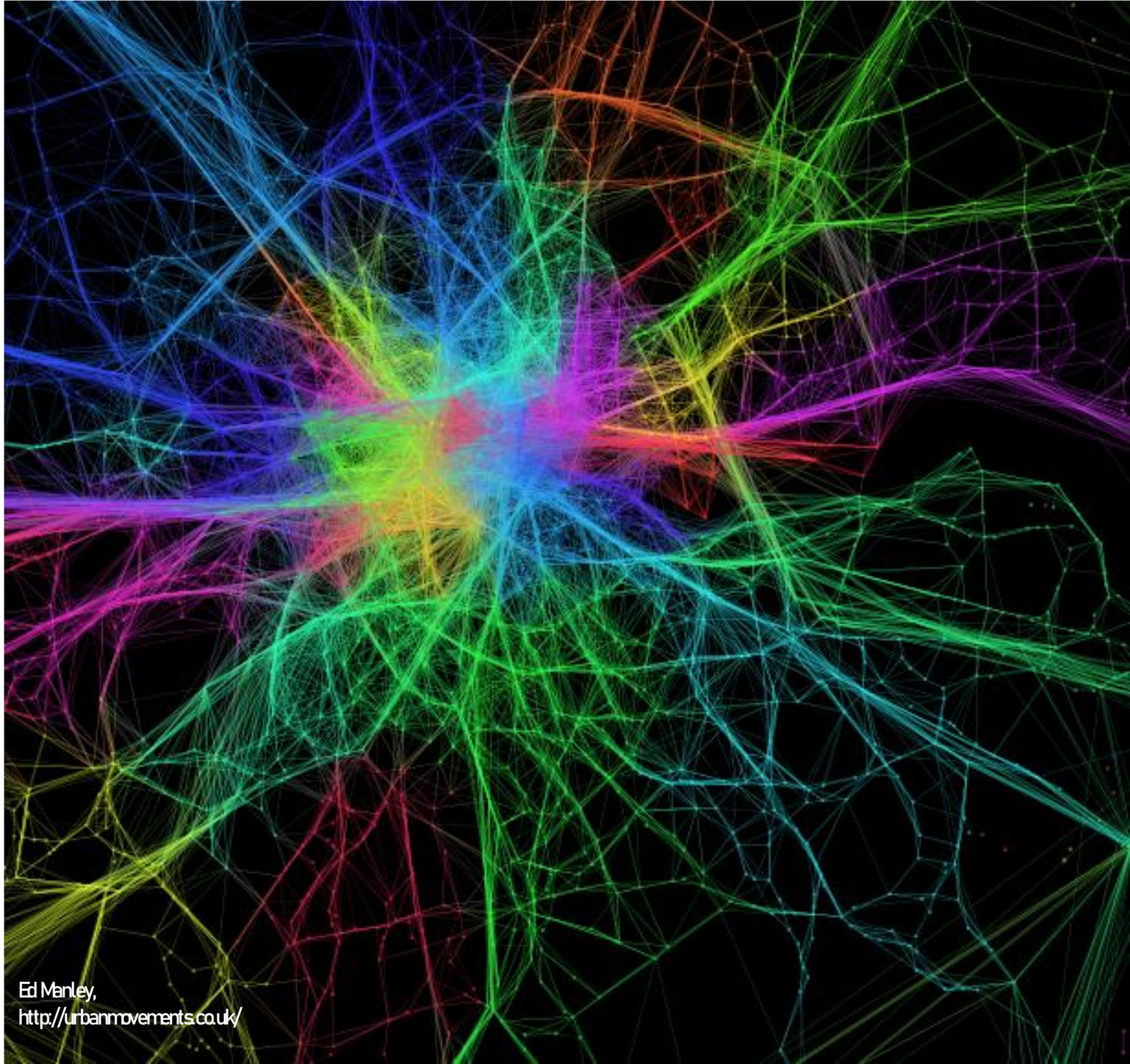
(Spatial) Networks and OpenStreetMap

ENVS456 – week 7

Gabriele Filomena



Ed Manley,
http://urbanmovements.co.uk/

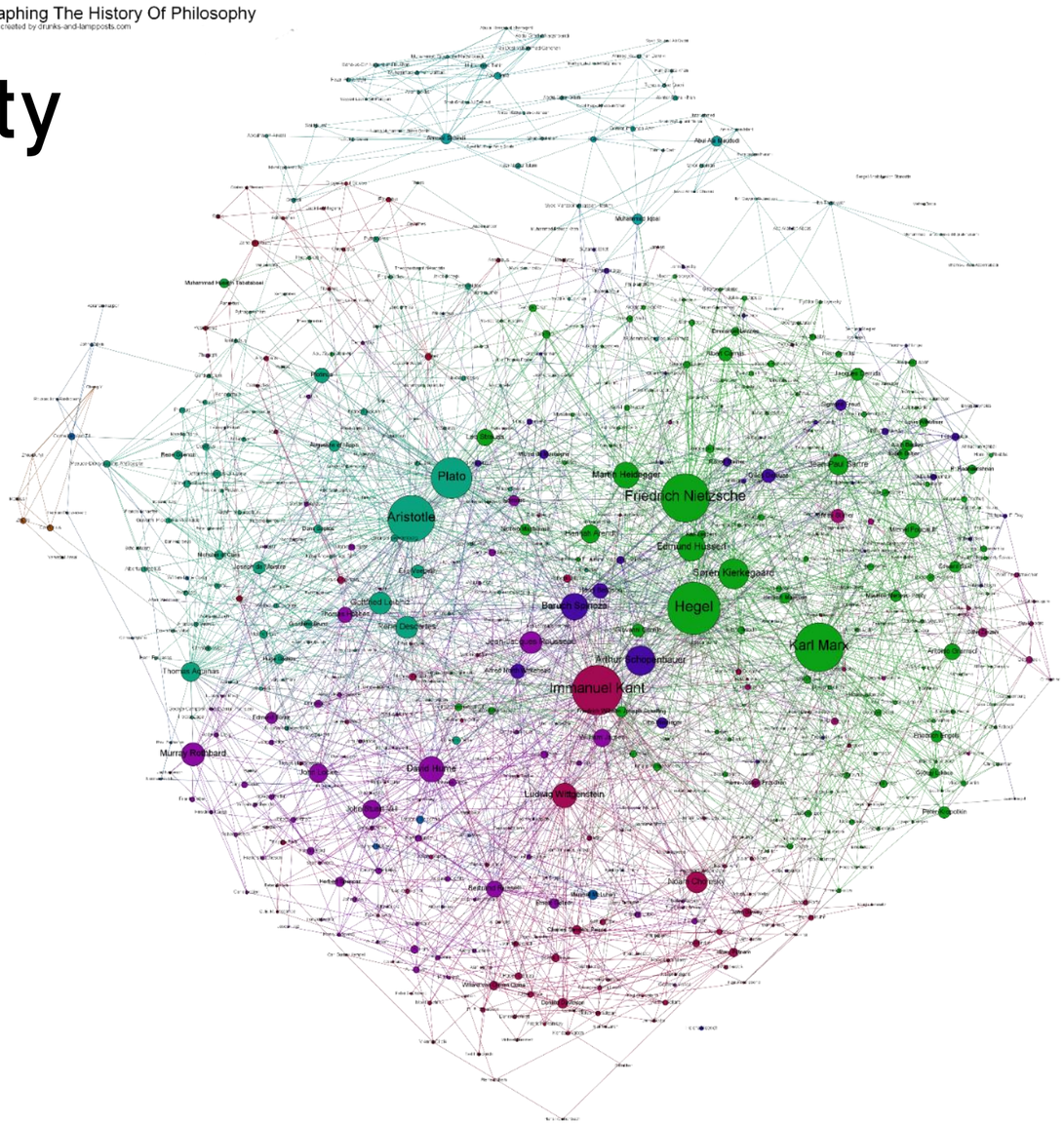
Agenda

- Why Networks?
- Graph theory: Basic concepts
- Graph theory: Centrality measures
- Street network analysis: representations and applications

Networks & Graphs

Network science and Complexity

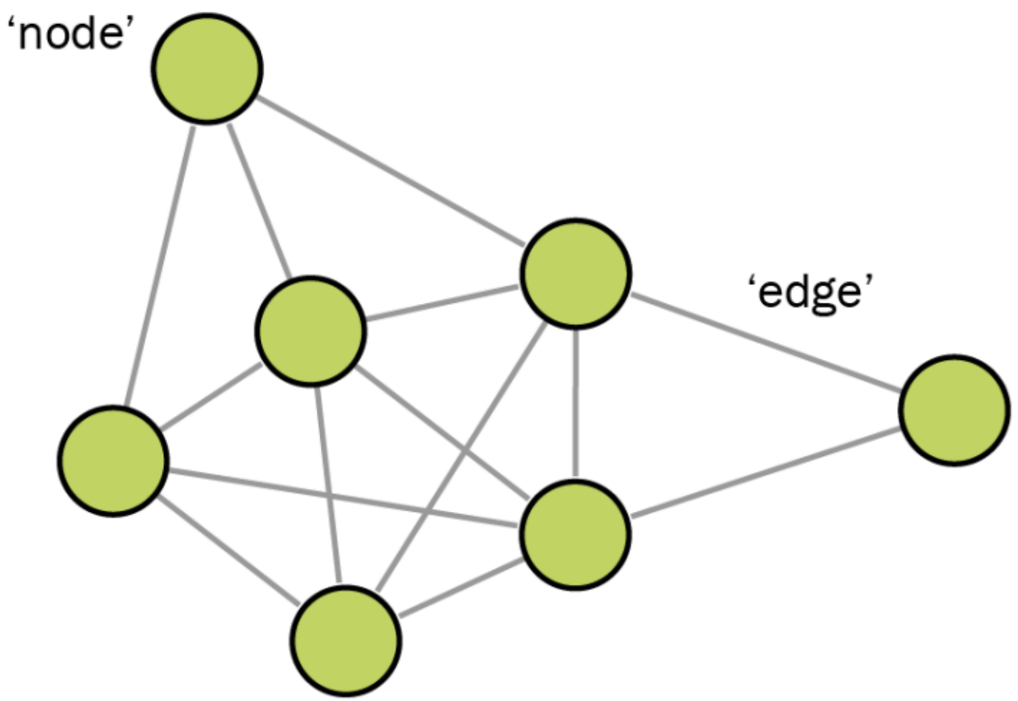
- Complex systems and interaction amongst its parts might be represented in various ways through networks.
- If we understand the dynamics of one system, we can extend the emerging patterns to different systems



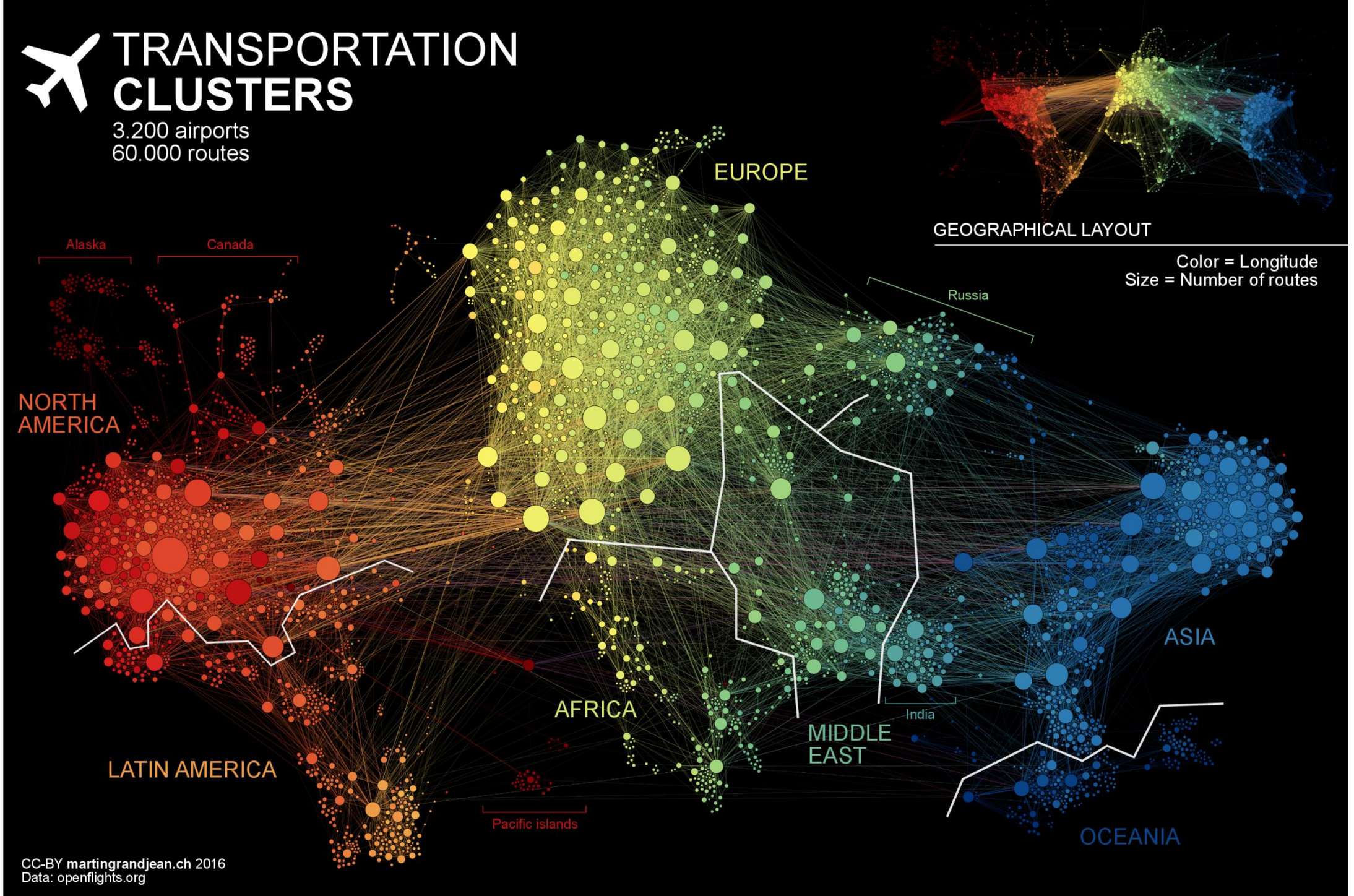
Infer generic functioning mechanisms.

