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# **DATA VISUALIZATION AND VISUAL ANALYTICS**



# **SPATIAL DATA AND GEOGRAPHY**

# Objective

- To show **spatial distribution** of data
- To show **relative positions** of data components
- Thematic maps
  - Mapping to attribute data (quantitative and qualitative) on a map
  - Geometry linked to fixed geographical position

# Map Design

- Projection
  - Map curved 3D objects to a plane
- Scale
  - Reduction of a map to the available space
- Symbolization and themes
  - Equivalent to encoding with Visual Variables



**SCALE**

# Map Scale

- Defines as the ratio between a distance on the map and the corresponding distance on the Earth
  - Usually expressed as verbal ratio
    - 1:100
    - Distance on the map is always expressed as one
  - The ratio is dimensionless
  - The larger the fraction, the greater the map's details

# Map scale (1:50,000,000)



# Map Scale (1:6,500,000)





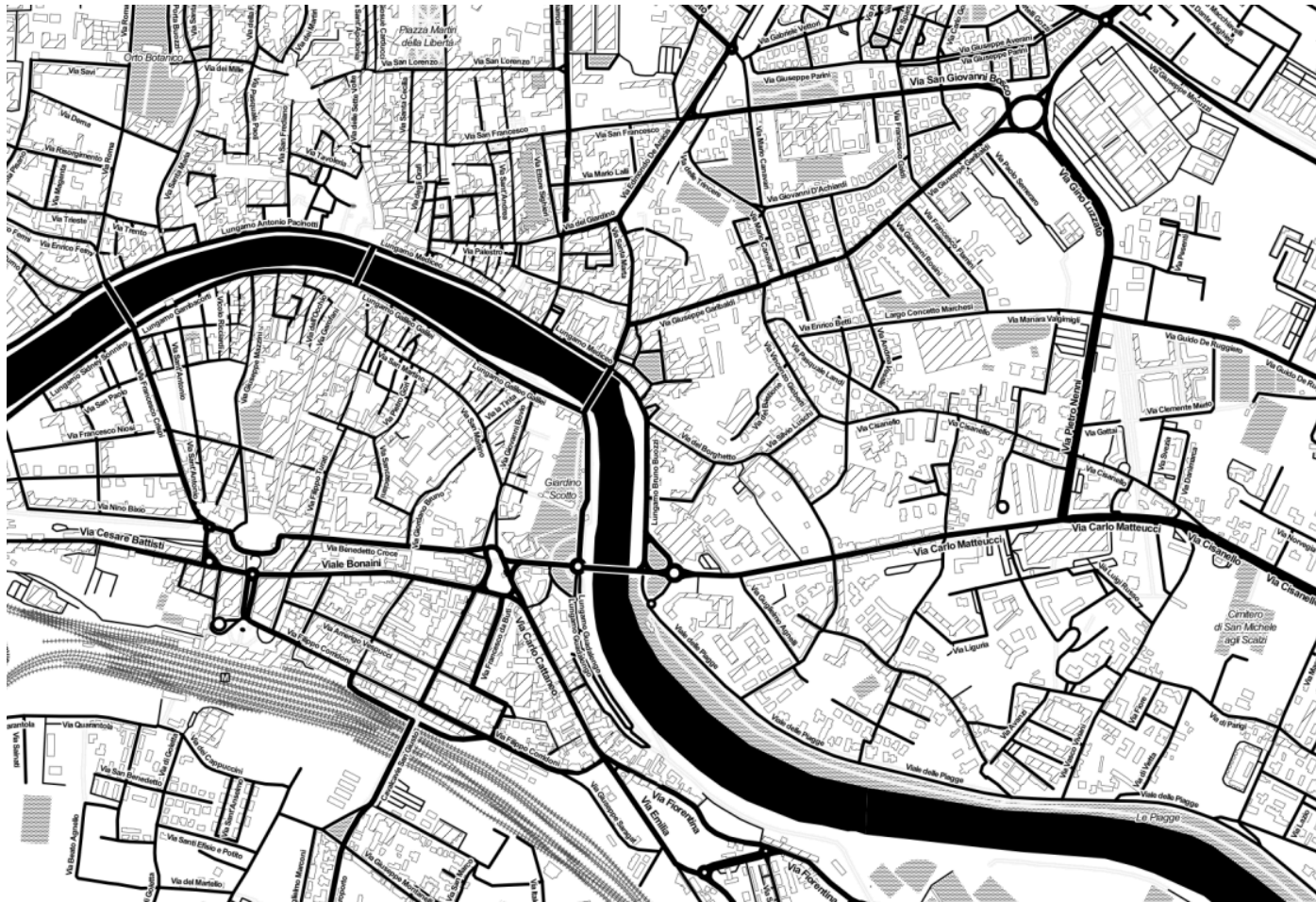
# Map Scale (1:1,500,000)



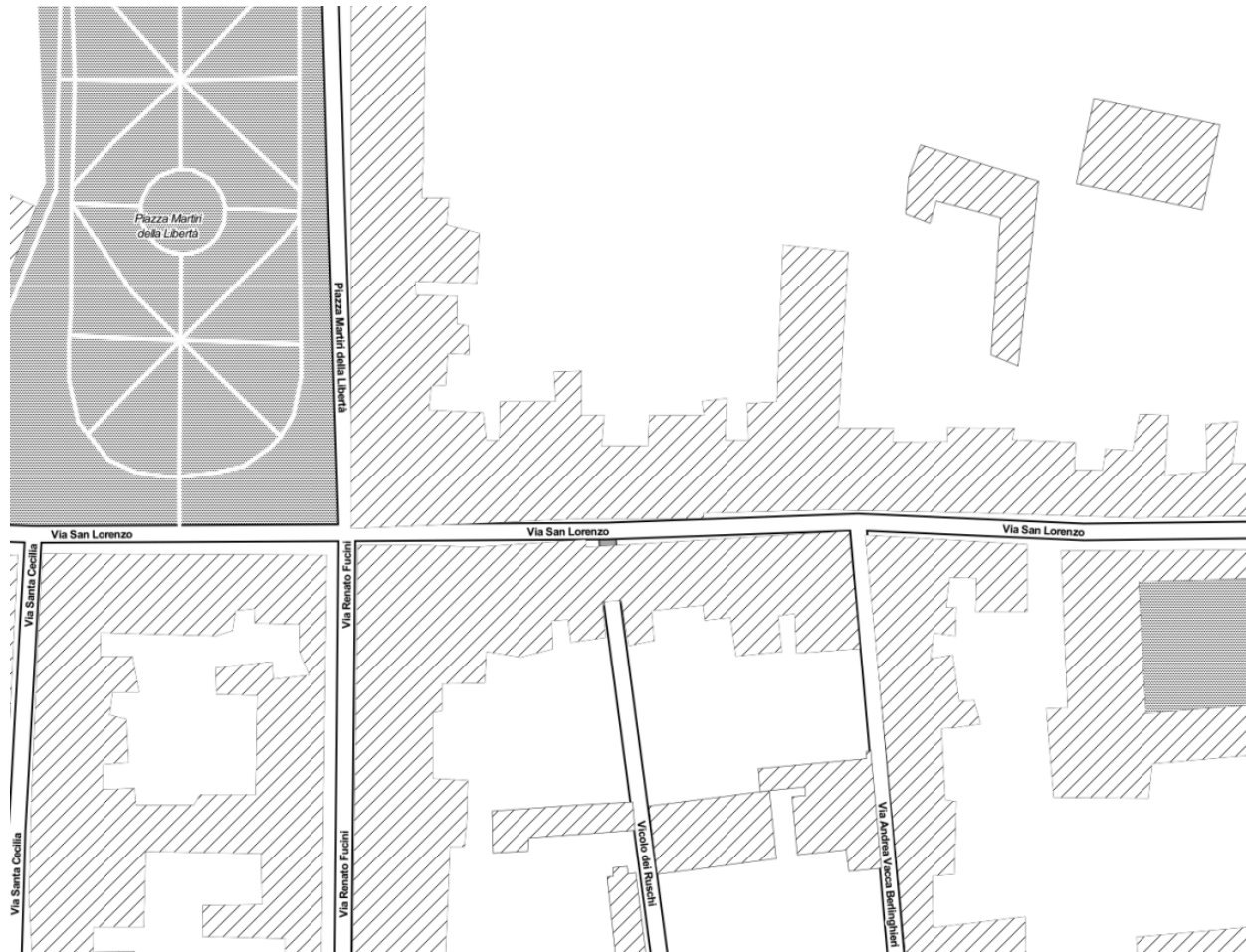
# Map Scale (1:100,000)



# Map Scale (1:10,000)



# Map Scale (1:1,000)





# PROJECTIONS

# Cartography as Art





**DESCRIPTION DE L'EUROPE**  
L'Europe est le continent le plus étendu de la terre, et le plus fertile. Elle est bornée au nord par le pôle arctique, au sud par le pôle méditerranéen, à l'est par l'Asie, et à l'ouest par l'océan atlantique. Elle est divisée en plusieurs régions, dont les principales sont le Nord, le Centre, le Sud, et l'Est. Elle est habitée par une multitude de peuples, et est le théâtre de la plus grande civilisation du monde.



Le continent d'Europe est le plus fertile de la terre, et le plus peuplé. Elle est bornée au nord par le pôle arctique, au sud par le pôle méditerranéen, à l'est par l'Asie, et à l'ouest par l'océan atlantique. Elle est divisée en plusieurs régions, dont les principales sont le Nord, le Centre, le Sud, et l'Est. Elle est habitée par une multitude de peuples, et est le théâtre de la plus grande civilisation du monde.







# The New World

- New challenges for geographers
- Since XVI century new methods to represent geography
- From plane to globe

## Basic components...

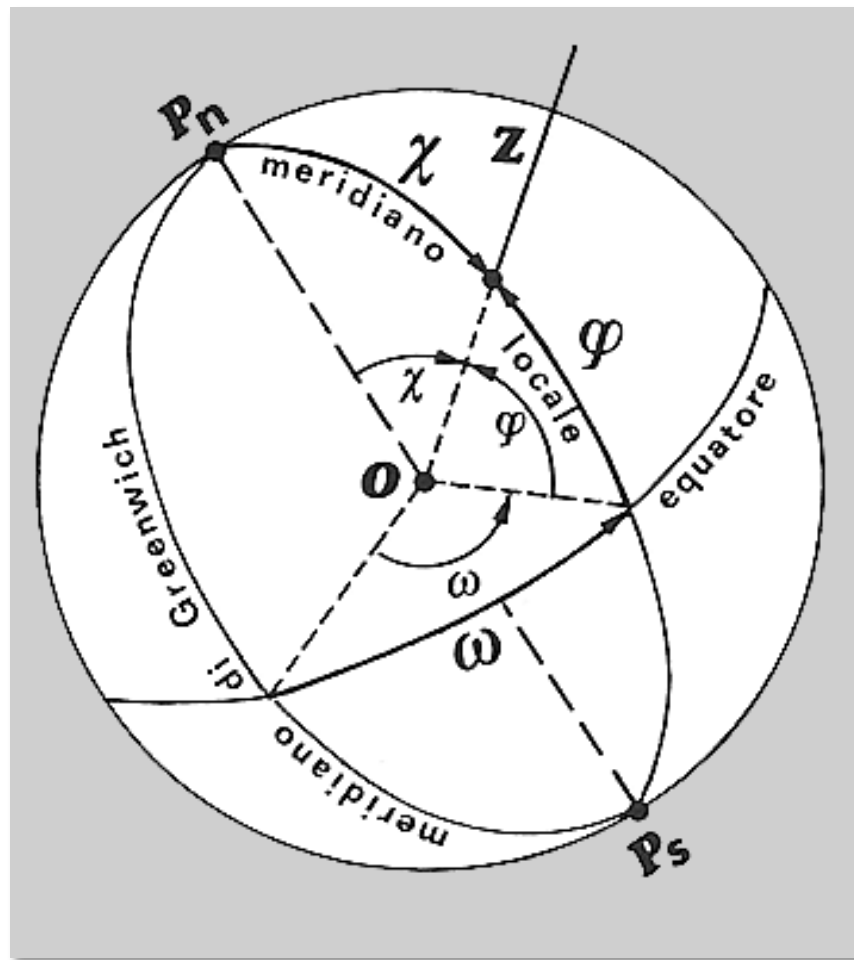
- A reference system
- A set of coordinates

# Reference System

- Univocally determine a position in 3D (2D+1D)
- Need for a simple model:
  - Mathematically tractable: surface
  - Link to physical world
- Typical surfaces:
  - Sphere
  - Ellipsoid (spheroid)
  - Geoid

