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Enhancing Automation in Dot Distribution Maps: From Algorithm to User

Natalia Dziuba-Brauner [a,*], Stanisław Szombara [a]

[a] *AGH University of Krakow, Kraków, Poland, ndziuba@agh.edu.pl, szombara@agh.edu.pl*

* Corresponding author

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Abstract:

The automation of map editing processes is a key issue in cartography. Particular attention should be paid to dot distribution maps, which are widely used for the representation of quantitative statistical data. However, their preparation remains highly time-consuming and complex due to the lack of support in GIS software, which does not enable the automatic generation of topographically arranged dots (Pasławski 2015). Previous attempts to automate dot placement have included approaches based on polygon-based clustering (Hey and Bill 2014), hexagonal tessellation (Szombara 2017), as well as iterative and clustering methods and Voronoi-based generalization (De Berg et al. 2004; Yan and Weibel 2008), which provide partial support for automation but still require further refinement.

This research addresses two primary objectives: (1) to present and evaluate an original approach to supporting the automation of dot distribution map editing based on an equal-size spectral clustering algorithm, and (2) to assess how maps generated with this method are perceived and interpreted by users. The methodological foundation builds upon prior work on the application of spectral clustering in thematic cartography (Dziuba and Szombara 2025).

The implemented algorithm extends classical spectral clustering by incorporating a mechanism for equalizing the number of points in clusters (Martínez Barbosa 2023). This modification addresses a key limitation of standard clustering methods, which do not consider cluster size constraints - an essential requirement in dot maps, where each dot represents a fixed number of units. The balancing procedure involves iterative redistribution of points between neighboring clusters to achieve near-equal sizes. Key algorithm parameters (including the number of clusters, iteration count, and balancing constraints) were derived from the cartographic specification of the map (dot value, scale, and spatial extent) and the input census dataset.

The algorithm was tested for different values and sizes of dots. The following were selected for testing: value 200 in sizes of 1 mm and 0.5 mm and value 150 in sizes of 1 mm and 0.5 mm (the target map was to cover the area of one district and be at a scale of 1:150,000). Figure 1 presents a detail of the map generated using the spectral clustering algorithm with a dot value of 200. Magnified view of the selected area illustrates the spatial distribution of points resulting from the algorithm, highlighting how dot placement reflects the underlying population data and the clustering process applied to achieve balanced cluster sizes.

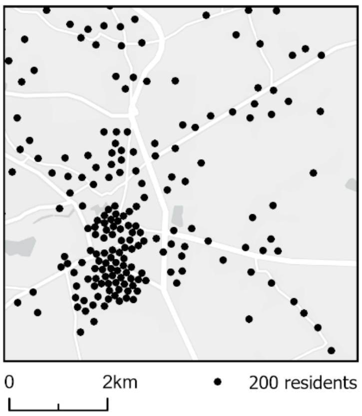

Figure 1. Magnified view of the map generated using the spectral clustering algorithm with a dot value of 200.

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In parallel, a general user evaluation of the generated dot maps was conducted. The evaluation involved users with varying levels of cartographic knowledge, who were asked to assess dot placement quality, map readability, and spatial pattern recognition. The study compared maps produced by different dot placement methods as well as maps with varying dot values and sizes. The primary focus was on how these automatically generated maps compare to manually created reference maps and to maps produced by alternative algorithms available in ArcGIS Pro. The visual comparison of selected variants illustrates the impact of these parameters on both the cartographic quality and overall user experience.

The results indicate that both the algorithmic performance and perception of dot maps are satisfactory. The total population error at the county level was -4.68% for a dot value of 200 and -3.60% for a value of 150, which can be considered acceptable in thematic cartography. From a user perspective, the generated maps were assessed as readable and interpretable, with no significant discrepancies in understanding compared to traditional approaches.

The study demonstrates that equal-size spectral clustering can serve as an effective tool supporting the automation of dot distribution maps while maintaining acceptable cartographic quality and usability. Future work should include more extensive user studies and testing on larger datasets, as well as further development toward fully automated workflows.

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