BIG DATA & VISUAL BEINGS

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URBAN COMPUTING

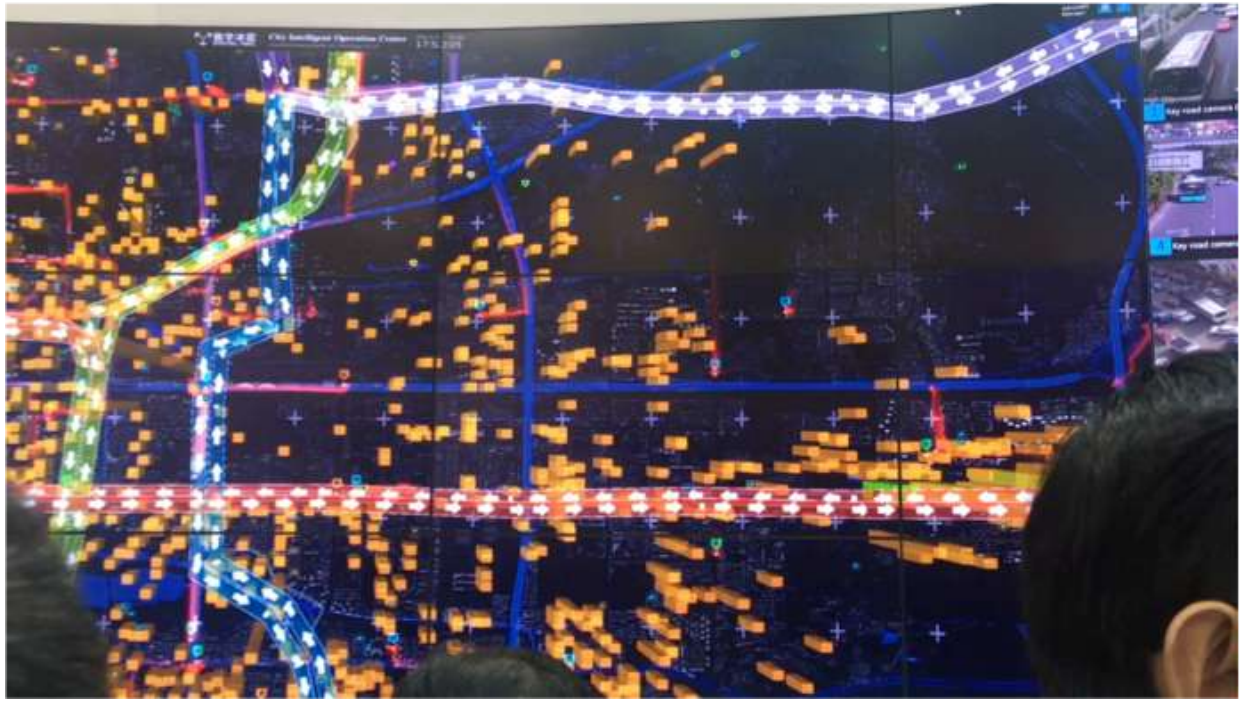
Improving cities, environment and people's live by processing **urban data**

Smart City

Data Analysis

- Increase Security
- Boost Tourism
- Fight Pollution
- Save Energy
- Reduce Traffic


40 ZETTABYTES
[43 TRILLION GIGABYTES]
of data will be created by 2020, an increase of 300 times from 2005
2005
2020
It's estimated that
2.5 QUINTILLION BYTES
[2.3 TRILLION GIGABYTES]
of data are created each day
6 BILLION PEOPLE
have cell phones
Volume
SCALE OF DATA
Most companies in the U.S. have at least
100 TERABYTES
[100,000 GIGABYTES]
of data stored
WORLD POPULATION: 7 BILLION
As of 2011, the global size of data in healthcare was estimated to be
150 EXABYTES
[161 BILLION GIGABYTES]
By 2014, it's anticipated there will be
420 MILLION WEARABLE, WIRELESS HEALTH MONITORS
Variety
DIFFERENT FORMS OF DATA
4 BILLION+ HOURS OF VIDEO
are watched on YouTube each month
30 BILLION PIECES OF CONTENT
are shared on Facebook every month
400 MILLION TWEETS
are sent per day by about 200 million monthly active users
BIG
URBAN
DATA
The New York Stock Exchange captures
1 TB OF TRADE INFORMATION
during each trading session
Modern cars have close to
100 SENSORS
that monitor items such as fuel level and tire pressure
Velocity
ANALYSIS OF STREAMING DATA
By 2016, it is projected there will be
18.9 BILLION NETWORK CONNECTIONS
– almost 2.5 connections per person on earth
1 IN 3 BUSINESS LEADERS
don't trust the information they use to make decisions
Poor data quality costs the US economy around
$3.1 TRILLION A YEAR
27% OF RESPONDENTS
in one survey were unsure of how much of their data was inaccurate
Veracity
UNCERTAINTY OF DATA



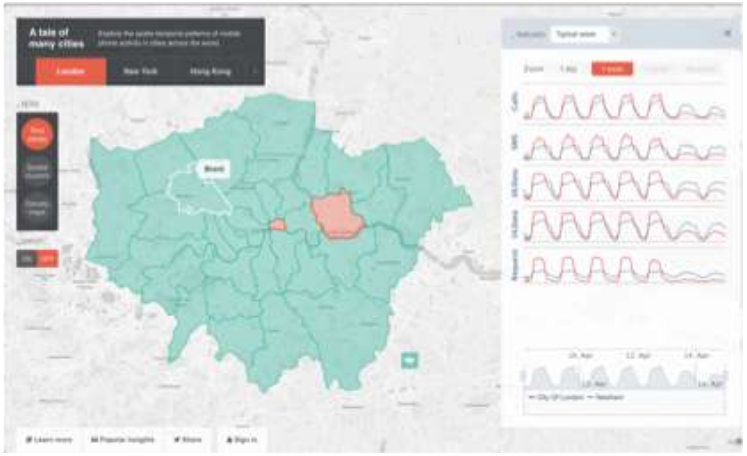
HUAWEII City Intelligence Operation Center, 2016 Smart City Conference, Barcelona

Real-Time Urban Data Analysis

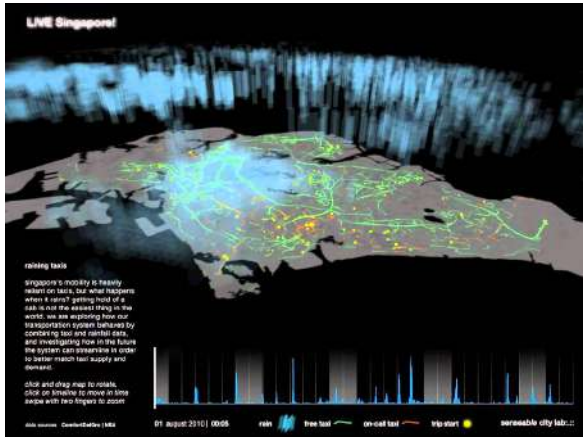
URBAN COMPUTING CHALLENGE

EXAMPLES

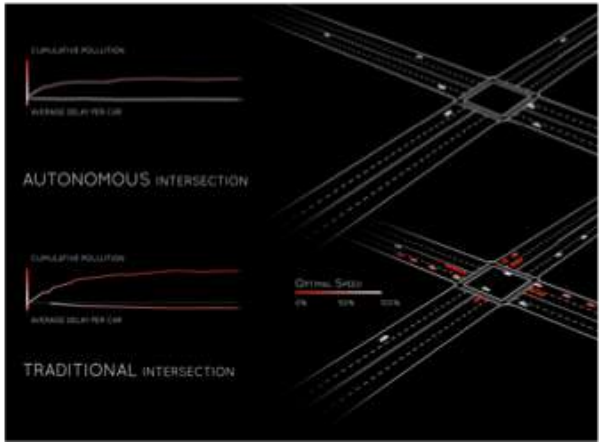
Real-time collection of traffic data



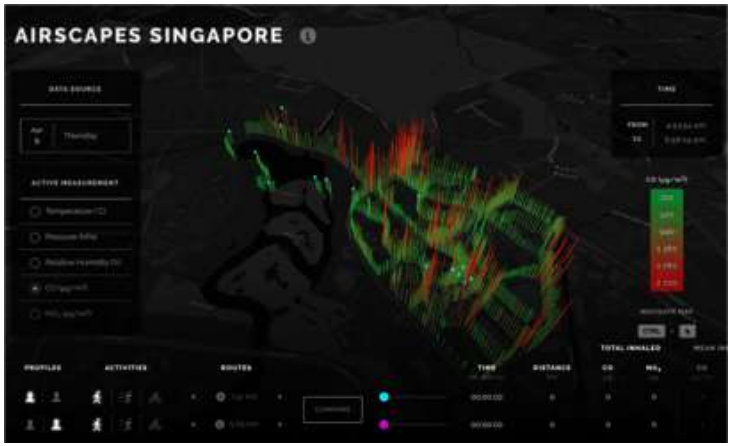
Patterns of mobile activity



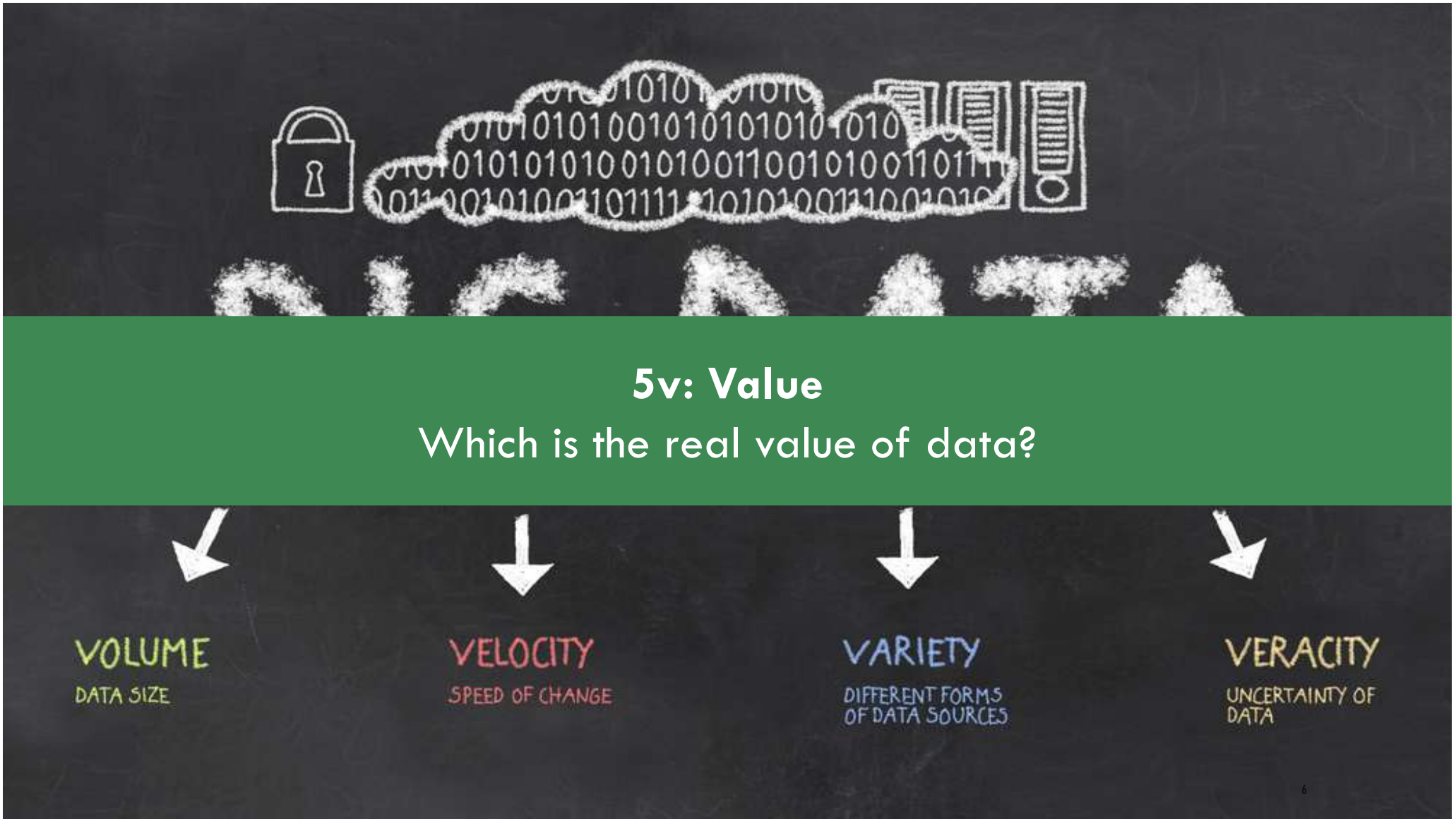
Raining day & taxi supply



Light Traffic



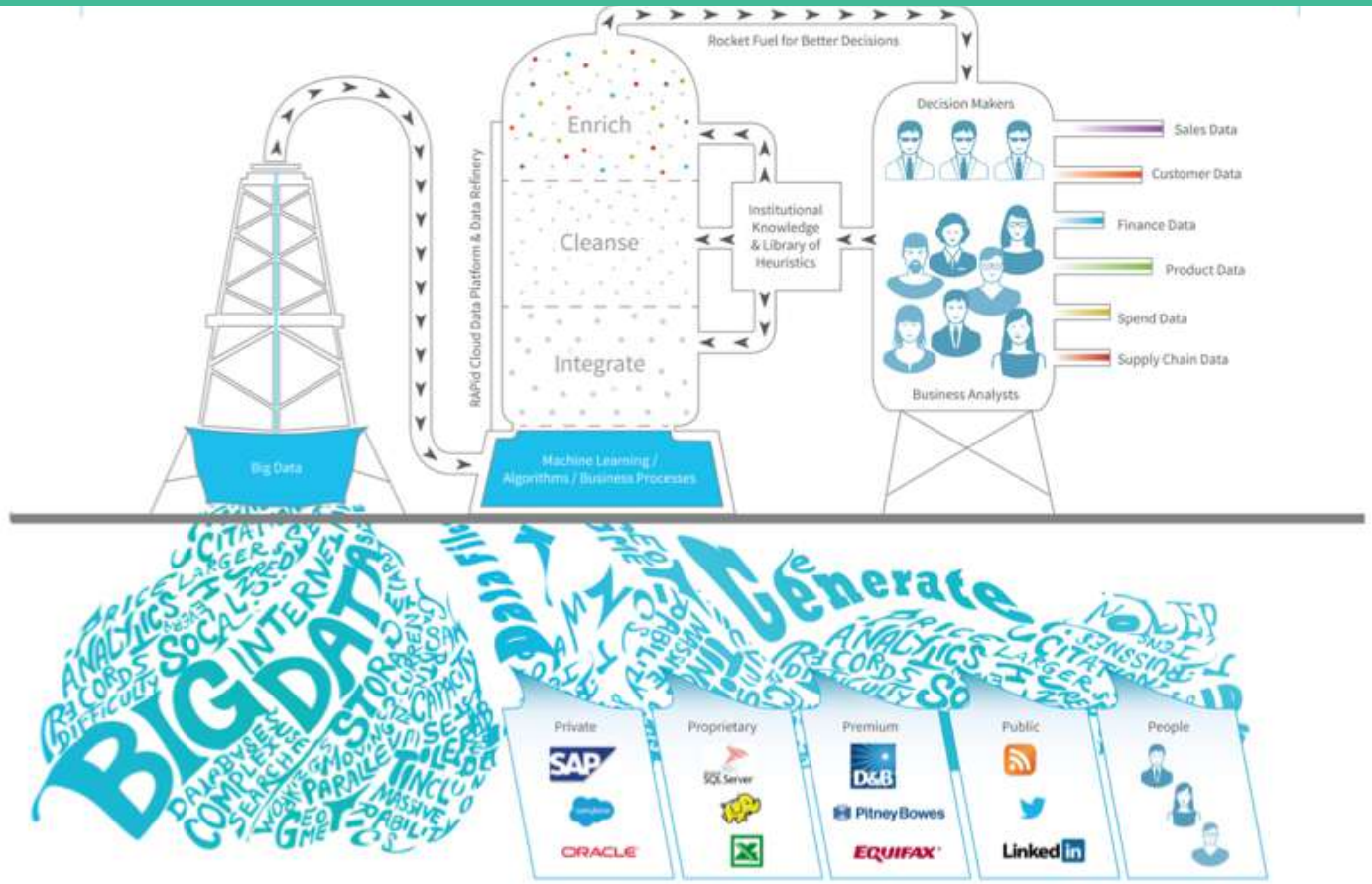
CO2 hot spots



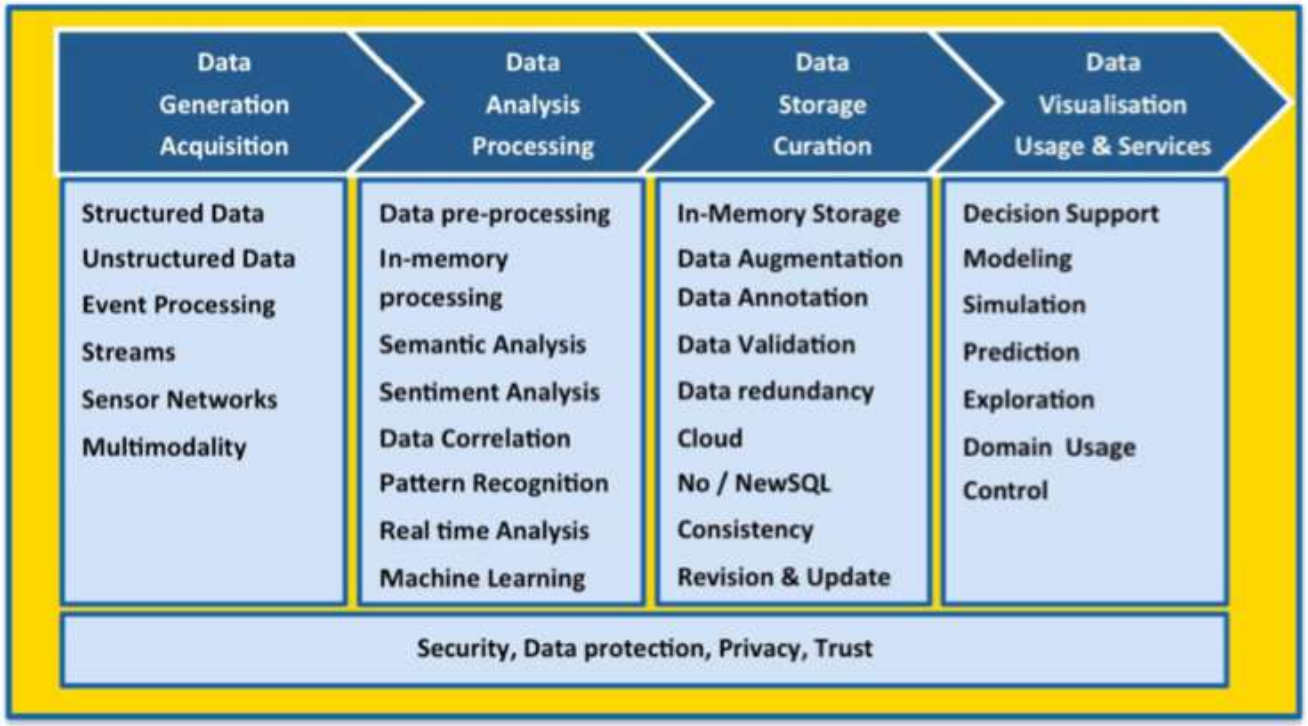
5v: Value

Which is the real value of data?

BIG DATA PROCESSING AT A GLANCE



BDVA: BIG DATA VALUE CHAIN



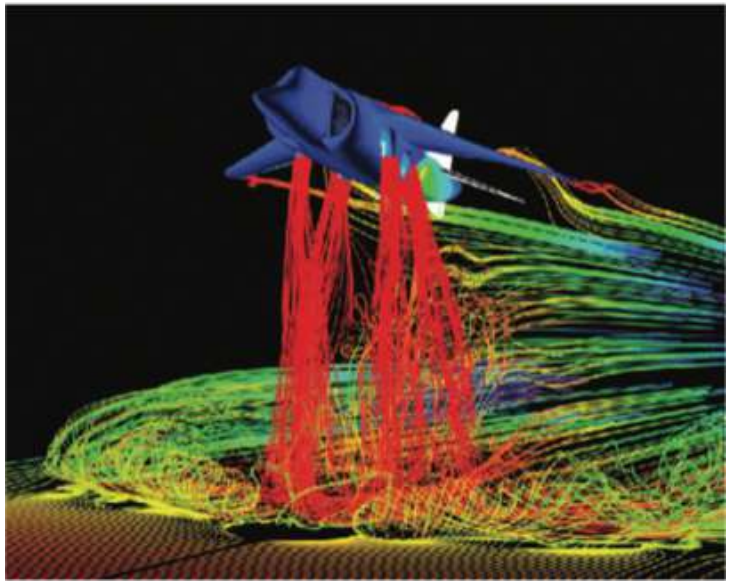
European Big Data Value Association
www.bdva.eu

WHAT IS DATA VISUALIZATION ?

DATA VISUALIZATION

- Techniques used to communicate information clearly and efficiently by encoding data as visual objects (e.g., *points, lines or bars*) in graphics.

- Sources of data and the way users interact and perceive it are important components to understand when presenting information



Various representation of **hypothetical clinical trial**

DATA VISUALIZATION GOALS

- Answer questions (or discover them)
- Make decisions
- See data in context
- Support graphical calculation
- Find patterns
- Present argument or tell a story

EXAMPLE: ANSCOMBE'S QUARTET

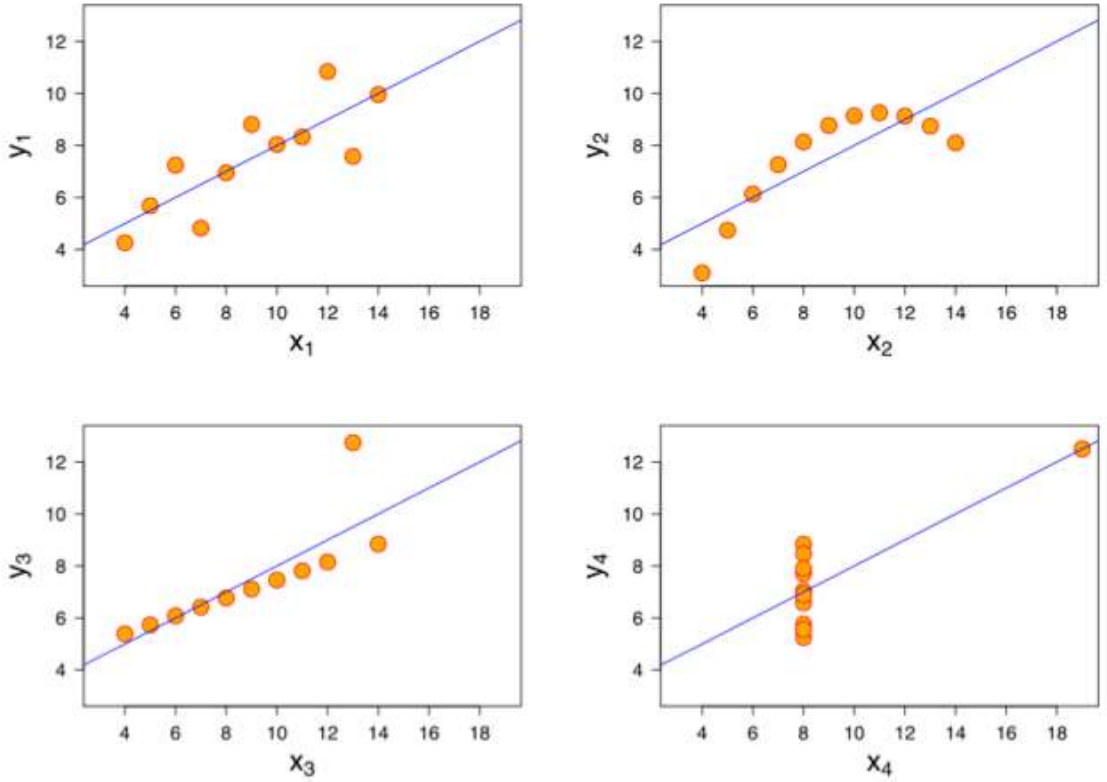
Datasets that have nearly identical simple statistical properties

I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

Property	Value
Mean of *x* in each case	9 (exact)
Sample variance of *x* in each case	11 (exact)
Mean of *y* in each case	7.50 (to 2 decimal places)
Sample variance of *y* in each case	4.122 or 4.127 (to 3 decimal places)
Correlation between *x* and *y* in each case	0.816 (to 3 decimal places)
Linear regression line in each case	$y = 3.00 + 0.500x$ (to 2 and 3 decimal places, respectively)

EXAMPLE: ANSCOMBE'S QUARTET

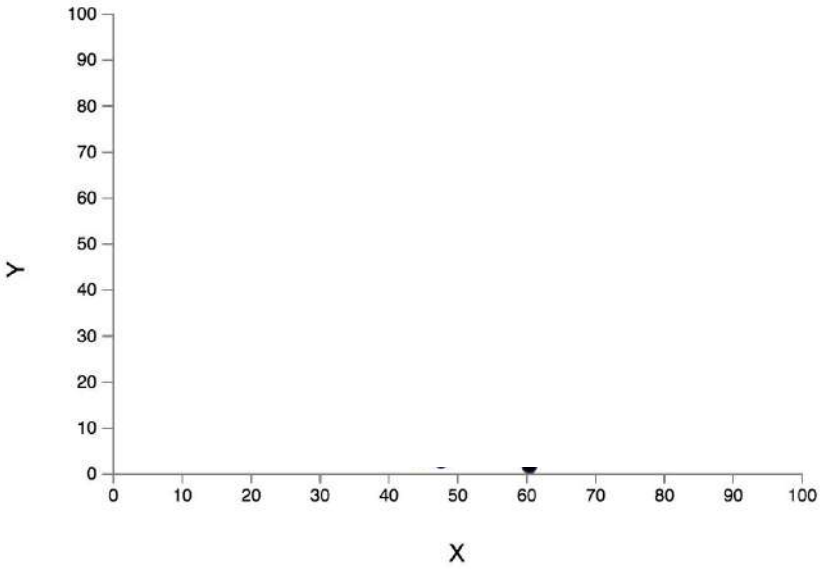
… but vary considerably when graphed



EXAMPLE: DRAW MY DATA

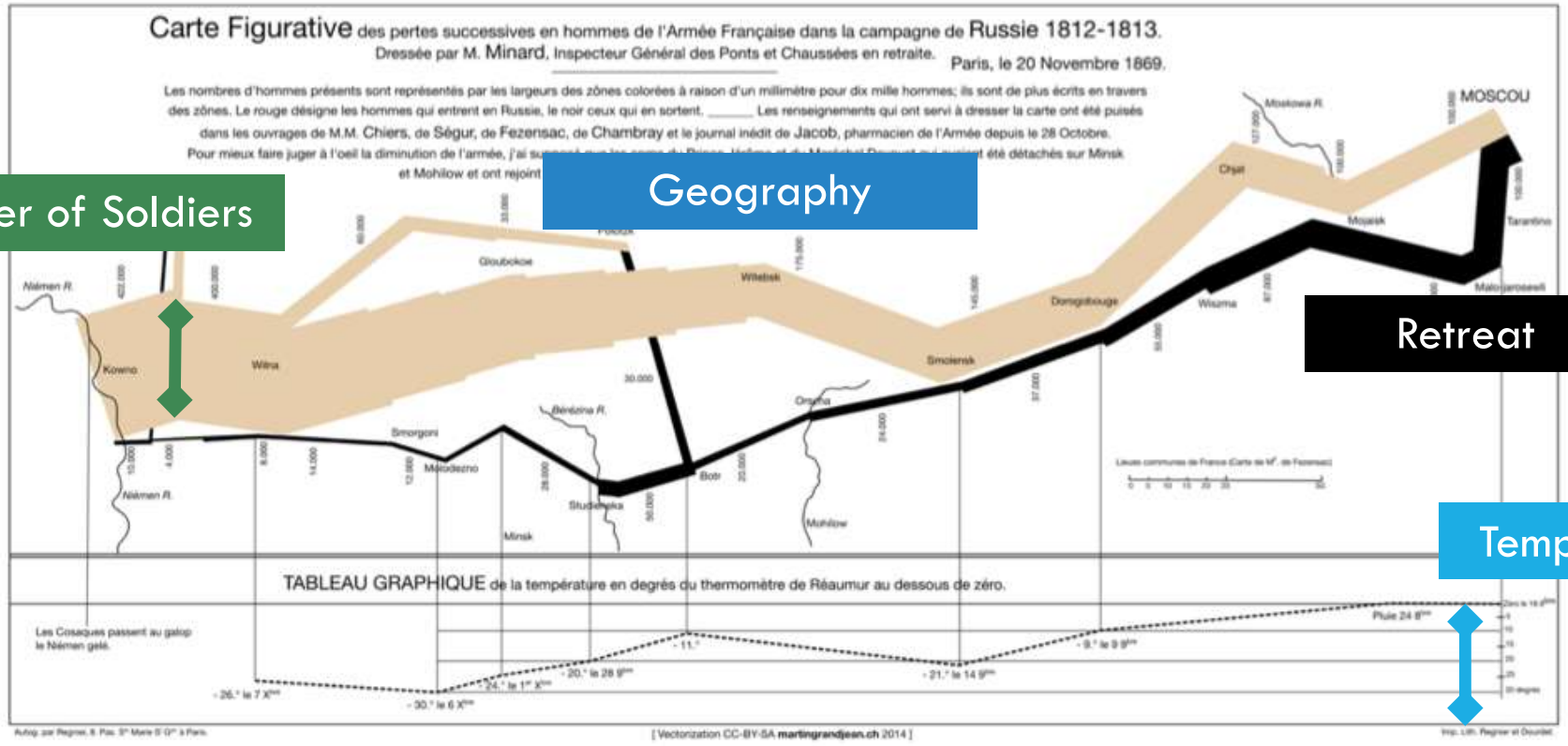
N = 157 ; X mean = 50.7333 ; X SD = 19.5661 ; Y mean = 46.495 ; Y SD = 27.2828 ;
Pearson correlation = -0.1772

55.3846	97.1795
51.5385	96.0256
46.1538	94.4872
42.8205	91.4103
40.7692	88.3333
38.7179	84.8718
35.641	79.8718
33.0769	77.5641
28.9744	74.4872
26.1538	71.4103
23.0769	66.4103
22.3077	61.7949
22.3077	57.1795
23.3333	52.9487
25.8974	51.0256
29.4872	51.0256
32.8205	51.0256



http://robertgrantstats.co.uk/drawmydata.html

EXAMPLE: NAPOLEON'S MARCH TO MOSCOW

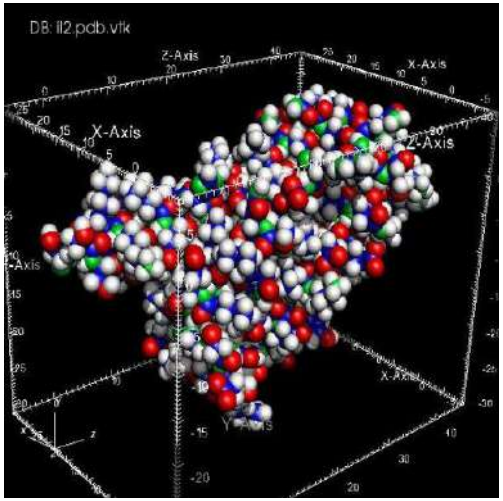


EXAMPLE: 1854 LONDON CHOLERA OUTBREAK

Water Pump

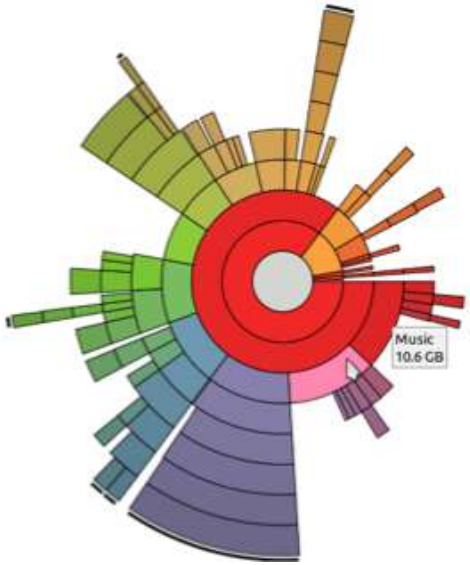
Founding event of the science of epidemiology

VISUALIZATION TYPES



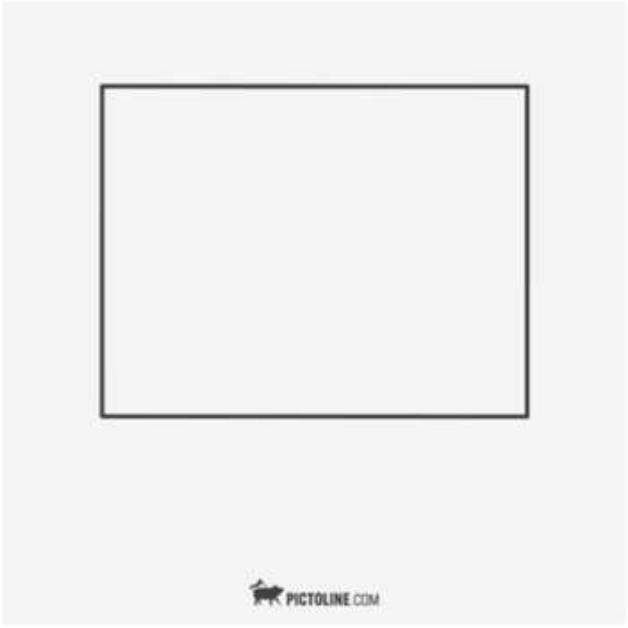
Scientific Visualization

Visualization of 3-dimensional phenomena
Data has a “physical” correspondence



Information Visualization

Visualization of abstract data that don’t necessarily have a spatial dimension



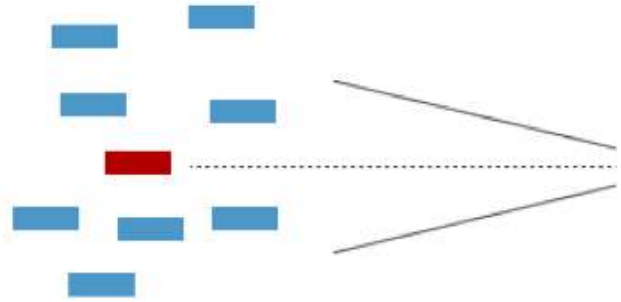
Information Graphics

Intended to present information quickly and clearly

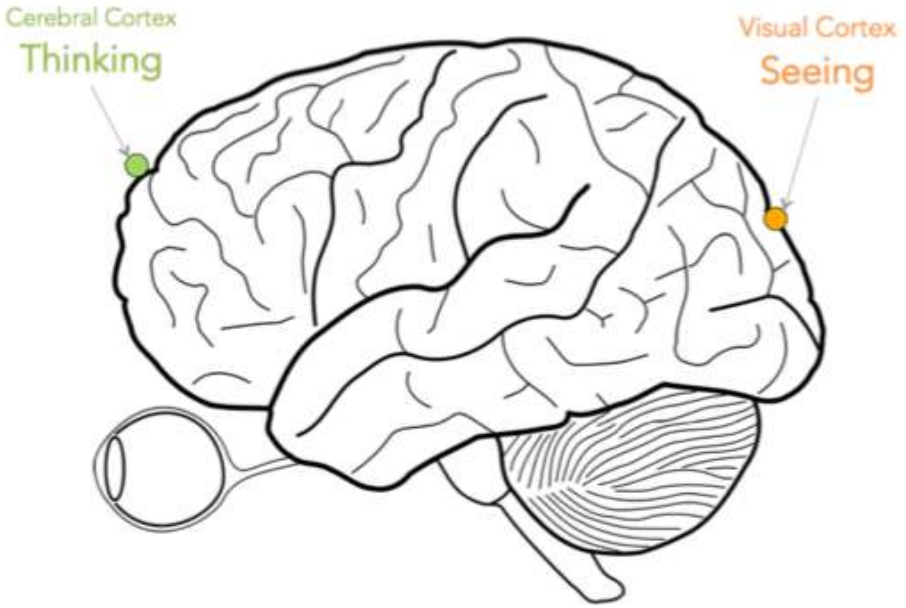
VISUAL PERCEPTION

PRE-ATTENTIVE PROCESSING
Perceives attributes without cognitive effort
(*250 milliseconds or less*)

Human cognitive process



Stimulus



HOW MANY 3'S ?

