HOW TO MAKE DECISIONS IN DATA VISUALIZATION

Alberto Cairo

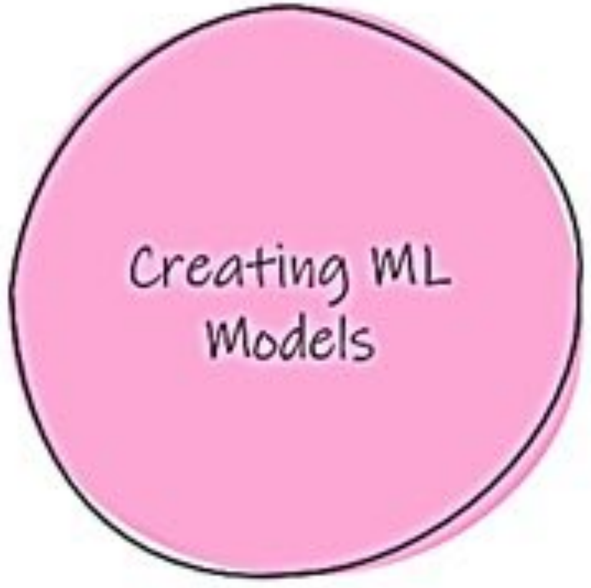
Banco de Portugal, 2020

Time spent in a life of a Data Scientist

@datavizzdom

Gulrez

Perception

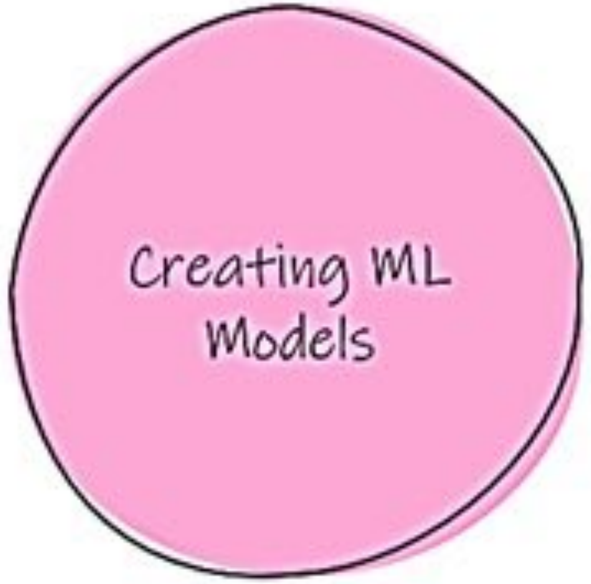


Time spent in a life of a Data Scientist

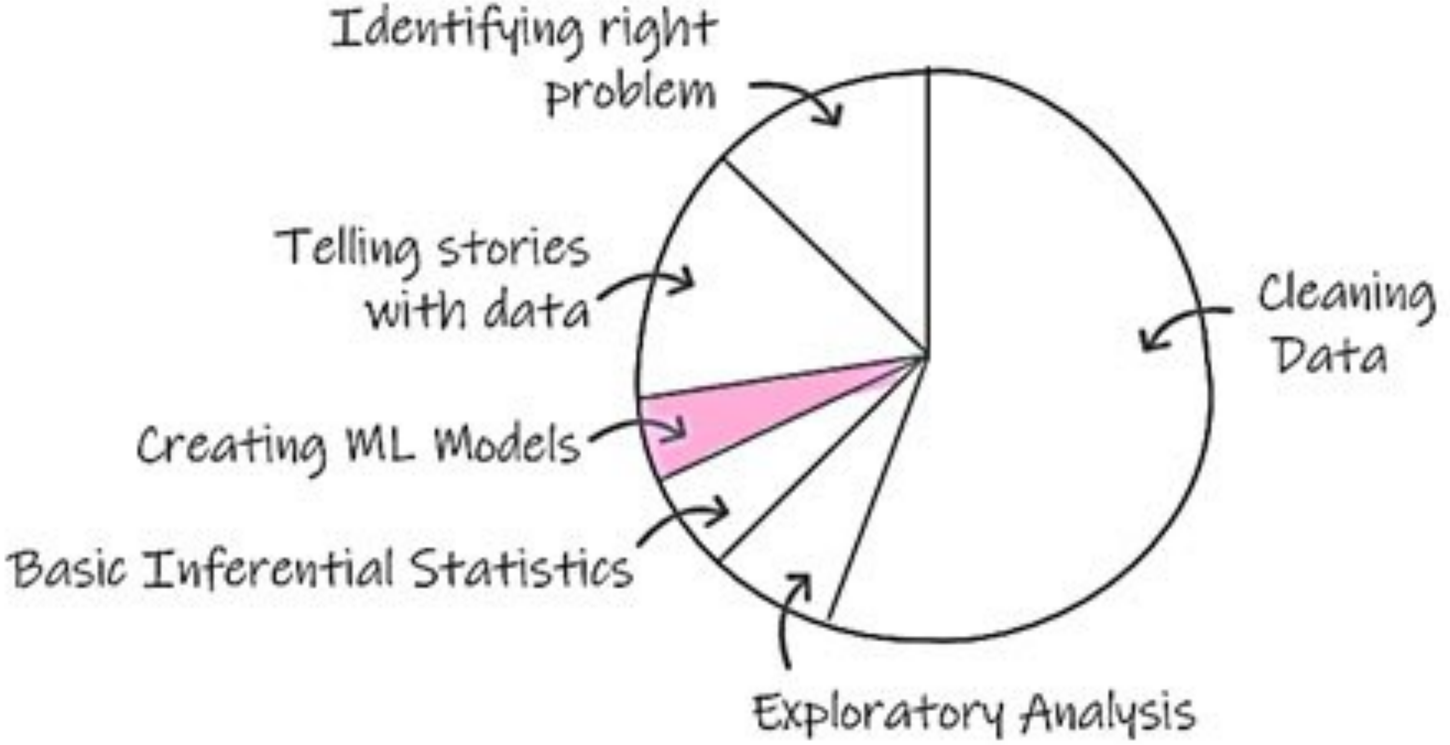
@datavizzdom

Gulrez

Perception



Reality

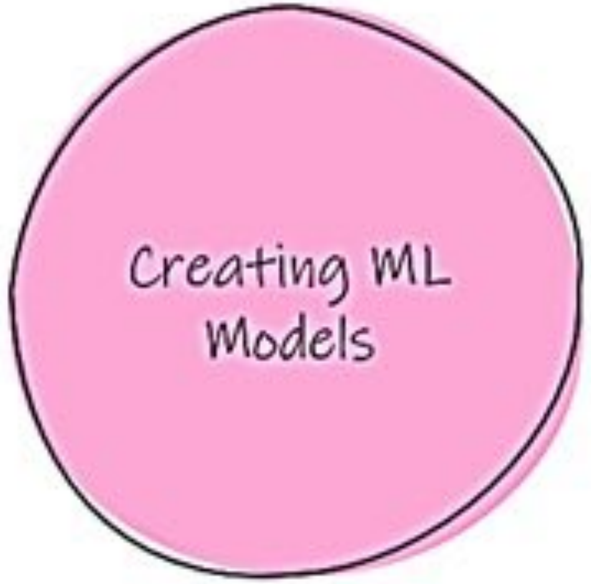


Time spent in a life of a Data Scientist

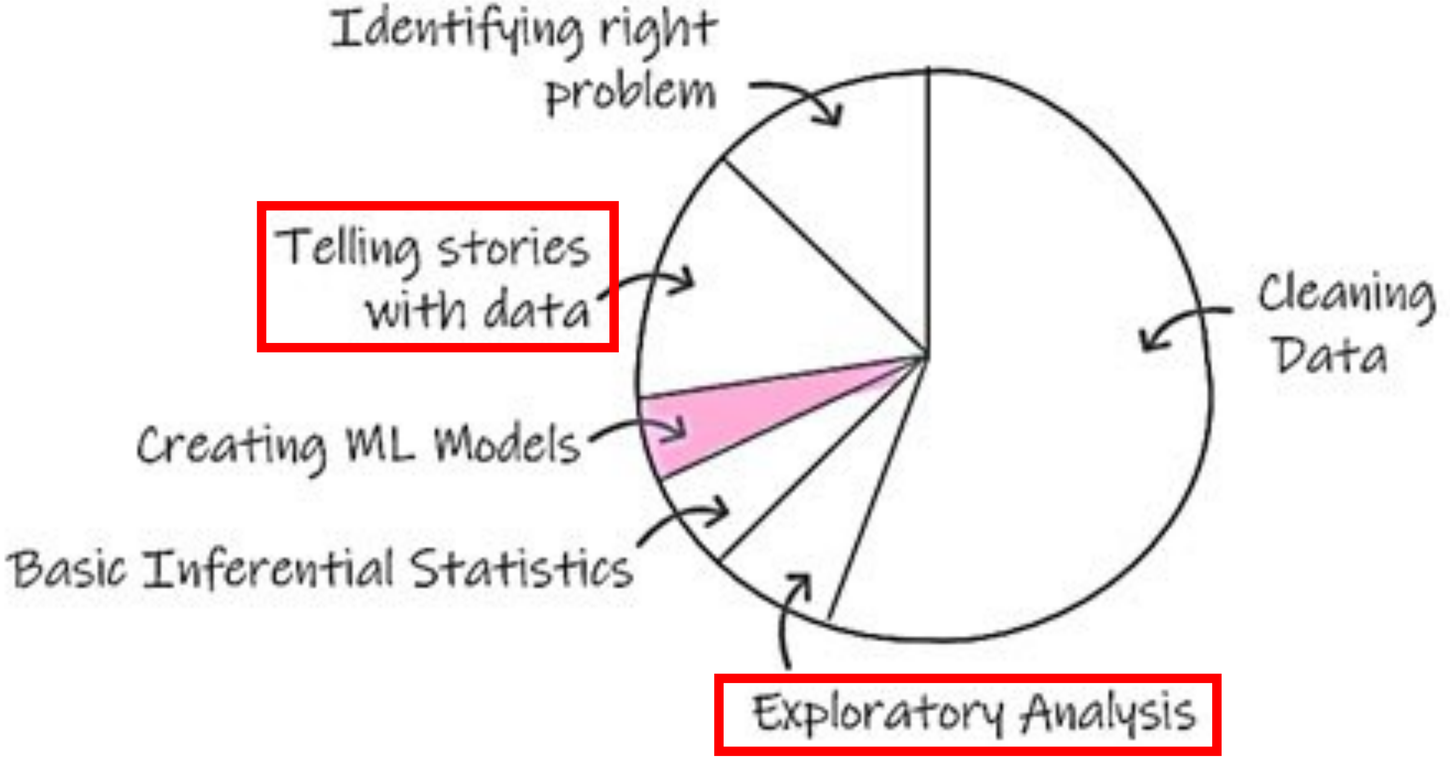
@datavizzdom

Gulrez

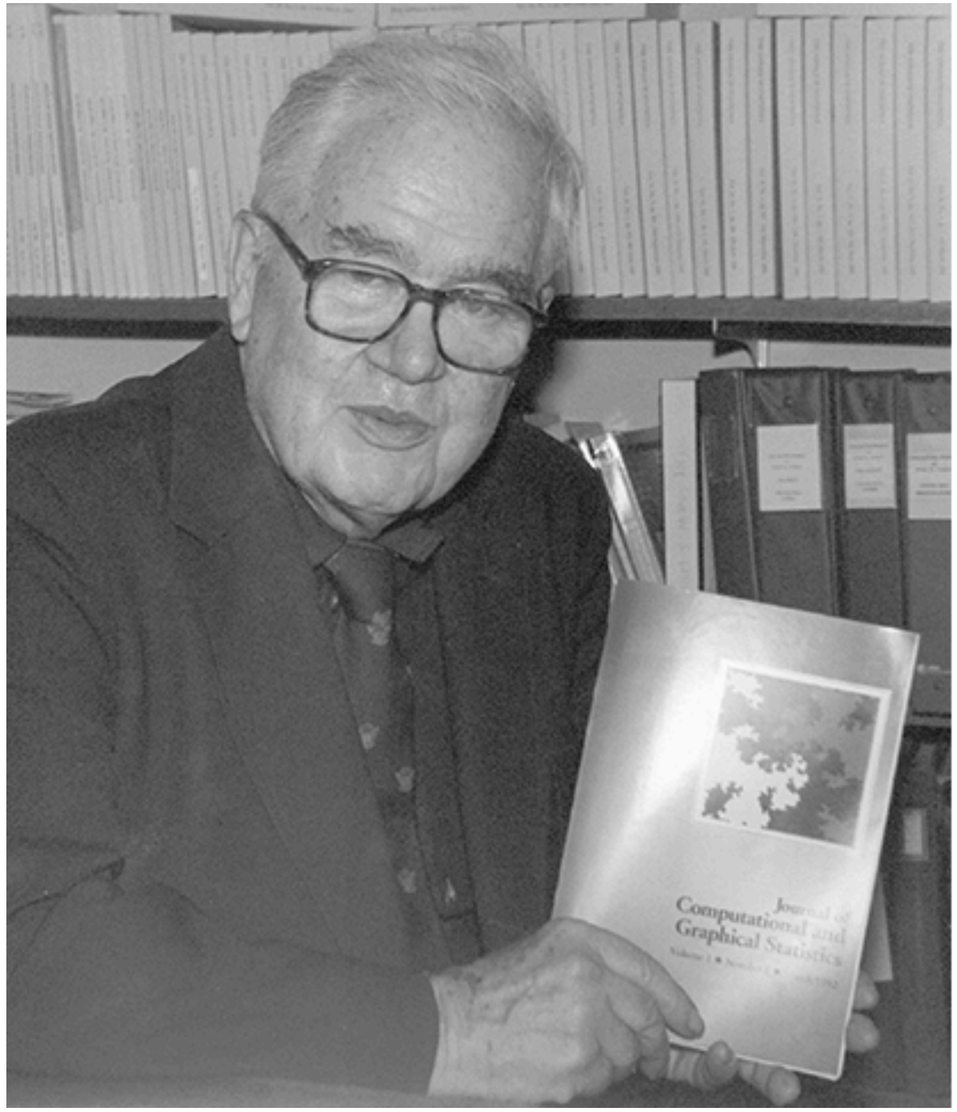
Perception

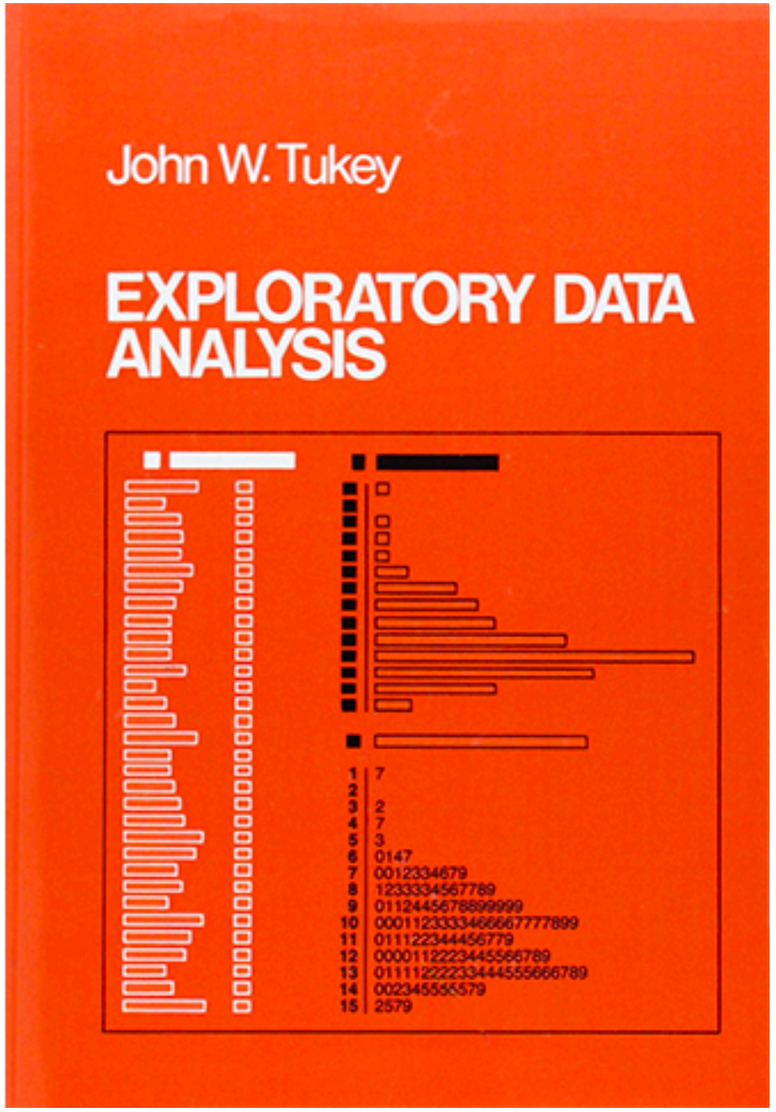


Reality



We are living in a Golden Age of visualization





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

John W. Tukey

We are living in a Golden Age of visualization

We are living in a Golden Age of visualization

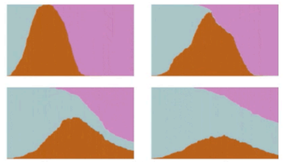
Ed Hawkins's 'Warming stripes' (read more: https://chezvoila.com/blog/warmingstripes/)

We are living in a Golden Age of visualization

Sections

The Washington Post
Democracy Dies in Darkness

Alberto Cairo To...



Health

Why outbreaks like coronavirus spread exponentially, and how to "flatten the curve"

By Harry Stevens March 14, 2020

PLEASE NOTE

The Washington Post is providing this story for free so that all readers have access to this important information about the coronavirus. For more free stories, sign up for our daily Coronavirus Updates newsletter.