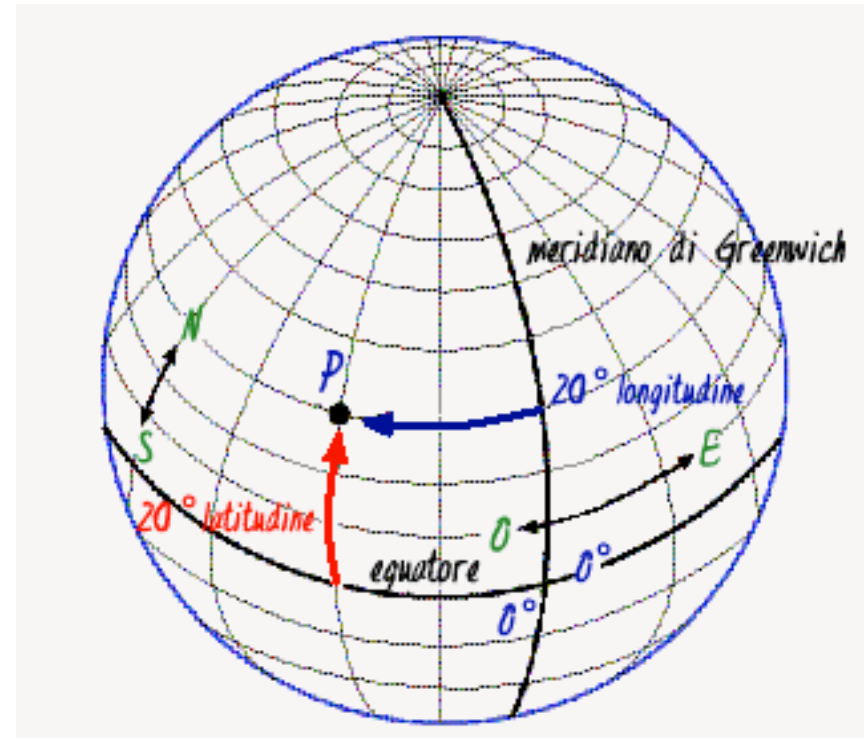
# Coordinate (2D+1D)

- Position relative to the reference system
- Angular coordinates
  - Longitude
  - Latitude
- Altitude as offset from the reference point



# Latitude and Longitude

- Latitude: angular distance from equator
- Longitude: angular distance from central meridian

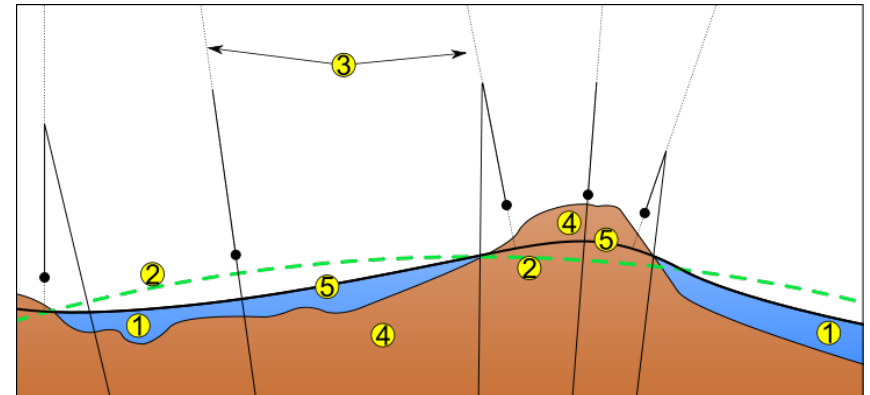


# Which Reference System?

- Earth present a complex surface, results of gravity, magnetical forces and different densities
- Mathematic representation is very complex

# Geoid

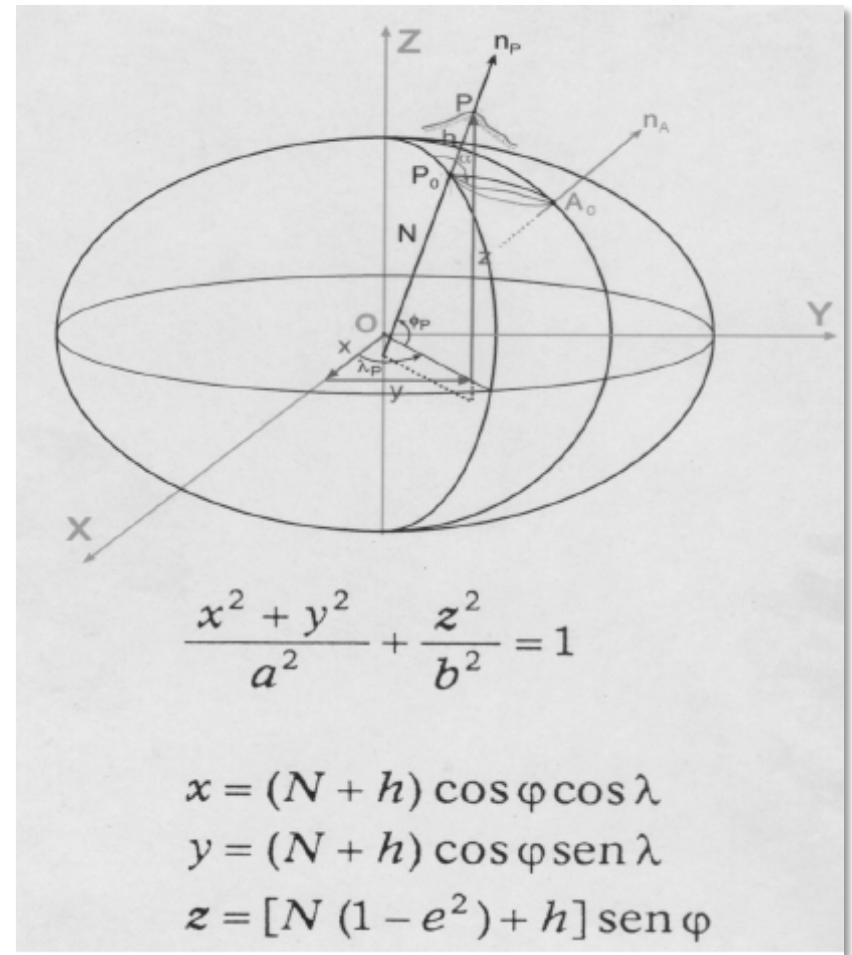
- Geoid: surface where gravity is constant in each point
- Average surface of seas





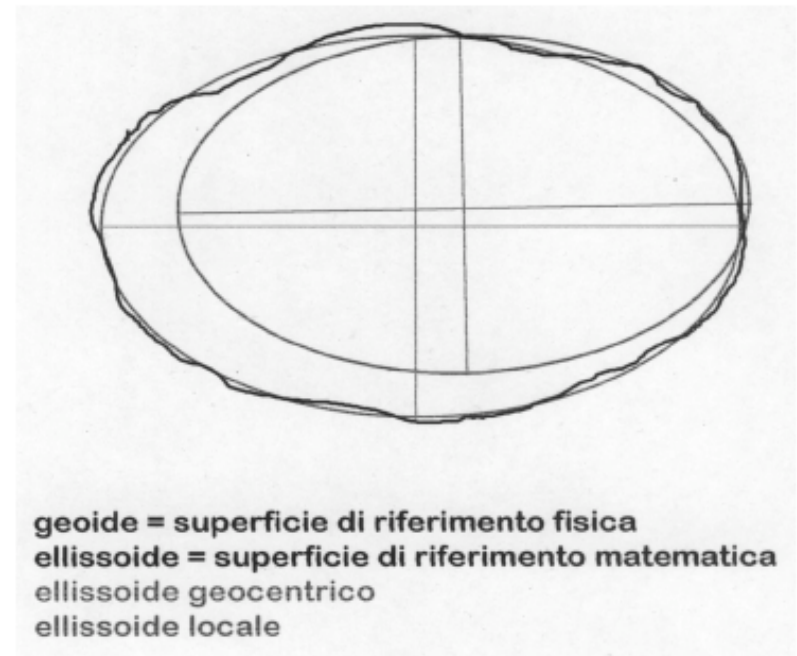
# Which Reference System?

- Ellipsoid: clear and easy mathematic definition
- Easy to define a position of a point in the space
- Low differences with the real geoid (~40m)



# Datum

- An ellipsoid is univocally determined by 8 parameters (named Datum)
  - 2 shape parameters:
    - Equatorial radius
    - Polar radius
  - 6 parameters for position and orientation



# Which Datum?

- Diffusion of GPS systems: WGS84 (World Geodetic System 1984)
- Many local cartograph systems use local defined datum
  - In Europe, datum ED50 (European Datum 1950, Ellissoide di Hayford) is largely used
- All datum can be mapped/translated to WGS84

# Projections

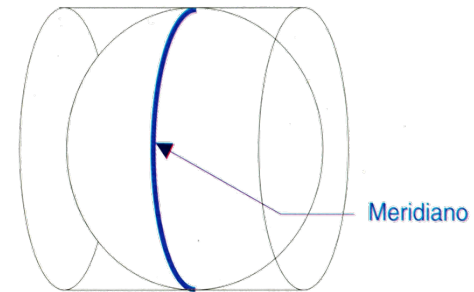
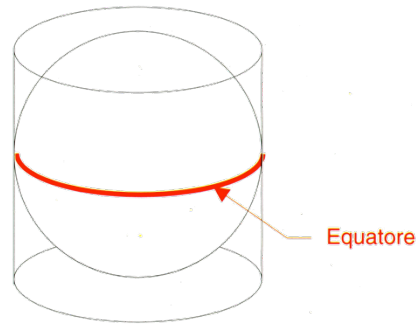
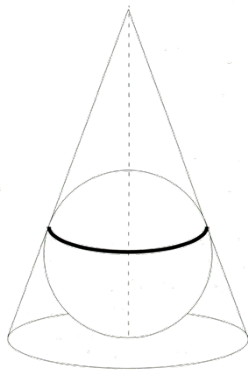
- Cartographic projections maps coordinates from the ellipsoid to the plane
- A direct mapping is not feasible without introducing deformations
- Families of mapping that preserve:
  - Angles (conformal projection)
  - Surfaces (equal area projection)
  - Minimizing both

# Projections

- Each projection assume a precise datum
- For example, UTM projection uses datum WGS84 and ED50

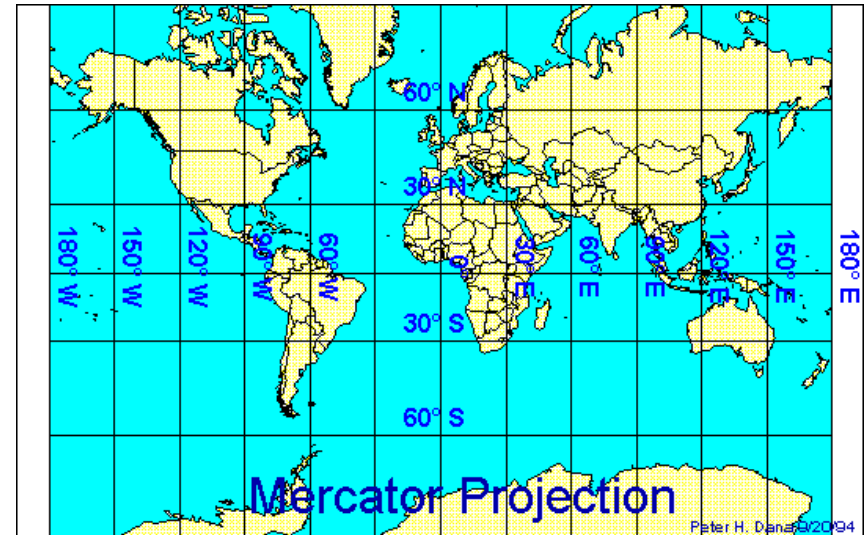
# Projections

- Three different types
  - Azimuthal: projection plane is tangent to a point on the earth
  - Conic: points are projected on a cone
  - Cylindrical: points are projected on a cylinder



