Cartographic Perspectives

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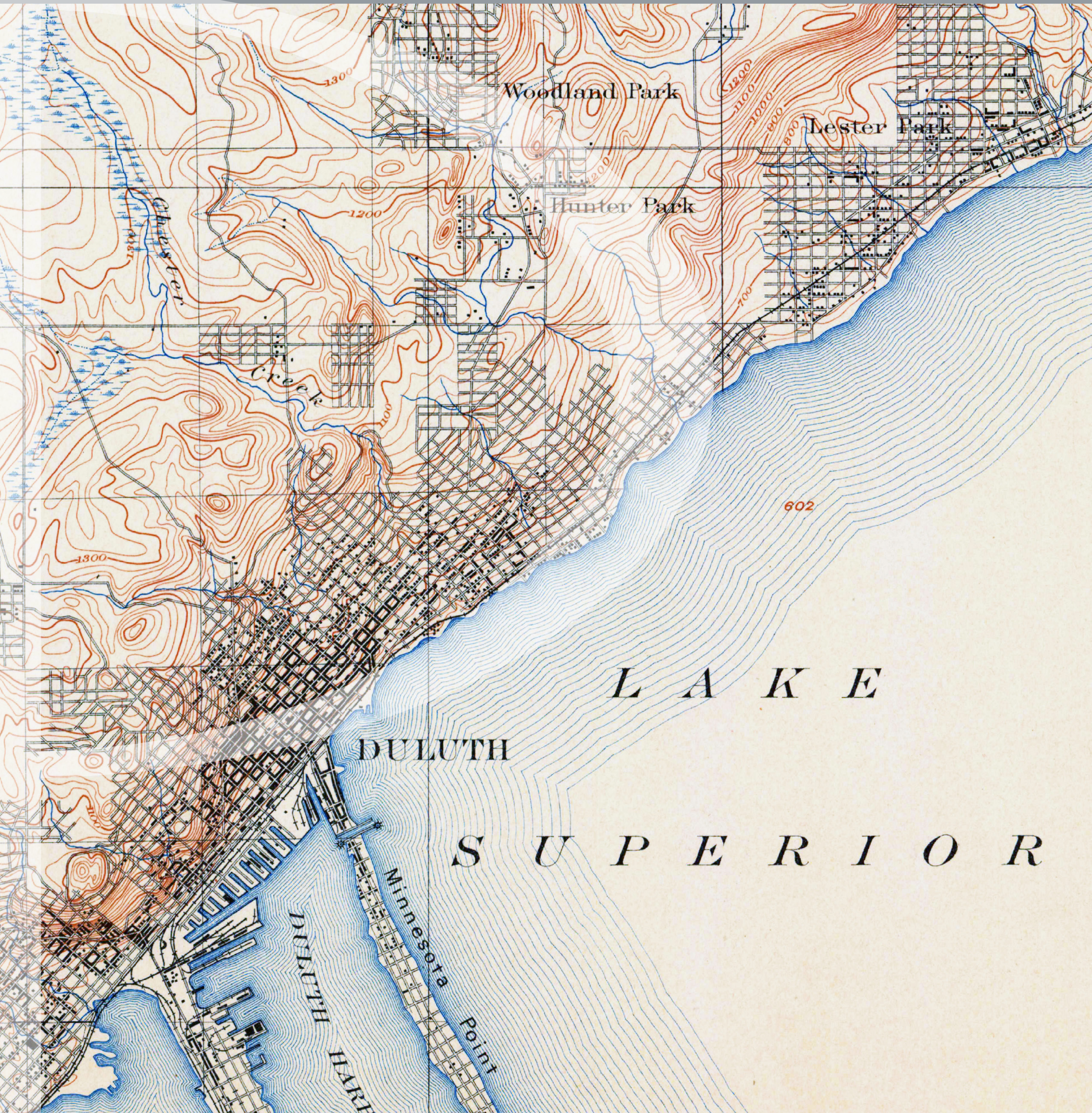

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IN THIS ISSUE

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ABOUT THE COVER: *Detail from an 1895 USGS topographic map of Duluth, Minnesota. This map was produced by a process of copperplate engraving. See Cartographic Collections, beginning on page 24, to learn more.*

LETTER FROM THE PRESIDENT

It is my pleasure and honor to have the opportunity to write on behalf of NACIS as its President. I attended my first NACIS Annual Meeting in 2005, while working on my Master's degree at Penn State. Since that time, I have never missed a NACIS meeting. What has made it easy for me to stay engaged with this community is the chance to work with so many people who share a passion for mapmaking. I am still amazed that I have had the chance to serve in a leadership role with this organization. Thank you for allowing me that opportunity.

The NACIS community is thriving. Its reach and diversity have never been better. Our membership is growing, interest in the Annual Meeting is reaching historically high levels, and we are able to provide more support than ever for students and professionals to attend. NACIS also continues to offer the only open access cartography journal with *Cartographic Perspectives*. These are all incredible accomplishments, made possible by everyone who has ever taken part in the Society's activities, including by presenting their work at the Annual Meeting, publishing in *Cartographic Perspectives*, serving on the NACIS Board of Directors, or representing cartography in their workplace, classroom, or community.

In October, 2016 the NACIS community came together in Colorado Springs to learn from one another at our Annual Meeting. We were fortunate to have keynotes by Kirk Goldsberry and Joshua Jelly-Schapiro, providing provocative and gripping messages about the power of creativity, rhetoric, and critical thinking in cartography and the realms with which it often overlaps. More than 100 presentations were submitted for consideration, with topics crossing the full spectrum of art, science, technology, and the societal dimensions of cartography. The most frequent feedback we hear about the conference is that people wish it were possible to see every single session.

We've begun to address that recently by launching the first-ever live video feed of NACIS. During the 2016 meeting, we were able stream and record Practical Cartography Day. NACIS members anywhere in the world were able to tune in and watch the presentations live, and the recorded videos were made available to the general public about a month after the conference. For 2017 we went even further, and live streamed and recorded the entire conference. As in 2016, NACIS members were able to enjoy the live streaming feature as a member benefit, while the recorded sessions will be posted for public consumption a few weeks after the conference concludes.

For 2017, NACIS Vice President Fritz Kessler and Vice President-Elect Ginny Mason worked hard to bring together another exciting Annual Meeting, this time in Montréal, Quebec. NACIS ventured to Canada for the first time since 1994, when we met in Ottawa. This journey northward was long overdue, and we are glad to have had the chance to make new connections in Montréal.

A tremendous amount of work is done each year by the volunteers who serve on the NACIS Board. I would like to thank everyone who contributes their time and energy to serving this community. If you have an interest in taking your commitment to NACIS to a new level, please let us know. We are always in need of new ideas, new voices, and new energy to propel our work forward.

Take some time to explore the contributions in this issue of *CP*. In the *peer-reviewed article* section, you will find a description of how a wizard can be used as a tool to help novice cartographers produce better thematic maps. The *cartographic collections* piece profiles an exhibition of copper plates that were used to print topographic maps of Minnesota in the early 1900s. In the *practical cartographer's corner*, you will find an exploration of the limits of QGIS and ArcGIS Pro's capabilities for producing unclassed choropleth maps. *visual fields* presents a series of stitched landscapes, some of them multiscale. Finally, this issue's *book reviews* evaluate books on cartography and navigation, cartographic curiosities and getting to know ArcGIS Pro.

Anthony Robinson
NACIS President

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PEER-REVIEWED ARTICLE

Designing a Rule-based Wizard for Visualizing Statistical Data on Thematic Maps

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Thematic maps are used in a wide range of scientific fields to illustrate specific geographic phenomena. For their correct construction, the mapmaker has to select the appropriate data, and then consider different parameters and constraints in order to visualize them effectively. In this paper, these parameters were analyzed, so that a consistent and standardized workflow for producing thematic maps could be set up. This workflow served as the basis for designing and implementing a step-by-step wizard-based application. Its goal is to guide mapmakers—experts or laypersons—to create cartographically sound thematic maps based on statistical data, in a user-friendly way. To standardize the procedure, we analyzed the relationships between different mapping techniques and the types of data with which they are used to illustrate a geographic phenomenon. Based on this analysis, we created a new taxonomy of mapping techniques and used it to automate the selection procedure within the wizard. This analysis could also be of general use for researchers producing thematic maps in different mapping applications.

KEYWORDS: thematic cartography; thematic mapping techniques; cartographic design principles; wizard-based application

INTRODUCTION

Thematic maps graphically represent a number of attributes or concepts in order to show the spatial distribution of a particular geographic phenomenon over an area (Spiess 1970a; 1970b; Dent 1996). To select the proper mapping technique to correctly visualize a geographic phenomenon, the mapmaker has to make several consecutive decisions based upon the data to be used. Thematic mapping techniques and map representations used for one type of data may be inappropriate for another type, potentially depicting the phenomenon in a misleading way (Hutzler and Spiess 1993).

A number of software applications that offer various techniques for producing thematic maps are available today. However, these applications do not usually inform mapmakers about the specific properties of each mapping technique or the data that they are suitable for representing. For this reason, there is value in developing an application to guide the mapmaker through the design of a proper thematic map, from the selection of the data, to the selection of an appropriate mapping technique, to the final construction of the map. To design such an application, it is important to first analyze the steps of the cartographic procedure usually followed in producing thematic maps. Additionally, it is necessary to study commonly applied cartographic principles and rules concerning the relationship between mapping techniques and the type of the data (interval/ratio data with absolute/relative values) they are based on.

In this paper, we present the results of this analysis, along with the schemes we created to show how the cartographic principles are interconnected, which together lead to a workflow that standardizes the whole procedure and systematizes the selection of appropriate mapping techniques. Based on this analysis and the detailed schemes, we design and implement an application to guide the user through a step-by-step wizard to create correct thematic maps following principles and rules commonly applied in thematic cartography. Using this wizard, the complexity of the visualization task in producing a thematic map is significantly simplified.

STATE-OF-THE-ART: SOFTWARE TO CREATE THEMATIC MAPS WITH STATISTICAL DATA

A number of software applications provide for the visualization of a theme on a map. Maps with proportional or graduated symbols, maps with charts, dot density maps, or choropleth maps may be designed using GIS software such as ArcGIS by Esri or QGIS. There is also dedicated cartographic software, such as Maptitude Mapping Software by Caliper, Regiograph by GfK GeoMarketing GmbH, and Cartovista by DBx Geomatics (a list of links to all software applications mentioned in this section is found at the end of this paper). Additionally, several online applications allow users to create thematic maps by uploading their own data or using the data already included in these platforms; examples include CARTO, Thematic Mapping API, Statplanet by StatSilk, and Indiemapper by Axis Maps.

Plug-ins and extensions allow several other programs to offer thematic map functionality. Thematic maps (including maps with charts, proportional or graduated symbol maps, dot density maps, and choropleth maps) may be created in Adobe Illustrator by using the plug-ins implemented at the Institute of Cartography and Geoinformation, ETH Zurich (Werner and Hutzler 2006; Hurni and Hutzler 2008). Microsoft Excel features the Excelcharts plug-in, which uses scripts and macros to produce thematic maps. Additionally, Excel's Power Map add-in lets users plot geographic and temporal data on a 3D globe or on a custom map, animate it over time, and also create visual tours. Finally, the Diagram map creator plug-in, implemented by Valent (2010) as an ArcGIS extension, allows users to produce various types of diagram maps in ArcGIS, under the condition that the statistical data are already included in the attribute table of the shapefile.

For the production of thematic maps, all these applications use *statistical data* in table form connected to the spatial *geometry data* that is used to cartographically depict the statistical data. For every shape in the geometry data, a specific record exists containing descriptive information—e.g., ID, name, or size properties—in an accompanying attribute table. In most applications, the procedure is similar: the statistical table is joined to the geometry's attribute table using common identifying values (ID), and the theme is visualized within the frame of the geometry by applying the appropriate mapping technique. In order to create a map using one of these applications, the mapmaker may apply any technique whether or not it is suitable for the selected statistical data. However, none of the applications provides an automatic procedure for the context-related selection of an appropriate visualization. Even in software with some automated processes, such as Golden Software's applications MapViewer, Grapher, and Scripter, the automation is achieved through scripts developed by users, and it is restricted to the selection of different chart styles to visualize the data.

In contrast, there are cases in the cartographic literature describing models of expert systems (Bollmann 1989; Forrest 1993) or knowledge-based systems (Mueller and Zeshen 1990; Zhang et al. 1992; Hutzler and Spiess 1993; Zhan and Buttenfield 1995) that automate the design of thematic maps. Bollmann designed a model (1989) in which the source data are analyzed, evaluated, and attributed with design and construction rules. Then, they are transferred into a digital map model, which is tested and corrected for the final modeling. Forrest (1993), on the other hand, describes the most basic model of an expert system as consisting of three main parts: the knowledge base (facts and rules), the inference engine (logic, procedures), and a user interface, adding also a database of relevant data. Additionally, he provides an overview of expert systems found in the literature, mainly covering three areas of interest: the design of map content and symbolization, the generalization, and the name arrangement.

In the knowledge-based system developed by Mueller and Zeshen (1990, 26), seven types of statistical maps—qualitative point and area maps, ordered point and area maps, proportional symbol maps, graphic maps (charts), and choropleth maps—were classified to help users "reach adequate decisions for the symbolic representation of statistical information based on physical or administrative units." The representation of numerical data was limited to proportional symbol and choropleth maps, omitting other methods, in order to simplify the development of the model.

Zhang et al. (1992) developed the MAPKEY expert system for producing thematic maps. This system is based upon GIS, integrating a database, a knowledge base, and computer graphics for visualization. It covers almost all production steps of thematic mapping, such as data preparation, map type selection, data classification, symbol and color design, four-color separation, and film output.

In the knowledge-based system modeled by Hutzler and Spiess (1993), the entire procedure is automated, starting from the source data and the initial map requirements and finishing with the production of the final map through different rules based on a large amount of expert knowledge incorporated into the system. However, the user makes the crucial decisions during the process, based on the full knowledge of possible alternatives and options, thus reducing the danger of inappropriate solutions.

Zhan and Buttenfield (1995) have suggested an object-oriented, knowledge-based system for use in symbol selection (point, line, area) for the visualization of spatial statistical information. In this system, depending on the developed prototype, "the fundamental step was the specification of knowledge associated with symbol selection. Specification of knowledge includes the review of the cartographic principles for symbol selection and identification of the relevant decision processes" (296). However, this system does not generate a graphic output; it stops at symbol selection without defining its properties (e.g., color, size) and without helping the user produce the final map. Moreover, the system does not include any explanations to guide the user at each branching point; nor does it give information about the procedure or the different options that may exist at each step.

Complementary to the models implemented for these systems is the intelligent system designed by Dobesova and Brus (2012) for the interactive support of thematic map design. The project was focused on the development of a cartographic ontology that could facilitate the creation of the cartographic knowledge base of the system.

Keeping all the above in mind, expert systems in cartography incorporating formulated rules for every procedural step are very useful, since they allow users to concentrate on the application, relying on the system to generate representations that are cartographically logical. Our project also relies on this concept, but it mainly focused on designing a standardized workflow based on the analysis of cartographic principles and rules. We then developed a novel, rule-based wizard to guide users in creating thematic maps, which featured a hardcoded version of these cartographic rules.

BASIC CARTOGRAPHIC TERMS AND PRINCIPLES IN THEMATIC CARTOGRAPHY

In our attempt to design a standardized workflow to support the production of thematic maps, it is necessary first to analyze basic terms and principles established in thematic cartography. Based on this analysis, it is then possible to automate the selection of the appropriate visualization technique for a given map. This is the foundation for developing a rule-based wizard to guide users in creating the final thematic map.

For this reason, we analyzed the connections between the levels of data measurement (i.e., nominal, ordinal, and interval/ratio—including both absolute and relative values) and commonly used thematic mapping techniques (e.g., proportional or graduated symbols, charts, proportional or graduated or lines, isolines, isopleths, choropleths, bivariate mapping, etc.). For this survey of techniques, we drew upon a wide variety of sources (Stevens 1946; Witt 1967; Imhof 1972; Tobler 1973; Spiess 1978; Bertin 1983; Tyner 1992; Arnberger 1993; Dent 1996; Kraak and Ormeling 1996; Hake et al. 2002; Asche and Herrmann 2002; Slocum et al. 2005; Leonowicz 2006; Stern et al. 2011; Hurni 2012; Elmer 2013; Ormeling 2014).

Based on this analysis, we created Table 1 to summarize the different data types and their combinations with the spatial dimensions of geographic phenomena (point, line, area, volume) and their distributional forms (discrete, sequential, continuous). In each case, we suggest the proper

Geographic phenomena	Data		Visualization		
Spatial dimension [distributional form]	**Level of measurement**	**Symbolization**	**Mapping Techniques**	**Visual (graphical) variable**	**Emphasis on**
Point [discrete]	Nominal	Qualitative data as point symbols	Point symbols	Color, orientation, shape	Point phenomena
	Ordinal	Ranked qualitative data as point symbols	Point symbols showing hierarchy	Value, size	
	Interval/Ratio (absolute values)	Dots	Dots density	Multitude shows size	Distribution/density of point phenomena in unit areas
		Repeated symbols	Repeated symbols	Multitude shows size	Density of point phenomena in area centroids or location points
		Proportional/graduated symbols	Proportional/ graduated symbols	Size	Total quantities of point phenomena in area centroids or location points
		Charts	Charts	Size	Quantities of several attributes of point phenomena in area centroids or location points
Line [sequential]	Nominal	Qualitative data as line symbols	Line symbols	Color, shape	Linear phenomena
	Ordinal	Ordinal qualitative data as line symbols	Line symbols showing hierarchy	Value, size	
	Interval/Ratio (absolute/relative values)	Proportional/graduated lines	Proportional/ graduated lines	Width shows size	Interactions among places, flows or desire lines
Area [continuous]	Nominal	Qualitative data as area patterns	Area patterns	Color	Areal phenomena
	Ordinal	Ordinal qualitative data as area patterns	Area patterns showing hierarchy	Value, pattern	
	Interval/Ratio (relative values)	Numerical data as area patterns	Choropleths/ dasymetric or bivariate choropleth	Value, pattern	Quantities in areal units
Volume (area) (2.5-D phenomena) [continuous]	Nominal	*(2.5-D phenomena cannot be mapped with nominal symbols)*			
	Ordinal	Ordinal area pattern	Area patterns showing hierarchy	Value	Relative variations of 2.5D phenomena
	Interval/Ratio (absolute/relative values)	Lines of same magnitude	Isometric mapping (Isolines)	Value, form	Lines of same magnitude interpolated from data
	Interval/Ratio (relative values)	Data values classified in equal intervals	Isoplethic mapping	Value	Geographic areas between the isolines

Table 1. Relationships between the properties of geographic phenomena (spatial dimensions and distributional form), data types, and appropriate thematic mapping techniques. (Dent 1996, 85; modified and adjusted by the authors based on Tyner 1992; Slocum et al. 2005; Hurni 2012; Ormeling 2014).

mapping technique, as well as an explanation of where to place the emphasis on the visualization. As it shows, the same data may be represented by multiple mapping techniques, thus it is necessary to categorize these mapping techniques.

AUTOMATING THE SELECTION OF THE APPROPRIATE MAPPING TECHNIQUE BASED ON THEMATIC DATA ANALYSIS

Based on the analysis summarized in Table 1, we developed a new taxonomy of mapping techniques for standardizing the cartographic design of thematic maps and automating the selection of the appropriate technique that fits the data. This taxonomy is based on categorizing specific parameters of the different mapping techniques, taking into account their individual characteristics.

DEFINING PARAMETERS TO SELECT THE APPROPRIATE MAPPING TECHNIQUE

The parameters that influence the selection of a suitable mapping technique are based on the data properties and spatial dimensions of the phenomenon to be visualized. The latter influences the geometry type that will be selected for visualizing the theme on the map.

