2024

### Looking to the future of accessible data interfaces HIGHJOFT



Frank Elavsky, PhD Student

frank.computer



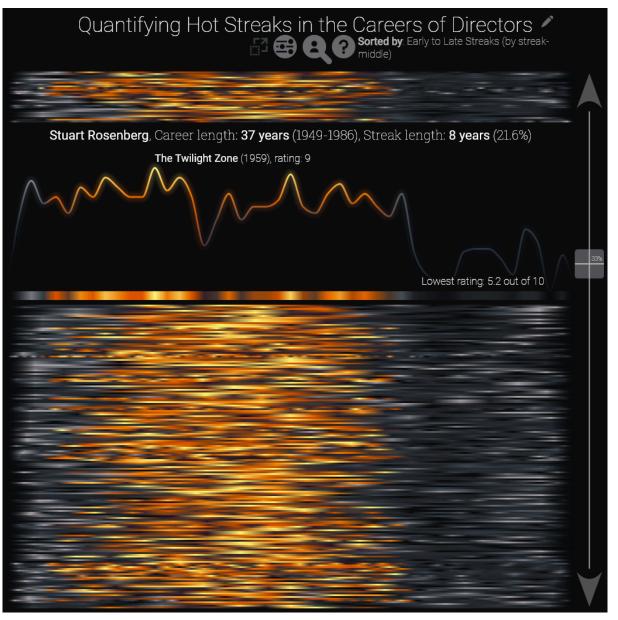
hcii.cmu.edu, axle-lab.com, dig.cmu.edu



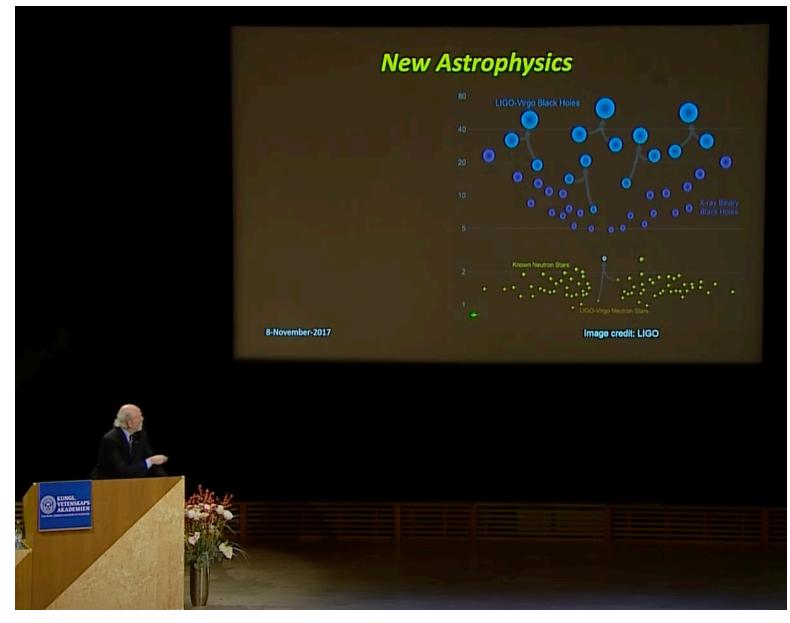


### My pre-phd work in visualization Industry and research engineering

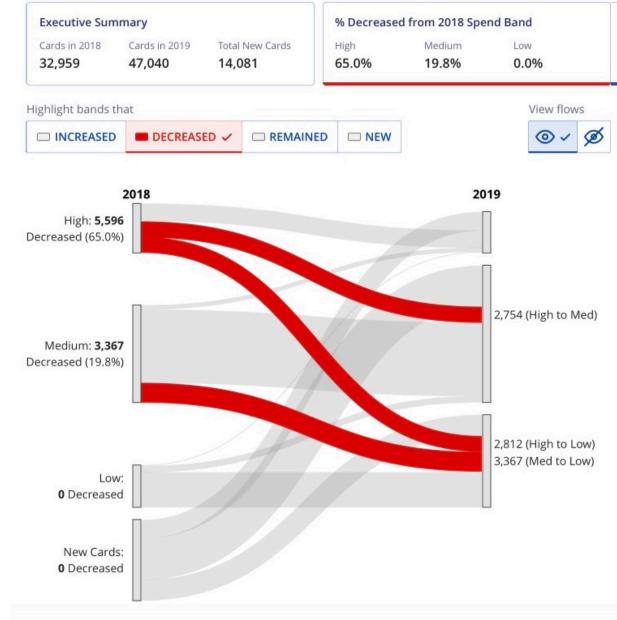
### Dense model visualizations



### **Domain-specific visualizations**



### Data visualization library





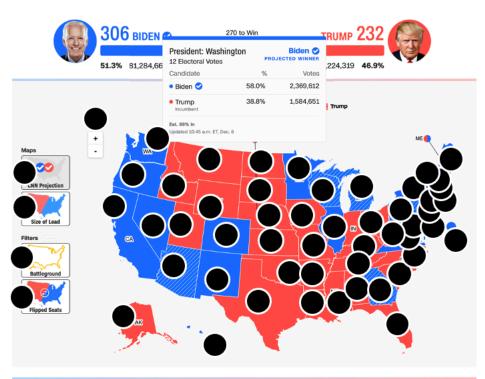
### What and how of visualization accessibility (My recent research)

### *Chartability*: **What** are accessibility barriers?

#### PRESIDENTIAL RESULTS

#### Joe Biden wins election to be the 46th US Presiden

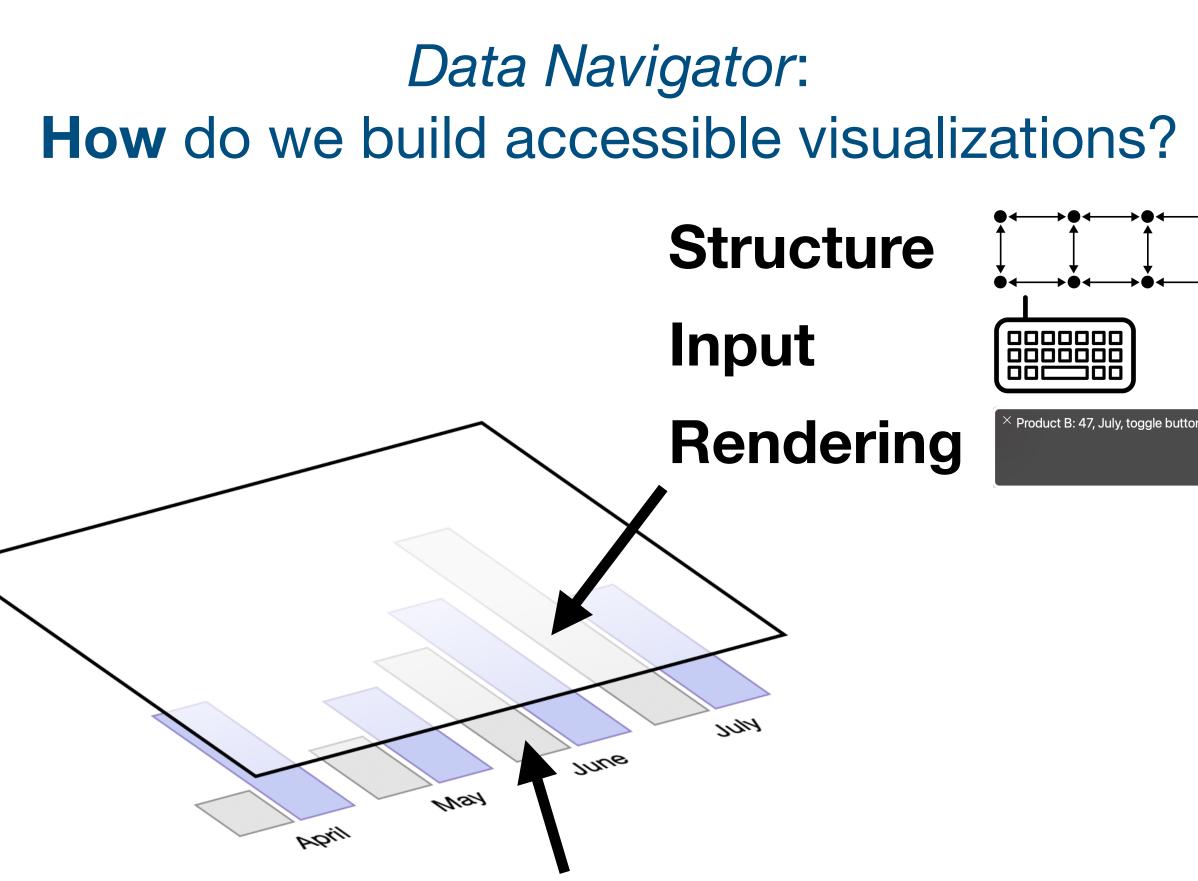
Pennsylvania's 20 electoral votes put native son Joe Biden above the 270 needed to become the 46th President of the United States. Born in Scranton, the former vice president and longtime Delaware senator defeated Donald Trump, the first President to lose a reelection bid since George H.W. Bush in 1992.



#### STATE RESULTS

| President: Alaba<br>9 Electoral Votes   | ma<br>PRC | Trump S<br>TED WINNER | President: Al<br>3 Electoral Vot  |            |     |            | President: /<br>BATTLEGROUND<br>11 Electoral V |                |             | Biden O<br>PROJECTED<br>WINNER |
|---|-----------|-----------------------|-----------------------------------|------------|-----|------------|--|----------------|-------------|--------------------------------|
| Candidate                               | %         | Votes                 | Candidate                         | %          | -   | Votes      | Candidate                                      | %              | •           | Votes                          |
| Trump 😏 62                              | .0% 💻 🛛   | 1,441,170             | • Trump 🔗                         | 52.8%      | 121 | 189,951    | • Biden 🥝                                      | 49.4%          |             | 1,672,143                      |
| Biden 36                                | .6% 🔳 🕬   | 849,624               | <ul> <li>Biden</li> </ul>         | 42.8%      | 021 | 153,778    | Trump Incumbent                                | 49.0%          | <b>0</b> 00 | 1,661,686                      |
| Est. 99% In<br>Jpdated 10:17 p.m. ET, M | ar. 6     | Full Details          | Est. 99% In<br>Updated 09:51 a.m. | ET, Dec. 2 | Fu  | II Details | Est. 99% in<br>Updated 04:11 p.r               | n. ET, Nov. 30 | (           | Full Details                   |

Show More States



To any visualization toolkit





### Chartability has helped me audit and train others **PRESIDENTIAL RESULTS** Joe Biden wins election to be the 46th US President

### **978** access failures found in ~60 minutes.

#### **Perceivable**:

- **6** Low contrast
- 57 Content is only visual
- 50 Color alone is used
- **3** Meaningful elements can be distinguished

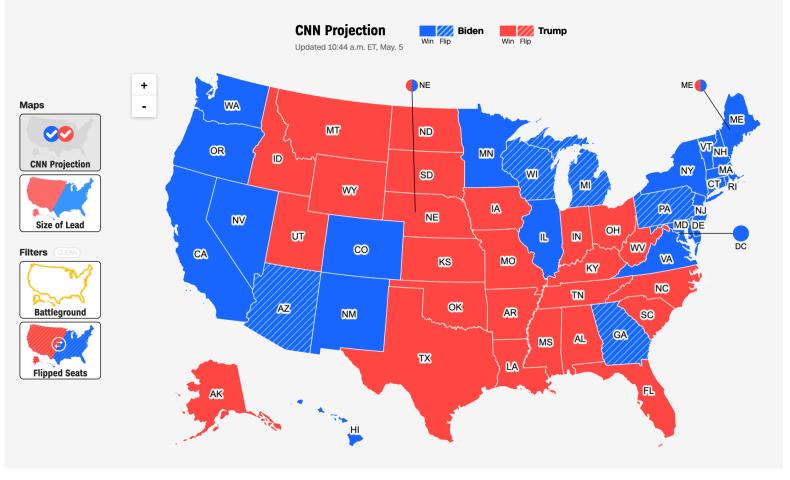
#### **Operable**:

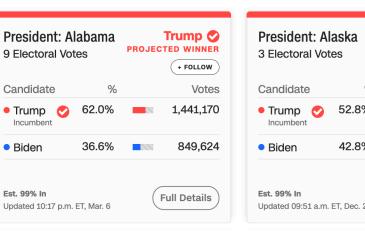
- 54 Interaction modality only has one input type
- 58 No interaction cues or instructions
- **5** Low contrast on interactive elements
- 4 Keyboard focus indicator missing
- **4** Complex actions have no alternative
- **18** Target pointer interaction is too small

