KN - Journal of Cartography and Geographic Information (2019) 69:121–130
https://doi.org/10.1007/s42489-019-00016-0

Empirical Study for a Deployment of a Methodology for Improving the Comparability Between Historical and Current Maps

Inga Schlegel[1]

Received: 13 March 2019 / Accepted: 25 April 2019 / Published online: 9 May 2019

Abstract
In the investigation of urban development over centuries, the comparison of appropriate maps forms an essential component. The aim of this project is an improvement of an effective and intuitive comparison of historical and current map features. An adjustment of uniform visual variables to individual maps is therefore suggested. An appropriate framework presenting potential solutions for the deployment of a new methodology is based on the analyzed users' demands. These requirements were identified and evaluated with the aid of purposive sampled experts interviewed with a pencil and paper questionnaire. Two major challenges concerning the comparison between historical and current maps were revealed in a statistical evaluation: a general lack of technical tools and great varieties in semiology. The familiarity with their semiology has the greatest effect on the identification and distinction of map features. Therefore, an adaption of color composition, textures, and labels seems crucial in particular. Various approaches such as feature extraction or similarity measures to meet the mentioned challenges are suggested for future research.

Keywords Historical map · Empirical study · Semiology · Visual variables

Empirische Studie zur Entwicklung einer Methodik für eine bessere Vergleichbarkeit zwischen historischen und aktuellen Karten

Abstrakt
In der Erforschung von urbanen Entwicklungen über Jahrhunderte ist der Vergleich entsprechender Karten essentieller Bestandteil. Das Ziel dieses Projektes ist eine Optimierung für einen effektiven und intuitiven Vergleich zwischen historischen und aktuellen Geoobjekten. Zu diesem Zweck wird eine Vereinheitlichung der visuellen Variablen (Semiologie) von individuellen Karten angestrebt. Ein Überblick, der mögliche Lösungsansätze zur Entwicklung einer neuen Methode hervorbringt, basiert auf erhobenen Nutzeranforderungen. Diese wurden im Rahmen eines Papierfragebogens, welcher von einer Zielstichprobe aus Experten beantwortet wurde, ermittelt. Eine statistische Auswertung brachte zwei große Herausforderungen beim Vergleich von historischen mit aktuellen Karten zum Vorschein: ein allgemeiner Mangel an technischen Werkzeugen sowie große Variationen in der Semiologie. Auf das Identifizieren und Differenzieren von Geoobjekten hat die Vertrautheit mit bekannter Semiologie den größten Einfluss. Insbesondere eine Anpassung der Farbzusammensetzung, Texturen und Beschriftungen ist daher wesentlich. Verschiedene Lösungsansätze wie Merkmalsextraktion oder Ähnlichkeitsmaße werden für künftige Forschungsvorhaben empfohlen, um die genannten Herausforderungen zu bewältigen.

Schlüsselwörter Historische Karte · Empirische Studie · Semiologie · Visuelle Variablen

1 Introduction

In the recent past, current geodata styled in a historical appearance is often seen on social media or in new-fashioned atlases. Modern city maps such as of London (see Fig. 1),

✉ Inga Schlegel
inga.schlegel@hcu-hamburg.de

[1] Lab for Geoinformatics and Geovisualization (g2lab), HafenCity University Hamburg, Hamburg, Germany

Fig. 1 Map of modern London inspired by John Rocque's 1746 Map of London, drawn up by map designer Mike Hall (Hall 2016a)

Paris, or Hamburg are visually transformed so that at first glance, they appear to be from and represent past centuries.

Assuming an appealing appearance to be the motivation for designers or printmakers to produce current maps in a historic style, the compliance of stylistic and especially cartographic conventions is of secondary importance as the use of colors, contours, textures, and illustrated details relies on highly subjective decisions. But what if such maps are applied in further scientific work—to measure distances, ascertain house owners, former street names, or the progress of urban structures?

As processing and analysis of historical maps is not as easy compared to their more recent counterparts, archivists, librarians, historians, urban planners, cartographers, and geographers are frequently confronted with challenges while comparing current with historical geodata portraying one and the same section of a city. In such a comparison process, long-term spatiotemporal urban transformations such as the development of demography, migration flows, or trading and road networks influencing urbanization processes are supposed to become visible. A possibility for extracting designations, addresses, or further database-supported information from simple (paper) images representing historical maps is therefore required.

Owing to the lack of alternatives, users yet partly rely on very unconventional methods (own evaluation, see Sect. 4.3). As a first step of an overall project, the present study aims at setting foundations for the deployment of a new methodology to compare historical and current maps in a more effective way. This is to be achieved by applying uniform rules of representation to gain new knowledge in the subject of urban development.

Only a handful of scientific research efforts take up a uniform adjustment of visual characteristics to better compare current with historical geodata. The study presented here regards the users' demands and the potential for an improvement concerning an intuitive comparability on the basis of the maps' semiological characteristics. This paper consequently first, clarifies the terms of and connection between historical maps and semiology, second, reports on and evaluates the outcomes of an on-topic user study implemented in terms of a requirement analysis, and third, based on its results, points out the rationale of the proposed following investigations.

