Visualization for Data Science
Representing Spatial Data
Geographic Maps

Project Updates

PM2 due October 31st at 6pm. Now moved to **November 7th at 6pm.**

- EDA analysis
  - One for each member of the team. Jupyter Notebook
  - In your report state what each person EDA covers, this falls under general

Team Member	Numerical Attributes	Temporal Attributes	Ordinal Attributes	Nominal	Type of Analysis
Frodo Baggins	(2) Cost, Emotion,	Age of Middle Earth	Feet size		Univariate on all mentioned. Bivariate on (feet size and cost)
Gandalf	(1) Length of beard,	Age of Universe		(2) Color of beard, Weapons	

  - Then for each person in your report you should include summaries of what you learned from your EDA. Feel free to include figures from your jupyter notebook. Note that we don't expect code in your report.
- INQUIRY FCOUS
  - Theme, questions, and analytic tasks – SEE UPDATED MILESTONE 2

Adminstrivia

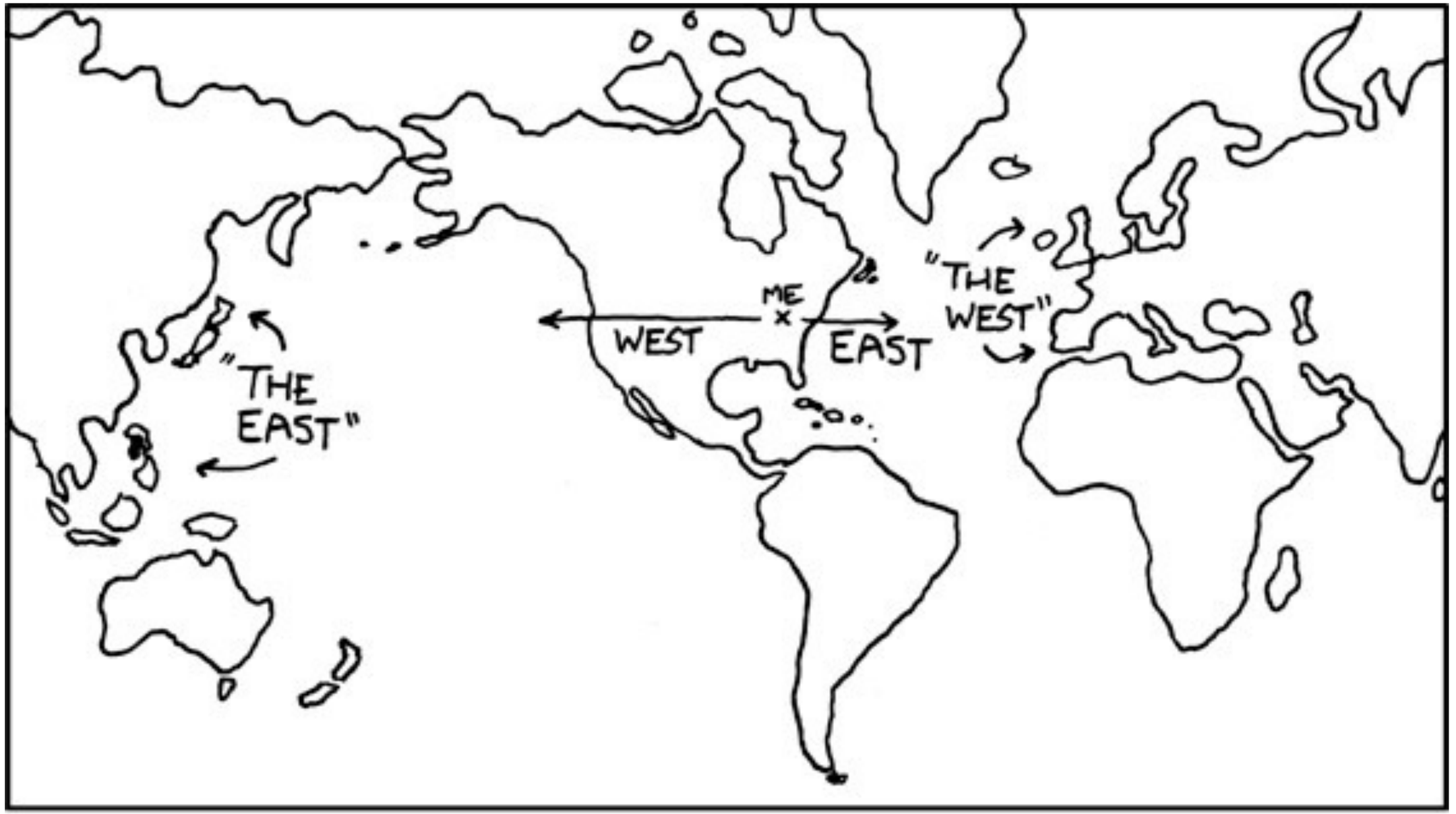
Final Exam is set by the University

- December 10th at 3:30pm in CBTF for most students
- CFA

  For those who typically write with CBTF, you have received a Ed Chat message from me. Please respond.

Tutorial 10 (Maps) and Tutorial 11 (Color) have been posted

- Work through them and complete the associated exercises.



THIS ALWAYS BUGGED ME.

https://xkcd.com/503/

Learning Outcomes

- List some common map projections, describe their characteristics and understand the (dis)advantages of each.
- Describe the different map types and what types of tasks they are used for
- Describe the map visualization pipeline and explain how different errors can occur in each stage.
- Learn what elements visually encode data in maps.
- Critique map visualizations
- Select the visualization technique best suited for a given task

Clicker Question

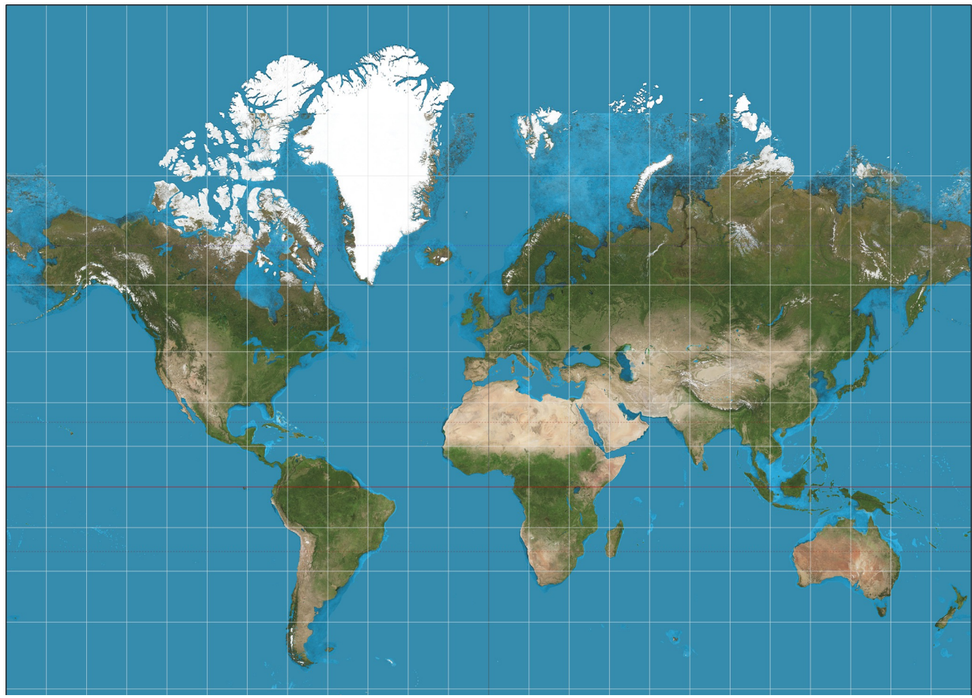
If Greenland and Africa were compared by size, which would be true?

A) Greenland is nearly twice the size of Africa.

B) Africa is significantly larger than Greenland.

C) Greenland and Africa are roughly the same size.

D) Greenland is slightly larger than Africa.



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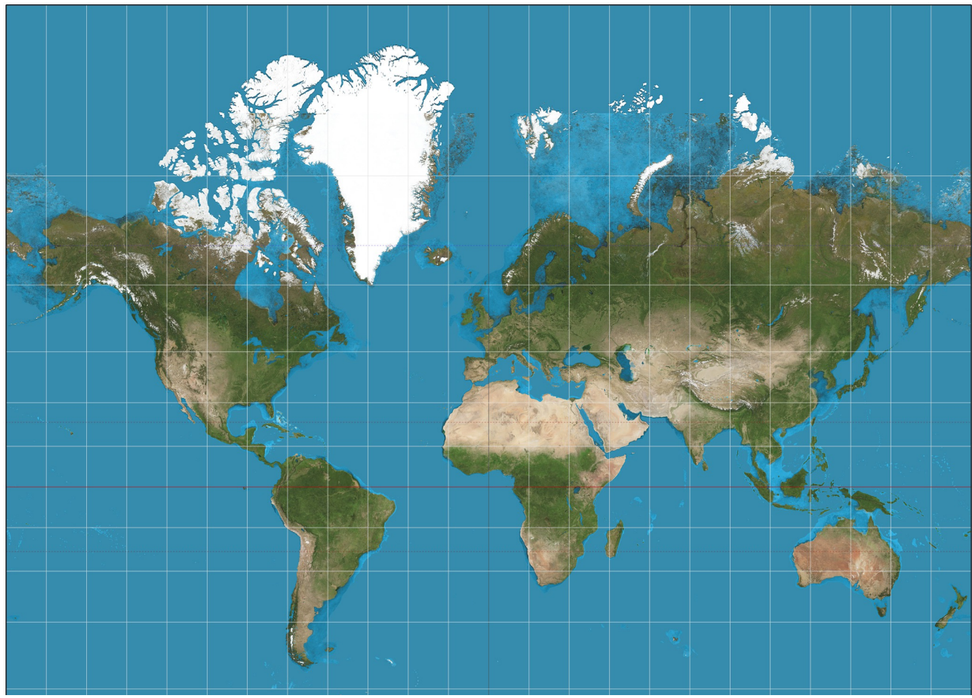
China, when superimposed on Africa, would:

A) Fit comfortably within the borders of East Africa.

B) Cover a significant portion, but not the majority, of Africa.

C) Extend from the north to the south of Africa.

D) Be nearly identical in size to Africa.



Clicker Question

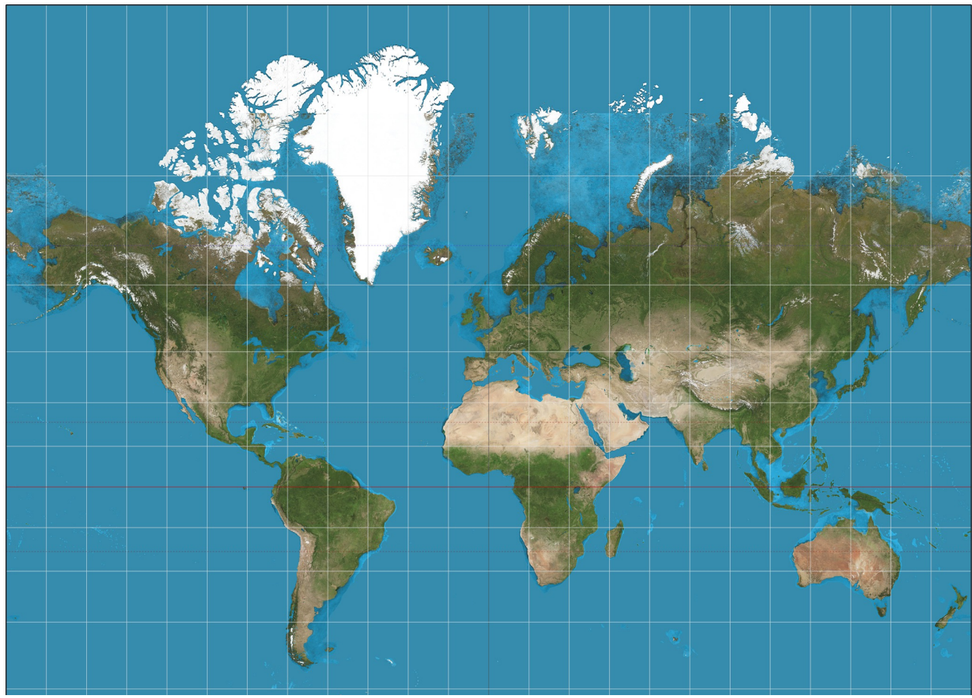
If Brazil were placed on top of Africa, how would it compare in size?

A) It would be roughly the same size as the Congo Basin.

B) It would be similar in size to West Africa.

C) It would occupy the majority of Southern Africa.

D) It would cover a comparable area to the Sahara Desert.



Clicker Question

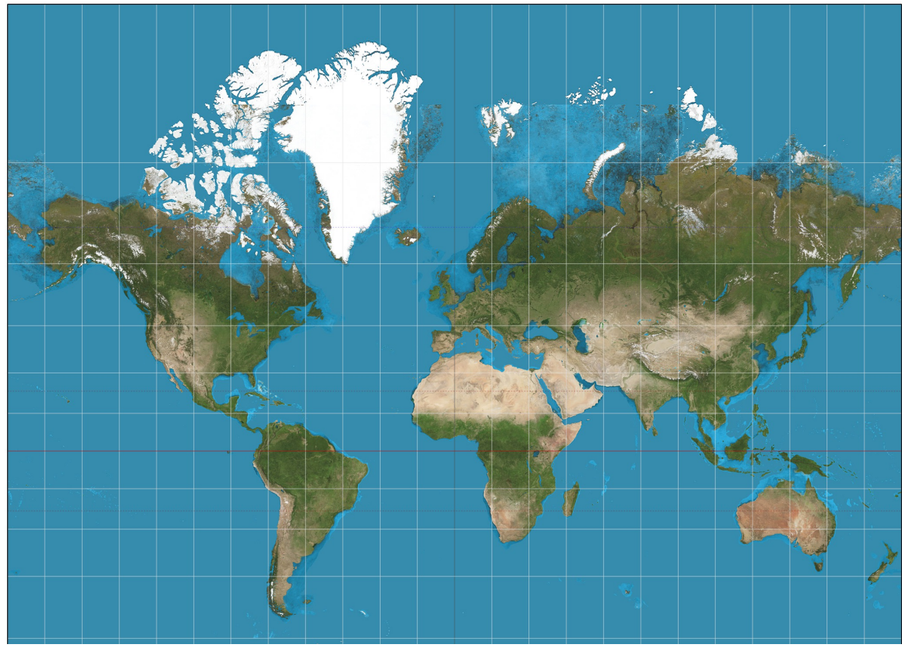
When comparing the actual size of Greenland to that of Brazil, how does it compare?

A) Greenland is nearly as large as Brazil.

B) Greenland is about half the size of Brazil.

C) Greenland is comparable in size to the Brazilian state of Amazonas.

D) Greenland is only slightly smaller than Brazil.



Clicker Question

If Greenland and India were compared by size, which would be true?

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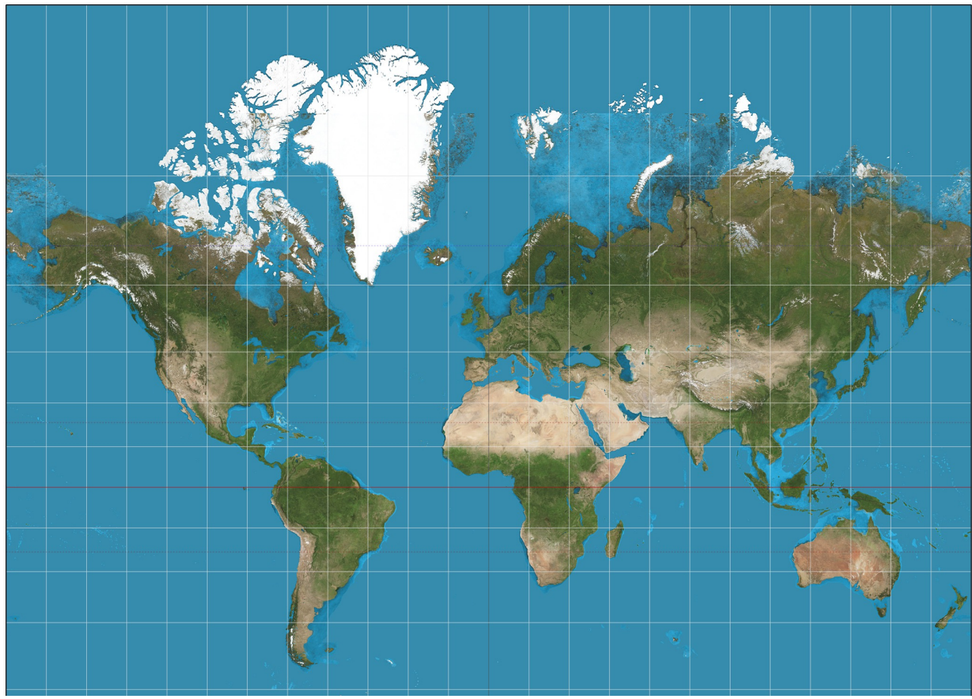
C) India is significantly larger than Greenland.

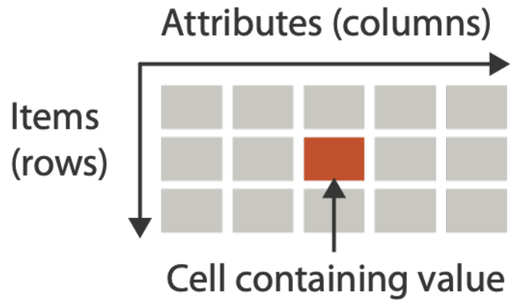
D) Greenland is slightly larger than India.



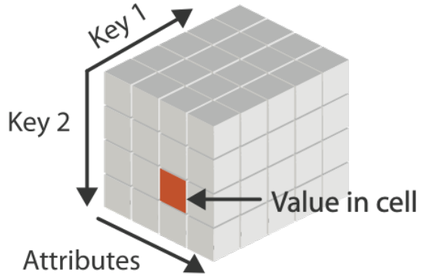
Focus on Spatial

Dataset Types

Tables

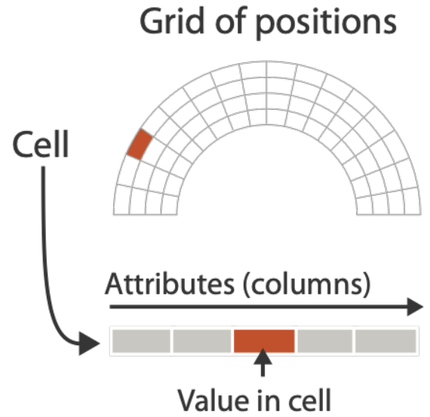


Multidimensional Table



Spatial

Fields (Continuous)



Geometry (Spatial)

How?

Encode

Arrange

- Express
- Separate
- Order
- Align
- Use

Map

from categorical and ordered attributes

- Color
  - *Hue*
  - *Saturation*
  - *Luminance*
- Size, Angle, Curvature, ...
- Shape
- Motion

Direction, Rate, Frequency, ...