#### **Understandable**:

- 4 Interactive context is not clear
- 6 Metrics or variables are undefined







Pennsylvania's 20 electoral votes put native son Joe Biden above the 270 needed to become the 46th President of States. Born in Scranton, the former vice president and longtime Delaware senator defeated Donald Trump, the first Preside to lose a reelection bid since George H.W. Bush in 1992

#### **STATE RESULTS**

| Trump S<br>PROJECTED WINNER<br>+ FOLLOW | President: Arizona<br>BATTLEGROUND<br>11 Electoral Votes | Biden O<br>PROJECTED<br>WINNER |
|---|--|--------------------------------|
| Votes                                   | Candidate %  | Votes                          |
| 189,951                                 | • Biden 父 49.4% 💻  | 1,672,143                      |
| 153,778                                 | • Trump 49.0%  | 1,661,686                      |
| Details                                 | <b>Est. 99% In</b><br>Updated 04:11 p.m. ET, Nov. 30     | Full Details                   |

#### **Robust:**

**275** - Does not conform to standards

- 82 Semantically invalid
- 12 Fragile technology support

#### **Compromising**:

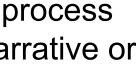
54 - Information can only be reached through single process 61 - Information cannot be navigated according to narrative or structure

#### **Assistive**:

**101** - Navigation and interaction is tedious

#### Flexible:

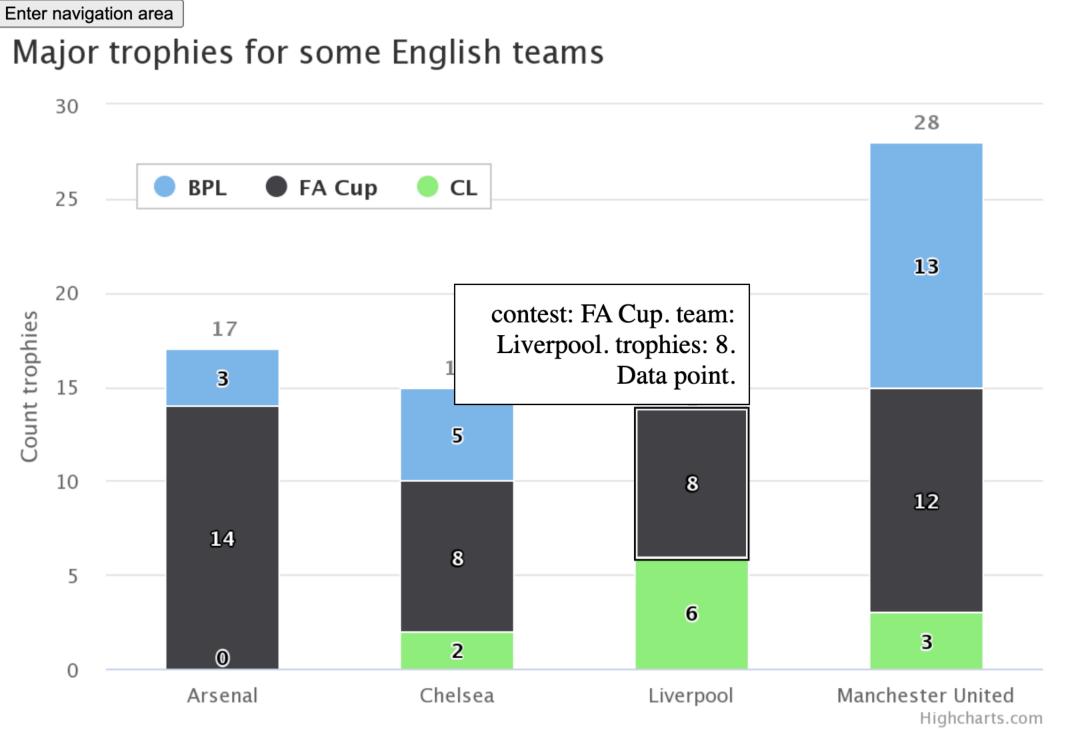
- 2 User style change not respected
- **121** User text adjustments are not respected
- 1 Scrolling experiences cannot be adjusted or opted out of
- Contrast and textures cannot be adjusted





4

### **Data Navigator makes previously** inaccessible formats more accessible



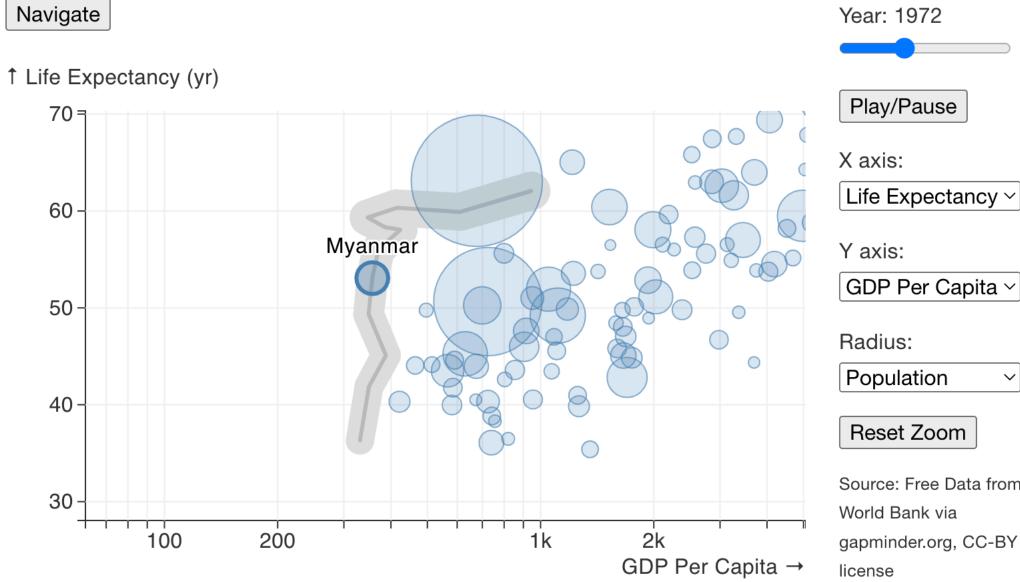
Interactive demo link

5

### Data Navigator also opened up new collaborations

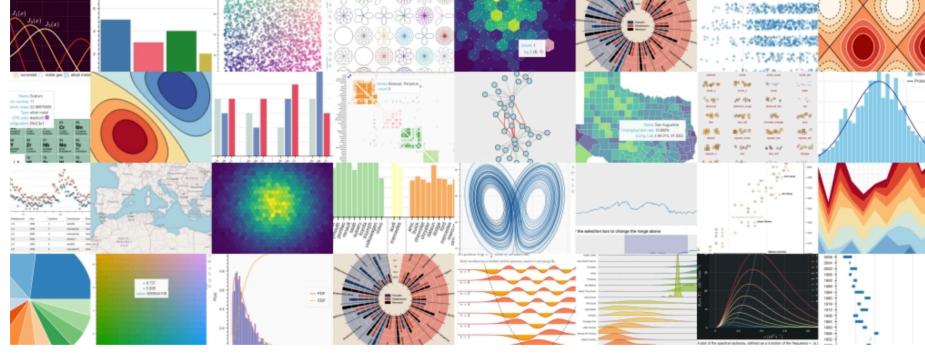
#### **Example: Accessible Gapminder Chart**

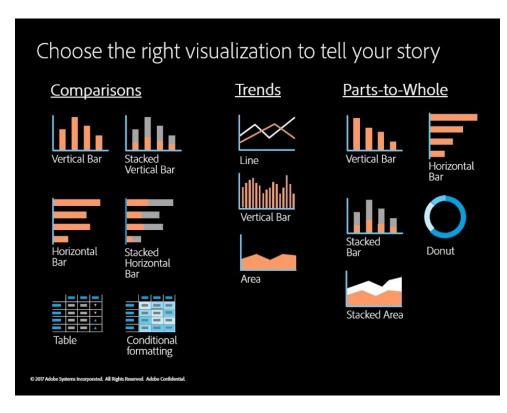
Below is a responsive, screen-reader-navigable version of the chart shown on the homepage. Press Navigate to enter keyboard navigation. Or, change your "prefers reduced motion" system setting to see fade animations instead of motion.



Myanmar 1972: GDP Per Capita is 357, Life Expectancy (yr) is 53.1, Population is 28,500,000. In 5 years, GDP Per Capita increases by 3.9% and Life Expectancy (yr) increases by 5.6%. left/right arrow to change country, up/down arrow to change year, space to summarize trend, backspace to return.

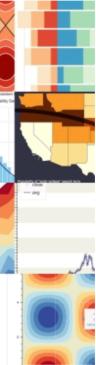
- Life Expectancy ~
- Source: Free Data from







Interactive demo link



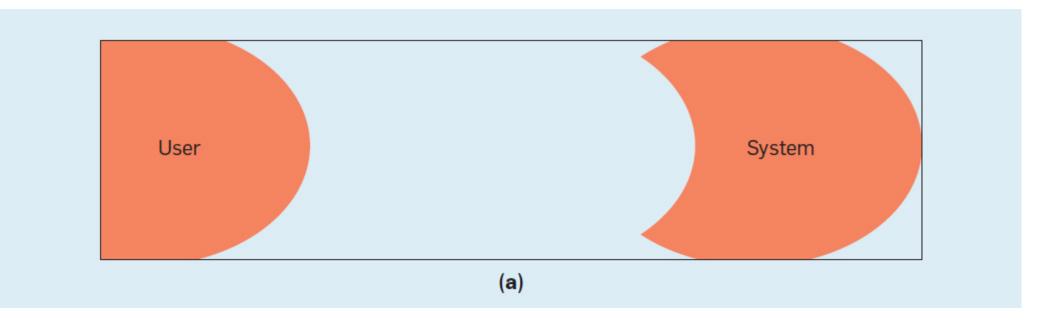




## What are some "big-P" Problems in accessibility and visualization?

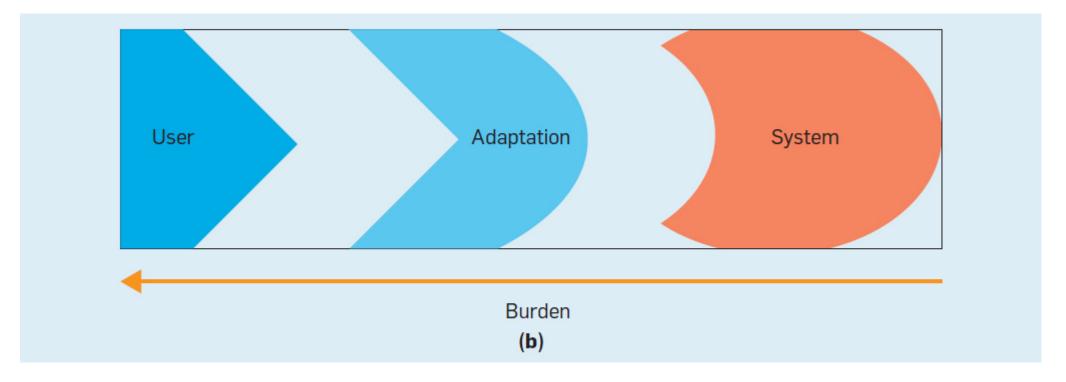
### Problem 1: **Ability Assumptions** produce static systems

