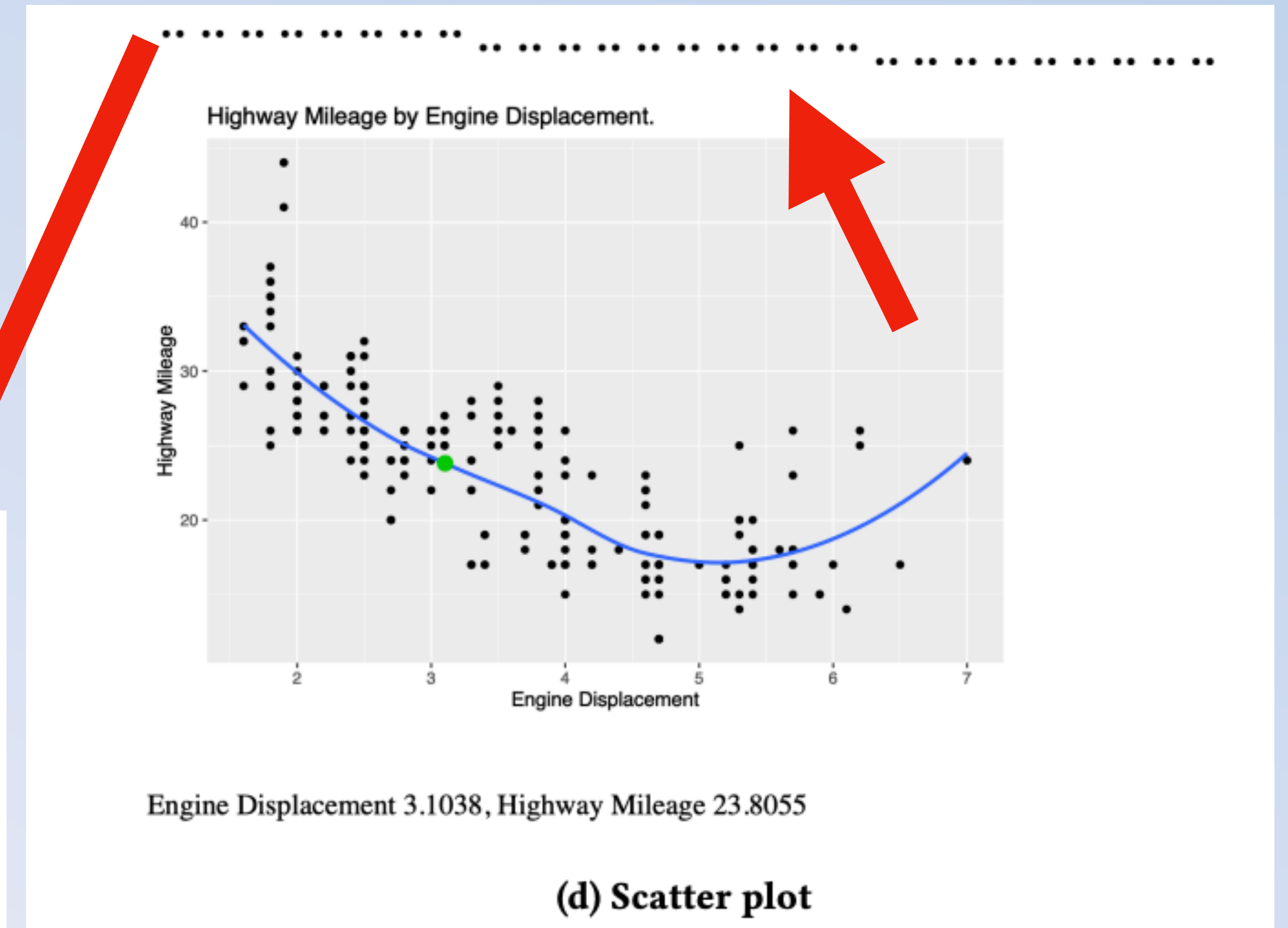
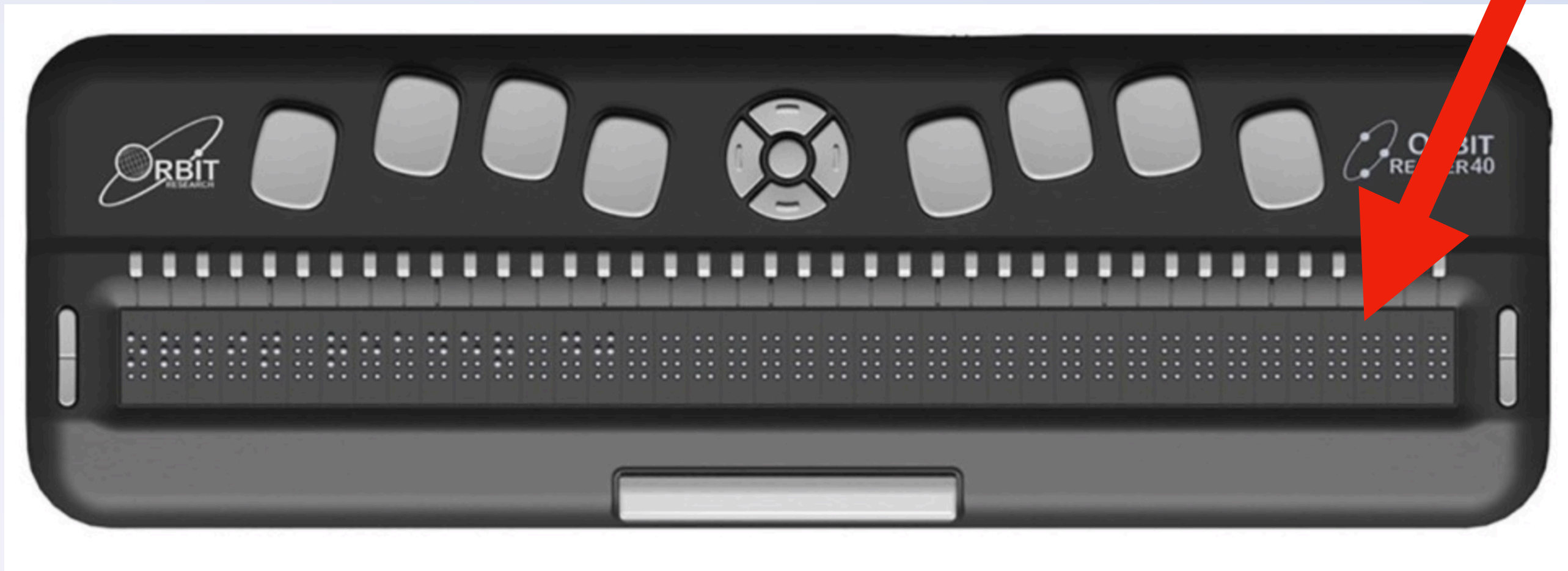
