

A three-in-one tool for cartographic generalization with the new version of CartAGen

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Abstract: The lack of open and free tools for cartographic generalisation restricts the use of generalization techniques to National Mapping Agencies that can afford the development of custom processes based on software such as ArcGIS. For the others, whether they are students, researchers, independent cartographers or data journalists, the release of the version 1.0 of the CartAGen library can be a solution. CartAGen can be seen as a three-in-one tool. It provides first an open Python library that is complementary to Shapely and GeoPandas libraries to build automated generalisation scripts. Then, CartAGen is now (2) a QGIS plugin that can be used to generalise QGIS layers with many different algorithms that can also be included in a model builder. Finally, we provide (3) several Python notebooks that can be used as tutorials to discover the challenges of map generalisation, and how the library can be used. A significant effort has been made to provide documentation that is aimed at both novice and trained cartographers.

Keywords: cartographic generalisation, open source, Python, QGIS

1. Introduction

Cartographic generalization is a very complex process to automate. It remains the territory of the National Mapping Agencies (NMA) of rich countries, despite more than 30 years of research and an active commission at the ICA (25 workshops organized in the past years). As a consequence, even though the principles of map generalization fully apply to thematic maps (Raposo et al., 2020), it is extremely rare to see map generalization applied to such maps in practice. But even topographic web maps appear to be not generalized enough (Courtial and Touya, 2023).

One of the reasons for the lack of democratization of map generalization is that we all lack accessible tools to automate this complex process. We can find generalization functionalities in several GIS tools. ESRI has included generalization algorithms in their toolbox for more than twenty years (Lee, 2003, Punt and Watkins, 2010) and ArcGIS is used in many NMAs to build automated or semi-automated cartographic production lines. However, the time and cost investment to use these tools is not accessible to new occasional users of map generalization. The same applies for 1Generalise, the tool proposed by 1Spatial (Regnauld, 2014), which derives from the LAMPS2 (Barrault et al., 2001) and Clarity (Hardy et al., 2003) platforms. Fifteen years ago, a benchmark of commercial software for map generalization was organized by EuroSDR, the association of European NMAs (Stoter et al., 2009). From the four software that were benchmarked at that time, only these two are still actively maintained, as Aexpand (Burghardt et al., 2005) does not focus anymore on map generalization (though algorithms are still available), and

the Change-Push-Typify suite has not been updated since then.

Researchers are specific users because they need to compare several solutions when they develop new algorithms. Since the beginning of research on automated generalization, custom research platforms have emerged in different coding environments, as the GIS software environment regularly changed in the past thirty years. For instance, the PlaGe platform developed at IGN during the 90s (Lecordix et al., 1997) was replaced when Ada became too complex to compile. This lack of continuity in the platforms accessible for researchers raises capitalization problems (Renard et al., 2010) as the algorithms implemented in the ancient platforms need to be coded once again in new languages and platforms. This capitalization problem occurred with the CartAGen platform initially implemented as Java tool (Touya et al., 2019), which was ported into Python (Touya et al., 2023) when the maintenance of the Java libraries, on which CartAGen was based, terminated.

However, we believe that it is possible to create a map generalization tool that will make this skill and this expertise accessible to a broader audience in the long term, and for more types of maps. In our opinion, such a tool should have the following guidelines:

- an easy-to-use platform that can be integrated into the working environment of most researchers and practitioners of cartography, i.e. within a GIS or within a programming environment.
- a highly parametrizable use, as each new map might require its own specific sequence of generalization operations.

- an open and free platform, to meet open science requirements.
- it should not compete with the current open-source spatial data science ecosystem (mostly in Python and Javascript), but should rather be complementary.
- it should provide access to 50 years of generalization algorithms, not only the "best" algorithm for each problem, to help with the capitalization problem and to better evaluate new propositions.
- it should increase the number of map generalization users beyond the traditional National Mapping Agencies (NMA), and thus not focus only on the generalization of topographic maps. The generalization of thematic maps should be addressed (Raposo et al., 2020).