The parameters describing the data properties are as follows:

- Nature of the geographic phenomenon that defines the map theme: point, line, area, or volume
- Level of measurement of the data: interval or ratio, since only numerical data were used in this study
- Number of attributes used to represent the theme
- Type of data values: absolute or relative
- Whether or not the data are classified

The parameters describing the spatial dimensions of the geographic phenomenon and the related visualization on the map are:

- Representation form of the phenomenon, which is connected to the theme of the map and defines its spatial dimensions: point, line, area, or volume
- The geometry used to depict the phenomenon on the map.
- For example, the population of European countries (theme) may be represented with proportional symbols (representation form: point), linked to a geometry consisting of the polygons of the countries (geometry: polygon).

THE NEW TAXONOMY OF MAPPING TECHNIQUES

Based on the above-mentioned parameters, Table 2 shows our new taxonomy of mapping techniques and their characteristics of data type, representation type, and geometry type. It also shows the techniques that can be used to visualize multiple attributes at the same time (e.g., a chart), or techniques suitable for a combined representation of multiple attributes in different layers.

At this point, our analysis indicates how to distinguish between the mapping techniques, in order to select the appropriate one. For techniques involving repeated, proportional, or graduated symbols, or involving charts, an in-depth knowledge of the symbol properties is required, because each symbol may express different characteristics of the original data. This additional categorization of symbols and charts eases the selection of the proper visualization technique in the wizard.

CATEGORIZATION OF SYMBOLS

In order to categorize the different symbols and the charts, we analyzed an extensive number of visualization types described in relevant cartographic literature (Witt 1967; Imhof 1972; Spiess 1978; Bertin 1983; White 1984; Arnberger 1993; Hake et al. 2002; Schnabel 2007a). Some particular styles of symbols or charts appear in the literature under multiple names. As an example, Figures 1 and 4 also include the terminology used by Brewer and Campbell (1998).

Categorization of Repeated Symbols

Density variations of phenomena in an area may be shown with dot symbols or repeated symbols. Figure 1 presents different types of repeated symbols, depicting

Mapping techniques	Representation type / Spatial dimensions (phenomenon)	Geometry to be used	Data				Techniques for visualizing attributes in different layers	Emphasis on (defined by the phenomenon)	
			Attributes	Values absolute/ relative	Values (+, -, 0)	Classification			
Dot symbols	point	polygon	1	absolute	+		• (colour or shape)	Density or distribution	
Repeated symbols[1]	point	point/polygon	1	absolute	+		• (colour or shape)		
Proportional symbols[1]	point	point/polygon	1	absolute	+, -, 0*		• (colour or shape)	Exact values	at specific locations
Graduated symbols[1]	point	point/polygon	1	absolute	+, -, 0*	•	• (colour or shape)	Classified magnitudes	
Charts[1]	point	point/polygon	several	absolute/ relative	+, -, 0*			Multivariate magnitudes	
Proportional lines/arrows	line	line	1	absolute/ relative	+, -		• (colour or shape)	Exact values	showing direction or movements
Graduated lines/arrows	line	line	1	absolute/ relative	+, -	•	• (colour or shape)	Classified values	
Dasymetric mapping	area	polygon	1	relative	+, -, 0	•	• (colour or pattern)	Magnitudes	at zones of uniformity
Choropleths	area	polygon	1	relative	+, -, 0	•	• (colour or pattern)		at enumeration units
Unclassified choropleths	area	polygon	1	relative	+, -, 0		• (colour or pattern)	Exact values of magnitudes	
Bivariate choropleth mapping	area	polygon	2	relative	+, -, 0	•	• (colour or pattern)	2 variables displayed as 1	
Isolines (isometric mapping)	volume[2] (shown on lines over areas)	line/polygon (pre-processing for point data interpolation)	1	absolute/ relative	+, -, 0			Lines of same magnitude	
Isopleths	volume[2] (shown on areas)	polygon (pre-processing for point data interpolation)	1	relative	+, -, 0	•	• (colour or pattern)	Values classified in equal intervals	
Multivariate mapping (representation of several attributes)	*(depending on the mapping technique)*	polygon	several	absolute/ relative	*(depending on the mapping technique)*			Representation of several attributes with the same/ different techniques	

[1] For charts, repeated, proportional, and graduated symbols, the appropriate type is selected based on additional parameters analysed in the section titled, "Categorization of Symbols."
[2] For volumetric (2.5-D) phenomena, the third dimension can be real (e.g., elevation above sea level) or conceptual (e.g., temperature over an area). These phenomena extend over areas.
** Zero values can be shown only in particular symbols such as bars or bar charts.*

Table 2. *The new taxonomy of mapping techniques and their characteristics.*

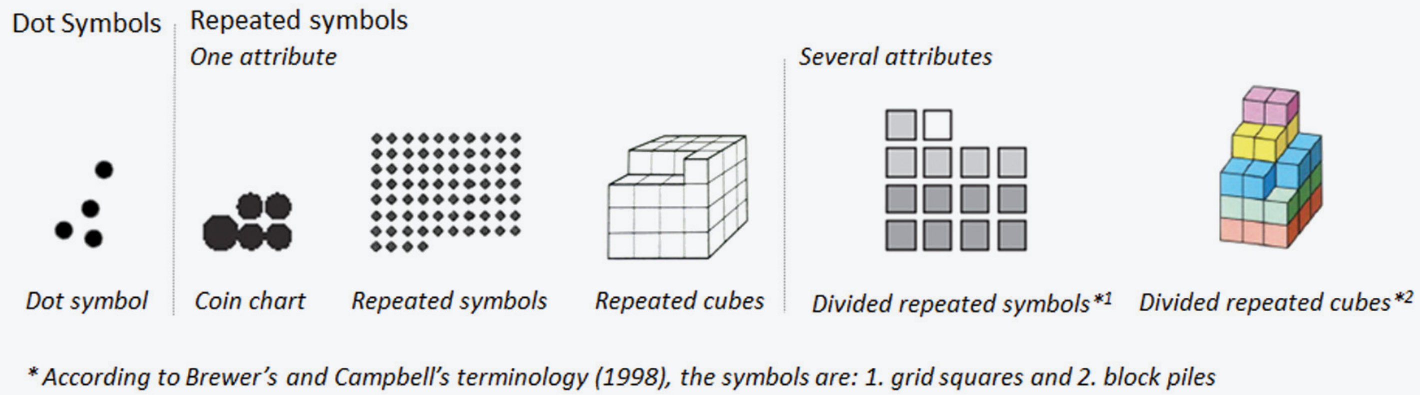

Figure 1. *Dot symbols and repeated symbols depicting one or several attributes in 2D and 3D (Imhof 1972; Brewer and Campbell 1998; Schnabel 2007a).*

one or several attributes as two- or three-dimensional representations.

Categorization of Proportional or Graduated Symbols

Proportional (or graduated) symbols may be pictographic symbols, showing image-like representations of the corresponding elements, or geometric symbols, such as circles, squares, triangles, bars, etc. According to Dent (1996), the circle is the predominant form. In Figure 2, pictorial and geometric symbols are categorized. The size (area, height, or volume) changes proportionally to data values.

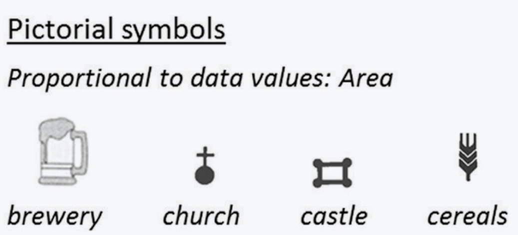

Figure 2. *Pictorial and geometric symbols illustrate a phenomenon according to the proportional or graduated symbol techniques (Imhof 1972; Brewer and Campbell 1998; Slocum et al. 2005; Schnabel 2007a; 2007b).*

Categorization of Charts

Charts are more sophisticated in design and construction than repeated and proportional symbols. Every chart has construction, style, and perceptive properties (Schnabel 2007a; Schnabel and Hurni 2009). Construction properties are based on a cartographic primitive: a point, line, or area. Style properties depend on the graphical variables used to represent the map symbol, while the perception properties are associated with the cognition of the map symbol by the user. Based on their construction properties, Schnabel (2007a; 2007b) described 49 categories of charts that can be found in thematic maps.

Following Schnabel's categorization, but also taking the multivariate structure of data into account, we examined the properties of each chart and developed a new categorization, in which attributes are organized in groups (a chart has 1 or more groups of attributes that are compared). Other chart properties include its specific arrangement principle (polar, linear, perpendicular, or triangular), how

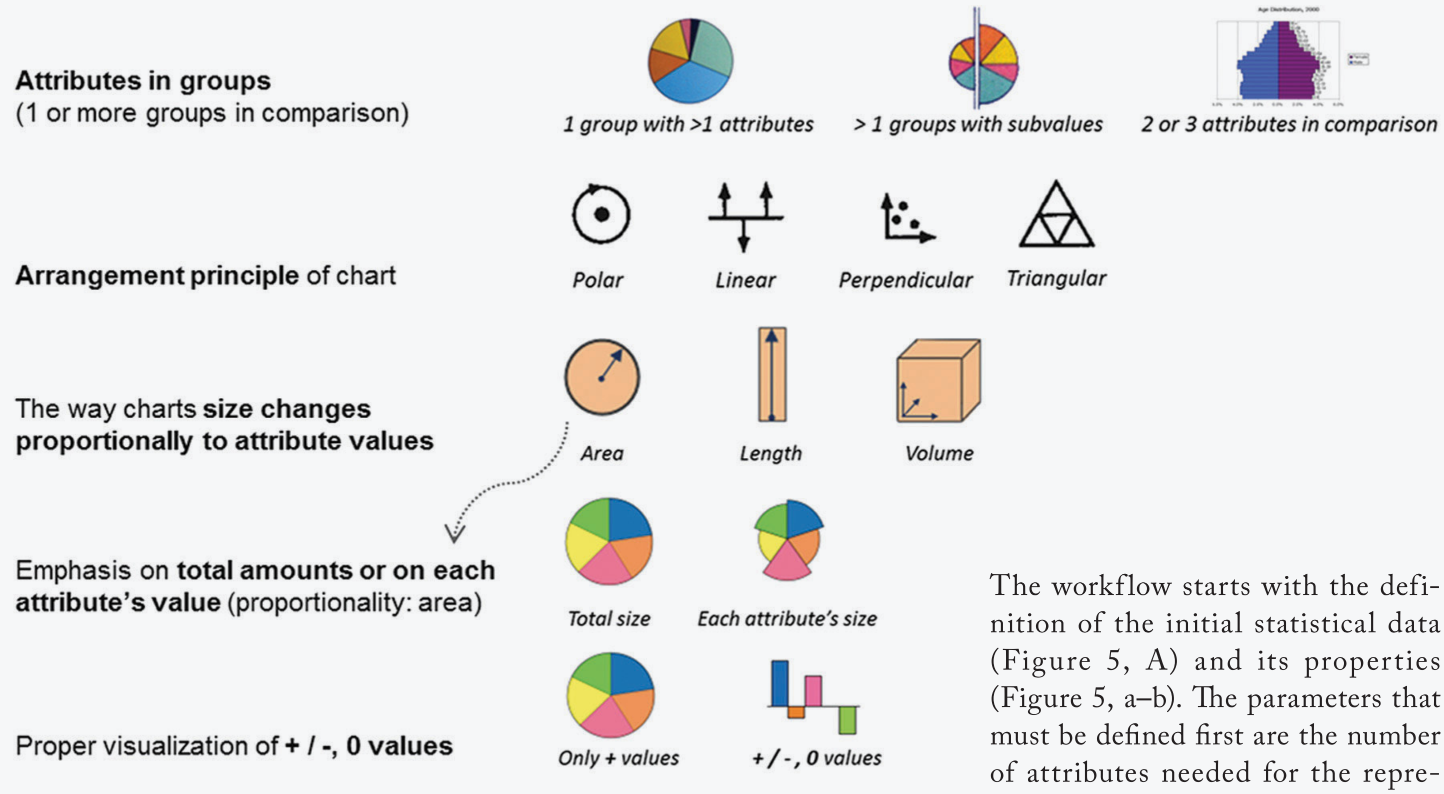

***Figure 3.** Parameters of charts as described by Schnabel (2007a).*

its size changes in relation to data values (proportional to area, length, or volume), and whether the emphasis is on the size of the whole chart (e.g., a pie chart), or on that of each attribute separately (e.g., a wing chart). One final important chart property is whether it can represent data values of different signs (positive, negative, or 0 values). All of these properties are illustrated in Figure 3. Our new categorization of charts is shown in Figure 4.

Based on these additional categorizations of charts, proportional symbols, and repeated symbols, supplementary conditions can be defined and used as criteria in the software wizard to automate the selection of an appropriate mapping technique for a thematic map.

SELECTING THE APPROPRIATE VISUALIZATION TECHNIQUE GUIDED BY A WORKFLOW

Our new taxonomy of mapping techniques, based on the examination of their various parameters above, facilitated the construction of the analytical workflow we mentioned previously. This workflow, which corresponds to the inference engine in an expert system (Forrest 1993), shows the process to follow and the parameters that influence the selection of the appropriate mapping technique (Figure 5).

The workflow starts with the definition of the initial statistical data (Figure 5, A) and its properties (Figure 5, a–b). The parameters that must be defined first are the number of attributes needed for the representation of the theme (Figure 5, a), the type of data values (Figure 5, b), the classification of data, if necessary (Figure 5, c), and the representation type (Figure 5, d). By sequentially determining these parameters, it is possible to choose the technique(s) most appropriate to the selected data (Figure 5, B). If the workflow offers more than one technique, then a short description of each technique's properties is presented (Figure 5, e) as decision support. Furthermore, the definition of the representation type (Figure 5, d) also determines the type of geometry data (Figure 5, f) that is used to visualize the map theme. For example, in order to create a map showing the population density on a continent (one attribute with relative, classified values) based on statistical data per country (representation type: area), the system recommends a choropleth representation. Dasymetric and isopleth mapping are other options that could be used, but they are not as suitable as choropleth mapping (see Table 2).

The workflow also offers techniques for visualizing multivariate geographic phenomena in different layers (Figure 5, g). In this case, the same mapping technique is used for each attribute separately. However, it is recommended not to choose too many attributes to be displayed on the same map, because its readability may be reduced. It is also possible to combine different mapping techniques that are based on "dissimilar" attributes on a thematic map, thus

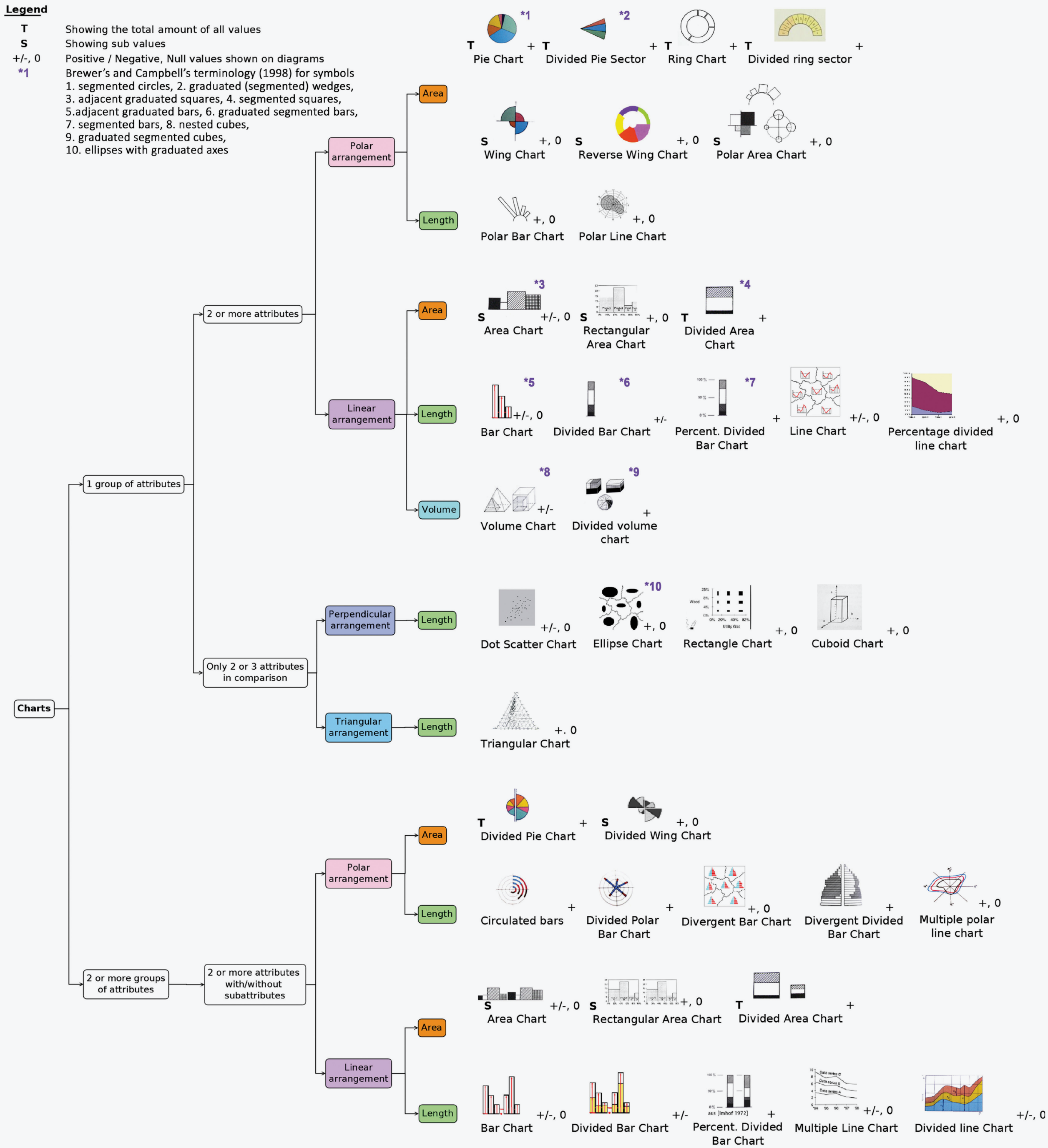

Figure 4. The new categorization of Schnabel's 49 charts (Schnabel 2007a) based on the properties listed in Figure 3.

