

CMU 05-319 and 05-619, Fall 2025

dig.cmu.edu/vis2025

Interactivity + Accessibility

Data Visualization



Frank Elavsky

based on materials by Dominik Moritz, Jeff Heer, Arvind Satyanarayan

dig.cmu.edu

What you will learn today

The value of interactivity

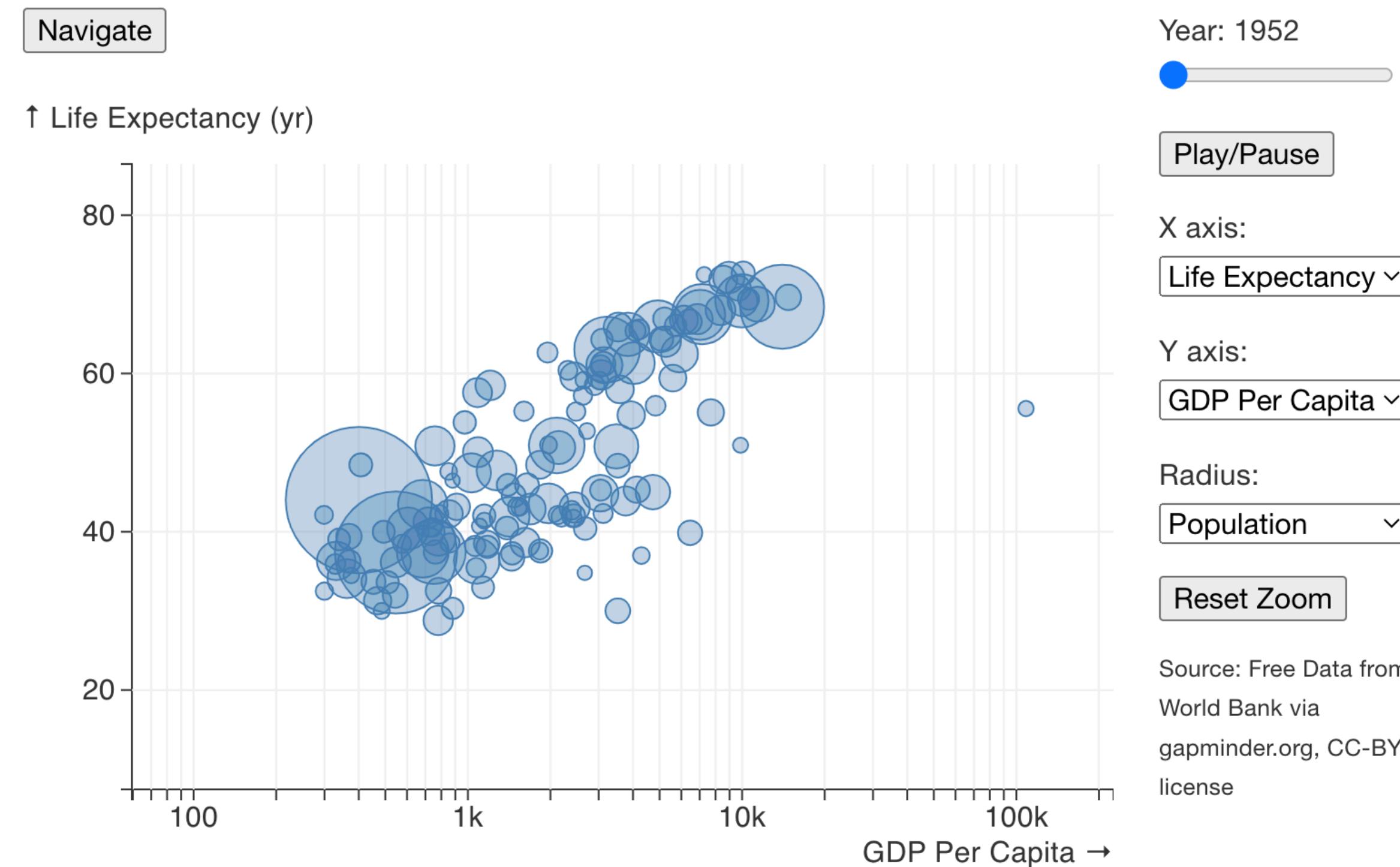
Principles of interaction design

Principles of accessible interaction design

The Value of Interactivity

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.

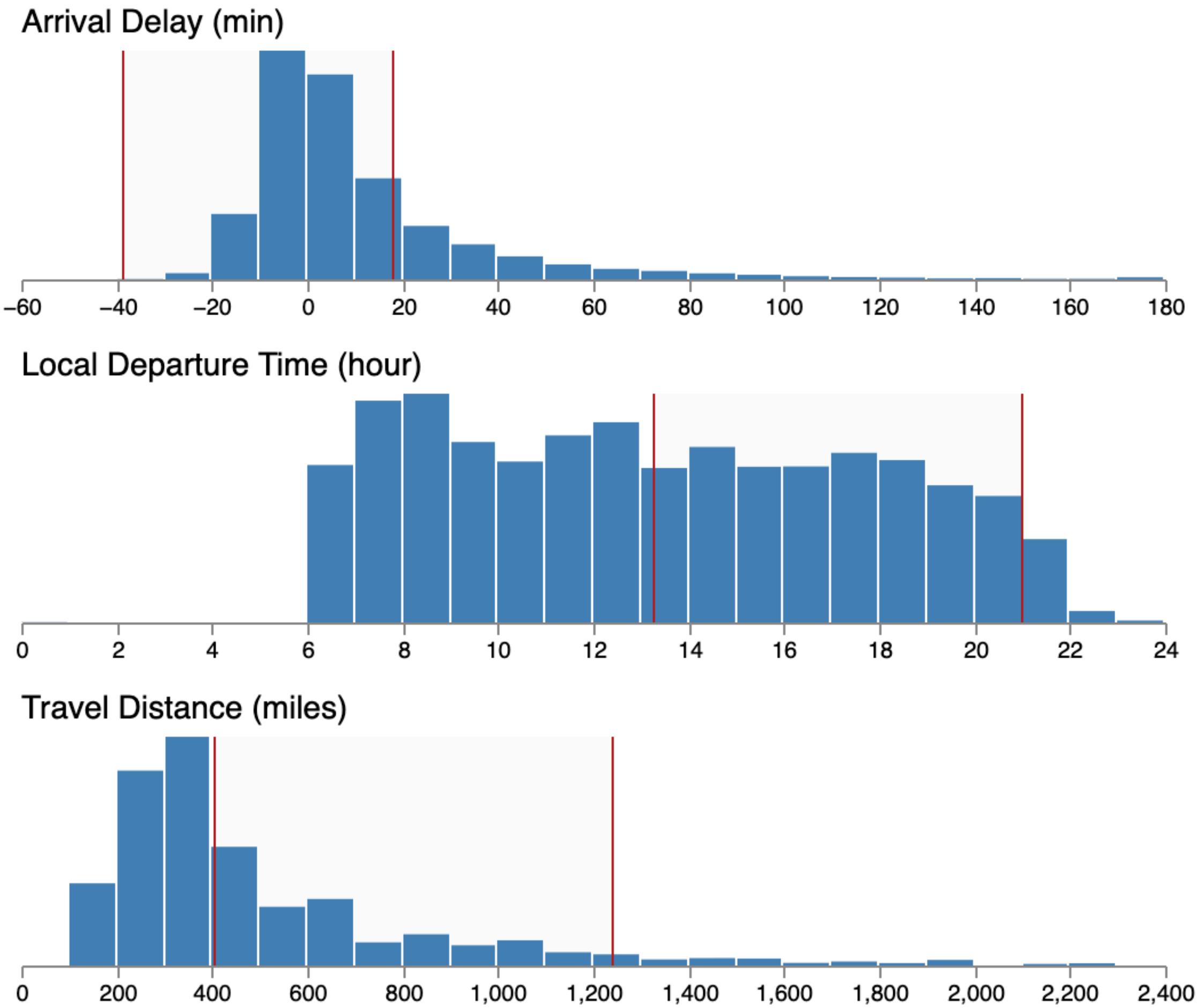


<https://dig.cmu.edu/counterpoint/2024/04/30/gapminder-accessible.html>



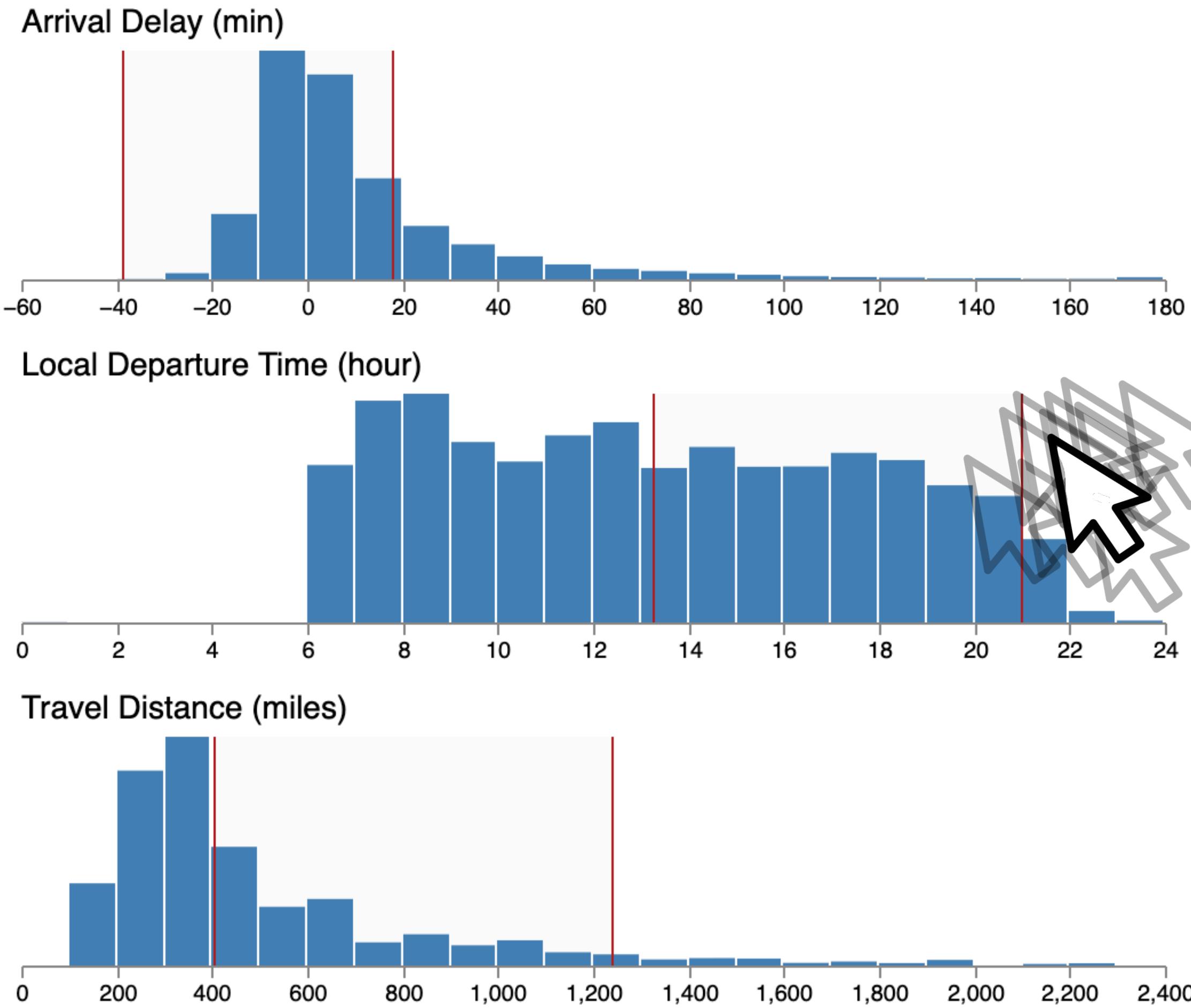
Dragicevic, P., Ramos, G., Bibliowicz, J., Nowrouzezahrai, D., Balakrishnan, R., and Singh, K. (2008).
Video Browsing by Direct Manipulation. CHI '08.

The Value of Interactivity



<https://vega.github.io/editor/#/examples/vega/crossfilter-flights>

The Value of Interactivity



Note: Expecting users to hover on something tiny is an accessibility design failure

The Value of Accessible (multi-modal) Interactivity

A video with sliders

Video loaded. You may now connect.

Connect Feelter

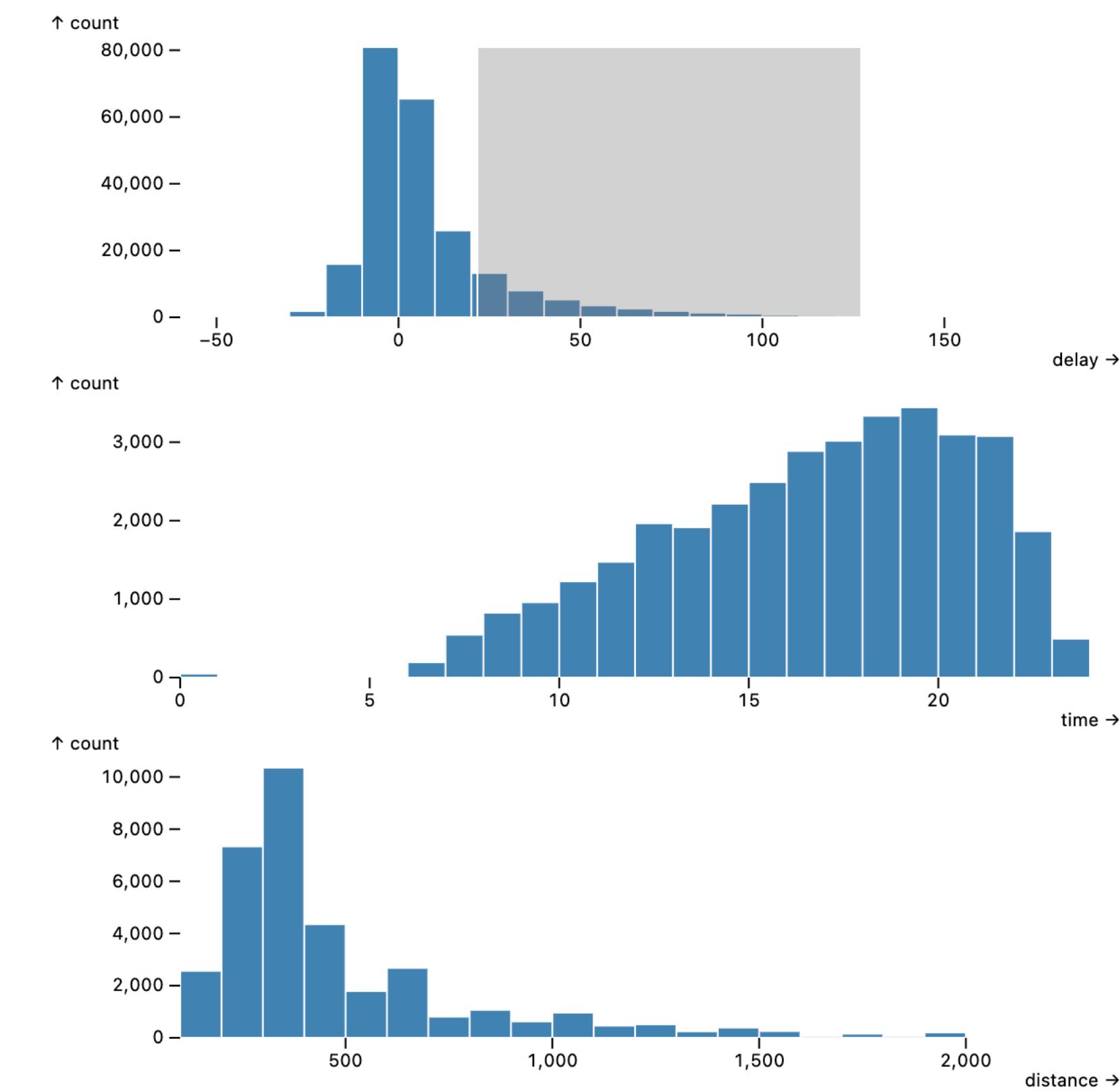
The top slider controls the volume, the bottom controls the video's progress. Moving the bottom slider will move you rapidly forward or backward through the video.

Tapping or touching the top slider will also pause or unpause the video. Note that adjusting the volume may pause or unpause the video. Simply tap the top slider again if it paused or unpause when you didn't want it to.



[Go back to main page](#)

<https://dig.cmu.edu/cross-feelter/video.html>



<https://dig.cmu.edu/cross-feelter/slider.html>

Accessibility principle: “Operability”

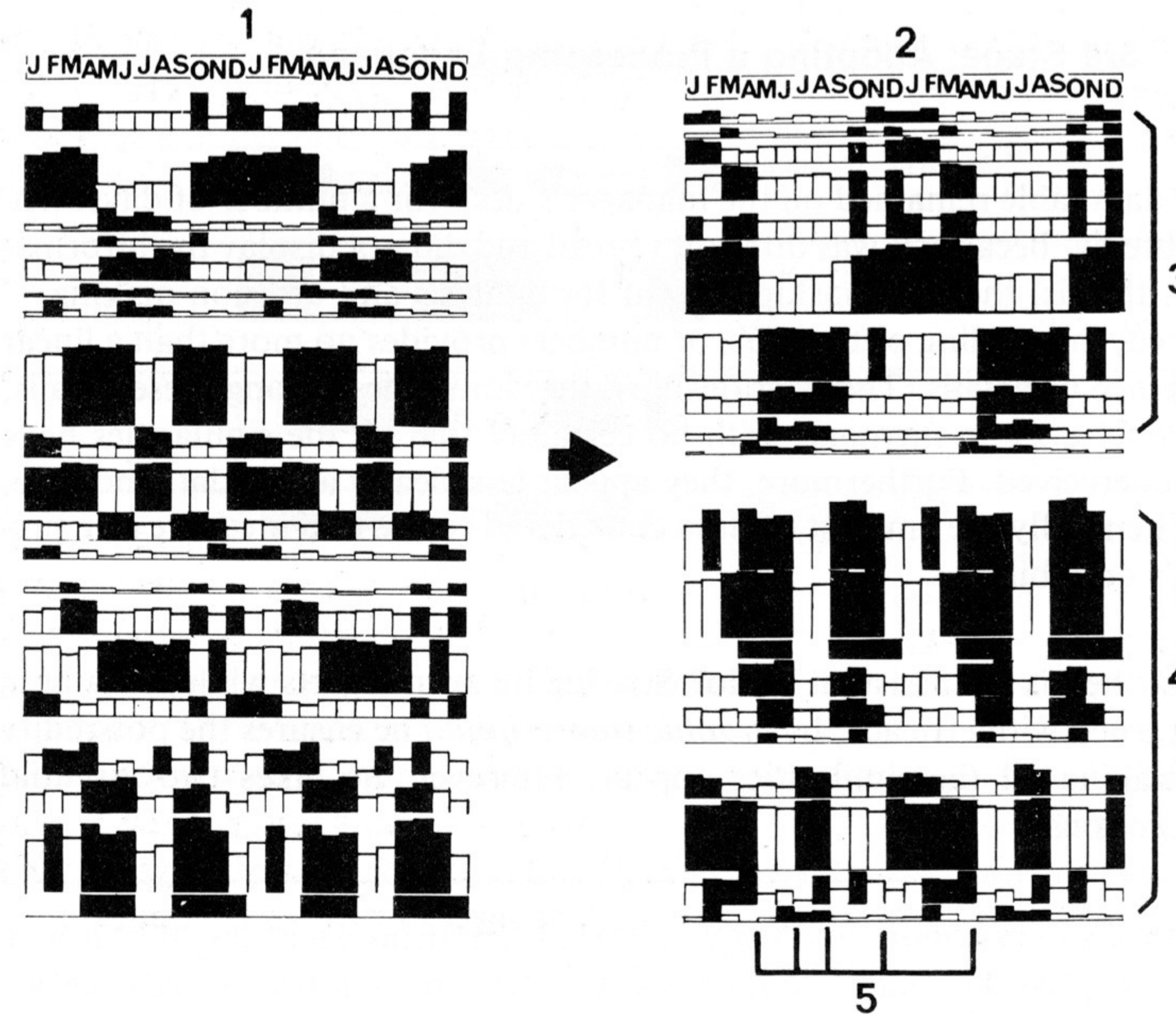
Can someone operate this in multiple ways? Is each way easy?

A graphic is not “drawn” once and for all; it is “constructed” and reconstructed until it reveals all the relationships constituted by the interplay of the data. The best graphic operations are those carried out by the decision-maker [themselves].

