Foundations of Effective Data Visualization

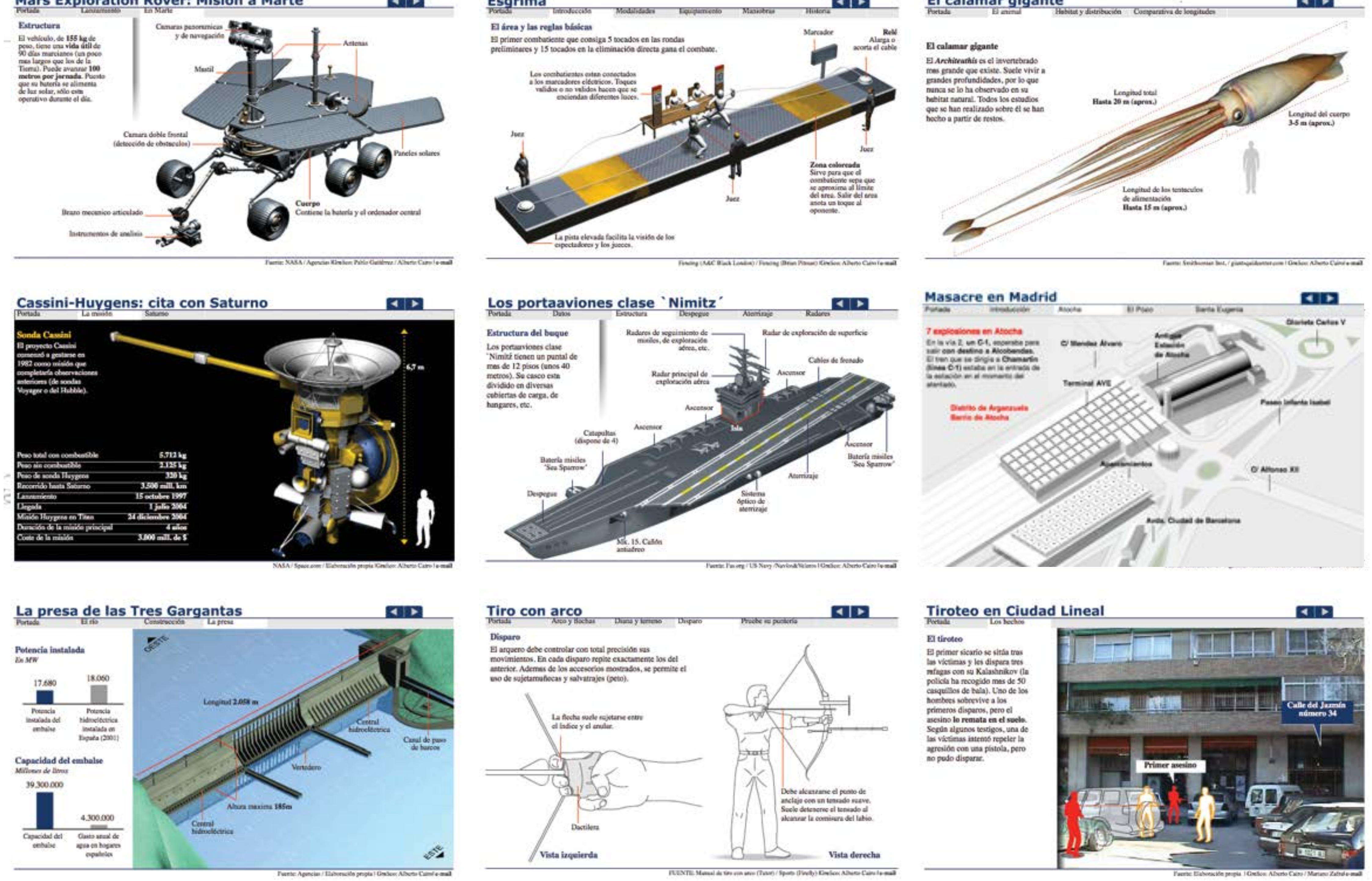
Alberto Cairo

OpenVisualizationAcademy.com

Information design
The intentional presentation of information within a certain set of constraints with the goal of aiding thought.

Data visualization
A branch of information design that focuses on the graphical encoding and presentation of data.

A bit about me


Esgrima
El calamar gigante
Cassini-Huygens: cita con Saturno
Los portaaviones clase `Nimitz´
Masacre en Madrid
La presa de las Tres Gargantas
Tiro con arco
Tiroteo en Ciudad Lineal

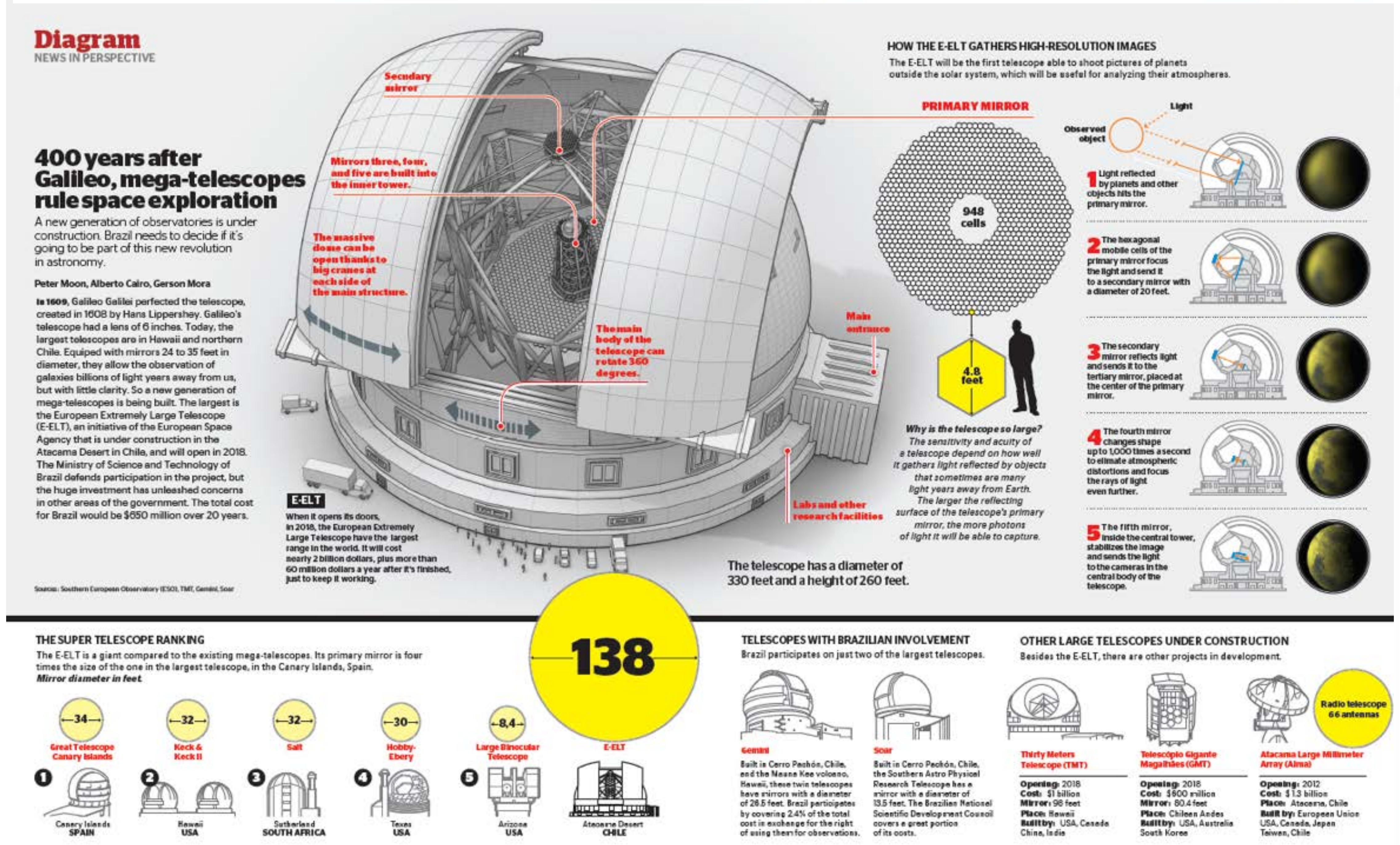


Diagram
NEWS IN PERSPECTIVE
400 years after Galileo, mega-telescopes rule space exploration
A new generation of observatories is under construction. Brazil needs to decide if it's going to be part of this new revolution in astronomy.
Peter Moon, Alberto Cairo, Gerson Mora
HOW THE E-ELT GATHERS HIGH-RESOLUTION IMAGES
PRIMARY MIRROR
948 cells
4.8 feet
E-ELT
The telescope has a diameter of 330 feet and a height of 260 feet.
138
THE SUPER TELESCOPE RANKING
TELESCOPES WITH BRAZILIAN INVOLVEMENT
OTHER LARGE TELESCOPES UNDER CONSTRUCTION

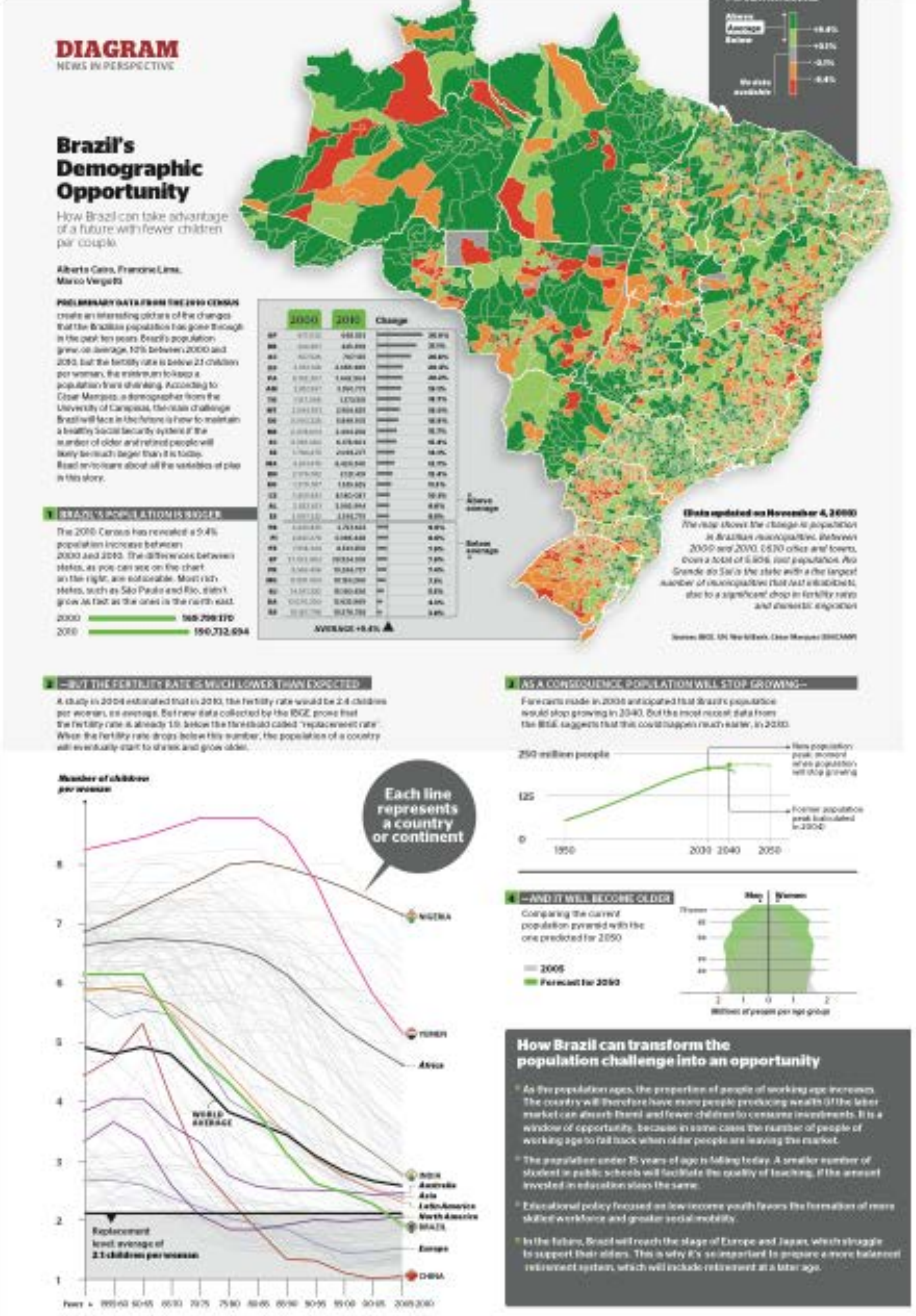
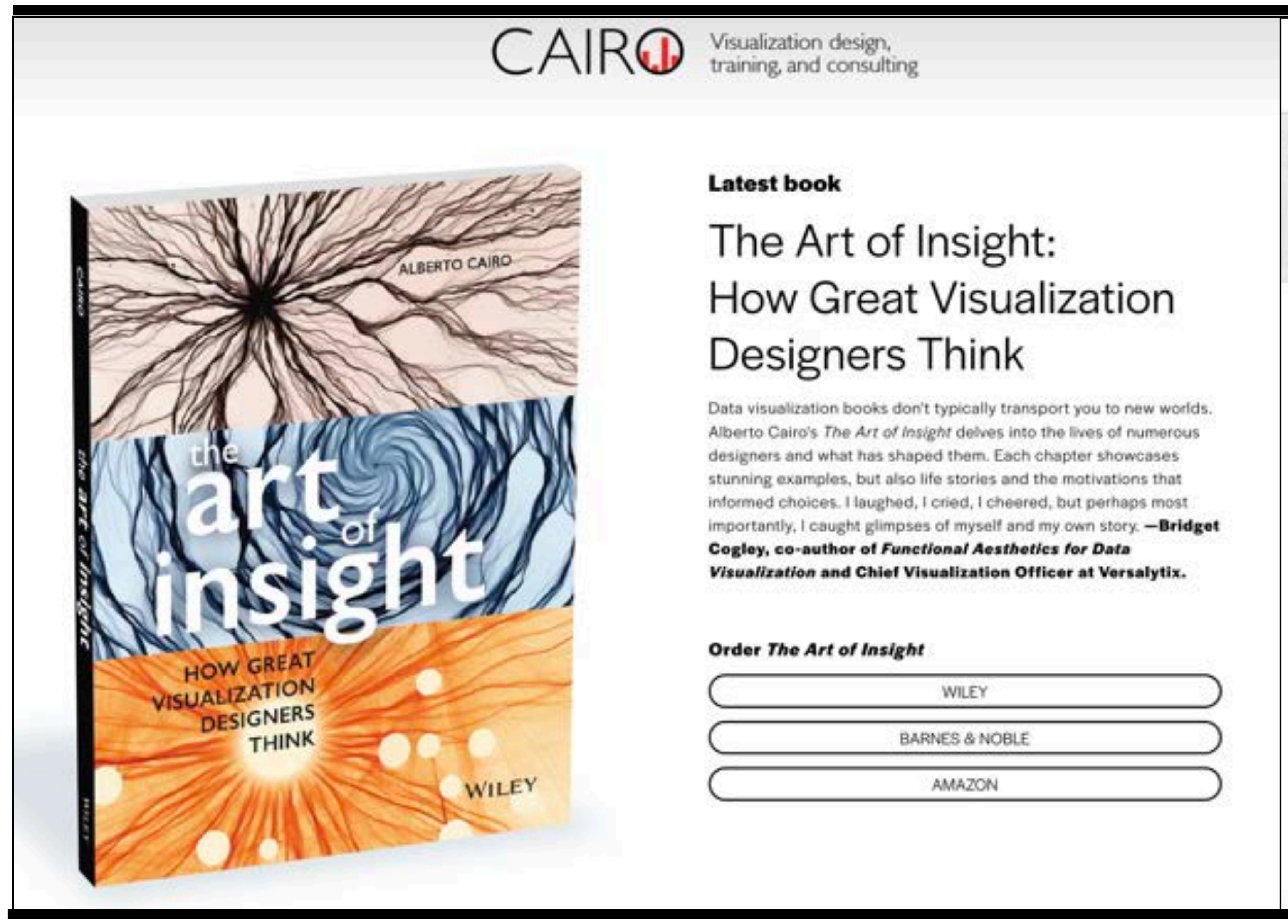
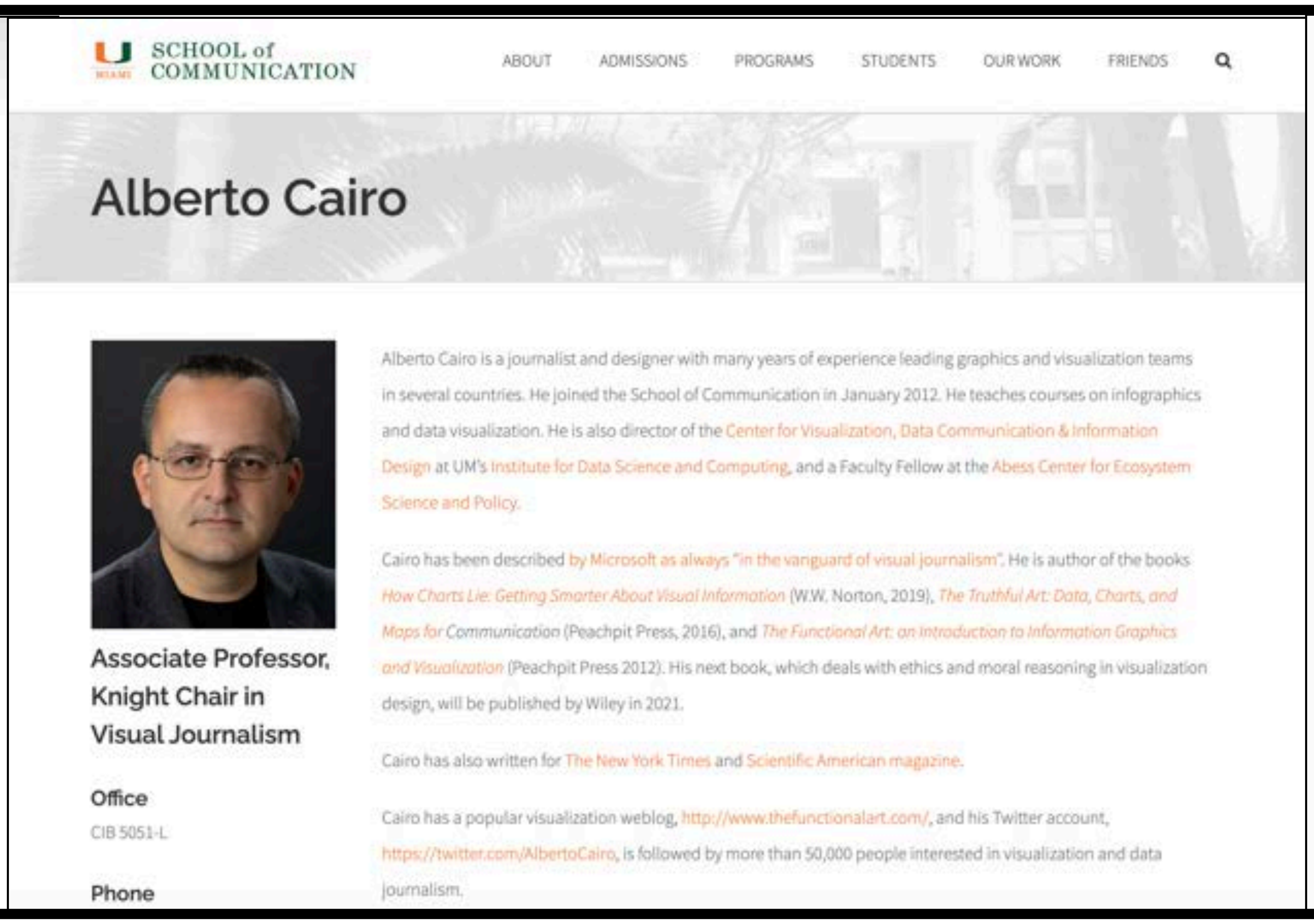


DIAGRAM
NEWS IN PERSPECTIVE
Brazil's Demographic Opportunity
How Brazil can take advantage of a future with fewer children per couple
Each line represents a country or continent
NIGERIA
CHINA
How Brazil can transform the population challenge into an opportunity

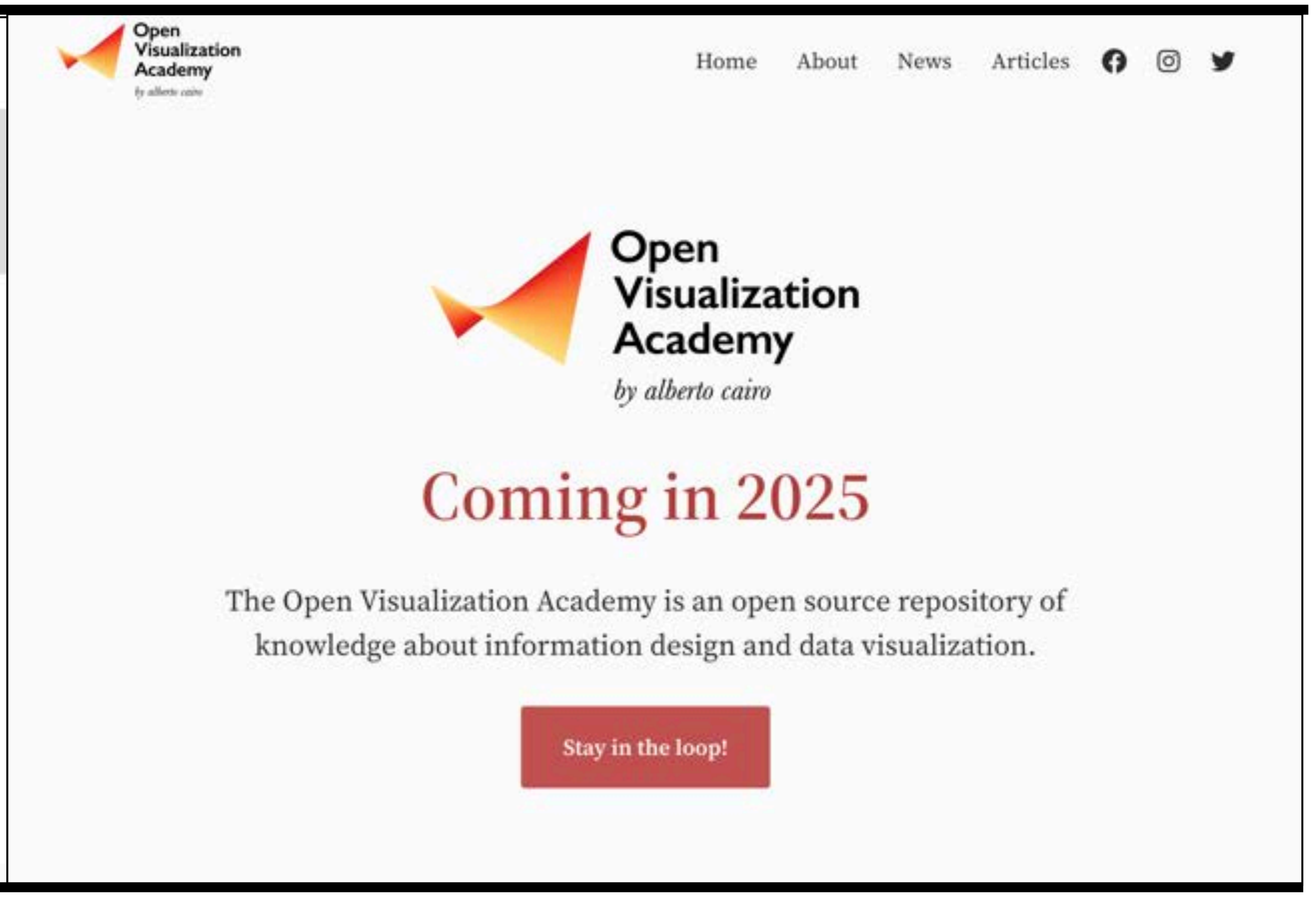
Teaching



www.albertocairo.com

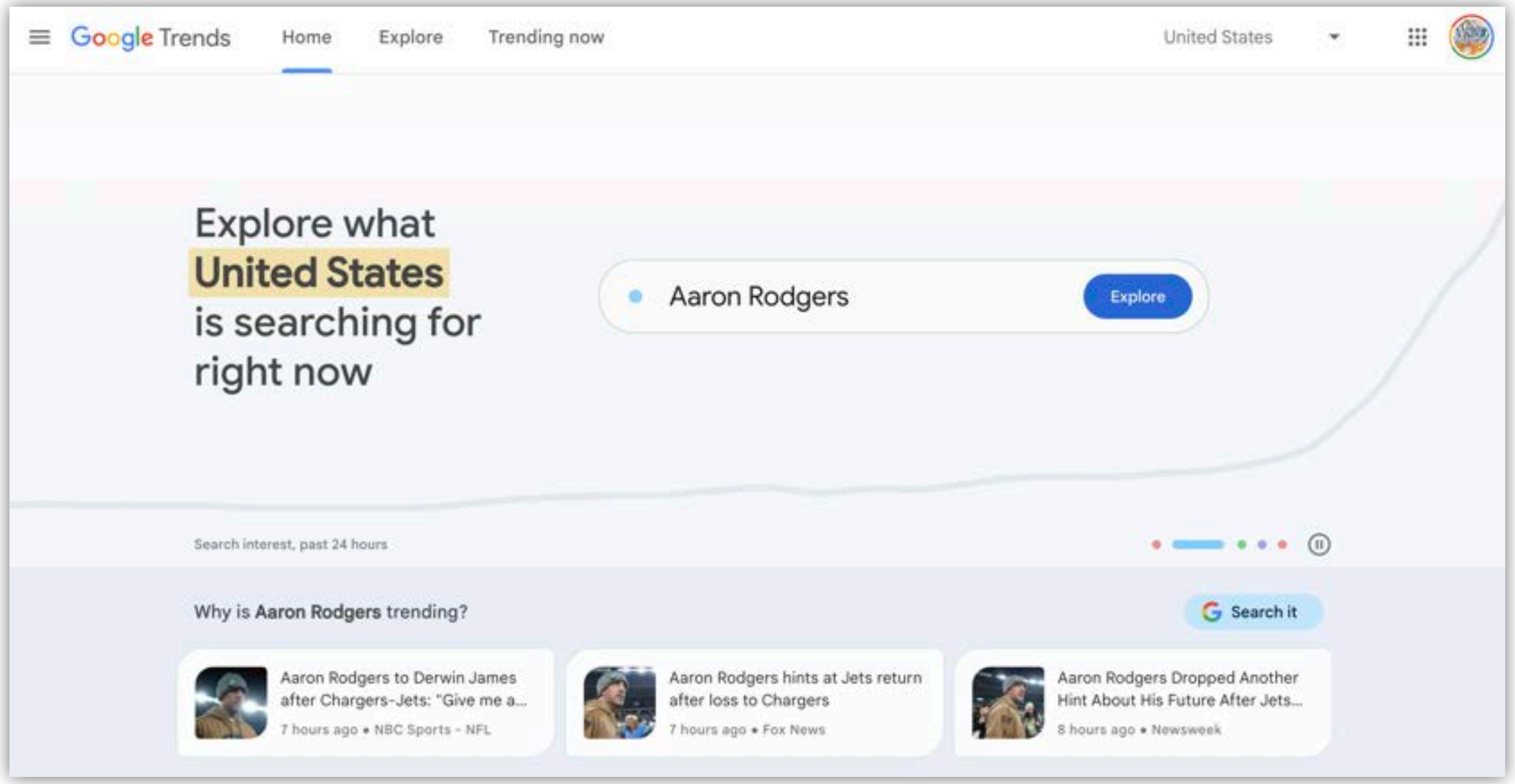


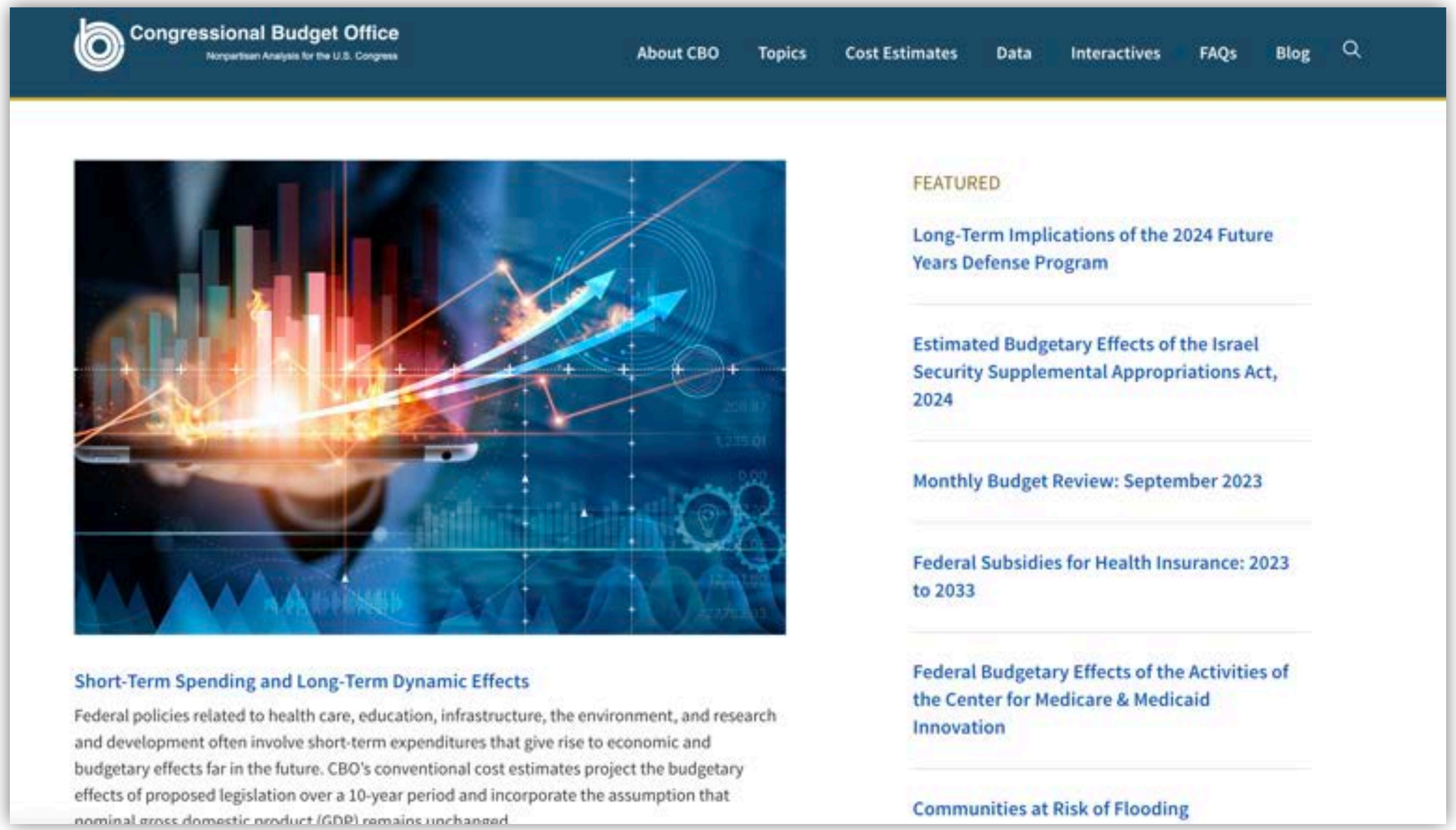
https://com.miami.edu/profile/alberto-cairo/