Manipulate

- Change
- Select
- Navigate

Facet

- Juxtapose
- Partition
- Superimpose

Reduce

- Filter
- Aggregate
- Embed

What?

Why?

How?

Geographic Map

Interlocking marks

- **shape** coded
- **area** coded
- **position** coded

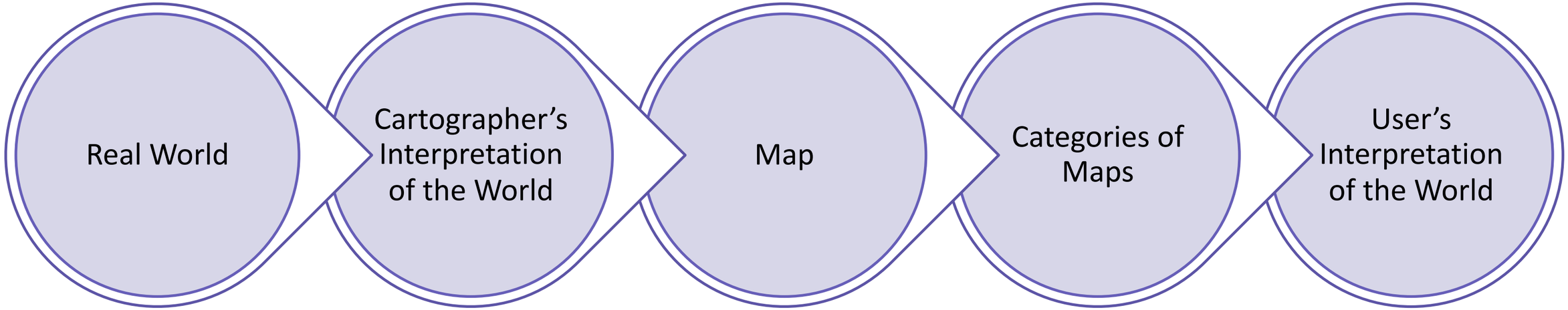
- cannot encode another attribute with these channels, they're "taken"

Spatial data

- use given spatial position
- when?
  - dataset contains spatial attributes and they have primary importance
  - central tasks revolve around understanding spatial relationships

- examples
  - geographical/cartographic data
  - sensor/simulation data

Geographic Map Pipeline



- Projections

- Reference Maps
- Thematic Maps
- Special-purpose Maps

https://web.archive.org/web/20180911104035/https:/www.e-education.psu.edu/geog486/node/1848

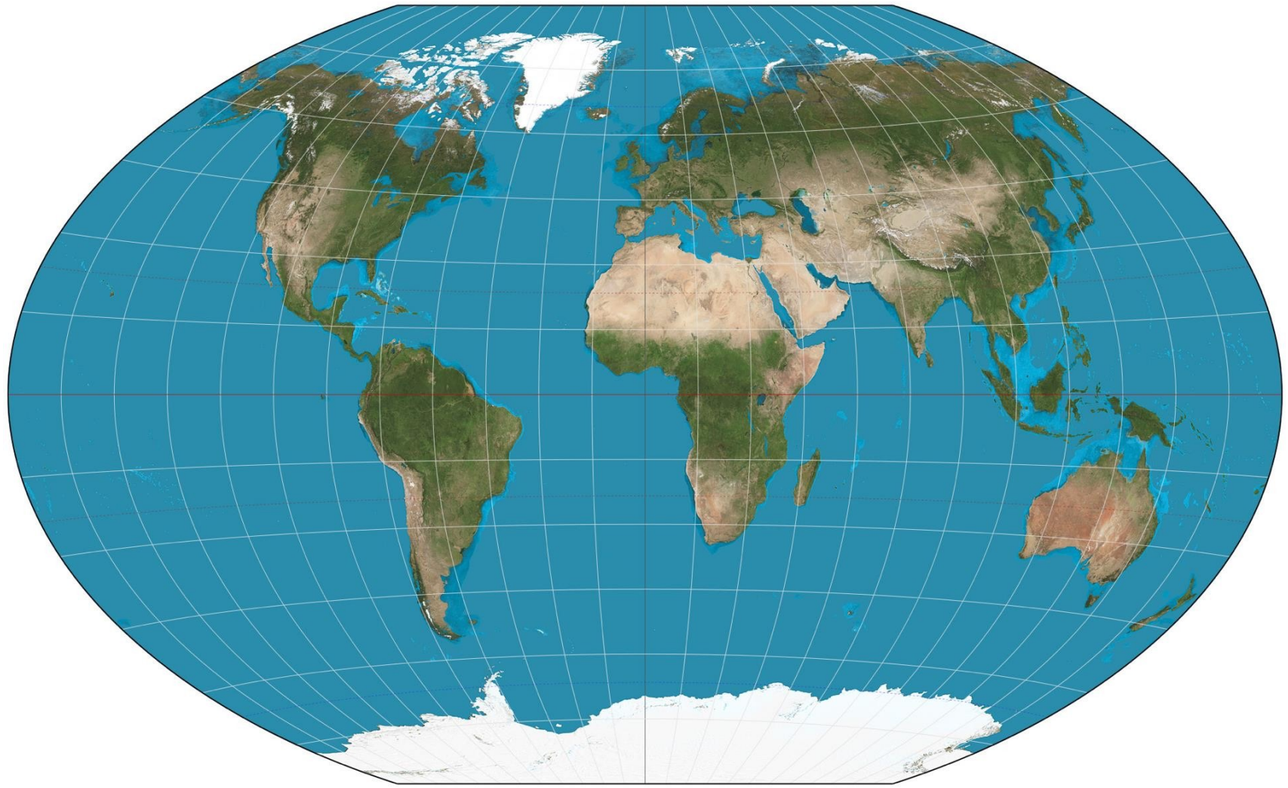
Simple Solution: Use Globe

Geographic Map Projections

Dimensionality reduction

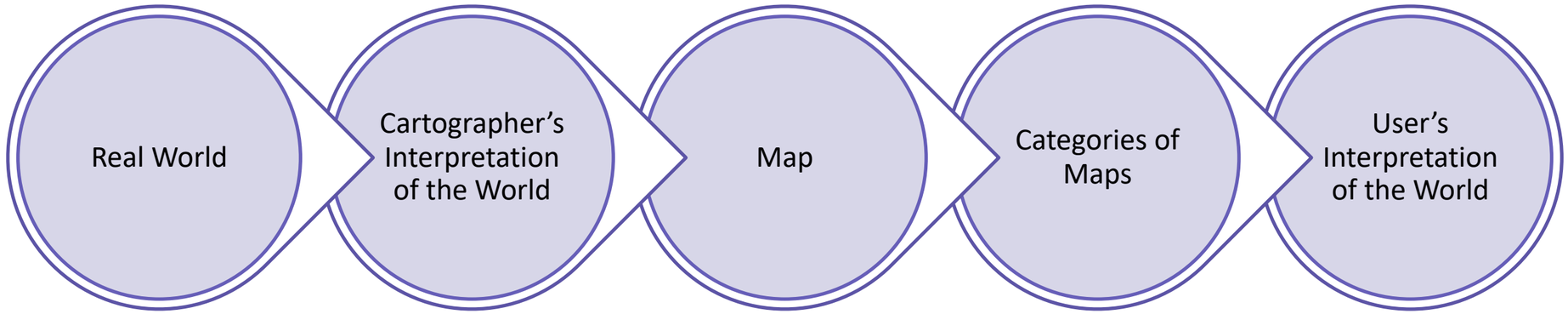
3D

2D



Why projections?

- Earth is a (flattened) Sphere
- Need to project or “unfold” the hull of the sphere to fit onto paper/ screens
- Relevant attributes: Area, Shape, Direction, Bearing, Distance, Scale



Projections

The West Wing – Mercator vs. Gall Peters

https://www.youtube.com/watch?v=vVX-PrBRtTY

Pay attention to

1. The strengths and limitation of the Mercator Projection
2. The impact a projection has on society

Vox – Why All Maps Are Wrong?

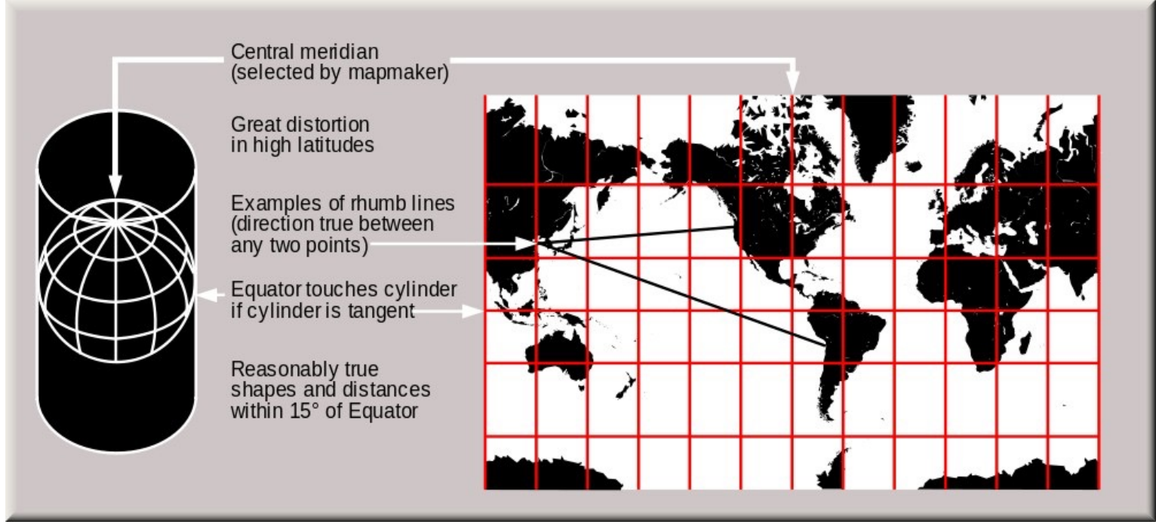
https://www.youtube.com/watch?v=kIID5FDi2JQ

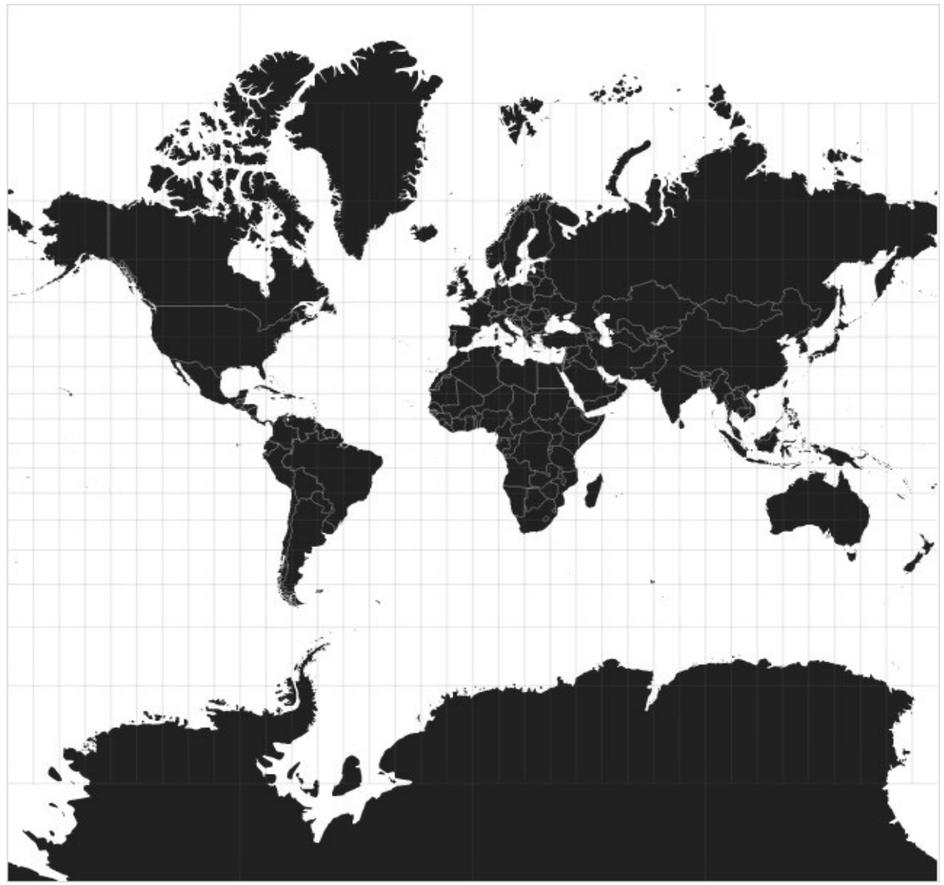
Watch after class

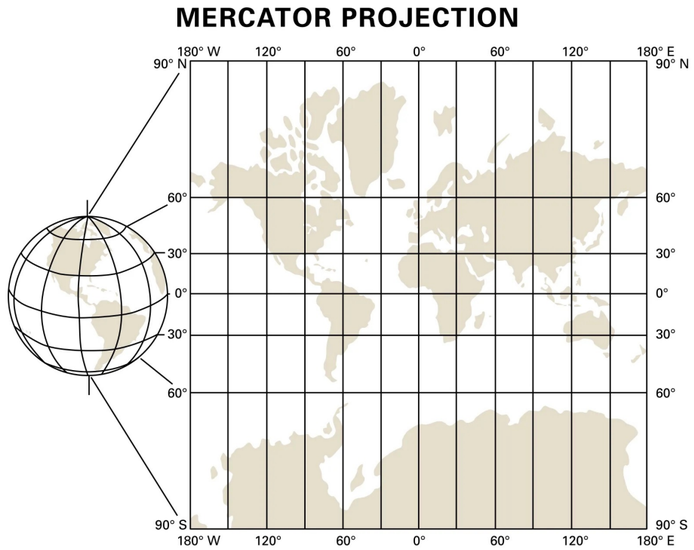
Pay attention to the description of various projections and why all are inherently flawed

Mercator Projection (1569)

- Projection onto a cylinder wrapped around the globe Angles are preserved.
- Lines of constant bearing are straight lines.
- Constant bearing means constant compass heading – developed for sailors



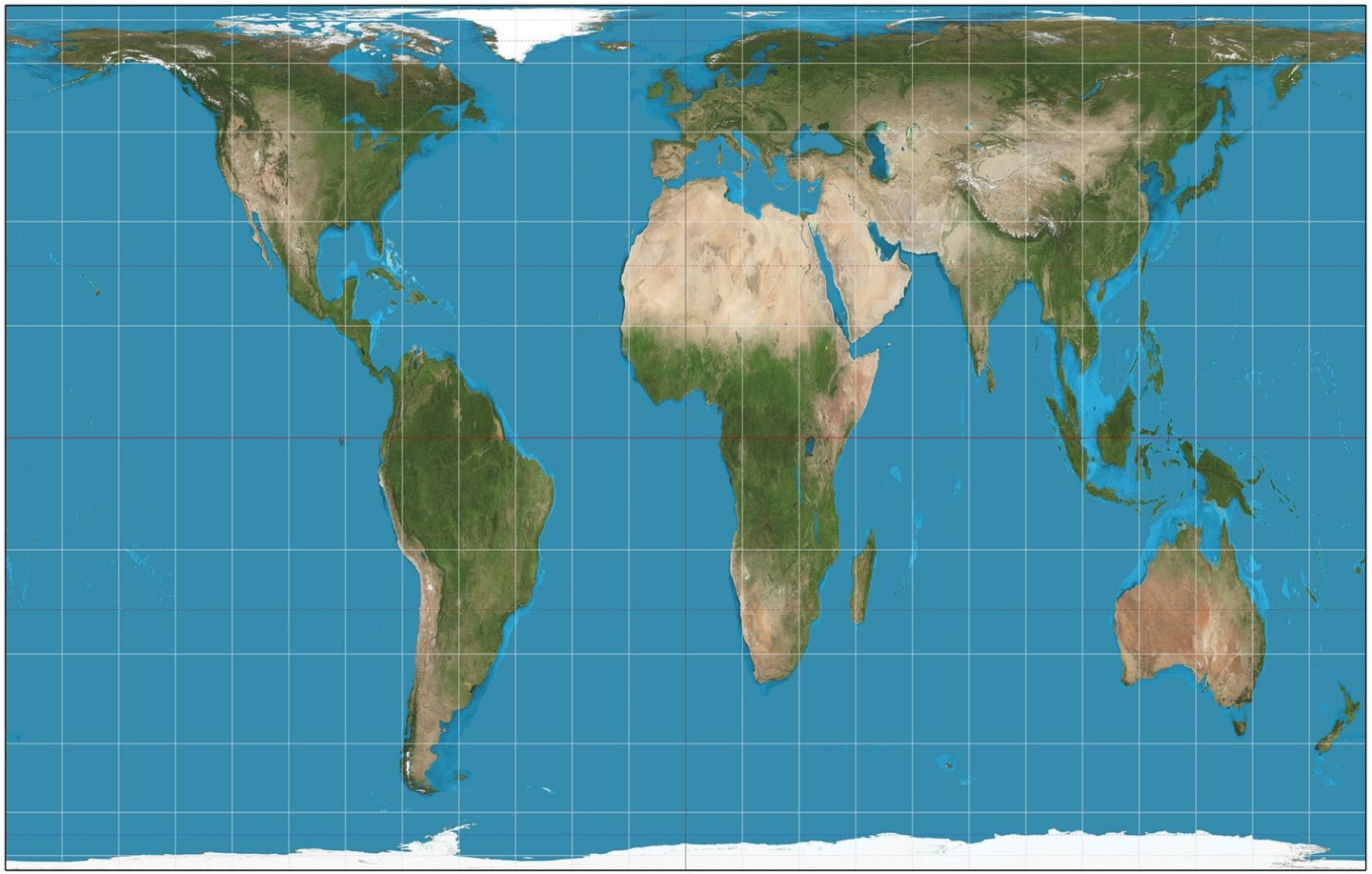




Mercator Projection

Great for ocean navigation,
but dramatically exaggerates poles.

Gall-Peters Projection



More accurate land areas.
(Officially endorsed by the UN.)