In this article, we present version 1.0 of CartAGen, the Python port of our old Java platform, previously known as CartAGen4Py, as a three-in-one tool that aims to fill this gap to make map generalization more accessible. The following section presents an overview of the generalization algorithms accessible in this new version. Section 3 describes the QGIS plugin for CartAGen that enables map generalization as a QGIS toolbox provider. Section 4 describes the jupyter notebooks that we developed to make the use of CartAGen easier for different users. Section 5 concludes the paper by describing the road map of CartAGen in the following years.

2. The algorithms available in CartAGen

The environment to develop scripts in Python is already composed of open libraries that are often used by geographic information scientists, such as GeoPandas¹ to load and structure spatial data, Shapely² to handle geometries, or PySAL³ to use spatial analysis methods. The CartAGen library does not replace these libraries but is complementary to them with map generalisation algorithms that are not available in these libraries. All geometric operations are based on shapely, and the input of the CartAGen algorithms is either a shapely geometry or a GeoPandas dataframe (when the semantic attributes are required, or when you need to keep track of the generalised features). The operations on the network features use the NetworkX library⁴. Contrary to the Java version, CartAGen is developed as a geoprocessing library instead of a complete built-in platform.

Despite the ambition to make accessible most of the algorithms proposed in the literature, we are not there yet, and the library proposes a limited portion of these existing algorithms, but that cover all of the existing operations (selection, smoothing, filtering, enlargement, aggregation, displacement, typification, squaring, etc.). The operation that was addressed the most in the literature, i.e. line simplification, is also the one with the most algorithms in the platform, with implementations of Douglas-Peucker

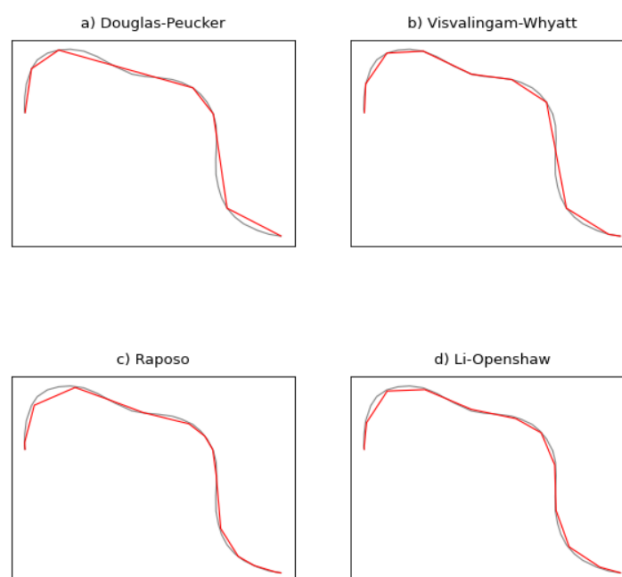


Figure 1. An extract of a river line (in grey) simplified (in red) with four different simplification algorithms from CartAGen.



Figure 2. Three different building simplification algorithms available in CartAGen: (a) building simplification from the AGENT project (Barrault et al., 2001), (b) recursive regression (Bayer, 2010), (c) simplify to rectangle (Barrault et al., 2001).

(Douglas and Peucker, 1973), Li-Openshaw (Li and Openshaw, 1993), (topology-aware) Visvalingam-Whyatt (Visvalingam and Wyatt, 1993), and Raposo (Raposo, 2013) algorithms (Figure 1).

Several algorithms for building generalization are also available, including building simplification algorithms (Barrault et al., 2001, Bayer, 2010) (Figure 2), and building squaring algorithms (Lokhat and Touya, 2016). CartAGen also contains algorithms for building groups with aggregation (Damen et al., 2008), deletion (Touya, 2021) and displacement (Wabiński et al., 2022).