2 Review of Related Literature and Approaches

From the esthetic point of view, numerous examples of current geodata having a historical appearance can be found. Map designer and illustrator Mike Hall creates maps in a historical manner, particularly inspired by sixteenth up to eighteenth century mapmakers such as Willem Blaeu, John Ogilby, or John Rocque (M. Hall, personal communication, October 22, 2018). Besides portraying the physical world, he also designs city maps such as his *Map of modern London inspired by John Rocque* (Hall 2016a) (see Fig. 1) or *Maps of Glasgow for Denise Mina's "The Long Drop"* (Hall 2016b). Nelson (2016) reports on the work of cartographer Christopher Wesson who transferred visual characteristics (colors, patterns, symbols, labels, and generalization) of an official ordnance survey map from 1801 to recent geodata of London. This mid-scale map was produced at a high level of detail mainly with the help of geographic information systems and image processing software. Similar works by Kay (2016) use OpenStreetMap to map the city of Edinburgh in the style of the early twentieth century. Also, Wellingtons Travel Co. (2017) illustrates a cityscape from 2012 appearing to be historical in the course of their hand drawing *The Grand Map of London*.

While the standard of design in digital (web) maps is often criticized as low, users point out a frequent visual overload of information in historical maps (Beconytè 2011; Christophe et al. 2016; Ory et al. 2013). Analyzing their historical content turns out to be complex and time-consuming. Also, the visual merger of labels with other map elements makes it difficult to differentiate. As a consequence of their heterogeneity due to varying manufacturing eras, different authors and drawing styles, old maps drawn by hand have considerable limitations regarding their machine readability. Besides these consequences of manual production, also technical challenges become apparent such as the age of the maps themselves or such arisen from scanning (e.g., blurring or pseudocolor), inducing a low image quality (Leyk and Boesch 2010). Though visually appealing, limitations of historical maps must be mentioned and considered as well.

Nevertheless, Field's (2018) statement coincides with the results of the study presented in Sect. 4 that historical maps are generally favored over current ones when only considering their esthetic point of view. This may be explained not only by nostalgic or fashion-oriented reasons, but also by major efforts needed in intellectuality and time for the production of maps in earlier times. People still have a high degree of confidence in ancient maps. Unlike today, maps used to be powerful instruments for the communication of meanings in the past. Nowadays, various maps may be produced and disseminated in a minimum of time—regardless of their validity.

For the reverse process—making maps representing spatial information on historical circumstances in a current style—a majority is found solely on a very large scale or seen as artistically playful. However, series of unified representations of the spatial development of antique cities such as Rome, Athens, or Jerusalem over various centuries are often seen in common school atlases (e.g., "Rom—Antike Metropole—Bauwerke" (n.d.), W.W. Norton and Company Inc. (2010)).

Aiming at the comparison between contemporary geodata and historical counterparts, various existing tools and approaches are known and applied by different users. One of the most common, but also most time-consuming methods is placing georeferenced historical maps on top of current satellite imagery or vector data—occasionally including functions to define different levels of opacity. The geoportals of Klokan Technologies GmbH (2017), of the *Archives nationales de Luxembourg & Musée d'Histoire de la Ville de Luxembourg* (n.d.) or of various municipal administration agencies are only a few following this approach.

In terms of city maps, a common way to compare corresponding geographic features or locations, but different cartographic styles are so-called side by side viewers. One example is provided by the National Library of Scotland (n.d.b): official topographic maps from England are placed side by side with scanned and georeferenced equivalents from former times and synchronized with another, while users pan one of the maps (O'Brien 2014).

Other overlay methodologies are suggested by sliding map comparisons of the University of Minnesota (n.d.) (see Fig. 2, left) or virtual and interactively moveable magnifying glasses showing historical map extracts on the base of their current counterparts [e.g., National Library of Scotland (n.d.a) (see Fig. 2, middle) and Geiling and Esri (2013)]. A superimposed printing of identical city map sections at the present time on one hand, as well as from 1800 on the other hand, was produced on behalf of the Landesbetrieb

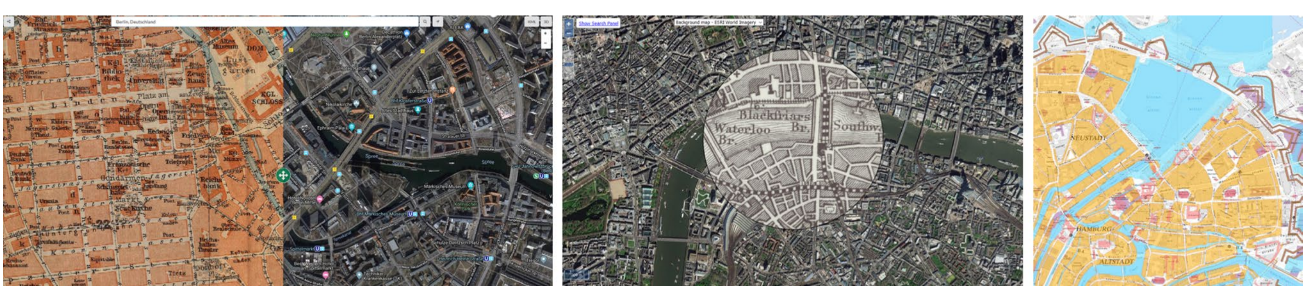

Fig. 2 Existing tools to compare historical with current geodata by the University of Minnesota (n.d.) (left), the National Library of Scotland (n.d.a) (middle), and the Landesbetrieb Geoinformation und Vermessung Hamburg (2014) (right)

Geoinformation und Vermessung Hamburg (2014) (Fig. 2, right).

