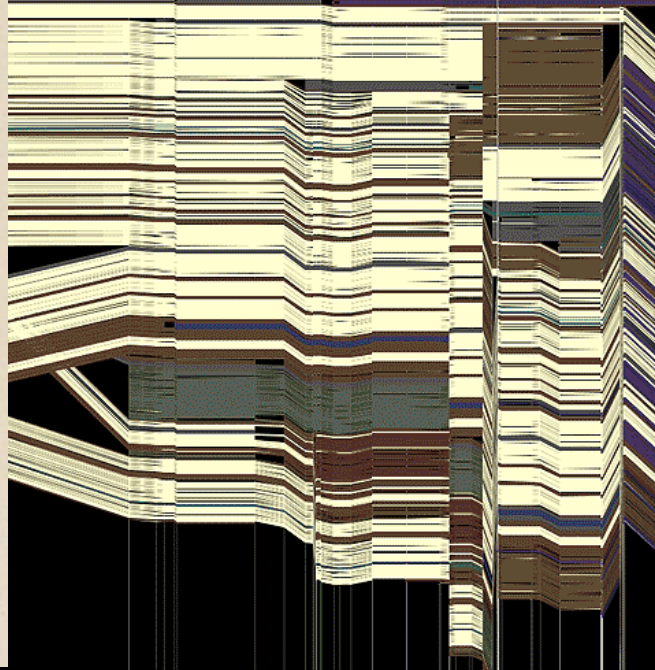
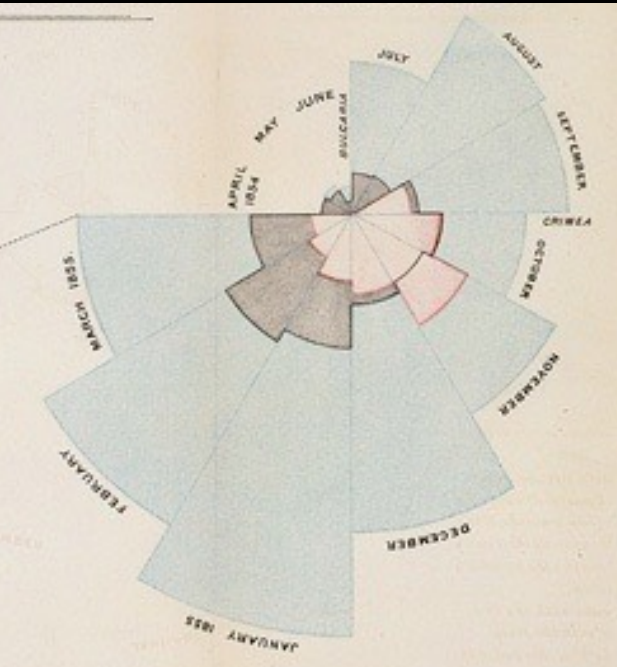


CSE 442 - Data Visualization

Mapping & Cartography

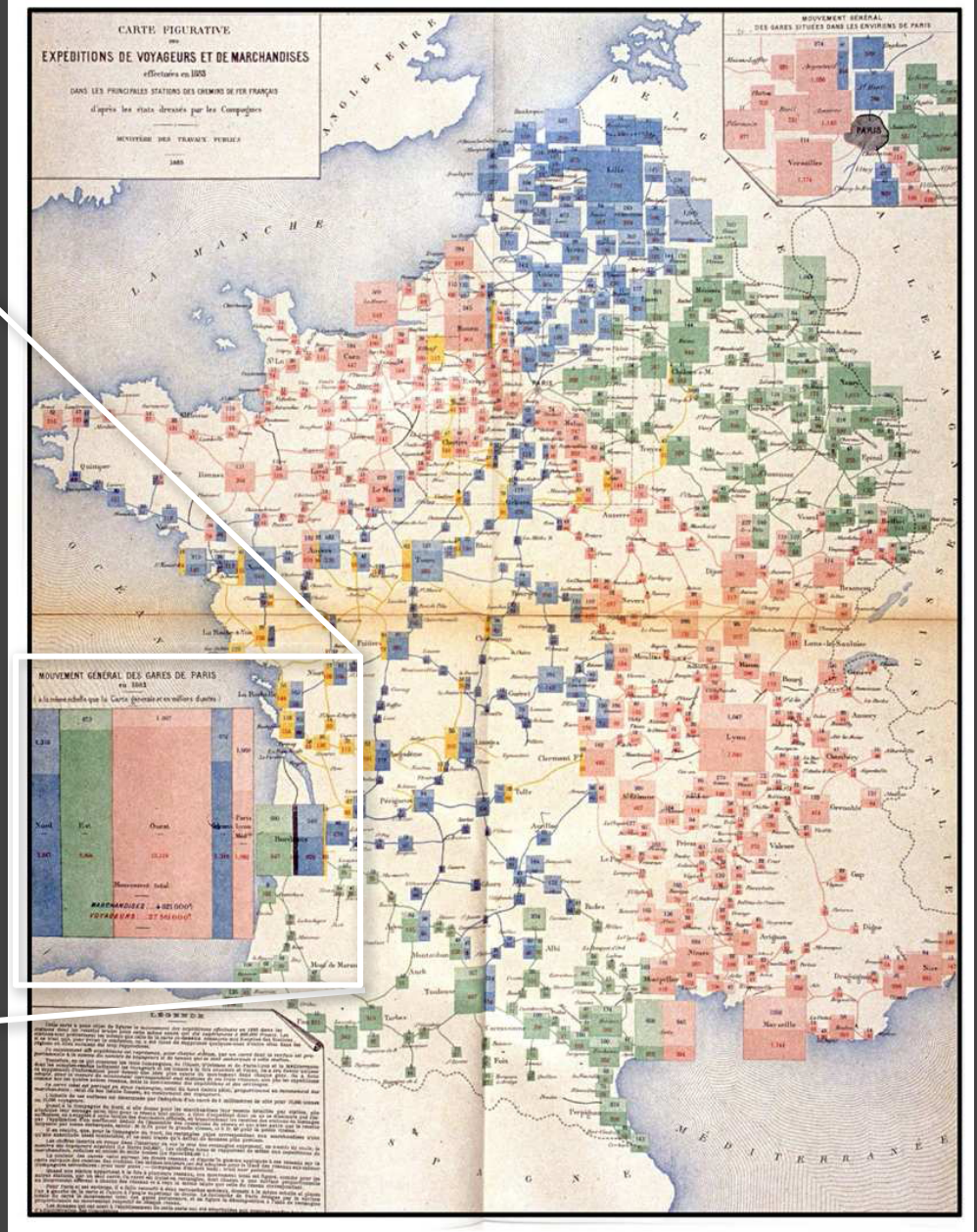
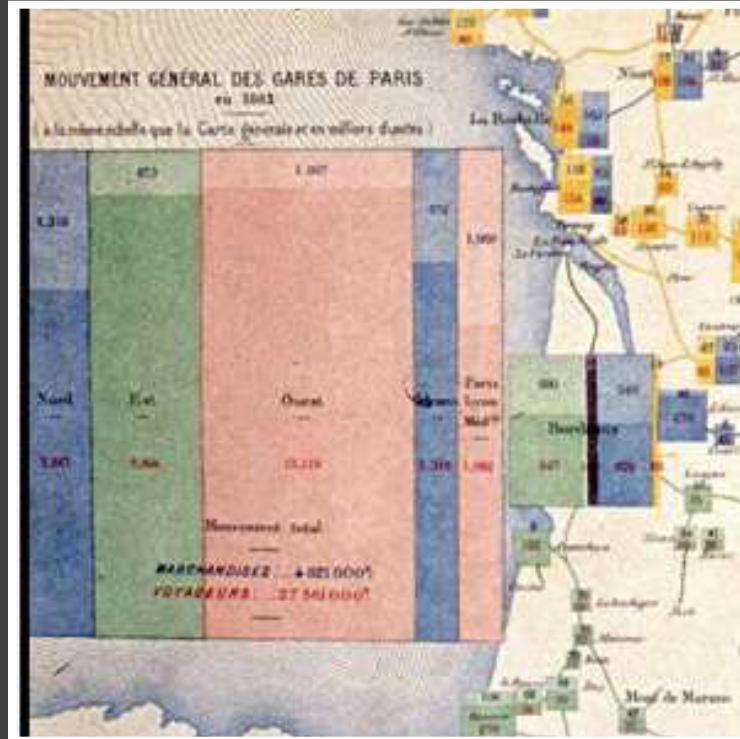


Jeffrey Heer University of Washington

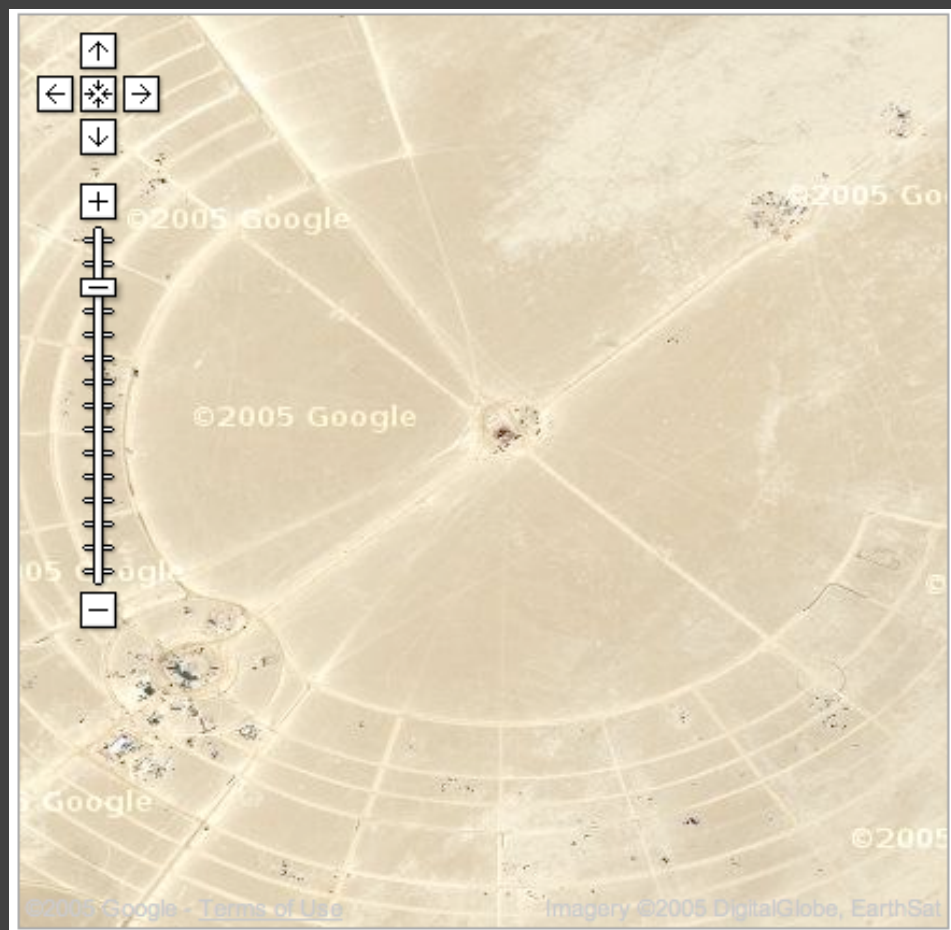
(with significant material from Michal Migurski)



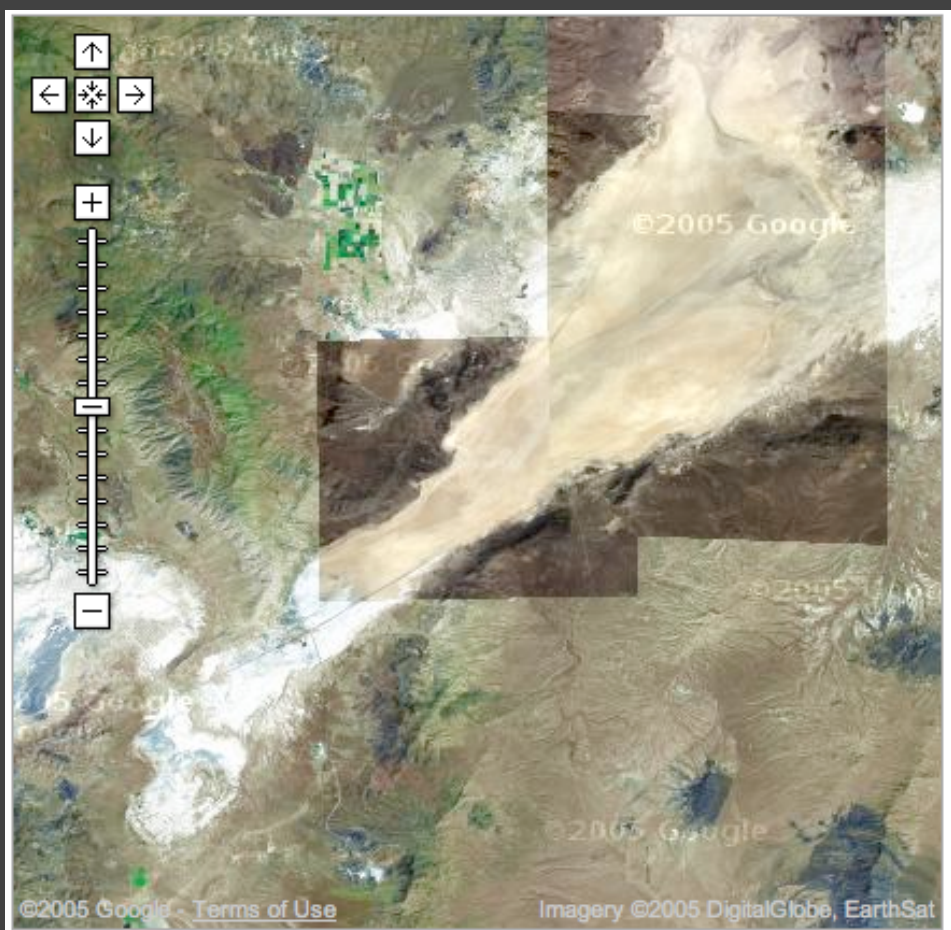
Ptolemy's Geographica
Original ~150AD, This Map ~1300AD



Rail Passengers and Freight from Paris 1884



Black Rock City, Nevada
(Burning Man)



Google Maps 2005

[WORLD](#) [U.S.](#) [N.Y. / REGION](#) [BUSINESS](#) [TECHNOLOGY](#) [SCIENCE](#) [HEALTH](#) [SPORTS](#) [OPINION](#) [ARTS](#) [STYLE](#) [TRAVEL](#) [JOBS](#) [REAL ESTATE](#) [AUTOS](#)
[POLITICS](#) [WASHINGTON](#) [EDUCATION](#)

Casualties of War

[FACES](#) [ANALYSIS](#) [THEIR STORIES](#)
[E-MAIL](#) [FEEDBACK](#)

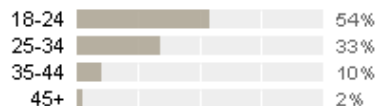
Use the slider below to investigate the demographics and military status of U.S. service members who died during the war in Iraq.

MARCH 16, 2003 JULY 5, 2008 (277 WEEKS)

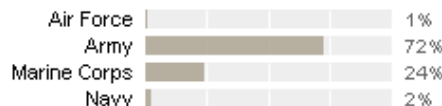
[Show all](#) | [Initial invasion](#) | [First invasion of Falluja](#) | [Second invasion of Falluja](#) | [Since troop buildup began](#)

4,097 deaths

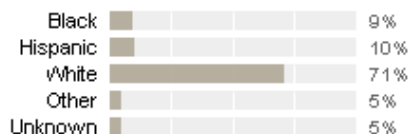
Age



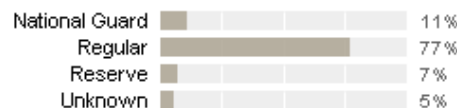
Branch of Military



Race



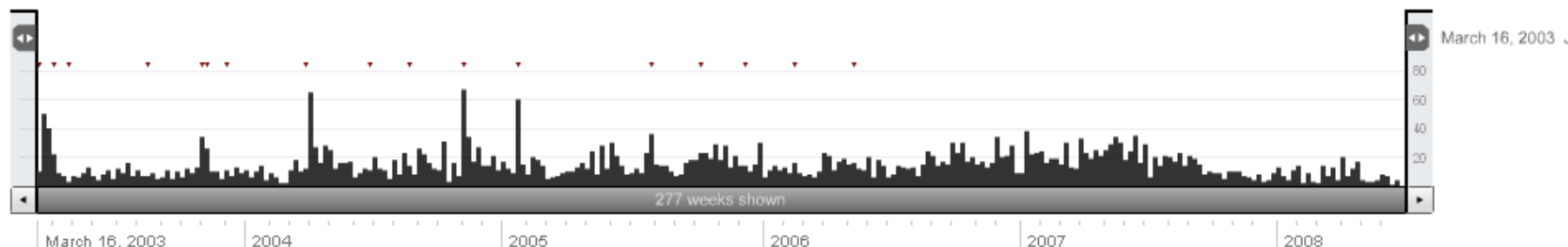
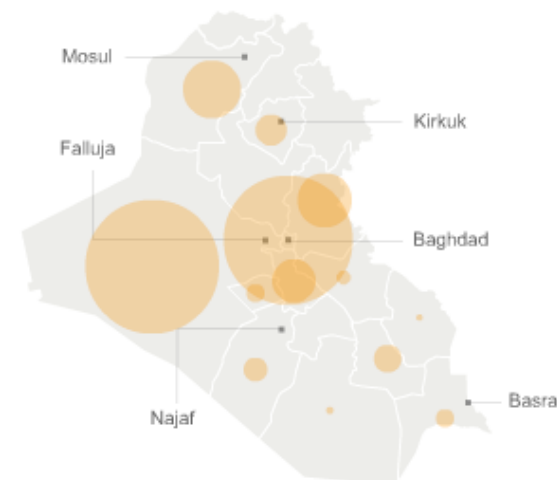
Type of Duty



Location of death

Circles sized according to percentage of deaths in each Iraqi province.

[Show home](#)





A Rogue State Along Two Rivers

How ISIS Came to Control Large Portions of Syria and Iraq

By JEREMY ASHKENAS, ARCHIE TSE, DEREK WATKINS and KAREN YOURISH July 3, 2014

The militant group called the Islamic State in Iraq and Syria, or ISIS, seemed to surprise many American and Iraqi officials with the recent gains it made in its violent campaign to create a new religious state. But the rapid-fire victories achieved over a few weeks in June were built on months of maneuvering along the Tigris and Euphrates Rivers.

The Euphrates

Aleppo: Ejected by Other Rebel Groups

In 2013, ISIS emerged from the remnants of Al Qaeda in Iraq and began to operate in Syria. The vacuum created by the country's civil war provided a place for ISIS to rebuild. Syrian rebel groups initially welcomed ISIS as an ally, but soon realized that they did not have the same goals. ISIS

Al Bab
ISIS Control

Jarablous: Supply Routes

ISIS Control

454 MILES TO BAGHDAD

237

Joseph R. Biden Jr.

70,098,068 votes (50.2%)

87

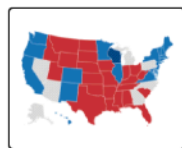
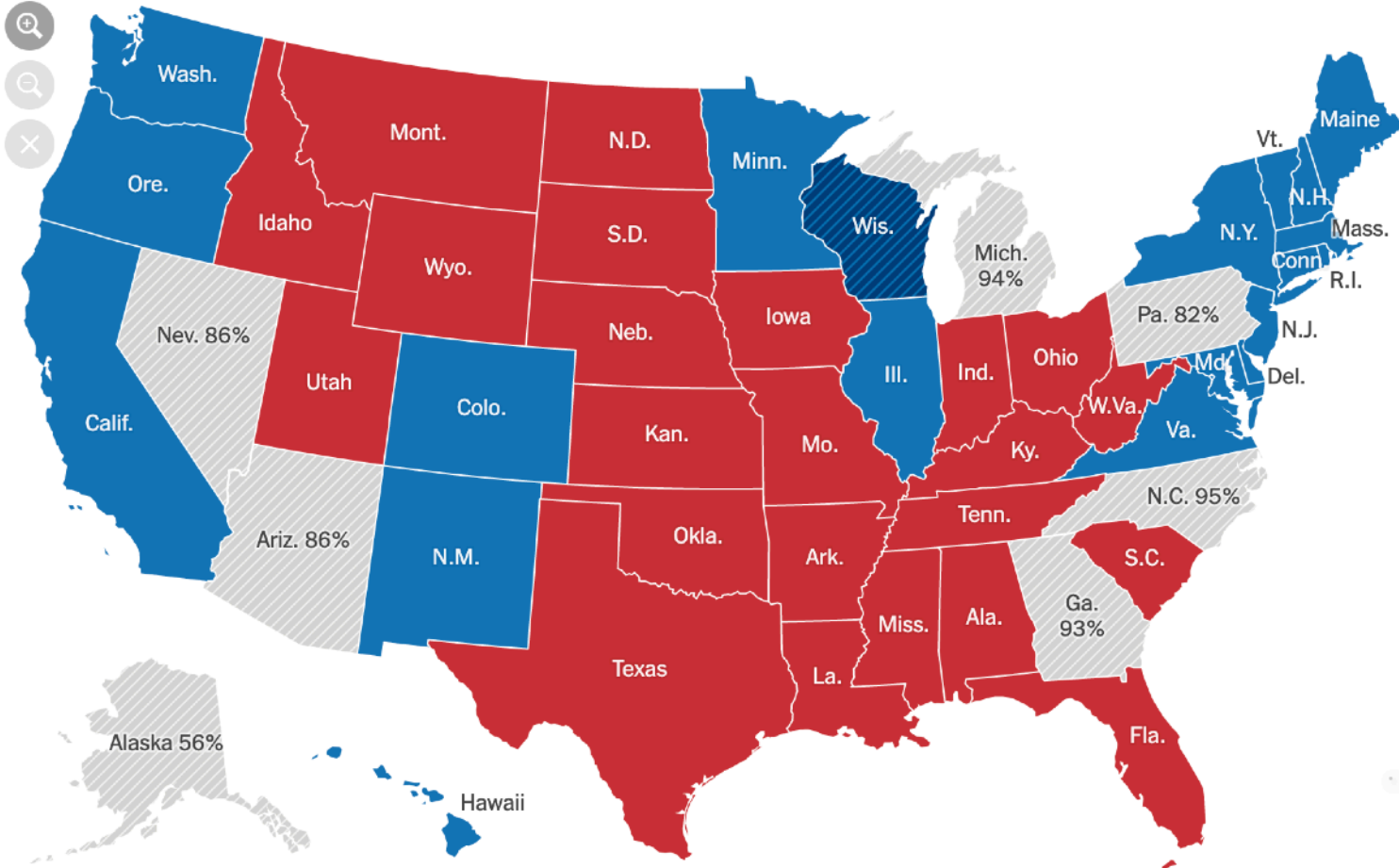
remaining

270
TO WIN

214

Donald J. Trump

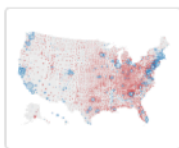
67,072,823 votes (48.1%)



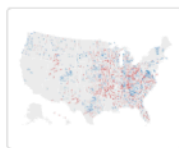
By winner



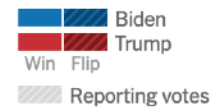
Electoral votes



Size of lead



Shift from 2016



Percentages are estimates of how much vote has been counted.

Choropleth Map
[NY Times]

237

Joseph R. Biden Jr.

70,122,063 votes (50.2%)

87

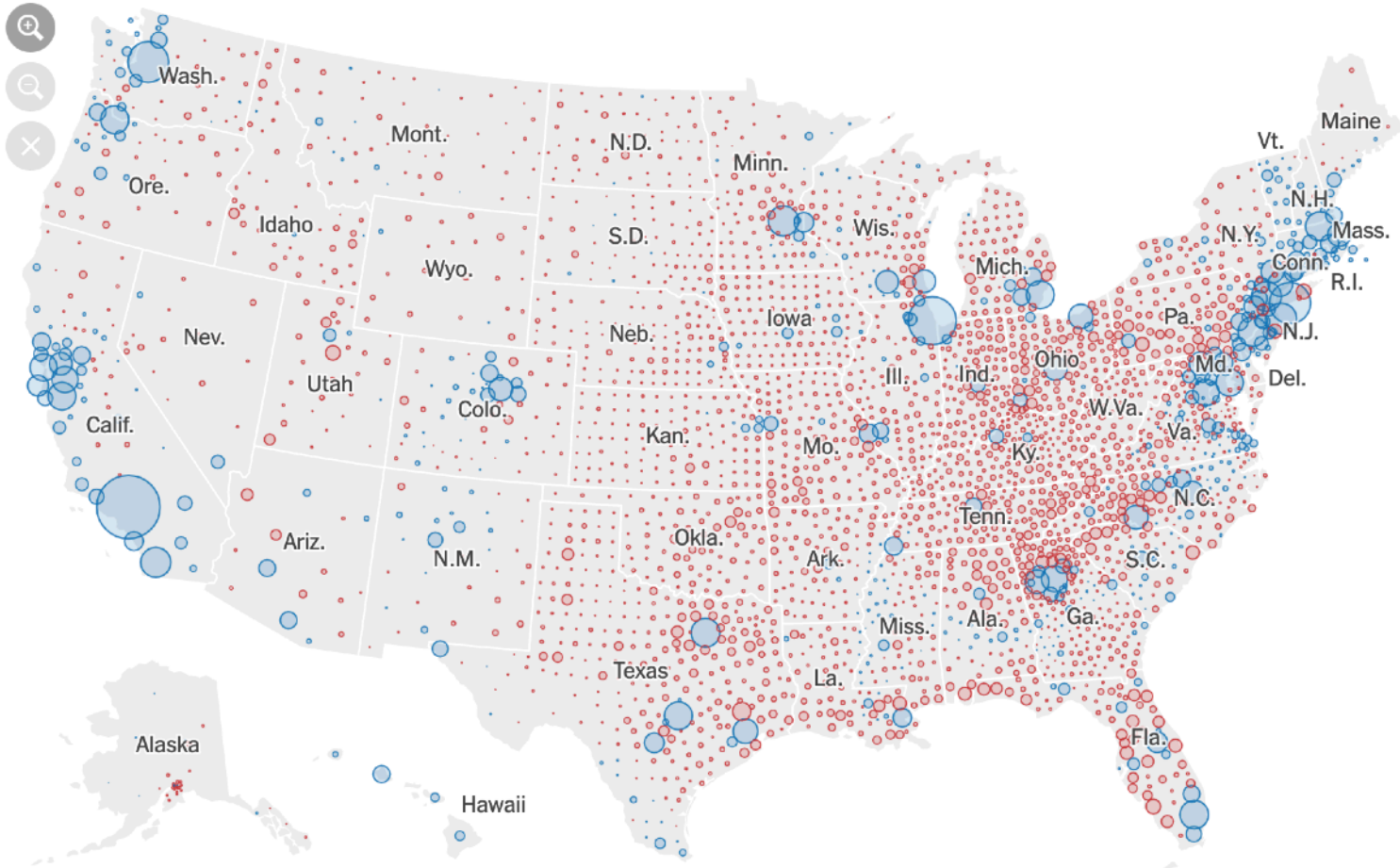
remaining

270
TO WIN

214

Donald J. Trump

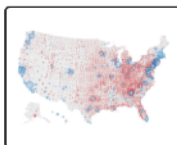
67,075,300 votes (48.0%)



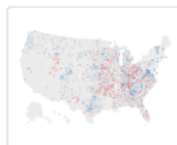
By winner



Electoral votes



Size of lead



Shift from 2016

LEADER: ● Biden ● Trump
Circle size is proportional to the amount each county's leading candidate is ahead.