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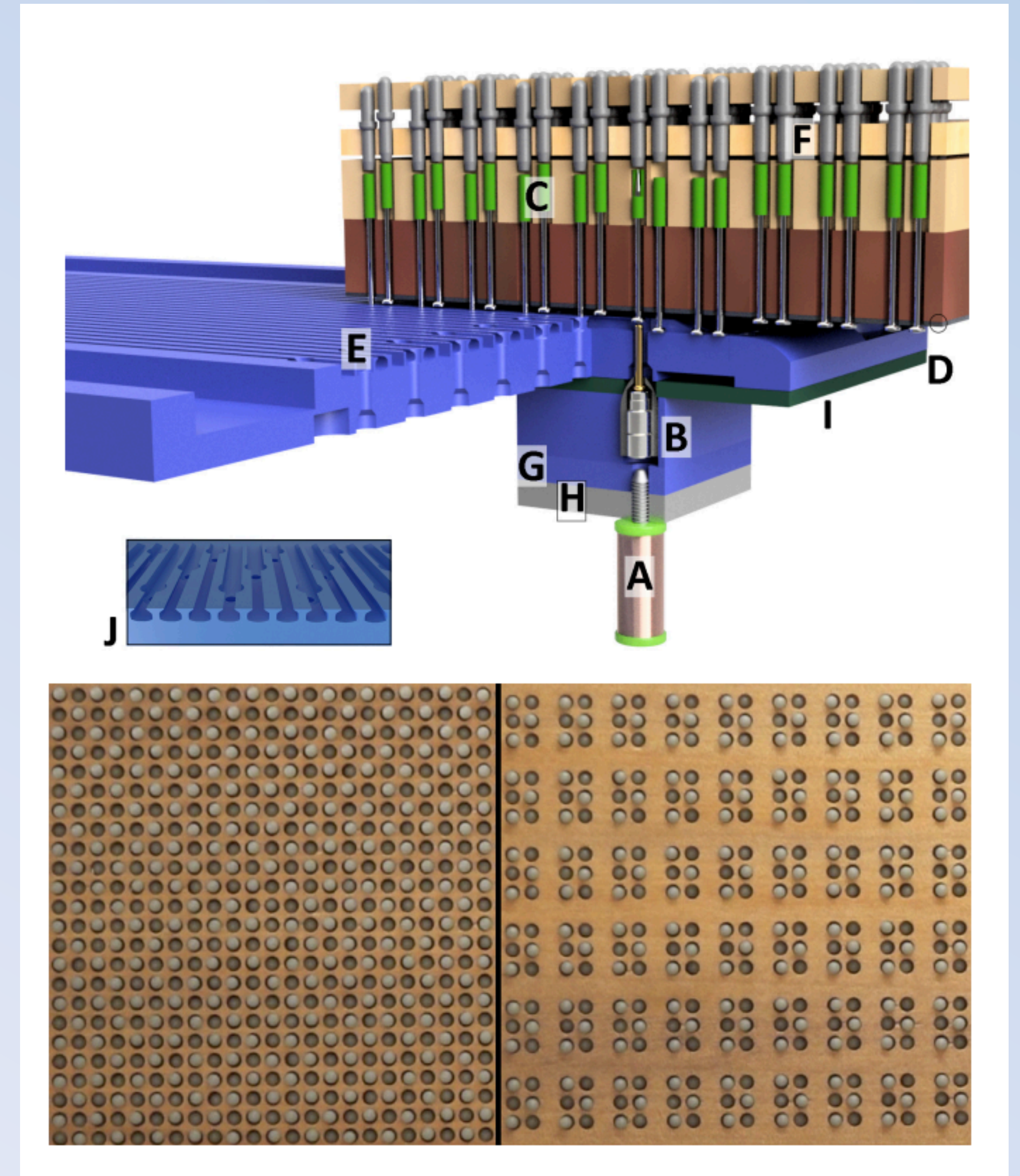
(d) Scatter plot