Further attempts on automated style conversion between various maps have already been made. Neural networks, as used, for instance, in self-controlled image tagging or user-specific product recommendations, could be used for an image classification with the help of trained images (Deshpande, 2016). This shape recognition may be implemented via decision tree, filter-based, or statistical approaches. Another possibility of unifying two map styles by interpolating their colors and line widths into average values is described by Ory et al. (2017). Besides the mentioned approaches, several others such as the modification of the data's visual portrayal via Styled Layer Descriptors and Symbology Encoding (Christophe et al. 2015, 2016) or the recognition of geometries and their spatial relationships (Gross 1994, as cited in Liu 2004) still cause problems when faced with hand-drawn lines and textures as well as overlapping features.

In terms of an effective extraction of information derived from historical maps—on various objects, real locations, or metadata—research is overdue. None of the aforementioned approaches considers a transfer or derivation of any kind of ancillary information. Especially, suggestions for a universal approach are missing so that an interoperability between different map styles cannot be given yet (Budig and van Dijk 2015; Christophe et al. 2016). Also, Field (2018, p. 323) confirms that "[…] replicating a[n] historical map with up-to-date information is an entirely valid approach". However, existing algorithms for extracting semantical information from bitmap images like historical maps are insufficient. An optimal balance between different ways of representation of maps needs to be achieved (Budig and van Dijk 2015; Christophe et al. 2016; Leyk and Boesch 2010). Setting out a framework to meet these challenges represents a further major objective addressed in Sect. 5.1 of this paper.

3 Terminology

3.1 Historical Maps

As different interpretations exist, a historical map in this paper describes a reduced and simplified representation of early geographic characteristics and structures produced in the past (based on Hake et al. 2002).

The boundary between the aforementioned and current maps is frequently drawn around the year 1850 (own evaluation, see Sect. 4.3). This estimation may be traced back to major developments in the fields of mathematics and technology in the late 19th century. At that time, cartography profited from innovative methods in terms of accuracy such as the triangulation using theodolites (Thompson 2017).

The term 'historical' is described with reference to past events or phenomena as well as to reproductions in historical presentations by different dictionaries such as The American Heritage dictionary of the English language (Historical 2018) and Merriam-Webster (Historical n.d.). Hake et al. (2002) characterize maps from former times generally by a great age and obsolescence. These are often replaced by newer, edited versions and adapted to a modern way of presentation. A more blurred boundary between historical and current maps must therefore be assumed.

3.2 Semiology

In this study, 'semiology' is referred to as the sum of visual variables to be perceived, recognized, and differentiated by an observer of a map (Ory et al. 2017). To visually match geographic features between historical and current maps, semiology is considered crucial in terms of this project.

Besides an appropriate structure, scale, and generalization, it is also its graphical representation contributing to an intuitive understanding of a map. The latter mainly consists of graphical elements (points, lines, and polygons) as well as composite signs (signatures, halftones, diagrams, and fonts) representing coded information. Variations in graphical (Hake et al. 2002) or rather visual variables (Slocum et al. 2009) being applied to a map's graphical representation serve not only an esthetic purpose, but also enable the differentiation of qualitative and quantitative contents (Roth 2017).

According to Bertin (1973), visual variables in cartography are limited to size, shape, texture, orientation, location, color value (brightness), and hue. Morrison (1974) additionally suggests color saturation and arrangement. Due to missing variables concerning uncertainties, MacEachren (1995) supplements crispness, resolution, and transparency (Hake et al. 2002; Roth 2017; Slocum et al. 2009).

Geographic features are represented by one or more visual variables. For a unique distinction and differentiation of cartographic content, visual variables such as the color black for buildings or rails, green for vegetation, or blue for water bodies are utilized (Hake et al. 2002; Larcher and Piovan 2018; Ory et al. 2015). In the special case of historical maps, water bodies for instance are often depicted with parallel dashed lines decreasing in their proximity and stroke width with an increasing distance as seen from the shore (Huffman 2010).

4 User Study

4.1 Aim

With the aim of analyzing present needs and requirements, a user study concerning the comparability between historical and current maps was conducted. Considering the following key questions, a statistical evaluation was performed:

- What are the major challenges in historical maps and their comparison to current counterparts (see Sect. 4.3.1)?
- What are the most common topics in such comparison processes (see Sect. 4.3.2)?
- Which explicit map types are (not) suitable for common tasks the users are confronted with in their everyday work? Which semiological characteristics are stated (not) being suitable regarding these tasks for each map type (see Sect. 4.3.3)?

In terms of contents, the focus in this study is on geospatial information most comparable to topographic city maps, both for recent and ancient analogs. Besides an inquiry for general challenges with historical maps and their comparison with current counterparts, explicit topographical maps representing the city of Hamburg were examined concerning their readability as well as the users' intuition regarding semiological characteristics.

4.2 Setup

As the interpretation of and between historical and current maps depends on different experiences from various user groups (Groupe µ 1992, as cited in Ory et al. 2015), 58 German archivists, librarians, historians, urban researchers, publishers, curators and similar experts were asked for survey participation. Due to the specified requirement of a regular study of historical as well as current geodata, they were deliberately selected. The interviewed target group should therefore be able to read, perceive, and interpret this data.

A pencil and paper questionnaire including brief instructions was delivered to the respondents by mail. In total, 22 questions were formulated as predominantly closed and semi-open questions. Only few open questions are included in the survey. This choice was made to enable a number of qualitative evaluations in addition to a quantitative analysis of results.

4.3 Results

After completion of the survey, a response rate of 57% ($n = 31$) was achieved. All gained information was anonymized, standardized and stored in a database to facilitate a statistical evaluation. Due to the small sampling and further non-response, a representativity in terms of demography (such as age, gender, and occupation group) was not possible. As the actual participant group corresponds to the desired user group selected by purposive sampling, demographic criteria are not of primary importance.

