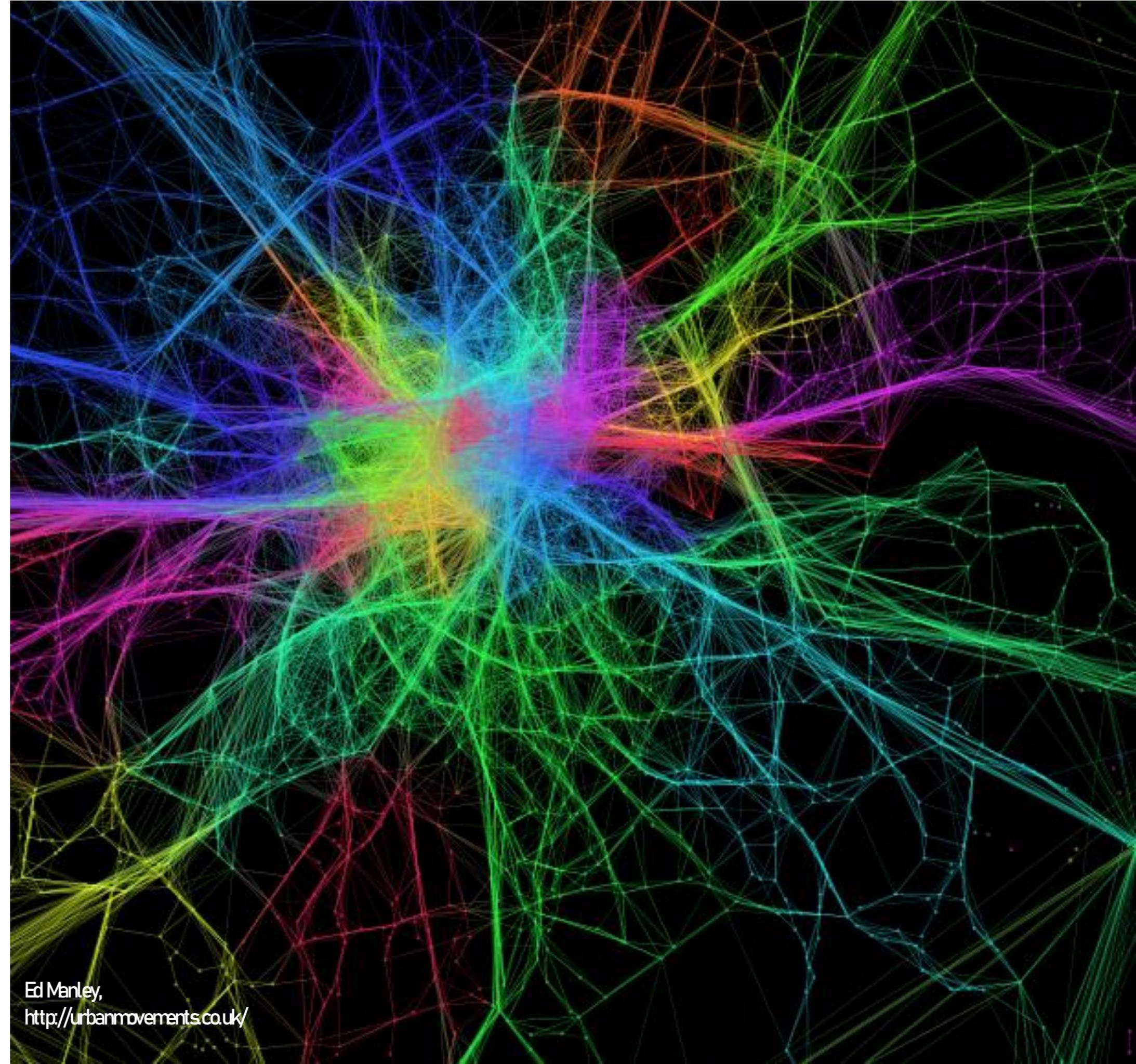


(Spatial) Networks and OpenStreetMap

ENVS456 – week 7
Gabriele Filomena



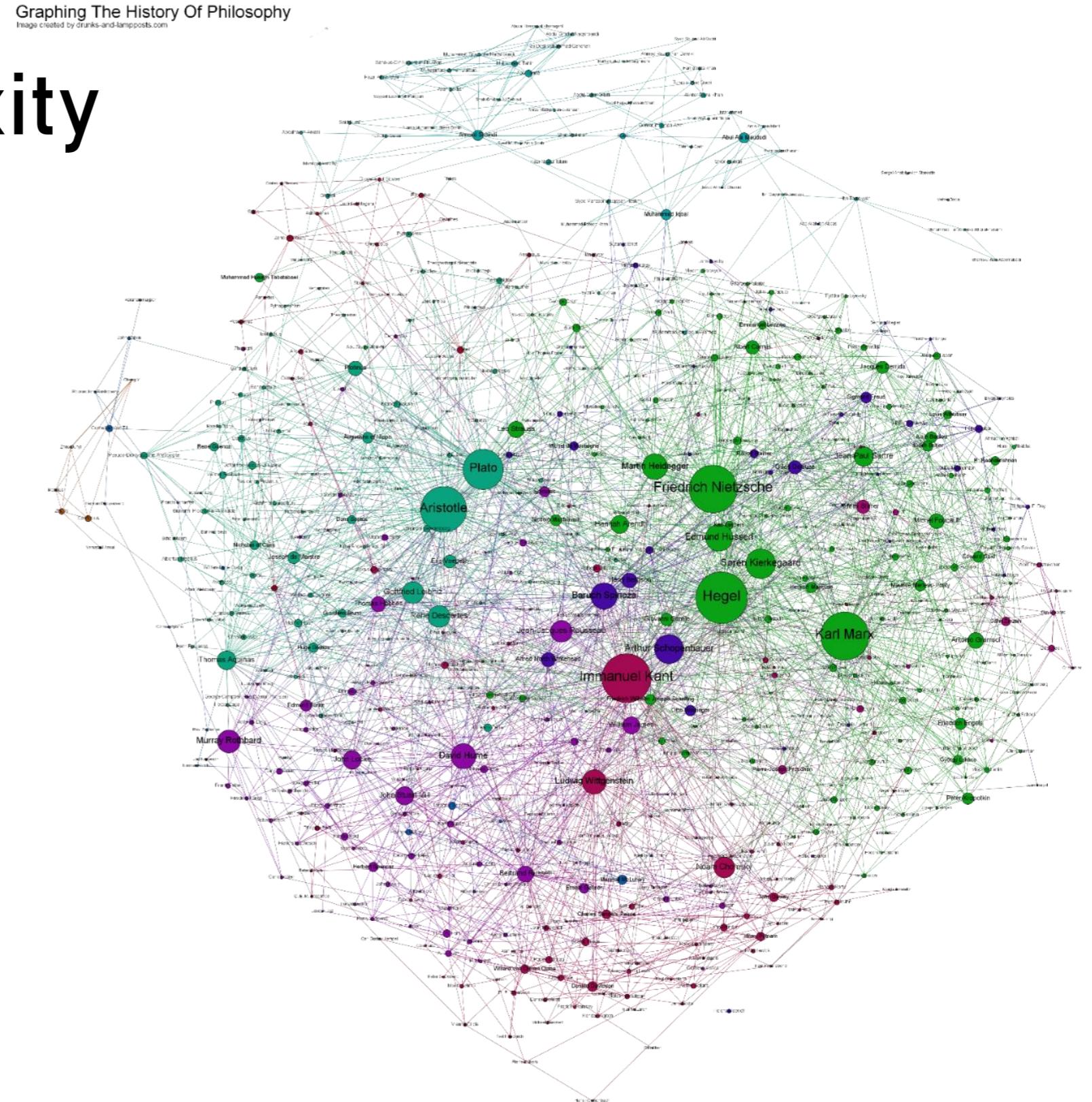
Agenda

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

Networks & Graphs

Network science and Complexity

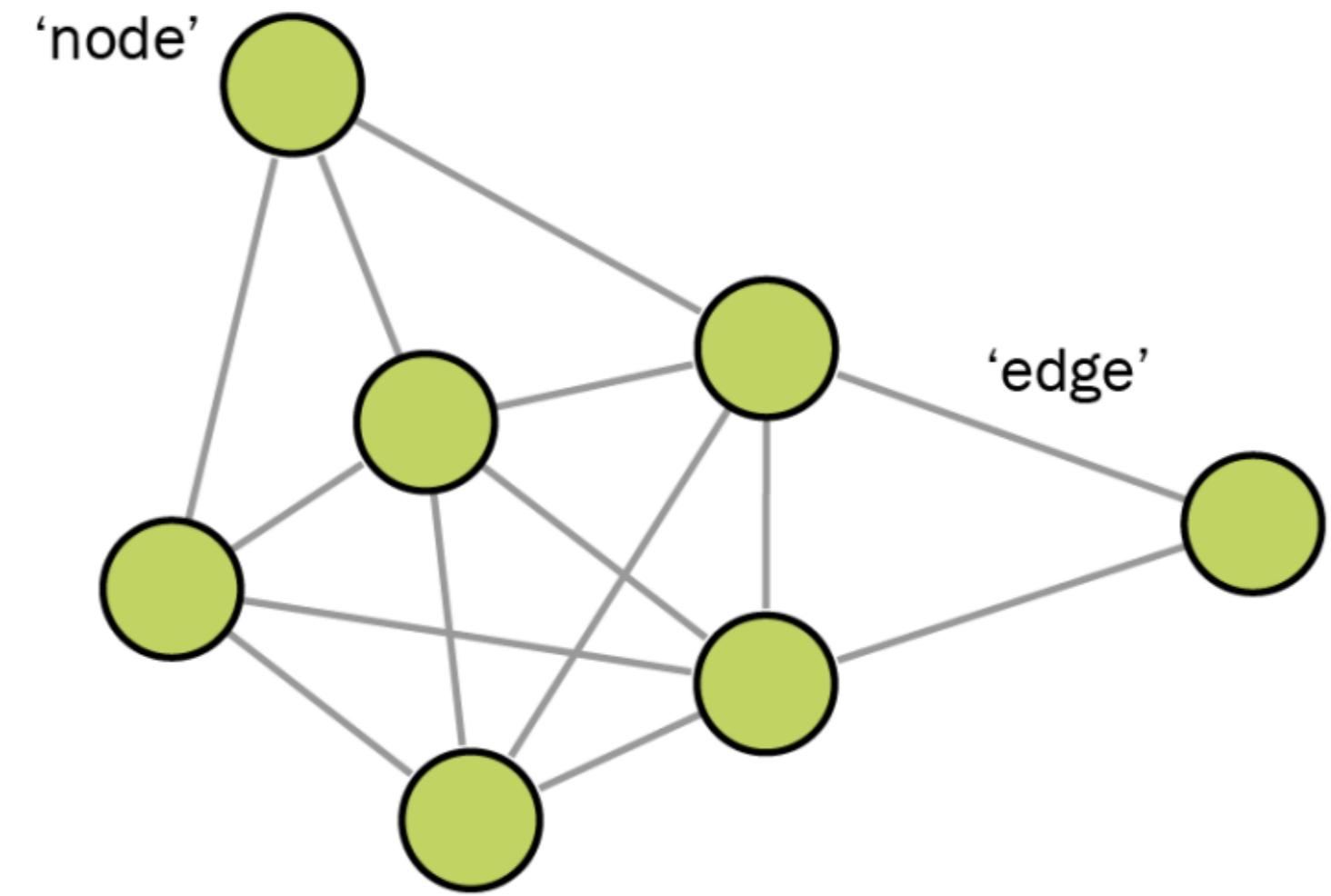
- Complex systems and interaction amongst its parts might be represented in various ways through networks.
- If we understand the dynamics of one system, we can extend the emerging patterns to different systems



Infer generic functioning mechanisms.

Graph Components

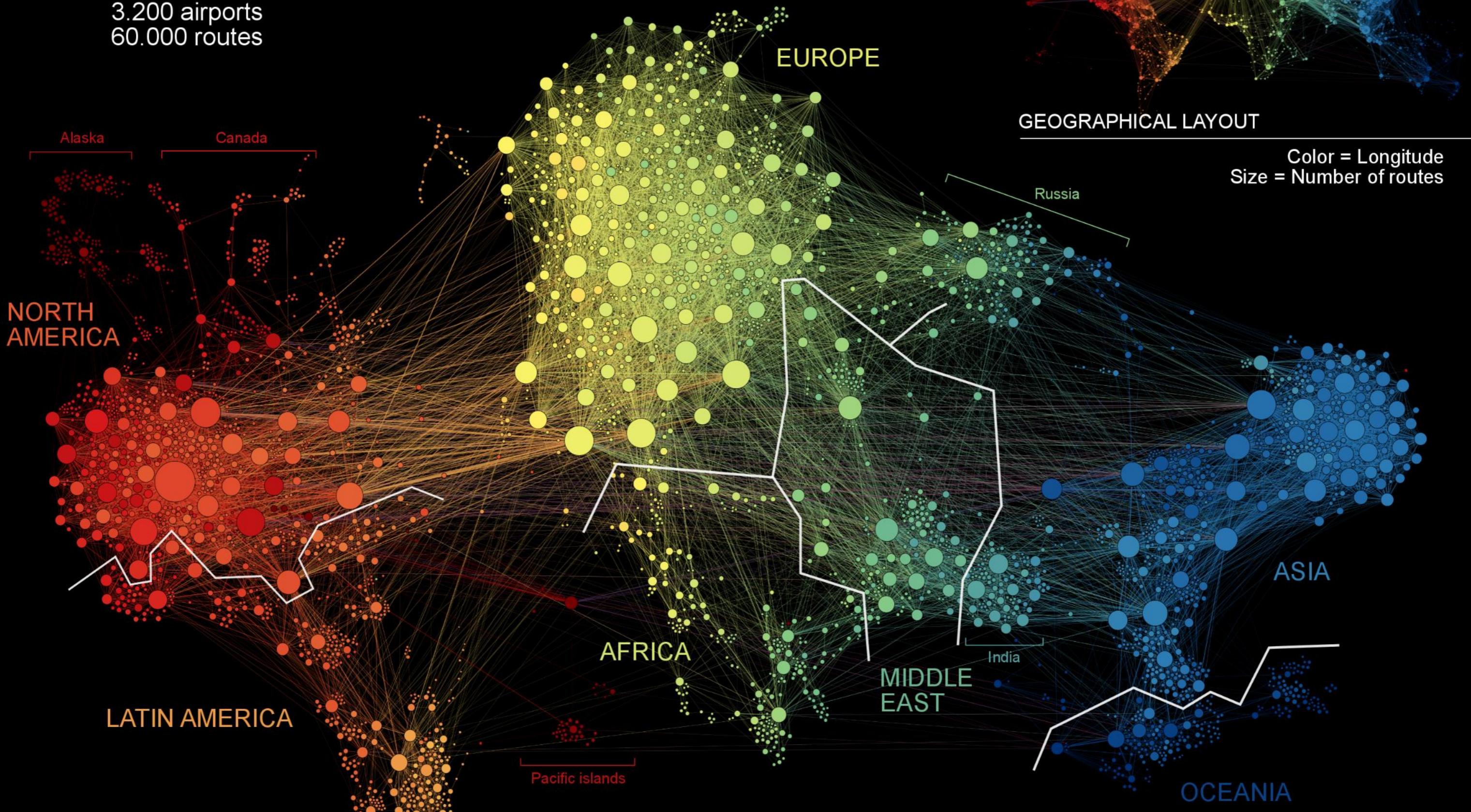
- Network science is built upon the foundation of graph theory.
- A *graph* is an abstract mathematical representation of a set of elements and the connections between them.

