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Georg Gartner
Markus Jobst
Haosheng Huang *Editors*

Progress in Cartography

EuroCarto 2015

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ISSN 1863-2246 ISSN 1863-2351 (electronic)
Lecture Notes in Geoinformation and Cartography
ISSN 2195-1705 ISSN 2195-1713 (electronic)
Publications of the International Cartographic Association (ICA)
ISBN 978-3-319-19601-5 ISBN 978-3-319-19602-2 (eBook)
DOI 10.1007/978-3-319-19602-2

Library of Congress Control Number: 2016939931

Printed on acid-free paper

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The registered company is Springer International Publishing AG Switzerland

Preface

Europe has a rich and long history in cartography. Many important improvements in mapping and cartography have been proposed and performed by cartographers and researchers of that region. The long and outstanding history has led to a lively and vivid presence. In recent years we have seen many innovative methods, technologies and applications being developed to depict, communicate, and analyze the earth and its natural and social aspects.

In response to these rapid advances, the first ICA European Symposium on Cartography (EuroCarto 2015) was organized in Vienna (Austria) in November 2015. It aimed to bring together cartographers, GI scientists, and those working in related disciplines to exchange and discuss contemporary developments, research, and results in modern cartography. EuroCarto 2015 was endorsed by the International Cartographic Association (ICA), the Austrian Cartographic Commission of the Austrian Geographic Society, and UN-GGIM: Europe (the regional committee of the global United Nations activities on Geoinformation Management). The event was organized by the Research Group Cartography of Technische Universität Wien (TU Wien). In total, more than 200 scientists from 32 countries participated in the conference.

The symposium featured a keynote from the current ICA president Prof. Menno-Jan Kraak, 77 oral presentations and 29 poster presentations, covering all major aspects of modern cartography. A selection of fully reviewed papers is included in this book and in a special issue of the International Journal of Cartography, and is meant as a mirror of the wide range of activities in the realm of modern cartography in Europe. These contributions reflect especially the contemporary areas of interest in cartography including cartographic modeling and design, spatial analysis and geovisual analytics, cartographic technologies, cartographic heritage and education, as well as application development.

We would like to thank all symposium participants for their active involvement, all authors for their excellent work, and all referees for their critical and constructive reviews. We also appreciate the professional help of Manuela Schmidt, Florian Ledermann, Wangshu Wang, Alice Rühl, Natalia Ipatow, Manuela Stögerer, Maja Pavlin, Violet Derman, and Edith Wandl during the symposium.

Vienna, Austria
March 2016

Georg Gartner
Markus Jobst
Haosheng Huang

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The production of this book would have not been possible without the professional help of our scientific committee. We would like to thank all the following experts who have helped to review the papers published in this book.

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Contents

Part I
Cartographic Modelling and Design

A Displacement Method for Maps Showing Dense Sets of Points of Interest

Sarah Tauscher and Karl Neumann

Abstract In the past, point data only play a minor role in map generalization, as points are either already the result of generalization or are used for objects which are only shown on large scale maps. Now, with the growing availability of web mapping services the role of point data has changed: Besides route planning, the most common function of web maps is the visualization of user queries for points of interest. The limited size of commonly used displays often results in a smaller scale as would be appropriate for the maps content. The state of the art to resolve occurring cluttered point sets, is on the one hand interactivity and on the other hand the selection of points. Thus, often the available space is not optimally used. Therefore, we propose a displacement method to improve the readability of dense sets of points of interest.

Keywords Displacement · Point symbol · Voronoi diagram

1 Introduction

Nowadays the use of web mapping services to present search results for points of interest (POIs) or to create maps showing the locations of personally relevant places, e.g. favorite places of one's last holiday, is a matter of course. Most often the locations are marked by uniform symbols, but the web mapping services also support the use of different customized symbols. Due to the limited size of commonly used displays, the map scale is often smaller as would be appropriate for the maps content. The state of the art to resolve occurring cluttered point sets, is on the one hand interactivity (pan and zoom) and on the other hand the selection of points. The selection has either to be performed manually or in the case of the presentation of search results it is rather based on the rankings of the results than on spatial criteria. Thus, often the available space is not optimally used.

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_1

Fig. 1 Emblems of German cities before and after displacement (Parts of base map of Figs. 1, 6, and 10 adopted from Natural Earth)

In order to support the creation of maps, on which not only the location of important places is marked, but also other relevant information is visualized by the map symbols, a displacement is necessary which guarantees the sufficient visibility of symbols and a certain positional accuracy. Figure 1 exemplifies the potential benefit of displacement for a map with individual map symbols. It shows some German cities, which have been symbolized by their emblems. On the left side, the center of each map symbol has been placed on the coordinate of the corresponding city, whereas on the right side the symbols are displaced, but the coordinate of the city remains covered by the symbol.

Surprisingly, there is no established generalization method, which could be readily applied to this use case. The reason for this is that point data only play a minor role in map generalization, in the past. In traditional maps, points are either already the result of generalization (by symbolization) or they are used for objects which are only shown on large scale maps (e.g. real estate maps). Consequently, conflicts arise generally between point and line or areal data and not between different points. Therefore we propose a displacement method to improve the readability of dense sets of POIs, which can be easily applied to web mapping services without expecting further cartographic knowledge from the user.

The rest of the paper is organized as follows: In Sect. 2 we summarize existing displacement methods, before we describe the method we developed in Sect. 3. In Sect. 4 some evaluation results are presented and discussed. A possibility to improve the efficiency of our proposed method for large data sets is described in Sect. 5, before Sect. 6 concludes the paper.

2 Related Work

If features on a map are too close to each other to be distinguishable, a way to resolve overlaps is to displace them. To do so there are two types of displacements methods: incremental improvements and holistic approaches.

In incremental methods often a set of predefined candidate positions is tested and either local search (Mackaness and Purves 2001) or simulated annealing (Ware and Jones 1998) are applied. Ruas (1998) proposed a deterministic greedy algorithm, which evaluates at each step the current worst conflict, which might be a side effect of a previous step and displace the involved objects. Another deterministic approach is the application of a gradient descent procedure in combination with on the fly generation of displacement actions (Lonergan and Jones 2001).

Holistic approaches process multiple map features. Mackaness (1994) applied a cluster analysis in order to detect all features which are involved in a conflict. These features are then spread radially outward from the conflict center. Thus, only the distances between conflicting objects are enlarged without distorting the topology.

Other studies formulate the problem as a system of equations that can be solved using an optimization method e.g. least squares methods (Harrie 1999; Sarjakoski and Kilpeläinen 1999; Sester 2001), finite element analysis (Højholt 2000), or by the use of snakes (Burghardt and Meier 1997).

Bereuter and Weibel (2013) utilized quadtrees in order to support real-time generalization of point data. Their algorithm reallocates points of a quadnode not satisfying cartographic proximity constraints to neighboring quadnodes.

3 Algorithm

Given are a set of geocoded POIs and their circular map symbols of a fixed size for a given scale. To guarantee a certain accuracy of the positioning, we require that the coordinates of each point are inside its corresponding map symbol. Thus, the distance between an original location and the center of its symbol is at most the radius of the symbol. The quality of the placement is measured by the sum of the areas of the intersections of all map symbols. The optimal value is zero, as it means that the symbols do not overlap at all. If different placements achieve the same value ($v > 0$), we consider the placement to be best, where the area of the largest intersection is the smallest. So the strategy is to assign a distinct area to each point, which is large enough to completely contain the symbol. In order to do so, we chose an iterative method, which applies Voronoi diagrams as auxiliary structures. The initial assignment of areas to the POIs is the Voronoi diagram of their coordinates and the center of the symbols are placed on the coordinates. Figure 2 visualizes three different cases, which have to be considered: First, the symbol already fits into the Voronoi cell. Second, the symbol overlaps with its nearest neighbor(s), but the Voronoi cell is large enough, so that the symbol could be placed completely within the Voronoi cell. Third, the Voronoi cell is too small to cover the symbol. In the latter two cases, the symbols have to be displaced and the Voronoi diagram is adapted. Then the new positions have to be evaluated again.

The method stops, if there are no more overlapping map symbols, or if no point can be moved without exceeding the given threshold (radius of the symbols), or if a given number of iterations is exceeded. So the algorithm consists basically of two

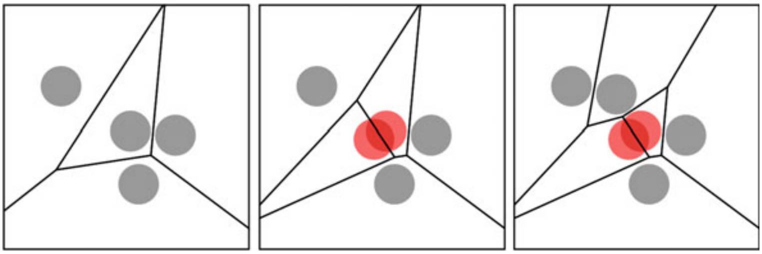

Fig. 2 Initial placement of POIs in Voronoi cells: possible constellations

nested loops (see Algorithm 1). In the inner loop new positions for all overlapping symbols are calculated and in the outer loop the Voronoi diagram is recalculated.

```
procedure displacePOIs(point set P, radius r)
    P′ ← ∅
    P″ ← P
    iter ← 0
    while (P′ ≠ P″ and iter < maxiter) do
        iter ← iter+1
        P′ ← P″
        P″ ← ∅
        vd ← calculate Voronoi diagram of P′
        for (each p ∈ P′) do
            if (symbol(p) inside vd.cell(p)) do
                P″ ← P″ ∪ {p}
            else
                P″ ← P″ ∪ {displace(p, r)}
            end if
        end for
    end while
```

Algorithm 1. Principle of point set displacement.

The quality of the displacement depends wholly on the calculation of the displacement vectors. So, as to improve the initial placement, small Voronoi cells

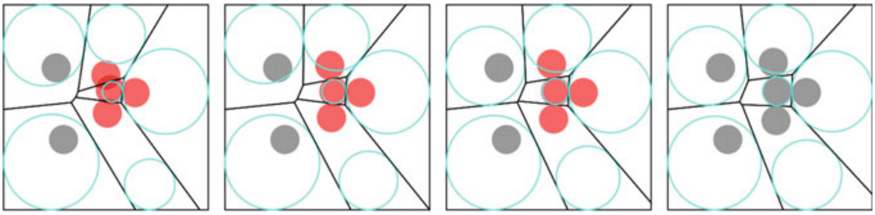

Fig. 3 Iteration one to three and final result applying heuristic (a)

(case 3) should be enlarged and the sites should be closer to the center of their Voronoi cells (case 2). In order to achieve this, we apply two alternative heuristics:

(a) Move point towards the center of a largest inner circle of its Voronoi cell (see Fig. 3). This is a greedy approach, which guarantees that the visibility of the least visible symbol is increased in every step.
(b) Move point towards the centroid of its Voronoi cell (see Fig. 4). This approach might decrease the visibility, but it is possible to overcome local optima.

If the Voronoi cells are elongated, as it is shown in Fig. 5, both heuristics will fail, because of the threshold. This problem can be avoided by restricting the Voronoi cell with a square whose edges measures two times the diameter of the symbol (see Fig. 5 right side).

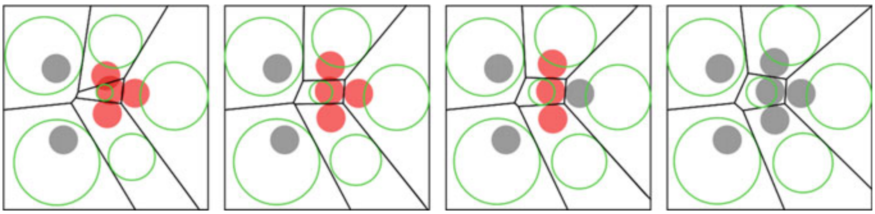

Fig. 4 Iteration one to three and final result applying heuristic (b)

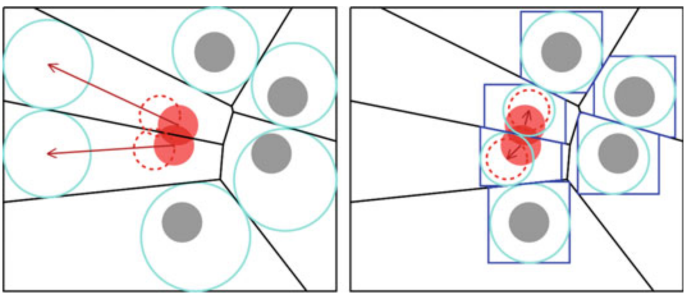

Fig. 5 Application of the threshold to the Voronoi cells

The same problem arises if the displacement result for a small scale is applied to a larger one. Although it is possible to use the displacement vector calculated for a larger scale and the radius of the actual scale to calculate a new valid position of a map symbol, the quality of the result will be decreased, as the direction of the vector is based on a larger restriction than appropriate for the actual scale. Furthermore, each symbol will be placed as far as possible from its POI. In the case that a displacement result of a large scale is applied to a smaller one, some overlaps cannot be resolved as the length of the displacement vectors is restricted according to the large scale radius.

The algorithm as presented above does not handle foreground-background constraints, as the calculation of the displacement vectors is solely based on the Voronoi diagram of the POIs. However, some constraints may easily be included by adding further restrictions that correspond to the background objects. E.g. it is possible to ensure that the center of a POIs symbol remains within the boundaries of a certain area, if the intersection of its Voronoi cell and a convex progressive approximation of the area is used for the calculation of the displacement vector. If the symbol should be completely within the area, the distance between each border point of the approximation and the nearest border point of the area has to be at least the radius of the map symbol.

4 Evaluation

We evaluated heuristic (a) with five datasets (European towns, airports, towers, hills and peaks) derived from Geonames for two different scales, thus resulting in ten test sets. We implemented our method in Java using the Java Topology Suite, an open source Java software library, to model geometries and for the calculation of Voronoi diagrams. In Fig. 6 on the left side the initial placement of symbols for one test set (airports in the smaller scale) is shown and on the right side the result of the displacement.

Table 1 gives an overview of our evaluation experiments using at most 1000 iterations. It lists the size of the point sets, the number of conflicts as well as four values concerning the visible area of symbols before and after displacement.

The results vary depending on the distribution of POIs. Hills, peaks and towers are strongly clustered whereas towns and airports are distributed more evenly across the area. As expected not only the number of initial conflicts increases for clustered data, but also the percentage of unsolved conflicts. Nevertheless the readability of map symbols is greatly improved for all test sets. Korpi et al. (2014) stated that an occlusion level of 25 % for point symbols decreases neither the accuracy nor the efficiency during map reading tasks and that an occlusion level of 50 % only effects the efficiency. Consequently, for five test sets the remaining conflicts do not decline the readability of the symbols significantly, as more than 90 % of each symbol is visible and for two test sets only the efficiency is slightly influenced. For the

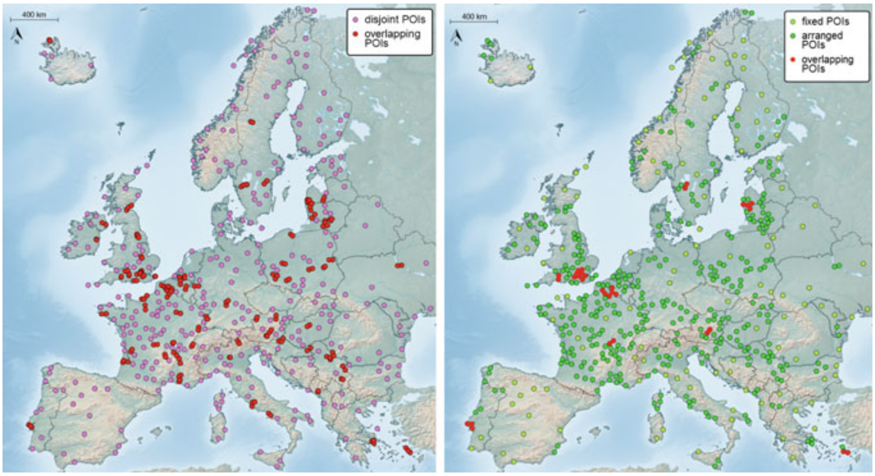

Fig. 6 Airports in Europe, initial placement and displacement result

remaining test sets the number of map symbols which are half-occluded is also reduced by more than 58 %.

Furthermore, we applied kernel density estimation to qualitatively investigate, how well the point distribution is maintained. Figure 7 shows a part of the kernel density map of the airport dataset before (a) and after (b) displacement, as well as a part of the peak dataset in (c) and (d) respectively.

After displacement the areas, where the local maxima of the densities are located, are blurred, their extents are increased and the maximum values are reduced. Nevertheless, the underlying spatial pattern is maintained.

5 Processing of Independent Subsets

One shortcoming of our method is that all POIs have to be considered in each iteration step. To improve the efficiency of our method, it would be desirable to consider only those sites which are actually occluded or might be occluded due to the displacement of other site symbols. Moreover, if the method fails, it is likely that in some areas the point set is too dense to be visualized in the given scale. So it would be beneficial to identify these areas, in order to either perform another generalization operation in advance or to give appropriate information to the user.

As the distance between a displaced symbol and its original coordinates is strictly limited, it is possible to identify fixed POIs, i.e. POIs that do not have to be displaced. Furthermore, the point set can be divided into disjoint subsets which might be processed independently. For both steps a Voronoi diagram can be used as auxiliary structure.

Table 1 Results of evaluation experiments

		Town		Hill		Peak		Tower		Airport	
Scale		1:10 m	1:5 m	1:10 m	1:5 m	1:10 m	1:5 m	1:10 m	1:5 m	1:10 m	1:5 m
# all sites		513	2050	513	2050	513	2050	513	2050	513	1435
#conflicts	Before	250	1094	425	1756	452	1823	334	1476	175	416
	After	87	277	365	1491	399	1575	224	1101	45	75
%visible area of least visible symbol	Before	4.78	1.25	0	0	0	0	0	0	0	0
	After	99.99	99.99	90.04	61.39	47.31	18.91	58.27	5.37	99.99	99.99
%visible area of symbols	Before	92.38	92.29	68.93	63.86	51.75	53.01	67.85	55.95	94.99	95.93
	After	99.99	99.99	99.96	99.47	91.51	83.10	98.17	90.21	99.99	99.99
#symbols w. visible area < ½	Before	31	92	155	714	244	976	142	808	20	33
	After	0	0	0	0	5	410	0	113	0	0
#symbols w. visible area < ¾	Before	53	244	210	1001	297	1201	191	949	28	52
	After	0	0	0	15	91	546	10	338	0	0

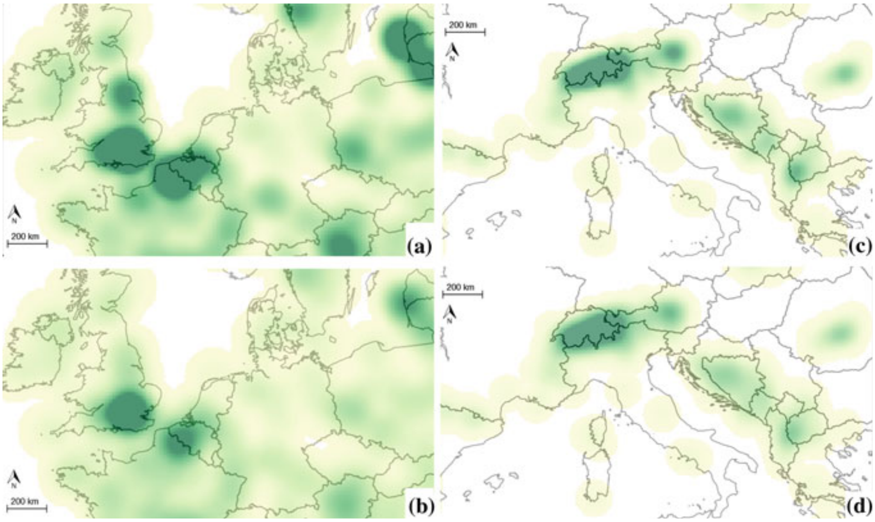

Fig. 7 Kernel density maps: airport/peak before (**a**, **c**) and after (**b**, **d**) displacement

To determine the fixed points, the distance between each POI and its nearest neighbor is calculated. If the distance is larger than two times the diameter of the map symbol, the nearest neighbor (and thus any other point) cannot be displaced in a way that it overlaps with the symbol.

To divide the point set into disjoint subsets, we calculate for each edge the distance to its two sites. If the distance is smaller than the diameter of the map symbol, the symbols might overlap after being displaced. Thus, they have to be processed in one subset and the edge cannot be used to split the Voronoi diagram and therefore is deleted. As an example for the deletions, in Fig. 8 on the left side the remaining edges of the Voronoi diagram of the airports in the smaller scale are shown. Afterwards, the diagram is recursively divided along an arbitrary path leading from one border point to another. In the first step, the border points are the intersection points of the Voronoi diagram and the clip polygon. In the following steps, the points of the path are also regarded as border points. The resulting subsets for the small scale airport test set are shown in Fig. 8 on the right side: The Voronoi cells of the original sites of each subset are filled with a different color and the Voronoi cells of fixed points are white.

In general, the complexity to find one path from one border point to another is linear to the number of edges. In our case the complexity to find all subsets is linear to the number of edges as well. The reason for this is that each edge only has to be considered once, as the following inspection of the only three possible cases, which are illustrated in Fig. 9a–c respectively, indicates:

(a) the search ends at a border point
(b) the path contains a circle (the algorithm stops as soon as it closes the circle)
(c) the path does not end at a border point, because of deleted edges

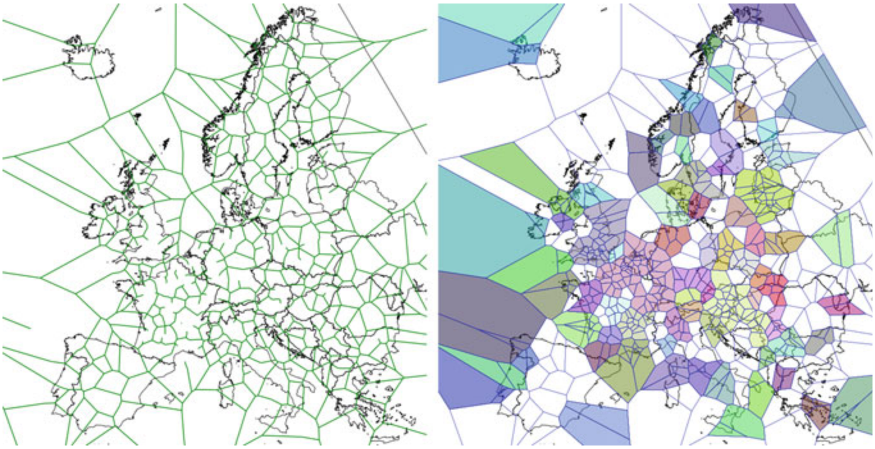

Fig. 8 Airports in Europe, Voronoi edges usable for divisions and resulting subsets

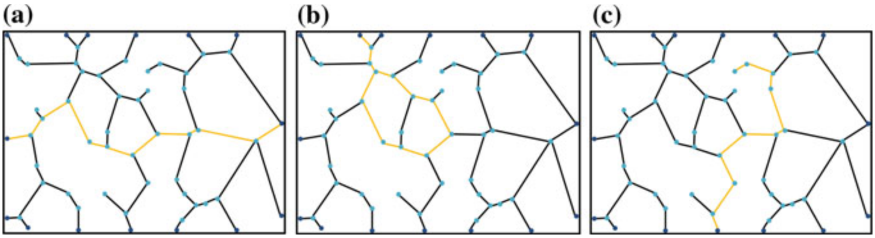

Fig. 9 Three different kinds of paths that might occur during division

In case (a) all visited edges are used to split the Voronoi diagram, i.e. only their endpoints are kept as border points for both divisions and the edges themselves are deleted. Same is true for case (b). The only difference is that the diagram is divided into the part inside and the part outside the circle instead of the part left and the part right of the path. In case (c) the subpath from the last branch to the end will be deleted, and the search continues from the last branch and then being classified again as (a), (b) or (c).

In Table 2 for each of the ten test sets (see Sect. 4) the number of fixed points as well as the minimal, maximal and average number of sites per subset is given.

As expected, the town and airport test sets can be divided into more and smaller subsets, whereas the hill and the peak test sets consists of considerably less subsets and the largest one contains roughly half of the POIs. This difference is exemplified in Fig. 10 showing the subsets for the airport and the peak test set in the larger scale.

Table 2 Characteristics of point subsets

		Town		Hill		Peak		Tower		Airport	
Scale		1:10 m	1:5 m	1:10 m	1:5 m	1:10 m	1:5 m	1:10 m	1:5 m	1:10 m	1:5 m
# all sites		513	2050	513	2050	513	2050	513	2050	513	1435
# fixed points		68	275	33	125	26	67	73	286	126	529
Divisions	#	56	203	12	58	20	66	46	157	79	217
#sites per division	min	2	2	2	2	2	2	2	2	2	2
	max	45	298	389	1492	248	1035	114	432	53	46
	avg	7.95	8.74	40.00	33.19	24.35	30.05	9.57	11.24	4.90	4.18

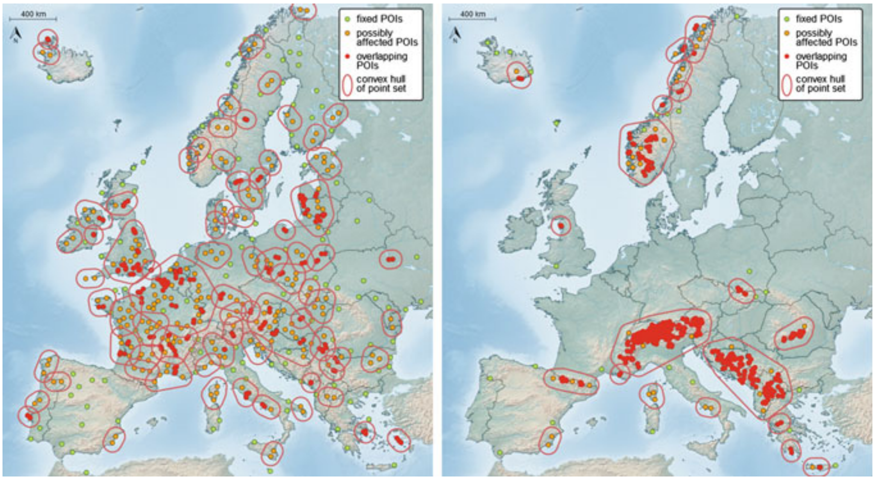

Fig. 10 Division of point sets, airports in Europe and peaks in Europe

The complexity of the algorithm is O(i*n log n), where i denotes the number of iterations and n the number of POIs. Although the complexity is not reduced, the runtime is improved due to several aspects. First, the calculation of a set of smaller Voronoi diagrams is faster than the calculation of a large one, as:

$$n \log n > \sum_{j=0}^{m} k_j \log k_j, \quad with \sum_{j=0}^{m} k_j = n$$

Second, the number of iterations to find the best solution according to our algorithm is reduced significantly for most point sets. The test set with the highest benefit was the airport data set, for which only for 9.16 % of POIs more than 10 iterations are necessary, and the least improvement was achieved for the peak dataset, for which the algorithm still iterates more than 10 times over 54.64 % of POIs.

Additionally, the division into subsets allows an easy parallelization leading to a further reduction of its runtime. Due to the iterative nature of the method on-the-fly behavior without the division into subsets is only possible for small and fixed values of i, which leads to worse displacement results. Preliminary tests show that on-the-fly behavior even for large numbers of iterations is probable, if the optimizations described above are applied. However, further investigations concerning the influence of characteristics of point sets on the runtime as well as on the quality of the displacement are needed.