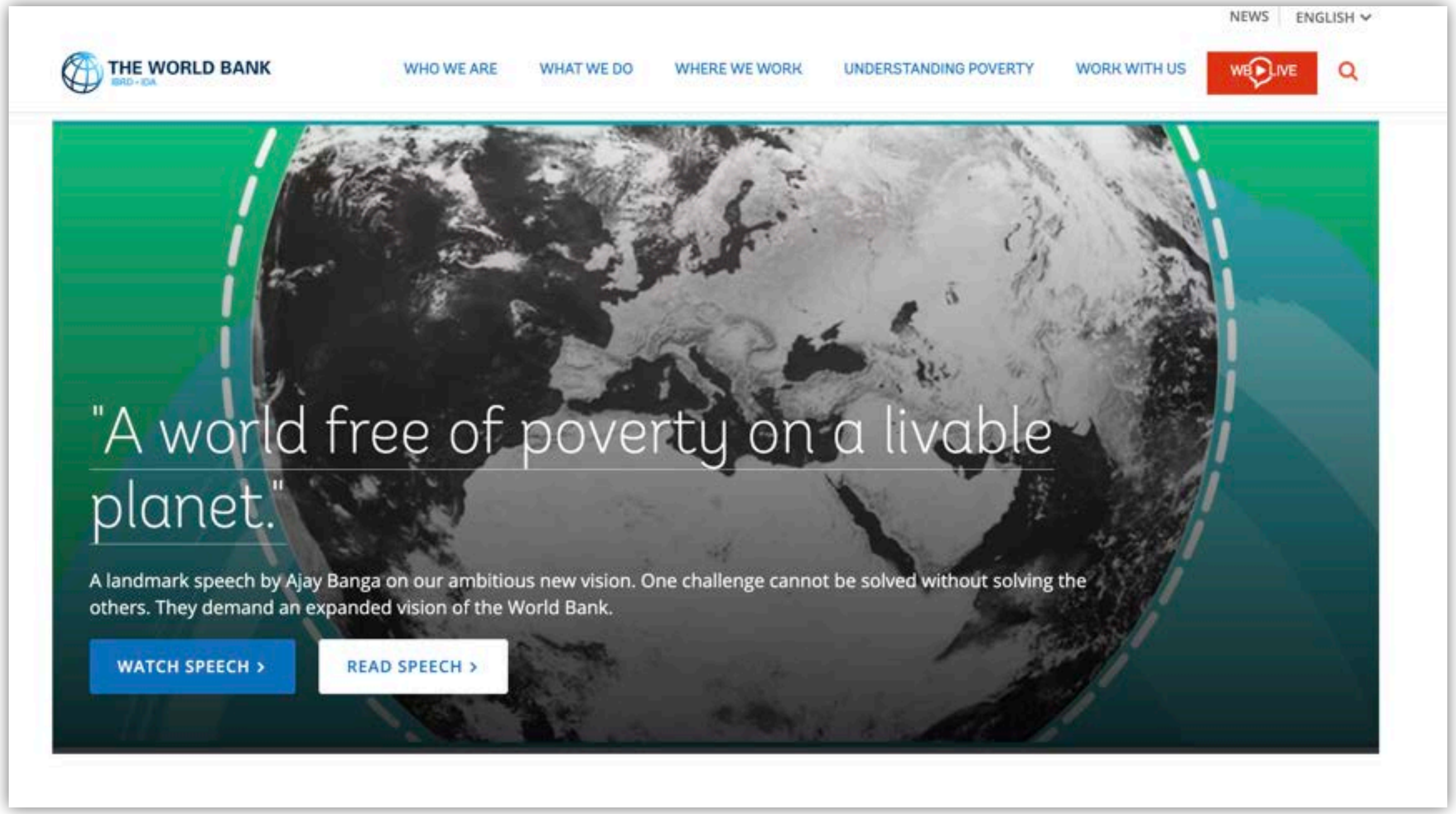


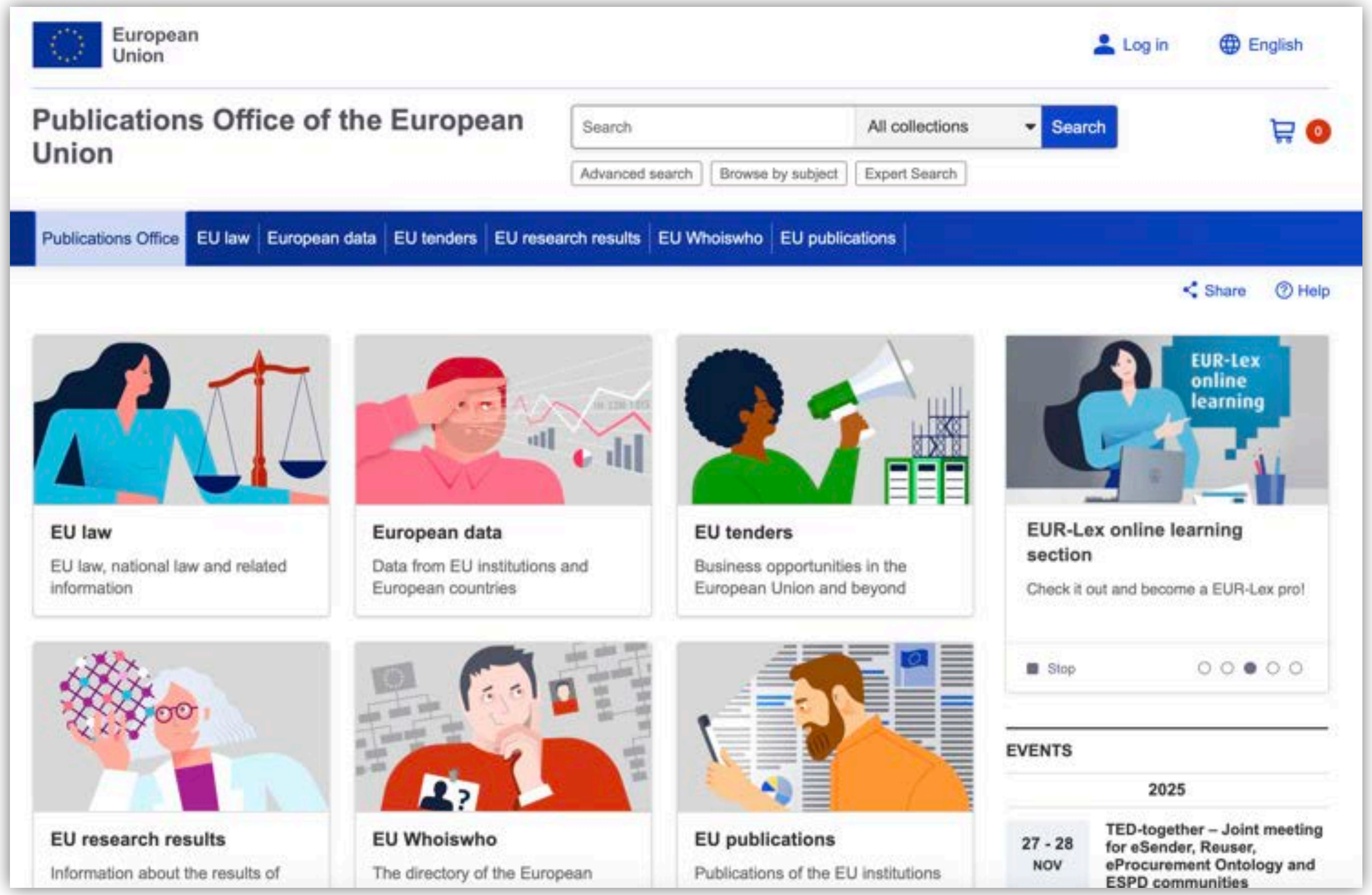
https://openvisualizationacademy.org/

Consulting, training, art direction





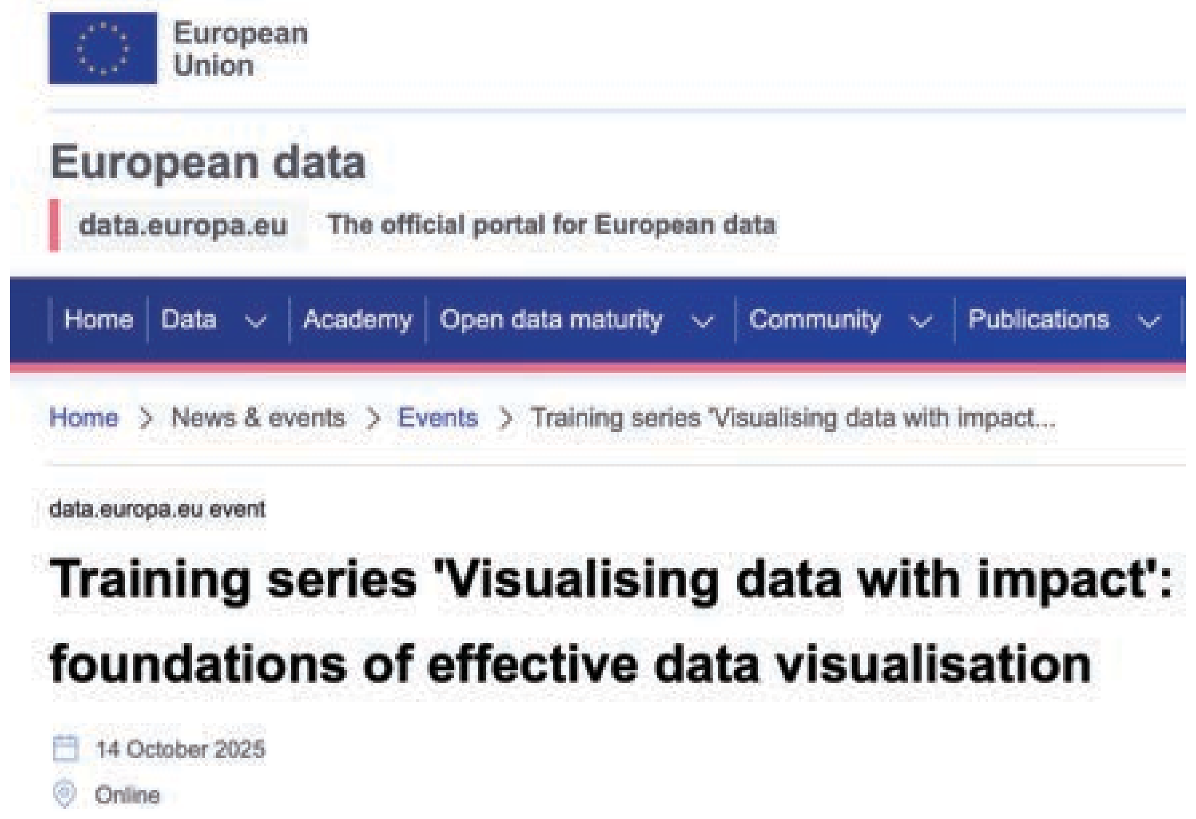




Books

2012 2016 2019 2023 2027

Housekeeping



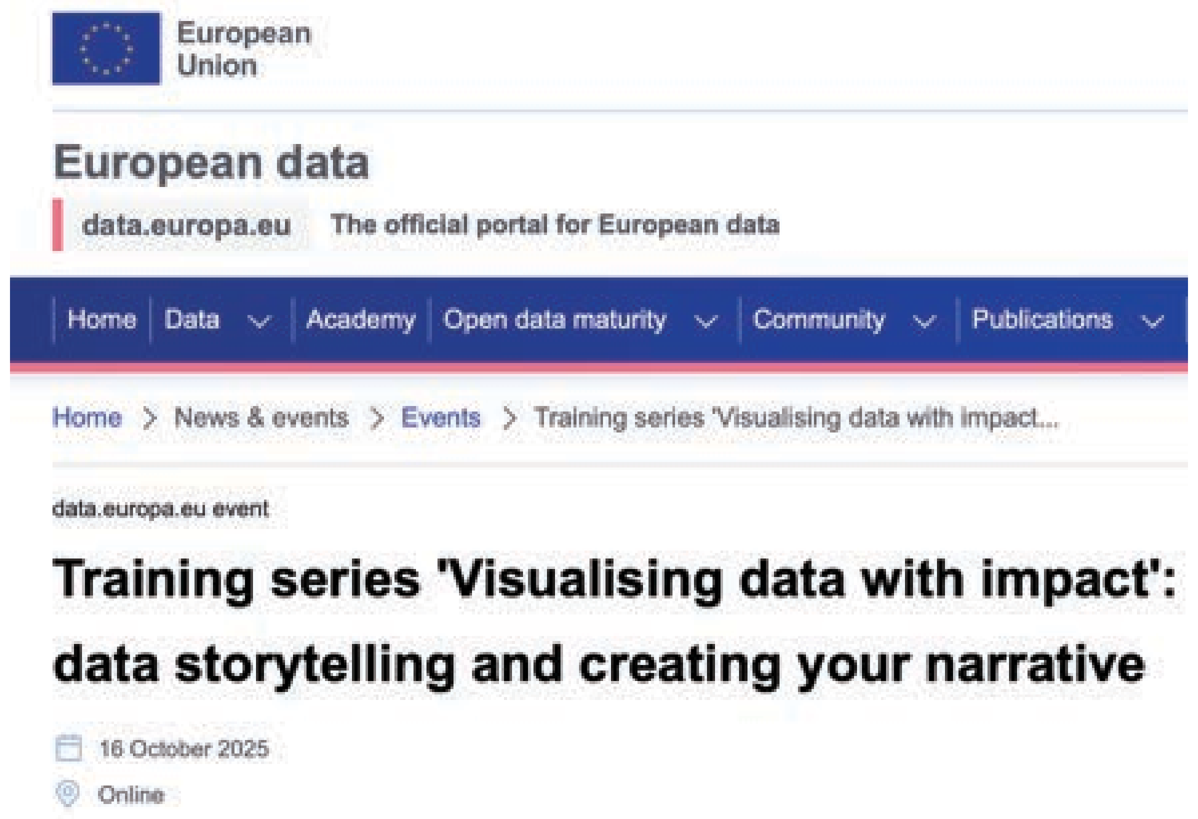
Today's webinar

Episode ONE - October 14

https://data.europa.eu/en/news-events/events/training-data-visualisation-session-1-foundations-effective-data-visualisation

Episode TWO - October 15

https://data.europa.eu/en/news-events/events/data-visualisation-training-session-2-designing-integrity



Episode THREE - October 16

https://data.europa.eu/en/news-events/events/data-visualisation-training-session-3-data-storytelling-and-creating-your

EPISODE ONE: Foundations of effective data visualization
Defining information design and data visualization
Exploration, exposition, explanation, expression in visualization
Why do we visualize? The basics
The grammar of graphics
"Rules" versus decision-making

EPISODE TWO: Designing with integrity
Myths of visualization: From "A picture is worth a thousand words" to "the data should speak for itself"
The role of mental models
Why and when do charts "lie", and what to do about it?
A structured way for thinking about visualization and minimizing misunderstanding

EPISODE THREE: Data storytelling and creating your narrative
Structuring a layout
Building a narrative
Considering visual design
Creative visualization
What comes next in visualization?

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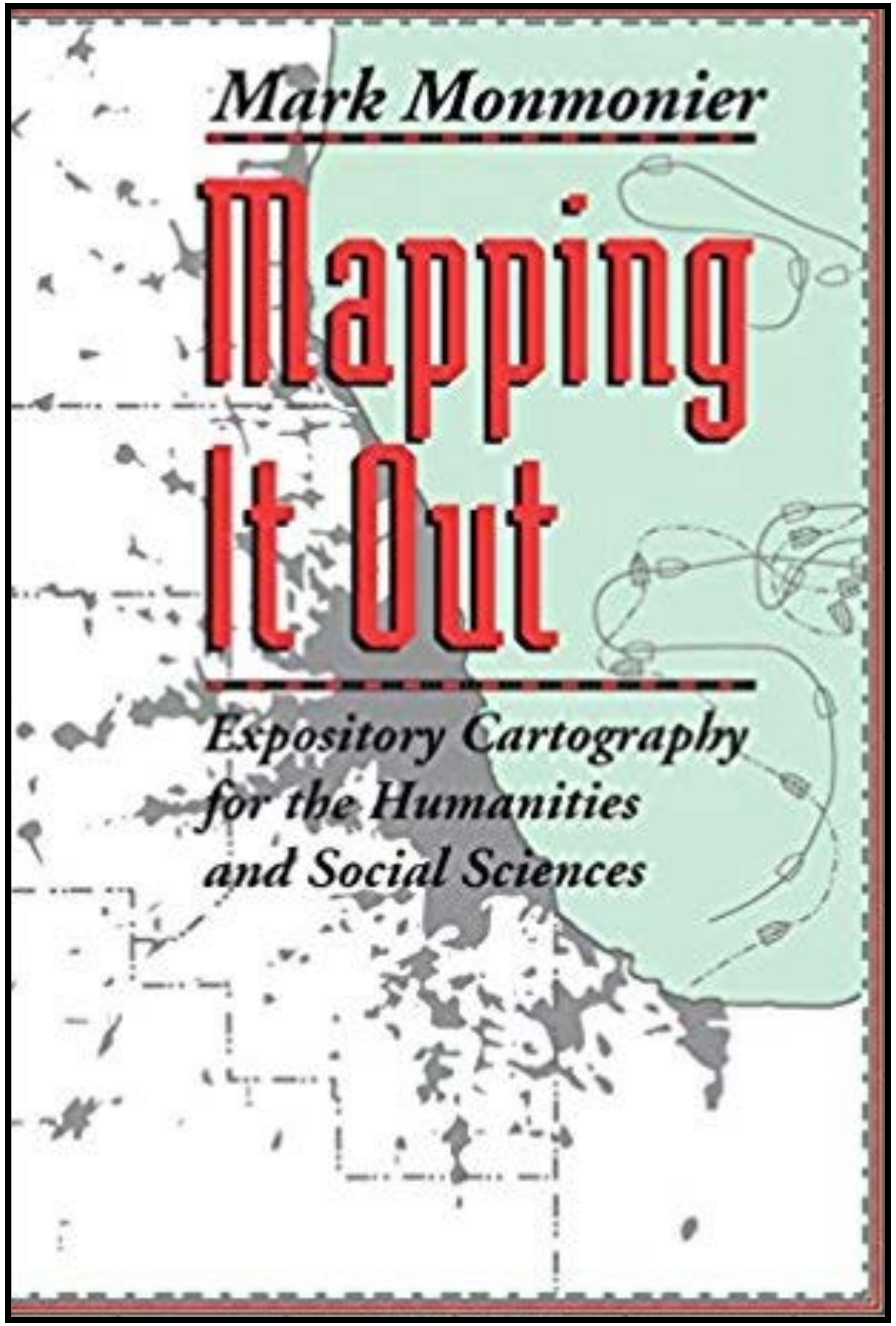
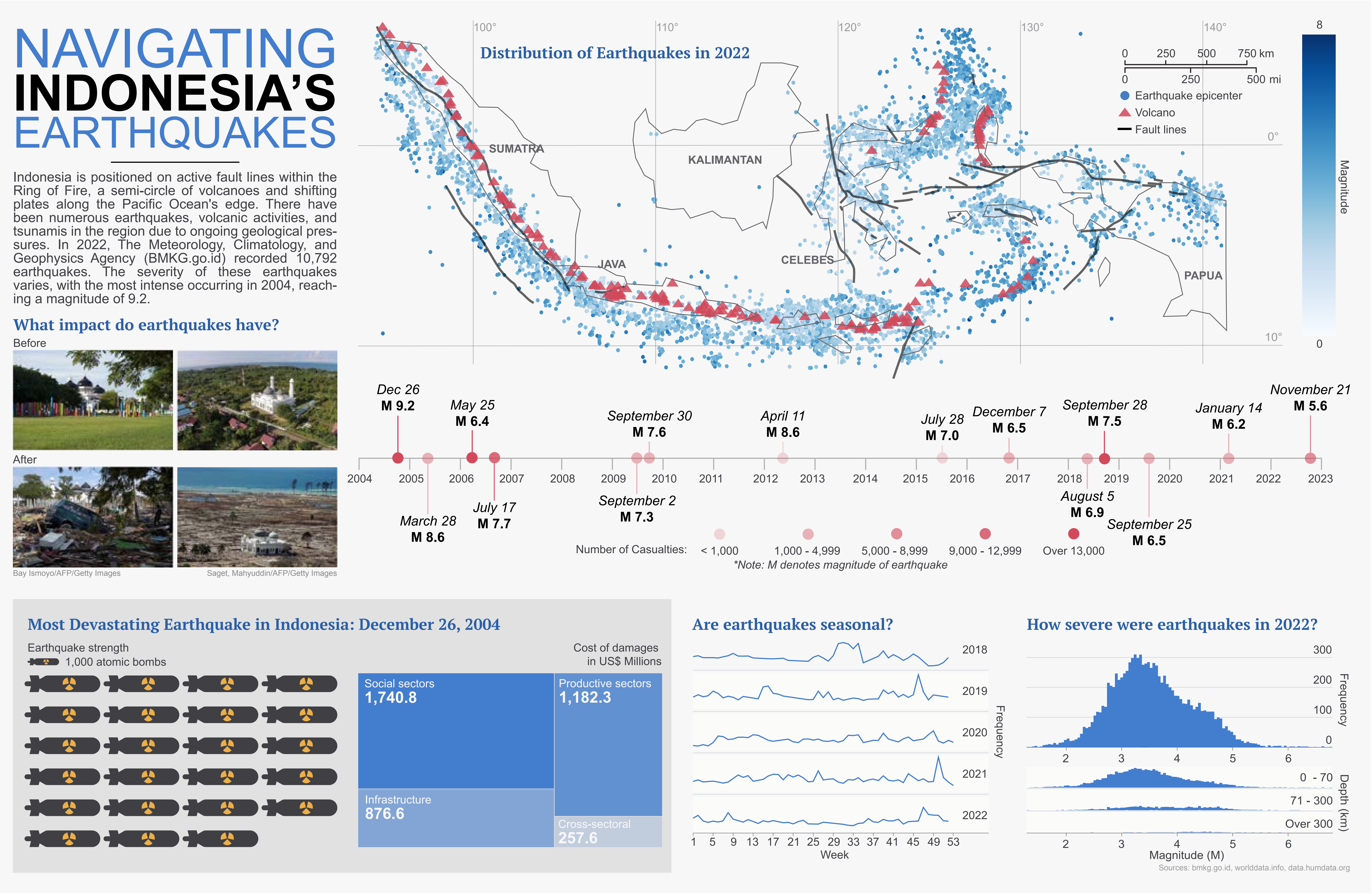
Everybody can (should!) design



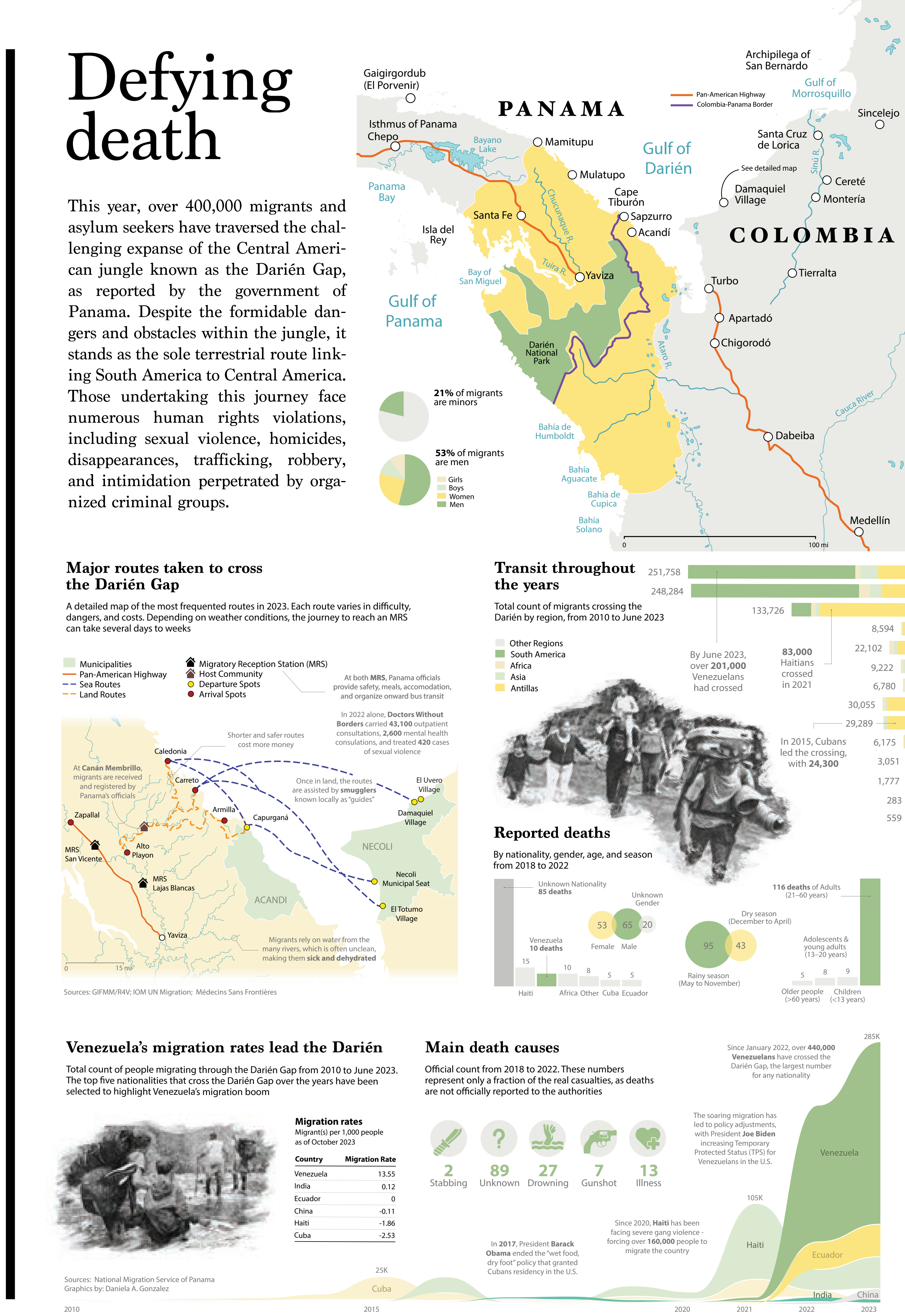
Modern literacy:

- **Literacy**
- **Articulacy**
- **Numeracy**
- **Graphicacy**

The same way that anyone can learn to **write** well, anyone can learn to **design** and **visualize** well