Bec Crew, 201723

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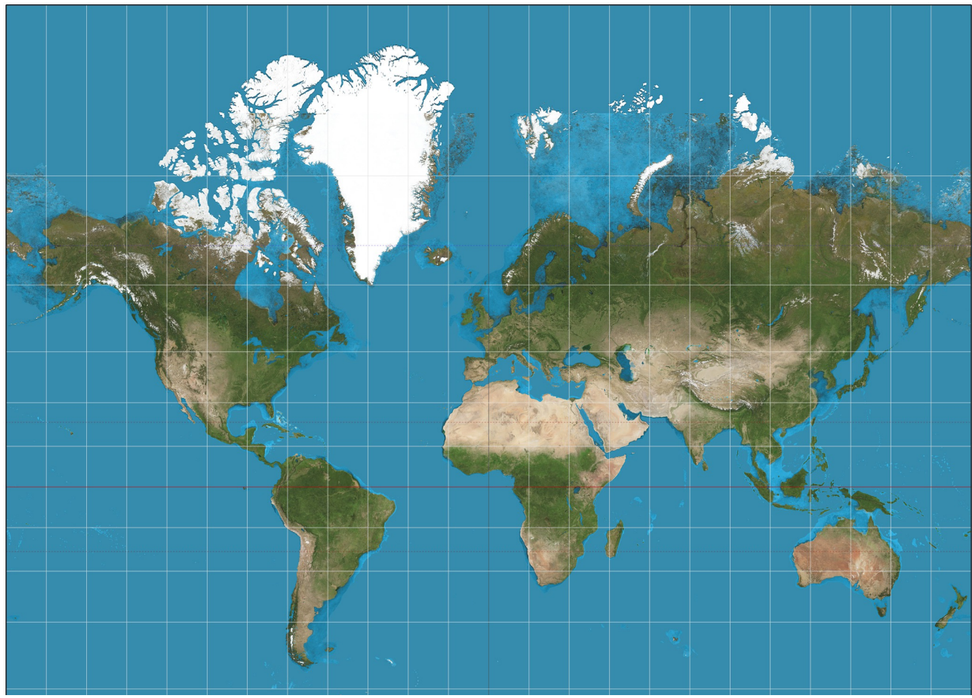
Africa is 30.3 mil km^2
Greenland is 2.1 mil km^2



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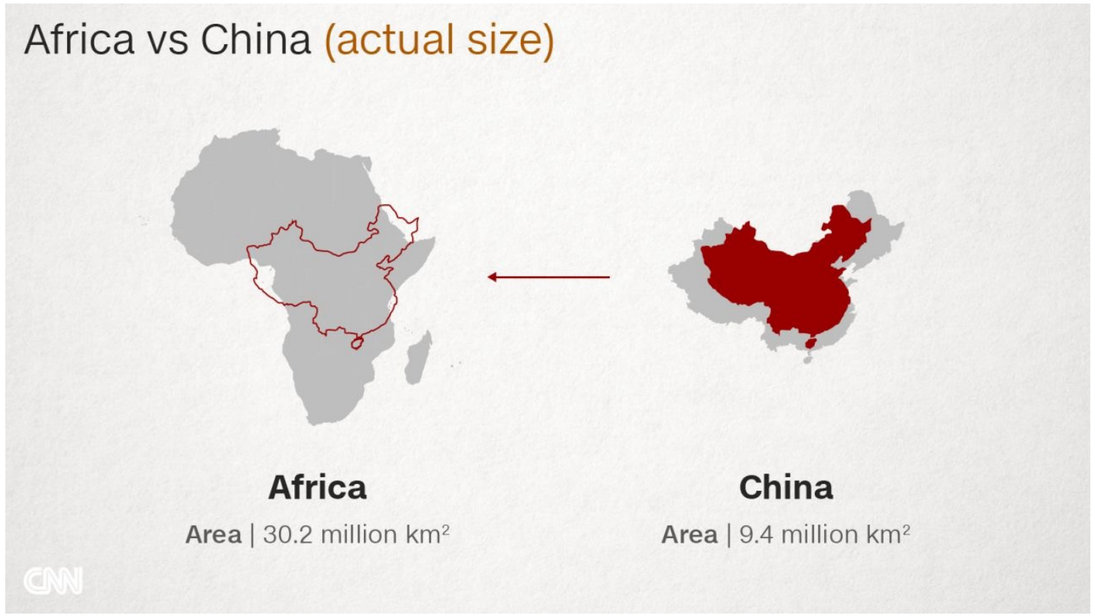
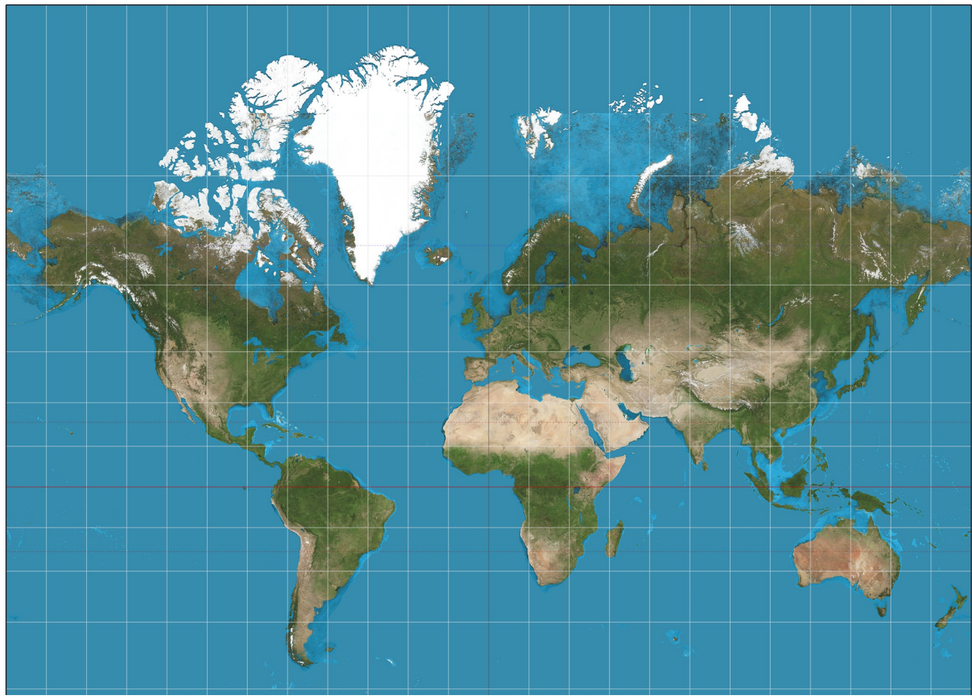


https://www.cnn.com/2016/08/18/africa/real-size-of-africa



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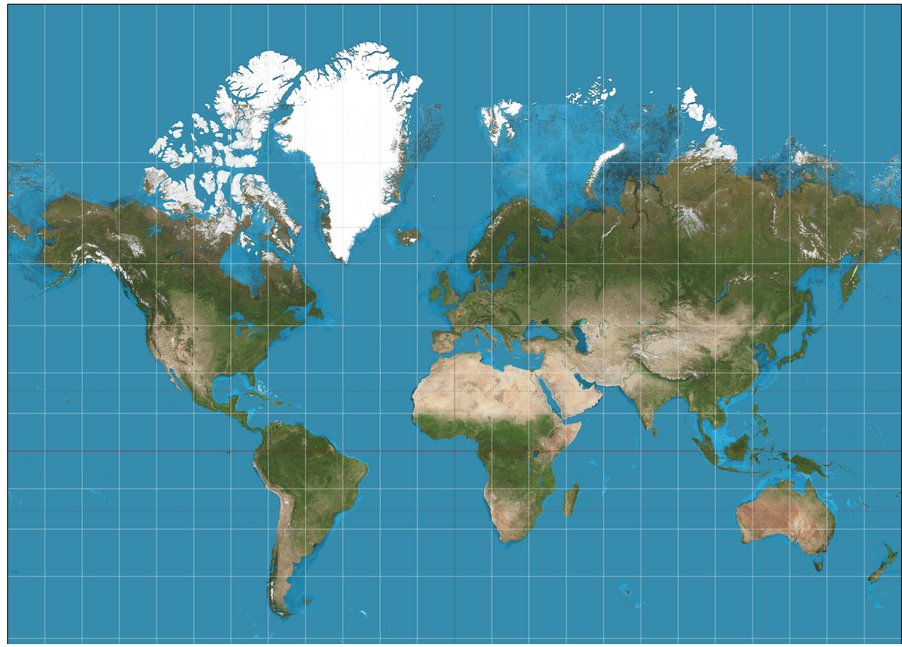

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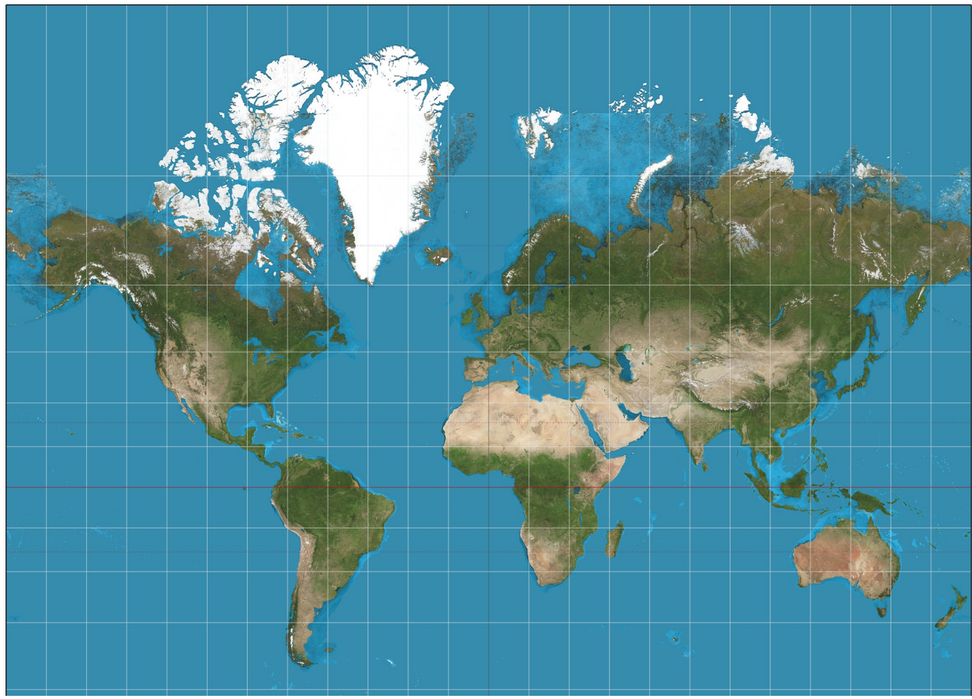


In-Class Exercise: The True Size (5 min)

Go to https://thetruesize.com
Clear the map.
Find at least two countries using the search bar.
Position them at the equator near each other
Does this match your perception of the shape and size of that country
Try putting your countries at other locations on the map closer to the poles. How does this affect the shape & size?

See if you can find the worst possible distortion you can between the original map and a more accurate view at the equator. Post on Ed Discussion

World Mercator projection with true country size added

Why Mercator ~~was~~ is Problematic

- Traditional map, was used to teach geography AND history

- Massive distortion (i.e., appear larger) of area distant from equator

- “unfair to the global South, making places that are mostly trees, snow, and better-off white people look huge, and the places where most of the world’s population lives look puny"

http://giscollective.org/slippy-map-projections-explained/

The **True Size** of **Africa**

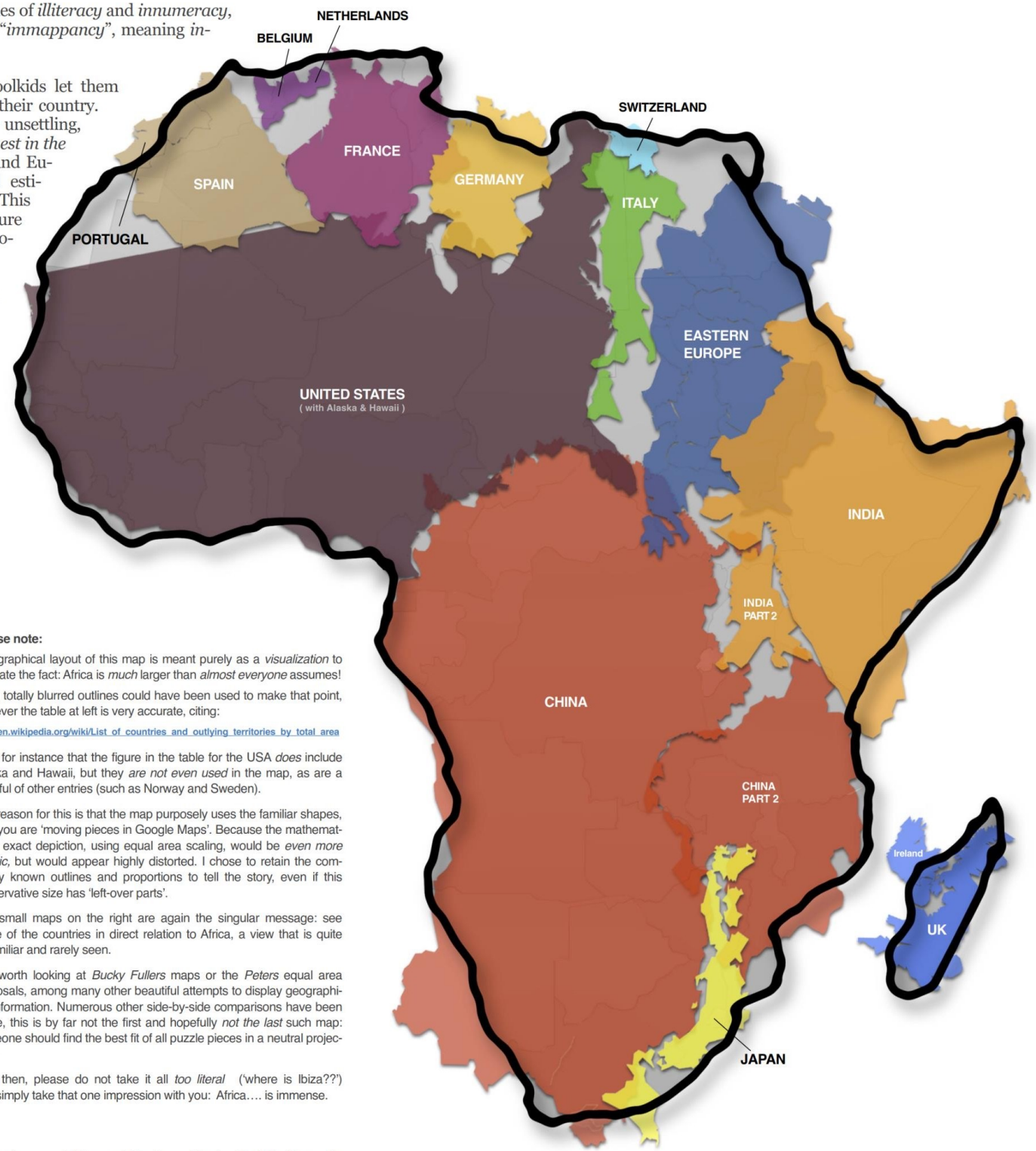
A small contribution in the fight against rampant *Immappancy,* by **Kai Krause**

In addition to the well known social issues of *illiteracy* and *innumeracy*, there also should be such a concept as "*immappancy*", meaning *insufficient geographical knowledge.*

A survey with random American schoolkids let them guess the population and land area of their country. Not entirely unexpected, but still rather unsettling, the majority chose *"1-2 billion"* and *"largest in the world"*, respectively. Even with Asian and European college students, geographical estimates were often off by factors of *2-3*. This is partly due to the highly distorted nature of the predominantly used mapping projections (such as *Mercator*).

A particularly extreme example is the worldwide misjudgement of the true size of Africa. This single image tries to embody the massive scale, which is larger than the *USA*, *China*, *India*, *Japan* and *all of Europe - combined!*

COUNTRY	AREA x 1000 km²
USA	9.629
China	9.573
India	3.287
Mexico	1.964
Peru	1.285
France	633
Spain	506
Papua New Guinea	462
Sweden	441
Japan	378
Germany	357
Norway	324
Italy	301
New Zealand	270
United Kingdom	243
Nepal	147
Bangladesh	144
Greece	132
TOTAL	**30.102**
AFRICA	**30.221**
Just for Reference: The Surface of the MOON	37.930



Please note:

The graphical layout of this map is meant purely as a *visualization* to illustrate the fact: Africa is *much* larger than *almost everyone* assumes!

Even totally blurred outlines could have been used to make that point, however the table at left is very accurate, citing:

http://en.wikipedia.org/wiki/List_of_countries_and_outlying_territories_by_total_area

Note for instance that the figure in the table for the USA *does* include Alaska and Hawaii, but they *are not even used* in the map, as are a handful of other entries (such as Norway and Sweden).

The reason for this is that the map purposely uses the familiar shapes, as if you are 'moving pieces in Google Maps'. Because the mathematically exact depiction, using equal area scaling, would be *even more drastic,* but would appear highly distorted. I chose to retain the commonly known outlines and proportions to tell the story, even if this conservative size has 'left-over parts'.

The small maps on the right are again the singular message: see some of the countries in direct relation to Africa, a view that is quite unfamiliar and rarely seen.

It is worth looking at *Bucky Fullers* maps or the *Peters* equal area proposals, among many other beautiful attempts to display geographical information. Numerous other side-by-side comparisons have been made, this is by far not the first and hopefully *not the last* such map: someone should find the best fit of all puzzle pieces in a neutral projection.

Until then, please do not take it all *too literal* ('where is Ibiza??') and simply take that one impression with you: Africa…. is immense.

