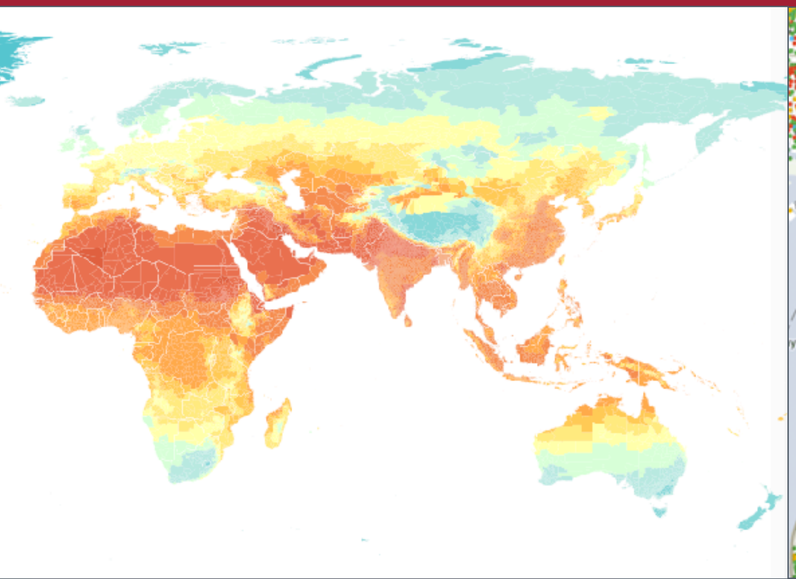
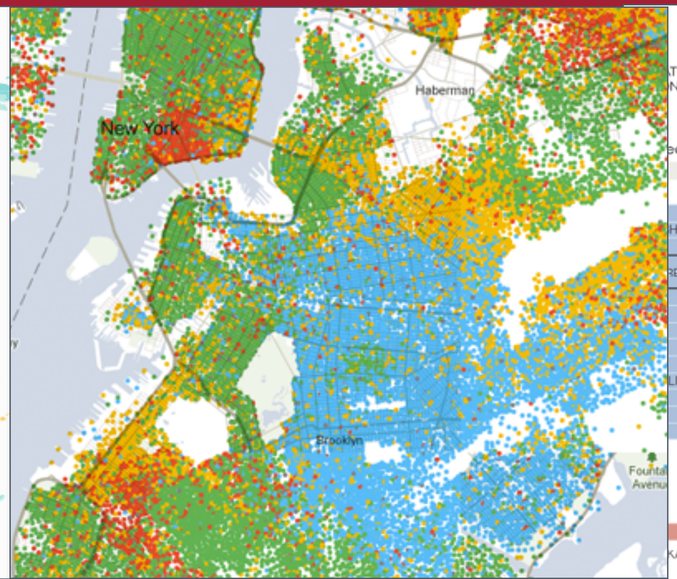
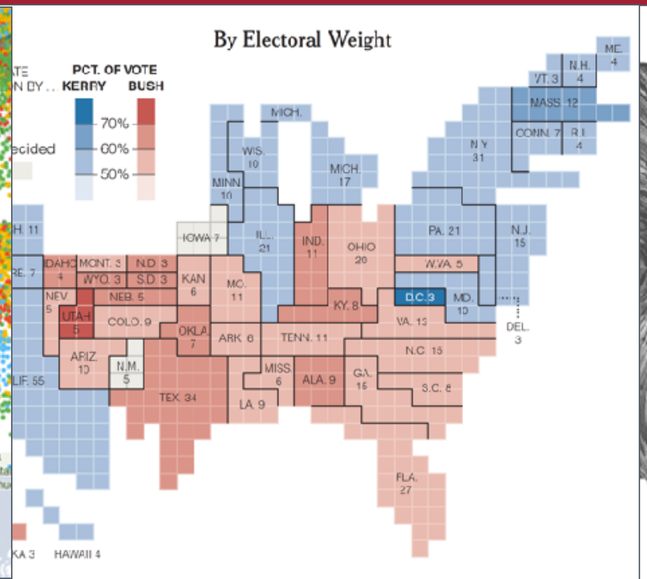
6.859: Interactive Data Visualization

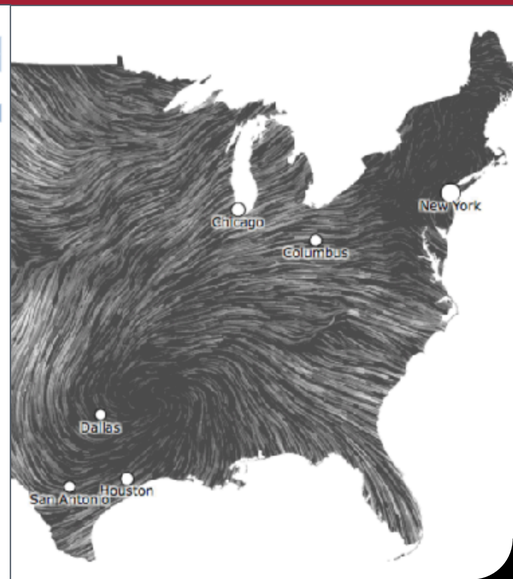
Mapping & Cartography

Arvind Satyanarayan









When should we use maps?

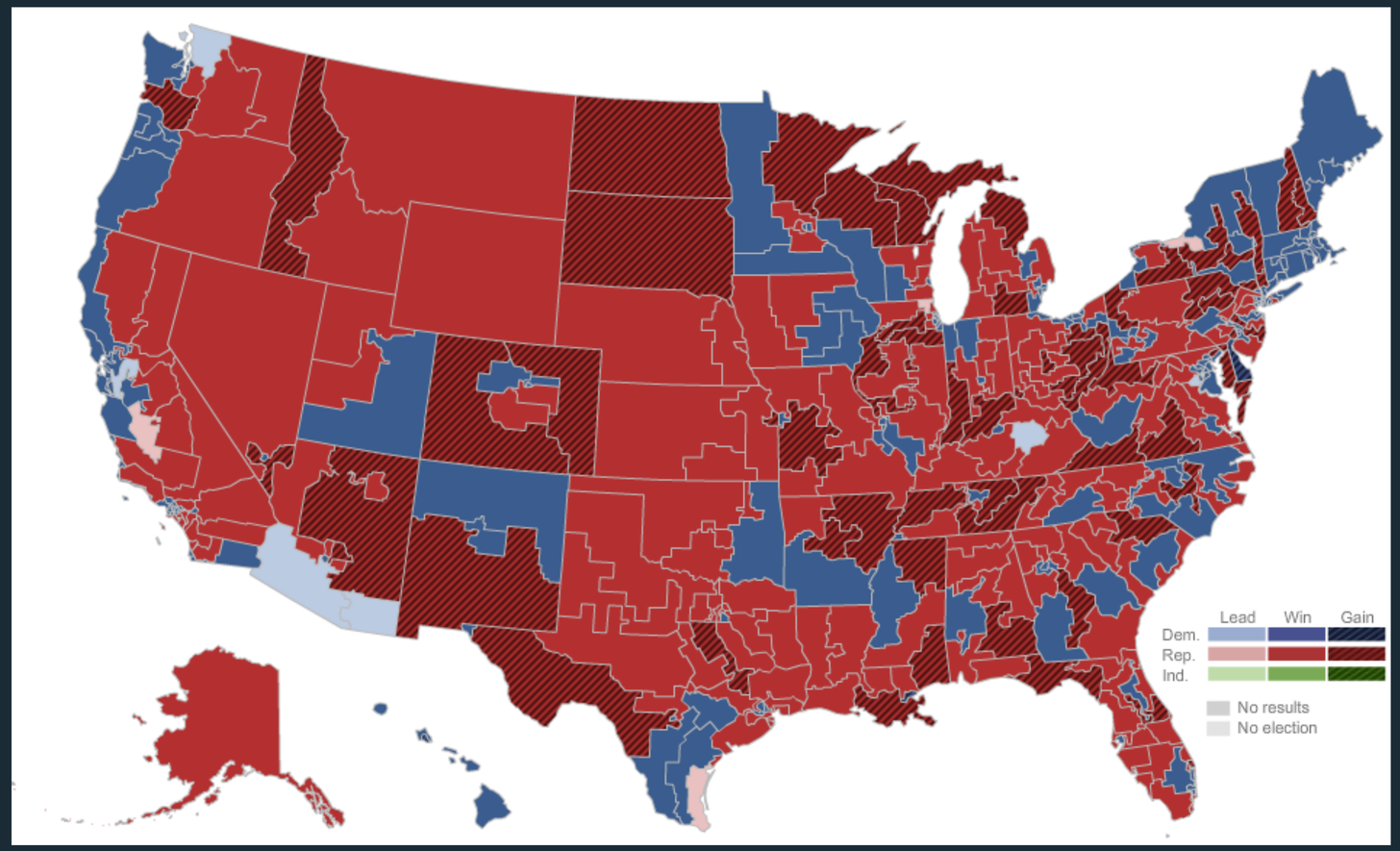
When should we use maps?

1. When our data contains geographical attributes (e.g., latitude, longitude, city, state, country, etc.).

2. When visualizing **geographic relationships** is important.

When should we use maps?

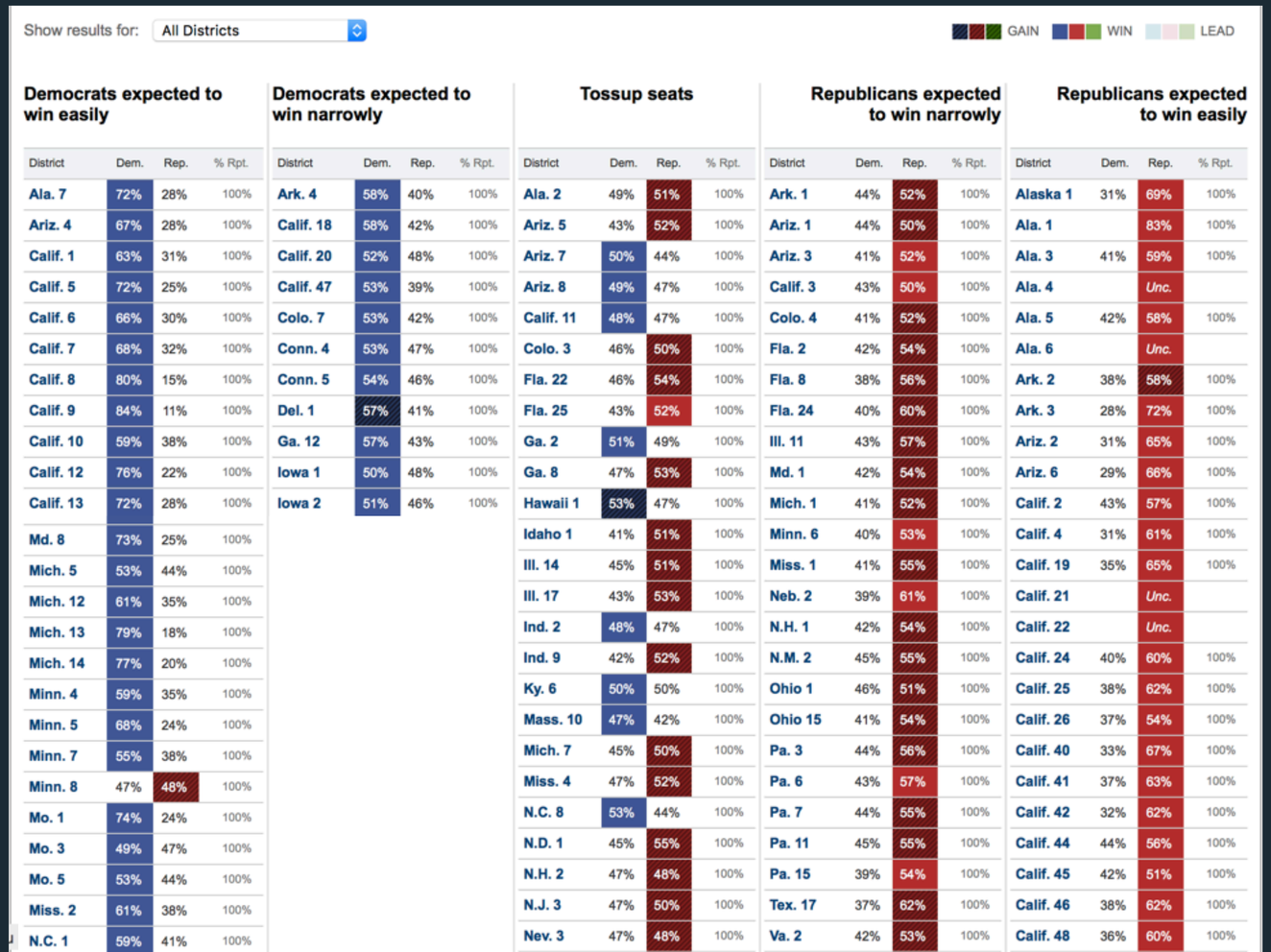
When visualizing **geographic relationships** is important.



- ✓ Who's winning my district?
- ✘ Is it a landslide?
- ✘ What are the paths to victory?

When should we use maps?

When visualizing **geographic relationships** is important.



Show results for: All Districts

GAIN WIN LEAD

Democrats expected to win easily

District	Dem.	Rep.	% Rpt.
Ala. 7	72%	28%	100%
Ariz. 4	67%	28%	100%
Calif. 1	63%	31%	100%
Calif. 5	72%	25%	100%
Calif. 6	66%	30%	100%
Calif. 7	68%	32%	100%
Calif. 8	80%	15%	100%
Calif. 9	84%	11%	100%
Calif. 10	59%	38%	100%
Calif. 12	76%	22%	100%
Calif. 13	72%	28%	100%
Md. 8	73%	25%	100%
Mich. 5	53%	44%	100%
Mich. 12	61%	35%	100%
Mich. 13	79%	18%	100%
Mich. 14	77%	20%	100%
Minn. 4	59%	35%	100%
Minn. 5	68%	24%	100%
Minn. 7	55%	38%	100%
Minn. 8	47%	48%	100%
Mo. 1	74%	24%	100%
Mo. 3	49%	47%	100%
Mo. 5	53%	44%	100%
Miss. 2	61%	38%	100%
N.C. 1	59%	41%	100%

Democrats expected to win narrowly

District	Dem.	Rep.	% Rpt.
Ark. 4	58%	40%	100%
Calif. 18	58%	42%	100%
Calif. 20	52%	48%	100%
Calif. 47	53%	39%	100%
Colo. 7	53%	42%	100%
Conn. 4	53%	47%	100%
Conn. 5	54%	46%	100%
Del. 1	57%	41%	100%
Ga. 12	57%	43%	100%
Iowa 1	50%	48%	100%
Iowa 2	51%	46%	100%

Tossup seats

District	Dem.	Rep.	% Rpt.
Ala. 2	49%	51%	100%
Ariz. 5	43%	52%	100%
Ariz. 7	50%	44%	100%
Ariz. 8	49%	47%	100%
Calif. 11	48%	47%	100%
Colo. 3	46%	50%	100%
Fla. 22	46%	54%	100%
Fla. 25	43%	52%	100%
Ga. 2	51%	49%	100%
Ga. 8	47%	53%	100%
Hawaii 1	53%	47%	100%
Idaho 1	41%	51%	100%
Ill. 14	45%	51%	100%
Ill. 17	43%	53%	100%
Ind. 2	48%	47%	100%
Ind. 9	42%	52%	100%
Ky. 6	50%	50%	100%
Mass. 10	47%	42%	100%
Mich. 7	45%	50%	100%
Miss. 4	47%	52%	100%
N.C. 8	53%	44%	100%
N.D. 1	45%	55%	100%
N.H. 2	47%	48%	100%
N.J. 3	47%	50%	100%
Nev. 3	47%	48%	100%

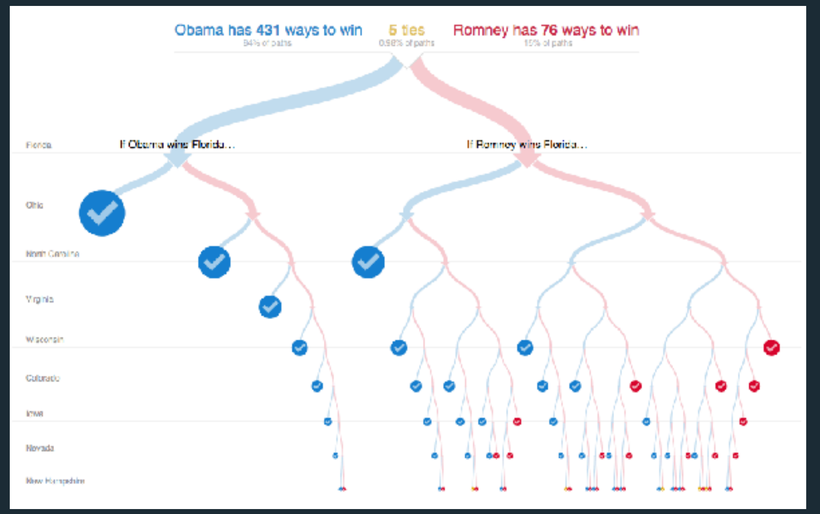
Republicans expected to win narrowly

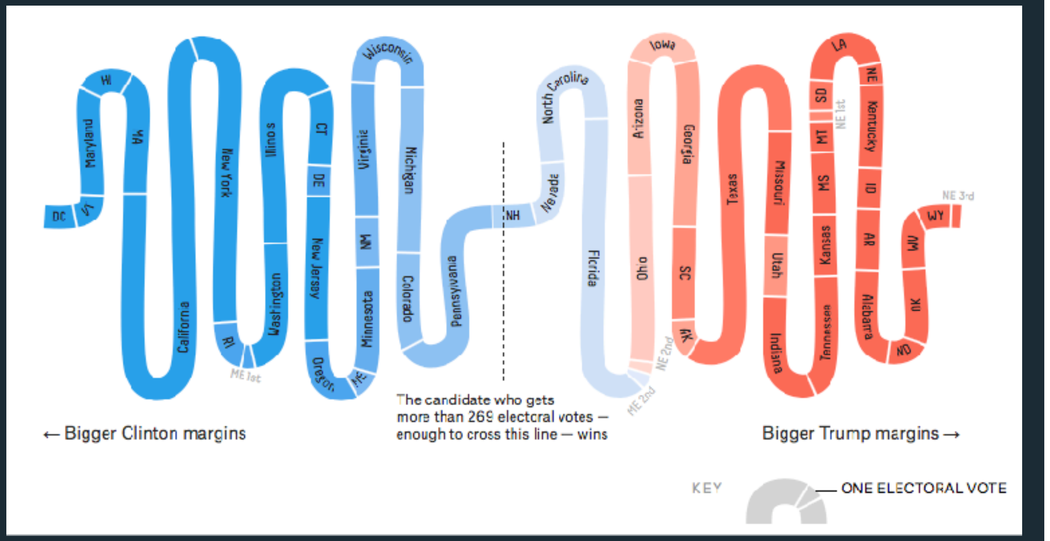
District	Dem.	Rep.	% Rpt.
Ark. 1	44%	52%	100%
Ariz. 1	44%	50%	100%
Ariz. 3	41%	52%	100%
Calif. 3	43%	50%	100%
Colo. 4	41%	52%	100%
Fla. 2	42%	54%	100%
Fla. 8	38%	56%	100%
Fla. 24	40%	60%	100%
Ill. 11	43%	57%	100%
Md. 1	42%	54%	100%
Mich. 1	41%	52%	100%
Minn. 6	40%	53%	100%
Miss. 1	41%	55%	100%
Neb. 2	39%	61%	100%
N.H. 1	42%	54%	100%
N.M. 2	45%	55%	100%
Ohio 1	46%	51%	100%
Ohio 15	41%	54%	100%
Pa. 3	44%	56%	100%
Pa. 6	43%	57%	100%
Pa. 7	44%	55%	100%
Pa. 11	45%	55%	100%
Pa. 15	39%	54%	100%
Tex. 17	37%	62%	100%
Va. 2	42%	53%	100%

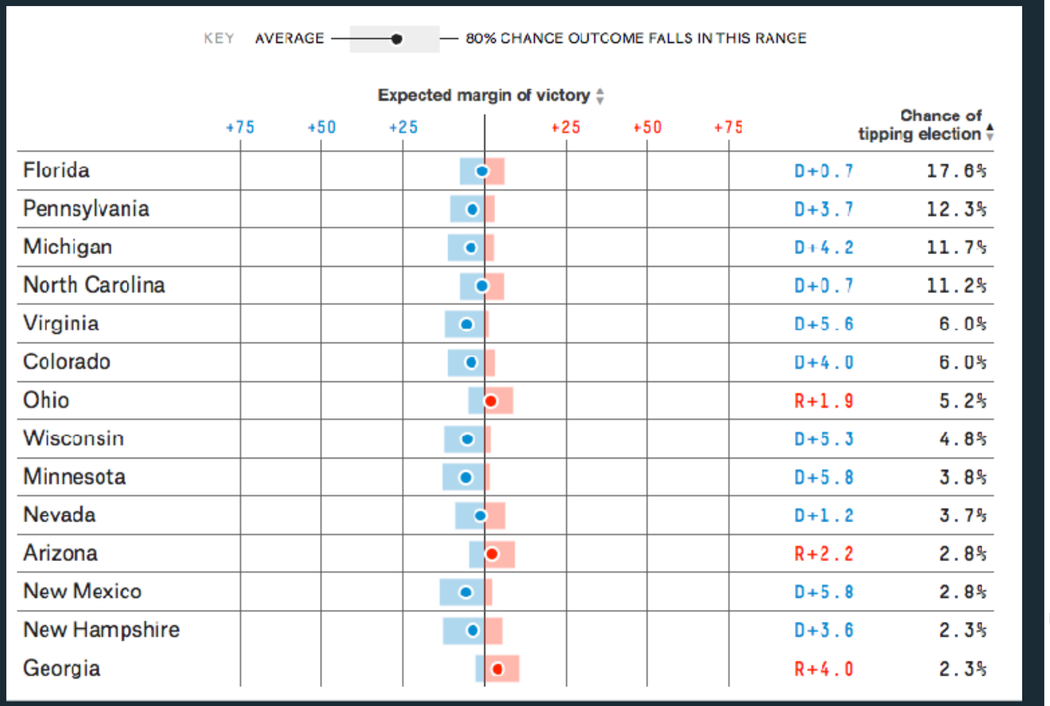
Republicans expected to win easily

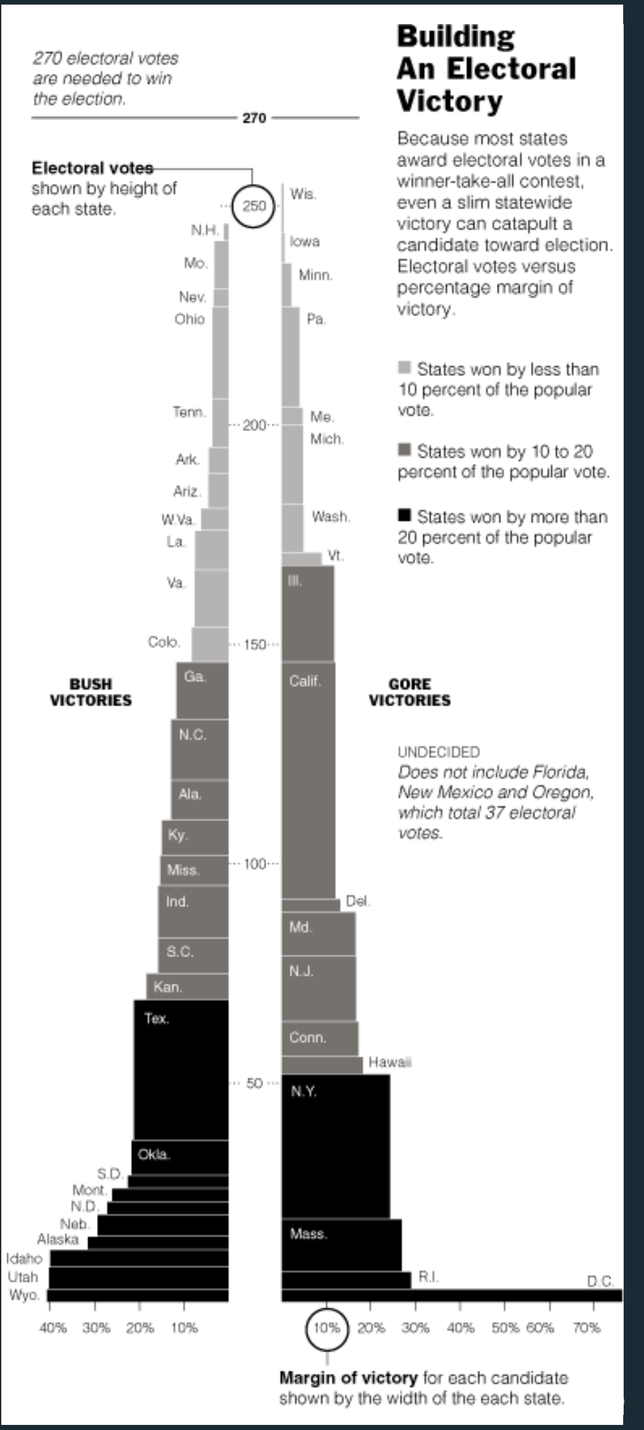
District	Dem.	Rep.	% Rpt.
Alaska 1	31%	69%	100%
Ala. 1		83%	100%
Ala. 3	41%	59%	100%
Ala. 4		Unc.	
Ala. 5	42%	58%	100%
Ala. 6		Unc.	
Ark. 2	38%	58%	100%
Ark. 3	28%	72%	100%
Ariz. 2	31%	65%	100%
Ariz. 6	29%	66%	100%
Calif. 2	43%	57%	100%
Calif. 4	31%	61%	100%
Calif. 19	35%	65%	100%
Calif. 21		Unc.	
Calif. 22		Unc.	
Calif. 24	40%	60%	100%
Calif. 25	38%	62%	100%
Calif. 26	37%	54%	100%
Calif. 40	33%	67%	100%
Calif. 41	37%	63%	100%
Calif. 42	32%	62%	100%
Calif. 44	44%	56%	100%
Calif. 45	42%	51%	100%
Calif. 46	38%	62%	100%
Calif. 48	36%	60%	100%

- ✓ Who's winning my district?
- ✓ Is it a landslide?
- ✘ What are the paths to victory?


Obama has 431 ways to win
5 ties
Romney has 76 ways to win
If Obama wins Florida...
If Romney wins Florida...


DC
MD
HI
VA
CA
NY
RI
IL
WA
NJ
OR
CT
DE
ME
VT
WI
MI
VA
NM
MN
CO
PA
NH
NC
NV
FL
IA
AZ
OH
GA
SC
NM
TX
MO
UT
IN
LA
MS
TN
KS
SD
NE
KY
ID
AR
AL
OK
WY
MT
ND
NE 1st
NE 2nd
NE 3rd
← Bigger Clinton margins
The candidate who gets more than 269 electoral votes — enough to cross this line — wins
Bigger Trump margins →
KEY
ONE ELECTORAL VOTE

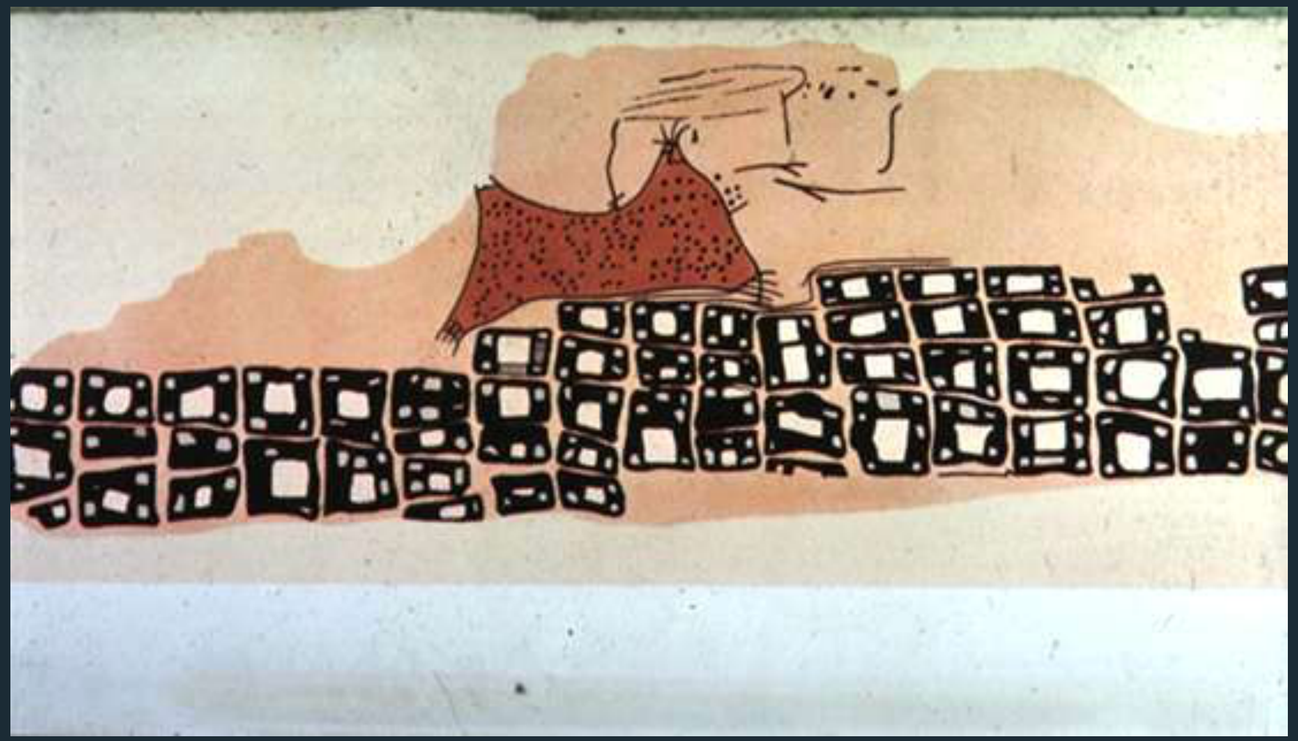

KEY
AVERAGE
80% CHANCE OUTCOME FALLS IN THIS RANGE
Expected margin of victory
+75
+50
+25
+25
+50
+75
Chance of tipping election
Florida D+0.7 17.6%
Pennsylvania D+3.7 12.3%
Michigan D+4.2 11.7%
North Carolina D+0.7 11.2%
Virginia D+5.6 6.0%
Colorado D+4.0 6.0%
Ohio R+1.9 5.2%
Wisconsin D+5.3 4.8%
Minnesota D+5.8 3.8%
Nevada D+1.2 3.7%
Arizona R+2.2 2.8%
New Mexico D+5.8 2.8%
New Hampshire D+3.6 2.3%
Georgia R+4.0 2.3%

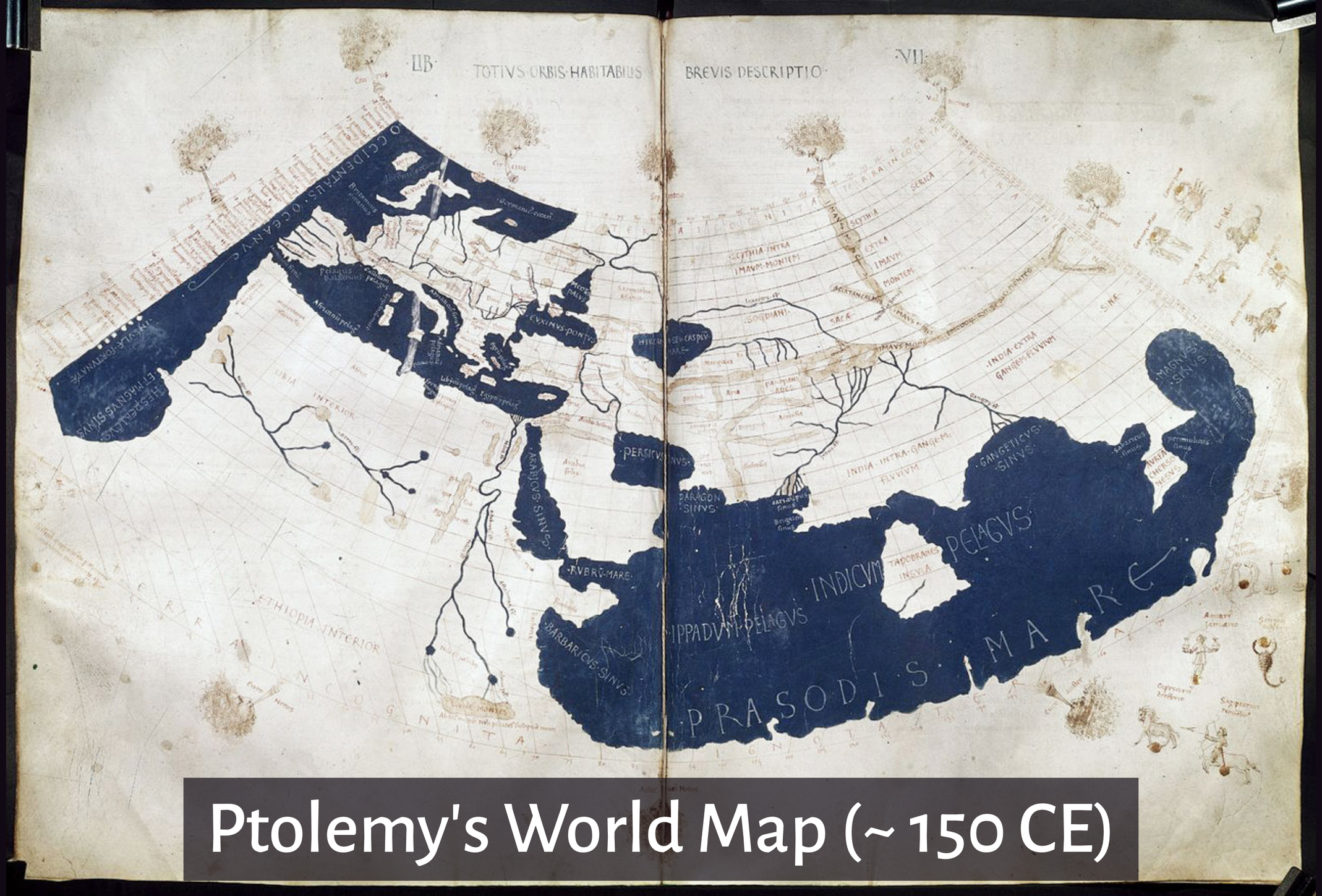

270 electoral votes are needed to win the election.
270
Building An Electoral Victory
Because most states award electoral votes in a winner-take-all contest, even a slim statewide victory can catapult a candidate toward election. Electoral votes versus percentage margin of victory.
Electoral votes shown by height of each state.
States won by less than 10 percent of the popular vote.
States won by 10 to 20 percent of the popular vote.
States won by more than 20 percent of the popular vote.
250
200
150
100
50
N.H.
Mo.
Nev.
Ohio
Tenn.
Ark.
Ariz.
W.Va.
La.
Va.
Colo.
Wis.
Iowa
Minn.
Pa.
Me.
Mich.
Wash.
Vt.
Ill.
Calif.
Del.
Md.
N.J.
Conn.
Hawaii
N.Y.
Mass.
R.I.
D.C.
BUSH VICTORIES
GORE VICTORIES
Ga.
N.C.
Ala.
Ky.
Miss.
Ind.
S.C.
Kan.
Tex.
Okla.
S.D.
Mont.
N.D.
Neb.
Alaska
Idaho
Utah
Wyo.
UNDECIDED
Does not include Florida, New Mexico and Oregon, which total 37 electoral votes.
40% 30% 20% 10%
10% 20% 30% 40% 50% 60% 70%
Margin of victory for each candidate shown by the width of the each state.