### **Ability Assumptions**



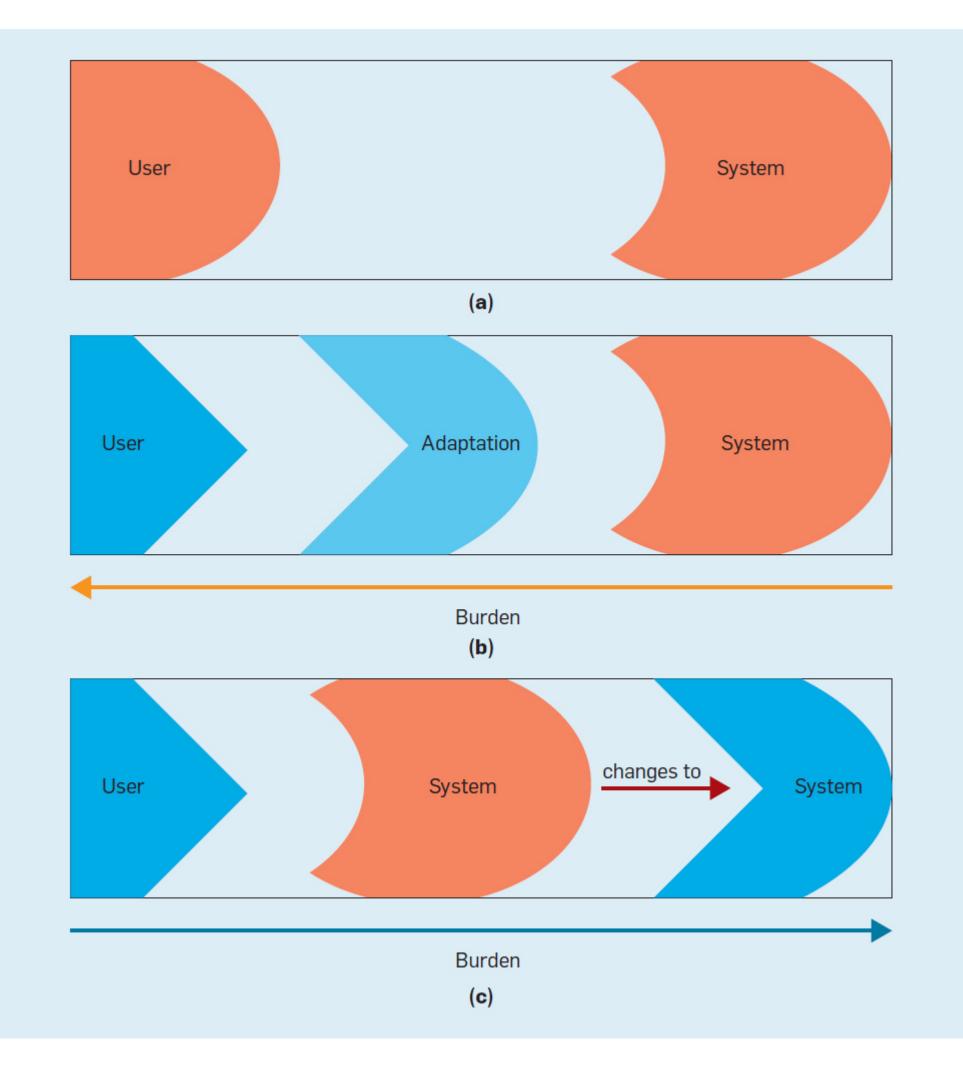
### (Wobbrock et al) https://cacm.acm.org/magazines/2018/6/228034-ability-based-design/fulltext

### **Ability Assumptions**



### (Wobbrock et al) https://cacm.acm.org/magazines/2018/6/228034-ability-based-design/fulltext

### **Ability Assumptions**

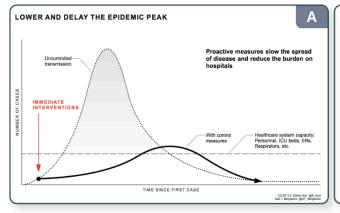


### (Wobbrock et al) https://cacm.acm.org/magazines/2018/6/228034-ability-based-design/fulltext

# blind people) limits what we can do

Problem 2: **Centering research** and development on screen readers (not

### Descriptions



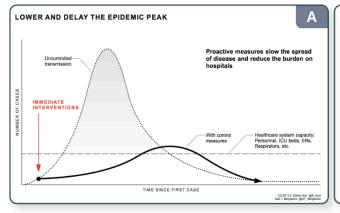
A multi-line chart entitled "Lower and Delay the Epidemic Peak" that plots the Number of Cases by the Time Since First Case. The Number of Cases is plotted on the vertical y-axis. The Time Since First Case is plotted on the horizontal x-axis. The chart shows two possible extremes of the rate of rise and decline of COVID-19 cases. If the transmission is uncontrolled, there are more simultaneous cases. If the transmission is controlled, there are fewer simultaneous cases. If the transmission is controlled, the healthcare system can support all the cases.

The purpose of the chart is not to provide exact numbers, but to communicate to the public that there are multiple ways the current crisis can play out. Without control measures the spread of the disease increases exponentially, making it harder to slow down and creating a big overload in the healthcare system. The number of cases is dramatically higher without controls, and this will likely lead to many deaths. In contrast, when controlled, the healthcare system capacity can handle all of the cases over a longer period of time, and this will save lives.

#### Long Description

Visualizations like "Flatten the Curve" (A) efficiently communicate critical public health information, while simultaneously excluding people with disabilities [11, 28]. To promote accessible visualization via natural language descriptions (B, C), we introduce a four-level model of semantic content. Our model categorizes and color codes sentences according to the semantic content they convey.

### Descriptions



A multi-line chart entitled "Lower and Delay the Epidemic Peak" that plots the Number of Cases by the Time Since First Case. The Number of Cases is plotted on the vertical y-axis. The Time Since First Case is plotted on the horizontal x-axis. The chart shows two possible extremes of the rate of rise and decline of COVID-19 cases. If the transmission is uncontrolled, there are more simultaneous cases. If the transmission is controlled, there are fewer simultaneous cases. If the transmission is controlled, the healthcare system can support all the cases.

The purpose of the chart is not to provide exact numbers, but to communicate to the public that there are multiple ways the current crisis can play out. Without control measures the spread of the disease increases exponentially, making it harder to slow down and creating a big overload in the healthcare system. The number of cases is dramatically higher without controls, and this will likely lead to many deaths. In contrast, when controlled, the healthcare system capacity can handle all of the cases over a longer period of time, and this will save lives.

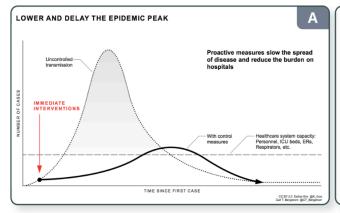
#### Long Description

Visualizations like "Flatten the Curve" (A) efficiently communicate critical public health information, while simultaneously excluding people with disabilities [11, 28]. To promote accessible visualization via natural language descriptions (B, C), we introduce a four-level model of semantic content. Our model categorizes and color codes sentences according to the semantic content they convey.

Image source

#### Structure B. Dual tree schema design A. Raster (png) visualization **D. Schema instantiated** Major trophies for some English teams start 🧹 start 🖒 🔵 BPL 🛛 🖷 FA Cup 👘 CL •(legend)**∢ →**(yaxis)∢ title end title -→( x axis ) axis item **C. Keyboard** navigation rules ESCAPE exits the LEFT/RIGHT move structure Press ENTER to mov axis item axis item end PERIOD moves back to any child item Press L to move out, towards the Press BACKSPACE user's last location to move out, towards the x axis any node any node legend item

### Descriptions



A multi-line chart entitled "Lower and Delay the Epidemic Peak" that plots the Number of Cases by the Time Since First Case. The Number of Cases is plotted on the vertical y-axis. The Time Since First Case is plotted on the horizontal x-axis. The chart shows two possible extremes of the rate of rise and decline of COVID-19 cases. If the transmission is uncontrolled, there are more simultaneous cases. If the transmission is controlled, there are fewer simultaneous cases. If the transmission is controlled, the healthcare system can support all the cases.

numbers, but to communicate to the public that there are multiple ways the current crisis can play out. Without control measures the spread of the disease increases exponentially, making it harder to slow down and creating a big overload in the healthcare system. The number of cases is dramatically higher without controls, and this will likely lead to many deaths. In contrast, when controlled, the healthcare system capacity can handle all of the cases over a longer period of time, and this will save lives.

#### Long Description

Visualizations like "Flatten the Curve" (A) efficiently communicate critical public health information, while simultaneously excluding people with disabilities [11, 28]. To promote accessible visualization via natural language descriptions (B, C), we introduce a four-level model of semantic content. Our model categorizes and color codes sentences according to the semantic content they convey.

#### Image source

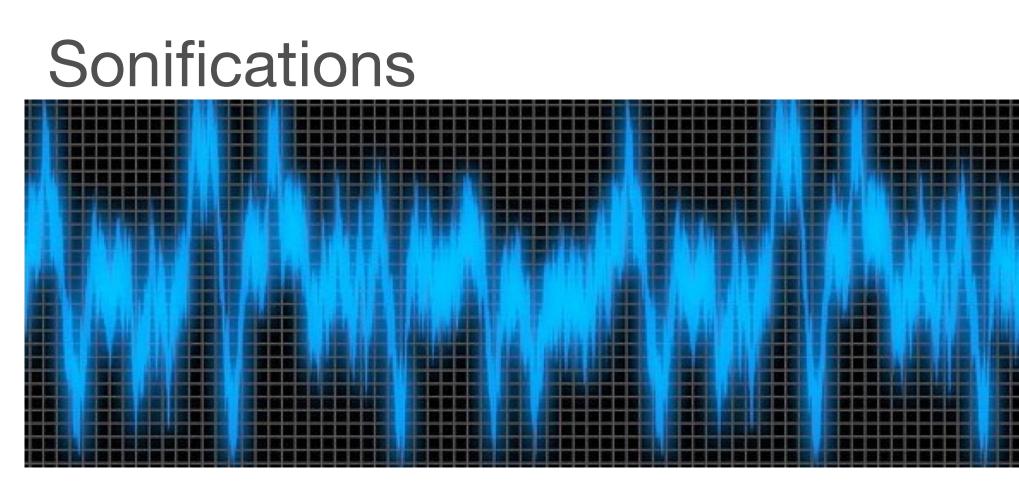
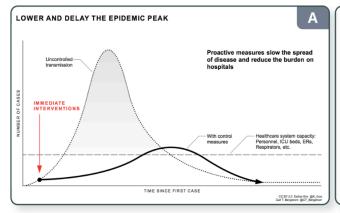


Image source

#### Structure **B. Dual tree schema design D. Schema instantiated** A. Raster (png) visualization Major trophies for some English teams start start 🔵 BPL 🛛 🖷 FA Cup 🛛 🔍 CL •(legend)**∢ →**(yaxis)∢ title **C. Keyboard** navigation rules ESCAPE exits the structure axis item axis item end PERIOD moves back to any child Press BACKSPAC Press L to move user's last location to *move out*, towards the x axis out, towards the any node any node

### Descriptions



A multi-line chart entitled "Lower and Delay the Epidemic Peak" that plots the Number of Cases by the Time Since First Case. The Number of Cases is plotted on the vertical y-axis. The Time Since First Case is plotted on the horizontal x-axis. The chart shows two possible extremes of the rate of rise and decline of COVID-19 cases. If the transmission is uncontrolled, there are more simultaneous cases. If the transmission is controlled, there are fewer simultaneous cases. If the transmission is controlled, the healthcare system can support all the cases.

numbers, but to communicate to the public that there are multiple ways the current crisis can play out. Without control measures the spread of the disease increases exponentially, making it harder to slow down and creating a big overload in the healthcare system. The number of cases is dramatically higher without controls, and this will likely lead to many deaths. In contrast, when controlled, the healthcare system capacity can handle all of the cases over a longer period of time, and this will save lives.

#### Long Description

Visualizations like "Flatten the Curve" (A) efficiently communicate critical public health information, while simultaneously excluding people with disabilities [11, 28]. To promote accessible visualization via natural language descriptions (B, C), we introduce a four-level model of semantic content. Our model categorizes and color codes sentences according to the semantic content they convey.