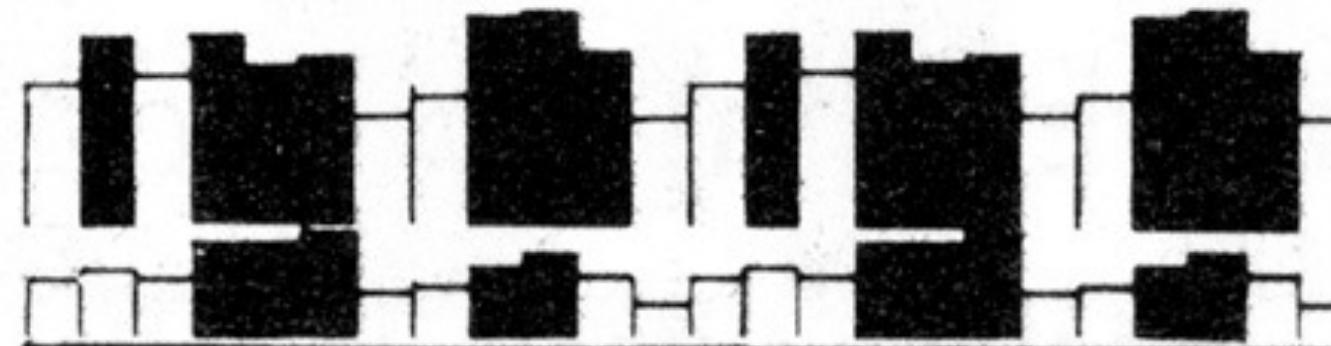
Jacques Bertin (1918 – 2010)



J	F	M	A	M	J	J	A	S	O	N	D								
26	21	26	28	20	20	20	20	40	15	40	1	% CLIENTELE FEMALE							
69	70	77	71	37	36	39	39	55	60	68	72	2	% —" LOCAL						
7	6	3	6	23	14	19	14	9	6	8	8	3	% —" U.S.A.						
0	0	0	0	8	6	6	4	2	12	0	0	4	% —" SOUTH AMERICA						
20	15	14	15	23	27	22	30	27	19	19	17	5	% —" EUROPE						
1	0	0	8	6	4	6	4	2	1	0	1	6	% —" M.EAST, AFRICA						
3	10	6	0	3	13	8	9	5	2	5	2	7	% —" ASIA						
78	80	85	86	85	87	70	76	87	85	87	80	8	% BUSINESSMEN						
22	20	15	14	15	13	30	24	13	15	13	20	9	% TOURISTS						
70	70	75	74	69	68	74	75	68	68	64	75	10	% DIRECT RESERVATIONS						
20	18	19	17	27	27	19	19	26	27	21	15	11	% AGENCY —" //						
10	12	6	9	4	5	7	6	6	5	15	10	12	% AIR CREWS						
2	2	4	2	2	1	1	2	2	4	2	5	13	% CLIENTS UNDER 20 YEARS						
25	27	37	35	25	25	27	28	24	30	24	30	14	% —" 20-35 —" //						
48	49	42	48	54	55	53	51	55	46	55	43	15	% —" 35-55 —" //						
25	22	17	15	19	19	19	19	20	19	22	16	% —" MORE THAN 55 —" //							
163	167	166	174	152	155	145	170	157	174	165	156	17	PRICE OF ROOMS						
1.65	1.71	1.65	1.91	1.90	2.	1.54	1.60	1.73	1.82	1.66	1.44	18	LENGTH OF STAY						
67	82	70	83	74	77	56	62	90	92	78	55	19	% OCCUPANCY CONVENTIONS						
		X	X	X			X	X	X	X	X	20	CONVENTIONS						

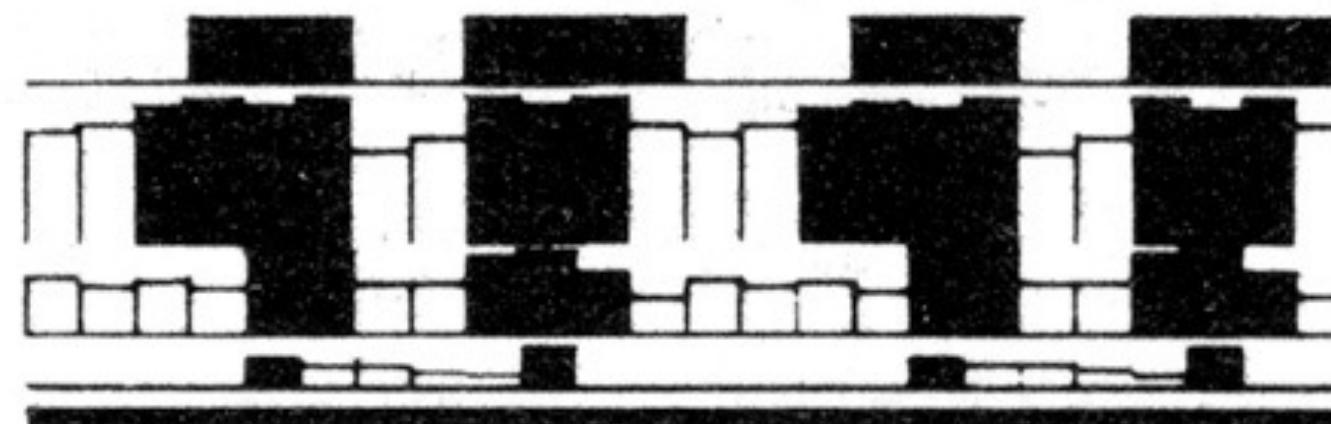


J F M A M J J A S O N D J F M A M J J A S O N D



19 % OCCUPANCY

18 LENGTH OF STAY



20 CONVENTIONS

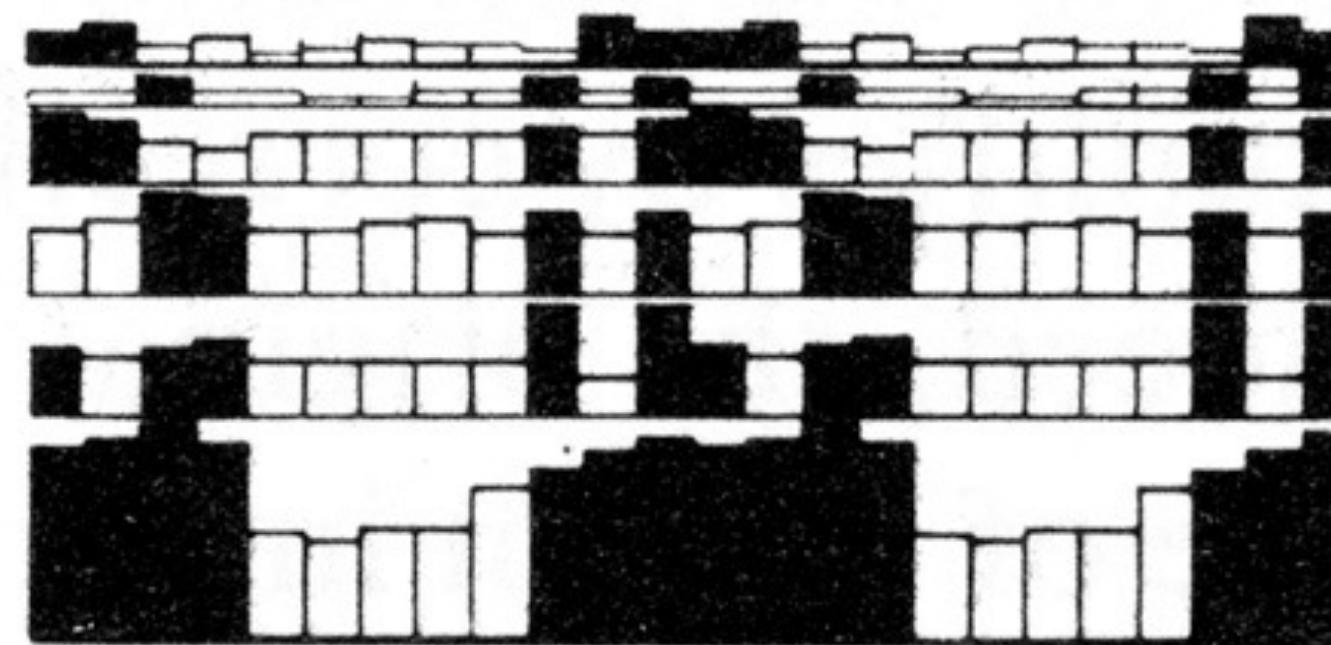
• BUSINESSMEN

11 AGENCY RESERVATIONS

4 SOUTH AMERICA

ACTIVE AND
SLOW PERIODS

DISCOVERY FACTORS



18 AIR CREWS

18 CLIENTS UNDER 20 YEARS

18 CLIENTS MORE THAN 55 YEARS

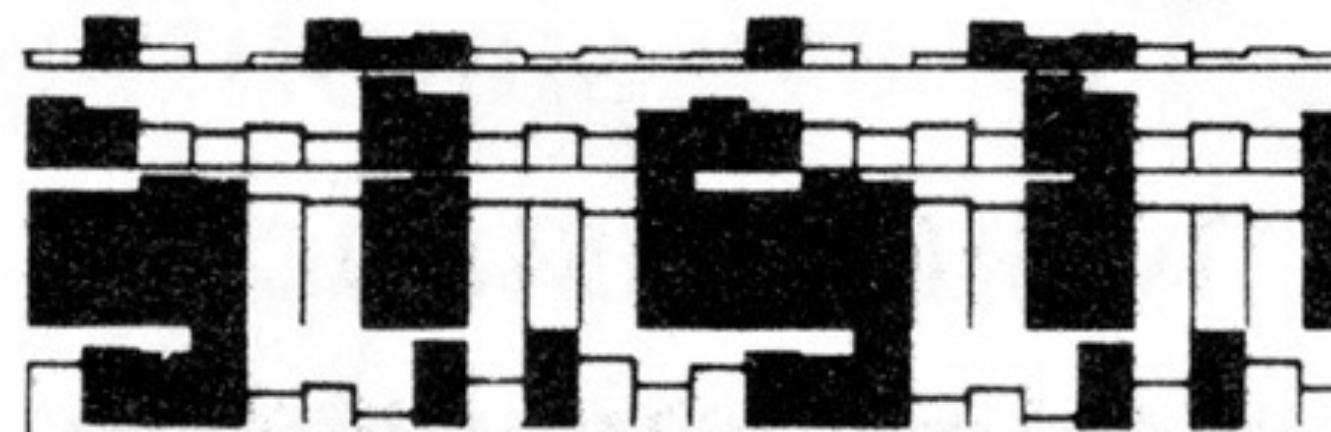
14 CLIENTS FROM 20-35 YEARS

1 FEMALE CLIENTELE

2 LOCAL CLIENTELE

RECOVERY FACTORS

WINTER



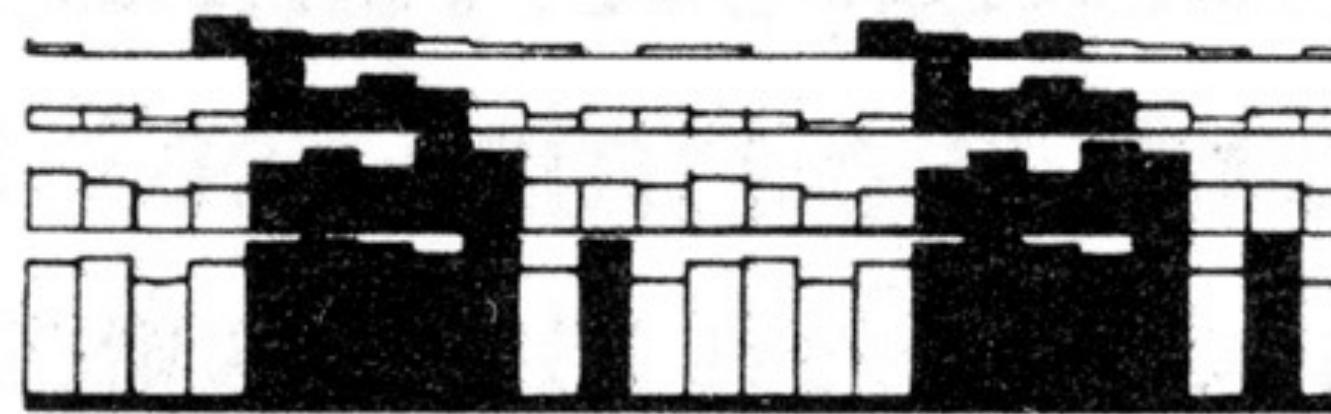
7 ASIA

9 TOURISTS

10 DIRECT RESERVATION

17 PRICE OF ROOMS

WINTER-SUMMER



6 MIDDLE EAST, AFRICA

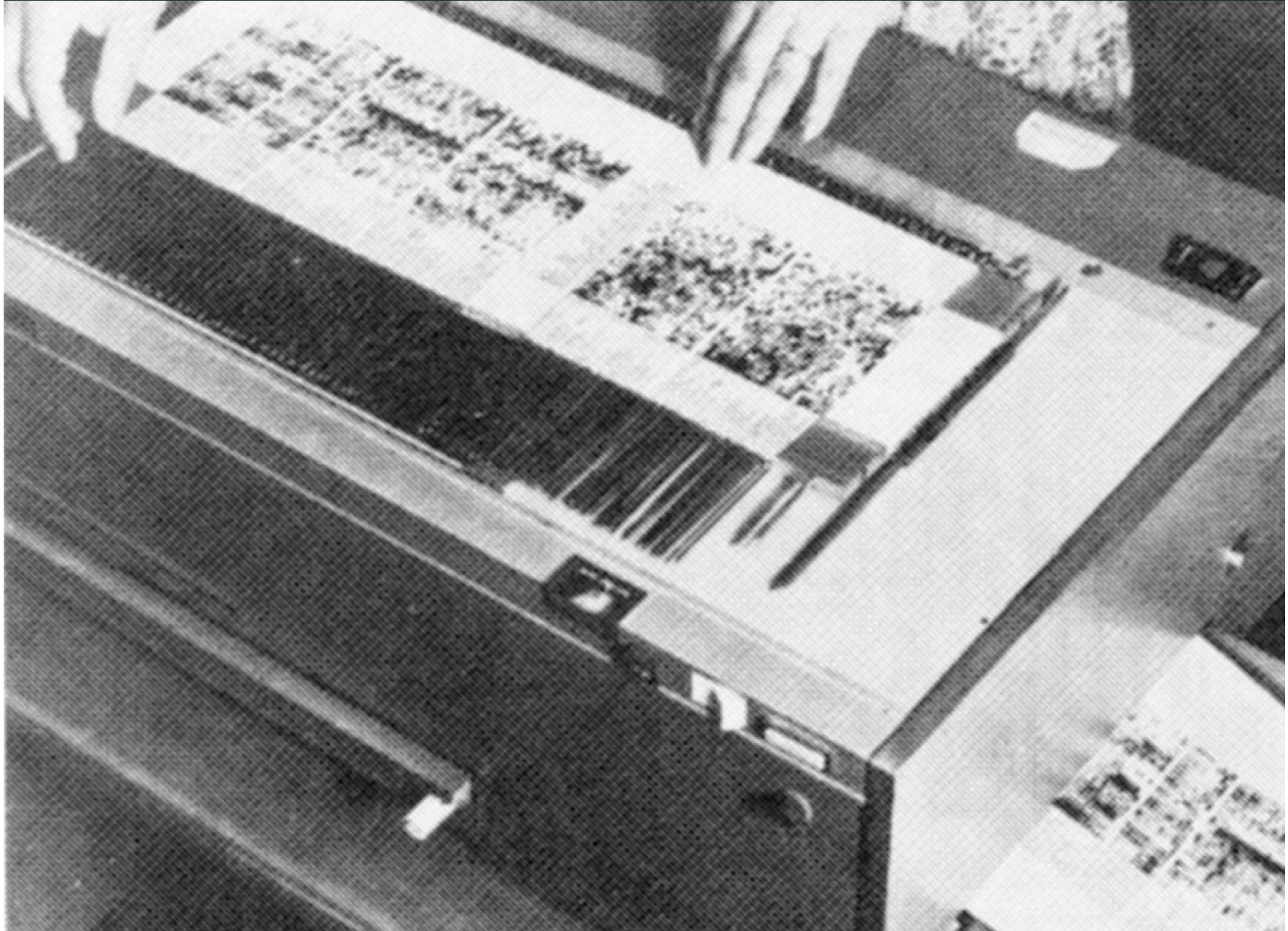
3 U. S. A.

5 EUROPE

15 CLIENTS FROM 35-55 YEARS

SUMMER

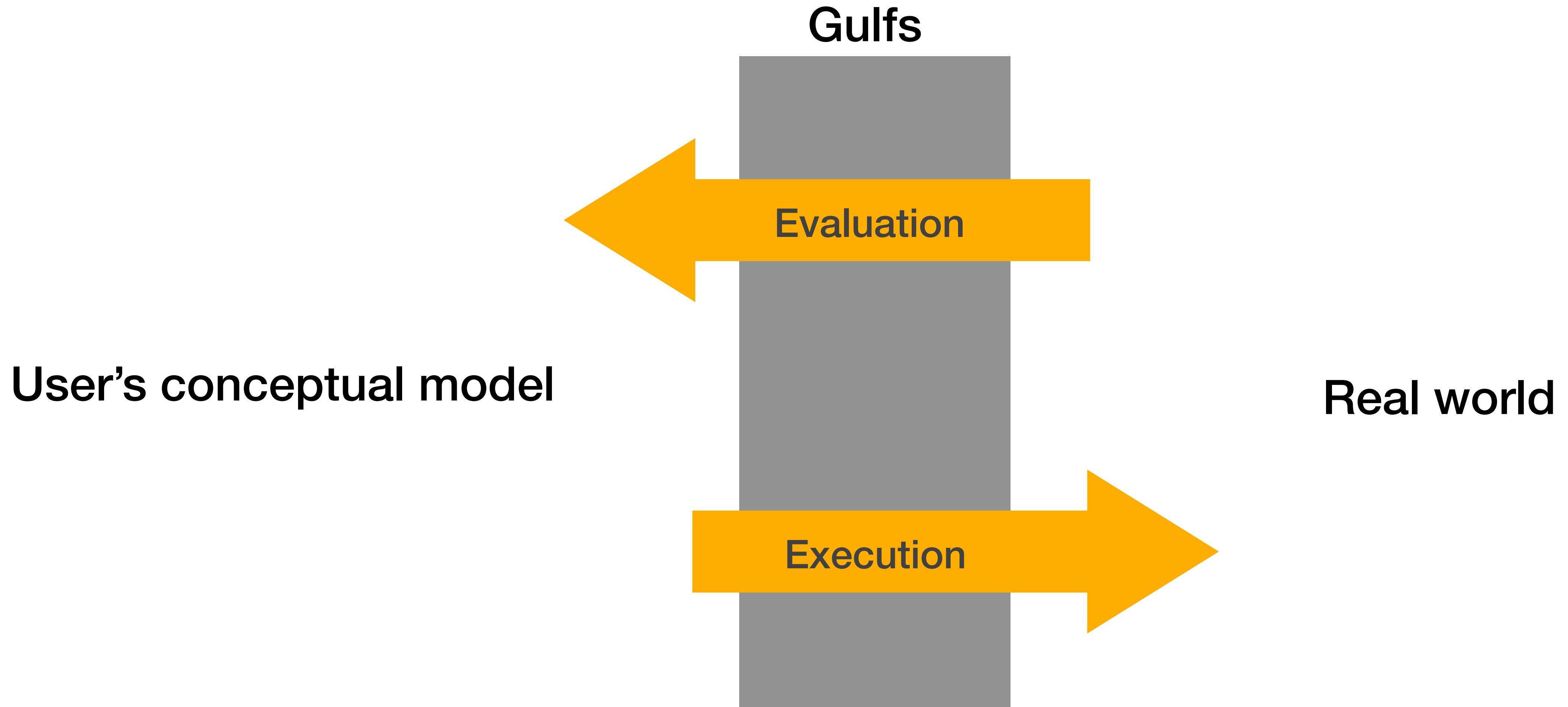






Interaction between people and machines requires mutual *intelligibility* or *shared understanding*.

Gulfs of Execution & Evaluation



[Hutchins, Hollan, and Norman, 1985]

Gulf of Evaluation

What's the state of the system?

Gulf of Execution

How do I change this system?

[Hutchins, Hollan, and Norman, 1985]

Gulf of Evaluation

The amount of effort that the person must exert to interpret the state of the system and to determine how well the expectations and intentions have been met.

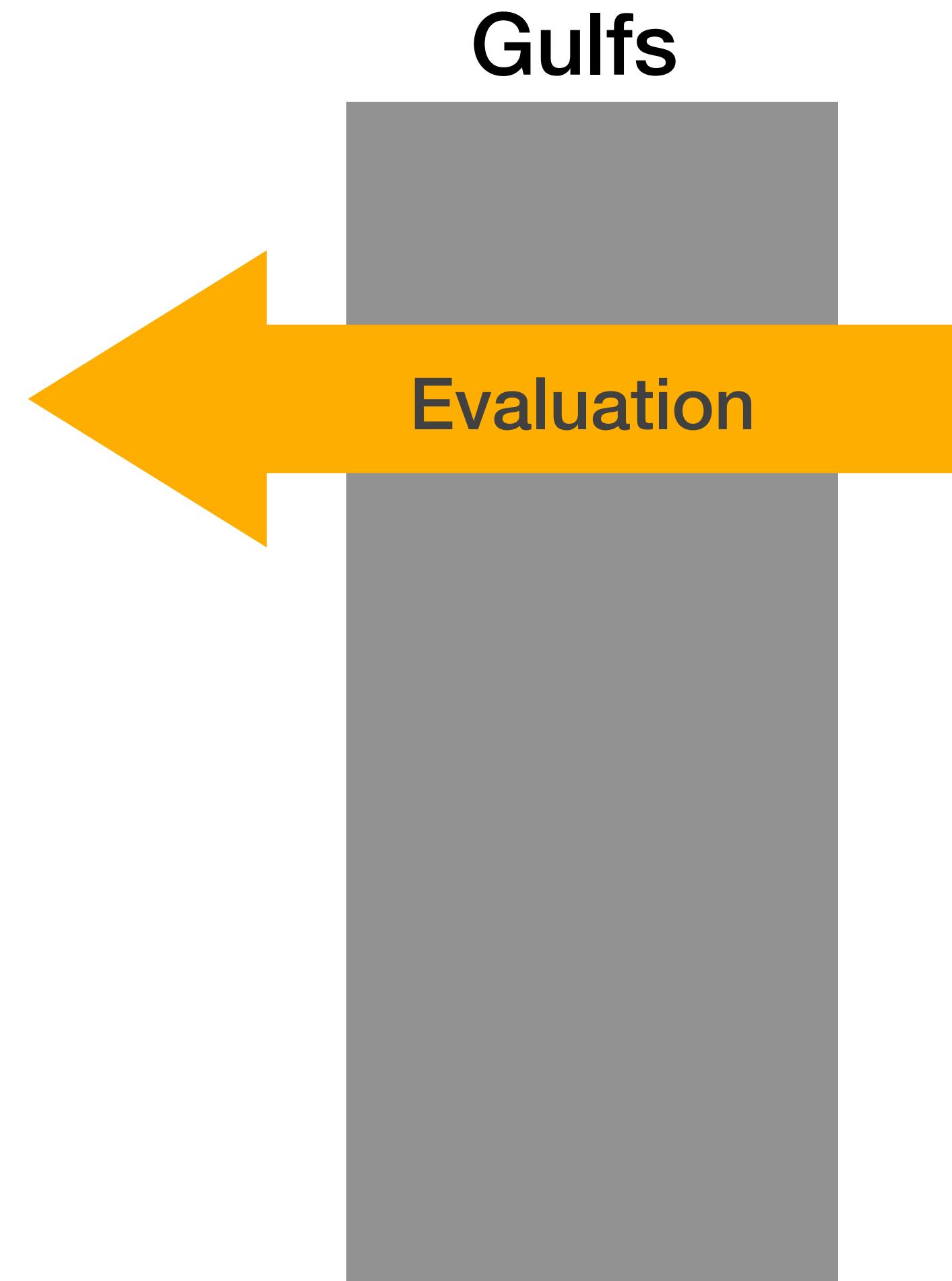
Gulf of Execution

The difference between the user's intentions and the allowable actions.