2.6k

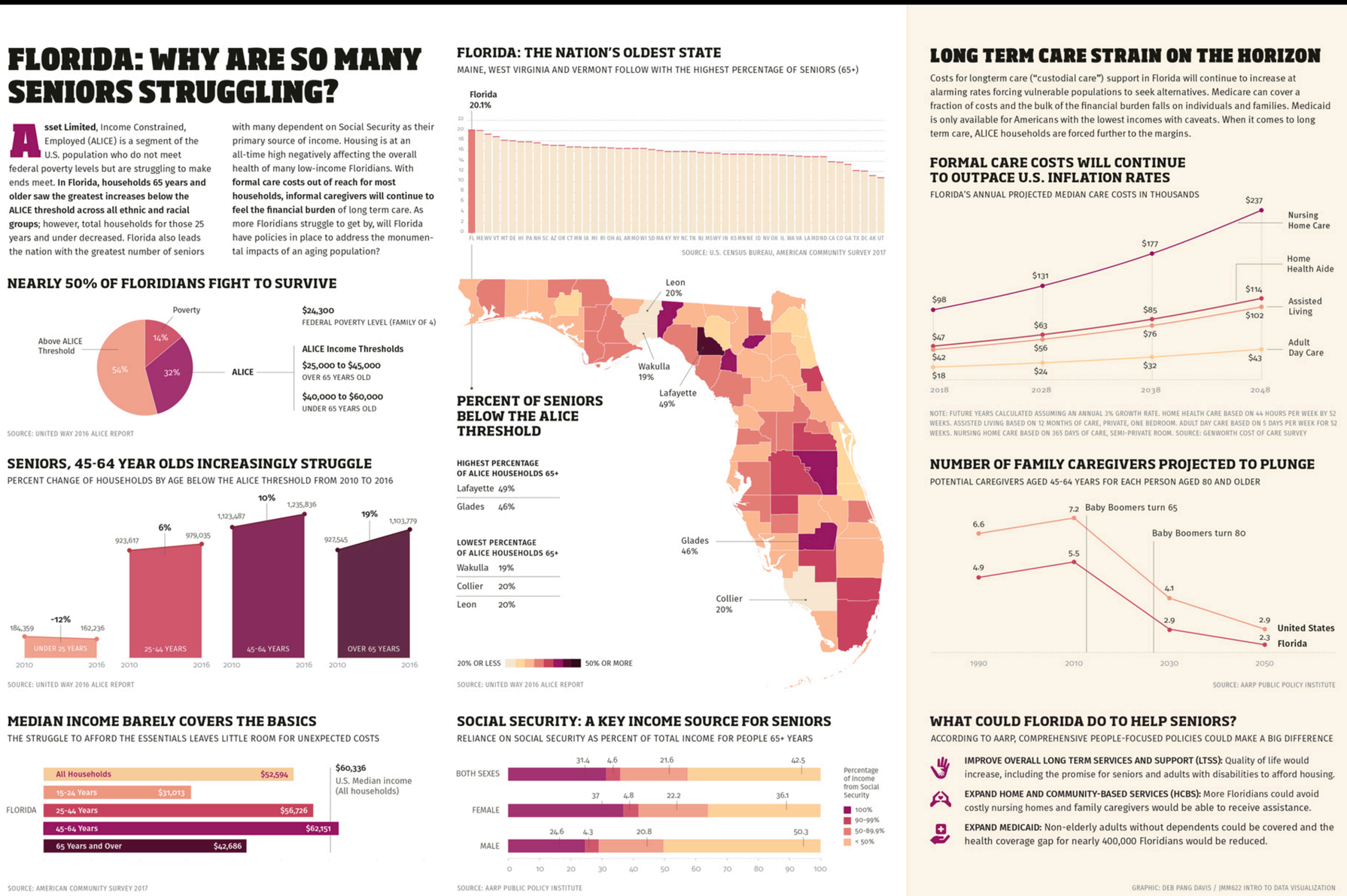
https://www.washingtonpost.com/graphics/2020/world/corona-simulator/

We are living in a Golden Age of visualization

The Post's visual journalism, which involves staff throughout the newsroom, has attracted large audiences and contributed to record subscriber growth. Six of the seven most visited stories in The Washington Post's history have been graphics, including the coronavirus simulator that became the most visited article in The Post's history, with more than three times as many visits as the second. It also includes this year's Democratic candidate quiz, which set the record for converting readers to subscribers.

https://www.washingtonpost.com/pr/2020/06/26/washington-post-expand-graphics-design-teams-with-14-new-positions/

We are living in a Golden Age of visualization



ANYONE can learn to make data visualizations.

Example of my students' work:
https://www.deb.is/

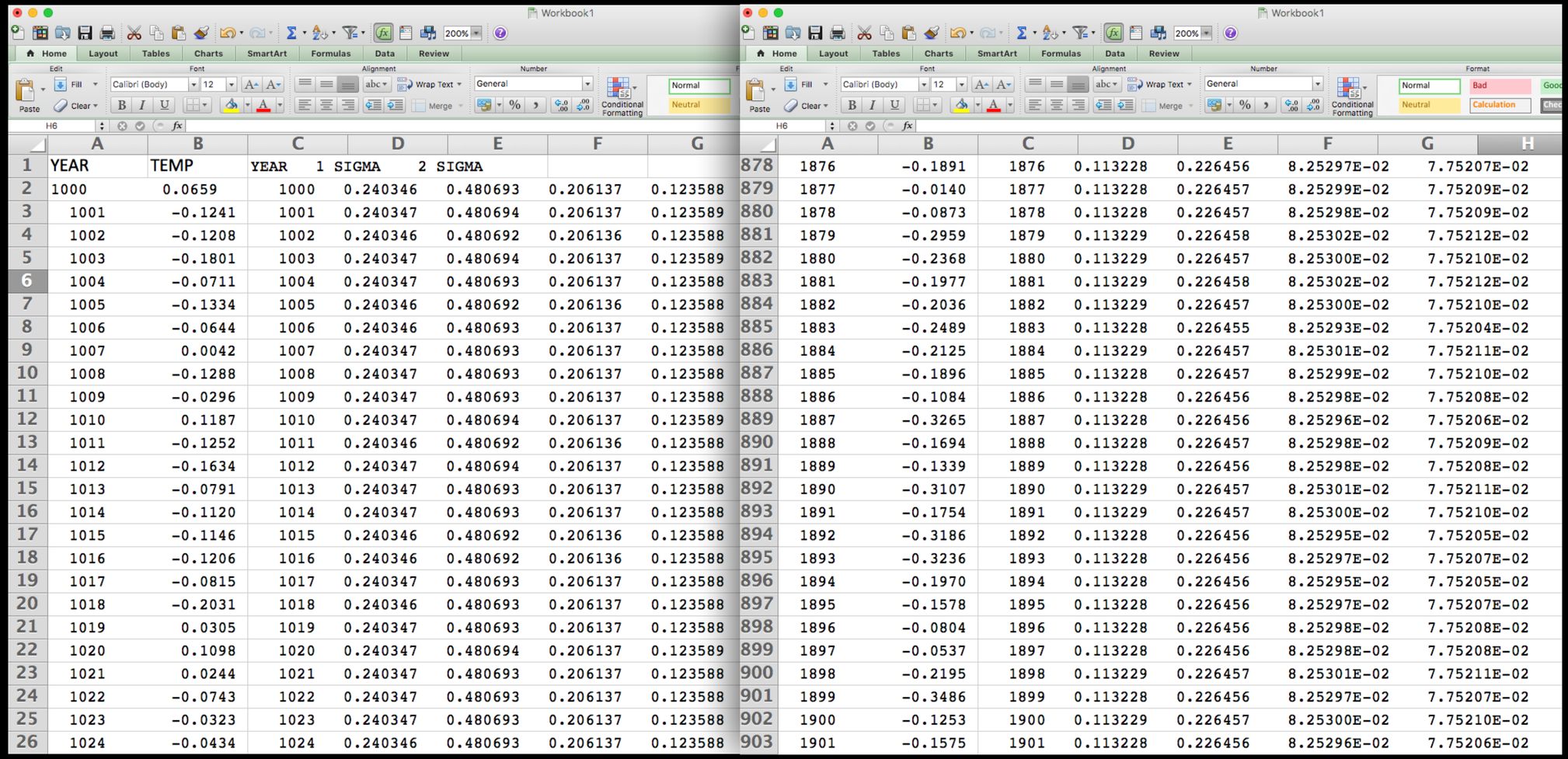
How to teach or learn data visualization?

Visualization is a bit like writing: beyond some conventions and constraints regarding symbols, visual grammar, perception, and cognition, visualization **can't be based on *"rules"* that are set in stone**.

Instead, when designing visualizations, we need to be guided by **reasoned, justifiable choices**.

1. Why should my visualization exist?

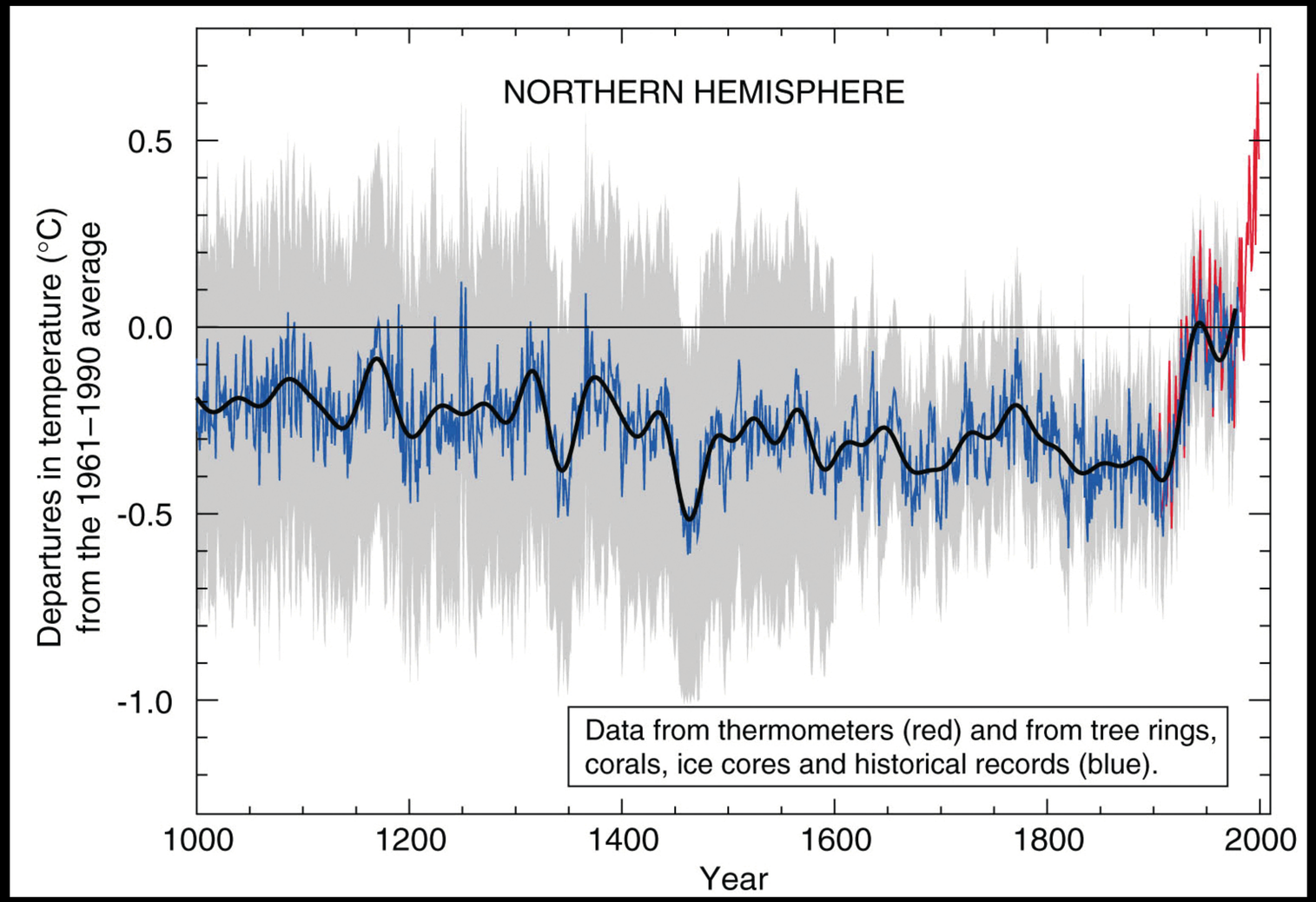
What are tables useful for?



	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	H
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	

Visualization is about patterns, trends, the big picture



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

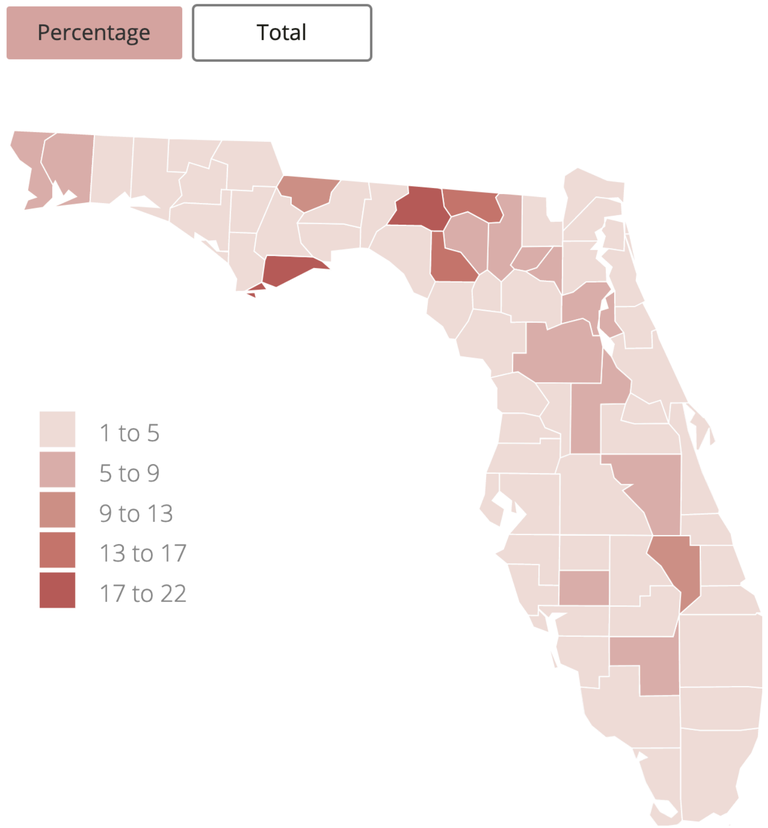
Intergovernmental Panel on Climate Change (IPCC), Third Report, 2001

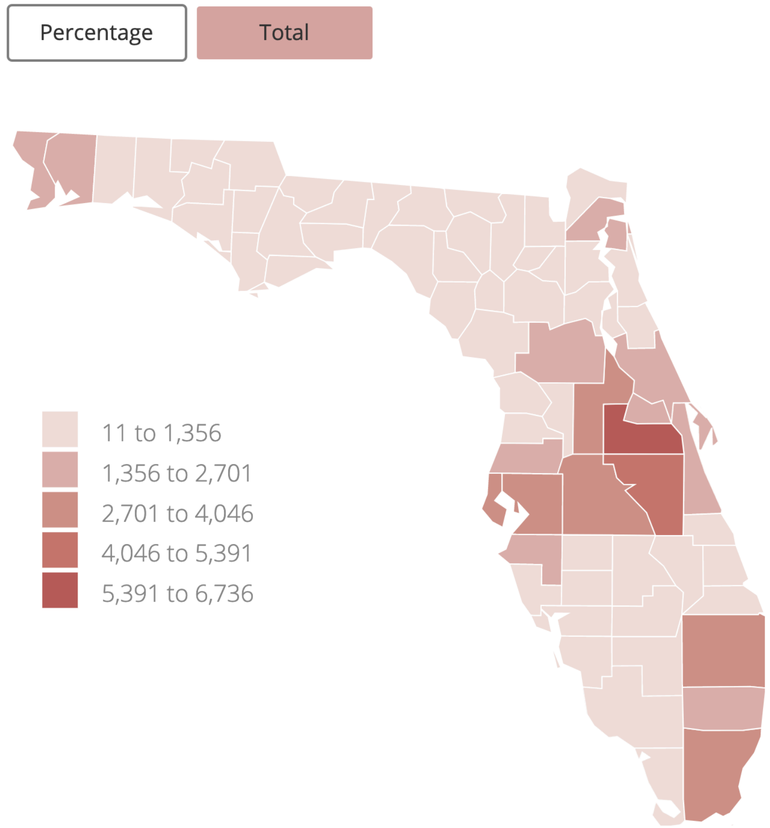
2. What to visualize?