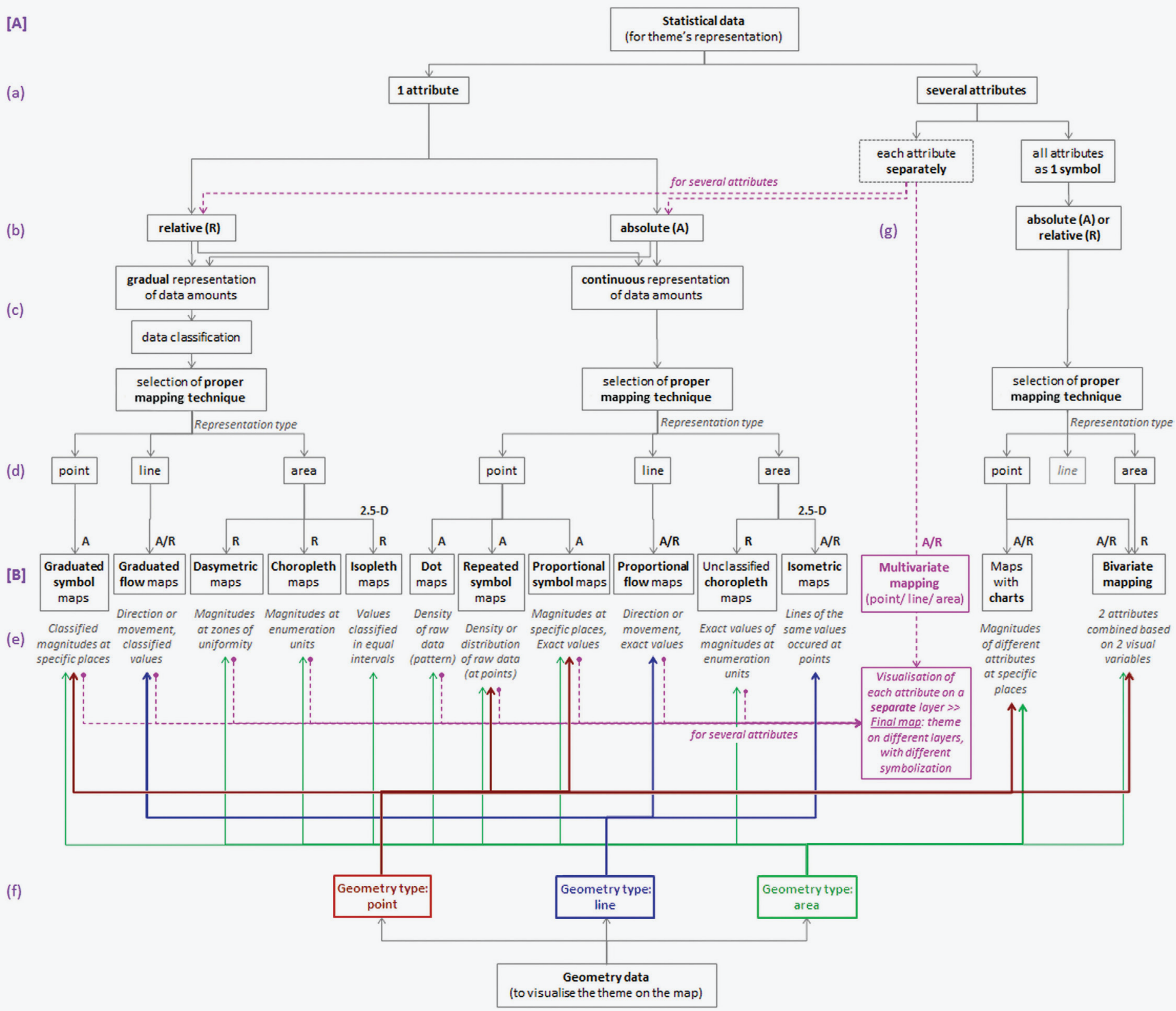

Figure 5. Workflow schema showing the process of selecting an appropriate mapping technique (B), beginning with the analysis of the statistical data (A, a–c) and the definition of the spatial dimensions of the geographic phenomenon [d]. The properties of each mapping technique [e] are also provided. Each technique is related to a specific geometry type [f]. Purple arrows and text show the special case of visualizing a multivariate phenomenon in different layers [g].

enriching the representation of the geographic phenomenon with additional information (Imhof 1972). In this case, techniques with different spatial dimensions may be "assembled"—for example, showing the production of cereals in an area as dot symbols and cereal imports and exports from the same area as percentages of overall production as choropleths.

Based on the process described by the workflow, we could next implement a software application, with a wizard as its main component, guiding the users step-by-step to create cartographically correct thematic maps.

DESIGNING THE WIZARD FOR CREATING THEMATIC MAPS

To DESIGN AND IMPLEMENT the software wizard, its main steps were first defined; their interactions with each other are described in the workflow in Figure 6. This workflow consists of three interdependent branches (marked in yellow). These are: (1) the statistical data, representing the theme of the map; (2) the geometry features (shapes), used to visualize the statistical data (theme) on the map; and (3) additional base map features (shapes), used to define and locate the area more precisely (Tsorlini et al. 2015). The six main steps of the procedure, which are also the steps of this wizard, are:

1. Selection and analysis of the statistical data to represent the spatially distributed phenomenon on the map.

2. Selection of the geometry features to be used for visualizing the statistical data, as well as definition of the scale and the layout properties of the map. Each geometry feature is linked to an attribute table containing descriptive information of all the elements.

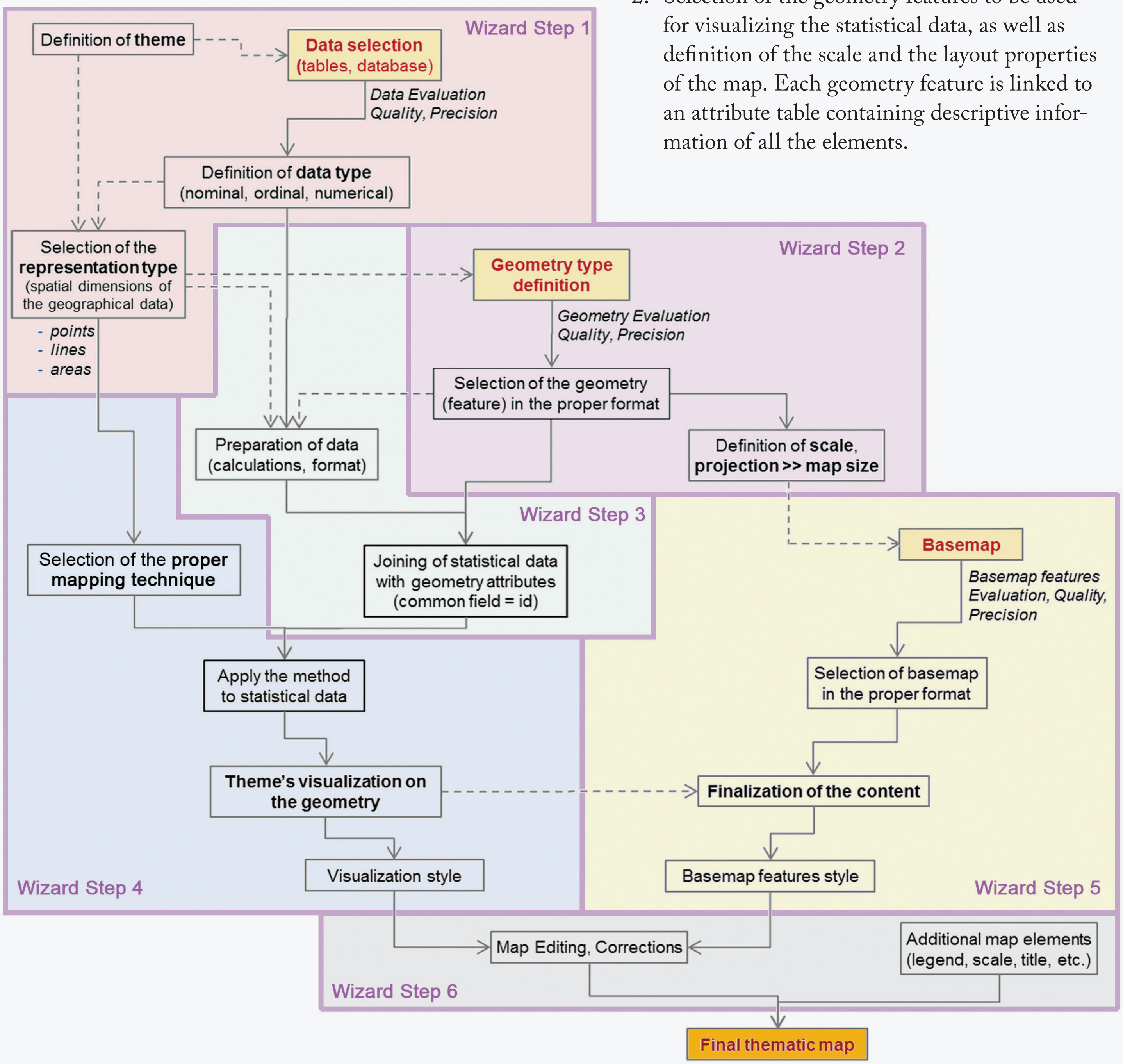

Figure 6. Workflow for the production of thematic maps, as implemented in the wizard. The beginnings of the three branches of the workflow (statistical data, geometry and base map features) are marked in yellow (Tsorlini et al. 2015).

3. Joining of statistical data to the geometry through the geometry attribute table. The statistical data are suitably prepared so that every spatial feature is linked to the corresponding statistical data record. The two tables are joined using identical unique values (such as an ID number) included in specific fields.

4. Selection of the appropriate mapping technique based on the data type, the spatial dimensions of the geographic phenomenon, and the correct symbolization of the features.

5. Optional inclusion of base map features in the background of the map to depict the geographic area.

6. Inclusion of a legend and other explanatory map elements, such as a scale, title, and other important map information.

The wizard was designed to simplify the whole procedure by gradually decreasing the number of available mapping techniques to those suitable for the data characteristics. Using this wizard, the user does not worry about all the cartographic principles and rules to be followed for the production of thematic maps.

Furthermore, in order to generate a cartographically correct thematic map, additional rules concerning the appearance of the map and the dimensions and position of the map symbols were integrated to the wizard. Each mapping technique is implemented in the wizard in such a way that it determines which visual variable (shape, color, value, and size) is used on the map to represent the geographic phenomenon. Additional cartographic rules for the overlapping of symbols or charts and the minimum dimensions for each symbol (Spiess 1970a; 1970b) were also included in the wizard, and colors were recommended for some techniques, such as choropleths. Special attention was given also to the design and the implementation of the legend, such that it was suitable for the special characteristics of each mapping technique. The inclusion of these additional rules in the system allows the generation of a final map that will not need a lot of processing to take its final form.

WIZARD-BASED CREATION OF A THEMATIC MAP: AN EXAMPLE

To give users a better understanding of the wizard's design and function, the six-step structure is described on the initial page of the wizard. Then, the user starts the mapping procedure guided step-by-step by the wizard. The interface of each step of the wizard is presented in Figures 7–14, showing the different options the user has in each case.

1. Step 1: Statistical data are loaded, the attributes to be visualized are selected, and their type is defined (Figure 7).

2. Step 2: The geometry to be used for the visualization is selected, the map scale is entered, and the size and projection are defined (Figure 8).

3. Step 3: The statistical data table is joined to the geometry attribute table through a field with common values (Figure 9).

4. Step 4: The wizard suggests an appropriate mapping technique based on the user's selection in

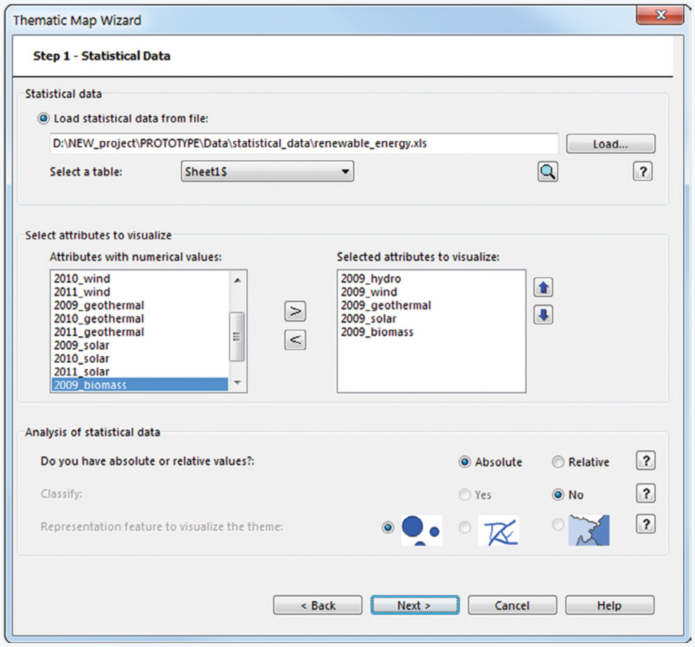

Figure 7. *The first step of the wizard, where the statistical data are loaded. In this example, a map showing the production of renewable energy in Europe will be created by the wizard.*

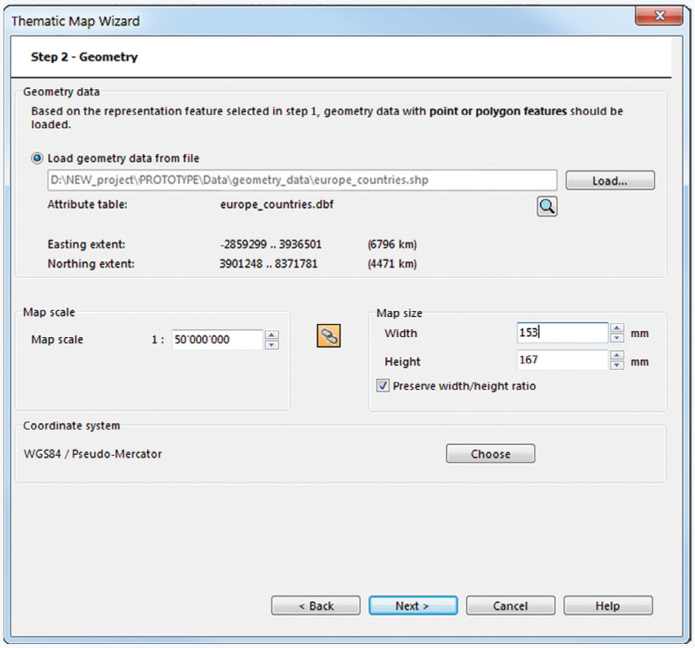

Figure 8. *The second step of the wizard, in which the geometry used for theme's visualization is loaded.*

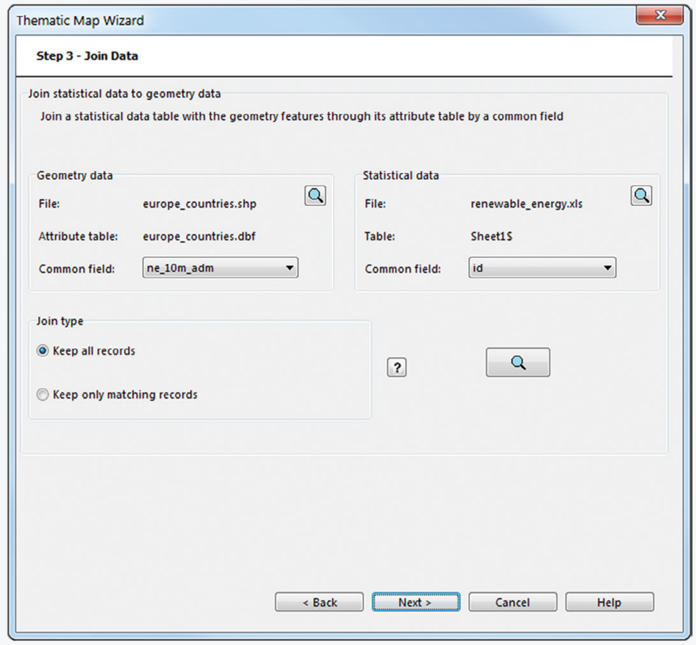

Figure 9. *The third step of the wizard lets users join the statistical and geometry data.*

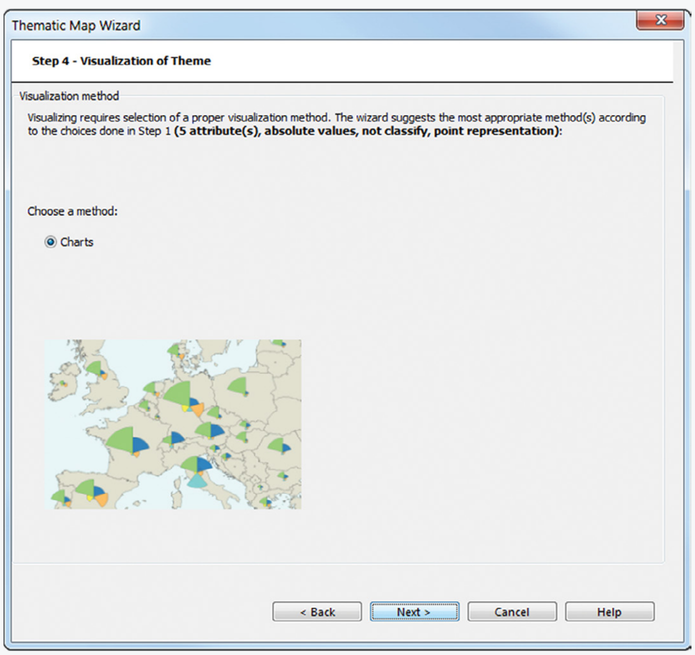

Figure 10. *In the fourth step of the wizard, the most appropriate technique for the map is suggested. In this case, it is a chart representation.*

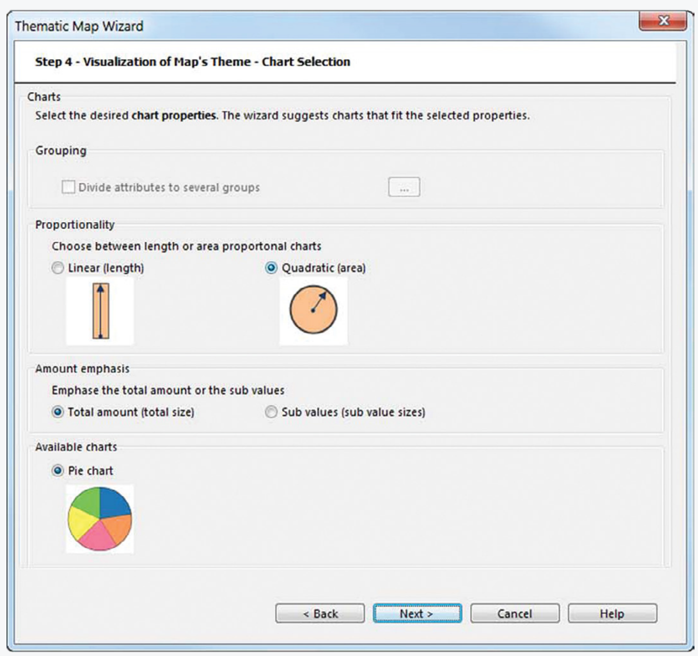

Figure 11. *In order to find the proper technique, additional criteria for creating the charts must be entered in step four.*

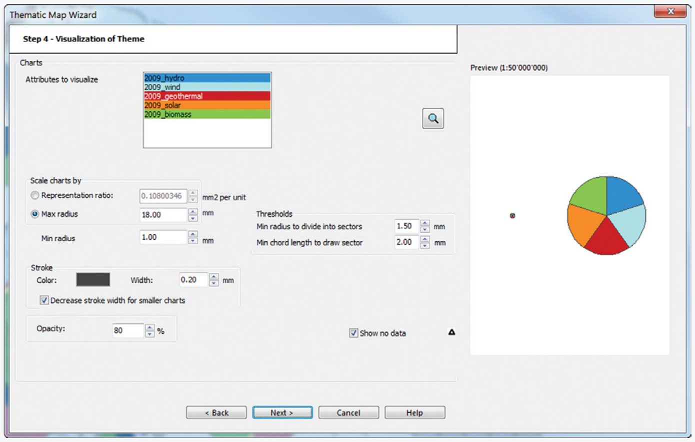

Figure 12. *At the end of step four, users further define the symbolization attributes of the charts.*

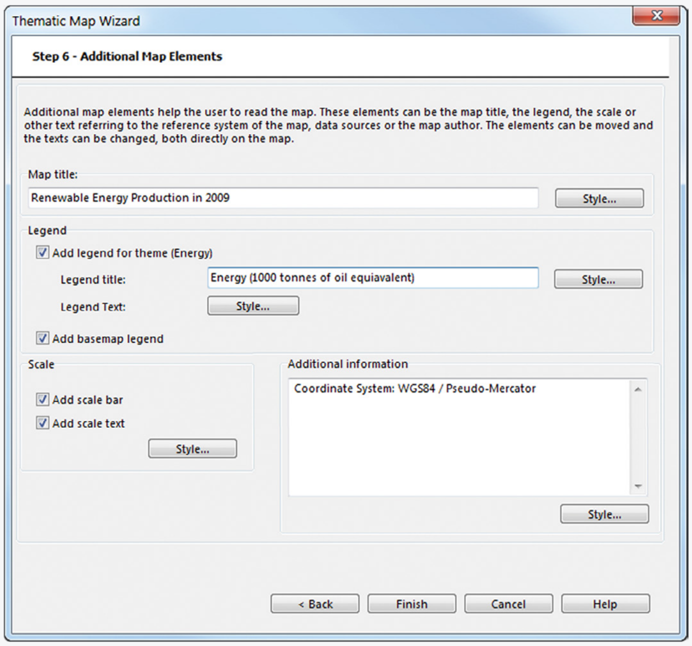

Figure 14. *Explanatory elements and texts, such as a legend, scale, etc. are inserted to complete the map.*

the first step (Figure 10), augmented, if necessary, by additional information requested on a subsequent screen (Figure 11). Finally, the user defines the properties and style of the selected technique (Figure 12).