6 Conclusion

In this paper we presented a method for the displacement of POIs in the context of user generated maps. In contrast to existing methods, the available space for each map symbol is modelled by cells of a Voronoi diagram. The POIs are iteratively moved within their Voronoi cell, with the objective to improve not only their visibility but also to achieve a more evenly distribution of the available space among adjoining POIs. Additionally, a threshold is introduced and directly applied to the Voronoi cells in order to guarantee a certain positional accuracy. We choose the radius of the map symbol as threshold, so that the map symbol still covers the original position of the POI. We proposed two different heuristics to determine the direction of movement of a POI and evaluated one on ten real world datasets. Moreover, we suggest a linear method to divide a point set into disjoint subsets that can be processed independently of each other. These subsets improve not only the efficiency of the algorithm, but they also allow identifying regions, which are too dense to be presented in the given scale.

The displacement algorithm can easily be adopted to handle circular map symbols of different size by using a power diagram (Aurenhammer 1987) instead of a regular Voronoi diagram. Moreover, it is possible to use our method to displace elliptical symbols more accurately than approximating them with circles as exemplified in Fig. 11. First, the transformation to convert the ellipse into a circle is determined and applied to the underlying map space. Second, the POIs are displaced by the algorithm described in Sect. 3. Finally, the inverse transformation is applied to the displacement result to restore the original map space.

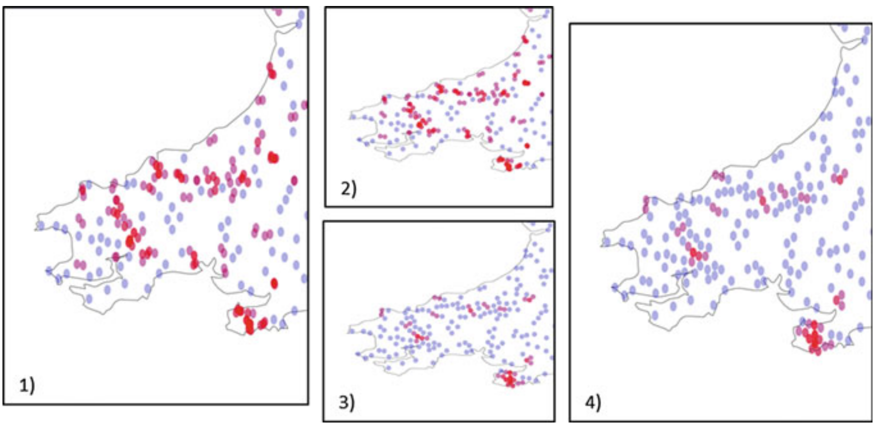

Fig. 11 Displacement of elliptical symbols. **1** Input. **2** Transformed map space. **3** Displaced POIs. **4** Restored map space

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Dynamic Cartography: A Concept for Multidimensional Point Symbols

Andrea Nass and Stephan van Gasselt

Abstract The exponential increase of acquired and managed geospatial data during the last decades, and the development of new hard- and software frameworks are two main drivers which have facilitated technological innovation in computer–animated cartography and cartographic animation (CA). In the Earth sciences cartographic animation are used for investigations, analyses and visual validation of complex settings and allow depicting a higher level of information by combining spatial data and attributes from different sources. To accomplish this, GIS technology is commonly used for processing, management and the presentation of spatial data. Despite the broad application field of GIS technology, temporal, i.e. dynamic, information is usually not covered in full depth and it remains challenging to manage and visualize such information in the same way as spatial information. Consequently, spatiotemporal data models need to be developed and adopted for each individual case by building an underlying structure which allows relating spatial geometry to cartographic as well as thematic attributes, including time. This contribution tries to discuss and establish a conceptual basis for a data model that allows connecting spatial data primitives with temporal attributes in order to manage, query and visualize the animation of map objects on a higher level.

Keywords GIS · Spatiotemporal data · Symbols · Cartographic animation

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_2

1 Introduction

Technological advances over the last decades have provided the settings for many rapid developments in the field of multimedia hard- and software (e.g. Brynjolfsson and McAfee 2012). Since then, daily life has accompanied by multimedia animation in entertainment, advertisement or in public outreach, education and science. As Nöllenburg (2007, p. 276) summarizes: “since the 1930s cartographers” have been “experimenting with map movies and animated maps”. Since the 1970s, technical environments and tools have been providing interactive visualization for information through efficient mapping of real and abstract objects and time-dependent phenomena (e.g. Friedhoff and Benzon 1989).

In the field of geoscientific research, process animation is commonly used for the visualization and exploration of temporal data, model validation and demonstration (e.g. Dransch 1997, 2014). Until today the integration of temporal data into GIS and the correlation of object changes are an open issue and require adaptations of the underlying data model, i.e. storage, management, and (carto-)graphic visualization.

In order to implement temporal changes the underlying data model has to be expanded by temporal basic types, the overall object structure requires rebuilding and graphical information needs to be implemented. This additional information level increases system complexity and the entire analysis process. Animation of thematic information does not only need an overarching concept and technical implementation of visualization techniques, but it also requires an efficient way of storing dynamic data in an underlying data structure (e.g. DiBiase et al. 1992; Harrower and Fabrikant 2008). However, the full representation of data’s temporal character has not been implemented in common off-the-shelf GI products yet (e.g. Andrienko et al. 2010). Based on these boundary conditions the higher–level aim is to develop a structural environment for storing and accessing spatial data primitives (see OGC 2011) as temporally dependent objects in a way that they can be accessed, visualized and animated by making use of spatial feature attributes.

In order to accomplish this, we here focus on the following tasks:

- Providing a brief summary about the theoretical background of map animations and variables within GI systems.
- Illustration of methods for storing and visualizing temporal objects in dynamic map animations.
- Establishing a concept for multidimensional animation of point symbols and description of the formalism on which this concept is based upon.

We here target in particular on animations that depict changes of objects through time caused by distinct processes. Here, distinct processes are actions that are defined by a distinct start and a distinct terminating event (see also Dransch 1997, 2014). Animations without temporal reference frame information, so called non-temporal animations, are not considered here. Furthermore, we here focus on point symbols which represent a generalized areal or linear object in an abstract way. While points represent the lowest level of geometry and topology they provide the highest level of abstraction, which furthermore implies that any higher level or derived object can be modelled in a similar way as well.

2 Background

This paper is concerned with a data concept that allows implementing spatial data primitives as time–dependent map objects in order to access, statistically evaluate and cartographically animate them. In order to do this, we first try to establish a connection between topical areas that are being addressed: variables (in Sect. 2.1), map animation (Sect. 2.2), and GIS and time (Sect. 2.3).

2.1 Graphical Variables

The way objects and their changing state can be displayed on a map depends on the complexity and number of attributes, and also on the level of measurement. Bertin (1983) defined the fundamental graphic variables as *size, shape, orientation, colour, pattern and value (also colour saturation)*. Beside this he proposed rules which help to describe and categorize the appropriate use of these graphical variables. Over time, it has been argued that his typology–syntactic set of graphic variables does not suffice to cover all aspects (MacEachren 1995), especially because of new advances and capabilities of computer-assisted mapping, map animation and geo–visualization. In addition to graphic variables used within static maps, "animated maps are composed of three basic design elements or dynamic variables: s*cene duration, rate of change between scenes*, and *scene order*. Dynamic variables can be used to emphasize the location of a phenomenon, to emphasize attributes, or to visualize change in its spatial, temporal, and attribute dimensions" (DiBiase et al. 1992, p. 201). Accordingly, six dynamic variables were suggested by MacEachren (2005): "(1) temporal position, i.e., when an object is displayed, (2) duration, i.e., how long an object is displayed, (3) order, i.e., the temporal sequence of events, (4) rate of change, e.g., the magnitude of change per time unit, (5) frequency, i.e., the speed of animation, and (6) synchronization, e.g., the temporal correspondence of two events" (Nöllenburg 2007, p. 268).

2.2 Cartographic Animation

Due to the interrelated nature of location, attributes and the temporal aspect, Ogao and Kraak (2002) underlined that animated maps work very well for the visual and explorative analyses of complex systems. Within cartographic animations the viewer is allowed to "deal with real world processes as a whole rather than as instances of time" (Ogao and Kraak 2002, p. 23).

For visualizing spatial data within a map as time–dependent sequence, map sequences representing individual frames (e.g. as animated Graphics Interchange Format, GIF) are commonly combined. This is demonstrated by Peuquet and Duan (1995) with the "snapshot" approach. In this concept all spatially relevant parameters are directly linked to each individual frame and temporal progression is managed by an external time line. This frame-based animation can be created within non-spatial graphic systems, mapping environments, or within GI systems. Apart from presenting map animation in such a flip-book style, other systems are capable of interpolating changing objects between two or more instances (e.g. Rase 2000; Marschallinger et al. 2006). For more background on *geo–visualization* in general see Dykes et al. (2005). A summary on the topic of *geographic visualization* is given e.g. by Nöllenburg (2007), and a general review of animated maps has been provided by Harrower (2004).

2.3 Temporal Databases in GIS

The origin of time geography can be dated back to 1970 when the concept of the space–time cube was proposed by Hägerstrand (Hedley et al. 1999). Within this concept space and time are considered as inextricable elements. "In its basic appearance the cube has on its base a representation of the geography (along the x- and y-axis), while the cube's height represents time (z-axis). A typical space–time–cube could contain the space–time paths of for instance individuals or bus routes" (Kraak 2003, p. 1988). Talking about an application of this space-time cube Kraak (2003) proposed, e.g. an extended interactive and dynamic visualization environment, where data can be viewed, manipulated and queried flexibly within the cube. For detailed information about the representation of space and time the reader is referred to Peuquet (2002).

Today these concepts serve as basis for integrating time aspects into existing GIS environments. The way how temporal animations—and thus time—can be arranged and managed within database management systems have been discussed since the 1990s (e.g. Ma and Wang 1999; Peuquet 1999; Wachowicz 1999; Ott and Swiaczny 2001). A comprehensive overview and in many parts philosophical treatment of multidimensional object in GIS is given by Raper (2000).

Current GIS–based implementations dealing with either time integration and/or animated maps approach the issue by either time fields addressed by time sliders (Graser 2011; Esri 2015) or via a multi-layered image formats, such as the Unidata netCDF format for array–oriented data, representing time slices within a space-time cube (now also adopted by Esri 2015).

Apart from mostly desktop-oriented solutions for time and space management there are a number of commercial and free online systems[1] with a focus on map animations. A practical example dealing with cartographical animation for visualizing geological processes is given by Marschallinger et al. (2006).

[1]CartoDB (2015) https://cartodb.com/gallery/lifewatch-inbo/ and GeoTime (2015) http://geotime.com/Home.aspx.

3 Methods and Approach

The approach presented herein is a combination of concepts described above. That means that spatial and attribute data (including their inherent time relation) as well as graphical attributes needed for cartographic animation are to be arranged, managed and stored in a single model. By doing so, this model covers all information needed for an efficient and ample visualization of a natural process and could potentially be transferred between different cartographic systems and GIS flavours.

In order to approach this issue, we here describe the theoretical concept for cartographic animation of multidimensional point symbols.

1. First we try to summarize the nature of temporal changes which characterize natural environments with their objects and processes. We then correlate these changes to graphical variables by which these changes could be visualized within cartographic representations.
2. In the second part we present the concept for multidimensional point symbols. The concept has some surficial resemblance to conventional approaches (e.g. the space-time cube discussed by Hedley et al. 1999; Kraak 2003) due to a similar graphical depiction of space–time.
3. Lastly, we briefly point towards the formalism on which the concept is based upon.

Regarding the conceptual arrangement and organization of data within its spatiotemporal context, some effort has been made in the past. One example is described by Peuquet and Duan (1995) and Peuquet (1999) in which the authors proposed to "maintaining the explicit storage of temporal topology as an adjunct to location- and entity-based representations in a temporal GIS. […]. All changes are stored as a sequence of events through time" (Peuquet 1999, p. 96). The concept presented herein picks up this approach and represents a conceptual implementation for storing temporal changes as a sequence of events.

By modelling cartographic animations within GIS environments, time parameters are arranged and stored as efficiently as spatial and non–spatial attributes. Thus, a direct link between object geometry and graphical visualization is established which allows to manage, visualize and store all correlated data.

4 Symbol-Cube Concept

4.1 Temporal Changes in Natural Environments

As explained by Kraak (2007 p. 317) spatial–data animations can depict change in *space* (position), in *place* (attribute), or in *time.* All objects and processes have at least two temporal attributes which are (1) time of origin or creation t_i and (2) time range of an object's existence Δt (see Sect. 4.3). In the same way as spatial location and extent are described by a map scale, time-relevant attributes can be described

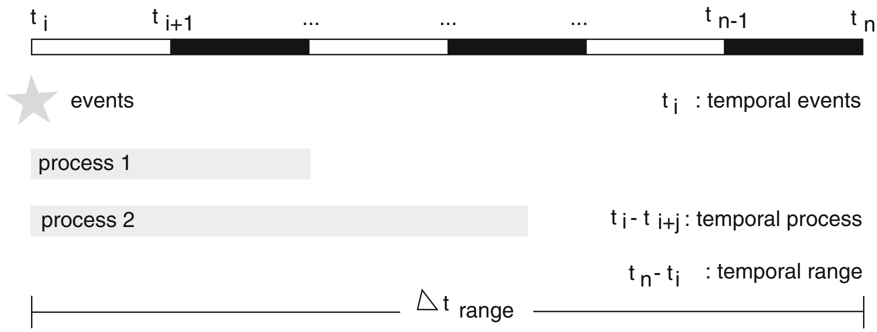

Fig. 1 Different temporal types that characterize the natural environment (Nass and van Gasselt 2015)

by a temporal scale allowing to capture events in real-time or in any slower or faster pace. It seems appropriate to differentiate processes in terms of their extent and their duration in order to (a) understand different scenarios which need to be depicted within a map-animation data model, and to (b) generate a set of rules for calculations based on these scenarios.

The different types of time-dependent attributes in which time-scale and objects or process can be characterized, are shown in Fig. 1. Whereas the *temporal range* covers the whole time period of an investigation period, a *process* represents one particular time period within this temporal range and start and end point are temporally located within this *range*. The *temporal event* describes a distinct incident and is defined by a concrete time stamp. However, it should be noticed here, that an *event* could also be described as a *process* on a larger time scale. These definitions serve as basis for implementing cartographic animation parameters into a subsequent data model. Other resp. comparable definitions are described by e.g. Galton (2009).

Time and all time-dependent information which describe objects and process changes require an adequate (carto-)graphical representation. Adequate here means that the temporal character is visualized in such a way, that the dynamic character of an object and process can be communicated by map animations.

Table 1 Level of measurements for graphical variables used for visualizing changes of physical object

Change of object	Classification on scaling level	Graphical variation	Examples
COMPOSITION, c	nominal and ordinal scale	colour (qualitative) or (colour) value (quantitative)	classes of risk (discrete classes), size of mass (continuous)
SIZE, s s(t) → growth	ratio and interval scale	size (quantitative)	landslide sizes, areas of flooding
DIRECTION, ϕ ϕ (t) → velocity	interval and ratio scale	orientation or rotation (quantitative)	process velocities

In which way the temporal aspects can be visualized by graphical variables and how these are classified within their scaling level is shown in Table 1. The possibilities of how changes can be displayed depend on the complexity and number of attributes but also on the scaling level (Bertin 1983). Changes may occur individually but also in combination (here called 1–3 dimensional). Such changes, when represented within their temporal framework, communicate rates of change, e.g. velocities, growth, decay rate, spreads.

As shown in Table 1 different changes of objects, i.e. composition, size (growth), and direction (velocity) could be represented by the graphical variables *colour, value, size, and orientation.* However, as the structural environment would allow for a higher complexity by taking also qualitative attributes into account, we here focus on quantitative object characteristics and their changes. This consequently means that graphical variables such as *shape* are not considered in order to keep a focus on the abstract point level.

Generally, object changes can be grouped into

1. changes from a discrete state *to* another discrete state by size, directional or compositional (colour) properties. Here, the change of state is either positive or negative and always absolute, and
2. changes of a discrete state *by* a value. Here, the change can be positive or negative, and is always relative with reference to an earlier state.

These temporal changes, i.e. temporal types (shown in Fig. 1), graphical variables and change rates serve as basis for cartographic animations of multidimensional point symbols within GIS. Thus, these parameters were used to provide a formalism which is needed for the structural environment is presents in the following section and is described in the Sect. 4.3.

4.2 The Time-Attribute/Symbol Cube

As shown in Table 1 there are three different types of how objects and environmental processes could be changed. Before it is possible to integrate these 1–3 dimensional changes within a structural environment for storing and accessing spatial data primitives it is necessary to arrange the graphical variables within a model. For illustrating this, a three-axial coordinate system is used. Each of the three axes represents one graphical variable by which changes of objects or processes can be described (see Table 1). The x-axis represents the *colour* attribute, the y-axis represents the *size*, and the z-axis describes the *orientation/rotation attribute* (see Fig. 2a).

The time–attribute's cube is placed on a timeline with its origin at an instance in time (see Fig. 2b). Figure 2c shows how the 1–3 dimensional change can be described independently of temporal scale (as inertial system) and changes on different axes.

The white dot at {0;0;0} in Fig. 2c represents the origin and a state without changes. The light grey dots on {0;1;0}, {1;0;0} and on {0;0;1} represent a 1-dimensional change either in *colour*, *size* or *orientation/rotation*, respectively.

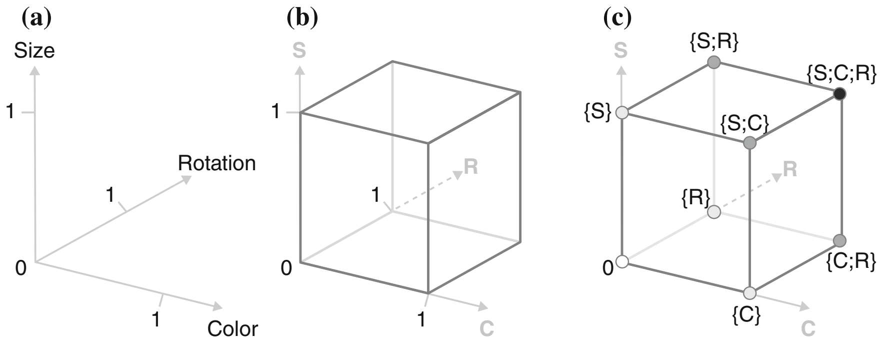

Fig. 2 Symbol-cube for 1–3 dimensional symbols (C represents colour, S size, and R represents rotation)

Middle grey dots on {1;1;0}, {1;0;1} or on {0;1;1} represent 2–dimensional changes either as combination of *colour* and *size, colour* and *rotation* or *size* and *rotation*. The dark grey dot on {1;1;1} represents the 3-dimensional change with changes in *colour*, *size* and orientation/*rotation.*

By using this parametric cube all conceivable 1–3 dimensional object and process changes can be represented. To establish a temporal context and cover not only *temporal events* but also *processes* and *ranges* (shown in Fig. 1), a timeline is needed which is associated to the symbol cube. It is, by definition, scaled by interval. In Fig. 3 the time–attribute cube and the timeline are illustrated with the cube's origin located on the time line.

By doing so, the temporal status is saved in *t1*, coded as *date time* field, and is complemented by 0–3 attributes $\{S_1;C_1;R_1\}$ describing the object's changes. By sliding the cube along the timeline to the next known object or process status the values can be updated: $\{t_2;S_2;C_2;R_2\}$.

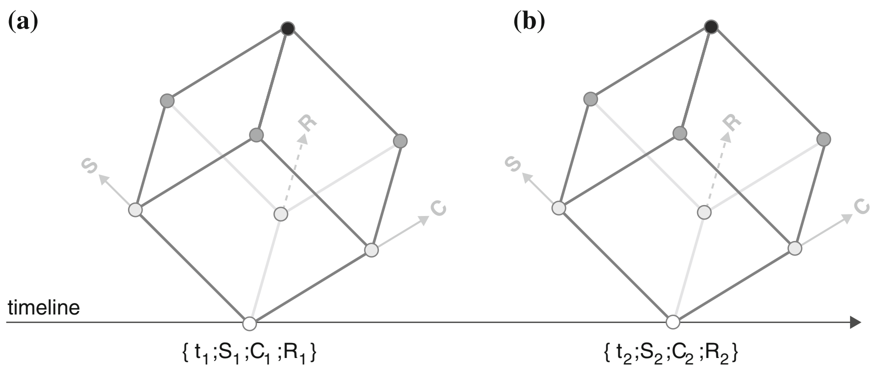

Fig. 3 Symbol-cube variations connected to temporal aspects by a timeline

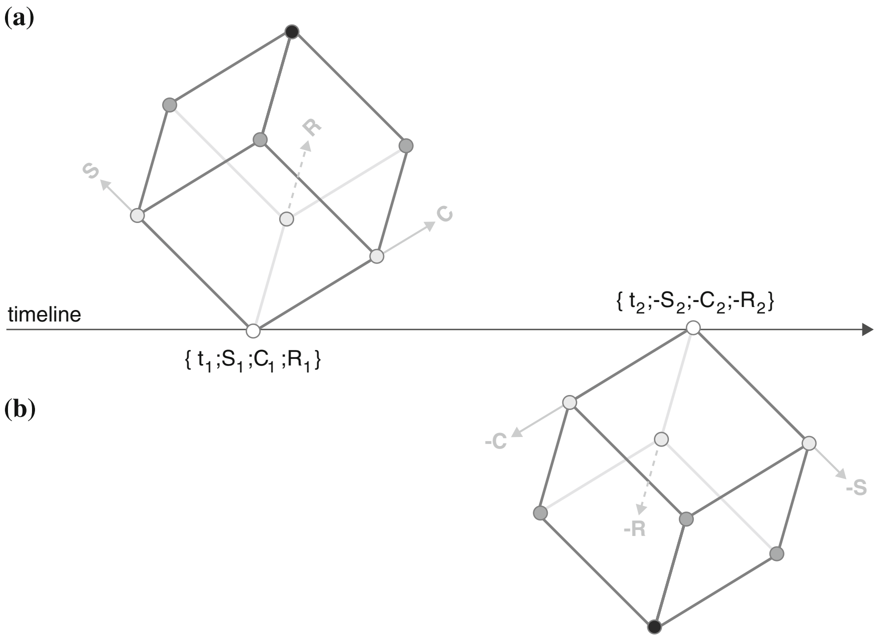

Fig. 4 Symbol-cube combination of positive and absolute as well as negative and relative (delta) values connected to temporal aspects by a timeline

In order to depict negative values, all axes are extended over the cube's origin. As shown in Fig. 4 the upper area covers all positive changes by $\{t_1;S_1;C_1;R_1\}$ and the lower area covers all negative values $\{t_2;-S_2;-C_2;R_2\}$.

In the same way, any other positive or negative value on one of the three axes can be depicted showing, e.g., $\{t_1;S_1;C_1;R_1\} \rightarrow \{t_2;-S_2;-C_2;R_2\}$ (shown in Fig. 5). This case would visualize a point symbol which depicts an object's decrease in size and a backward rotation by an absolute value. The graphical variable *colour* represents a change of class or composition.

The concept of the attribute-time cube and the underlying model allows animations based on single–object sequences. All corresponding attributes describing objects spatially, graphically, and temporally are stored in one structured environment which can potentially be integrated within a GI environment.

Before such a concept and its formalisms (see Sect. 4.3) can potentially be implemented in a data model, it has to be supplemented by additional auxiliary attribute information describing graphical variables and operations in more detail.

- *Scales:* sizes and rotations can be modelled on a relative as well as on an absolute scale, or even as a combination of both. While absolute changes are easy to implement, there are two possibilities to depict relative changes: by value or by percentage. Additionally absolute and relative rotations require directional information as each angle (domain 0…360°) can be approached in both, clock-wise and counter-clock wise directions.

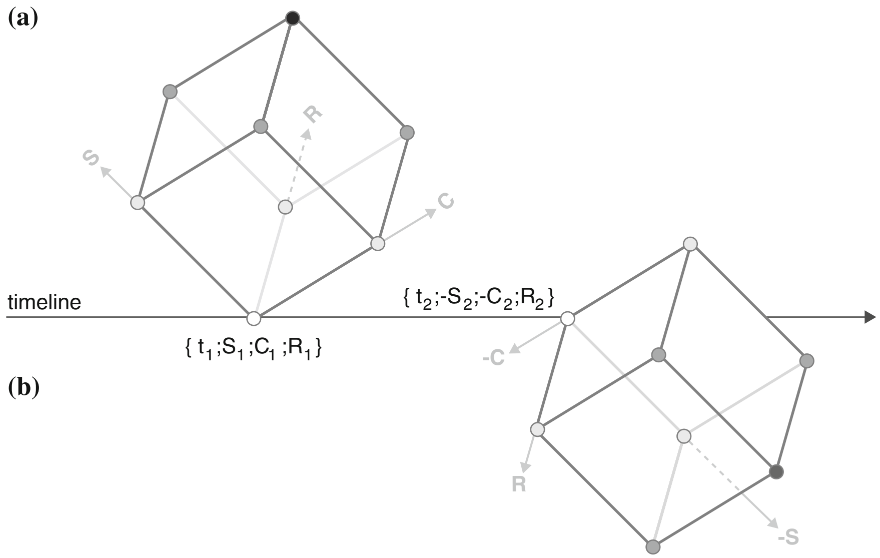

Fig. 5 By individual rotation on all 3 cube axes all object changes and changing combination (positive, negative, relative and absolute) could be visualize

- *Units:* each attribute axis has a specific unit which can change between different models. Rather than assuming a fixed unit, a unit needs to be assigned within the data model.
- *Colour:* an attribute must be reserved which describes the colour model and the actual change within this colour model (ramps, hex values, RGB, IHS, CMYK, …).

For related concepts handling timelines the reader is referred to Peuquet and Duan (1995) and the *event list* presented there.

4.3 Formalism

The time–attribute cube described in Sect. 4.2 provides a visual interpretation of some of the formal background briefly highlighted hereafter. It is, however, an attractive representation as we do not have more than three graphical variables which need to be depicted.

As a first definition, we assume a linear progression of time along a universally valid and linear scale. Each instance of time t_i, each discrete event is described by a date–time attribute (such as yyyy-mm-dd-hh-mm-ss.sss) to which the individual state of three non-spatial and non-temporal symbol attributes (i.e. graphical variables) are related: (1) colour c, size s, and rotation ϕ. Thus, variables are described by attributes and exist within their individual inertial system which is moved along the t-axis.

A state of attributes at an instance *i* is described as $\{t_i; c_i; s_i; r_i\}$. At another instance of time t_{i+j}, attribute values may have changed completely, partially or not at all $\{t_{i+j}; c_{i+j}; s_{i+j}; r_{i+j}\}$. The change of attributes between two time instances is described by the absolute difference between attribute values at two instances t_i and t_{i-i} with $\Delta t = t_{i+j} - t_i$:

1. absolute difference
   $\{\Delta c; \Delta s; \Delta r\} = \{c_{i+j} - c_i; s_{i+j} - s_i; r_{i+j} - r_i\}$
2. relative change
   $\{\delta c; \delta s; \delta r\} = \{c_{i+j}/c_i; s_{i+j}/s_i; r_{i+j}/r_i\}$
3. rate of change
   $\{\dot{c}; \dot{s}; \dot{r}\} = \{(c_{i+j} - c_i)/(t_{i+j} - t_j); (s_{i+j} - s_i)/(t_{i+j} - t_j); (r_{i+j} - r_i)/(t_{i+j} - t_j)\}$

Each attribute and each value can be accessed using relational operations by selecting over the time attribute.

A point symbol may represent a size s of a real-world-feature which has an initial size s_i and which increases to a size s_{i+j} at t_{i+j} and it may decrease to size s_{i+k} at t_{i+k}. Its total size difference is given by $\Delta s = s_i - s_{i+k}$ which might be positive or negative. It can also be depicted as sum of differences $\Sigma\Delta t$ along each instance of time: $s_i - s_{i+j} - s_{i+k}$.

