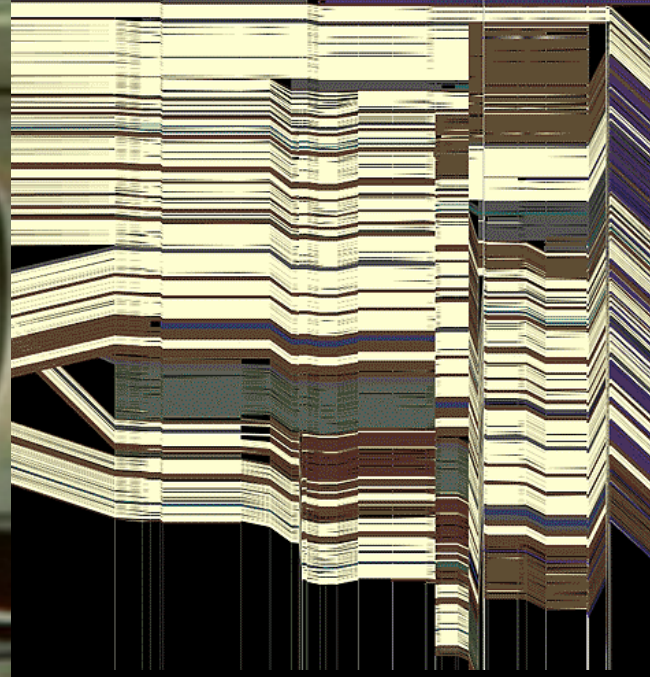
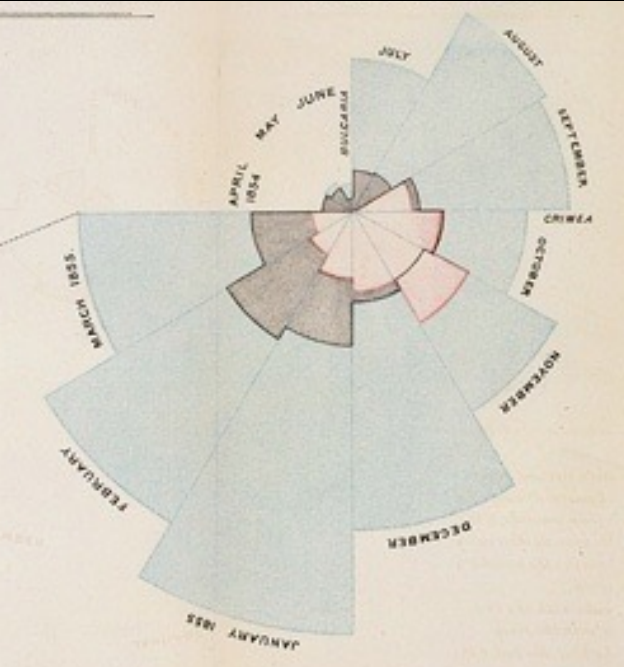


CSE 512 - Data Visualization

# Mapping & Cartography

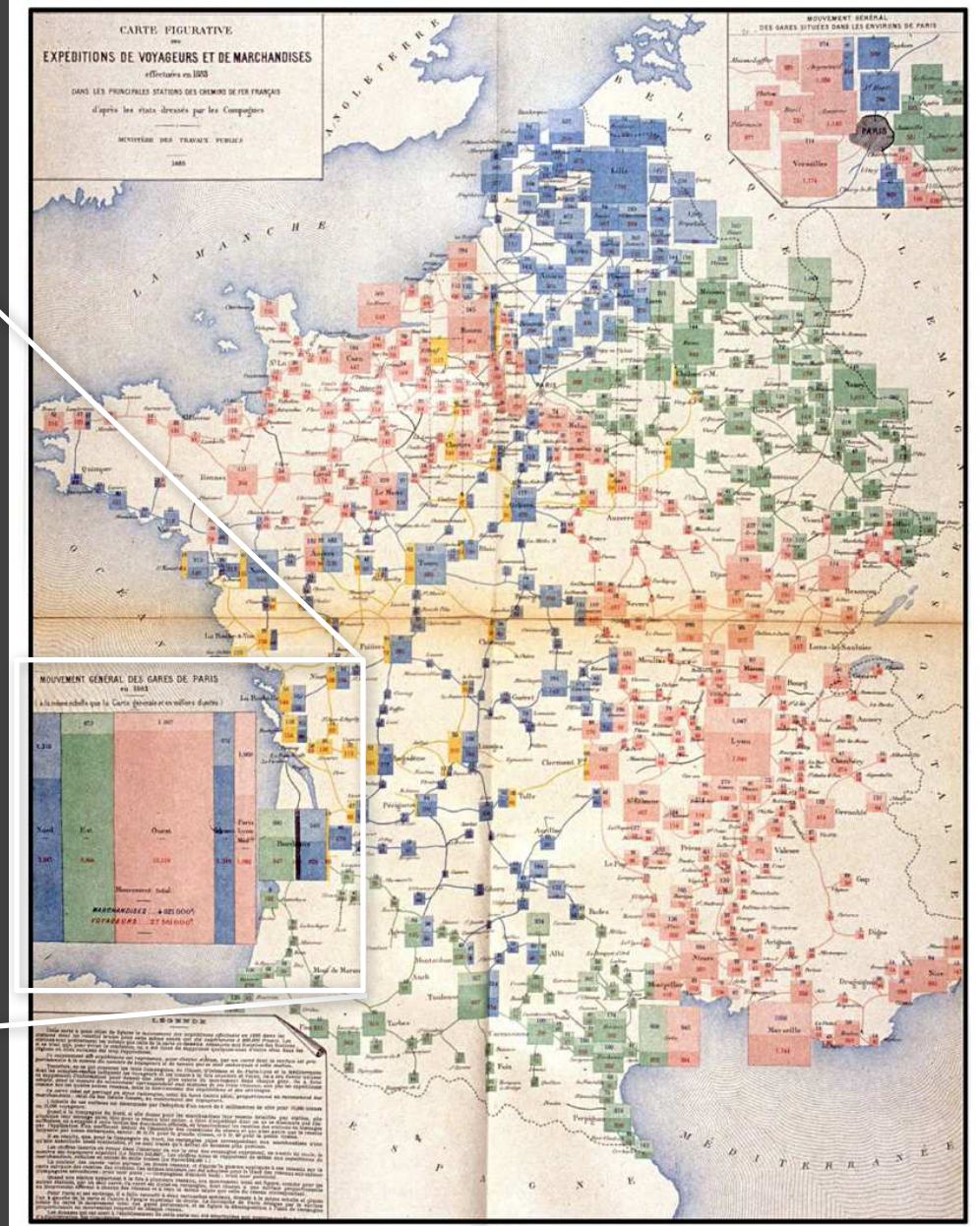
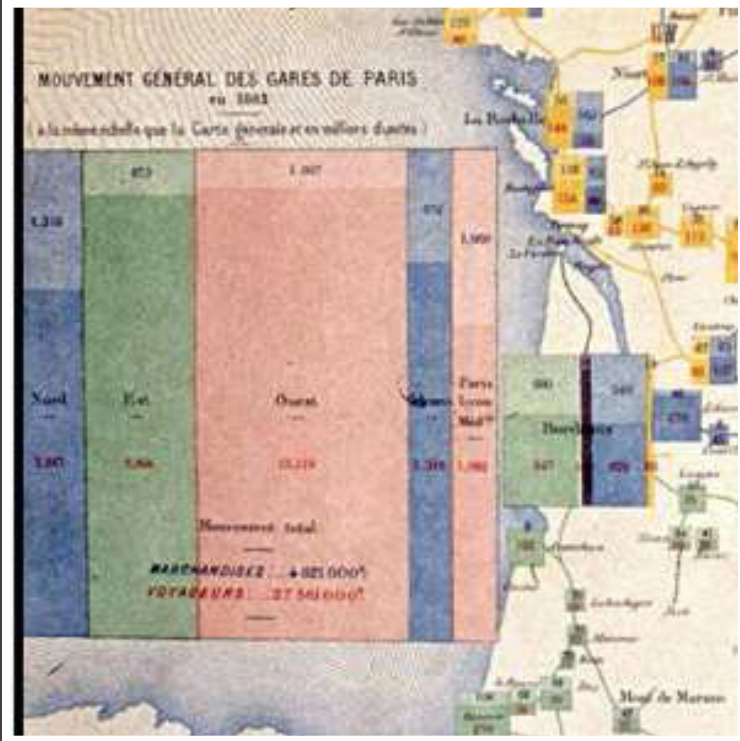


**Jeffrey Heer** University of Washington  
(with significant material from Michal Migurski)



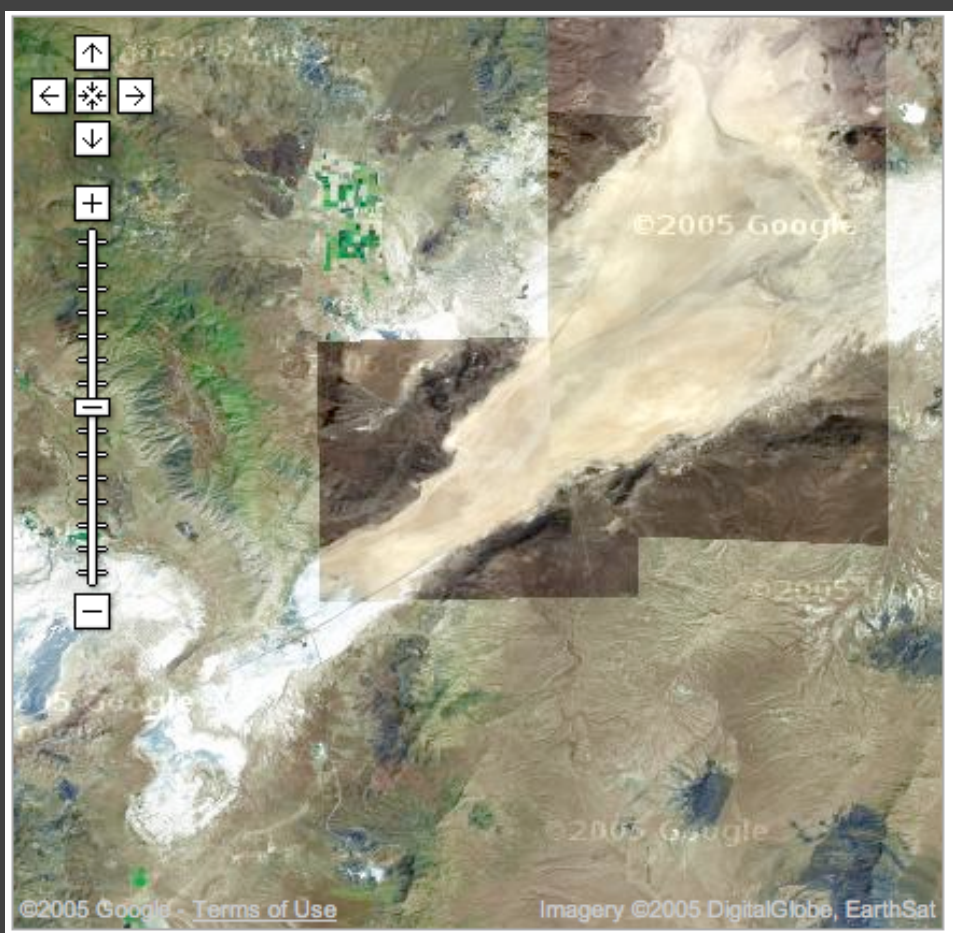
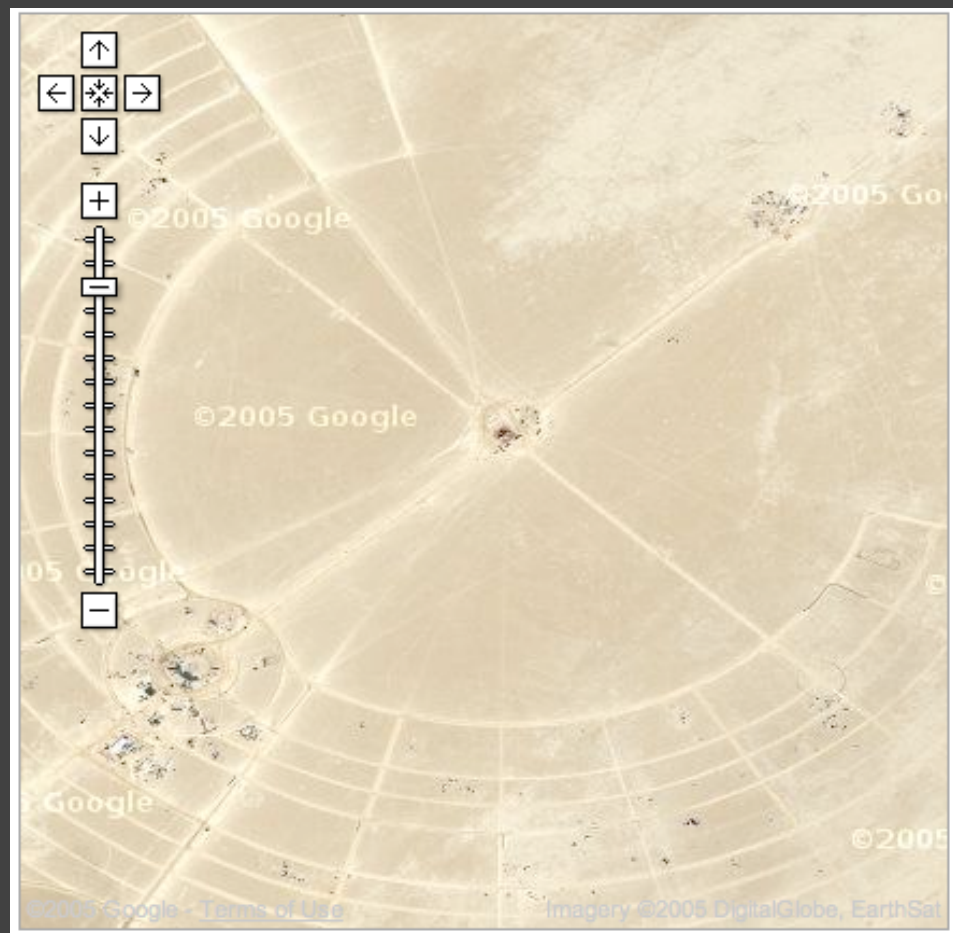
Ptolemy's Geographica  
Original ~150AD, This Map ~1300AD





Rail Passengers and Freight from Paris 1884





Google Maps 2005



# Casualties of War

FACES | ANALYSIS | THEIR STORIES

E-MAIL | FEEDBACK

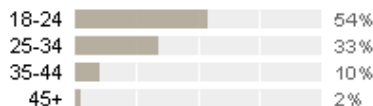
Use the slider below to investigate the demographics and military status of U.S. service members who died during the war in Iraq.

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

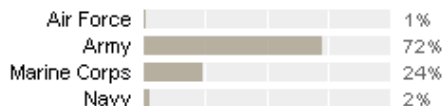
Show all | Initial invasion | First invasion of Falluja | Second invasion of Falluja | Since troop buildup began

4,097 deaths

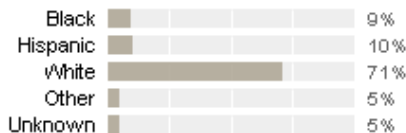
### Age



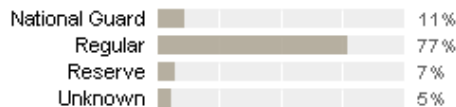
### Branch of Military



### Race



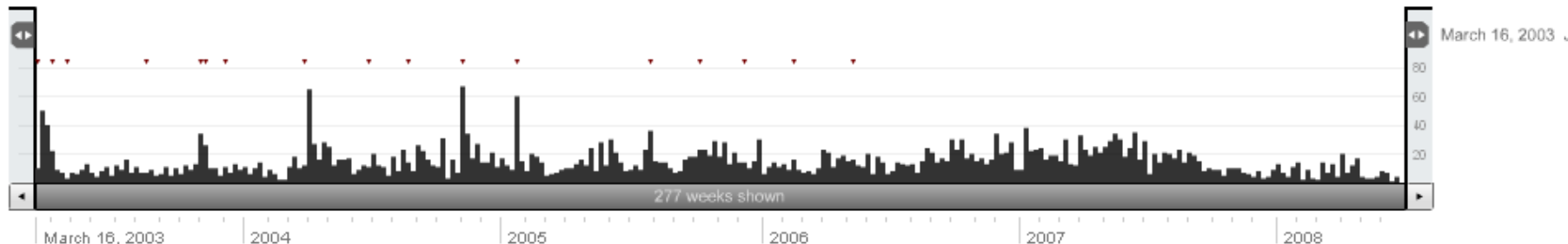
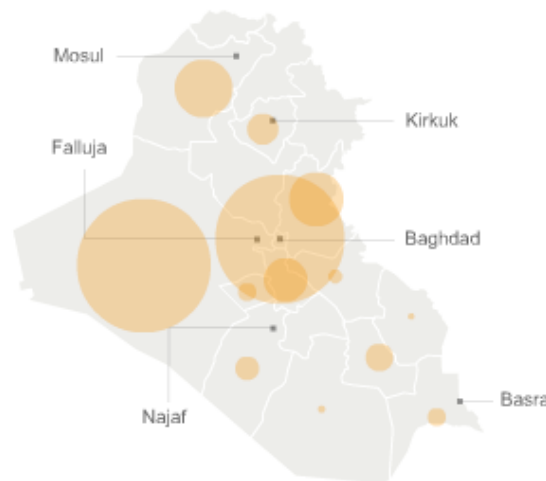
### Type of Duty



### Location of death

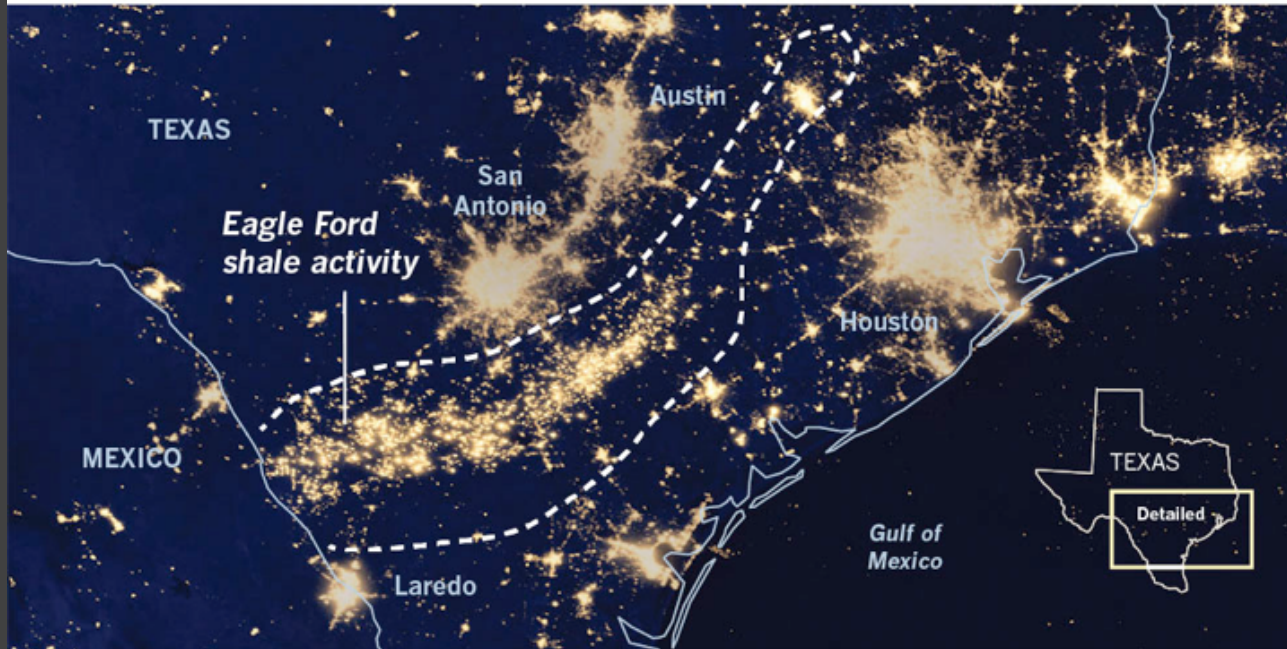
Circles sized according to percentage of deaths in each Iraqi province.

Show home



# Texas oil boom is visible from space

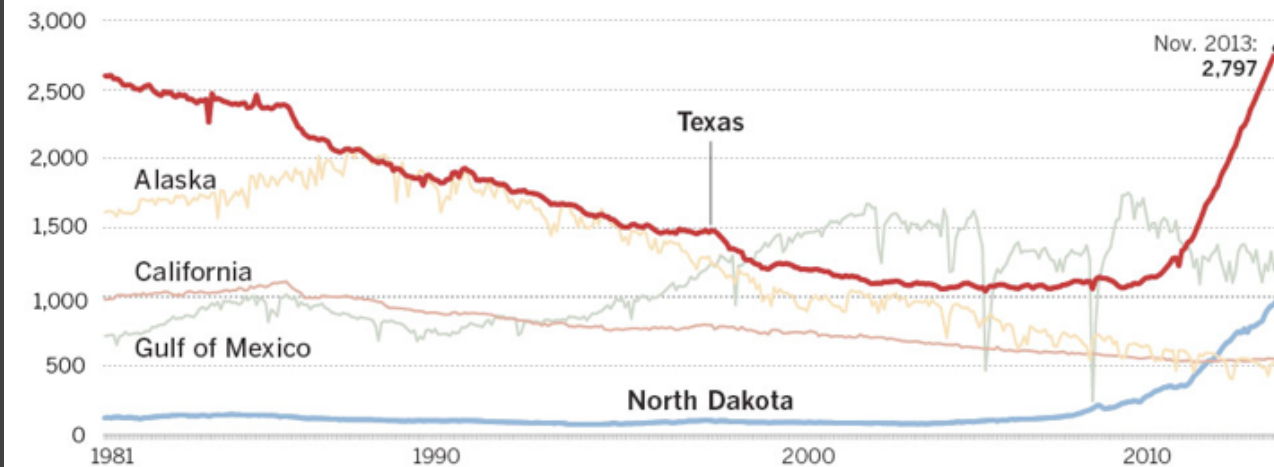
Lighting and natural gas flares from drilling on the 400-mile-long Eagle Ford shale formation can be seen from space in this image.



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.

