2025

frank.computer

Tools for **Accessible Data Interaction**

Frank Elavsky

Human-Computer Interaction Institute

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

Credit: Jeff Kubina, Wikimedia

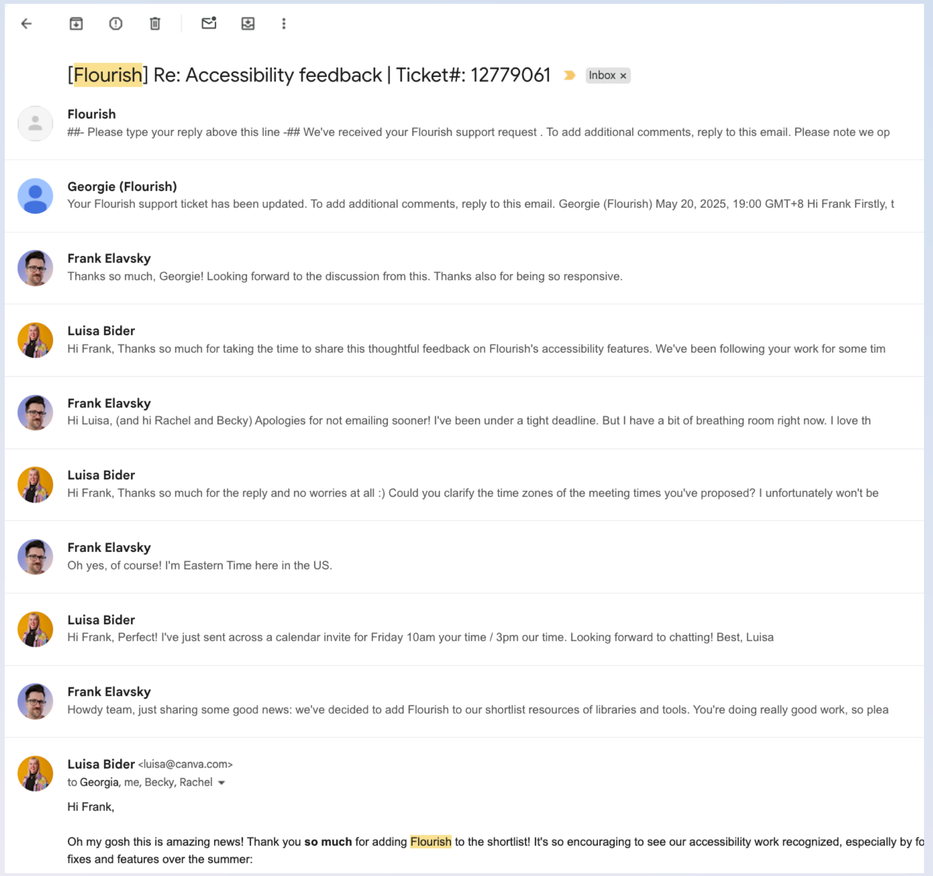
Tools matter

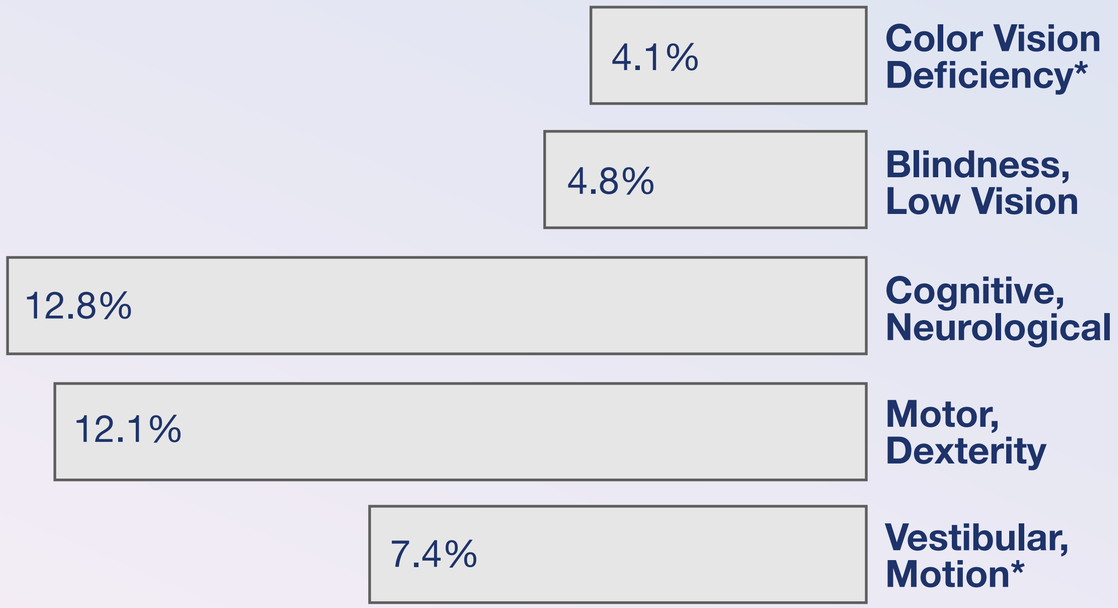
You are currently on a frame. To enter the web area, press Control-Option-Shift-Down Arrow.

ge that

Republican. No need to take that from me: it's a well-evidenced

Some change is easier to make happen than others



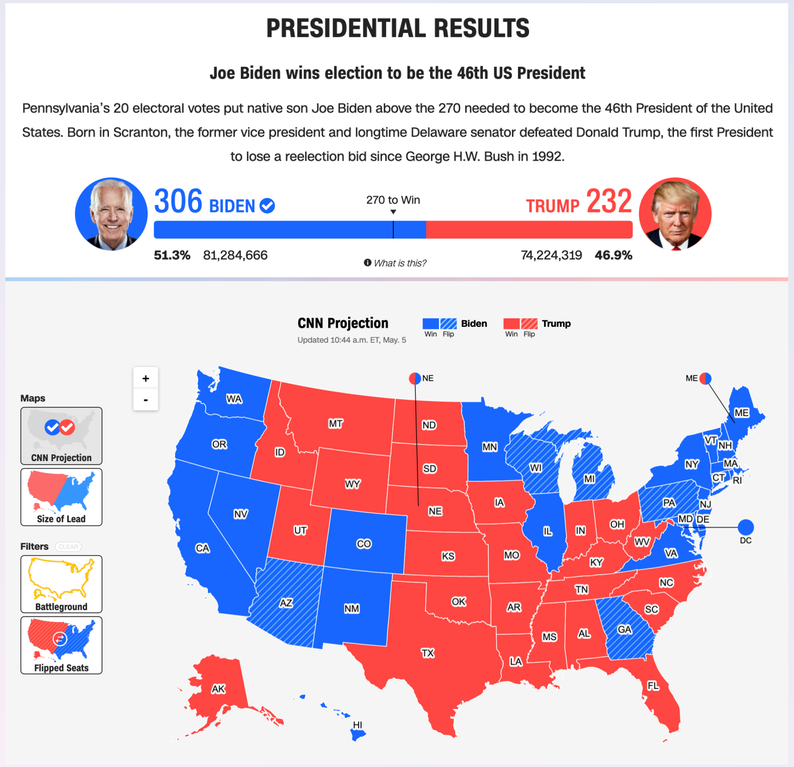


Centers for Disease Control and Prevention. Disability and Health Data System (DHDS). 2023. Available from: http://dhds.cdc.gov
*No new data

~27% of people living in the United States self-report living with a disability that affects their daily life (2023)

People with disabilities deserve to:

Participate in politics



Credit: CNN

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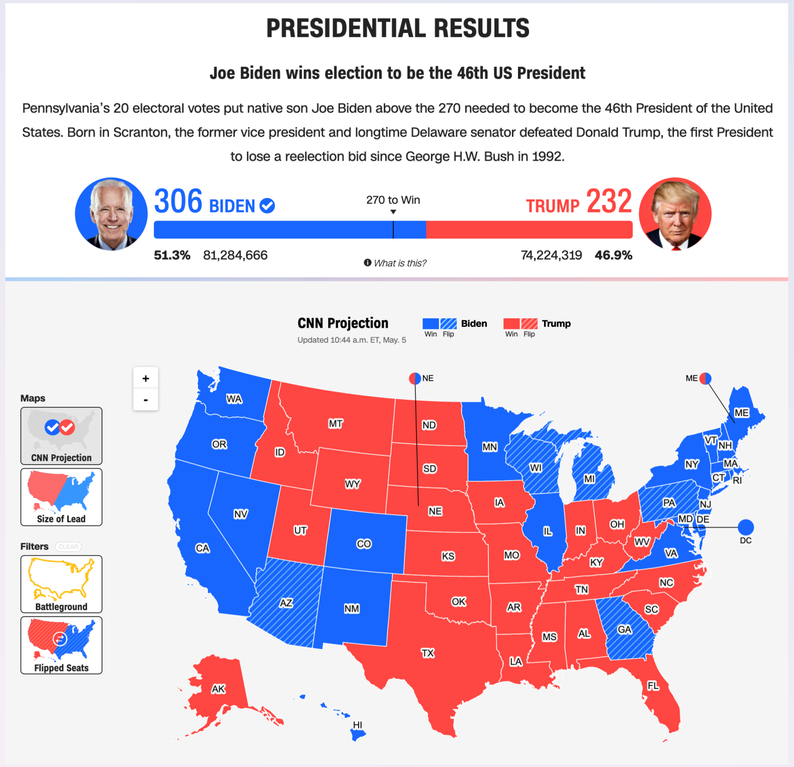
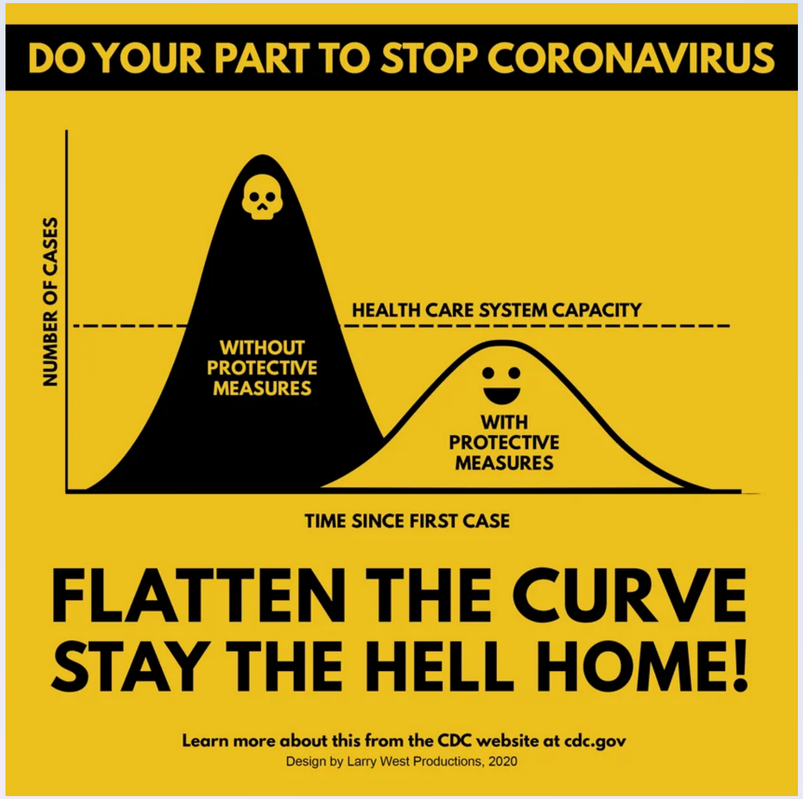


Credit: CNN

Make informed decisions



Credit: Reddit

People with disabilities deserve to:

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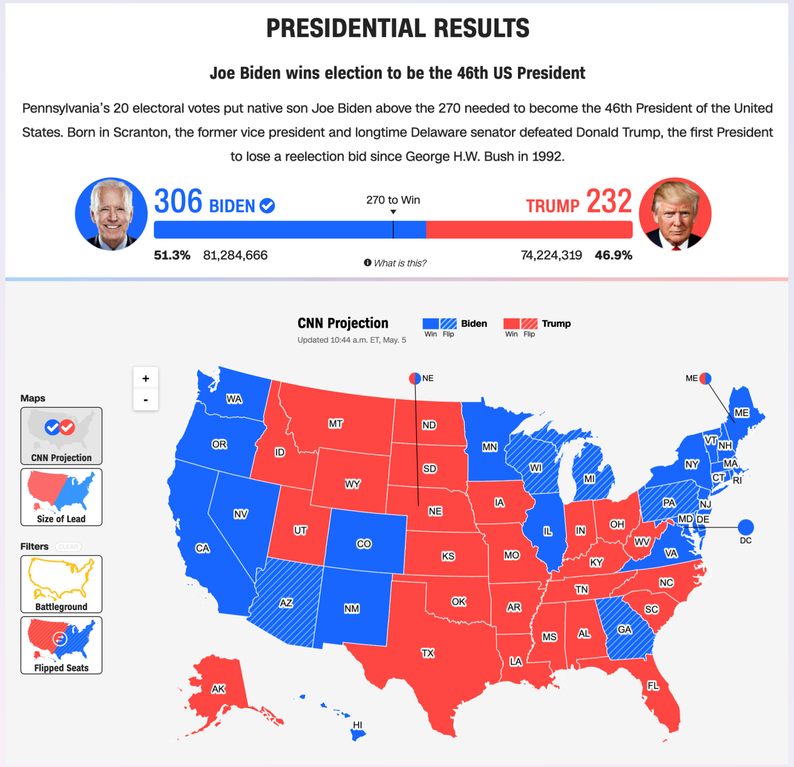
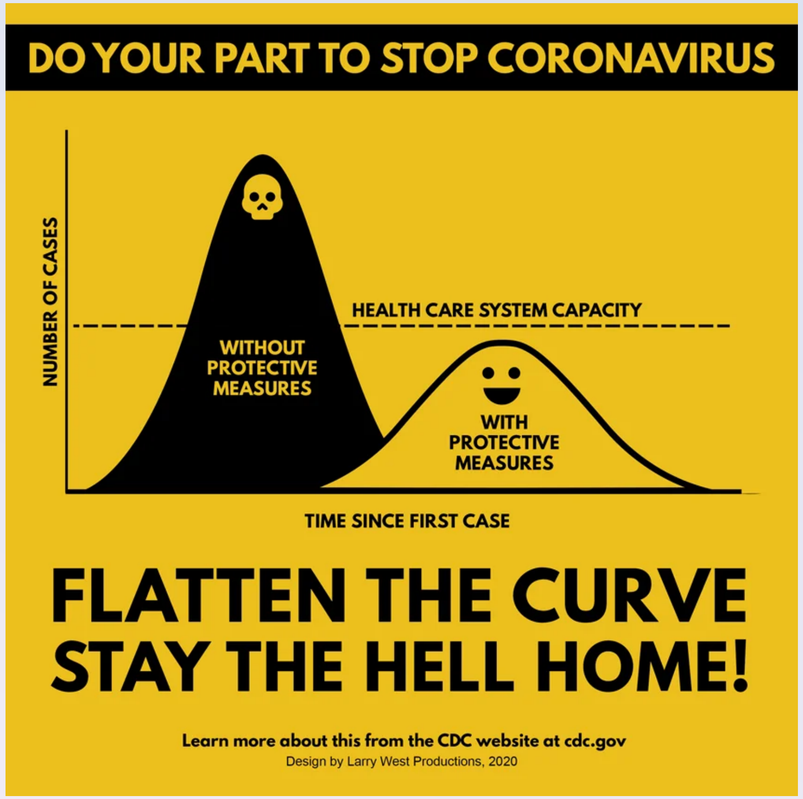


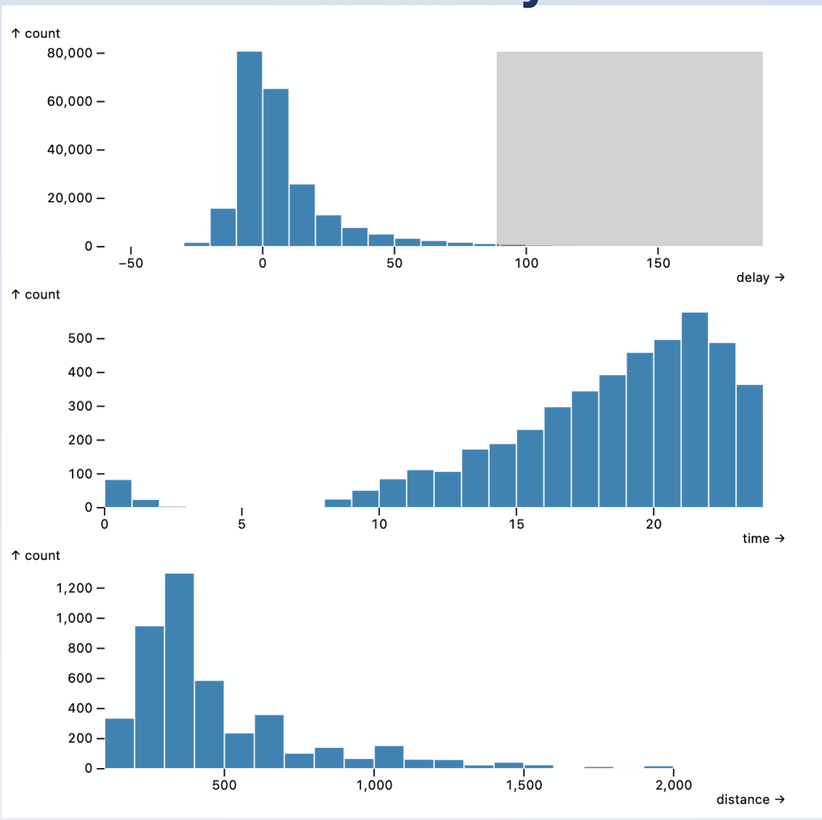
Credit: CNN

Make informed decisions

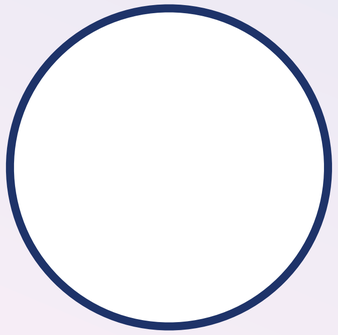


Credit: Reddit

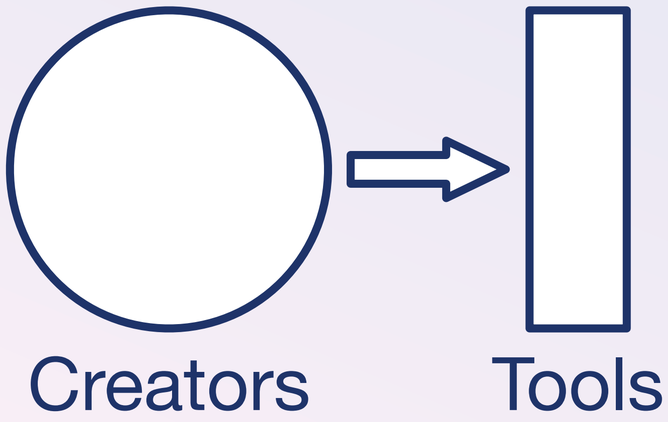
Analyze data quickly and efficiently

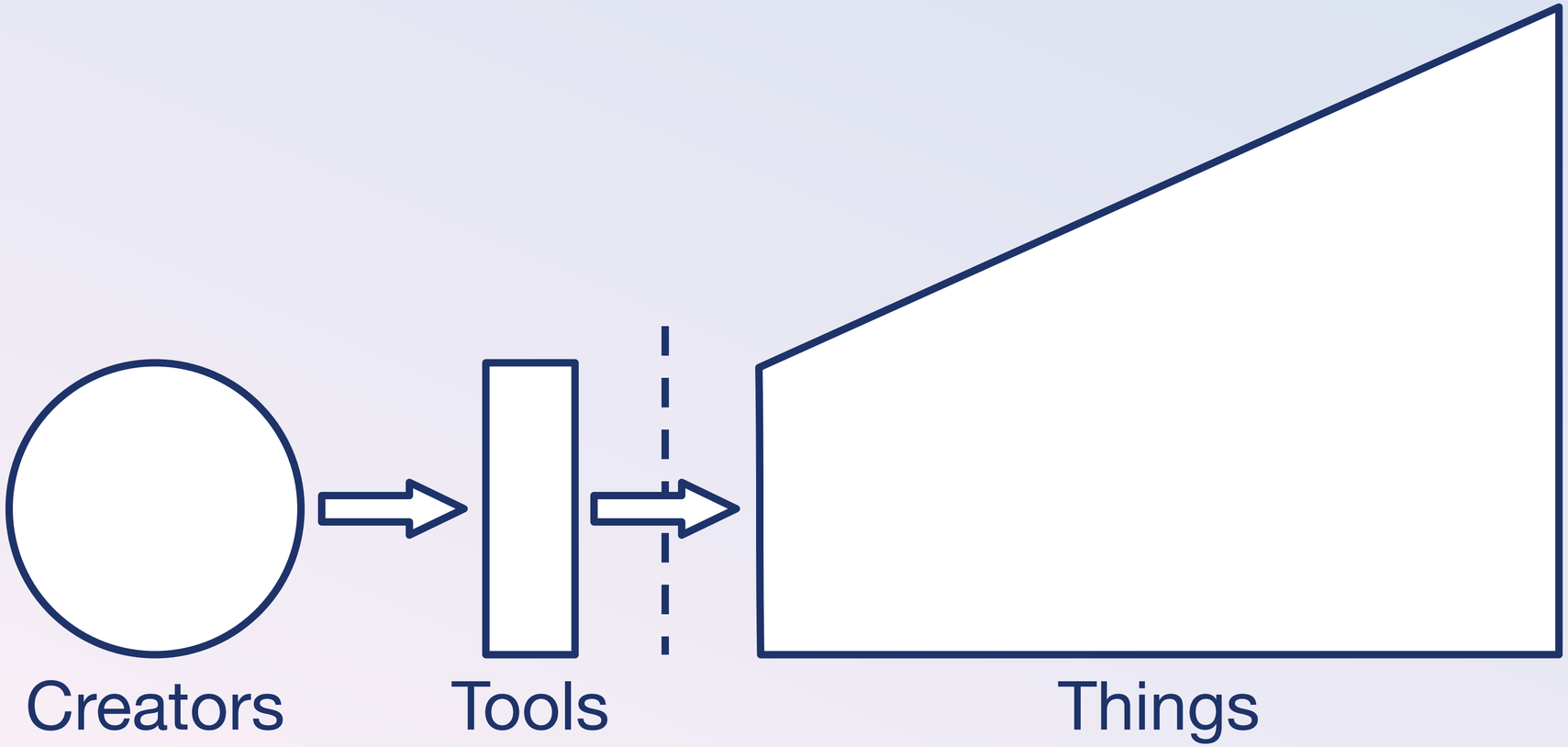


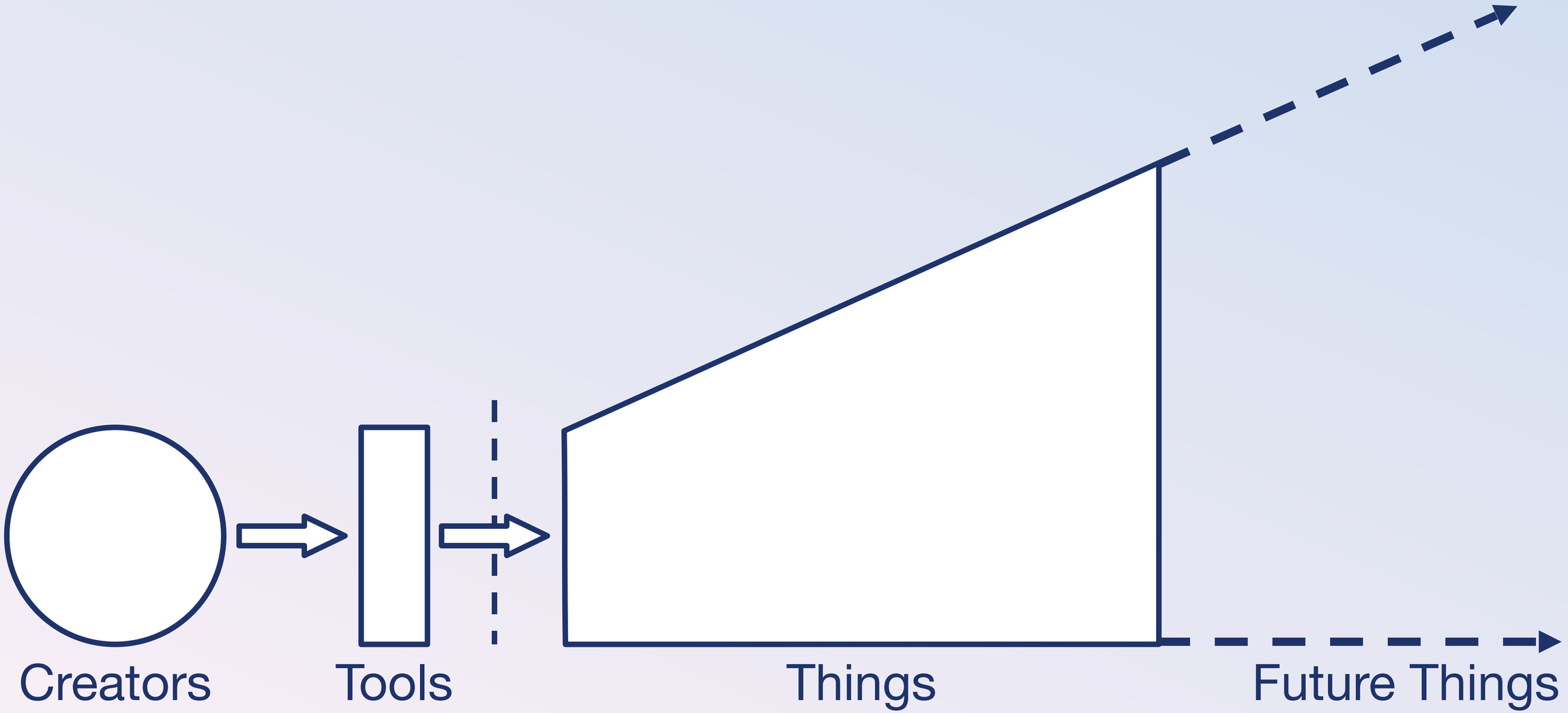
Credit: Our research



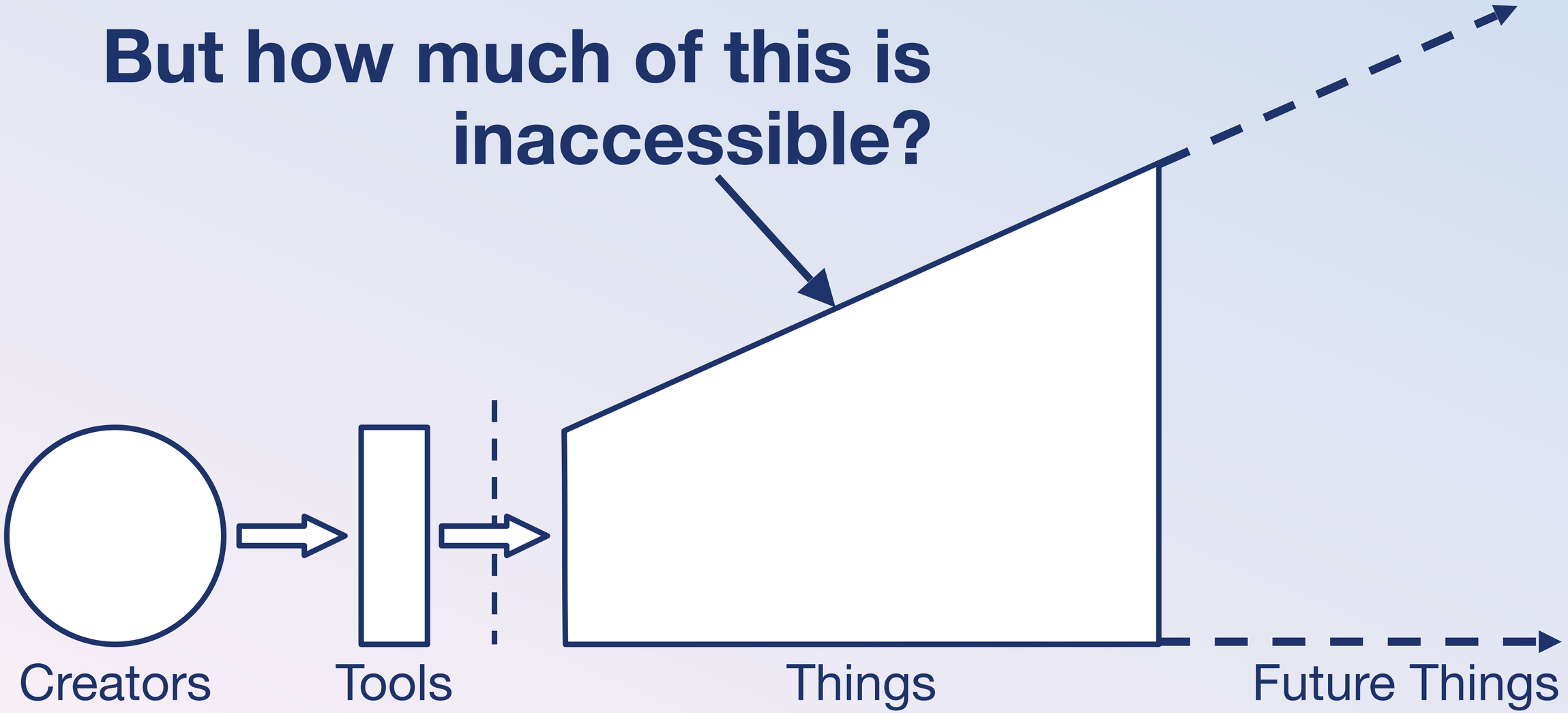
Creators


Creators
Tools


Creators
Tools
Things

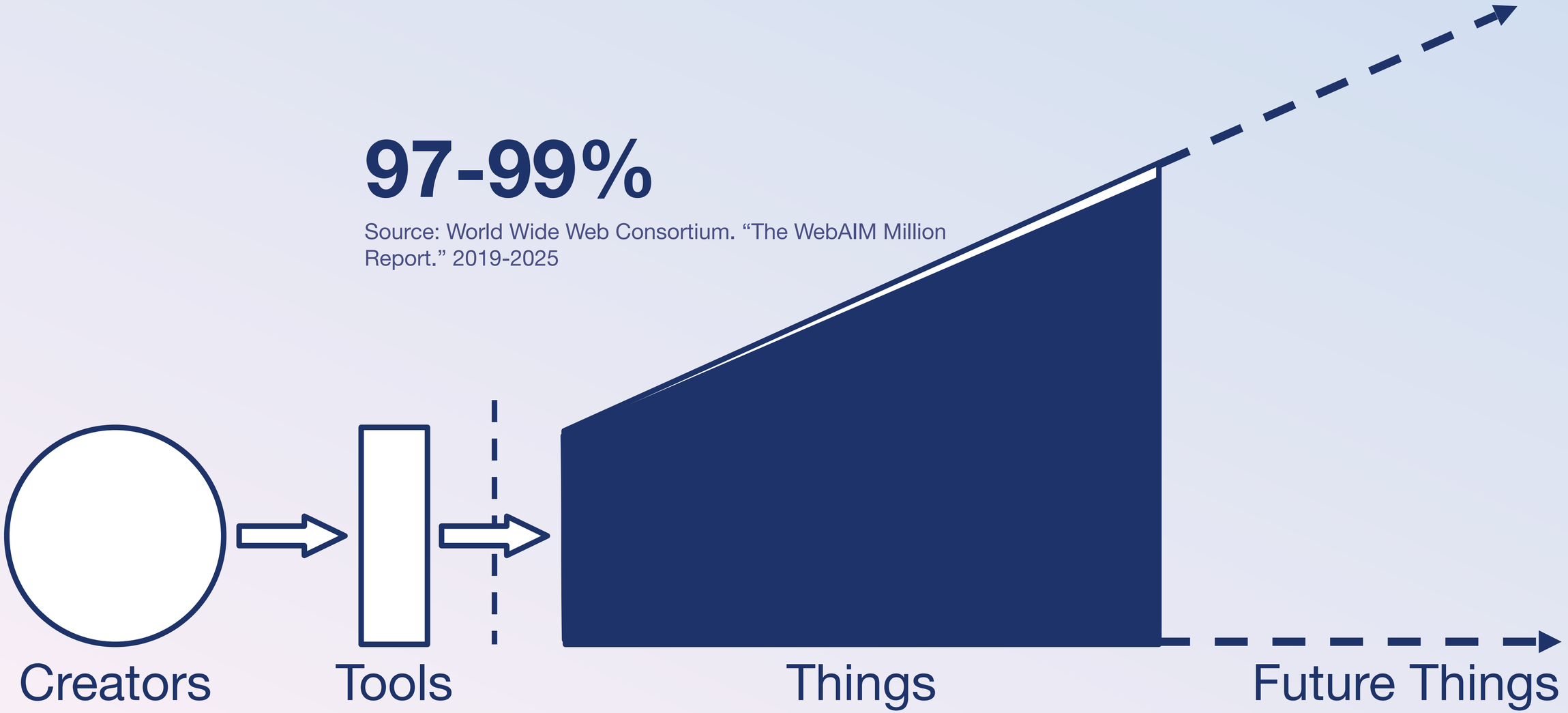

Creators
Tools
Things
Future Things

But how much of this is inaccessible?