Cartography

(Map Making)

Oldest Known Map: Konya, Turkey (~6200 BC)





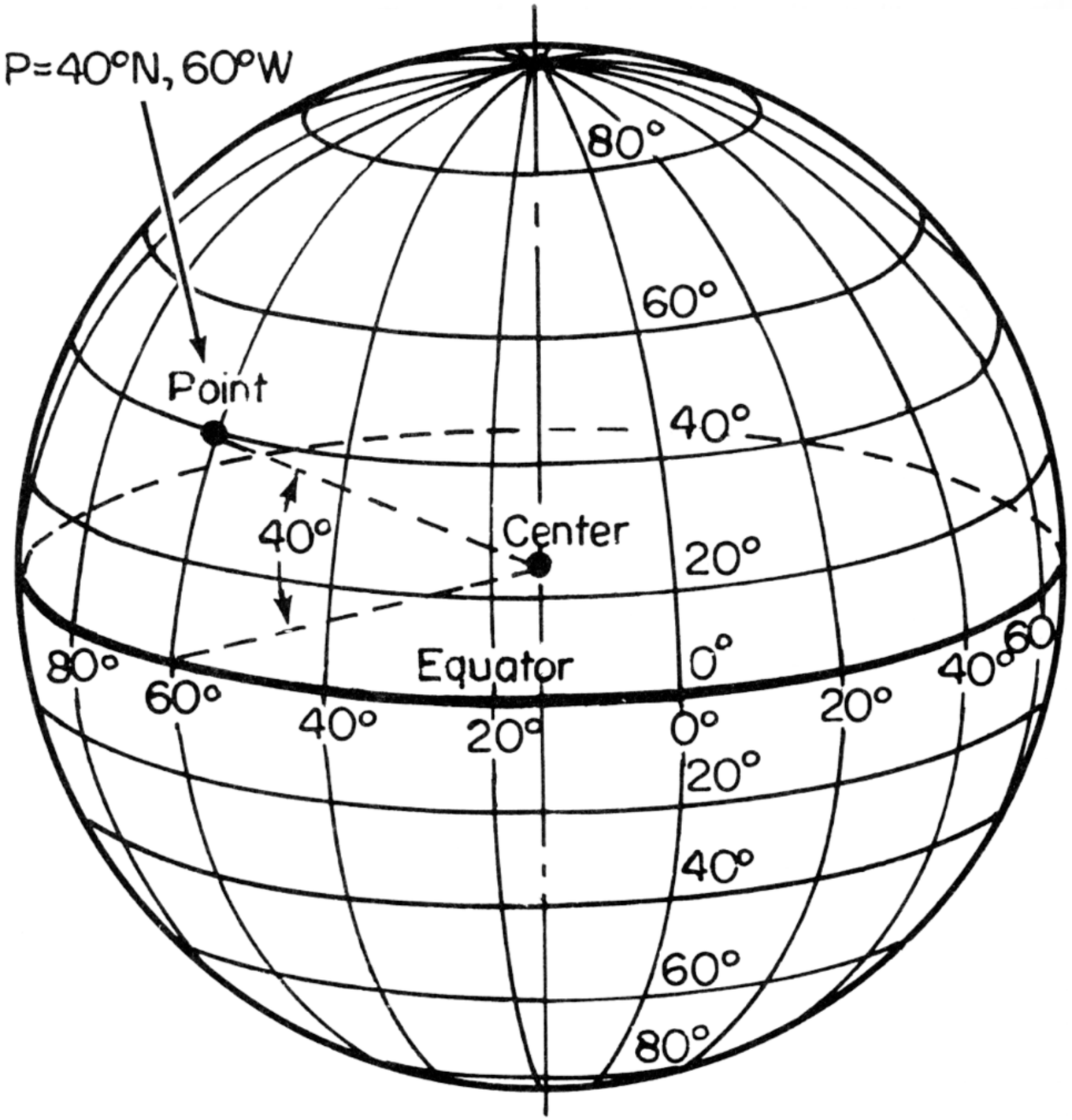
Ptolemy's World Map (~ 150 CE)

Peutinger Map
(~328 CE)

Latitude (ϕ): Angle north/south from the equator.

Longitude (λ): Angle east/west from the Prime Meridian.

Graticule: The grid formed by lines of latitude and longitude.



What's the right way to flatten a sphere?

Map Projections

Projection Surface

Cylindrical

Conic

Planar (Azimuthal)

Metric Preservation

Equal-Area

Equidistant

Conformal (Preserve Angle)

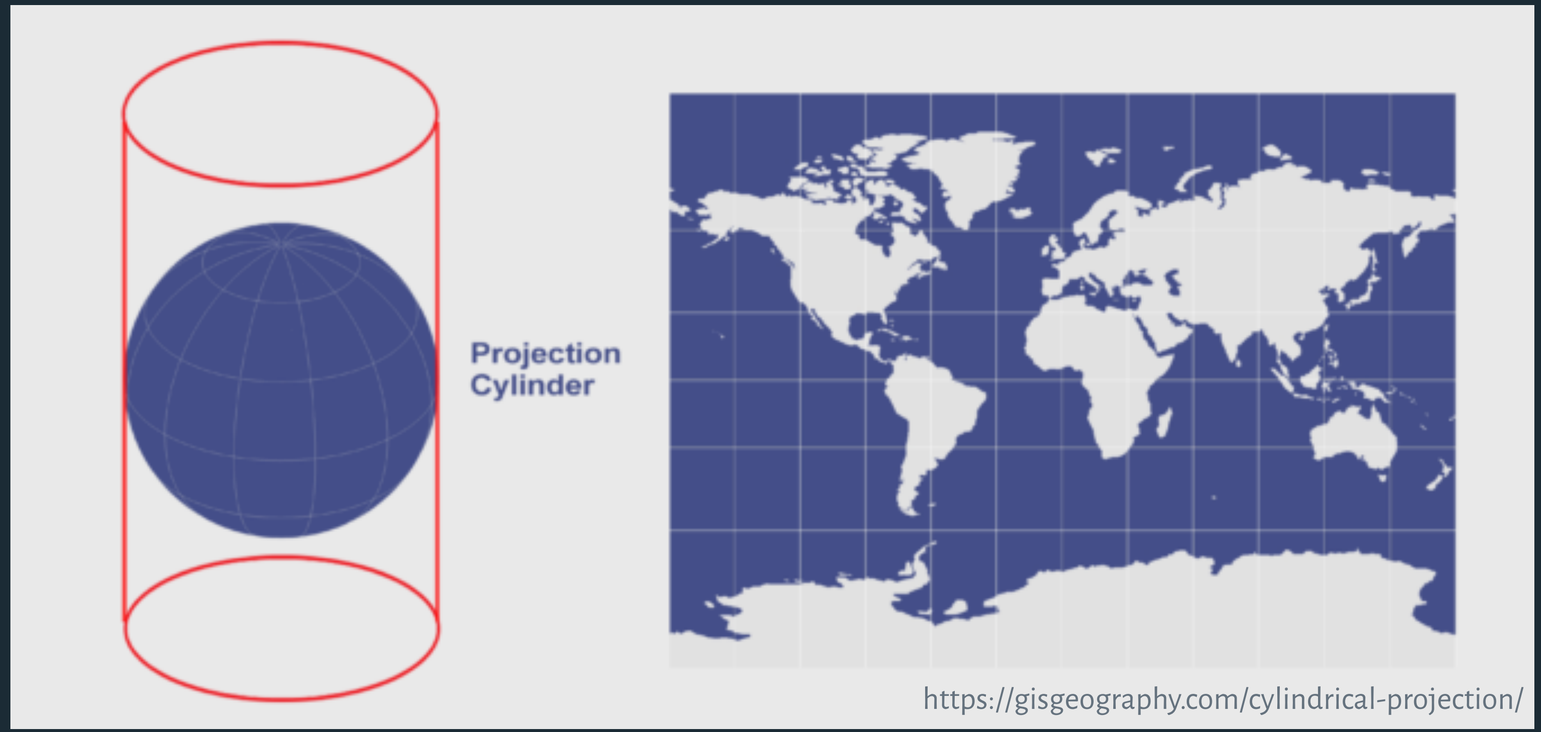
Map Projections

Projection Surface

Cylindrical

Conic

Planar (Azimuthal)



https://gisgeography.com/cylindrical-projection/

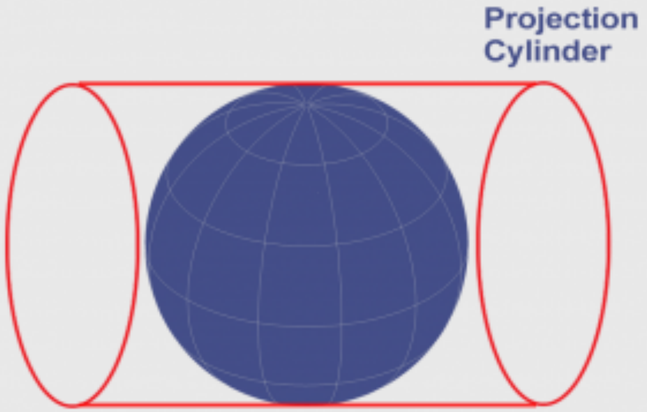
Map Projections

Projection Surface

Cylindrical

Conic

Planar (Azimuthal)



https://gisgeography.com/cylindrical-projection/

Map Projections

Projection Surface

Cylindrical

Conic

Planar (Azimuthal)

https://gisgeography.com/conic-projection-lambert-albers-polyconic/

Map Projections

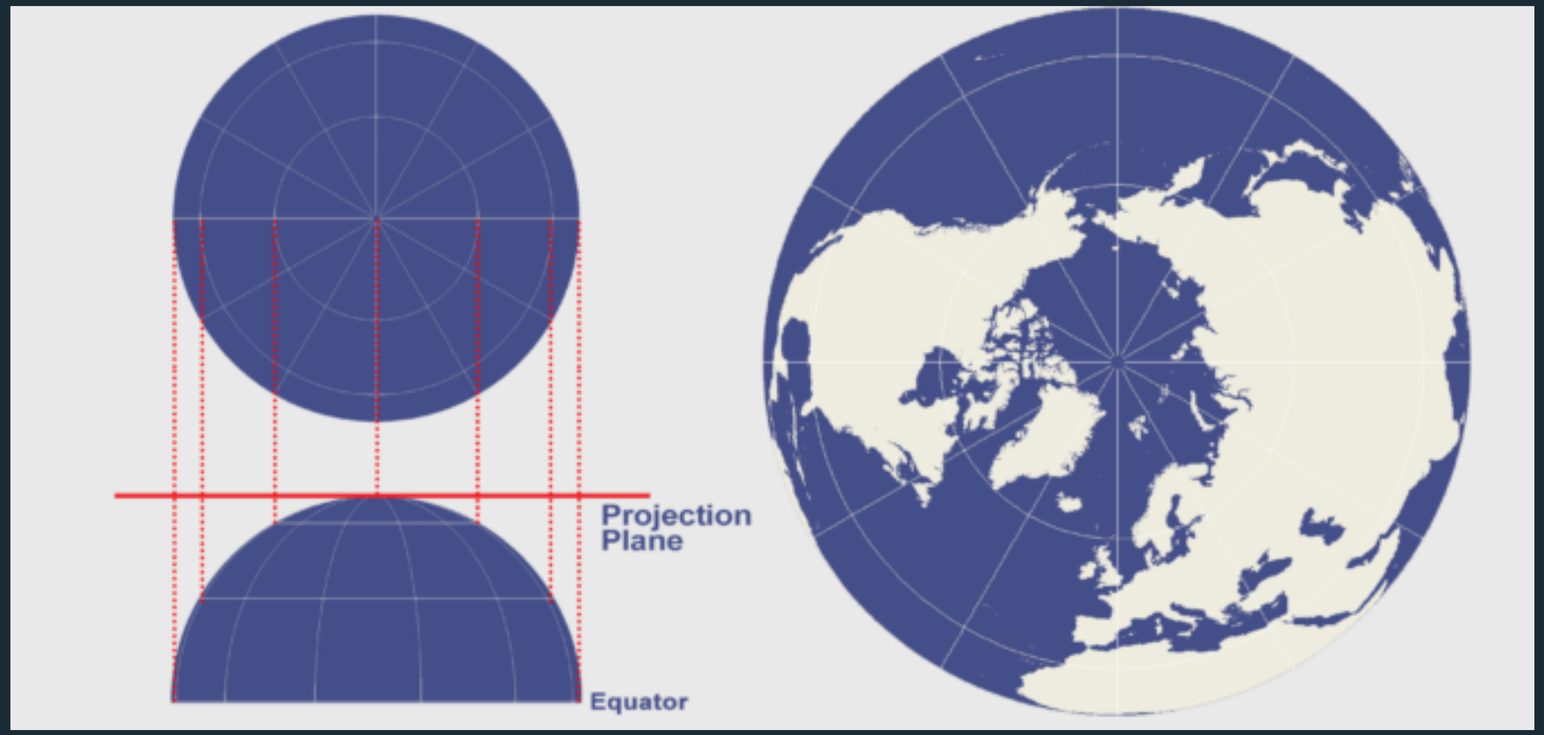
Projection Surface

Cylindrical

Conic

Planar (Azimuthal)

Orthographic Projection



https://gisgeography.com/azimuthal-projection-orthographic-stereographic-gnomonic/

Map Projections

Projection Surface

Cylindrical

Conic

Planar (Azimuthal)

Orthographic Projection

Map Projections

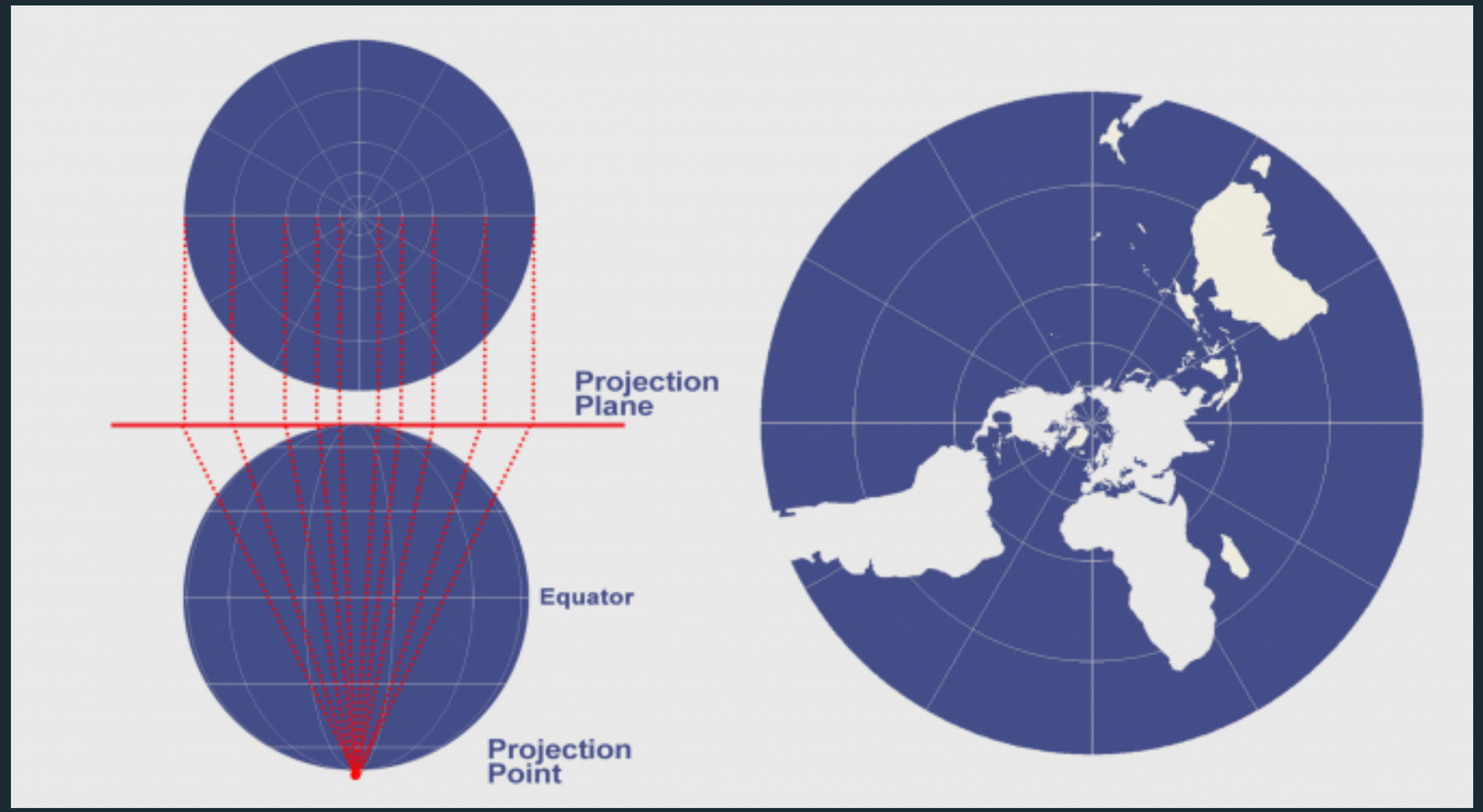
Projection Surface

Cylindrical

Conic

Planar (Azimuthal)

Stereographic Projection



https://gisgeography.com/azimuthal-projection-orthographic-stereographic-gnomonic/

Map Projections

Projection Surface

Cylindrical

Conic

Planar (Azimuthal)

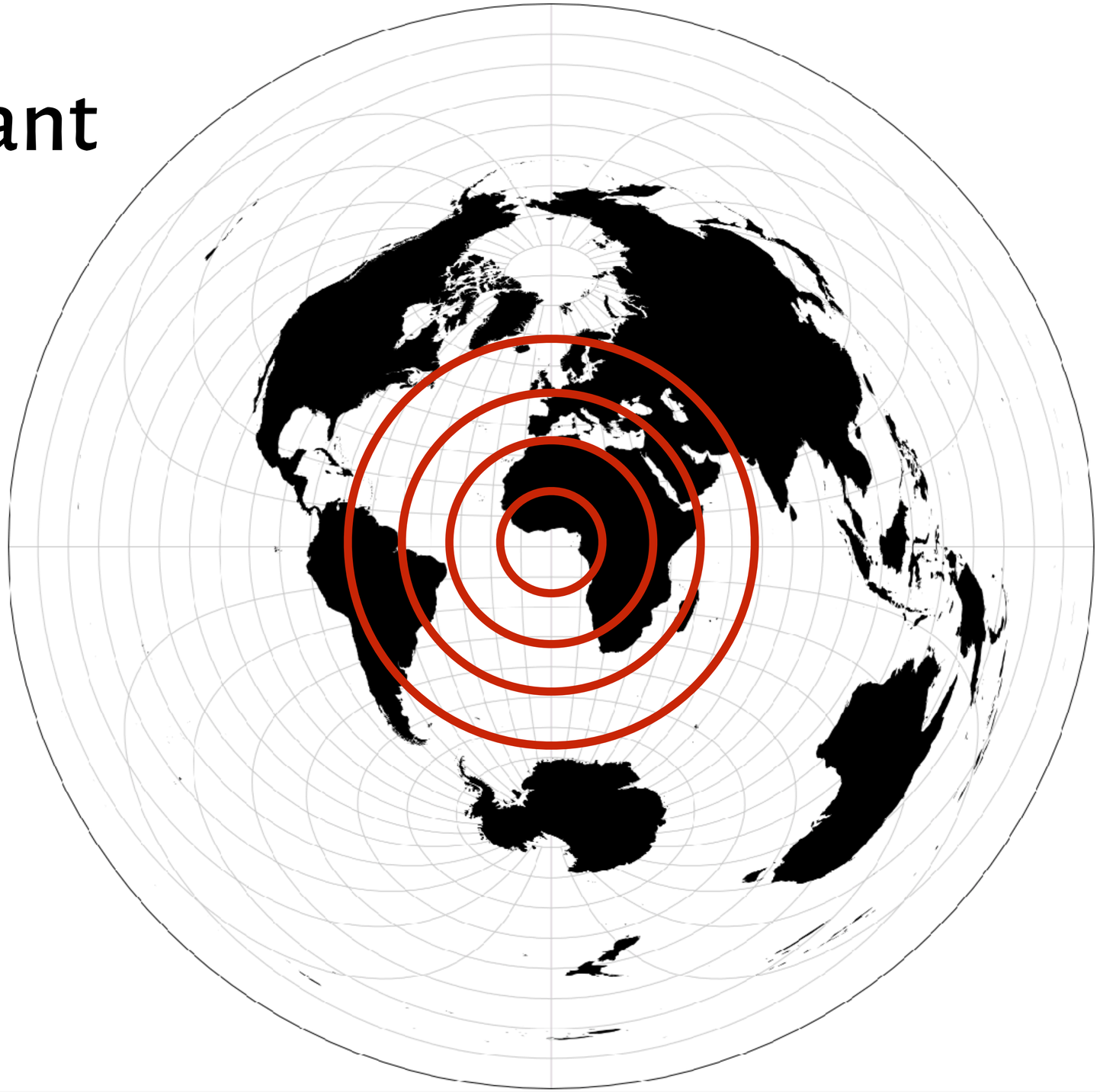
Metric Preservation

Equal-Area

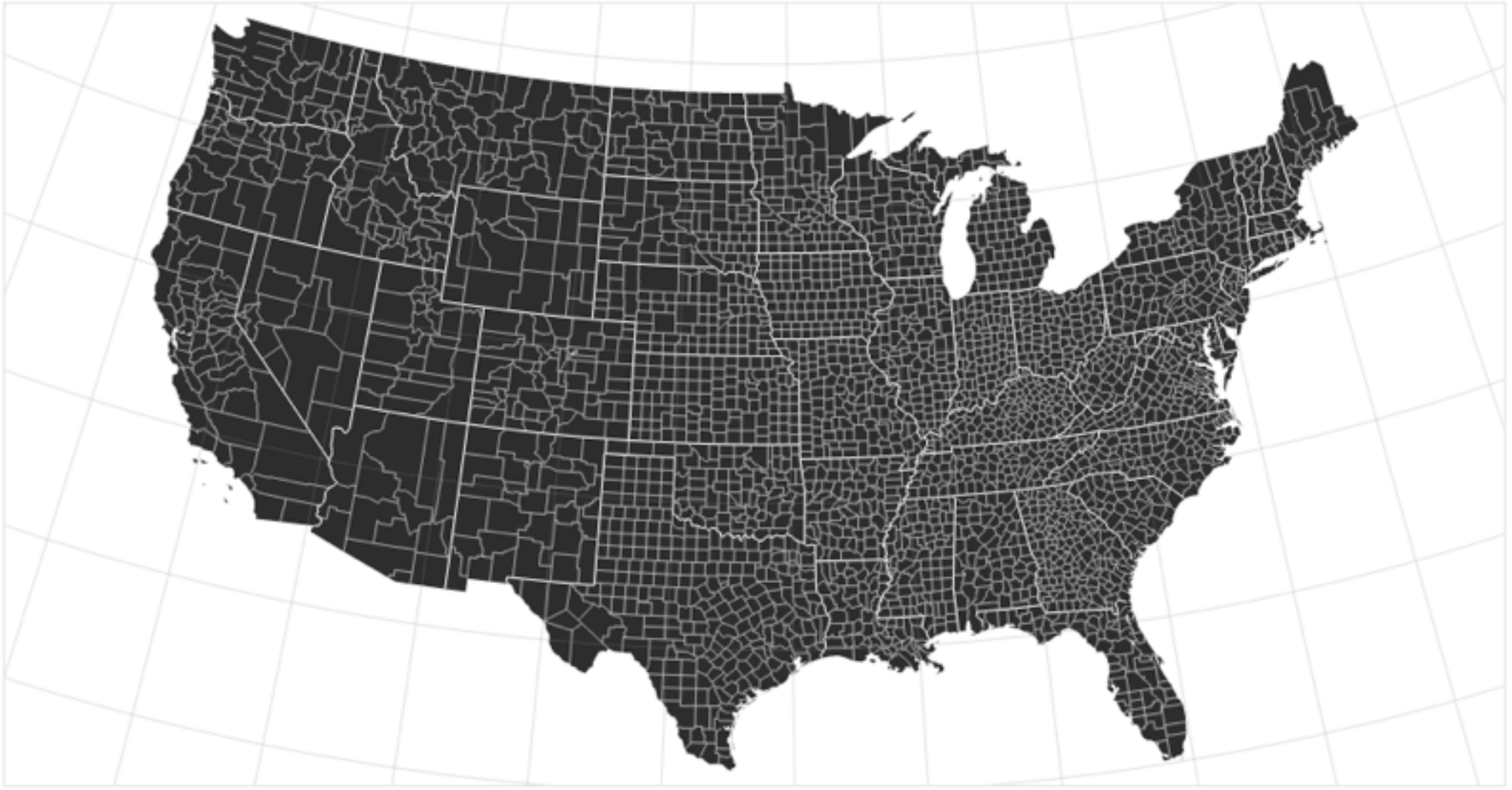
Equidistant

Conformal (Preserve Angle)

