GIS4Graph: a tool for analyzing (geo)graphs applied to study efficiency in a street network

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Abstract. *Geographic networks are everywhere, as rivers, power grids and street networks. Computational and mathematical tools for traditional analysis of graphs and recent studies on complex networks have been incorporating the geographic component. This article presents a general tool, in development process, for visualizing geographic networks: the GIS4Graph tool. An application is presented in the analysis of efficiency in a street network, based on the straightness centrality index. The case study is done using the OpenStreetMap data from the city of Lorena/SP. The results are showed visually in a map or graph, highlighting the main streets that contribute to the city's efficiency in terms of straight displacement.*

1. Introduction

Representing diverse systems in nature and society, networks usually have properties encoded in their structure that limit or enhance their behavior. This modeling can become simpler and easily when the structure is represented as a graph. Such representation is composed of nodes, that symbolize the network's components, and edges, that indicate the interactions between them [Barabasi, 2014].

A lot of complex systems are often represented under the form of networks where nodes and edges are embedded in space. Transportation networks, Internet, power grids, social and contact networks, in all of these examples topology by itself does not contain all the information [Barthelemy, 2011].

A geo(graph) is a structure in which each object in a geographic space is represented as a node and the connection between these elements is described as an edge, which demonstrates a spatial relationship between them [Santos et al., 2017].

The GIS4Graph tool was developed for visualizing of both nodes and edges, and their properties, in a Geographical Information System [Jorge et al., 2017].

In this paper is presented an application of the GIS4Graph tool for analyzing efficiency in a street network, based on the straightness centrality index [Crucitti et al., 2007].

2. Materials and Methods

The geodata representing the street network of Lorena were acquired through a request on OpenStreetMap Extended API by specifying the bounding box of the city. It delivers an XML response wrapped in an <osm> element that includes basically the description of the ways (polylines that represent linear features such as roads) and their relationships [OpenStreetMap, 2017]. More precisely, each line segment between crossroads is a way, and the relationships between ways are indicated by 'osm_source' and 'osm_target' fields. There is also the information if they are one way or not.

In relation to the tool itself, it was developed as a Web tool, aiming to make it easier for the users in general to access it, since it discards the need of installations. The only requirements to use it are: Internet access and a browser. Currently, the application is hosted at a Virtual Machine in Google Cloud and it can be accessed at http://gis4graph.info or http://gis4graph.com.

The employed methodology is shown in Figure 1. The whole processing flow is composed of 3 main modules: 1) Spatial Data Handling, 2) Graph Metrics Calculation, and 3) Results Visualization.

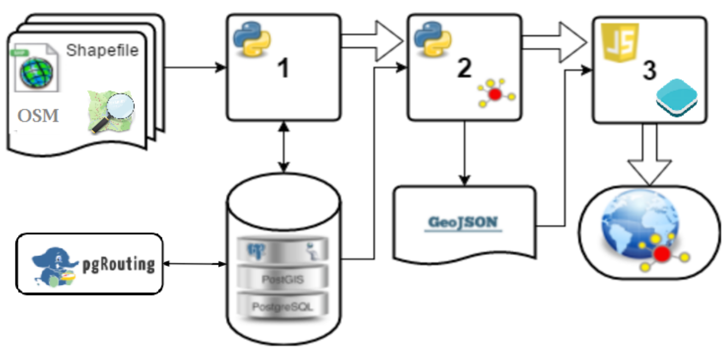

Figure 1. Processing Flow on the GIS4Graph tool.

2.1. Spatial Data Handling

In terms of input data, GIS4Graph is able to work not only with OSM files but also with shapefiles, although just the first one was used in this case study. In order to handle all these data, specially the geographic features, the tool uses a free and opensource database, PostgreSQL, with its spatial extension, PostGIS. Additionally, in order to handle OSM files, pgRouting extension was used to import all the OSM data into a database and convert each way into a geometric feature. Python was chosen as the programming language to manage and integrate all these resources.

For the proposed analysis, every avenue or street was represented as a single node. Therefore a union operation was performed between geometries with the same 'osm_id' - this attribute identifies uniquely each element in the network – resulting in MultiLineString geometry for each street.