## 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.



17 MILES TO BAGHDAD

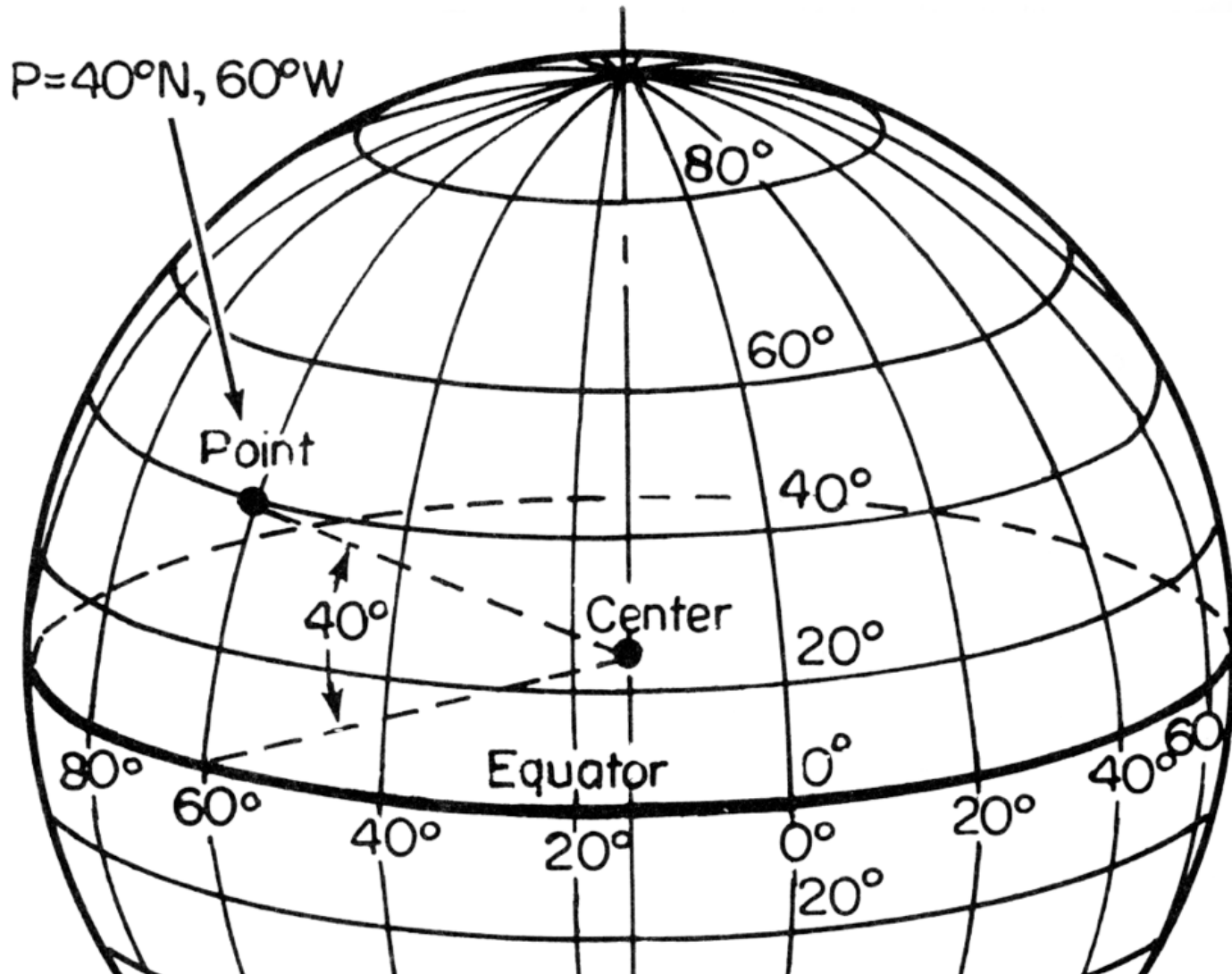
# Cartography

The Making of Maps

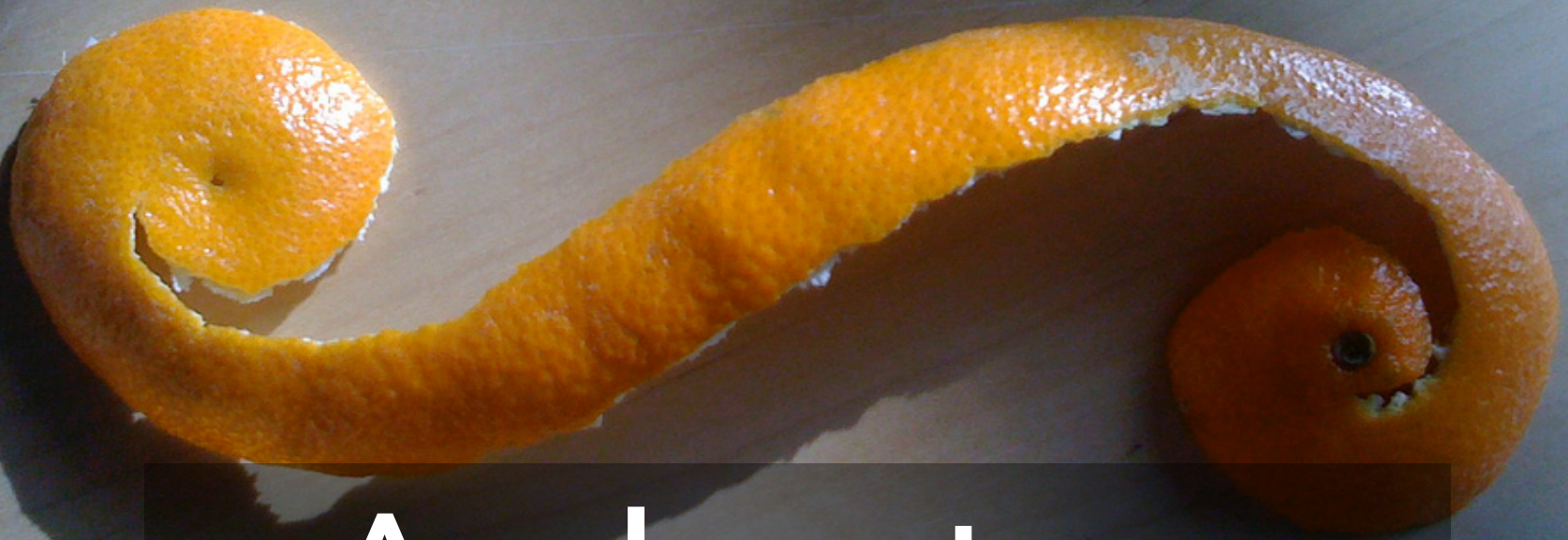


# Projections

# Latitude, Longitude







**A sphere tears  
when you flatten it**

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

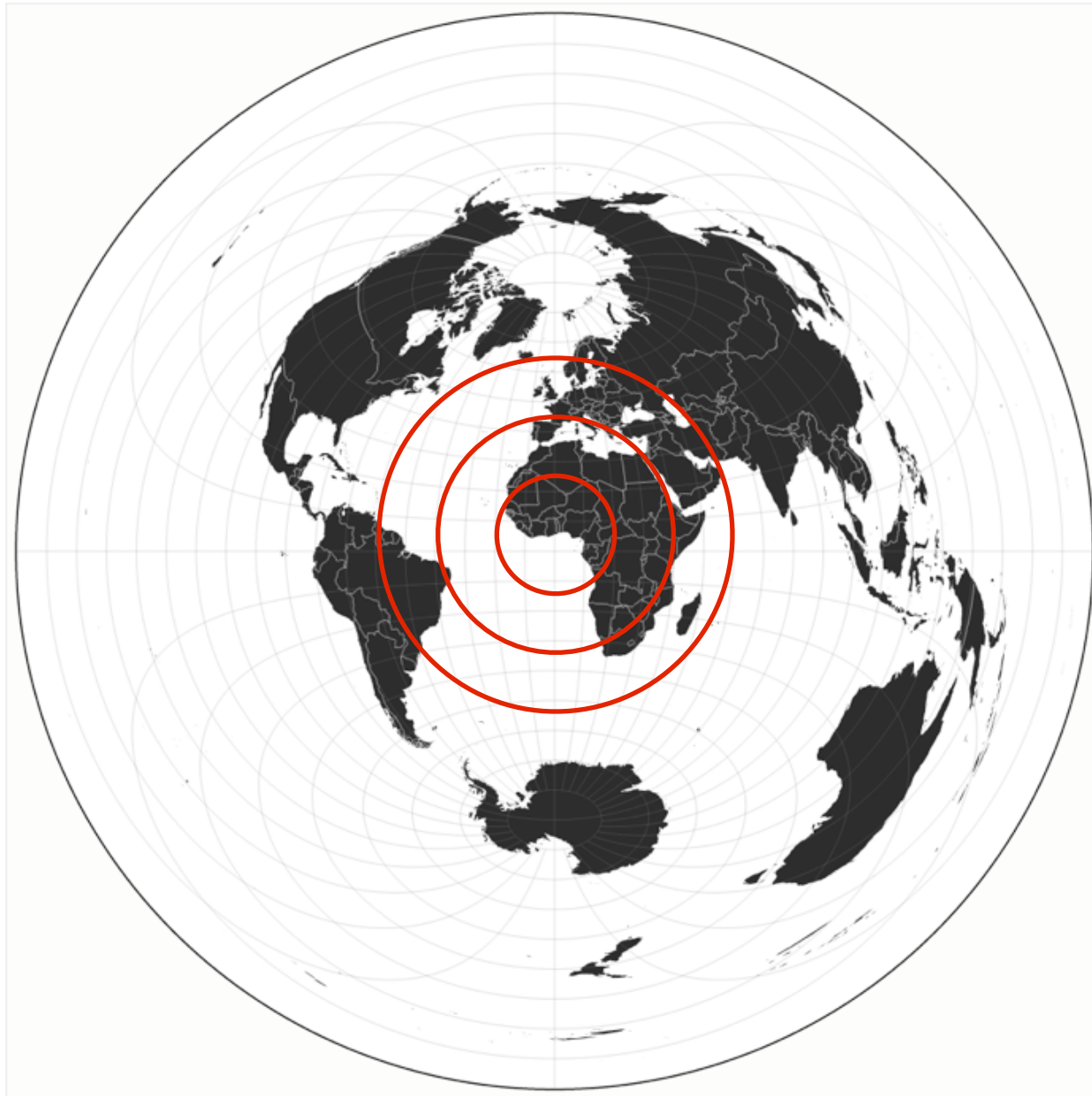


# Azimuthal

Preserves direction / distance



# Azimuthal Equidistant

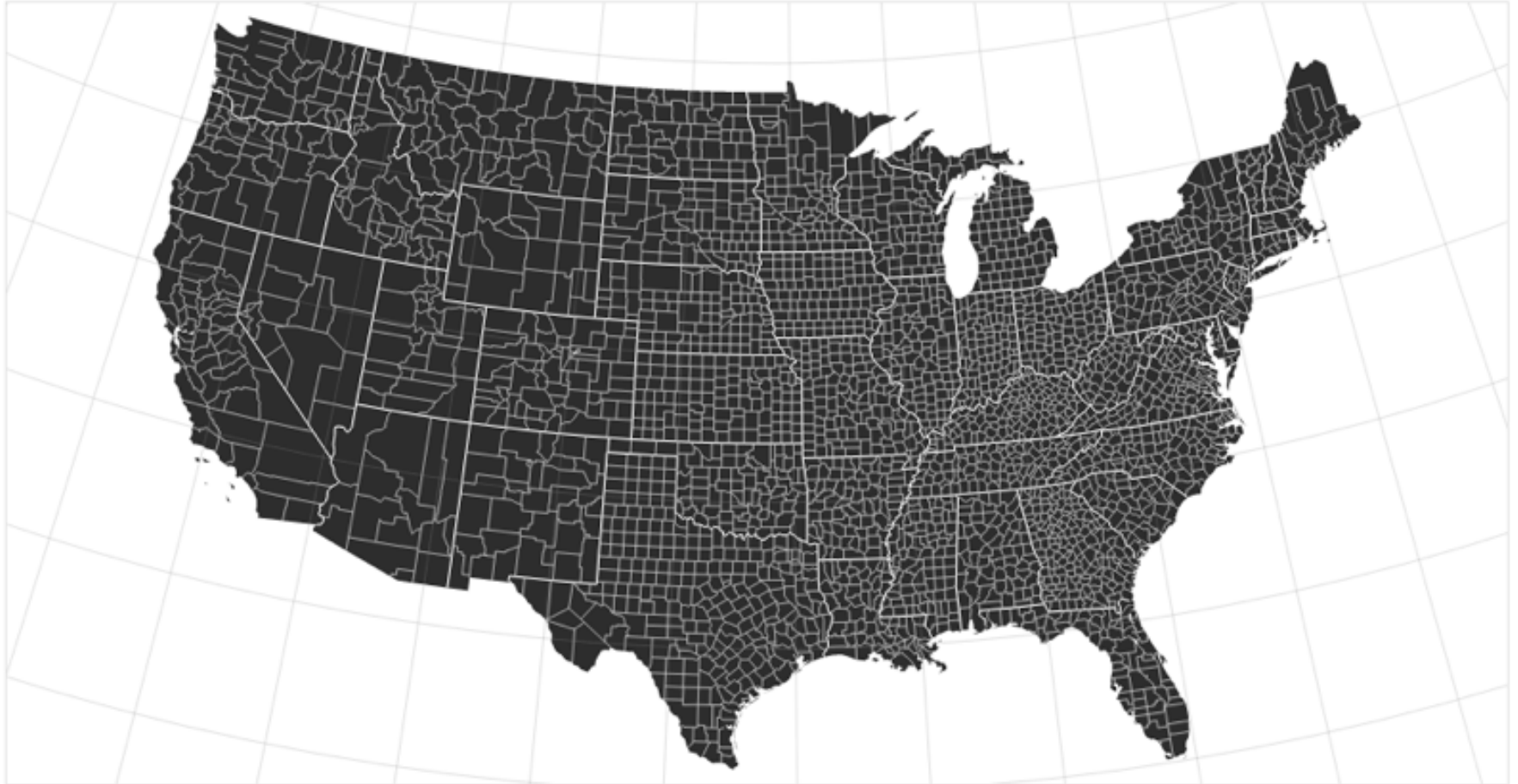




# Equal-Area

Preserves 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 dark gray background and yellow landmasses. A semi-transparent dark gray rectangular box is centered over the map, containing the text 'Conformal' and 'Preserves local angles'.

# Conformal

Preserves local angles

# Spherical Mercator





Traffic

More...

Map

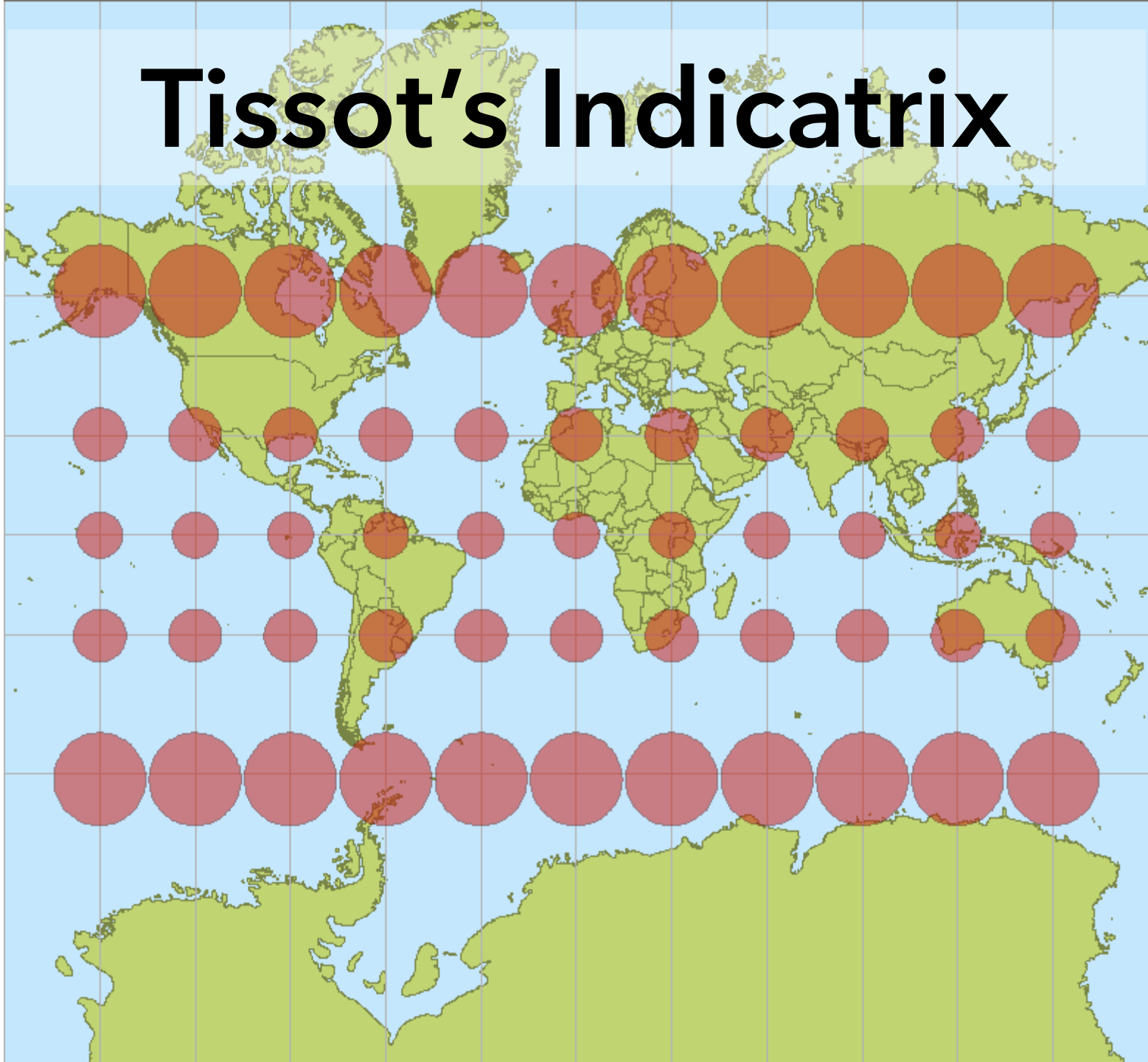
Satellite

Terrain

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



# Tissot's Indicatrix



# 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.

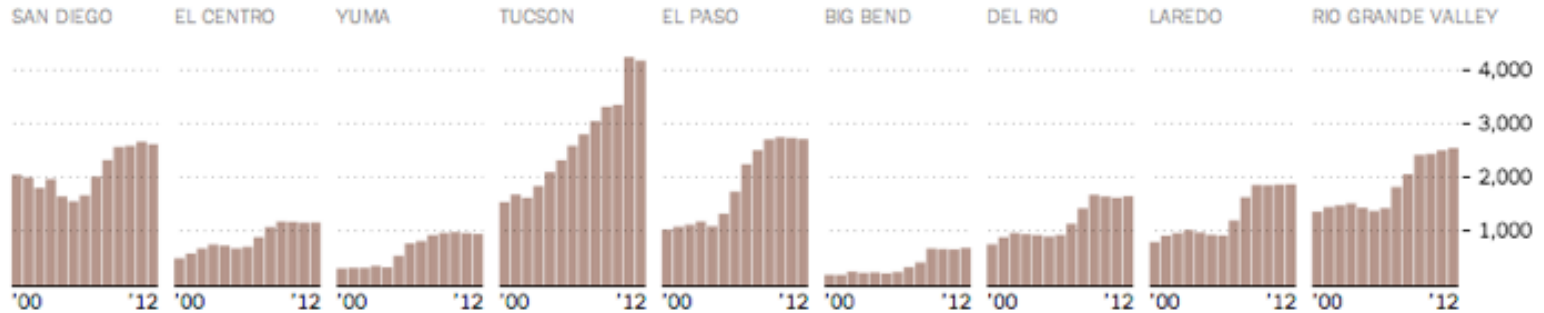
Projections usually  
have a home

# 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.

A world map with a grid of latitude and longitude lines. The landmasses are colored in a light tan or yellowish-brown, while the oceans are light blue. A series of white, jagged lines represent a path where the sphere is being torn, starting from the top left and moving towards the bottom right, passing through the Atlantic and Indian Oceans. The map is presented in a slightly distorted, non-rectangular shape.

**There are interesting  
ways to tear spheres**

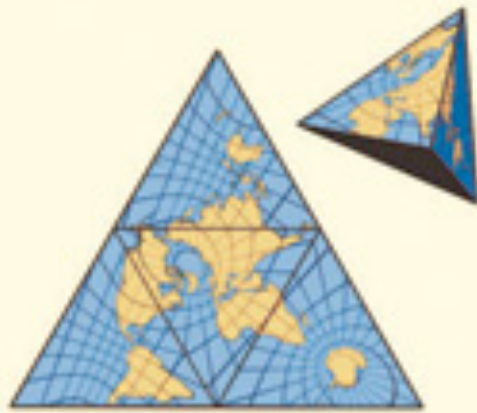


One notable interesting  
way to tear a sphere

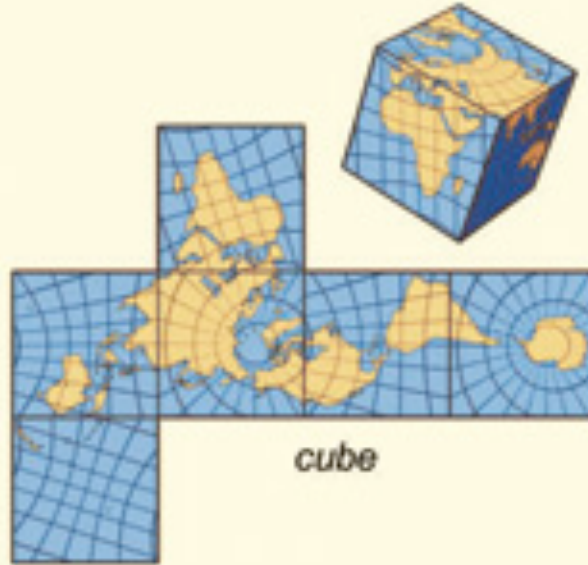




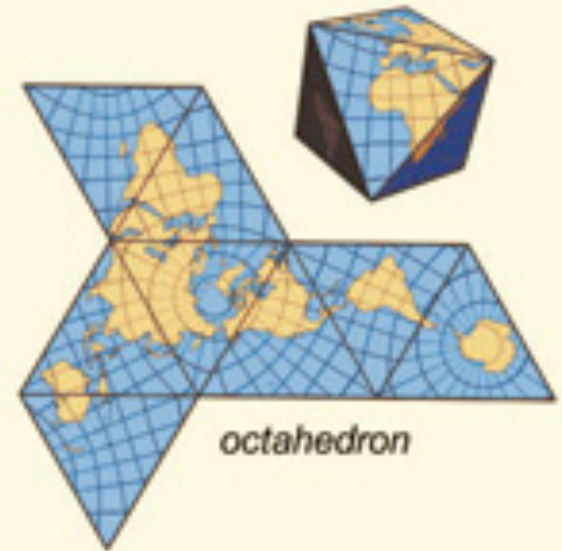




*tetrahedron*



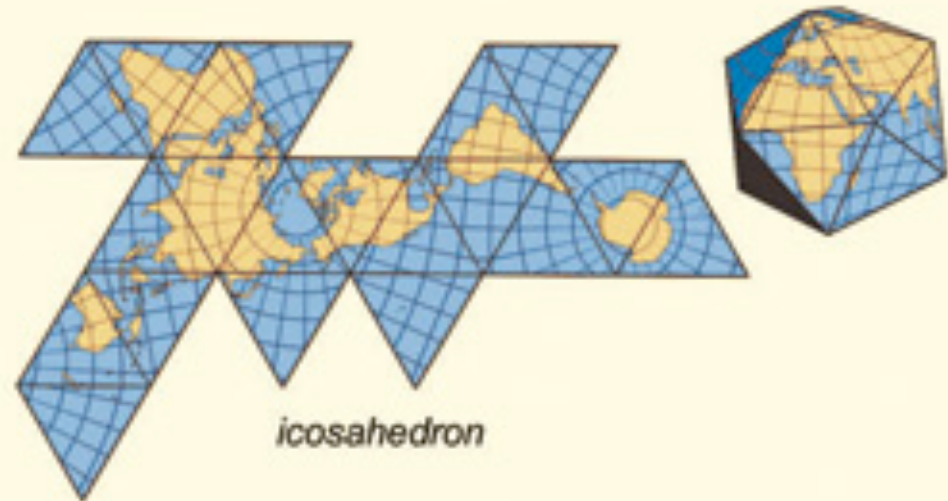
*cube*



*octahedron*



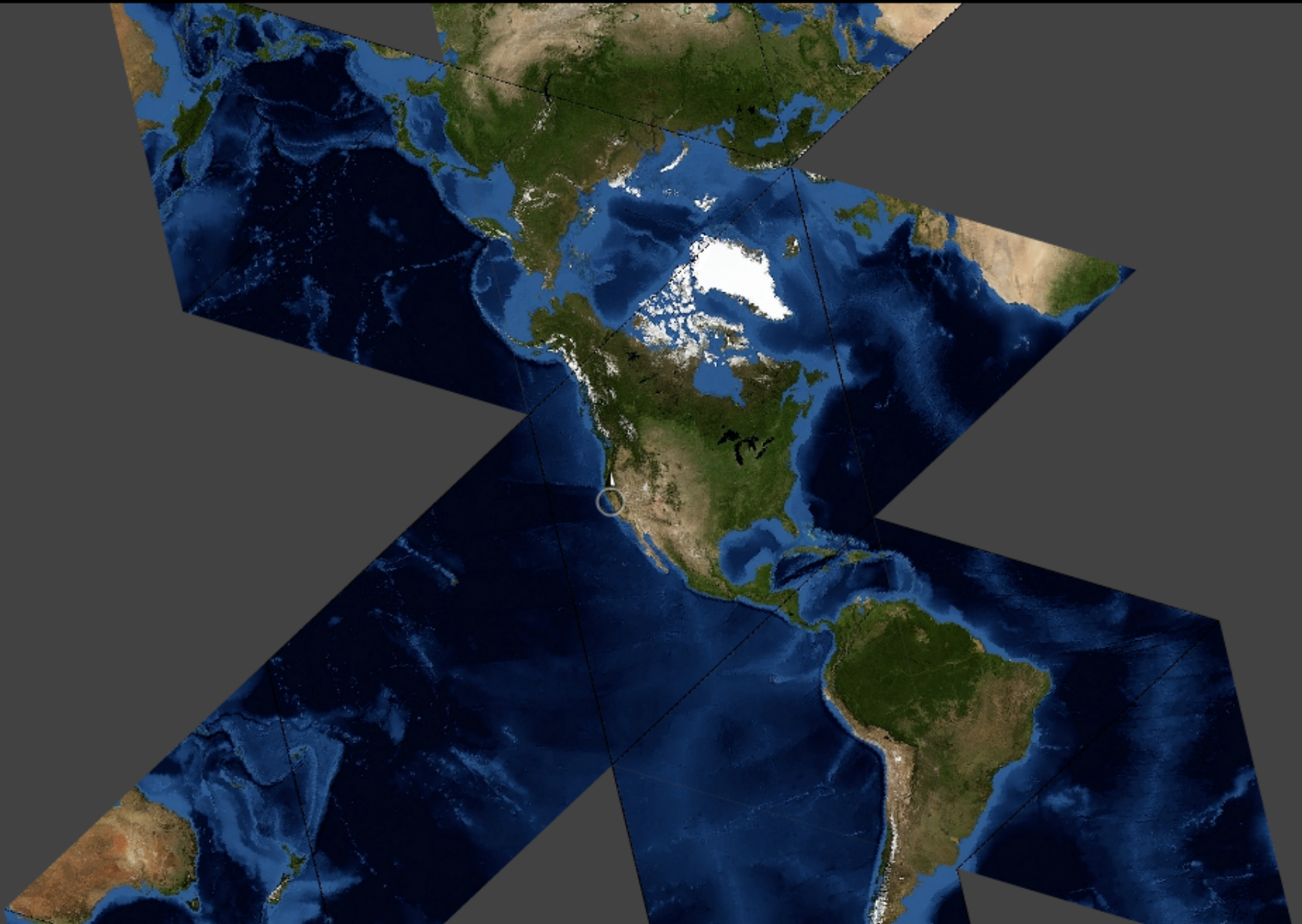
*dodecahedron*



*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**





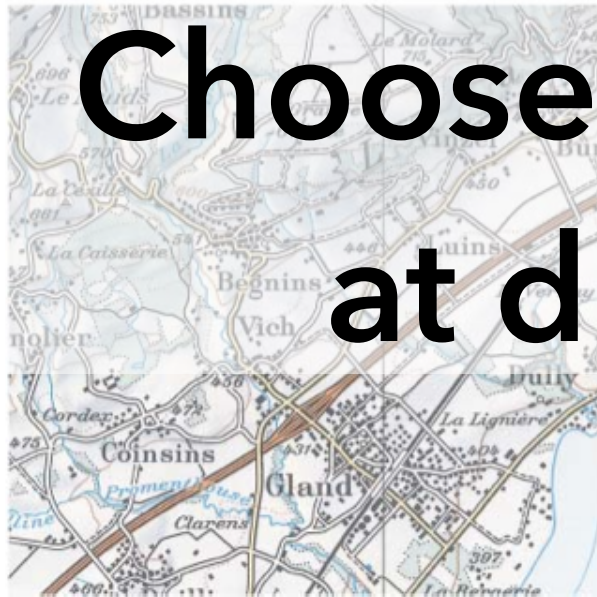
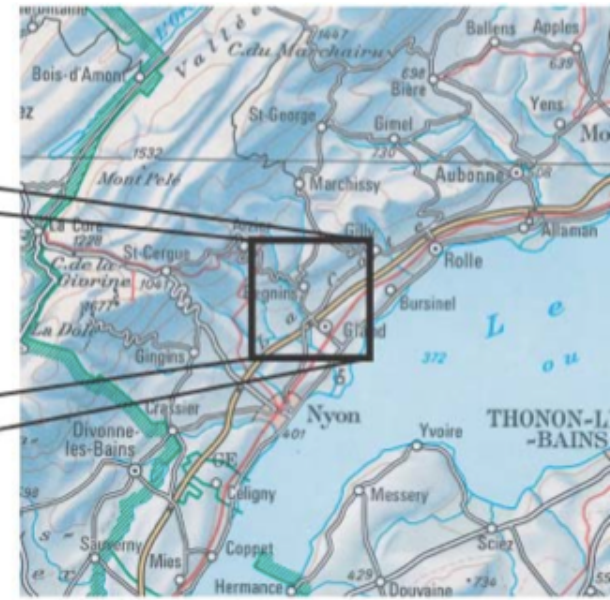
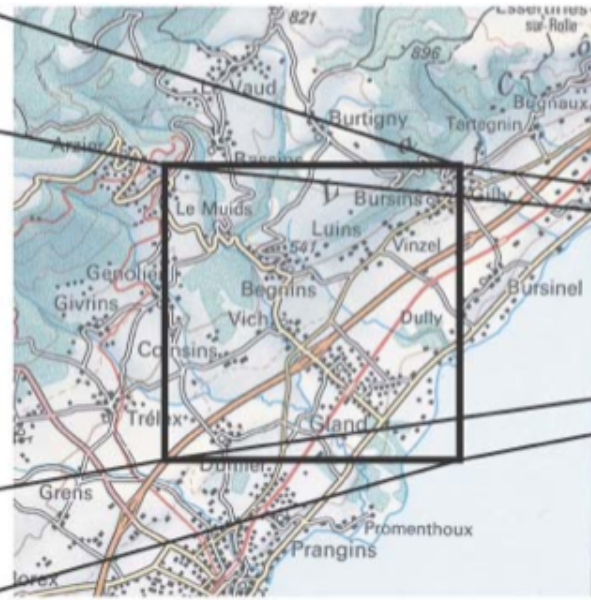
**This is not "scale"**