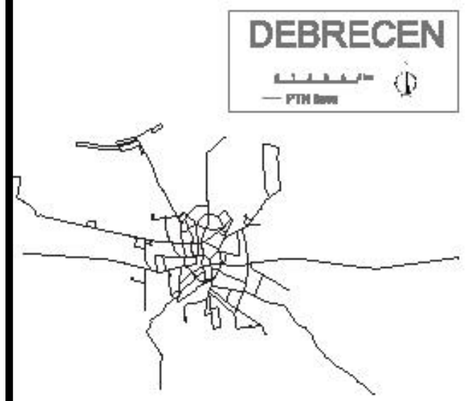
Graph Components

- Network science is built upon the foundation of graph theory.
- A *graph* is an abstract mathematical representation of a set of elements and the connections between them.

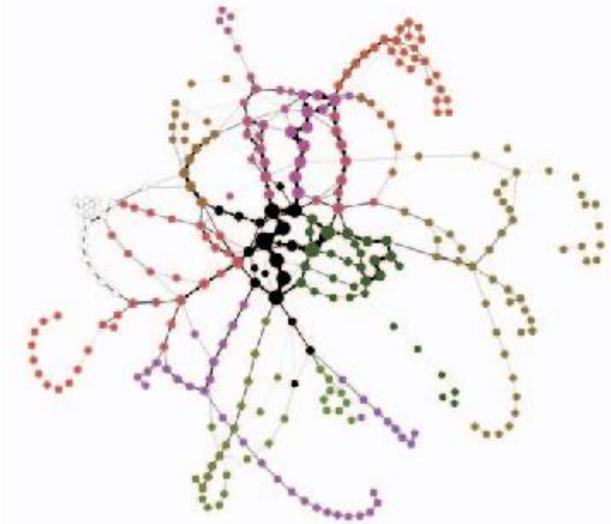


- components: nodes, vertices (*n*)
- interactions: links, edges (*m*)
- system: network, graph *G*(*n, m*)

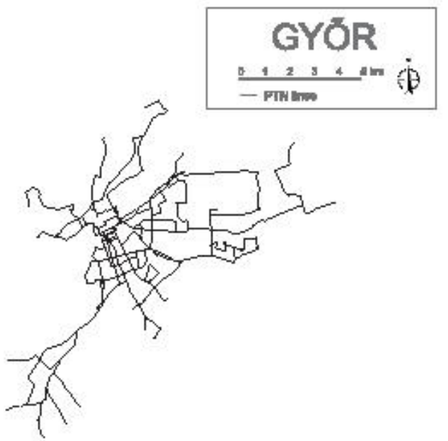

TRANSPORTATION
CLUSTERS
3.200 airports
60.000 routes
EUROPE
GEOGRAPHICAL LAYOUT
Color = Longitude
Size = Number of routes
Alaska
Canada
Russia
NORTH
AMERICA
ASIA
AFRICA
India
MIDDLE
EAST
LATIN AMERICA
Pacific islands
OCEANIA
CC-BY martingrandjean.ch 2016
Data: openflights.org



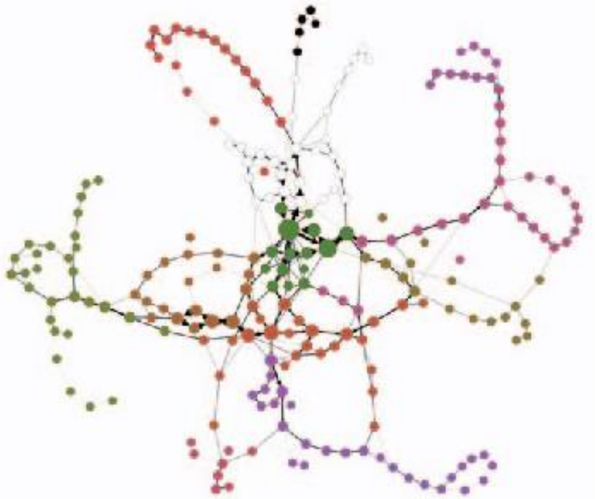
(a)



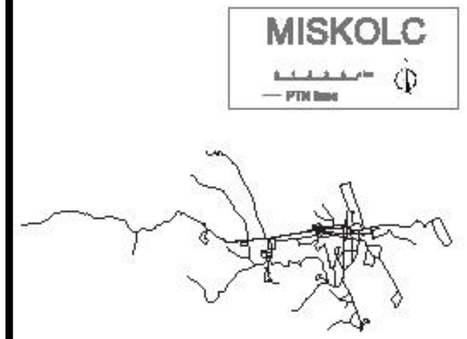
(b)



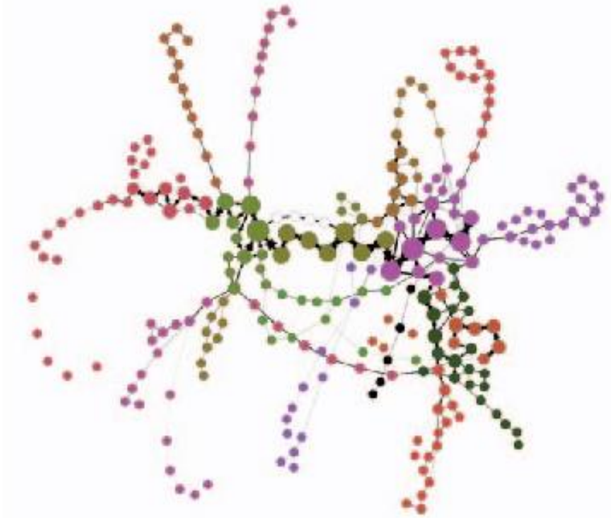
(c)



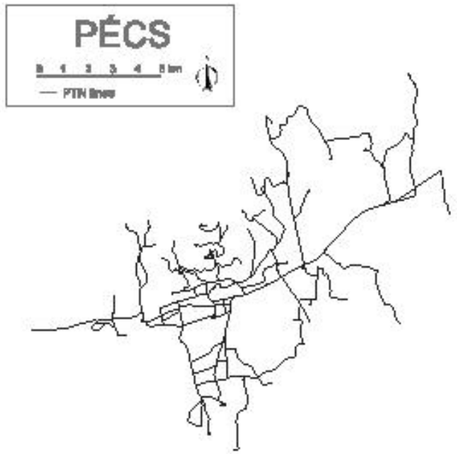
(d)



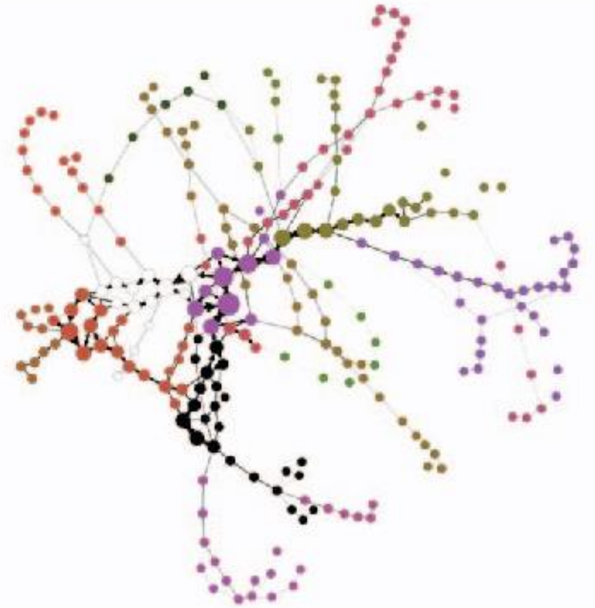
(e)



(f)



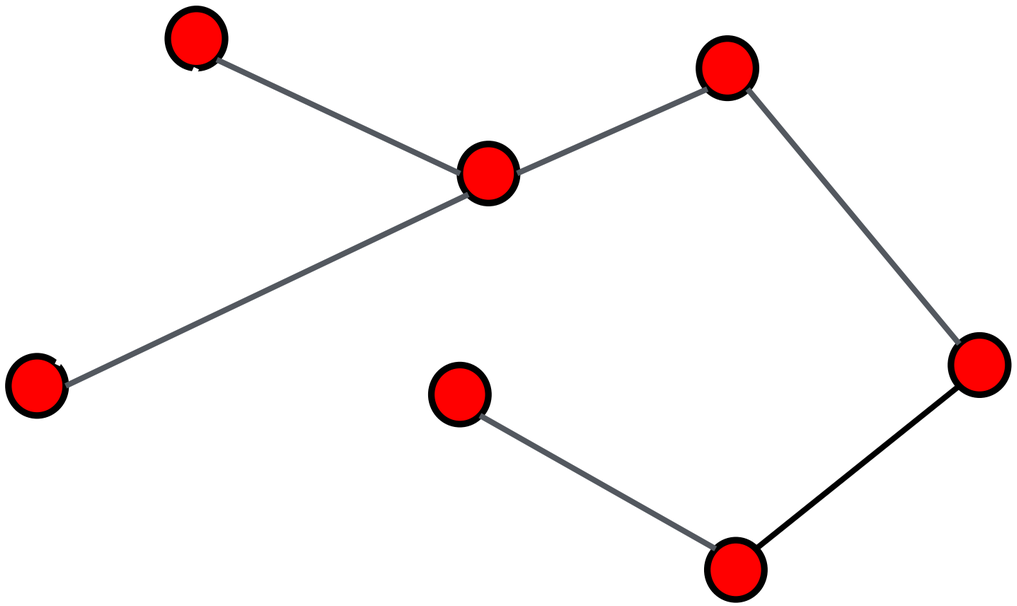
(g)



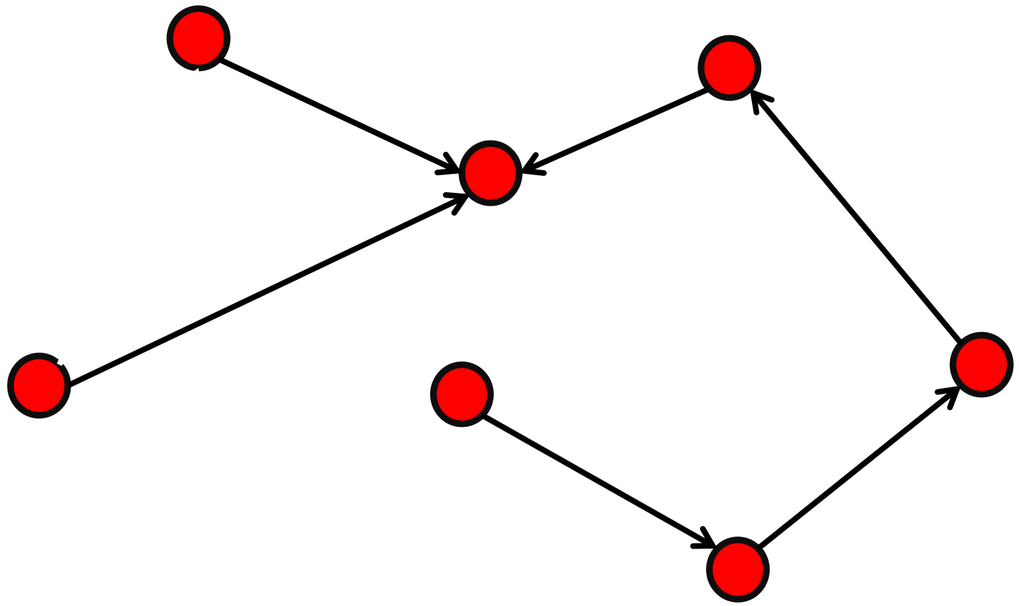
(h)

Source Haznagy et al. (2015)

Undirected graph

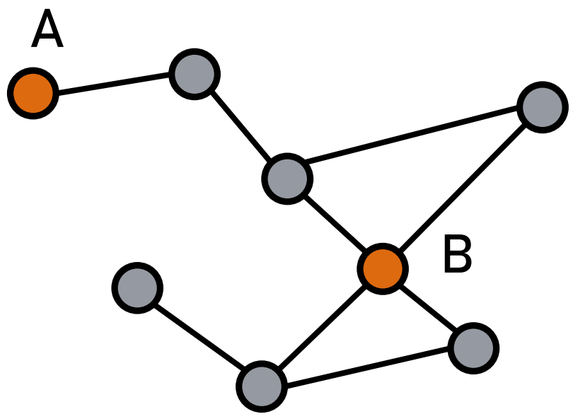


Directed graph (digraph)