Since each time–attribute cube on the timeline represents a change in time, and a distinct state of attributes colour, size, rotation with either none, one, two or three values deviating from zero, we can depict each state of attributes at a given time by a positional vector along the timeline to the instance of time and direction vectors indicating the change. Geometrically, the difference between two direction vectors at different instances of time returns the measure of change for each attribute from which absolute, relative as well rates of change can be easily extracted. One should note, however, that a depiction of changes is always dependent on sampling, i.e., observation intervals, e.g. for directions a change of 360° between two observations results in no visible change on the map. This, however, needs to be kept in mind when working with all sort of sampling data and a map animation can only represent what has been measured in the field. While the map would not be able to show this type of change, a temporal query would allow to see it.

5 Conclusion and Outlook

Today, various branches such as weather forecasts and simulation in news media or maps on web pages make use of cartographic animations. Such animations communicate complex and mostly time-dependent information in an accessible way, i.e. if such information is conveyed in a natural way, it can be accessed intuitively by any recipient. In order to allow this complex data analyses and representations are needed. To combine spatial information with non-spatial attributes and temporal characteristics and, finally, in order to relate them to other entities GIS technology is frequently used but it requires to be set up individually for specific use cases and implementations to allow for temporal visualization. In conventional GIS all pieces of information are stored as attribute values in relations. As long as temporal information is not readily supported in the same way as spatial information, workarounds need to be designed to store the temporal dimension within standard relational data models.

By making use of a time–attribute cube it is possible to visualize all combinations of point features which represent changes of objects and processes. That concept serves as basis for a GIS–based data structure that directly integrates temporal character of objects within a data model, and allows cartographic animations of map features.

Storing and accessing time–attribute data is straightforward and can be accomplished in any relational data model. However, issues of accessing such information and making use of them for map animation need to be addressed by the GI system backend which cannot be solved on an abstract level. A number of question remain:

- How can values for colour, size and rotation be stored in such a way that different GIS implementations can access them for map animation?
- What are the advantages and disadvantages of combining graphical information within a data model and how could this implementation be accomplished?
- How can the concept and the proposed conceptual level of a data model be connected to a dynamic and web-based mapping service?
- Is there a way for generating, storing and visualizing animations via moving paths or via automatic interpolation?

These are just few questions concerned with the topic of implementing cartographic animations. Integration of time (as dimension) in GIS significantly increases the complexity of any data model and by that usability can easily be limited. For the time being it seems therefore straightforward to focus on specific (concrete) problems in temporal design to allow future review of different approaches and to find a common abstract formalism.

Next steps in our approach will be to establish a full abstract formalism on which the concept is built, provide use cases and present a data model implementation (physical model) which may be accessed and adapted for other use cases.

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Model of the Dynamic Labelling of Populated Places in Slovakia for the Purposes of the State Map Series

Jakub Straka, Marta Sojčáková and Róbert Fencík

Abstract This paper is focused on the point labelling of populated places for multi-scale mapping for the new state map series of the Slovak Republic (SR). The importance of creating new categories suitable for dynamic digital maps as well as the current state of the art is described. The proposed font parameters for the new categorizations are described along with a comparison of the current categorization. Furthermore, new label placement rules as well as the dynamic labelling model created for the populated places are described.

Keywords Multi-scale mapping · Cartographic conflict · Map legibility

1 Introduction

The text on maps has an irreplaceable function. It increases the value of the information and completes the whole appearance of maps. To communicate spatial information effectively, map features such as rivers, lakes and towns need to be labelled. The effectiveness and functionality of a map as a communication medium undoubtedly depends on how it is labelled (Michna 2009). The issue of the label placement on the maps and its importance is described in detail in the literature (Imhof 1975; Bratz 1970; Cuenin 1972; Kučera 1964; Hojovec et al. 1987; Wood 2000). Clarity and legibility are two of the main objectives which a cartographer strives to achieve and which have a direct influence on the perceptual and cognitive processes used by map readers to search for a certain name on a map and determine its meaning.

While technological developments in interactive mapping have been spectacular, cartographic science has thus far failed to keep pace with practice. Cartographic

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_3

science must expand its reach to provide actionable knowledge about and practical guidelines for the design and use of this new generation of interactive maps (Roth 2013).

The efficiency of a web map is thus related to the rapid calculation of a new display after an interaction. On the other hand, an exceptionally efficient algorithm is useless if the result is chaotic and thus difficult to process by the user (Ooms et al. 2012).

When creating an interactive map product that is meant to be viewed at multiple scales, all of the design issues become increasingly complicated. Labelling map features is an especially problem. There have been numerous approaches over the past thirty years for automating the label placement problem. There are many of the cartographic literature on the algorithms for the label placement (Hirsch 1982; Huffman and Cromley 2002; Freeman 2005; Kern and Brewer 2008).

The new state map series of the SR is supposed to be created on the basis of the Basic Database for Geographic Information System (BDGIS); it is an object-oriented spatial database and is a reference basis for spatial information for the national infrastructure. Thus, a new labelling model needs to be proposed for displaying the geographical names of the populated places on the maps of the state map series. This proposed model must be created according to the basic cartographic rules for placing labels on maps. Numerous authors (Imhof 1975; Freeman and Ahn 1987; Freeman 2007; Jordan 2009) have conducted research in this field of cartography.

The need is to categorize these places into unique categories, while the number of categories should take into consideration the rule (Imhof 1975) that the arrangement of the type should reflect the classification and hierarchy of the objects on the map. The second need is to minimize the cartographic conflicts caused by the label placement, because the labels should disturb the other map contents as little as possible (Imhof 1975).

The aim of this paper is to describe the application of a methodology for labelling the populated places in the state map series of the SR. The features and attributes of the model have been proposed to ensure a good degree of legibility and clarity in an interactive environment. We reduced the number of currently used categories for the populated places. This improvement helps the reader obtain information about the populated places from the interactive maps effectively. New categories have been designed for scales from 1:10,000 to 1:100,000. Furthermore, we applied new font parameters in the model for the categories of populated places and new label placement rules.

2 Current State

2.1 Labels in the State Map Series

The maps of the valid state map series of the Slovak Republic (SR) were created in the 1980s. The labelling placement rules, methods and techniques as well as the font types and parameters were designed for analogue maps. These labelling placement rules need to be transferred into a digital environment; moreover, the labelling methods and techniques need to be improved and transformed into a new dynamic labelling model for the new state map series.

Populated places are sorted into unique categories according to the number of inhabitants. This categorization defines the font type and parameters for the labels in each category based on a hierarchy of the populated places. The currently used categorization is designed for analogue maps and does not meet the requirements for digital maps. For instance, the categorization designed for the Basic map on a scale of 1:50,000 has nineteen unique categories (Fig. 1).

As digital maps continue to replace paper maps, cartographers continue to find suitable techniques for the production of these digital maps in a multiscale environment (Kraak and Ormeling 2010). It is necessary to reduce the number of

Číslo značky	Predmet	b) Podľa vzorníka Slovenskej kartografie, n. p., Bratislava			
		Vzor písma	Typ písma	Prídomky	Popis v ráme
701	hlavné mesto ČSSR				
	obce so sídlom KNV				
	obce so sídlom ONV				
	Obce s MsNV				prídomky typ/1,6
	nad 500 000 obyv.	BRAT.	750445/6,5V	750445/6,0	750445/1,8V
	100 001 – 500 000	KOŠICE	760445/6,0V	760445/5,5	760445/1,8V
	50 001 – 100 000	HRANIČ.	750443/5,5V	750443/5,0	750443/1,8V
	25 001 – 50 000	ČALOVEC	750443/5,0V	750443/4,5	750443/1,8V
	10 001 – 25 000	KOLÁROVO	750443/4,2V	750443/3,7	750443/1,8V
	5 001 – 10 000	STROPKOV	750417/3,8V	750417/3,3	750417/1,8V
	do 5000 obyv.	LUBENÍK	750417/3,2V	750417/2,7	750417/1,8V
	Obce				
	nad 2000 obyv.	Vojnice	750417/4,2	750417/3,7	750417/1,8 prídomky 750417/1,6
	501 – 2000	Valice	750417/3,8	750417/3,3	
	101 – 500	Slatina	750417/3,2	750417/2,7	
	do 100 obyv.	Kysak	750417/2,4	750417/2,4	
702	**Časti obcí v obciach s MsNV**				
	nad 25 000 obyv.	PETRŽALKA	750412/3,6V	750412/3,1	750412/1,5V prídomky 750412/1,5
	10 001 – 25 000	RUŽINOV	750412/3,4V	750412/2,9	
	5 001 – 10 000	VRAKUŇA	750412/3,0V	750412/2,5	
	do 5 000 obyv.	VAJNORY	750412/2,4V	750412/2,4	
	Časti obcí (ostatných)				
	nad 100 obyv.	Nižné	750412/3,0	750412/2,5	750412/1,5 prídomky 750412/1,5
	do 100 obyv.	Gregorovce	750412/2,4	750412/2,4	
703	**Miestne časti obcí**				
	nad 10 domov	*Buková*	Un. 56/2,6	Un. 56/2,6	Un. 56/1,5 prídomky Un. 56/1,5
	do 10 domov	*Ďurišovci*	Un. 56/2,2	Un. 56/2,2	

Fig. 1 Categorization used for labelling populated places for the basic map 1:50,000 (Instruction 1984)

categories and create a new categorization model that will be applicable to the dynamic labelling model of the new state map series.

2.2 Source for Geographical Names

The new state map series will be created from BDGIS data. This database is part of the information system of surveying, mapping and cadastre and ensures the forms of the SR on the basis of Act No. 215/1995 on geodesy and cartography, as amended. The BDGIS object-oriented spatial database is the reference basis for the national infrastructure for spatial information. It creates the locations and geometric foundations for the creation of a thematic extension of geographical information systems and is binding for the creation of the national primary and thematic mapping works. The purpose of the construction of BDGIS is to create a base of relevant spatial information on the territory of the SR in a system to allow it to be stored, updated, handled, analysed and imaged/displayed. BDGIS consists of data and metadata about spatial objects, spatial and thematic attributes, and reciprocal links. A range of data about the objects managed within the framework of BDGIS specifies the catalogue of the classes of the objects (CCO BDGIS). Visualization of the BDGIS data is available at the Web Mapping client application; the composition of the map is by BDGIS (Geoportal 2015).

Part of BDGIS consists of the point layer of geographical names (GN). Names are stored as an attribute value associated with each GN record. This point layer should serve for the placement of populated place labels. All GN records contain names in a standardized form. Some also contain a variant or multiple variants, which may represent additional spellings or historical variations. These variant names are not used for labelling. Unfortunately, this point layer contains no information about the categorization of populated places.

2.3 Dynamic Labelling

The cartographer can no longer simply consider a limited geographic area on a fixed scale when weighing which elements are essential to a map. Labelling map features is an especially burdensome problem, even with advanced label placement tools (Stroh et al. 2010). The term “dynamic labelling” refers to such labelling, the characteristics of which are adapted to the creation of labelling on dynamic maps. They are characterized by allowing for continuous zooming and panning. A change in the zoom level results in a change in the scale and also in a change in the size of the displayed territory. Panning results in a change in the territory of interest. The aim of dynamic map labelling is the filtering, selection and placement of labels on a map. As long as a label is visible on a map view, its position and size should change continuously under the panning and zooming operations (Fig. 2).

Fig. 2 Labelling of populated places on a scale of 1:100,000 (*left*) and labels for the same territory on a scale of 1:50,000 (*right*)

Database-driven mapping often simply relies on what labels fit best in a map frame. This causes many cartographic conflicts when generating dynamic labels (Brewer 2010). The legibility and clarity of a map must be ensured during the panning and zooming operations. To achieve this goal it is necessary to correctly define the dynamic labelling model within the meaning of setting the placement rules and hierarchy. On a large-scale map it is easier to observe label placement rules as there are fewer labels competing with each other.

Based on the legislation (Instruction 1984–1986, 1989) there is a rule that the maps of the state map series visualize and label all the populated places across all the scales. These maps are binding for the creation of all the derived thematic maps in the SR.

Cartographic rules must be used to solve cartographic conflicts such as overlapping of labels, crossing labels with line objects, etc.

3 The Dynamic Labelling Model

A map is a tool for transferring information between the cartographer and the map's reader. Correctly designed categories of populated places and defined rules of label placement have a direct impact on obtaining information from a map. This paper describes the creation of a dynamic labelling model of the populated places in the SR. Furthermore, a new categorization of populated places was proposed as well as new font parameters. The model is designed for multi-scale mapping for the new state map series of the SR.

The dynamic labelling model of the populated places of the SR was created in ArcGIS v.10.2.2 with its *Maplex* extension. This extension provides a special set of tools that allows for improving the quality of label placements (Makram 2011). The data used for creating and testing the model was obtained from the Geodetic and Cartographic Institute of Bratislava. The data contains BDGIS and GN records for *Senec,* the territory of interest. The details can be seen in Fig. 3. This territory contains 146 GN records for the populated places, including the parts villages and towns.

Fig. 3 Detail from the territory of interest used for the labelling of populated places based on the point character of the GN record (*red dot*)—scale 1:25,000

3.1 New Categorization of Populated Places

For the purpose of publishing a new state map series through web services, it was necessary to redesign the currently used categorization.

The previous categories were designed in the era of the former Czechoslovakia; these categories therefore do not meet current requirements from the viewpoint of the number of populated places and their inhabitants.

The proposed new categories are based on the number of inhabitants obtained from the last census. The categorization is designed for use with scales of 1:10,000, 1:25,000, 1:50,000 and 1:100,000 (Sojčáková 2015).

In the SR 138 populated places are defined as towns. The largest city and also the capital is Bratislava, with more than 400,000 inhabitants; the smallest town is Dudince with around 1400 inhabitants. Only 10 towns have more than 50,000 inhabitants. The number of villages is 2752; most of them (1916) have less than 1000 inhabitants. This information was obtained from the Statistical Office of the SR (Statistical lexicon 2011).

It is necessary to reduce the number of categories to achieve a good legibility of maps in a digital environment. We reduced the number of currently used categories for populated places. This improvement helps in obtaining information about populated places from interactive maps effectively. The towns and villages have been divided into new categories. We designed four new categories for towns and three categories for villages.

The division of populated places according to their administrative meaning (towns and villages) is defined in the legislation of the SR (Act 1990).

Table 1 New categorization for the labelling of populated places (Sojčáková 2015)

CATEGORY	Number of places
Town more than 50,001 inhabitants	10
Town 20,001–50,000 inhabitants	29
Town 10,001–20,000 inhabitants	33
Town less than 10,000 inhabitants	66
Village more than 2001 inhabitants	275
Village 1001–2000 inhabitants	561
Village less than 1000 inhabitants	1916
Town district	1785
Village district	
Districts of Bratislava and Košice	39

Additionally, the parts of towns and villages with names different from the name of the town or village have their own category. The new categorization is shown in Table 1.

In comparison with the previous categorization for the state map series, we significantly reduced the number of categories.

Furthermore, we applied digital typography rules (Sojčáková 2015) for designing the font parameters such as the colour, height, width and spacing of the letters for each category and the defined scale. The proposed font has to meet requirements for simplicity and good readability in different sizes, depending on the digital environment. Serifed fonts are overwhelmingly preferred for printed texts such as labels on analogue maps. On the other hand, sans-serif fonts are considered to be more legible on computer screens (Michael et al. 2003; Josephson 2008; Deeb et al. 2012).

Numerous font types were tested on the same territory of interest, namely, Times New Roman, Baskerville Old Face, Verdana and Arial. The best legibility was achieved using the Arial font, which is a sans-serif font type.

Based on the tests, the smallest usable size of label was set at 8 points (pt). The labels in each category have to be different in size by least 2 pt to ensure clarity. The proposed colour of the populated place labels is 80 % grey scale. This new categorization is designed for use on dynamic multi-scale maps.

The designed categories are the same across all the scales. The font sizes remain the same for the scales from 1:10,000 to 1:50,000. For the scale of 1:100,000, we proposed a reduced font size by 2 pt for each category due to the smaller scale number; thus a larger territory and more labels are displayed.

Table 2 shows the labels classified according to the new categorization as well as their display with the proposed font parameters. The categorization shown in Table 2 is designed for the dynamic labelling model for scales of 1:10,000, 1:25,000 and 1:50,000.

Table 2 Labels classified according to the new categorization (Sojčáková 2015)

Category of populated place		Size [pt]	Example of label
Town	50,001 and more	22	BRATISLAVA
	20,001 – 50,000	20	BREZNO
	10,001 – 20,000	18	SENEC
	10,000 and less	16	MODRA
Village	2,001 and more	14	Rovinka
	1,001 – 2,000	12	Reca
	1,000 and less	10	Igram
Populated place district (town or village)		10	*Studené*
Districts of Bratislava and Košice		16	*Ružinov*

3.2 Placement Rules for the Labelling of the Populated Places

When generating dynamic labels under the panning and zooming operations without correctly defined placement rules, numerous cartographic conflicts can arise. To avoid these conflicts or minimize their number, it is crucial to define the placement rules. Furthermore, the *Maplex* extension offers priority, weight, and hierarchy settings to enhance the overall legibility and clarity of the map (Maplex 2009). Our previous work (Straka et al. 2014; Křehnáčová 2014; Gmitterová 2015) has been focused on the labelling of line character objects such as roads and rivers; now we have extended this labelling model by the labelling of populated places. The placement rules must be harmonized to create a homogenous-looking map.

To achieve the dynamic behavior of labels according to the changes in position and size under the zooming operation, we created a labelling model for each reference scale and defined the scale range where the set rules have to be applied. The list of reference scales and scale ranges is shown in Table 3.

For each reference scale and category of populated place, we created a unique *Label Class*. Each label class defines the individual font parameters as well as the placement rules. In the GN database we created a new attribute (the number of

Table 3 Reference scales used for setting up the labelling model. The rules set for the reference scale are valid for all the scales between the minimum and maximum displayed scales

Reference scale	Maximum displayed scale	Minimum displayed scale
1:10,000	1:7,501	1:17,500
1:25,000	1:17,501	1:37,500
1:50,000	1:37,501	1:75,000
1:100,000	1:75,001	1:175,000

inhabitants). Based on this new attribute and *the Category* attribute, which defines the category of the geographical name, we selected the populated places and sorted them into corresponding label classes (Fig. 4). We used the SQL language for the selection.

In the next step we defined the weights and priorities for each layer which could cause cartographic conflicts with the populated place labels. *Maplex* allows the setting of weights between the values 0 and 1000; 0 means the lowest weight, and each layer is displayed according to the priorities. The value 1000 means the highest priority, and this layer must not be crossed with other map symbols or labels. The negative effect of the weight value of 1000 for our purposes is that if the label cannot be placed without any crossing, then the label will not be displayed at all. This problem was solved by not using the maximum weight of 1000 while creating the labelling model for the populated places because all the populated places must be labeled on the state map series. The ideal solution is when the populated place label is not in any cartographic conflict with any line object. Many times, especially when using smaller scales, it is not possible to satisfy all the placement rules necessary. We tested various placement possibilities to improve the

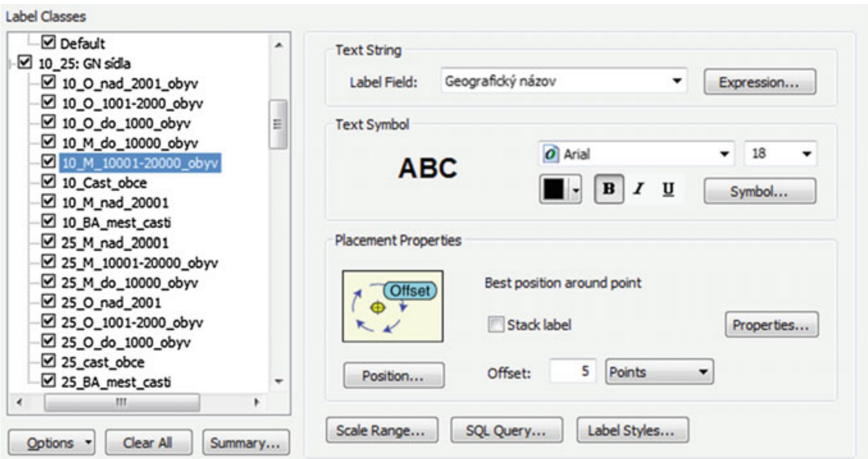

Fig. 4 Defining *the Label Classes* for each reference scale and category

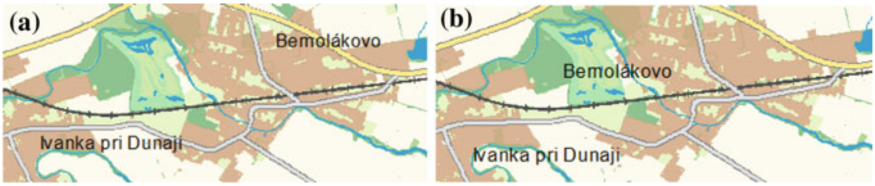

Fig. 5 **a** Road weights: 700, rivers: 900. **b** Road weights: 900, rivers: 700

Table 4 Layers and their weights used for defining the placement rules of the populated place labels

Layer	Weight
Road_select	700
Highway, road	700
Railroad	700
River	600
River_area	600
Water_area	600
Swamp, marsh	600

dynamic labelling model. Figure 5 demonstrates the difference in label placements based on weight values. Figure 5a shows a solution where a river has priority over a road, while Fig. 5b shows a solution with reversed priorities. Better legibility was achieved in a solution with a higher weight value for the river layer.

The primary goal was to avoid cartographic conflicts between the line objects (roads, rivers) and the populated place labels. Firstly, we created an invisible layer called *Road_select*. This layer only contains roads of the 1st, 2nd and 3rd classes and has a higher weight than other roads like rural roads. This layer (Road_select) is not visible on the map and is used only for setting the placement rules. Table 4 contains all the layers used and their weights. The weight setting is identical for all the reference scales.

3.3 Label Offset and Character Spacing as an Improvement in Legibility

The populated place labels are created from the point records of the GN database. Based on the position of the GN record, the position of the label is calculated. A label offset defines the distance between the GN reference point and the final position of the label. With the reference scales of 1:10,000 and 1:25,000, the populated place is displayed on a large enough area so that a larger offset is applicable. For the reference scales of 1:50,000 and 1:100,000, it is necessary to set a smaller offset value to provide the relevant label position. The proposed offset values can be seen in Table 5.

Table 5 Label offset values used in the dynamic labelling model proposed for the populated places

Category	Scale 1:10,000 and 1:25,000		Scale 1:50,000 and 1:100,000	
	(pt)	(mm)	(pt)	(mm)
Town	15	5.272	15	5.272
Village	15	5.272	10	3.515
Part of town or village	15	5.272	5	1.757
Town district (Bratislava, Košice)	15	5.272	10	3.515

The best results were obtained with a proper combination of the setting layer weights and label offsets. The labels act dynamically according to these rules under zooming and panning operations. Figure 6 demonstrates the difference between the default label placement and the label placement according to the proposed rules on a scale of 1:25,000.

The last improvement in the map is legibility, which was achieved by enhancing the character spacing and width. The default character spacing is set to 0 pt and the character width to 100 pt. Based on numerous tests with different settings, we determined the optimal character spacing to be 5 pt and the character width to be 107 pt. The difference between the default values and proposed values is shown in Fig. 7a, b.

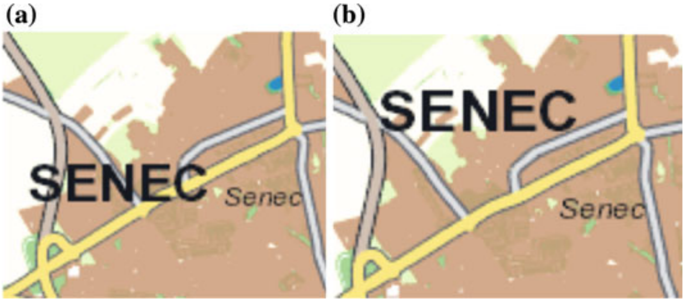

Fig. 6 **a** Road weights: 0, offset: 1 pt. **b** Road weights: 900, offset: 15 pt

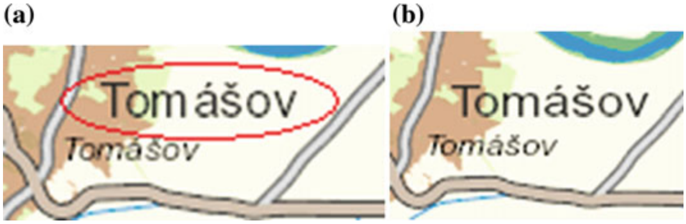

Fig. 7 **a** Default settings. **b** Adjusted settings

The new categorization of the populated places described as well as the mentioned rules, methods and techniques were used for the creation of the dynamic labelling model of populated places in the SR. In this paper we focused on reference scales from 1:10,000 to 1:100,000. Figures 8 and 9, which have been reduced from the originals, show the results of the dynamic labeling of the populated places with

Fig. 8 Populated place labels captured at 1:25,000. Detailed view from the territory of interest

Fig. 9 Populated place labels captured at 1:50,000. Detailed view from the territory of interest

the parameters and rules which were defined in the new model for the selected scales of 1:25,000 and 1:50,000. It is important to note that these maps will eventually have other labels for features such as the hydrography, road networks, etc.

4 Conclusion

In this paper, we have described our work to improve the labeling of populated places on digital maps in a multi-scale environment. The new state map series will be created from the data of the BDGIS and the point layer of the geographical names. Our main efforts were aimed at improving the map's legibility and providing clarity under the panning and zooming operations. Firstly, it was essential to design a new categorization for the populated places. We applied the rules of digital typography for designing the font parameters for each category and scale.

In the next step numerous cartographic conflicts were solved using the correct label placement rules. The majority of the cartographic conflicts were caused either by overlapping labels, crossing labels with line objects or crossing labels with areal objects. We used weights to determine which objects must not be overlapped. For additional legibility and enhancing the map's design, we used a combination of label offsets and character spacing.

The insights gained and the mentioned rules, methods and techniques were used for the creation of the dynamic labelling model of the populated places in the SR. The new dynamic labelling model is intended to be used for the new state map series of the SR. The state map series is published through web services. The dynamic labelling model was created in ArcGIS v.10.2.2 and its *Maplex* extension for reference scales of 1:10,000, 1:25,000, 1:50,000 and 1:100,000. Our results will be incorporated into the overall redesign of the state map series.

The goal in the featured work was to solve the problem caused by the point character of the GN features. We wanted to define a new relational linkage of names of towns stored in the GN database with the polygons which represent their area. The areal features may provide better placement results in the labelling of populated places. We also intend to conduct tests of the labelling model based on eye-tracking technology to obtain feedback from the map readers and improve our dynamic labelling model of the populated places.

Acknowledgement The research for this paper was financially supported by the Scientific Grant Agency VEGA of the Ministry of Education, Science, Research and Sport of the Slovak Republic, Grant No. 1/0710/15 and the European Commission's Seventh Framework Project RECARE, Contract No. 603498.

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Methodology for Automating the Cartometric Evaluation of Urban Topographic Maps of Brazil

Mônica Cristina de Castro and Claudia Robbi Sluter

Abstract Cartometric evaluation is part of the cartographic generalization process and can indicate which operator should be applied and which features should be generalized. Those decisions are based on the occurrence of geometric conditions and spatial and holistic measures. Those aspects can be understood as legibility and visibility problems, and this knowledge can be described as rules of an expert system. The automation of cartographic generalization is a challenge partly because of subjective decisions made during the process. Cartometric evaluation show this subjectivity. The formalization and automated identification of the representation problems can make this process more holistic and less dependent on human control and influence and, therefore, more efficient. The objective of this paper is to present a method for developing a cartometric evaluation for topographic maps at 1:5000 derived from 1:2000 scale that is appropriate for the Brazilian landscape. Our approach consists of designing an expert system based on a decision tree. We present the first results of the expert system developed using ArcGIS and its application ModelBuilder to detect automatically map representation problems.