Micro-tactiles (MAIDR, SparkBraille, etc)



DIY, refreshable, low-cost pin displays

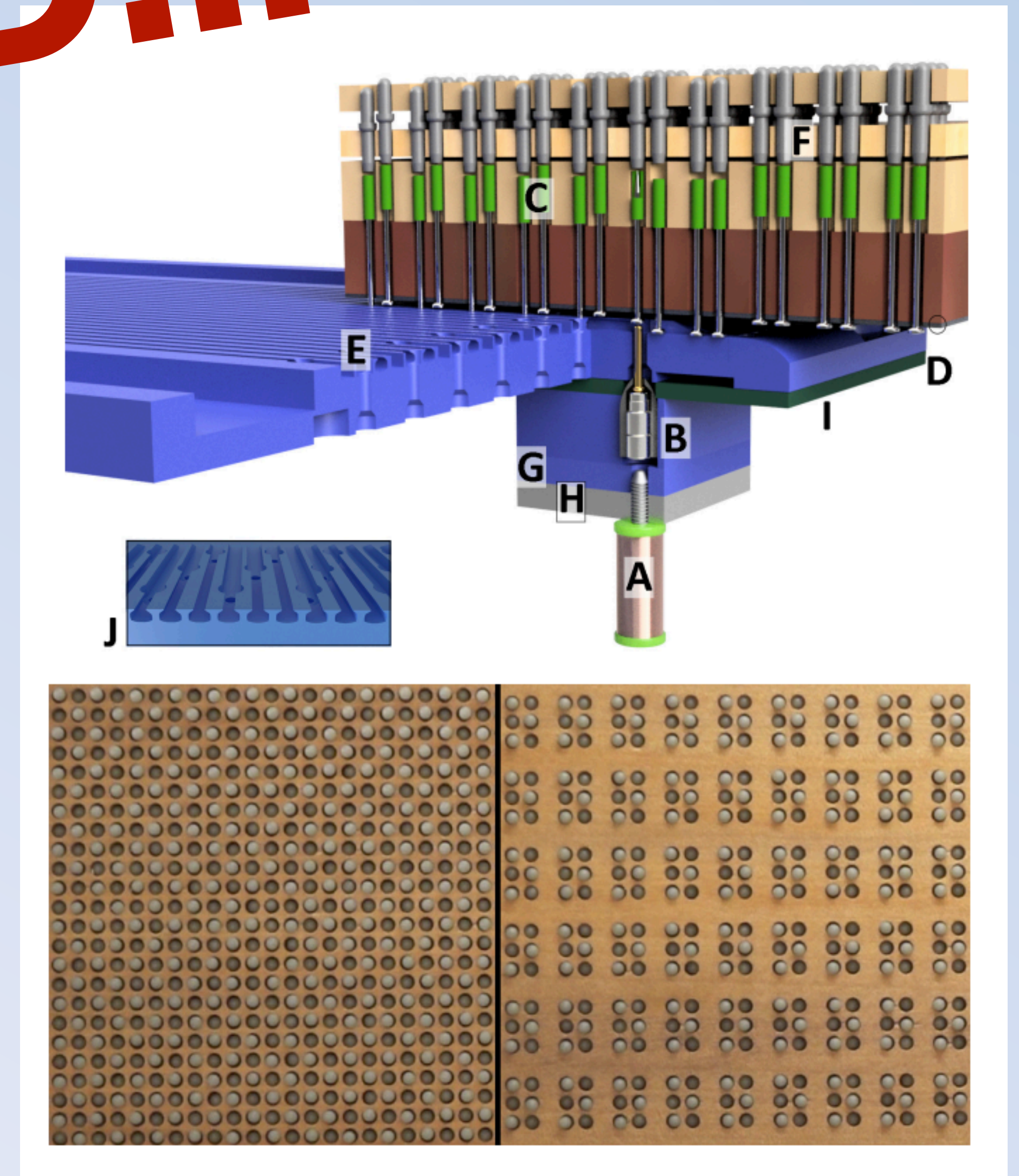
Smiley et al, “MagnePins”
(2025)



~250 USD!!!