This module was also responsible for delivering all spatial measures needed to compose metric calculations, such as straightness centrality, which demands the euclidean distance and the shortest route between two geometries, respectively answered by a PostGIS function, *st_distance,* and a pgRouting function*, pgr_dijkstra*.

2.2. Graph Metrics Calculation

At this stage, the first step was to build a graph based on the analyzed network. It was done by adding a node for each street and edges corresponding to every existing connection between them. The connections, including their directions, were identified based on the information provided by 'osm_source', 'osm_target' and 'oneway' fields.

The igraph library, which is a collection of network analysis tools [Igraph, 2017], was employed as a Python package to support this process of graph creation and also for calculating some default metrics, such as vertex degree, clustering coefficient, and shortest paths.

Finally, this module provided the resultant dataset in geoJSON files that were consumed by the third module for producing the results visualization.

2.3. Results Visualization

GIS4Graph interface was built upon OpenLayers, a JavaScript framework to work with interactive maps and geographic elements, allowing applying visualization styles to features individually. In addition, a filter to show features according to thresholds defined by users in relation to any calculated metric was implemented.

A sample of results is shown in the next Section.

3. Results

One interesting metric provided by igraph, and incorporated to GIS4Graph, is a centrality index called betweeness, which is defined by the number of shortest paths going through a vertex [Costa et al., 2007]. In terms of street networks, it may identify the main ways used by most of transport routes in a city. The output based on the city of Lorena, which is the case study for all results presented, is shown in Figure 2.

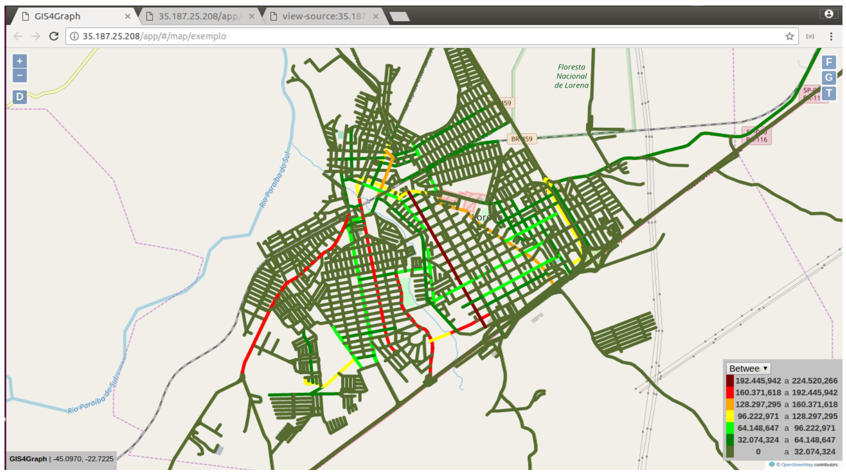

Figure 2. Betweeness in Lorena's street network.

The straightness centrality index, which is the focus of this case study, is not yet implemented by igraph, so it was codified apart. This index is a combination of geographic measures, specifically defined for each node as:

$$C_i^S = \frac{1}{N-1} \sum_{j \in G,\, j \neq i} d_{ij}^{Eucl} / d_{ij} ,$$

where d_{ij}^{Eucl} is the Euclidean distance between nodes *i* and *j* along a straight line, d_{ij} is the shortest route length between such nodes, and N is the total number of nodes. It originates from the idea that the efficiency in the communication between two nodes is equal to the inverse of the shortest path length. This measure captures to which extent the connecting route between nodes deviates from the virtual straight route [Crucitti, 2006].

In Figure 3, the results are presented concerning the straightness centrality index, filtering just the streets with values above 0.6 (in a range from 0 to 1). According to the color legend on the bottom right corner, the streets in hotter colors are the ones that most contribute to the network's efficiency in a general way, for resulting in less deviations, in average, with relation to the entire network.

