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A comprehensive workflow for automating thematic map geovisualization from univariate big geospatial point data

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Abstract: The increase in massive volumes of point data that are continuously being generated calls for more powerful solutions to analyze and explore this data. Very often, such data includes a direct or indirect reference to a location on the Earth and can then be referred to as 'big geospatial data'. Maps are one of the best ways to assist humans with understanding geospatial relationships in such data. In this paper, we present a comprehensive workflow for generating all possible thematic map types from two-dimensional univariate big geospatial point data. The objective is twofold: to facilitate and support thematic map automation, and to make this information accessible to software developers. The workflow illustrates processing steps, design choices and dependencies between them based on the characteristics of input data. Processing steps and design choices that can be automated and those requiring human intervention are identified. The scope of the workflow in this paper was restricted to two-dimensional univariate geospatial point data and planar and true geometrical map depictions. The results presented in this paper support the development of geovisualization and geovisual analytics tools for big geospatial data.

Keywords: thematic mapping, big data, point features, geospatial data, workflow

1. Introduction

In recent years, there has been a massive increase in the volumes of geospatial point data that are continuously being generated. Among these are social media posts, mobile tracking information and observations from devices on the Internet of Things (IoT). This data forms part of what is known as 'big data'. Four characteristics distinguish big data from other data: volume, variety, velocity, and veracity (IBM 2012). In many cases, big data includes a direct or indirect reference to a location on the Earth and can then be referred to as 'big geospatial data' (Coetzee and Rautenbach, 2017). In this paper we focus on big geospatial point data.

Big data sources are of limited utility if we cannot find meaning in them (Robinson et al., 2017). Cartography and geographic visualization are uniquely placed to assist humans with visually discovering hidden content in geospatial data (MacEachren and Kraak, 2001). Maps do not only help to better understand geospatial relationships in data (Kraak and Ormeling, 2010), they remain one of the best ways to reduce complexity and to render complex spatial data sets (Robinson et al., 2017). Visualizations have the power to stir the imagination for exploration and problem solving and to facilitate pattern discovery in complex geospatial datasets (Dodge, 2014). The results presented in this paper support the development of geovisualization and visual analytics tools for big geospatial data.

Traditionally, maps were designed and produced by cartographic professionals. Due to technological advances, developers of software tools and their users, often without any cartographic expertise, are now in control of map making. Already in 1997, Dorling and Fairbairn acknowledged that IT developments were leading to a diminishing importance of the craft skills required for map making when software tools for map making started to emerge. They referred to the 'democratization' of cartography. However, restrictions of map making software at that time often resulted in poor quality maps. The term, neocartography, was coined later and refers to empowered non-expert or lay individuals collecting data and producing maps (Cartwright, 2012). Open data releases, open source software and cloud services have expanded the user base of online cartographers who now have total control over the entire map design (Smith, 2016). Smith argues that due to trends, such as infographics and data journalism, online thematic mapping tools with powerful data exploration functionality are becoming more and more popular. Ever more powerful solutions are required due to increased volumes of unprocessed data. From a cartography point of view, the timing for such tools is perfect because technologies are now advanced enough to also support effective online thematic mapping.

The Web allows everyone with access to this medium to create maps (Kraak and Ormeling, 2010). More generally, digital tools allow anyone to become a cartographer

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(Waldt, 2008). However, the fundamental principles of cartography should be considered when making a map, otherwise, mapping is reduced to mere manipulation of data using online tools (Peterson 2013). According to Kraak and Ormeling (2010), cartographers have to take responsibility for convincing the many potential map makers to stick to proven cartographic design principles when visualizing geospatial data. Similarly, Poiker (2005) reminded cartographers that it is their responsibility to tell the world what they do if they wish to claim the role of leaders in aesthetics.

In this paper, the fundamental principles of cartography are presented in a way that is accessible to developers of software. We present a workflow (flowchart) for the process of making a map from univariate geospatial point data. The workflow is based on cartographic design principles, guidelines and rules so that the output maps are correct and effective for communicating the underlying information. It considers spatial completeness and spatial (in)dependence of geographical phenomena (MacEachren, 1995) and can be used as a blueprint for the development of software that produces a set of valid maps (Coetzee and Rautenbach, 2017) from univariate geospatial point data.