Symbol Map
[NY Times]

237

Joseph R. Biden Jr.

70,122,064 votes (50.2%)

87

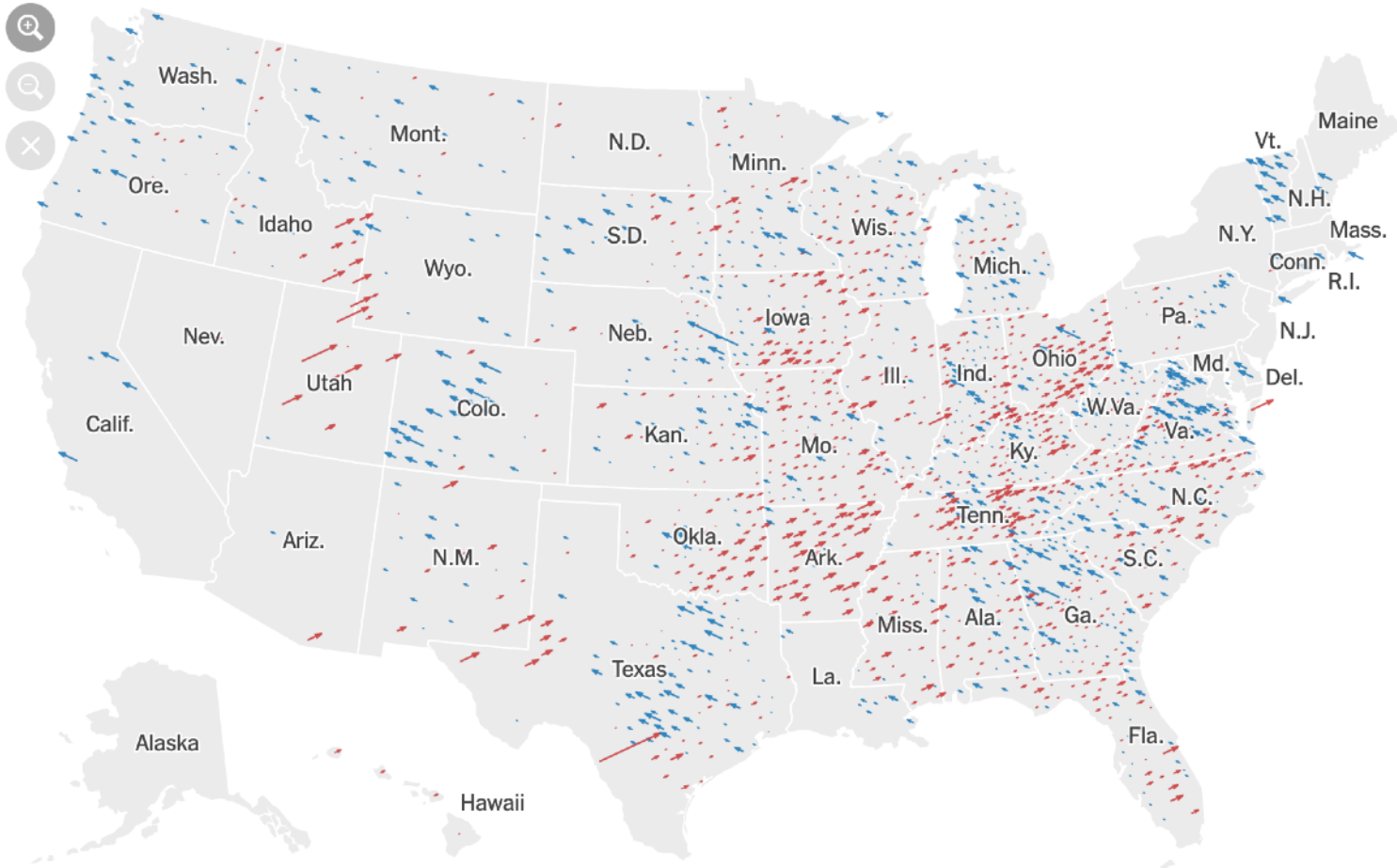
remaining

270
TO WIN

214

Donald J. Trump

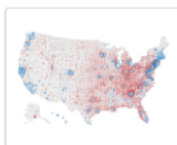
67,075,309 votes (48.0%)



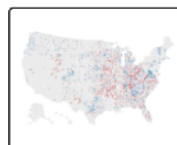
By winner



Electoral votes



Size of lead



Shift from 2016

SHIFT IN MARGIN
In counties that have reported almost all of their votes

More Democratic
More Republican

Symbol Map
[NY Times]

237

Joseph R. Biden Jr.

70,122,063 votes (50.2%)

87

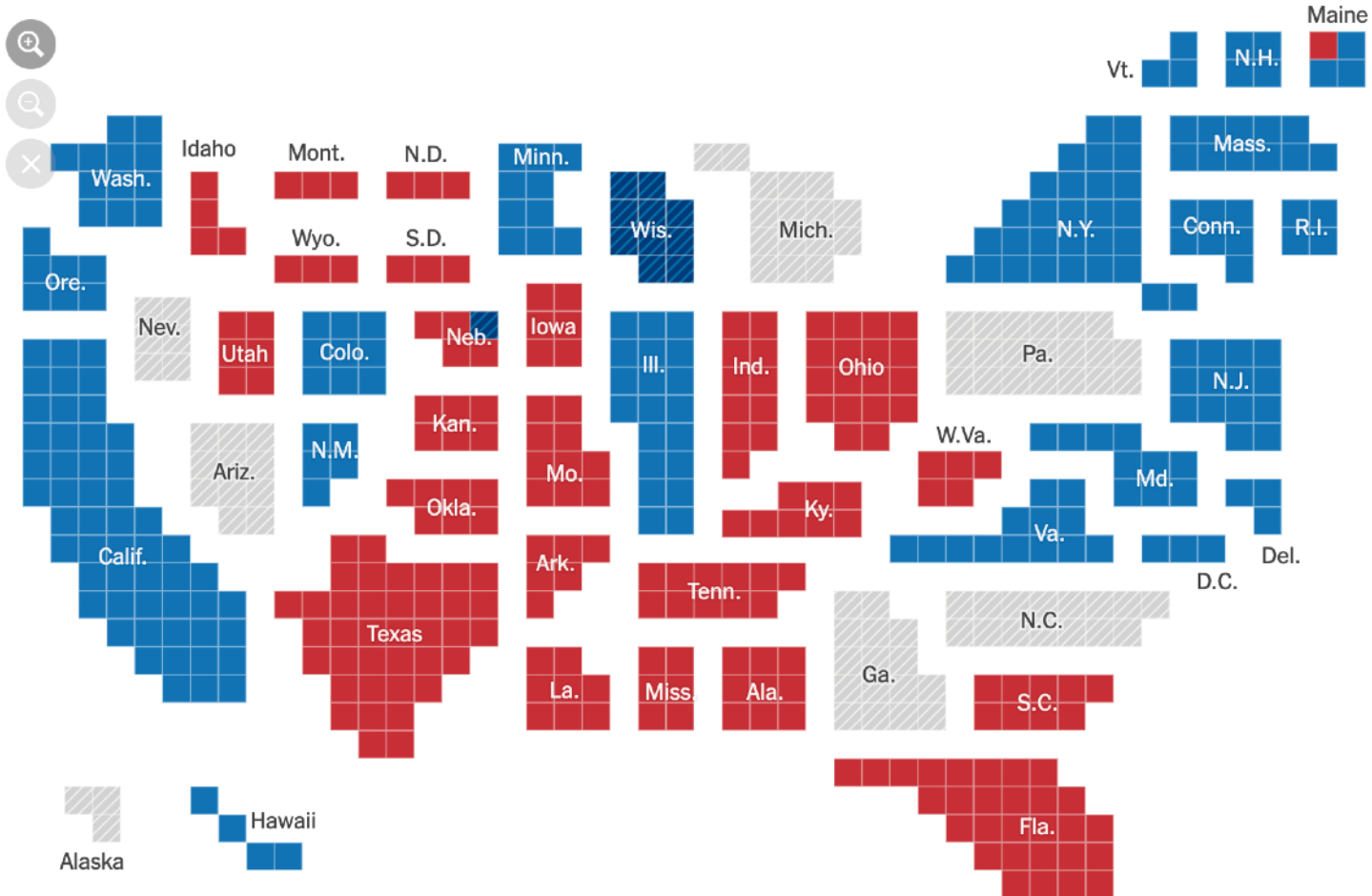
remaining

270
TO WIN

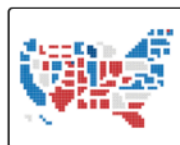
214

Donald J. Trump

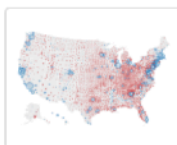
67,075,300 votes (48.0%)



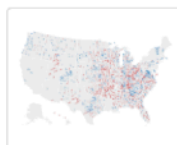
By winner



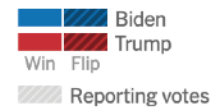
Electoral votes



Size of lead



Shift from 2016



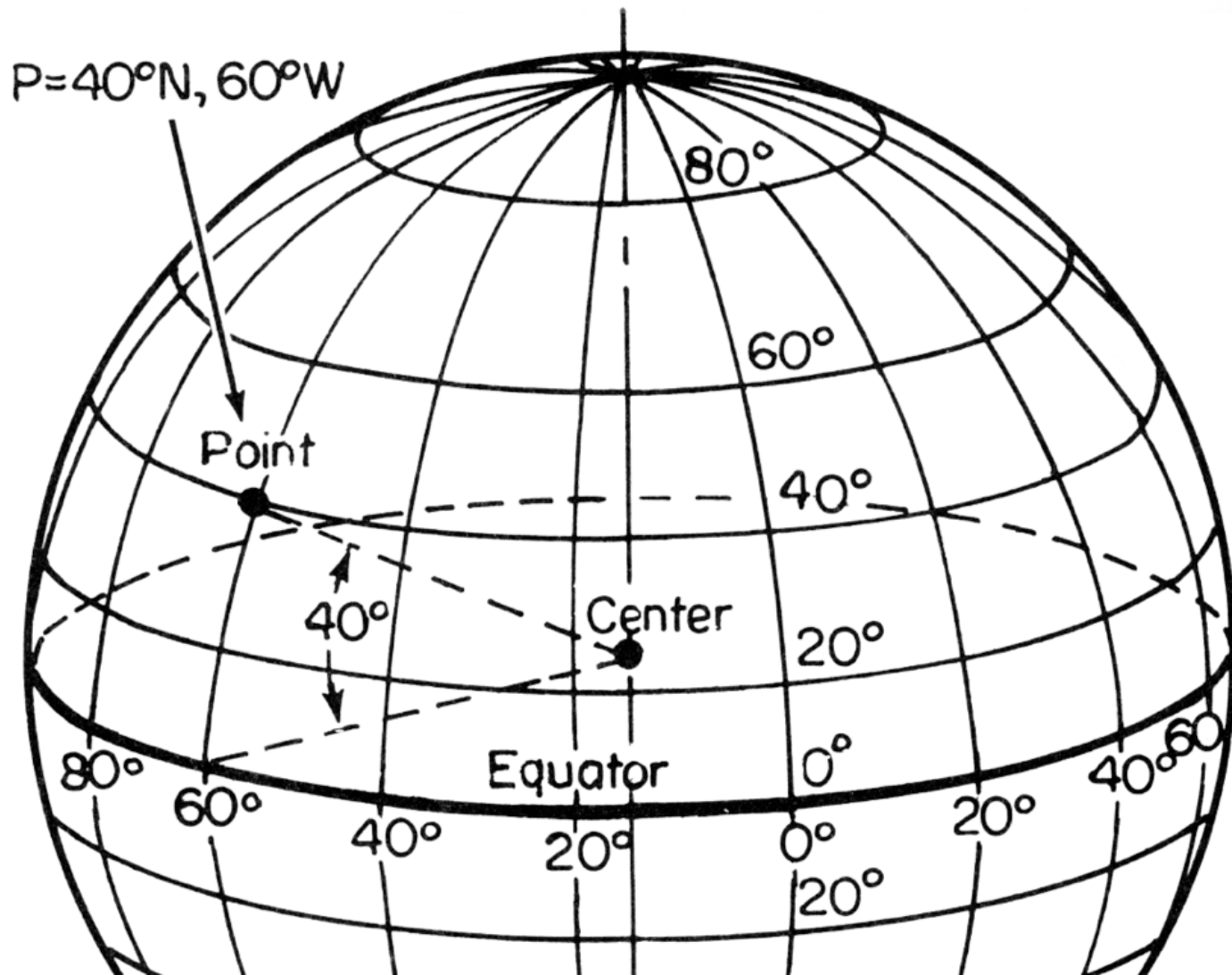
Cartogram
[NY Times]

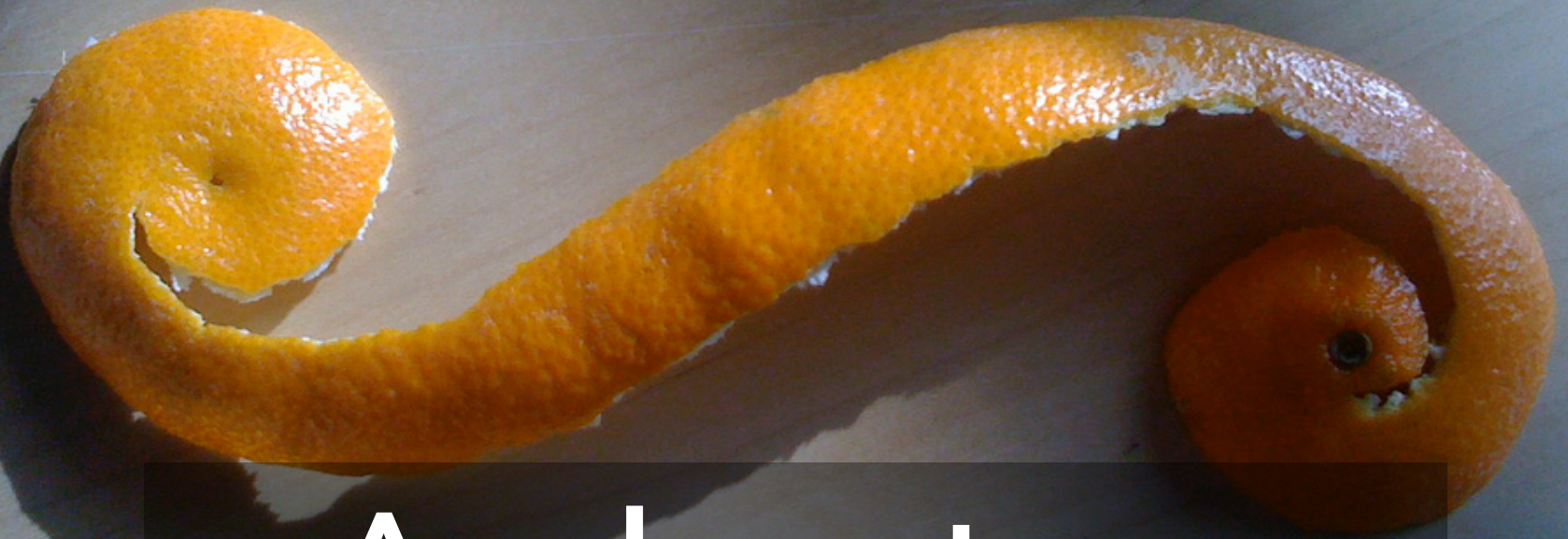
Cartography

The Making of Maps

Projections

Latitude, Longitude





A sphere tears
when you flatten it

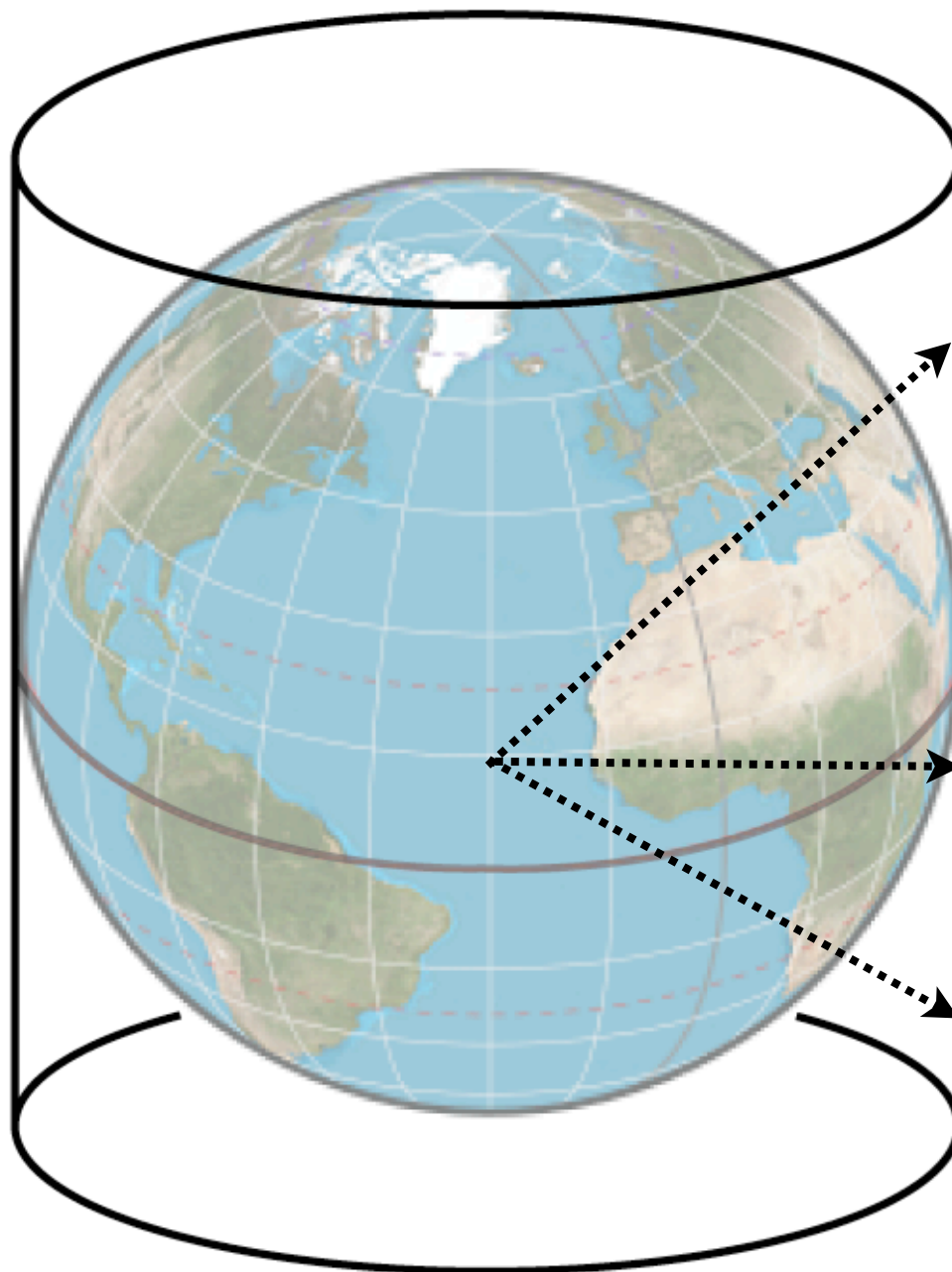
Projections

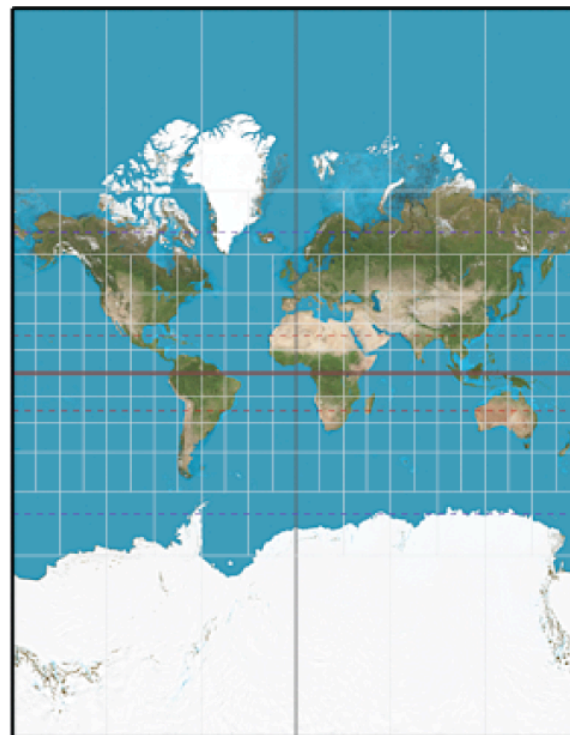
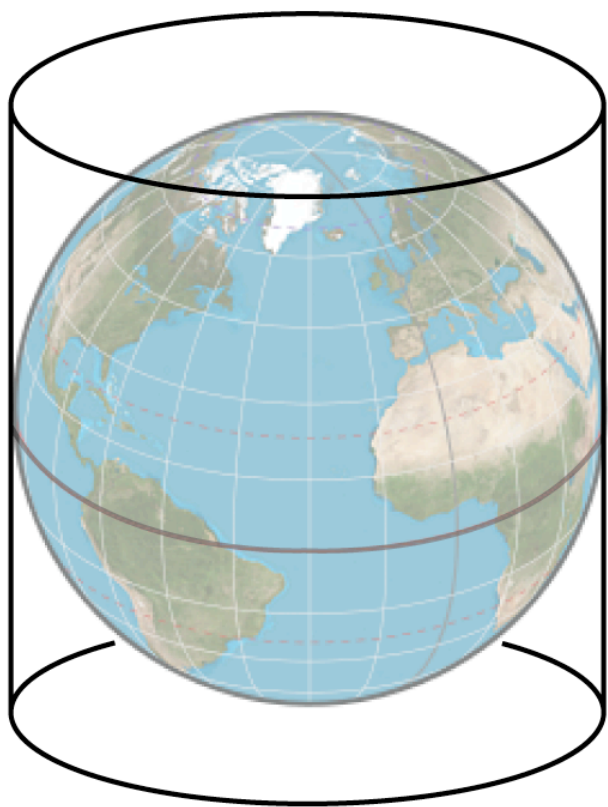
$$f(\varphi, \lambda) \rightarrow (x, y)$$

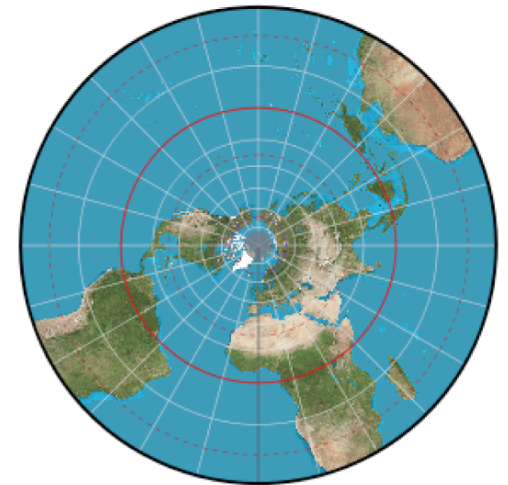
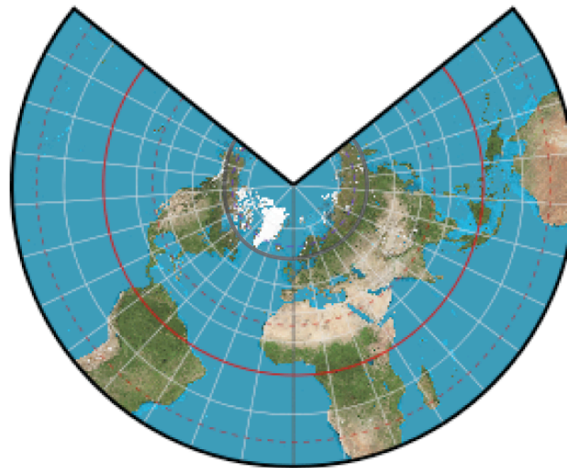
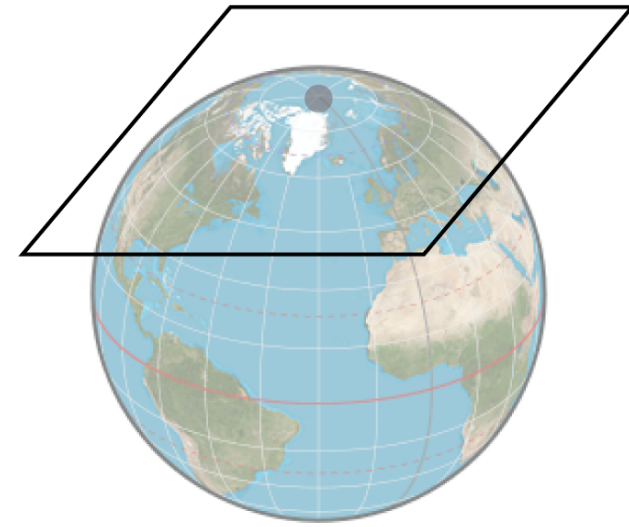
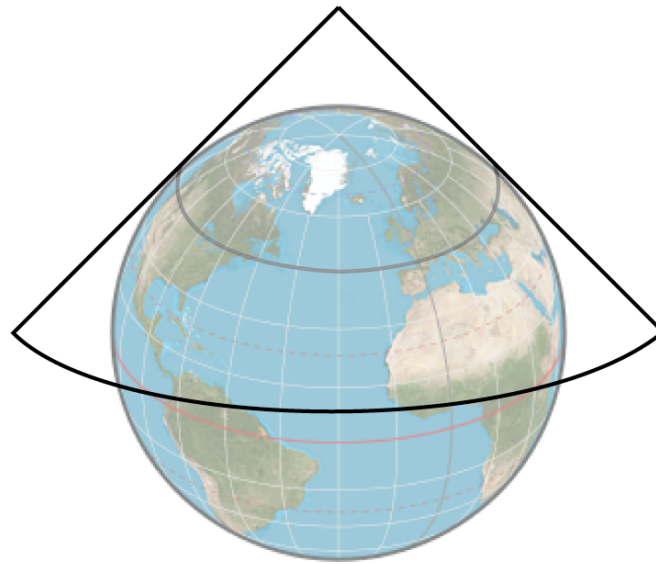
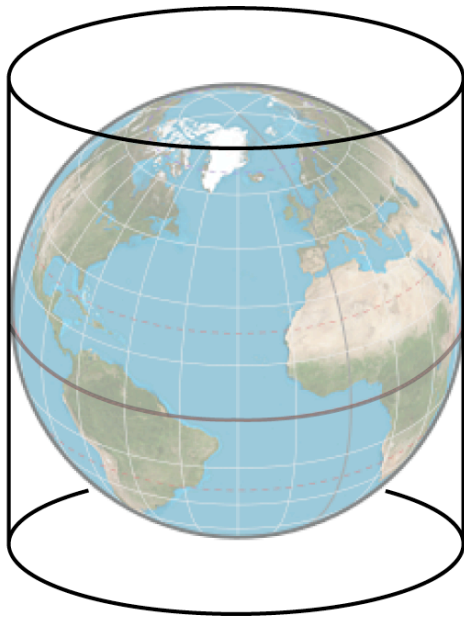
Projections

$$f(\varphi, \lambda) \Leftrightarrow (x, y)$$

??