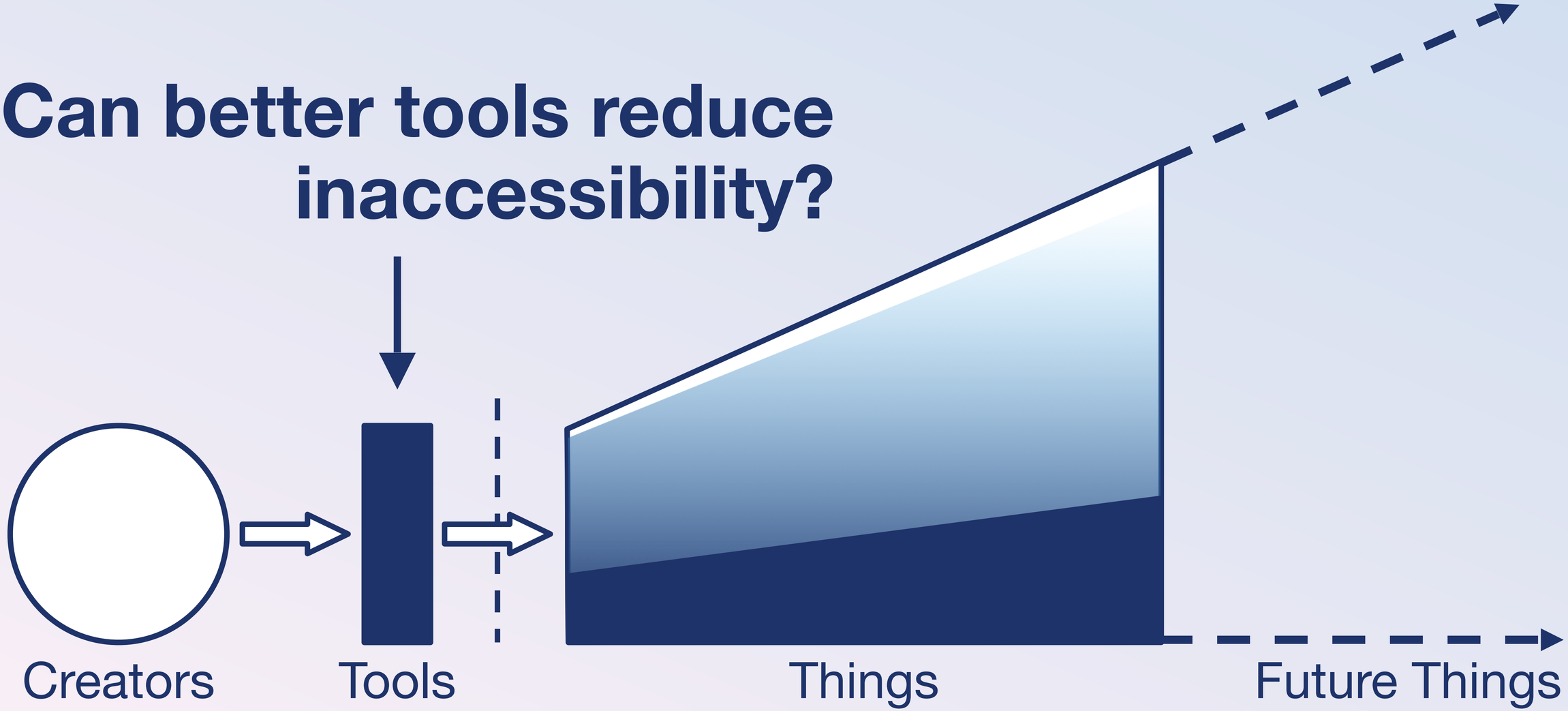
97-99%

Source: World Wide Web Consortium. “The WebAIM Million Report.” 2019-2025

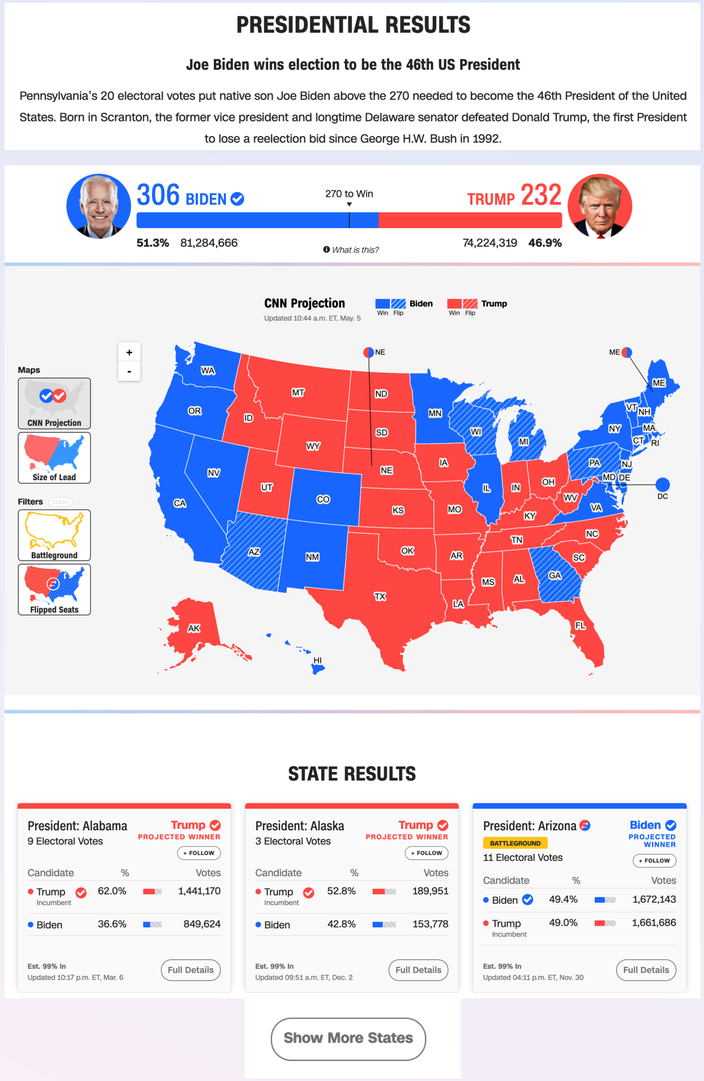


The builders and the makers (*that's us*) are responsible for access.

Can better tools reduce inaccessibility?



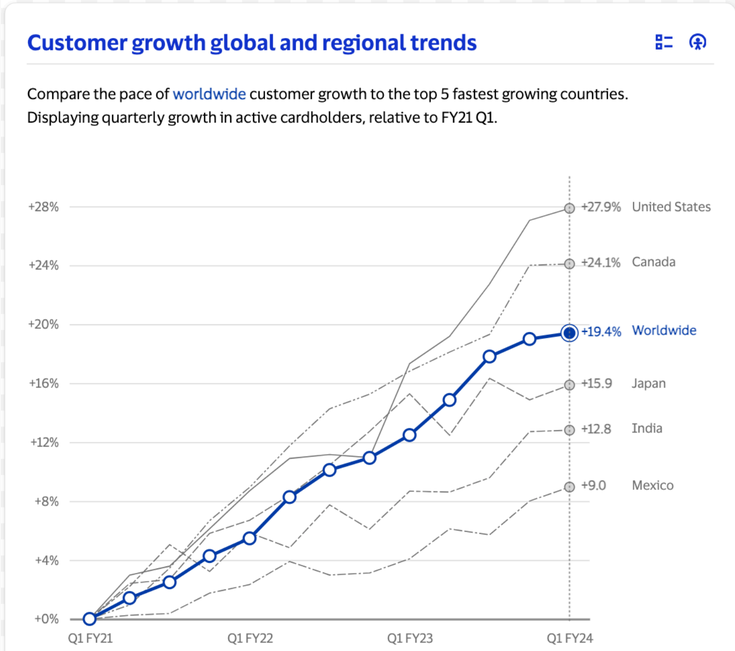
Section 1:
Helping practitioners consider accessibility

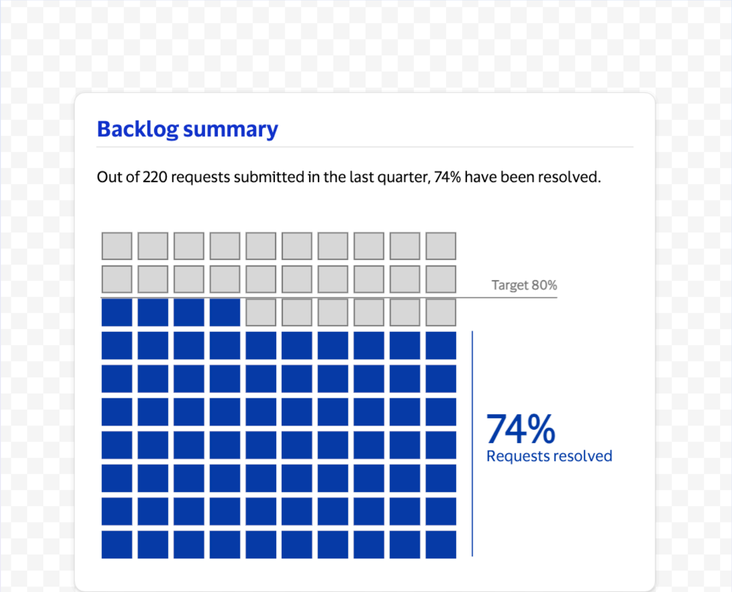


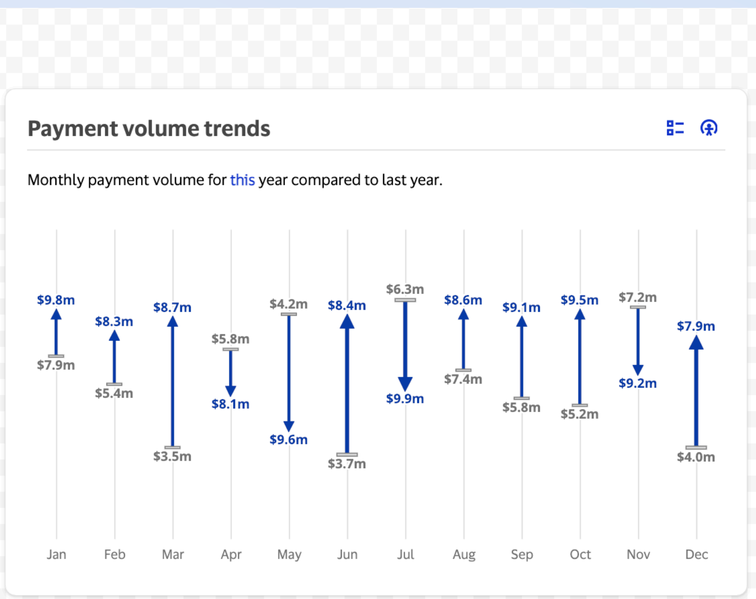
Research problem:

How do you find and evaluate access barriers in interactive visualizations?

Prior work: Staff-level engineer making a visualization library







Chartability is a workbook of tests, tools, and principles

How do you use Chartability?

There are a lot of different ways to perform an audit, and so there are also many different ways to use Chartability. Sometimes an audit is as casual as checking your work while you do it. And other times it is a big affair that involves teams of specialists and lawyers.

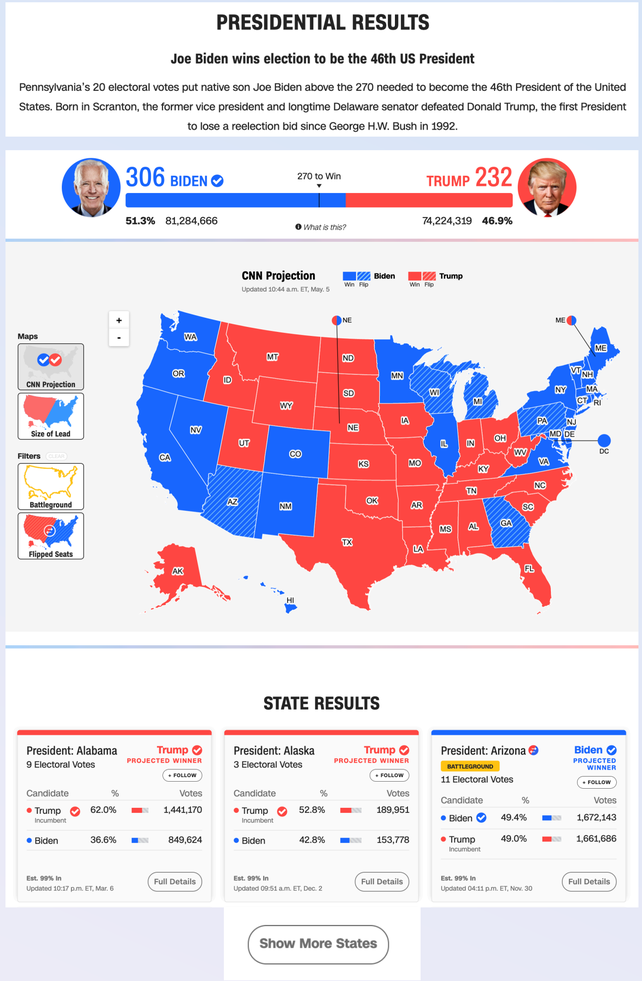
Realistically, while a highly trained auditor may be able to casually evaluate an artifact in as little as 30 minutes or even hold heuristics in mind as they are doing their own creative work, those new to auditing may take anywhere between 2 and 8 hours to complete a full pass of Chartability. Professional audits, which can take weeks or months, often include multiple auditors and provide rigorous documentation and detailed recommendations for remediation, typically in the form of a report. Chartability is meant to serve both quick pass and deep dive styles of audits, so users are expected to leverage it as they see fit.

Below we give an example of what might be a fast pass audit, using Chartability, in 5 steps. This isn't super thorough, but a good way to quickly check a handful of access barriers quickly.

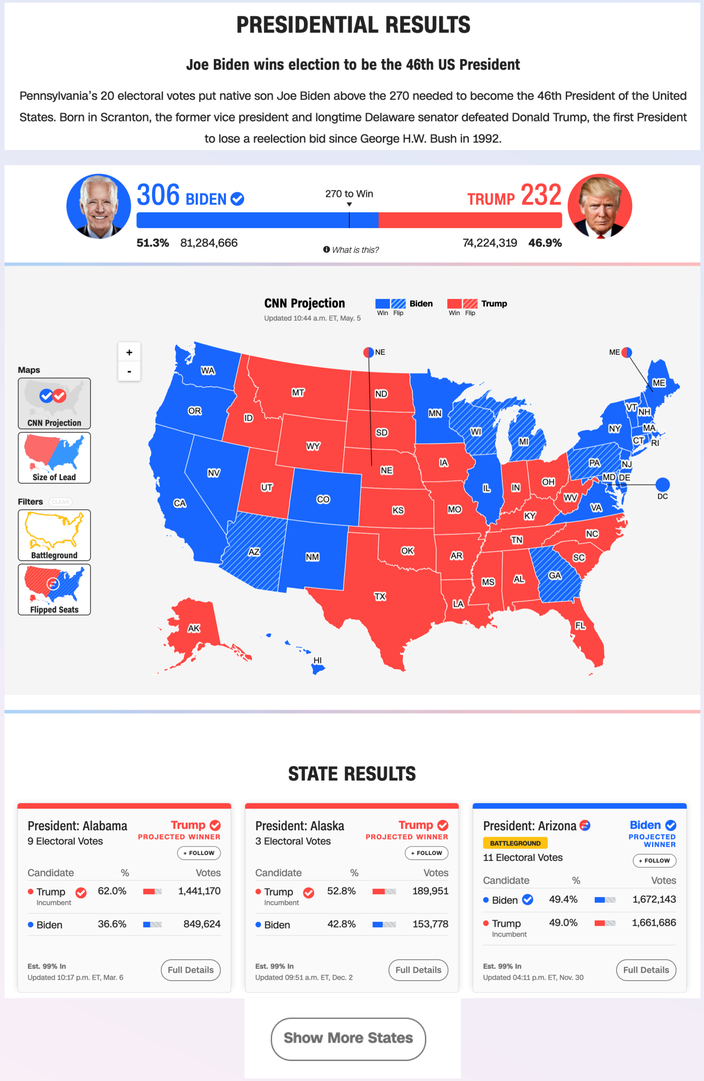
1. Visual Testing

Figure 1: A low contrast chart (left) compared to a higher contrast version (right). A dropper tool is extracting the fill color of the bar and then a contrast ratio has been calculated. Note that the fill color is the same on both bars, but darker borders have been added to ensure the visualization passes contrast tests.

Checking for contrast is the most common critical failure across all of our audits (88% of audits failed this heuristic). In order to evaluate contrast, often a combination of automatic (code-driven) and manual tooling is performed. When manually auditing, practitioners typically use a dropper and a contrast calculator (Figure 1). Contrast is measured by finding adjacent colors that are intended to convey meaning or boundaries, and finding a ratio between them. Standards require a different minimum contrast for text (4.5:1) than geometries like marks in a chart (3:1). Most auditors find this to be one of the easiest tasks to perform, but techniques can be tricky to handle. Testing for contrast accomplishes 3 different heuristics in Chartability: ensuring text/geometries have contrast, interactive states for elements have enough contrast change, and the keyboard focus indicator is easy to distinguish.

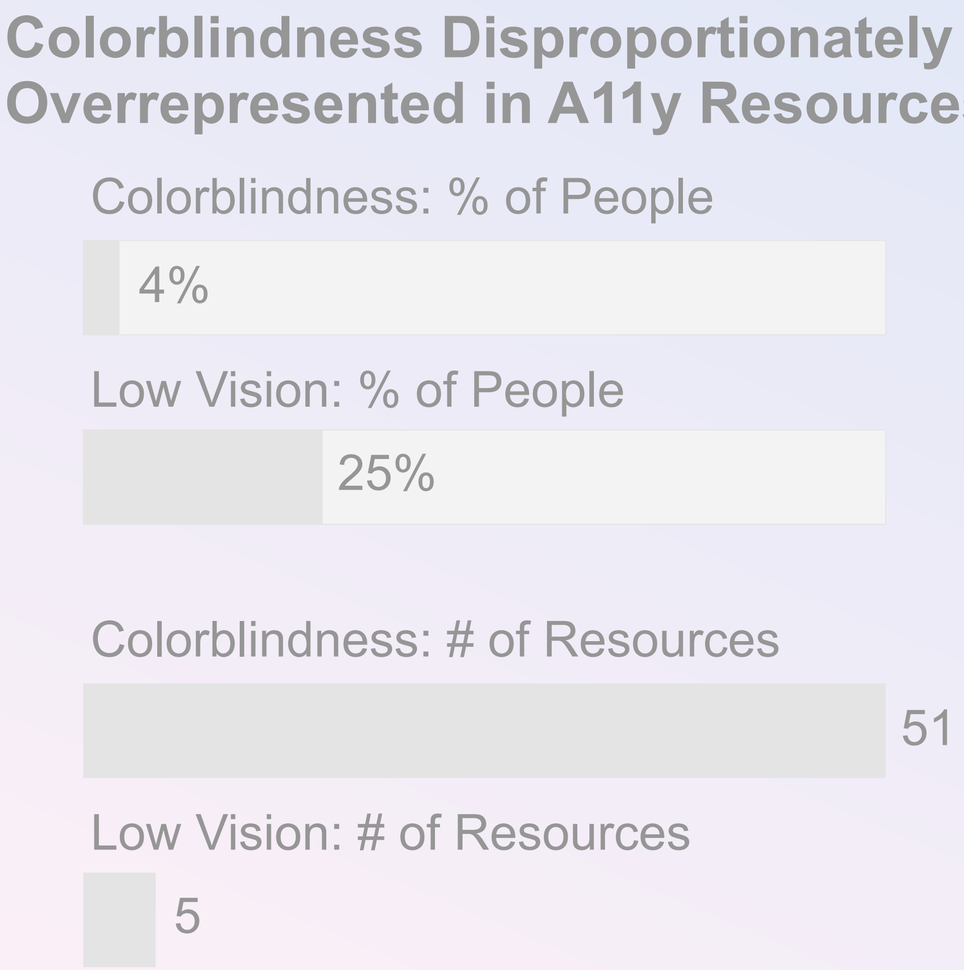


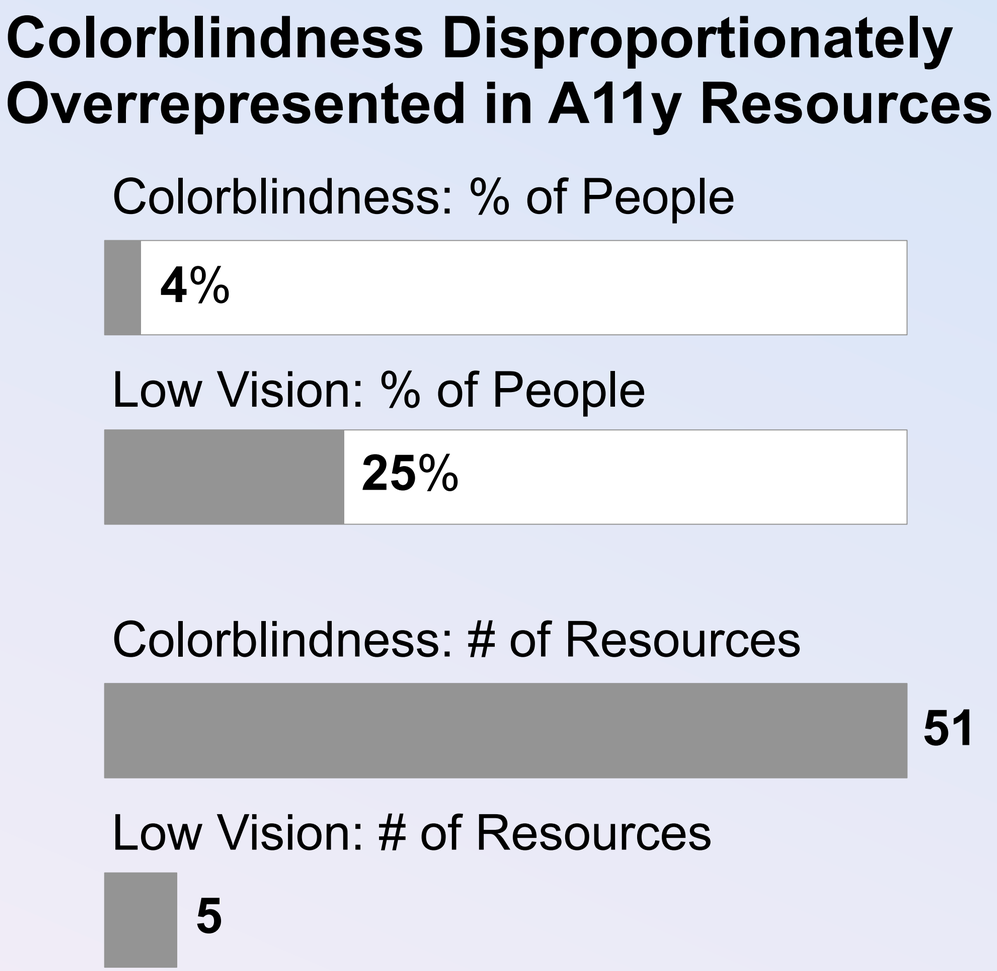
F. Elavsky, C. Bennett, and D. Moritz, "How accessible is my visualization? Evaluating visualization accessibility with *Chartability*," Computer Graphics Forum, 2022.



Let's evaluate this map from CNN with Chartability.

Design with high contrast

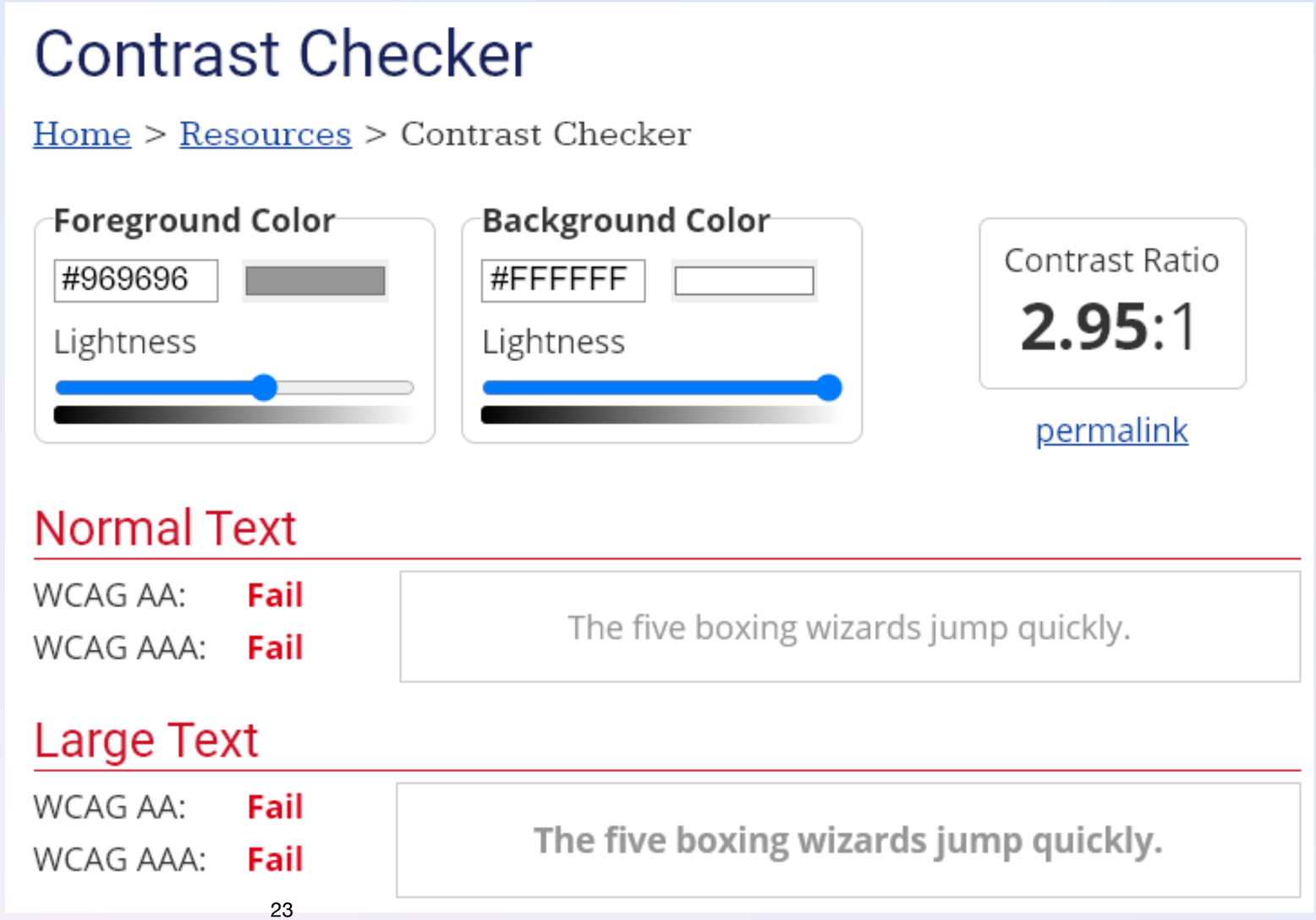




Use High Contrast Text

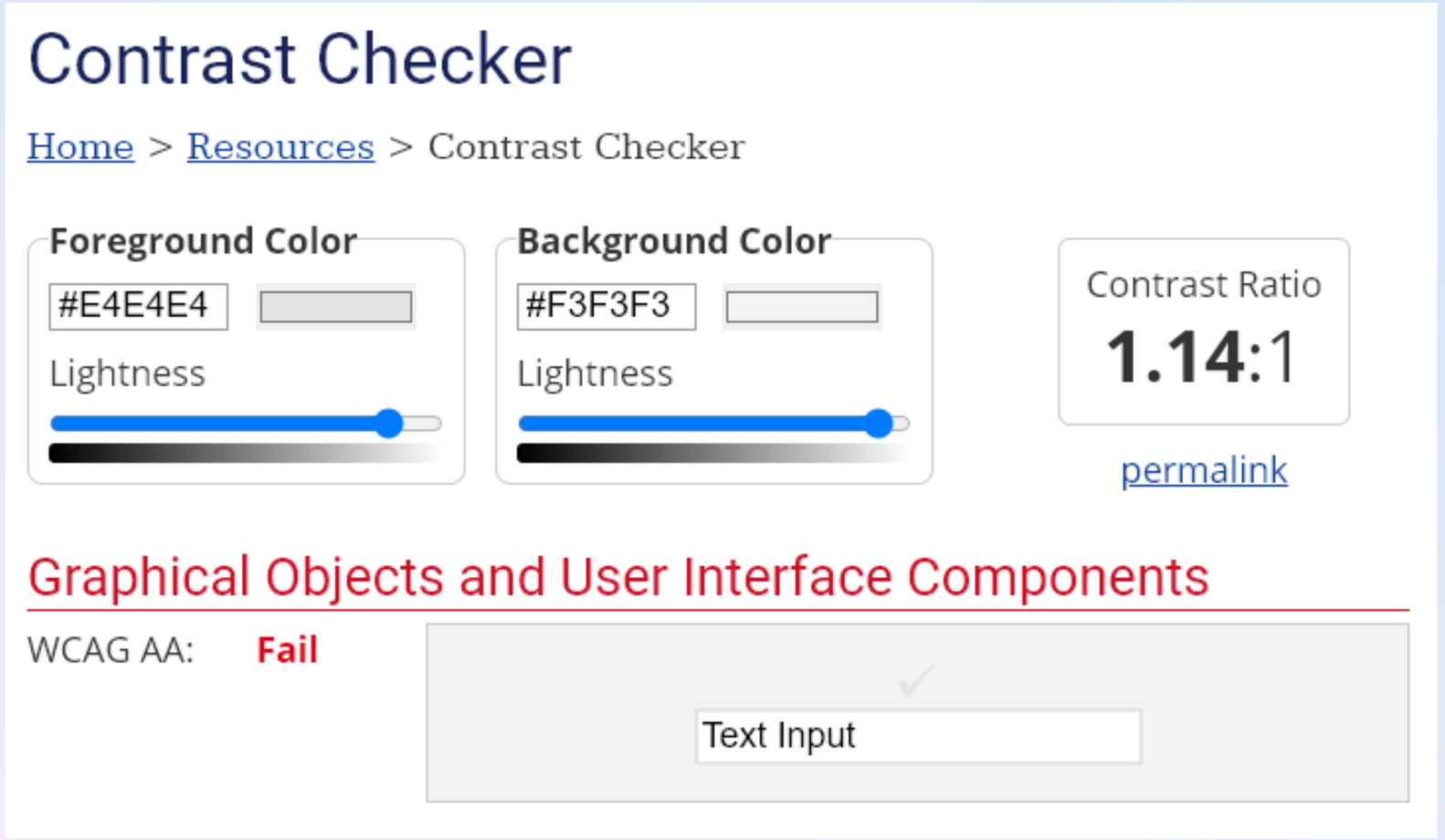
Text needs at least 4.5:1 contrast against its background.

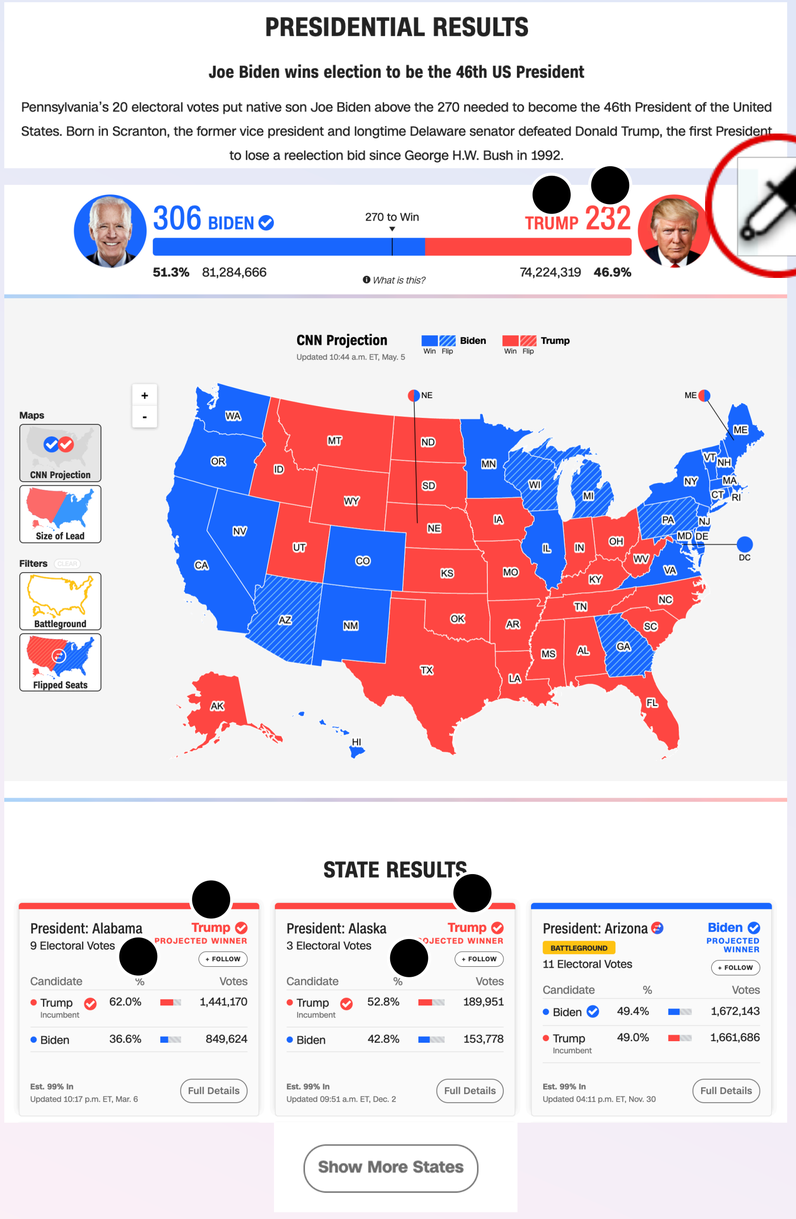
Large text (bold and 16pt or larger) can be 3:1 or higher.

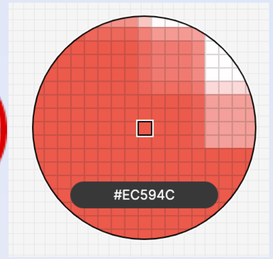


Use High Contrast Geometries

Chart elements need at least 3:1 contrast against their background.