Node Degree

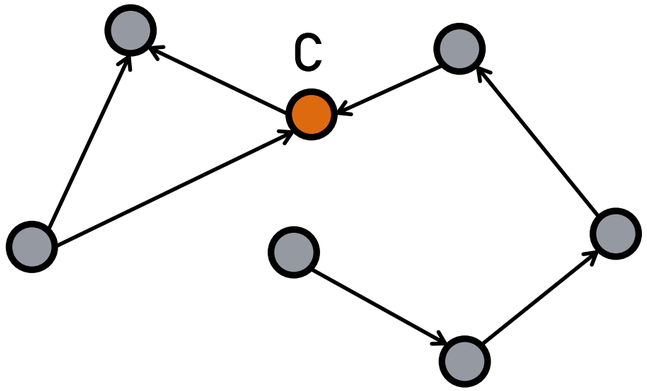
Undirected



The number of links connected to the node

$$k_A = 1 \quad k_B = 4$$

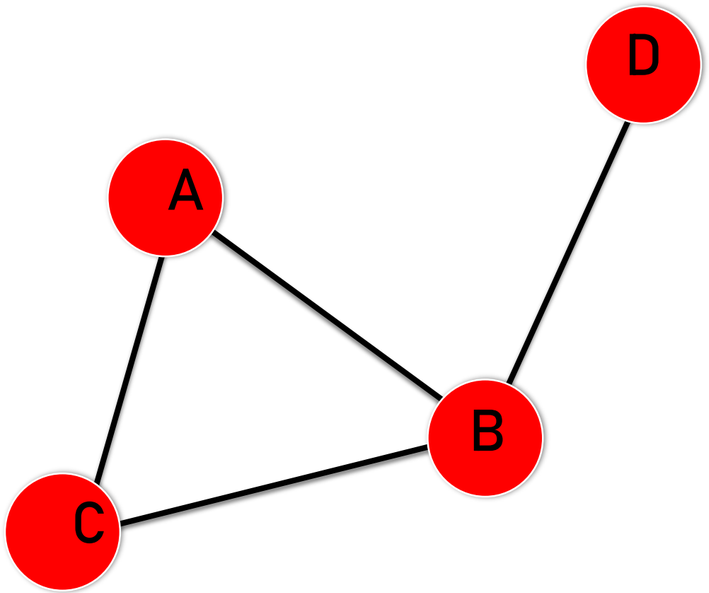
Directed



In directed networks we can define an in-degree and out-degree. The (total) degree is the sum of in- and out-degree.

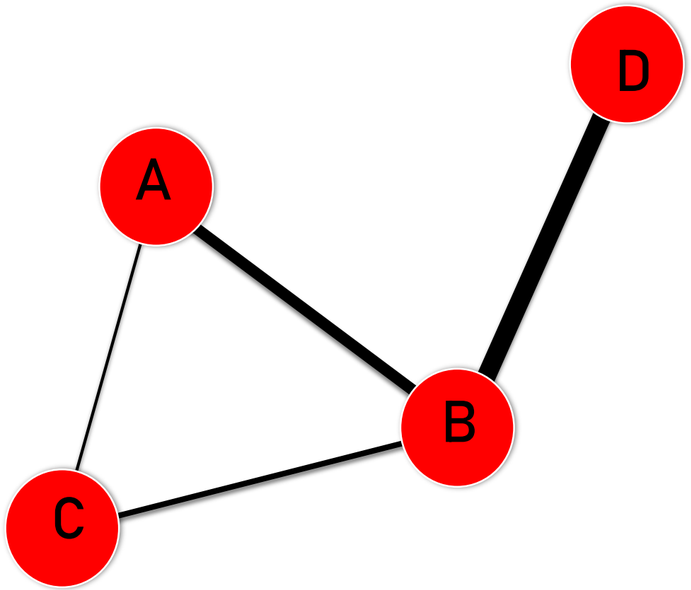
$$k_C^{in} = 2 \qquad k_C^{out} = 1 \qquad k_C = 3$$

Unweighted Graph



$$A_{ij} = \begin{pmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

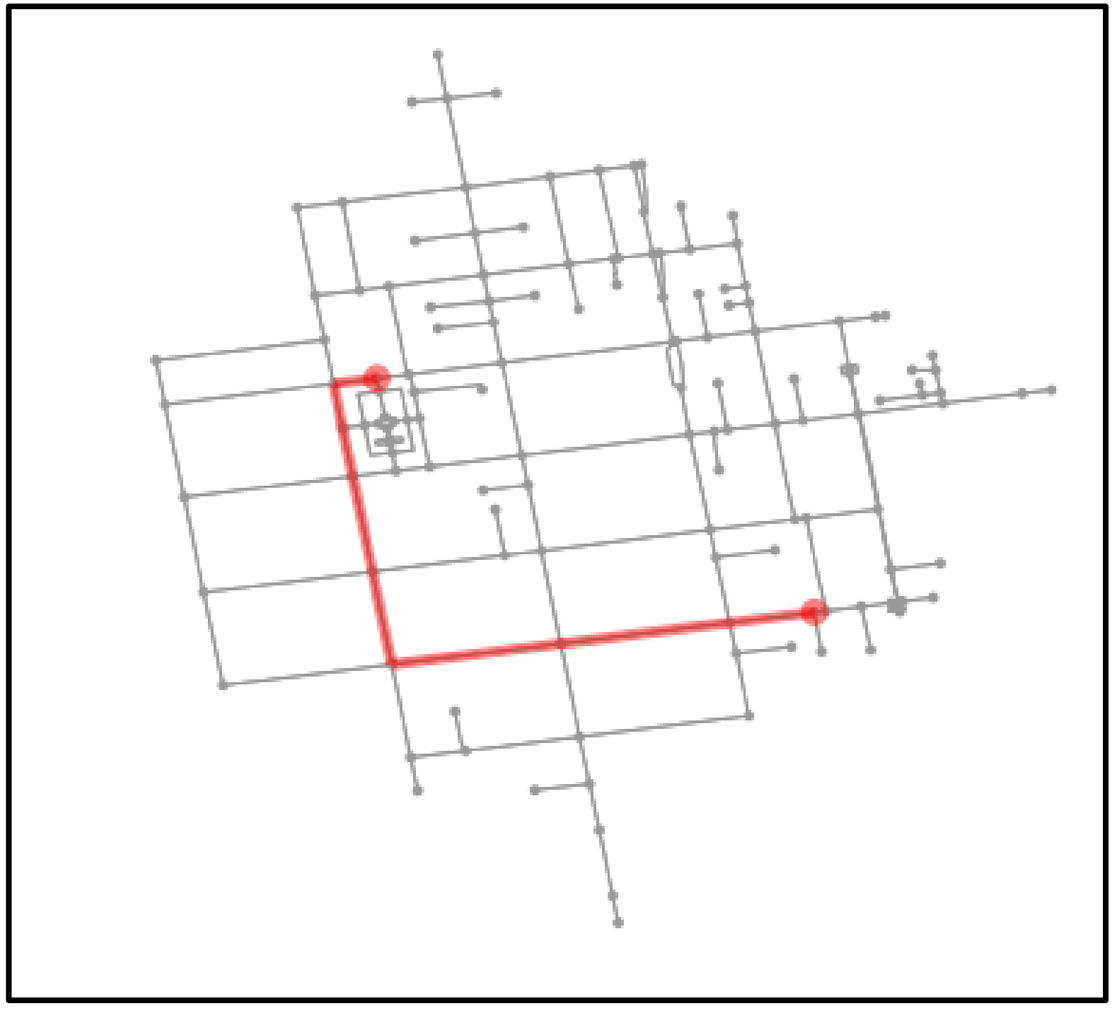
Weighted Graph

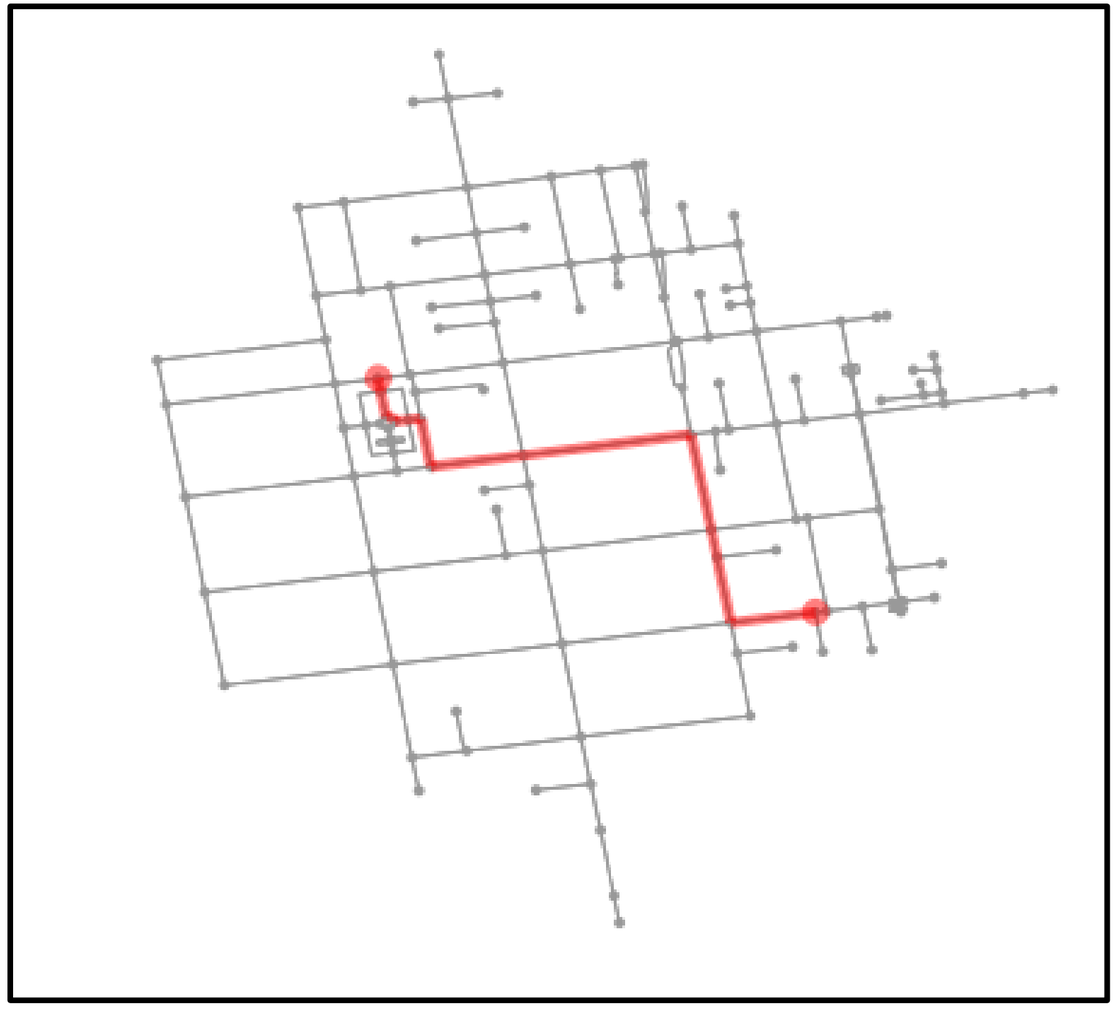


$$A_{ij} = \begin{pmatrix} 0 & 2 & 0.5 & 0 \\ 2 & 0 & 1 & 4 \\ 0.5 & 1 & 0 & 0 \\ 0 & 4 & 0 & 0 \end{pmatrix}$$

Distances and shortest path

- The distance between 2 nodes is defined as the number of links along the shortest path connecting them – TOPOLOGICAL DISTANCE
- In *digraphs* each path needs to follow the direction of the arrows. Thus the distance from node A to B may be different from the distance from B to A.
- Graphs representing street networks are usually weighted – *ROAD DISTANCE*