In recent related work, Tsorlini et al. (2017) developed a workflow for producing thematic maps from statistical data related to point, line or area geometries. Based on this, a rule-based wizard was developed, which allows users to make map design choices according to a taxonomy that categorizes mapping techniques based on parameters and characteristics of different techniques. Our work is different because we focus on 'raw' point data, i.e. not (yet) aggregated into statistics, from which a set of valid maps can be automatically produced, with minimal user intervention. The aim is to develop a comprehensive workflow that is embedded in cartographic theory and that can be used for software development.

The rest of the paper is structured as follows: in section 2 (method), we explain how the workflow was developed. In section 3 (results), the flowchart representing the workflow is presented. Results are discussed in section 4 and the paper is concluded in section 5.

2. Method

We created a workflow based on the cartographic design process, comprising the steps taken to create a map, from the selection and preparation of the data to the final rendering of the map (Kraak and Ormeling, 2010). The workflow expands on *MapDesign*, a design pattern for generating any kind of thematic map from big geospatial data. *MapDesign* identifies map design choices and dependencies between them, which allows developers to build software that automatically produces a set of maps from which the user can choose one (Coetzee and Rautenbach, 2017). The workflow presented in this paper provides more details about processing steps and choices to be made when geovisualizing thematic maps, specifically from univariate big geospatial point data.

Before designing a thematic map, the characteristics of the input data need to be inspected because they dictate the kinds of thematic maps that can be produced. The workflow is based on a review of scientific literature (Table 1). The workflow branches first into different parts, depending on the dimension of the data (2D, 3D or 4D including time), and then on the feature type (point, line or polygon) (Slocum et al., 2010). The scope of our workflow was determined by considering the potential complexity of data and thus the number of visualisation possibilities. Due to the high complexity of multivariate data, which can result in an endless number of visualisation possibilities, in this paper we therefore focus only on the sub-workflow for producing thematic maps from two-dimensional (2D) univariate point data.

This sub-workflow branches depending on further data characteristics and visualization choices. For data characteristics the most relevant choices are: data category (qualitative, quantitative) (Asche and Hermann, 2002); data measurement scale (nominal, ordinal) for qualitative data (MacEachren 1995); spatial completeness of the geographic phenomenon (discrete to continuous) and spatial (in)dependence (abrupt to smooth) for quantitative data (MacEachren, 1995). For visualization options, the workflow branches into different map types based on: the projection or viewing perspective (planar, perspective) (Robinson et al., 1978); true vs distorted geometry (Burgdorf, 2008); and different visual variables (Bertin, 1983/2011). The workflow terminates in different map types based on the visual variables used dependent on similarities, differences or hierarchies in the data values and consequently, on the geographical relationships they allow map users to perceive (Ormeling, 2014). We included all possible planar visualisations of 2D univariate geospatial point data in the elaborated workflows. Figure 1 provides one of four matrices visualizing the considered map types, in this case all potential planar map types for 2D quantitative univariate data. Due to space constraints, matrices for qualitative data, cartograms and perspective views are not included here.

The workflow was developed iteratively. Map types were identified for 2D univariate geospatial point data. Aggregation, interpolation, data standardisation, classification, symbol scaling, as well as selecting base map features, colour schemes and styling were included in the workflow. The workflow was then verified by confirming that each map type in the workflow could be produced from the steps outlined in the workflow. As the ongoing literature review (including the study of atlas maps) revealed additional map types, these were added to the workflow and the verification process was repeated.

This process was repeated until we were satisfied that all map types had been considered.