Contrast Checker

Home > Resources > Contrast Checker

Foreground Color

#EC594C

Lightness

↔

Background Color

#FFFFFF

Lightness

Contrast Ratio

3.44:1

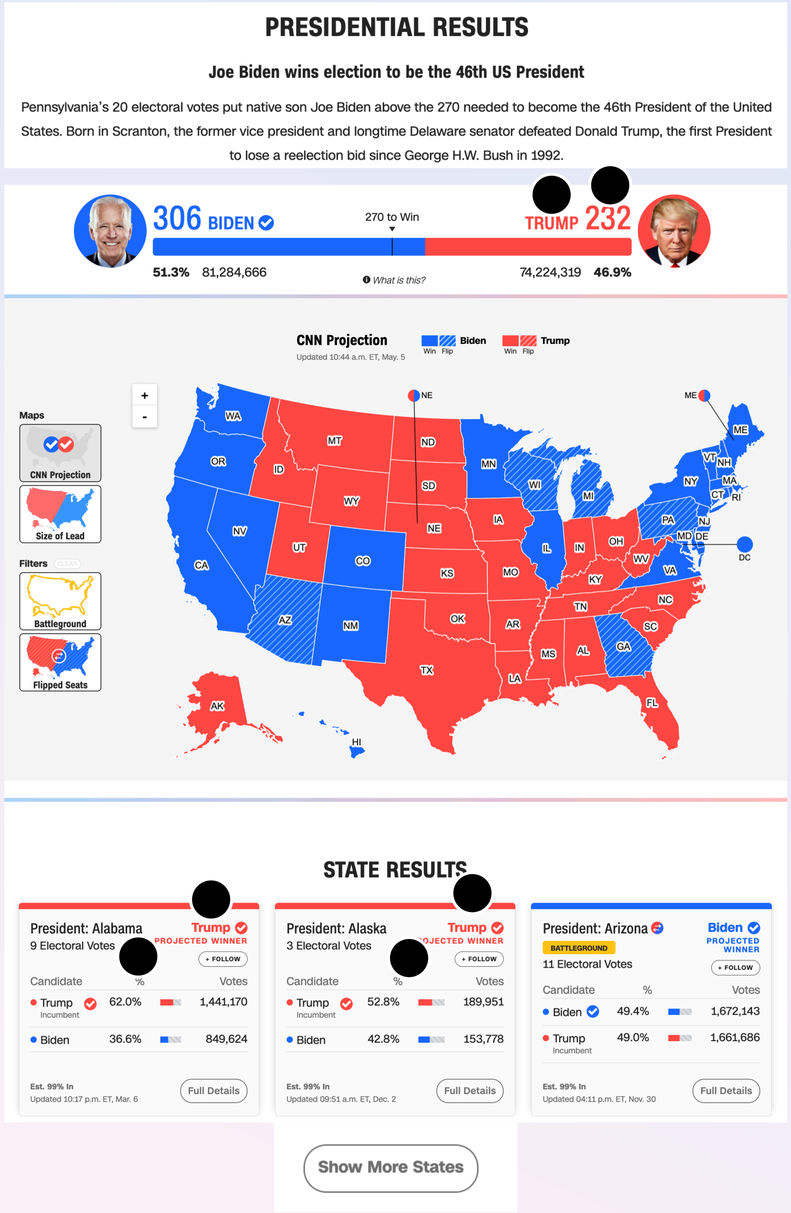
permalink

Normal Text

WCAG AA: **Fail**

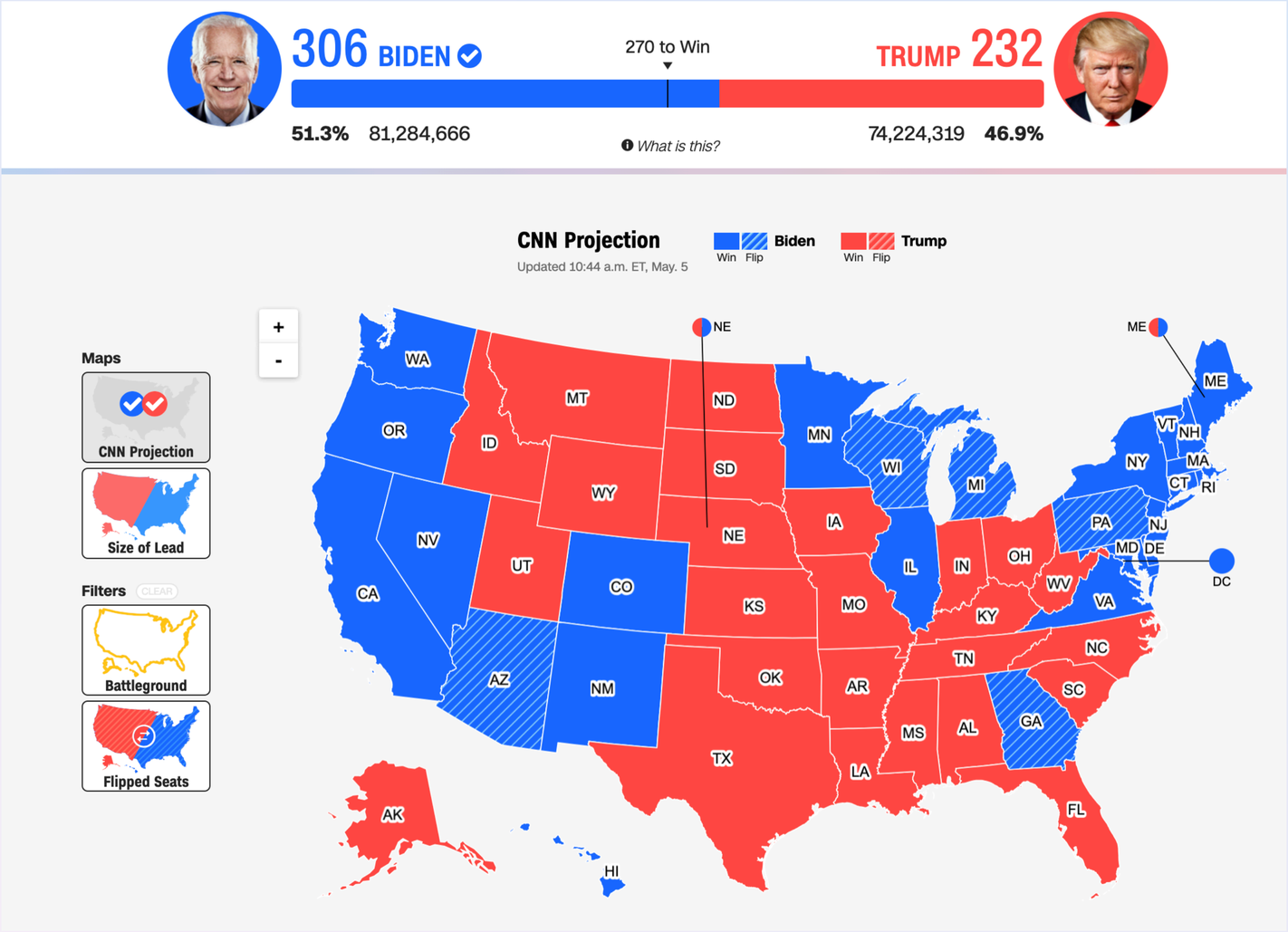
WCAG AAA: **Fail**

The five boxing wizards jump quickly.

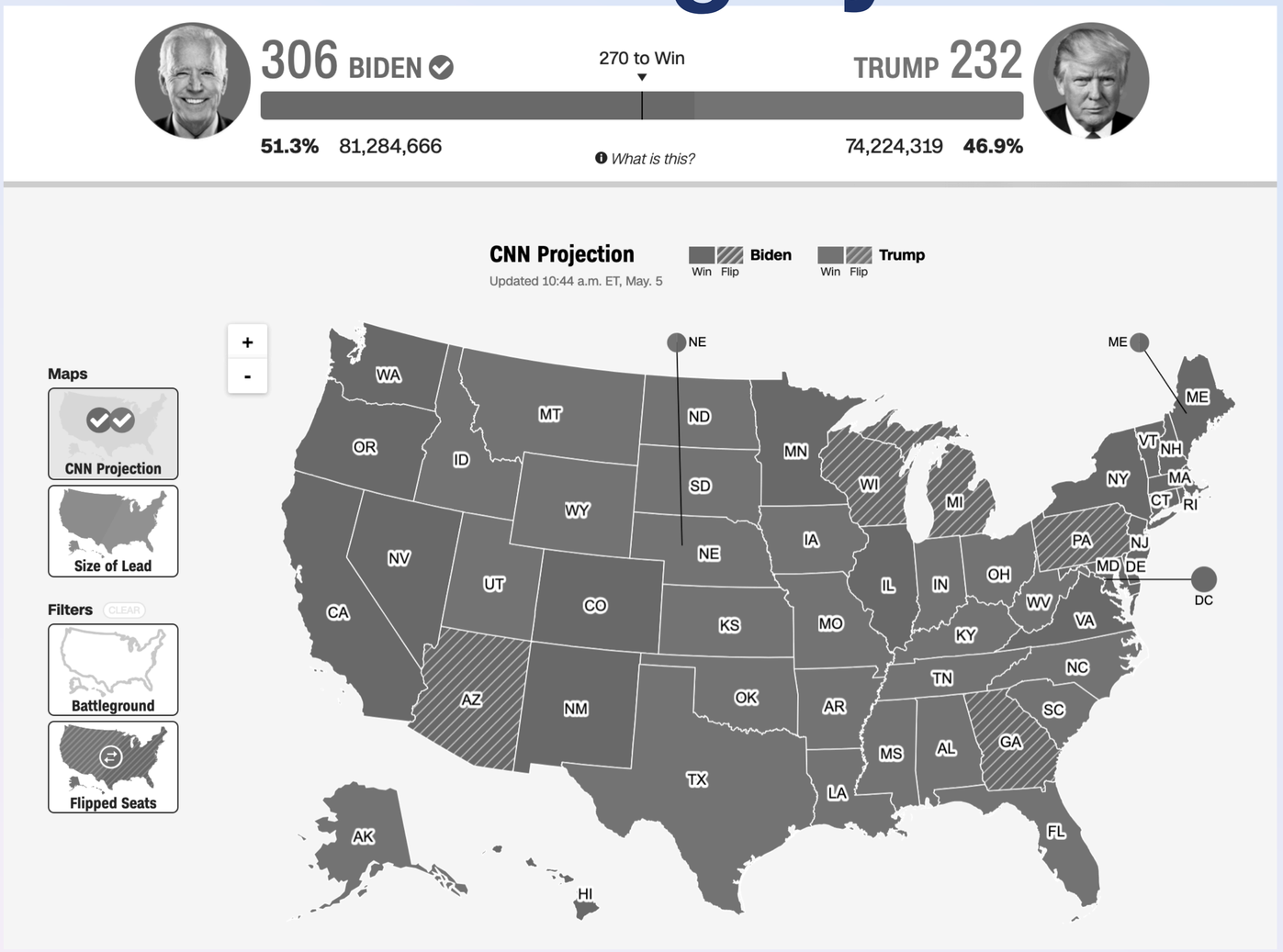


6 instances of low contrast

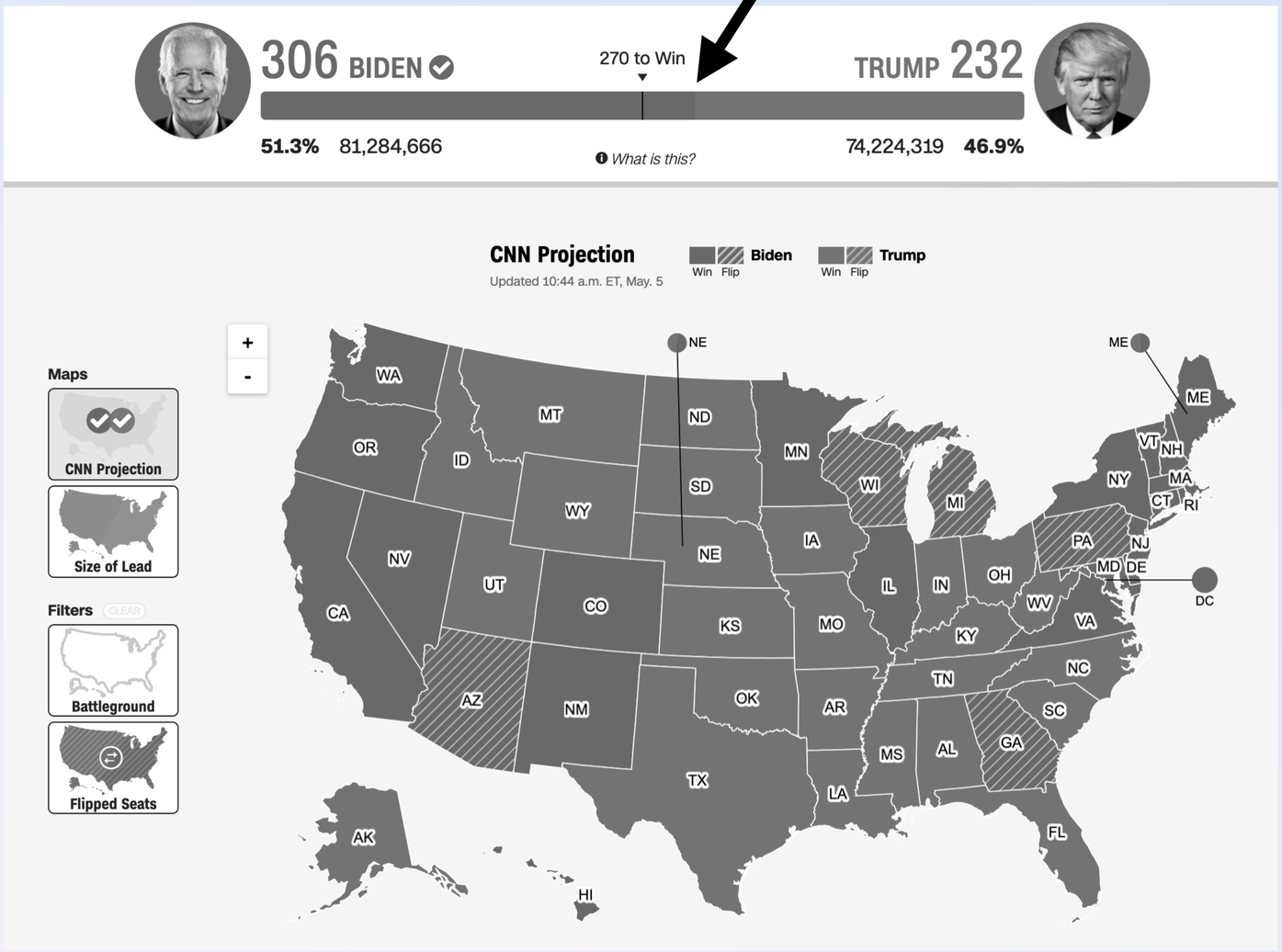
How can we fix this?



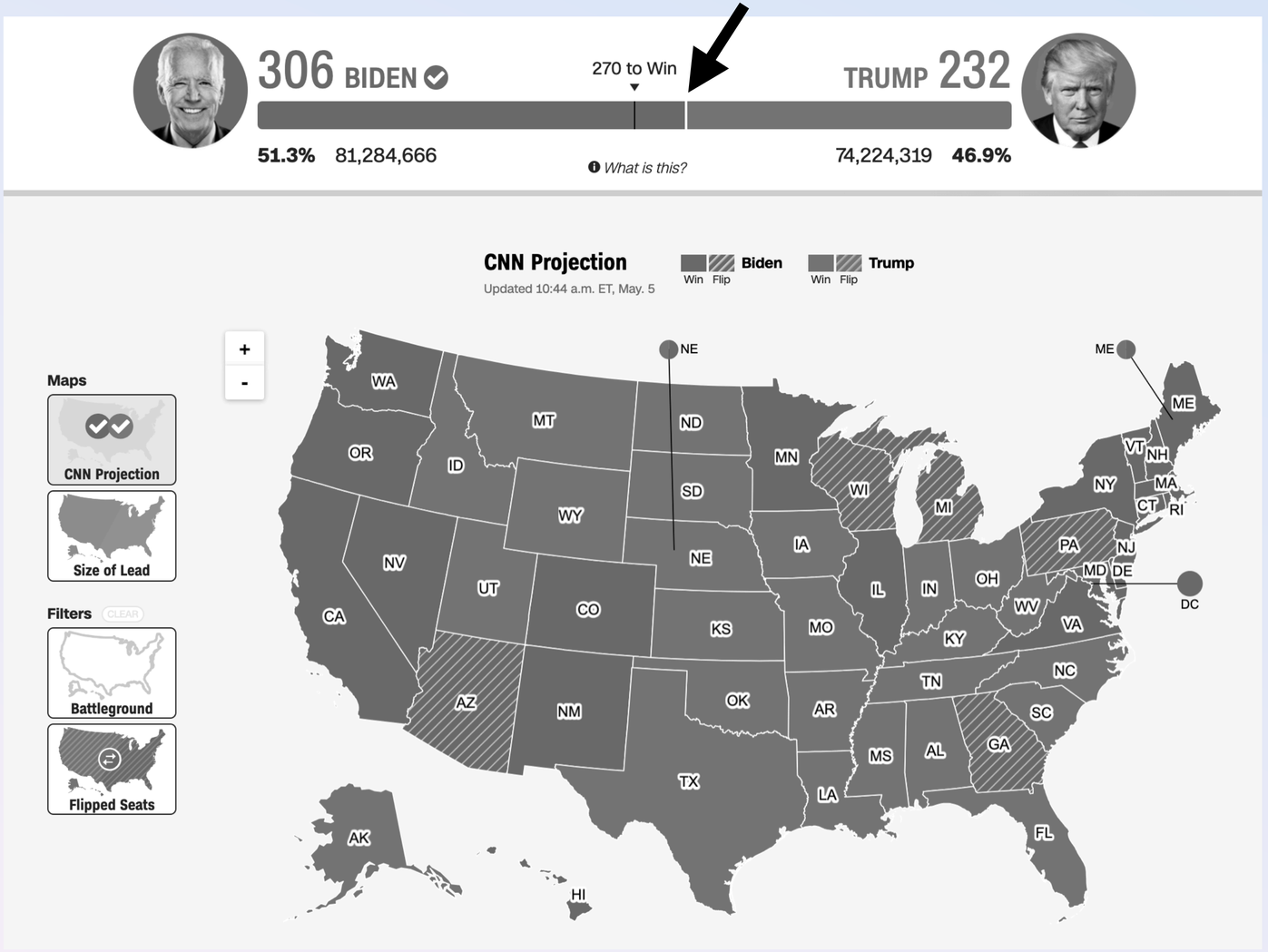
This map is trouble in greyscale



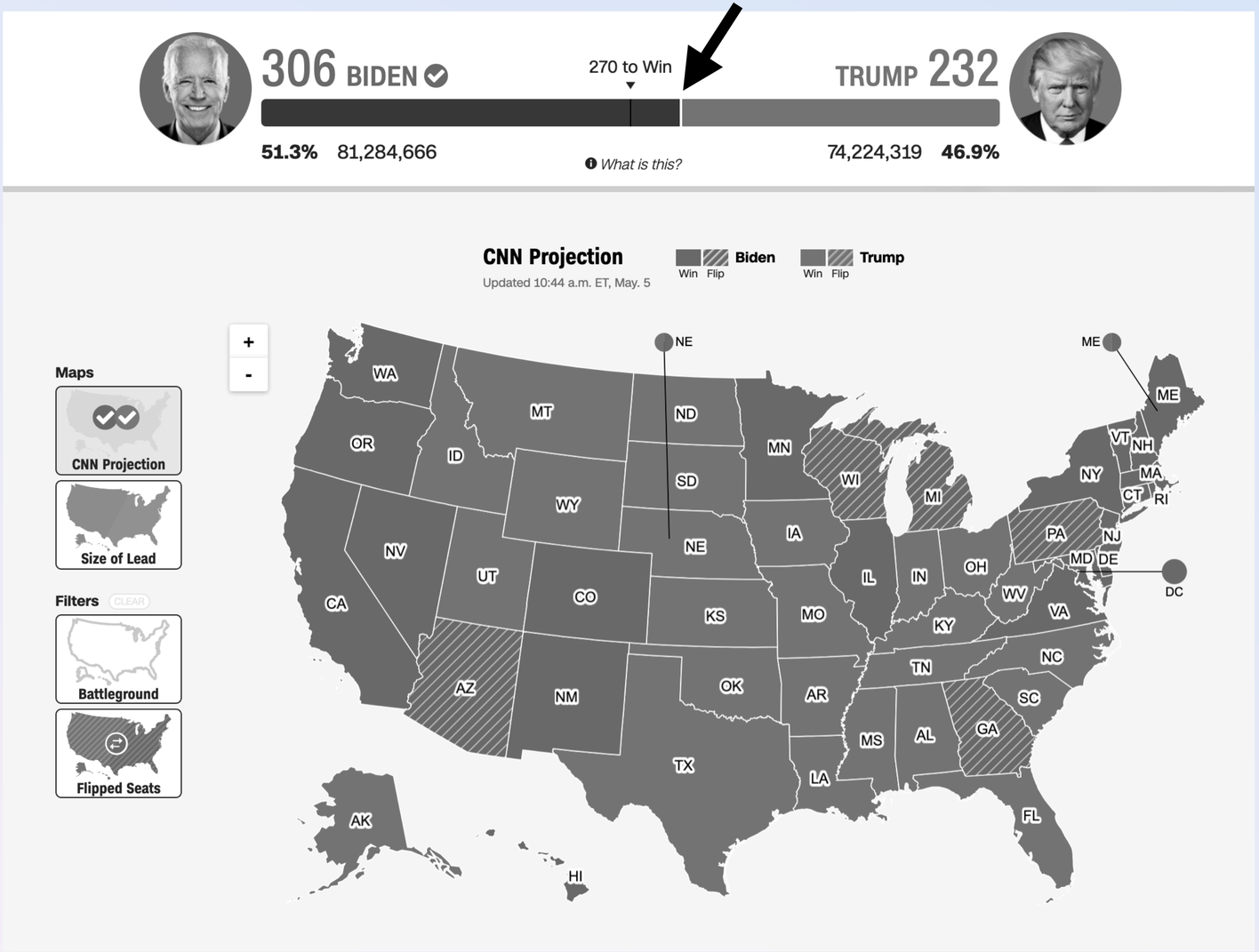
The division here matters!



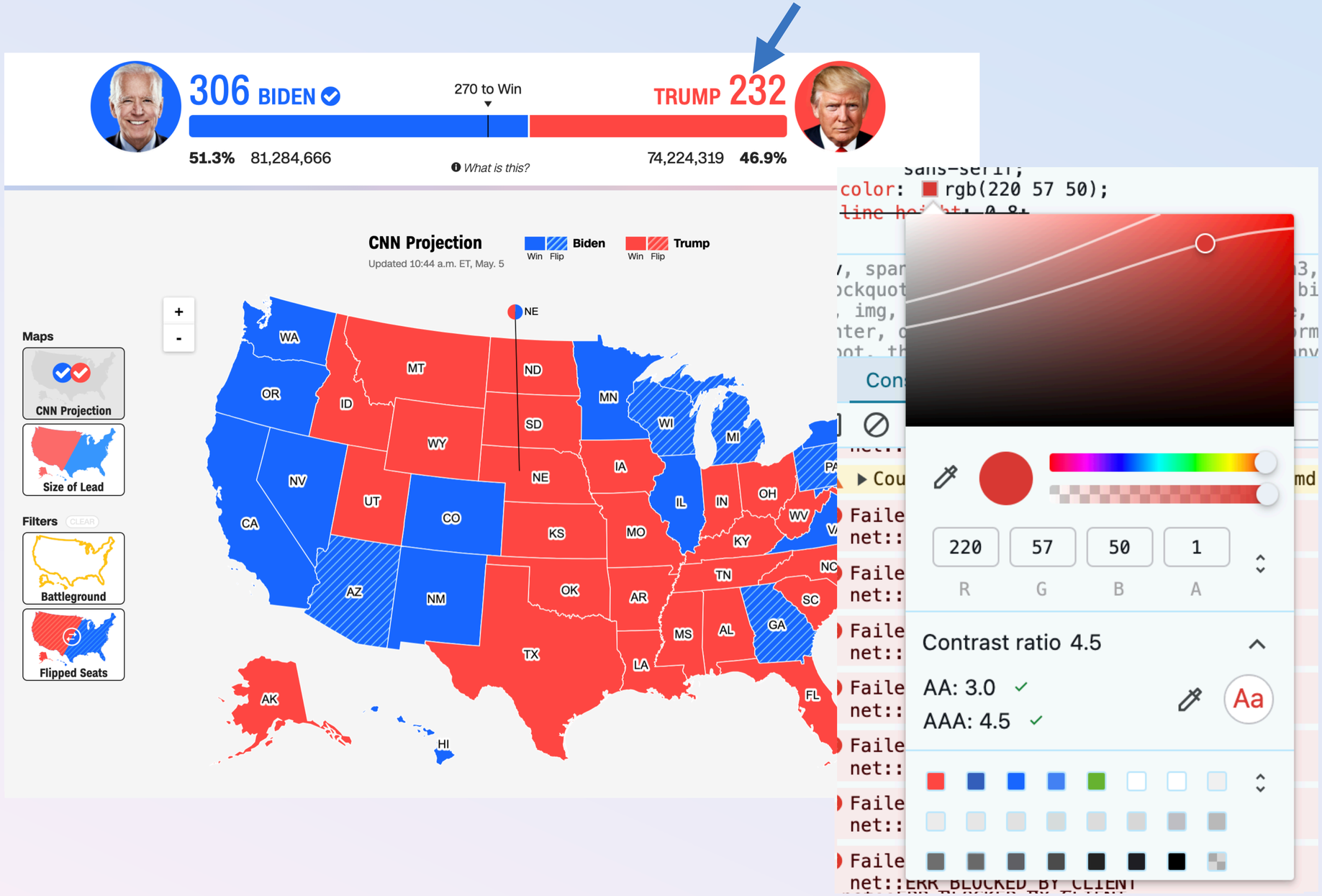
Maybe a small white divider, like the states?



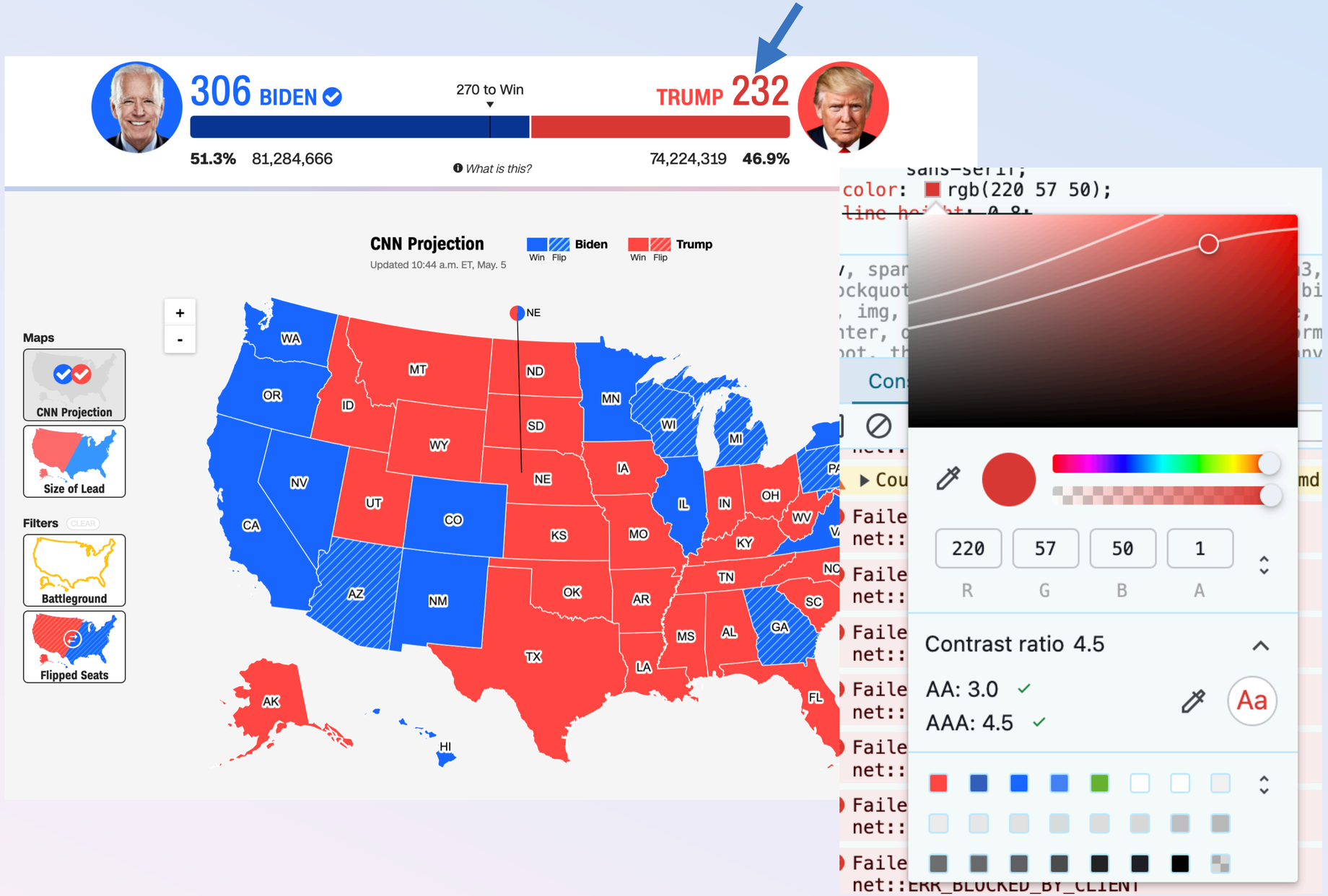
Perhaps test a darker blue too?



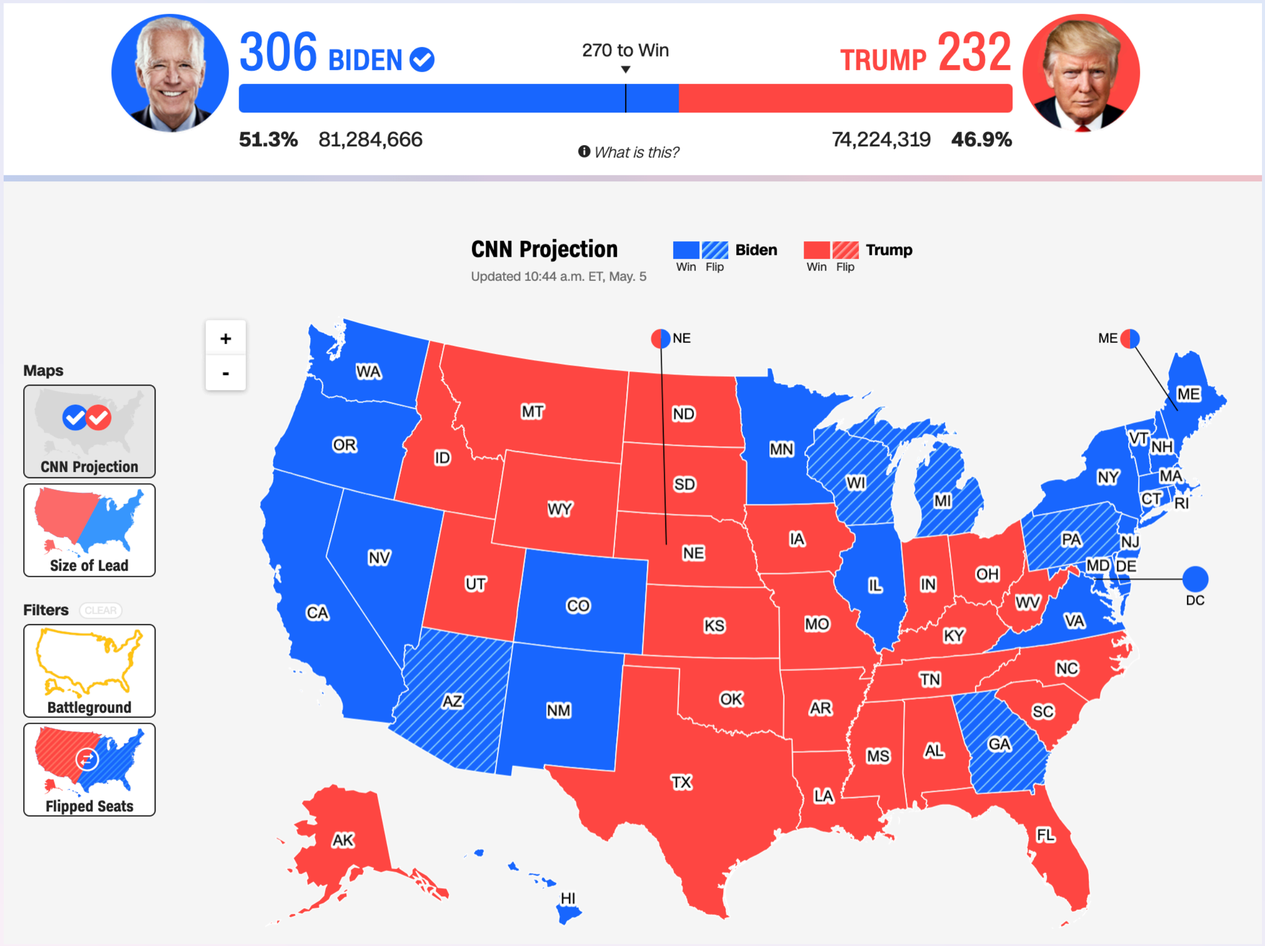
What if we fix the contrast failures at the same time?

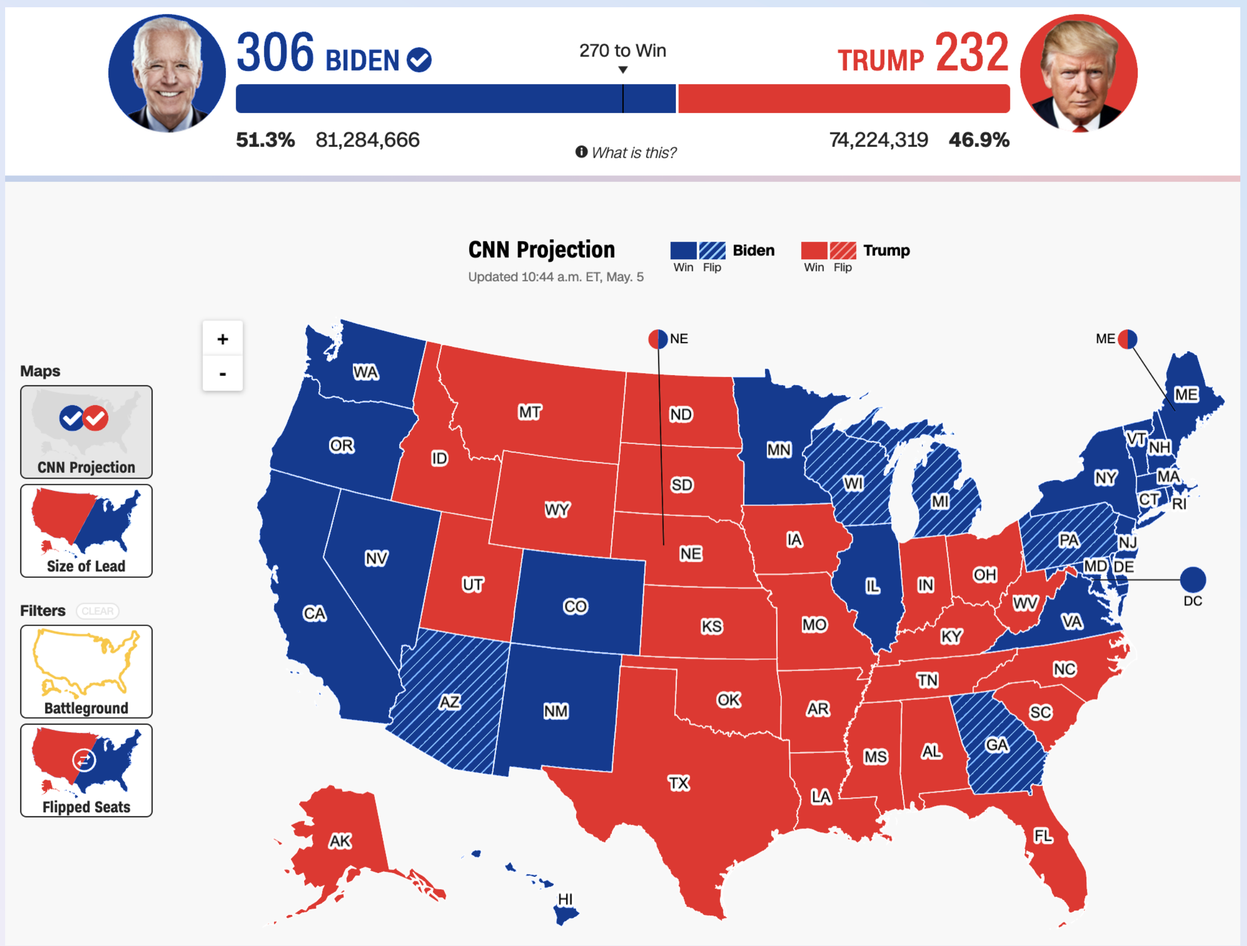


This text now passes!

