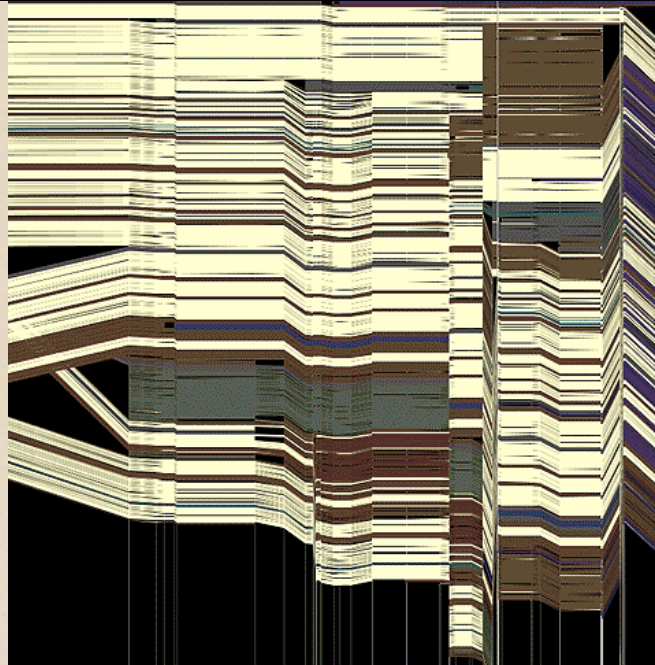
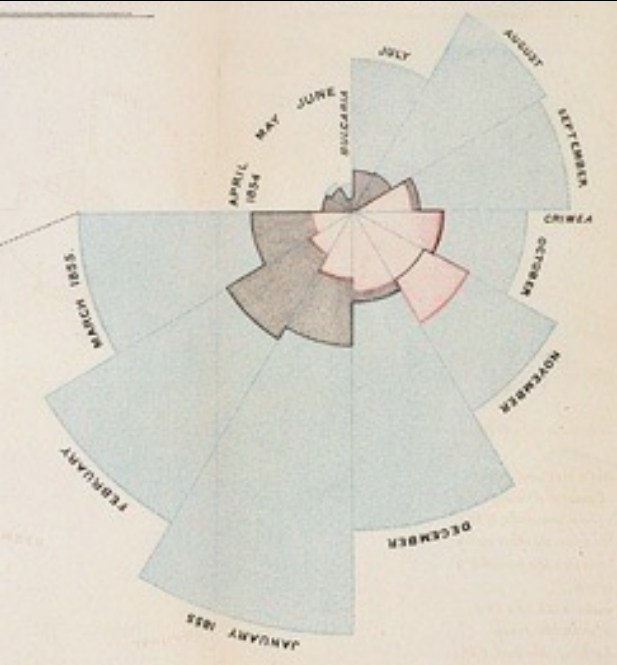


CSE 442 - Data Visualization

Mapping & Cartography

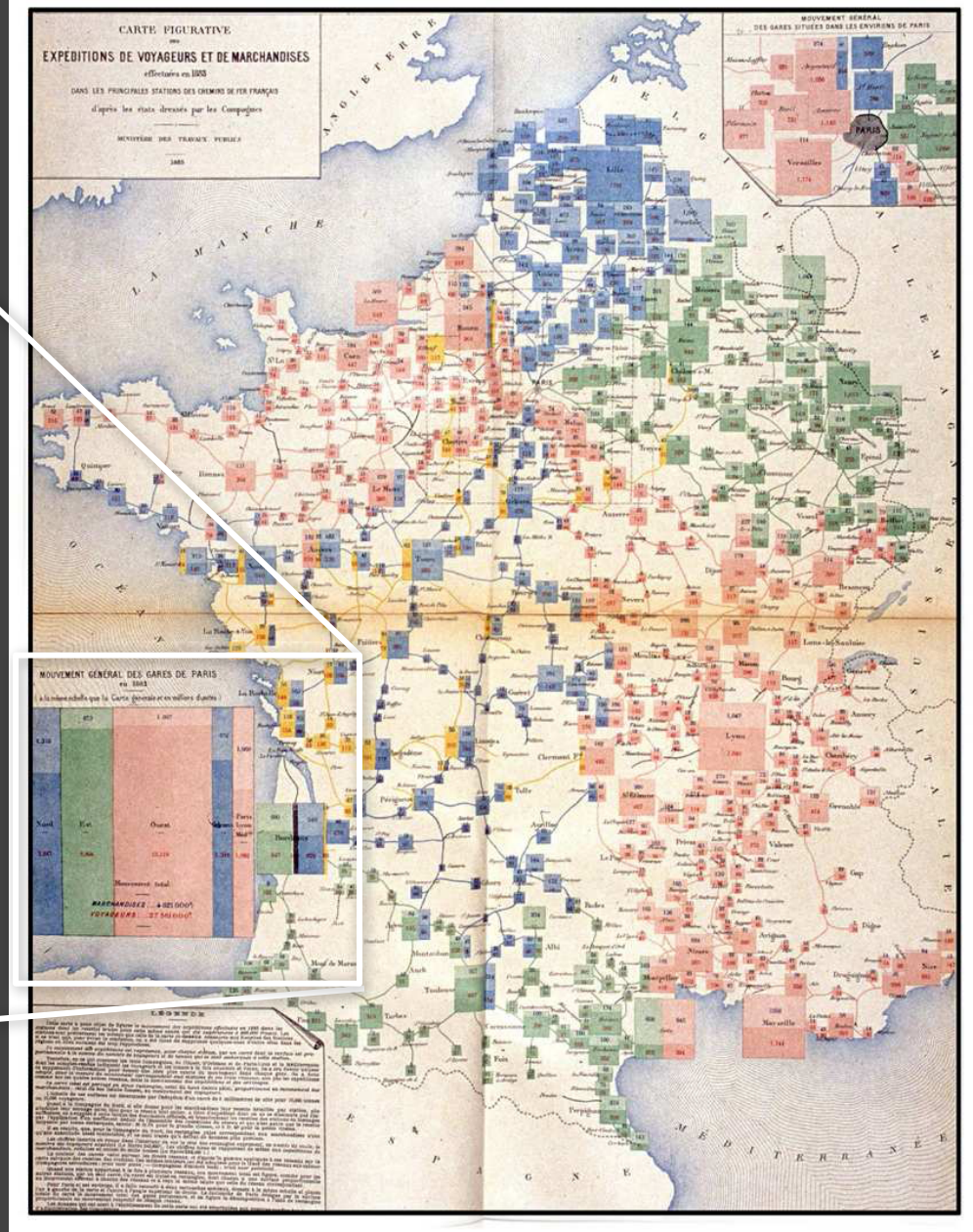
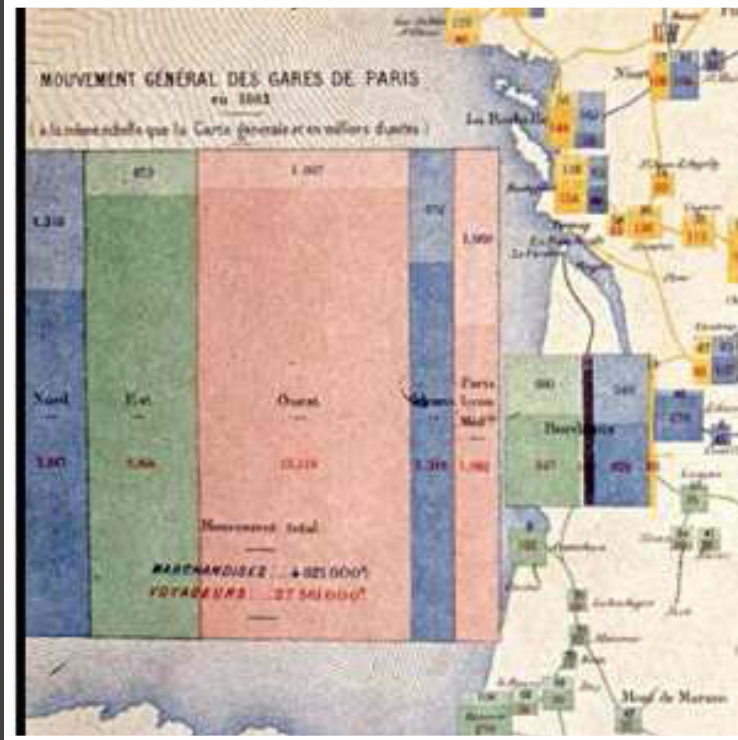


Jeffrey Heer University of Washington

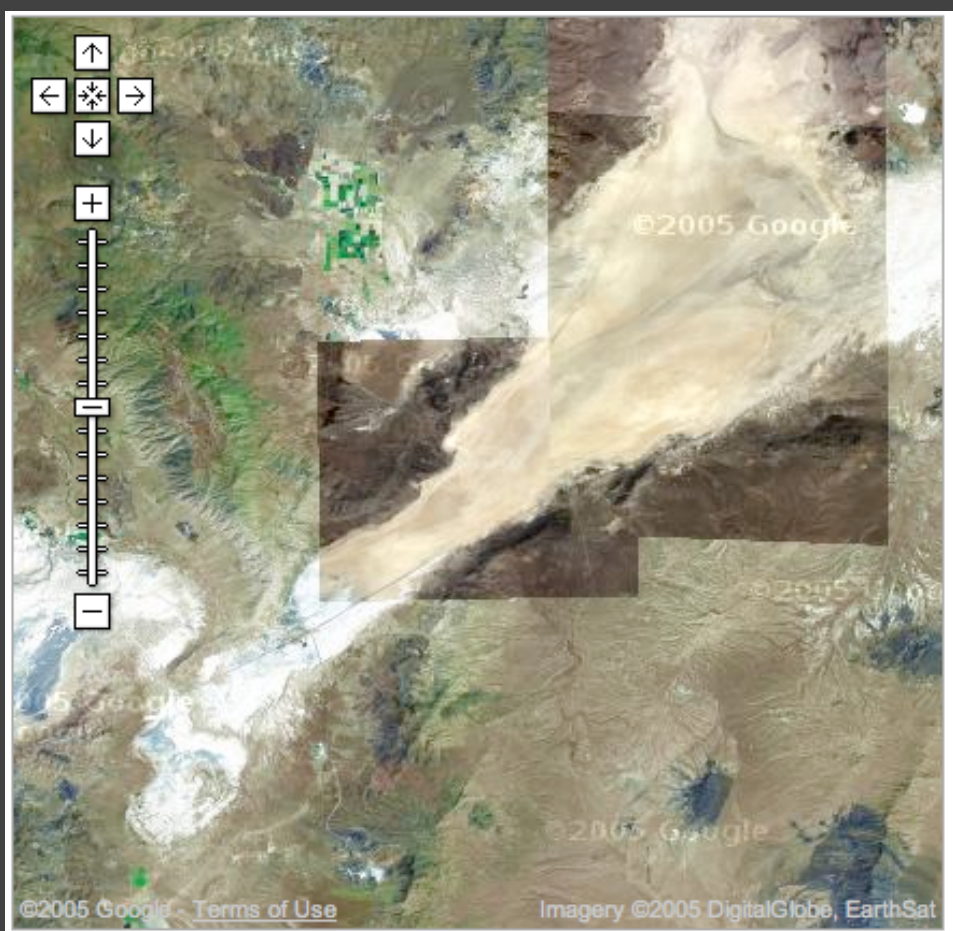
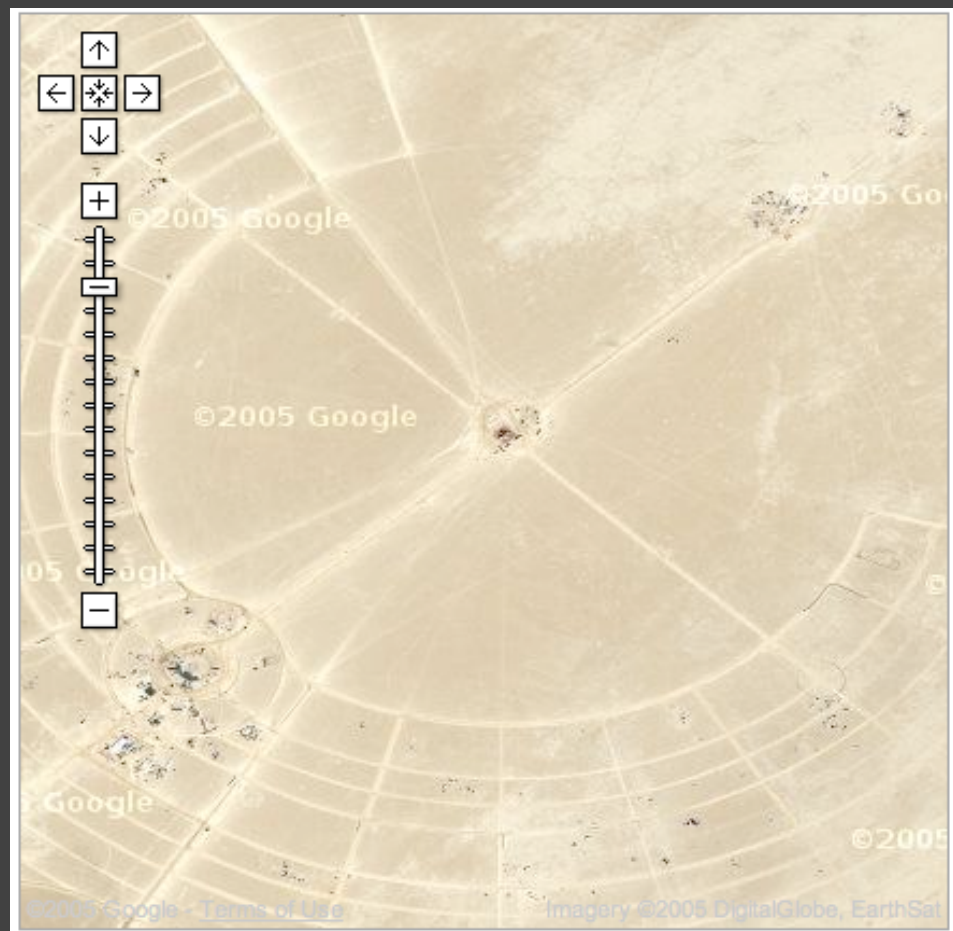
(with significant material from Michal Migurski)



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



Rail Passengers and Freight from Paris 1884



Google Maps 2005

Casualties of War

FACES | ANALYSIS | THEIR STORIES

E-MAIL | FEEDBACK

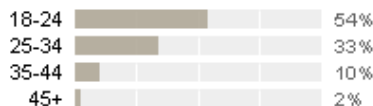
Use the slider below to investigate the demographics and military status of U.S. service members who died during the war in Iraq.

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

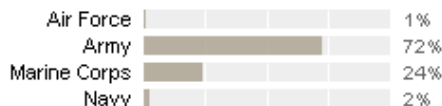
Show all | Initial invasion | First invasion of Falluja | Second invasion of Falluja | Since troop buildup began

4,097 deaths

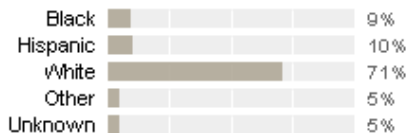
Age



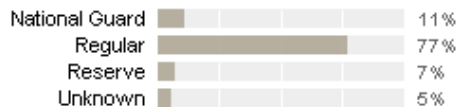
Branch of Military



Race



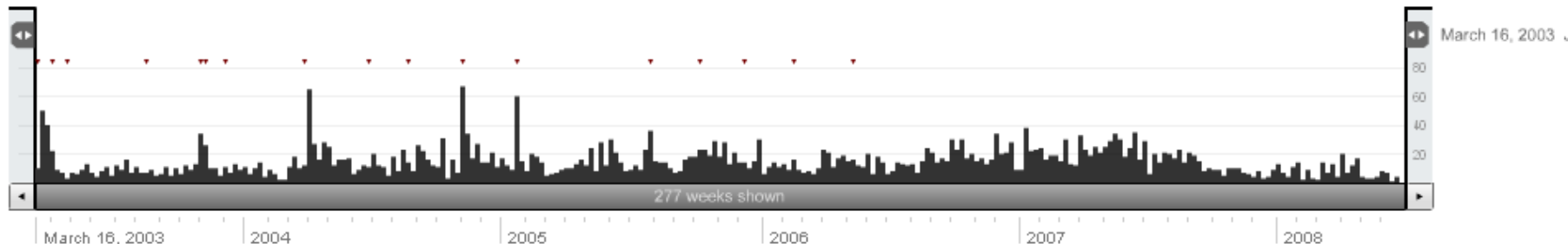
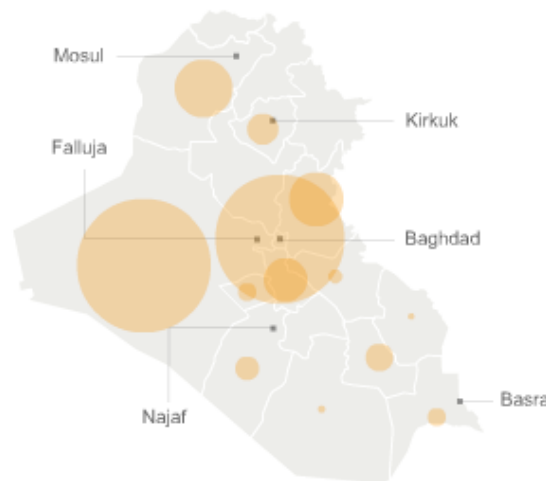
Type of Duty



Location of death

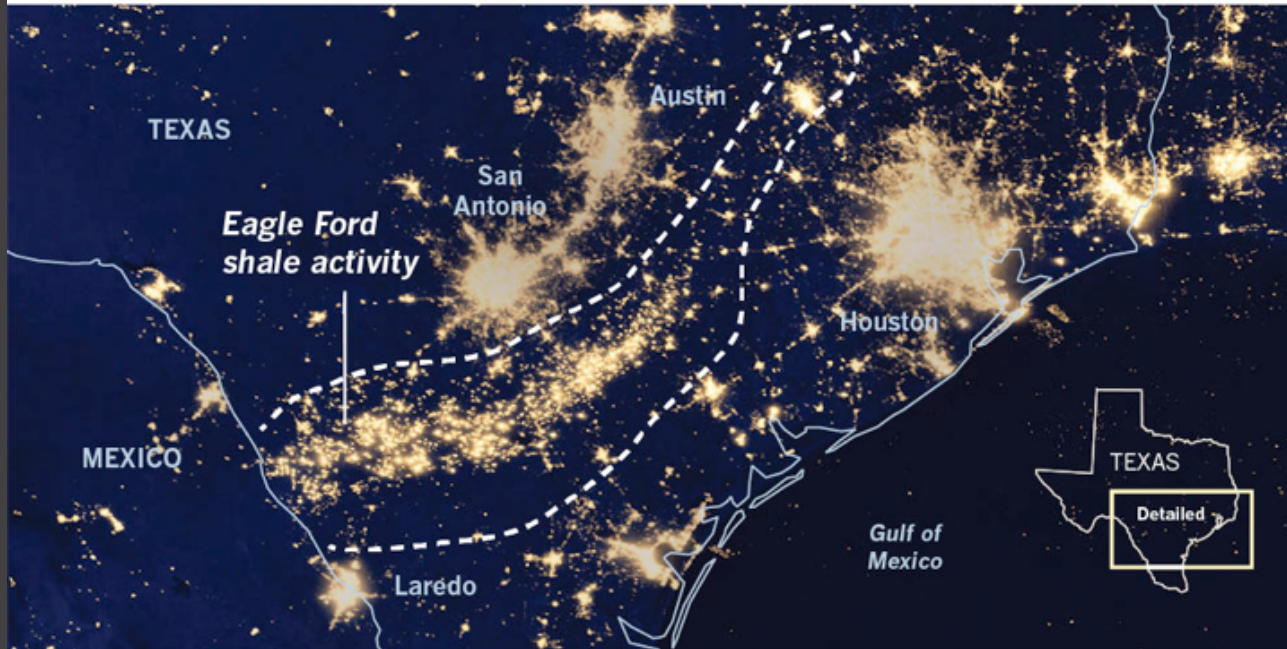
Circles sized according to percentage of deaths in each Iraqi province.

Show home



Texas oil boom is visible from space

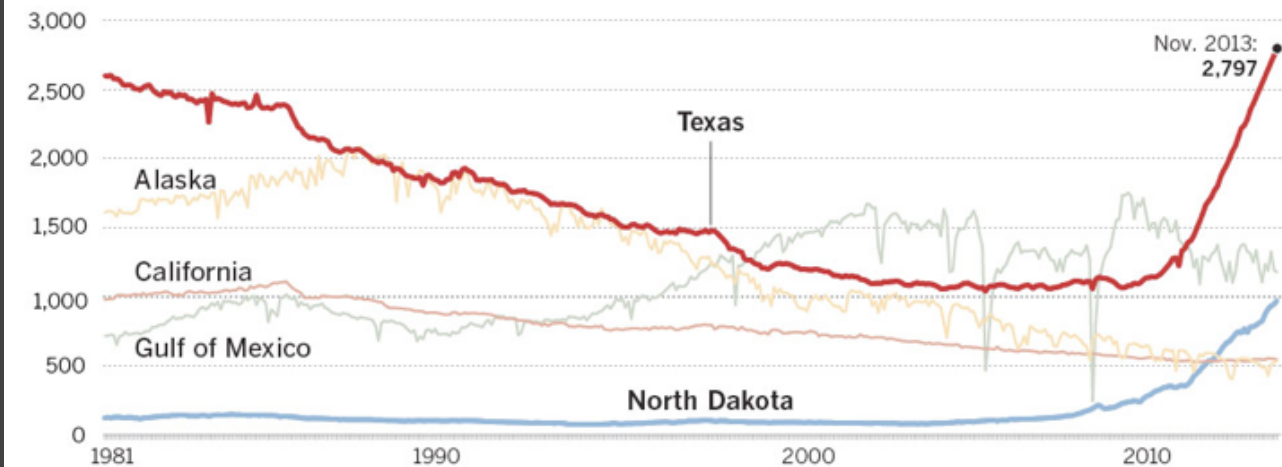
Lighting and natural gas flares from drilling on the 400-mile-long Eagle Ford shale formation can be seen from space in this image.



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

Ramadi: The Government Provides an Opening for ISIS **ISIS Control**

Tensions between this city's residents, who are mostly Sunni, and the central government had been brewing here for at least a year. Then in December, Iraq's prime minister, Nuri Kamal al-Maliki, ordered security forces to dismantle a protest camp — an outlet for disenchanting Sunnis angered at their treatment by the Shiite-dominated government. The action ignited days of violence and created the opening ISIS needed to seize parts of the city, the provincial capital.

Lake Tharthar

Falluja: A Symbolic Fall **ISIS Control**

Just days after the raid on the camp in Ramadi, ISIS fighters destroyed the Police Headquarters and mayor's office here, planted their flag on government buildings and decreed the city to be theirs. Ten years earlier, American forces had captured this city from Qaeda-style insurgents at a considerable cost of American lives.

Lake Habbaniya

Balad



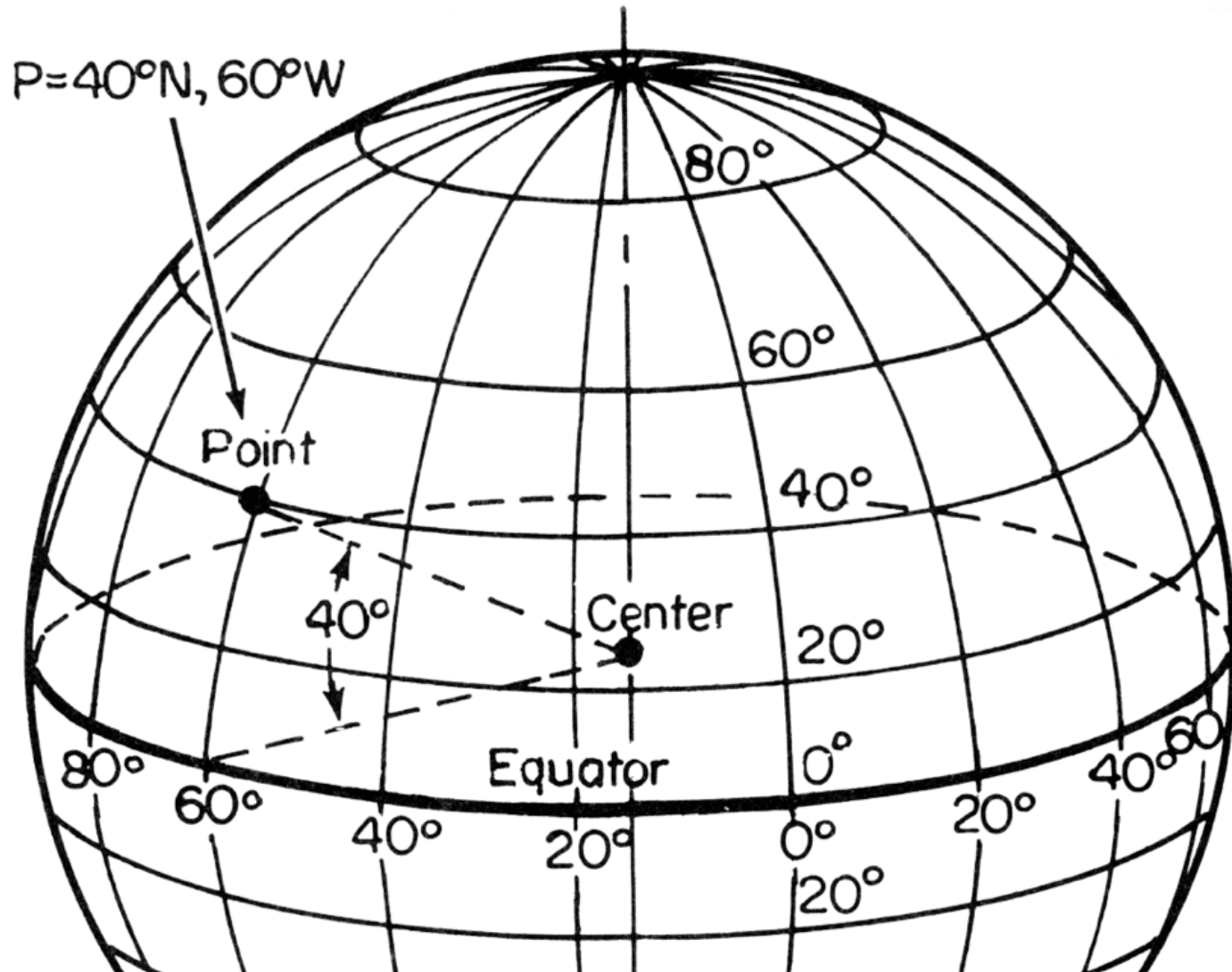
17 MILES TO BAGHDAD

Cartography

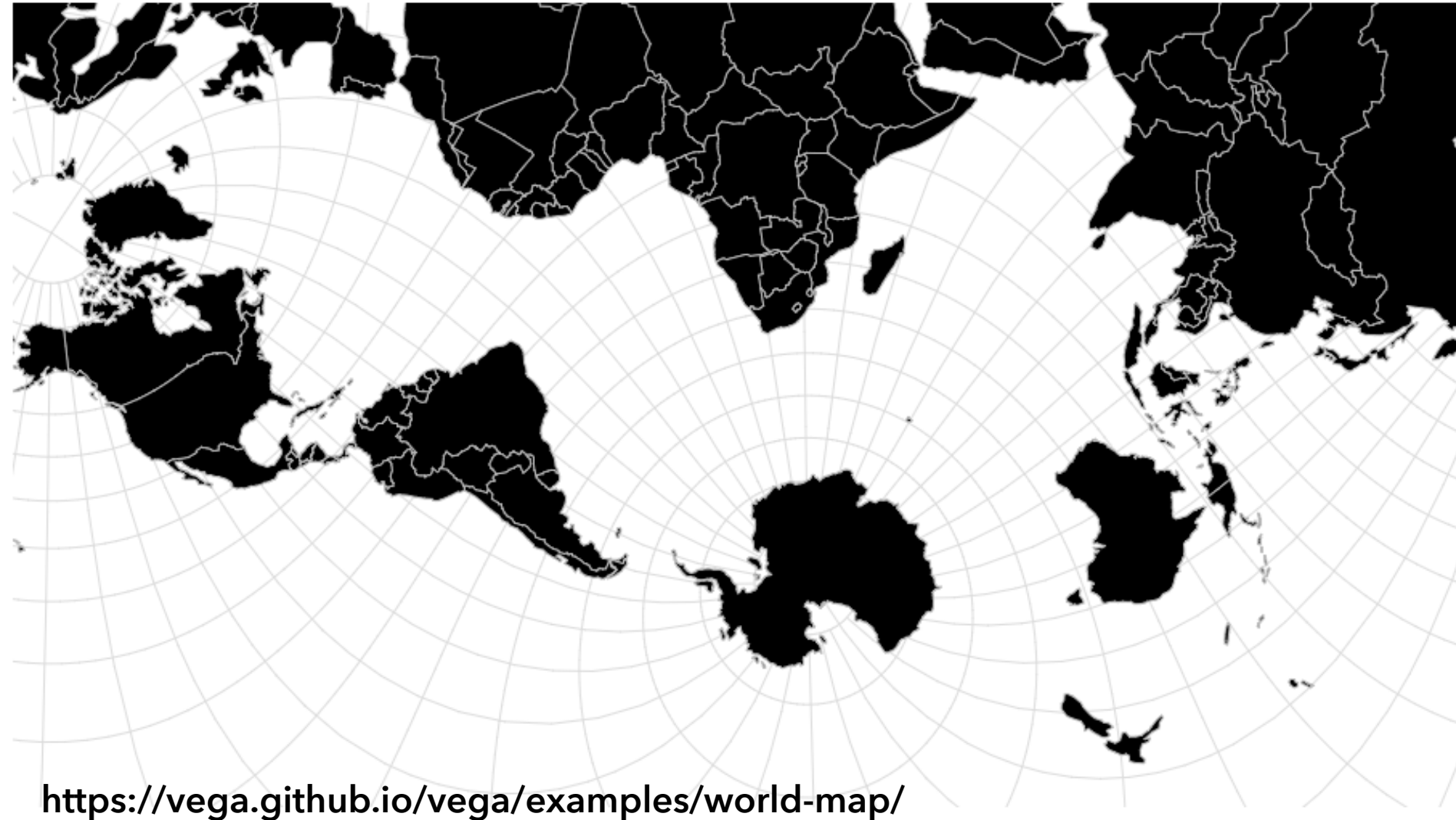
The Making of Maps

Projections

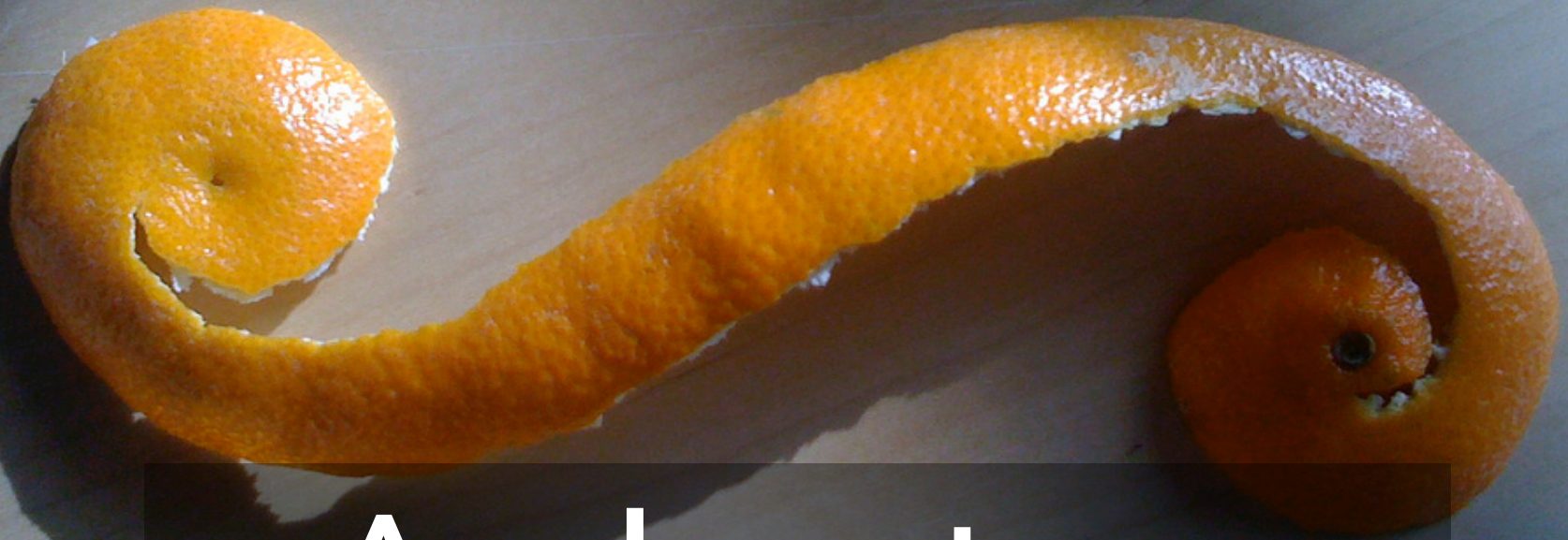
Latitude, Longitude



Exploring Projections...