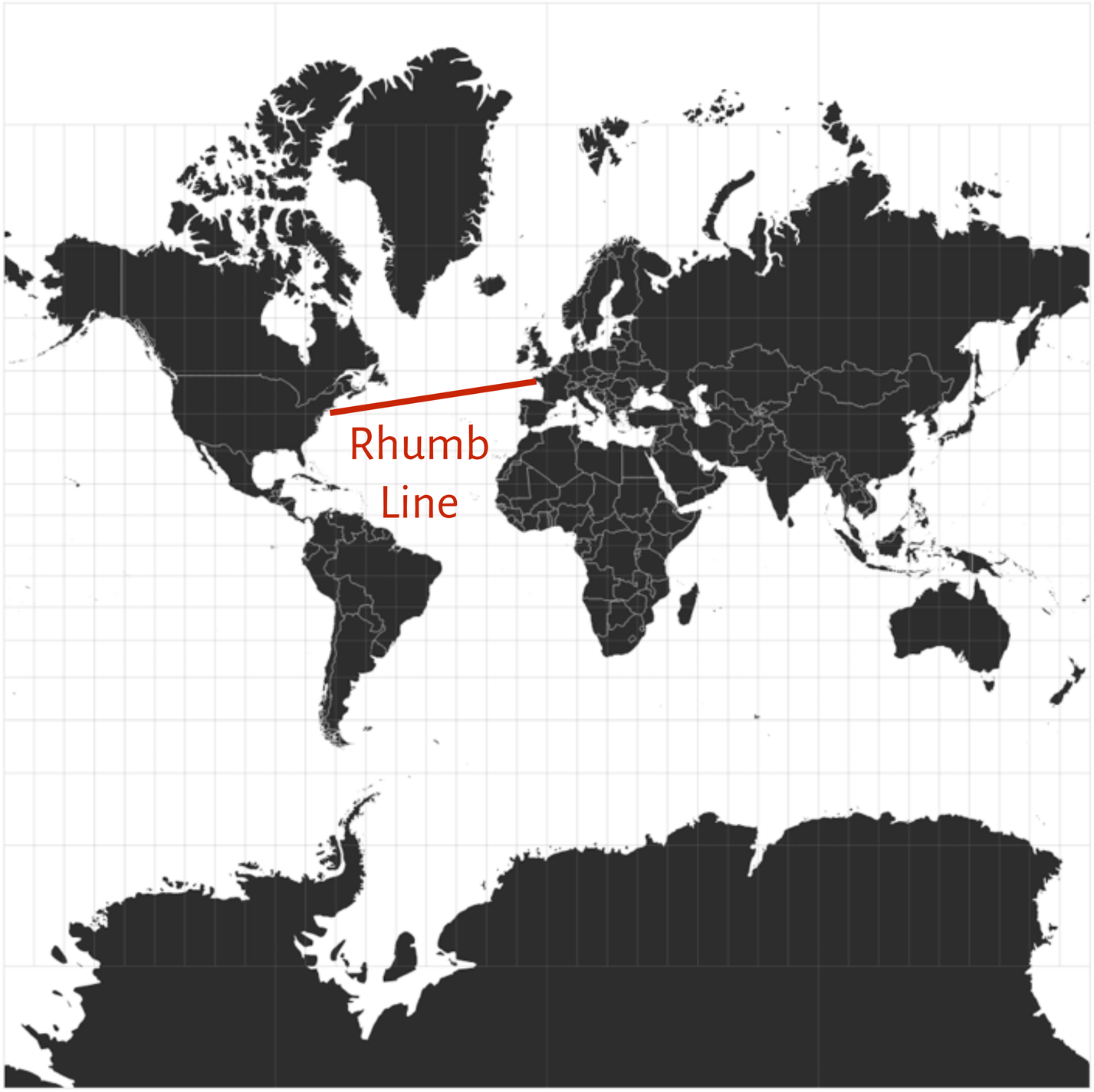
Azimuthal Equidistant



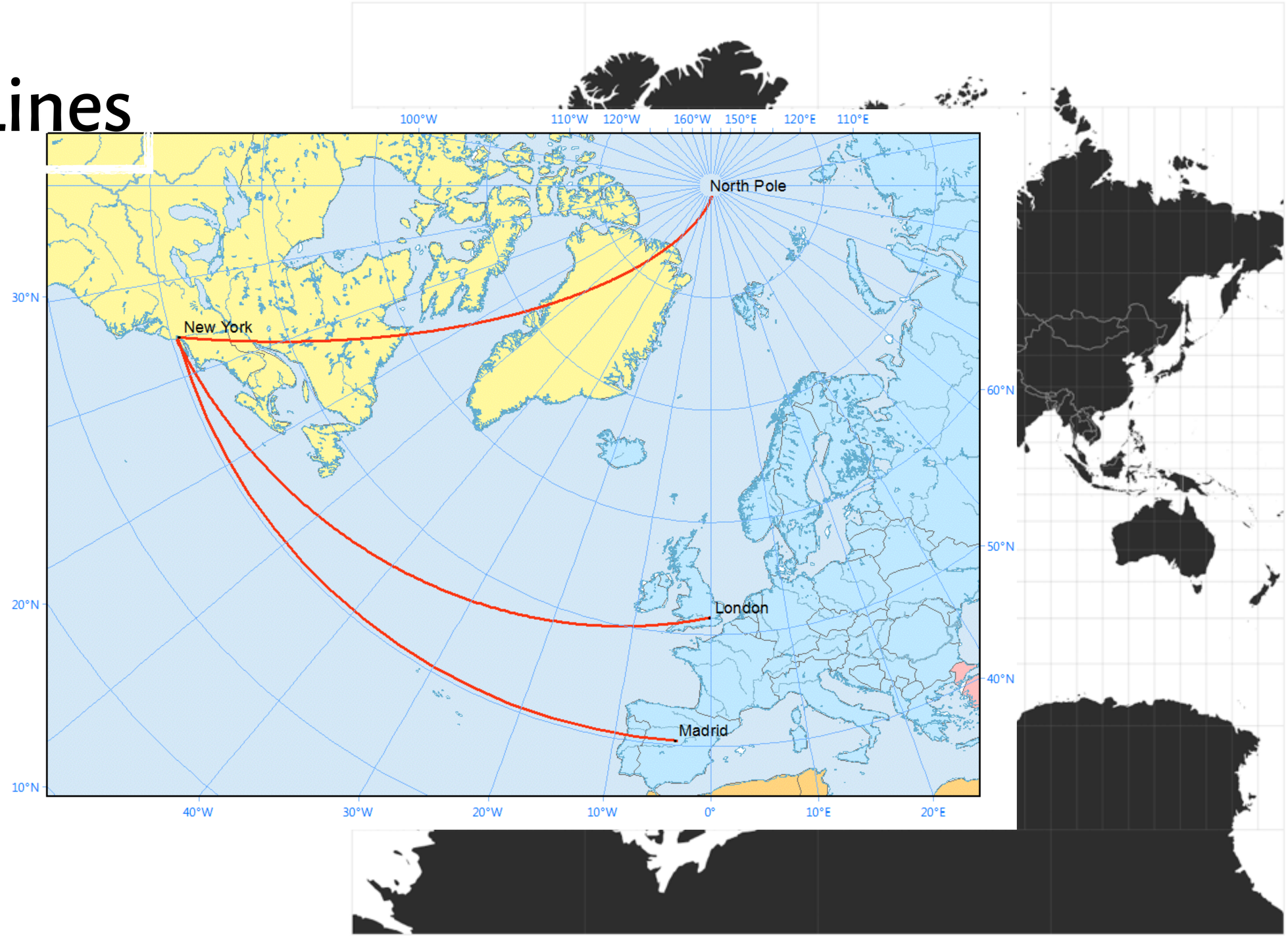
Albers Equal-Area Conic



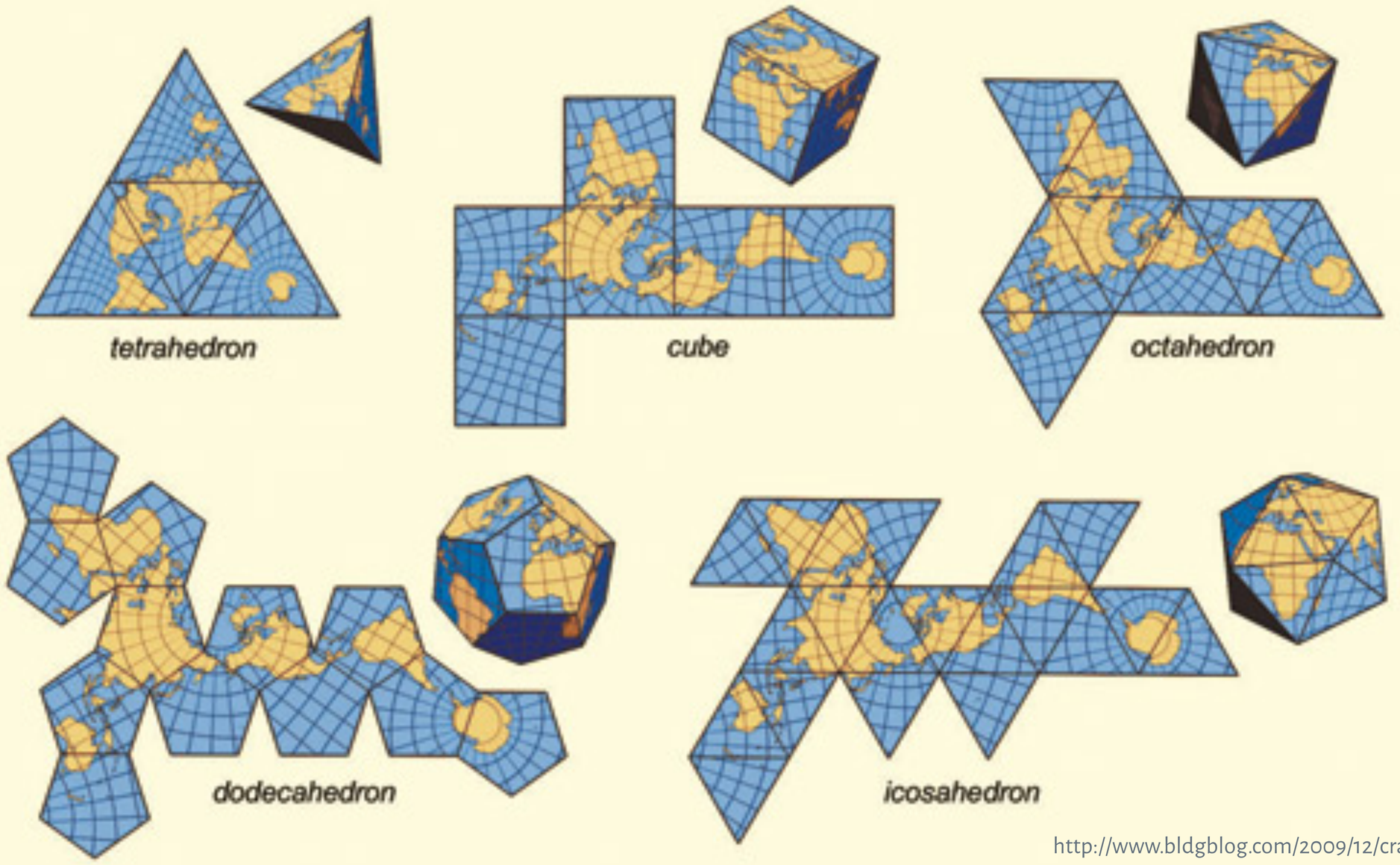
Mercator



Rhumb Lines

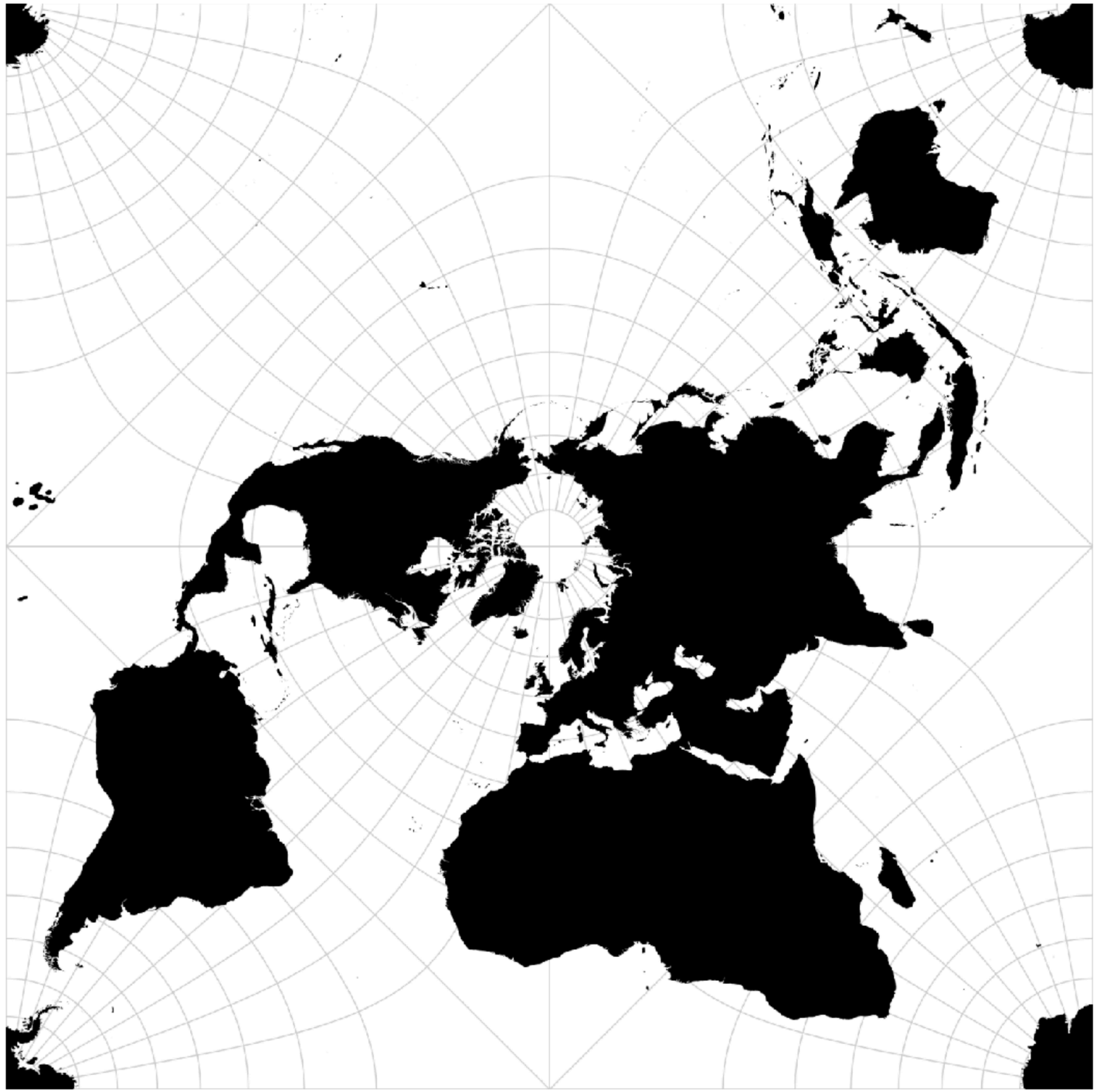

100°W
110°W
120°W
160°W
150°E
120°E
110°E
North Pole
New York
London
Madrid
30°N
20°N
10°N
60°N
50°N
40°N
40°W
30°W
20°W
10°W
0°
10°E
20°E

There's no right way to flatten the Earth!

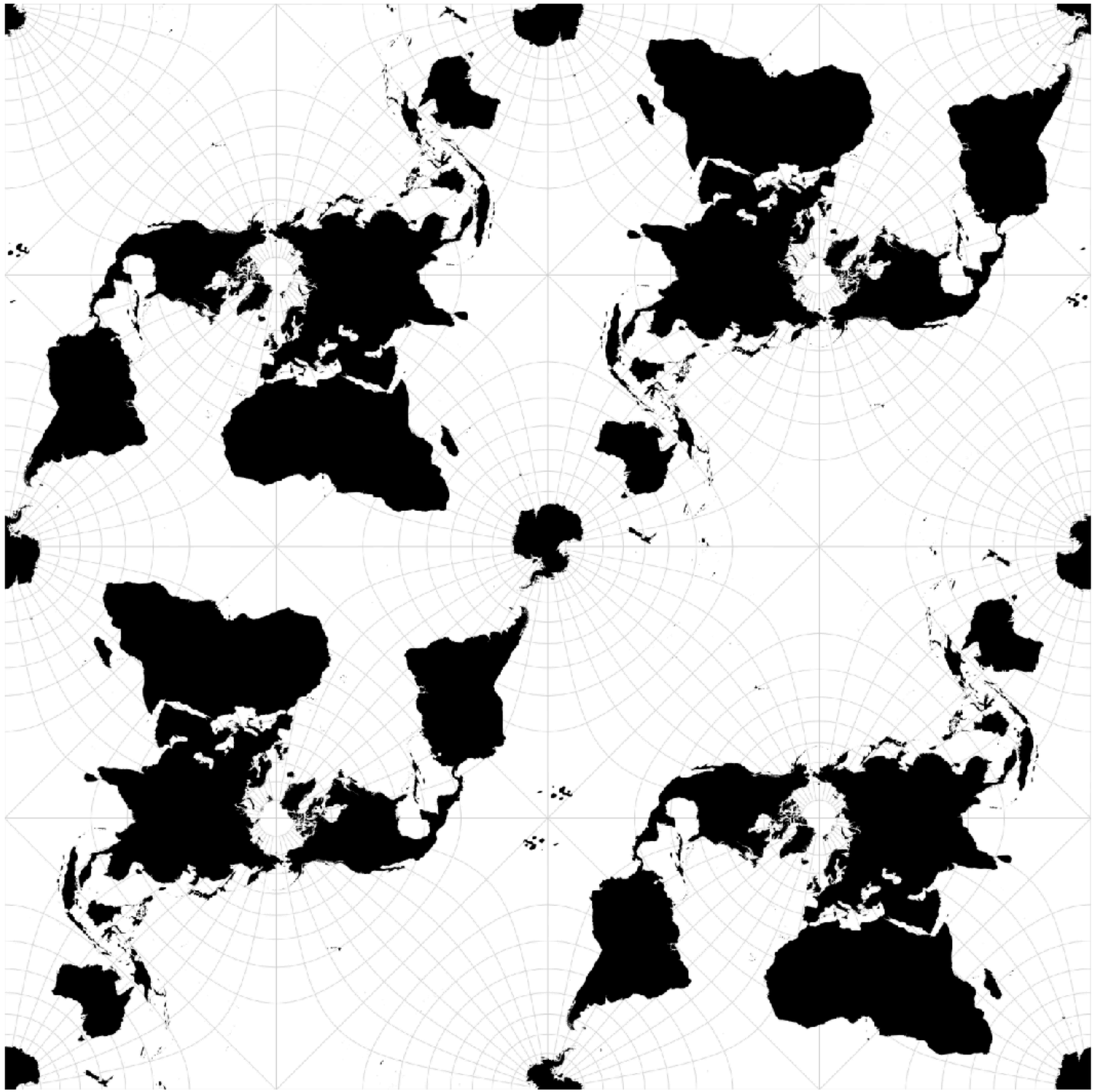


http://www.bldgblog.com/2009/12/cracking-the-planet/

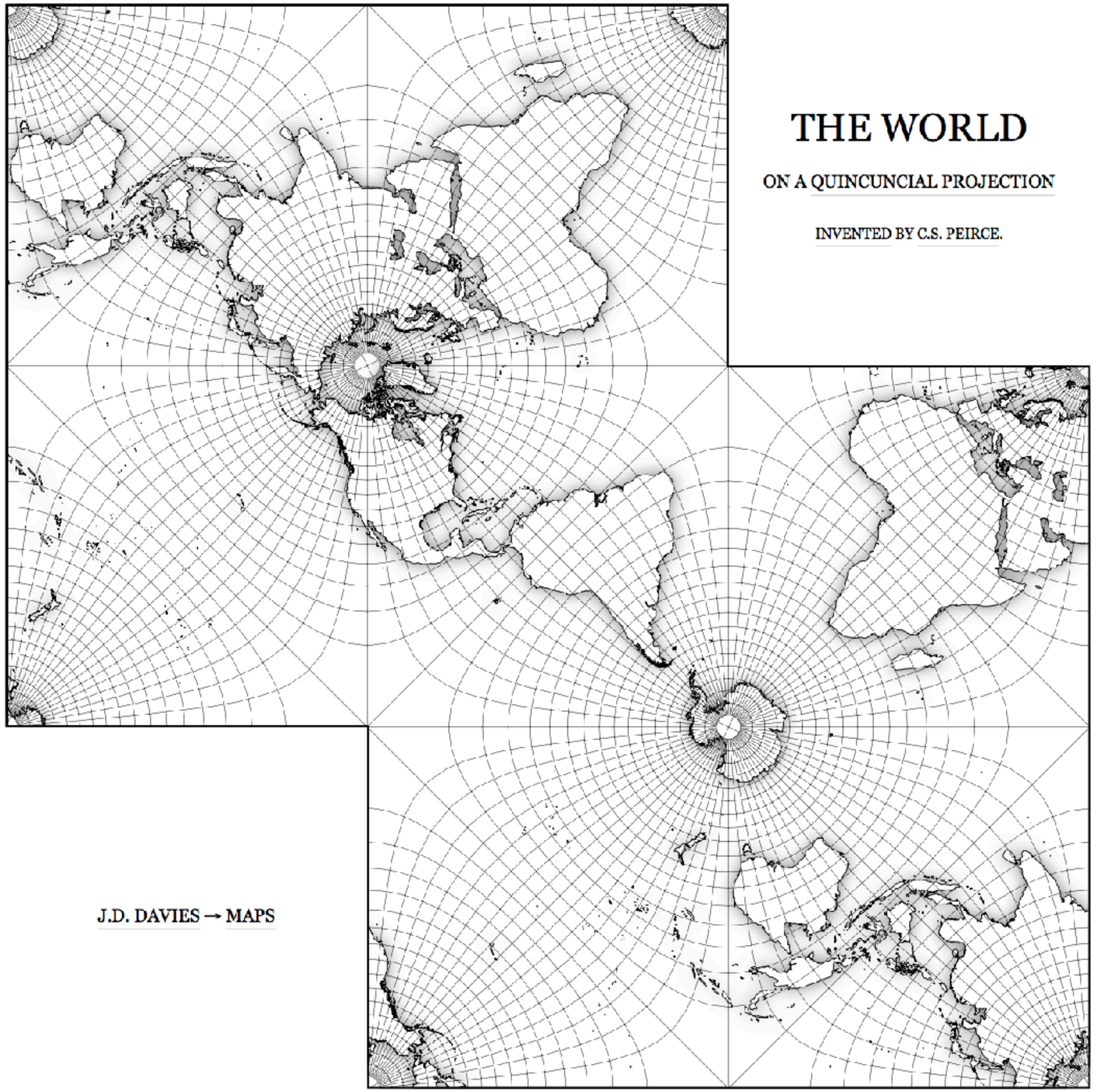
Peirce Quincuncial



Peirce Quincuncial

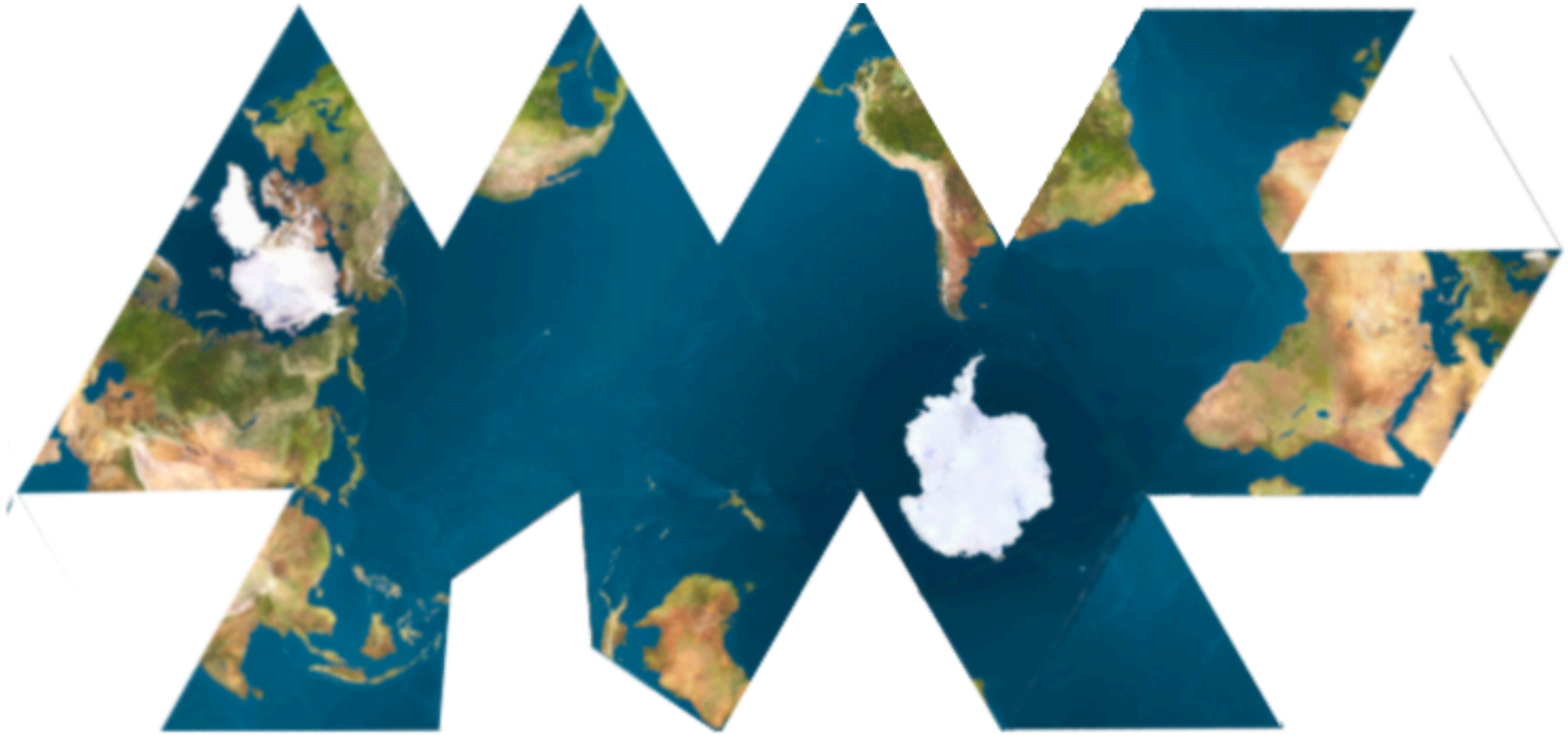


Peirce Quincuncial



Dymaxion (Fuller) Map

Dymaxion (Fuller) Map



https://xkcd.com/977/

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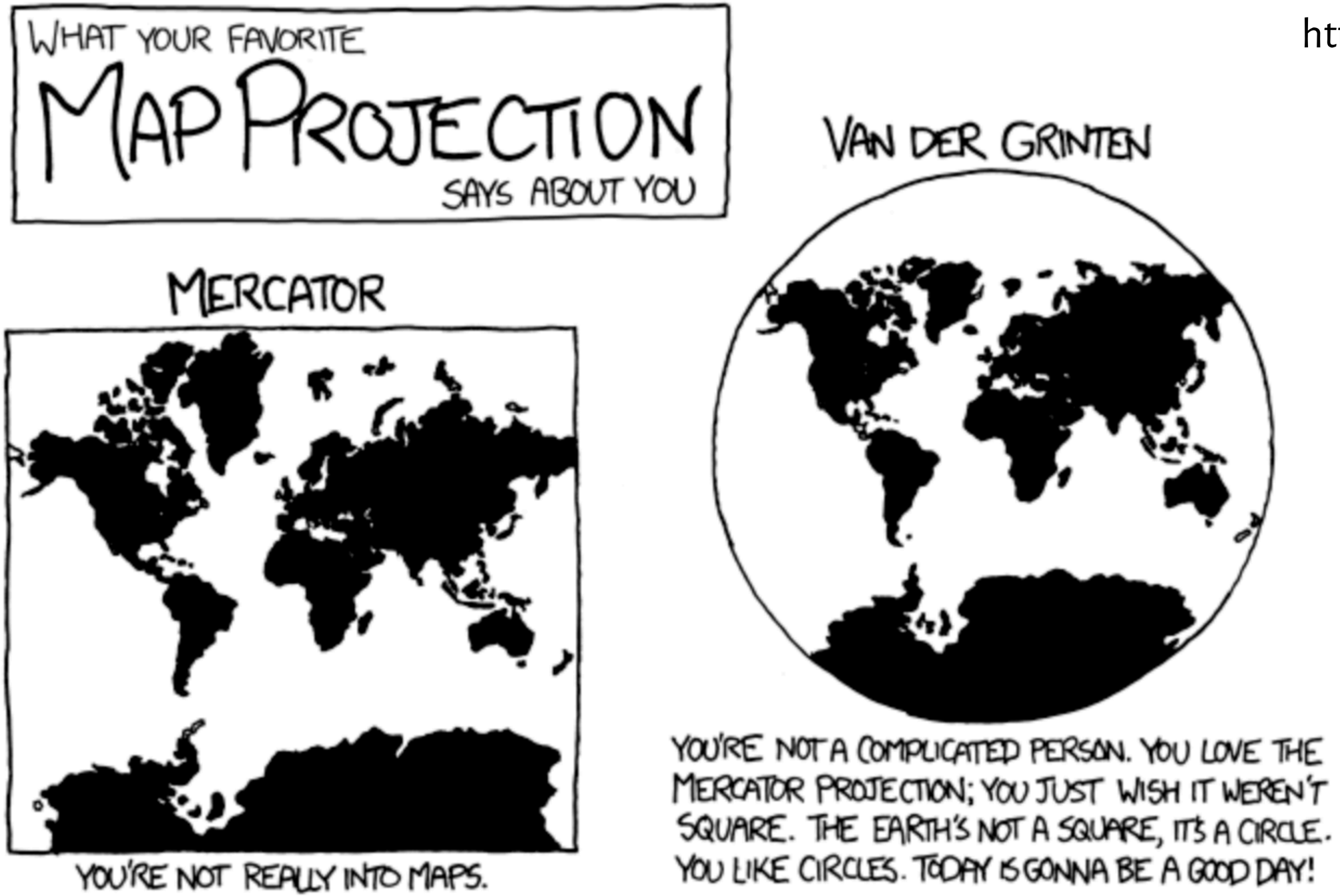


WHAT YOUR FAVORITE

MAP PROJECTION

SAYS ABOUT YOU

https://xkcd.com/977/

YOU LIKE ISAAC ASIMOV, XML, AND SHOES WITH TOES. YOU THINK THE SEGWAY GOT A BAD RAP. YOU OWN 3D GOGGLES, WHICH YOU USE TO VIEW ROTATING MODELS OF BETTER 3D GOGGLES. YOU TYPE IN DVORAK.

WHAT YOUR FAVORITE

MAP PROJECTION

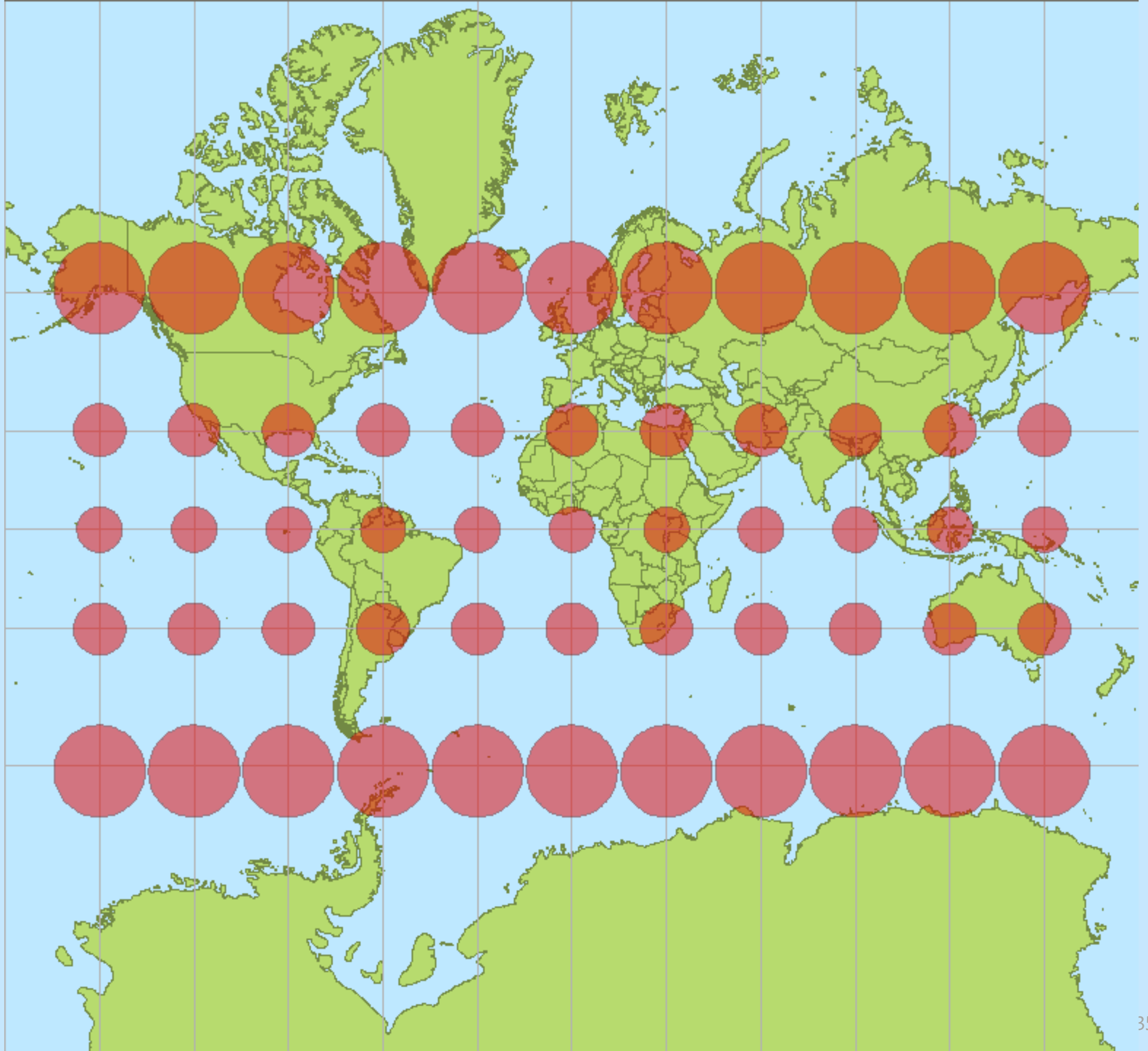
SAYS ABOUT YOU

PEIRCE QUINCUNCIAL

YOU THINK THAT WHEN WE LOOK AT A MAP, WHAT WE REALLY SEE IS OURSELVES. AFTER YOU FIRST SAW *INCEPTION*, YOU SAT SILENT IN THE THEATER FOR SIX HOURS. IT FREAKS YOU OUT TO REALIZE THAT EVERYONE AROUND YOU HAS A SKELETON INSIDE THEM. YOU *HAVE* REALLY LOOKED AT YOUR HANDS.