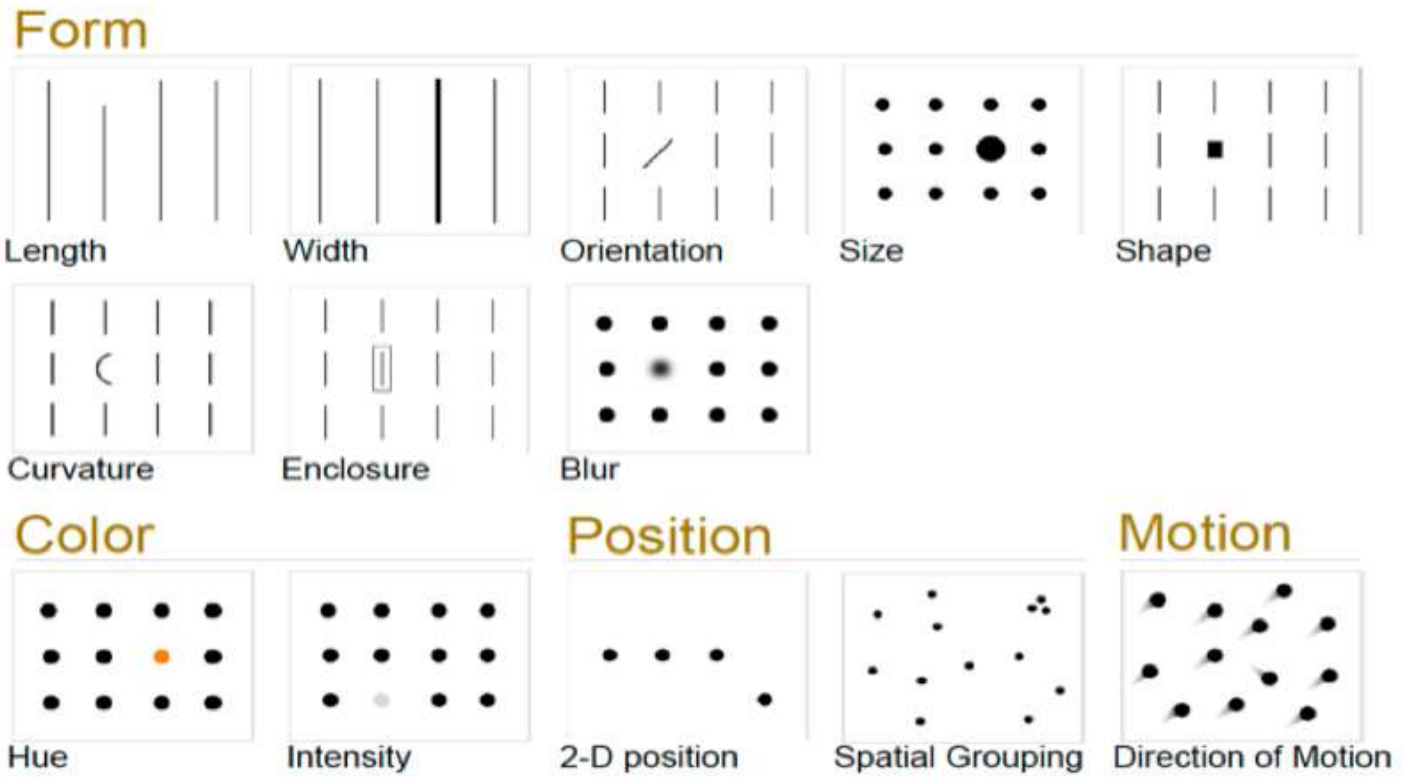
2487218401238740921659014760985609324720912562906509852659048275829856809609863095843905640958789503745092847509894750929 84

HOW MANY 3'S ?

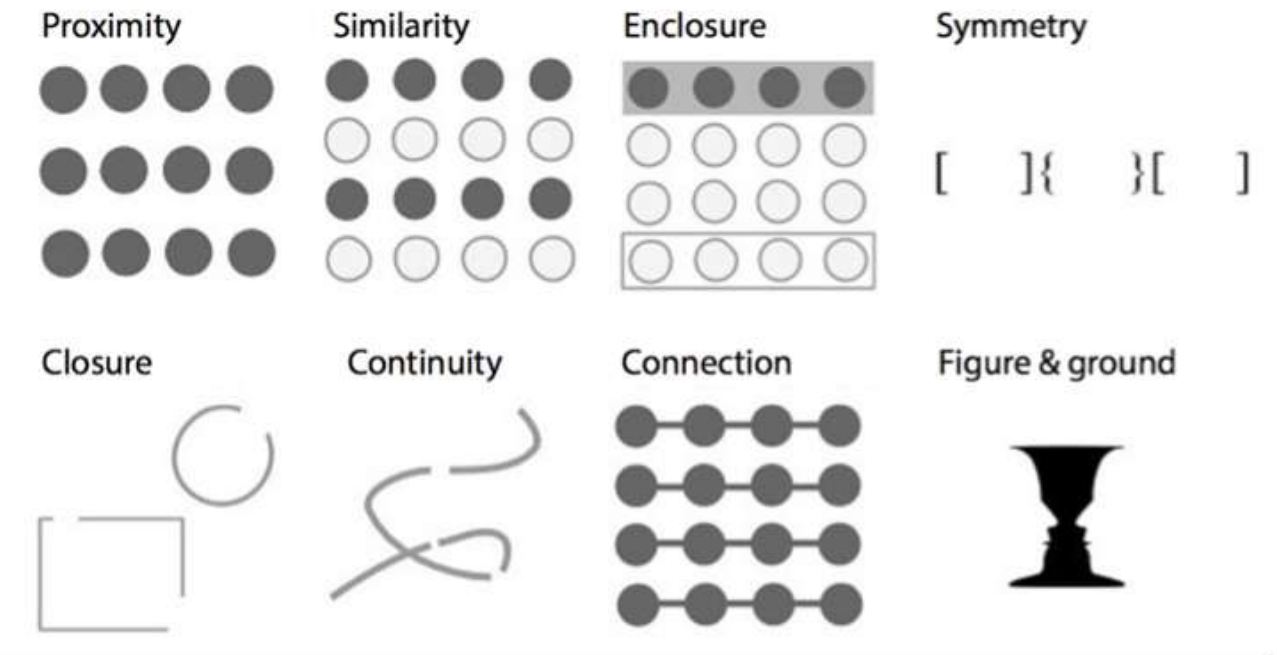
248721840123874092165901476098
560932472091256290650985265904
827582985680960986309584390564
095878950374509284750989475092
984

DETERMINE MAX AND MINIMUM VALUES

PRE-ATTENTIVE VISUAL ATTRIBUTES

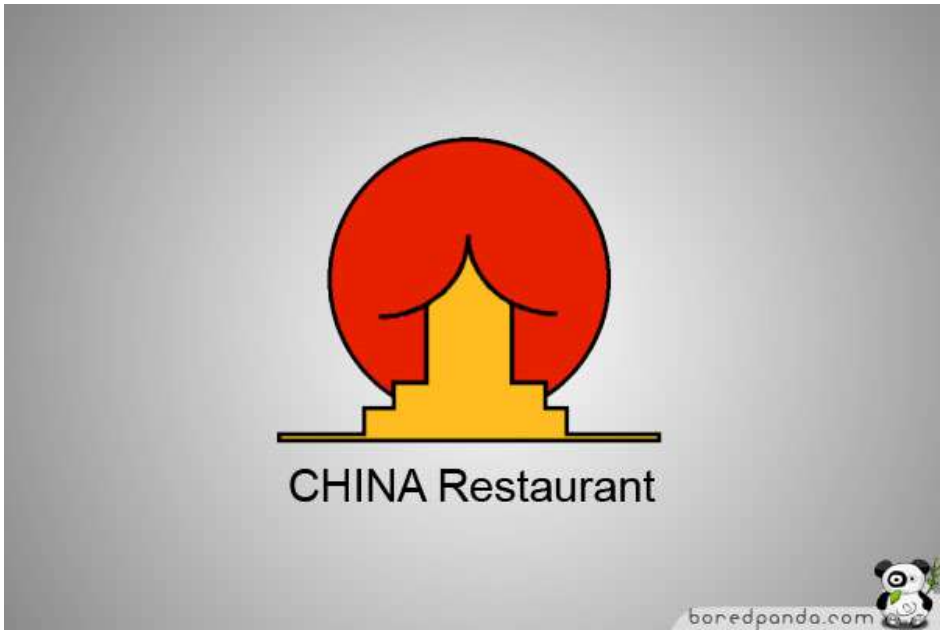


GESTALT PERCEPTION VISUAL PATTERNS



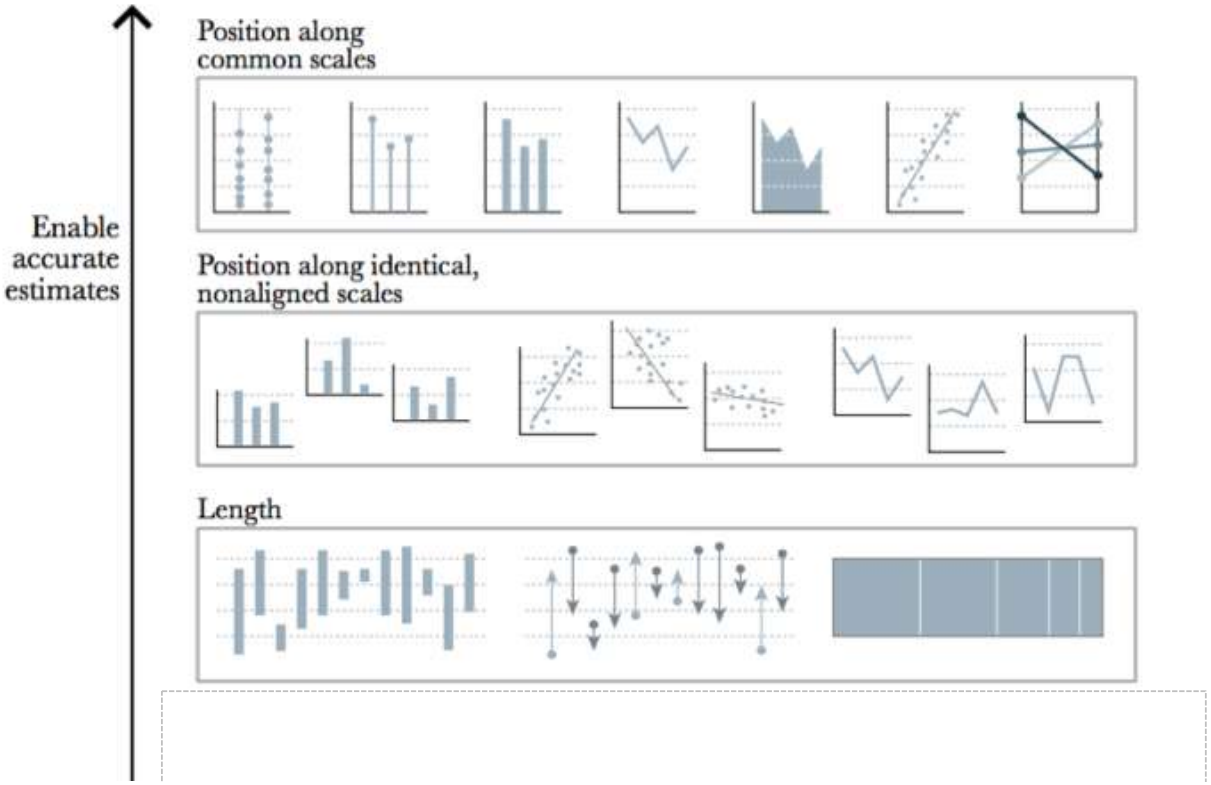
https://en.wikipedia.org/wiki/Gestalt_psychology

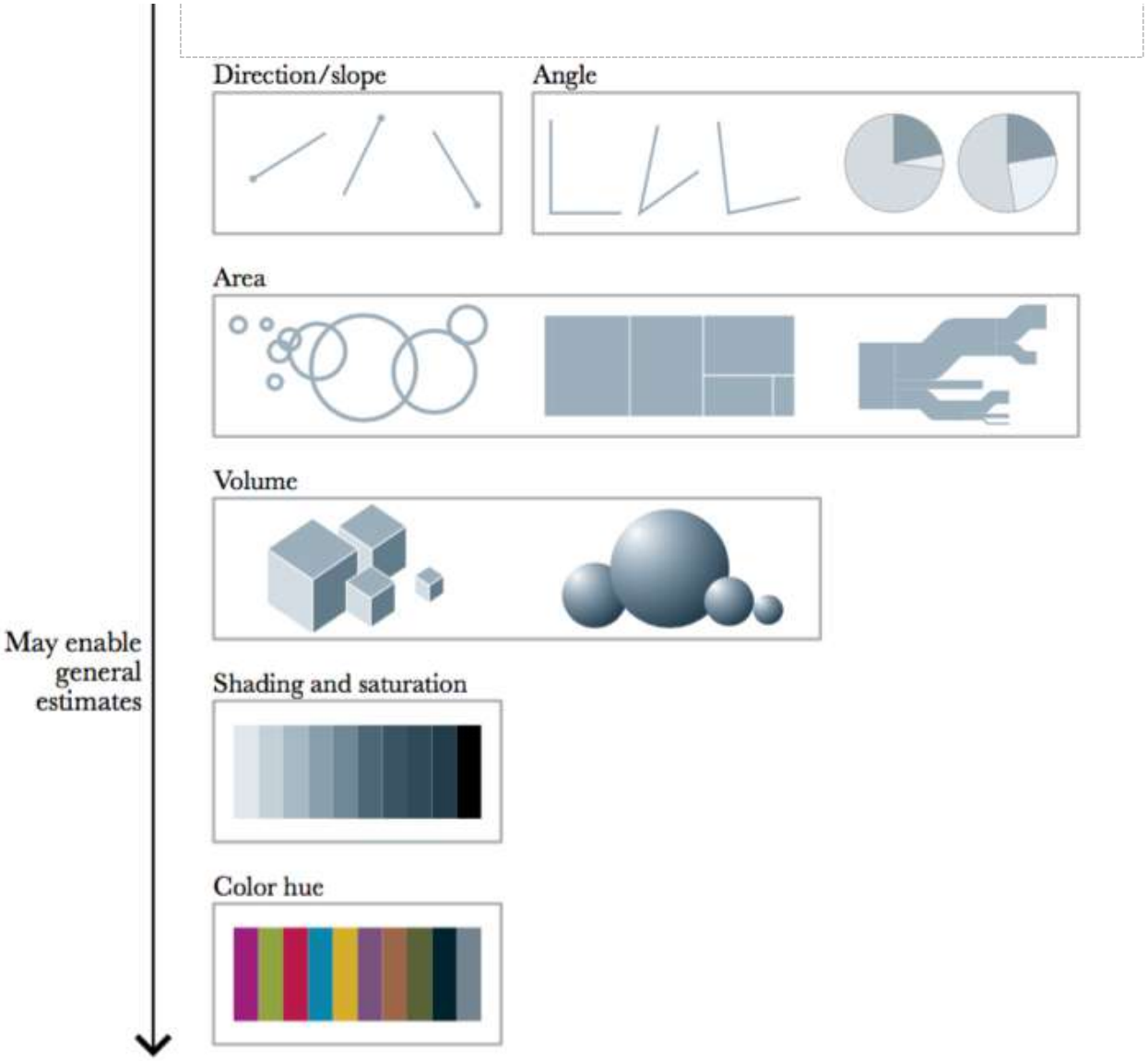
EXAMPLE: LOGO FAILURES ?



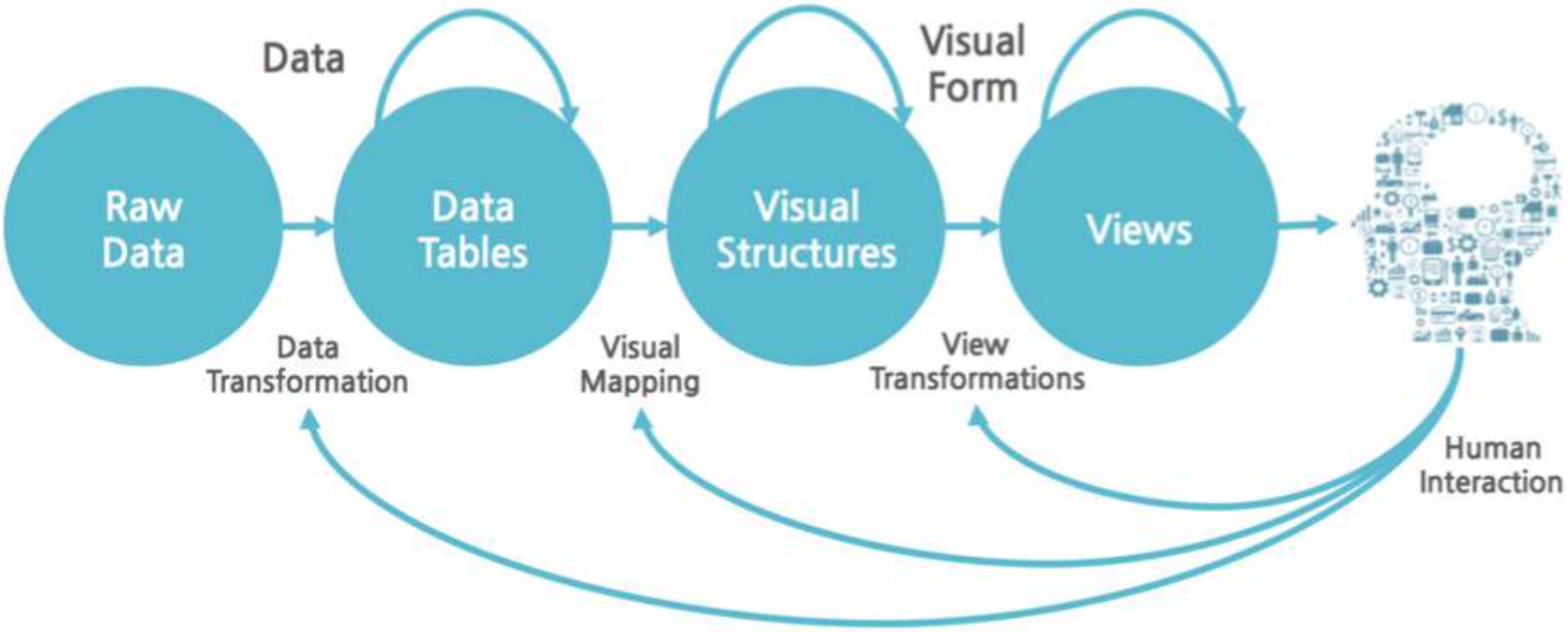
"Pagoda in front of the rising sun" - Designer

RANKING VISUAL ENCODINGS



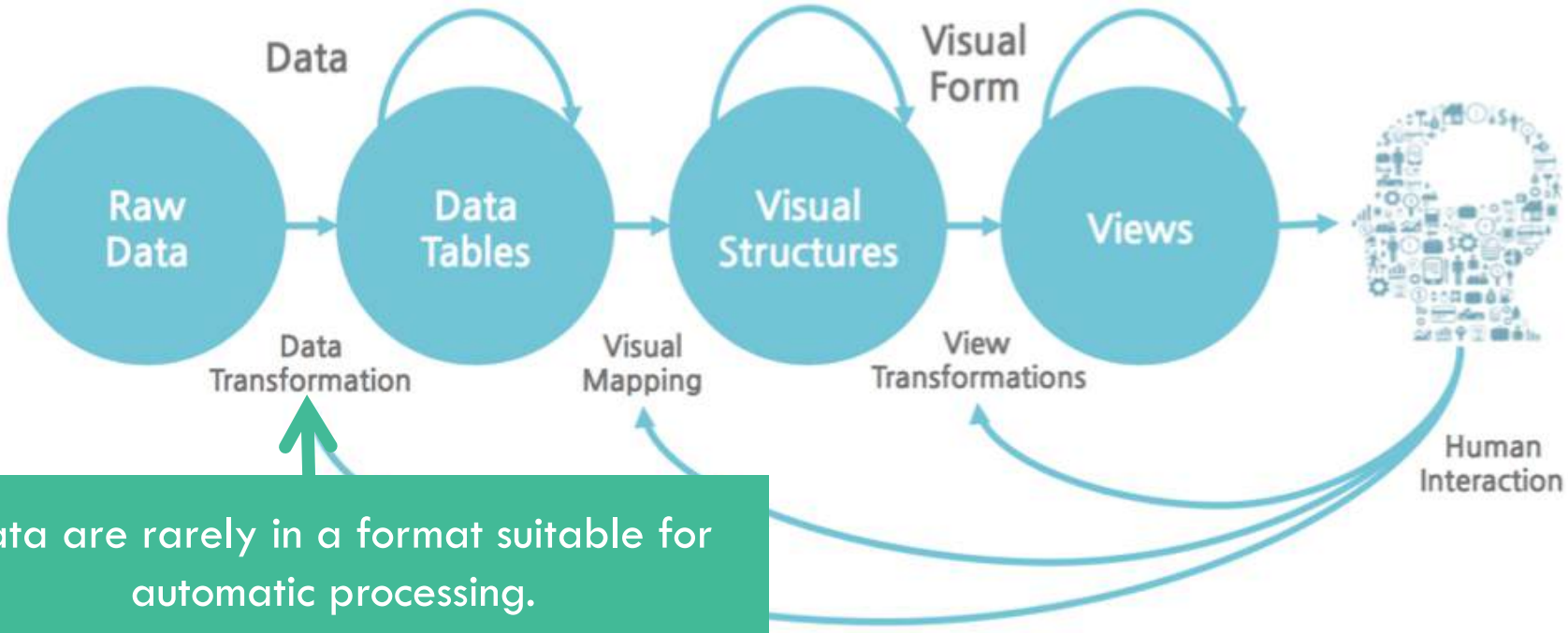

Direction/slope
Angle
Area
Volume
Shading and saturation
Color hue
May enable general estimates

DATA VISUALIZATION PROCESS



Information Visualization Reference Model Kb S. K. Card

DATA VISUALIZATION PROCESS

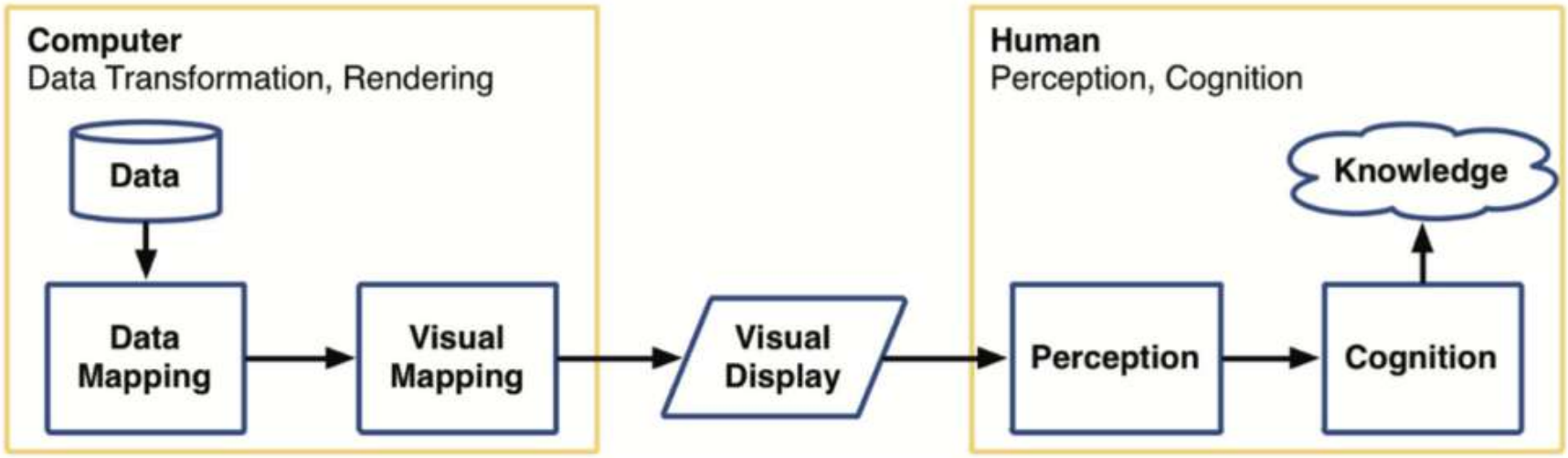


Data are rarely in a format suitable for automatic processing.

It must be ***filtered*** and ***processed***

n Reference Model Kb S. K. Card

DATA VISUALIZATION PIPELINE



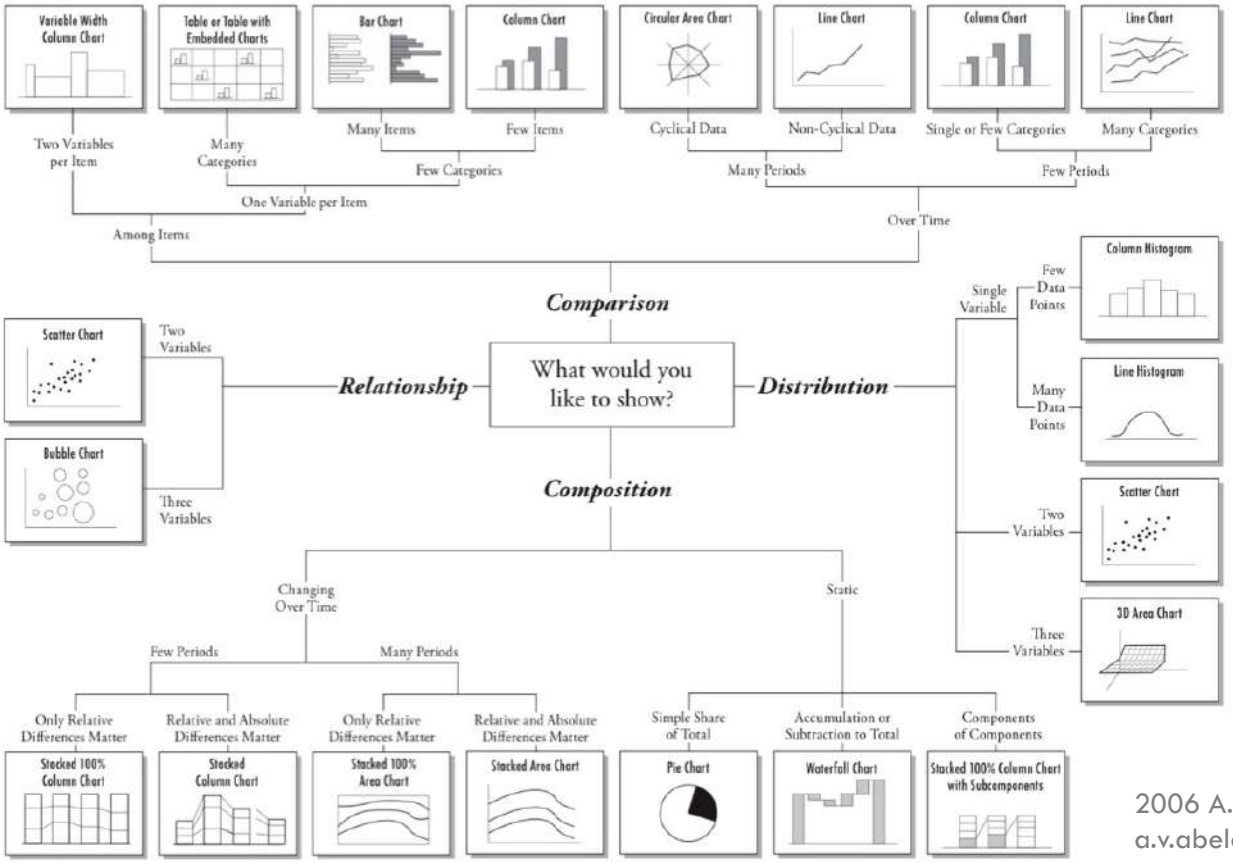
INFORMATION VISUALIZATION

VISUALIZATION TECHNIQUES

- Categorized by data nature, objective and intended audience

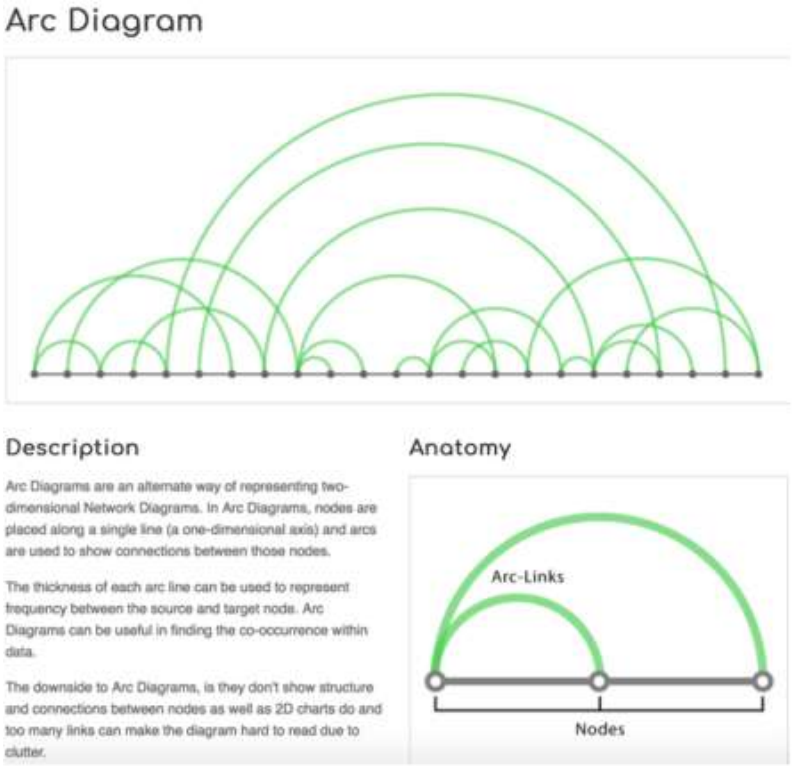
Problem	Data type	Dimensions	Data structure	Type of interaction
Communicate	Quantitative	Univariate	Linear	Static
Explore	Ordinal	Bivariate	Temporal	Transformable
Confirm	Categorical	Trivariate	Spatial	Manipulable
		Multivariate	Hierarchical	
			Network	

VISUALIZATION TAXONOMY



2006 A. Abela
a.v.abela@gmail.com

VISUALIZATION CATALOGUE



http://www.datavizcatalogue.com

VISUALIZATION GUIDELINES

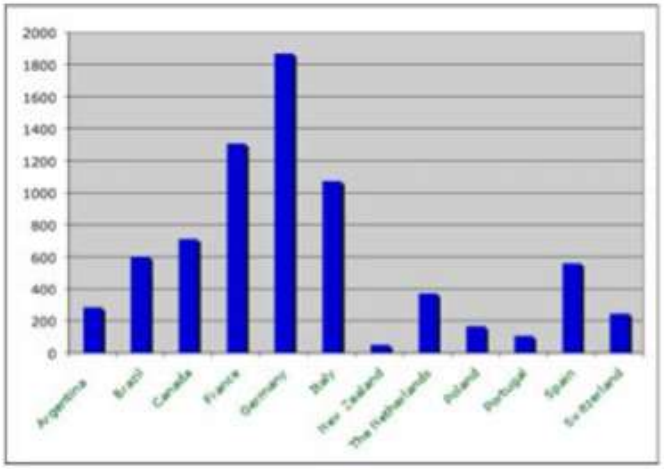
http://ft.com/vocabulary

FT Financial Times

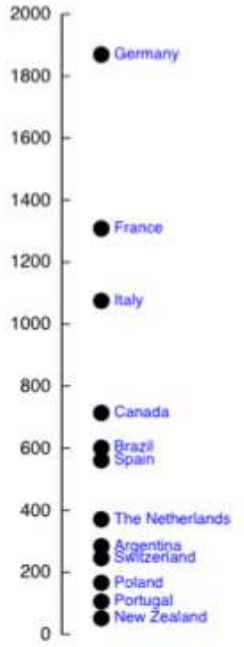
EXAMPLE: UNIVARIATE DATA

Gross National Product (**GNP**)