Cartographic principles, guidelines and rules	Source
general process of creating a map	Kraak and Ormeling (2010)
map projections in thematic maps, for WebMercator as quasi-standard in Web map services	Wilhelmy (2002); Battersby et al. 2014
geometric dimensions and geometric primitives	Slocum et al. (2010)
data categories: qualitative vs. quantitative	Asche and Hermann (2002)
visual variables according to measurement scale	Bertin (1983/2011); MacEachren (1995)
perspective views (three-dimensional effect; as compared to planar maps in horizontal projection)	Robinson et al. (1978)
cartograms	Burgdorf (2008); Dorling (1996)
geographical phenomena's spatial completeness and spatial (in)dependence	MacEachren (1995)
basemap features	Wilhelmy (2002)
map symbol type	Tyner (2010)
scaling of proportional symbols (mathematical: area or volume vs. range grading)	Slocum et al. (2010)
data standardization	Slocum et al. (2010)
bipolar versus unipolar data	Slocum et al. (2010)
natural or meaningful dividing points as classification breaks	Slocum et al. (2010)
classification methods	Slocum et al. (2010); Robinson et al. (2017)
colour schemes	Brewer (1994)
un-standardized data depiction in case of equally-sized spatial reference units	Friesen et al. (2018)
map types	Arnberger (1997); Kraak and Ormeling (2010); MacEachren and DiBiase (1991); Robinson et al. (1978); Schnabel (2007); Slocum et al. (2010); Tyner (2010)

Table 1. Literature for developing a workflow for rendering thematic maps from two-dimensional univariate point data.

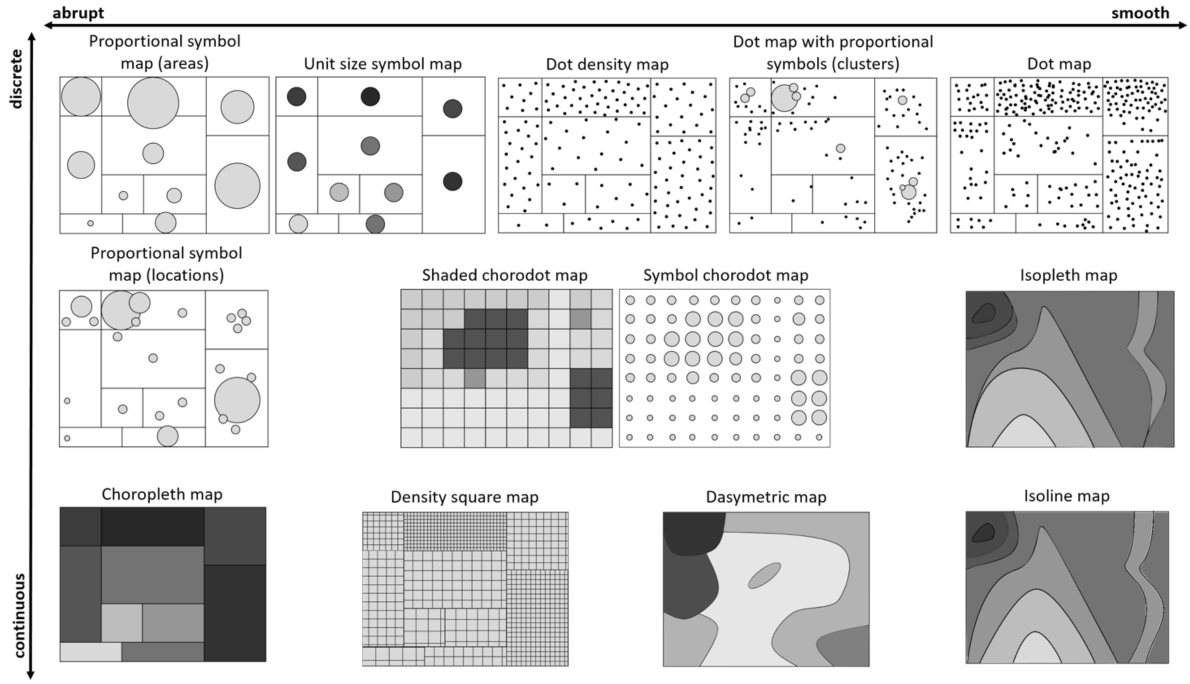

Figure 1. Planar map types for quantitative univariate point data (MacEachren, 1995, Fig. 6.53 extended)

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3. Results

The comprehensive literature review resulted in a detailed workflow which in its entirety can be best presented as a high-level overview of the primary steps and all possible map types that can be produced from 2D univariate point data (Figure 2). Depending on the characteristics of the data and a few decisions by the user, which could depend on the purpose of the map, different types of maps are possible.