#### Image source

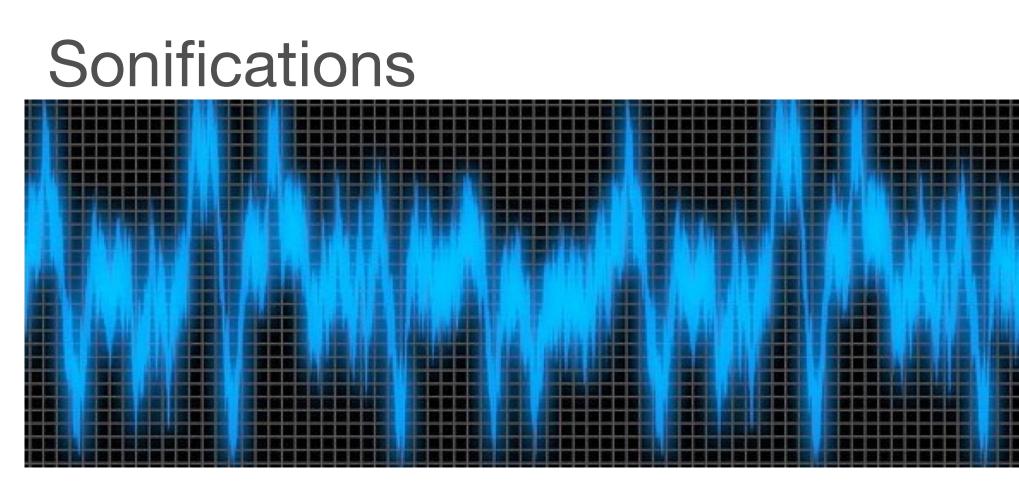
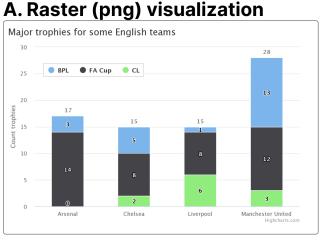


Image source

### A. Raster (png) visualization B. Dual tree schema design



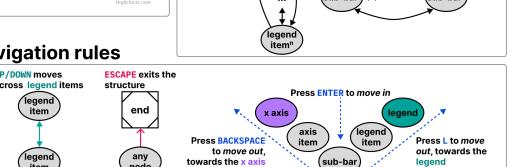
#### **C. Keyboard** navigation rules

axis item

any node axis item

PERIOD moves back to

user's last location



start

title

#### D. Schema instantiated

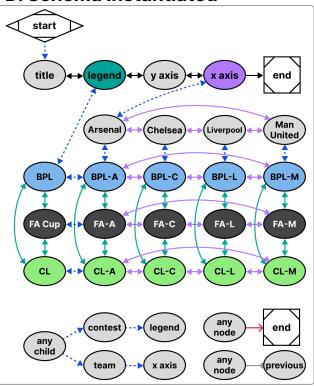
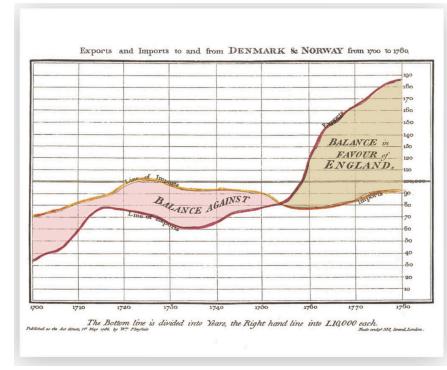
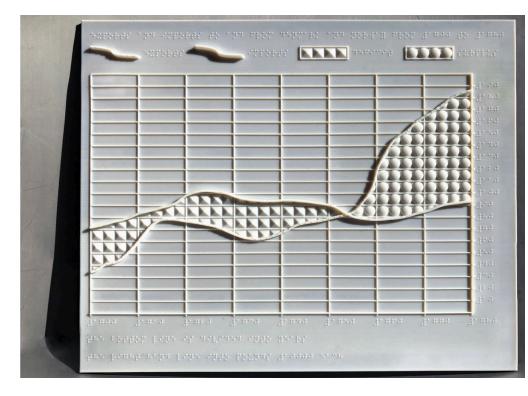


Image source

(legend) ↔ (yaxis) ↔ (xaxis)

### **Tactiles**





### But what about *interactivity?* Output has been our focus, primarily. But what about *input*?

### But screen readers processes 1 input at a time



 $\equiv$ 

WikipediA

The Free Encyclopedia

(disambigu,-\*\*---)

The cat (*Felis* species in the f domestication ( and farm cat, b companionship prey like mice a

### 67 Nav points ~32s

sense of smell are well developed. It is a social species, but a solitar Cat communication includes vocalizations like meawing, purring, trill as well as cat body language. It can hear sounds too faint or too high as those made by small mammals. It also secretes and perceives ph

Female domestic cats can have kittens from spring to late autumn in temperate zones and throughout the year in equatorial regions, with litter sizes often ranging from two to five kittens. Domestic cats are bred and shown at events as registered pedigreed cats, a hobby known as cat fancy. Animal population control of cats may be achieved by spaying and neutering, but their proliferation and the abandonment of pets has resulted in large numbers of feral cats worldwide, contributing to the extinction of bird, mammal

|   | ×A 262 languages                                 |
|---|--|
|   |  |
|   | Pood View courses , Teele                        |
|   |  |
|   |  |
| at, is the only domesticated have shown that the  | Cat<br>Temporal range: 9,500 years ago – present |
| monly kept as a house pet<br>is valued by humans for<br>it is adapted to killing small<br>eth, and its night vision and |  |
| r and a crepuscular predator.<br>sing, growling, and grunting   |  |
| uency for human ears, such  |  |
| nes.  | STATE IN   |
| erate zones and throughout  |  |
| kittens. Domestic cats are  |  |

### Movement between tasks becomes cognitively expensive



 $\equiv$ 

WikipediA

The Free Encyclopedia

From Wikipedia, the free encyclopedia

(disambigu,-\*\*---)

The **cat** (*Felis* species in the f domestication ( and farm cat, b companionship prey like mice a

Car

### 67 Nav point ~32s

sense of smell are well developed. It is a social species, but a solita Cat communication includes vocalizations like meowing, purring, tri as well as cat body language. It can hear sounds too faint or too hig as those made by small mammals. It also secretes and perceives p

Female domestic cats can have kittens from spring to late autumn in temperate zones and throughout the year in equatorial regions, with litter sizes often ranging from two to five kittens. Domestic cats are bred and shown at events as registered pedigreed cats, a hobby known as cat fancy. Animal population control of cats may be achieved by spaying and neutering, but their proliferation and the abandonment of pets has resulted in large numbers of feral cats worldwide, contributing to the extinction of bird, mammal

| earen                                     |  |
|---|--|
|   |  |
|   |  |
|   |  |
|   | ×A zoz languages   |
|   |  |
| C   | Pood View opurer Toolo   |
|   |  |
|   |  |
|   |  |
| cat rannity, see Felidae. For other uses, | see Cat (disambiguation) and Cats  |
| $\bigcirc$                                |  |
| at, is the only domesticated              |  |
| have shown that the                       | Cat  |
| monly kept as a house pet                 | Temporal range: 9,500 years ago – present  |
| is valued by humans for                   |  |
| it is adapted to killing small            |  |
|   |  |
| eth, and its night vision and             | Care Sale  |
| hunter and a crepuscular predator.        |  |
| ng, hissing, growling, and grunting       |  |
| in frequency for human ears, such         |  |
| eromones.                                 |  |
|   |  |
| temperate zones and throughout            |  |
| to five kittens. Domestic cats are        |  |
| wn as cat fancy. Animal population        |  |
| roliferation and the abandonment of       |  |
|   | A REAL PROPERTY AND A REAL |

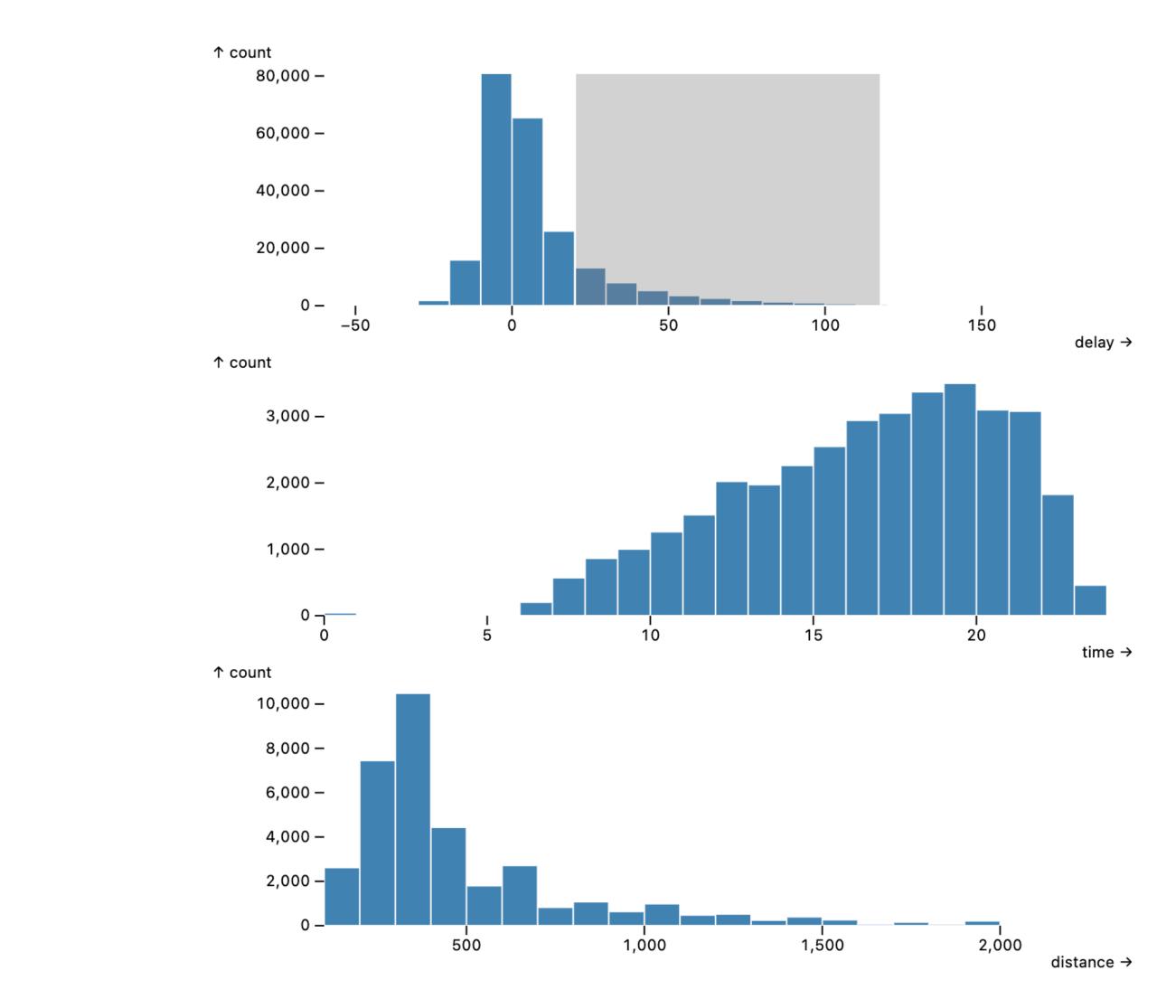
### Auditory processing struggles with dual-task paradigms\*

\*Citation

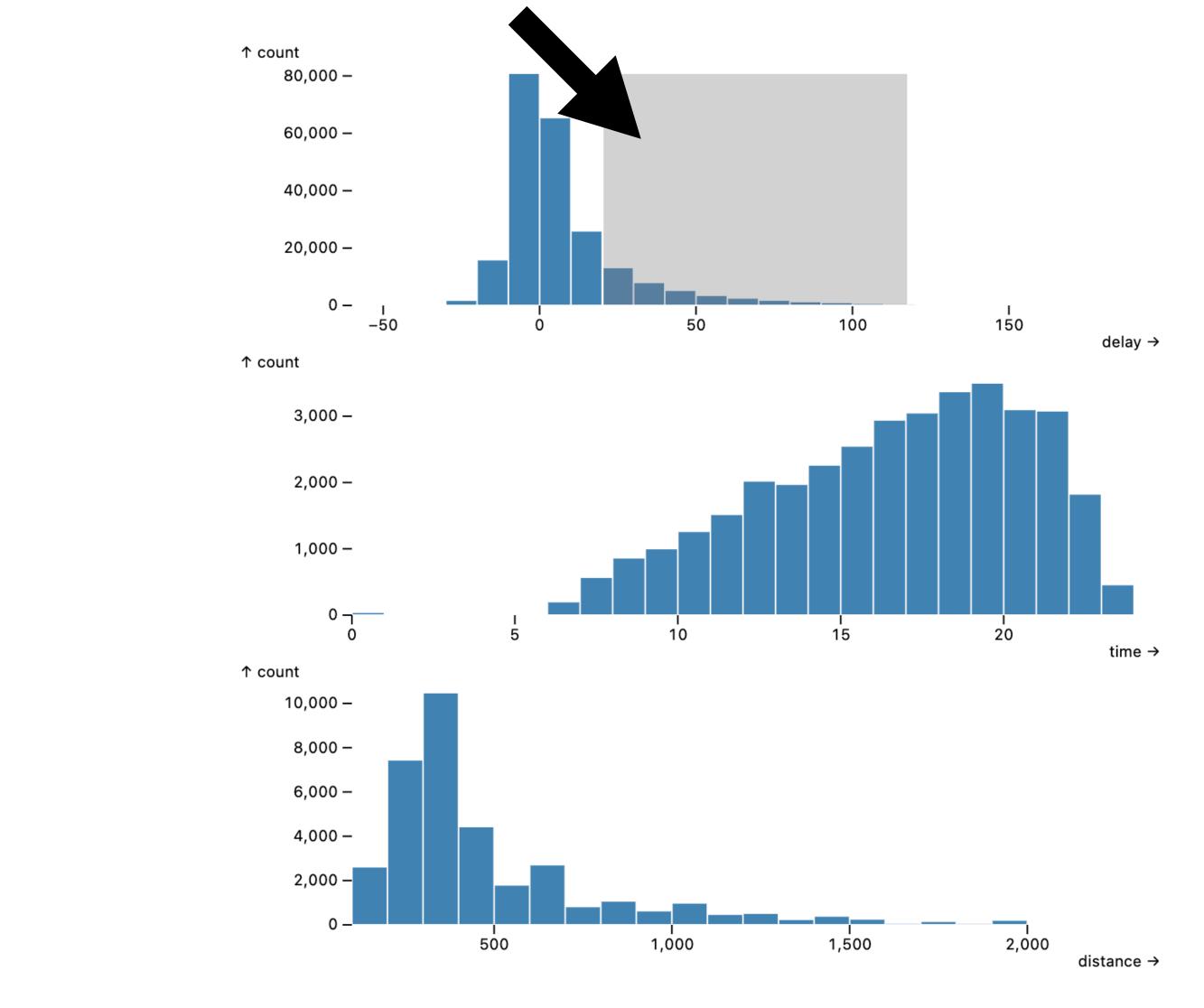
### So what about cross-filtering?