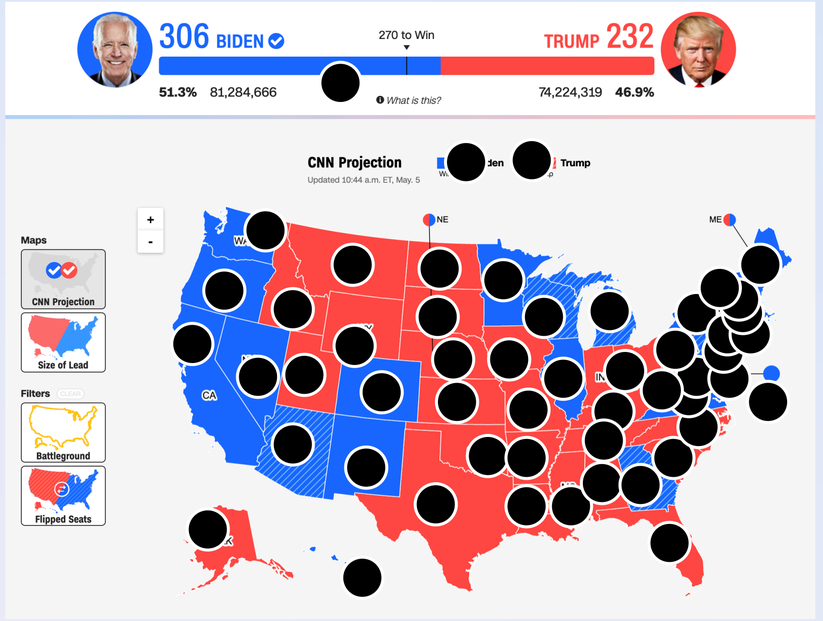


Sufficient contrast can help folks differentiate





(repeat for 49 other heuristics)



Chartability is used in:

15+ Policy orgs and governments worldwide

World Health Organization

European Commission

USWDS

110+ Tech, news, and non-profit companies/orgs

Microsoft

GitHub

Azure

HIGHCHARTS

Adobe

jupyter

The New York Times

REUTERS

BBC

20+ Undergraduate and graduate courses

Carnegie Mellon University

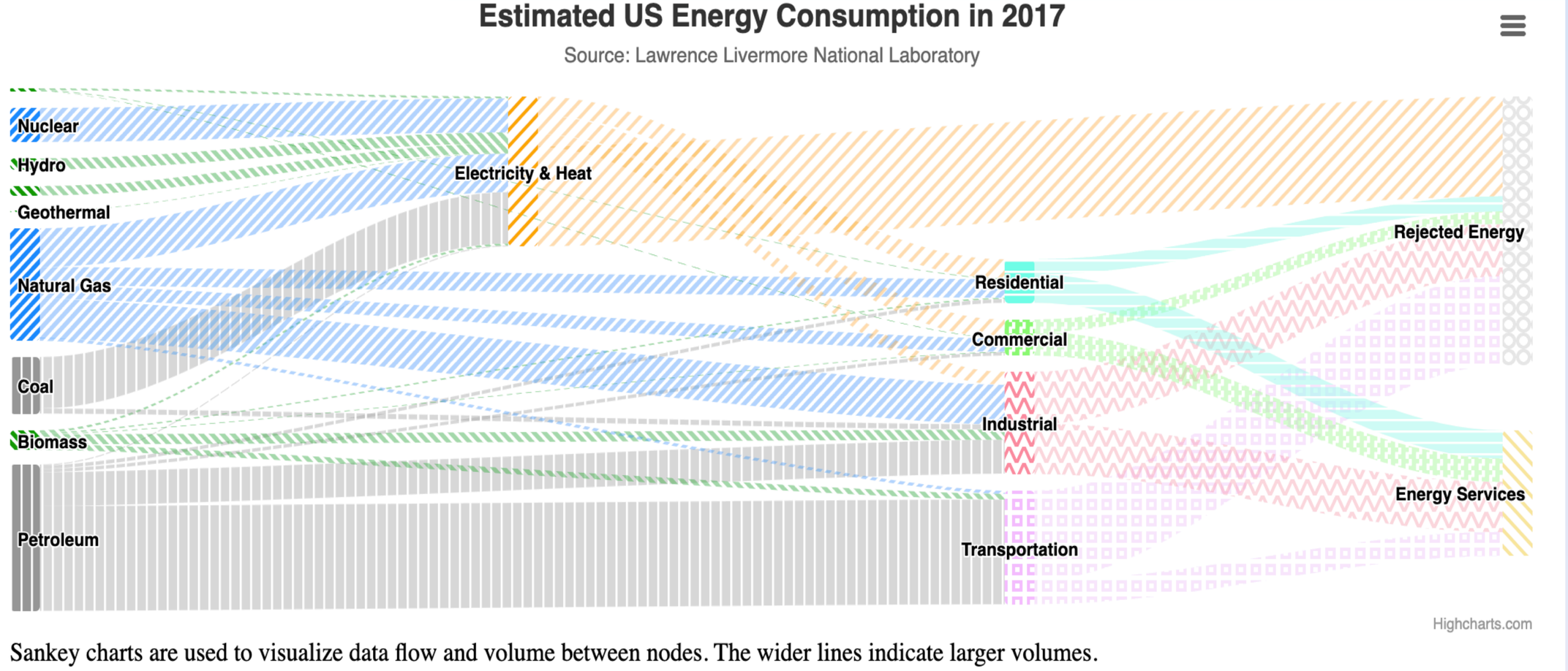
Massachusetts Institute of Technology

UNIVERSITY of WASHINGTON

Northwestern University

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

What about this visualization might be a barrier?



Sankey charts are used to visualize data flow and volume between nodes. The wider lines indicate larger volumes.

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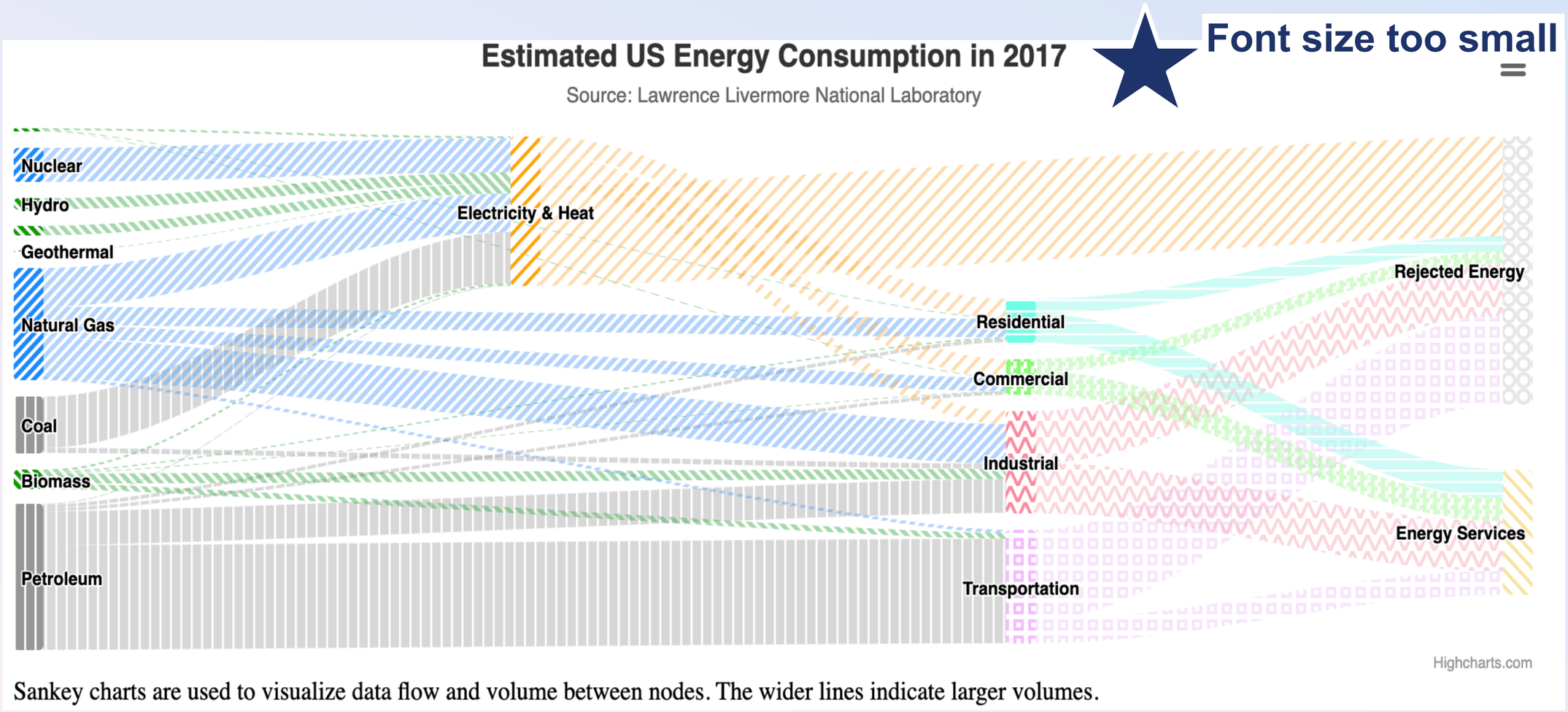

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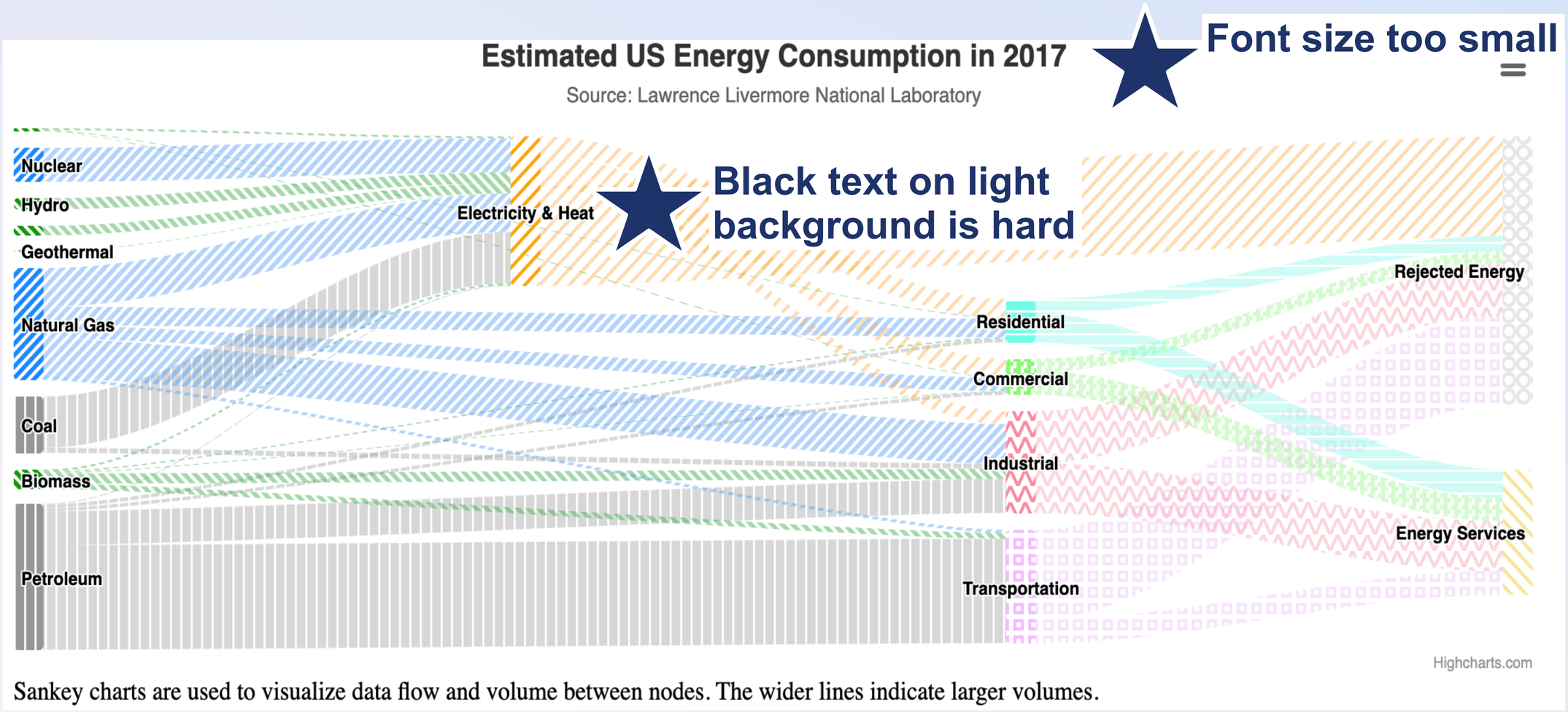

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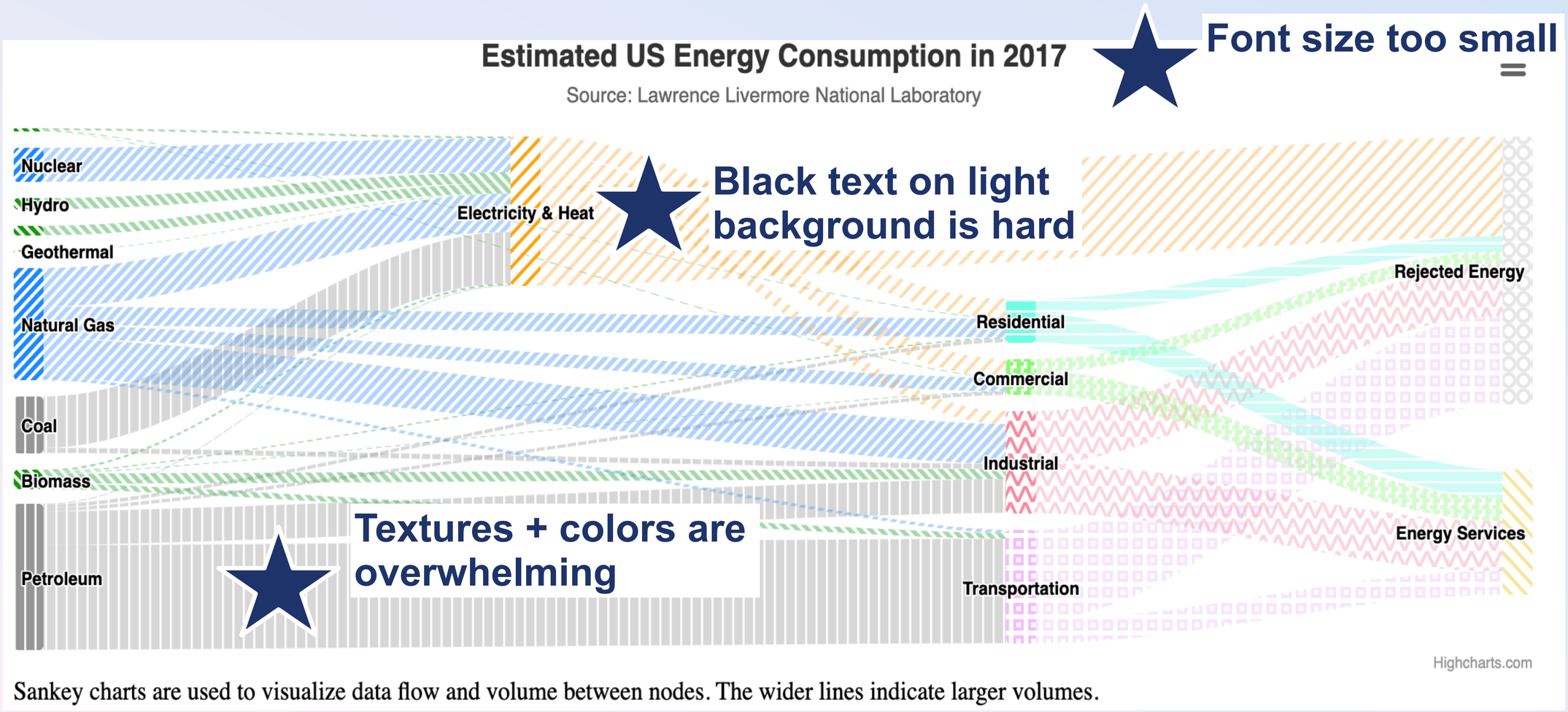

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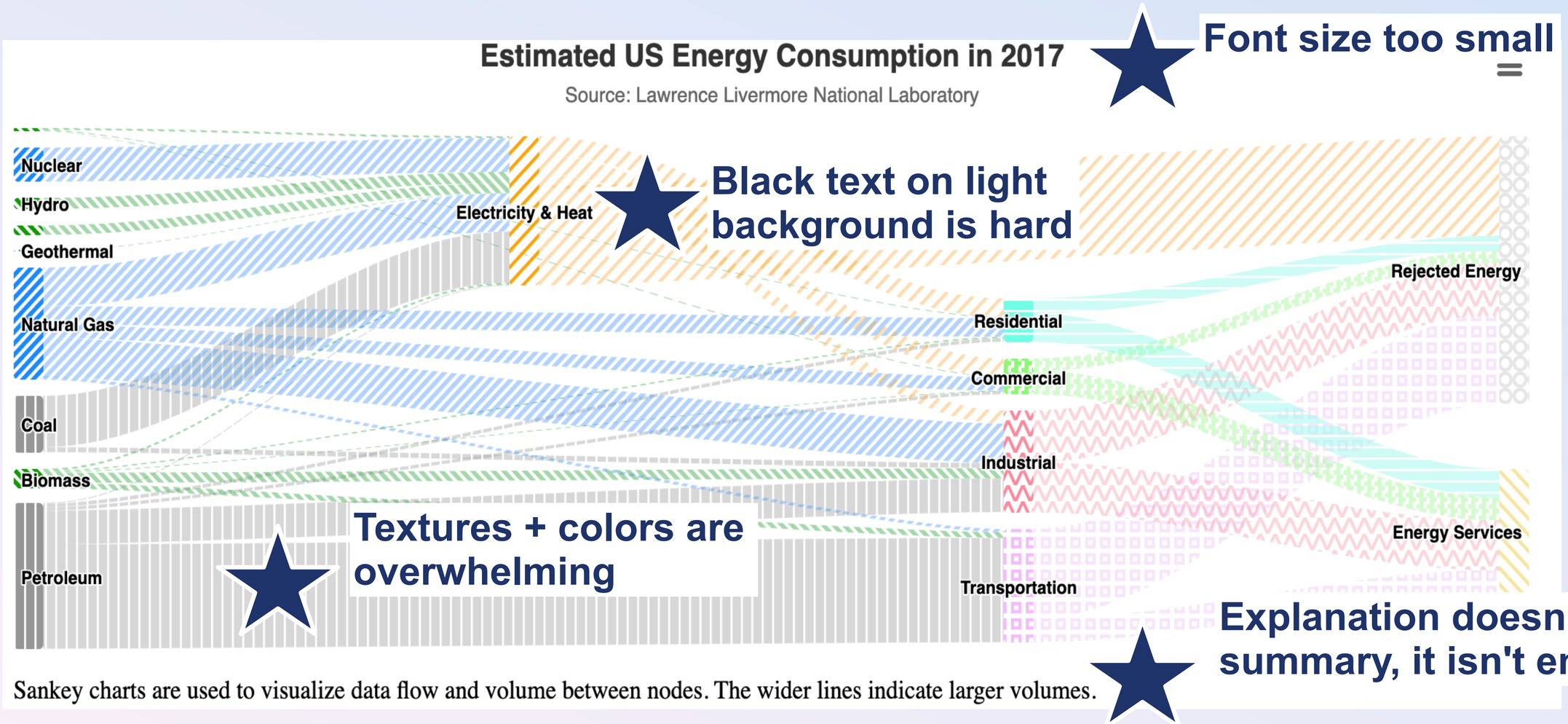
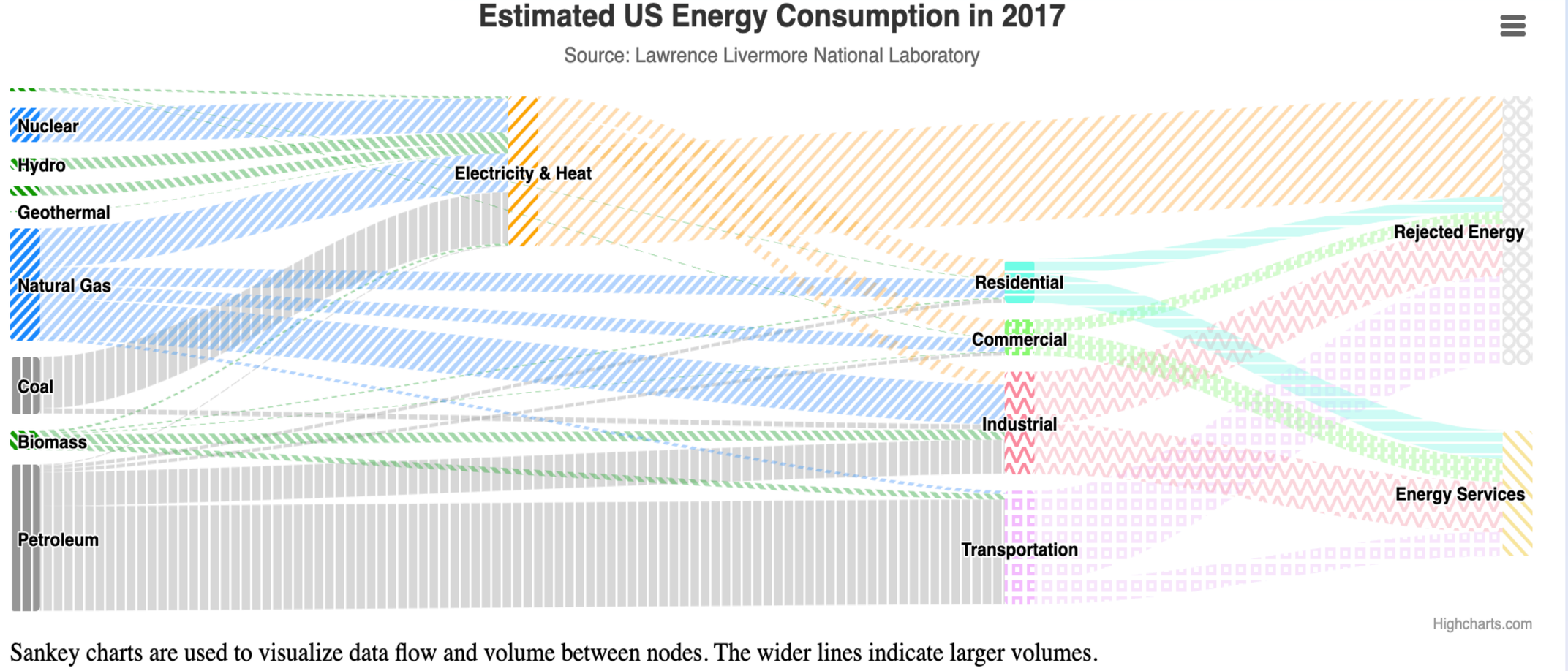
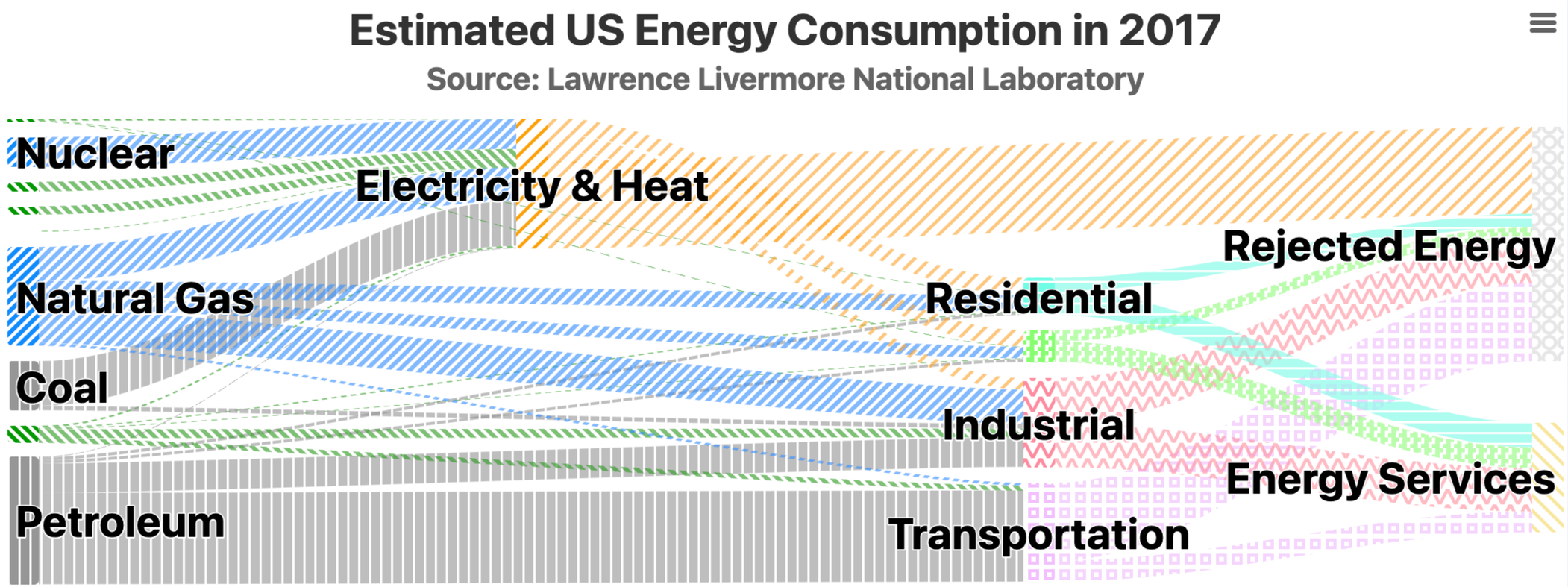


Can we fix this?



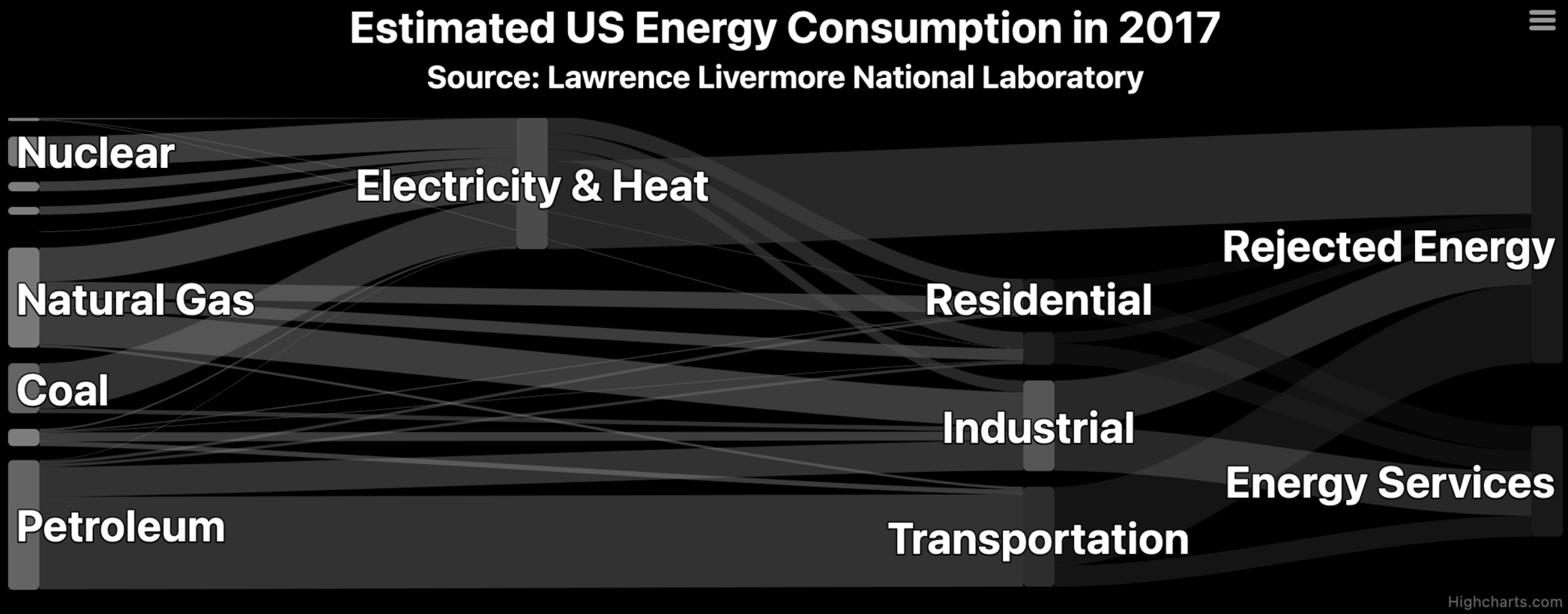
Sankey charts are used to visualize data flow and volume between nodes. The wider lines indicate larger volumes.

Maybe we can bump up the text size



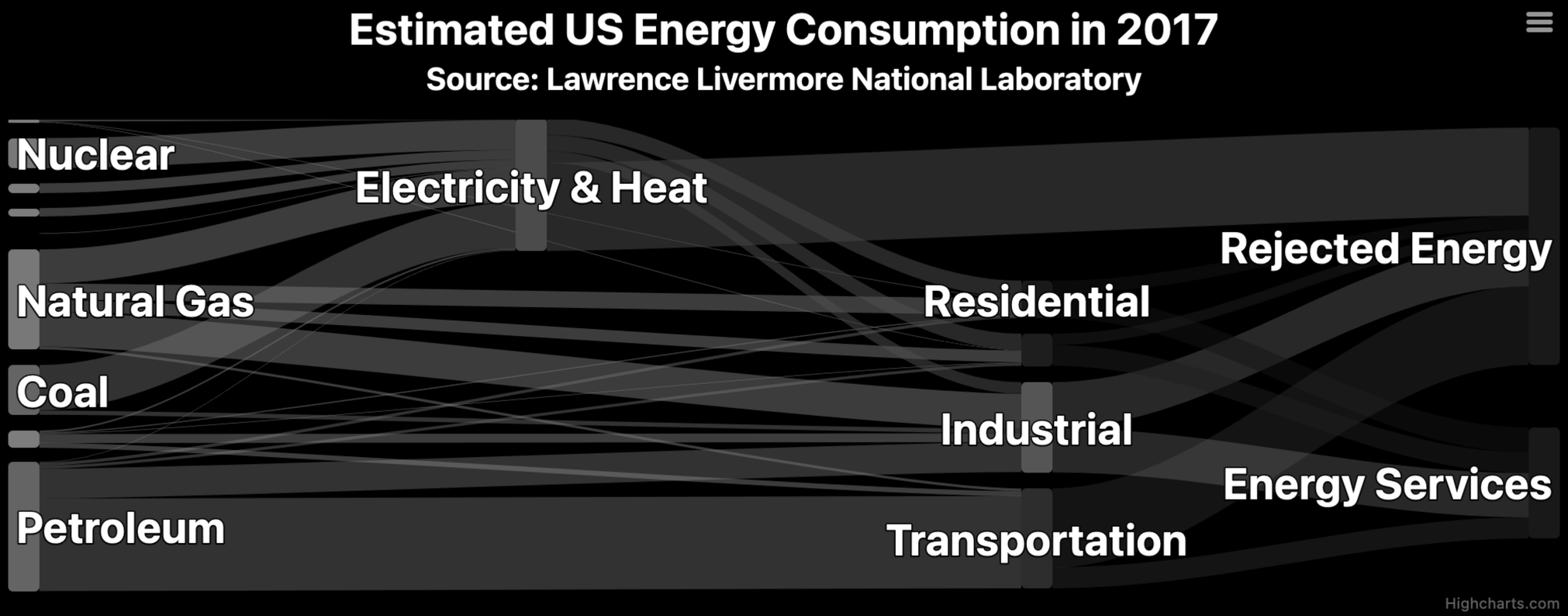
Sankey charts are used to visualize data flow and volume between nodes. The wider lines indicate larger volumes.

We can reduce visual complexity too



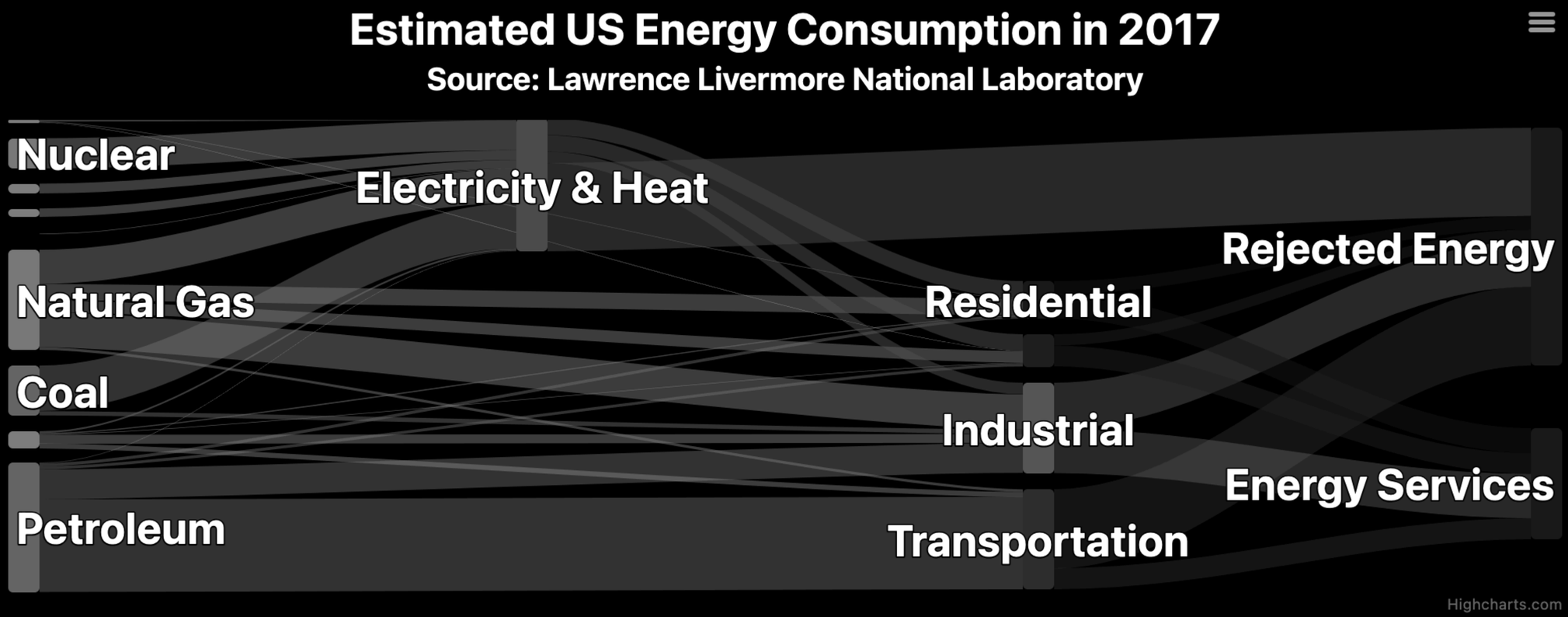
Sankey charts are used to visualize data flow and volume between nodes. The wider lines indicate larger volumes.

We can add a more descriptive explanation



Sankey charts are used to visualize data flow and volume between nodes. Visually wider lines indicate larger volumes. This chart is showing energy consumption and types. Interacting with this chart by selecting a node or flow (such as with a click) will update the stacked bar chart below.

Is this the perfect, most accessible design?