The first step in the process of making a thematic map is to collect the data that would be used and to make some initial decisions, for example, *which attribute do I want to visualize?*; *what is the scale?*; and *which map projection would be best?* These steps cannot or have not yet been considered for automatization in *MapDesign*, i.e. the user needs to provide the initial input aligned to the specific data set they would like to convey on a map for revealing a spatial pattern.

Depending on the data, or more specifically the attribute selected by the user in the initial decisions, two very different categories of maps are produced. If the attribute data is qualitative (i.e. categorical data), based on the representation selected the resulting map type can either be a chorochromatic map (area-wise representation), a symbol map (point-wise representation) or a flow map (connecting two points). In Figure 2, the resulting map types are indicated as an oval at the end of each branch.

If the attribute selected is quantitative (i.e. numerical data), the workflow leads to a different set of map types, determined by the choice of representation (i.e. true geometry or distortion leading to cartograms) and the viewing perspective (i.e. planar maps in a horizontal projection or perspective views adding 3D effects to 2D data). In Figure 2 only the branches leading to planar map types are shown in more detail. In addition, spatial completeness (i.e. discrete, continuous or intermediate) and spatial (in)dependence (i.e. ranging from abrupt to smooth) of the geographic phenomenon depicted, as well as the appropriate visual variable (value or size) determine the map type.

The workflow in Figure 2 illustrates that if the user has a 2D univariate point data set of which the specified attribute is quantitative, discrete and its spatial dependence is generally smooth, and wants to display this on a (planar) map using the true geometry, a dot map is the appropriate map type.

To demonstrate this in more detail, Figure 3 provides an overview of the processes and decisions to produce maps from attribute data that are continuous with a spatial (in)dependence that is either smooth (isoline map) or abrupt using value as the visual variable (choropleth map). First, the spatial (in)dependence of the attribute needs to be evaluated to decide if it is abrupt, abrupt-smooth or smooth. In the case of smooth, a shaded isoline map is rendered using value as the visual variable. Next, the attribute data needs to be interpolated and isolines created based on an interval and base value. In between, the data needs to be standardised, the specific method depends on the purpose of the map. Next, the user can decide on styling with the option of colouring the created ranges and on base map features, i.e. depending on the purpose of the map and readability, a number of base map features can be included in the map for orientation purposes (e.g. settlements, roads, hydrology or hillshade). The final map is then rendered.

Another example is the case of abrupt data where administrative areas are used for aggregating the point data and value is selected as the visual variable. This results in either a classified or unclassified choropleth map, depending on user preference. However, this decision to classify the data can be automated as it would generally depend on the range and distribution of the data. For the correct depiction of the visual variable value, the range of data values needs to be investigated for natural (or meaningful) dividing points. Similar to the isoline map, the final steps would include the possibility for specifying base map features before rendering the choropleth map.