Top 100 Countries

Area in square kilometers, Percentage of World Total
Sources: Britannica, Wikipedia, Almanac 2010

		AREA km²	%
1	Russia	17.098.242	11,50
2	Canada	9.984.670	6,70
3	China	9.596.961	6,40
4	United States	9.629.091	6,40
5	Brazil	8.514.877	5,70
6	Australia	7.692.024	5,20
7	India	3.287.263	2,30
8	Argentina	2.780.400	2,00
9	Kazakhstan	2.724.900	1,80
10	Sudan	2.505.813	1,70
11	Algeria	2.381.741	1,60
12	Congo	2.344.858	1,60
13	Greenland	2.166.086	1,50
14	Saudi Arabia	2.149.690	1,40
15	Mexico	1.964.375	1,30
16	Indonesia	1.860.360	1,30
17	Libya	1.759.540	1,20
18	Iran	1.628.750	1,10
19	Mongolia	1.564.100	1,10
20	Peru	1.285.216	0,86
21	Chad	1.284.000	0,86
22	Niger	1.267.000	0,85
23	Angola	1.246.700	0,85
24	Mali	1.240.192	0,83
25	South Africa	1.221.037	0,82
26	Colombia	1.141.748	0,76
27	Ethiopia	1.104.300	0,74
28	Bolivia	1.098.581	0,74
29	Mauritania	1.025.520	0,69
30	Egypt	1.002.000	0,67
31	Tanzania	945.087	0,63
32	Nigeria	923.768	0,62
33	Venezuela	912.050	0,61
34	Namibia	824.116	0,55
35	Mozambique	801.590	0,54
36	Pakistan	796.095	0,53
37	Turkey	783.562	0,53
38	Chile	756.102	0,51
39	Zambia	752.612	0,51
40	Myanmar	676.578	0,45
41	Afghanistan	652.090	0,44
42	Somalia	637.657	0,43
43	France	632.834	0,43
44	C. African Rep	622.984	0,42
45	Ukraine	603.500	0,41
46	Madagascar	587.041	0,39
47	Botswana	582.000	0,39
48	Kenya	580.367	0,39
49	Yemen	527.968	0,35
50	Thailand	513.120	0,34
51	Spain	505.992	0,34
52	Turkmenistan	488.100	0,33
53	Cameroon	475.442	0,32
54	Papua New Guinea	462.840	0,31
55	Uzbekistan	447.400	0,30
56	Morocco	446.550	0,30
57	Sweden	441.370	0,30
58	Iraq	438.317	0,29
59	Paraguay	406.752	0,27
60	Zimbabwe	390.757	0,26
61	Japan	377.930	0,25
62	Germany	357.114	0,24
63	Rep o.t. Congo	342.000	0,23
64	Finland	338.419	0,23
65	Vietnam	331.212	0,22
66	Malaysia	330.803	0,22
67	Norway	323.802	0,22
68	Côte d'Ivoire	322.463	0,22
69	Poland	312.685	0,21
70	Oman	309.500	0,21
71	Italy	301.336	0,20
72	Philippines	300.000	0,20
73	Burkina Faso	274.222	0,18
74	New Zealand	270.467	0,18
75	Gabon	267.668	0,18
76	Western Sahara	266.000	0,18
77	Ecuador	256.369	0,20
78	Guinea	245.857	0,17
79	United Kingdom	242.900	0,16
80	Uganda	241.038	0,16
81	Ghana	238.539	0,16
82	Romania	238.391	0,16
83	Laos	236.800	0,16
84	Guyana	214.969	0,14
85	Belarus	207.600	0,14
86	Kyrgyzstan	199.951	0,13
87	Senegal	196.722	0,13
88	Syria	185.180	0,12
89	Cambodia	181.035	0,12
90	Uruguay	176.215	0,12
91	Suriname	163.820	0,11
92	Tunisia	163.610	0,11
93	Nepal	147.181	0,10
94	Bangladesh	143.998	0,10
95	Tajikistan	143.100	0,10
96	Greece	131.957	0,09
97	Nicaragua	130.373	0,09
98	North Korea	120.538	0,08
99	Malawi	118.484	0,08
100	Eritrea	117.600	0,08
	TOP 100 TOTAL	132.632.524	89,34


United States


Europe


India

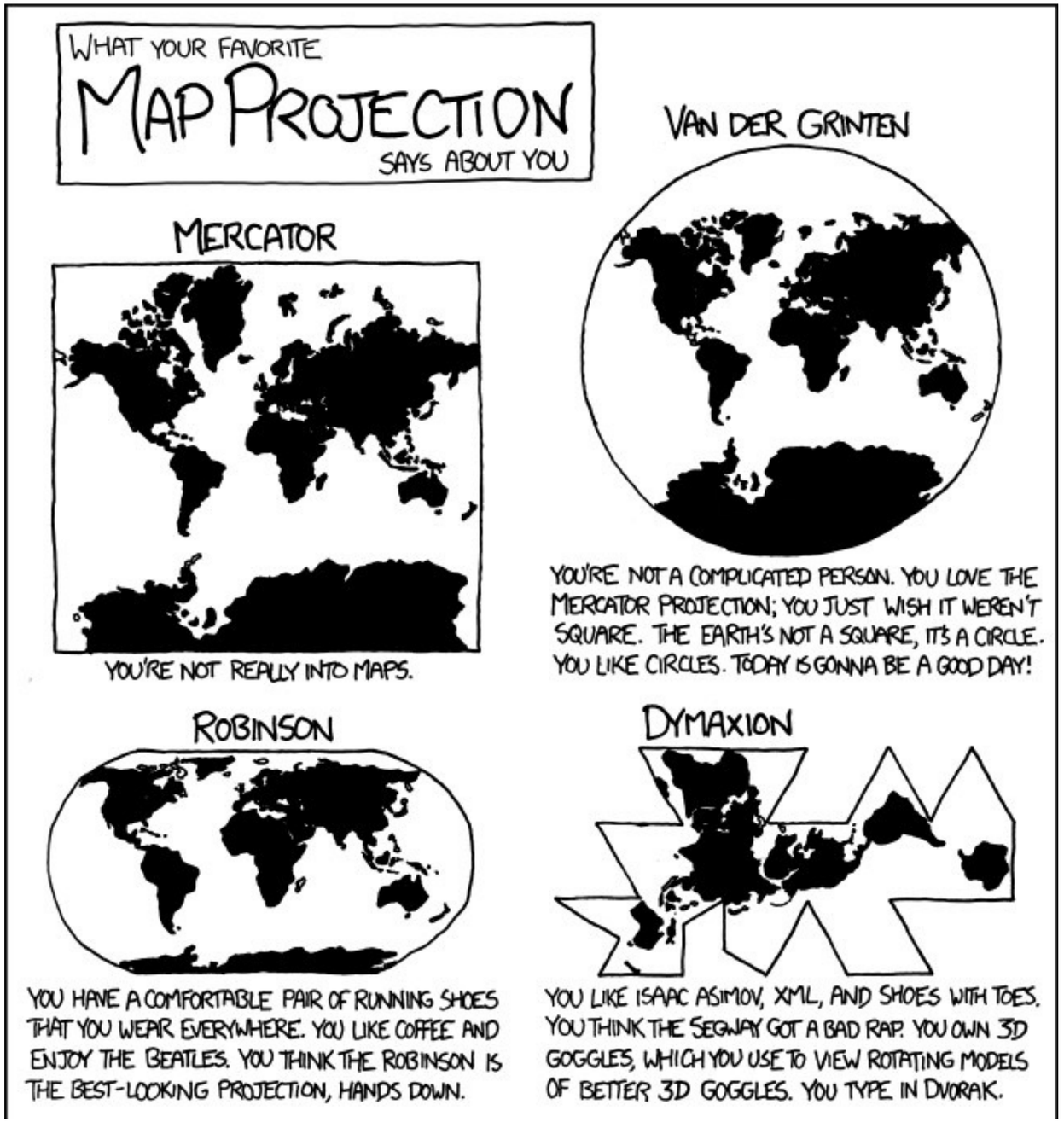

Japan


China

[Kai Krause, 2010]

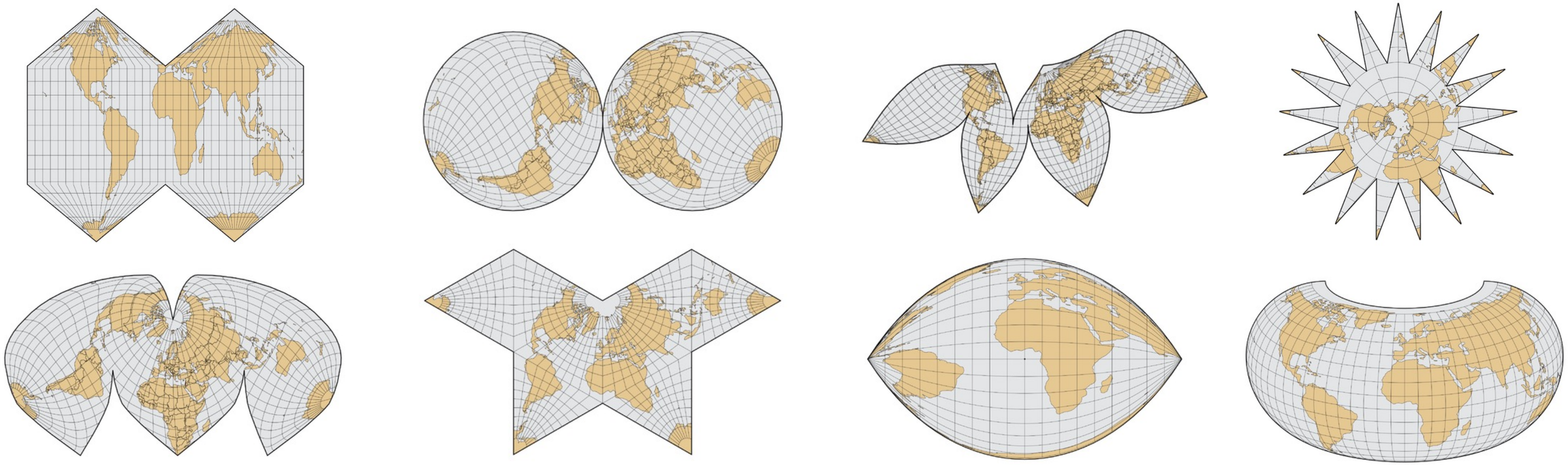
Map Projections

Projection Transitions - https://observablehq.com/@d3/projection-transitions

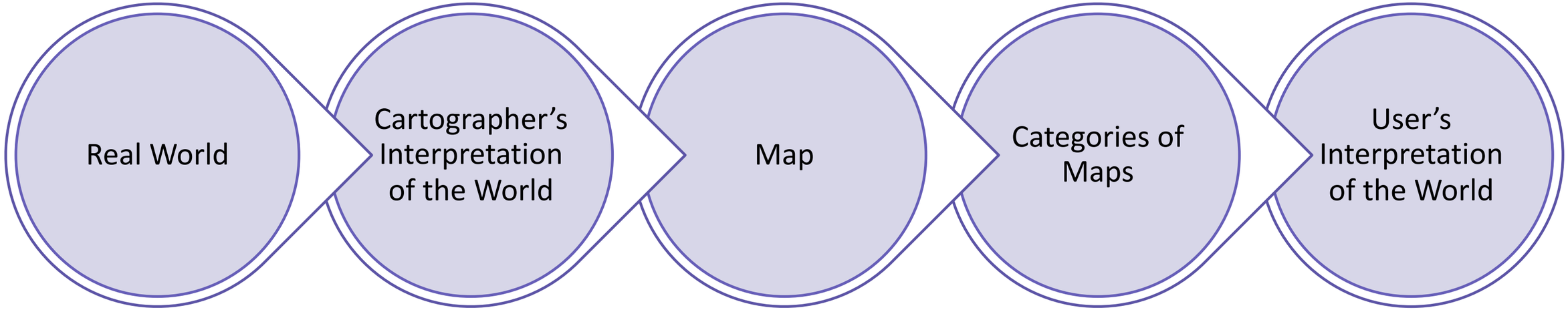


Map Projections

- mathematical functions that map 3D surface geometry of the Earth to 2D maps
- **all projections** of sphere on plane necessarily **distort surface** in some way
- interactive: philogb.github.io/page/myriahedral/ and jasondavies.com/maps/



Geographic Map Pipeline



- Projections

- Reference Maps
- Thematic Maps
- Special-purpose Maps

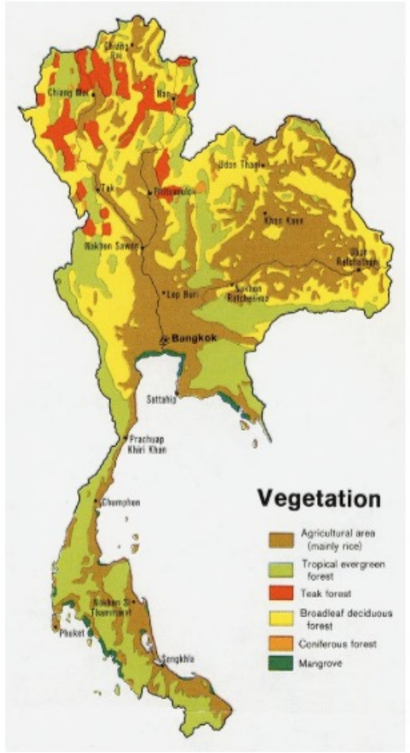
https://web.archive.org/web/20180911104035/https:/www.e-education.psu.edu/geog486/node/1848

Categories of Maps

Reference: show several types of spatial data without specific emphasis on one type over another

Thematic: have a specific focus, typically display attributes of features that vary spatially in a qualitative or nominal way

Special-purpose: typically thematic maps but are task/user specific (i.e., used like reference maps but for specific tasks or specific types of data).



LEFT: Reference map of Thailand.
CENTER: Thematic map classes of vegetation in 1974
RIGHT: Special purpose map – Thailand rail map

https://web.archive.org/web/20180911104035/https://www.e-education.psu.edu/geog486/node/1848

Thematic maps

show spatial variability of attribute ("theme")

- combine geographic / reference map with (simple, flat) tabular data
- join together
  - region: interlocking area marks (provinces, countries with outline shapes)
    - also could have point marks (cities, locations with 2D lat/lon coordinates)
  - region: categorical key attribute in table
    - use to look up value attributes

- major idioms
  - choropleth
  - symbol maps
  - cartograms
  - dot density maps

Principles

Use maps when spatial relationships are paramount

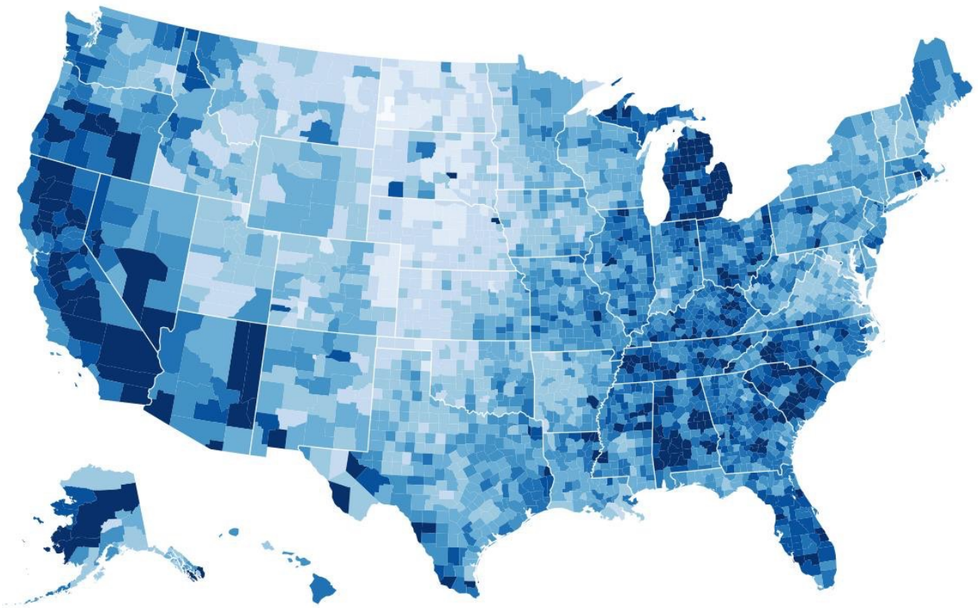
Map Tasks:

- Find location / feature (county, country, city, street)
- Find route
- Identify attribute associated with location (elevation, land/water, GDP)
- Compare attributes between locations/features

CAVEAT: Thematic maps are misleading for large areas (e.g. at country level) but distortion is not a problem at (city or county level)

Idiom: **choropleth map**

- use given spatial data
  - when central task is understanding spatial relationships
- data
  - geographic geometry
  - table with 1 quant attribute per region
- encoding
  - position:
    use given geometry for area mark boundaries
  - color:
    sequential segmented colormap



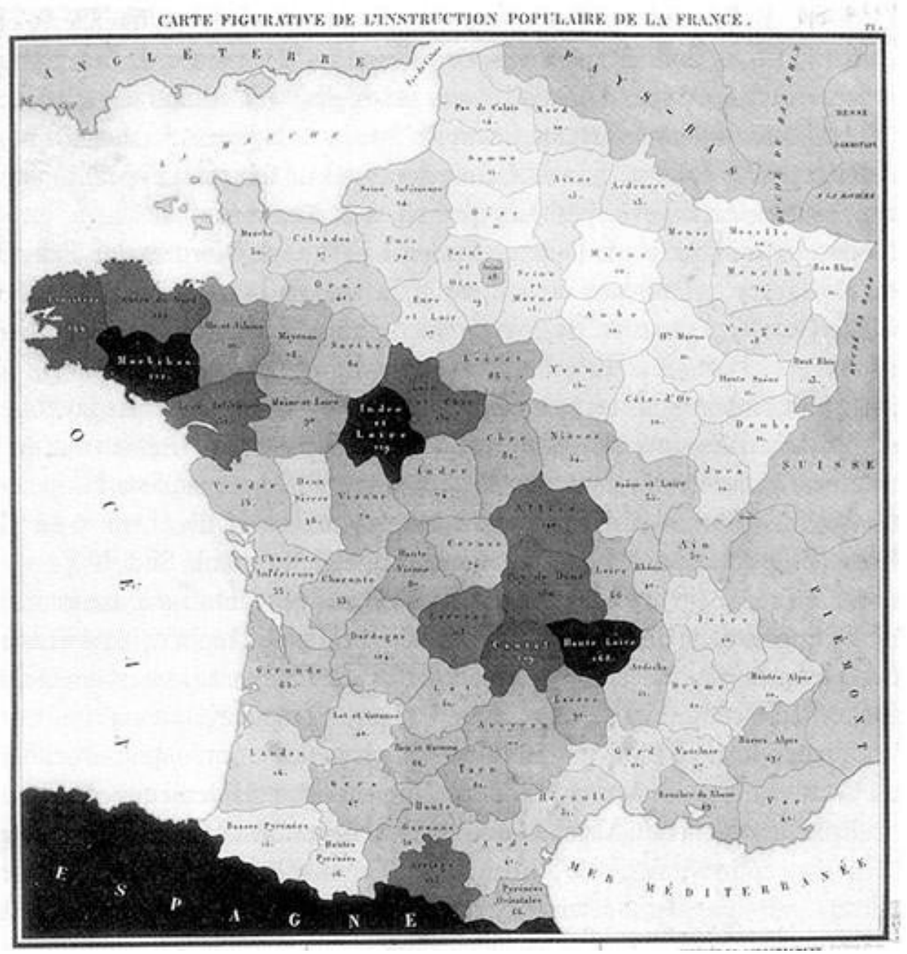
http://bl.ocks.org/mbostock/4060606

Idiom: **choropleth map**

Areas are shaded or patterned in proportion to measurement

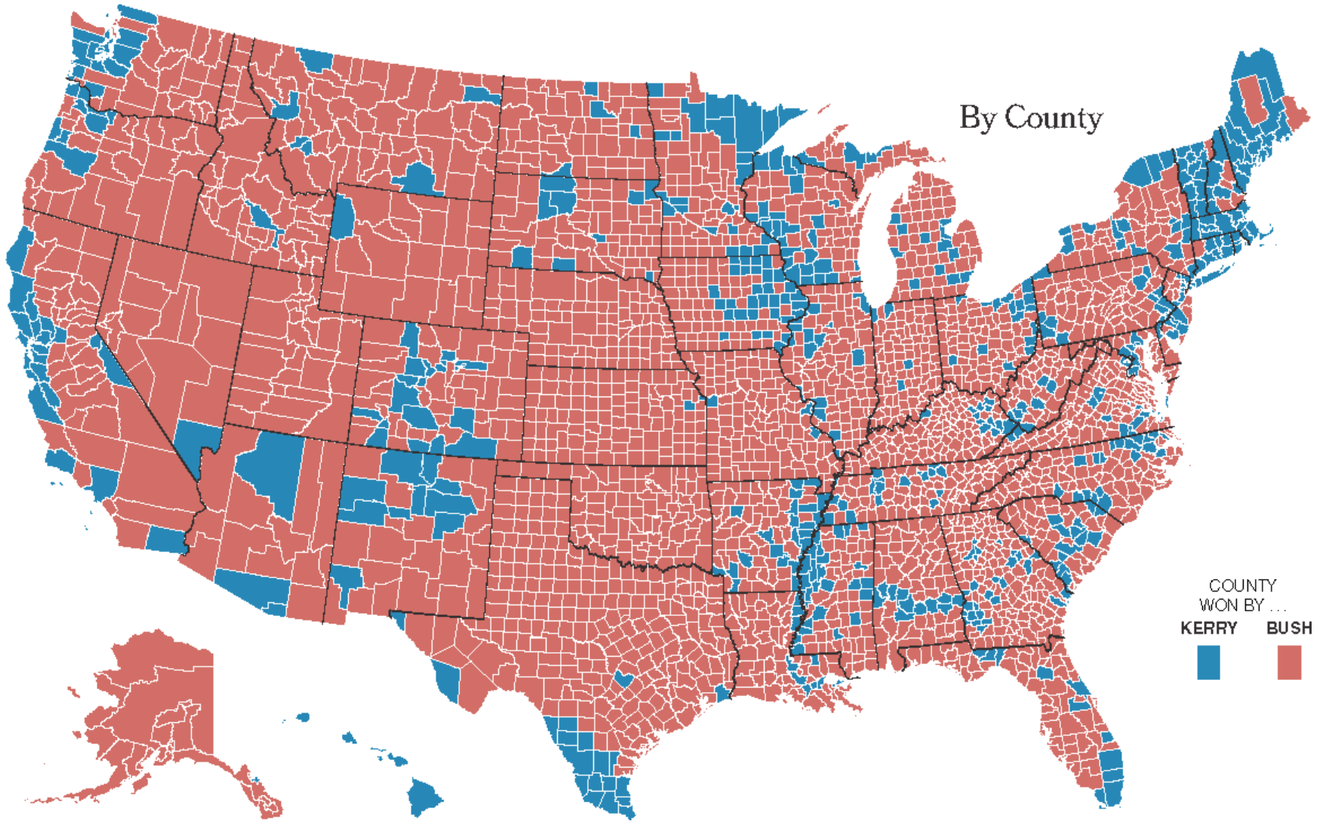
Each spatial unit is filled with a uniform color or pattern

Illiteracy in France



Charles Dupin, 1826

Presidential Elections in United States



Based on this map, what percentage of the population do you think voted Blue (for Kerry) vs voted for Red (for Bush).

