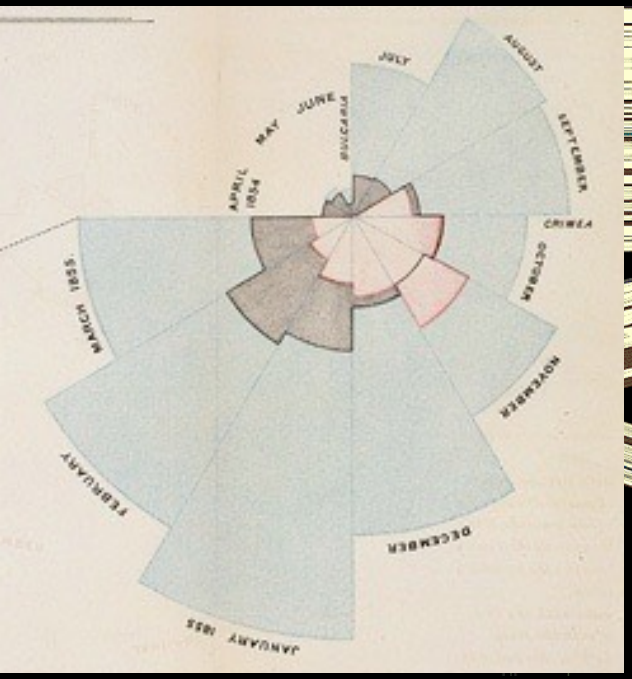
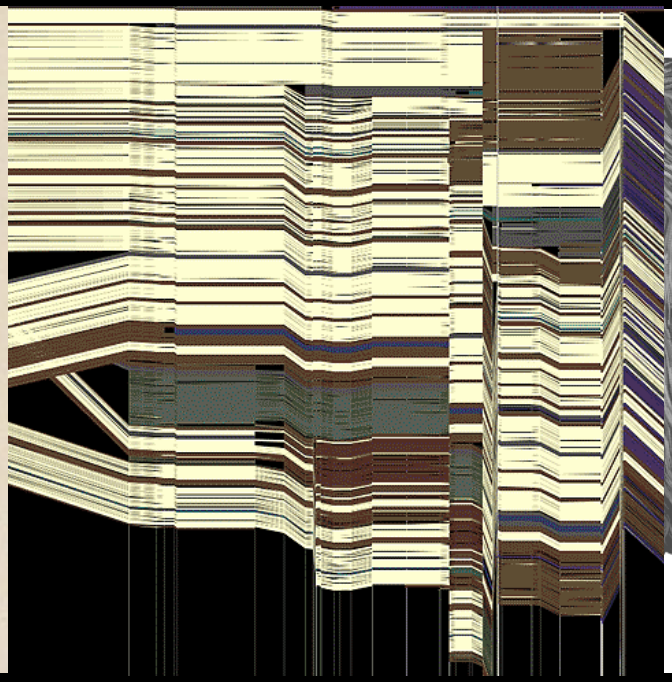
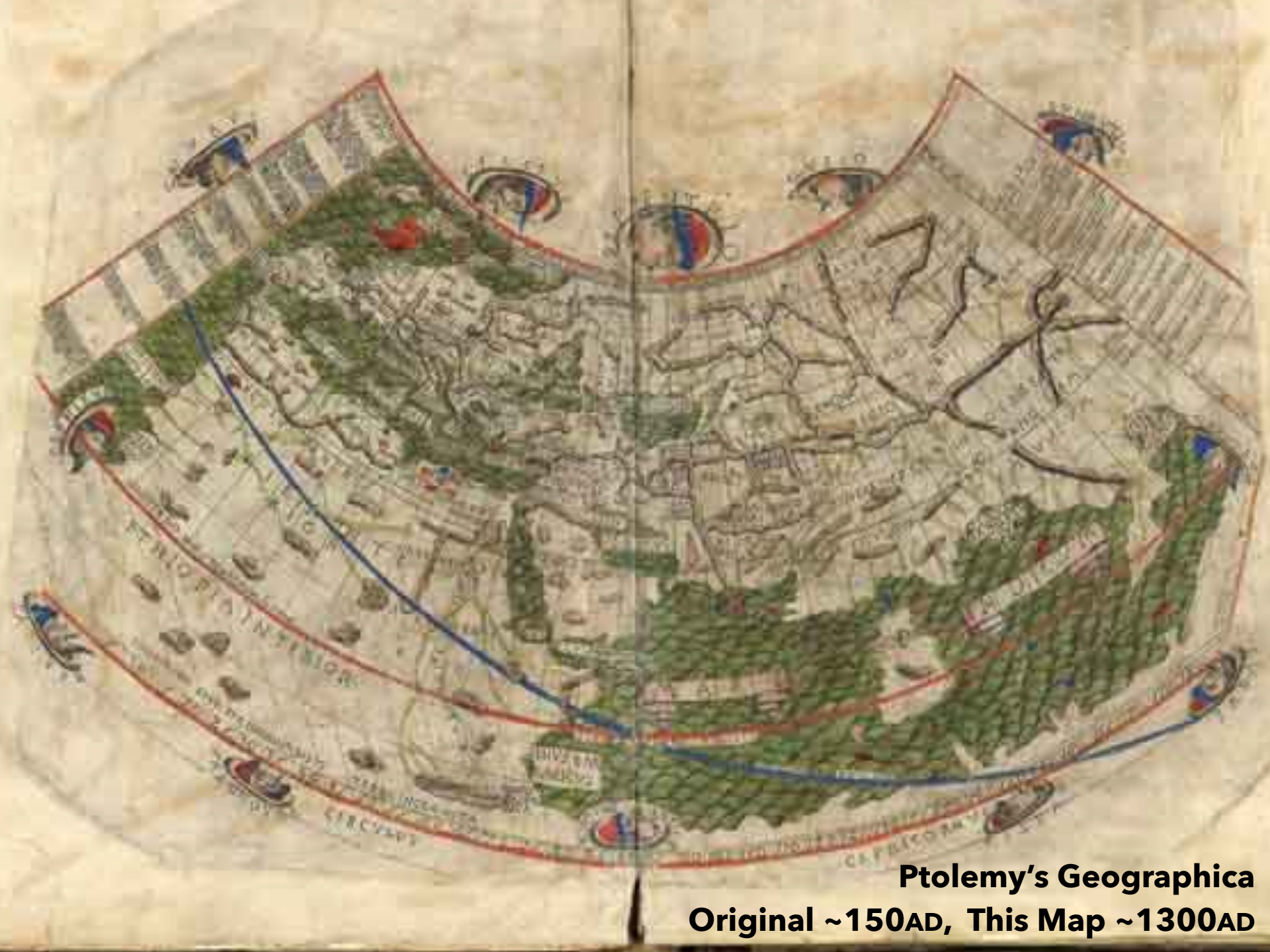
CSE 442 - Data Visualization

Mapping & Cartography

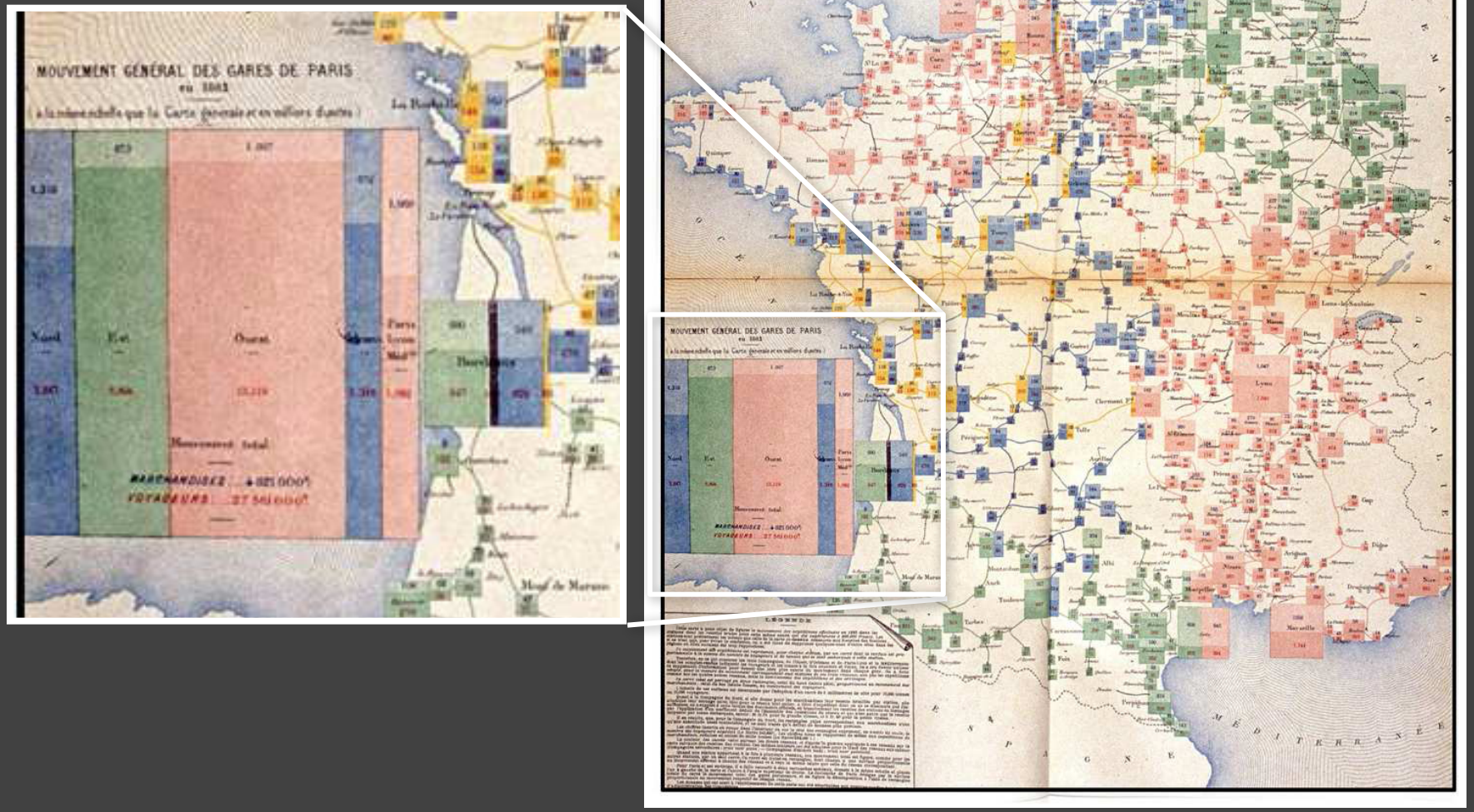




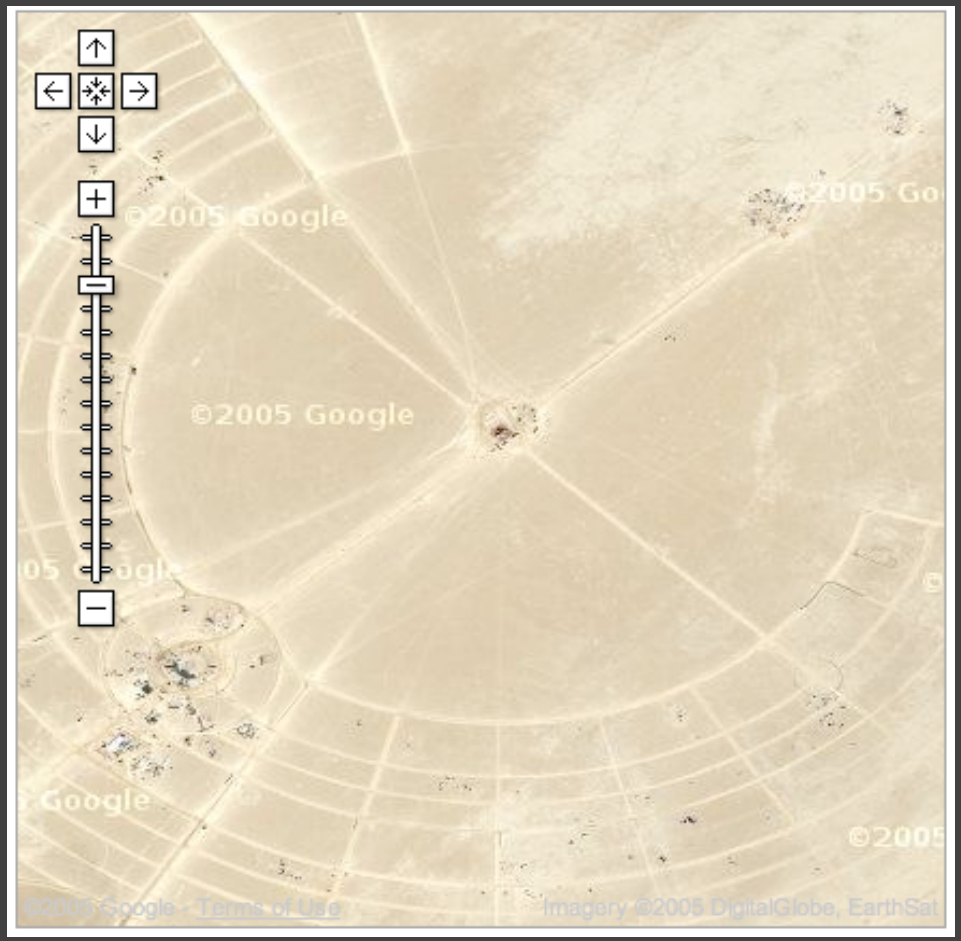
Jeffrey Heer University of Washington
(with significant material from Michal Migurski)

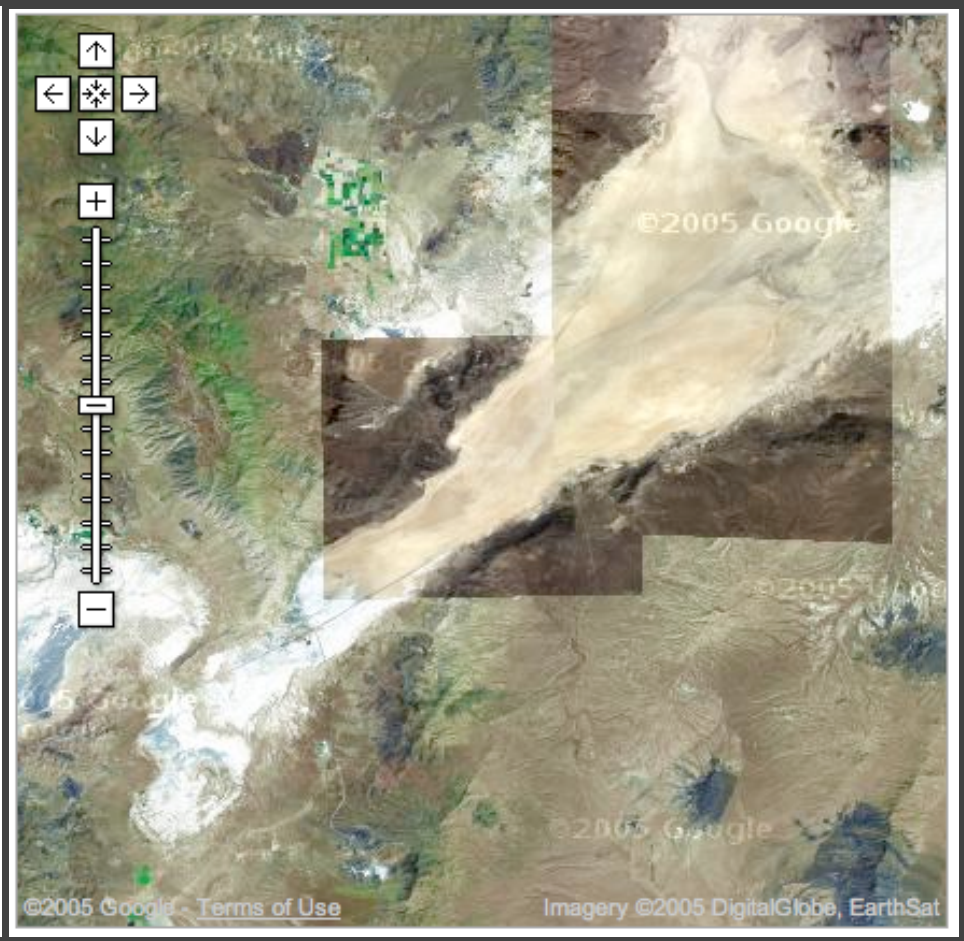


Ptolemy's Geographica
Original ~150AD, This Map ~1300AD

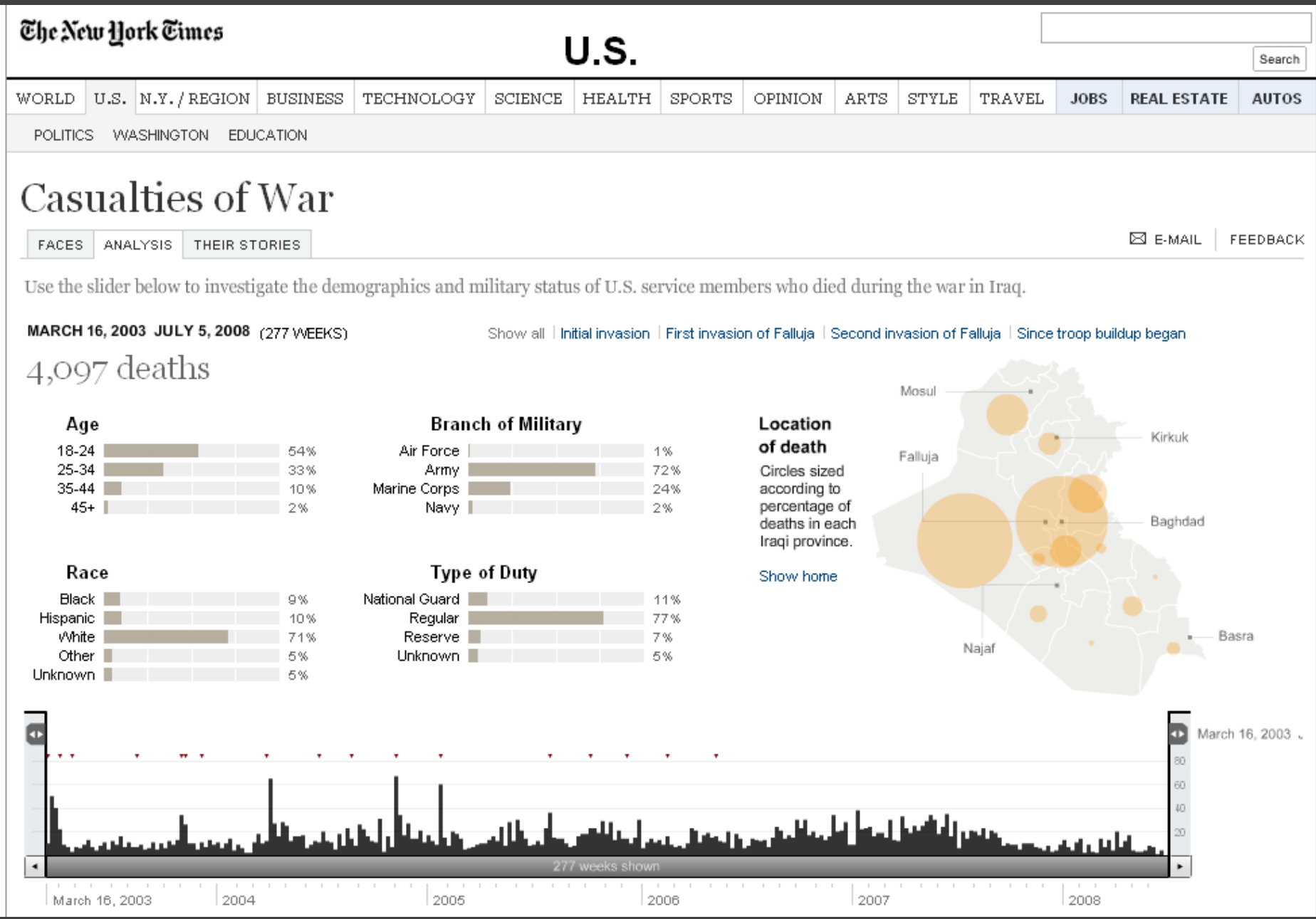


Rail Passengers and Freight from Paris 1884





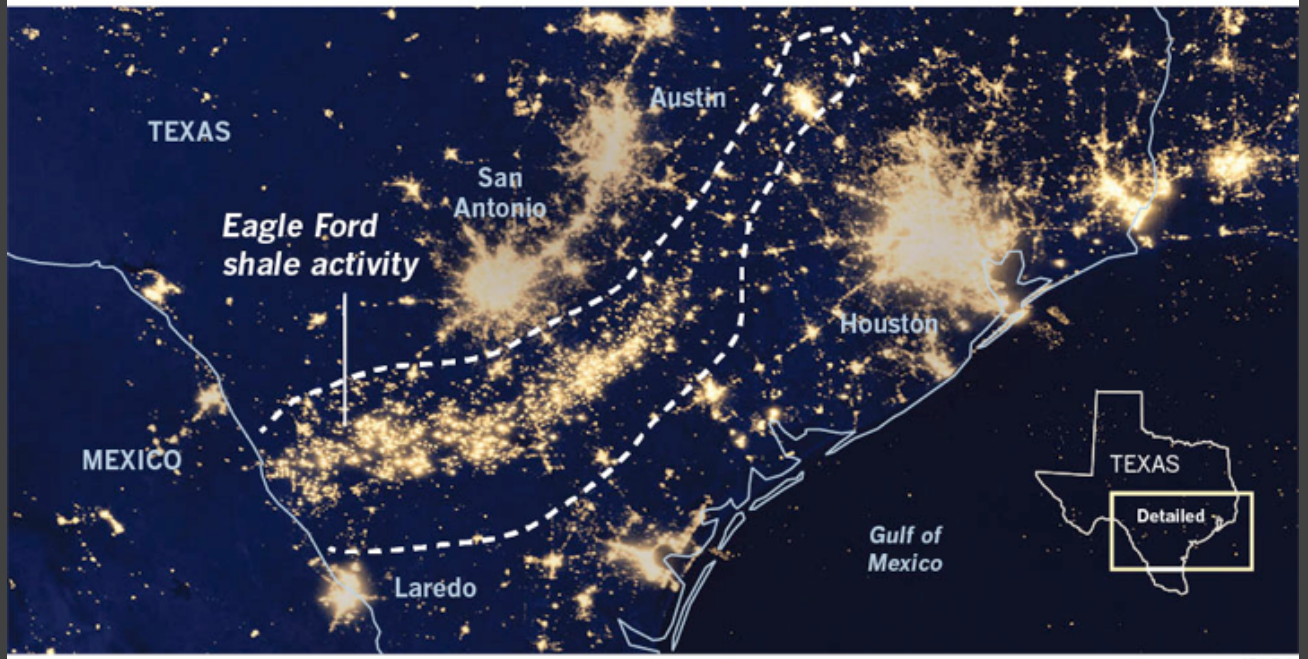
Google Maps 2005



Casualties of War, New York Times 2006

Texas oil boom is visible from space

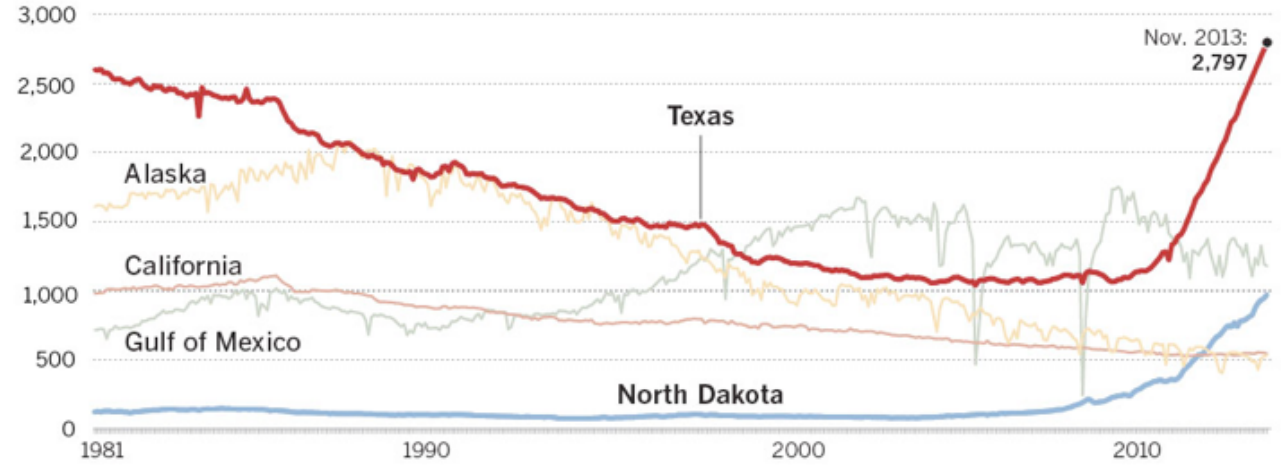
Lighting and natural gas flares from drilling on the 400-mile-long Eagle Ford shale formation can be seen from space in this image.



NASA

The new formation has helped make Texas the No. 1 oil-producing state in the nation.

Oil production from different U.S. regions (in thousands of barrels per day)