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



**A sphere tears
when you flatten it**

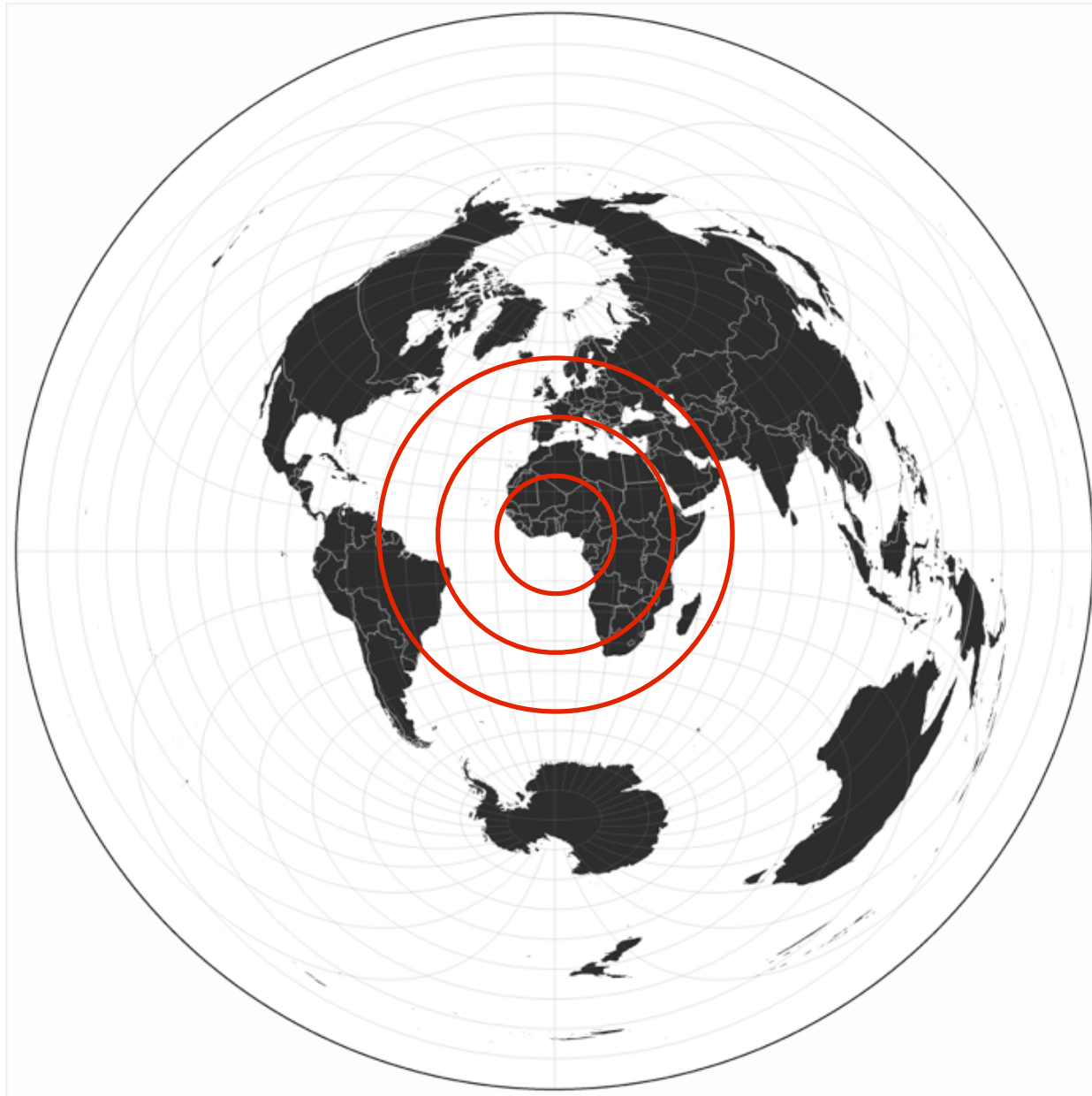
**Three example
ways to categorize
projections...**



Azimuthal

Preserve direction / distance from center

Azimuthal Equidistant

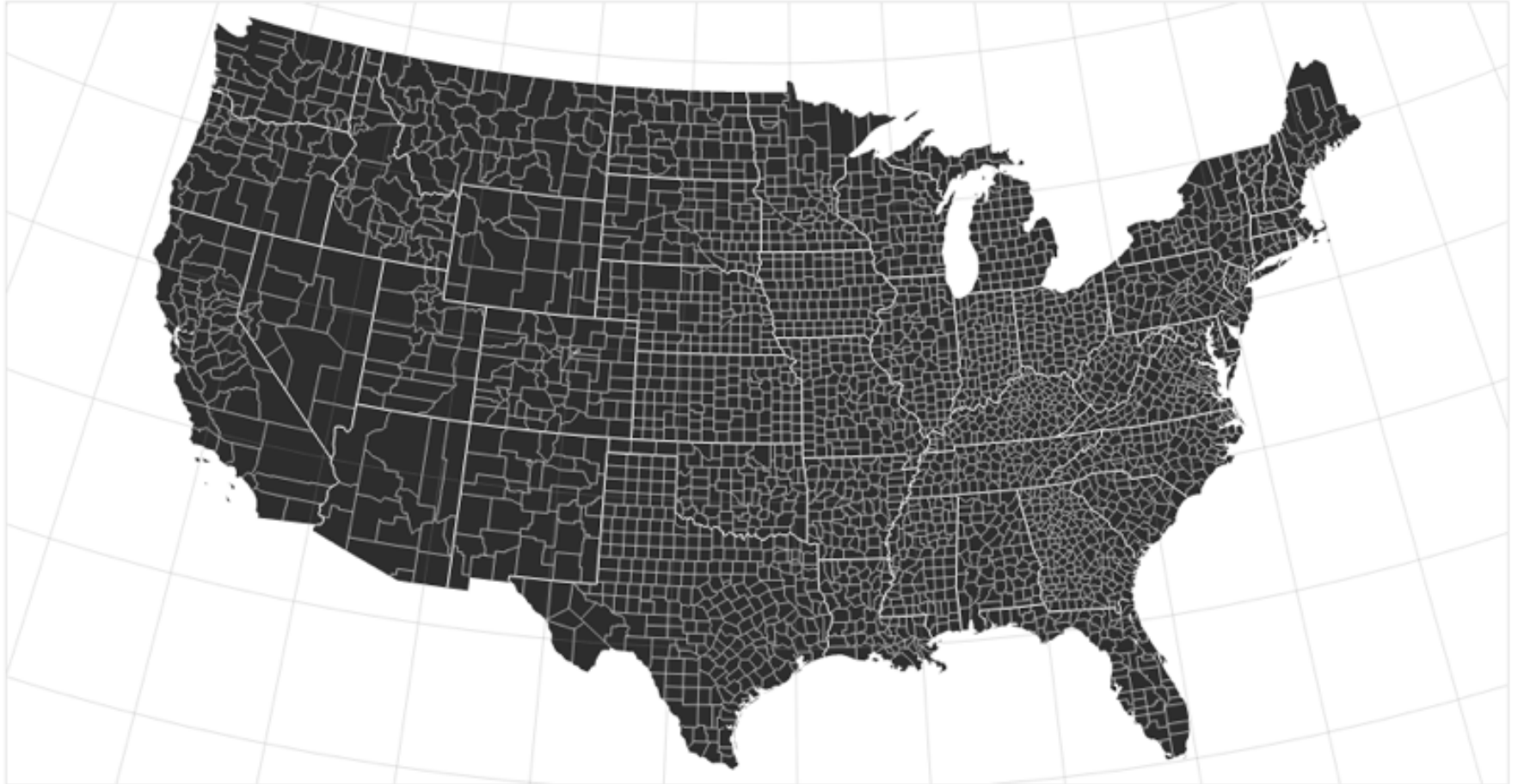


A world map with a dark gray background. Landmasses are outlined in black. A large area in the North Pacific, including Alaska, the Yukon, and parts of Canada, is highlighted in a light yellow color. A semi-transparent dark gray rectangular box is overlaid on the map, containing the text 'Equal-Area' and 'Preserve area'.

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.](#)

A world map with a yellow background and black outlines for continents and country borders. A semi-transparent grey rectangular box is centered over the map, containing text. The text is white and reads "Conformal" in a large font, and "Preserve local angles ('shape')" in a smaller font below it.

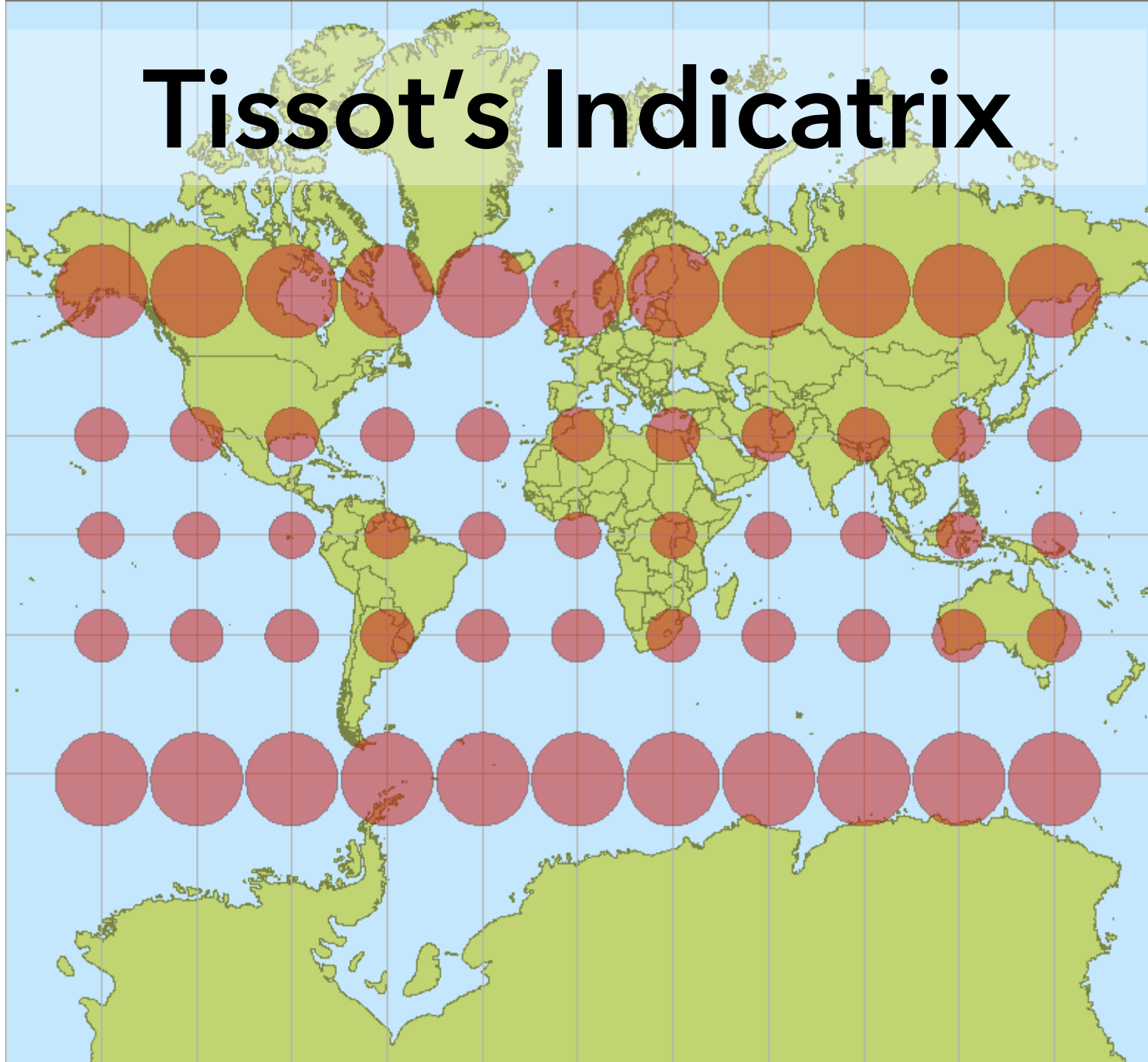
Conformal

Preserve local angles ("shape")

Spherical Mercator



Tissot's Indicatrix





**Spherical Mercator
is ubiquitous on
the web—why?**

Web Mercator

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

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

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.

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.](#)

A map of the Americas, including North and South America, is shown in yellow. A vertical orange rectangular box highlights the western coast of North America, from the Canadian border down to the Mexican border. The text "Projections usually have a home" is overlaid in white on a semi-transparent grey background at the bottom of the map.

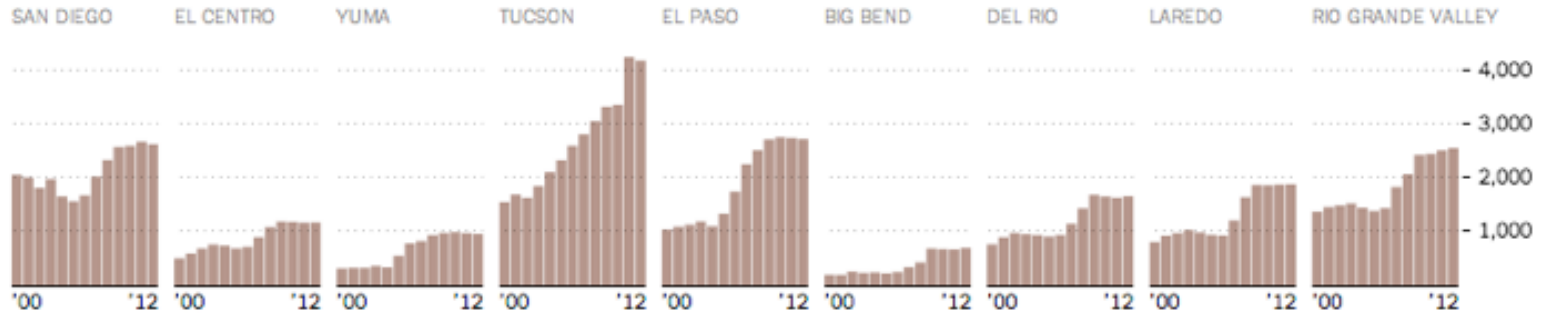
Projections usually
have a home

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



ADAPTIVE COMPOSITE MAP PROJECTIONS

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

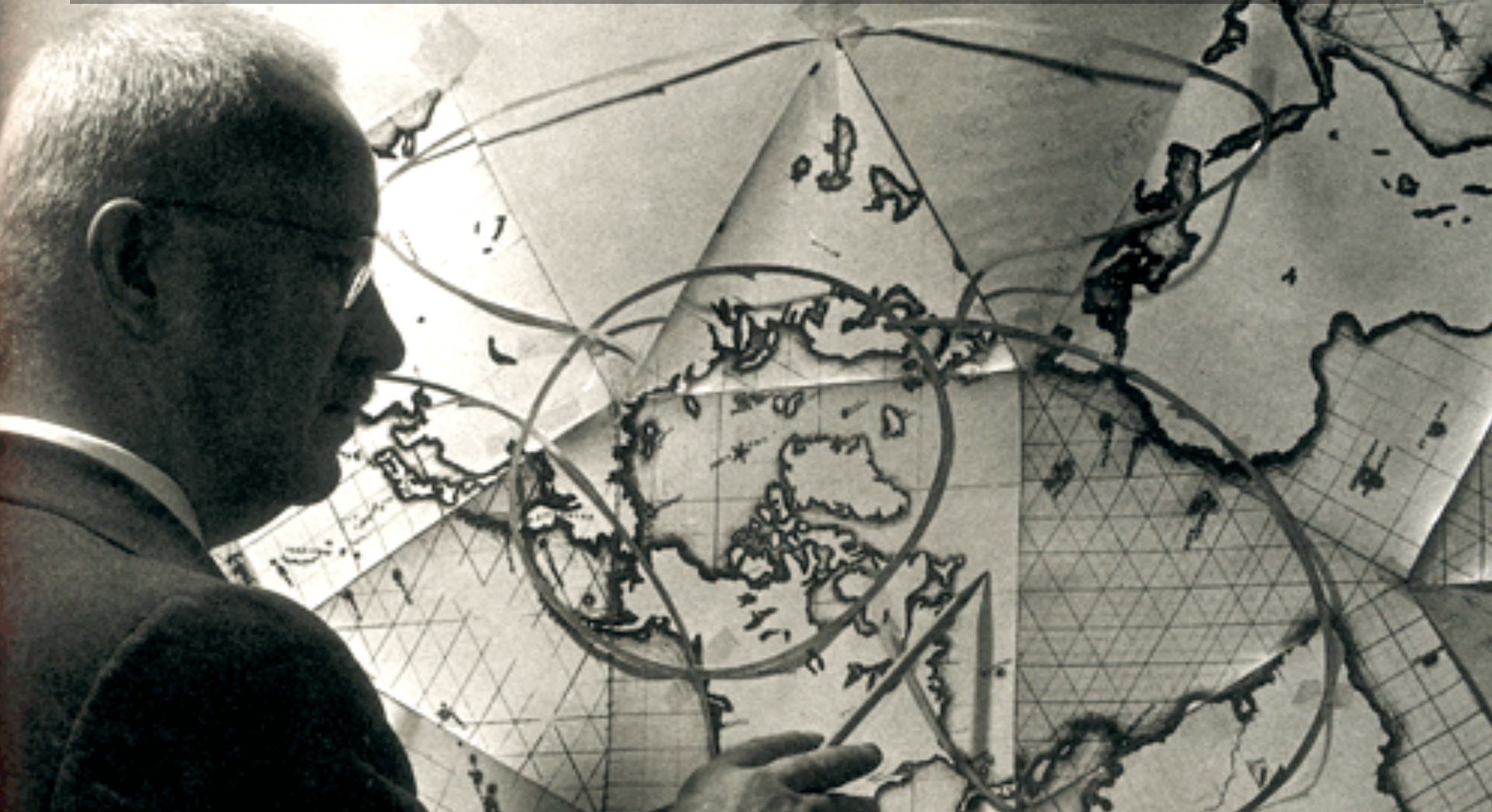


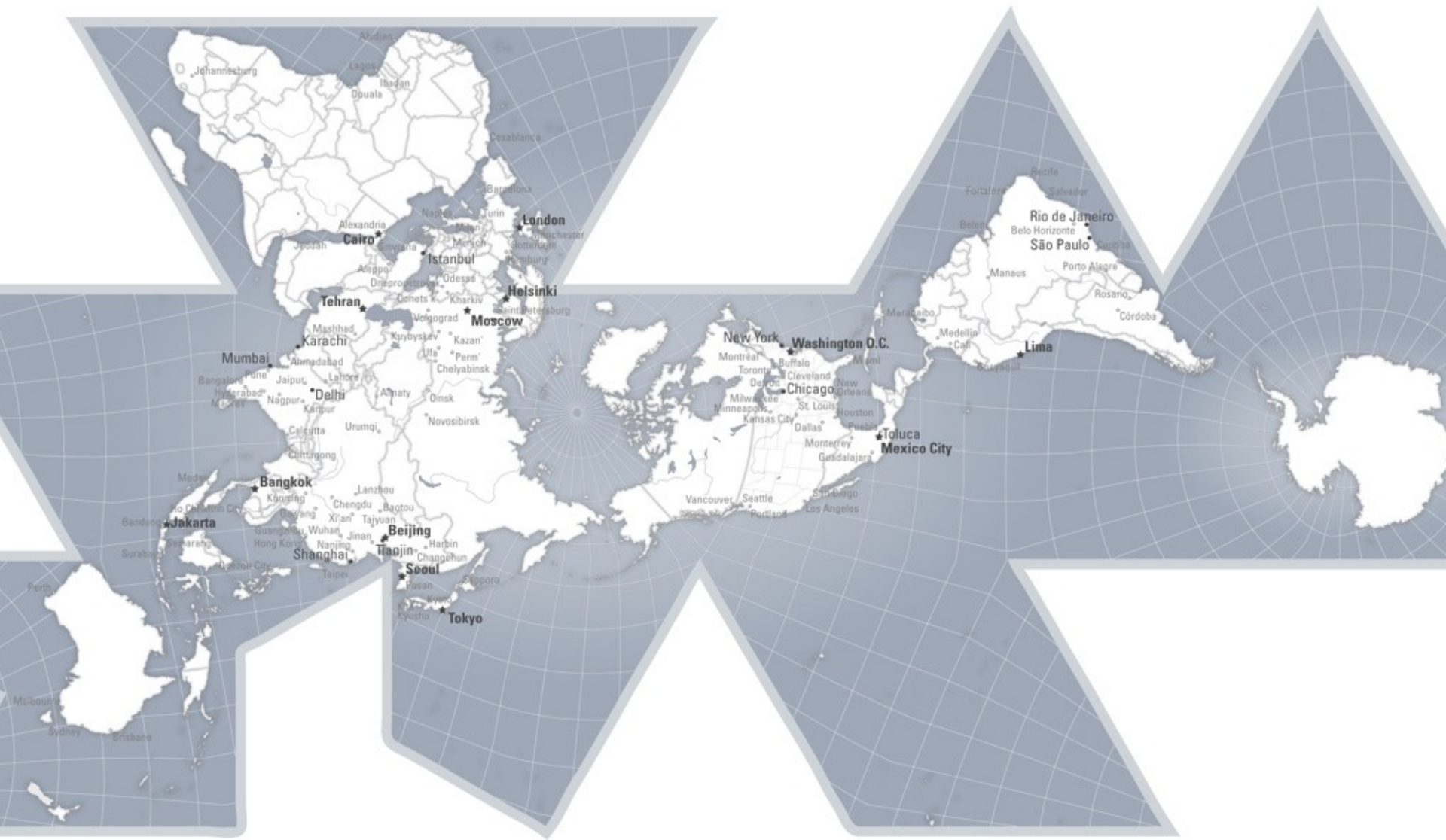
YOU THINK THAT WHEN WE LOOK AT A MAP, WHAT WE REALLY SEE IS OURSELVES. AFTER YOU FIRST SAW *INCEPTION*, YOU SAT SILENT IN THE THEATER FOR SIX HOURS. IT FREAKS YOU OUT TO REALIZE THAT EVERYONE AROUND YOU HAS A SKELETON INSIDE THEM. YOU *HAVE* REALLY LOOKED AT YOUR HANDS.

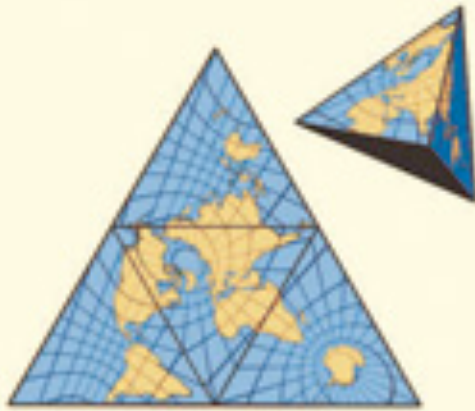


**There are interesting
ways to tear spheres**

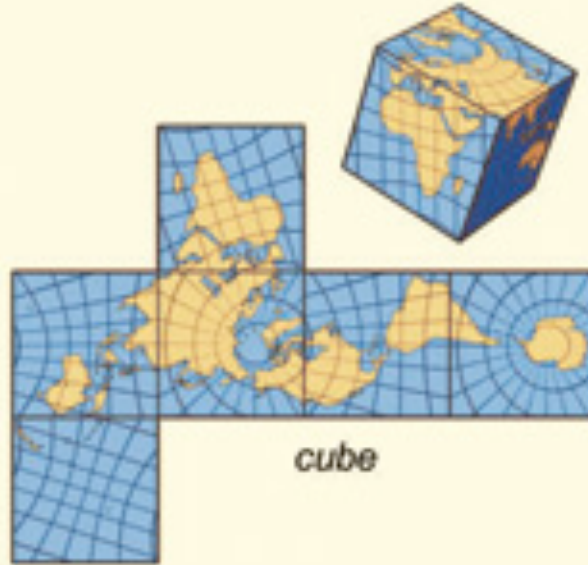
One notable interesting
way to tear a sphere



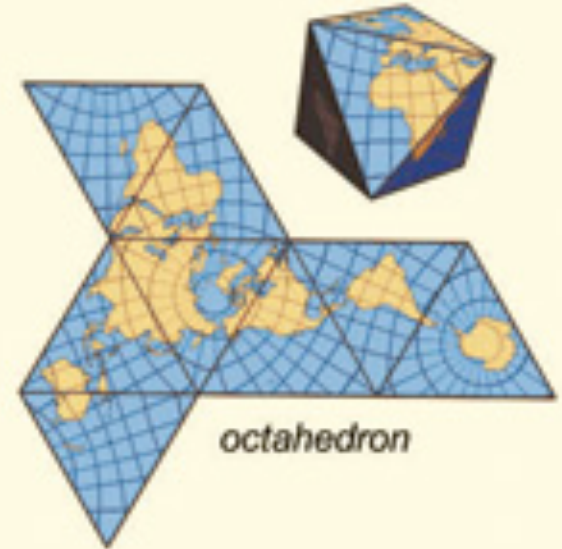




tetrahedron



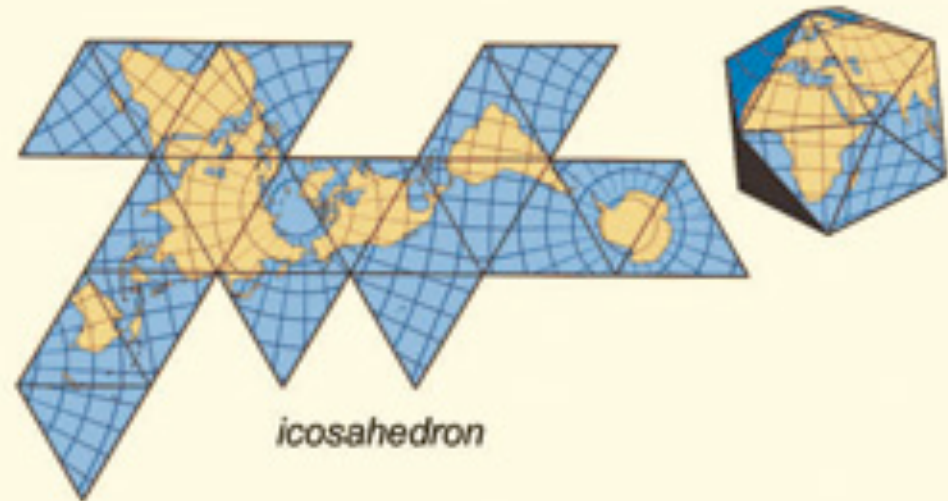
cube



octahedron

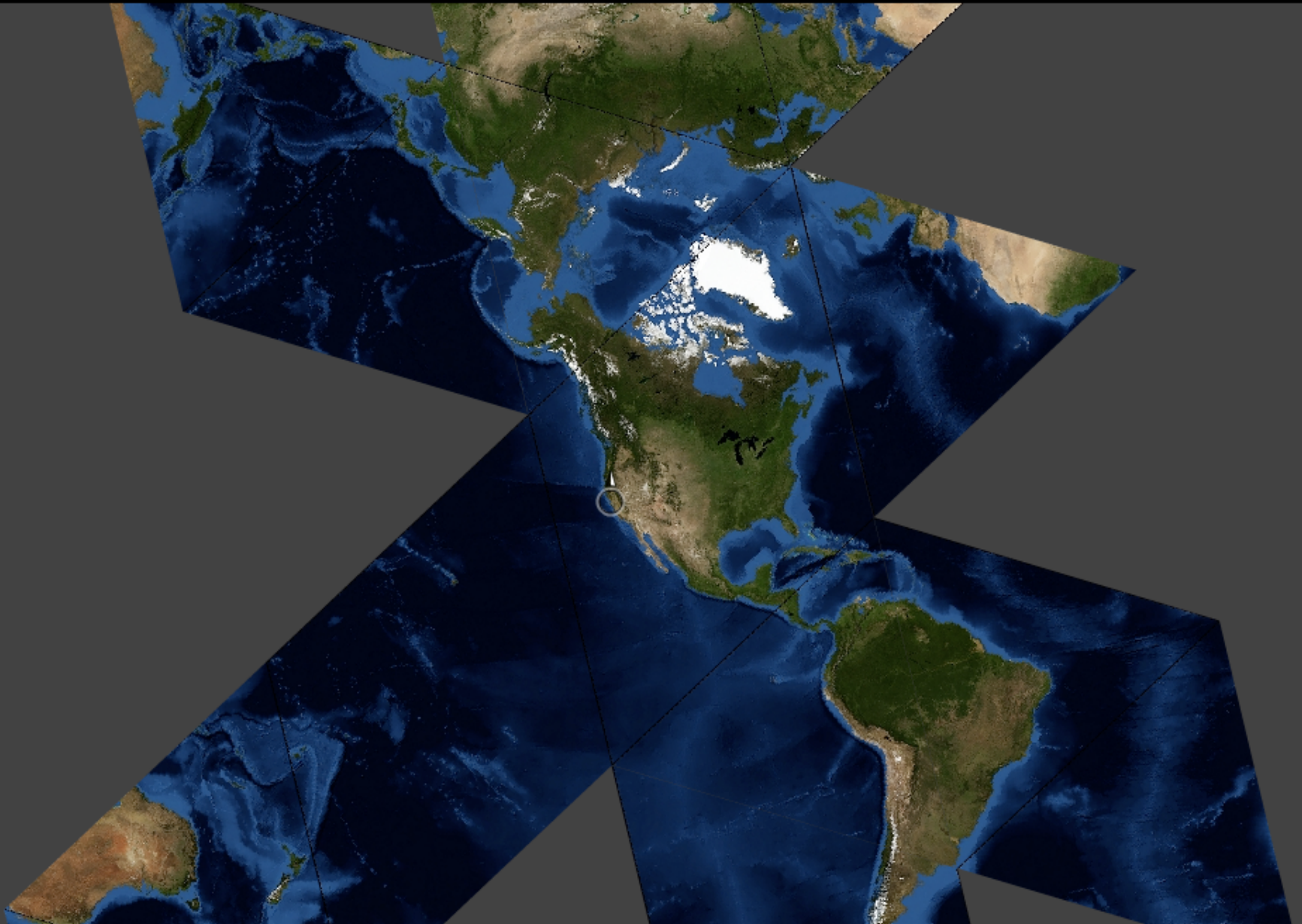


dodecahedron



icosahedron

You can drag the map with your mouse, and use the +/- buttons to zoom. The circle in the center will always indicate North for that point, and when you stop dragging the map will re-orient itself automatically. [Read more about this on my blog.](#)