Gulfs of Execution & Evaluation

Conceptual model:

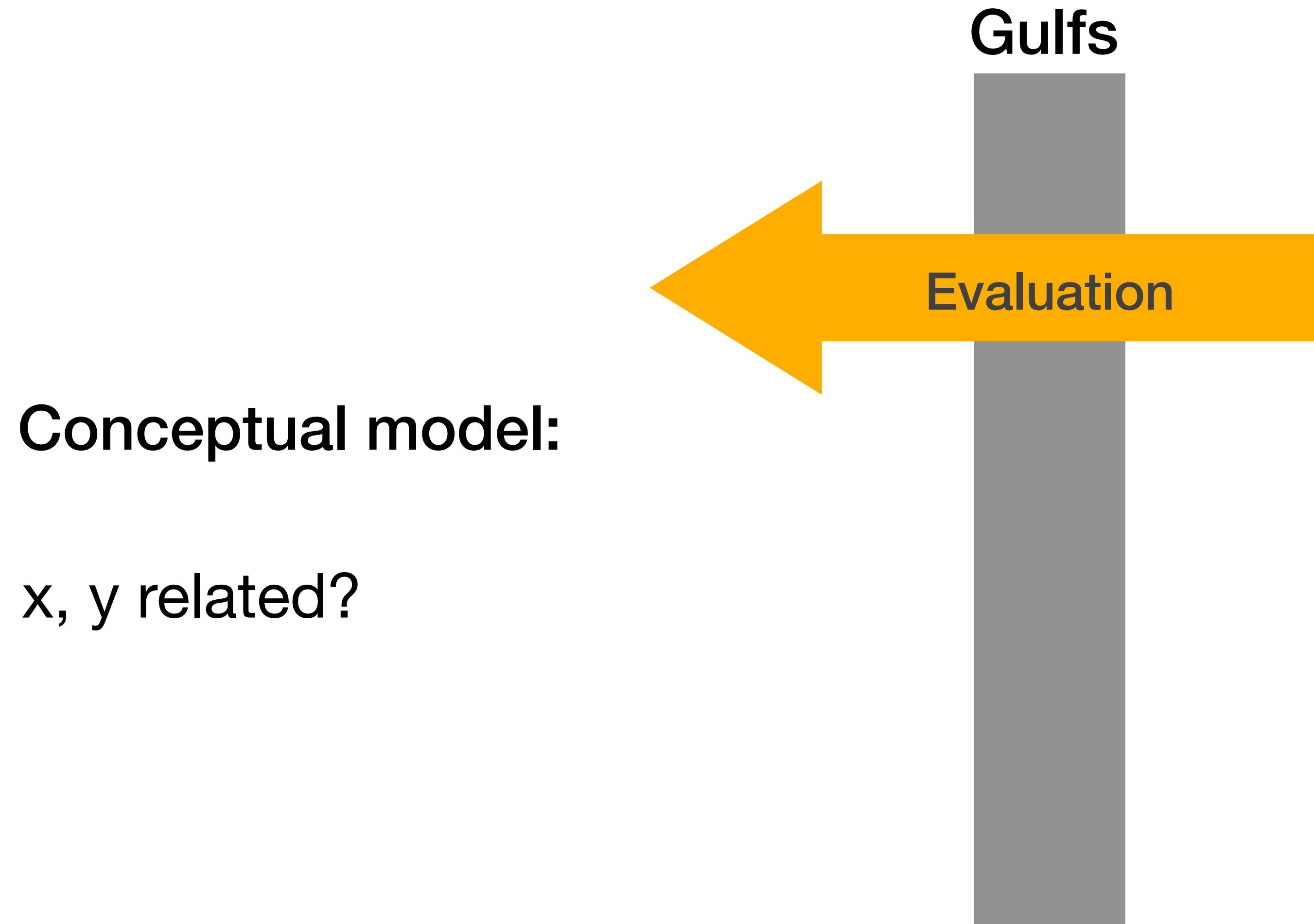
x, y related?



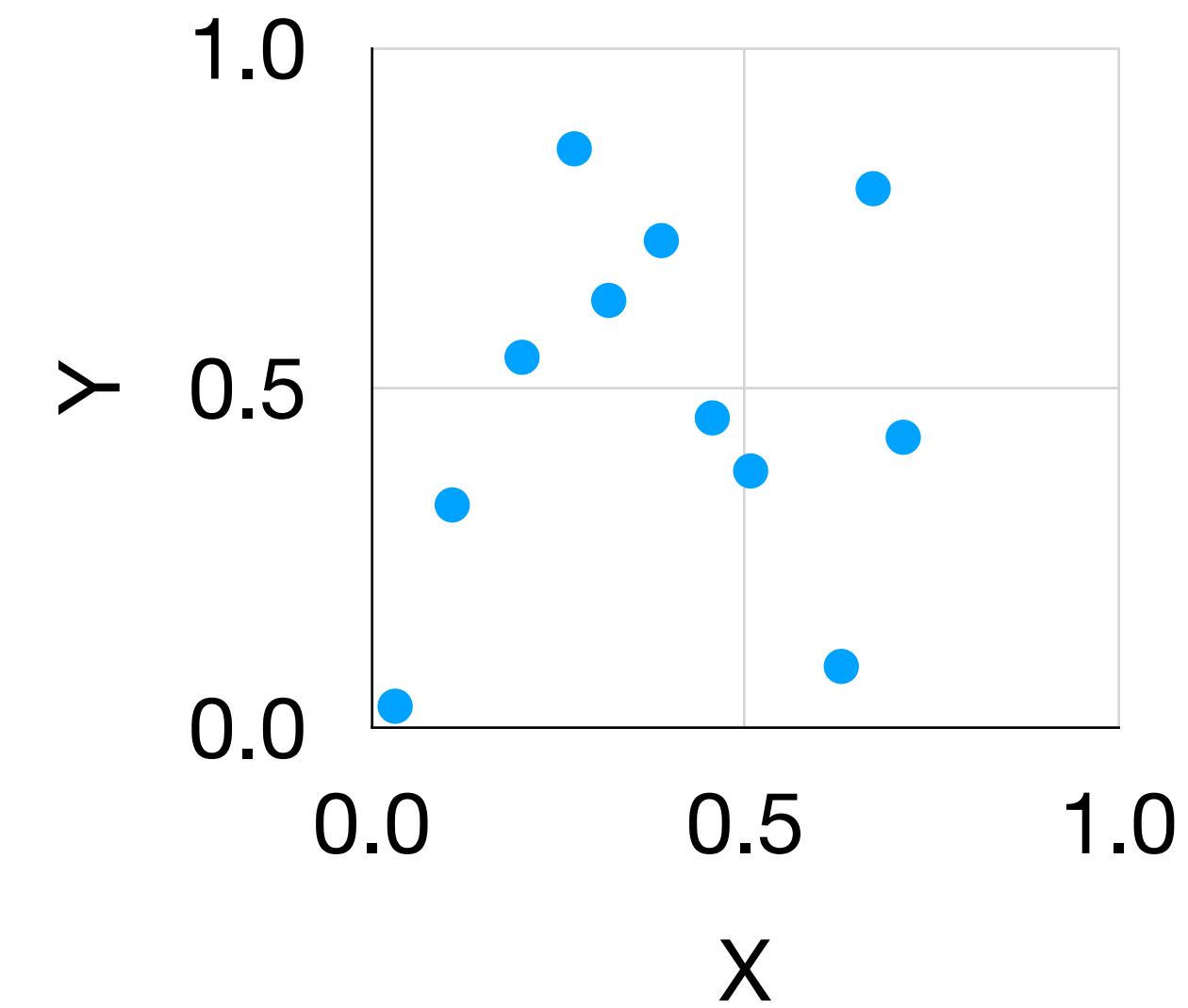
Real world state

X	Y
0.67	0.79
0.32	0.63
0.39	0.72
0.27	0.85
0.71	0.43
0.63	0.09
0.03	0.03
0.20	0.54
0.51	0.38
0.11	0.33
0.46	0.46

Gulfs of Execution & Evaluation



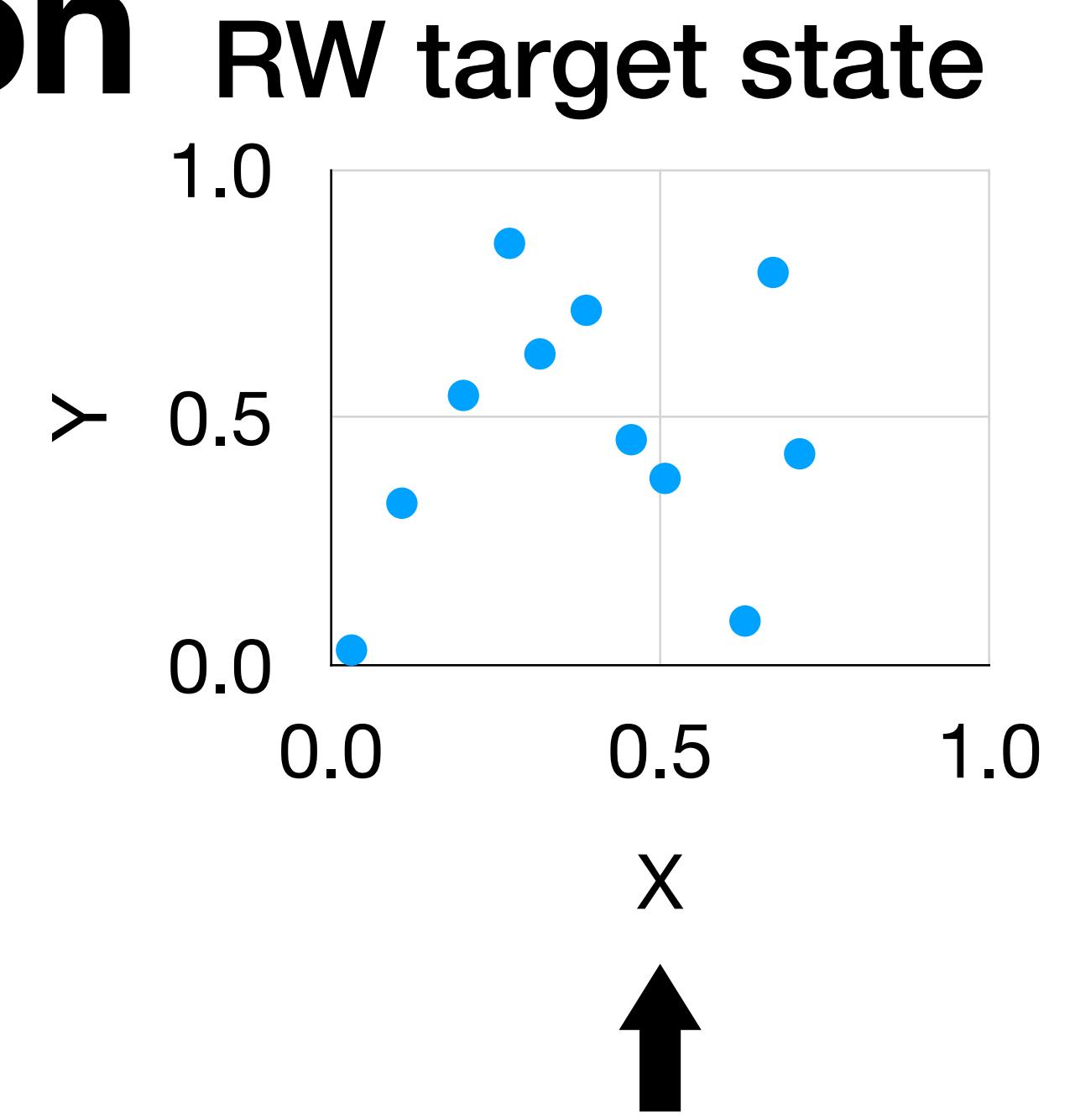
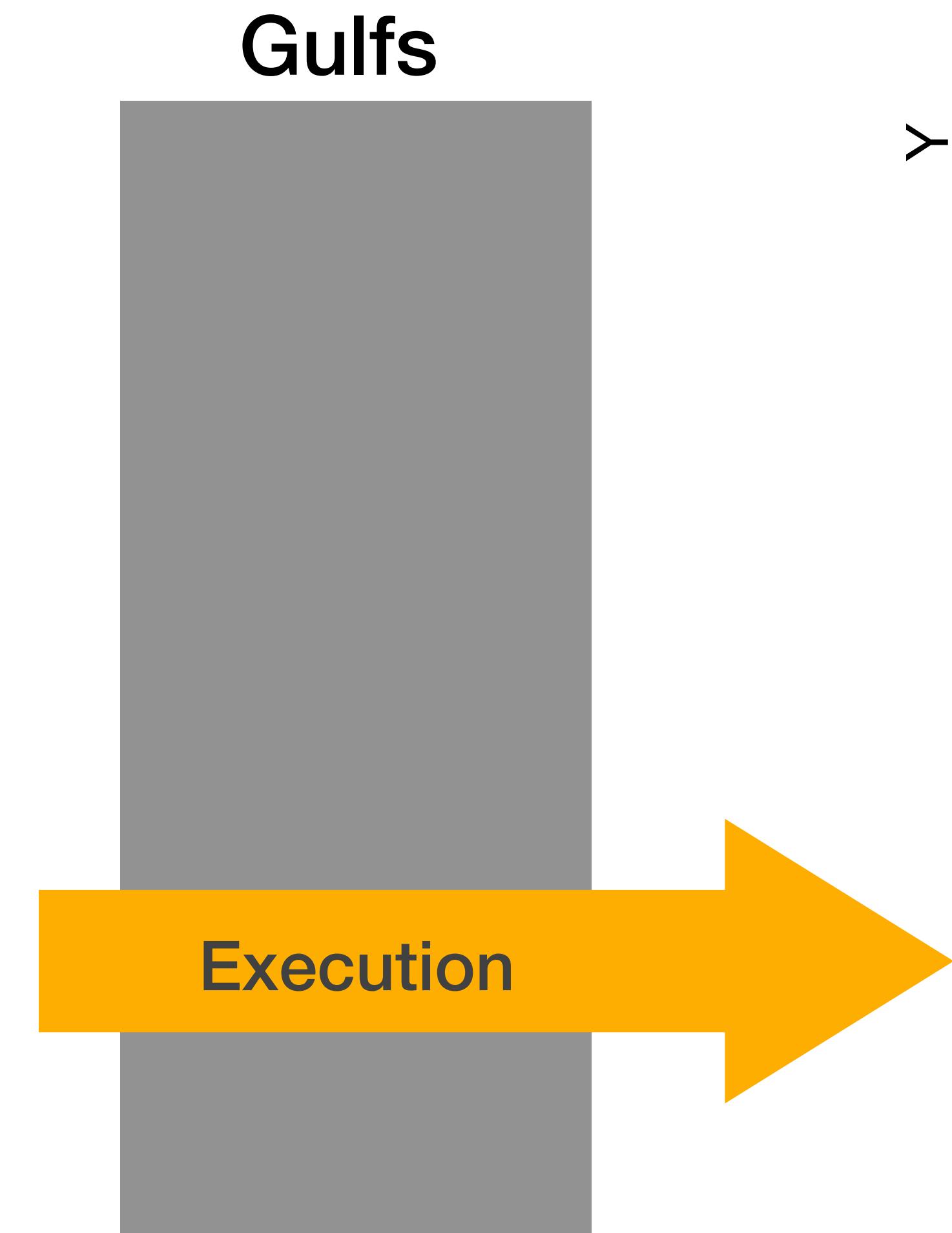
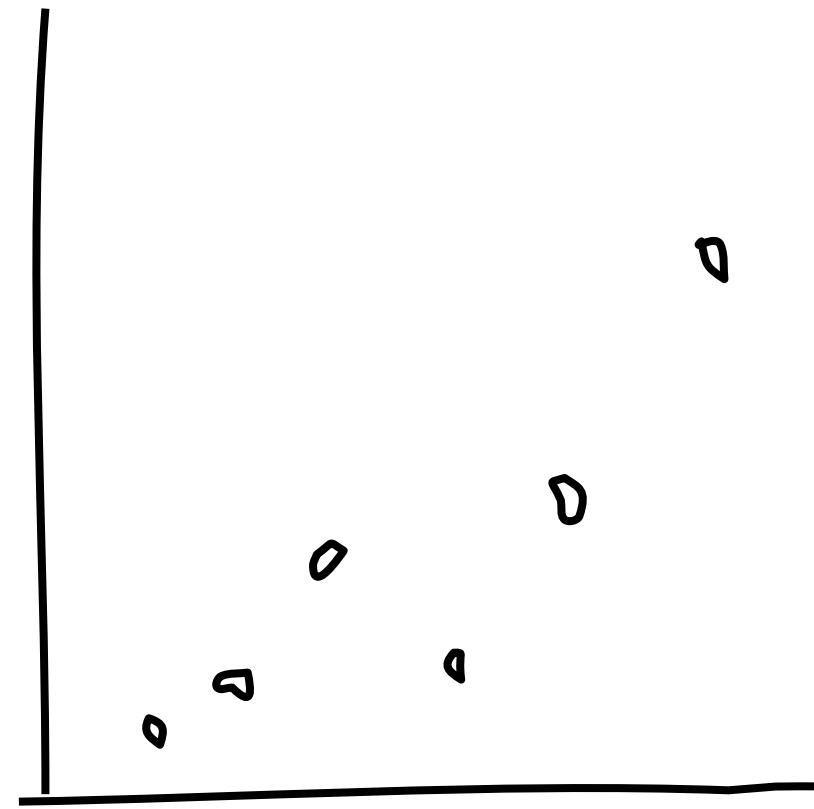
Real world state



more effective visual encoding

Gulfs of Execution & Evaluation

Conceptual model:



Move 90 30
Rotate 35
Pen down
...

[Hutchins, Hollan, and Norman, 1985]

Gulfs of Execution & Evaluation

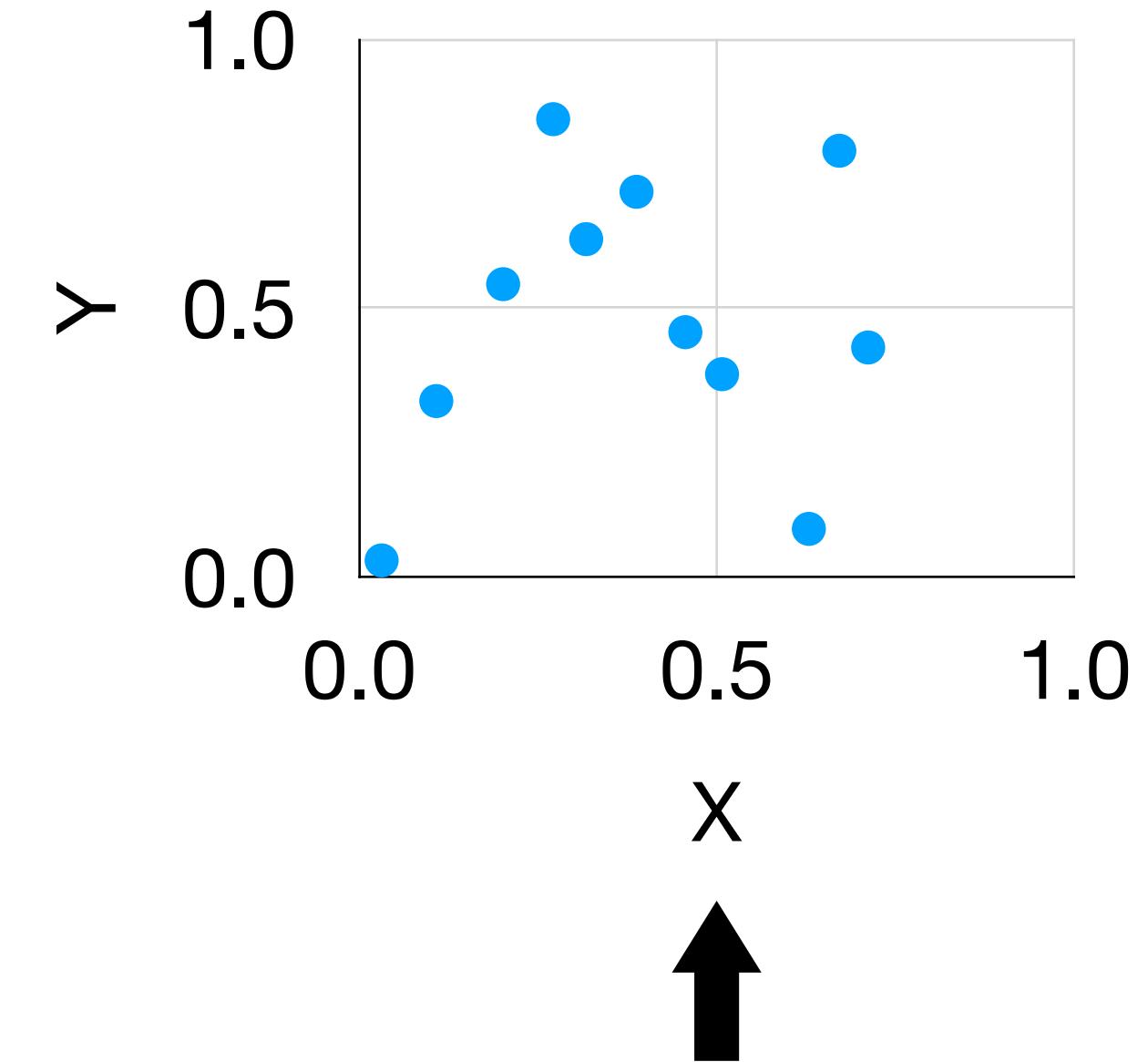
Conceptual model:



Gulfs



RW target state



X	Y
0.67	0.79
0.32	0.63
0.39	0.72
0.27	0.85
0.71	0.43
0.63	0.09
...	...

[Hutchins, Hollan, and Norman, 1985]

more effective interaction design

⚙️ Bluetooth & other devices



Add Bluetooth or other device

Bluetooth



Off

Mouse, keyboard, & pen



Dell KB216 Wired Keyboard

⚙️ Bluetooth & other devices



Add Bluetooth or other device

Bluetooth



On

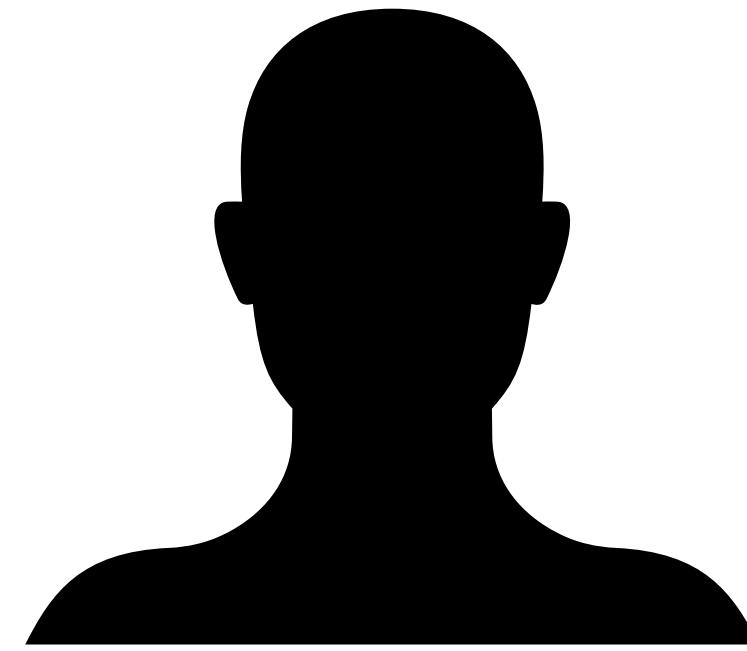
Now discoverable as "DESKTOP-ISFRCAL"

Mouse, keyboard, & pen



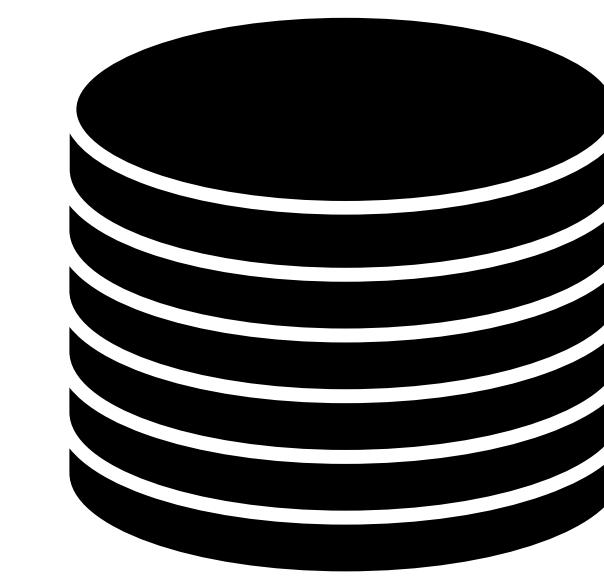
Dell KB216 Wired Keyboard

<https://www.nngroup.com/articles/two-ux-gulfs-evaluation-execution/>



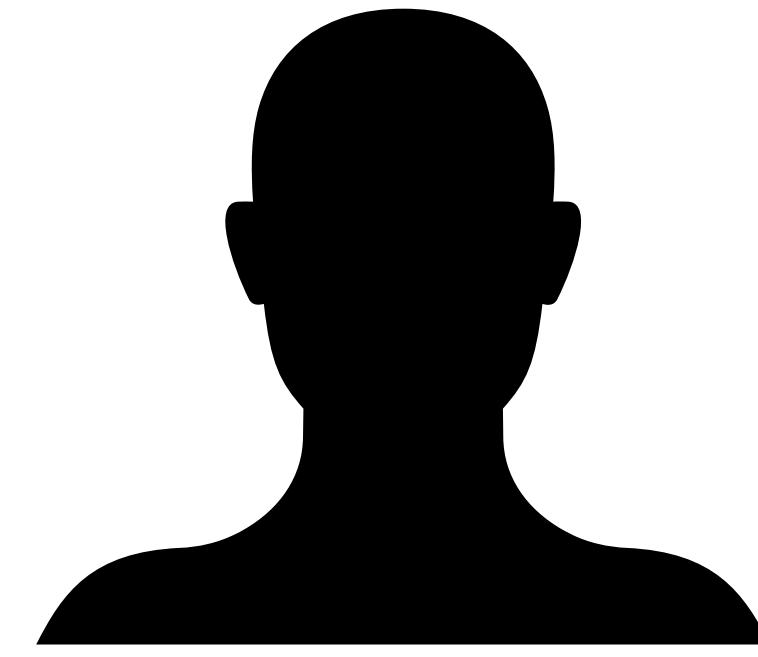
User Goals

- ✗ Results returned as a table.
- ✗ No hint on how to reformulate query.
- ✗ Slow question-answer loop.