5. Step 5: The user can upload supplementary base map features to complete the content of the map (Figure 13).

6. Step 6: Additional map elements, such as a legend, title, scale, and other explanatory elements and

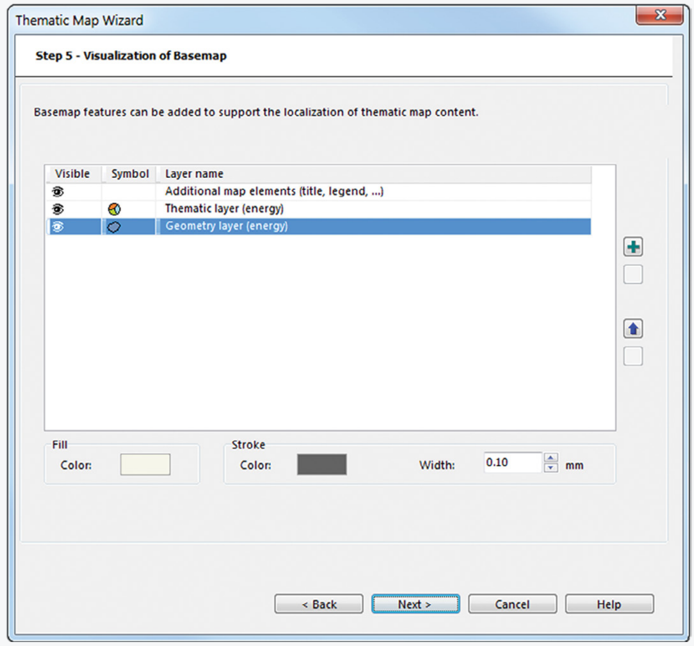

Figure 13. *Additional base map features are inserted to complete the background of the map.*

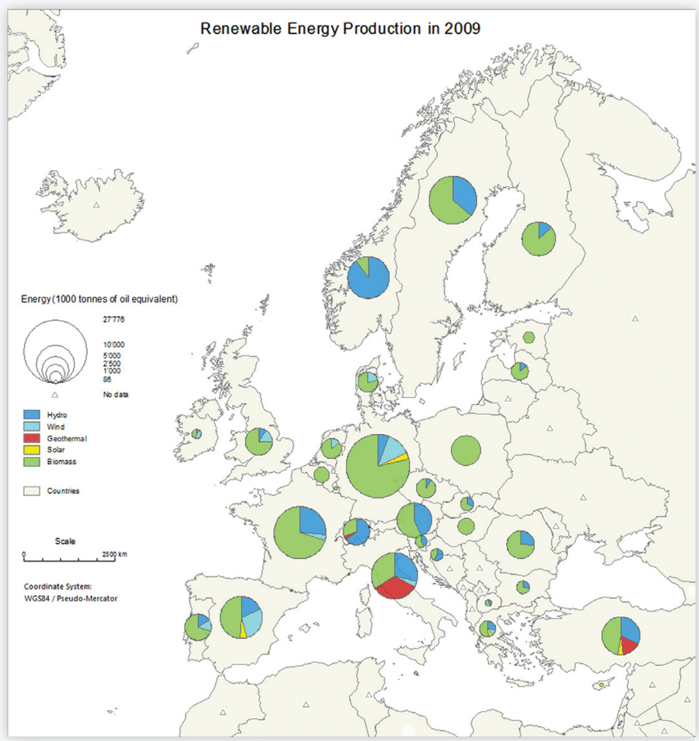

Figure 15. *The final thematic map generated by the wizard, showing the renewable energy production in Europe in 2009.*

text (Figure 14) may be added to the final thematic map (Figure 15). If necessary, small changes to the final appearance and the position of the map elements can be directly made to each layer. In the end, the final map can be exported in different formats and printed after defining the relevant options.

The novel part of this wizard is that it automatically suggests the most appropriate mapping technique for the visualization of the data, based on the data property definition made in the first step. It also gives the user the opportunity to edit the statistical and attribute table within its environment, in order to create a field with identical unique values in both tables. This will then allow joining the tables.

Furthermore, throughout the entire procedure, the wizard provides information panels that explain the differences between the options and also show a preview of the selected data (Figure 16). If either the combination of choices made in preceding steps, or the input data, do not fulfill the specific criteria of the selected mapping technique, warning messages appear (Figure 17). These messages inform the user about inconsistencies and provide other options, which can lead to a better visualization of the theme. Moreover, in case there is more than one suitable mapping technique fitting the data definition made in the first step, the wizard informs the user about the differences between the techniques, helping them select the most suitable one and reach an adequate symbolization.

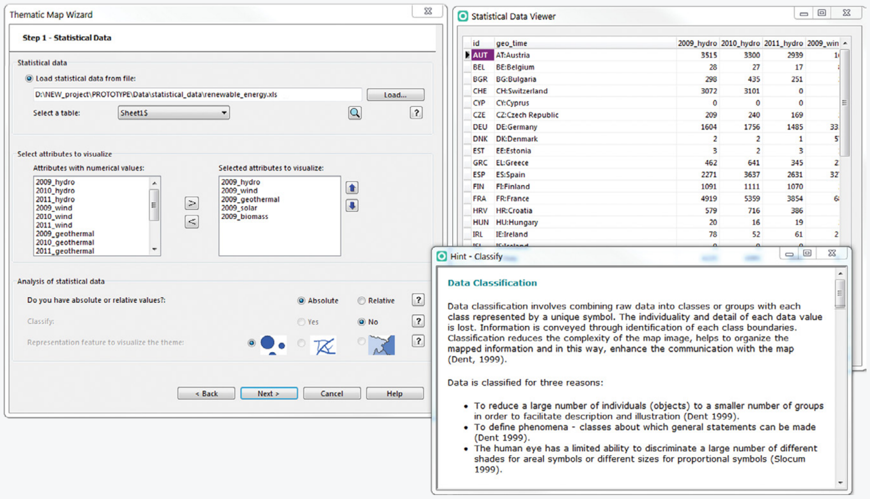

Figure 16. *Panels provide information about data classification and a preview of the statistical table.*

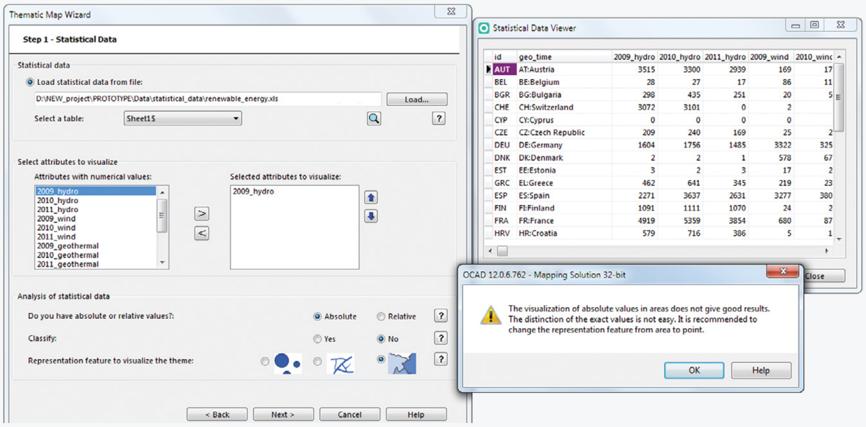

Figure 17. *The warning message shown in this case informs the user that they have selected absolute values to visualize hydro energy over areas. This selection would lead to an improper visualization of the phenomenon.*

EVALUATING THE WIZARD

The feasibility of the wizard was tested and evaluated in two qualitative studies conducted during the research and the implementation phase. Each was based on questionnaires, in which the users had to complete some tasks in order to create different types of thematic maps. The main goal of these studies was to test the practicality of the designed wizard, in order to see if it could correctly guide the users from step to step, providing them with the necessary information at every step. Ten people participated in the first study and thirteen in the second one. All of the participants created maps using different mapping techniques and answered questions concerning the structure of the steps. Additionally, they evaluated the actions they had to make in each step, along with the map the wizard generated for them, and then gave their overall impression of the process.

The participants had different levels of experience in cartography and the construction of thematic maps. Some of them were experts in cartography, geoinformatics, or geovisualization, and had worked for several years in these fields, while others were students currently attending relevant courses. For these two qualitative studies, twenty and twenty-six tests, respectively, were successfully completed on six different visualization techniques (proportional symbols, graduated arrows, choropleths, and three types of charts: wing, bar, and divided pie). The feedback clearly showed that the wizard could guide a user to select a proper mapping technique, simplifying the entire procedure and helping create a cartographically correct thematic map in a short time. Additionally, from their actions and comments we could see that users were generally satisfied with the generated map, making only minor changes to the colors they initially used or to the position of the explanatory map elements.

According to participants' comments, the wizard's suggestion of an appropriate technique for visualizing the selected data was helpful, especially for those who are not experts in thematic cartography. It saved them time in creating a thematic map based on cartographic principles and rules, which are normally only described in cartographic literature.

Additionally, participants regarded the information panels presented in every step explaining the different choices, as well as the warning messages appearing when an action deviated from an advisable workflow, as essential. These messages helped the users make proper decisions at each step and protected them from making serious mistakes during the production of the thematic map. More specifically, they informed the users about the type of geometry data necessary to use with the selected statistical data (step two), explained how statistical data could be joined with geometry data (step three), and, when multiple mapping techniques were appropriate, gave them hints that explained the differences between the types (step four; e.g., different types of charts).

The participants also found the parallel preview of the statistical table and the geometry's attribute table, as well as the "on the fly" editing of the tables within the wizard, useful. This helps them to create a field with common values to connect the statistical and geometry data. This functionality is not included in most software; users are often obliged to first make the statistical data table compatible with the geometry table outside the software's environment. We also received positive feedback for allowing users to save selections in an XML file; this file can be used to symbolize thematic and base map layers on future maps without having to start from scratch.

Among participants' comments, especially during the first study, there were remarks indicating which parts of the wizard required further clarification or needed to be simplified. Based on these comments, the text of the information panels was simplified and formulated in a more comprehensible way during the implementation phase. More information panels were added to explain the different tasks and to help users select an appropriate technique and correctly define its properties. Diagrams were inserted to show the possible results of each option (e.g., the case of keeping all records, or only the matching records, when joining statistical data with geometry in step three). Pictures were included to show the different types of charts and their symbolization options (step four) and histograms to illustrate the different classification methods (step four).

During this phase, the features of each step's interface were better arranged in the window, with our goal being to keep the wizard interface as simple as possible and requiring users to take the fewest possible actions. We also embedded tools controlling the locking of layers and the visibility of map features of the final map, in order to make the modification of map elements on the different layers easier. All the comments and users' feedback played a significant role in the design and implementation of the wizard.

CONCLUSIONS AND DISCUSSION

The results of our qualitative studies, as well as the positive feedback from people who have started using it through the commercial cartographic software in which it has been integrated, show that the wizard is a useful tool for the production of maps based on statistical data. It actively guides the user to create proper thematic maps, suggesting the most appropriate mapping techniques for a specific data set, providing more information about data properties, and proposing alternative solutions. Moreover, the warning messages inform the users about erroneous decisions, guiding them toward creating cartographically correct thematic maps.

The thorough standardization of the cartographic procedure for creating thematic maps played a crucial role in developing each step of the wizard, as it included and combined all the important guidelines and rules to be taken into consideration. The analysis of each mapping technique's properties, and their categorization based on data characteristics, were also critical for designing the wizard. Without this analysis and our new taxonomy of mapping techniques based on their individual characteristics, it would have been difficult to automate the selection of the proper technique in a wizard. The use of a rule-based wizard, which guides the users step-by-step in creating proper thematic maps, is beneficial for mapmakers, whether or not they are experts in thematic cartography, since it allows them to create thematic maps in a short time while being sure that the final result will follow the cartographic principles and rules that lead to correct map representations.

The workflows that we created to systematize the entire procedure are generic and applicable also to other cases involving the creation of thematic maps. Moreover, the analysis of the cartographic rules and principles to automate the procedure may be also useful to scholars and students for understanding the parameters and the cartographic procedure of creating thematic maps.

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SOFTWARE APPLICATIONS

- *ArcGIS*, Esri: **esri.com**
- *Adobe Illustrator Plug-ins for Cartographic Composition*, Institute for Cartography and Geoinformation, ETH Zürich, Switzerland: **ika.ethz.ch/plugins/index.html**
- *CARTO*: **carto.com**
- *Cartovista,* DBx Geomatics: **cartovista.com**
- *Indiemapper*, Axis Maps: **indiemapper.io**
- *Maptitude Mapping Software*, Caliper Corporation: **caliper.com/maptovu.htm**
- *MapViewer, Grapher, and Scripter*, Golden Software: **goldensoftware.com**
- *QGIS*: **qgis.org**
- *Statplanet*, StatSilk: **statsilk.com**
- *Regiograph,* GfK GeoMarketing GmbH: **regiograph.gfk.com**
- *Thematic Mapping API*, Bjørn Sandvik: **thematicmapping.org/api**
- *Thematic maps in Excel*: **excelcharts.com/blog/how-to-create-thematic-map-excel**

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Engraved in Copper: The Art of Mapping Minnesota

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This exhibit highlighted unique engraved copper plates that were used to print topographic maps of Minnesota in the early 1900s, as well as surveying and mapmaking techniques, and government documents related to the process. The plates are part of the evolution of government mapping and cartography and the history of the United States Geological Survey (USGS), from early mapping efforts to modern Geographic Information Systems (Figure 1).

The idea for this exhibit formed in early 2015, shortly after the University of Minnesota Libraries received its first shipment of copper plates from the USGS. Once the exhibit proposal had been accepted, we worked with staff

Figure 1. *The exhibit in the Elmer L. Andersen Library at the University of Minnesota.*

***Figure 2.** Left: detail of a copper plate showing before and after cleaning. Right: display case highlighting the cleaning process.*

from the Preservation Department in order to clean the plates and prepare them for display (Figure 2).

Preparing the exhibit also involved securing the use of several artifacts and objects for display. These included engraving tools from the USGS office in Rolla, Missouri, as well as examples of numerous types of surveying equipment from the local Historical Surveyors group, such as a transit, a heliotrope, an alidade, and a surveyor's chain, just to name a few.

The systematic topographic mapping of the United States commenced after John Wesley Powell, Director of the USGS, convinced Congress to begin to fund the effort in the 1880s. By 1954, the USGS had mapped nearly 1 million square miles (approximately 33%) of the land in the continental United States (Evans 2009, 144). During this period, maps printed using copper plates were produced by the Map Division of the USGS. In addition to elevation and water features, they generally indicated cultural features such as roads, streets, cities, towns, buildings, cemeteries, and mines. Three copper plates were needed to produce each printed map. Each plate was used to print a single color—black ink for text and to indicate human or cultural landscape features, brown ink for topographic contour lines indicating elevation, and blue ink for water and wetland features.

Between the 1930s and the 1950s, the USGS transitioned away from the copper plate engraving process due to the rise of the photolithographic printing process, which was faster and less expensive (Evans 2009, 97). The last maps produced by the USGS using copper plates were printed in the early 1950s. In 2014, the USGS announced the offer of more than 1,200 sets of copper plates as donations to federal, state, and local government agencies and departments, as well as qualifying non-profit organizations and educational institutions (USGS 2015). The John R. Borchert Map Library at the University of Minnesota received 12 sets, including some of the sets featured in the exhibit (Figure 3).

The copper plates are the main feature of the exhibit but, to give additional context to the plates, it also included an

***Figure 3.** Three of the copper plates featured in the exhibit.*

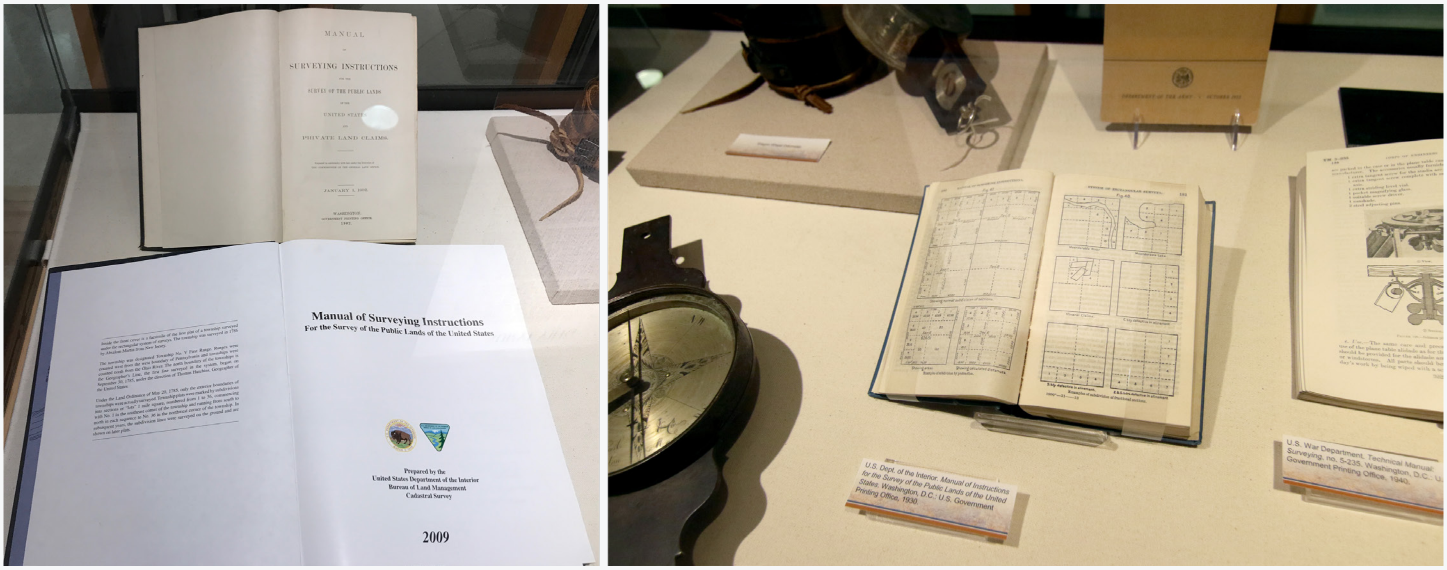


Figure 4. *Interior of a display case focused on surveying.*

overview of mapmaking, beginning with the surveying process.

The art of surveying dates back to ancient times, beginning with the construction of the pyramids nearly 7000 years ago by the Egyptians (US Dept. of the Interior 1988, 1). In the United States, surveying began after the Revolutionary War and the subsequent Louisiana Purchase in 1803 (US Dept. of the Interior 1988, 3). The American government recognized the need to map the vast amount of unsettled land west of Pennsylvania that had come into the public domain, and thus the public land surveys began. Various editions of the *Manual of Surveying Instructions*, published by the Department of Interior and spanning from the early 1900s to early 2000s, were displayed to demonstrate the continuing importance and evolution of surveying. In addition, a variety of technical manuals and field guides from the Army, War Department, and Department of Interior were used by surveyors. These were included in the exhibit as well (Figure 4).

Surveying is generally defined as the art of measuring the earth's surface using angles and distances (US Dept. of the Interior 1969, 4). There are three types of surveying: geodetic surveying determines shape and size of the earth; topographic surveying measures the features of the earth's surface including hills, valleys, rivers, and lakes as well as cultural features like buildings, railroads, and cemeteries; and cadastral surveying defines property boundaries for land ownership.

The types of tools used for these different classes of surveying are largely the same, even though they have changed as modern mapping technology has taken hold. When out in the field, surveyors usually affixed their tools to a tripod, as seen in many historical photographs. An assortment of surveying tools was displayed within the exhibit including an alidade, clinometer, planimeter, wagon wheel odometer, compass, and survey marker (Figure 5). The alidade consists of a telescope attached to a level plane and was a key tool used in topographic surveying. The telescope can determine vertical angles and therefore changes in elevation or land surface between points. In the field, the alidade would be mounted to a drafting table on a tripod set at an optimal height for topographers to create topographic maps in the field while surveying. The clinometer is a device used to measure vertical angles of slope and the planimeter is used to measure the area of a two-dimensional space on a map.