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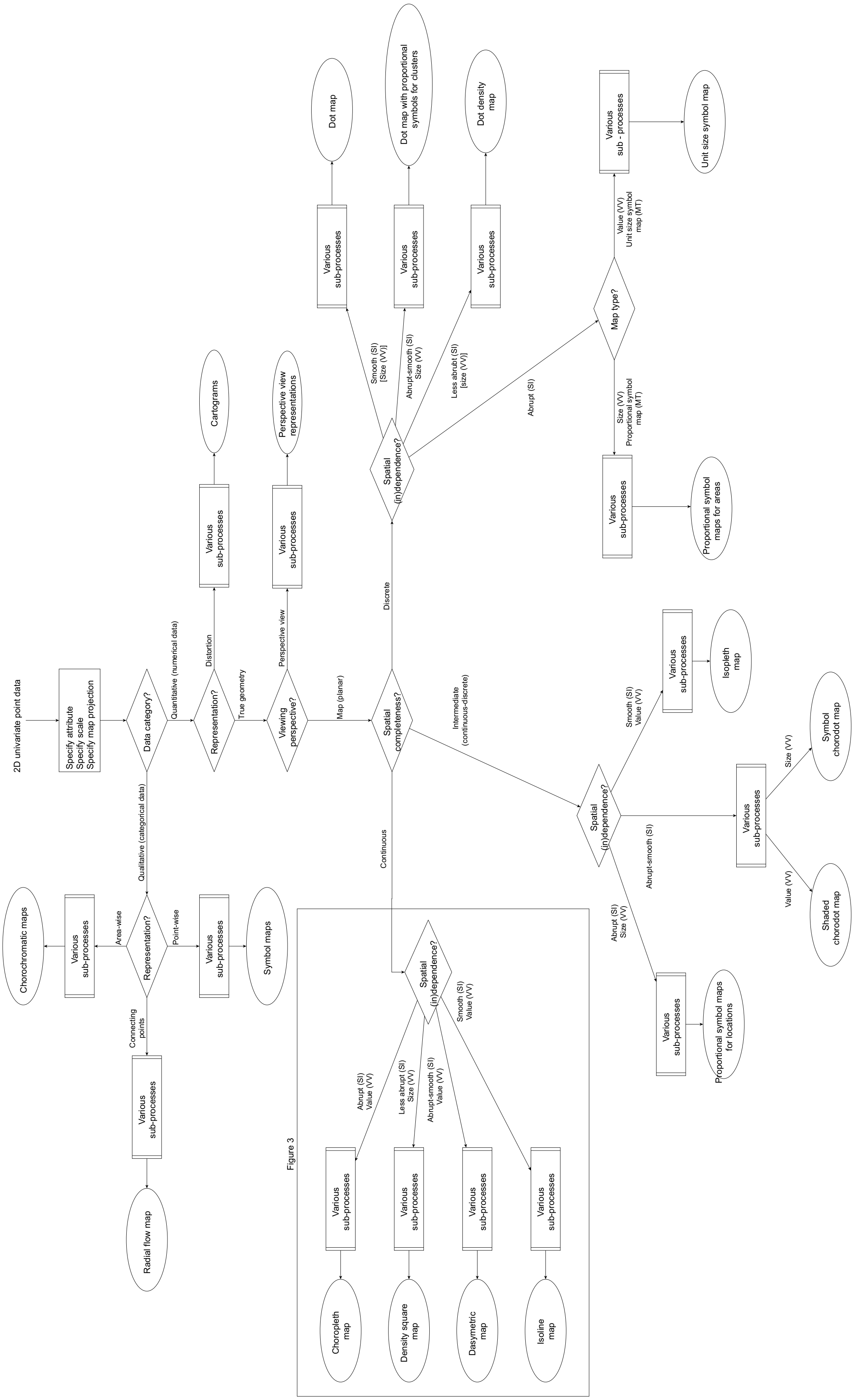

Figure 2. Workflow for automating the rendering of thematic maps from 2D univariate point data, excluding perspective views and cartograms. The following abbreviations are used: MT (map type), SI (spatial (in)dependence) and VV (visual variable).