4.3.1 Challenges with Historical Maps and Their Comparison with Current Counterparts

In juxtaposing historical with current maps, distinct objects represent frequent challenges considering their identifiability and comparability as well as the derivation of further information. All respondents have been faced with these difficulties at least once in their work routine. In this context, an important reason mentioned by some of them are distortions caused by cartographic processes or regarding the presented state of reality. For half of them, these difficulties are due to great semiological varieties.

To facilitate the technical effort, 20% of interviewees use web tools such as Klokan's Georeferencer (Klokan Technologies GmbH 2017) or similar map viewers to georeference, overlay, or view maps side by side. Even more respondents manage with Desktop-GIS (37%) or related tools and methods such as image processing software or they meet their needs for an analog comparison (40%). Among the different user groups, librarians, archivists, and historians rarely make use of existing tools and software for a comparison between historical and current maps. Instead, especially librarians prefer using historical paper maps in combination with printed or digital, georeferenced maps representing a current urban image (see Fig. 3). Whereas one quarter of the surveyed librarians compared spatial data with each other, even none of the archivists do so.

Digital and georeferenced data on present circumstances are used almost exclusively by map experts such as cartographers. They utilize this for a juxtaposition with analog, digitized, as well as georeferenced historical data.

4.3.2 Content of Map Comparisons

Regarding the content, more than half of the respondents stated that they regularly (at least once a month, see Fig. 4) compare certain geoobjects—more precisely buildings and roads—between historical and current equivalents. As these two object types make up a rough urban structure, they seem to be the most relevant features for the majority of respondents. On the contrary, changes of water or vegetation areas over time as well as accompanying texts are of minor interest. In the following course of this project, a focus will therefore be placed on the semiological characteristics of buildings and roads as well as on their context within the urban structure.

4.3.3 Different Semiological Characteristics for Different Tasks

With the aid of explicit examples—both showing historical and current maps—the interviewees were asked for the most appropriate representations concerning various common

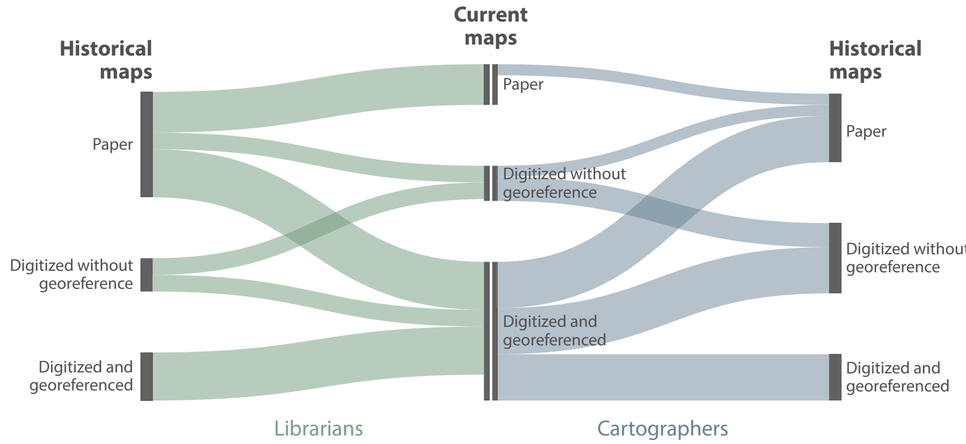

Fig. 3 Share of resources used for both historical and current maps for their mutual comparison by librarians (left) and cartographers (right)

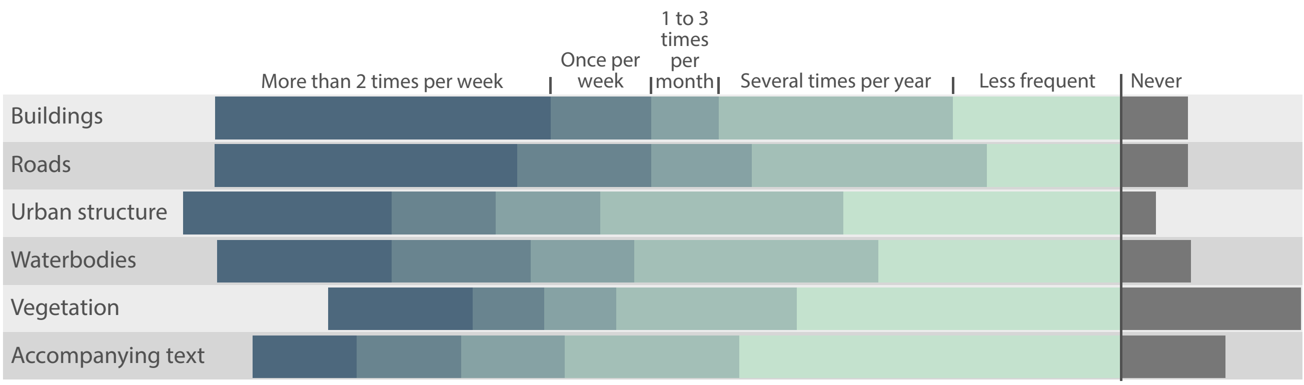

Fig. 4 Interviewees' frequencies (relative) of comparing specific features, structures, or content between historical and current maps

tasks (see Fig. 5). The tasks include the identification and the differentiation of geographic features such as buildings, roads, water bodies, and vegetation, as well as the visual recognition of an urban structure.