Source: Energy Information Administration

MATT MOODY Los Angeles Times

LA Times
2014

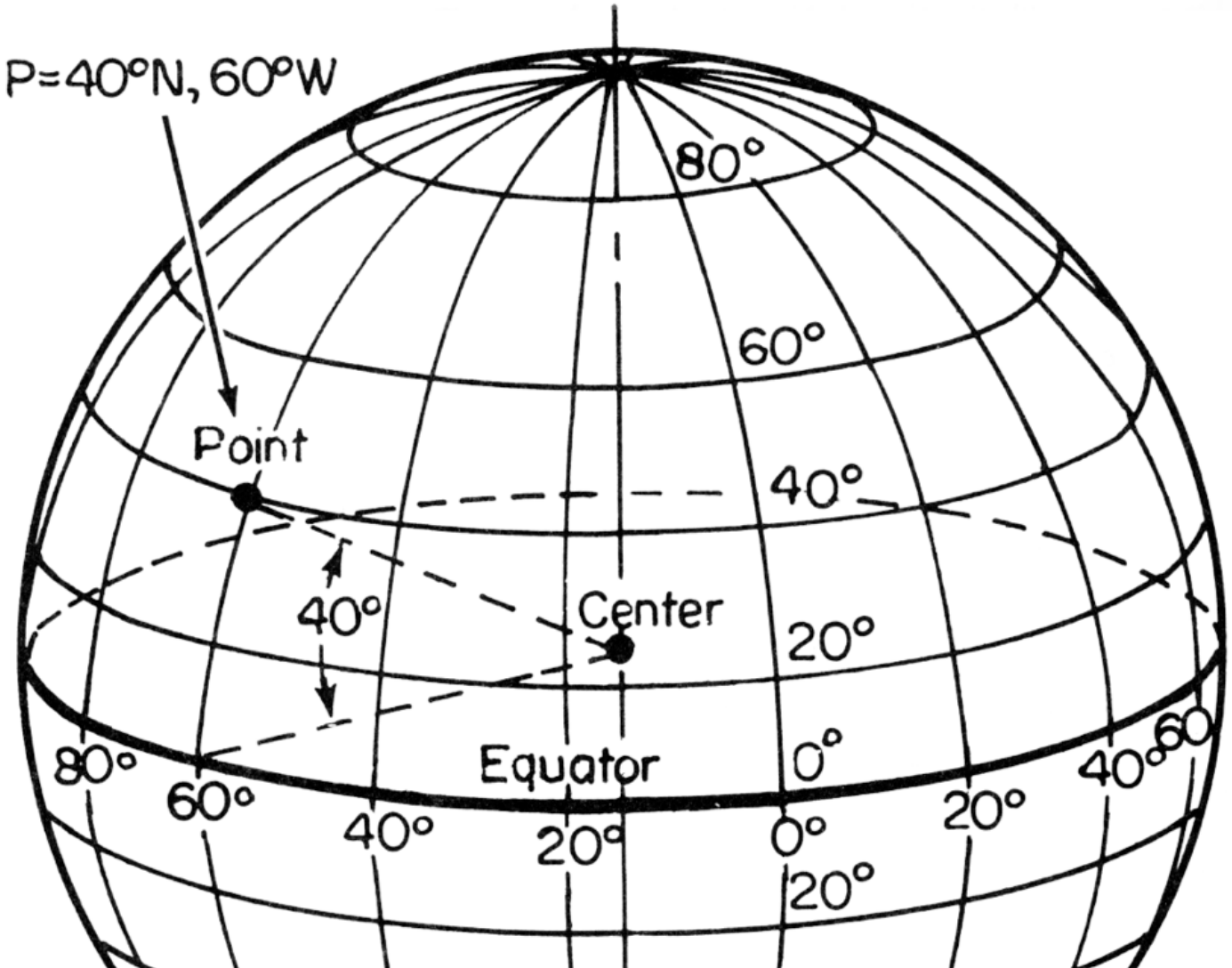
NY Times
2014

Cartography

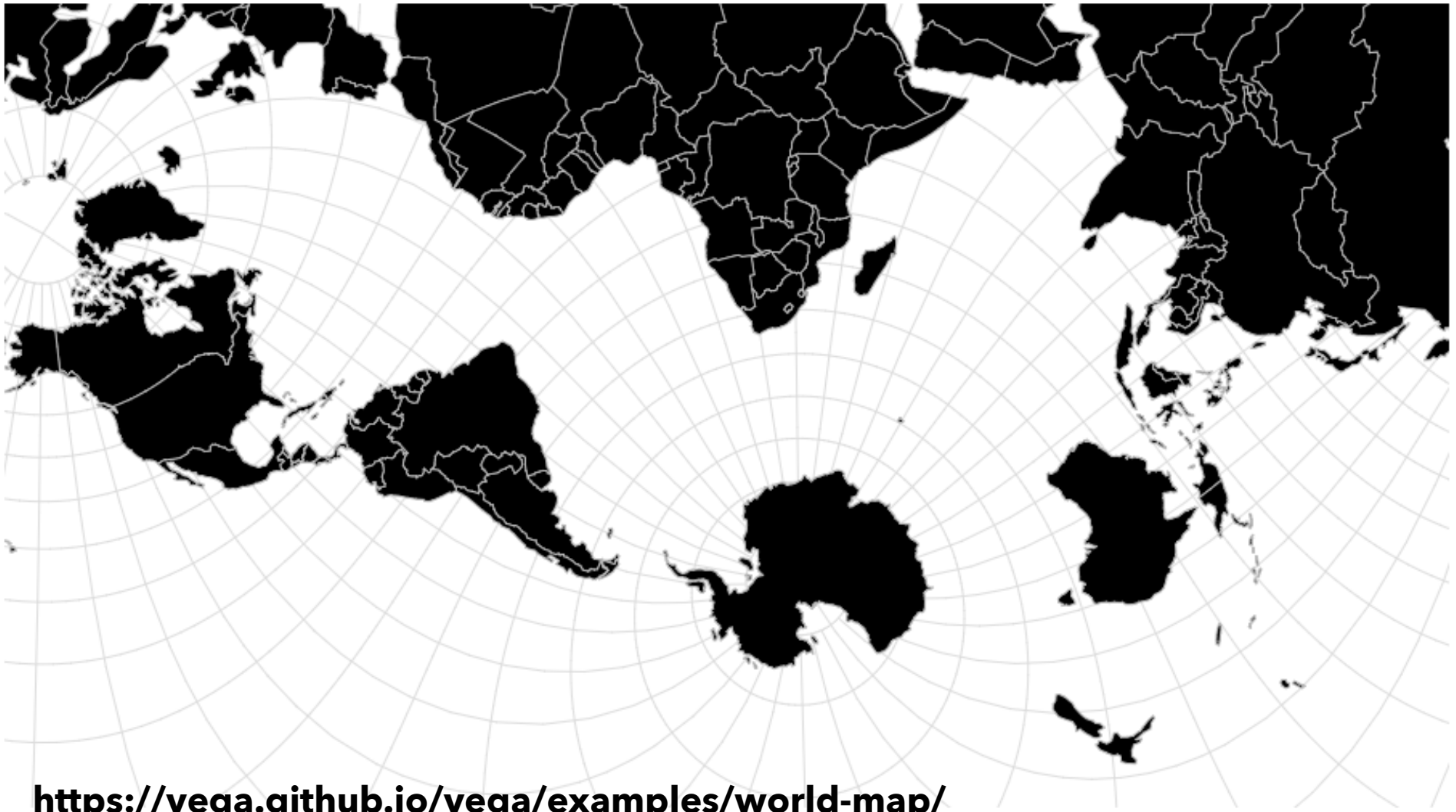
The Making of Maps

Projections

Latitude, Longitude



Exploring Projections…



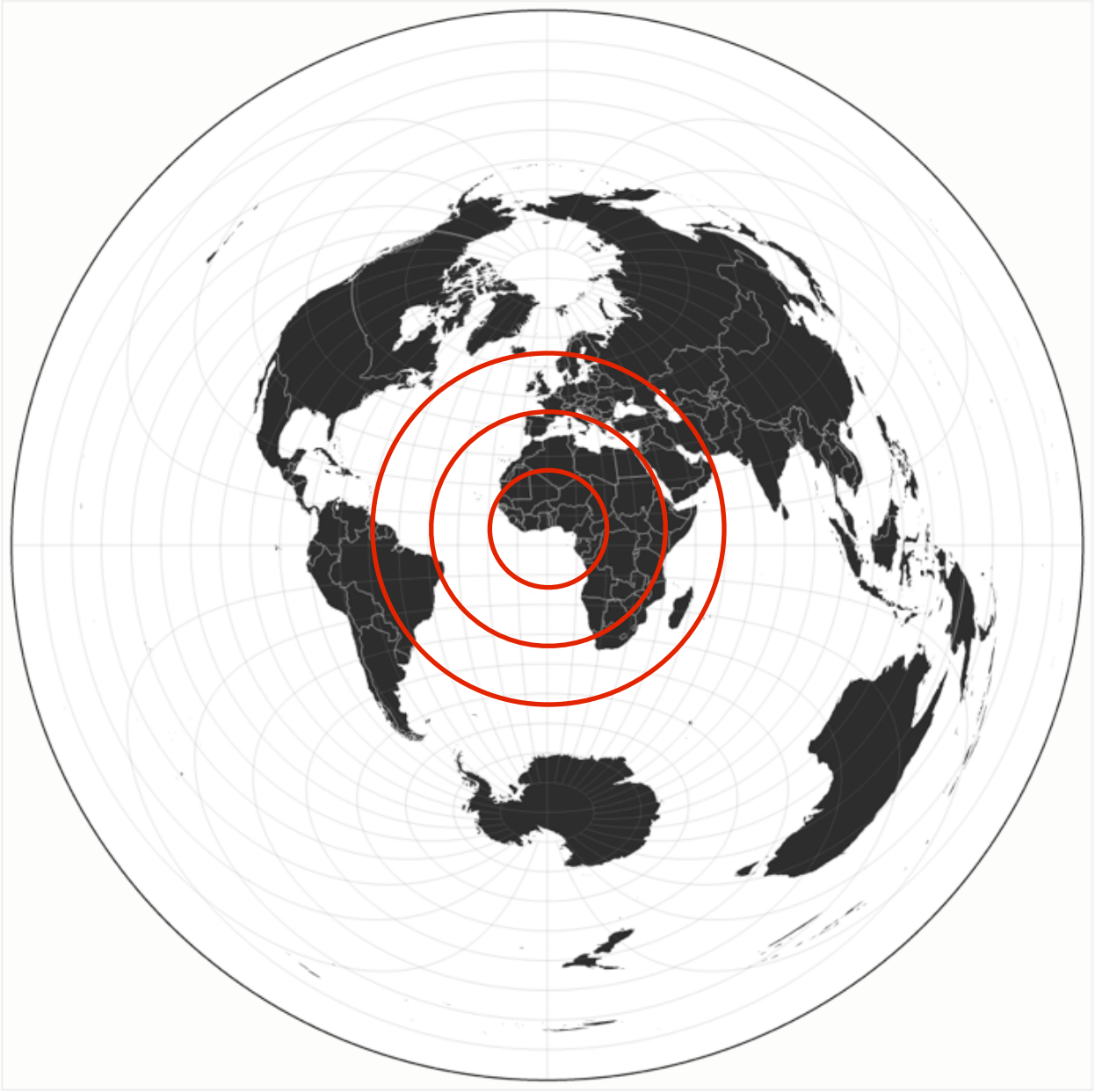
https://vega.github.io/vega/examples/world-map/


A sphere tears
when you flatten it

Three example ways to categorize projections…

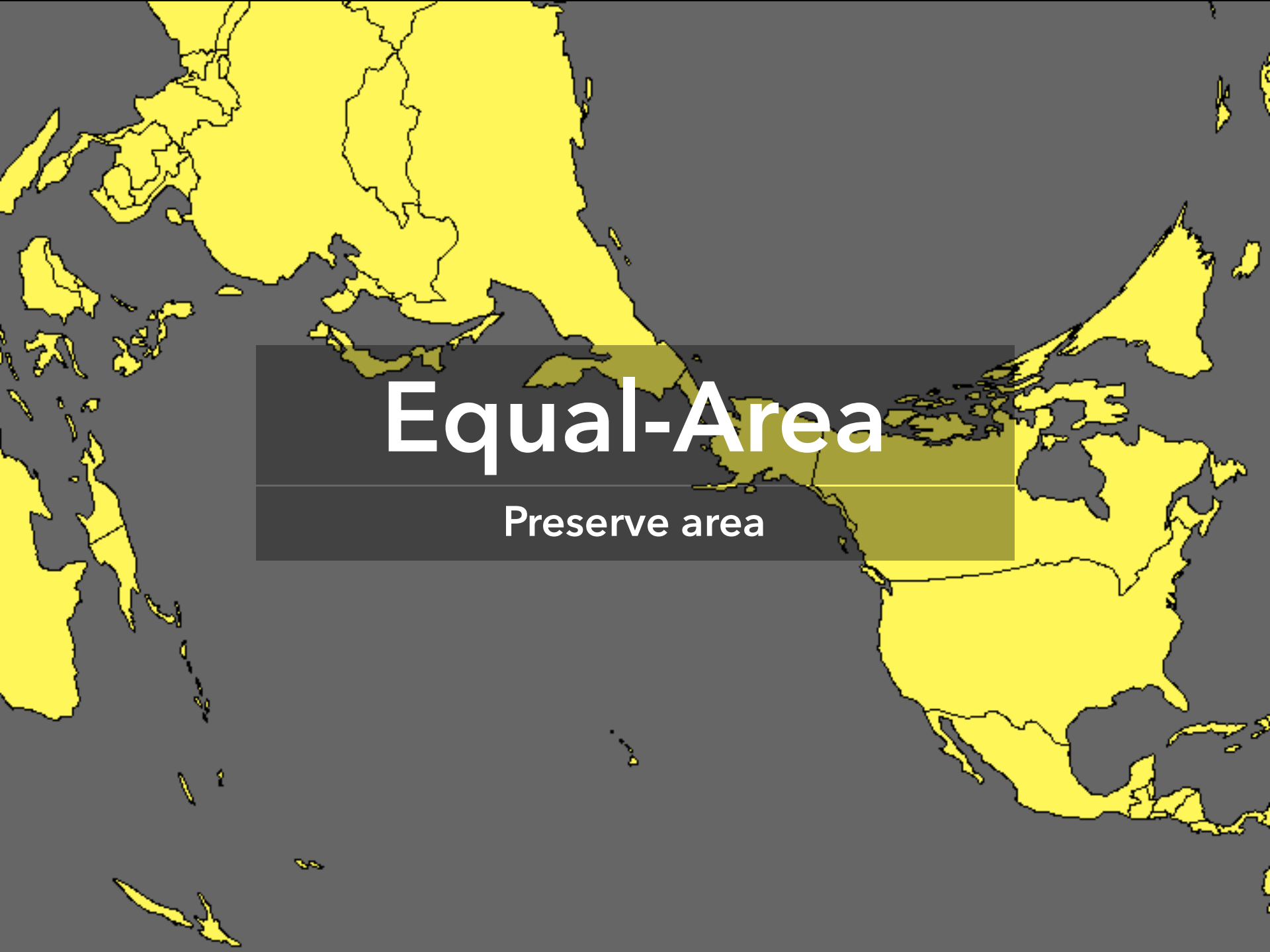

Azimuthal
Preserve direction / distance from center

Azimuthal Equidistant

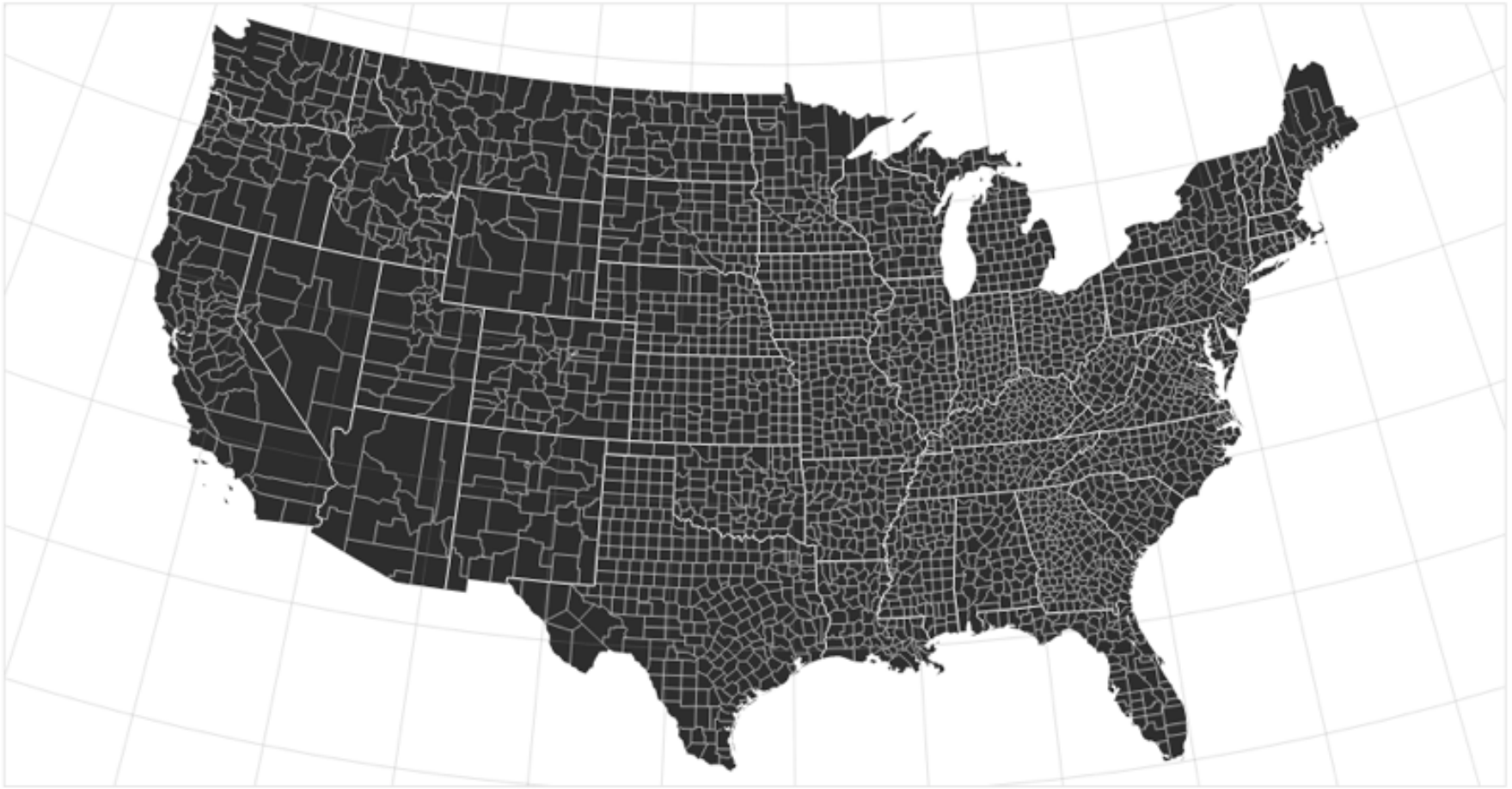


The azimuthal equidistant projection is available as d3.geo.azimuthalEquidistant.

Open in a new window.


Equal-Area
Preserve area

Albers Equal-Area Conic

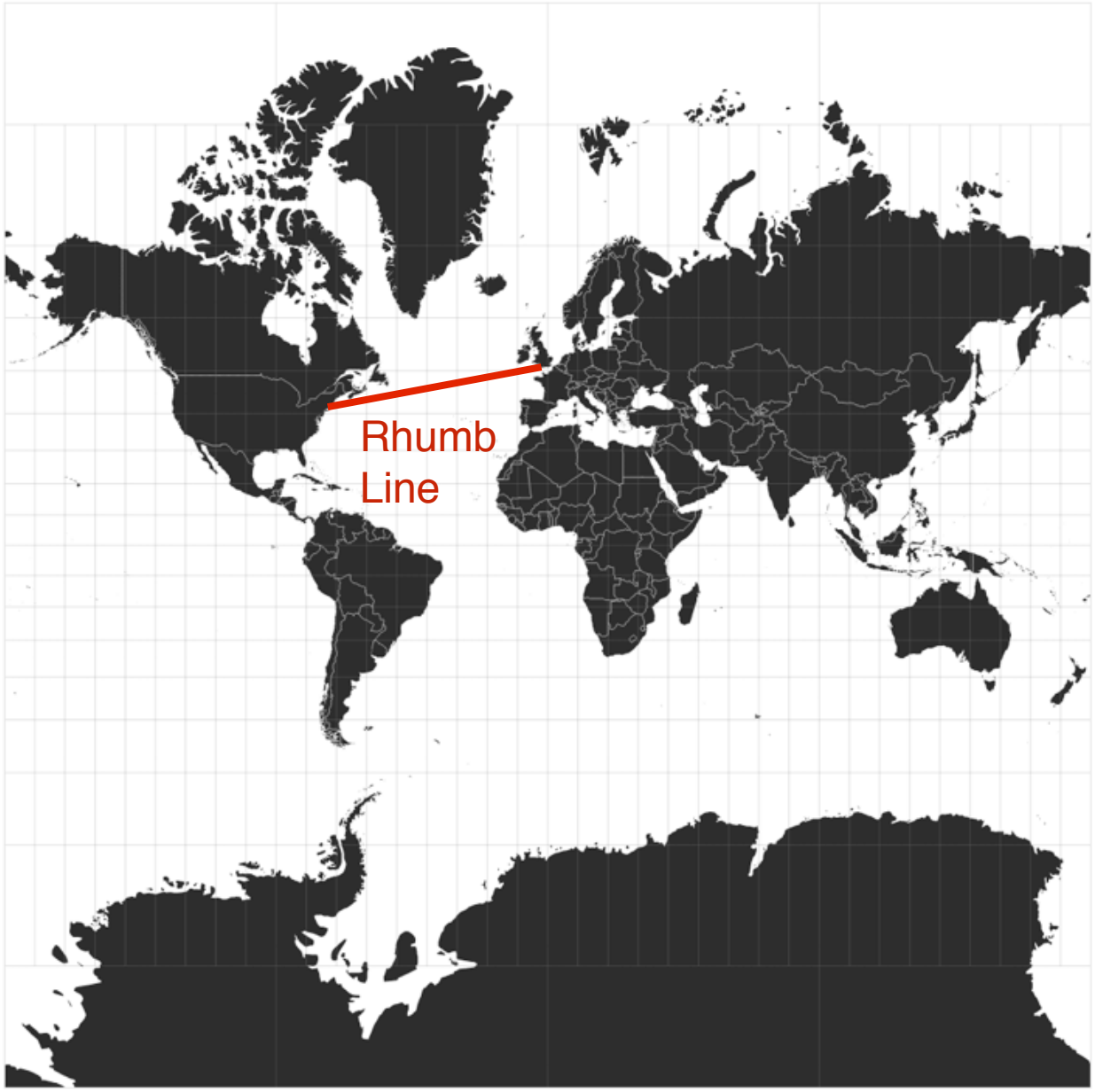


The Albers equal-area conic projection is available as d3.geo.albers. See also the interactive version.

Open in a new window.


Conformal
Preserve local angles (“shape”)

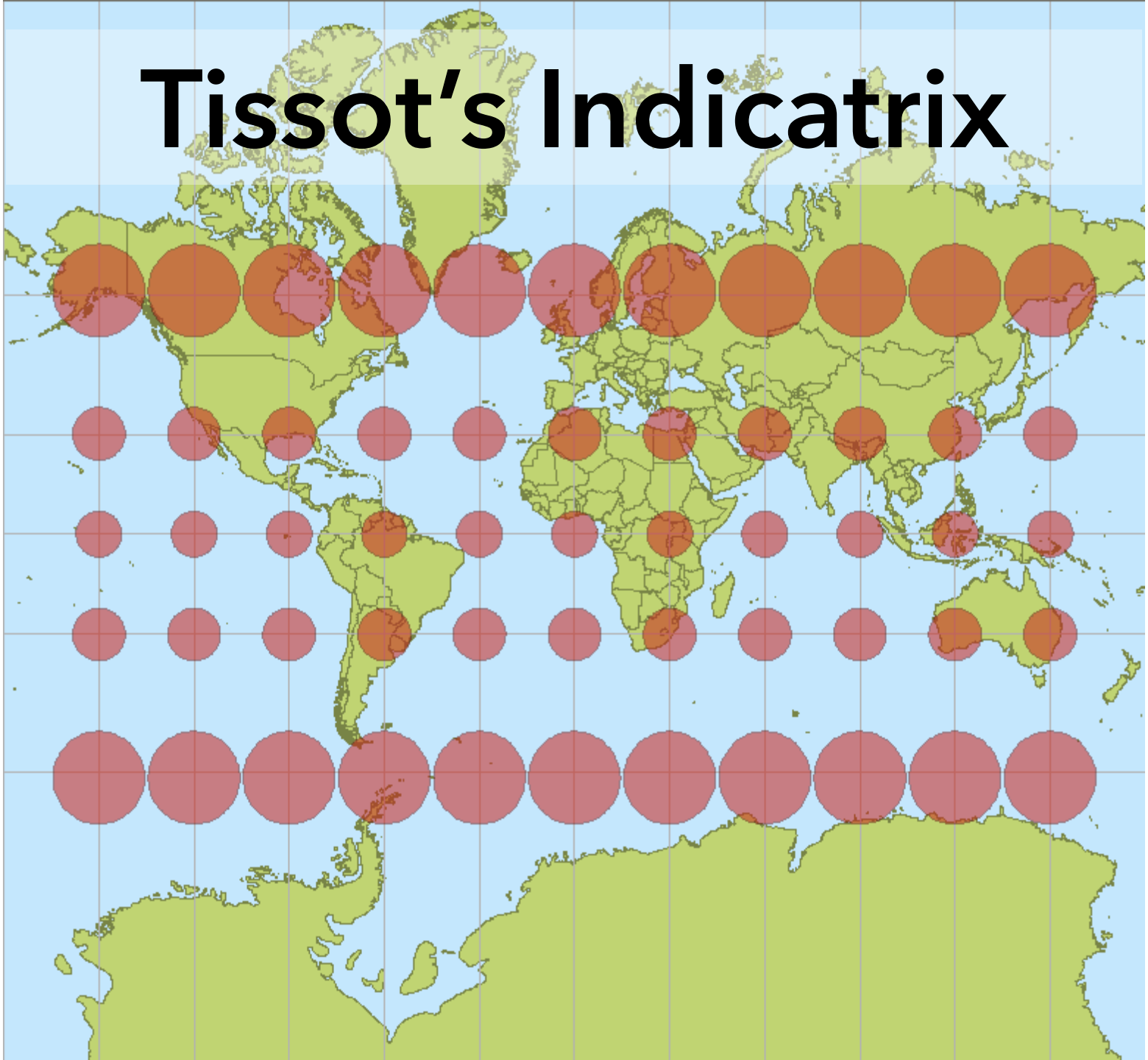
Spherical Mercator



The Mercator projection is available as d3.geo.mercator.

Open in a new window.

Tissot's Indicatrix



Spherical Mercator is ubiquitous on the web—why?

Web Mercator

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

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

World coordinates adjusted to map to 256 x 256 pixels.

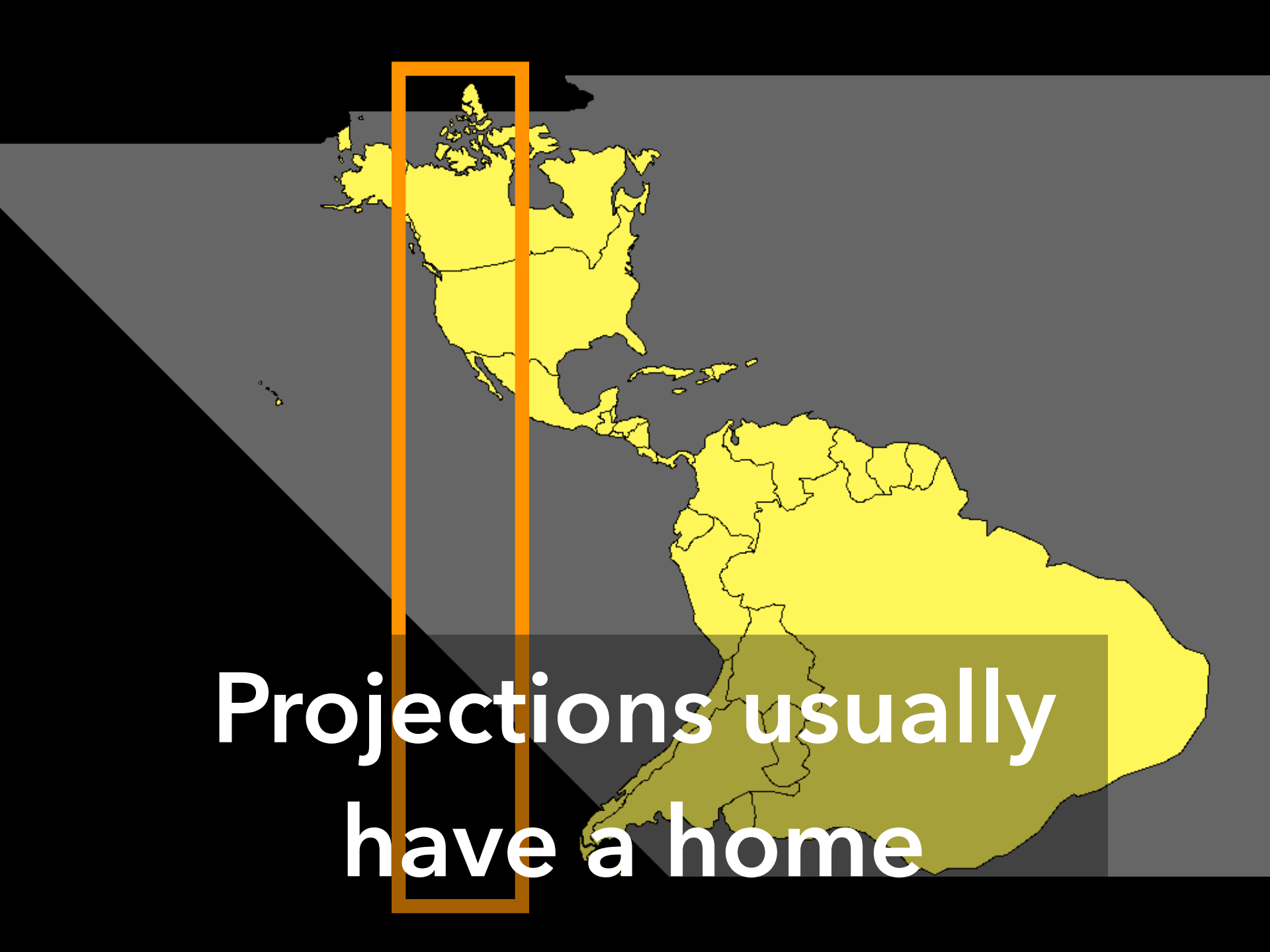
Latitude cut-offs at 85.051129 degrees: the exact point at which the projection frames the world in a square.

The Earth as a Square

Peirce Quincuncial

The Peirce quincuncial projection is implemented as `d3.geo.peirceQuincuncial` in the geo.projection D3 plugin. It is derived from the Guyou projection.

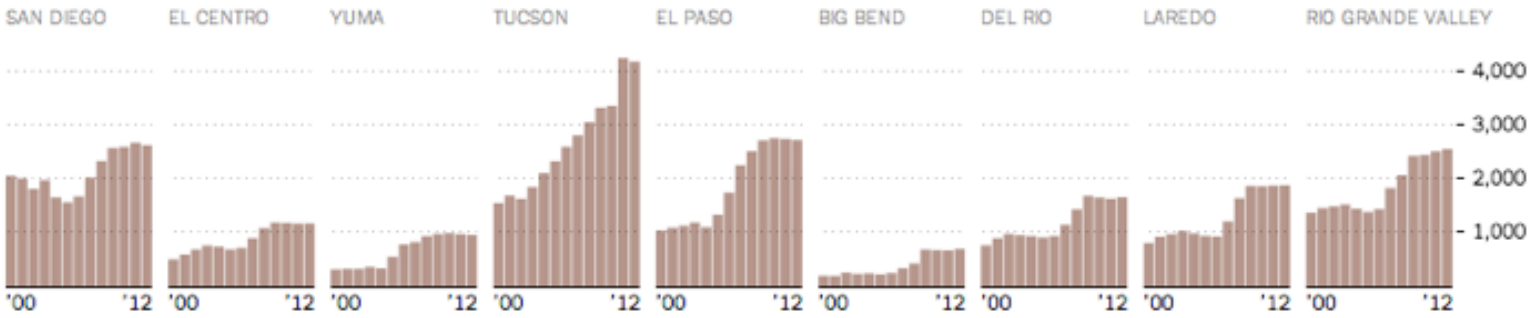
Open in a new window.


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

http://xkcd.com/977

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!

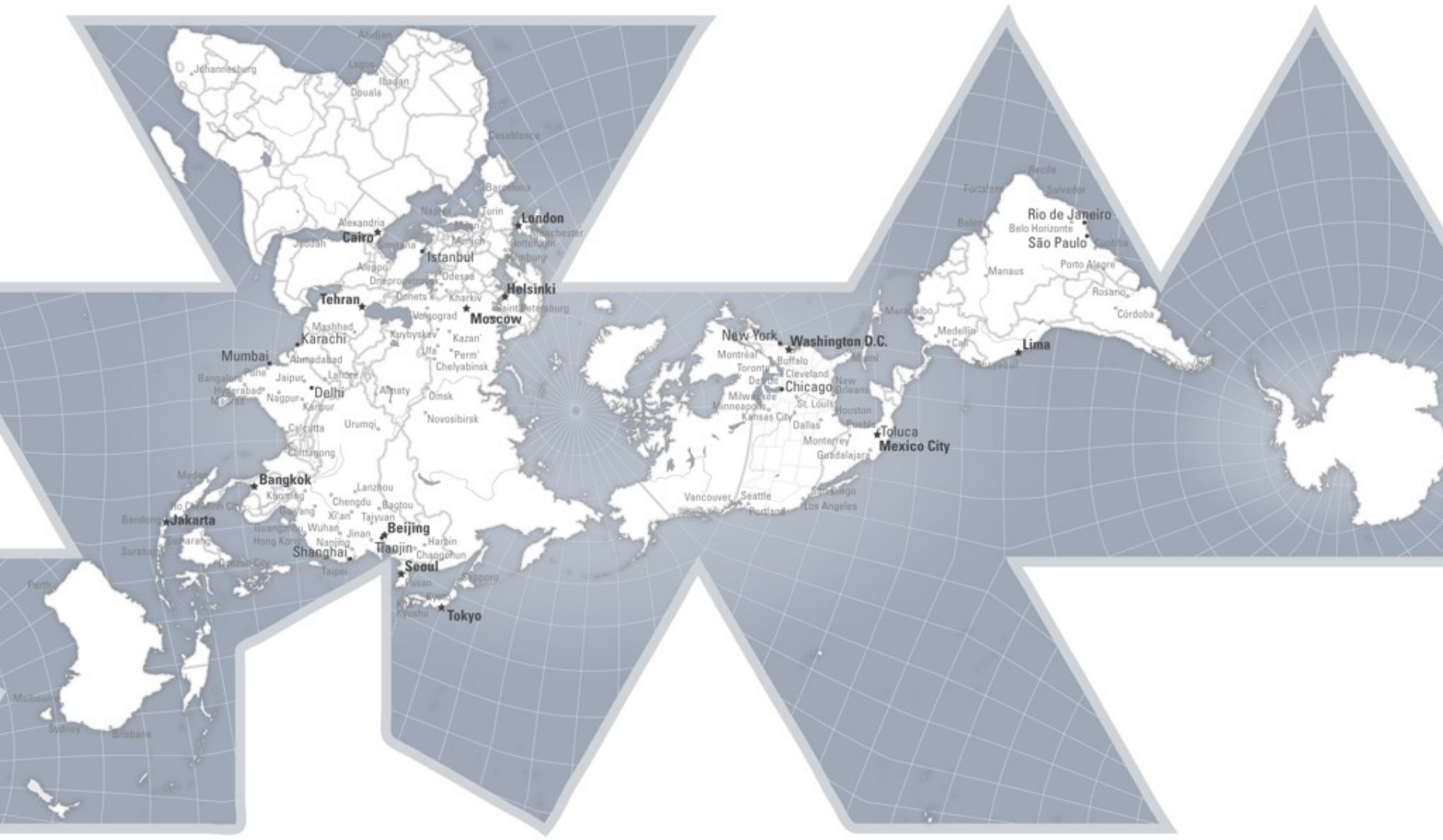
PEIRCE QUINCUNCIAL

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.