# Mercator Projection

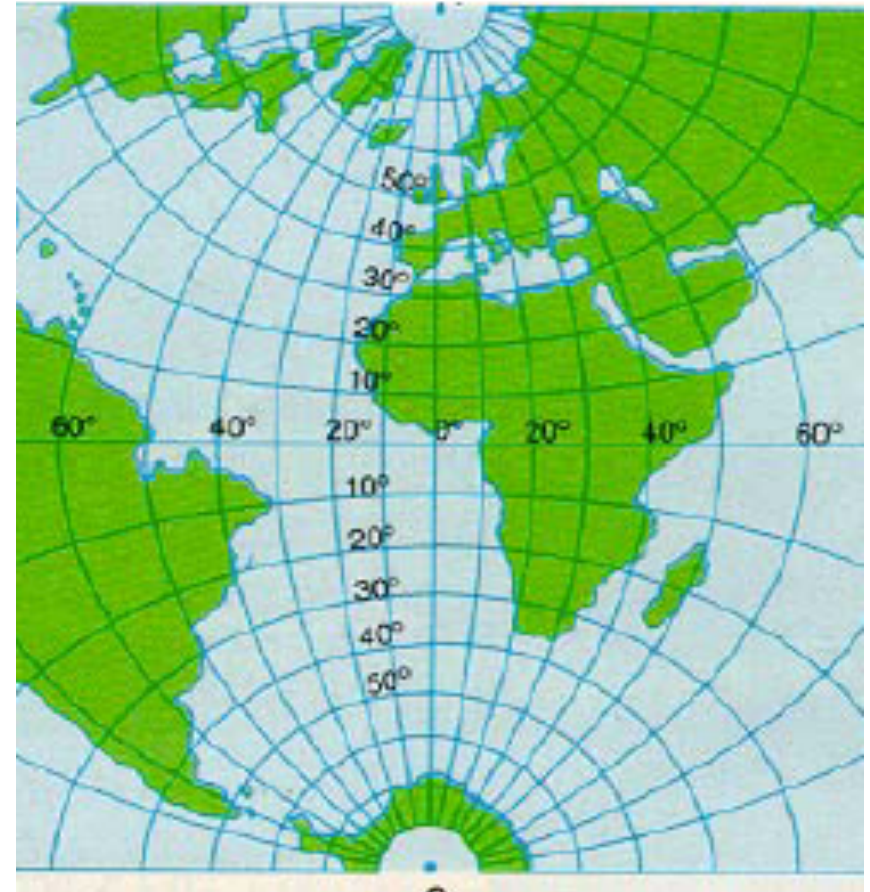
- Cylindrical projections
- Cylinder tangent to equator
- Meridians are parallel
- Low distortion for tropical zones



# UTM

## (Universal Transverse Mercator)

- Transverse Mercator Projection
- Cylinder tangent to one of the meridians
- Low deformation around the reference meridian

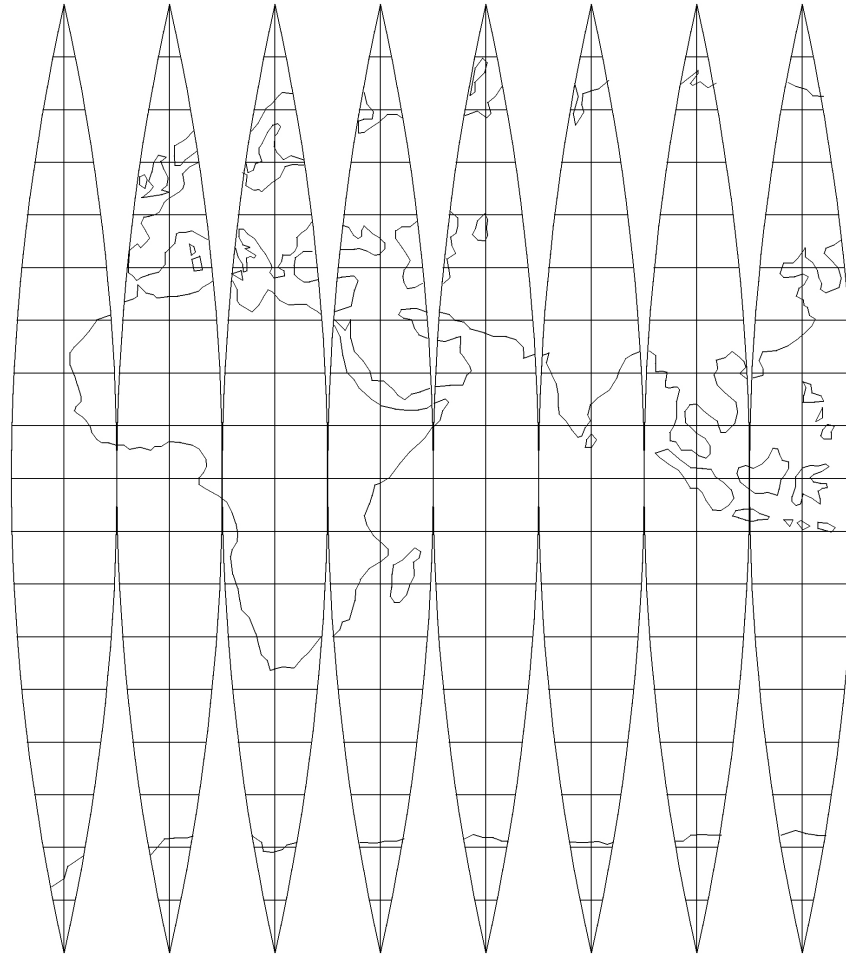




# UTM Projection

- Minimize distortion
  - Each projection is limited to a zone of 6 degrees
  - Central meridian is contracted by 0.9996
  - To ensure positive coordinates, each zone has a false easting origin at 500000 m on the east of central meridian
  - Projection is limited to latitudes between -80 N and +80 N

# UTM Zones



# UTM zones in Italy

- Italy is covered by zones 32, 33 e 34



# Reference Systems: catalogue

Spatial Reference epsg projection 3003 - monte mario / italy zone 1

[Home](#) | [Upload Your Own](#) | [List user-contributed references](#) | [List all references](#)

Previous: [EPSG:3002: Makassar / NEIEZ](#) | Next: [EPSG:3004: Monte Mario / Italy zone 2](#) [Link to this Page](#)

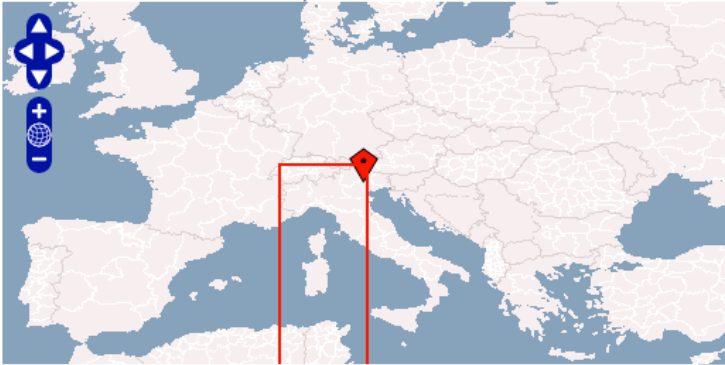
## EPSG:3003

Monte Mario / Italy zone 1 ([Google it](#))

- **WGS84 Bounds:** 6.6500, 8.8000, 12.0000, 47.0500
- **Projected Bounds:** 1241482.0019, 973563.1609, 1830078.9331, 5215189.0853
- **Scope:** Large and medium scale topographic mapping and engineering survey.
- **Last Revised:** 2005-05-27
- **Area:** Italy - west of 12°E

- [Well Known Text as HTML](#)
- [Human-Readable OGC WKT](#)
- [Proj4](#)
- [OGC WKT](#)
- [JSON](#)
- [GML](#)
- [ESRI WKT](#)
- [.PRJ File](#)
- [USGS](#)
- [MapServer Mapfile](#) | [Python](#)
- [Mapnik XML](#) | [Python](#)
- [GeoServer](#)
- [PostGIS spatial\\_ref\\_sys INSERT statement](#)

Input Coordinates: 12.049609375, 45.8546875 Output Coordinates: 1736763.5444, 5082521.817528



The map shows Europe with a red box highlighting the area around Italy. A red diamond marker is placed on the northern coast of Italy, indicating the location of Monte Mario. The map includes navigation controls (compass, zoom in, zoom out) on the left side.

<http://spatialreference.org/>

## D3.js references

- d3.geo API reference
  - <https://github.com/mbostock/d3/wiki/Geo-Projections>
- topojson API reference
  - <https://github.com/mbostock/topojson/wiki/API-Reference>



# **CARTOGRAFIA IN D3**

# Dati Geografici - GeoJSON

- Descrive i poligoni geografici tramite oggetti javascript
- Organizzato in tre proprietà:
  - type (di solito: “FeatureCollection”)
  - crs (Coordinate Reference System)
  - features (elenco di oggetti geografici)
- Ogni Feature è organizzata in tre proprietà:
  - type (di solito “Feature”)
  - properties (dizionario di attributi della feature)
  - geometry (descrittore della geometria)

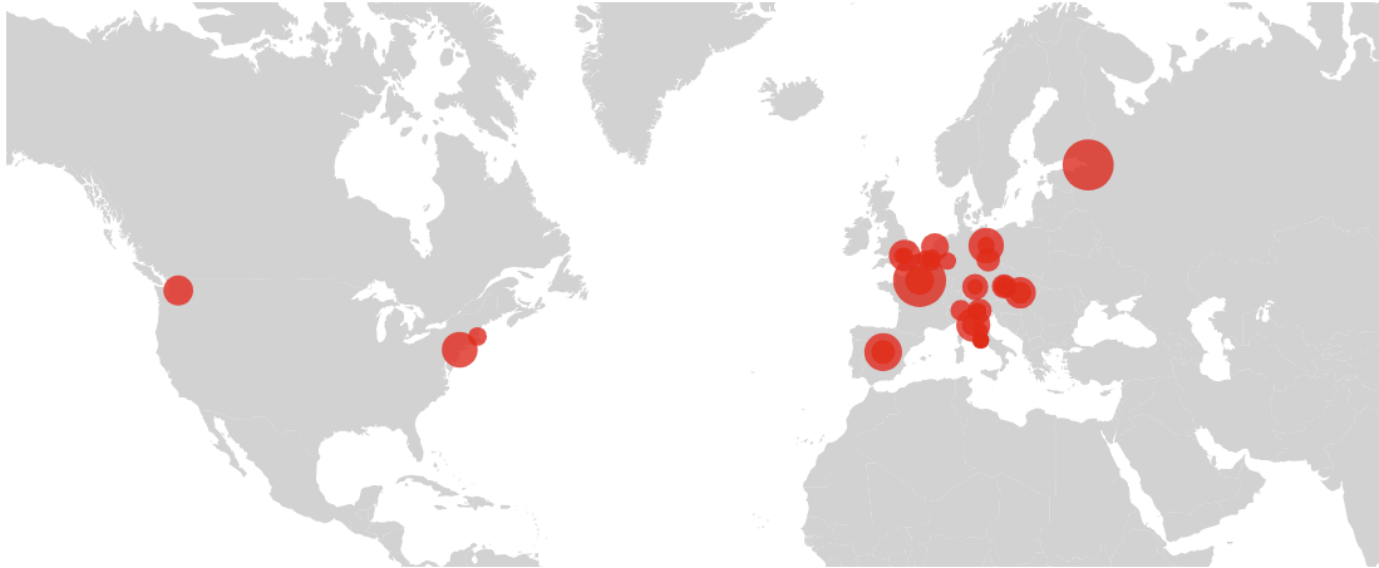
## Dai dati a SVG

- Creazione di una **proiezione** per trasformare le **coordinate geografiche** in coordinate sullo schermo
  - Definizione di una **scala**, una **traslazione**, eventuale **rotazione**
  - Oggetto: **d3.geo.projection**
- Creazione di una definizione di path per il disegno di un contorno
  - Oggetto: **d3.geo.path**



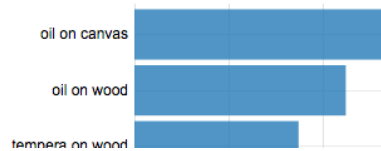
# Example: Map of paintings

## Geography of Paintings

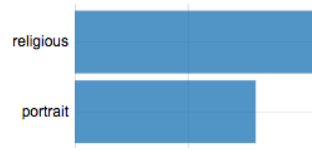


## Location: Galleria degli Uffizi

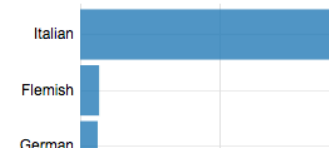
### Technique



### Type



### School





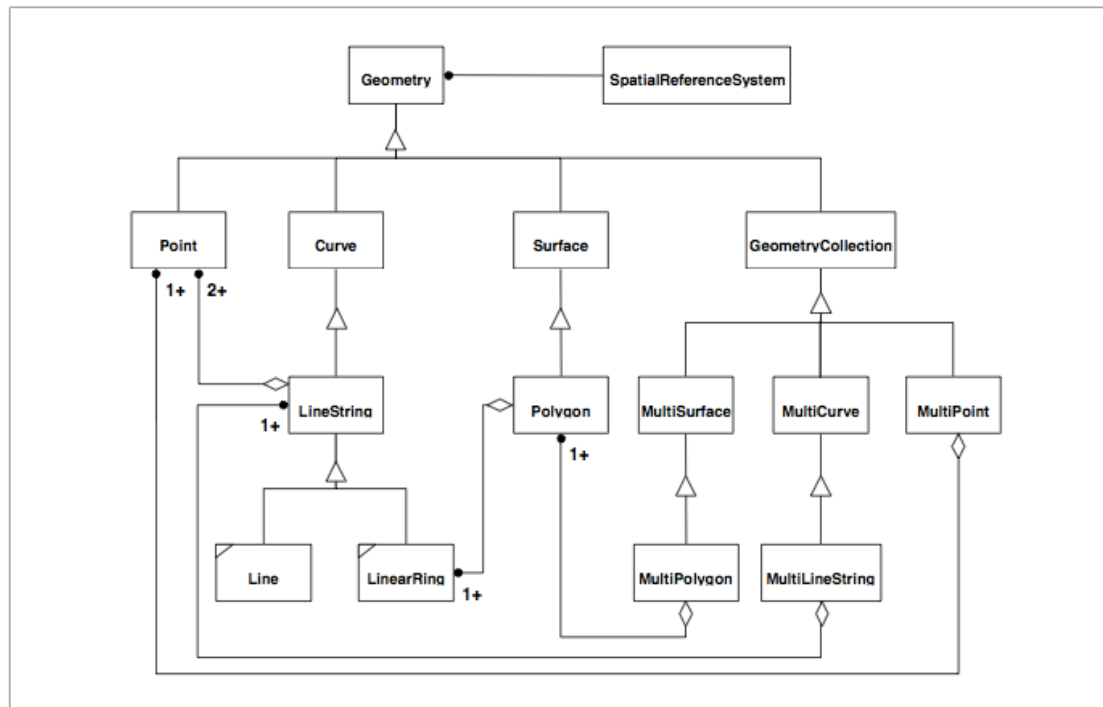
# **Geometries and Standards**

# Open GIS Consortium – OGC

- Consortium to define protocols to transmit territorial and geographic information