Nation	GNP
Argentina	284.2
Brazil	601.7
Canada	713.8
France	1308.4
Germany	1870.2
Italy	1074.8
New Zealand	52.2
Poland	166.5
Portugal	106.5
Spain	561.8
Switzerland	246.2
The Netherlands	370.6



Bar Chart

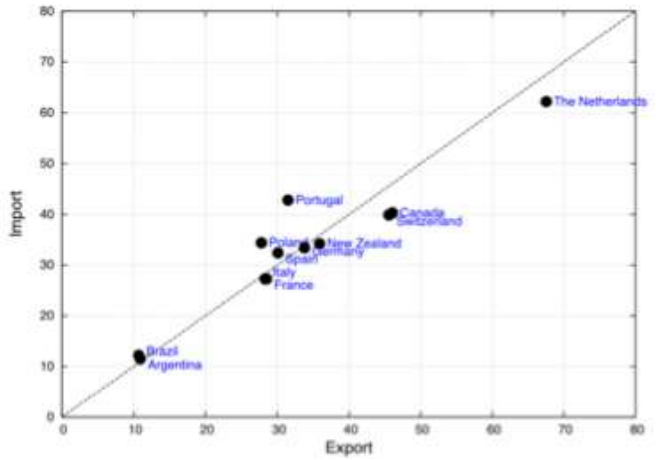


Single-axis Scatterplot

EXAMPLE: BIVARIATE DATA

Nations overseas **Import** and **Exports**

Nation	Export	Import
Argentina	10.9	11.5
Brazil	10.7	12.2
Canada	46.1	40.3
France	28.5	27.3
Germany	33.8	33.4
Italy	28.3	27.3
New Zealand	35.9	34.2
Poland	27.8	34.4
Portugal	31.5	42.8
Spain	30.1	32.4
Switzerland	45.6	39.9
The Netherlands	67.5	62.2

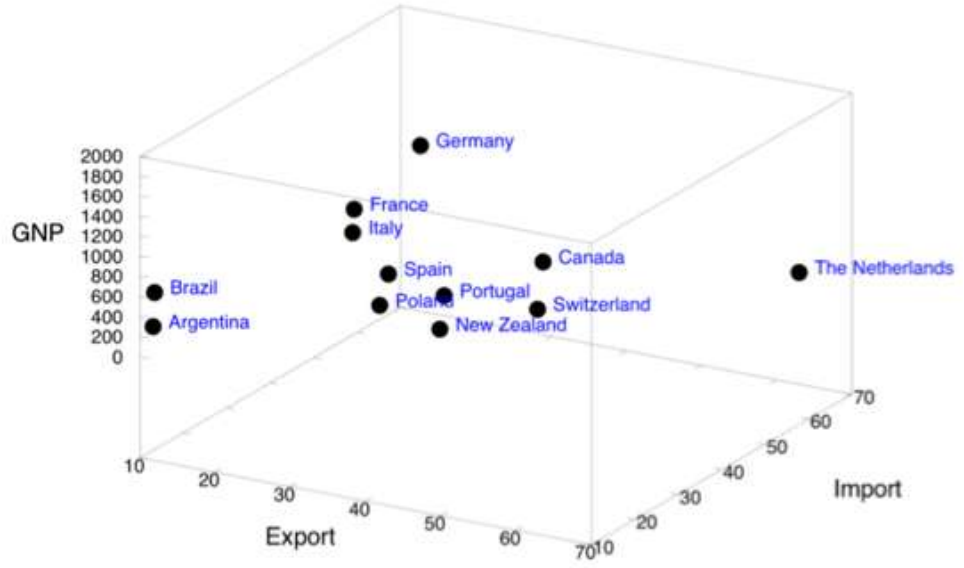


2D Scatterplot

EXAMPLE: TRIVARIATE DATA

Nations **Imports, Exports** and **GNPs**

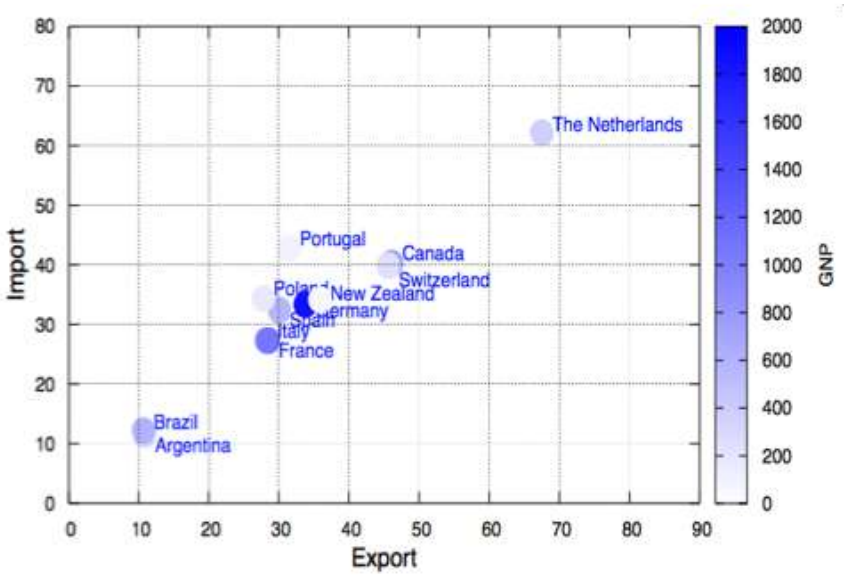
OCLUSION PROBLEM
Graphical elements may be "hidden" by other elements



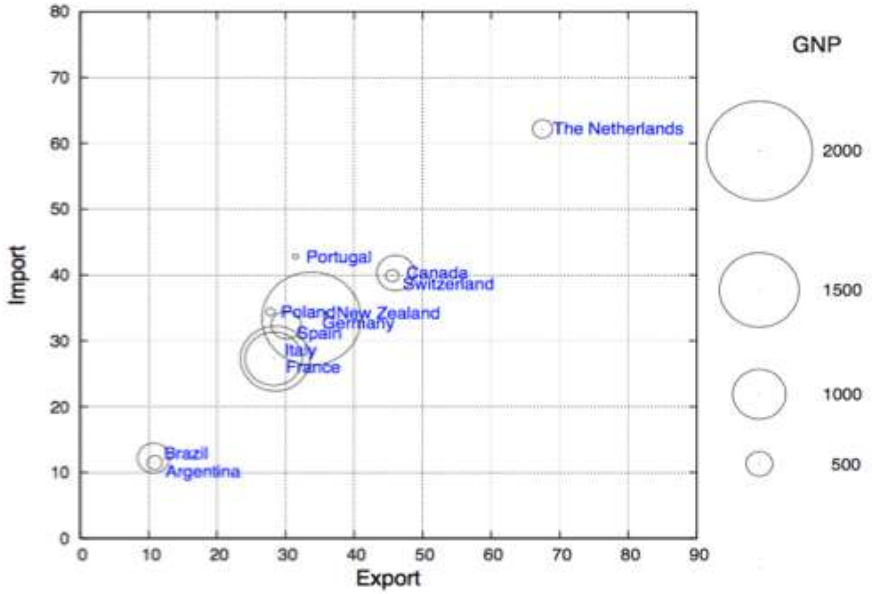
3D Scatterplot

EXAMPLE: TRIVARIATE DATA

Nations **Imports, Exports** and **GNPs**



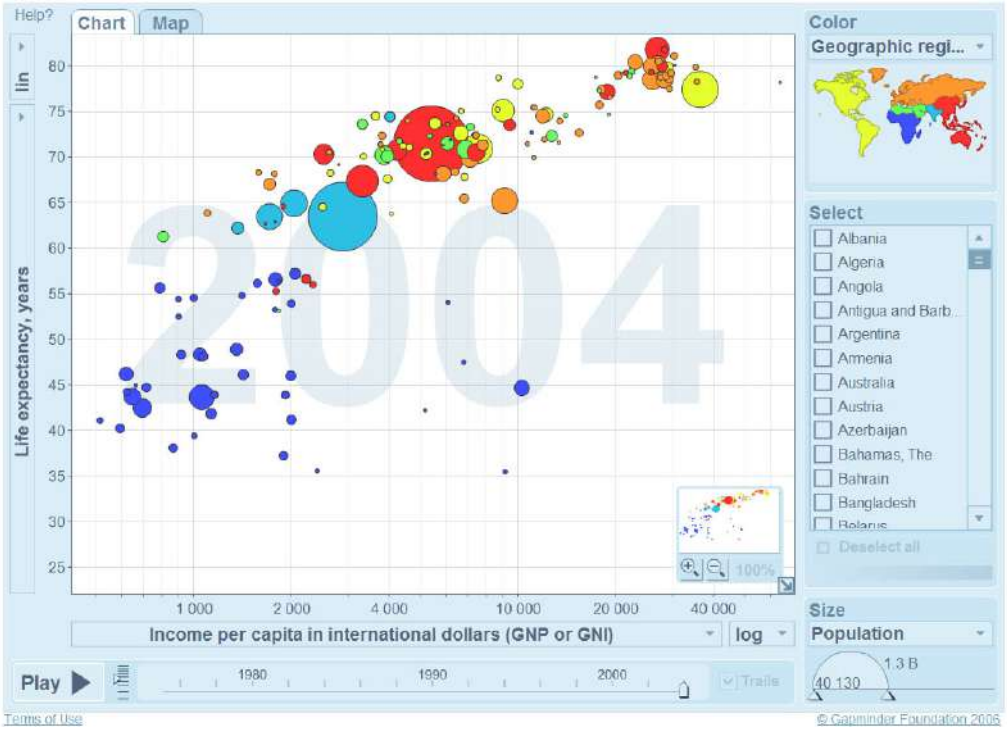
2D Scatterplot + Color



2D Scatterplot + Shapes

EXAMPLE: MULTIVARIATE DATA

Correlation **Wealth** & **Health**



SCATTERPLOTS

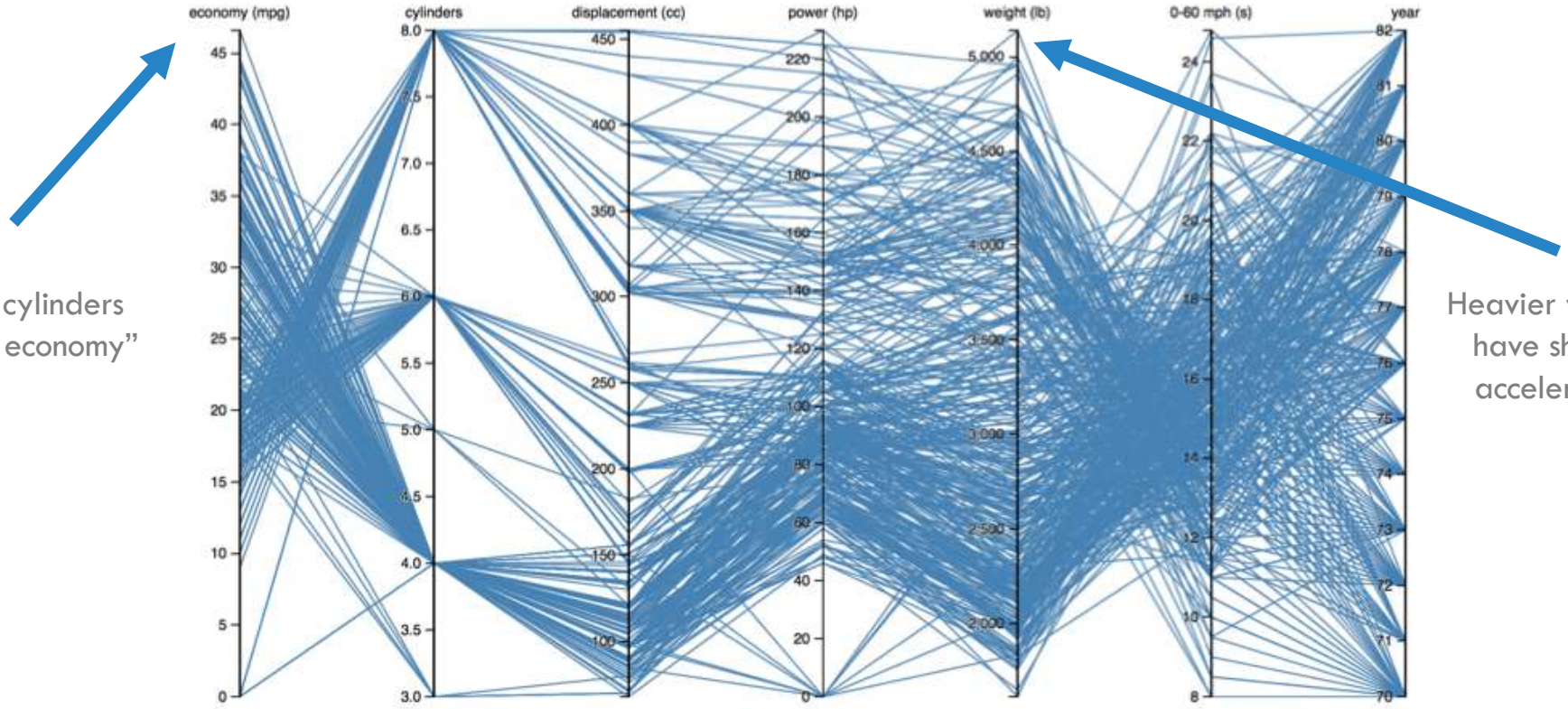
Can be used for plotting up to 7 dimensions

VISUALIZATION OF MULTIVARIATE DATA

- Scatterplots are not suitable for all types of problems and data
- Alternatives
  - **Geometric**: *maps data to attributes on a geometric space*
    - Useful for explorative analysis
  - **Iconic**: *uses the geometric properties of a figure (e.g., star, faces)*
  - **Pixel-based**: *uses the pixels of the screen as unit of representation*

EXAMPLE: PARALLEL COORDINATES

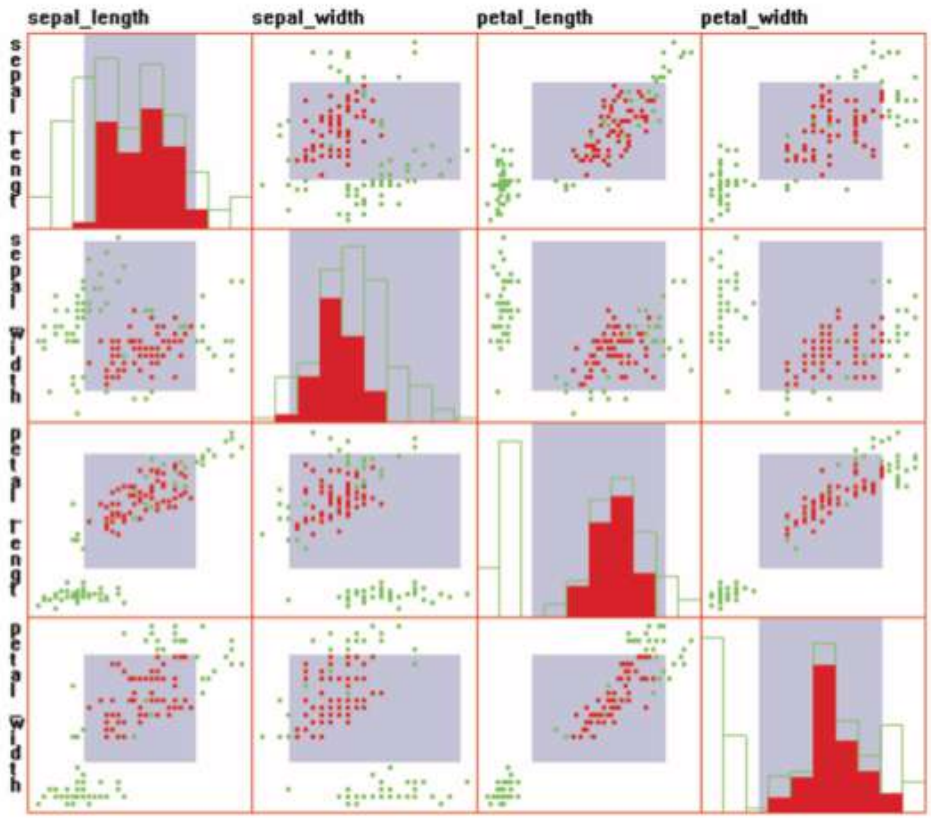
Vehicles produced in the 70's



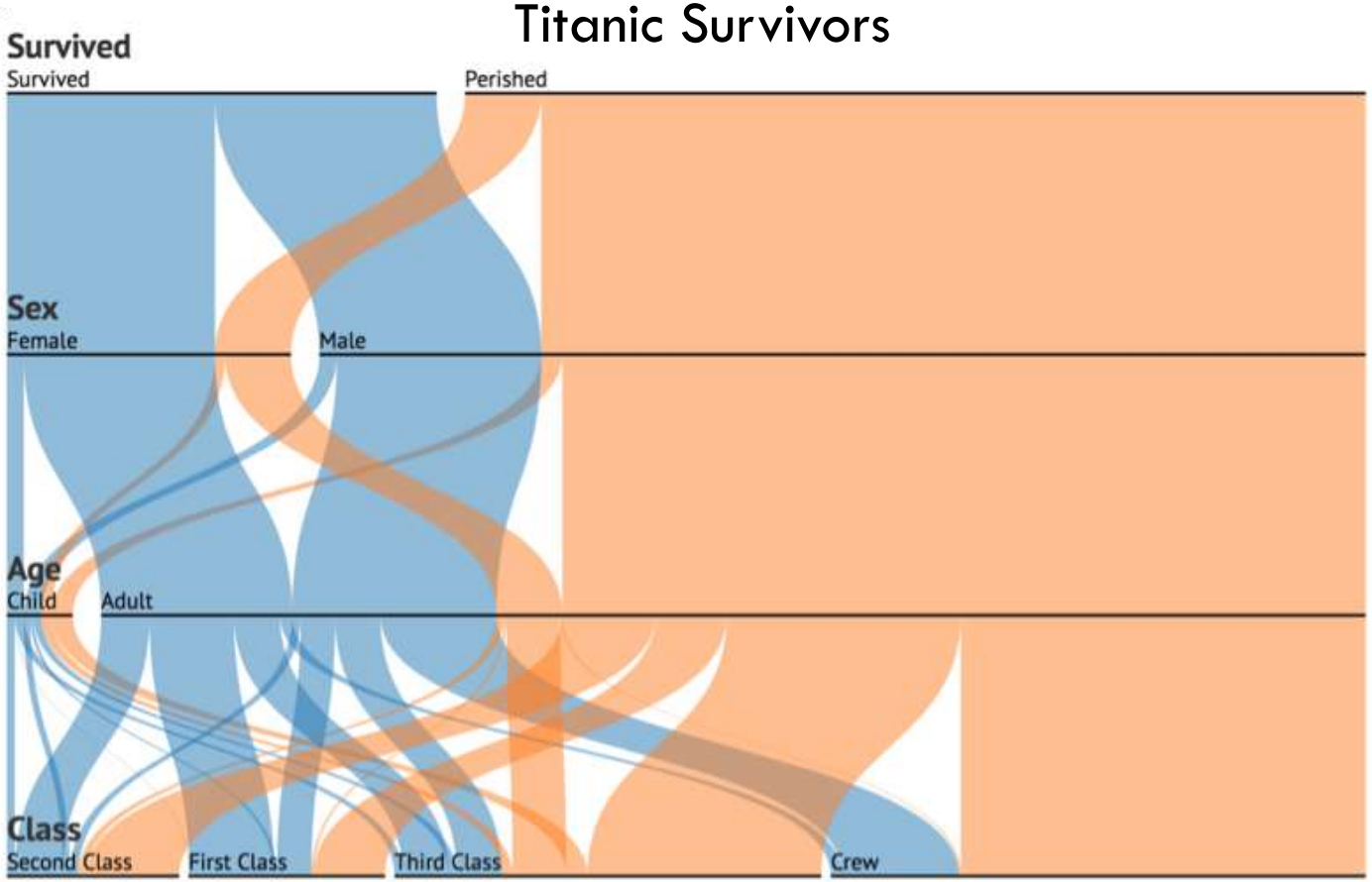
Less cylinders more economy"

Heavier vehicles have shorter acceleration

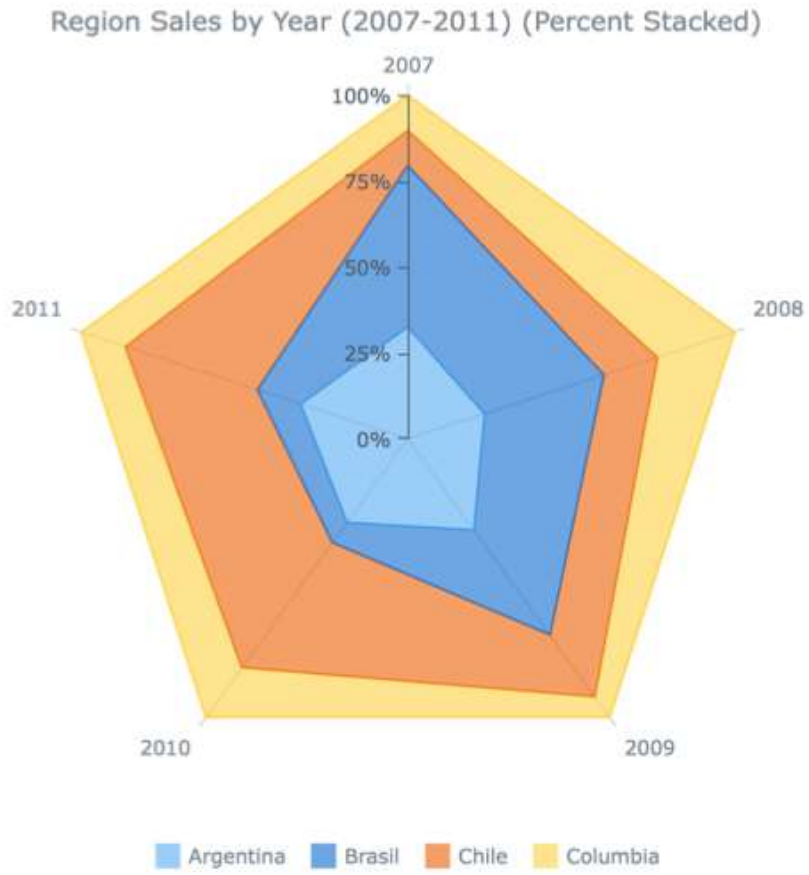
EXAMPLE: SCATTERPLOT MATRIX



EXAMPLE: PARALLEL SETS



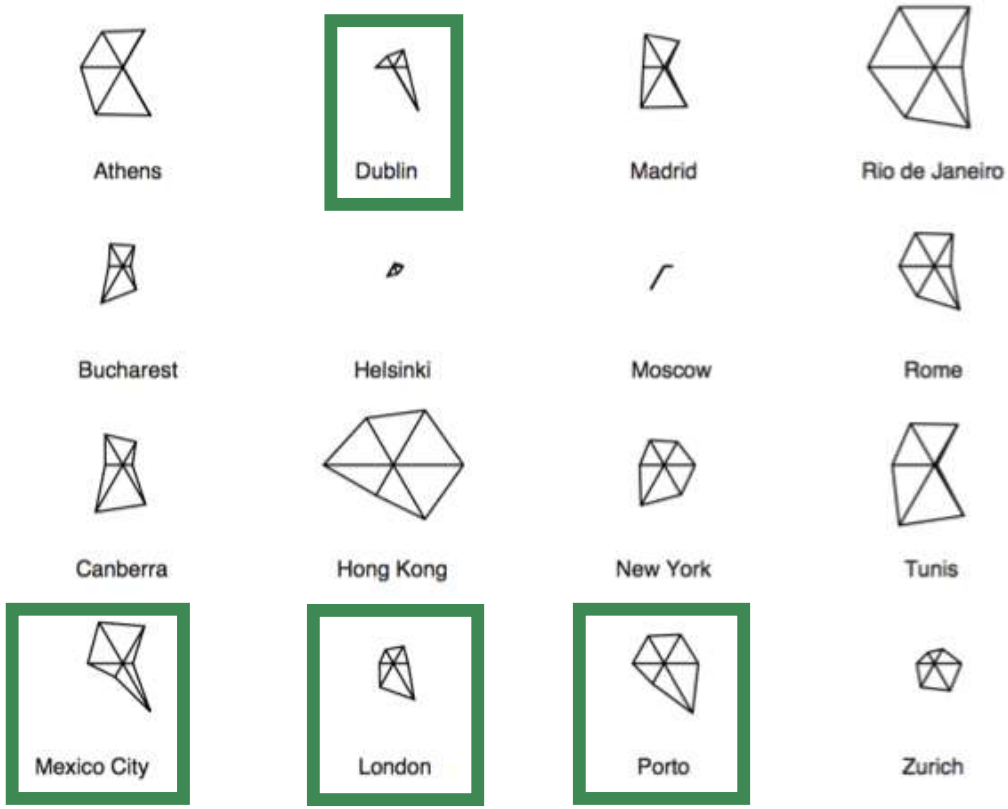
EXAMPLE: STAR PLOT



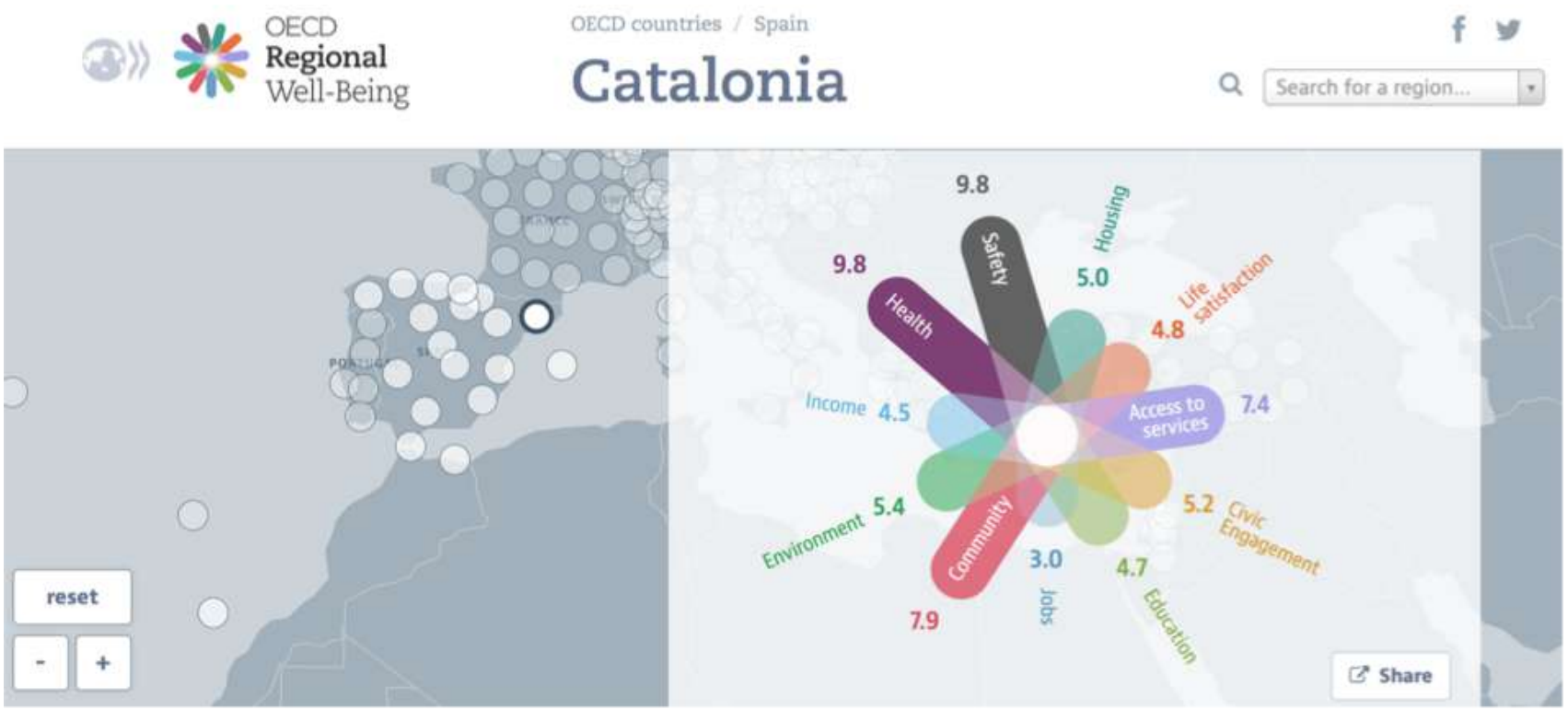
EXAMPLE: STAR PLOT

Temperatures per City

City	Precip. average	Temp. average	Temp. max average	Temp. min average	Record max	Record min
Athens	37	17	21	13	42	−3
Bucharest	58	11	16	5	49	−23
Canberra	62	12	19	6	42	−10
Dublin	74	10	12	6	28	−7
Helsinki	63	5	8	1	31	−36
Hong Kong	218	23	25	21	37	2
London	75	10	13	5	35	−13
Madrid	45	13	20	7	40	−10
Mexico City	63	17	23	11	32	−3
Moscow	59	4	8	1	35	−42
New York	118	12	17	8	40	−18
Porto	126	14	18	10	34	−2
Rio de Janeiro	109	25	30	20	43	7
Rome	80	15	20	11	37	−7
Tunis	44	18	23	13	46	−1
Zurich	107	9	12	6	35	−20

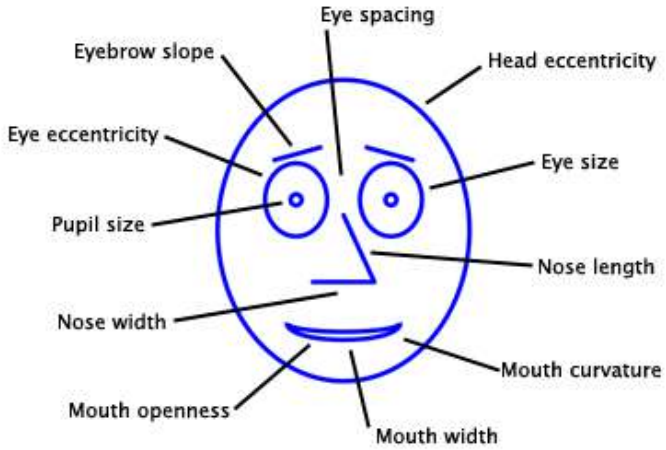


EXAMPLE: STAR PLOT



https://www.oecdregionalwellbeing.org

EXAMPLE: CHERNOFF FACES



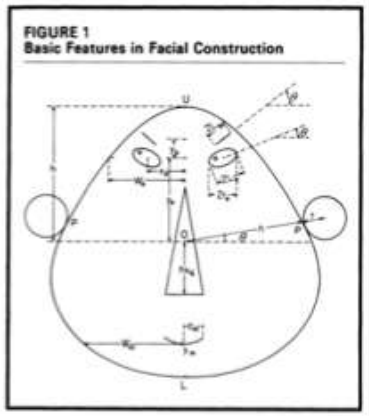
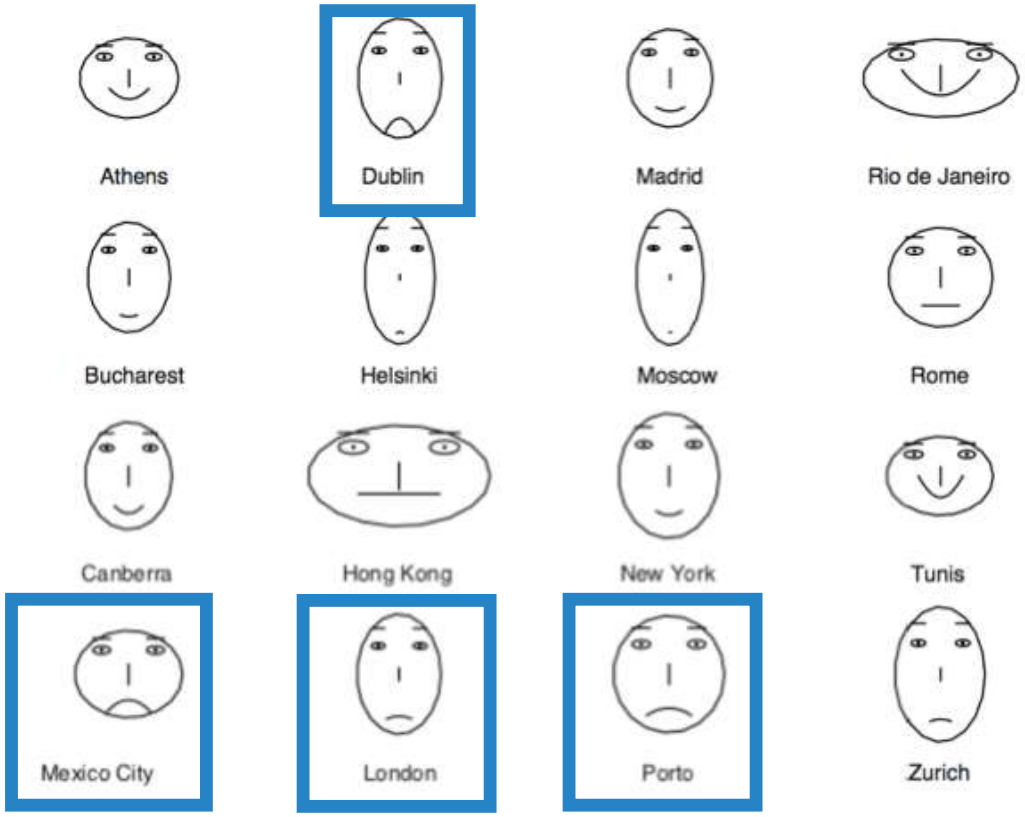