Keywords Cartographic generalization · Cartometric evaluation · Representation problems

1 Introduction

Brazilian official mapping for urban areas should be based on a 1:2000 basic map scale and maps at smaller scales should be produced by cartographic generalization. In Brazil, however, the official topographic maps at different scales are not produced

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_4

by generalization. Instead, they are produced directly from surveying techniques such as photogrammetric surveys. Therefore, we need to propose a methodology for producing topographic maps at different scales by cartographic generalization appropriate to the Brazilian landscape. In our proposed methodology, the generalization process includes cartometric evaluation. That evaluation can be used to define which operator should be applied and which features should be generalized.

As a complex and subjective process, the transition from manual to digital and automated generalization has been difficult. There have been attempts to define and formalize all aspects of the generalization process by creating conceptual models (Ratajski 1967; Morrison 1974; Brassel and Weibel 1988; Nickerson and Freeman 1986). Among the generalization models, there is the one developed by McMaster and Shea (1992) which is composed of three components: philosophical objectives, cartometric evaluation, and spatial and attributes transformations. Cartometric evaluation indicates when to generalize, and that decision is highly subjective and difficult to quantify (McMaster and Shea 1992).

Cartometric evaluation requires that the measurements of features at the derived scale are made to identify specific situations that require the application of the generalization operators to guarantee the efficiency of cartographic communication. The measurements for cartometric evaluation can be performed in elements of the geo-information data structures such as points, lines, and polygons. These measures are related to the elements' geometric conditions and spatial measures as also described by McMaster and Shea (1992).

The automation of the generalization process has been studied since the 1980s (Regnauld 2001). At that time, the focus was on the development of algorithms to perform spatial transformations or to act as generalization operators for mainly single problems and features such as roads and hydrography. Thus, only a single element of the McMaster and Shea model (1992) was considered: how to generalize spatial and attribute transformations. More recently, scientific studies have aimed to formalize map specifications to evaluate the generalization operators applied to single features or on the whole map (Bard and Ruas 2004; Filippovska et al. 2008; Stoter et al. 2009).

These specifications consider the minimal dimensions and shape of features, distances between features and the topologies and spatial distributions of geographic features. Those aspects are included in cartometric evaluation as defined by McMaster and Shea (1992). Solutions for automatically calculating those measures are not new in the cartographic literature. However, they have not been treated as a 'cartometric evaluation' step, which means that they are not used for defining which features should be generalized and the choice of generalization operators. Therefore, the automation of cartometric evaluation or part of its evaluation is possible. The evaluation components are known as constraints, restrictions, map specifications, geometric distortions, guidelines, cartographic rules and graphical parameters (Mustiere 2005; Filippovska et al. 2008; Stoter et al. 2009; Taillandier et al. 2011).

These aspects can be described as geometric measurements that can be used as expert system rules to perform the automatically cartometric evaluation. To know exactly which features to generalize and how to generalize them before applying the generalization operators can make the whole automated generalization process less time consuming and more effective because the decisions may control the process.

This paper presents a method for performing the cartometric evaluation of buildings, property boundaries and streets at topographic maps of 1:5000 derived from 1:2000 scale. We propose an automated approach using an expert system based on a decision tree developed with the support of the ArcGIS software and its ModelBuilder application.

In Sect. 2, we present the general context in which this work takes place. In Sect. 3, we describe a methodology for developing the expert system and difficulties in automating the generalization process. In Sect. 4, we then describe our conclusion from the achieved results and propose future investigation.

2 Cartometric Evaluation

McMaster and Shea (1992) referred to cartometric evaluation as one step of the generalization process. It can be used to know when a map does not meet its initial objective, that is when the cartographic visualization and communication do not match. This evaluation can be performed based on two main aspects: geometric conditions and spatial and holistic measures. When the scale of a map is reduced, and any of those aspects occur, it indicates that the map requires the application of generalization operators, so that those conditions can be eliminated or minimized (Slocum et al. 2009).

There are six known geometric conditions: congestion, coalescence, conflict, complication, inconsistency and imperceptibility. Complication and inconsistency are evidence that the generalization process must be performed again because there are ambiguities in the performances of the generalization techniques (complication) or inconsistencies in the results of applying generalization decisions (McMaster and Shea 1992). Congestion, coalescence, conflict, and imperceptibility are consequences of changing scale. In order to detect the presence of these conditions, measurements must be performed on some of the map features (a single feature or a group of features) at the reduced scale.

Spatial and holistic measures can be described as basic geometric properties of features. Some of the aspects are density, distribution, length, sinuosity, shape, distance, Gestalt and abstract measures (McMaster and Shea 1992). The majority of the measures can be established as rules of an expert system and associated with the geometric conditions. McMaster and Shea (1992) confirmed that Gestalt theory can aid in indicating the perceptual characteristics of feature distributions and that holistic measurements can be used to evaluate the conceptual nature of spatial distributions. However, they are not easy to formalize as specific rules.

Currently, these conditions and measures are understood and used as constraints and map specifications to guide cartographic generalization or to evaluate the final results of the process (Regnauld 2001; Mustiere 2005; Filippovska et al. 2008; Stoter et al. 2009; Taillandier et al. 2011).

3 Expert System Development

We applied the proposed methodology to two topographic maps. They are maps of the cities of Campo Largo and Pinhais, which are located in the state of Paraná, Brazil. The location of Paraná in Brazil is illustrated in Fig. 1. The locations of the cities with regard to the capital of the state are shown in Fig. 2.

Fig. 1 The state of Paraná in Brazil and its capital

Fig. 2 The Curitiba Metropolitan Region. The capital and the cities under study are highlighted

The expert system should properly run and be useful in different urban areas regardless of occupation type and urbanization level. Regarding occupation type and urbanization level, the cities have different characteristics. Both cities have a high level of urbanization. Campo Largo has an area of 1248.674 km^2 and 112,377 inhabitants. Pinhais is the smallest city in the state of Paraná and has an area of 60.865 km^2 and 117,088 inhabitants (IBGE 2010).

Campo Largo is divided into 5 districts: Campo Largo (city county), Ferraria, Bateias, Três Corregos, São Silvestre. In spite of the high urbanization level only the first two are considered urban areas while the others are rural areas. Unlike Campo Largo, Pinhais is not divided into districts and does not have a rural population; it is considered a totally urbanized city (IBGE 2010).

Figure 3 shows part of the Campo Largo city topographic map at the original scale of 1:2000 with all its features represented, which include blocks; city boundaries; buildings; hydrography; roads and streets; subdivisions; topographic contours, and vegetation. The features used for the development of this work were buildings, property boundaries and streets (Fig. 4). Industrial buildings are represented as gray polygons, commercial buildings as yellow and residential buildings as pink polygons.

The Pinhais topographic map at 1:2000 scale is shown in Fig. 5 with all its features represented, and Fig. 6 only shows the target features used in this work, buildings, properties boundaries, and streets. Topographic maps of urban areas of

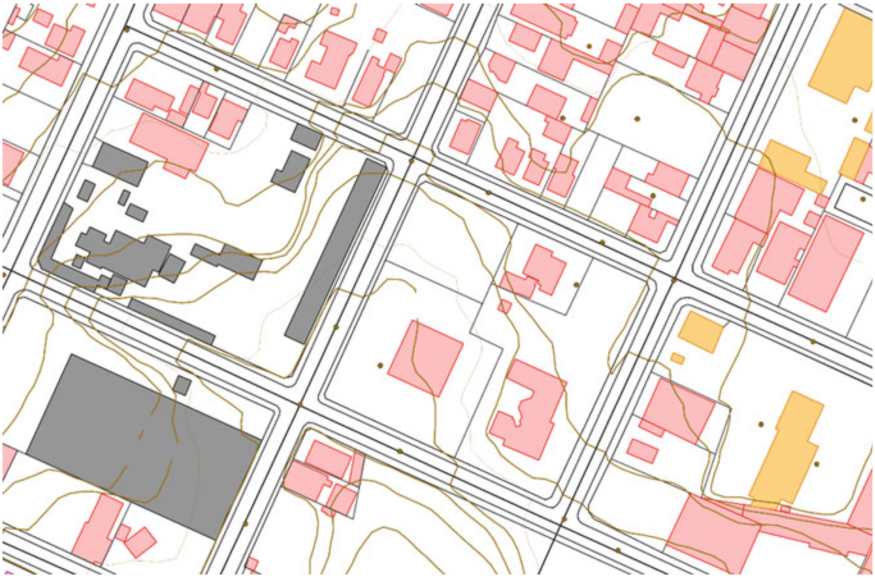


Fig. 3 Campo Largo city topographic map with all of its features represented

Fig. 4 Campo Largo city topographic map with only the target features represented

Fig. 5 Pinhais city topographic map with all of its features represented

Fig. 6 Pinhais city topographic map with only the target features represented

the state of Paraná are made with cartographic conventions defined by the Technical Chamber of Cartography and GIS of the state. These conventions define the classification of buildings, streets, vegetation, hydrography and the symbolization of each single class.

Figure 7 shows the proposed method, which includes the following steps: (1) identify the representation problems on the map when its scale is reduced, (2) define the constraints related to each representation problem, (3) define the

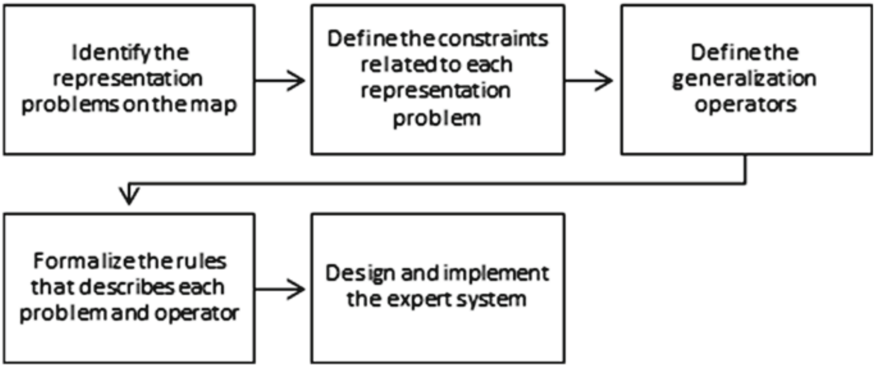


Fig. 7 Steps of the proposed method

generalization operators, (4) formalize the rules that describe each problem and operator and (5) design and implement the expert system.

3.1 Representation Problems

To perform the first step, which was to identify the geometric conditions that cause legibility and visibility problems, we reduced the scale of the maps from 1:2000 to 1:5000. We then visually analyzed the map at 1:5000 scale so that we could identify the regions where there were problems related to map reading and map representation.

The visual analysis made on the reduced map had two main objectives: (1) to verify which geometric conditions exist and, therefore, must be foreseen on the expert system, and (2) to gather enough knowledge about the logical sequence of operations that the system should do to detect automatically what was visually detected by the human operator.

Figure 8 shows the same region of the topographic map of the city of Campo Largo at a 1:2000 scale (*a*) and at 1:5000 (*b*). The red circles indicate examples of specific features that had representation problems because of the reduction in scale. Because of the proximity of buildings, it was difficult to visualize individually and identify some of the features. As a consequence, the legibility of the map was impaired. Moreover, there are buildings and interior corners of buildings that are not visible because of the reduction of their sizes. This situation, which was related to a visibility problem, contributed to a legibility problem.

We identified three geometric conditions as described by McMaster and Shea (1992). One of them was congestion, in which several residential buildings (represented in pink) were depicted on a smaller area and resulted in an overcrowded representation. The coalescence condition, under which residential buildings were too close to each other or to other features, caused a total or partial overlap of

Fig. 8 **a** Campo Largo city topographic map representation problems are identified by *red circles* at 1:2000 scale. **b** Campo Largo city topographic map representation problems are identified by *red circles* at 1:5000 scale

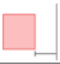
features on the map. We detected the occurrence of those two conditions in all of the analyzed features (buildings, property boundaries, and streets). The imperceptibility condition occurred because many features or the interior corners of buildings were represented below the minimum size that could be seen. That condition occurred in all of the buildings classes. Based on those observations, we defined the constraints to be used to detect automatically each problem or condition. The distance and length were among the constraints.

The representation problems can be understood as a consequence of the geometric conditions, and there are problems related to visibility and legibility. A legibility problem occurs when the user has difficulty reading the

Table 1 Geometric conditions, their constraints and representation problems

Geometric conditions	Constraints	Representation Problems
Imperceptibility	Length of solid square or rectangular side Length of interior corner	Visibility
Congestion Coalescence	Distance—line and building Distance—buildings	Legibility

Table 2 Symbols, constraints and their minimum values

Symbol	Constraints	Minimum value (mm)
	Distance between buildings	0.25
	Distance between a line and a building	0.25
	Length—interior corner	0.30
	Length—solid square	0.30

map. The visibility problem occurs when the user cannot identify single features or see their interior corners. Table 1 shows the geometric conditions, their constraints and the representation problems that we identified in the topographic maps.

We defined the value of each constraint based on the geometric conditions previously identified. We used the distance and length values determined by Taura (2010), which are shown in Table 2. These values were established from users' tests that were a result of experiments on symbol visual perception. The constraints were therefore divided into two types, 'distance' and 'length' because the evaluated basic geometric aspect and constraint value were the same. Based on that knowledge, we developed two sets of rules for the expert systems; one set to detect legibility problems (distance constraint) and the other set to detect visibility problems (length constraint).

3.2 *Expert System*

We established the rules for the expert system based on the geometric conditions previously identified, the established constraints and the spatial analysis tools available in ArcGIS. The starting point for proposing the two set of rules was to select the generalization problem, whether visibility or legibility. Then, for each of the problems, we needed to formalize the decision tree elements and their relationships (decisions). The automation of the decisions was based on the constraints, related geometric conditions and the ArcGIS tools for spatial analysis.

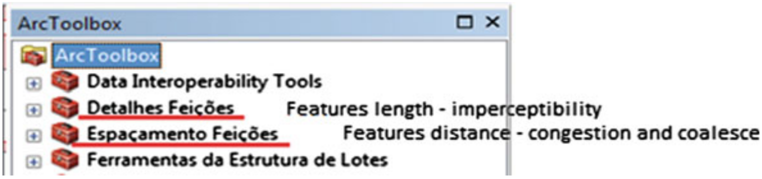


Fig. 9 Expert systems were developed to detect legibility and imperceptibility problems according to the geometric conditions

We implemented the decision trees using ModelBuilder, which is an ArcGIS application. In our implementation, the minimum values of the graphic parameters (constraints), which we mentioned in Table 2, were defined as default values. However, the users (cartographers) can change those values when they decide that it is necessary. The users can also choose which representation problem and features class they need to analyze (Fig. 9).

In ModelBuilder the classes to be analyzed were represented in blue, which we called the target classes, the applied actions or tools were represented in yellow, and the results were shown in green. The figures below that represent how the systems worked have components colored according to the ModelBuilder representation. The components, therefore, can be easily identified.

3.2.1 Legibility Problems

Figure 10 shows an example of the decision tree workflow that we established to detect legibility problems. For each building class, the expert system defined a buffer according to the constraint distance at the new scale. A new layer was created that only contained the buffer results. The next step was the application of the ArcGIS intersection tool between the new layer and the other layers, which were buildings, property boundaries, and streets.

The result of the overlay operations was a new layer in which the buildings and the part of those buildings that did not match the distance constraint, in accordance with the generalization conditions, were represented. As an example, Fig. 11 illustrates a part of Pinhais topographic map where the commercial buildings, by convention represented as yellow polygons, were the target of the cartometric evaluation. The buildings that exceed the constraint value are represented as cyan polygons and the part of those buildings that contribute to the legibility problem are represented as black polygons.

3.2.2 Visibility Problems

We designed an expert system that can be used to detect imperceptibility problems and implemented it based on the same reasoning that we implemented for detecting

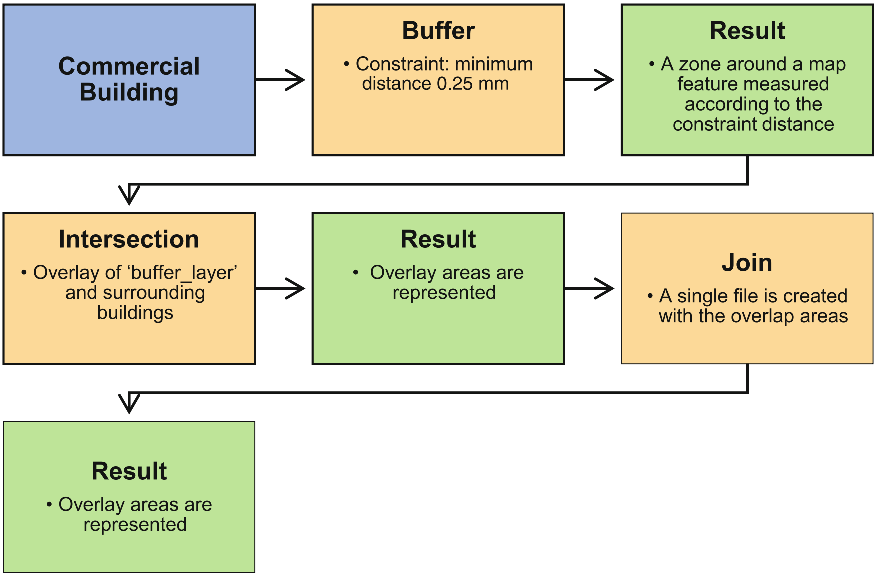


Fig. 10 Expert system workflow used to detect legibility problems

Fig. 11 Pinhais city topographic map with the result of the overlay operations using commercial buildings as a target at 1:5000 scale

legibility problems Fig. 8. However, for the imperceptibility problem, we used more ArcGIS tools. Because the imperceptibility constraints involve the length of a building or of its interior corners, each feature must be analyzed individually. It was, therefore, necessary to apply an ArcGIS spatial tool to create a new layer with all of the vertices of all of the features of the target class. Next, we used a tool that added the (X, Y) coordinates of all of the feature vertices to the attribute table. Figure 12 shows the workflow of the expert system used to detect imperceptibility.

The 'Selection' tool was used to select single features according to their identification numbers (FIDs). With the 'Proximity' tool, the system could calculate the distance between each vertex of a single feature and add that value to the attribute

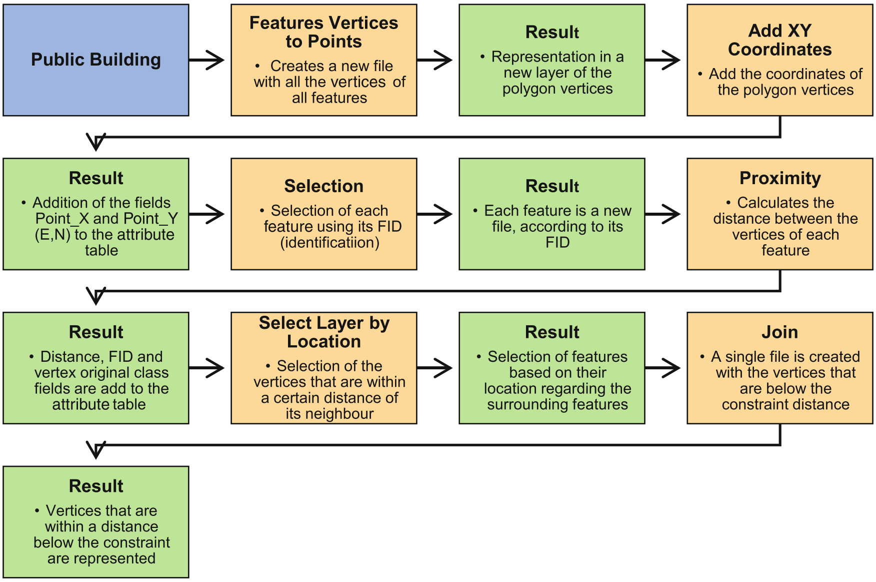


Fig. 12 Expert system workflow used to detect imperceptibility problems

table. From that step, the ‘Selection Layer by Location’ tool was applied to select only those vertices that did not match the distance constraint on the length of the sides and the length of the interior corners and then created a new layer.

As a final result, the system created a new file for every analyzed feature class. As an example, Campo Largo city topographic map has 9 classes of buildings, 2 classes of streets and 1 property boundary class. When used to analyze Commercial Buildings, the system created a new file for every analyzed class with commercial buildings, and the result was 11 new files. The ‘Join’ tool was used for the last operation and was executed on both sets of rules of the expert system. The tool created a single file with all of the features that had representation problems, according to the defined constraints. Therefore, only one new layer was added to the visualization screen.

4 Results and Future Research

4.1 Expert System—ModelBuilder

The system creates new output layers in which the features that have representation problems are stored. Figure 13 shows the results of detecting features that have legibility problems at the 1:5000 scale. In this example, the target class was commercial buildings, conventionally represented as yellow polygons. The system

Fig. 13 The result of the expert system to detect legibility problem on Campo Largo city topographic map at 1:5000 scale

detected which commercial buildings were too close to other buildings or to any other features classes. If the distance between a commercial building and any other feature was below the distance constraint, the commercial building was shown in cyan.

The system also created two new layers with black polygons and red lines, as shown in Fig. 14. The black polygons overlap the buffer applied on the commercial buildings and the buildings near them. The overlays between the commercial buildings and property boundaries are represented by red lines. The figure below is at a 1:2000 scale for better visualization.

The layer created as a result of the expert system to detect imperceptibility problems shows vertices that are too close to each other and, therefore, at a scale of 1:5000 cannot be seen as a single vertex. Figure 15 shows an example of an industrial building. The points represented in cyan characterize interior corners that do not match the minimum length constraint. This indicates that this building should be simplified. The figure below is at a 1:500 scale for better visualization of the results.

Fig. 14 Black polygons and red lines—legibility problems detected on Campo Largo city topographic map at 1:2000 for better visualization

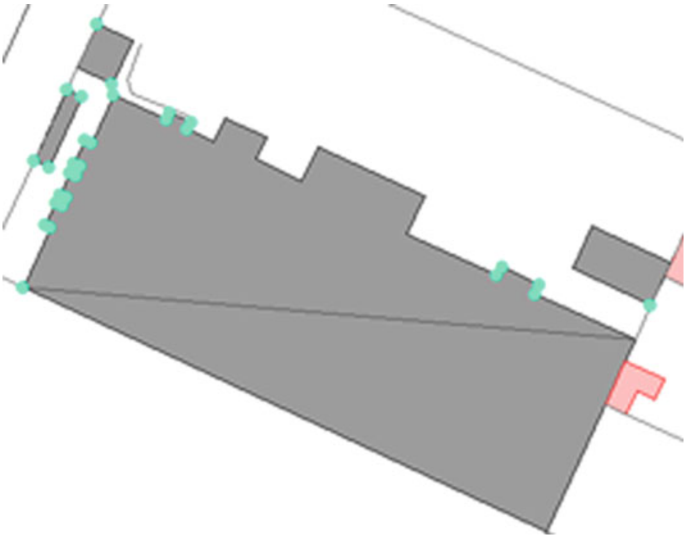


Fig. 15 Cyan dots—imperceptibility problem detected in an industrial building from Pinhais city topographic map at 1:500 scale for better visualization

4.2 Expert System—QGIS

Because the automated detection of geometric conditions using an expert system based on rules of a decision tree was successful, our current goal is to develop a similar solution implemented for QGIS.

Figure 16 shows the workflow for a general system to perform cartometric evaluation and apply generalization operators based on this evaluation. The expert system is based on the same logic as the system created with ModelBuilder. The cartometric evaluation is performed using the rules of a decision tree and constraints that are formalized based on the representation problems. The spatial measurements will result in new rules and constraints that will be added to the system. The application of the generalization operators is based on these rules. As an example, a region that has a coalescence condition has represented features that are too close to another, and the proximity of the features are defined from a minimum value that is the distance constraint. The system will indicate which features cause this condition and which operator must be applied: an amalgamation if the features are from the same class or a displacement if the features are from different classes.

The rules and constraints will be created using the Python language (www.python.org). Spatial analysis tools and new rules will be added because the cartometric evaluation includes spatial and holistic measures.

The system will analyze each feature class directly from a database, and there will be only one set of rules for the entire cartometric evaluation, unlike the system

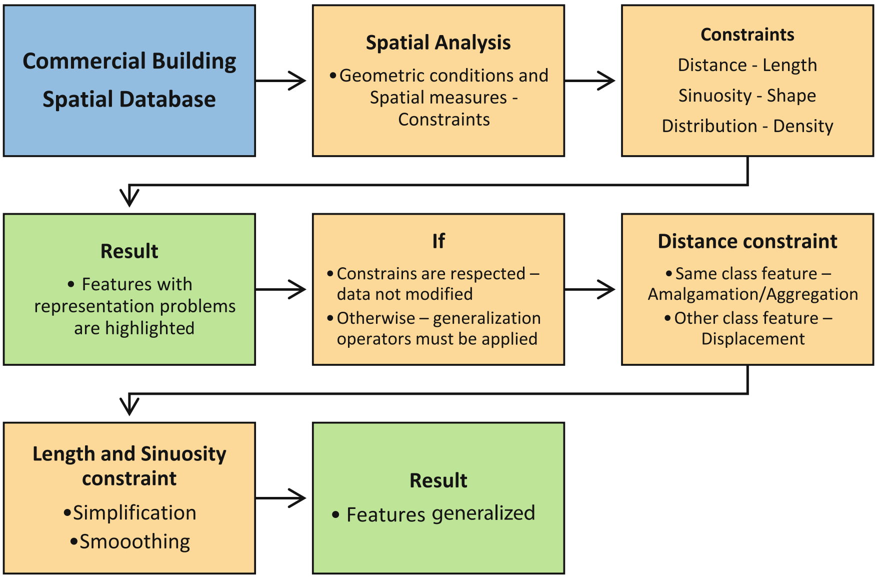


Fig. 16 Expert system workflow to perform cartometric evaluation and spatial transformations

developed on ModelBuilder, which has a single separated set of rules for each representation problem and worked with classes already uploaded on ArcGIS.

Because it is known that geometric conditions can be described as representation problems, we need to establish relationships between the spatial measurements and representation problems. With this knowledge, it is possible to formalize new constraints and create new rules for the expert system.

The expected results are two types of layers. One type of layer shows the features that have representation problems, and the other contains the generalized features.

5 Conclusion

The results obtained using the expert system developed on ModelBuilder required that the user interacted with the computer by choosing which problem to detect and the class to be analyzed. The user also had the option to change the constraint values.

The proposed solution for detecting legibility problems achieved good results. All features of a map class were analyzed together and at the same time. The rules and constraints for visibility problem detection were difficult to formalize using ModelBuilder, and the features had to be individually analyzed. This could make the generalization process time consuming.

The expert system under development using Python and QGIS will be designed to perform automated cartometric evaluation on topographic maps and at a minimum to indicate which generalization operators should be applied to eliminate or minimize representation problems.

Automating the generalization process faces one great challenge: translating subjective ideas and actions into specific rules. However, automatically executing the cartometric evaluation or detection of representation problems using expert systems can make this process less dependent on human interactions and more efficient.

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Cartographic Visualization of Historical Source Data on AtlasFontium.pl

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Abstract The purpose of the paper is to present an ongoing project of AtlasFontium.pl which is intended to serve as a platform for publishing spatially-related historical source data along with their cartographic visualization concerning polish territory. The text describes the main assumptions on which the web page was based, its current state, and characteristics.