An adjacent exhibit case also contained larger historical surveying tools including a surveyor's chain, heliotrope, and transit (Figure 5). The surveyor's chain was an early measurement tool, 66 feet in length and made of iron to keep it functional despite being dragged across rough terrain. The rings comprising each link were made in such a way that the chain could never tangle when thrown.

The heliotrope was invented by the famed mathematician Friedrich Gauss in 1821 to measure longer distances. This instrument uses a small mirror to reflect sunlight

Figure 5. *From left to right: survey marker, transit, and heliotrope.*

to another surveyor or station and, through triangulation, measures the distance between the two points. Thus the name *heliotrope*, which is derived from the Greek words *helios*, meaning "the sun," and *tropos*, meaning "to turn." Consequently, the heliotrope could only be used on sunny days but its usefulness outweighed this drawback.

A surveyor used a transit to determine angles and measure straight distances. The transit comprised a telescope, a vernier scale (similar to a protractor), and a compass, and was used in conjunction with the heliotrope. A surveyor on the other side of the heliotrope would line up the transit with the heliotrope using the compass to make sure a straight line was made. Then the telescope was used to sight the mirror reflecting the light. The vernier scale is attached to the telescope, so that moving the telescope to find the mirror would give the surveyor the angle between the ground and the light, to a precision of minutes of an angle. Using these angles, surveyors could determine the distance between the two points.

After surveying was completed, various printing methods were used to create a map. The copper plates featured in this exhibit were used to print topographic maps with surveying data for the first half of the 20th century.

Each copper plate was hand etched by a map engraver in the Map Division of the USGS. A transfer method was then used to reproduce the image from the copper plate onto a lithographic stone for mass production printing. This was necessary because the copper plate engraving would have degraded given the very large volume of maps printed by the USGS. Between the 1880s and the 1950s, more than 25,000,000 sheets were printed (Evans 2009, 149).

The mapmaking process was somewhat complicated. Drawings of field data from surveyors and topographers were prepared by drafting technicians. The drawings were then transferred to the copper plates. One early method was to coat the copper plate with a thin layer of wax and then use carbon paper to transfer the image (Phillips 1997, 13). A later method involved photographing the original drawing, using the glass negative to make a contact print on a zinc plate, transferring the image from the zinc plate to a celluloid sheet with graphite ink, and finally burnishing the image onto the wax layer on the copper plate (Phillips 1997, 14).

The exhibit also featured government documents related to mapmaking including items from the Topographic Instructions series published by the USGS (Figure 6). The series constitutes a comprehensive manual of topographic surveying and map production.

In addition to displaying the copper plates, we were able to work with the Art Department at the University of Minnesota to create new prints from the historic plates. In order to highlight the three separate colors used to print the original maps, they made new prints using a single color for each sheet (Figure 7).

The exhibit also touched on the evolution of government mapping. The Department of Defense (DoD) began using Global Positioning System (GPS) technology in the 1970s and today most government made maps are generated by the collection of geographic data via GIS databases (NASA 2012). Consequently, the USGS and DoD published a variety of government publications on the usage of geographic data in mapmaking as well as modern uses for cartographic information. Some of these government publications along with other monographs about GIS and its real-world applications were on display in the exhibit (Figure 8).

With the change in technology came a change in hardware and software formats. To help demonstrate this, an old computer keyboard and mouse set were placed in the exhibit next to a CD-ROM about using GIS to analyze topographic changes in Pennsylvania and other documents and monographs about GIS usage in various sectors (Figure 8).

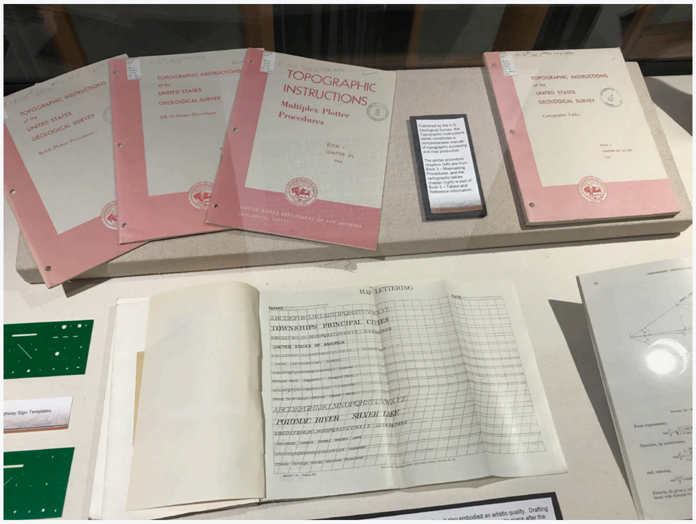
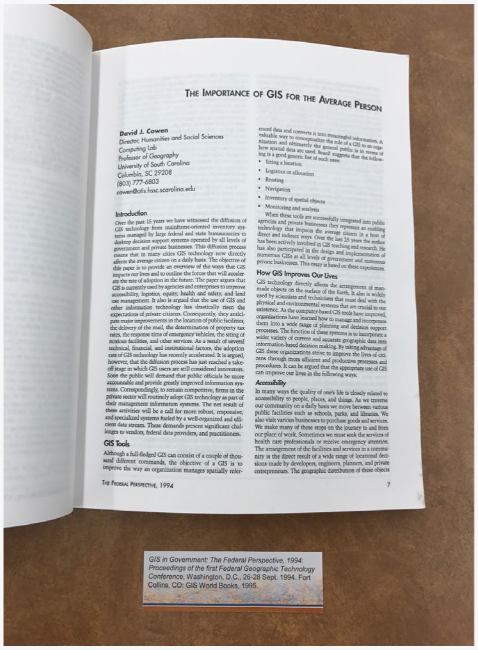


Figure 6. *Government documents from the* USGS Topographic Instructions *series.*

Figure 7. *New prints from the historical copper plates.*



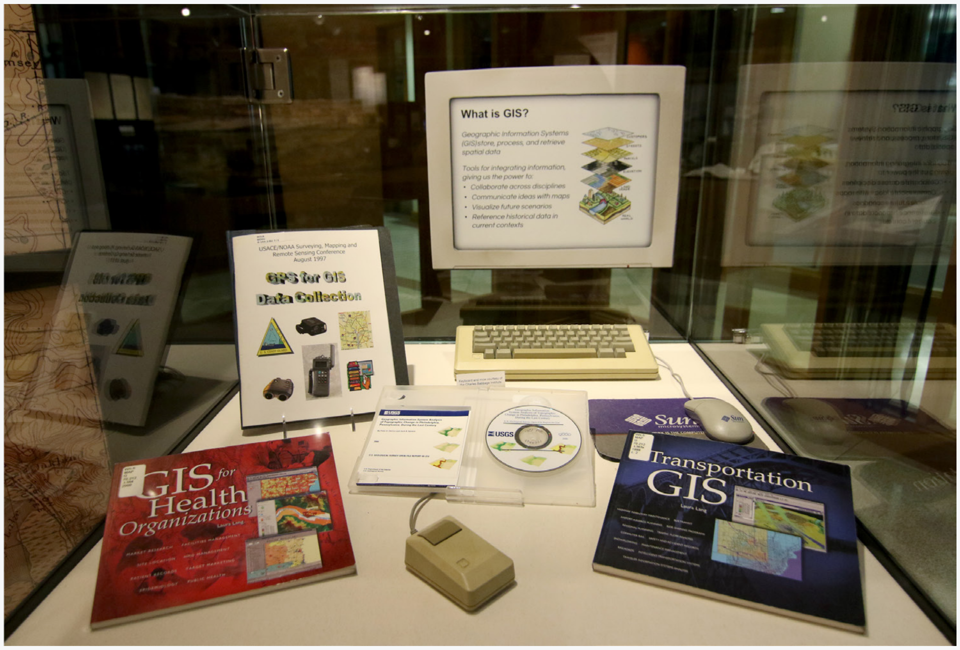


Figure 8. *Left: "The Importance of GIS for the Average Person" from* GIS in Government: The Federal Perspective, *1994. Right: interior of the GIS case.*

An exhibit opening was held on March 8, 2017 in the Elmer L. Andersen Library with approximately 140 attendees including alumni, map enthusiasts and experts, community members, faculty, students, and artists. There were two speakers at the event: Edie Overturf, Visiting Assistant Professor of Printmaking in the University of Minnesota's Art Department, and Ron Wencl, US Geological Survey National Map Liaison to Minnesota and Wisconsin.

Edie discussed the technical process of making prints with the copper plates, using photographs taken during the printing process to give the audience a visual representation of the steps involved in creating a print (Figure 9). The prints Edie and her graduate student made from the Duluth cultural, topographic, and hydrographic plates were showcased in the exhibit next to the plates from which the prints were pulled.

Ron spoke about the evolving mapping techniques and tools utilized by the USGS, the history of the Department of Interior and directors of the USGS, and how to access various types of maps online through different USGS portals and databases.

This exhibit was a great opportunity to highlight the richness of the map and government publications collections at the University of Minnesota, and to showcase the USGS copper plates that were a vital part of mapmaking history. Through this exhibit, attendees were able to learn about the complexity and artistry of mapmaking, the myriad tools necessary for the surveying and map production processes, and the plethora of uses for maps in a contemporary world.

Figure 9. Edie Overturf speaking at the event.

Figure 10. *Close up of three copper plates.*

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Review of Unclassed Choropleth Mapping

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Although unclassed choropleth maps lead to a more accurate representation of data, grouping of data into classes is still common. Commonly-used data classification techniques such as equal-interval, quantiles, and natural breaks produce very different and possibly misleading representations. An unclassed map creates a distinct color for each unique value. The method was introduced by Tobler in 1973 using an x, y coordinate plotter that created crossed-line shadings. Tobler's unclassed proposal used grayscale values because color displays were not yet available. Current color monitors have the ability to display 16.7 million colors, while most GIS software packages have limits to their color ramps. QGIS defines color ramps with up to 999 classes. It is also possible to define up to 1000 classes in ArcMap, and ArcGIS Pro has an "Unclassed" option when styling choropleth maps. Utilizing more color classes results in a more truthful map due to minimizing error from the grouping of data. The unclassed method is examined here along with color ramps and classification schemes in QGIS and Esri's ArcMap/ArcGIS Pro. It is demonstrated that it is usually impossible to create a truly unclassed choropleth map using the default color schemes in these programs.

KEYWORDS: unclassed; choropleth; QGIS; ArcGIS; data classification

INTRODUCTION

Tobler (1973) developed a method of creating choropleth maps in which shading intensity is directly proportional to the data values (Figure 1). This introduction of unclassed choropleth maps challenged the practice of classifying data. Since classification was viewed as a central component of cartographic abstraction, unclassed choropleth mapping was never widely adopted.

Peterson (1979) and Müller (1979) tested the usability of unclassed choropleth maps. Peterson found that subjects had a better understanding of relative and absolute values for individual areas on an unclassed crossed-line map, compared with a classed one. Dobson (1980a) asserted that this method of mapping leads to information overload. Müller found that participants in a study could mentally sort unclassed map units into three classes (low, medium, and high) and that participants could thereby generalize the unclassed maps on their own. In commenting on this study, Dobson (1980b, 107) stated that Müller's task focused on pattern delineation but it should also focus on the map user's ability to memorize the map. Dobson argued that the classed map is more useful since it creates a "simpler, more efficient communication device."

The generalization of data is a common method in cartography (Peterson 2009; Axis Maps 2015) and has been

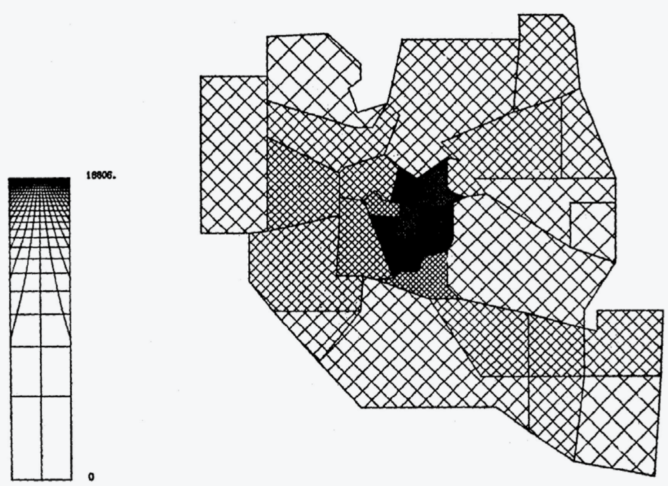

Figure 1. Tobler's (1973) crossed-line shading method first made it possible to create unclassed choropleth maps.

the focus of much research and discussion (Gilmartin and Shelton 1990; Slocum et al. 2008). Jenks and Caspall (1971) determined different types of error associated with data classification and developed an algorithm that balanced the level of these errors. This resulted in a method that uses statistical "natural breaks" in the data to create classes. This method is usually the preferred classification option, along with equal-interval and quantiles. These different classification schemes can be difficult for the average map-reader to comprehend. The point of unclassed mapping is not to be able to efficiently match data values to a specific color on a legend, but rather to represent a dataset without introducing error.

Other research has considered alternative methods for creating a continuum of shadings. Peterson (1992) used PostScript to create a large number of dot shadings for printing. Cromley (1995) criticized this method and proposed an alternative classification scheme that used fewer classes. Stewart and Kennelly (2010) created a method of using soft shadows (Figure 2) from an unclassed map, and mashing that up with a classed choropleth map. The free (but discontinued) Java applet *mapresso* allowed the cartographer to create a continuous-tone map as seen in Figure 3. The algorithm in the applet handled extreme values by placing them into their own classes (Herzog 2015). By classifying the outlier values separately, the applet does not correctly represent the true intensity of the data, but does create a more visually appealing map. Kenneth Field (2013) used a diverging color scheme to create what he called an unclassed map of the 2012 US presidential election (Figure 4), using blue and red to represent Democratic and Republican support; many counties have the same color.

THE 999-CLASS MAP

QGIS, AN OPEN SOURCE program for GIS, allows a maximum number of 999 classes in a graduated color ramp. In some datasets, more than 999 different colors would be needed to ensure a map was truly unclassed. Additionally, limitations on the number of colors in a gradient can make creating unclassed maps difficult. In ArcMap, it is possible to use the "Defined Interval" option to create up to 1,000 classes for maps (Figure 5). The technique to achieve this many classes is to shrink the interval size until the number of classes equals 1,000. An error will result if more than 1,000 classes are specified.

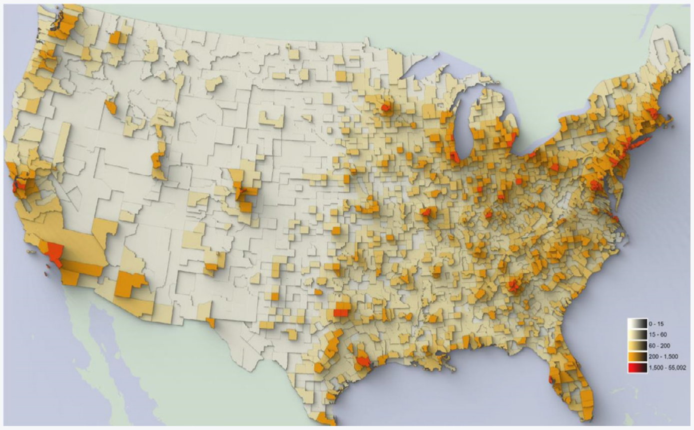

Figure 2. *Stewart and Kennelly's (2010) classed with unclassed soft shadows method.*

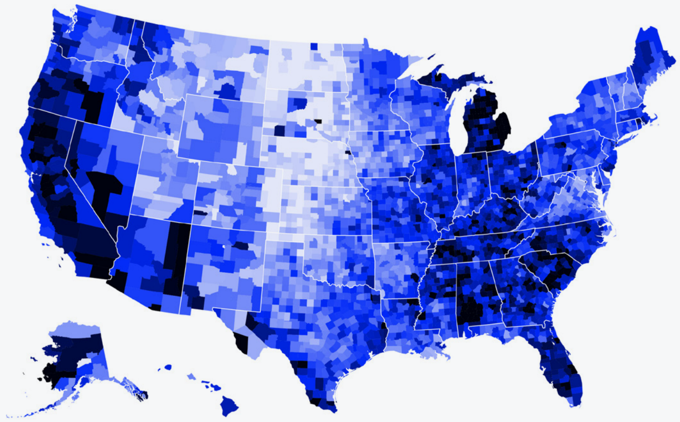

Figure 3. *Mapresso continuous-tone map (Herzog 2015). This map shows unemployment rates by county in 2008. This method deals with the issue of extreme values by classing them at the top and bottom. The mapresso applet has since been discontinued due to issues with Java support in web browsers.*

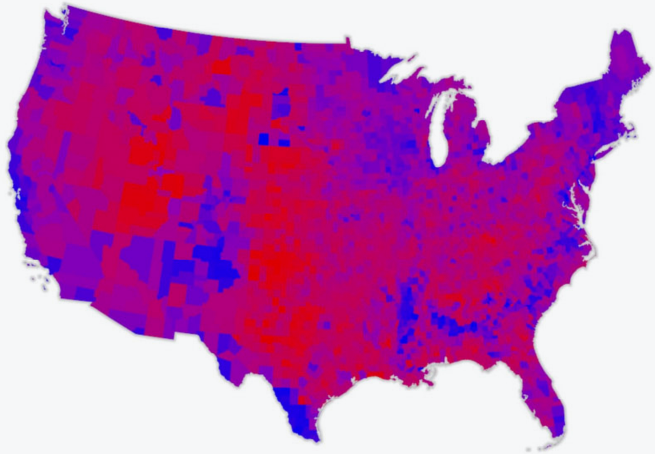

Figure 4. *Field's (2013) map shows the presidential election results from 2012. Different shades of blue and red in a diverging color scheme are used to indicate the percent of Republican and Democratic votes in each county.*

A problem arises in both ArcGIS and QGIS when using the default color gradients. Instead of a specific, unique color for each distinct data value, each color spans a large number of values. The maps are de facto classed, essentially due to too few colors in the gradient. This was determined by finding the RGB values of the color for each county for the two maps in Figure 6 using a color picking program. In QGIS, there are 12 duplicate colors. This means that only 81 colors are being used to represent the 93 values (each county had a different data value). In ArcMap, there were 23 duplicates, two triples, five where four counties had the same color, and four instances where five counties had the same color. This means only 43 unique colors are representing 93 unique values.