FIGURE 1
Basic Features in Facial Construction

EXAMPLE: CHERNOFF FACES

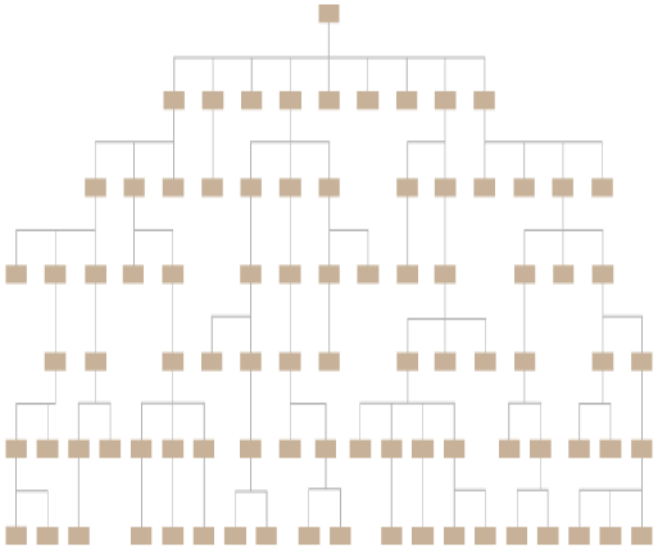
Temperatures per City

City	Precip. average	Temp. average	Temp. max average	Temp. min average	Record max	Record min
Athens	37	17	21	13	42	−3
Bucharest	58	11	16	5	49	−23
Canberra	62	12	19	6	42	−10
Dublin	74	10	12	6	28	−7
Helsinki	63	5	8	1	31	−36
Hong Kong	218	23	25	21	37	2
London	75	10	13	5	35	−13
Madrid	45	13	20	7	40	−10
Mexico City	63	17	23	11	32	−3
Moscow	59	4	8	1	35	−42
New York	118	12	17	8	40	−18
Porto	126	14	18	10	34	−2
Rio de Janeiro	109	25	30	20	43	7
Rome	80	15	20	11	37	−7
Tunis	44	18	23	13	46	−1
Zurich	107	9	12	6	35	−20

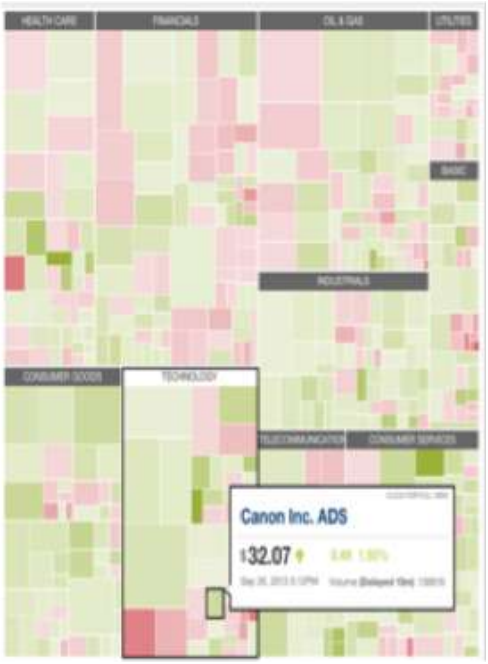


EXAMPLE: HIERARCHIES

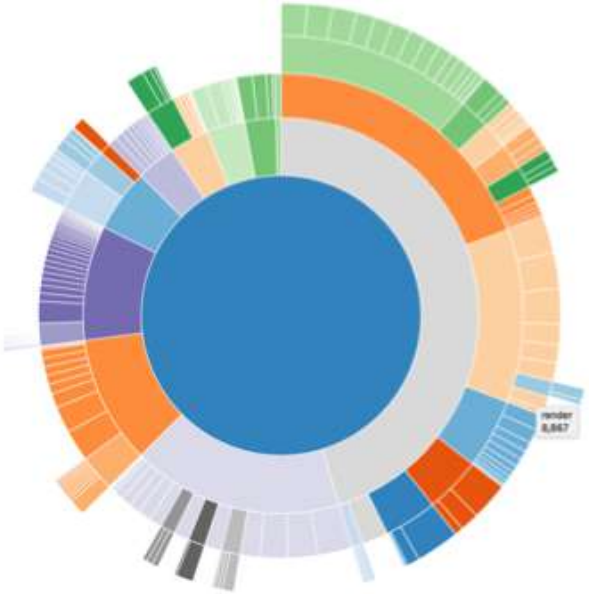
TREE



TREE MAPS

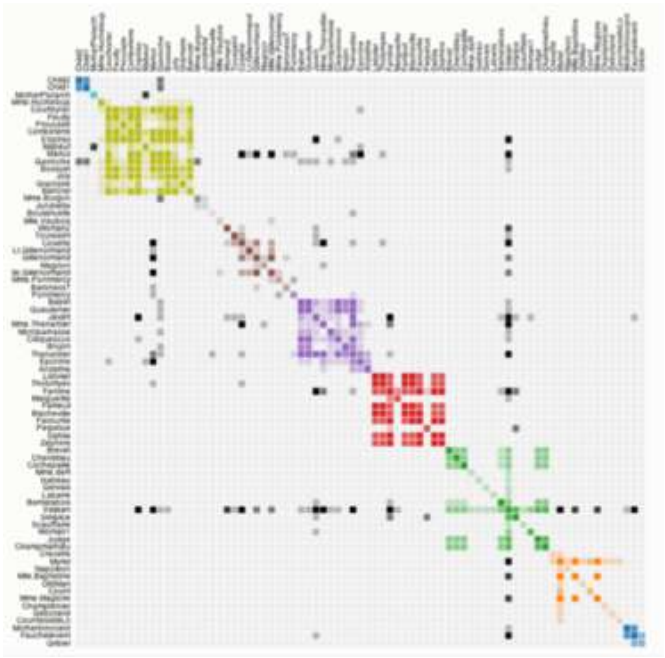


STARBURST



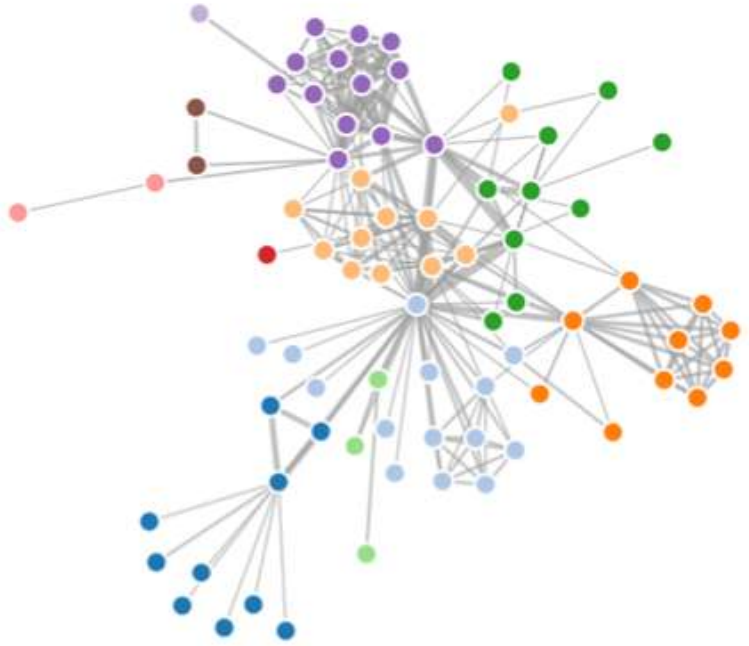
EXAMPLE: NETWORKS

MATRIX



https://bost.ocks.org/mike/miserables/

NODE-LINK DIAGRAM



BIG DATA VISUALIZATION

DATA SCIENTIST T-SHAPED SKILLS

VISUALIZATION TOOLS

Option 1: Programming library

You have to write code.

Option 2: Packaged software

(Mostly) no coding involved

VISUALIZATION TOOLS

Programming Libraries

d3.js

plotly

R

Packaged software

Tableau (multi-dimensional)

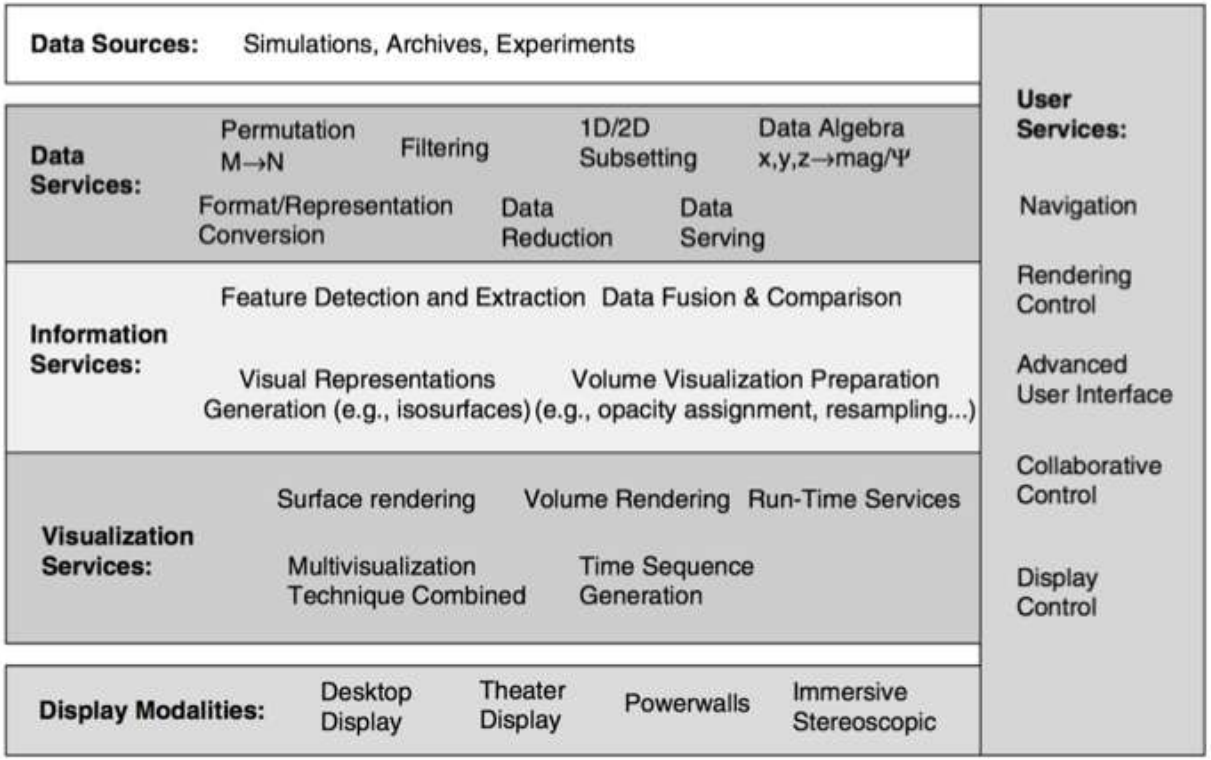
Gephi (graph)

NodeXL (graph)

https://flourish.studio

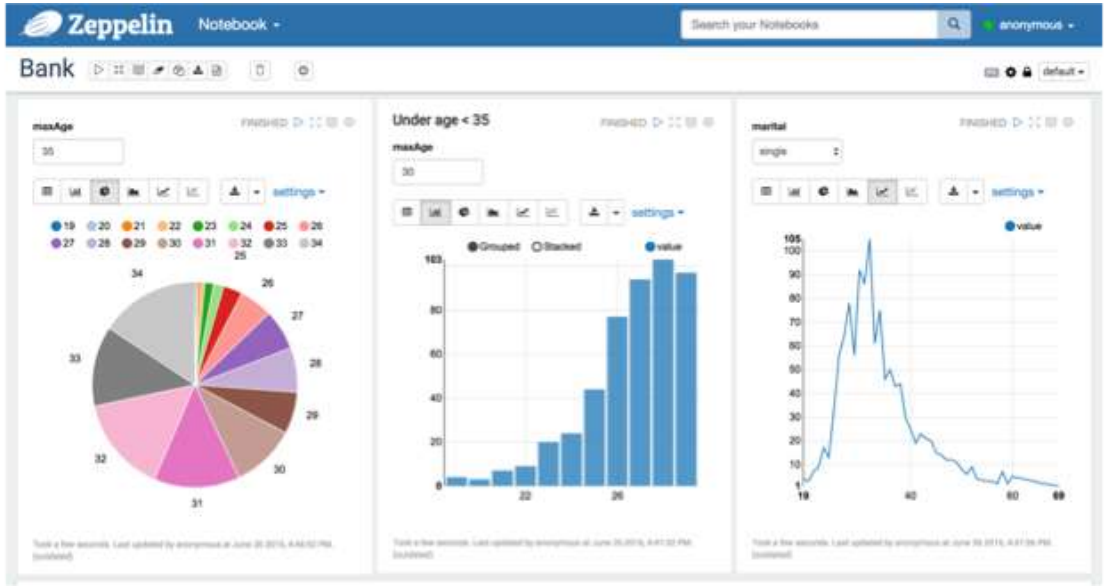
ARCHITECTURE FOR VISUALIZING LARGE DATASET

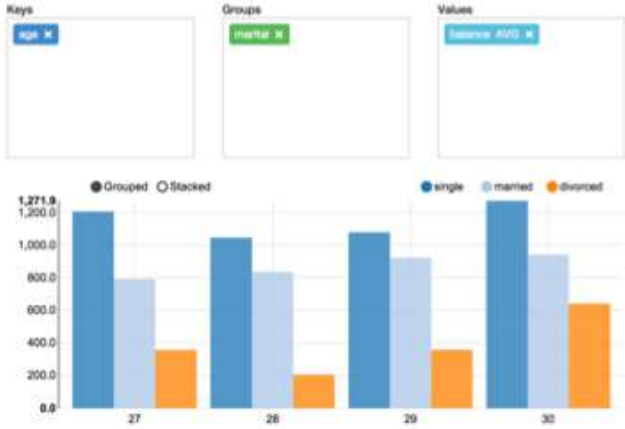
SANDIA LABS
Reference Architecture



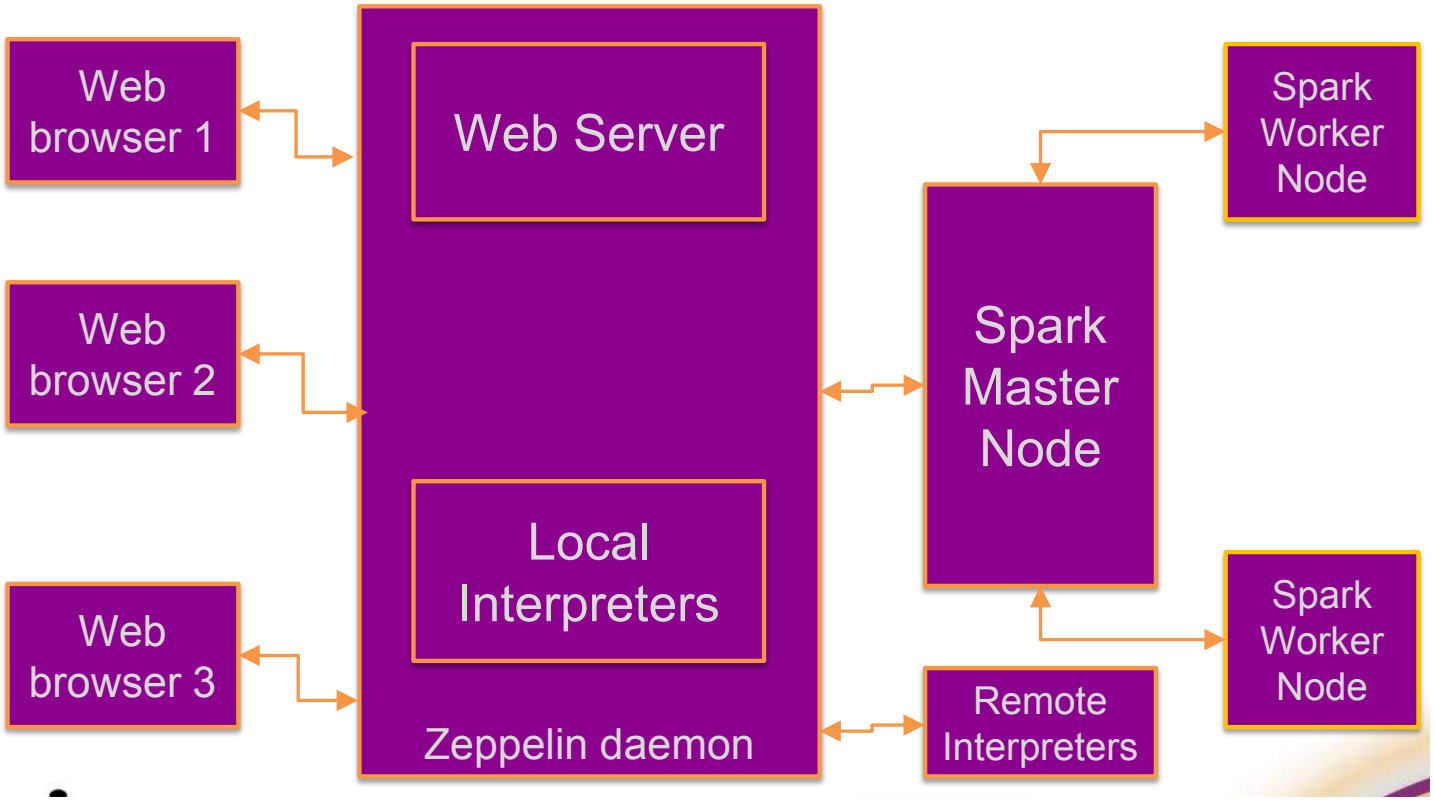
APACHE ZEPPELIN

- Notebook for interactive data analysis





EXAMPLE: ZEPPELIN ARCHITECTURE



Data Visualization

@Twitter

data·visualization

at Twitter

data
at Twitter

"Tweets"

#events

TV Shows New Year
Earthquake Protest
Oscars Super Bowl
World Cup Election
Breaking news …

#curiosity

Sleep pattern
Human behavior
Language …

What could we learn from the Tweets?

Get data

data

1

vis

at Twitter

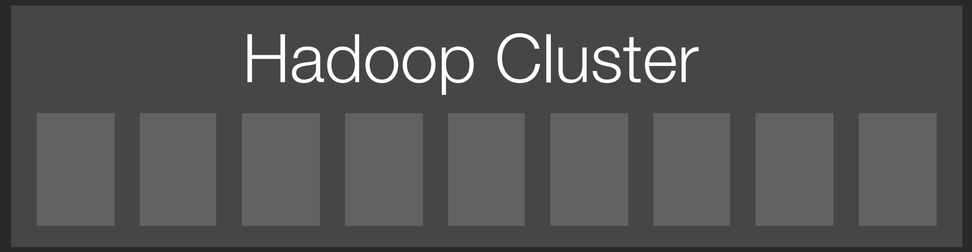
“Tweets”

Challenges

- Too much data
  - Want only relevant Tweets
    - hashtag: #BRA
    - keywords: “goal”
  - Need to aggregate & reduce size
  - Long processing time (hours)

Workflow

Data Storage



Tool

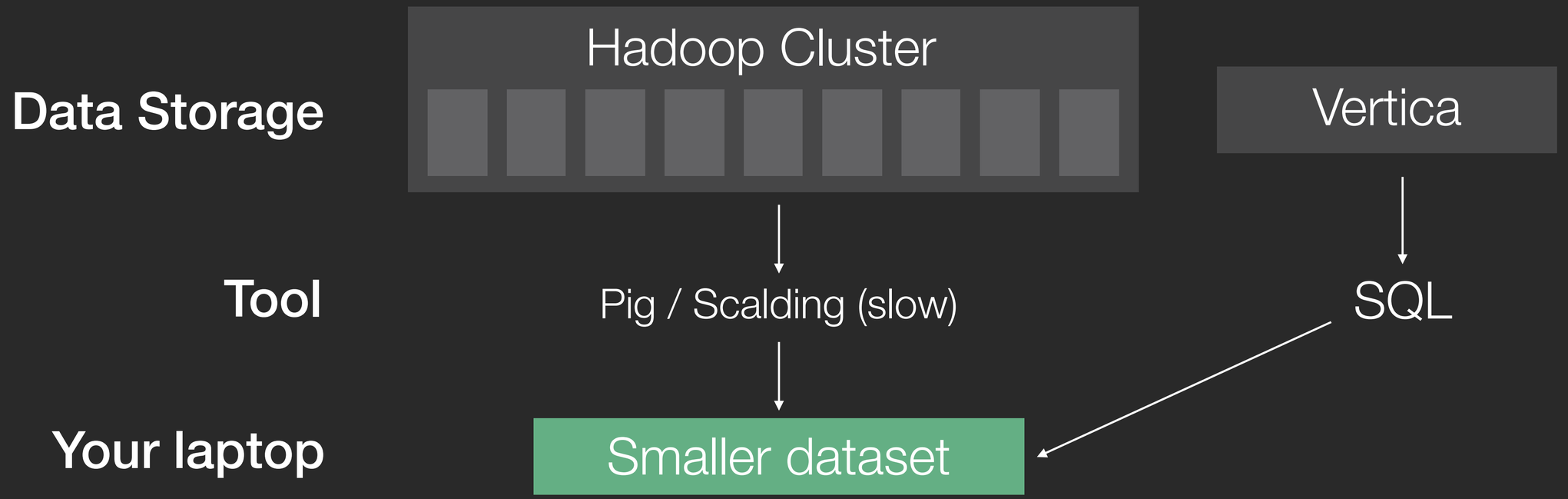
Pig / Scalding (slow)

SQL

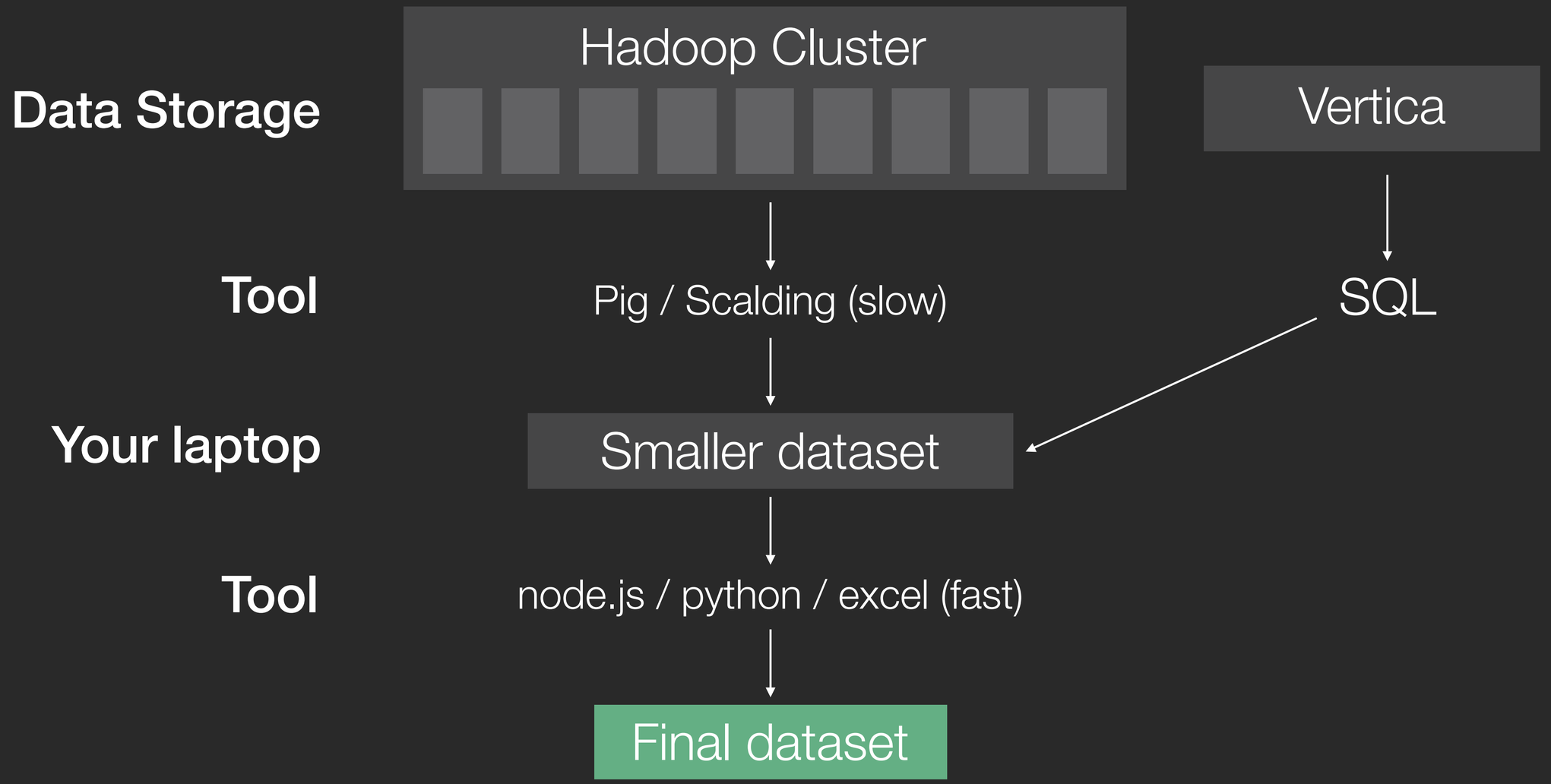
Workflow

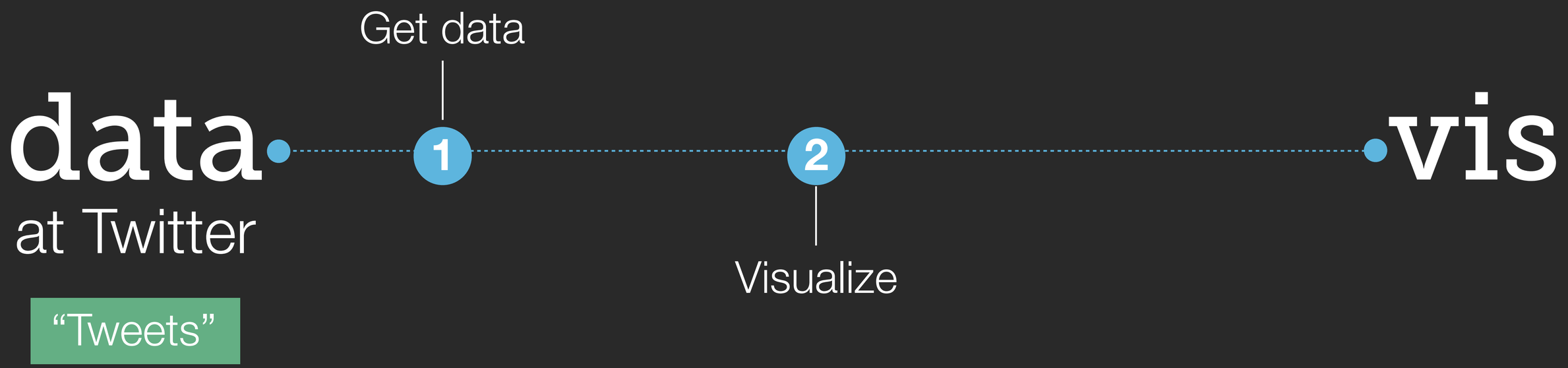

```
-- PIG

tweets = load '/tables/statuses/$DATE' using TwadoopLoader();

filtered_tweets = filter tweets by twtext matches '.*#BRA.*';
filtered_tweets = foreach filtered_tweets
  generate '#BRA' as name:chararray, extract_minute(created_at) as minute;
counted_hashflag = foreach (group filtered_tweets by minute)
  generate FLATTEN(group) as (name), COUNT(filtered_tweets) as count;
```

Workflow


Data Storage
Hadoop Cluster
Vertica
Tool
Pig / Scalding (slow)
SQL
Your laptop
Smaller dataset

Workflow

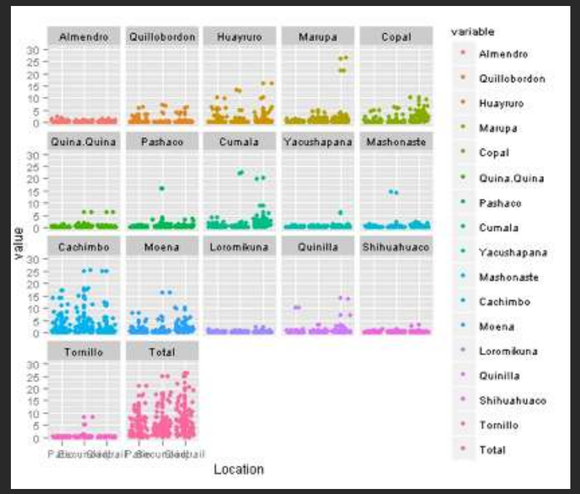

Data Storage
Hadoop Cluster
Vertica
Tool
Pig / Scalding (slow)
SQL
Your laptop
Smaller dataset
Tool
node.js / python / excel (fast)
Final dataset


Get data
data
1
2
vis
at Twitter
Visualize
“Tweets”

Visualize

- Peek into data
  - Check data & test ideas
- Decide how to visualize
  - Guided by data type
- Choose tools
- Start building