# SFS – Simple Feature Specification

- Definition of an abstract data type:
  - Geometry

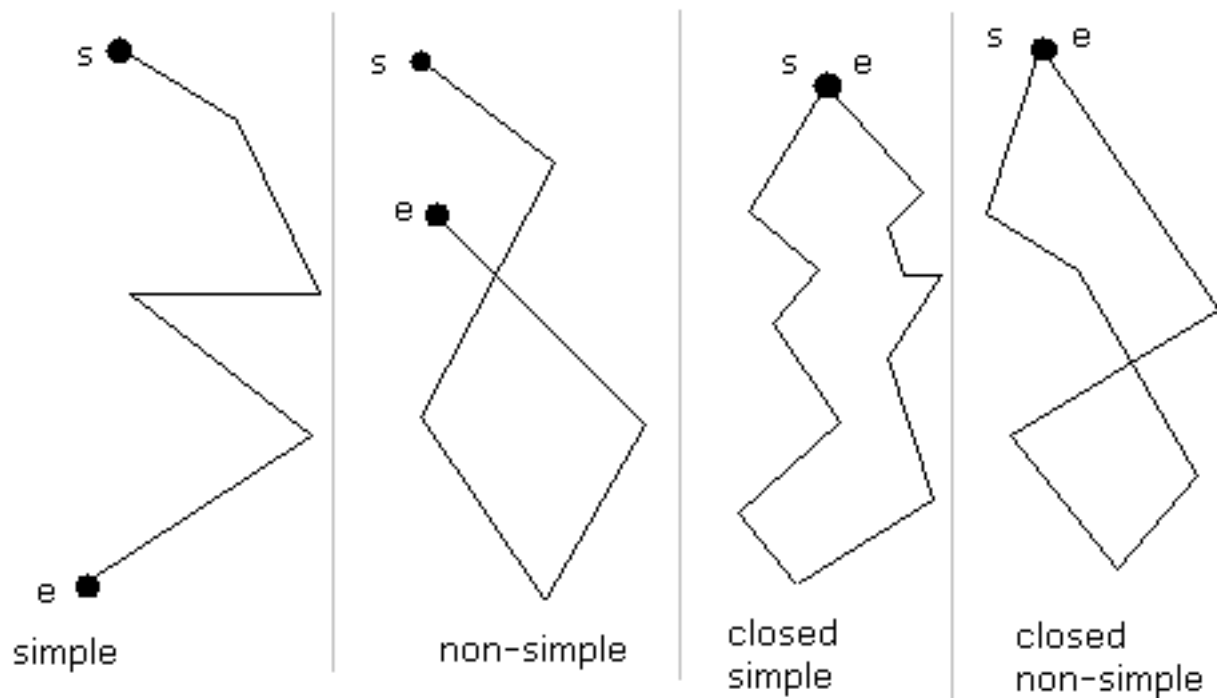


# Point

•  $[x, y]$

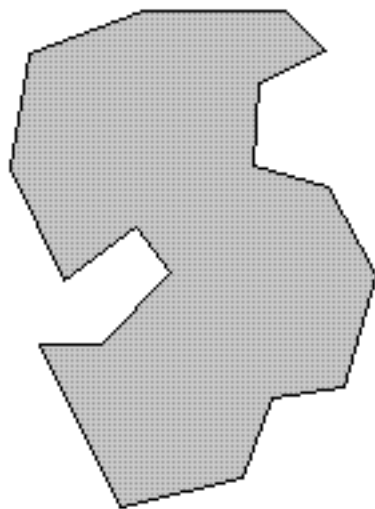
POINT

# Linestring

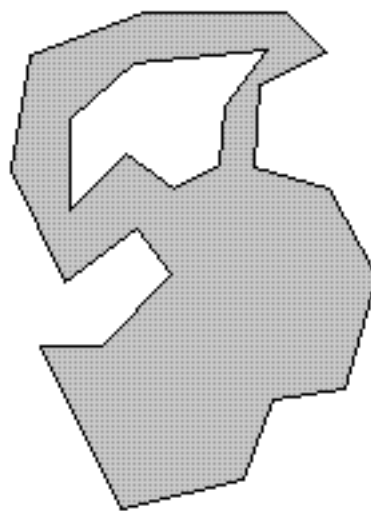


LINESTRINGs

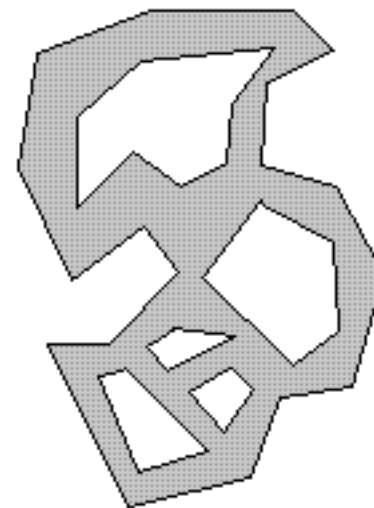
# Polygon



exterior ring  
no interior rings



exterior ring  
1 interior ring



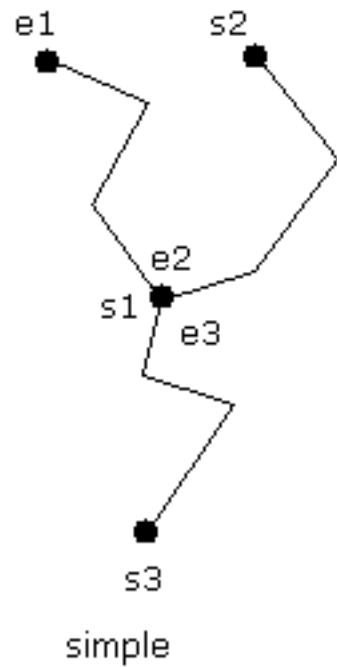
exterior ring  
5 interior rings

POLYGONS

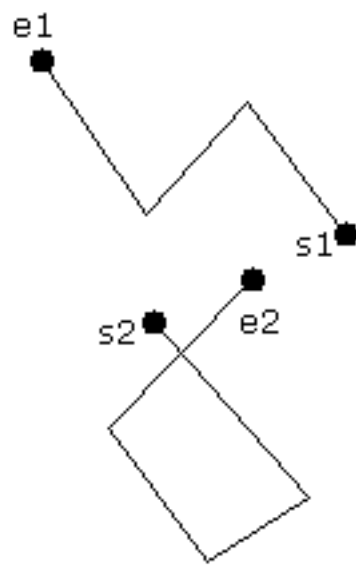
# Multipoint, Multilinestring



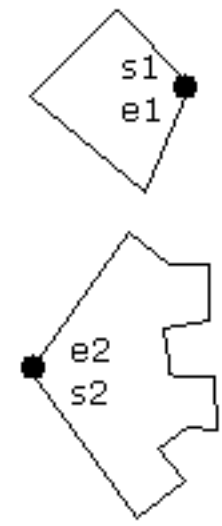
MULTIPOINT



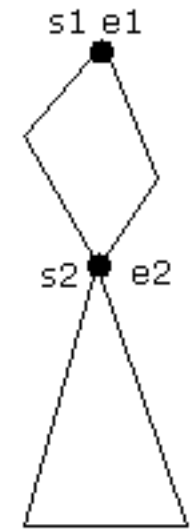
simple



non-simple



closed  
simple

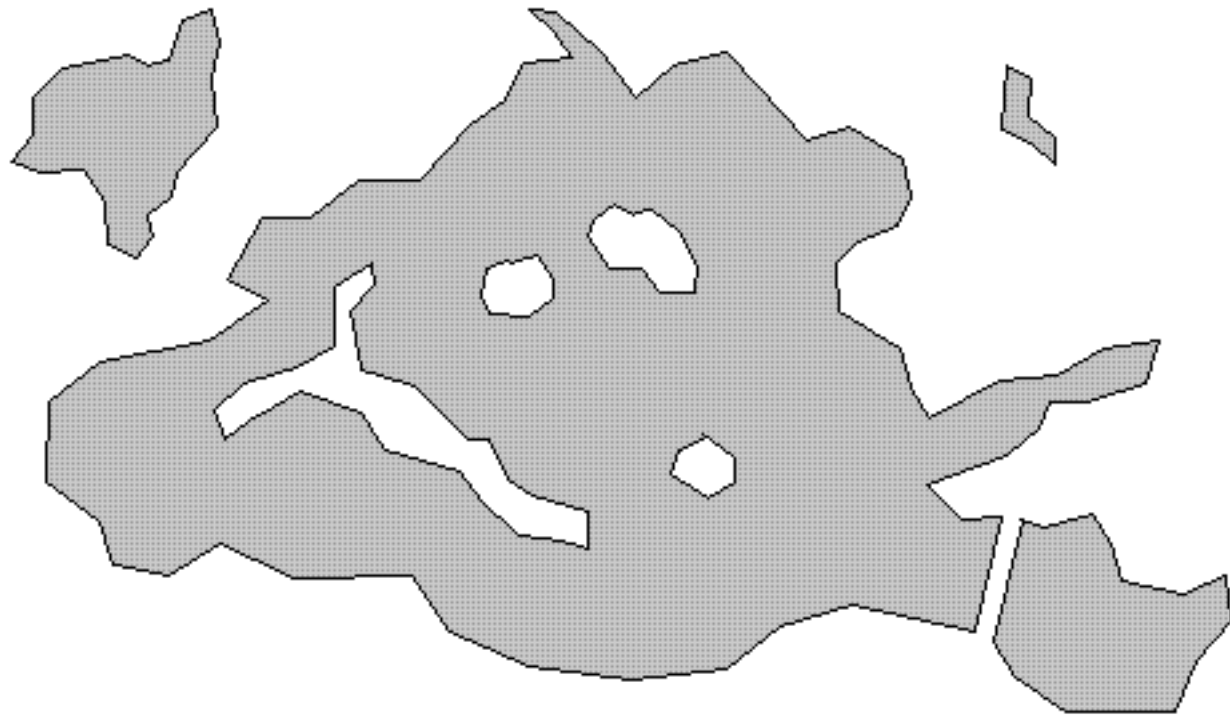


closed  
non-simple

MULTILINESTRINGs



# Multipolygon



MULTIPOLYGON

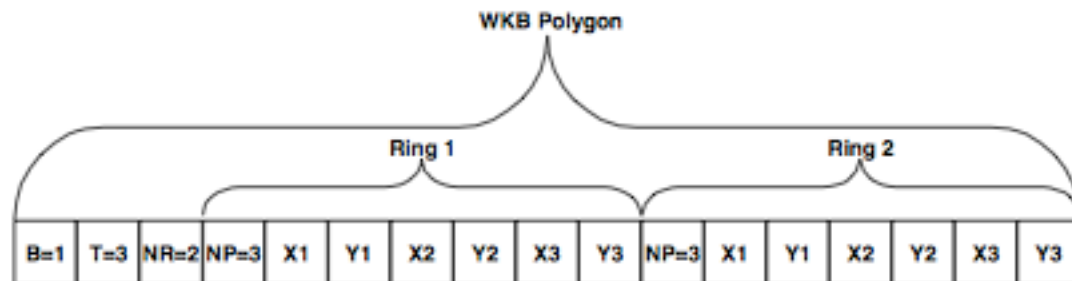
# WKT – Well Known Text Format

- POINT(123.45 543.21)
- LINESTRING(100.0 200.0, 201.5 102.5, 1234.56 123.89)
- POLYGON((101.23 171.82, 201.32 101.5, 215.7 201.953, 101.23 171.82))
- POLYGON((10 10, 20 10, 20 20, 10 20, 10 10),(13 13, 17 13, 17 17, 13 17, 13 13))
- MULTILINESTRING((1 2, 3 4), (5 6, 7 8, 9 10), (11 12, 13 14))
- MULTIPOLYGON(((0 0,10 20,30 40,0 0),(1 1,2 2,3 3,1 1)), ((100 100,110 110,120 120,100 100)))
- GEOMETRYCOLLECTION(POINT(1 1), LINESTRING(4 5, 6 7, 8 9), POINT(30 30))