DIY, refreshable, low-cost pin displays

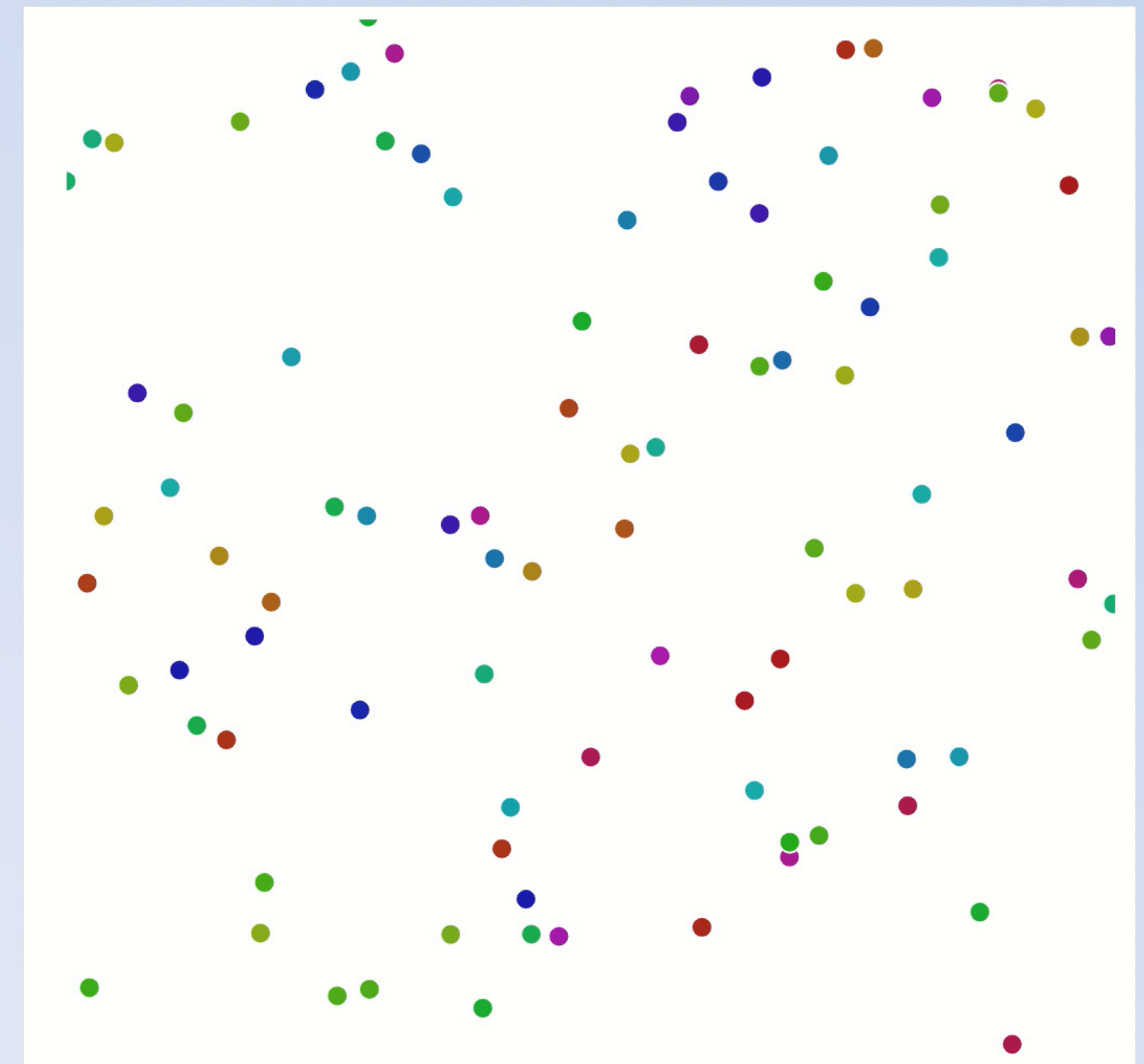