Among current maps, a generally high suitability of the representation of OpenStreetMap is noticeable (see Fig. 5, example 1). According to the study participants, it represents the most appropriate map for all mentioned tasks except the identification and differentiation of buildings. Color composition as well as the line width constitutes the deciding factors for a quick and intuitive identification of streets, water bodies, and vegetation and, in particular, for distinguishing different types of roads.

Against expectations, this choice does not seem to depend on users' habits or the familiarity with map services: unlike the presentation of OpenStreetMap, Google Maps performs poorly for each of the mentioned tasks (Fig. 5, example 5). Instead, a local map design emerged as the most efficient concerning the identification of buildings and their distinction between different types (Fig. 5, example 2). In this map, differing building types are represented by varying texture patterns; furthermore, public buildings clearly differ from others in color. Labels indicating house numbers or abbreviations, to designate, for instance, public institutions, appear to be a key component for an intuitive recognition of map features. Besides labels, textures as well as the color composition of geometries can therefore be seen as major semiological elements enhancing the recognition of different objects in maps.

Also among the historical maps shown in Fig. 5 (examples 6–9), the applicability of one representation is salient. Being the only colored historical map, the color composition of example 6 represents the most appropriate semiological component facilitating the perception of different geoobjects. Although it might seem that solely water bodies differ substantially from other features due to their divergent color hue, color composition is also considered to be applicable for the identification and differentiation of buildings and roads. For buildings, the variance of color values seems to be crucial, whereas the decisive factor for roads may be solely determined by the high-contrast overall presentation of the map. As the presented historical maps—apart from example 6—are grayscale images, the perception of their geoobjects based on color composition is correspondingly considered minimal.

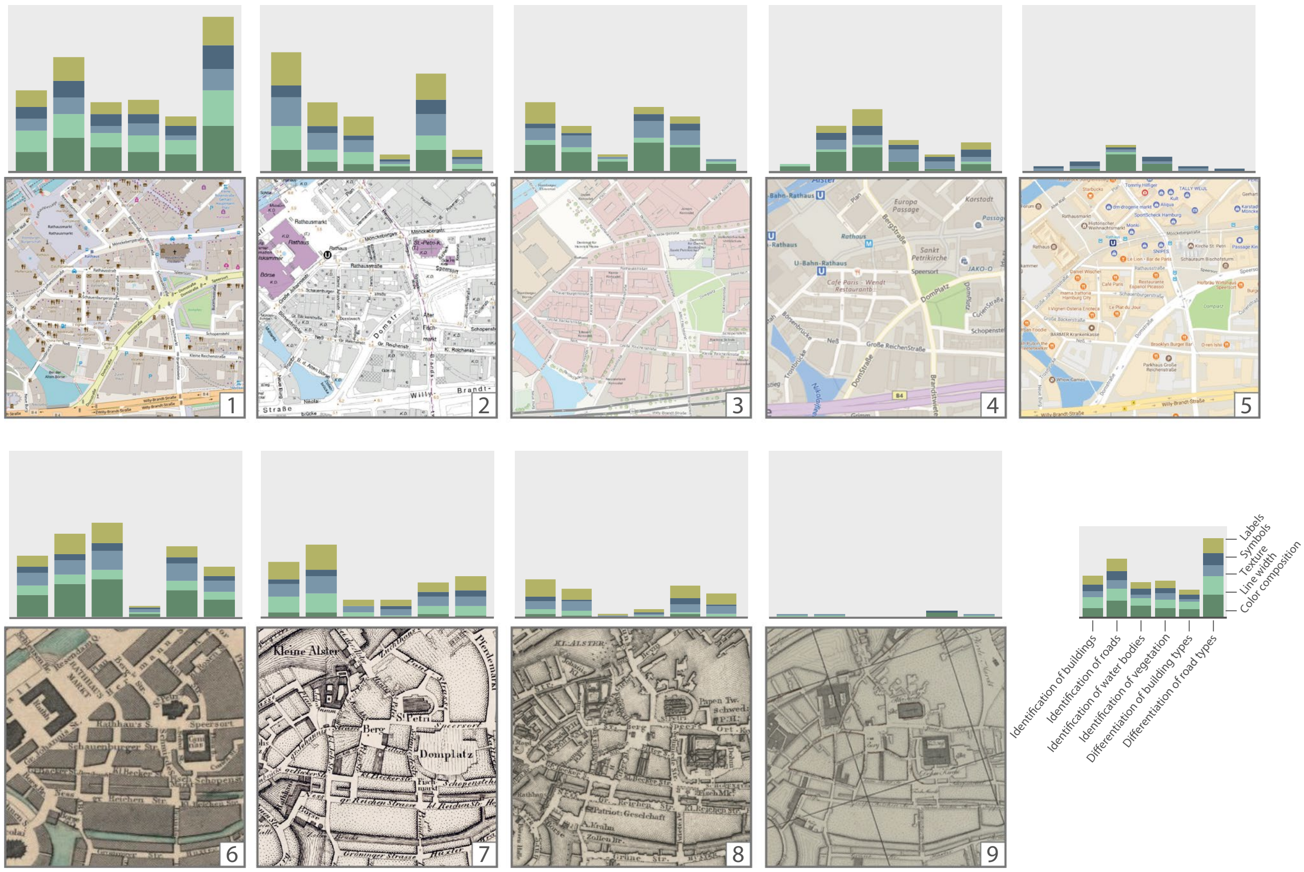

Fig. 5 Map examples of current (top) and historical (bottom) maps shown in the user study for an evaluation of their applicability with respect to the identification of buildings, roads, water bodies, and vegetation, as well as to the differentiation of building types and road types in consequence of color composition, line width, texture, symbols, and labels (see diagrams). Top, from left to right: (1) OpenStreetMap contributors; (2) Freie und Hansestadt Hamburg; (3) Esri et al.; (4) ©2018 Microsoft Cooperation ©2018 HERE; (5) ©2018 GeoBasis-DE/BKG (©2009); Bottom, from left to right: (6) Harvard University (n.d.); (7) Terstegge (n.d.); (8) Europeana (n.d.); (9) © SLUB/Kartensammlung (2018)