Scale

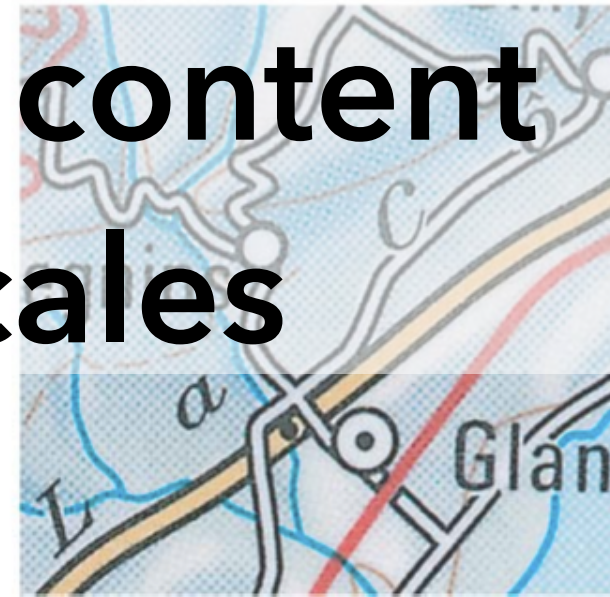
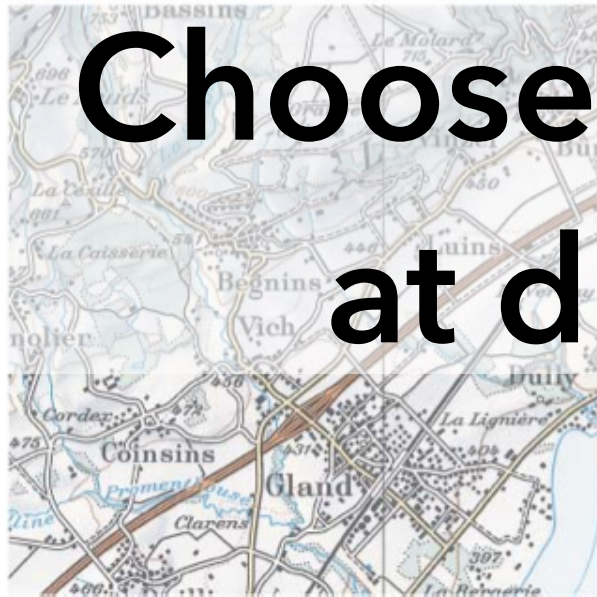
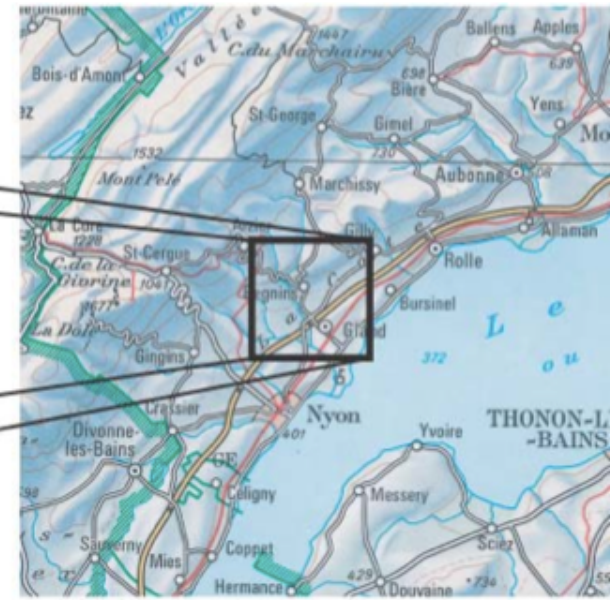
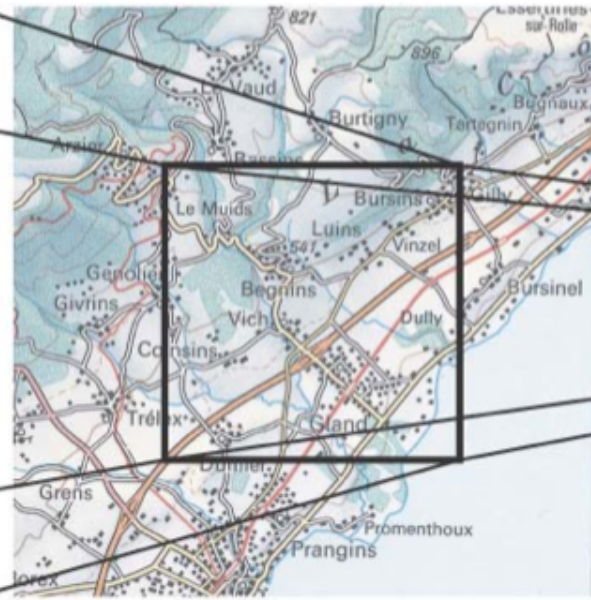


This is not "scale"

Texas-Europe Size Comparison

Scale is an idea imported from print





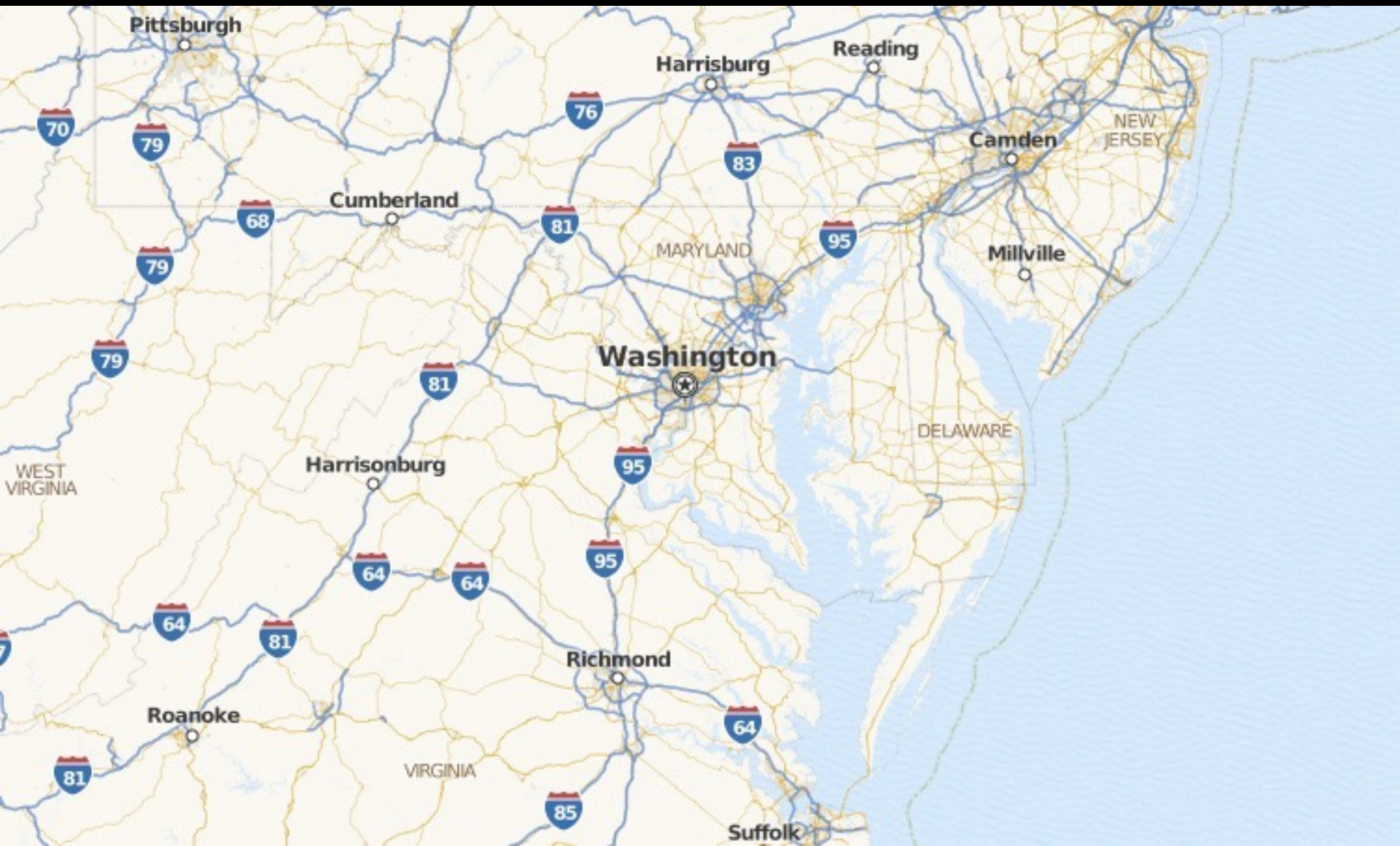
**Choose the right content
at different scales**

Four maps, same area



What shows at different scales?





Pittsburgh

Harrisburg

Reading

NEW JERSEY

Camden

Cumberland

MARYLAND

Millville

Washington

DELAWARE

Harrisonburg

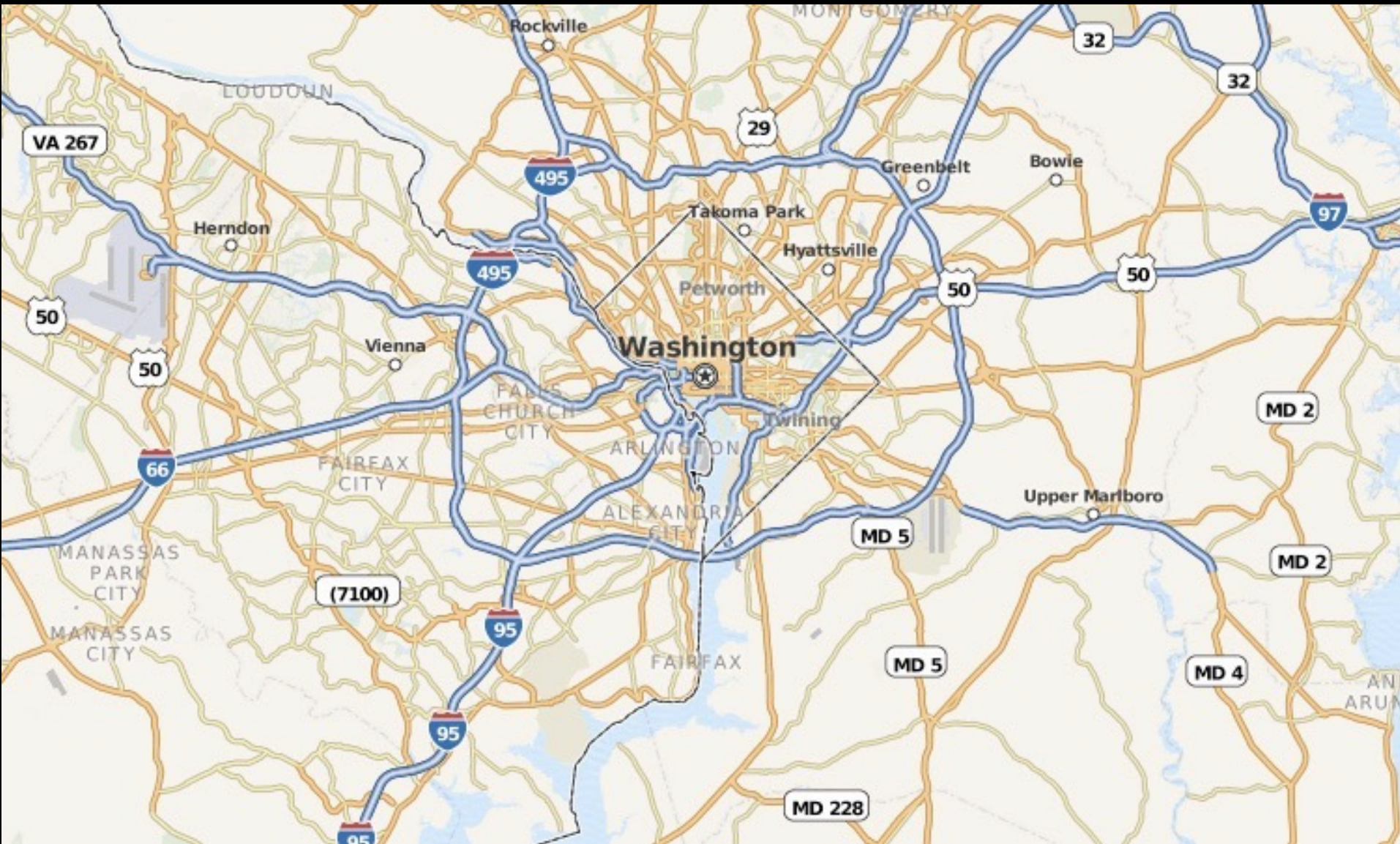
WEST VIRGINIA

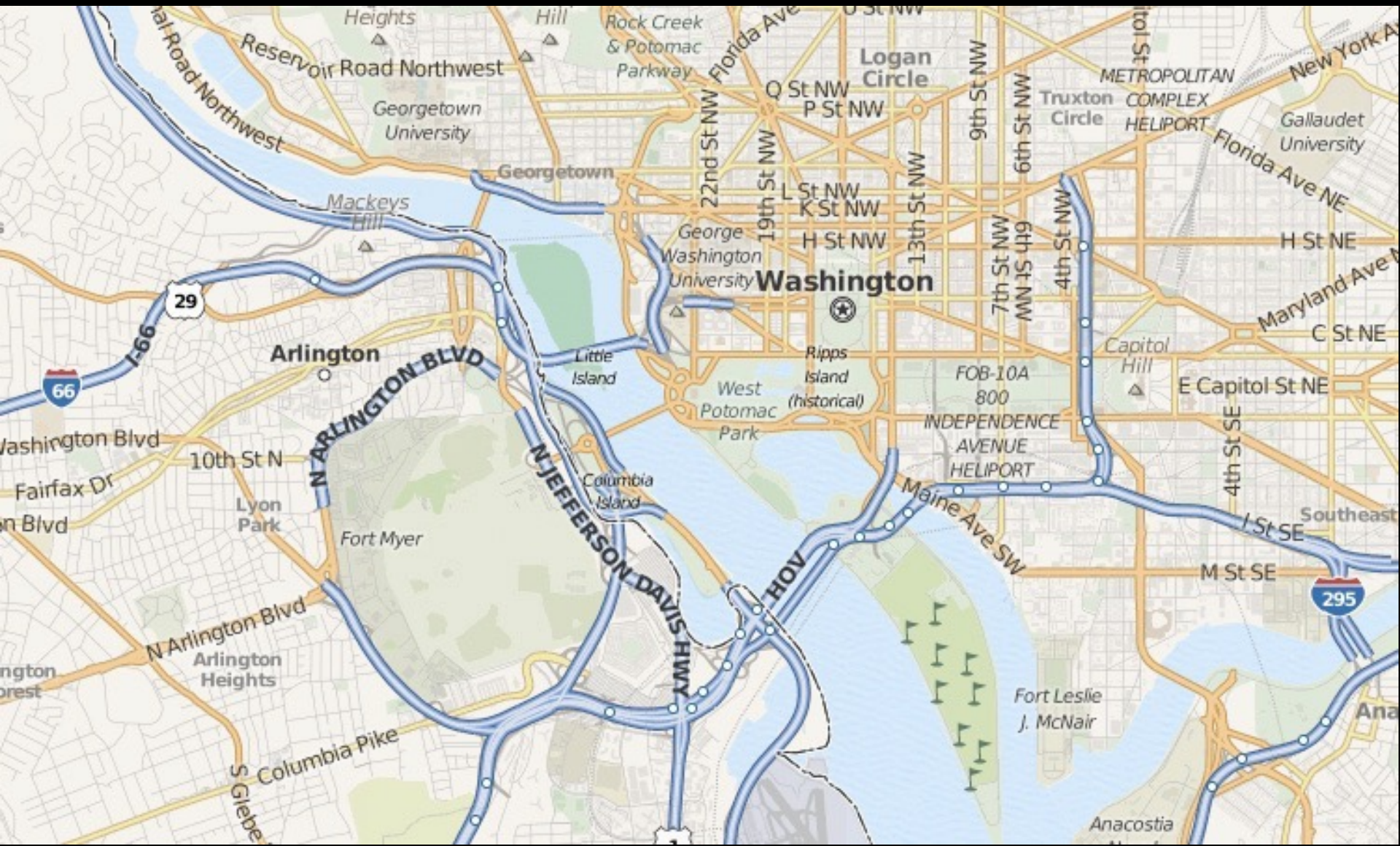
Richmond

Roanoke

VIRGINIA

Suffolk





Reservoir Road Northwest
Georgetown University
Mackeys Hill

Georgetown
George Washington University
Washington
Logan Circle
Truxton Circle
Capitol Hill

Metropolitan Complex Heliport
Gallaudet University
Florida Ave NE
Maryland Ave NE

Arlington
Fort Myer
Lyon Park
Arlington Heights

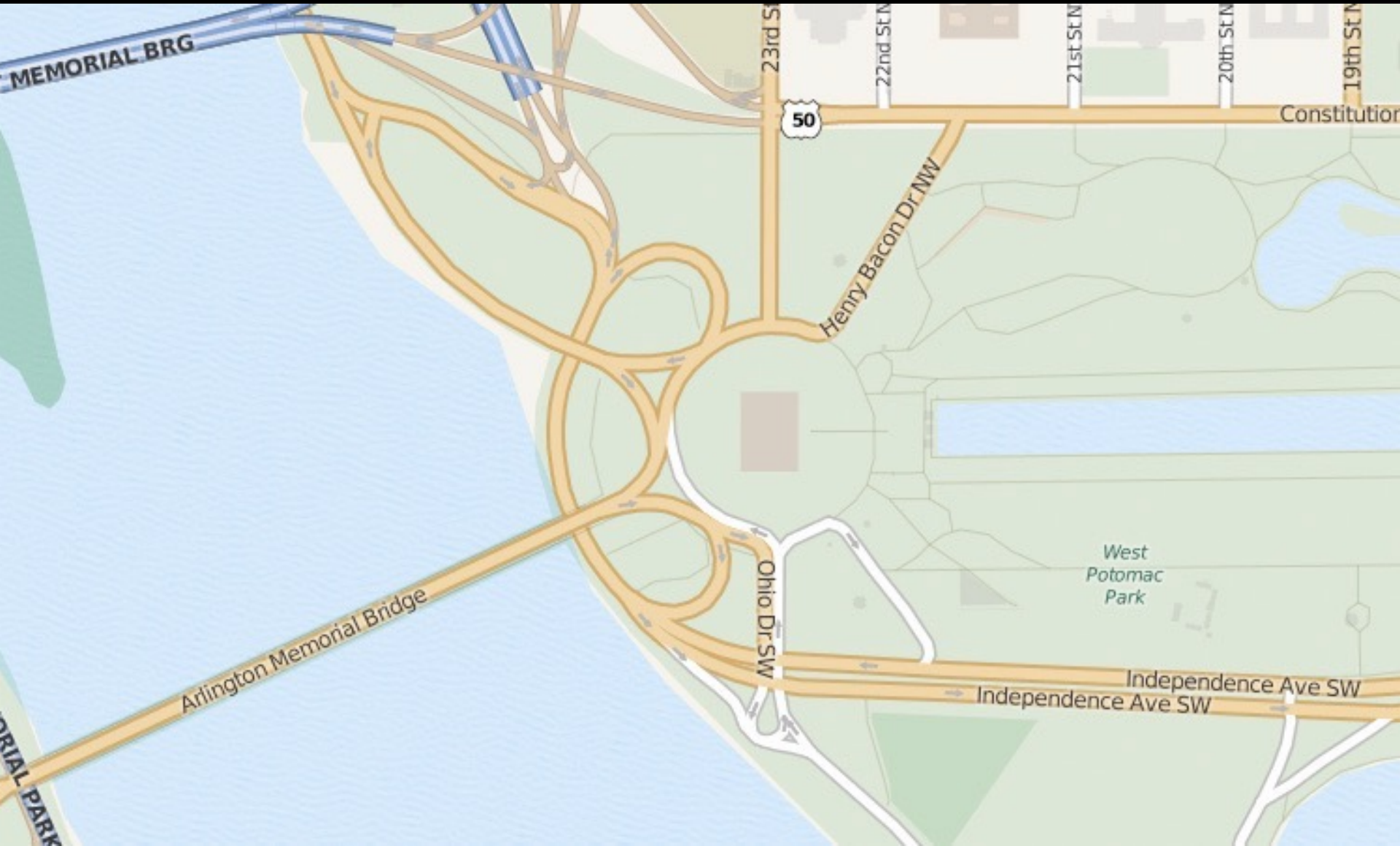
Little Island
Columbia Island
West Potomac Park
Ripps Island (historical)

Independence Avenue Heliport
Maine Ave SW
E Capitol St NE
Southeast

N Arlington Blvd
S Glebe
Columbia Pike

N Jefferson Davis Hwy
Hoy

Fort Leslie J. McNair
Anacostia



MEMORIAL BRG

50

Henry Bacon Dr NW

Constitution

Arlington Memorial Bridge

West Potomac Park

Ohio Dr SW

Independence Ave SW

MEMORIAL PARK

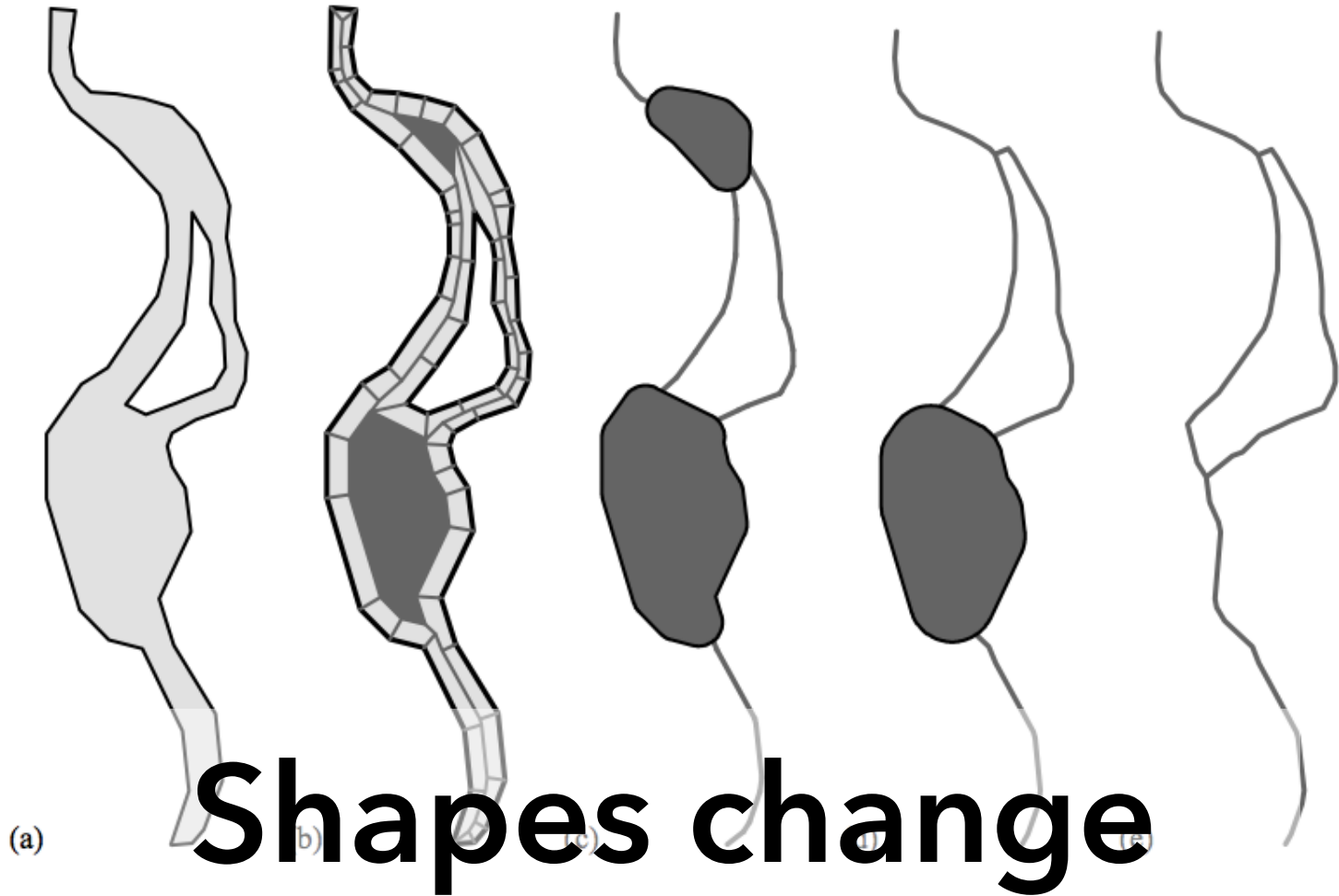
23rd St N

22nd St N

21st St N

20th St N

19th St N



Shapes change

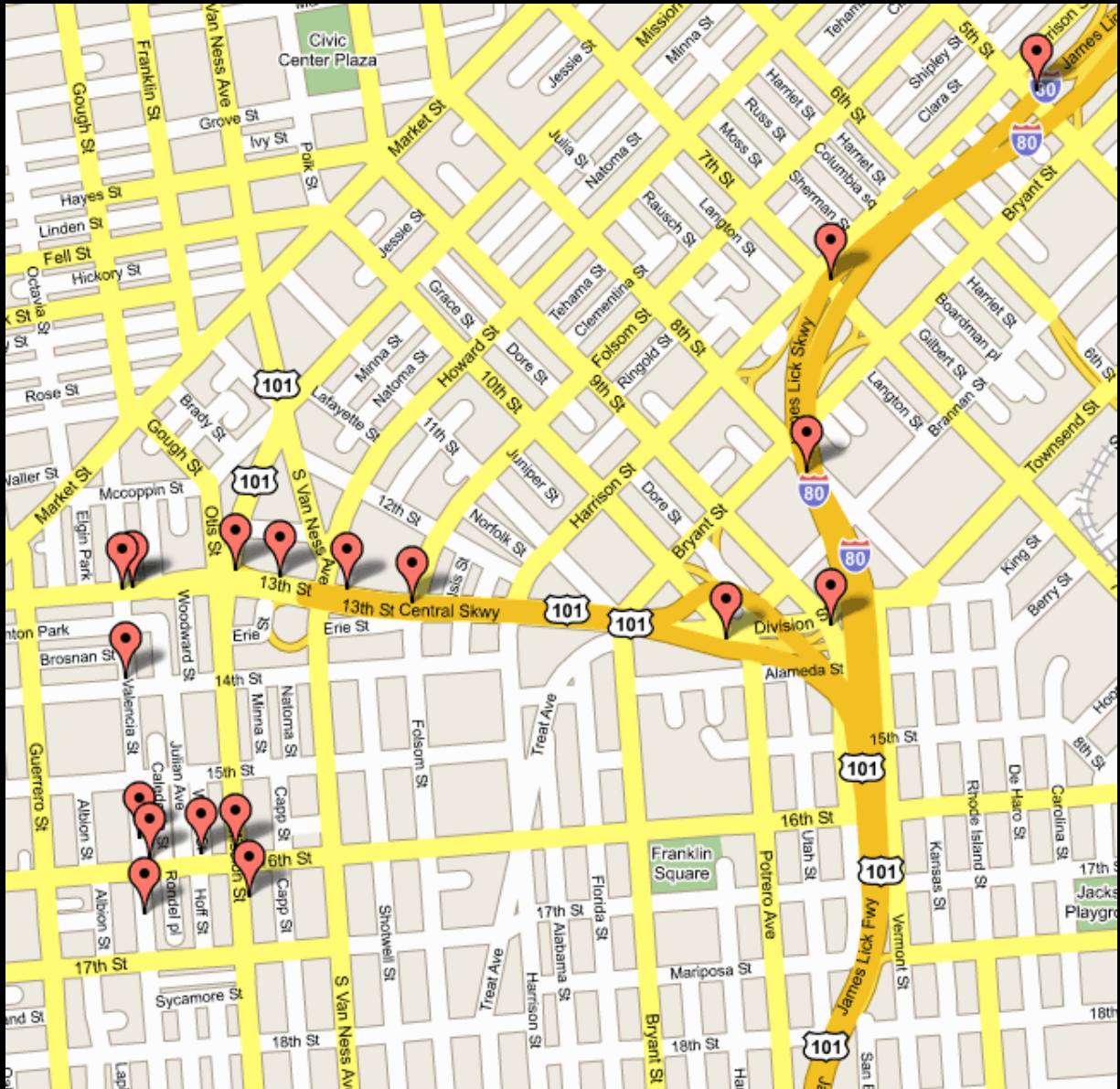
Figure 11. Fragmentation of a river into polygons and lines with different thresholds leading to different results (c, d, e).