Network selection is also a problem that has attracted many publications in the past twenty years, and CartAGen provides a mix of database enrichment for important structures, including the creation of Strokes (Thomson and Richardson, 1999), and selection methods for both roads (Touya, 2010) and rivers (Touya, 2007). Figure 3 shows the use of a combination of these algorithms for the generalization of a small extract of a road network: detection of roundabouts, branching crossroads, dual carriageways and dead-end groups, and then the collapse of the roundabouts, branching crossroads, and dual carriageways, and finally the typification of the dead end group. Sometimes,

¹<https://geopandas.org/en/stable/>

²<https://shapely.readthedocs.io/en/stable/>

³<https://pysal.org/>

⁴<https://networkx.org/>

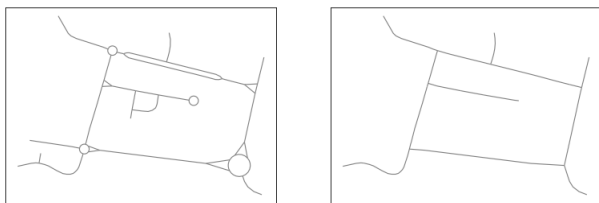


Figure 3. A small extract of a road network selected with a combination of several algorithms: the detection and collapse of roundabouts, branching crossroads and dual carriageways, typification of dead ends.

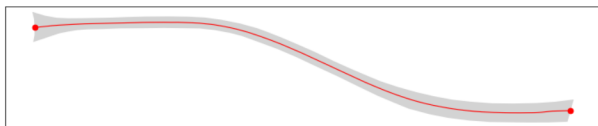


Figure 4. A long and thin polygon (in grey) collapsed into a line (in red) with the *spinalize* algorithm from CartAGen.

roads and rivers can be represented by polygons, and collapse algorithms are necessary to convert the polygons into connected lines. Two algorithms are available, one based on a Delaunay triangulation (Wang, 2009), and one based on a Voronoï partition (Touya and Girres, 2013) (Figure 4).

In France, there are many mountain roads, mainly in the Alps and the Pyrenees with series of sinuous bends, which require specific algorithms such as Max break and Min break (Mustière and Duchêne, 2001) to enlarge the summit of a bend, or Accordion (Lecordix et al., 1997) that stretches a series of bends to avoid symbol coalescence, or Bend schematization that removes one or more bends in a series but preserves the general shape of the bend series (Lecordix et al., 1997). All these algorithms are available in CartAGen (Figure 5) as well as shape measures to cut a road into a homogeneous series of bends.

CartAGen also contains more complex processes that combine several generalization operators at once. First, the least-squares based generalization (Harrie, 1999, Sester, 2000) can be used on polygon and line data to avoid symbol overlaps between the features. Then, the AGENT

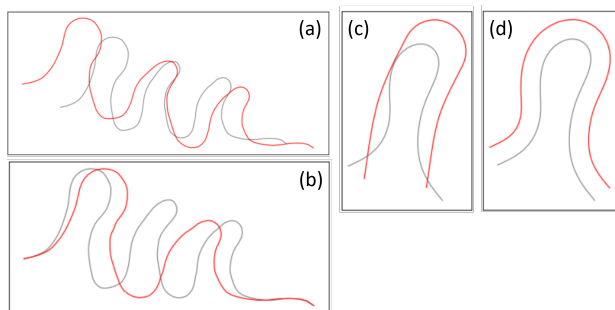


Figure 5. Four different mountain road generalization algorithms from CartAGen (the generalized line is in red): (a) accordion (Lecordix et al., 1997), (b) bend schematization (Lecordix et al., 1997), (c) min break (Mustière and Duchêne, 2001), (d) max break (Mustière and Duchêne, 2001).

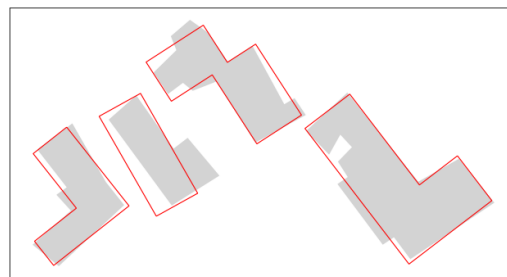


Figure 6. Four buildings generalized with the AGENT process that triggers sequences of algorithms. The initial buildings are in grey and the generalized buildings are displayed in red.

model (Barrault et al., 2001) is partially integrated with the micro generalization of buildings. Figure 6 shows the generalization of four buildings to the 1:35K scale with the AGENT process, where three constraints were defined (minimum size, granularity, squareness).