# WKB – Well Known Binary Format

- Compact representation
- Useful to store geometries on DBMS

```
WKBPolygon {  
    byte          byteOrder;  
    uint32        wkbType;           // 3  
    uint32        numRings;  
    LinearRing    rings[numRings];  
}
```



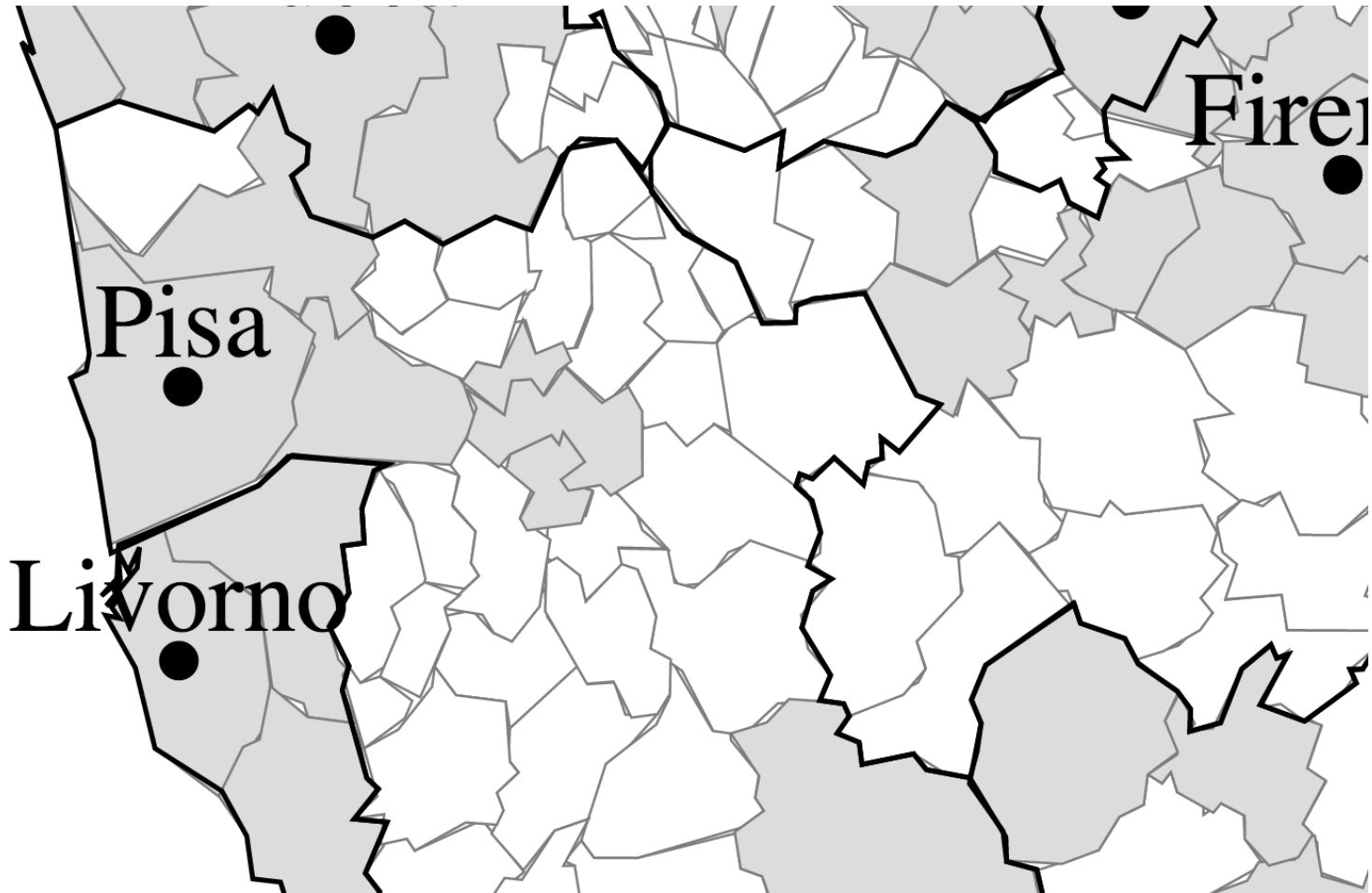
# GeoJSON format

```
{ "type": "FeatureCollection",
  "features": [
    { "type": "Feature",
      "geometry": { "type": "Point", "coordinates": [102.0, 0.5]},
      "properties": { "prop0": "value0" }
    },
    { "type": "Feature",
      "geometry": {
        "type": "LineString",
        "coordinates": [
          [102.0, 0.0], [103.0, 1.0], [104.0, 0.0], [105.0, 1.0]
        ]
      },
      "properties": {
        "prop0": "value0",
        "prop1": 0.0
      }
    },
    { "type": "Feature",
      "geometry": {
        "type": "Polygon",
        "coordinates": [
          [ [100.0, 0.0], [101.0, 0.0], [101.0, 1.0],
            [100.0, 1.0], [100.0, 0.0] ]
        ]
      },
      "properties": {
        "prop0": "value0",
        "prop1": { "this": "that" }
      }
    }
  ]
}
```

# TopoJSON

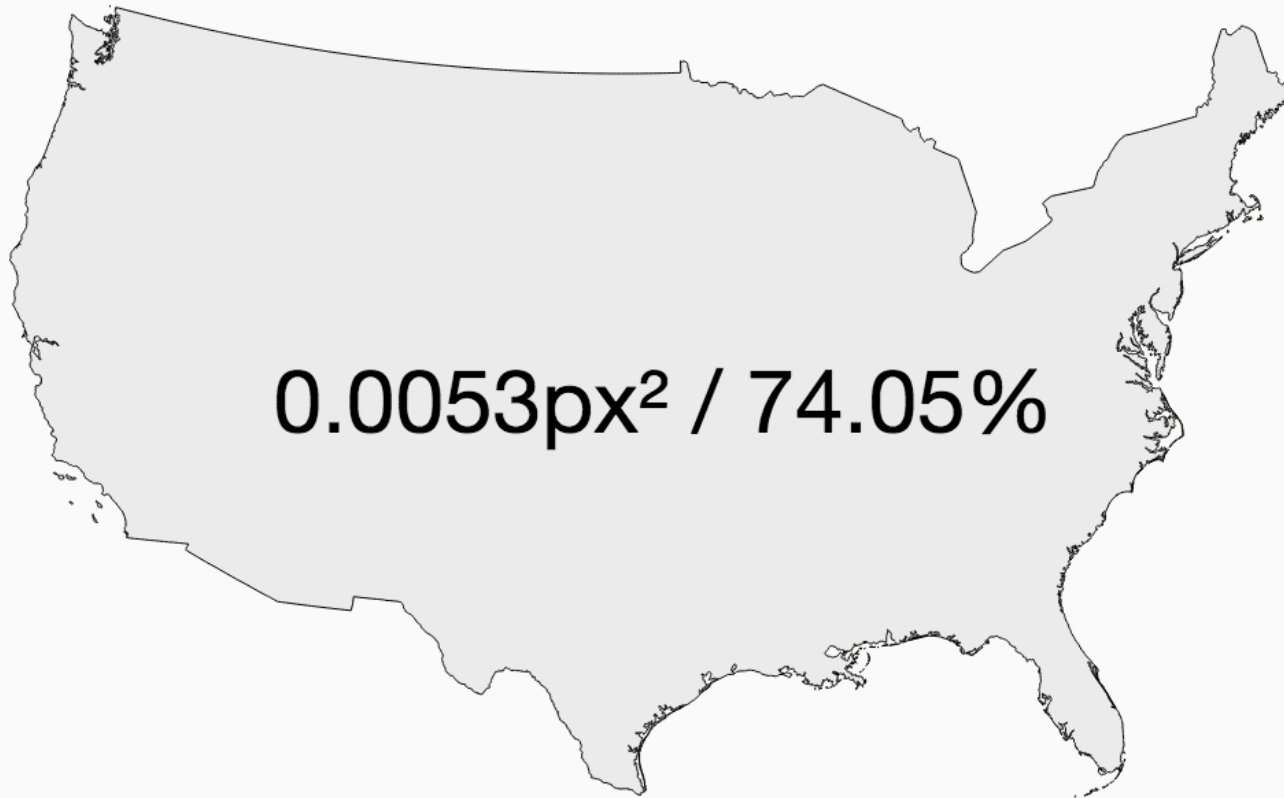
- Extends GeoJSON and encodes topology
- Shared lines are represented as arcs
- Reduce redundancy and decrease file size
- Topology can be exploited in specific applications