at different scales

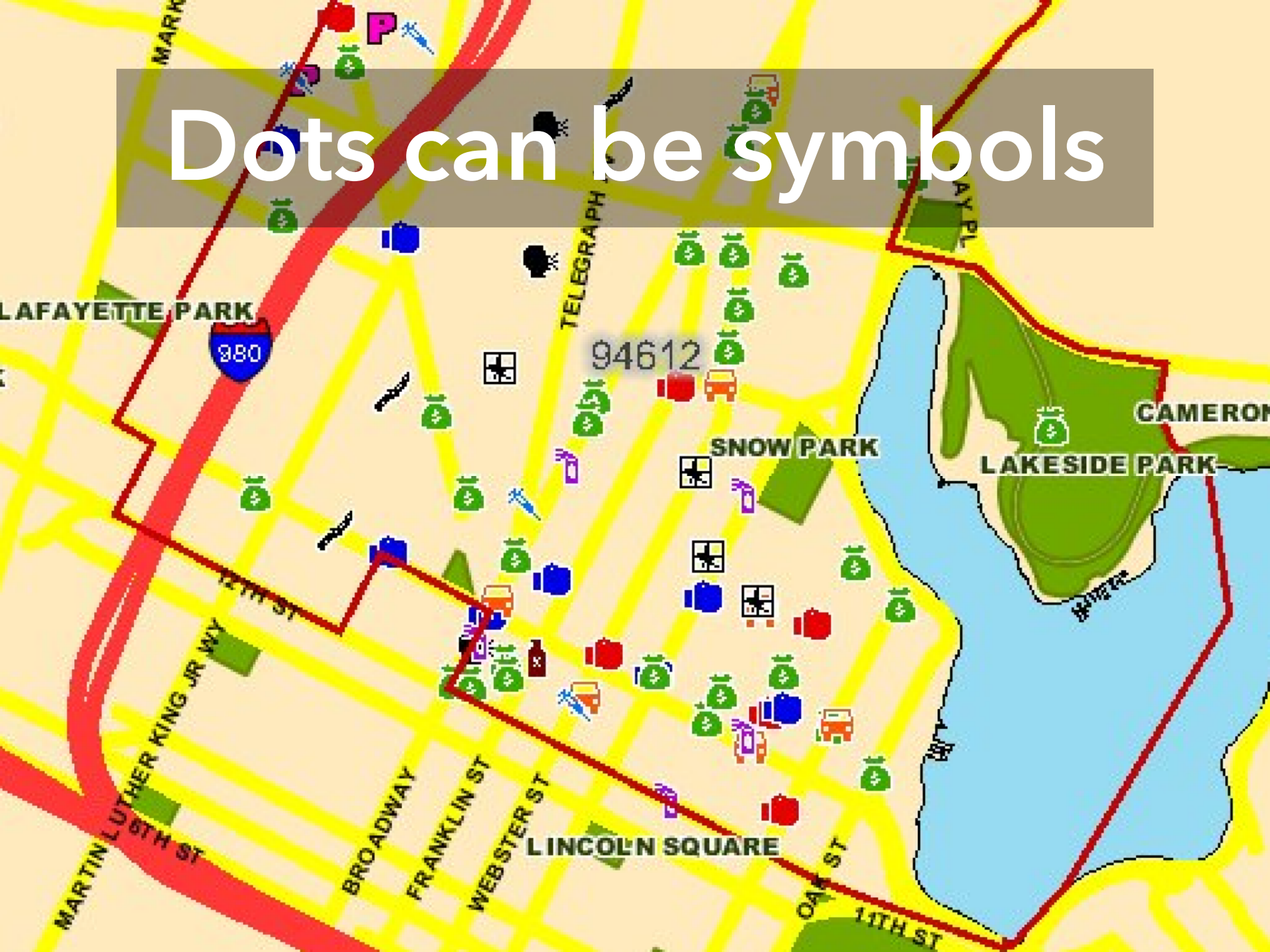
Mapping

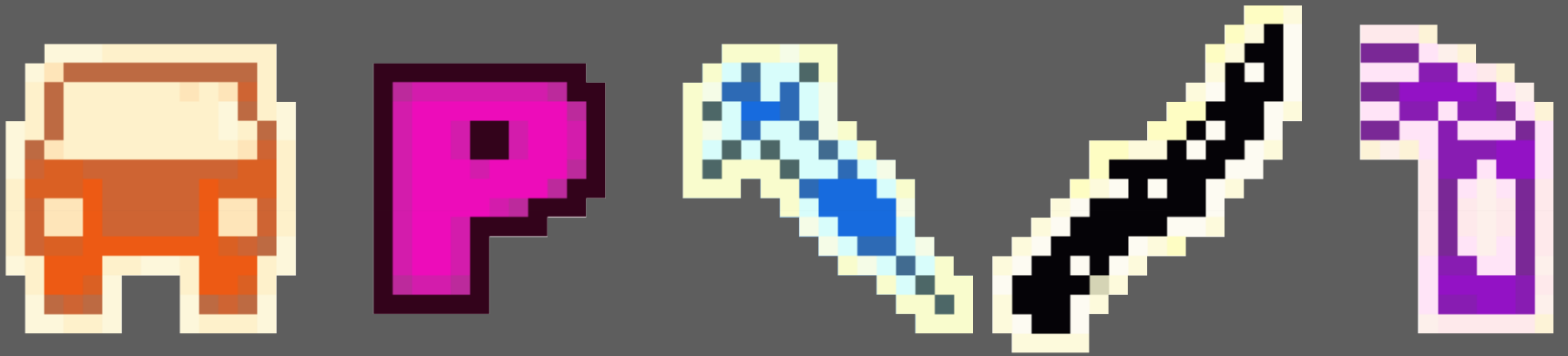
Visualizing Geospatial Data

Symbol Maps



Dots can be symbols





Guess the crime

Dots can can be good symbols

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

TIME OF DAY
Show All | Hide All
Light | Dark [nearest hour]
Commute | Nightlife
Day | Night | Swing Shift





Dots can include data

Dots are ubiquitous



"Red Dot Fever"



Mapping America: Every City, Every Block

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

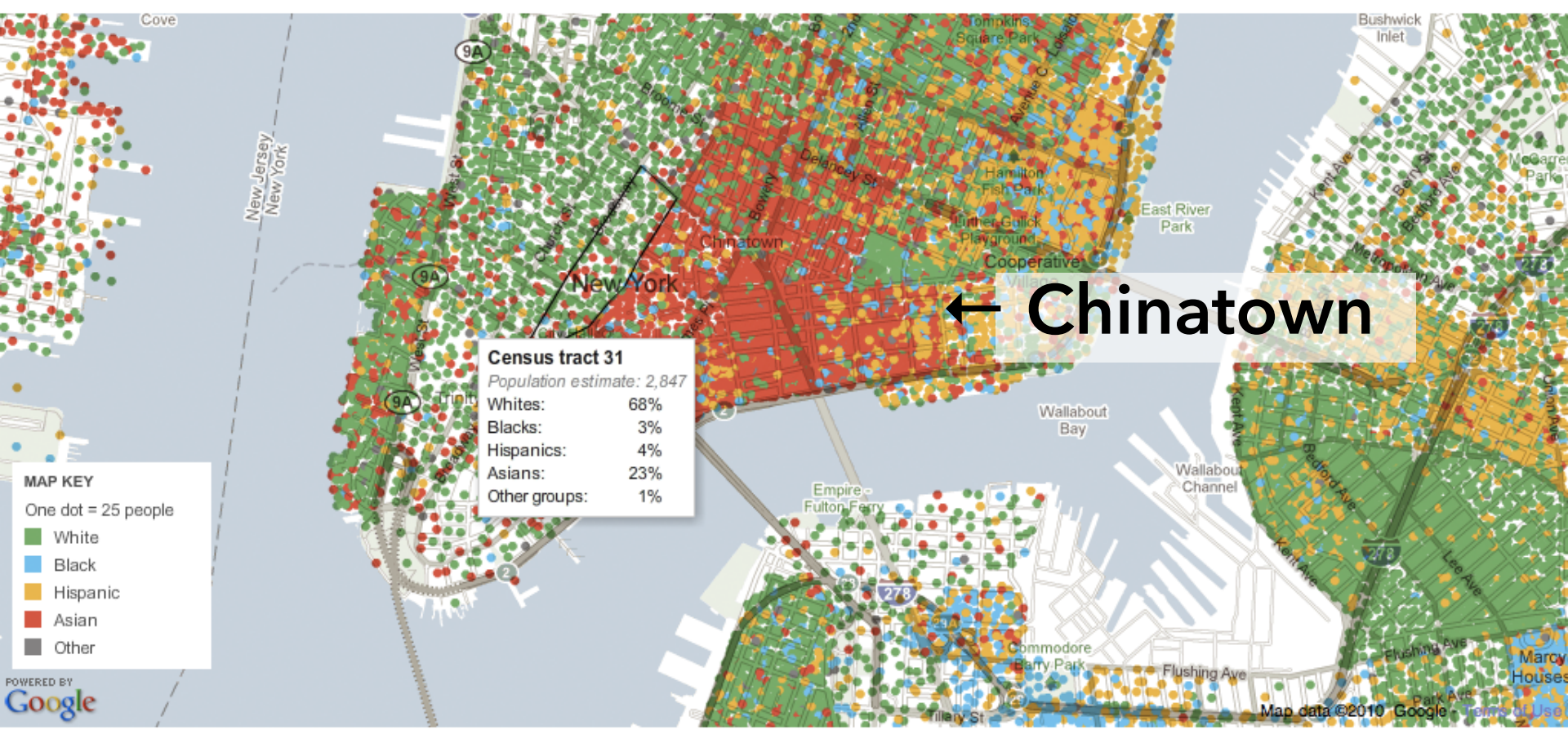
Browse local data from the Census Bureau's American Community Survey, based on samples from 2005 to 2009. Because these figures are based on [View Readers Maps \(49\)](#) samples, they are subject to a margin of error, particularly in places with a low population, and are best regarded as estimates.

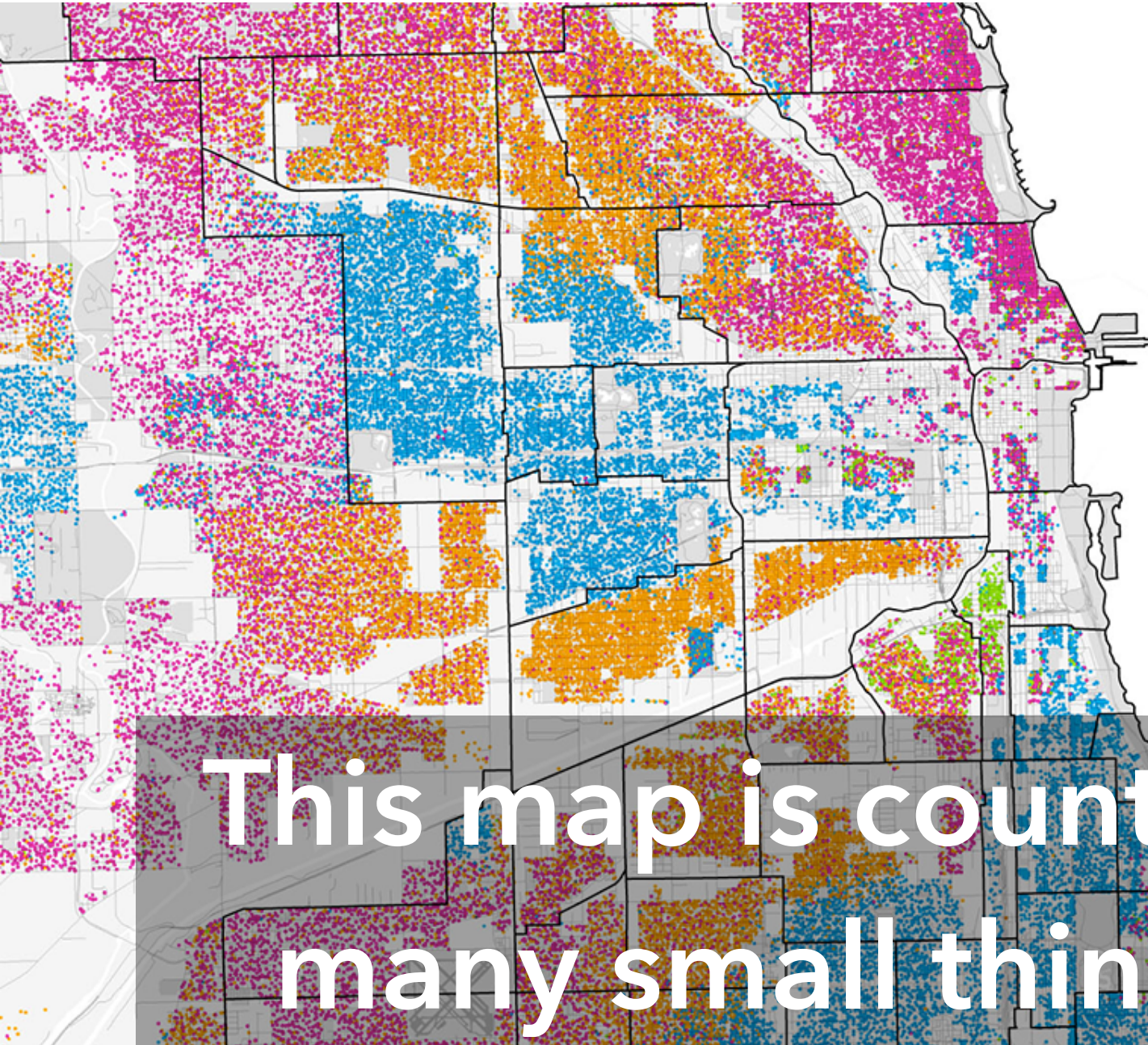
Distribution of racial and ethnic groups

[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

Clustering, grouping



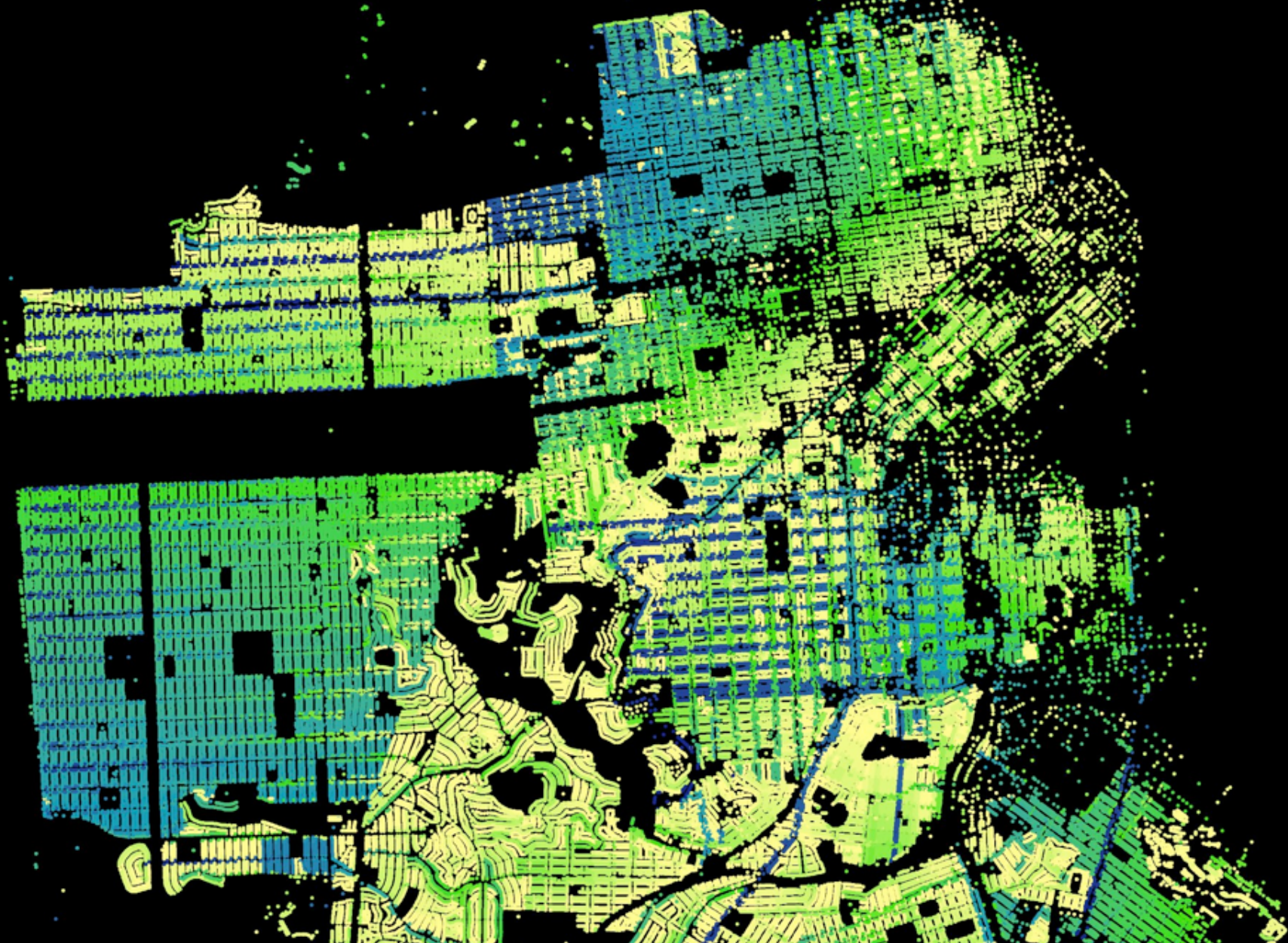


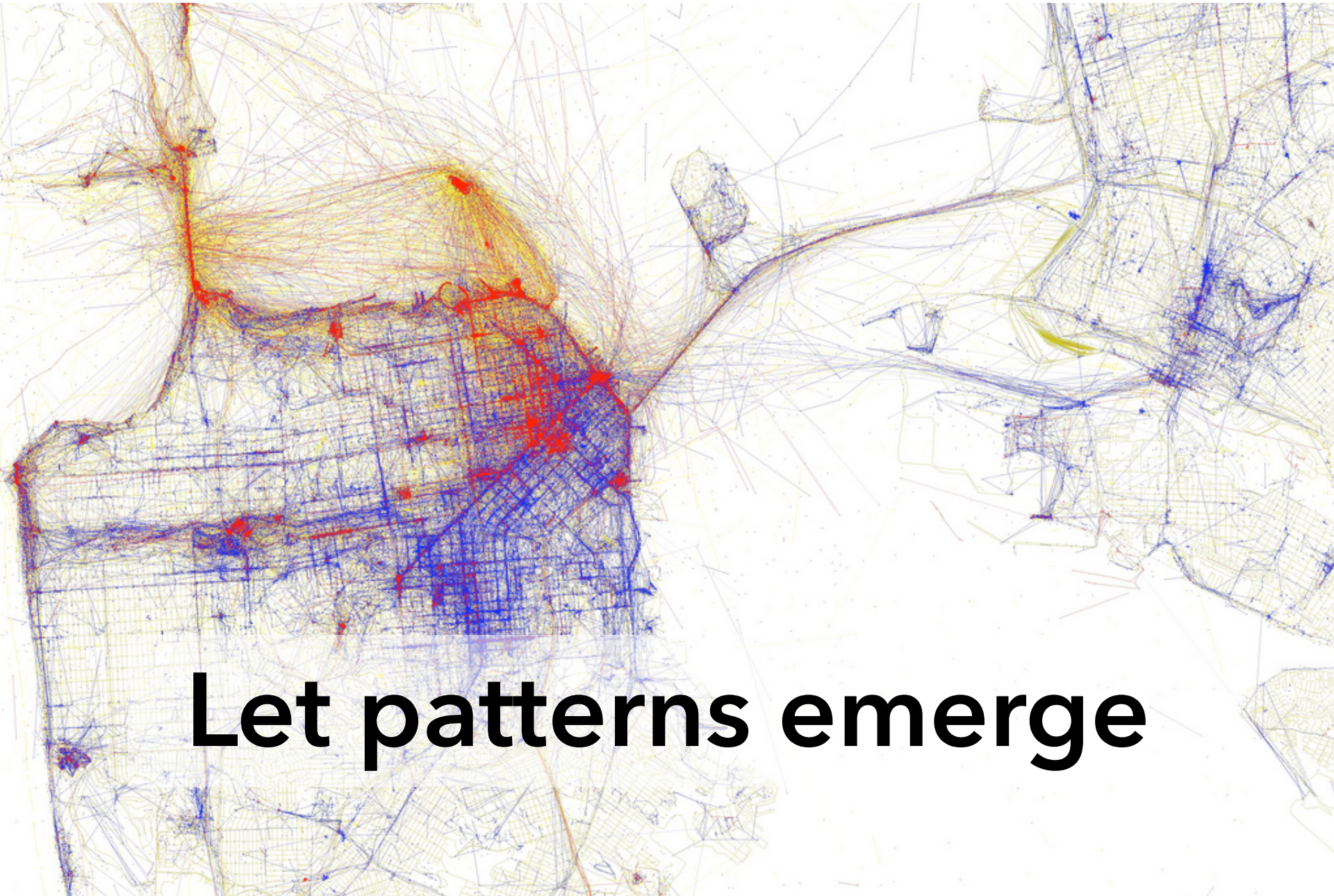
**Three dimensions
shown by color (?)**



One dimension, shown by hue

<http://sta.mn/hn9>

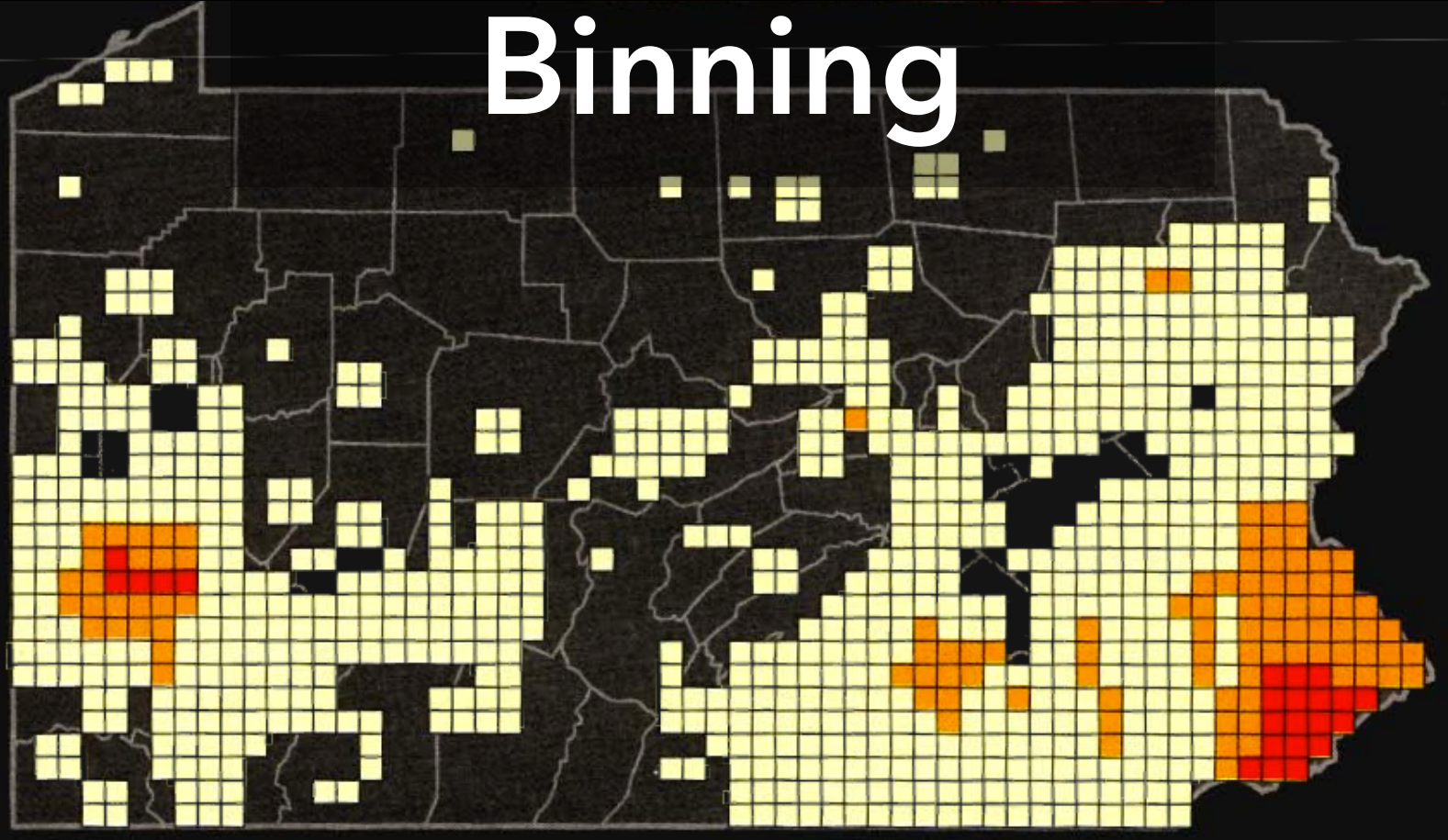


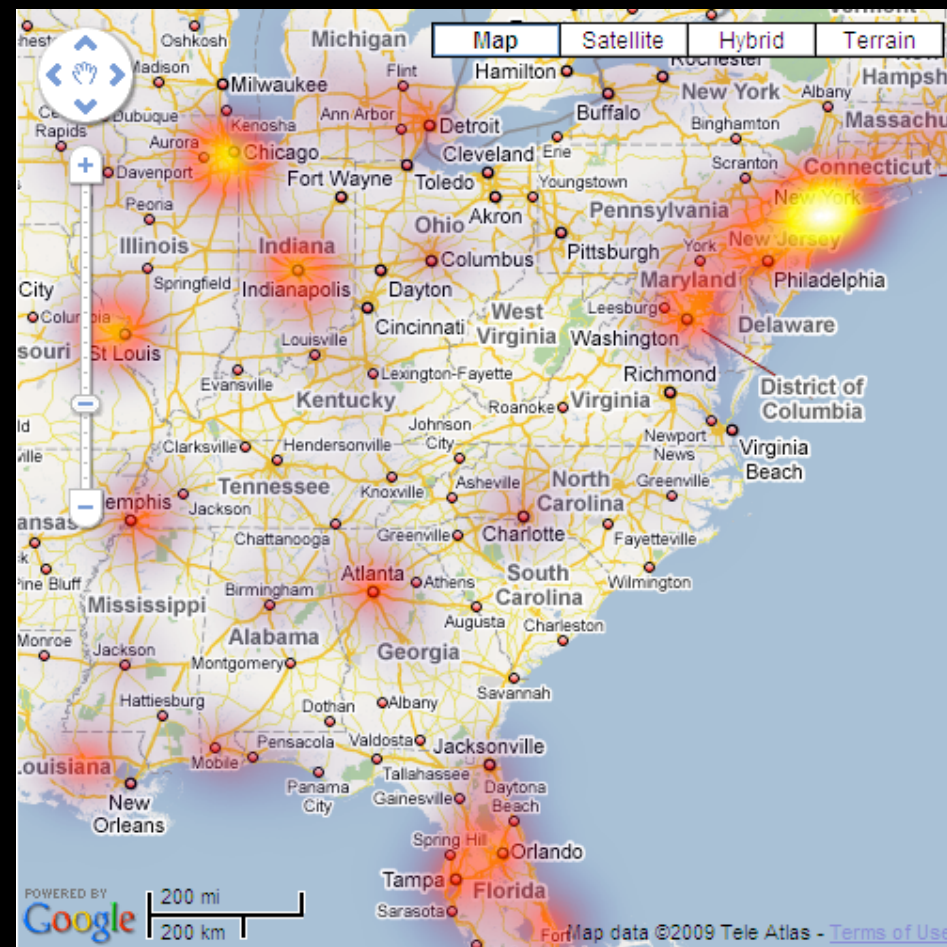
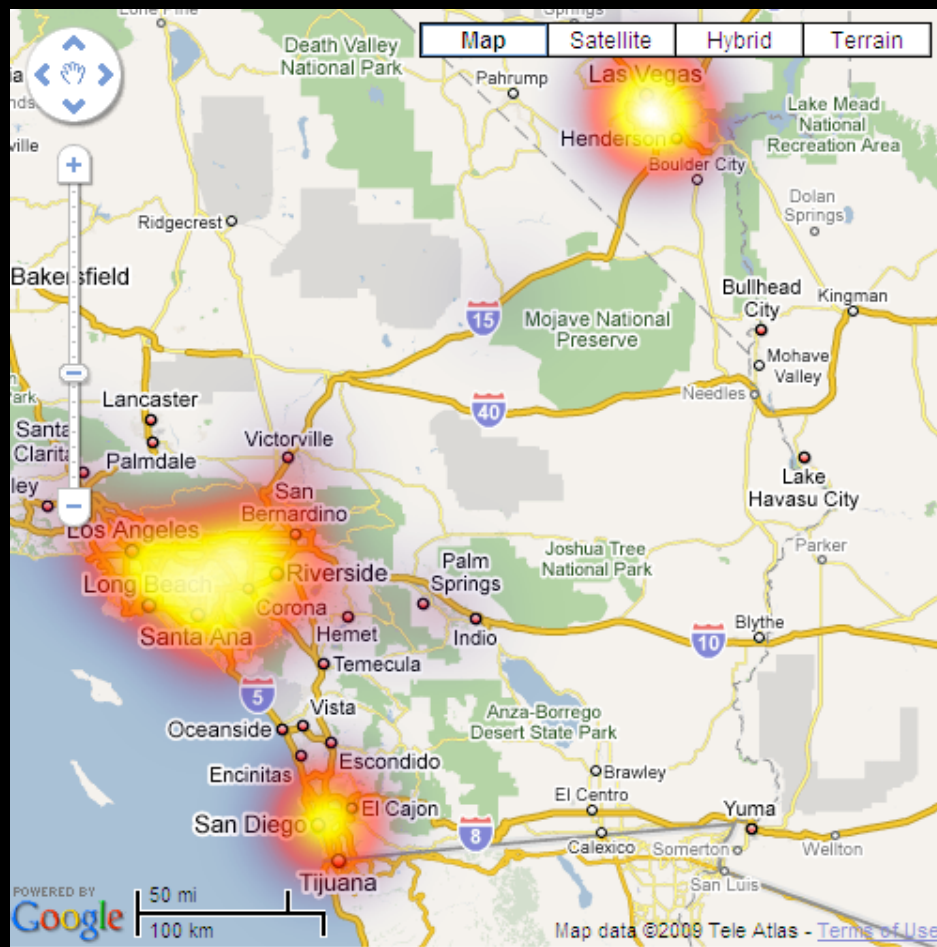