AT SCHOOL WITHOUT A ROOF

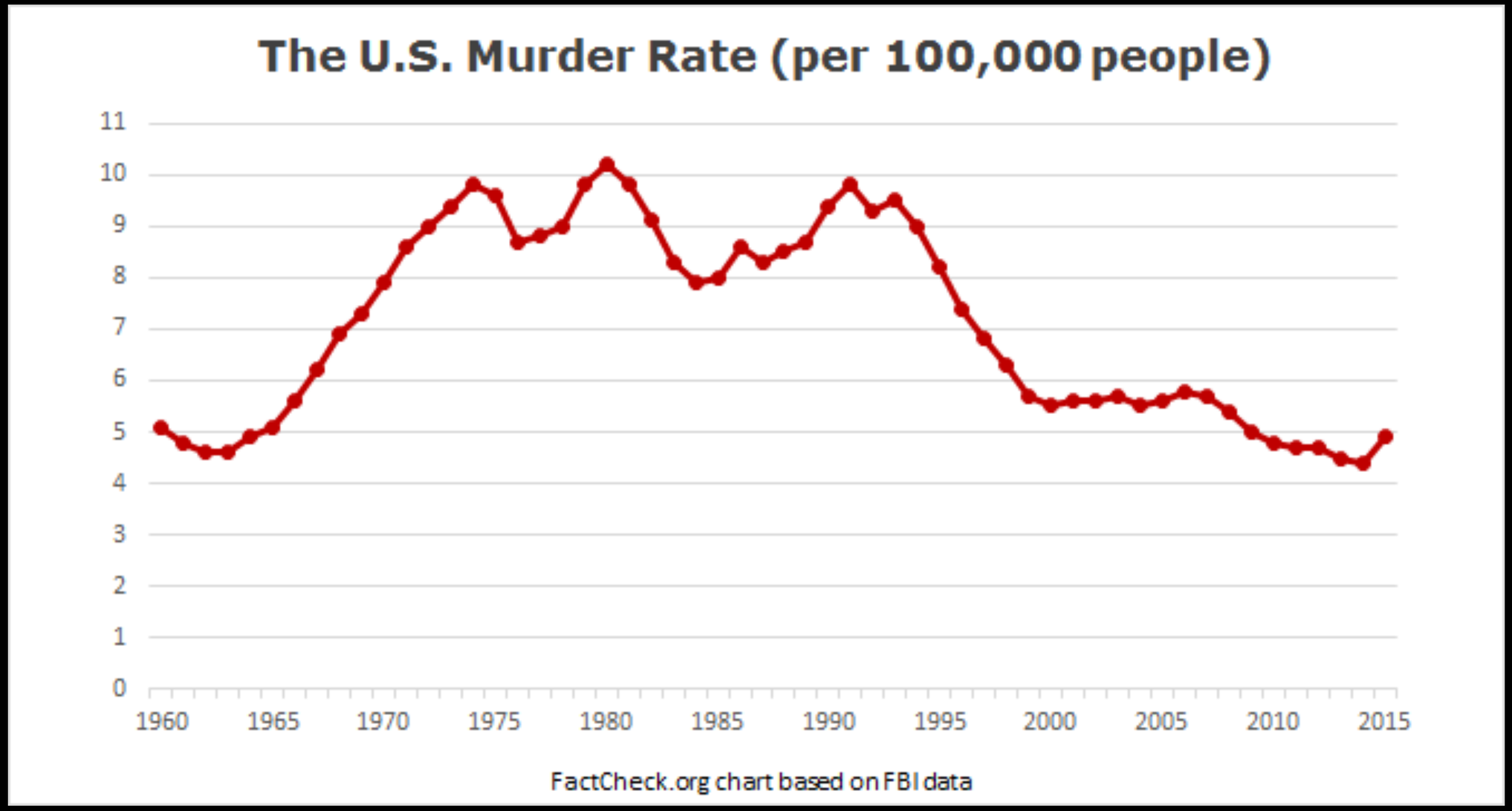
http://www.lmelgar.me/without-a-roof/

In Florida more than 71,000 students are homeless. During the last decade, this population rocketed as a result of the recession and how hard it has become for the poorest families to find affordable housing.

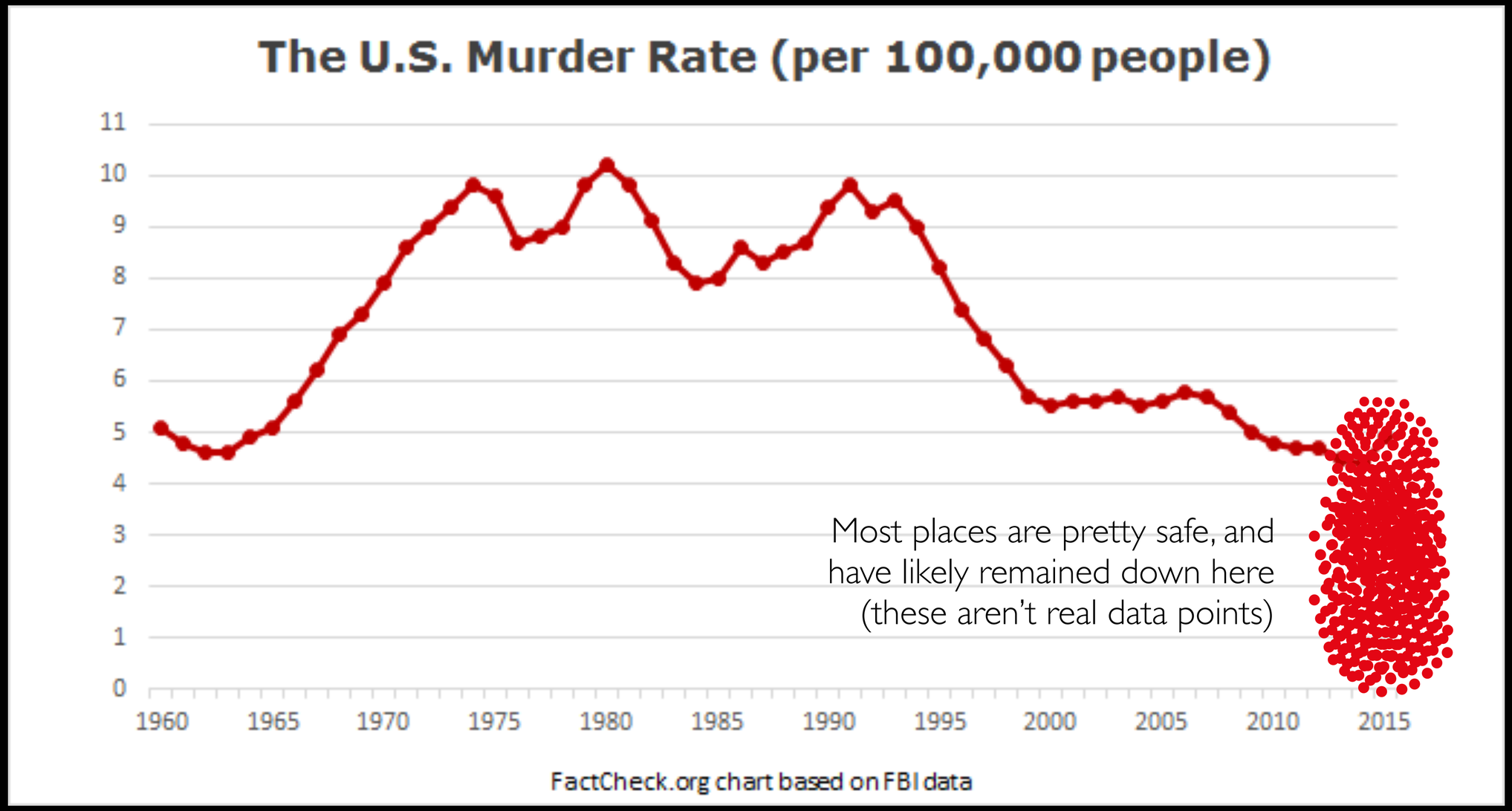




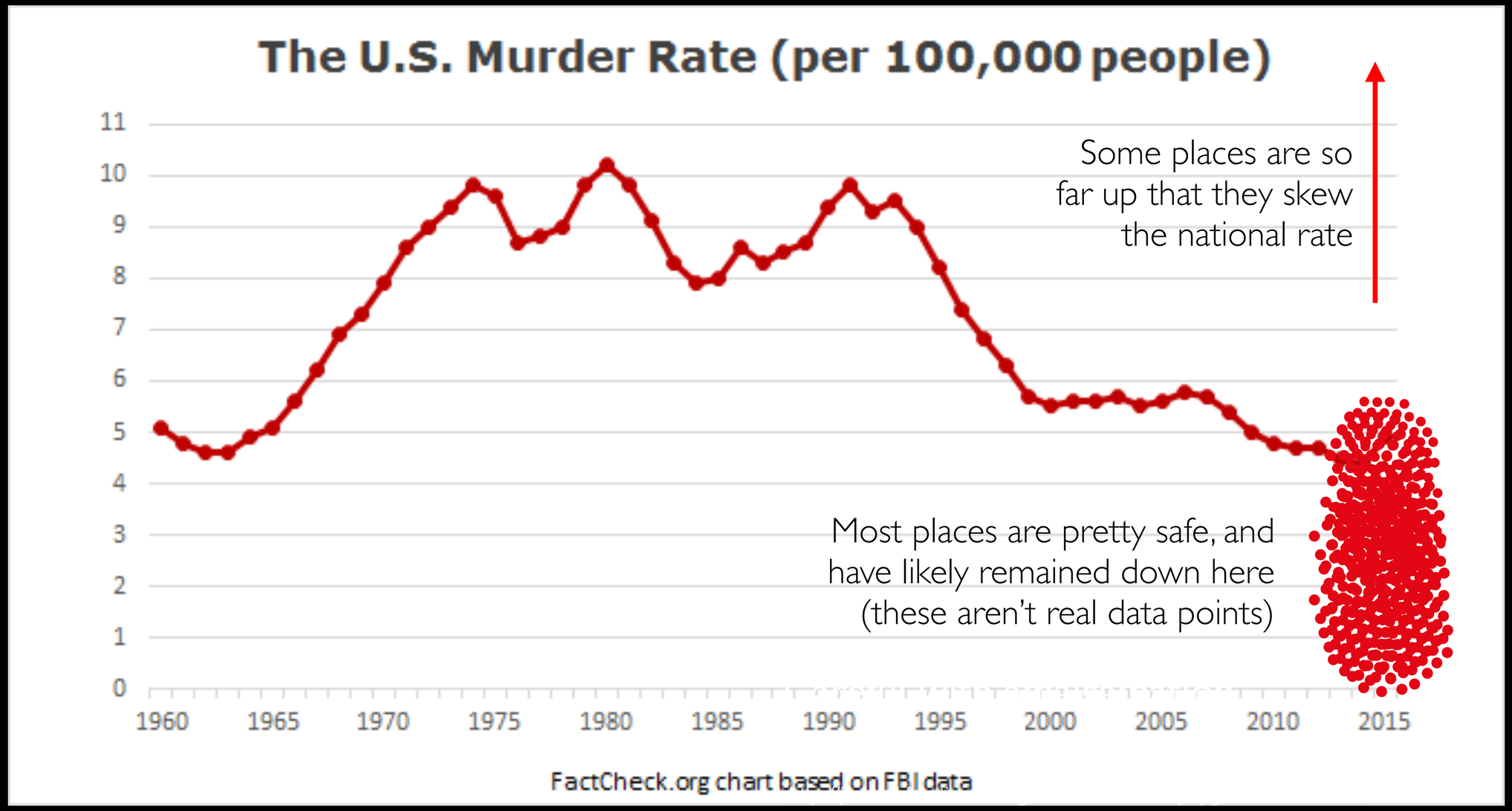
3. How much to visualize?


The U.S. Murder Rate (per 100,000 people)
11
10
9
8
7
6
5
4
3
2
1
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
FactCheck.org chart based on FBI data

The danger of aggregating data too much, and presenting just averages and other statistical summaries



The danger of aggregating data too much, and presenting just averages and other statistical summaries



4. How to visualize it?

Figure 2 - Main nationalities of arriving migrants – 2016

Greece

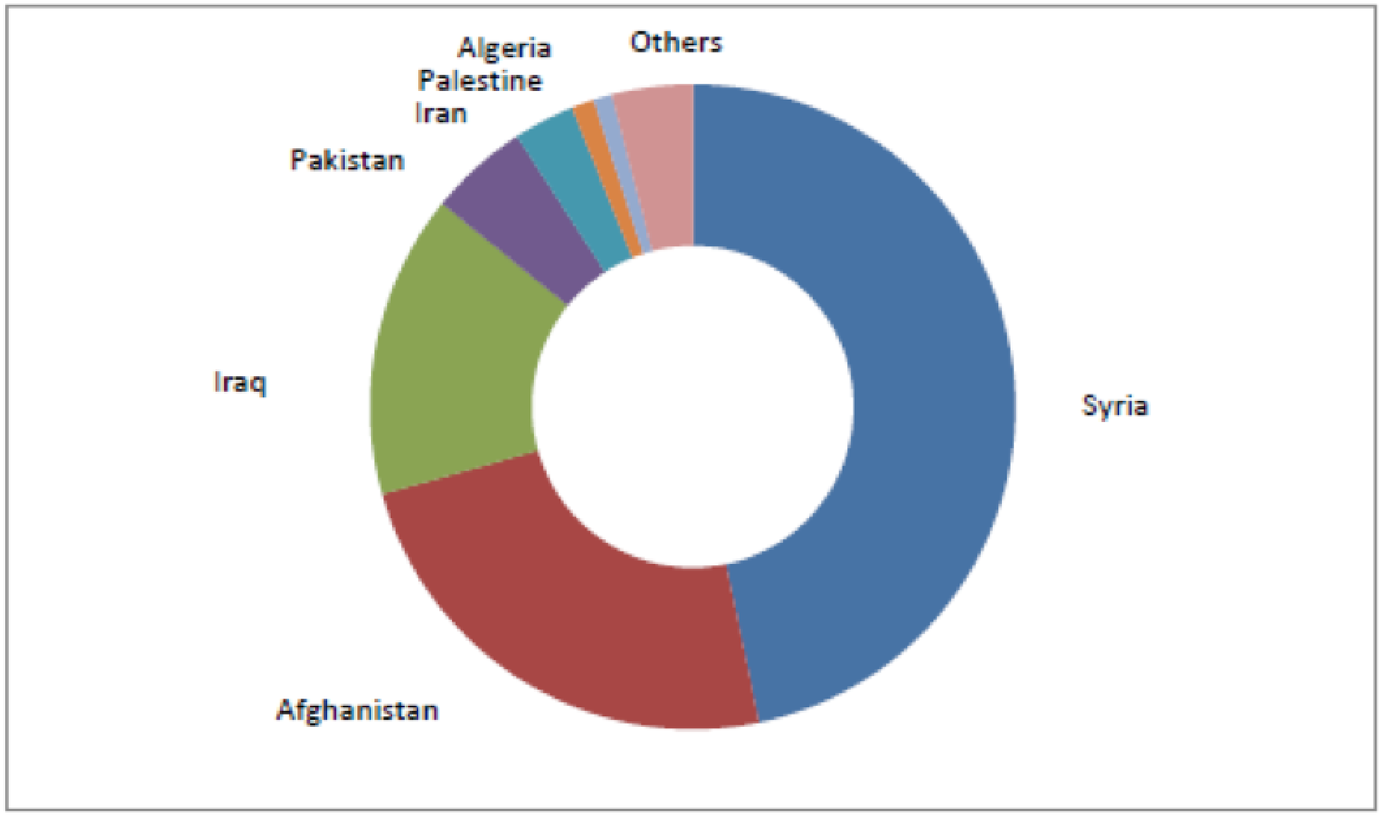
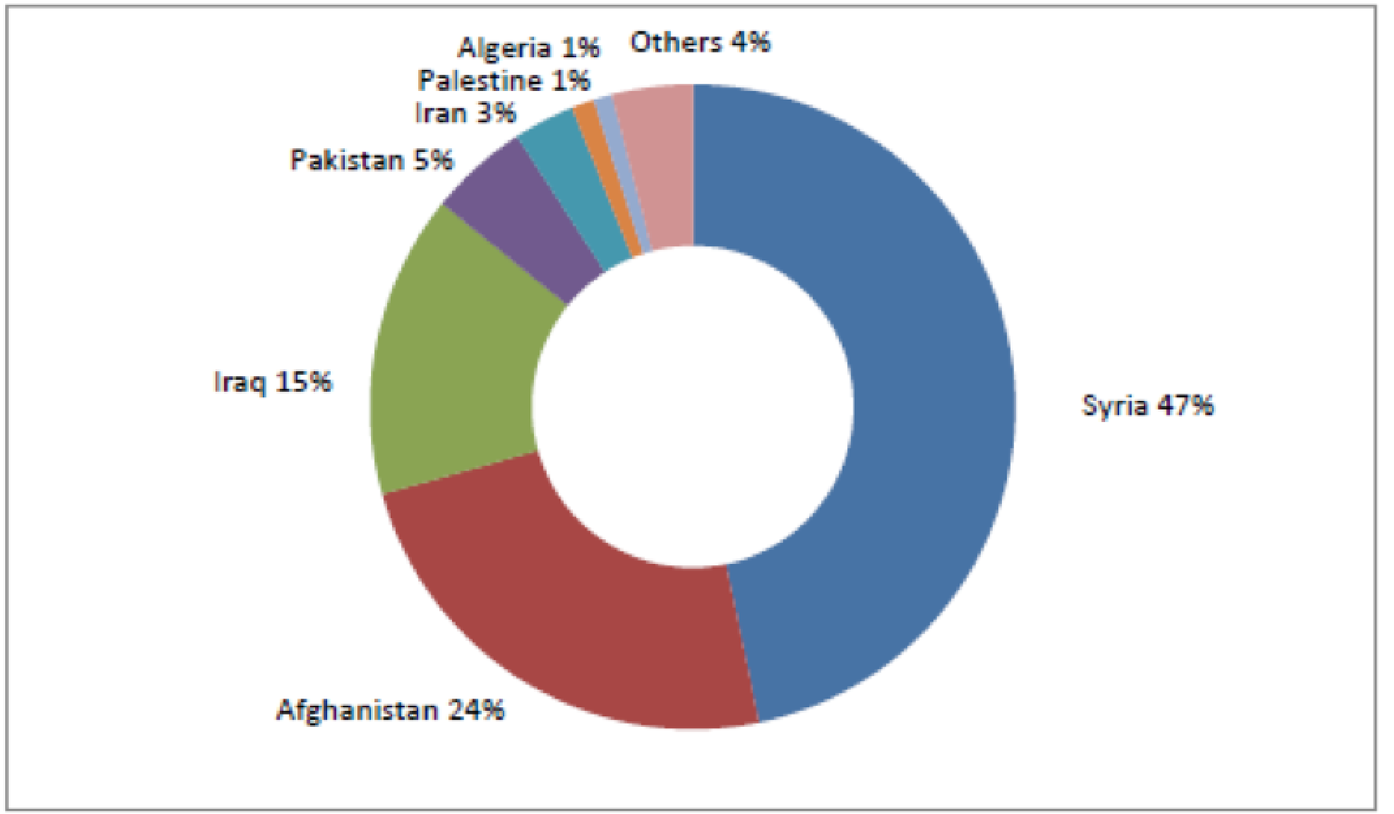
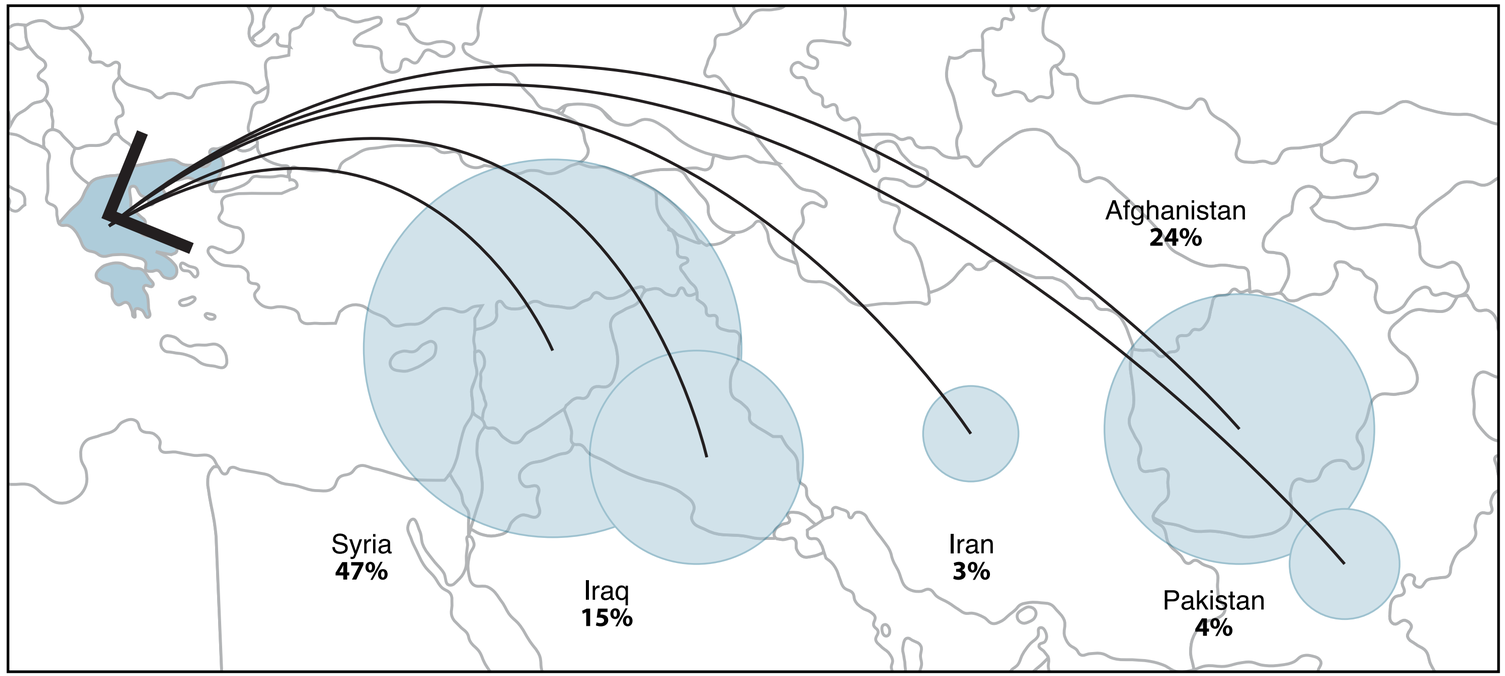
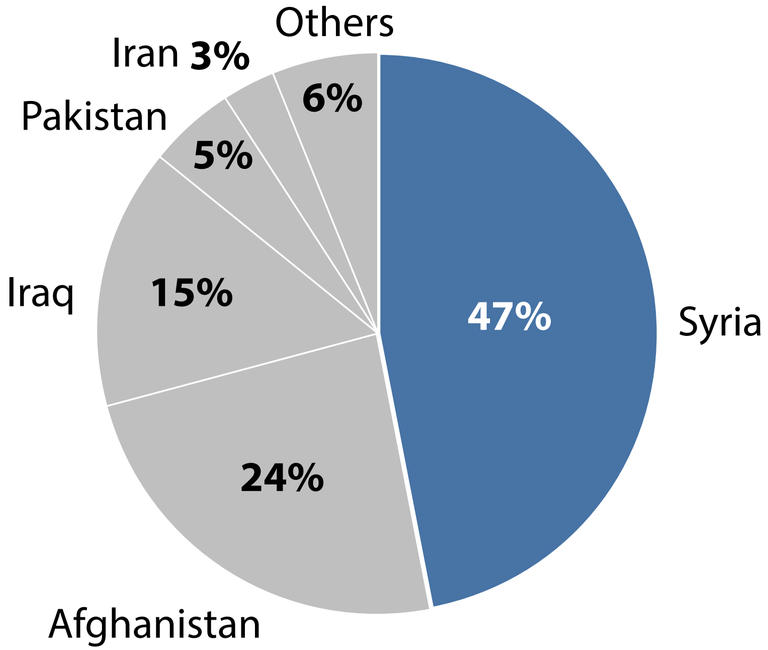