Database

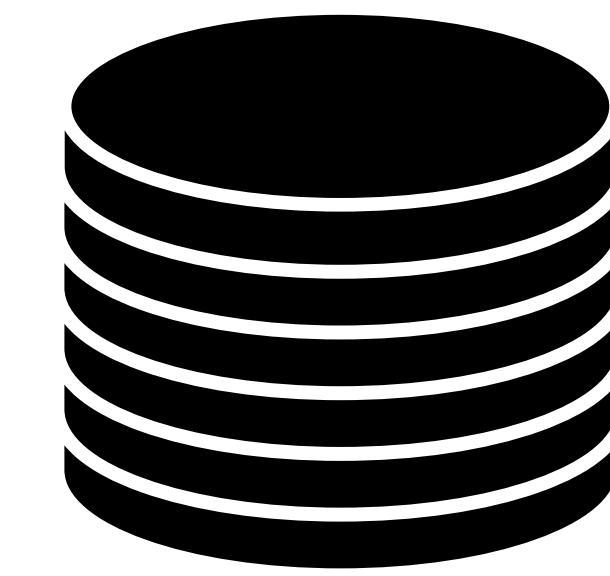
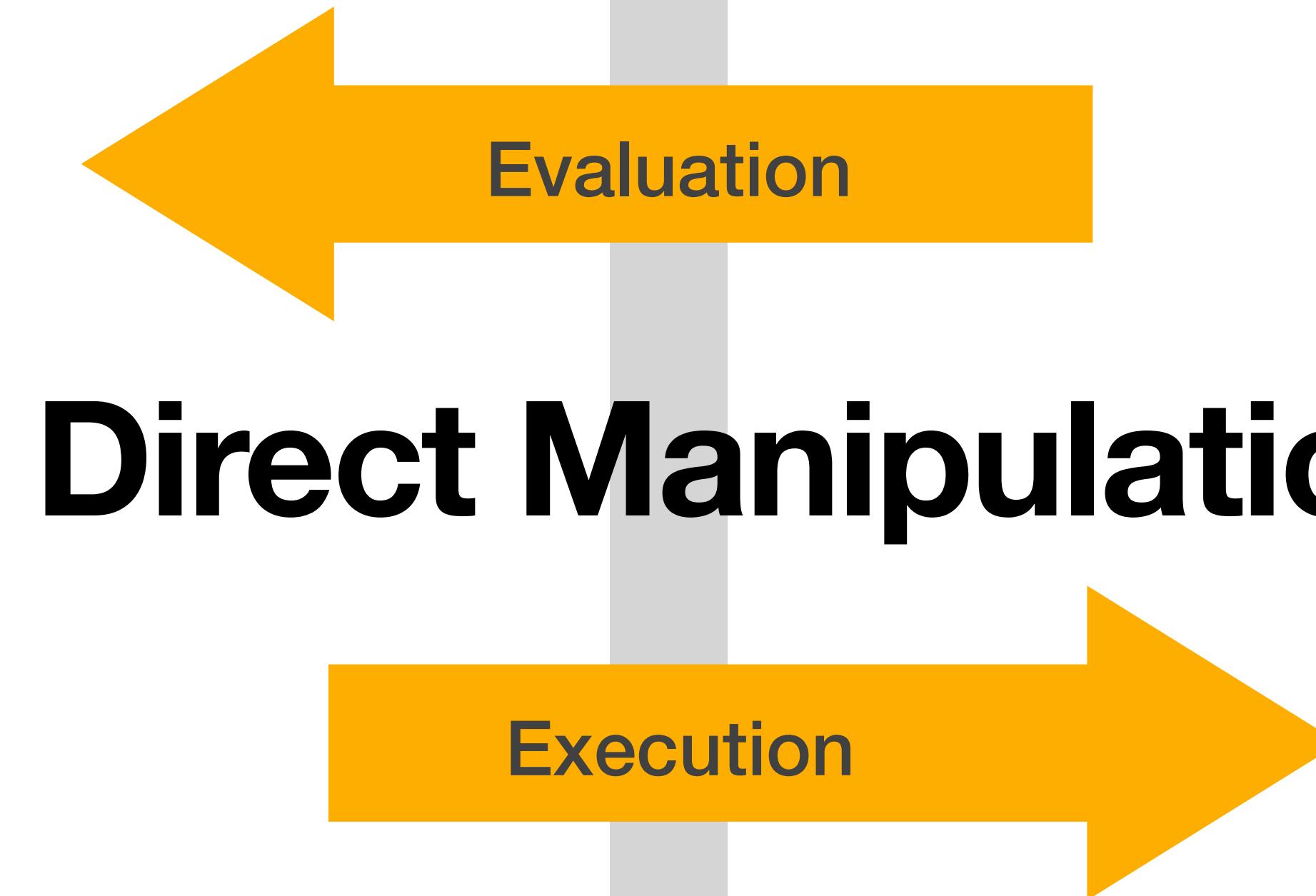
- ✗ A rigid syntax designed by/for programmers.
- ✗ Difficult to do "fuzzy" matching.



User Goals

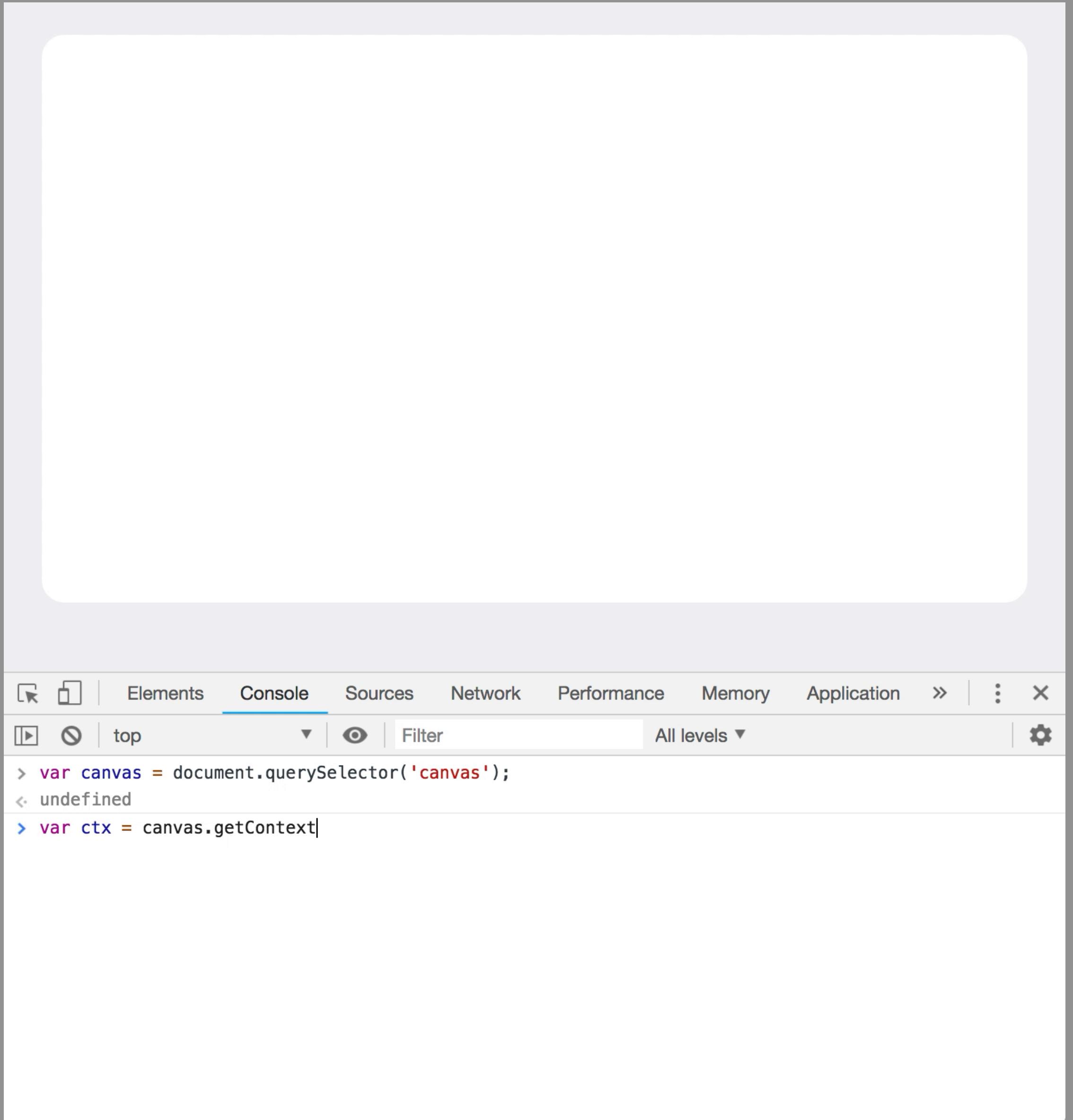
Direct Manipulation

- ✓ Visual representation of objects + actions.
- ✓ Immediate + continuous display of results.



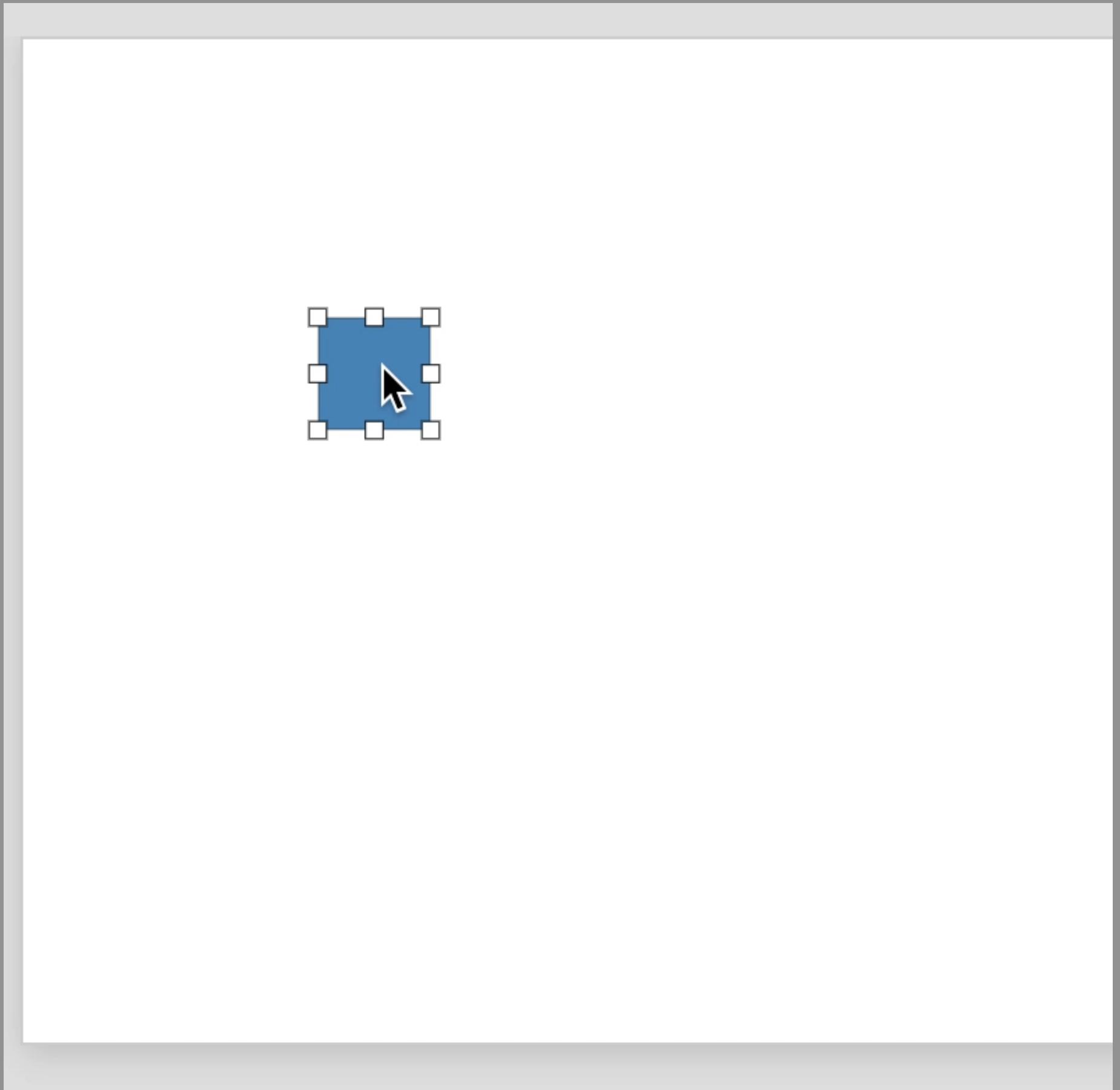
Database

- ✓ Physical actions or labeled buttons instead of complex syntax.
- ✓ Rapid, incremental, and reversible actions.



The screenshot shows the Chrome DevTools interface with the 'Console' tab selected. The console window displays the following JavaScript code:

```
> var canvas = document.querySelector('canvas');
< undefined
> var ctx = canvas.getContext|
```



Interaction with Visualization

Select – identify something as interesting.

Connect – show me related items.

Abstract/Elaborate – show me more or less detail.

Filter – show me something conditionally.

Reconfigure – show me a different arrangement.

Explore – show me something else.

Encode – show me a different visual representation.

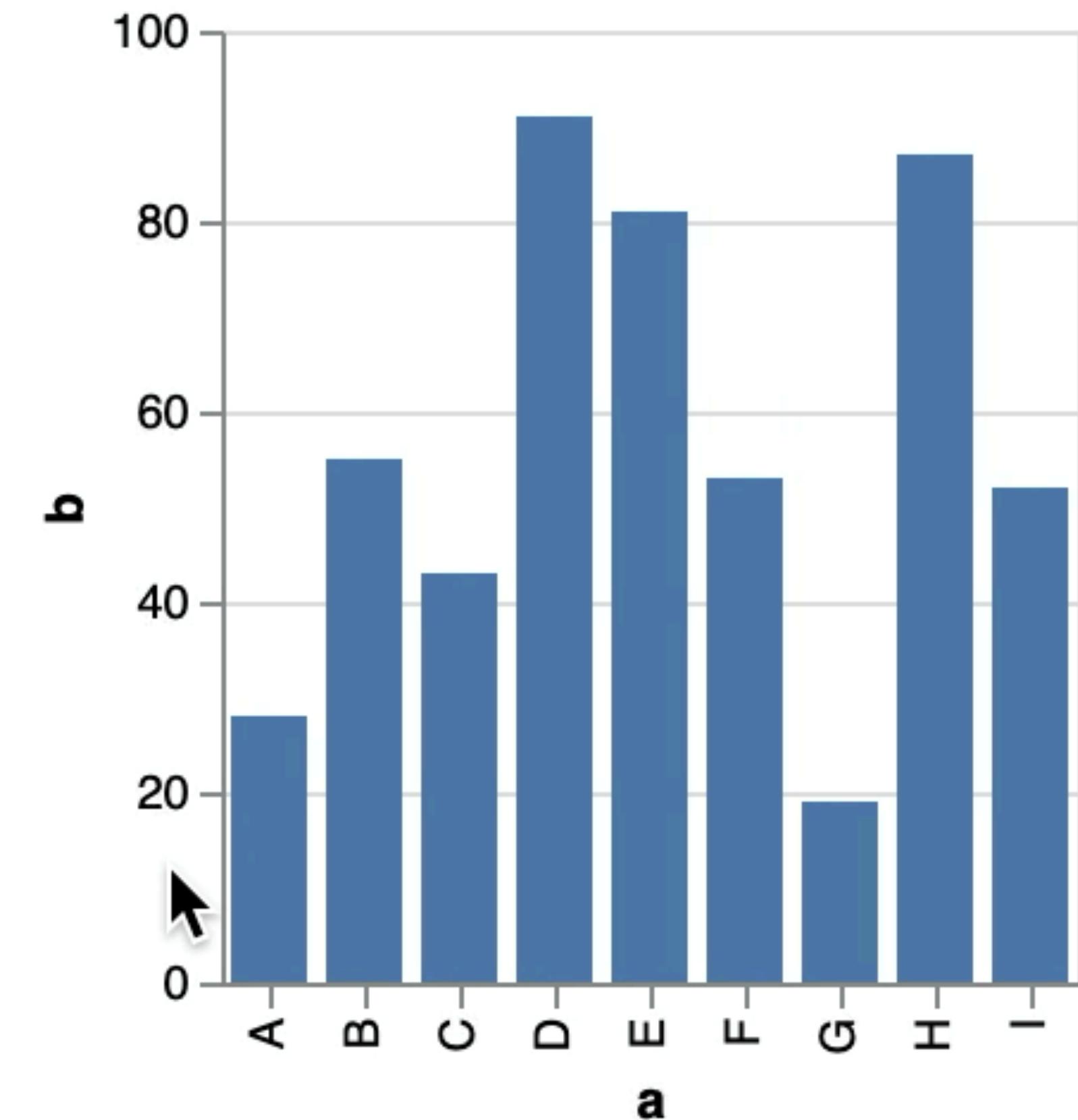
Point Selection

Identify something as interesting

Select discrete data values.

How many points are selected? 1, 2, 3, ...

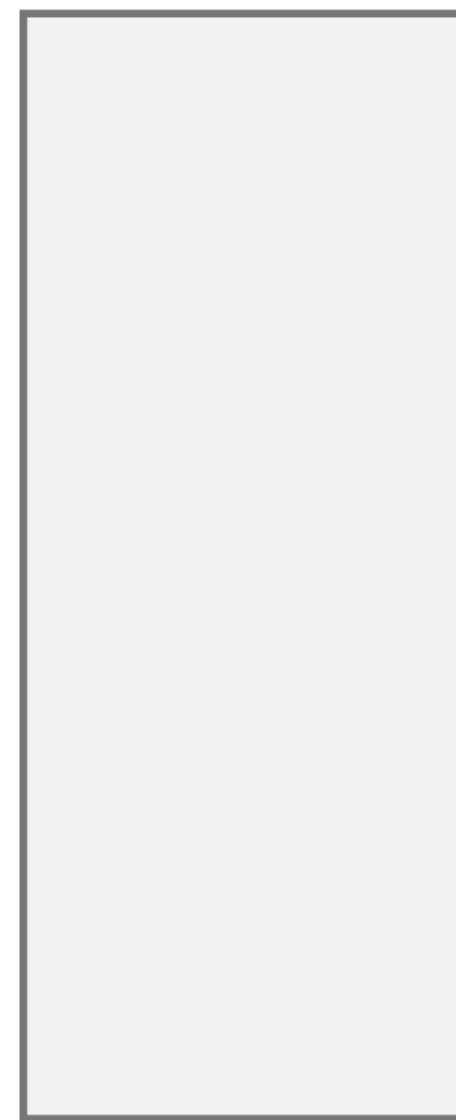
How are points selected? Mouse hover, click, tap, ...