*Texas-Europe Size Comparison*

# Scale is an idea imported from print







**Choose the right content  
at different scales**



**Four maps, same area**









Pittsburgh

Harrisburg

Reading

NEW JERSEY

Camden

Cumberland

MARYLAND

Millville

Washington

DELAWARE

Harrisonburg

WEST VIRGINIA

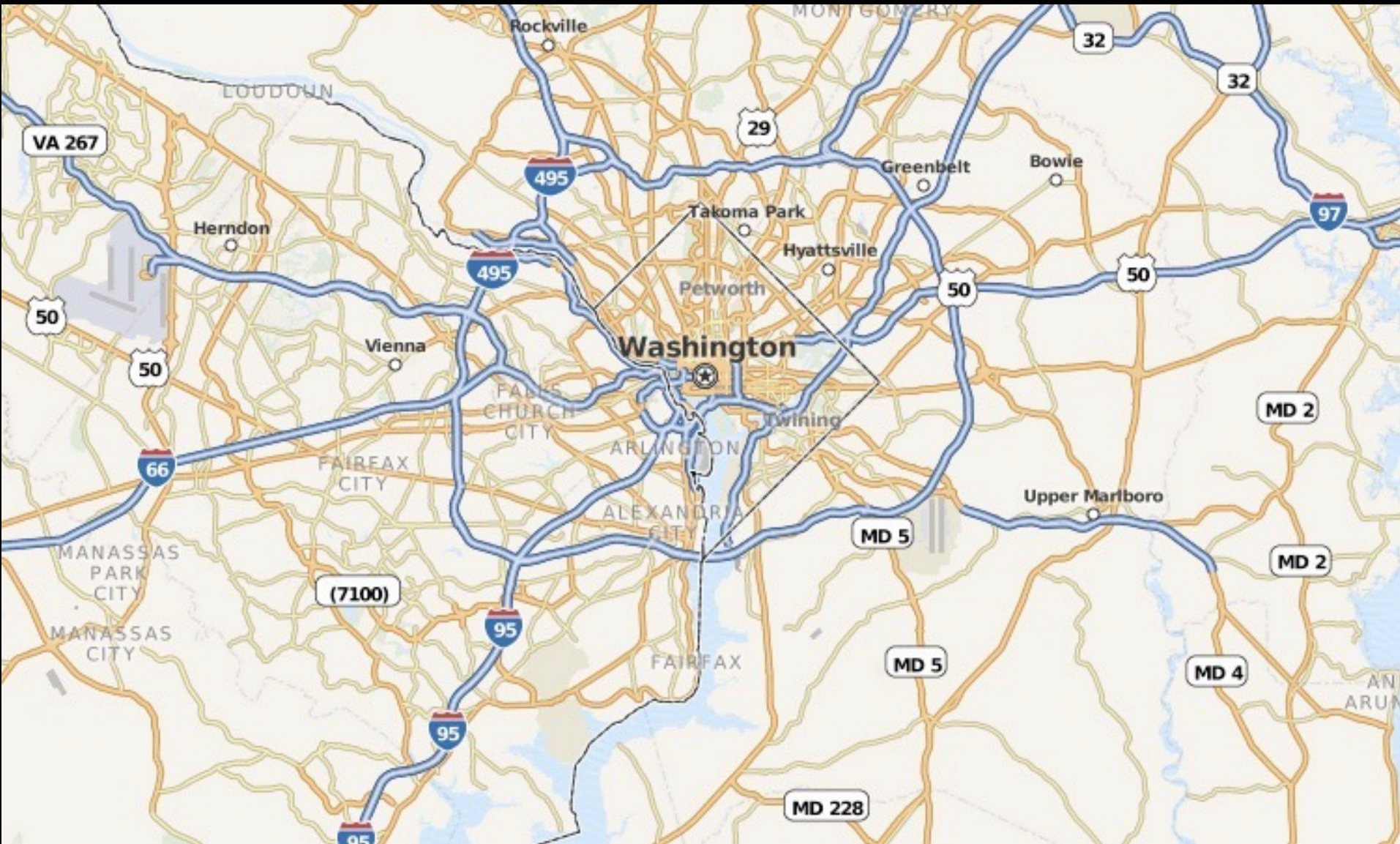
Richmond

Roanoke

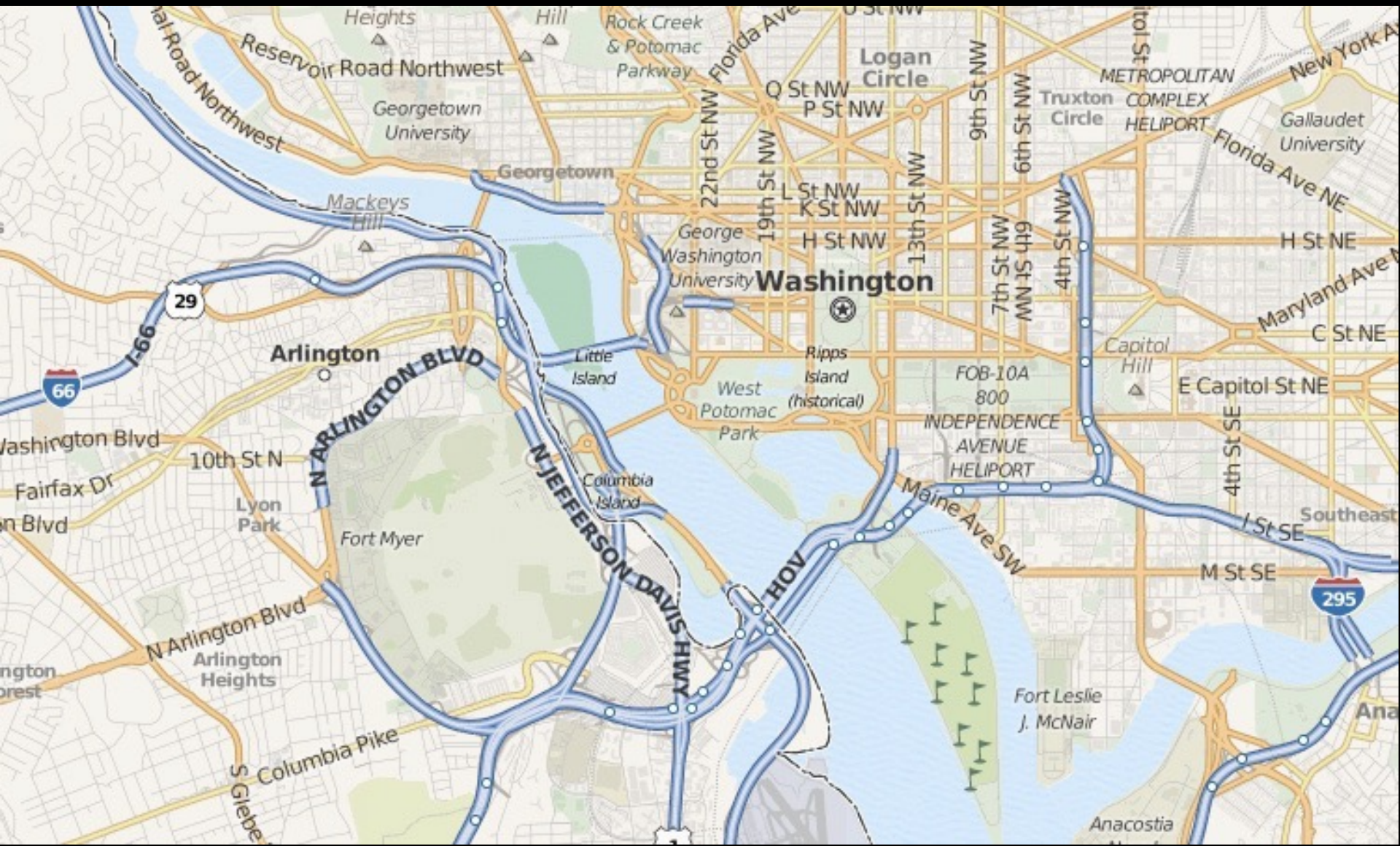
VIRGINIA

Suffolk

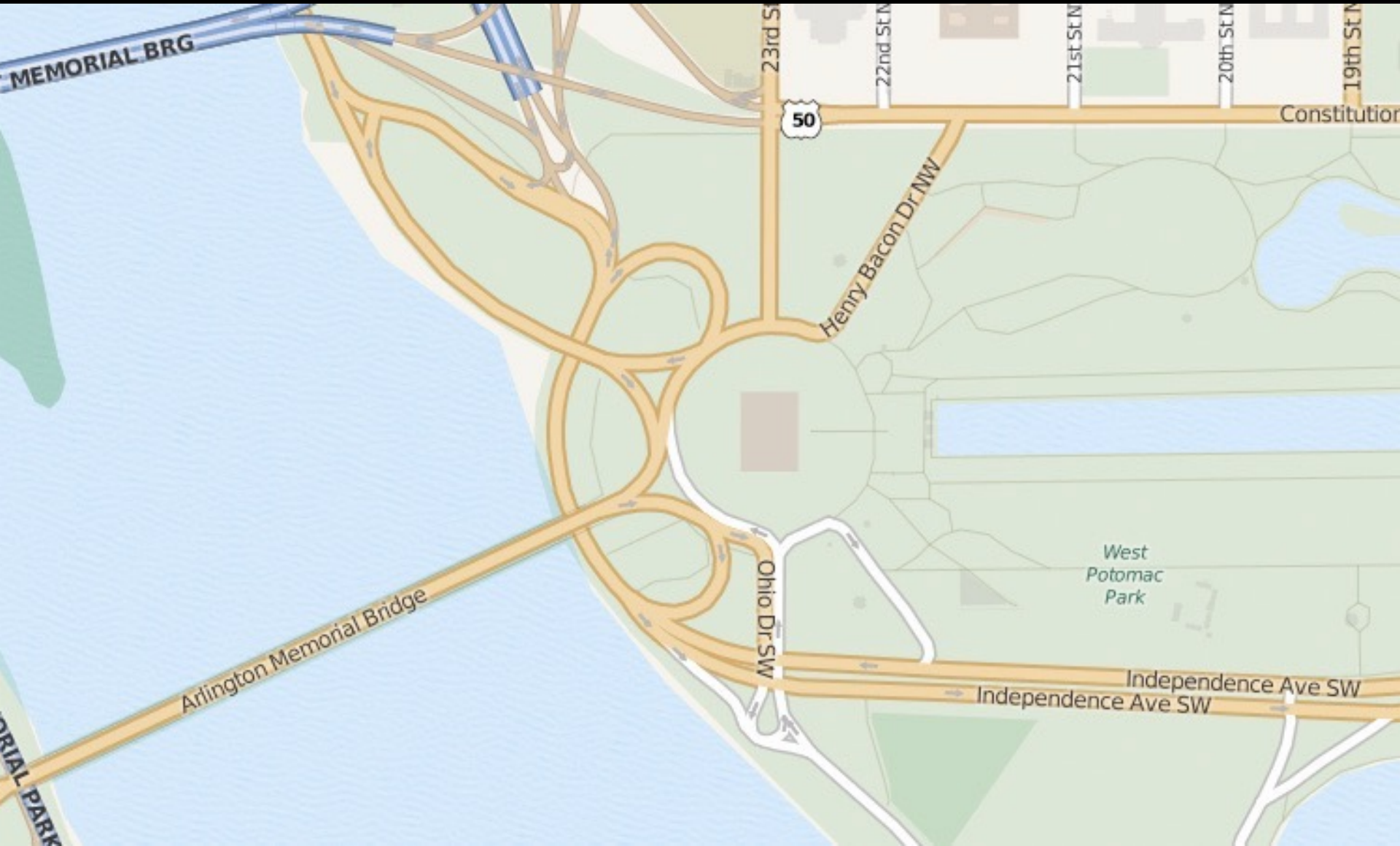












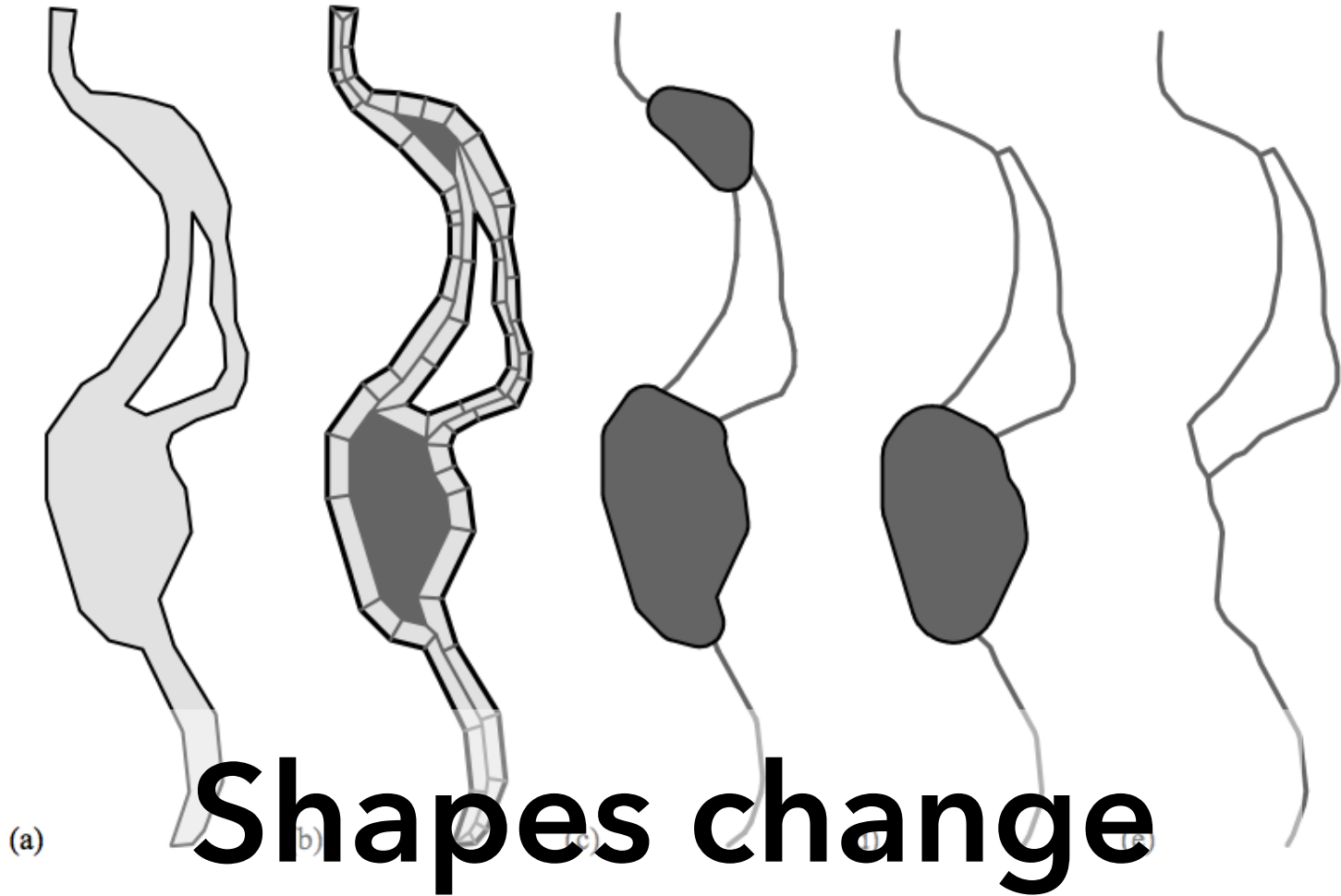


Figure 11. Fragmentation of a river into polygons and lines with different thresholds leading to different results (c, d, e).

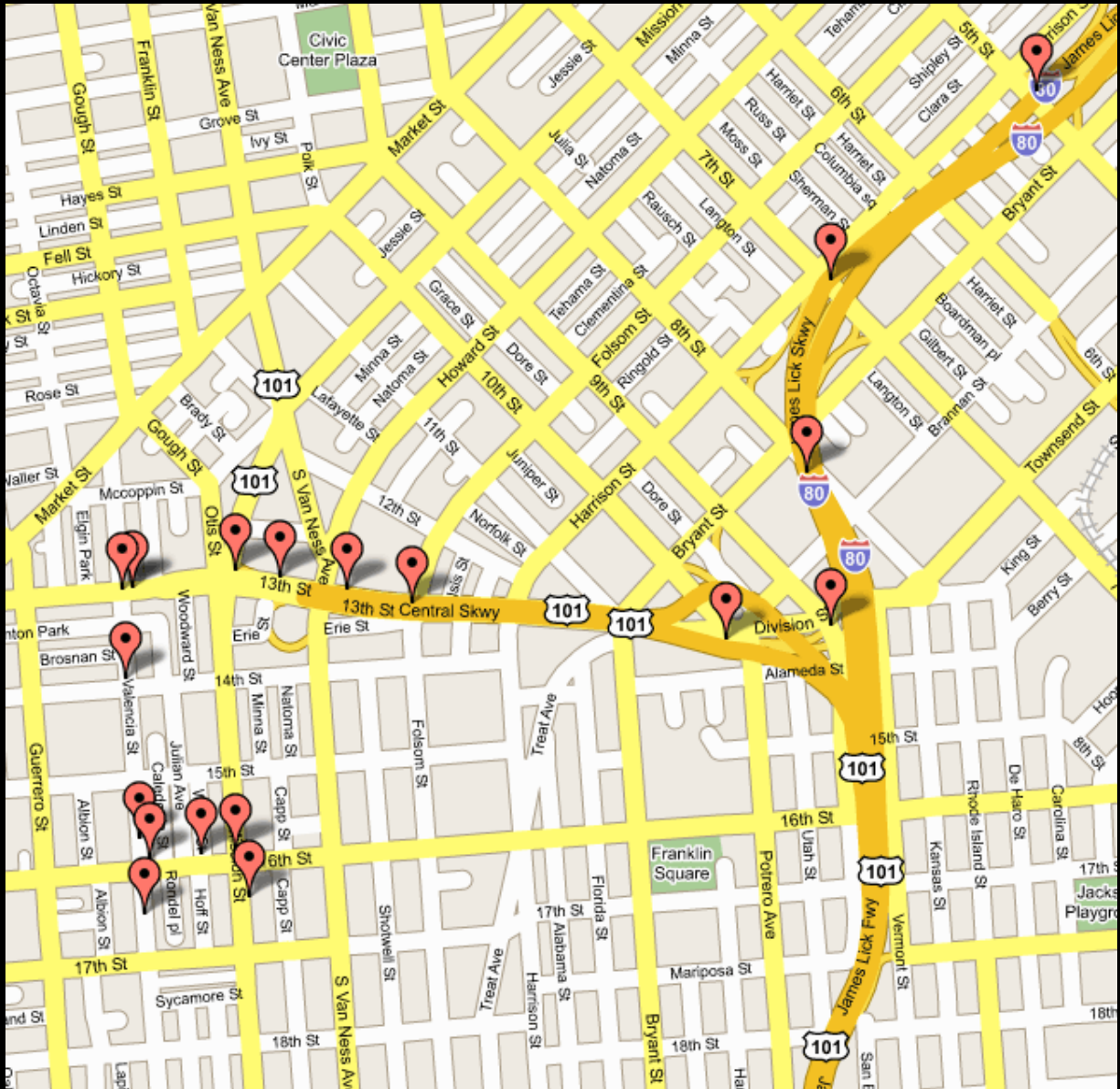
# Shapes change at different scales

# Mapping

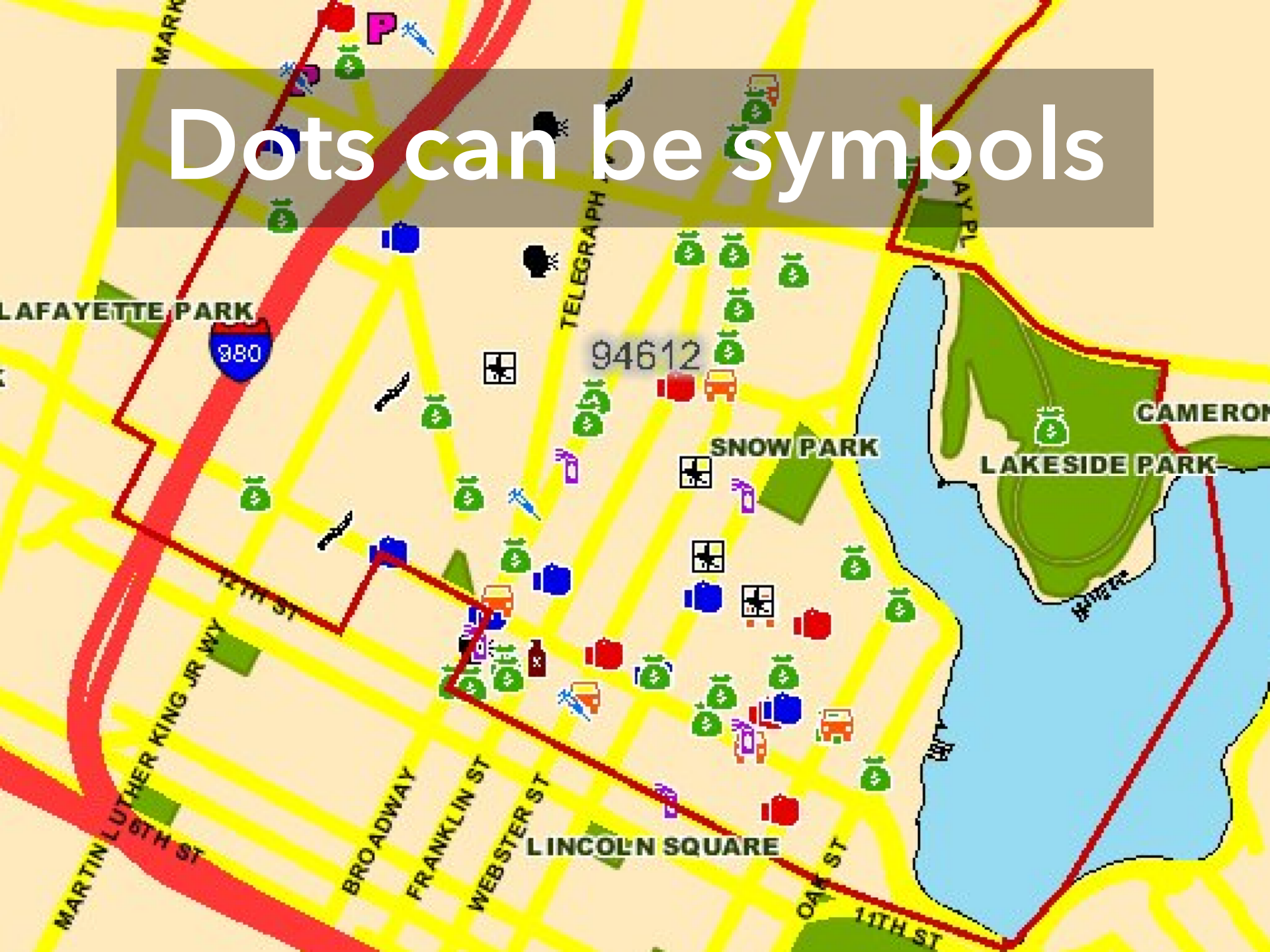
Visualizing Geospatial Data



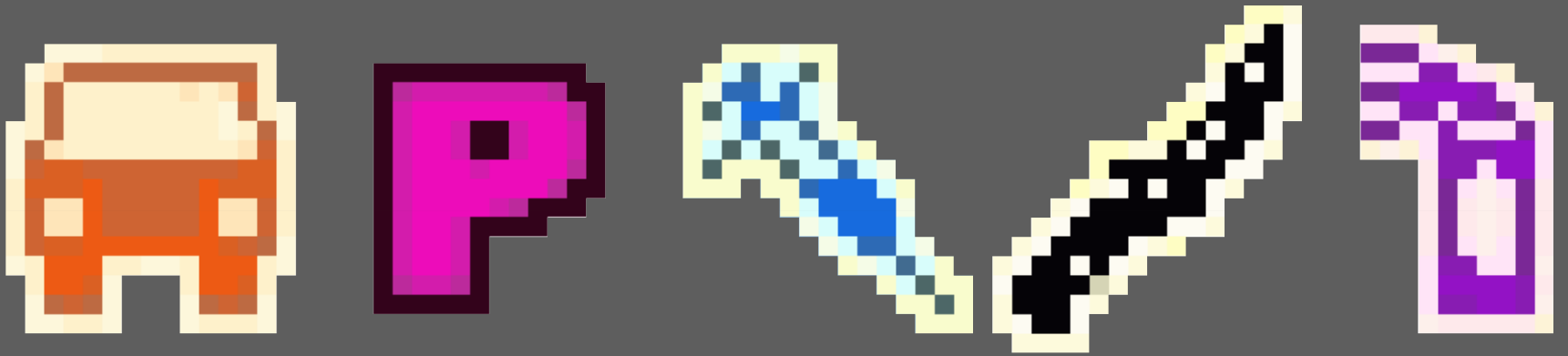
# Symbol Maps



# 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

NOON  
12 3 6 PM  
9 6  
AM 3 12  
MIDNIGHT

**DATE** Past Week  
Sep 2009  
AUG 17 2009 AUG 24 2009 AUG 31 2009 SEP 7 2009

T W Th F S S M T W Th F S S M T W Th F S S M



**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](#)

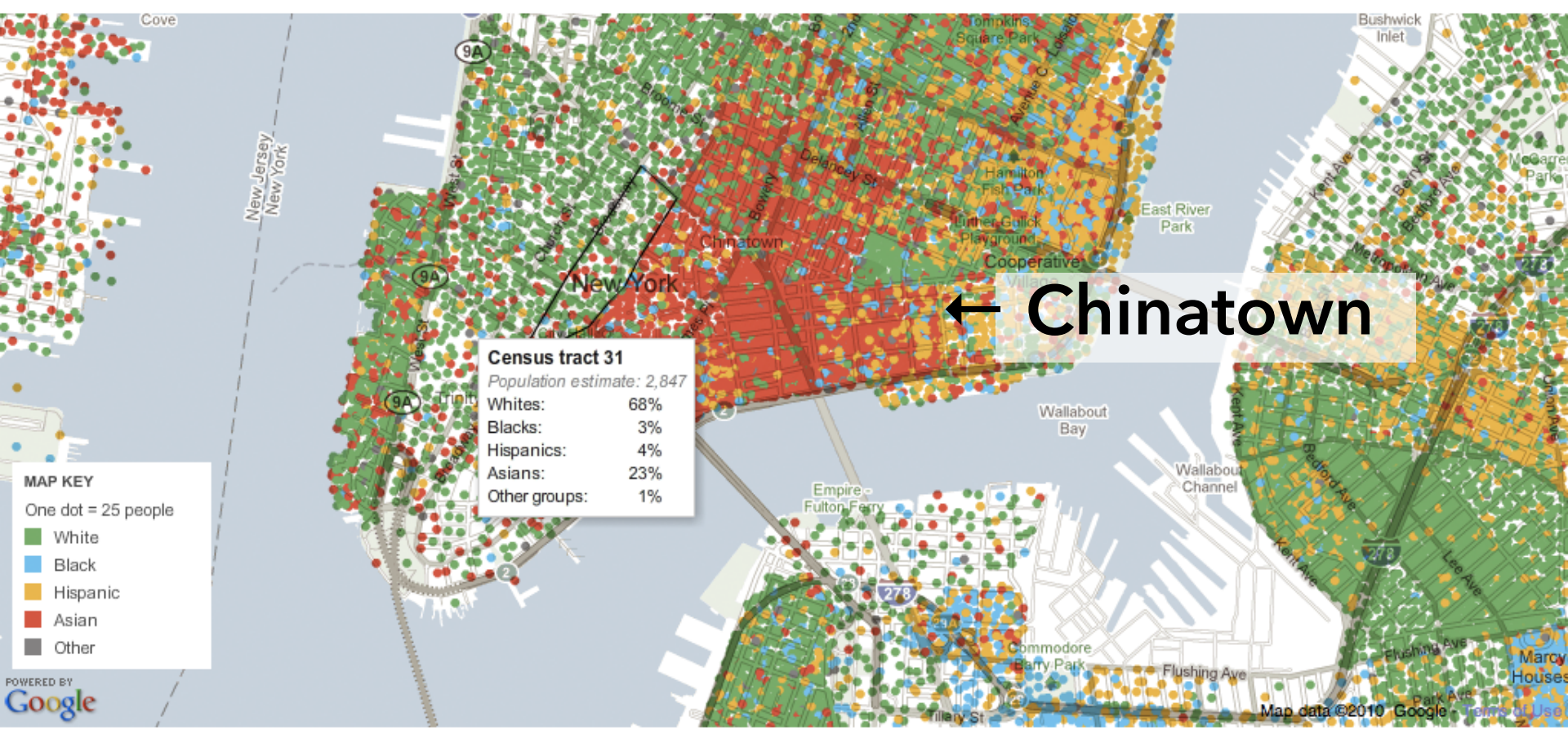
Browse local data from the Census Bureau's American Community Survey, based on samples from 2005 to 2009. Because these figures are based on [View Readers Maps \(49\)](#) samples, they are subject to a margin of error, particularly in places with a low population, and are best regarded as estimates.