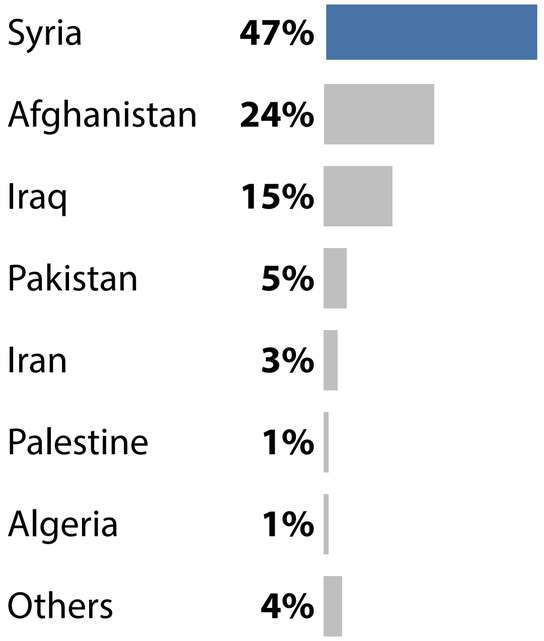
Figure 2 - Main nationalities of arriving migrants – 2016

Greece

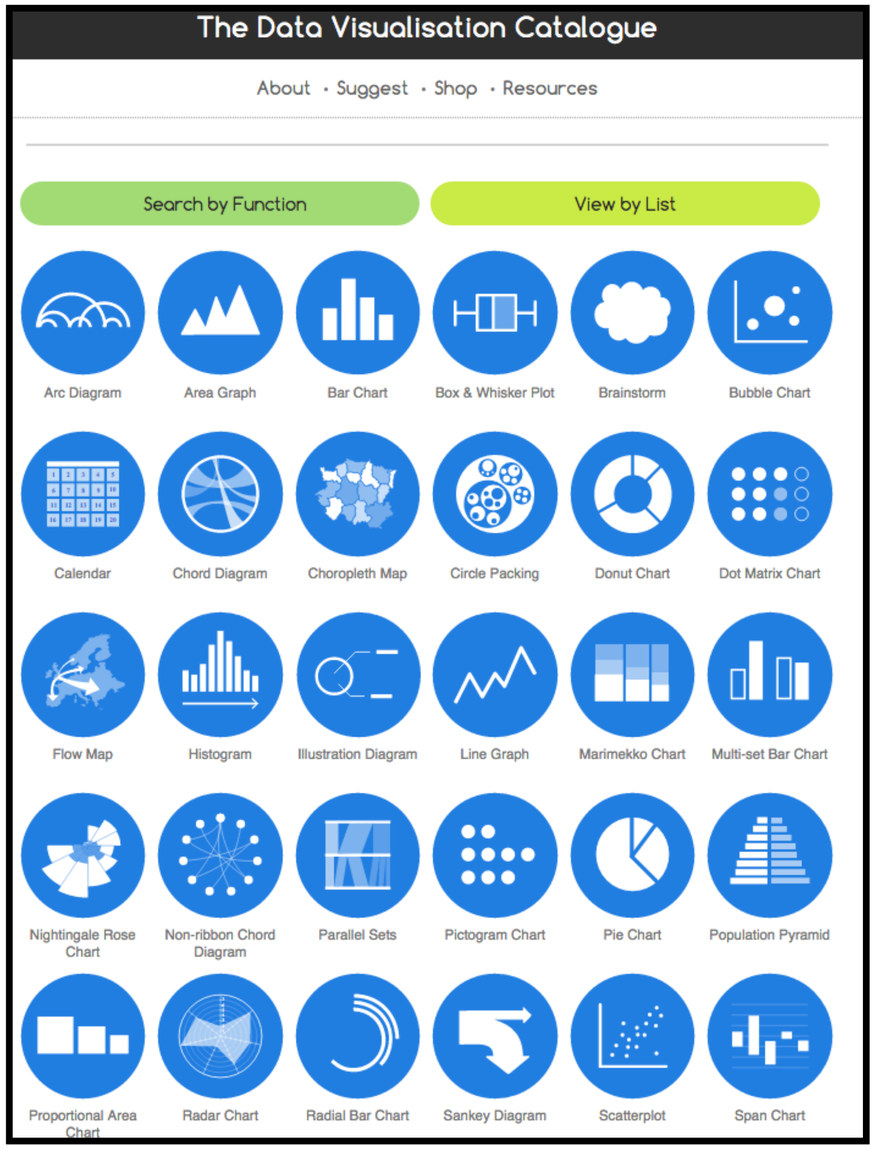


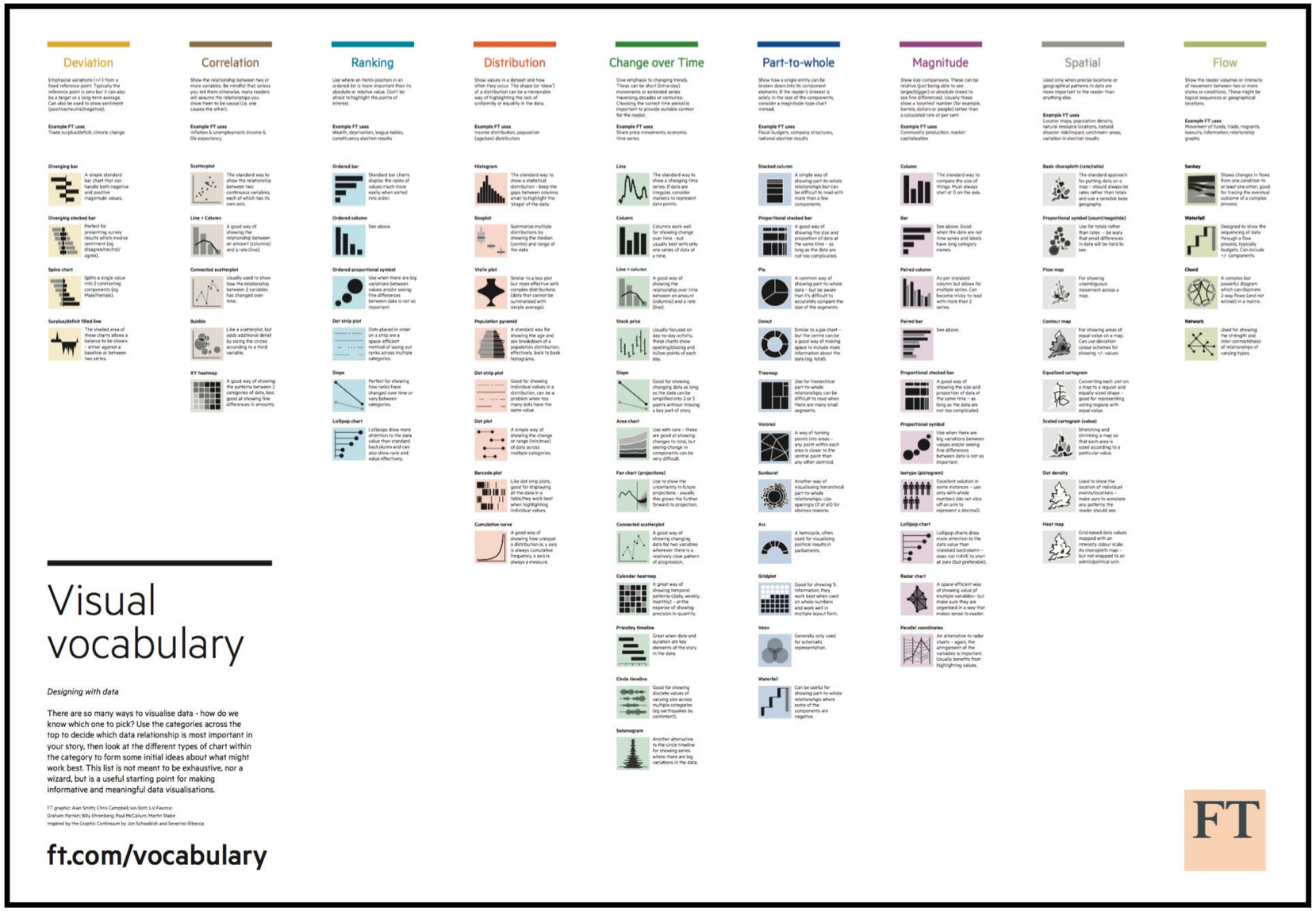






Alberto Cairo • University of Miami • www.thefunctionalart.com • Twitter: @albertocairo



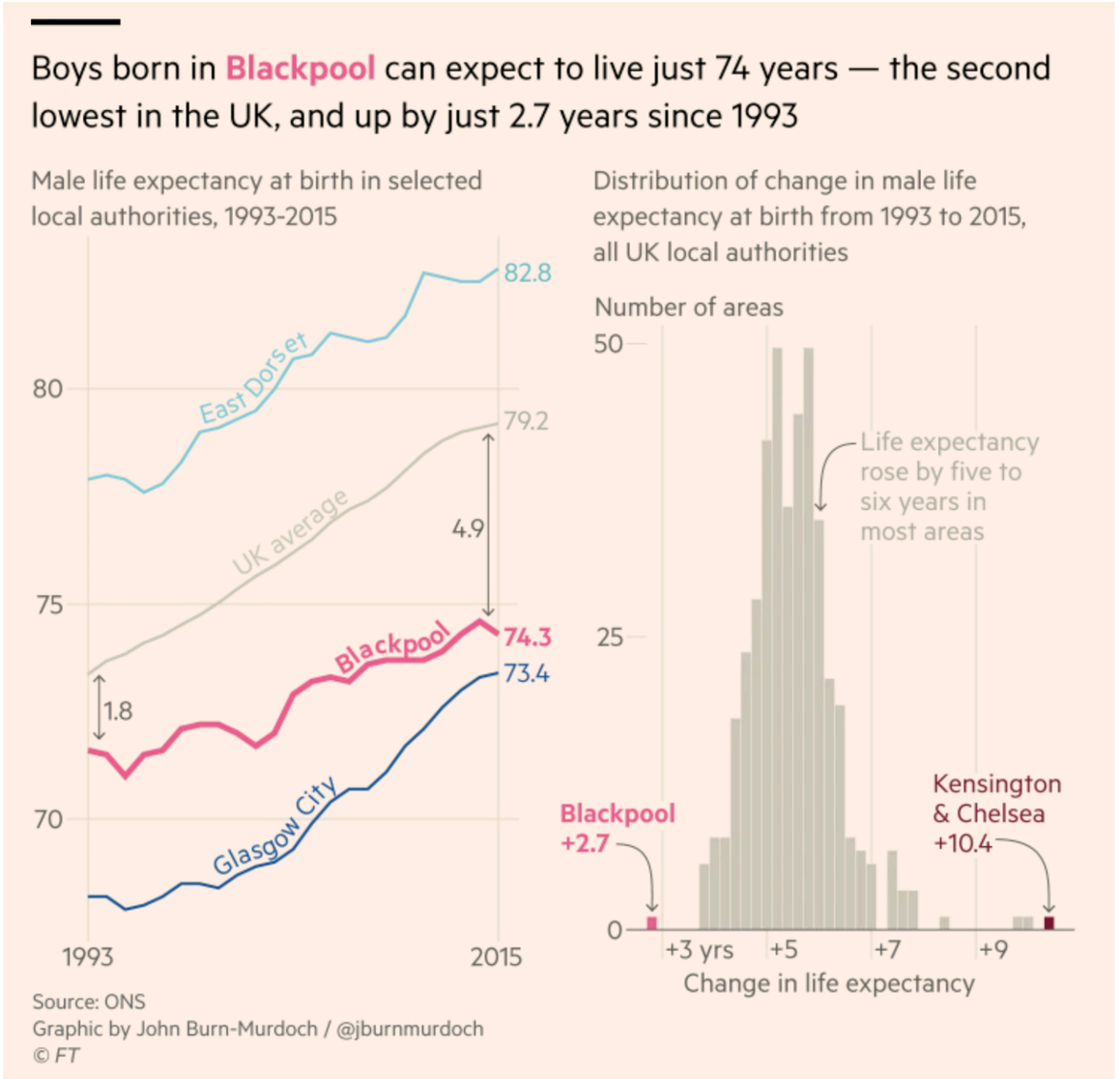


http://www.datavizcatalogue.com/

https://github.com/ft-interactive/chart-doctor/blob/master/visual-vocabulary/Visual-vocabulary.pdf

5. What words to add?

Visualization for communication isn't just about drawing things,
but also about verbally or textually explaining those things



"Design secrets behind the FT's best charts of the year"
https://www.ft.com/content/4743ce96-e4bf-11e7-97e2-916d4fbac0da