As our goal as CartAGen developers is to extend the pool of users of map generalization techniques, we recently added several algorithms dedicated to thematic maps (Raposo et al., 2020), and particularly a type of thematic maps: the ones with massive point data layered on top of a map background. We integrated several alternatives to thin massive point data, with clustering-based algorithms (K-Means, DBSCAN), a quad-tree based algorithm (Bereuter and Weibel, 2013), and an algorithm based on a regular grid (Gröbe and Burghardt, 2021) (Figure 7). But sometimes, the best transformation is not to reduce the amount of data but to convert the points into polygons. The swinging arm algorithm and a Delaunay concave hull (Galton and Duckham, 2006) are available, as well as an algorithm to convert the set of points into a heatmap.

Finally, there is a specific focus in CartAGen on database enrichment algorithms that are essential to characterise better the properties and relations of the initial geographic data (Mackaness and Edwards, 2002). Several measures such as polygon compactness (Maceachren, 1985), elongation, orientation (Duchêne et al., 2003), or building block congestion (Ruas, 1998) are available in the current version. It is also possible to create the outline of urban areas from building footprints (Boffet, 2000) (Figure 8).

During the past year, the effort was not put on adding many more algorithms, but on the design of thorough documentation for the algorithms⁵. The documentation contains explanations, illustrations, references and example code for each algorithm making their use easier for new users.

3. The QGIS plugin

QGIS is now not only the main open-source and free GIS, but also a well-established tool with plenty of users worldwide. Extensions of QGIS are based on plugins that are developed by the community of users and made available through an official repository⁶. Among the different types

⁵<https://cartagen.readthedocs.io>

⁶<https://plugins.qgis.org/plugins/>

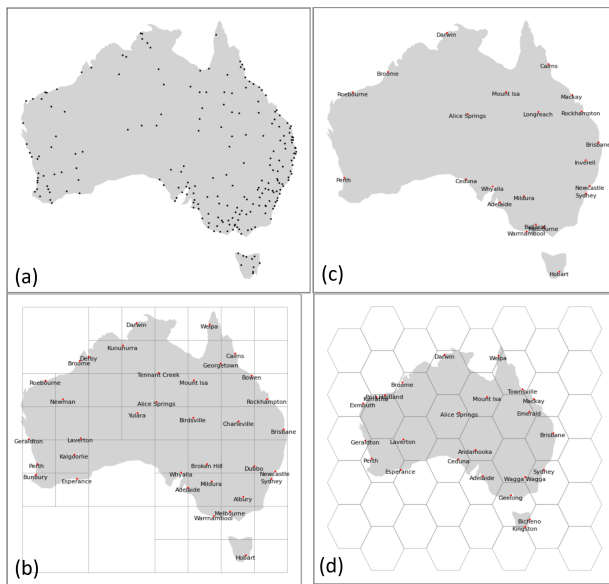


Figure 7. (a) The main Australian cities. Made with Natural Earth. (b) Australian cities generalized with the Quadtree algorithm (Bereuter and Weibel, 2013) and a depth of 3. (c) Australian cities reduced with the K-means algorithm from CartAGen with a shrinking ratio of 0.1. (d) Australian cities generalized with the Label Grid algorithm (Gröbe and Burghardt, 2021) and a hexagonal grid.

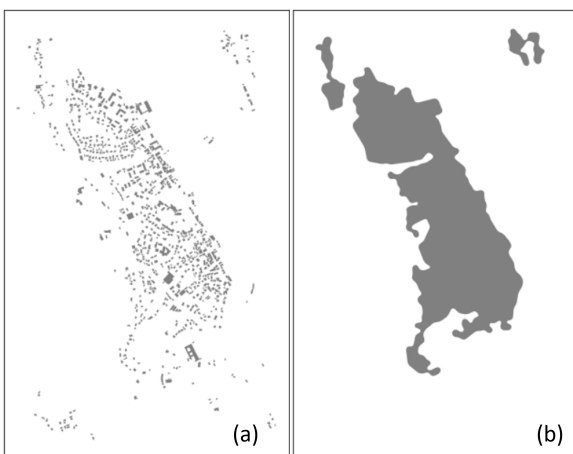


Figure 8. (a) Building footprints (©IGN France). (b) urban area footprints computed from buildings using erosion and dilation operations (Boffet, 2000).