According to the majority of interviewees, the applicability of map example 7 for the identification of buildings is comparable to the one of example 6. Contributing to a high degree of recognizability of roads in the case of example 7 are rather the labels than the color composition. Furthermore, differences in textures (e.g., between parallel and contour hatching, stippling, and blending) and line widths are mentioned for an intuitive recognition of buildings and streets in map examples 6–8 of Fig. 5.

However, in examples 7–9, the perception of water bodies as well as vegetation is hardly feasible as related familiar semiology is not assigned. According to human intuition, visual variables such as the color green standing for vegetation and blue for water bodies usually serve to identify the appropriate features. This conclusion is also supported by the lack of color for vegetation areas in map examples 2 and 6 in Fig. 5.

As can be seen from example 9 of Fig. 5, an unintuitive representation preventing recognizing and distinguishing map features may be induced by overlaying grids, missing contrast throughout the entire map, as well as insufficient labels.

With the aim of explaining a relationship between one dependent (e.g., identifying buildings) and several independent variables (color composition, line width, texture, symbols, and labels), a logistic regression analysis was performed. As results vary considerably, a general statement cannot be made regarding the impact of visual variables on the probability that one of the mentioned tasks can be performed intuitively.

4.4 Summary

By conducting a first needs assessment among appropriate user groups, major challenges in working with historical maps could be identified. Also, considerable difficulties regarding the comparison process between historical and current maps were presented in detail.

Firstly, besides perspective distortions or unrealistic presentations, variations in semiology make it difficult to distinguish between map objects. To collate former and present buildings and roads, the overall appearance of a map seems to have a major impact. While contrasting color values best serve for demarcating vegetation areas and water bodies, additional textures may be helpful to distinguish buildings, roads, and their particular types. Labels designating various map features seem to be advantageous for their intuitive recognition predominantly in colorless maps. The distinction of map objects such as buildings, roads, vegetation areas, and water bodies does not appear to depend on a map's familiarity, but rather on the awareness of visual variables being assigned to corresponding objects.

A second lesson—according to actual users such as archivists, librarians, historians, urban planners, cartographers, and geographers—is a current lack of helpful tools and instruments for an intuitive comparison between historical and current maps.

5 Future Research and Conclusion

5.1 Derived Project Concept for Further Investigations

Existing concepts solely considering partial aspects of the defined problem area (see Sect. 2) shall be optimized to provide a possible holistic solution. Appropriate approaches to facilitate the comparison process between historical and current maps are suggested in this section. These will be examined and implemented in the further course of the overall project.

With the aim of making historical geodata as editable and applicable as its current counterpart, several methods for *feature extraction and classification* may be applied in a first stage. As a result, geometric shapes (especially lines and polygons) can be derived from a historical map and assigned to different feature classes (e.g., roads and buildings as well as their subgroups), thus improving the information content compared to the original bitmap image.

- Similarly to the procedure with satellite imagery, *image segmentation* may be used to separate a bitmap image into patches having internally consistent properties (e.g., in size, shape, and texture). An object-based image analysis even considers adjacent pixel values to generate and classify map features into buildings, roads, vegetation areas, and water bodies based on predefined rules (Lobo 2018). A previous filtering process may be useful to reduce noise and stains which frequently exist in historical maps.
- *Corner detectors* such as the Harris corner detector further enable the identification and distinction of plain surfaces, edges, and corners and therefore detect geometric features in bitmap images. One advantage of the Harris detector is its independence of scale and orientation of individual features (Collins n.d.). Further testing is required to determine individual parameters.
- In decision tree-based approaches, fuzzy classifiers contribute to vectorization processes in the course of *shape recognition*. Based on its adjacency to others, the average belonging of a curve segment can be estimated and assigned to classes representing lines, ellipses, or curves (Liu 2004, as cited in Chen and Xie 1996).
- For detecting textures of map features, *pattern recognition* appears to be useful. The approach of local binary pattern, for instance, enables the description of textural characteristics of a pixel's surface in an image. By applying Gabor filters, differences between neighboring pixels and thus between textures can be detected (Prakasa 2016).

Instead of performing visual analyses, *similarity measures* regarding the equality of objects between historical and current maps may be used for a matching process. With the help of this statistical correlation analysis, map objects are divided into elementary geometries representing nodes in a graph model. In combination with their relations to each other and depending on the relative distance, the most similar objects may be determined and assigned (Liu 2004, as cited in Li et al. 2000; Lladós et al. 2001; Peng et al. 2003).

Finally, the *generation of a spatial database* is desirable to assign former urban images and geoobjects to current ones.