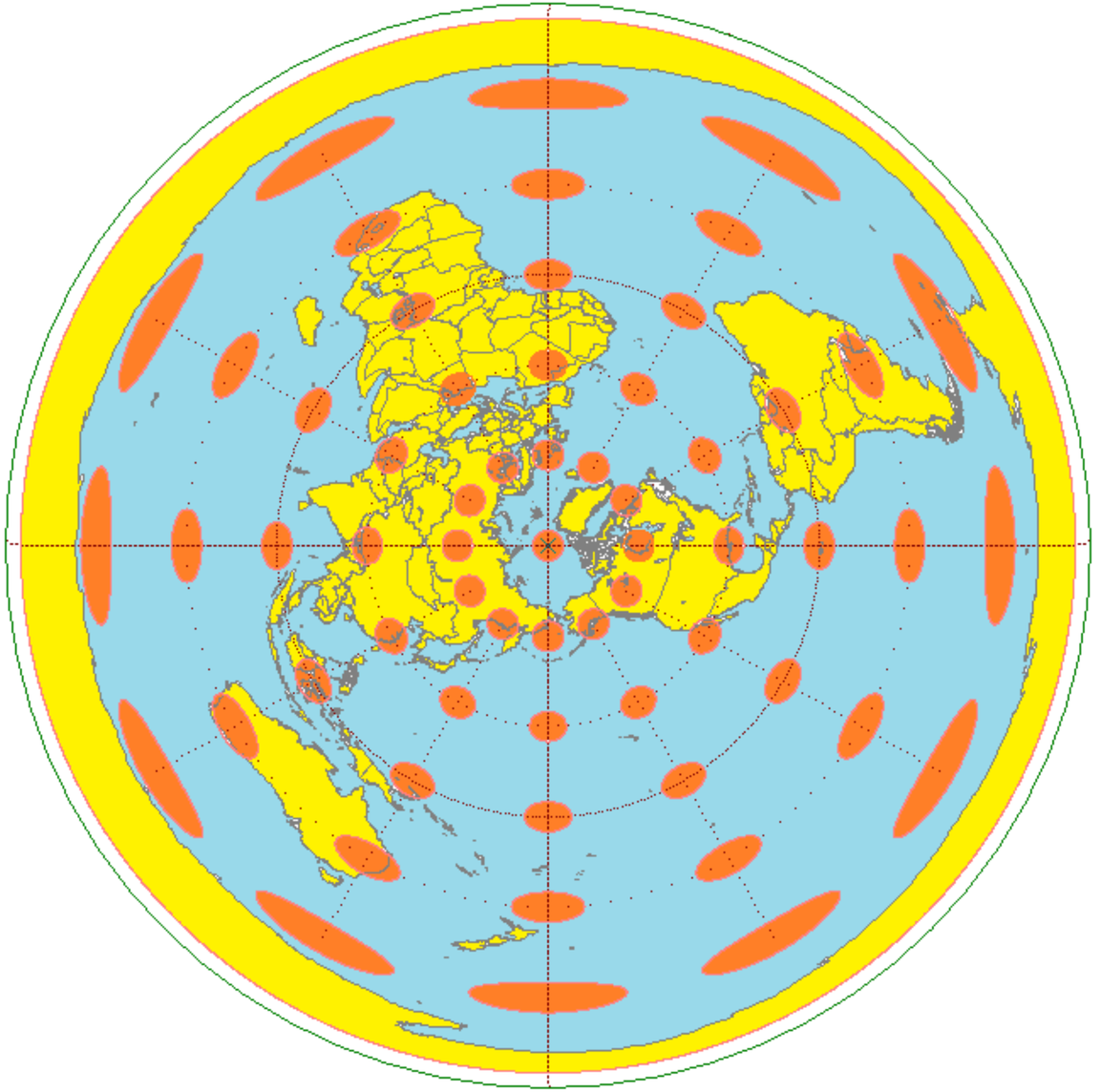
https://xkcd.com/977/

Tissot's Indicatrix



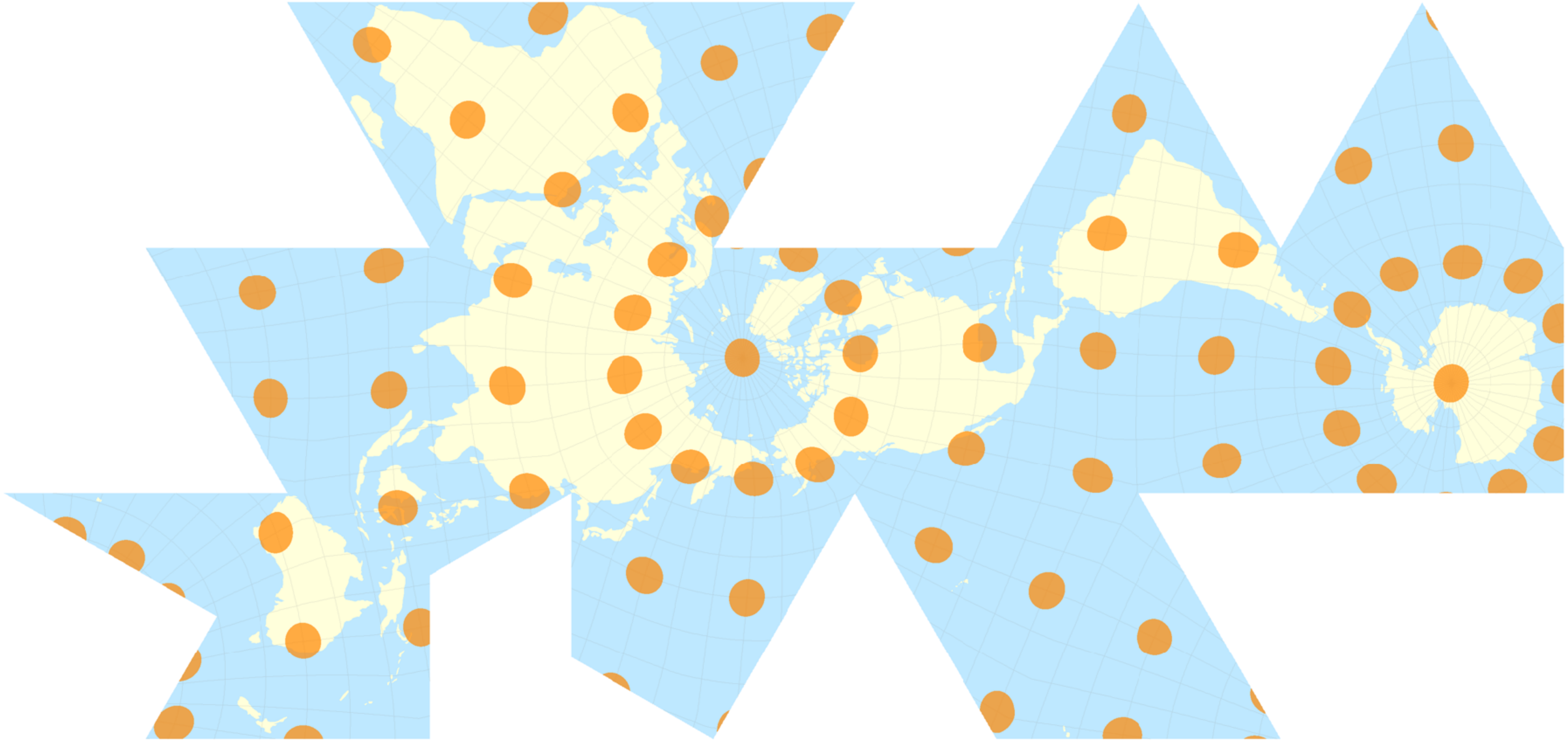
https://en.wikipedia.org/wiki/Tissot's_indicatrix

Tissot's Indicatrix (Azimuthal Equidistant)

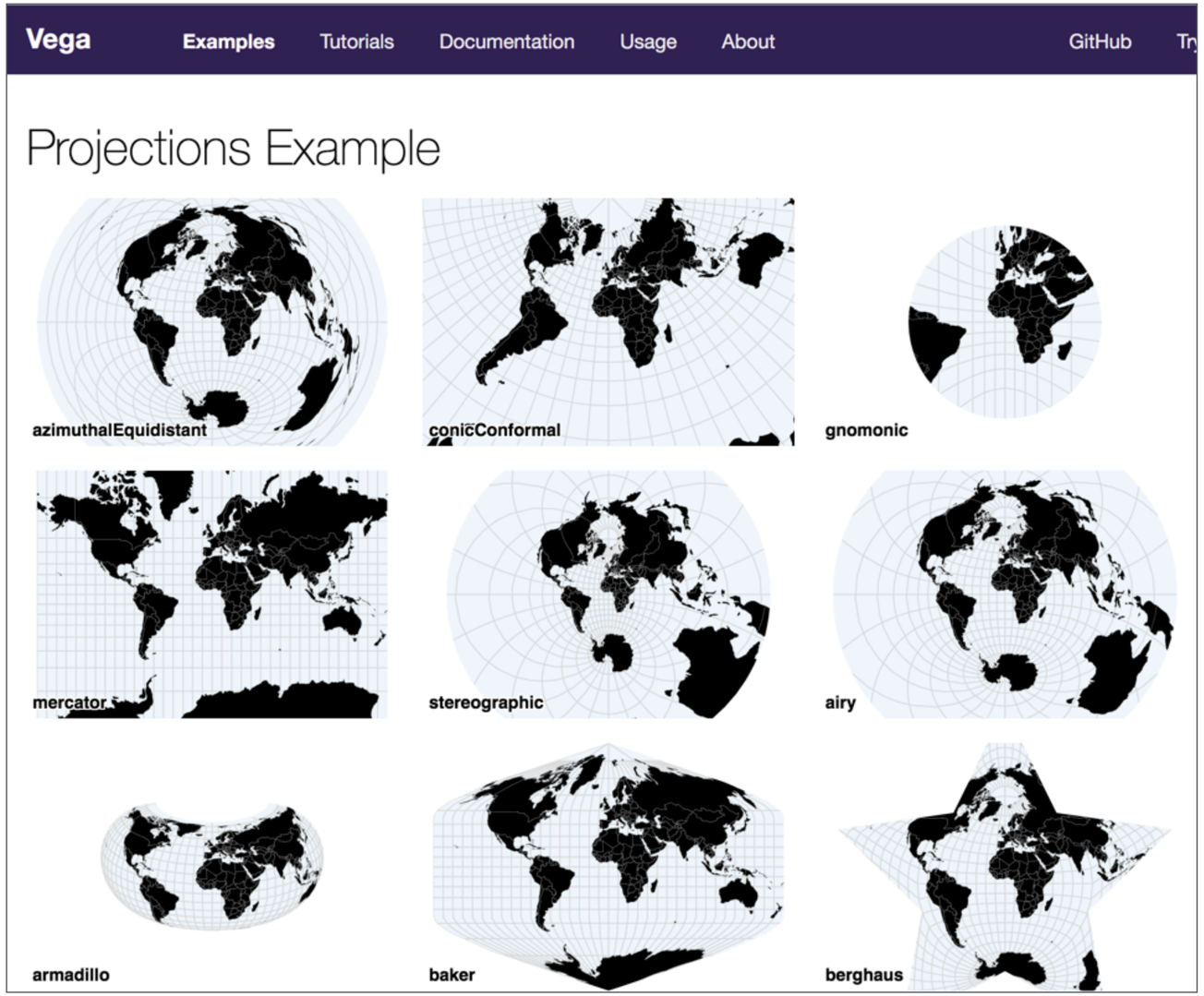


https://en.wikipedia.org/wiki/Tissot's_indicatrix

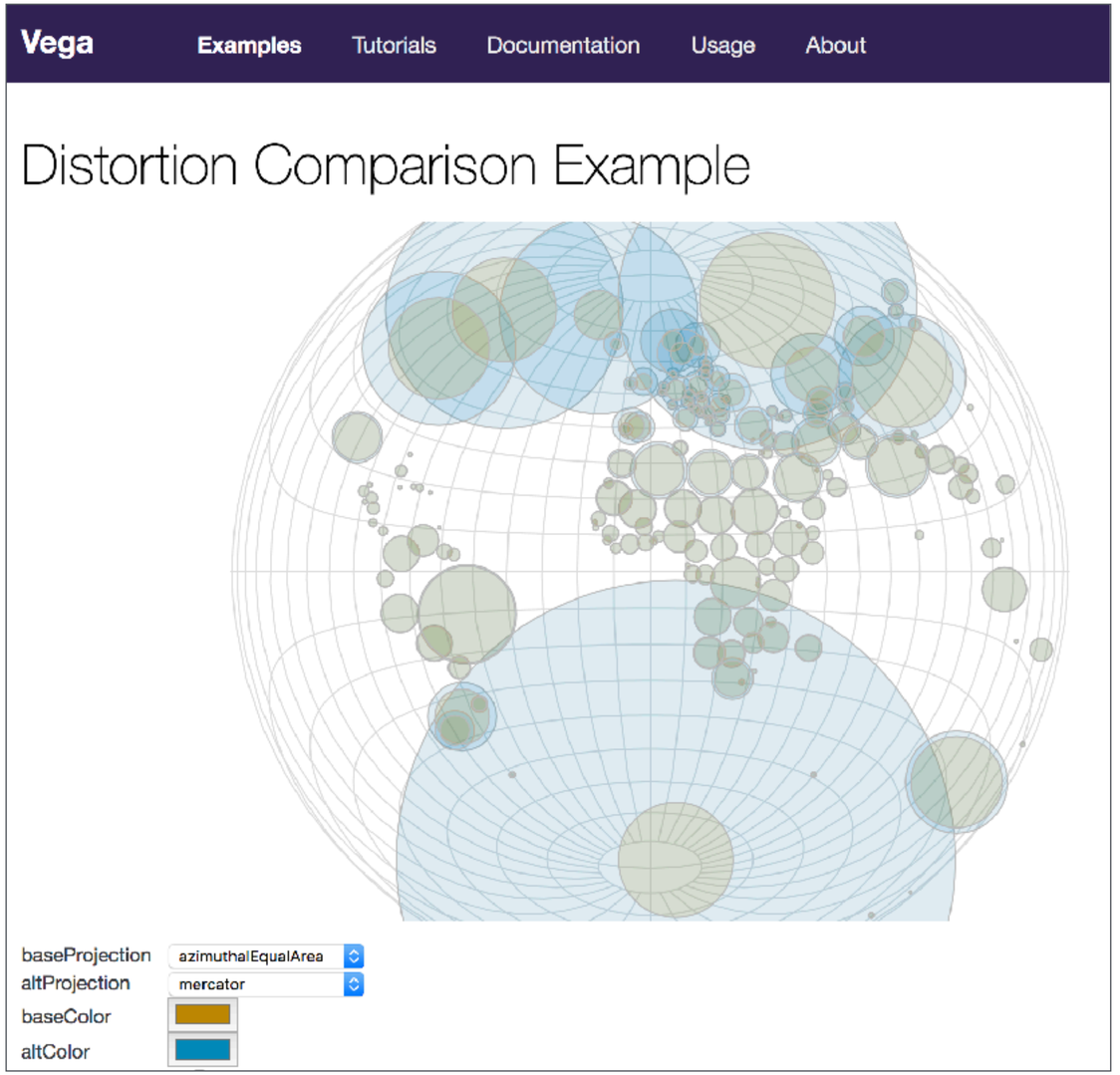
Tissot's Indicatrix (Dymaxion Map)



https://en.wikipedia.org/wiki/Tissot's_indicatrix



https://vega.github.io/vega/examples/projections/



https://vega.github.io/vega/examples/distortion-comparison/

Cartography

(Map Making)

Mapping

(Visualizing Geospatial Data)

How does the data change?

Where does the data occur?

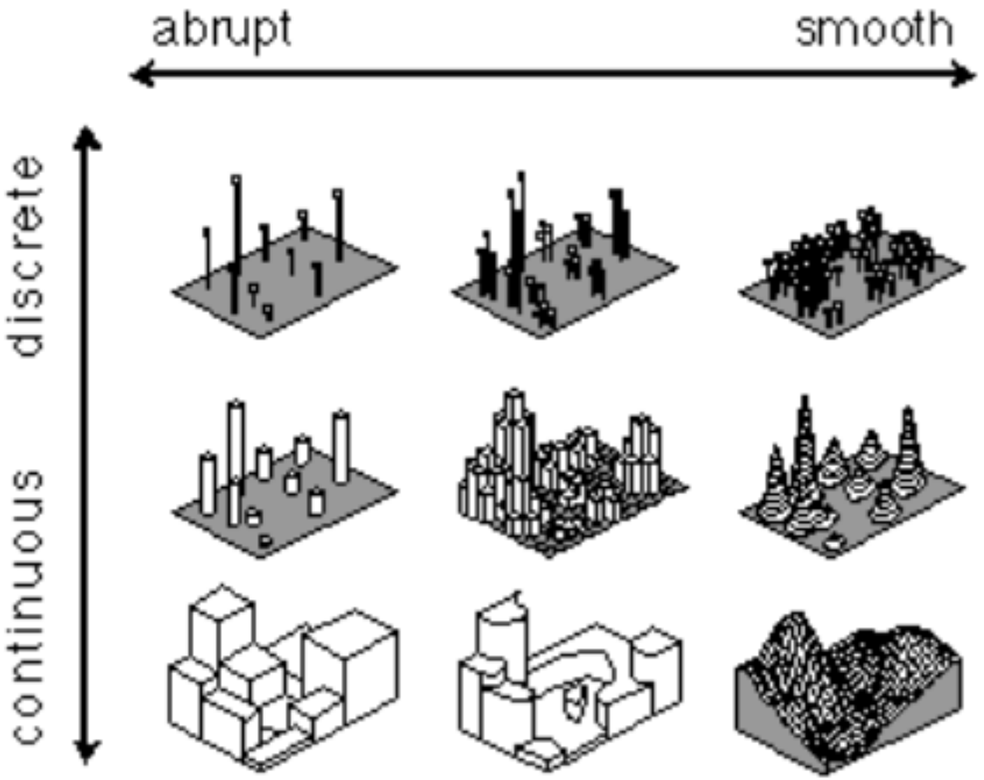


Fig. 8. Data models representing points in the continuity-abruptness phenomena space.

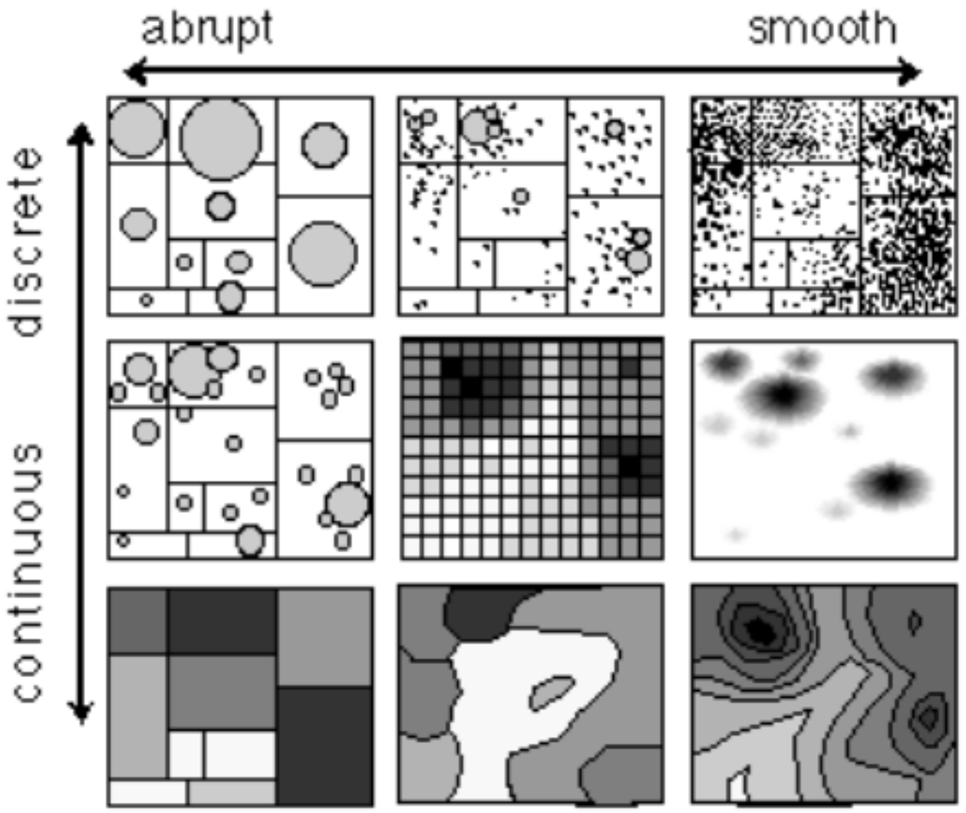
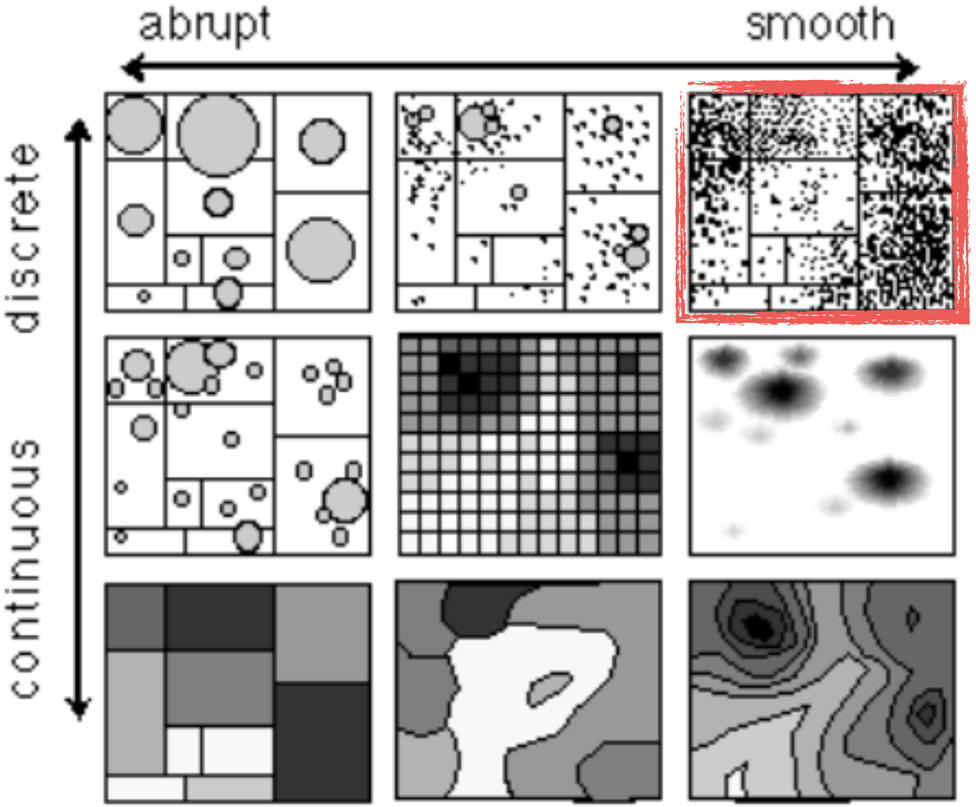


Fig. 9. Possible 2D translations of the 3D data models shown in figure 8.

[MacEachren. Visualizing Uncertain Information. 1992]

Dot Distribution Map



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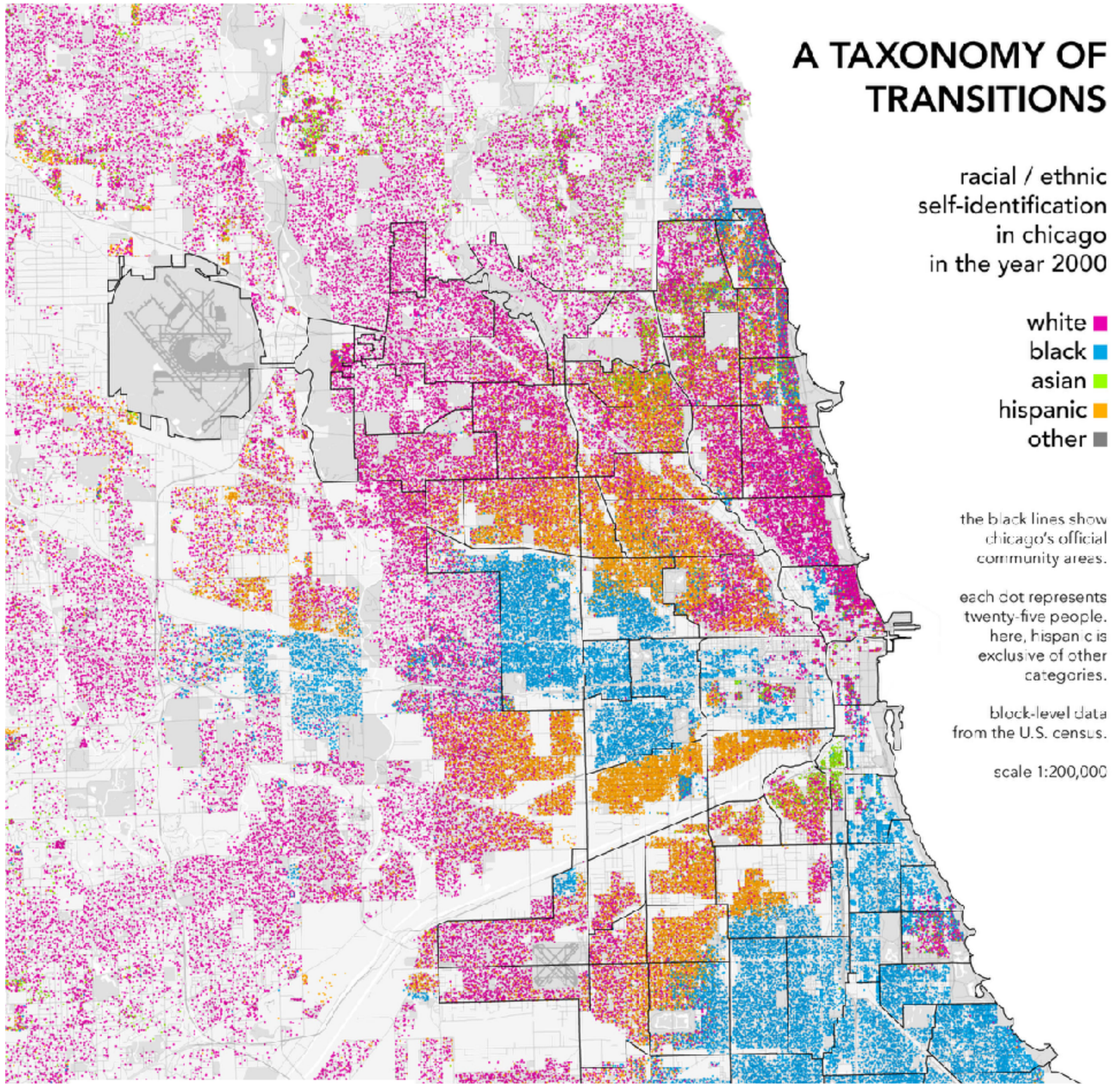
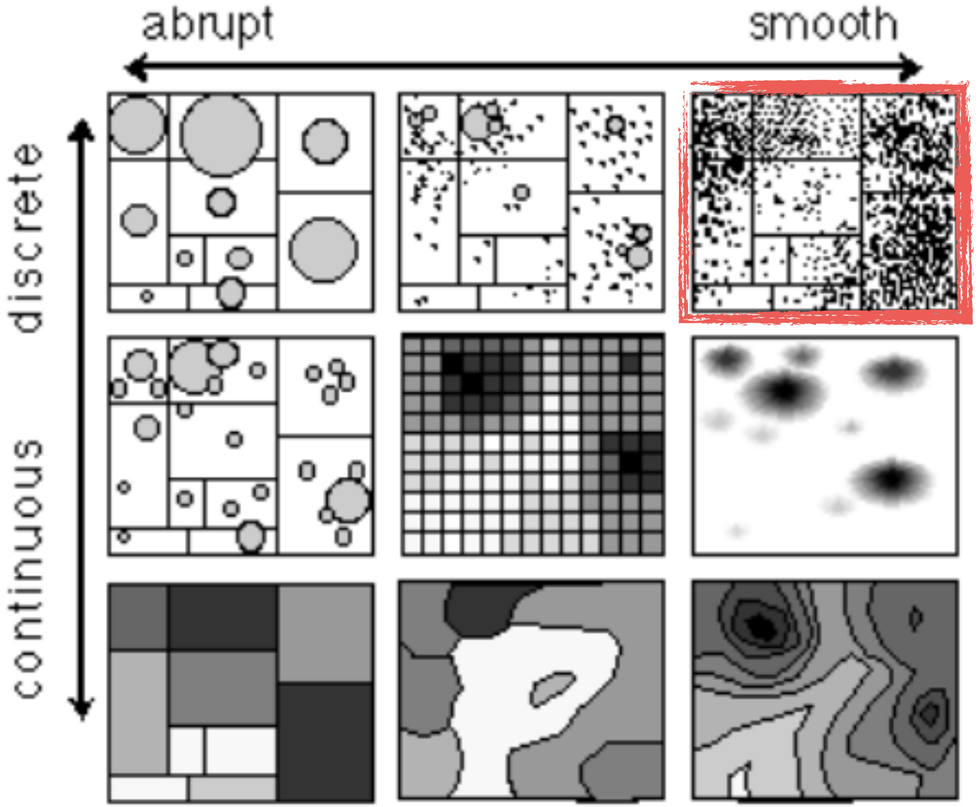


http://www.radicalcartography.net/index.html?chicagodots

Dot Distribution Map



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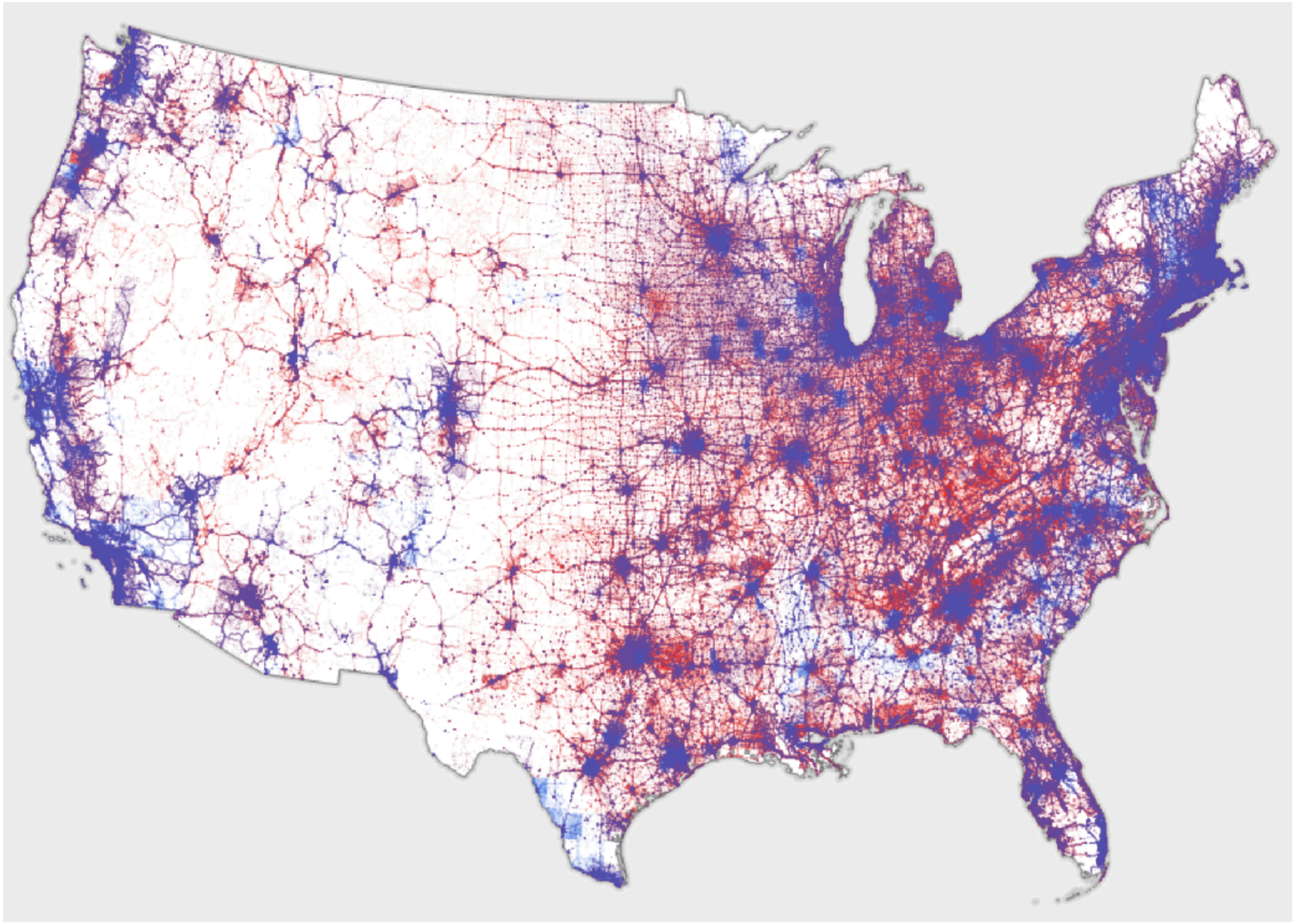
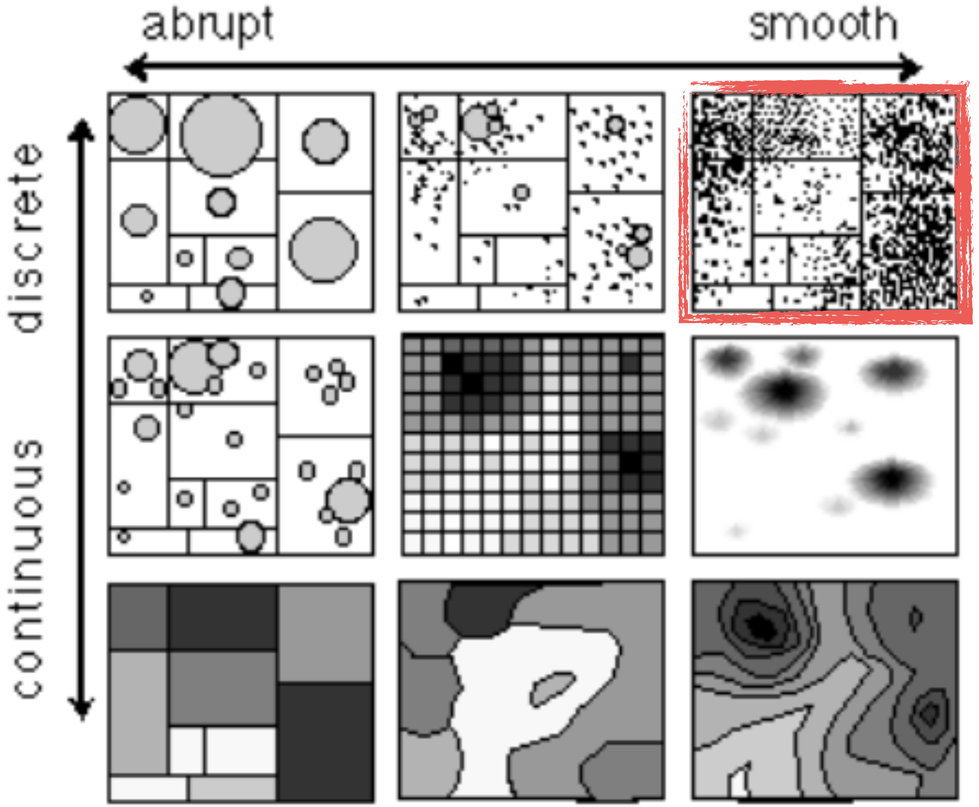