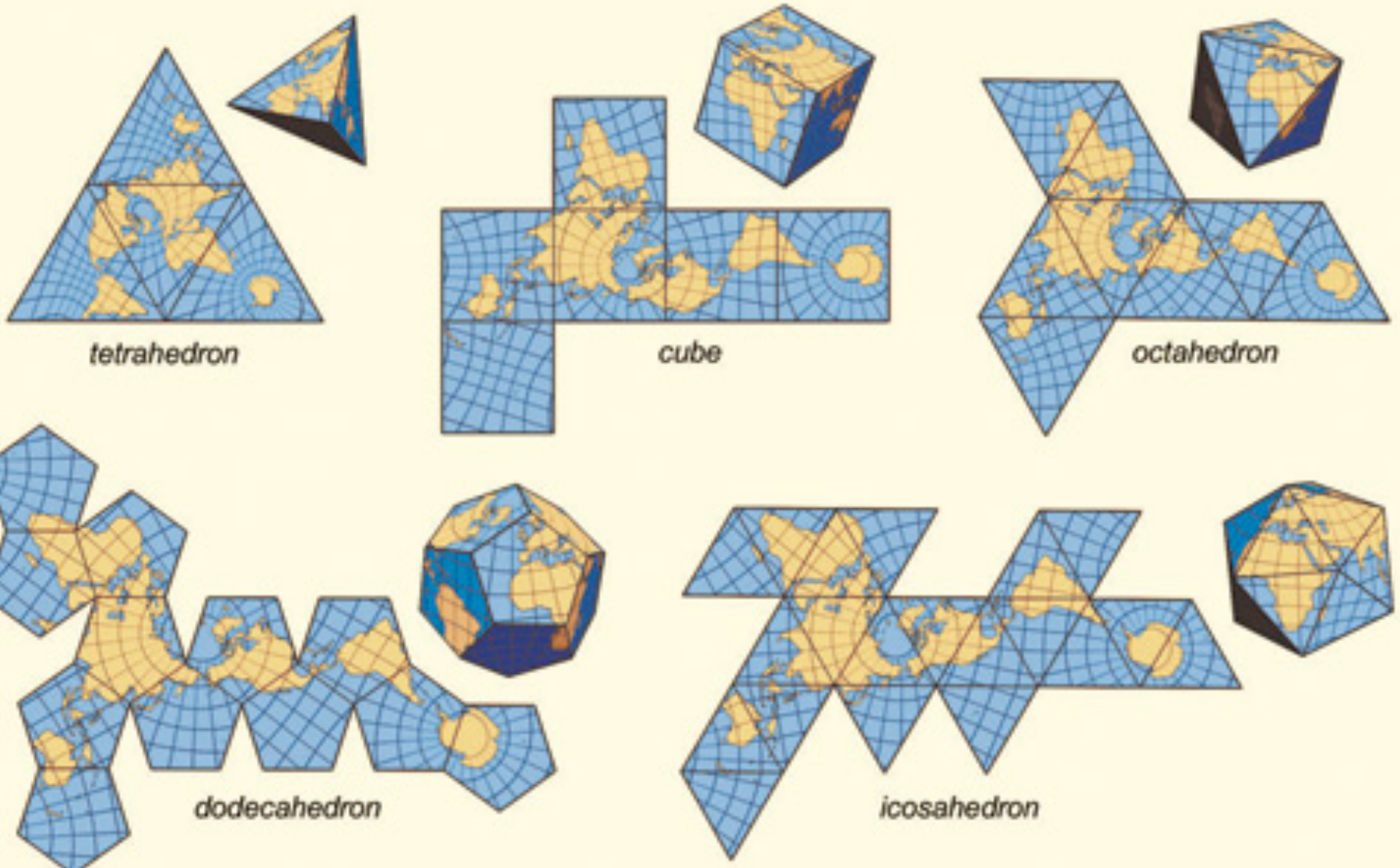
http://sta.mn/y9p

There are interesting ways to tear spheres

One notable interesting way to tear a sphere


Johannesburg
Lagos
Ibadan
Douala
Casablanca
Alexandria
Cairo
Jeddah
Istanbul
Aleppo
Odessa
Dnepropetrovsk
Donets'k
Kharkiv
Volgograd
Saint Petersburg
Helsinki
Moscow
Tehran
Mashhad
Karachi
Kuybyshev
Kazan'
Ufa
Perm'
Chelyabinsk
Mumbai
Ahmadabad
Pune
Jaipur
Lahore
Bangalore
Hyderabad
Nagpur
Kanpur
Delhi
Almaty
Omsk
Novosibirsk
Calcutta
Urumqi
Chittagong
Bangkok
Khonkaen
Lanzhou
Chengdu
Baotou
Taiyuan
Xi'an
Jakarta
Surabaya
Wuhan
Jinan
Nanjing
Hong Kong
Shanghai
Beijing
Tianjin
Harbin
Changchun
Seoul
Busan
Taipei
Kyoto
Kyushu
Sapporo
Tokyo
Perth
Melbourne
Sydney
Brisbane
London
Manchester
Rotterdam
Hamburg
Barcelona
Napoli
Turin
Milan
Munich
Recife
Fortaleza
Salvador
Belem
Rio de Janeiro
Belo Horizonte
São Paulo
Curitiba
Manaus
Porto Alegre
Rosario
Córdoba
Maracaibo
Medellin
Cali
Lima
Arequipa
New York
Washington D.C.
Montreal
Toronto
Buffalo
Cleveland
Detroit
Chicago
Miami
New Orleans
Milwaukee
Minneapolis
St. Louis
Kansas City
Houston
Dallas
Puebla
Monterrey
Guadalajara
Toluca
Mexico City
Vancouver
Seattle
Portland
San Diego
Los Angeles

http://sta.mn/y9p



Oregon State University OSU

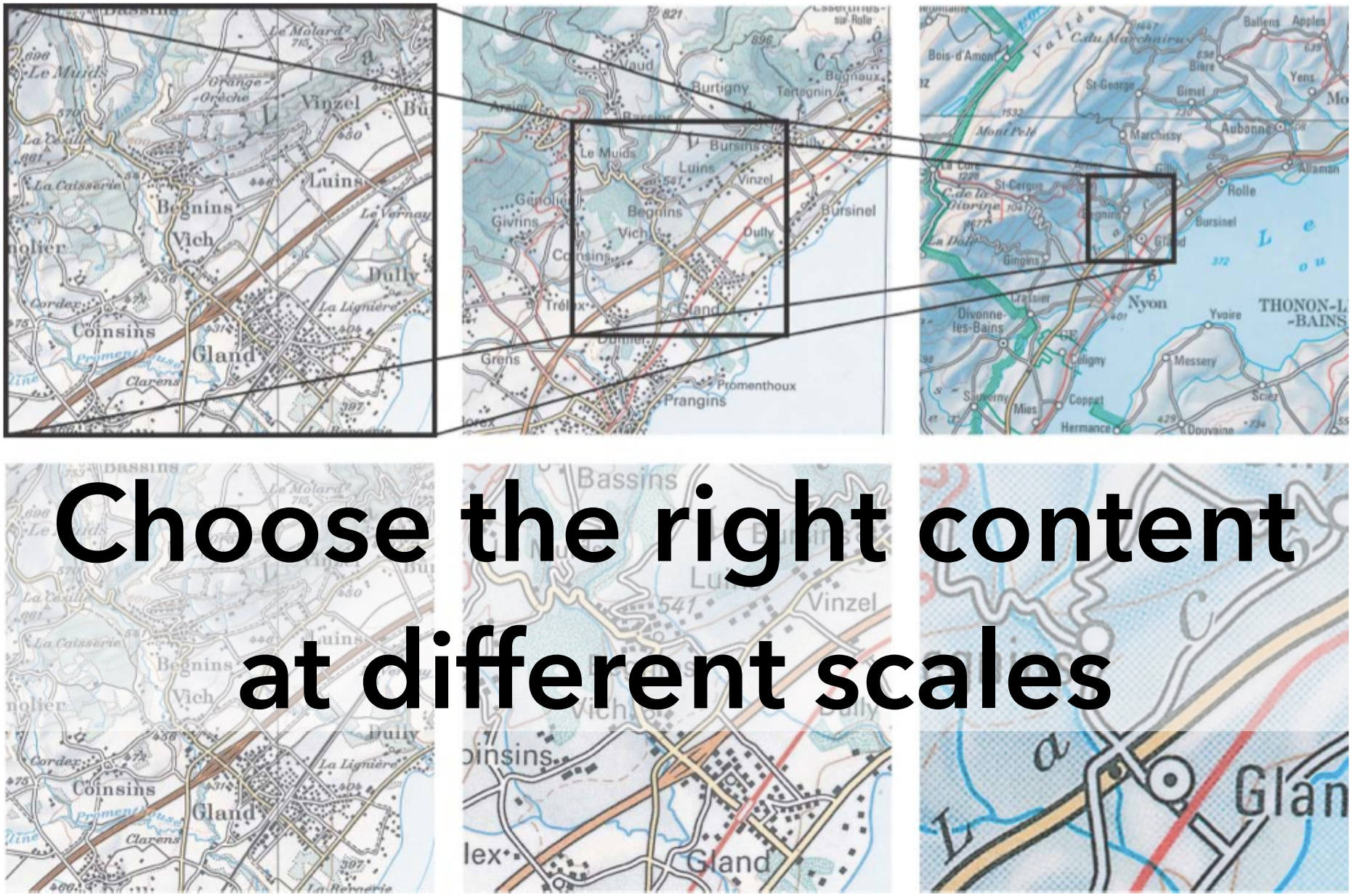
CARTO GROUP GRAPHY & GEOVISUALIZATION

ADAPTIVE COMPOSITE MAP PROJECTIONS

Scale


This is not “scale”
Texas-Europe Size Comparison
0
300 Kilometers
0
300 Miles
Copenhagen
Kaliningrad
RUSSIA
Bornholm
Gdańsk
Hamburg
Bremen
Berlin
Poznań
POLAND
Warsaw
Łódź
Wrocław
Amsterdam
NETH.
Rotterdam
London
Cardiff
Birmingham
Leeds
Manchester
Liverpool
KINGDOM
Isle of Man (U.K.)
Irish Sea
Essen
Leipzig
Cologne
GERMANY
Brussels
Luxembourg
Paris
Frankfurt am Main
CZECH REPUBLIC
Brno
SLOVAKIA
Kraków
Stuttgart
Munich
Strasbourg
Nantes
Bratislava
Vienna
AUSTRIA
Budapest
HUNGARY
LIECH.
Vaduz
Zurich
Bern
SWITZ.
Geneva
FRANCE
Ljubljana
SLOVENIA
Zagreb
Lyon
Milan
Turin
Nice
Bordeaux
Genoa
CROATIA
BOSNIA AND HERZEGOVINA
Sarajevo
Bilbao
Toulouse
MONACO
SAN MARINO
ITALY
Adriatic Sea
Marseille
Jersey (U.K.)
Guernsey (U.K.)

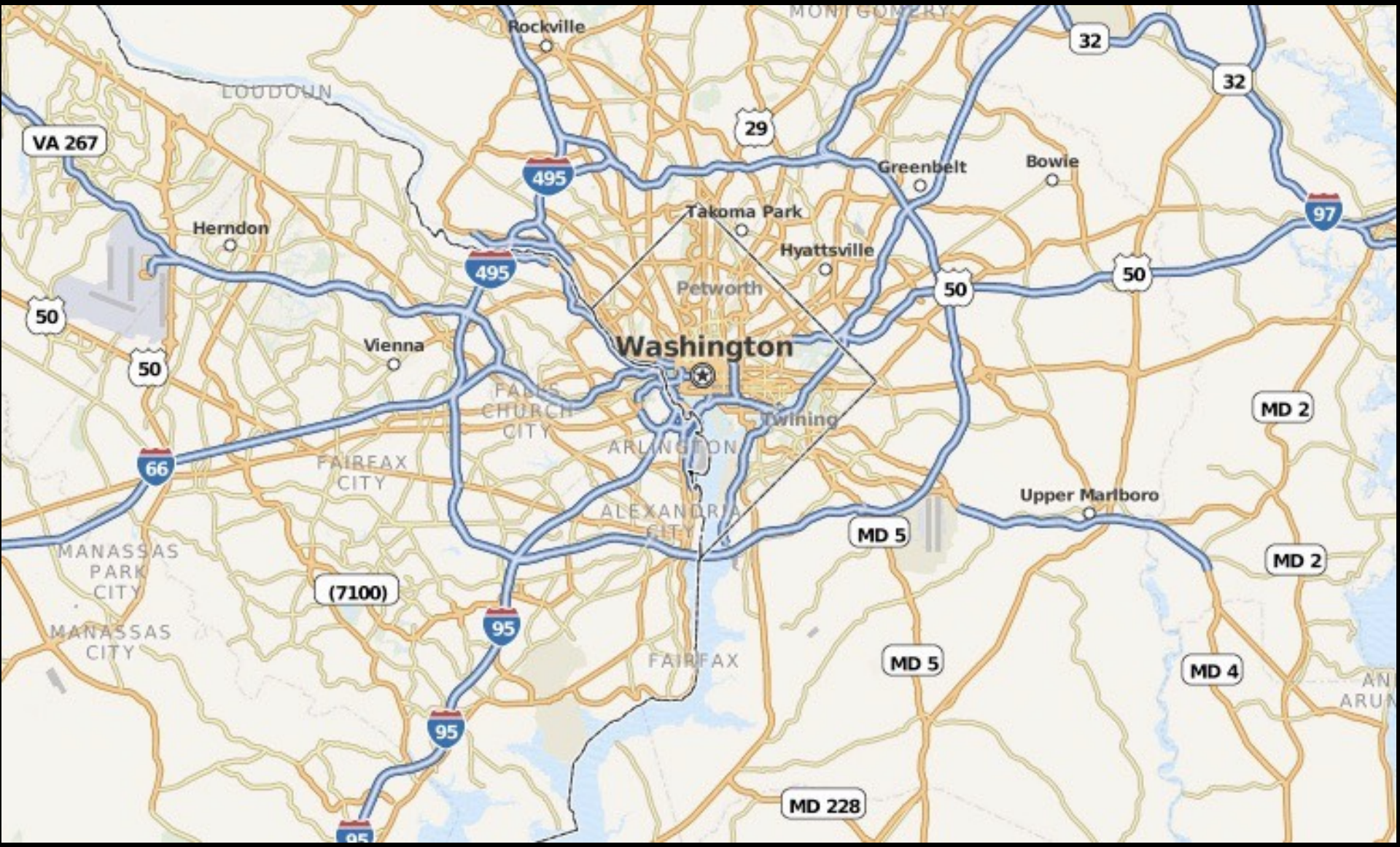
Scale is an idea imported from print

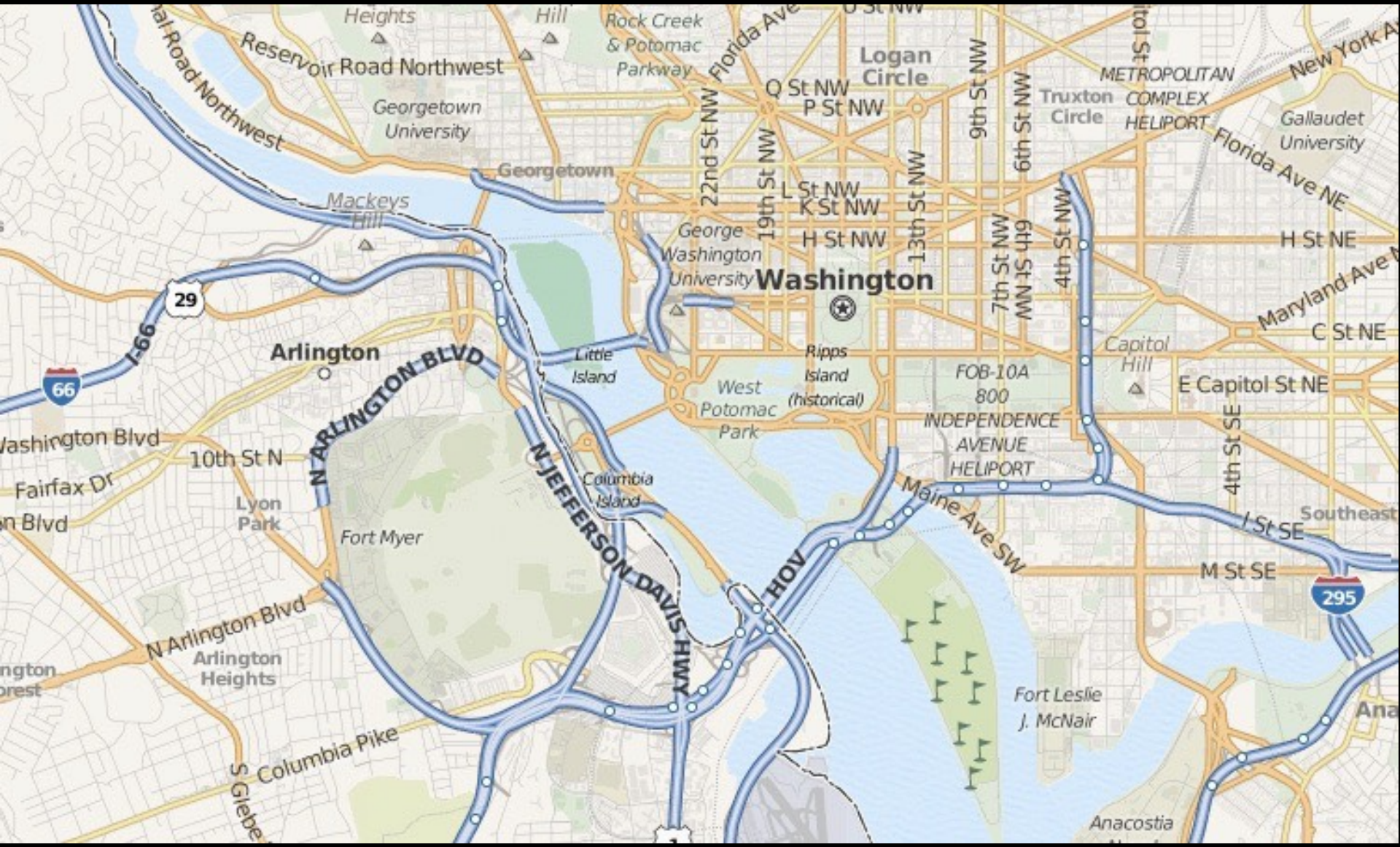

Choose the right content
at different scales

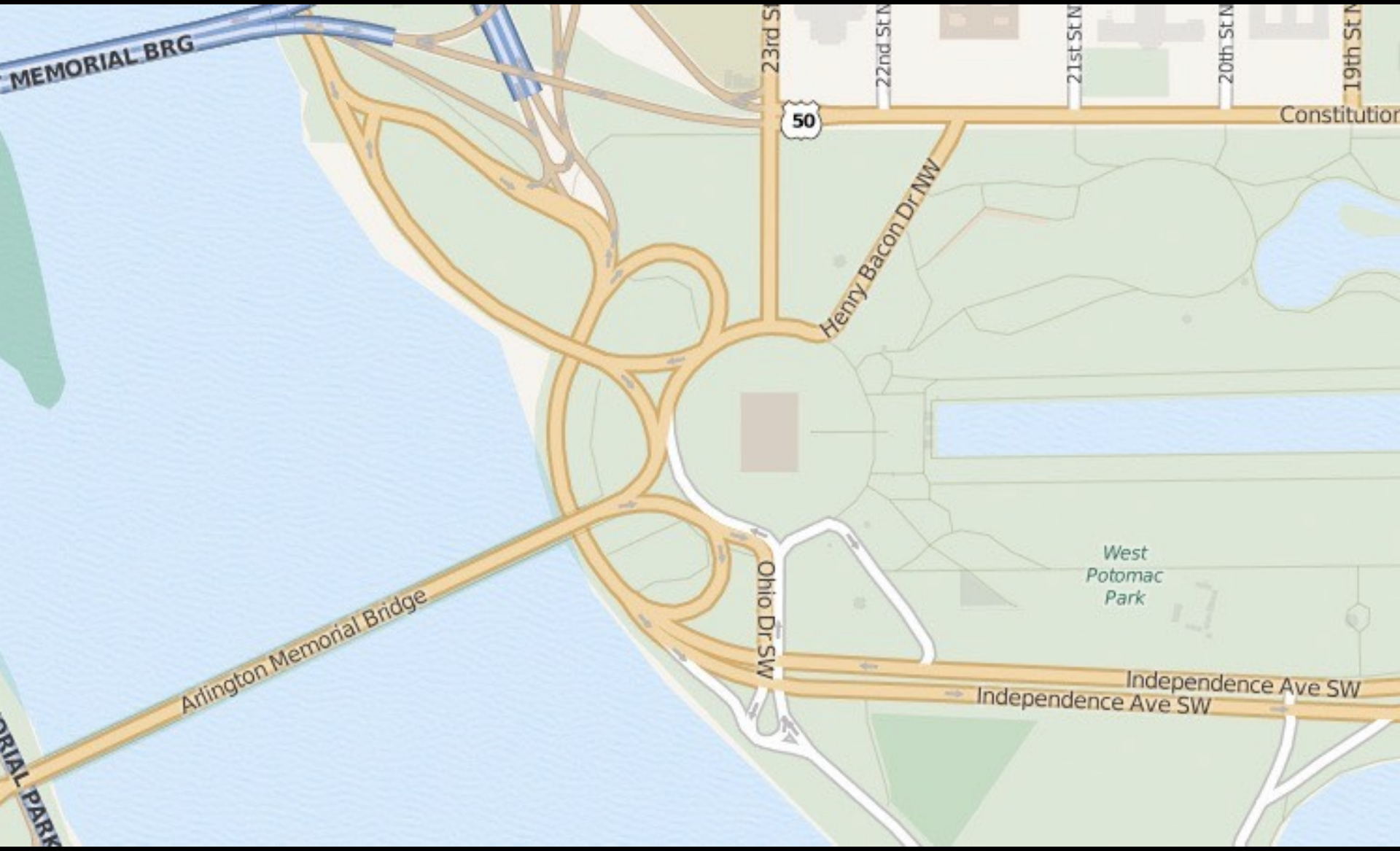
Four maps, same area

What shows at different scales?


Pittsburgh
Harrisburg
Reading
Camden
NEW JERSEY
Millville
Cumberland
MARYLAND
Washington
DELAWARE
Harrisonburg
WEST VIRGINIA
Richmond
Roanoke
VIRGINIA
Suffolk
70
79
76
83
68
81
95
64
85


Rockville
MONTGOMERY
LOUDOUN
VA 267
29
32
32
495
Greenbelt
Bowie
Takoma Park
97
Herndon
Hyattsville
495
50
50
Petworth
50
Vienna
Washington
50
FALLS CHURCH CITY
Twining
MD 2
66
FAIRFAX CITY
ARLINGTON
Upper Marlboro
ALEXANDRIA CITY
MD 5
MD 2
MANASSAS PARK CITY
(7100)
95
MANASSAS CITY
FAIRFAX
MD 5
MD 4
95
MD 228


Heights
Hill
Rock Creek & Potomac Parkway
Florida Ave
Logan Circle
Q St NW
P St NW
9th St NW
6th St NW
Truxton Circle
METROPOLITAN COMPLEX HELIPORT
New York A
Reservoir Road Northwest
Georgetown University
Georgetown
22nd St NW
19th St NW
13th St NW
L St NW
K St NW
H St NW
Gallaudet University
Florida Ave NE
Mackeys Hill
George Washington University
Washington
7th St NW
6th St NW
4th St NW
H St NE
Maryland Ave
C St NE
29
I-66
66
Arlington
N ARLINGTON BLVD
Little Island
Ripps Island (historical)
West Potomac Park
FOB-10A
800 INDEPENDENCE AVENUE HELIPORT
Capitol Hill
E Capitol St NE
4th St SE
Washington Blvd
10th St N
Fairfax Dr
Lyon Park
Fort Myer
N JEFFERSON DAVIS HWY
Columbia Island
Maine Ave SW
I St SE
Southeast
M St SE
295
HOV
N Arlington Blvd
Arlington Heights
Fort Leslie J. McNair
Columbia Pike
Anacostia


MEMORIAL BRG
23rd St
22nd St N
21st St N
20th St N
19th St N
50
Constitution
Henry Bacon Dr NW
West
Potomac
Park
Ohio Dr SW
Arlington Memorial Bridge
Independence Ave SW
Independence Ave SW

http://sta.mn/y2d

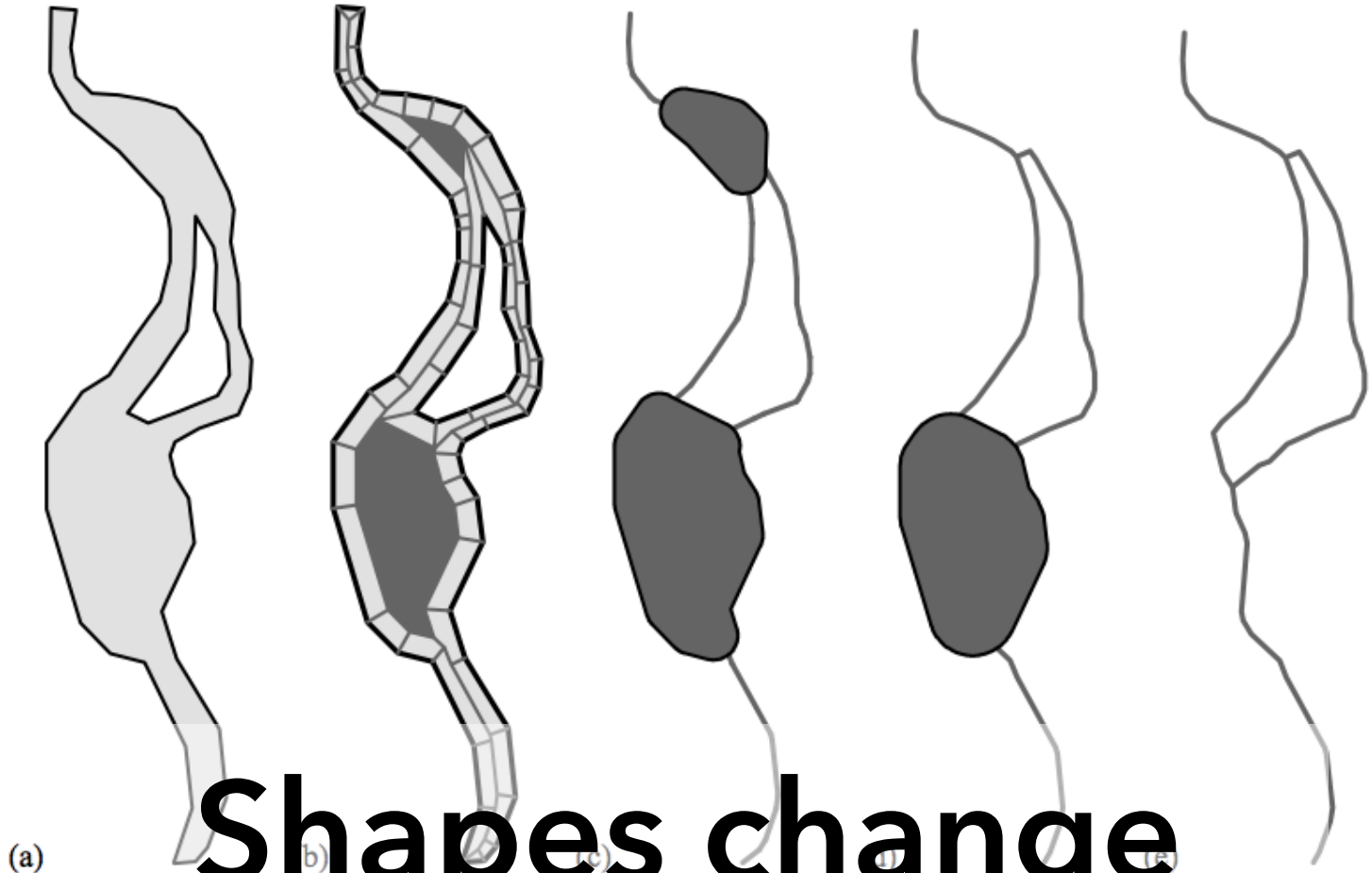


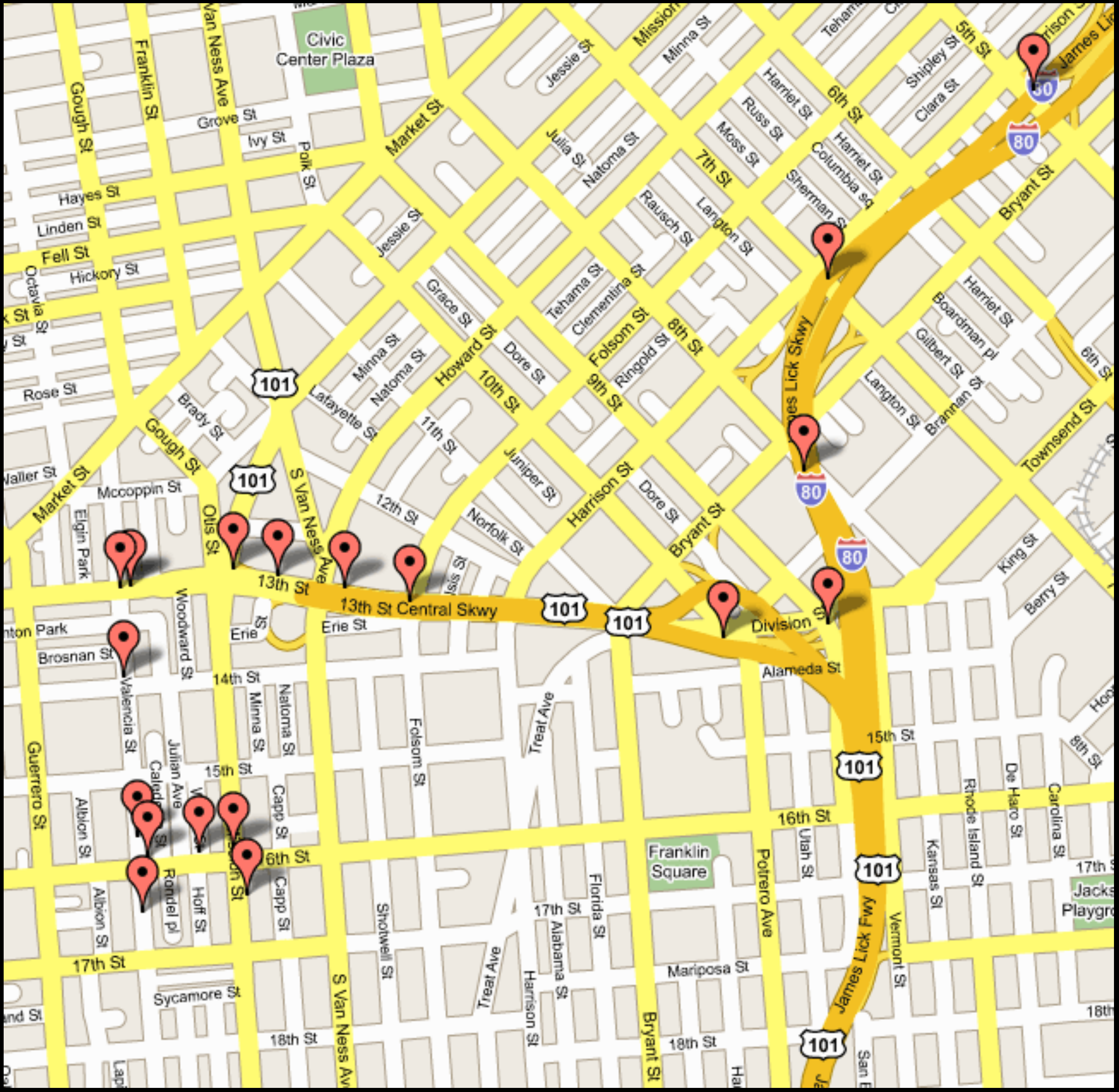
Figure 11. Fragmentation of a river into polygons and lines with different thresholds leading to different results (c, d, e).