Neither the default color ramps in QGIS nor ArcMap can produce an unclassed choropleth map for these 93 values. A separate program, ArcGIS Pro, provides an "unclassed"

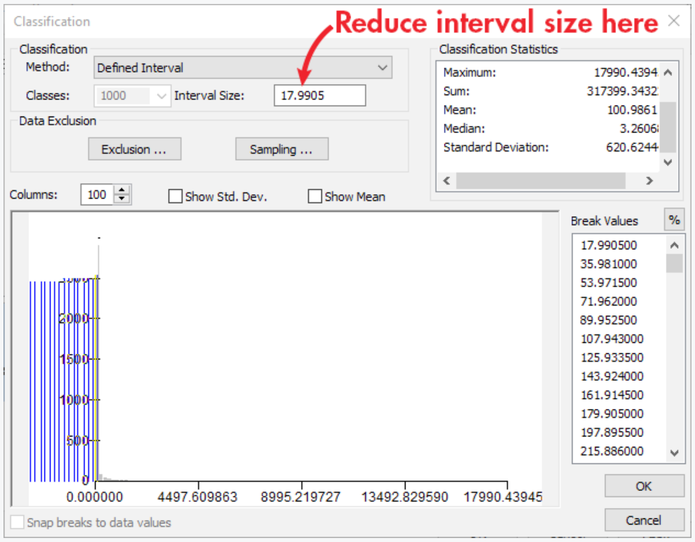

Figure 5. *The "Interval Size" can be reduced until the number of classes equals 1,000. In this case, 17.9905 is the smallest usable interval size that will create 1,000 classes.*

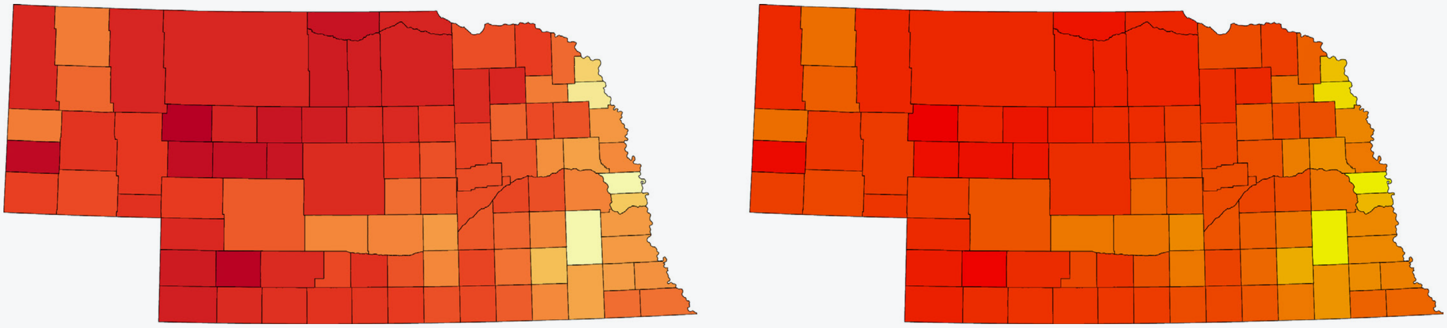

Figure 6. *A 999-class QGIS map (left) and a 1,000-class ArcGIS map (right) showing percent of vote for Donald Trump by county in Nebraska. The two programs have different default color ramps. The QGIS map has 81 different colors for the 93 different values while the map from ArcMap only has 43 colors. This difference is likely due to the lack of available colors in Esri's ArcMap color palette.*

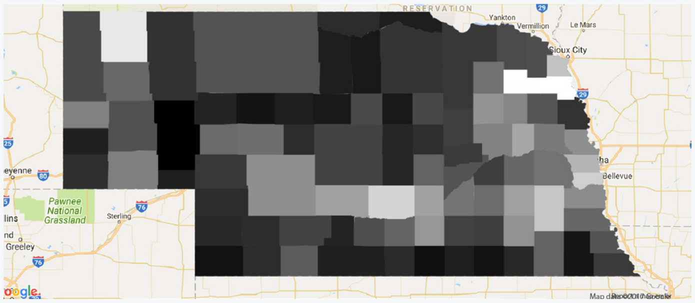

Figure 7. *This map of median age in Nebraska (2000) has different shades for every unique value. The data set has 24 duplicate values so only 69 different shades are needed (93 counties – 24 duplicate data values = 69). The minimum difference in data values is 0.1 and the range is 24.2, so 242 different gray shades are needed to create an unclassed map (working example available at: maps.unomaha.edu/cloud). It should be noted here that ArcGIS and QGIS could also produce unclassed maps of this data set.*

option for choropleth mapping (Esri 2017), but the same problem occurs. Multiple areas on the map have the same color. The name of the option in ArcGIS Pro misleads the user into thinking that this option can actually create an unclassed map in all cases. Of the three programs, QGIS's default color schemes come closest to producing an unclassed map with the 999 shadings setting. Note that this research is focused on the default color ramps used in these programs. There are custom options in both ArcGIS and QGIS that may enable a user to incorporate their own color ramps. The use of Javascript alongside some experimentation with the Google Maps API yields an unclassed choropleth map with some datasets.

Figure 7 shows an unclassed map of the median age of Nebraska's population, made with the Google Maps API. This data is linear in nature, and with duplicates, there

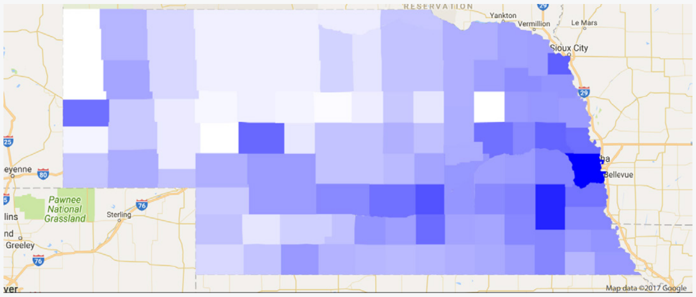

Figure 8. *Population density in Nebraska in 2010. In this map, there are 80 different colors used for 85 different data values (including 8 duplicate values). It is not an unclassed map, so a "percent unclassed" value can be calculated. There are five counties that are classified, and 88 counties that are not. Dividing the number of unclassed counties by the total number of counties equals 94.62%. In this case a simple disclaimer, "94.62% Unclassed" OR "Percent Classed: 5.38%," should be included with the map to describe the amount of classification caused by an insufficient number of colors. Working example available at: maps.unomaha.edu/cloud.*

are only 69 different values among the 93 counties. The number of unique colors needed to display this map as unclassed is found by dividing the range of values, 24.2, by the minimum difference between two non-duplicate data values, which is 0.1. 242 different colors are needed. Using the minimum difference between two values as the interval size ensures that there are no identical colors being used for different values. Since the range is small enough, and the difference between the two closest values is large enough, 256 brightness values or gray shades are sufficient for an unclassed map of this data distribution. This formula can be used to determine the number of colors or shades of gray that are needed for any data set. It is also possible to provide a percentage of classed or unclassed values for any given choropleth map (Figure 8), by dividing the number of classed or unclassed values by the total number of values. Working examples of these two figures on the web are available at **maps.unomaha.edu/cloud**, the companion website to Michael Peterson's *Mapping in the Cloud* (2014), under Code 14. Note that through customization, both ArcGIS and QGIS should be able to create the maps seen in Figures 7 and 8.

THE 16.7 MILLION-COLOR SOLUTION

A typical computer screen can display 16.7 million colors. This is because most computer screens use a 24-bit color depth of red, green and blue (RGB) values. Each hue (red, green and blue) has a value between zero and 255, resulting in 16.7 million (or 2^{24}) possible colors. With 16.7 million colors, an unclassed color gradient with more than 1,000 colors is conceivable.

Simultaneous contrast, or the psychological effect of differences in color perception based on surrounding colors, is certainly an issue when using this many colors (Gruver 2017). Although our screens display 16.7 million colors, we may have difficulty determining whether two colors are the same or different. This has been one justification for data classification. Of course, the amount of error in interpretation caused by simultaneous contrast, that is, the inability of the map reader to differentiate colors, is minor compared to the error introduced by classification. The common classification methods in QGIS and ArcMap use five to seven colors, and group large swaths of data values into the same category. Since these methods vary on how they divide and represent the same data, more interpretive error is introduced by relying on a default classification method and color gradient, than by using a greater number of colors to distinguish between different data values.

The misrepresentation of data is common with classification, as demonstrated by Monmonier (2005) with different maps showing crude birth rate in the United States. He described how a person with malicious intent could purposefully deceive their audience by manipulating class intervals to show too few or too many births. A more common scenario is a mapmaker using a common classification method without understanding how it may misrepresent the data. This can happen every time a classed choropleth map is made, if the cartographer is not familiar with these methods.

The 999-class QGIS option provides the map user with more information because it displays a map with many colors. Although the method usually does not actually create 999 unique colors, it still promotes a less-generalized graphic representation. The default color ramps in ArcMap and ArcGIS Pro provide far fewer colors.

COLOR RAMPS

An example of many of the default color ramps from QGIS and ArcMap can be seen in Figure 9. Each color ramp consists of 11 boxes ranging from zero to 100 (e.g., 0%, 10%, 20%, etc.). These color ramps were created using the maximum number of classes for both QGIS and ArcGIS. Both packages lack sufficient colors for unclassed choropleth maps. They also use very different default color schemes. The QGIS color ramps span a greater visual range, with much lighter and much darker values than their equivalents in ArcGIS. Consider the lightest value of blue in the "Blues" color ramp below; it is much lighter in QGIS, in fact it is nearly white. Compare this to the blue gradient in ArcGIS.

CONCLUSION

The use of color ramps to create a 999-class map in QGIS is a straightforward task, but, depending on the dataset, does not usually yield 999 different colors. In ArcMap, it is not as easy to create the 1,000-class map, and the software does not use 1,000 different colors. ArcGIS Pro has a misleading "unclassed" option, and it does not provide unique colors for every unique data value. In fact, it uses fewer colors than QGIS's 999-class option. Future research should study the potential of developing color ramps with many more colors to facilitate true unclassed choropleth mapping.

It is nearly impossible to create an unclassed choropleth map with the currently available software unless the data values permit it (i.e., there are a small number of unique data values that are sufficiently spaced). A method to calculate whether an unclassed map is possible for a particular dataset is included in the Google Maps API example showing median age in Nebraska. This method that displays the level of classification caused by an insufficient number of colors should be incorporated in all choropleth mapping software.

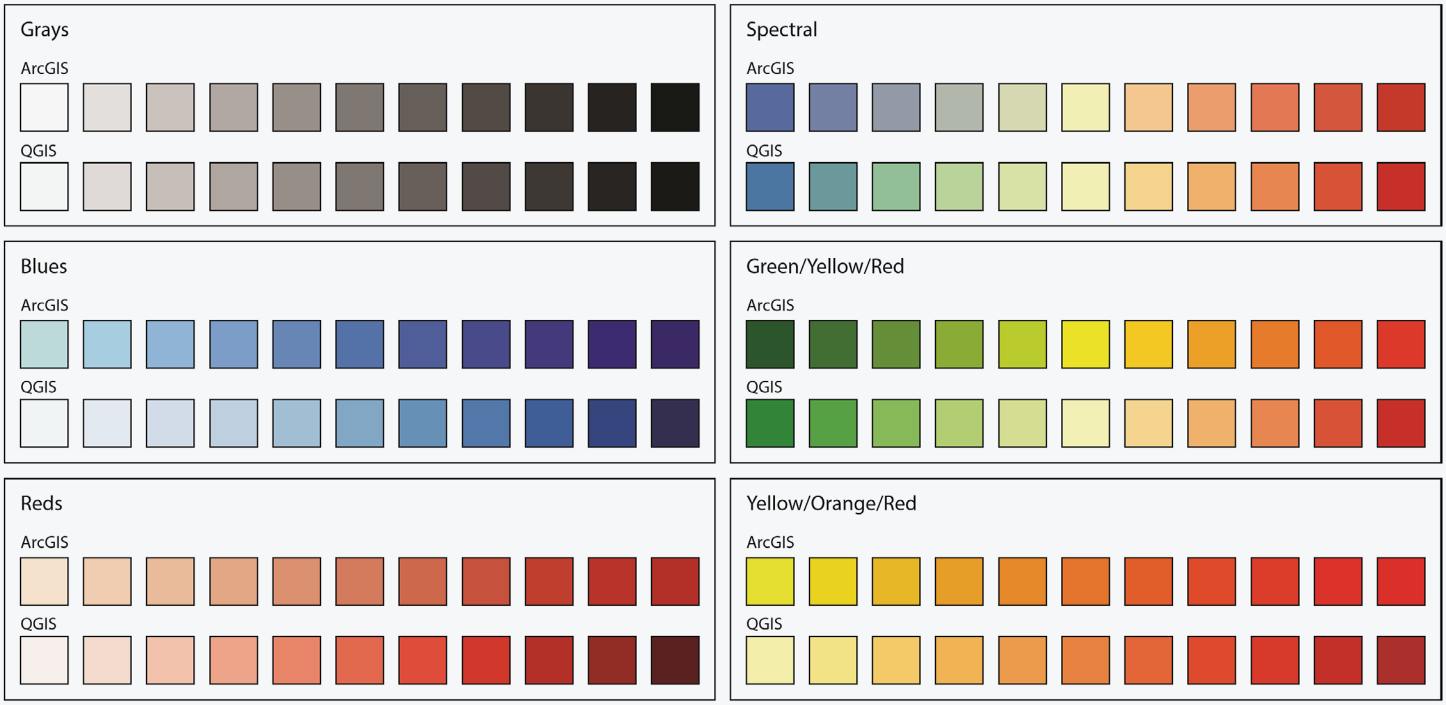

Figure 9. *A comparison of color palettes from ArcGIS and QGIS using the generic graduated color symbols provided by each software. The boxes represent 11 polygons with attributes ranging from zero to 100 (0 on the left, 50 in the middle, and 100 on the right for each ramp).*

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Stitched Cartographies

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My work combines aerial photography, USGS maps, soil surveys, and satellite imagery. I also incorporate the more minute systems of the microbial world. I enjoy the play between the two scales of magnified microbial life and remotely sensed images of huge tracts of land: both deal with the translation of scientific information into a visual form. In my present work, these once-separate themes have merged. The overlap is seen in vessel-like arteries of water, tundra pools that look cellular, and circuit board-shaped canals.

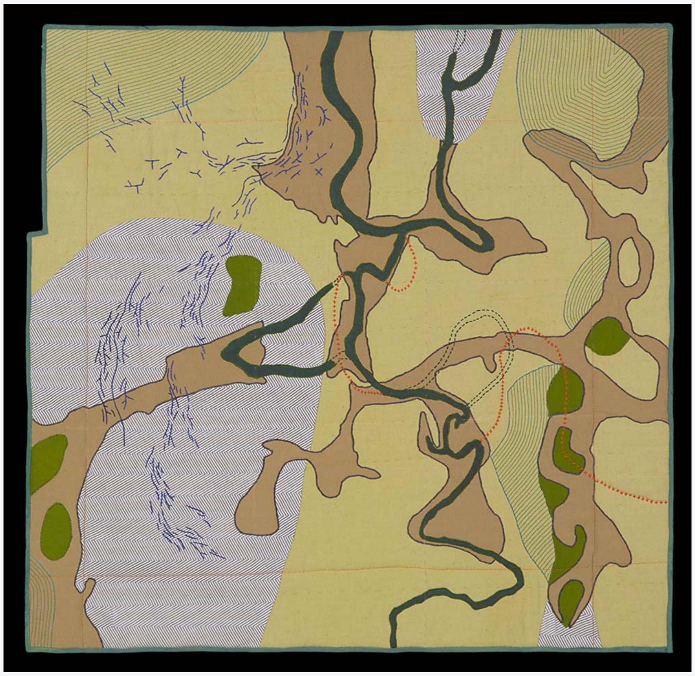
It is the use of maps in organizing our ideas of land that interests me most of all. My focus is usually on human-impacted landscapes and visual evidence of our interaction with land. Many of my pieces are not based on specific places, but occasionally I will work from historic maps or use imagery from existing maps, creating an entirely new experience. For me, the pieces are intimate explorations of map language and imagined landscapes. The story is enhanced by my use of salvaged materials like secondhand clothing, upholstery scraps, and vintage kimonos. My process involves layering cloth by machine stitching, cutting, and hand sewing. The subtractive technique of reverse appliqué creates water boundaries and mimics erosion. Layering cloth and stitching lends itself to representing development.

While the work relies in part on modern mapping technology for inspiration, my process is relatively low tech. I do not use a computer or any imaging software in creating my work, and I strive to use hand techniques and tools as opposed to electric. Through my research and methodical hand work I have determined that maps create more questions than they answer.

SOIL SURVEY

2016. (23 × 22.5 in). Textile.

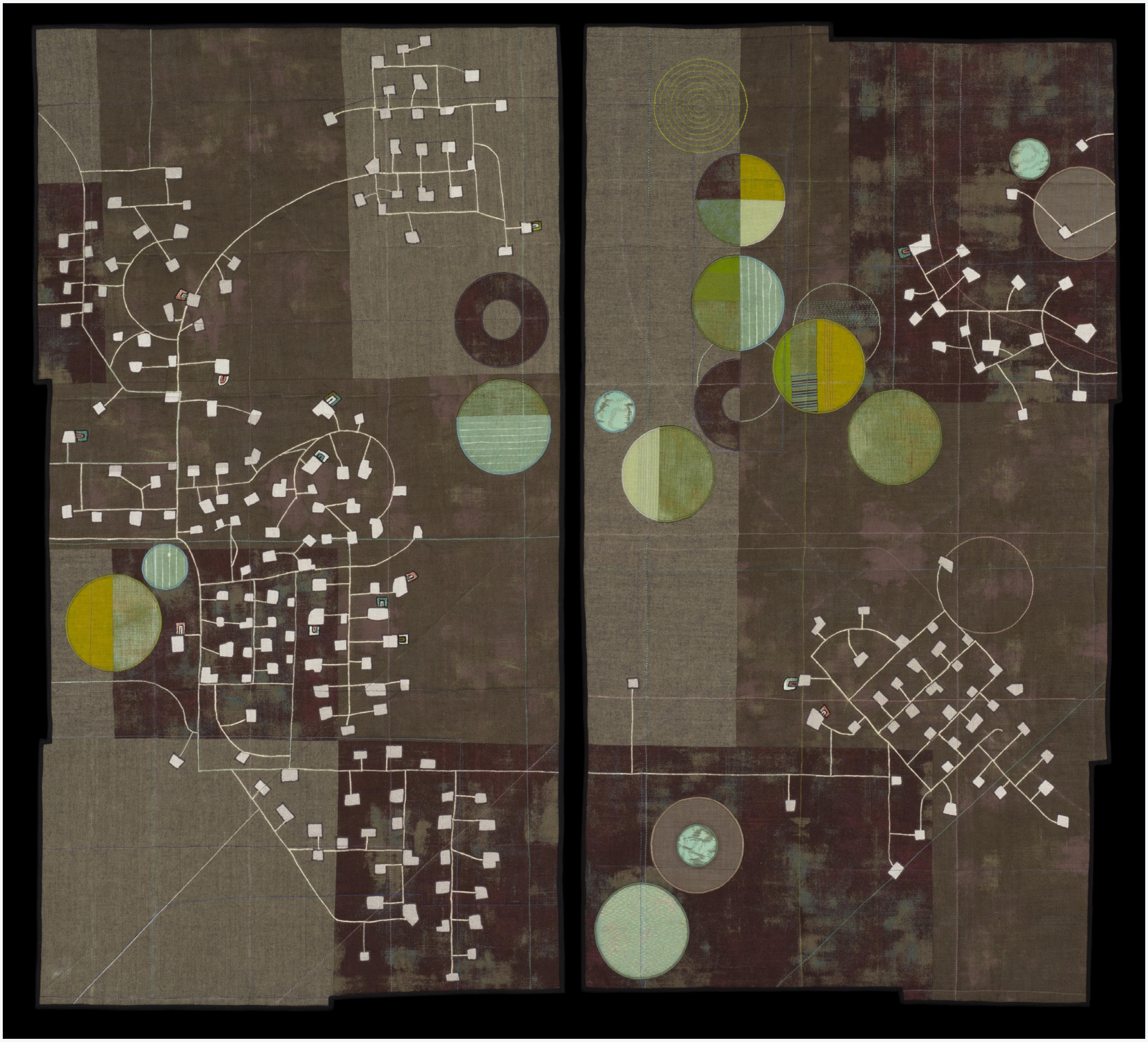
This work is inspired by an obsession with an online collection of African soil maps from the 1960s. The idea of analyzing and categorizing soil types intrigues me as much as the energy and color of the maps themselves. Being interested in scientific illustration, I cannot help but connect the map forms to the microscopic realm. In a time where information can be relayed at the touch of a button, it is satisfying to slowly craft work that is inspired by cartographers and biologists of the past.



OIL AND WATER DIPTYCH

2015. (47 × 41 in). Textile.

This piece is based on the West Texas landscape of oil pump jacks and pivot irrigation arms. Following my brother's relocation to that area, I searched online to see what it looked like. I was surprised by the expanses of the oil fields interspersed with patches of irrigated farmland. It made me wonder what it all might look like when the oil and water reserves inevitably run dry.