Keywords Historical geography · Historical cartography · Historical GIS · WebGIS

1 Introduction

The scientific project in the form of a website "Atlas of Sources and Materials for History of Old Poland" (Atlas Fontium Antiquae Poloniae) also called the AtlasFontium.pl was created in order to establish a platform aimed at collecting and disseminating historical sources and materials, primarily those with a spatial reference. The project is developed by the Department of Historical Atlas in the "Tadeusz Manteuffel" Institute of History in Polish Academy of Sciences (hereinafter DHA) in collaboration with the Laboratory of Historical Geoinformation at John Paul II Catholic University of Lublin. The key objective of the project is to elaborate a consistent digital model of historical sources editions which combines several elements including: direct access to the scanned manuscript, ability to analyse the data within the spatial database, visualizing the outcomes in WebGIS application as a digital map.

Chronological and spatial framework of the project are currently limited to Polish lands before 1772, i.e. the first partition of Poland. However, in the future it will be possible to add materials related to neighbouring areas, not being a part of

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_5

the Crown of the Polish Kingdom, such as: Lithuania, Silesia, Pomerania and Prussia. Since this period is rather flexible it is possible to publish materials or data from other periods.

Projects published on the website may be diverse in nature and may consist of traditional studies of historical issues, historical sources editions and materials intended to be applied by other researchers. The website acts on the basis of a scientific journal with its own ISSN number (2353-9216), editorial board, scientific council and the reviewing procedure.

The concept of developing such a platform results due to several reasons. Firstly, a phenomenon of "spatial turn" can be observed in the humanities, i.e. conducting analysis within spatial and geographical paradigm, what often obliges researchers to use set of IT tools including the Geographic Information System—GIS (Withers 2009).

The effect of this "turn" is easily visible on various internet platform which become a powerful accelerator of this change and a suitable ground for historical GIS (hGIS) projects publication. Number and range of offered resources is wide, although they all deal with different kinds of issues. Some of them concentrate on specific historical topics like itineraries (Digitized travel accounts of late medieval and early modern Europe, www.digiberichte.de/; accessed: 15.12.2015), depiction of space in medieval written sources (Digitising Patterns of Power, http://dpp.oeaw.ac.at/; accessed: 15.12.2015) or Jewish communities (Mapping the Jewish Communities of the Byzantine Empire, www.mjcb.eu/; accessed: 15.12.2015), travels in the antiquity (Orbis, http://orbis.stanford.edu/; accessed: 15.12.2015; Meeks and Grossner 2012; Scheidel 2015) or combining historical-cultural context with space (Digital Atlas of Roman and Medieval Civilization, http://darmc.harvard.edu/; accessed: 15.12.2015). There are also initiatives focusing on reconstruction of historical urban topography (Mapping the Medieval Urban Landscape www.qub.ac.uk/urban_mapping/index.htm/; accessed: 15.12.2015; Mapping Medieval Chester, www.medievalchester.ac.uk/; accessed: 15.12.2015; Lilley et al. 2005). They vary also in matter of their outcome: they often provide downloadable data as well as their visualization as WebGIS. Some of them intend to prepare vector layers for the GIS software (China Historical GIS, http://www.fas.harvard.edu/~chgis/; accessed: 15.12.2015) sometimes with dedicated data sets (National Historical Geographical Information System, https://www.nhgis.org; accessed: 5.03.2016) while others' aim is to create data sets connecting information with geographical coordinates (Pelagios, http://pelagios-project.blogspot.nl/; accessed: 15.12.2015, Pleiades, http://pleiades.stoa.org/; accessed: 15.12.2015) or produce "total" hGIS platform for a particular area (A Vision of Britain through Time, http://www.visionofbritain.org.uk; accessed: 15.12.2015; Southall 2011, 2012, 2014).

In spite of vast array of European hGIS projects, the idea behind AtlasFontium.pl came mostly from the current work conducted in DHA related to historical sources editing. This led to the conclusion that there is a need to integrate traditional editing methods (i.e. reading and rewriting the manuscript) with IT tools and GIS. Therefore, a main direction for change comes from the use of GIS, including spatial databases, source materials digitization and cartographic visualization in order to extend and deepen historical phenomena analysis.

The platform aims to serve as a repository of works dealing with historical-geographical issues, but projects gathering and making them available is not an aim in itself. It is more of a starting point for creating a universal database using a developed standardized form of describing basic spatial objects, particularly elements of cultural landscape, having regard to changes they underwent with time. The database is meant to be a foundation used to provide more information about various geographic objects—providing them with social, economic, legal, or cultural context (Szady 2013a).

Followed by this *modus operandi,* it can be stated that the platform varies from above-mentioned hGIS projects. The platform provides an IT infrastructure and methods of historical spatial data analysis and visualization as well as basic data sets (see below) for other historians, who are willing to present their space-related data or research.

2 Current State and System Architecture

At this time (April 2016), AtlasFontium.pl combines 9 projects including spatial database of Poland in 16th century, digital and spatial edition of tax registers form 16th century, followed be an array of spatially-oriented historical sources encapsulated in a database form and depicted on a digital map (Table 1).

Resources published on the website are available through a three-tier architecture which consists of a database, data server, and two applications used for data visualization and sharing. Information about features' geometry (position in the adopted geographical coordinate system) and attributes (descriptive data) are stored in the spatio-relational database (PostgreSQL PostGIS 9.5 + 2.1 W). Data are available on-line using spatial data server (MapServer 6.4) or as separate files in *.mdb, *.xls, *.csv formats.

As mentioned above, the website supports two applications for content depiction. The first (PMapper 4.2) is a WebGIS application used for cartographic visualization of spatial data, while the second (INDXr) allows to view scanned manuscripts on-line.

PMapper presents spatial data both in vector and raster formats, as well as allows to join external source layers through spatial data services such as Web Map Service (WMS). Application functionality also includes toggling layers' visibility along with their descriptions, changing transparency, identifying individual features, as well as performing search queries based on SQL syntax.

The second application (INDXr) was created for the electronic edition of the Wschowa Court Book in 1495–1526 and serves as the browser for scanned manuscripts in raster format. Its main functionality involves not only scanned material visualizing, but also a capability of its indexing with the application of a database and a digital map. Manuscript content's digital indexing is one of the methods of historical sources editing developed by the DHA research group and is described afterwards.

Table 1 Resources published on AtlasFontium.pl along with their type, spatial coverage and period (http://atlasfontium.pl)

Resource title	Period	Spatial coverage	Subject
Corona Regni Poloniae. Map in scale 1:250,000, Atlas Źródeł i Materiałów do Dziejów Dawnej Polski, No. 1, The Tadeusz Manteuffel Institute of History of the Polish Academy of Sciences	2nd half of 16th century	Central part of Polish Kingdom	Raster basemap
Tax Registers from the Voivodeship of Kalisz in the 16th century, Atlas Źródeł i Materiałów do Dziejów Dawnej Polski, No. 2, ed. by M. Słoń, The Tadeusz Manteuffel Institute of History of the Polish Academy of Sciences	2nd half of 16th century	Voivodeship of kalisz	Digital sources edition (tax registers)
Tax Registers from the Voivodeship of Poznań in the 16th century, Atlas Źródeł i Materiałów do Dziejów Dawnej Polski, No. 3, ed. by M. Słoń, The Tadeusz Manteuffel Institute of History of the Polish Academy of Sciences	2nd half of 16th century	Voivodeship of poznań	Digital sources edition (tax registers)
Materials for the dictionary of the land of Liw in Middle Ages and 16th century, Atlas Źródeł i Materiałów do Dziejów Dawnej Polski, No. 4, Kazimerz Pacuski, technical ed. M. Gochna, B. Szady	Middle Ages	Land of Liw	Gazetteer
Polish Territories of the Crown in the 16th century. Spatial Database, The Tadeusz Manteuffel Institute of History of the Polish Academy of Sciences	16th century	Polish part of Polish Kingdom	Vector basemap
Religions and Confessions in the Polish Crown in the 2nd half of the 18th Century, Bogumił Szady, Historical Geoinformation Laboratory, Catholic University in Lublin	2nd half of 18th century	Polish Kingdom	Geography of religions
The Court Records of Wschowa, 1495–1526 (working version), ed. by M. Słoń, The Tadeusz Manteuffel Institute of History of the Polish Academy of Sciences	Begin of 16th century	Land of Wschowa	Digital sources edition (court books)
Register of Protestant communities in the Polish-Lithuanian Commonwealth in the 16th–18th centuries, ed. Maciej Ptaszyński, Early Polish Culture Research Team, Institute of History, University of Warsaw	16th–18th century	Polish-Lithuanian Commonwealth	Geography of religions
Parish libraries of Wiślica praeposite in the second half of the 1th ventury, Joanna Szady, Insitute of History, John Paul II Catholic University of Lublin	2nd half of 18th century	Praeposite of Wiślica	Geographical distribution of books

An important element of the website is a search engine that allows to search all available publications (databases) based on various attributes, e.g. settlements' names both contemporary and historical, establishment date, feature's spatial location, etc. In addition to the global search capability, each publication has its own search engine adopted to the specificity of the stored data (Fig. 1).

It is worth mentioning, that using particular software for data storage and presentation does not preclude the platform to be interoperational with others. Since the PostgreSQL/PostGIS database environment is an OGC standard, it is easy to disseminate data to other formats.

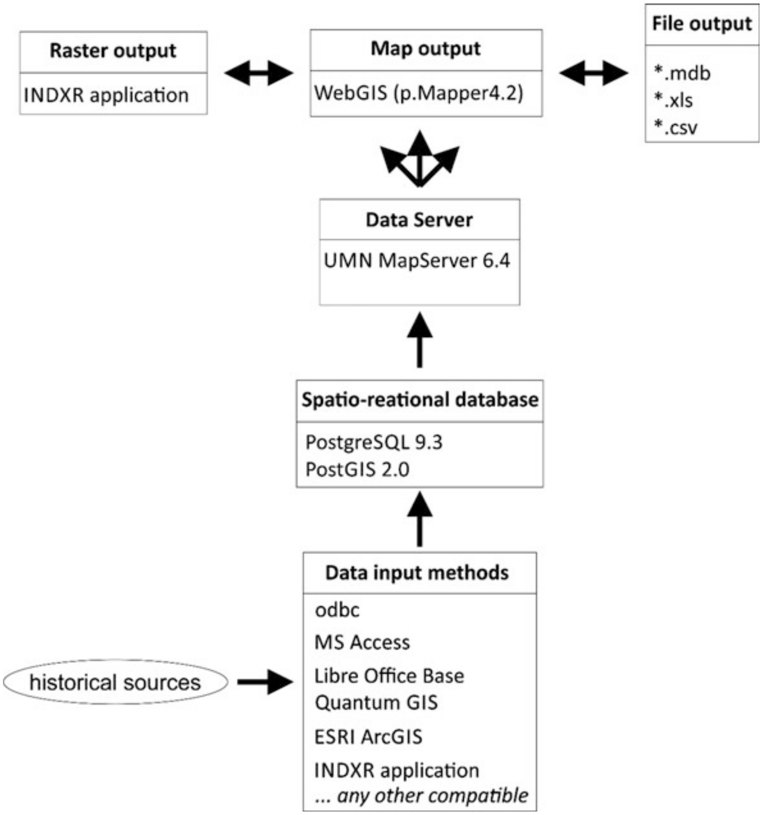

Fig. 1 General architecture schema of AtlasFontium.pl resources (*source* own elaboration)

3 Main Resources

It is important to describe relationships between main resources published on AtlasFontium.pl as an example of a concept of basic data and its use and expansion in subsequent publications. The main resources include the spatial database of Polish Territories of the Crown in the 16th century, Tax Registers from the Voivodeship of Kalisz and Poznań in the 16th century and the Digital edition of the Court registers of Wschowa from 1495 to 1526.

3.1 Polish Territories of the Crown in the 16th Century Spatial Database

The map of Polish Crown in the 16th century is the digitalized database version of main maps published in Historical Atlas of Poland, Detailed maps of the 16th century series (hereinafter HAP) (Słoń 2014). In addition to HAP maps elaborated from 1966 to 2008, this digital map has been also supplemented by certain elements connected with the volumes which are being elaborated at this time, i.e. Kalisz and Poznan Voivodeship. Furthermore, it also covers and the areas of Pomerania, Cuyavia, Dobrzyń land, and Podlasie which are to be covered by HAP series to the end of 2020.

Therefore, the range and scope of digital map's content is not homogeneous. For HAP series elaborated from 1966 to 2008 the digital map stores information about the settlement network, administrative and ecclesiastical boundaries and hydrography (lakes and rivers). In addition to these elements, in Kalisz and Poznan Voivodeship afforestation is also covered. On the other hand, for those areas which are to be developed by 2020, the range and scope of map's content is rather schematic. The settlement network for these territories has not been developed on the basis of historical sources analysis, but with the use of previously published scientific descriptions (Biskup and Tomczak 1955; Biskup 1961; Guldon 1964, 1967; Laszuk 1998; Mikulski 1994). The map also lacks administrative and ecclesiastical borders as well as afforestation.

The database schema, both for the settlement layer (points) and administrative units (polygons) is based on the relationship between the spatial table containing features' geometry and the attribute table with descriptive data (names of settlements or units, etc.). The spatial table contains two columns: a unique feature's identifier and its coordinates according to the "ETRS89/Poland CS92" coordinate system (Olszewski and Gotlib 2013). In the case of polyline or polygon layers all features' nodes are stored in the database in order to present requested shape.

The attribute table also called the "summary table" stores descriptive information about features. The main attributes are: unique identifier linking spatial and attribute data, settlement's 16th century name along with its varieties, contemporary name, type of ownership (nobility, royal, church, town), parochial affiliation, type of settlement; type of location and any necessary commentary.

These fields are compulsory for areas covered by HAP series. For Poznan and Kalisz Voivodeship, the database schema also includes field related to the settlement's owner (institution or person), administrative and ecclesiastical functions, the approximate number of population and the name under which the village exists in Historical and Geographical Dictionary of the Polish Land in the Middle Ages (http://www.slownik.ihpan.edu.pl/; accessed: 06.07.2015). At this moment, the database contains information on more than 24,000 settlement points of which nearly 23,500 was located and presented in the form of a point layer on a digital map (Fig. 2).

For administrative and ecclesiastical units modelling the Least Common Geometry method developed by Langran (1989) was used. Each polygon is constructed as the smallest possible homogeneous parts in terms of its attribute data, i.e. administrative and ecclesiastical affiliation. Each of the polygons is supplied with an identifier of the powiat (district—the smallest administrative unit) and parish (the smallest ecclesiastical unit). As a result, the database has no geometrical data redundancy and thusly topological errors are quickly identified and solved. Visualising administrative and ecclesiastical units like districts or parishes, and consequently voivodeships, deaneries or archdeaconries is based on the spatial

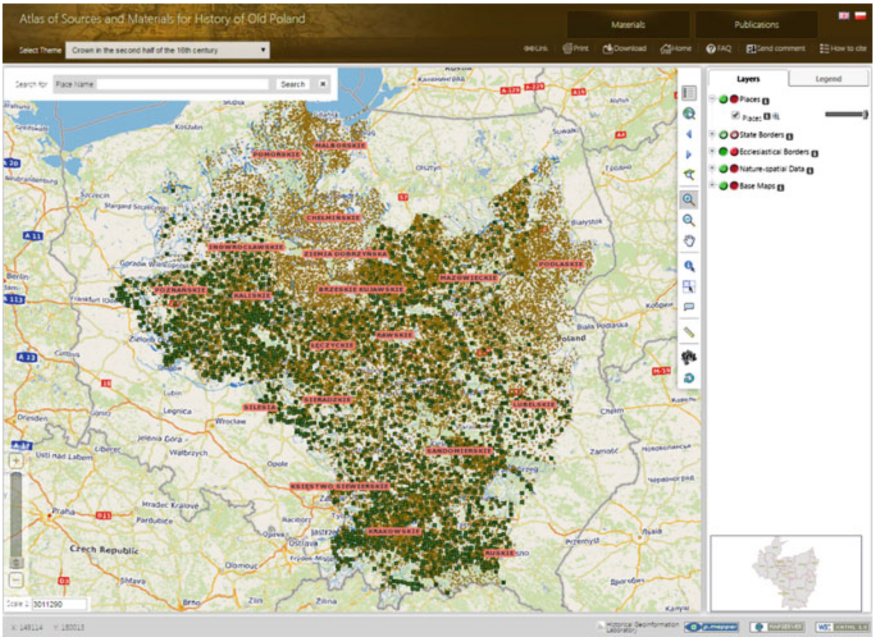

Fig. 2 Reconstruction of the settlement network in 16th century on AtlasFontium.pl (http://atlasfontium.pl/index.php?article=korona&language=en)

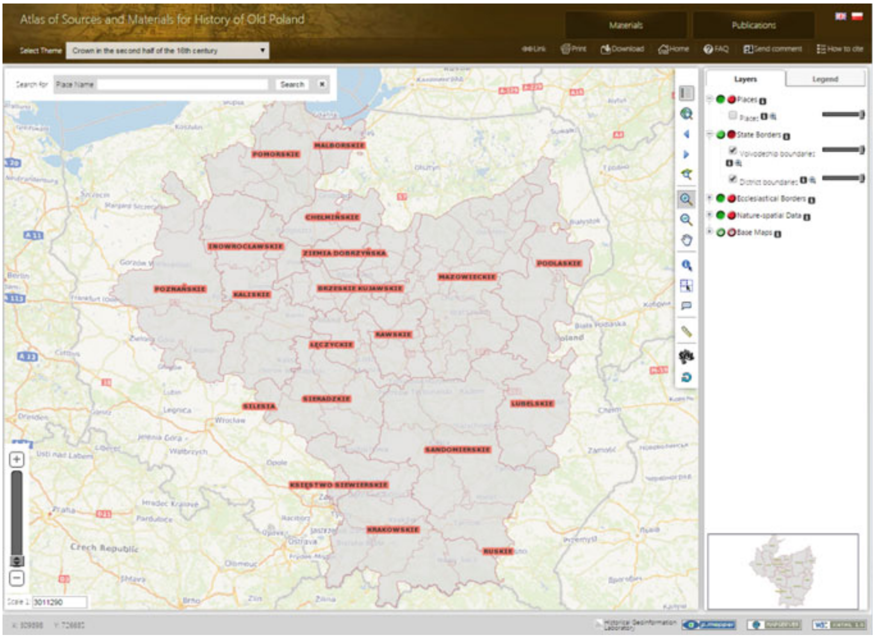

Fig. 3 Reconstruction of administrative and ecclesiastical borders in 16th century on AtlasFontium.pl (http://atlasfontium.pl/index.php?article=korona&language=en)

query (such as "ST_UNION" in PostGIS or "Dissolve" in ArcGIS), which dissolves and combines features sharing the same attribute (Fig. 3).

The basemap contains hydrography as well with both line (rivers) and polygon (lakes, large rivers) vector layers. It presents partially the natural landscape from 16th century as it is a reconstruction based on a retrogressive method based on 18th/19th century topographic maps (Słoń 2014; Leturq 2015). In the areas not yet covered by exhaustive HAP works, the river network is derived from contemporary spatial database of topographic objects although the information about data source of each feature is stored in the database so that users can easily distinguish historical reconstruction and current state presentation (Fig. 4).

This database is intended to serve as a basemap for other projects as it provides spatial and attribute information about settlements in 16th century—as in case of two editions of sources presented below that use the data as a foundation for spatial reference of source information. The database is downloadable in *.mdb ArcGIS geodatabase format directly from the website.

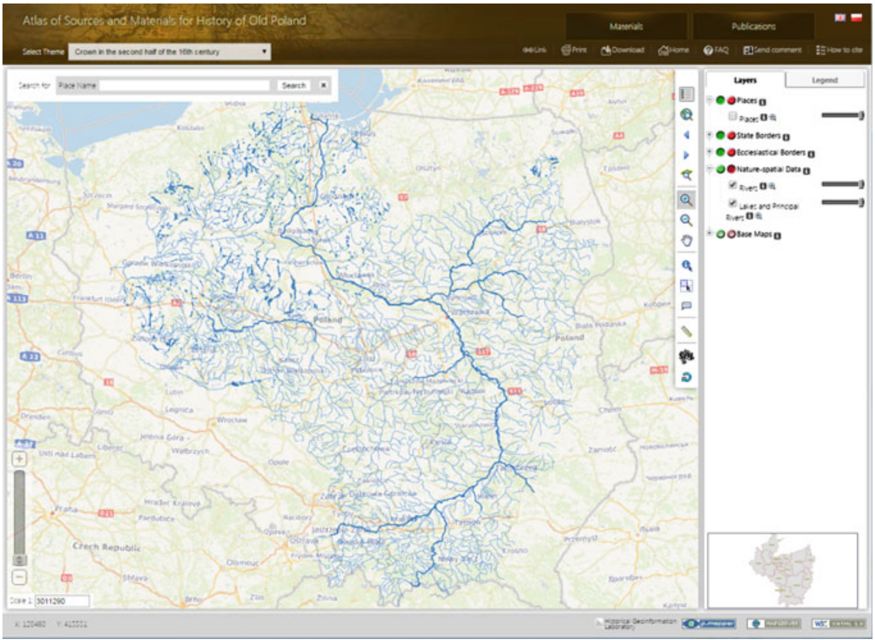

Fig. 4 Reconstruction of hydrography on AtlasFontium.pl (http://atlasfontium.pl/index.php?article=korona&language=en)

3.2 Kalisz and Poznań Voivodeship 16th Century Tax Registers

Tax registers are one of the primary sources of Polish economic landscape reconstruction in the 16th century as they were created as a result of extraordinary tax collecting enacted by parliament for war purposes. Tax registers record various taxing categories including: land acreage expressed in lans (except for demesne lands and villages newly-located), outbuildings (e.g. mills, windmills, taverns), rural and urban population (e.g. hortulani, artisans), etc. (Gochna 2014). In addition, for 16th century, there are several tax registers for each for area coming from different years. It allows to compare the changes both in time and space occurring in the economic landscape. What is important, tax registers remain a very valuable source of spatial data—information is assigned to a specific settlement point. Hence, it is possible to place it on a digital map, analyse in terms of spatial correlation, elaborate thematic maps, etc. Tax registers have gained great importance during HAP works where they served as a basis for the settlement network reconstruction since they provide a possibility of almost full settlements' recognition in the particular area. This is due to the fact that the taxed items were assigned to specific settlements which were aggregated at the levels of a district.

The digital edition of the Poznan and Kalisz Voievodeships tax registers consists essentially of two separate publications for each province in a total number of almost 100 individual registers. It was developed using three-tier system architecture: spatial database, WebGIS application supplemented by the module designed for scanned document sharing. The edition is based on scanned registers acquired from the Archive of the Crown Treasury and spatial database as a technological background.

The method used for editing tax registers is based on conversion their informational structure into table. In accordance with the source, a single settlement point was chosen as the basic unit of information organizing. Each record contains technical, source and "varia" fields. Technical fields have several functions including establishing relations between various application modules (scanned manuscript, database, digital map) or helping to perform statistical analysis by noting total tax value or total acreage. Source fields contain tabular information derived from each tax register, such as: settlement name, parochial affiliation recording its name, ownership, the date of payment, and the amount of tax paid. The main content of the entry involves taxed items and is stored mostly in the form of numeric data type (taxed acreage, economic facilities, professional groups). Another field ("varia") stores any other information that cannot be cast as a number (e.g. justification why a particular acreage was not taxed) or taxation objects so seldom mentioned in the records, that it unnecessary to create a separate column for them. Any important comments related to the entry are also included in "varia" (e.g. various types of handwriting in the registry or total tax paid calculated wrongly). This tabular editing form is supplemented by the source commentary which characterizes each tax register.

It is worth noting that all data records stored in tabular form are available to download as an *.xls file. Each file contains a single sheet based on "summary table" with the set of settlements located in the district and a few sheets (depending on the number of tax register available) with tabular tax records of consecutive years. These tables are to reflect the structure and extent of the source, simultaneously allowing the data to be applied for statistical analysis.

The WebGIS application providing cartographic data visualisation is the second edition module. End user gets an opportunity to display the source layers, in the form of individual records of conscripts or all at once. After selecting one of these options, settlements which are listed in the source will be marked on a map. The tax register information will be provided for a selected settlement. The main role of a digital map is enrich the information with the spatial context. From this application module it is also possible to download *.xls files with tabular tax data, access the source commentary and scanned registers (Gochna 2014). As it was mentioned before, tax data is visualized on the basemap which consists of layer from the spatial database of Polish Territories of the Crown in the 16th century

The last module implemented in the edition is the ability view scanned manuscripts. Scanned materials are available from both the downloadable *.xls files as well as WebGIS application through a system of hyperlinks. In both cases, the entry (record) is associated with the page manuscript. With direct connection to the

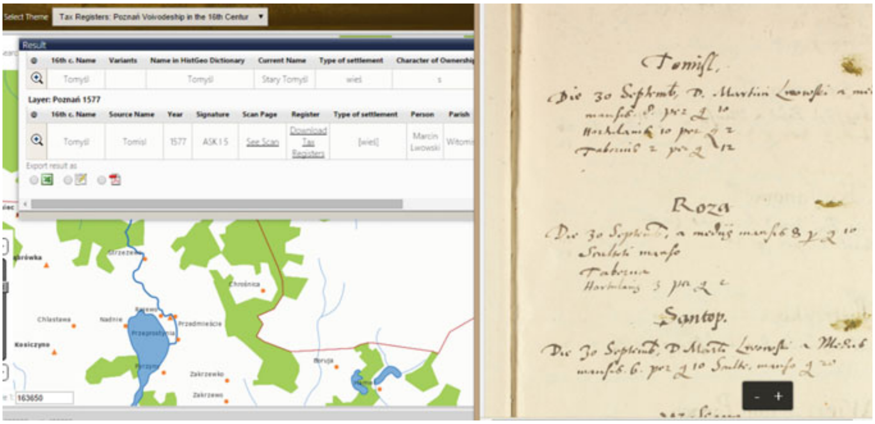

Fig. 5 Tax register of Tomyśl village from 1577: map visualization, tabular form and manuscript viewer (http://atlasfontium.pl/index.php?article=poznanskie)

manuscript, end user has the ability to verify the value which was stored in the database (Fig. 5).

The tax registers edition in a digital form allows to analyse this data source more efficiently. Since its nature is largely statistical and based on standardized and reproducible data, it allows to be adopted in a tabular form in natural way and thusly more easily applied for statistical analysis. What is worth noting, combining the tabular edition with a facsimile of the document still allows the user to work with the source in its original form and to verify the outcomes resulting from the edition.

3.3 *Wschowa Court Book from 1495 to 1526*

Another publishing project posted on the site, is the edition of Wschowa Court Book from 1495 to 1526. The project, executed by a team of researchers from various scientific units in Poland was the pilot work of INDXr application used for manuscripts editing. The court book itself has a completely different structure than tax registers and its spatial significance is considerably weaker.

Wschowa Court Book can be classified as a kind historical source, which is defined as the register of entries. They were kept in chancelleries of many offices in Poland in the late Middle Ages and Early Modern period and used for recording the activity of a given institutions and foreign documents that were needed to be authenticated. They make a collection of various entries in chronological order combined into one physical unit as because the cases they concerned fell within the competences of one institution (Brzeziński 2014).

The structure of this project is similar to tax registers edition and consists of a database, INDXr application used for scanned documents indexation and a WebGIS module responsible for cartographic data visualisation. The backend core of the edition is represented by two tables: table of entries and index table. The first contains information about the main unit of the manuscript, i.e. single entry. These are described by the several columns (Table 2).

Both tables are available to the user via a web browser providing basic functionality including sorting and searching. There is also a possibility to gain access to the scanned manuscript as well as the WebGIS application from the tables through a system of hyperlinks.