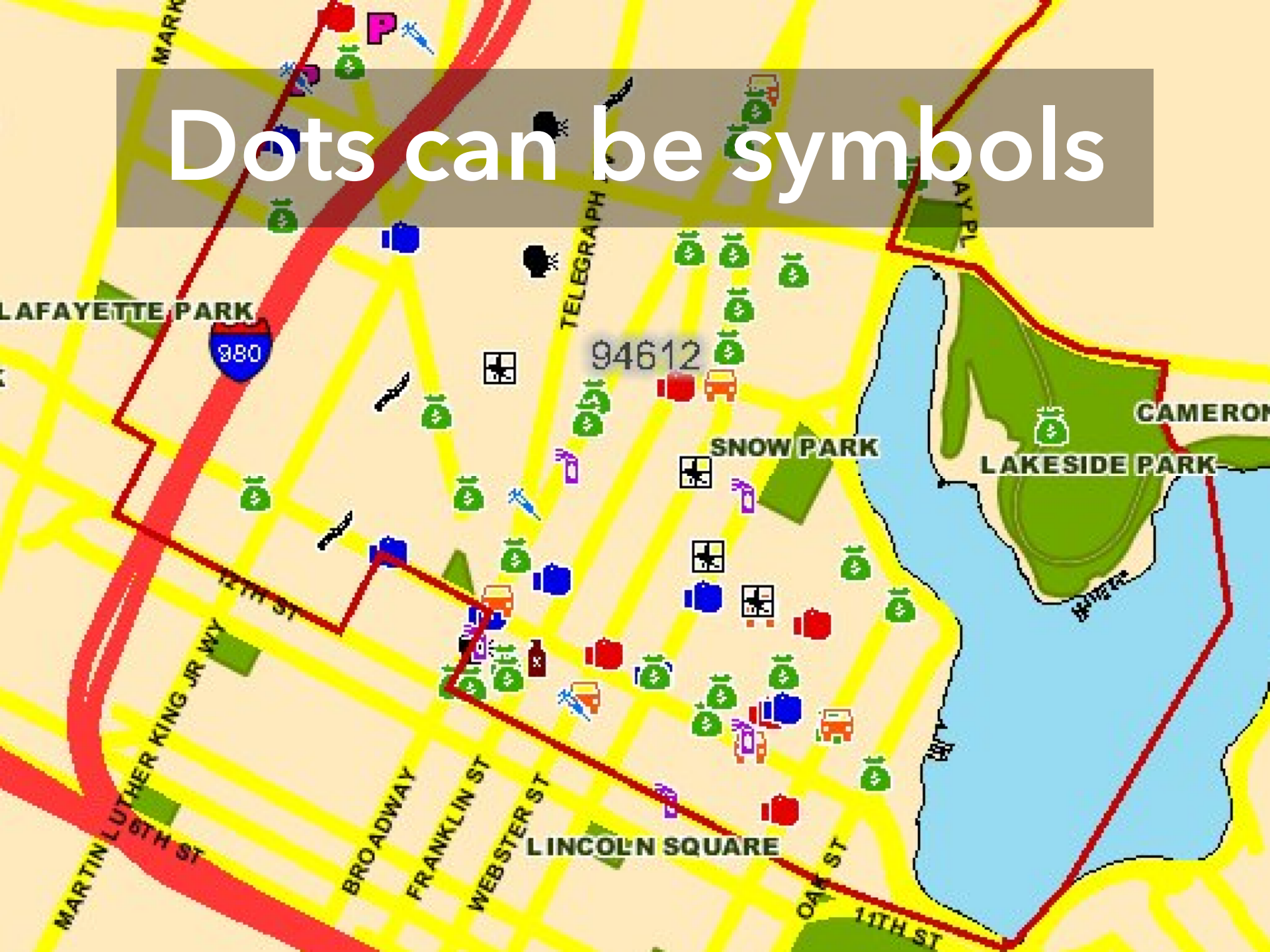
Shapes change at different scales

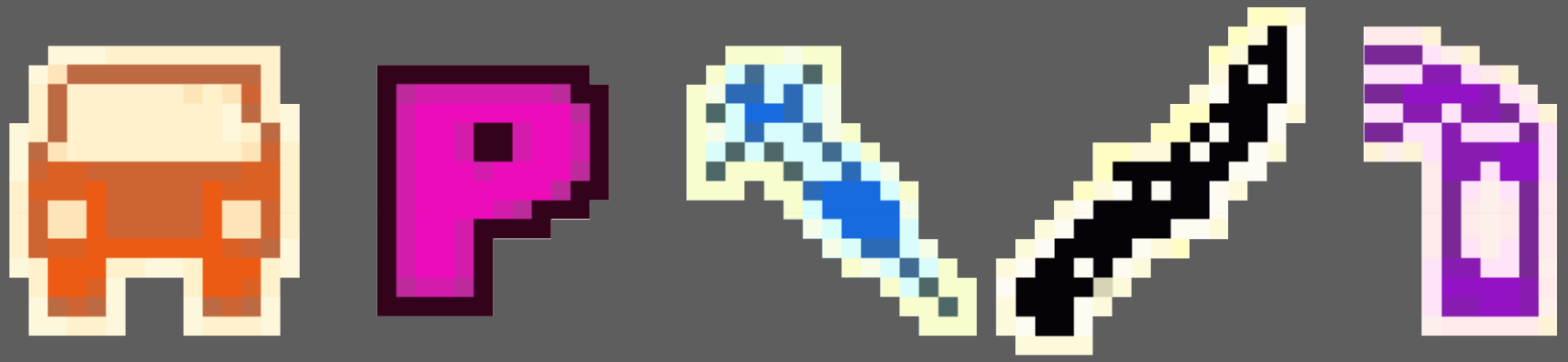
Mapping

Visualizing Geospatial Data

Symbol Maps

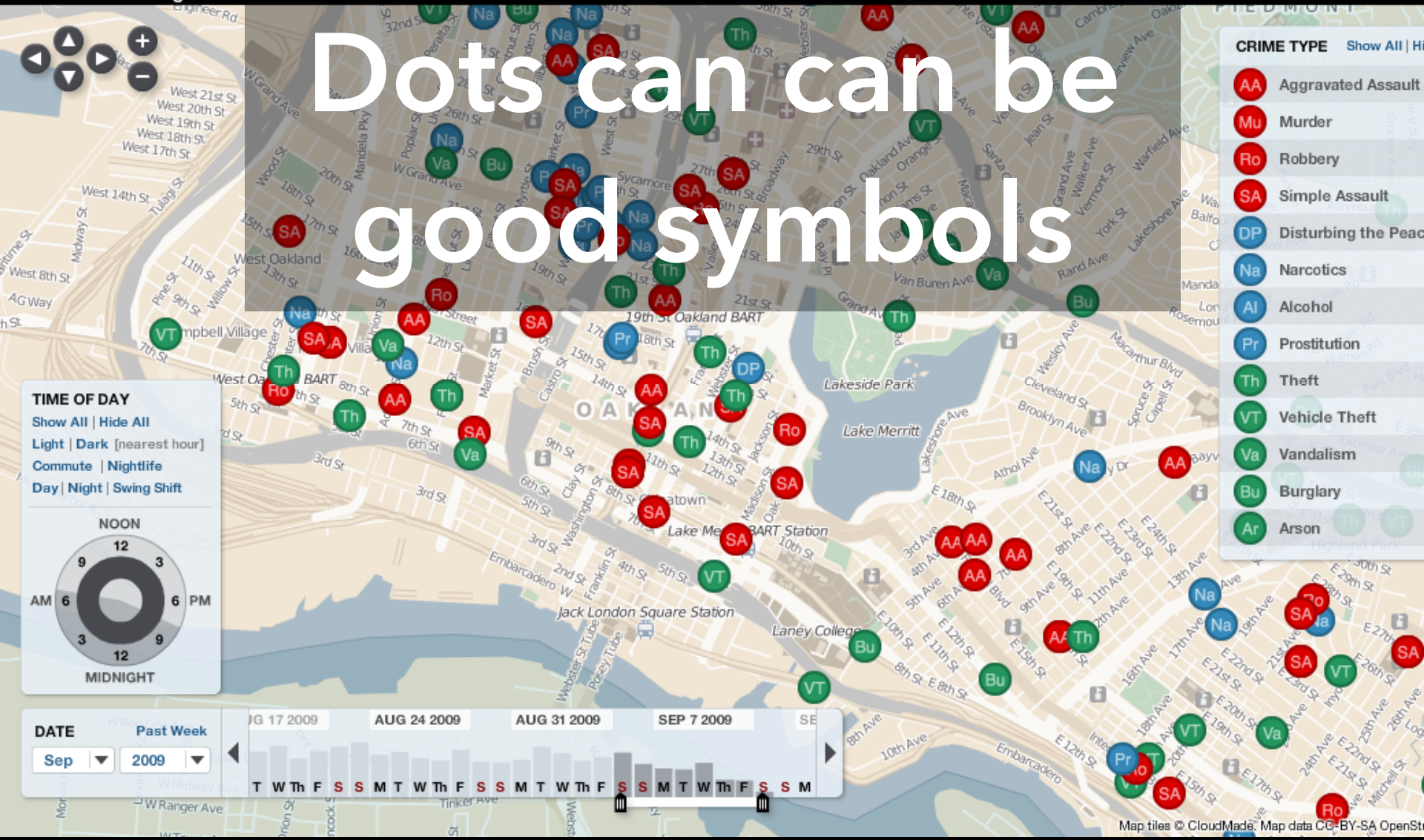

Civic
Center Plaza
Gough St
Franklin St
Van Ness Ave
Grove St
Ivy St
Polk St
Market St
Mission
Minna St
Jessie St
Hayes St
Linden St
Fell St
Hickory St
Octavia St
Rose St
Brady St
Gough St
101
Lafayette St
Minna St
Natoma St
Howard St
10th St
11th St
Grace St
Dore St
Julia St
Natoma St
7th St
Harriet St
Russ St
Moss St
6th St
5th St
Shipley St
Clara St
80
Columbia sq
Sherman St
Rausch St
Langton St
Tehama St
Clementina St
Folsom St
8th St
9th St
Ringold St
James Lick Skwy
Bryant St
Harriet St
Boardman pl
Gilbert St
Langton St
Brannan St
Townsend St
6th St
Waller St
Market St
Mccoppin St
Elgin Park
Otis St
S Van Ness Ave
12th St
Juniper St
Norfolk St
Harrison St
Dore St
Bryant St
King St
Berry St
13th St
13th St Central Skwy
Division St
Alameda St
Erie St
Woodward St
Brosnan St
Valencia St
14th St
Minna St
Natoma St
Folsom St
Treat Ave
15th St
Guerrero St
Albion St
Julian Ave
Capp St
16th St
Utah St
Franklin
Square
Potrero Ave
Kansas St
Rhode Island St
De Haro St
Carolina St
17th St
Rondel pl
Hoff St
Shotwell St
Florida St
Alabama St
17th St
Mariposa St
James Lick Fwy
Vermont St
Sycamore St
18th St
Treat Ave
Harrison St
Bryant St
18th St
S Van Ness Ave


Dots can be symbols
LAFAYETTE PARK
980
TELEGRAPH
94612
SNOW PARK
LAKESIDE PARK
CAMERON
12TH ST
MARTIN LUTHER KING JR WY
BROADWAY
FRANKLIN ST
WEBSTER ST
LINCOLN SQUARE
OAK ST
11TH ST



Guess the crime

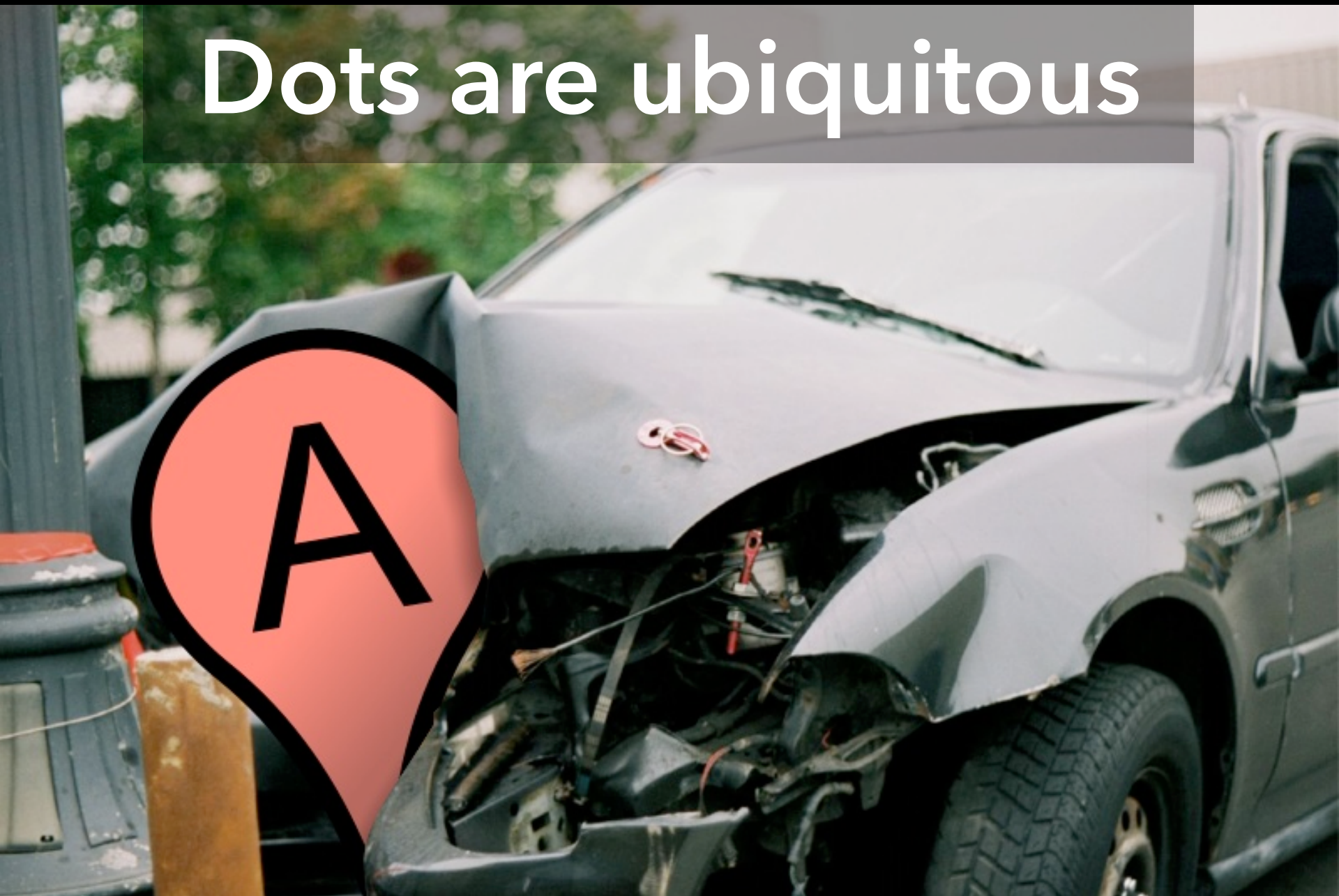
http://sta.mn/sw



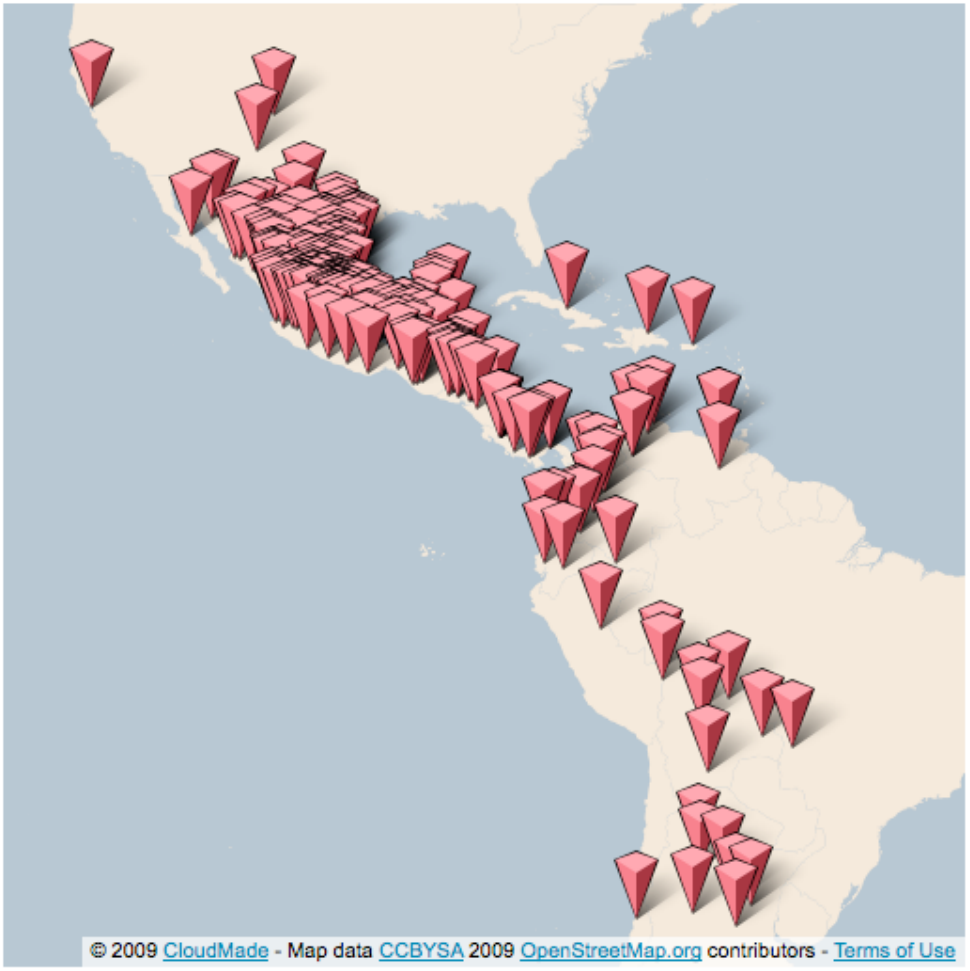

Dots can include data

http://sta.mn/8tm

Dots are ubiquitous



“Red Dot Fever”



http://sta.mn/y8v

The New York Times

Mapping America: Every City, Every Block

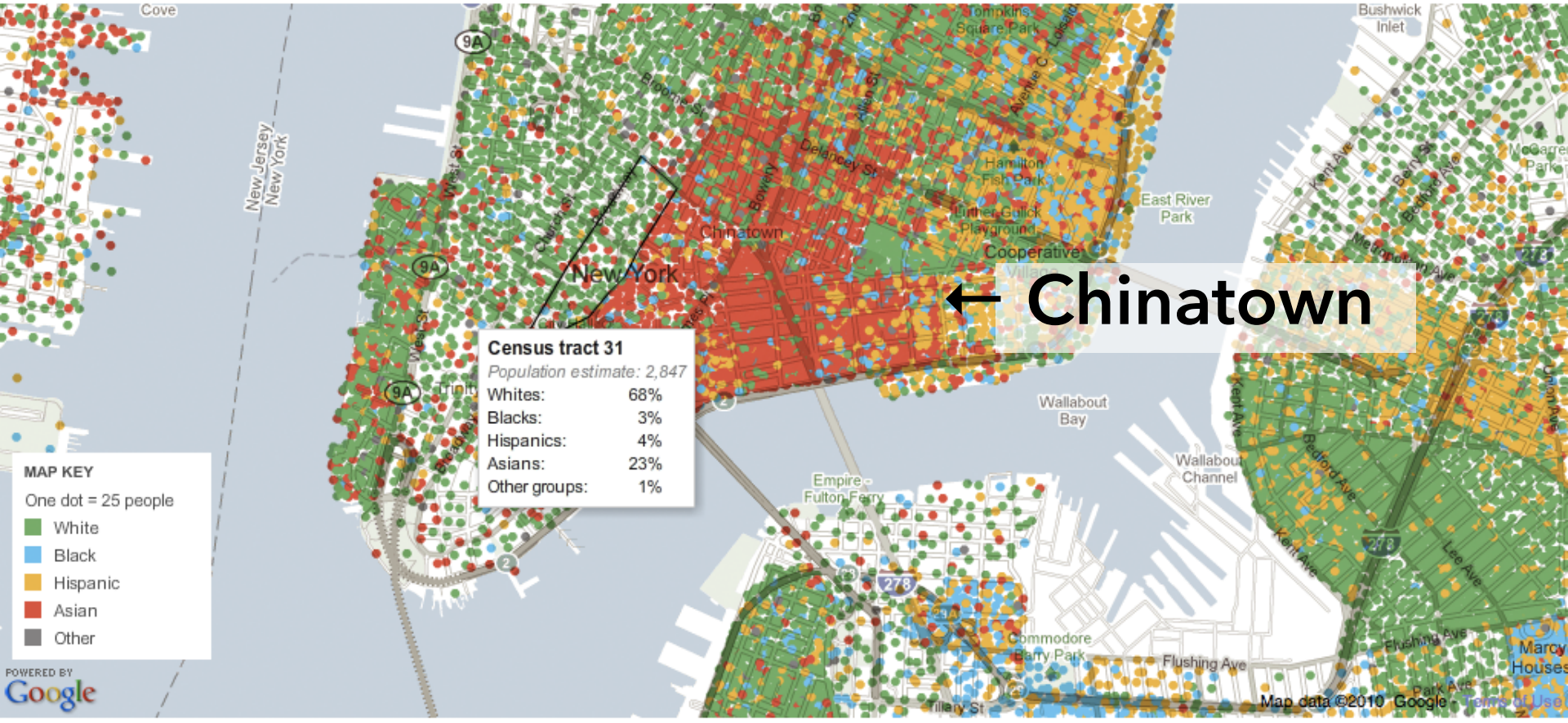
Find something interesting? Share this view on Twitter or Facebook

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

View Readers Maps (49)

Distribution of racial and ethnic groups

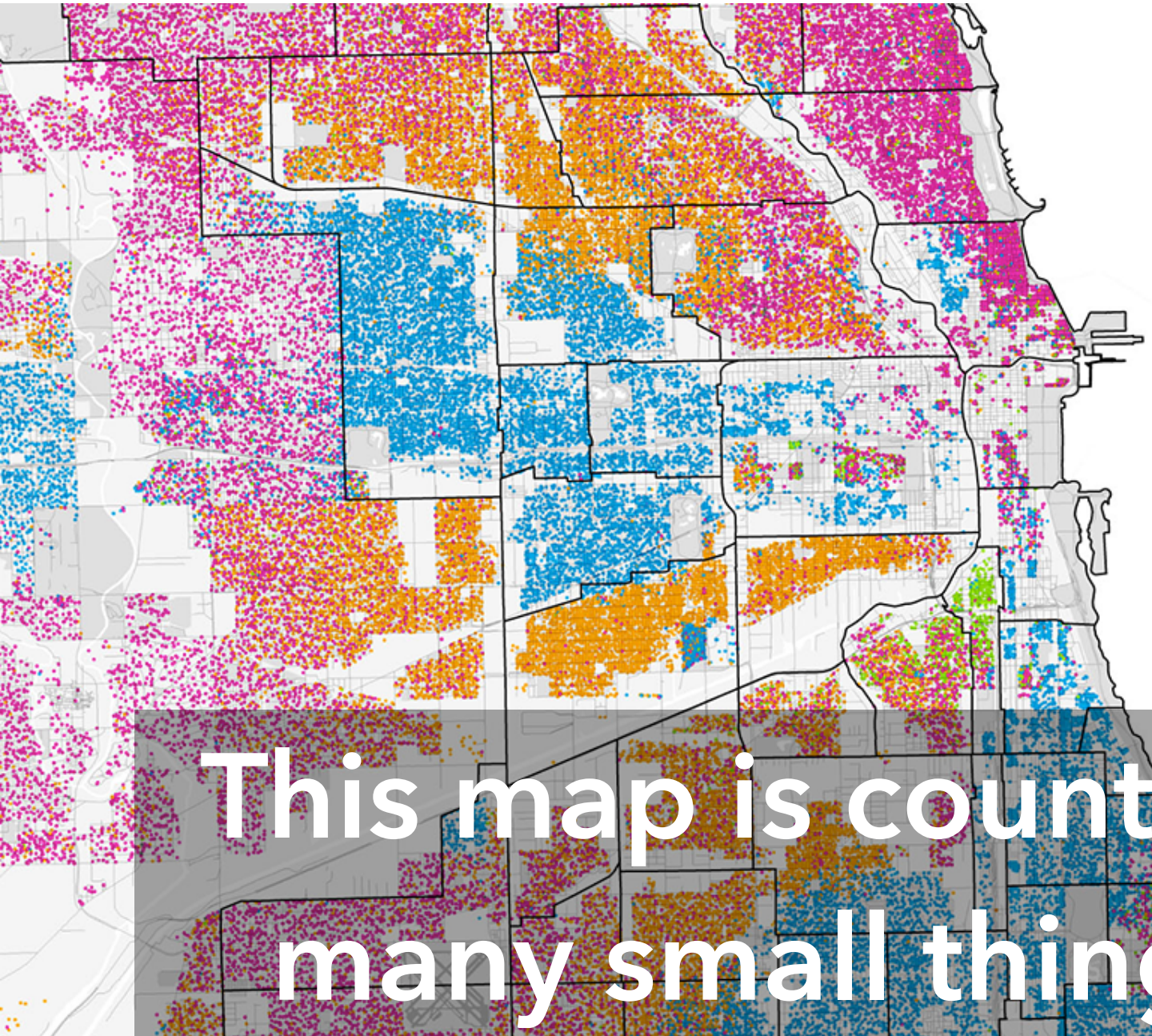
View More Maps | Address, ZIP code or city Go



By MATTHEW BLOCH, SHAN CARTER and ALAN McLEAN | Source: 2005-9 American Community Survey, Census Bureau; socialexplorer.com

Note: Dots are evenly distributed across each Census tract or county. Dollar amounts are adjusted for inflation.