https://vega.github.io/vega-lite/examples/interactive_bar_select_highlight.html

Accessible strategies showing the state of interaction

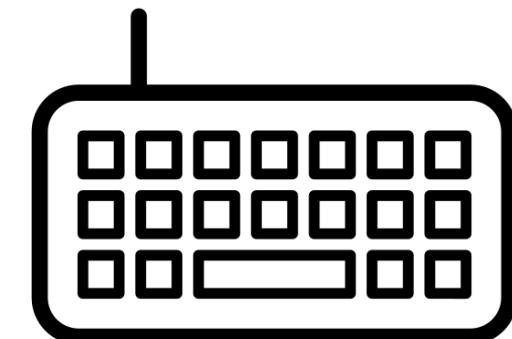
Default



Hovered



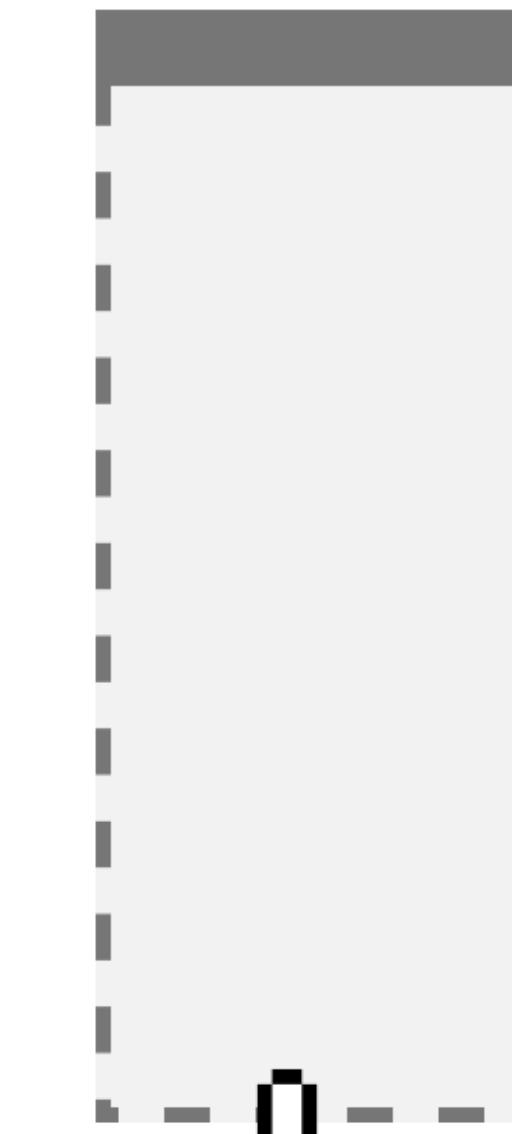
Focused



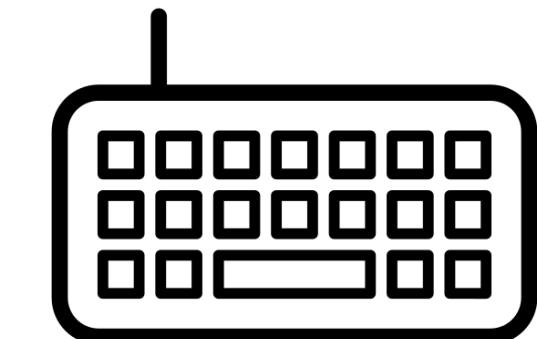
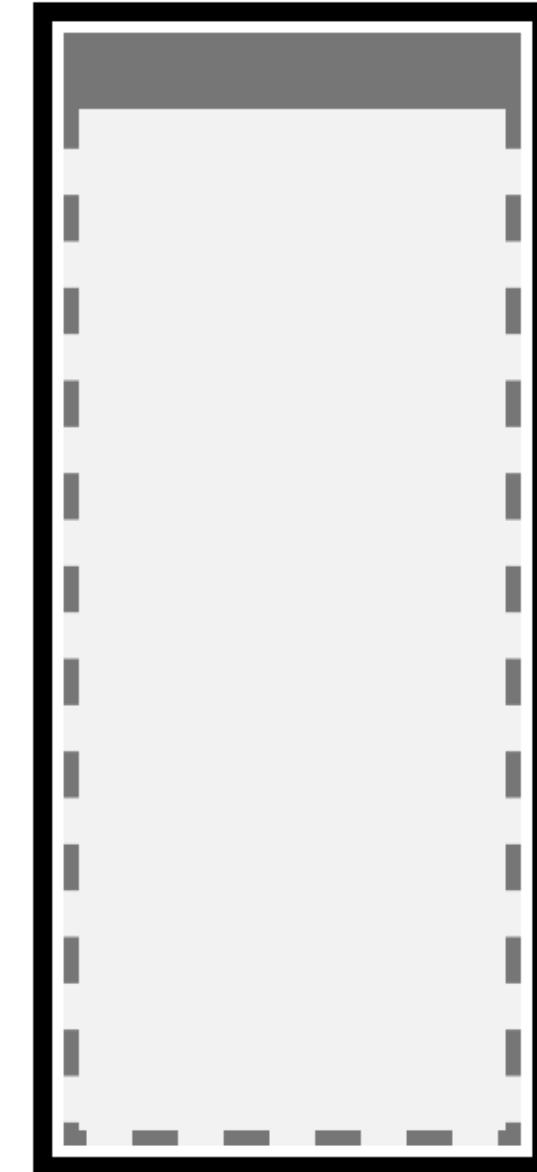
Selected



Hovered + Selected



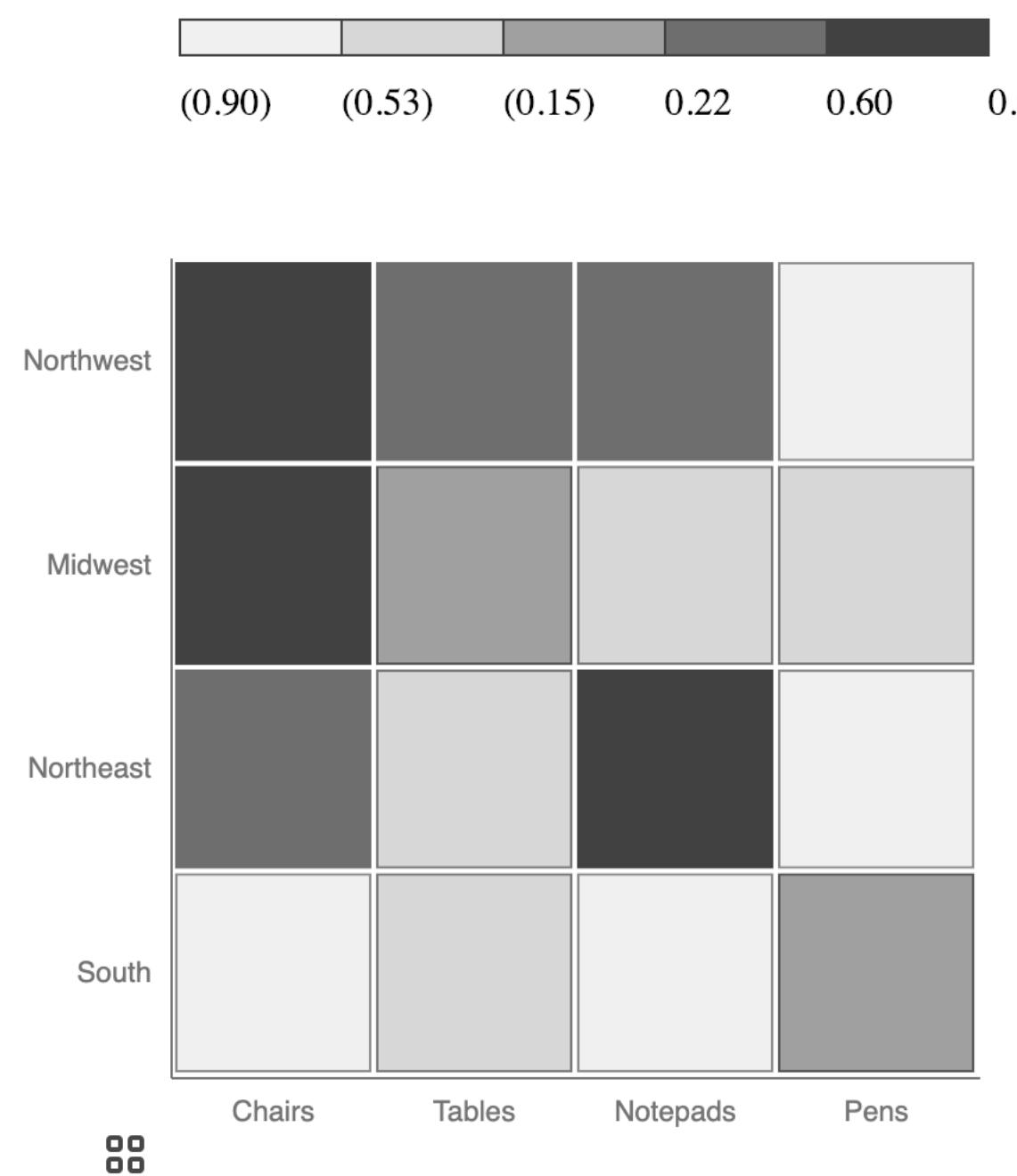
Focused + Selected



Show system state (visually and non-visually)

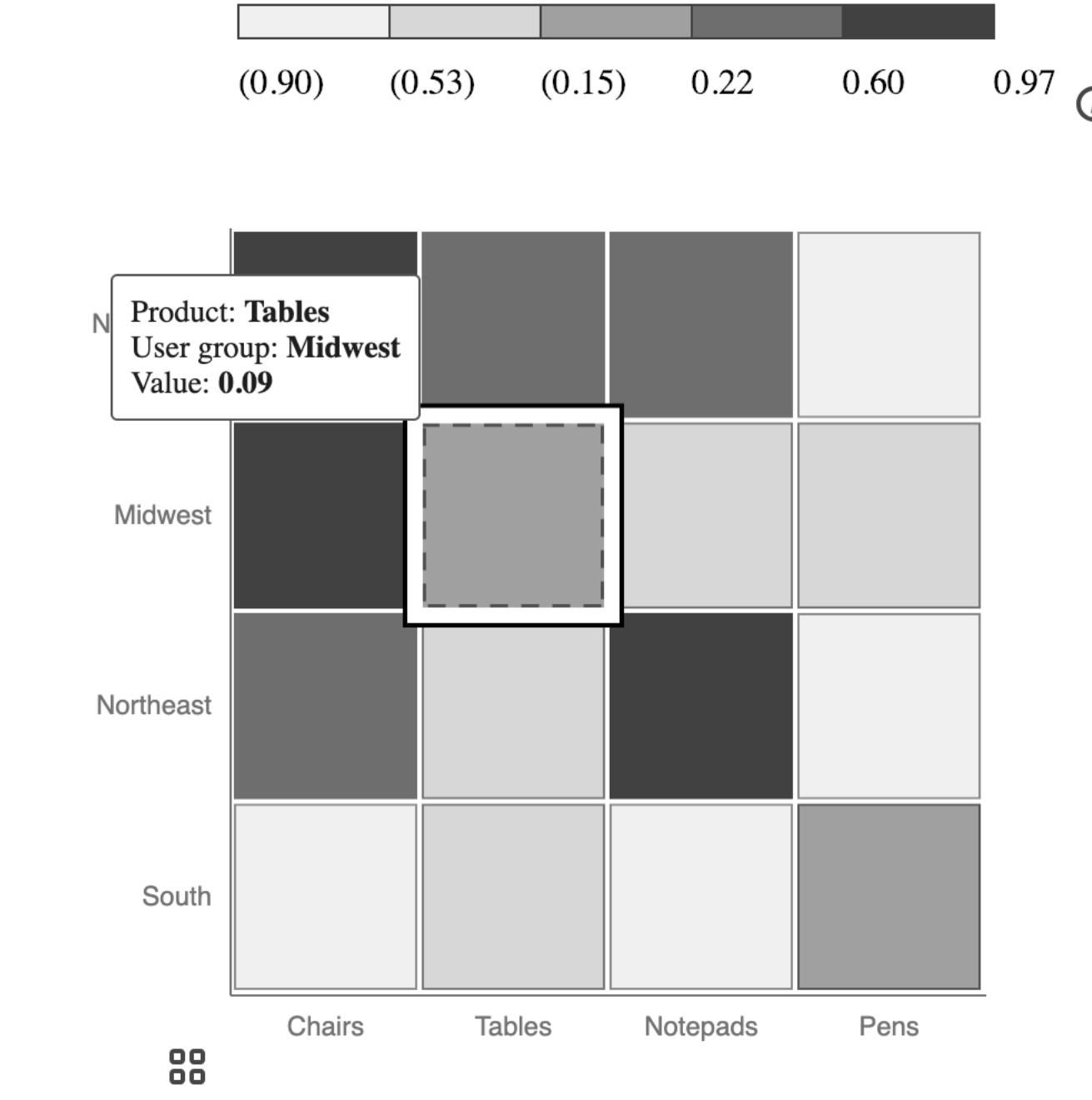
Comparing how user groups correlate to approval rates of product types

A high correlation value (close to 1) indicates that these users have a high approval rate of that product. A low correlation value (close to -1) indicates a negative approval rate of those products.



Comparing how user groups correlate to approval rates of product types

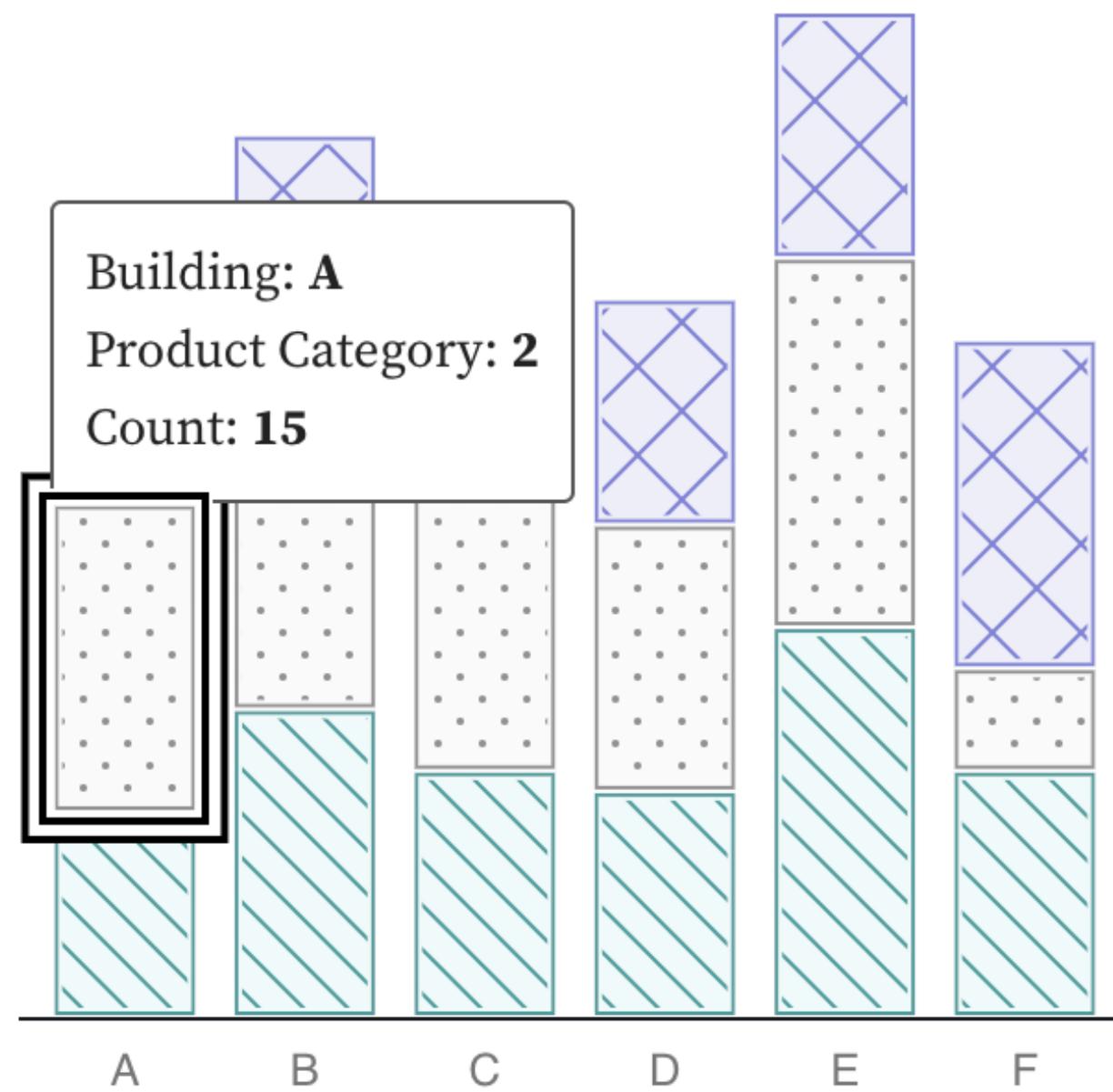
A high correlation value (close to 1) indicates that these users have a high approval rate of that product. A low correlation value (close to -1) indicates a negative approval rate of those products.



See “Fourth Chart” in [my accessible demos of Visa Chart Components](#)

Alt text should communicate operability

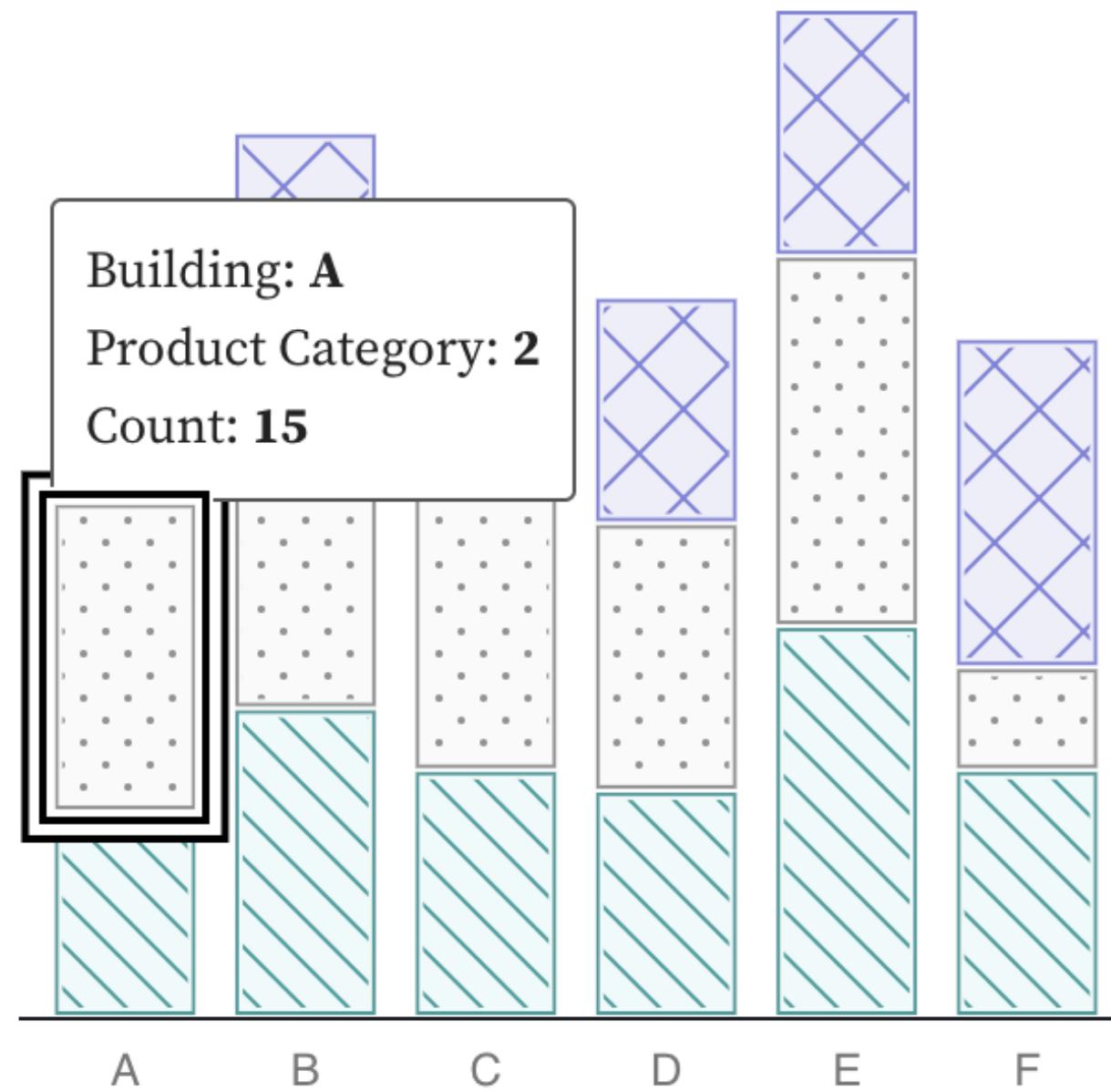
1 2 3



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

Semantics matter

1 2 3

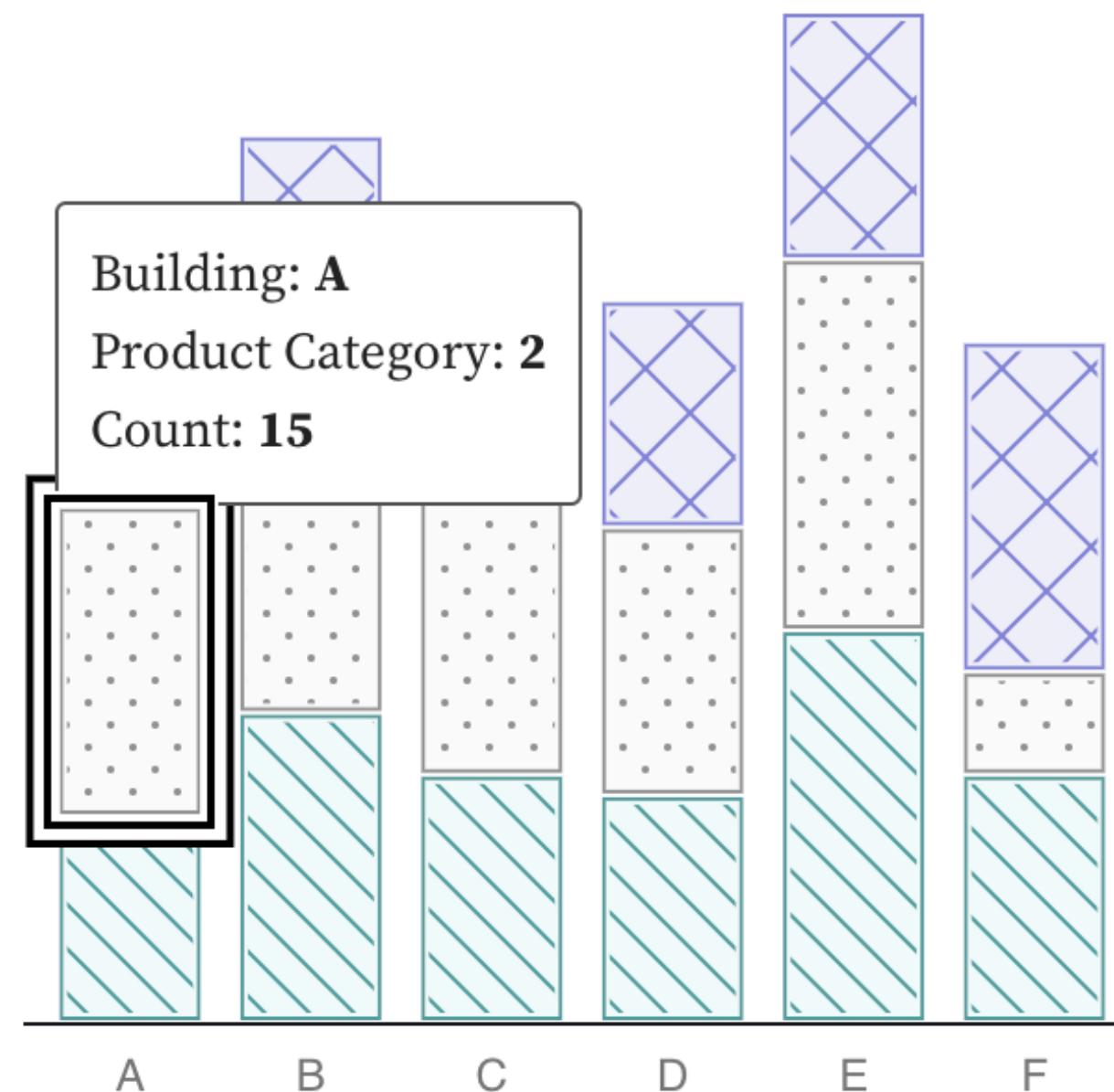


“Image” doesn’t signal interactivity!