CHANGING COURSE

2015. (33.5 × 33 in). Textile.

This piece is a study of how riparian farmland can record the changes a river goes through over the years. In aerial photos, the previous banks of the river can be seen etched into the fields.

FISK'S GHOST

2014. (25 × 41 in). Textile.

This piece is based on Harold Fisk's map created for the Mississippi River Commission in 1944. While it is not an accurate portrayal of Fisk's map, it is inspired by how his map shows "traces of [the rivers'] previous courses, twisting and writhing in a vast intestinal tangle." The white silk represents the idea of "tamed" boundaries of a river after being set by the Corps of Engineers. I think of it as the skeleton left behind after the more lively parts of the river, the muscle and sinew, were suppressed. The numbered long lots show a history of people re-establishing ownership in response to the changing river.

SOIL SURVEY

2016. (23 × 22.5 in). Textile.

This piece is inspired by a fascination with the imagery of soil maps and years of working with microbial imagery. The abstract qualities of the soil surveys invite people to find recognizable images. They remind me of the liveliness and narrative qualities of old scientific illustrations.

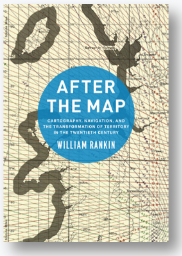
CROSSING OVER: GEE'S BEND

2010. (38 × 37 in). Textile.

This is a fairly accurate map of Gee's Bend, Alabama and is inspired by J. R. Moehringer's Pulitzer Prize-winning article titled *Crossing Over*. The article explores the journey of life and death as it relates to the history of the bend in the Alabama River, near Boykin, Alabama. This is a place where freed slaves were marginalized, yet found ways to thrive. The piece is also inspired by the quilt traditions of the women who lived and worked on the land. The pieced sections reference the strip quilting of the women and property divisions common to the South. In the article, the Alabama River becomes a metaphor for the River Jordan. The place names are those of existing cemeteries and the dotted lines represent the passage between the graves and the river.

Visual Fields focuses on the appreciation of cartographic aesthetics and design, featuring examples of inspirational, beautiful, and intriguing work. Suggestions of works that will help enhance the appreciation and understanding of the cartographic arts are welcomed, and should be directed to Section Editor Matt Dooley: **mapdooley@gmail.com**.

AFTER THE MAP: CARTOGRAPHY, NAVIGATION, AND THE TRANSFORMATION OF TERRITORY IN THE TWENTIETH CENTURY



By William Rankin.

University of Chicago Press, 2016.

416 pages, 13 color plates, 144 halftones. $55.00, hardcover.

ISBN: 978-0-226-33936-8

Review by: Mark Denil

After the Map: Cartography, Navigation, and the Transformation of Territory in the Twentieth Century, by William Rankin of Yale University, is an impressive bit of research wrapped in a readable text that consistently trims the cloth of history to support a questionable thesis. It is Dr. Rankin's contention that, over the past century or so, we have been progressively abandoning the "representative" map in favor of a "real," full scale, world of points, and he is quite prepared to play Procrustes to prove it.

The book itself is solidly bound with cream pages between tan cloth-covered boards: a typically fine University of Chicago Press product. The dust cover illustration of a detail of a British Gee Lattice radio navigation chart from the 1940s strikes one as a tad garish, but it is actually quite an apt image selection: radio navigation aids play a key role in the book's narrative.

After the Map opens with an Introduction ("Territory and the Mapping Sciences") and is closed by a Conclusion ("The Politics in My Pocket"), with most supporting matter ("Acknowledgments," "Acronyms and Codenames," plus "Notes" and an Index) grouped at the end, save a list of "Possibly Ambiguous Terms" slotted in right at the beginning. A variety of other supporting material, such as image files of the illustrations, spreadsheet and GIS data, and a bibliography, is available at afterthemap.info.

The main body of the text is organized into three Parts: (I) The International Map of the World and the Logic of Representation; (II) Cartographic Grids and New Territories of Calculation; and (III) Electronic Navigation and Territorial Pointillism; each of which contains two chapters. In the first two parts the paired chapters break at about the Second World War, but in the third part they break in the early 1960s.

Each of the three Parts is given over to exploration of one of three projects easily identified by a Three Letter Acronym (TLA). Part I is devoted to the International Map of the World (IMW), the second to the Universal Transverse Mercator (UTM) system, and the third Part to the Global Positioning System (GPS). The author proposes that these three projects "form a remarkably unified historical narrative," that "is about the emerging logic of the grid and its significance as a new way of structuring knowledge" (17).

The author sets the stage in the Introduction by noting a mid-twentieth century shift in news coverage of military mapping. Before 1960, he reports, news reports focused on the sheer quantity of maps produced (sixty-five million in the First World War, and over a billion in the Second), but by Vietnam War days the talk was of the new geographic precision of "smart bombs" — though this reviewer does not recollect anyone talking about "smart bombs" in the 60s: that blather came much later, didn't it? The goal of *After the Map*, we learn, "is to understand the larger stakes of this shift" (2) through what Rankin later refers to as "a global history of geographic knowledge" (16). The chosen approach is something the author calls geo-epistemology: not just what is known about the earth but how it is known. This overall intention, one might suggest, is a tall order. It is also a relatively important and potentially engaging one, depending in large part just how the author comes to find a grip on the matter.

The reader is introduced to the key dichotomy of the proposed discourse almost immediately. On the one side the author sets up the IMW as the crown of early- to mid-century positivist cartographic mythology, and on the other he places…well, he places GPS. "Rather" he writes, "than creating a miniature substitute for the world, the radio signals sent from GPS satellites instead create a full-scale system of coordinates that overlays and coexists with the physical terrain…," something that is "much more geographically embedded than the experience of using a map" (3).

Rankin refines his map/GPS dichotomy into a representation/post-representation conflict. He explains that

> coordinates shift attention from the area to the point: a stable electronic grid makes it possible to aim missiles, drill for offshore oil, or conduct field research without any overarching awareness of a larger geographic region. The overall ambition is quite different as well. Being glib, one could say that with representation the goal is to know about a place without having to visit. With technologies like GPS, the goal is instead to visit a place without having to know much about it. (3)

This actually makes (some) sense; abstraction to coordinates does indeed redirect attention, and this can be extremely complex and possibly problematic. Drone operators, for example, navigate primarily by coordinates supplemented by an on-board camera for very local observation: some operators have described this this way of "watching targets as 'looking down a soda straw'" (Scahill 2016, 107). However, Rankin seems, in many or most instances, to be over-freighting bald coordinates. Coordinates are not usually used exclusively in the abstract; they are placed into context on a base map that may be explicit or implied. Arguably, the only tasks that use bald GPS coordinates are the same (or analogous to) tasks that had earlier been performed on paper maps using geographic coordinates. If indeed the artificial stars of the GPS constellation "create a full-scale system of coordinates that overlays and coexists with the physical terrain" (3), then so too did (and do) the long-existing stars which have been used in the past for coordinate calculation and are still available for that role (despite a shocking lack of government maintenance funding).

The rest of the Introduction is taken up with an outline of the historically growing instability of territoriality brought on by such things as the expanded and refined definitions of geographic sovereignty, of globalization, and of conflicts between the two. These issues form the environment that both affects and is affected by the three projects and the thesis' central dichotomies.

In "The Authority of Representation: A Single Map for All Countries, 1891–1939" and "Maps as Tools: Globalism, Regionalism, and the Erosion of Universal Cartography, 1940–1965," the two chapters focused on the IMW, Rankin discusses the proposal and life cycle of the world map, with particular focus on on the concepts of "legitimacy," "legibility," and "representational mapping." These terms are deliberately left vague, which allows the author a great deal of dancing room in his analysis.

Noting that "as the flagship project of twentieth-century cartography, the IMW is therefore a window into the geo-epistemology of representation as a whole" (26), Rankin recognizes that IMW was indeed the embodiment of an elaborate and pervasive positivist world-view that has since been revealed as seriously flawed and shopworn, but he then segues into ascribing to the IMW's proponents a most unlikely conceptual fallacy. By the end of the paragraph he has seized on the IMW as "conceptually … a paper replacement for the physical landscape" (26), and "a view from nowhere": this is an astonishing accusatory leap. It seems rather a projection of present-day concepts onto actors in the past.

The impression left the reader is of an IMW project born in a cauldron of confusion, careerist self-serving, imperial machination, colonialist paternalism, and political wrangling. In this telling, the project struggled through a life of pointlessness and impotence, beset by fruitless arguments over "seemingly minor details like standardized symbols, colors, and typefaces" (35), only to die a banal, lingering death long past hope or caring. That this impression may, in fact, be a reasonable one is not the point; the point is that the history is trimmed and folded to fit the thesis of an unstoppable historical march away from a "view from nowhere" type of "representational mapping" to a magical, mystical, Cloud-cuckoo-land (as Aristophanes called it in *The Birds*) "framework of points."

Chapters 3 and 4, "Aiming Guns, Recording Land, and Stitching Map to Territory: The Invention of Cartographic Grid Systems, 1914–1939" and "Territoriality without Borders: Global Grids and the Universal Transverse Mercator, 1940–1965," deal with the rise of measured grid coordinate systems. This story begins with the widespread use of measured grids in the First World War, particularly for ordnance applications. It does brush off or ignore earlier land-griding systems (the US Public Land Survey System, or Canadian Western Land Survey, anyone?), but, granted, a DNA test would likely not find evidence of paternity for UTM much past Flanders Fields.

"Legibility" continues to be a key concept in these chapters. The term seems to be used in reference to an affordance of usability: it is the *legibility* of the grid that allows a concealed howitzer to drop high explosives on an out-of-sight target, or for a boundary monument to be located without anecdotal reference.

All, or most, of the armies in the 1914–17 conflict employed various grid based mapping coordinates in some manner or another, and although there were attempts to merge what were local, piecemeal, and often overlapping systems, for various reasons none were successful. In the interwar period there were additional moves towards a more unified matrix, but a variety of other impediments helped to thwart these initiatives, too. It was not until the 1939–45 war that a new, energetic player, largely uninterested in the concerns of others, began to implement a world-wide system suited to its own needs. Rankin clearly views the unilateral US Army UTM initiative as quite innocuous, in stark contrast to the less than sympathetic view he had taken of the provisional IMW mapping of South America by the American Geographical Society. That earlier effort was seen as "geographic knowledge in its most privileged and powerful form," and the resulting "tensions between empire and national self-determination" proved to the author that "the legitimacy of the American mapping effort was at best ambiguous" (63–4). By contrast, the US Army's efforts to persuade, cajole, bribe, blackmail, trick, or force (not always hostilely, but generally aggressively) broad military adoption of UTM at home and abroad, which in turn helped lead to broad civilian adoption, is viewed as perfectly "legitimate"; more a cause for quips than concern. But, after all, Rankin has already told us that UTM was on the right side of history, as IMW was not.

UTM gets an easy ride in regard to zone boundaries too. The discontinuities between the various hodgepodge of small European wartime grids comes in for a lot of attention, but discontinuities between UTM zones are largely dismissed as irrelevant. Coordinate distortions at the zone edges near the equator get a word or two, but the radical zone overlaps at high latitudes are never mentioned as problematic at all.

Part III contains the chapters "Inhabiting the Grid: Radionavigation and Electronic Coordinates, 1920–1965" and "The Politics of Global Coverage: The Navy, NASA, and GPS, 1960–2010." The first surveys the rise of the various competing and complementary radio navigation systems. The two main system types are distinguished by their approach: the one a directional beacon and the other an area pattern. Each provided a very different kind of navigational assistance. The area systems, Decca, Loran-A, and Loran-C, facilitated location identification anywhere covered by the network, while directional systems provided guide tracks that were often compared to railroad tracks. Each system type and individual system had strengths and weaknesses, but in time, combined receivers of growing sophistication came to simultaneously leverage several radio aids, and to make the technical details and idiosyncrasies of the individual systems transparent to the user. The elaborate printed map accessories used by the earlier generations of the radio systems came to be subsumed into the receivers, much to the relief of anyone who has ever had to use a chart overprinted with a Decca chain or Loran net: whether using the radio aids or not, all that ink on the paper could be a real pain. The really significant feature of these radio systems was, as Rankin points out (in different words), the way they provided sensible benchmarks wherever the network operated.

Replacing radio base stations on the ground with stations in orbital space went hand in hand with technological computing power advances to make possible the modern GPS system. The convoluted story of how GPS came to be is told in the second chapter of Part III. Did you know that, originally, civilian GPS use was intended to require a $370 annual subscription? Or that the individual military services were, on the whole, rather hostile to the whole idea, each preferring its own pet project? GPS only survived as a Department of Defense–level "go-for-broke" (275) gamble to rationalize the proliferating and competing systems. GPS, we learn:

> was a managerial reaction to the 1960s preference for redundant systems and custom solutions. It was a rationalization of radio navigation pushed by administrators rather than users, and it superseded existing systems as much by bureaucratic force as any practical appeal. And even though GPS today is functionally and politically quite universalist—it is used for a wide variety of tasks, all around the

> world—these features are largely the result of its all-or-nothing agenda migrating from military administration up the American political hierarchy. The universalism of GPS grew slowly over time, and it did not emerge by consensus. (274)

After the Map concludes with "The Politics in My Pocket," wherein Dr. Rankin sums up his findings. He writes that:

> Together, the IMW, UTM, and GPS tell a relatively coherent story about globalism and the mapping sciences in the twentieth century. They show a gradual but decisive shift from paper to electronic signals, from the logic of representation to the logic of the grid, from a focus on contiguous areas of space to a framework of points." (295)

On the book's web site (**afterthemap.info**), he goes on to remark that:

> This book can be read at two scales. Narrowly, it is a history of the mapping sciences in the twentieth century that situates technologies like GPS within a longer trajectory of spatial knowledge. But more expansively, by connecting geographic knowledge to territorial politics and new ways of navigating the world, it is also a political and cultural history of geographic space itself.

After the Map: *Cartography, Navigation, and the Transformation of Territory in the Twentieth Century*, has a wealth of good, interesting information. It is, for the most part, well written, despite the author's tedious and annoying habit of starting *so* many sentences with a particular conjunction. Rankin has peered into committee reports and artillery manuals, and drawn it all together quite readably. He is, however, quite selective in his narration. For example, although he found and cites the two sentences about the IMW in *What Really Happened at Paris: The Story of the Peace Conference, 1918–1919*, he doesn't quote it. Perhaps a report that "The world series of millionth maps proved to be sufficient for all needs. They constituted a sort of international currency, readily accessible, familiar to all participants, and inexpensive," just didn't jibe with the good doctor's program (House and Seymour 1921, 5). Similarly, Rankin provides a very engaging and detailed telling of the proposal and campaign to promote the IMW, but he breathes not a single word about the then-prevailing situation in world and regional mapping. No mention is made of any chaos or confusion caused by the hodgepodge of laissez-faire, parochial, and often eccentric patchwork of practices that obtained in various parts of the world before the establishment of a canonical standard in the IMW. He also seems uninterested in the entrenched influence of both the Enlightenment and European Romanticism that persisted into the early twentieth century; in particular of intellectual encyclopedia-ism and Romanticized scientific-ism epitomized by figures such as Diderot and Humboldt, respectively. Albrecht Penck's 1891 proposal for the IMW is conceptually rooted in both these movements, and understanding them is key to understanding the IMW project. Instead, Rankin finds it adventitious to allow Penck and his supporters to float free in a history-less sea, contextualized only by events that transpired after they had left the stage.

In a later chapter, discussing the expanding use of measured locational grids, the author delves deeply into the confusion and dissonance arising from a patchwork of individual abutting or partially overlapping grids, but befuddles the explanation by forcing it into his thesis matrix. This thesis is that, for him, not only are grids simultaneously both "local horizons" and "global systems," but they somehow both sensibly exist and are accessible to users "at full scale." The author opines that "GPS has created a separate reality: an intangible knowledge space of electronic points that shares space with the physical world, but does not refer to it" (280). He apparently believes that, although grids are abstract and wholly artificial, the user somehow inhabits them directly, foregoing any "representative" conceptual analog. Roads, buildings, deserts, rivers, and national boundaries become irrelevant and immaterial to the inhabitants of Rankin's gridded (and later, pointillist) cloud-cuckoo-land. A "brave new world" indeed, for Syrian refugees and Mesoamerican migrants.

At one point (no pun intended) Rankin enters the artillery plotting board as evidence for the triumph of the grid over the "representative" map. In his mind the plotting board is somehow not a map, seemingly because it does not immediately resemble an IMW sheet. This assertion, however, is simply untenable; a plotting board is as much a map as any other map. Assuredly, a plotting board, like a marine navigation plotting sheet, is a profoundly *terse* map, but it is a map nonetheless (see, for example, NGA Nautical Chart 27).

A great deal of emphasis is freighted on the autonomy of points, but the primary value of points is not their independent existence as points, but their place in a topological context; a context represented by "a projection of a mental schema on a medium, the materialization of an abstract intellectual order extracted from the empirical universe" (Jacob 2006, 30). To wit: a place contextualized on an explicit or implicit map.

The author writes frequently of a geo-epistemology, which he finally defines (on page 298) as equivalent to geographic tools, but he seems to have a rather faulty grip on the ontology and epistemology of the map. It might seem necessary, if one is going to dismiss the relevance of the map, to engage with it; but, when Rankin gets close to doing so, he grandly dismisses the map as "representational," and thus an artifact of the past.

This sort of thing is what makes reading *After the Map* by turns so interesting, tedious, and infuriating: Rankin's persistent strong arming of a great deal of well-researched information into the straitjacket of his vaulting vision of the march of technology leaving the map behind for the utopia of a cloud of autonomous points.

Unfortunately for Dr. Rankin, the fact remains that the map has not been, and will not be, left behind: outmoded forms and practices are not "the map," they are just forms and practices. "The map" is an entirely artificial, cultural construct, and cartographic epistemology relies on a schema of mapicity that is mutable. The map, and its epistemology, is not tied to any particular form or style of artifact. While the map is ontologically stable as a useful, usable, and persuasive rhetorical artifact, its epistemology is culturally contingent. Maps can and will change: that is indisputable. That they are being left behind, as William Rankin contends in *After the Map*, remains, at best, unproven.

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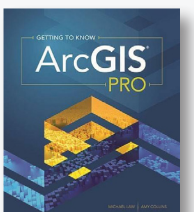
GETTING TO KNOW ARCGIS PRO



By Michael Law and Amy Collins.

Esri Press, 2016.

467 pages. $85.99, softcover

ISBN: 978-1-58948-457-3

Review by: Tara LaLonde, The Pennsylvania State University

Getting to Know ArcGIS Pro provides the reader with ten well-structured chapters introducing features of ArcGIS Pro 1.1. The book includes background material on geographic information systems (GIS) principles, and the chapters build on one another in a manner appealing to both new and experienced GIS users, while at the same time incorporating new terminology specific to ArcGIS Pro. Sample data are provided by Esri via a companion website, for use with each chapter's exercises. Each of the text's exercises occurs in the context of a scenario related to a real-world problem or question. This project-based learning mirrors how GIS is taught in educational settings and how learners apply GIS concepts to new software and data.

Law and Collins guide readers through the application of practical and relevant GIS concepts in ArcGIS Pro through ten chapters. Each begins with an introduction, followed by a description of exercise datasets, exercise instructions, a summary, and a glossary of terms. This consistent framework and layout provides the reader with an easy to follow pattern as the material progresses from introductory GIS techniques to more advanced topics in later chapters.

Chapter 1, "Introducing GIS," provides an introduction to basic GIS principles of vectors, layers, rasters, and attributes, along with an exercise in ArcGIS Online. The exercise presents the reader with opportunity to explore ArcGIS Online through an organizational account, offering an opportunity to understand how an ArcGIS Online organizational account works in relation to ArcGIS Pro. The text points readers to the State of Michigan's GIS data resources, providing them with an example of an open data site, which are becoming increasingly common. Many additional data sources and websites are presented, enhancing the value of the book as a guide to learning ArcGIS Pro and GIS principles.