Poster by Michela Effendi



Poster by Daniela González

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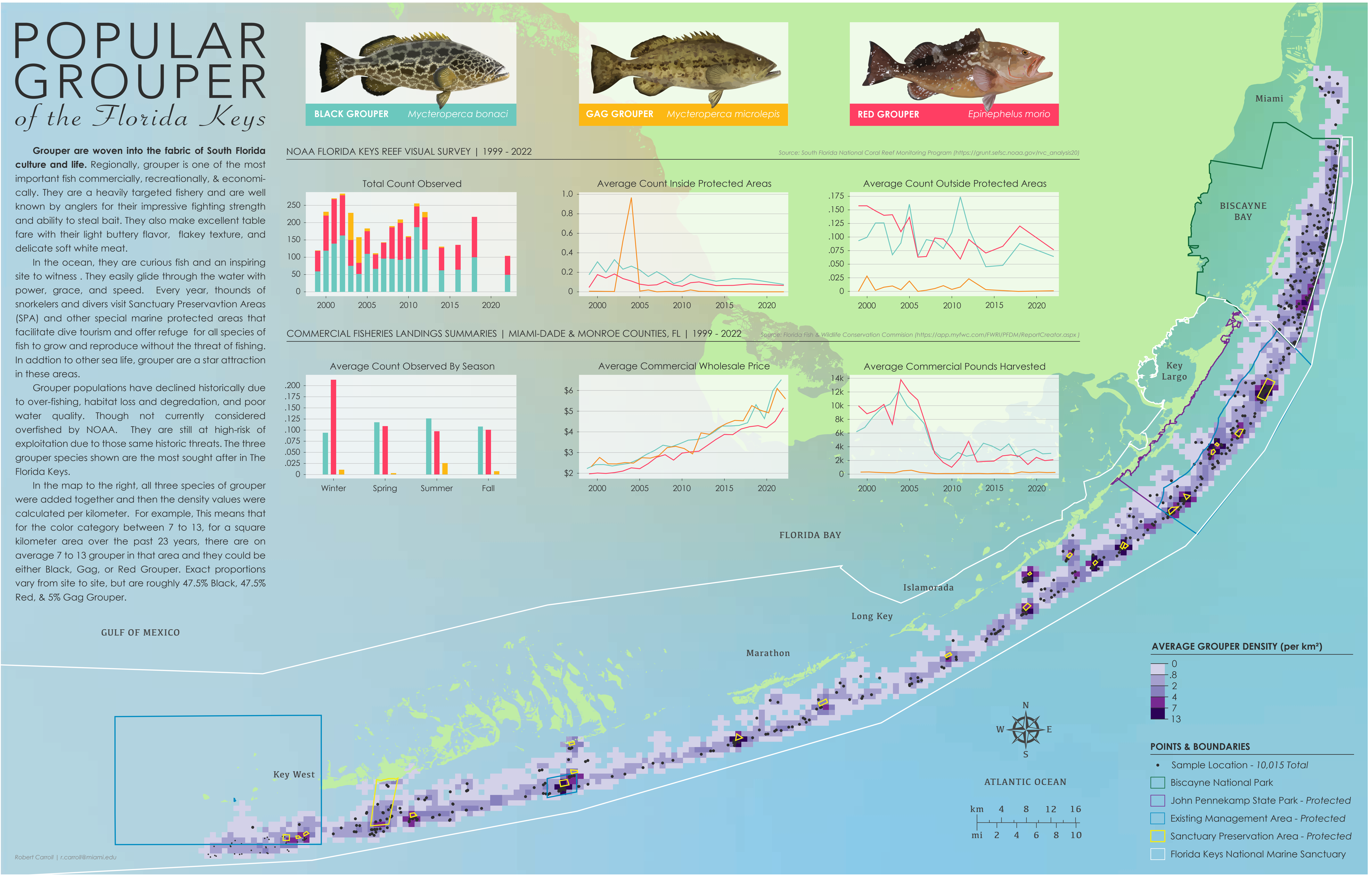
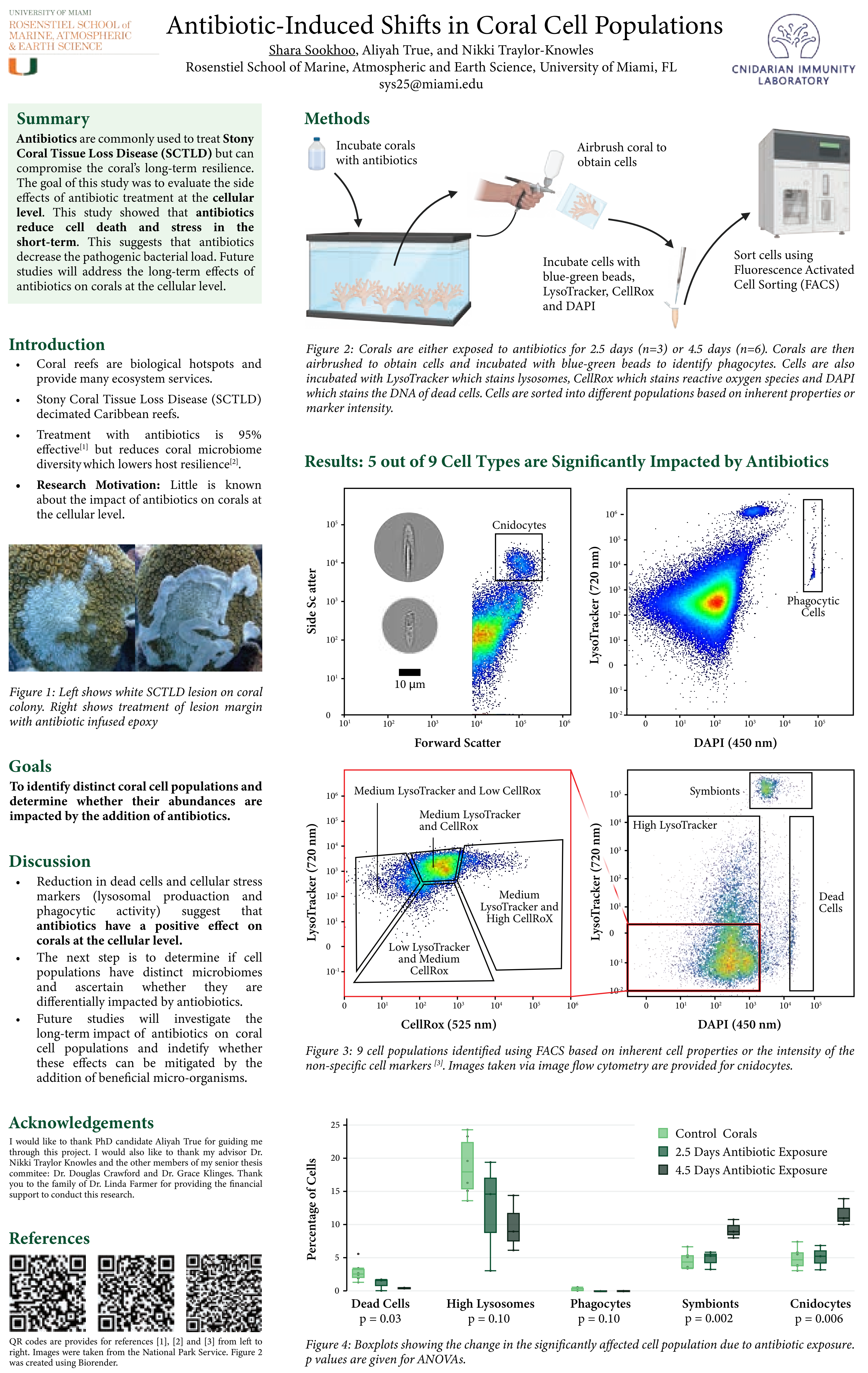


Poster by Robert Carroll



Poster by Shara Sokhoo

The same way that anyone can learn to **write** well, anyone can learn to **design** and **visualize** well

It does require some effort, though…

SK [redacted]

To: Cairo, Alberto

Wed 4/26/2023 5:08 PM

I have really enjoyed this course, wanted to pull my hair out many times, but it has completely changed the way I think about charts and design.

Poster by Robert Carroll

Poster by Shara Sokhoo

“…It has completely changed the way I think about charts and design.”

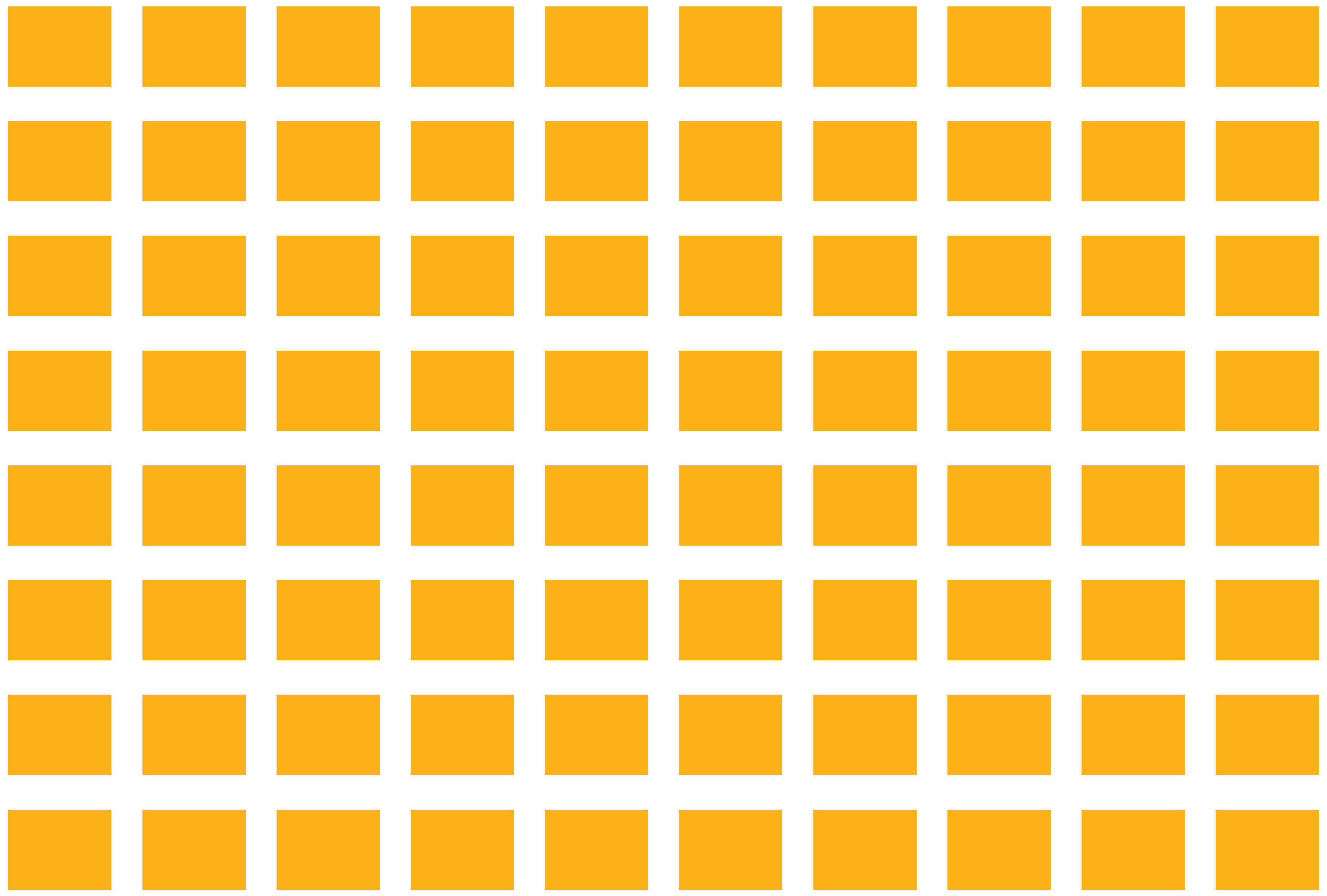
Spoiler alert: Like the class that changed this student’s mind, these three webinars aren’t about ***how to*** make visualizations.

They are about ***how I*****, an individual designer**, makes visualizations.

The basics of visualization

The type of visualizations I typically design are graphical displays intended to enable either **exploration**, **discovery**, or **communication** by letting us see what we cannot normally see.

We visualize because the human visual brain evolved to detect **patterns**…



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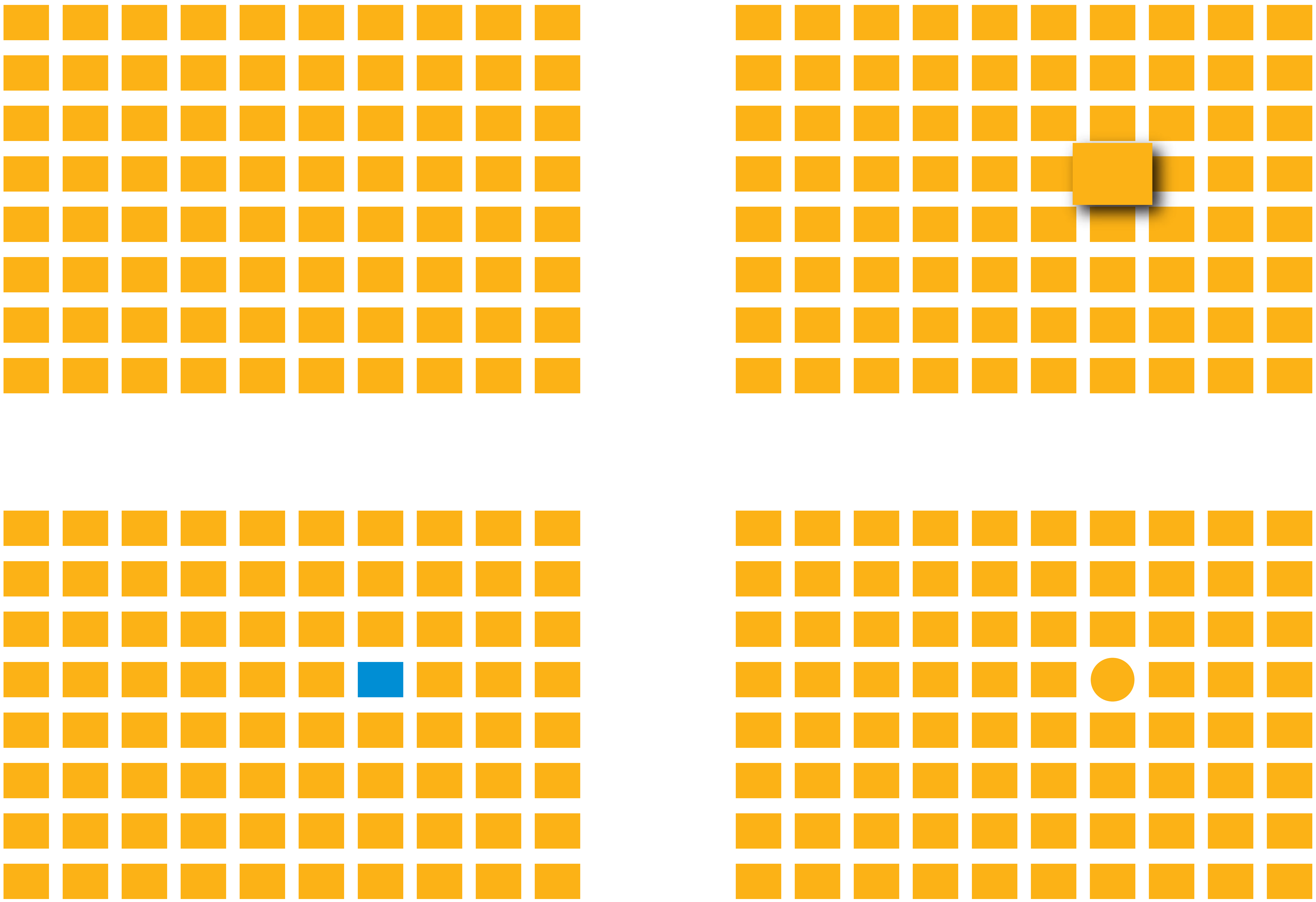
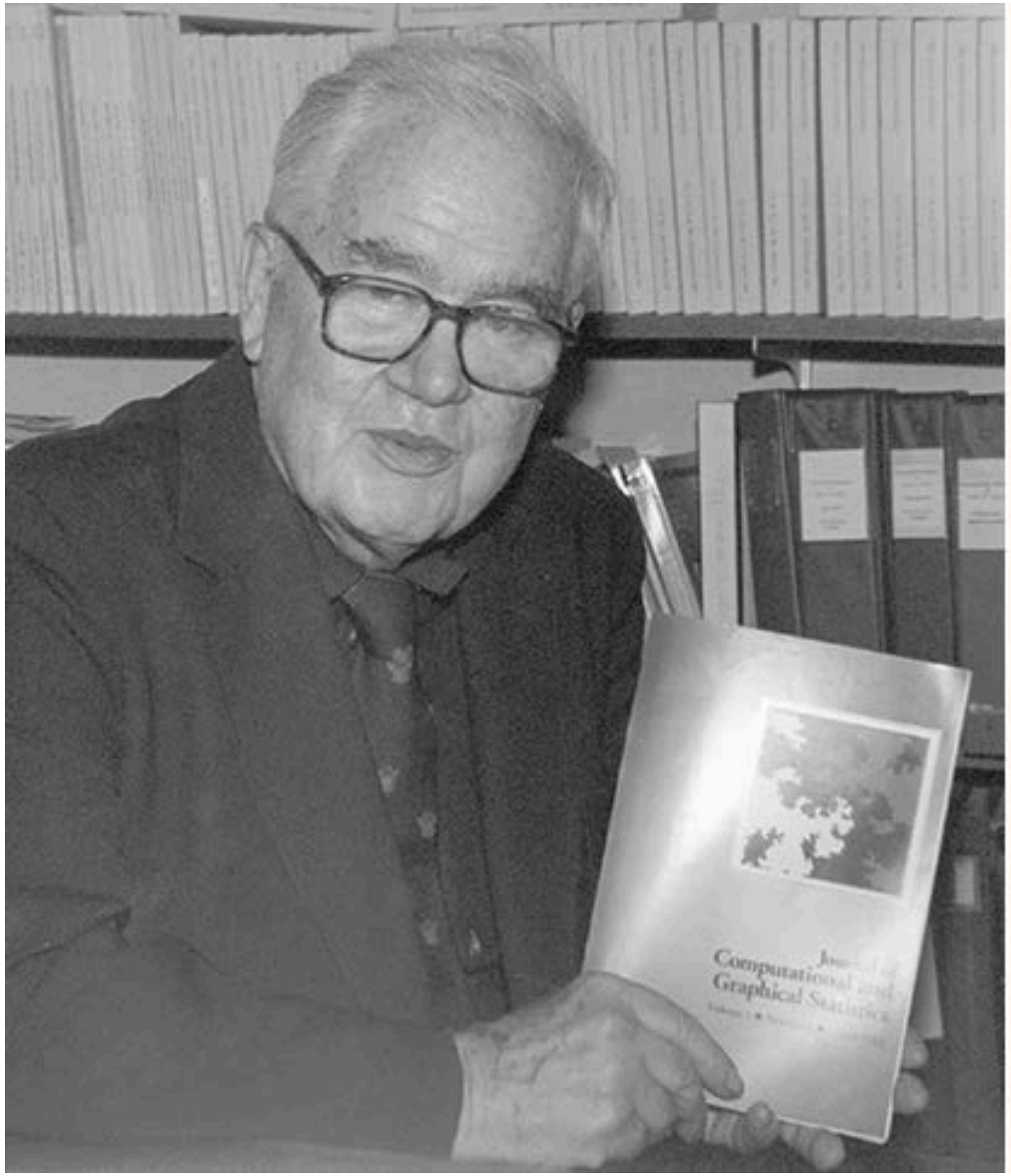
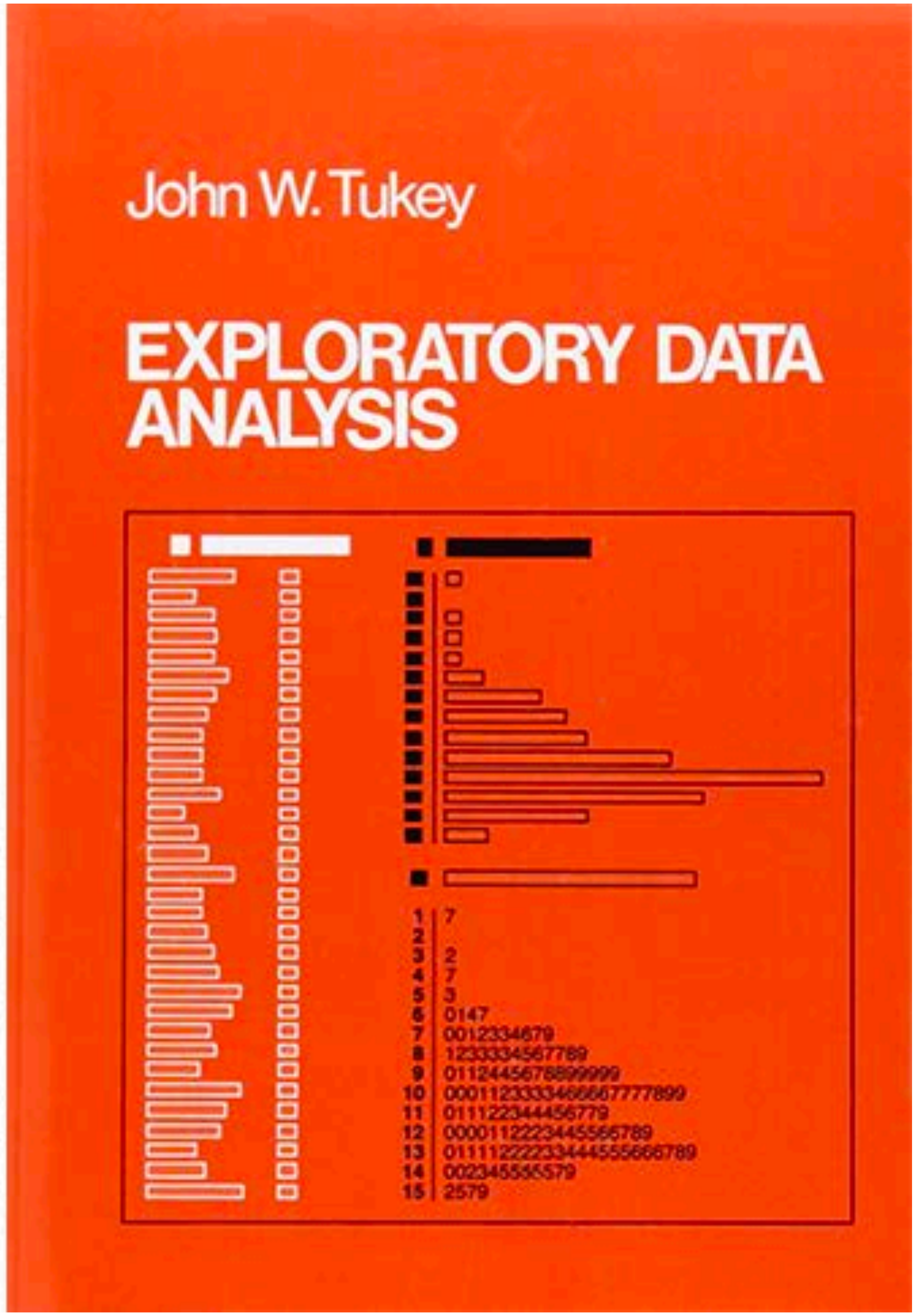


…and the **exceptions** to those patterns.

The relationship between patterns and their exceptions is a key principle of data exploration: to reveal **patterns and trends**, but also the **exceptions** to them.





"The greatest value of a picture is when it forces us to notice what we never expected to see."

John W. Tukey

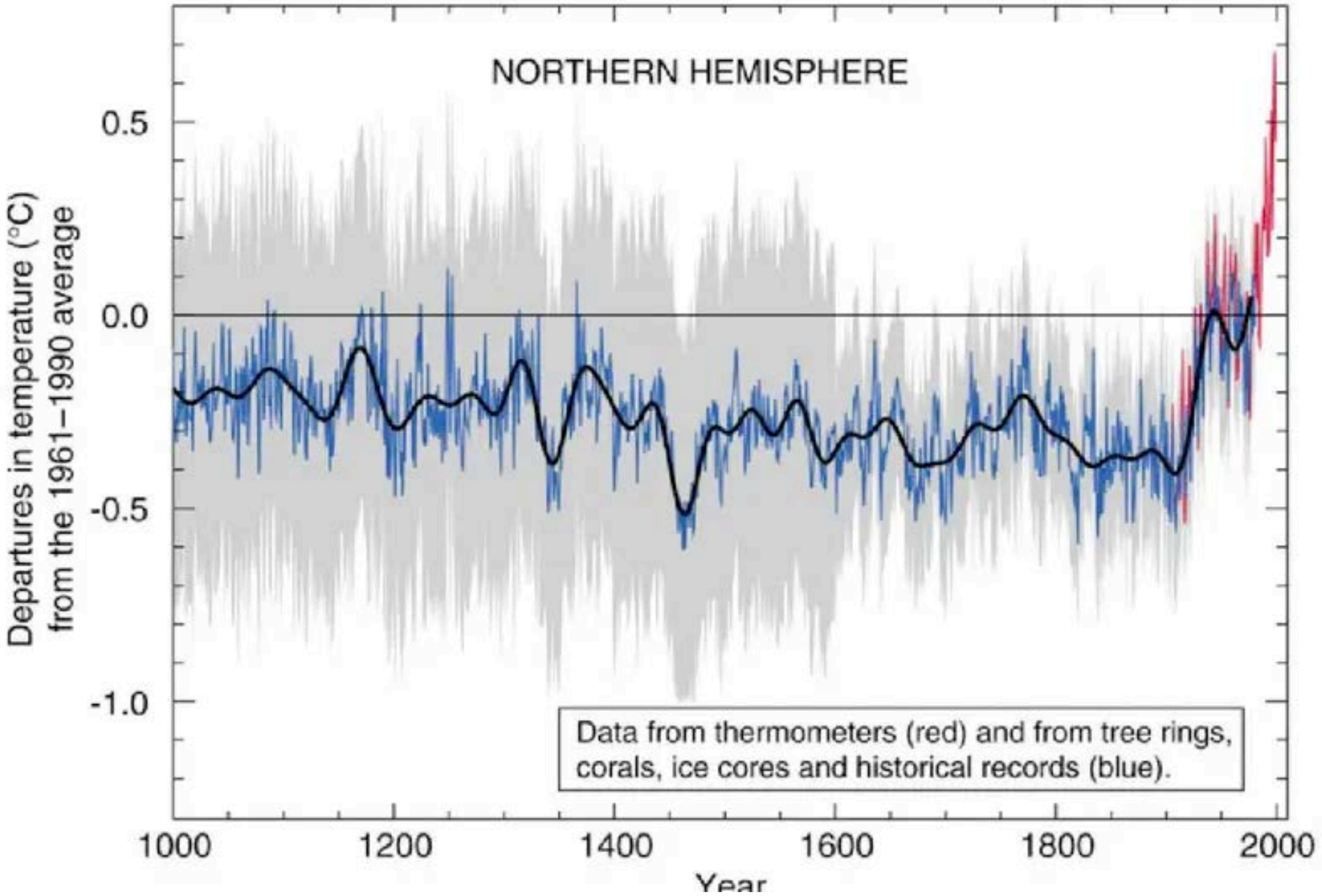
If we want to see each value, show each value…

	A	B	C	D	E	F	G
1	YEAR	TEMP	YEAR 1 SIGMA 2 SIGMA				
2	1000	0.0659	1000	0.240346	0.480693	0.206137	0.123588
3	1001	-0.1241	1001	0.240347	0.480694	0.206137	0.123589
4	1002	-0.1208	1002	0.240346	0.480692	0.206136	0.123588
5	1003	-0.1801	1003	0.240347	0.480694	0.206137	0.123589
6	1004	-0.0711	1004	0.240347	0.480693	0.206137	0.123588
7	1005	-0.1334	1005	0.240346	0.480692	0.206136	0.123588
8	1006	-0.0644	1006	0.240346	0.480693	0.206137	0.123588
9	1007	0.0042	1007	0.240347	0.480693	0.206137	0.123588
10	1008	-0.1288	1008	0.240347	0.480693	0.206137	0.123588
11	1009	-0.0296	1009	0.240347	0.480693	0.206137	0.123588
12	1010	0.1187	1010	0.240347	0.480694	0.206137	0.123589
13	1011	-0.1252	1011	0.240346	0.480692	0.206136	0.123588
14	1012	-0.1634	1012	0.240347	0.480694	0.206137	0.123588
15	1013	-0.0791	1013	0.240347	0.480693	0.206137	0.123588
16	1014	-0.1120	1014	0.240347	0.480693	0.206137	0.123588
17	1015	-0.1146	1015	0.240346	0.480692	0.206136	0.123588
18	1016	-0.1206	1016	0.240346	0.480692	0.206136	0.123588
19	1017	-0.0815	1017	0.240347	0.480693	0.206137	0.123588
20	1018	-0.2031	1018	0.240346	0.480693	0.206137	0.123588
21	1019	0.0305	1019	0.240347	0.480693	0.206137	0.123588
22	1020	0.1098	1020	0.240347	0.480694	0.206137	0.123589
23	1021	0.0244	1021	0.240347	0.480693	0.206137	0.123588
24	1022	-0.0743	1022	0.240347	0.480693	0.206137	0.123588
25	1023	-0.0323	1023	0.240347	0.480693	0.206137	0.123588
26	1024	-0.0434	1024	0.240346	0.480693	0.206137	0.123588