In the further course of the project, a generic approach will be pursued, thus avoiding restrictions in existing solutions such as the unique applicability due to colored geometries or high-contrast contours. To further reduce limitations (see Sect. 2), an initial noise reduction—originating from, e.g., hand drawings or scanning processes of historical maps—to a minimum promises an enhanced readability of historical maps and will therefore be pursued.

5.2 Conclusion

With the aim of improving the comparison between historical and current maps, this project addresses a wide spectrum of challenges which users have to face in their daily working routine. The main issues have been identified with the help of a user study.

Visual variables have a significant impact on the identification and differentiation of map objects. The homogenization of the diverse visual variables of maps (made by varying authors applying different production methods in different eras) is supposed to improve users' former comparing processes. Color was found to be the variable most appropriate for an intuitive detection of vegetation and water areas. Texture, however, turned out to be suited for identifying and differentiating buildings and roads. These findings ought to be investigated in further research.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

©2018 GeoBasis-DE/BKG (©2009), Google

©2018 Microsoft Cooperation ©2018 HERE, Microsoft product screen shot reprinted with permission from Microsoft Corporation

Archives nationales de Luxembourg & Musée d'Histoire de la Ville de Luxembourg. (n.d.). Mapping Luxembourg. http://www.mapping-luxembourg.lu/view/index.html. Accessed 20 Sept 2018

Beconytè G (2011) Cartographic styles: criteria and parameters. In: Ruas A (ed) Proceedings of the 25th international cartographic conference (ICC 2011). Paris, France

Bertin J (1973) Graphische Semiologie. Diagramme, Netze, Karten. In: Jensch G, Schade D, Scharfe W (eds) Translated from the 2nd French Edition, 2nd edn. De Gruyter, Berlin

Bildungshaus Schulbuchverlage & Westermann Schroedel Diesterweg Schöningh Winklers GmbH (Eds.). (n.d.). Rom—Antike Metropole—Bauwerke. https://www.diercke.de/content/rom-antike-metropole-978-3-14-100870-8-141-4-2 Accessed 26 September 2018

Budig B, van Dijk TC (2015) Active learning for classifying template matches in historical maps. In: Japkowicz N, Matwin S (eds) Discovery science. 18th International conference, vol 9356. Springer, p 33–47

Christophe S, Hoarau C, Boulanger L, Turbet J, Vanderhaeghe D (2015) Automatic rendering of a Cassini style. In: 27th International cartographic conference

Christophe S, Duménieu B, Turbet J, Hoarau C, Mellado N, Ory J, Loi H, Masse A, Arbelot B, Vergne R et al (2016) Map style formalization: rendering techniques extension for cartography. In: Bénard P, Winnemoeller H (eds) Expressive 2016 the joint symposium on computational aesthetics and sketch-based interfaces and modeling and non-photorealistic animation and rendering. The Eurographics Association, pp 59–68

Collins R (n.d.) Lecture 06: Harris corner detector (powerpoint slides). http://www.cse.psu.edu/~rtc12/CSE486/lecture06.pdf. Accessed 14 Dec 2018

Deshpande A (2016) A beginner's guide to understanding convolutional neural networks. https://adeshpande3.github.io/A-Beginner's-Guide-To-Understanding-Convolutional-Neural-Networks. Accessed 7 August 2017

Esri, DeLorme, HERE TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia and the GIS User Community

Europeana (n.d.) Plan von Hamburg, 1:11 000, Lithographie, 1834

Field K (2018) Cartography, 1st edn. Esri Press, Redlands

Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung, veröffentlicht unter der Datenlizenz Deutschland—Namensnennung—version 2.0 (https://www.govdata.de/dl-de/by-2-0), https://registry.gdi-de.org/id/de.hh/2AE6D23E-48A5-4D85-BC0A-160737E0C8D2

Geiling N, Esri (2013) What did San Francisco look like in the mid-1800s? Smithsonian.Com. https://www.smithsonianmag.com/history/what-did-san-francisco-look-mid-1800s-180947904. Accessed 21 September 2018

Groupe µ (1992) Traité du signe visuel. Pour une rhétorique de l'image. Paris: Seuil

Hake G, Grünreich D, Meng L (2002) Kartographie. Visualisierung raum-zeitlicher Informationen, 8th edn. Berlin; New York: de Gruyter

Hall M (2016a) Map of modern London inspired by John Rocque. https://www.behance.net/gallery/45230883/Map-of-modern-London-inspired-by-John-Rocques-1746-map. Accessed 19 Sep 2018

Hall M (2016b) Maps of Glasgow for Denise Mina's "The Long Drop." http://www.thisismikehall.com/maps-of-glasgow. Accessed 19 Sep 2018

Harvard University (n.d.) Harvard Map Collection, Harvard College Library. Hamburg, drawn under the direction of Willm. Lindley, Esqr. C.E. April 1841; engraved by B.R. Davies, G6299_H3_1853_L5_3302414041

Historical (2018) In The American Heritage dictionary of the English language, 5th edn. https://ahdictionary.com/word/search.html?q=historical. Accessed 8 Oct 2018

Historical (n.d.) In Merriam-Webster. https://www.merriam-webster.com/dictionary/historical. Accessed 8 Oct 2018

Huffman DP (2010) On waterlines: arguments for their Employment, Advice on their Generation. Cartogr Perspect 66:23–30

Kay S (2016) Edinburgh 2016, mapped in the style of early 1900s Ordnance Survey maps. https://www.flickr.com/photos/stevefaeembra/31246139421/in/pool-qgis. Accessed 19 Sept 2018

Klokan Technologies GmbH (2017) Georeferencer. http://www.georeferencer.com. Accessed 20 Sept 2018