## Distribution of racial and ethnic groups

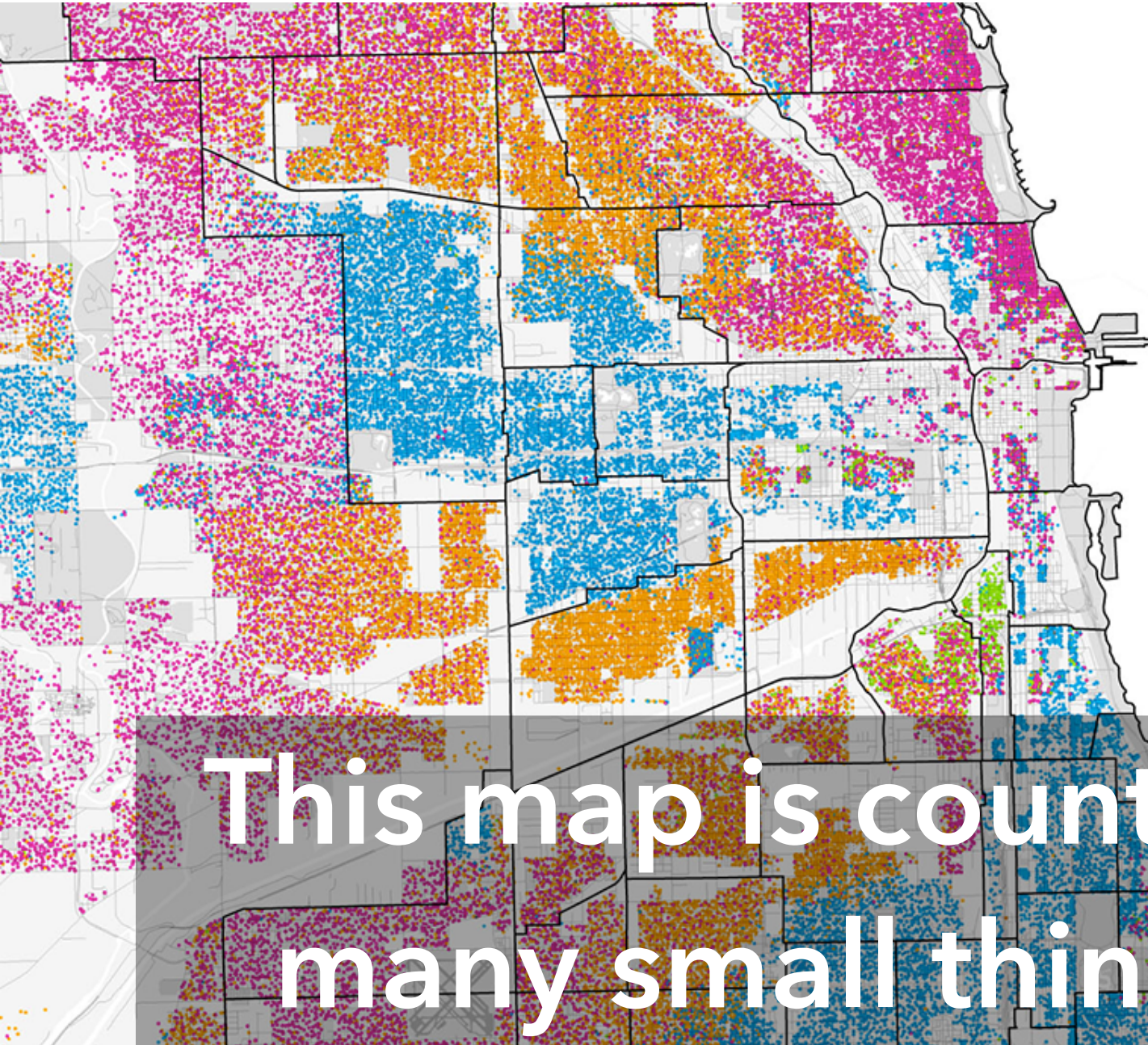
[View More Maps](#)

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





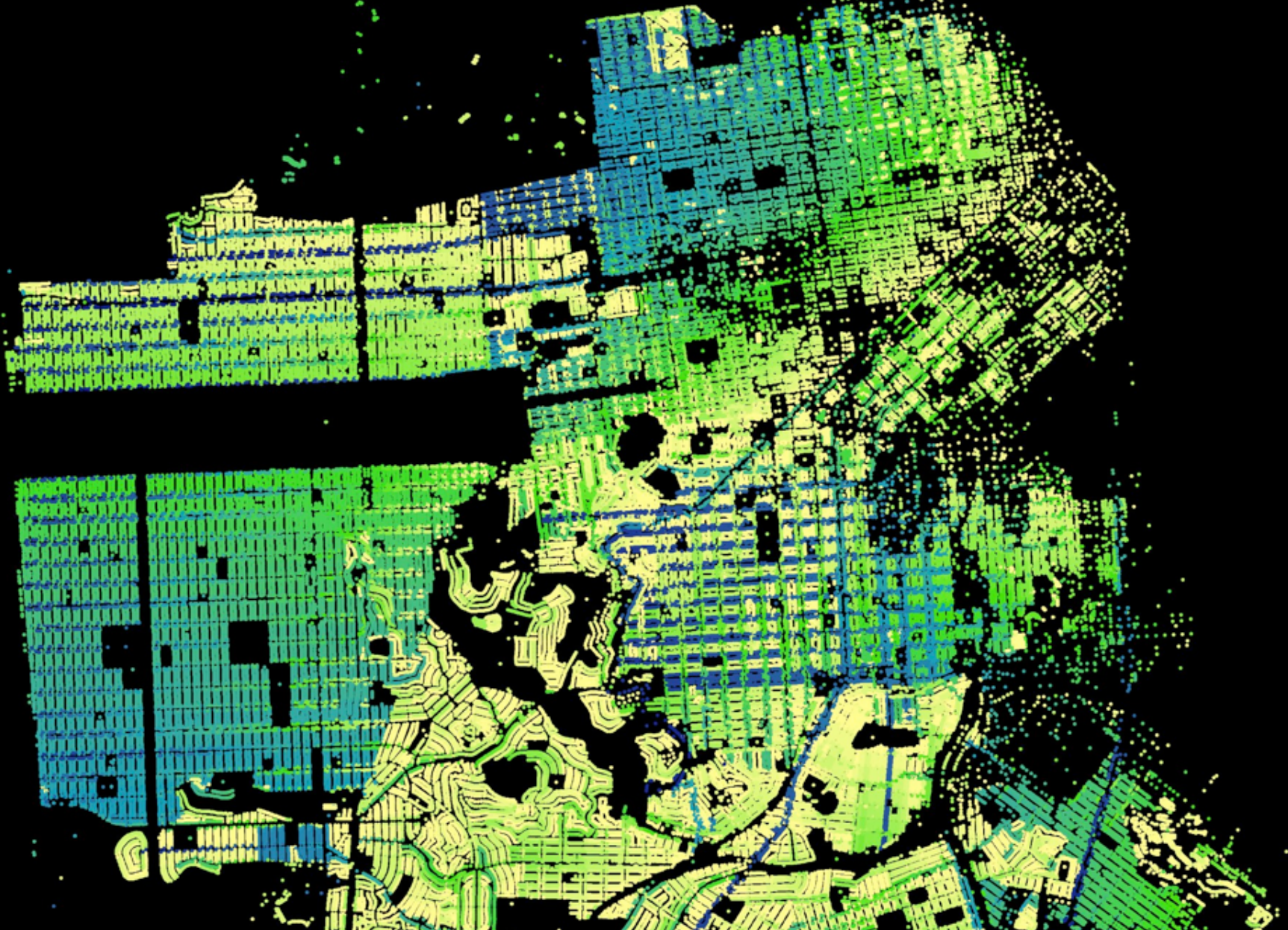
**Three dimensions  
shown by color**



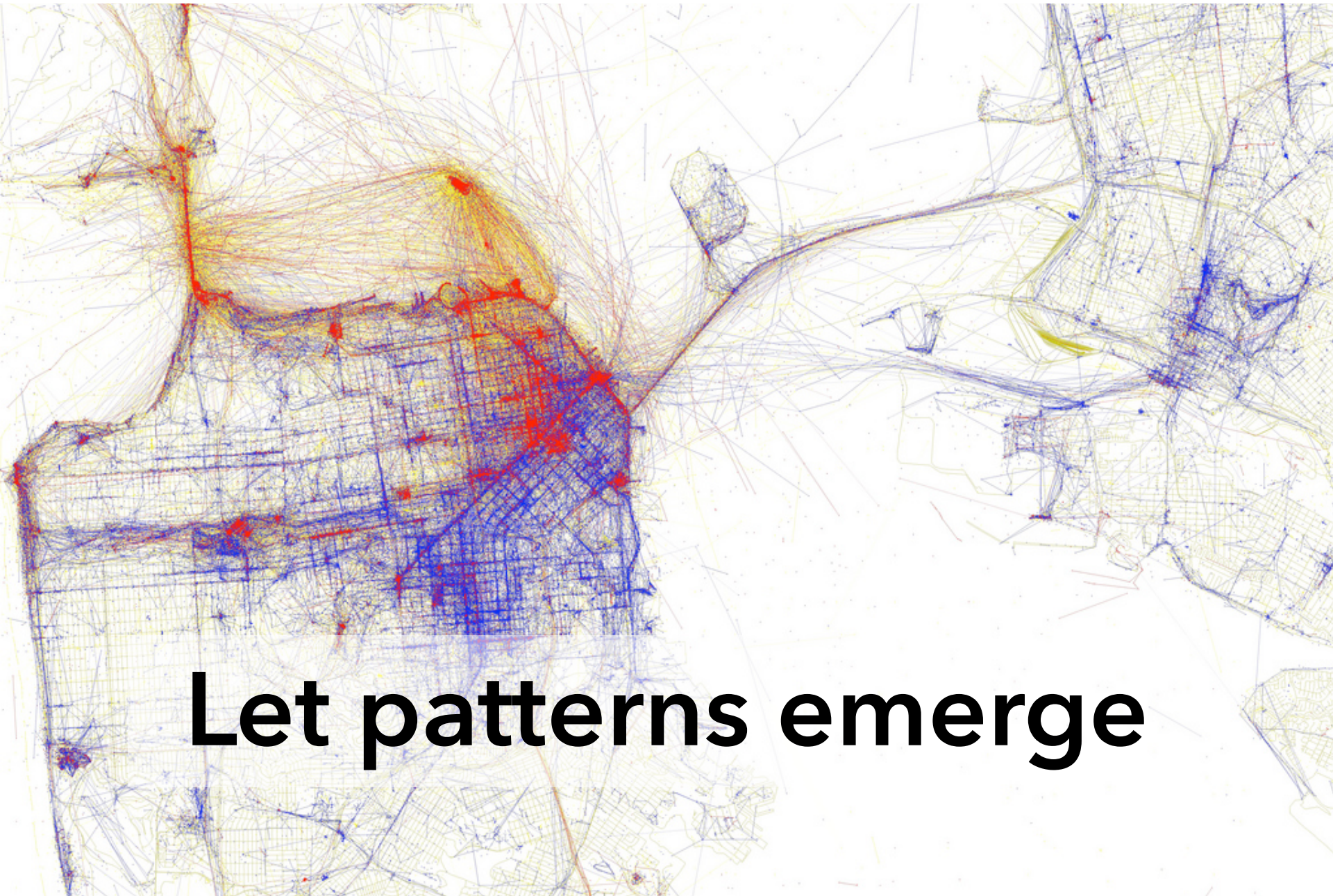


One dimension, shown by hue

<http://sta.mn/hn9>





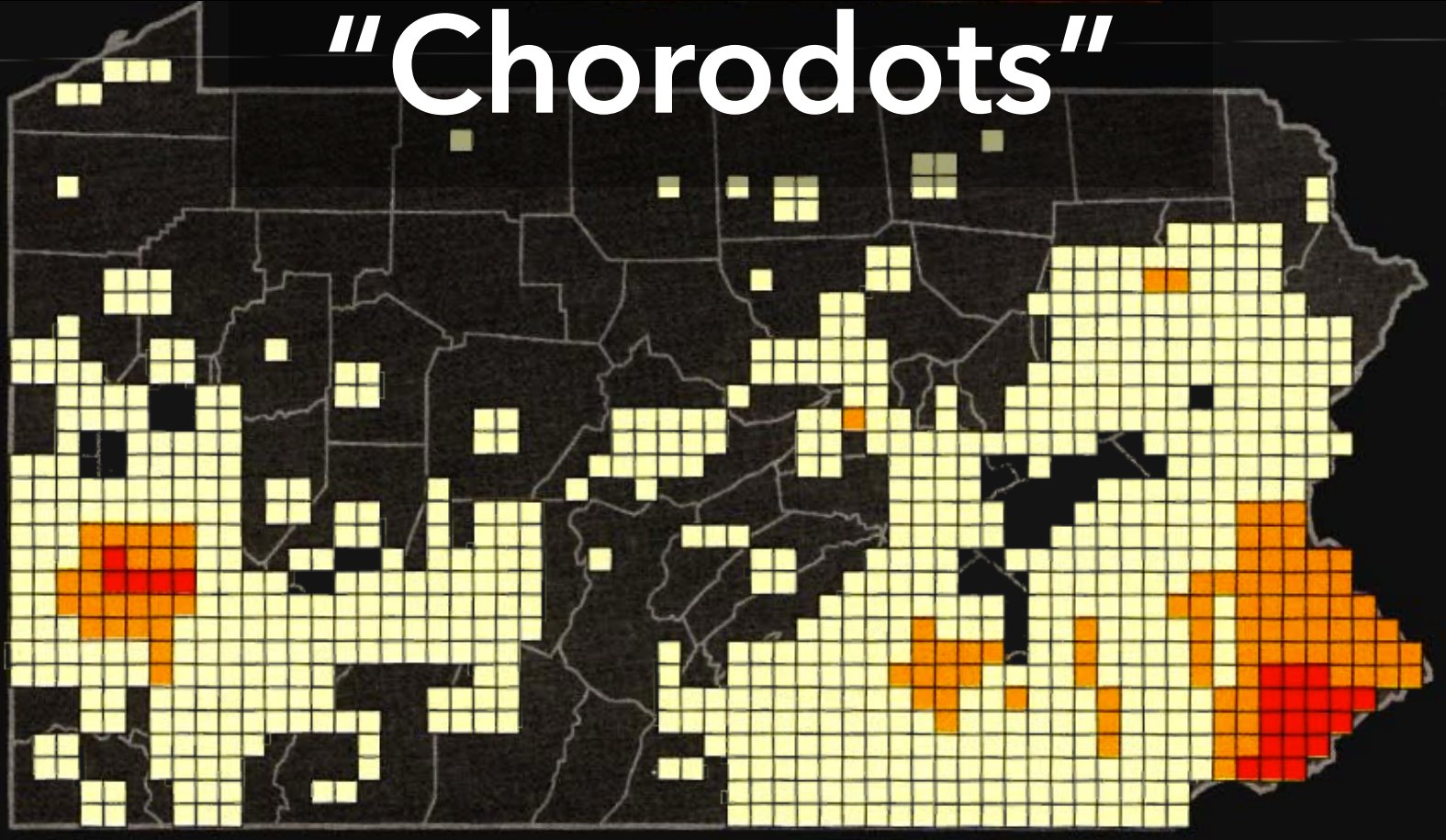


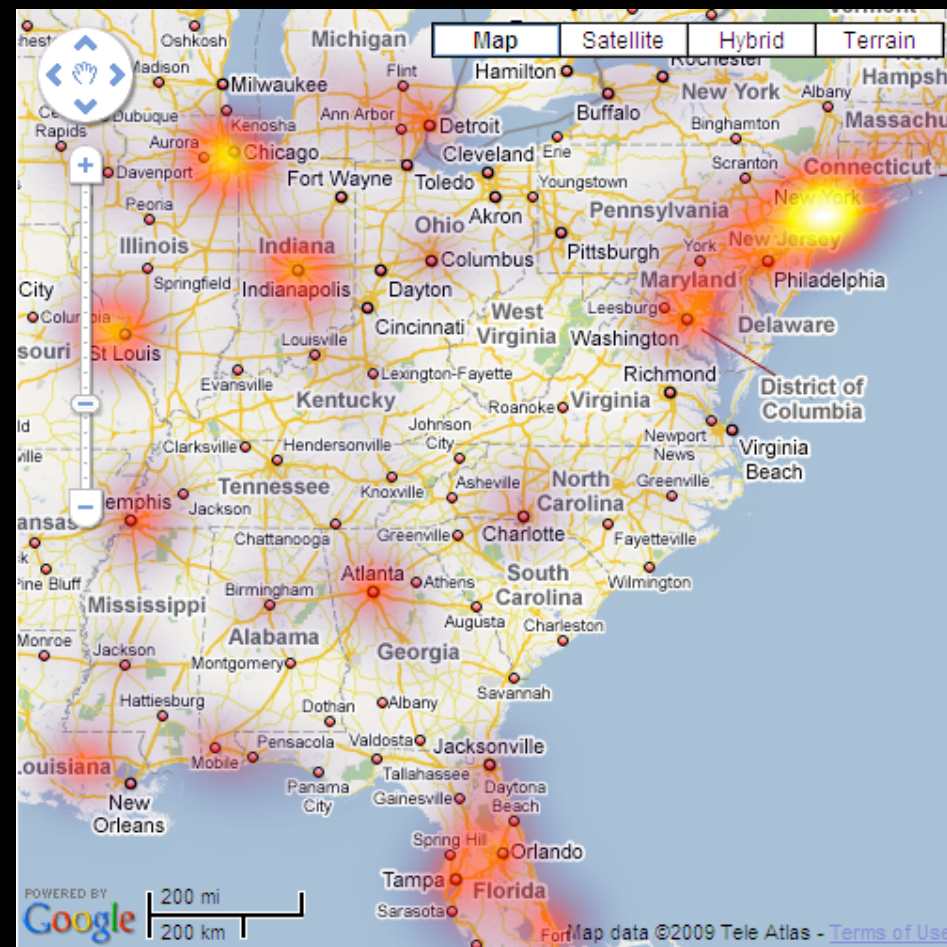
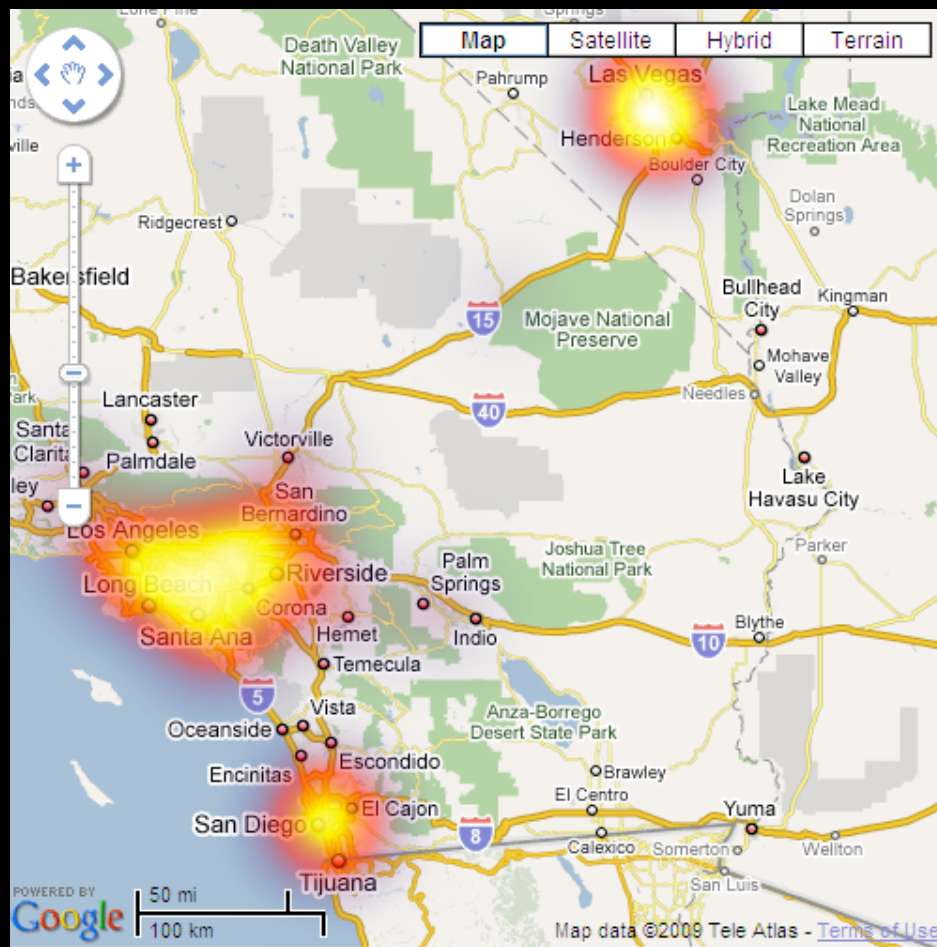
**Let patterns emerge**