	A	B	C	D	E	F	G
878	1876	-0.1891	1876	0.113228	0.226456	8.25297E-02	7.75207E-02
879	1877	-0.0140	1877	0.113228	0.226457	8.25299E-02	7.75209E-02
880	1878	-0.0873	1878	0.113228	0.226457	8.25298E-02	7.75209E-02
881	1879	-0.2959	1879	0.113229	0.226458	8.25302E-02	7.75212E-02
882	1880	-0.2368	1880	0.113229	0.226457	8.25300E-02	7.75210E-02
883	1881	-0.1977	1881	0.113229	0.226458	8.25302E-02	7.75212E-02
884	1882	-0.2036	1882	0.113229	0.226457	8.25300E-02	7.75210E-02
885	1883	-0.2489	1883	0.113228	0.226455	8.25293E-02	7.75204E-02
886	1884	-0.2125	1884	0.113229	0.226457	8.25301E-02	7.75211E-02
887	1885	-0.1896	1885	0.113228	0.226457	8.25299E-02	7.75210E-02
888	1886	-0.1084	1886	0.113228	0.226456	8.25298E-02	7.75208E-02
889	1887	-0.3265	1887	0.113228	0.226456	8.25296E-02	7.75206E-02
890	1888	-0.1694	1888	0.113228	0.226457	8.25298E-02	7.75209E-02
891	1889	-0.1339	1889	0.113228	0.226456	8.25298E-02	7.75208E-02
892	1890	-0.3107	1890	0.113229	0.226457	8.25301E-02	7.75211E-02
893	1891	-0.1754	1891	0.113229	0.226457	8.25300E-02	7.75210E-02
894	1892	-0.3186	1892	0.113228	0.226456	8.25295E-02	7.75205E-02
895	1893	-0.3236	1893	0.113228	0.226456	8.25297E-02	7.75207E-02
896	1894	-0.1970	1894	0.113228	0.226456	8.25295E-02	7.75205E-02
897	1895	-0.1578	1895	0.113228	0.226456	8.25297E-02	7.75207E-02
898	1896	-0.0804	1896	0.113228	0.226456	8.25298E-02	7.75208E-02
899	1897	-0.0537	1897	0.113228	0.226456	8.25298E-02	7.75208E-02
900	1898	-0.2195	1898	0.113229	0.226457	8.25301E-02	7.75211E-02
901	1899	-0.3486	1899	0.113228	0.226456	8.25297E-02	7.75207E-02
902	1900	-0.1253	1900	0.113229	0.226457	8.25300E-02	7.75210E-02
903	1901	-0.1575	1901	0.113228	0.226456	8.25296E-02	7.75206E-02

…but if we care more about general patterns and trends than we care about individual values, then we should think about visualizations

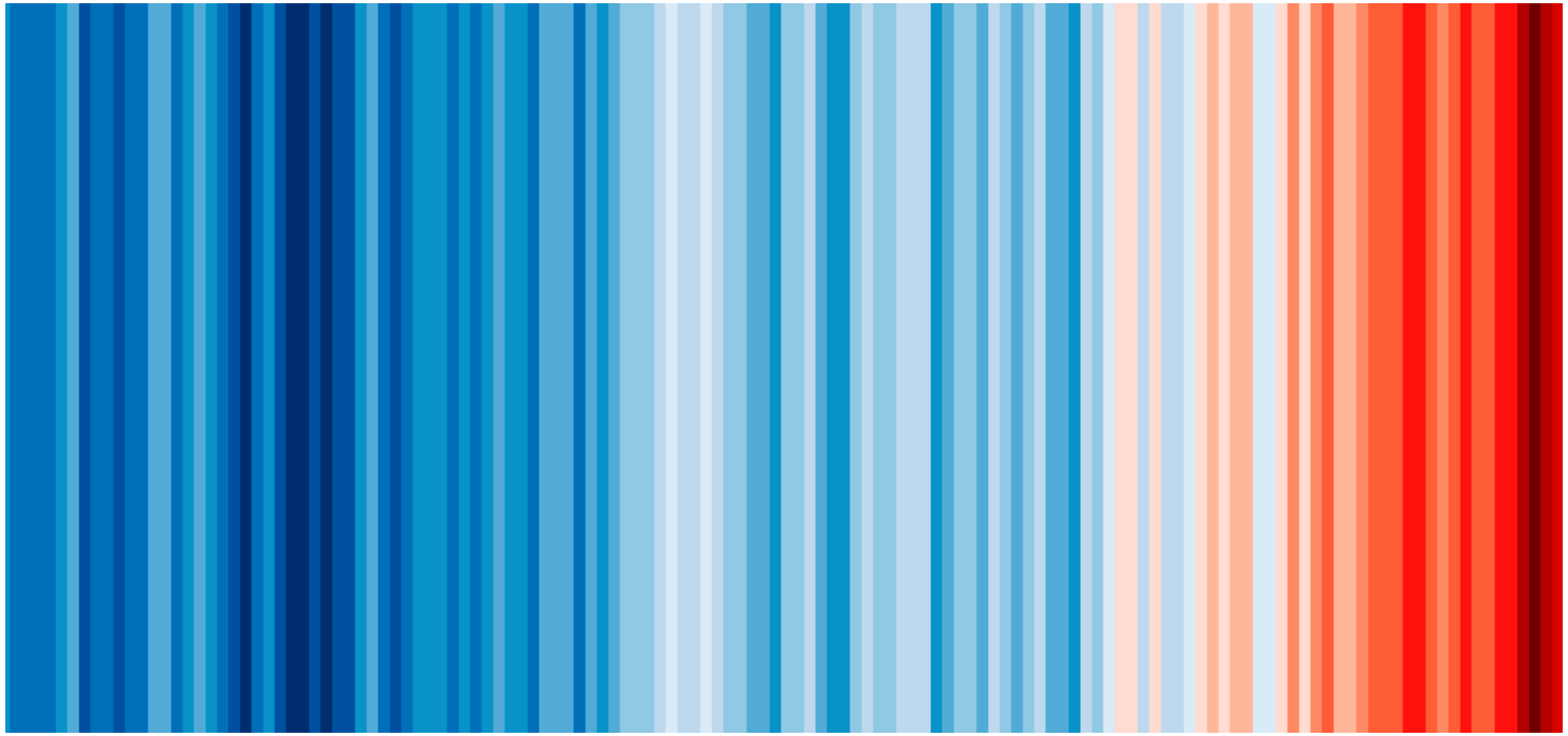
The hockey stick chart



Michael E. Mann, Raymond S. Bradley, and Malcolm K. Hughes

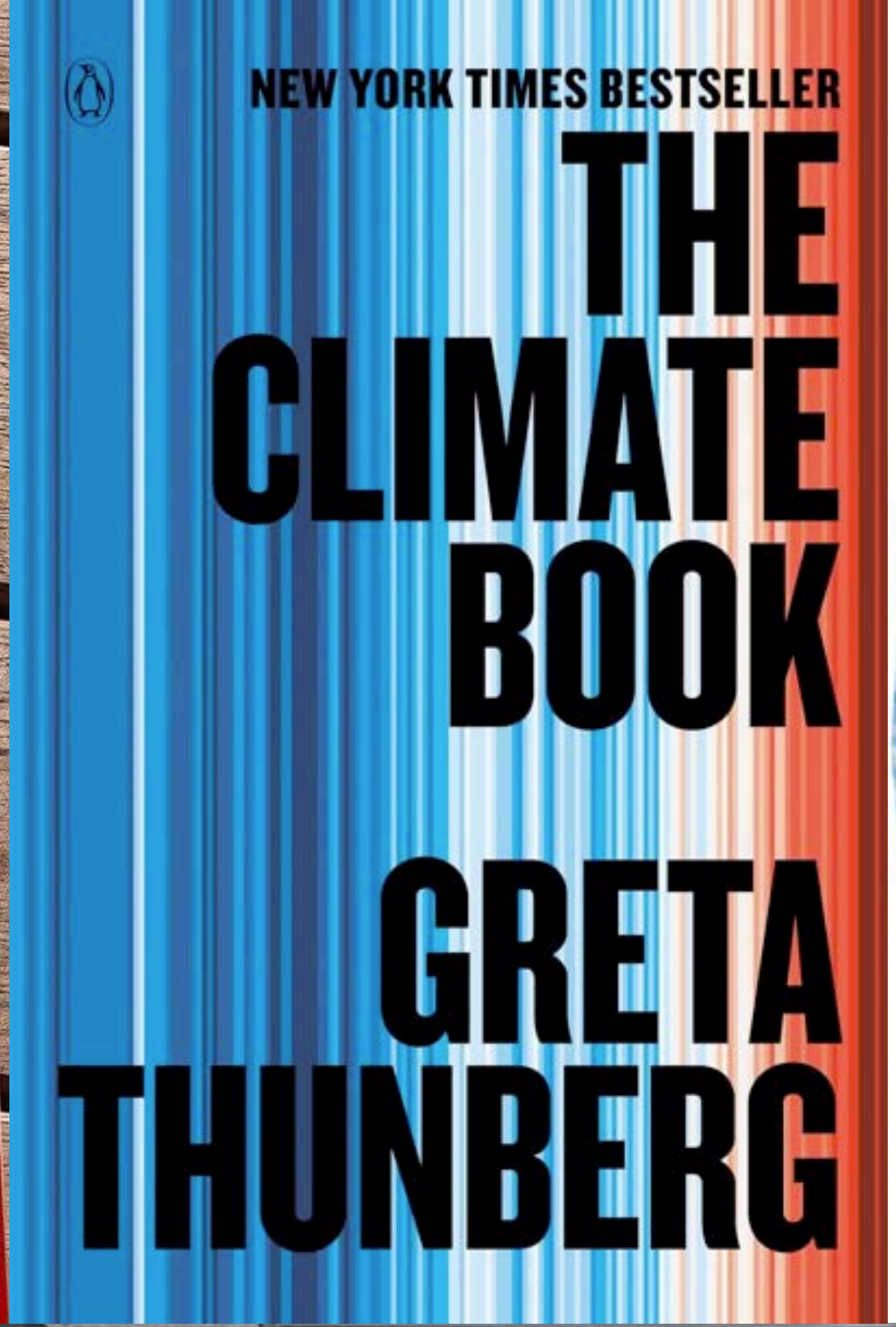
Intergovernmental Panel on Climate Change (IPCC), Third Report, 2001

Ed Hawkins's 'Warming Stripes'



https://showyourstripes.info/s/globe


The Economist
Iran's dangerous game
Lessons from a Wall Street titan
Why rent controls are wrong-headed
Goddess of the Taiwan Strait
SEPTEMBER 21ST–27TH 2019
The climate issue
1850
1900
1950
2000


NEW YORK TIMES BESTSELLER
THE CLIMATE BOOK
GRETA THUNBERG


we're sick of this SHIT
1850
2018

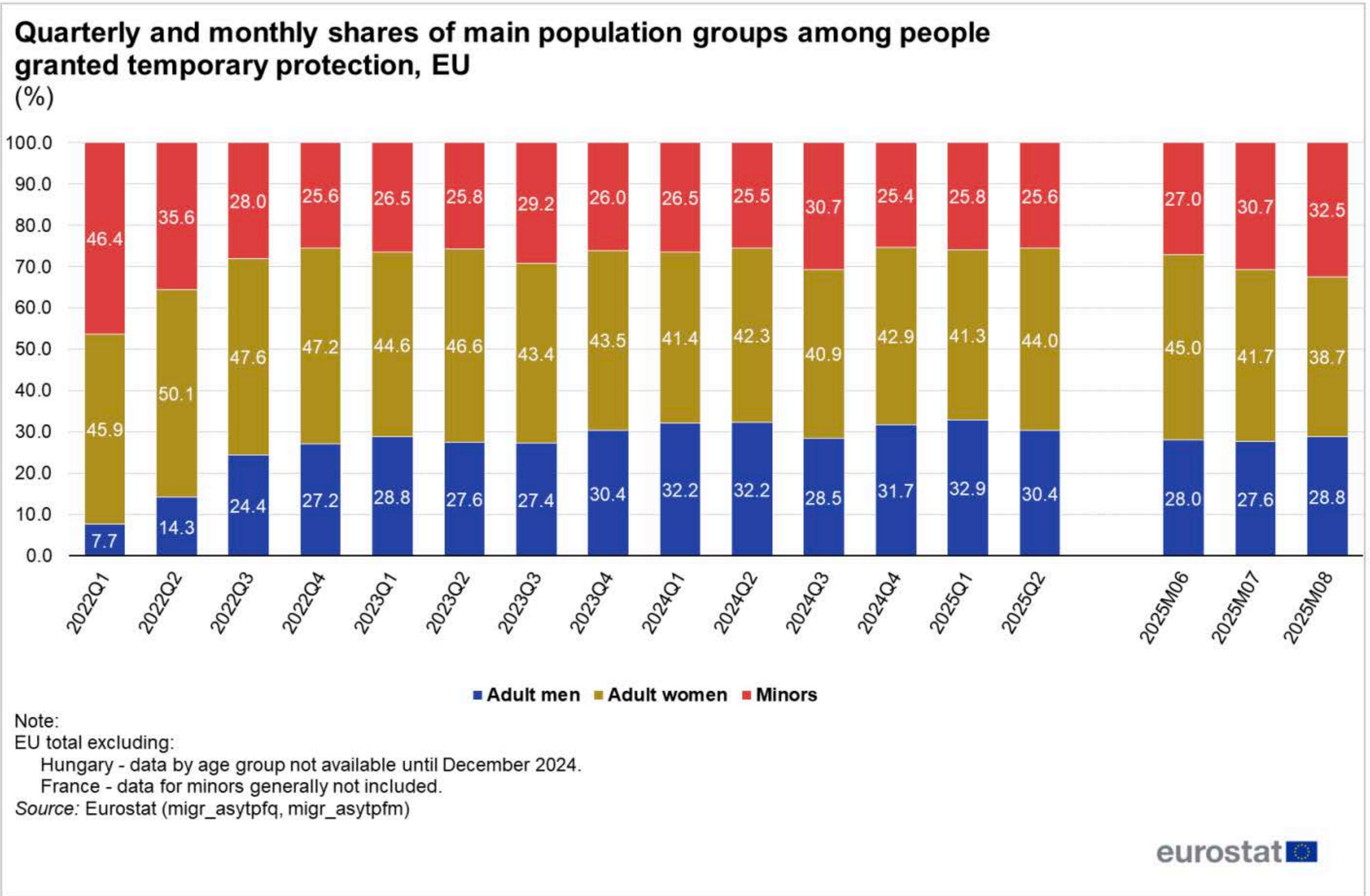


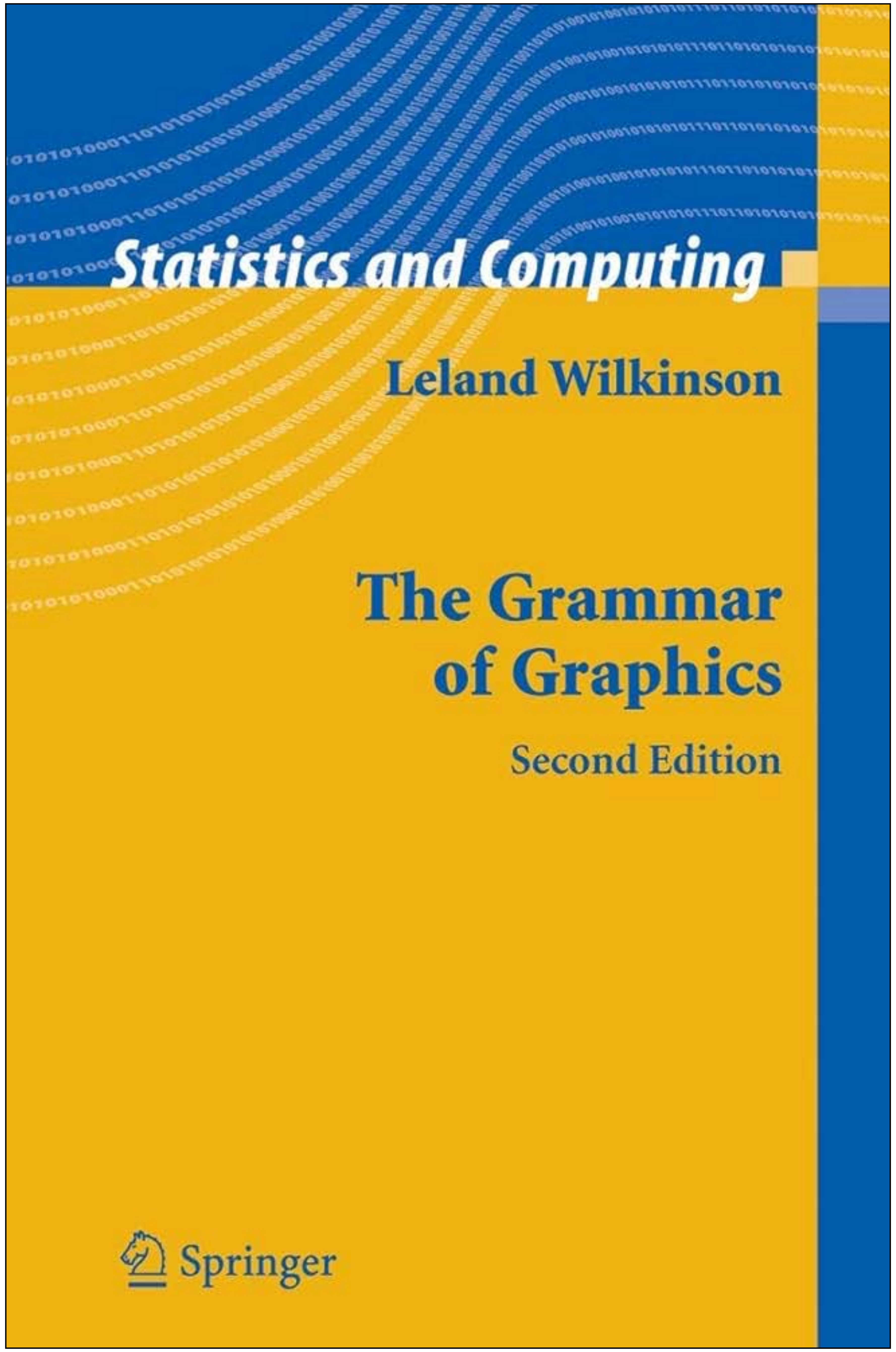
Figure 3: Quarterly and monthly shares of main population groups among people granted temporary protection, EU
Source: Eurostat (migr_asytpfm)

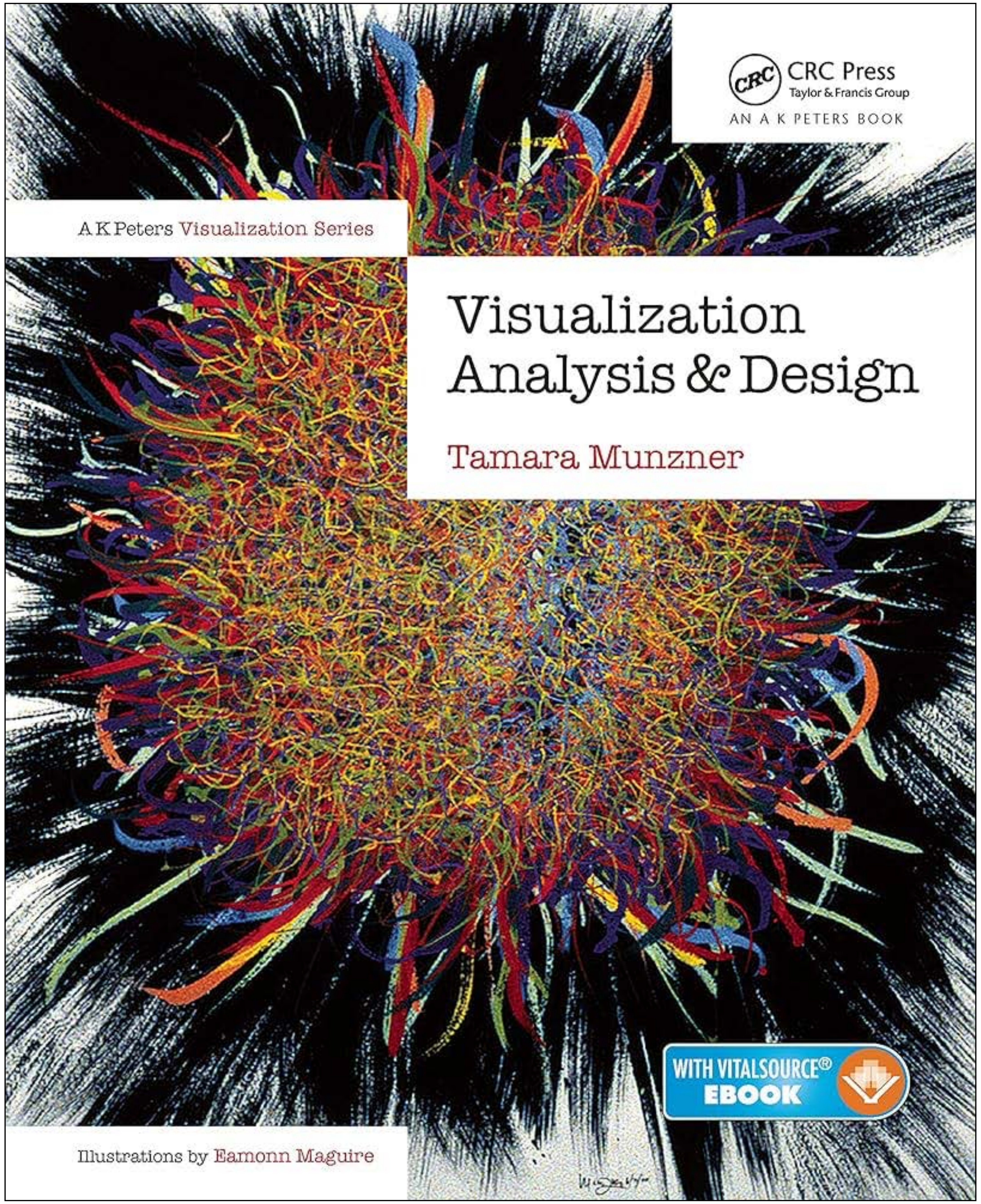
Should we include all figures in a chart? I'd say: Only if we have a very good reason to.

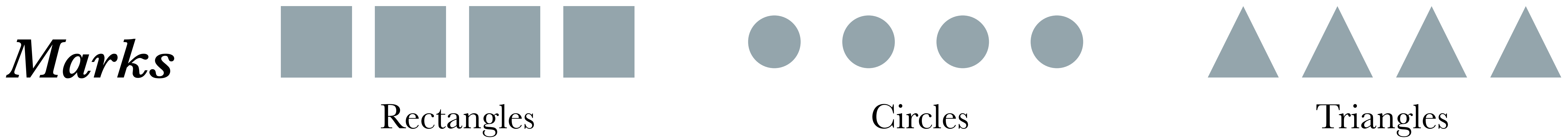
If not, it's better to design a table.

https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Temporary_protection_for_persons_fleeing_Ukraine_-_monthly_statistics

The grammar of graphics

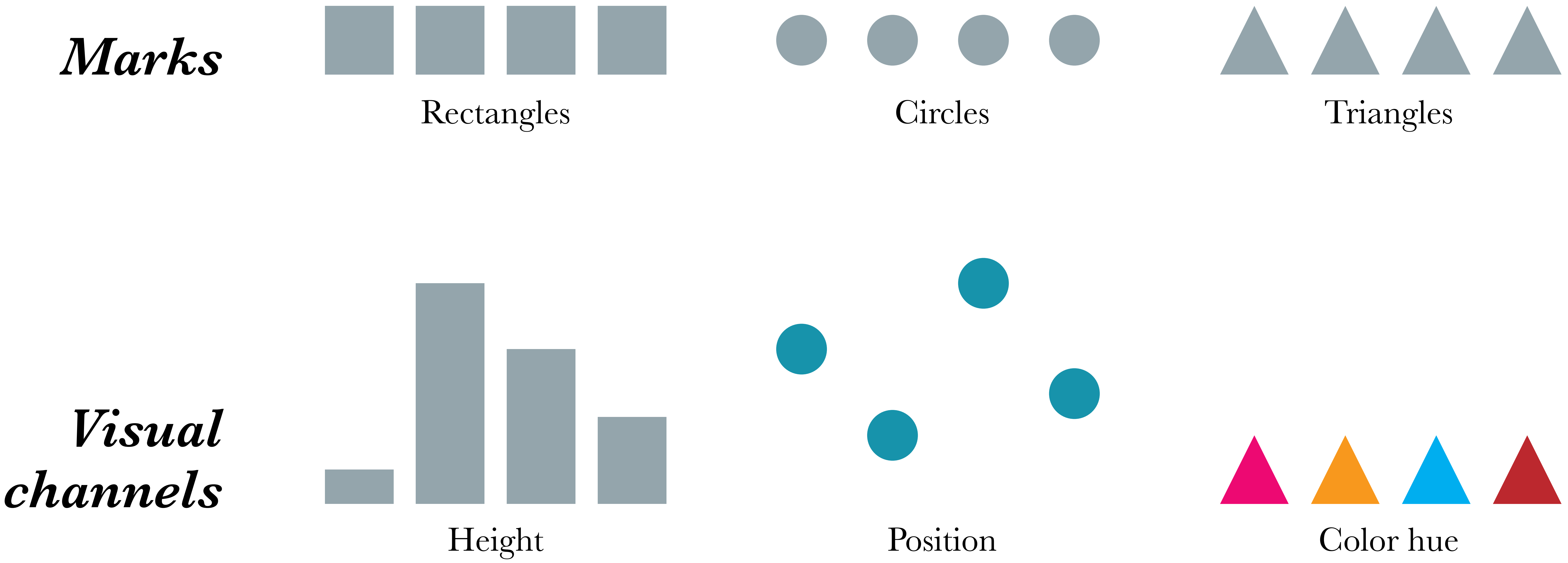

Statistics and Computing
Leland Wilkinson
The Grammar of Graphics
Second Edition
Springer


CRC Press
Taylor & Francis Group
AN A K PETERS BOOK
A K Peters Visualization Series
Visualization Analysis & Design
Tamara Munzner
WITH VITALSOURCE® EBOOK
Illustrations by Eamonn Maguire



Encoding data

Data visualization consists of mapping data onto attributes of objects—commonly abstract shapes, called **“marks”**.