To provide a foundation in ArcGIS Pro terminology, Chapter 2, "A First Look at ArcGIS Pro," introduces the reader to key terms unique to the software, such as a project files and project packages, along with ways for sharing data and files with collaborators and other users. The tabs-and-panel structure of the software is presented in an easy to read layout, with examples that could relate to many projects across disciplines. To prepare the reader for navigating later exercises, this chapter describes the folder structures of the exercise data and associated files within geodatabases, and also introduces the reader to an engaging feature of ArcGIS Pro: the application's side-by-side view of 2D and 3D.

In subsequent chapters, readers build on this foundation of working with spatial data, but are also provided helpful tips and reminders of earlier chapters to reinforce material already covered. In Chapter 3, "Exploring Geospatial Relationships," the reader works through the process of joining data and creating an index. Helpful descriptions of the different symbology classifications are provided to aid the user in selecting the most appropriate classification scheme. A key feature presented in this exercise is the ability to swipe across layers, which provides the user with unique comparison opportunities. The concept of multiple map tabs is also introduced, allowing the user to have multiple maps as part of the same project file. Finally, key terminology related to feature classes, layer files, and layer packages provide context to the use of these files in exercises. Readers use this solid foundation as they next work through an introduction to geodatabases, geoprocessing tools, and editing spatial data in Chapter 4, "Creating and Editing Spatial Data." This chapter also introduces the reader to working with XY data, and the concept of metadata; however, additional material on metadata could have further conveyed its importance in identifying dataset characteristics.

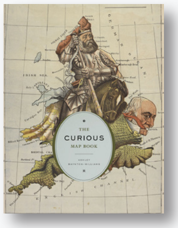
In Chapter 5, "Facilitating Workflows," the reader is introduced to ModelBuilder and working with Python scripts. Users are guided through the process of creating their own tasks, which is a new concept in the ArcGIS Pro software. Pre-configured tasks are used to walk the user through the different features of creating and describing a task, which can then be packaged and shared so that others can repeat them; this automation is a key part of the creation of tasks. The emphasis on making collaboration easier is followed by Chapter 6, "Collaborative Mapping," which focuses on collaborative mapping fieldwork through the creation of a tree inventory geodatabase. The reader is given additional experience with the use of geodatabase domains and properties, along with the connections to Collector for ArcGIS. They also learn about publishing map layers to ArcGIS Online, which further demonstrates how layers can be shared between ArcGIS Pro and ArcGIS Online.

Once they have a grasp of GIS foundations, navigating the ArcGIS Pro panels and layout, and the collaborative possibilities available, readers gain more advanced experience with geospatial analysis in the last four chapters. In Chapter 7, "Geoenabling Your Project," the reader is exposed to the concepts of geocoding and creating buffers, which are analysis techniques they may find useful in a variety of later contexts. This is followed by a crime scenario in Chapter 8, "Analyzing Spatial and Temporal Patterns." Here, the user examines data across time and space using the kernel density function, hot spot analysis, and a space-time cube. The exercise's 3D scenes demonstrate ArcGIS Pro's 3D capabilities and potential. In addition to presenting new software functions in each chapter, different geospatial file formats are also incorporated in the exercises, such as the netCDF (network Common Data Form) format for multidimensional data.

The path toward more advanced GIS concepts continues through a vineyard suitability example in Chapter 9, "Determining Suitability." This scenario exposes the reader to elevation models, hillshade, slope, and aspect, reclassification, the Model Builder, and the raster calculator. This scenario demonstrates how raster files are analyzed in ArcGIS Pro and teaches skills that relate to other suitability tasks the reader may eventually have. The text also points readers toward a valuable, web-based resource for determining the altitude and azimuth of the sun at a given location for any given time and date, which can be used to determine hillshade parameters. Finally, following this suitability analysis, the text takes readers through the software's presentation options in Chapter 10, "Presenting Your Project." An example related to mapping broadband service providers is used to explain to readers how to display a subset of a layer's features, label locations, and lets them explore page layout and export options. This page layout section in particular offers a good overview of features that are crucial to communicating results from geospatial analysis in ArcGIS Pro.

This book serves as a valuable resource for GIS users desiring to learn more about the ArcGIS Pro application, educators incorporating ArcGIS Pro into curricula, libraries providing software access to patrons, and individuals interested in exploring GIS software for the first time. It presents many of the common tasks users perform to manipulate and analyze geospatial information. The scenario exercises include a range of subject areas including population, conflict, broadband access, and demographics, providing the reader with many real-world applications involving geospatial data; these could be adopted by educators and tailored to specific course curricula. The current edition of the book includes a limited number of scenarios, allowing students and educators to complete the book in a realistic timeframe. However, it would be helpful in future editions to see exercise scenarios extended to additional geographic areas and application fields, in order to appeal to a broader audience of users. Overall, the book achieves its aims in offering a good introduction to ArcGIS Pro, as well as providing readers with a foundational understanding of how to work with geospatial data that they can apply to additional GIS resources, learning opportunities, and workplace environments.

THE CURIOUS MAP BOOK



by Ashley Baynton-Williams

University of Chicago Press, 2015

240 pages, 100 color plates. $45.00, hardcover.

ISBN: 978-0-226-23715-2

Review by: Mark Denil

Cartographic curiosities are always engaging, as demonstrated by the variety of map miscellanies available on the market. *The Curious Map Book* by Ashley Baynton-Williams might, at first glance, seem to be just another such compendium of a few odds and sods tossed together to milk the trade; but that impression would be wrong. It is, in fact, an excellent, long-baseline overview of unique and interesting cartographic curiosities assembled by someone with a comprehensive grasp of the historical horizon.

The layout of the book is familiar enough: two columns of descriptive text on the left page and a full-map, full-color illustration on the right. Although the author, Baynton-Williams, "is an antiquarian map dealer and researcher," his commentary is equally far from both dreary pedantry and salesroom sophistry. His remarks are short and concise, with enough description to illuminate the exhibit and enough context to establish the map's position in history. The accompanying photos are clear and sharp, and provide a reasonably good view of the map under consideration. The main photo pages are supplemented with twenty-two additional detail images (on the appropriate description pages) and five two-page photo spreads of particularly large and detailed maps. The maps with two-page spreads usually use their regular illustration page for a full-bleed detail shot.

The volume itself is solidly bound, with pages that fall open easily and sit between boards covered with green cloth. The dust cover has fine, large, illustrations front and back, and has a spine title block that mimics a pasted label. The book has a nice heft, and is sized to balance well in the hand. The paper has a medium gloss, and, while it is not particularly opaque, the book design makes that less of a problem than it might be. The left-hand pages have lots of clear white space with sharp black text, while the right-hand pages (that are, in practice, the back sides of the left-hand pages) are covered with solid, full-bleed ink: the parts not covered by the map are filled with a dense background color that varies by book section. This helps to give the white page areas on the reverse a good, smooth, non-distracting ground; this is an effect that may or may not have been in the mind of the book designer, but which is appreciated.

The book opens with an Introduction, followed by four chapters: "The Dawn Of Mapmaking (To 1594)," "Early Published Maps (1598–1760)," "Commercial Cartography and Education (1760–1850)," and "The Victorian Era and Growth of the Mass Market (1850–)." A list of "Cartobibliographical Details" and an Index round things out.

The great majority of the maps, dating from 1493 to 2008, are drawn from the British Library; only seven or so are from foundation, dealer, or private collections. Two-thirds of the maps are from British publishers. Of the non-Britannic maps, two-thirds come from the large Continental mapping centers: France, Germany, and the Low Countries, but only four are extra-European (including two from the US). Interestingly, the two maps made in the US were authored by a visiting English actress / illustrator / cartographer, Eliza Jane (Lilian) Lancaster, and are the only two manuscript maps included.

As might well be expected, wood cut maps dominate the first, 1493–1594, chapter. Copper engravings then fill up the middle chapters (to 1760 and to 1850, respectively), although lithographed maps start cropping up in the later part of the latter period. After 1850, it is, of course, monochrome or color lithography that dominates. Besides these mainstream products (in whatever era) and the manuscripts already mentioned, the volume includes a pair of steel engravings, a couple of etchings, a pair of rugs, and a ceramic pitcher, plus a handful of maps from unidentified production processes.

In his Introduction, the author taxonomizes his map selections as "breaking down into five broad bands, not neccessarily [*sic*] mutually exclusive: game maps, maps in animal form, maps in human form, maps on objects, and allegorical maps — moral, political or religious" (6), and he briefly discusses the distinguishing features of each type, before plunging into the maps themselves.

The map descriptions are succinct and informative, and are clearly epitomes of larger bodies of information. Where hard information is short (in the case, say, of a game missing its instruction sheet), the author goes no further in speculation than is reasonable, and where there is likely a wealth of detail available, his remarks seem pertinent and well chosen.

Yes, there are one or two typographic errors; yes, some of the maps could have been rotated and shown slightly larger (in any event, a magnifying glass is useful); and, yes, there a real preponderance of British maps; but there is really very little to quibble about.

One nagging peculiarity is the constantly varying placement of the map image on the right-hand page. All maps are oriented with the top up, so, of necessity, landscape-oriented maps are shown somewhat smaller than they might be; their size is limited by the page width. The book designer tried, wherever possible, to align the top of the map image (on the right-hand page) with the top of the two-column text block on the left-hand page. As the page headers vary in depth (some titles take up three, four, or even five lines, and other header information like title translations and artifact measurements may also run that long), the text block may start quite far down the page. The tops of the photos, then, are never at a set distance from the top of the page. I counted at least eighteen different positions for the tops of the maps; a couple were a good four inches down page: more than a third of the way down! Compounding the matter, it was not always possible to get the whole map onto the remaining page, so in some cases the photo had to be moved up the page anyway, violating the convention. One would think that once a layout convention had shown itself unworkable, another, more consistently applicable approach would be adopted. As it stands, as one pages through the book, successive maps seem to pogo up and down like Commander Keen.

Nonetheless, there are plenty of quaint and curious treasures to be discovered in these 240 pages, both in the first and in subsequent readings. If you are looking for a book on cartographic curiosities, *The Curious Map Book* is well worth consideration: the exhibits are well chosen, the collection covers a considerable sweep of time, and it includes examples not too likely to be overly well known. Furthermore, it contains a wealth of information plainly and engagingly expounded. At less than fifty dollars, you can't go far wrong choosing *The Curious Map Book*.

Student Peer-Reviewed Paper Competition

Students can win an award of $1350 by contributing peer-reviewed articles to *Cartographic Perspectives* (*CP*). Any peer-reviewed manuscript accepted for publication whose first author is a student, is automatically entered into the Student Peer-Reviewed Paper Competition, which is judged annually by the Editor and Editorial Board of *CP*.

PAST WINNERS

2016 **Carolyn S. Fish** *An Analysis of Interactive Solar Energy Web Maps for Urban Energy Sustainability*

2015 **Joel Radunzel** *Using the Right Tool: David Woodward's Suggested Framework and the Study of Military Cartography*

2014 **Maxim Rylov** *Pairwise Line Labeling of Geographic Boundaries: An Efficient and Practical Algorithm*

2013 **Nick Perdue** *The Vertical Space Problem: Rethinking Population Visualizations in Contemporary Cities*

2012 **Bin Mo** *Mapping Potential Metro Rail Ridership in Los Angeles County*

OFFICIAL RULES

1. Any manuscript accepted for publication without additional peer-review *and* having a student as a first author can be eligible for the competition. Specific requirements and stipulations include:

    a. The first author must have been a student during the time that the research was conducted.

    b. Manuscripts must be submitted by active students or graduates within a year of graduation.

    c. The entire cash prize is awarded to the first author. Any distribution of this prize among other authors (whether students or others) is left to the discretion of the first author.

2. Upon acceptance of a manuscript, the student/graduate will be asked to have his/her academic advisor submit a short note stating that this work was in fact completed during the time the student was in an academic program. A record of a student's graduation date may also be required for graduates submitting student research within one year of graduation.

3. Student papers will be judged annually, and include all papers published in the issues of Cartographic Perspectives for that calendar year.

4. Papers will be judged by a committee composed of members of the Editorial Board of CP. Each committee member will use the same rubric to evaluate all student papers. The rubric follows on the next page.

5. The editor will tally results of all rubrics. The paper with the highest overall score will be named winner of the competition at the next NACIS Annual Meeting. In the event of a tie, the editor will determine the winner.

EVALUATION RUBRIC

	Fails to meet expectations	Meets expectations	Exceeds expectations	Greatly Exceeds expectations	Comments	Score
The abstract is a clear and concise description of the paper.	☐ 0	☐ 3	☐ 6	☐ 10		
The author introduces the research problem succinctly and clearly and explains the purpose of the article.	☐ 0	☐ 3	☐ 6	☐ 10		
The author addresses how the present research fits into previous research in the appropriate cartographic discipline.	☐ 0	☐ 3	☐ 6	☐ 10		
The methodology/analysis is technically/scientifically sound and well documented.	☐ 0	☐ 3	☐ 6	☐ 10		
The results are valid or the design innovation is shown to be useful/effective AND the results or design innovation are presented/illustrated clearly.	☐ 0	☐ 3	☐ 6	☐ 10		
The discussion addresses the way in which the research aligns with existing knowledge or design practice and its implications for future work.	☐ 0	☐ 3	☐ 6	☐ 10		
The conclusions state the most important findings of the research.	☐ 0	☐ 3	☐ 6	☐ 10		
Novelty and significance/potential impact on the field.	☐ 0	☐ 3	☐ 6	☐ 10		
Maps and illustrations are well designed and communicate effectively.	☐ 0	☐ 3	☐ 6	☐ 10		
Writing is organized, grammatically correct, clear and concise.	☐ 0	☐ 3	☐ 6	☐ 10		
TOTAL						

Cartographic Perspectives (*CP*) publishes original articles demonstrating creative and rigorous research in cartography and geographic visualization under open-source licensing. Papers undergo double-blind peer review; those accepted for publication must meet the highest standards of scholarship, address important research problems and issues, and appeal to a diverse audience.

Articles should be submitted online, in OpenOffice, Microsoft Word, or RTF file format. Each manuscript is reviewed by the editor, one or more members of the editorial board, and at least one external reviewer. By uploading to the *CP* website, authors agree to not submit the manuscript elsewhere until the *CP* editor has reached a decision. Any submitted manuscript must not duplicate substantial portions of previously published material.

GENERAL GUIDELINES

Content should be submitted online via the *Cartographic Perspectives* website, **cartographicperspectives.org**.

STYLE: Grammar and punctuation should conform to the latest edition of the Chicago Manual of Style, and all manuscripts should make use of American spellings.

OPINION/RESPONSE PIECES: *CP* welcomes topical responses to previously published articles. The length of such pieces may vary; however, we suggest 2,000 words or less as an informal guide.

ILLUSTRATIONS: Maps, graphs, and photos should convey ideas efficiently and tastefully. Graphics should be legible, clean, and clearly referenced by call-outs in the text. Sound principles of design should be employed in the construction of graphic materials, and the results should be visually interesting and attractive.

- All graphics must be in digital form, either digitally generated or scanned. Preferred formats are .tif, .ai, .jpg, or press-ready .pdf.
- Images must both be embedded in the manuscript, and sent as separate files.
- Images in raster format must, at minimum, be 1000px wide; at least 2000px is strongly preferred.
- Where possible, graphics should have a transparent, rather than a white, background.
- The editors the right to make minor adjustments to illustrations.
- Authors are responsible for ensuring that they have permission to use all illustrations.
- Image orientation should be the same as intended for final publication.
- For vector files, fonts should be embedded or converted to outlines.
- Type sizes below 6 point should be avoided.
- Captions should not be part of the illustration. Instead, please supply captions within the text of the article.

For questions on specific guidelines for graphics, please contact Assistant Editor Daniel Huffman for more information: **daniel.p.huffman@gmail.com**.

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PEER-REVIEWED ARTICLES

TITLE: The title serves as the author's invitation to a diverse audience. It should be chosen wisely. The title section should include the full names of the authors, their email addresses, and their academic or professional affiliations.

ABSTRACT: An abstract of 250 words or less should summarize the purpose, methods, and major findings of the paper.

KEYWORDS: Five to ten keywords should be listed at the end of the abstract.

REFERENCES: References should be cited parenthetically in the text, following the author-date system found in *The Chicago Manual of Style*, 16th ed. (**chicagomanualofstyle.org**). When making a direct quote, include the page number. Examples: (Doe 2001) and (Doe 2001, 38).

Books: Invert the first author's name (last name, first initial or name, and middle initial). Middle initials should be given wherever known. For books with multiple authors, authors' names are listed in the order in which they appear on the title page, with the last author's name preceded by a comma and *and*. Note: With more than ten authors, invert first author's name and follow it with a comma and the words et al. without italics in the reference list.

The general format is: Name of author(s). Year. *Title in Italics*. City of Publication: Publisher Name.

Robinson, Arthur H., Joel L. Morrison, Phillip C. Muehrcke, A. Jon Kimerling, and Stephen C. Guptill. 1995. *Elements of Cartography, 6th Edition.* New York: John Wiley & Sons.

Articles in Periodicals: Author's or authors' names as in *Books,* above. Year. "Title of Article." *Title of Periodical,* volume number, page numbers, DOI if available. Follow punctuation and spacing shown in the following example.

Peterson, M. 2008. "Choropleth Google Maps." *Cartographic Perspectives* 60: 80–83. doi: 10.14714/CP60.237.

Articles in edited volumes: Name of author(s). Year. "Title of Article." In *Title of Edited Volume*, edited by [Editor's or Editors' names, not inverted], page numbers. City of Publication: Publisher's Name.

Danzer, Gerald. 1990. "Bird's-Eye Views of Towns and Cities." In *From Sea Charts to Satellite Images: Interpreting North American History through Maps*, edited by David Buisseret, 143–163. Chicago: University of Chicago Press.

Websites: Websites may be generally referenced in running text ("On its website, the Evanston Public Library Board of Trustees states…") rather than with a URL listing. For more formal citations, use the following format: Name of author(s). Year. "Title of Document." *Title of Complete Work (if relevant)*. Access date. URL.

Cartography Associates. 2009. "David Rumsey Donates 150,000 Maps to Stanford University." *David Rumsey Map Collection*. Accessed January 3, 2011. http://www.davidrumsey.com/blog/2009/8/29/david-rumsey-donates-150-000-maps-to-stanford.

Maps: Maps should be treated similarly to books, to the extent possible. Specific treatment may vary, however, and it is often preferable to list the map title first. Provide sufficient information to clearly identify the document.

A Plan of the City of New York and its Environs. P. Andrews, sold by A. Dury in Dukes Court, St. Martins Lane, surveyed by John Montressor, 1775.

E-mail correspondence: E-mail messages may be cited in running text ("In an e-mail message to the author on October 31, 2005, John Doe revealed…") instead of in a note or an in-text citation, and they are rarely listed in a bibliography or reference list.

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REFERENCES LIST: The list of references should begin in a separate section, immediately after the text. Entitle the section "References" and list all references alphabetically by the author's last name, then chronologically. Provide full, unabbreviated titles of books and periodicals.

FOOTNOTES: Footnotes should be used sparingly: i.e., only when substantive enough to amplify arguments in the text. They should be addressed to a single point in the manuscript. Footnotes should be numbered sequentially in the text and will appear at the bottom of the page.

UNITS OF MEASURE: *Cartographic Perspectives* uses the International System of Units (metric). Other units should be noted in parentheses.

EQUATIONS: Equations should be numbered sequentially and parenthetically on the right-hand edge of the text. If special type styles are required, instructions should be provided in the margin adjoining the first case of usage. Authors should carefully distinguish between capital and lower-case letters, Latin and Greek characters, and letters and numerals.

TABLES: Tables should be discussed in the text and denoted by call-outs therein, but the meaning of a table should be clear without reading the text. Each table should have a descriptive title as well as informational column headings. Titles should accent the relationships or patterns presented in the table.

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