Table 2 Wschowa Court Book database fields (*source* own elaboration)

Table of entries		Index table	
Field name	Field description	Field name	Field description
Technical identifier	It consists of: archival book signature, page number on which the entry appears and sequence number specifying its order on the page	Location of an index term	
Number of sheet on which the entry appears		The first form which appears in the entry	
Date of the legal action		Standardized term form	
Date in source form	According to the liturgical calendar	Additional information	In case of settlements, its character and in terms of people, the occupied the position or family relationship mentioned in the source
Header	If it was absent in the source, the kind of legal action the entry concerned	Any necessary commentary	
Indication of the writer's hand		Term type	Personal, geographical or any other keyword
Any necessary comments			
Selected entries reading meant to provide palaeographic support			

The second and the most important and innovative module is the INDXr application which is used for viewing the manuscript of Wschowa Court Book. Due to the possibility of labelling (tagging) fragments of the manuscript it is possible to create a relationship between the scanned document and the database. Therefore, the content of the manuscript is essentially structured and through its indexation also possible to be searched. The whole operation can be divided into two phases.

In the first phase individual entries are marked (tagged) on the scanned document (raster component) for which the application automatically generates IDs which are brought to the table of entries. The second phase is to apply another tag on the raster—index terms on already-marked entries. These fields are associated with the index table. Again, marking a manuscript fragment that contains an index term automatically creates related record in the table, with identifying number and information about the entry in which the term appears (link with the entry's primary key ID). At the same time, a dialogue box is opened, so that the user can enter the term. Finally, the scan of the manuscript page is shown with marked entry fields, and the side box lists all terms on the page. They can be checked and highlighted at will. There is also the possibility of passing directly into the index table and maps (Fig. 6).

The last module is a digital map of the Wschowa district. In fact, this is a part of previously mentioned database of Polish Territories of the Crown in the 16th century. In addition to basic data about the settlements, acquired from the "summary table", the map has been supplemented with information about the their presence in Wschowa Court Book. After selecting each settlement, a list of all records, in which it appeared is provided along with a link to the scanned manuscript (Fig. 7).

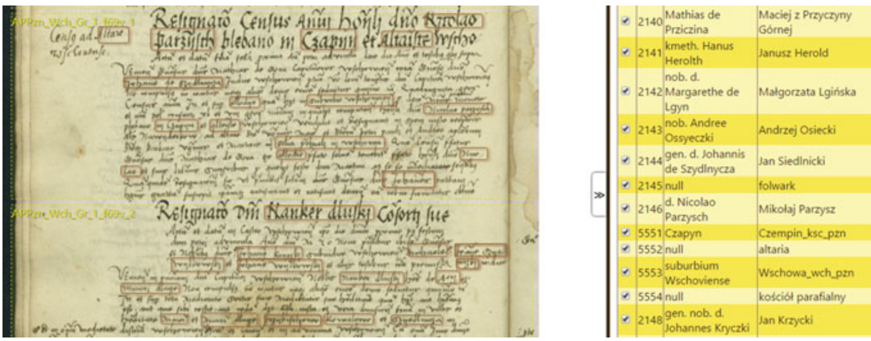

Fig. 6 INDXr application allows users to tag manuscript fragments and append them to database structure (http://atlasfontium.pl/index.php?article=wschowa)

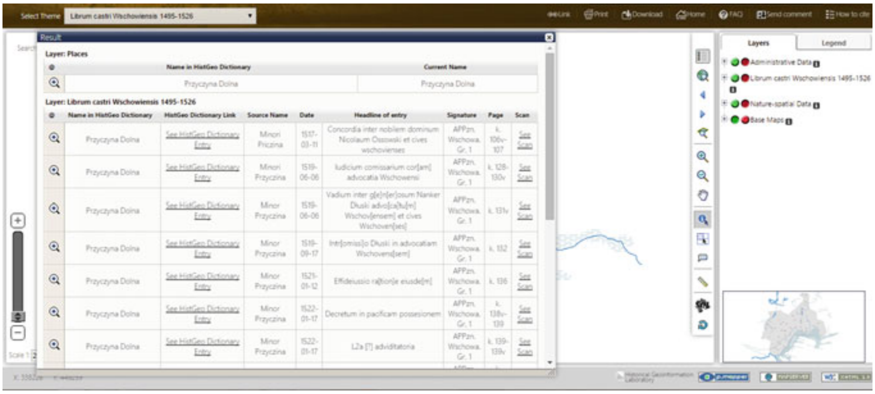

Fig. 7 Digital map of Wschowa Court books allows to link map, tabular index and manuscript with INDXr application (http://atlasfontium.pl/index.php?article=wschowa)

3.4 Summary

The presented model of platform functionality is focused on data integrity, i.e. common spatial reference of every publication what is maintained by the database of Polish Territories of the Crown in the 16th century (see: Paragraph 3.1). The integrity does not preclude the platform form its interoperability: it is possible to add external sources as long as there is a set of common identifiers between databases. Each publication based on different sources is treated separately as it is based on different attribute model (i.e. the database structure should correspond with the structure of the source). For example, tax registers were prepared in the tabular form, but data from the Wschowa court book was elaborated as a spatial and attribute index. For these reasons, the concept linking scanned manuscripts, digitalized data and the WebGIS application for cartographic presentation is proven to be optimal for historical-geographical studies.

4 Platform Future Development

The platform is barely two years old, and for now its set of basic spatial data is still concentrated on settlement network in 16th century. This is caused by the fact that data for this period were most easily accessible and convertible to form of a spatial database. But future development and utility of AtlasFontium.pl depends on extension of its chronological scope. The platform targets the more complex and holistic answer, which is remodelling database to time-variable structure where settlements can be described by attributes with "data_start" and "data_end" fields (Gregory and Healey 2007; Szady 2013b).

In the current version of the platform, data can be downloaded in tabular *.xls file format or spatial database in *.mdb. The next step should be to implement the possibility of downloading user-specific thematic layers in *.shp (ESRI shapefile). For example, features selected by spatial or attribute query can be made downloadable instead of the necessity of acquiring the entire database which will expand in a time and thusly taking large amount of computer's memory. Those users who do not want to retrieve data, should be able to display them in GIS applications through spatial data services in accordance with the INSPIRE directive (http://inspire.ec.europa.eu/index.cfm; accessed: 07.06.2015). This initiative aims to build a European Spatial Information Infrastructure by providing access to spatial data for each user from the European Union. Currently, the most popular spatial data services are WMS and WFS. With WMS, each user can view a digital map in their own PC using specific GIS software (e.g. QGIS, ArcGIS, Geomedia, etc.) in the form of raster tiles. Through WFS it is possible to not only view, but also save and edit maps in vector format, execute SQL queries and perform spatial analysis.

The platform development will also mean adding new components and projects, e.g. cartographic sources. The first of such projects will be the digital edition of "Mapa topograficzna, wojskowa i statystyczna Wielkopolski" (in English: "Topographic, military and statistical map of Grater Poland"). It was being developed in 1807–1812 by German cartographer Ernest Gaul while the patron of this work was count Edward Raczynski—the founder of Raczynski Library in Poznan. The map was designed to cover the Poznań Department in the Duchy of Warsaw in a large and detailed scale but was prepared solely for the 8 out of 14 counties (Żyszkowska 2012). Furthermore, it was being elaborated in coloured version, but it was lost during the World War II and remains today only in the form of black-and-white photocopies. Map edition, which will also serve as a basis of developing a model of digital cartographic source editions will be based on IT tools including GIS, and will involve map's georeferencing, symbols' graphics reconstruction and spatial database elaboration.

Another type of new materials that will find its place on the website will be contemporary thematic maps based on historical data, e.g. statistical maps based on tax registers. Maps based on such data will encompass primarily fiscal issues (e.g. total sum of paid tax), the number of taxable goods (e.g. windmills) and other settlements' characteristics. They will be supplemented by the historical commentary and made available not only as graphic files, but also in vector (*.shp) and georeferenced raster format (GeoTIFF) and as a spatial data services (WMS/WFS).

The third aspect of platform development will be referencing and linking historical spatial data with contemporary geographical repositories. One of the effects will include supplementing the WebGIS application with modern topographic base maps, e.g. those derived from the national Geoportal or OpenStreetMap. This will allow the user to place historical geographic information in contemporary context and build spatial relationships between the past and present. Another goal which requires much more work will be to develop in the future Historical Spatial Data Infrastructure. It will integrate historical and modern spatial data in terms of attributes and geometry, so that spatio-temporal analysis will be possible between various kinds of cartographic and spatial data. One of the methods will involve establishing relations between AtlasFontium.pl features and these stored in the national "Database of Topographic Objects (BDOT10K)" (Olszewski and Gotlib 2013).

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Pins or Points?—Challenges in Producing Cartographically Appealing Webmaps Within an Editorial Environment for LiD *Online*

Jana Moser and Sebastian Koslitz

Abstract Cartographers are facing several challenges in transforming geographic knowledge into interactive webmaps. Of course there are different webmapping technologies that can be used by everybody. Nevertheless implementing special forms of cartographic expression require cartographic knowledge as well as sophisticated programming skills and depend on technical limitations. This paper presents the newly developed cross-media production for the publication series 'Landschaften in Deutschland' (LiD) and discusses different webmapping solutions, their benefits and disadvantages as well as some challenges concerning prosumer-webmapping.

Keywords Webmapping · Cross-media production · Applied geography · Interactive cartography · Spatial CMS

1 Introduction

Why should a cartographer use pins when there are 'better' ways of expressing the same data?

Consider new methods of multimedia production, for example an established book series that goes online: in June 2015 the volume 'Leipzig' of the 'Landschaften in Deutschland' (LiD) book series was published. Initially an accompanying web presentation with additional and multimedia content was prepared. For its publications—print and online (IfL 2000–2007; Meusburger and Schuch 2011; Hanewinkel and Losang 2013)—as well as for the transfer of geographic knowledge to a wider public (Lentz and Moser 2013), the Leibniz Institute for Regional Geography

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_6

(IfL) always puts emphasis on high quality cartographic representation of spatial phenomena in forms of thematic maps and visualisations.

'LiD *online*' shall be seen in strong connection to the book as an interactive medium for presenting additional and linked information. At the same time it has to work as single solution as it is open access without necessity to buy the book. The website uses different mapping solutions to visualise spatial information. Occasionally static maps are displayed in the printed book as well as on the Internet. Certainly the website focuses on interactive maps. These were developed using programming languages like ActionScript and JavaScript, as well as the D3.js and Leaflet.js programming libraries. In addition, Mappetizer software was used to transfer ArcGIS-based projects into HTML5-based web applications. The base layer for nearly all maps is based on OpenStreetMap (OSM) data. The base map layout was designed with CartoCSS and the map itself delivered as vector tiles hosted by Software as a Service (SaaS) platform Mapbox.

During the process of developing and implementing the Content Management System-based website we discovered various challenges and obstructions in the use of cartographic methods in webmaps. The following chapters discuss possible approaches for solving these problems. Chapter 2 gives a very brief overview of the technical requirements and sociocultural challenges of webmapping technologies. This is followed by an introduction into the aims of the book series 'Landschaften in Deutschland' and its way to the Internet (Chap. 3). Chapter 4 introduces the webmapping technologies used for LiD *online* and balances pros and cons relating to our developed CMS. To conclude, Chap. 5 discusses these approaches and our findings in the context of the argument that webmapping is easy to use by prosumers (non-experts in cartography, which produce and use maps using tools in Web 2.0). From our point of view, a reflection on defined production approaches for creating webmaps in connection to forms of cartographic expression is called for.

2 Webmapping—A Brief Overview of its Socio-Cultural and Technical Requirements

The webmapping landscape (Haklay et al. 2008) is currently as huge as mapping products in general and constantly changing (Roth et al. 2014). Different concepts and tools as well as very fast wireless Internet access through cheap devices of different size, high screen resolution and good equipment allow everybody to create maps on the Internet. This functions not only at home at the desk but everywhere in the world.

The internet as well as the wide distribution of mobile devices changed the use and production of maps fundamentally. Mapping can be—but not necessarily is—

no longer just a one-way transfer but a real communicative process. The sociocultural impact of cartographic practices has to be analysed bidirectionally: (1) in terms of the opportunities and challenges of creating webmaps that includes technological requirements on one hand and the (critical) reflection of production processes on the other hand, and (2) concerning the impact and influences of spatial visualisations itself by using them (e.g. Plantin 2011; Muehlenhaus 2012). Both impacts stay in relationship to concepts of critical geography and critical cartography (Harley 1989, 1990; Crampton and Krygier 2005). Facing the processes of production, use and reflection of maps and visualizations within the IfL and observing similar processes during our research on different webmapping projects (e.g. for biodiversity) we have to state a gap between (critical) reflection about maps and concrete production processes.

The technical developments allow many people to create maps very easily. The possibilities of creating maps on the Internet, especially interactive, multimedia, mobile, modifiable, collaborative and/or participative ones, range from high-end GIS systems to very simple mashup maps using APIs. For a review of the dynamic technical developments in the past two decades see Plewe (2007), Haklay et al. (2008), Lienert et al. (2012) and Hoffmann (2013). The benefits of these mapping possibilities from everyday life are well known. One owns position can be seen in real time, navigating through an unknown city is far easier as well as finding the nearest open café at midnight, or informing others about interesting places. It is possible to share the route of the last hiking trek with the community or to warn people to avoid places because of traffic jams or other obstacles. This all is possible by simply mapping the data, with the aid of small devices and an Internet connection. In addition, it is possible to use the act of mapping to assist others in crisis situations.

Visualising different kind of (location-based) data is easy but designing good thematic webmaps (see Jenny et al. 2008) is still a challenge and needs cartographic knowledge as well as programming skills. Peterson (2008: 5) argues that users of online-GIS need to be highly-motivated; the same is needed to create good designed and cartographically appealing webmaps. Furthermore it is not only a question of technique to create meaningful webmaps. “*The main point of Web mapping is not to use the latest and greatest technologies. The point is to create maps that communicate clearly and intuitively and that people can readily access from myriad interfaces. […] Cartography and mapmaking are forever evolving, just as all forms of communication are. The primary goals of communication remain the same regardless of medium and regardless of technology; they are to inform, persuade, and explain. It does not matter how you do it*” (Muehlenhaus 2014: 226).

Initial—still unpublished—findings from our research project on critical map production and use in the Internet referring to the term ‘democratisation of map making’ (see Moser et al. 2015) show a wide and mostly unreflected use of few modes of visual expression and little concern about basemaps. Colour is widely used, and often the usage of simple cartographic/graphic rules could make the maps statements much clearer. Also many webmapping projects show little critical reflection on what the visualised data communicate. One more of the challenges is a reasonable conception of the visibility of thematic maps on different screen resolutions depending on the communicative strategy of a map designed and the importance of detail versus overview.

As said before webmapping provides also benefits in communicating knowledge by collaboration and participation of various groups of interest instead of simply transferring it. The fast adding of data and the ubiquitous availability of spatial visualisations result in new and growing challenges concerning their (powerful) usage for different interests and a (critical) public involvement (e.g. Wood and Krygier 2009; Parker 2006; Lingel and Bishop 2014). Prosumers (e.g. experts in biodiversity that map their monitoring results for further scientific analysis) often need and sometimes ask for guidance to get the 'right' webmap for their purposes as long as they do not want to spend much time learning cartographic rules and different programming languages.

3 A Long-Standing Book Series Goes Online

3.1 Landschaften in Deutschland (Landscapes in Germany) —A Short Outline

In 1957, the first volume of a book series was published, known today as *Landschaften in Deutschland* (Landscapes in Germany). The aim of the series is to transfer knowledge about various cultural landscapes in Germany to a wider public. Special considerations were made for students. Therefore small parts of the landscape—single plane-table sheets in the beginning, today normally interrelated cultural landscapes—are described, bringing together different disciplinary experts of a region. As can be seen in the map overview (Fig. 1), the series started in East Germany (Saxony). Until the end of 2015, 73 volumes have been published.

With its concept of a regional and cultural overview in the first part, as well as the comprehensive description of single features of the landscape in the second part, the book series met public demand for a long time. All volumes concentrate on quality, especially in terms of maps and images. Compared to other products, they contain numerous thematic maps covering a wide range of themes on Geography, Geology, Botany, Zoology, Archaeology, History, Linguistics, Economics, etc. In one part of the book, maps of the same scale—depending on the extent of the region —present the dissemination of languages or dialects, the development of settlements, archaeological findings and other topics. This can be seen as a kind of atlas of the region. In the second part of the book, there are various map-based illustrations of different scales and different content, such as construction plans of churches, developments of industrial areas and maps of conservation areas.

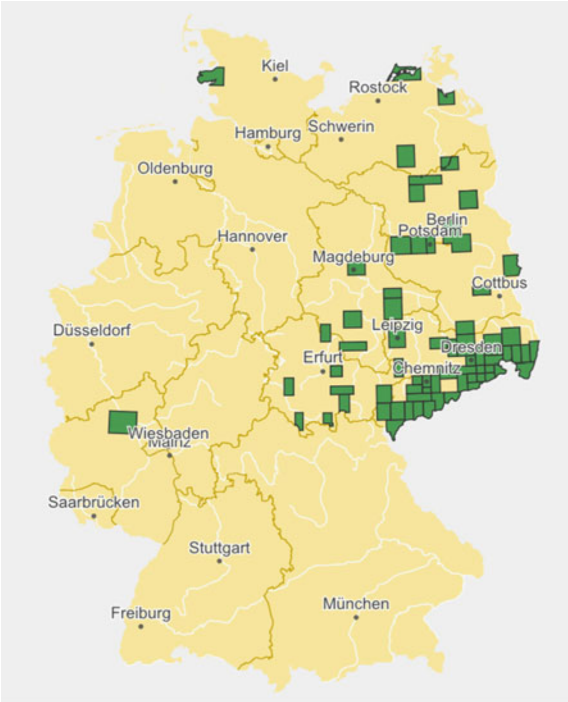

Fig. 1 Map overview of cultural landscapes in Germany described in the *Landschaften in Deutschland* book series (www.lid-online.de/regionen)

To meet the interdisciplinary approach and to gain a readable compendium for a wide range of interested parties, the IfL established an intensive editing process. Figure 2 shows the organisational structure for one book of the series.

3.2 Relaunch of the Series

For about three years, the IfL and the publishing house—the Böhlau Verlag—have been thinking about a reorientation of the series. The developments in digital media combined with changing reading habits and changes in how users consume information led the publishers—the Leibniz Institute for Regional Geography and the Saxon Academy of Sciences—, to intensively consider new possibilities for the transfer of cultural landscape knowledge. Another approach of this development was the additional wish to connect with a younger audience.

In 2015, the published volume ‘Leipzig’ was relaunched as a cross-media publication in three parts (Denzer et al. 2015; IfL 2015):

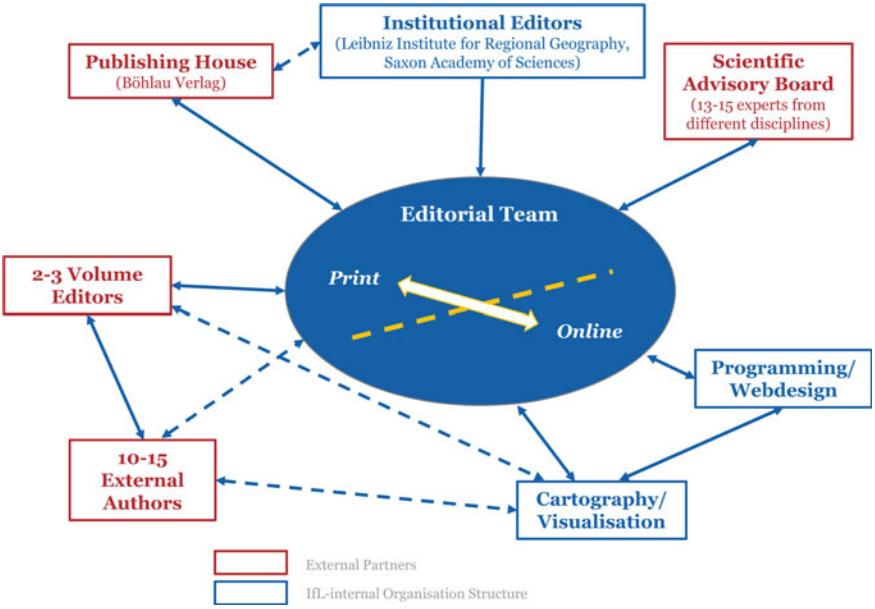

Fig. 2 Organisational structure of Landschaften in Deutschland (print and online), own compilation

- The printed book received a new format and cover layout. Various changes were implemented in the interior, such as a two-columned layout, about 1.5 images per page which is approx. 50 % more than previously, establishment of highlighted short and long boxes with special explanations in the form of text and visualisations.
- In addition to the printed book, the reader can download an identical e-book in pdf format. Analyses by the publishing house and the IfL showed the necessity for a digital product to search the texts and take the contents into the field without the need to carry the printed volume. It is not possible to purchase the e-book without the printed book.
- The third part of the cross-media production is the newly developed www.lid-online.de website. The site was developed by the IfL and is free of charge to any user, whether purchasing the book or not. Hence it is a standalone product that can be used independently of the book. The publishers decided to connect book and website by integrating QR codes in the volume. With this concept, it is possible to obtain more in-depth descriptions and additional interactive material for various topics that can only be touched on in the book due to length restrictions and printing technology.

3.3 Conception and Implementation of the Website

Realisation of the website followed different aims. In addition to the above mentioned aims of reaching a younger audience and keeping up with the times in terms of the ubiquitous consuming of different content by digital media at any time and place, the IfL wanted to provide additional value to the book. This entails not reflecting the book contents one-on-one, but providing the user with the possibility of engaging with special themes of the landscape in different and more in-depth ways. The objective was to bring together the user, the contents and the landscape. Last but not least, the website should assist the user in learning something without even recognising it as such, by means of a more playful approach. The Website's approach is to provide a meaningful content-oriented combination of interactive maps, texts, pictures, figures and multimedia to support a reflective communication of regional geospatial knowledge. It never was planned and should not be taken as a Web-GIS.

Starting the process we defined some conditions and limitations that are related to the demands of a research institute like the IfL and combine methodological developments with product developments and research in visual communication: (1) getting a well-structured simple website; (2) having a clear and homogeneous design that should also count for the webmaps; (3) implementing a robust CMS with only small administrative needs due to limited resources; (4) providing fast access; (5) initially user registration and contribution was not required; (6) additional content should be integrated easily in the system; (7) the webbased site had to be responsive—no additional App-programming is necessary as we count for further developments in mobile browser technology; (8) integrating existing maps and mapping projects; and (9) last but not least evaluation of different webmapping technologies to find advantages and rate expenses for further IfL projects.

We had a total of approximately two years for the conception of the website. The implementation was done within a half year.

The content was structured in three main parts:

- *Themes* can be seen as a thematic contribution. They follow the principles of authorship. Using text and different multimedia elements such as images, animated or interactive maps and graphics, as well as videos or slide shows, the user can develop a much deeper understanding of different themes than only from the book with its inherent limitations.
- *On the Move* goes back to the origin of the book series: the books should contain information for teaching the History, Geography, Biology, etc. of the environment in school and university courses. Therefore this part suggests some routes for excursions and may be developed into an offer to users to compile their own routes with the given or even with additional information. One main purpose of this website is to force users to discover a city or landscape by moving within the field and not only by sitting in an armchair. Related to this, the editors want people to learn something about their surroundings and geographical relationships without even knowing that they are learning, merely by having fun.

- *Landscapes* is in the form of an archive of the 72 volumes published before the website was initiated. The regional spread can be seen on an interactive map and for every volume at least the cover, an abstract, the contents and different indexes such as authors and registers are given.

Technically, we wanted to enable users to consult the website on different devices and with different screen resolutions. Due to the fact that additional App-programming was not thought about, we decided on a responsive design of the web browser delivered site. Some special decisions had to be taken, especially with regard to the maps. The thematic maps in the books have to provide an atlas-like overview and the possibility of discovering details at ones. This aim results in the 'normal' cartographic decision process of map design. With screens one has not only to think about one shape of a map, but has to decide which content can be seen on different scales and in special technical contexts, especially for mobile devices.

Due to the fact that the website and its CMS was developed parallel to the new layout and creation of the book, and that there were some interactive maps and data from former projects that should be integrated in the website, different mapping solutions came into account (for details see next chapter). While implementing these webmapping technologies they were evaluated regarding possibilities, impacts, disadvantages and necessary resources for further webmapping projects and developments.

The website's CMS was developed using a Golang based Static Site Generator which compiles the website in prior. Advantages are the ease of handling regarding transfer and hosting issues, very short response times and its safety against attacks. Therefore it needs less regular care.

4 Webmaps in LiD *Online*

As introduced, LiD *online* uses different mapping solutions to achieve the desired communication goals. Often the communication purpose lies in knowledge transfer of the spatial environment on several topics. In addition to the communication goals, we had to meet the aims of integrating existing data and sources and also different formerly produced mapping projects in our CMS. Beyond that, some maps give the user the ability to interact with the map to receive more information that exist outside the map, others are animated to show changes within the discussed topic. All maps are designed as thematic maps, as navigation purposes do not exist. The maps produced for LiD *online* currently follow the "Web's pull technology" (Cartwright 2008: 12) with the editorial team and the authors as the main instances to decide about the content and the way to visualise.

In the following section, several case studies demonstrate the technologies and map characteristics used. Table 1 shows used technologies and their suitability as to different parameters.

Table 1 Pros and Cons of used libraries and software (own compilation)

Software	CMS integration	Mobile usage	Custom map styling	Output graphic
Flash	–	–	+	Vector
D3.js	+	+	++	Vector
Leaflet.js	++	++	++	Vector/raster
Mapbox API	++	++	+	Vector/raster
Mappetizer	–	–	–	Vector/raster

4.1 Slippy Maps for Excursion Article Series

Solid browser and CMS integrated slippy maps were developed using JavaScript library leaflet.js and APIs from the SaaS platform, Mapbox Inc. The OSM base map design was extended by using CartoCSS to style OSM data layers to the desired needs. The base map was delivered as vector tiles hosted by Mapbox. Other thematic map layers were implemented using leaflet.js ui layers. Metadata of the thematic layers were delivered through the developed CMS.

Throughout the website, several mapping applications are based on this stack. Firstly it is developed for the 'On the Move' section to show and explain the locations on the excursion. In addition, it is used for some topics when there is a number of different locations, each with a separate description or interpretation (e.g. the age of buildings). Due to the lack of time, we used the given push-pins with integrated numbers as markers for the location-based content and published all maps in this form (Fig. 3). From a cartographic point of view, this is not satisfactory. Figure 6 presents one of the main disadvantages of this method, the overlapping of symbols within initial scales and some zoom levels. Clustering could be one solution but should depend on the theme and not only to use the technique. Therefore we developed a cartographically more appealing design with point symbols (see Sect. 4.5 below for further explanation).

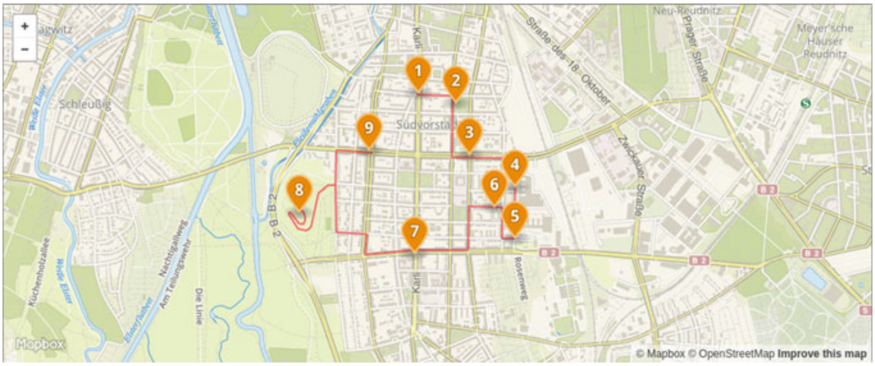

Fig. 3 Excursion map with given push-pins and representation of the proposed excursion route (www.lid-online.de/78532)

4.2 LiD Landscape View

Unlike most of the existing maps within LiD *online*, this map was developed from scratch. Using the JavaScript d3.js library, a small-scale map with equal-area projection of German State territory and regions which are already published within the LiD series was prepared (see Fig. 1). The base map should be limited only to some elements such as Federal State boundaries, main rivers and selected cities for orientation. Data for the base map were obtained from naturalearth.com shapes. The thematic overlay of LiD regions was received from GIS project data. All spatial data were optimised for browser usage by transformation to TopoJSON file format. The main communication goals of this map were a clear and intuitive survey of published regions within German State territory, as well as a content overview of the regions with user interface to obtain additional regional information by clicking on the region's shape. As the map was developed with the d3.js library, a high level of programming knowledge was required. But nearly every map detail (except labelling issues) could be designed as needed.