Encoding data

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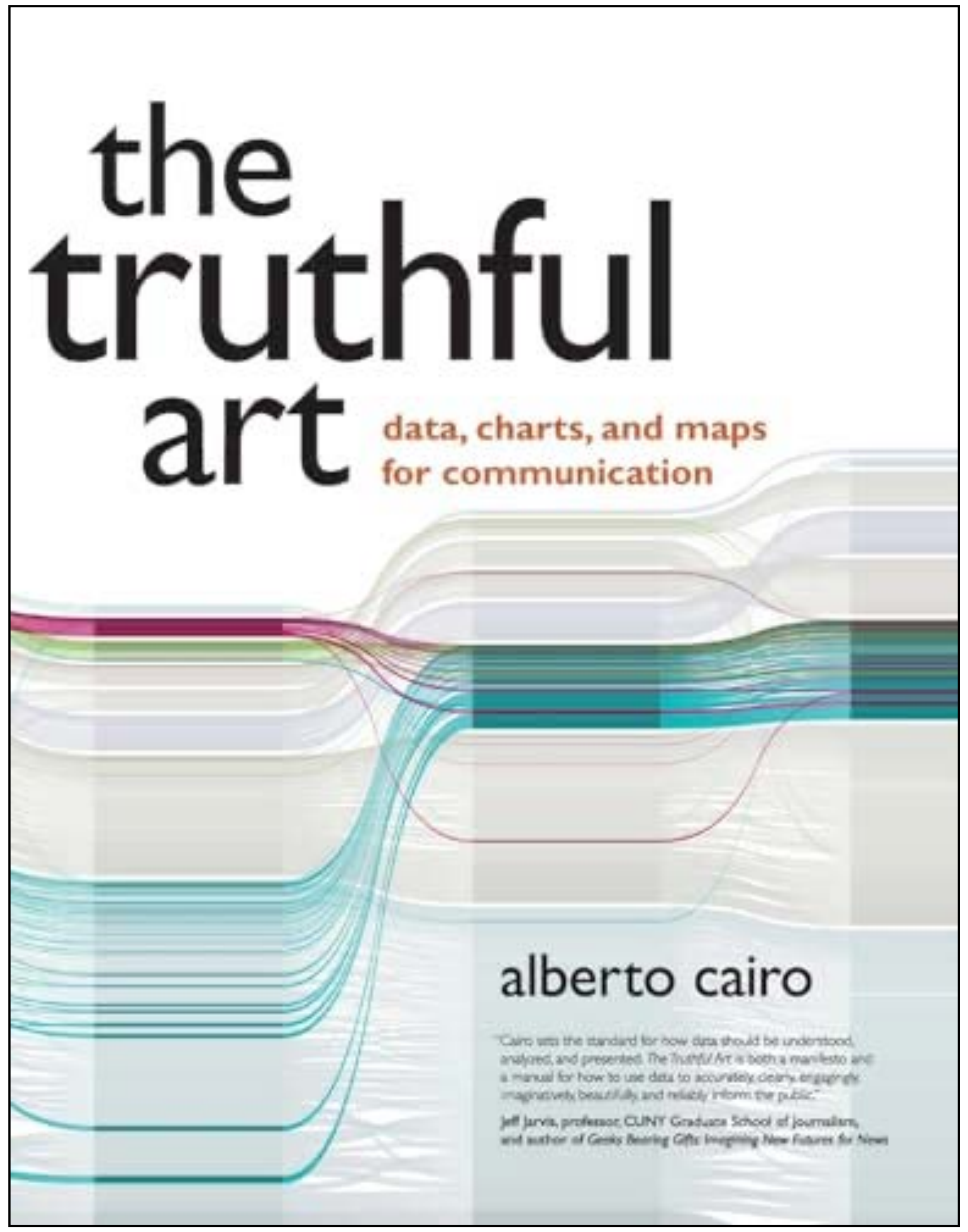
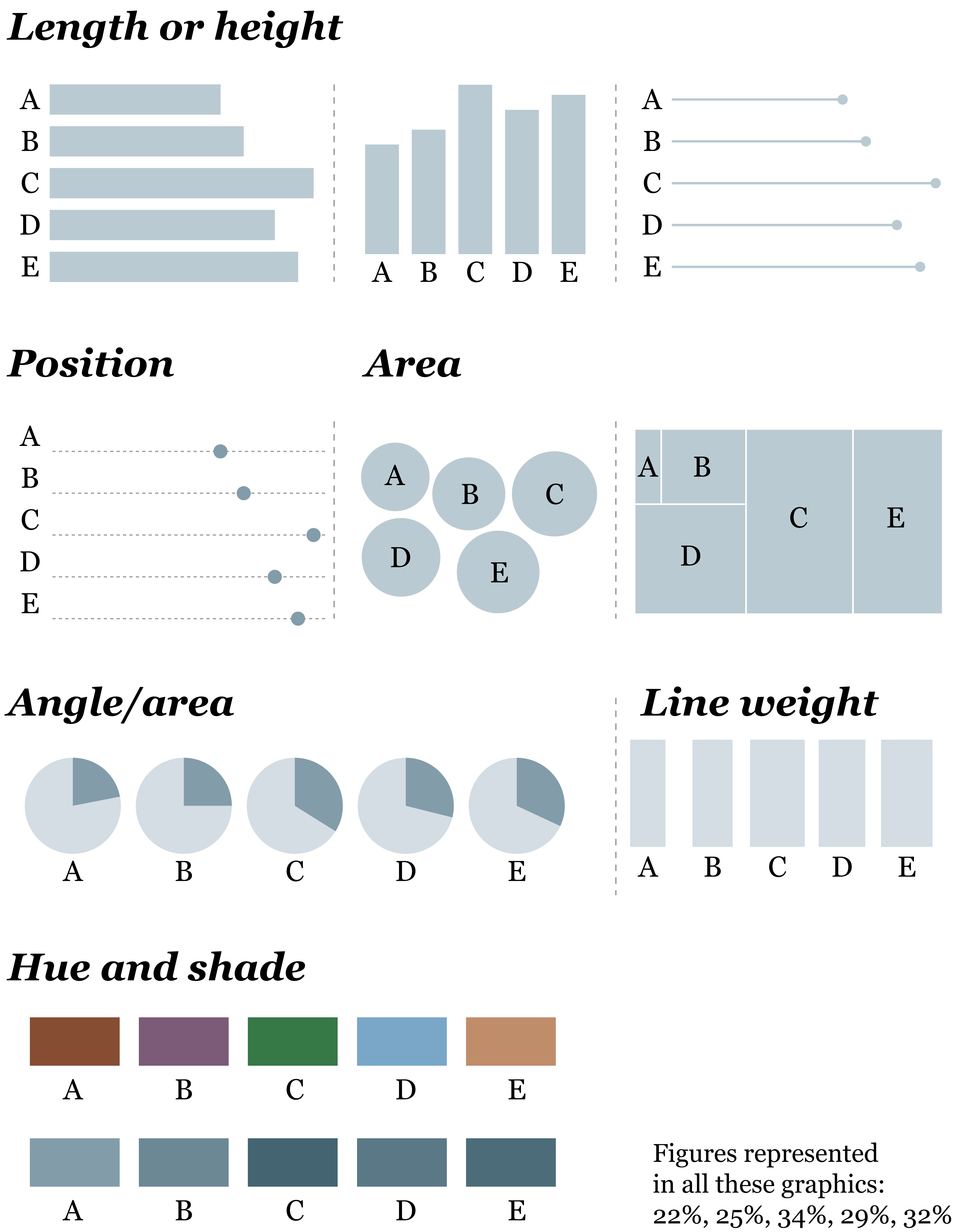
These attributes that vary in relation to the data are called **“visual channels”.**





Encoding data

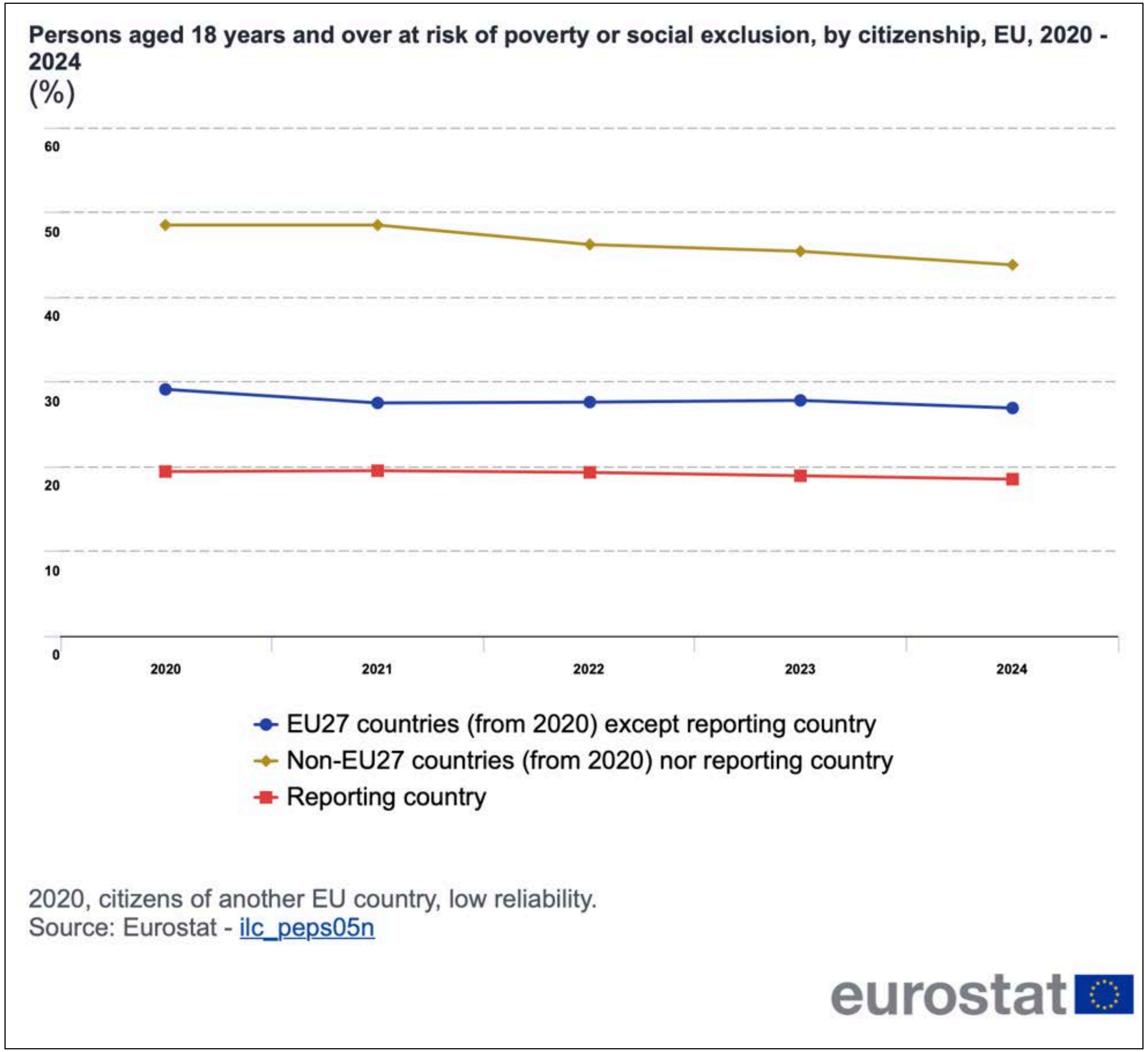
Data visualization consists of mapping data onto attributes of objects—commonly abstract shapes, called **"marks"**.

These attributes that vary in relation to the data are called **"visual channels".**

What visual channels do you see here?

https://facts-and-figures.europarl.europa.eu/snapshot/term-10/current

What visual channels do you see here?



https://ec.europa.eu/eurostat/statistics-explained/index.php

Something I hear often:

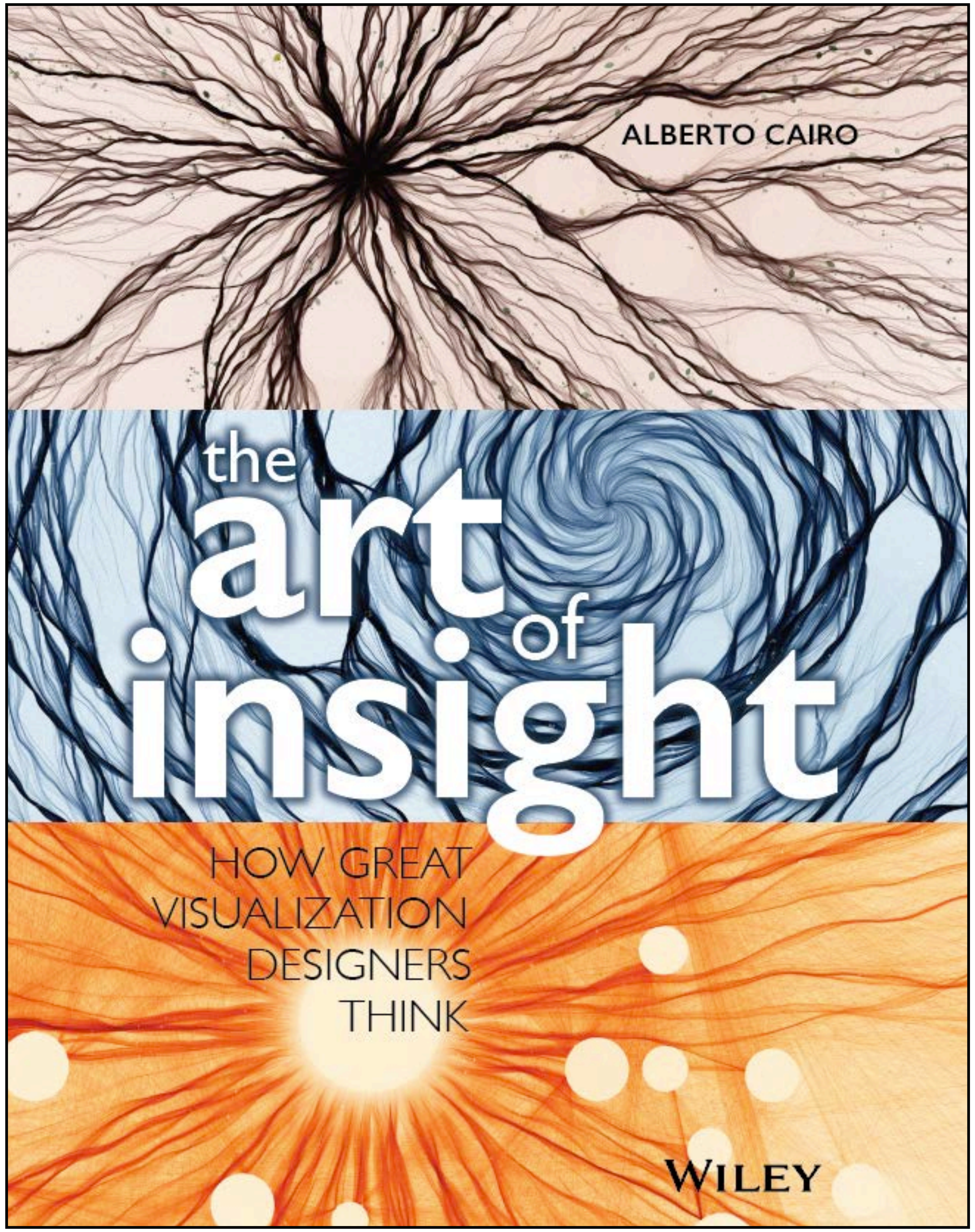
"OK, let's cut to the chase: What are the rules of data visualization?"

Visualization is **similar to writing** in many ways.

First, it's based on a vocabulary and a grammar.

Second, **there are few "rules" that are set in stone and that can be memorized** when it comes to designing visualizations. **It's not that easy!** Like writing, this is a craft takes time, dedication, study, and practice to master.

Third —again like writing— visualization **can be used for many purposes**: Communication, reasoning, exploration, or even artistic expression.



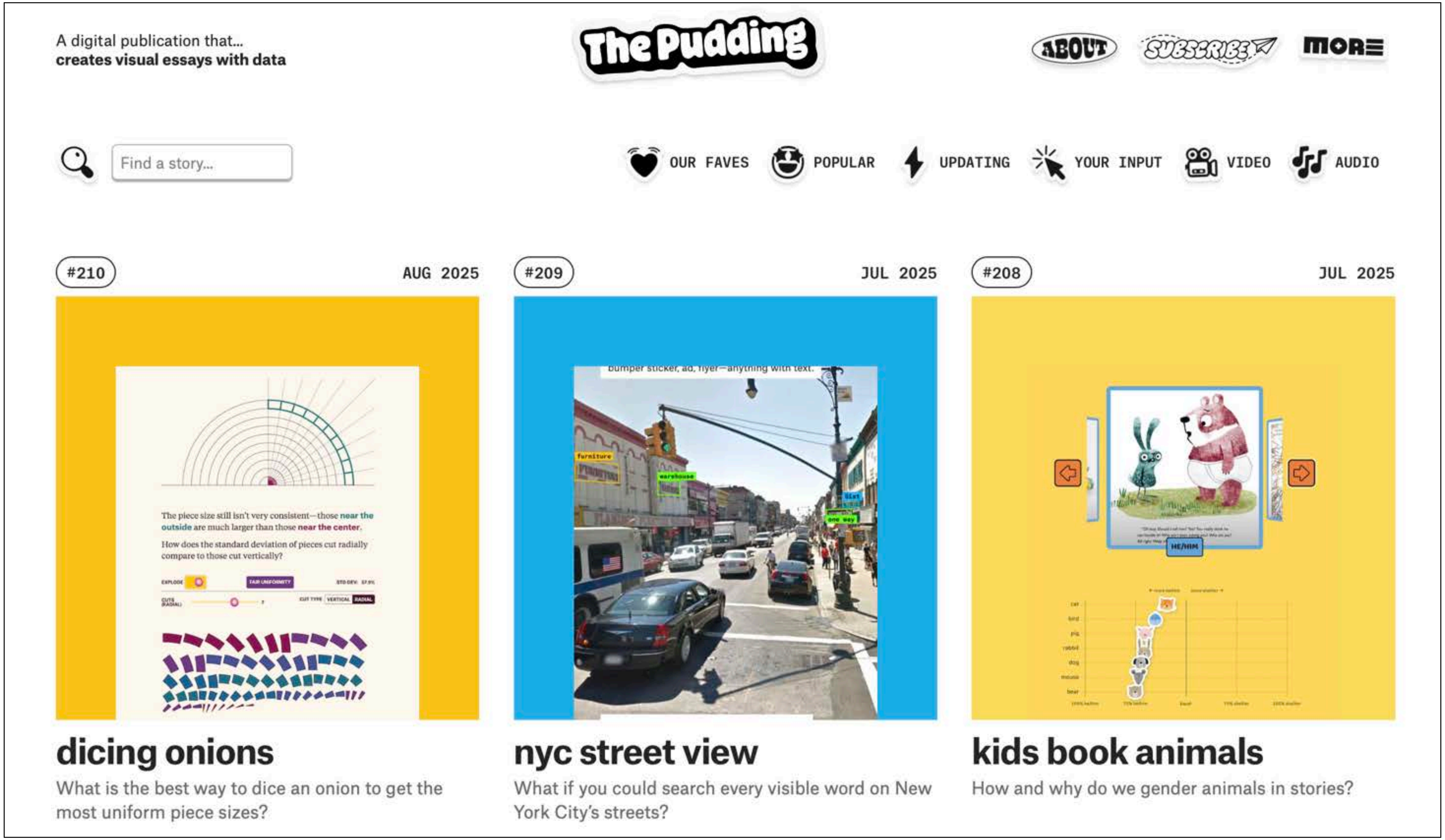
Visualization design consists of **reasoning** about possible **choices** by considering the interplay between:

1. **Content:** The nature, origin, and limitations of the data.
2. **People:** Your audience.
3. **Intent:** The purpose(s) that we define.
4. **Constraints:** The limitations that we may face.
5. **Outcomes:** How the graphic is received.

Every design choice must be **deliberate.**

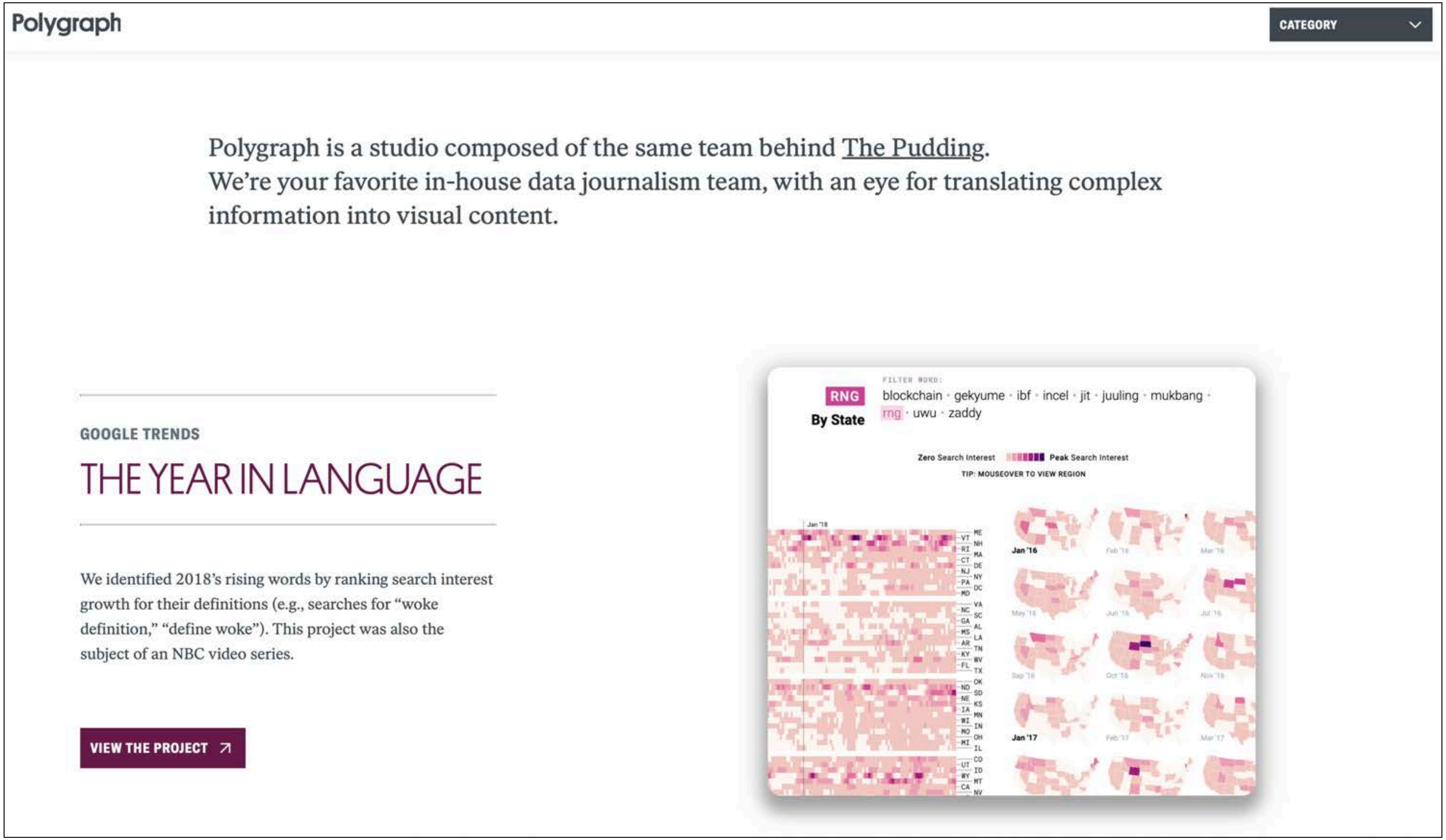
It is inevitably **subjective**, but it should never be **arbitrary**.

Aside: Reading recommendation



https://pudding.cool/

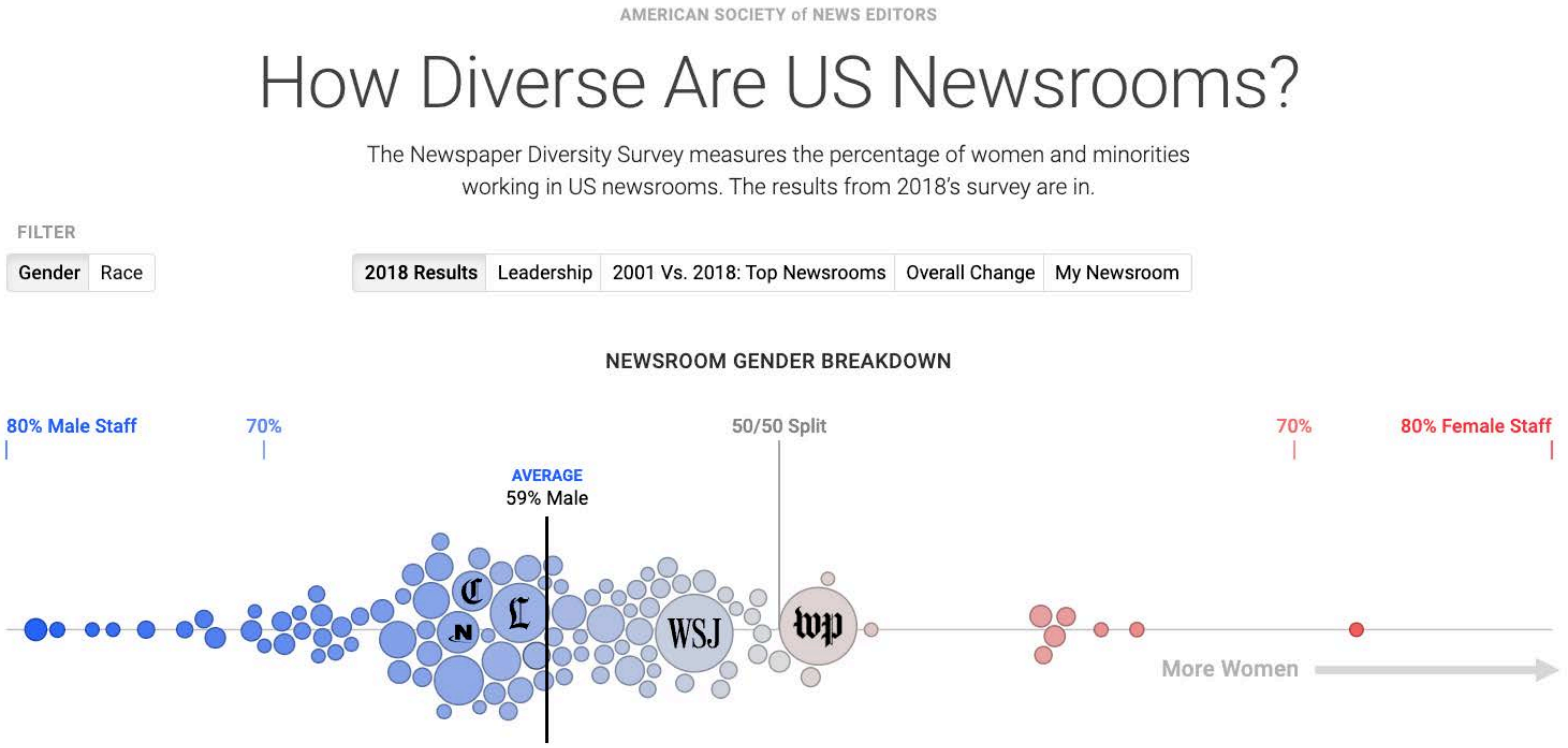
Aside: Reading recommendation



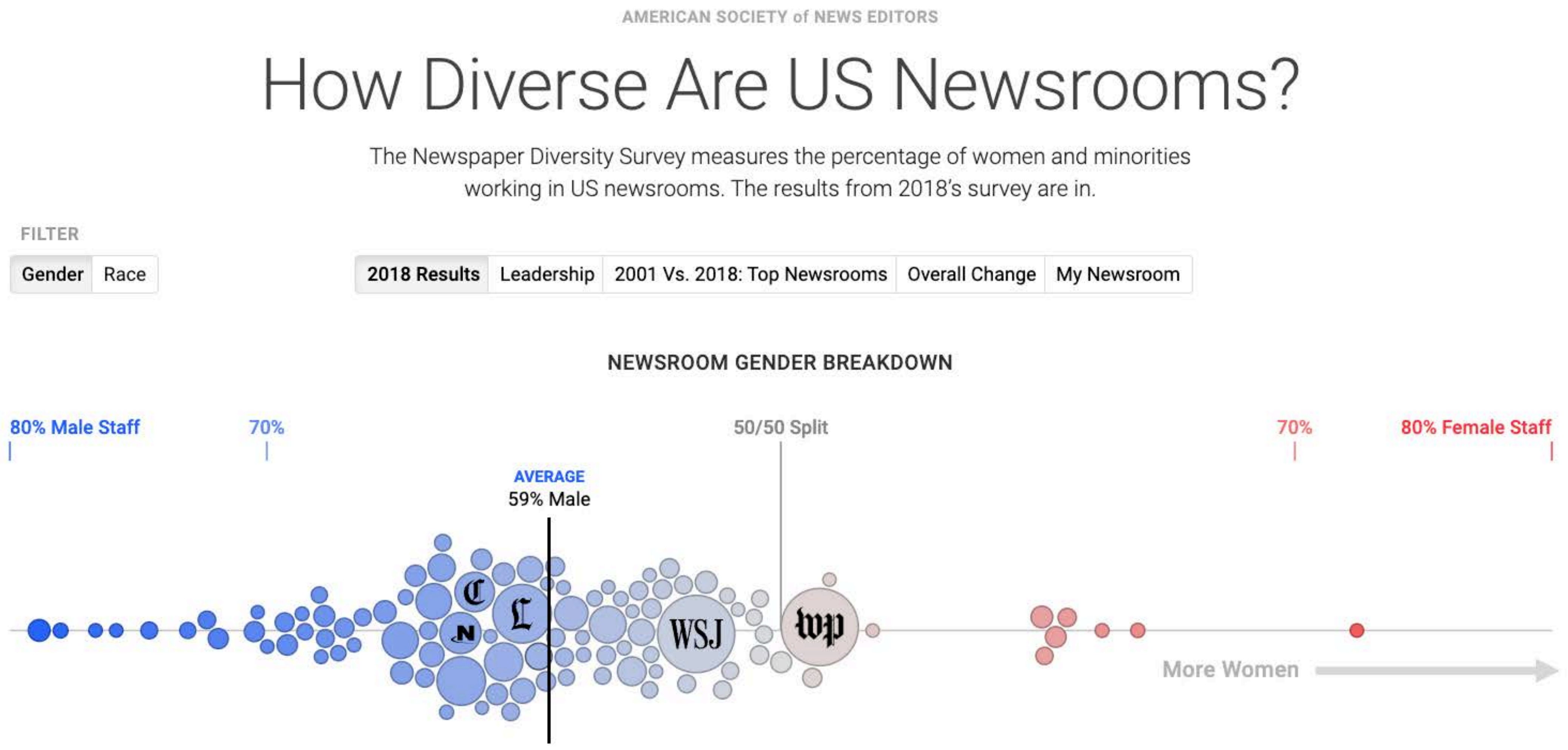
https://polygraph.cool/

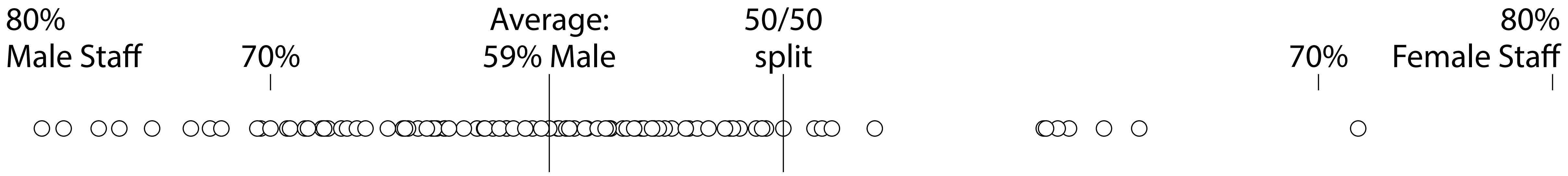
A good exercise: To reverse-engineer existing visualizations

"If I were the designer who created this, what choices would lead me to this solution?"