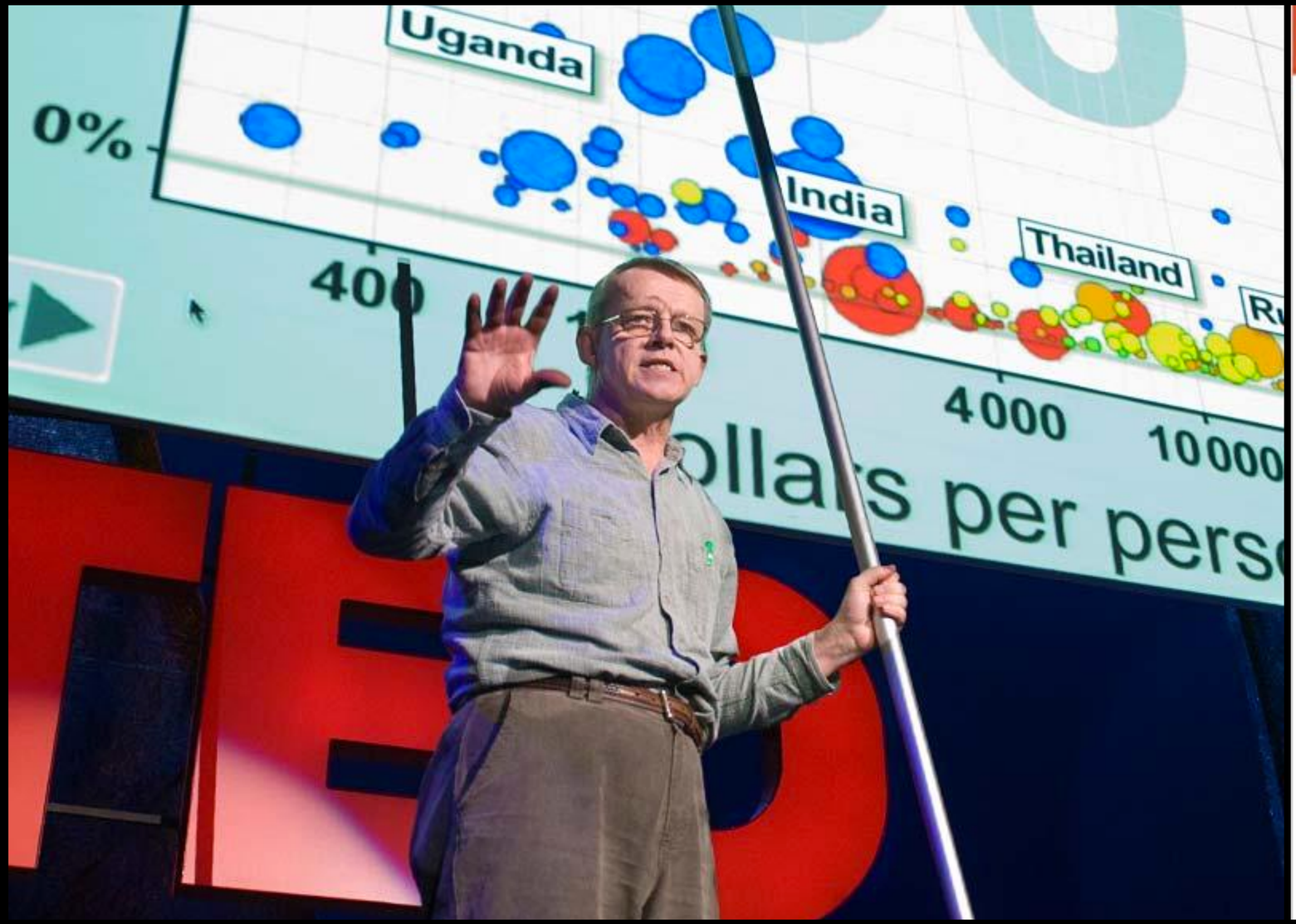
"I and my colleagues here at the FT, we really do think one of the most valuable things we can do as data visualization practitioners is add this expert annotation layer."

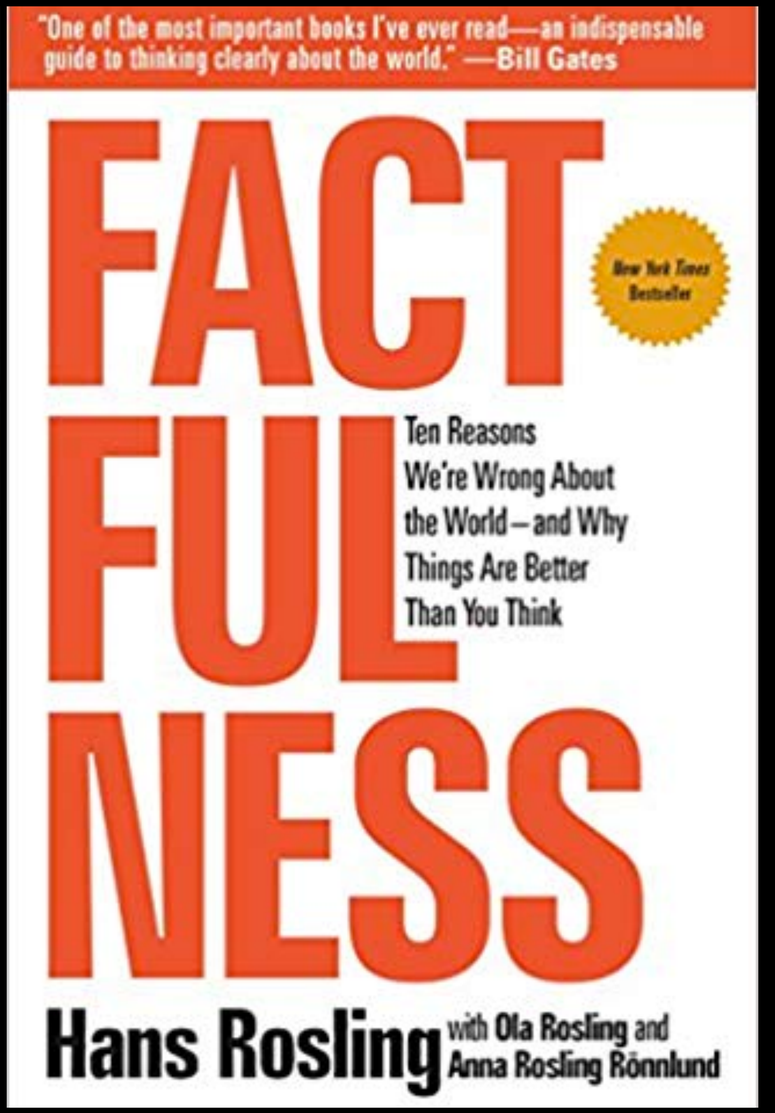
John Burn-Murdoch

Financial Times

https://policyviz.com/podcast/episode-155-john-burn-murdoch/

Show AND tell





Hans Rosling, www.gapminder.org

Show AND tell

Hans Rosling, *The Joy of Stats*

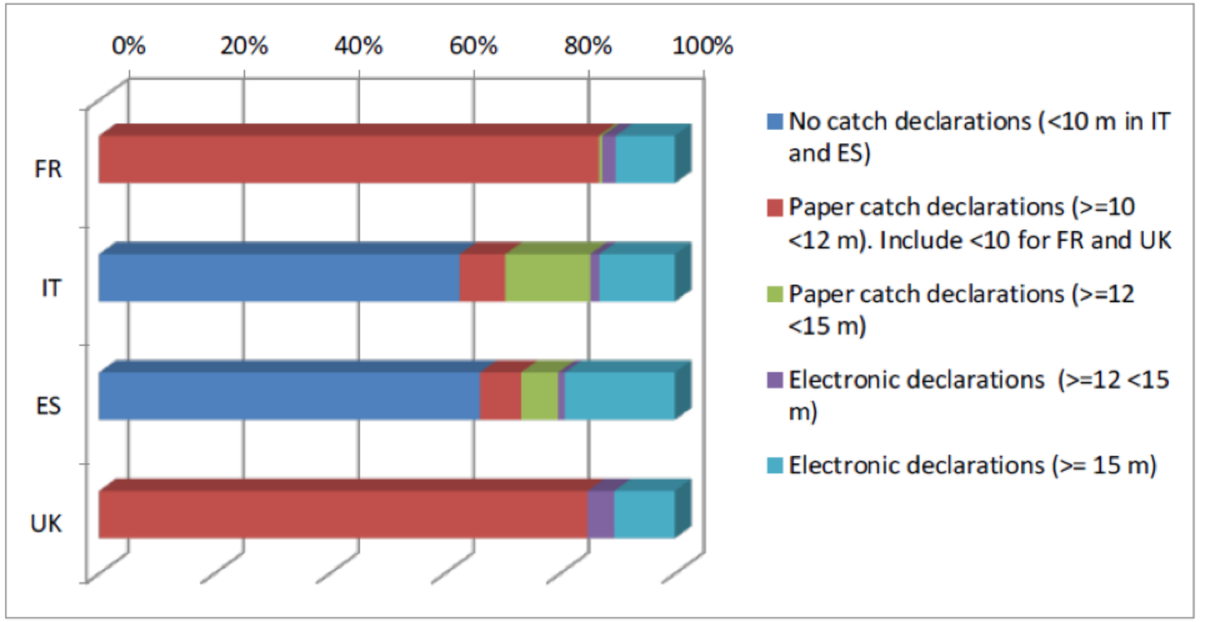
Alberto Cairo • University of Miami • www.thefunctionalart.com • Twitter: @albertocairo

6. What visual design and style should I use?

Pay attention to visual design and style. Polishing your design should never be an afterthought. If after writing a paper, you polish the language, you should do the same with charts.

(Also, don't trust software defaults!)

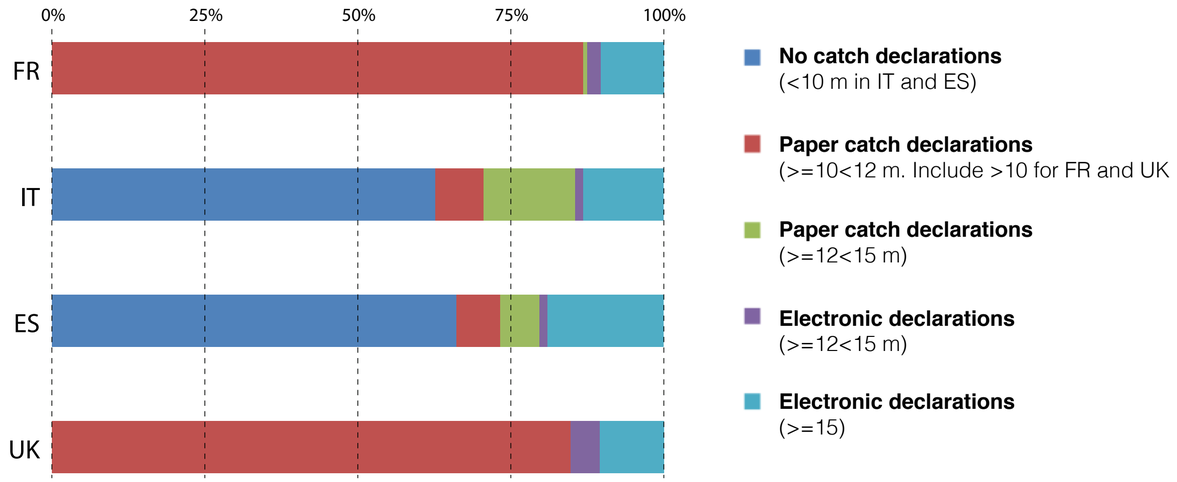
Figure 6 - Proportion of vessels that register catch and landing data, and data format



Pay attention to visual design and style. Polishing your design should never be an afterthought. If after writing a paper, you polish the language, you should do the same with charts.

(Also, don't trust software defaults!)

Figure 6 - Proportion of vessels that register catch and landing data, and data format



Multi-scale Modeling and Assessment of Malaria Risk in Northern South America

Alimi, T. O.[1]; Fuller, D. O.[1,2] and Beier, J.C.[1,3]

[1] Abess Center for Ecosystem Science and Policy; [2] Department of Geography and Regional Studies; [3] Department of Epidemiology and Public Health, University of Miami

UNIVERSITY OF MIAMI
ABESS CENTER for ECOSYSTEM SCIENCE & POLICY

1. Introduction

The public health problem posed by malaria has made it a top priority for control efforts and the general consensus globally, is that its elimination is crucial for continued international development. Consequently, there is ongoing research in different regions including South America (SA) to better understand the disease dynamics with the intent that findings may establish scientific framework that would support the development of new intervention strategies for malaria elimination in areas with seasonal malaria. One of such investigations is undertaken by the International Centers of Excellence in Malaria Research (ICEMR) under a National Institutes of Health (NIH) grant.

While only about 3% of the global malaria burden is borne by SA[1], undertaking malaria research in the region is currently important because an estimated 23million people are still at risk[2] and approximately about 80% of clinical cases are found in Northern South America (NSA)[3]. A key factor limiting effective control is lack of data and uneven implementation of control measures, including use of bed-nets, sprays, early diagnosis, and treatment. As part of the ICEMR investigation, this project seeks to model the spatial patterns of malaria risk in NSA through vector distribution and land-use changes. Furthermore, I intend to investigate the perceptions of malaria risk in order to identify barriers to adoption and how they can be circumvented.

2. Significance

Spatial distribution of malaria risk is still perceived as broadly categorized by the WHO's traditional risk maps which are highly generalized, of low resolution and have broad categories with uncertain boundaries (see da Nunes-Silva et al. 2012). There is need for up- to-date high resolution risk maps which can aid malaria control efforts. Secondly, modeling distribution of principal malaria vectors and land use changes which may explain the observed distribution and risk are useful tools which would guide future management strategies. Finally, understanding the perceptions of at risk populations may help address barriers to adoption of interventions and influence policies. Overall, findings will empower NMCPs to achieve effective control and move them closer to elimination.

3. Specific Aims

- Specific Aim 1: Model the spatial patterns of malaria risk through vector distribution and land use changes
  - Hypothesis 1.1: GIS-based Multi-Criteria Evaluation (MCE) model can accurately predict spatial extent of malaria risk areas. Objective: Generate risk maps that represent risk of malaria transmission.
  - Hypothesis 1.2: The Maximum Entropy (Maxent) model can accurately depict actual and predict potential distribution of three *Anopheles* species. Objective: Model observed and potential spread of *An. albimanus, An. darlingi,* and *An. nuneztovari.*
  - Hypothesis 1.3: Land- use changes can explain the variations in predicted malaria risk. Objective: Characterize land use land cover (LULC) and investigate changes in areas of risk.
- Specific Aim 2: Investigate the perceptions of malaria risk in order to identify barriers to adoption and how they can be circumvented.
  - Hypothesis 2.1: Knowledge of perception of malaria risk can aid design of malaria control strategies. Objective: Obtain and analyze data on subjective perceptions of risk.
  - Hypothesis 2.2: Identification of barriers to adoption of malaria control interventions provide means of tackling them. Objective: Analyze data addressing perceived barriers and policy implications

*Only ongoing work on Hypothesis 1.1 in presented here

4. Materials and Methods

- Study Area: is NSA comprising of ten countries- Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Panama, Peru, Suriname and Venezuela. These countries account for approximately 90% of clinical cases in the region hence, the choice as study area (Fig. 1).

Figure1: Map of study area

- Research Approach: Due to the complexity of malaria problem, I'm employing an interdisciplinary approach to address the problem (Fig. 2).

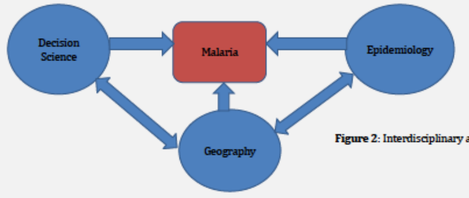


Figure 2: Interdisciplinary approach

- Materials: Raster data layers of environmental, climatic and anthropogenic parameters from satellite imageries, weather monitoring stations, global land cover and population data were collected from Worldclim, Digital Charts of the World, Globcover and Landscan. Vector data was collected from field sampling by our collaborators and the Walter Reed Biosystematics Unit. Sociological data would be collected through questionnaires to be administered in one of the study area. Other data will be collected as needed.
- Procedure: To test hypothesis 1.1, raster data of parameters that influence mosquito distribution (rivers, wetlands, urban areas, roads, population and elevation) were combined using a Multi-Criteria Evaluation in Idrisi GIS package. This produced a map of potential exposure to malaria vectors which is used as a proxy for risk of malaria transmission. All the data layers were gridded at 1km spatial resolution. A set of distance layers had been created for discrete factors using standard GIS operations. All factors were subsequently standardized into a continuous common numeric range on a byte 0-255 probability scale using a fuzzy function based on knowledge of mosquito interaction with the factor. Weights were generated for each factor based on the importance of the factor to malaria transmission by expert opinions and then assigned using Analytical Hierarchy Process. The risk maps produced were validated statistically using data on *An. darlingi* distribution and malaria case data from some parts of the study area. See preliminary results (Fig. 3,4,5)

5. Preliminary Results

- Areas of high to moderate risk corresponded with locations of some of the anophelines collected.

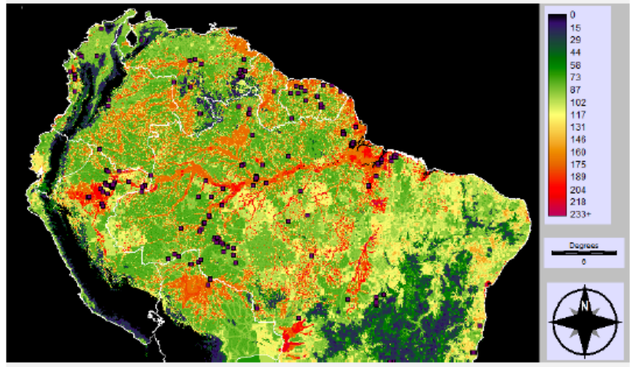


Figure 3: Potential risk of exposure to malaria vectors across NSA (0 indicate little or no risk while 233 indicate high risk)

- Risk scores for mosquito occurrence points were significantly higher than those generated randomly (Fig. 4).