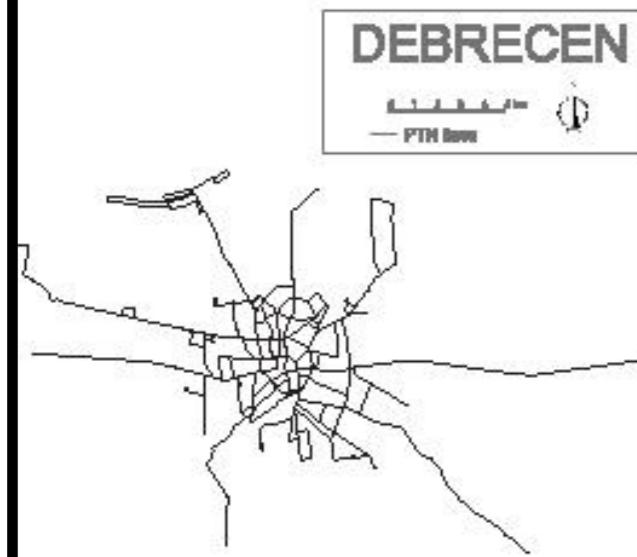


- components: nodes, vertices (n)
- interactions: links, edges (m)
- system: network, graph $G(n, m)$

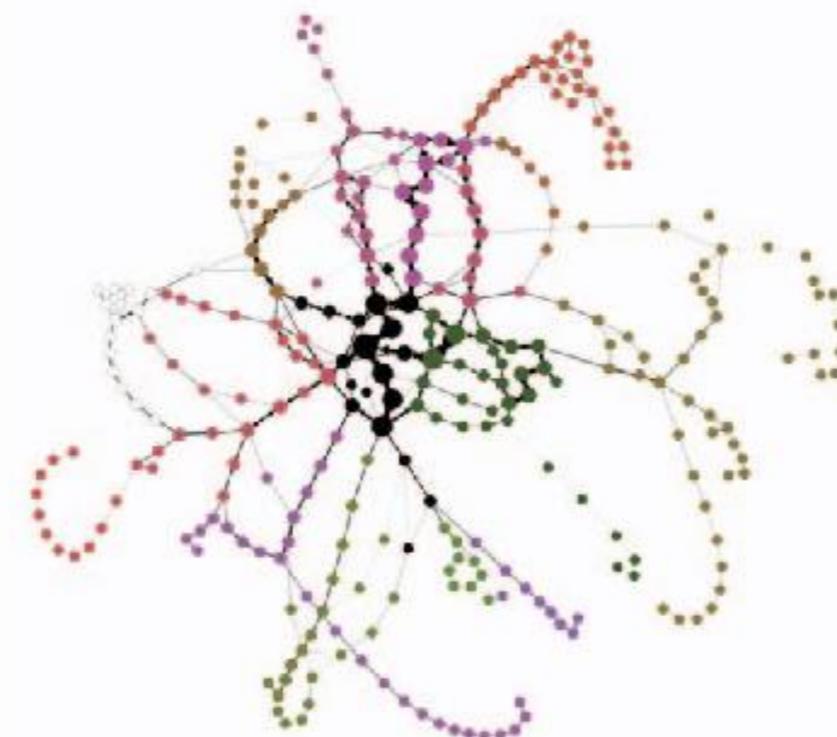
TRANSPORTATION CLUSTERS

3.200 airports
60.000 routes

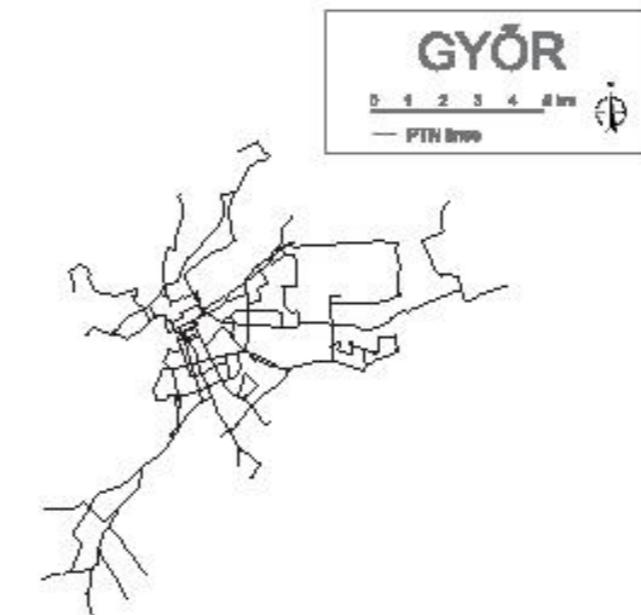




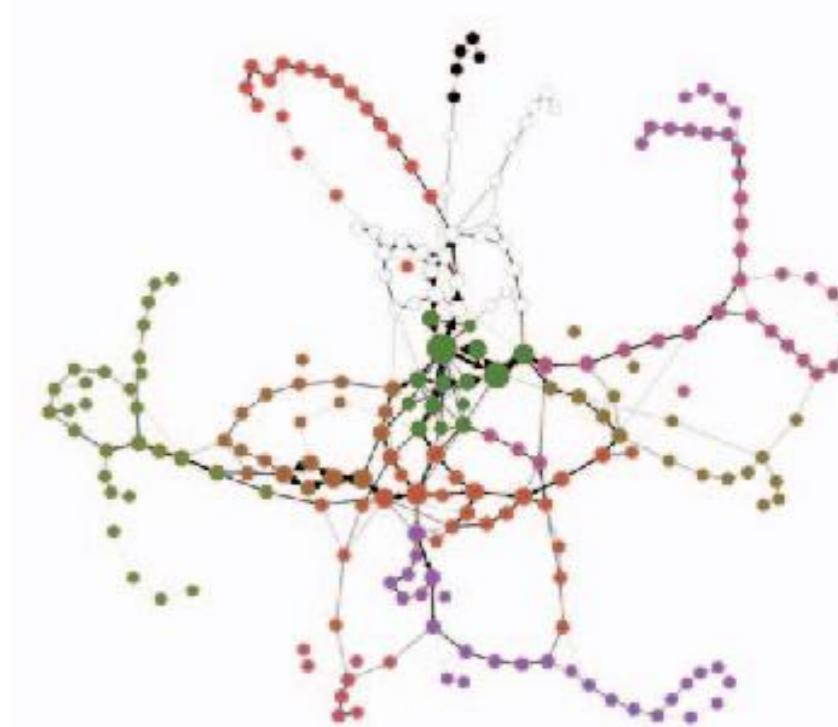
(a)



(b)



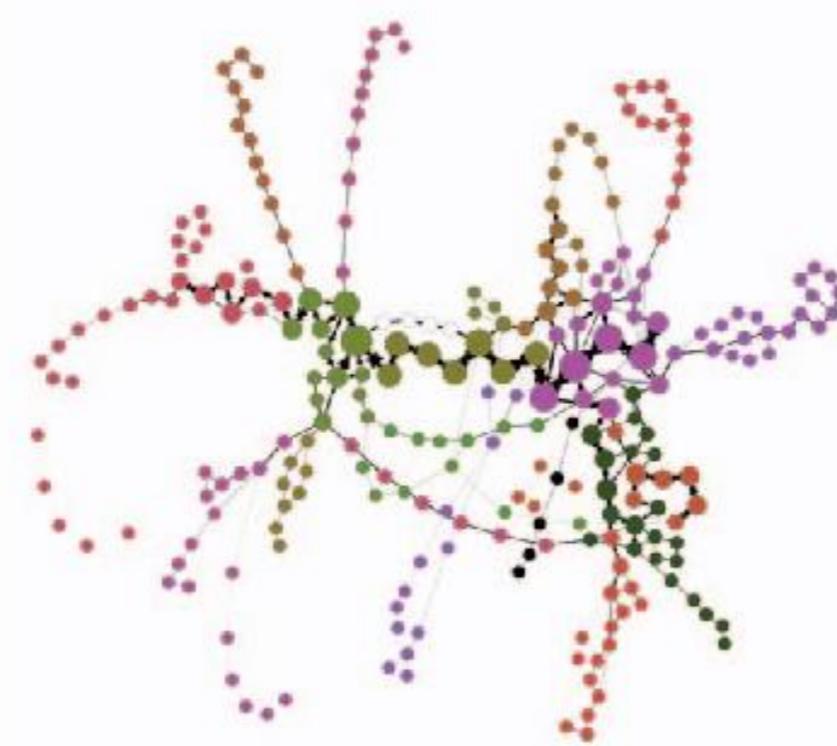
(c)



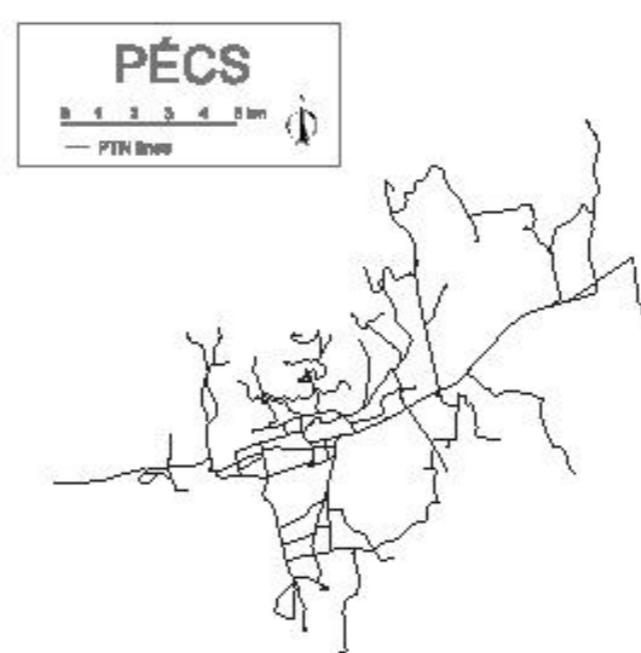
(d)



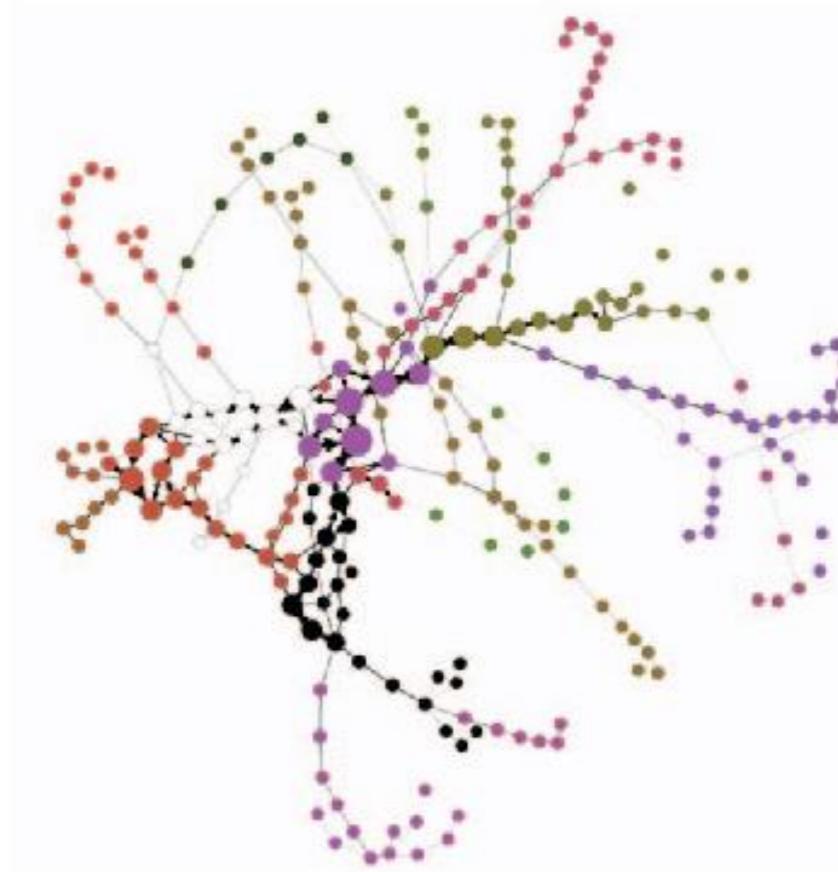
(e)



(f)

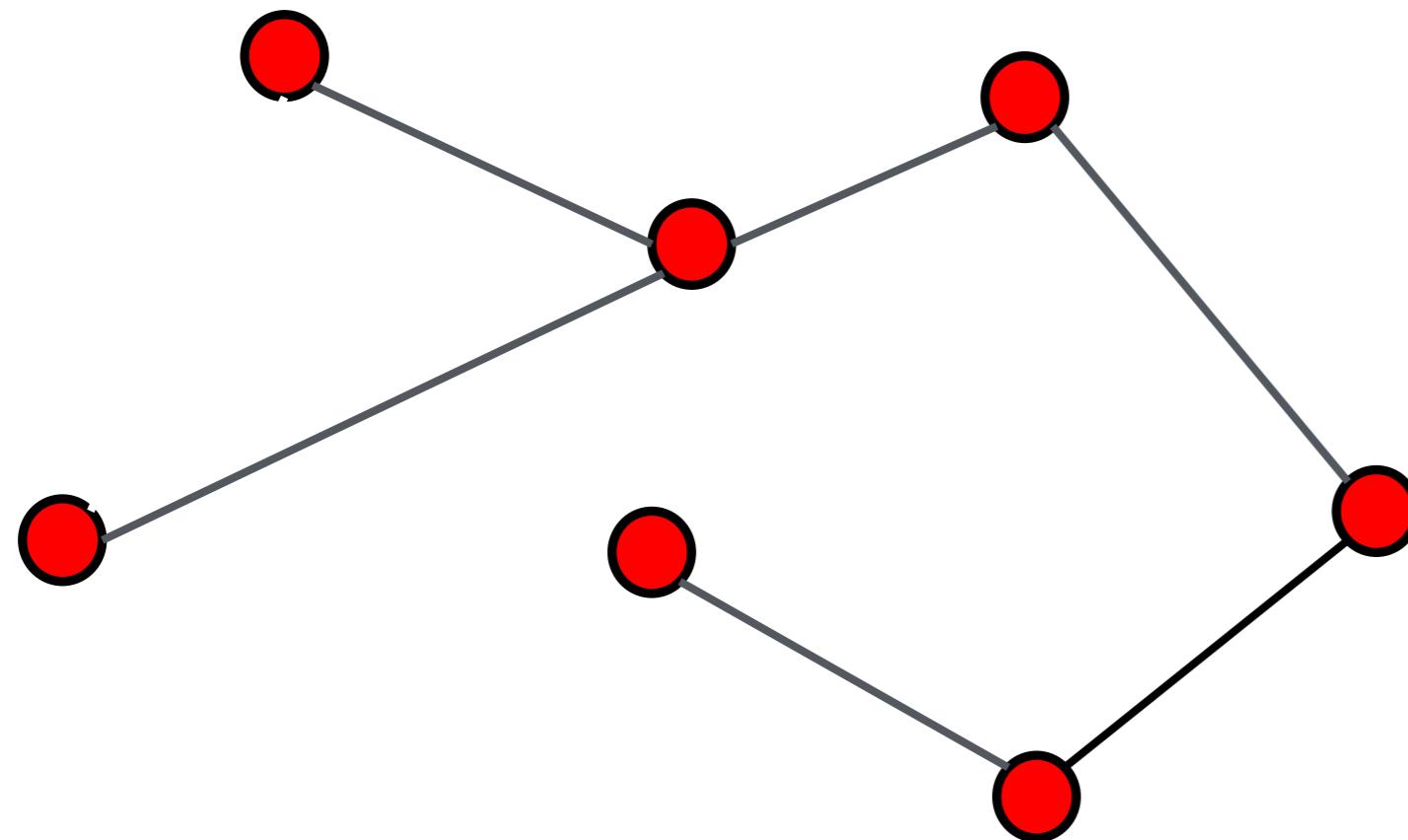


(g)