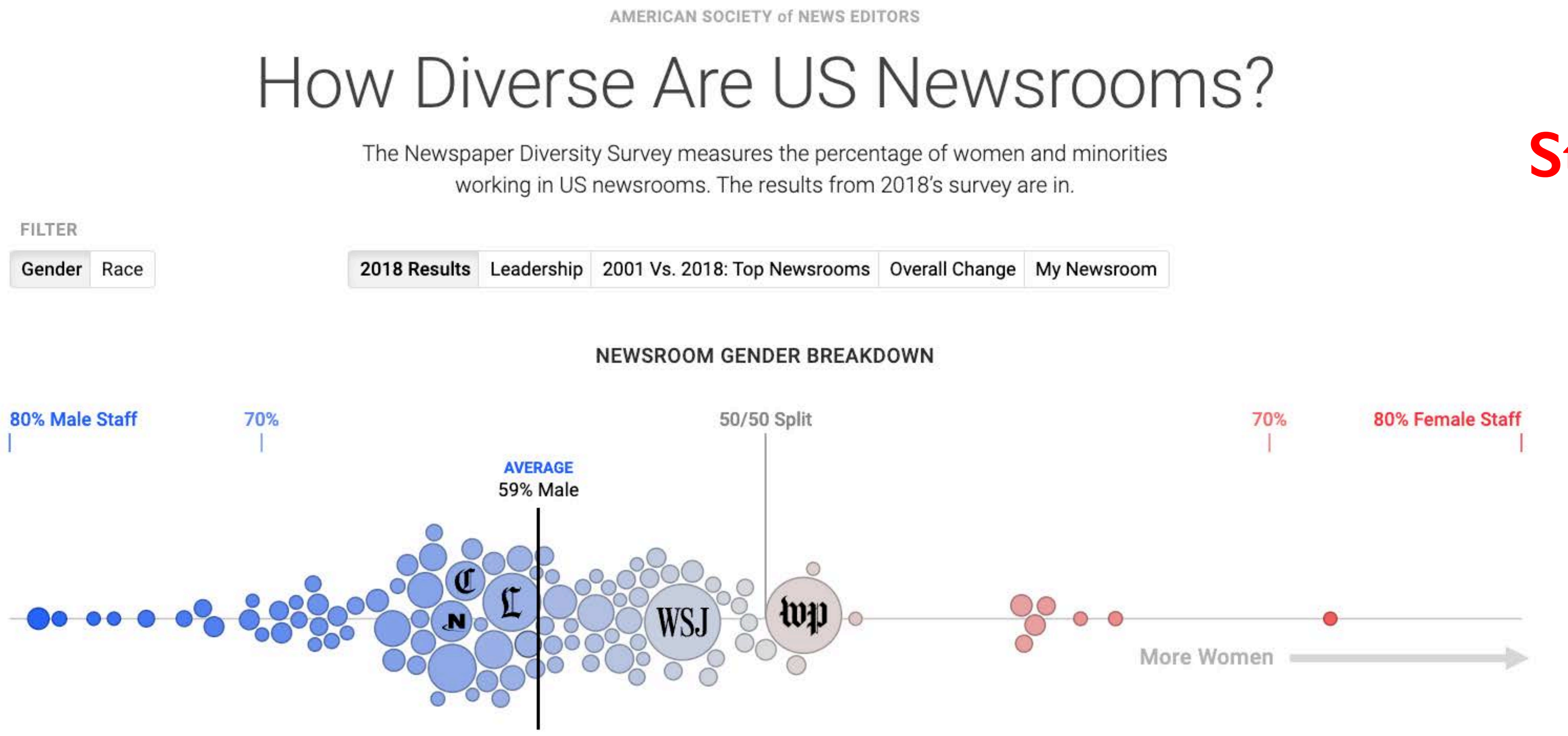
https://googletrends.github.io/asne/



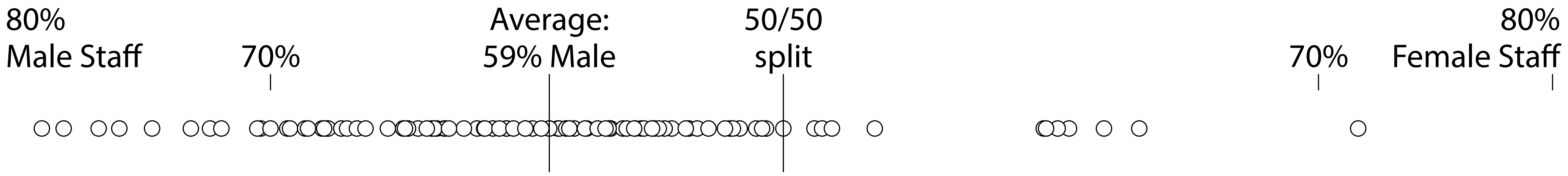


Designing information graphics and data visualizations doesn't consist of applying **rules**, but of **reasoning** about choices, and **justifying** them.

Every choice in design is **subjective**, and therefore debatable,
but it should never be **arbitrary**.


AMERICAN SOCIETY of NEWS EDITORS
How Diverse Are US Newsrooms?
The Newspaper Diversity Survey measures the percentage of women and minorities working in US newsrooms. The results from 2018's survey are in.
FILTER
Gender
Race
2018 Results
Leadership
2001 Vs. 2018: Top Newsrooms
Overall Change
My Newsroom
NEWSROOM GENDER BREAKDOWN
80% Male Staff
70%
50/50 Split
70%
80% Female Staff
AVERAGE
59% Male
WSJ
More Women

Strip plot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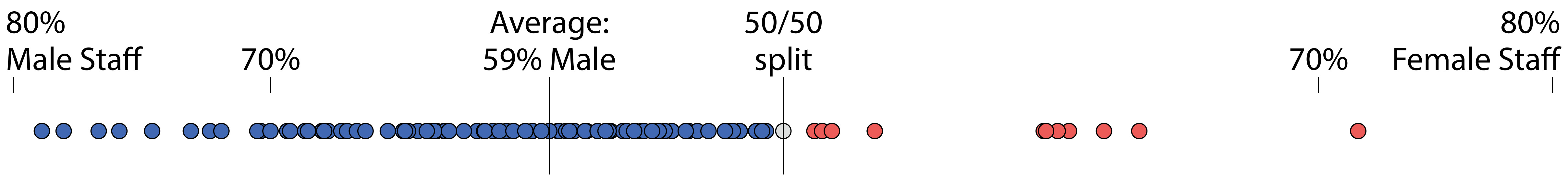
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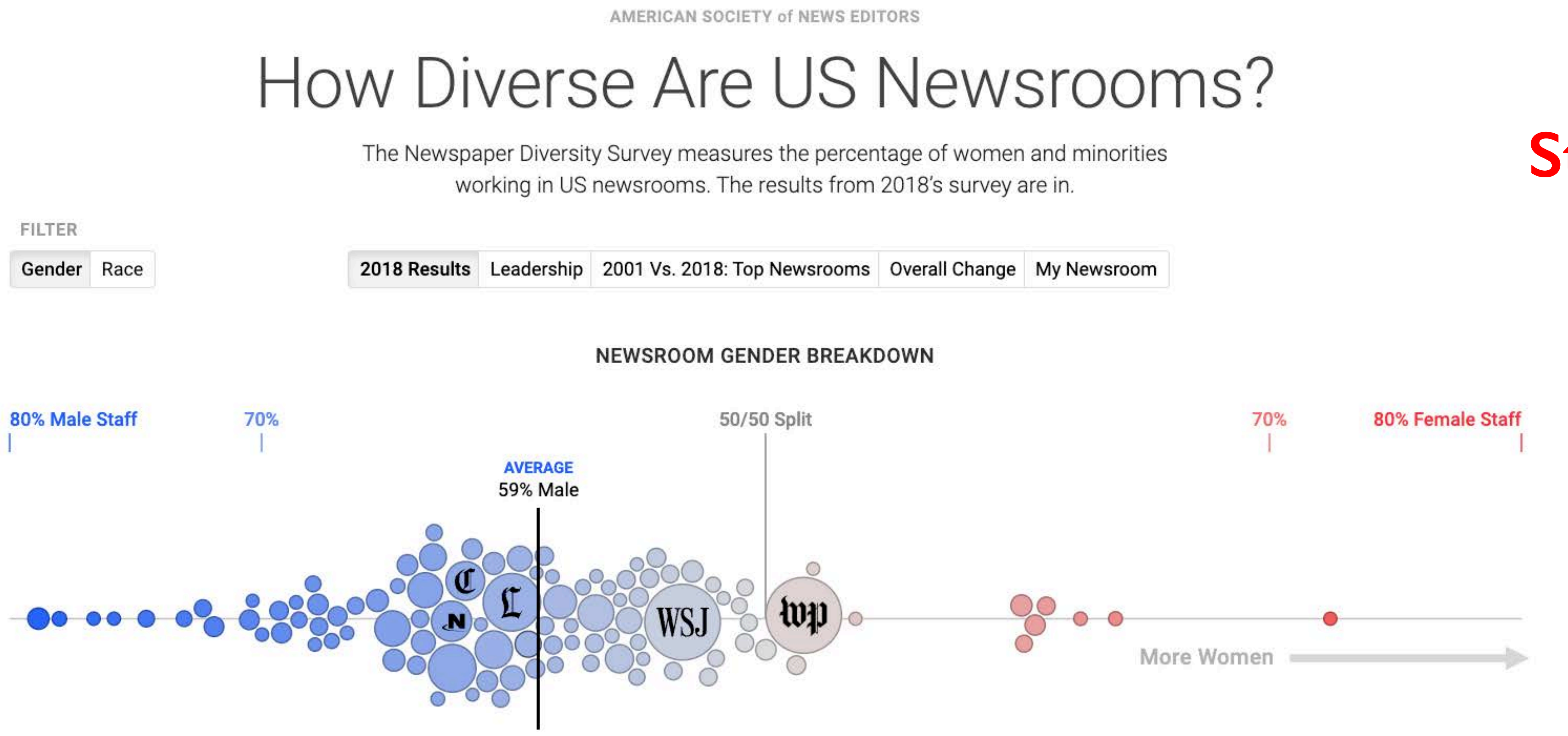
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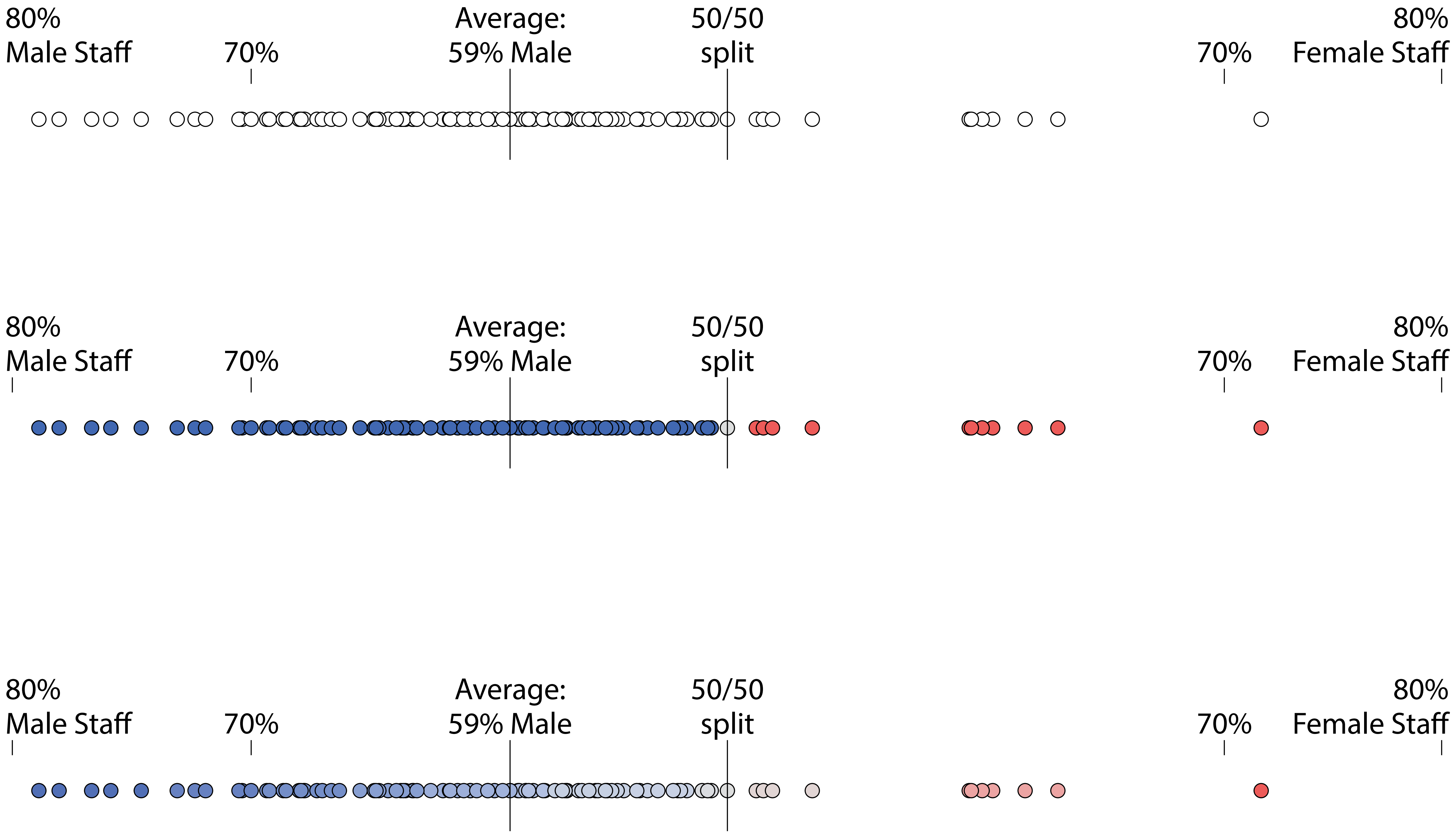
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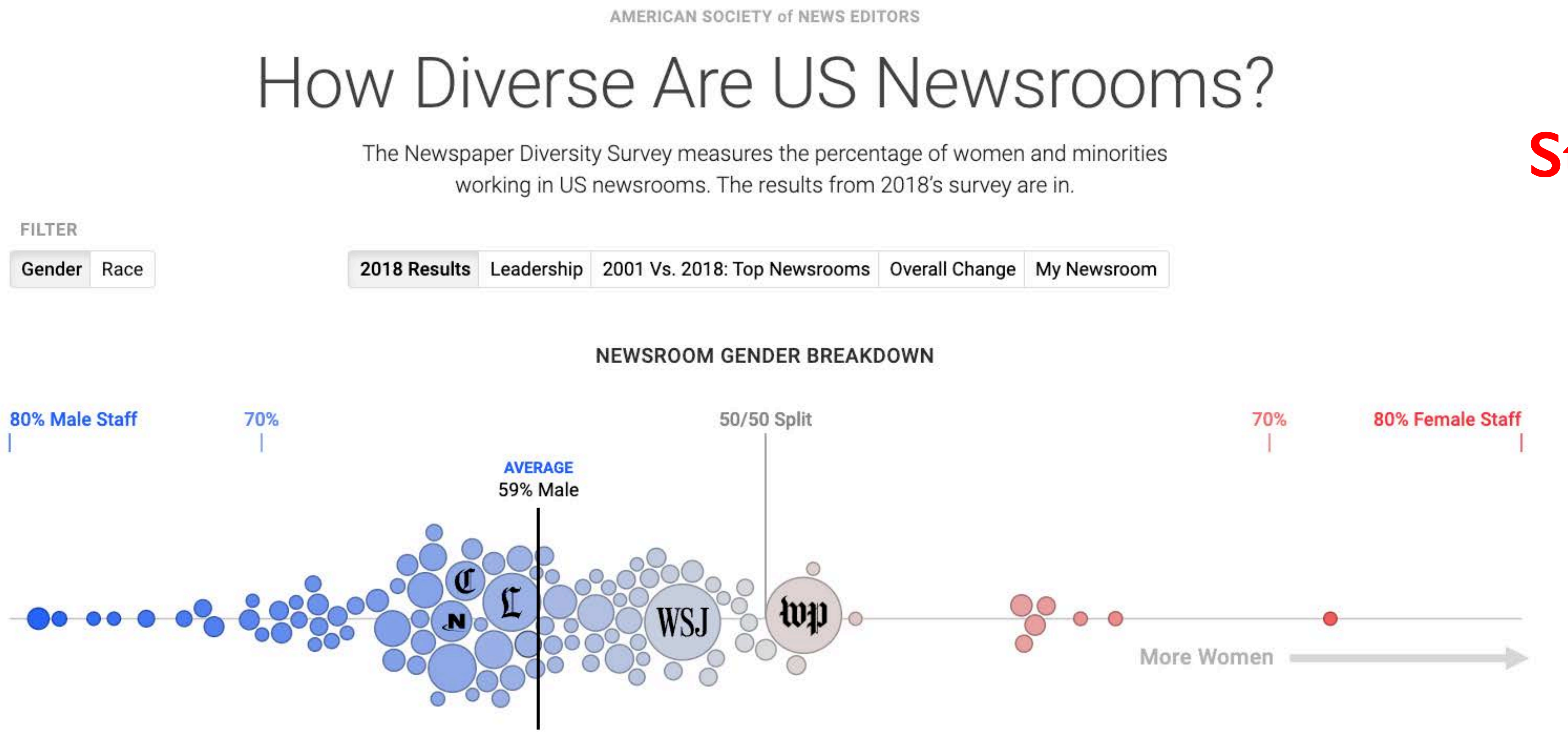
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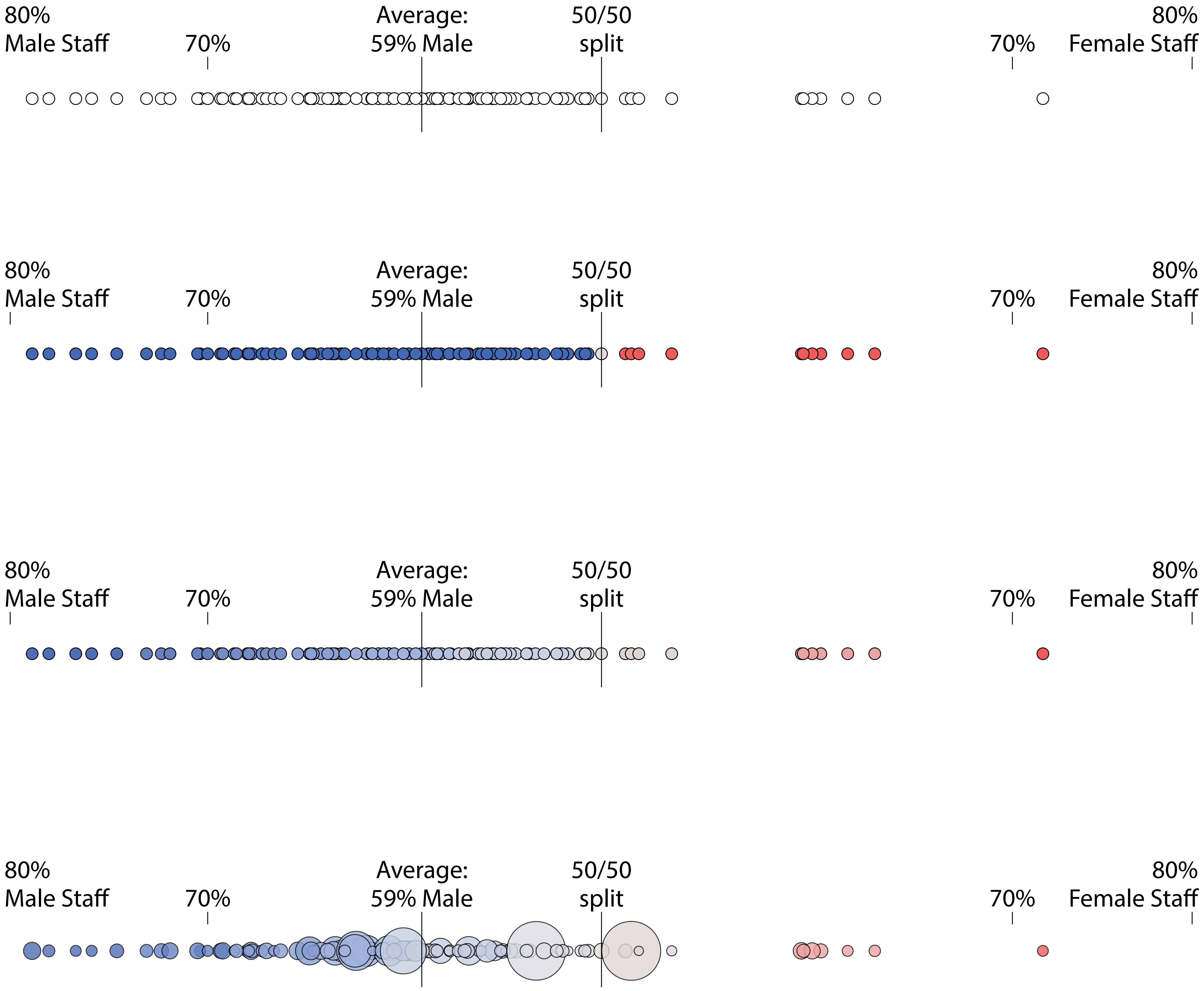
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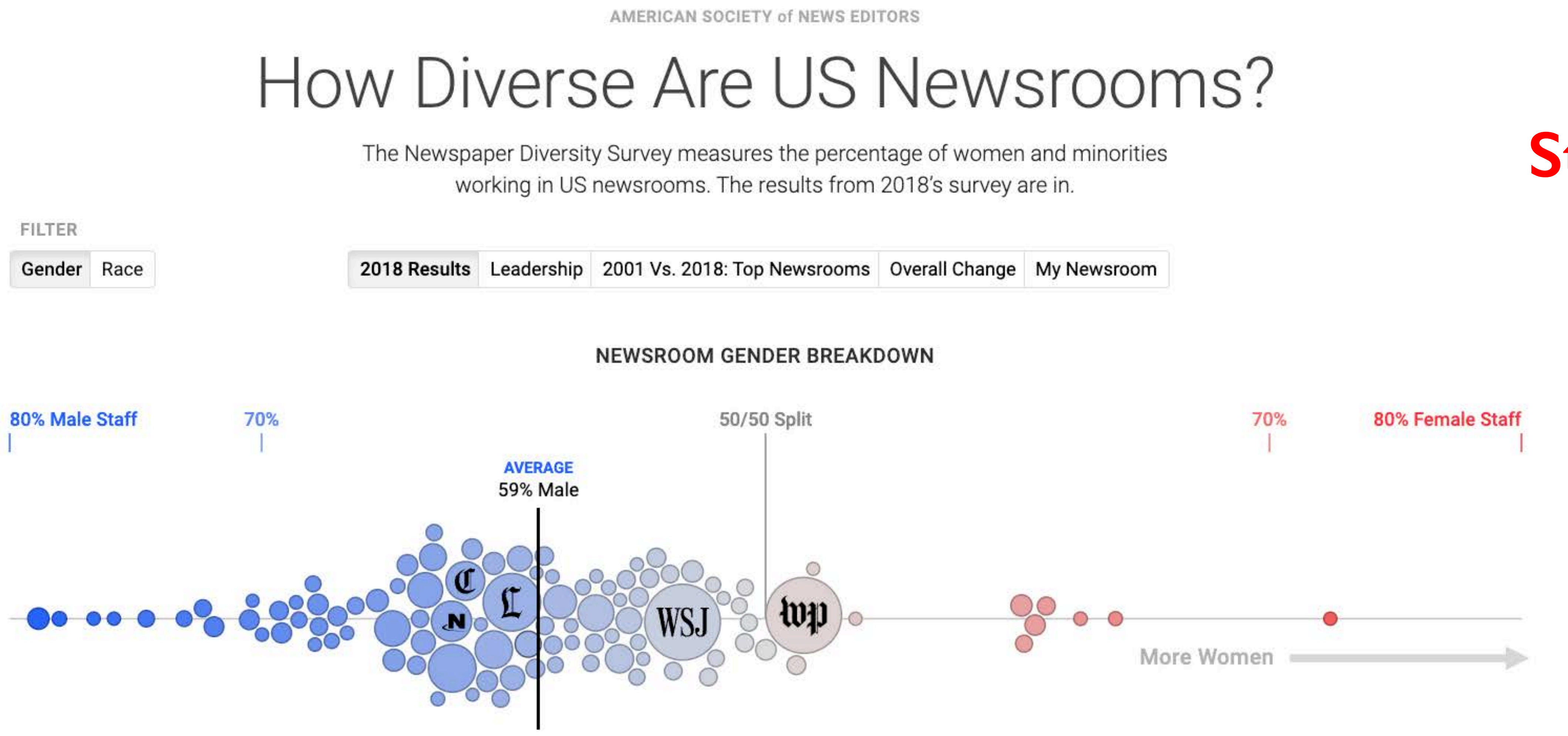

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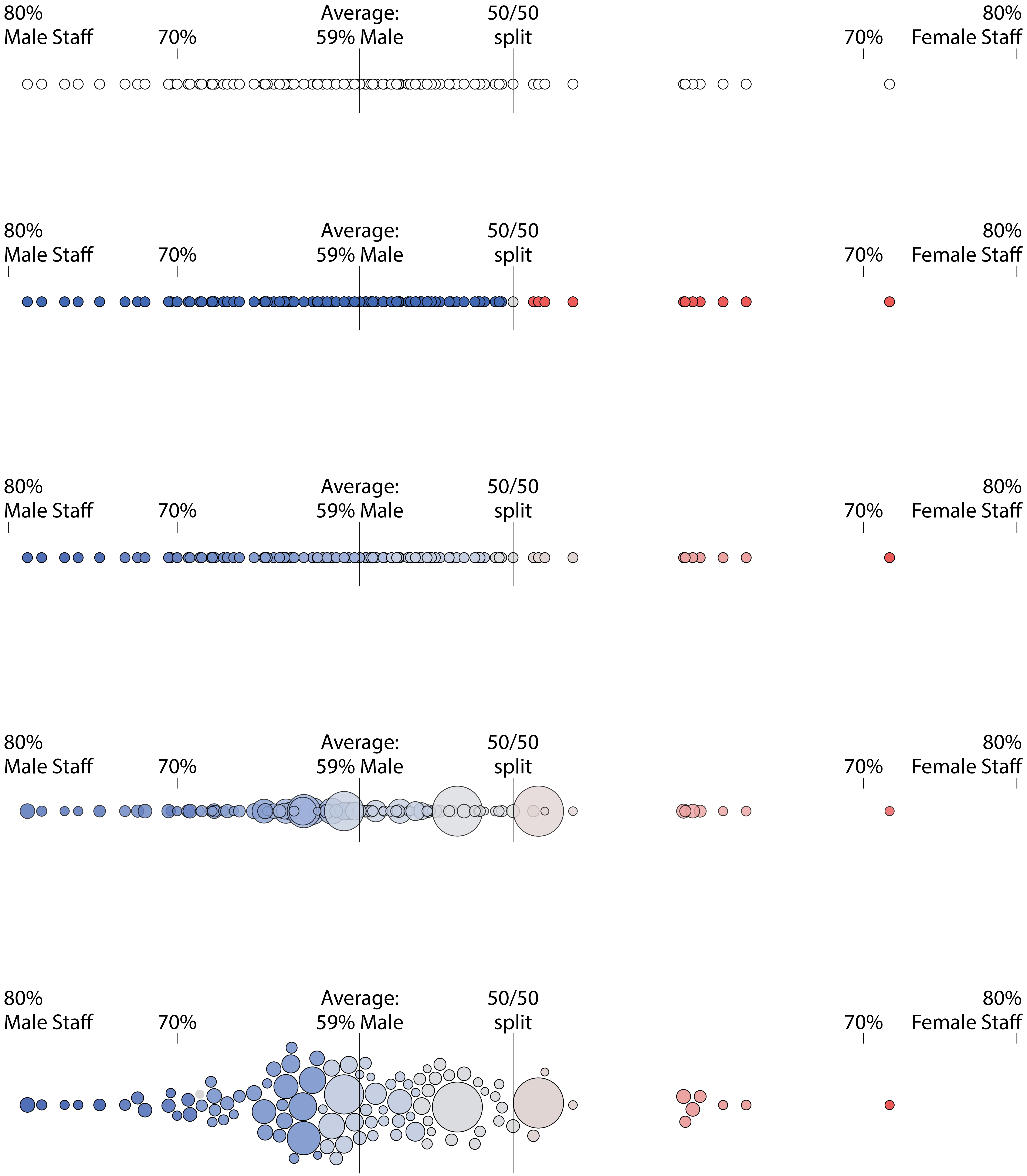
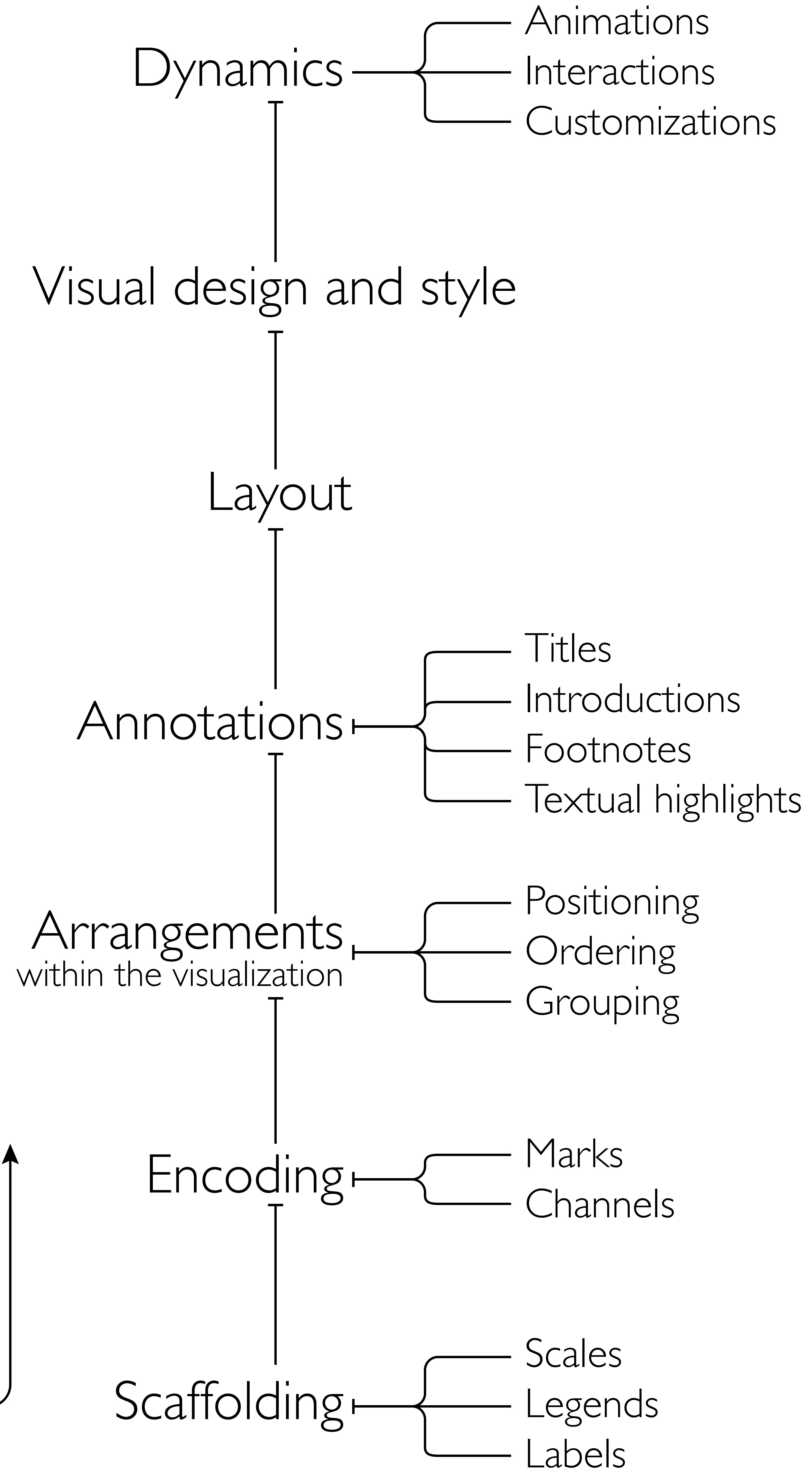