R

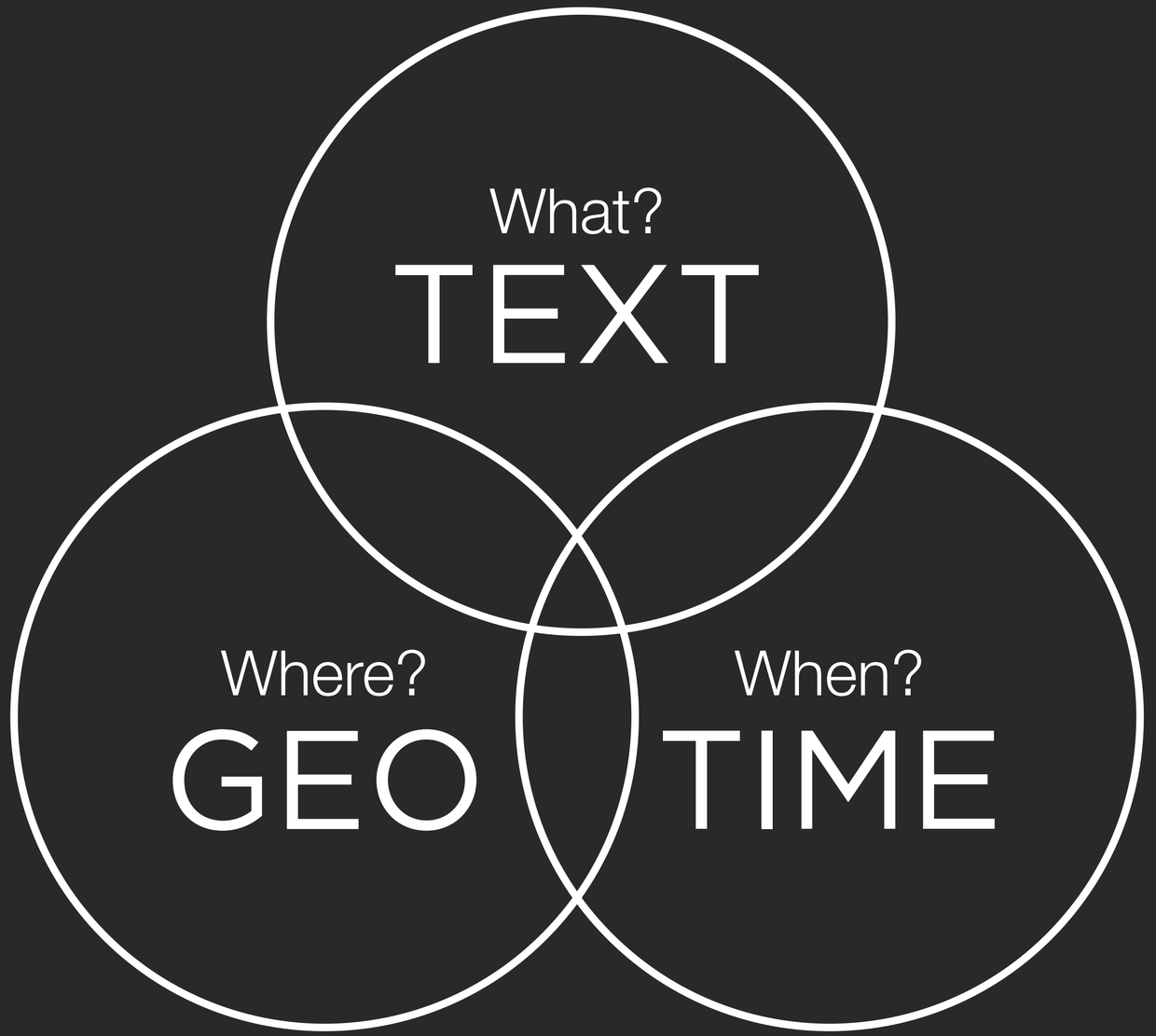


d3

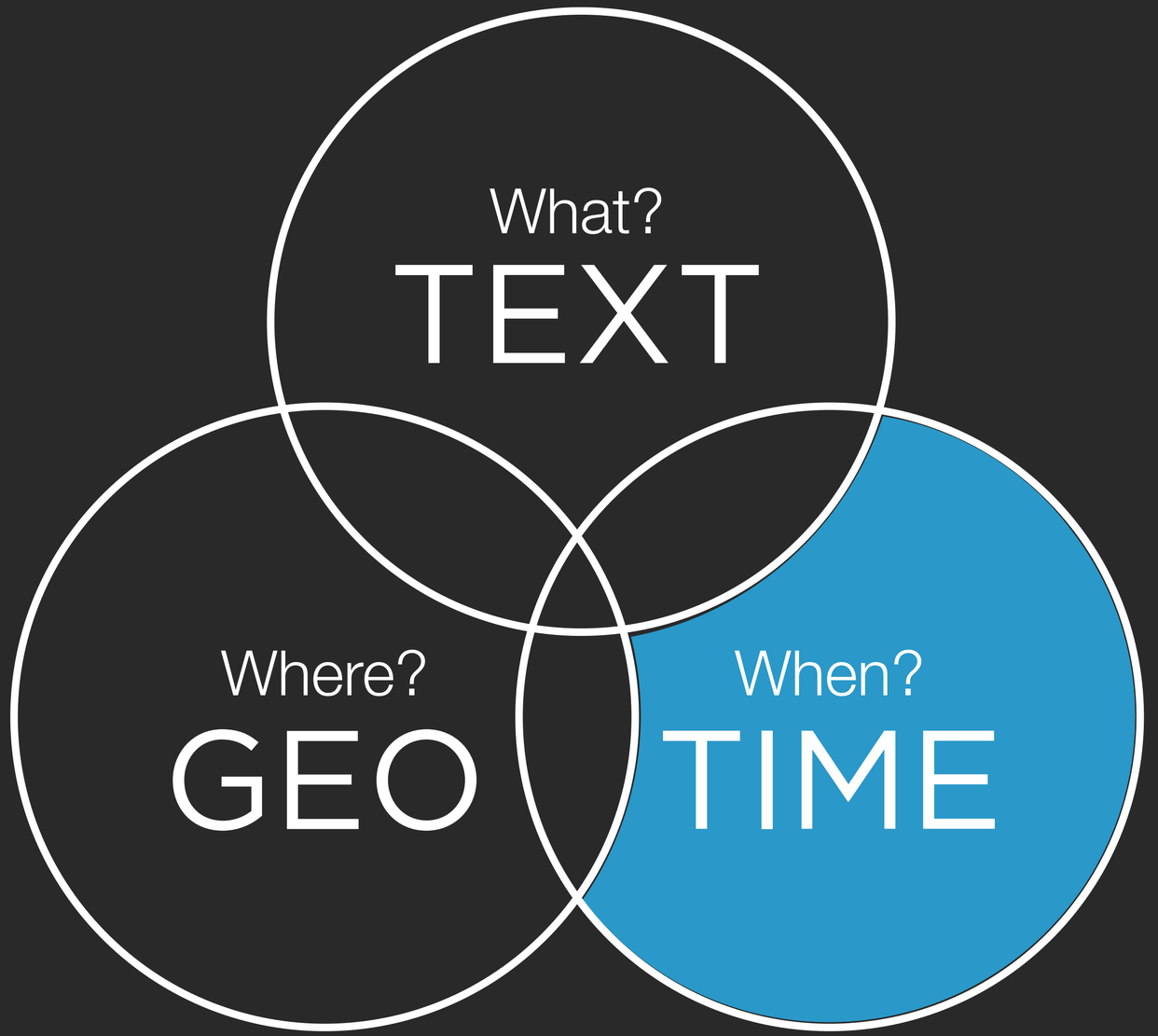
Tableau

Yeoman

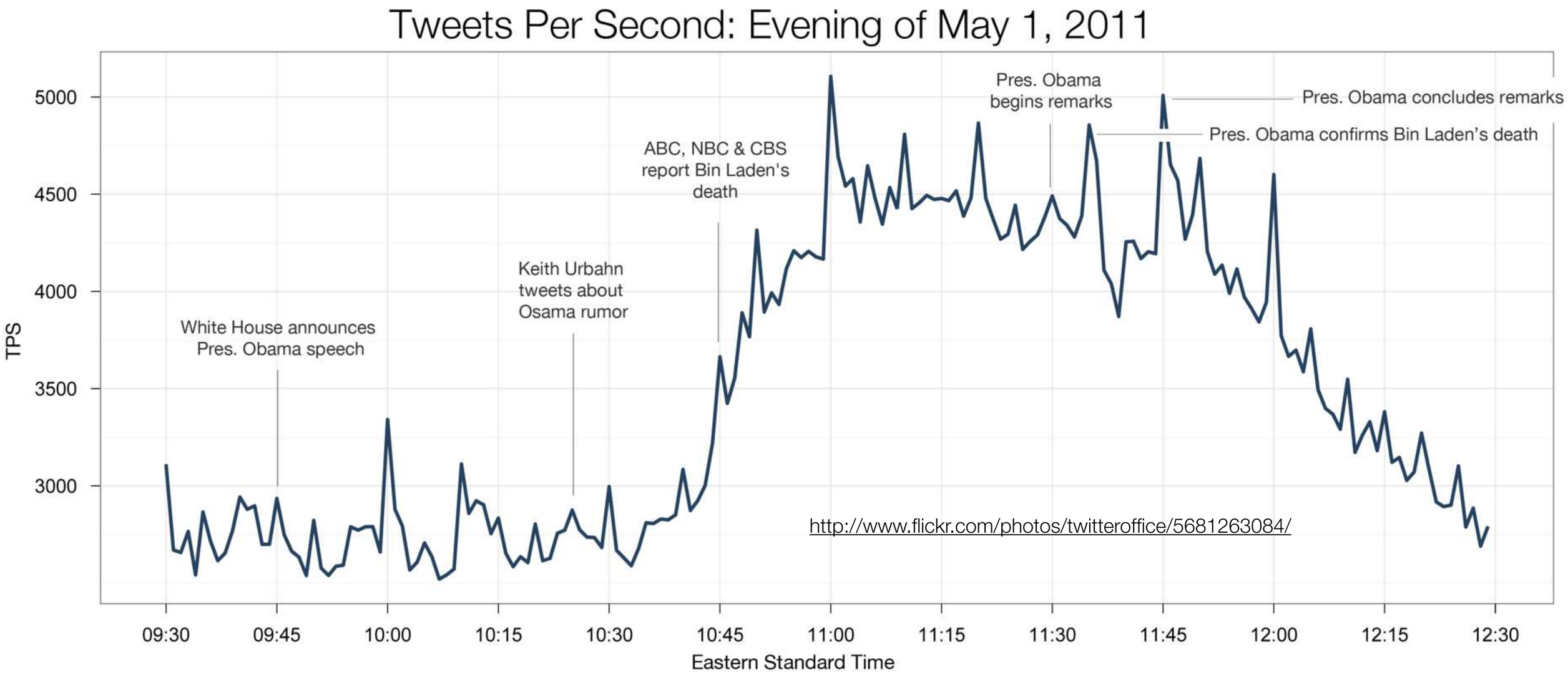
Visualize Data



Visualize Data



Time Tweets/second + Annotation



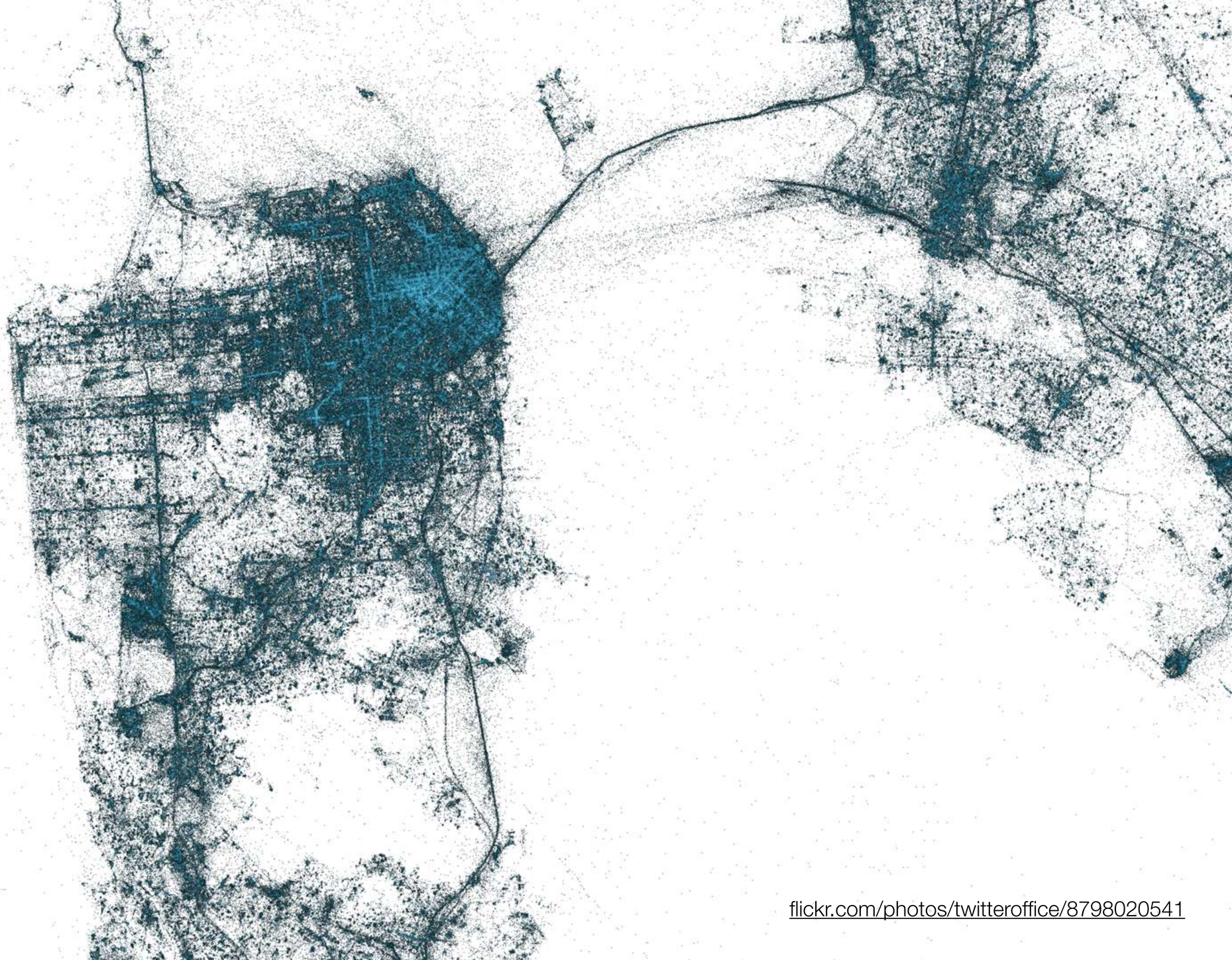
Visualize Data

Geo

San Francisco

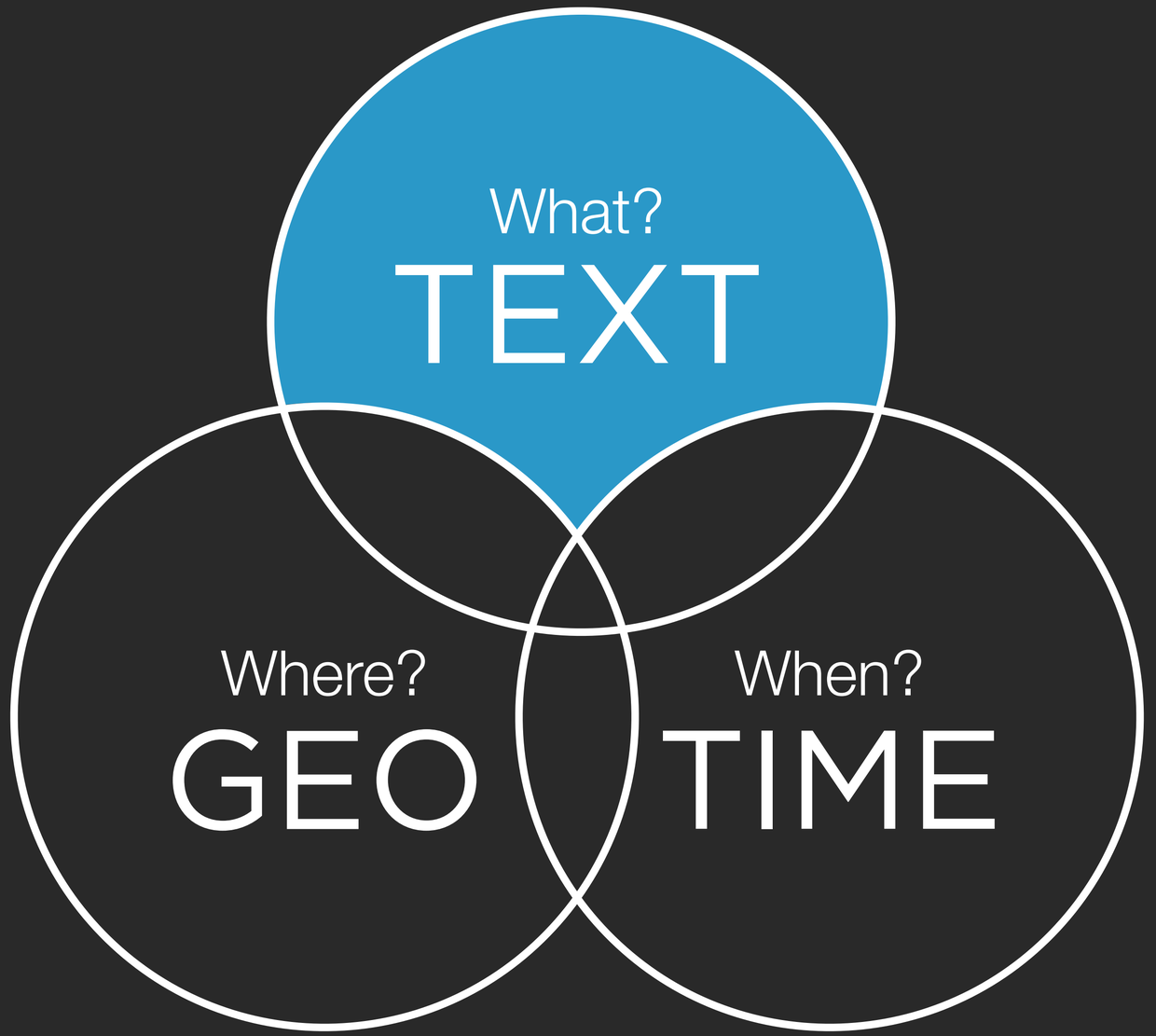
Low density

High density



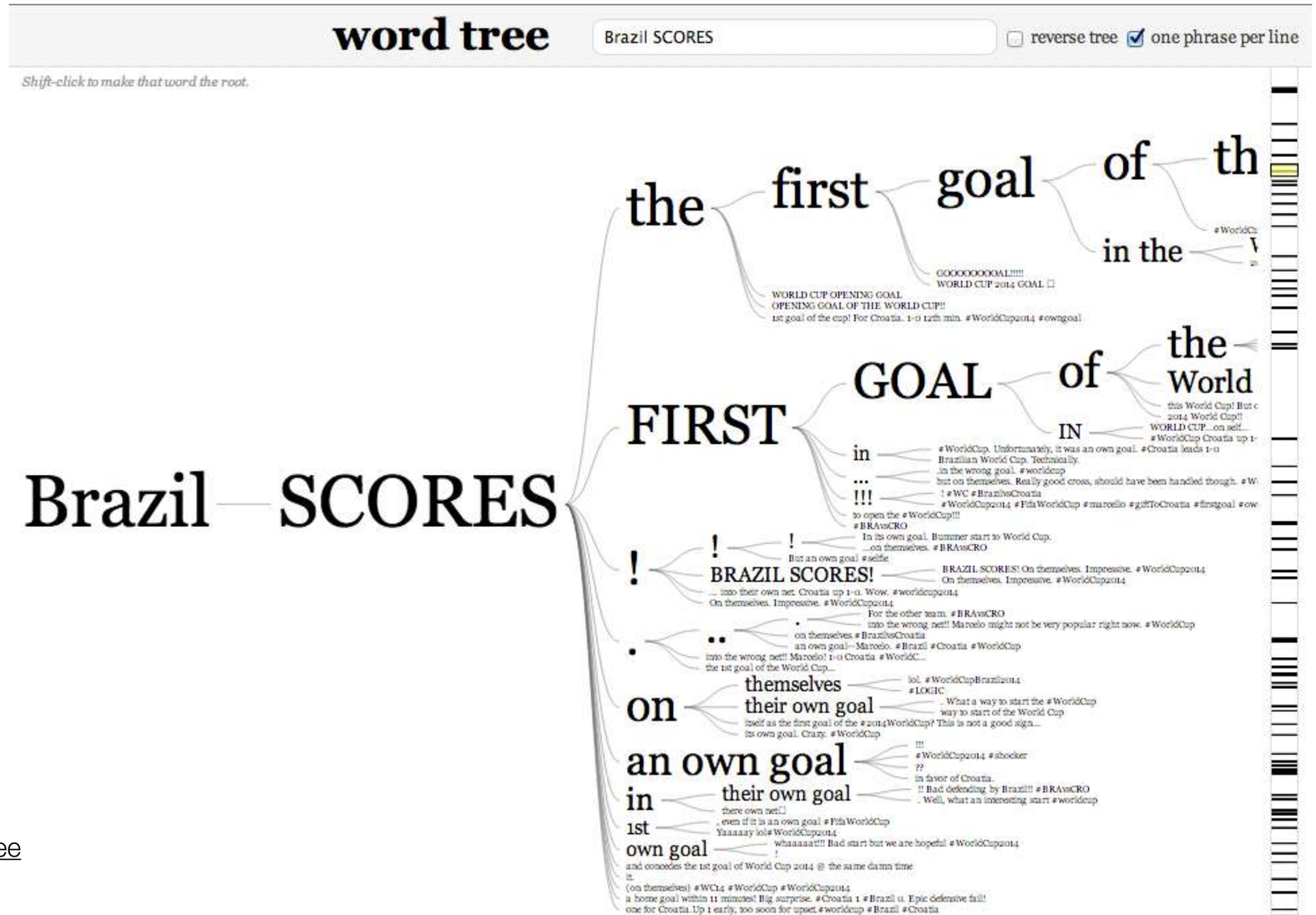
flickr.com/photos/twitteroffice/8798020541

Visualize Data



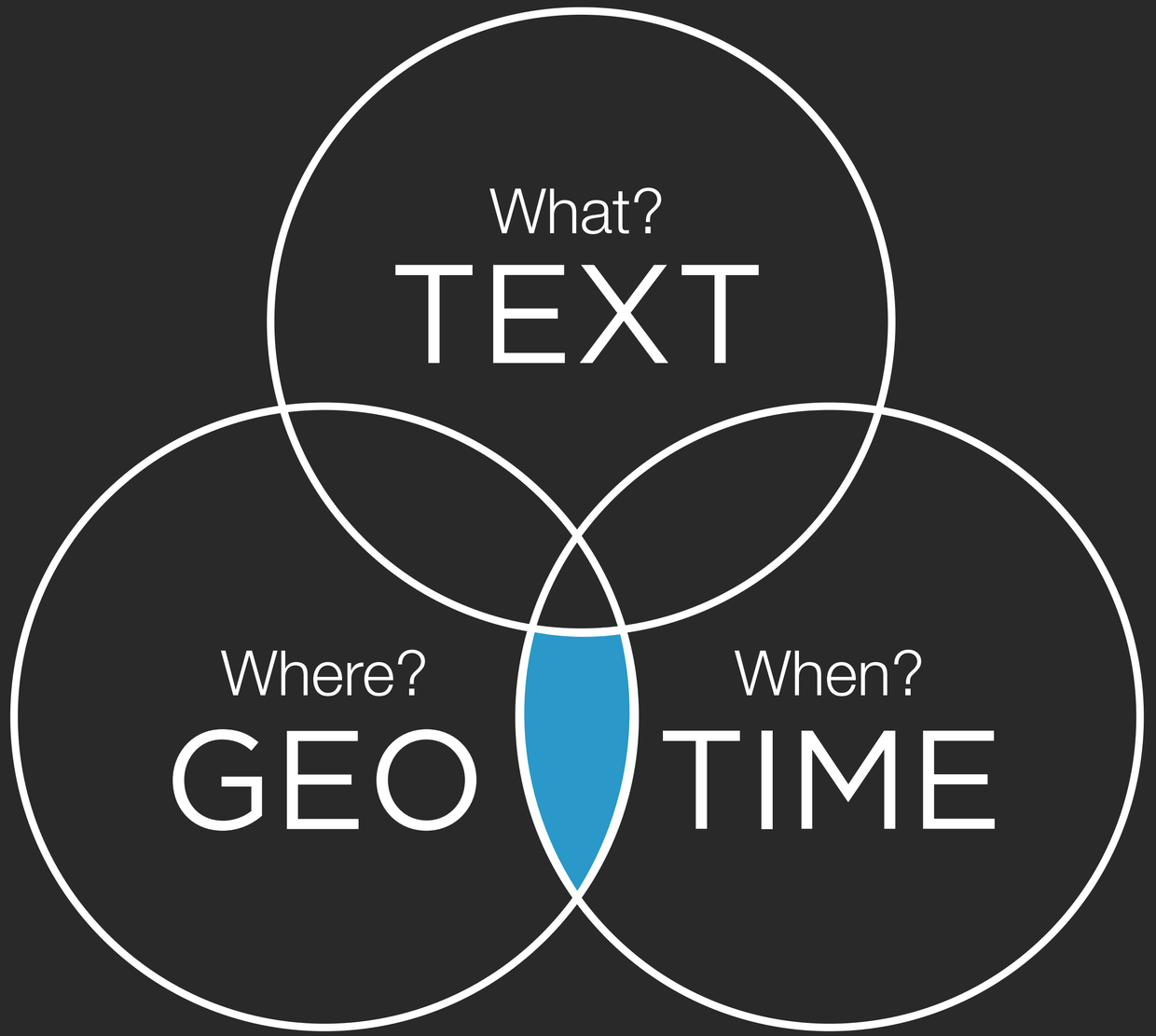
Text

WordTree [Wattenberg & Viégas 2008]



www.jasondavies.com/wordtree

Visualize Data



Time + Geo

Tweet pattern [Rios & Lin 2012]