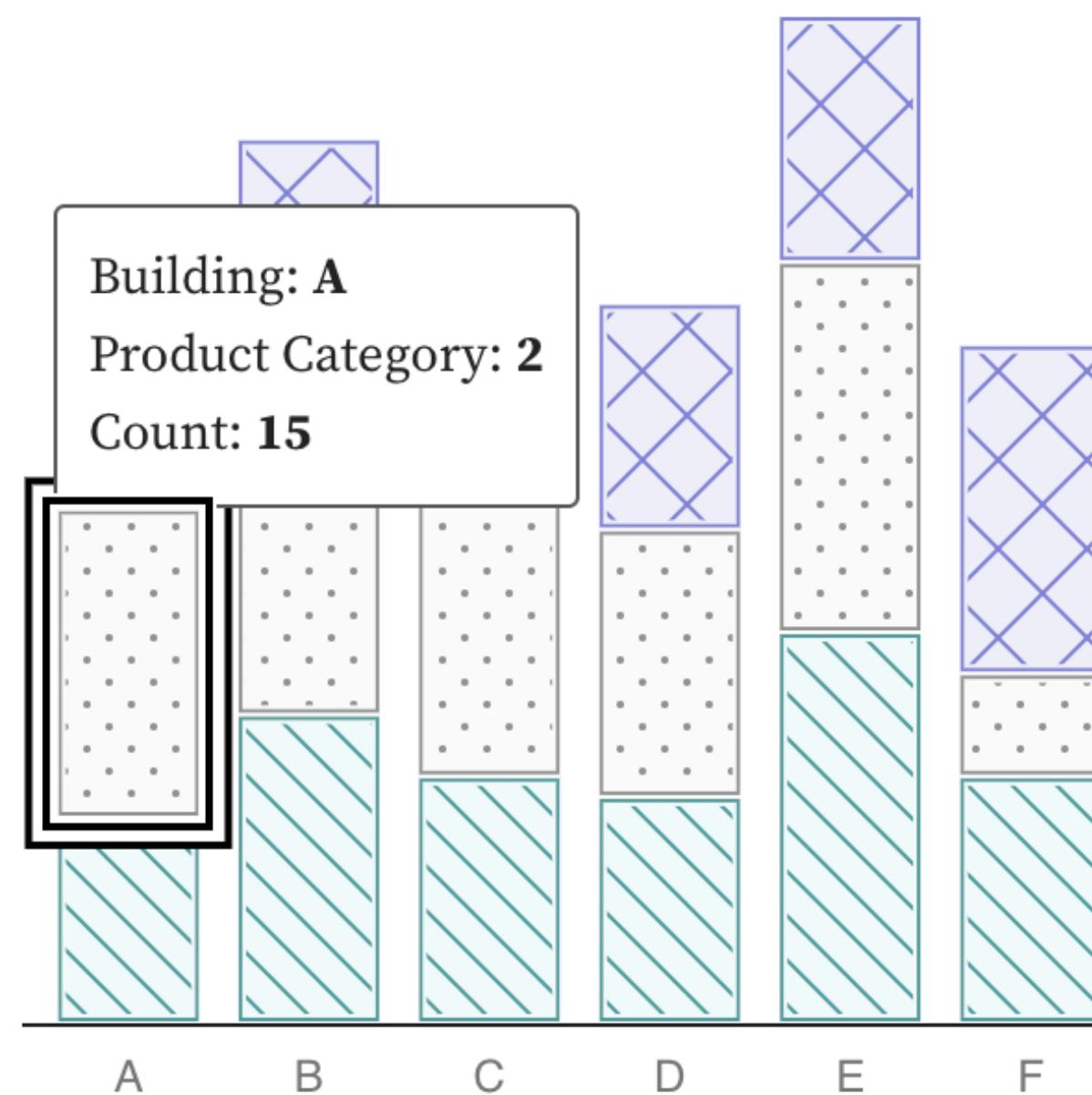
✗ Building A. Product Category 2.
Count 15. Bar 2 of 3. Image.

“Aria” states and roles are standardized

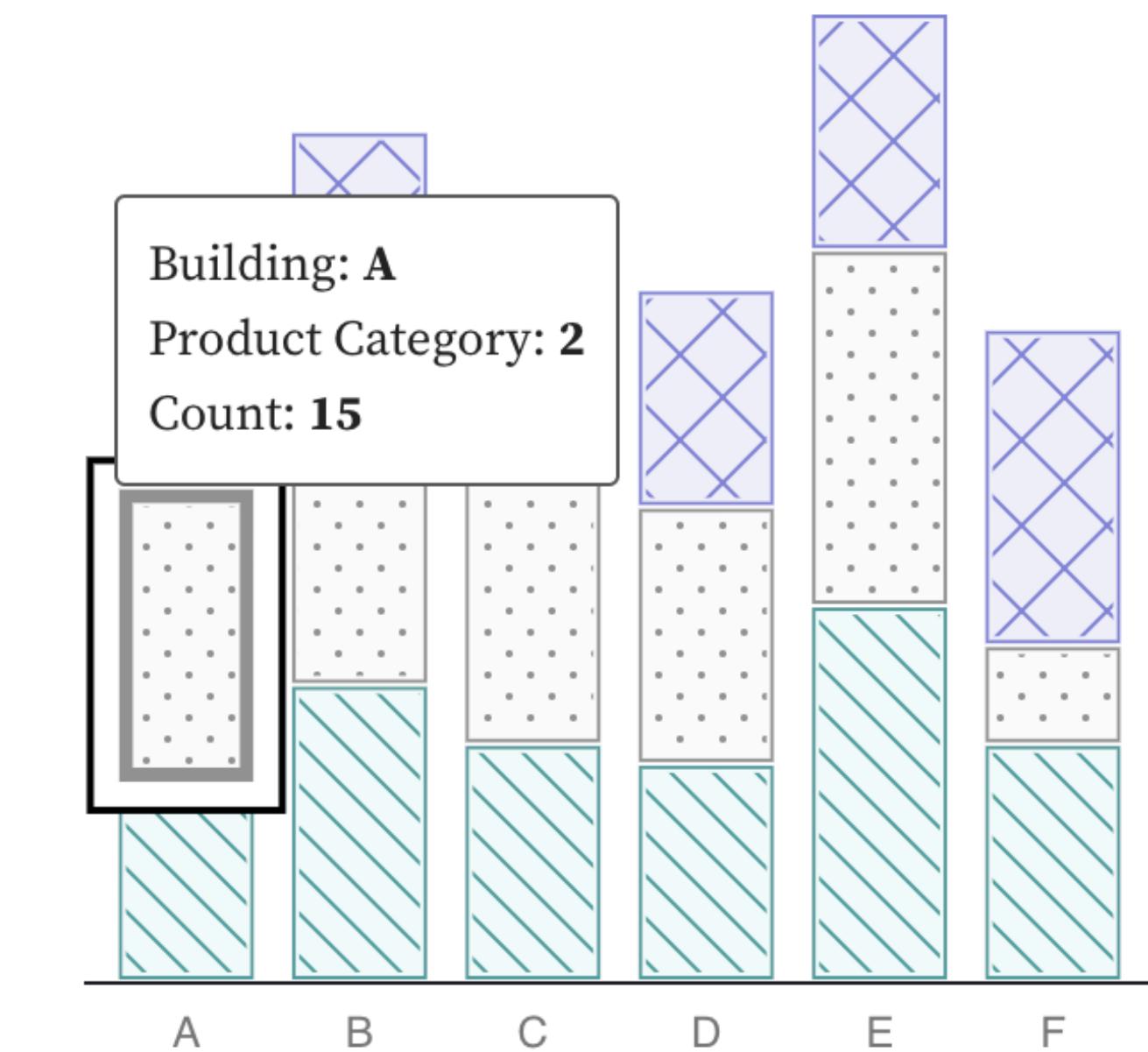
1 2 3



1 2 3



1 2 3

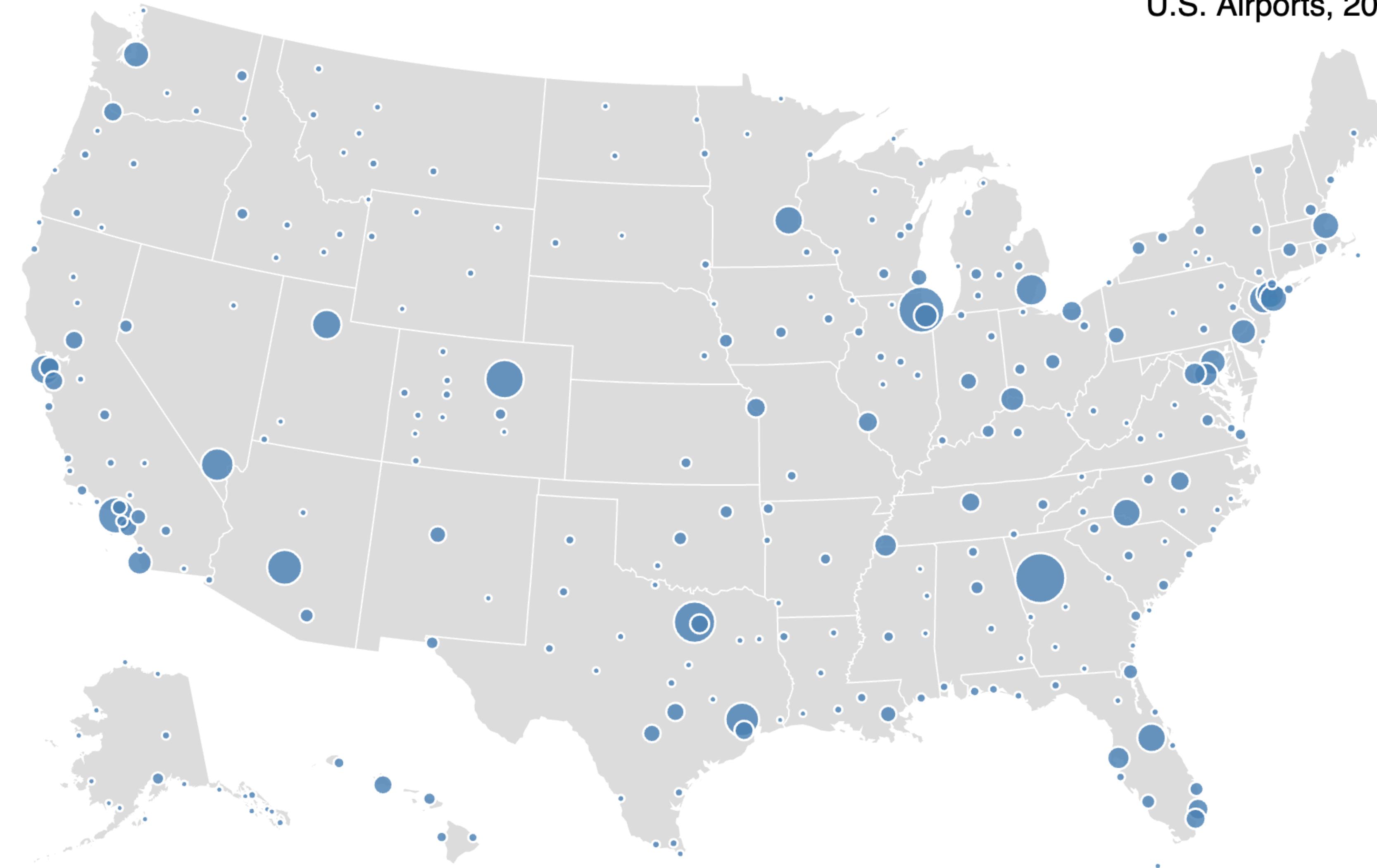


× Building A. Product Category 2.
Count 15. Bar 2 of 3. Image.

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

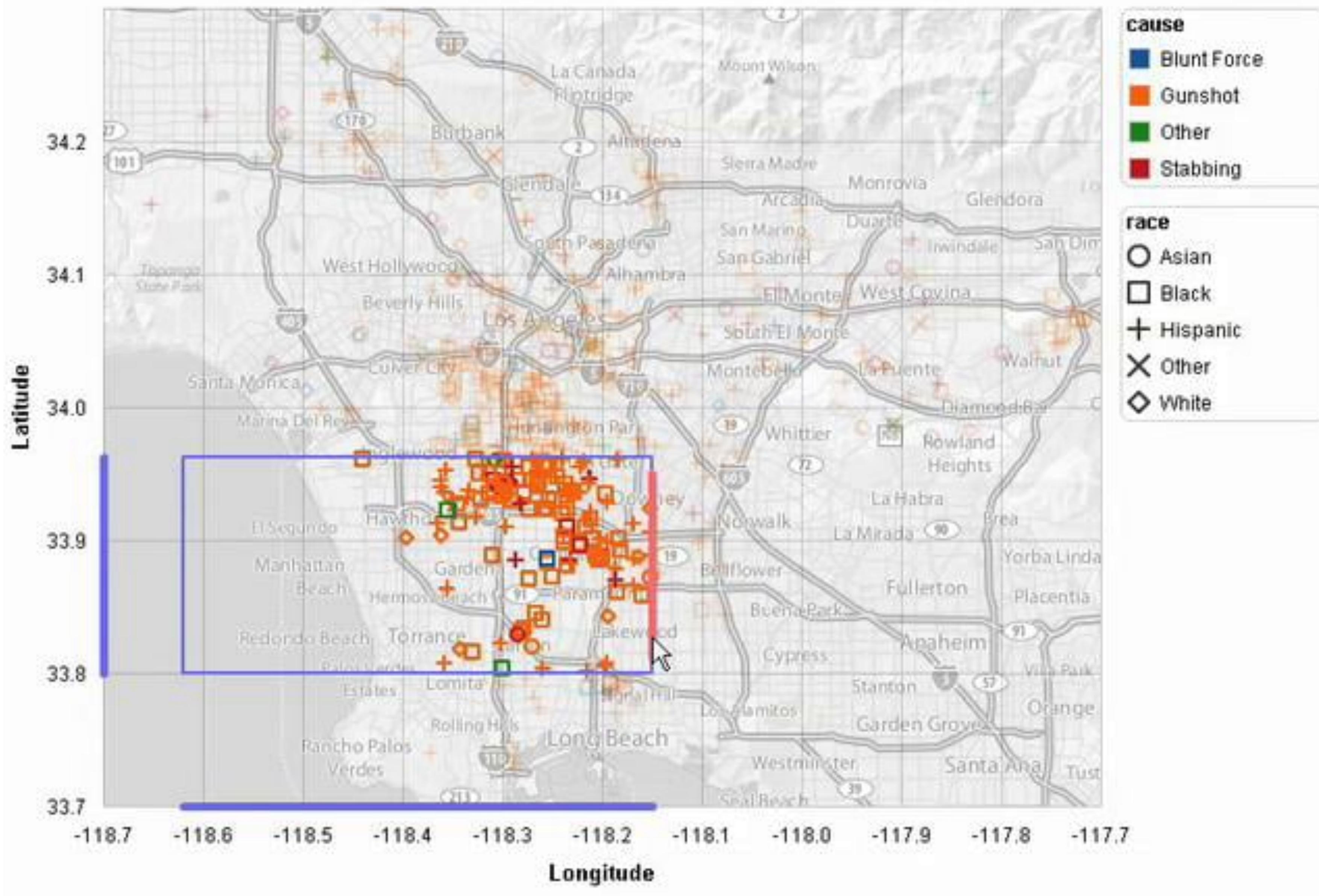
× selected, Building A. Product
Category 2. Count 15. Bar 2 of
3., toggle button

U.S. Airports, 2008



<https://vega.github.io/vega/examples/airport-connections/>

Homicide Victims in Los Angeles County, 2007 (Source: LA Times)



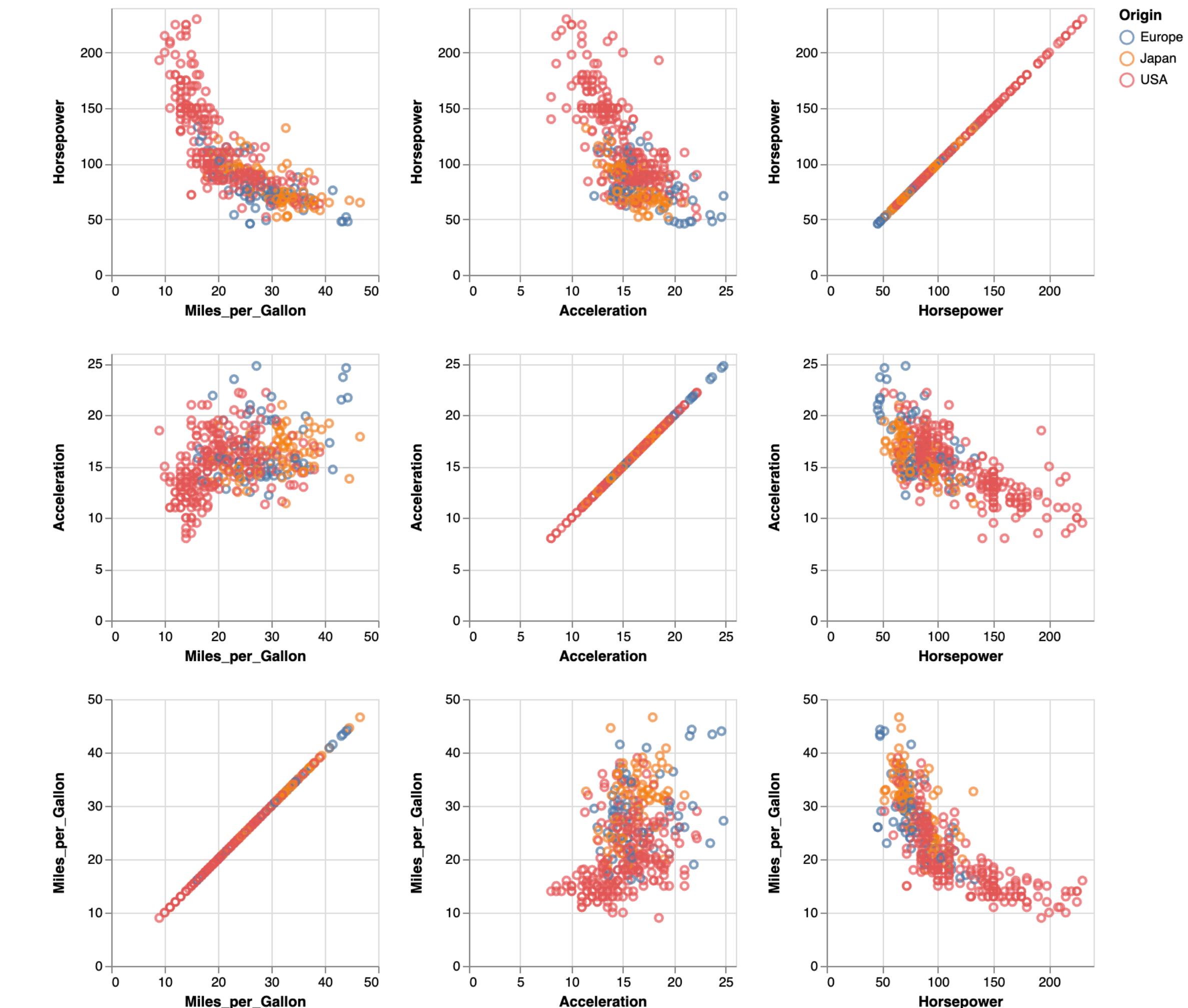
Heer et al., Generalized Selection via Interactive Query Relaxation

Connect

show me related items

Brushing & linking:
selection is called a "brush", and
the selected data is shown
("linked") in other views.

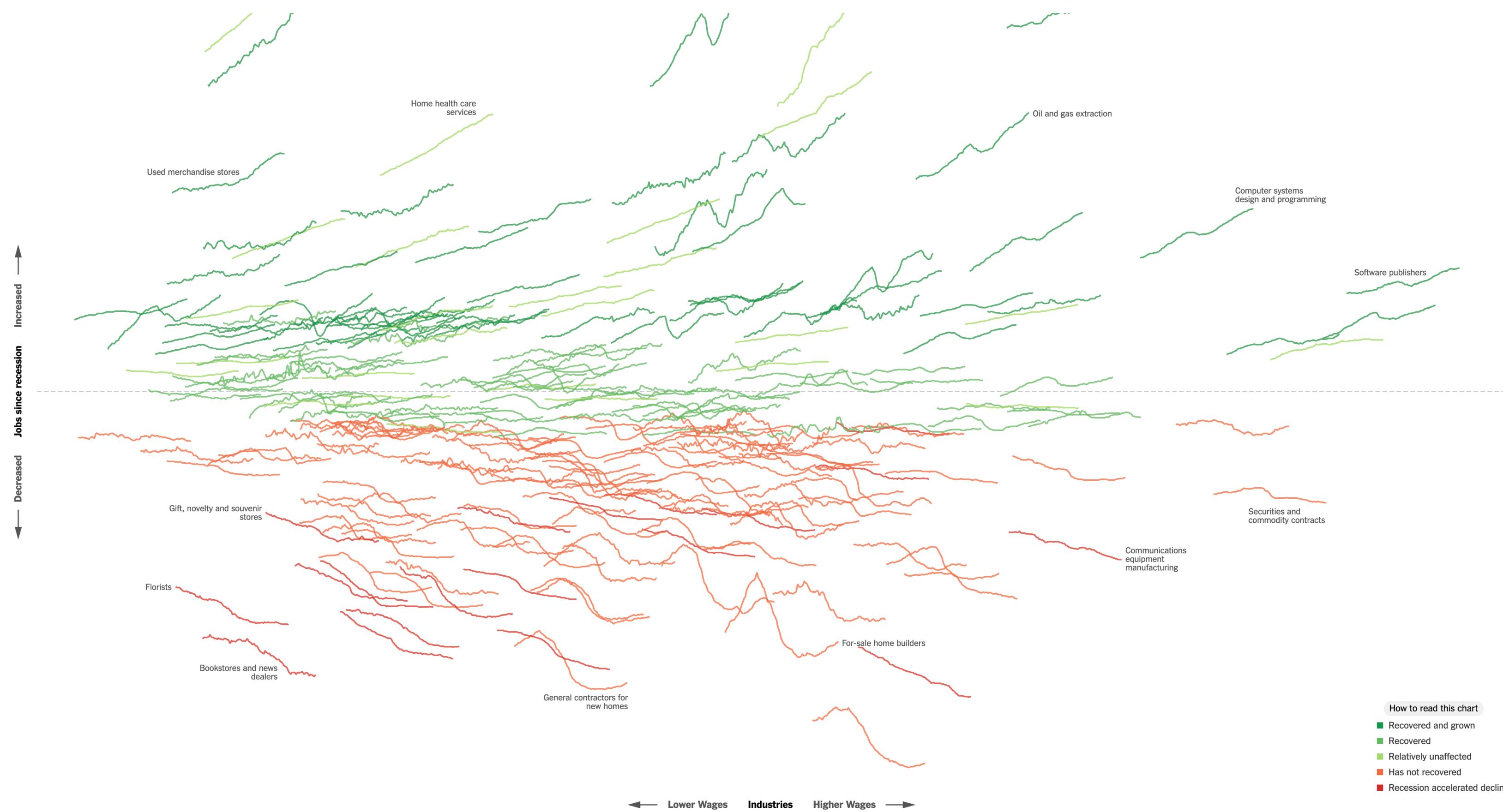
Link by *tuple* (i.e., explicitly identify
and match the same data values
across every view).