Beeswarm plot

Visualization: Layers and elements to think about

The nature of the data to be visualized influences everything else

Read from the bottom-up

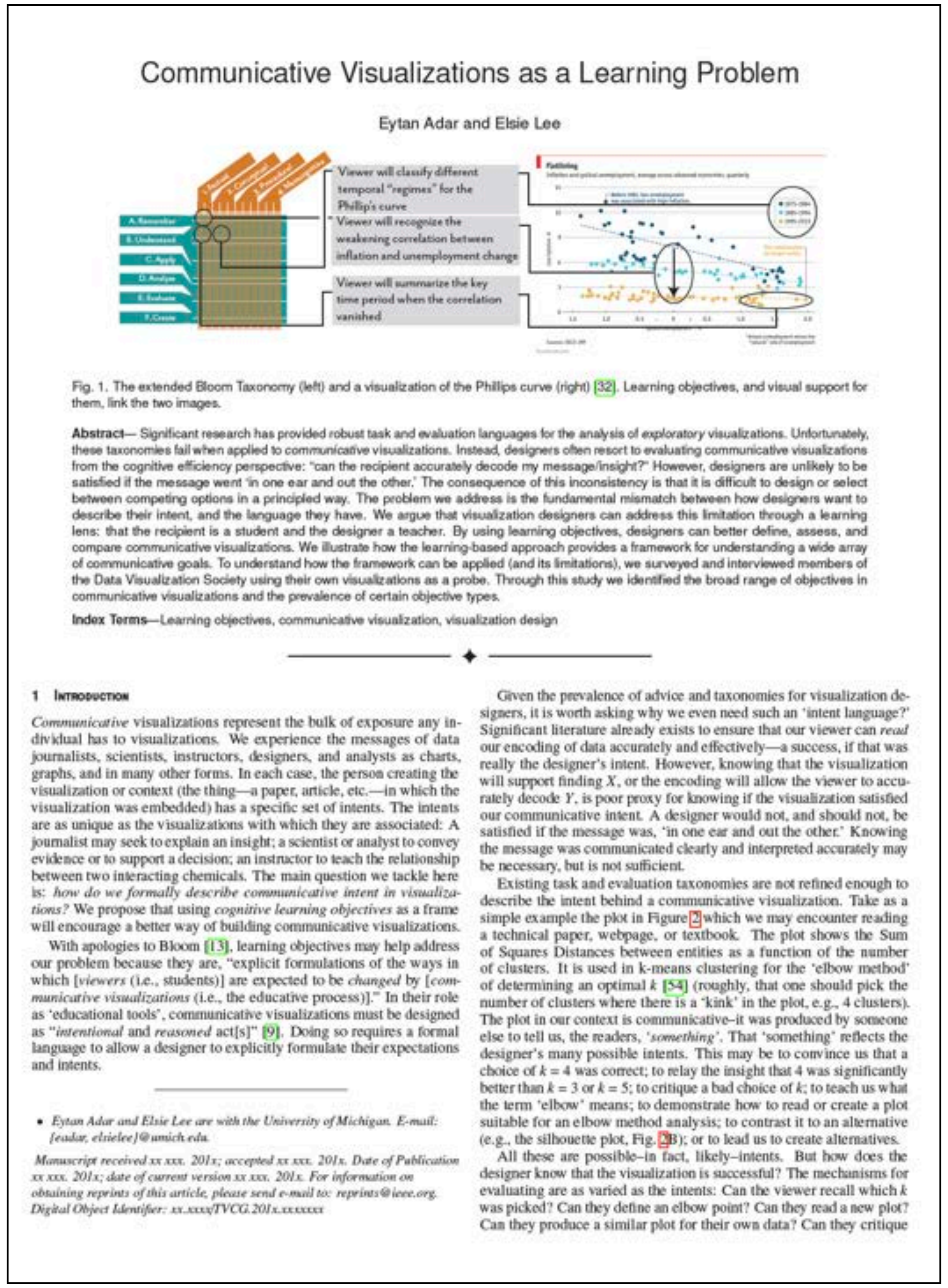


Reasoning based on our intent

Learning objectives framework

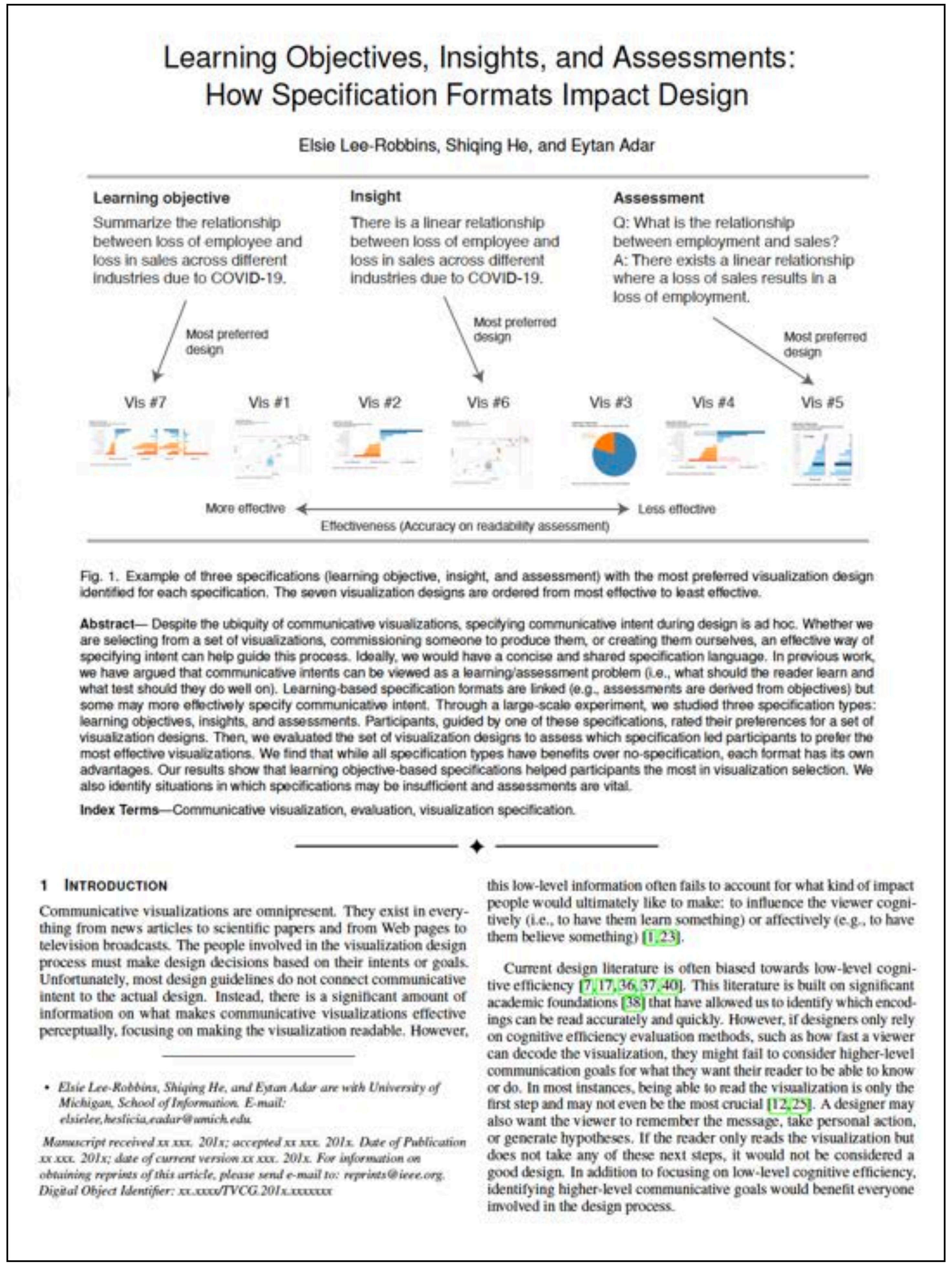
The reader willl [verb][noun]

Papers by Elsie Lee-Robbins et al. https://elsieleerobbins.com/publications.html


Communicative Visualizations as a Learning Problem

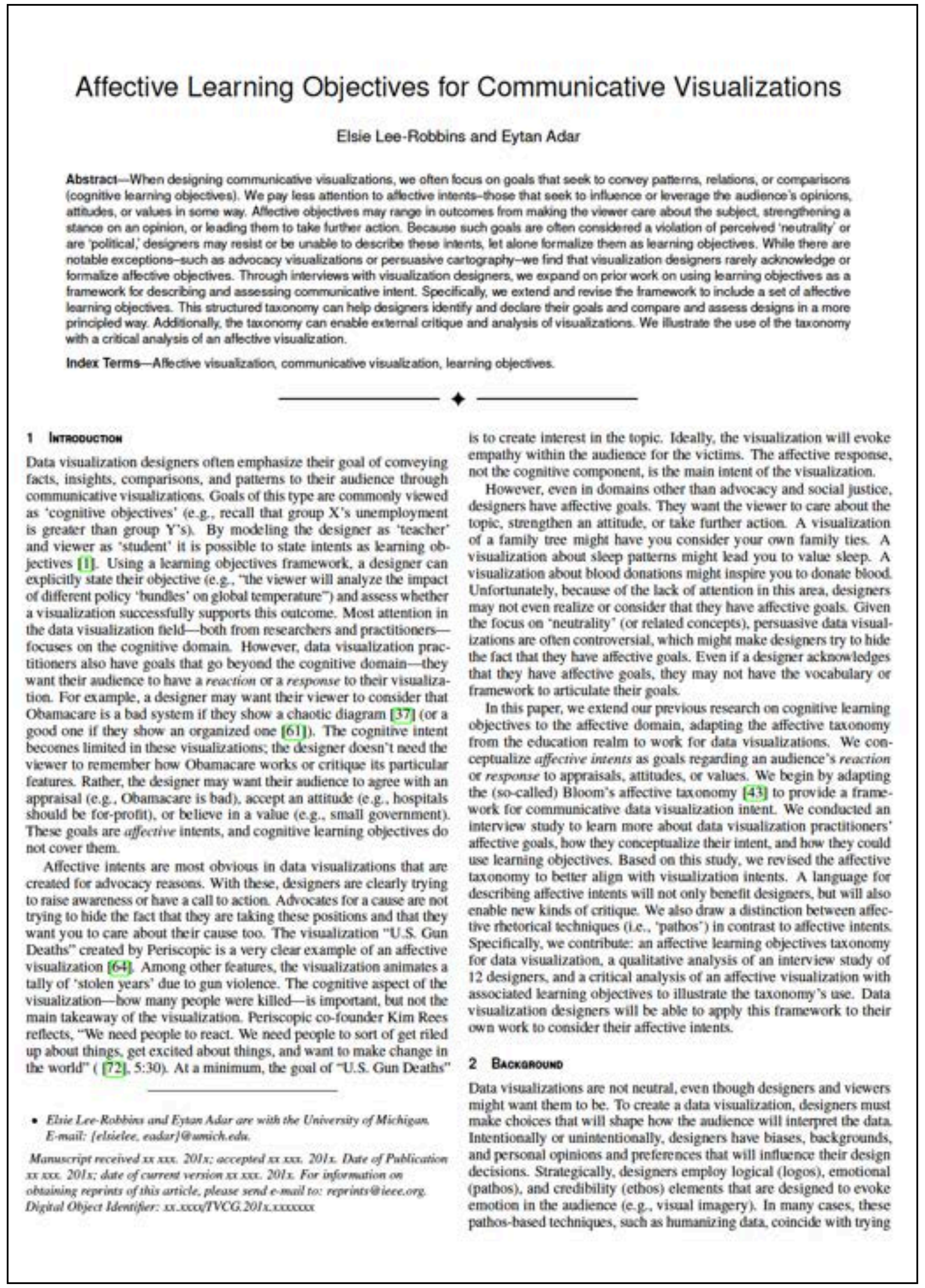
Eytan Adar and Elsie Lee

Fig. 1. The extended Bloom Taxonomy (left) and a visualization of the Phillips curve (right) [32]. Learning objectives, and visual support for them, link the two images.


Learning Objectives, Insights, and Assessments: How Specification Formats Impact Design

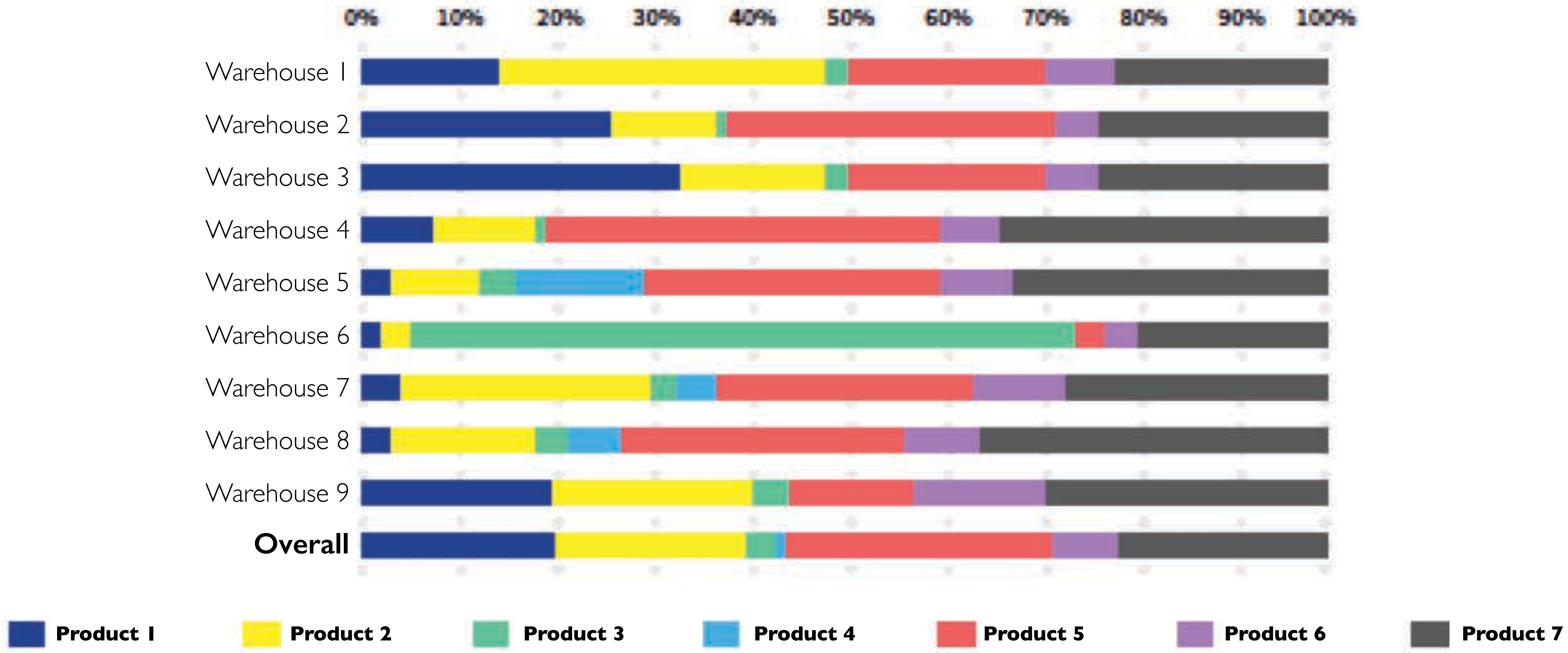
Elsie Lee-Robbins, Shiqing He, and Eytan Adar

Fig. 1. Example of three specifications (learning objective, insight, and assessment) with the most preferred visualization design identified for each specification. The seven visualization designs are ordered from most effective to least effective.


Affective Learning Objectives for Communicative Visualizations

Elsie Lee-Robbins and Eytan Adar

PROPORTION OF PRODUCTS SOLD PER WAREHOUSE



The reader will see that the data corresponding to each category adds up to 100%.

The reader will get a general (not very precise) impression of the portions of that total.

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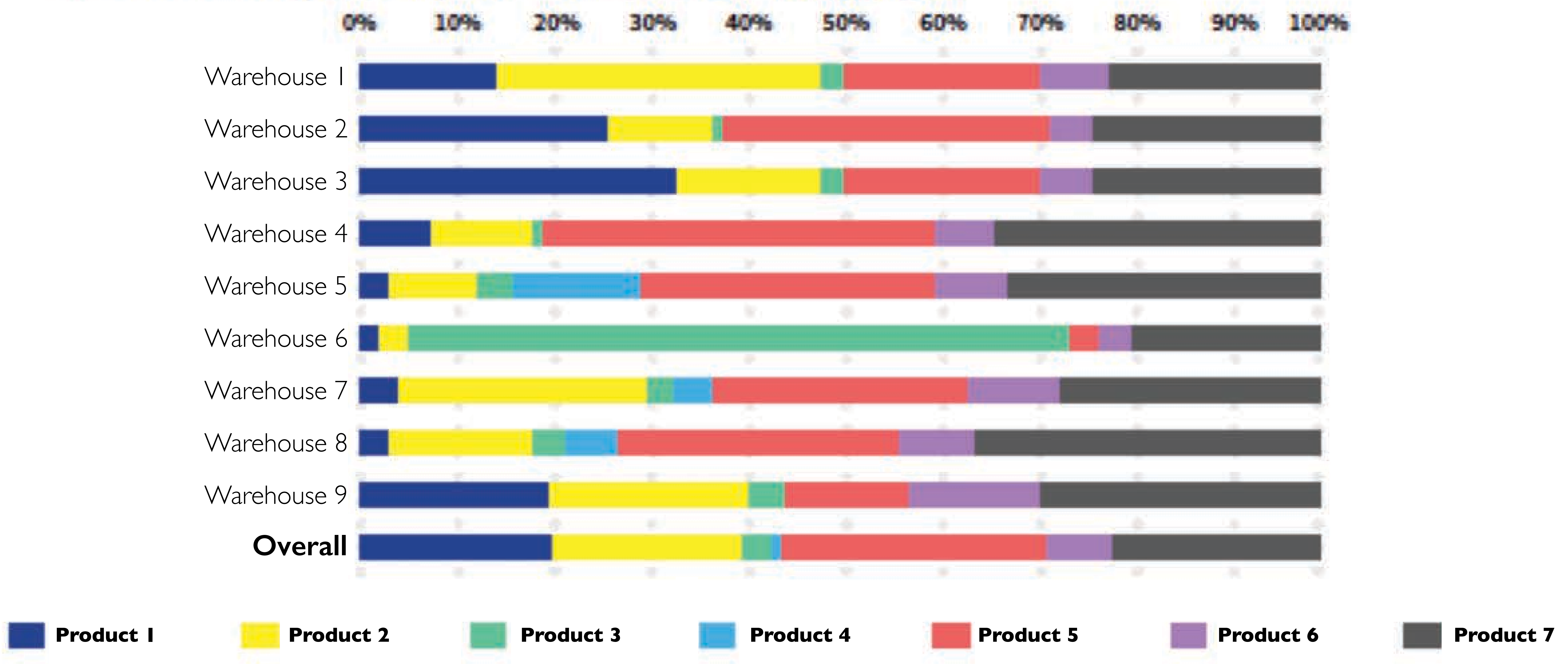

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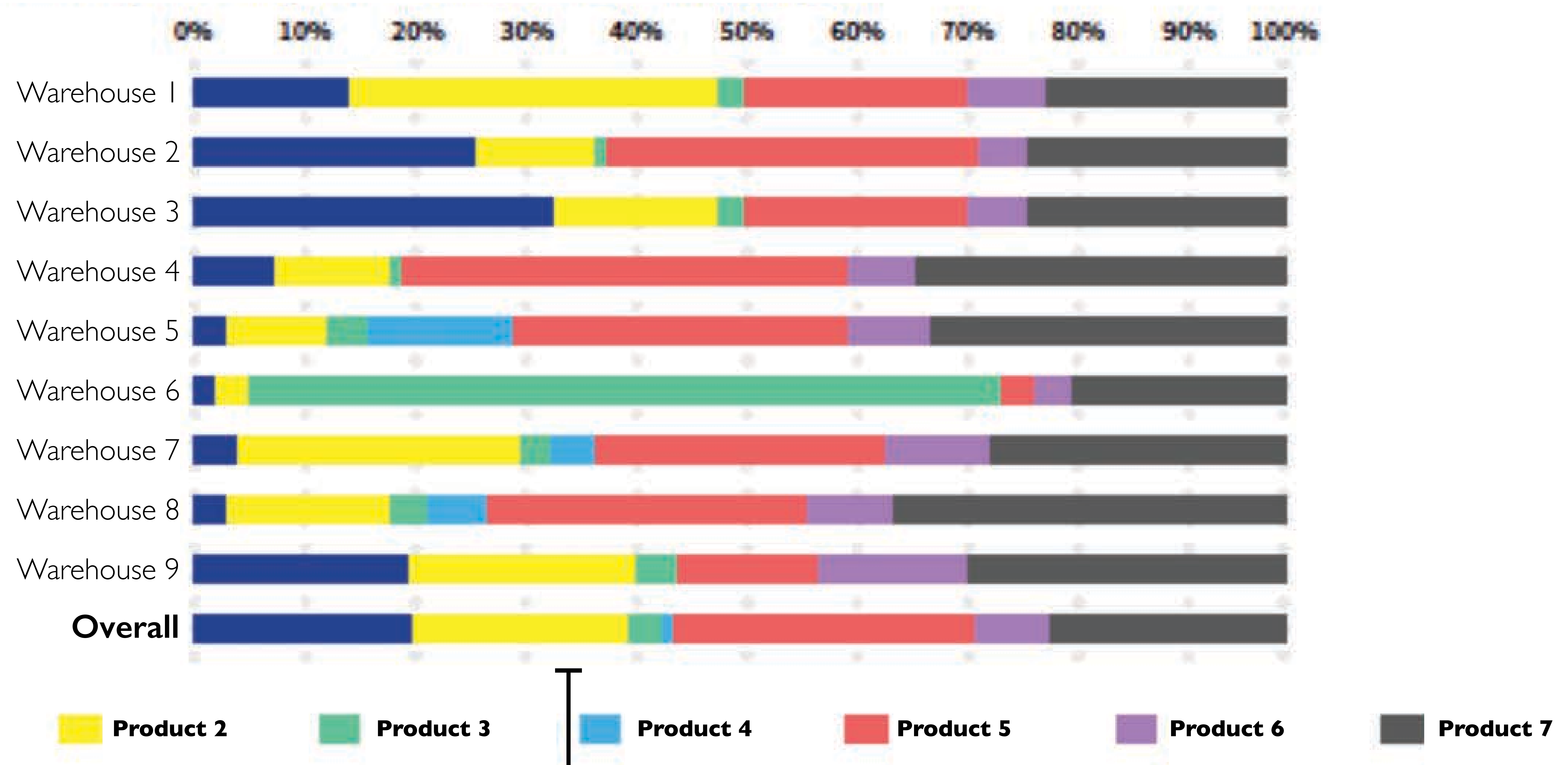
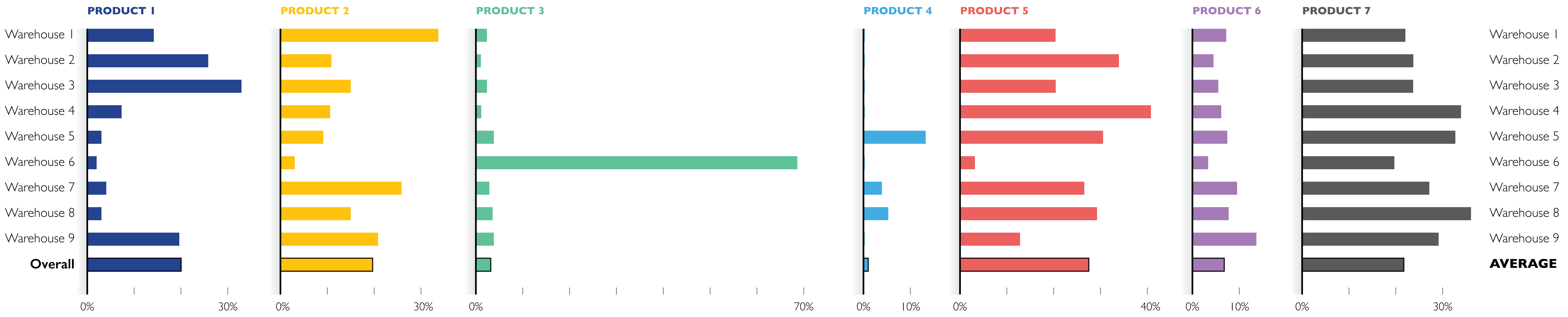


The reader will be able to compare percentages within each category of products.



An example of decision-making


You are the jury
(Probably the largest one in history!)
Photo by Mariakray
https://pixabay.com/users/mariakray-23567841/

Take two companies, **Company A** —our client; the one suing —and **Company B**—the one being sued.