Night

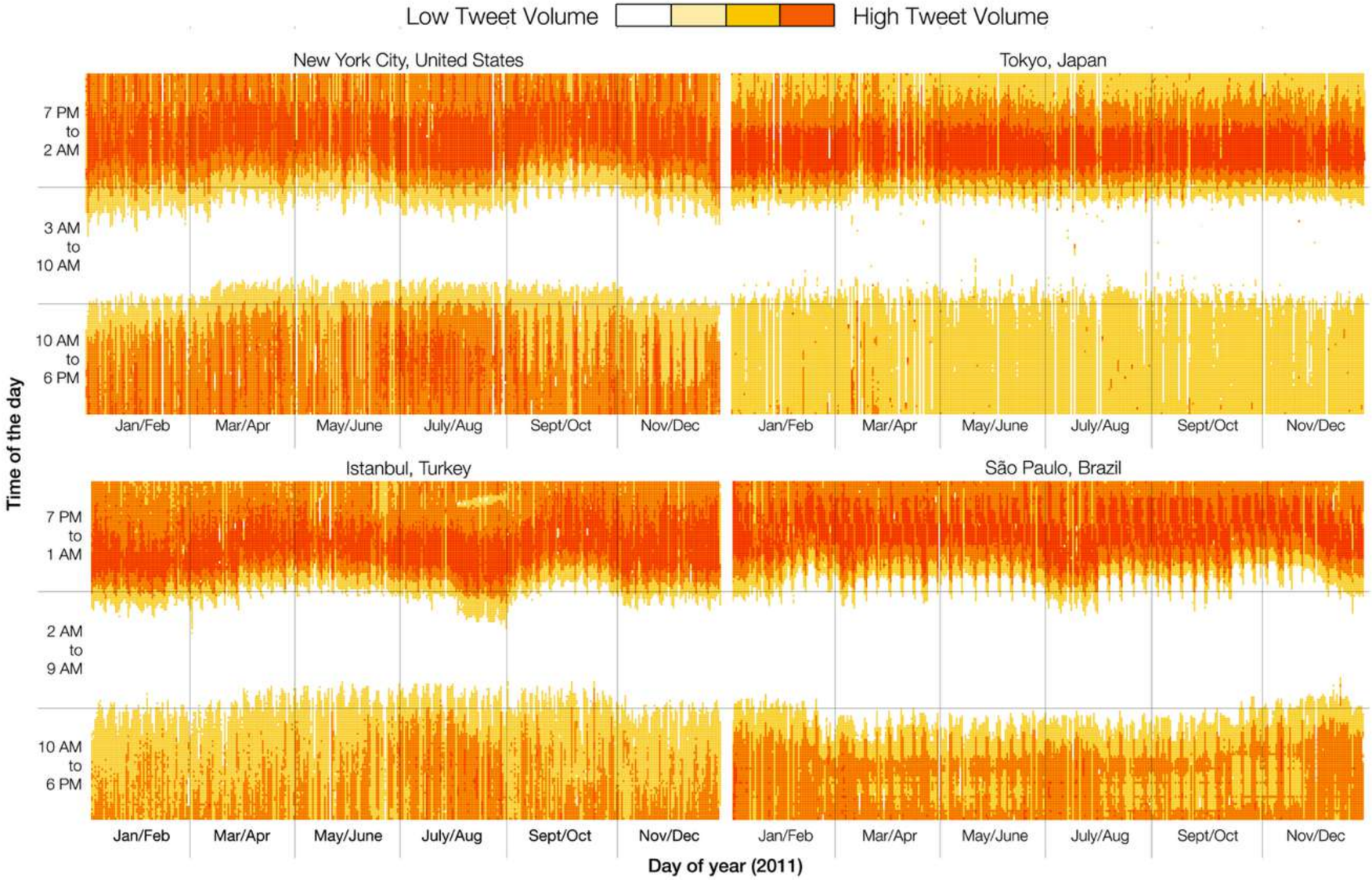
Late night

Daytime

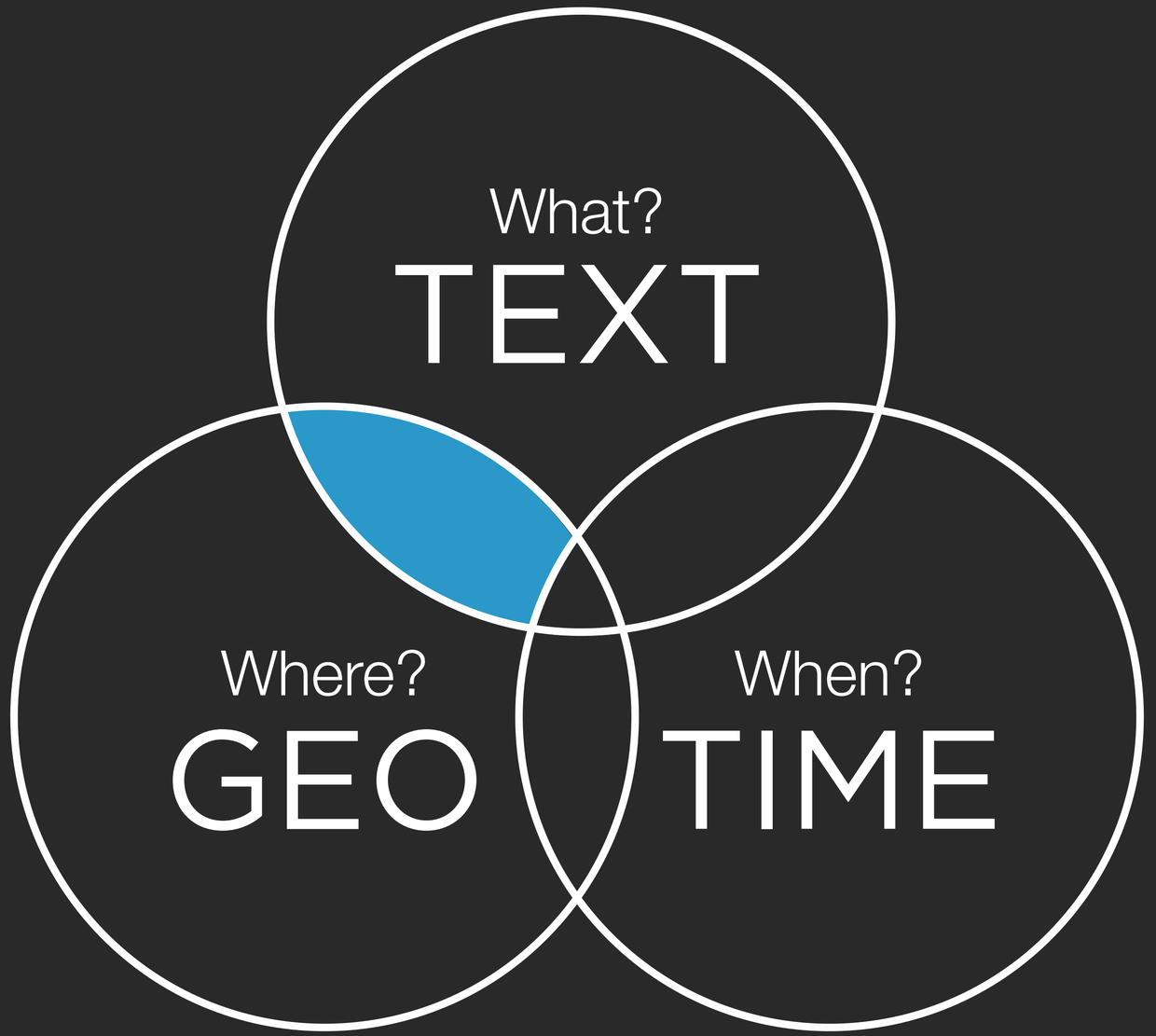
Night

Late night

Daytime

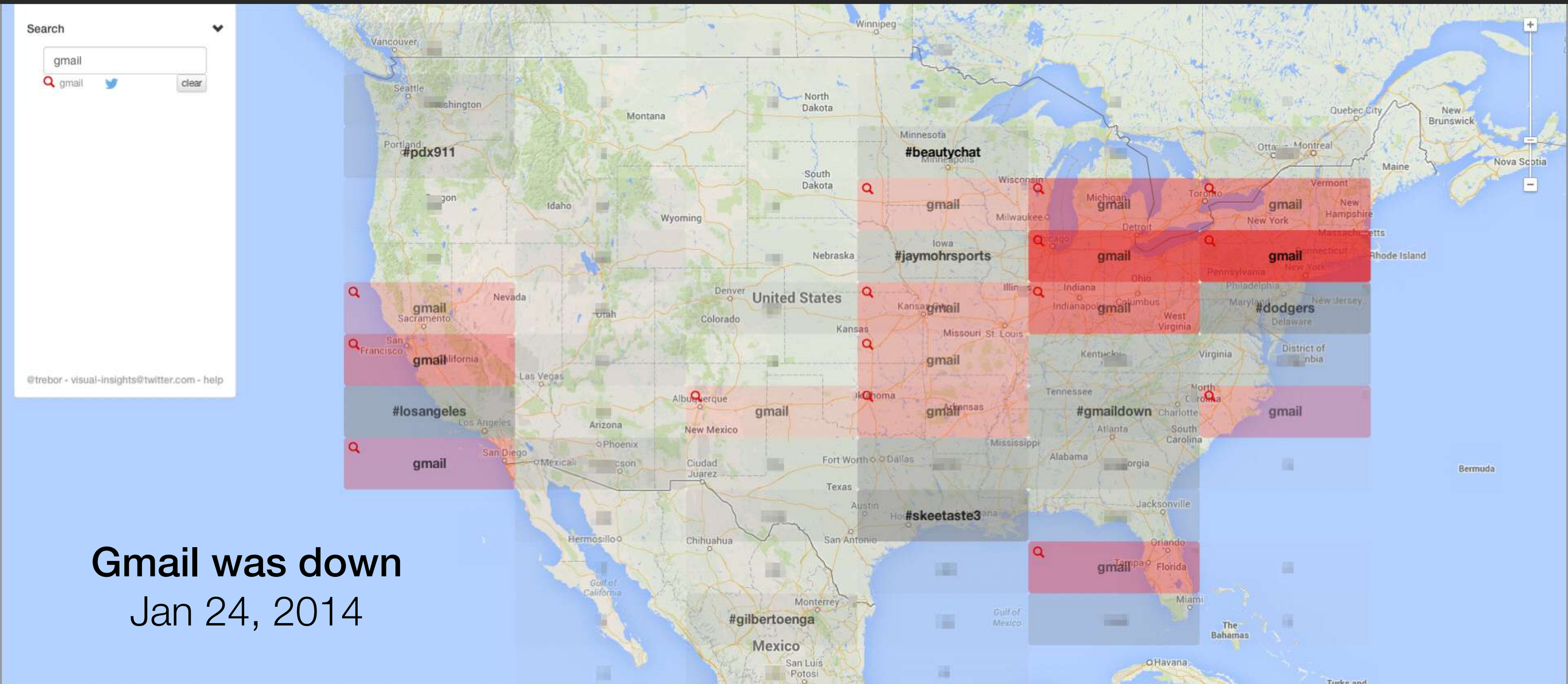


Visualize Data



Geo + Text

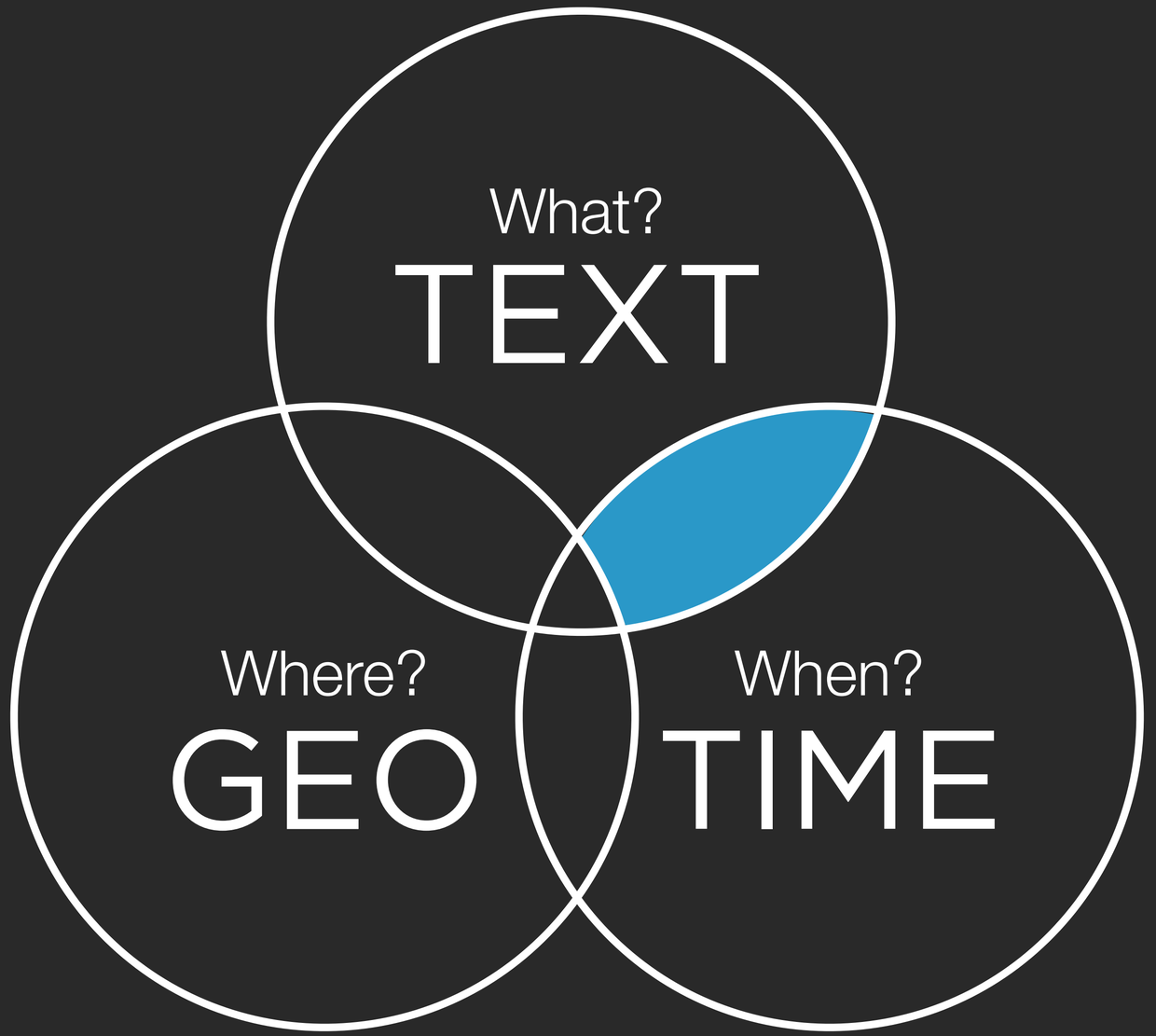
Real-time Tweet map



Gmail was down

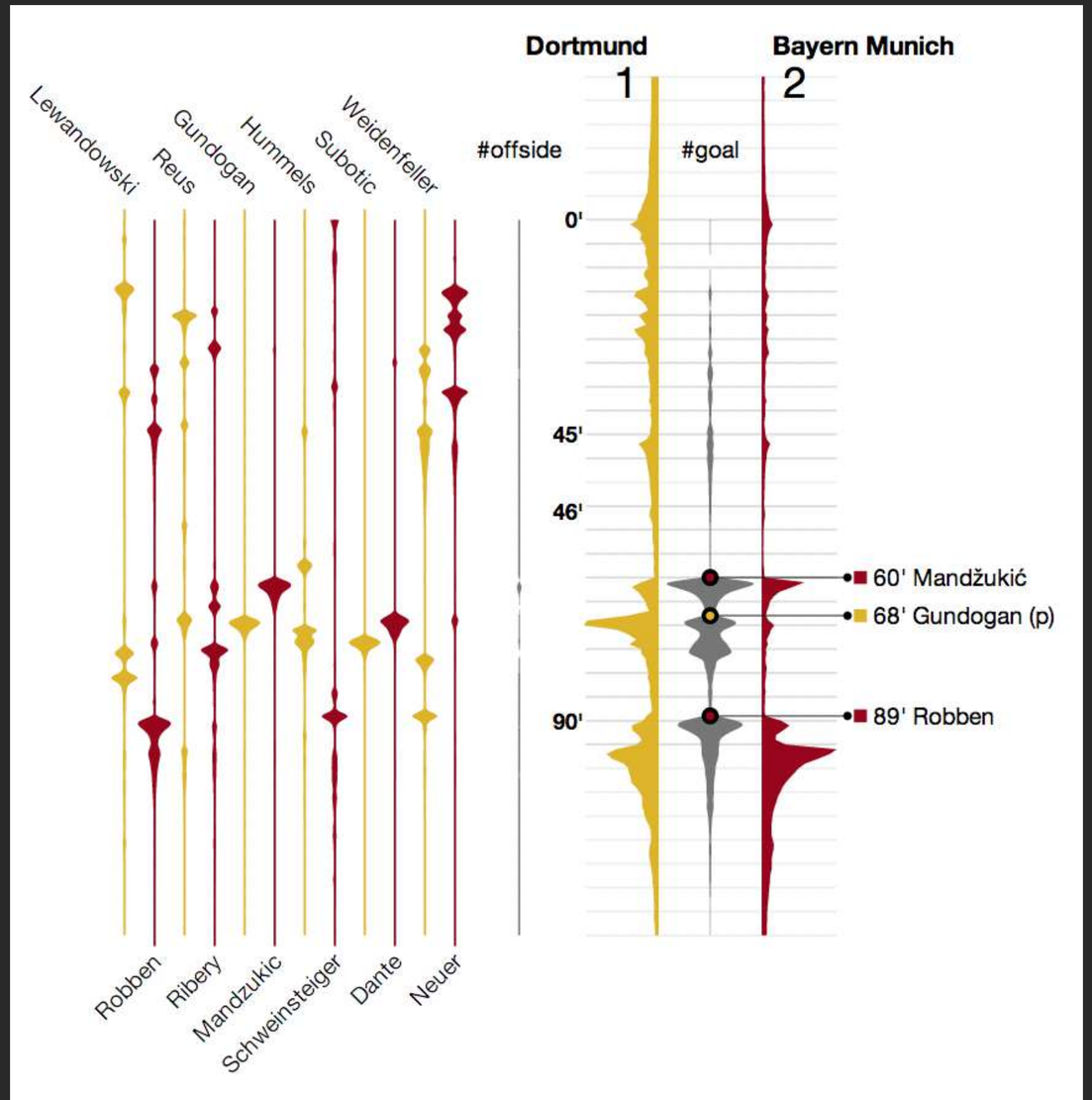
Jan 24, 2014

Visualize Data



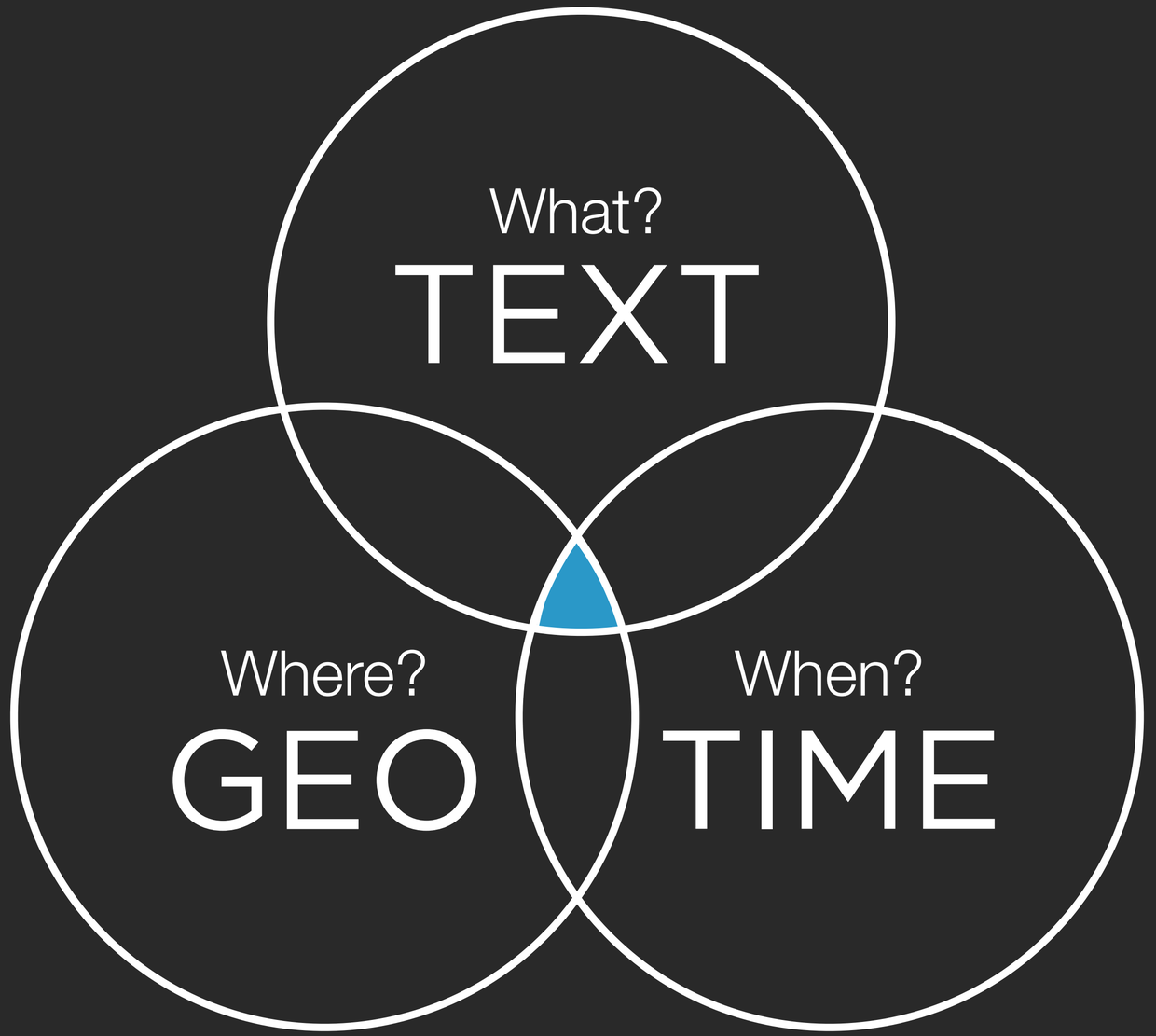
Time + Text

UEFA Champions League

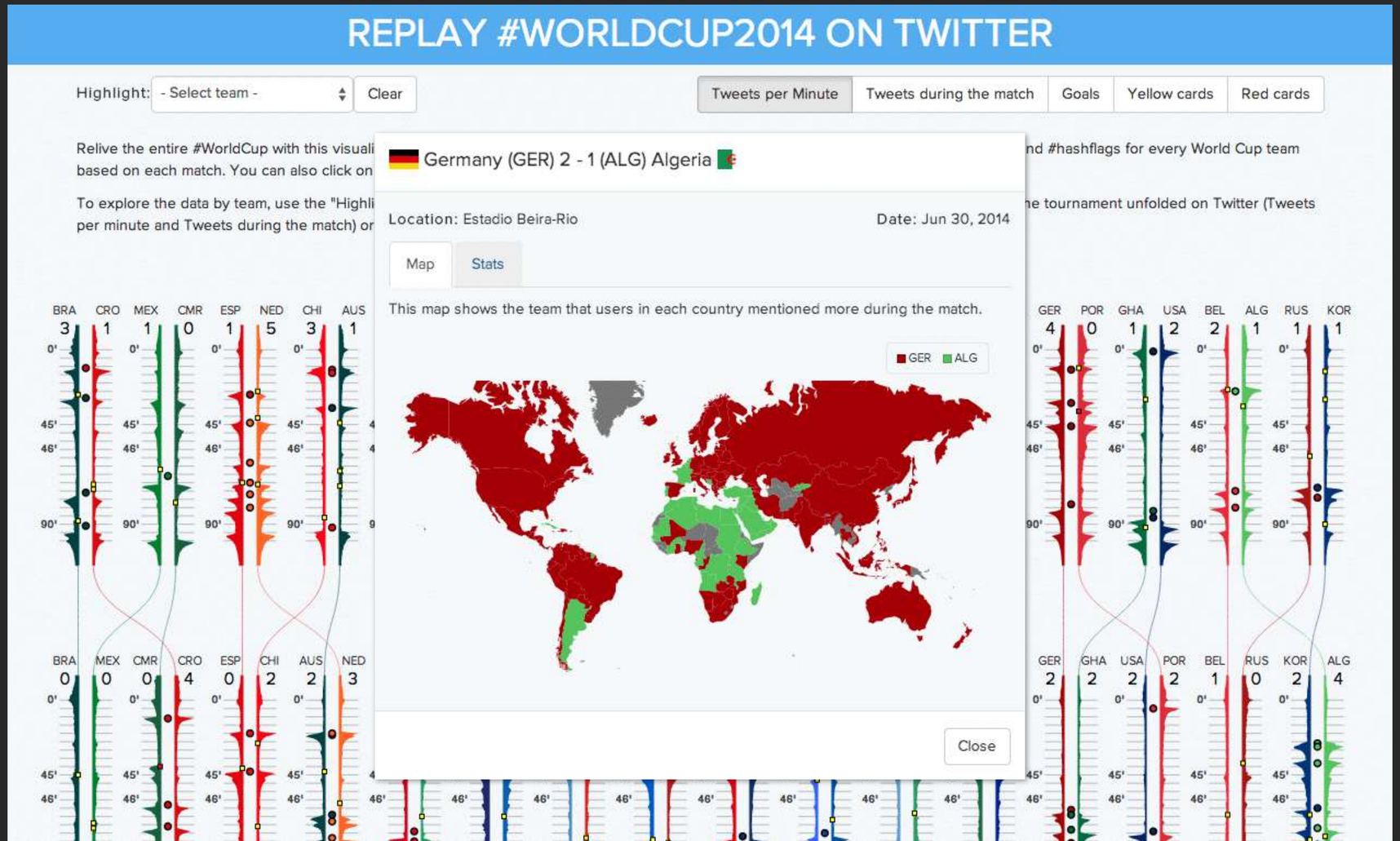


+ players

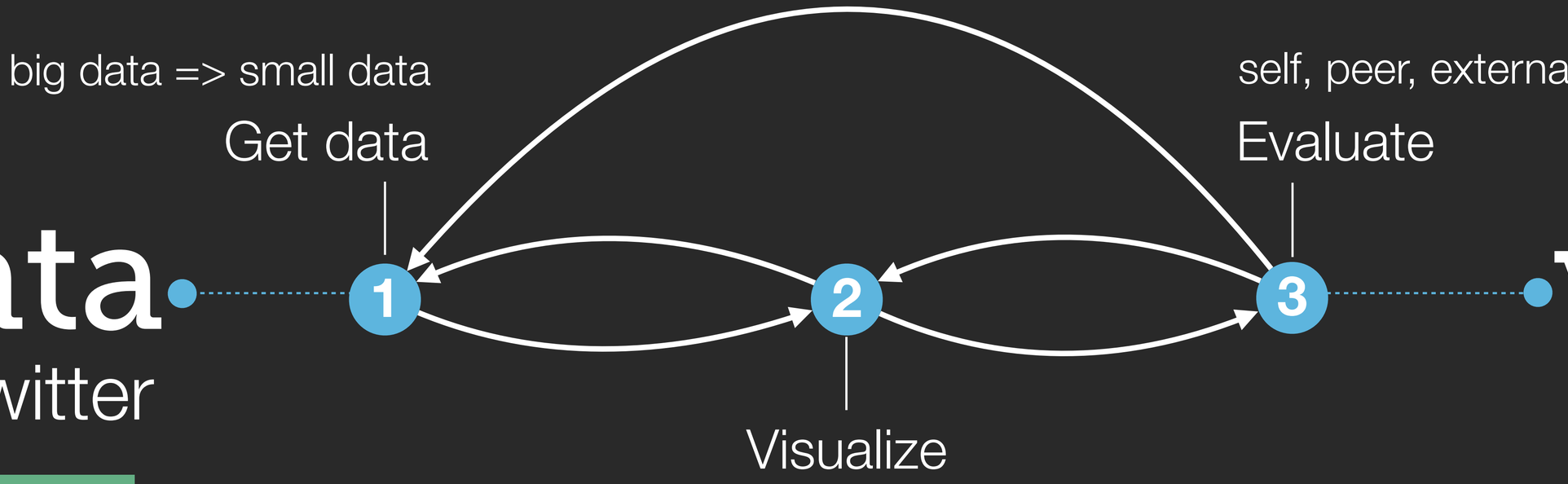
Visualize Data



Time + Text + Geo World Cup 2014



data at Twitter



vis

“Tweets”

- users
- followers graph
- logs
- etc.

(with deadline)

@kristw / https://interactive.twitter.com

+ visualizations by @philogb, @miguelrios & @trebor

?

GEO VISUALIZATION

GEO VISUALIZATION

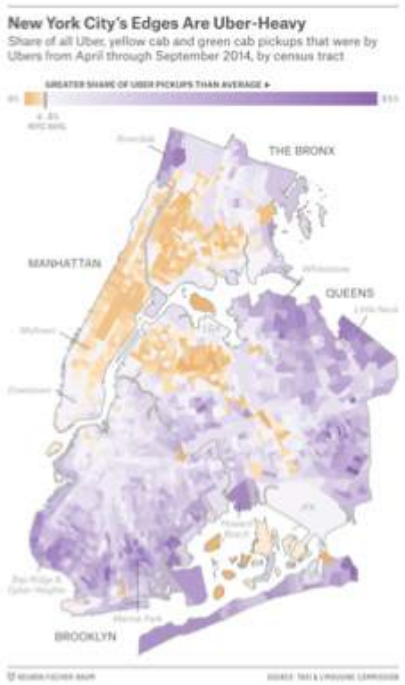
- Tools and techniques supporting the analysis of **spatial data**

Cartography
Science of drawing maps

+

Spatial Data

=



Map Visualization
Projection of spatial data in a map

SPATIAL DATA TYPES

- Spatial data describe objects or phenomena:
  - Having a specific location in the real (or virtual) world
  - Moving in the space

Point

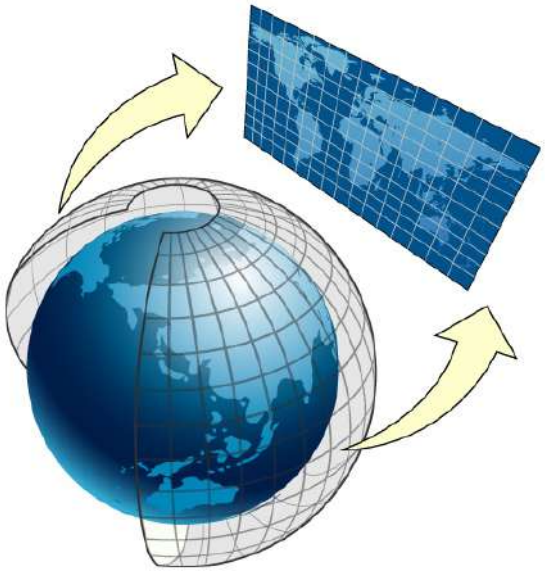
Line

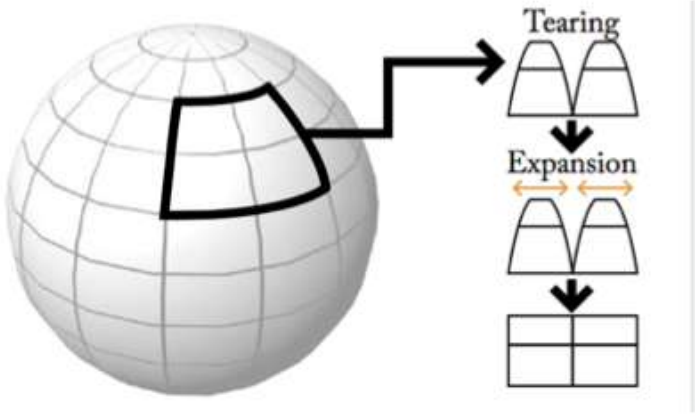
Polygon

Surface (2.5)

MAP PROJECTION

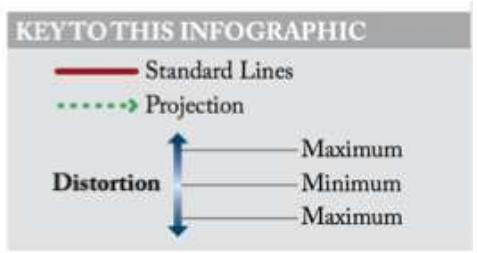
- Transformation of **Geographic Coordinates** (lat, lot) to **Cartesian** (x, y)

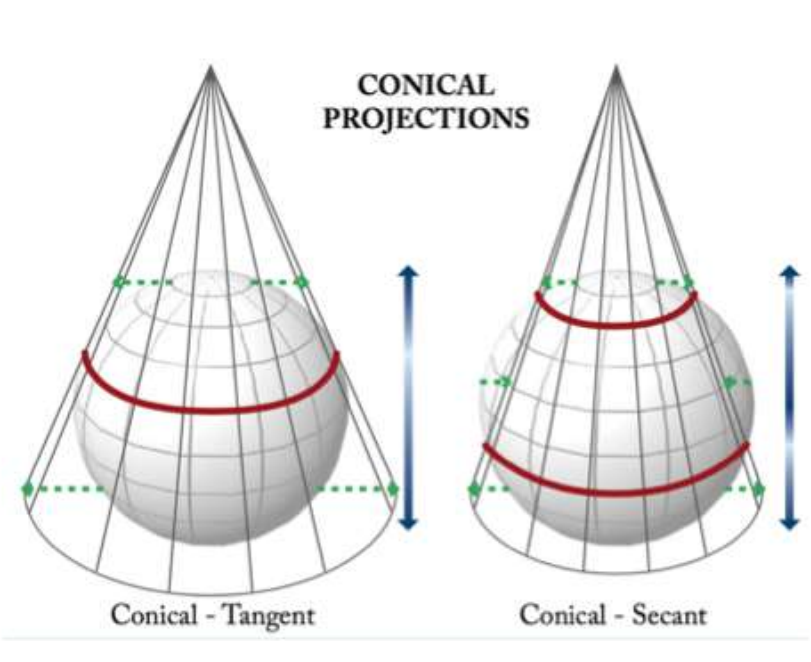


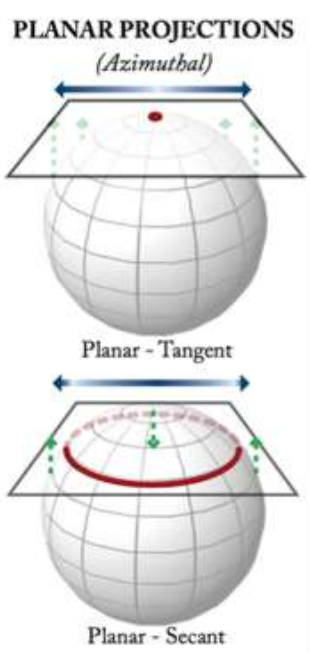


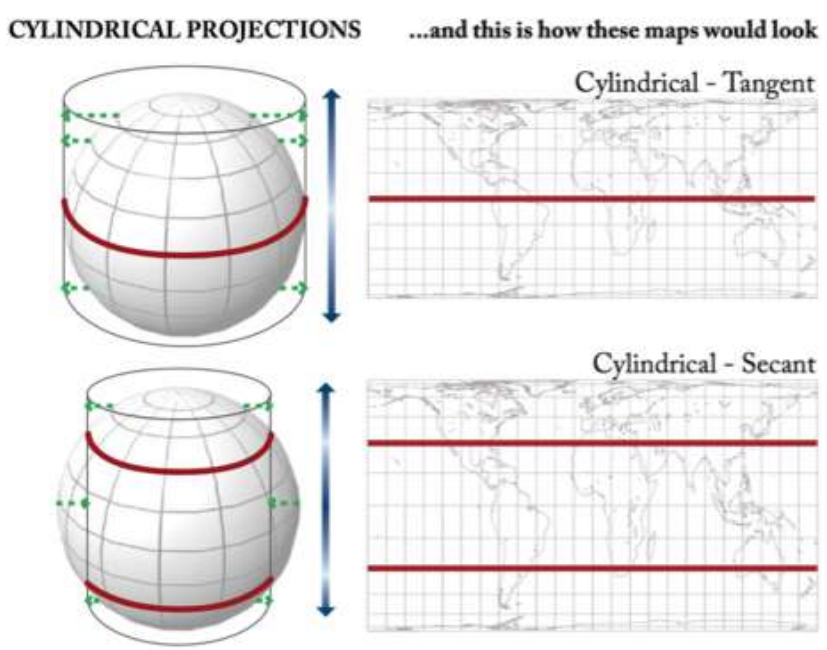

A sphere tears
when you flatten it

MAP PROJECTION

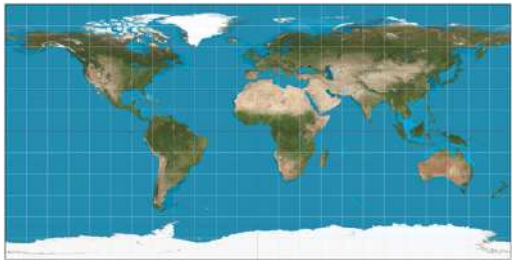




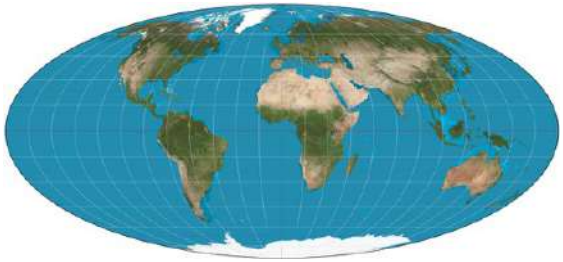




MAP PROJECTION

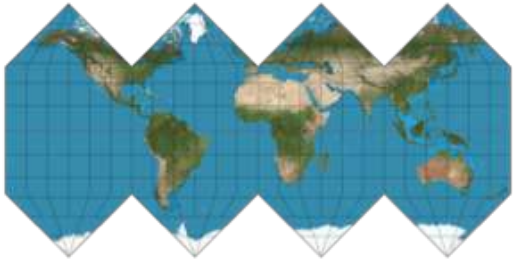


Equirectangular

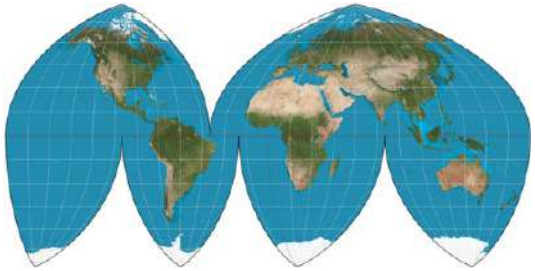


Mollweide

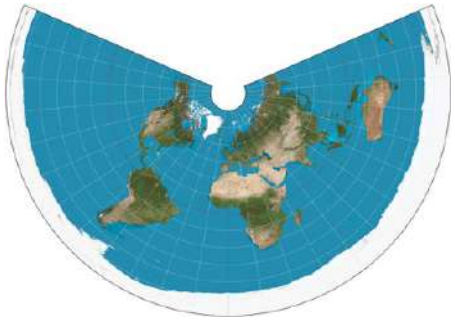
Web Mercator



HEALPix



HEALPix



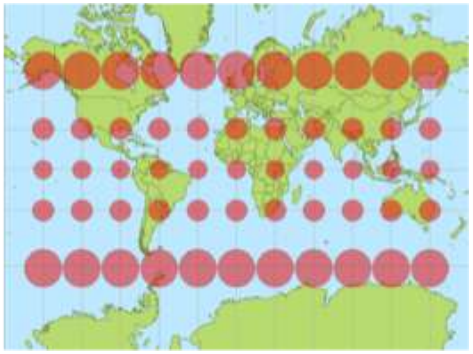
Equidistant conique

https://en.wikipedia.org/wiki/List_of_map_projections

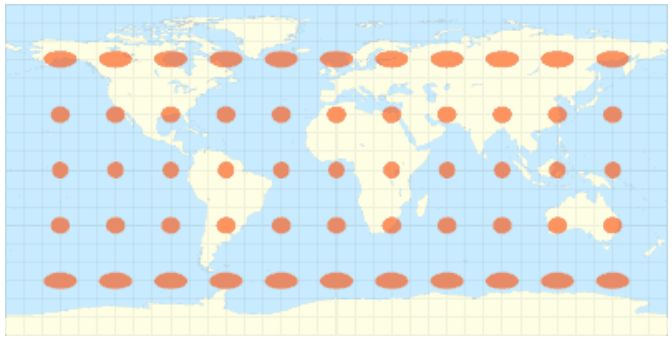
MAP PROJECTION

- Map projections cause always **distortions**
  - ex. area, shape, direction, scale, distance

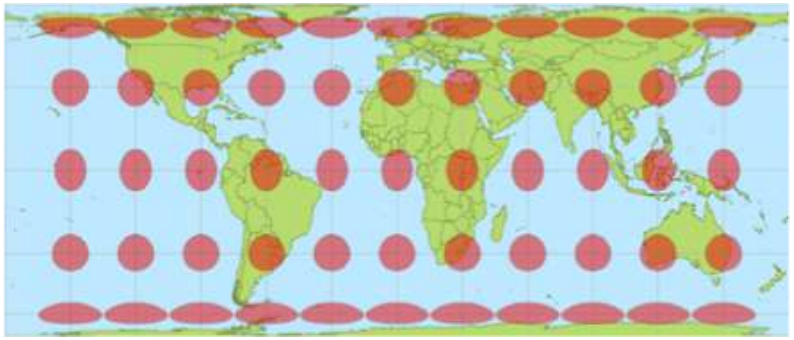
Tissot's indicatrix



Mercator projection

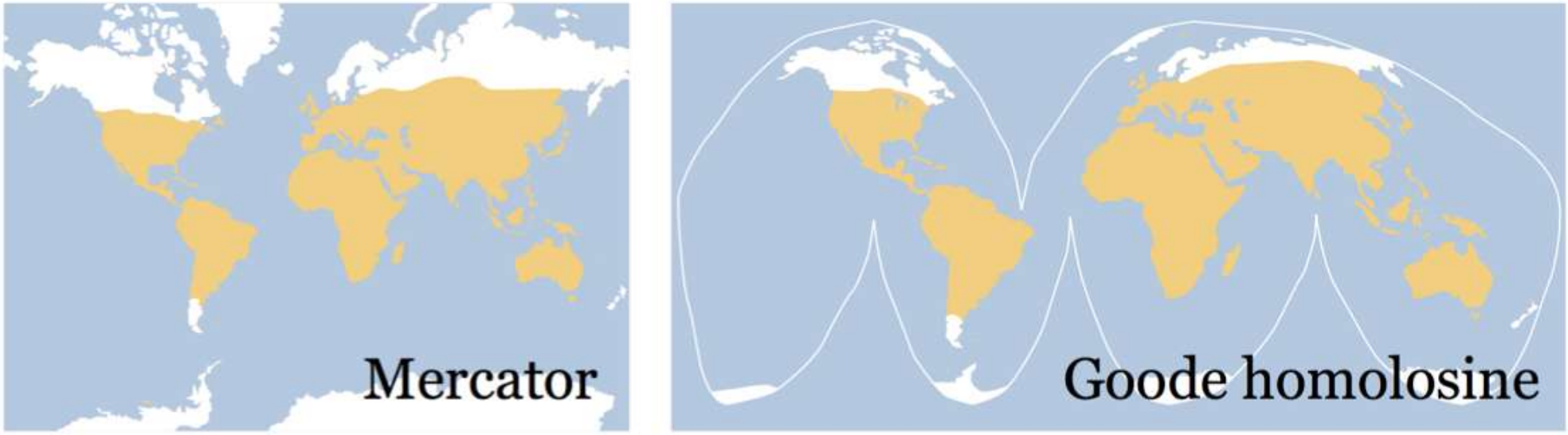


Equirectangular projection



Behrmann projection

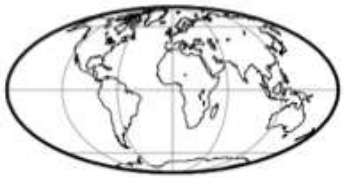
MAP PROJECTION



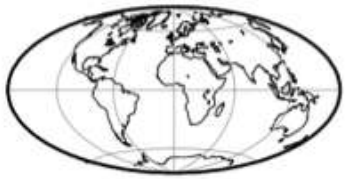
Areas of the world may be covered with ice for more than 90 percent of the year in 2020

Which projections you could use if you're mapping...