Choose the one that you think is closest to what the map shows.

A. 80% Red, 20% Blue

B. 70% Red, 30 % Blue

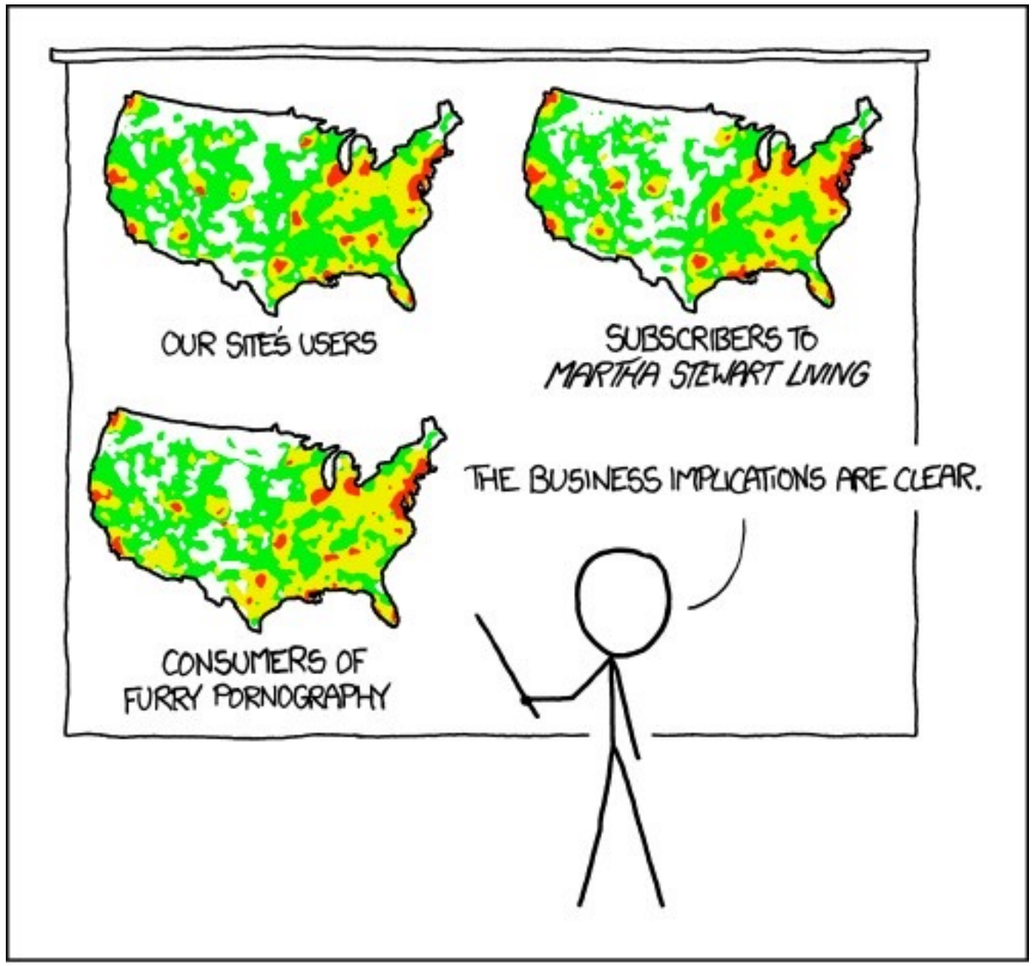
C. 60% Red, 40% Blue

D. 50% Red, 50% Blue

Beware: Population maps trickiness!

spurious correlations: most attributes just show where people live

- consider when to normalize by population density
  - encode raw data values
    - tied to underlying population
  - but should use normalized values
    - unemployed people per 100 citizens, mean family income
- general issue
  - absolute counts vs relative/normalized data
  - failure to normalize is common error



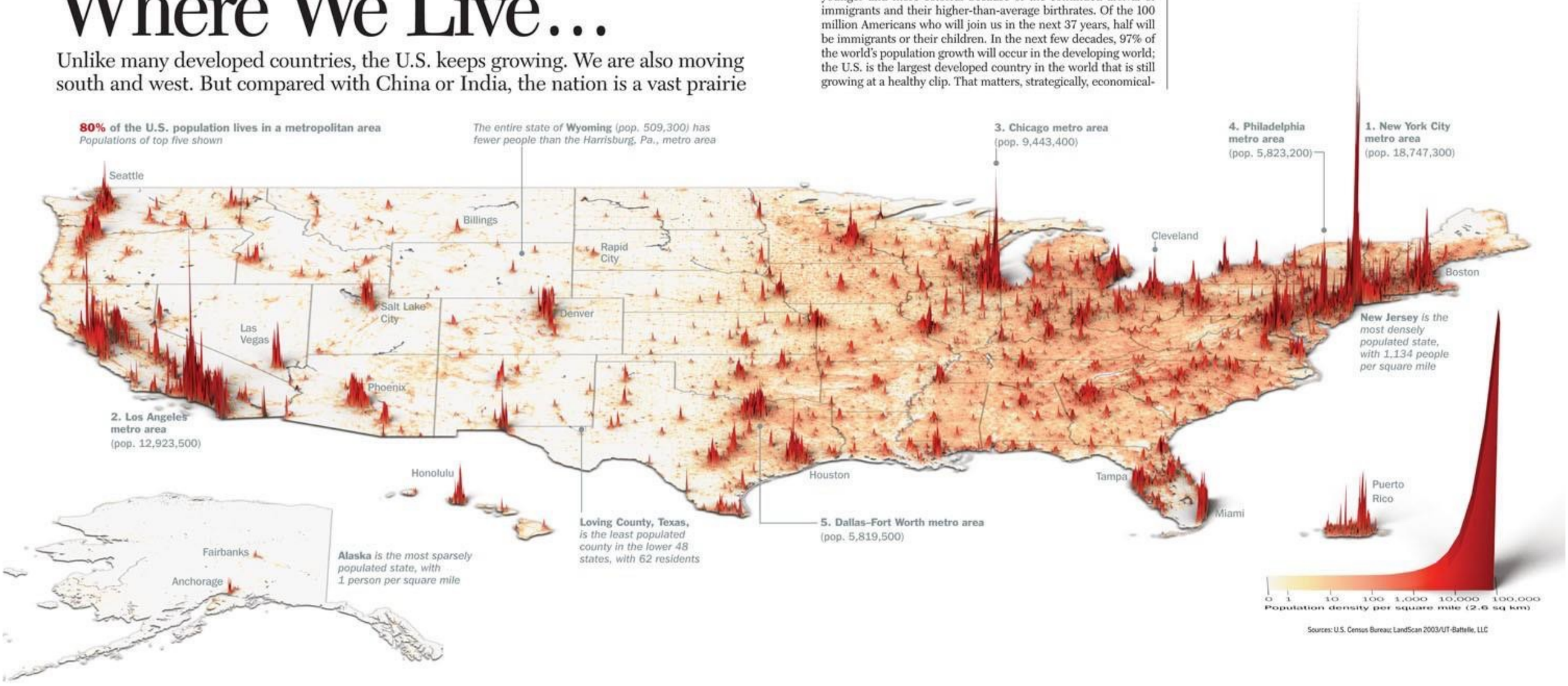
PET PEEVE #208:
GEOGRAPHIC PROFILE MAPS WHICH ARE BASICALLY JUST POPULATION MAPS

[https://xkcd.com/1138]

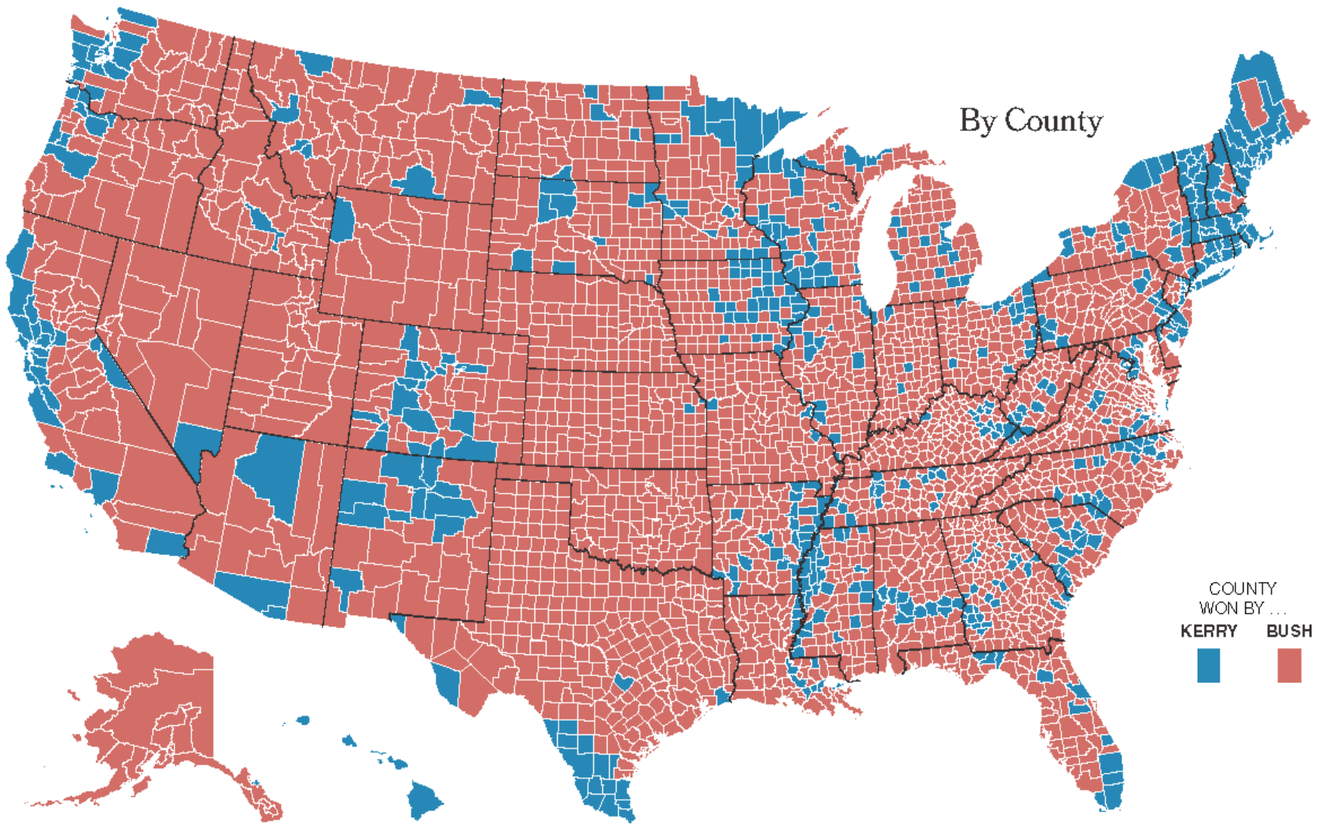
Where We Live...

Unlike many developed countries, the U.S. keeps growing. We are also moving south and west. But compared with China or India, the nation is a vast prairie

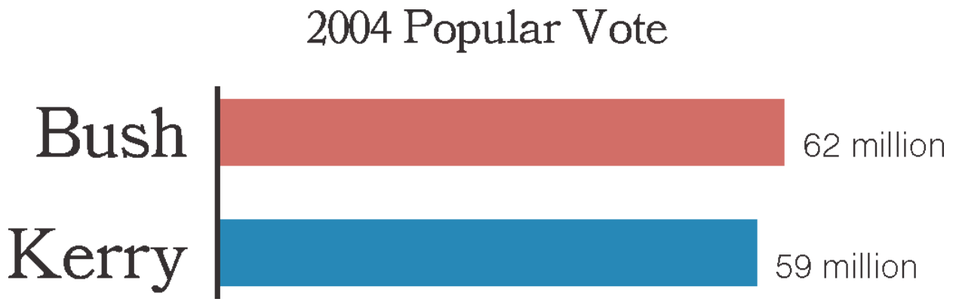
Our families are getting smaller—with one vital exception. Compared with those of Europe and Japan, the U.S. population is younger and more colorful because of the continued arrival of immigrants and their higher-than-average birthrates. Of the 100 million Americans who will join us in the next 37 years, half will be immigrants or their children. In the next few decades, 97% of the world's population growth will occur in the developing world; the U.S. is the largest developed country in the world that is still growing at a healthy clip. That matters, strategically, economically. Ala.; Possum Trot, Ky.; or Lonelyville, N.Y. But they are all probably close to someone's idea of paradise. *—By Nancy Gibbs*