Let patterns emerge

Continuous Data

Binning

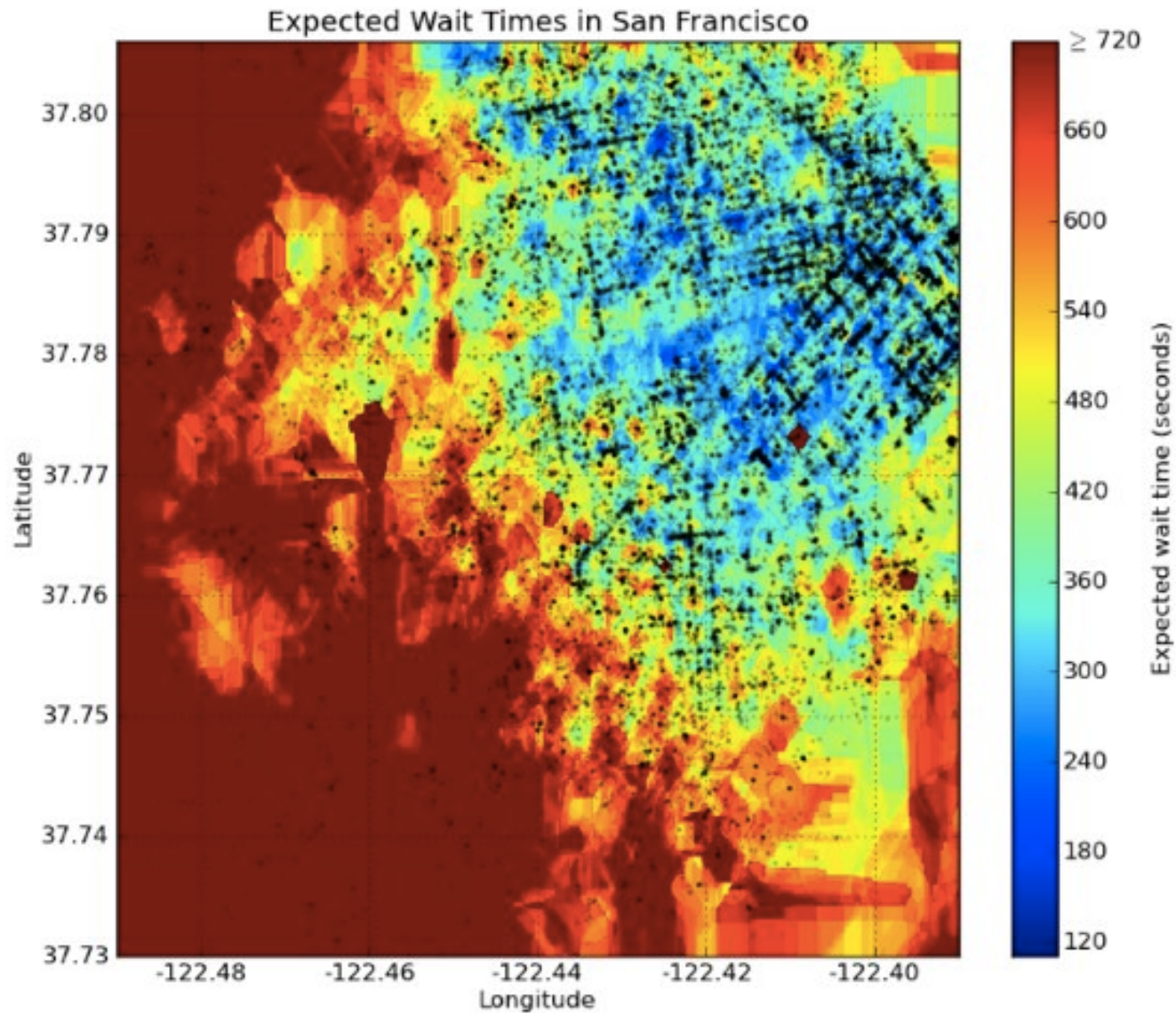




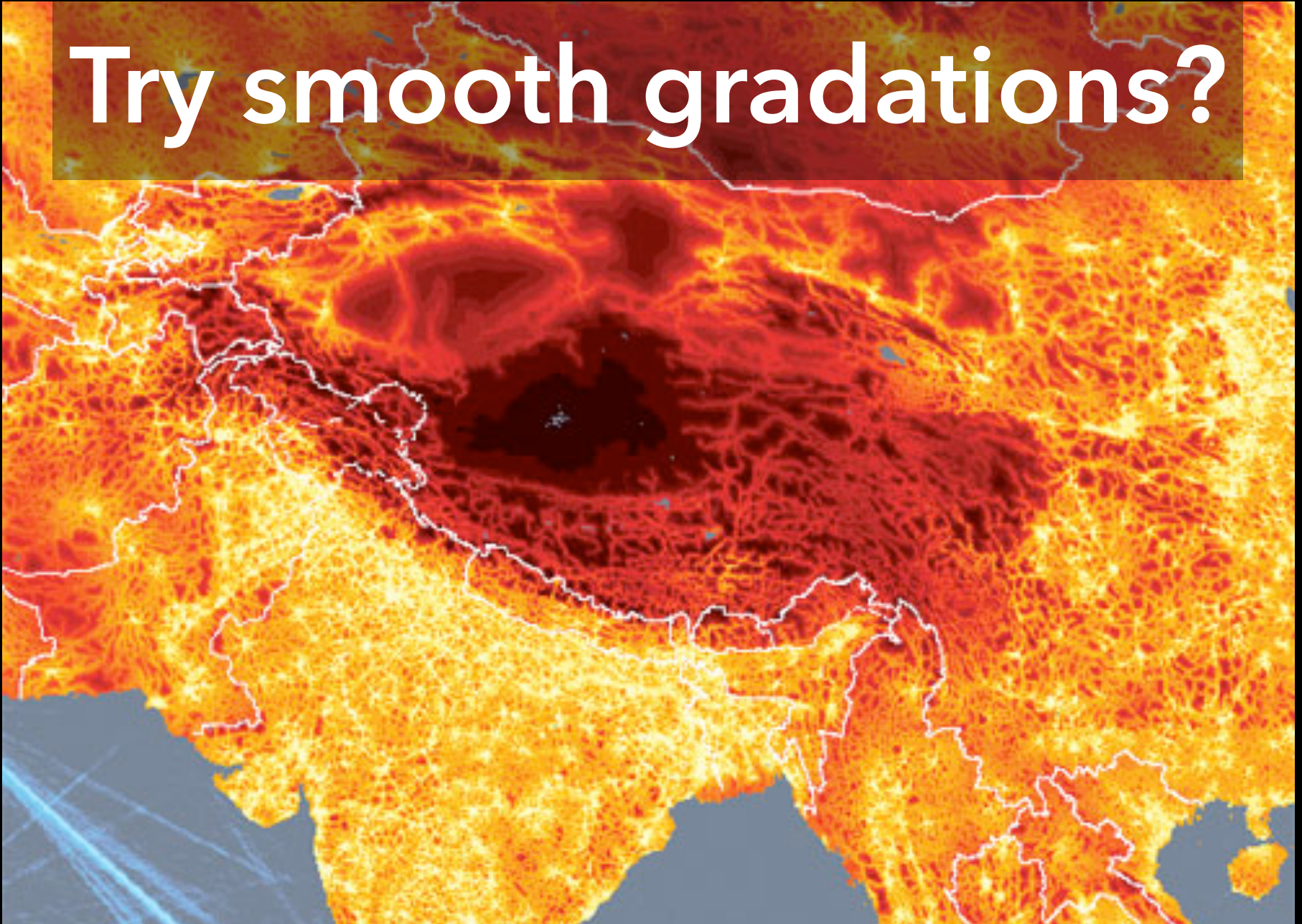
Don't hide the context

Uber Wait Times, 2011

<http://sta.mn/6x27>



Try smooth gradations?



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

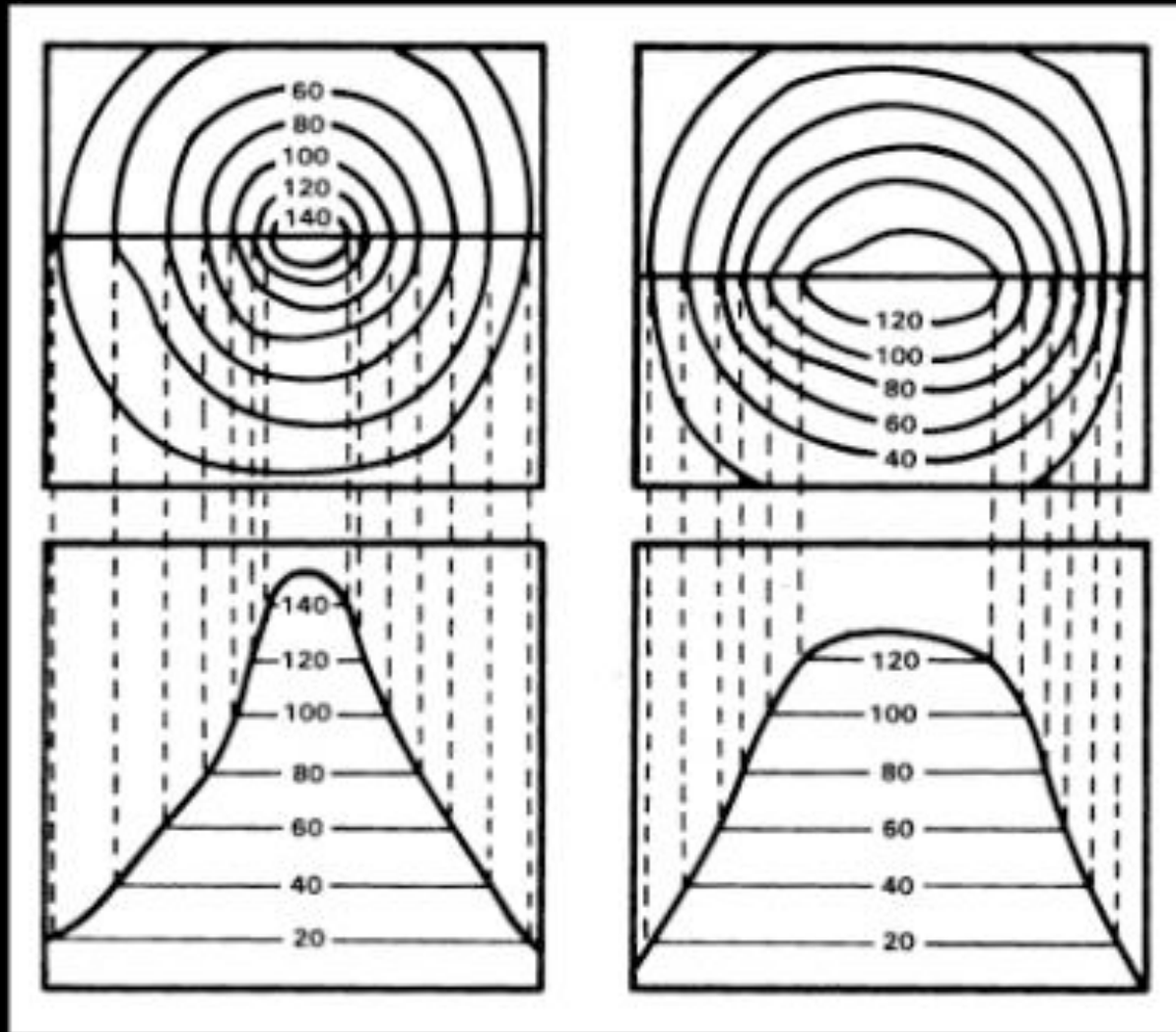
KEY

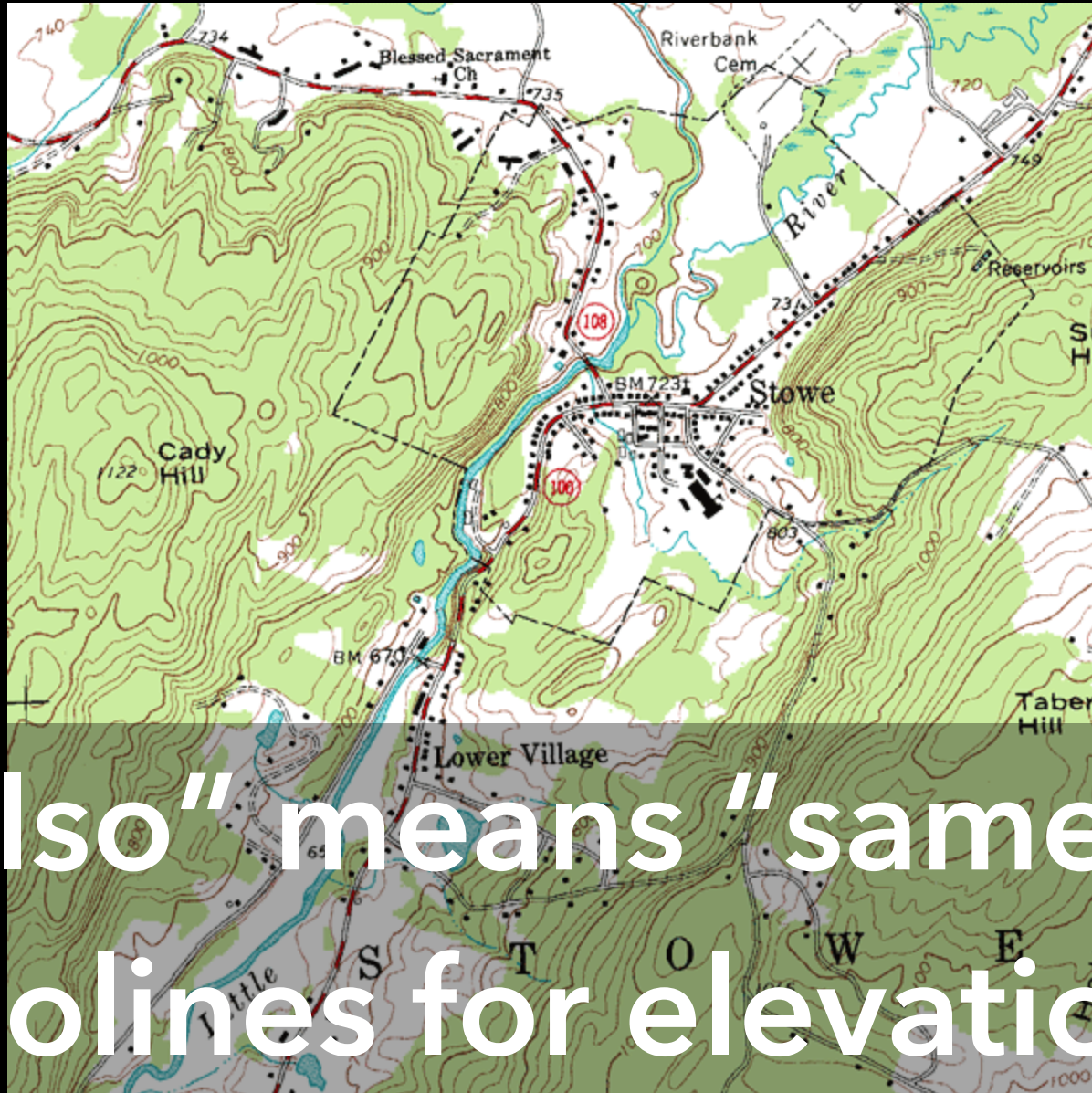
Colours show how recently a crime was reported in a given part of Oakland

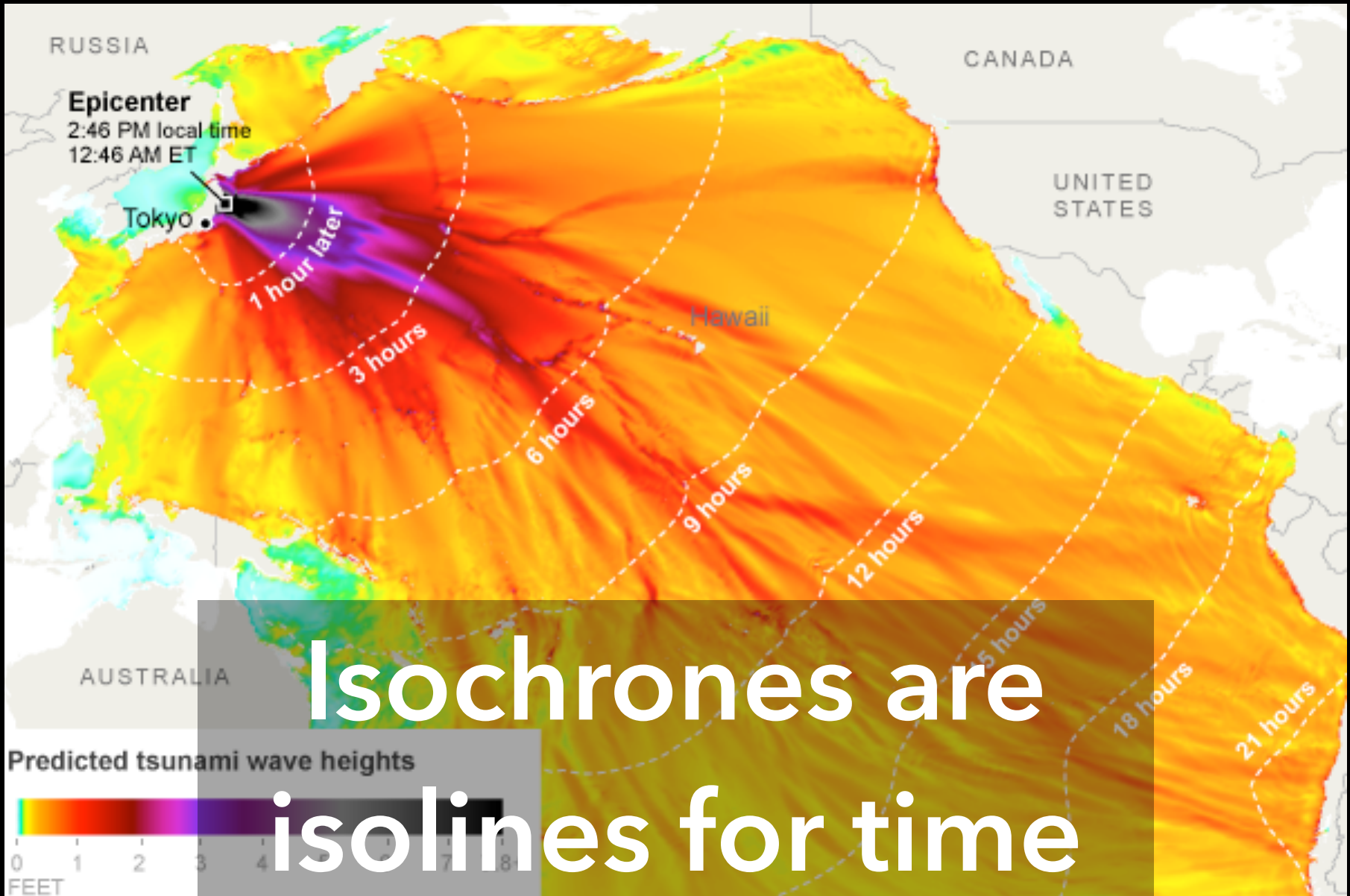
- A week ago
- Two weeks ago
- A month ago
- Two months ago
- Three months ago
- Four months ago
- Five months ago