https://vega.github.io/vega-lite/examples/interactive_splov.html

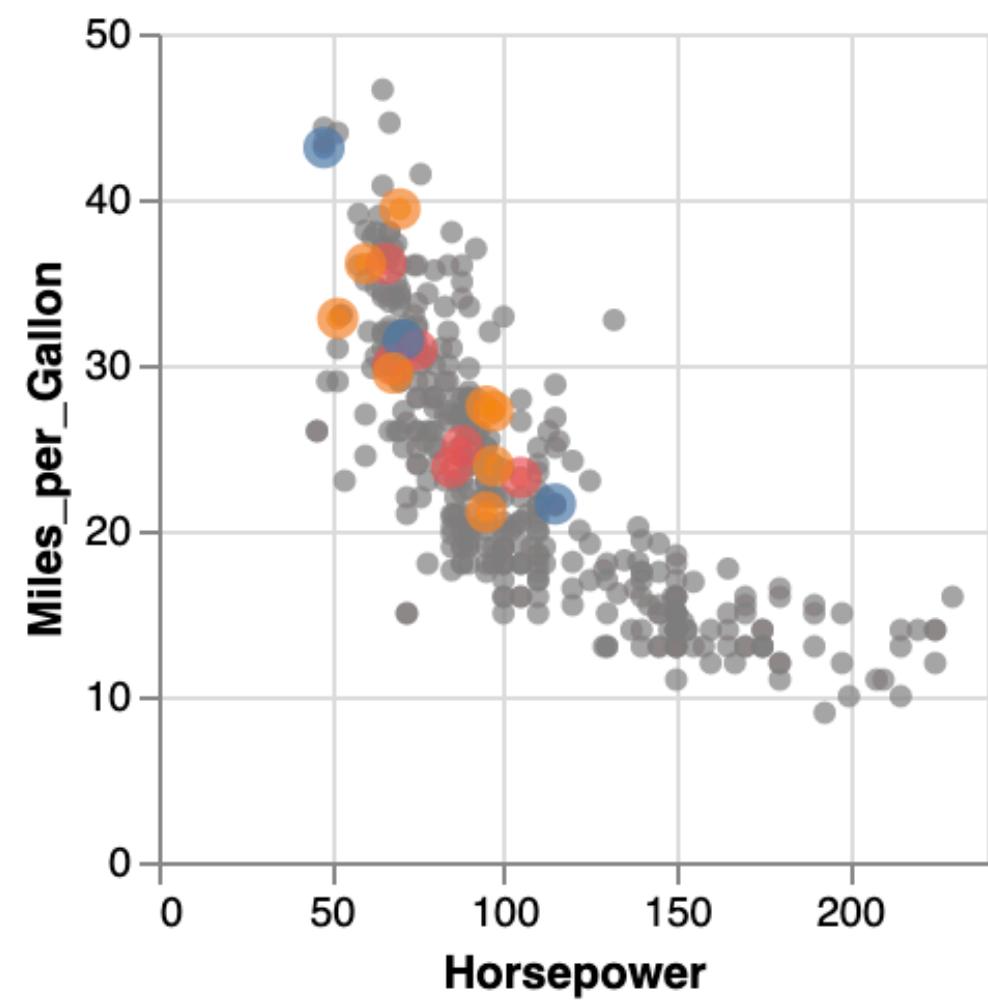
Abstract/Elaborate

show me more or less detail



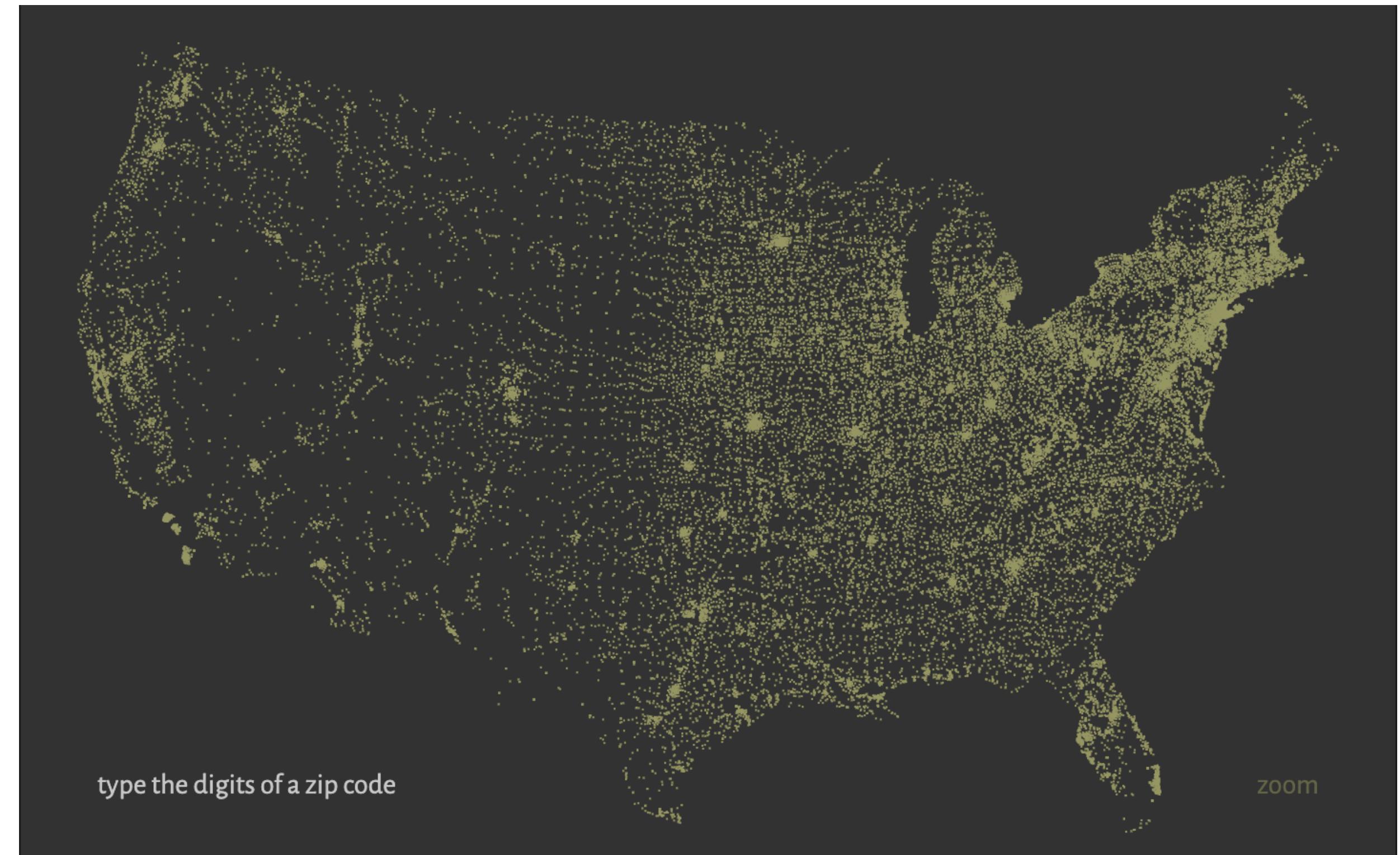
Filter

show me something conditionally



CylYr_Year 1977

CylYr_Cylinders 4

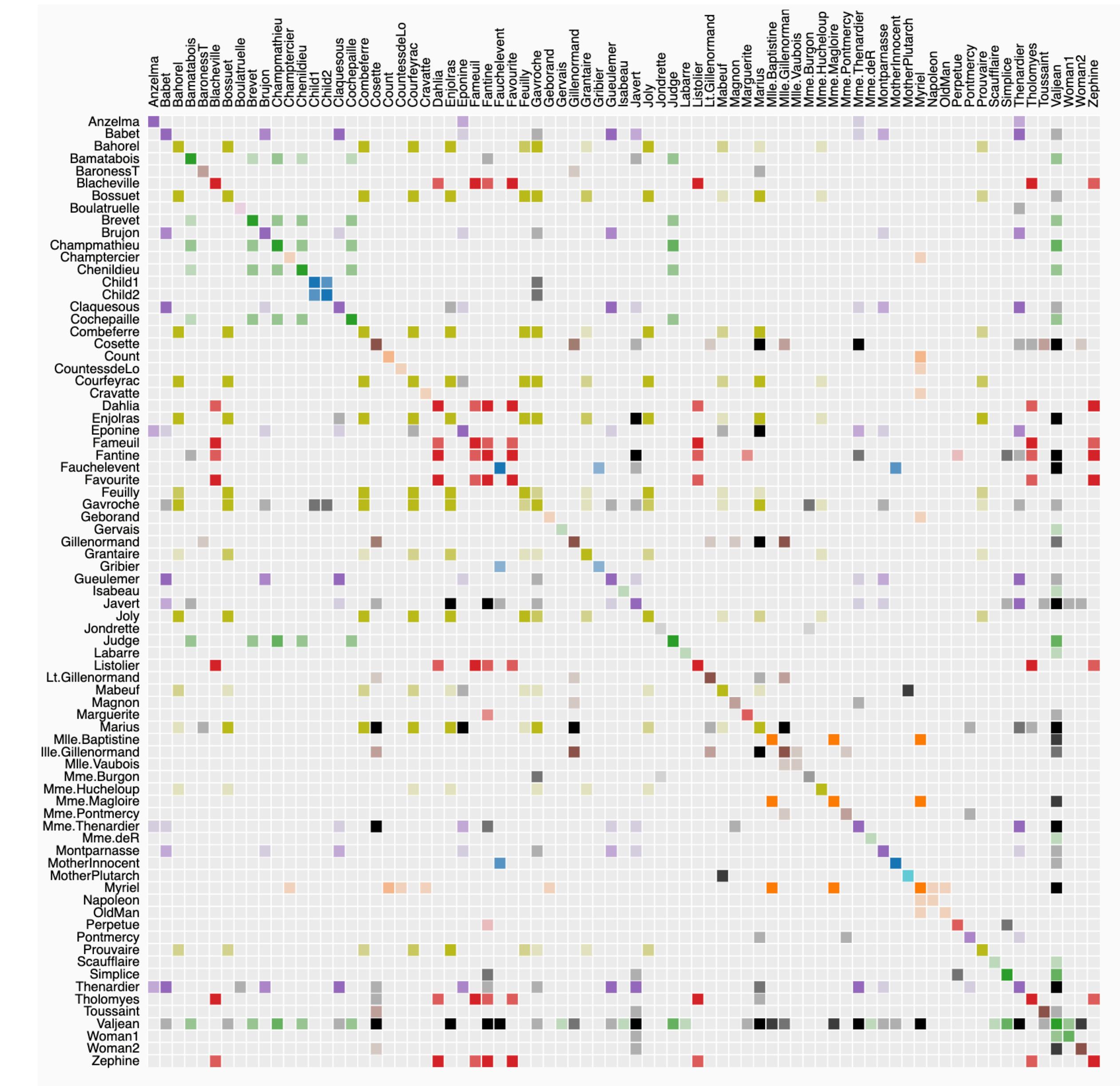


https://vega.github.io/vega-lite/examples/interactive_query_widgets.html

<https://benfry.com/zipdecode/>

Reconfigure

show me a different arrangement

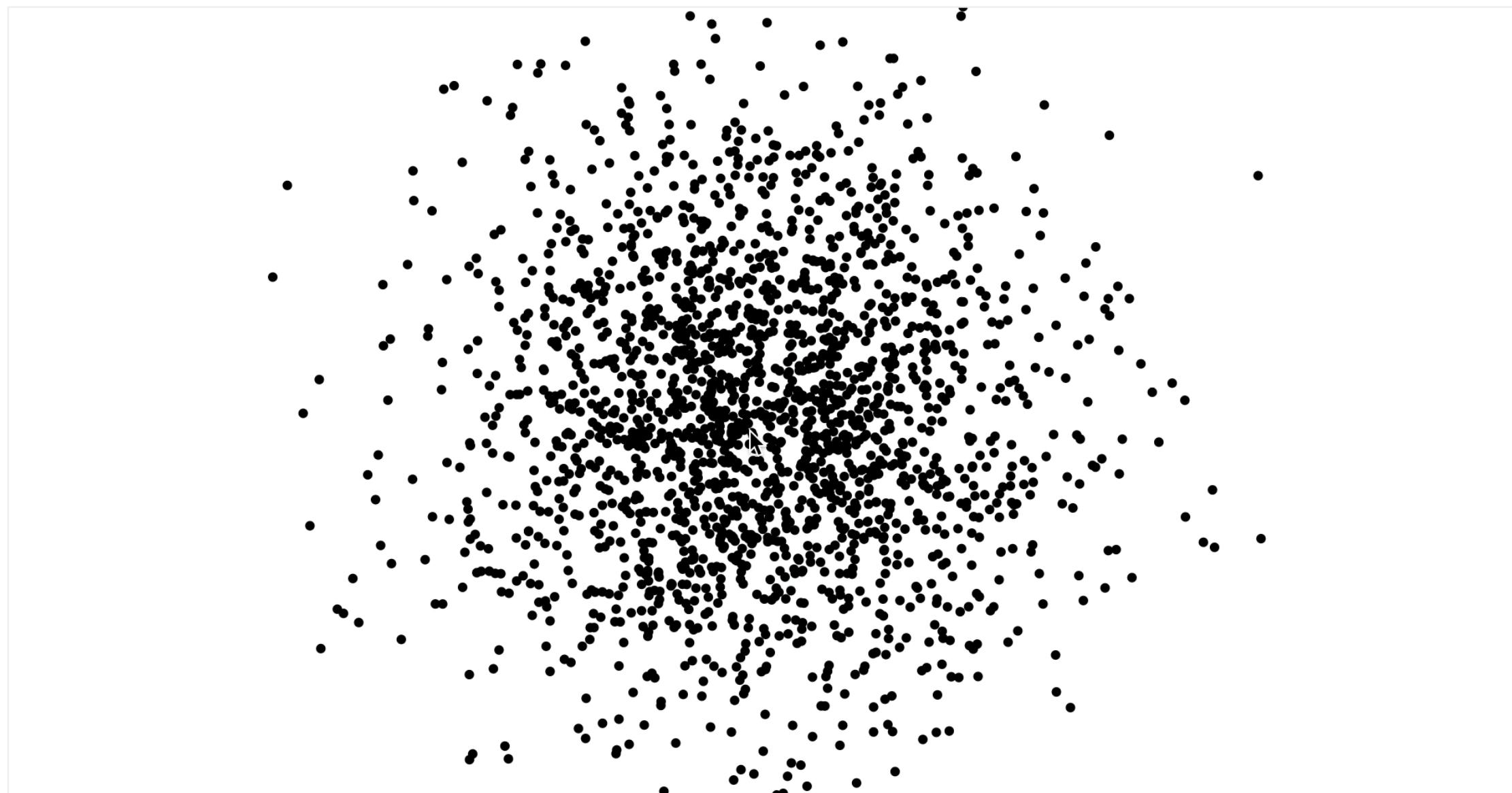


<https://bostocks.org/mike/miserables/>

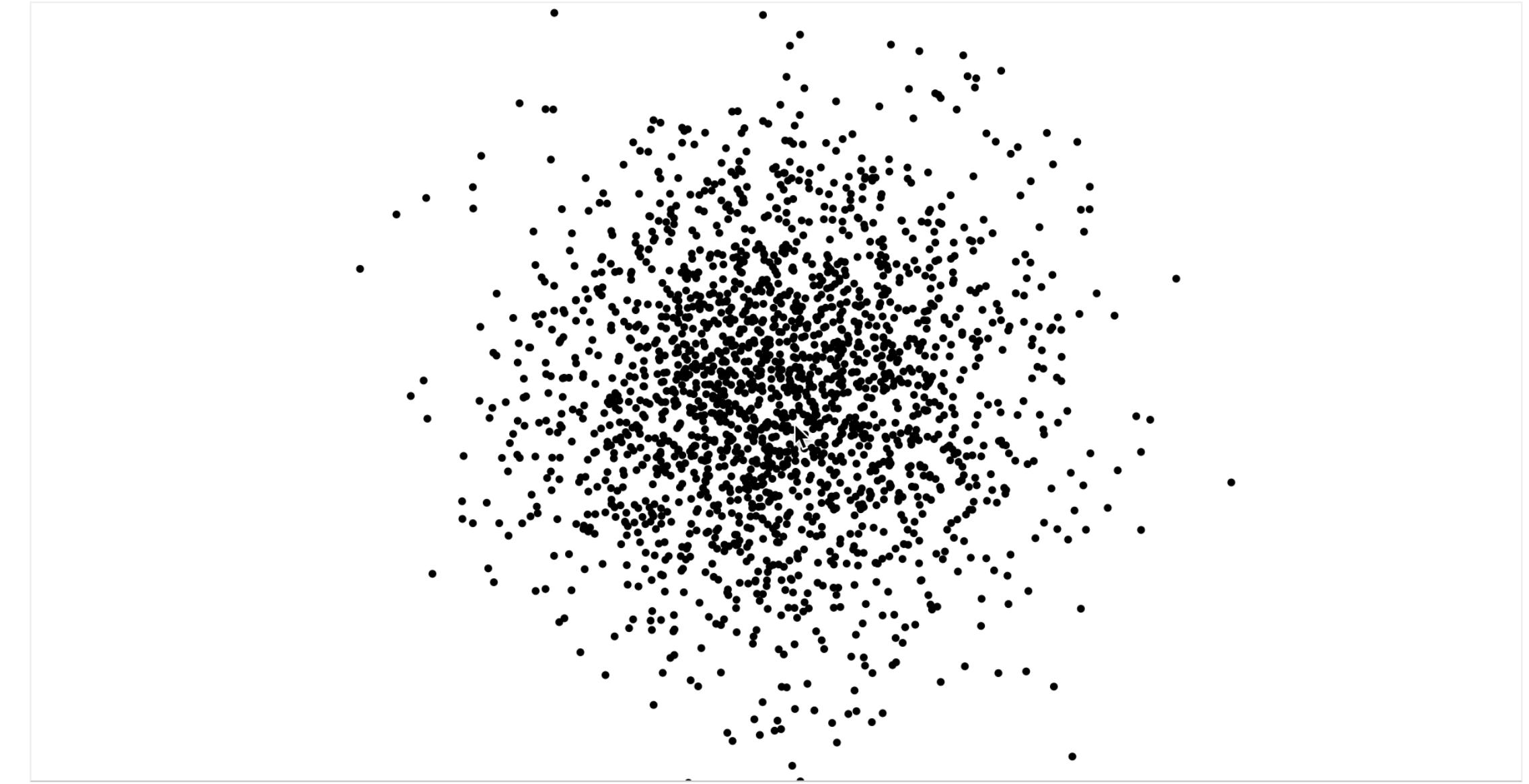
Explore

show me something else

Geometric Zoom



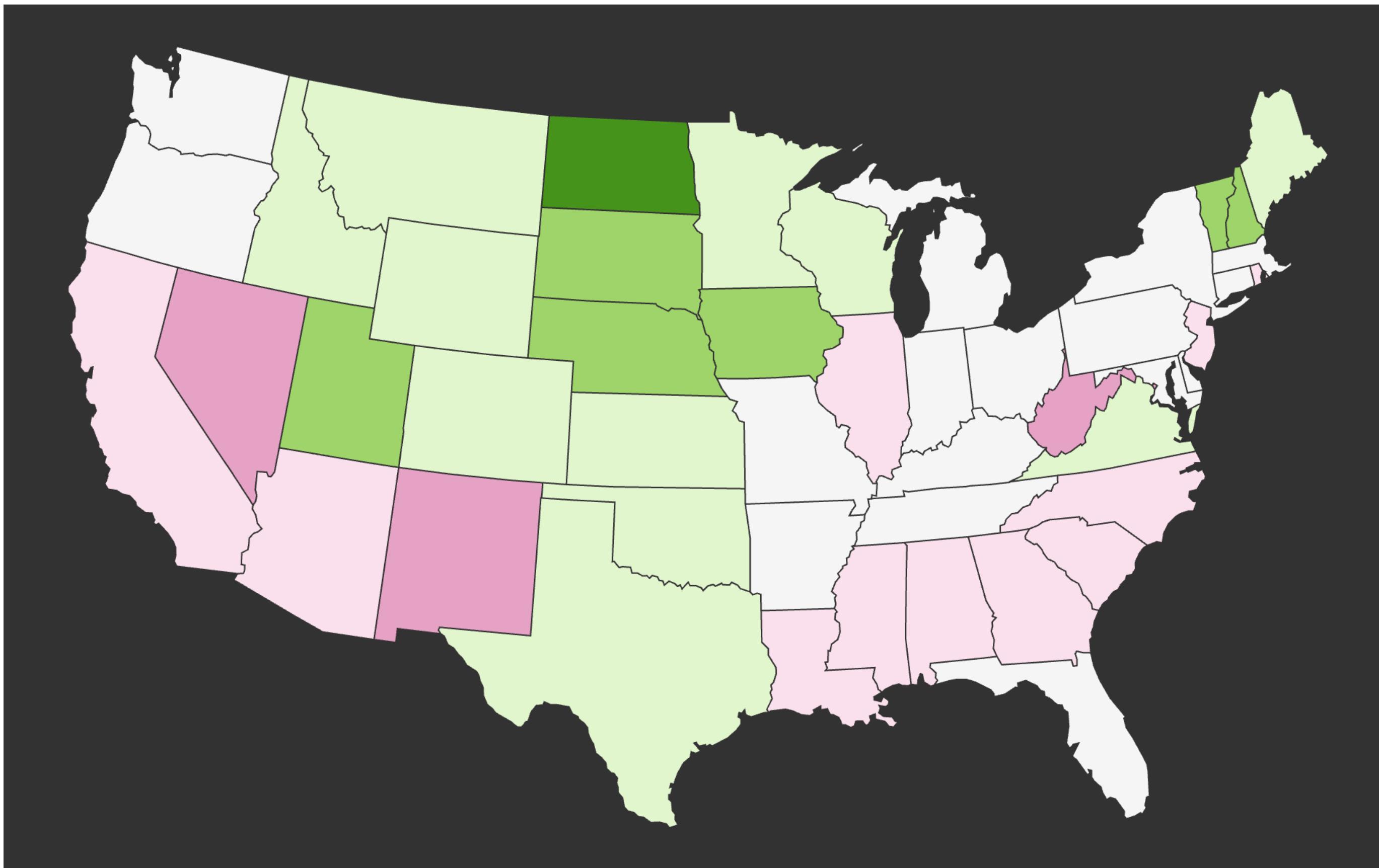
Semantic Zoom



<https://bl.ocks.org/mbostock/3680957>

Explore

show me something else

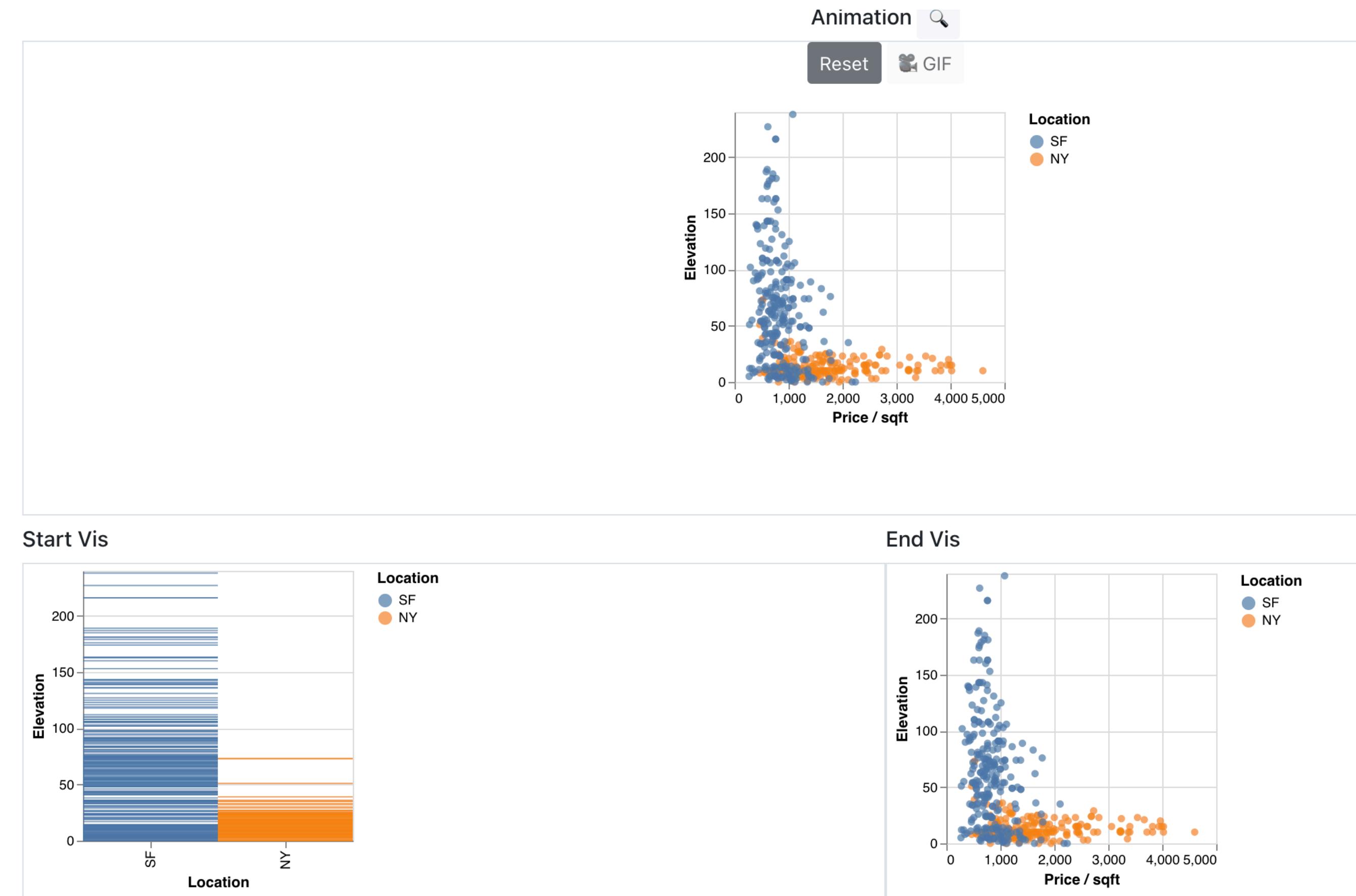


<https://bl.ocks.org/cmgiven/d39ec773c4f063a463137748097ff52f>

Encode

show me a different visual representation

<https://uwdata.github.io/gemini-editor/>
→ dot plot to scatter plot



What are common ways you
could enable interaction of a
data table?