Interactive link

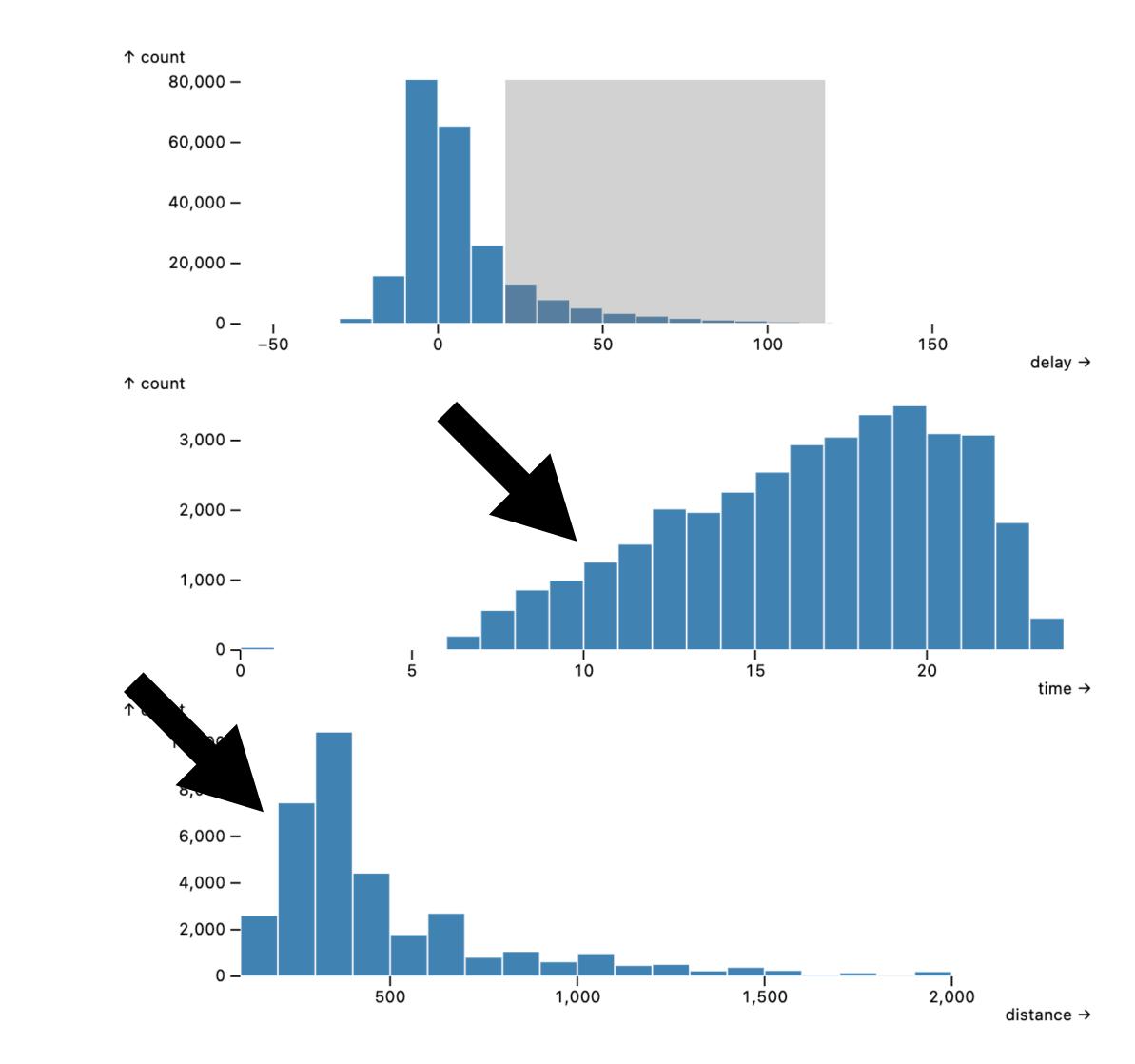
### So what about cross-filtering?



### Interaction in one space...



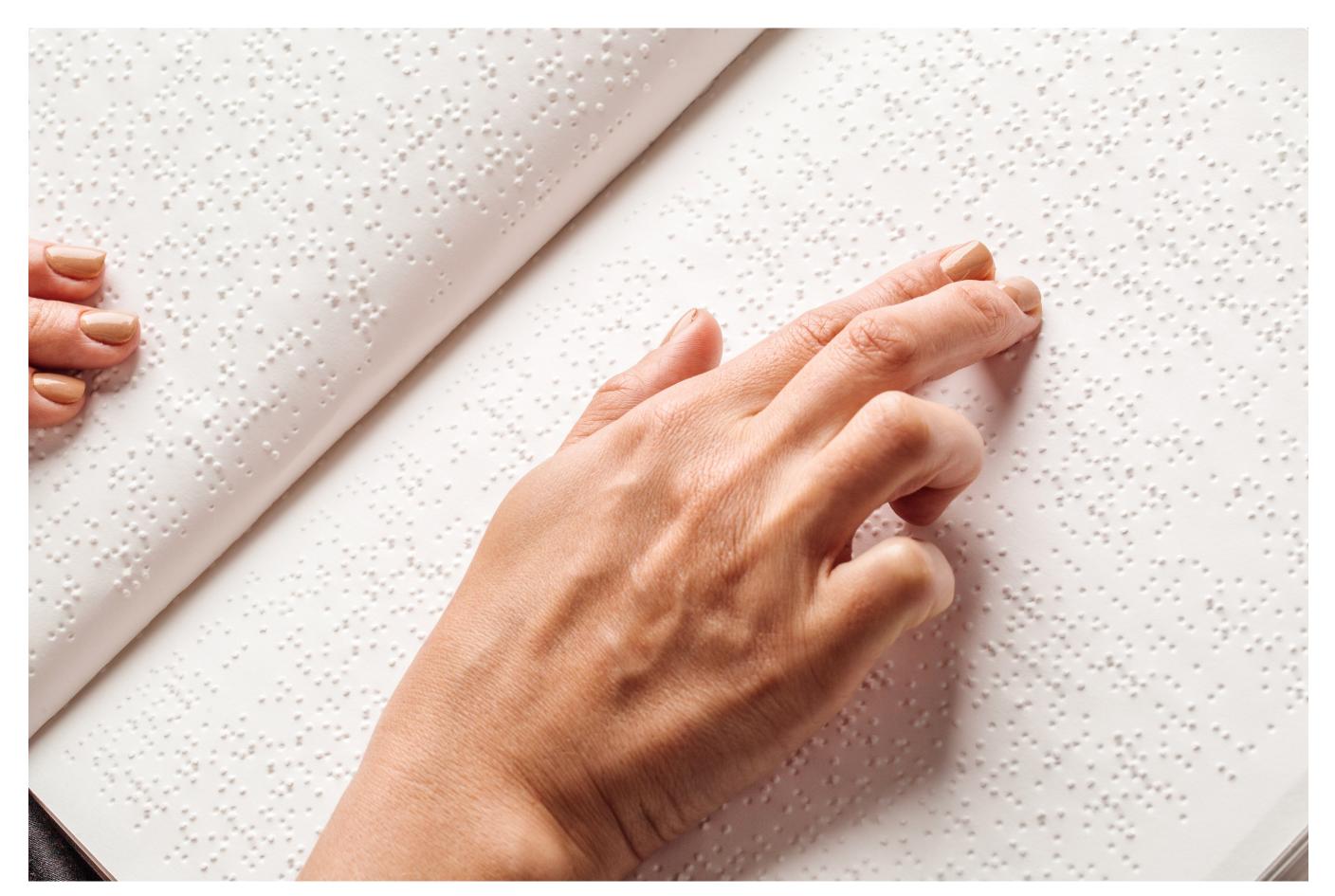
### Produces simultaneous, coordinated change in another.



# For blind users, descriptions, structural navigation, and sonifications will likely *not* solve this challenge.

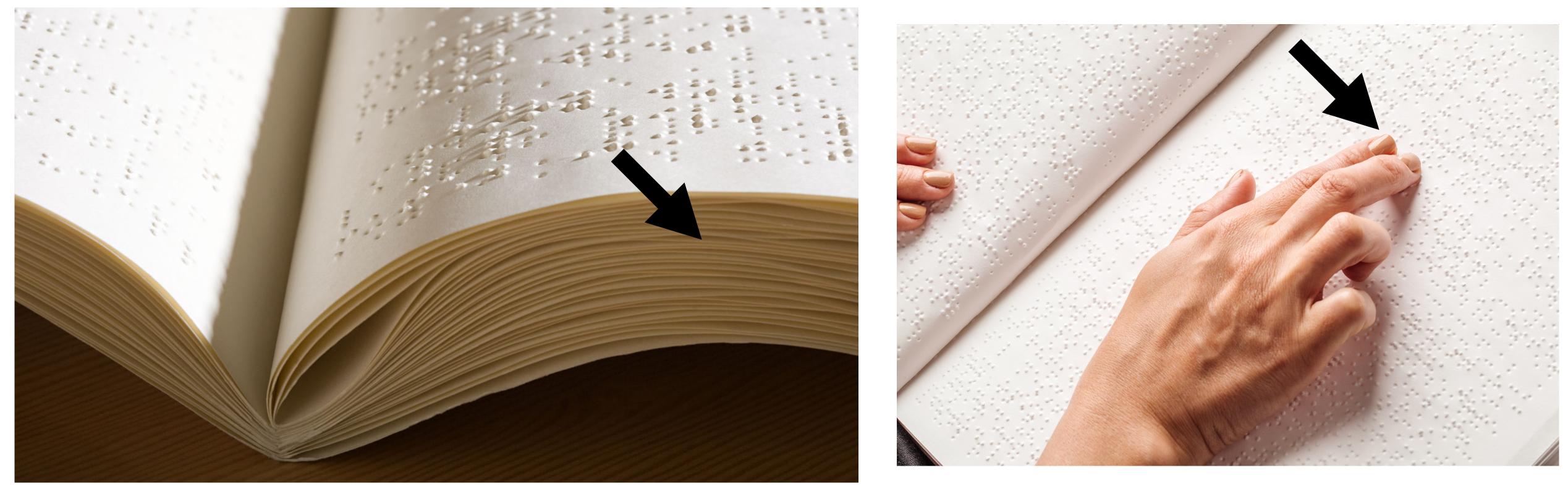
### **Preliminary research question:** How do blind people interact with *multiple* tactile media simultaneously?

### **Observing: Embossed braille in a research context**



### **Observation 1: Spatial memory storage**

My friend didn't remember the details of a math equation exactly, but he knew *where* that equation was located in his stack of braille pages and *where* on the page the equation was.