Centrality Measures

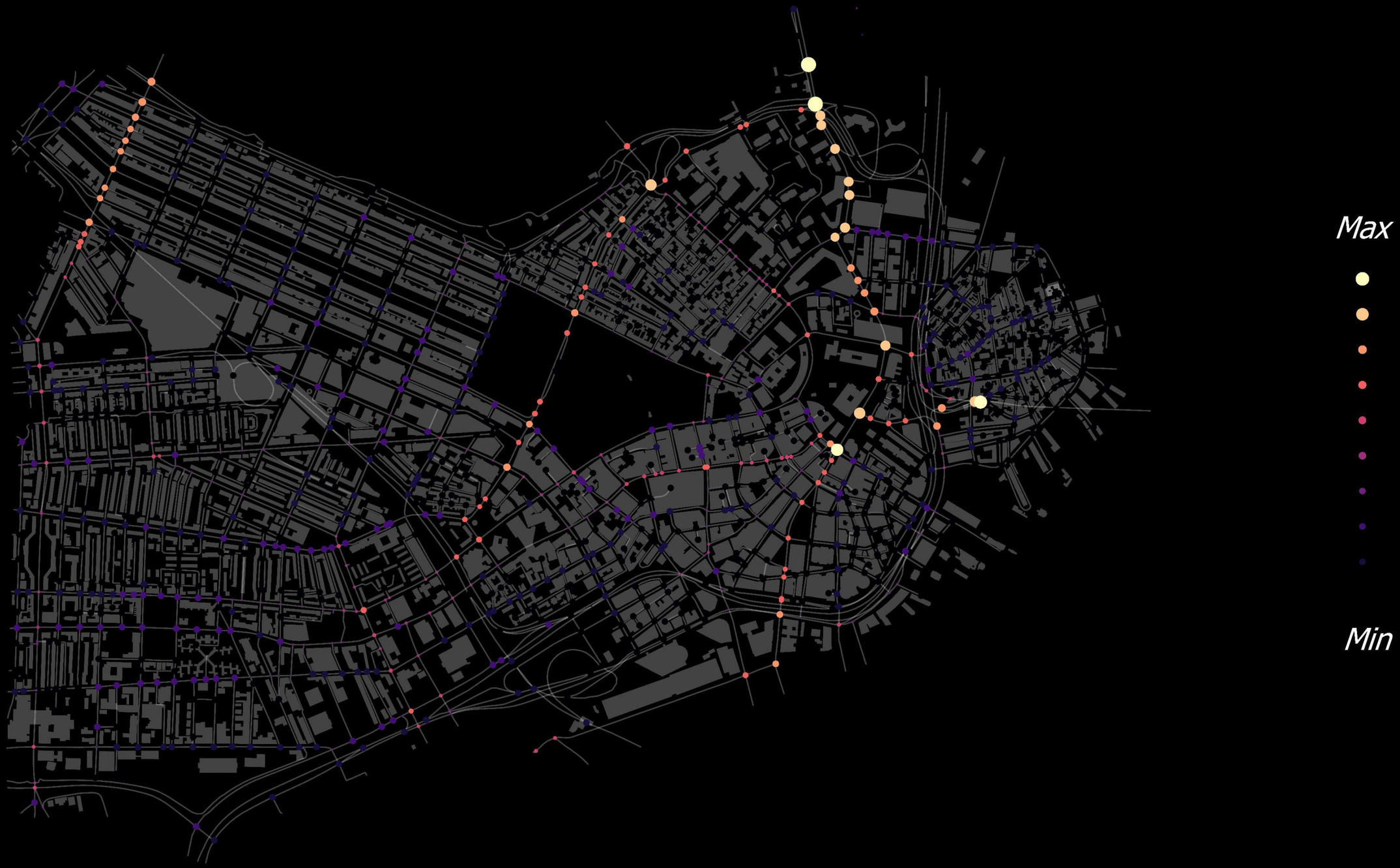
- Key measures for extracting the topological properties of the network.

- *Closeness centrality* measures to which extent a node i is near to all the other nodes.

$$C_i^C = \frac{N - 1}{\sum_{j \in N, j \neq i} d_{ij}}$$

- *Betweenness centrality* is based on the idea that a node is central if it lies between many other nodes, when it is traversed by many of the shortest paths connecting couples of nodes.

$$C_i^B = \sum_{j,k \in G, j \neq k \neq i} \frac{n_{jk}(i)}{n_{jk}}$$

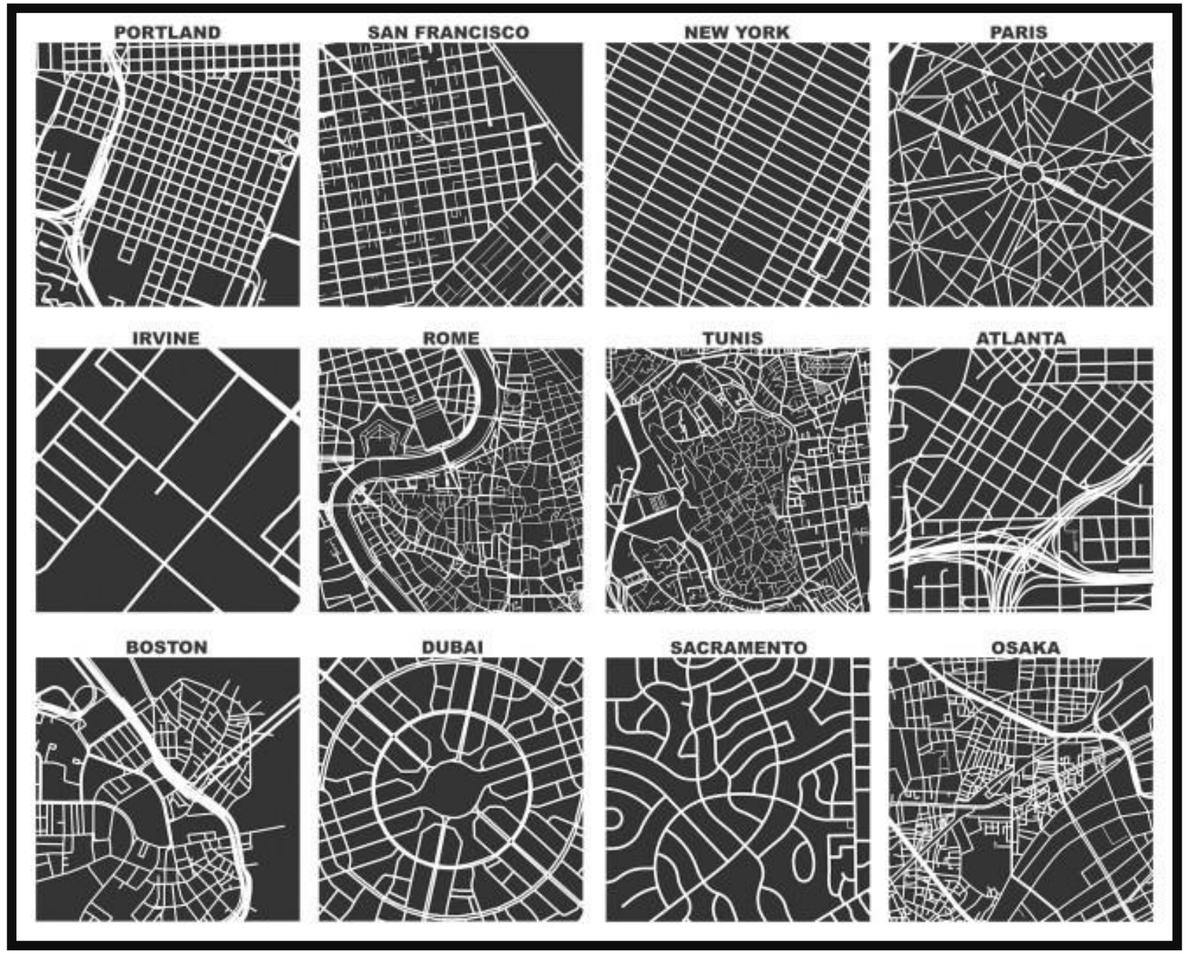

Max
Min


Max
Min

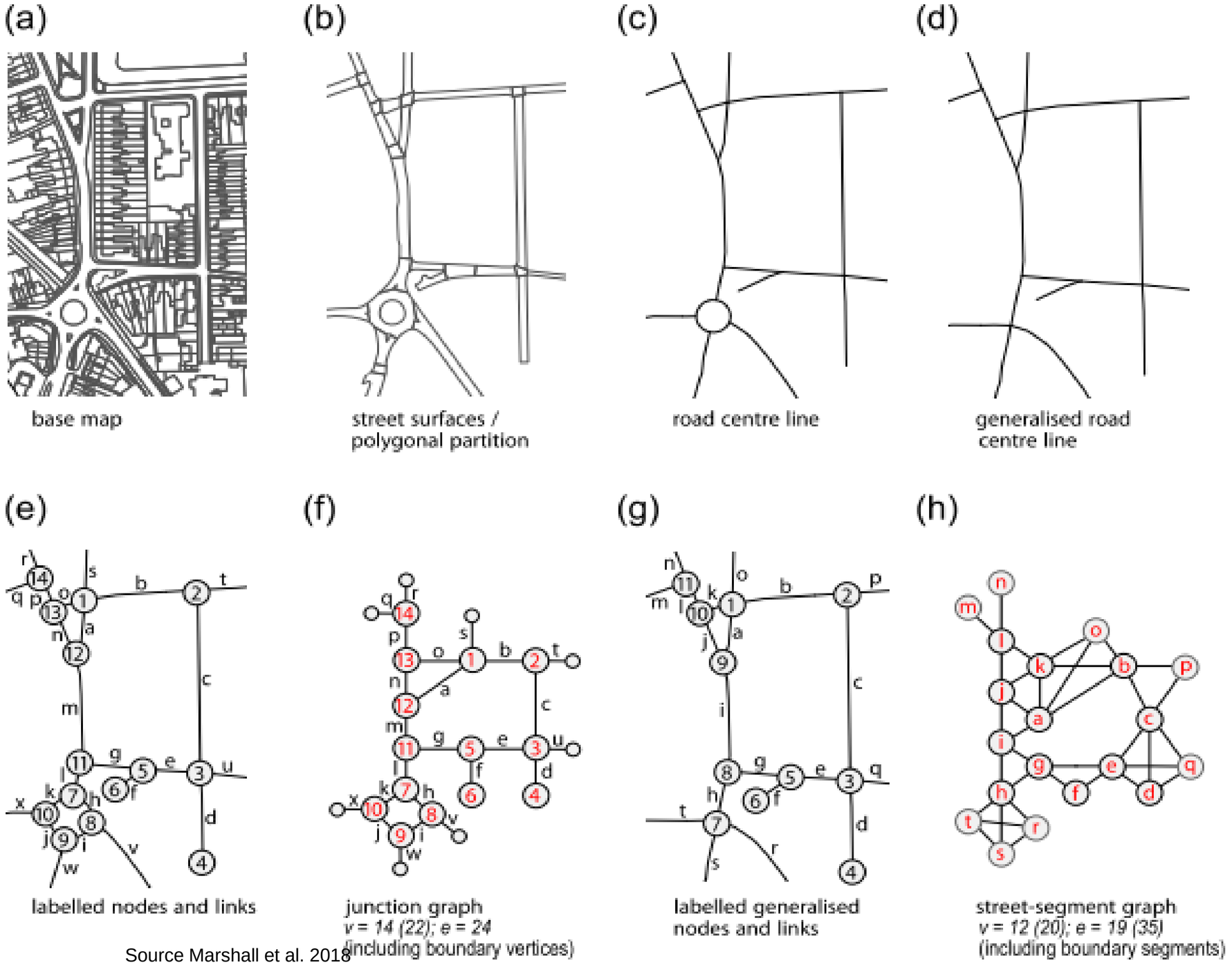
Spatial Networks

Network science and cities

- Cultural aspects of cities.
- Organic vs planned cities.
- Mental representation of space, mobility patterns and transport planning analysis.
- Services distribution and allocation, crime, segregation…