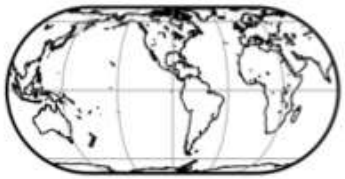
The World



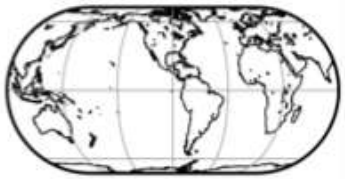
Mollweide



Hammer



Eckert IV



Robinson

Continental areas: Asia & North America

Lambert azimuthal

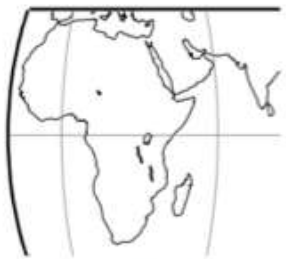
Albers equal-area

Continental areas: Europe and Australia

Lambert azimuthal

Albers equal-area

Continental areas: Africa and South America



Mollweide

Lambert azimuthal

Sinusoidal

Countries in mid-latitudes

Large countries

Lambert azimuthal

Albers equal-area

Cylindrical equal-area*

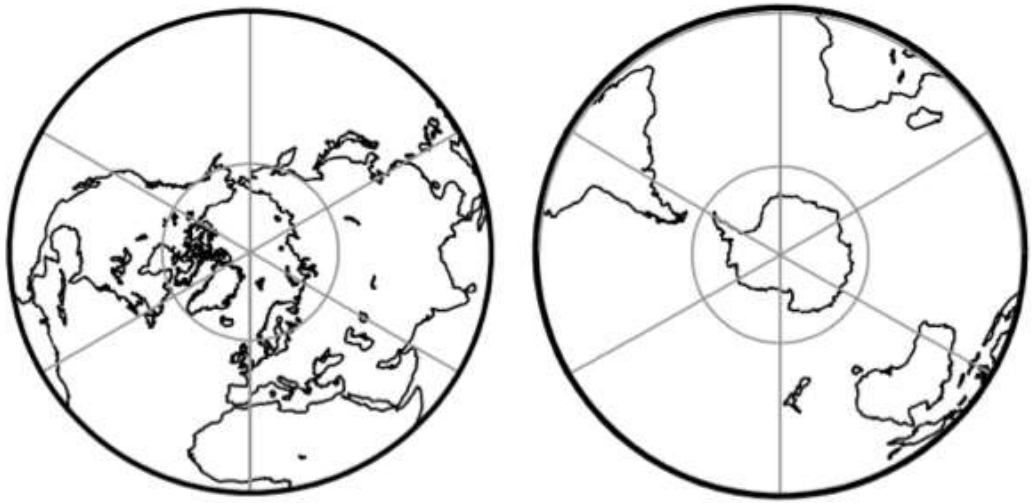
Small countries

Albers equal-area

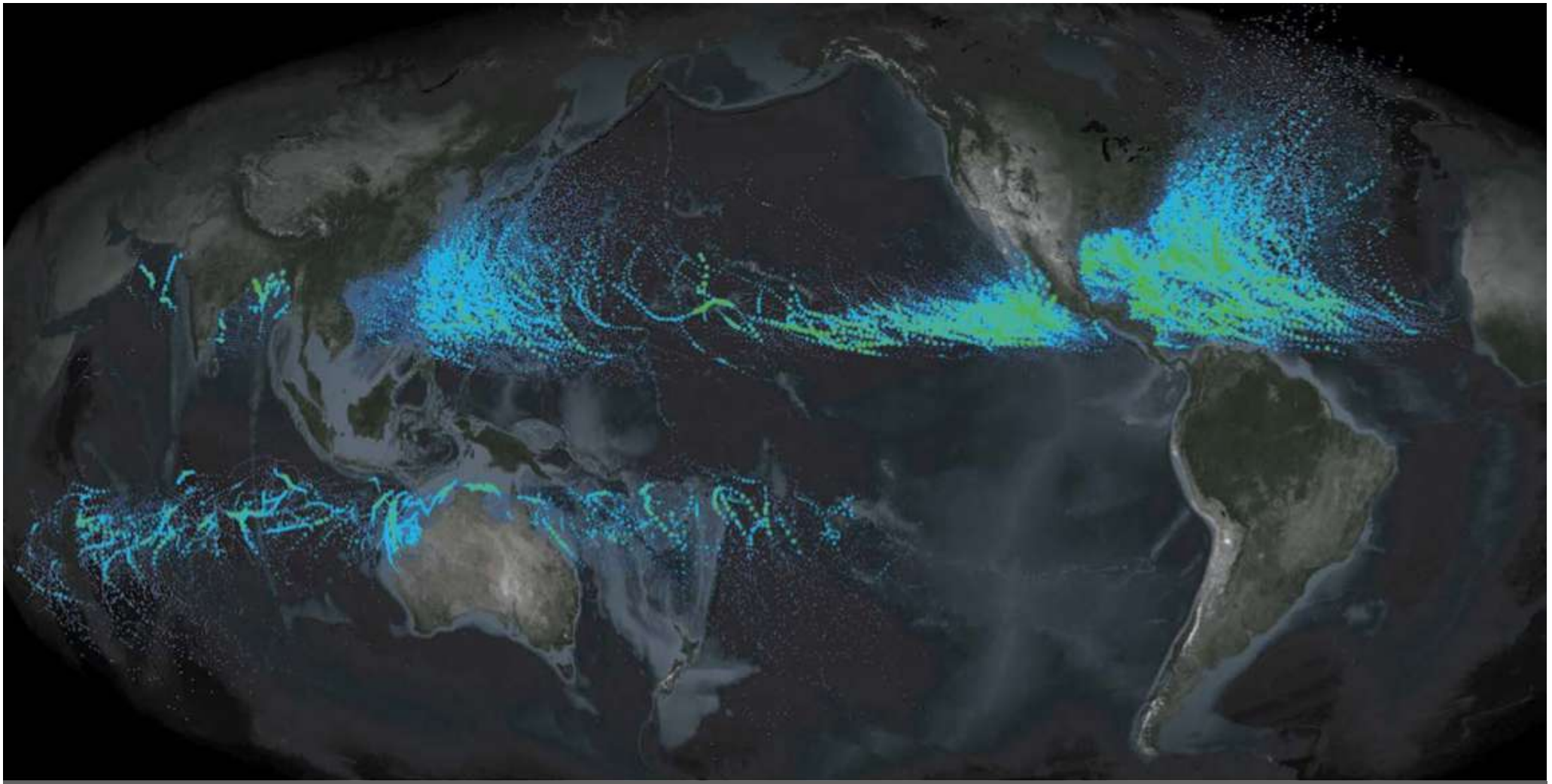
Cylindrical equal-area*

(*For areas with a North-South orientation)

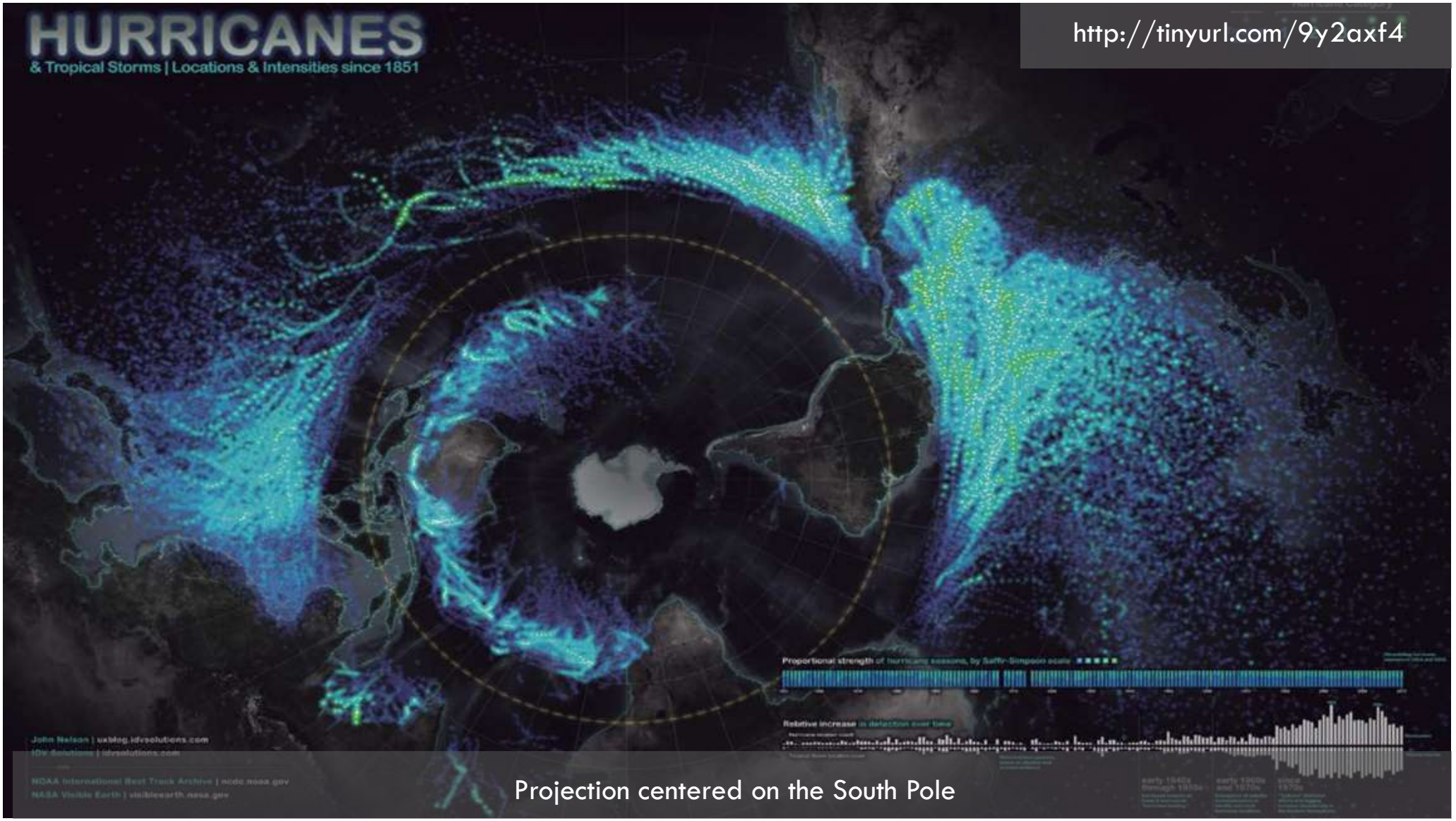
Polar regions



Lambert azimuthal



Hurricanes and tropical storms since 1851 – *John Nelson*



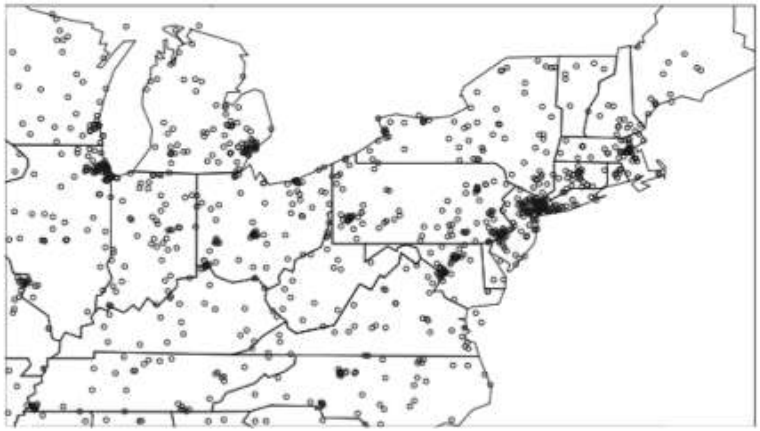
Projection centered on the South Pole


AMCHARTS
HTTP://PIXELMAP.AMCHARTS.COM

VISUALIZATION OF POINT DATA

- Symbol based maps

VISUALIZATION OF POINT DATA



DOT MAPS

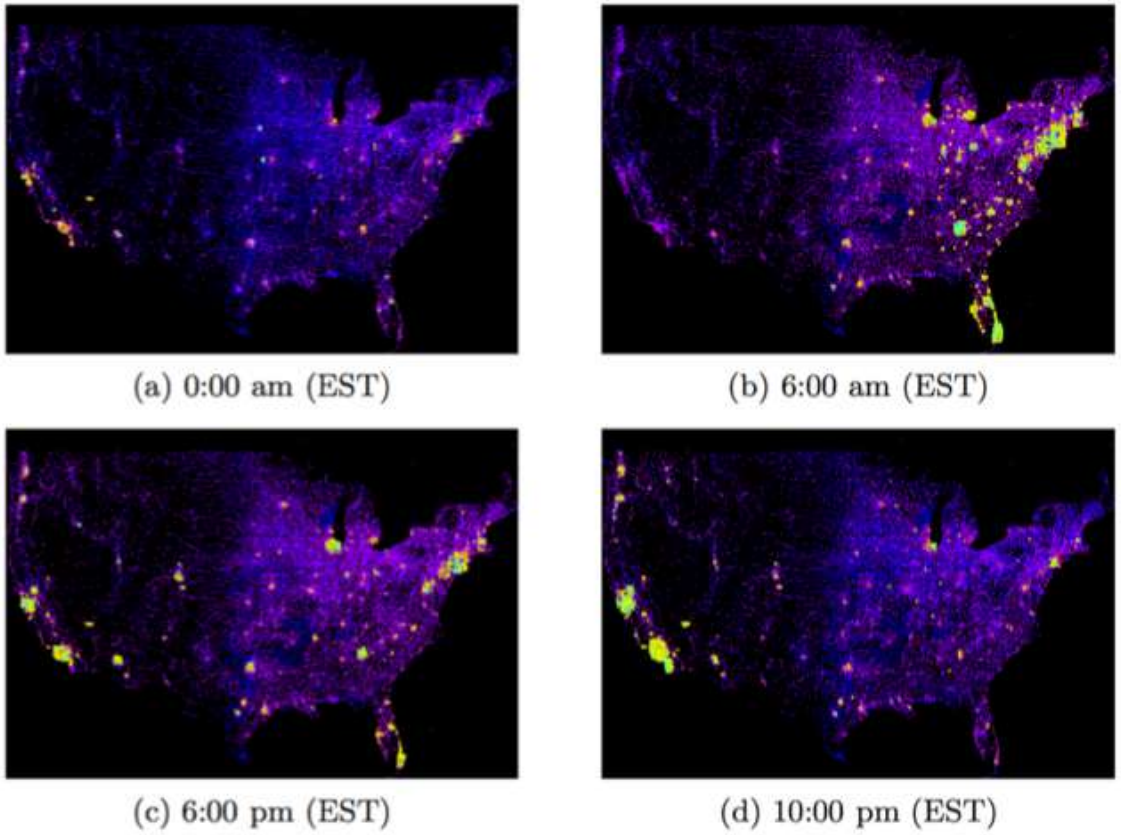
Circles represent the spatial location of an event

Remark: large degree of overlap

VISUALIZATION OF POINT DATA

PIXEL MAPS

Emphasize clusters while avoiding overlaps



(a) 0:00 am (EST)

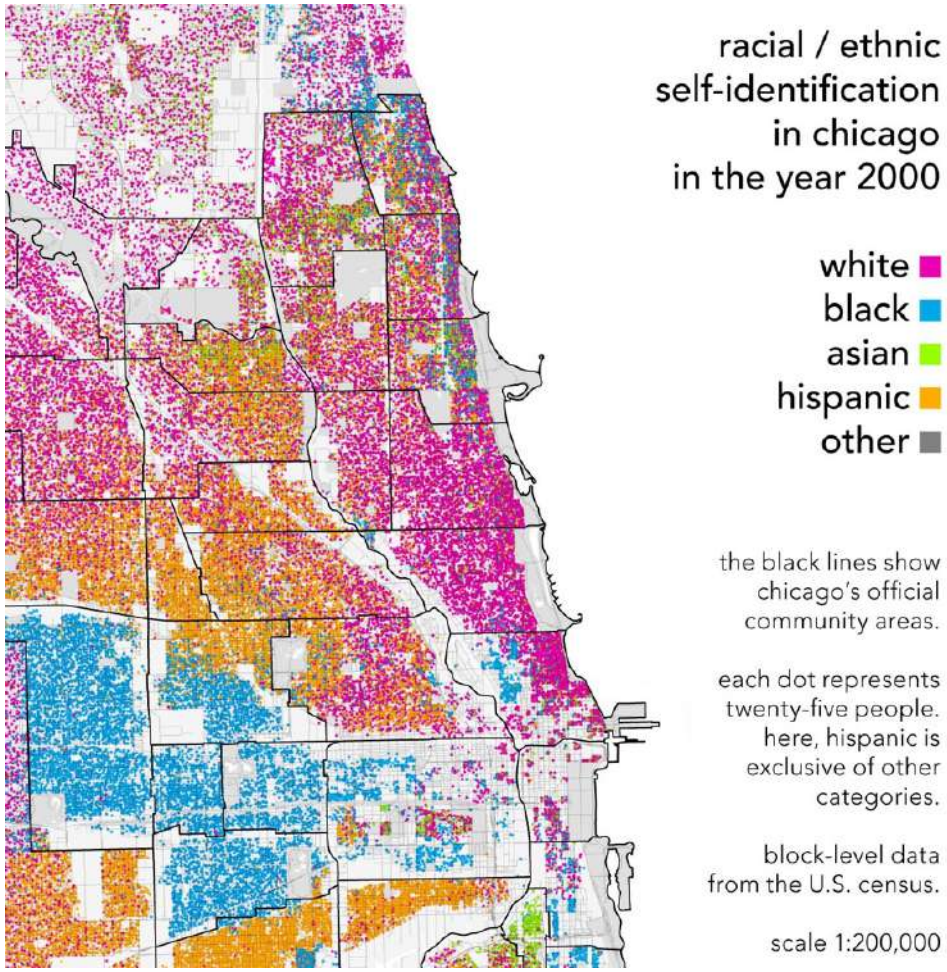
(b) 6:00 am (EST)

(c) 6:00 pm (EST)

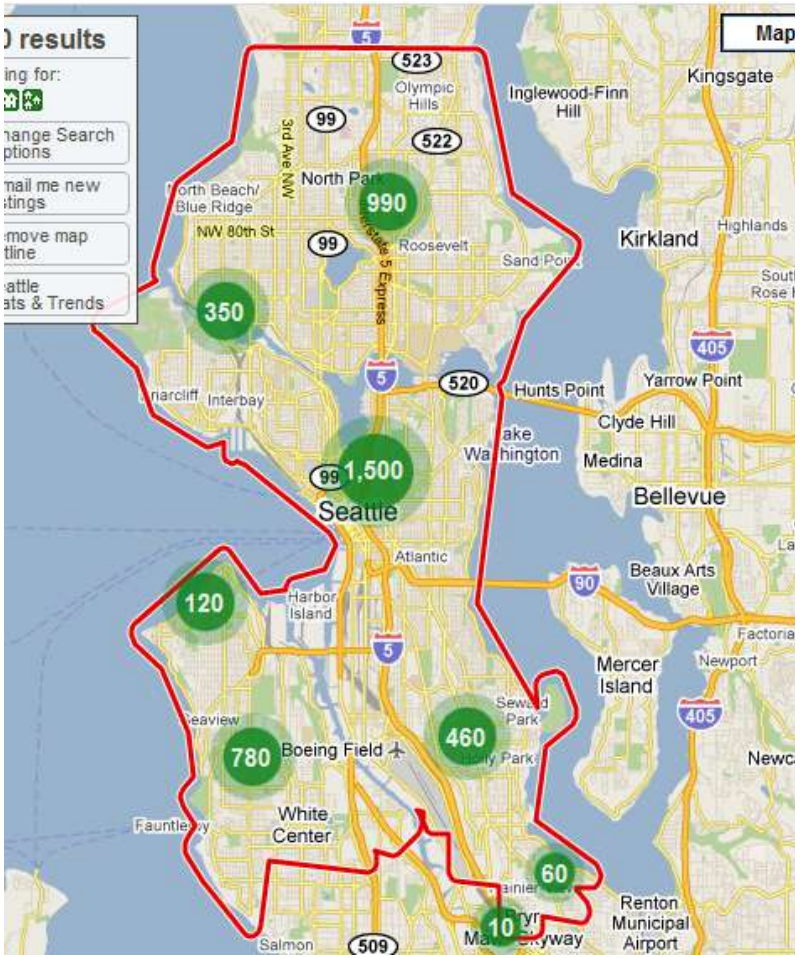
(d) 10:00 pm (EST)

Telephone call volume

WEST = EST-3h

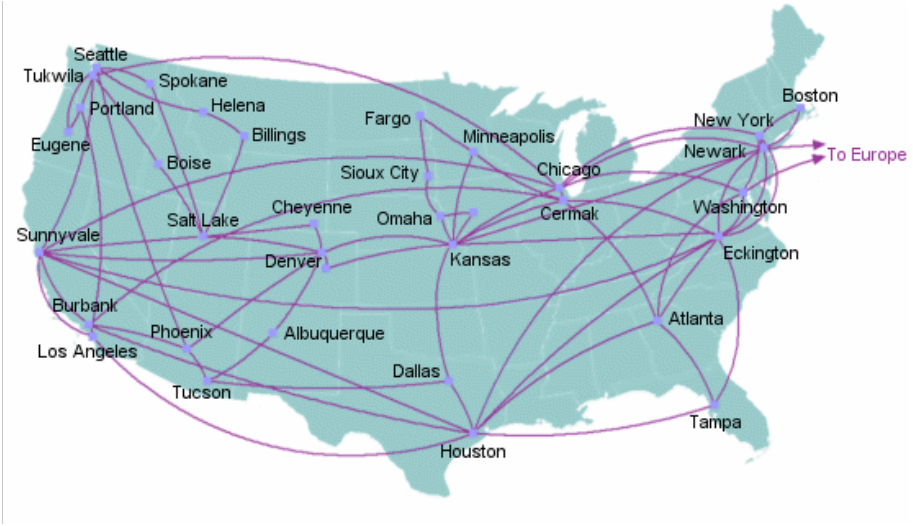


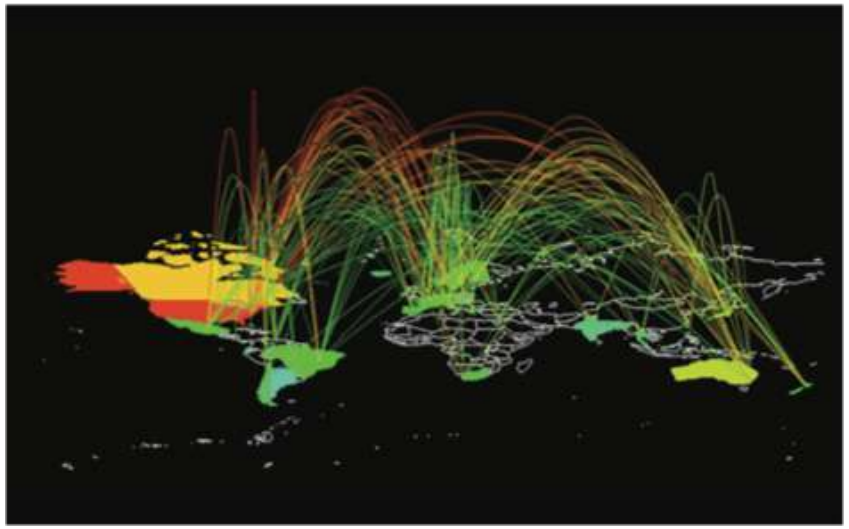
http://sta.mn/zzz



http://sta.mn/htj

VISUALIZATION OF LINE DATA



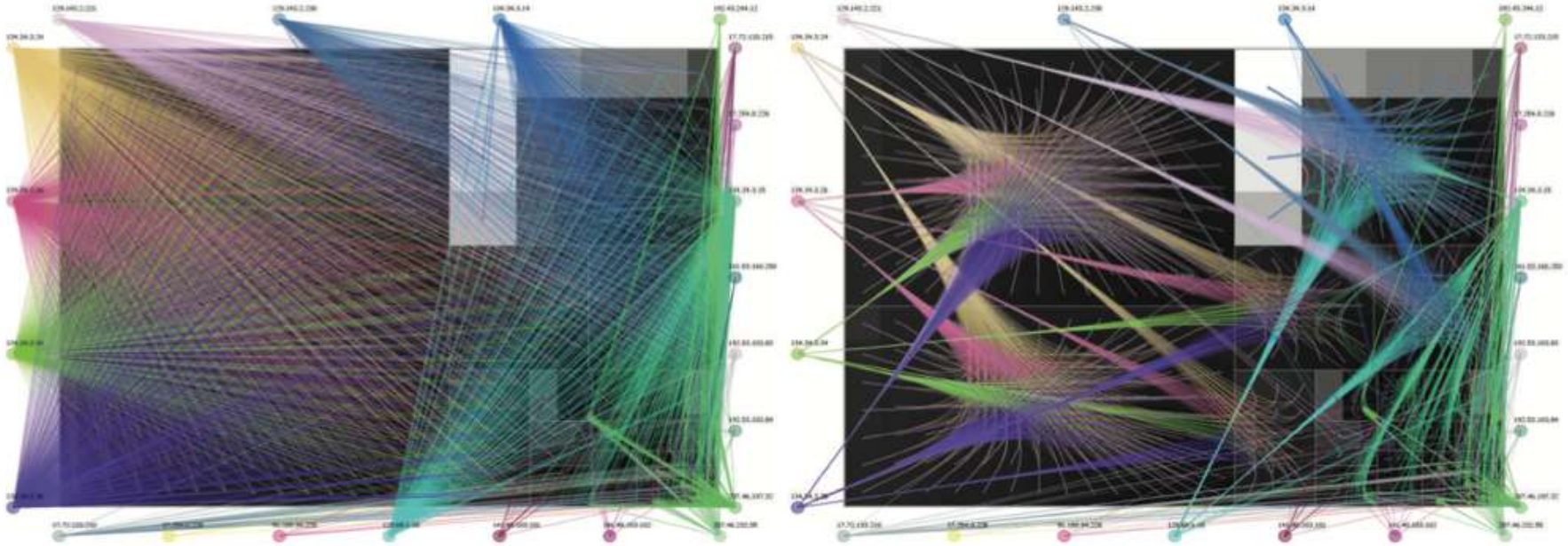


NETWORK MAPS

Line segments connecting pairs of coordinates

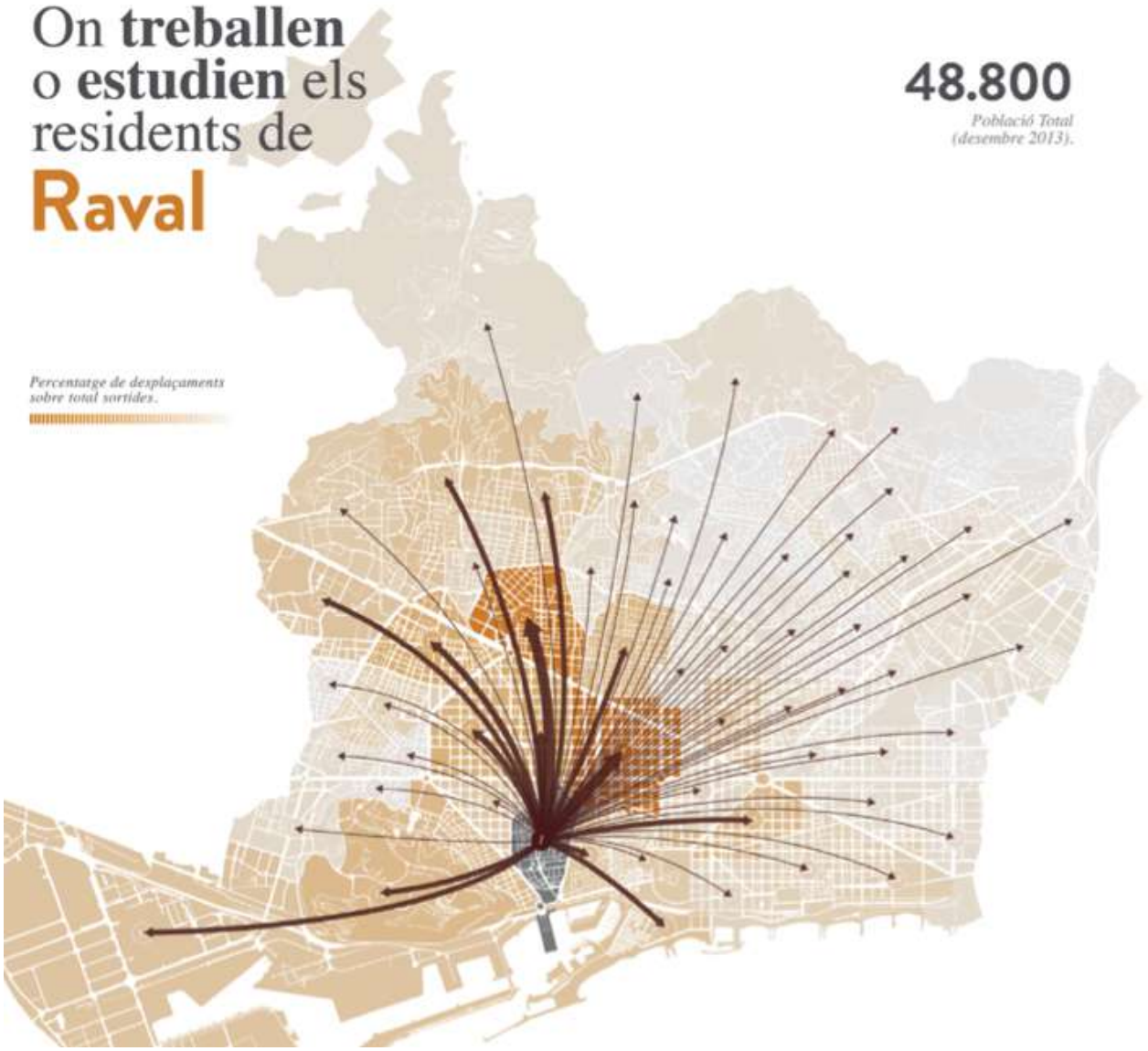
Remark: overlap problem in dense areas

VISUALIZATION OF LINE DATA



IP flow traffic from external nodes on the outside to internal nodes

Edge bundling *reduces the clutter in line drawings*



FLOW MAPS

Shows the movement of entities between geographic areas

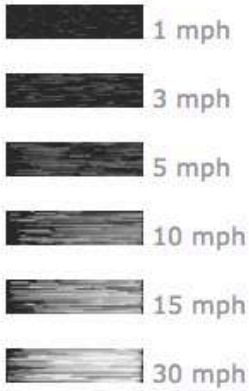
avoid overlapping

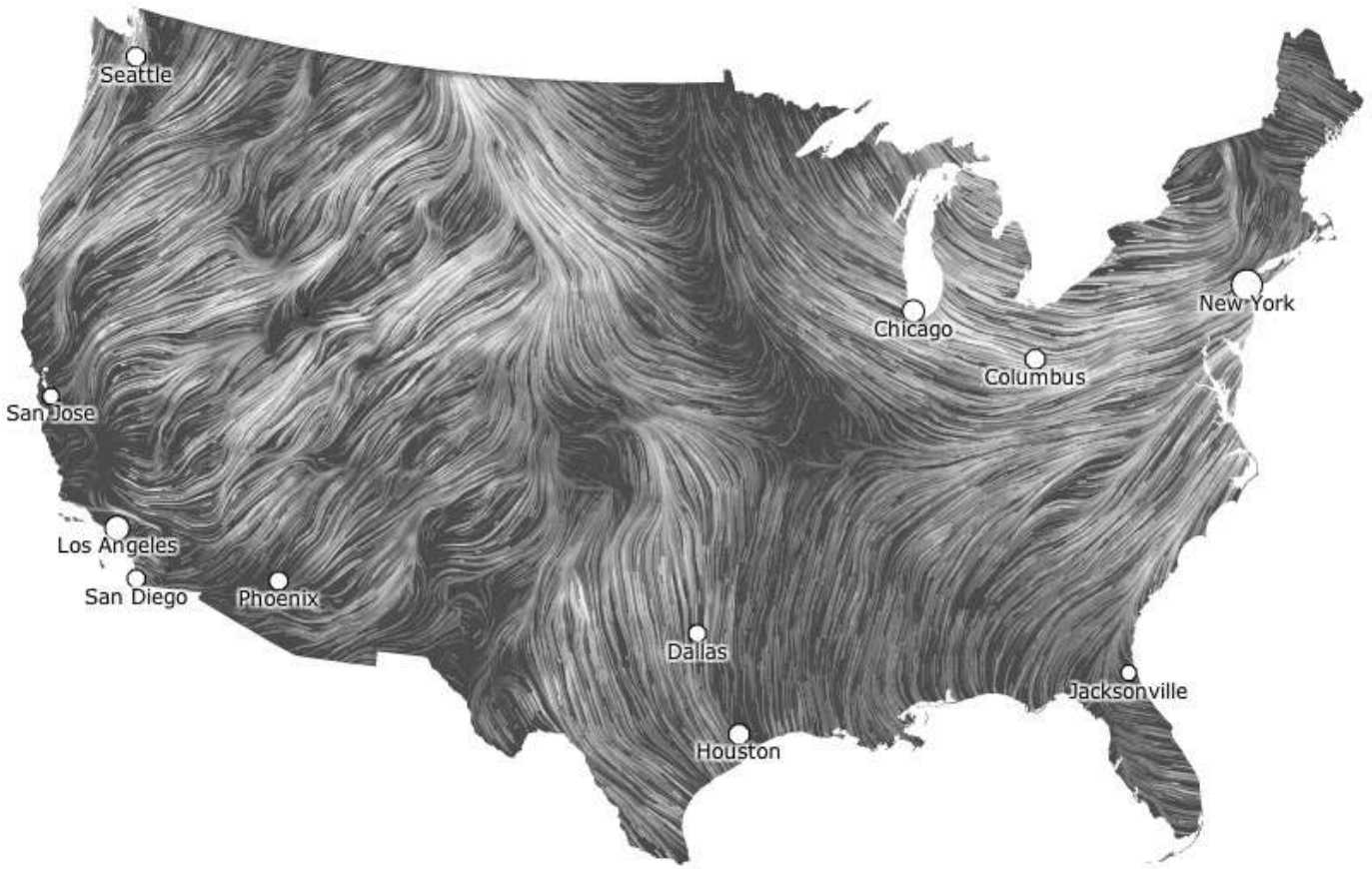
https://www.youtube.com/watch?v=holrRwDv_3U