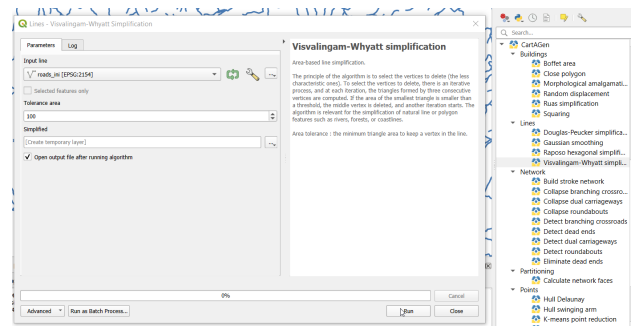


Figure 9. Caption of the window to parameter the Visvalingam-Whyatt algorithm with the CartAGen QGIS plugin, with a glimpse on the algorithms accessible in the plugin on the right.

of QGIS plugins, we decided to develop a QGIS geoprocessing plugin (Graser and Olaya, 2015), which adds new geoprocessing algorithms in the QGIS toolbox (Figure 9). As a result, CartAGen is not a black-box end-to-end process that fully generalizes data layers from QGIS. It is rather intended as a large set of tools that can be used for simple transformations, e.g. simplify a polygon layer, or combined into more complex processes. As shown in Figure 9 with the Visvalingam-Whyatt algorithm, the processes can be used by clicking on the interface and then filling the parameters, including the input and output layers. We also tried to expose as many parameters as possible, using the advanced parameters of QGIS tools, to be able to tweak and fit each dataset's specificities while providing default values to keep it easy to use. For instance, the building squaring algorithm accessible in the QGIS plugin (Lokhat and Touya, 2016) can be used by only specifying the layer to be squared. But the user can access to 7 advanced parameters to tune how the squaring is done, e.g. by defining how close angles have to be to 90° to be squared⁷. A simple explanation of the algorithm is given in the process window, but this documentation is less complete than what is provided on the library website⁸. With this plugin, it is not necessary to know how to code in Python to use CartAGen and to try advanced map generalization algorithms.

For more complex processes, it is possible to use the QGIS model builder to create workflows with CartAGen geoprocesses. Workflows are important to create automated processes for map generalization with a combination of multiple operators and enrichments, with algorithms' outputs feeding the inputs of other algorithms (Harrie and Weibel, 2007, Regnauld et al., 2014). For instance, Figure 10 shows the detection and collapse of roundabouts and branching crossroads in a road network. First, the road network layer is processed in parallel by two algorithms that detect the roundabouts and the branching crossroads, creating two temporary new layers. Then, the third process uses the road layer and the roundabout and branching crossroads to collapse them when they are smaller than a

⁷https://cartagen.readthedocs.io/en/latest/reference/cartagen.square_polygon_ls.html#cartagen.square_polygon_ls

⁸<https://cartagen.readthedocs.io>

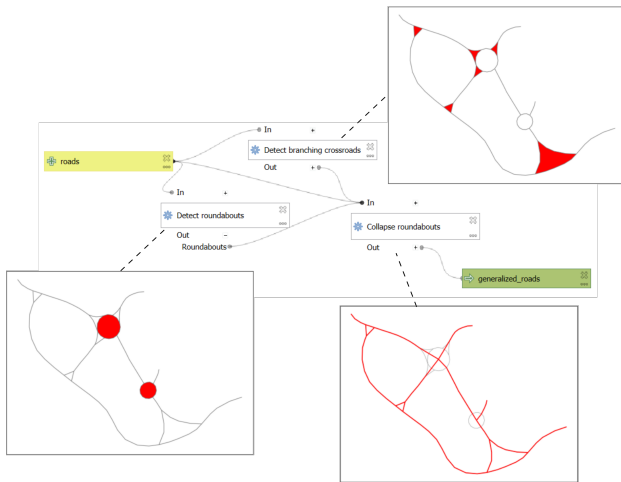


Figure 10. A QGIS workflow to detect and collapse some road network patterns (roundabouts and branching crossroads), combining three different algorithms from CartAGen.

threshold and reconnect the road network. Those workflows can be exported and imported, so we consider providing, in the future, default workflows for specific generalization tasks such as road network (Touya, 2010) and river network (Touya, 2007) selection.