# Continuous Data



# "Chorodots"



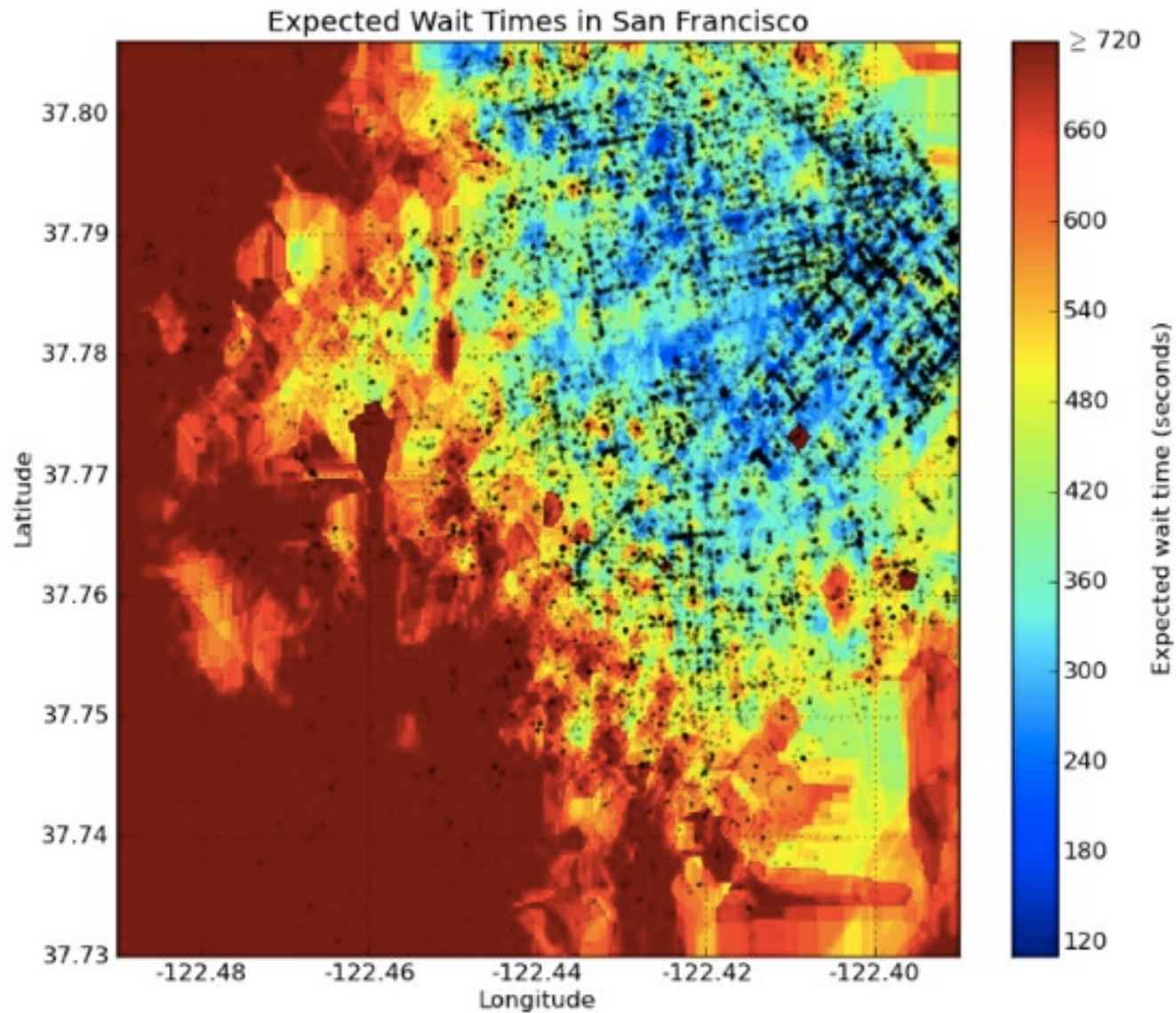


Don't hide the context



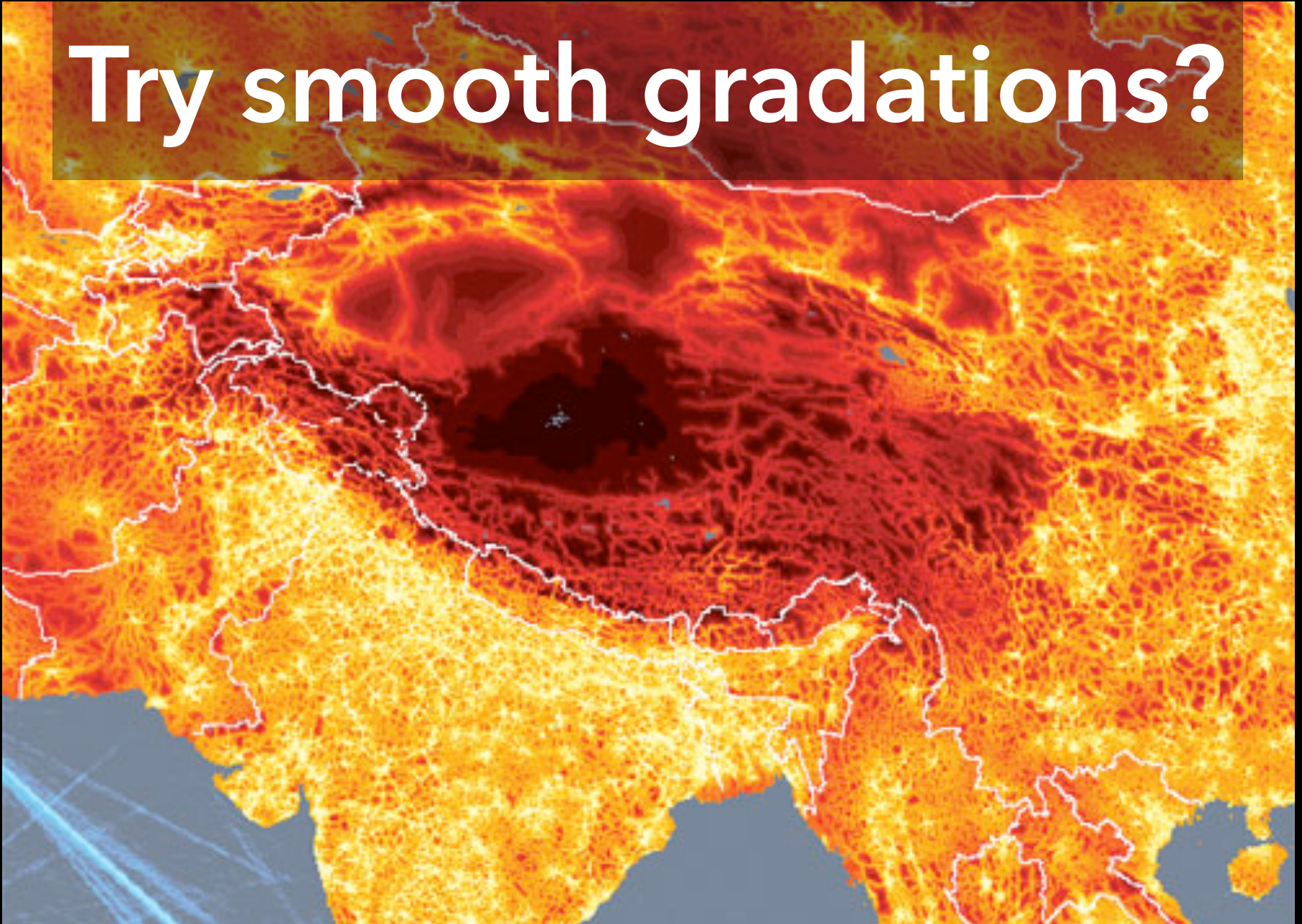
# Uber Wait Times, 2011

<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,

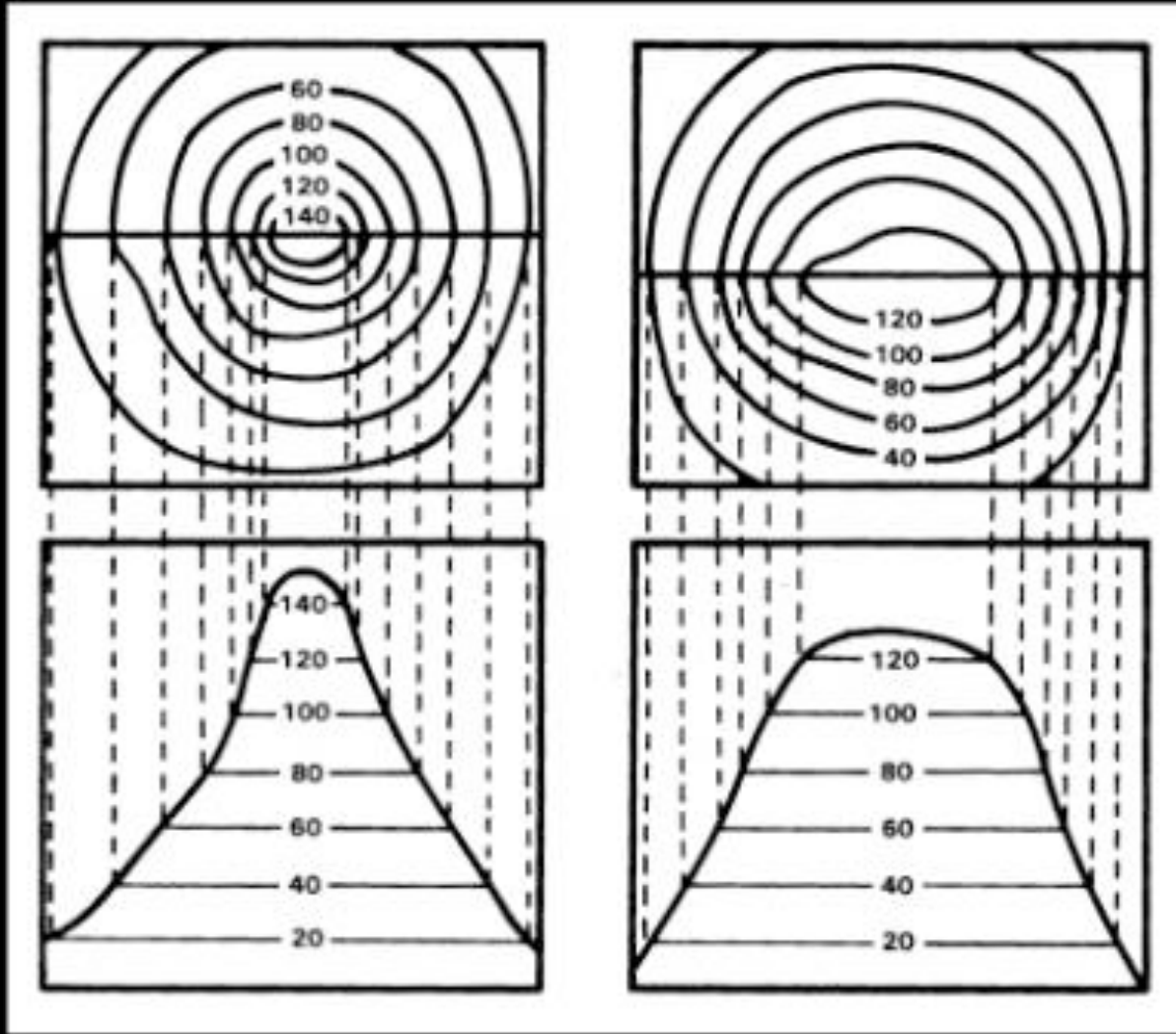
to show the gaps between crimes at a given intersection: white is high-crime; darker areas are safe. [stamen.com](http://stamen.com)

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

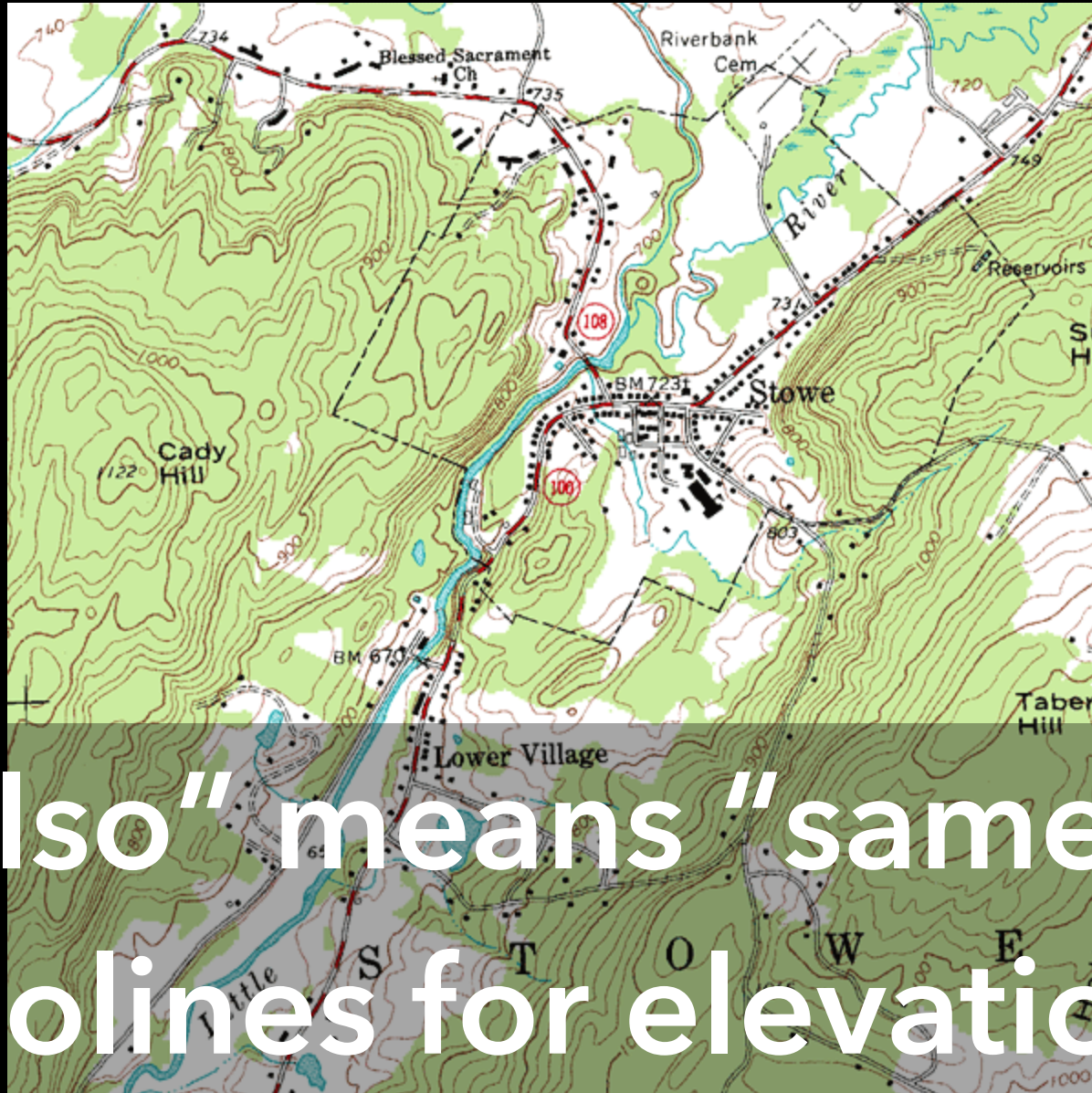
- A week ago
- Two weeks ago
- A month ago
- Two months ago
- Three months ago
- Four months ago
- Five months ago

# Meaningful buckets

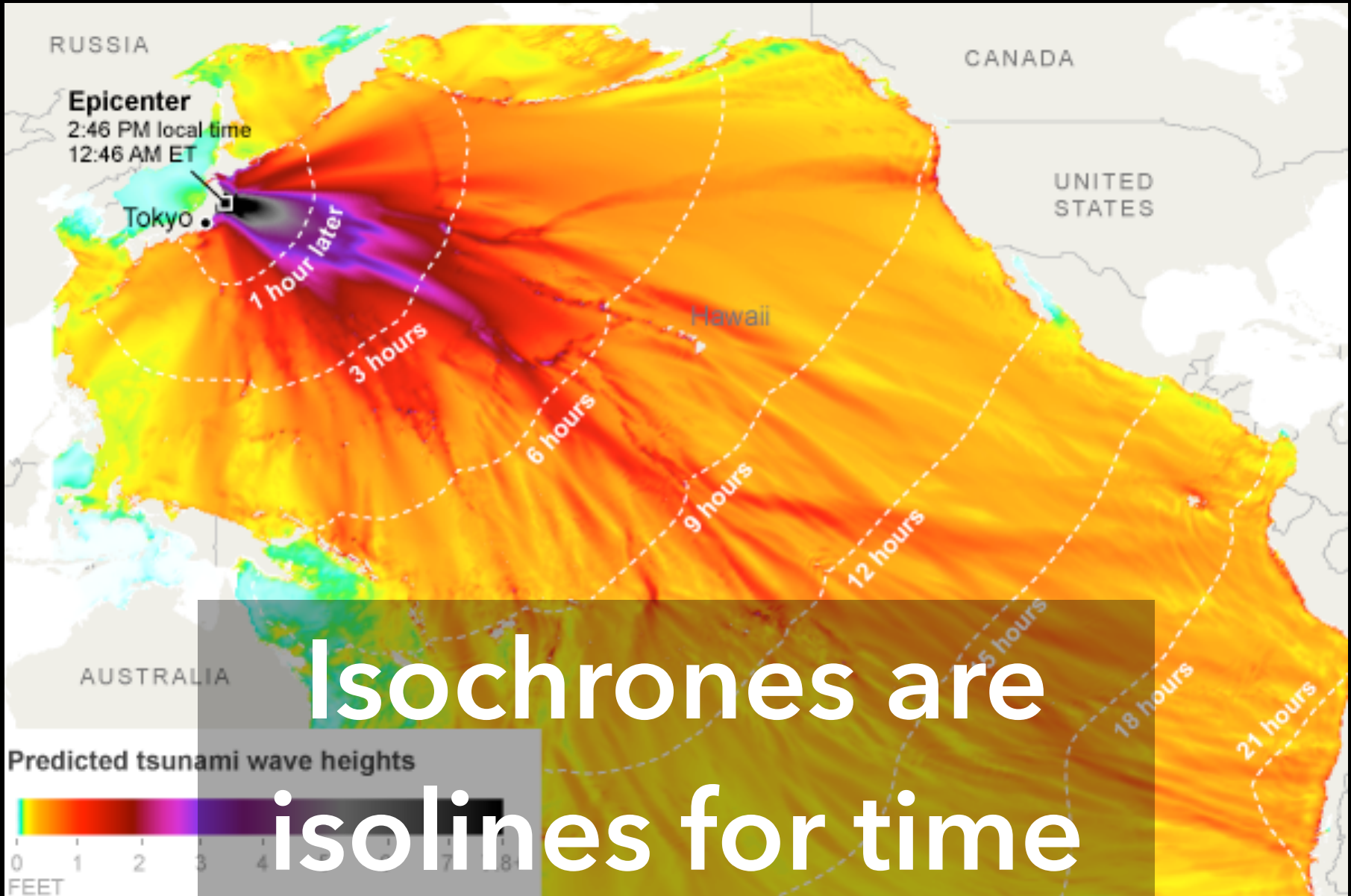
<http://sta.mn/b6>







“Iso” means “same”  
Isolines for elevation



Isochrones are  
isolines for time

# 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.

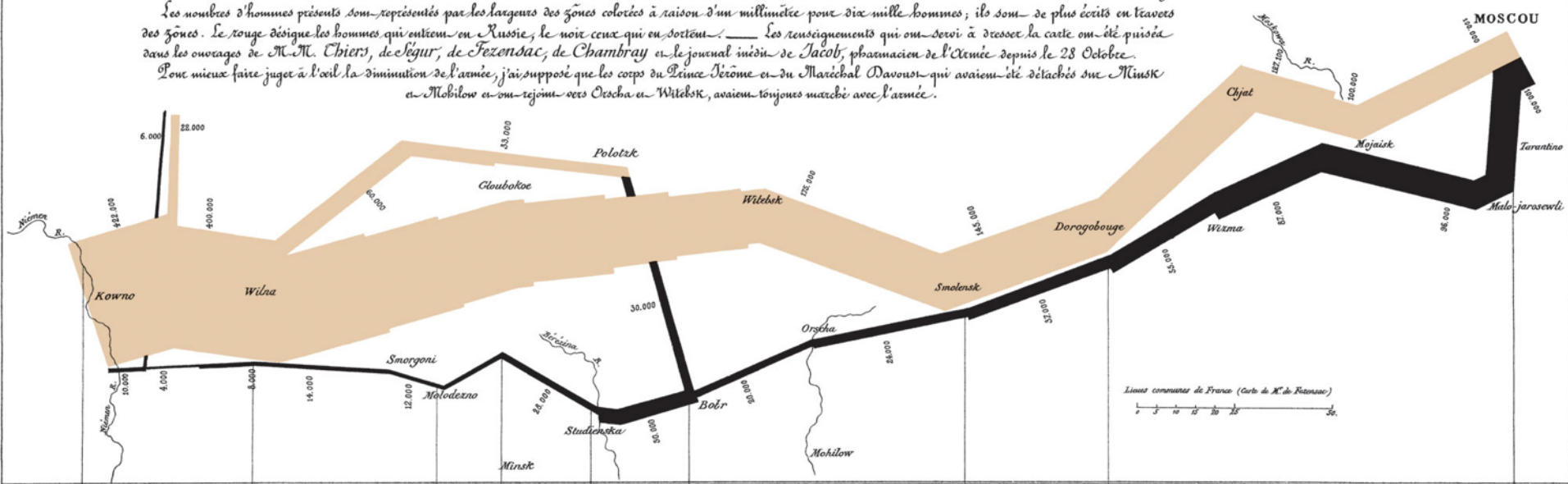
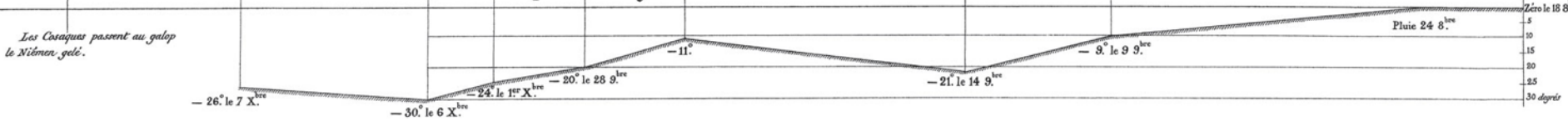


TABLEAU GRAPHIQUE de la température en degrés du thermomètre de Réaumur au dessous de zéro.



Autog. par Regnier, 8. Par. S<sup>te</sup> Marie S<sup>t</sup> O<sup>g</sup> à Paris.

Imp. Lit. Regnier et Dourdet.



**CARTE** figurative et approximative de la **Houille Anglaise** exportée en 1864 dessinée par M<sup>r</sup> MINARD, Ingénieur Civil des Ponts et Chaussées en France.

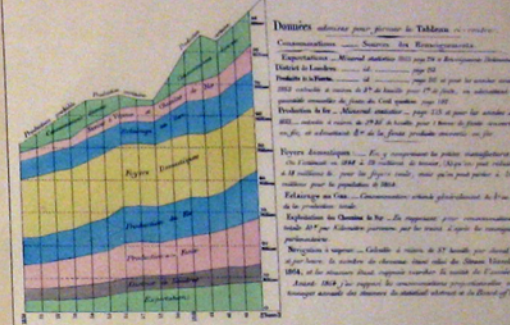
Les tracés sont basés sur les chiffres de M<sup>r</sup> Robert Bunt pour l'année 1864 (page 18 & 19) en ce qui concerne l'Amérique du Nord et l'Amérique du Sud.

**Observation.** — Les lignes de couleur verte et les chiffres qui les accompagnent indiquent la quantité de houille exportée et les chiffres qui les accompagnent indiquent la quantité de houille consommée dans les divers pays mentionnés. Les chiffres sont en millions de tonnes métriques. Les chiffres sont en italique pour les pays qui n'ont pas encore été visités par les navires anglais. Les chiffres sont en noir pour les pays qui ont été visités par les navires anglais. Les chiffres sont en rouge pour les pays qui ont été visités par les navires anglais.

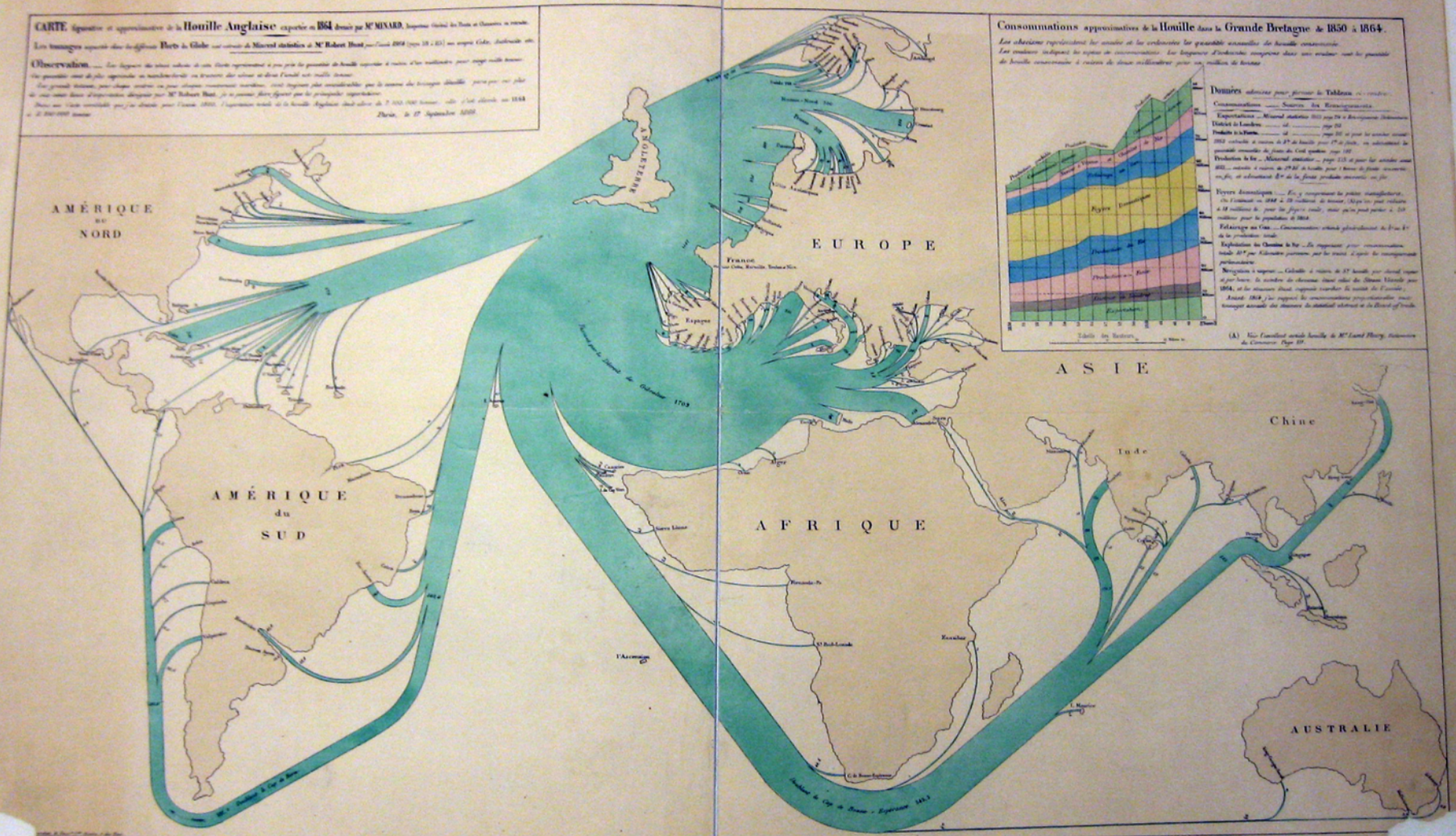
**Consommations approximatives de la Houille dans la Grande Bretagne** de 1850 à 1864.

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

Les chiffres indiquent les années de consommation. Les chiffres d'indication expriment dans une colonne sur la gauche de la houille consommée le nombre de millions de tonnes.



**Données relatives pour former les tableaux ci-dessus.**  
 Consommation de houille dans la Grande-Bretagne.  
 Exportation de houille en 1864 page 18 & 19. (Méthode de M. Minard.)  
 Production de la houille en 1864 page 18 & 19. (Méthode de M. Minard.)  
 Production de fer en 1864 page 18 & 19. (Méthode de M. Minard.)  
 Production de charbon en 1864 page 18 & 19. (Méthode de M. Minard.)  
 Production de sucre en 1864 page 18 & 19. (Méthode de M. Minard.)  
 Production de coton en 1864 page 18 & 19. (Méthode de M. Minard.)