## Example, without topology



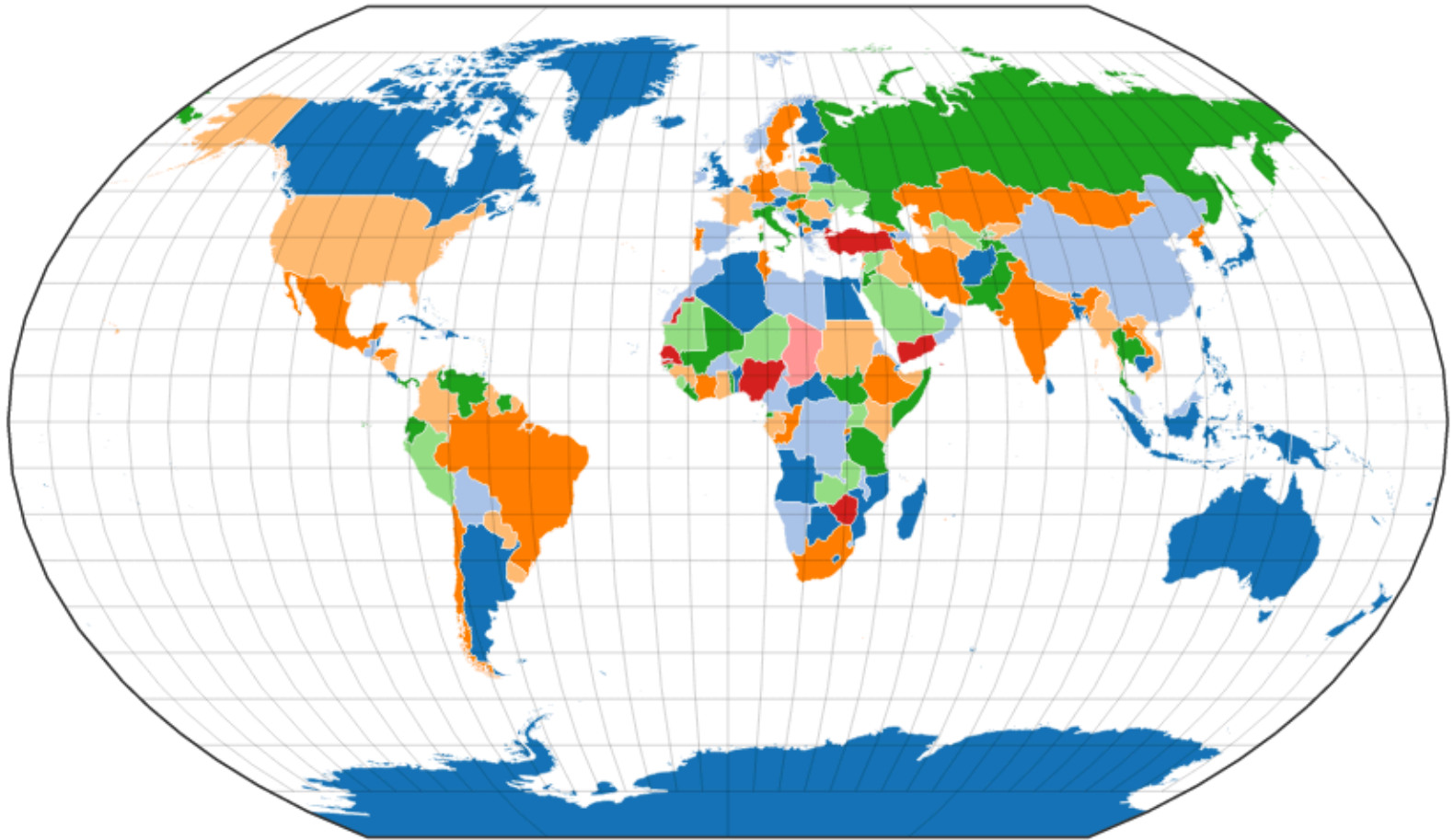
# Line Simplification

## Line Simplification



<https://bost.ocks.org/mike/simplify/>

# Color Mapping



<http://bl.ocks.org/jasondavies/4188334>

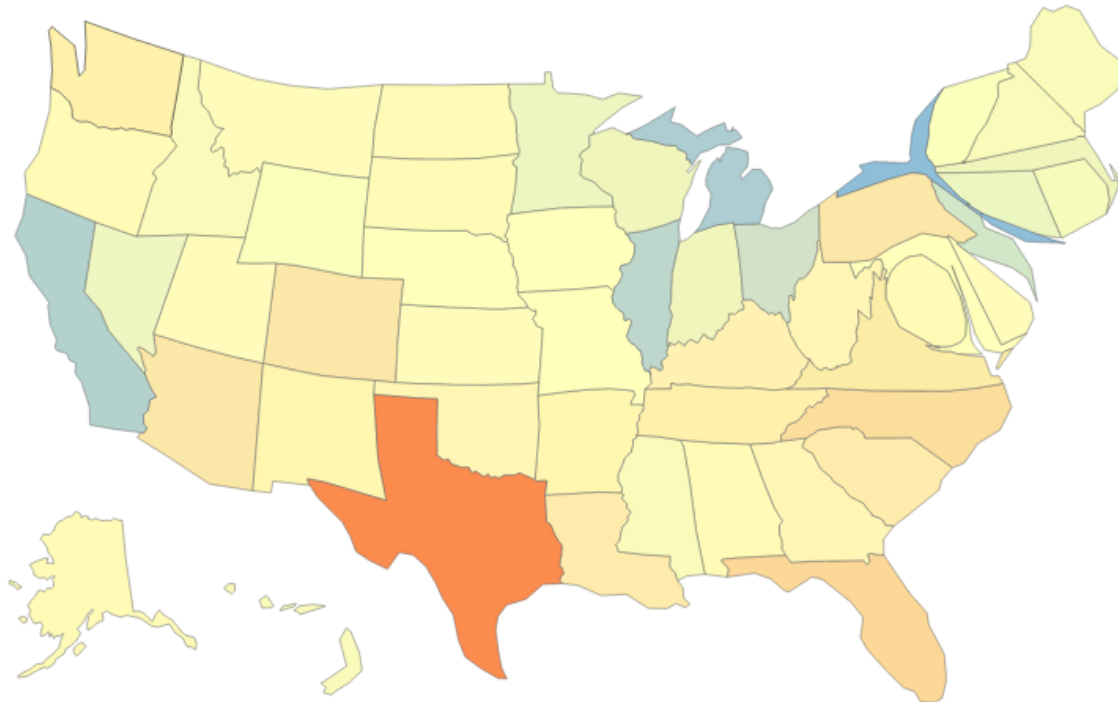


# Cartograms

## Cartograms with d3 & TopoJSON

Scale by  in  calculated in 0.1 seconds

Washington: +3,626



<http://prag.ma/code/d3-cartogram/>

# Dot distribution

The New York Times

## Mapping the 2010 U.S. Census

Explore population growth and decline, changes in racial and ethnic concentrations and patterns of housing development.

Share this view on [Twitter](#) or [Facebook](#)

View More Maps



### Distribution of racial and ethnic groups in 2010

One dot = 100 people

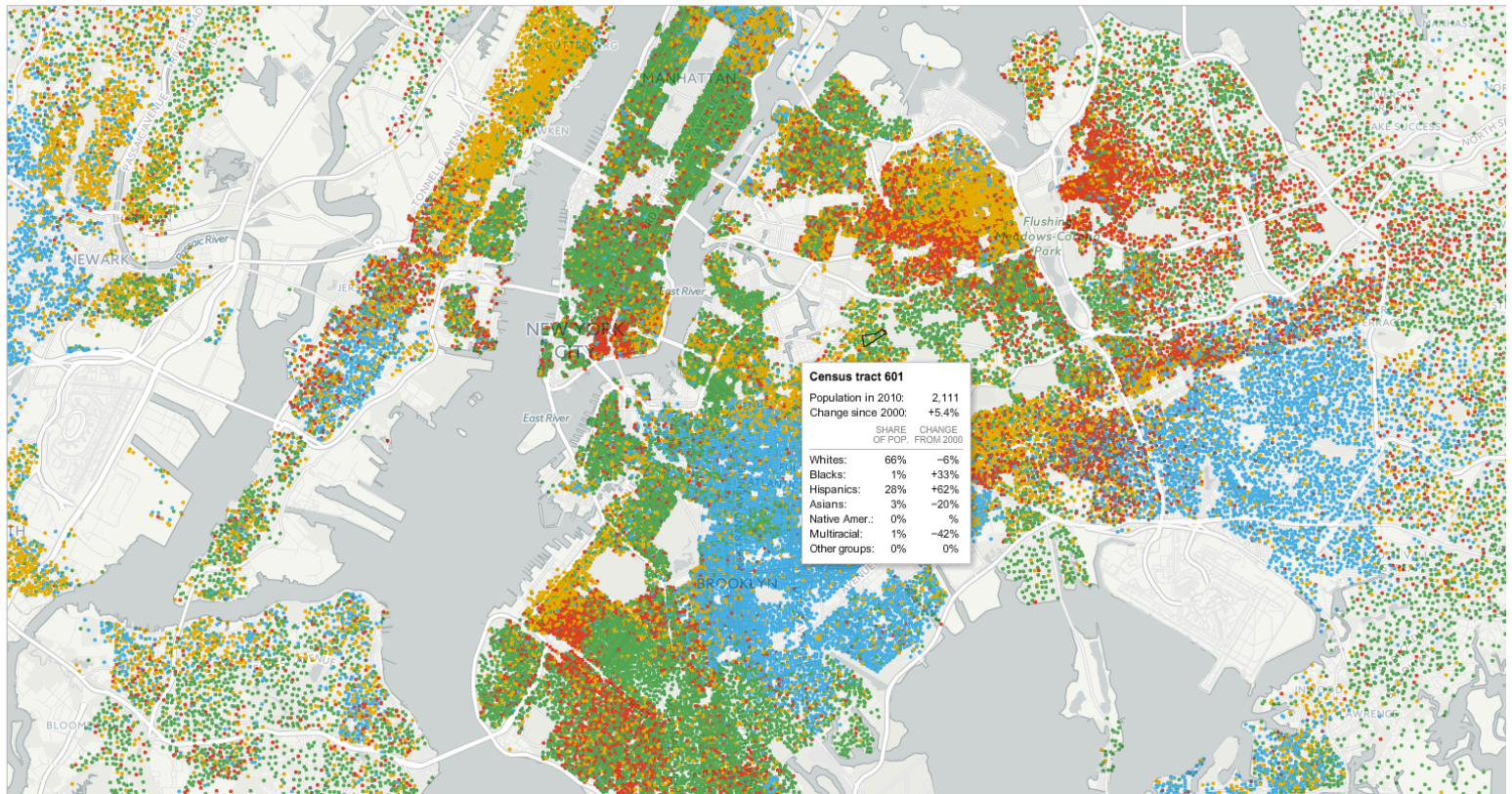
- White
- Black
- Hispanic
- Asian
- Native American
- Other

Zoom to a State

### New York

2010 POPULATION: 19,378,102  
CHANGE FROM 2000: +2.1%

RACE/ETHNICITY	SHARE OF POP.	CHANGE FROM 2000
Whites:	58%	-4%
Blacks:	14%	-1%
Hispanics:	18%	+19%
Asians:	7%	+36%
Native Amer.:	0%	+3%
Multiracial:	2%	-11%
Other groups:	0%	+8%



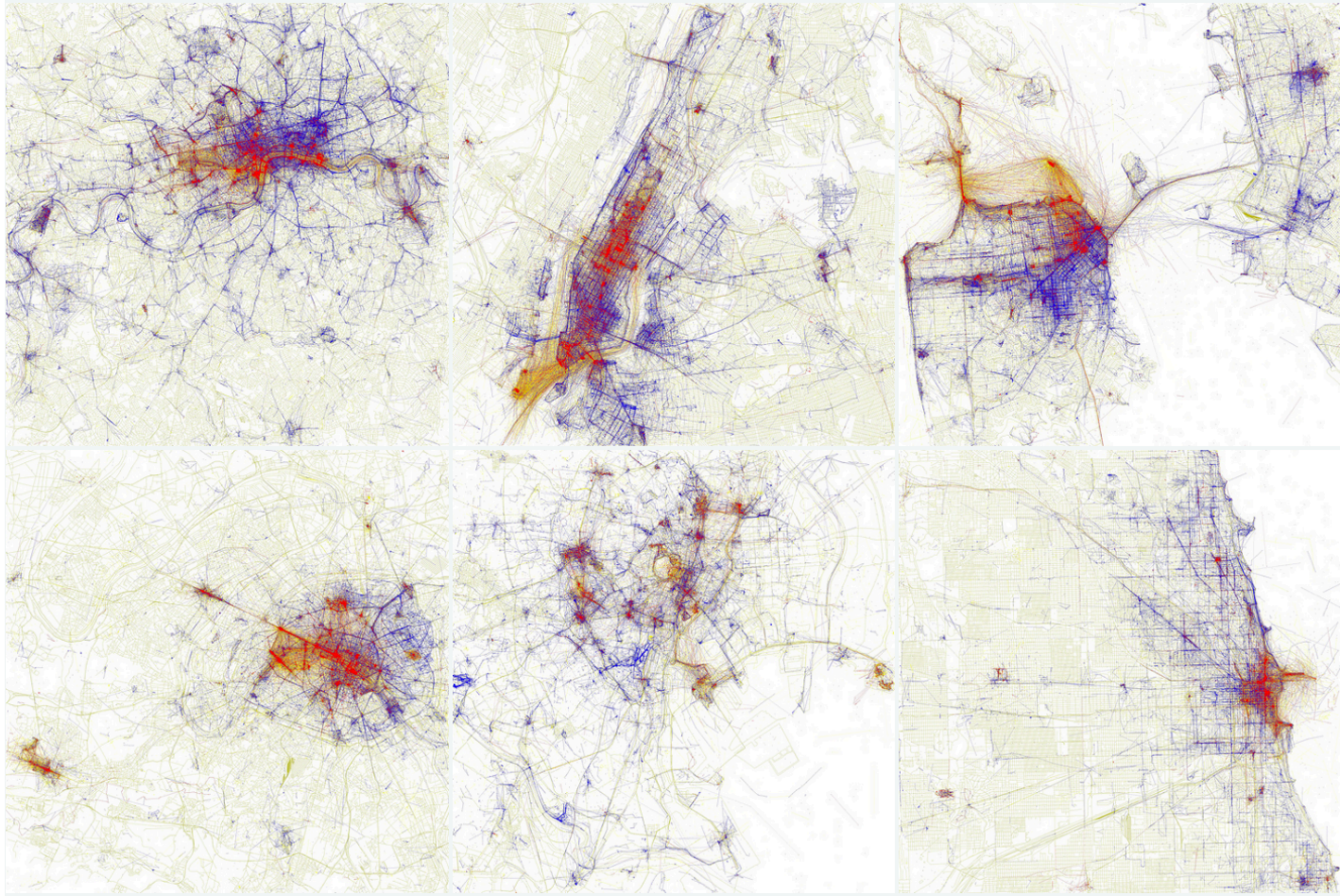
**Census tract 601**

Population in 2010: 2,111  
Change since 2000: +5.4%

RACE/ETHNICITY	SHARE OF POP.	CHANGE FROM 2000
Whites:	66%	-6%
Blacks:	1%	+33%
Hispanics:	28%	+62%
Asians:	3%	-20%
Native Amer.:	0%	0%
Multiracial:	1%	-42%
Other groups:	0%	0%

<http://projects.nytimes.com/census/2010/map>

# Lines distribution



<https://www.flickr.com/photos/walkingsf/albums/72157624209158632>

# Graduated Symbol Map

**365**  **Obama**  
Electoral Votes  
Projected Winner

**0**  
undecided

**173** **McCain**  
Electoral Votes

Popular vote: 66,862,039

270 needed to win

Popular vote: 58,319,442

- State winners
- County bubbles**
- County leaders
- Voting shifts

ZOOM IN

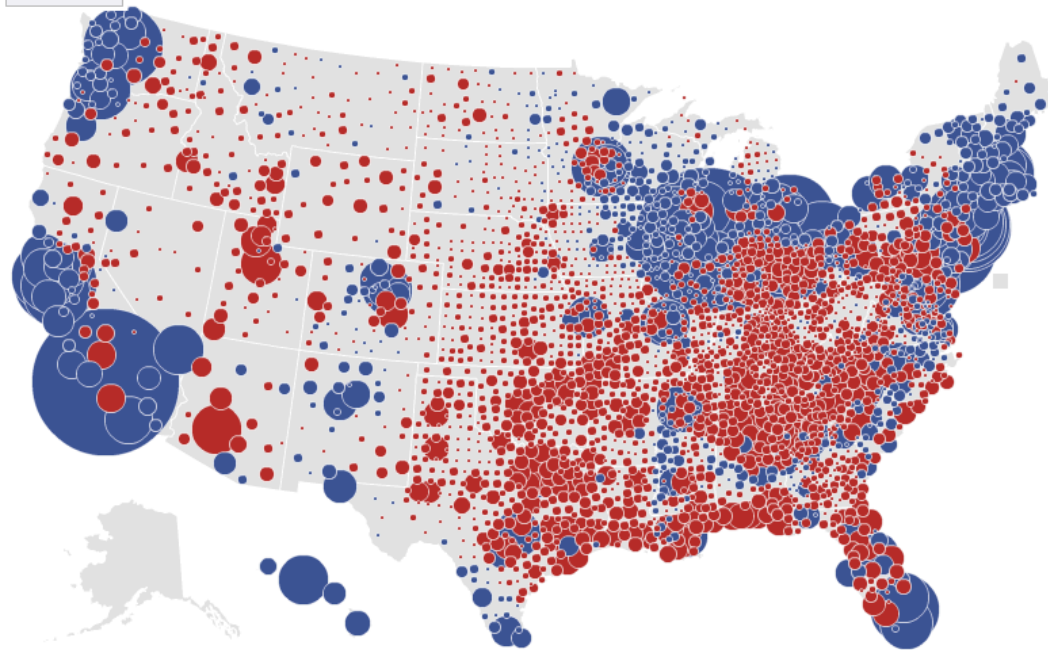
Year

'08 '04 '00 '96 '92

Map key

Circle size is proportional to the amount each county's leading candidate is ahead.