As ArcGIS is also largely used for cartography, and already contains extensive generalization functionalities, we also plan to develop a similar plugin for the users of this software. A port on the R platform is also considered, as many thematic cartographers use R to process their data and generate maps.

4. Learning map generalisation with CartAGen notebooks

One of the goals that guided the recent development of CartAGen was to make map generalization techniques more accessible to new types of users, not limited to NMAs. Though the QGIS plugin presented in the previous section already helps making generalization more accessible, we wanted to develop interactive tutorials for Python developers. This is why we designed three Jupyter Python notebooks that can help users learn how to develop automated generalization processes with CartAGen. A Jupyter notebook is an interactive environment that can combine code, text, images, and the outputs of the code (Davies et al., 2020). This environment is particularly adapted to map generalization where the visualization of the data before and after the process is often mandatory to fully understand an algorithm (Figure 11).

One of the difficulties when dealing with map generalization algorithms is that they often include several parameters that are complex to set for a given map purpose (Foerster et al., 2007). To give a good view of the impact of the parameters, we used advanced functionalities of Jupyter notebooks to include interactive buttons or slide bar when visualizing the algorithm: the user can then interactively change the parameters and the algorithms is re-processed (Figure 12).

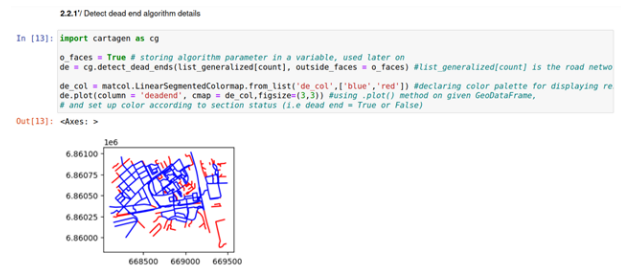


Figure 11. Extract of the CartAGen notebooks with text (above), a code block, and the visualization of the results of the code.



Figure 12. Extract of a CartAGen notebook showing the results of a point selection algorithm based on a K-means clustering with two slide bars that help adjusting interactively the parameters of the algorithm.

The first of the three notebooks is dedicated to the classical task of map generalization for topographic maps⁹. Starting from an open topographic dataset from IGN, the French NMA, the notebook shows how the data enrichment algorithms can be chained with generalization algorithms to fully process the map (Figure 13).

The second notebook¹⁰ is specifically dedicated to map generalization for thematic maps (Raposo et al., 2020), and more specifically to one type of thematic map, a map with a large set of point data. The notebook showcases all the al-

⁹https://mybinder.org/v2/gh/LostInZoom/cartagen-notebooks/HEAD?filepath=tuto_basemap_creation.ipynb

¹⁰https://mybinder.org/v2/gh/LostInZoom/cartagen-notebooks/HEAD?filepath=tuto_point_dataset_generalisation.ipynb



Figure 13. Topographic data generalized in many steps with the topographic generalization notebook of CartAGen.

gorithms available in the library combined with usual cartographic design techniques, to improve the layout of interactive and multi-scale thematic maps (Figure 14).

Finally, we designed a third notebook that aims at teaching generalization to students or new cartographers¹¹. Though the first two notebooks already had an educational dimension, this one is specifically designed to teach generalization algorithmic design to students. Based on the four line simplification algorithms integrated in CartAGen at the time of writing this paper (Douglas-Peucker, Visvalingam-Whyatt, Li-Openshaw, Raposo), the notebook visually breaks down the principles of each algorithm with interactive buttons (Figure 15).