Votes cast in the 2016 Presidential Election

Dot Distribution Map



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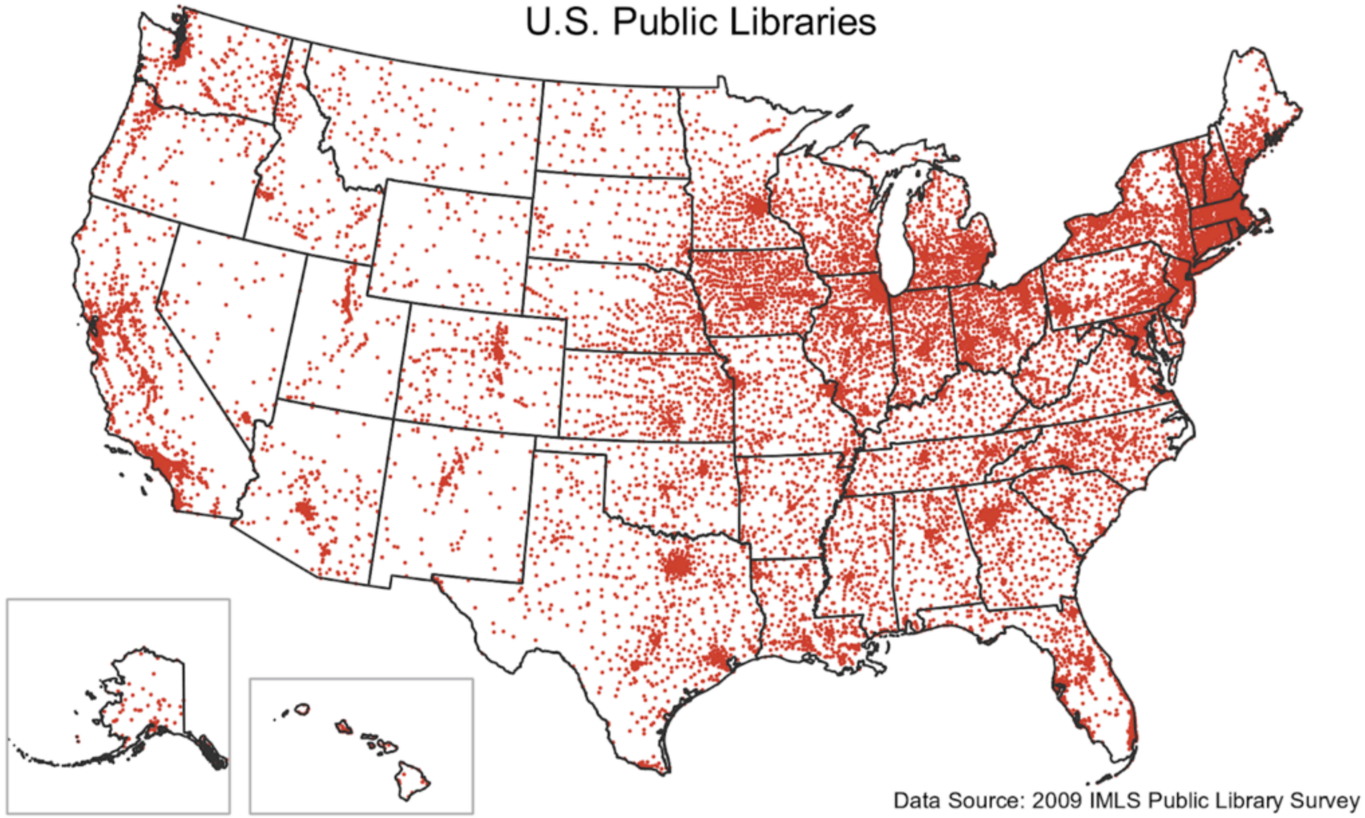
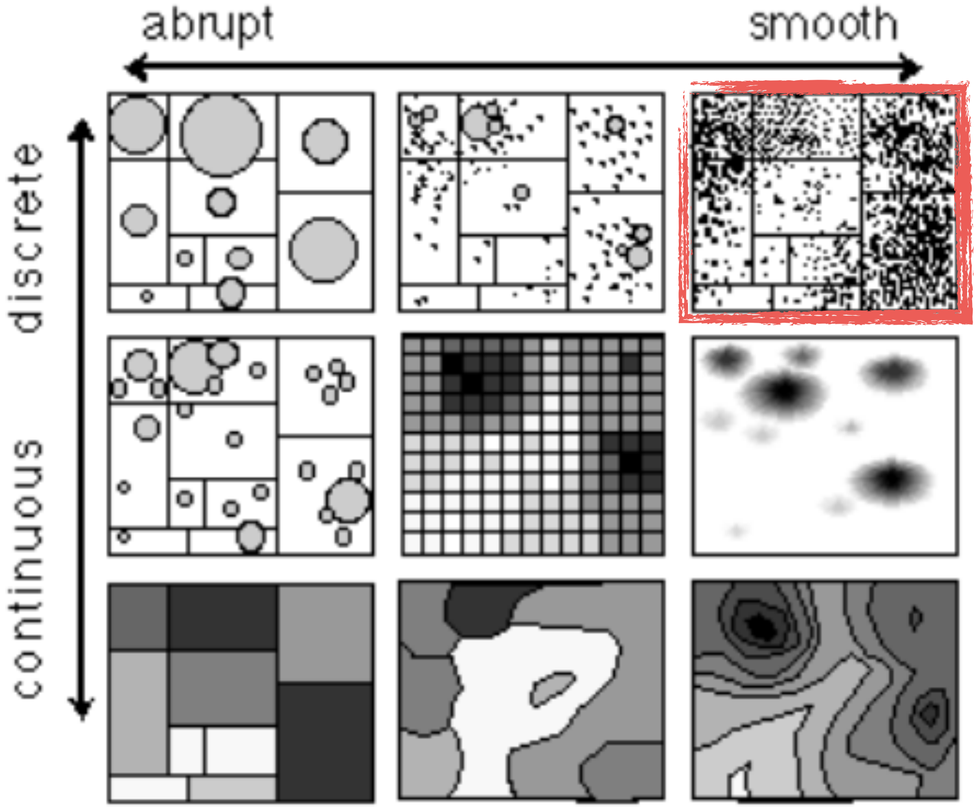


[MacEachren. Visualizing Uncertain Information. 1992]

Dot Distribution Map



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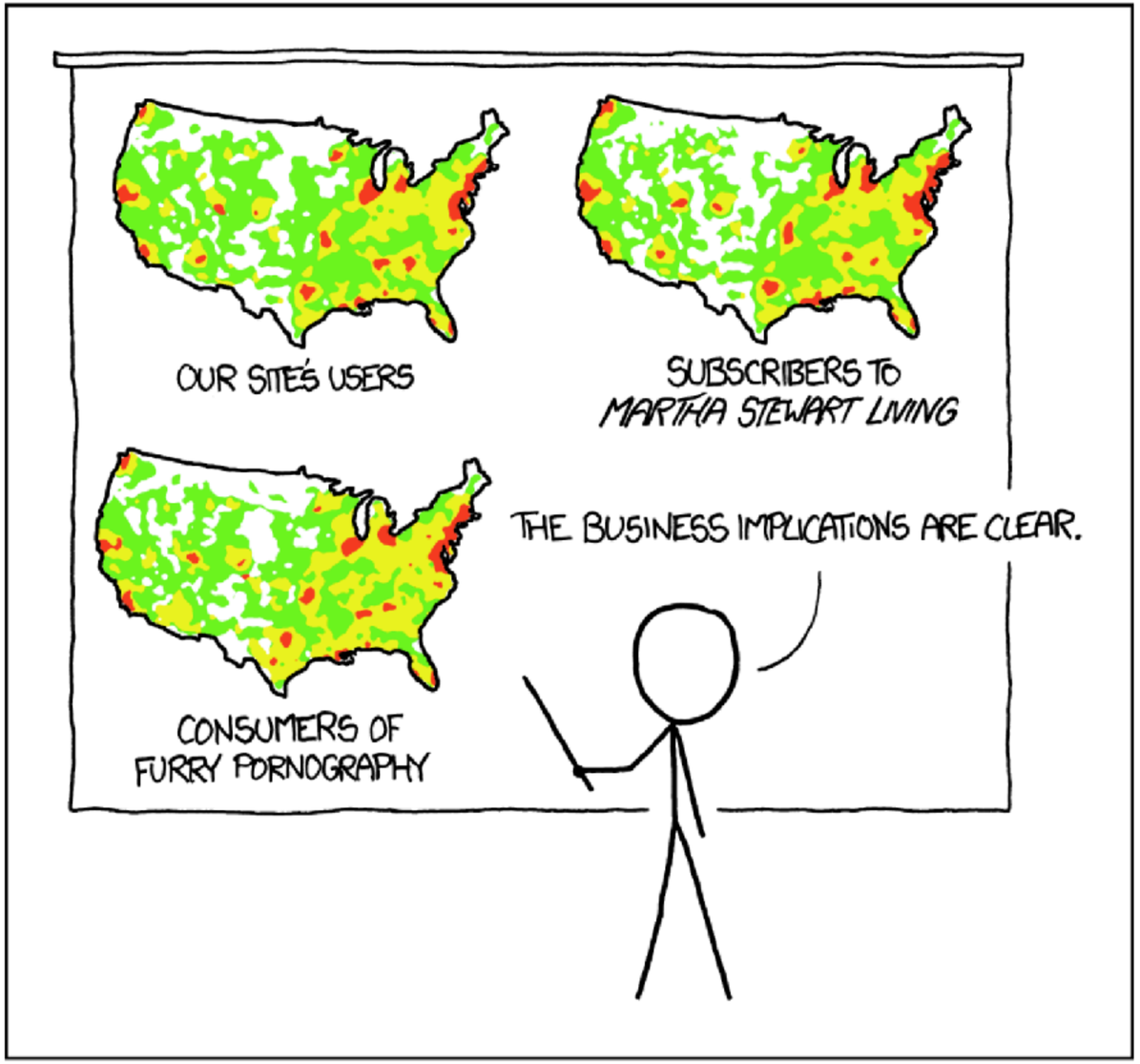
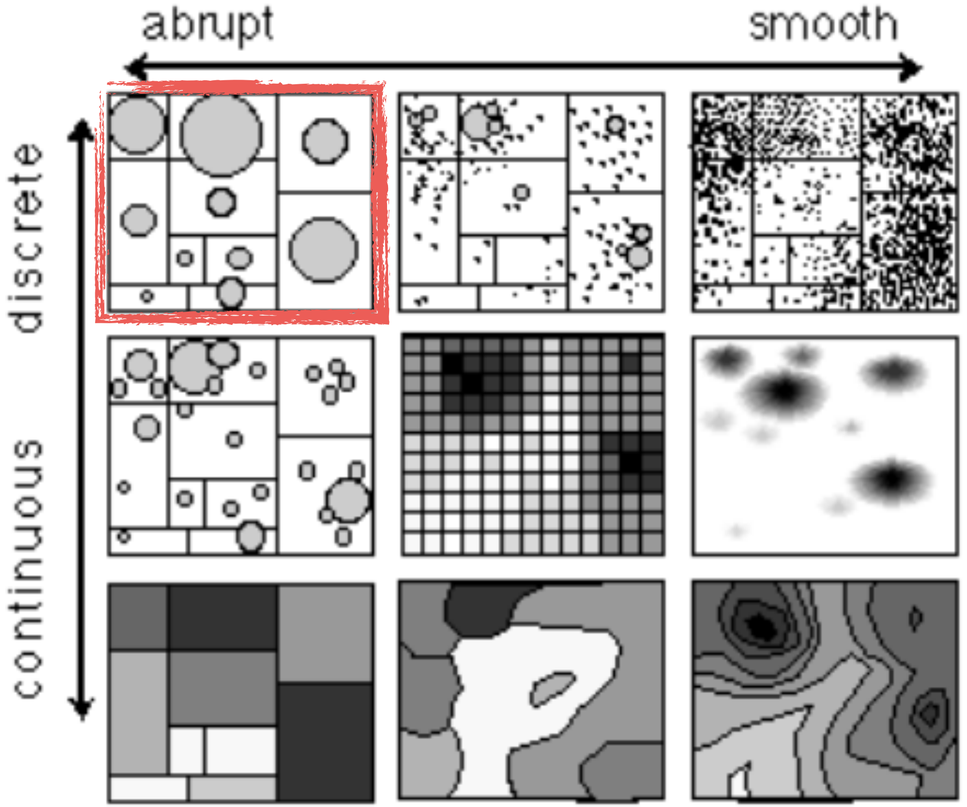


PET PEEVE #208:
GEOGRAPHIC PROFILE MAPS WHICH ARE BASICALLY JUST POPULATION MAPS

https://xkcd.com/1138/

Proportional Symbol Map



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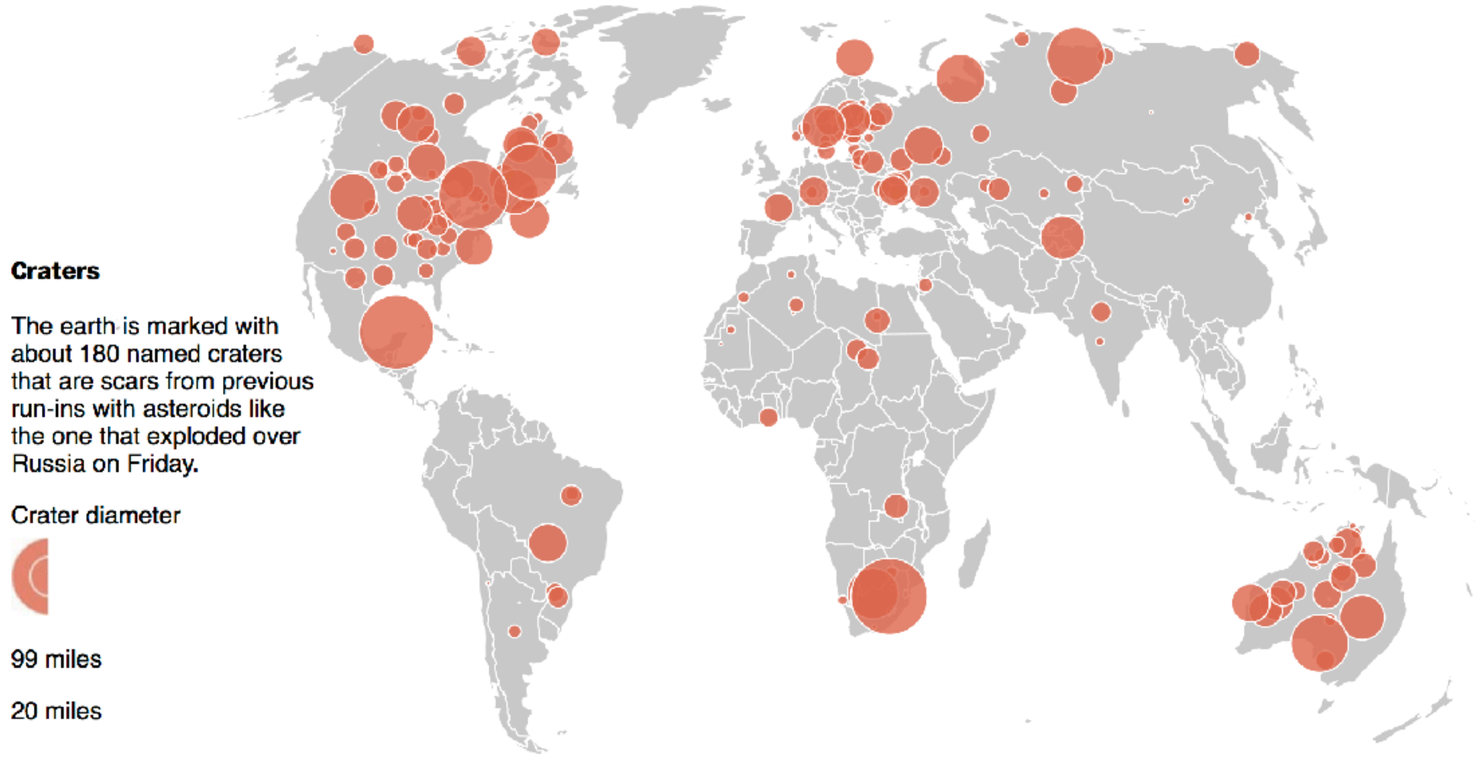
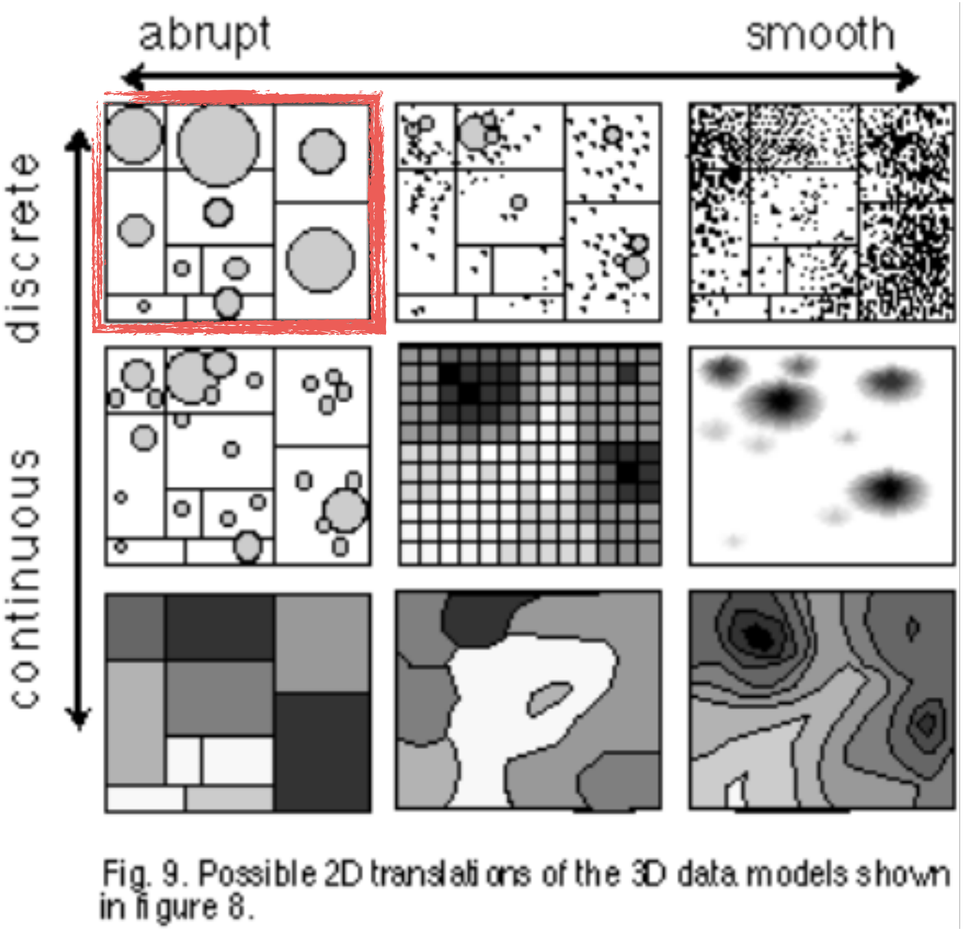


http://www.washingtonpost.com/wp-srv/special/world/russia-meteor/index.html

Proportional Symbol Map



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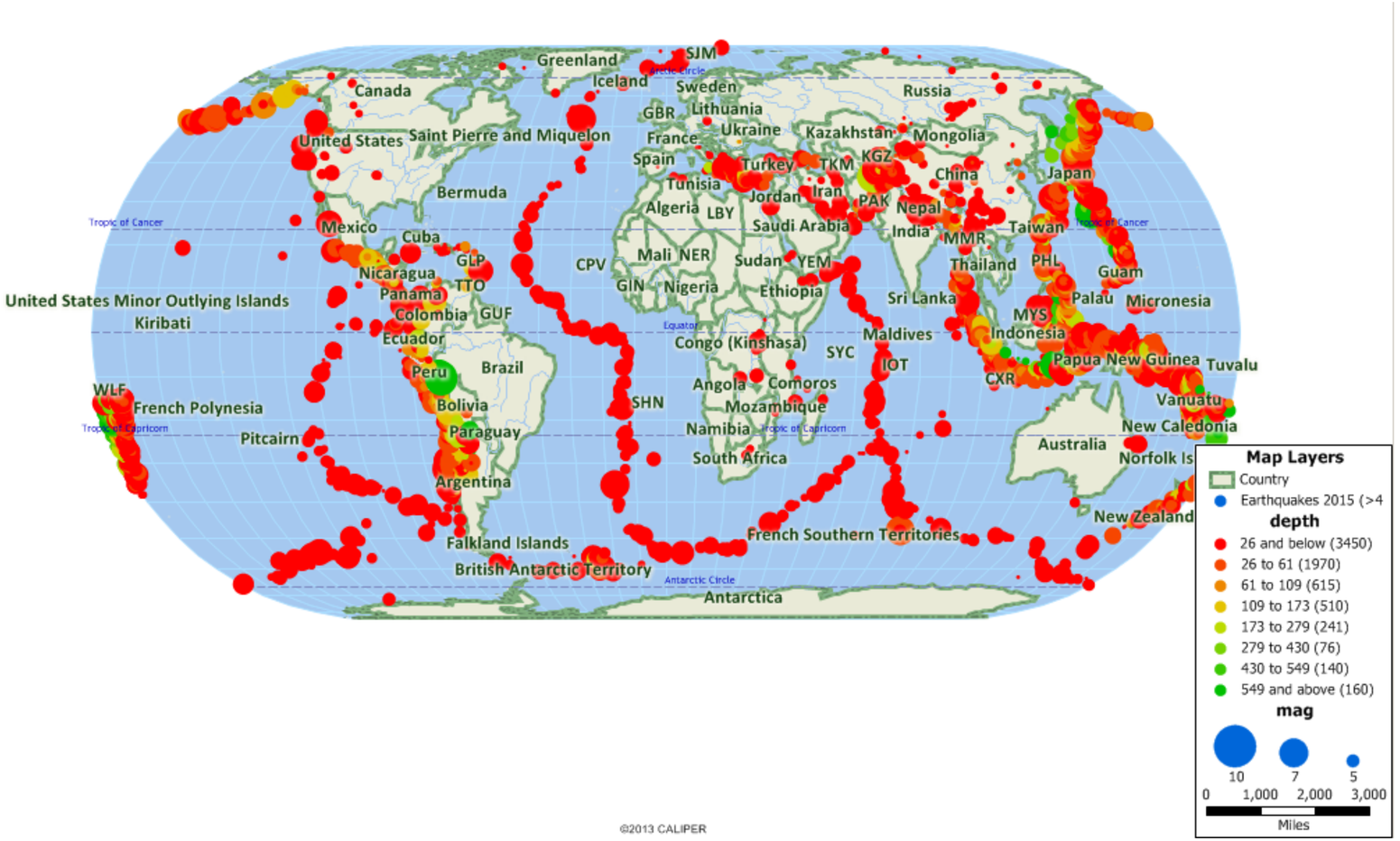
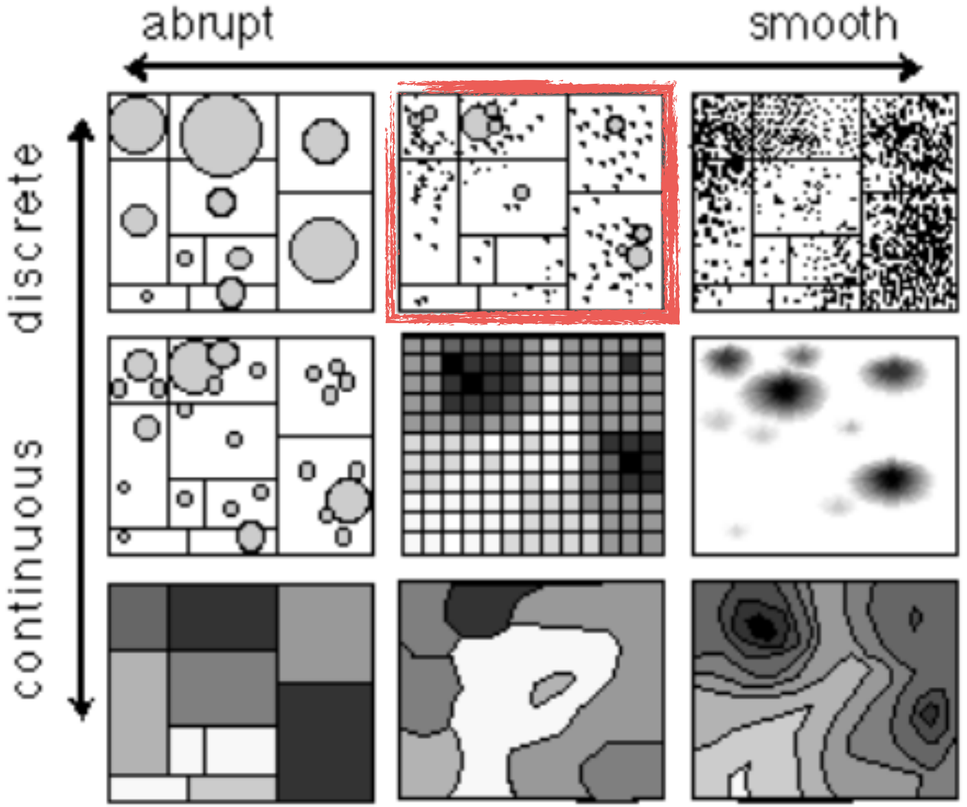


[MacEachren. Visualizing Uncertain Information. 1992]

Graduated Symbol Map



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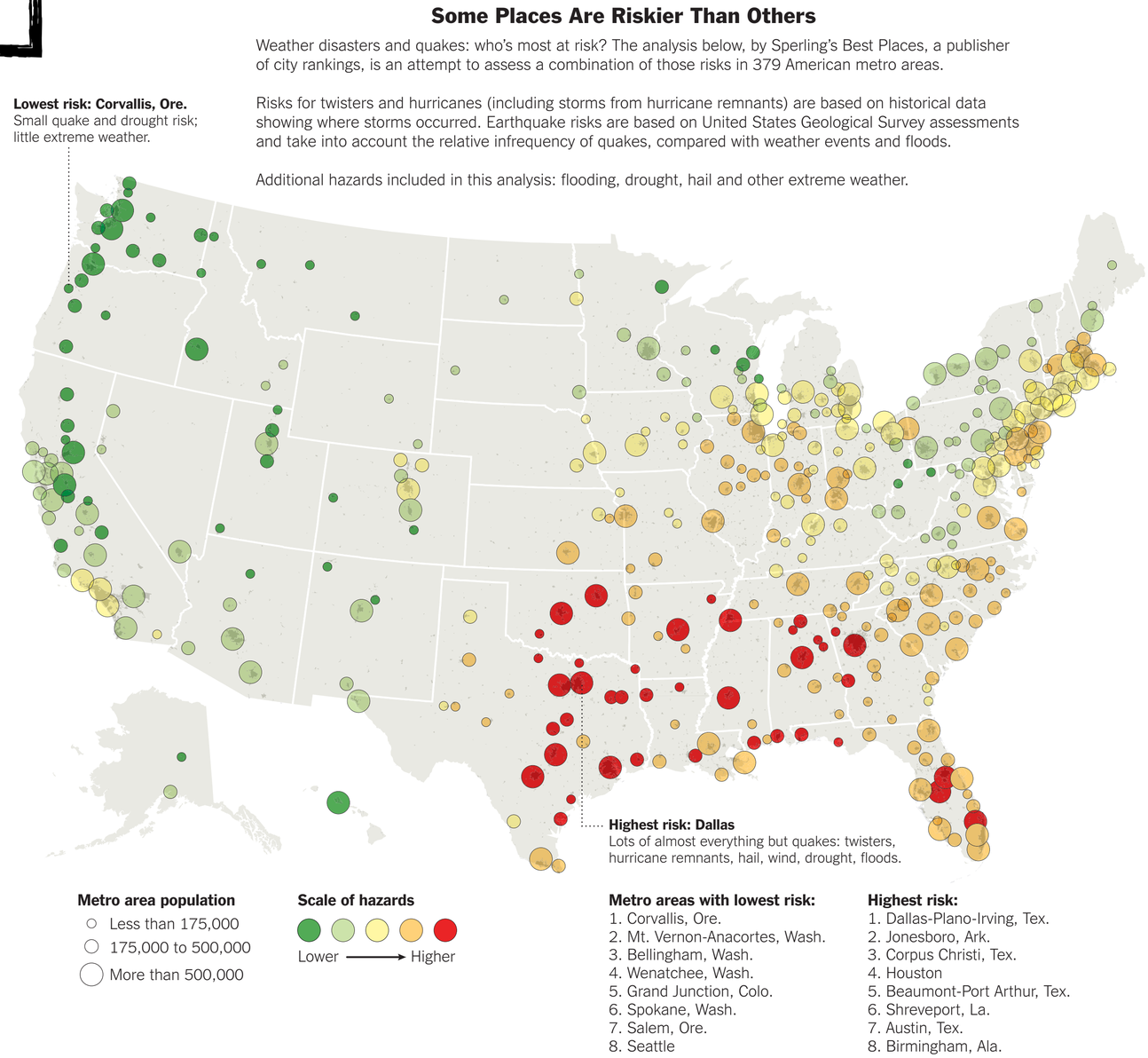
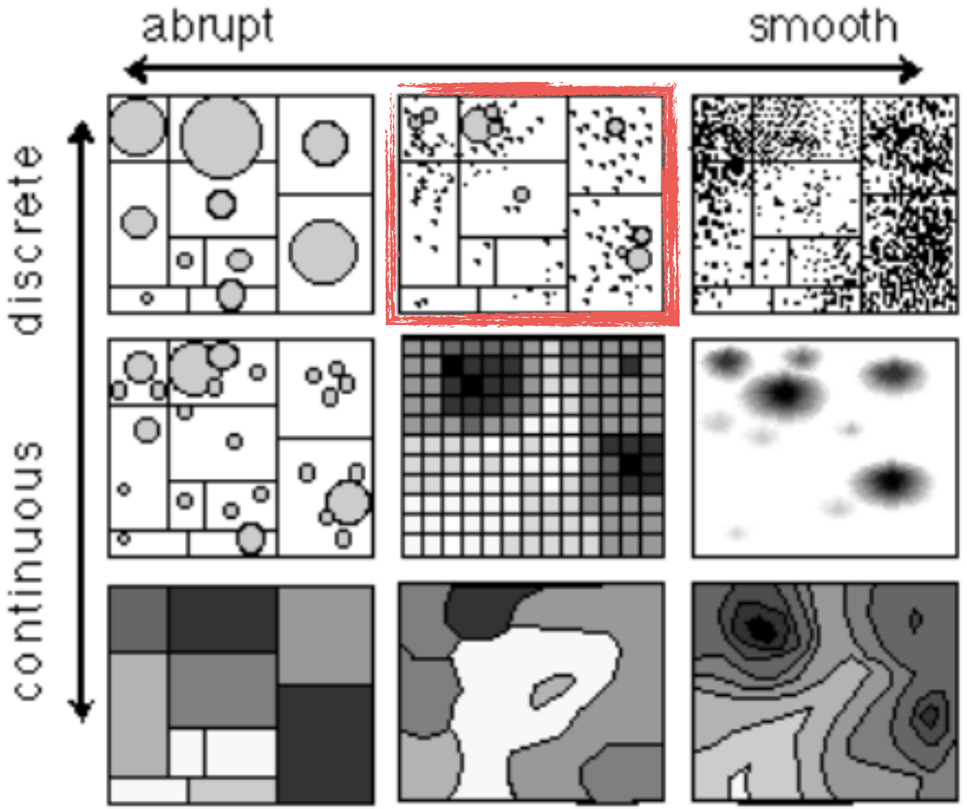
[MacEachren. Visualizing Uncertain Information. 1992]



[Ericson, Burgess, and Marsh. Where to Live to Avoid a Natural Disaster. The New York Times, April 2011]

Graduated Symbol Map



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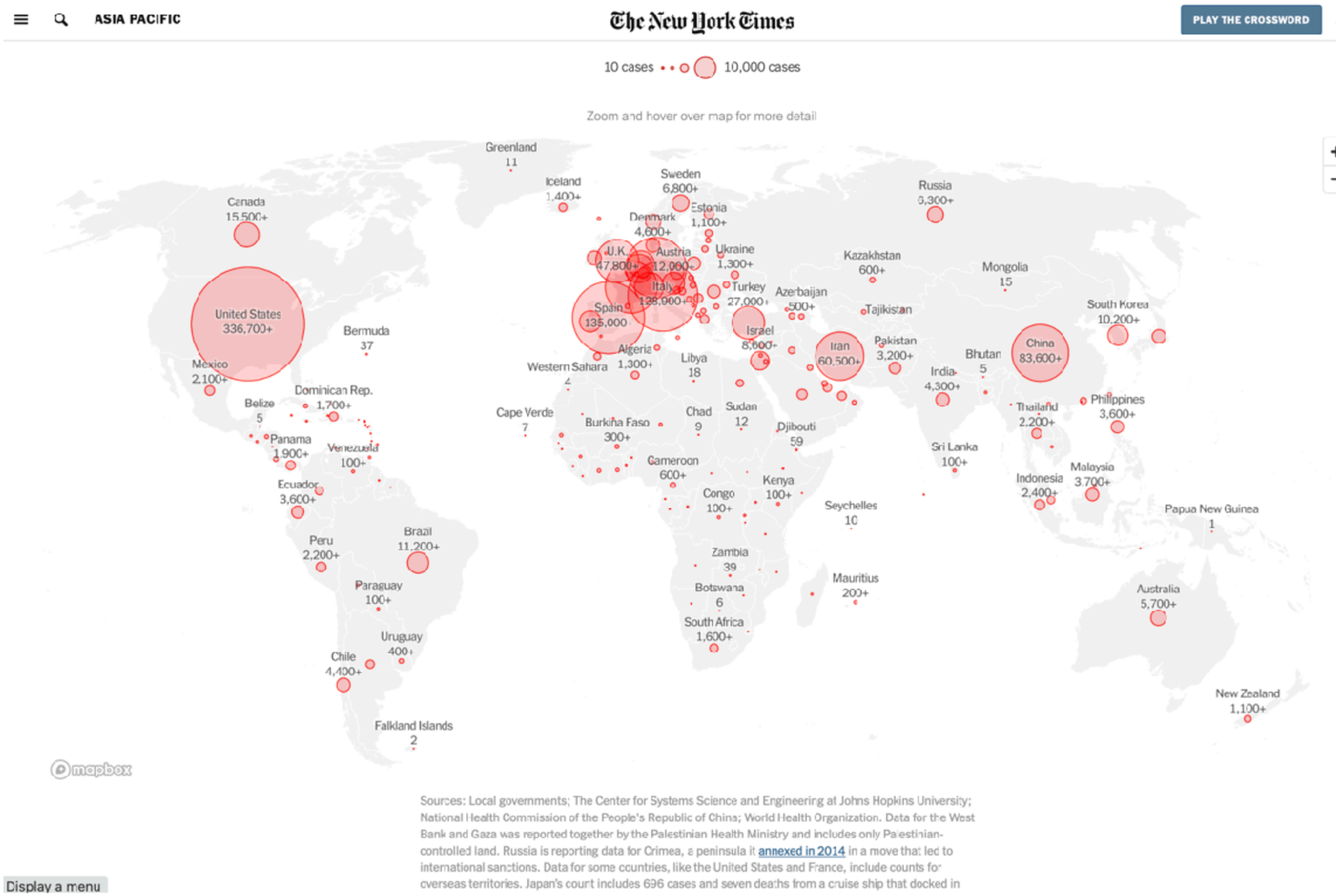