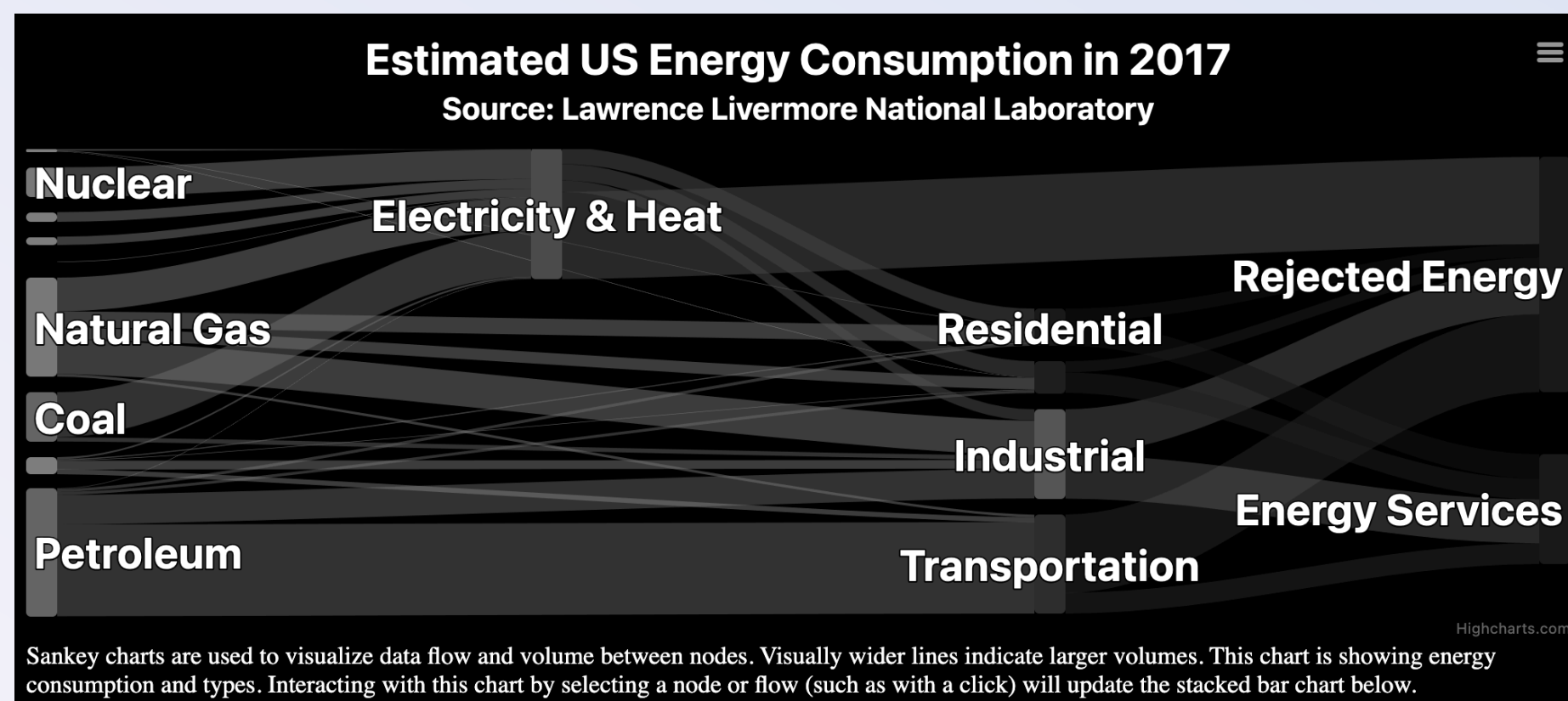