Meaningful buckets

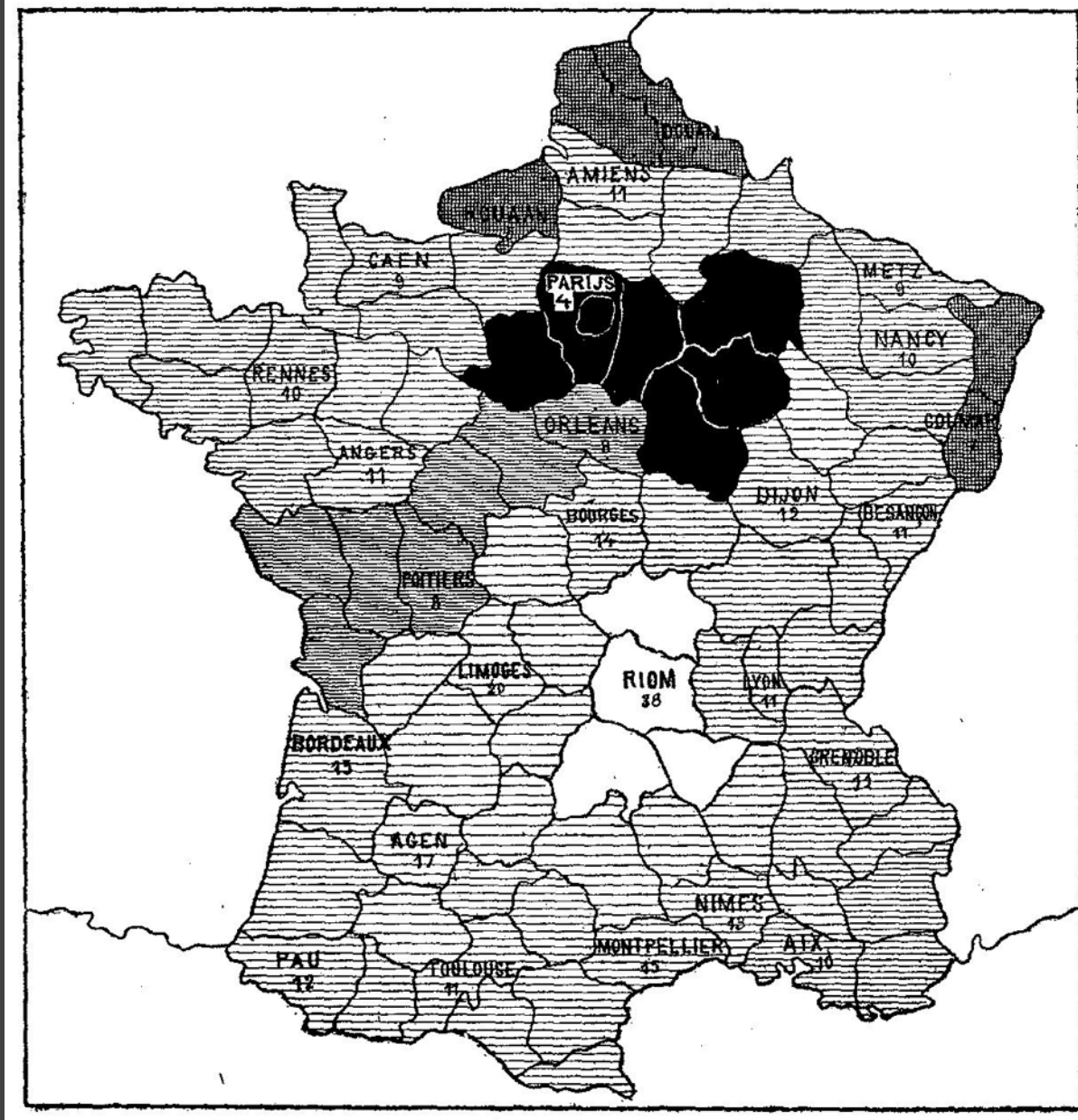
<http://sta.mn/b6>





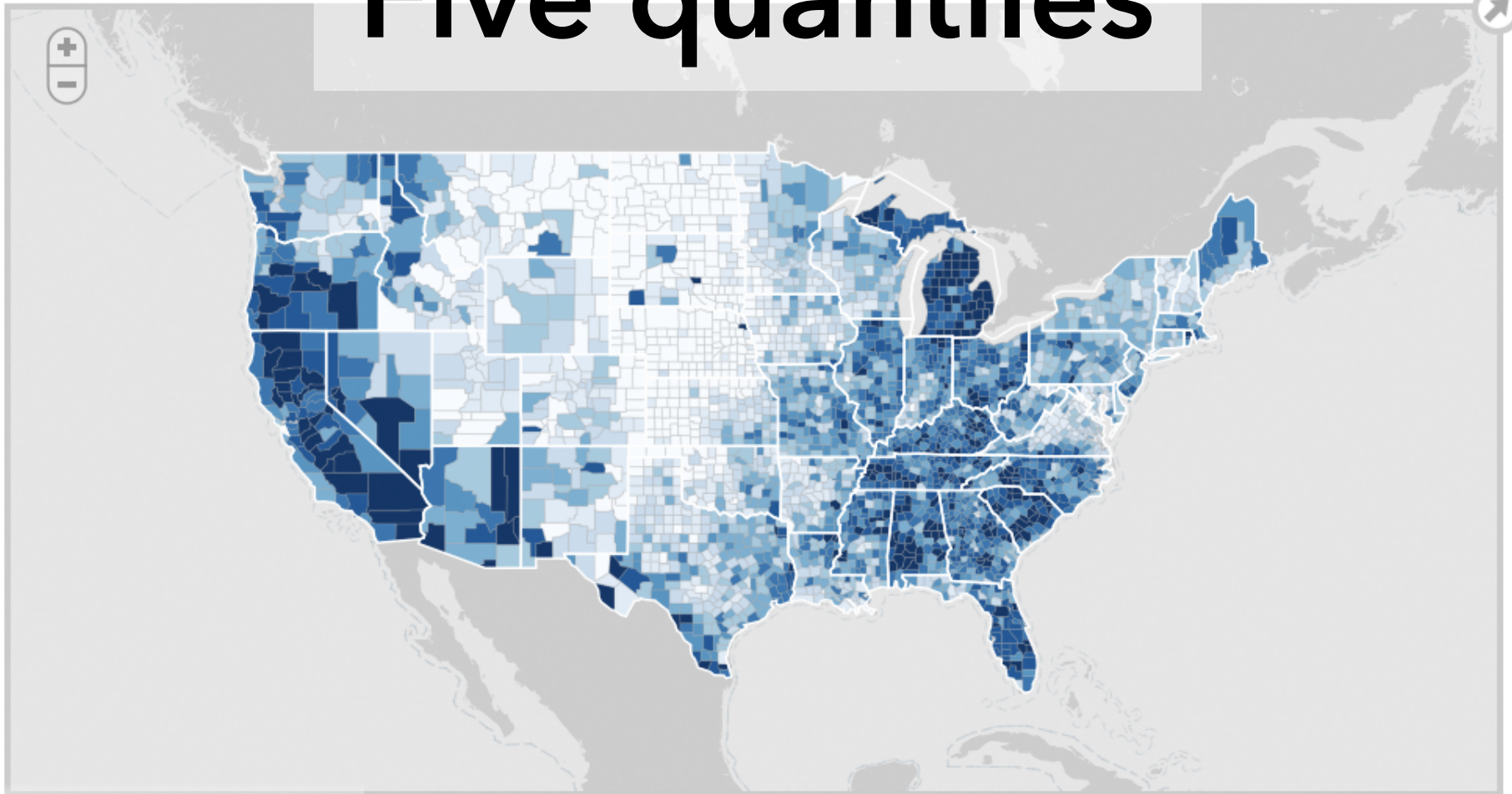


Choropleth Maps

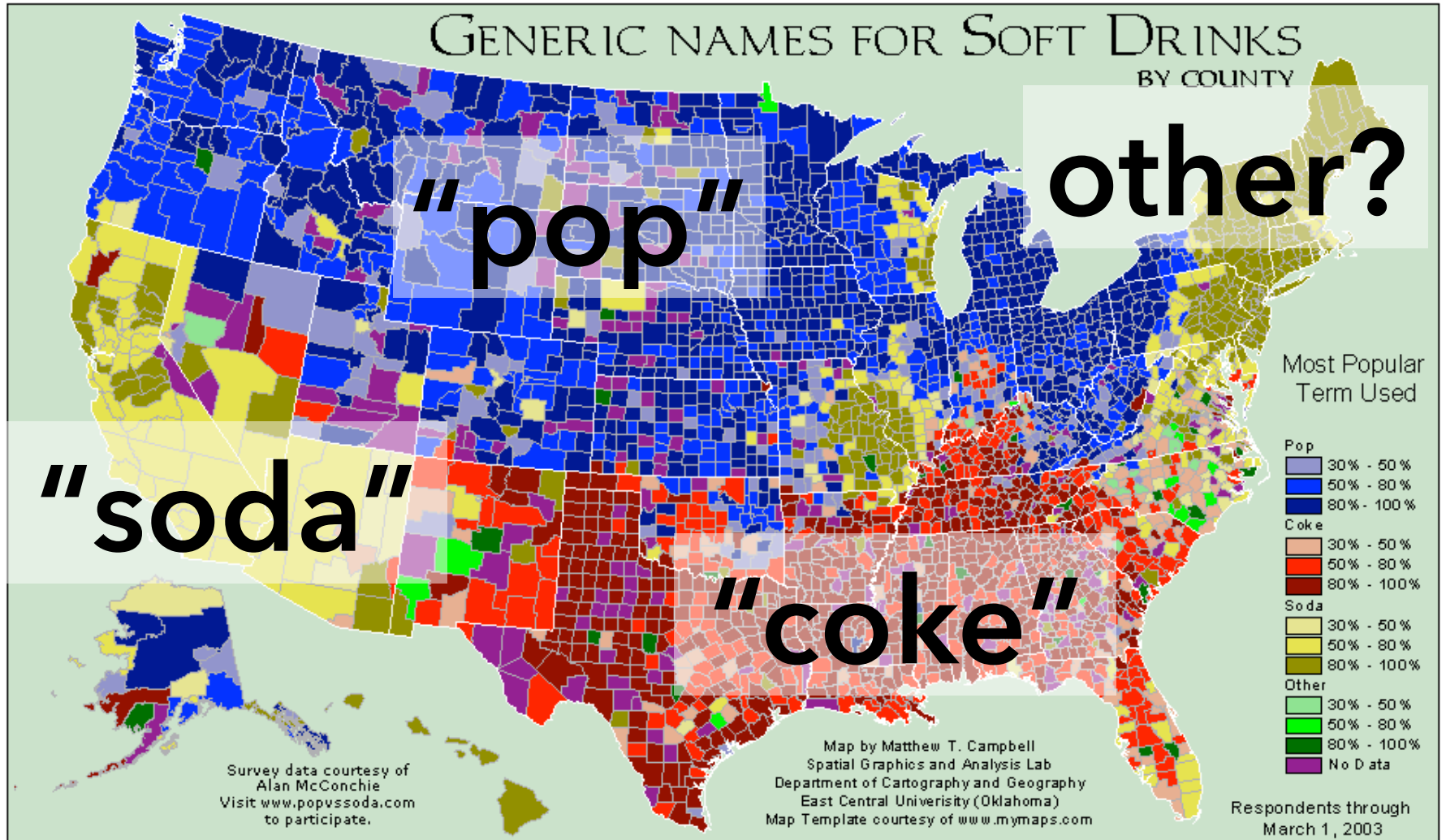


1826(?) Illiteracy in France, Pierre Charles Dupin

Five quantiles

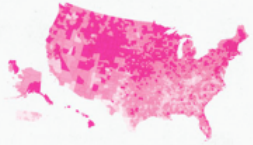


GENERIC NAMES FOR SOFT DRINKS BY COUNTY



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%

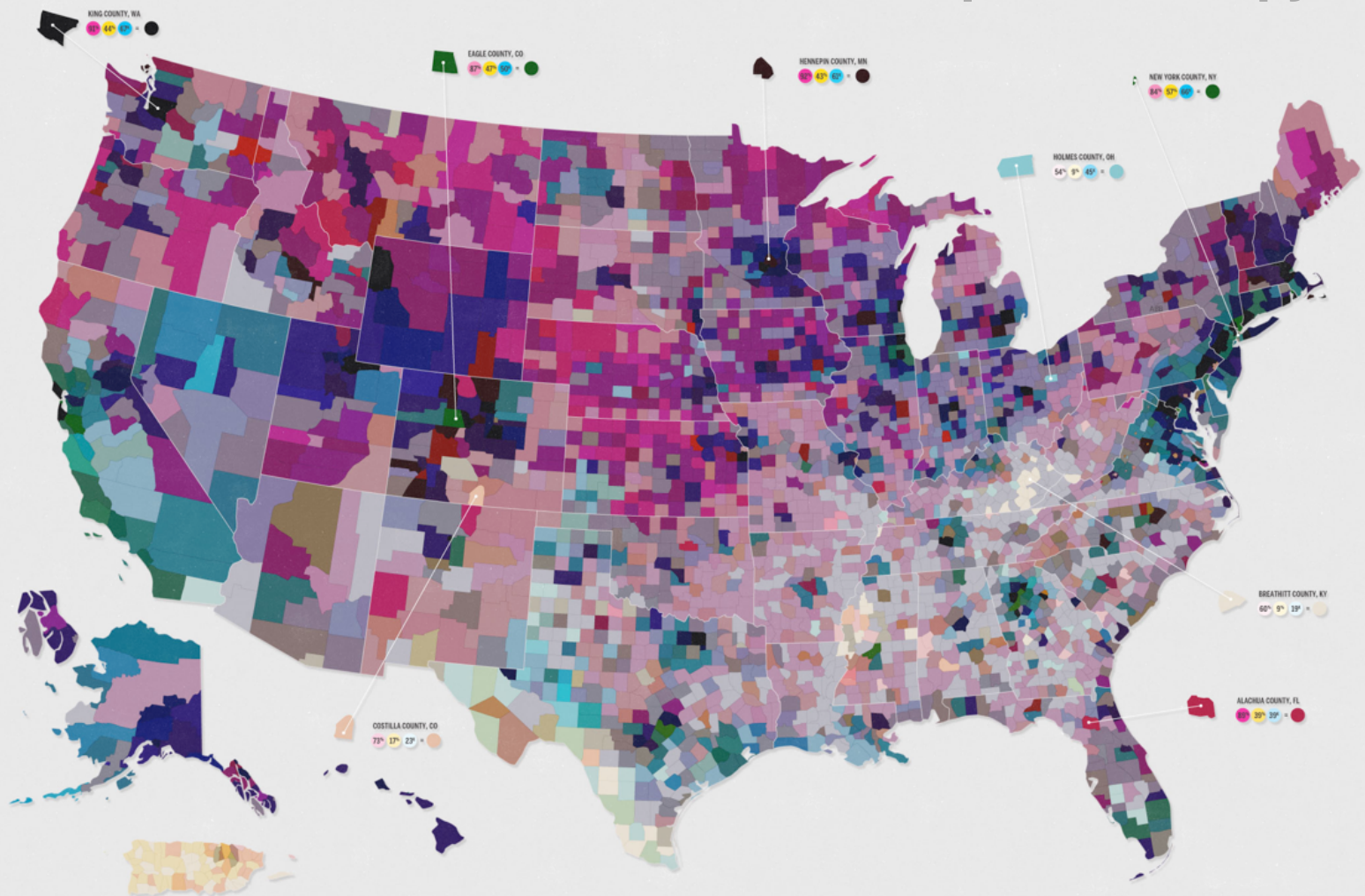


C MEDIAN HOUSEHOLD INCOME 25K 40K 50K 60K

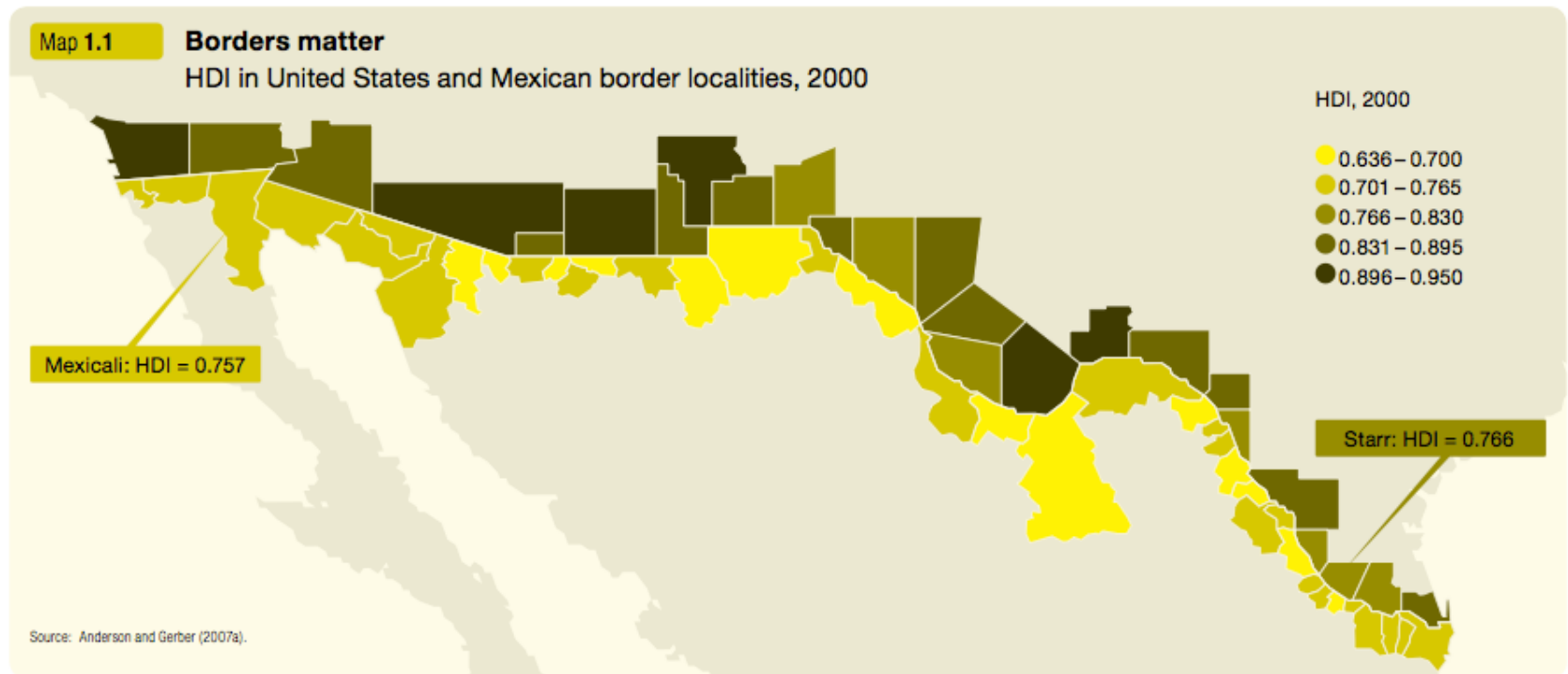
The map at right is a product of overlaying the three sets of data. The variation in hue and value has been produced from the data shown above. In general, darker counties represent a more educated, better paid population while lighter areas represent communities with fewer graduates and lower incomes.



A collaboration between GOOD and Gregory Huback
SOURCE: US Census



Choose colors well



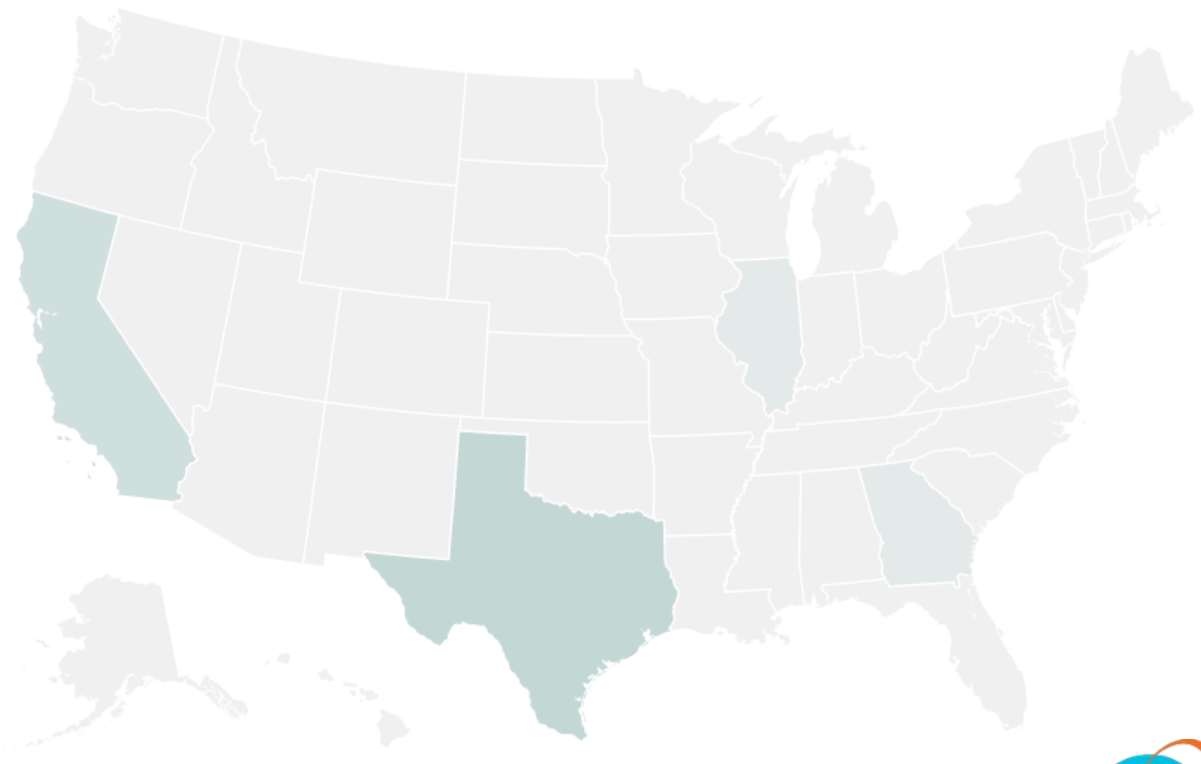
Focus on the foreground

Sort: Default Edit

State



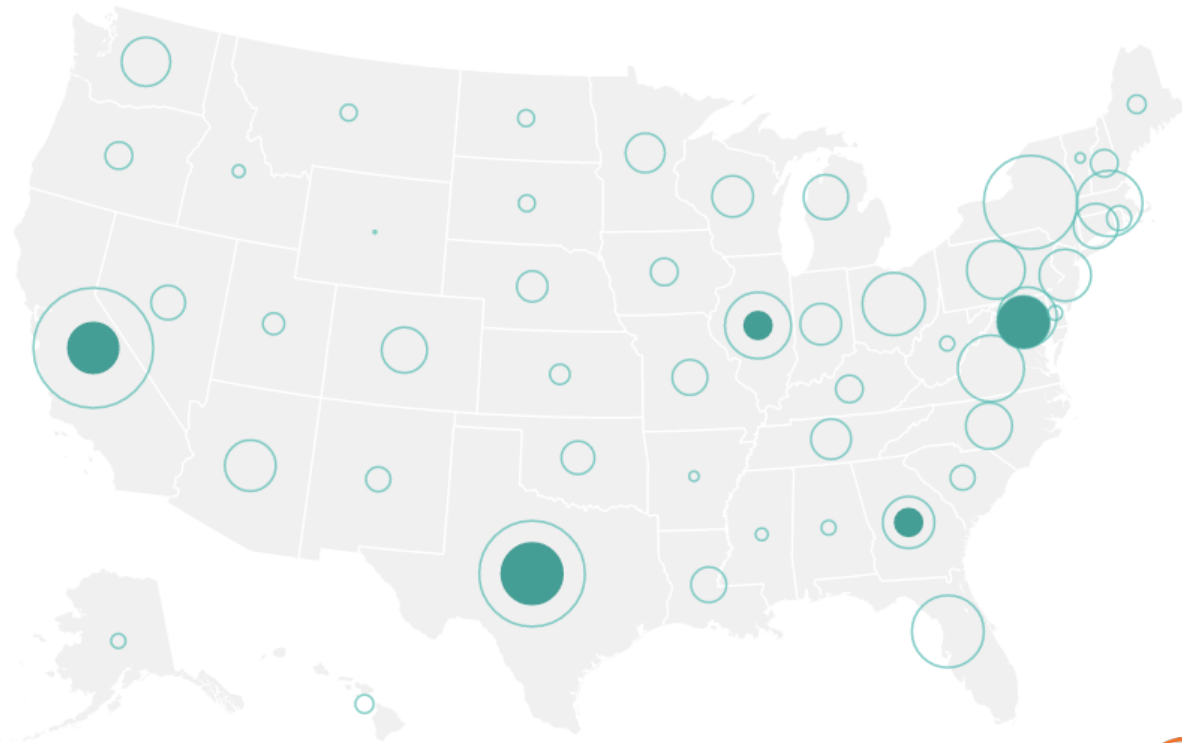
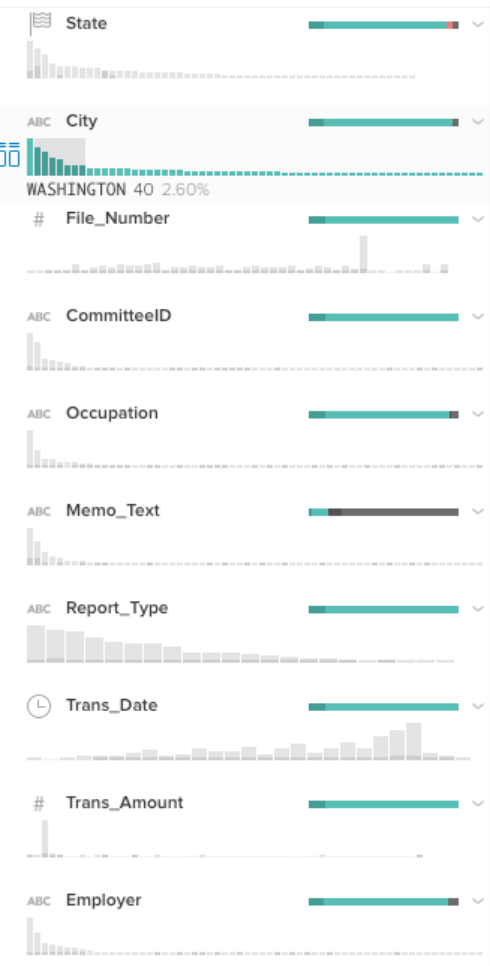
- State
- City: WASHINGTON 40 2.60%
- File_Number
- CommitteeID
- Occupation
- Memo_Text
- Report_Type
- Trans_Date
- Trans_Amount
- Employer



What is obscured?

Sort: Default Edit

State



Regions -> Symbols

Cartograms

New York Times ratings

198
Safe Dem.

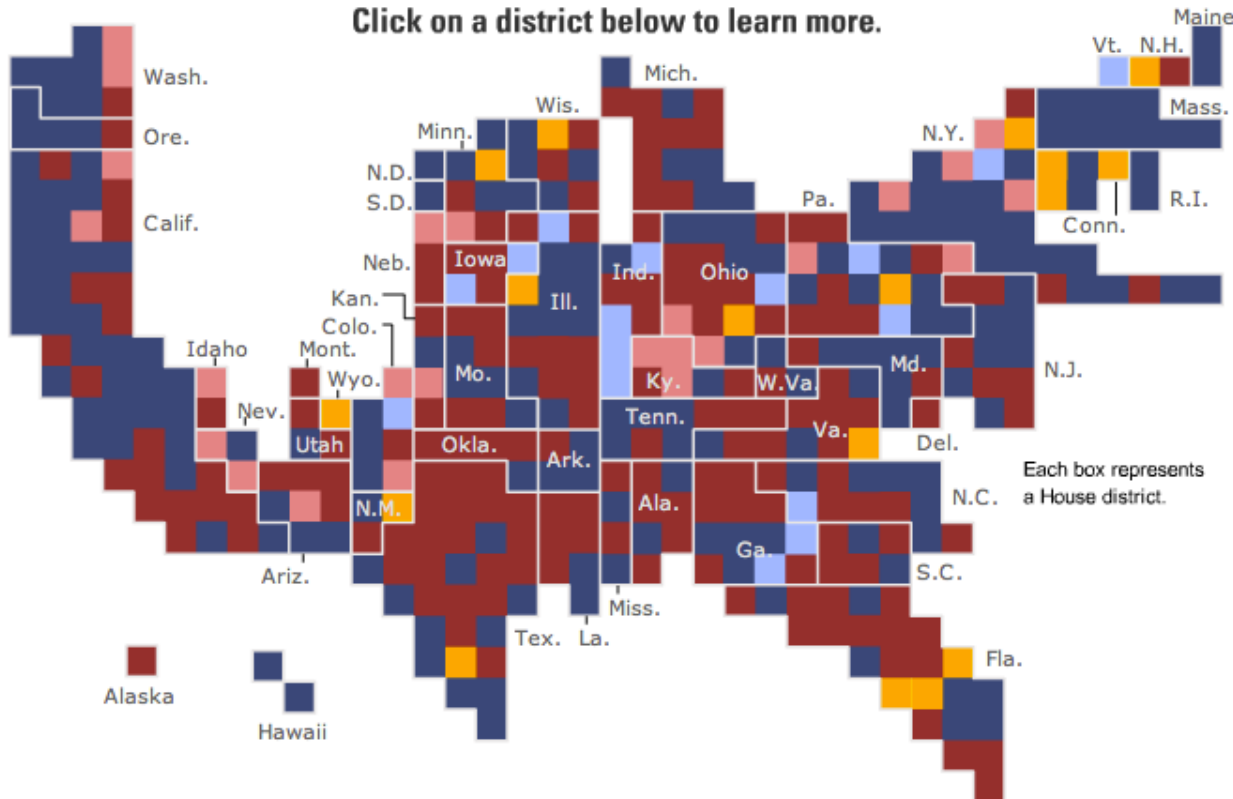
16
Leaning Dem.

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 [dropdown menu]