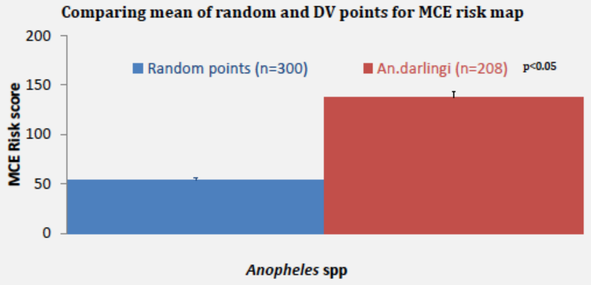


Figure 4: Plot showing the MCE risk values for randomly sampled points and for occurrence points of a DV, *An. darlingi*

6. Conclusion

Findings from preliminary results suggest that the MCE approach is a viable method to modeling spatial risk. The high resolution risk map produced aligned well with sampled vector points and may therefore be used to plan control of malaria vectors. Further analysis is planned to generate and validate risk maps with actual measures of malaria transmission, results of which could be used to plan containment of future outbreaks.

References

1. WHO. (2007). MALARIA ELIMINATION: A field manual for low and moderate endemic countries
2. PAHO (2012) PAHO Honors 2012 Malaria Champions of the Americas. Available: http://new.paho.org/hq/index.php?option=com_content&view=article&id=7429&Itemid=39639
3. Gusmao R. (1999) Overview of malaria control in the Americas. Parasitologia 41:355-60.
4. Da Silva-Nunes, M., Moreno, M., Conn, J.E., Gamboa, D., Abeles, S., Vinetz, J.M., and Ferreira, M.U. (2012) Amazonian malaria: Asymptomatic human reservoirs, diagnostic challenges, environmentally driven changes in mosquito vector populations, and the mandate for sustainable control strategies. *Acta Tropica* **121** (3): 281-29

Multi-scale Modeling and Assessment of Malaria Risk in Northern South America

Alimi, T. O.[1]; Fuller, D. O.[1,2] and Beier, J.C.[1,3]

UNIVERSITY OF MIAMI
ABESS CENTER for ECOSYSTEM SCIENCE & POLICY

INTRODUCTION

Malaria as a public health problem has become a priority for control efforts worldwide. The global consensus is that **its elimination is crucial for continual development**. Ongoing research projects in different regions, including South America (SA), try to improve our understanding of the disease dynamics. Their goal is to establish a new framework that would lead to new intervention strategies for malaria elimination in areas where the disease is seasonal. **One of such investigations is undertaken by the International Centers of Excellence in Malaria Research (ICEMR) under a National Institutes of Health grant.**

While only about 3% of the global malaria burden is borne by SA1, undertaking malaria research in the region is currently important because an estimated 23million people are still at risk 2 and approximately about 80% of clinical cases are found in **Northern South America (NSA)** 3. A key factor limiting eective control is lack of data and uneven implementation of control measures, including use of bednets, sprays, early diagnosis, and treatment. As part of the ICEMR investigation, this project seeks to model the spatial patterns of malaria risk in NSA through vector distribution and land-use changes. Furthermore, I intend to investigate the perceptions of malaria risk in order to identify barriers to adoption and how they can be circumvented.

SIGNIFICANCE

Spatial distribution of malaria risk is still perceived as broadly categorized by the WHO's traditional risk maps which are highly generalized, of low resolution and have broad categories with uncertain boundaries (see da Nunes-Silva et al. 2012). There is need for up- to-date high resolution risk maps which can aid malaria control eorts . Secondly, modeling distribution of principal malaria vectors and land use changes which may explain the observed distribution and risk are useful tools which would guide future management strategies . Finally, understanding the perceptions of at risk populations may help address barriers to adoption of interventions and influence policies. Overall, findings will empower NMCPs to achieve eective control and move them closer to elimination .

AIMS

Specific Aim 1: Model the spatial patterns of malaria risk through vector distribution and land use changes

- **Hypothesis 1.1:** GIS-based Multi-Criteria Evaluation (MCE) model can accurately predict spatial extent of malaria risk areas. **Objective:** Generate risk maps that represent risk of malaria transmission
- **Hypothesis 1.2:** The Maximum Entropy (Maxent) model can accurately depict actual and predict potential distribution of three Anopheles species. **Objective:** Model observed and potential spread of An. albimanus, An. darlingi , and An. nuneztovari.
- **Hypothesis 1.3:** Land- use changes can explain the variations in predicted malaria risk. **Objective:** Characterize land use land cover (LULC) and investigate changes in areas of risk

Specific Aim 2: Investigate the perceptions of malaria risk in order to identify barriers to adoption and how they can be circumvented.

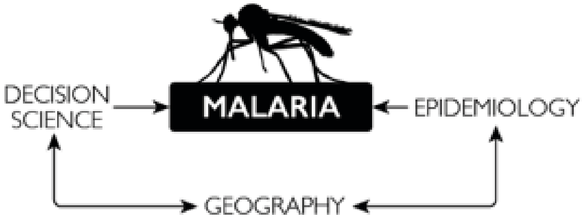
- **Hypothesis 2.1:** Knowledge of perception of malaria risk can aid design of malaria control strategies. **Objective:** Obtain and analyze data on subjective perceptions of risk .
- **Hypothesis 2.2:** Identification of barriers to adoption of malaria control interventions provide means of tackling them. **Objective:** Analyze data addressing perceived barriers and policy implications

***Only ongoing work on Hypothesis 1.1 in presented here**

MATERIALS AND METHODS

NSA comprising of ten countries - Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Panama, Peru, Suriname and Venezuela. These countries account for approximately 90% of clinical cases in the region

Research approach: Due to the complexity of malaria problem, I'm employing an interdisciplinary approach to address the problem.

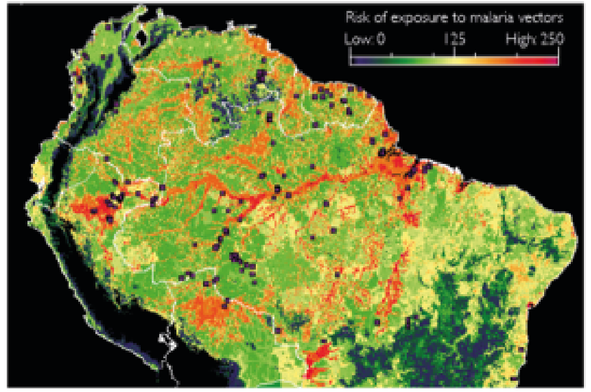


Materials: Raster data layers of environmental, climatic and anthropogenic parameters from satellite imageries, weather monitoring stations, global land cover and population data were collected from Worldclim , Digital Charts of the World, Globcover and Landscan. Vector data was collected from field sampling by our collaborators and the Walter Reed Biosystematics Unit. Sociological data would be collected through questionnaires to be administered in one of the study area. Other data will be collected as needed.

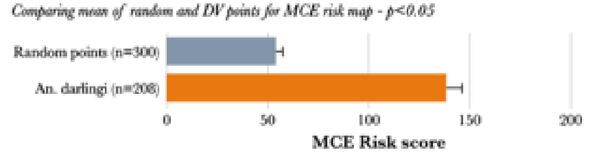
Procedure: To test hypothesis 1.1, raster data of parameters that inence mosquito distribution (rivers , wetlands, urban areas, roads, population and elevation) were combined using a Multi-Criteria Evaluation in Idrisi GIS package. This produced a map of potential exposure to malaria vectors which is used as a proxy for risk of malaria transmission . All the data layers were gridded at 1km spatial resolution . A set of distance layers had been created for discrete factors using standard GIS operations. All factors were subsequently standardized into a continuous common numeric range on a byte 0-255 probability scale using a fuzzy function based on knowledge of mosquito interaction with the factor. Weights were generated for each factor based on the importance of the factor to malaria transmission by expert opinions and then assigned using Analytical Hierarchy Process . The risk maps produced were validated statistically using data on An. darlingi distribution and malaria case data from some parts of the study area. See preliminary results

RESULTS

Areas of high to moderate risk corresponded with locations of some of the anophelines collected.



Risk scores for mosquito occurrence points were significantly higher than those generated randomly.



CONCLUSION

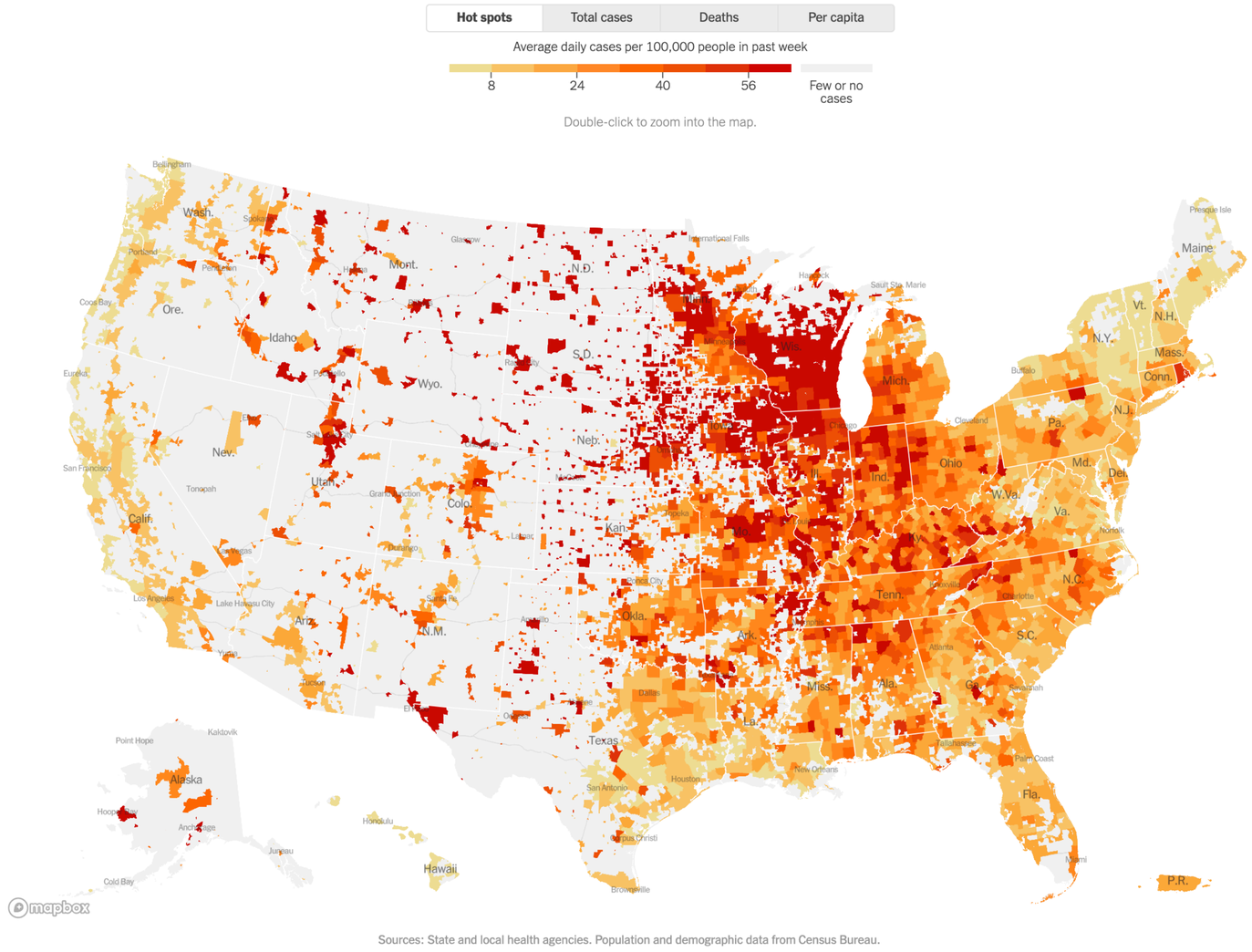
Findings from preliminary results suggest that the MCE approach is a viable methods to modeling spatial risk. The high resolution risk map produced aligned well with sample vector points and may therefore be used to plan control of malaria vectors. Further analysis is planned to generate and validate risk maps with actual measures of malaria transmission, results of which could be used to plan containment of future outbreaks.

References

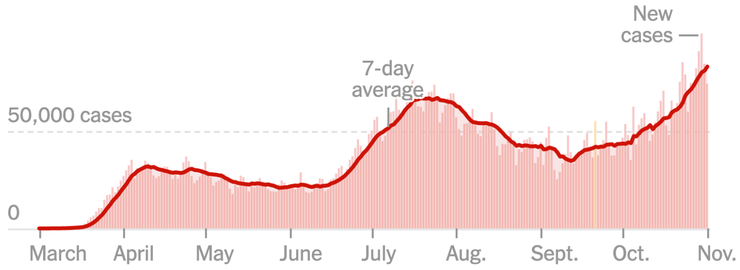
1. WHO. (2007). MALARIA ELIMINATION : A field manual for low and moderate endemic countries
2. PAHO (2012) PAHO Honors 2012 Malaria Champions of the Americas. Available: http:// new.paho.org/hq/index. php?option=com_content&view=article&id= 7429:&Itemid= 39639
3. Gusmao R. (1999) Overview of malaria control in the Americas. Parasitologia 41:355-60.
4. Da Silva-Nunes, M., Moreno, M., Conn, JE., Gamboa, D., Abeles, S., Vinetz, JM., and Ferreira, MU. (2012) Amazonian malaria: Asymptomatic human reservoirs, diagnostic challenges, environmentally driven changes in mosquito vector populations, and the mandate for sustainable control strategies. Acta Tropica 121 (3): 281-29

Standard visualizations

Appropriate for graphics we use all the time



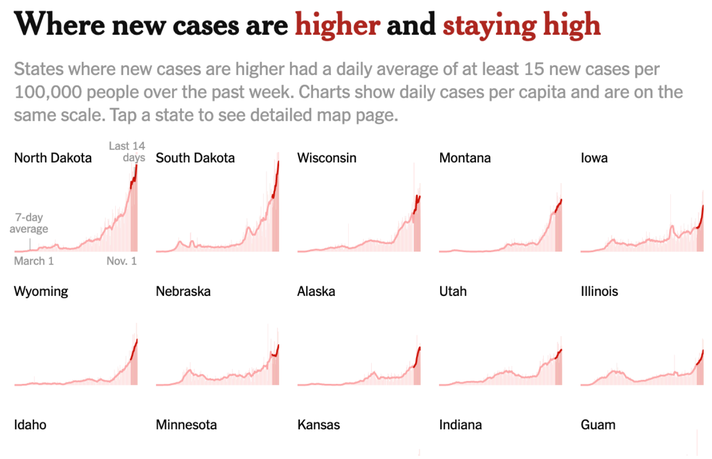
Sources: State and local health agencies. Population and demographic data from Census Bureau.



	TOTAL REPORTED	ON NOV. 1	14-DAY CHANGE
Cases	9.2 million+	74,113	+45% ↗
Deaths	230,937	427	+17% →

Day with data reporting anomaly.

Includes confirmed and probable cases where available. 14-day change trends use 7-day averages.



https://www.nytimes.com/interactive/2020/us/coronavirus-us-cases.html

Alberto Cairo • University of Miami • www.thefunctionalart.com • Twitter: @albertocairo

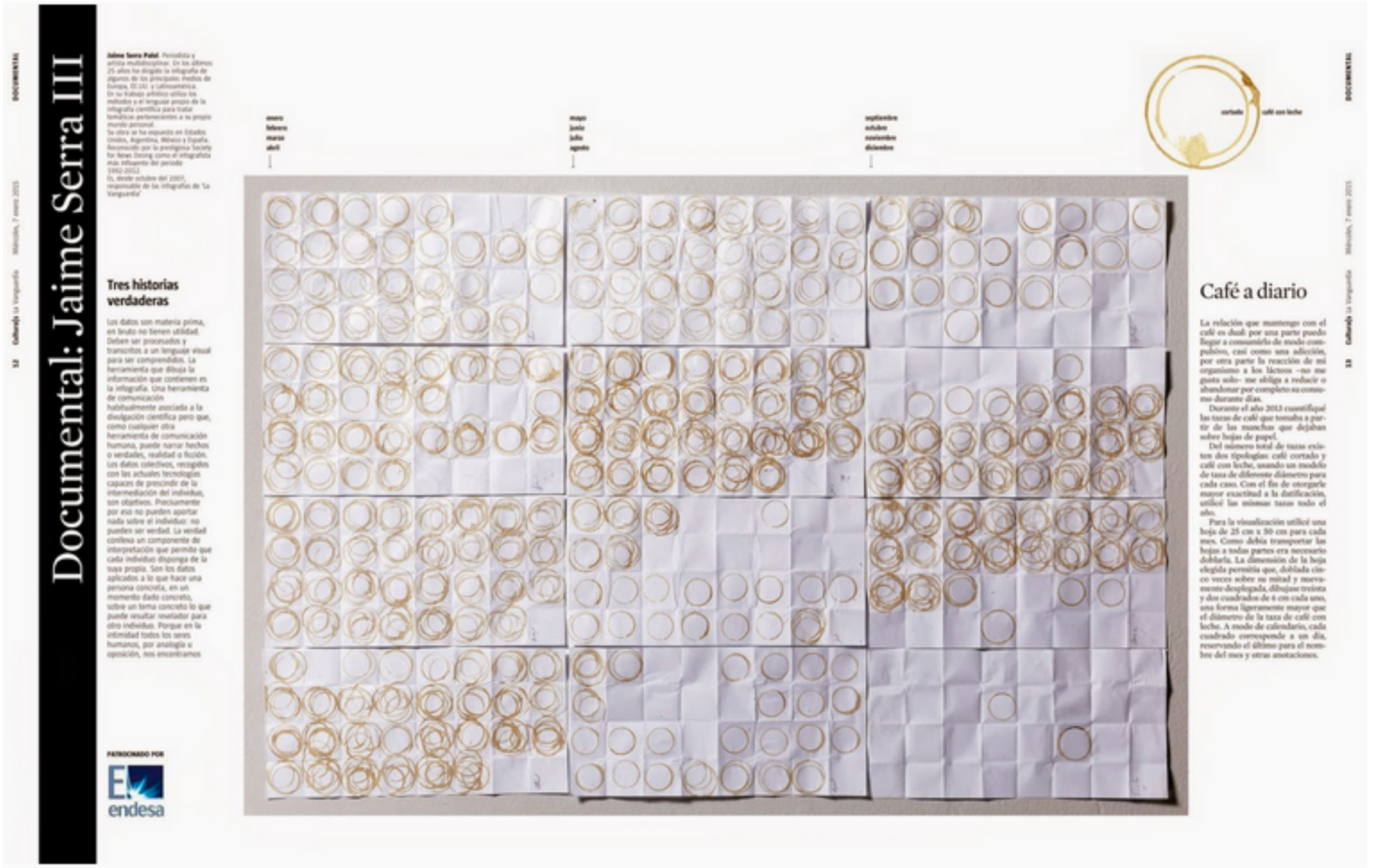
Fully customized style:

Appropriate for one-time use when we want to provoke curiosity, surprise —or simply a smile

https://jaimeserra-archivos.blogspot.com/

Fully customized style:

Appropriate for one-time use when we want to provoke curiosity, surprise —or simply a smile



Why does all this matter?