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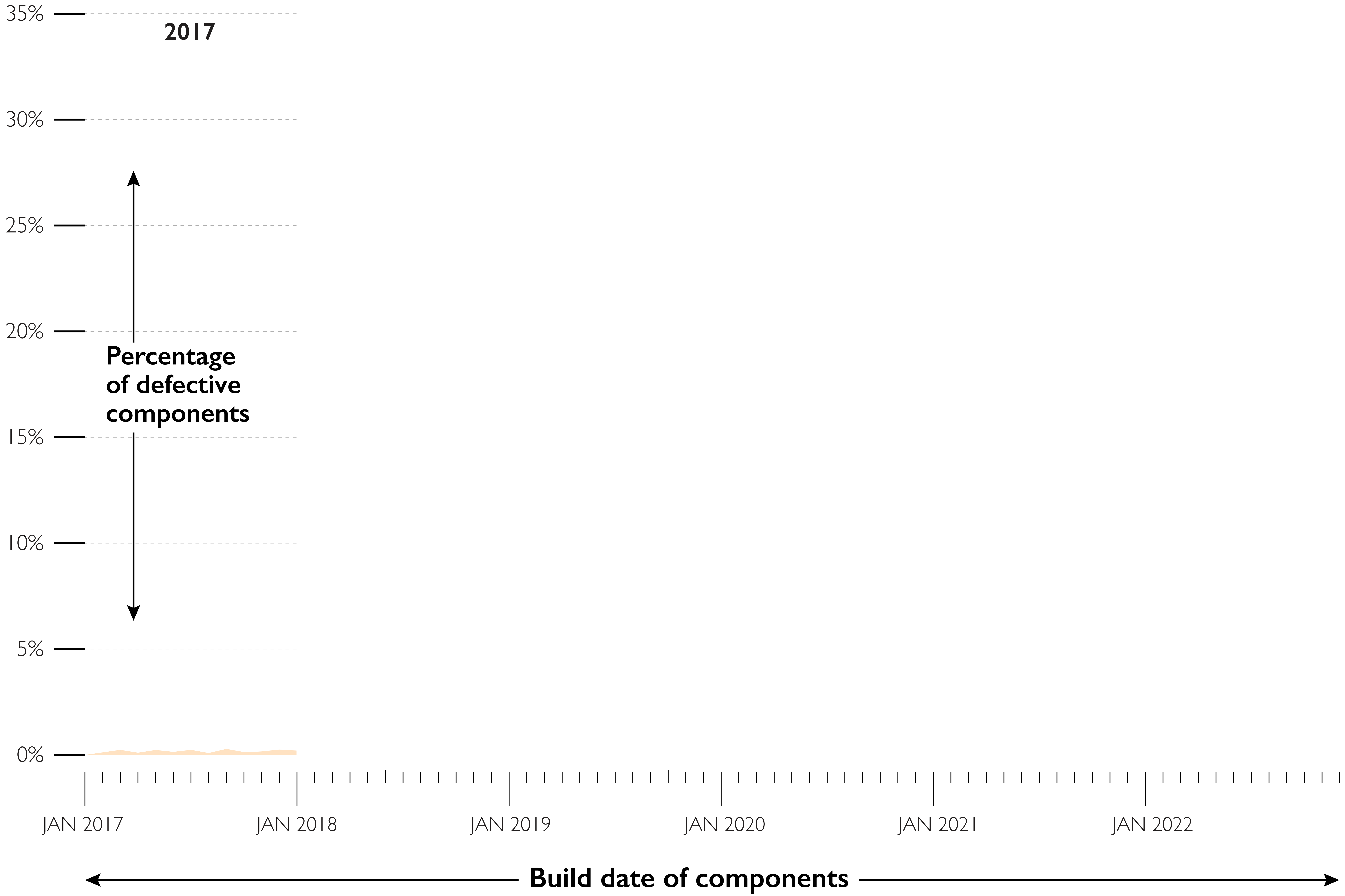

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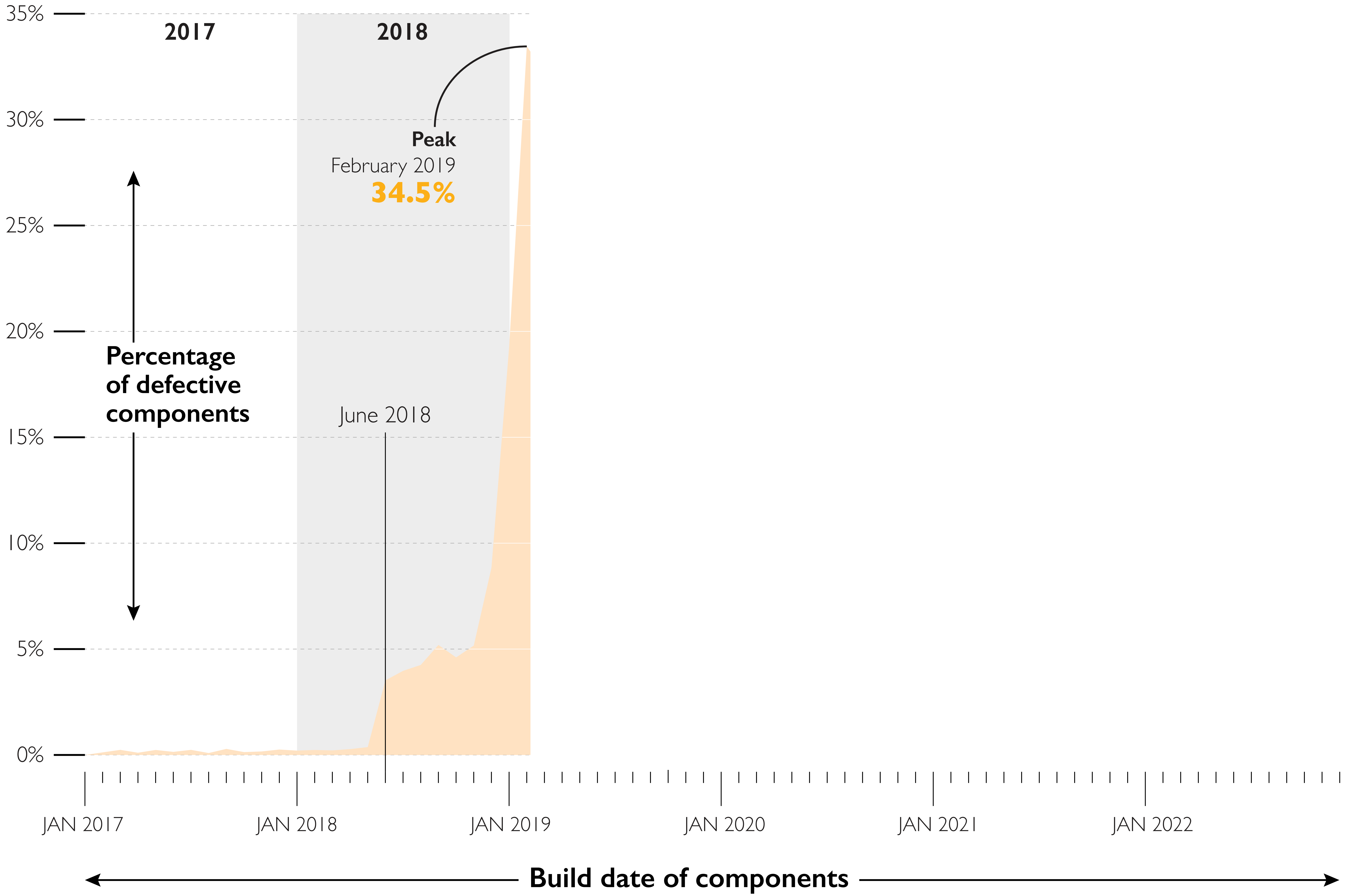

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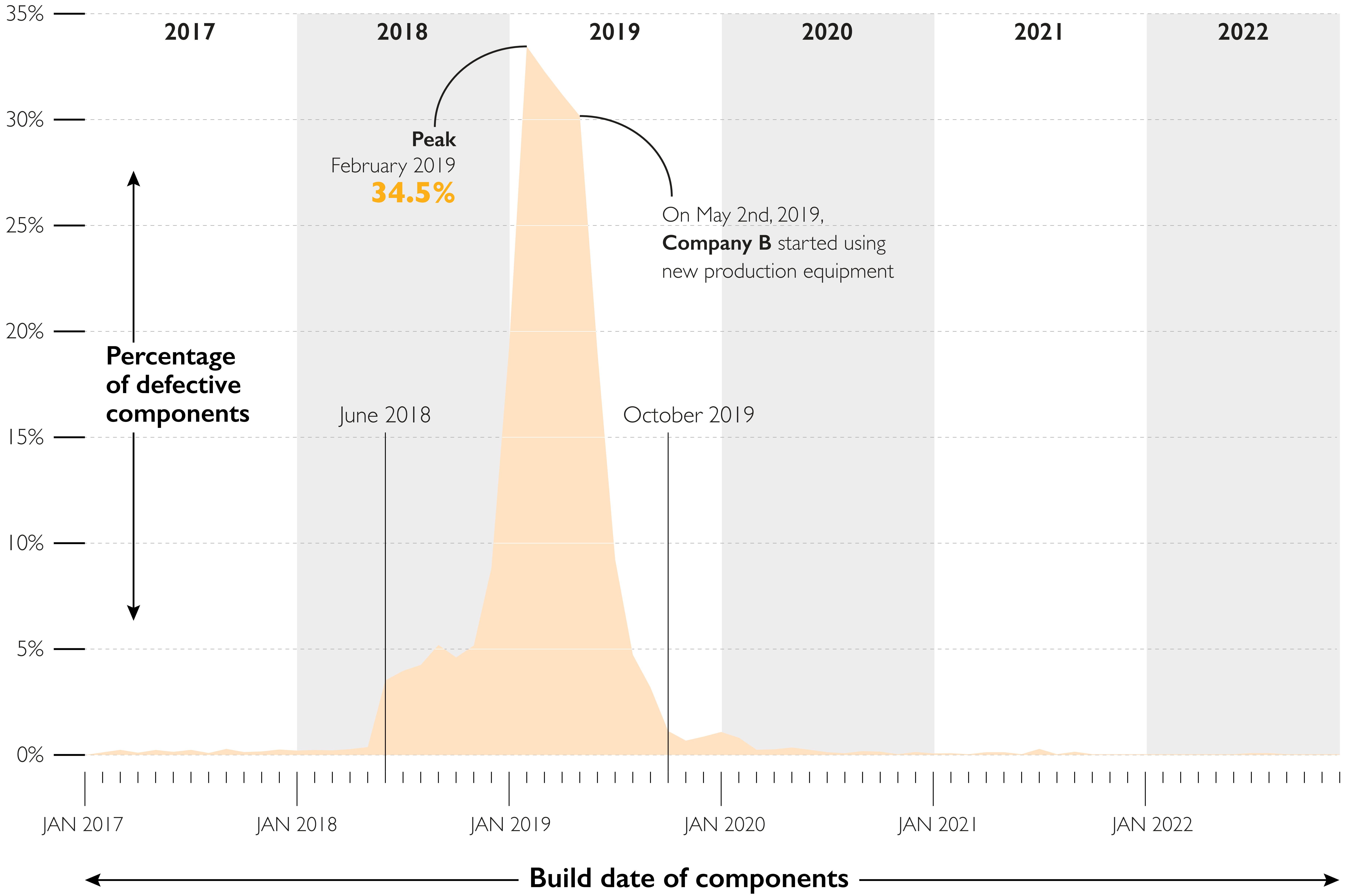

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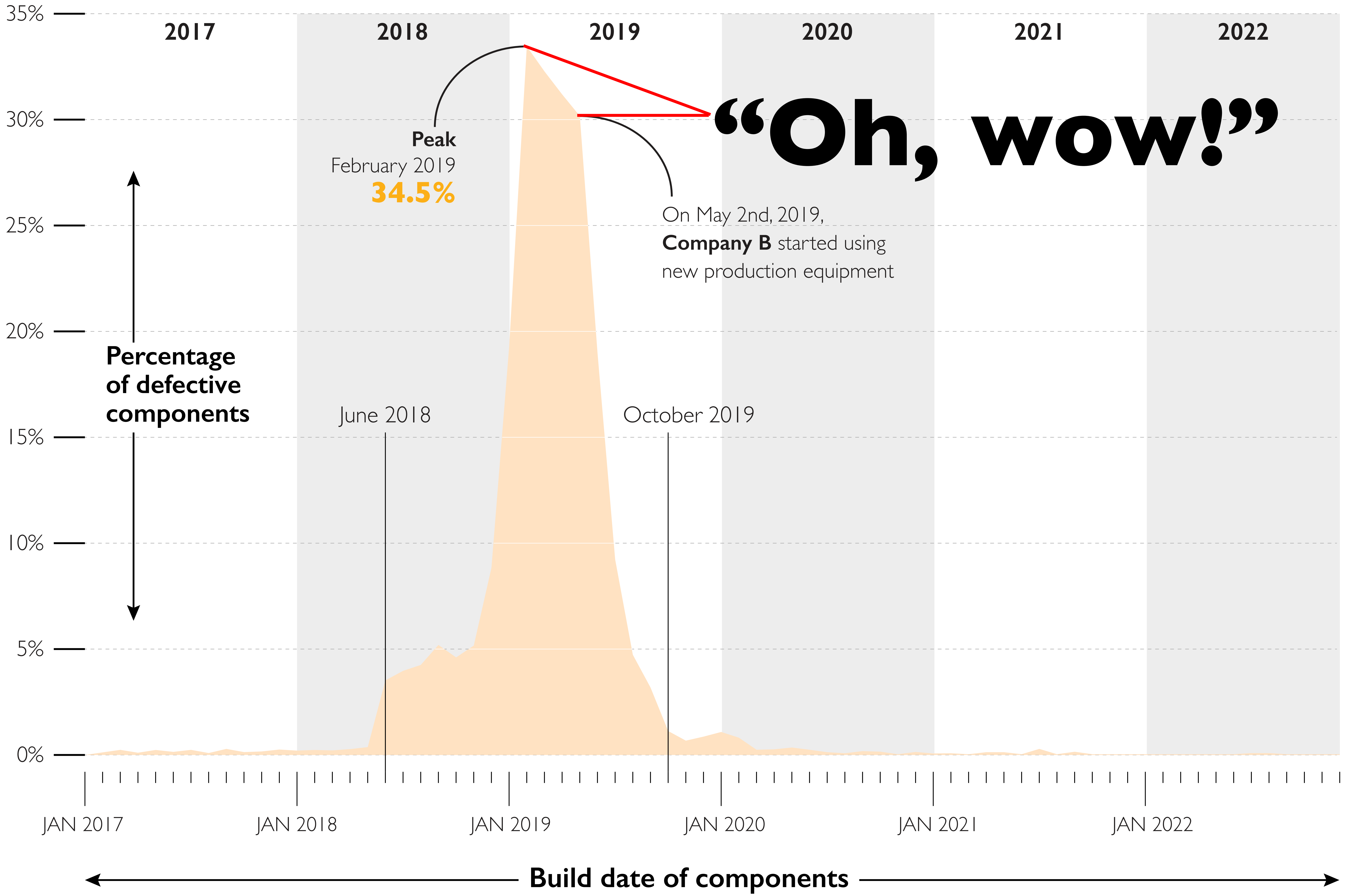
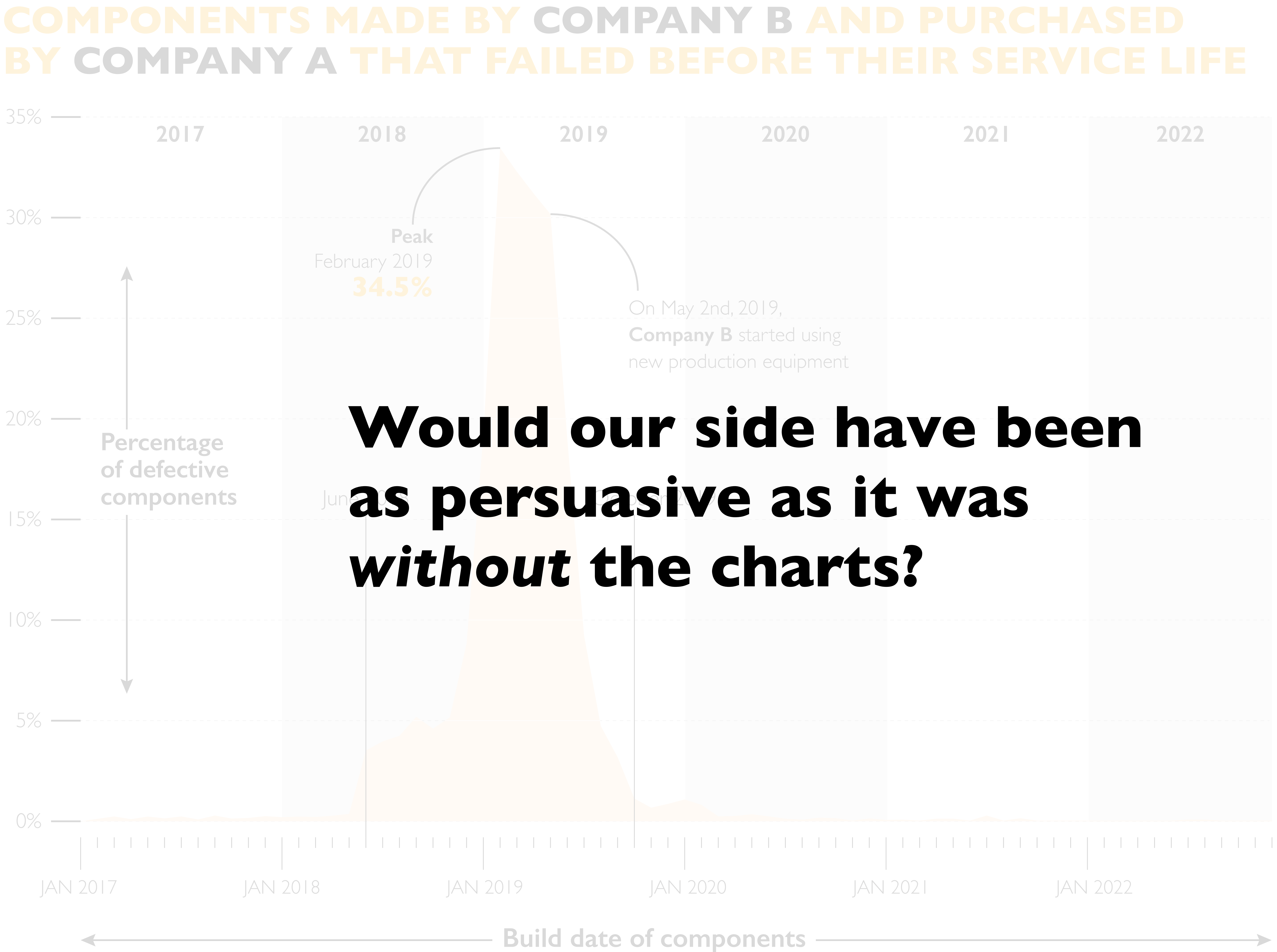
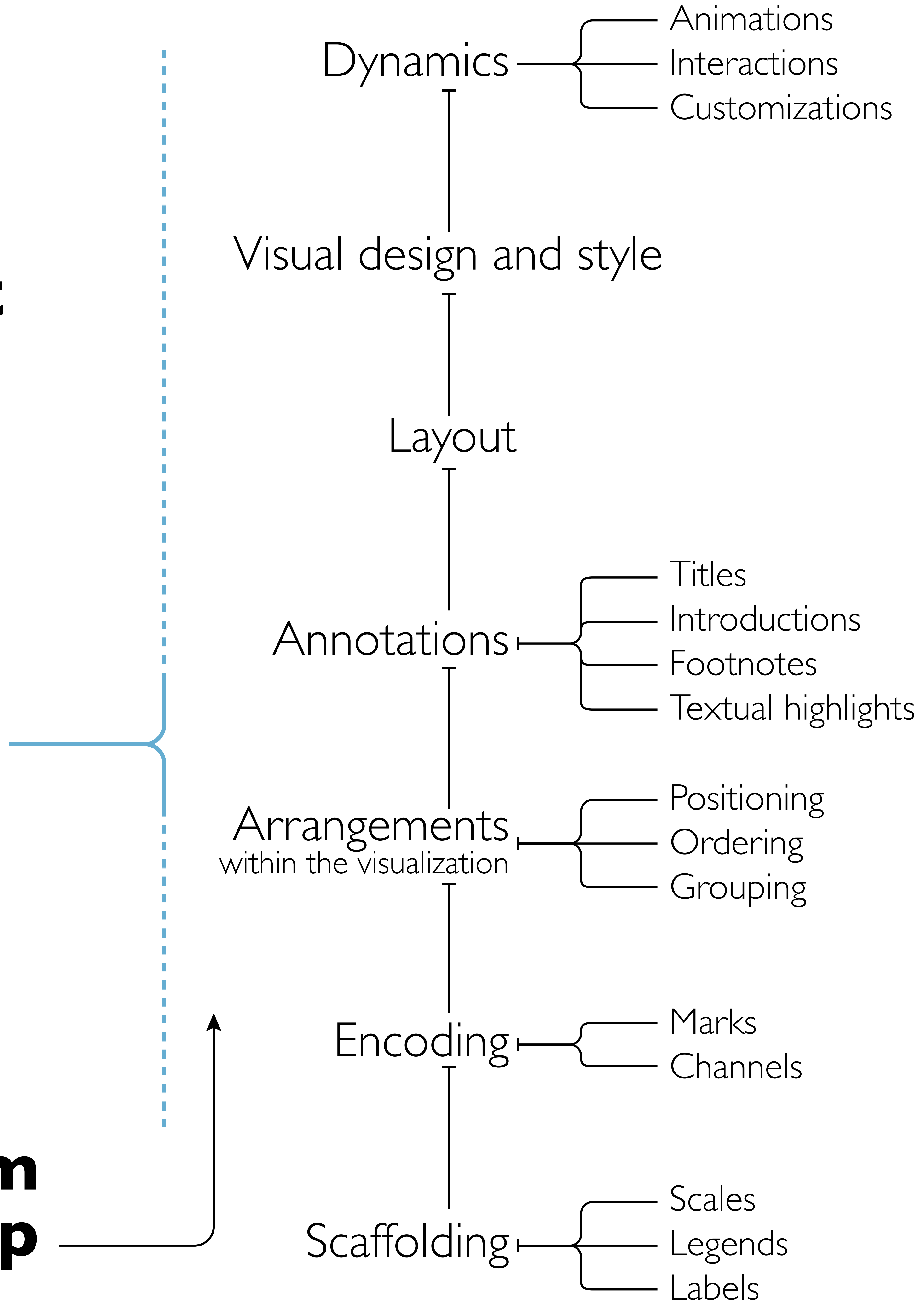




Would our side have been as persuasive as it was *without* the charts?

Visualization: Layers and elements to think about

The nature of the data to be visualized influences everything else



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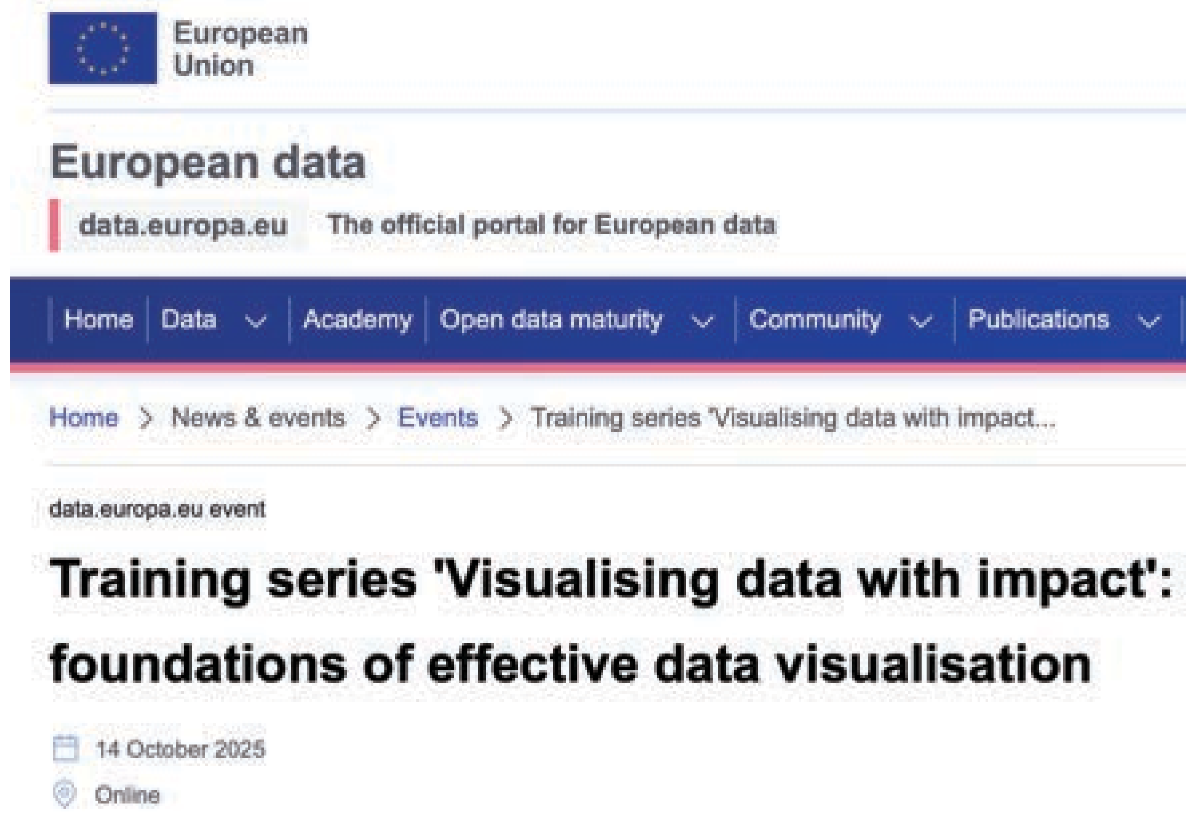

European Union
European data
data.europa.eu The official portal for European data
Home | Data | Academy | Open data maturity | Community | Publications
Home > News & events > Events > Training series 'Visualising data with impact...
data.europa.eu event
Training series 'Visualising data with impact': foundations of effective data visualisation
14 October 2025
Online

Episode ONE - October 14

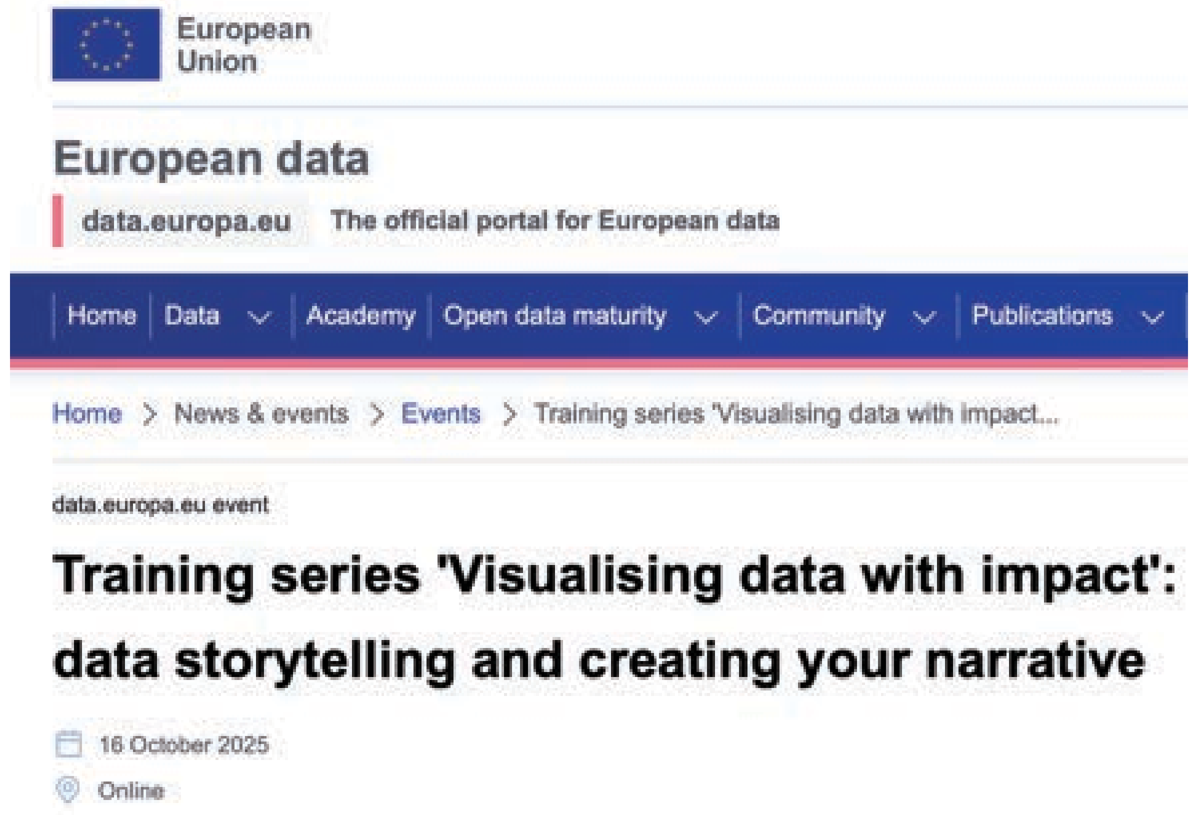
https://data.europa.eu/en/news-events/events/training-data-visualisation-session-1-foundations-effective-data-visualisation


European Union
European data
data.europa.eu The official portal for European data
Home | Data | Academy | Open data maturity | Community | Publications
Home > News & events > Events > Training series 'Visualising data with impact...
data.europa.eu event
Training series 'Visualising data with impact': designing with integrity
15 October 2025
Online

Episode TWO - October 15

Tomorrow's webinar

https://data.europa.eu/en/news-events/events/data-visualisation-training-session-2-designing-integrity


European Union
European data
data.europa.eu The official portal for European data
Home | Data | Academy | Open data maturity | Community | Publications
Home > News & events > Events > Training series 'Visualising data with impact...
data.europa.eu event
Training series 'Visualising data with impact': data storytelling and creating your narrative
16 October 2025
Online

Episode THREE - October 16

https://data.europa.eu/en/news-events/events/data-visualisation-training-session-3-data-storytelling-and-creating-your

- 1_The_Basics
- 2_History
- 3_Chart_Taxonomies
- 4_Perception_and_Accessibility
- 5_Visual_Design
- 6_Annotations_And_Storytelling
- 7_Uncertainty
- 8_Maps

Extra readings

https://tinyurl.com/mr2st327

Foundations of Effective Data Visualization

Thank you!

Alberto Cairo

OpenVisualizationAcademy.com