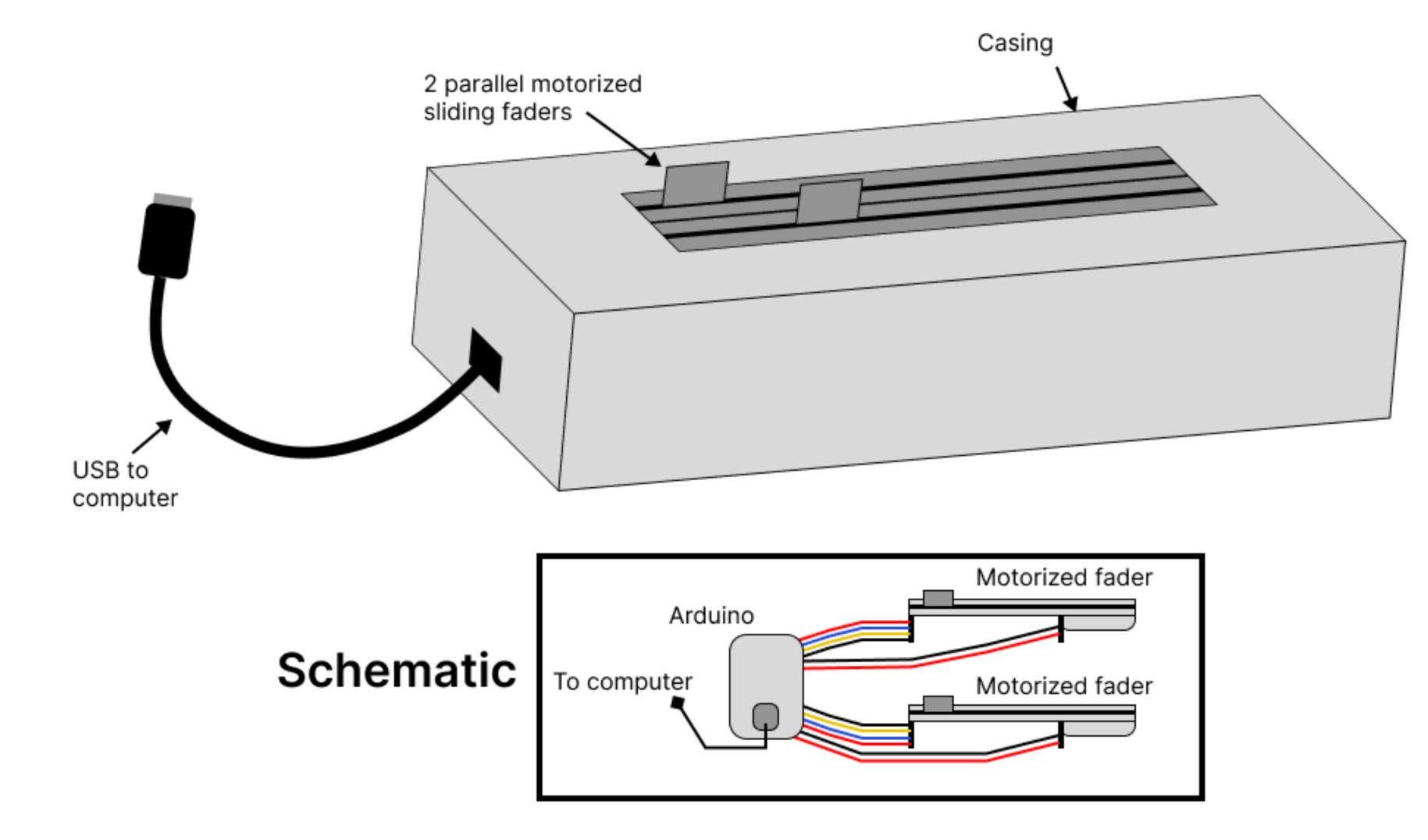
### **Observation 2: Coordinating perception and comparison**

He then compared 2 equations at once. The details of each weren't important. He was *feeling* for differences simultaneously.



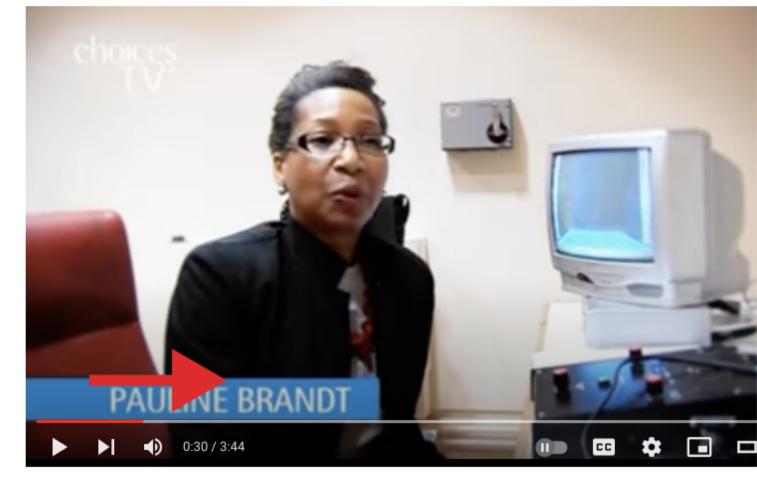


### Prototype 2: the cross-feelter, 2 motorized faders

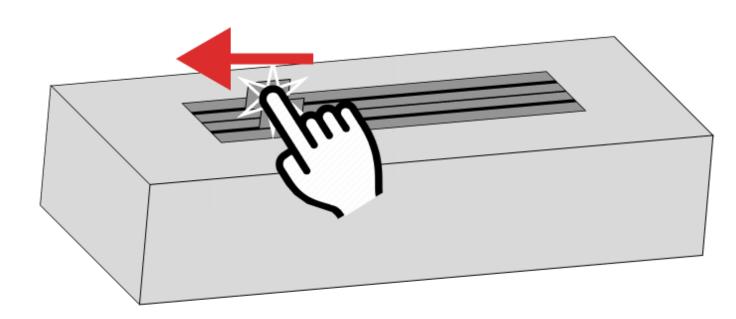


### **One slider can work with video**

#### 1. Video plays with progress slider moving

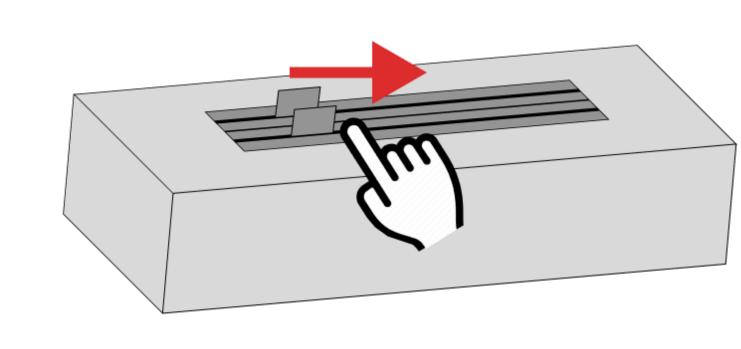


#### 3. User can move slider

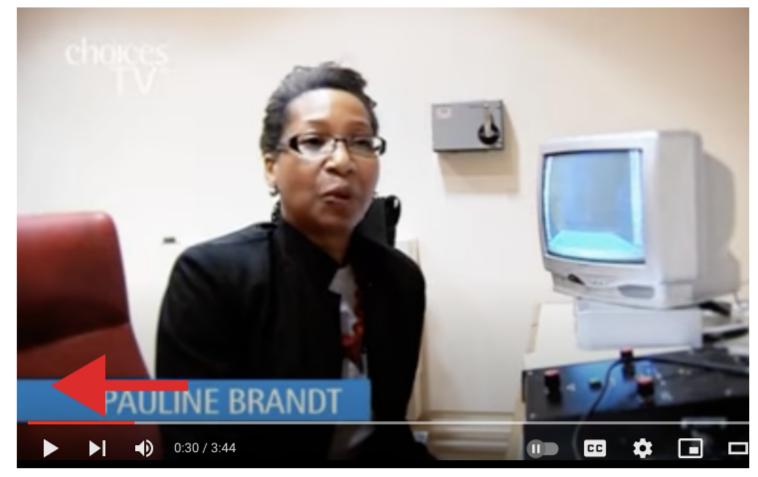




#### 2. Slider follows, can be felt

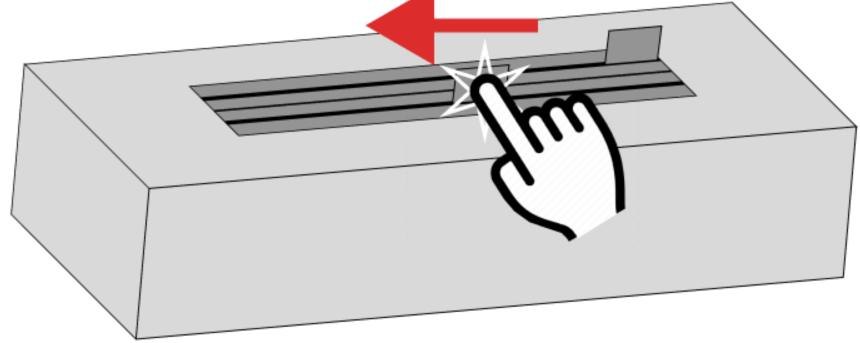


#### 4. Video slider will move with slider change

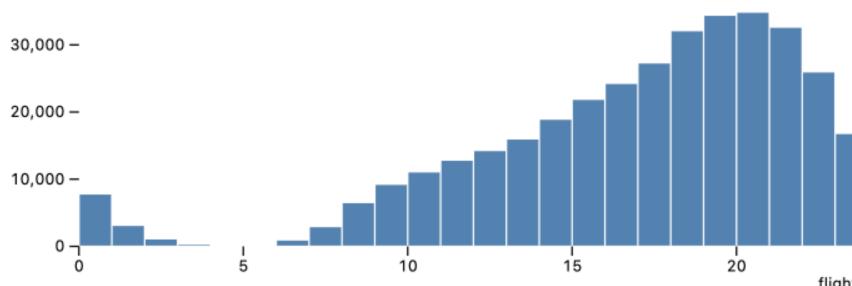


### While 2 sliders works for cross-filtering

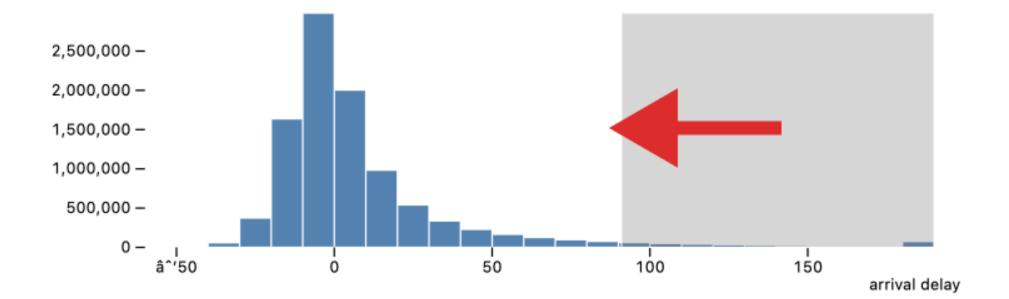
#### 1. User moves a slider



#### 3. Secondary visualization updates



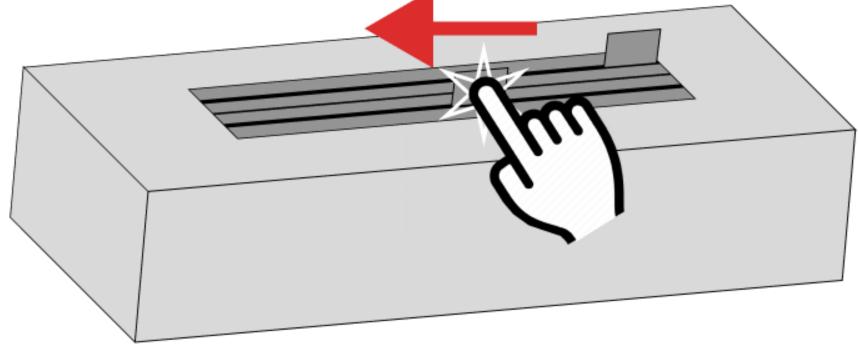
### 2. Corresponding filter edge moves with