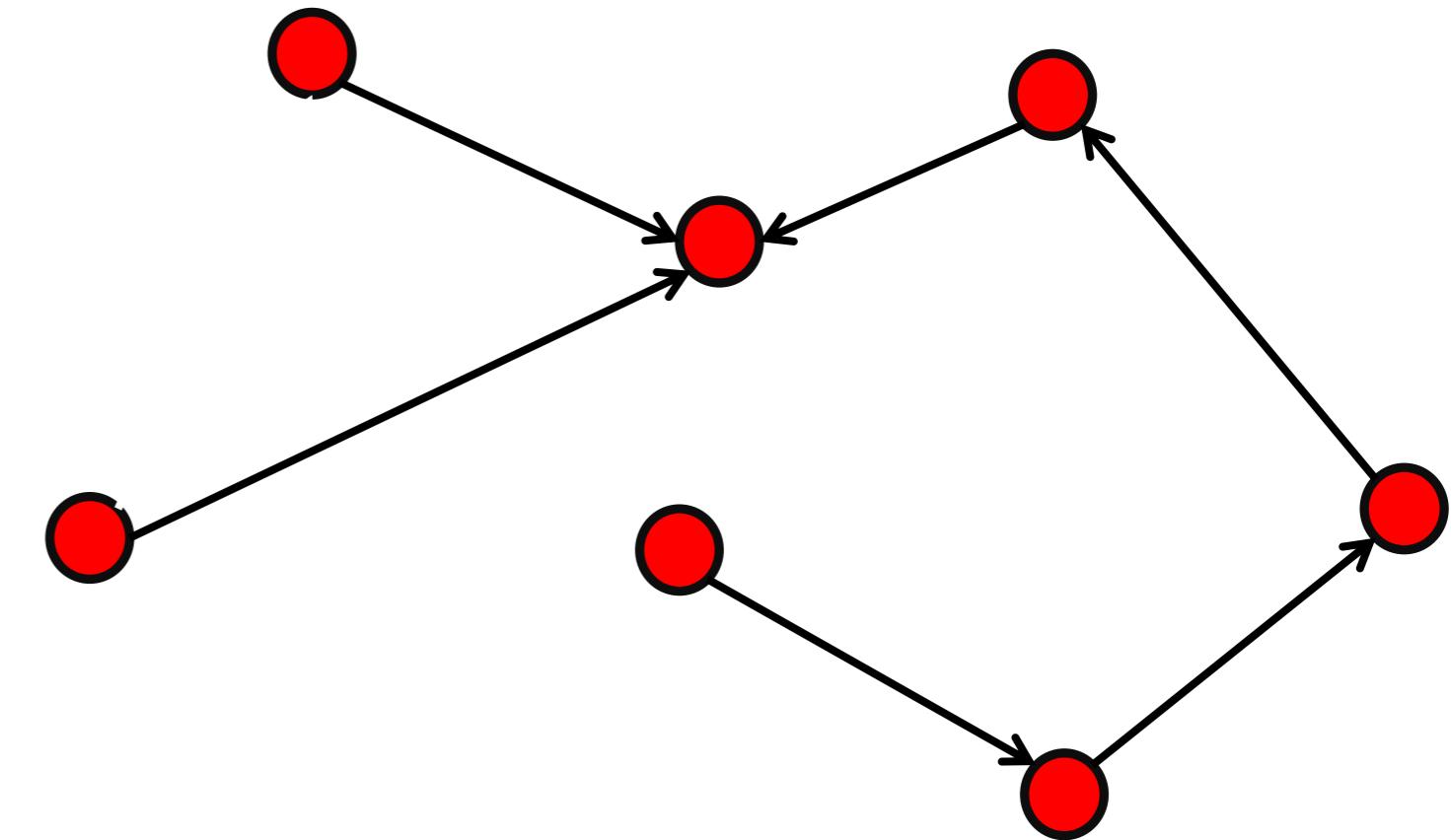


(h)

Undirected graph

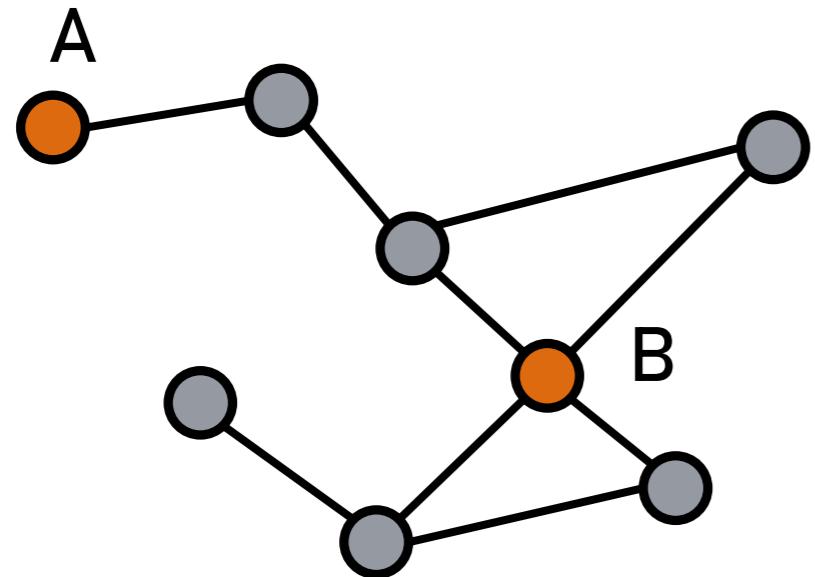


Directed graph (digraph)



Node Degree

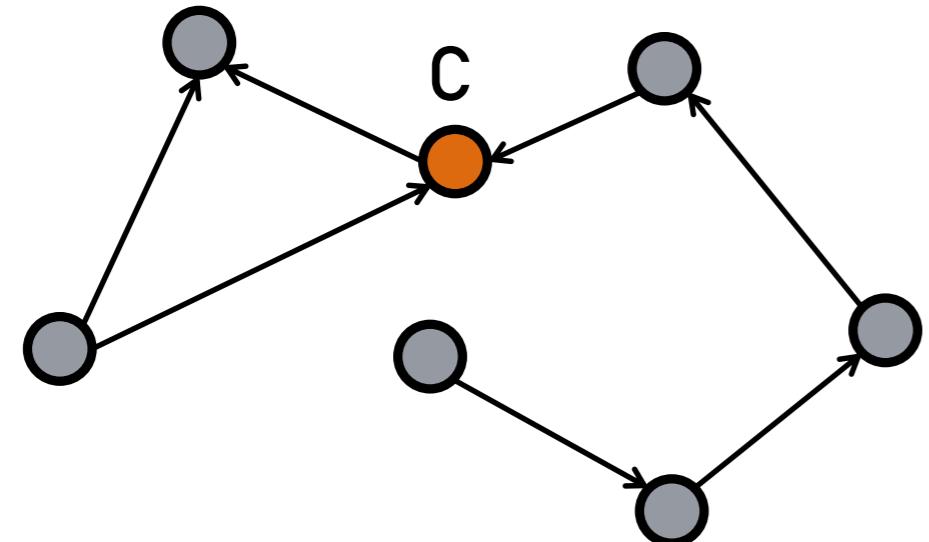
Undirected



The number of links connected to the node

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

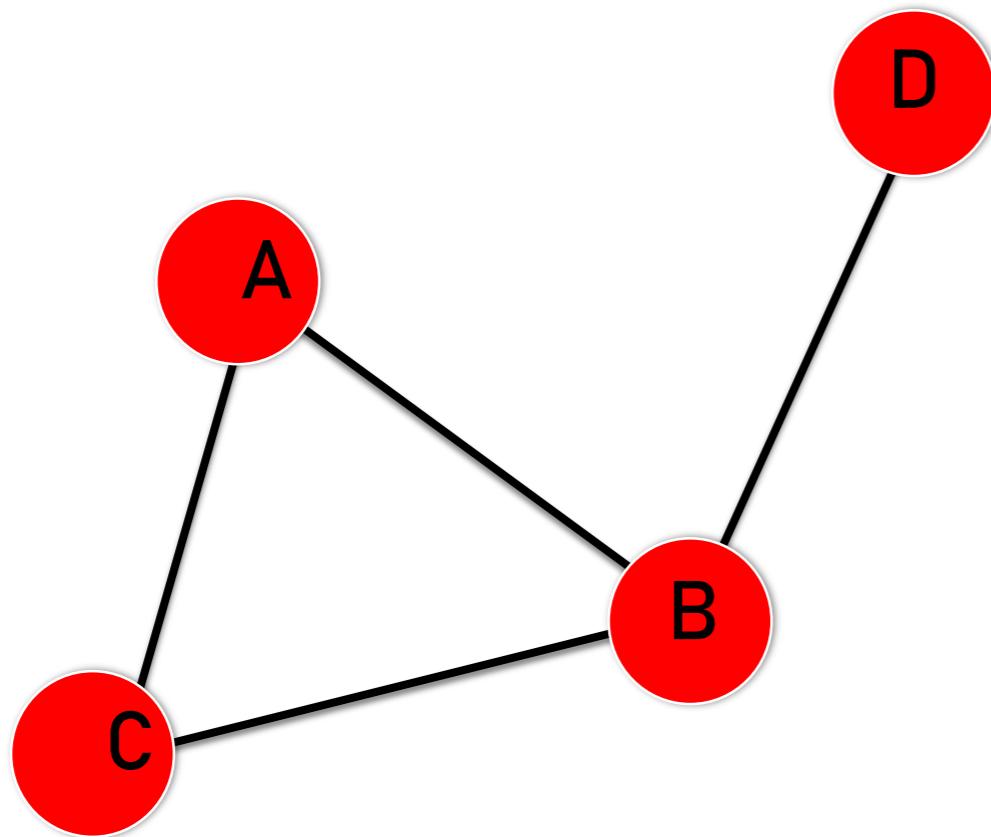
Directed



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

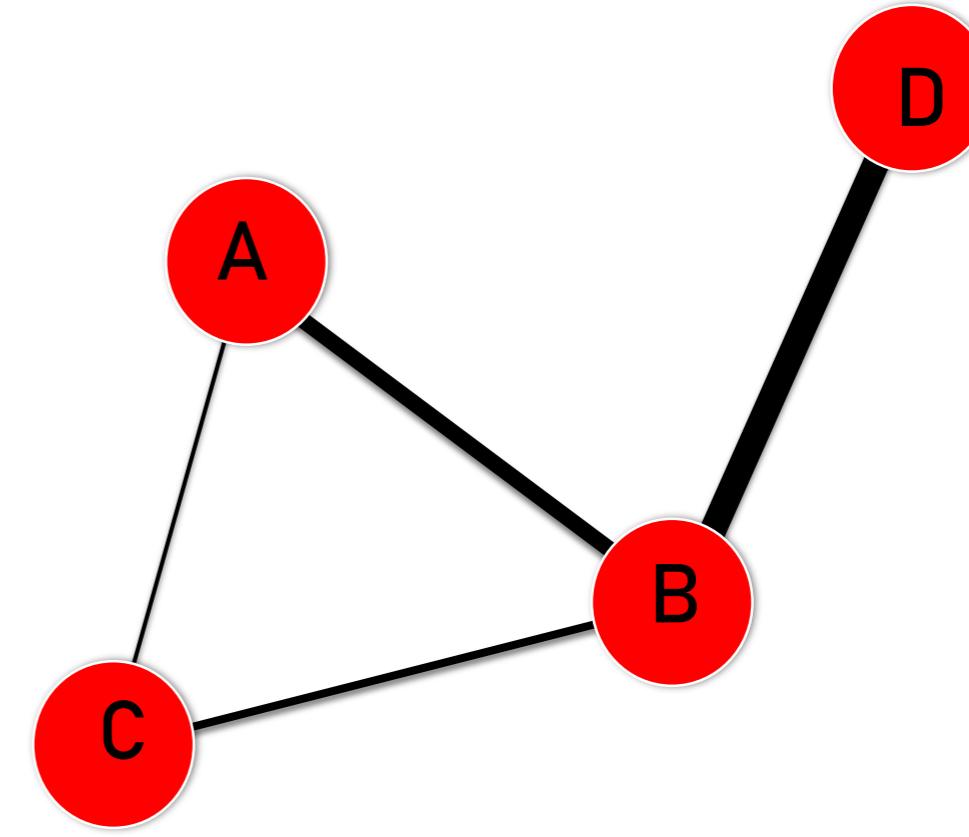
$$k_C^{in} = 2 \quad k_C^{out} = 1 \quad k_C = 3$$

Unweighted Graph



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

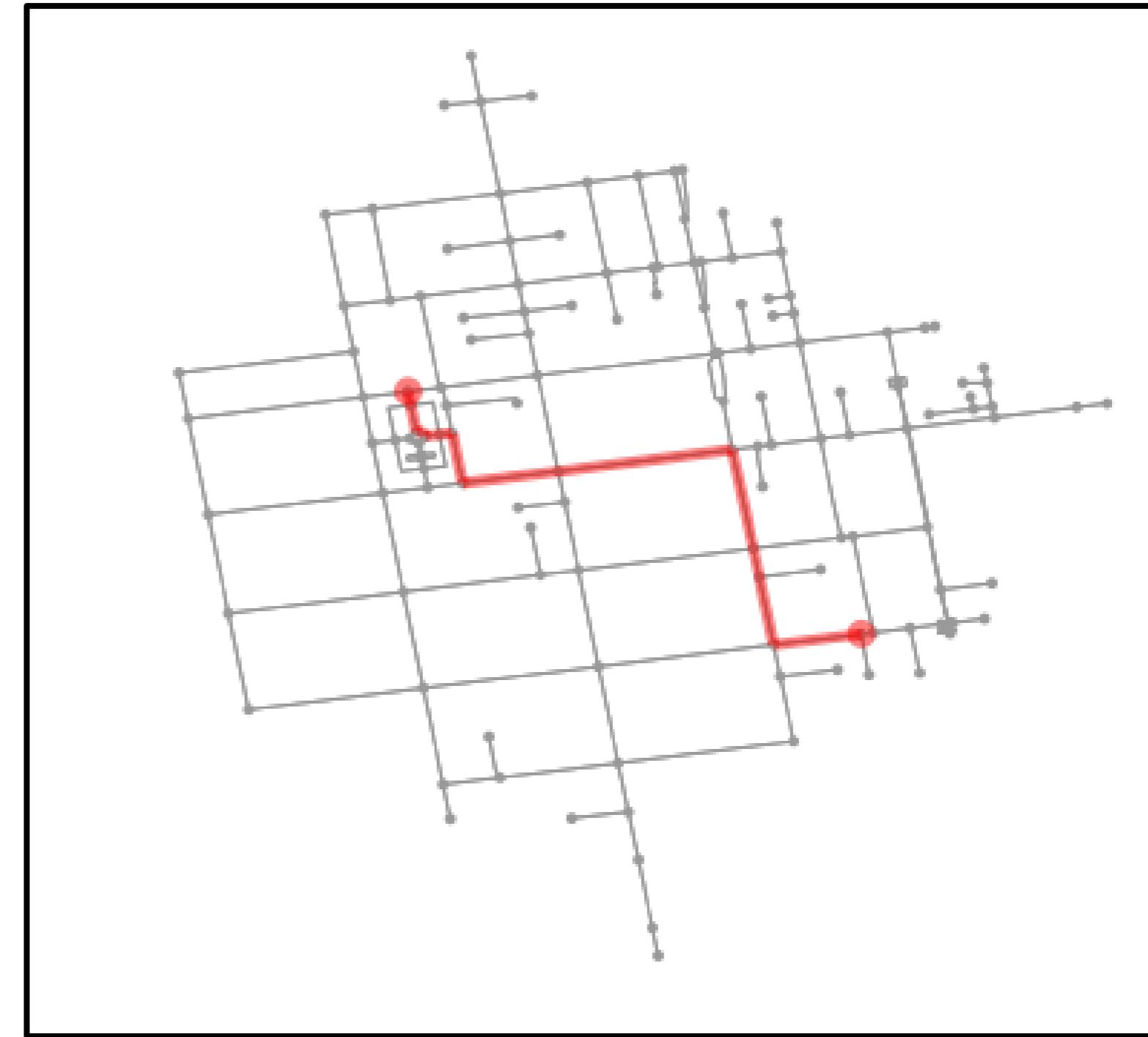
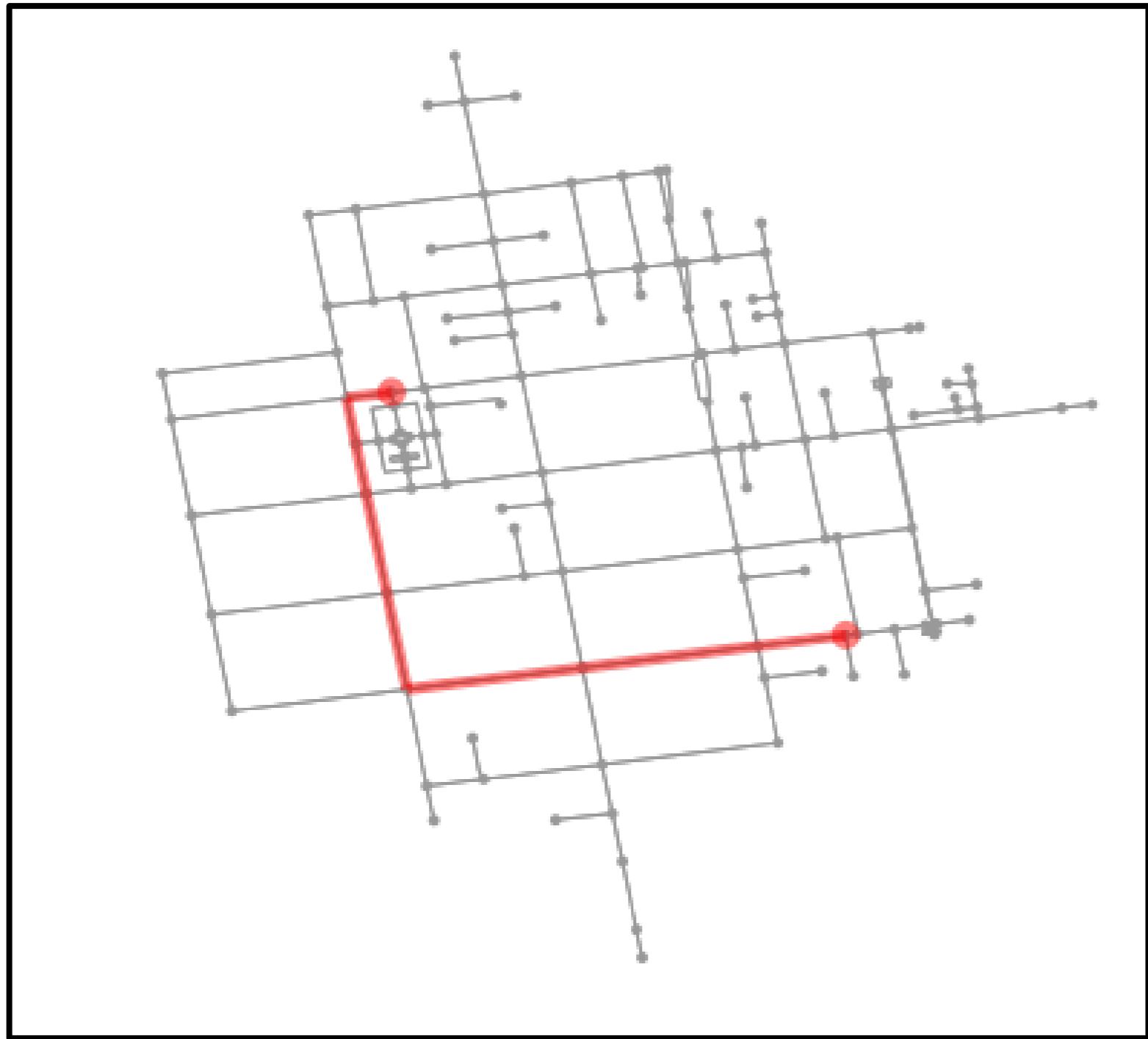
Weighted Graph