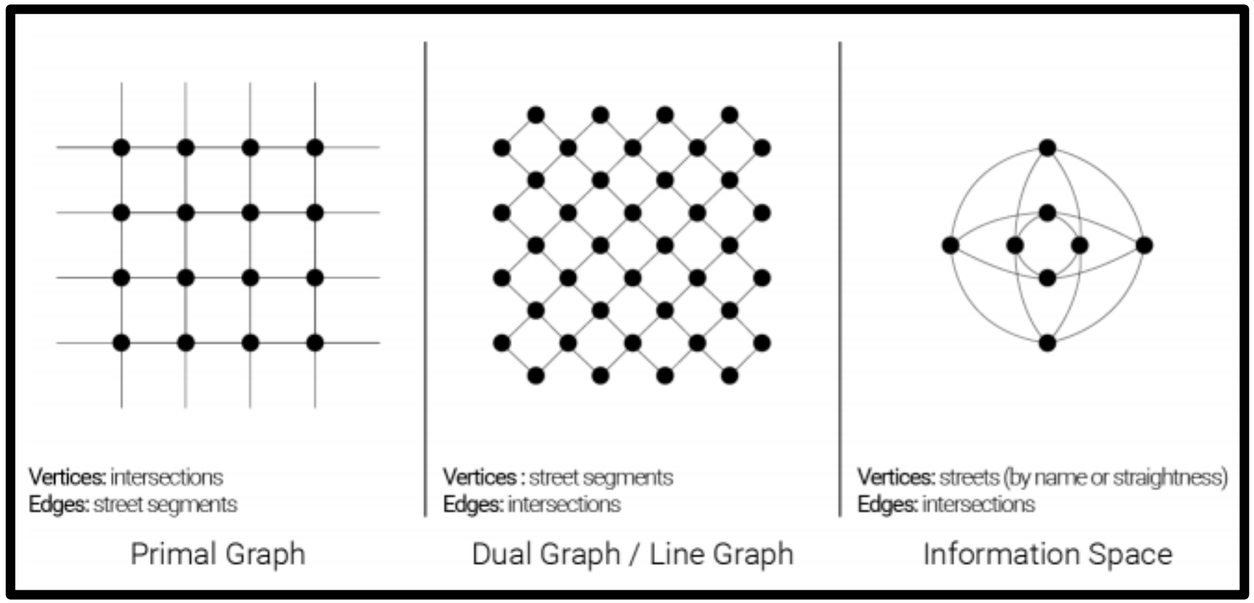
Source geoffboeing.com



Source Marshall et al. 2018

Primal *vs* Dual representations

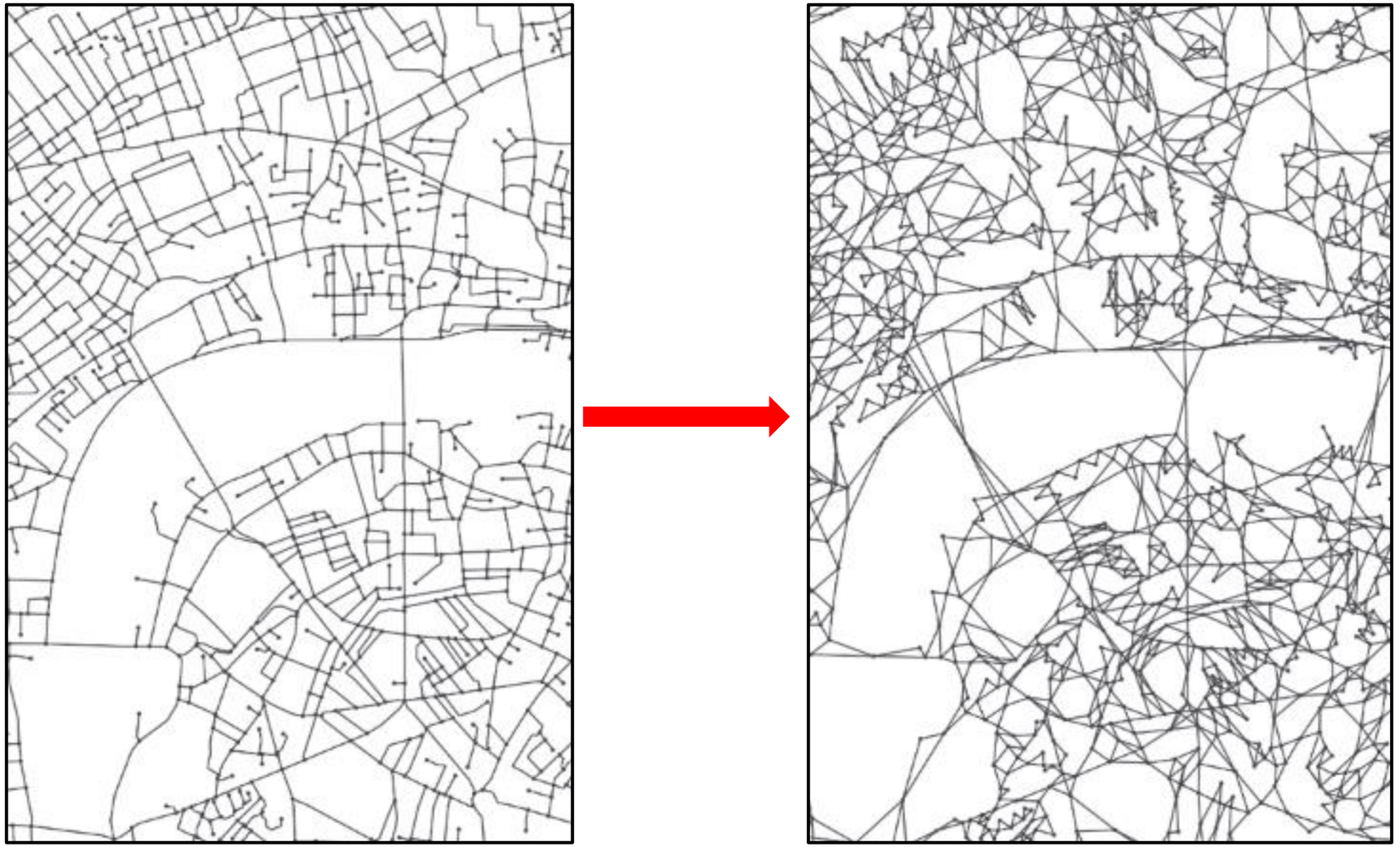
- Primal:
  - Node = street junction
  - Link = street segment
- Dual
  - Node = street segment (e.g. its centroid)
  - Links = they connect vertexes if the segments are linked in the original representation.



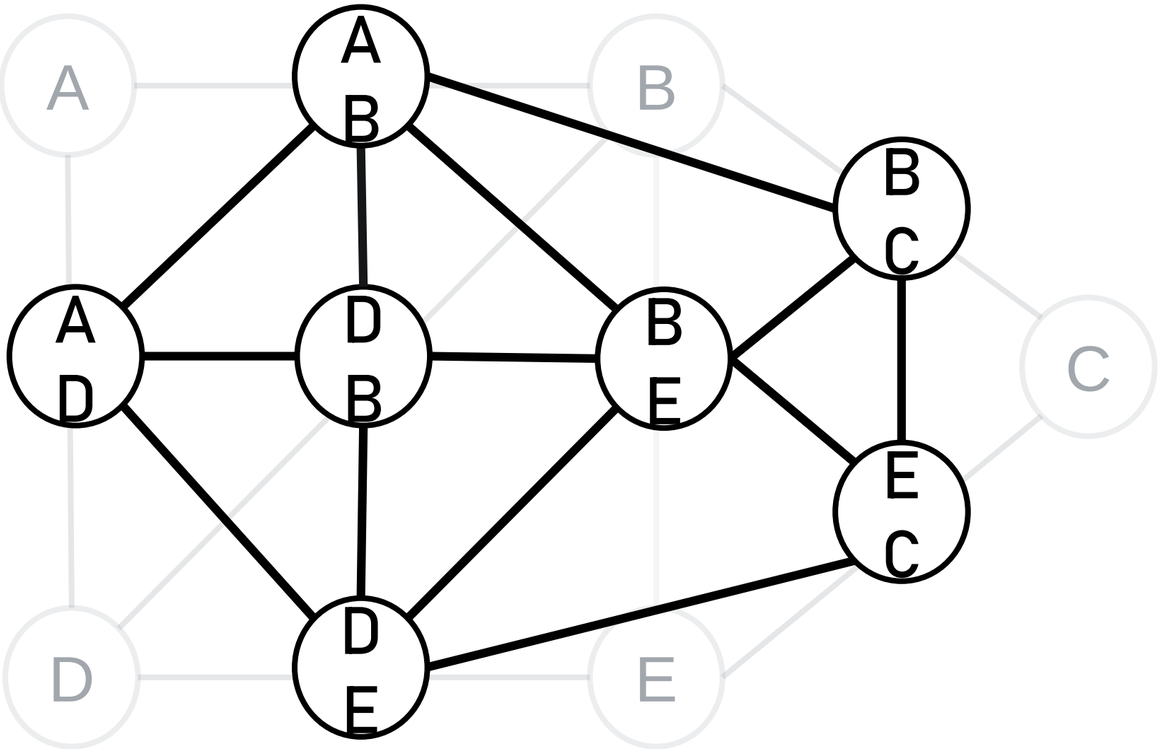
Source Neira (2017)