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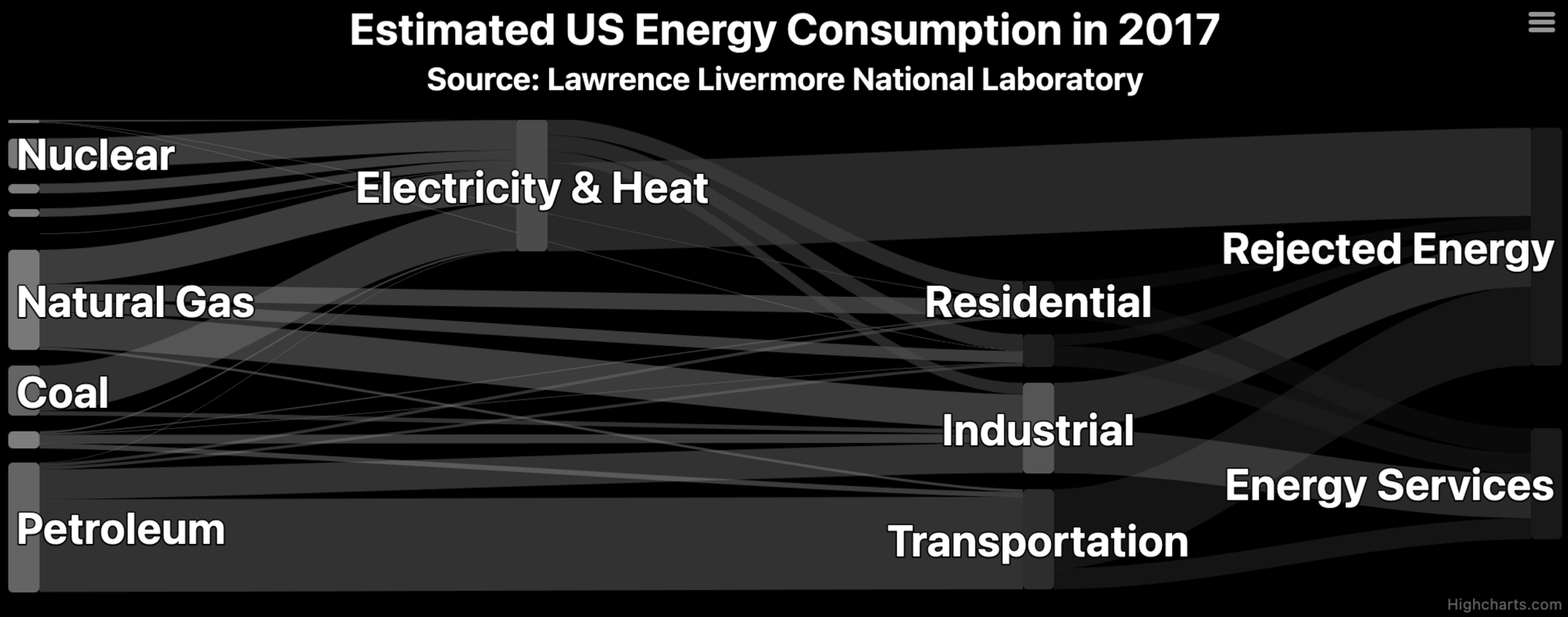
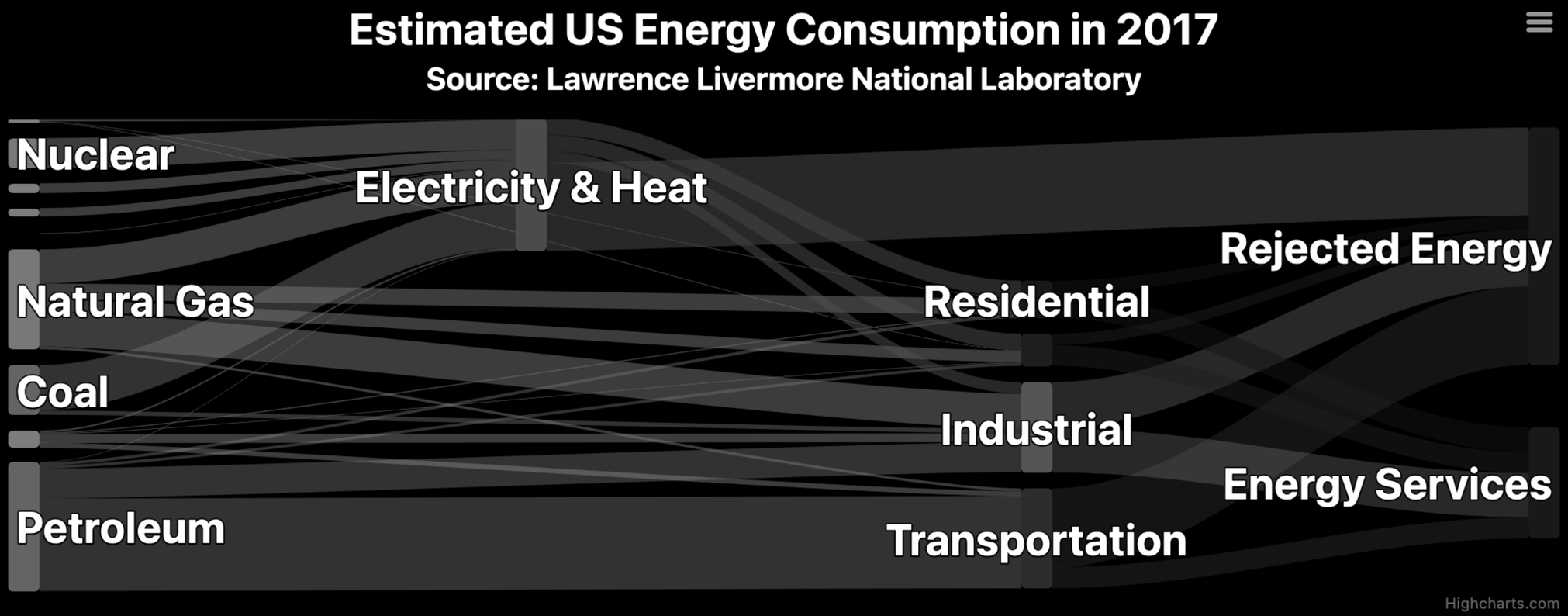
Bad news...



Sankey charts are used to visualize data flow and volume between nodes. Visually wider lines indicate larger volumes. This chart is showing energy consumption and types. Interacting with this chart by selecting a node or flow (such as with a click) will update the stacked bar chart below.

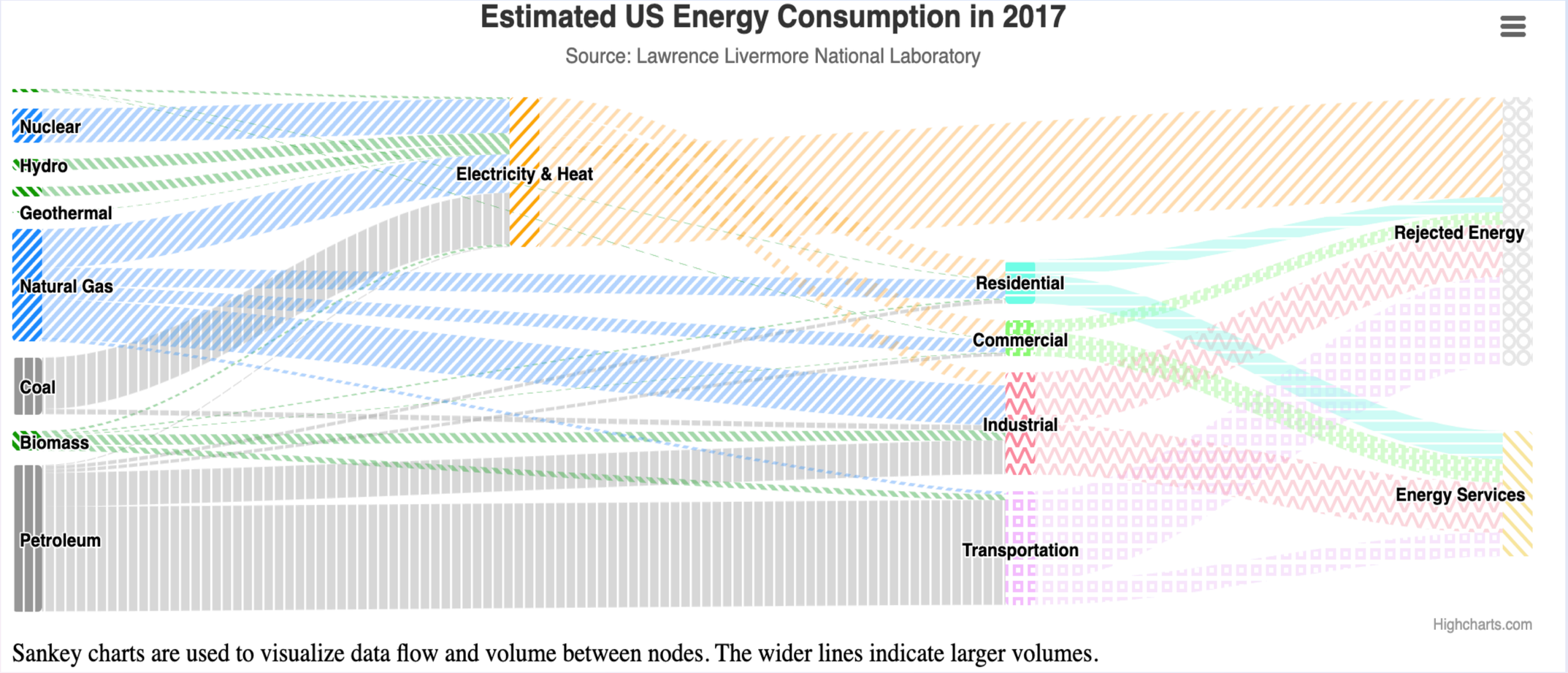
Bad news...

This design has accessibility issues too



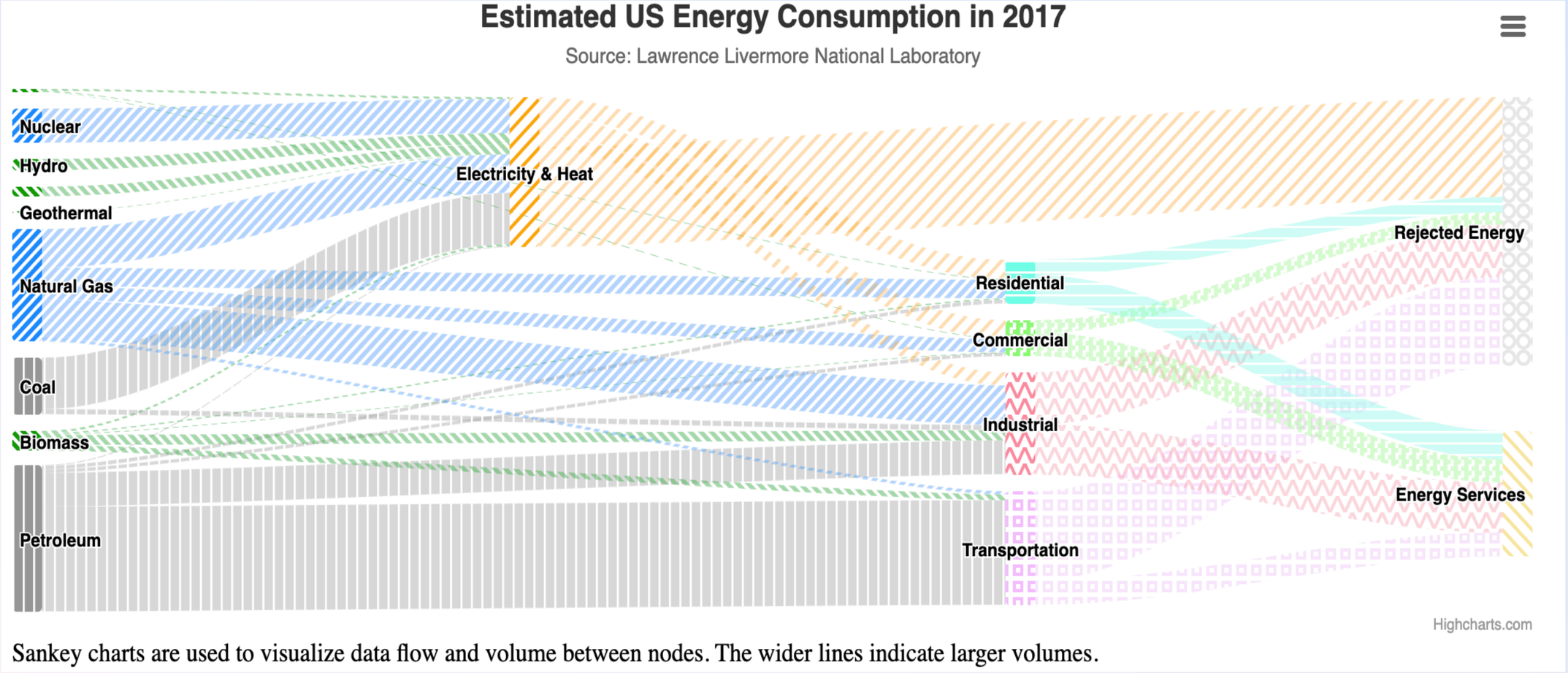
Sankey charts are used to visualize data flow and volume between nodes. Visually wider lines indicate larger volumes. This chart is showing energy consumption and types. Interacting with this chart by selecting a node or flow (such as with a click) will update the stacked bar chart below.

There is no such thing as a single, perfect design



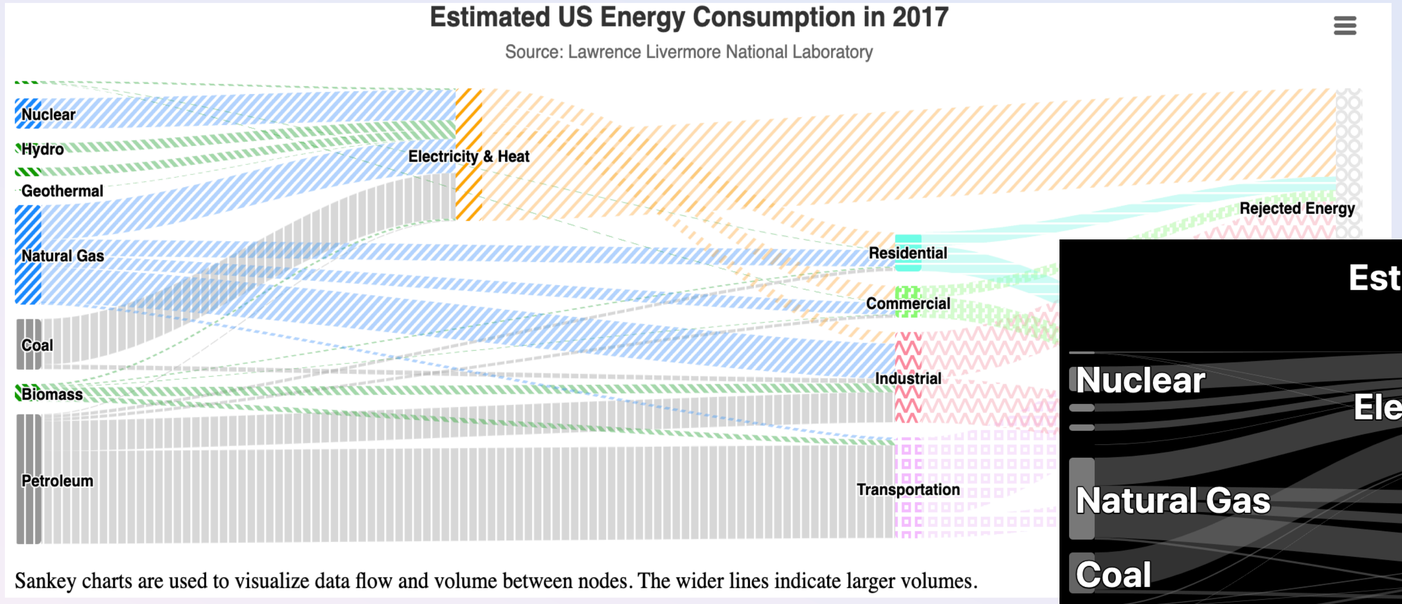
Sankey charts are used to visualize data flow and volume between nodes. The wider lines indicate larger volumes.

One design *cannot* fit all



Sankey charts are used to visualize data flow and volume between nodes. The wider lines indicate larger volumes.

Research problem: **How do we resolve this “access friction”?**



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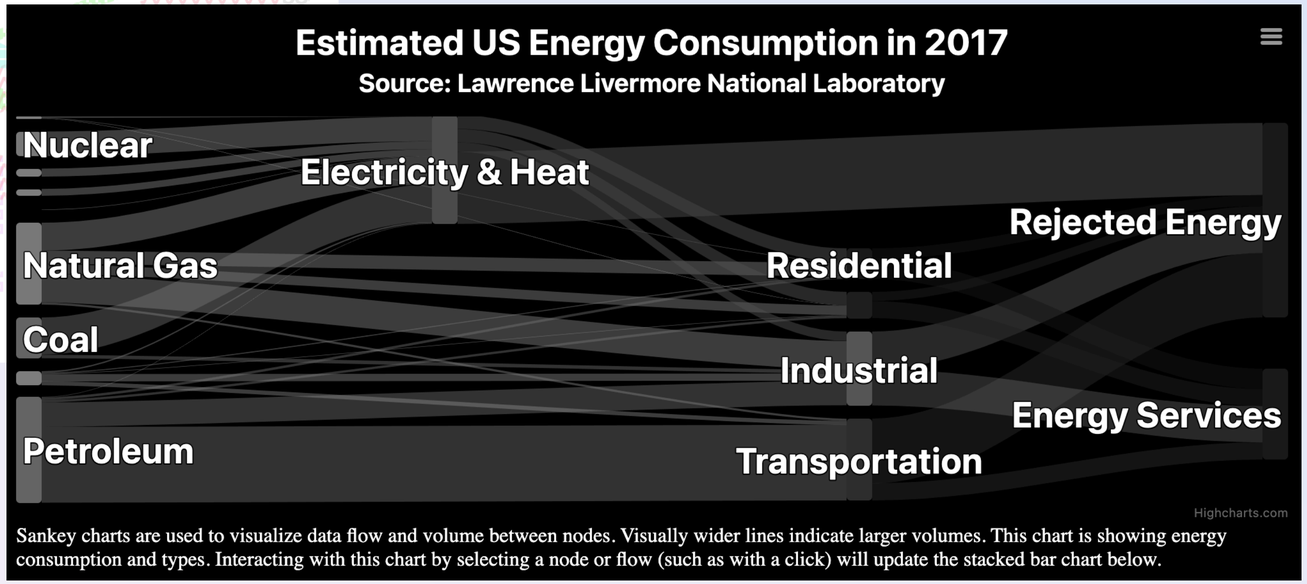

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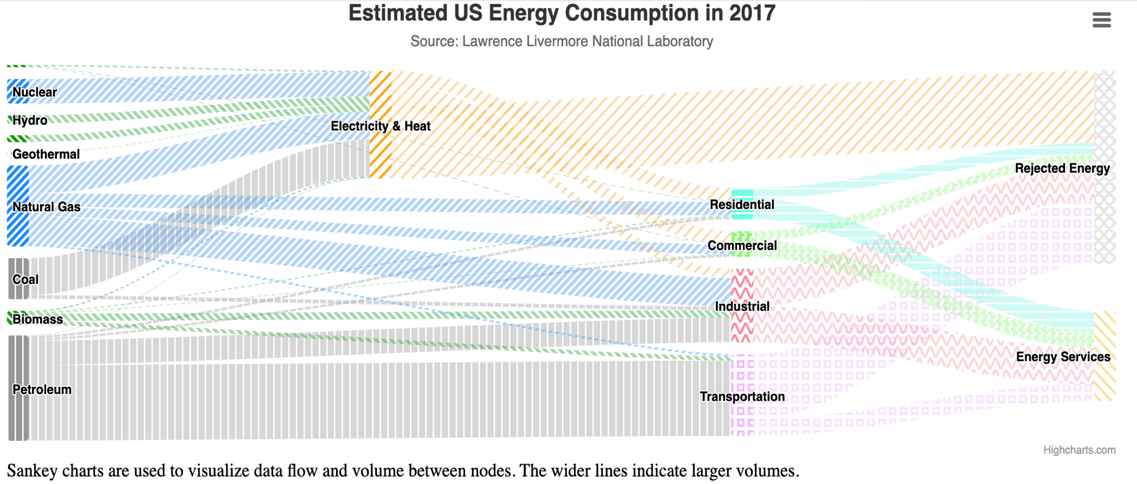
Why should our designs be one-size-fits-all?

What if we let users personalize?



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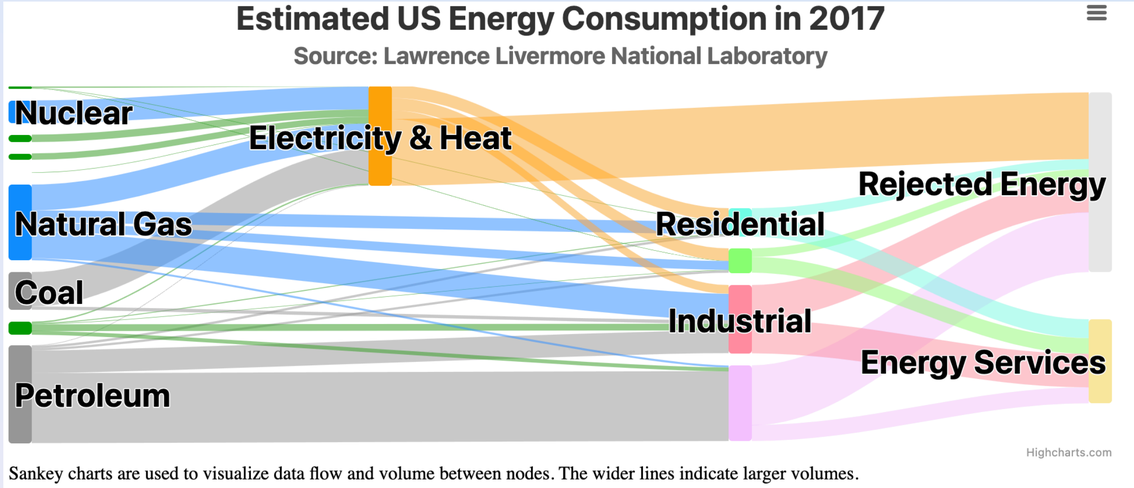

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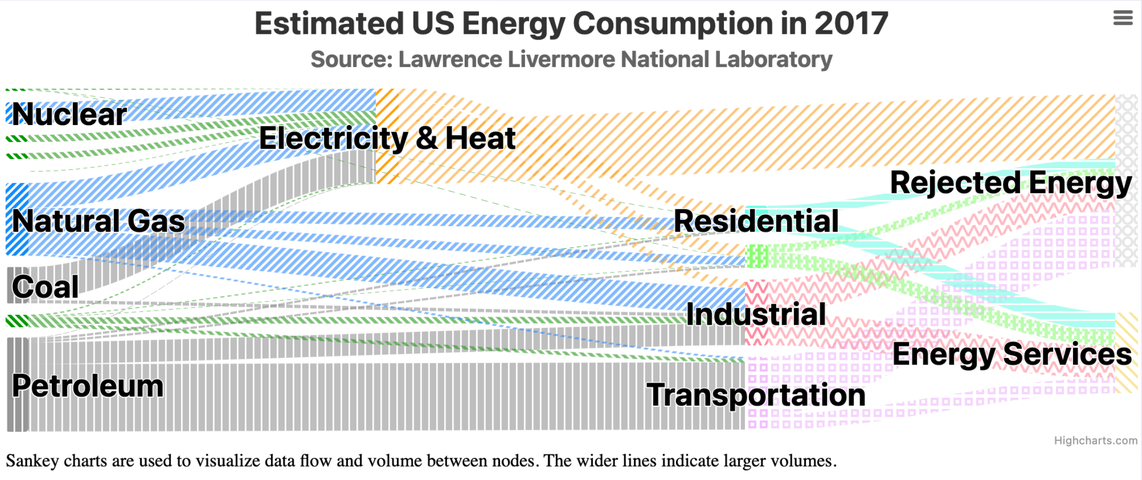

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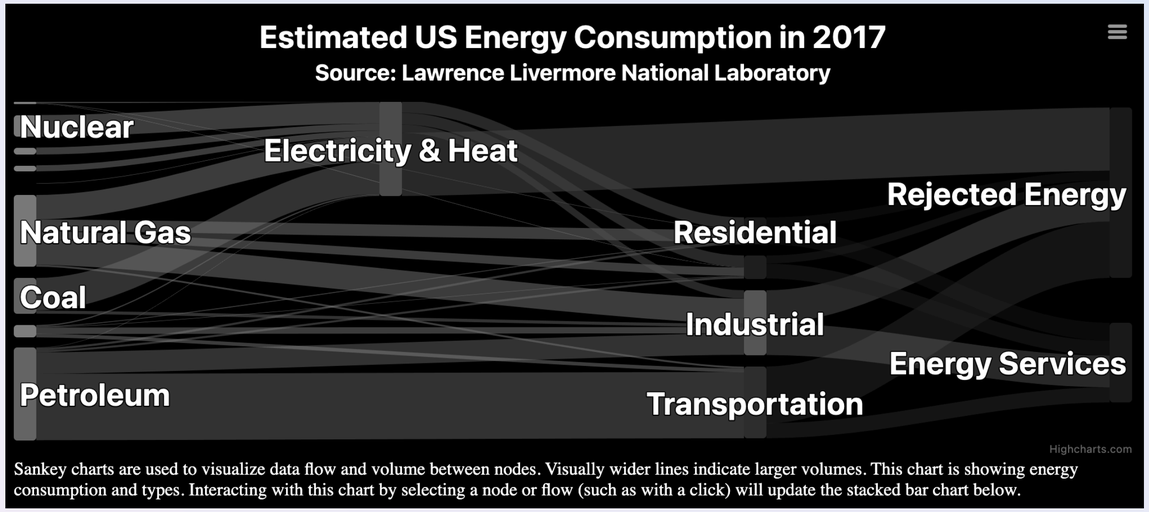

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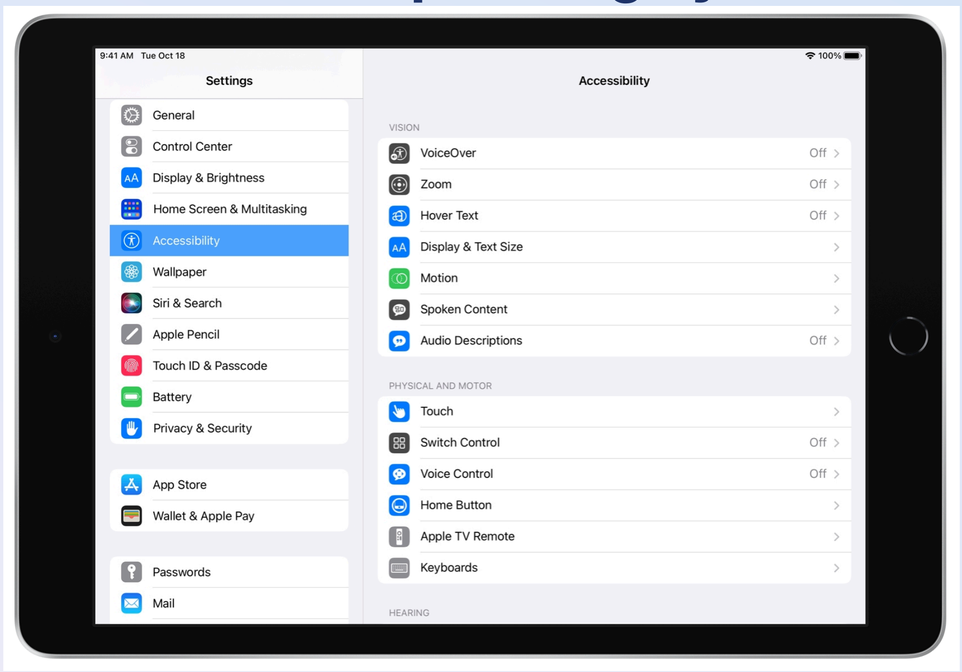
We have been enabling personalization for years

Video games

The Last of Us 2 has more than 60 settings

Devices and operating systems



"Make it yours" is the motto for Apple's accessibility personalization

We built a preferences menu!

Preferences

This menu provides a way to customize charts and graphs. The menu is organized into categories, and adjusting the settings at the category level will adjust all of the settings within that category. Some settings within categories also have sub-settings which will also inherit higher level settings that they belong to. If wording for a category's setting is hard to understand, try changing that setting and then navigating into the menu to see which children settings it affected.

Hide unavailable options ☑

Comprehension

default moderate robust

▶ Show more comprehension options...

Text visuals

default minimalist moderate maximalist

▼Show more text visuals options...

Font Size

default small medium large

▶ Show more font size options...

Font Weight

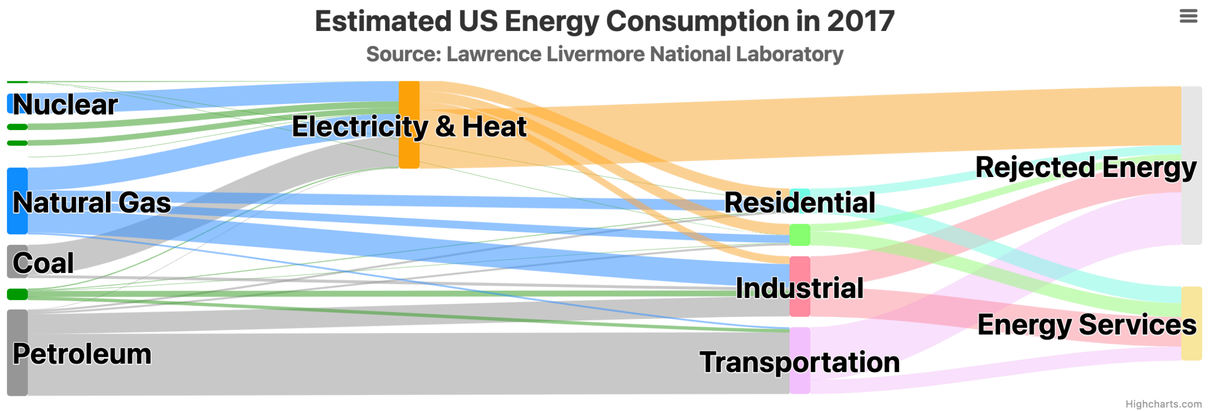
default 100 400 700

▶ Show more font weight options...

Color and contrast

default minimalist maximalist

▼Show more color and contrast options...



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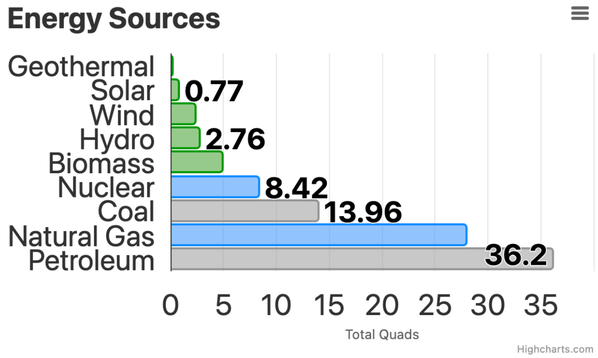
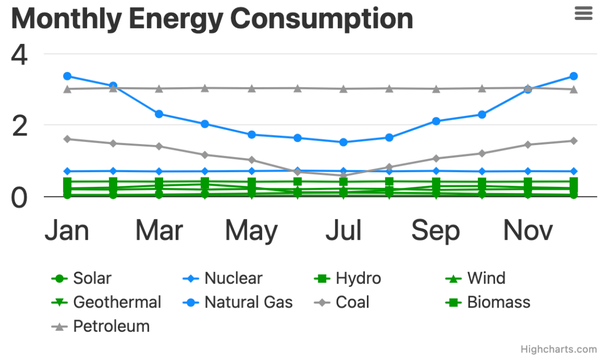


Chart showing stacked columns for comparing quantities. Stacked charts are often used to visualize data that accumulates to a sum.



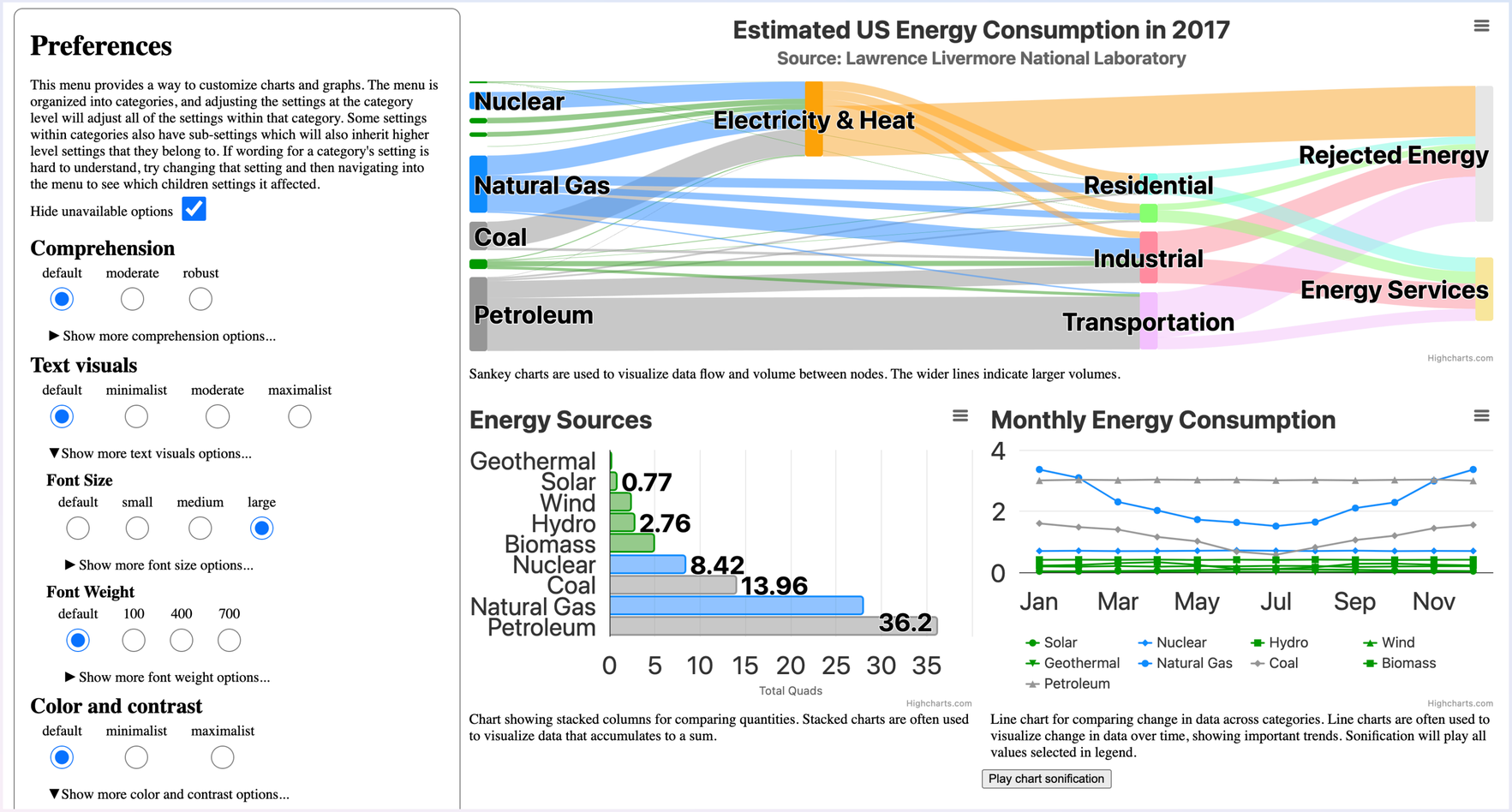
Line chart for comparing change in data across categories. Line charts are often used to visualize change in data over time, showing important trends. Sonification will play all values selected in legend.

Play chart sonification

What do people with disabilities want to personalize with visualizations?

And how does personalization change how we design visualization libraries, systems, and tools?

We gave 9 BLV users and 4 developers some levers to pull



(What is accessible for one...)

“If anything has dark mode? That’s great. I wish everything used dark mode.”

Participant #4

(...might be a barrier for another.)

“Oh, I can’t use dark mode at all. I hate when websites have [dark mode] because it can be virtually impossible to use.”

Participant #7

Results

⚠ Malleable interfaces need guardrails

- It is possible to design harmful visualizations, so system designers should anticipate ways to help users personalize safely.

F. Elavsky, M. Vindedal, T. Gies, P. Carrington, D. Moritz, and Ø. Mousing, “Towards *Softerware*: Enabling personalization of interactive data representations for users with disabilities,” *Computer Graphics and Applications*, 2025.

Results

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🎯 Our ethical responsibility: Accessible defaults first

- Some users won't want to personalize or manipulate interfaces at all, so they will still rely on smart, effective defaults.

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🪪 Persistence, profiles, and "effort-to-usage" ratio

- Everything about malleable interfaces should save users time and energy. Let them save, reuse, and share their personalization.

F. Elavsky, M. Vindedal, T. Gies, P. Carrington, D. Moritz, and Ø. Mousing, “Towards *Softerware*: Enabling personalization of interactive data representations for users with disabilities,” *Computer Graphics and Applications*, 2025.