The purpose of visualization isn't visualization per se. The purpose of visualization is to help people **make sense of the world** through a combination of visuals and words.

Where to go from here?

(reading recommendations)

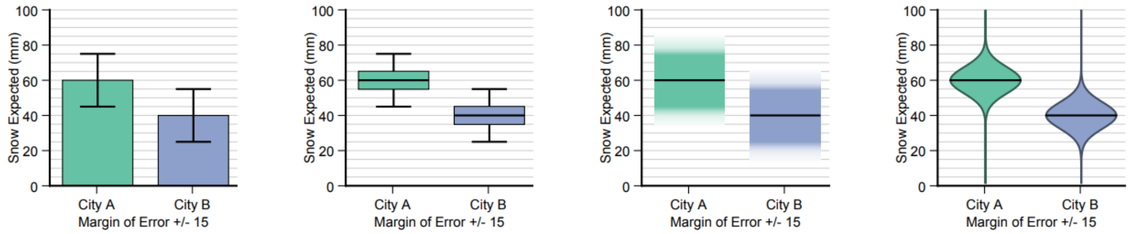
Disclosing limitations and uncertainty

Uncertainty and graphicacy
How should statisticians, journalists, and designers reveal uncertainty in graphics for public consumption?

https://ec.europa.eu/eurostat/cros/powerfromstatistics/OR/PfS-OutlookReport-Cairo.pdf

Error Bars Considered Harmful:
Exploring Alternate Encodings for Mean and Error

Michael Correll *Student Member, IEEE*, and Michael Gleicher *Member, IEEE*



(a) **Bar chart** with error bars: the height of the bars encodes the sample mean, and the whiskers encode a 95% t-confidence interval.

(b) **Modified box plot**: The whiskers are the 95% t-confidence interval, the box is a 50% t-confidence interval.

(c) **Gradient plot**: the transparency of the colored region corresponds to the cumulative density function of a t-distribution.

(d) **Violin plot**: the width of the colored region corresponds to the probability density function of a t-distribution.

https://graphics.cs.wisc.edu/Papers/2014/CG14/Preprint.pdf

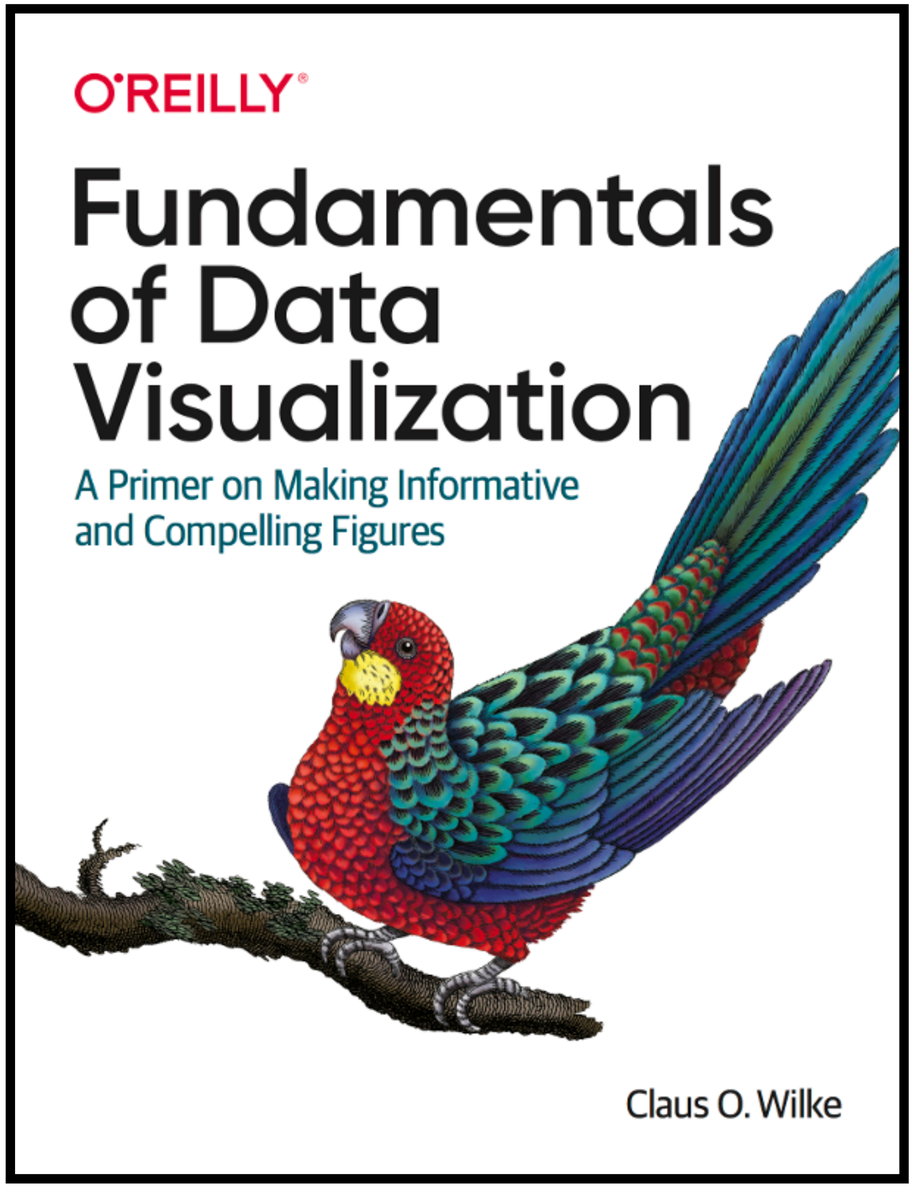
Collection of papers about visualizing uncertainty:
https://www.dropbox.com/sh/jk4ginxyai6ylqu/AABvqdyT1hJtyFN9nKNHyX9Ba?dl=0

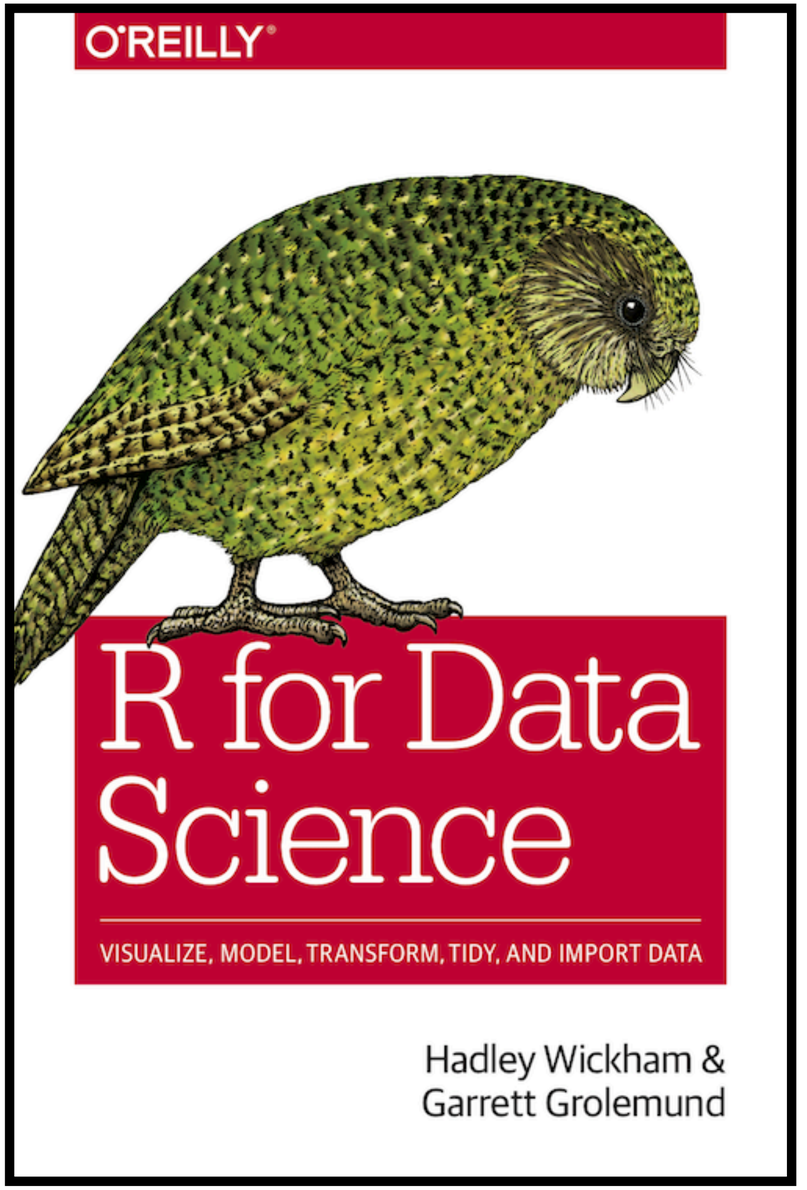
Articles and materials

The Financial Times series of articles about data visualization
https://www.dropbox.com/sh/9hbdxqsoel4n3zy/AABh1k59lSo4dUb765DbLxjHa?dl=0

Various articles about data visualization
https://www.dropbox.com/sh/elp612msxsawrkq/AABga-vZ_0McK30_zEThEtW1a?dl=0

Books available online

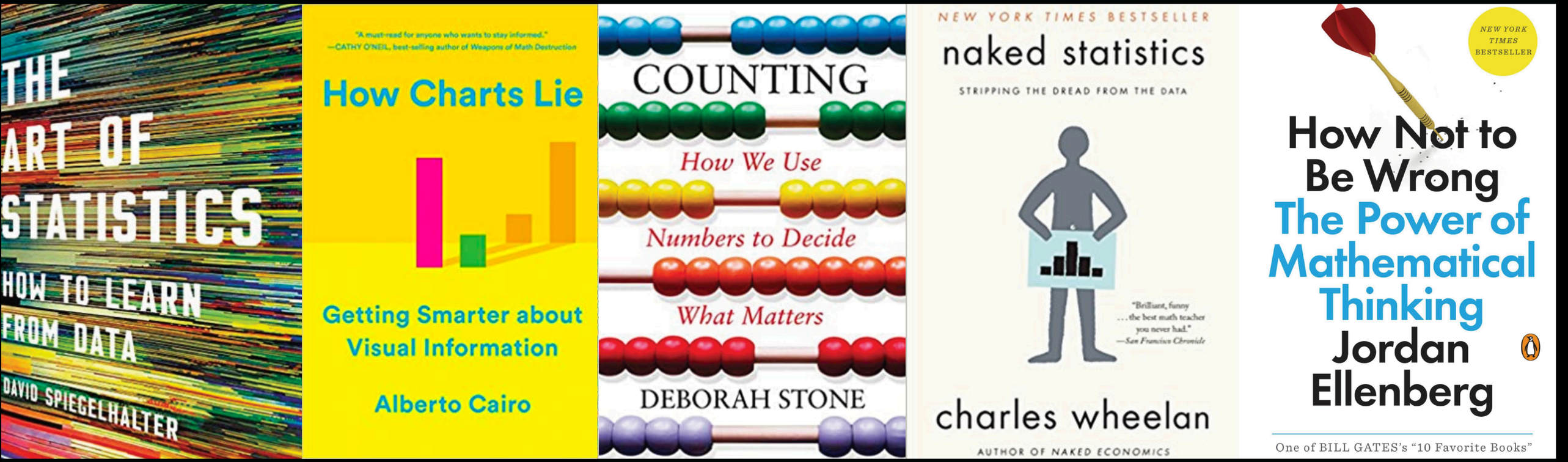




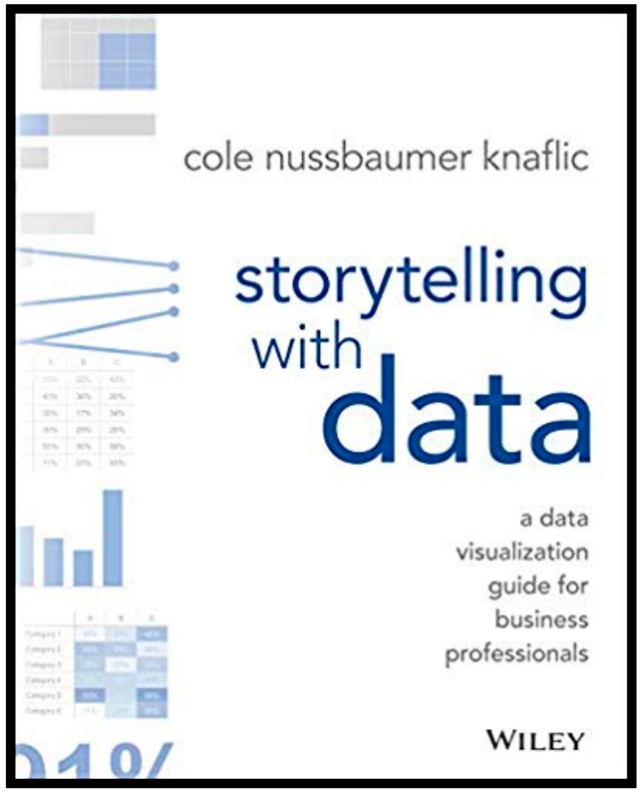
https://serialmentor.com/dataviz/

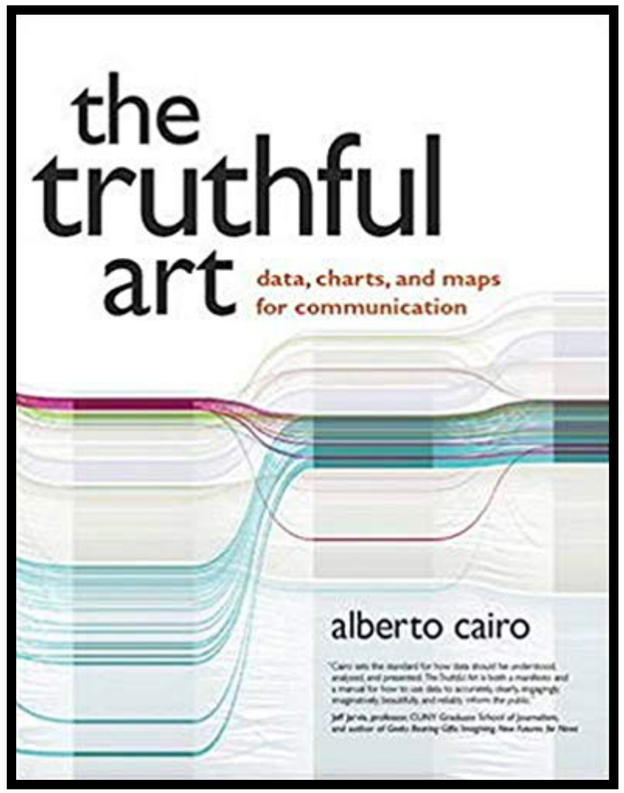
https://r4ds.had.co.nz/

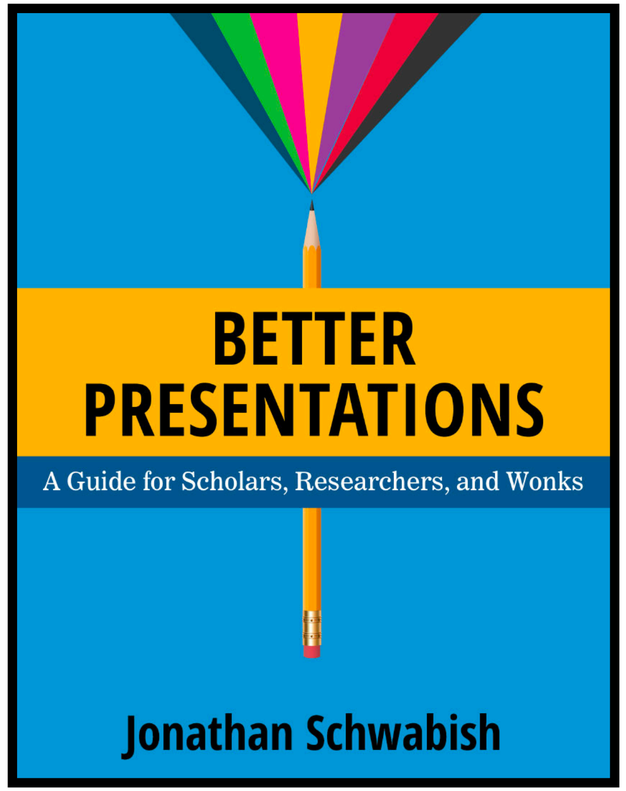
Popular science books about statistics and visualization