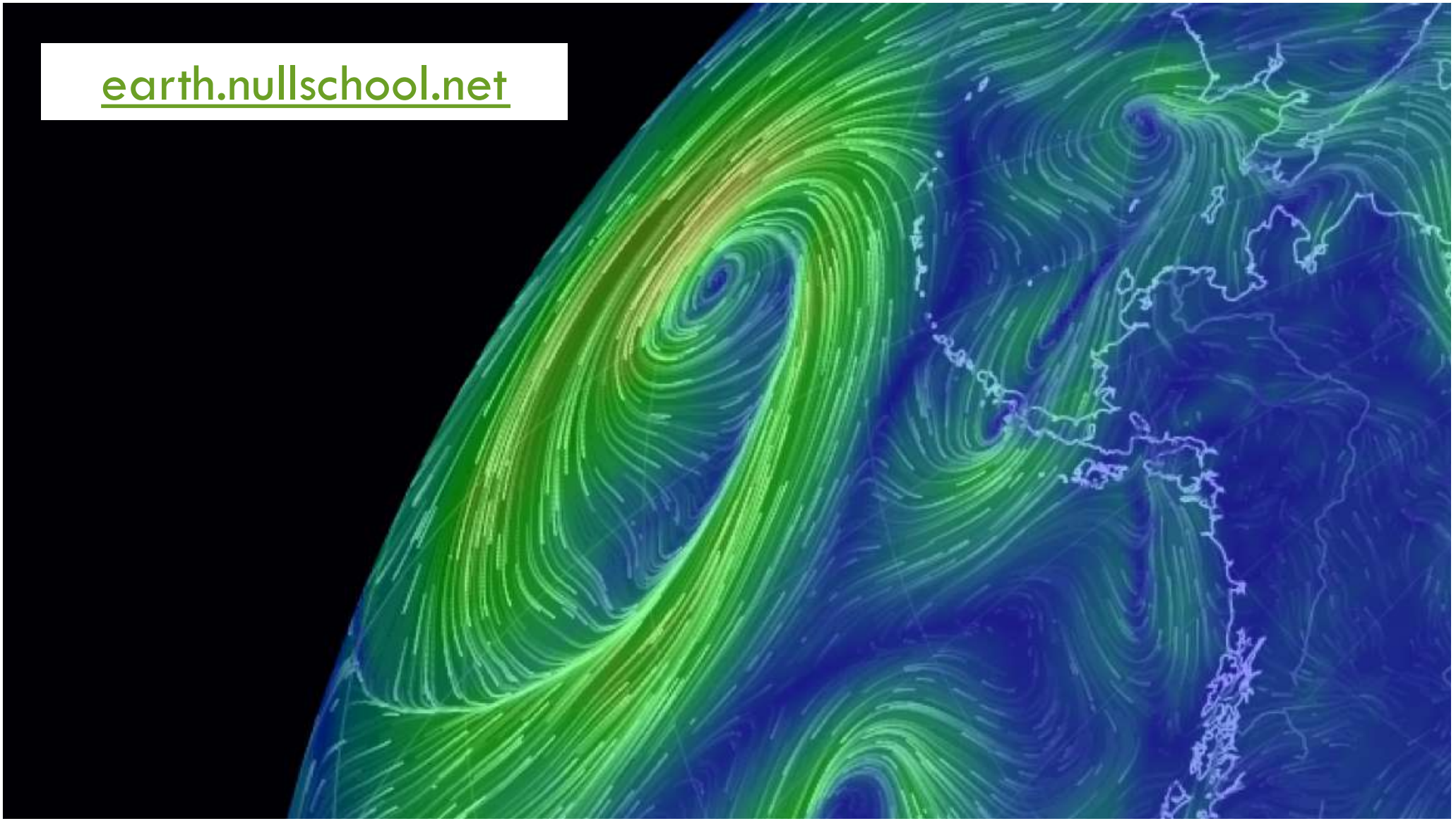
wind map

March 28, 2012
at 5:00 pm

top speed: **34.0 mph**
average: **10.6 mph**

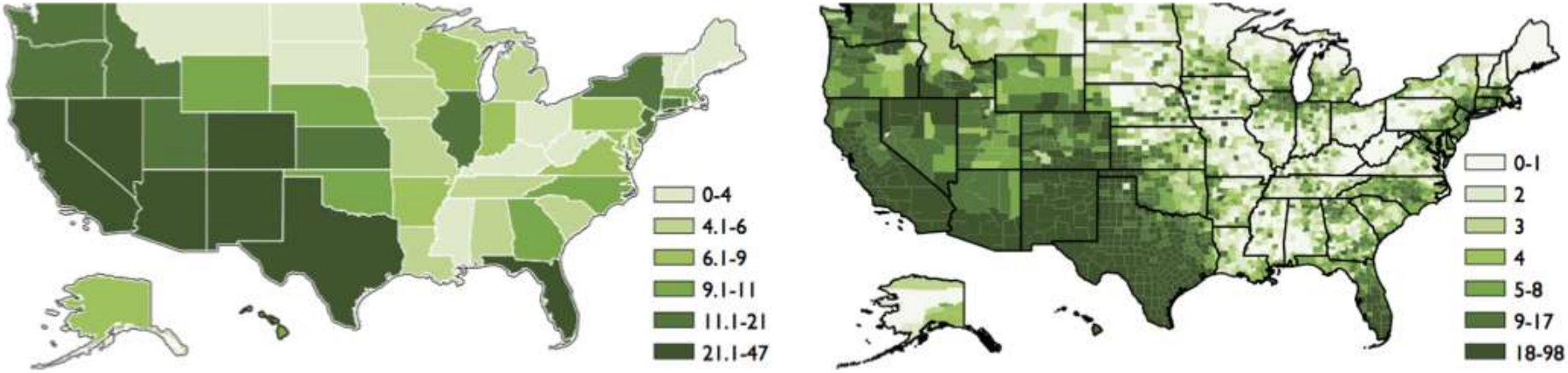





earth.nullschool.net

VISUALIZATION OF AREA DATA

Hispanic Population %



more classes = better spatial distribution

CHOROPLETH MAPS

Attributes or statistical variable encoded as colored/shaded regions

Remark: interesting values may concentrate in densely populated areas with small visibility

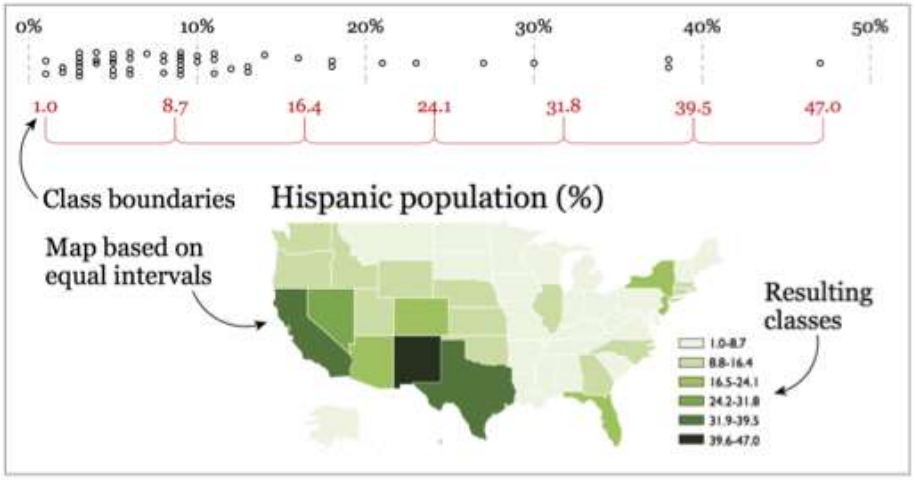


Figure 10.25 Choropleth map based on classes (intervals) of roughly equal size.

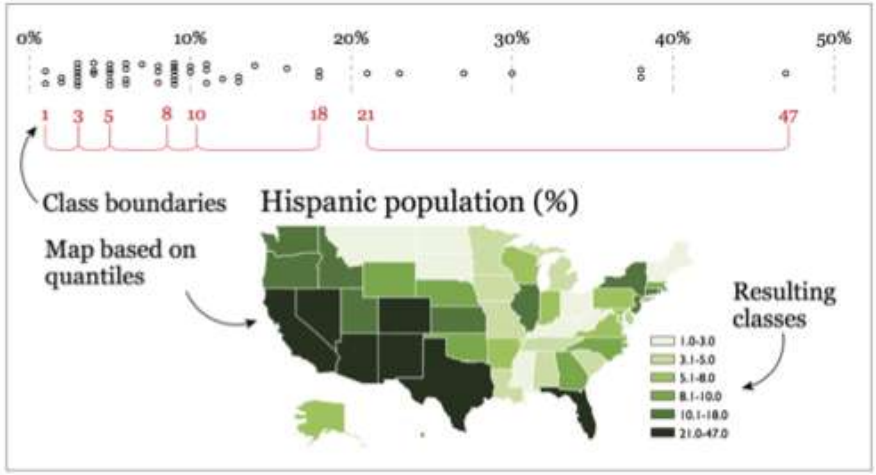


Figure 10.26 Choropleth map based on classes that contain roughly similar number of observations, between seven and ten each.

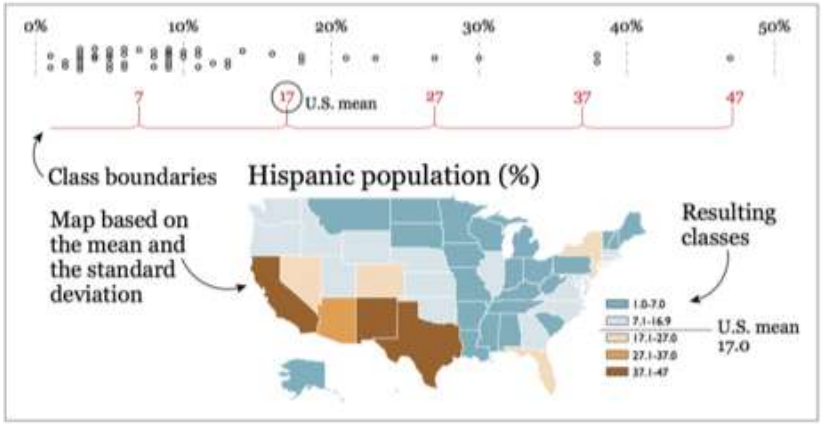


Figure 10.27 A divergent color scheme based on the mean and the standard deviation.

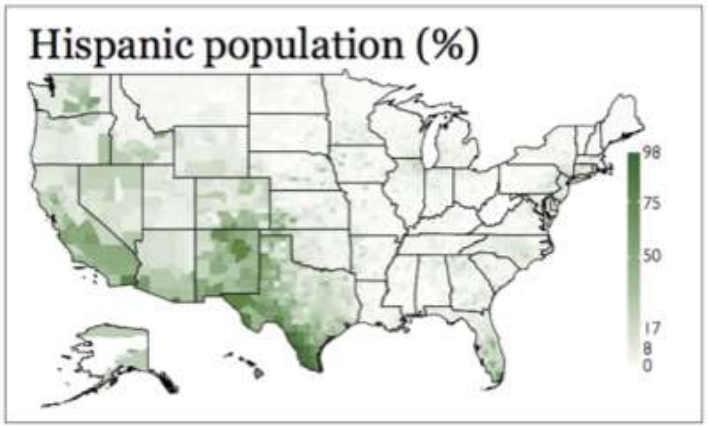


Figure 10.23 Adjusting the color scale to reveal more detail.

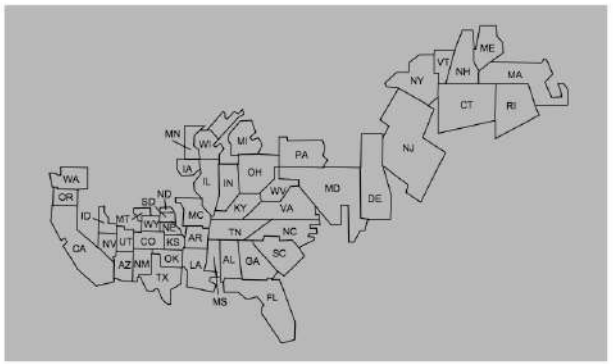
VISUALIZATION OF AREA DATA

CARTOGRAMS

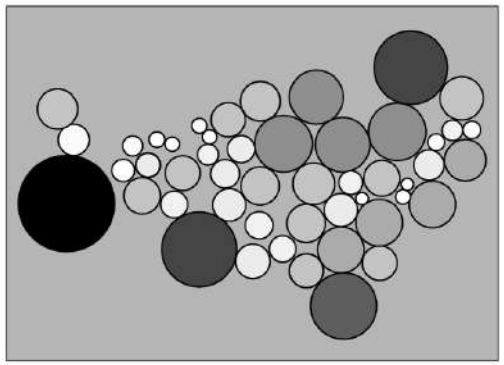
Distorts geography according to the displayed statistical value

NP optimization problem:
compromise shape vs area preservation

(a) Noncontinuous cartogram.

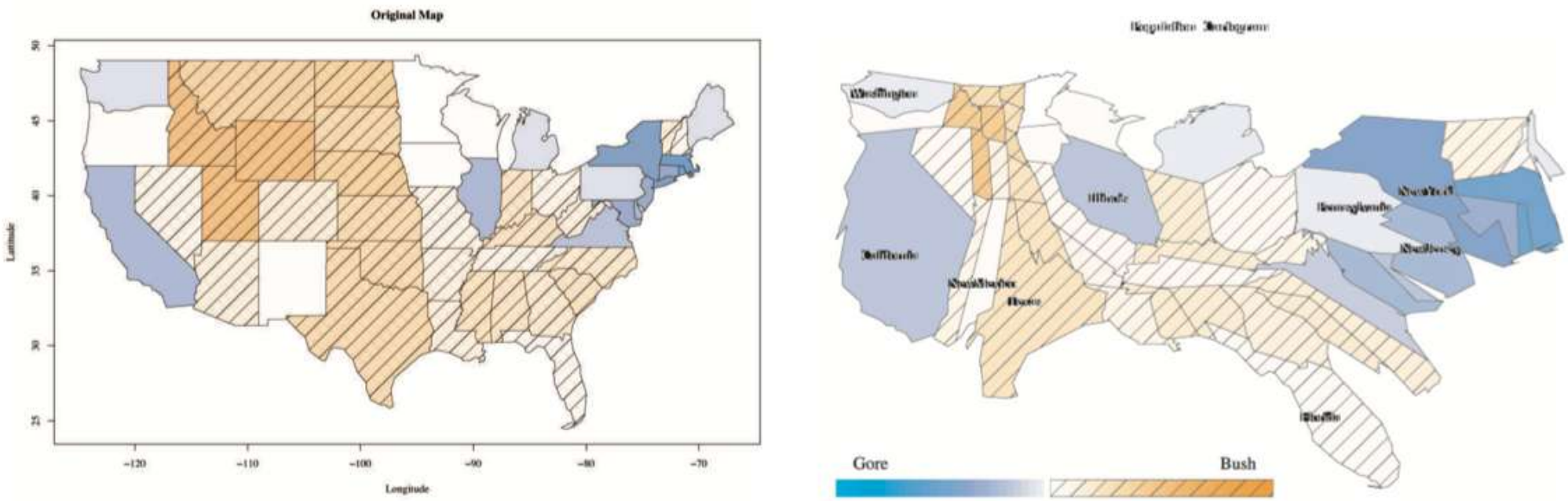


(b) Noncontiguous cartogram.



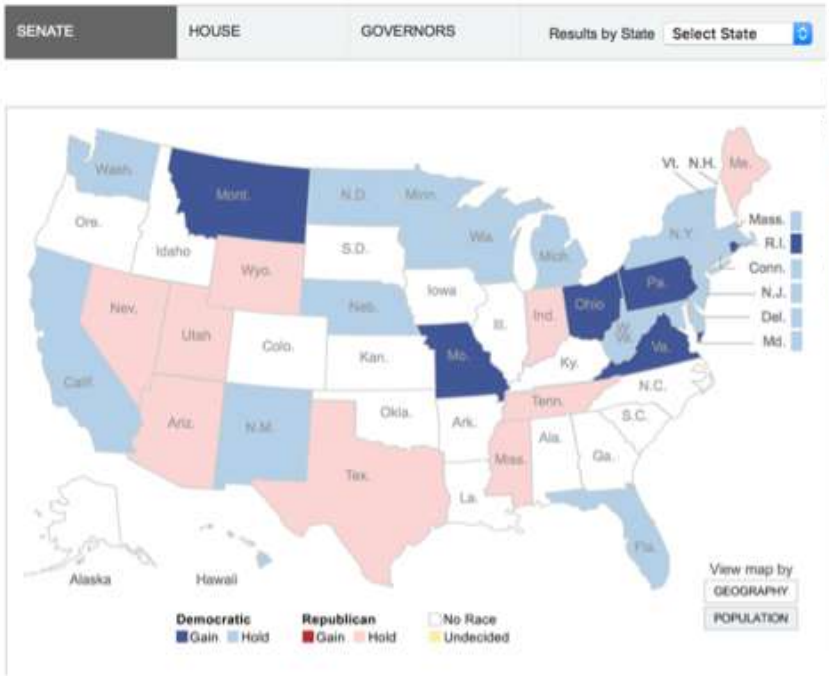
(c) Circular cartogram.

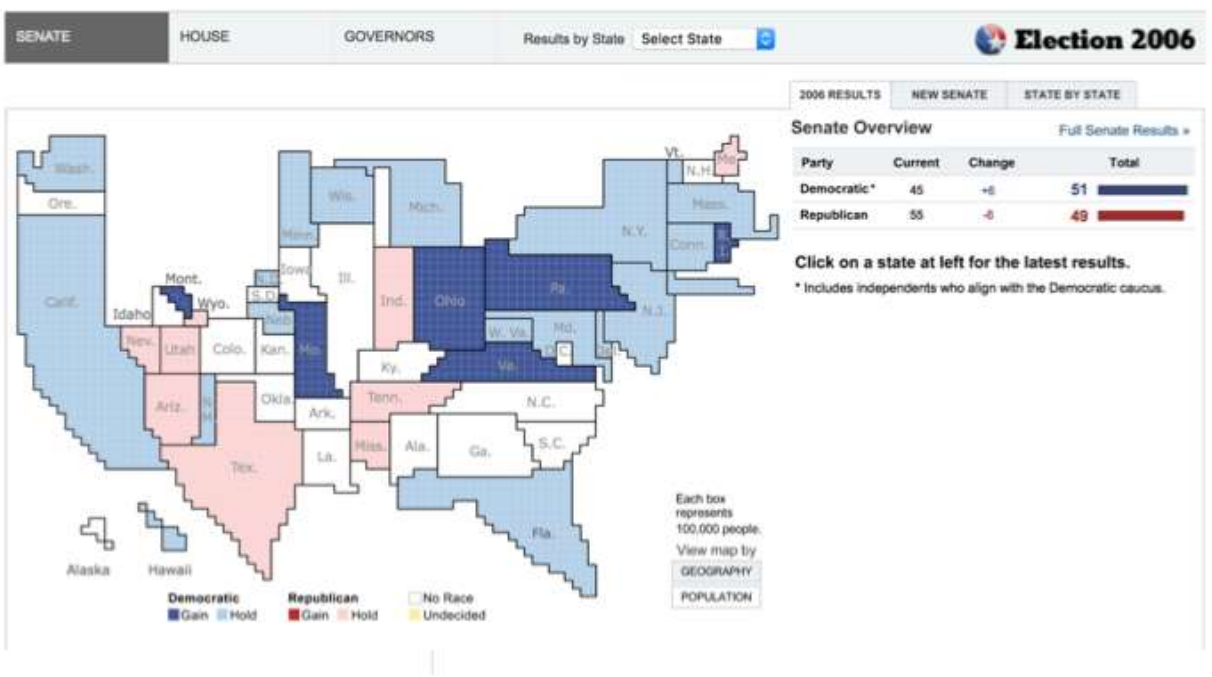
(d) Continuous cartogram.



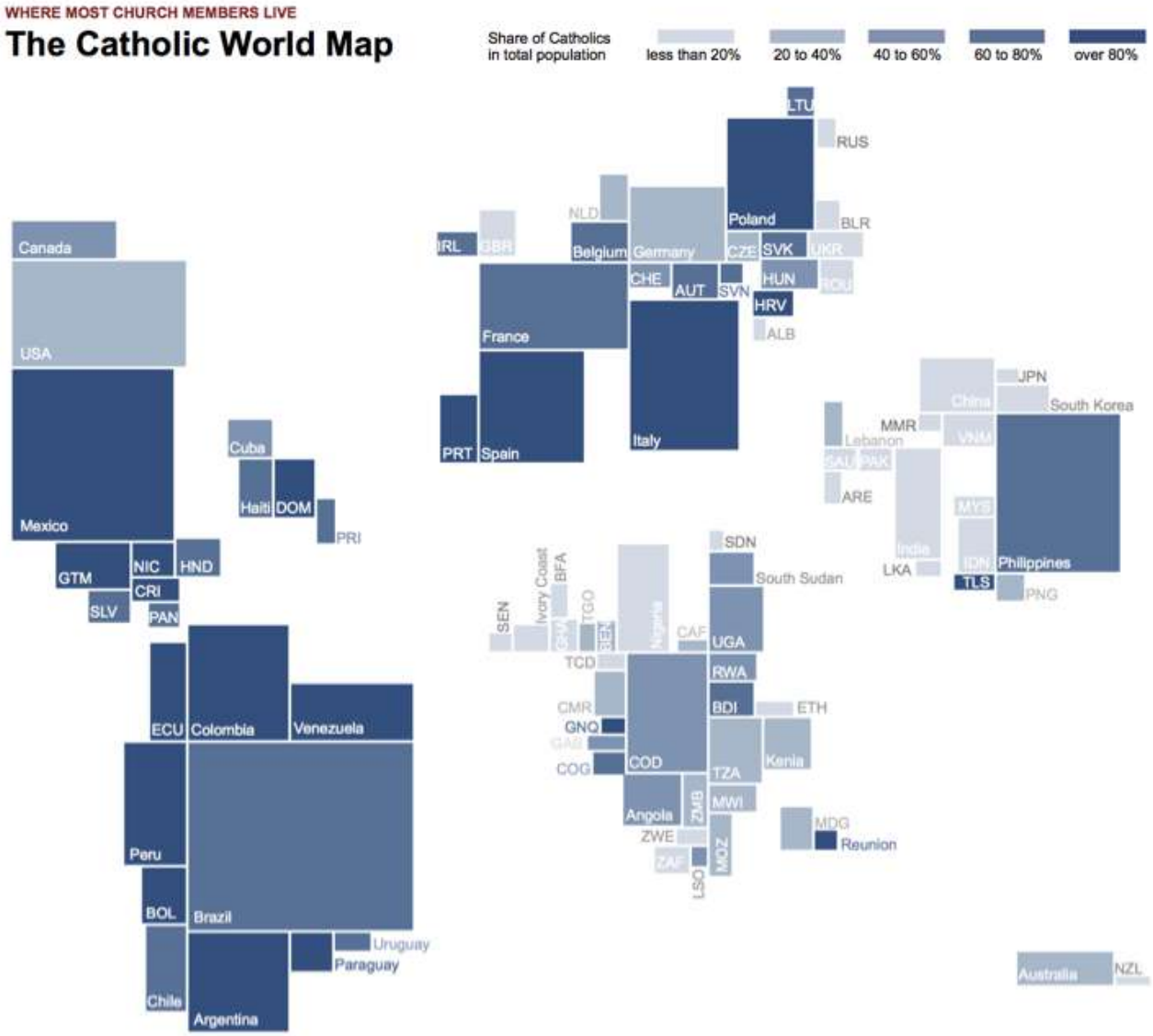
Presidential election results of 2000

The area of the states in the cartogram corresponds to the population and the color corresponds to the percentage of the vote





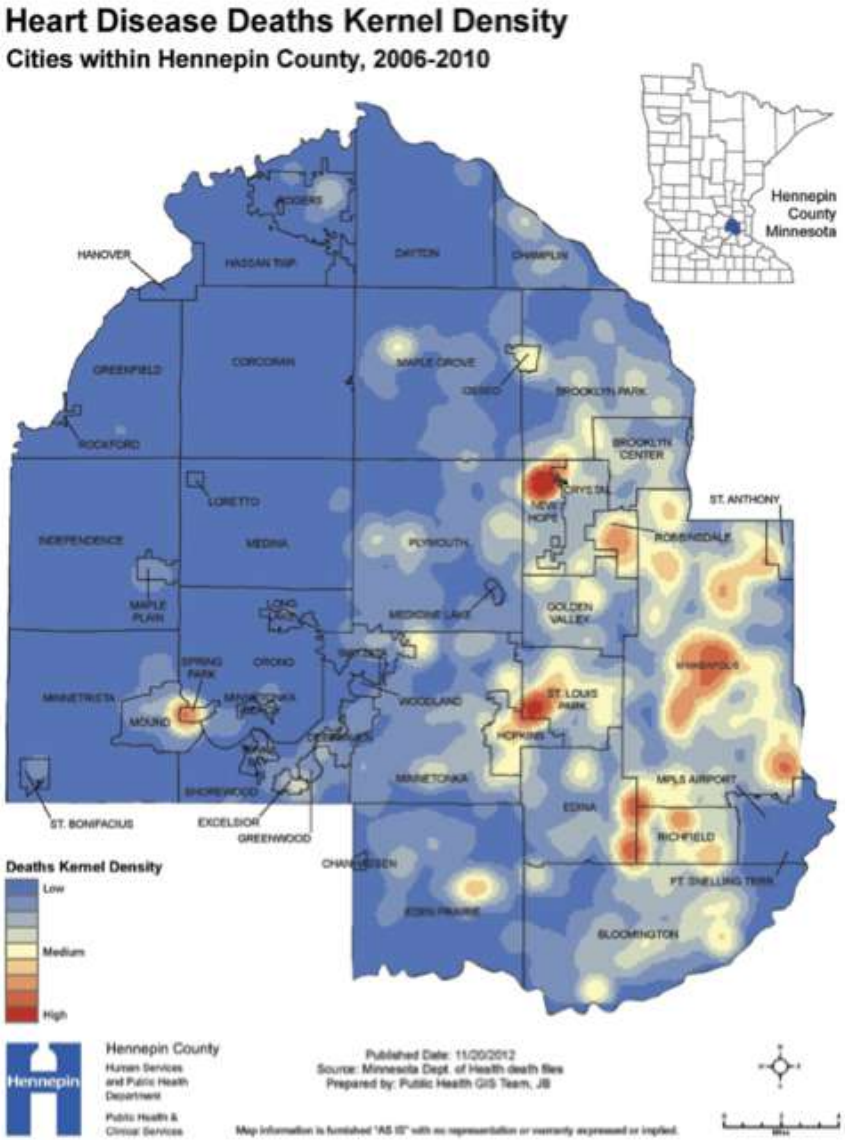
http://sta.mn/4xk

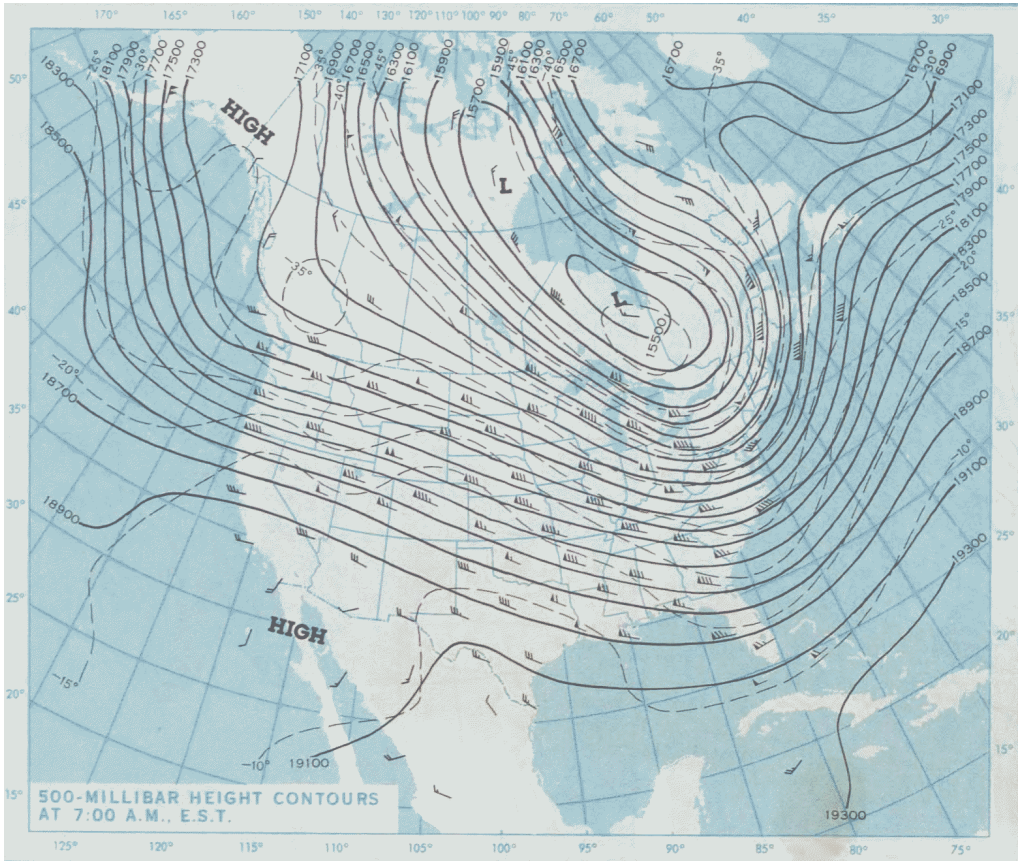


"Proportionally scaled rectangles reveal quantities more effectively than choroplethic methods of shading would do so."

ZEIT ONLINE

source

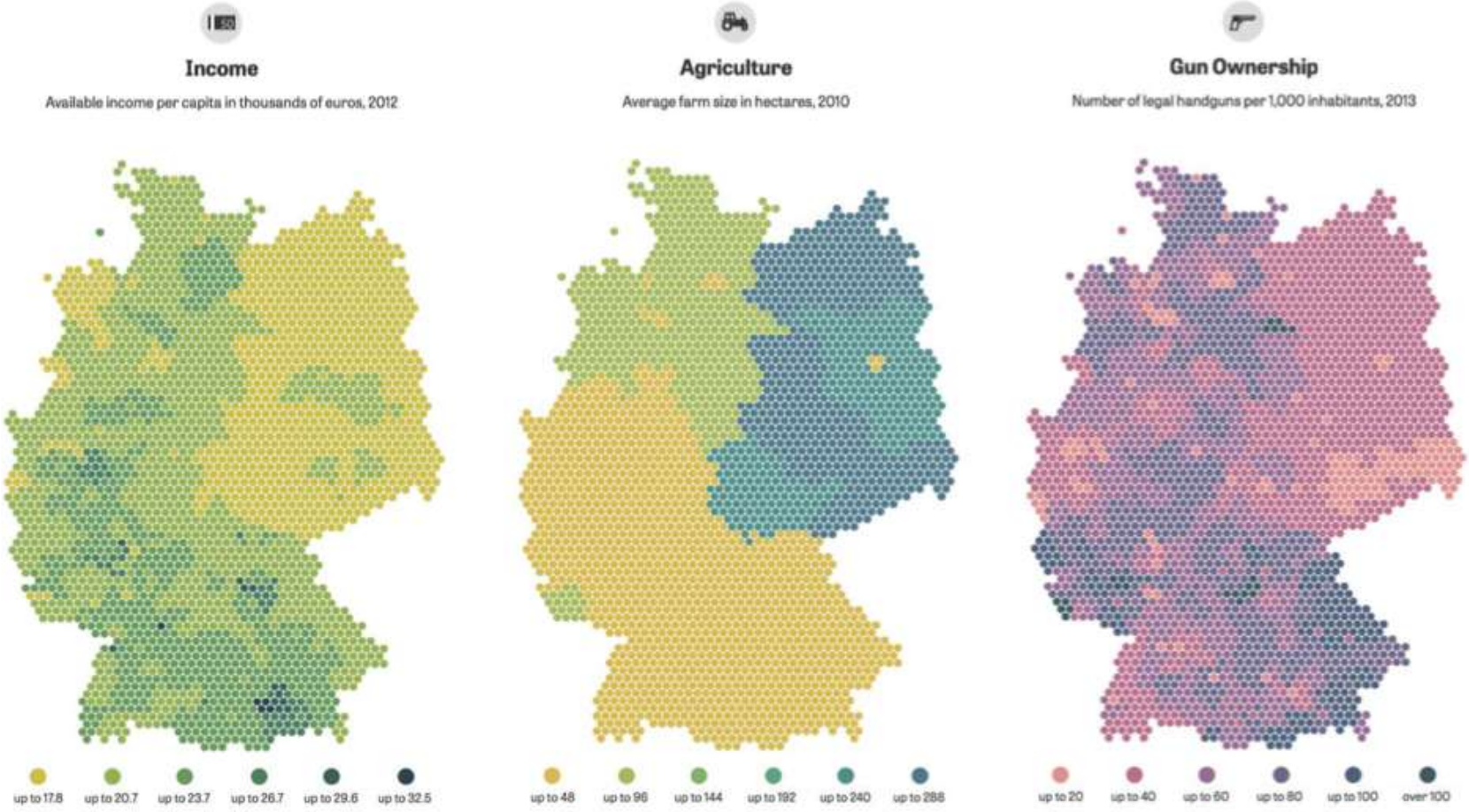




ISARITHMIC MAPS

Line-bounded areas represent regions with the same value

Germany, "A Nation Divided"



Shapes in isarithmic maps don't need to be curvy and smooth

http://www.zeit.de/feature/german-unification-a-nation-divided

GEO VISUALIZATION TOOLS & RESOURCES

- Tools
  - **d3.geo** (*projections, paths, etc.*)
  - **GeoJSON** (*JSON format for geo data*)
  - **Leaflet** (*open-source map tile system*)
  - **PostGIS** (*Postgres extensions for spatial data*)

- Data
  - **OpenStreetMap**
  - **Natural Earth Data**

GEOJSON

General Structure

```
{
  "type": "Feature",
  "geometry": {
    "type": "Point",
    "coordinates": [125.6, 10.1]
  },
  "properties": {
    "name": "Dinagat Islands"
  }
}
```

Geometry primitives

Type	Examples	
Point		`{ "type": "Point", "coordinates": [30, 10] }`
LineString		`{ "type": "LineString", "coordinates": [ [30, 10], [10, 30], [40, 40] ] }`
Polygon		`{ "type": "Polygon", "coordinates": [ [[30, 10], [40, 40], [20, 40], [10, 20], [30, 10]] ] }`
		`{ "type": "Polygon", "coordinates": [ [[35, 10], [45, 45], [15, 40], [10, 20], [35, 10]], [[20, 30], [35, 35], [30, 20], [20, 30]] ] }`

HANDS ON !