[MacEachren. Visualizing Uncertain Information. 1992]

Graduated Symbol Map

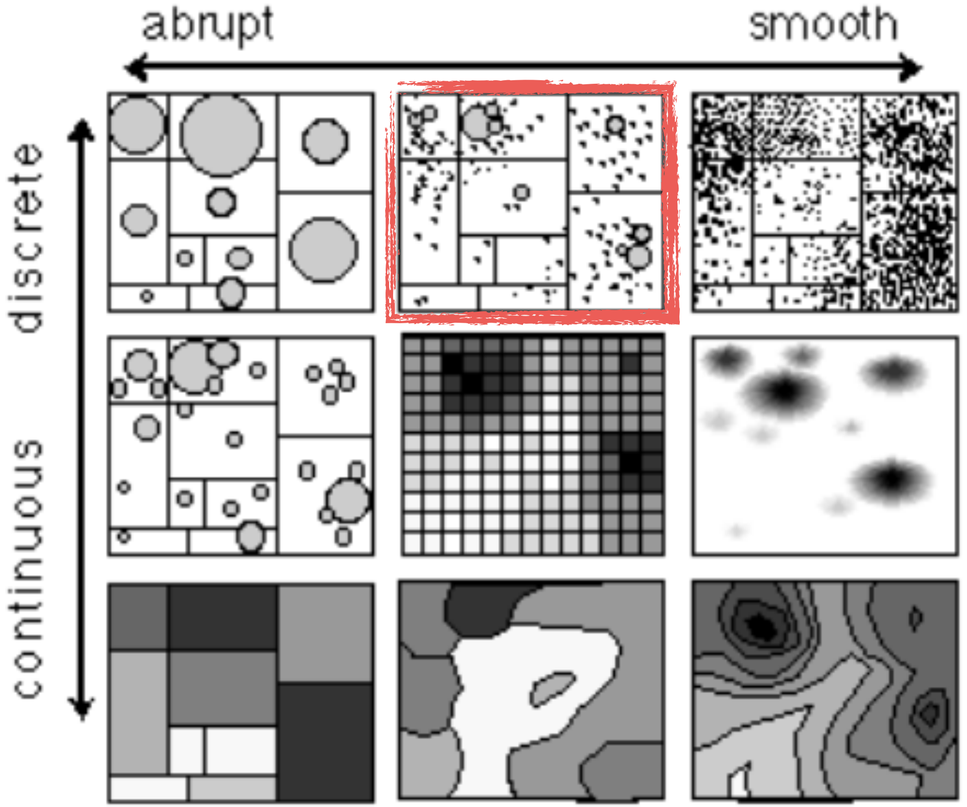
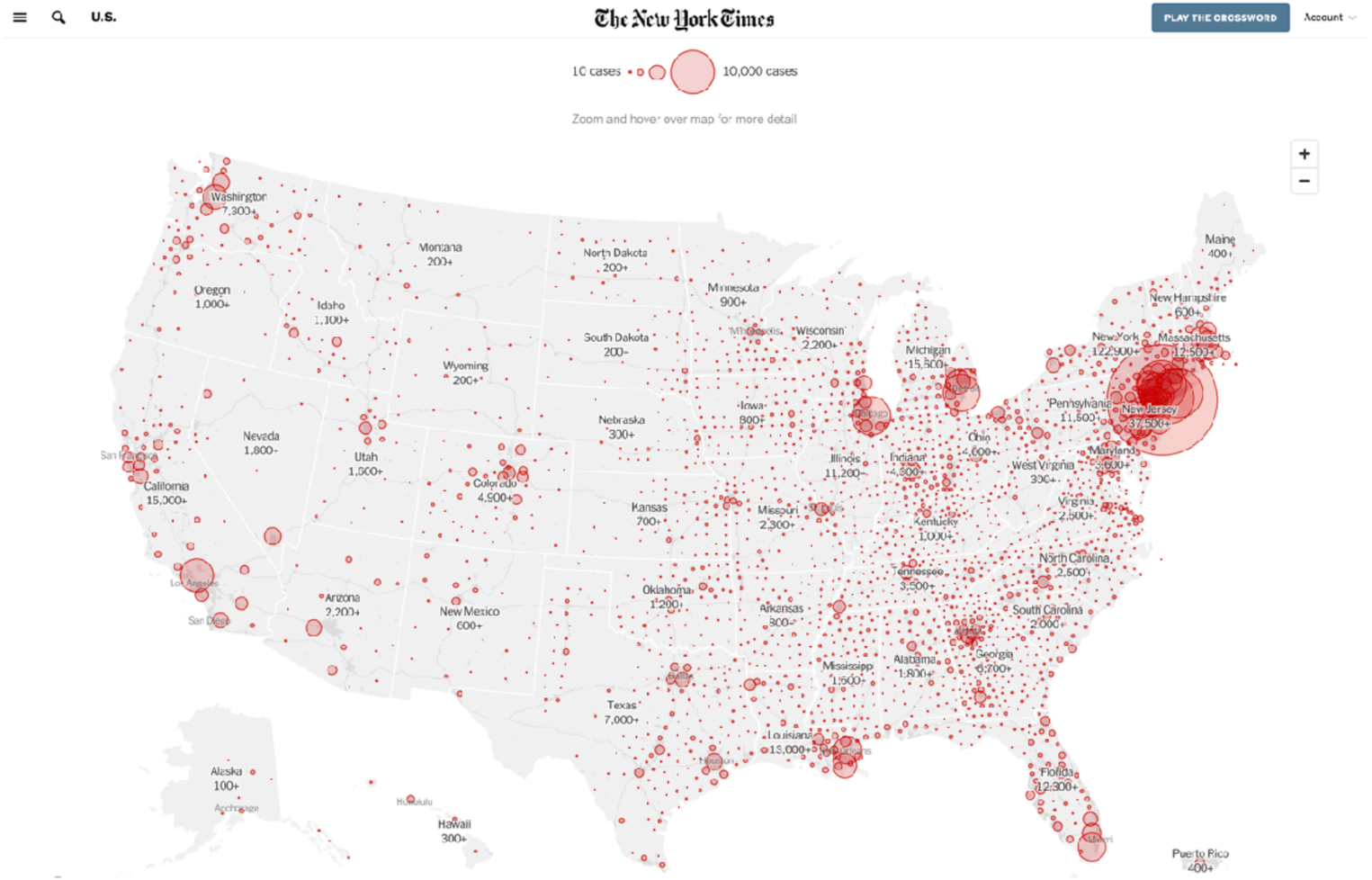
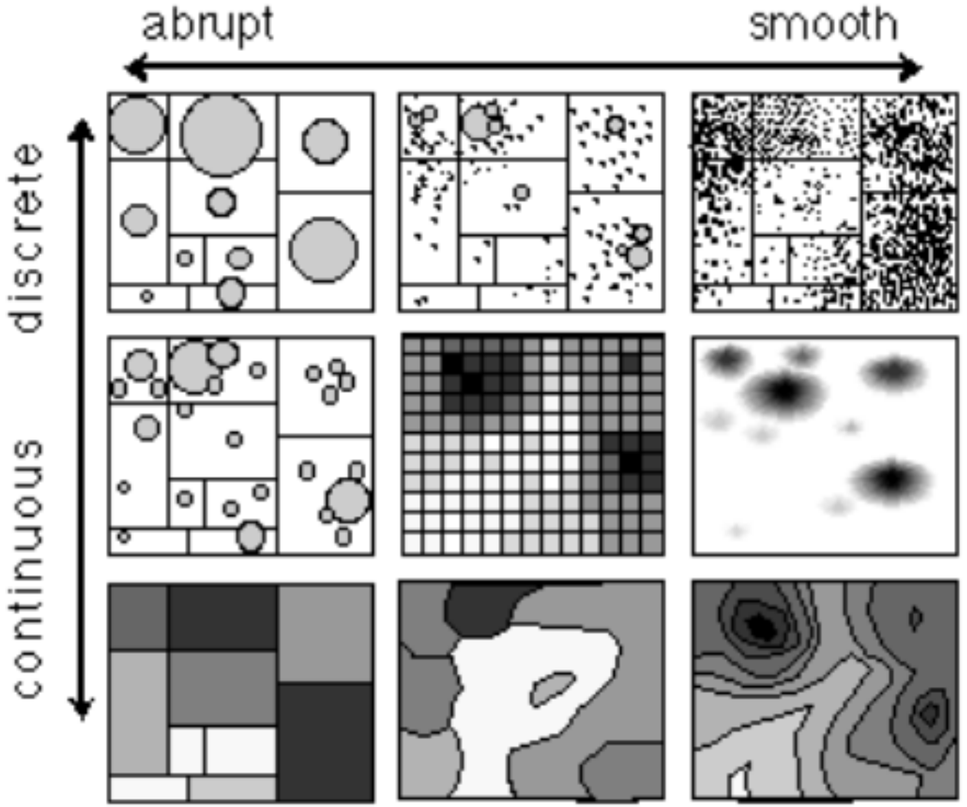


Fig. 9. Possible 2D translations of the 3D data models shown in figure 8.



[MacEachren. Visualizing Uncertain Information. 1992]



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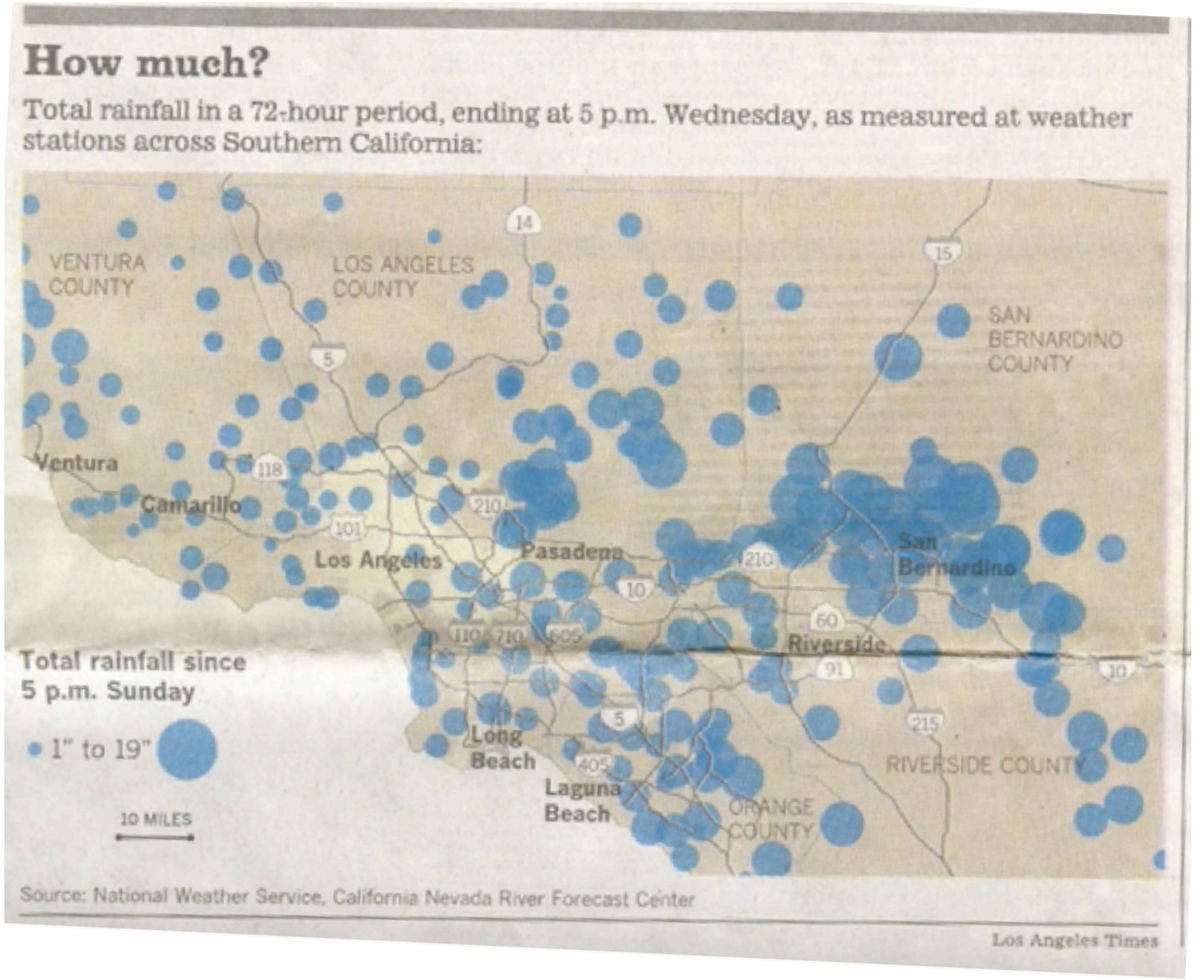
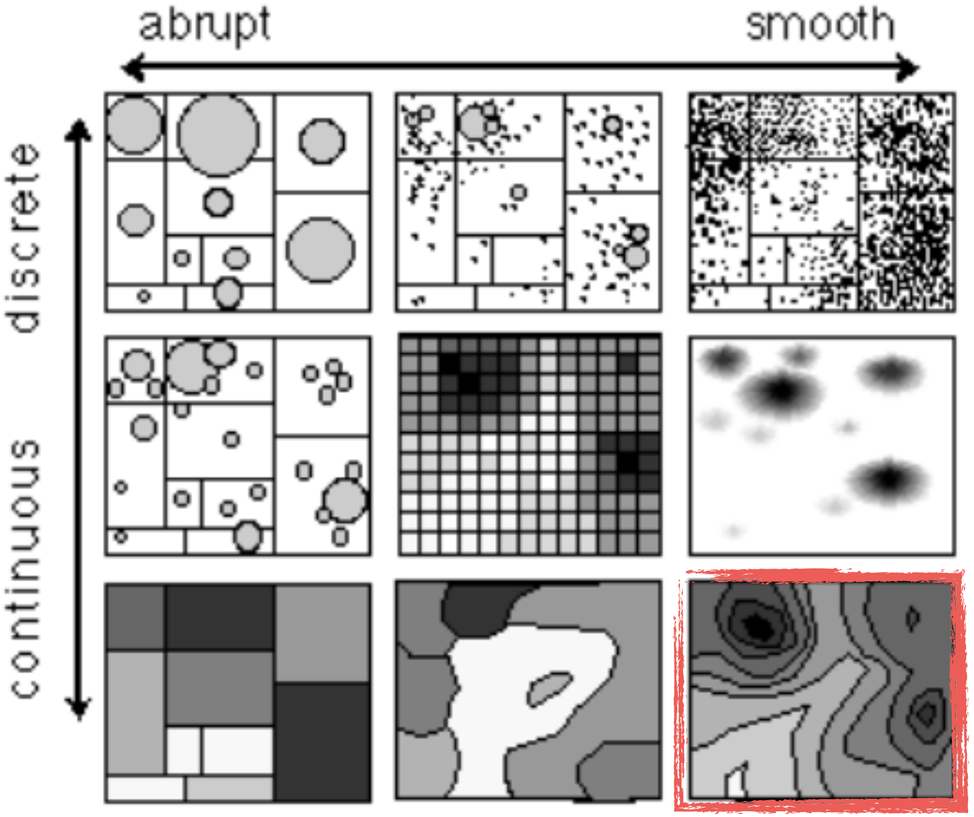


Isopleth / Heat Map



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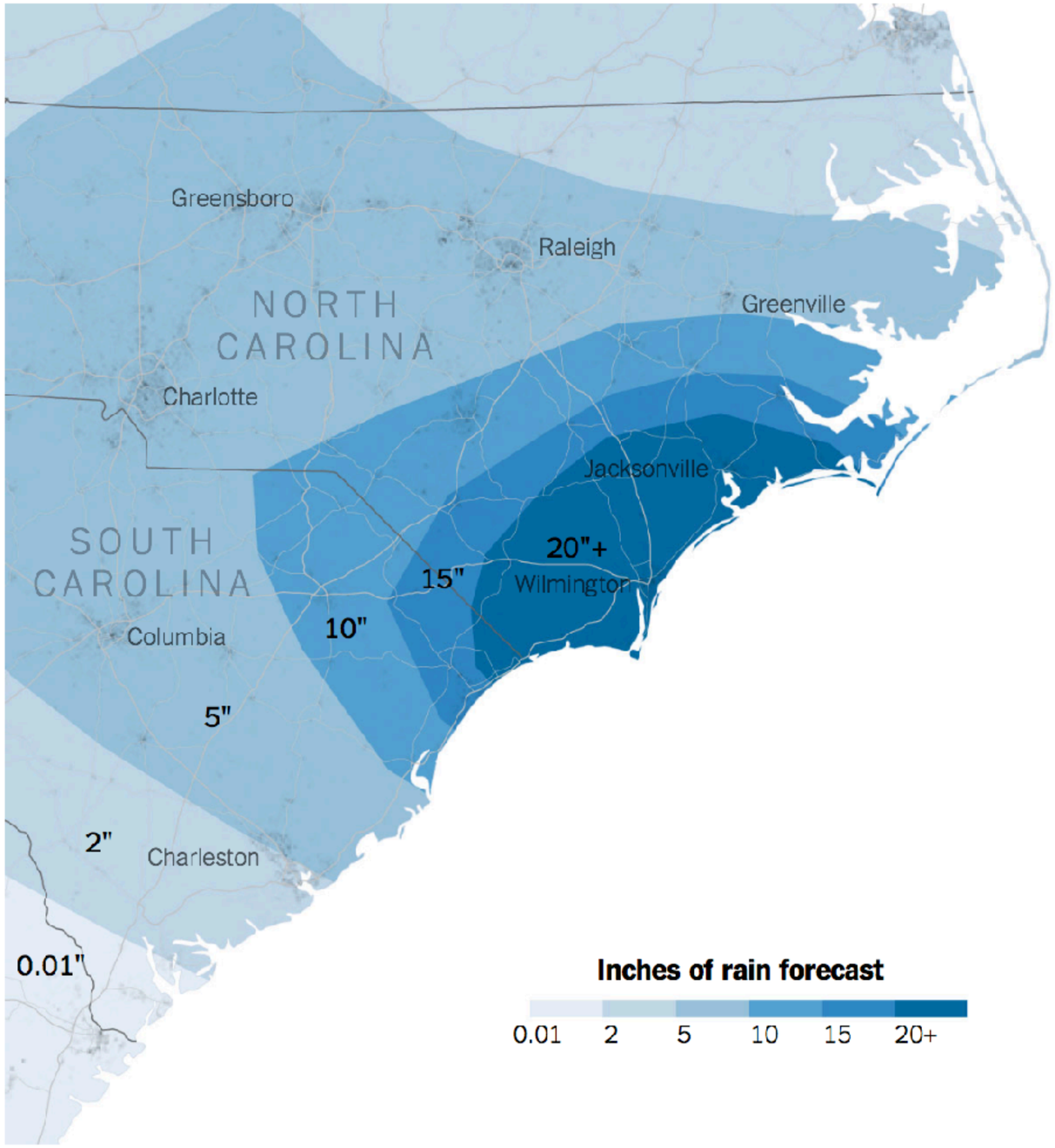
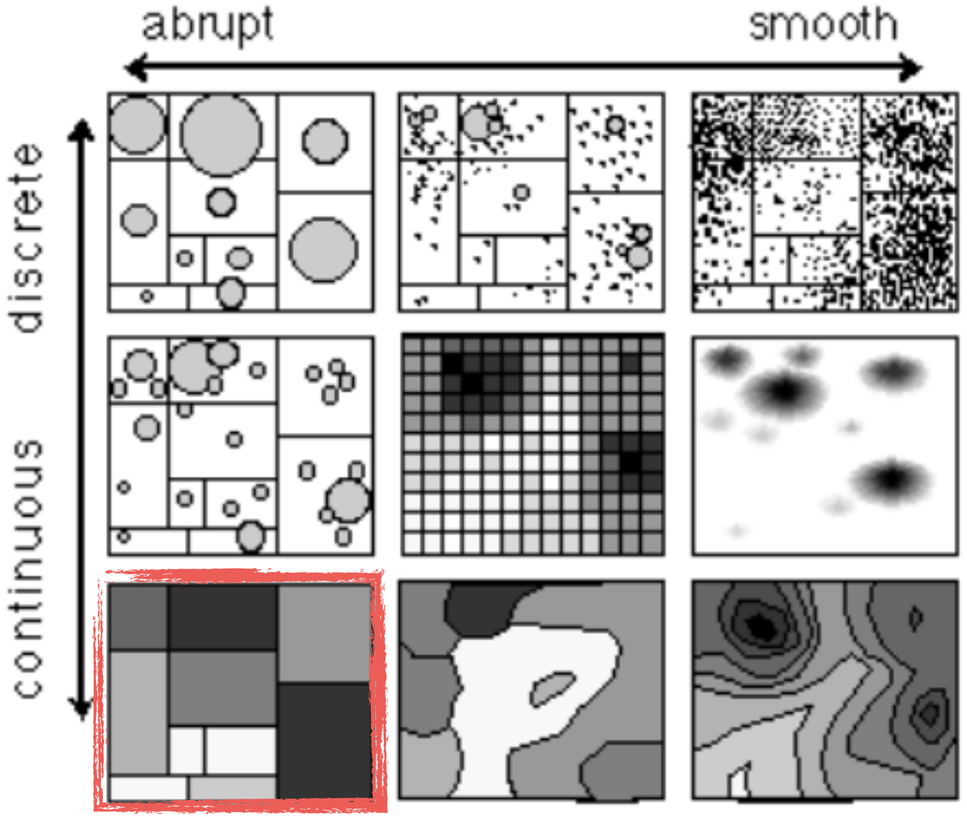


Source: National Weather Service

Choropleth



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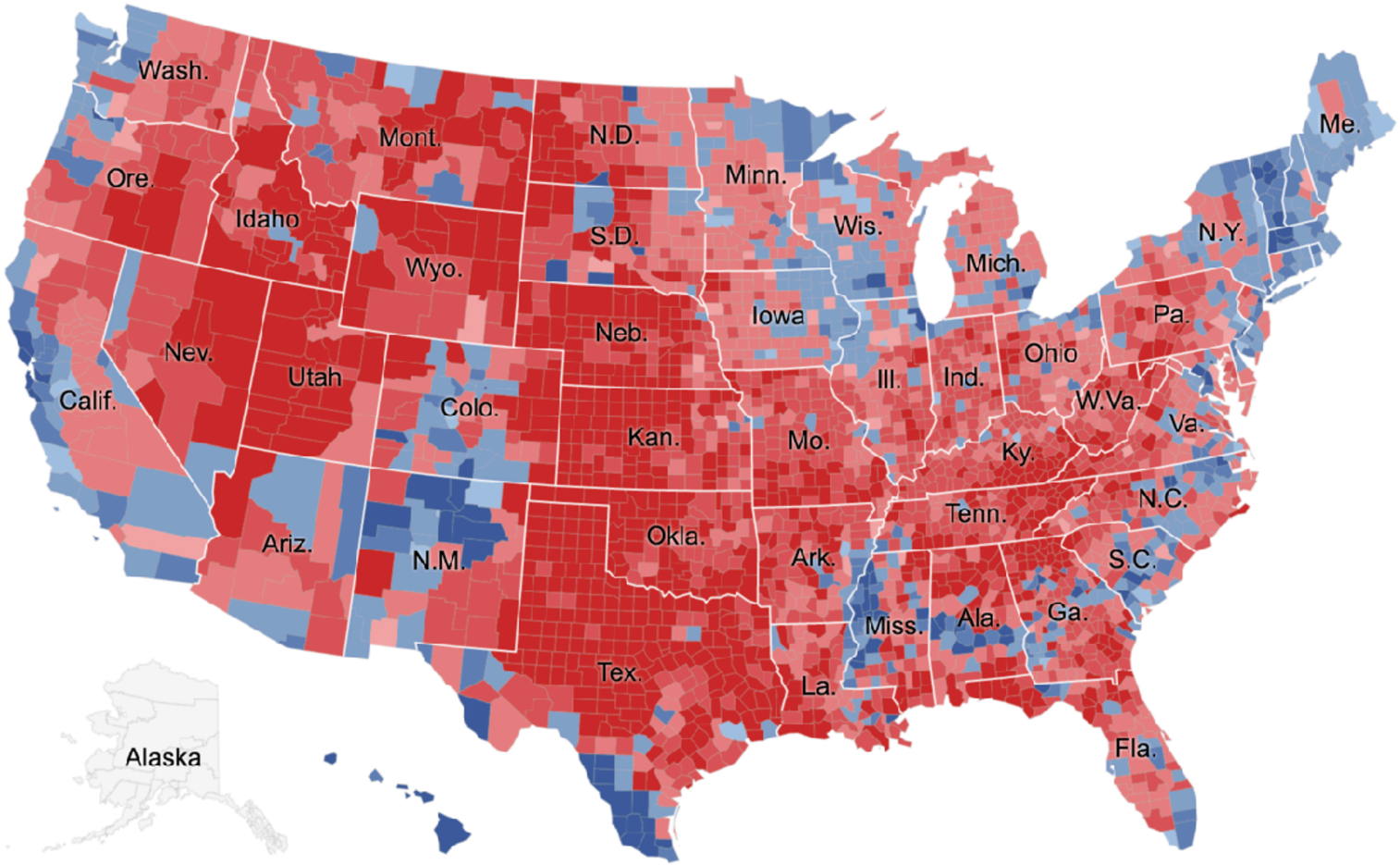
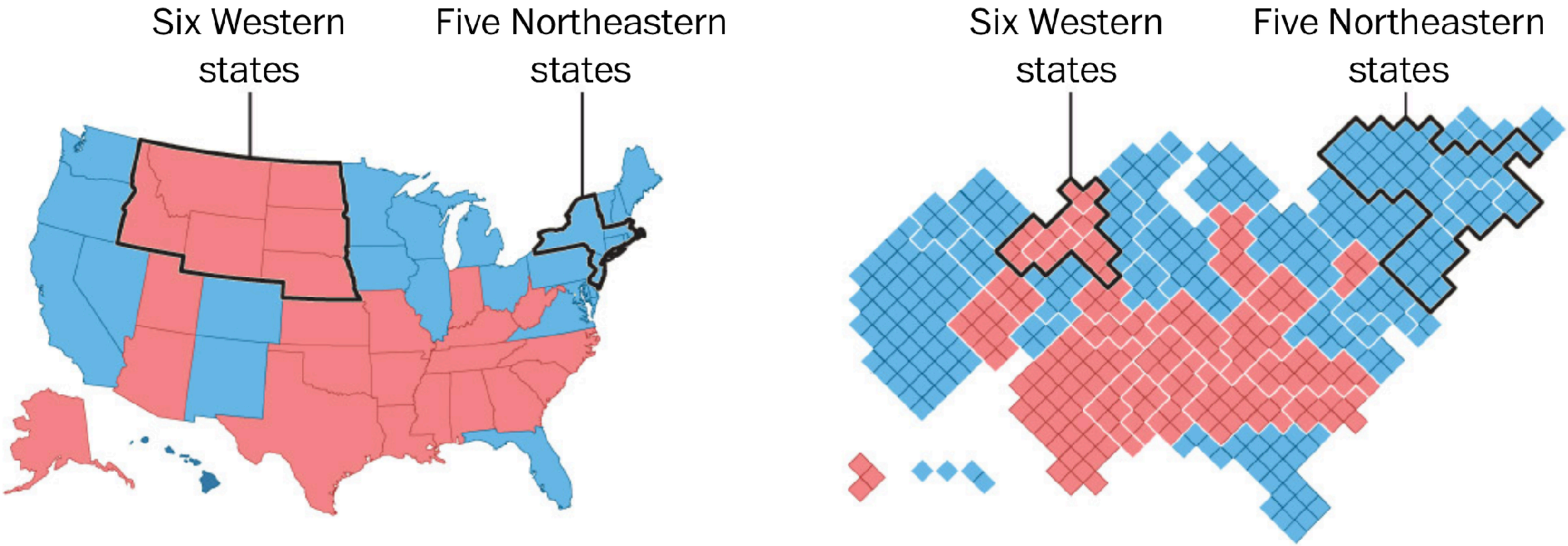
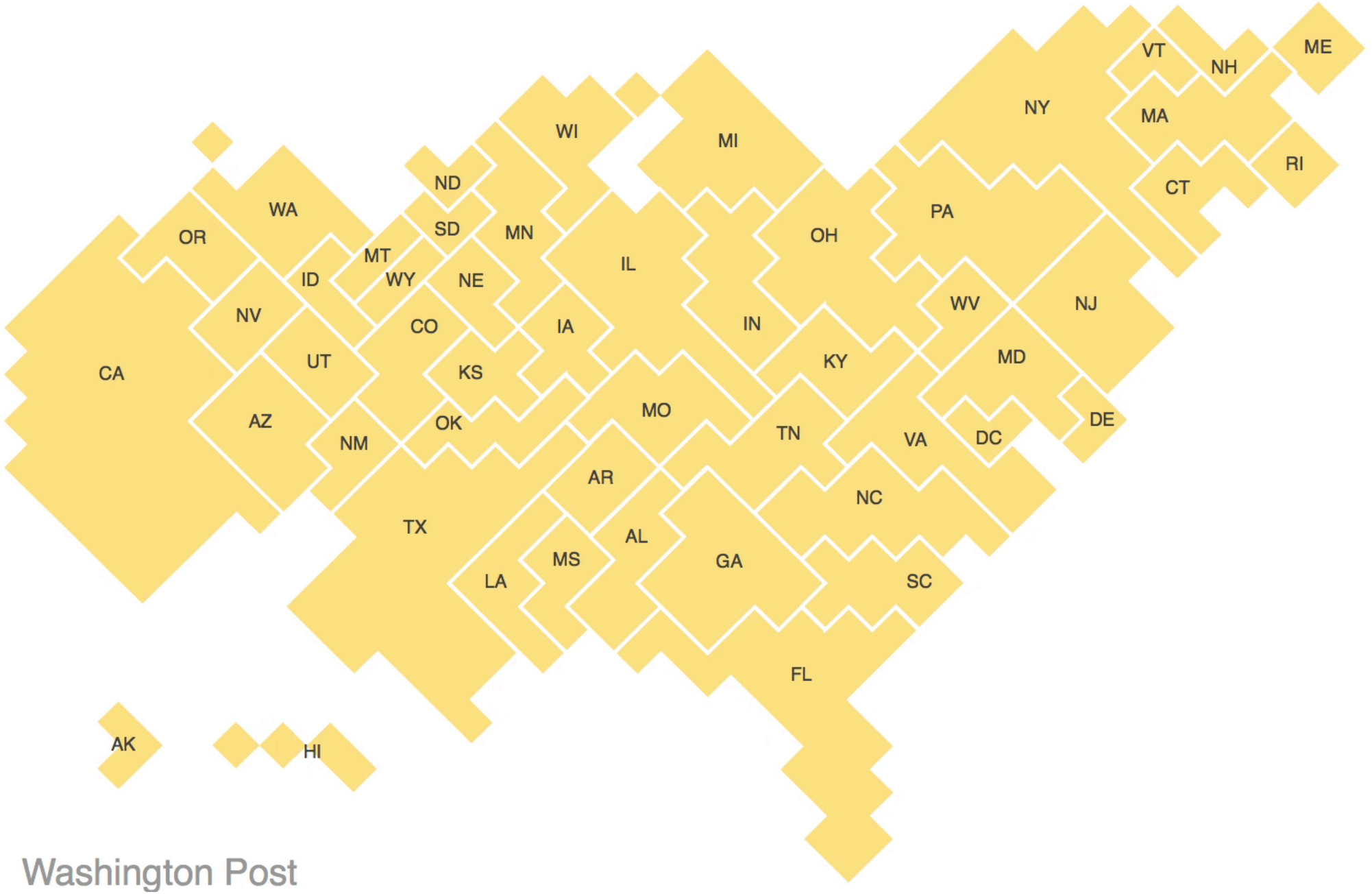


https://www.nytimes.com/interactive/2016/11/01/upshot/many-ways-to-map-election-results.html