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Persistence, profiles, and "effort-to-usage" ratio

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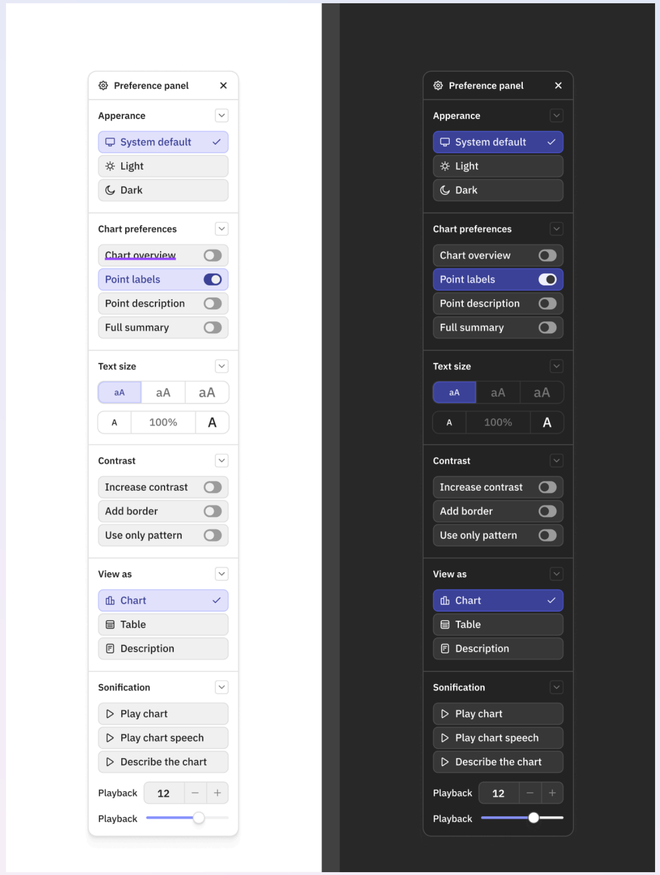
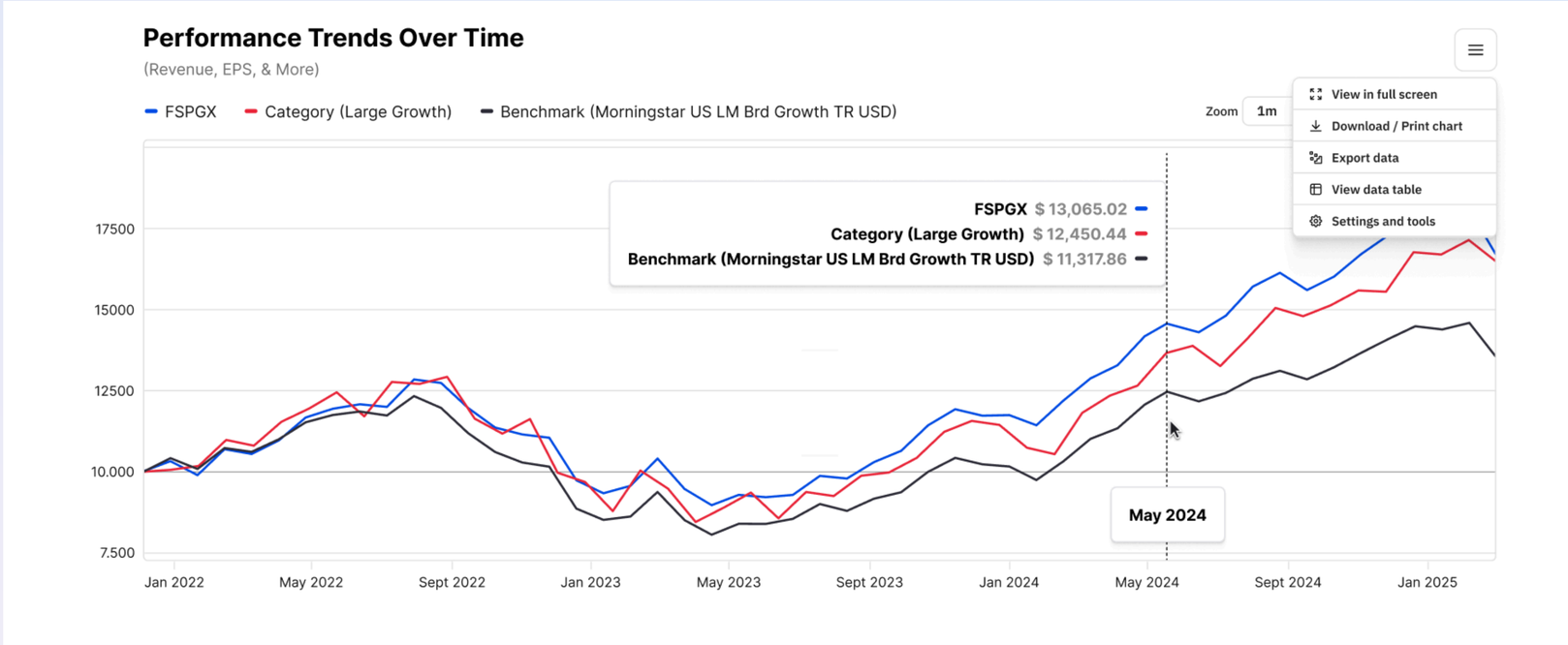
Interoperability: *everyone*'s job

- One visualization library isn't enough: the way users personalize a chart in one place should carry over to other platforms and tools.

F. Elavsky, M. Vindedal, T. Gies, P. Carrington, D. Moritz, and Ø. Mousing, “Towards *Softerware*: Enabling personalization of interactive data representations for users with disabilities,” *Computer Graphics and Applications*, 2025.

Deployment in Highcharts, >6m downloads/month





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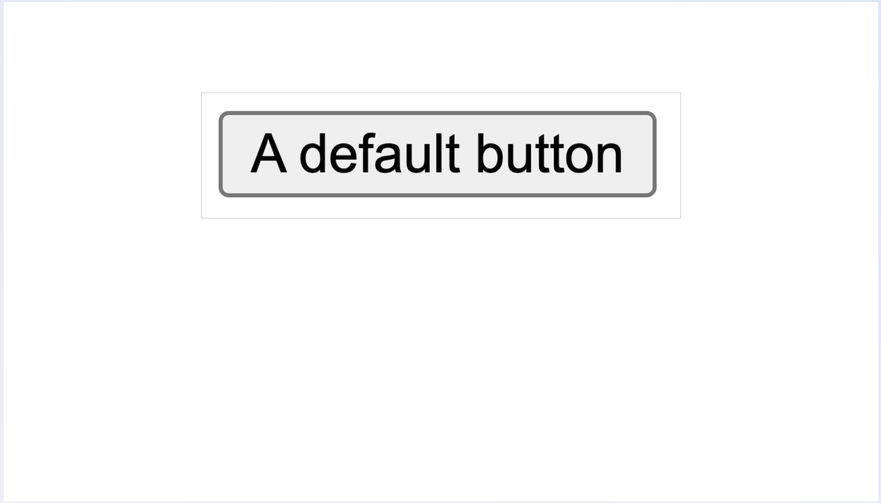
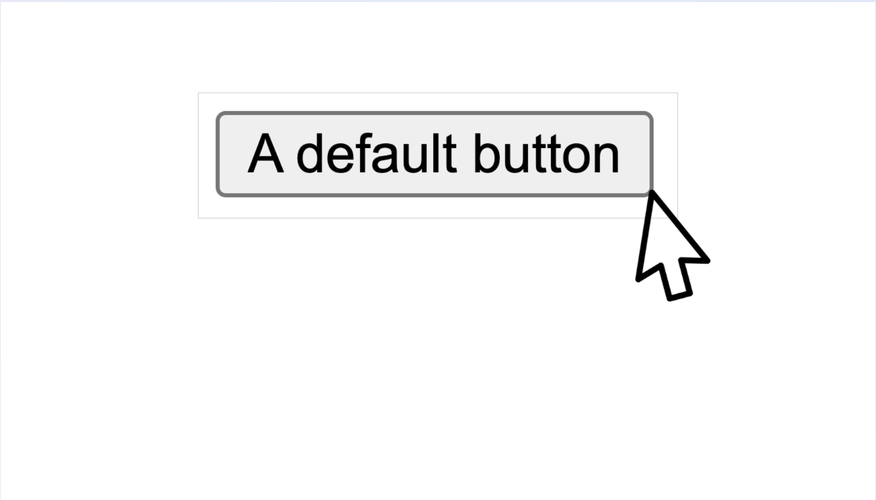
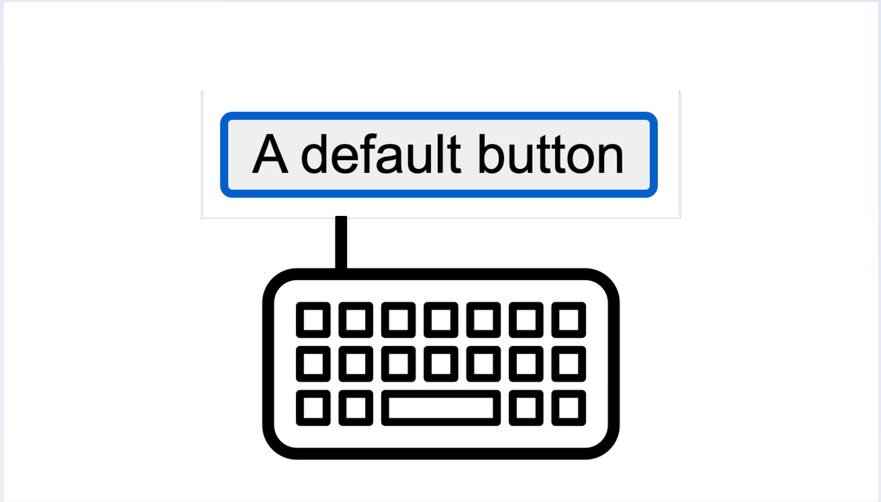
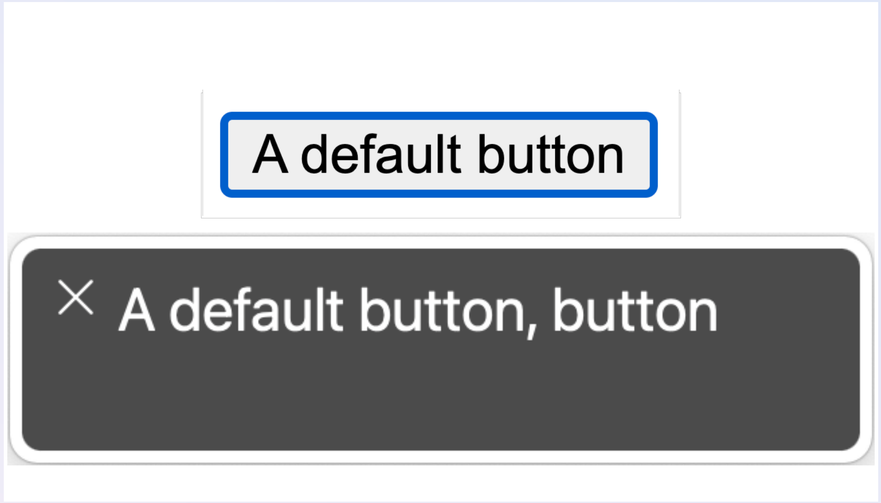
Section 2:
Low-level building blocks

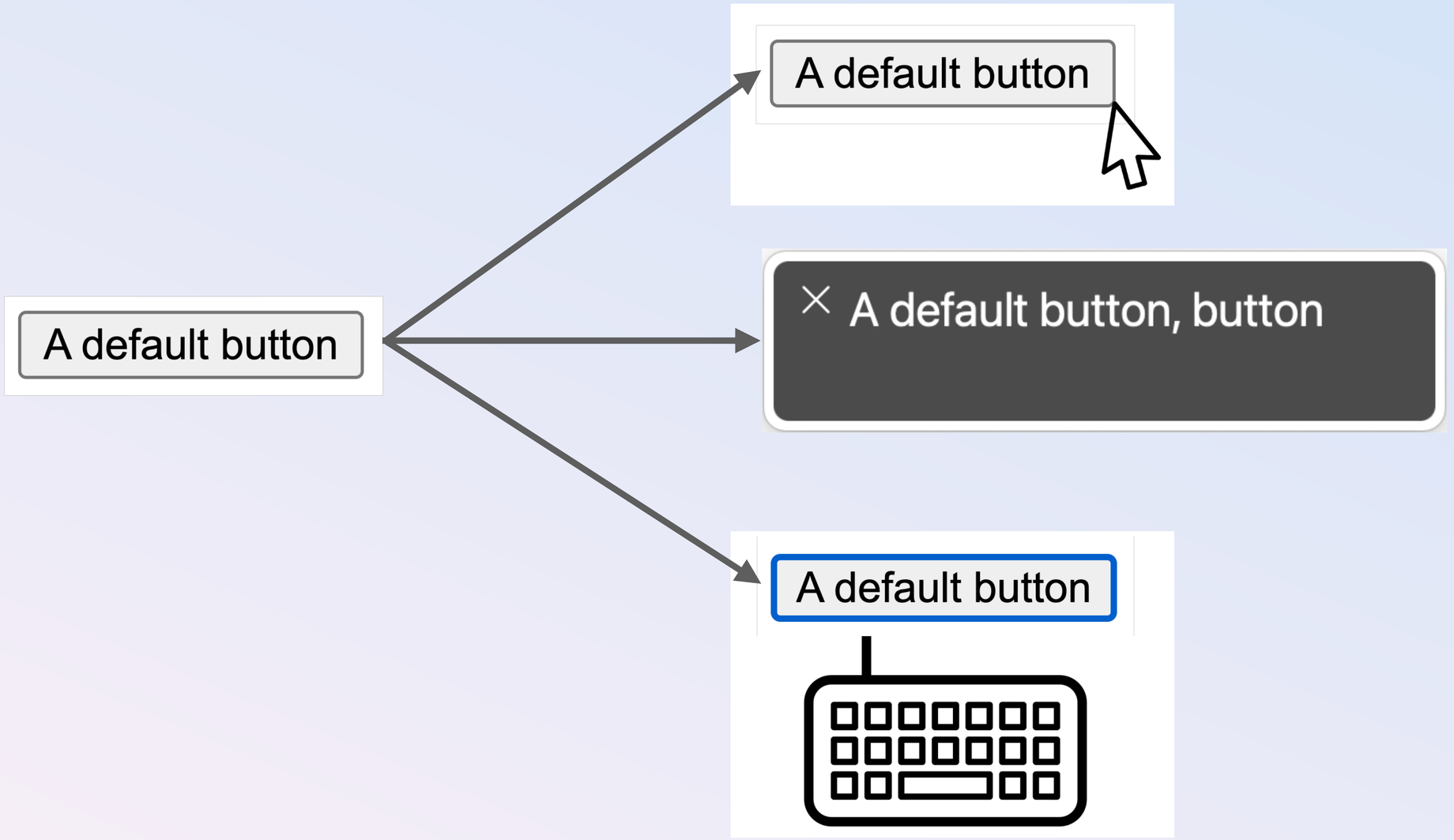
Research problem: **How can we enable people to *build* accessible visualizations?**

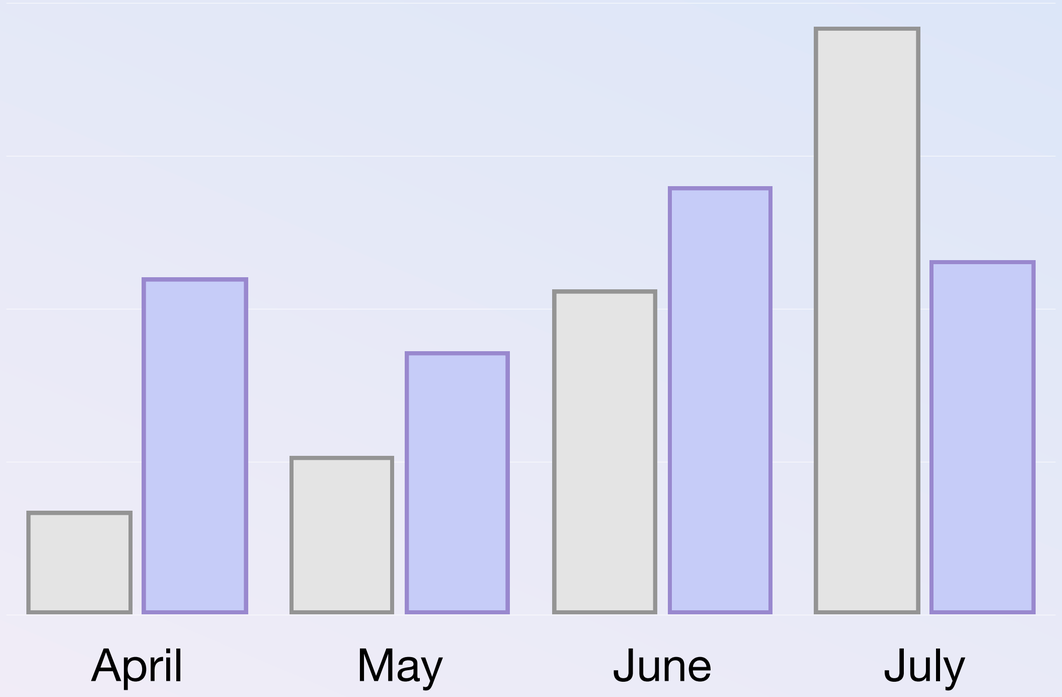

A default button


A default button


A default button

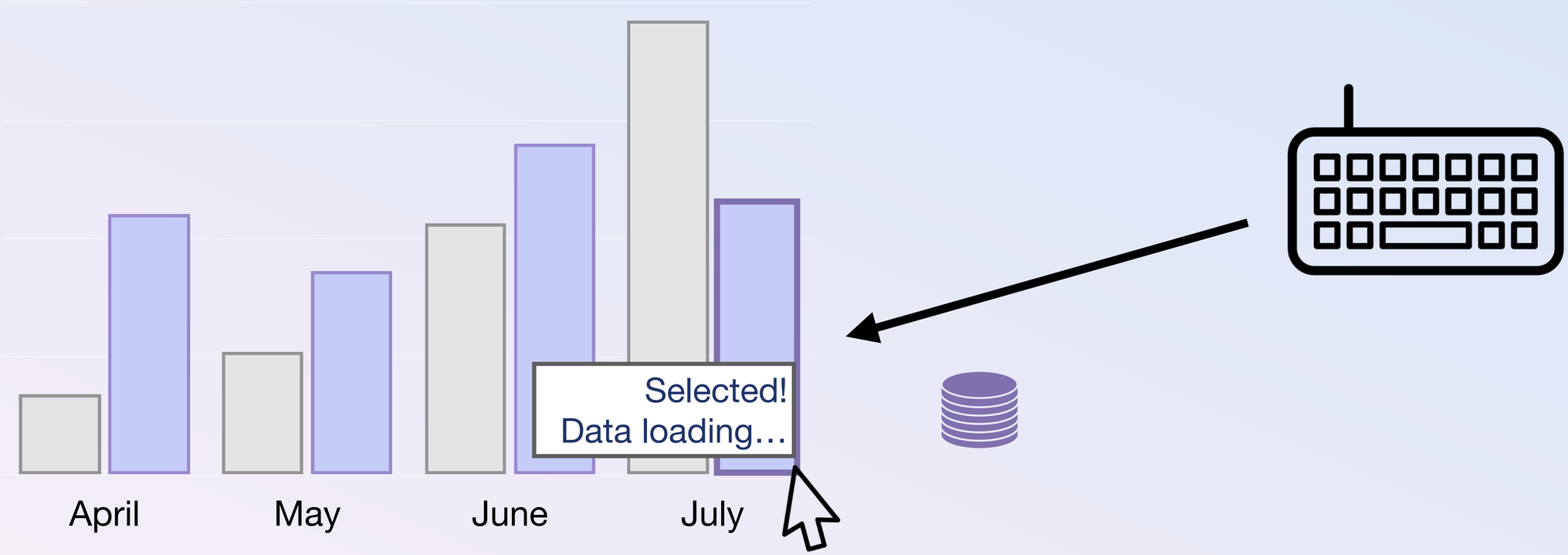

A default button
A default button, button


A default button
A default button
A default button, button
A default button


April
May
June
July

The mouse rules all

A keyboard should be able to do everything a mouse can



WAI. “Understanding success criterion 2.1.1: keyboard.” *WCAG standard*, W3C, 2017.

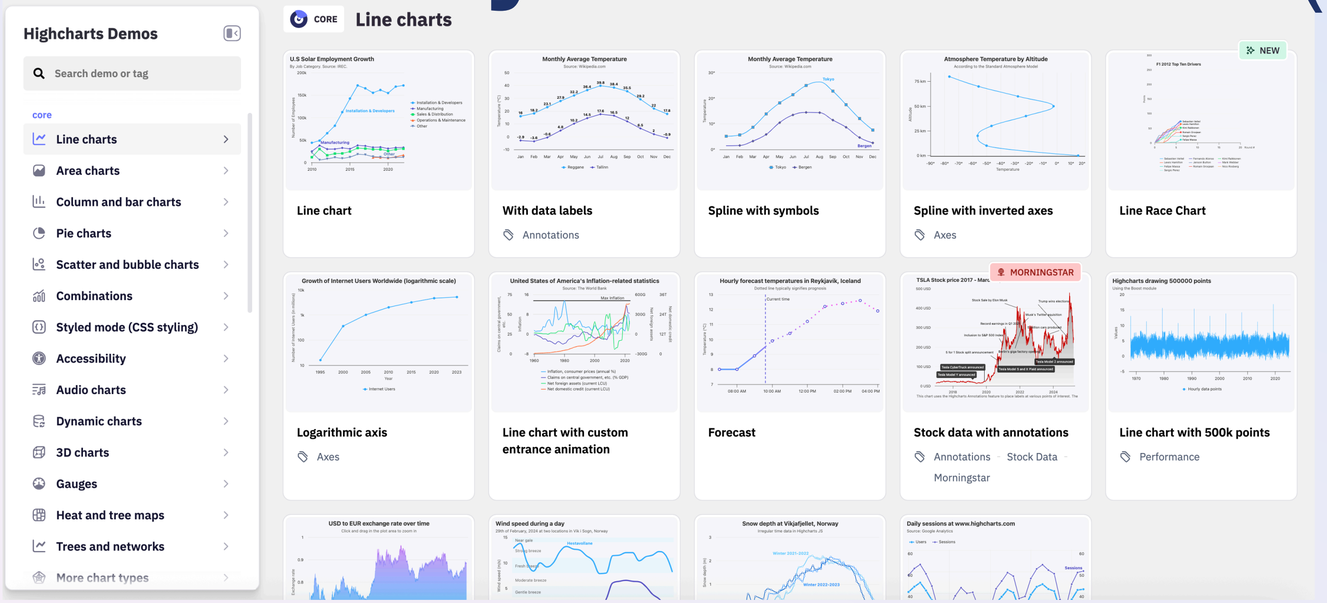
Discrete and direct navigation face more barriers

A person in a wheelchair operating an old computer using a desk-mounted sip and puff device called the POSSUM.

Image credit: Wikipedia, Public Domain, 1960. Photographer: Possum Ltd.

Rich navigation (a short history)

2015: “beyond the table” (highcharts)



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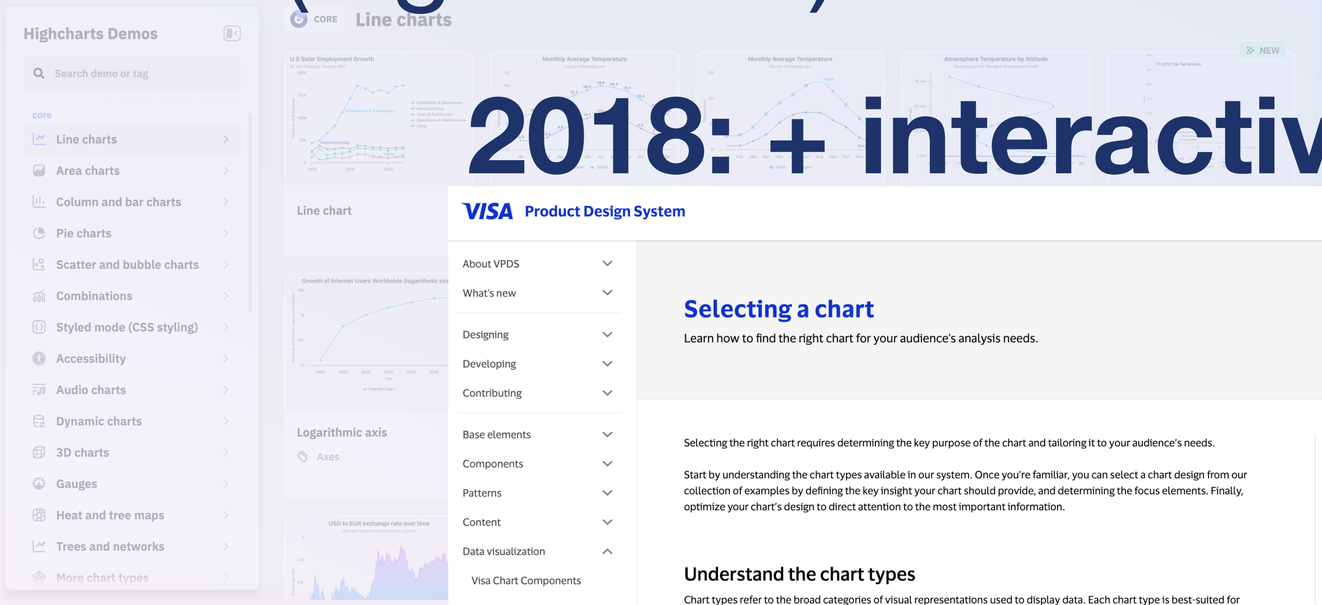
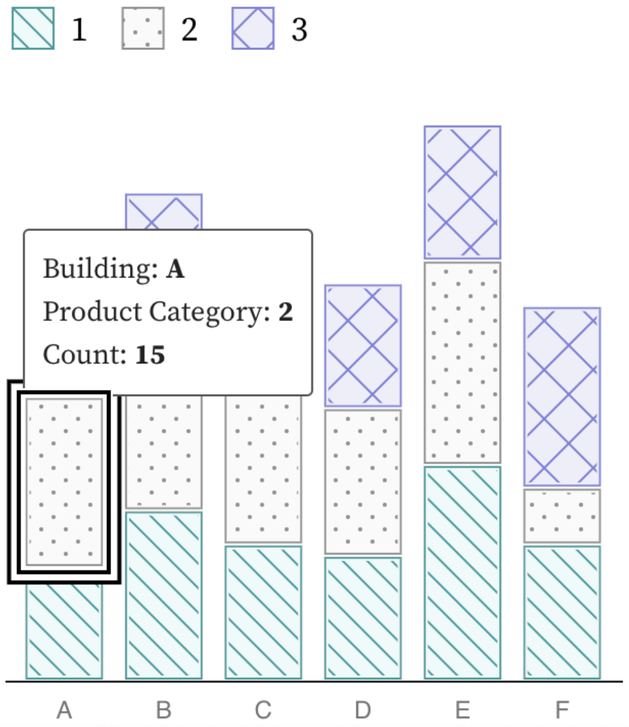
2015 (highcharts)



2018: + interactivity (visa charts)

Alt text should communicate operability

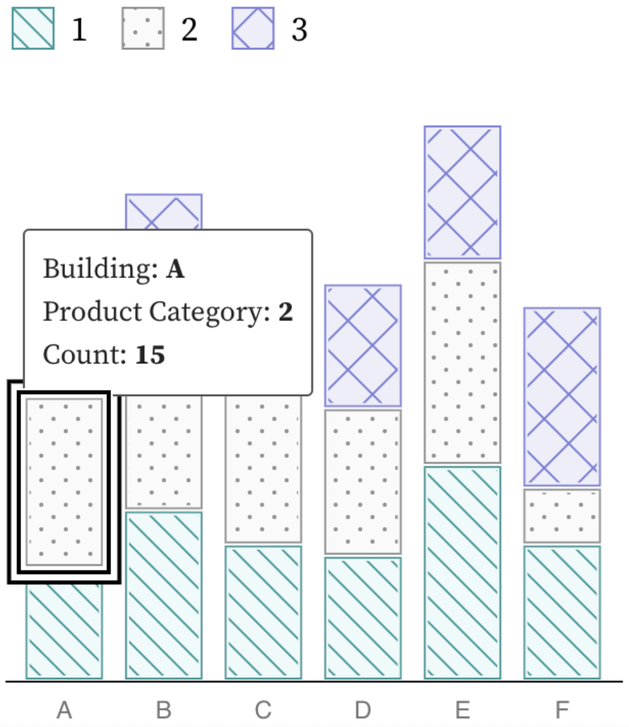
Source: Visa Chart Components, Frank Elavsky (2017-2019)



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

Semantics matter

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

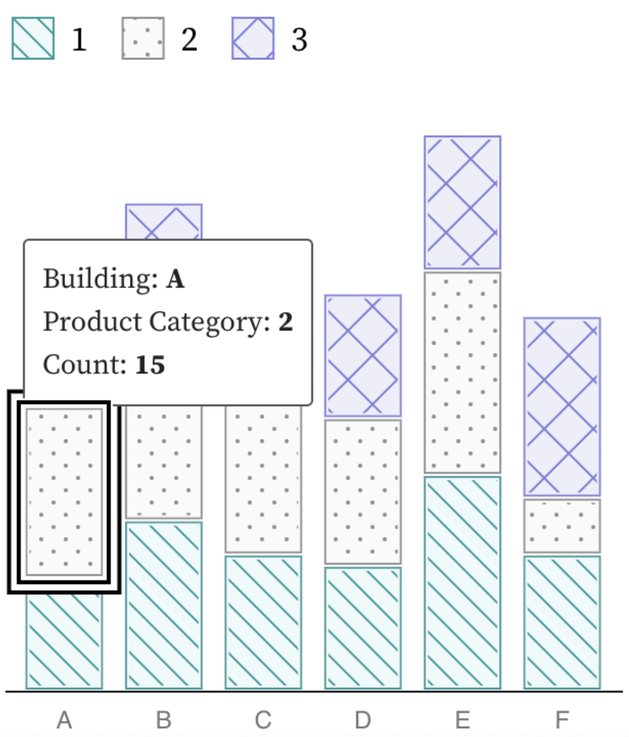


Building A. Product Category 2. Count 15. Bar 2 of 3. Image.

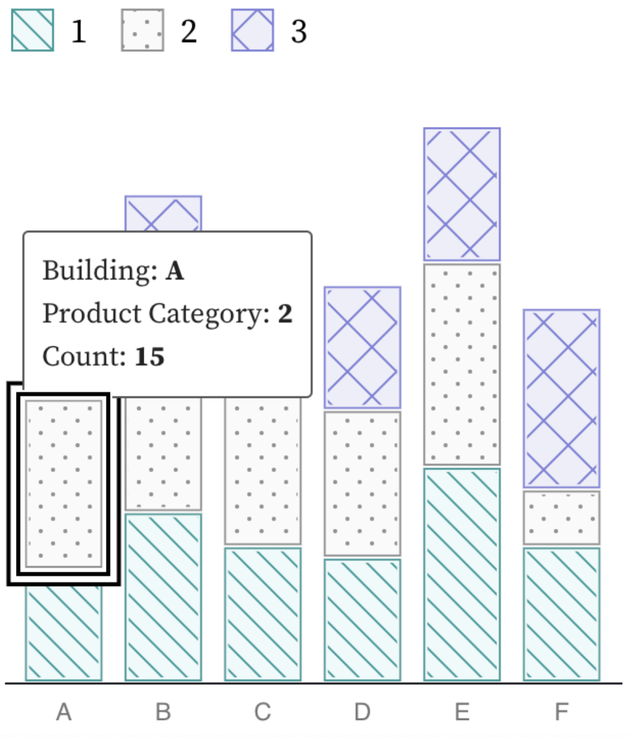
“Image” doesn’t signal interactivity!

ARIA semantics are standardized

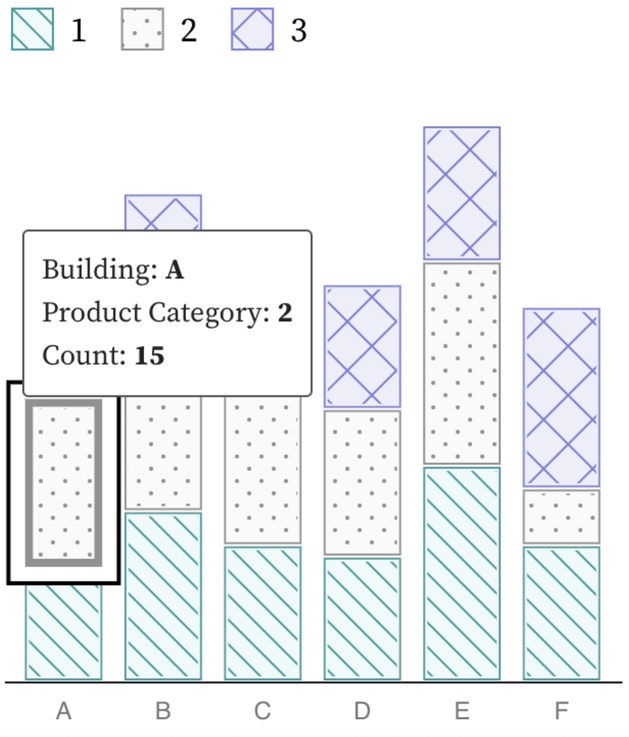
Source: Visa Chart Components, Frank Elavsky (2017-2019)



× 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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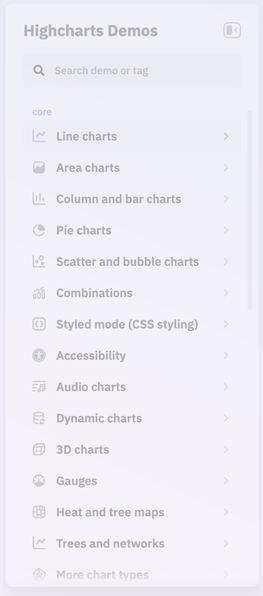
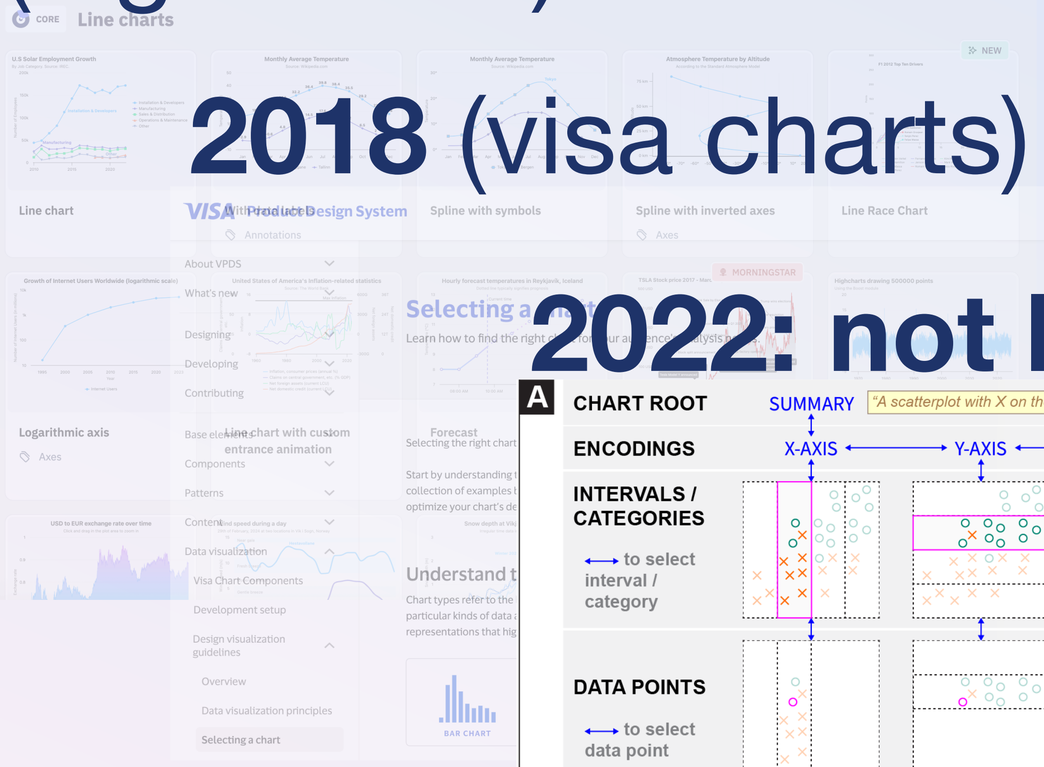
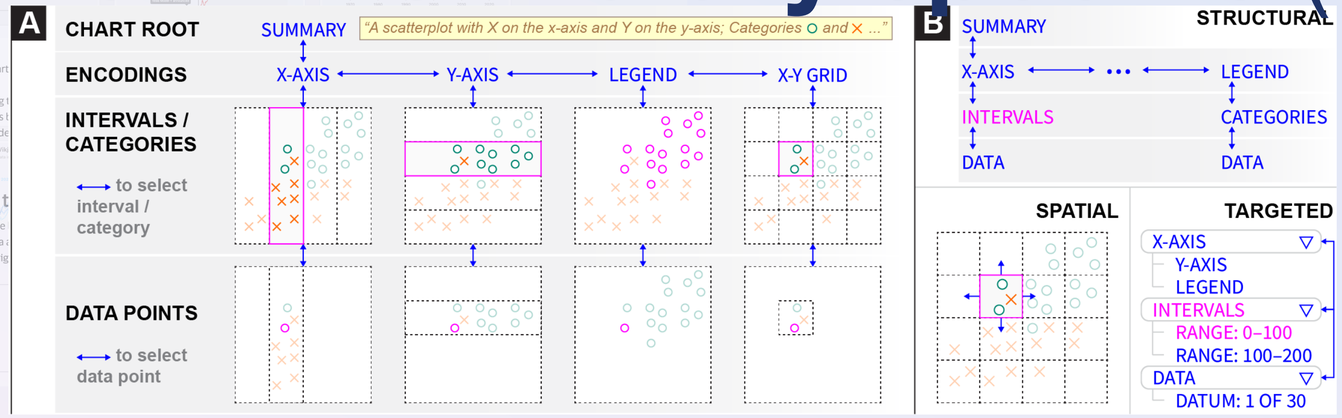
2015 (highcharts)





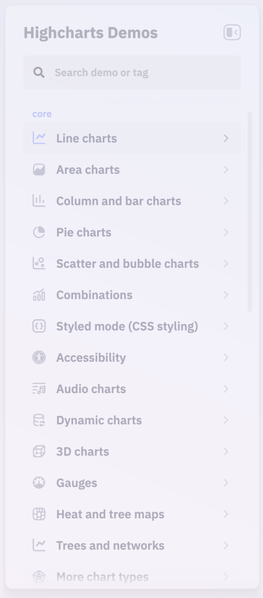
2018 (visa charts)

2022: not library specific (olli)



Rich navigation (a short history)

2015 (highcharts)



2018 (visa charts)

2022 (olli)

2023 (data navigator)

F. Elavsky, L. Nadolskis, and D. Moritz, "*Data Navigator*: An Accessibility-Centered Data Navigation Toolkit," *IEEE Transactions on Visualization and Computer Graphics*, 2023.