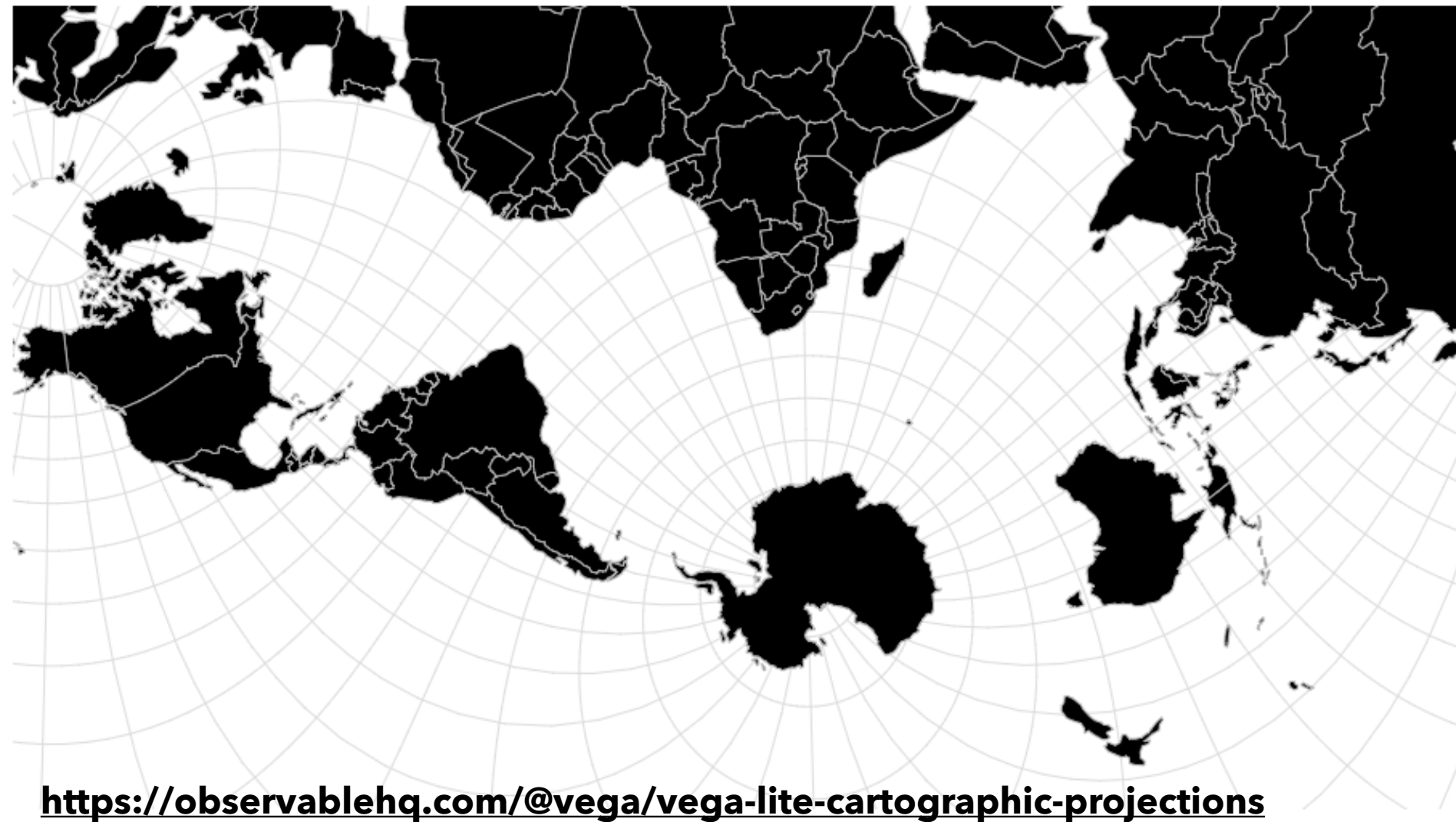


Cylindrical

Conical

Azimuthal

Exploring Projections...



<https://observablehq.com/@vega/vega-lite-cartographic-projections>



Type

mercator

Scale



140

Yaw



0

Pitch



0

Roll



0



Type

mercator ▾

Scale



Yaw

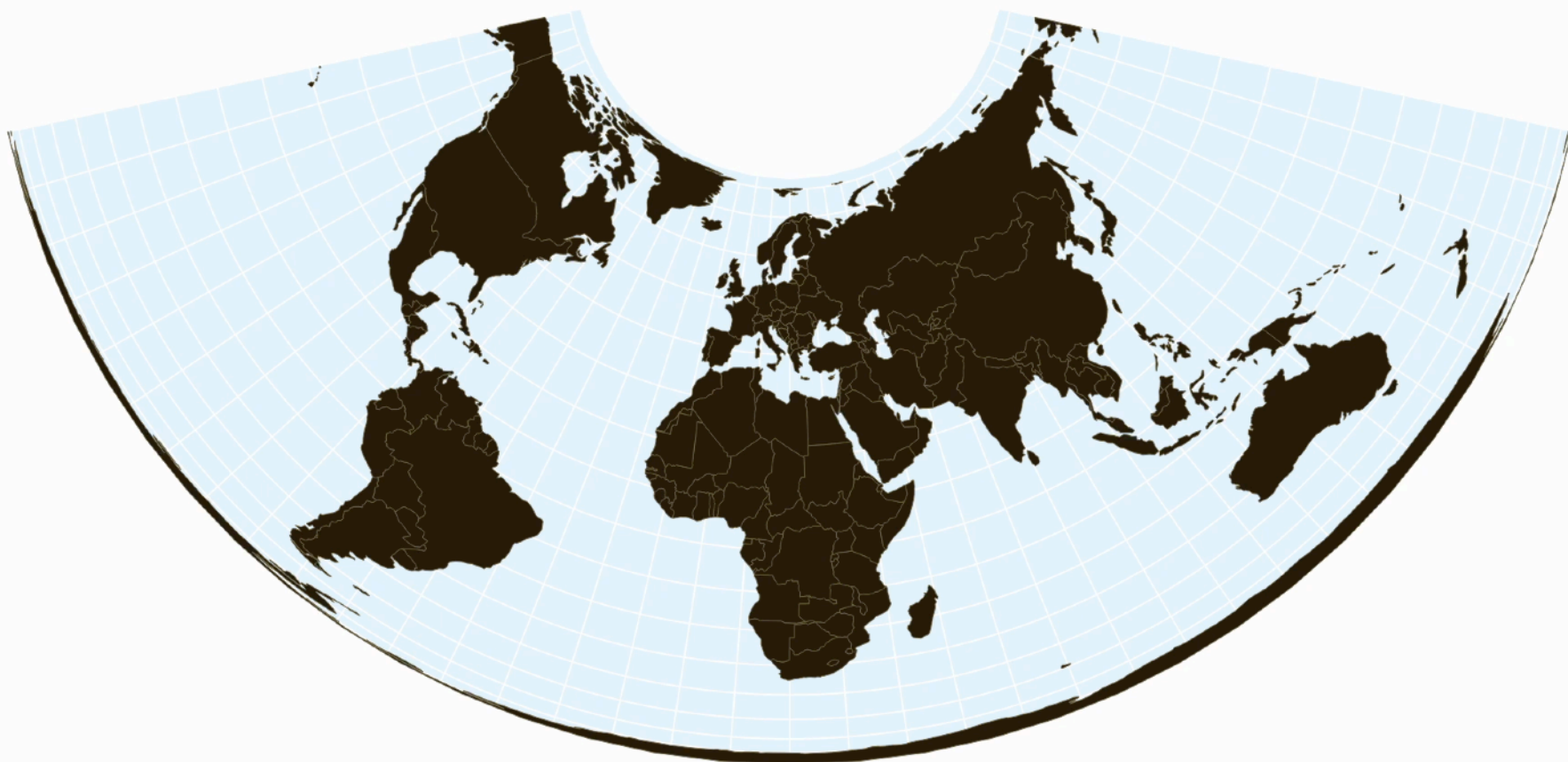


Pitch



Roll





Type

conicEqualArea

Scale

140

Yaw

-20

Pitch

0

Roll

0



Type

orthographic ▾

Scale



Yaw



Pitch



Roll



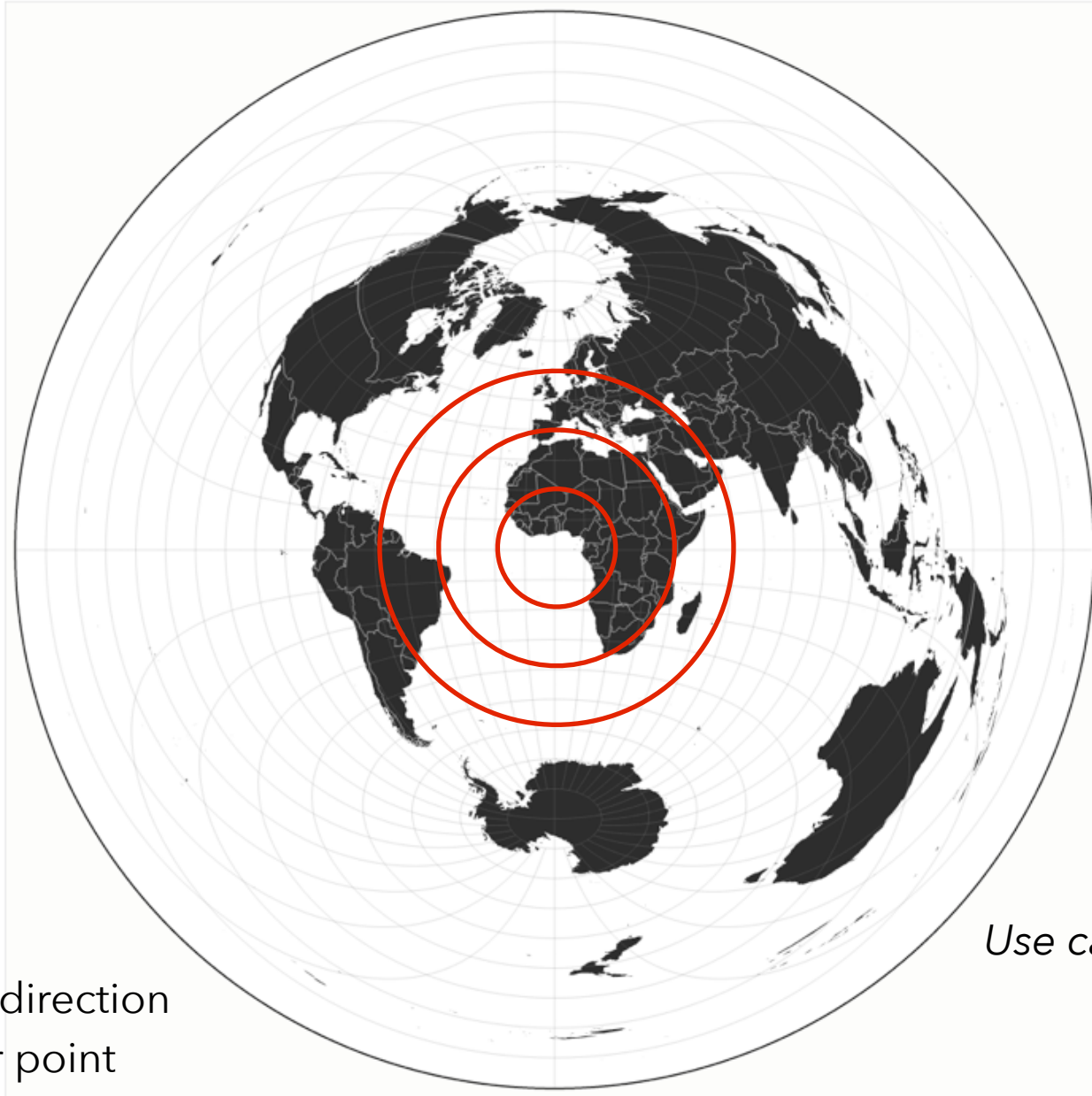
**We can categorize
projections by what
they preserve...**

A world map with a yellow landmass overlay. The overlay is centered on North America and extends across the Atlantic and Pacific Oceans. The overlay is semi-transparent, showing the underlying map. The text "Distance" is written in large white letters over the overlay. Below it, the text "Preserve distance / direction from center" is written in smaller white letters. The map shows the outlines of continents and countries in a light gray color.

Distance

Preserve distance / direction from center

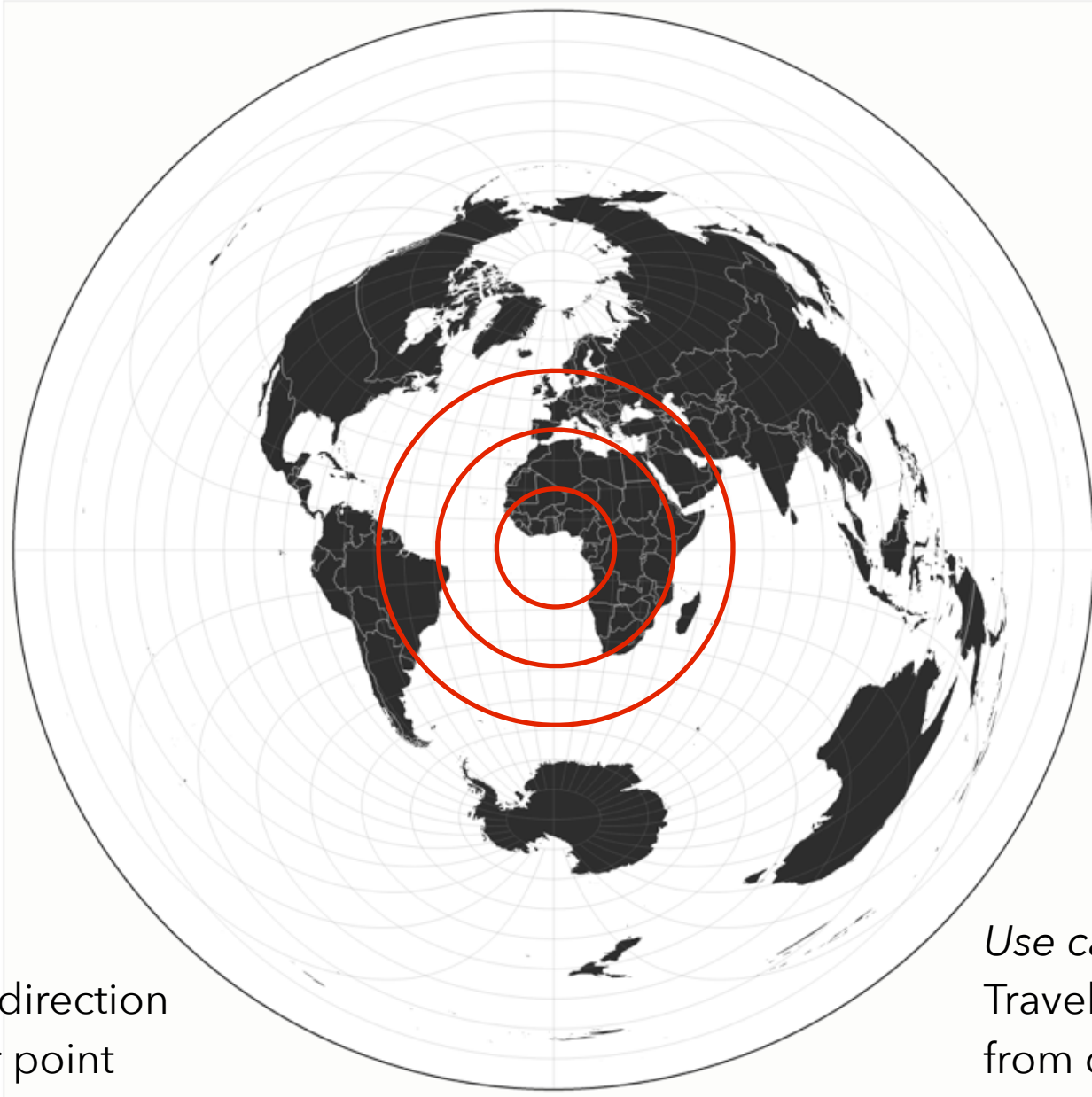
Azimuthal Equidistant



Preserves:
Distance & direction
from center point

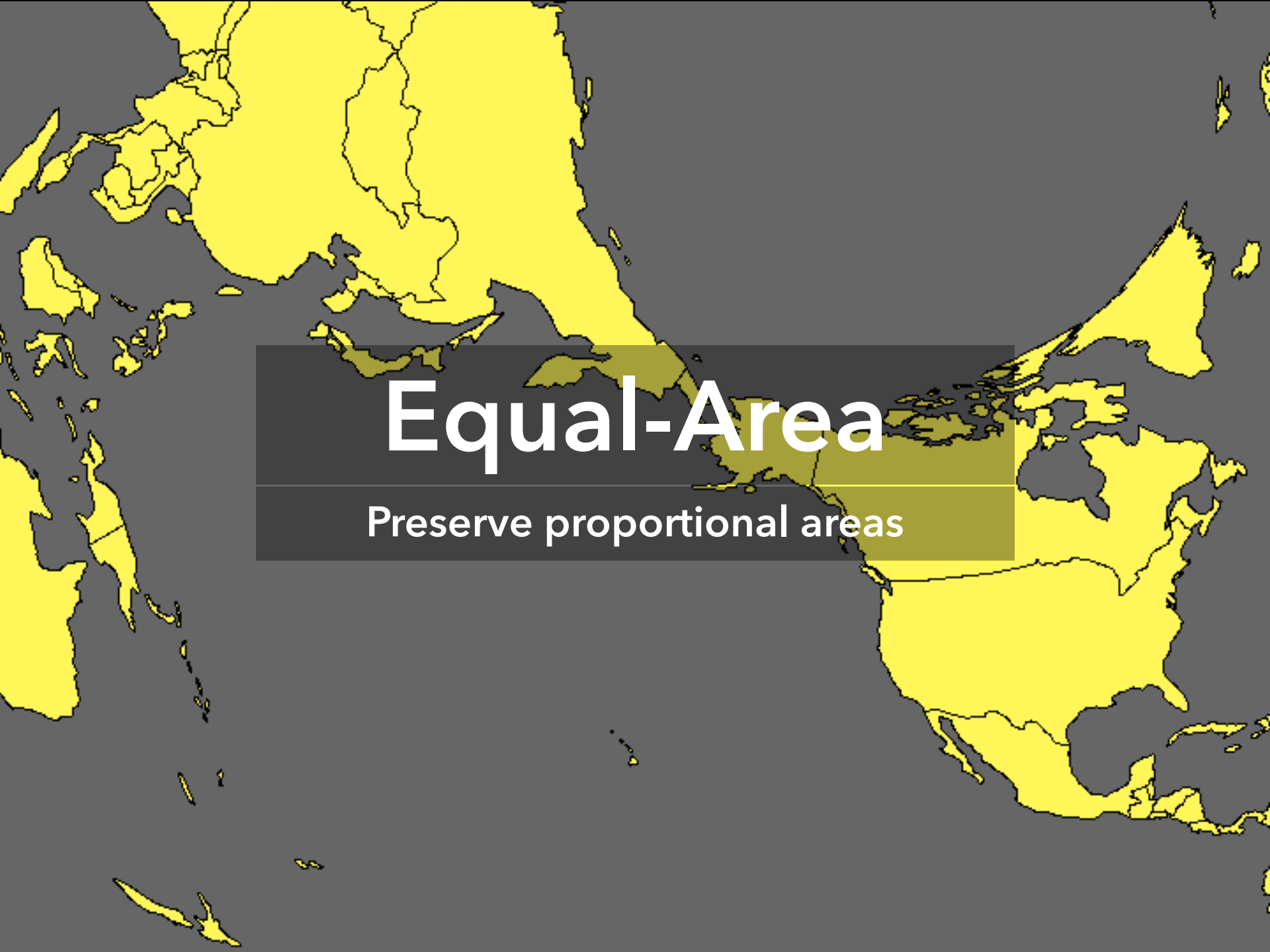
Use cases?

Azimuthal Equidistant



Preserves:
Distance & direction
from center point

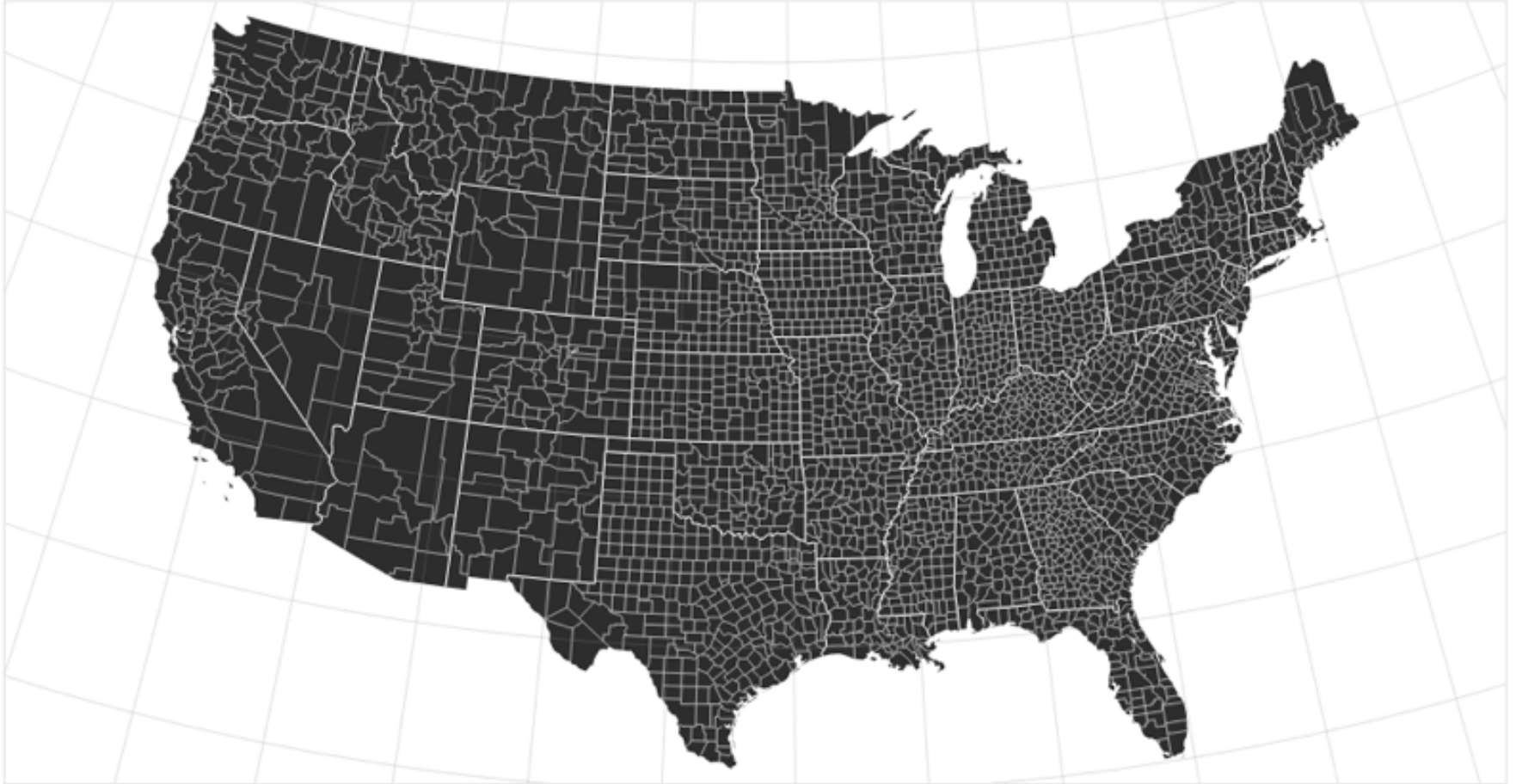
Use cases:
Travel / propagation
from center point



Equal-Area

Preserve proportional areas

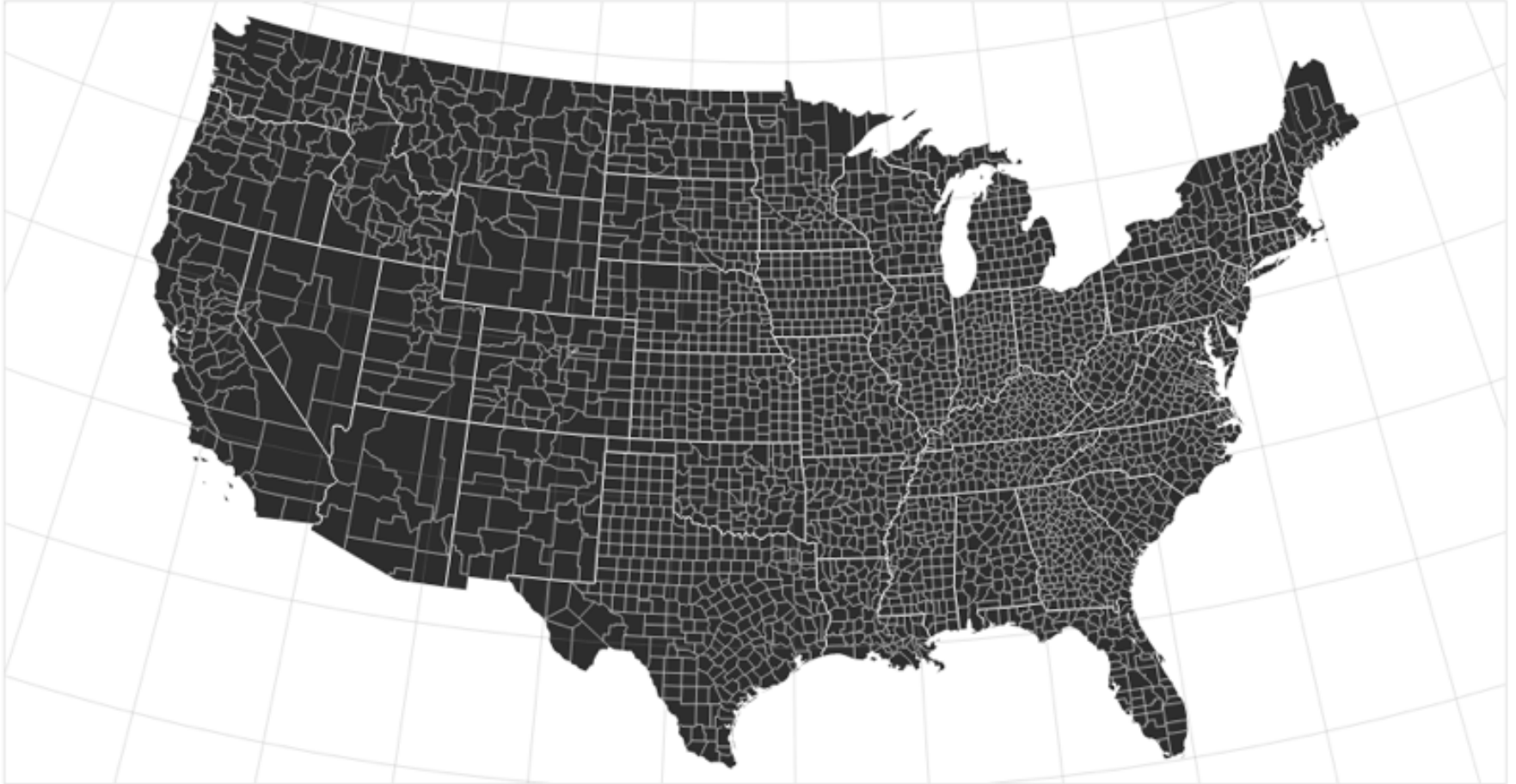
Albers Equal-Area Conic



Preserves: Proportional area of geographic regions

Use cases?