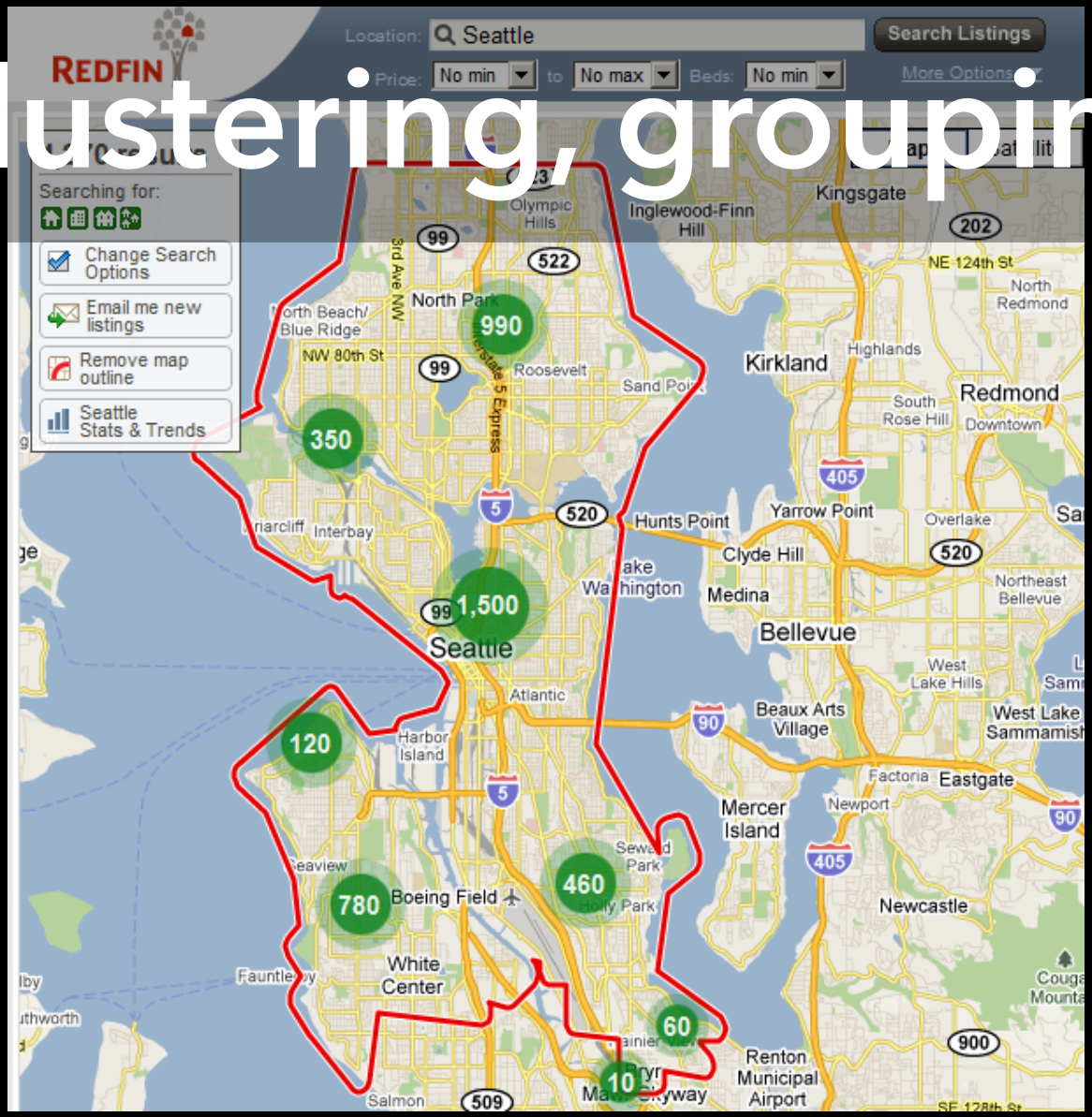
http://sta.mn/zzz



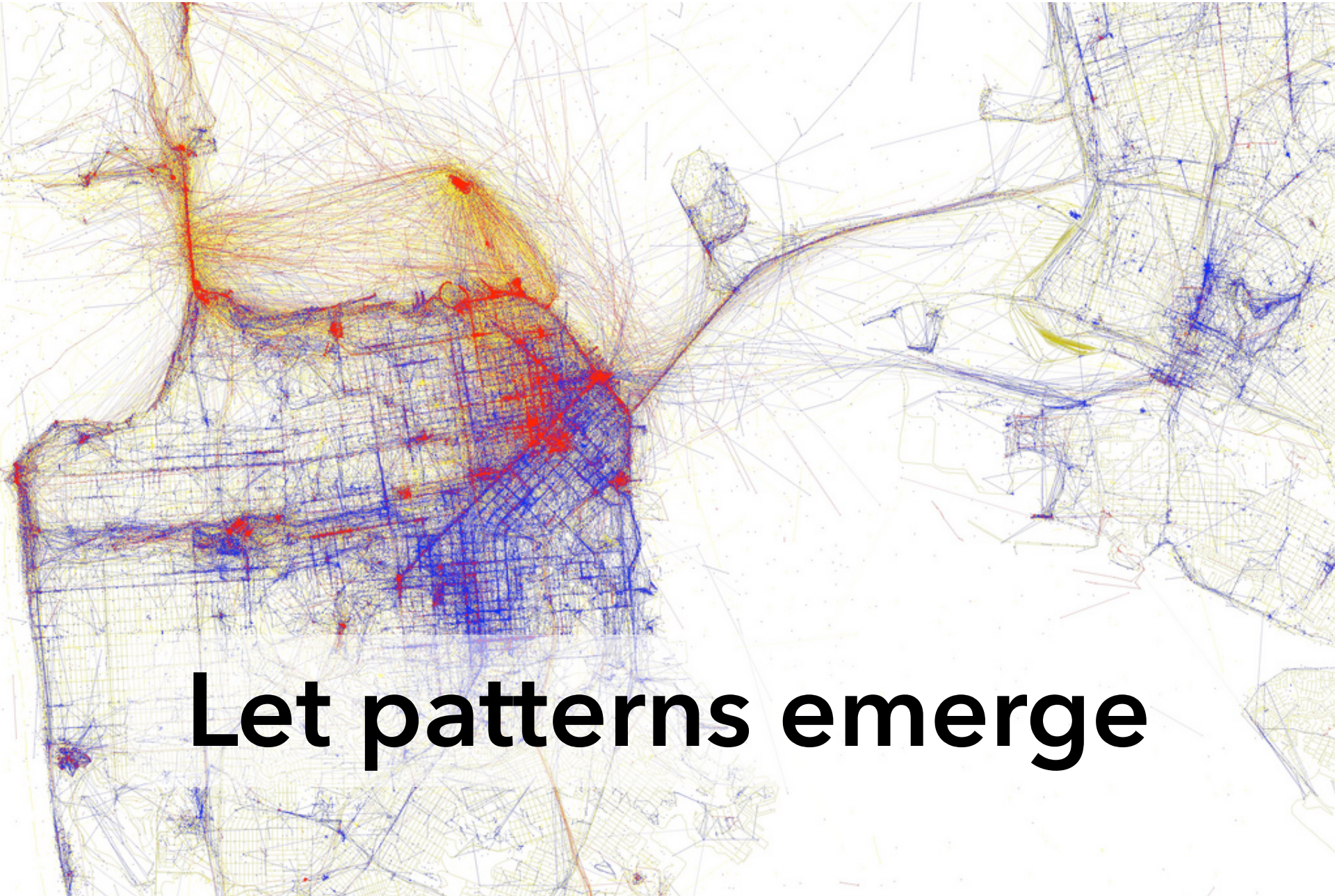
This map is counting many small things

http://sta.mn/htj

Clustering, grouping



http://sta.mn/hrw

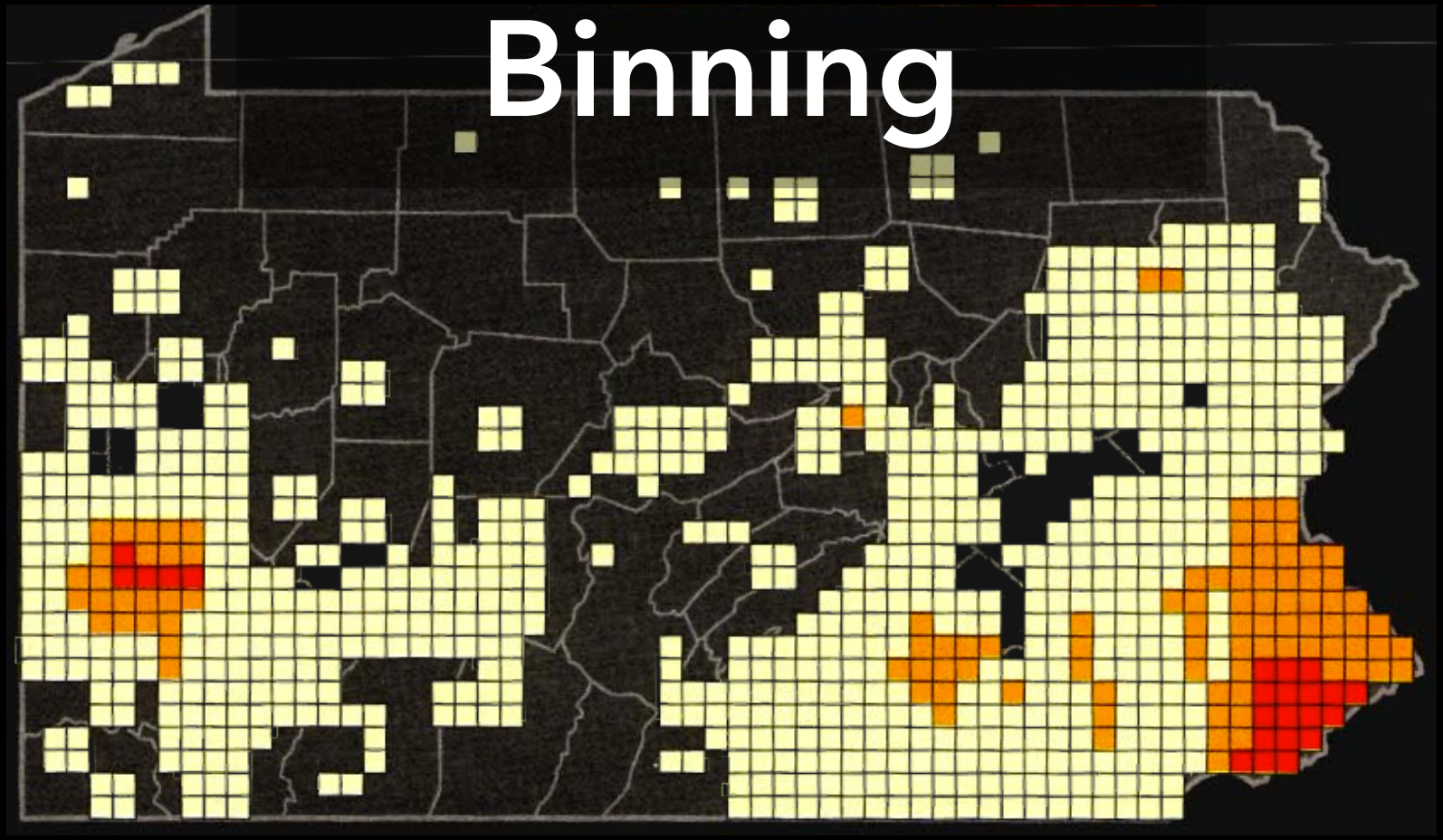


Let patterns emerge

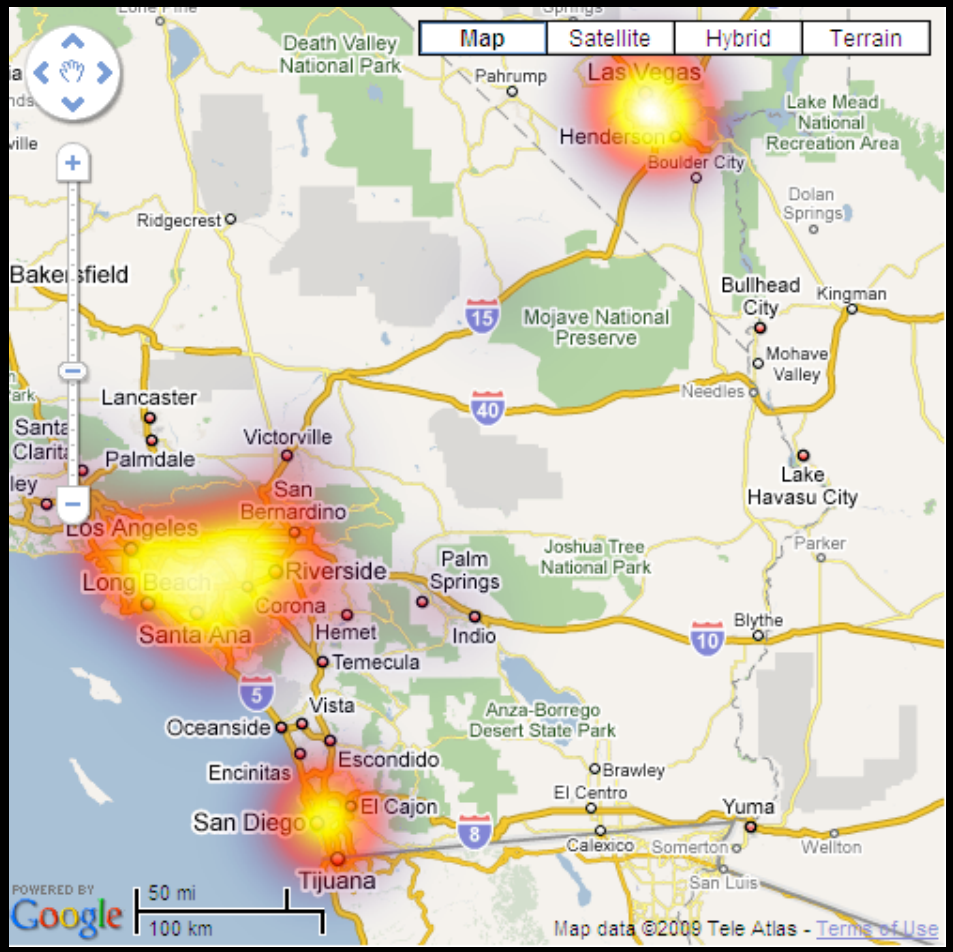
Continuous Data

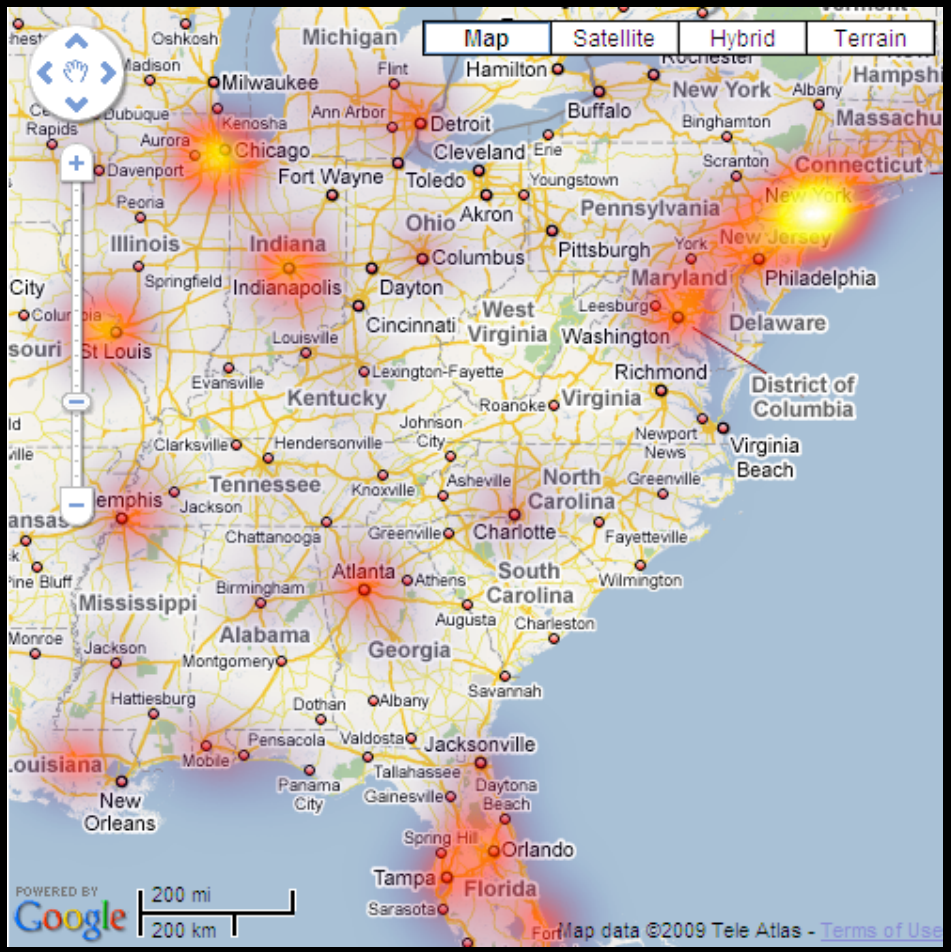
http://sta.mn/527

Binning



http://sta.mn/zwh

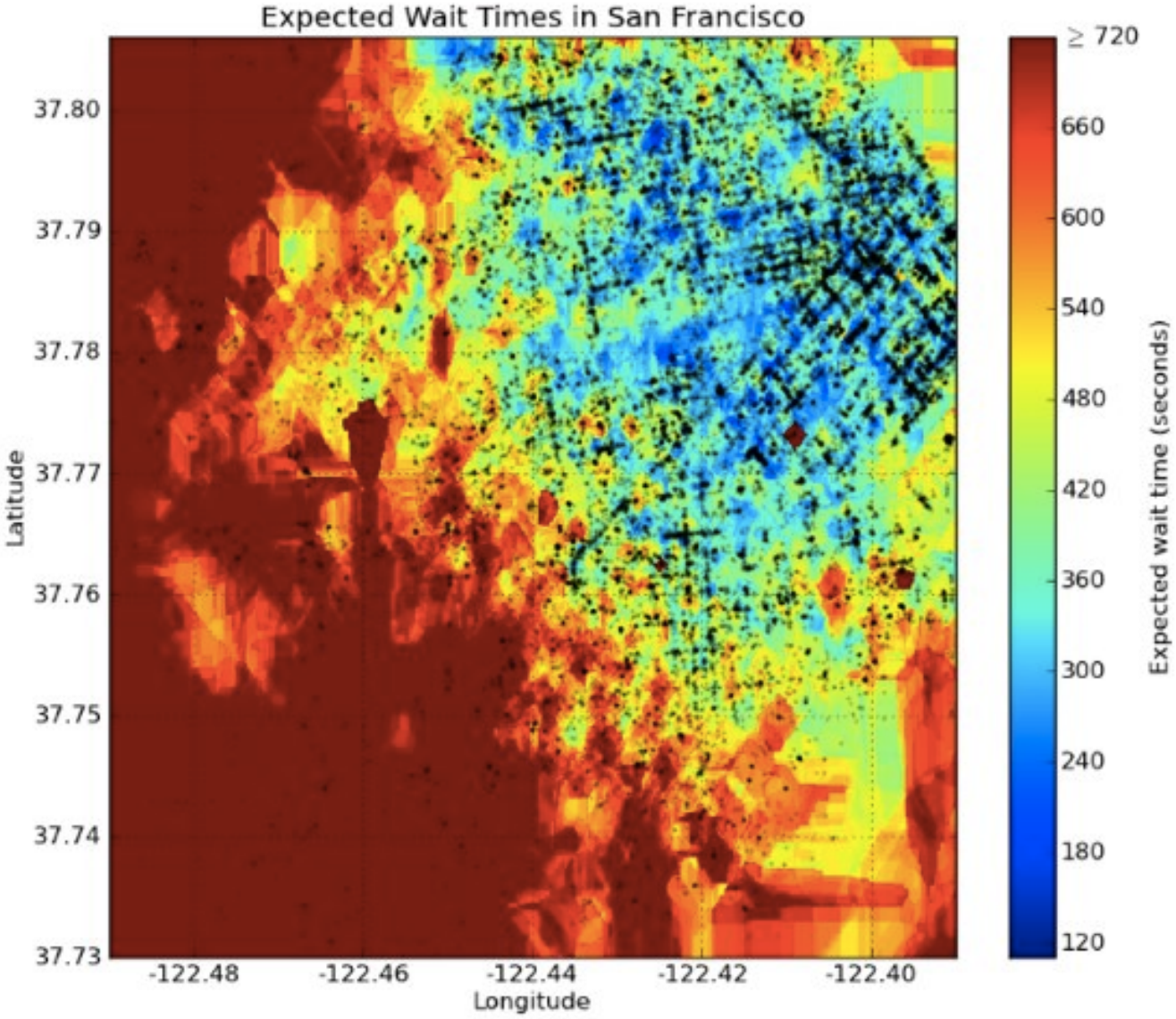




Don’t hide the context

Uber Wait Times, 2011

http://sta.mn/6x27



Break data into buckets

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

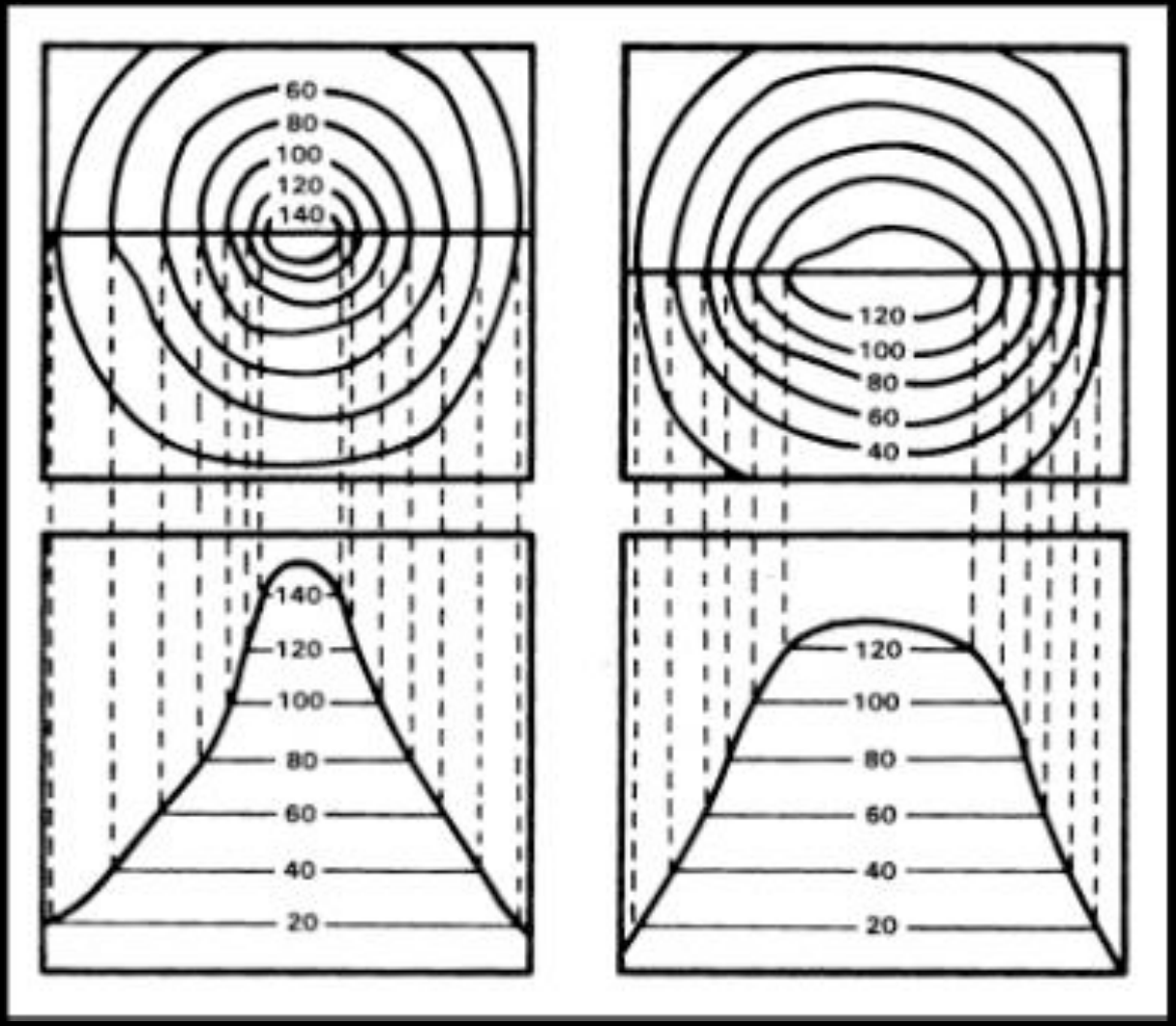
- A week ago
- Two weeks ago
- A month ago
- Two months ago
- Three months ago
- Four months ago
- Five months ago

CRIMESPOTTING_

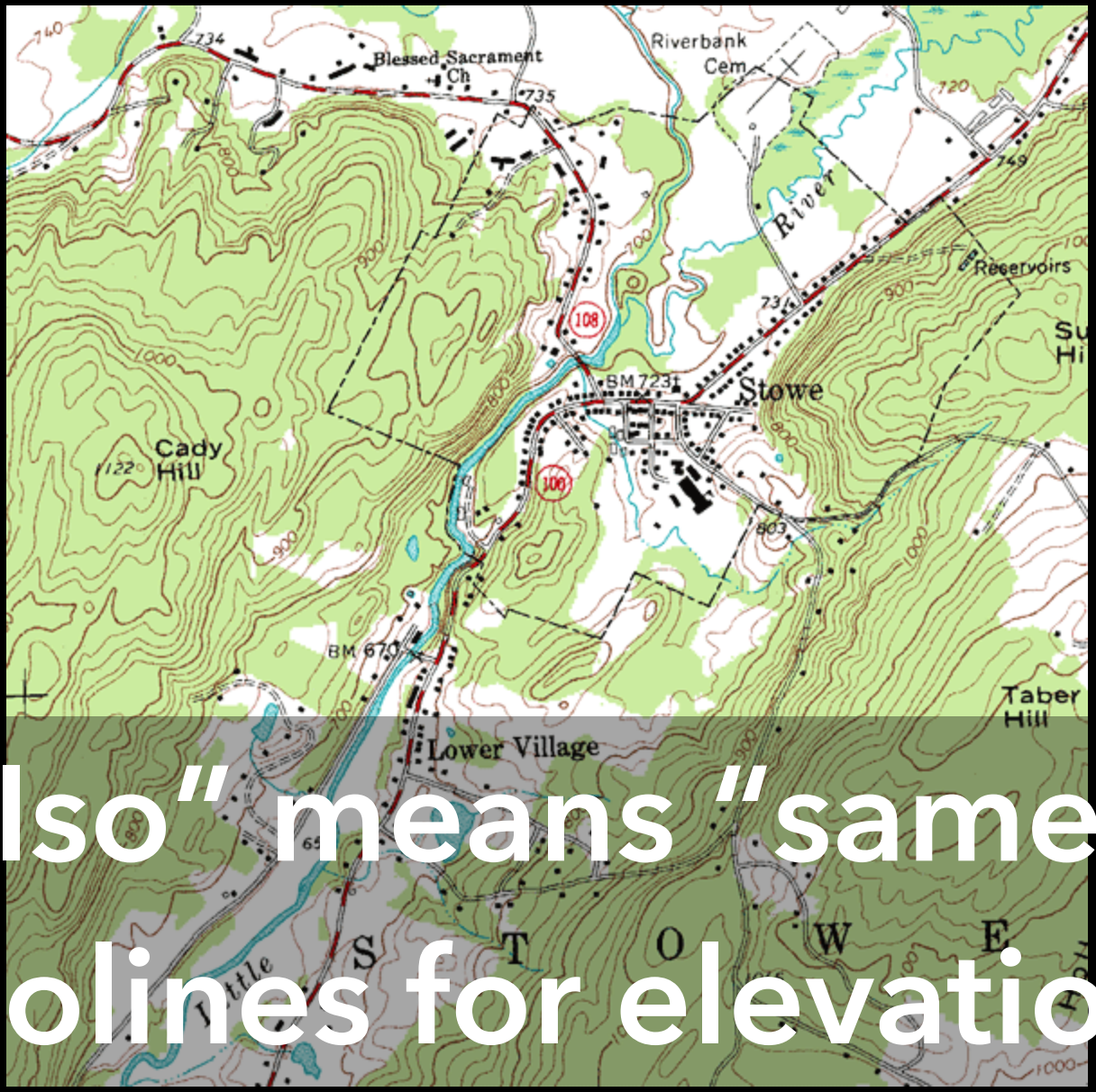
The brazen 2007 murder of journalist Chauncey Bailey in Oakland, California, led Stamen partner Mike Migurski to make the city's crime data more accessible. This heat map of downtown uses data from CrimeWatch, a community website, to show the gaps between crimes at a given intersection: white is high-crime; darker areas are safe. *stamen.com*

Meaningful buckets

http://sta.mn/b6

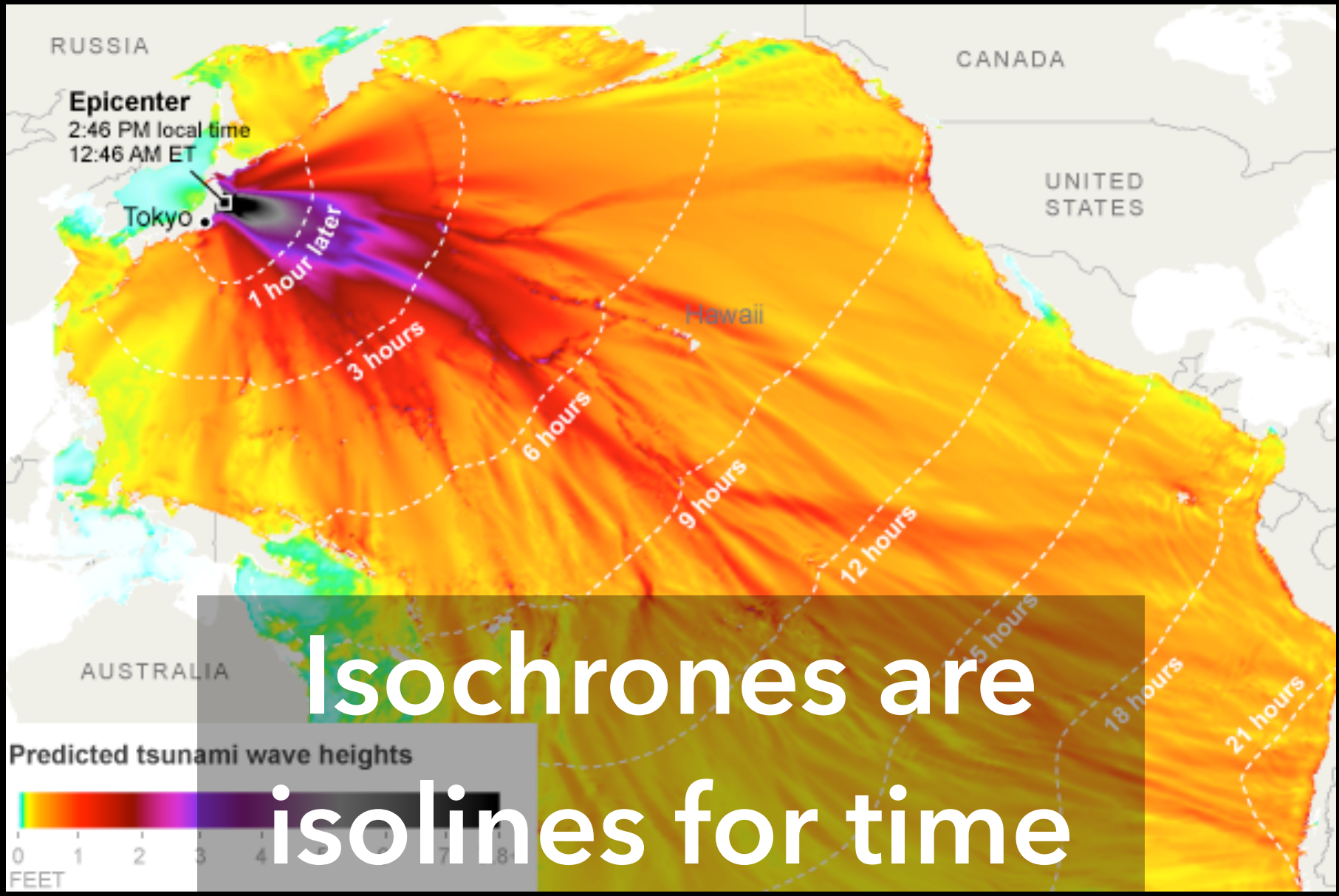


http://sta.mn/mhd



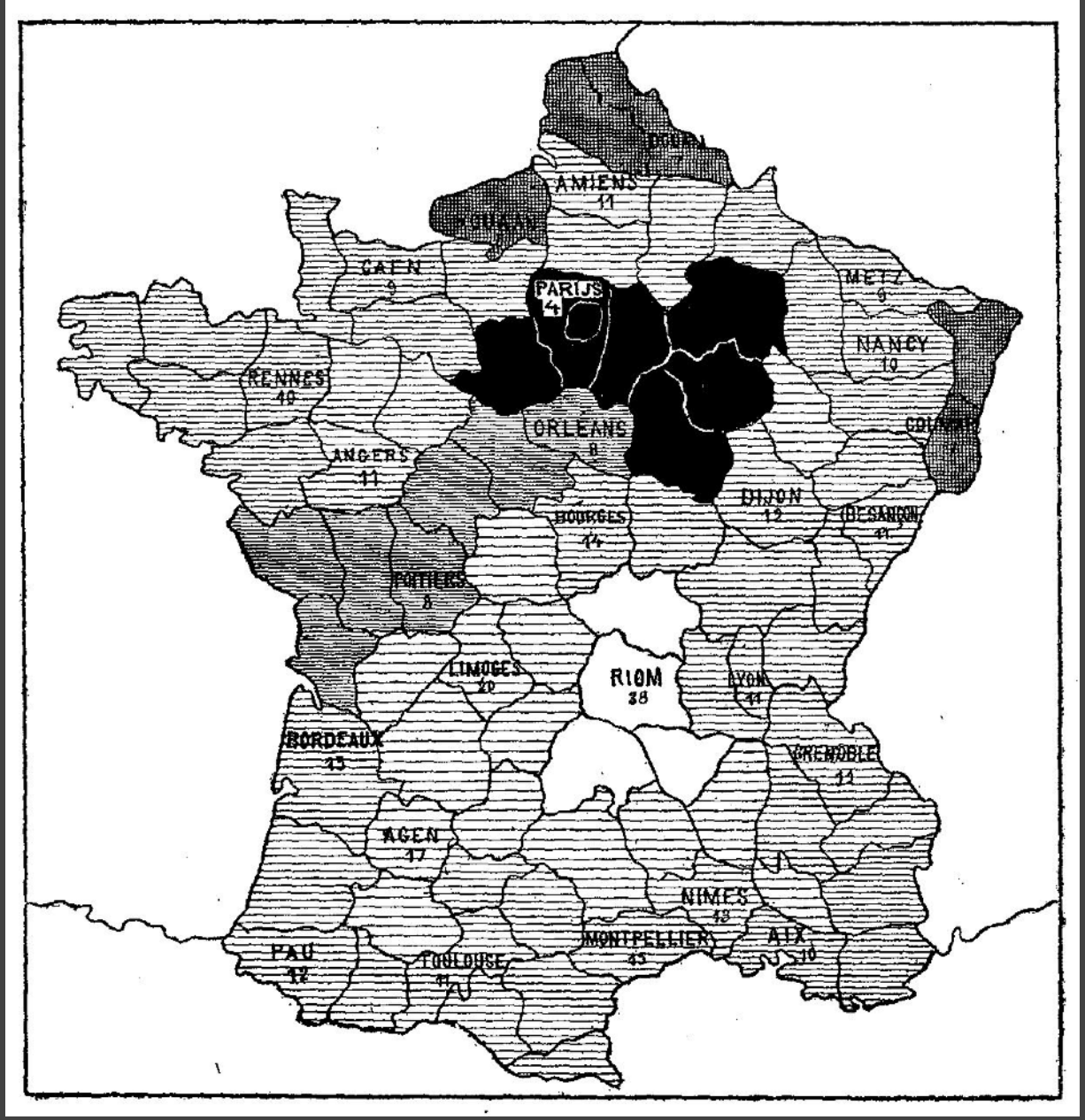
"Iso" means "same"
Isolines for elevation