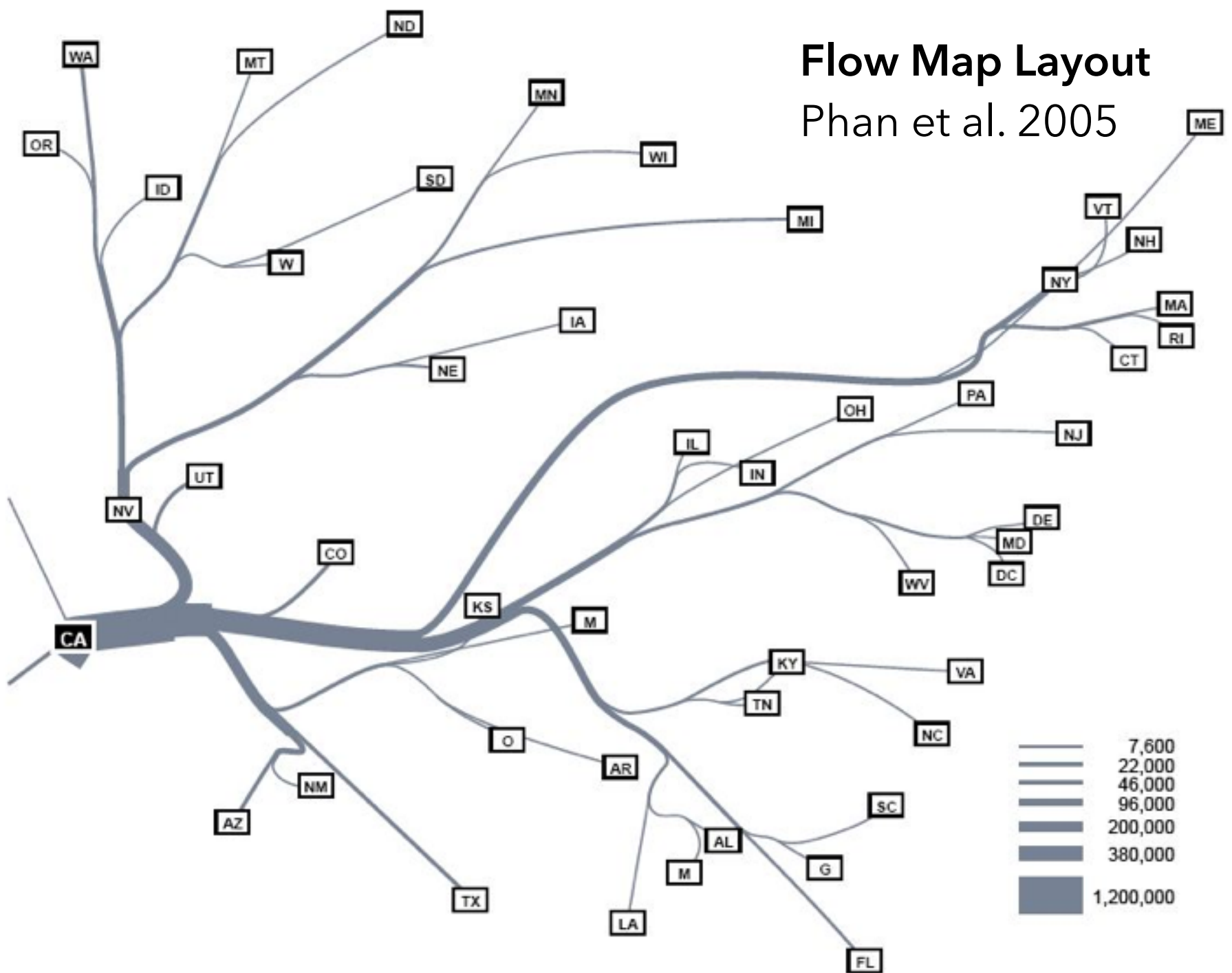
2204-62628

C2201-14-1864-M5

1864 British Coal Exports, Charles Minard

# Flow Map Layout

Phan et al. 2005



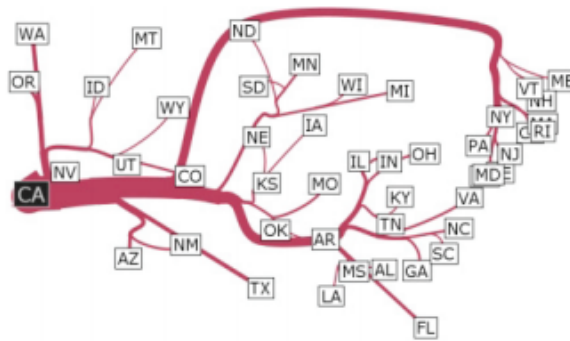


# Migration from California, 95-00

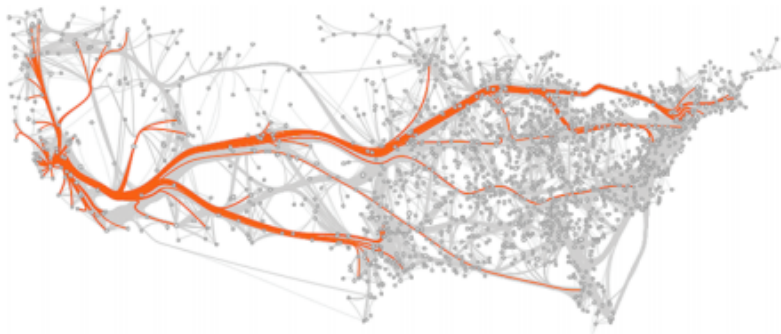
Tobler 1987



Phan et al. 2005



Verbeek et al. 2011



Cui et al. 2008



Holten & van Wijk 2009

# wind map

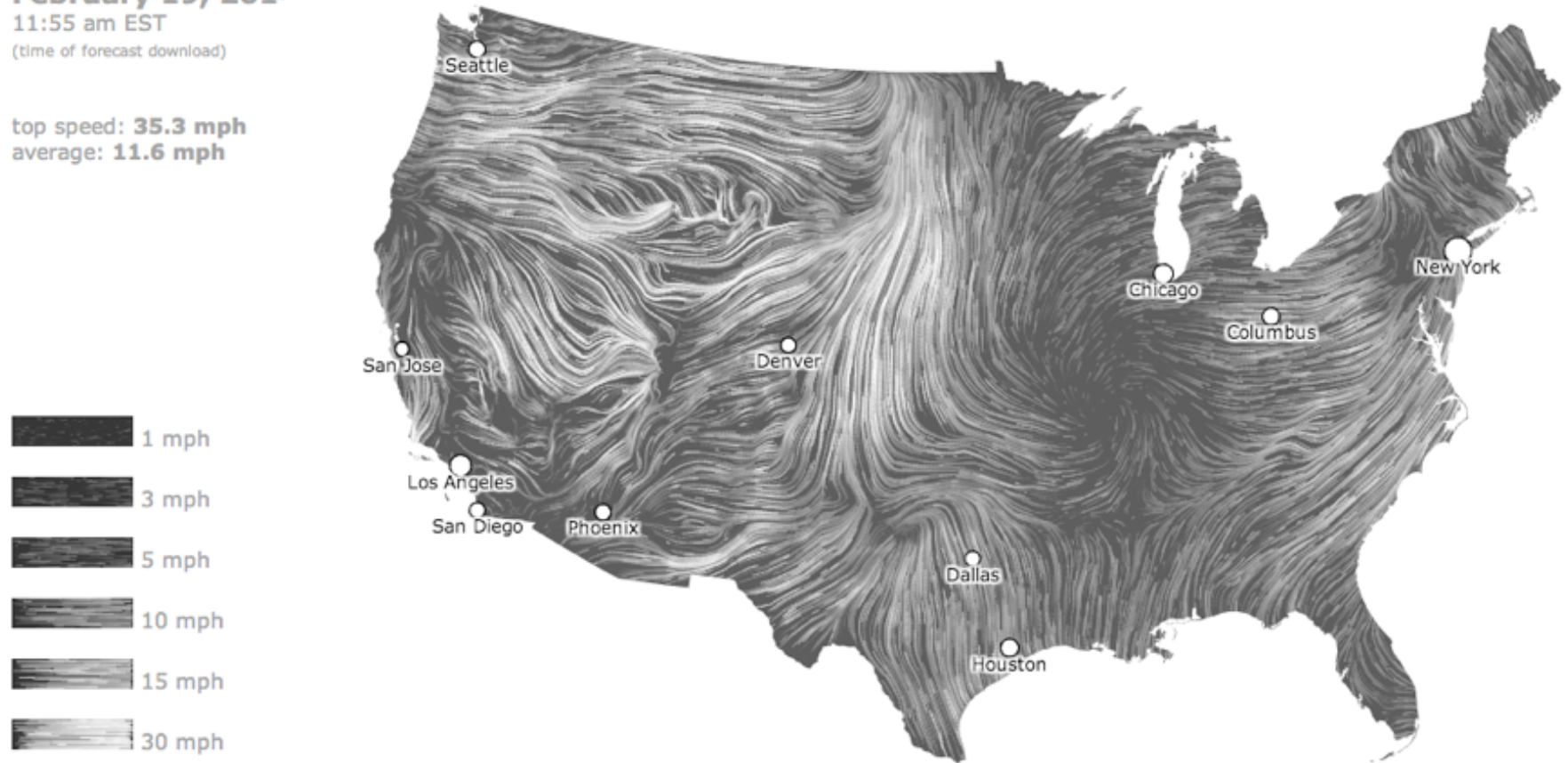
**February 19, 2014**

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

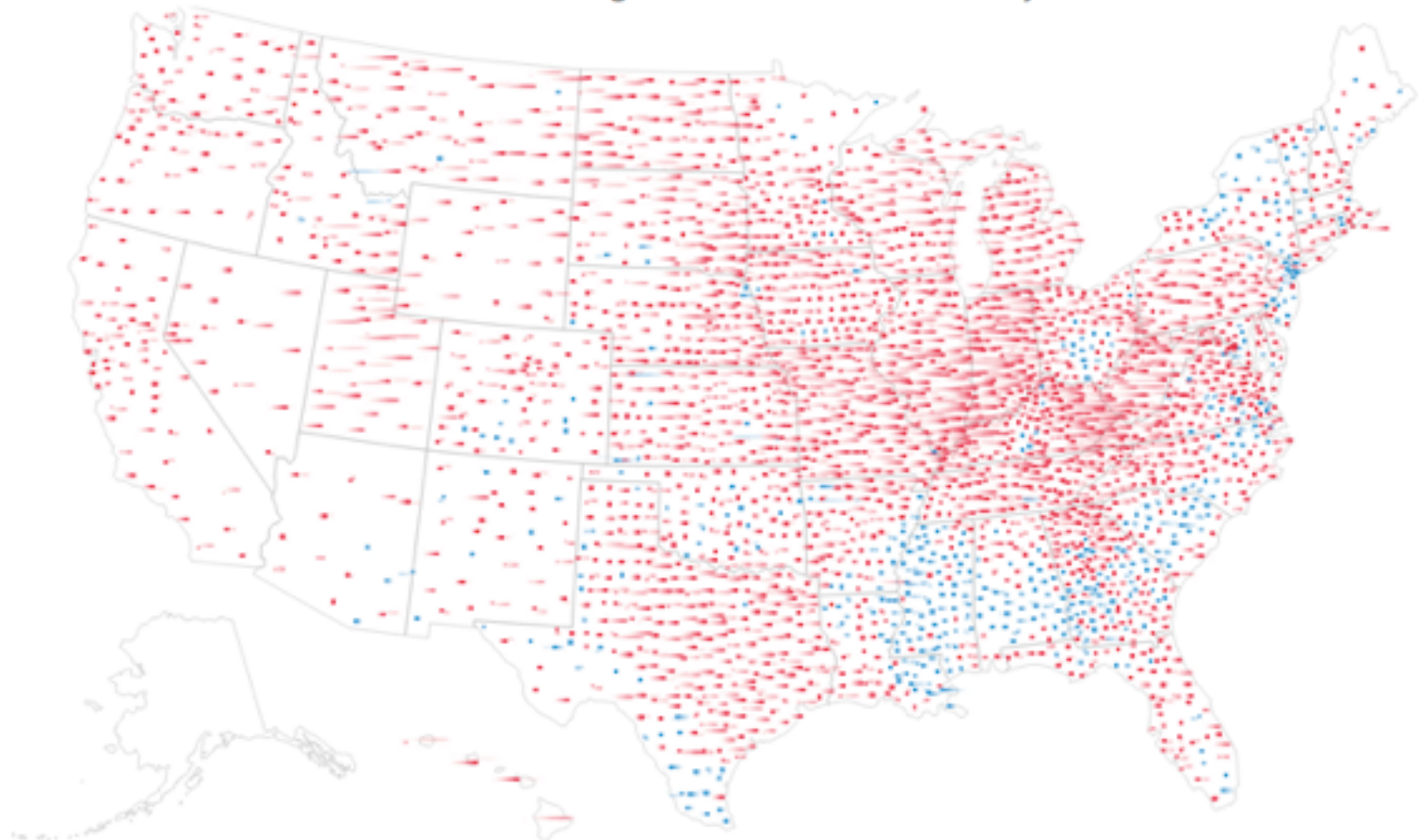
Youth

## 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.

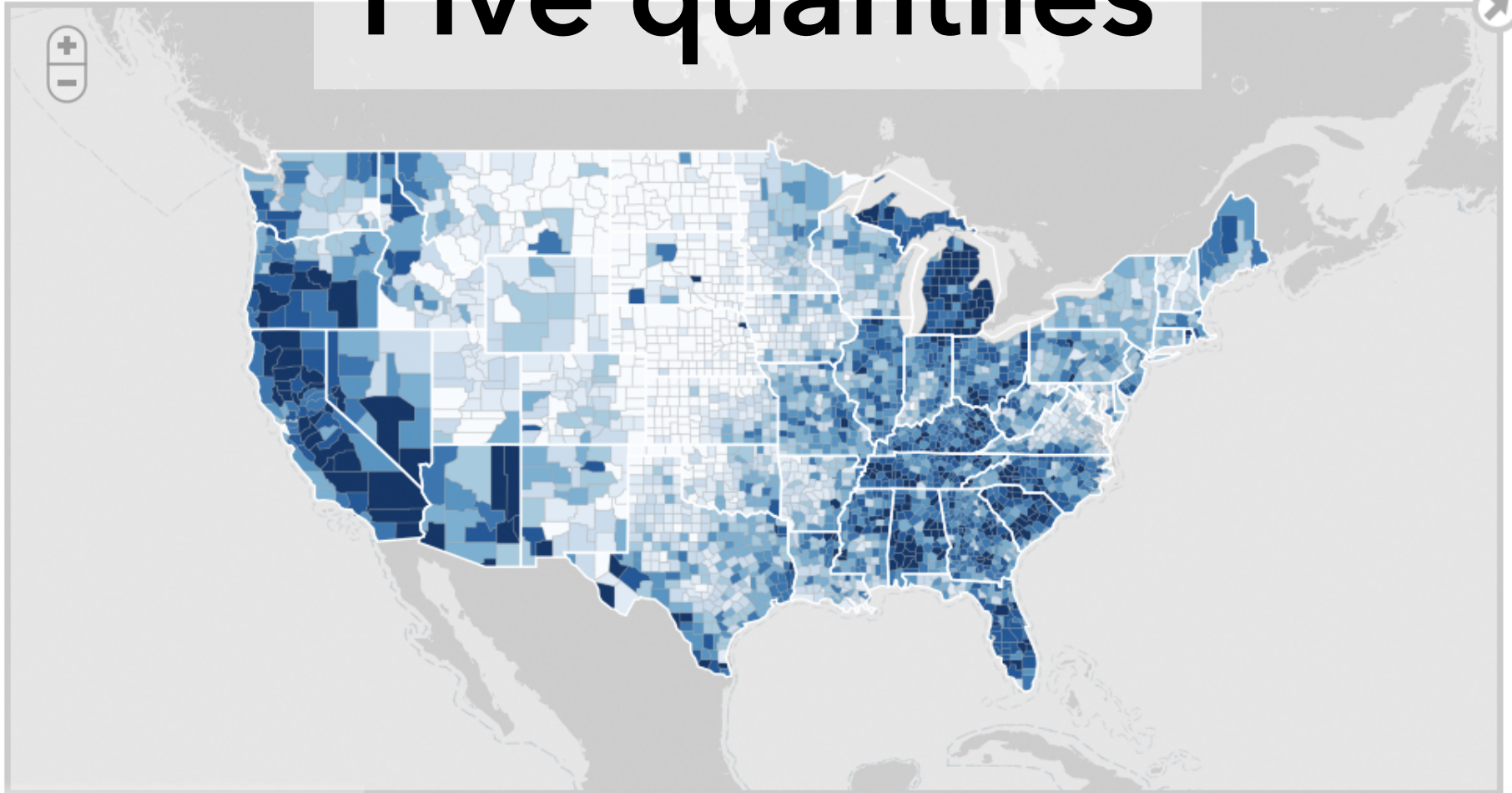




# Choropleth Maps

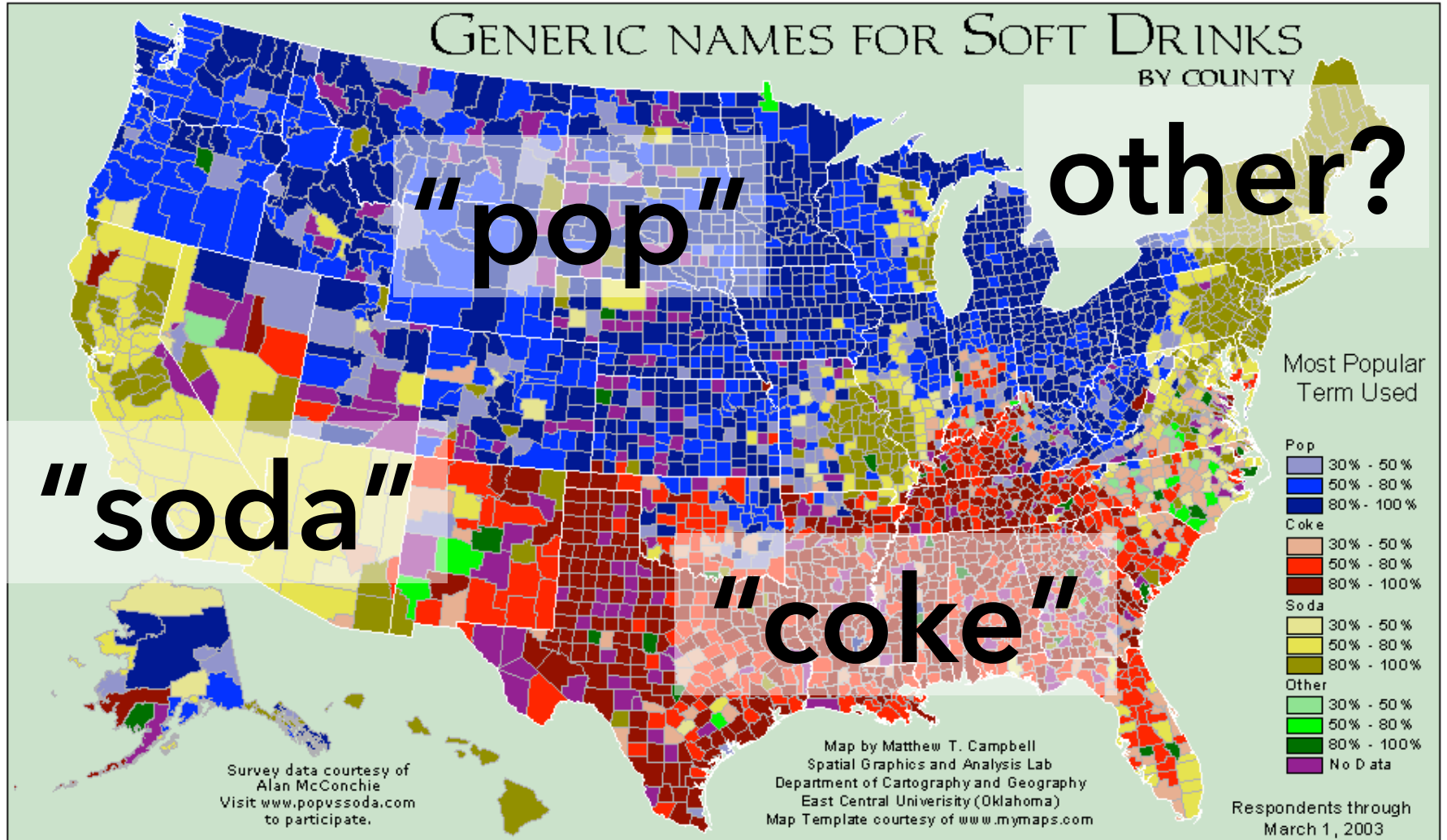


# Five quantiles



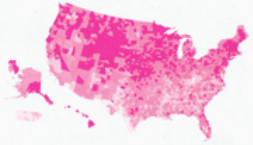


# GENERIC NAMES FOR SOFT DRINKS BY COUNTY



## READING, WRITING, AND EARNING MONEY

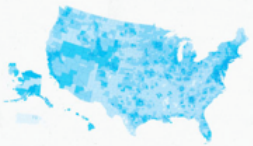
The latest data from the U.S. Census's American Community Survey paints a fascinating picture of the United States at the county level. We've looked at the educational achievement and the median income of the entire nation, to see where people are going to school, where they're earning money, and if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



A HIGH SCHOOL GRADUATES 65% 75% 82% 88%



B COLLEGE GRADUATES 15% 22% 30% 40%

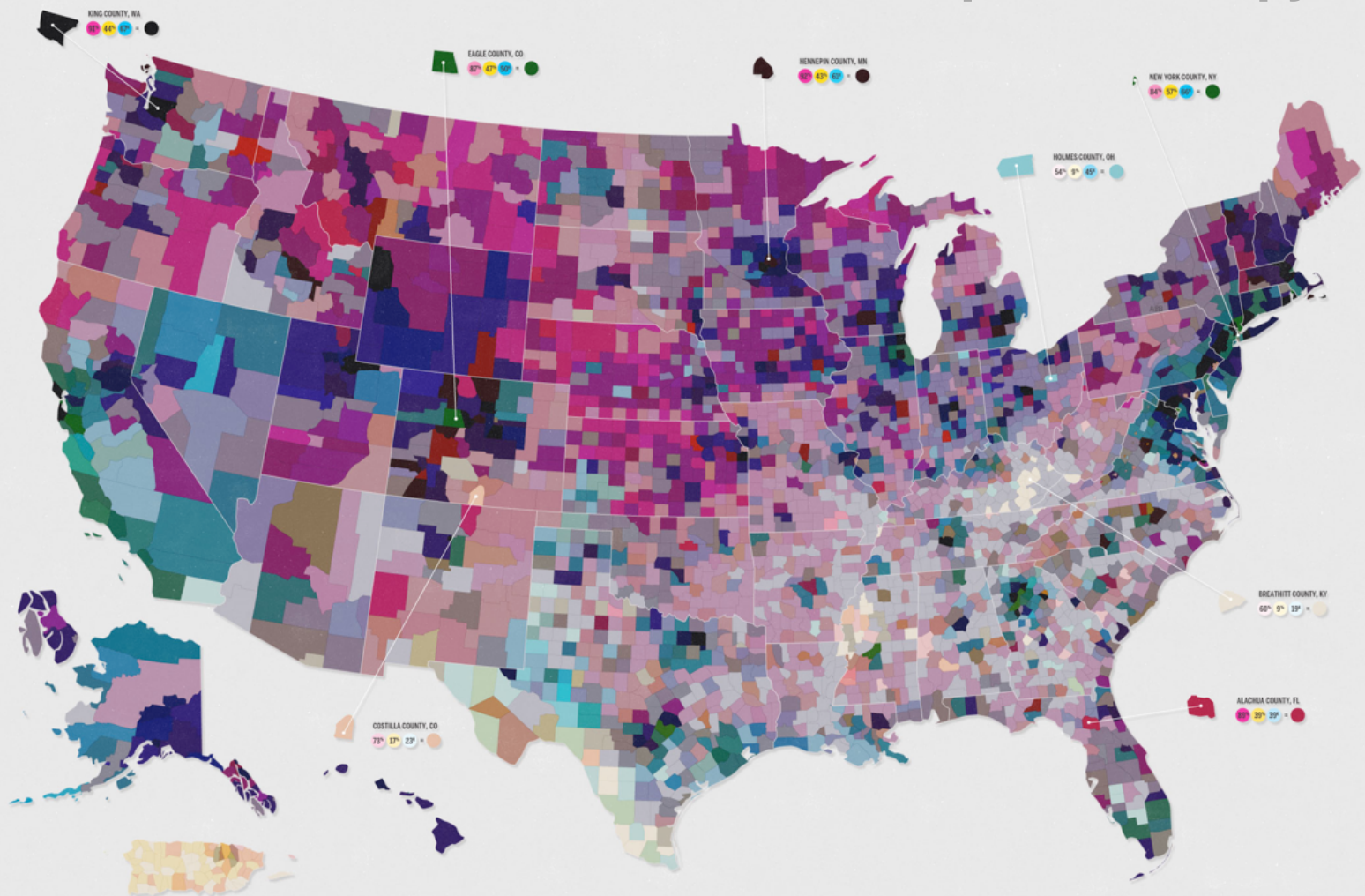


C MEDIAN HOUSEHOLD INCOME 25K 40K 50K 60K

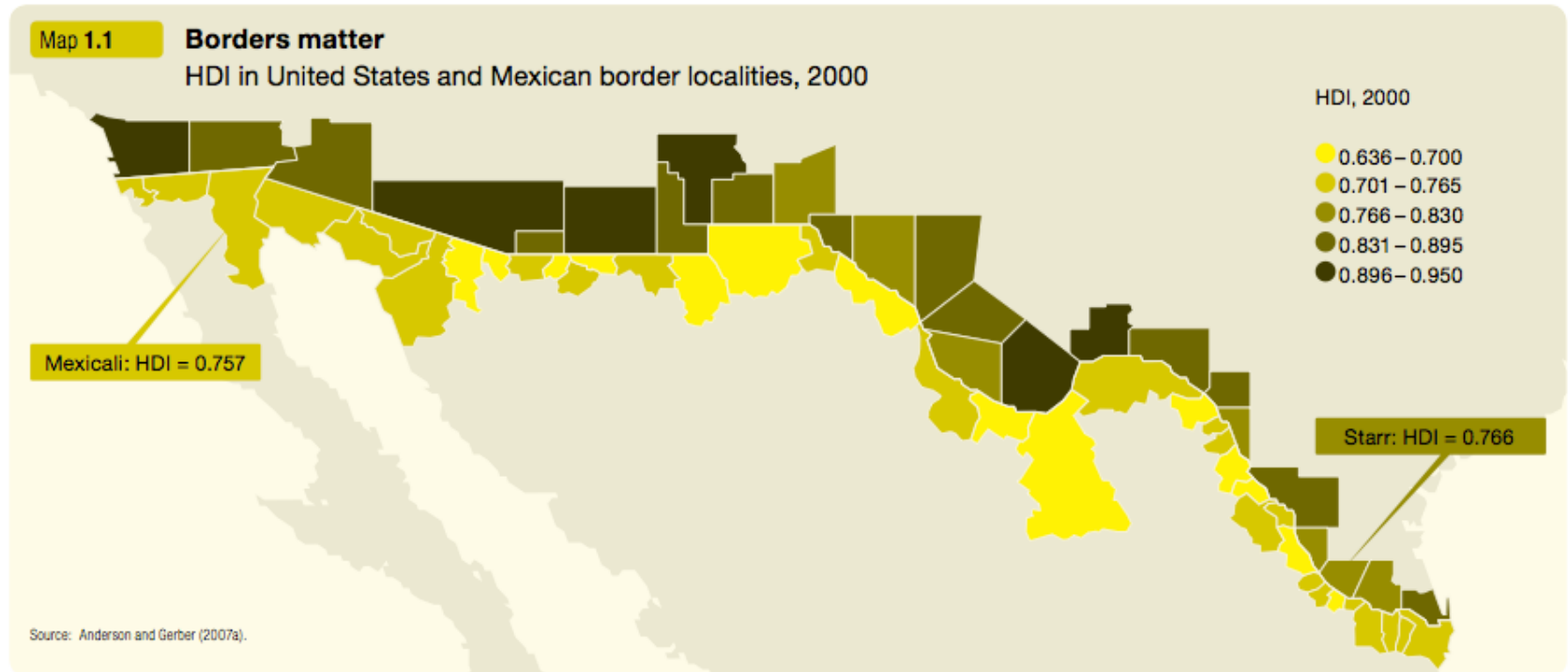
The map at right is a product of overlaying the three sets of data. The variation in hue and value has been produced from the data shown above. In general, darker counties represent a more educated, better paid population while lighter areas represent communities with fewer graduates and lower incomes.