Albers Equal-Area Conic



Preserves: Proportional area of geographic regions

Use cases: Land surveys, choropleth (shaded) maps

A world map with yellow landmasses and dark grey oceans. A semi-transparent grey rectangular box is centered over the Atlantic Ocean and Western Europe. Inside this box, the word "Conformal" is written in large white letters, and below it, the phrase "Preserve local angles ('shape')" is written in smaller white letters.

Conformal

Preserve local angles ("shape")

Spherical Mercator



Preserves:
Compass bearing
as a straight line

Use cases?

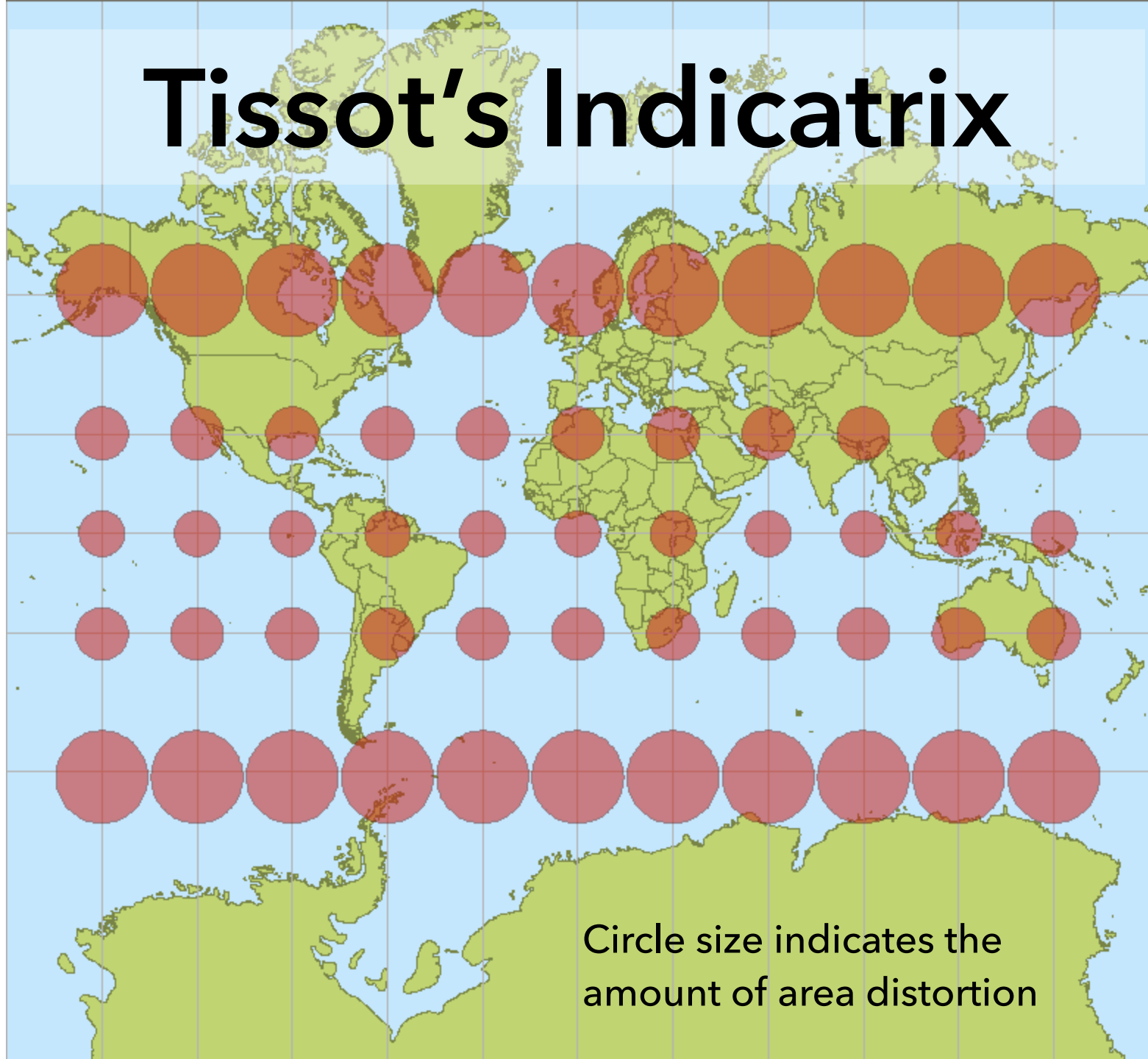
Spherical Mercator

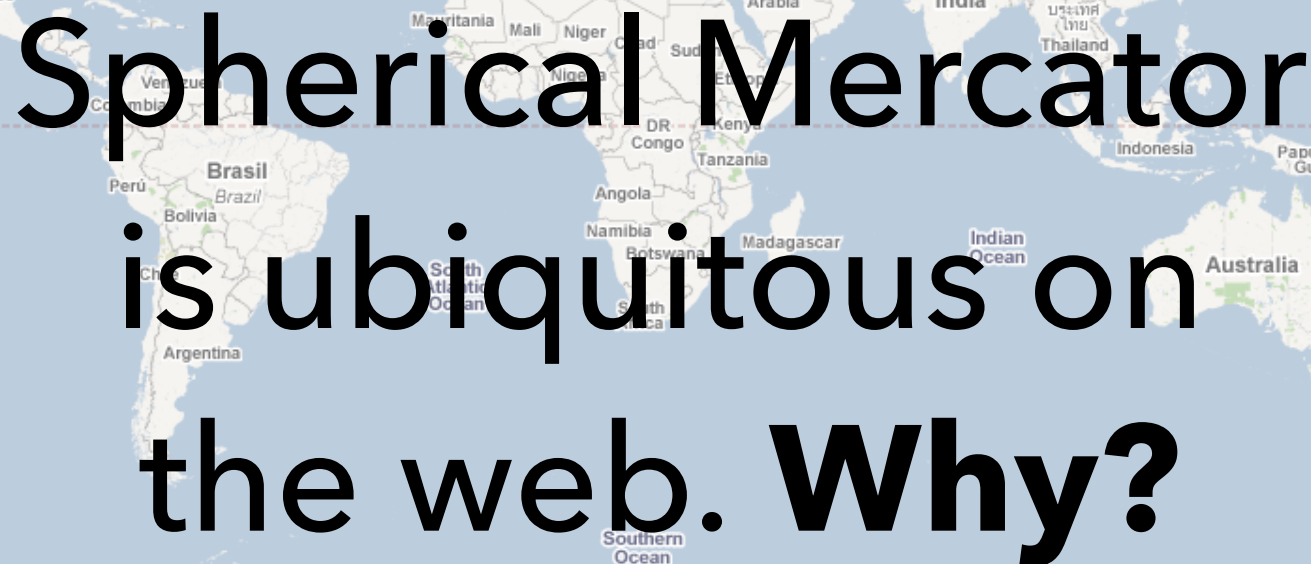


Preserves:
Compass bearing
as a straight line

Use cases:
Navigation

Tissot's Indicatrix





Spherical Mercator is ubiquitous on the web. Why?

The Earth as a Square



Web Mercator

$$x = \frac{128}{\pi} 2^{\text{zoom level}} (\lambda + \pi) \text{ pixels}$$

$$y = \frac{128}{\pi} 2^{\text{zoom level}} \left(\pi - \ln \left[\tan \left(\frac{\pi}{4} + \frac{\varphi}{2} \right) \right] \right) \text{ pixels}$$

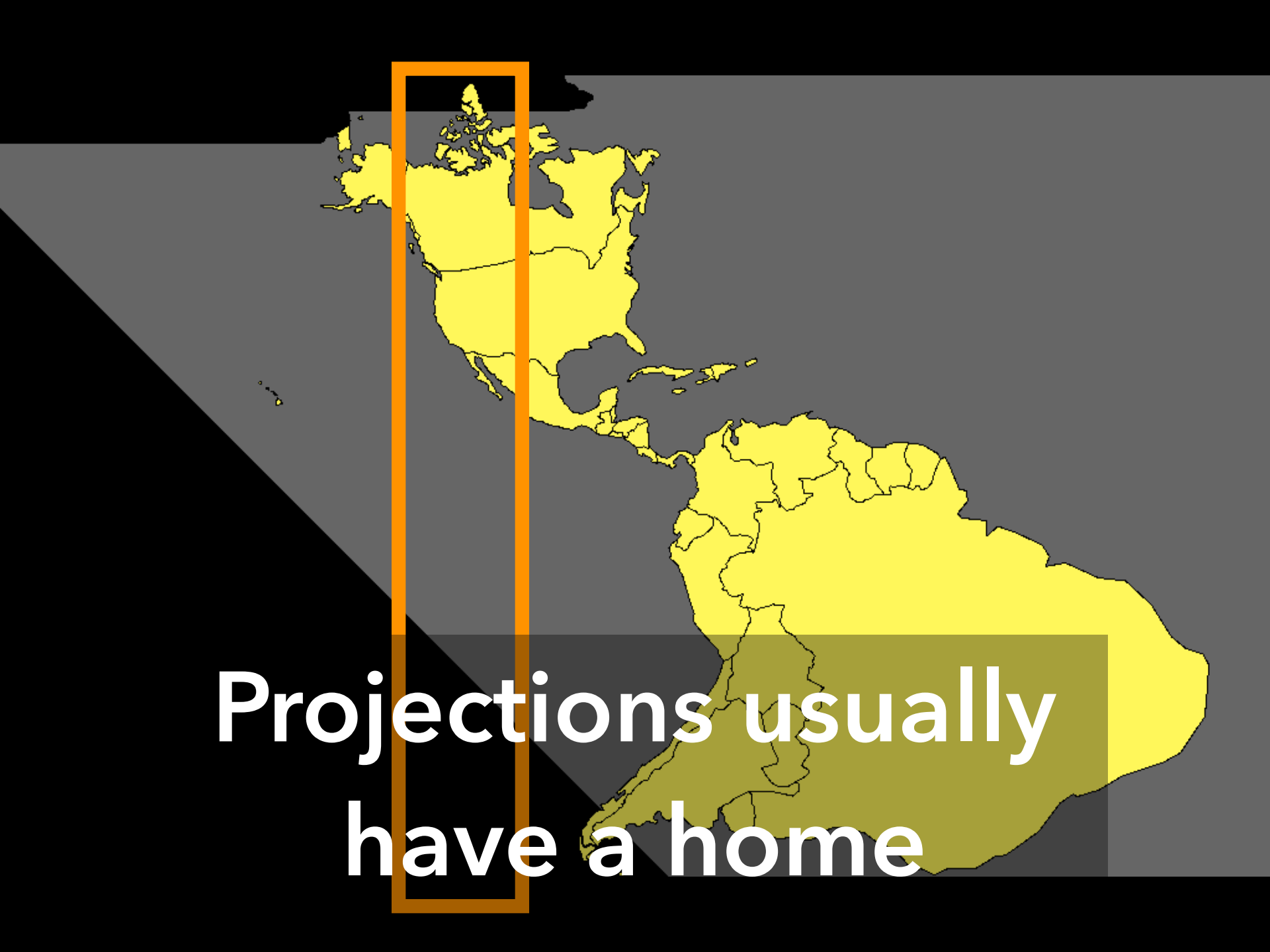
World coordinates adjusted to map to 256 x 256 pixels.

Latitude cut-offs at 85.051129 degrees: the exact point at which the projection frames the world in a square.

Peirce Quincuncial



But there are other
ways to fit the Earth
into a square...

A map of the Americas, including North and South America, is shown in yellow against a dark gray background. A vertical orange line runs through the center of the continent. A semi-transparent gray box is overlaid on the lower right portion of the map, containing the text "Projections usually have a home".

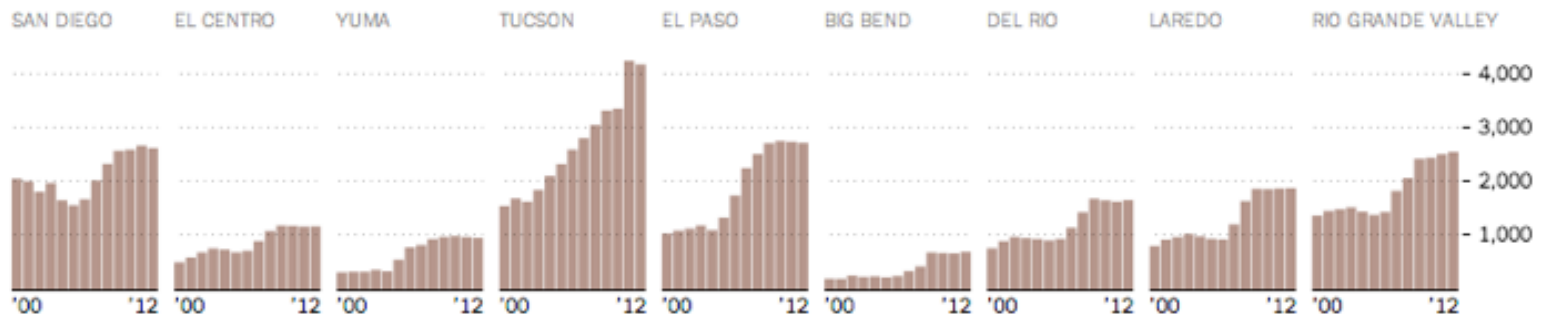
Projections usually
have a home

Increased Border Enforcement, With Varying Results



There are now more agents along the 1,954 mile-long border than ever before...

Border agents per sector.



Satellite Projection, NY Times

Not appropriate for the whole Earth,
but fits the chosen focus region!

WHAT YOUR FAVORITE
MAP PROJECTION
SAYS ABOUT YOU

MERCATOR



YOU'RE NOT REALLY INTO MAPS.

VAN DER GRINTEN



YOU'RE NOT A COMPLICATED PERSON. YOU LOVE THE MERCATOR PROJECTION; YOU JUST WISH IT WEREN'T SQUARE. THE EARTH'S NOT A SQUARE, IT'S A CIRCLE. YOU LIKE CIRCLES. TODAY IS GONNA BE A GOOD DAY!

PEIRCE QUINCUNCIAL



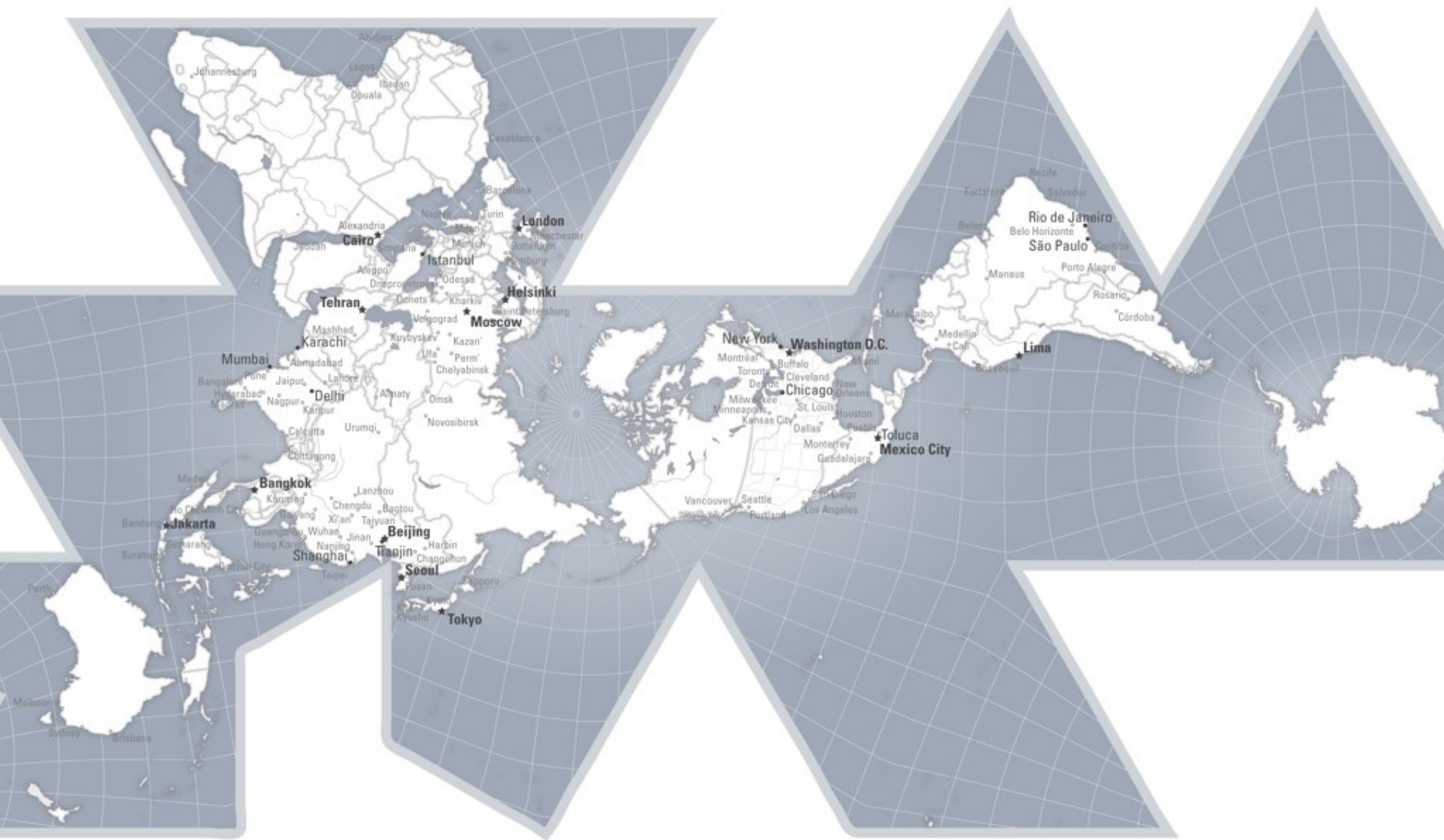
YOU THINK THAT WHEN WE LOOK AT A MAP, WHAT WE REALLY SEE IS OURSELVES. AFTER YOU FIRST SAW *INCEPTION*, YOU SAT SILENT IN THE THEATER FOR SIX HOURS. IT FREAKS YOU OUT TO REALIZE THAT EVERYONE AROUND YOU HAS A SKELETON INSIDE THEM. YOU *HAVE* REALLY LOOKED AT YOUR HANDS.



**There are interesting
ways to tear spheres**

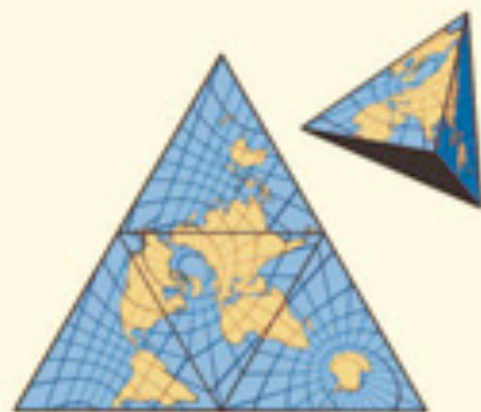
One notable interesting
way to tear a sphere



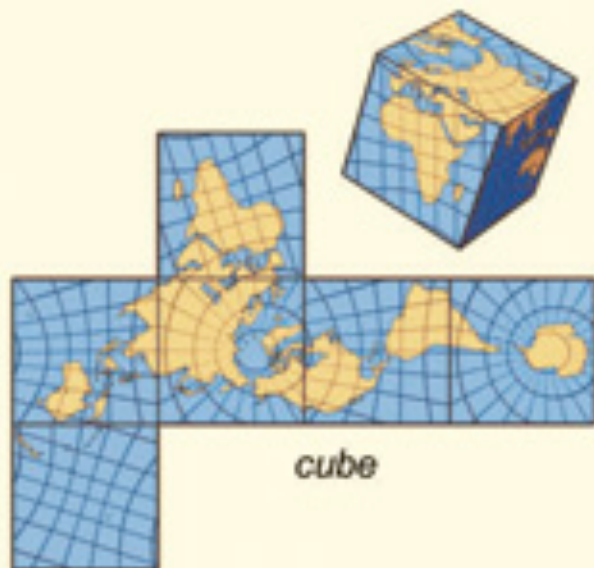


Balances preservation of area and shape.

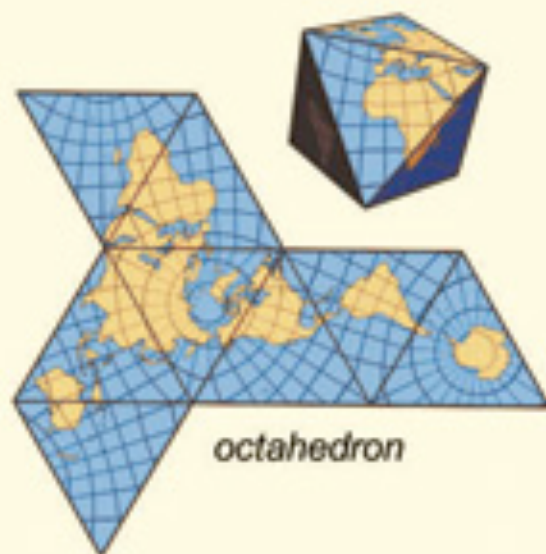
Provides different ways of thinking about the world!



tetrahedron



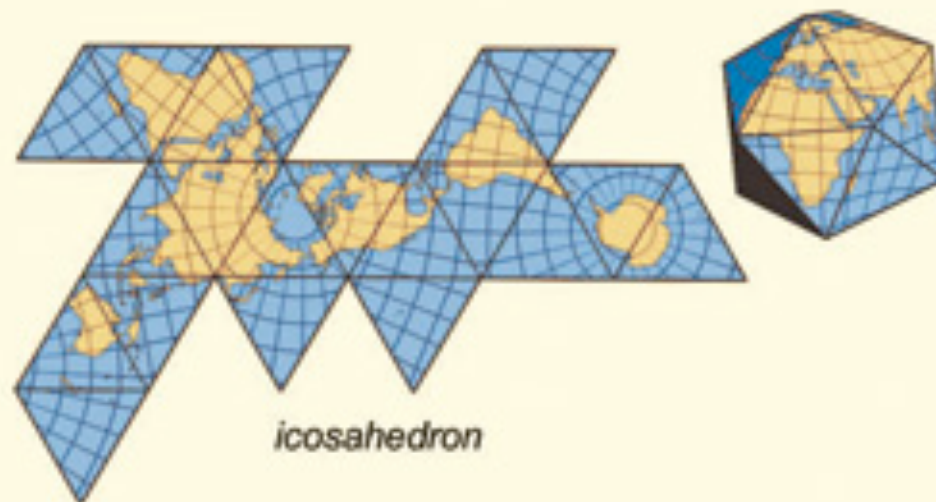
cube



octahedron



dodecahedron



icosahedron



ADAPTIVE COMPOSITE MAP PROJECTIONS

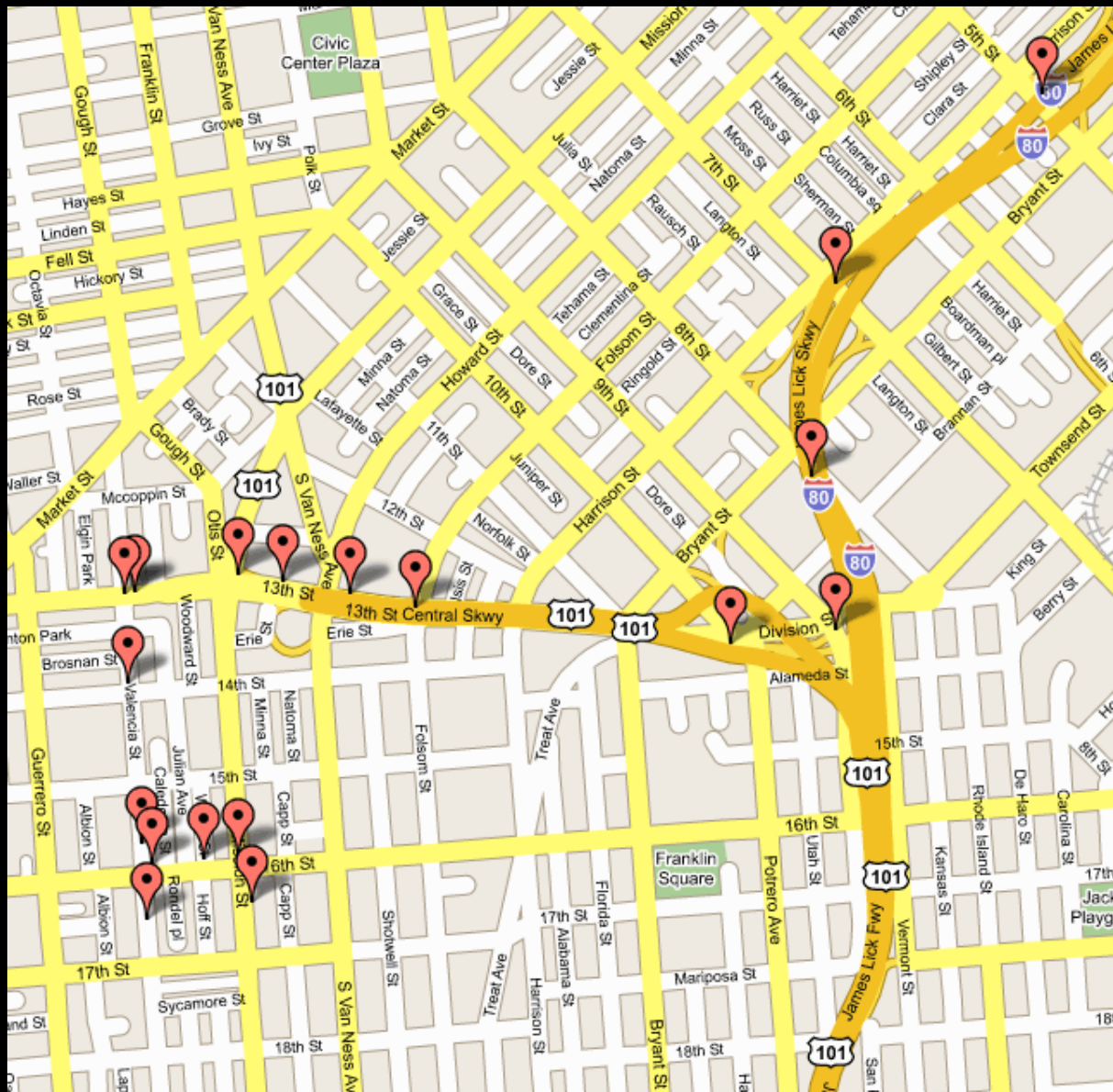
Idea: switch *between* projections by location and zoom level