http://sta.mn/xrg



Isochrones are isolines for time

Choropleth Maps



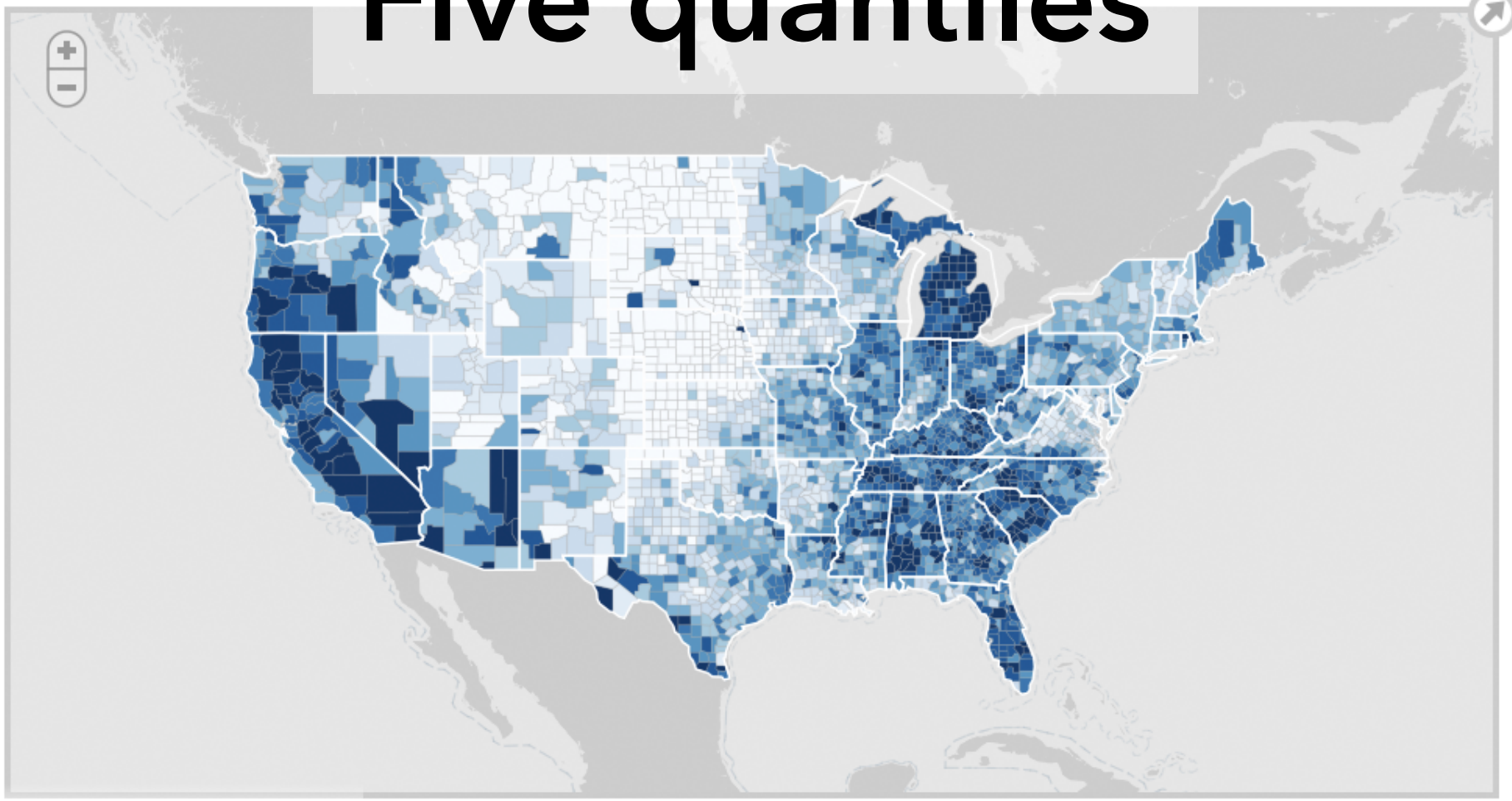
1826(?) Illiteracy in France, Pierre Charles Dupin

http://sta.mn/87

Polymaps

Overview Examples Documentation Download

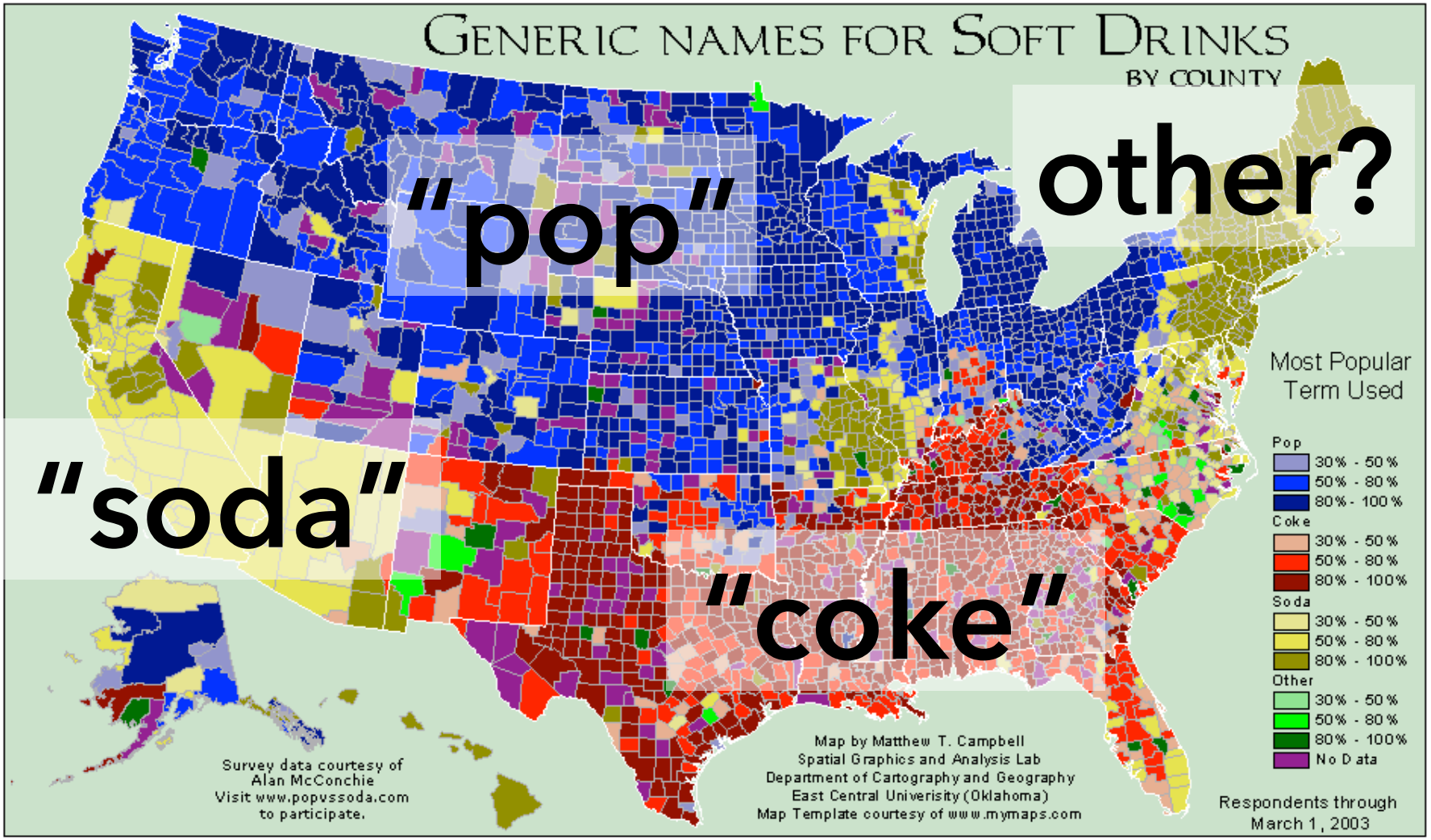
Five quantiles



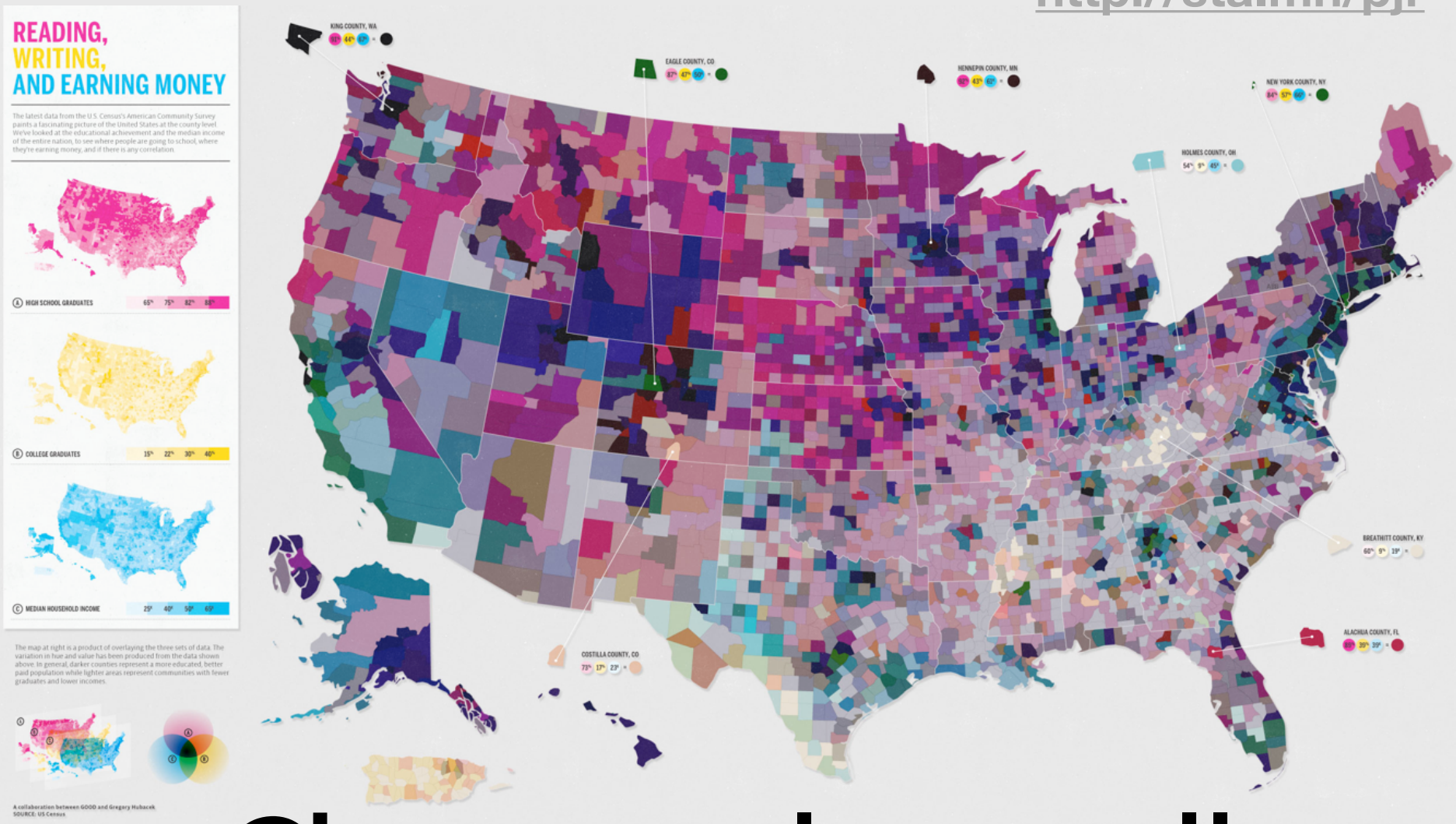
Polymaps is a project from SimpleGeo and Stamen.

Unemployment

http://popvssoda.com

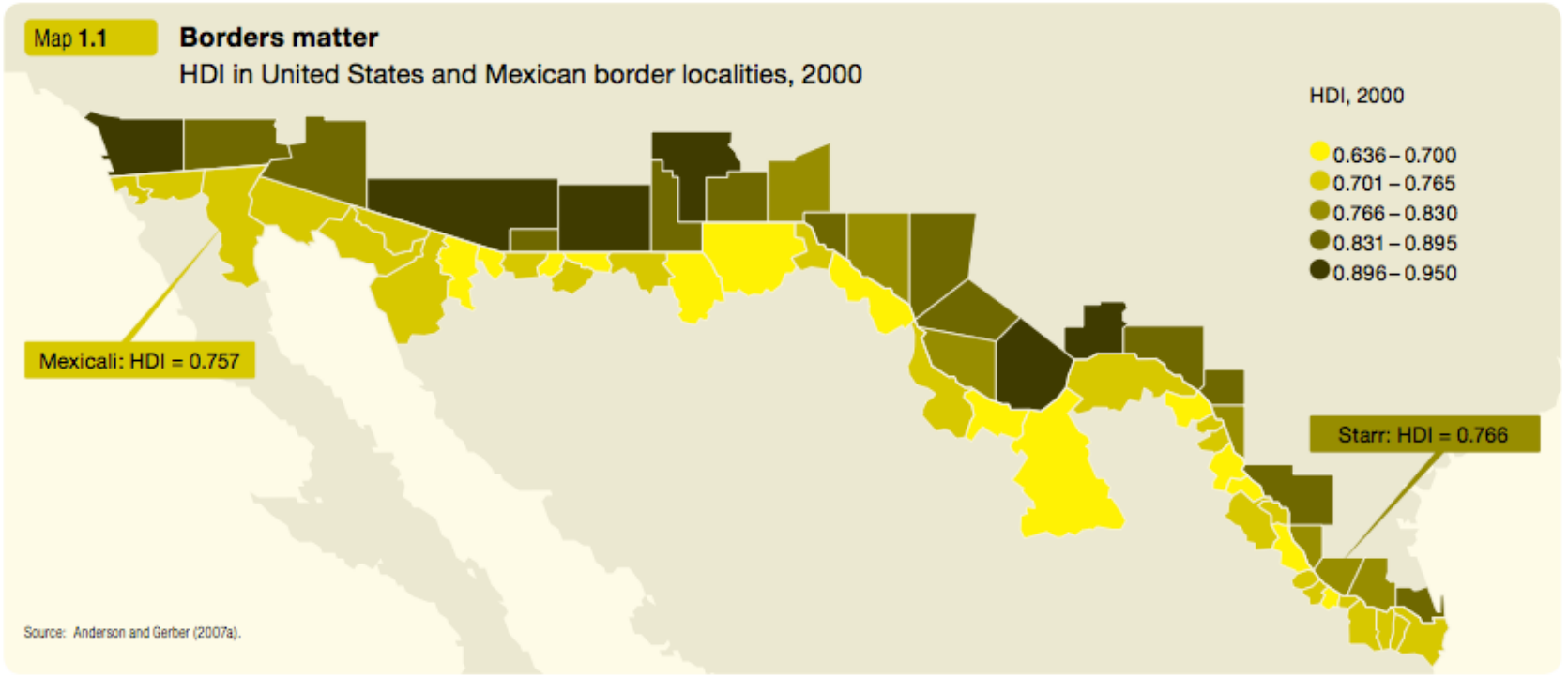


http://sta.mn/pjr

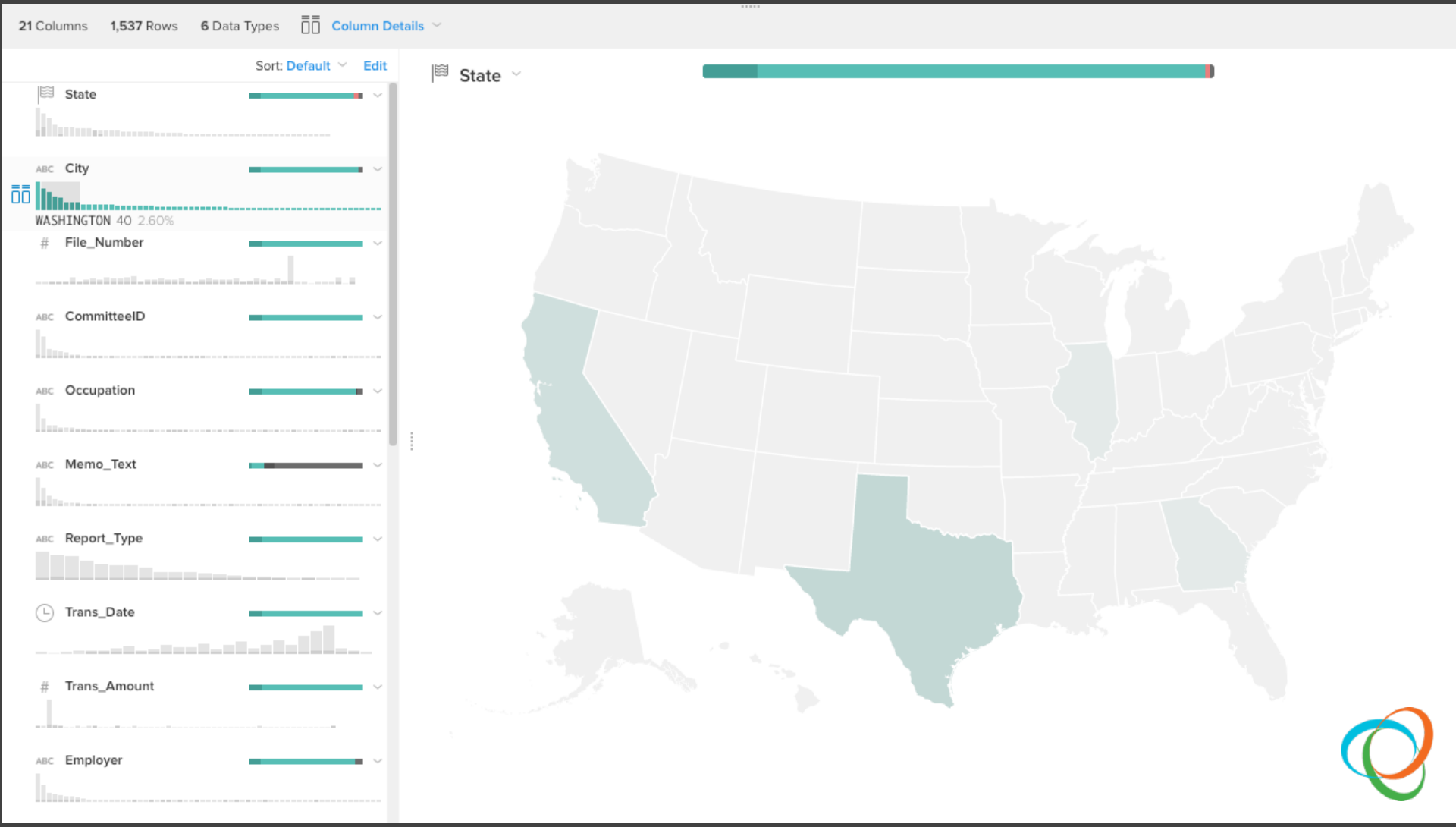


Choose colors well

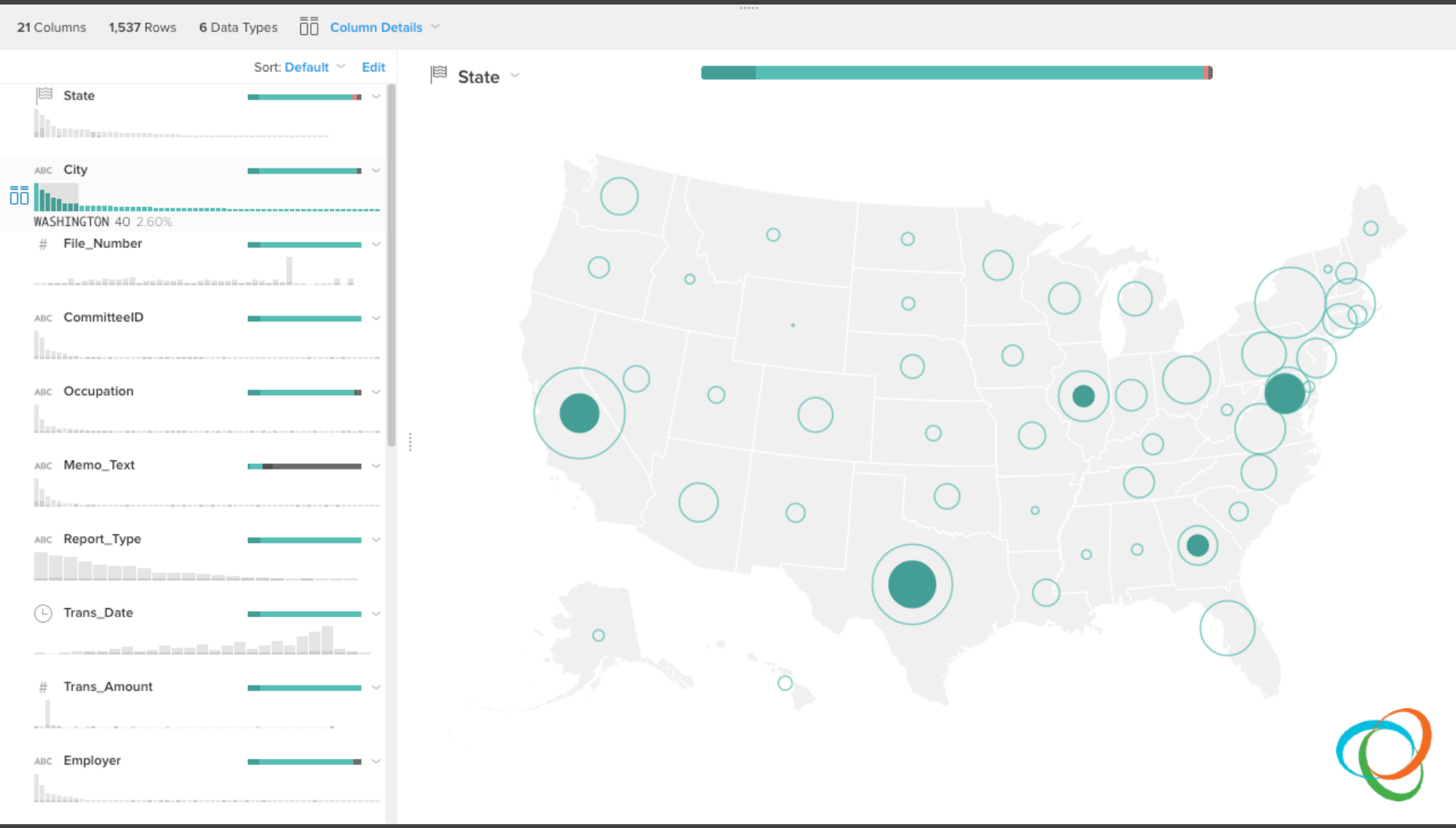
http://sta.mn/3vq



Focus on the foreground



What is obscured?