GEOGRAPHIC MAP → **CARTOGRAM OF ELECTORAL VOTES**

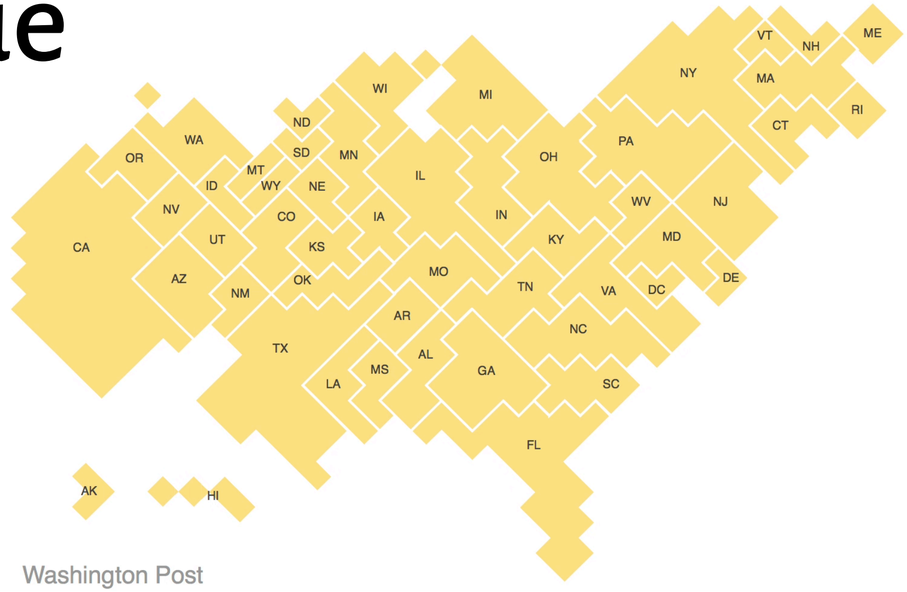




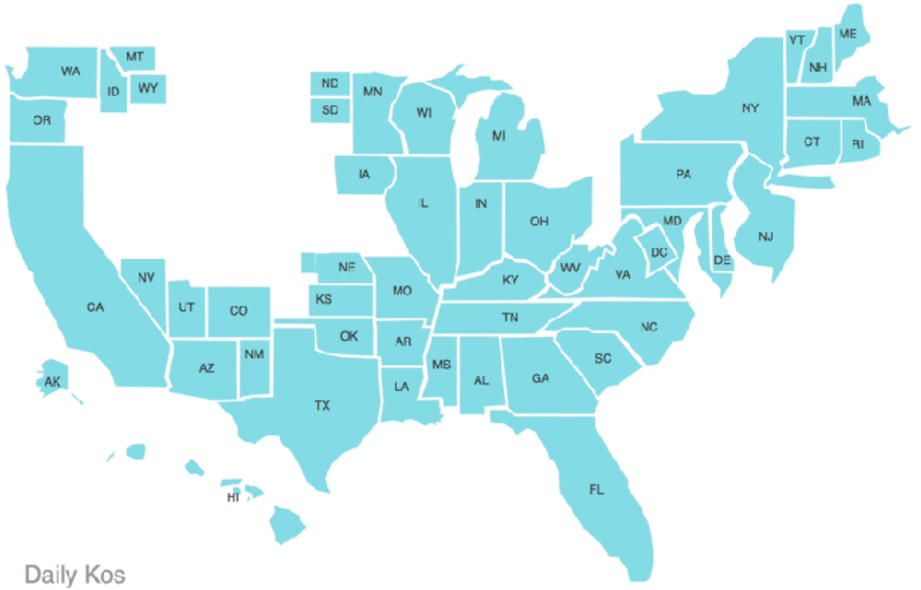
[Noah Veltman. December 2018]

Design Critique

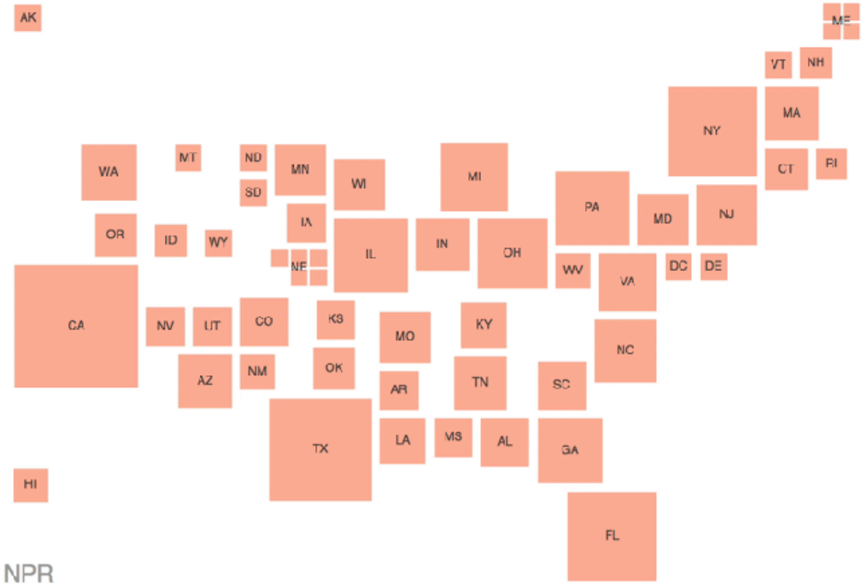
yellkey.com/within



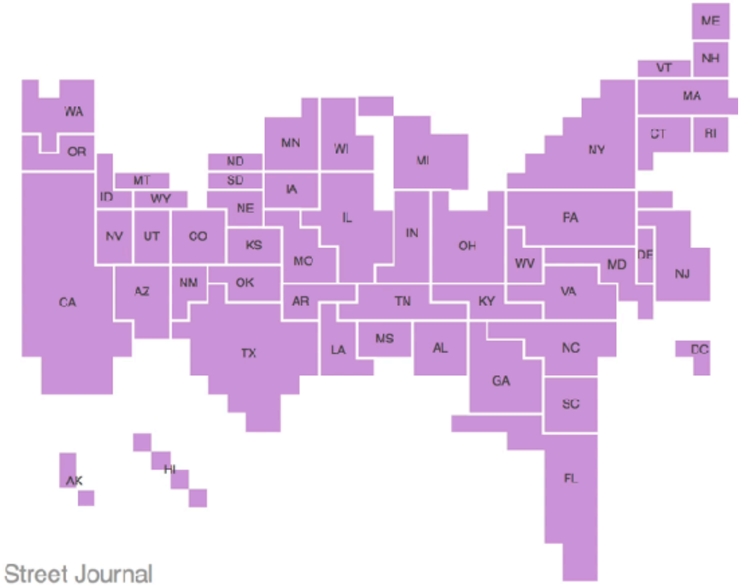
Washington Post



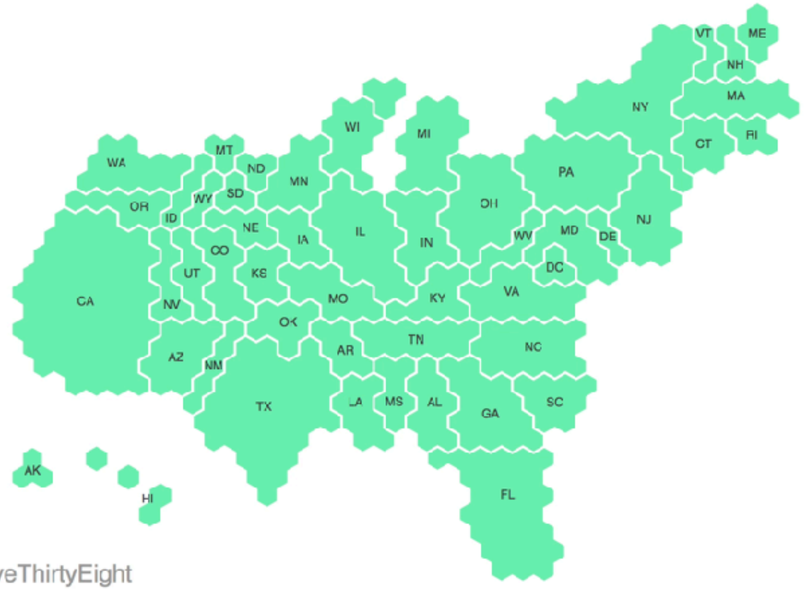
Daily Kos



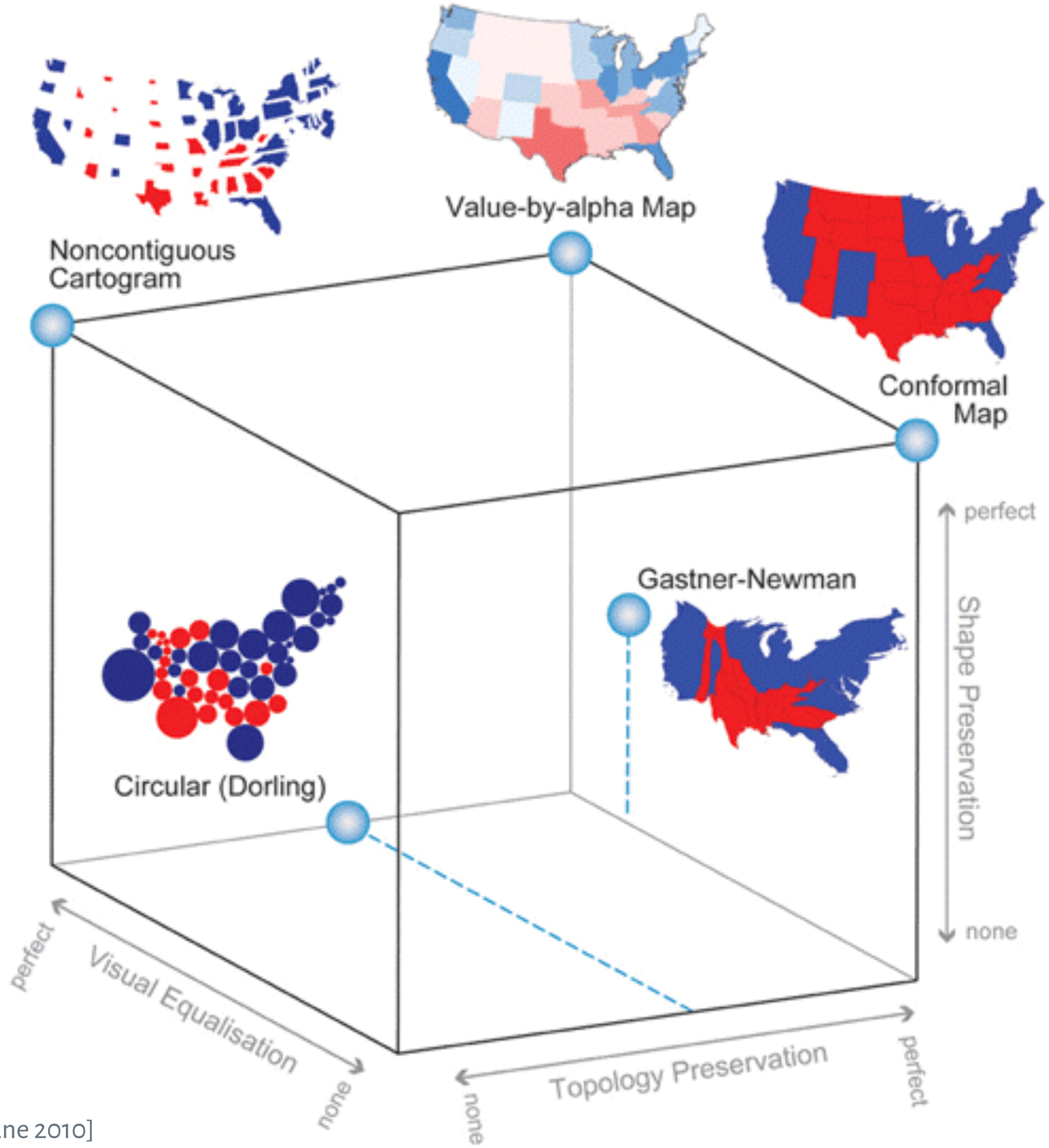
NPR



Wall Street Journal



FiveThirtyEight

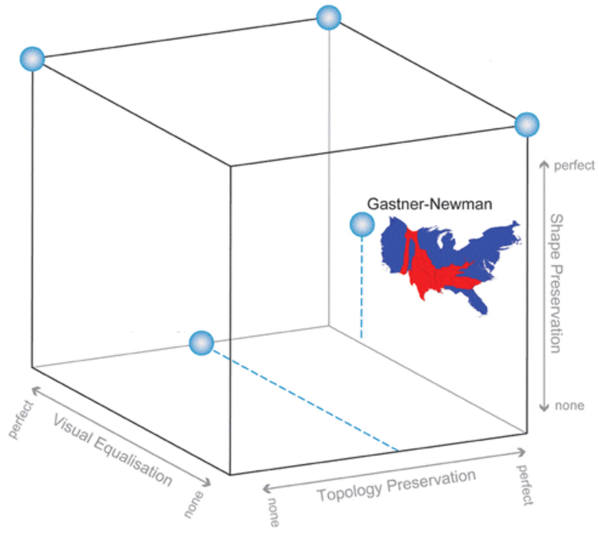


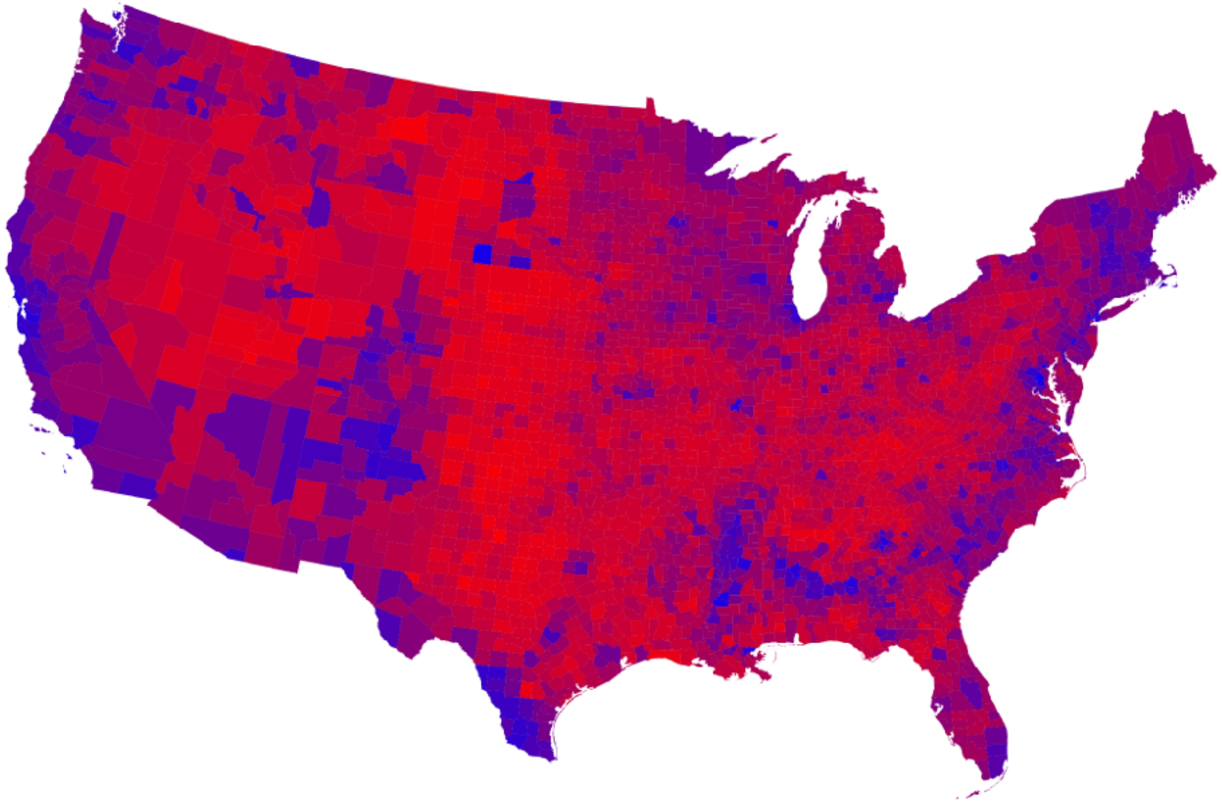
[Rob Roth, Andy Woodruff, Zach Johnson. June 2010]

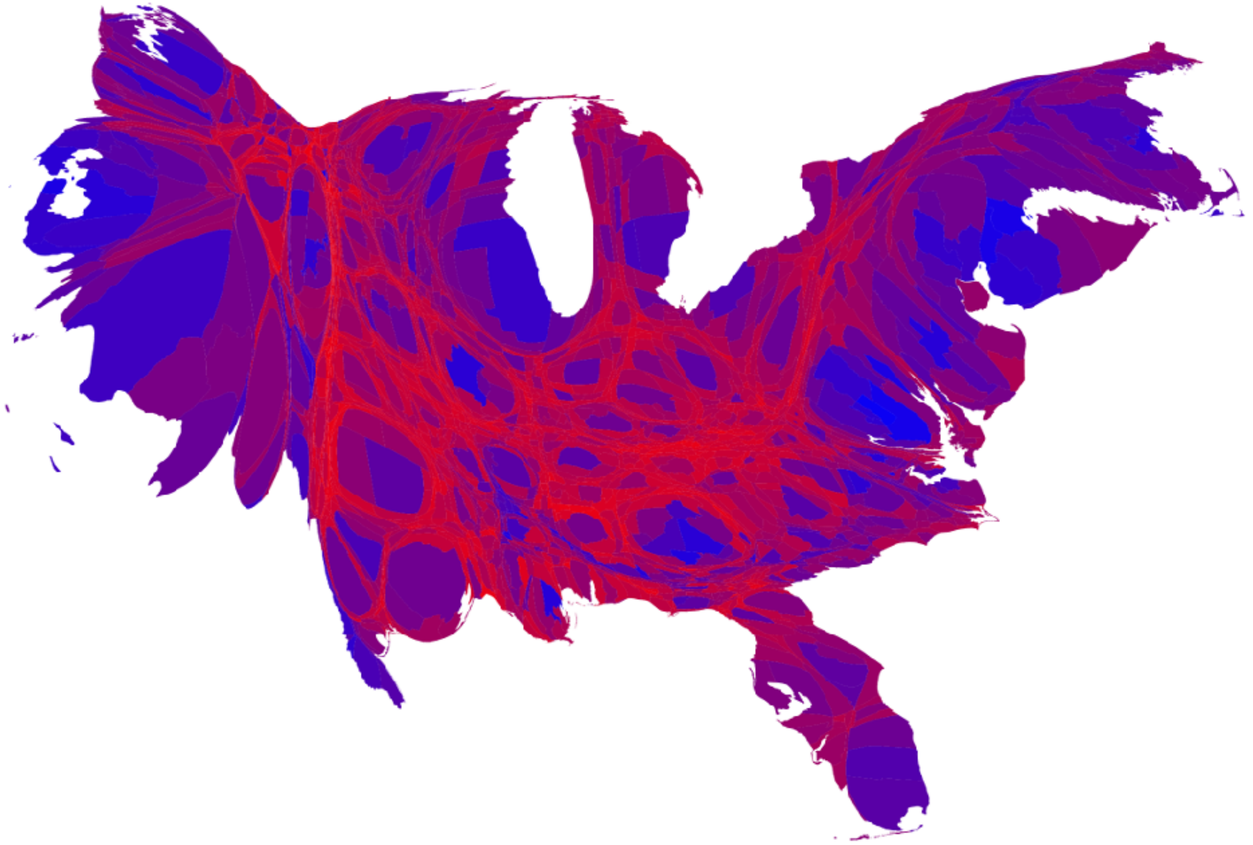
Gastner-Newman

Physical diffusion model.

Population "flows" from high-density areas to low-density areas until density is roughly equal everywhere.







[M. E. J. Newman. 2016]

China Still Dominates, but Some Manufacturers Look Elsewhere

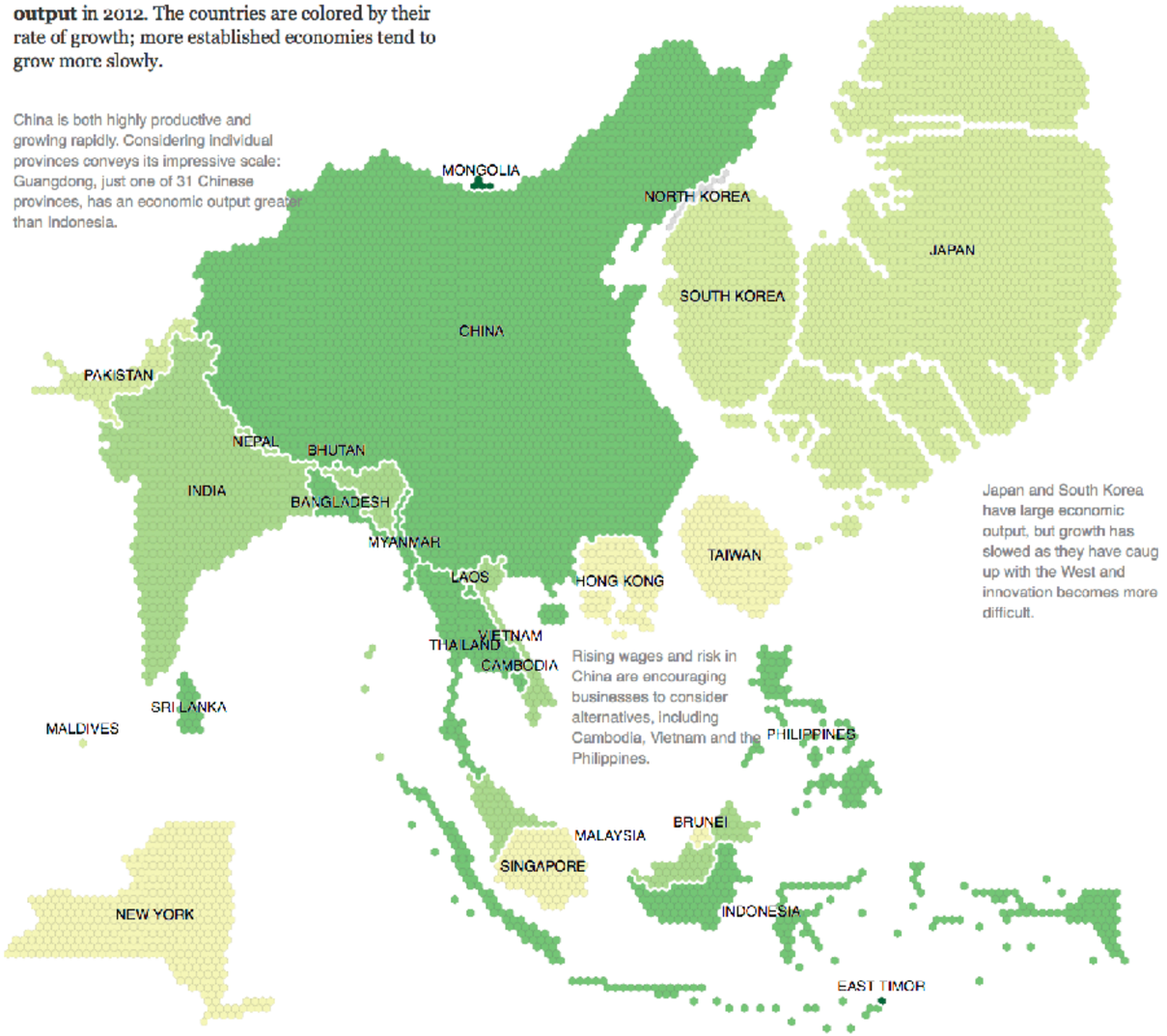
While China maintains its overwhelming dominance in manufacturing, multinational companies are looking for ways to limit their reliance on factories there. Related Article »

Economic Output

In this map, geography is distorted so that each country is **sized according to its economic output** in 2012. The countries are colored by their rate of growth; more established economies tend to grow more slowly.

Each hexagon represents $2.7 billion in G.D.P.

G.D.P. growth, 2011 to 2012: 2 4 6 8 +10%



China is both highly productive and growing rapidly. Considering individual provinces conveys its impressive scale: Guangdong, just one of 31 Chinese provinces, has an economic output greater than Indonesia.

Japan and South Korea have large economic output, but growth has slowed as they have caug up with the West and innovation becomes more difficult.

Rising wages and risk in China are encouraging businesses to consider alternatives, including Cambodia, Vietnam and the Philippines.

New York shown for comparison.

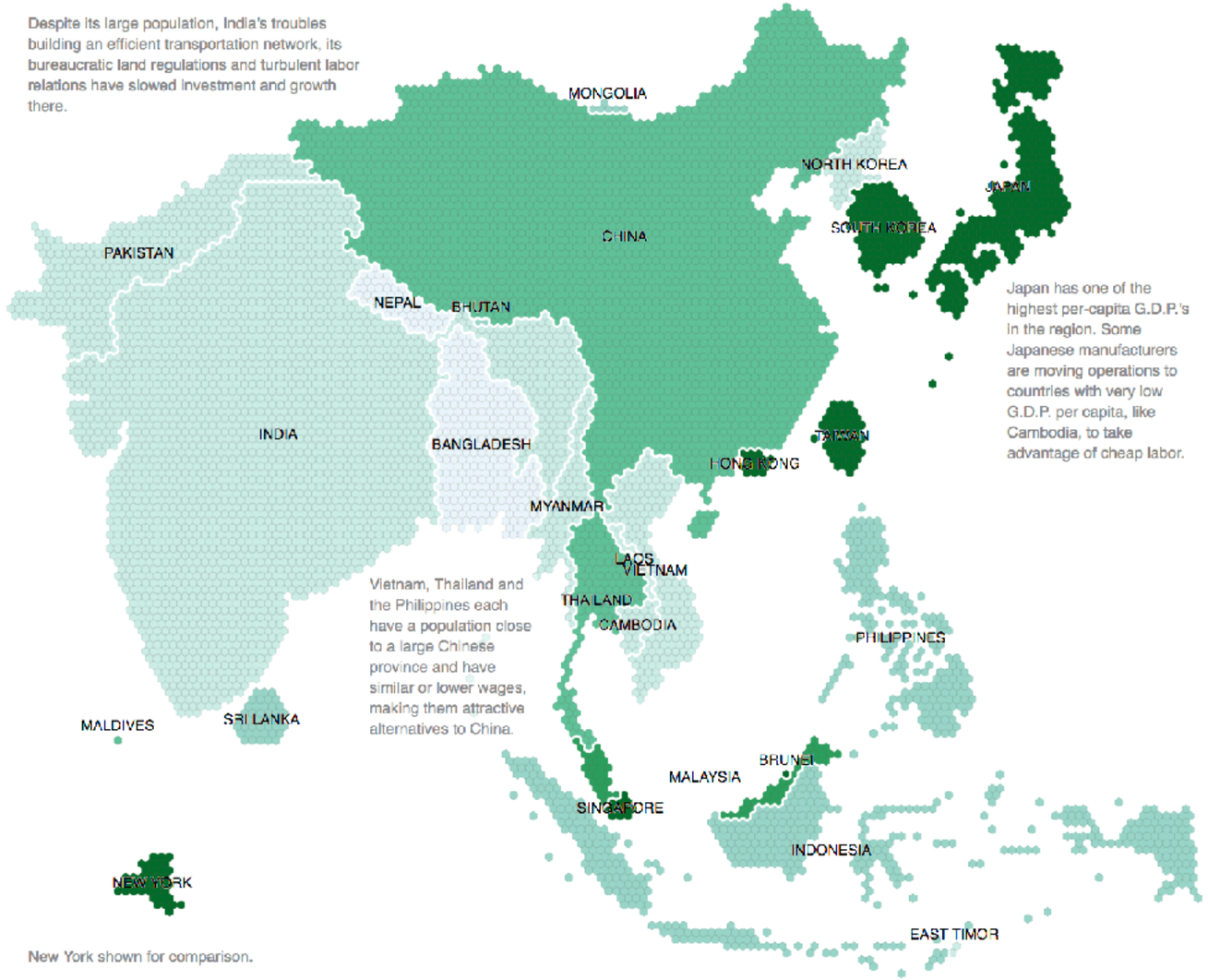
Population

Sizing by population instead gives an estimate of a country's economic potential, at least for labor-based manufacturing. The color here shows the economic output per capita: a measure of how effectively that potential has been realized, and a proxy for labor cost.

Each hexagon represents 500,000 people

G.D.P. per capita, 2012: 1 2 5 10 $20K

Despite its large population, India's troubles building an efficient transportation network, its bureaucratic land regulations and turbulent labor relations have slowed investment and growth there.



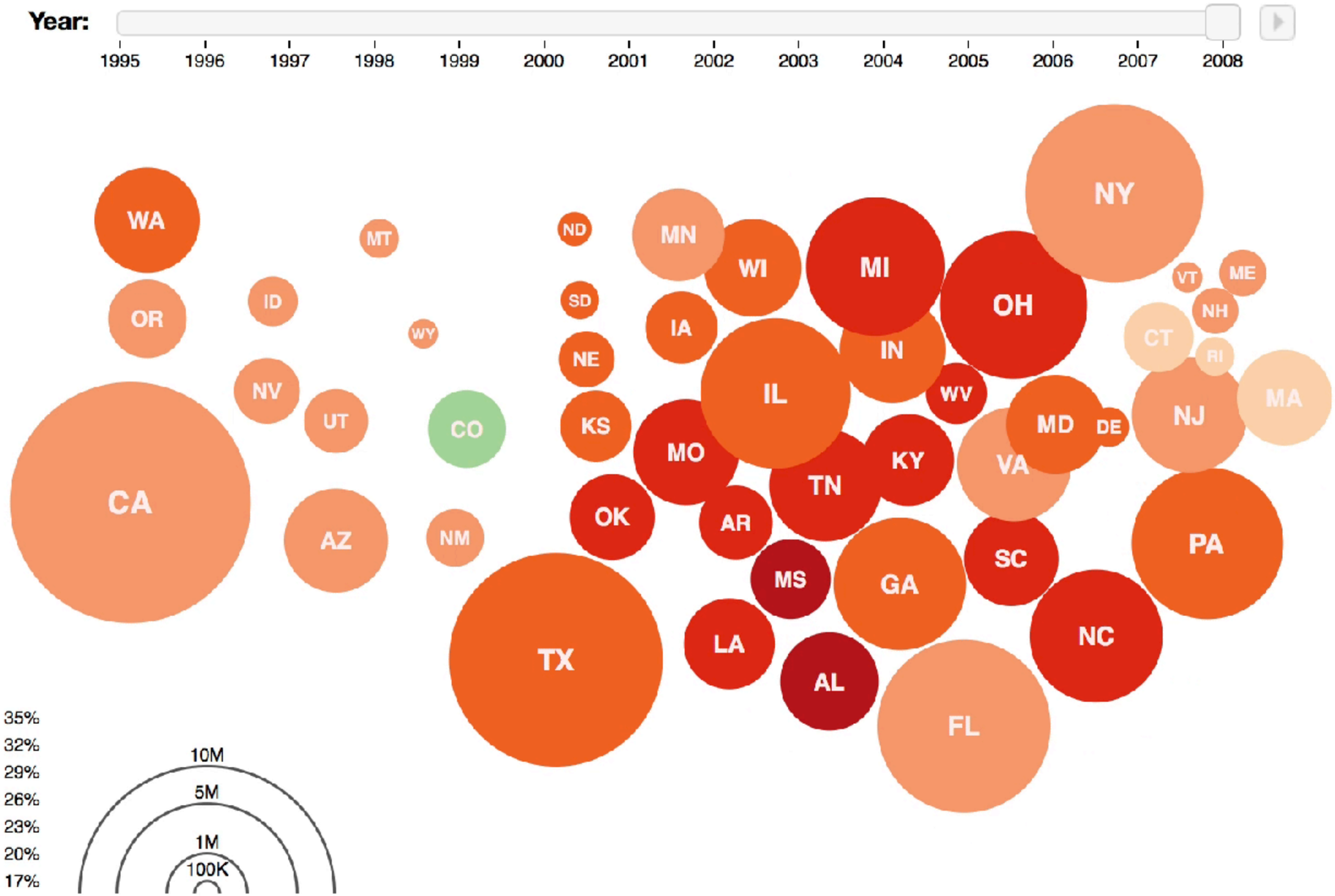
Japan has one of the highest per-capita G.D.P.'s in the region. Some Japanese manufacturers are moving operations to countries with very low G.D.P. per capita, like Cambodia, to take advantage of cheap labor.