Mapping

Visualizing Geospatial Data

Symbol Maps

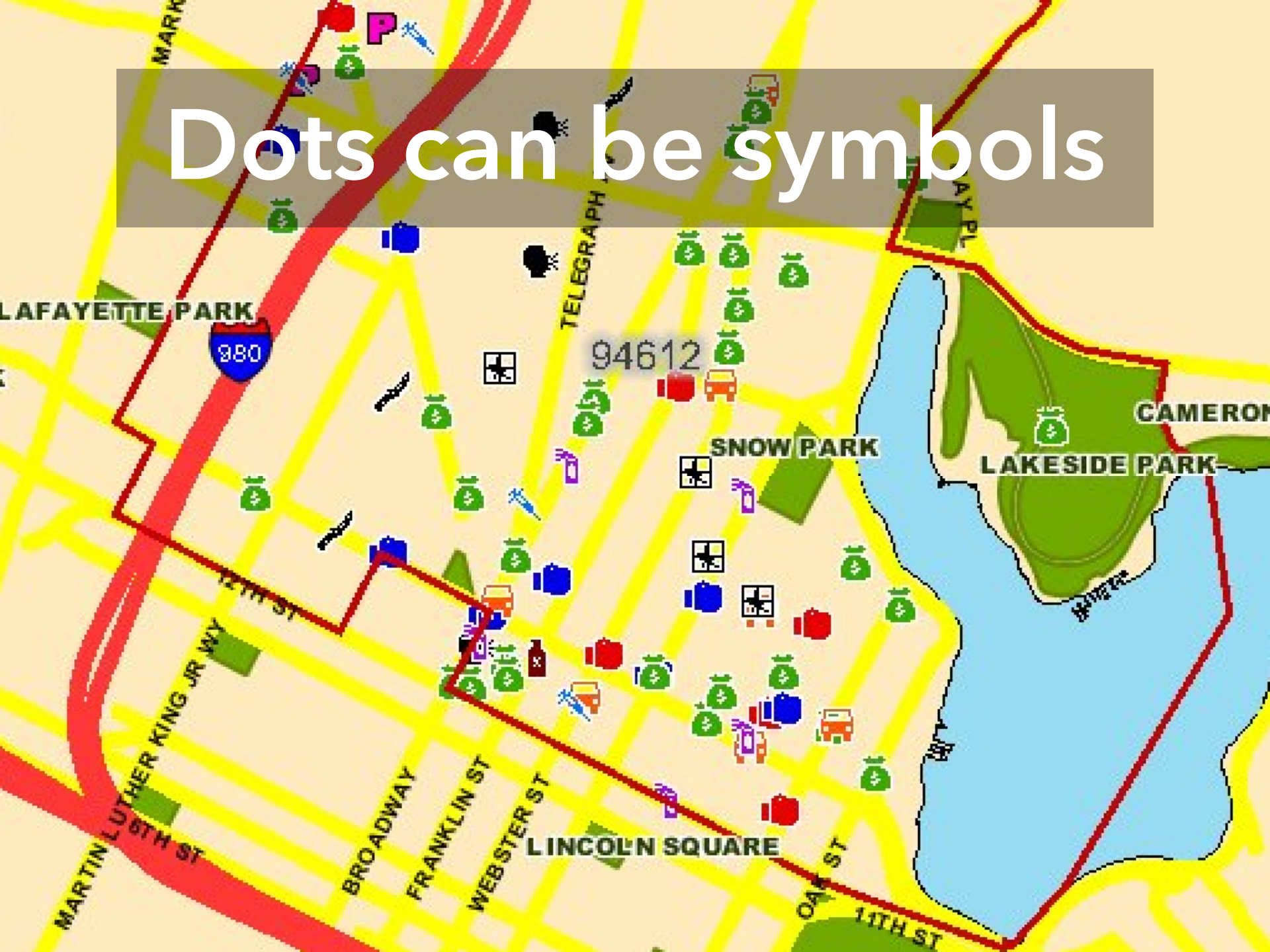
Convey Locations & Magnitudes

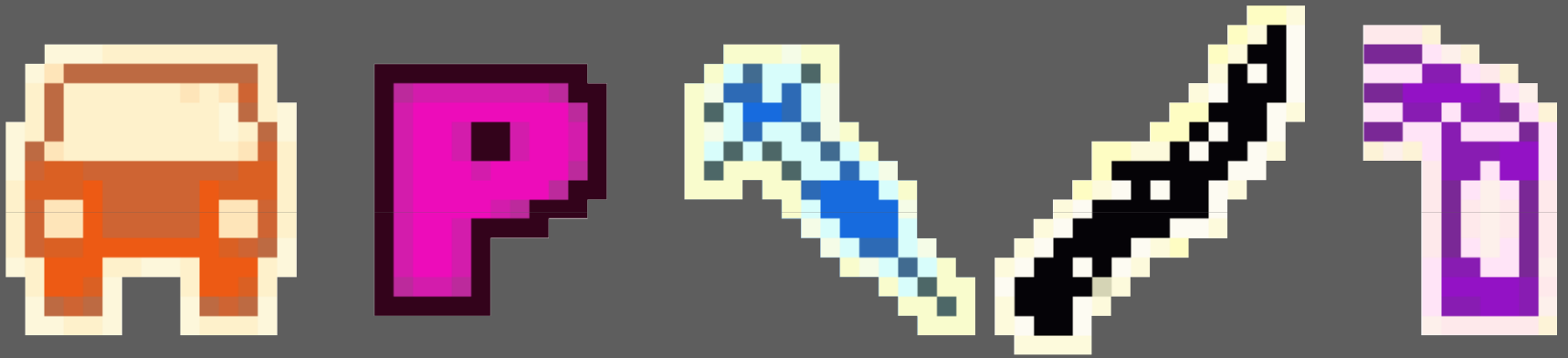


Dots are ubiquitous



Dots can be symbols





Guess the crime

Dots can can be good symbols

TIME OF DAY

Show All | Hide All

Light | Dark [nearest hour]

Commute | Nightlife

Day | Night | Swing Shift



DATE

Past Week

Sep 2009



CRIME TYPE [Show All](#) | [Hide All](#)

- AA Aggravated Assault
- Mu Murder
- Ro Robbery
- SA Simple Assault
- DP Disturbing the Peace
- Na Narcotics
- Al Alcohol
- Pr Prostitution
- Th Theft
- VT Vehicle Theft
- Va Vandalism
- Bu Burglary
- Ar Arson

237

Joseph R. Biden Jr.

70,122,063 votes (50.2%)

87

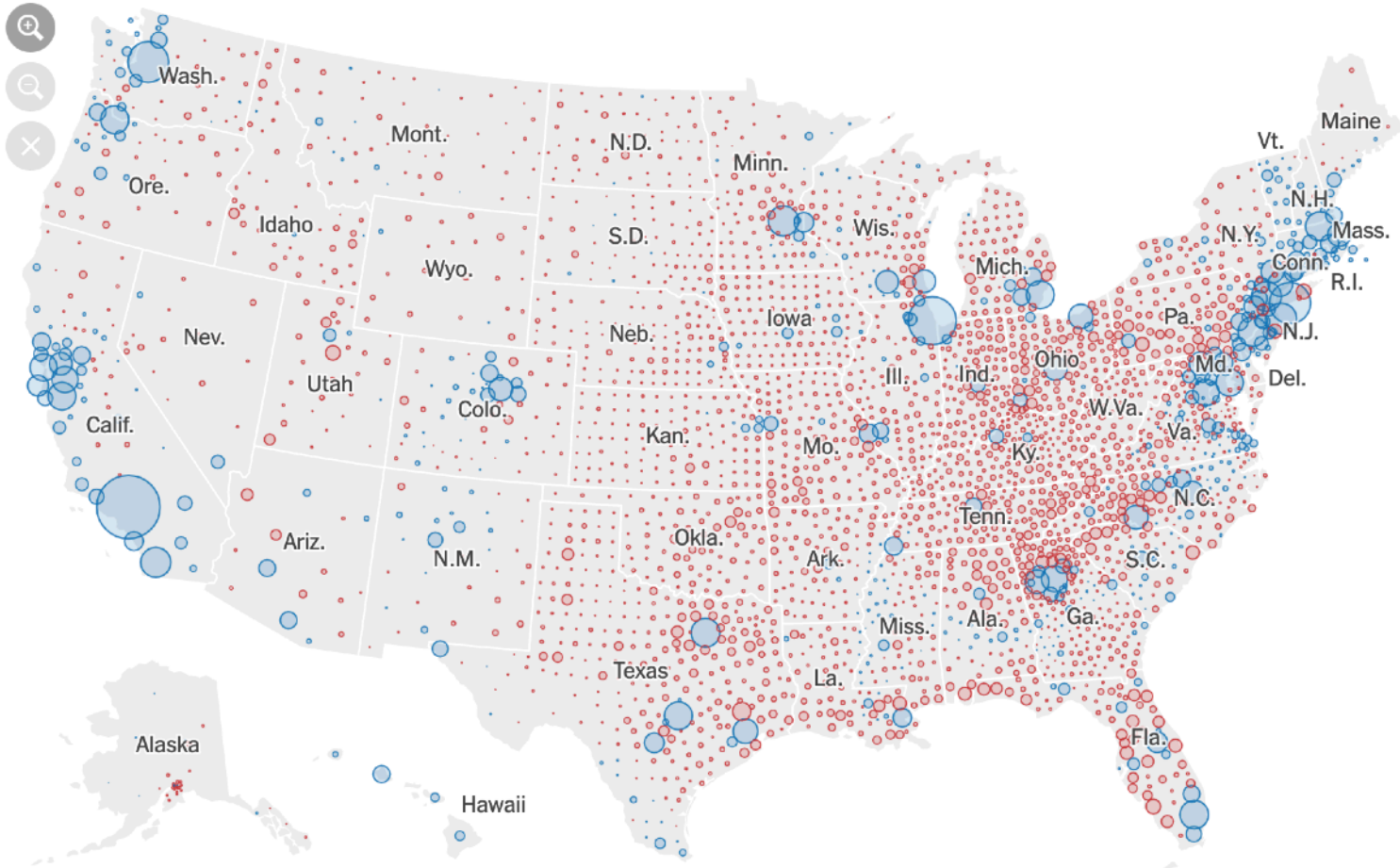
remaining

270
TO WIN

214

Donald J. Trump

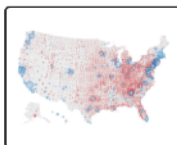
67,075,300 votes (48.0%)



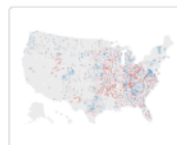
By winner



Electoral votes



Size of lead

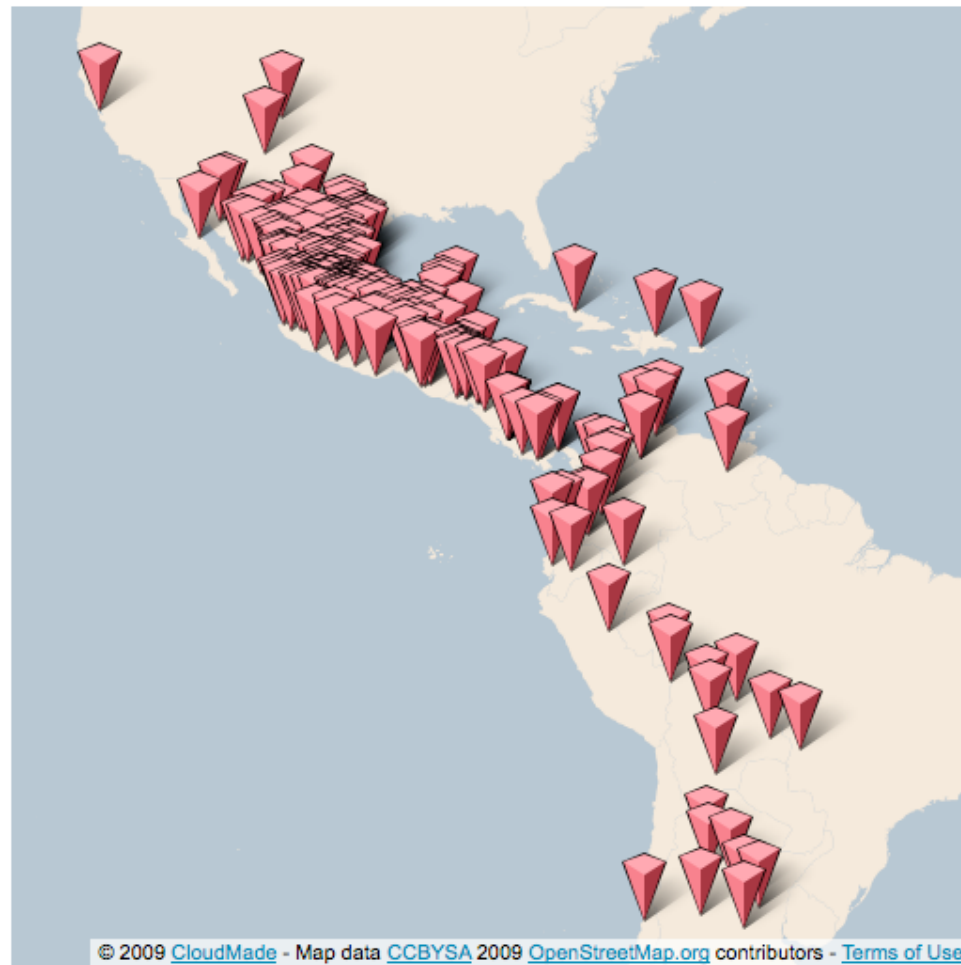


Shift from 2016

LEADER: ● Biden ● Trump
Circle size is proportional to the amount each county's leading candidate is ahead.

Symbol Map
[NY Times]

"Red Dot Fever"



Mapping America: Every City, Every Block

Find something interesting? Share this view on [Twitter](#) or [Facebook](#)

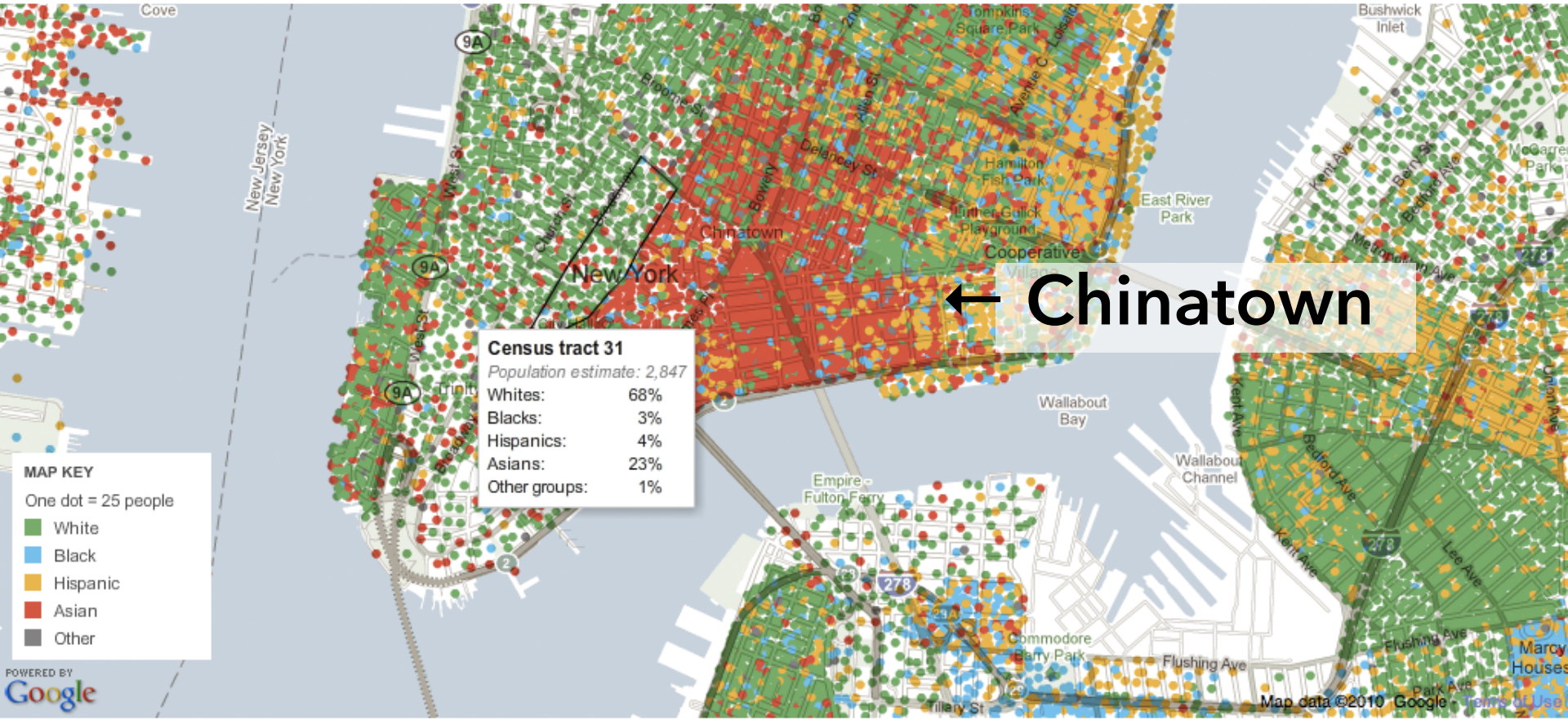
Browse local data from the Census Bureau's American Community Survey, based on samples from 2005 to 2009. Because these figures are based on [View Readers Maps \(49\)](#) samples, they are subject to a margin of error, particularly in places with a low population, and are best regarded as estimates.

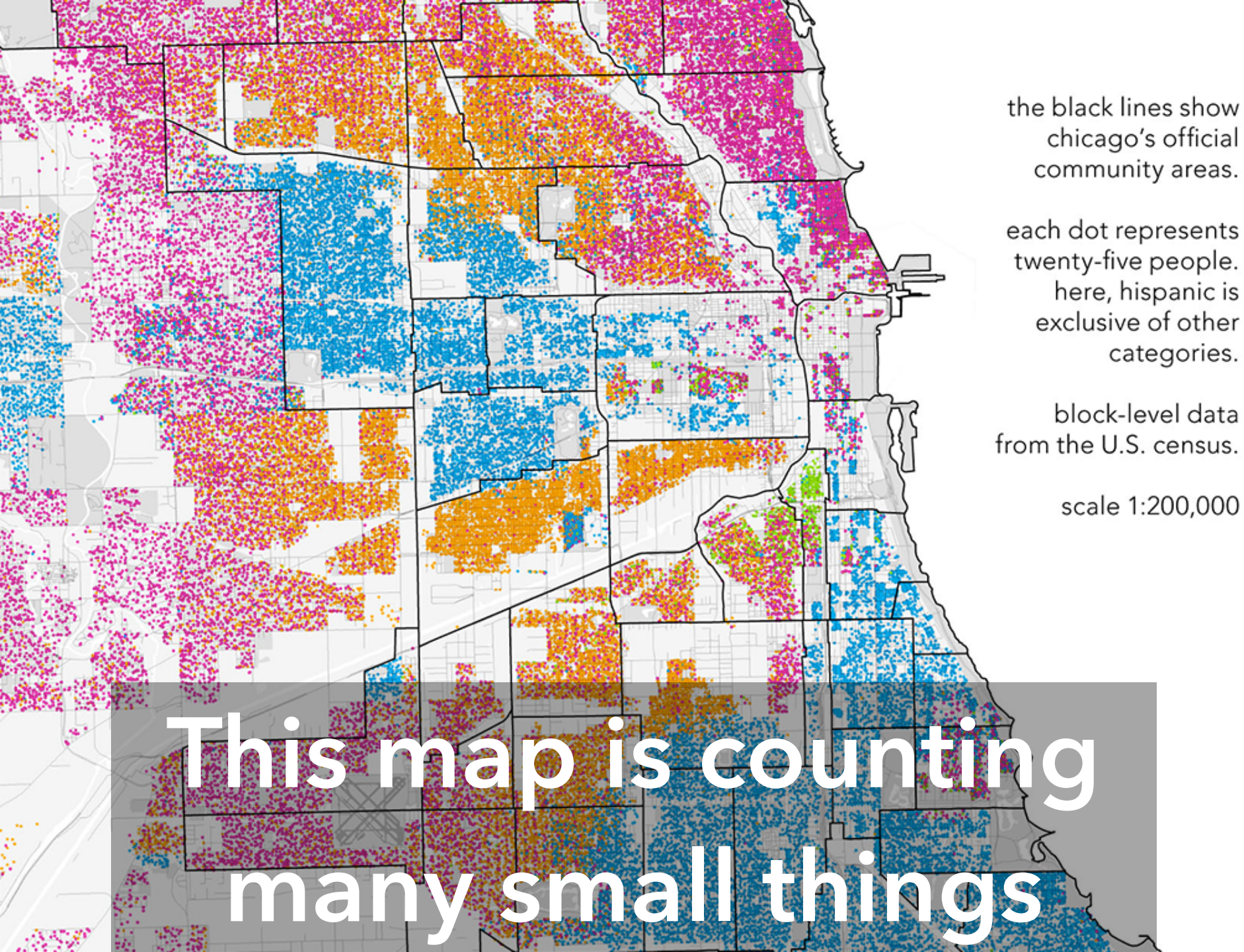
Distribution of racial and ethnic groups

[View More Maps](#)

Address, ZIP code or city

Go





the black lines show
chicago's official
community areas.

each dot represents
twenty-five people.
here, hispanic is
exclusive of other
categories.

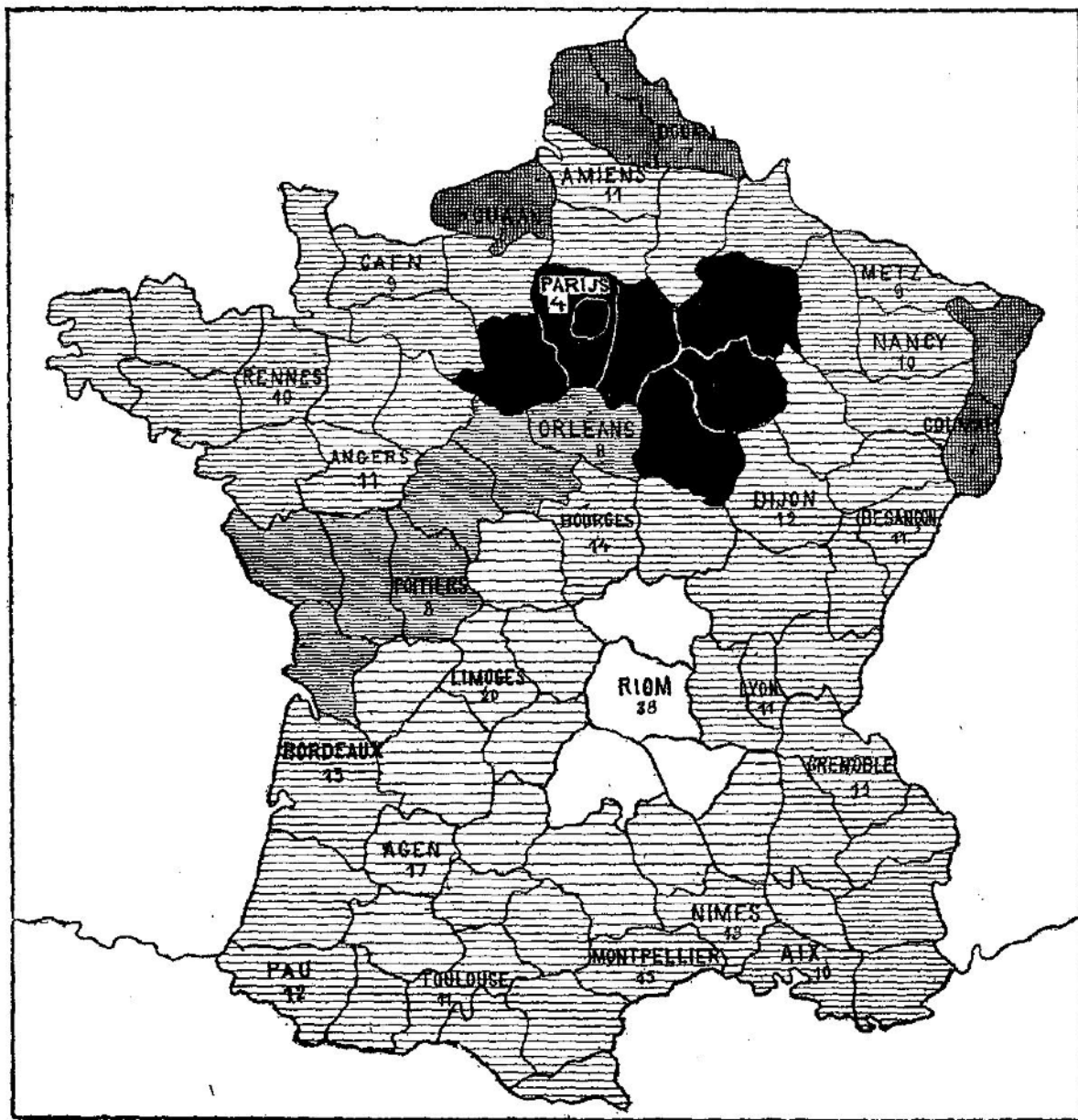
block-level data
from the U.S. census.

scale 1:200,000

This map is counting
many small things

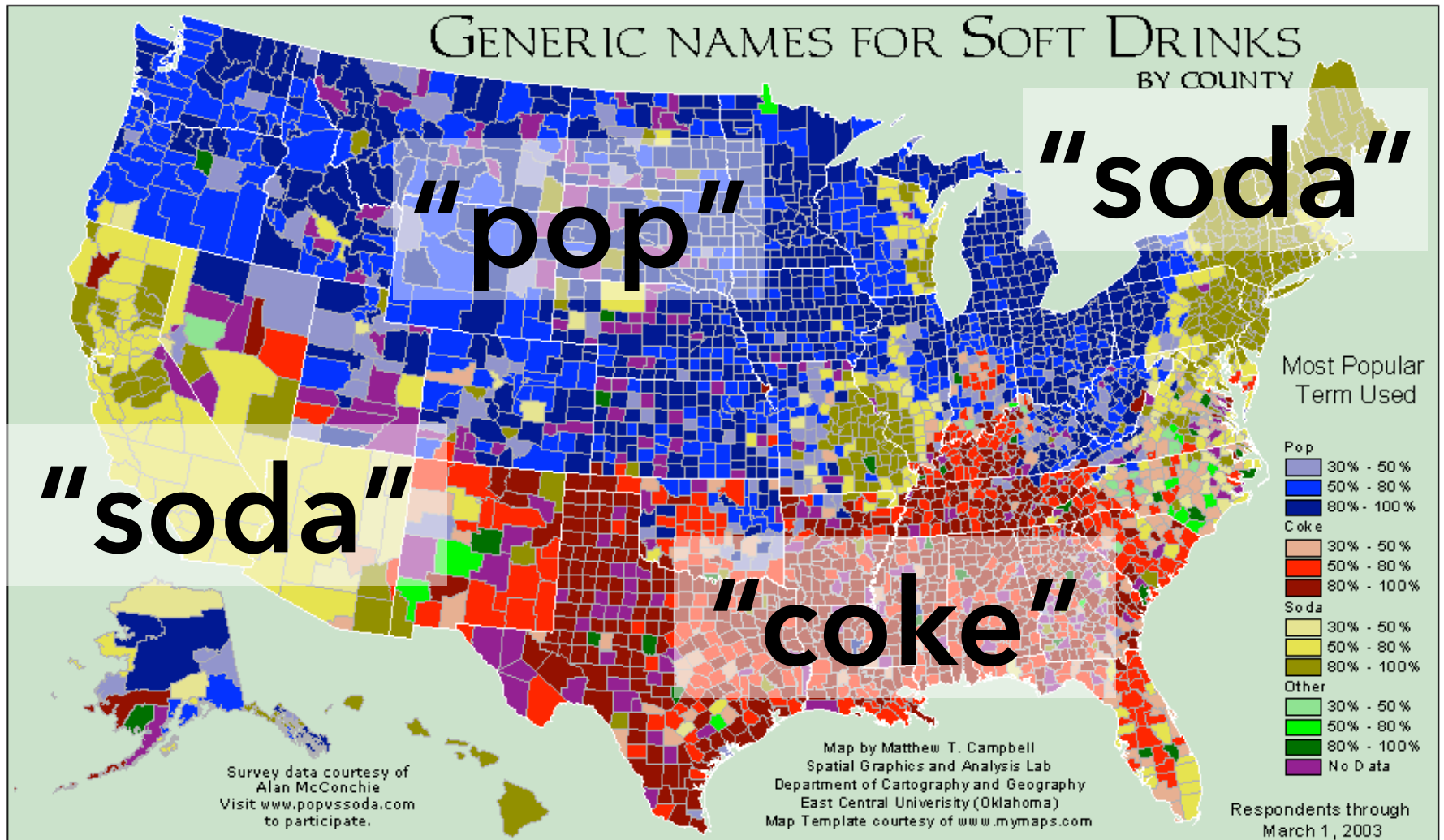
Choropleth Maps

Convey Rates Across Regions



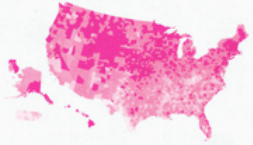
1826(?) Illiteracy in France, Pierre Charles Dupin

GENERIC NAMES FOR SOFT DRINKS BY COUNTY



READING, WRITING, AND EARNING MONEY

The latest data from the U.S. Census's American Community Survey paints a fascinating picture of the United States at the county level. We've looked at the educational achievement and the median income of the entire nation, to see where people are going to school, where they're earning money, and if there is any correlation.