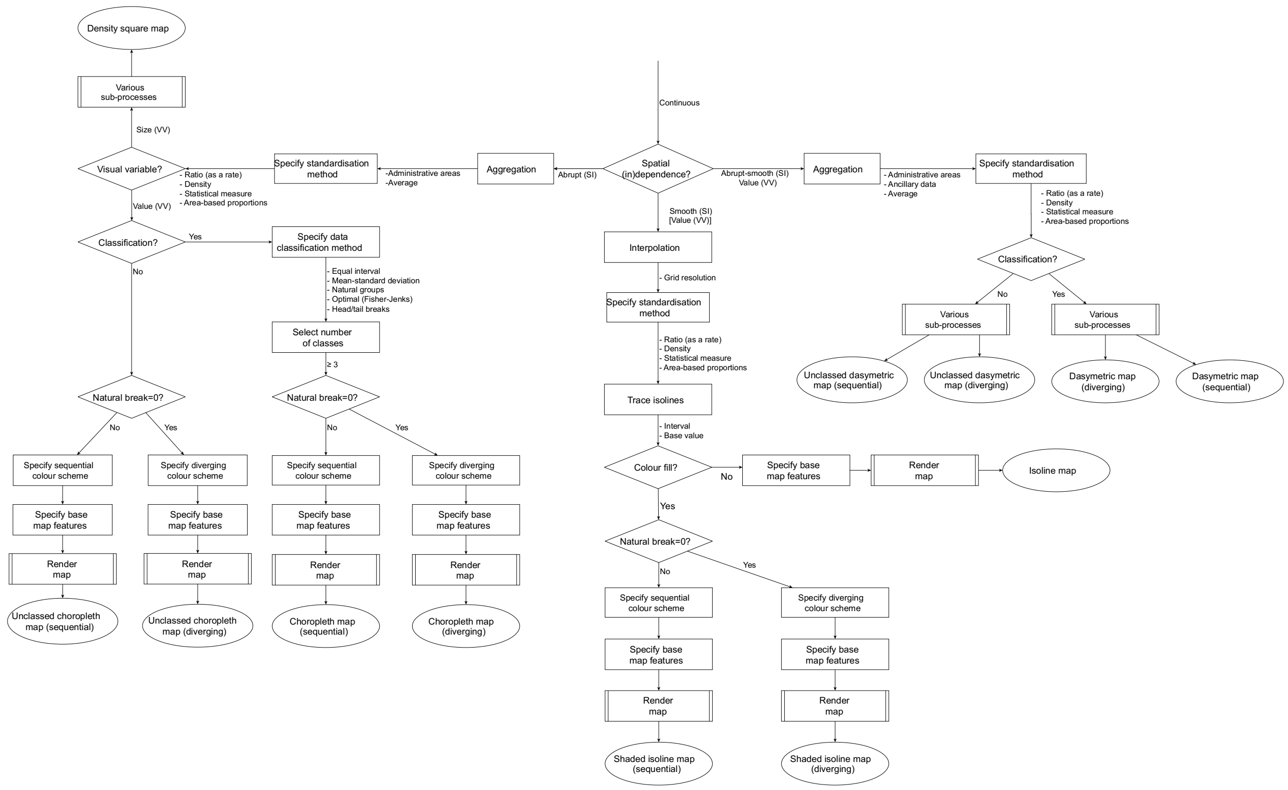

Figure 3. Sub-workflow (of high level workflow in Figure 2) for rendering thematic maps for continuous (i.e. space-filling) 2D quantitative univariate data. The following abbreviations are used, MT (map type), SI (spatial (in)dependence) and VV (visual variable).

4. Discussion

In this paper, we presented a workflow towards automated rendering of thematic maps from big geospatial point data. Through this research, we aim to make cartographic design principles readily accessible to non-cartographers. This facilitates their participation in correct and effective thematic map making, as suggested by Kraak and Ormeling (2010) and Poiker (2005). Tests of the rule-based thematic map wizard developed by Tsorlini et al. (2017) showed that guiding explanations and comparative information are essential to ensure that lay-persons produce correct and effective maps. One can assume that this will also apply to software produced from the workflow in this paper. The extent of user help will depend on the amount of user input required, which we aim to keep to a minimum with the novel approach that we have taken.

According to Smith (2016), current online interactive mapping tools provide a hybrid of presentational and exploratory mapping functionality. The width in geovisualisation functionality and user interaction comes at the cost of requiring more cartographic engagement from users, and a longer development time from map makers. Big data will add to the costs as this data often needs to be analyzed before it can be visualized (Robinson et al., 2017). Our workflow can be used as a blueprint for the development of software that produces a limited set of valid maps from univariate geospatial point data, from which the user could choose one. This would facilitate and support exploration of big geospatial data.

In future, instead of leaving the decision to the user, machine learning algorithms could be employed to search for and decide on the best or most appropriate map type based on input data. Knowledge-based data abstraction is required to reduce the workload when computing visual representations and to keep the perceptual efforts for their interpretation low by suppressing irrelevant details (Aigner et al., 2011). Analysis can be done automatically by using data mining techniques that create multiple visualizations (Kraak, 2014). In this context, Robinson et al. (2017) call for new mapping solutions that directly link visualization methods with the data characteristics and the phenomena they represent. The comprehensive workflow presented in this paper is an important step towards the development of such mapping solutions.