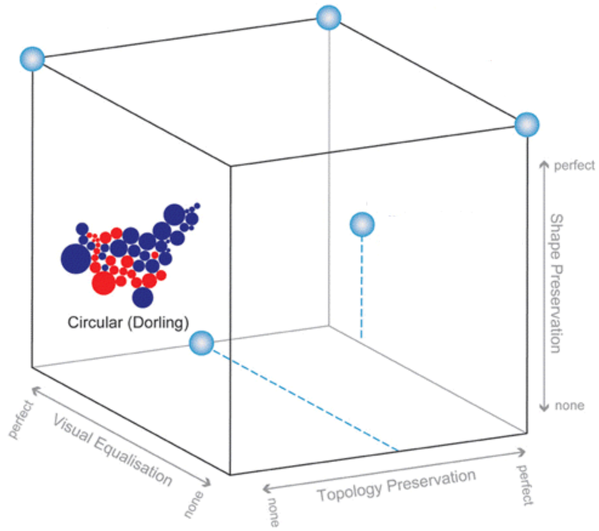
Vietnam, Thailand and the Philippines each have a population close to a large Chinese province and have similar or lower wages, making them attractive alternatives to China.

New York shown for comparison.

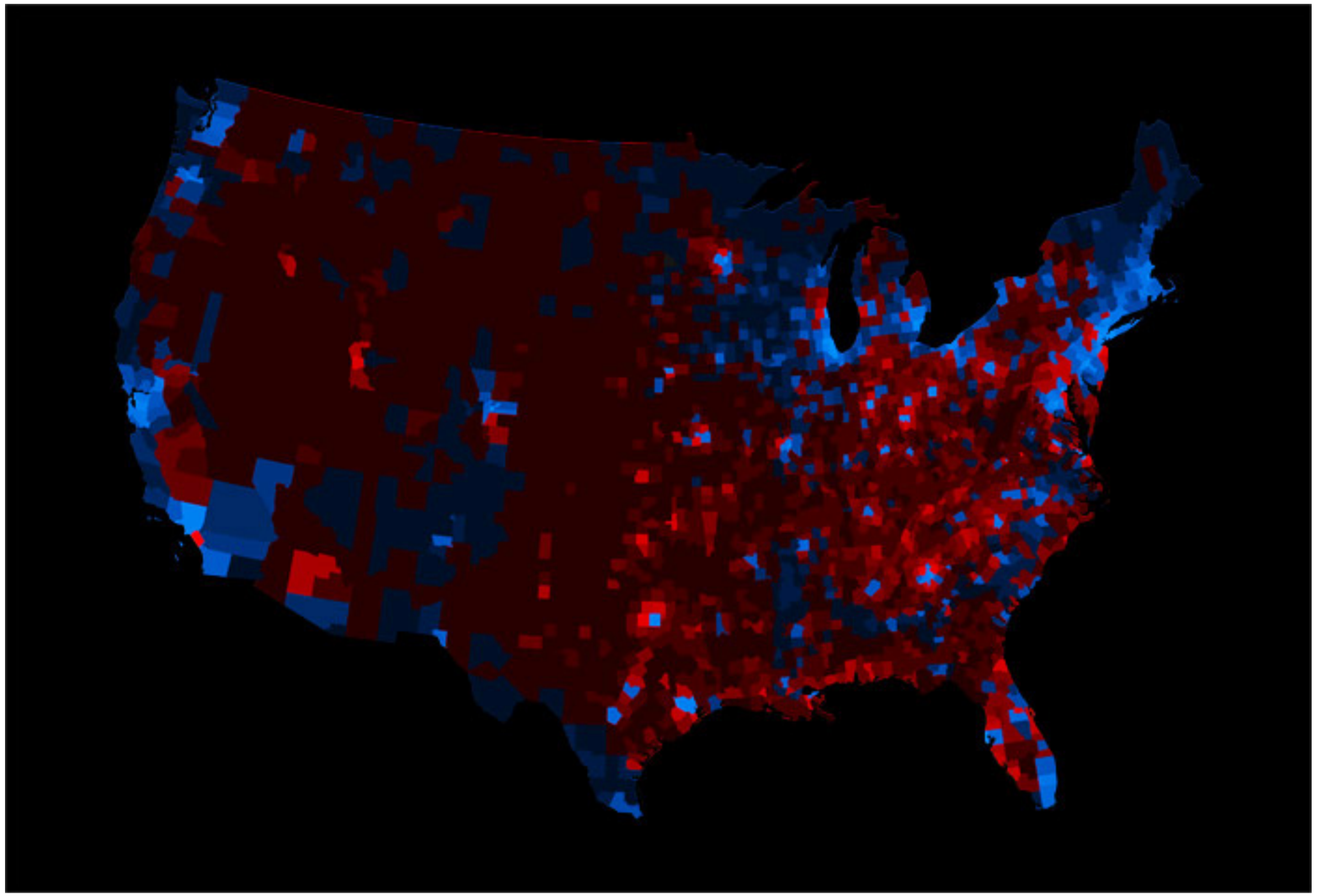
By MIKE BOSTOCK; Additional reporting by KEITH BRADSHER

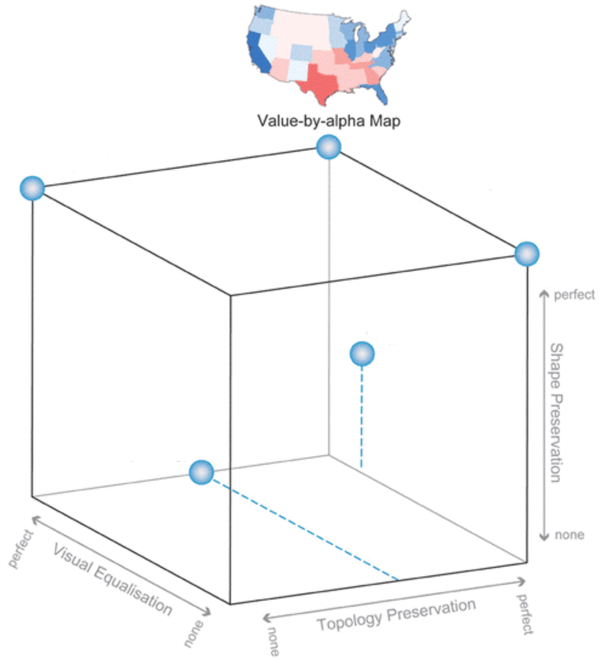
Dorling Cartograms





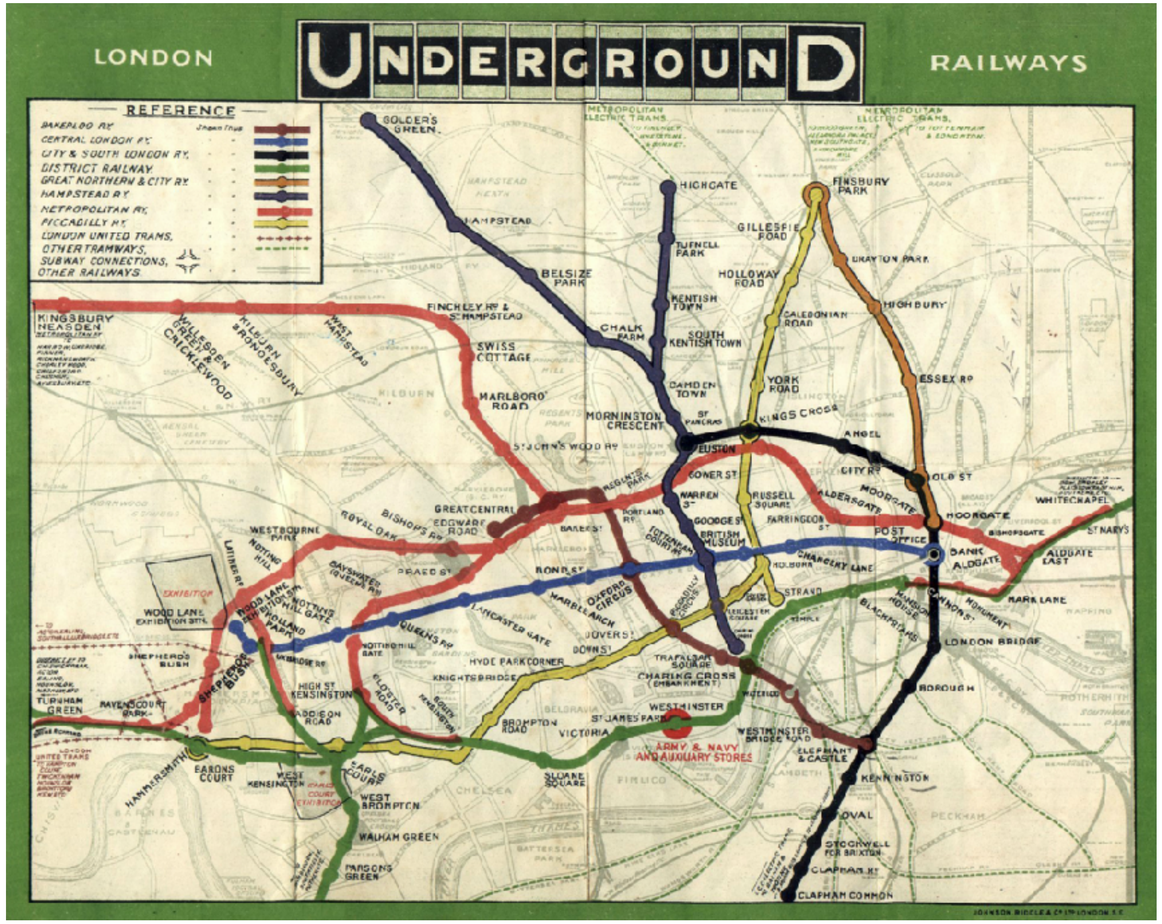
Value-By-Alpha





[Rob Roth, Andy Woodruff, Zach Johnson. June 2010]

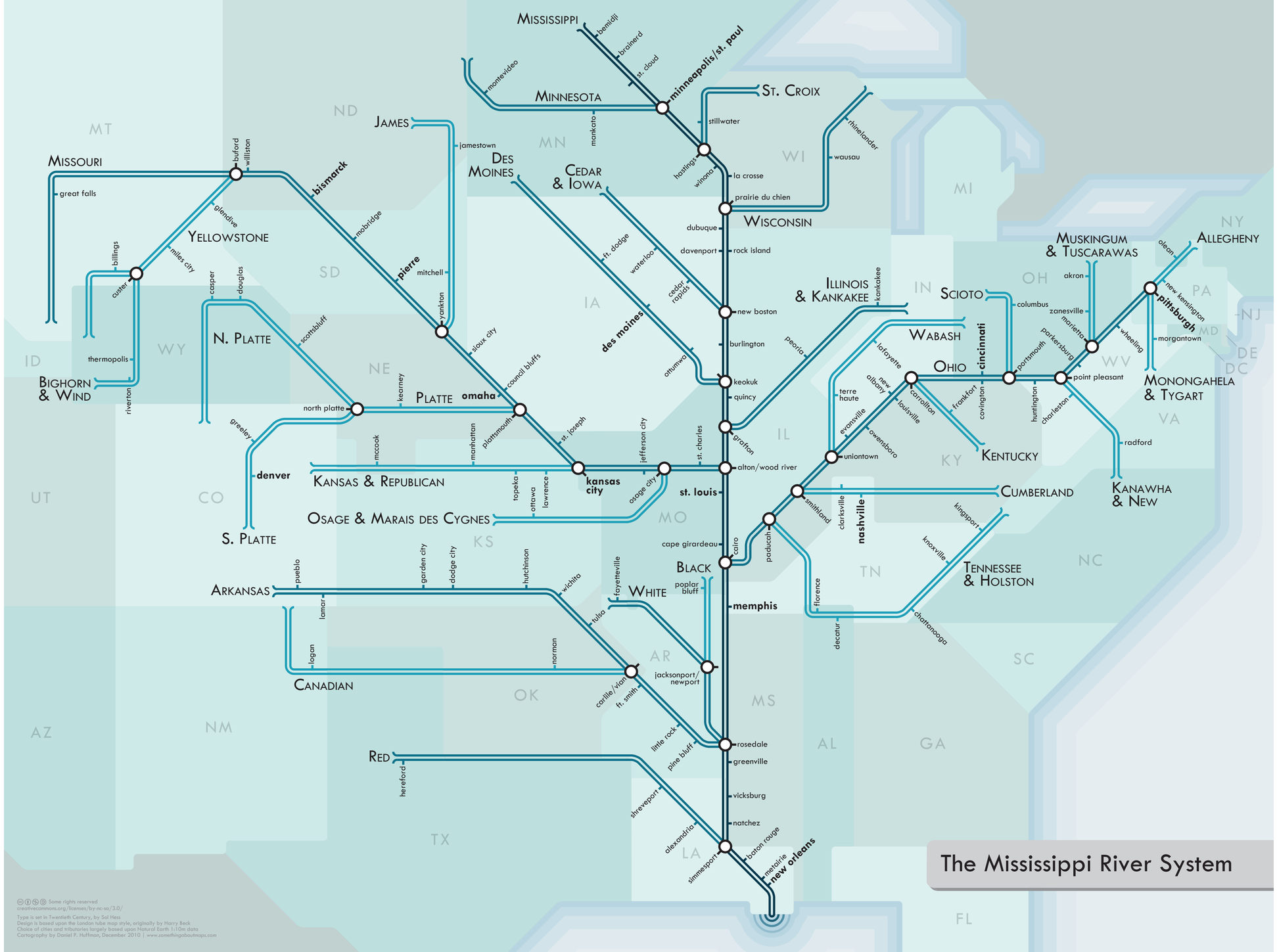
Route Maps

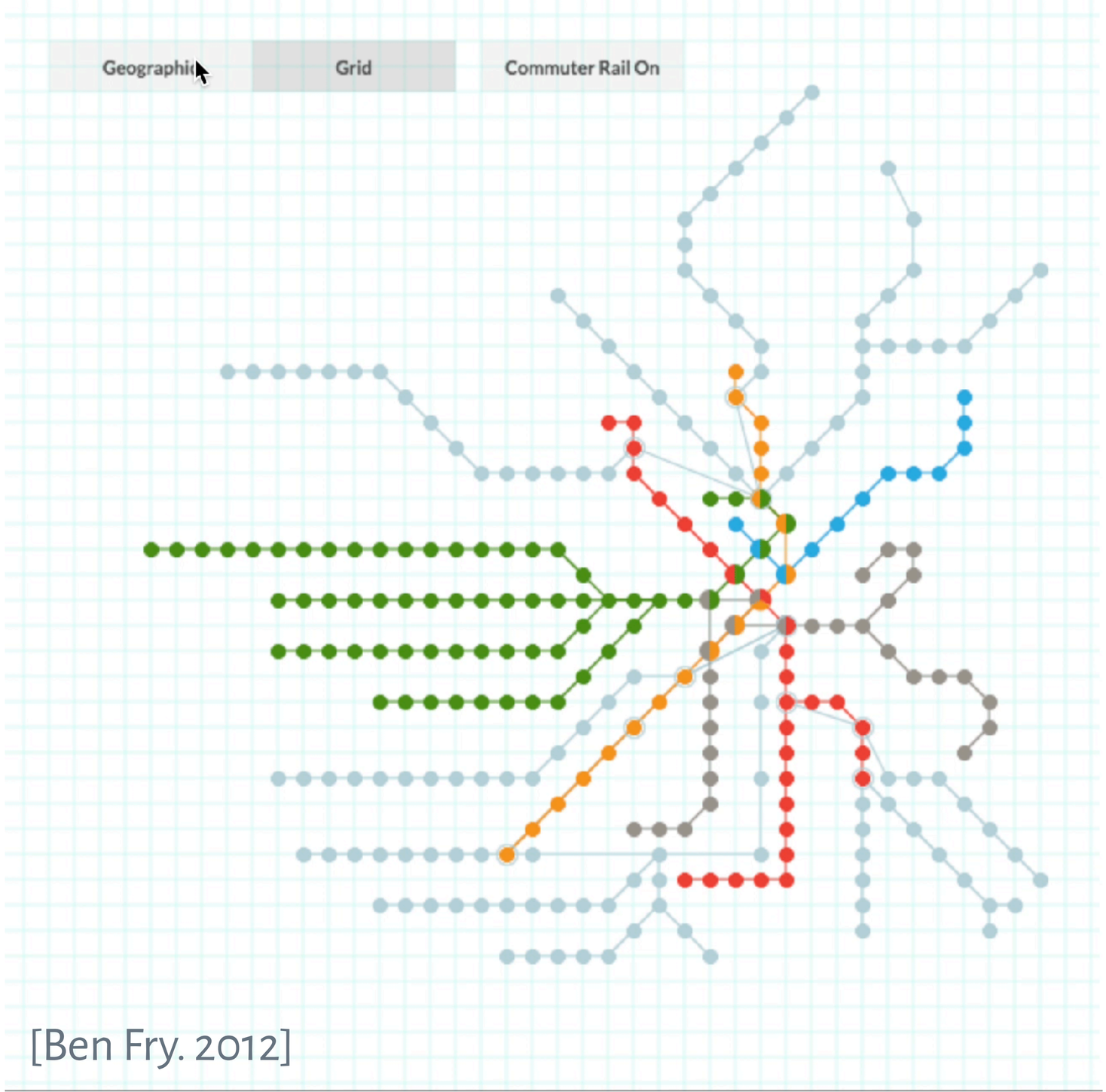


Geographic version of map

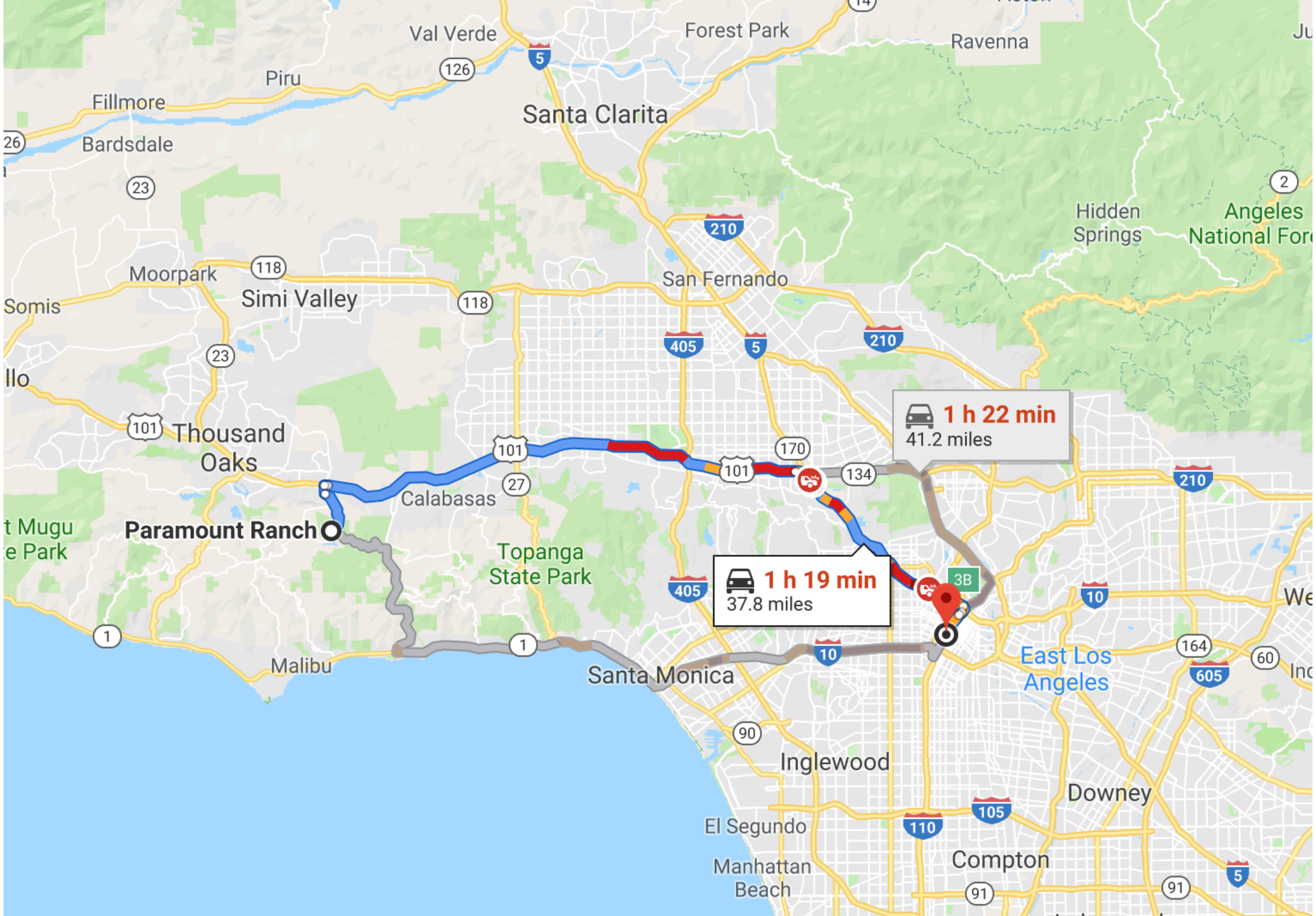
London Underground [Beck 33]

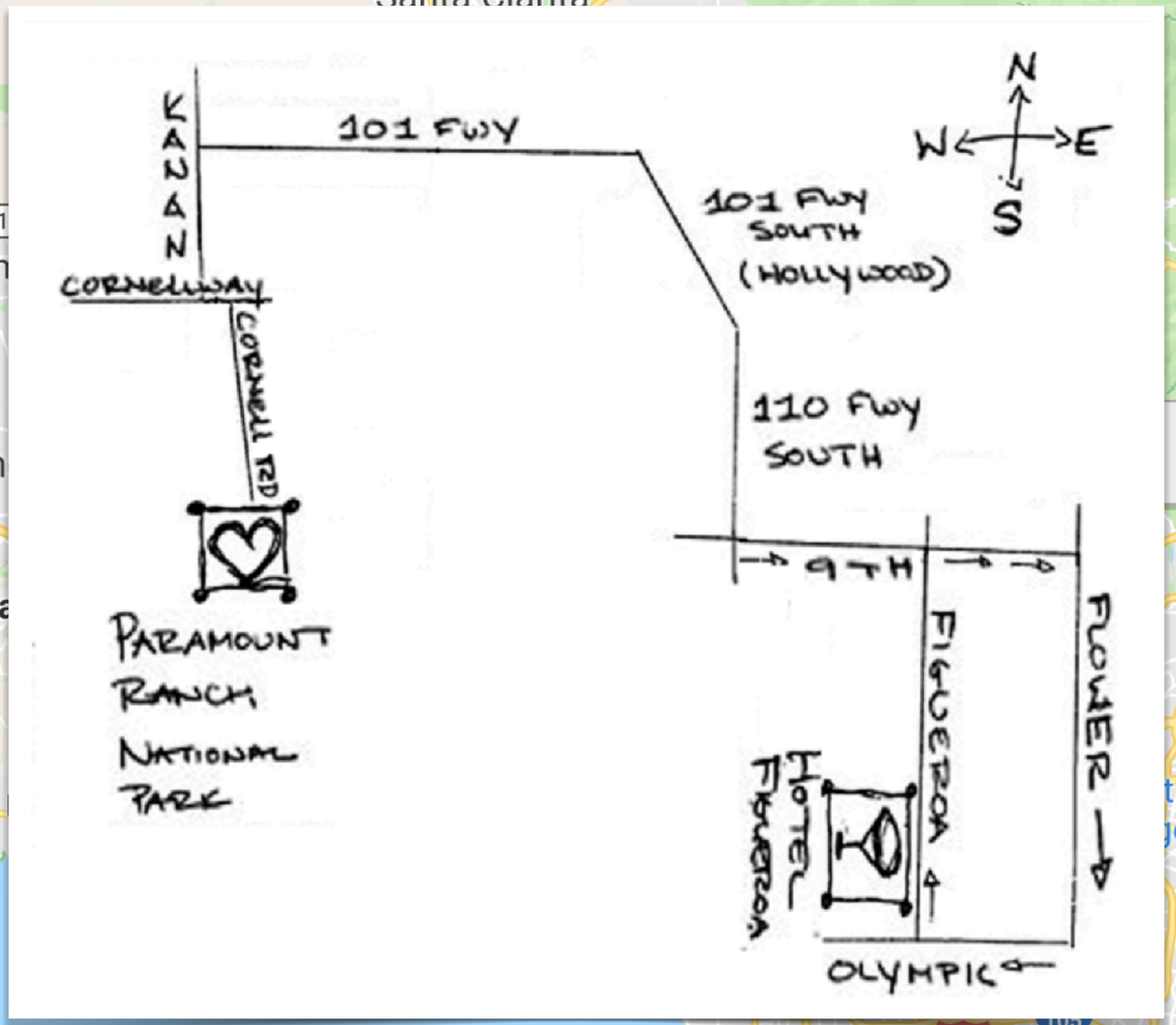
[Daniel Huffman. River Maps]





[Ben Fry. 2012]


1 h 22 min
41.2 miles
1 h 19 min
37.8 miles
Paramount Ranch
Thousand Oaks
Simi Valley
Moorpark
Somis
Fillmore
Bardsdale
Piru
Val Verde
Santa Clarita
Forest Park
Ravenna
Hidden Springs
Angeles National Fore
San Fernando
Calabasas
Topanga State Park
Malibu
Santa Monica
East Los Angeles
Inglewood
Downey
El Segundo
Manhattan Beach
Compton
3B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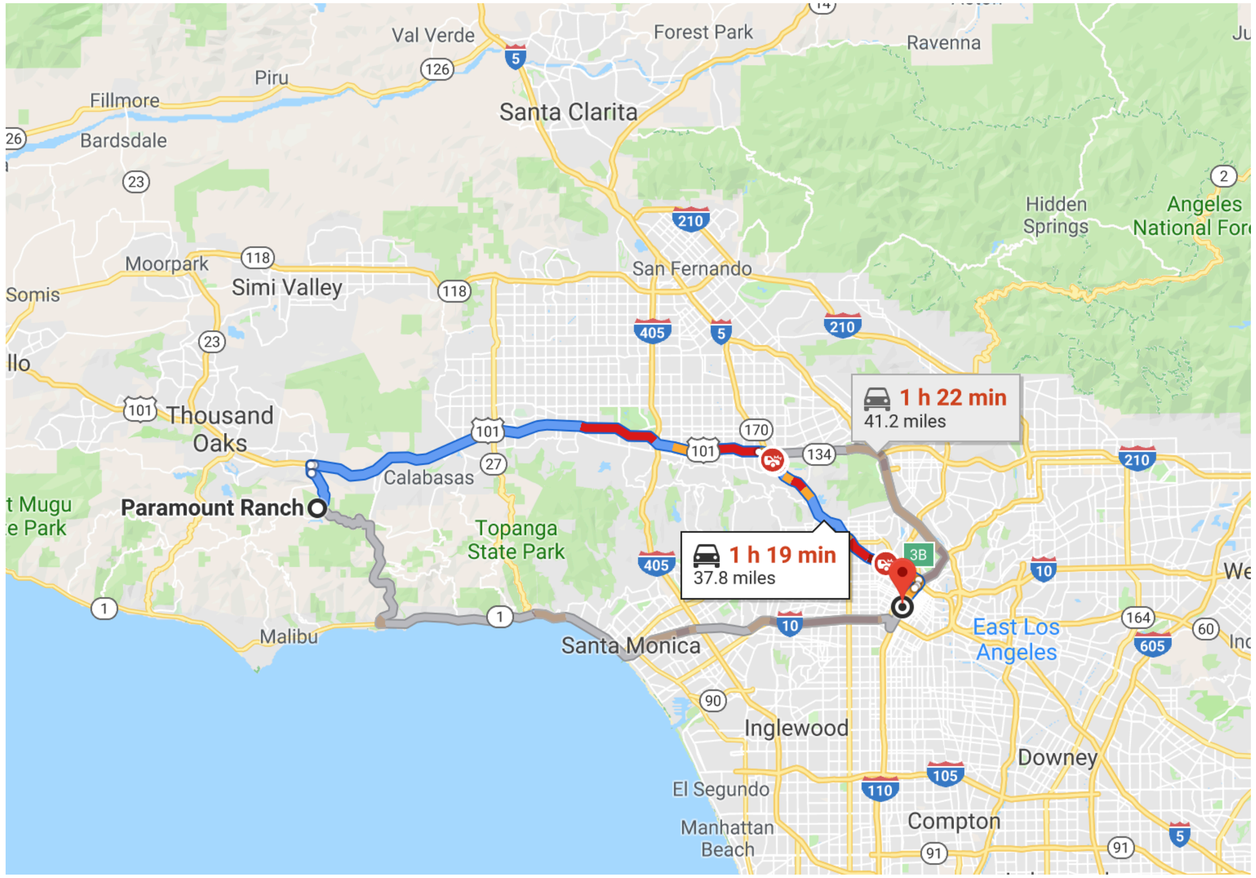
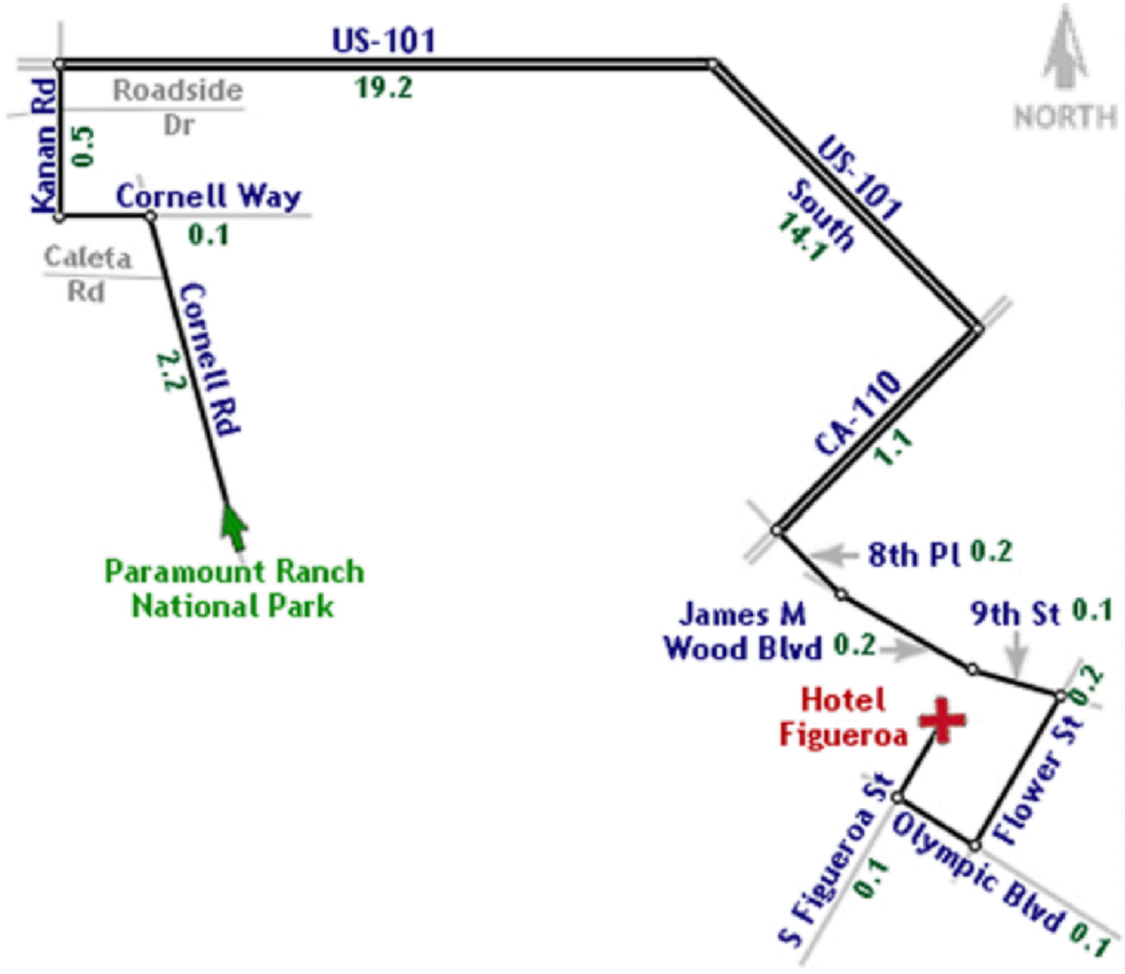
KANAN
CORNELL WAY
CORNELL RD
PARAMOUNT RANCH, NATIONAL PARK
101 FWY SOUTH (HOLLYWOOD)
110 FWY SOUTH
9TH
FIGUEROA
FLOWER
OLYMPIC
HOTEL FIGUEROA
N
W
E
S

Line Drive





[Agrawala and Stolte. SIGGRAPH 2001]

Tooling

Web Tools

- **D3/Vega/Vega-Lite:** Projections, paths, graticules, etc.
- **GeoJSON**: JSON format for geo data.
- **TopoJSON**: Topology → compressed GeoJSON.
- **Leaflet**: open-source, customizable map tile system.

Data Resources

- **Natural Earth Data**: naturalearthdata.com
- **OpenStreetMap**: openstreetmap.org
- **U.S. Government**: nationalatlas.gov, usgs.gov

Tutorials

- **Command Line Cartography**, by Mike Bostock
  https://medium.com/@mbostock/command-line-cartography-part-1-897aa8f8ca2c