A collaboration between GOOD and Gregory Huback  
SOURCE: US Census



# Choose colors well



# Focus on the foreground



Sort: Default Edit

State



City



WASHINGTON 40 2.60%

File\_Number



CommitteeID



Occupation



Memo\_Text



Report\_Type



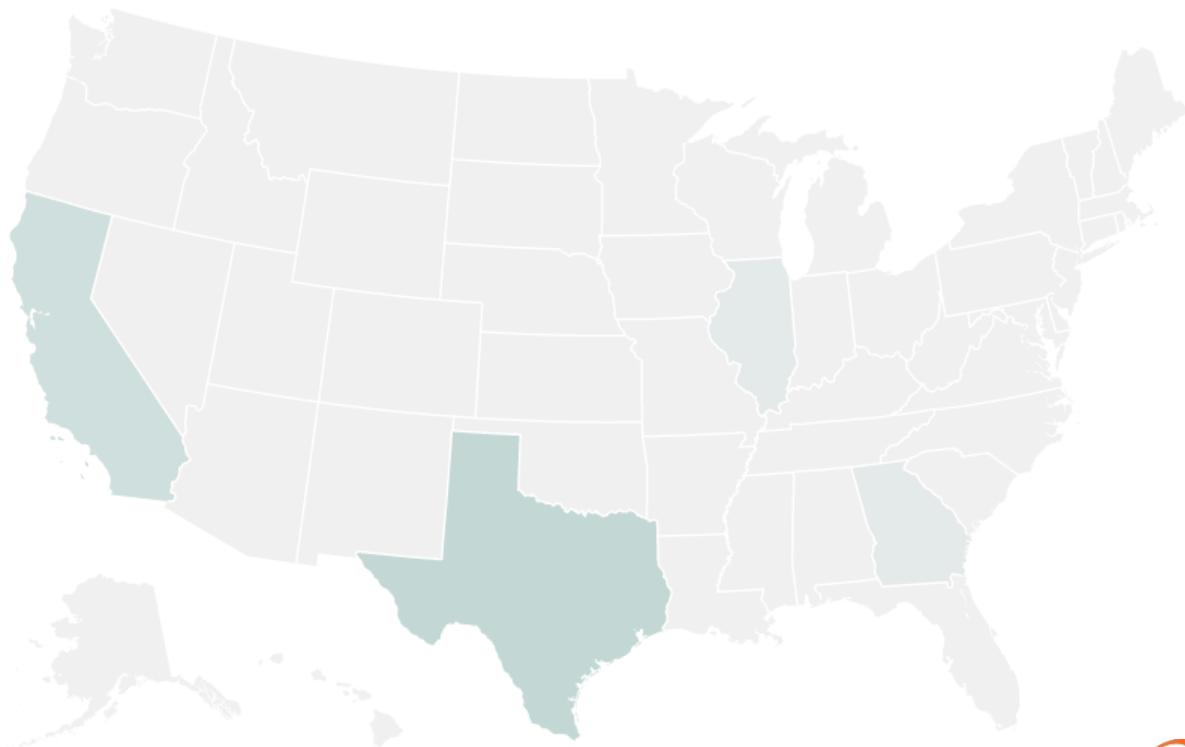
Trans\_Date



Trans\_Amount



Employer



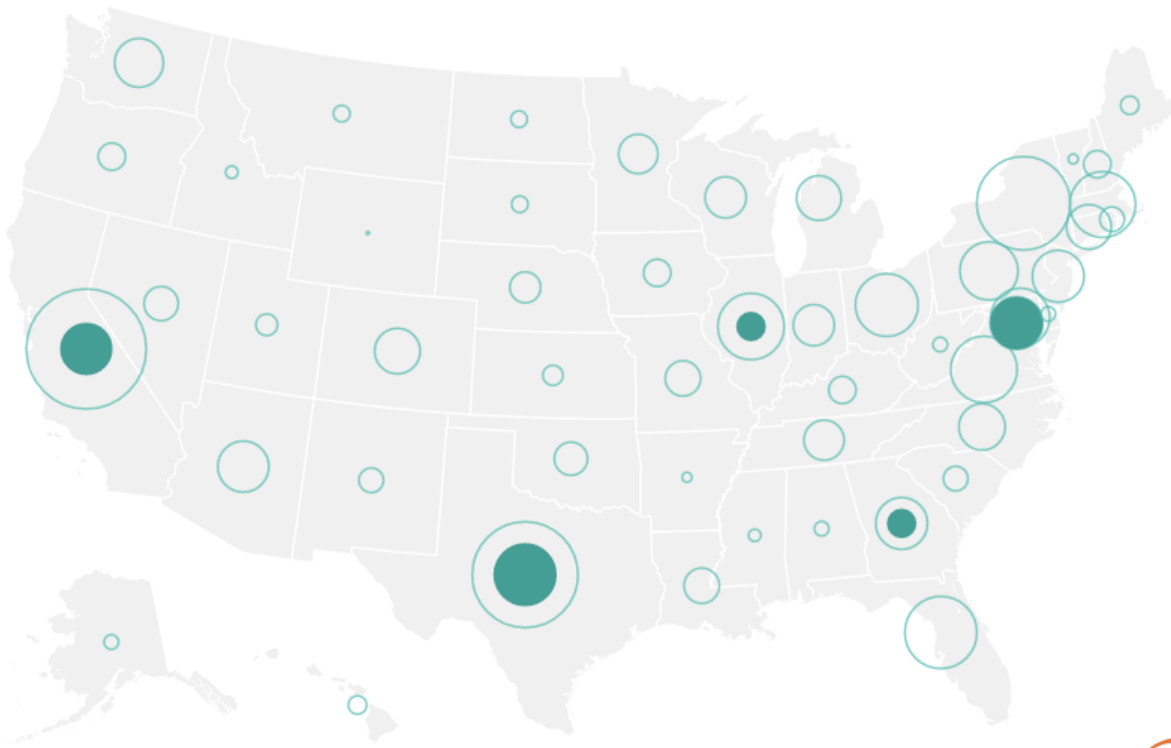
# What is obscured?

Sort: Default Edit

State



WASHINGTON 40 2.60%



# Regions -> Symbols

# Cartograms



# New York Times ratings

**198**  
Safe Dem.

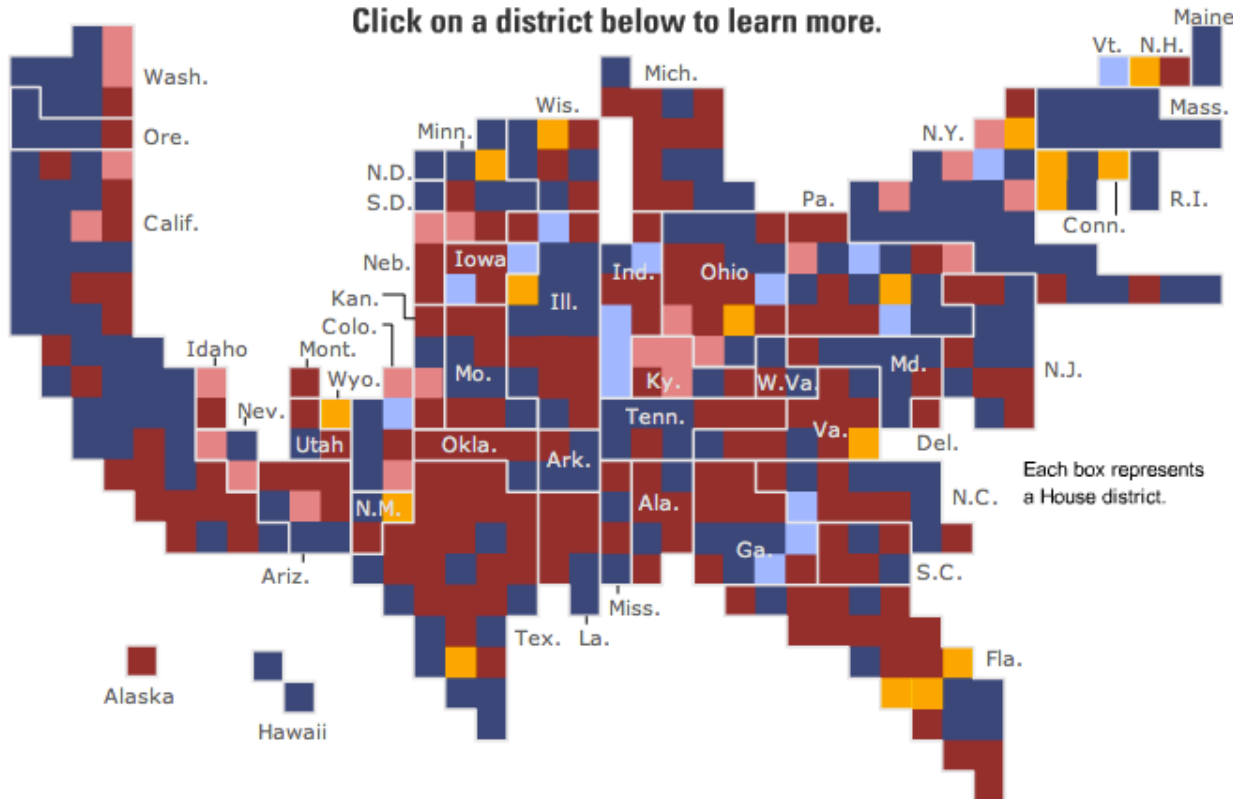
**16**  
Leaning Dem.

**17**  
Toss up

**24**  
Leaning Rep.

**180**  
Safe Rep.

Click on a district below to learn more.



Each box represents a House district.

### 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

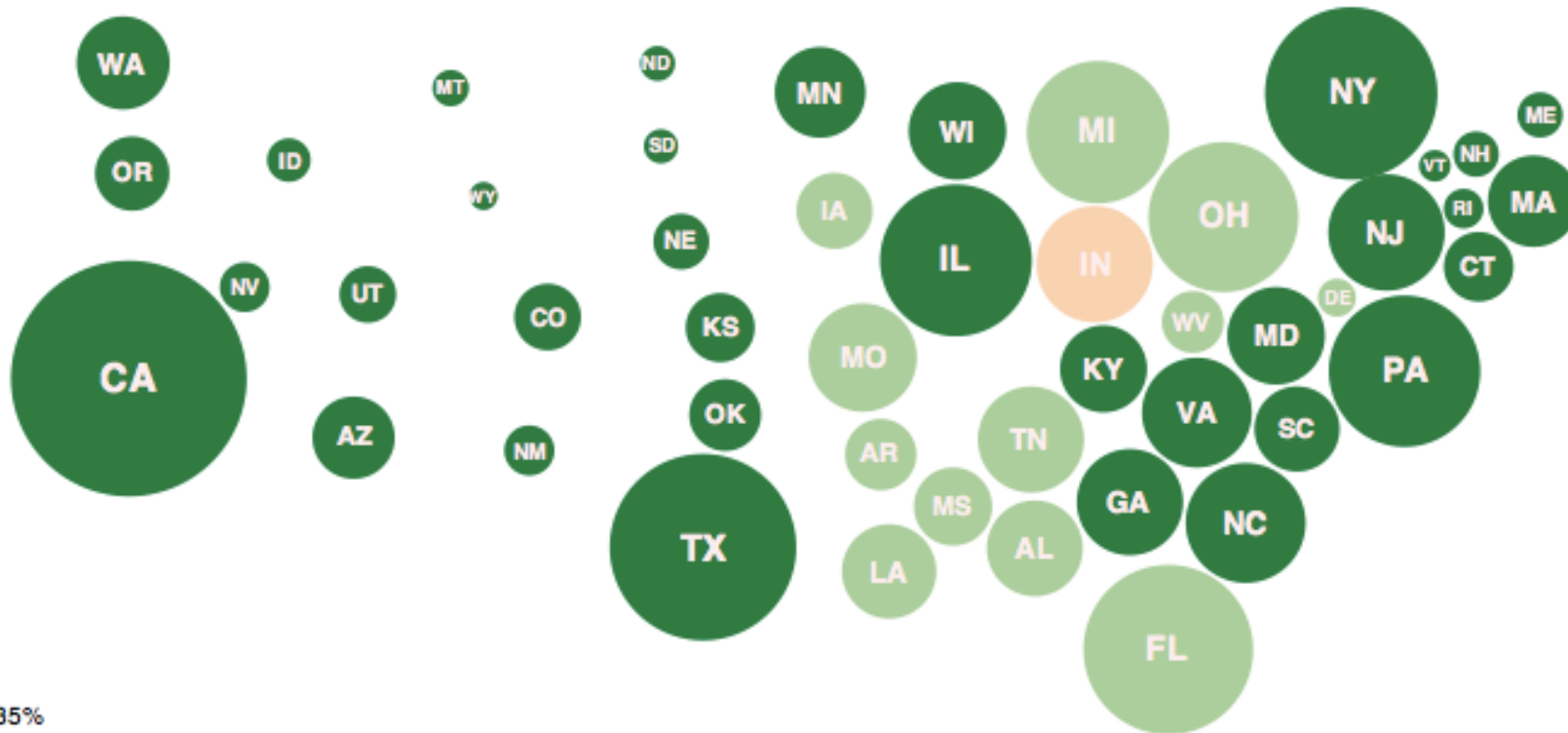
Race/Ethnicity

White  Black  Hispanic

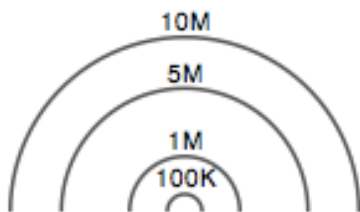
Median income

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

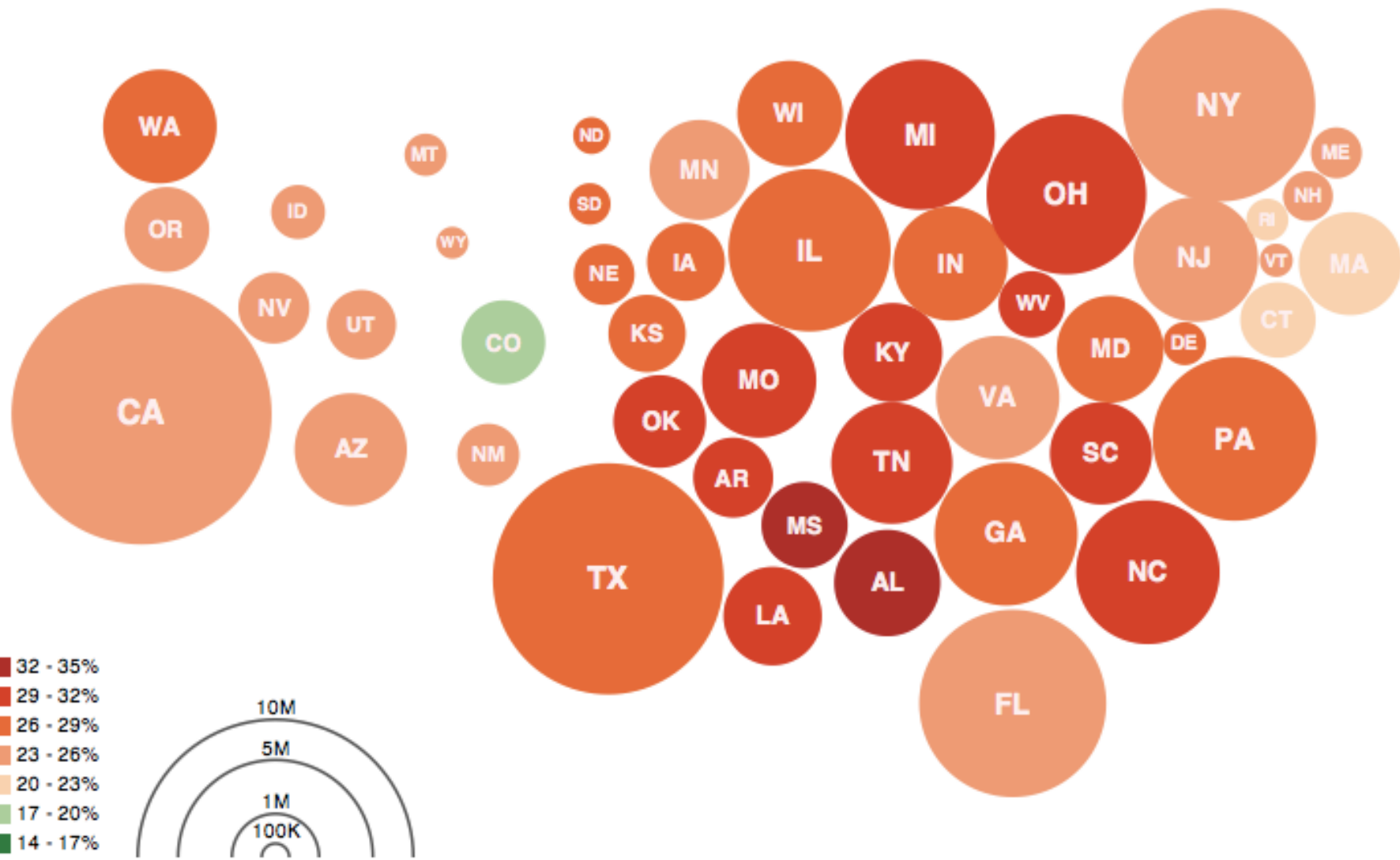
RESET



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

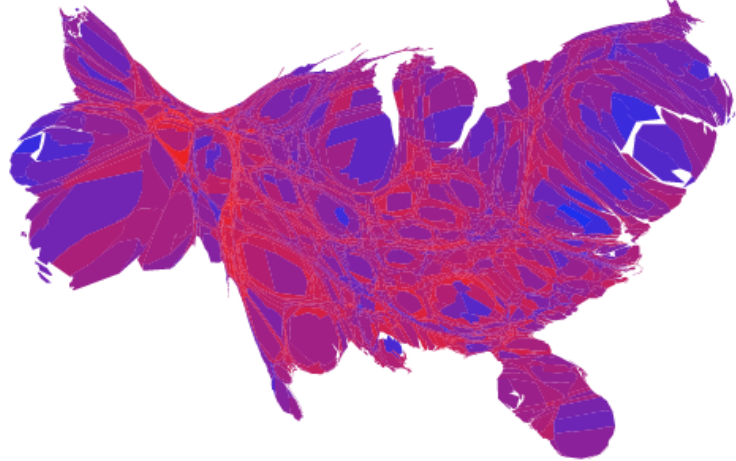
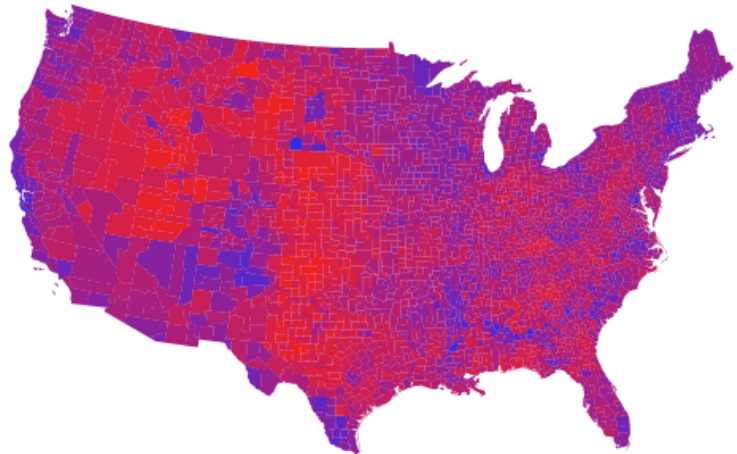
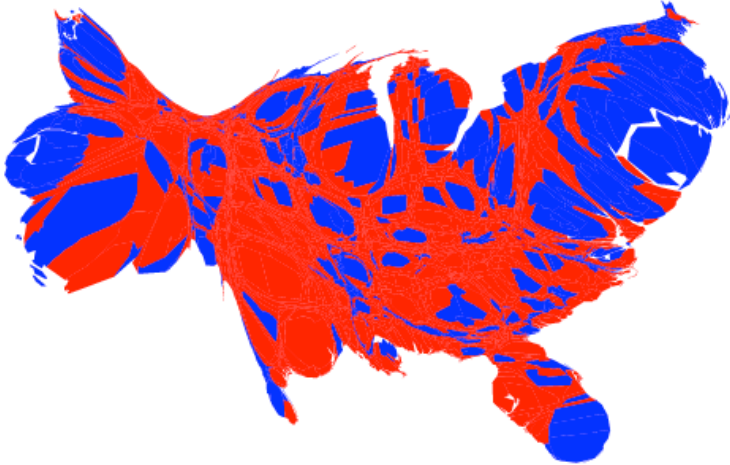
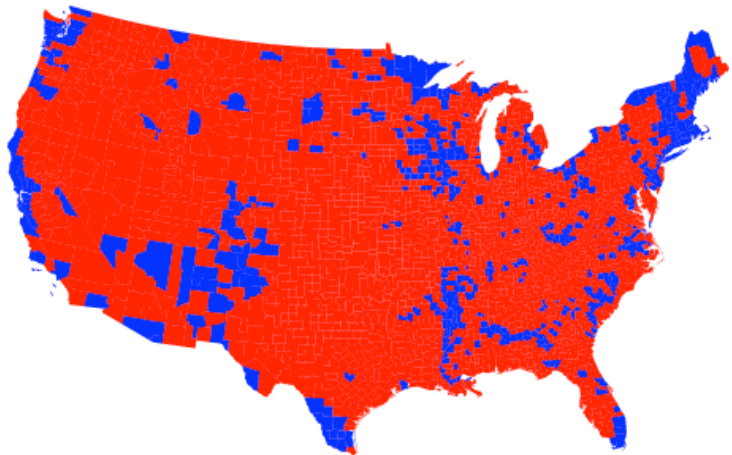
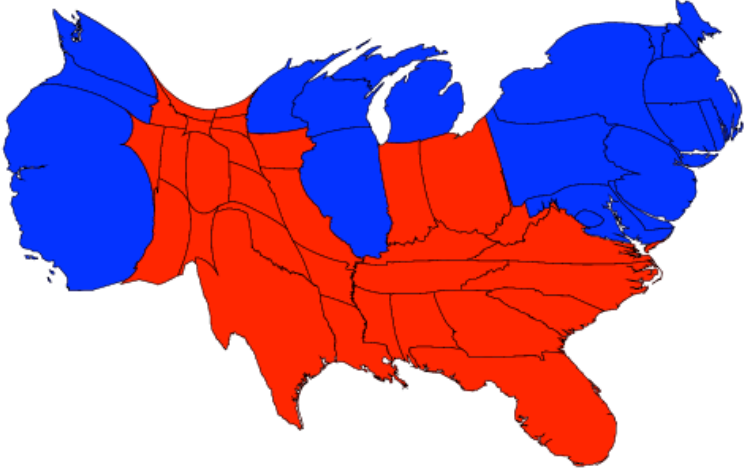
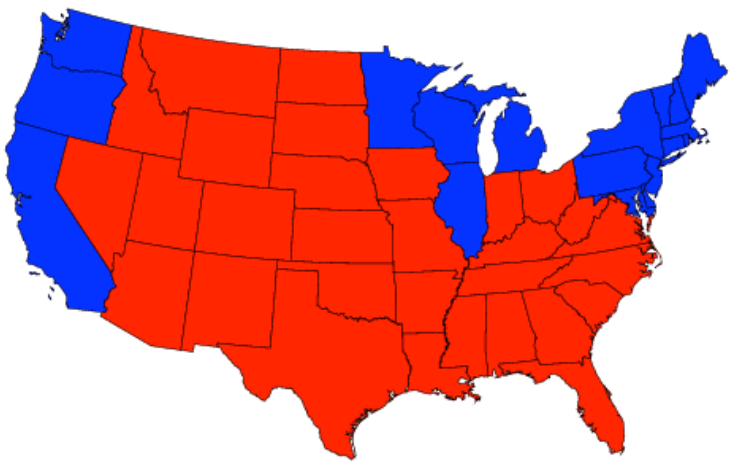