Regions -> Symbols

Cartograms

http://sta.mn/4xk

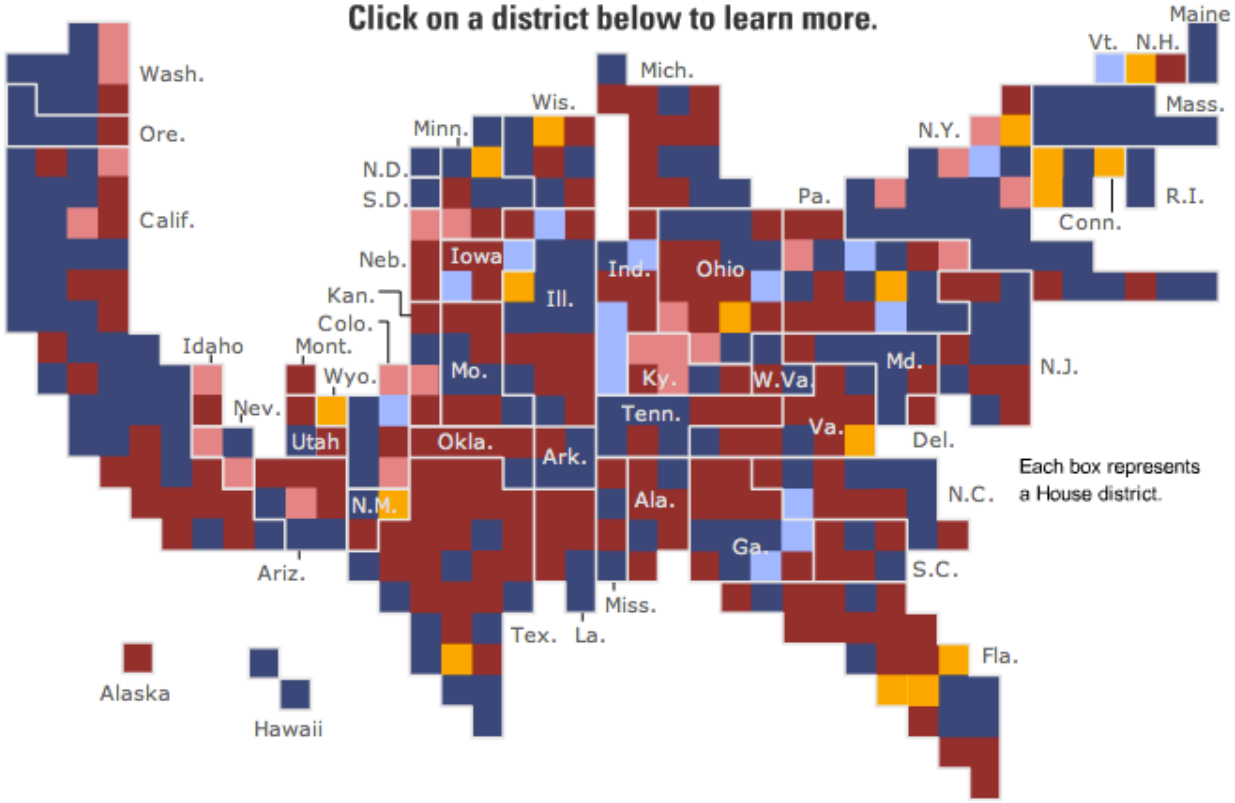
SOURCES, CREDITS AND FEEDBACK

2006 ELECTION GUIDE | SENATE RACES | HOUSE RACES | Ggovernors' RACES | RACE PROFILES

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

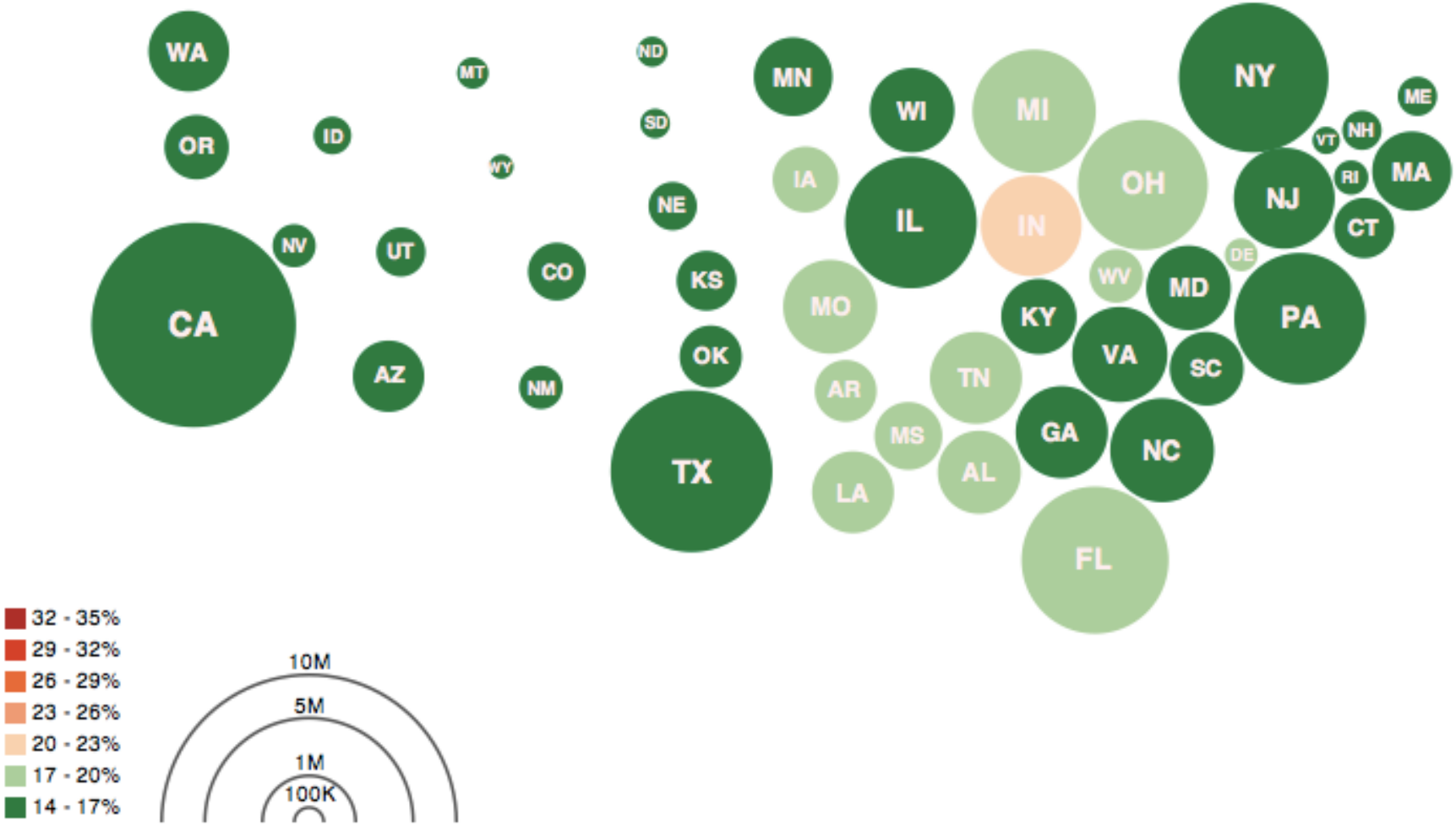
Race/Ethnicity

☐ White ☐ Black ☐ Hispanic

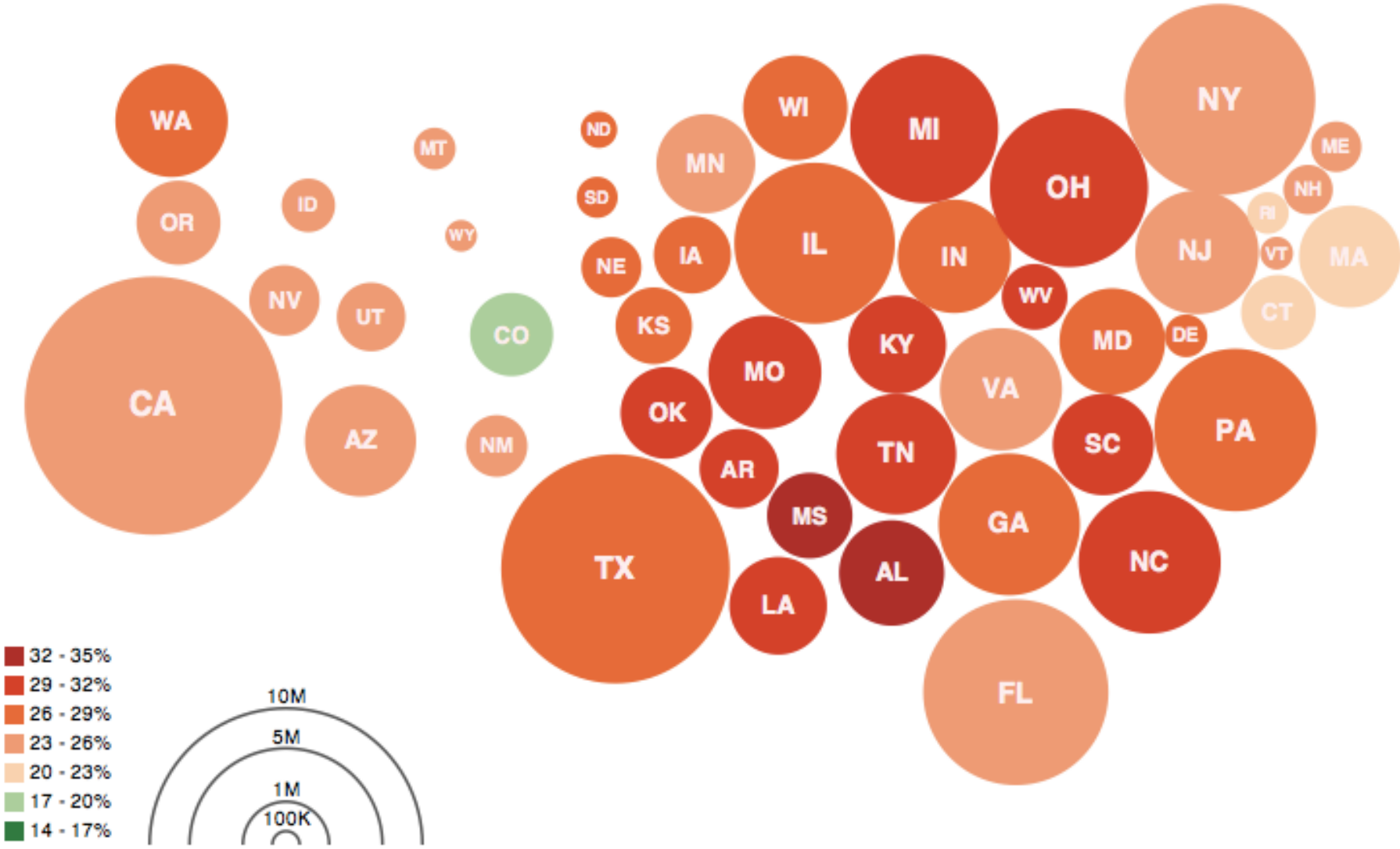
Median income

☐ <$30K ☐ $30-50K ☐ >$50K

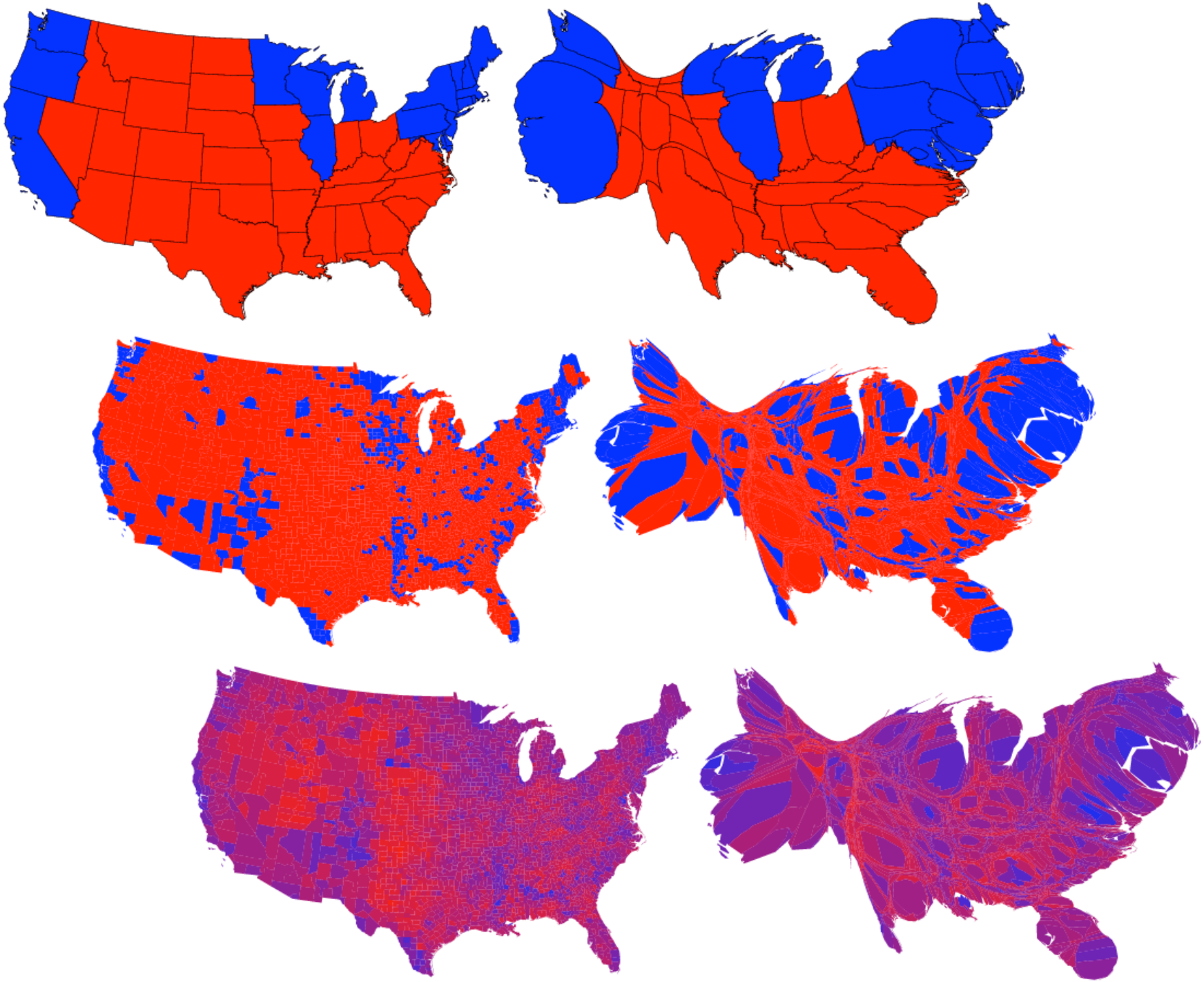
RESET



Obesity Map (Dorling Cartogram) Vadim Ogievetsky

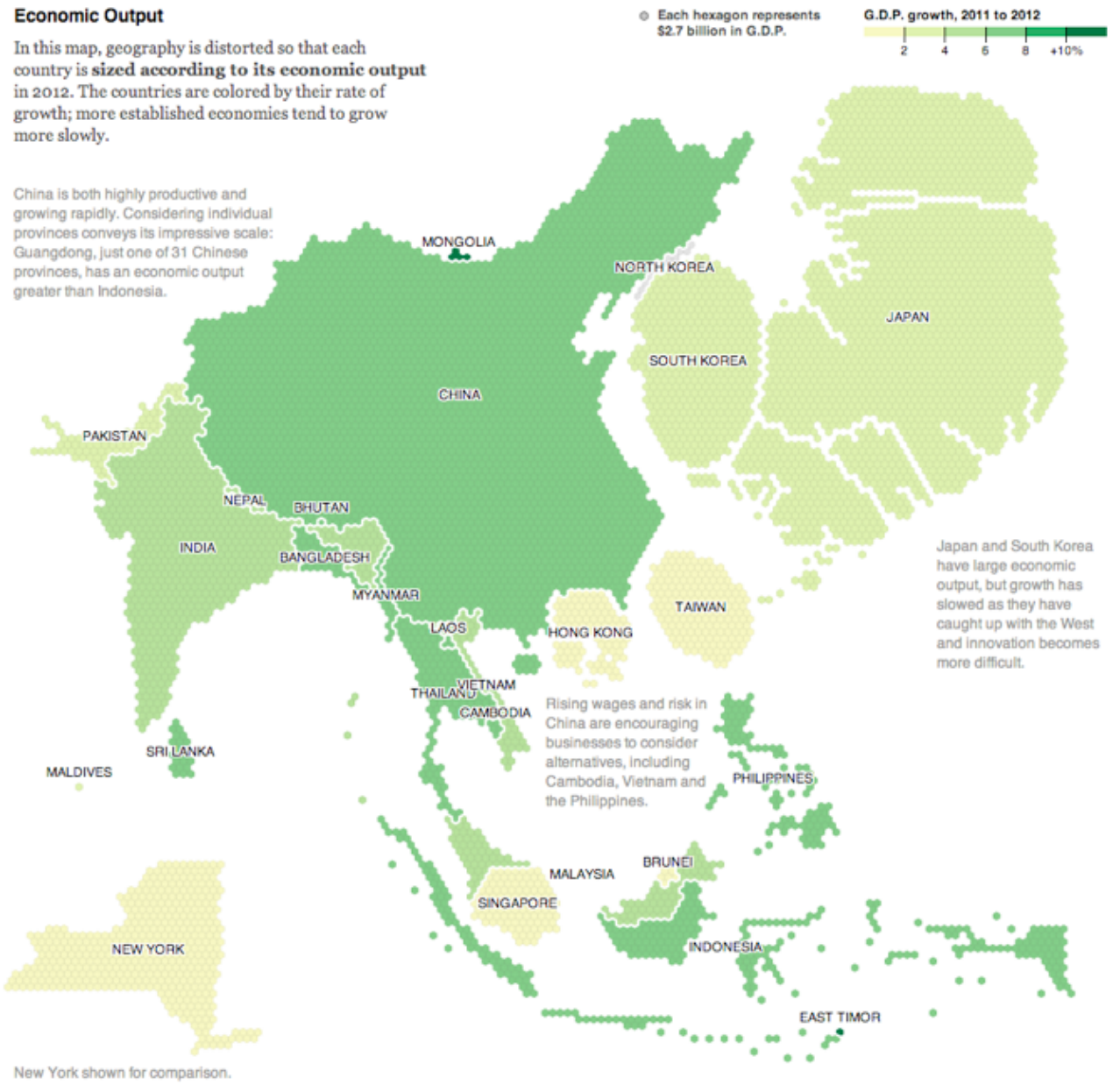


Obesity Map (Dorling Cartogram) Vadim Ogievetsky

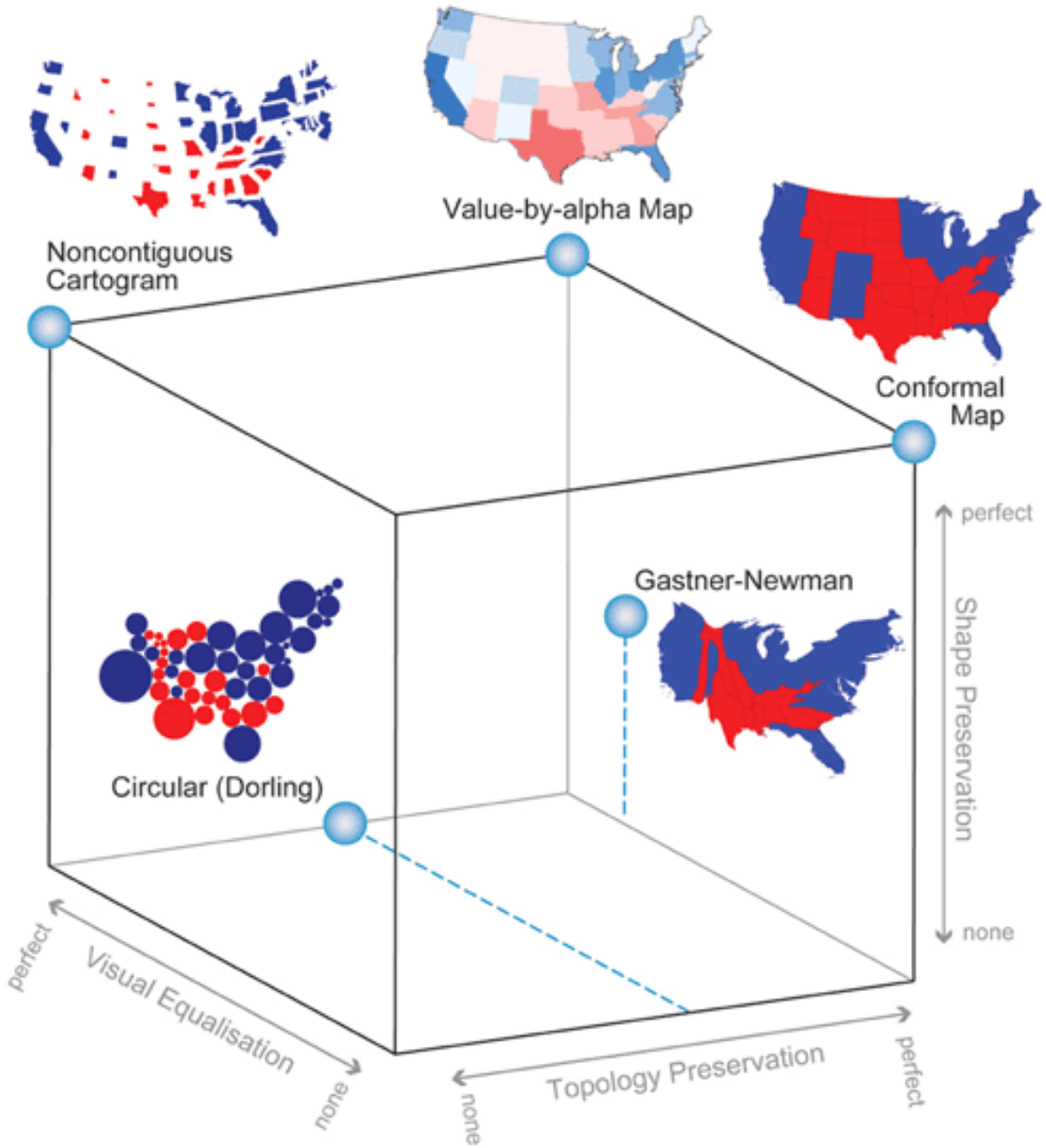


China Still Dominates, but Some Manufacturers Look Elsewhere

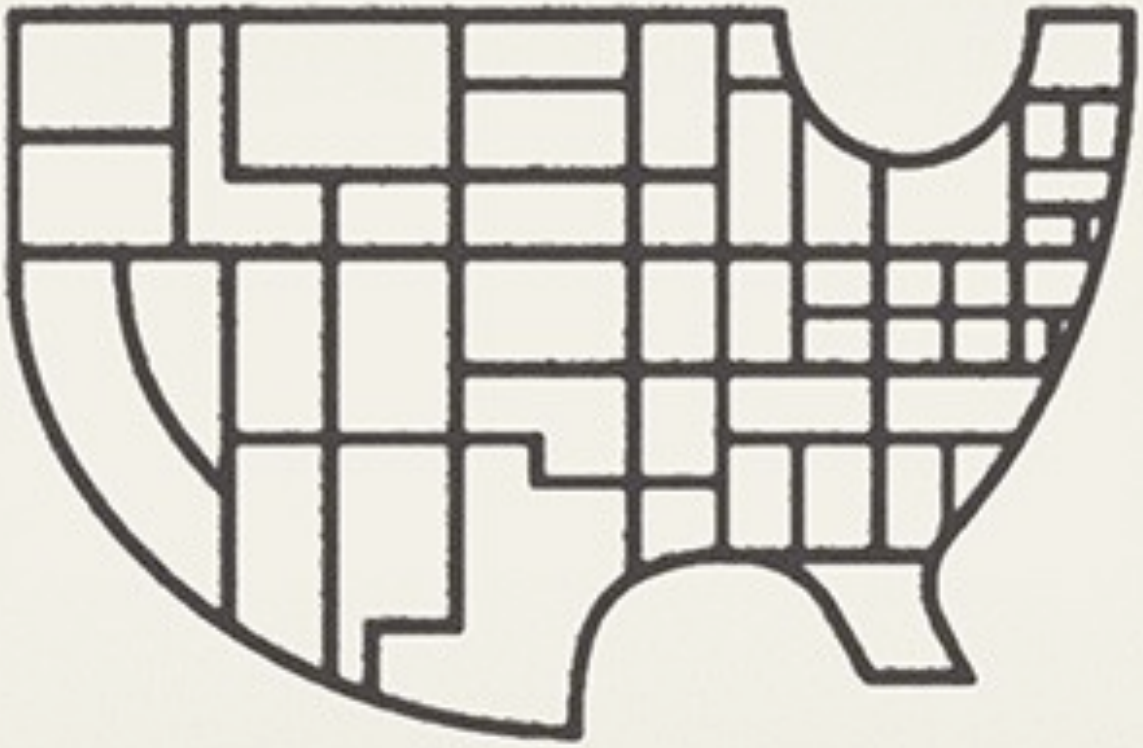
While China maintains its overwhelming dominance in manufacturing, multinational companies are looking for ways to limit their reliance on factories there. Related Article »



http://sta.mn/wz

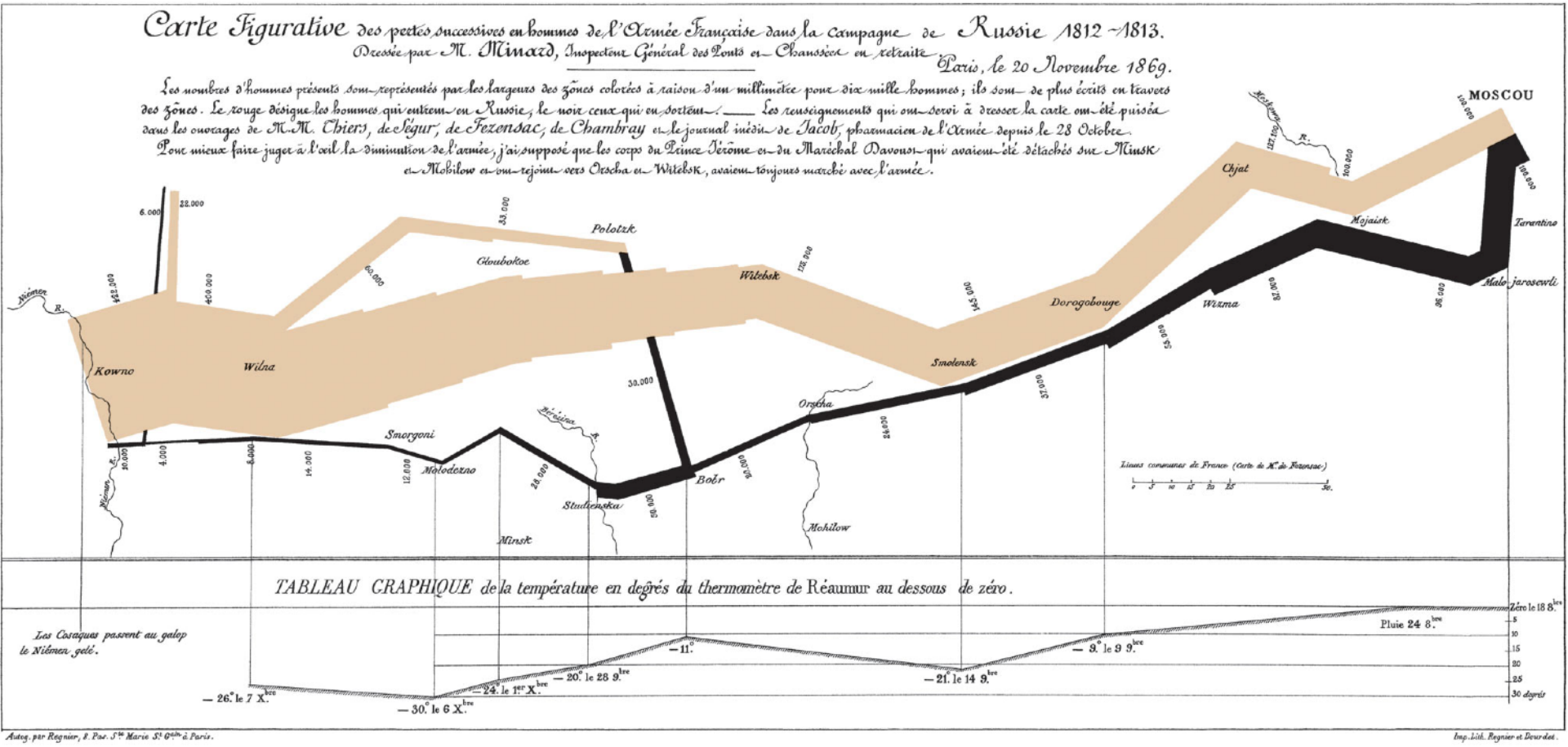


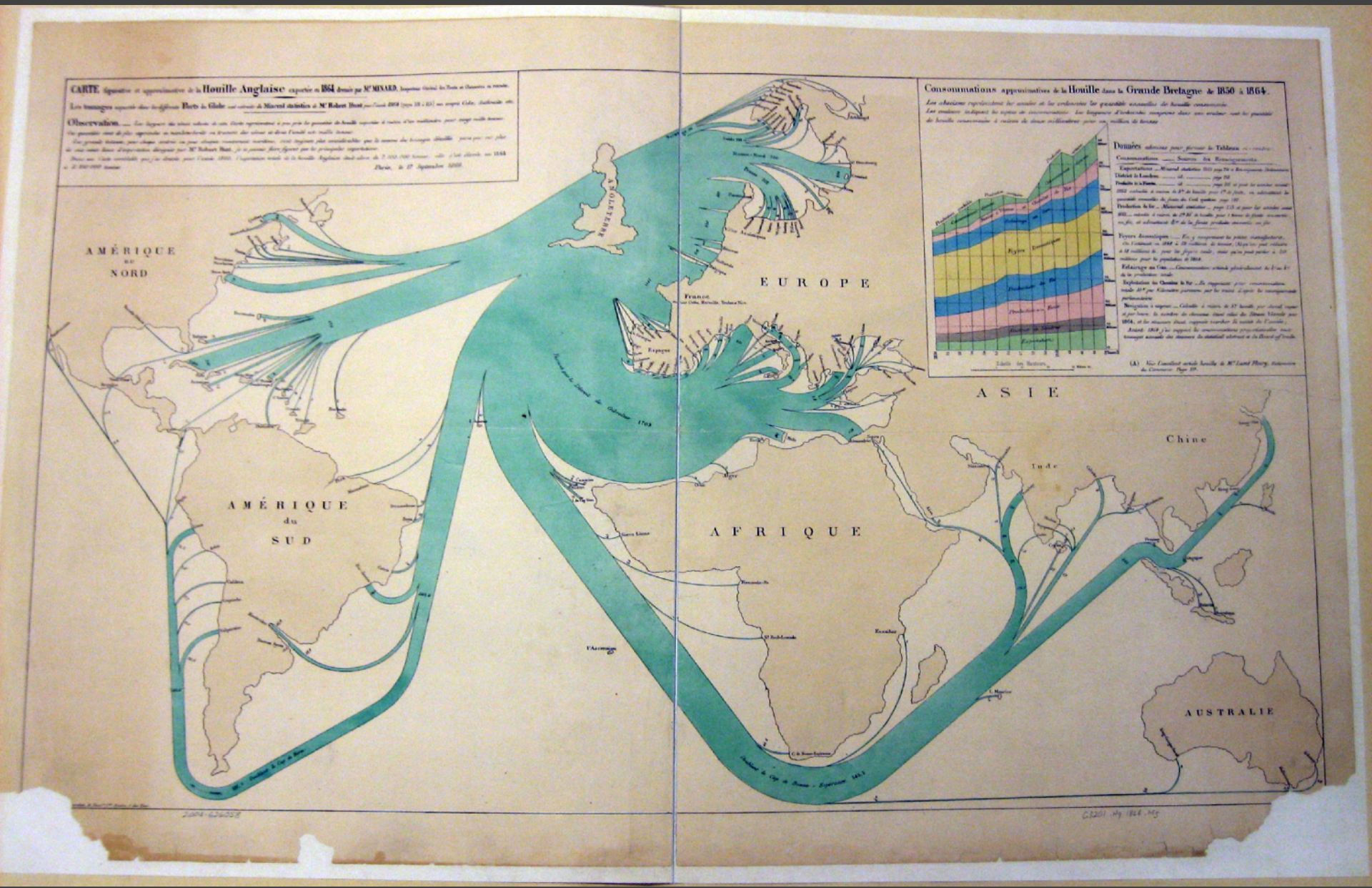
Major distortions can stay recognizable



Flow Maps

Minard 1869: Napoleon's march

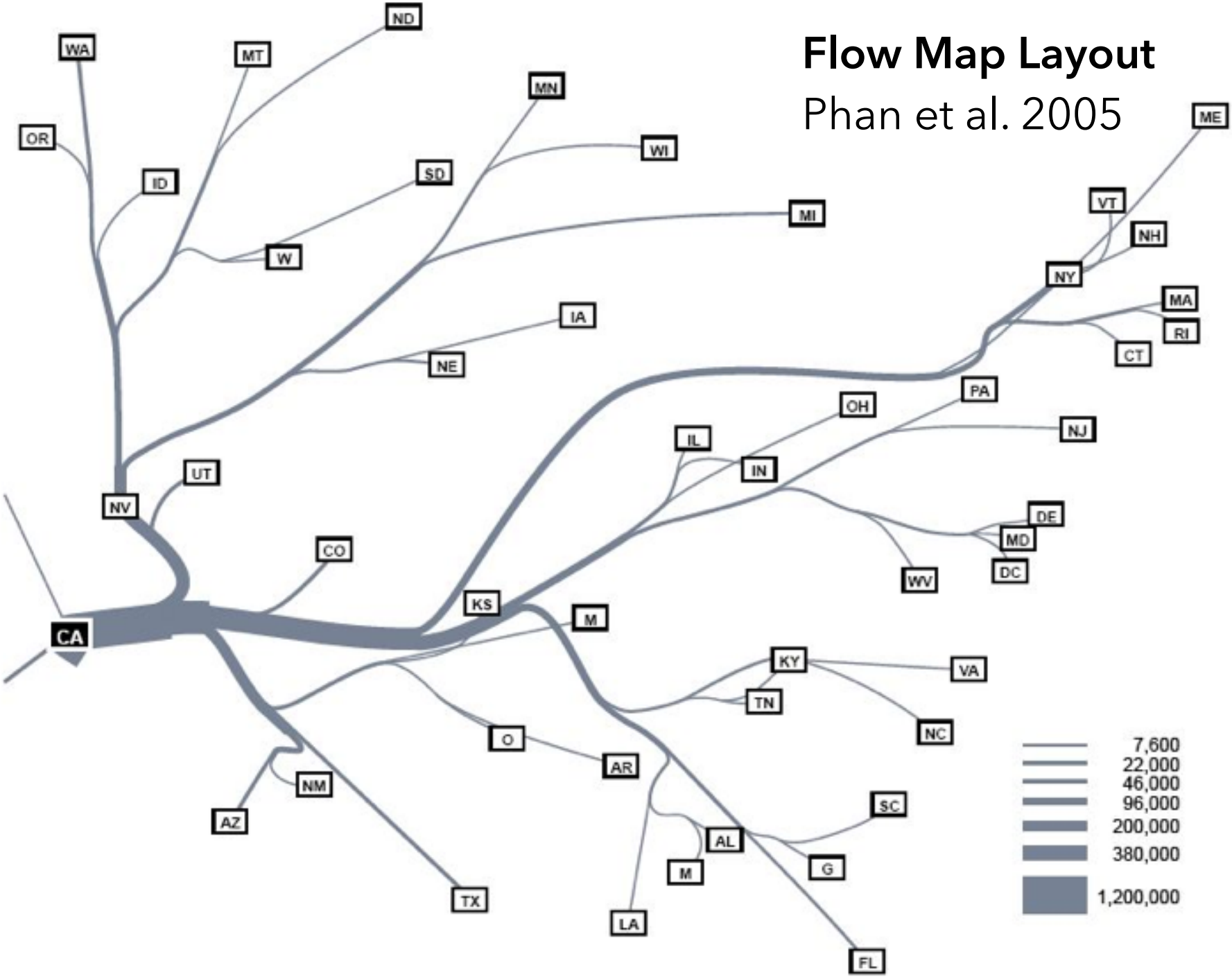




1864 British Coal Exports, Charles Minard

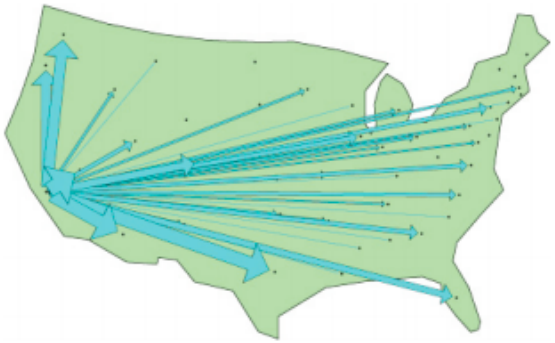
Flow Map Layout

Phan et al. 2005

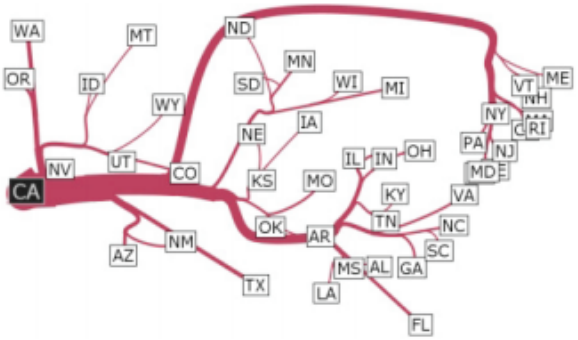


Migration from California, 95-00

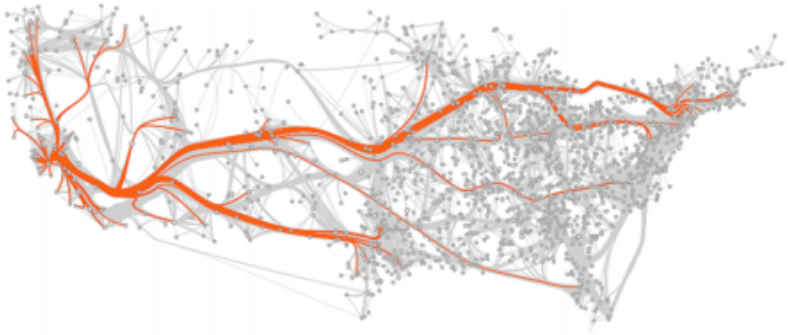
Tobler 1987



Phan et al. 2005



Verbeek et al. 2011



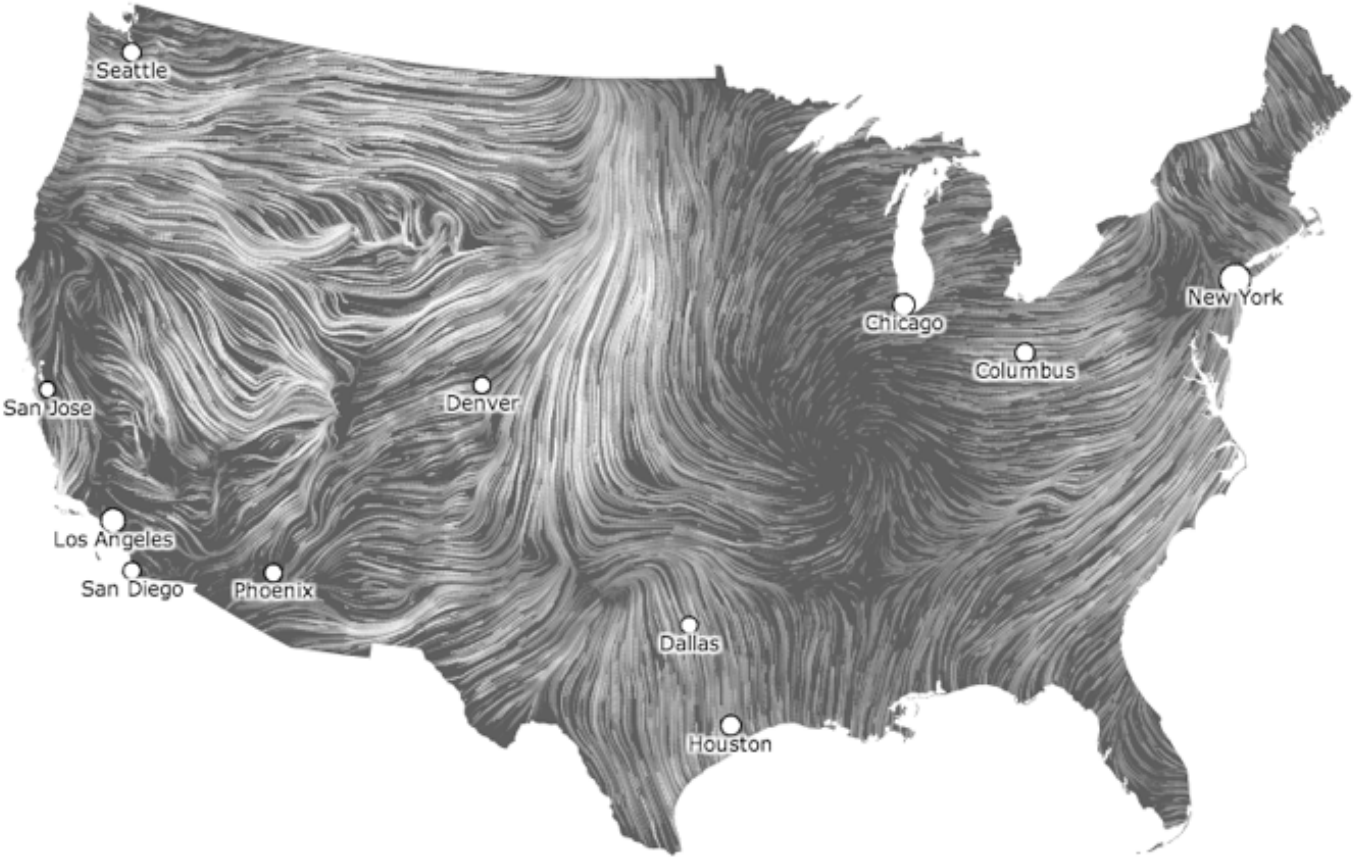
Cui et al. 2008

Holten & van Wijk 2009

wind map

February 19, 201
11:55 am EST
(time of forecast download)