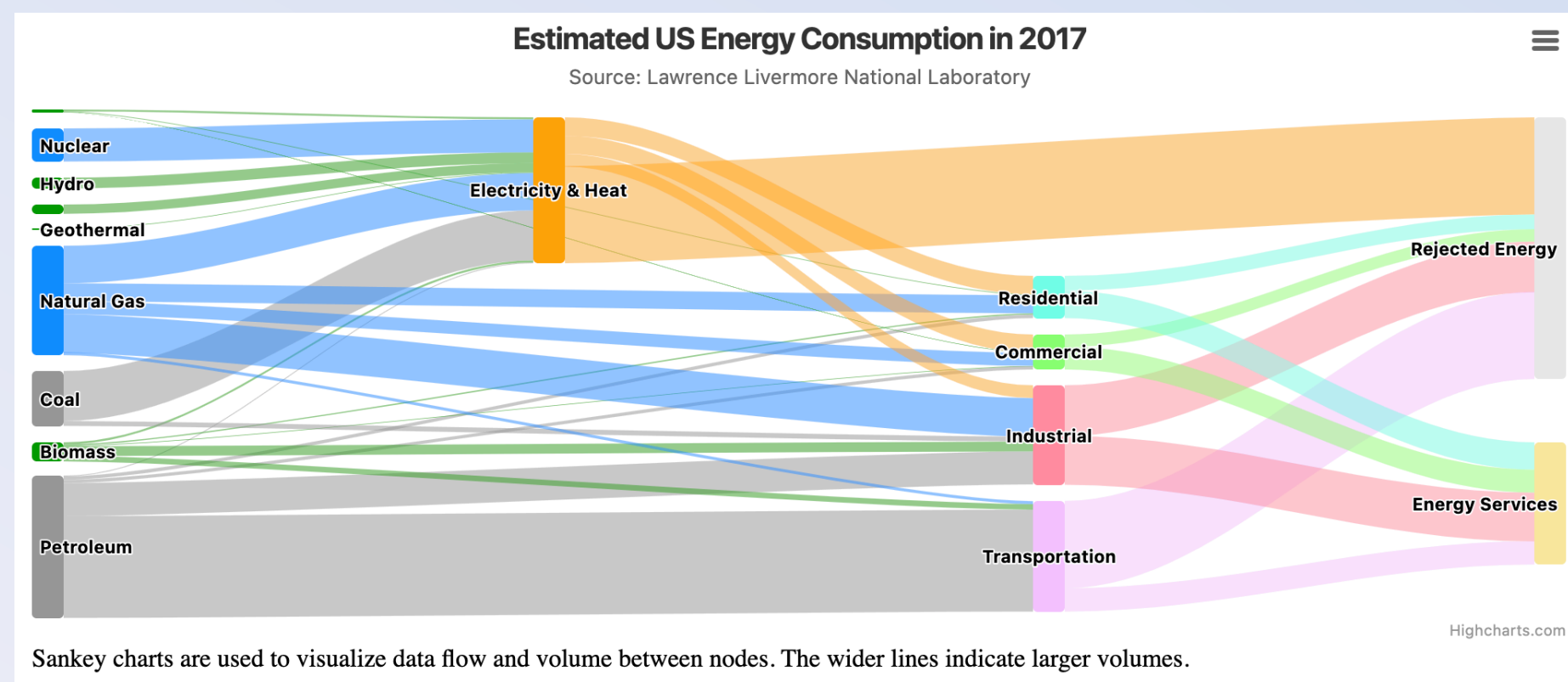
Smiley et al, “MagnePins”
(2025)