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

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*

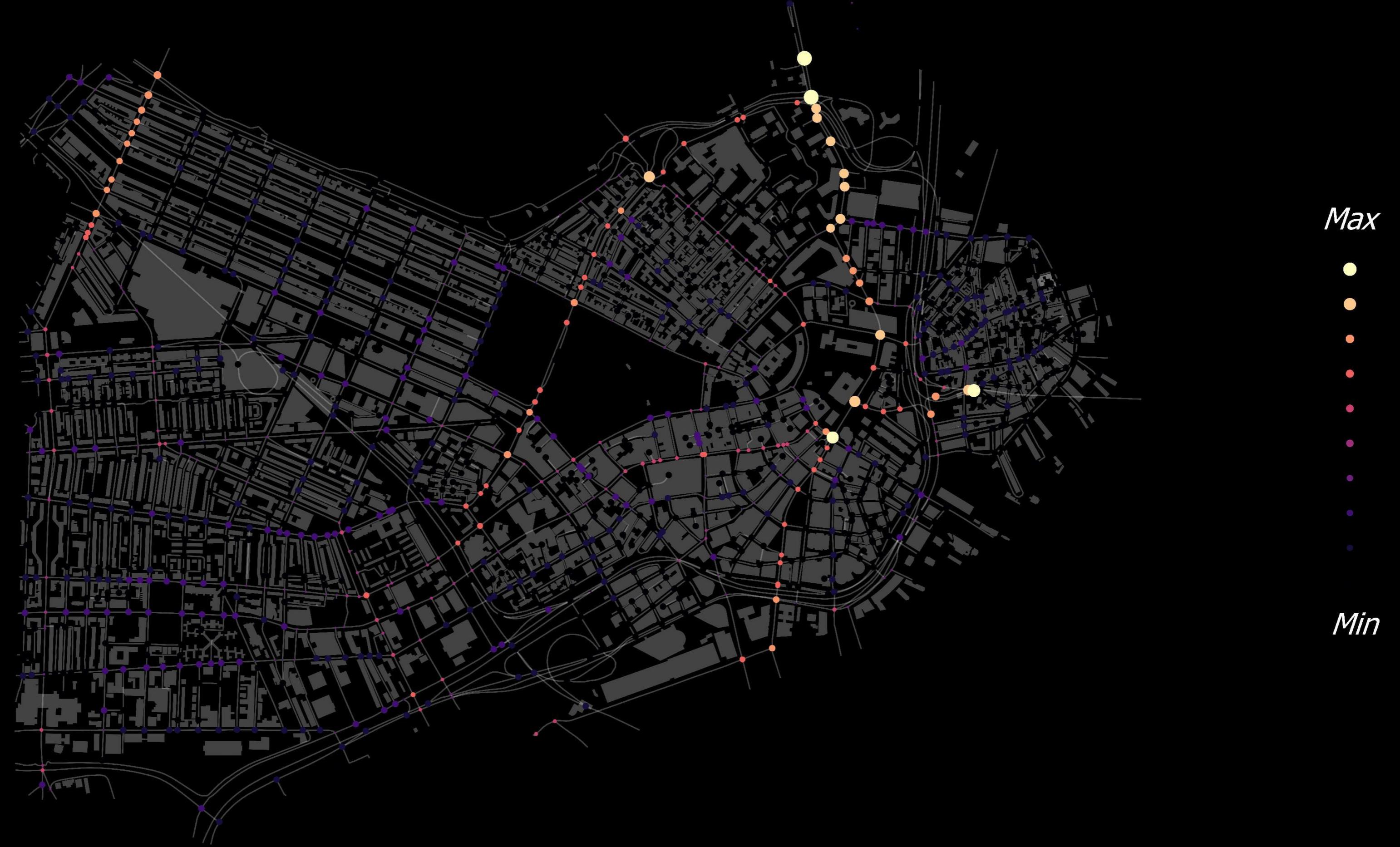


Centrality Measures

- 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.
- *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.

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

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

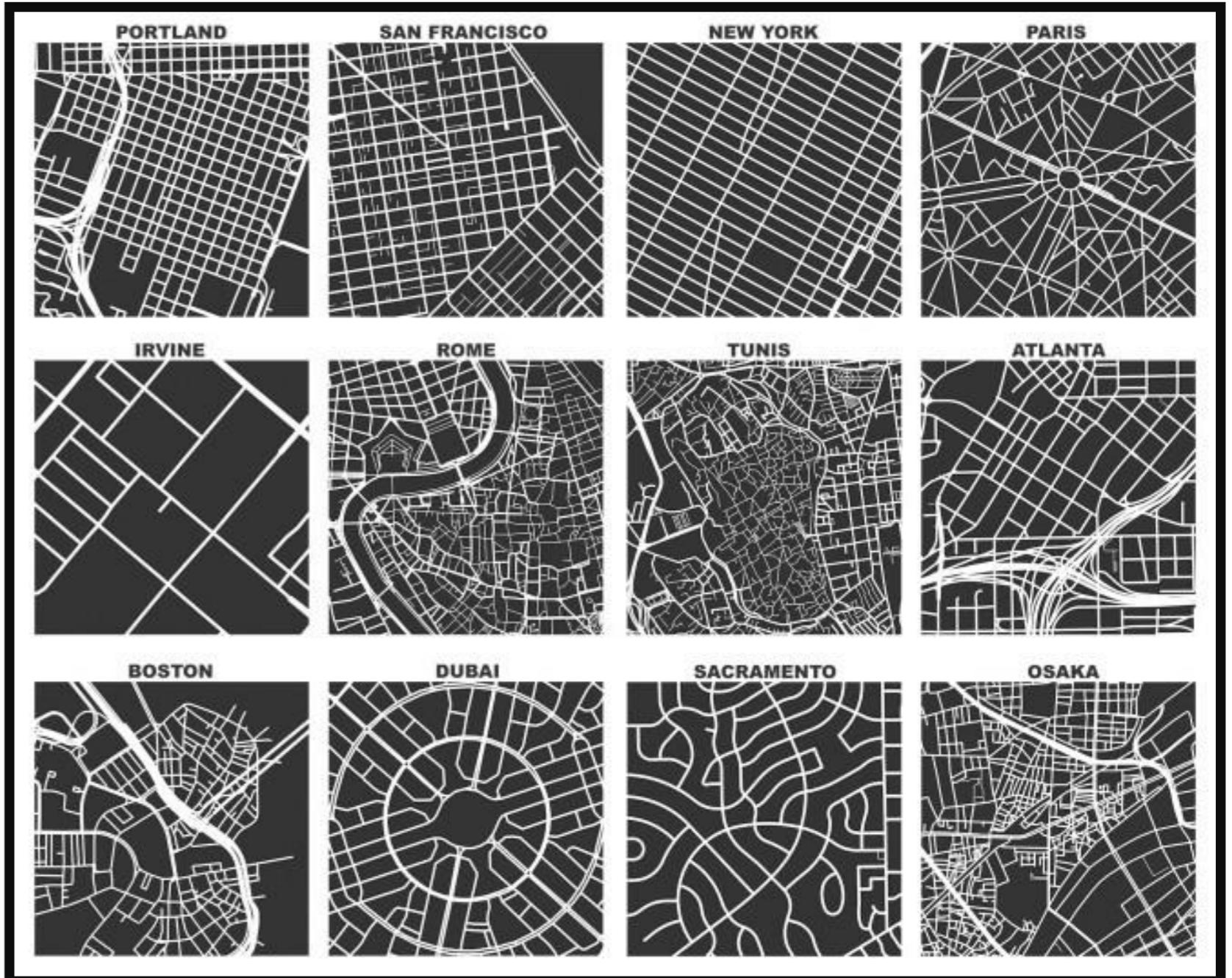


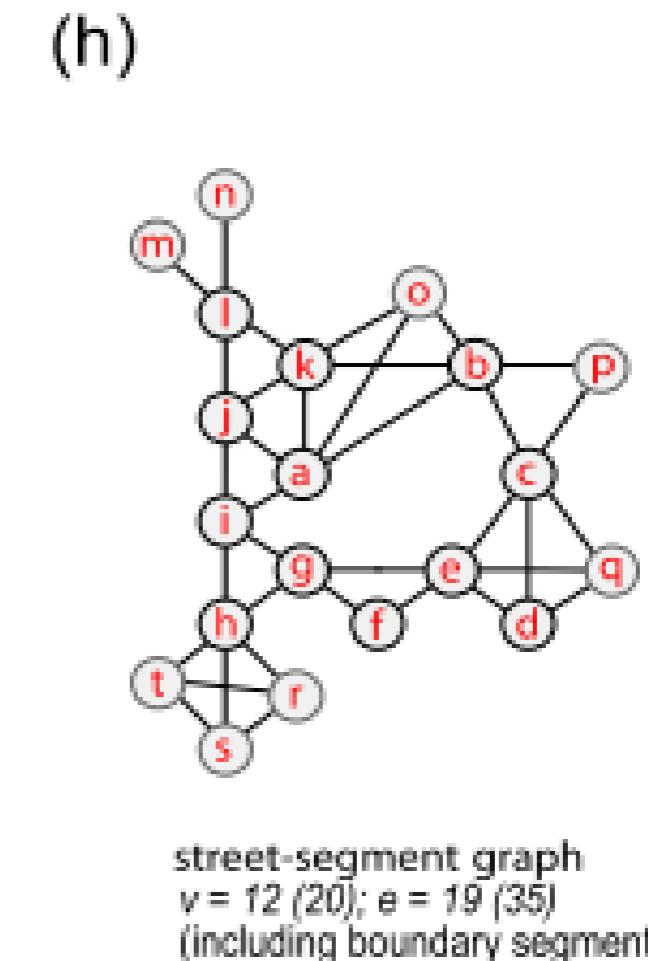
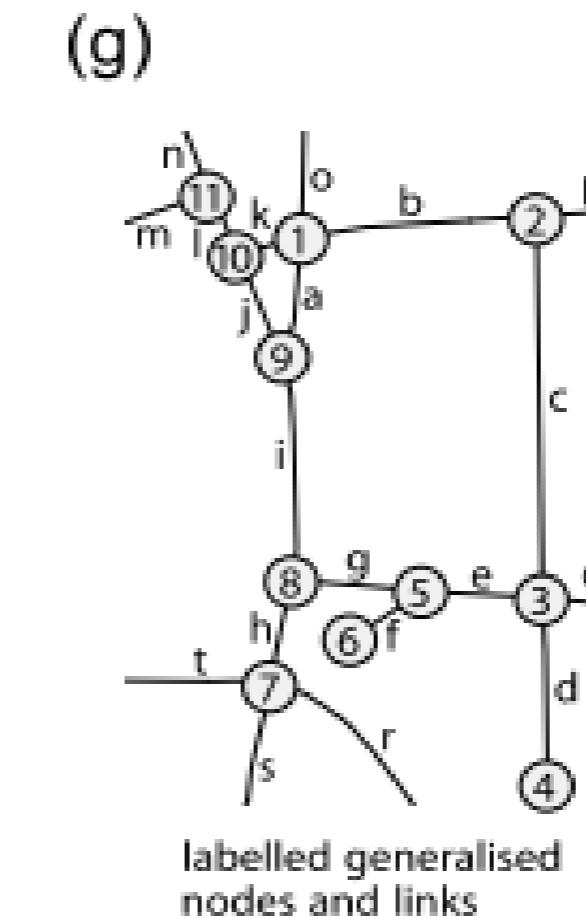
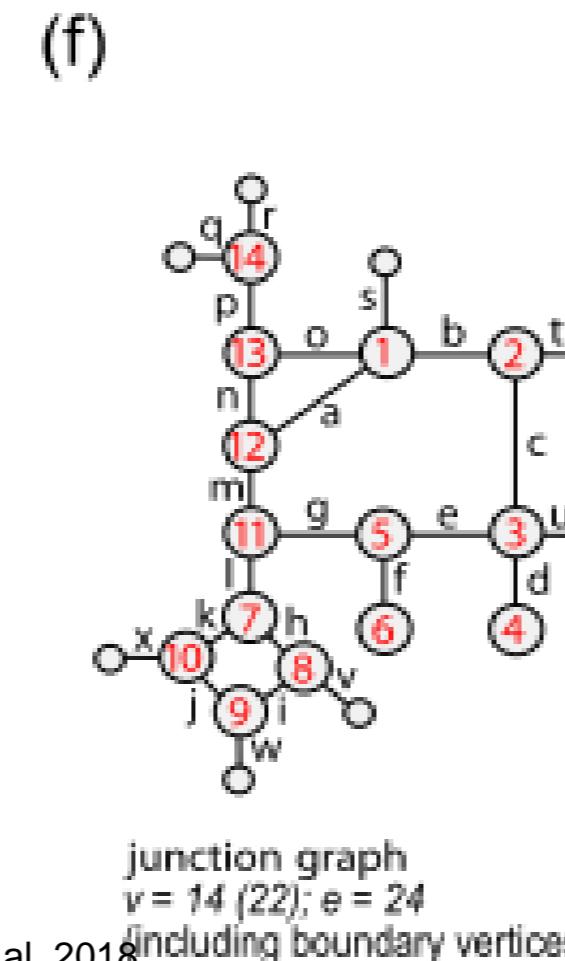
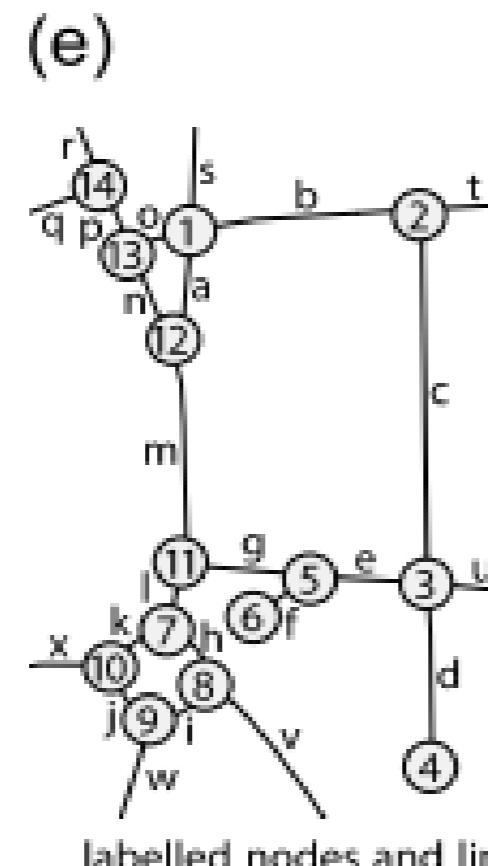
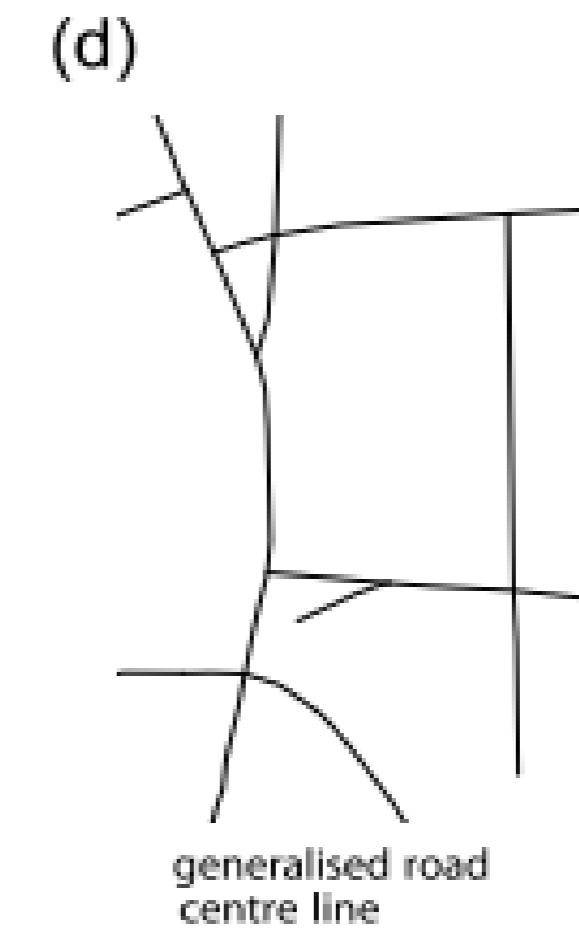
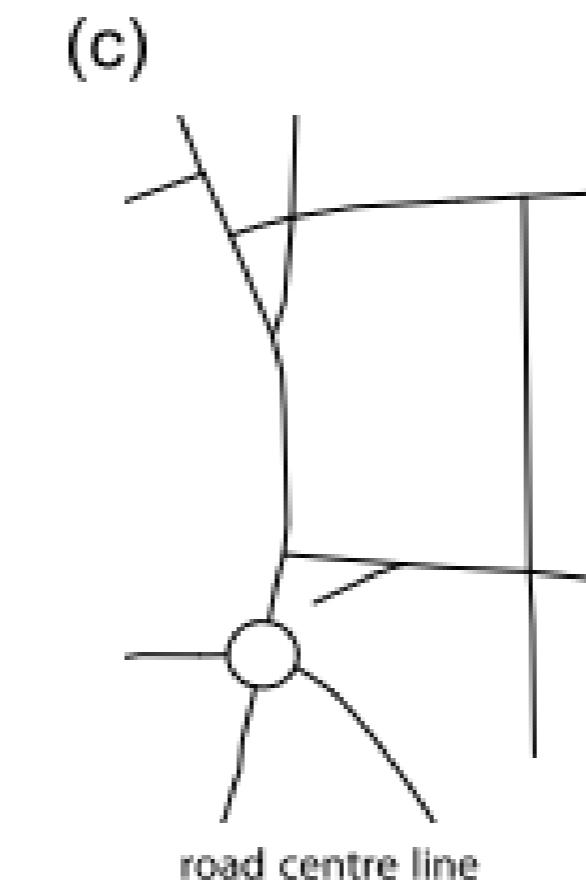
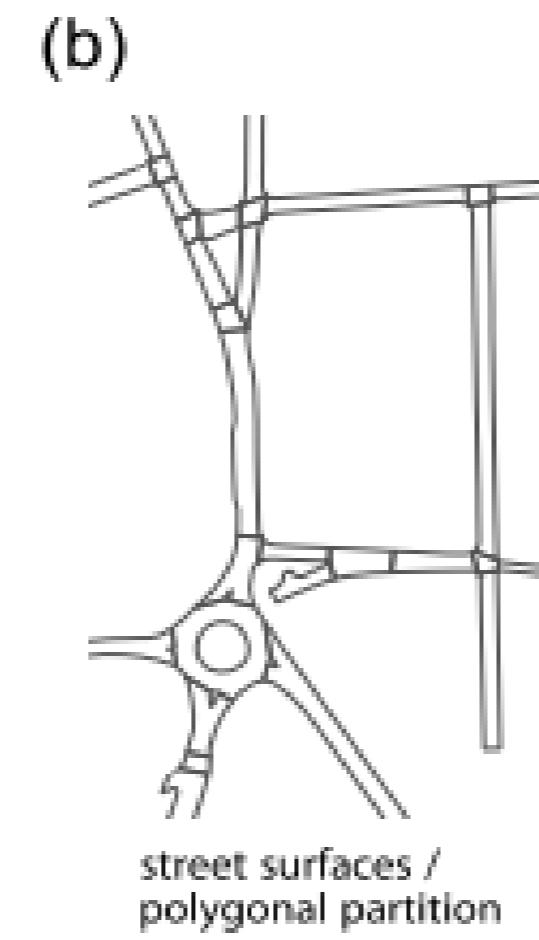