top speed: **35.3 mph**
average: **11.6 mph**



1 mph
3 mph
5 mph
10 mph
15 mph
30 mph

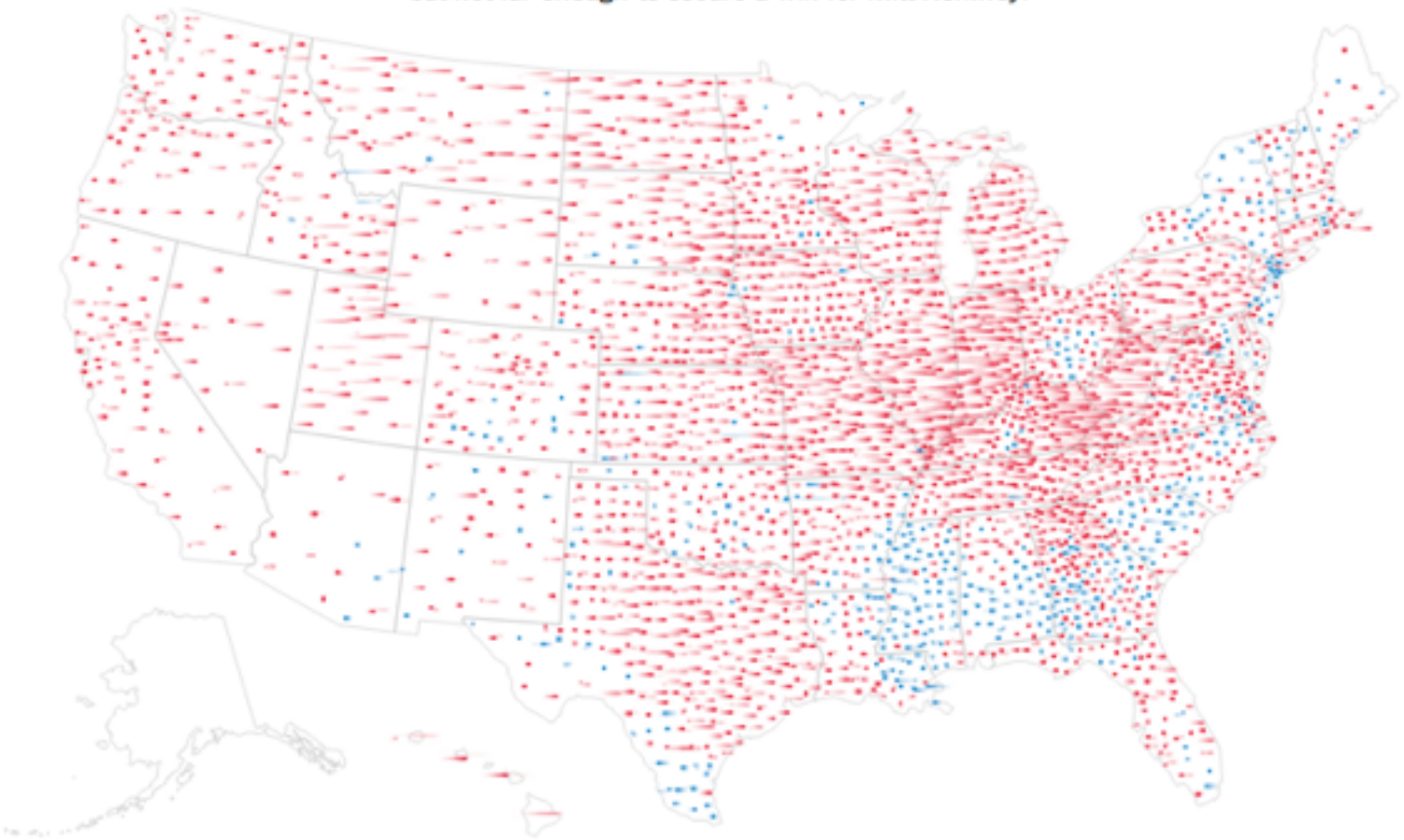
How Obama Won Re-election

Whites Were Outvoted | Women | Hispanics | Youth

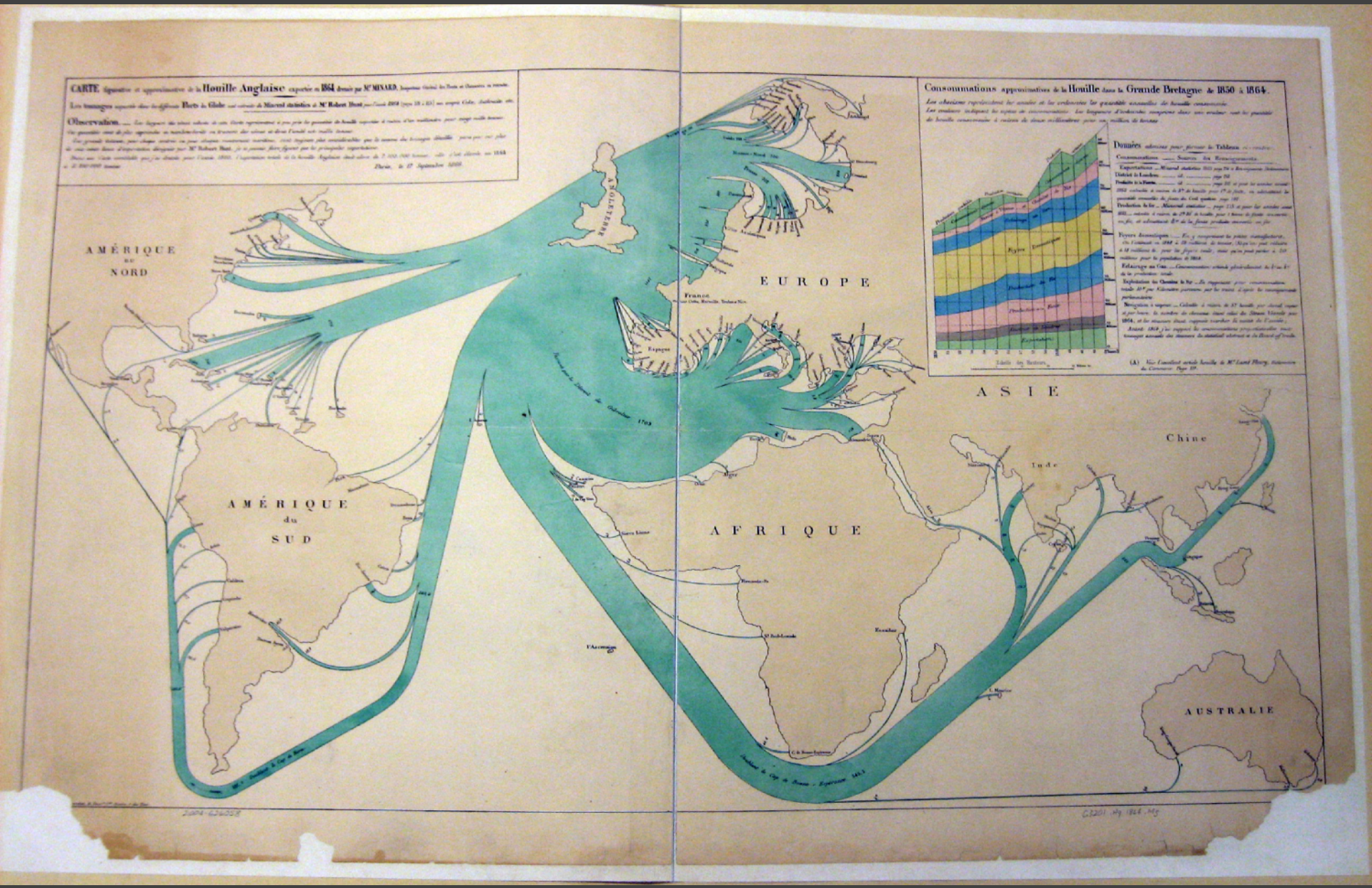
Romney's Shift Wasn't Enough

2008 | 2012

Most of the nation shifted to the right in Tuesday's vote, but not far enough to secure a win for Mitt Romney.

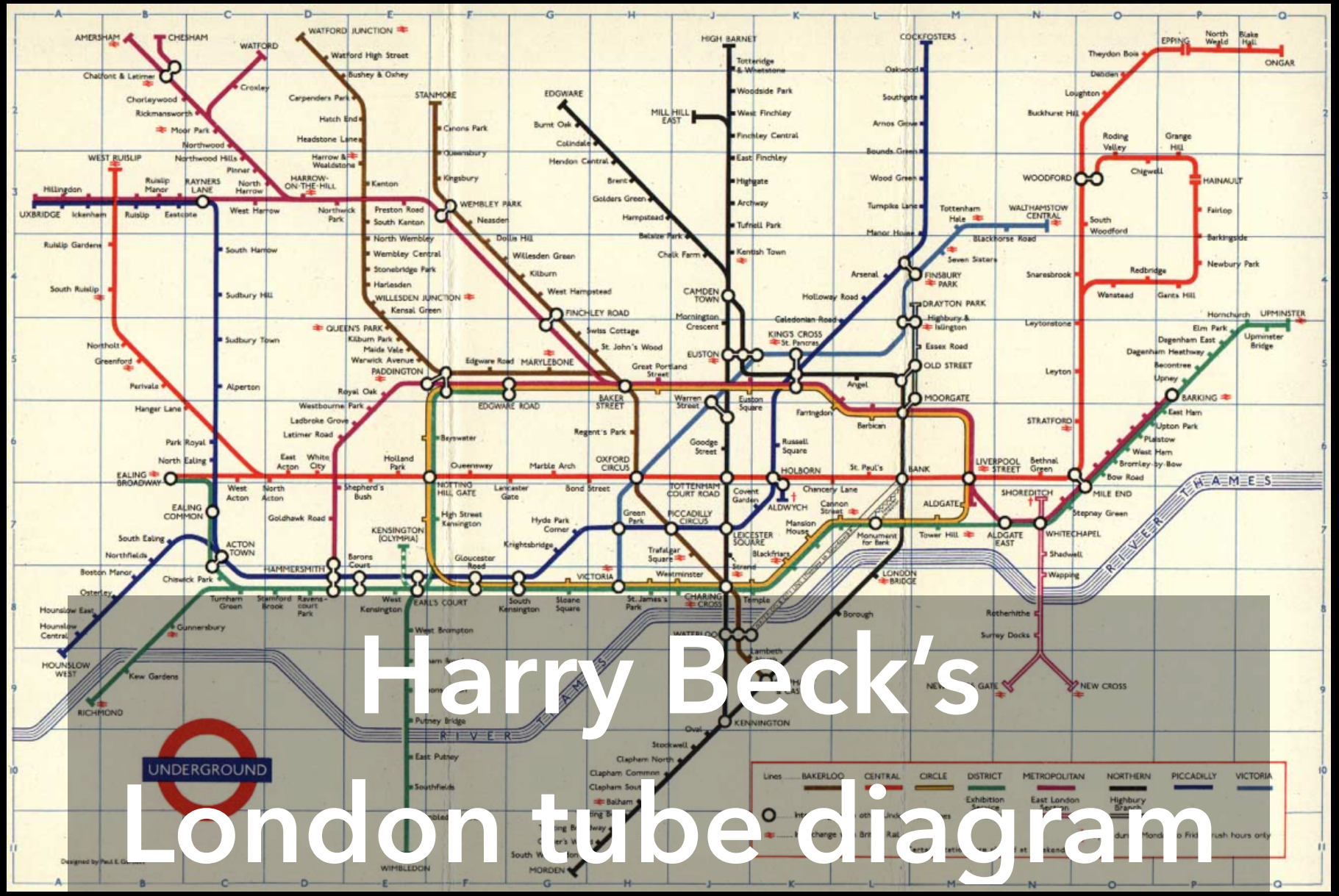


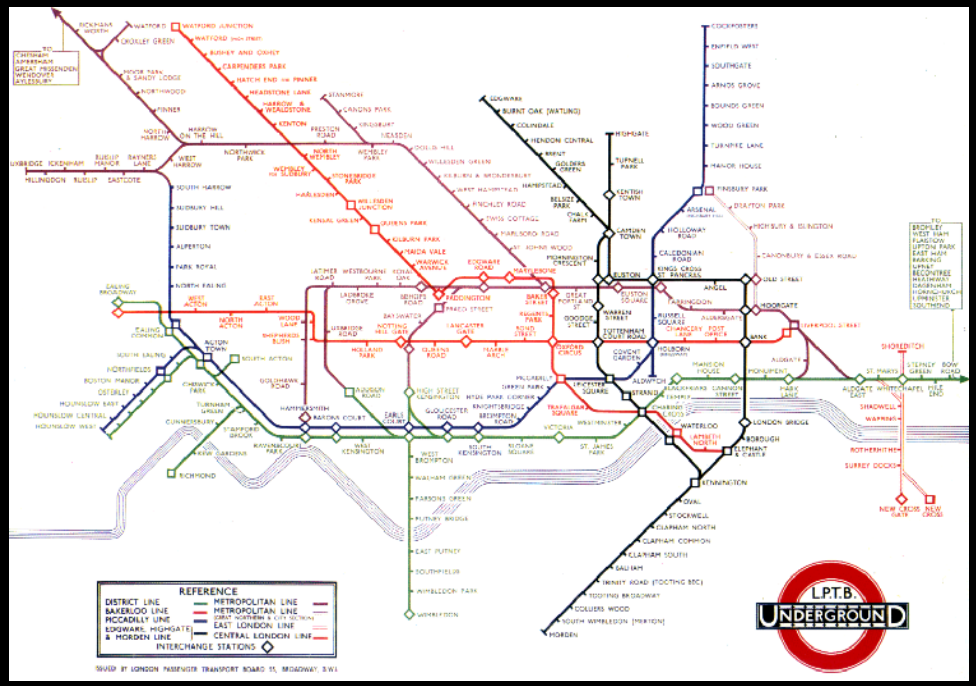
Generalization



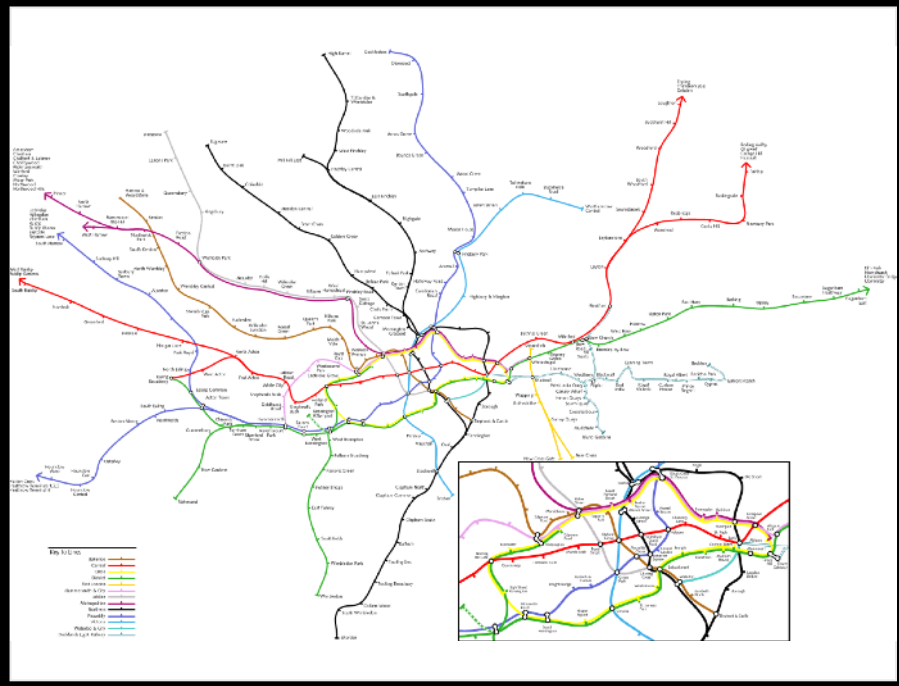
1864 British Coal Exports, Charles Minard

http://sta.mn/nzh





London Underground [Beck 33]

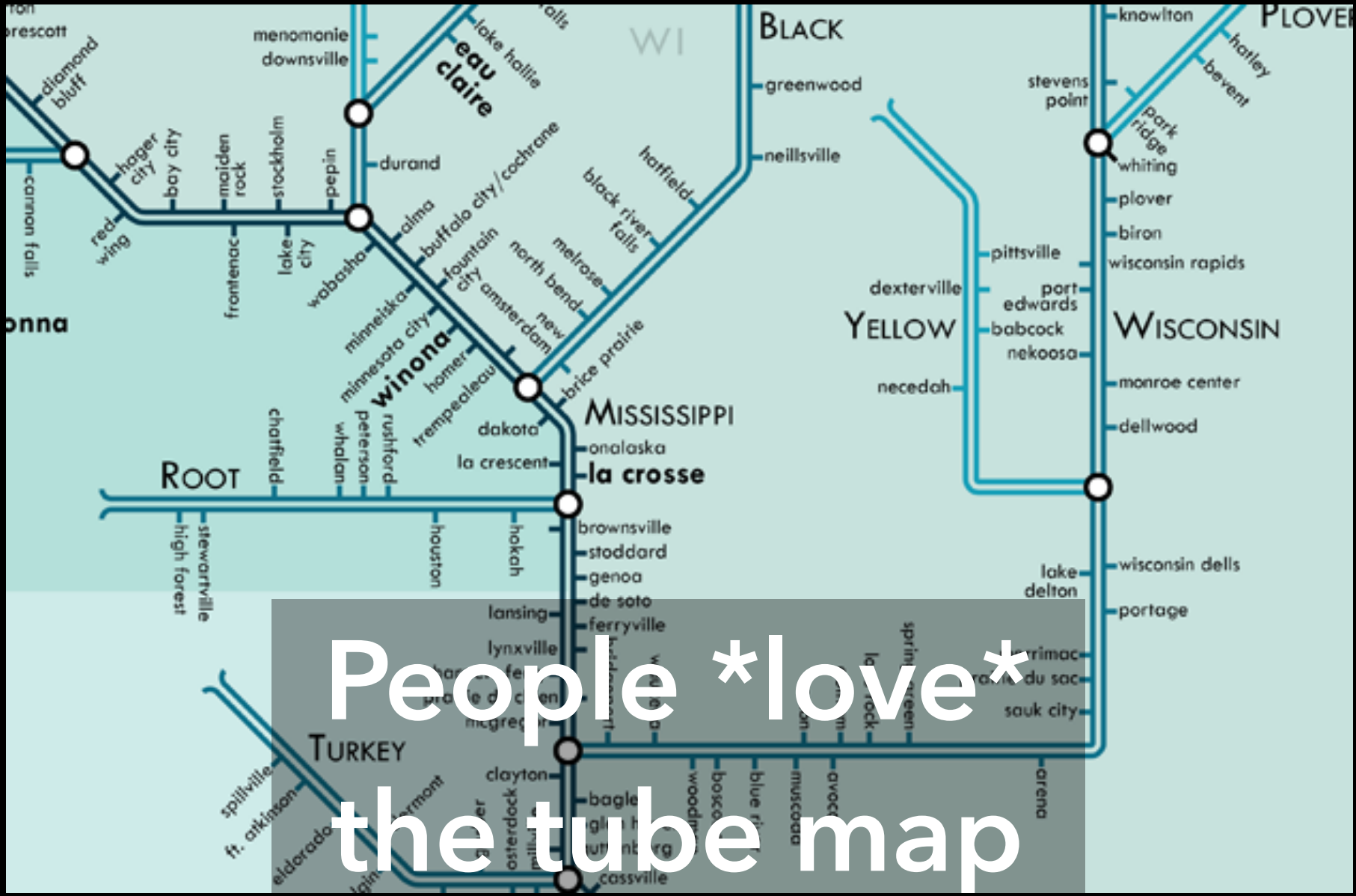


Geographic version of map

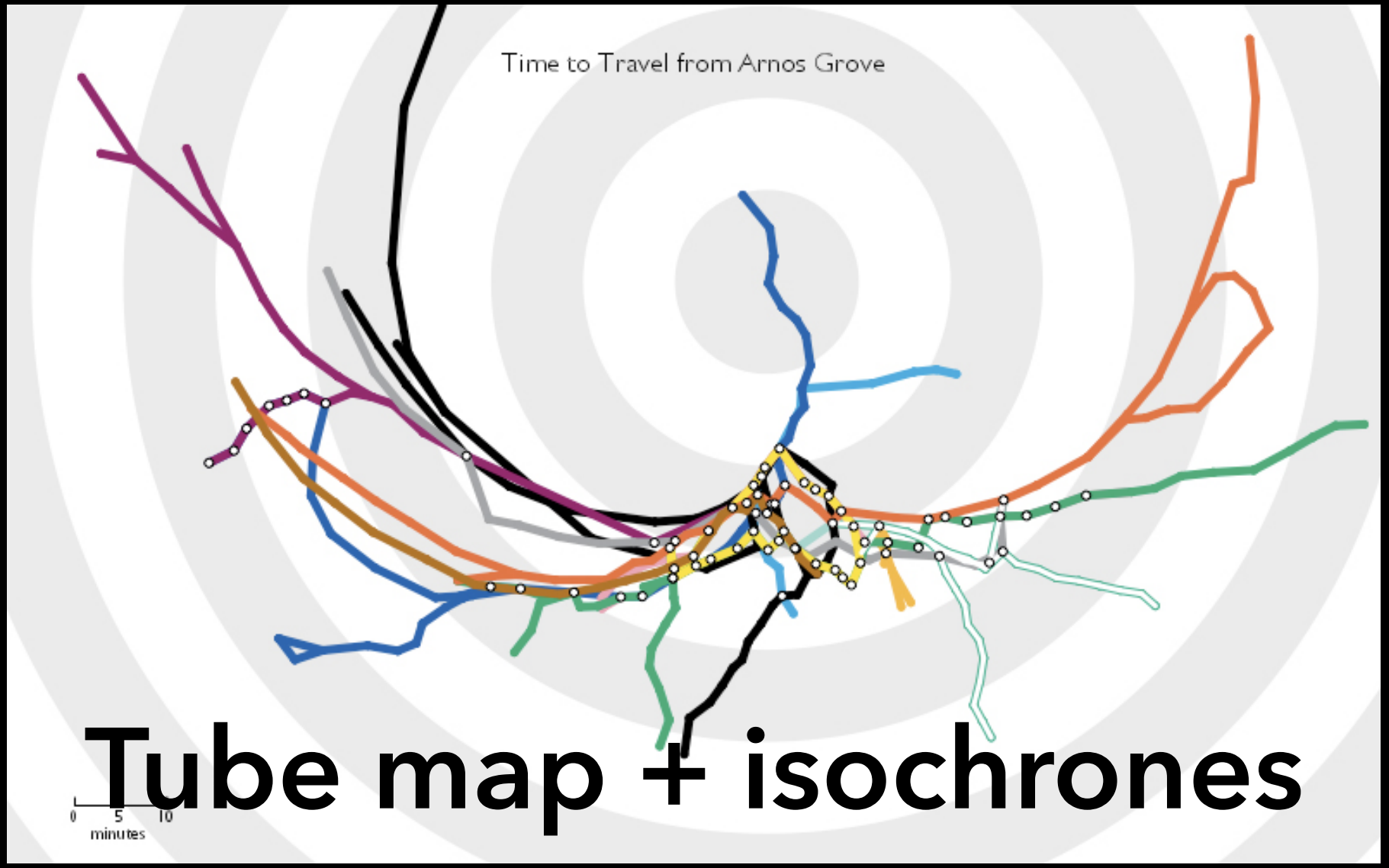
Principle: Straighten lines to emphasize stop sequence

Technique used to emphasize/de-emphasize information

http://sta.mn/nhc3



http://sta.mn/nb



Tube map + isochrones

Route Maps: Bellevue to Seattle

Map Design via Optimization [Agrawala '01]

Set of graphic elements

- Roads, labels, cross-streets, …

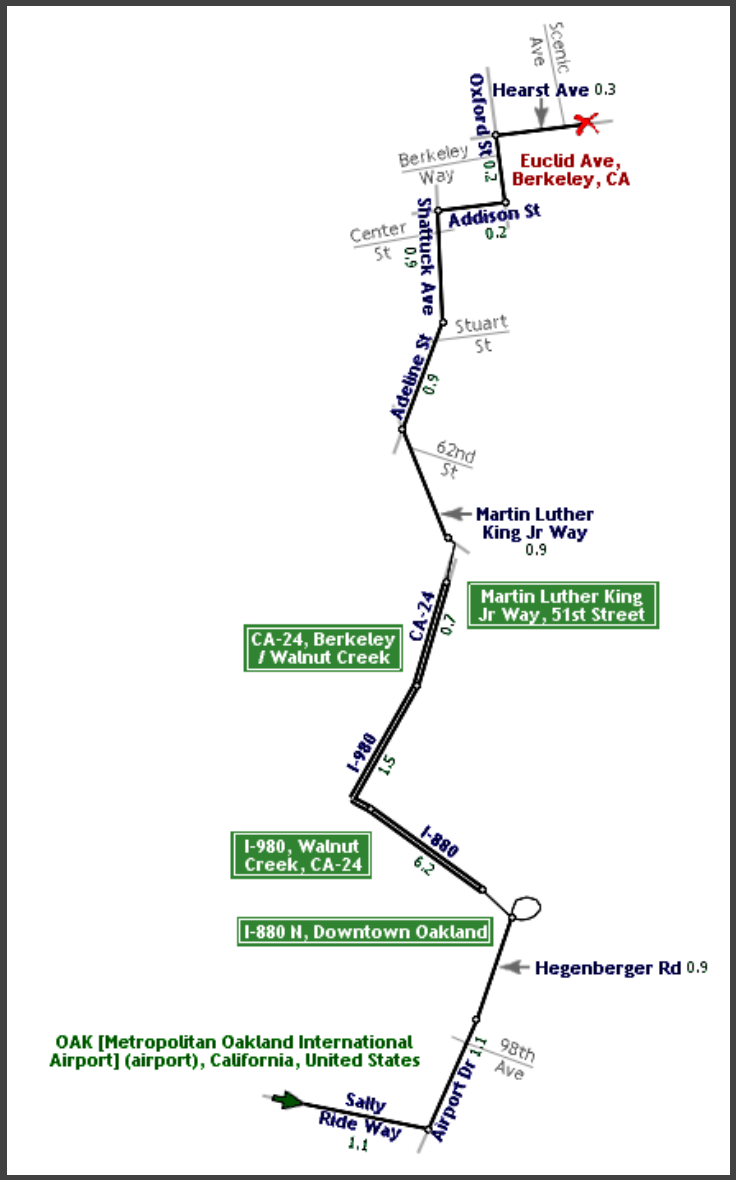
Choose visual attributes

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

Maintain ordering by length $W_{shuffle}$

Orientation

Maintain original orientation $|a_{curr}(r_i) - a_{orig}(r_i)| * W_{orient}$

Topological errors

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

Prevent missing $d * W_{missing}$

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

Overall route shape

Maintain endpoint direction $|a_{curr}(v) - a_{orig}(v)| * W_{enddir}$

Maintain endpoint distance $|d_{curr}(v) - d_{orig}(v)| * W_{enddist}$

Tools

Software Tools

Web Tools

d3.geo: projections, paths and more
GeoJSON: JSON format for geo data
TopoJSON: topology -> compressed GeoJSON
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

Let's Make a Map!

http://bost.ocks.org/mike/map/

How to Infer Topology

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