PG preserve geographic and metric information

Primal vs *Dual* graph

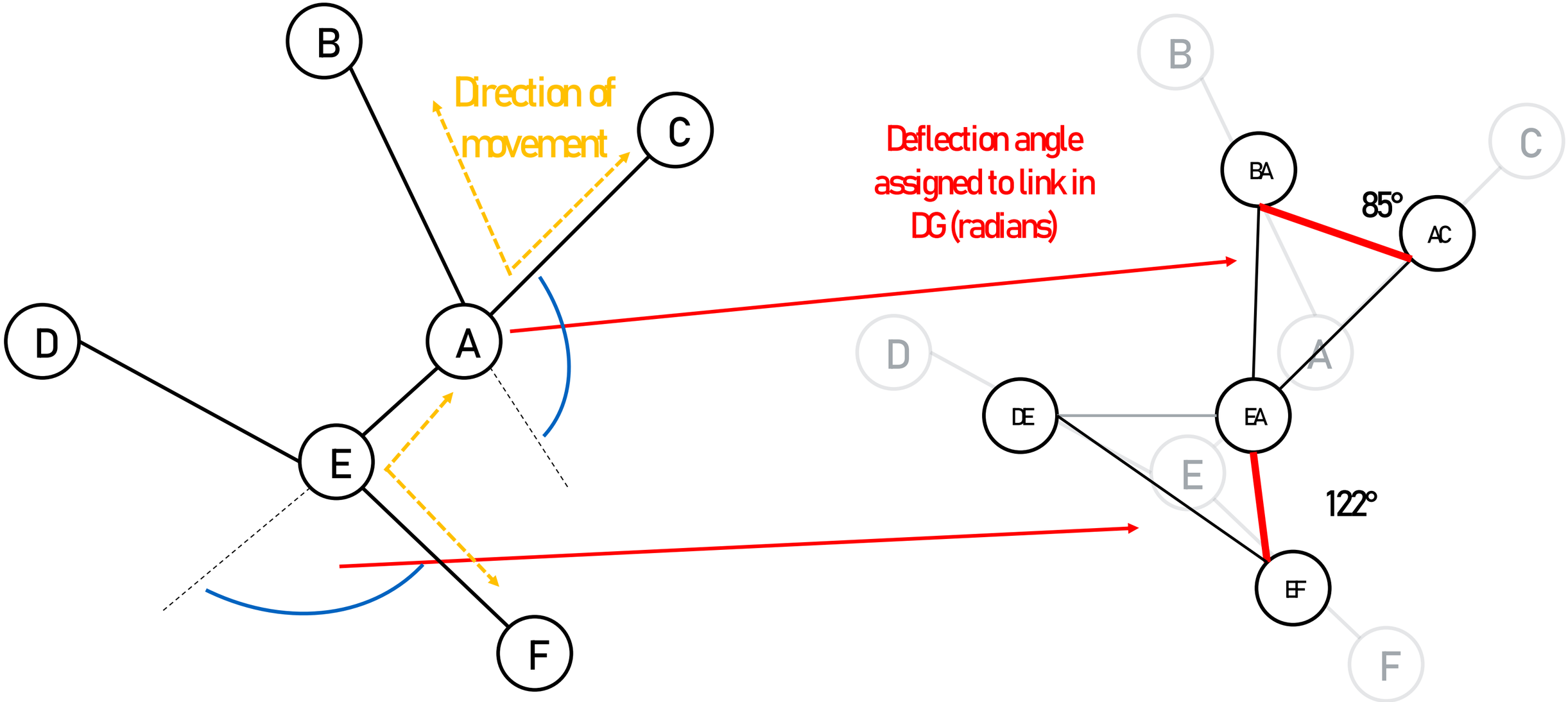


From Primal to Dual representation

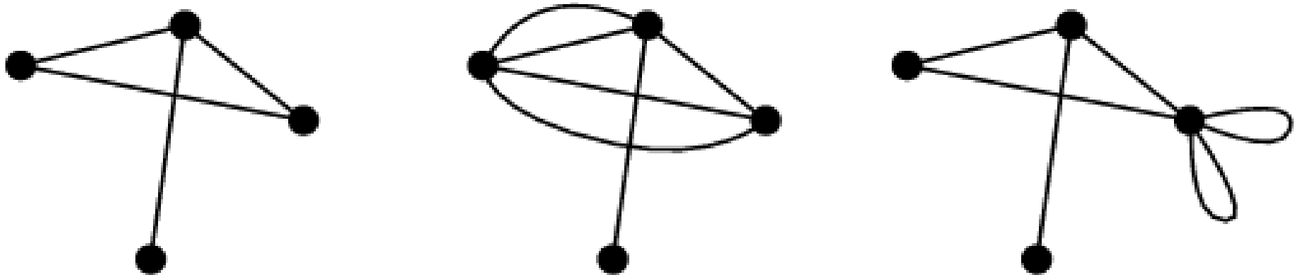


DG allows to compute ANGULAR-CHANGE shortest-path

Computing deflection angles



Simple graph and pseudo-nodes

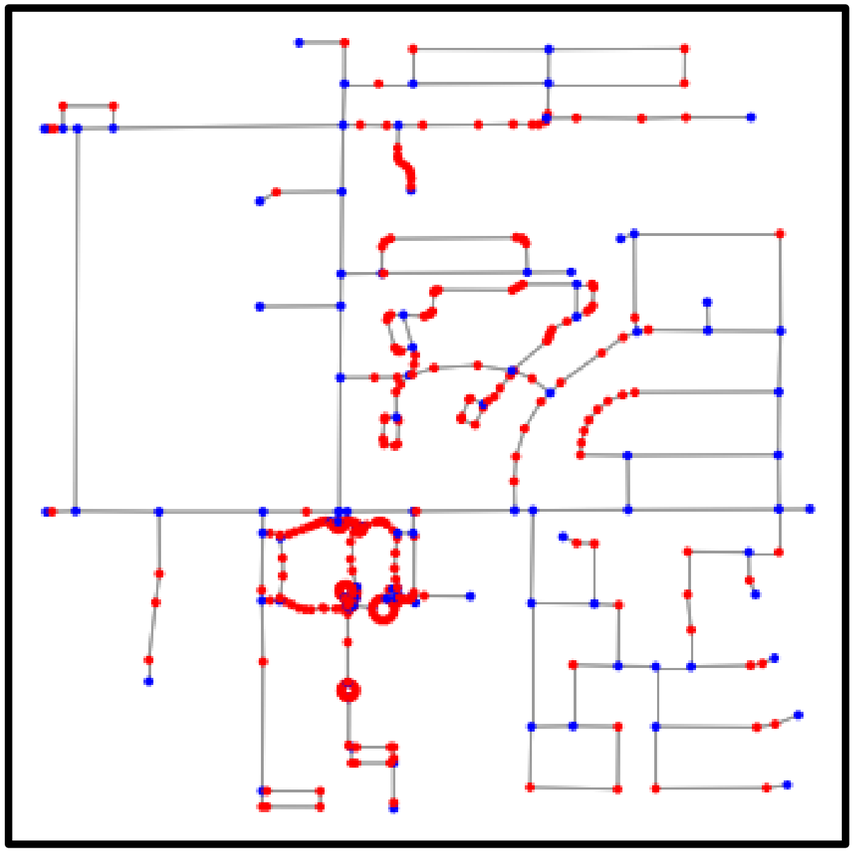


simple graph

nonsimple graph with multiple edges

nonsimple graph with loops

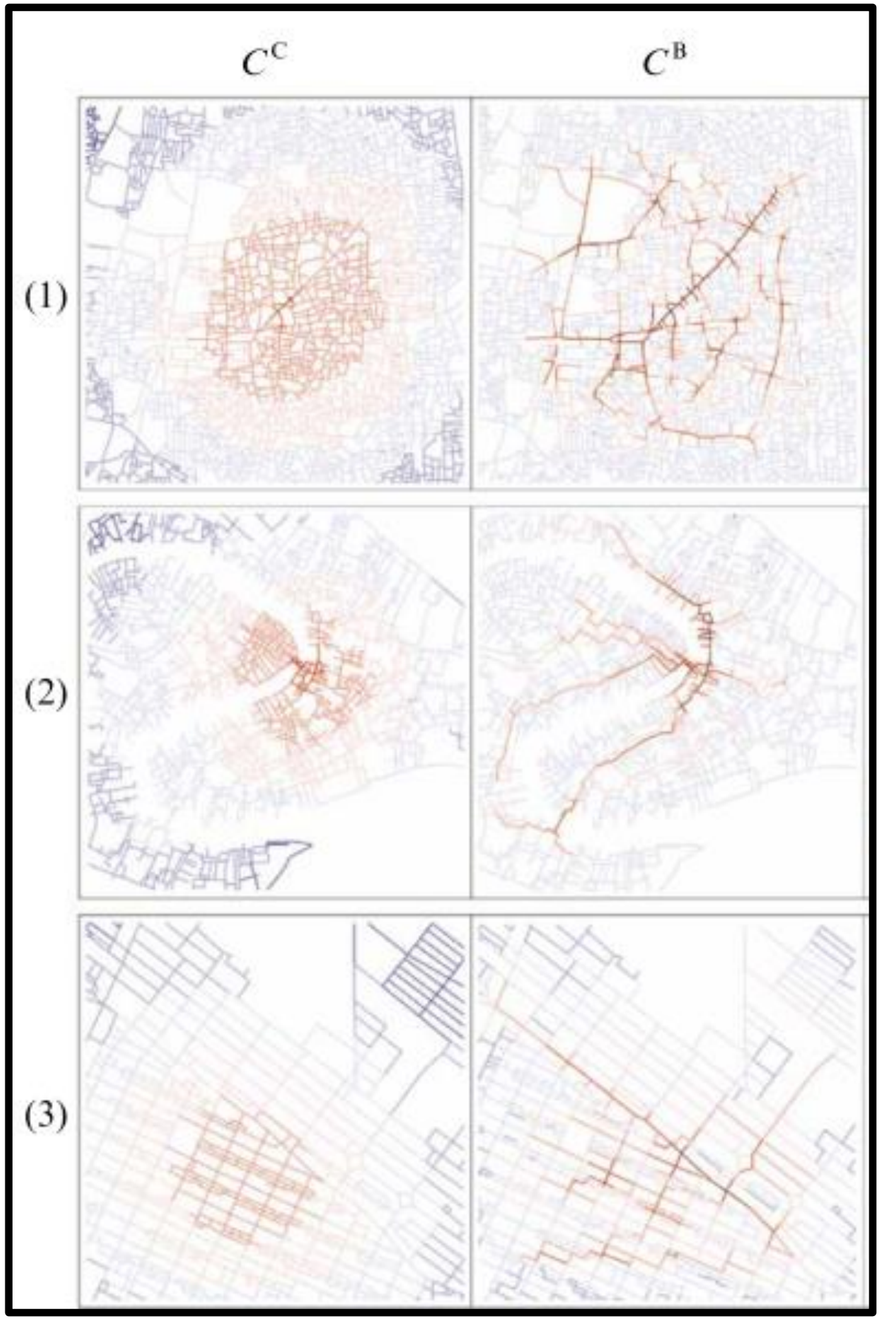
Source: mathworld.wolfram.com



Source Boeing (2017)

Centrality measures in cities

- Closeness centrality or betweenness centrality?
- What do they tell about the city?
- Connectivity and network resilience
- Drawbacks?



Source Porta et al. (2006a)

Python Tools

- *OSMNx* (street-network specific)
- *NetworkX*
- *iGraph* (faster than NetworkX)

OSMnx: Python for Street Networks

Check out the journal article about OSMnx.

OSMnx is a Python package for downloading administrative boundary shapes and street networks from OpenStreetMap. It allows you to easily construct, project, visualize, and analyze complex street networks in Python with NetworkX. You can get a city's or neighborhood's walking, driving, or biking network with a single line of Python code. Then you can simply visualize cul-de-sacs or one-way streets, plot shortest-path routes, or calculate stats like intersection density, average node connectivity, or betweenness centrality. You can download/cite the paper here.

In a single line of code, OSMnx lets you download, construct, and visualize the street network for, say, Modena Italy:

```
1 import osmnx as ox
2 ox.plot_graph(ox.graph_from_place('Modena, Italy
```

OpenStreetMap

History and Quality

Readapted from Michael Szell's slides
see https://github.com/mszell/geospatialdatascience/tree/main/unit08_openstreetmap/materials

OpenStreetMap (OSM) is like Wikipedia for maps

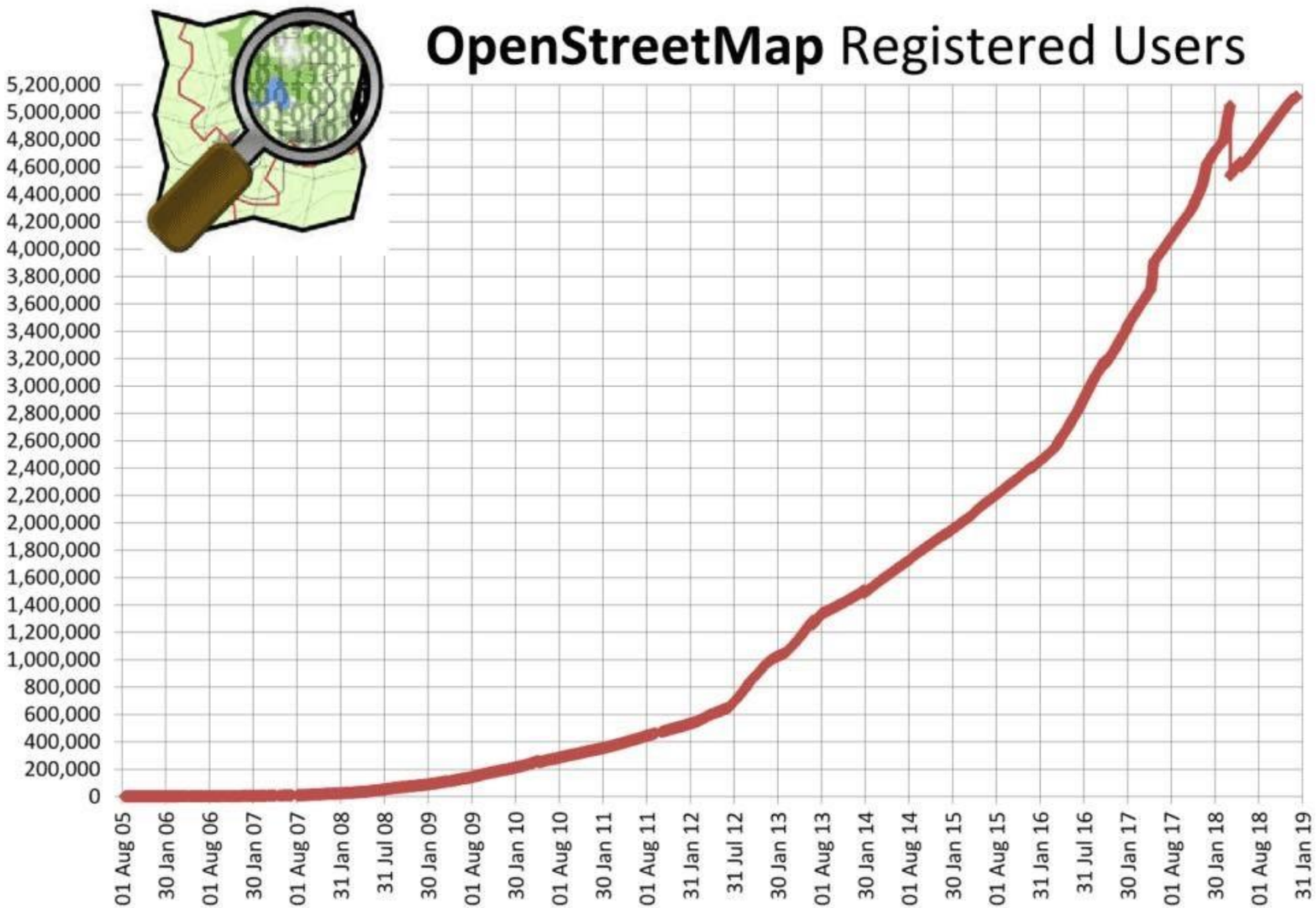
- Established in 2004 by Steve Coast
- Volunteered Geographical Information (VGI)
- The basis for most routing apps and many geo services (Amazon, Mapbox, Tesla, …)
- Contributors are not just local mappers, but huge organizations

openstreetmap.org

OSM is huge

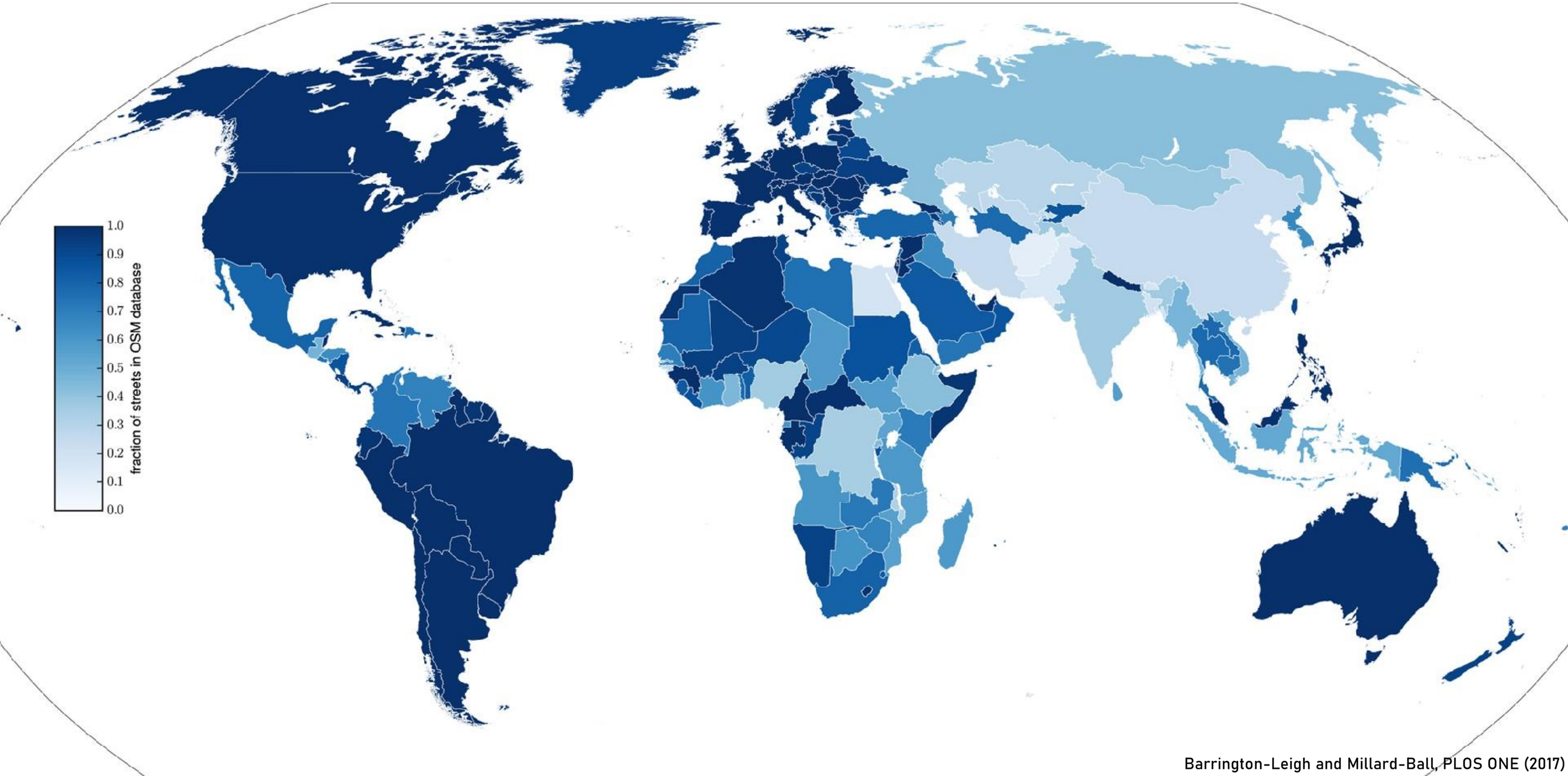
- 6 Million contributors
- 9 Billion elements