Select to apply a group action (delete, format,...)

Export to CSV + New Delete

Search

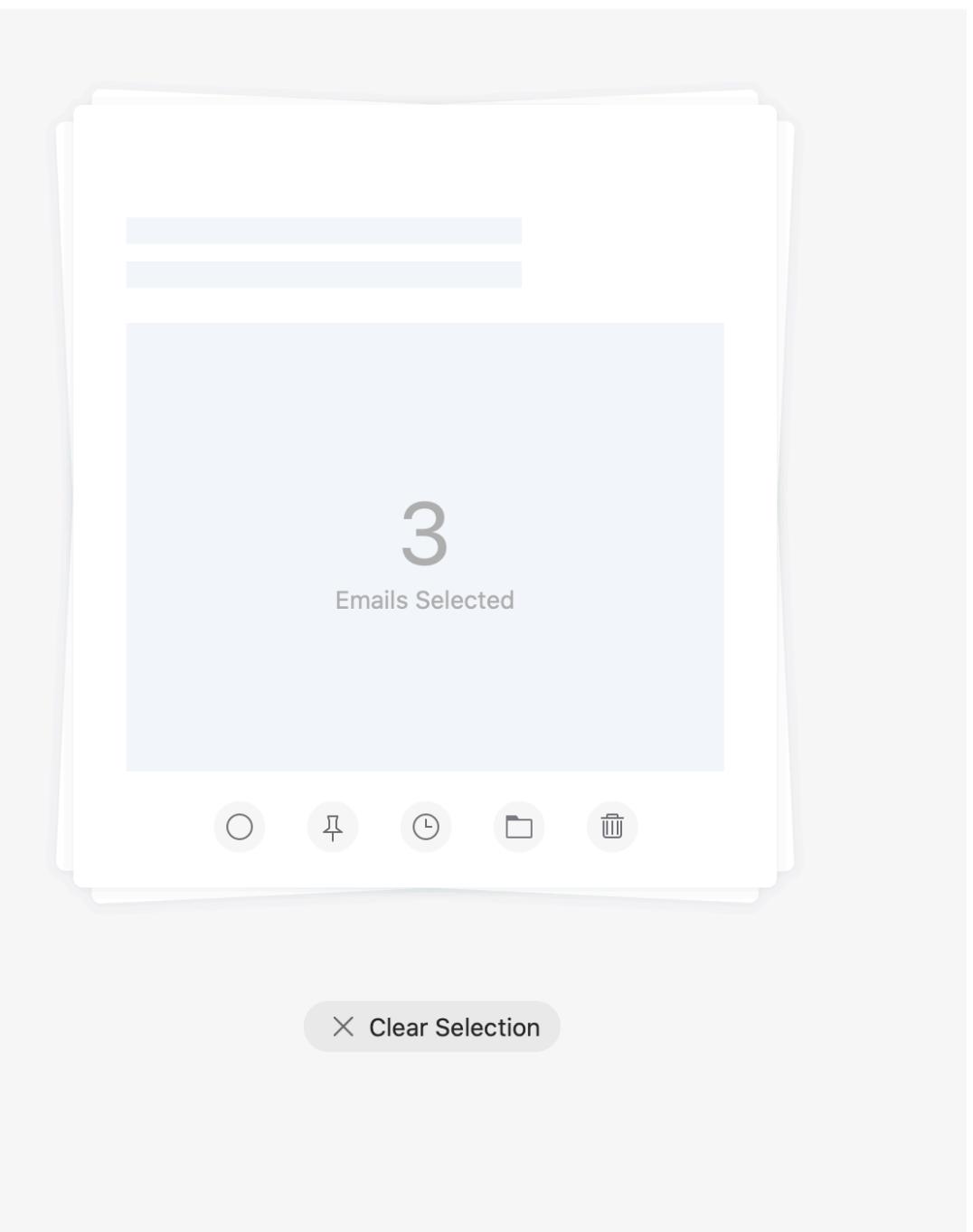
ID	Product			In stock	Customer	
	name	price ▾	Coupon		name	order ▾
0	Item name 0	2100	no	yes	Customer 0	0
1	Item name 1	2101	yes	no	Customer 1	1
2	Item name 2	2102	no	no	Customer 2	2
3	Item name 3	2103	no	no	Customer 3	3
4	Item name 4	1500	no	no	Customer 4	4
5	Item name 5	2105	no	no	Customer 5	5
6	Item name 6	2106	no	no	Customer 6	6
7	Item name 7	2107	yes	yes	Customer 7	7
8	Item name 8	2108	no	no	Customer 8	8
9	Item name 9	2109	yes	no	Customer 9	9

10 ▾

1 2 3 4 5 >

Spam Empty Spam

- Journal of Biosciences and M... Feb 18 Welcome to Submit Articles to Special... Journal of Biosciences and Medicines (JBM) Impact Factor: 0.87; h5-index: 17;
- World Journal of Veterinary S... Feb 18 Followup: Dear Dr. Hendrik Strobelt - I... Dear Dr. Hendrik Strobelt, Greetings from Vanessa..! Based on your research expertise,
- Dreside Feb 15 Sale DAY! New Brand KN95 Executive... Same Day Free Shipping via USPS. Also we offer samples
- Nutrition and Nutraceuticals... Feb 15 Follow-up/ Response Awaited- Nutriti... Dear Researcher, Greetings. We would like to know your interest to deliver Oral or Poster
- Venture Summit Feb 11 Venture Summit Only One Week To Ap... Showcase your company to active investors...submission deadline extended to
- Secret Boston Feb 10 Boston Pops In Love ❤ Streaming LIVE from Symphony Hall! Brand Name Boston Pops in Love ❤ Streaming
- Forensic Science Today Feb 10 mail to hendrik@strobelt.com Dear Strobelt H, Hope you are doing well. We need one article for successful release of



<http://allenfang.github.io/react-bootstrap-table/>

Reconfigure sorting

Sr. No.	Book Title ▼	Author ▼ ▲	Price ▼ ▲
1	Angels and Demons	Shivam	890
2	Harry Porter	Anuj	650
3	Hobbit	Aman	700
4	Lord of the rings	Sameer 	1000
5	The little prince	Jatin	870

<https://www.webcodeexpert.com/2016/07/angularjs-how-to-sort-data-in-table.html>

Filter

“Facetting”

≡ Faceted Search

Go

Neighborhood: Bayview X

Room Type: Entire home/apt X

Private room X

Price: <50 X

[Clear All](#)

Neighborhood Clear

- Bayview (9)
- Bernal Heights (4)
- Downtown/Civic Center (10)
- Excelsior (21)
- Financial District (1)

[Show More](#)

Room Type Clear

- Private room (9)
- Shared room (1)

Price Clear

- <50 (9)
- 50 - 120 (111)

Rental Name	Host ID	Host Name	Neighborhood	Room Type	Price	Minimum Nights	Number of Reviews	Last Review
Quiet Private Room in Artsy Shared Home/Urban Farm	35151167	Jen	Bayview	Private room	36	2	96	28-JUL-2019
Home Away From Home Too! Room #1	17572711	James	Bayview	Private room	44	1	29	18-JUL-2019
Home Away From Home Too! Room #2	17572711	James	Bayview	Private room	44	1	23	19-JUL-2019
Home Away From Home Too! Room #3	17572711	James	Bayview	Private room	44			
Home Away From Home Too! Room #4	17572711	James	Bayview	Private room	44			
VERY LIMITED DEAL: Cheap Clean & Central (SF City)	58389796	Arjun	Bayview	Private room	49			
THE BEST DEAL: Cheap Clean & Convenient (SF City)	58389796	Arjun	Bayview	Private room	39			
Large Bedroom Comfortable Home - Full Bed	28502179	Tammy	Bayview	Private room	42			
Large Sunny Bedroom - Queen Bed	28502179	Tammy	Bayview	Private room	48			

goPubMed

Alzheimer
Find it!

top five & more

- Alzheimer Disease
- Dementia
- Proteins
- Humans
- Neurons
- more ...
- Biological Sciences
- Technology, Industry, Agriculture
- Techniques and Equipment
- Diseases
- biological_process
- Organisms
- molecular_function
- Natural Sciences
- Anatomy
- Health Care
- Psychiatry and Psychology
- Chemicals and Drugs
- Proteins
- Peptides
- Pharmaceutical Preparation
- Amyloid
- Oxides
- Enzymes
- Cholinesterase Inhibitors
- Amyloid beta-Protein
- Butorphanol
- Apolipoproteins E
- cellular_component

hierarchy of content

- Psychiatry and Psychology (104)
- Diseases (116)
- Biological Sciences (848)
- Techniques and Equipment (742)
- Chemicals and Drugs (689)
- Health Care (697)
- Natural Sciences (625)

50 articles for query "Alzheimer" relating to "Amyloid beta-Protein"

go to page: 1 2 3 Previous | Next

Show statistics for term Amyloid beta-Protein

description: A 4-kDa protein, 39-43 amino acids long, expressed by a gene located on chromosome 21. It is the major protein subunit of the vascular and plaque amyloid filaments in individuals with Alzheimer's disease and in aged individuals with trisomy 21 (DOWN SYNDROME). The protein is found predominantly in the nervous system, but there have been reports of its presence in non-neuronal tissues.

synonyms: "Amyloid AD AP" "ABP (Alzheimer's)" "Alzheimer beta-Protein" "Amyloid Protein A4" "Beta Amyloid Protein" "Alzheimer beta-Protein" "Amyloid AD-AP" "Amyloid beta Protein" "beta-Amyloid Protein" "Amyloid Fibril Protein (Alzheimer's)"

Show statistics for these 50 articles

Export to: RDF XML BibTeX EndNote PlainText

43: Reduction of sortilin-1 in Alzheimer hippocampus and in cytokine-stressed human brain cells. PMID: 17589324

Zhao Y et al., *NeuroReport*, 18 (11): 1187-1191, 2007

Sortilin 1 (S0RL1) is a transmembrane sorting receptor that regulates the intracellular trafficking of beta-amyloid precursor protein (betaAPP).

149: [Inhibition of neuronal death by promoting degradation of intracellular amyloid beta-protein] PMID: 17515111

Ohyagi Y et al., *Neuroscience Research*, 47 (2): 57-62, 2007

Inhibition of aggregation of amyloid beta-protein (AP) and promotion of extracellular AP removal are known

keyword filter + Facetting

Abstract/Elaborate

Interactive Detail View & Table Lens

The screenshot shows the ONOS interface with a list of 25 devices. A specific device, 'WASH', is selected and shown in a detailed view panel. The detailed view includes fields for URI, Type, Master ID, Chassis ID, Vendor, H/W Version, S/W Version, Protocol, and Serial #. Below this, a 'Ports' table lists port details such as Enabled, ID, Speed, Type, Egress Links, and Name.

Enabled	ID	Speed	Type	Egress Links	Name
false	Local	0	Copper		s7
true	1	10000	Copper		s7-eth1
true	2	10000	Copper	of:0000000000000019/8	s7-eth2
true	3	10000	Copper	of:0000000000000004/3	s7-eth3
true	4	10000	Copper	of:0000000000000005/3	s7-eth4
true	5	10000	Copper	of:0000000000000006/7	s7-eth5

The screenshot shows the 'Insight Table Lens' application. It displays a table with columns for Year, Quarter, Product, Channel, Region, Salesperson, Units, Revenue, and Profits. A heatmap overlay is applied to the data, with colors representing values across the rows and columns. A red border highlights a subset of the data in the second column of the first four rows.

Year	Quarter	Product	Channel	Region	Salesperson	Units	Revenue	Profits	
126	1993	2	ForeCode Pro	Direct Sales	Southwest	Kevin Polen	1029	439898	171561
444	1993	4	ForeCode Pro	VAR	West	Tom Tuttle	302	122310	51371
445	1993	4	ForeCode Pro	VAR	West	Ann Thomas	302	122310	51371
446	1993	3	ForeMost S...	Direct Sales	Midwest	Sal Vitatone	301	2.8595e+006	929338
447	1993	3	ForeMost S...	VAR	South	Gary Copper	301	2.709e+006	948150

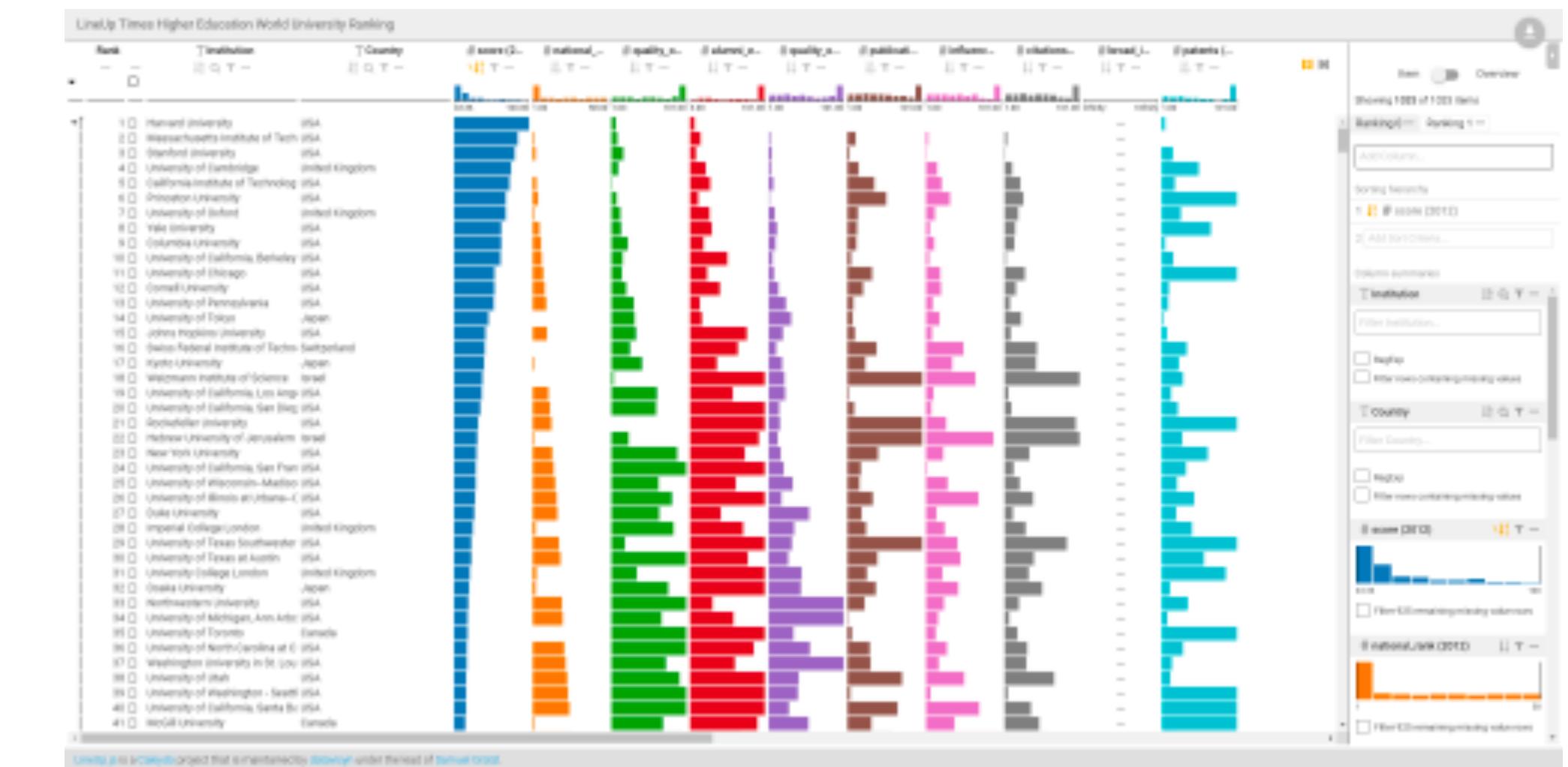
<https://wiki.onosproject.org/display/ONOS/GUI+Tabular+View>

Rao, Ramana, and Stuart K. Card. "The table lens: merging graphical and symbolic representations in an interactive focus+ context visualization for tabular information." *CHI 1994*.
48

Encode

Conditional Formatting & LineUp

# Tickers	7d	1mo	3mo	1yr	1mo (2y stack)	3mo (2y stack)	1yr (2y stack)
12	-2.4%	-4.8%	-5.8%	-5.9%	-4.8%	-5.8%	-5.9%
7	-16.4%	-8.7%	-10.6%	-6.9%	-8.7%	-10.6%	-6.9%
8	-0.8%	-5.4%	-3.7%	-4.2%	-5.4%	-3.7%	-4.2%
13	2.5%	0.7%	2.4%	2.1%	0.7%	2.4%	2.1%
7	-10.0%	-4.1%	-3.9%	-7.0%	-4.1%	-3.9%	-7.0%
13	-4.3%	-6.3%	-5.6%	-5.9%	-6.3%	-5.6%	-5.9%
6	-4.8%	-7.1%	-5.6%	-1.9%	-7.1%	-5.6%	-1.9%
14	-8.3%	-5.7%	-6.7%	-4.0%	-5.7%	-6.7%	-4.0%
2	9.4%	12.4%	11.0%	11.4%	12.4%	11.0%	11.4%
4	8.6%	10.4%	8.7%	8.8%	10.4%	8.7%	8.8%



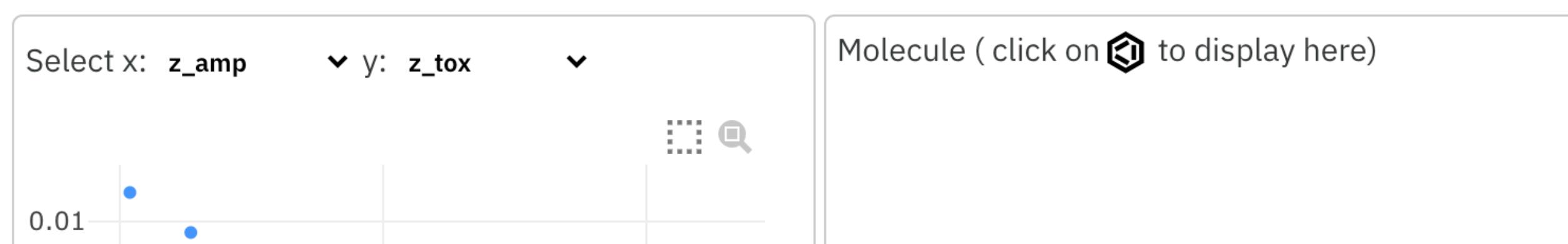
<https://stackoverflow.com/questions/28075699/coloring-cells-in-pandas>

<https://lineup.js.org/app/>

They can mix well

Interpolated Samples - using **linear** ▾ interpolation

interpol	peptide	mol	Aro	Chrg	evo_end	evo_start	HMom	Inst	MolW	z_amp	z_tox
—	YVSVPLH	hexagon	0.1429	0	-4.655	27.75	0.1165	36.09	813.9	0.8408	0.01037
—	YVSVPLH	hexagon	0.1429	0	-4.655	27.75	0.1165	36.09	813.9	0.8454	0.009851
—	YVSVPLH	hexagon	0.1429	0	-4.655	27.75	0.1165	36.09	813.9	0.8499	0.009356
—	YVSVPLPH	hexagon	0.125	0	-0.449	22.38	0.09246	56.9	911.1	0.8543	0.008885
—	YVSPVTP H	hexagon	0.125	0	0.449	9.948	0.1454	77.14	899	0.8586	0.008437
—	YLV PVTLHH	hexagon	0.1111	0	1.308	7.752	0.08646	42.26	1078	0.8628	0.008012
—	YL PPVTPHH	hexagon	0.1111	0	3.925	3.876	0.07213	63.66	1060	0.8669	0.007608
—	FLPPTTVFPH	hexagon	0.2222	0	14.83	-1.938	0.04968	73.09	1054	0.8709	0.007225
—	FLP TKTFPHH	hexagon	0.2	1	22.13	-2.37	0.105	59.86	1224	0.8748	0.00686
—	FLPTKTFTPH	hexagon	0.2	1	29.37	-4.267	0.07208	40.6	1188	0.8786	0.006514
—	FLPTKTFTFPH	hexagon	0.2727	1	36.28	-4.655	0.06431	66.55	1336	0.8823	0.006185
—	FLPTKTFTFPH	hexagon	0.2727	1	36.28	-4.655	0.06431	66.55	1336	0.8858	0.005873



<https://peptide-walk.mybluemix.net/>

Interaction with Visualization

Select – identify something as interesting.

Connect – show me related items.

Abstract/Elaborate – show me more or less detail.

Filter – show me something conditionally.

Reconfigure – show me a different arrangement.

Explore – show me something else.

Encode – show me a different visual representation.

What you will learn today

The value of interactivity

Principles of interaction design

Principles of accessible interaction design