Spatial Networks

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...

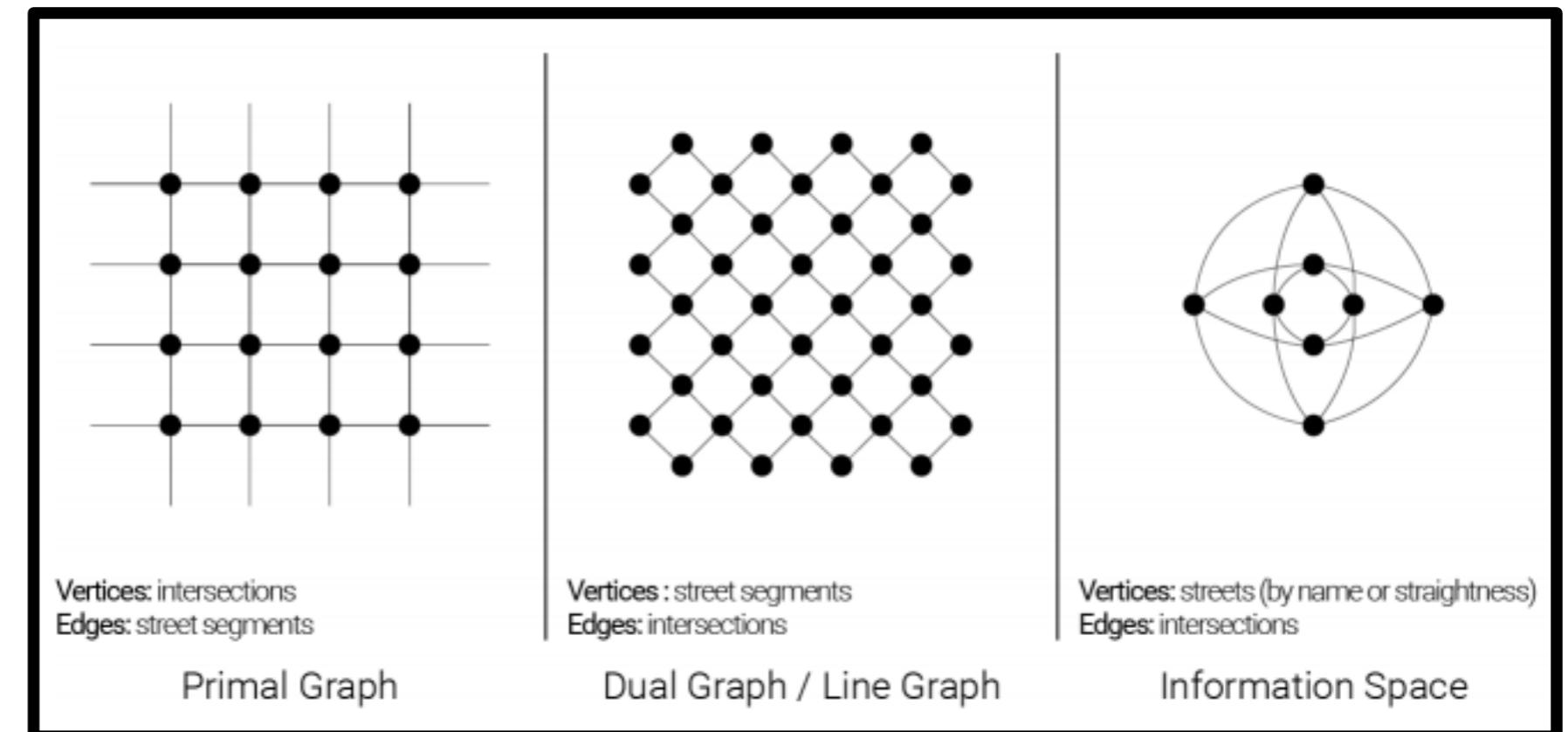




Source Marshall et al. 2018

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.



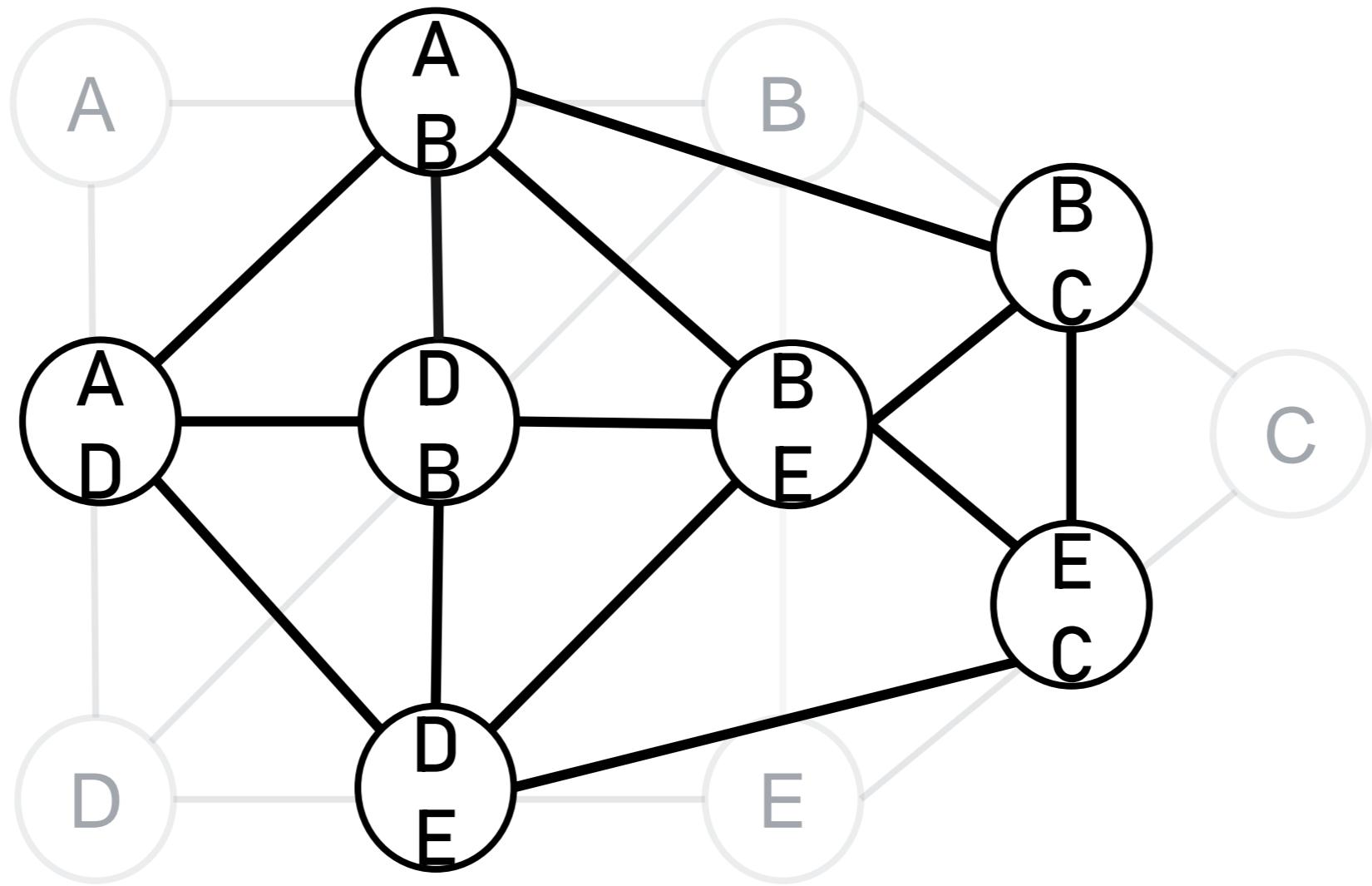
Source Neira (2017)