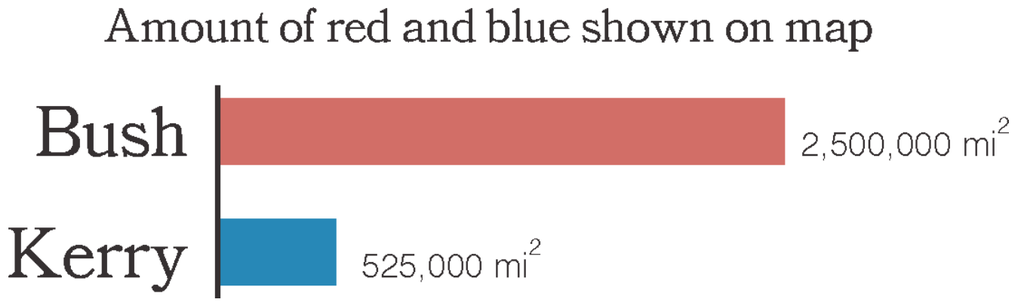


Presidential Elections in United States

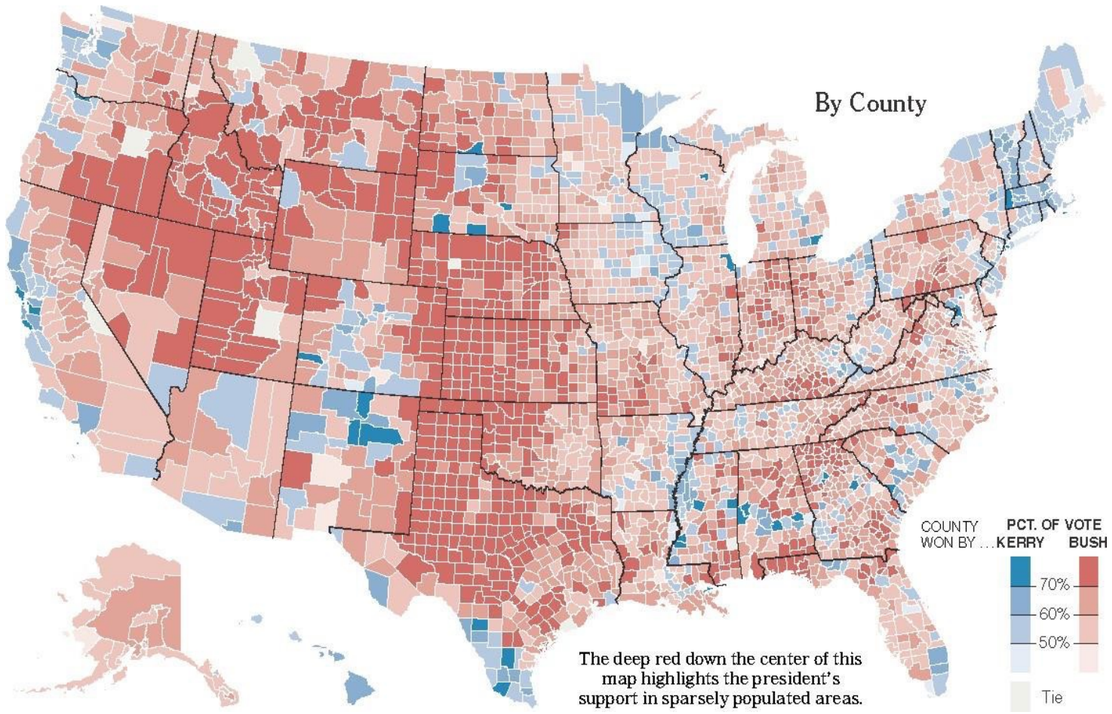


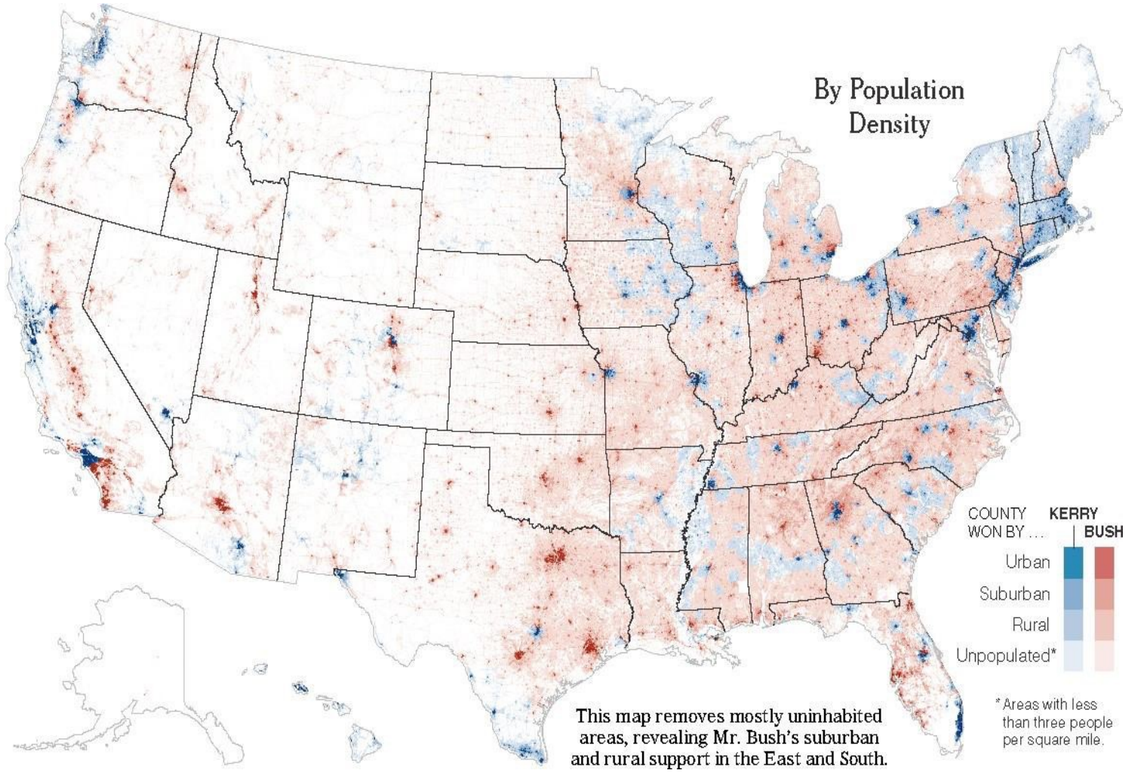
Magnitude of Effect vs Perceived Effect





Matthew Ericson, NY Times

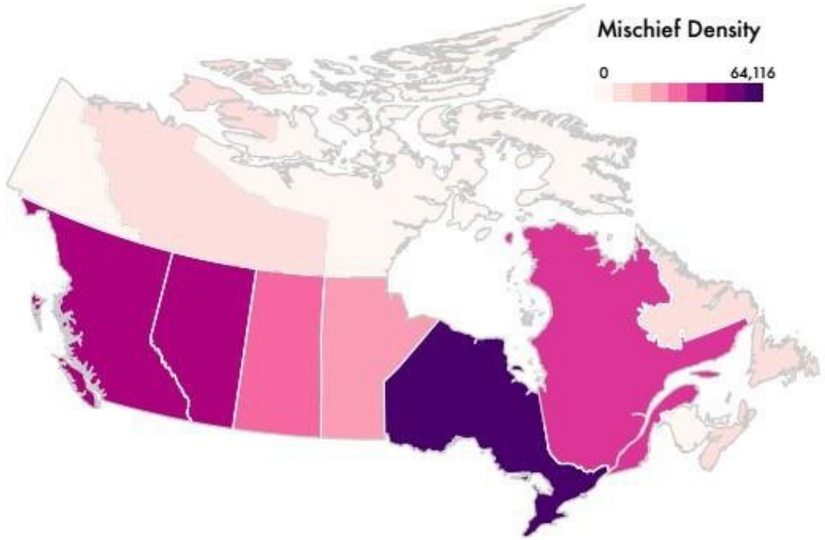




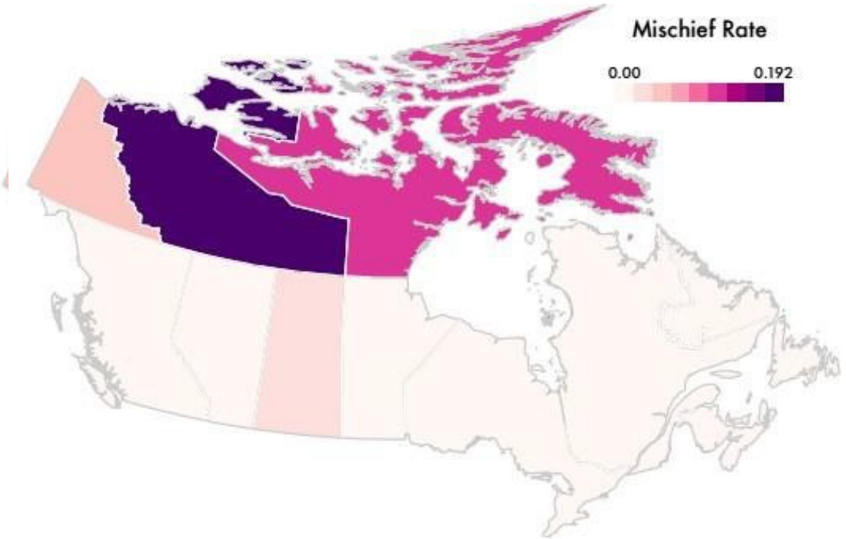
Matthew Ericson, NY Times

Approach: Use a Prior, show difference. Which province is safest?

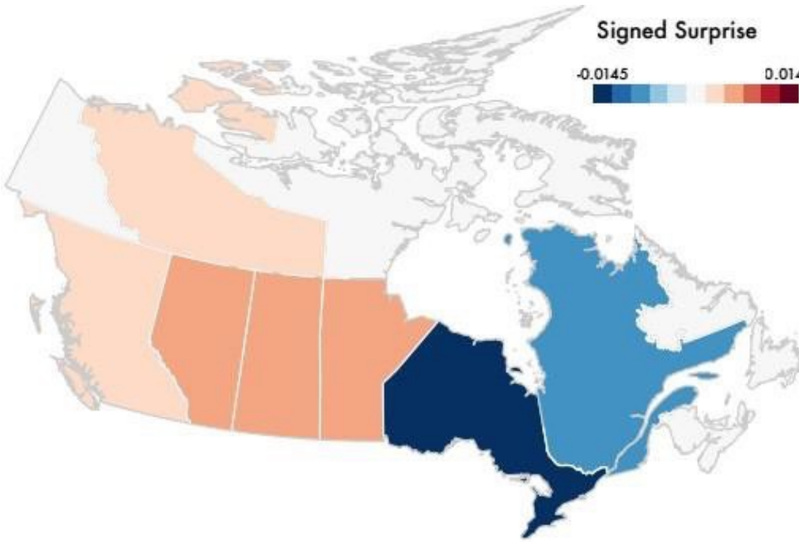
mischief *"is a category of property crime: it includes things like vandalism and graffiti, where the intent is neither to steal anything nor hurt anybody."*



(a) The **Event Density** of "mischief" in Canada.



(b) The per-capita **Event Rate** of mischief.



(c) The **Surprise Map** of mischief.

Provinces with either unusually high/low per capita rates, or large populations with significant deviations from the average.

https://medium.com/@uwdata/surprise-maps-showing-the-unexpected-e92b67398865

Choropleth maps: Recommendations

- only use when central task is understanding spatial relationships
- show only one variable at a time
- normalize when appropriate
- be careful when choosing colors & bins
- best case: regions are roughly equal sized

Choropleth map: Pros & cons

- pros
  - easy to read and understand
  - well established visualization (no learning curve)
  - data is often collected and aggregated by geographical regions
- cons
  - most effective visual variable used for geographic location
  - visual salience depends on region size, not true importance wrt attribute value
    - large regions appear more important than small ones
  - color palette choice has a huge influence on the result

Idiom: **Symbol maps**

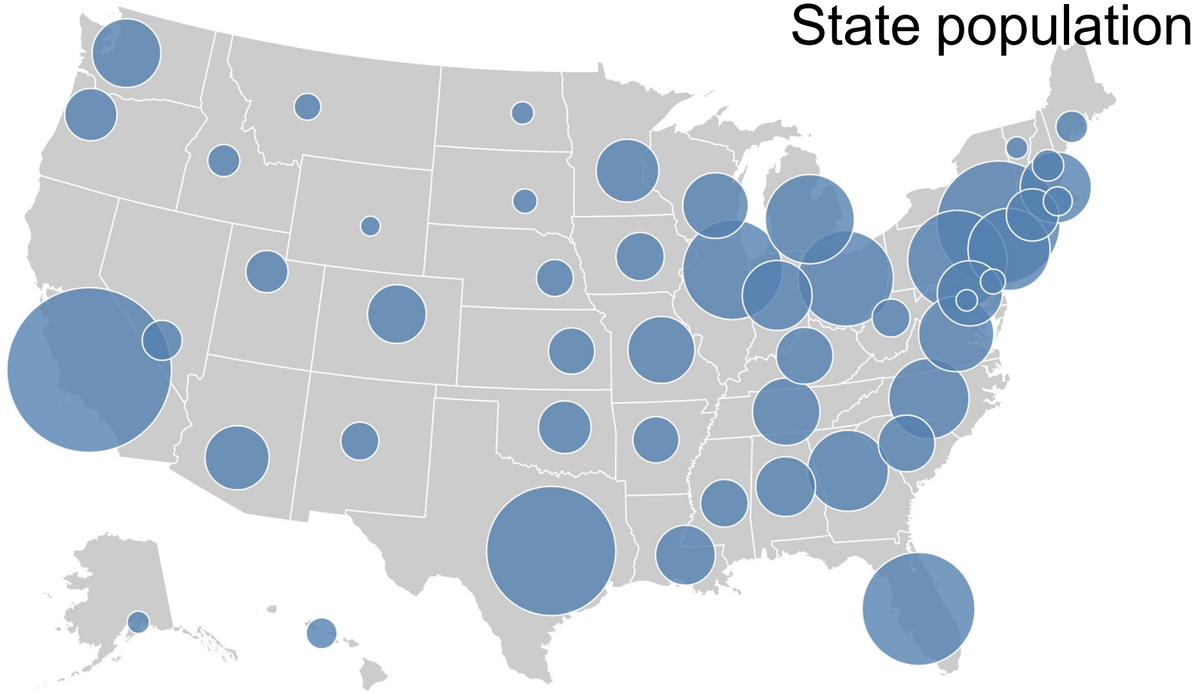
symbol is used to represent aggregated data (mark or glyph)

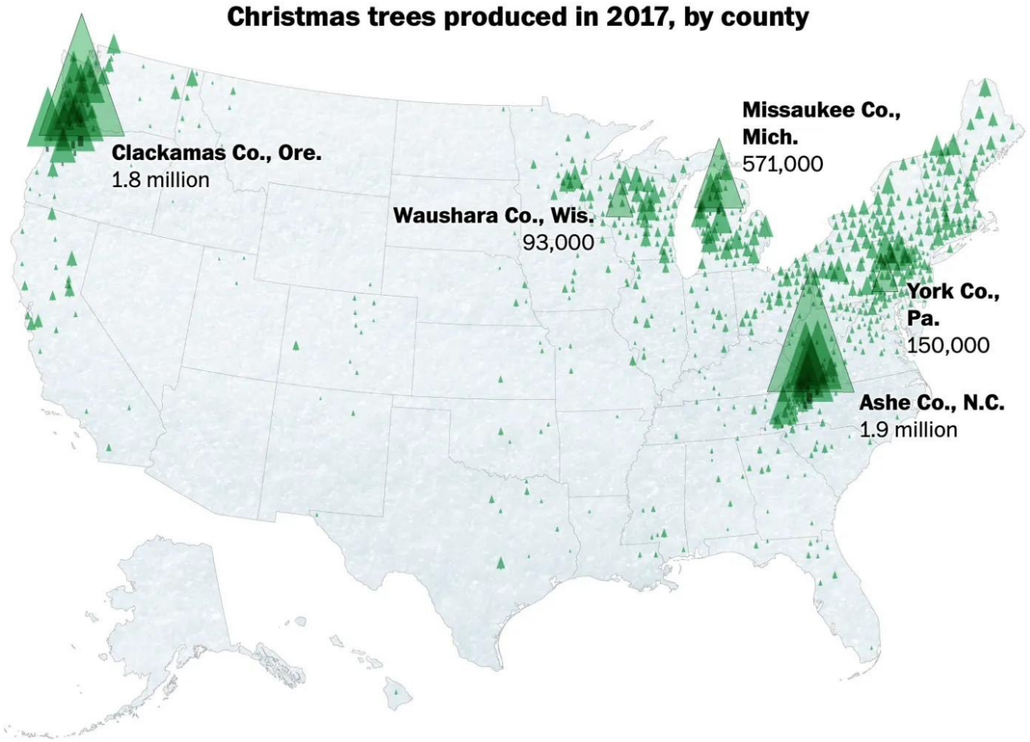
allows use of size and shape and color channels

aka proportional symbol maps, graduated symbol maps

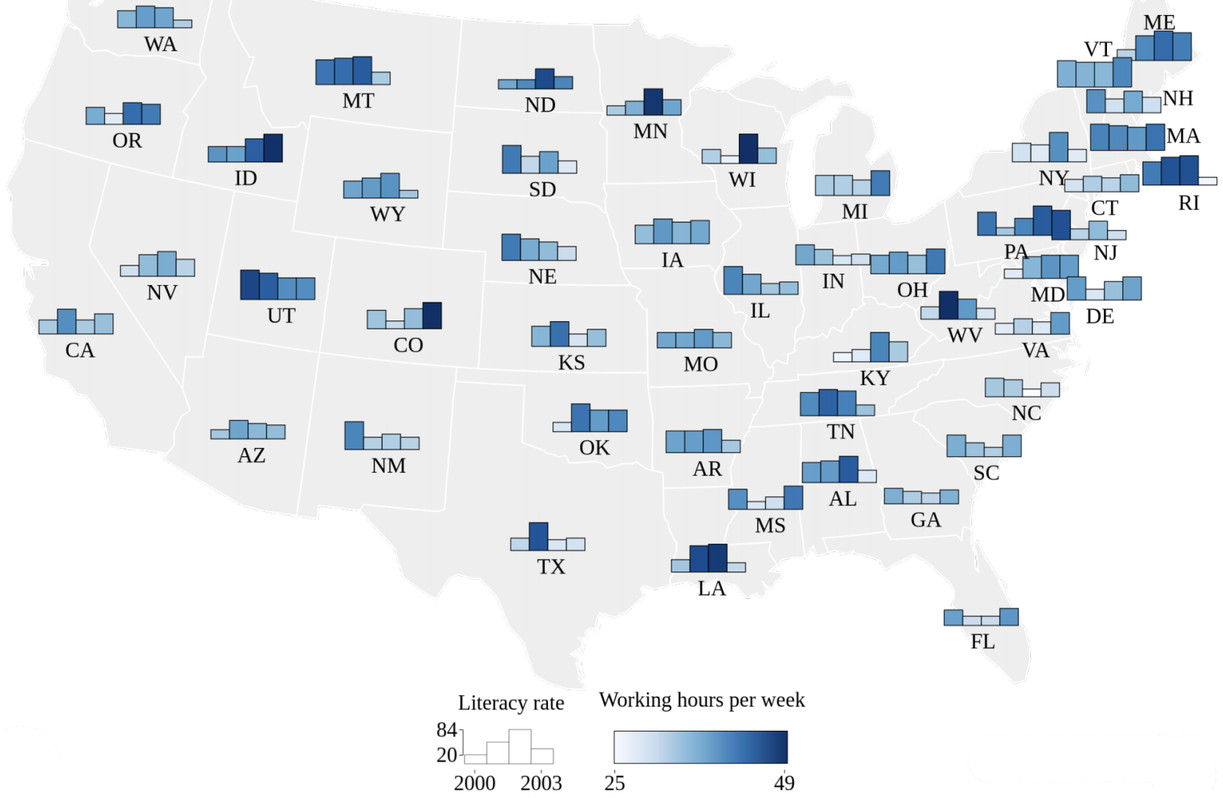
keep original spatial geometry in the background