A HIGH SCHOOL GRADUATES 65% 75% 82% 85%



B COLLEGE GRADUATES 15% 22% 30% 40%

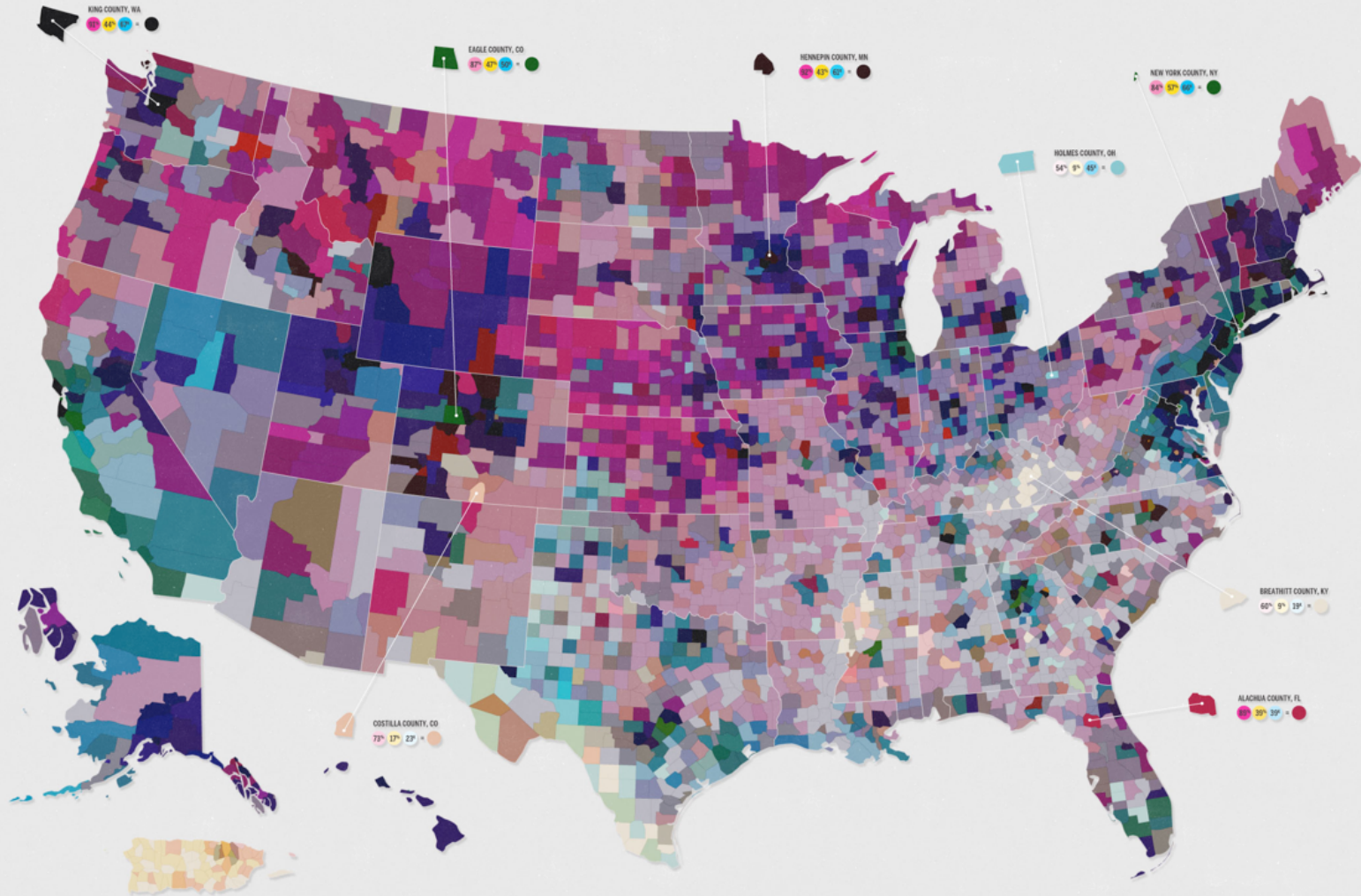


C MEDIAN HOUSEHOLD INCOME 25% 40% 50% 60%

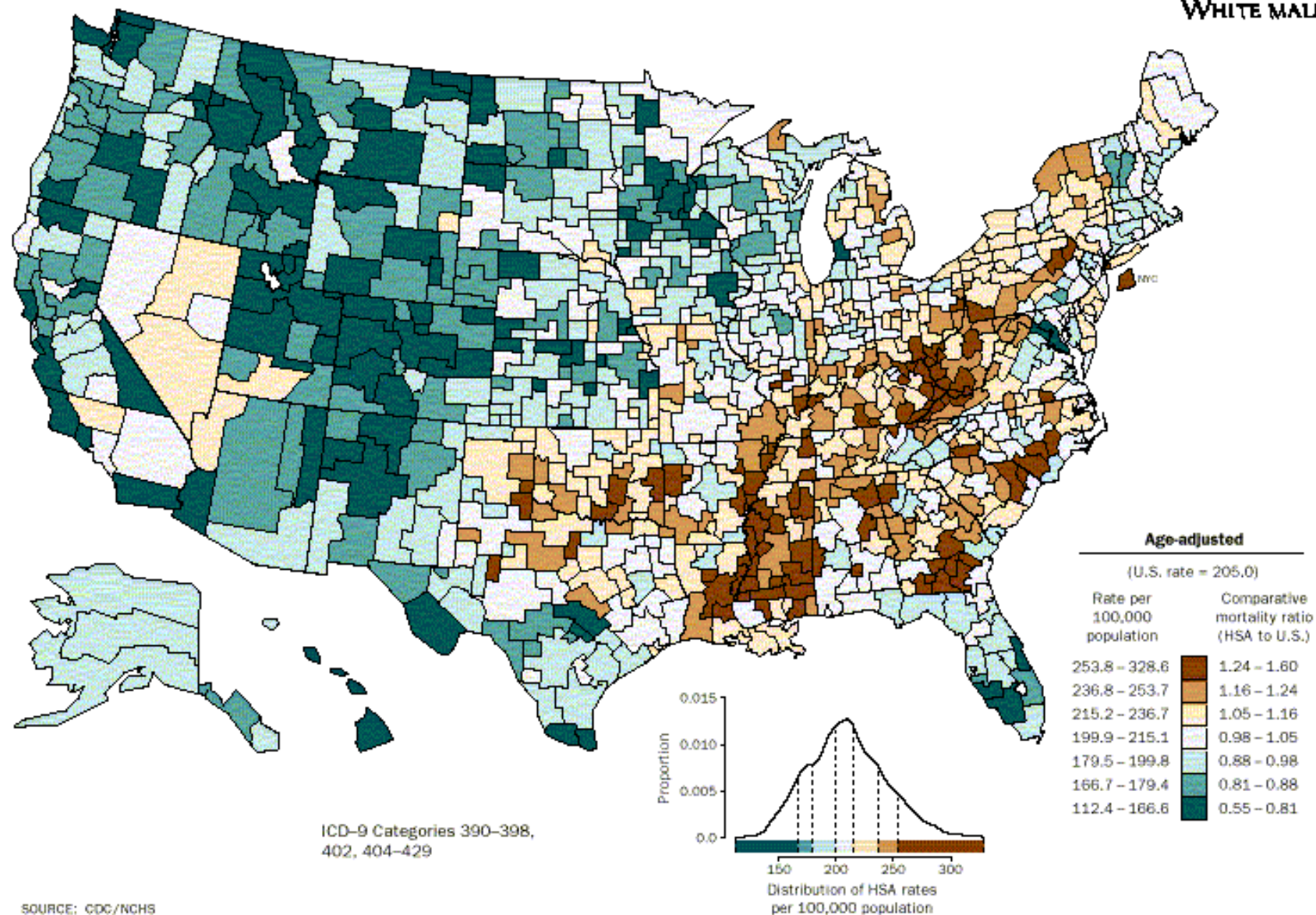
The map at right is a product of overlaying the three sets of data. The variation in hue and value has been produced from the data shown above. In general, darker counties represent a more educated, better paid population while lighter areas represent communities with fewer graduates and lower incomes.



A collaboration between GOOD and Gregory Huback
SOURCE: US Census

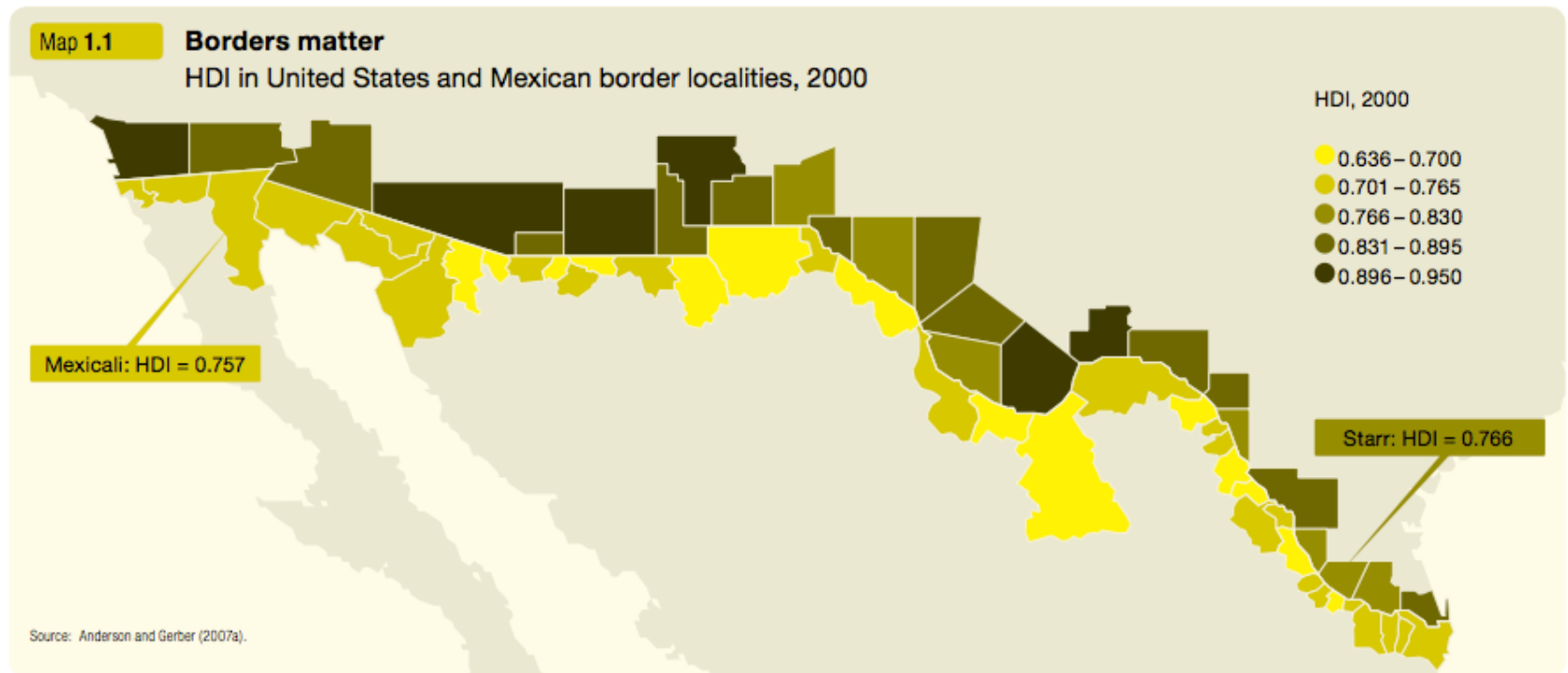


Choose colors with care



SOURCE: CDC/NCHS

Seven quantiles

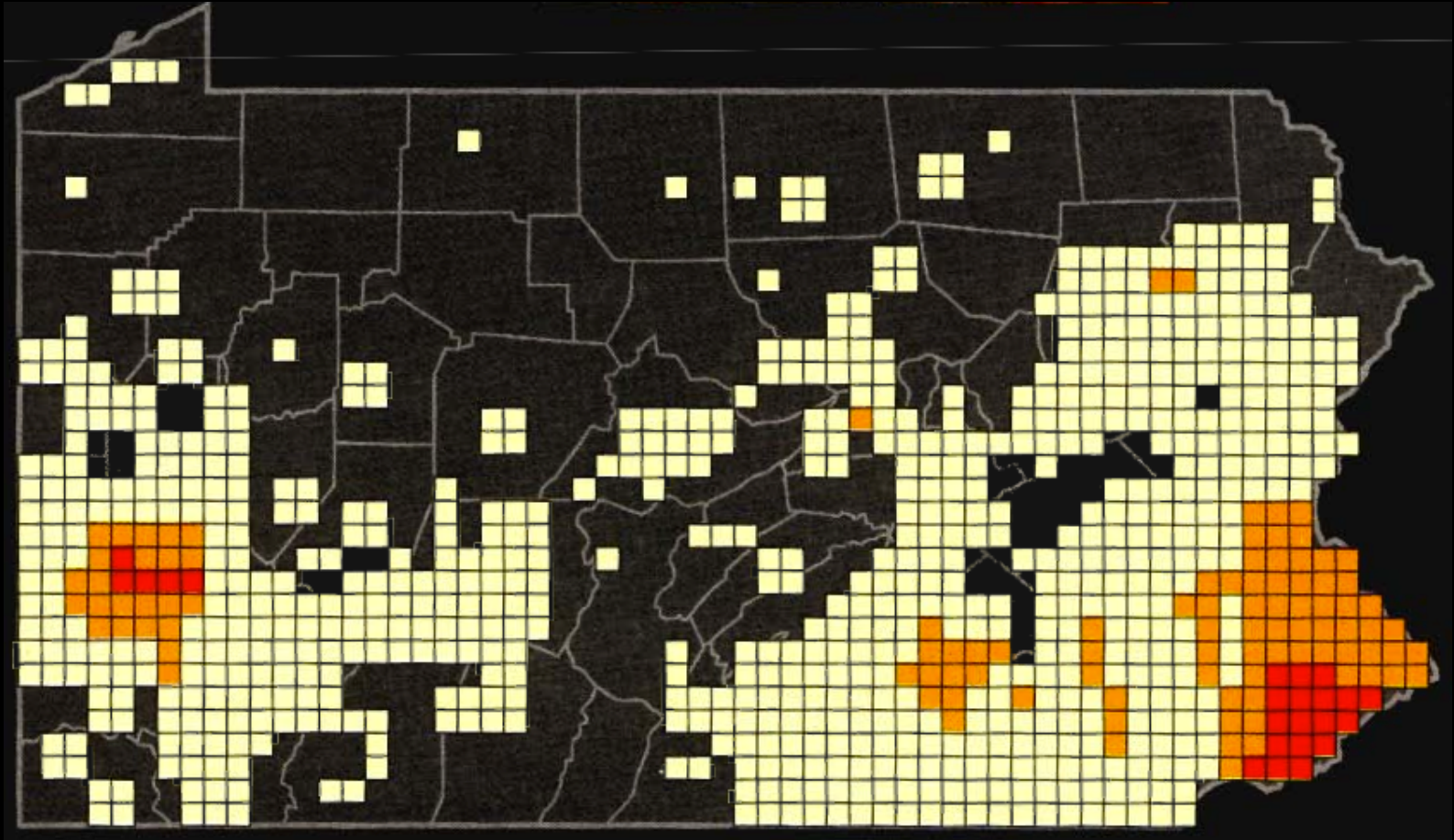


Focus on the foreground

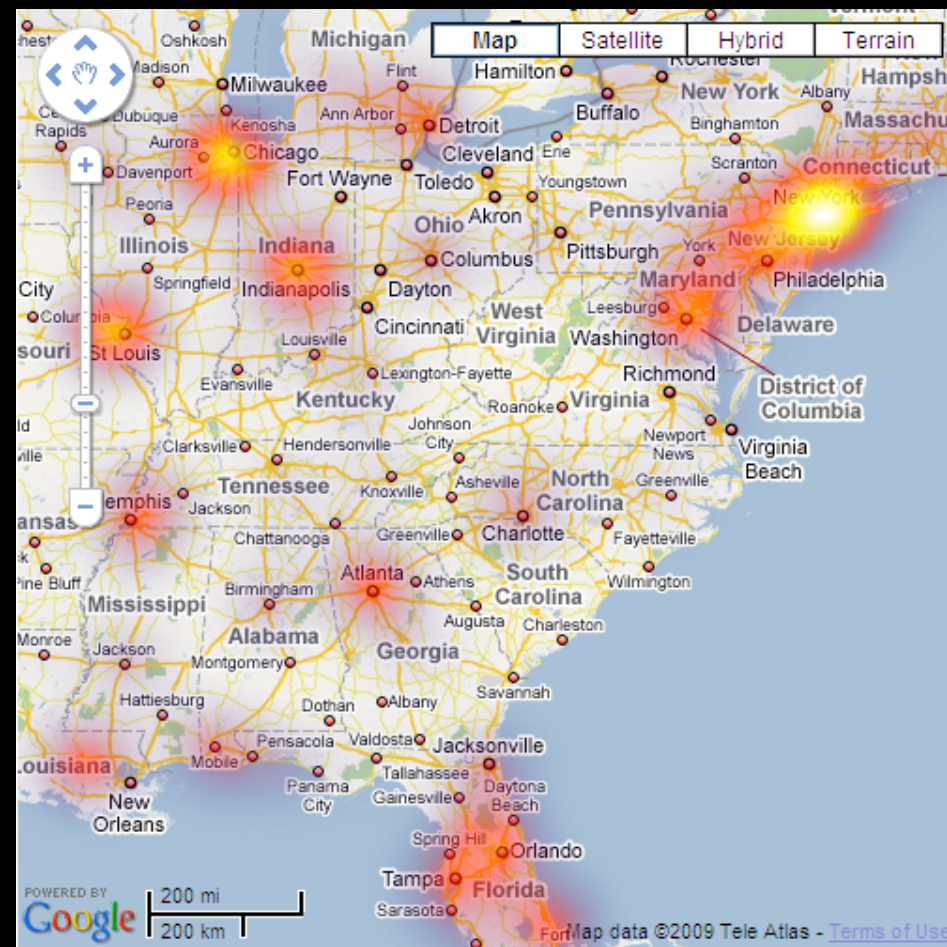
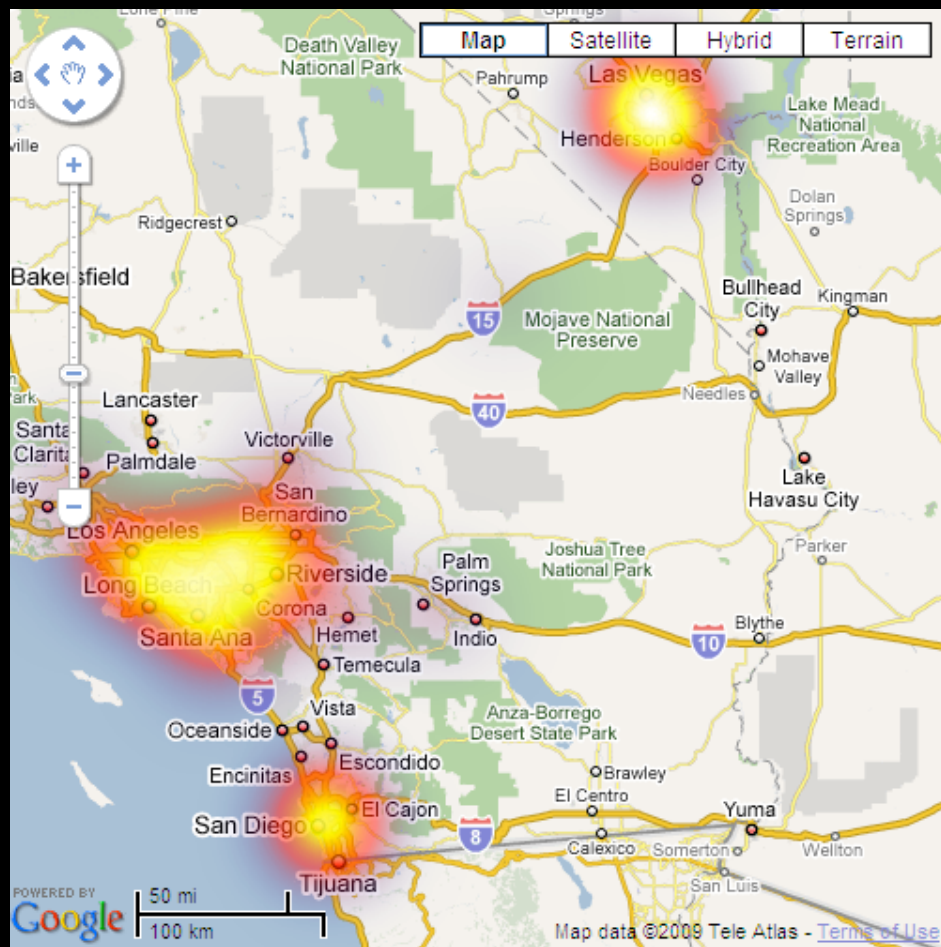
Heatmaps / Contour Maps

Convey Continuous Data

Binning

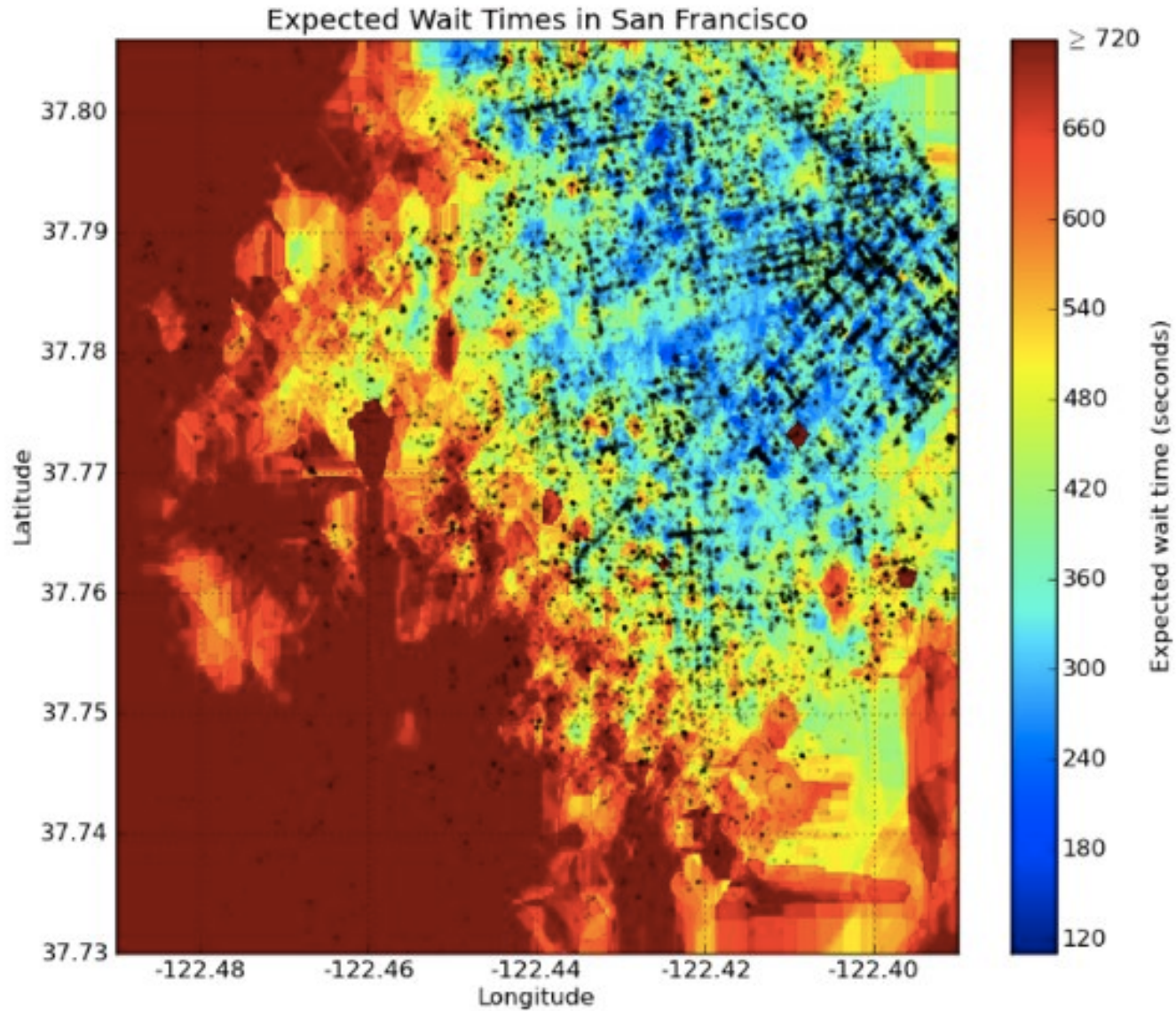


Chorodot Maps: Alan MacEachren and David DiBiase, 1991



Don't hide the context

Uber Wait Times, 2011



Break data into buckets

CRIMESPOTTING

The brazen 2007 murder of journalist Chauncey Bailey in Oakland, California, led Stamen partner Mike Migurski to