Larger Smaller



<http://elections.nytimes.com/2008/results/president/map.html>



# Tile Map Server

# Tile Map Server

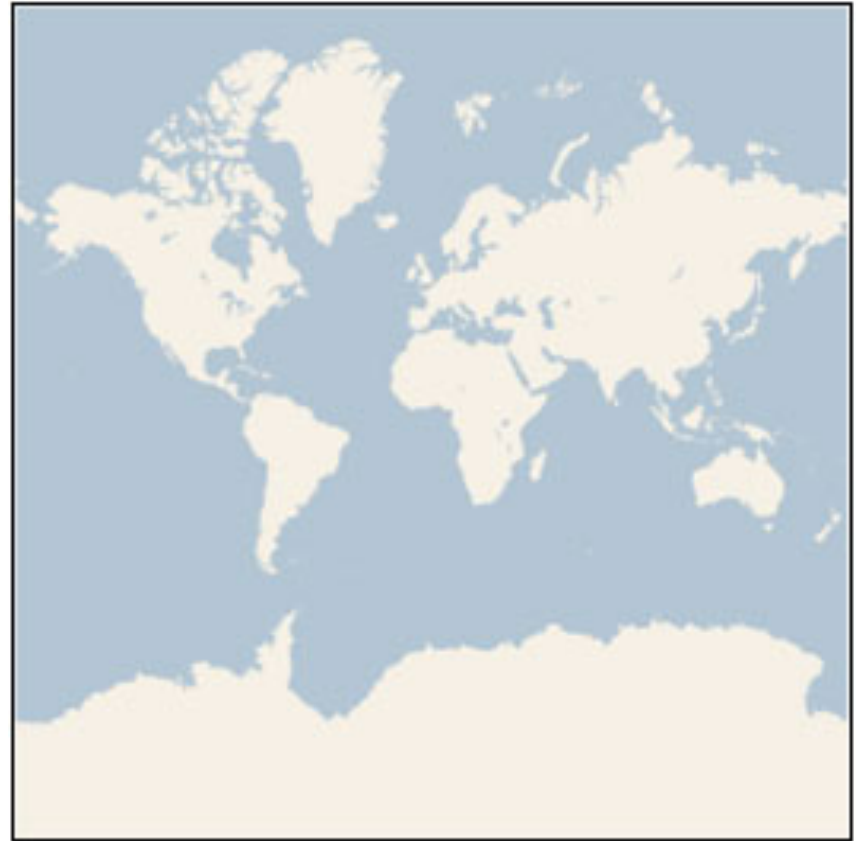
- An efficient solution to publish maps on the web
  - Complexity in space (rather than in time)
  - Used by many providers:
    - Google Maps, Bing, Yahoo Maps, OpenStreetMaps
- Maps is generated once for all level of zoom and then sliced into **tiles**
- A map for a finite set of zoom levels

## Tile Map Server (2)

- To simplify coordinate mapping: cylindrical projection
- Two main reference systems:
  - Sphere Mercator (53004)
  - World Mercator (54004)
- Mercator Cyndric projection
  - Meridians are parallels
  - Conformal (preserves shapes)
  - Preserves directions

## Tile Map Server (3): scale

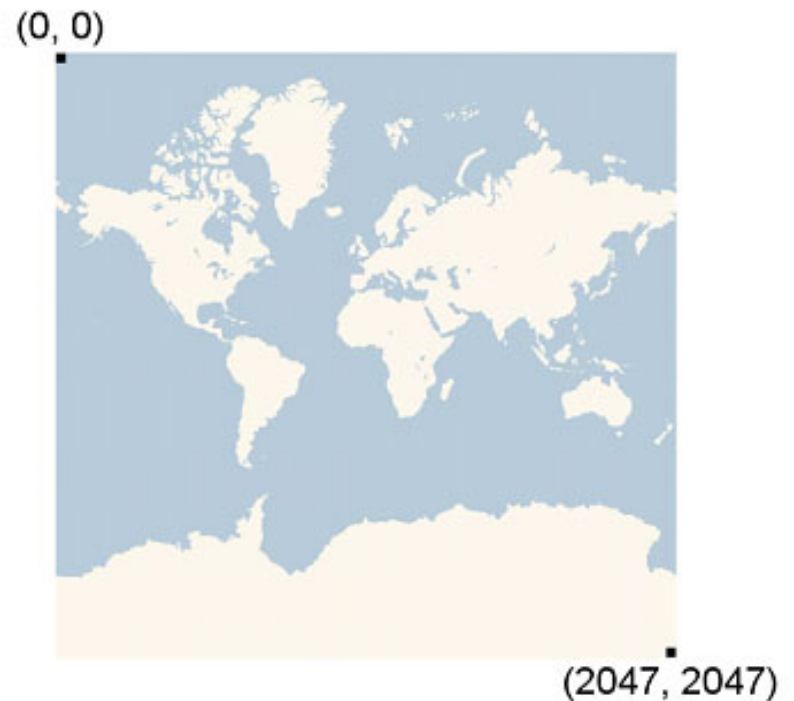
- Hierarchy division of plane
- Every tile (any zoom) has a fixed dimension: 256x256
- Each zoom level increases (doubles) the number of tiles
- At level 1: only 4 tiles





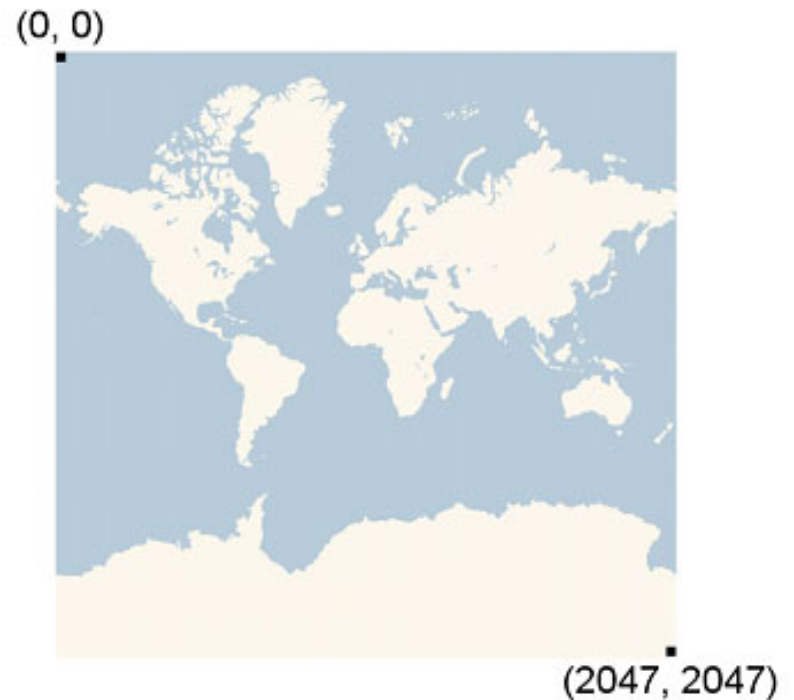
## Tile Map Server (4): scale

- At each zoom level, the number of tiles increases
  - Every tile at level  $n$  generates 4 tiles at level  $n+1$
- At level  $n$  tiles cover  $256 * 2^n$  pixel
- For example, at level 3 map has a side  $256 * 2^3 = 2048$  pixel



# Tile Map Server (5): coordinates

- Given coordinate (lat,lon) and zoom level n, how to determine position on the image?
- Which tile correspond to coordinate?



$$\text{pixelX} = ((\text{longitude} + 180) / 360) * 256 * 2^{\text{level}}$$

$$\text{pixelY} = (1 - \log(\tan(\text{Latitude}) + \sinh(\text{Latitude})) / \pi) / 2 * 256 * 2^{\text{level}}$$

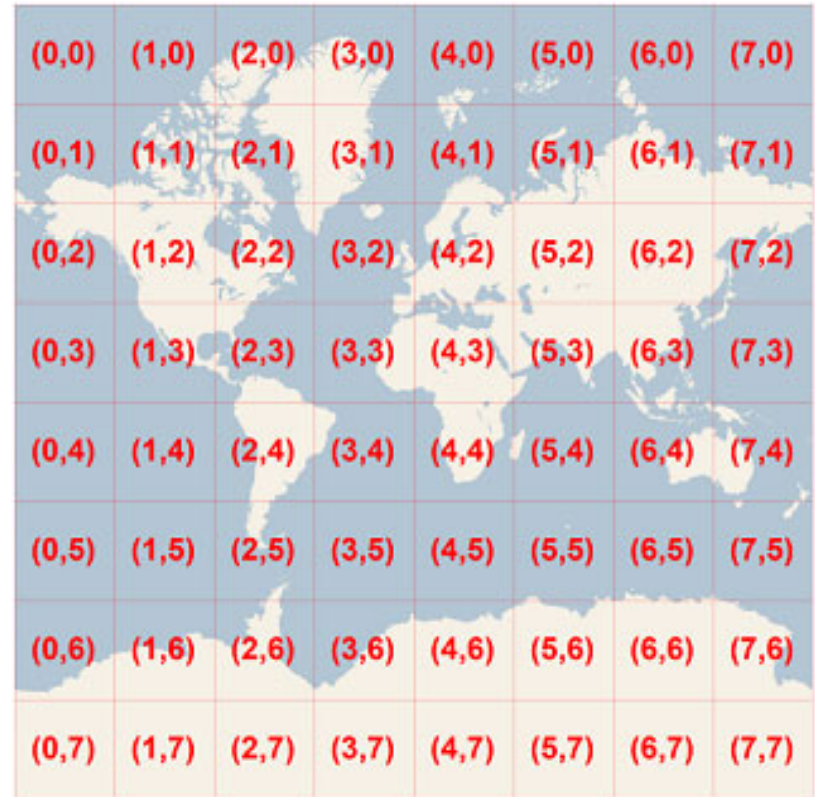
# Tile Map Server (6): tile number

- Given pixelX e pixelY
- Which tile contains that pixel?