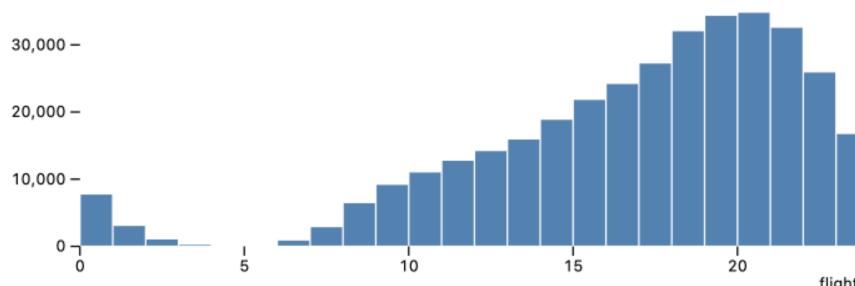
flight time

### A tactile display can render the input or output chart

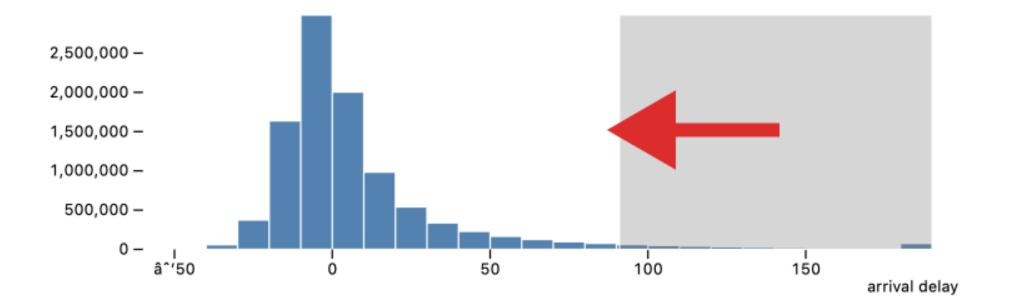
1. User moves a slider



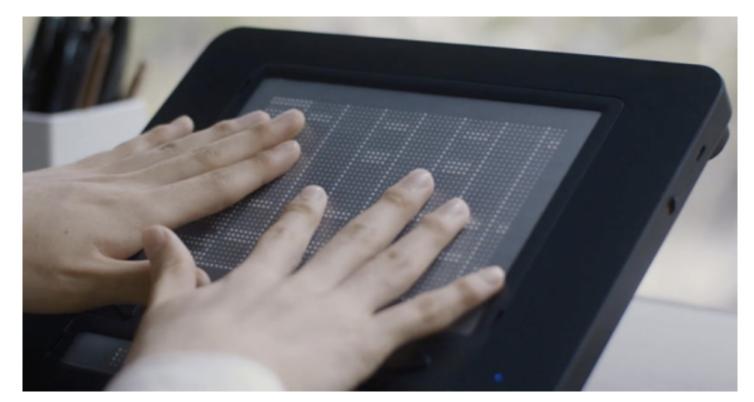
#### 3. Secondary visualization updates



#### 2. Corresponding filter edge moves with



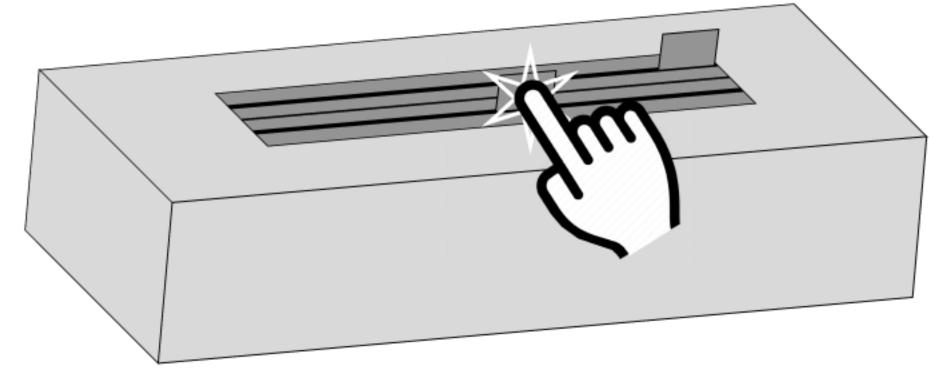
#### 4. Tactile display renders

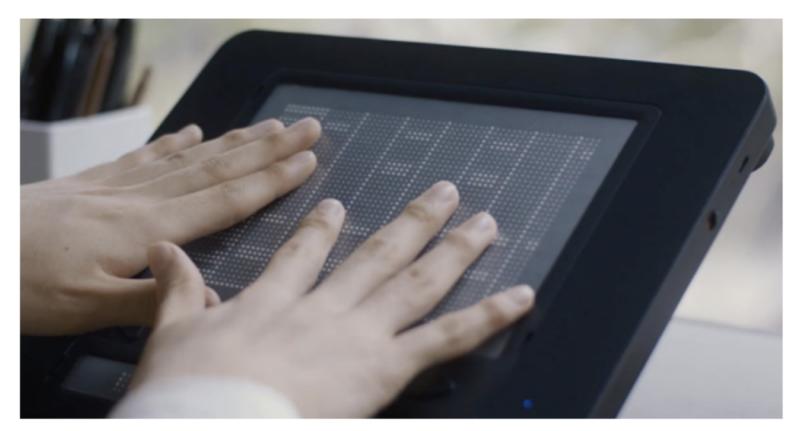


flight time

### Cross-coordination! A tactile, dual-task paradigm.

### User can interact with a space separate from their current focus!



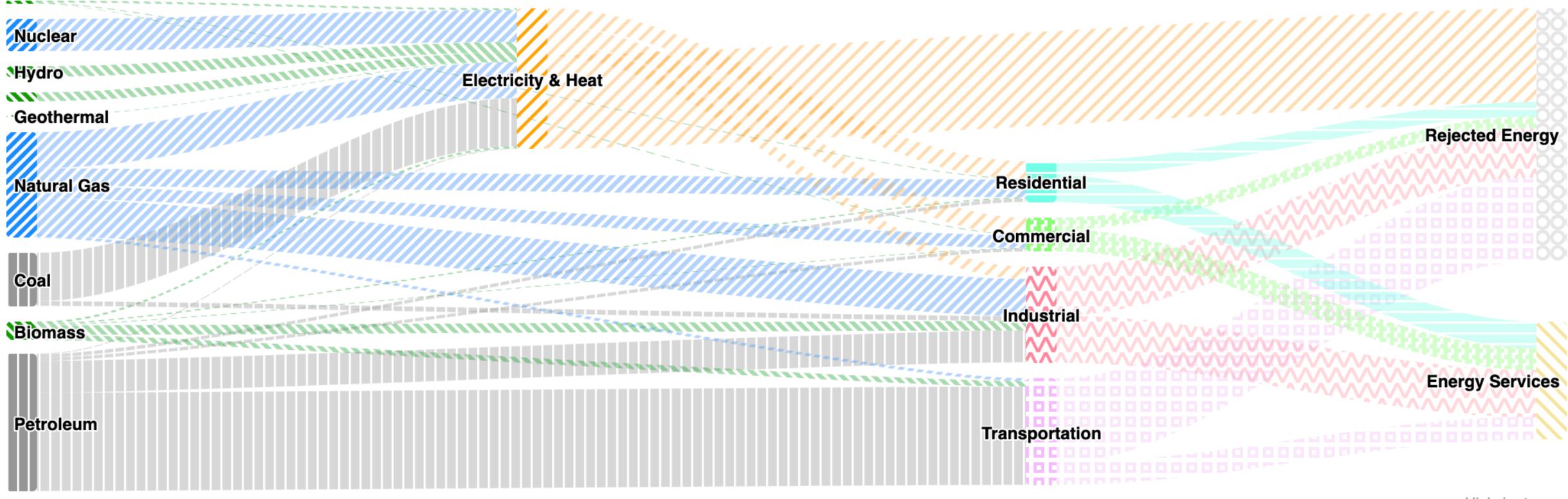


### Problem 3: **Access Friction** is when accessibility for someone produces a barrier for others

## What about this is accessible? Why?

### **Estimated US Energy Consumption in 2017**

Source: Lawrence Livermore National Laboratory



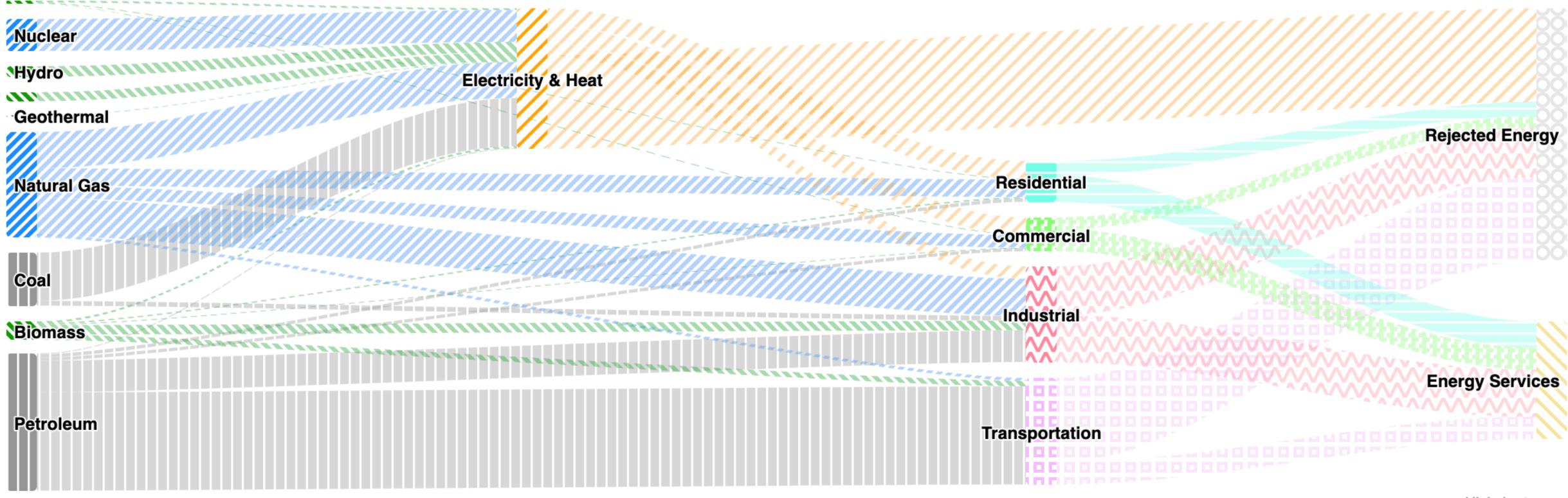
Sankey charts are used to visualize data flow and volume between nodes. The wider lines indicate larger volumes.

Highcharts.com

## What about this might be a barrier? Why?

### **Estimated US Energy Consumption in 2017**

Source: Lawrence Livermore National Laboratory



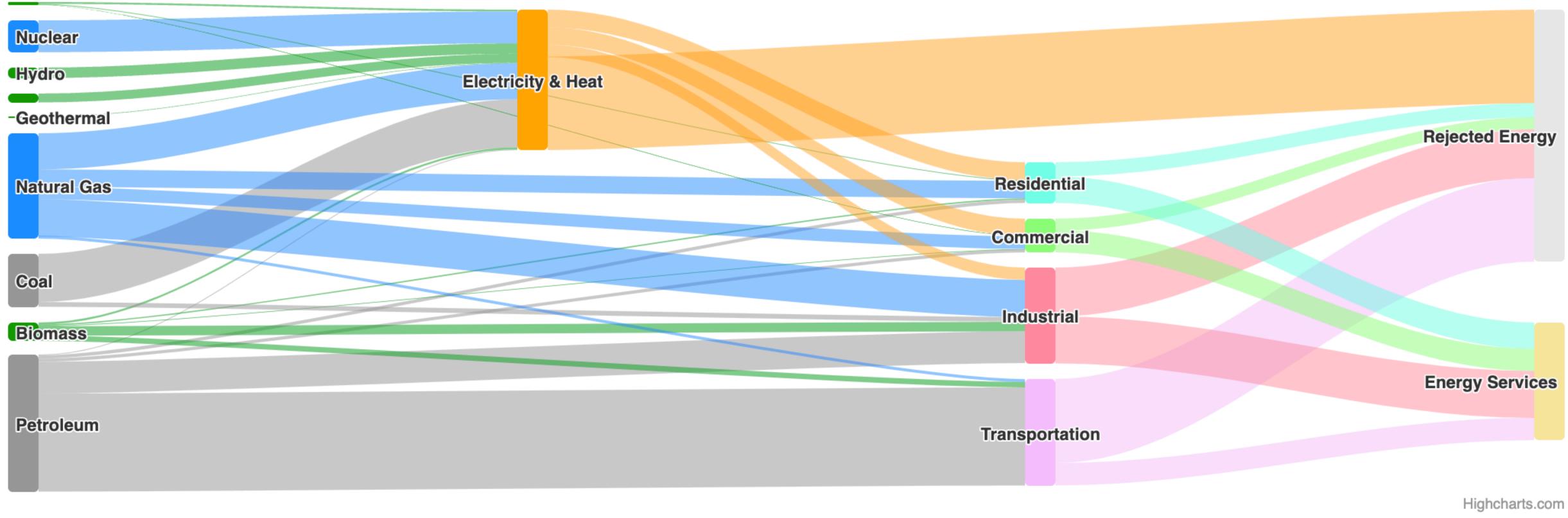
Sankey charts are used to visualize data flow and volume between nodes. The wider lines indicate larger volumes.