...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

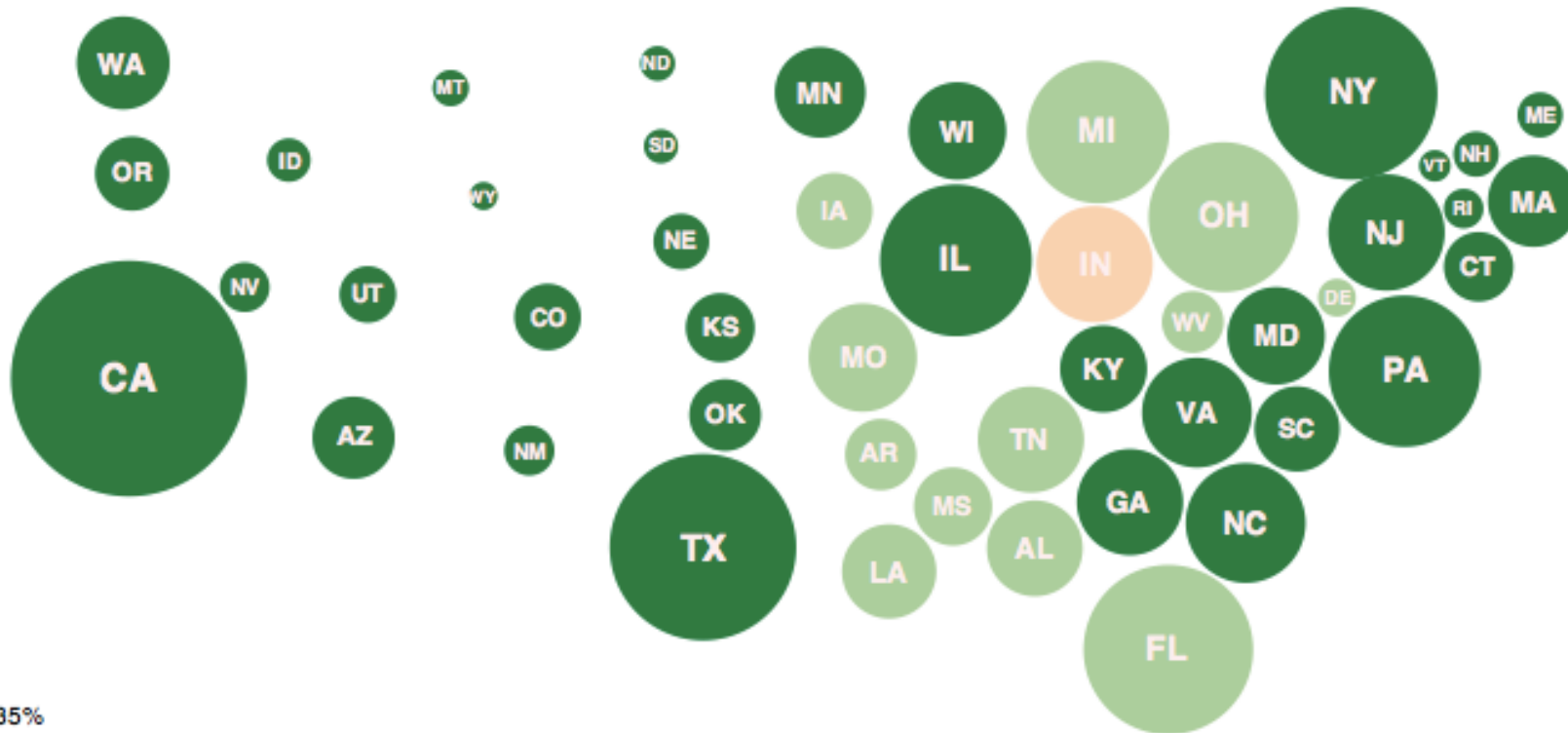
Race/Ethnicity

White Black Hispanic

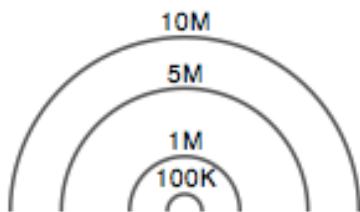
Median income

<\$30K \$30-50K >\$50K

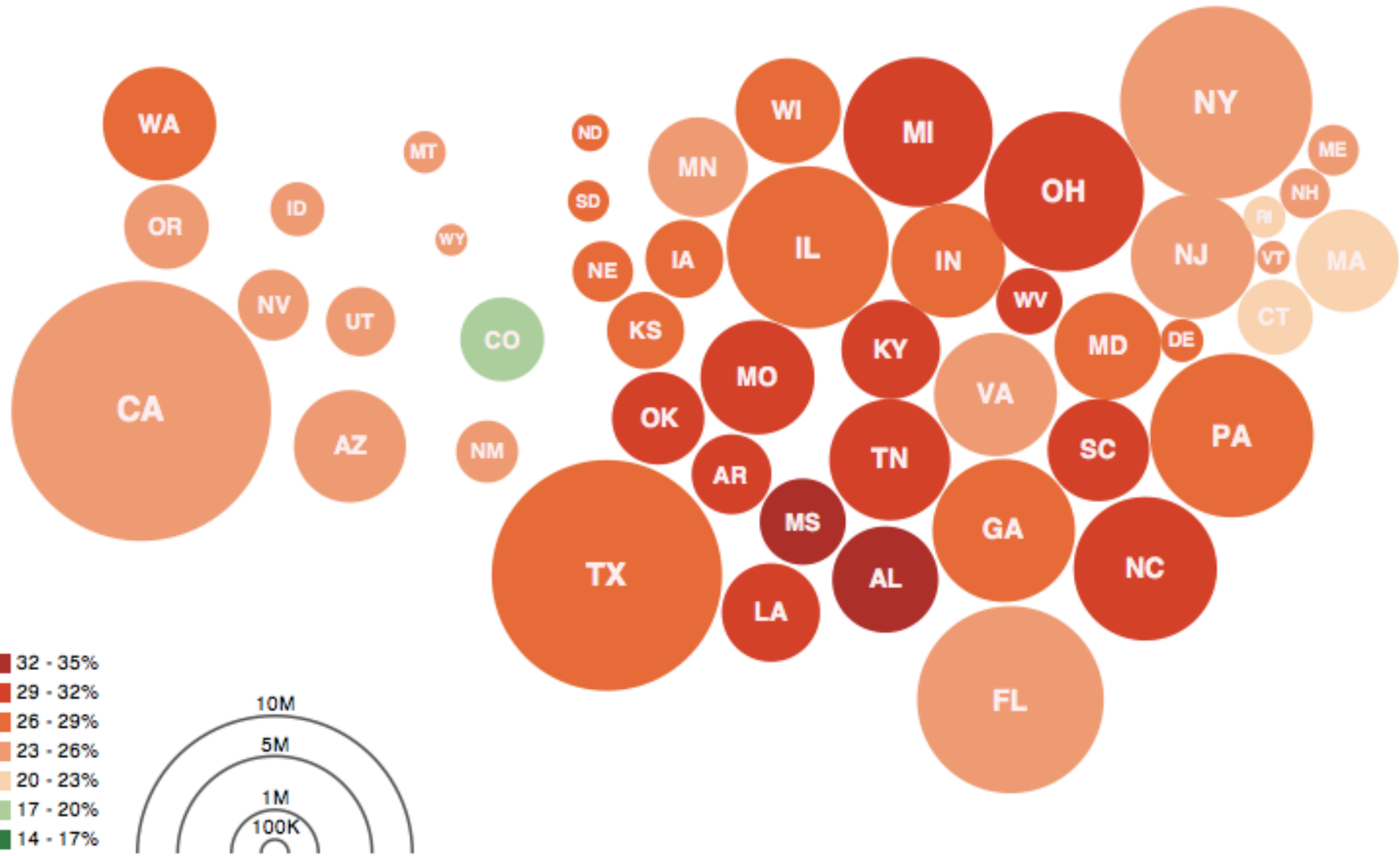
RESET



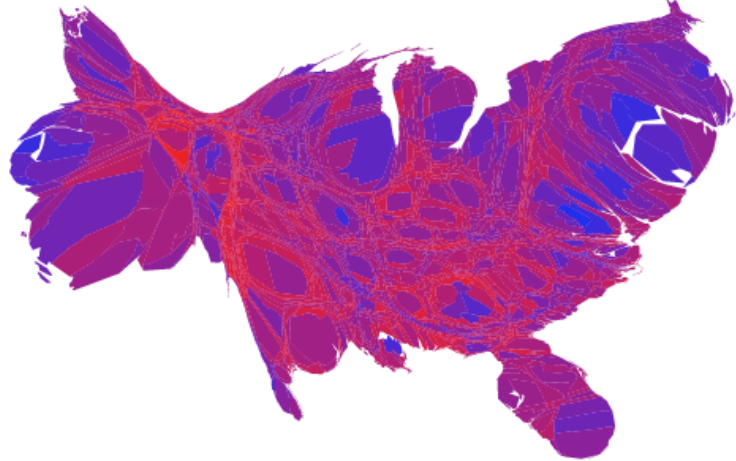
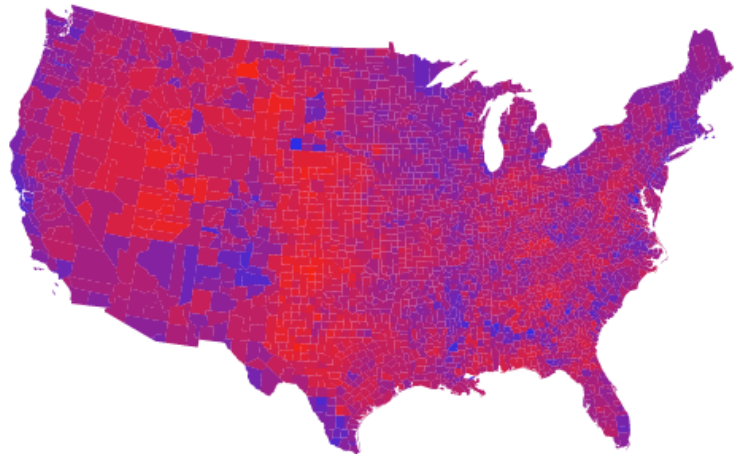
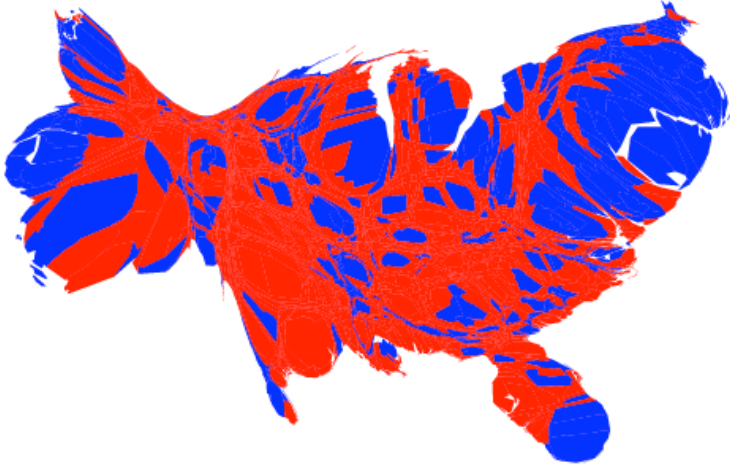
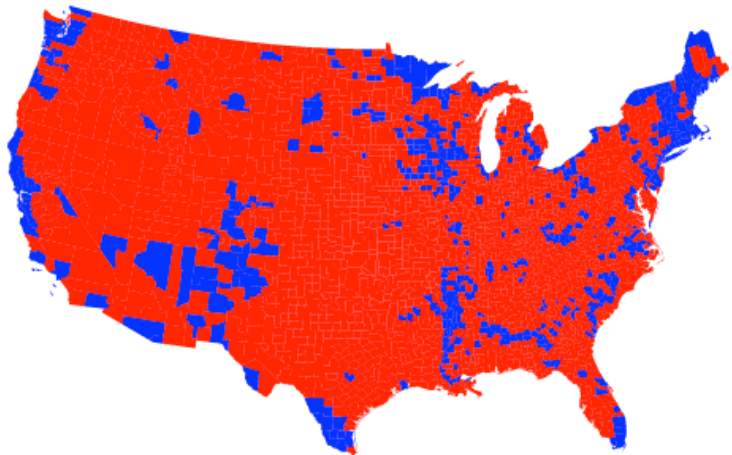
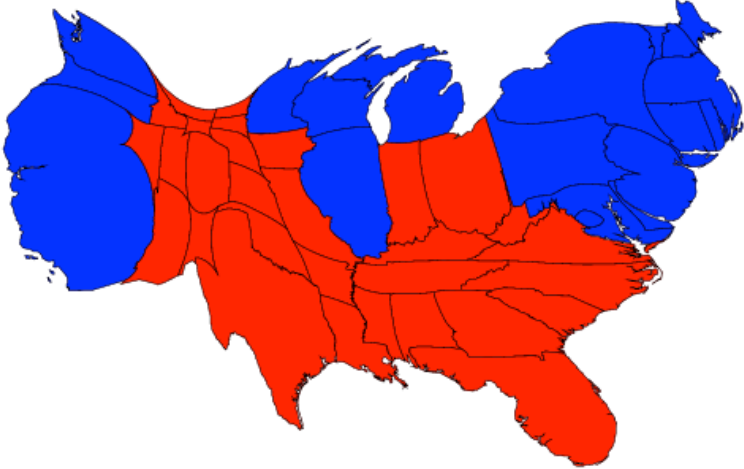
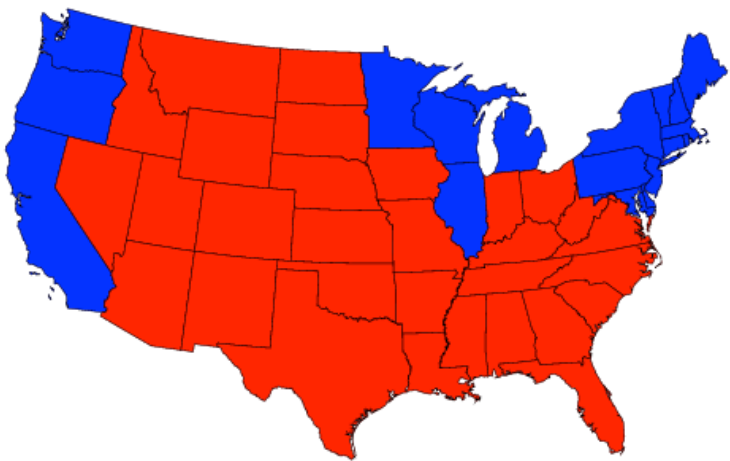
- 32 - 35%
- 29 - 32%
- 26 - 29%
- 23 - 26%
- 20 - 23%
- 17 - 20%
- 14 - 17%



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 »](#)

Economic Output

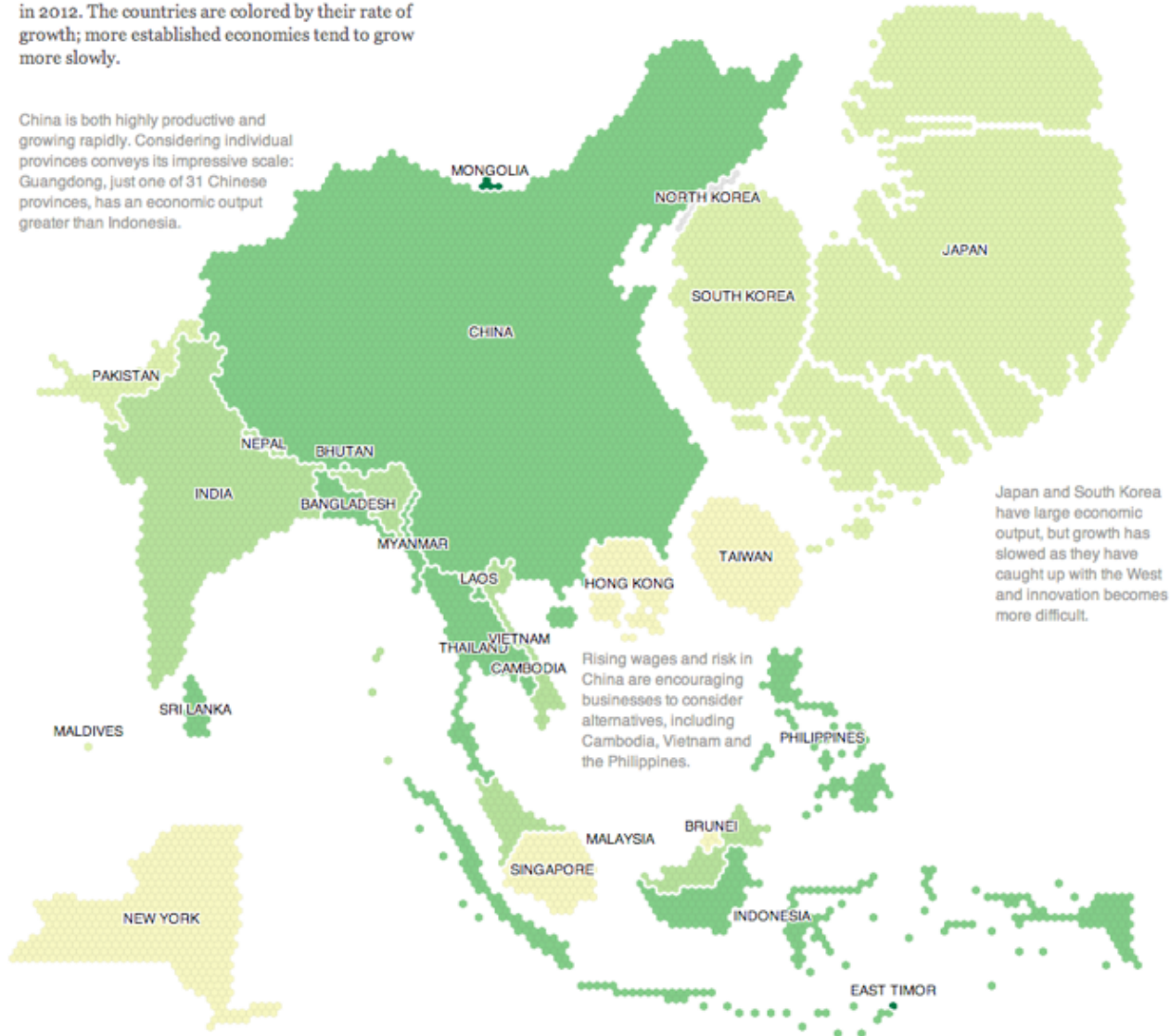
In this map, geography is distorted so that each country is **sized according to its economic output in 2012**. The countries are colored by their rate of growth; more established economies tend to grow more slowly.

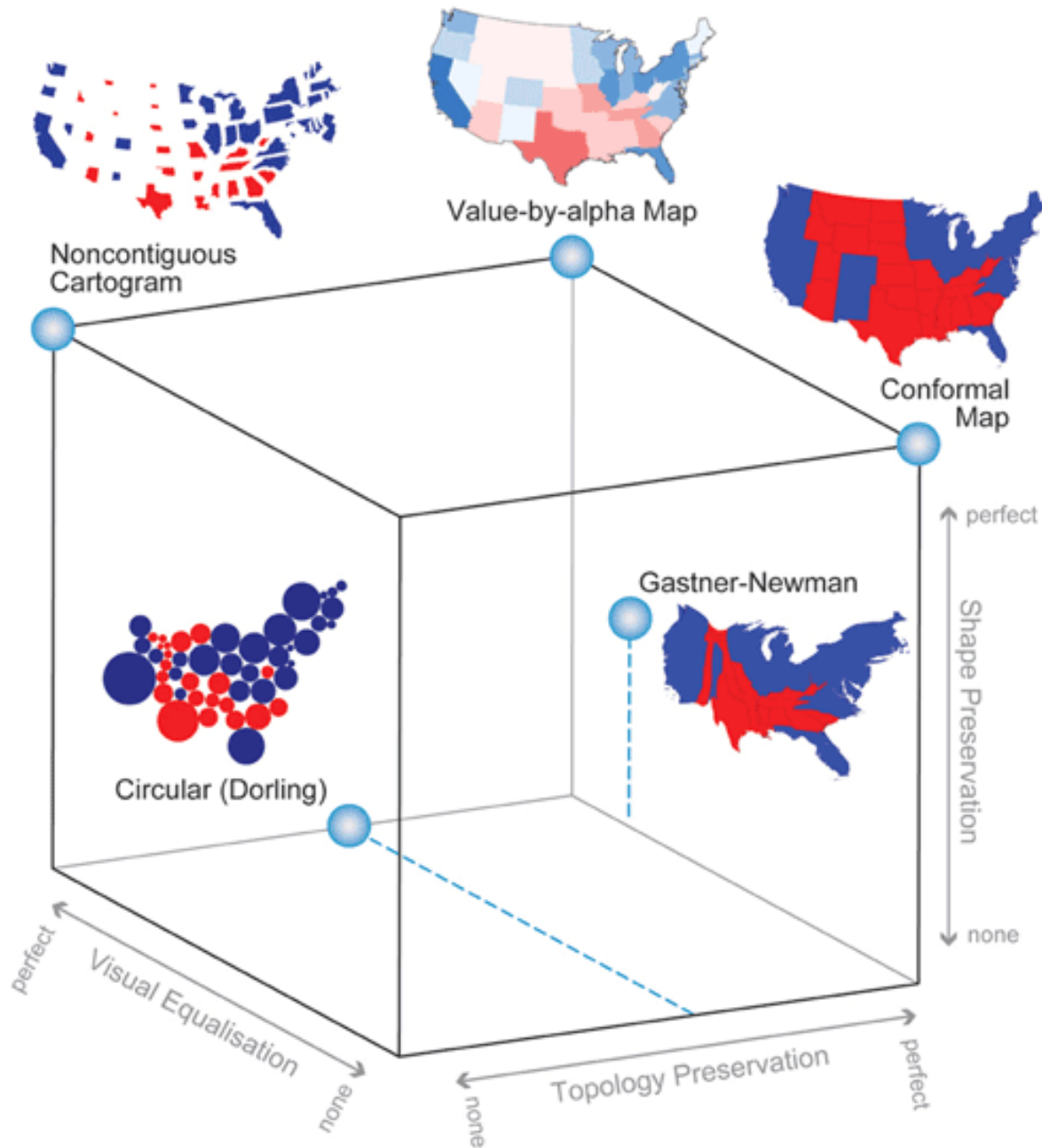
China is both highly productive and growing rapidly. Considering individual provinces conveys its impressive scale: Guangdong, just one of 31 Chinese provinces, has an economic output greater than Indonesia.

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

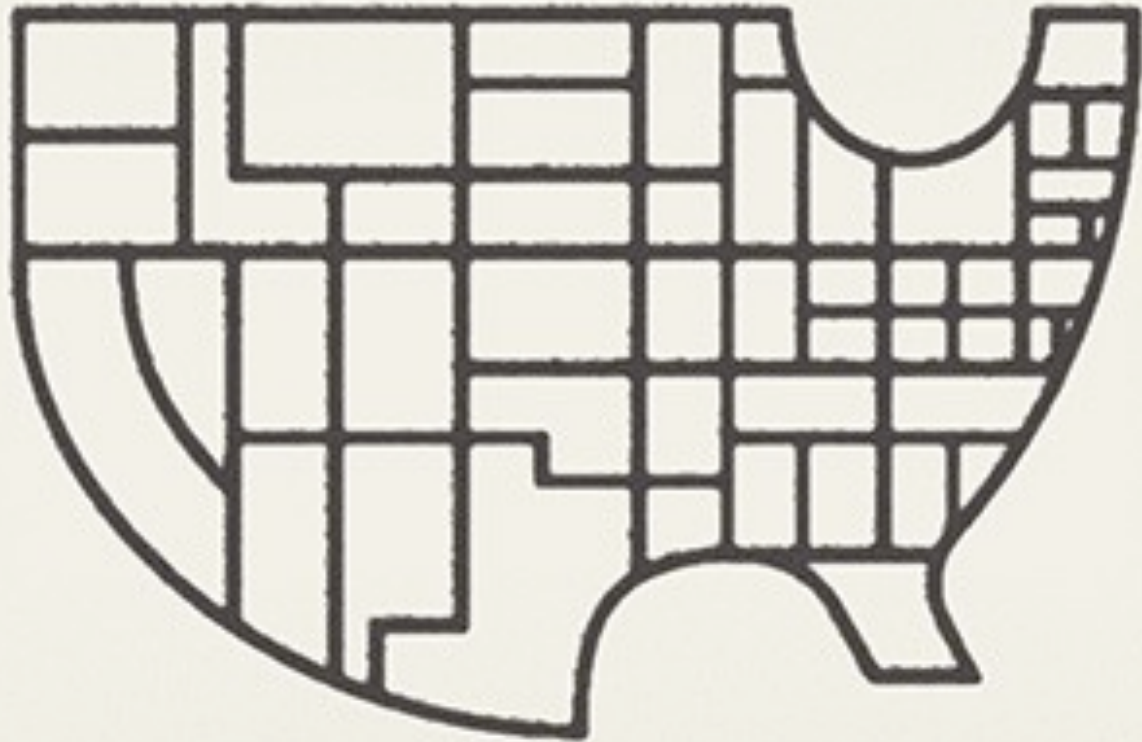
G.D.P. growth, 2011 to 2012

2 4 6 8 +10%





**Major distortions
can stay recognizable**



Flow Maps

Minard 1869: Napoleon's march

Carte Figurative des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812-1813.
 Dessiné 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. Chiers, de Légar, 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 Davoust qui avaient été détachés sur Minsk et Mohilow et qui s'étaient joints à Orscha et Witebsk, avaient toujours marché avec l'armée.

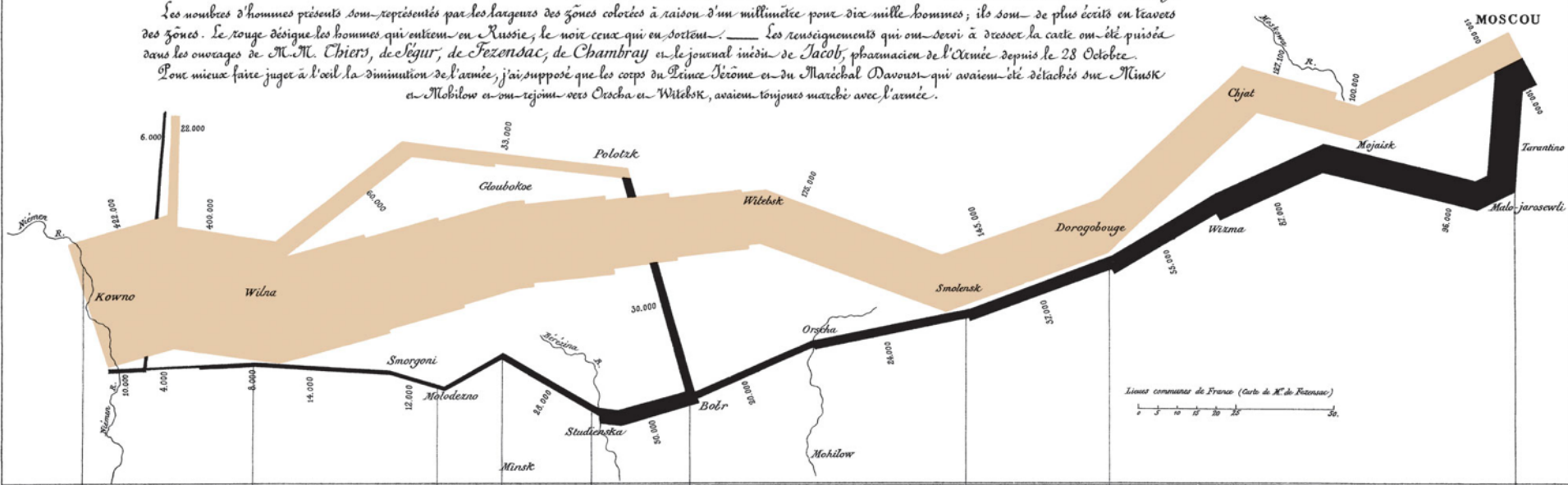
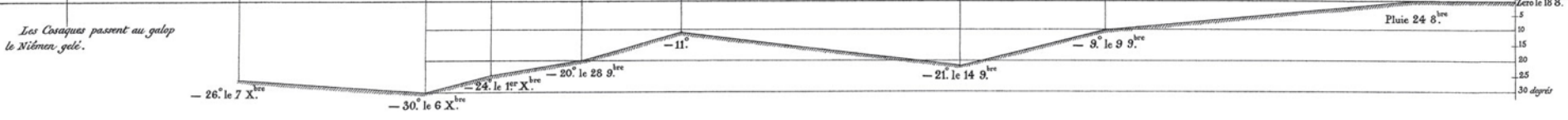


TABLEAU GRAPHIQUE de la température en degrés du thermomètre de Réaumur au dessous de zéro.



Autog. par Regnier, 8. Par. S^{te} Marie S^t O^g à Paris.

Imp. Lit. Regnier et Doucet.

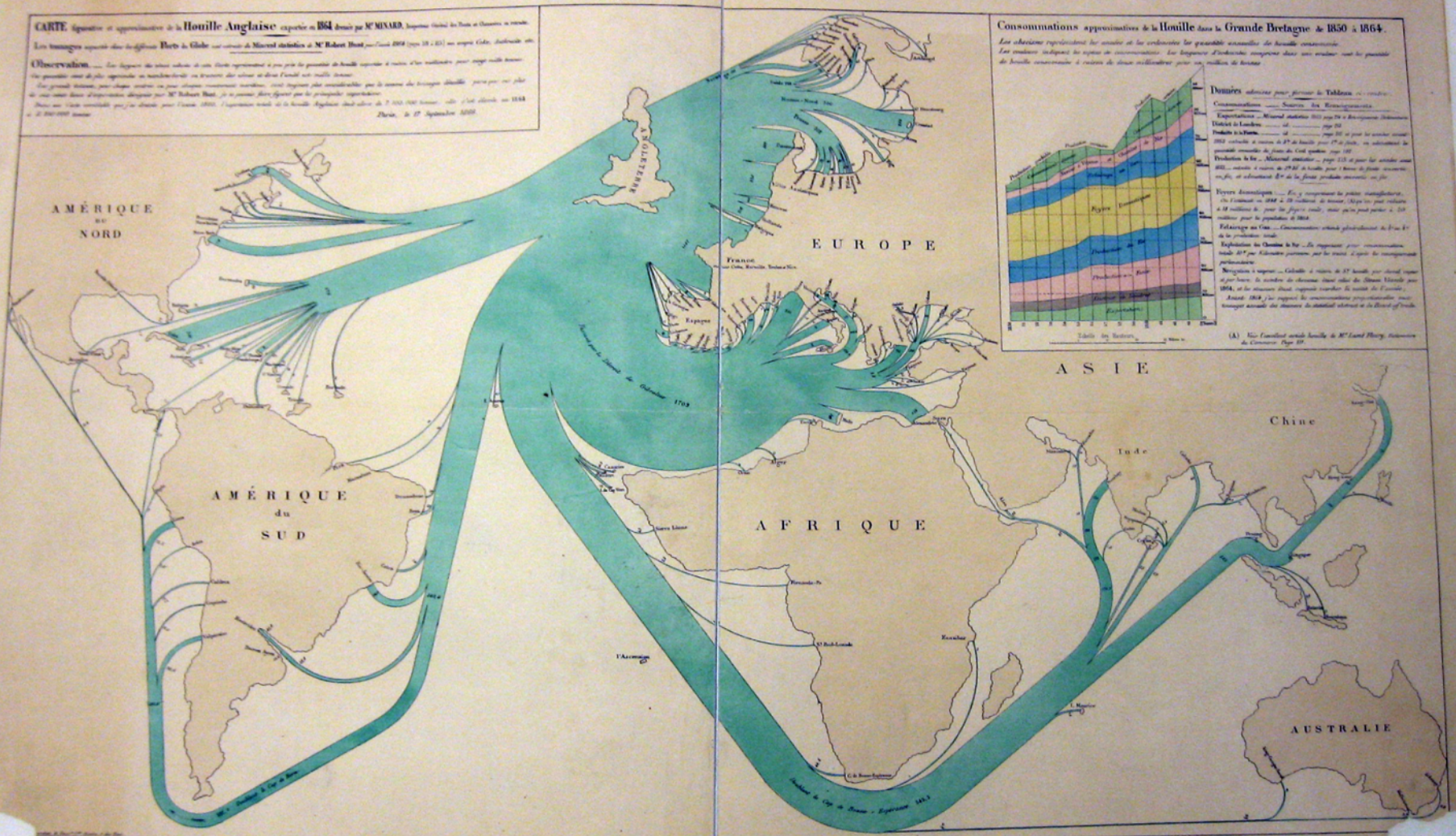
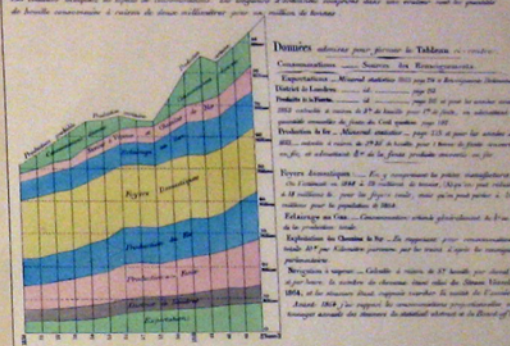
CARTE figurative et approximative de la Houille Anglaise exportée en 1864 dressée par M^r MINARD, Ingénieur Civil des Ponts et Chaussées en France.

Les tracés sont basés sur les chiffres de l'Annuaire de M^r Robert Bunt pour l'année 1864 (page 18 & 19) en ce qui concerne l'Angleterre et sur les données de M^r Robert Bunt pour l'année 1864 (page 18 & 19) en ce qui concerne l'Angleterre et sur les données de M^r Robert Bunt pour l'année 1864 (page 18 & 19) en ce qui concerne l'Angleterre.

Observation. — Les lignes de couleur indiquent la destination approximative de la houille anglaise exportée et non de son utilisation pour usage local. Les données sont basées sur les chiffres de l'Annuaire de M^r Robert Bunt pour l'année 1864 (page 18 & 19) en ce qui concerne l'Angleterre et sur les données de M^r Robert Bunt pour l'année 1864 (page 18 & 19) en ce qui concerne l'Angleterre.

Consommations approximatives de la Houille dans la Grande Bretagne et 1850 à 1864.

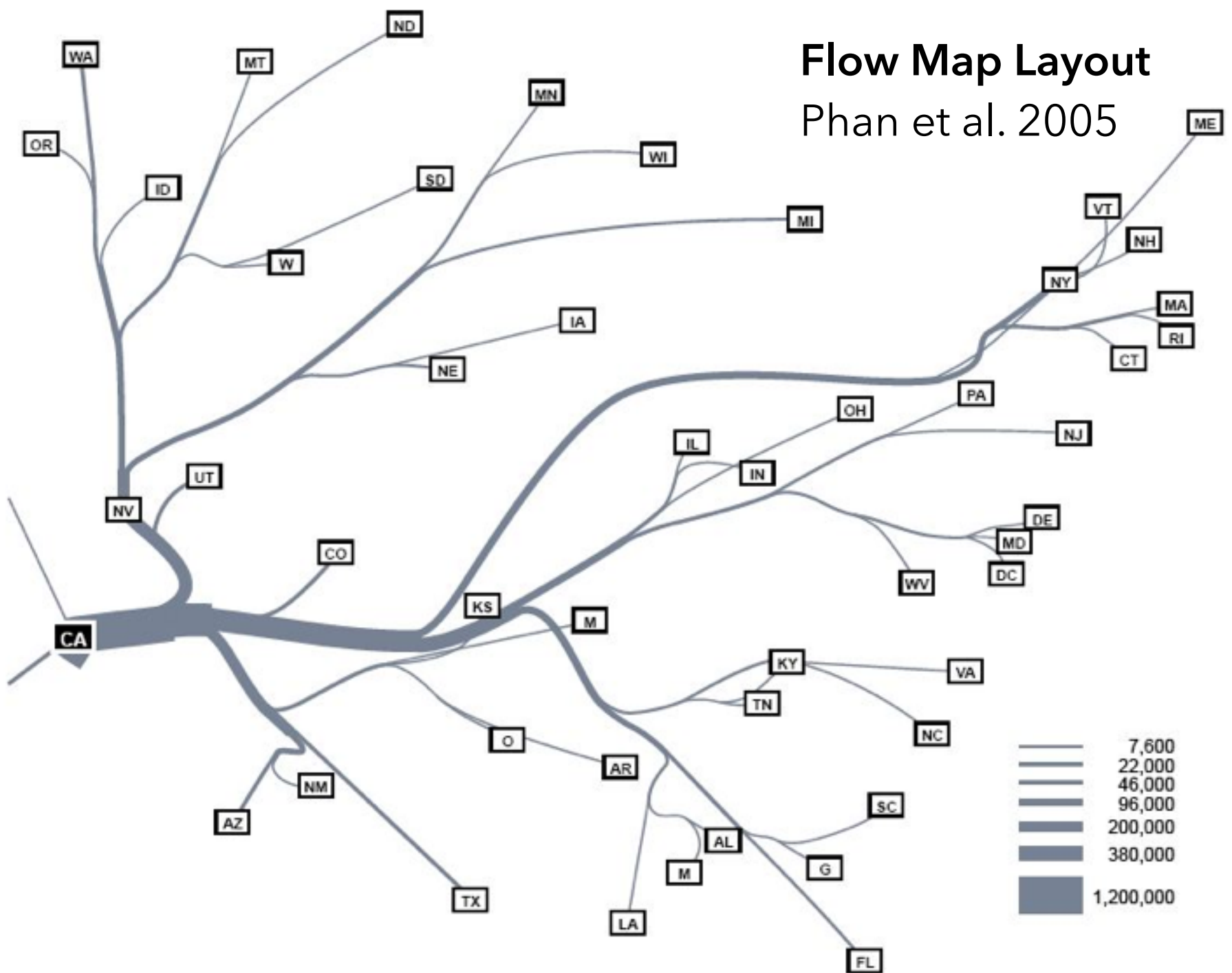
Les chiffres expriment les tonnes et les volumes les quantités annuelles de houille consommées.