**Obesity Map (Dorling Cartogram)** Vadim Ogievetsky

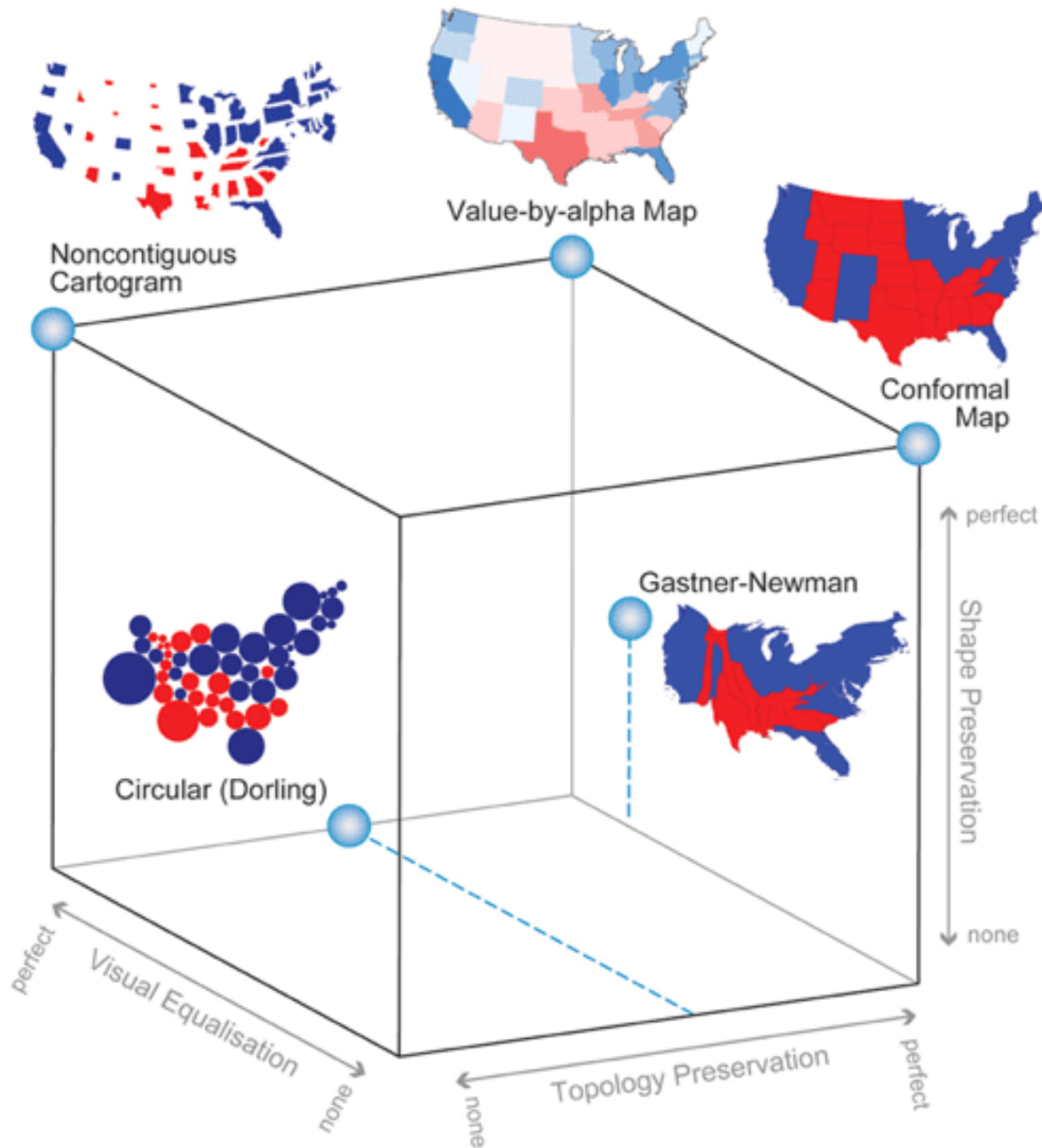


**Obesity Map (Dorling Cartogram)** Vadim Ogievetsky



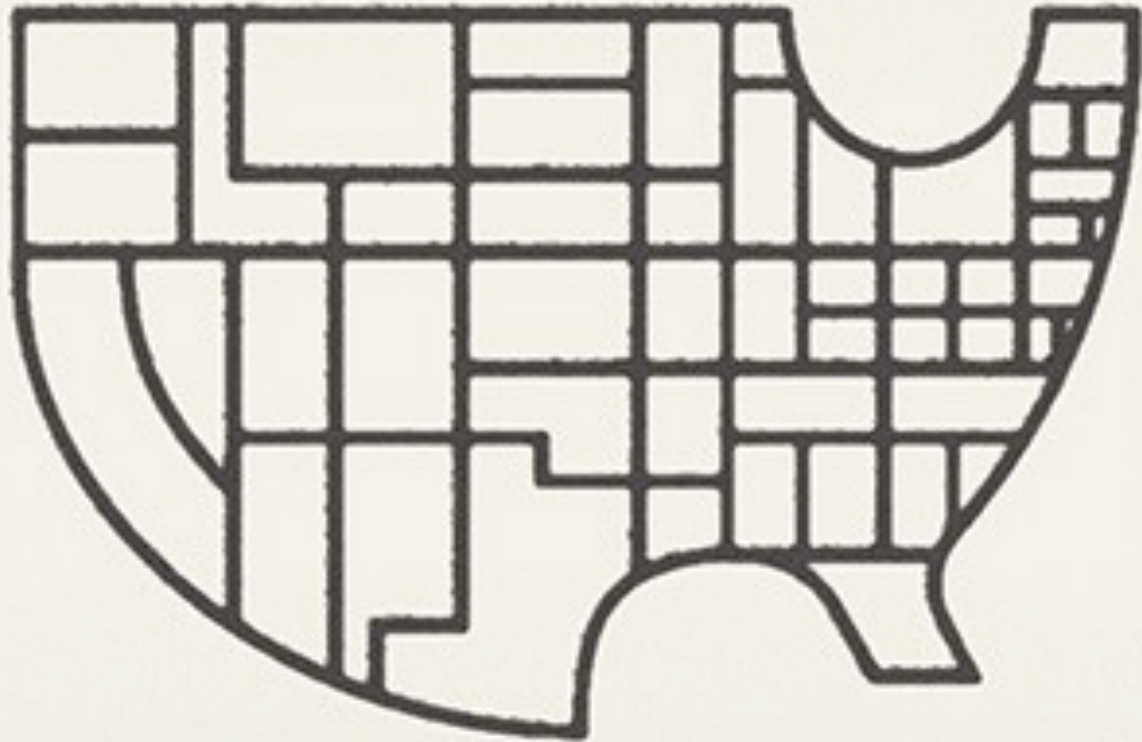








**Major distortions  
can stay recognizable**



# Generalization

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

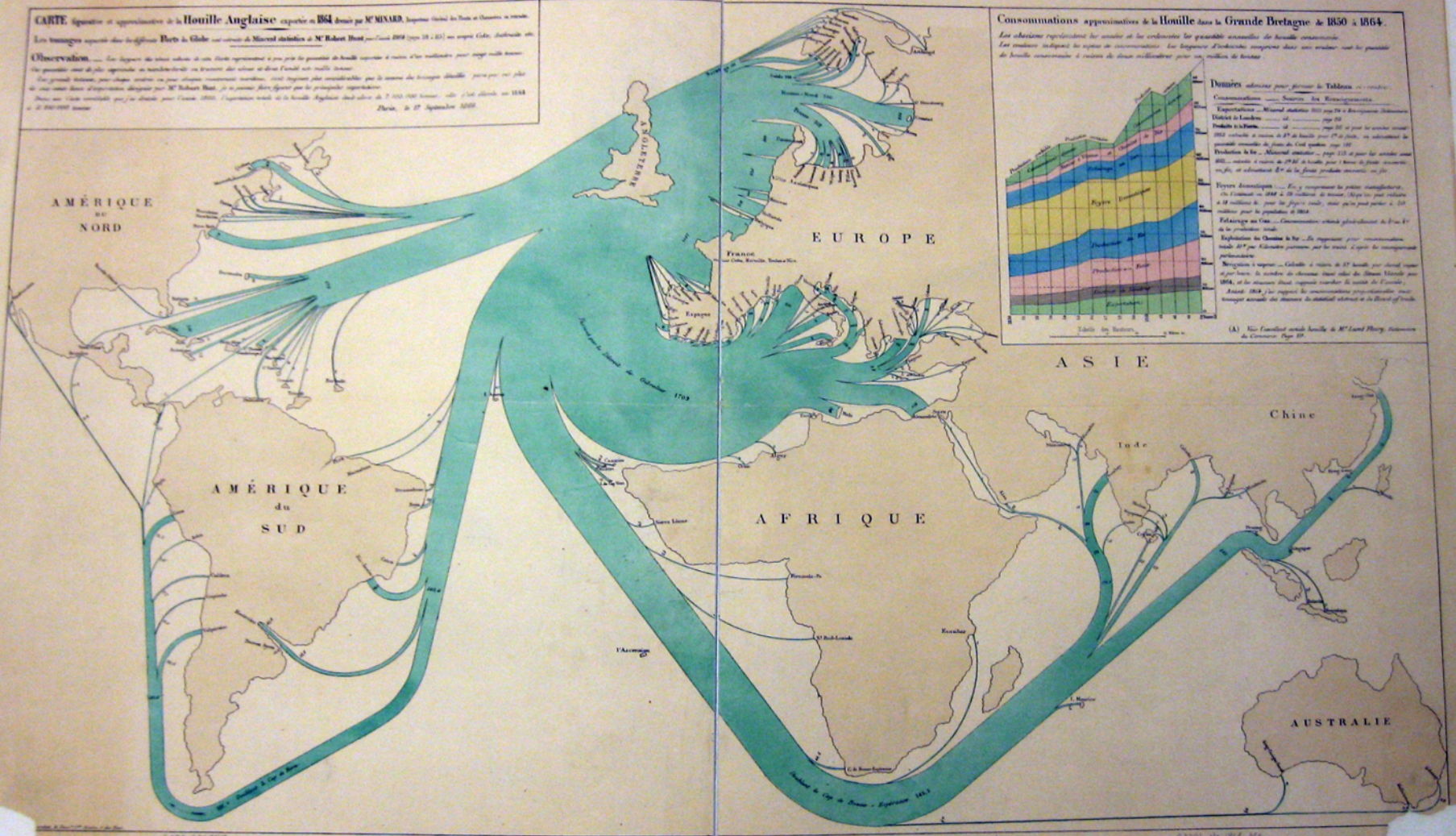
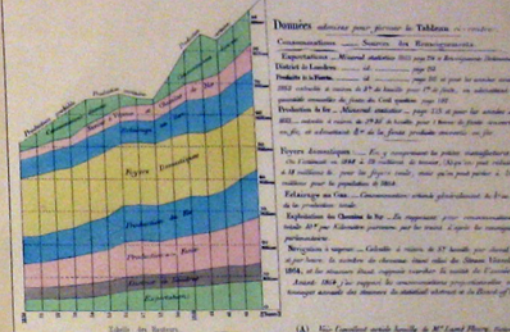
Les passages indiqués dans les différents Ports et Golfs ont été calculés de M. Robert Duret, par l'Année 1864 (page 18 & 19) sur un rapport Gêner. distribué en 1864.

**Observation.** Les lignes de couleur verte de cette Carte représentent à peu près la quantité de Houille exportée à l'étranger, et les lignes de couleur rouge celle qui est consommée dans le Royaume de France. Les lignes de couleur verte sont tracées en France, dans les limites de son territoire, et les lignes de couleur rouge sont tracées dans les limites de son territoire. Les lignes de couleur verte sont tracées dans les limites de son territoire, et les lignes de couleur rouge sont tracées dans les limites de son territoire.

Paris, le 27 Septembre 1864.

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

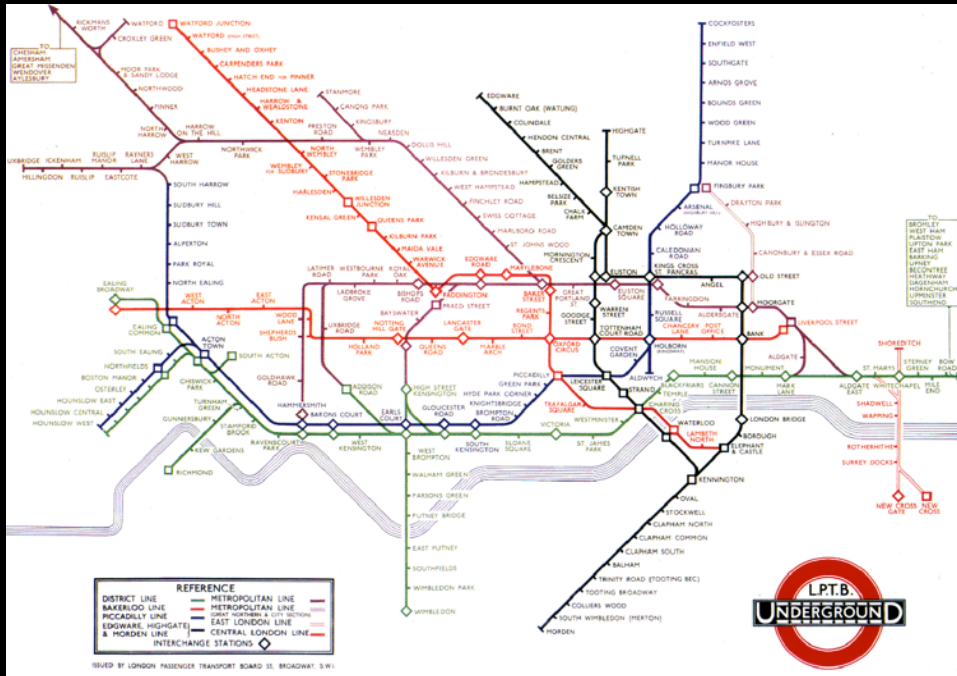
Les chiffres indiqués sur les courbes et les courbes les quantités annuelles de houille consommées. Les courbes indiquent le rapport de consommation. Les lignes d'ordonnée comptent dans un million de tonnes, et les courbes de houille consommée à raison de deux millions de tonnes par million de tonnes.



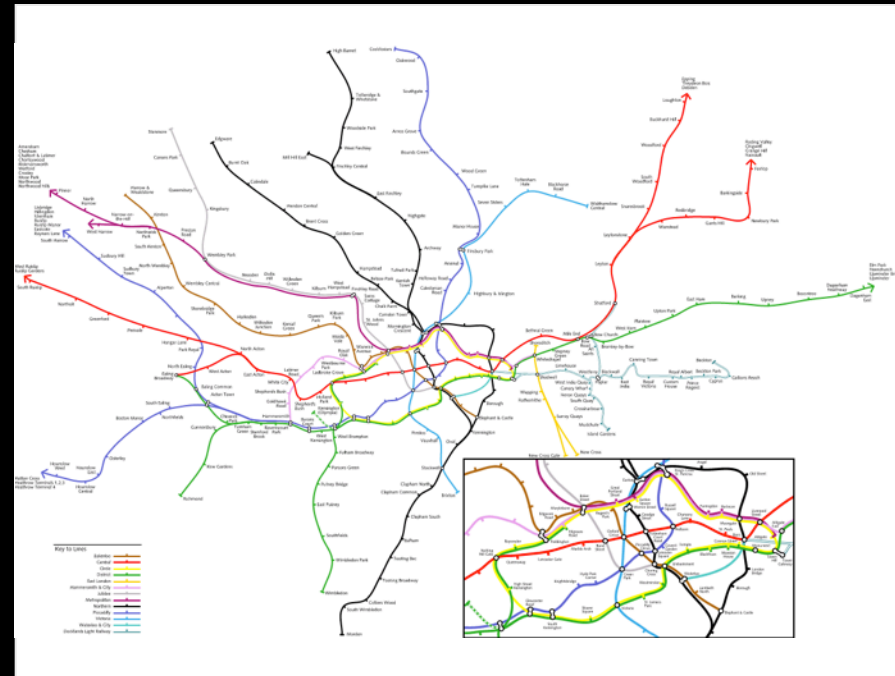
1864 British Coal Exports, Charles Minard







London Underground [Beck 33]



Geographic version of map

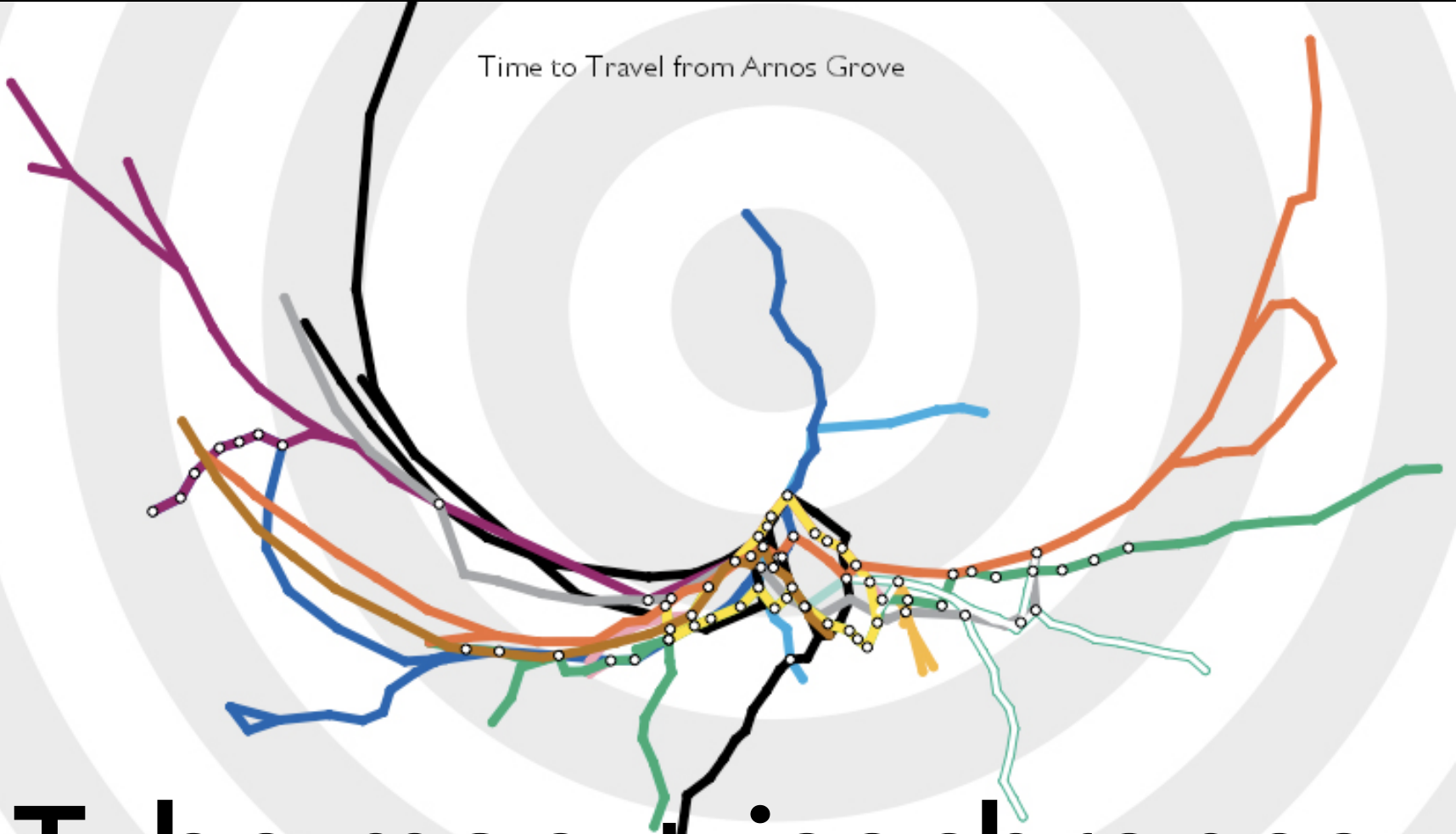
**Principle:** Straighten lines to emphasize stop sequence  
**Technique used to emphasize/de-emphasize information**



People \*love\*  
the tube map



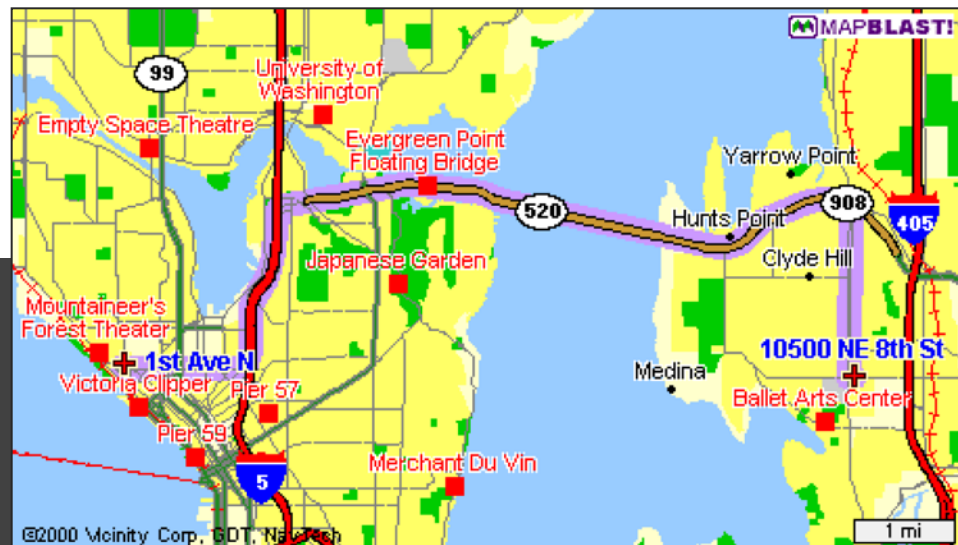
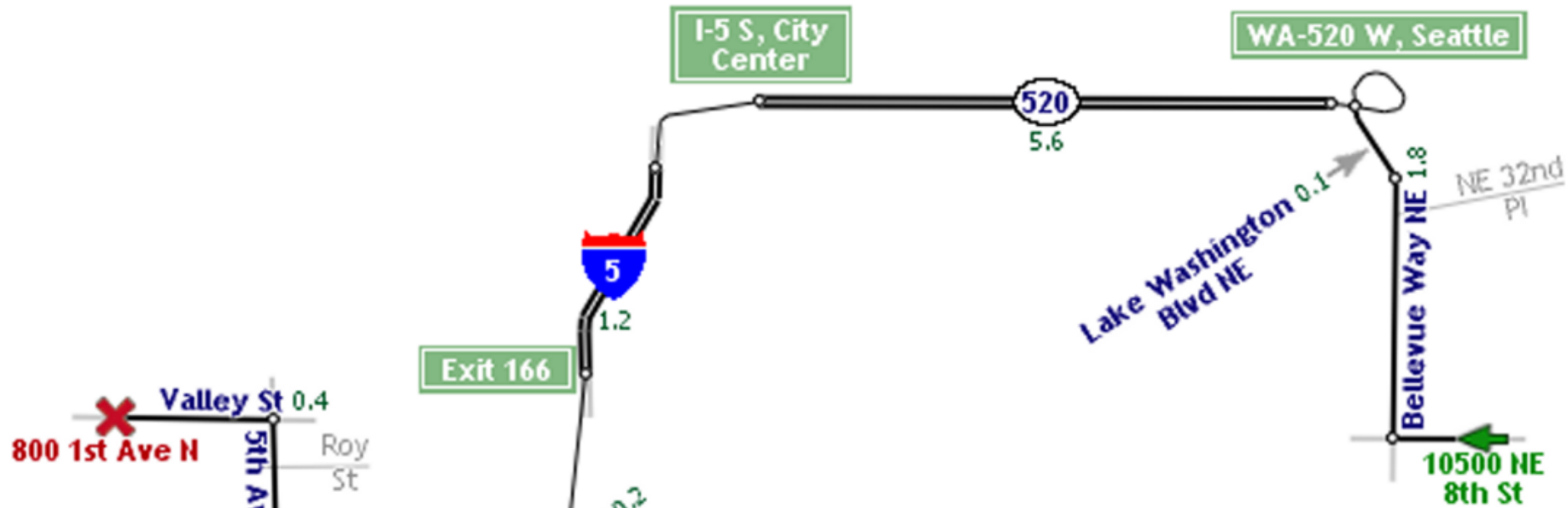
Time to Travel from Arnos Grove



# 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

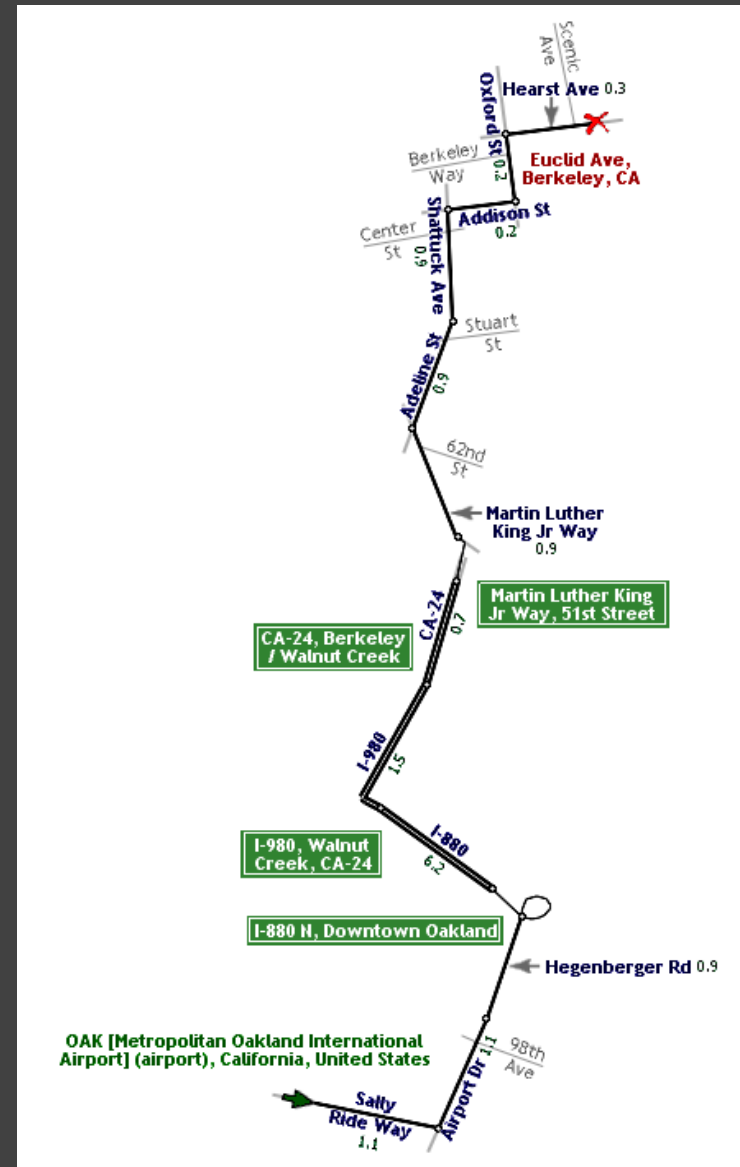
## Develop constraints based on design principles

## 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](https://naturalearthdata.com)

## OpenStreetMap

[openstreetmap.org](https://openstreetmap.org)

## U.S. Government

[nationalatlas.gov](https://nationalatlas.gov), [census.gov](https://census.gov), [usgs.gov](https://usgs.gov)

# Tutorials

## Let's Make a Map!

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

## How to Infer Topology

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