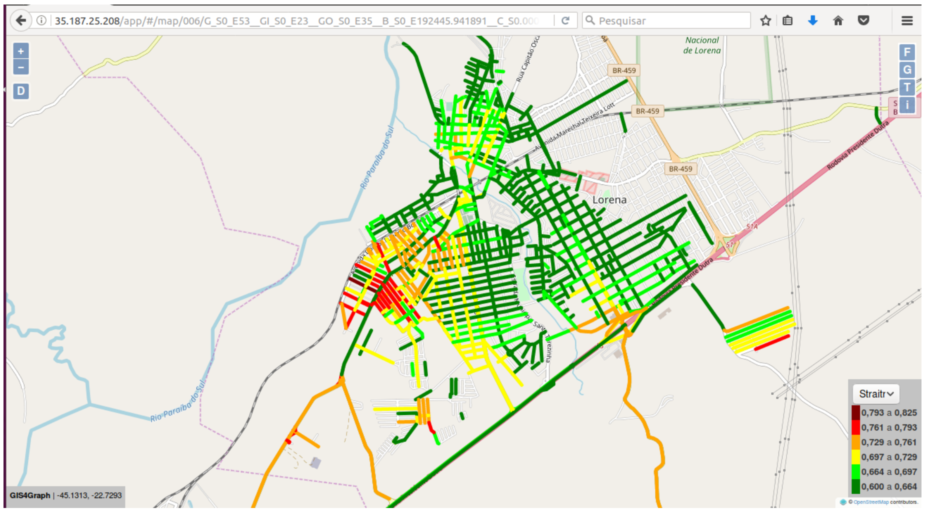

Figure 3. Straightness Centrality in Lorena's street network

GIS4Graph also gives another perspective of the result showing it visually in a graph structure, which is the basis of the whole data processing realized. This option highlights nodes with higher values of an specific index, as chosen by the user. In Figure 4 is shown the output for the degree metric, which consists in the number of connections of a vertex [Costa et al. 2007].

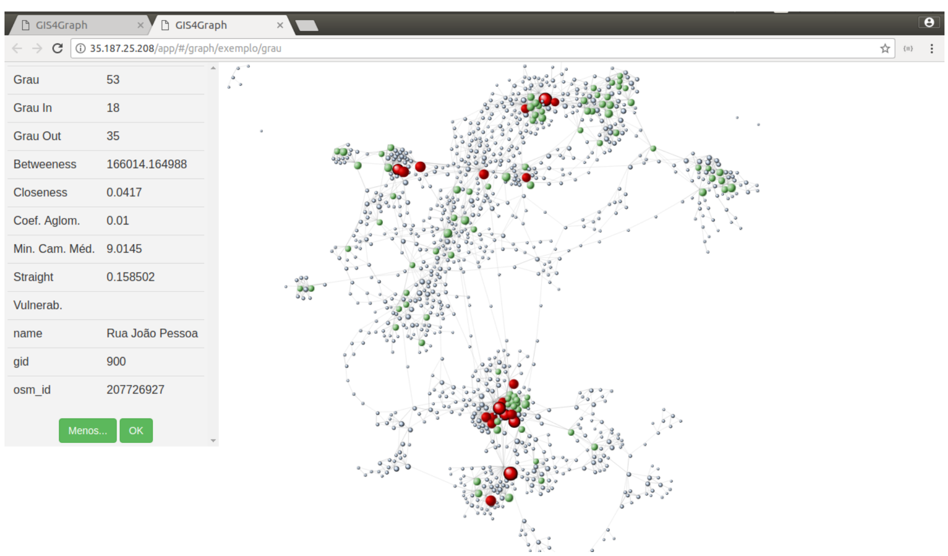

Figure 4. Graph visualization.

4. Final considerations

This paper presented the GIS4Graph tool and its application in the scope of urban networks. Moreover, this paper highlighted the relevance of bringing together geographic aspects and graph metrics in spatial network analysis, and furthermore, the importance of geotechnologies applied in this context.

GIS4Graph is an open source software and its code is entirely available at http://github.com/aurelienne/gis4graph, expecting to help the interested community to use it as a base to develop similar and more evolved applications for metric analysis in geographic networks.

As a continuation of this ongoing study, there is an intention to aggregate route analyzes and perform deeper studies related to efficiency in transport systems. Besides, there is a perspective of working with vulnerability metrics, applying them to same case study.

Acknowledgments

This research was partially supported by projects CNPq 454267/2014-2 and FAPESP 2015/50122-0 & DFG-IRTK 1740/2

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