Landesbetrieb Geoinformation und Vermessung Hamburg (2014) Hamburg einst und jetzt. Das historische Kartenbild der Innenstadt maßstabgerecht dargestellt auf dem Grundriß der Gegenwart. In: Facklam F, Fleischhauer CO (eds). Verein für Hamburgische Geschichte

Larcher V, Piovan S (2018) The use of colours in historical atlases. Cartographica Int J Geogr Inf Geovis 53(2):115–128

Leyk S, Boesch R (2010) Colors of the past: color image segmentation in historical topographic maps based on homogeneity. GeoInformatica 14(1):1–21

Li C, Yang B, Xie W (2000) On-line hand-sketched graphics recognition based on attributed relation graph matching. In: Proceedings of the 3rd world congress on intelligent control and automation, IEEE, pp 2549–2533

Liu W (2004) On-line graphics recognition: state-of-the-art. In: Lladós J, Kwon YB (eds) Graphics recognition. Recent advances and perspectives. 5th International Workshop, GREC 2003. Springer, p 291–304

Lladós J, Martií E, José J (2001) Symbol recognition by error-tolerant subgraph matching between region adjacency graphs. In: IEEE transactions on pattern analysis and machine intelligence, vol 23. IEEE, p 1137–1143

Lobo A (2018) Testing OTB segmentation methods. Talk at the OTB user day 2018, Montpellier, France. https://gitlab.orfeo-toolbox.org/orfeotoolbox/otb/wikis/uploads/45755e7d4fabf2b5d4613308f62bd244/3-alobo_otb2018.pdf. Accessed 14 Dec 2018

MacEachren AM (1995) How maps work. Guilford Press, New York

Morrison JL (1974) A theoretical framework for cartographic generalization with the emphasis on the process of symbolization. Int Yearbook Cartography 14:115–127

National Library of Scotland (n.d.a) Explore Georeferenced maps—spy viewer. View historic mapping within a spyglass circle. https://maps.nls.uk/geo/explore/spy/#zoom=5&lat=56.0000&lon=-4.0000&layers=1&b=1&r=30. Accessed 21 Sept 2018

National Library of Scotland (n.d.b) Side by side georeferenced maps viewer. https://maps.nls.uk/geo/explore/side-by-side. Accessed 21 Sept 2018

Nelson G (2016) Recreating historic maps: interview with Christopher Wesson (blog post). The Official OS Blog; for everything geography, GI and Mapping. https://www.ordnancesurvey.co.uk/blog/2016/06/recreating-historic-maps-interview-with-christopher-wesson/?utm_medium=social&utm_campaign=SocialSignIn&utm_source=Twitter. Accessed 2 June 2018

O'Brien O (2014) London, 100 years ago (blog post). http://mappinglondon.co.uk/2014/london-100-years-ago 21 Sep 2018

Ory J, Christophe S, Fabrikant SI (2013) Identification of styles in topographic maps. In: Buchroithner M, Prechtel N, Burghardt D, Pippig K, Schröter B (eds) The 26th international cartographic conference, p 183

Ory J, Christophe S, Fabrikant SI, Bucher B (2015) How do map readers recognize a topographic mapping style? Cartographic J 52(2):193–203

Ory J, Touya G, Hoarau C, Christophe S (2017) How to design a cartographic continuum to help users to navigate between two topographic styles? In: Proceedings of the international cartographic conference ICC 2017

OpenStreetMap contributors, licensed under the Open Data Commons Open Database License (ODbL) by the OpenStreetMap Foundation (OSMF)

Peng B, Sun Z, Liu W, Cong L (2003) Dynamic user modeling for sketchy shape recognition. In: Proceedings of GREC 2003, p 355–365

Prakasa E (2016) Texture feature extraction by using local binary pattern. INKOM J 9(2):45–48

Roth RE (2017) Visual variables. In: Richardson D, Castree N, Goodchild MF, Kobayashi A, Liu W, Marston RA (eds) International encyclopedia of geography: people, the earth, environment and technology. Wiley, Hoboken, pp 1–11

Slocum TA, McMaster RB, Kessler FC, Howard HH (2009) Prentice Hall series in geographic information science. In: Clarke KK (ed) Thematic cartography and geovisualization, 3rd edn. Pearson Education, Upper Saddle River

© SLUB/Kartensammlung (2018) published under Creative Commons Namensnennung. http://www.deutschefotothek.de/documents/obj/90008382. Accessed 31 May 2018

Terstegge C (n.d.) 1834, von Johannes Ludwig Semmelrahn. http://christian-terstegge.de/hamburg/karten_hamburg/files/1834_semmelrahn_600dpi.jpeg. Accessed 14 Dec 2018

Thompson C (2017) From ptolemy to GPS, the brief history of maps. Smithsonian.Com. http://www.smithsonianmag.com/innovation/brief-history-maps-180963685. Accessed 7 August 2017

University of Minnesota (n.d.) Mapjunction. https://www.mapjunction.com/index.html?id=/9214. Accessed 21 Sept 2018

Wellingtons Travel Co. (2017) A map in the reign of Queen Elizabeth II. https://www.wellingtonstravel.com/hand-drawn-map-of-london.html. Accessed 19 Sept 2018

W.W. Norton and Company Inc (2010) The civilization of ancient Rome. Interpreting the Visual Evidence. http://www.wwnorton.com/college/history/western-civilization17/ch/05/visual-evidence.aspx. Accessed 26 Sept 2018