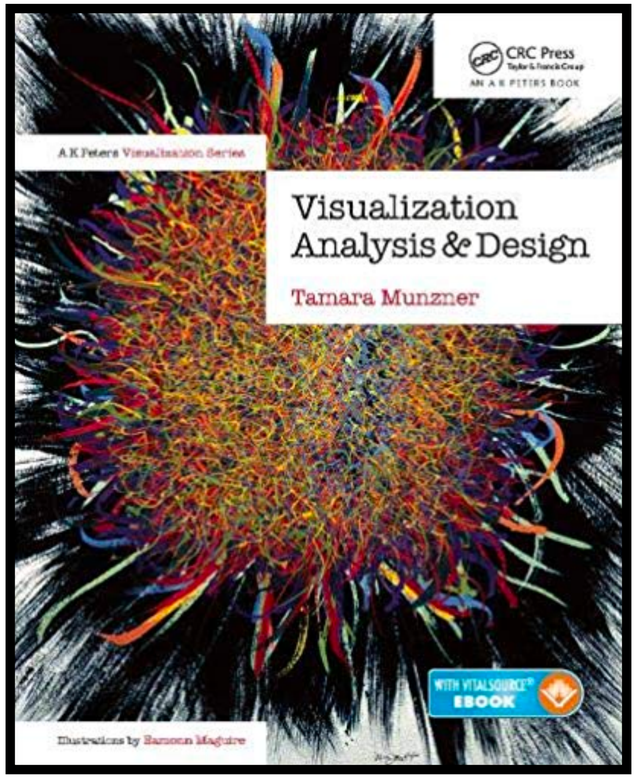
Fundamentals of visualization for communication

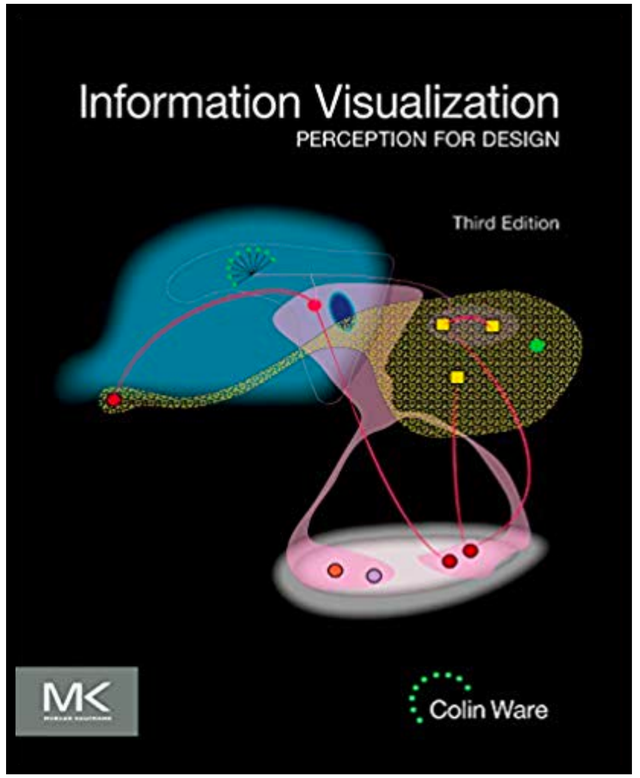


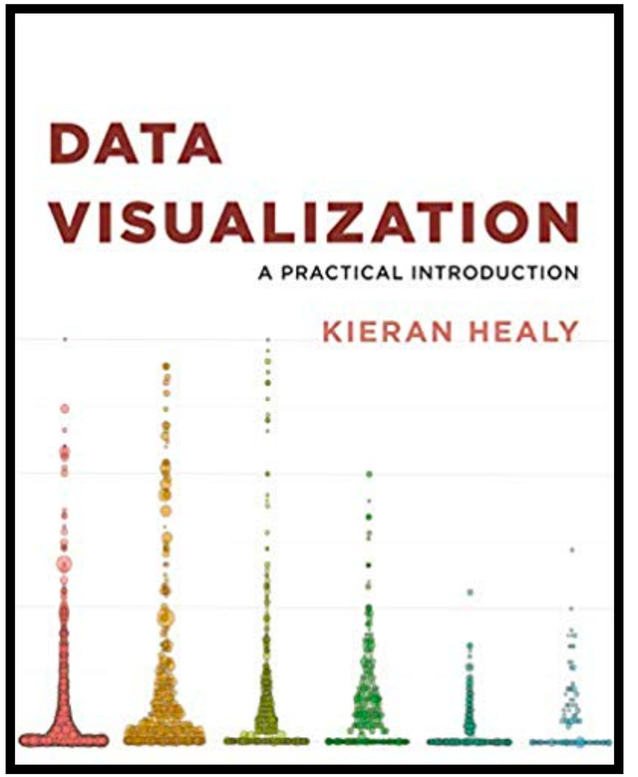




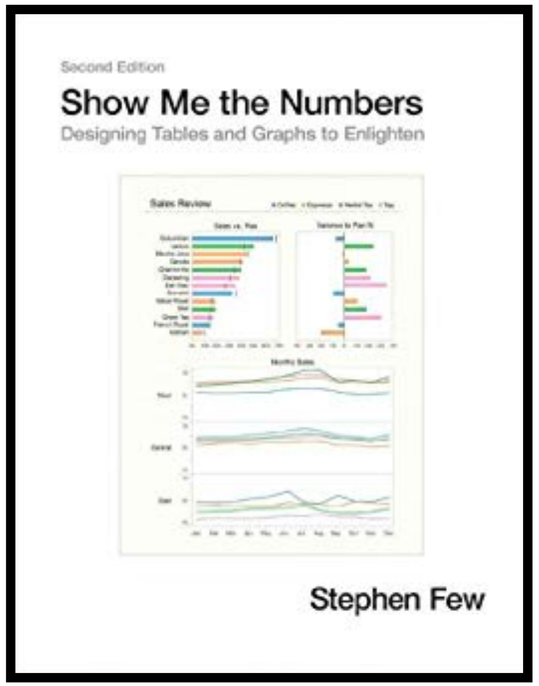
Exploratory and scientific visualization

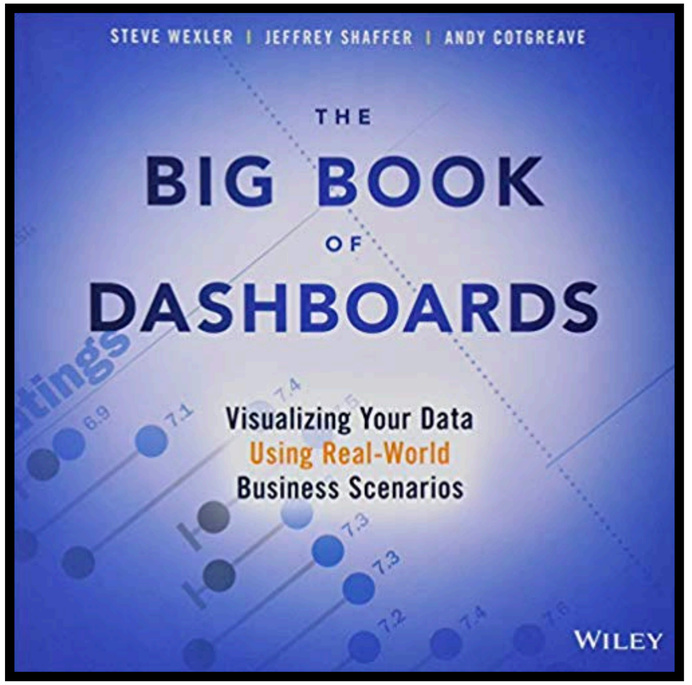




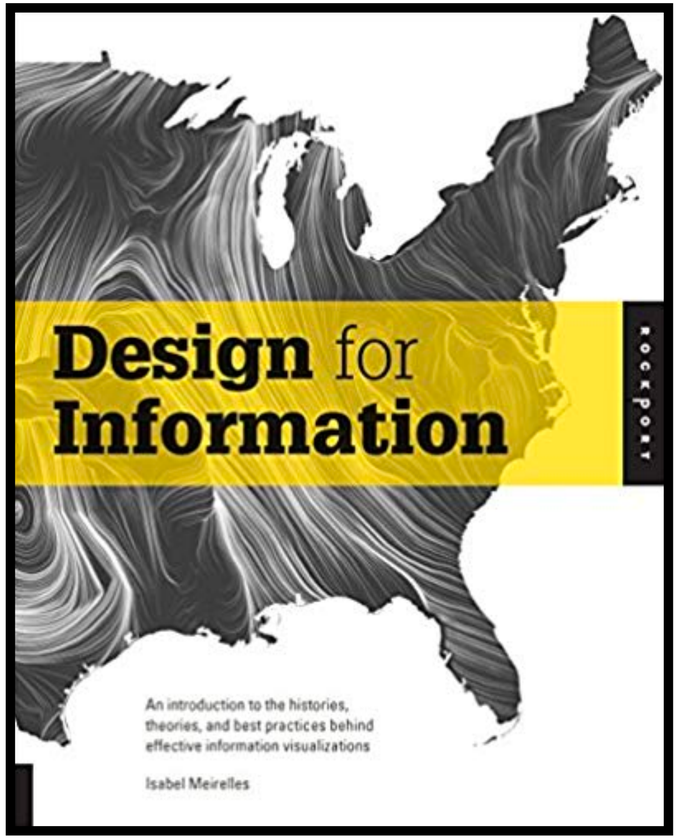


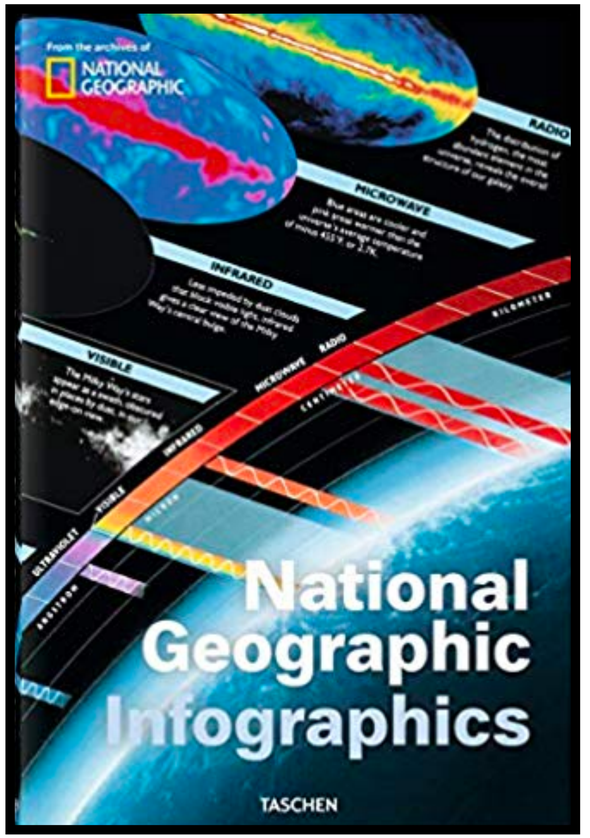
Business analytics and dashboard design

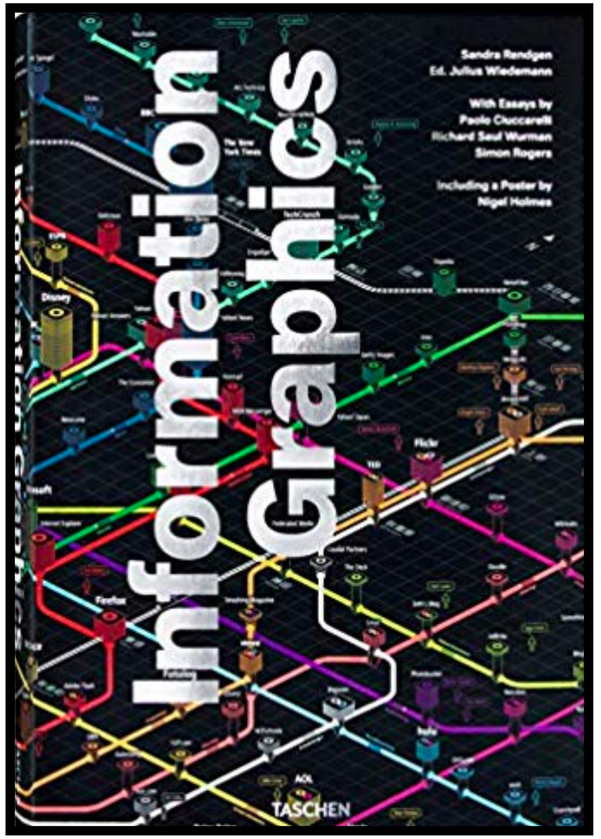




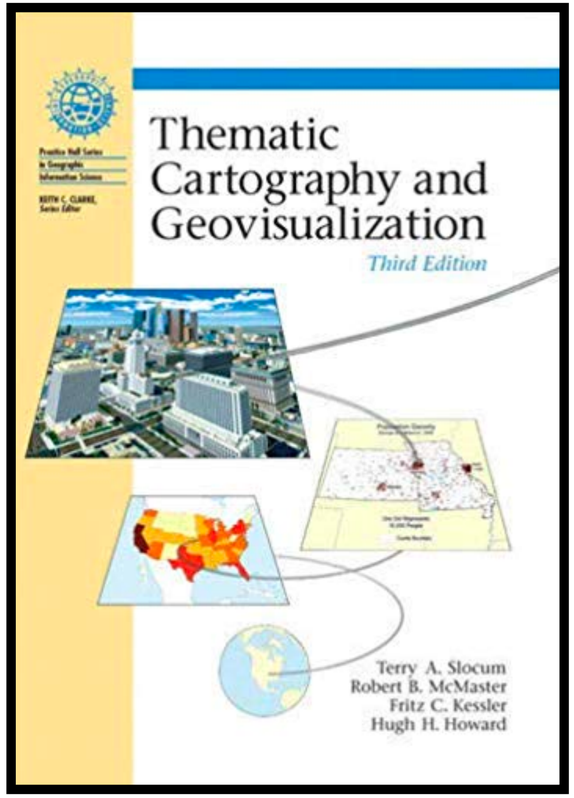
Inspirational books

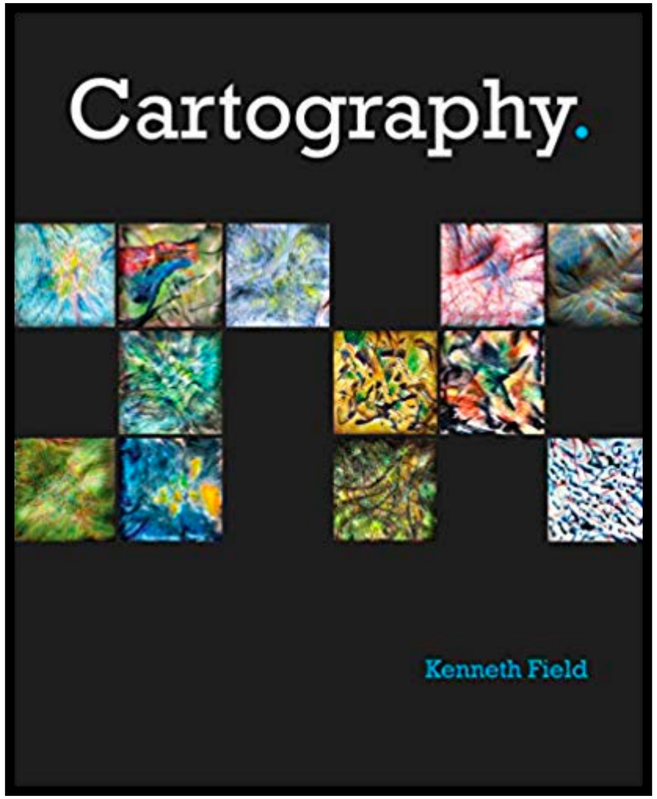


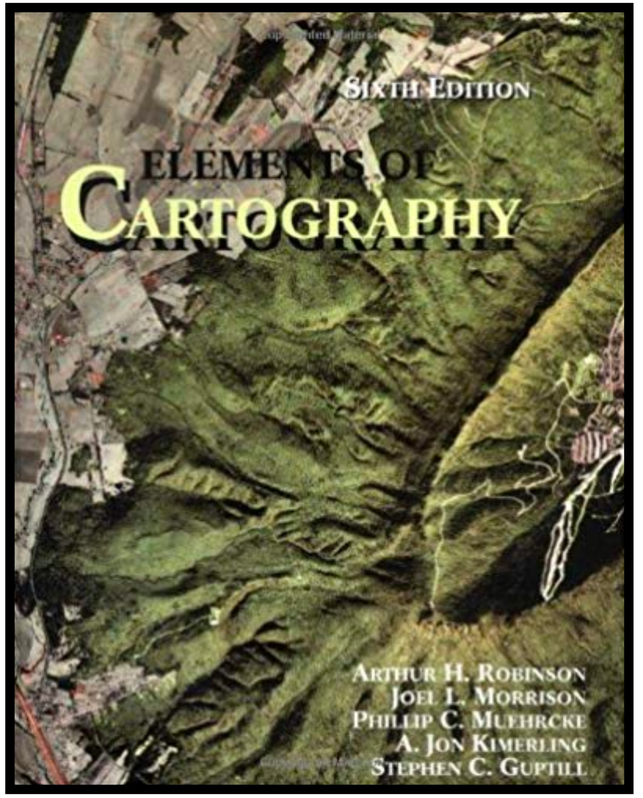




Cartography







The End.

www.thefunctionalart.com , www.albertocairo.com , alberto.cairo@gmail.com