PG preserve geographic and metric information

Primal vs Dual graph

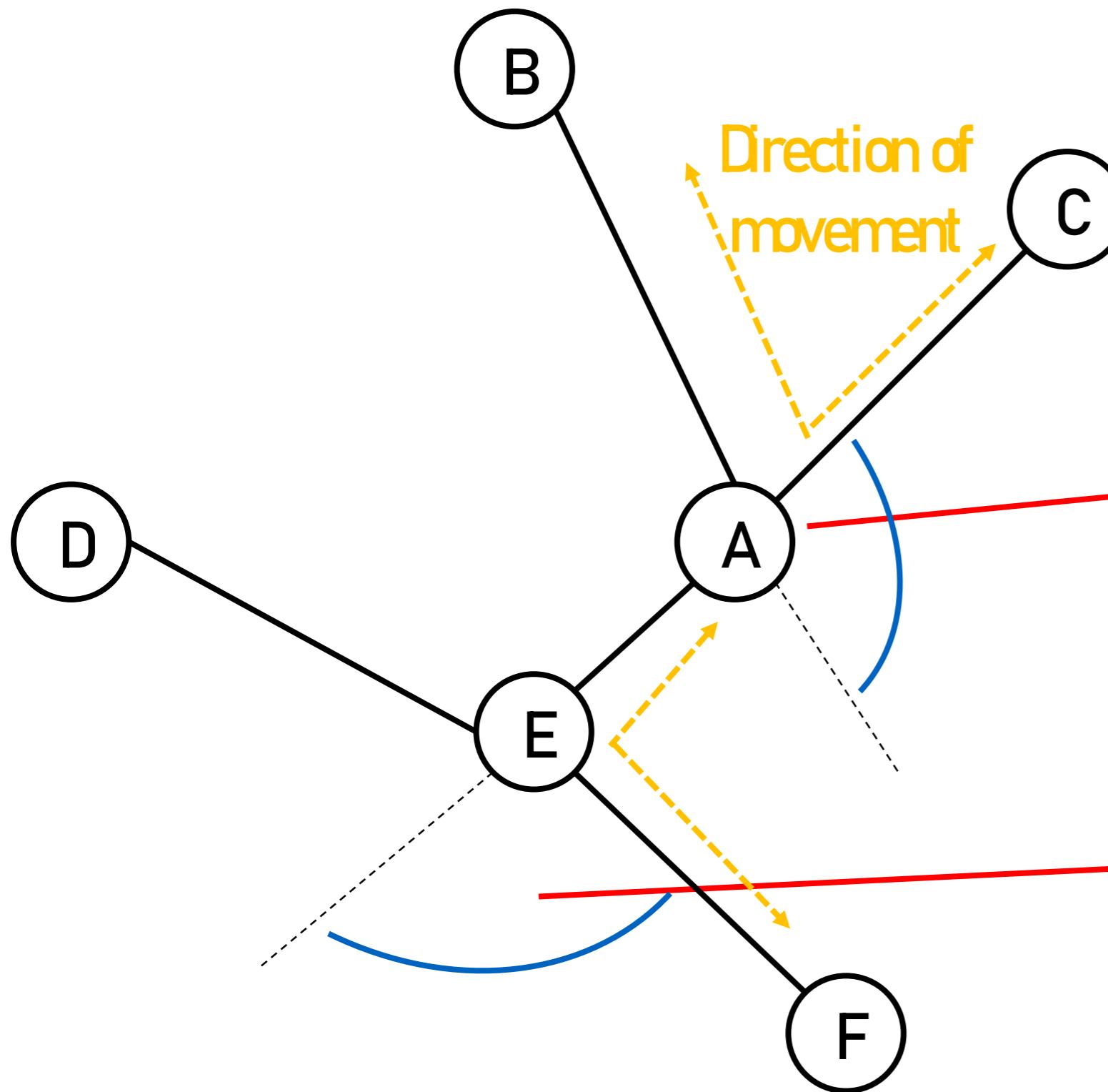


From Primal to Dual representation



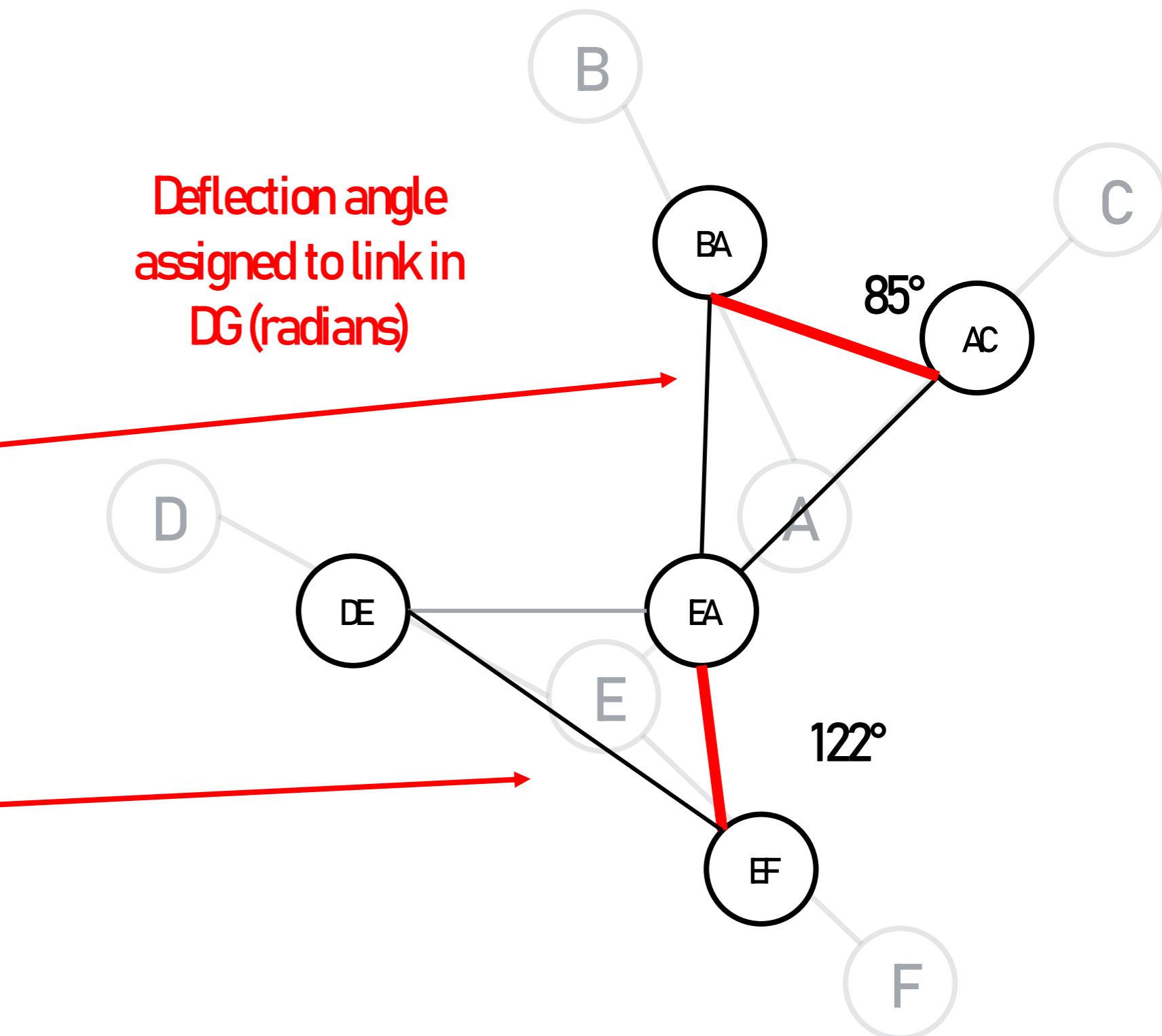
DG allows to compute ANGULAR-CHANGE shortest-path

Computing deflection angles

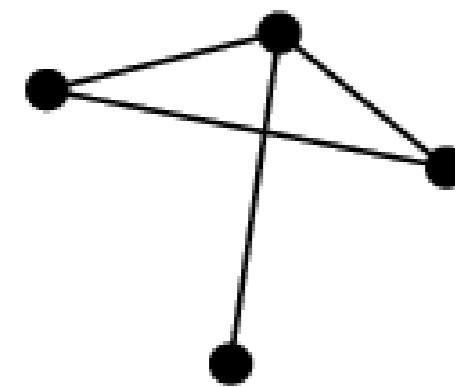


Direction of movement

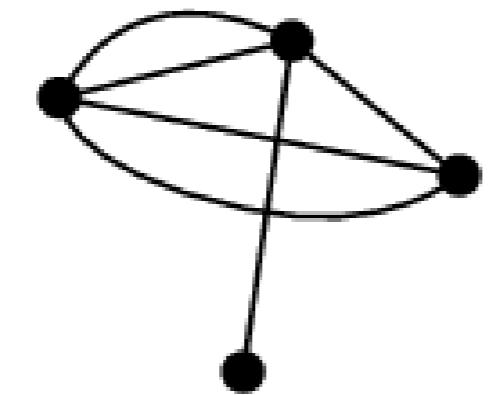
Deflection angle assigned to link in DG (radians)