often a good alternative to choropleth maps

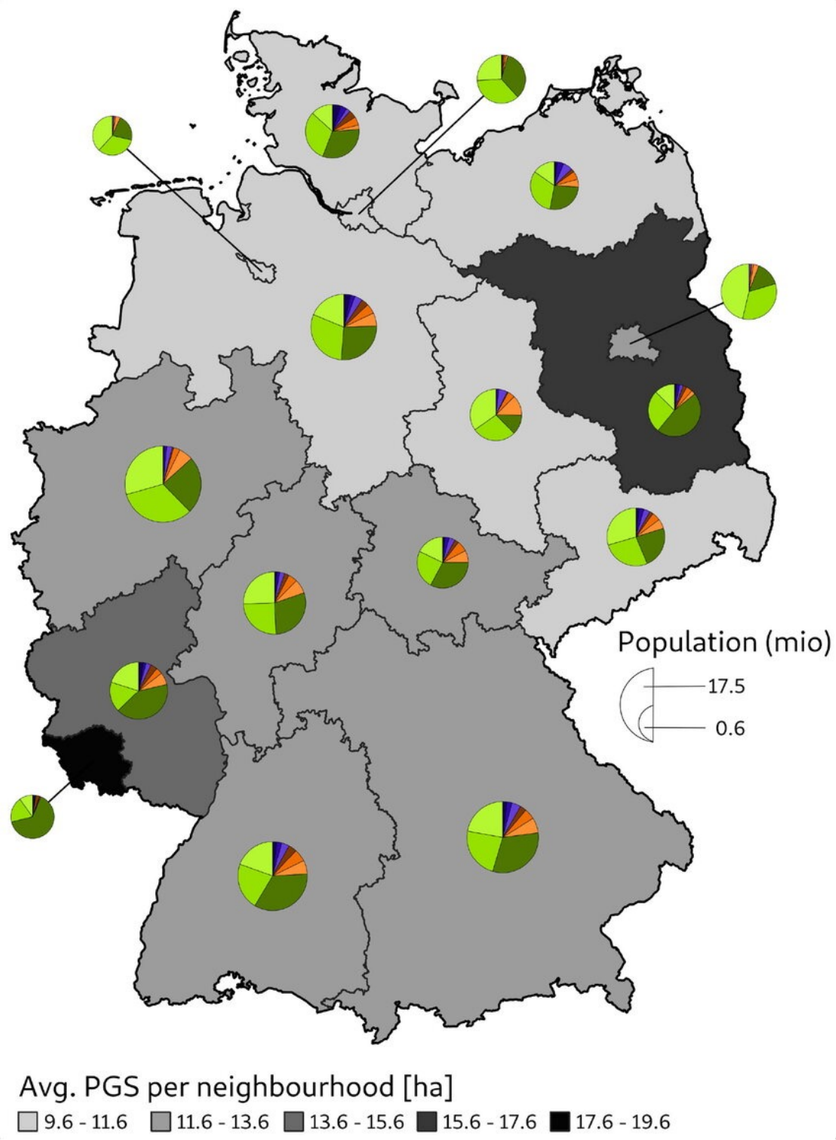




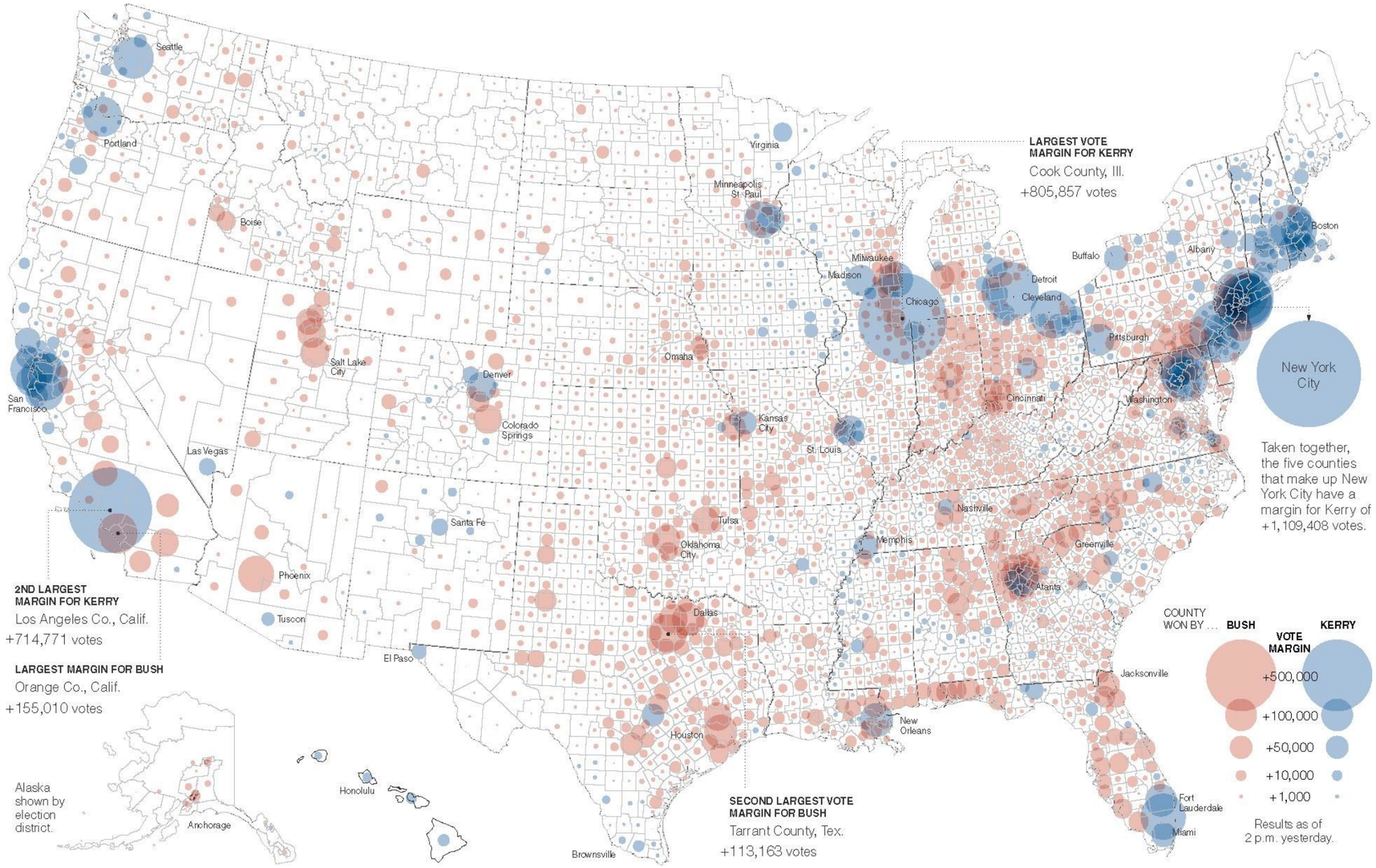
https://www.washingtonpost.com/nation/2019/12/12/where-christmas-trees-come/

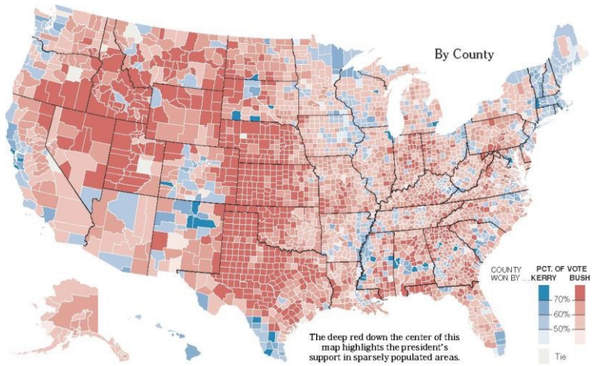


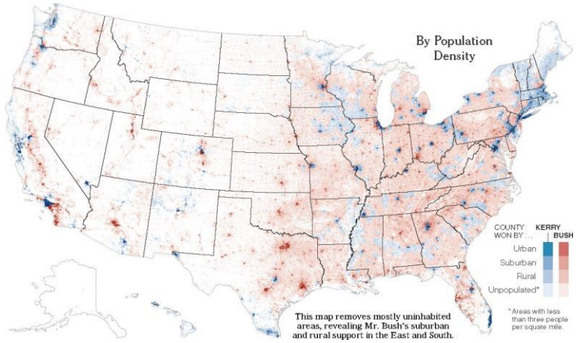
https://hal.science/hal-02320617v1/file/main.pdf



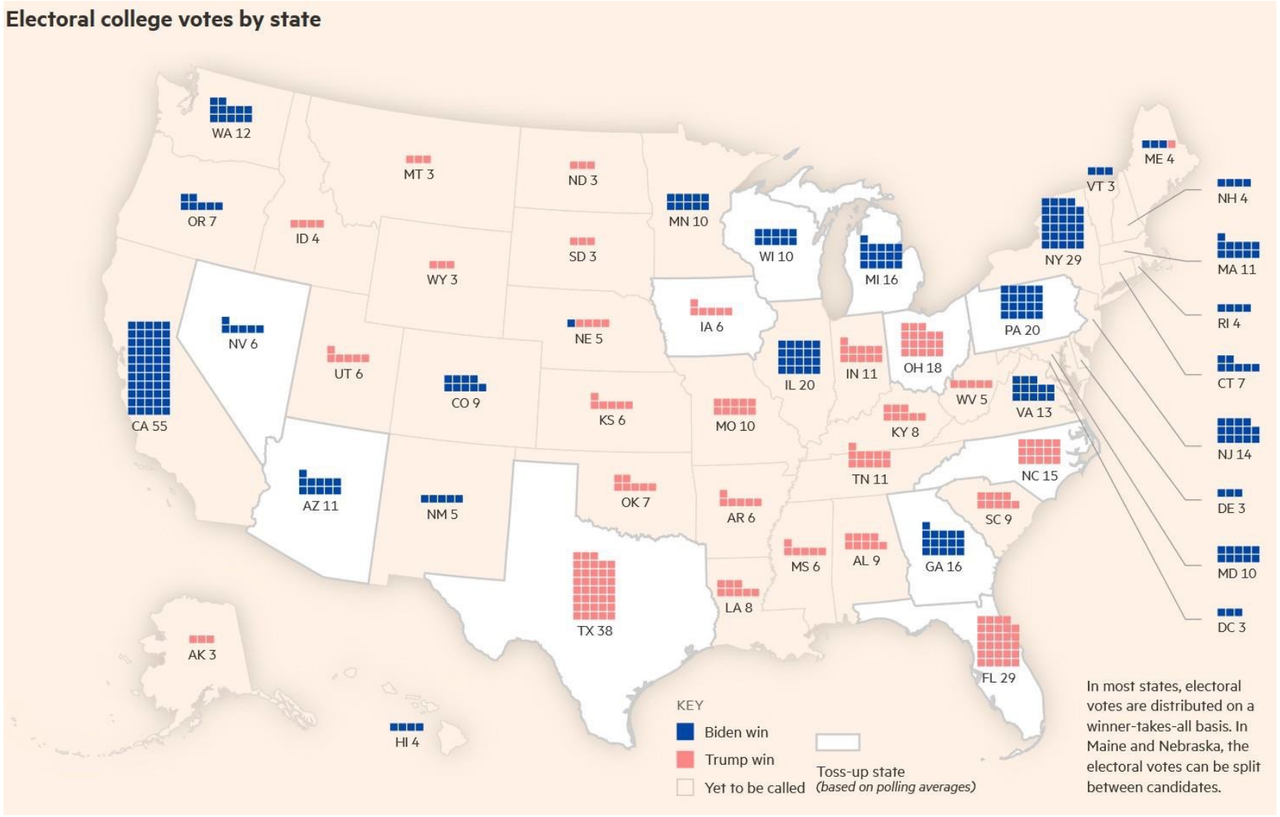
https://www.researchgate.net/figure/Green-space-availability-in-Germany-by-federal-states-States-are-shaded-by-the_fig3_375816455

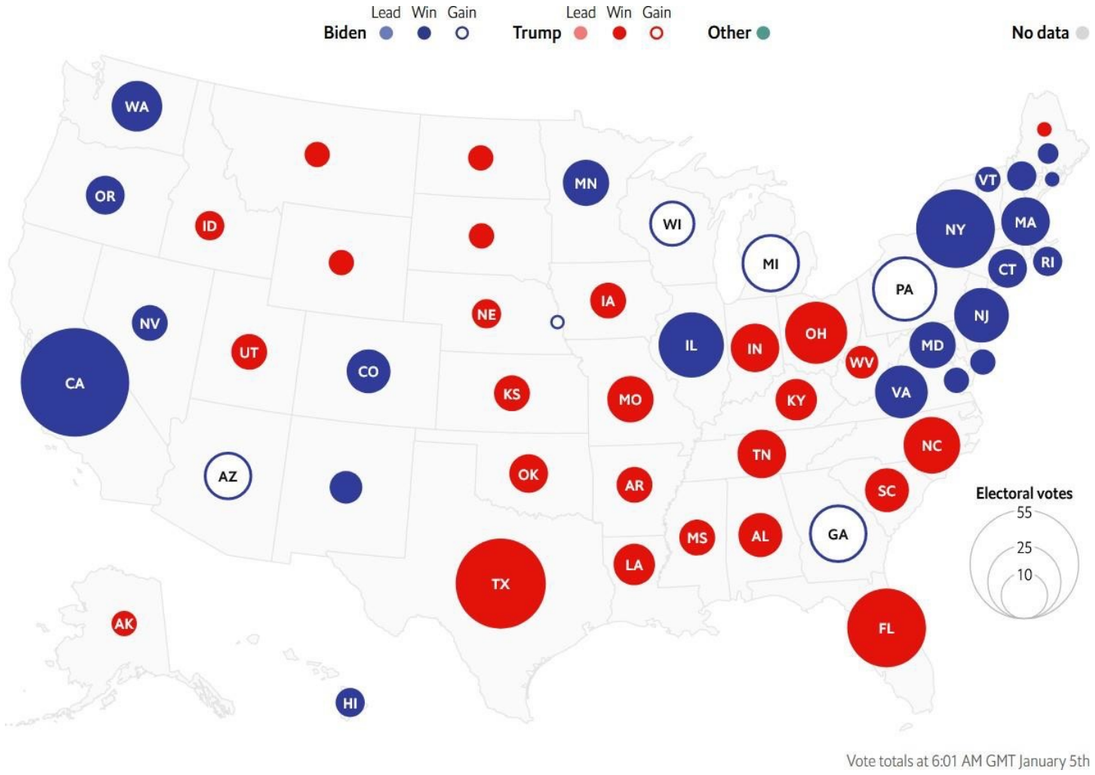






Matthew Ericson, NY Times


Electoral college votes by state
WA 12
OR 7
ID 4
MT 3
ND 3
SD 3
WY 3
NV 6
UT 6
CO 9
NE 5
KS 6
CA 55
AZ 11
NM 5
OK 7
TX 38
MN 10
IA 6
MO 10
AR 6
LA 8
WI 10
IL 20
MS 6
MI 16
IN 11
AL 9
OH 18
KY 8
TN 11
GA 16
WV 5
SC 9
PA 20
VA 13
NC 15
FL 29
NY 29
VT 3
ME 4
NH 4
MA 11
RI 4
CT 7
NJ 14
DE 3
MD 10
DC 3
AK 3
HI 4
KEY
Biden win
Trump win
Yet to be called
Toss-up state
(based on polling averages)
In most states, electoral votes are distributed on a winner-takes-all basis. In Maine and Nebraska, the electoral votes can be split between candidates.

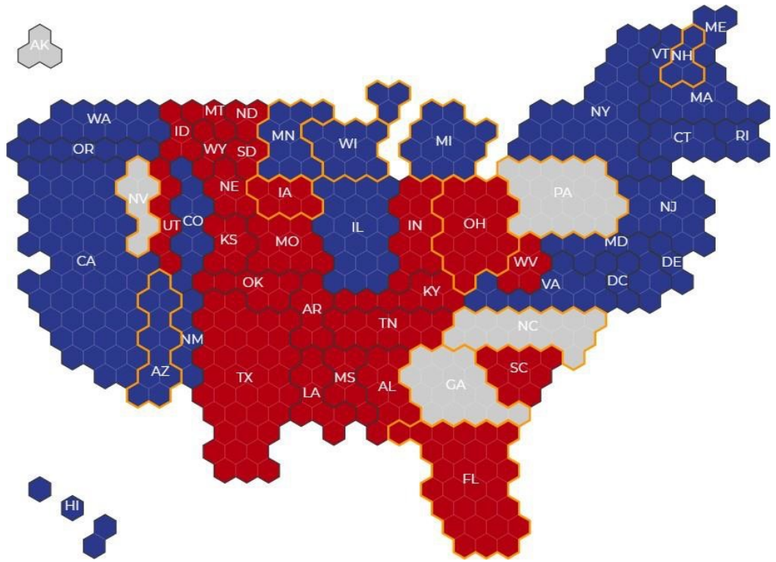

Lead Win Gain
Biden
Lead Win Gain
Trump
Other
No data
WA
OR
CA
ID
NV
MT
WY
UT
AZ
CO
NM
ND
SD
NE
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MS
MI
IN
KY
TN
AL
OH
WV
GA
SC
NC
VA
PA
NY
MD
DE
NJ
CT
RI
MA
VT
AK
HI
FL
Electoral votes
55
25
10
Vote totals at 6:01 AM GMT January 5th

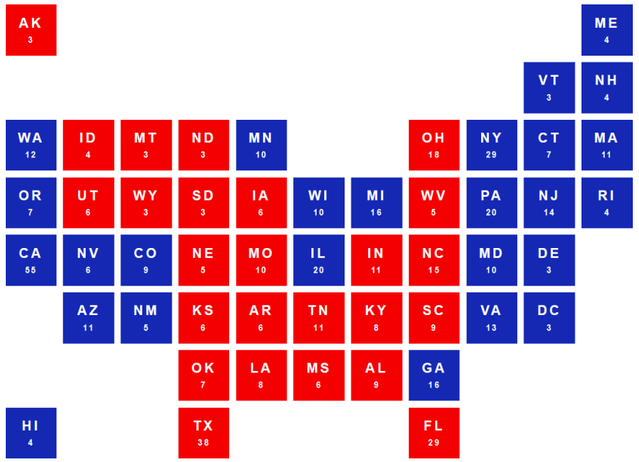
Symbol map: Pros & cons

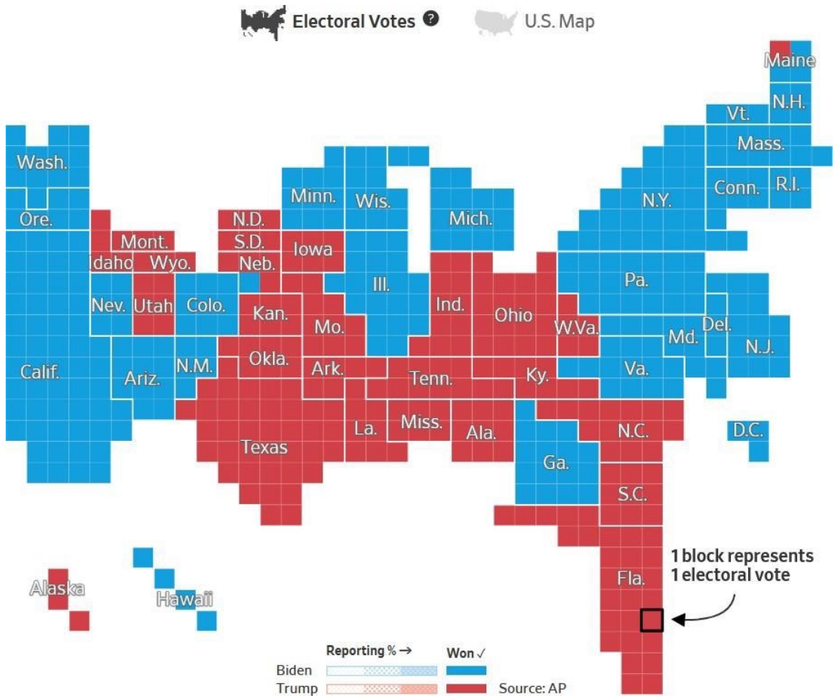
- pros
  - somewhat intuitive to read and understand
  - mitigate problems with region size vs data salience
    - marks: symbol size follows attribute value
    - glyphs: symbol size can be uniform
- cons
  - possible occlusion / overlap
    - symbols could overlap each other
    - symbols could occlude region boundaries
  - complex glyphs may require explanation / training

Idiom: **Grid Cartogram**

- uniform-sized shapes arranged in rectilinear grid
- maintain approximate spatial position and arrangement