5. The Roadmap of the library

The CartAGen project includes a continuously updated roadmap¹² that shows our current plans to improve the library, the plugin, and the notebooks. However, suggestions can be made to modify this roadmap by raising issues on the Github page of the project¹³, as the development of the library will be driven by its users. The current plan is to add the following missing functionalities:

- relief generalization, whether it is raster DTM generalization (Raposo and Samsonov, 2014), or contour line generalization (Guilbert et al., 2014).
- multi-agent systems beyond the basic use of AGENT; meso agents, CartACom (Duchêne et al., 2012), GAEL (Gaffuri, 2007), or the recent point generalization model (Knura and Schiewe, 2024) should be added in the next years.
- line displacement algorithms such as the Snakes (Burghardt and Meier, 1997) or the Elastic Beams (Bader et al., 2005).
- evaluation of map generalization can be complex (Mackaness and Ruas, 2007, Stoter et al., 2014) and may require specific algorithms, quite similar to the ones required for database enrichment, to measure how much a map is legible, or to assess how much the initial data were transformed.
- algorithms to schematize maps (Mackaness and Reimer, 2014) as those algorithms can be extremely useful in designing thematic maps.
- ArcGIS and R plugins. The ArcGIS plugin is under development for use in production at IGN France.

Acknowledgements

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¹¹https://mybinder.org/v2/gh/LostInZoom/cartagen-notebooks/HEAD?filepath=algorithm_explanation.ipynb

¹²<https://cartagen.readthedocs.io/en/latest/roadmap.html>

¹³<https://github.com/LostInZoom/cartagen/issues>

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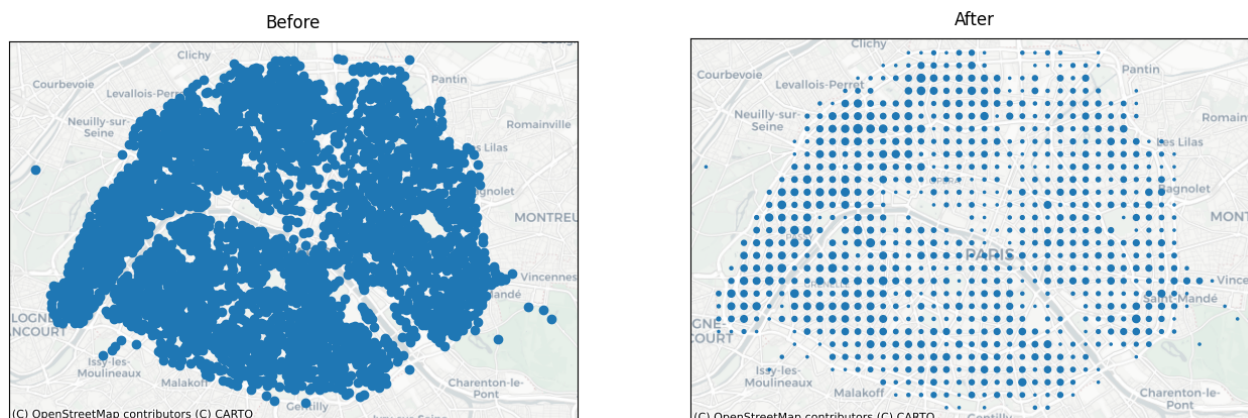


Figure 14. A point dataset (parking meters in Paris) generalized with the Label Grid algorithm (Gröbe and Burghardt, 2021) adapted to operate an aggregation instead of a selection.

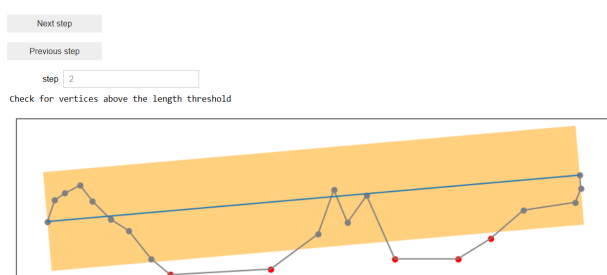


Figure 15. Step-by-step interactive visualization of the Douglas-Peucker algorithm (Douglas and Peucker, 1973) included in the third CartAGen notebook.

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