Highcharts.com

## What about this now might be a barrier?

### **Estimated US Energy Consumption in 2017**

Source: Lawrence Livermore National Laboratory

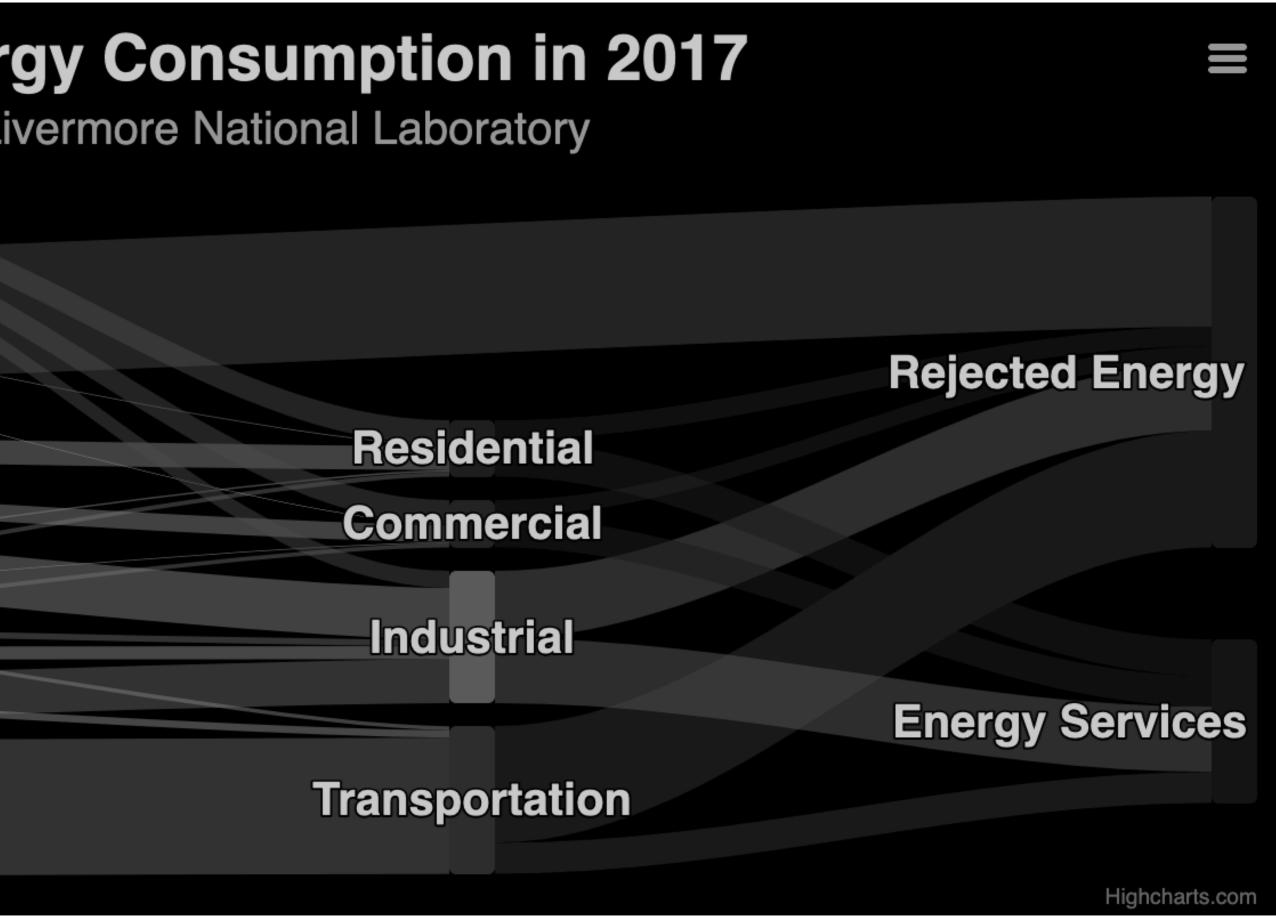


Sankey charts are used to visualize data flow and volume between nodes. The wider lines indicate larger volumes.

### So some folks use tools to hack what they want

|                  | Estimated US Ener<br>Source: Lawrence Li |
|------------------|--|
| Nuclear<br>-Wind | Electricity & Heat                       |
| Natural Gas      |  |
| Coal             |  |
| Petroleum        |  |

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

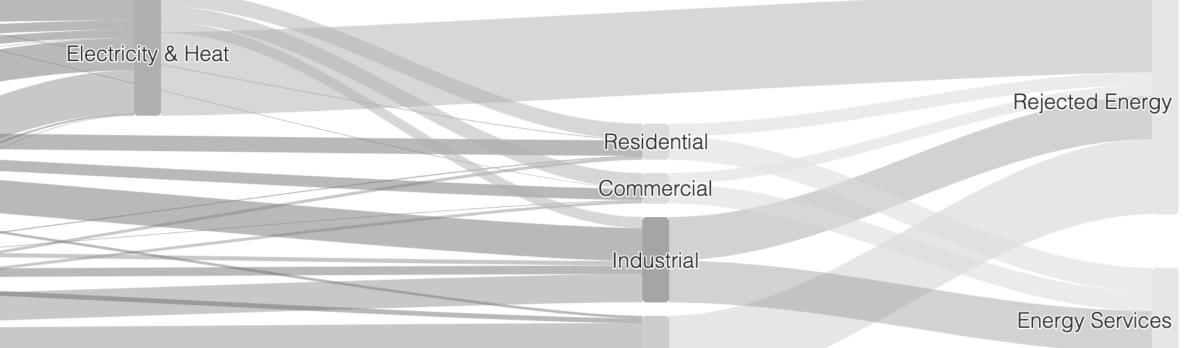


## What if we let users hack the design?

| Preferences   |            |            |                 |    |
|---|------------|------------|-----------------|----|
| Hide unavailable options 🗸  |            |            | Nuclear         |    |
| Comprehension   |            |            | INderedi        |    |
| default moderate robust   |            |            | Wind            |    |
| $\bigcirc \qquad \bigcirc \qquad \bigcirc$  |            |            |                 |    |
| Alt text appearance   |            |            | Natural Gas     |    |
| default show high level show all  |            |            |                 |    |
| $\bigcirc \qquad \bigcirc \qquad \bigcirc$  |            |            | Coal            |    |
| Description verbosity   |            |            | Biomass         |    |
| default disable minimal verbose   |            |            |                 |    |
| $\bigcirc \bigcirc $ |            |            | Petroleum       |    |
| ▼ Text  |            |            |                 |    |
| default minimalist moderate maximalis   | st         |            |                 |    |
| $\bigcirc  \bigcirc  \bigcirc  \bigcirc  \bigcirc$  |            |            | Energy Sources  |    |
| ▼ Font Size   |            |            | Geothermal 0.21 |    |
| default small medium large  |            |            | Solar 0.77      |    |
| $\bigcirc$ $\bigcirc$ $\bigcirc$ $\bigcirc$   |            |            | Wind 2.35       |    |
| Title   |            |            | Hydro 2.76      |    |
| default small small+ medium   | medium+    | large      | Biomass 4.92    |    |
| $\bigcirc$ $\bigcirc$ $\bigcirc$ $\bigcirc$   | $\bigcirc$ | $\bigcirc$ | Nuclear 8.42    |    |
| Subtitle  |            |            | Coal            | 13 |
| default small small+ medium   | medium+    | large      | Natural Gas     |    |
| $\bigcirc  \bigcirc  \bigcirc  \bigcirc  \bigcirc  \bigcirc  \bigcirc  \bigcirc  \bigcirc  \bigcirc $   | $\bigcirc$ | $\bigcirc$ | Petroleum       |    |
| Series Labels   |            |            | 0 5 10          | 15 |
| default small small+ medium   | medium+    | large      |                 |    |
| $\bigcirc$ $\bigcirc$ $\bigcirc$ $\bigcirc$   | $\bigcirc$ | $\bigcirc$ |                 |    |

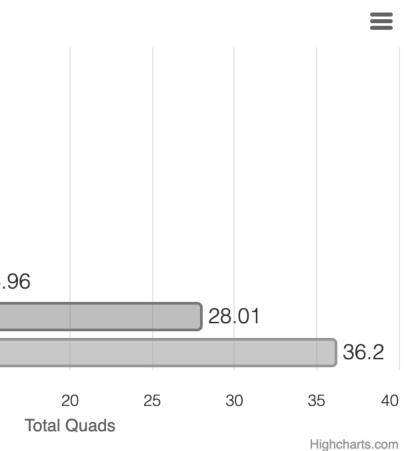
#### Estimated US Energy Consumption in 2017

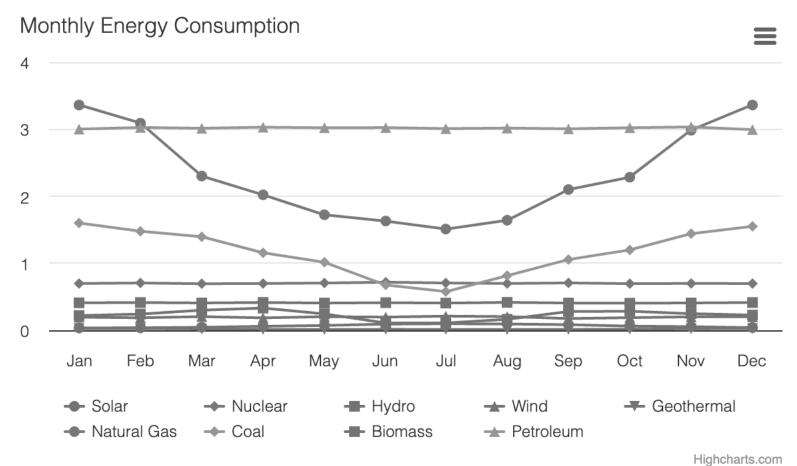
Source: Lawrence Livermore National Laboratory





Highcharts.com





#### Interactive demo link

### Designers do their best but it isn't always enough

https://dl.acm.org/doi/10.1145/1952383.1952384

## Systems cannot always be adaptive/smart

https://dl.acm.org/doi/abs/10.1145/3373625.3416990 https://link.springer.com/article/10.1007/s42979-022-01239-1

# We believe that users should have control over systems in these circumstances.

## Summer plan:

- 1. Build a bunch of visualizations that are pretty accessible by default
- 2. Come up with areas we think users will still want control
- 3. Ask developers what they think of the core idea, from a dev perspective 1. Challenges for devs and for users

  - 2. Opportunities
  - 3. Most important preferences to give users control of
- 4. Build a prototype that enables user customization of a dashboard
- 5. Show the prototype to users with a spectrum of different disabilities
  - 1. Challenges with the prototype
  - 2. Opportunities for the core idea
  - 3. Additional ideas

# We organized personalization options (as "preferences") into categories

Comprehension Text visuals Color and contrast Element size Motion + Interactivity

# We created subcategories that fit a given preference category

Comprehension Text visuals Color and contrast Element size Motion + Interactivity

- Showing alt text
- Description verbosity
- Explanation verbosity
  - Cues and labels

### And then we created finer-levels of control

Comprehension Text visuals Color and contrast Element size Motion + Interactivity

Showing alt text

#### **Description verbosity** ► Chart

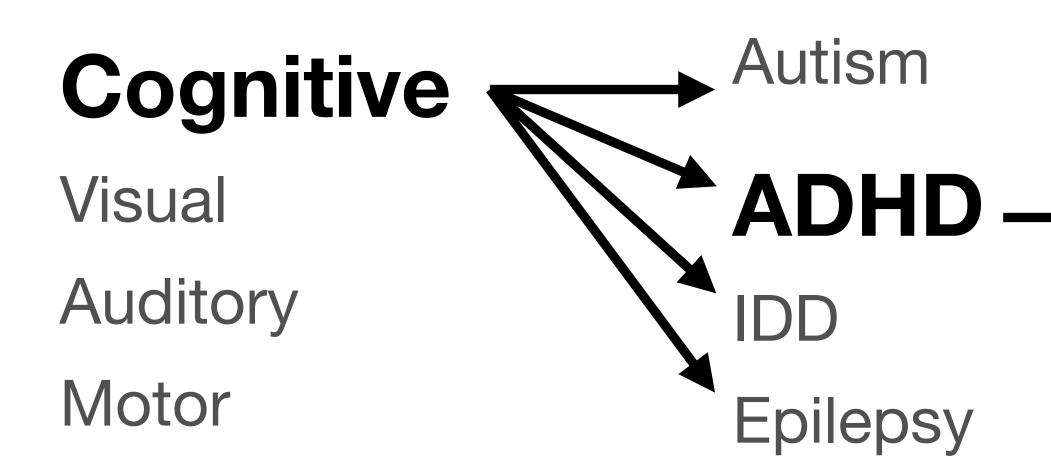
**Explanation verbosity** 

Cues and labels

Region alt Interactions Animations



## Why not "low vision," "blindness," or "ADHD" categories of disability?



Reduce complexity
 Minimize colors
 Shorten textual explanations
 Provide interaction cues
 Enable action logging

### People don't think of themselves as disabled, but often value accessibility

There is a reason behind this omission, and that reason is internalized ableism. People don't think of themselves as disabled, so they don't think the accessibility preference area applies to them.

"Wow, I had no idea this existed!" and, "This is going to be life changing!"

From Eric Bailey's recent and amazing blog post on customization and accessibility

# We came up with over 200 items for possible customization

## (Demo time)

Interactive demo link

2024

# Looking to the future of accessible data interfaces HIGHJOFT



Frank Elavsky, PhD Student







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