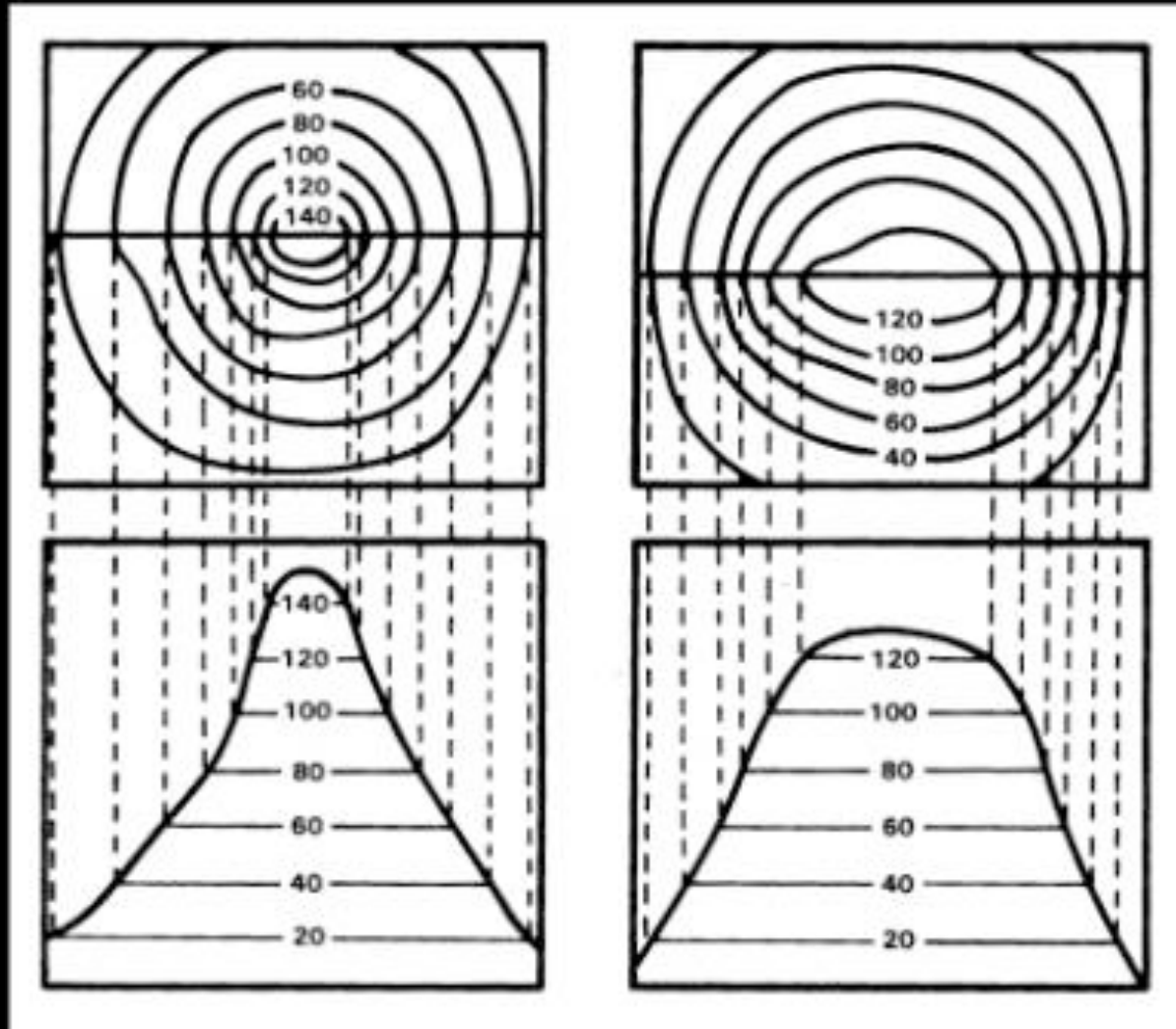
make the city's crime data more accessible. This heat map of downtown uses data from CrimeWatch, a community website,

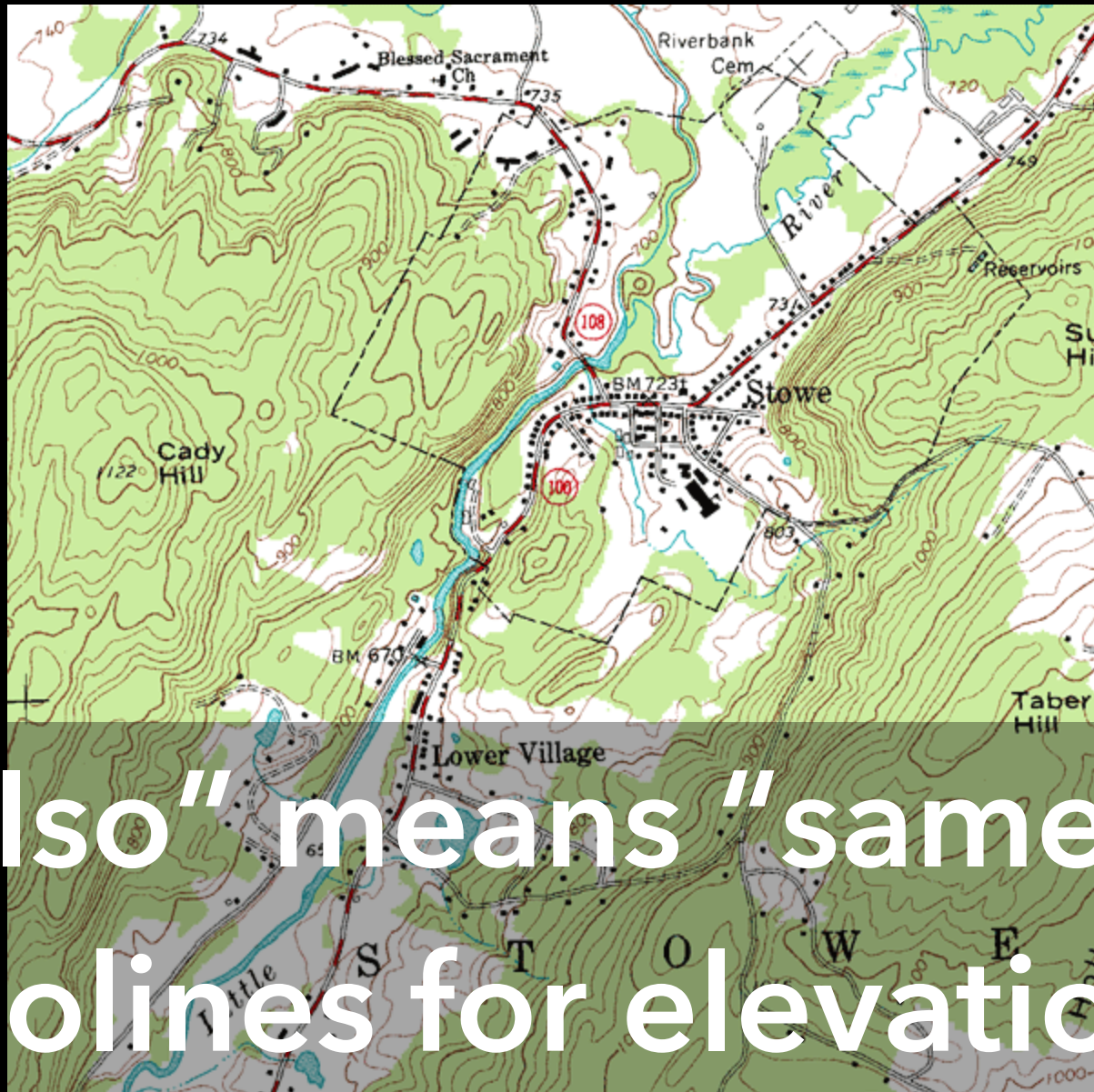
to show the gaps between crimes at a given intersection: white is high-crime; darker areas are safe. stamen.com

KEY
Colours show how recently a crime was reported in a given part of Oakland

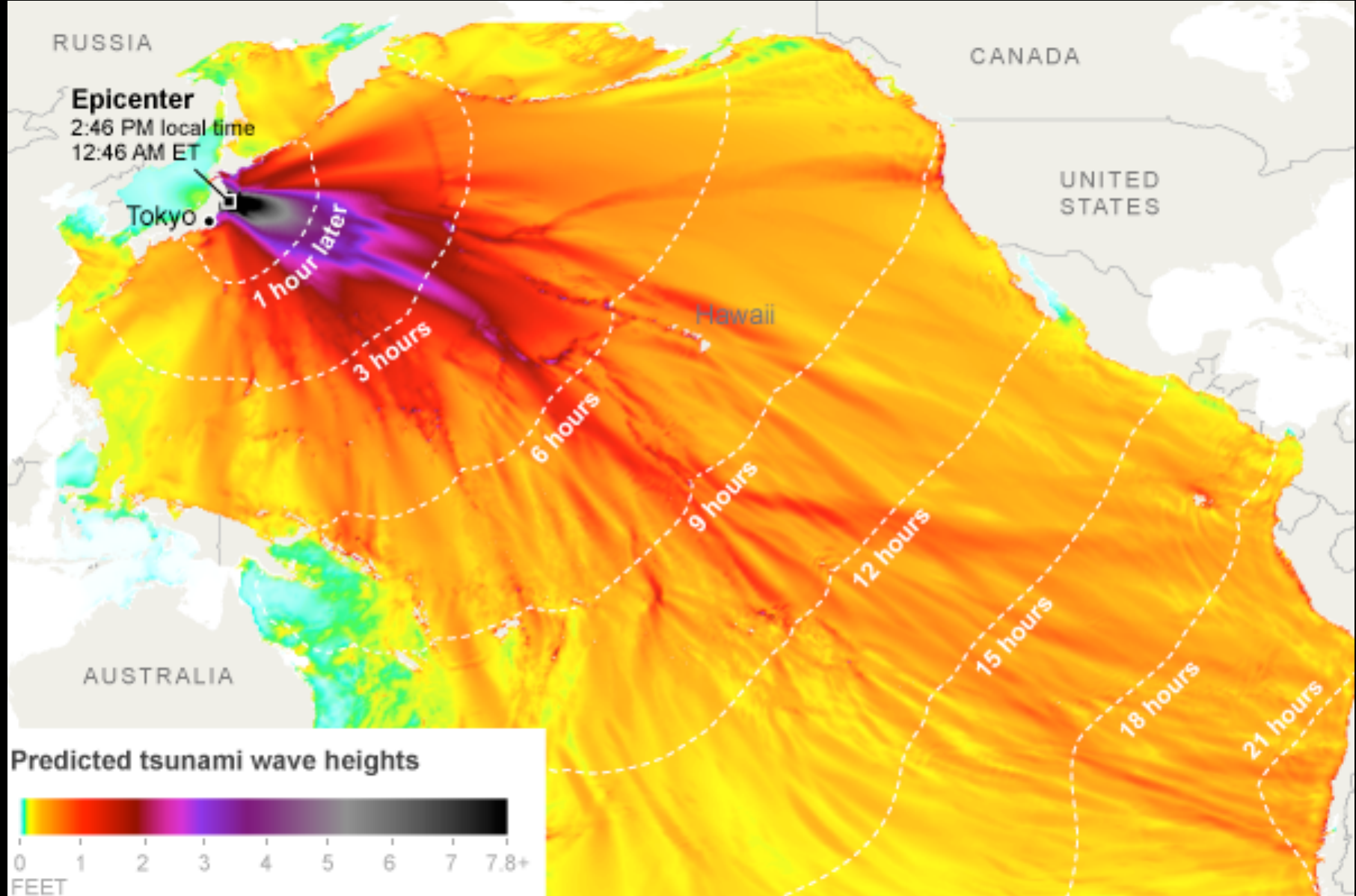
- A week ago
- Two weeks ago
- A month ago
- Two months ago
- Three months ago
- Four months ago
- Five months ago

Meaningful buckets, isolines





“Iso” means “same”
Isolines for elevation

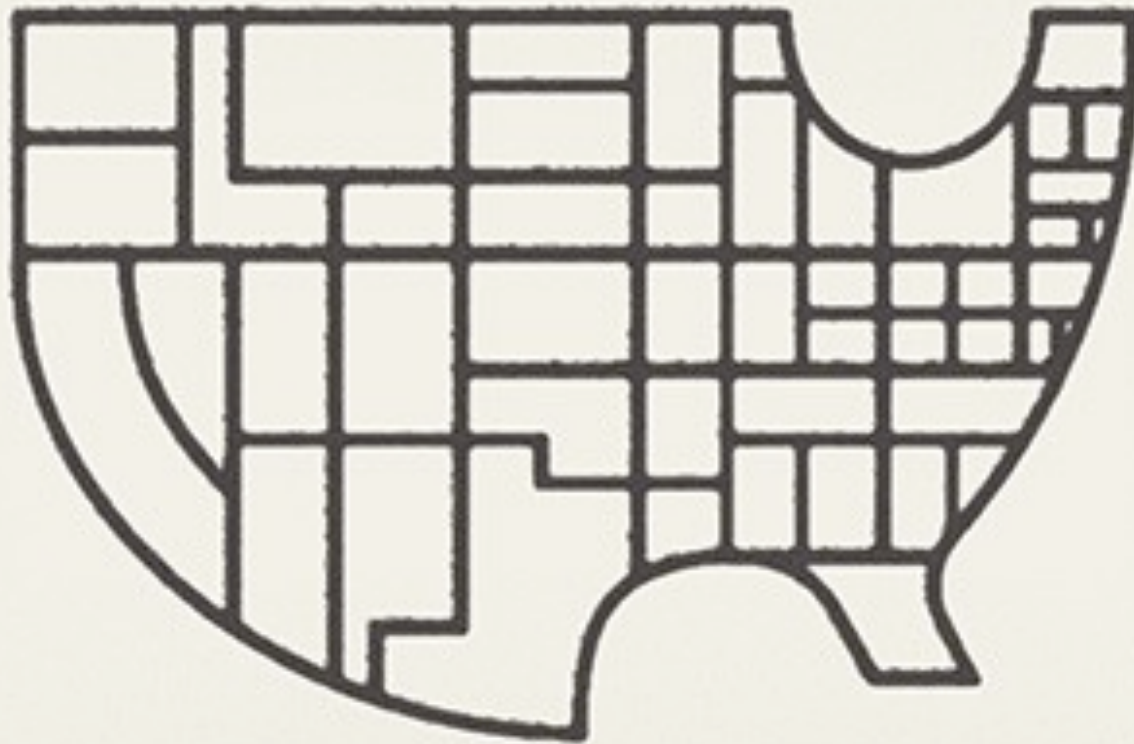


Isochrones are isolines for time

Cartograms

Distort Shape to Convey Quantities

**Major distortions
can stay recognizable**



New York Times ratings

198

Safe Dem.

16

Leaning Dem.

17

Toss up

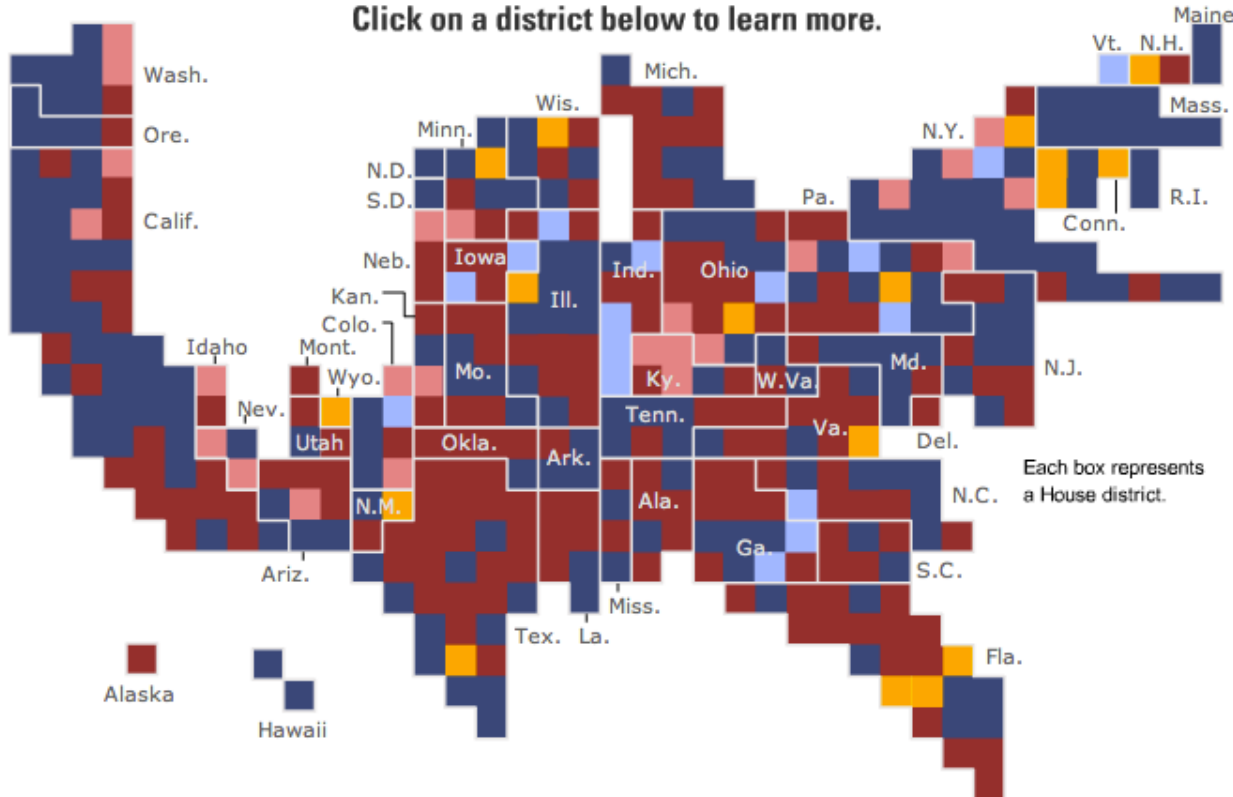
24

Leaning Rep.

180

Safe Rep.

Click on a district below to learn more.



ANALYZE RACES

CREATE OUTCOMES

Shade the map using the pulldown...

New York Times ratings

...then show only certain states

New York Times ratings ?

Democrat: ☐ Safe ☐ Leaning ☐ Toss Up

Republican: ☐ Safe ☐ Leaning

Current Rep. ☐ Dem. ☐ Rep.

Margin in 2004 House race

Democrat: ☐ >50% ☐ 25-50% ☐ <25%

Republican: ☐ >50% ☐ 25-50% ☐ <25%

Votes for president

☐ Kerry ☐ Gore

☐ Bush ☐ Bush

Appearances by big fundraisers ?

☐ George W. Bush ☐ Bill Clinton

☐ Races to watch ?

☐ Open races

☐ Switch districts ?

Urbanization

☐ Urban ☐ Suburban ☐ Rural ☐ Mixed

Race/Ethnicity

☐ White ☐ Black ☐ Hispanic

Median income

☐ <\$30K ☐ \$30-50K ☐ >\$50K

RESET

Block Cartogram: Discrete Units

NY Times

237

Joseph R. Biden Jr.

70,122,063 votes (50.2%)

87

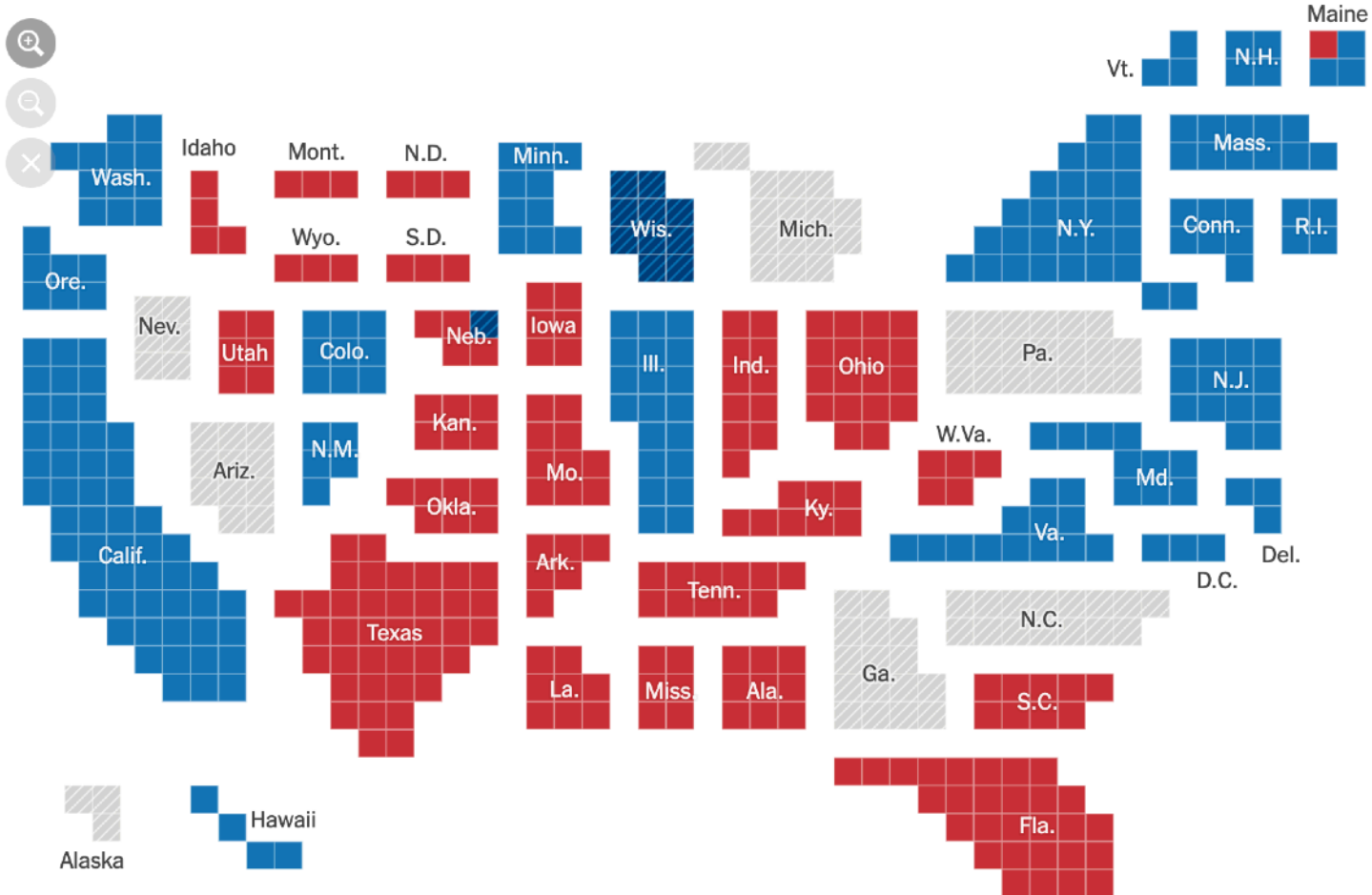
remaining

270
TO WIN

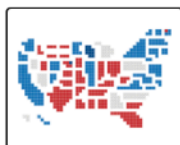
214

Donald J. Trump

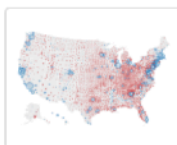
67,075,300 votes (48.0%)



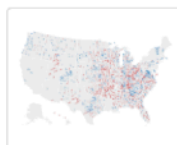
By winner



Electoral votes



Size of lead



Shift from 2016

Cartogram
[NY Times]

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 »](#)

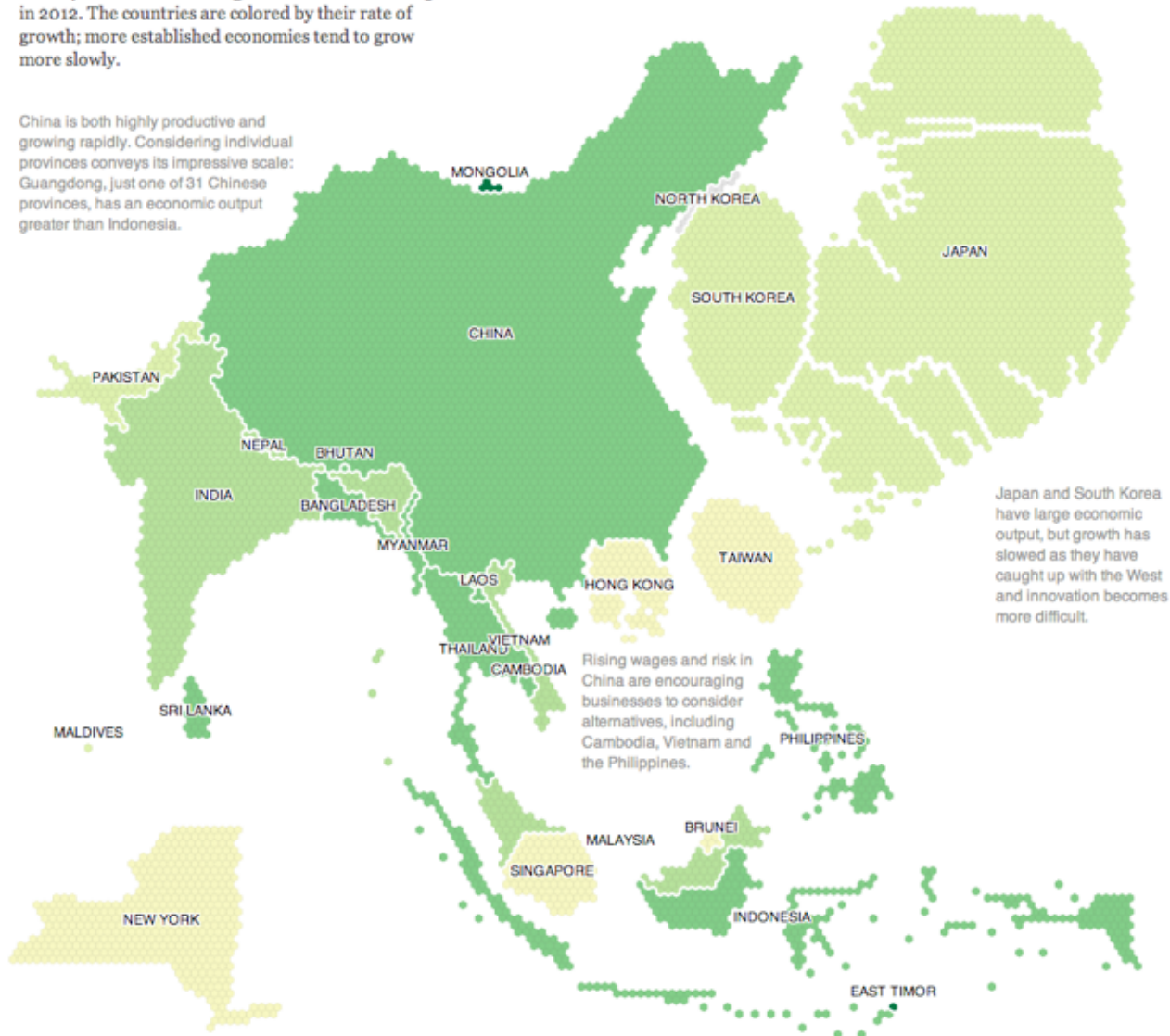
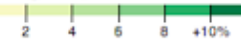
Economic Output

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.

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.