Personalization

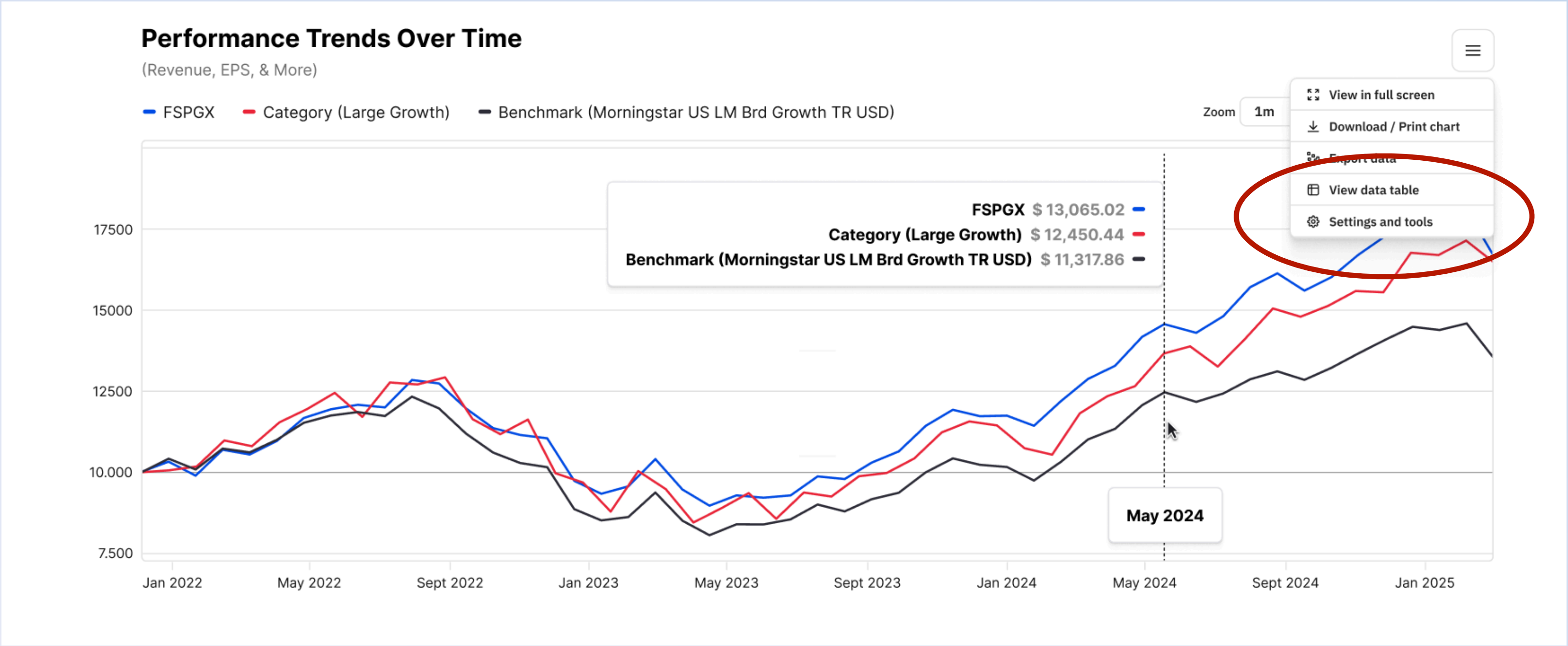
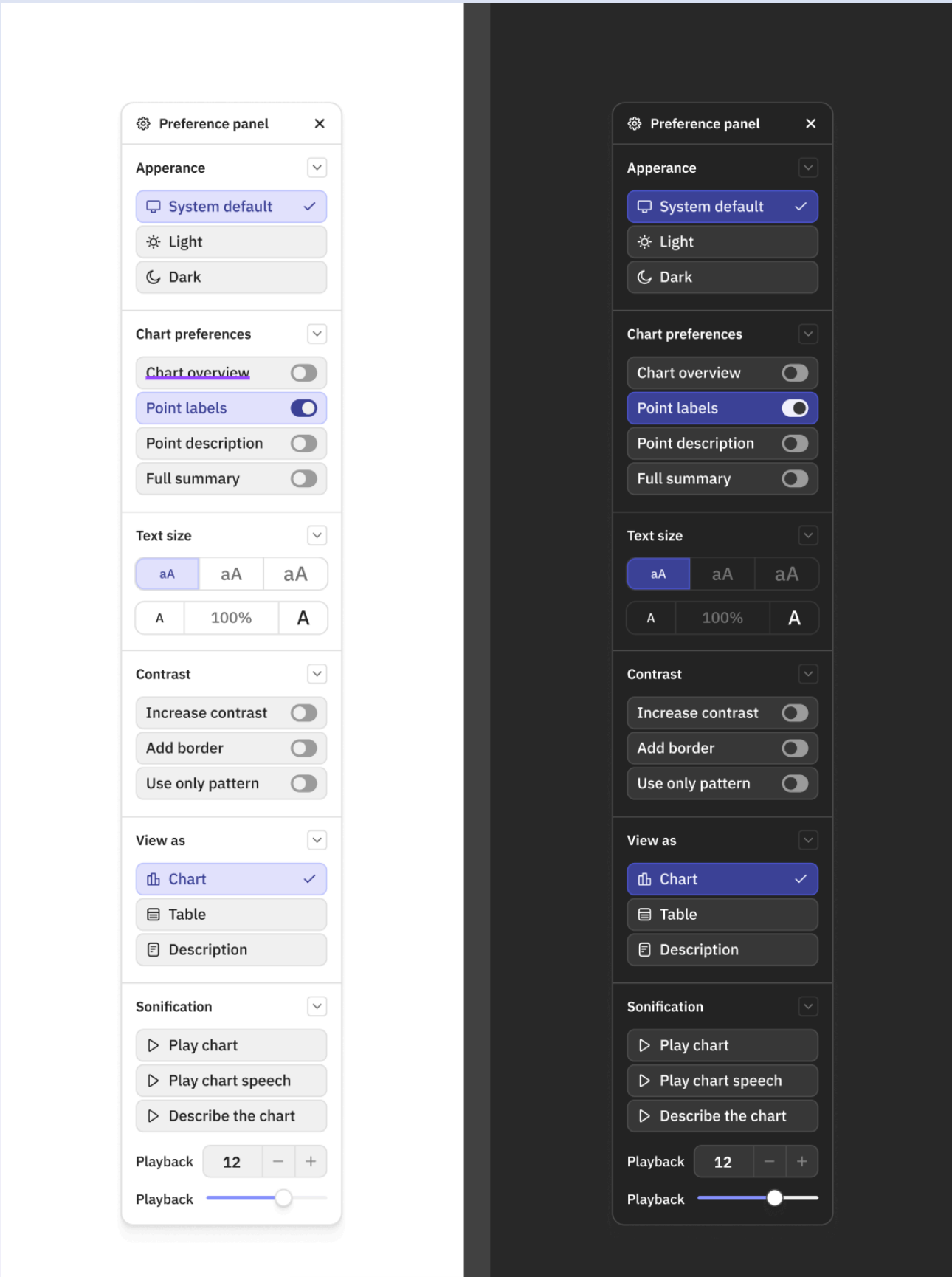
Adjusting to system settings: font size, dark mode, motion reduction

Source: Highcharts, 2016ish?, Visa Chart Components (2017-2019), Counterpoint (2024)



Enabling user profiles

Source: Highcharts 2025+, Elavsky et al, *Software*, 2025



2025

Slides here  frank.computer

Visualization and accessibility: The state of the art, 2025



I'm on the job market!

Frank Elavsky, PhD **Candidate**



Human-
Computer
Interaction
Institute



hcii.cmu.edu, axle-lab.com, dig.cmu.edu