1864 British Coal Exports, Charles Minard

Flow Map Layout

Phan et al. 2005

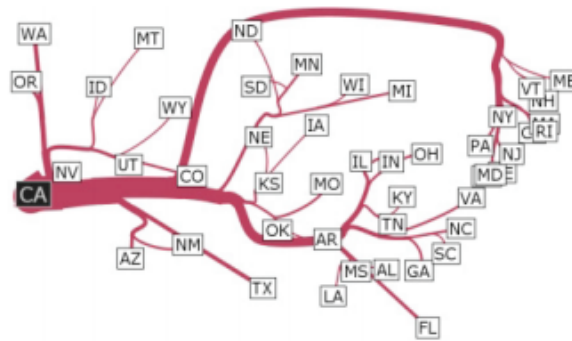


Migration from California, 95-00

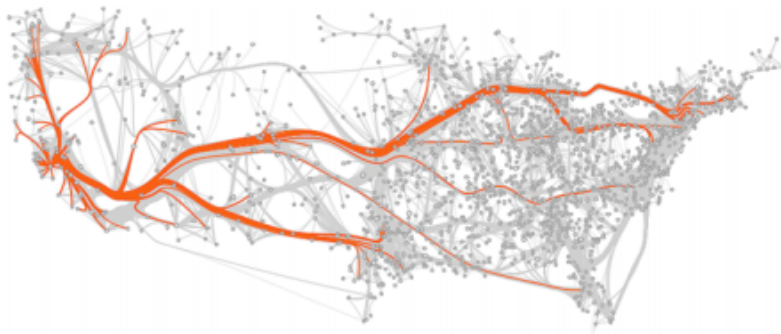
Tobler 1987



Phan et al. 2005



Verbeek et al. 2011



Cui et al. 2008



Holten & van Wijk 2009

wind map

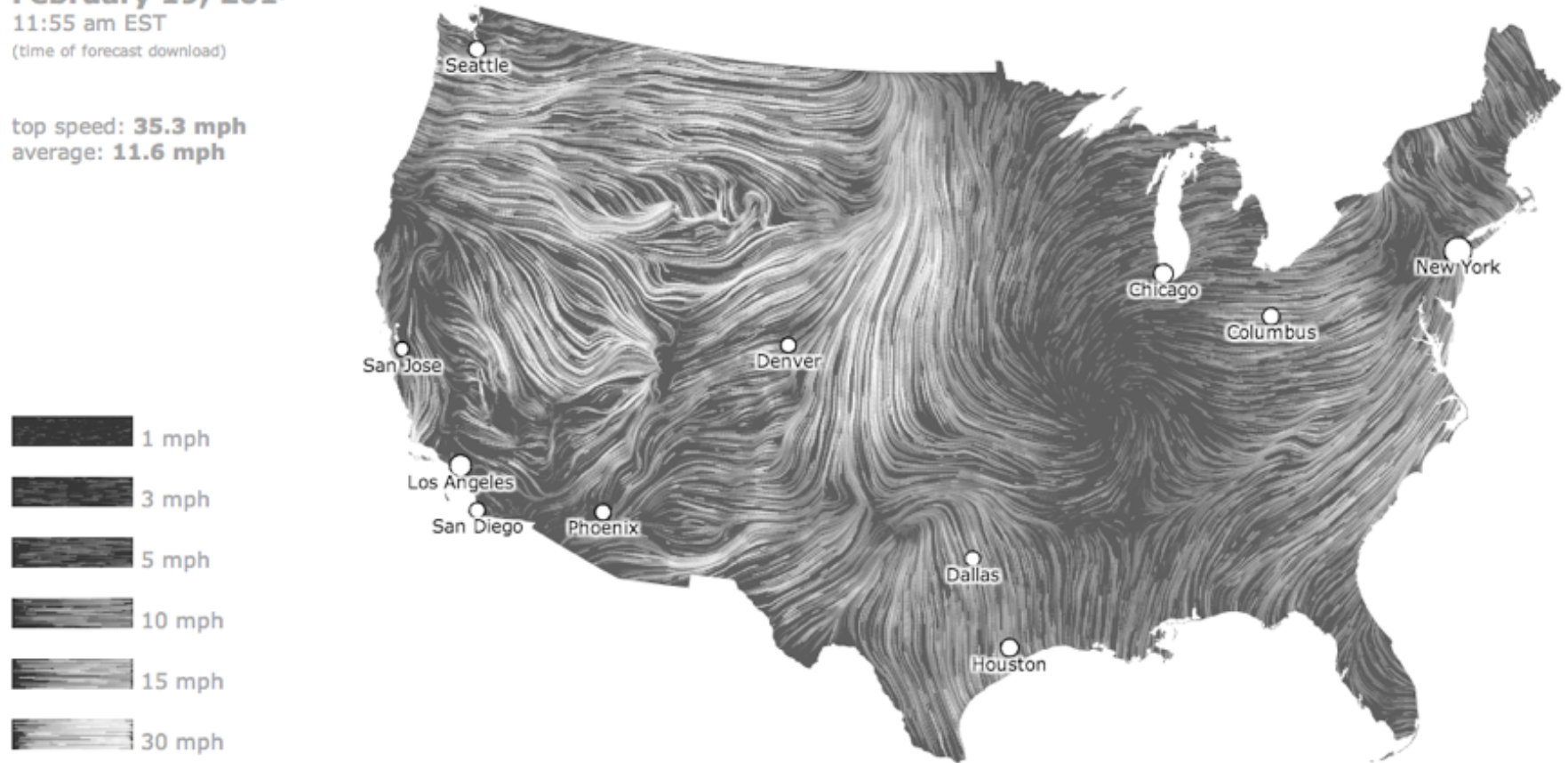
February 19, 2014

11:55 am EST

(time of forecast download)

top speed: **35.3 mph**

average: **11.6 mph**



How Obama Won Re-election

Whites Were Outvoted

Women

Hispanics

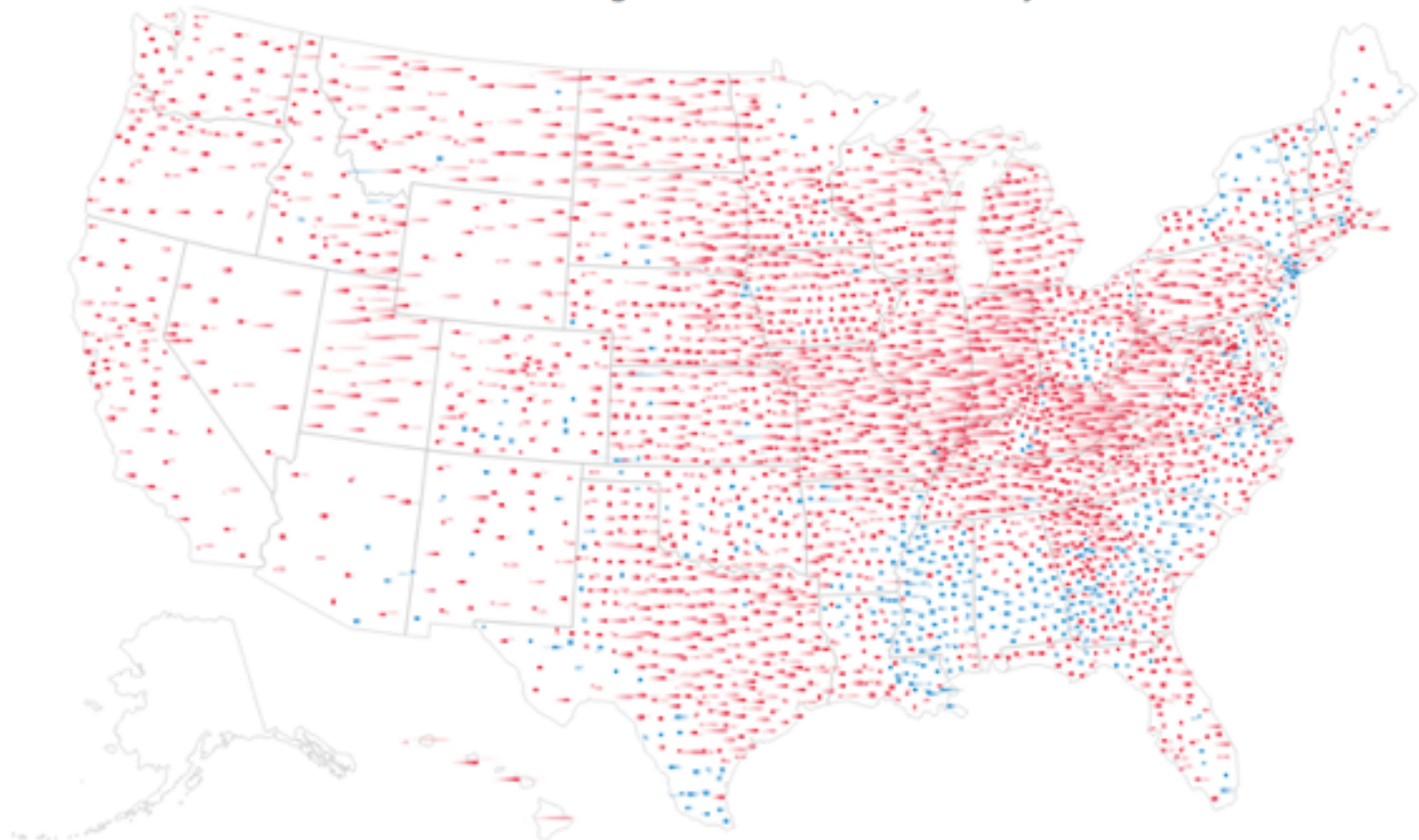
Youth

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.



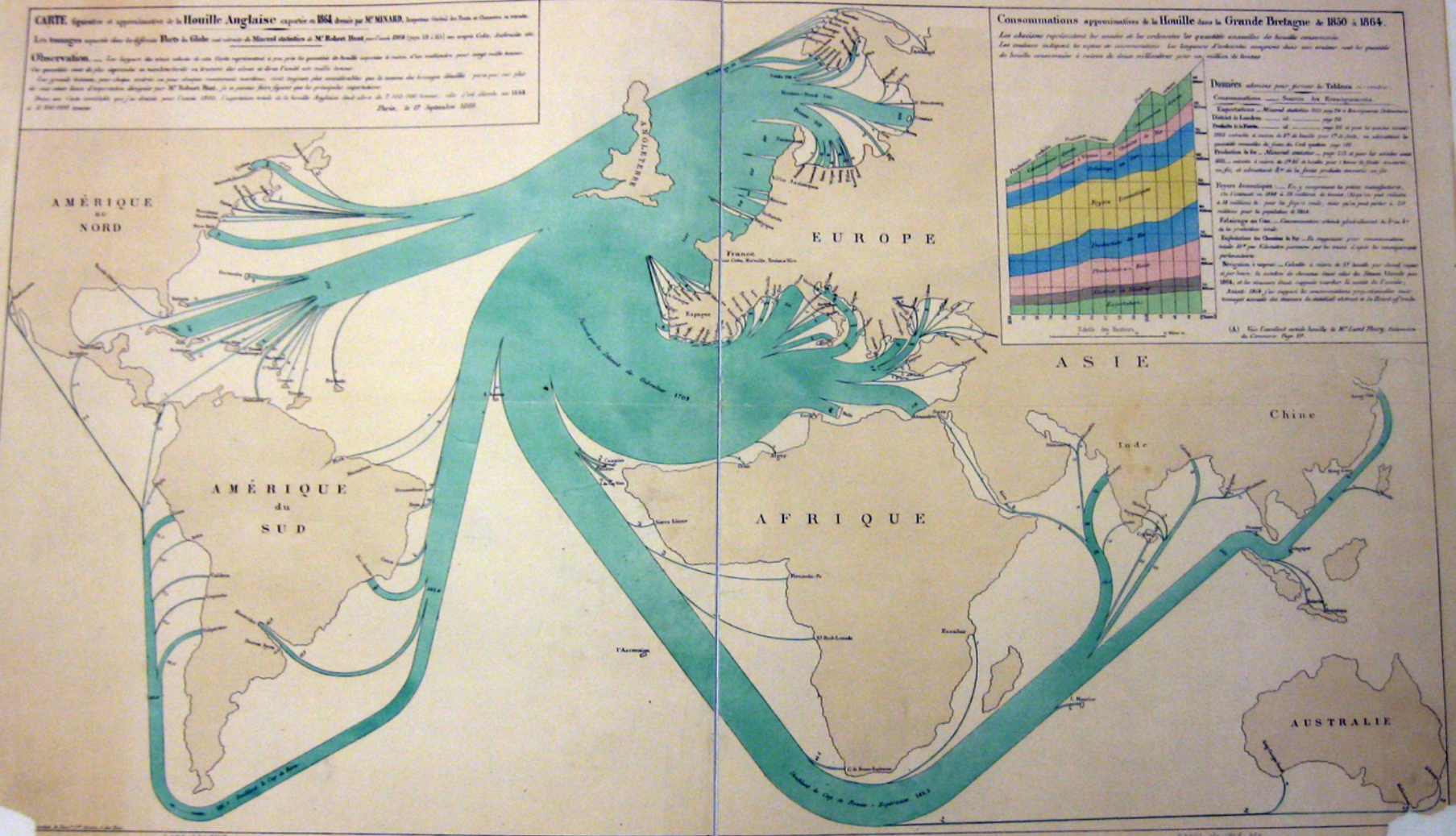
Generalization

CARTE approximative et approximative de la **Houille Anglaise** exportée en 1864 dessinée par M. MINARD, Ingénieur Général des Ponts et Chaussées à Paris.

Les passages indiqués dans les différents Ports et Golfs ont été calculés de M. Robert Duret, pour l'Année 1864 (pages 18 & 19) sur un rapport Gêner. distribué en 1864.

Observation. Les lignes de couleur indiquent le tonnage approximatif en millions de tonnes de houille exportée et non le nombre de navires pour chaque route. Une grande route de plus apparaît au Nord-Ouest en France, elle est de couleur verte, elle est destinée à servir de route de secours pour le cas où les routes principales seraient interrompues.

Paris, le 27 Septembre 1864.



Consommations approximatives de la Houille dans la Grande Bretagne de 1850 à 1864.

Les chiffres représentent les années et les courbes les quantités annuelles de houille consommée. Les courbes indiquent le degré de consommation. Les lignes d'horizontales marquent dans un million de tonnes le nombre de houille consommée à raison de deux millions pour un million de tonnes.

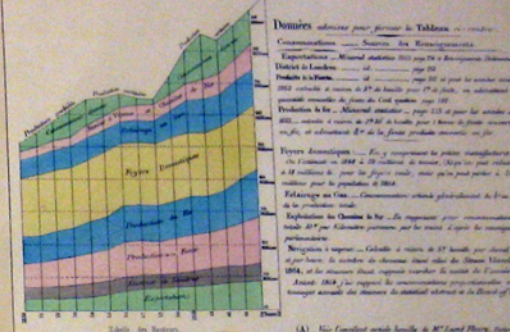
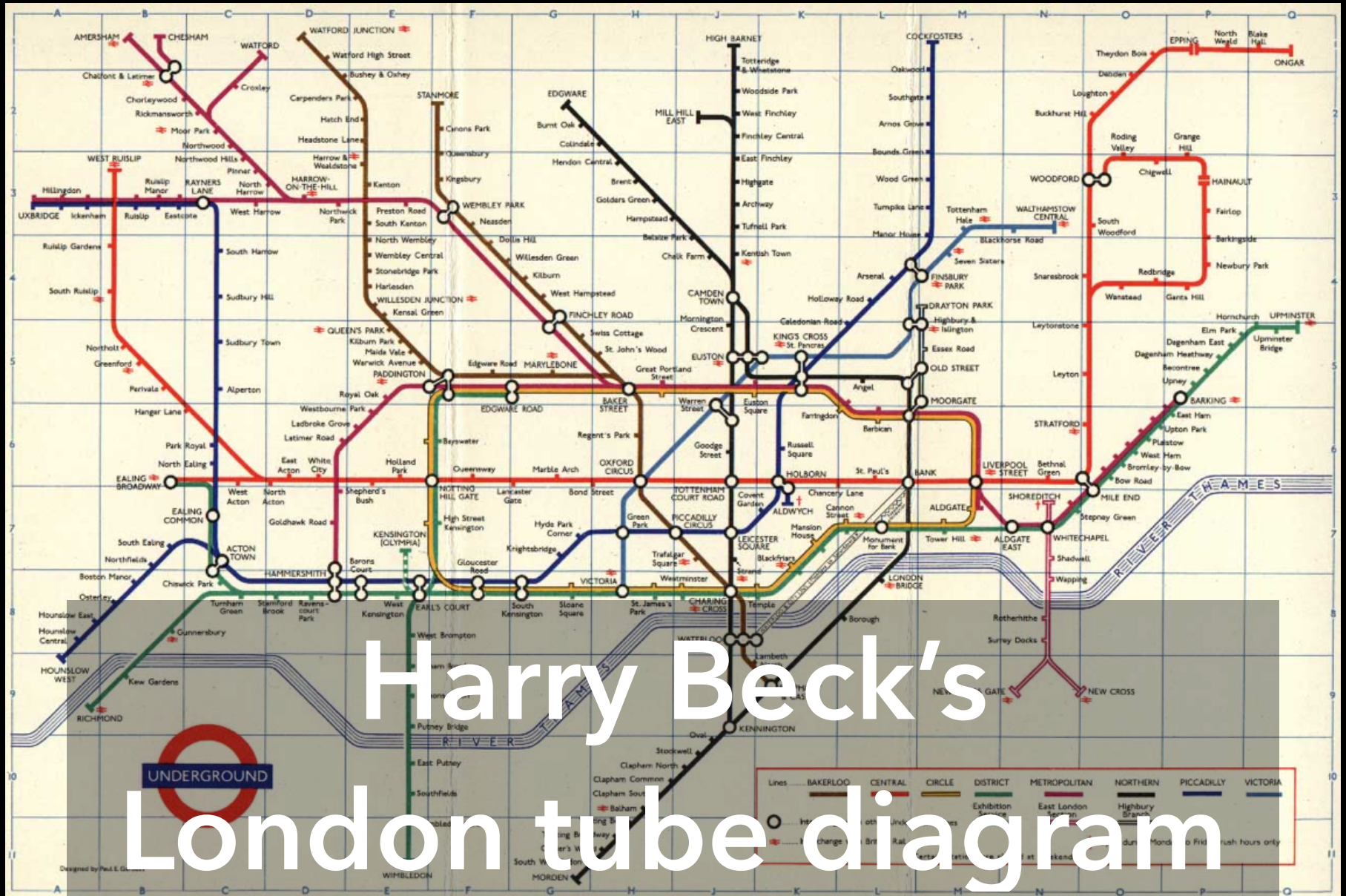
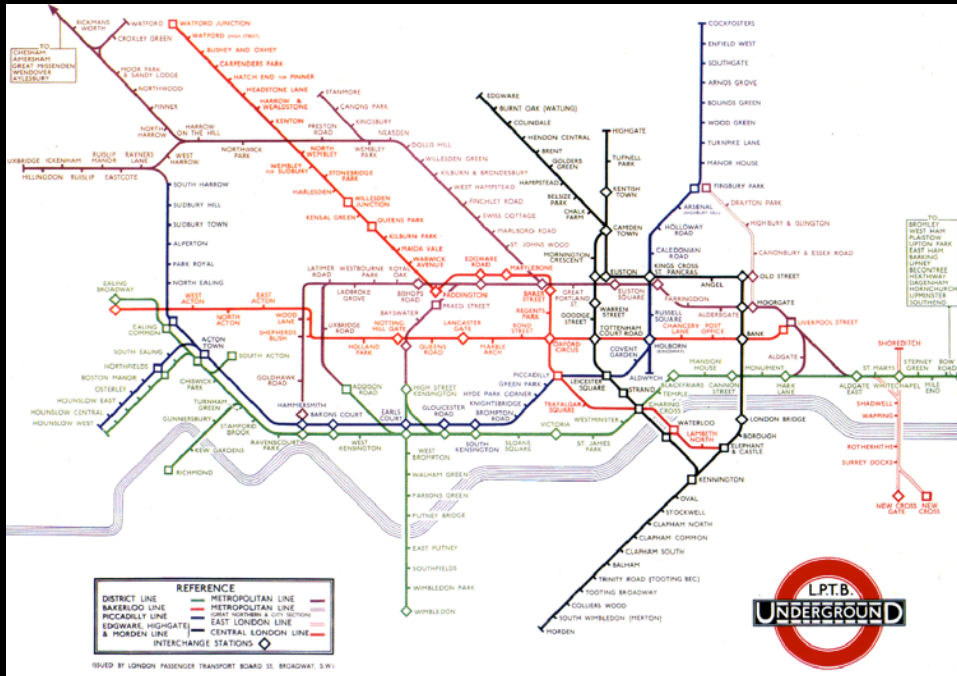


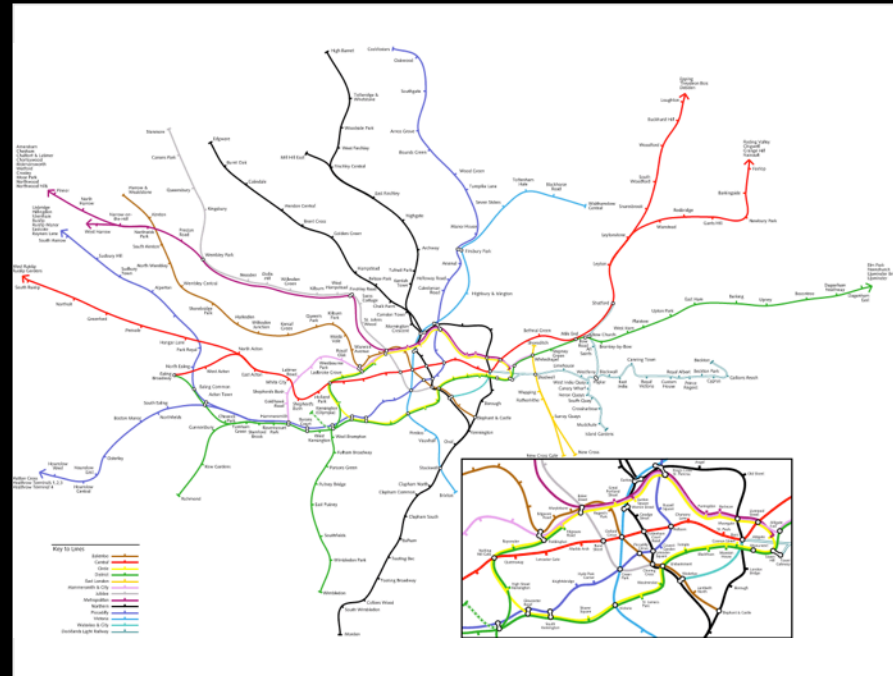
Tableau des Revenus, par M. de la Roche, Ingénieur des Ponts et Chaussées, page 10.

1864 British Coal Exports, Charles Minard





London Underground [Beck 33]



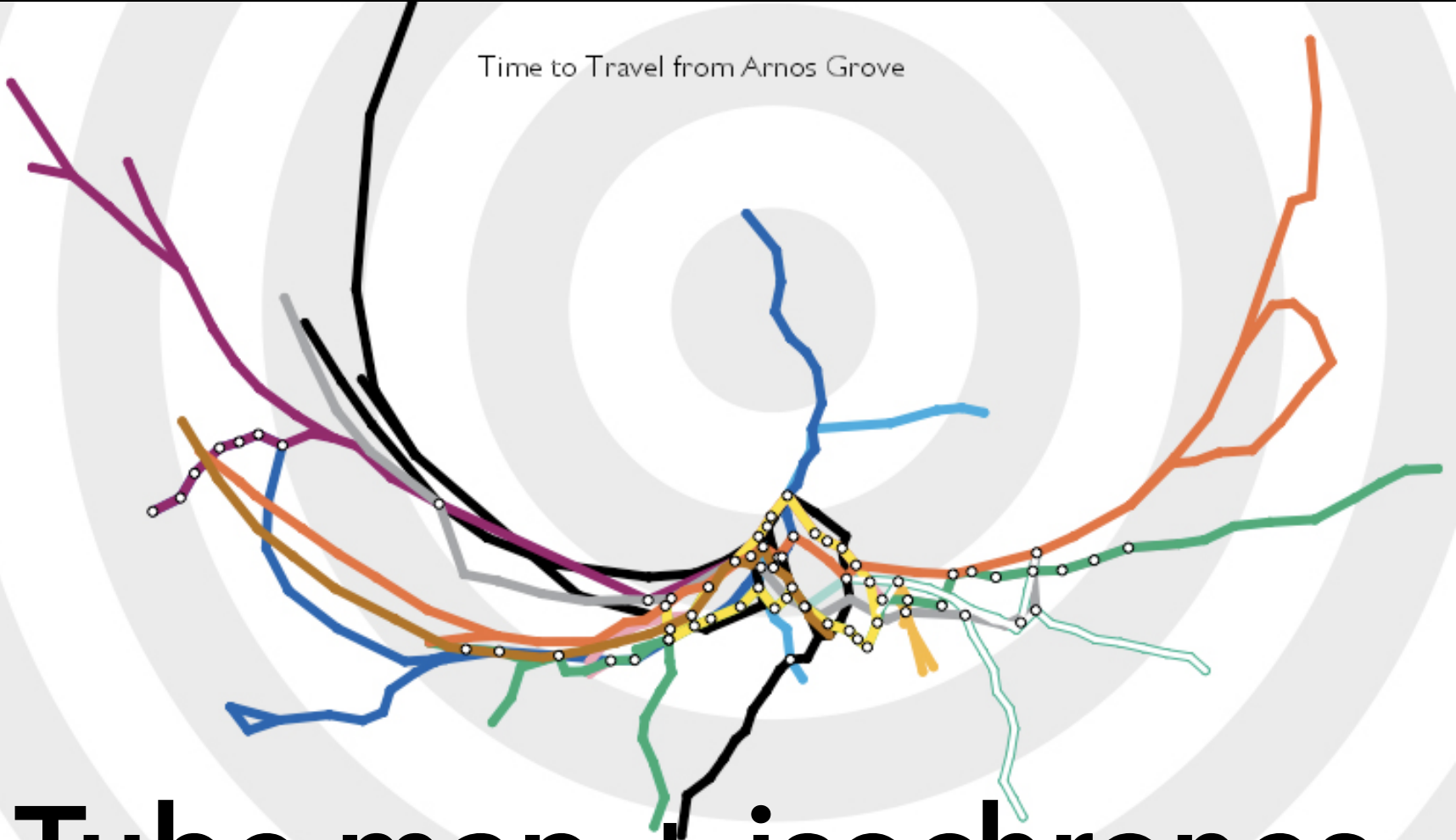
Geographic version of map

Principle: Straighten lines to emphasize stop sequence
Technique used to emphasize/de-emphasize information



People *love*
the tube map

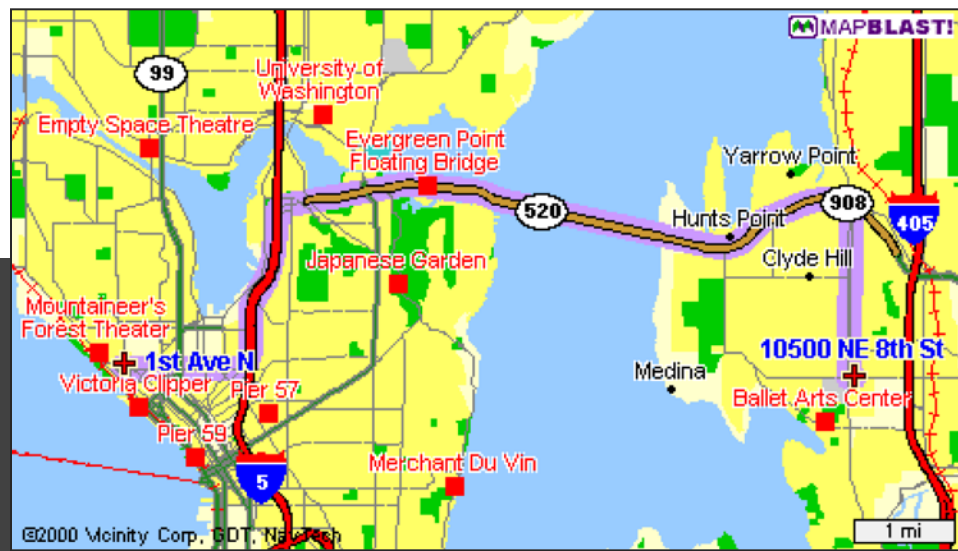
Time to Travel from Arnos Grove



Tube map + isochrones

0 5 10
minutes

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

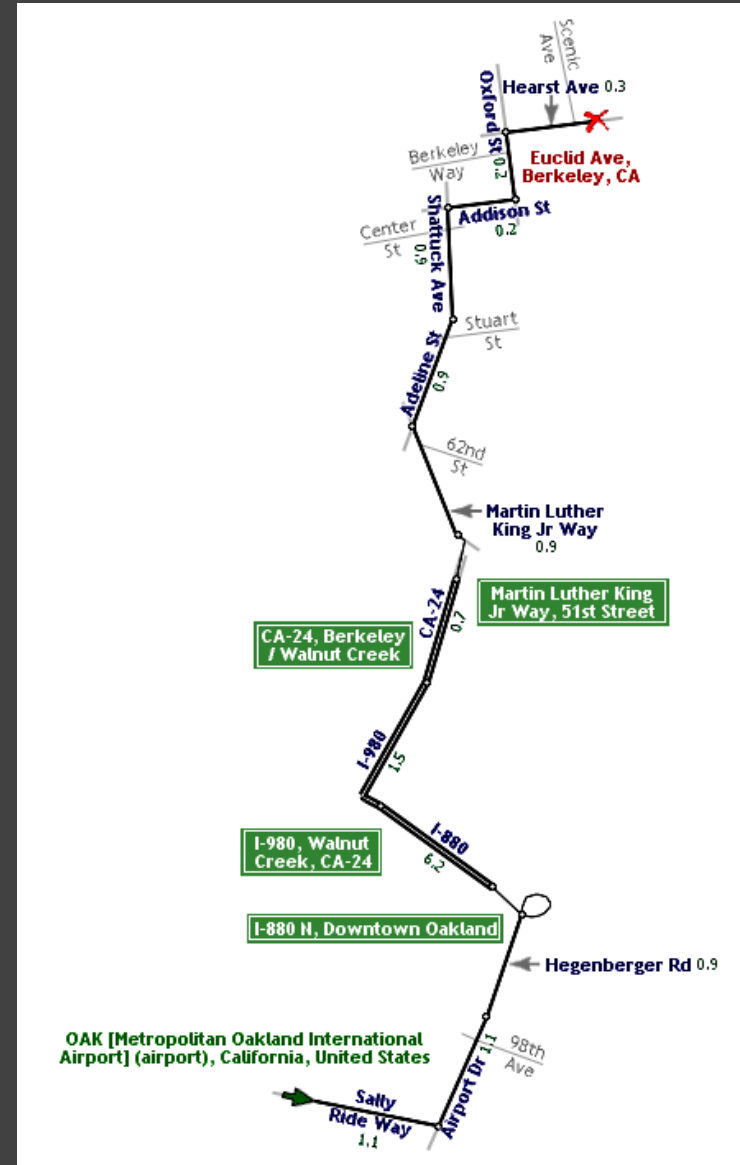
Develop constraints based on design principles

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

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

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/>