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

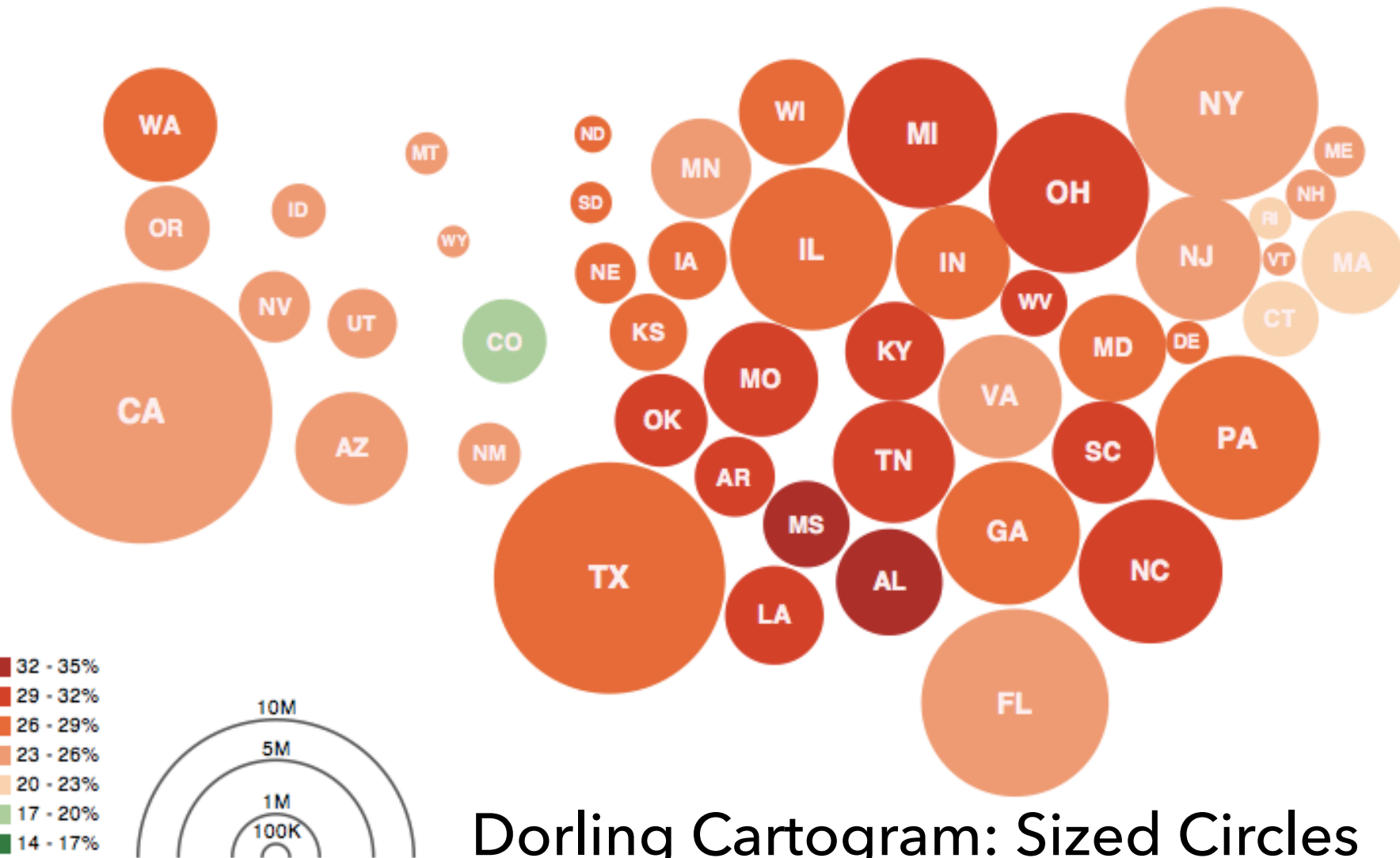
G.D.P. growth, 2011 to 2012



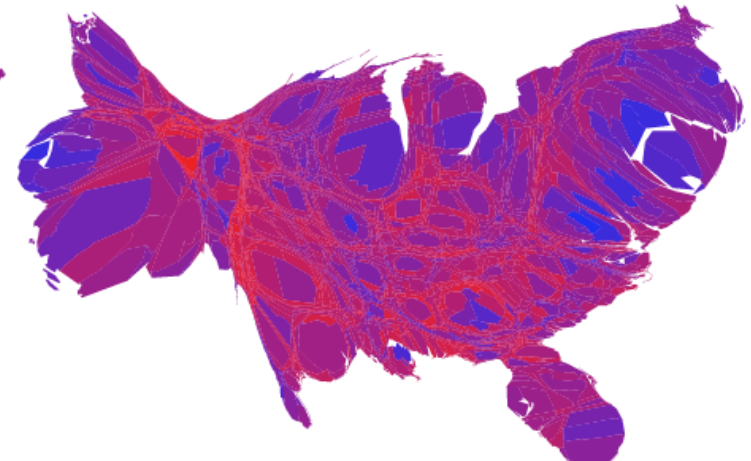
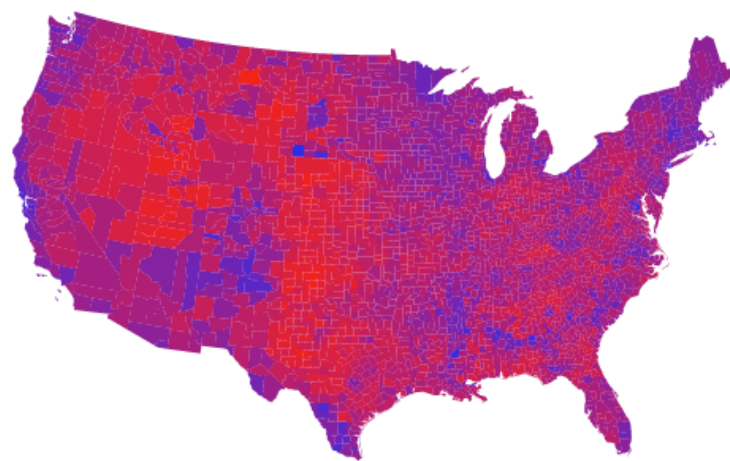
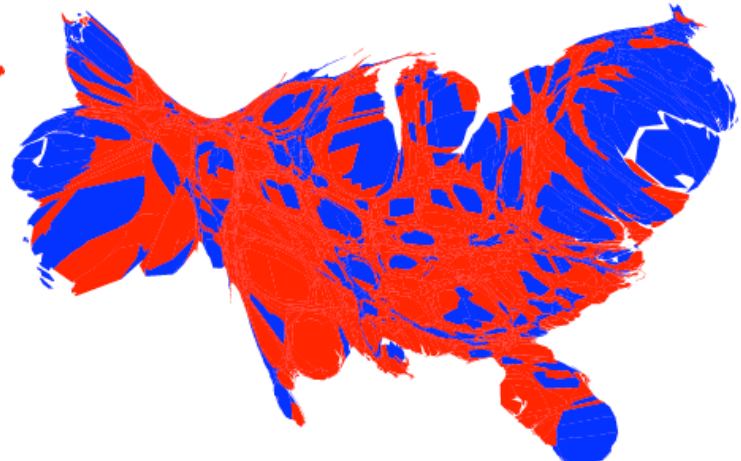
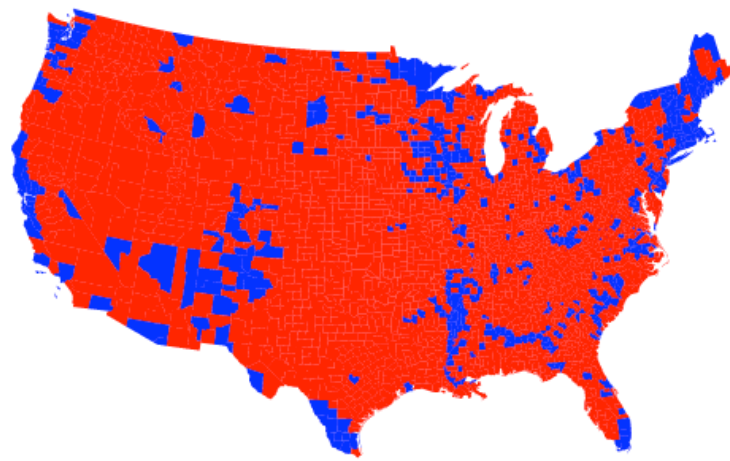
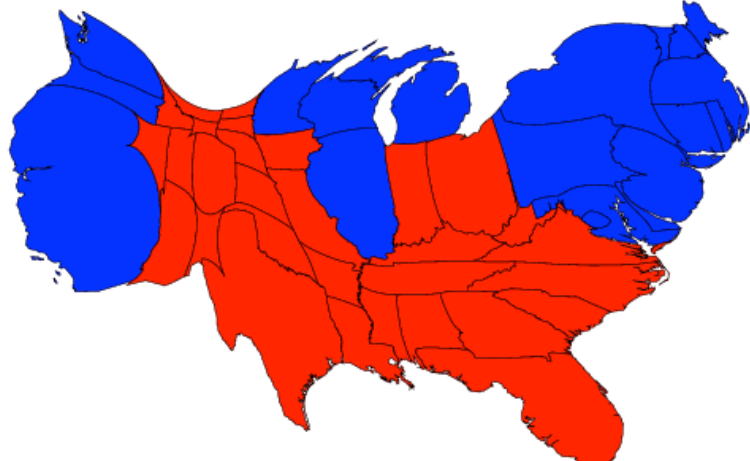
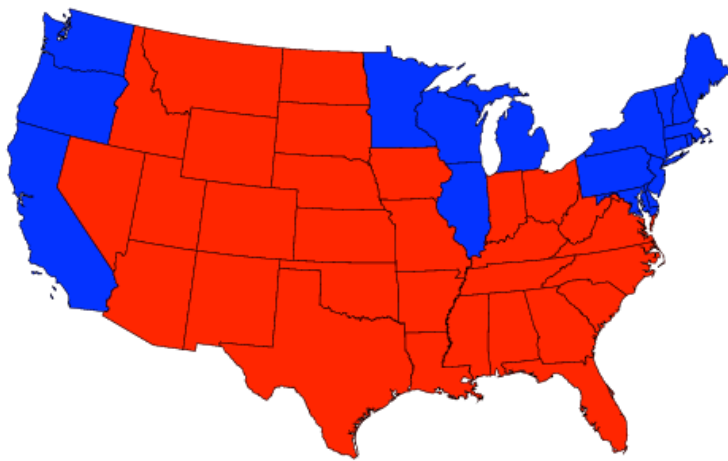
Japan and South Korea have large economic output, but growth has slowed as they have caught up with the West and innovation becomes more difficult.

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

New York shown for comparison.



Dorling Cartogram: Sized Circles



Physical Diffusion Model

[Newman 2004]

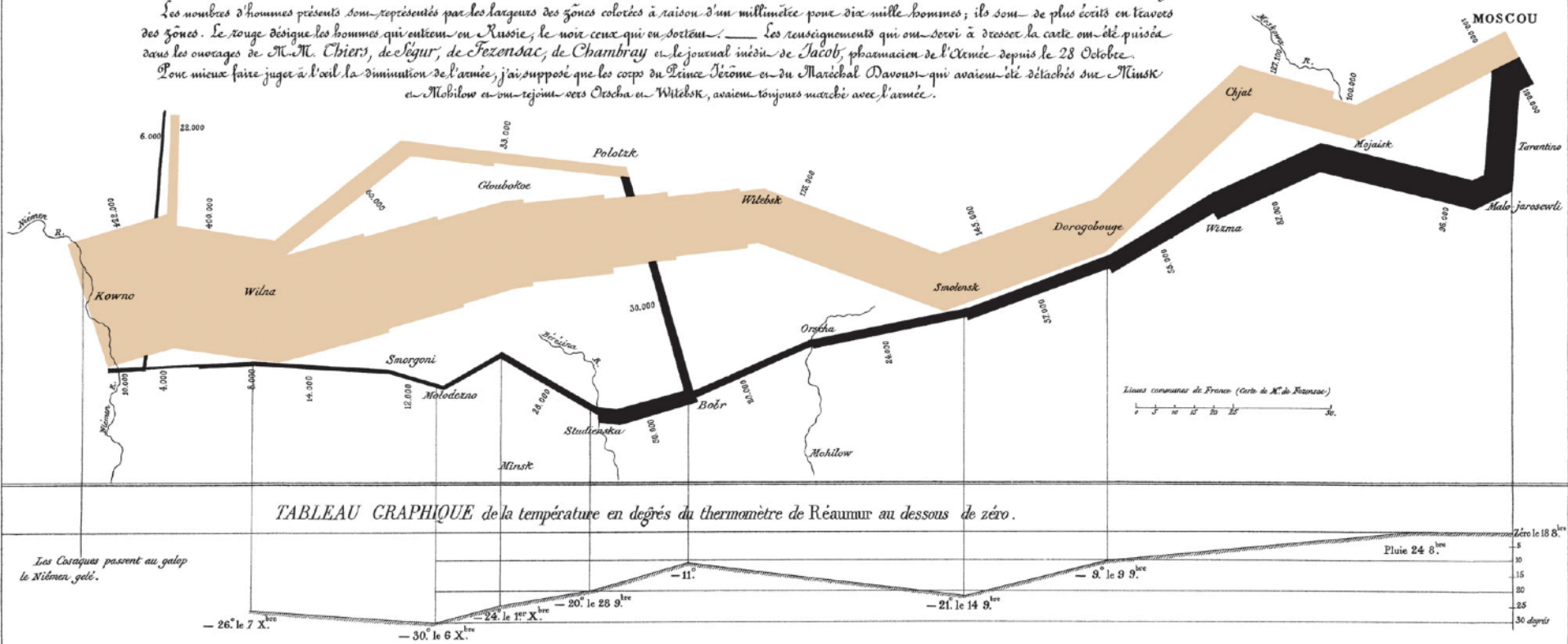
Flow Maps

Convey Flux Between Locations

Minard 1869: Napoleon's march

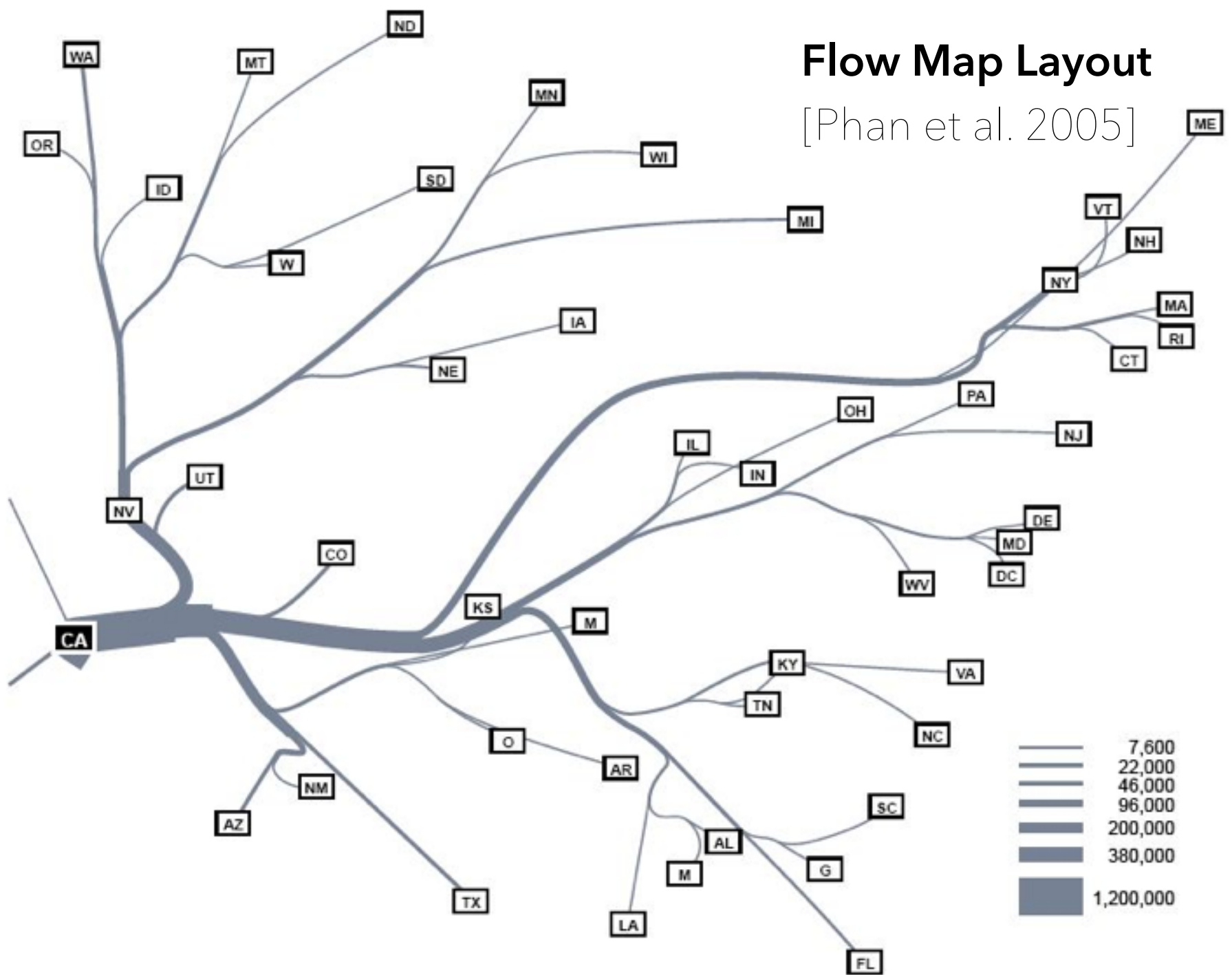
Carte Figurative des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812-1813.
Dressée par M. Minard, Inspecteur Général des Ponts et Chaussées en retraite Paris, le 20 Novembre 1869.

Les nombres d'hommes présents sont représentés par les largeurs des zones colorées à raison d'un millimètre pour dix mille hommes; ils sont de plus écrits en travers des zones. Le rouge désigne les hommes qui entrent en Russie, le noir ceux qui en sortent. Les renseignements qui ont servi à dresser la carte ont été puisés dans les ouvrages de M. M. Thiers, de Ségur, de Fezensac, de Chambray et le journal inédit de Jacob, pharmacien de l'Armée depuis le 28 Octobre. Pour mieux faire juger à l'œil la diminution de l'armée, j'ai supposé que les corps du Prince Jérôme et du Maréchal Davout, qui avaient été détachés sur Minsk et Mohilew et qui rejoignent vers Orscha et Witebsk, avaient toujours marché avec l'armée.



Flow Map Layout

[Phan et al. 2005]

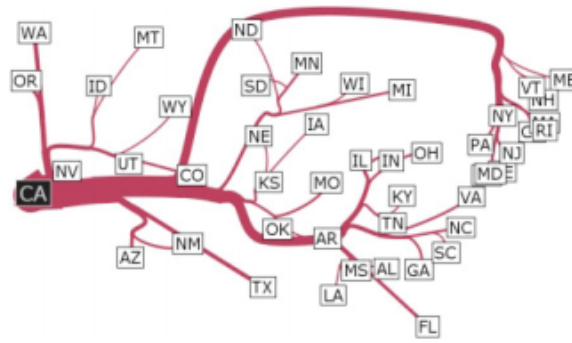


Migration from California, '95-'00

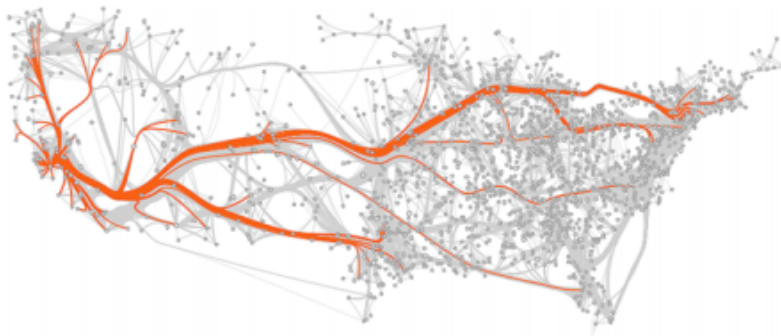
Tobler 1987



Phan et al. 2005



Verbeek et al. 2011



Cui et al. 2008



Holten & van Wijk 2009

wind map

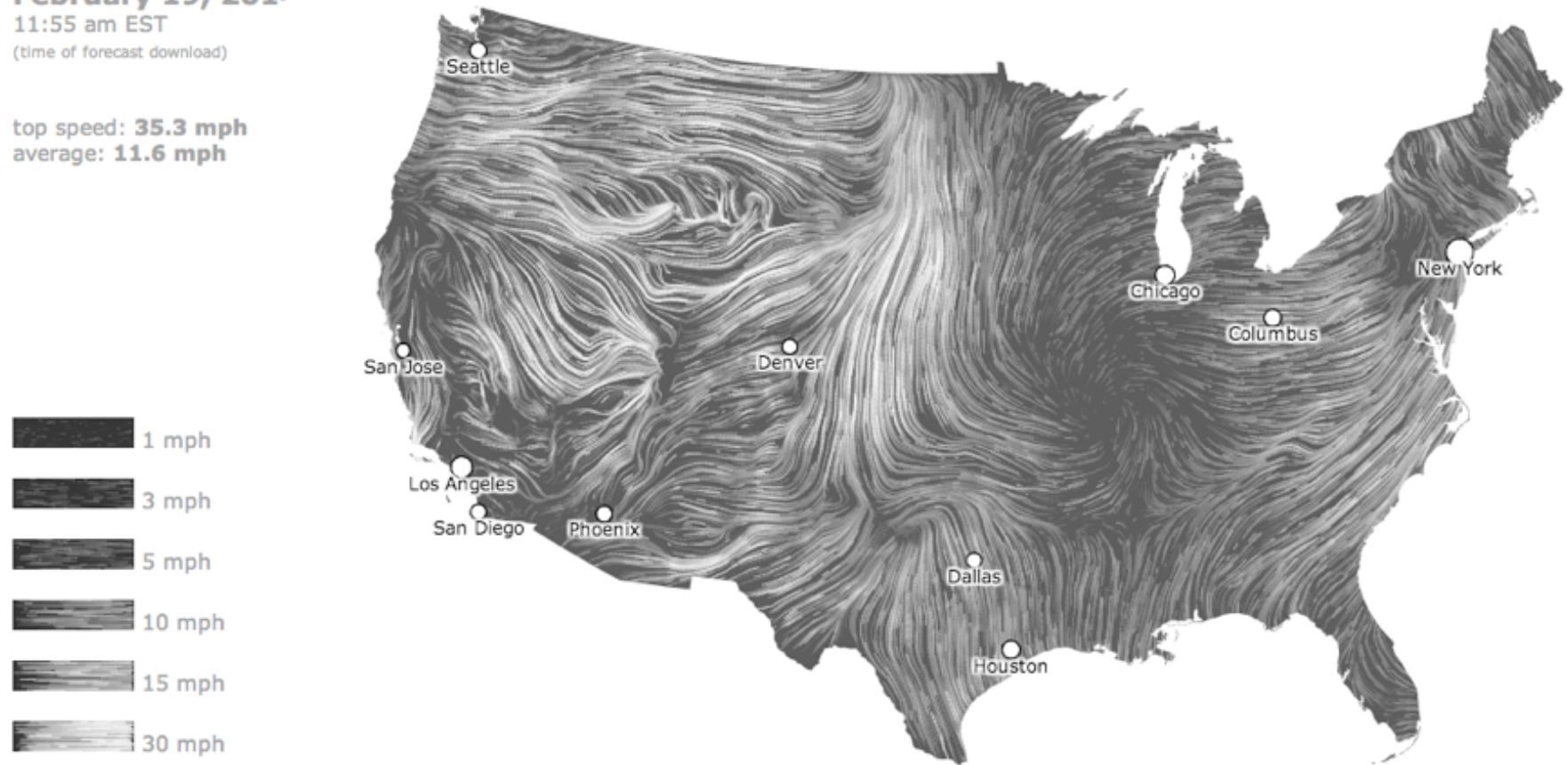
February 19, 2014

11:55 am EST

(time of forecast download)

top speed: **35.3 mph**

average: **11.6 mph**



Wattenberg & Viegas

Generalization

Abstraction to Convey Topology



Beck's London tube diagram



Principle: Straighten lines to emphasize stop sequence

Technique used to emphasize/de-emphasize information

Route Maps: Bellevue to Seattle



Map Design via Optimization [Agrawala '01]

Set of graphic elements

Roads, labels, cross-streets, ...

Choose visual attributes

Position, orientation, size, ...

Distortions increase flexibility

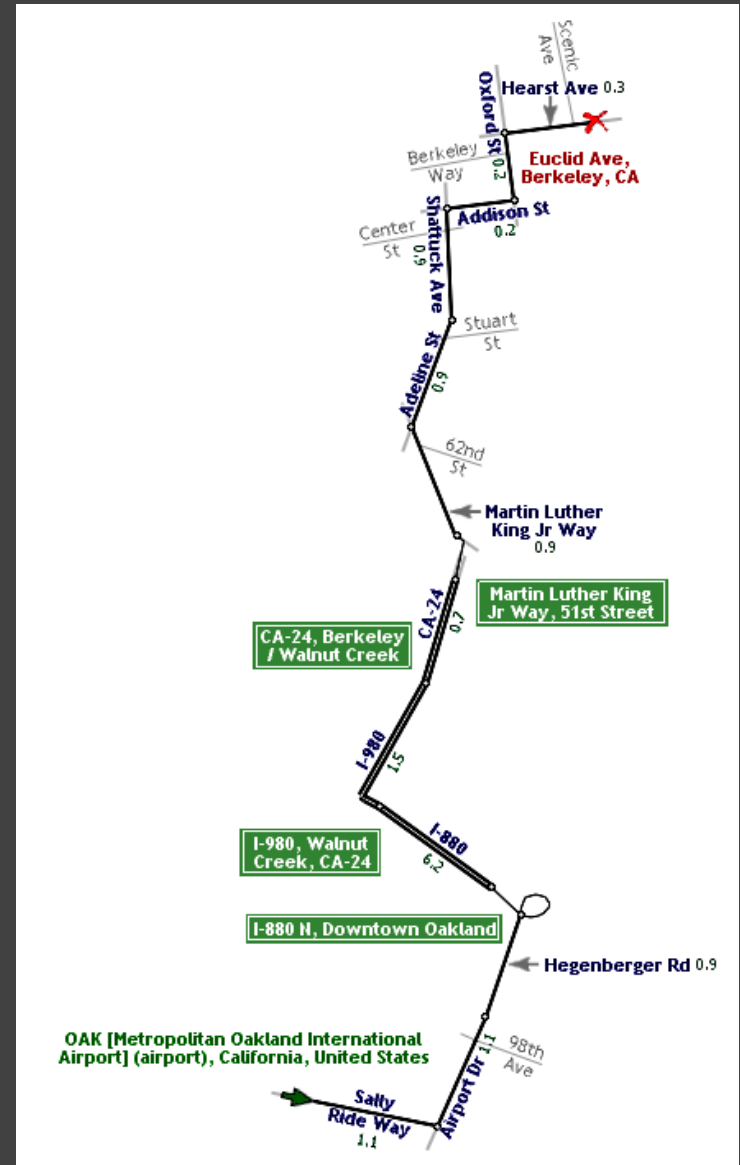
Develop constraints based on design principles

Simulated annealing

Perturb: Form a layout

Score: Evaluate quality

Minimize score



Road Layout Constraints [Agrawala '01]

Length

Ensure all roads visible

$$((L_{\min} - l(r_i)) / L_{\min})^2 * W_{\text{small}}$$

Maintain ordering by length

$$W_{\text{shuffle}}$$

Orientation

Maintain original orientation

$$|\alpha_{\text{curr}}(r_i) - \alpha_{\text{orig}}(r_i)| * W_{\text{orient}}$$

Topological errors

Prevent false

$$\min(d_{\text{origin}}, d_{\text{dest}}) * W_{\text{false}}$$

Prevent missing

$$d * W_{\text{missing}}$$

Ensure separation

$$\min(d_{\text{ext}}, E) * \text{Ext}$$

Overall route shape

Maintain endpoint direction

$$|\alpha_{\text{curr}}(v) - \alpha_{\text{orig}}(v)| * W_{\text{enddir}}$$

Maintain endpoint distance

$$|d_{\text{curr}}(v) - d_{\text{orig}}(v)| * W_{\text{enddist}}$$

Approaches to Mapping Data

Symbol Maps → plot data over a map

Choropleth Maps → colored regions

Heatmaps & Contours → show densities

Cartograms → distort to show quantities

Flow Maps → flux across regions

Generalization → distort/abstract to aid tasks

Resources

Software Tools

Web Tools

d3-geo: projections, paths and more

GeoJSON: JSON format for geo data

TopoJSON: topology -> compressed GeoJSON

MapShaper: online editor for map data

Leaflet: open-source, customizable map tile system

Other

PostGIS: Postgres DB extensions for geo data

Mapnik: Render your own map tiles!

Data Resources

Natural Earth Data

naturalearthdata.com

OpenStreetMap

openstreetmap.org

U.S. Government

nationalatlas.gov, census.gov, usgs.gov

Tutorials

Cartographic Visualization in Vega-Lite

<https://observablehq.com/@uwdata/cartographic-visualization>

Command-Line Cartography

<https://medium.com/@mbostock/command-line-cartography-part-1-897aa8f8ca2c>

How to Infer Topology

<http://bost.ocks.org/mike/topology/>