Rich navigation (a short history)

2015 (highcharts)

2018 (visa charts)

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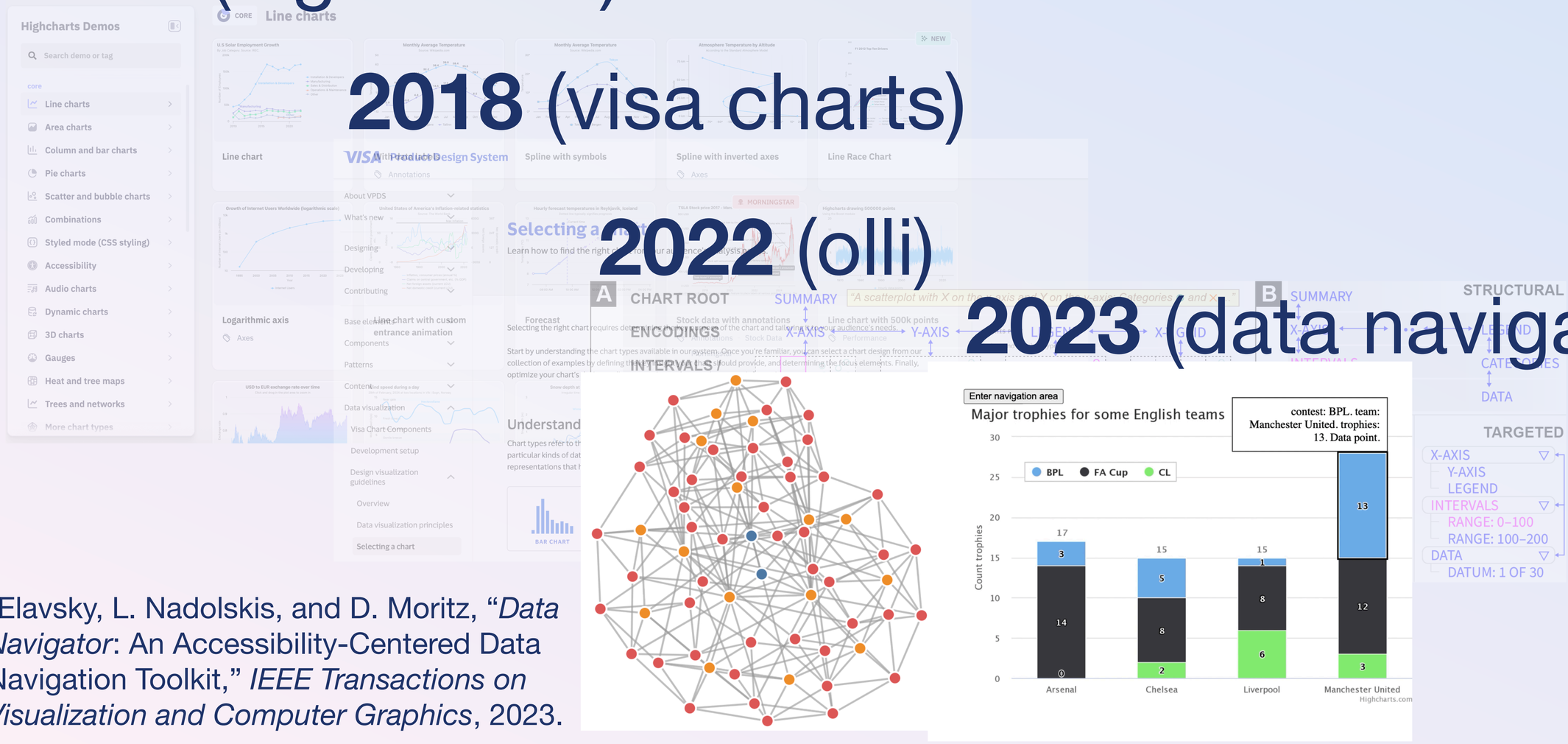

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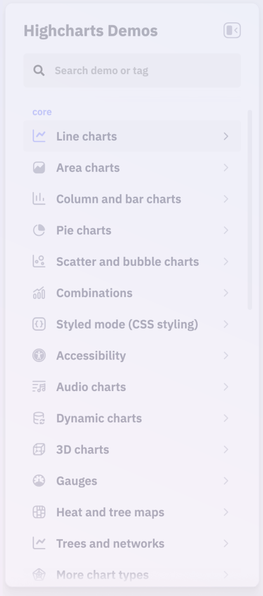
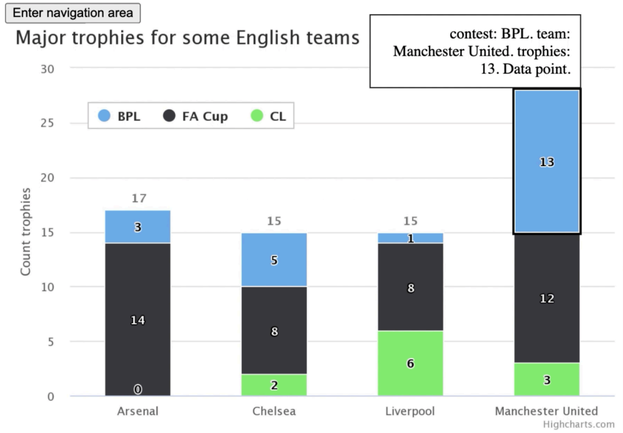
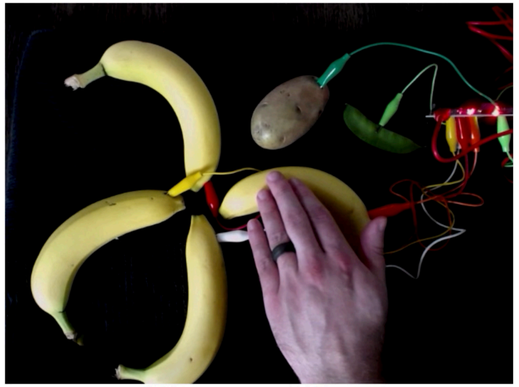


2018 (visa charts)

2022 (olli)

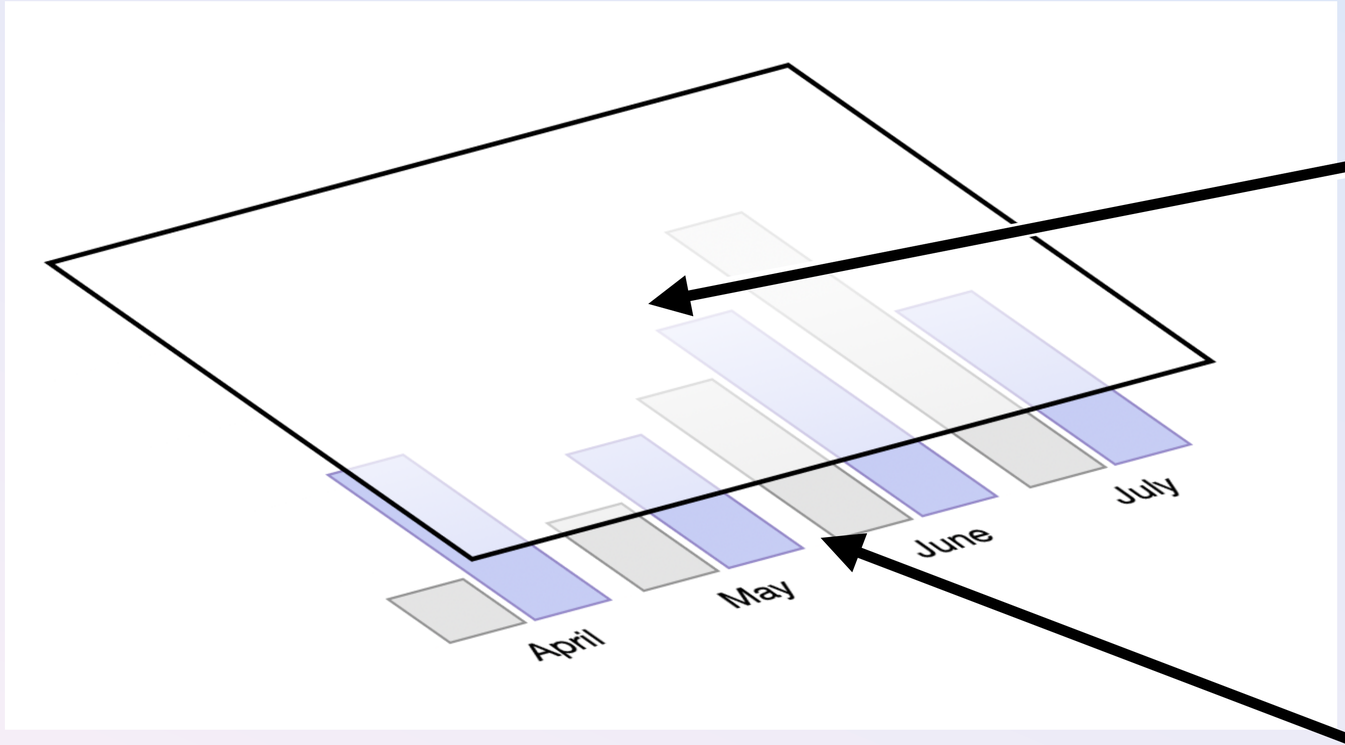
2023 (data navigator)





F. Elavsky, L. Nadolskis, and D. Moritz, "*Data Navigator*: An Accessibility-Centered Data Navigation Toolkit," *IEEE Transactions on Visualization and Computer Graphics*, 2023.

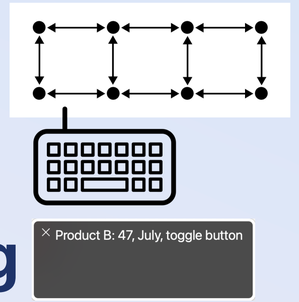
How does data navigator work?



Structure

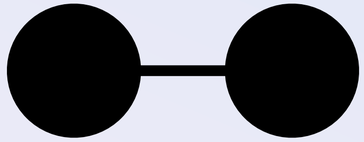
Input

Rendering



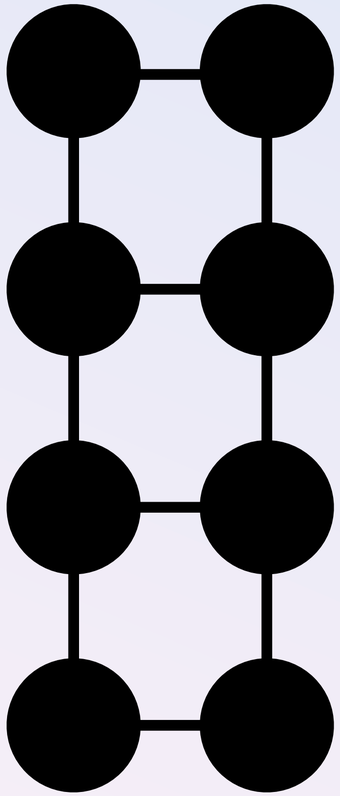
To visualization toolkits

Structure is a *graph*: nodes and edges

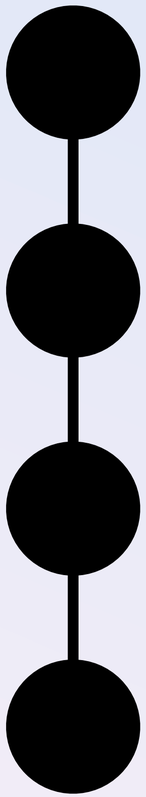


Graphs can create nearly all *other* structures

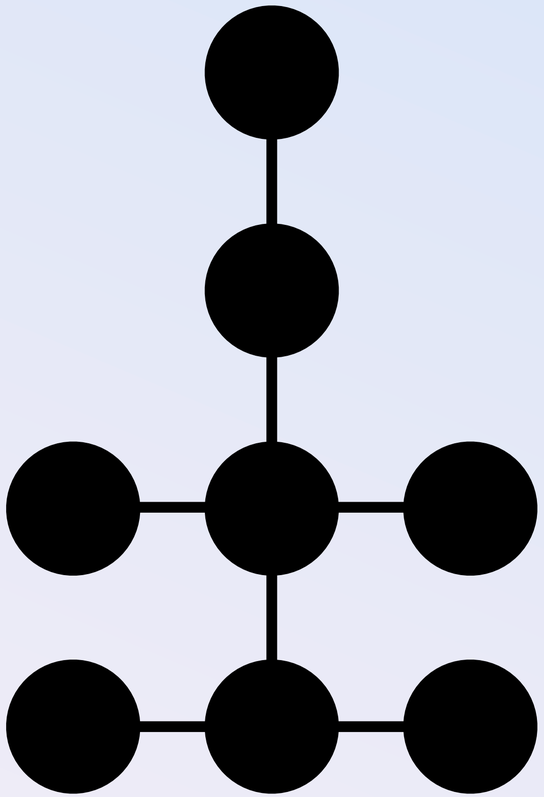
Tables



Lists

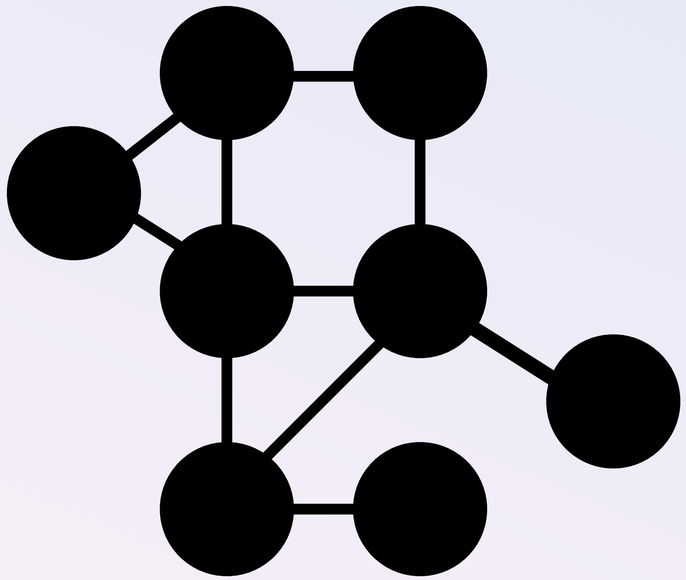


Hierarchies

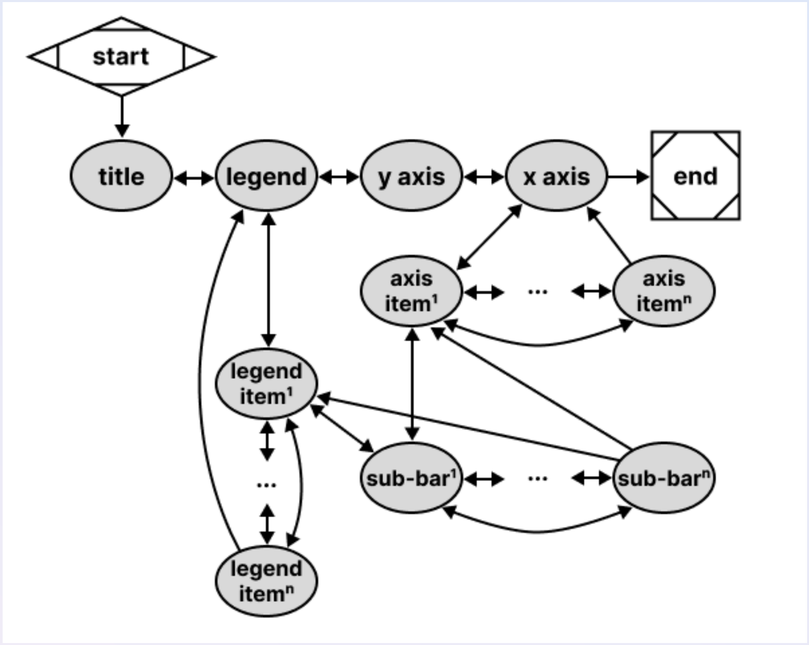


Nodes can become virtually anything

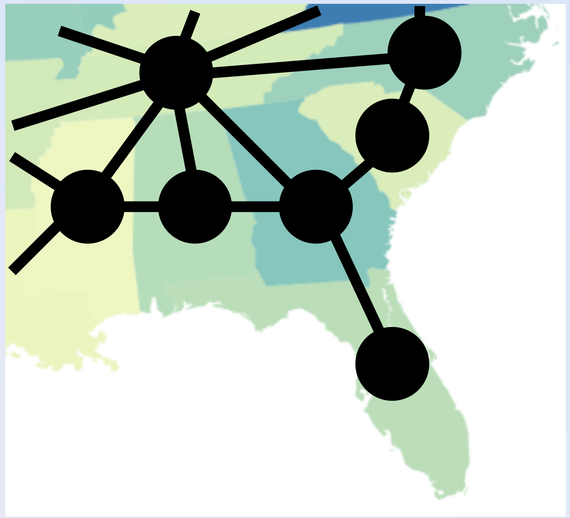
Network graphs



Diagrams



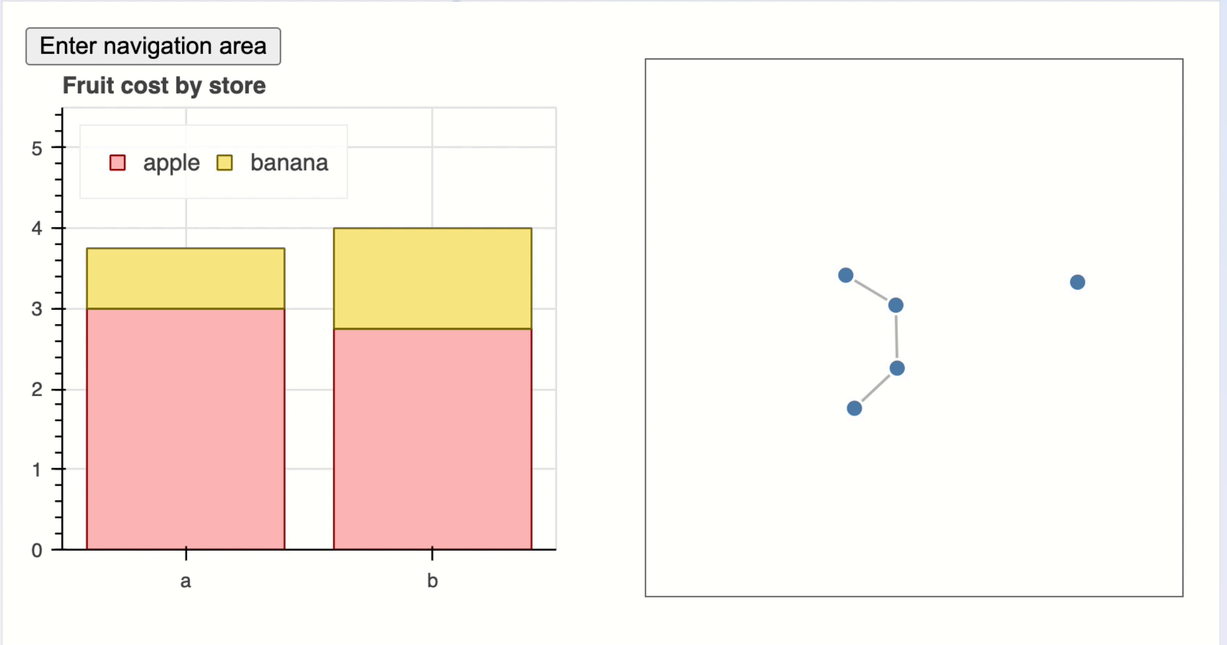
Maps



Data Navigator: Empowering practitioners

Bokeh, a python visualization library,

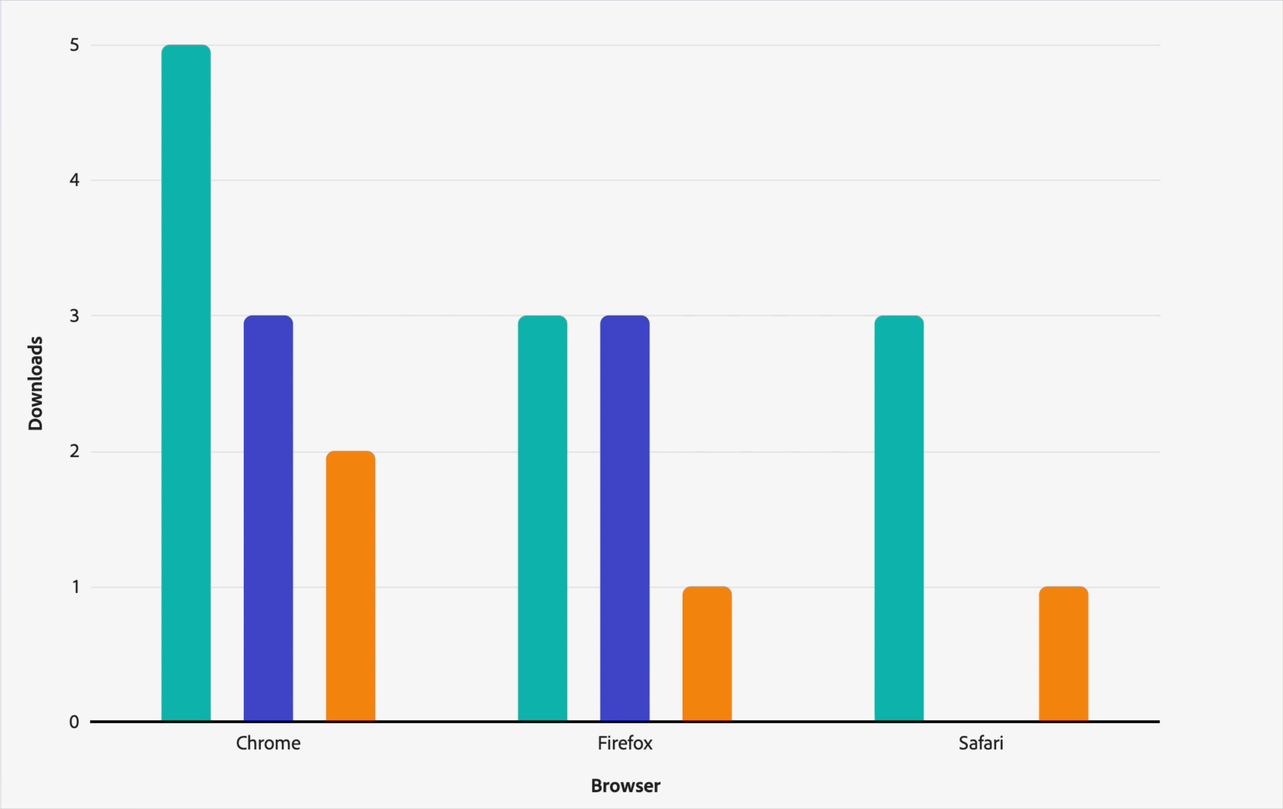
Work enabled thanks to a CZI EOSS Cycle 6 Grant



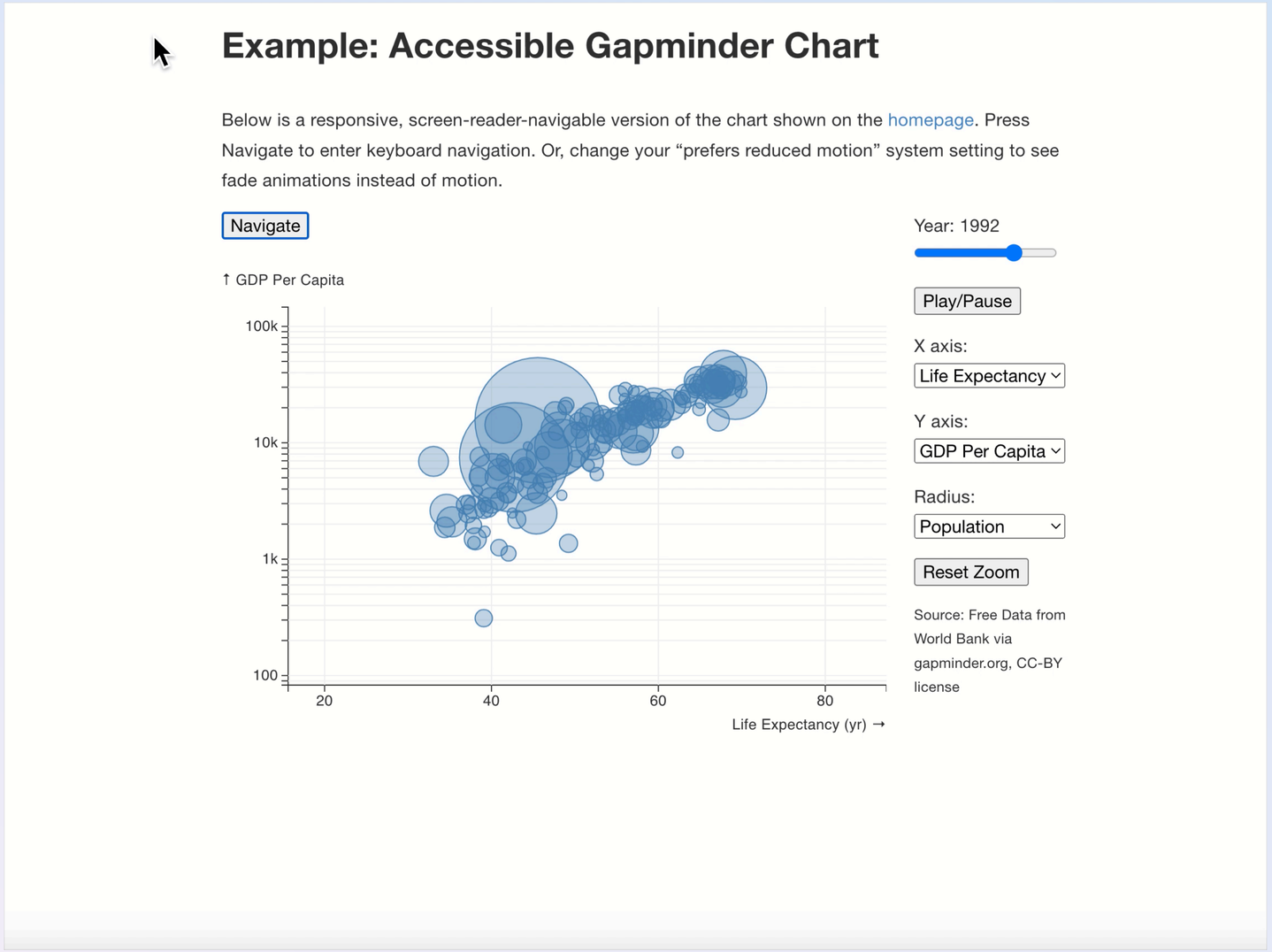
Data Navigator: Empowering practitioners

React Spectrum Charts, Adobe's visualization design system

Work enabled thanks to 2x funding from Adobe



Navigation + Animation



V. Sivaraman, **F. Elavsky**, D. Moritz, and A. Perer. “Counterpoint: Orchestrating large- scale custom animated visualizations.” *IEEE Visualization and Visual Analytics,* 2024.

Section 3:
Current work

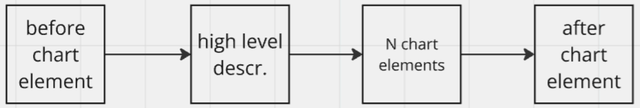
Skeleton: a graphical user interface that visualizes non-visual data experiences

Skeleton

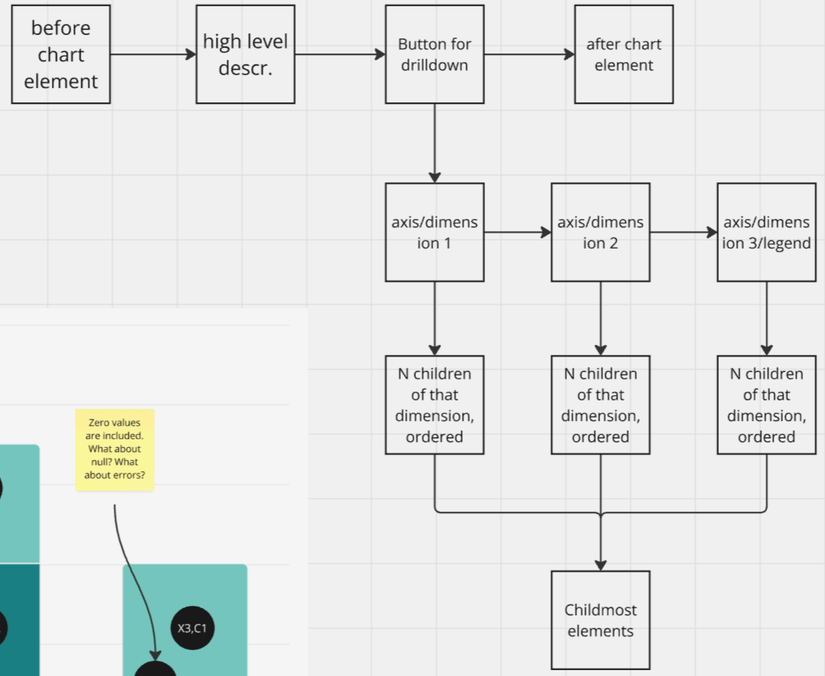
Conjecture: **non-visual experiences are an accessibility barrier for *sighted* people**

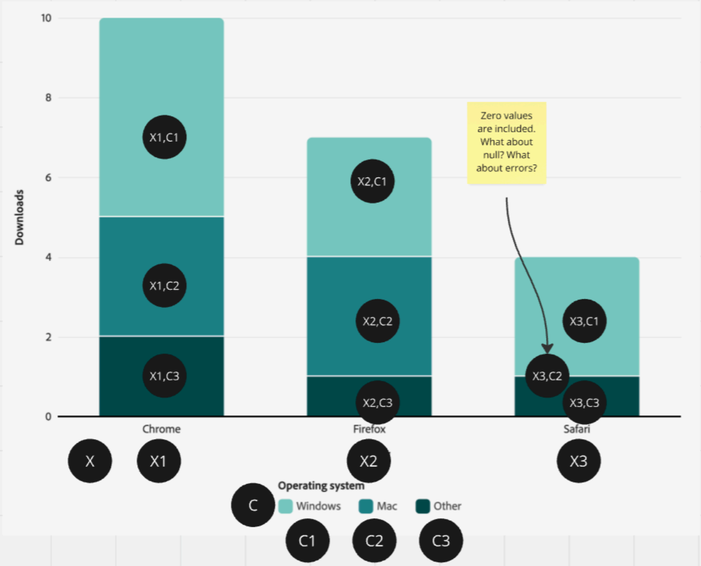
Designing navigation schema is hard

Currently how SVG + ARIA works (n elements must be navigated)



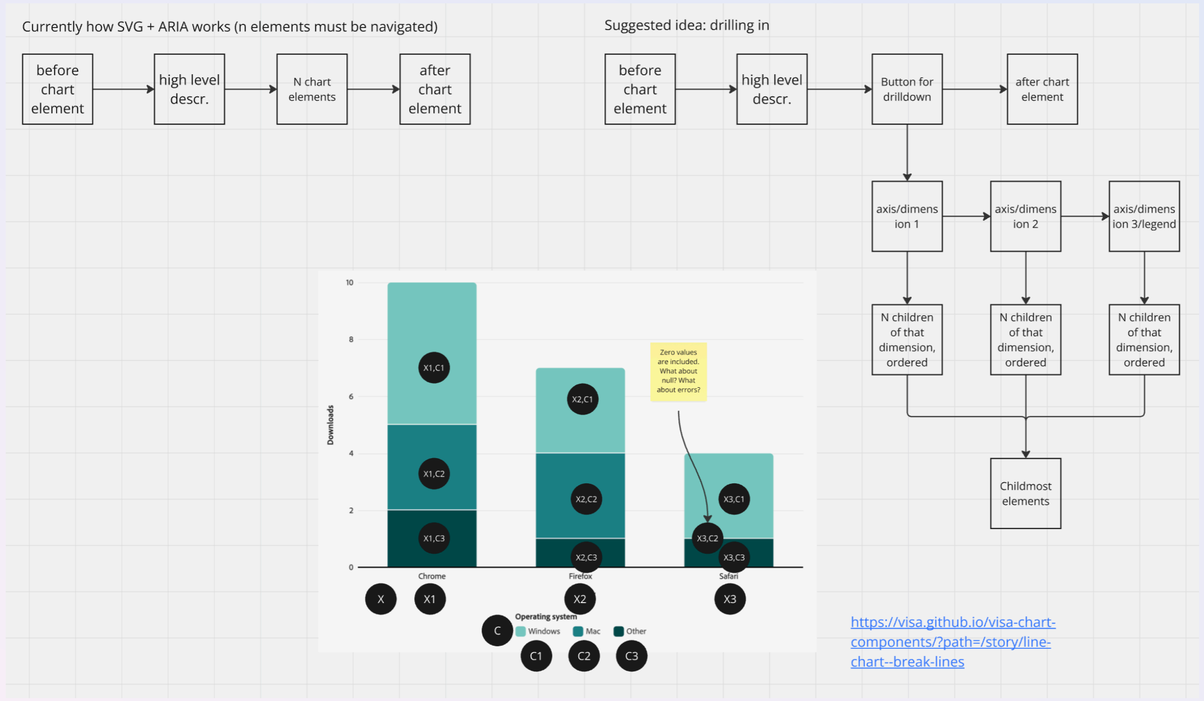
Suggested idea: drilling in





https://visa.github.io/visa-chart-components/?path=/story/line-chart--break-lines