Probably more



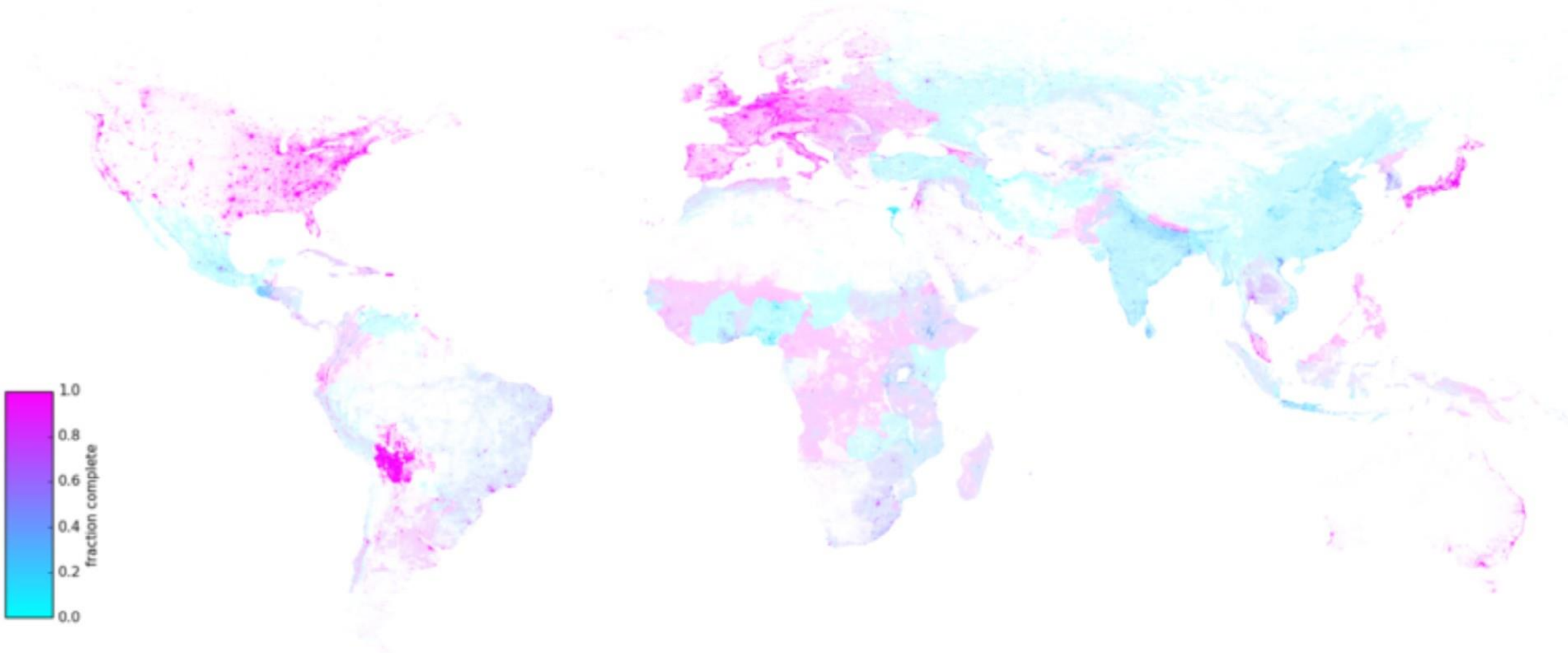
openstreetmap.org

OSM is relatively complete



Barrington-Leigh and Millard-Ball, PLOS ONE (2017)

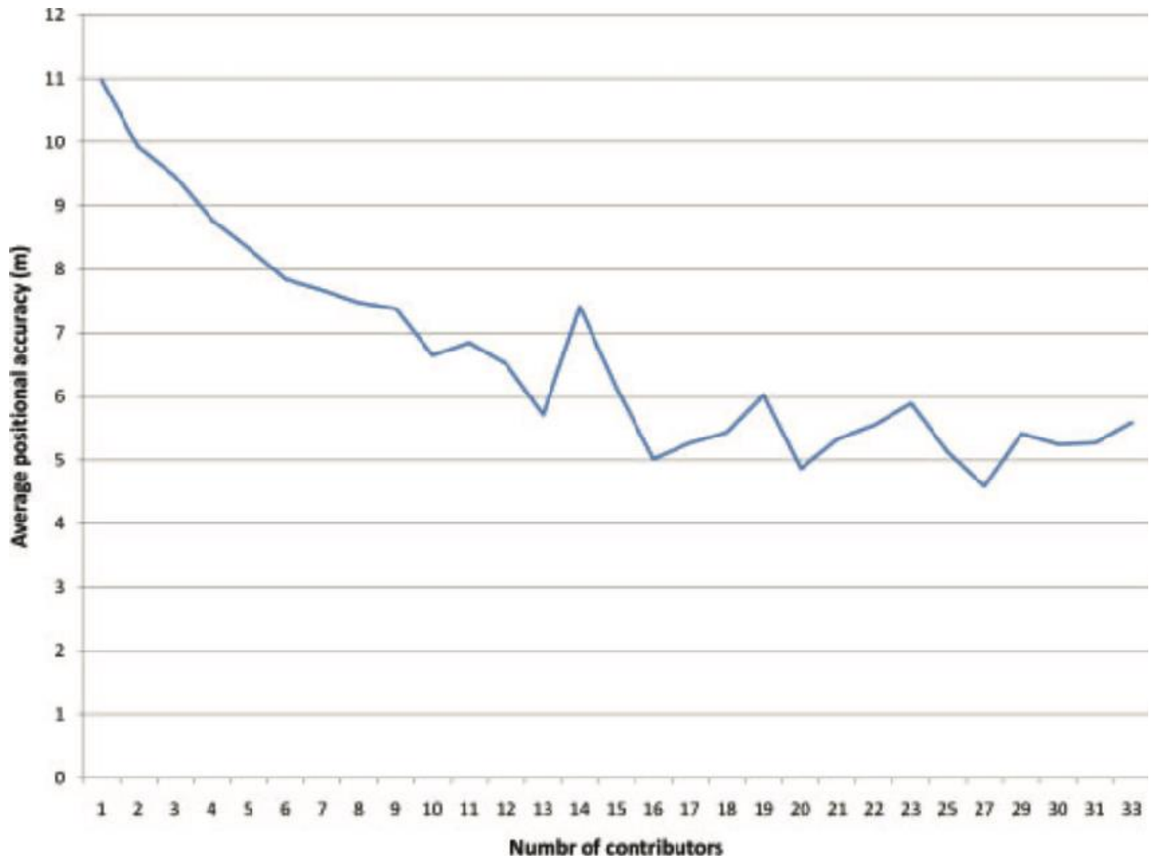
OSM is relatively complete



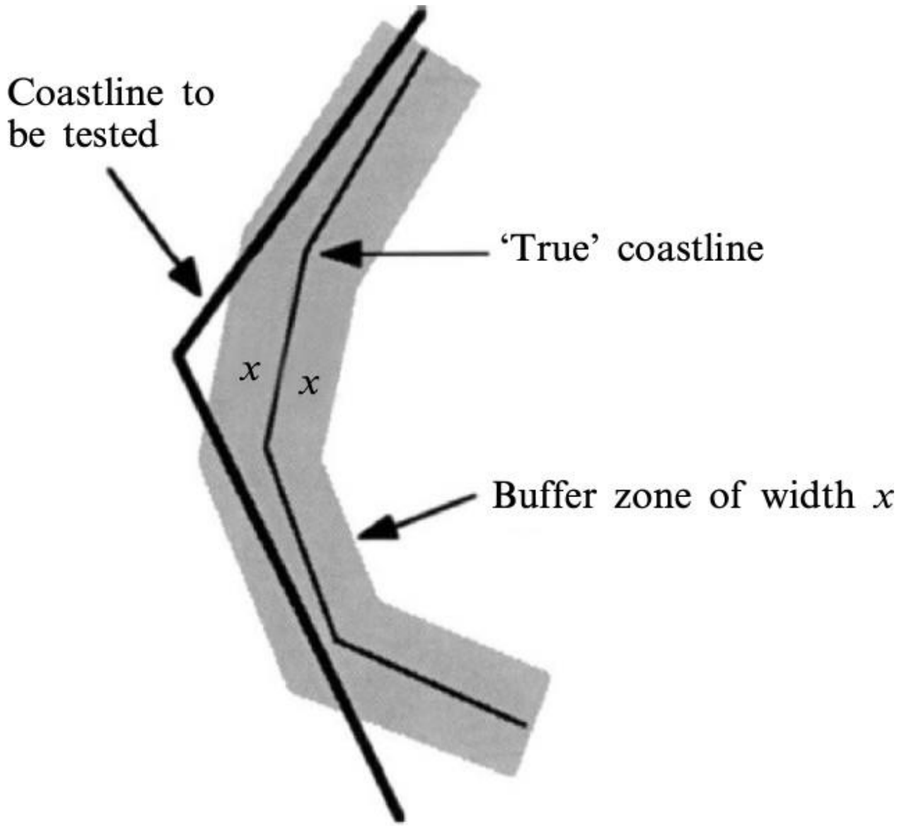
Barrington-Leigh and Millard-Ball, PLOS ONE (2017)

OSM is relatively accurate

The more contributors, the better the accuracy



Buffer-zone method between OSM and ground truth



Haklay et al. (2010)


POUL HENNINGSENS PLADS ST
JAGTVEJ
JAGTVEJ
Jagtvej
Poul Henningsens Plad
Nyborg

Why OSM and not Google maps?

OSM	*Google maps*
Free, also for commercial applications	Not free, licensing and fees at whim of management
Ecosystem of open tools, research	Proprietary
Less polished rendering and UX	More polished rendering and UX
Underlies most map-based software	Integration with Google products
Maps cycle paths, footpaths, etc.	Car-centric, less complete

https://studiosoftware.com/blog/google-maps-vs-openstreetmap/

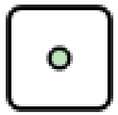
OpenStreetMap

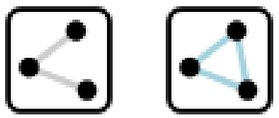
Accessing & Handling OSM Data

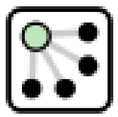
Readapted from Michael Szell's slides
see https://github.com/mszell/geospatialdatascience/tree/main/unit08_openstreetmap/materials

OSM topological data structure

3 elements / primitives:


Node *id, lat, lon*

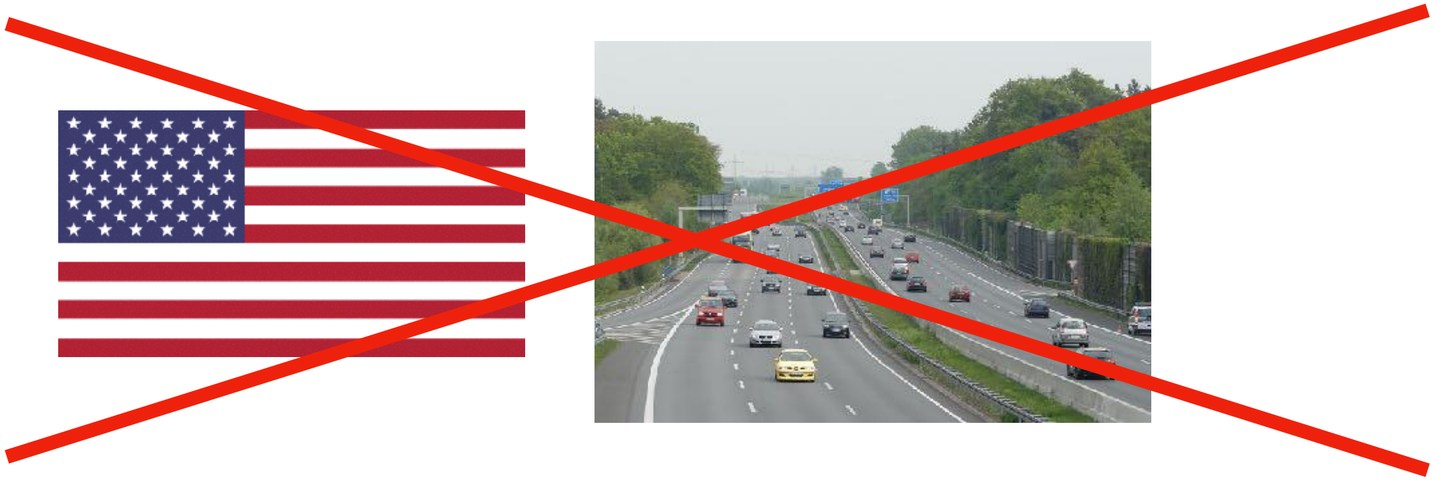

Way *ordered list of nodes*

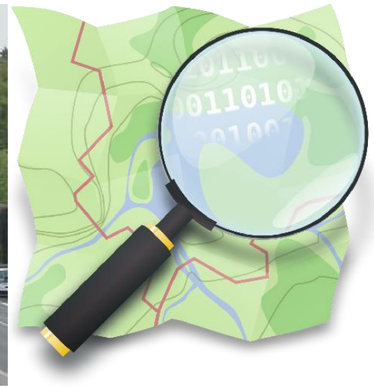

Relation *multiple elements*

Tag key=value, *describing an element's feature*

https://wiki.openstreetmap.org/wiki/Elements

The “highway” tag



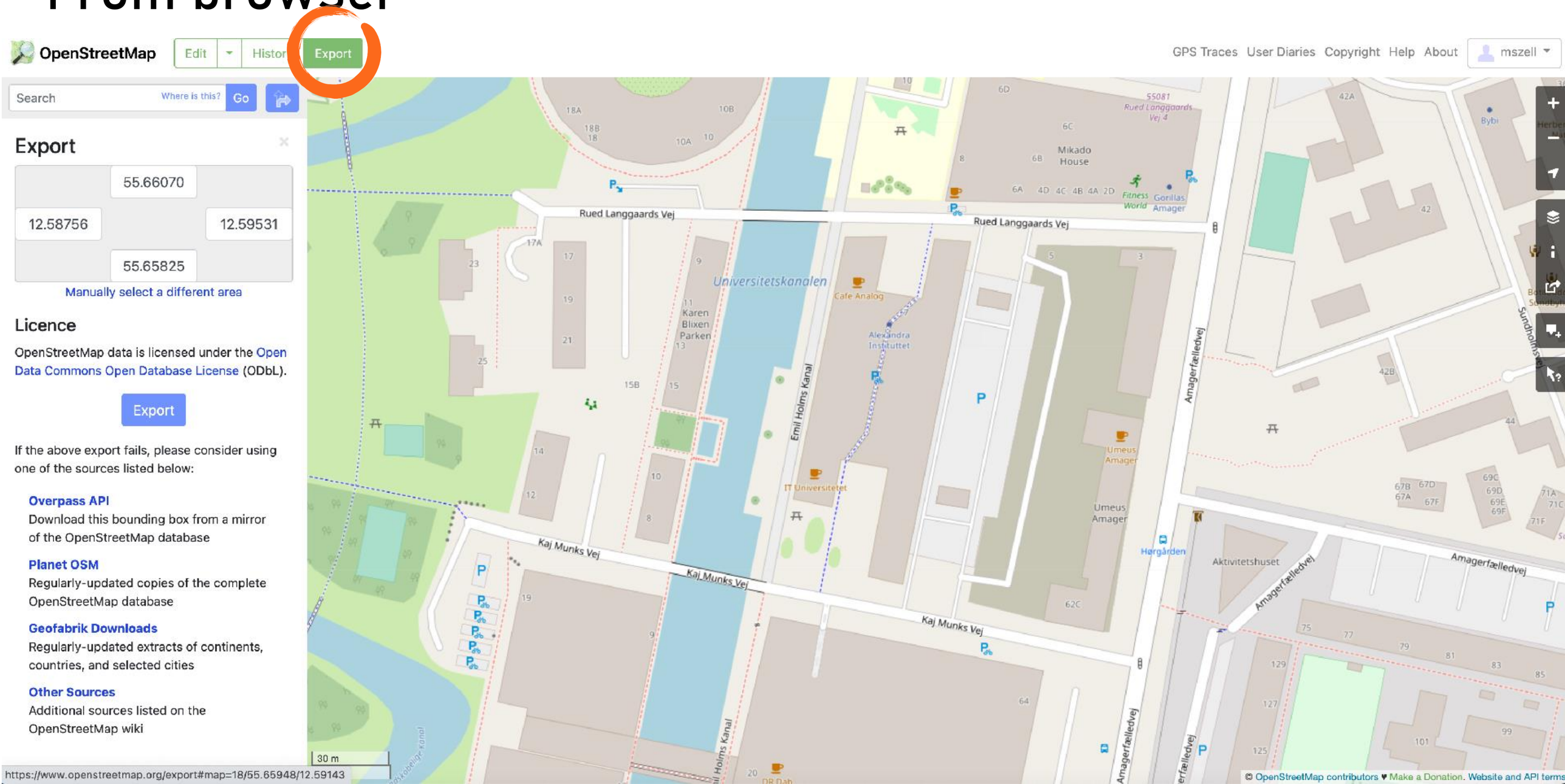


https://wiki.openstreetmap.org/wiki/Highways

How to access OSM Data

- Export from browser.
- Download via Overpass API/turbo .
- Download extracted region from distributor.
- Download via software (like JSOM) -> AVOID
- Download via Python (OSMnx) -> YES

From browser

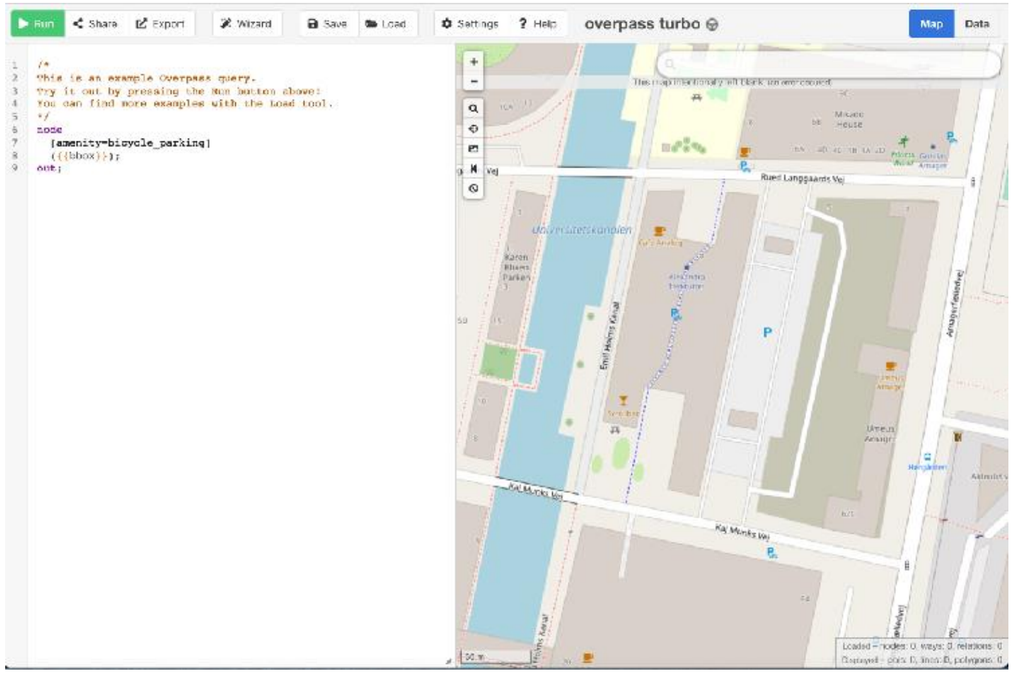


From Overpass API

- The Overpass API is a read-only API that serves up parts of the OSM map data.
- It acts as a database over the web: the client sends a query to the API and gets back the data set that corresponds to the query.
- Uses regex, is quite human-unreadable Syntax is limited

See https://wiki.openstreetmap.org/wiki/Overpass_API

```
/*
This query looks for nodes, ways and relations
with the given key/value combination.
Choose your region and hit the Run button above!
*/
[out:json][timeout:25];
// gather results
(
  // query part for: “amenity=post_box”
  node["amenity"="post_box"]({{bbox}});
  way["amenity"="post_box"]({{bbox}});
  relation["amenity"="post_box"]({{bbox}});
);
// print results
out body;
>;
out skel qt;
```



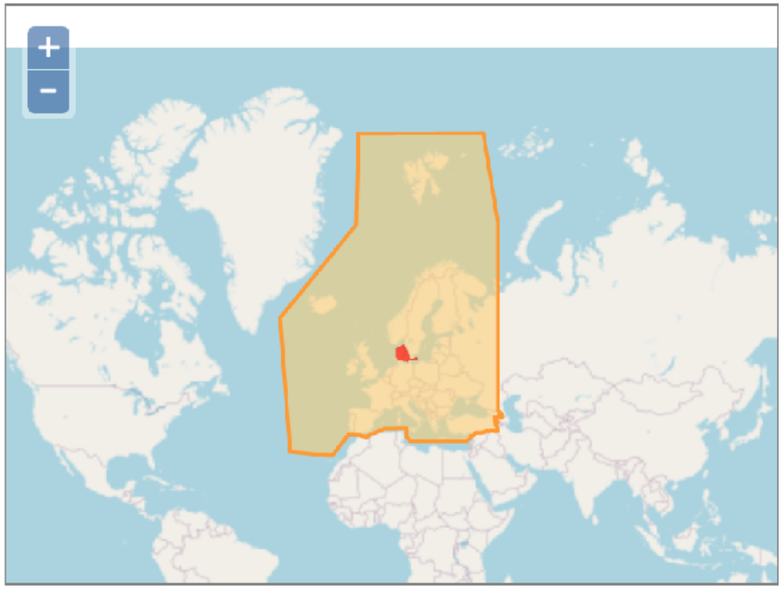
https://overpass-turbo.eu/

From Distributors

Sub Regions

Click on the region name to see the overview page for that region, or select one of the file extension links for quick access.

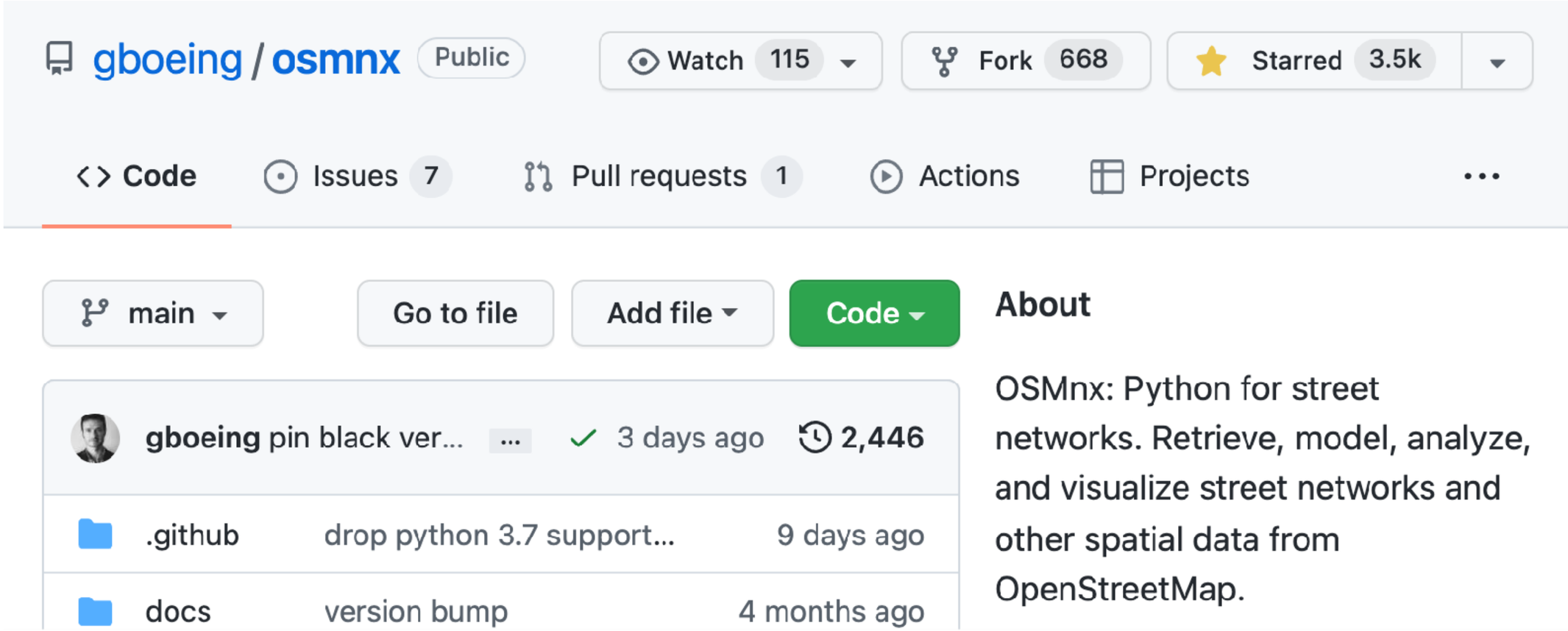
Sub Region	Quick Links		
	.osm.pbf	.shp.zip	.osm.bz2
Albania	[.osm.pbf] (42.7 MB)	[.shp.zip]	[.osm.bz2]
Andorra	[.osm.pbf] (1.8 MB)	[.shp.zip]	[.osm.bz2]
Austria	[.osm.pbf] (644 MB)	[.shp.zip]	[.osm.bz2]
Azores	[.osm.pbf] (12.4 MB)	[.shp.zip]	[.osm.bz2]
Belarus	[.osm.pbf] (244 MB)	[.shp.zip]	[.osm.bz2]
Belgium	[.osm.pbf] (462 MB)	[.shp.zip]	[.osm.bz2]
Bosnia-Herzegovina	[.osm.pbf] (107 MB)	[.shp.zip]	[.osm.bz2]
Bulgaria	[.osm.pbf] (111 MB)	[.shp.zip]	[.osm.bz2]
Croatia	[.osm.pbf] (135 MB)	[.shp.zip]	[.osm.bz2]
Cyprus	[.osm.pbf] (20.0 MB)	[.shp.zip]	[.osm.bz2]
Czech Republic	[.osm.pbf] (758 MB)	[.shp.zip]	[.osm.bz2]
Denmark	[.osm.pbf] (394 MB)	[.shp.zip]	[.osm.bz2]
Estonia	[.osm.pbf] (94 MB)	[.shp.zip]	[.osm.bz2]



https://download.geofabrik.de/

Custom extract https://extract.bbbike.org/

Via OSMnx (OSM + NetworkX)



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