$\text{tileX} = \text{floor}(\text{pixelX} / 256)$

$\text{tileY} = \text{floor}(\text{pixelY} / 256)$

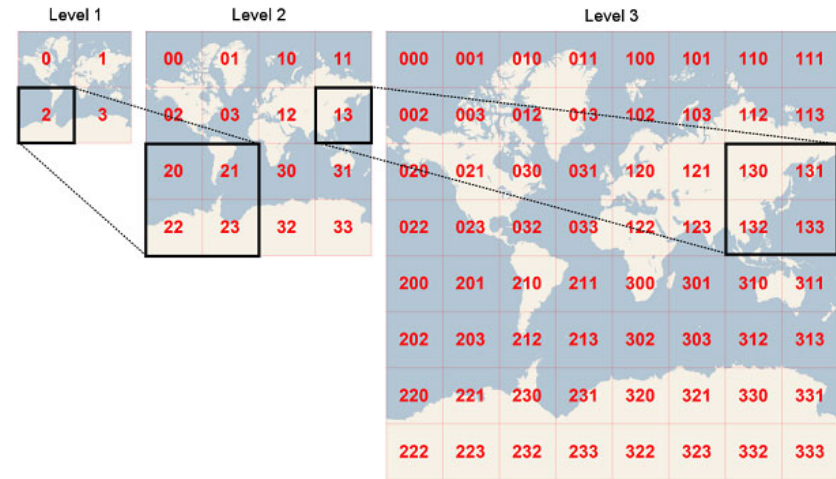
- URL to tile:
  - `/zoom/tx/ty`
  - quadkey



<http://otile2.mqcdn.com/tiles/1.0.0/osm/1/0/0.png>

# Tile Map Server (7): quadkey

- Used by Bing
- Length of the key corresponds to the zoom level



tileX = 3 = 011

tileY = 5 = 101

quadkey = 100111 = 2134 = "213"

# Tile Map Server (8): zoom in

- Given a tile a zoom level  $n$
- Successive tile at level  $n+1$  are:
  - $2x, 2y$
  - $2x+1, 2y$
  - $2x, 2y+1$
  - $2x+1, 2y+1$



/3/4/2.png



# Tile Viewer Example

14/14/5	15/14/5	16/14/5	17/14/5	18/14/5
14/15/5	15/15/5	16/15/5	17/15/5	18/15/5
14/16/5	15/16/5	16/16/5	17/16/5	18/16/5

<https://bl.ocks.org/mbostock/f9f91fd9148bdc5aa6db>



# **TILE SERVICES**



# Leaflet.js



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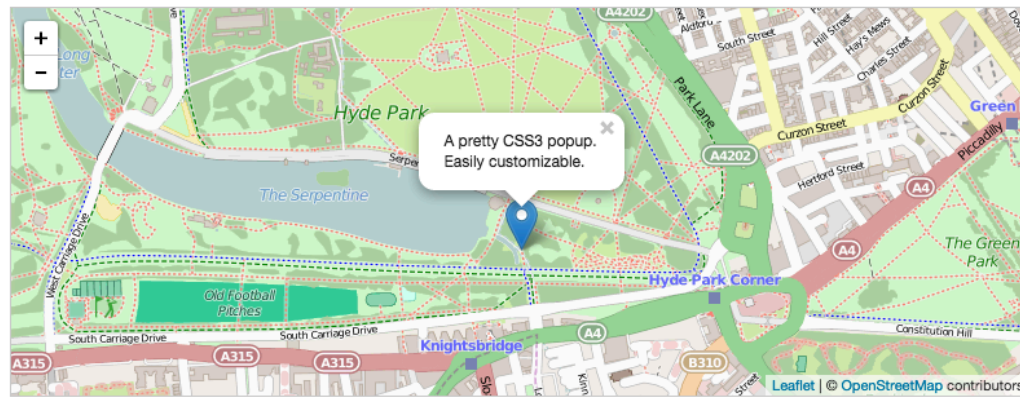
An Open-Source JavaScript Library for Mobile-Friendly Interactive Maps

Overview Features Tutorials API Download Plugins Blog GitHub Twitter Forum

Leaflet is a modern open-source JavaScript library for mobile-friendly interactive maps. It is developed by [Vladimir Agafonkin](#) with a team of dedicated [contributors](#). Weighing just about 33 KB of JS, it has all the [features](#) most developers ever need for online maps.

Leaflet is designed with *simplicity*, *performance* and *usability* in mind. It works efficiently across all major desktop and mobile platforms out of the box, taking advantage of HTML5 and CSS3 on modern browsers while still being accessible on older ones. It can be extended with a huge amount of [plugins](#), has a beautiful, easy to use and [well-documented API](#) and a simple, readable [source code](#) that is a joy to [contribute](#) to.

Used by: Flickr foursquare Pinterest craigslist Data.gov IGN Wikimedia OSM Meetup WSJ Mapbox CartoDB GIS Cloud ...



# Leaflet.js - APIs

*An Open-Source JavaScript Library for Mobile-Friendly Interactive Maps*

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## Misc

[global switches](#)

[noConflict](#)

[version](#)

# Leaflet.js

- A valid tool to provide tile-based maps
  - Open Source
  - Open Data (<http://tools.geofabrik.de/mc/>)
  - Free
- Easy to use API
- Lightweight lib (only 64k)
- Support mobile applications
- Alternative to Google Maps (<http://flink.com.au/tips-tricks/27-reasons-not-to-use-google-maps>)

# Free Tiles Providers

- OpenStreetMap
  - Some issues for high traffic services
- MapQuest Open License
  - Free, by attribution
  - Special configuration for heavy usage
- MapBox
  - Free tier
  - Customizable design (see next slide)
  - Same family as Leaflet.js



**Access blocked**

This application is  
blocked for overusing  
OpenStreetMap's  
volunteer-run servers:  
[wiki.osm.org/Blocked](http://wiki.osm.org/Blocked)

# Commercial Tile Providers

- CloudMade
  - Mirror of OSM data till few years ago
  - Leaflet was born here
  - \$30 per 1M tiles
- MapBox
  - Free for low traffic
  - \$30 for 900k tiles

# Easy to install/use

## ■ HTML (Setting the stage)

### ■ Link CSS (via CDN)

- `<link rel="stylesheet" href="http://cdnjs.cloudflare.com/ajax/libs/leaflet/0.7.3/leaflet.css" />`

### ■ Link JS (via CDN)

- `<script src="http://cdnjs.cloudflare.com/ajax/libs/leaflet/0.7.3/leaflet.js"></script>`

### ■ Create a div to contain the map

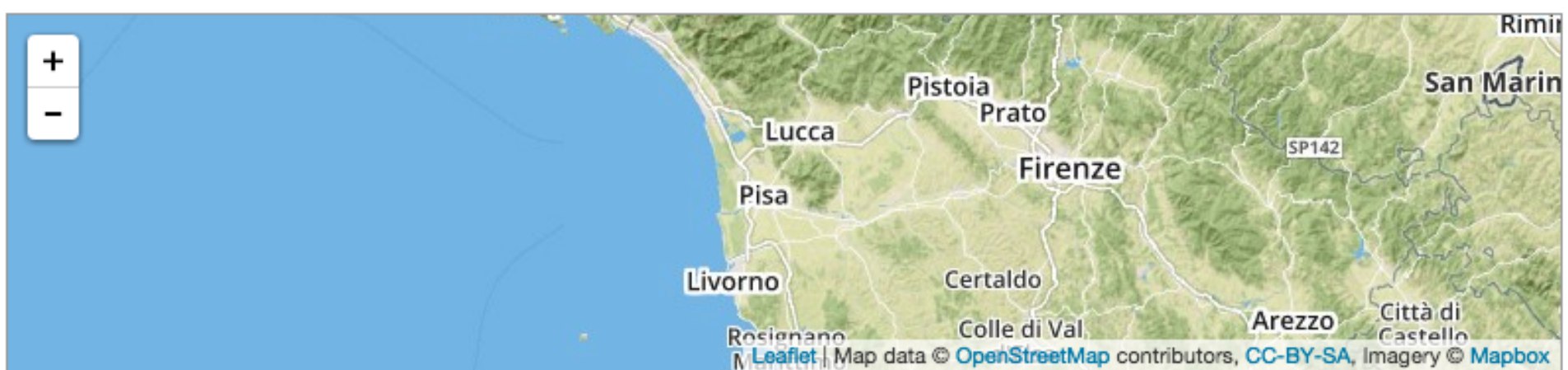
- `<div id="map"></div>`

### ■ Set height for the container

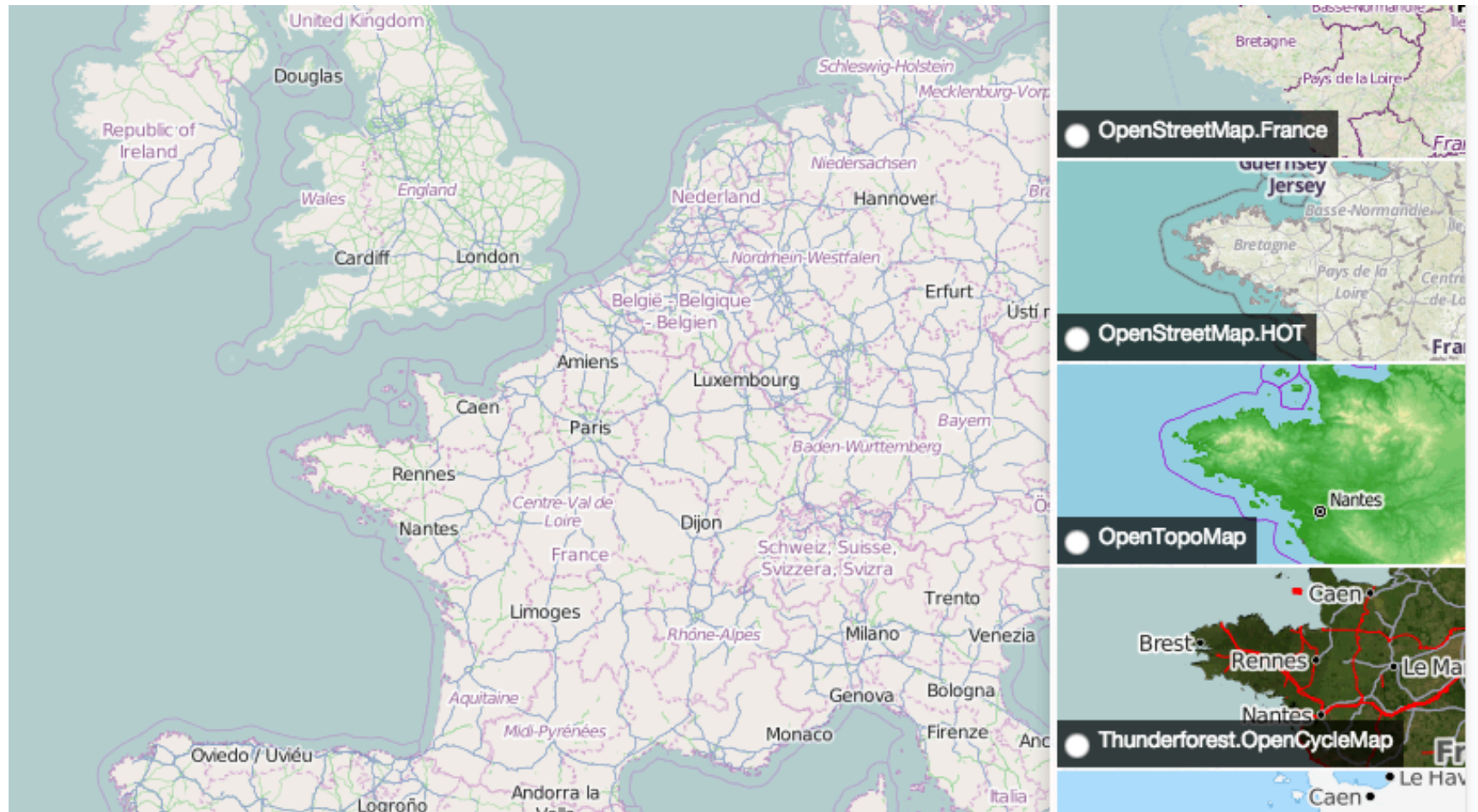
- `#map { height: 180px; }`

# Easy to install/use

- Create an object to handle the map
  - `var map = L.map('map').setView([51.505, -0.09], 13);`



# Tile map providers



<http://leaflet-extras.github.io/leaflet-providers/preview/>



# Markers and geometries

- `var marker = L.marker([51.5, -0.09]).addTo(map);`
- `var circle = L.circle([51.508, -0.11], 500, {  
    color: 'red',  
    fillColor: '#f03',  
    fillOpacity: 0.5  
}).addTo(map);`
- `var polygon = L.polygon([  
    [51.509, -0.08],  
    [51.503, -0.06],  
    [51.51, -0.047]  
]).addTo(map);`

# Interactions

- `marker.bindPopup("<b>Hello world!</b><br>I am a popup. ").openPopup();`
- `circle.bindPopup("I am a circle.");`
- `polygon.bindPopup("I am a polygon.");`

# Event handling

- ```
function onMapClick(e) {  
    alert("You clicked the map at " + e.latlng);  
}
```
- ```
map.on('click', onMapClick);
```
  
- ```
var popup = L.popup();
```
- ```
function onMapClick(e) {  
    popup  
        .setLatLng(e.latlng)  
        .setContent("You clicked the map at " + e.latlng.toString())  
        .openOn(map);  
}
```
- ```
map.on('click', onMapClick);
```

# Other Examples

- Mobile app
  - <http://leafletjs.com/examples/mobile.html>
- GeoJSON
  - <http://leafletjs.com/examples/geojson.html>
  - <http://geojson.io/>
- Tutorials
  - <http://leafletjs.com/examples.html>