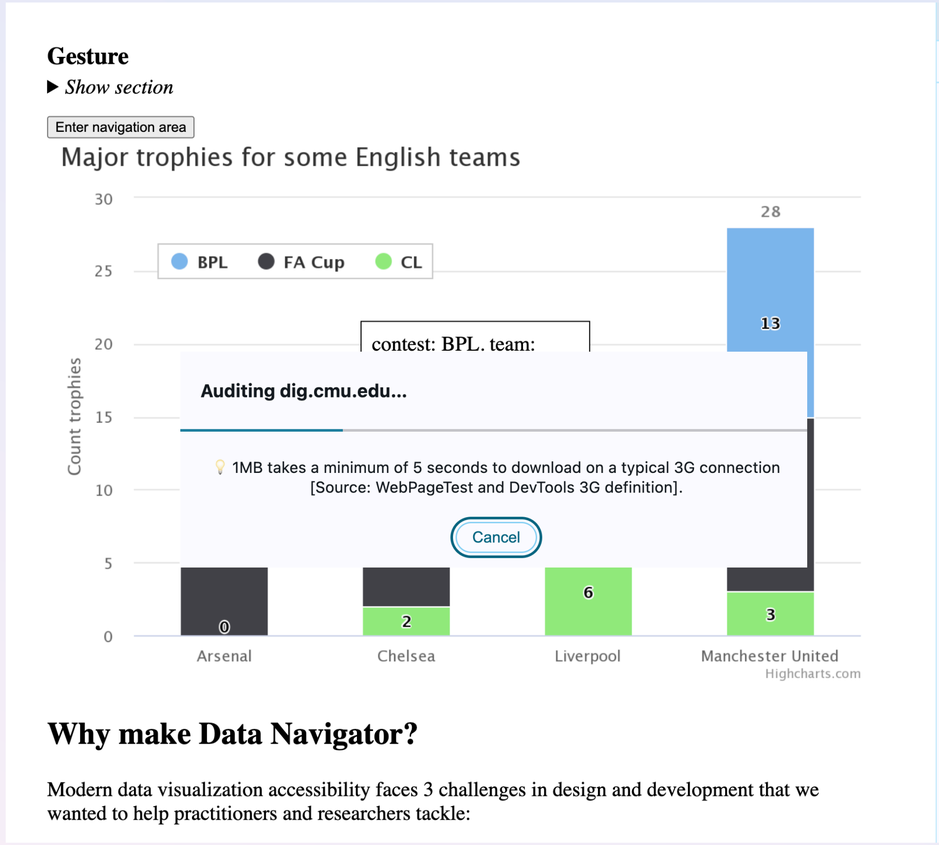
Design and dev iteration becomes error-prone and slow

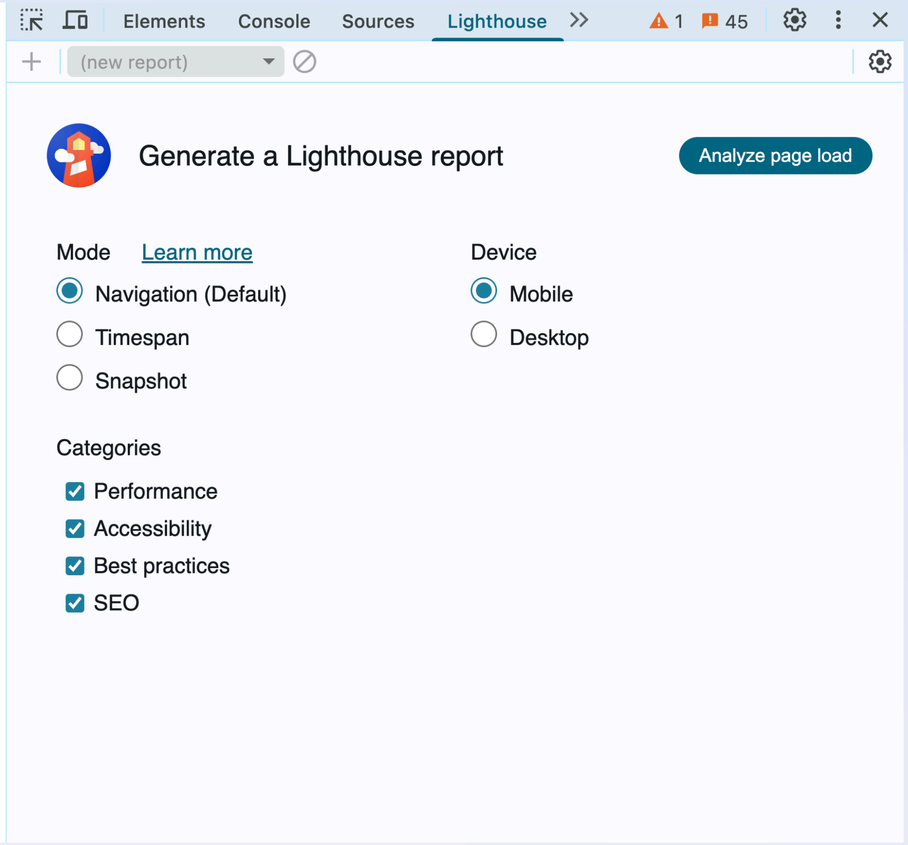


```
274  let simpleStructure = dataNavigator.structure({
275      data: simpleDataTest,
276      idKey: 'id',
277      dimensions: {
278          values: [
279              {
280                  dimensionKey: 'cat',
281                  type: 'categorical',
282                  behavior: {
283                      extents: 'circular'
284                  }
285              },
286              {
287                  dimensionKey: 'num',
288                  type: 'numerical',
289                  behavior: {
290                      extents: 'terminal'
291                  }
292              }
293          ]
294      },
295      genericEdges: [
296          {
297              edgeId: 'any-exit',
298              edge: {
299                  source: (_d, c) => c,
300                  target: () => {
301                      exit['simple']();
302                      return '';
303                  },
304                  navigationRules: ['exit']
305              }
306          }
307      ]
308  });
```

We plan to make an interface for authoring and debugging

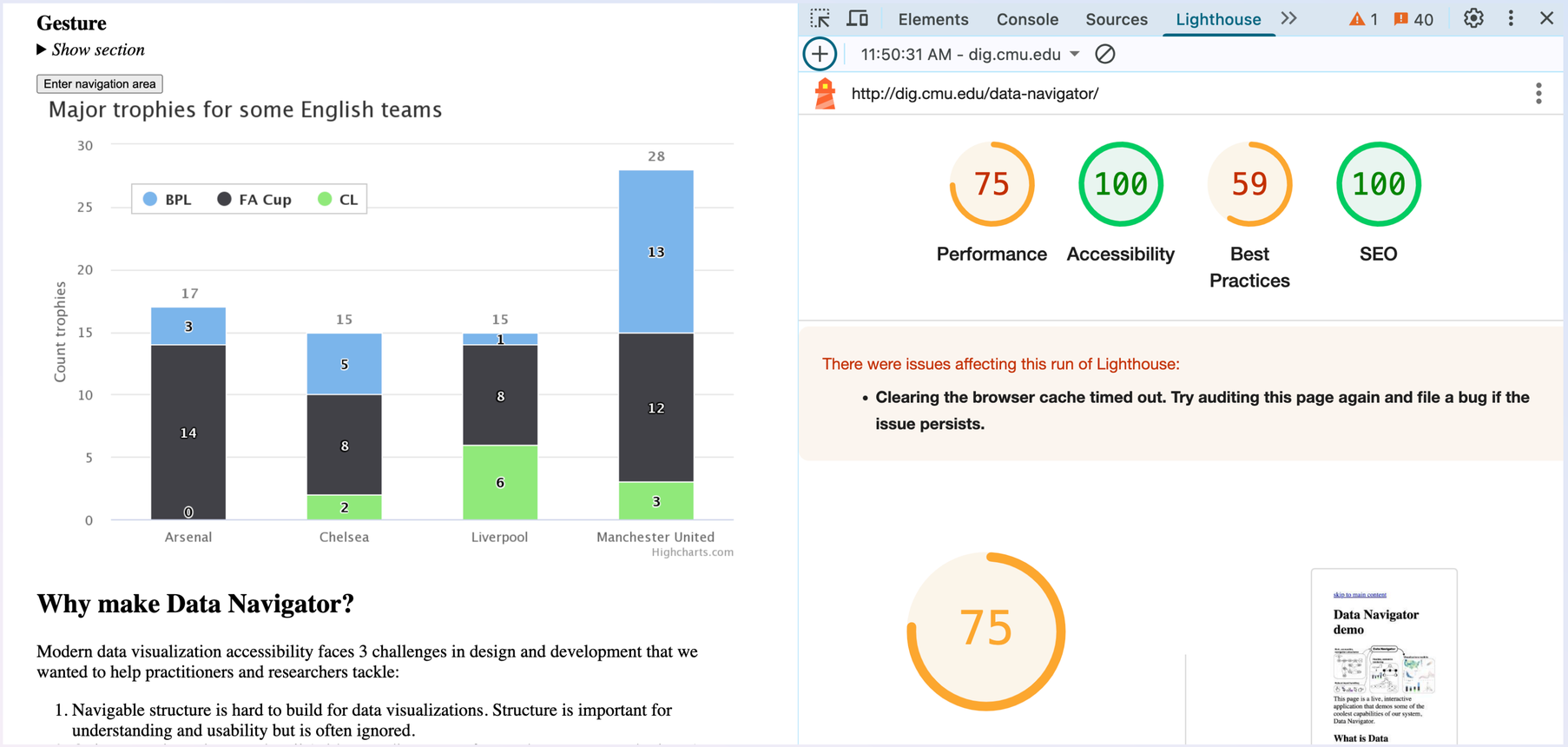
Web development accessibility tooling





Skeleton

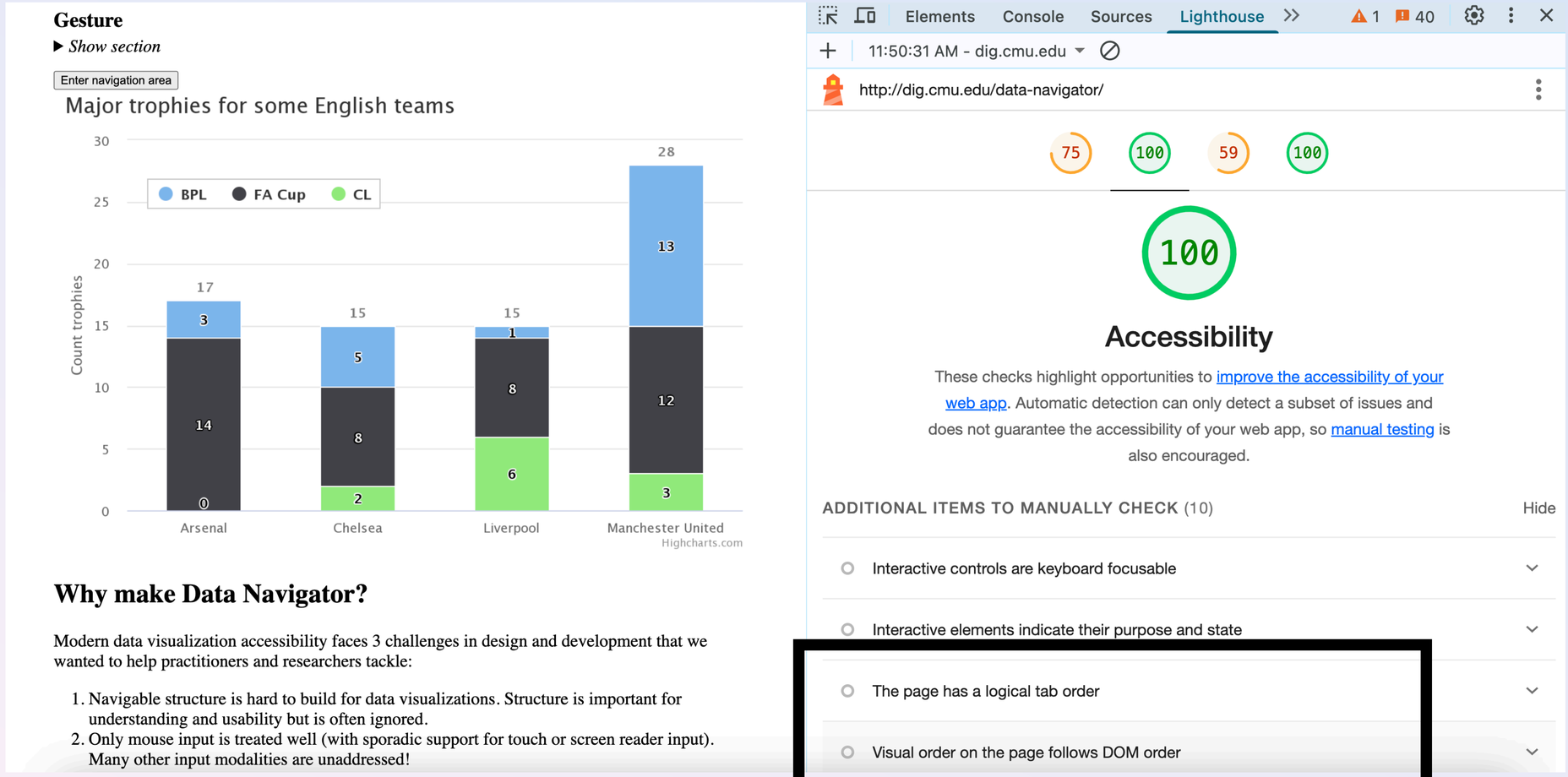
Web development accessibility tooling



Skeleton

What if you could see AT navigation?

Currently navigation is still manually verified!



Skeleton

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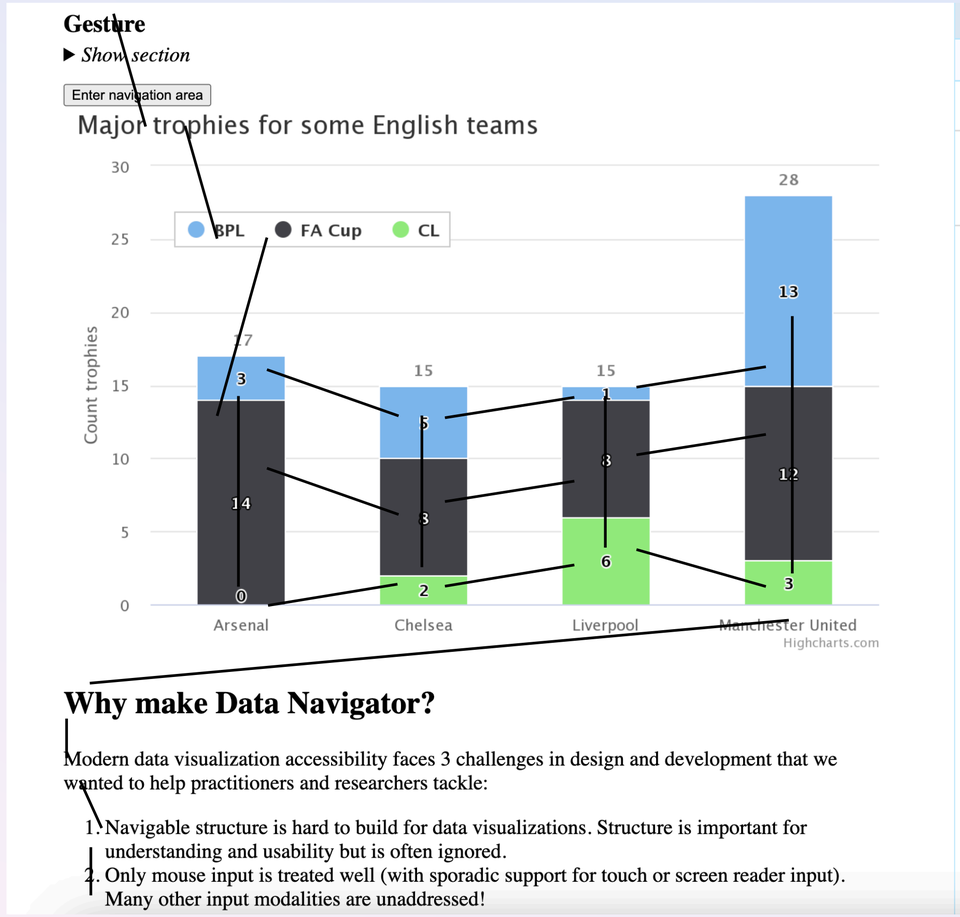
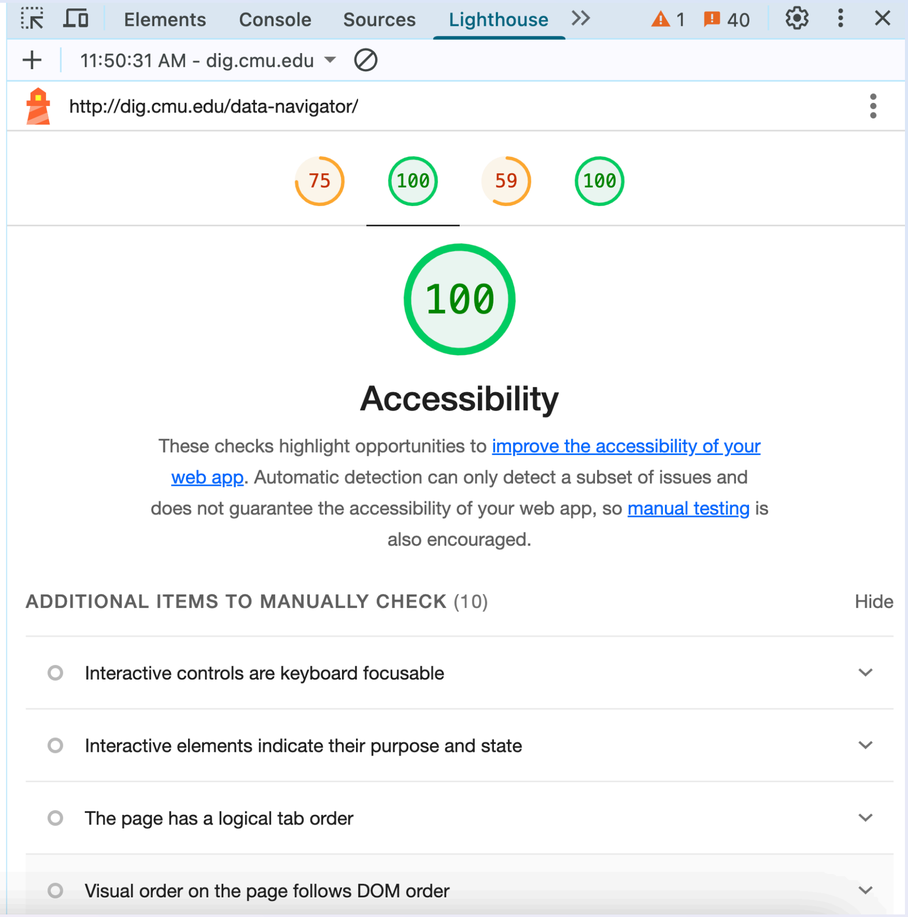
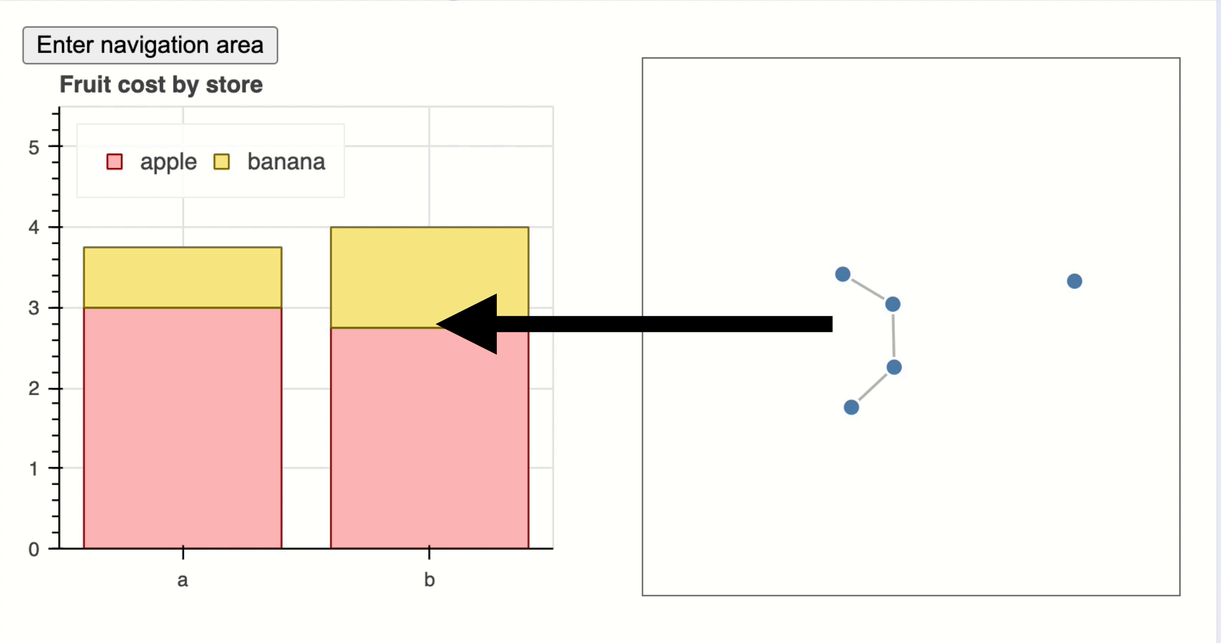


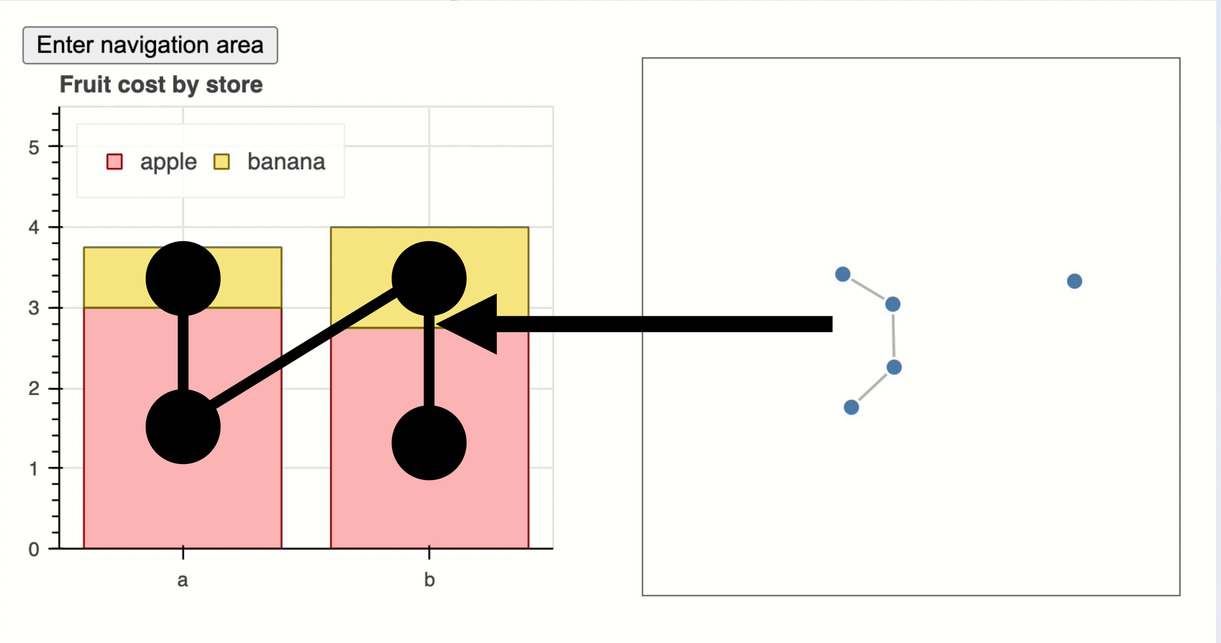


Skeleton

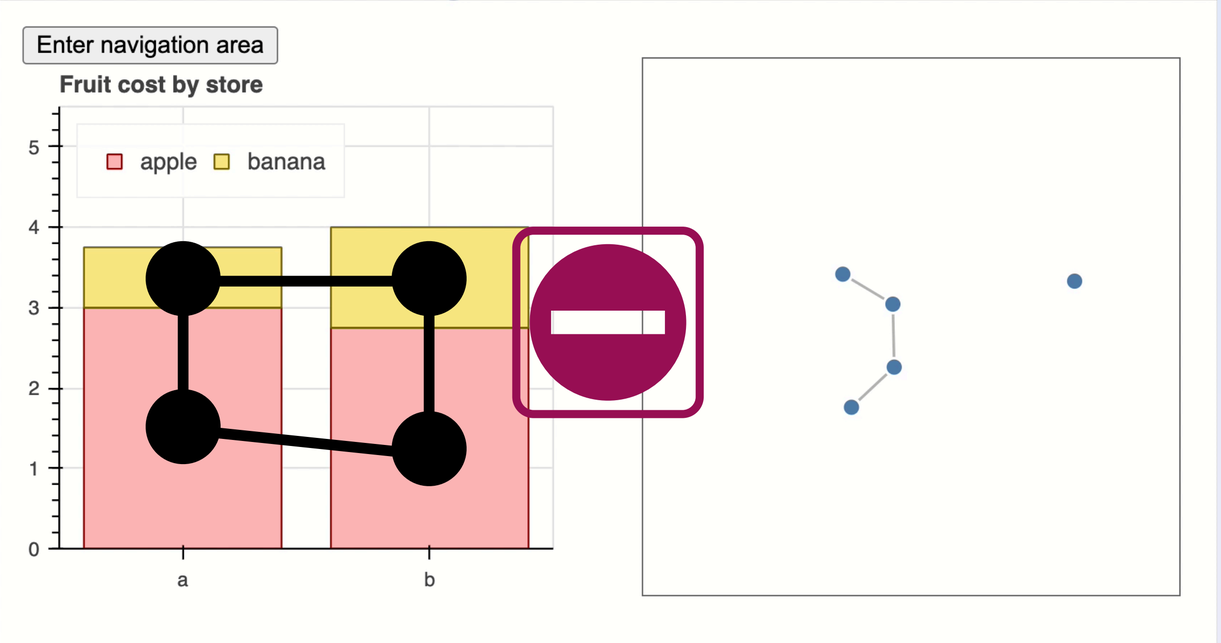
What if you could see the navigation structure?



What if you could see the navigation structure?



What if you could see the navigation structure?



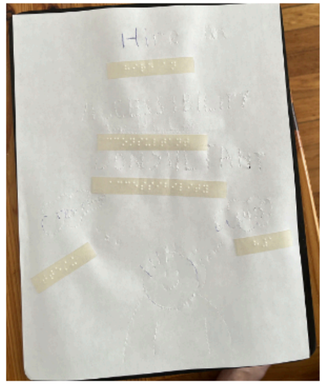
My latest community and critical work

Blind-led innovation and using community response to build a *how-not-to* guide

(a) Tactile maps of grocery store with standardized symbols, by P2

(b) Smart glasses with AI capabilities, by P9

(c) A photo of craft suppliess in a shopping app, by P10



(d) Example of semantically correct HTML headings structure, by P4

(e) Phone interface with navigation consistency, by P6

(f) A device to aid with touch screen interaction, by P11

Fig. 2. Participant's prototypes in response to the Grocery shopping prompt.

How *Not* To Make Bad Assistive Tech: A Guide

Created by Iman Ouzzani, Advised by Frank Elavsky

Some technologies that are created with "good" intentions can end up effectively useless, sometimes even harmful. This can especially be true when technology is made for people with disabilities. So how do you avoid making bad assistive technologies? We created this guide and framework to help you ask questions about your own work and suggest directions for how you can rethink, reframe, and adjust your approach.

Motivation: Avoiding Disability Dongles

Consider the following examples of bad assistive technology:

Sign-Language Glove

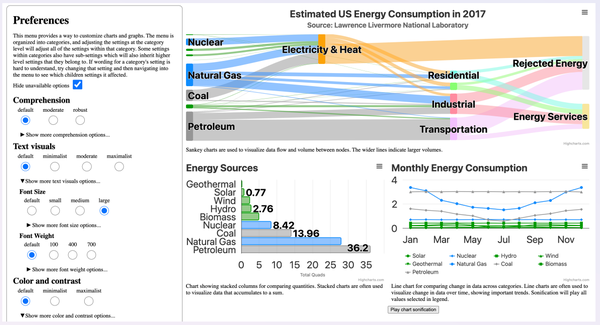
SignAloud - The Index Project

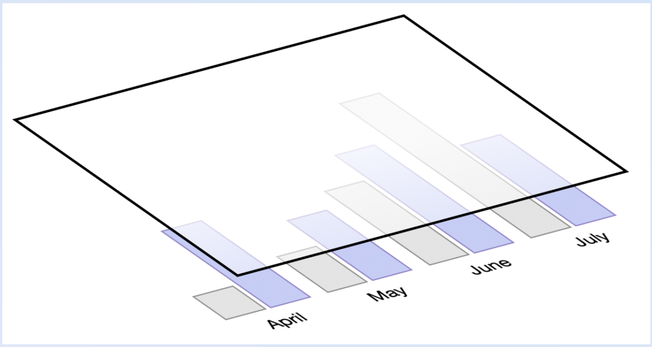
Why is it *bad*? The people who make these projects rarely consult with deaf people when they create it, which results in gloves that make an assumption that sign language only occurs in the movement of the hands, rather than with facial expressions and body language as well.

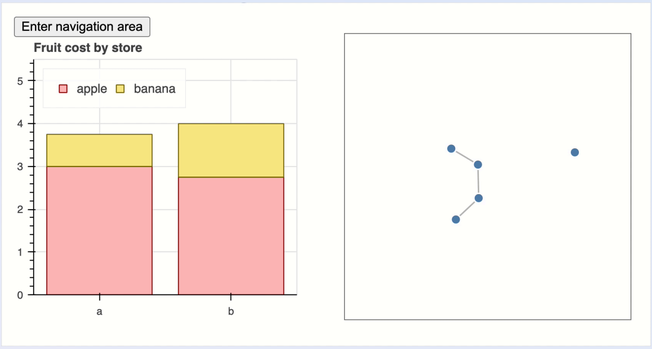
Stair-Climbing Wheelchair

Section 4:
Summary

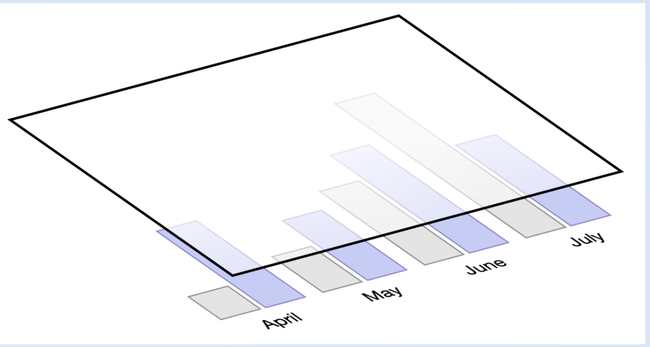
"Strictly speaking, nothing is a tool unless during actual use."
Samuel Butler

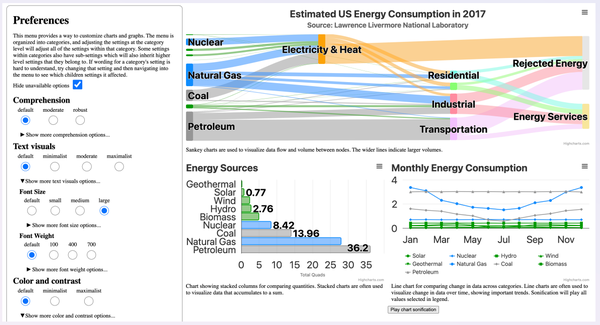


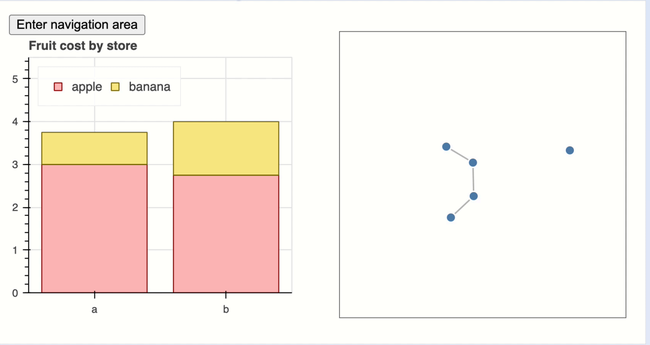




"Strictly speaking, nothing is a tool unless during actual use."
Samuel Butler



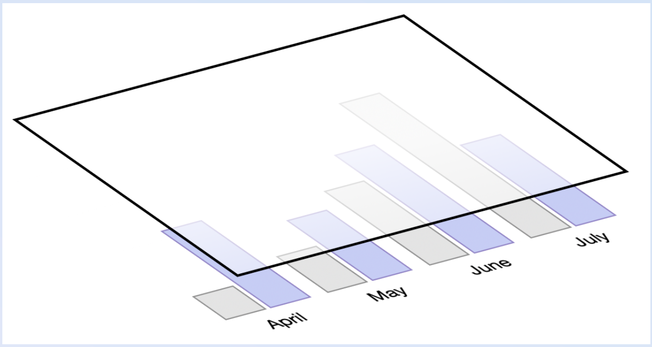


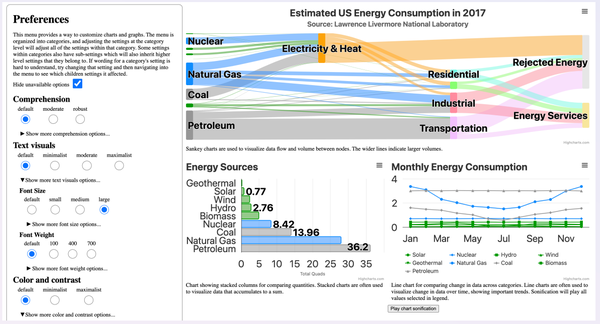


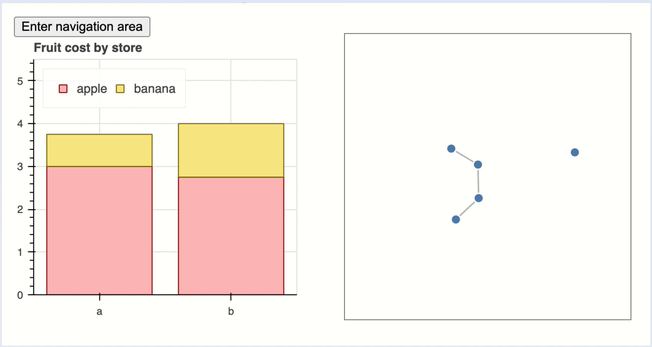
Working with people as they work with data is how you **build effective tools**.

Section 5:
Future Work

"Strictly speaking, nothing is a tool unless during actual use."
Samuel Butler







Working with people as they work with [3D graphics, games, data] is how you **build effective tools**.

2025

frank.computer

Tools for **Accessible Data Interaction**

Frank Elavsky

Human-Computer Interaction Institute

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