4.3 Choropleths for Statistical Datasets of Population

Choropleth maps were used to represent standardised data within articles. Several map projects already existed as finished GIS projects and therefore were implemented as WebGIS with Mappetizer® web mapping software, whereas other thematic maps were created from scratch by using the d3.js library (Fig. 4).

In so doing, it was realised that the WebGIS-based maps were not suitable for mobile browsers, due to a significant amount of library assets and performance issues. Likewise, some limitations exist within the WebGIS solution related to the map design which could be partially overcome with additional expenses of manual adjustments.

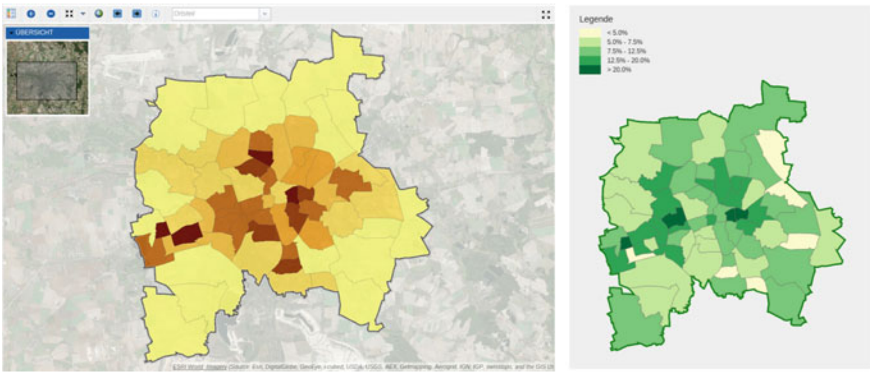

Fig. 4 Two examples of choropleth maps using WebGIS with Mappetizer® (*left*) and D3.js library (*right*) (*left* www.lid-online.de/78110; *right* www.lid-online.de/78107)

The d3-based choropleth map was developed using the library itself as well as the handy JavaScript libraries colorbrewer.js (for use of effective colour schema) and underscore.js (preparation of data).

By comparison, the d3-based map offers a more intuitive and effective method of data exploration than the WebGIS interface, which is less suitable for users who are unfamiliar with GIS itself. Furthermore, the d3-based solution was much smaller in application size due to optimisation with TopoJSON format, the disuse of map tiles and the library size itself but resulted in expenses for adaption to different browsers.

4.4 Animated Flash-Based Maps

Just like the existing GIS projects, thematic maps already existed as ActionScript-based projects. To overcome the limitations that come with Flash applications (e.g. plug-in installation and partly no support on mobile browsers), a Flash to HTML5 converter (Google Swiffy) was used (Fig. 5). However, some limitations still exist. Mobile device usage does not exist because all converted map applications show a lack of performance. Furthermore, the converter library itself sets a maximum application size. But it has to be mentioned that the library is commonly used for web advertising and not for web mapping.

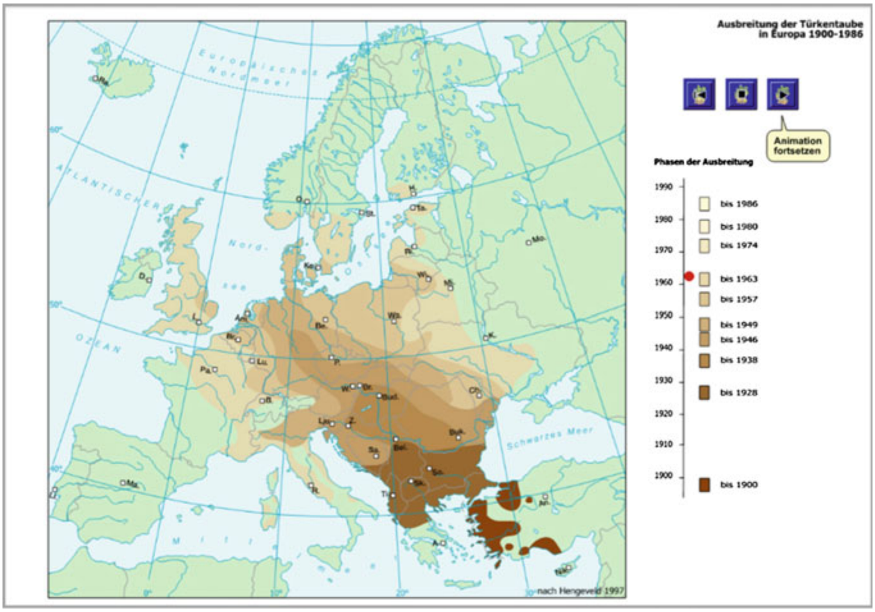

Fig. 5 Animated Flash-based map on the temporal and regional spread of the (Eurasian) collared dove (www.lid-online.de/78152)

4.5 Improvements of Slippy-Style Maps Symbology

As explained, the cartographic solution for some maps, especially concerning thematic maps with point-related data, was not satisfactory (Fig. 6). Due to the lack of time, we used given push-pins with integrated numbers which results in quite large pins that very often overlie. Therefore the user is not able to get an overview of the thematic content of the points given at initial scale and zoom level.

Having the clickable map on top of the webpage covering the whole column and up to 80 corresponding descriptions below, we needed the numbers to link the content visually. Especially coming back from the description to the map by clicking the link, the user needs to know where to find the position corresponding to the description he has come from.

Referring to Huang and Gartner (2012) and Meier (2016) we had more than one option of avoiding cluttering of push-pins. Due to maps initial scale and zoom factor pin filtering and clustering were not satisfactory approaches as this visual representation would annoy cartographic communication. Aggregation methods like heatmaps and tiled heatmaps were not applicable due to the low size of pin related data. We decided to follow different approaches.

The first one, designing a very new georeferenced map colouring the building's polygons would be the most cartographic one and give the best opportunities e.g. in

Fig. 6 Overview over buildings and their construction phases in the city centre of Leipzig using common push-pins (www.lid-online.de/78104)

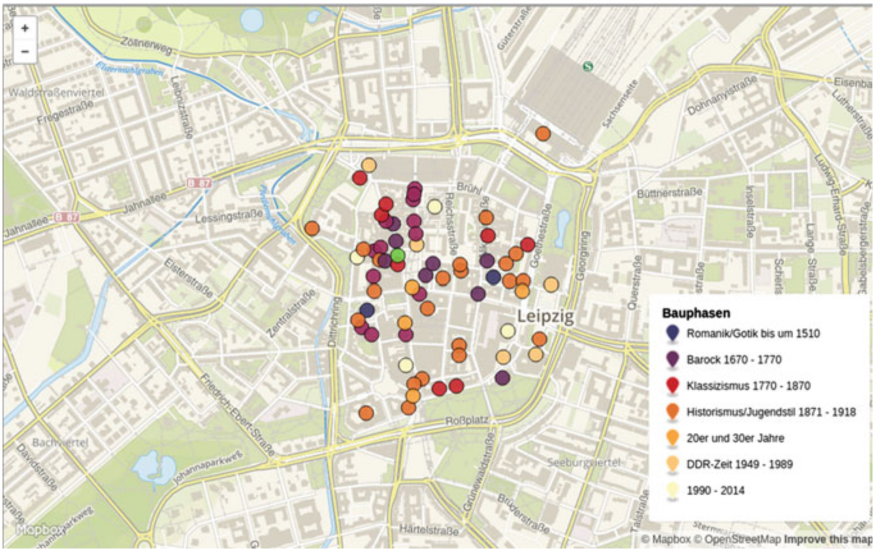

Fig. 7 Overview over buildings and their construction phases in the city centre of Leipzig using point symbols and highlighting technology (blinking green point) (not yet published)

highlighting phases of building construction, but had to be rejected in terms of the cost-benefit ratio.

Another cartographically plausible approach is the use of dots instead of pins, without numbering (Fig. 7). To achieve this form of custom styled map layers, the leaflet-based map could easily be extended. In addition to the dots, an interaction was needed to call the user's attention to a point caused by avoidance of the numbers inside the dots. For this, an animated circle marker with event listener was programmed, resulting in a blinking dot. It was not that difficult to reach this goal, but definitely needed much deeper programming skills than the integration of push-pins.

5 Conclusion

By developing the website and formulating the wish to create a platform for information on the landscape, learning about regional structures and discovering a city as an inhabitant or tourist, we faced some challenges not only in terms of content, authorship and editing.

Using self-edited Openstreetmap-Layer was fine for the Leipzig Project, as urban areas are normally well mapped. But comparing different sources in the editing process of the excursion routes, such as OSM, Google Maps and administrative data, we discovered amazing distinctions. Regarding this findings as well as comparative studies on the differences between OSM and administrative data (e.g. Schoof et al. 2012; Dreesmann 2012) we must rethink our approach for the next volumes that will be placed in more rural landscapes.

In addition, our experience in preparing the site led us to the well-known insight that having good webmaps is not only a problem of cartography and cartographers, but depends on the cooperation between programmers (see Schmidt and Weiser 2012; Plewe 2007) and cartographers. Currently, cartographers are normally not able to combine map making with necessary programming knowledge. We also argue that an effective communication process between both disciplines is seldom found as there is a strong need for compromise.

We are faced with thousands of webmap applications and websites with maps around the world, with many more appearing daily. We all know different tools that allow everyone—whether cartographic or programming professional, self-proclaimed expert, or any other persons—to make their own maps and to share them with the world. We rightly celebrate this as a huge advance, because people—implicitly or explicitly—become aware of the meaning of Geography, of space, places and locations, of links or even gaps between features in the landscape, merely by mapping them.

In facing our challenges to produce different kinds of webmaps, we have to ask how non-experts can create maps with comparable systems. It seems that the use of specific webmapping features is closely connected to the starting conditions of website systems. We argue that prosumers neither have the time to analyse different potentials of webmapping tools to meet their purposes nor the capabilities of programming and cartography to do so. Therefore they will use simple webmapping tools that—admittedly from a cartographer's point of view—in the most cases do not meet all the requirements. But we may also assume that most of the untrained map producers are content with their own maps.

To date, the wishes of the so-called prosumers are largely unknown, either in terms of producing maps on the Internet or in consuming them. We do not know if people use some tools because they are simple to use or because these tools give an impression of a map that they want to have. We do not know if the maps produced meet the starting aim of the producer and if any other user will understand the result in the same way. Sometimes we argue that maps are pleasant to have and a nice picture like art, rather than a medium of representation, communication or for discovery (see Field 2014). To date, very little research has been done in this field.

With this paper and our 'Landschaften in Deutschland' developing project, we concentrate more on the production side. Coincidentally we try to analyse the broad contexts between producing and using webmaps, about the influence of culture, common monopolised perceptions and semiotics used in special contexts (see Perkins 2007). With our project 'Democratisation of Expert Knowledge. The Production and Use of Maps in New Media World' we get started with this challenge. But we are still at the very beginning as questionnaires are much more complex comparing with printed maps because of far more initial conditions for webmaps, such as zoom steps with potentially different symbology and different methods of interaction and animation. As we have shown, it is possible to create good webmaps for specific and personal purposes. However, we have to bear in mind that programming a simple webmap feature is one thing, producing good quality and purpose-oriented webmaps is something different that needs more time, much closer collaboration between different disciplines and, of course, an understanding of different ideas and intentions.

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Part II
Spatial Analysis and Geovisual Analytics

Structuring Relations between User Tasks and Interactive Tasks Using a Visual Problem-Solving Approach

Qiuju Zhang, Menno-Jan Kraak and Connie A. Blok

Abstract This paper presents a refined taxonomy of user tasks and interactive tasks based on a review of the fields of information visualization, geovisualization and visual analytics. Our aim is to find common ground across previous studies to support those who seek parameters for designing visual solutions to users' domain problems. We first abstract the design procedure for providing visual solutions to address users' problems as a visual problem-solving approach. Then, we relate user and interactive tasks according to the roles they play in the approach. User tasks, which are translations of user problems, guide the design of the visualization and interactive tasks. Interactive tasks provide users with the means to manipulate the visualization environment to accomplish user tasks. We then identify three primitive user tasks—*identify*, *localize* and *compare*—and all other user tasks are considered as compound tasks consisting of sequential primitives. Furthermore, we extract and merge the interaction operators in interactive tasks with the same or similar functions among the existing taxonomies into eleven categories: *re-encode*, *arrange*, *coordinate*, *aggregate/segregate*, *filter*, *derive*, *navigate*, *query*, *search*, *select* and *enabling*. We expect this refined taxonomy to provide a more intuitive view of the logical relations between tasks.

Keywords User task · Interactive task · Interaction · Visual solution · Visual problem solving

1 Introduction

When designing a visualization environment with the intent of providing visual solutions to users' domain problems, visual designers must consider the tasks that the user intends to accomplish. Tasks typically refer to a sequence of interaction

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_7

activities to be conducted in the visualization environment. We should focus on the fact that these interactive activities have particular user objectives. Thus, a task is a two-faceted concept that includes the objectives pursued in interaction activities (called *user tasks*) and the sequential interaction operators used to perform those user tasks (called *interactive tasks*).

User tasks are translated from users' domain problems, corresponding to *what* is to be accomplished with the aid of the visualization environment (Knapp 1995). An example of a user task is the identification of a cluster pattern on an animal distribution map. Interactive tasks refer to sequential interaction operators provided to the user of a visualization environment to assist in achieving user tasks, corresponding to *how* the user works with and manipulates data, visual representations and the visualization environment. The main components in an interactive task are the interaction operators, which should be organized in a logical sequence. Therefore, an interactive task includes two subtasks: one is to select suitable interaction operators, and the other is to organize those operators in a logical sequence. For example, if a user is interested in a particular cluster of a particular species of animal in an animal distribution map, filter and zoom operators are required to filter out the non-targeted animal species and to further investigate the details of the cluster of interest.

Both user and interactive tasks consist of multiple primitive components, leading to the existence of many task taxonomies described from diverse perspectives. Moreover, the associations between user tasks and interactive tasks are often overlooked in the visualization design process. These factors result in a clear need to classify all the primitives and organize them into a logical structure. In this paper, we identify a catalog of task primitives from the literature and categorize them into groups based on the roles they play in the data. Moreover, we define the relations between user tasks and interactive tasks according to their role in the visual problem-solving process.

The remainder of this paper is organized as follows. In Sect. 2, we summarize the related background contexts and studies, and based on these literature reviews and discussions, we derive a refined task taxonomy in Sect. 3. We then debate the properties and limitations of this taxonomy and present concluding remarks in Sect. 4.

2 Background Context

User tasks are also referred to as "visual tasks" (Zhou and Feiner 1998) and "analytical tasks" (MacEachren 1995) in the literature. Similarly, alternative terminology for interaction operators in interactive tasks include "operations", "primitives" (Roth 2013), "tasks" (Amar et al. 2005), and "actions" (Gotz and Zhou 2009). The diverse terminology used in the literature illustrates the importance of explicitly defining and distinguishing between user tasks and interactive tasks.

Previous works have distinguished different tasks and addressed two methods of organizing them into a taxonomy. One method is based on levels of semantic richness. For example, Gotz and Zhou (2009) shaped a taxonomy based on 4 semantic levels, from high to low: *tasks* (a user's high-level analytic goals), *subtasks* (more concrete analytic goals, corresponding to user tasks in this paper), *actions* (atomic analytic steps performed by a user, corresponding to interactive tasks), and *events* (low-level user interaction events, corresponding to interaction operators). A similar organization can be found in Roth (2013), in which the levels of the taxonomy are identified as *goals* (high-level motivations of using the visualization environment), *objectives* (corresponding to user tasks), *operators* (corresponding to interaction operators), *and operands* (physical or virtual targets with which a user interacts). The other taxonomic organizational method is based on distinguishing *why* and *how* a task is performed on *what*. The dimension of why corresponds to high-level user goals or more concrete user tasks, the dimension of how corresponds to interactive tasks and interaction operators, and the dimension of what corresponds to the targets (e.g., data components) on which a task is performed. For example, Brehmer and Munzner (2013) abstracted a task taxonomy in a *why*-*what*-*how* structure, and Schulz et al. (2013) added a further *where* dimension to address the cardinality of data entities within a target on which a task is performed.

2.1 Existing Taxonomies of High-Level User Goals and User Tasks

High-level user goals define the broader motivations for using a visualization environment. Examples include the use of a visualization environment for exploratory analysis, confirmatory analysis or presentation (Schulz et al. 2013). Additional examples are summarized in Table 1. User tasks are more concrete goals oriented toward achieving the high-level user goals.

Table 1 summarizes the existing taxonomies of user tasks, some of which account for high-level user goals (Wehrend and Lewis 1990; Zhou and Feiner 1998; Andrienko et al. 2003; Brehmer and Munzner 2013; Roth 2013). These taxonomies include different types and numbers of user tasks. Only the *identify and compare* task exists in all of these the taxonomies. The most evident contradiction is the appearance of same terms on different levels, e.g., summarize and explore are categorized as high-level user goals in Zhou and Feiner (1998), whereas they are categorized as low-level user tasks in Brehmer and Munzner (2013). This divergence suggests that user tasks can be defined in multiple ways with varying levels of semantic detail. Therefore, defining a comprehensive taxonomy remains a challenging task.

Table 1 Taxonomies of high-level user goals and user tasks to achieve those user goals

Publications	Taxonomies of high-level user goals			Taxonomies of user tasks
Wehrend and Lewis (1990)				Identify, locate, distinguish, categorize, cluster, distribution, rank, compare, within and between relations, associate, and correlate
Zhou and Feiner (1998)	Inform	Elaborate		Emphasize, reveal
		Summarize		Associate, background, categorize, cluster, compare, correlate, distinguish, generalize, identify, locate, rank
	Enable	Explore	Search	Categorize, cluster, compare, correlate, distinguish, emphasize, identify, locate, rank, reveal
			Verify	Categorize, compare, correlate, distinguish, identify, locate, rank, reveal
		Compute	Sum	Correlate, locate, rank
			Differentiate	Correlate, locate, rank
Andrienko et al. (2003)				Identify, compare
Brehmer and Munzner (2013)	Produce			
	Consume			Present, discover, enjoy
	Search			Lookup, browse, locate, explore
	Query			Identify, compare, summarize
Roth (2013)	Procure			Identify, compare, rank, associate, delineate
	Predict			
	Prescribe			

2.2 *Existing Taxonomies of Interactive Tasks*

The main components of interactive tasks are interaction operators, which define the functionalities used to manipulate data and visualizations. Interaction operators have been defined and classified in various ways in the literature, resulting in blurred and overloaded terms. A comprehensive summary of interaction operators is reviewed in Brehmer and Munzner (2013), which covers the literature in the fields of visualization, visual analytics, human-computer interaction, cartography, and information retrieval.

Many studies have presented taxonomies of interaction operators to resolve the ambiguity of terminology. These taxonomies classify interaction operators into a small number of descriptive categories, either based on the user intentions that the interactions achieve (Amar et al. 2005; Yi et al. 2007; Edsall et al. 2008; Gotz and Zhou 2009; Brehmer and Munzner 2013) or based on the targets (e.g., data or views

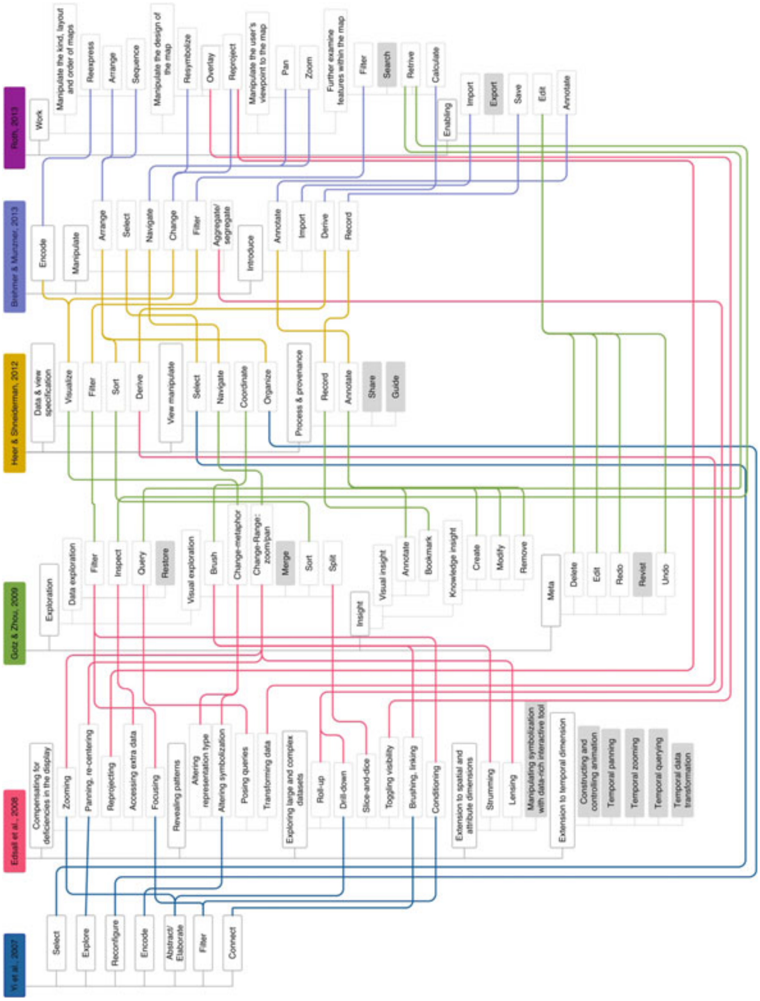

Fig. 1 Summary of recent taxonomies of interaction operators. Orthogonal lines connect the operators that have the same end purpose. The operators that are shaded in *gray* are the unique ones that are not included in any other taxonomies

in a visualization environment) on which the interaction performs (Chi and Riedl 1998; Crampton 2002; Heer and Shneiderman 2012; Roth 2013).

We summarize the relatively recent taxonomies, chosen because they were developed based on reviews of previous taxonomies, to obtain an overview and to analyze the differences among them (Fig. 1). Each vertical string in Fig. 1 represents a taxonomy consisting of categories of interaction operators. We analyze the definitions and examples of each operator in these taxonomies to classify the end purpose of each operator. We further connect the operators in different taxonomies that have the same end purpose using orthogonal lines. Different color hues are assigned to the orthogonal lines for each taxonomy to make the connections easy to identify. The operators shaded in gray are unique; they are not included in any other taxonomies.

The connections in Fig. 1 aim to clarify the relations among different terms in different taxonomies that have the same end purpose. The connections are equivalent to a matrix and do not imply any progressive relationship among these operators. A connection map was chosen rather than of a matrix because a connection map maintains the original structure of categories in the taxonomies. Some connections are easy to understand because the terms are synonymous. For example, *encode* in Yi et al. (2007), *altering symbolization* in Edsall et al. (2008), *change-metaphor* in Gotz and Zhou (2009), *visualize* in Heer and Shneiderman (2012), *encode* and *change* in Brehmer and Munzner (2013), and *reexpress*, *resymbolize* and *reproject* in Roth (2013) all have the same purpose of altering the visual appearance of visual representations of data elements. However, some connections appear to be ambiguous because irrelevant terms are applied. For example, *Abstract/Elaborate* (Yi et al. 2007) includes operators that can adjust the level of details using e.g., zooming and other details-on-demand operators. Therefore, *abstract/elaborate* is connected to *zooming* and *drill-down* operators in Edsall et al. (2008), although, at first glance, the two terms do not seem to be related.

This figure reflects the issue in which either inconsistent terms are used in different taxonomies to describe the same (group of) interaction operations or the same term is used to describe different interaction operators. Moreover, the extent of the connection among terms shows that many categories occur consistently in all the taxonomies but do not all have one-to-one relations, i.e., some of them have one-to-many relations. The divergence implies that defining a universal taxonomy is a challenging task.

3 Taxonomy of Tasks

3.1 Relation between User Tasks and Interactive Tasks

We define the process of designing a visualization environment to provide visual solutions to user's domain problems as a visual problem-solving approach (Kraak

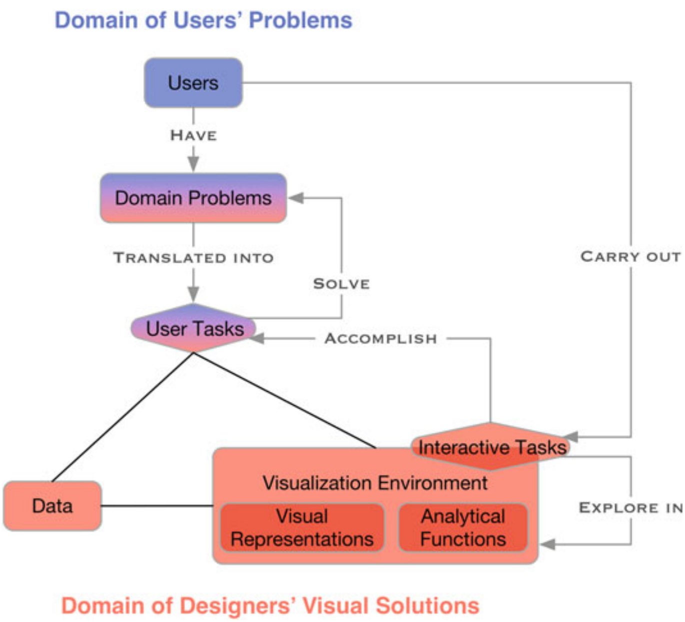

Fig. 2 The roles that user tasks and interactive tasks play in an approach of visual problem solving. *Blue* and *red* represent the problem and the solution domain, respectively. Domain problems and user tasks, represented in both colors, bridge the two domains

2011). We associate user tasks and interactive tasks by means of their roles in this approach (Fig. 2).

The visual problem-solving approach includes the domain of users' problems and the domain of designers' visual solutions (Fig. 2). The first domain describes the user tasks that are translated from users' domain problems. The second domain describes the visual solution designers' designs for seeking solutions to user problems. Visual solution designers should be familiar with the users' domain and have knowledge of visualization software design and development.

User problems exist mostly as a series of vague questions in users' head. Therefore, visual solution designers should first collect these questions and translate them into a uniform format of user tasks. Then visual solution designers should develop a visualization environment consisting of a variety of visual representations, analytical functions and interaction operators based on the user tasks and data. Interactive tasks are further designed by arranging the use sequence of different interaction operators. Finally, users can execute these interactive tasks to explore data in the visualization environment to accomplish the user tasks and further solve their problems.

User problems and user tasks bridge the domains of problems and solutions. At an abstract level, interactive tasks that exist between the user tasks and the solution domain function as "*the fuel for analytical discourse*" (Thomas and Cook 2005,

p. 9). Therefore, user tasks and interactive tasks are interrelated and have more than a "what-how" relation, i.e., a user task occurs first, followed by an interactive task. User tasks can be achieved through a series of interactive tasks. The sequence in which these tasks are to be performed is often application-oriented. A common recurring sequence of tasks in visualization is summarized in Shneiderman's *information seeking mantra*: "Overview first, zoom and filter, then details-on-demand" (Shneiderman 1996).

Tasks often need to be decomposed into a sequence of primitives to reduce their complexity. The following subsections describe the identified primitives of both tasks.