Wills and Wilkinson (2010) describe such an automatic visualization system (AutoVis) for statistical graphics based on decisions about what is to be visualized and designed to provide a first glance at data before modeling and analysis are done. They claim that expert visualization systems need to follow the same rules that expert analysts follow when screening data. The tool is able to recognize the type of file or data source, and produces graphs without any user interventions (based on a Grammar of Graphics as analytic strategy, thus protecting users from false conclusions, and prioritizing for presenting the most interesting results, thus meeting the purpose). But as Aigner et al. (2011) point out, design efforts significantly increase if a spatial frame is added to the data. The increase is even more significant when multiple scales, in both space and time, have to be considered.

Because online maps are rendered at multiple scales, map design is inevitably rule-based (Smith, 2016). In addition, to facilitate automatization and parallelization in online mapping, it must be possible to generate a map from a combination of pre-defined processing steps and design choices. If this is based on object-orientation and design patterns, as in the case of *MapDesign*, the solution is extensible (Coetzee and Rautenbach, 2017), which is of advantage when adding options or filling in details, such as those introduced in this paper.

Online mapping tools with a high level of user interaction require more cartographic engagement from users. Developing mapping tools for both specialist researchers and more general audiences leads to a fundamental design tension (Smith, 2016). Deciding on the purpose and intended audience can therefore not only be considered as the most important step in the cartographic design process (Coetzee and Rautenbach, 2017), but also the most difficult to automate. Robinson et al. (2017) call for cartographic visualization solutions that can even be applied by users at varying levels of expertise. Developing the detailed workflows facilitates the identification of those processing steps and design choices which are difficult to automate. Opportunities for automation, e.g. detecting spatial completeness and spatial (in)dependence, need to be further explored.

By limiting the initial scope of our study to automating the cartographic design process for big univariate geospatial point data, we have not yet touched multivariate data complexity, nor the aspect of time-dependency of data. Map-making for such data is likely to require human engagement, i.e. skill and thought, as well as considerable effort for coming up with sound representations of space (cp. Dodge, 2014). Extending our work to multivariate and time-dependent data will allow us to thoroughly test the statement "that cartography is not just a series of checkboxes on a technological flowline" (Fairbairn, 2014). An additional challenge provides the need to tweak map designs for each map scale or 'zoom level' of online mapping tools (which render large areas of the globe at multiple scales) in order to provide appropriate levels of detail (Smith, 2016).

Without question, there is a large demand for training and sensitizing software developers to succeed in effective map graphics: cartography matters and should take advantage of the latest technological advances (Schaab and Stern, in print). According to MacEachren (2013), however, the discipline is too small to meet all the needs; but, cartographers have always played their role in an interdisciplinary working environment and should continue to contribute strategies for how best to represent the world.

MapDesign, which builds on the concept of design patterns, presented a first opportunity for closing the semantic gap when cartographers and computer scientists collaborate (Coetzee and Rautenbach, 2017), albeit at a very high level of abstraction (for any data and thematic map). The workflow presented in this paper adds more details at a lower level of abstraction (for data with specific characteristics and for a specific set of thematic maps). Instead of a mere increase in map throughput in the age of big geospatial data, correct and appropriate maps should be produced based on the characteristics of the input data, thus deserving the term intelligent map design. Schaab et al. (2009) summarized that cartographers still believe that cartographic design rules are needed to ensure effective communication, i.e. to allow the conveying of geospatial relationships. In the age of big data, automated data analysis will be required before any visualization can take place. This points to a reversed order compared to geovisualization where analysis follows visualization (Robinson et al., 2017).

5. Conclusion

In this paper we presented a comprehensive workflow for generating all possible map types from univariate geospatial point data. The workflow illustrates processing steps, design choices and dependencies between them based on the characteristics of input data. Processing steps and design choices that can be automated and those requiring human intervention were identified. The scope of the workflow was restricted to univariate geospatial point data, and only planar and true geometrical map types were covered. Workflows for perspective views and cartograms (distorted geometries) are in progress. In future work, the workflow could be expanded to include multivariate data as well as time-dependent data. Even more challenging is that map types vary with map scale, which should also be investigated. Another idea is to link thematic content with typical map types. Such complex workflows would be very useful, not only for software development, but also for communicating the principles of thematic mapping to non-cartographic experts. Finally, the workflows should be objectively tested, for example, through the development of software and evaluation experiments with different datasets and users.

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