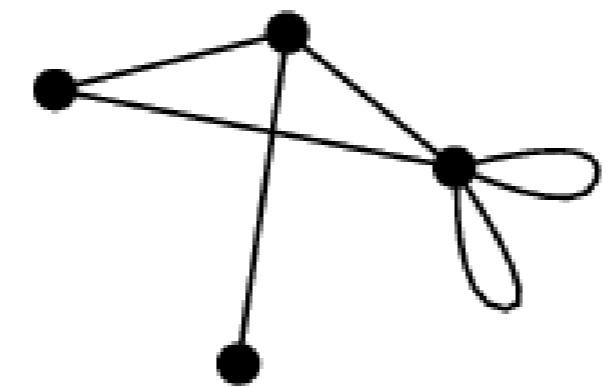
Simple graph and pseudo-nodes



simple graph

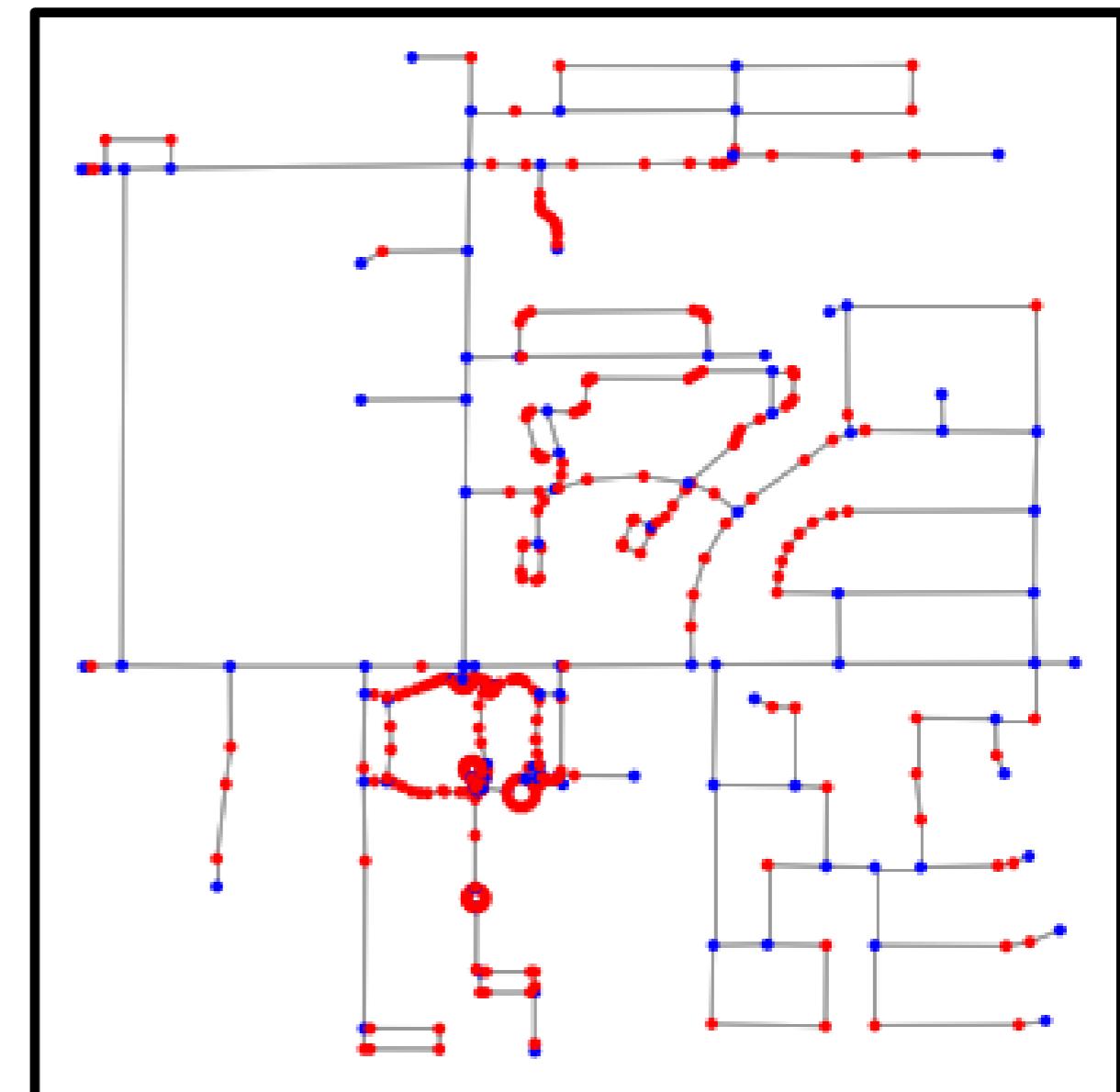


*nonsimple graph
with multiple edges*



*nonsimple graph
with loops*

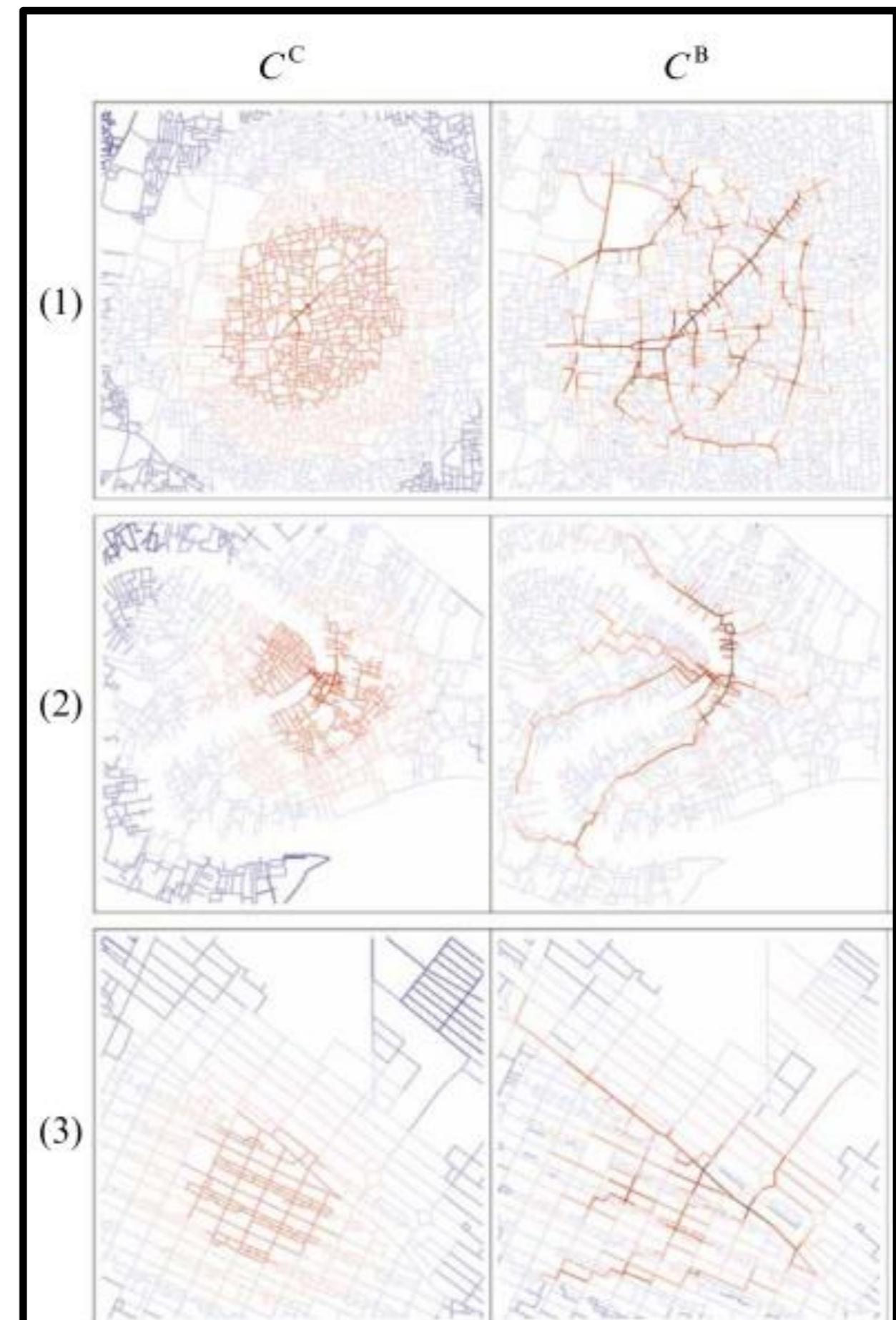
Source: mathworld.wolfram.com



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

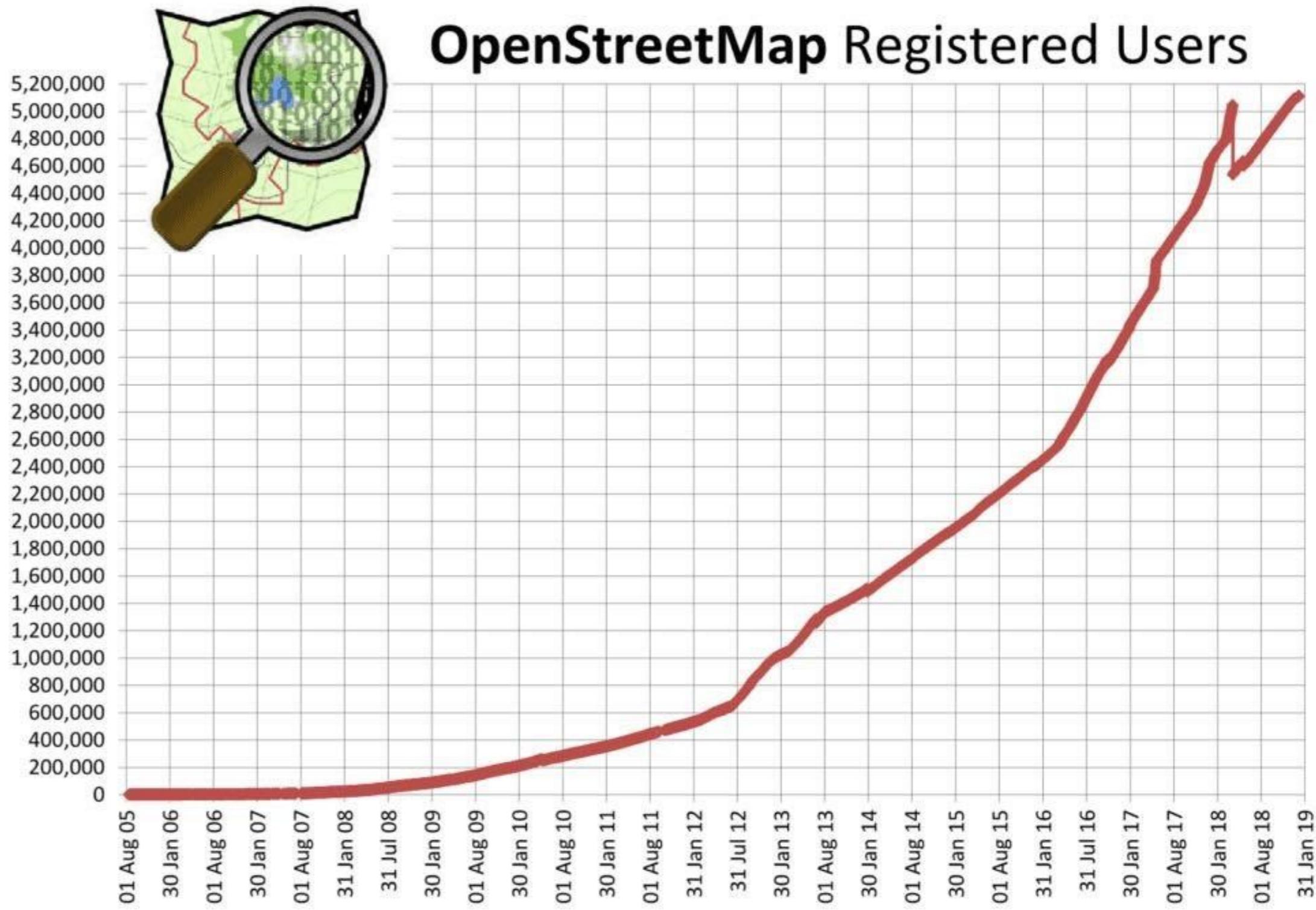
- Established in 2004 by Steve Coast
- Volunteered Geographical Information (VGI)
- The basis for most routing apps and many geo services (Amazon, Mapbox, Tesla, ...)
- Contributors are not just local mappers, but huge organizations