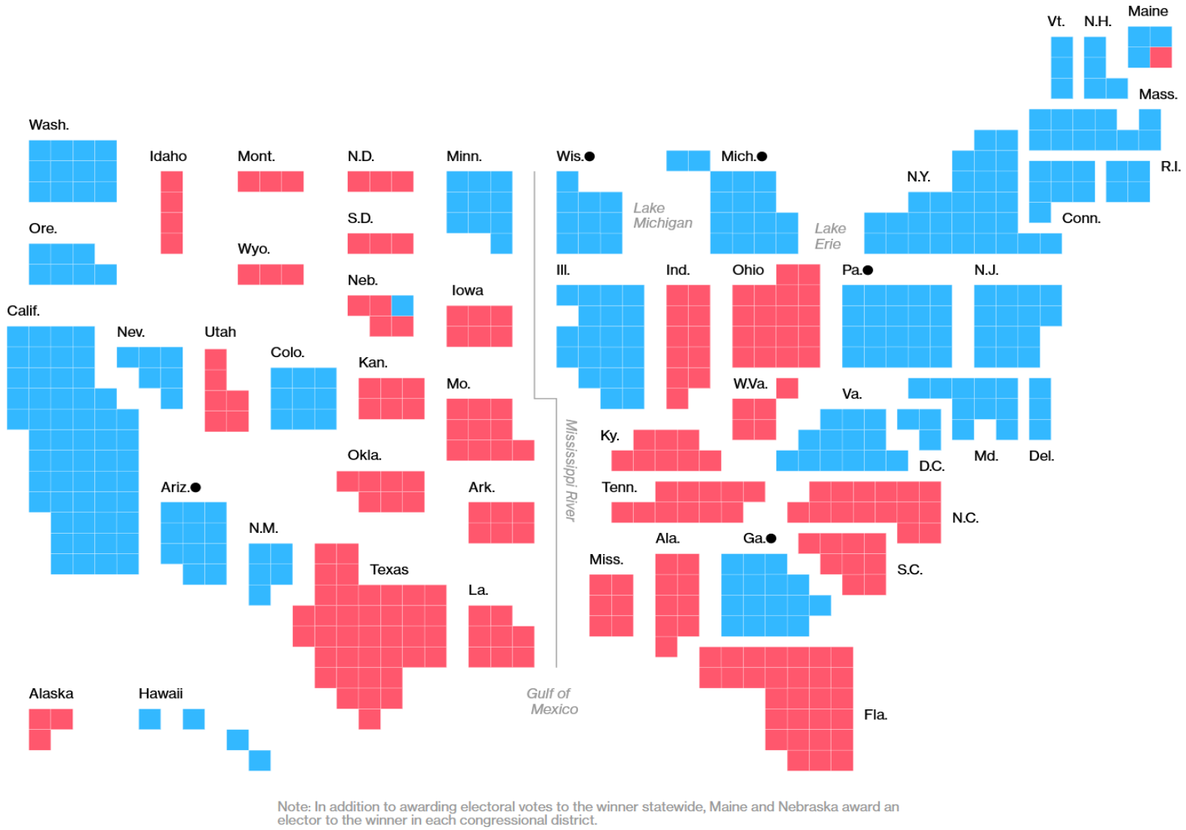




Al Jazeera, CBS, WSJ

Idiom: **Contiguous cartogram**

- We are changing the size of regions on the map
- Compromise between geospatial accuracy and quality of data encoding.



https://www.bloomberg.com/graphics/2020-us-election-results/

Idiom: **Contiguous cartogram**

Also known as anamorphic map

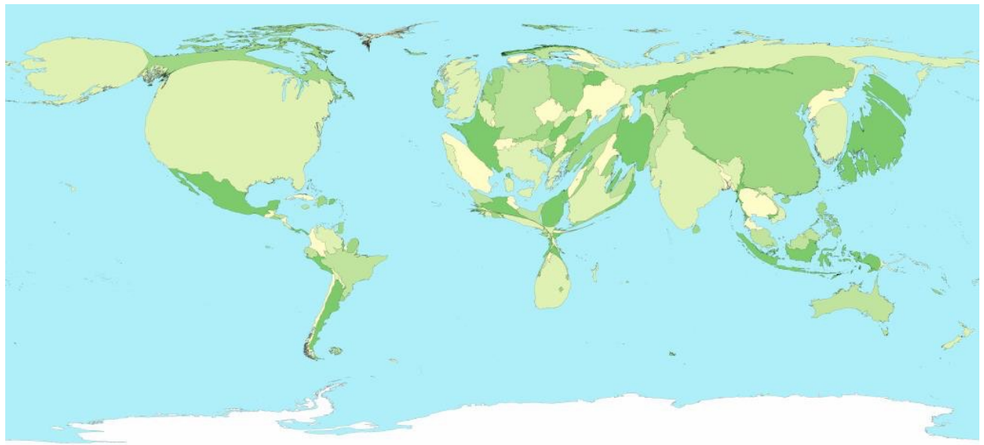
interlocking marks:
shape, area, and position coded

derive new interlocking marks

based on combination of original interlocking marks and new quantitative attribute

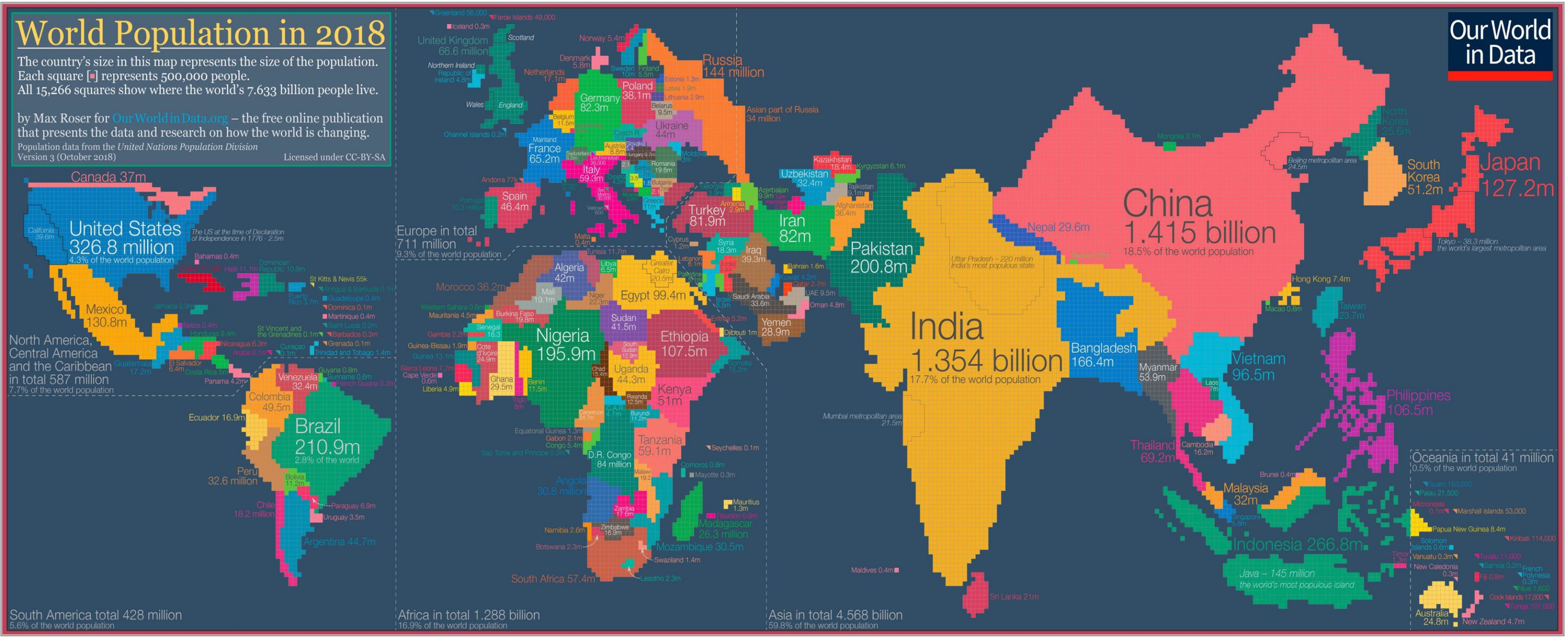
- algorithm to create new marks
  - input: target size
  - goal: shape as close to the original as possible
  - requirement: maintain constraints
    - relative position
    - contiguous boundaries with their neighbours

Greenhouse Emissions



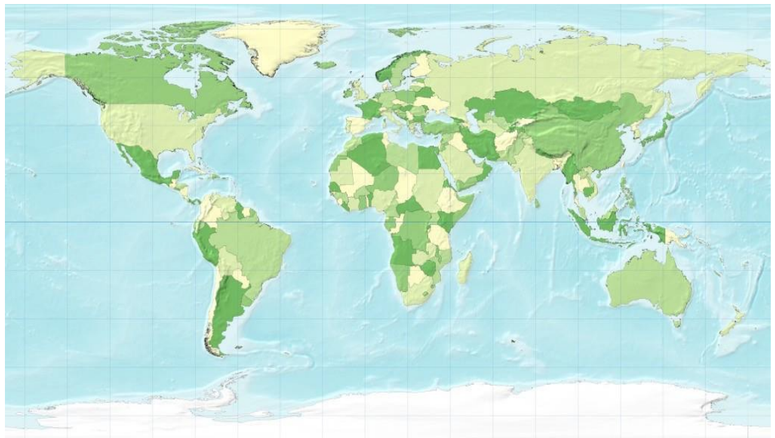
Population

Mark Newman, Univ. Michigan



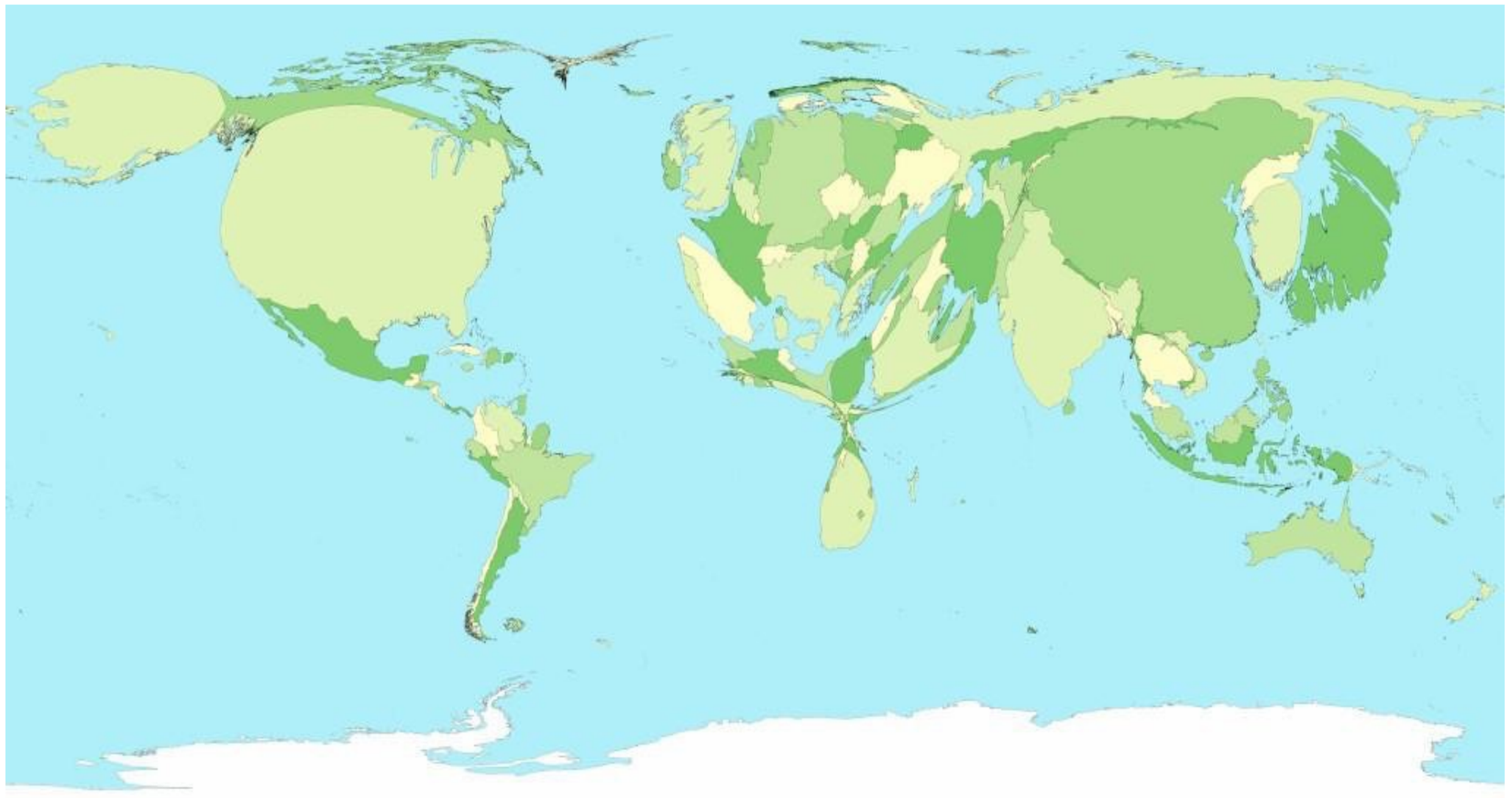
https://ourworldindata.org/world-population-cartogram

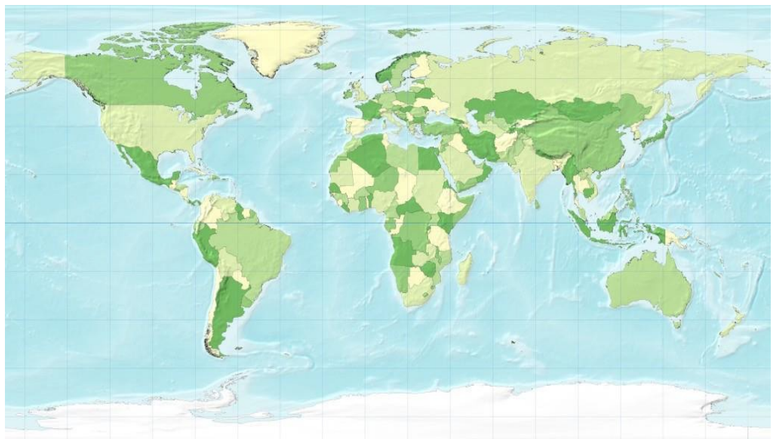
Population



Mark Newman, Univ. Michigan

Greenhouse Emissions





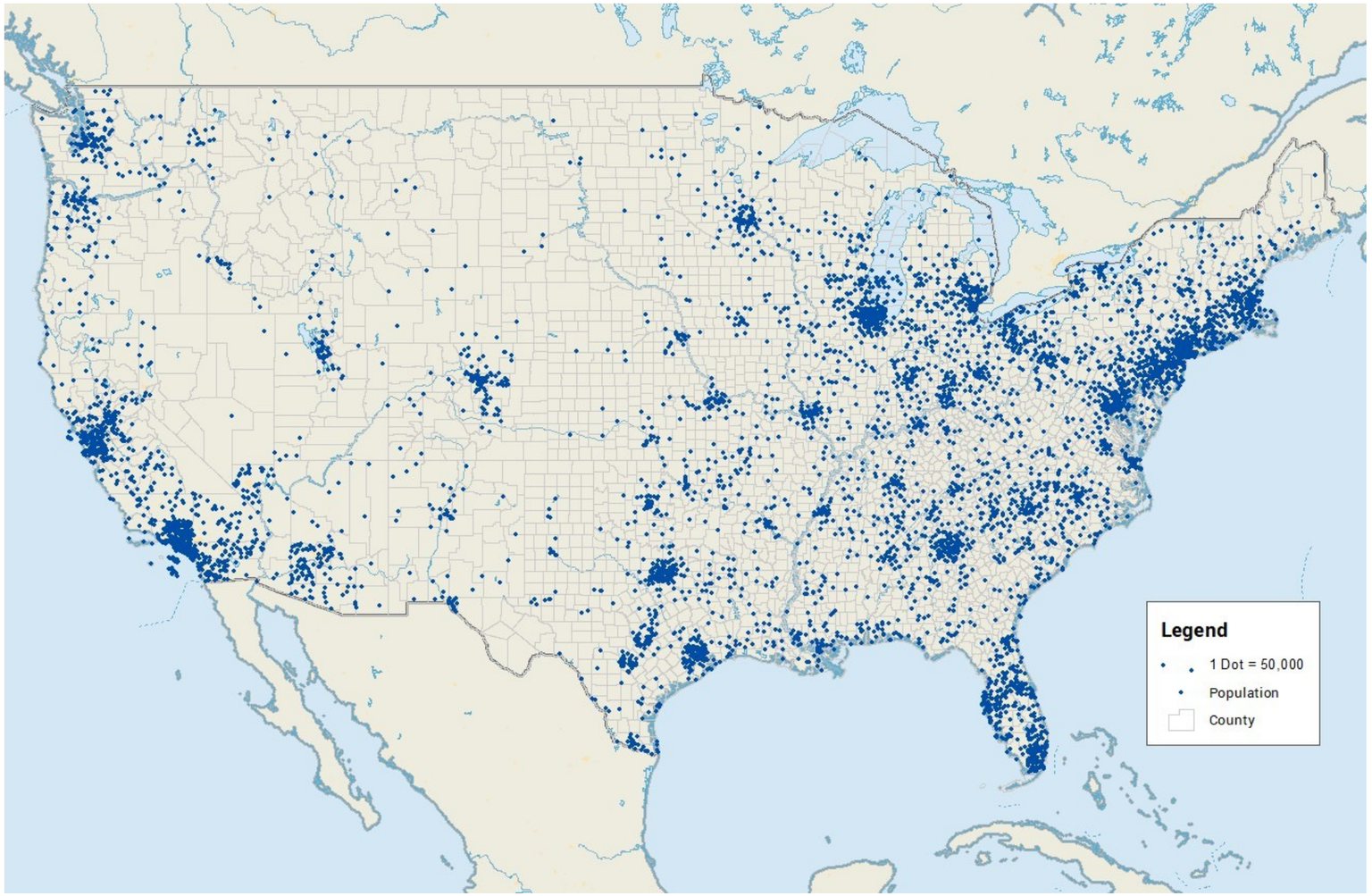
Mark Newman, Univ. Michigan

Cartogram: Pros & cons

- pros
  - can be intriguing and engaging
  - best case: strong and surprising size disparities
  - non-contiguous cartograms often easier to understand
- cons
  - require substantial familiarity with original dataset & use of memory
    - compare distorted marks to memory of original marks
    - mitigation strategies: transitions or side by side views
  - major distortion is problematic
    - may be aesthetically displeasing
    - may result in unrecognizable marks
  - difficult to extract exact quantities

Idiom: **Dot density maps**

- visualize distribution of a phenomenon by placing dots
- one symbol represents a constant number of items
  - dots have uniform size & shape
  - allows use of color channel
- task:
  show spatial patterns, clusters



Dot density maps: Pros and cons

- pros
  - straightforward to understand
  - avoids choropleth non-uniform region size problems
- cons
  - challenge: normalization, just like choropleths
    - show population density (correlated with attribute), not effect of interest
  - perceptual disadvantage:
    difficult to extract quantities
  - performance disadvantage:
    rendering many dots can be slow