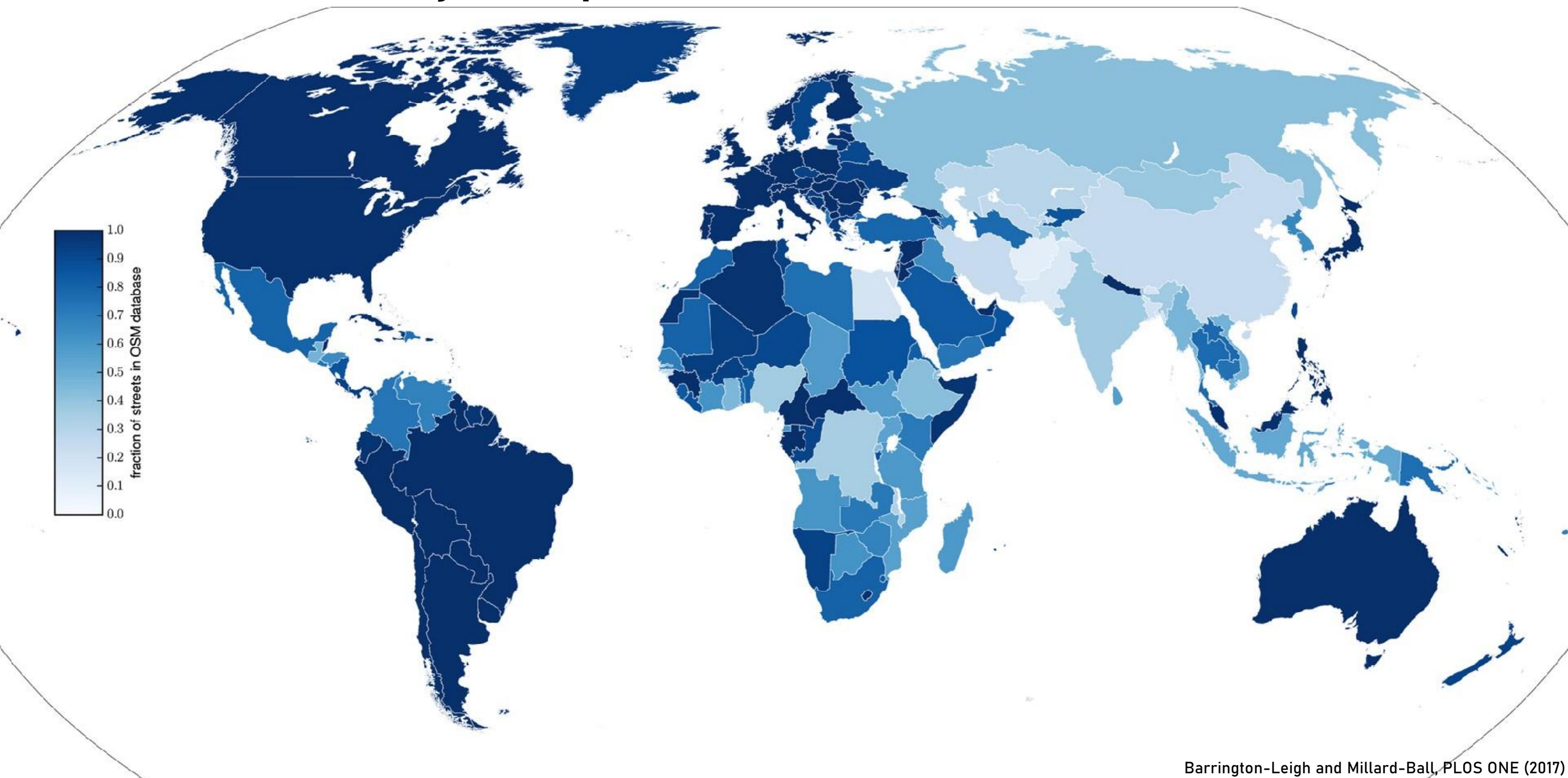
OSM is huge

- 6 Million contributors
- 9 Billion elements

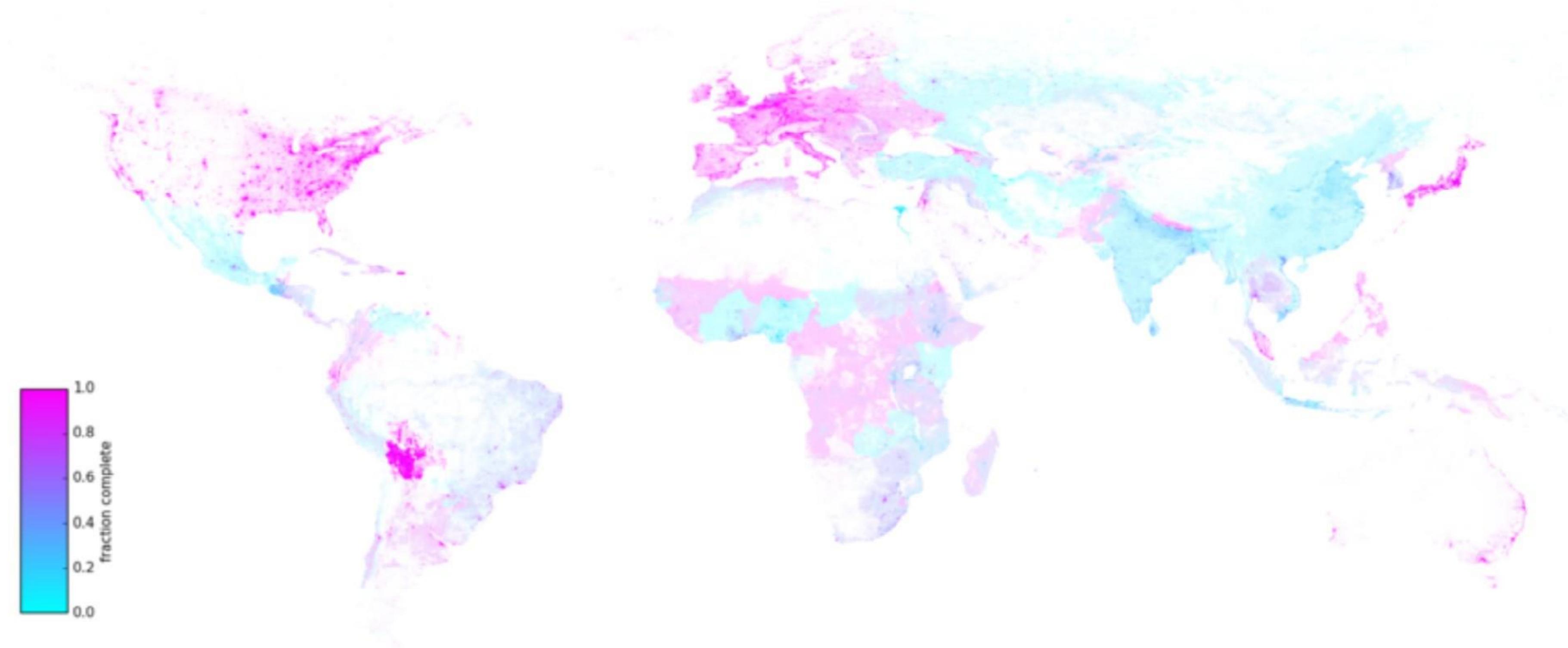
Probably more



OSM is relatively complete

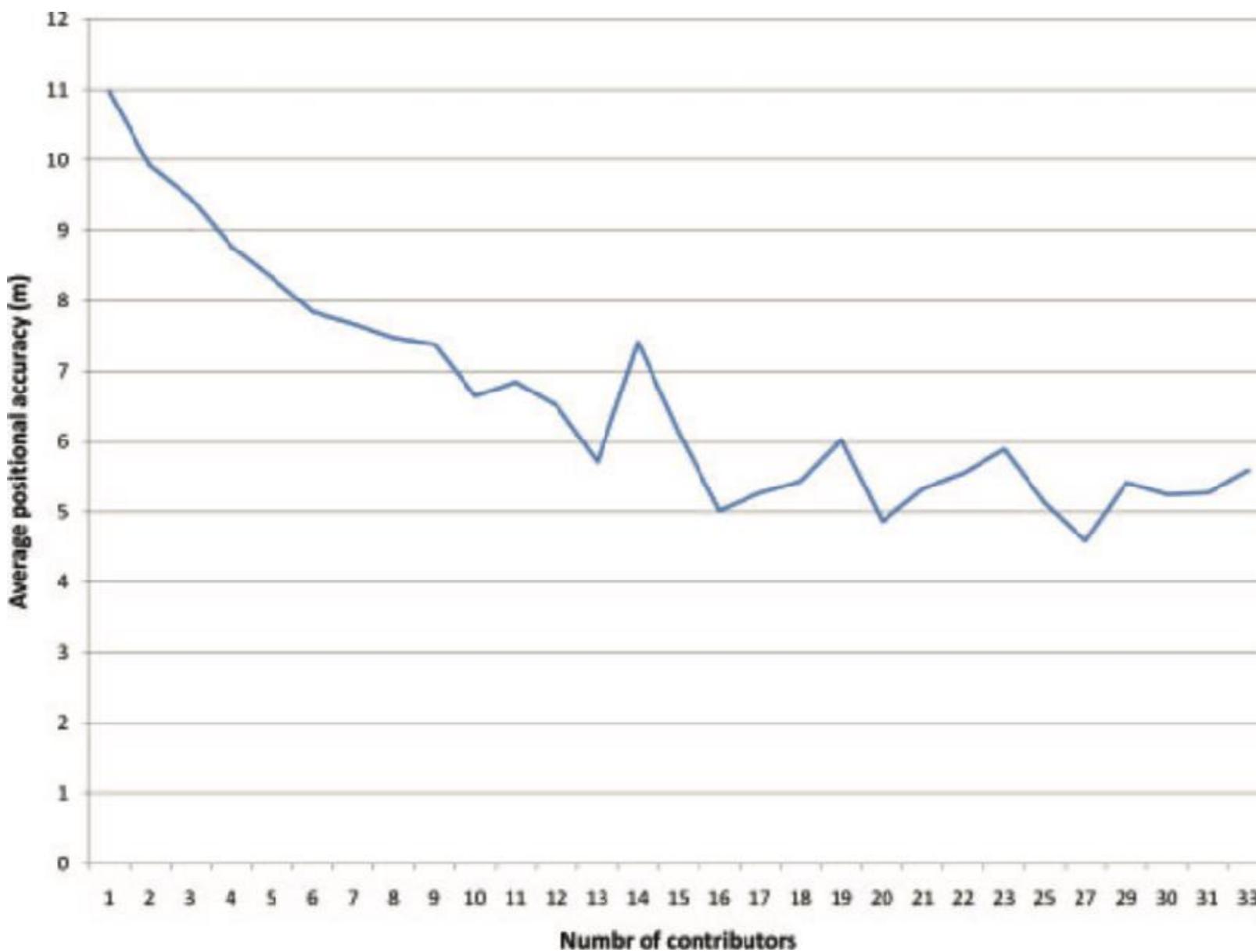


OSM is relatively complete

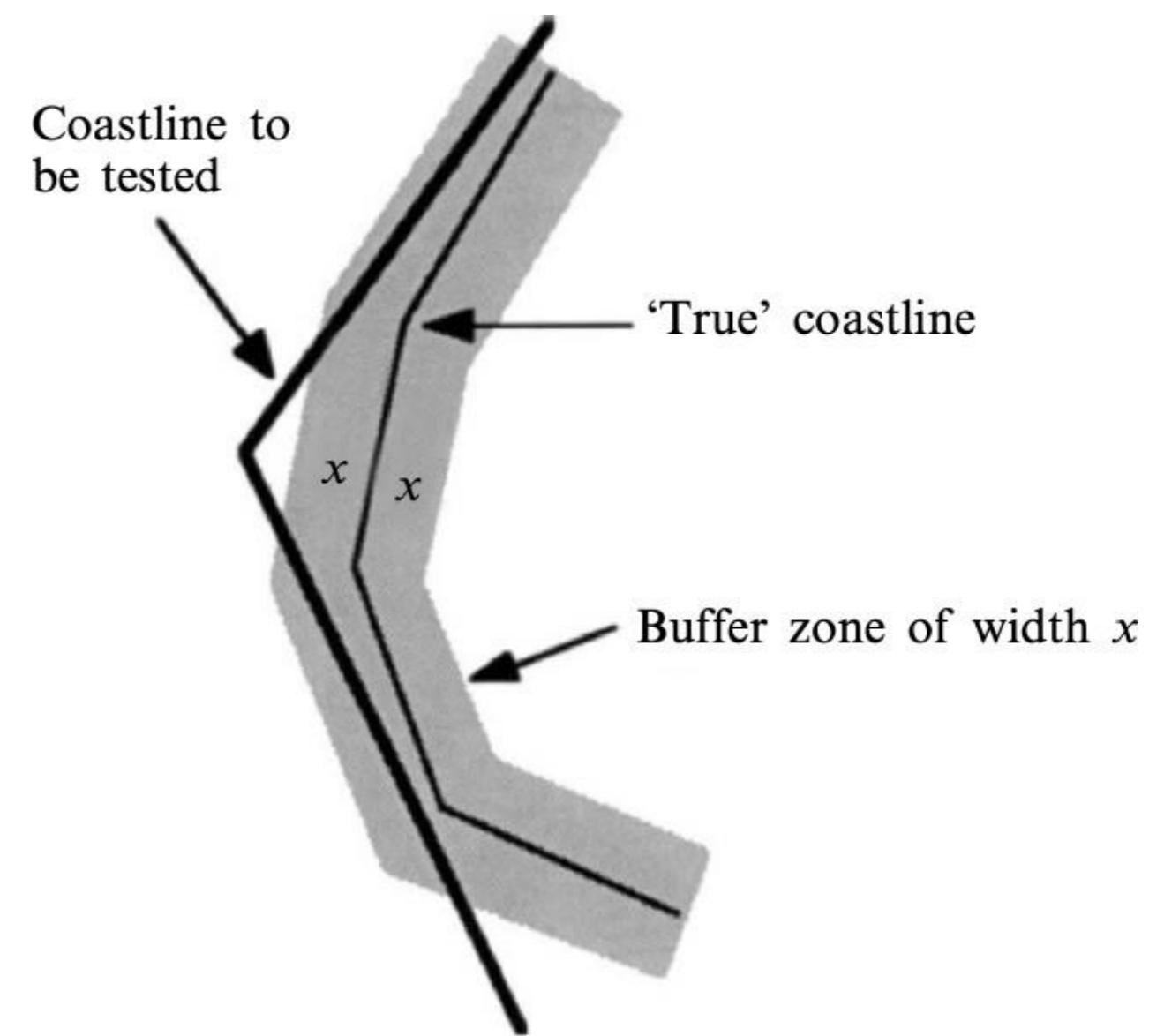


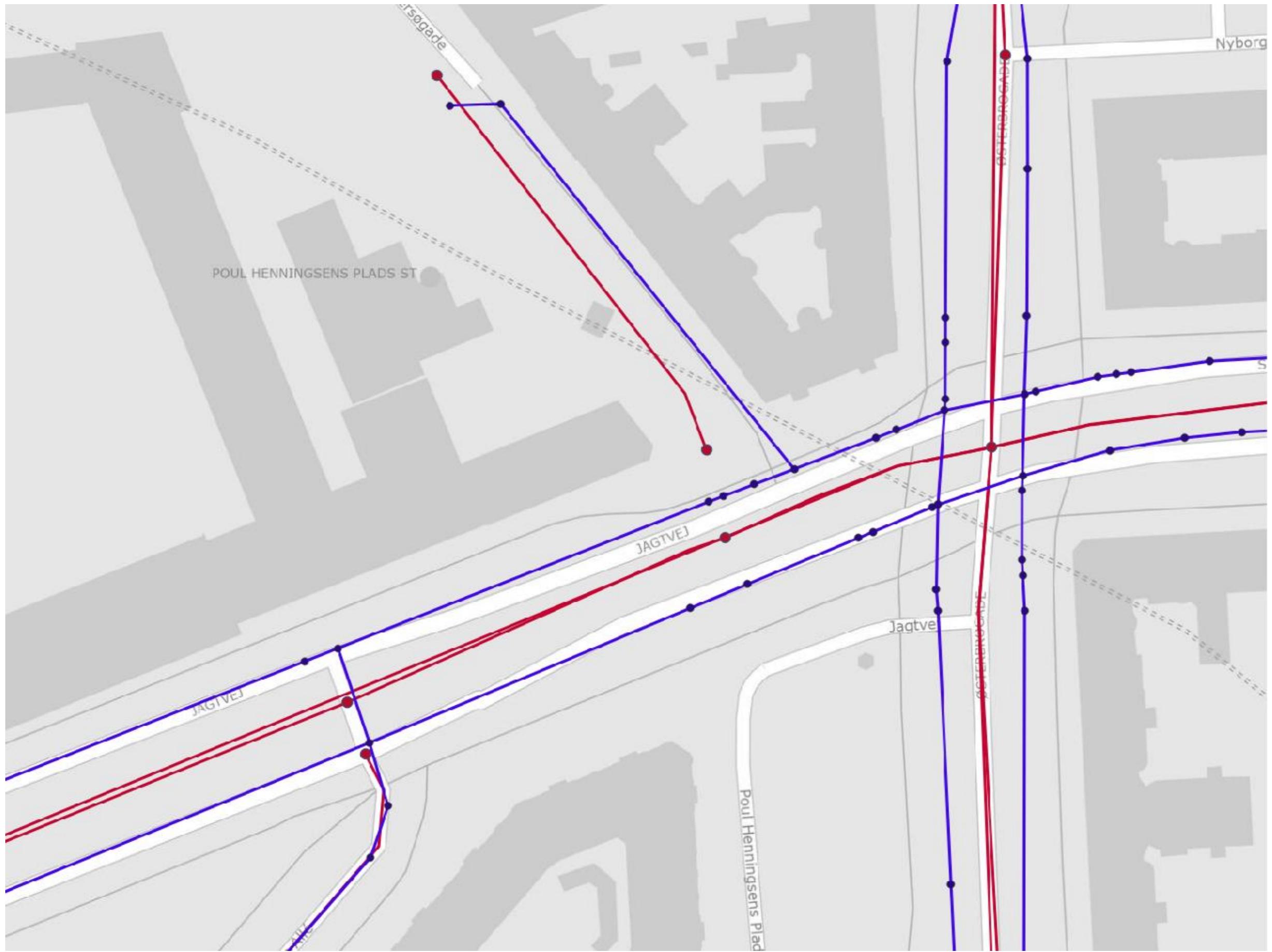
OSM is relatively accurate

The more contributors, the better the accuracy



Buffer-zone method between OSM and ground truth





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

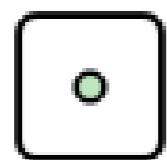
OpenStreetMap

Accessing & Handling OSM Data

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

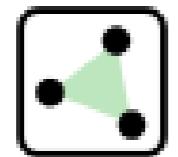
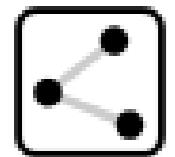
OSM topological data structure

3 elements / primitives:



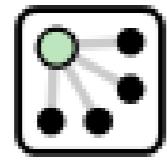
Node

id, lat, lon



Way

ordered list of nodes



Relation

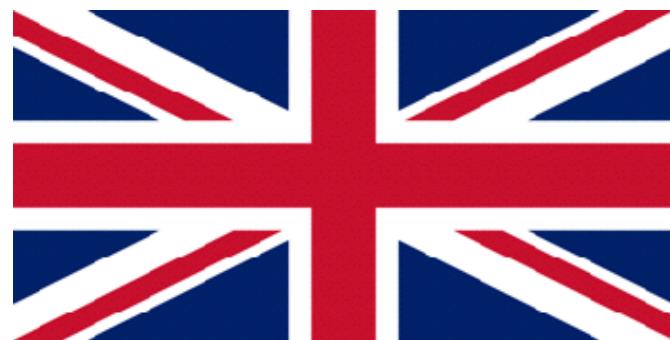
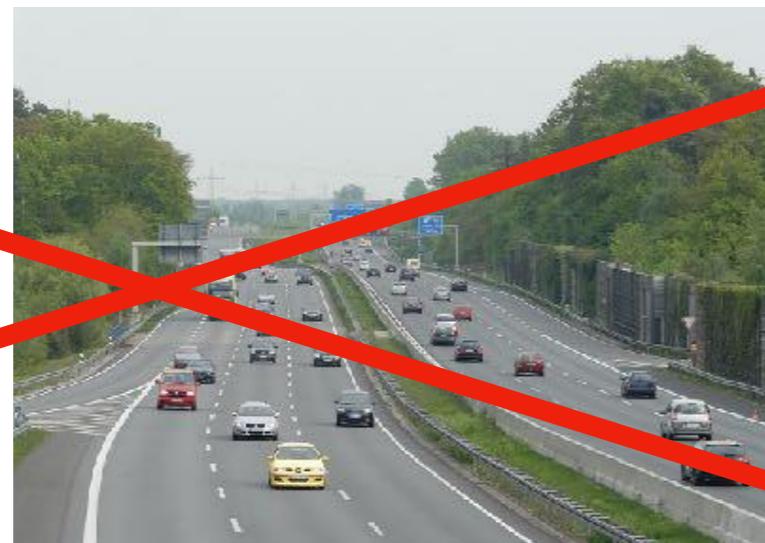
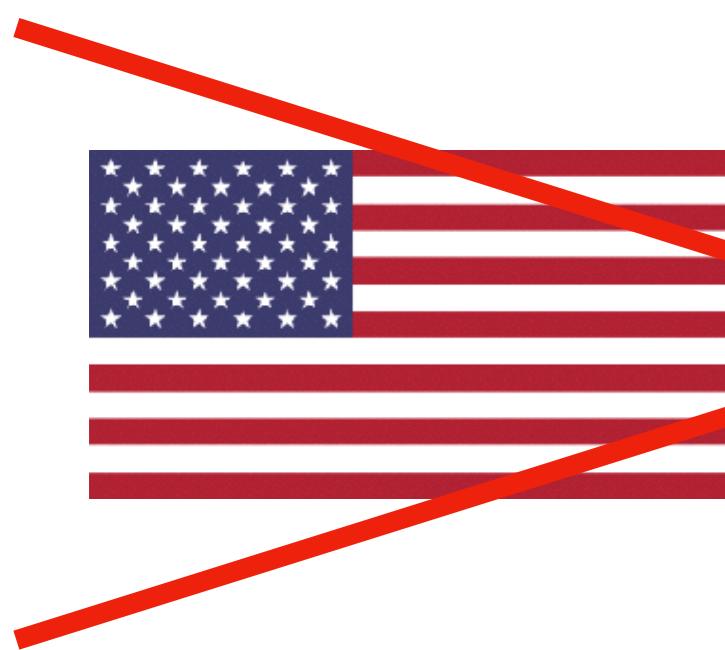
multiple elements



Tag

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

The “highway” tag



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

The screenshot shows the OpenStreetMap website interface. At the top, there is a navigation bar with links for 'Edit', 'Historical', 'Export' (which is highlighted with a red circle), 'GPS Traces', 'User Diaries', 'Copyright', 'Help', and 'About'. On the right side of the top bar, there is a user profile icon for 'mszell'. Below the navigation bar is a search bar with placeholder text 'Search' and a 'Go' button. To the right of the search bar is a 'Where is this?' button and a location pin icon.

Export

Manually select a different area

55.66070
12.58756
12.59531
55.65825

Licence

OpenStreetMap data is licensed under the [Open Data Commons Open Database License \(ODbL\)](#).

Export

If the above export fails, please consider using one of the sources listed below:

Overpass API
Download this bounding box from a mirror of the OpenStreetMap database

Planet OSM
Regularly-updated copies of the complete OpenStreetMap database

Geofabrik Downloads
Regularly-updated extracts of continents, countries, and selected cities

Other Sources
Additional sources listed on the OpenStreetMap wiki

30 m

https://www.openstreetmap.org/export#map=18/55.65948/12.59143

The main content area displays a map of a residential area with several streets labeled: Rued Langgaards Vej, Universitetskanalen, Emil Holms Kanal, Kaj Munks Vej, and Amagerfælledvej. There are also labels for Karen Blixen Parken, IT Universitetet, Alexandra Institutet, Cafe Analog, Mikado House, Fitness World, Gorillas Amager, Umeus Amager, Hørgården, and Aktivitetshuset. The map includes various building footprints, green spaces, and water bodies. A legend in the bottom right corner indicates symbols for buildings, roads, water, and other geographical features.

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;

```

The screenshot shows the Overpass Turbo web application. At the top, there's a toolbar with buttons for Run, Share, Export, Wizard, Save, Load, Settings, Help, and a map icon. The main area has a map of a city, likely Umeå, with several locations highlighted in blue. Below the map is a results pane containing the Overpass API query:

```

1  /*
2   * This is an example Overpass query.
3   * Try it out by pressing the Run button above.
4   * You can find more examples with the tool tip.
5   */
6   node
7     ["amenity=bicycle_parking"]
8     {{bbox}};
9   out;

```

The status bar at the bottom of the interface shows 'Loaded - nodes: 0, ways: 0, relations: 0'.

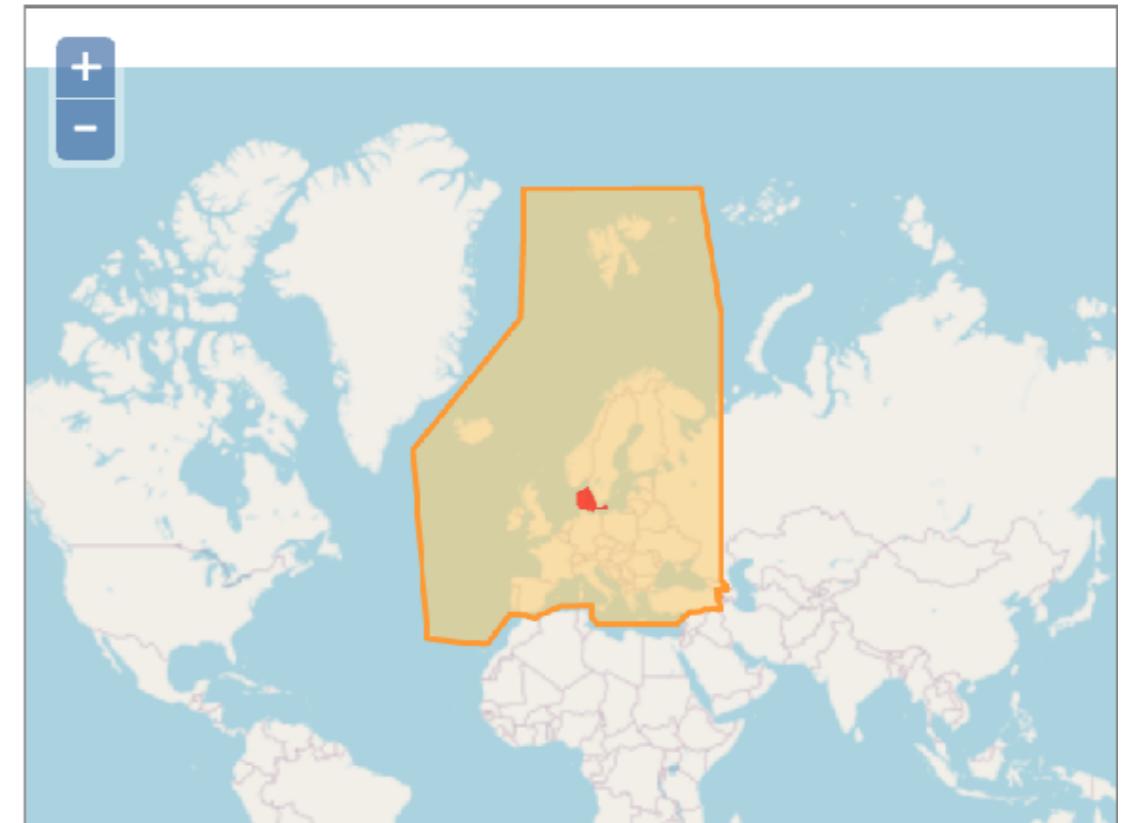
<https://overpass-turbo.eu/>

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]
Faroe Islands	[.osm.pbf] (4.6 MB)	[.shp.zip]	[.osm.bz2]



<https://download.geofabrik.de/>

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

Via OSMnx (OSM + NetworkX)

The screenshot shows the GitHub repository page for `gboeing/osmnx`. The repository is public, has 115 watchers, 668 forks, and 3.5k stars. The main tab is selected, showing the `main` branch. The repository description is: "OSMnx: Python for street networks. Retrieve, model, analyze, and visualize street networks and other spatial data from OpenStreetMap." Below the description, there are three recent commits:

- gboeing pin black ver... 3 days ago
- .github drop python 3.7 support... 9 days ago
- docs version bump 4 months ago

<https://osmnx.readthedocs.io/en/stable/>

Sources and references

- Albert-László Barabasi's slides - networksciencebook.com
- Blanchard, P. & Volchenkov, D, 2009. *Mathematical Analysis Of Urban Spatial Networks*, Berlin, Heidelberg: Springer.
- Boeing, G, 2017. OSMnx: New Methods For Acquiring, Constructing, Analyzing, And Visualizing Complex Street Networks. *Computers, Environment and Urban Systems*, 65, pp.126–139.
- Háznyay, A, Fi, I., London, A & Németh, T., 2015. Complex Network Analysis Of Public Transportation Networks: A Comprehensive Study. In *2015 Models and Technologies for Intelligent Transportation Systems (MT-ITS)*. Budapest.
- Marshall, S, Gil, J., Kropf, K, Tamko, M, & Figueiredo, L (2018). Street Network Studies: from Networks to Models and their Representations. *Networks and Spatial Economics*
- Neira, M, 2017. *Urban Complexity And Spatial Justice: Measuring Effects Of Urban Morphology On Spatial Inequality And Segregation* UCL
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