3.2 Primitive User Tasks

User tasks are derived by analyzing users' domain problems. Identifying the primitives of user tasks is an essential step to ensure the uniform format of the translation. Based on literature reviews, we identified only three primitive user tasks—*identify*, *localize* and *compare*. Other user tasks are considered as compound tasks consisting of sequential primitives.

Elementary and general tasks are further distinguished based on the level of the data that the tasks target, referring to the reading levels proposed by Bertin (1967) and the search levels proposed by Andrienko et al. (2003) and Andrienko and Andrienko (2006). Elementary tasks make simple observations about the low-level data characteristics of individuals, such as the data values of a dataset. These observations can be obtained through visual interpretation, e.g., looking at legends and labels. General tasks aim at discovering more complex patterns and relations in the data, such as the spatial distribution of objects, clusters and outliers. Obtaining such characteristics requires exploration of the "big picture" of the data and applying a series of interactive visual analyses to deduce patterns. Therefore, elementary tasks address individual data components and return the attributes and values of data components through visual interpretation, whereas general tasks address the data as a whole and return patterns in the data through visual analysis (Fig. 3). A task usually implies two parts: a starting point and a target to be sought or compared with. The table in Fig. 3 indicates the targets of identify, localize and compare tasks at the elementary and general levels.

Identify tasks focus on finding attribute values at the elementary level or patterns at the general level, corresponding to the questions of who and what.

Localize tasks focus on positioning the known data components and their attributes at the elementary level or known patterns at the general level in space and/or time, corresponding to the questions of where and when. Many of the taxonomies do not distinguish localize tasks from identify tasks; instead, localize tasks are considered as identify tasks that occur in space. Considering the increasing attention to the spatial and temporal characteristics of data, we discriminate between

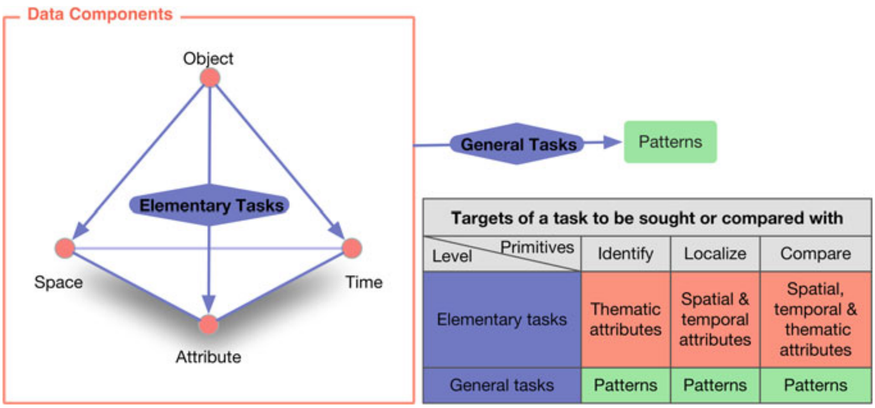

Fig. 3 User tasks are performed on data. Elementary tasks target data characteristics of individual data components (i.e., data values of attributes), whereas general tasks target pattern detection from the data components as a whole. *Arrows* indicate the starting point and the target. The table shows the targets of primitive tasks at the elementary and general levels

identifying in space and time (as localize tasks) and identifying the thematic attributes (as identify tasks).

Compare tasks focus on finding the similarities and differences among multiple data components, corresponding to the questions of how. An elementary comparison aims at comparing the low-level data characteristics, whereas a general comparison aims at comparing high-level patterns.

3.3 Other User Tasks

Other user tasks—apart from the above three primitives—can be decomposed into a sequence of primitive tasks. For example, *categorize* and *cluster*, which classify data in groups by some attributes, can be achieved by first comparing attributes and then identifying the data with the same values of attribute. *Distinguish* and *emphasize* attempt to isolate and highlight the data components that attract attention or fit the users' requirements; these tasks are equivalent to identifying salient data components. *Rank* aims at determining the order of values of data attributes; it can be decomposed into identifying the targeted data attributes and then comparing them to identify the order based on most/least, first/last or nearest/farthest. *Associate* and *correlate*, which aim at establishing a relationship or connection among multiple visualization elements, is equal to the general identify task, which finds relationships, such as connections, correlations and trends among multiple data components.

3.4 Taxonomy of Interaction Operators

We extract the interaction operators from the literature reviewed in Sect. 2.2. By analyzing the definitions and examples of each operator in the literature, we merge the interaction operators in different taxonomies that have the same/similar functions (Fig. 4). For example, *sequence/sort*, *overlay/toggling visibility*, *split/slice-and-dice* and *merge*, which all have the same purpose of spatially arranging the layout of the views or arranging visualization elements in the views are grouped into the *arrange* category.

In Fig. 4, the gray blocks represent the categories and subcategories of the taxonomy. The colored blocks represent interaction operators with the same end purposes but that have different names in the existing taxonomies summarized in Fig. 1. Different color hues are assigned to distinguish different taxonomies.

Re-encode: alters the initial representation method (e.g., by altering the size of symbolization) or redesigns the representation types (e.g., by changing the map

Fig. 4 The taxonomy of interaction operators based on the review of the existing taxonomies. This figure adopts the same colors used in Fig. 1 to distinguish taxonomies

types). Similar operators/categories in other taxonomies include *encode/visualize*, *re-express/change/change-metaphor*, *re-symbolize/altering symbolization*, *re-project* and *altering representation type*.

Arrange: refers to the process of spatially arranging the layout of the views or arranging visualization elements in the views, also called *reconfigure* and *organize*. Interaction operators of *sequence/sort*, *overlay/toggling visibility*, *split/slice-and-dice* and *merge* belong to this category.

Coordinate: (also known as *connect*) refers to the process of linking multiple views to enable a user to discover associations and relations among data items that are represented in multiple views. *Brushing*, which retrieves the same data items in multiple views, and *linking*, which coordinates multiple views, belong to this category.

Aggregate/Segregate: can change the granularity of visualization elements. Also known as *roll-up/drill-down* and *abstraction*.

Filter: refers to the removal of the data that do not satisfy query constraints from the user's view, which are typically controlled by slider bars. Filter is synonymous with *focusing* and *conditioning*.

Derive: refers to the derivation of new information from source data via computation. Synonymous with *calculate* and *transform*.

Navigate: subsumes the means of modifying the extent of the data shown without reorganizing data, thereby enabling the user to examine a different subset of data. *Navigate* is synonymous with *explore*. Well-known operators include *overview to details*, *zooming and panning*, *direct-walk*, *fisheye*, *lensing* and *semantic zooming*.

Query: requests details about the visualization elements by positioning the mouse cursor over an element of interest or drawing a box to select elements within the enclosed area. Query is synonymous with *retrieve*, *inspect* and *accessing extra data*.

Search: localizes the known elements of interest within the view. Search is conceptually synonymous with *query*. The difference between search and query is that search supports the localize task by performing a direct match with visualization elements in a view, whereas query aims at providing additional information regarding the elements of interest.

Select: is a basic interaction function, by means of elements can be highlighted and further filtered, manipulated or brushed in the coordinated views.

Enabling: includes operators that are further classified into sub-categories of *recording history*, *basic editing*, *share and guide*. The recording history category stores the interaction history, enabling the user to review and refine the proceeding operation. It includes the operators *record/save/bookmark*, *redo/revisit/restore* and *undo*. Basic editing operators allow the user to manipulate the visualization elements or the data behind them. This category includes operators such as *delete*, which removes the visualization elements, *import*, which adds new elements to the visualization, *annotate*, which adds graphic or textual notes on the visualization, and *edit/modify*, which changes the value of data attributes. The share operator, also known as *export*, helps the user present and collaborate the results. The guide operator provides guidance to the user through the interactive analysis process.

4 Discussion and Conclusion

The design of a visualization environment that provides users with visual solutions to their domain problems must consider complex factors, including user tasks and interactive tasks. Explicitly acknowledging this complexity draws attention to their composition and helps to identify a logical structure for assembling them. In this paper, we reviewed the existing taxonomies of user tasks and interactive tasks with the goal of finding common ground among them to support those who seek parameters for visual solution design.

We first established a structure that relates user tasks and interactive tasks through the roles they play in the visual solution design process. Previous works have integrated user and interactive tasks according to levels of semantic richness (Gotz and Zhou 2009; Roth 2013) or according to the relations between why and how a task is performed (Brehmer and Munzner 2013; Schulz et al. 2013). On this basis, our taxonomy assigns these abstract concepts to different stages of the visual solution design process. These two types of tasks are interrelated. User tasks help to close the gap between users and visual solution designers. By focusing on user tasks, visual solution designers can first translate users' problems into a uniform format and then make appropriate design decisions. Interactive tasks serve as a bridge between user tasks and visual solutions. Interactive tasks aim to provide users with an appropriate sequence of interaction operators that they can apply. The formulation of interactive tasks is guided by an understanding of user tasks. Users accomplish user tasks by executing these interactive tasks to explore data in the visualization environment. We believe that this structure provide visual solution designers with a more intuitive view for understanding the roles played by both types of tasks and for the further development of suitable visual designs.

We investigated the composition of both types of tasks in the literature. We first identified the primitive user tasks to allow complex tasks to be decomposed into sequences of simpler tasks: *identify*, *localize* and *compare*. Moreover, we extracted and merged the interaction operators that have the same or similar functions among existing taxonomies. Doing this cleared up the confusion caused by the diverse use of vocabulary such as *re-encode*, *arrange*, *coordinate*, *aggregate/segregate*, *filter*, *derive*, *navigate*, *query*, *search*, *select* and *enabling*.

Some limitations remain such as evaluations of the taxonomy, that will require additional research. The proposed taxonomy was refined based on a review of the literature. All examples from the literature were carefully investigated to ensure a correct understanding of the authors' original semantic meaning for each definition. The final results were visually presented and described in detail. The overall visual problem-solving approach is widely applicable. We designed and implemented a case study using this approach (Zhang et al. 2014). It consists of a visualization environment to help an urban study group investigate how suburban residents use space in the city. The design of the related user and interactive tasks were guided by the taxonomy presented in this paper. The urban study group provided a positive feedback about the effectiveness of our design, which helped them address their research questions. Further research should conduct an evaluation in collaboration with visualization designers, e.g., a focus group session (Krueger and Casey 2000), to justify the taxonomy and obtain feedback that may enable further improvements.

In addition, we aggregated existing interaction operators from previous publications into a number of categories to enhance the necessary overview. Further clarification and subcategorization of these operators will be required. Finally, user tasks are regarded as guides for selecting and designing appropriate interactions in the taxonomy. Setting up a one-to-many relation between primitive user tasks and interaction operators would provide a detailed guide for visual solution designers, e.g., a matrix to show all the related interaction operators that can help accomplish a task. Setting up such a matrix will require a considerable amount of work and a systematic evaluation. To achieve this, further research will be needed.

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Visual Analysis of Floating Taxi Data Based on Interconnected and Timestamped Area Selections

Andreas Keler and Jukka M. Krisp

Abstract Floating Car Data (FCD) is GNSS-tracked vehicle movement, includes often large data size and is difficult to handle, especially in terms of visualization. Recently, FCD is often the base for interactive traffic maps for navigation and traffic forecasting. Handling FCD includes problems of large computational efforts, especially in case of connecting tracked vehicle positions to digitized road networks and subsequent traffic state derivations. Established interactive traffic maps show one possible visual representation for FCD. We propose a user-adapted map for the visual analysis of massive vehicle movement data. In our visual analysis approach we distinguish between a global and a local view on the data. Global views show the distribution of user-defined selection areas, in the way of focus maps. Local views show user-defined polygons with 2-D and 3-D traffic parameter visualizations and additional diagrams. Each area selection is timestamped with the time of its creation by the user. After defining a number of area selections it is possible to calculate weekday-dependent travel times based on historical taxi FCD. There are 3 different types of defined connections in global views. This has the aim to provide personalization for specific commuters by delivering only traffic and travel time information for and between user-selected areas. In a case study we inspect traffic parameters based on taxi FCD from Shanghai observed within 15 days in 2007. We introduce test selection areas, calculate their average traffic parameters and compare them with recent (2015) and typical traffic states coming from the Google traffic layer.

Keywords Floating car data (FCD) · Traffic map · Focus map · Travel time estimation · Velocity estimation · Movement data · Visual analysis · Linked views

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_8

1 Introduction

Floating Car Data (FCD) is a relatively new technology, which appeared as a useful source of information about the actual traffic situation (Liu et al. 2012). It is acquired by a tracking device inside a vehicle, which is in this case the sensor itself (Cohn and Bischoff 2012). FCD is often provided by whole taxi fleets for long time periods. The resulting massive data sets are difficult to handle with common analysis and visualization methods and need advanced methods. In the case of FCD of a taxi fleet, information on the traffic situation within selected investigation areas is detectable due to thousands of simultaneously tracked vehicles. Besides detection of traffic patterns, the traffic information visualization is challenging. One common possibility for describing the traffic situation of urban areas is the use of interactive traffic maps. These products allow users to detect traffic movement patterns, visualized by only differently colored road segments in a scalable 2-D map.

These maps are not only used as traffic prediction services but as well as tools for transportation planning (Sohr et al. 2010). The classification of two-dimensional road segments in traffic maps can be provided qualitatively by the values for traffic congestion high, medium, low (Liu et al. 2008; Goldsberry 2005) or quantitatively by classes of average velocity (Goldsberry 2008). The connection between traffic data coming from FCD and digitized road segments is realized by Map Matching (MM) algorithms. For the case of pneumatic counters (Dirks et al. 2003) and inductive loops (Leduc 2008), the connection to the road element is already set previously. Since there are still positioning errors in the acquired positions by using GNSS devices the connection with road segments is more difficult, especially in areas near intersections. That's why Map Matching (MM) has become a frequently used group of methods with over 36 different algorithms in the year 2006 (Zhao et al. 2012; Quddus et al. 2007). We have to respect the fact that MM achieves differing results and quality dependent on the different inspected road networks. In case of complex transportation infrastructure elements, matching is difficult. Another fact is the high computational effort of MM (Zhao et al. 2012), especially in dense situated road segments in large surface areas.

Keeping this in mind, we want to design a simpler way to connect vehicle trajectories to road segments. One basic aspect in doing this is to localize personalized areas of interest. The idea behind this is to derive detailed vehicle traffic information in short spatial distance to personal points of interest (POI). The arcs of the inspected road network are then enriched with information on relationships between the defined selection areas. One simple example for relationships is the connectivity of road segments between two area selections and the calculated traffic-aware travel times.

The base for this kind of personalization is the recording of time stamps, representing time of creation and inspection of each user-defined selection area.

In terms of visualization, these user-defined area selections are not following the already mentioned interactive traffic maps but other approaches, where visual analysis tools with linked views are used. In these examples large FCD sets were visualized by different interconnected views on the data (Tominski et al. 2012; Guo et al. 2011; Ferreira et al. 2013; Wang et al. 2013). All these examples make, similar to our idea, use of area selections for recorded tracks of moving objects with the aim of representing more detailed information at certain locations. Our idea consists of designing a geovisualization tool for interactive inspection of historical traffic information derived from taxi FCD. We follow the idea of a focus map (Zipf 2002; MacEachren 1995; Freksa 1999), where important areas are emphasized in a specific way. Based on our idea the emphasized areas are user-defined and represent average values of travel times, vehicle speeds and vehicle densities in a so called local view on the data. The global view corresponds to the focus map itself, which is simply a usual overview map containing the emphasized selection areas that have varying size, shape and a time component. The last mentioned is generated user-dependently and may give some support for inspecting time-dependent traffic pattern.

Within user-generated selection areas (in "local view") other points of interest (POI) may be included, such as "my house", "the place I work" or "where I want to go". In the end we can define different types of relations between the user-generated selection areas.

2 Analysis and Visualization Methods for Large FCD Sets

The analysis of massive FCD includes often data visualization, which might help to discover new insights into various traffic patterns. The visual analysis process itself is dynamic and implies testing of different visualization techniques. This follows rudimentary the idea of an exploratory data analysis (EDA). In addition to this fact we have the established visual analytics methods for movement data. Starting from both ideas, we want to discover if personalized analysis on FCD benefits from personal inspection of individual mobility and travel times.

2.1 Visual Analysis of FCD

The possibly simplest method for visualizing massive positions of vehicle movement, especially for the case without pre-processing, includes the generation of Dot maps (Stanica et al. 2013). The dots are often represented with differing color based on the classification of instantaneous attribute values, such as velocity or driving direction. Dependent on the selected data partition more or less point overlapping appears. The reason for this appearance results often from the high number of tracked vehicles. Due to overlapping of the dot symbols it is difficult to detect stop-and-go traffic patterns (Liu and Ban 2013). This might be solved by aggregation methods (Andrienko and Andrienko 2013). Andrienko and Andrienko (2007) for example use grid cells to summarize the values describing traffic (velocity, vehicle density). Additionally it is possible to represent individual movement of an object as a sequence of grid identification numbers (Moosavi and Hovestadt 2013). The visual representation of the latter might imply coloration or other symbolization of grid cells. Influenced by point aggregation, Sun and Li (2012) use of a pyramid-based approach for the visual exploration of large FCD sets.

Other visual analysis approaches use point clustering techniques on FCD for the detection of traffic patterns. Krisp et al. (2012) extract pick-up and drop-off points of taxi passengers for applying k-means point clustering with the aim to detect the busiest places in Shanghai. Others studies use density-based point clustering methods like DBSCAN (Tang et al. 2015) or OPTICS (Rinzivillo et al. 2008) for detecting vehicle movement patterns. In case of dense point distributions it is possible to use kernel density estimation (KDE). Krisp et al. (2011) extend this idea and use adaptive and directed KDE for the visual traffic analysis, which helps to detect movement trends within dynamic point data.

2.2 Exploratory Data Analysis (EDA)

In general it is to say that some of the mentioned visual analysis examples make use of procedure flow, which is described by the term exploratory data analysis (EDA). This term was summarized by Keim et al. (2004) as a sequence of the three steps “Overview”, “Zoom and Filter” and “Details on demand”. The overview represents the inspected data in a summarized view, which will be called in our case the global view. By using the “Zoom and Filter” functions, which are the used data analysis methods, it is possible to detect movement patterns. After some patterns are detected “Details on demand” refers to the inspection of certain details in the data, which is dependent on the field of interest for analysis. This inspection in a detailed view on the data is called in our case local view. The aim of “Details on demand” or the local view is to propose a hypothesis in the end (Keim et al. 2004).

2.3 Geovisual Analytics of Movement Data

Exploratory Data Analysis and the mentioned examples for visual analysis of FCD will be the theoretical base for creating selection areas for our test data set.

Additionally it is to mention that the term selection area refers to area wise selection of spatio-temporal data sets for further visualization.

In a similar way selection areas are termed differently in numerous Visual Analytics approaches. They are named time lenses in Tominski et al. (2012), trip views in Liu et al. (2011) and spatial traffic views in Guo et al. (2011). The general connection of these examples to our term selection area is the use of a dynamic spatial query (Tominski et al. 2012). By using dynamic spatial queries data partitions of a vehicle movement data set are selected and inspected further by other linked views on the data. With the use of a time lense it is possible to inspect certain partitions of the data set in time steps. Tominski et al. (2012) show that numerous trajectories of multiple moving objects can be inspected visually for long time periods. In Guo et al. (2011) the TripVista application has an interlinkage between global and local views with selection possibilities for certain trajectories. Examples for windows or views despite the selection area are histograms, parallel coordinate plots, scatterplots and heat maps.

Keeping this in mind, an additional aim for using selection areas for FCD is interactive linking to other reasonable views on the data.

3 Test Traffic Data for the Vehicle Transportation Network of Shanghai

For testing our approach we use 3 different data sources. Besides FCD from taxis, we use obtained traffic states from the Google traffic layer. The base for comparing the different traffic states is an extracted partition of the road network in Shanghai, coming from the OpenStreetMap (OSM) project. In the following we will discuss the properties of our used test data sets.

3.1 Floating Taxi Data from Shanghai

The inspected FCD set is the result of a survey on a taxi fleet in Shanghai with an average of 7120 frequently observed vehicles. This number represents the average for each hour. In total there are around 10,000 different taxi identifications. We can detect this important pattern by simple inspection of vehicle identifications for certain hours of the day. Depending on the time of day some of the taxi drivers turn their tracking device off and some new appearing turn it on. The data structure of the inspected data set is shown in the following Table 1.

Most of the inspected original 10 attributes are not used in our study. A pre-processing step was provided by means of selecting certain attributes, where only the car ID, longitude, latitude, time and instantaneous velocity are kept for

Table 1 Data structure of the inspected taxi FCD set of Shanghai

Fieldname	Details
Car ID	The unique ID of the car, in 5 digits
Longitude	In degree [°]; accurate to the 6th decimal place
Latitude	In degree [°]; accurate to the 6th decimal place
Instantaneous velocity (km/h)	accurate to 0.1
Record date	In form of yyyy-mm-dd
Record time	In form of hh:mm:ss

further analysis. We inspect in our study FCD partitions of 15 selected days between the 1st of February and 1st of March 2007.

By previous inspection of the data it should be noted that the sampling interval in time is differing. This means the jumps in time between consecutive points of one and the same vehicle are not constant. These time jumps vary between 1 s and 30 s and have an average of around 12 s for each inspected hour of the data set.

3.2 Street Network from OpenStreetMap (OSM)

We extracted the street network of the entire city extent of Shanghai from the OpenStreetMap (OSM) project. Based on Stanica et al. (2013) the digitized road network of this source has one of the best quality of accessible street geodata. Nevertheless, we have to inspect the reasonability of this information, mainly in road types, driving directions and restrictions. All these attributes of the OSM road segments are crucial for achieving reasonable routing results.

In terms of connectivity of different road segments, we tested Shanghai's road network with computed test routes. The results indicate a more or less realistic connection between the roads, with some small mistakes in driving directions and in complicated crossing. For comparing the reliability of the computed OSM network routes the routing service of Google Maps was used.

In a case study the quality of the OSM road network was already evaluated for its suitability for vehicle routing (Graser et al. 2014). For the city of Shanghai, we extract all available road networks that are accessible by car. For testing reasons we will mainly focus on the highway network in Shanghai.

3.3 Web-crawled Traffic States from Google Traffic Layer

The Google traffic layer is an additional layer, which can be optionally switched on, in the Google Maps service. Within this service it is possible to inspect segments of the road networks by their recent traffic situation. There are 4 quality values ranging from slow moving traffic to fast moving. As an extension users may use the Google route service within the Google Maps GUI and predict the certain travel times for the routes between selected start and end points. The simplest routing strategy is shortest path based on Dijkstra (1959), which is not always the best solution for users, as for example traffic congestion can influence the travel time. Therefore, a traffic-aware route is often proposed as the best route, respectively the fastest route within specific time windows. Traffic-aware routing means that the information that is partially visualized in the Google traffic layer is respected. Besides the information that is usually transmitted via TMC, such as accidents or closed roads, the travel time for each segment is calculated based on tracked data. The traffic layer itself is updated in irregular time intervals always dependent on available input data.

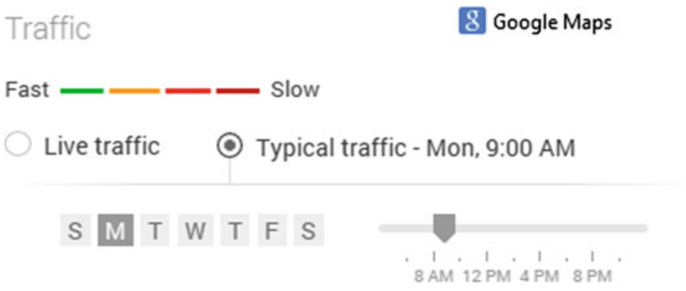

Fig. 1 Interactive legend of the Google traffic layer in Google Maps for the visualization of different traffic states

The data source for the Google traffic layer or any kind of metadata is not given by the service provider. Nevertheless direct information from Google state that the data source is a merged solution from several sources.[1] This includes data from government departments of transportation, private data providers and mobile phone users. The last mentioned provide anonymous speed information via Google's traffic crowdsourcing feature. In reality users of Google of Google Maps for mobile phones that enable the "My Location" function are helping Google to provide traffic information more accurately.[2] This should be seen critically, since no information is available on positioning quality of the data source, quality of the MM results and reliability of the provided traffic information.

In our approach we inspect the live and the typical traffic information from Google's traffic layer, which is an available option within an interactive legend in Google Maps. Figure 1 pictures one example of such an interactive legend. We use a web-crawling technique that was already tested for the traffic layer in Bing Maps by Tostes et al. (2013) for extracting time dependent traffic states (4 different) for each weekday in Shanghai. The weekdays are important for providing comparable traffic situations. Unfortunately all the Google traffic information is from 2015 and is difficult to compare with taxi FCD from 2007. This is problematic due to the fact that numerous changes in the urban transportation infrastructure appeared in the last 7 years in Shanghai.

We use historical traffic information of the road segments in Shanghai for comparing it with the taxi FCD-based traffic situation weekday-wise. This has the idea that same weekdays appear more similar than differing ones. After the first inspections of the traffic layer from Google Maps for Shanghai, we detected that there is only typical or live traffic information available for highways. Resulting from this we will only inspect and compare input data associated to the highway segments in Shanghai.

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[1]http://geeknizer.com/how-google-maps-traffic-works/.

[2]https://googleblog.blogspot.in/2009/08/bright-side-of-sitting-in-traffic.html.

4 Introducing Selection Areas for Visual Analysis of Taxi FCD

The first part of our approach consists of introducing selection areas for the inspection of certain FCD partitions in time and space. The inspection is mainly a visualization of averaged traffic parameters such as velocity and vehicle density. Since each selection area has a timestamp, we connect several defined areas by spatiotemporal and semantic relations. The spatiotemporal relations, mainly on the connected road segments, are then enriched with traffic information such as congestion level or travel times for computed traffic-aware routes based on various data sources. The aim of the approach is to provide exploratory data analysis on taxi FCD based on selected areas of interest with recent and historical travel time information.

4.1 User-defined Spatial Area Selection

The selection areas appear in two forms: as a selection circle without association with a given road network and as road selectors with dependency on certain road segments. Figure 2 shows the usual appearance of the selection areas used in our approach.

The introduction of these elements is user-dependent and can indicate a personal context like “at home” or “place of employment”. In our approach the shape of selection areas has the two options as pictured in Fig. 2, mainly dependent on the selected point or line of interest. This means that selection areas are similar to spatial point and line buffers. The size of these buffers is selected by the user and gives an indication how much area is included into specific interests. Selection areas represent areas of interest and define the localization of subsequent calculation and visualization of spatially intersecting taxi FCD.

Fig. 2 Selection areas as **a** selection circle and as **b** road selector

4.2 Different Views on Taxi FCD: Global View and Local View

With our visual representation we want to give insight into parts of the inspected FCD sets. Therefore, we focus on associating selection areas with the deduced FCD information on average velocity and vehicle density.

For reasons of achieving overview there is a differentiation between a global view and a local view on inspected taxi FCD sets. Figure 3 pictures this differentiation by the workflow of data selection and visual inspection. Additionally, Fig. 3 shows how we link supplementary views, which may be charts on temporal distributions, on the data spatially included within selection areas.

As can be seen in Fig. 3 two differently calculated attributes are presented for the local view, which are always based on the selected area of interest. In our case, we make use of two types of simple calculations for two different attributes. For calculating the vehicle density we simply use the sum of counted vehicle positions within the selection areas. The average velocity is calculated by the average of n points within the selection area.

These are the 2 basic attributes, which are fixed in our approach, since this method relies on the existence of at least one small FCD set.

In Fig. 3 there is a global and a local view on the data. The global view has the intention to give some orientation on the investigation area and to show interesting appearance for placing a selection area. The base or base map of a global view for example can imply a usual traffic map with 3 qualitative values describing congestion (low, medium, high) or classified by ranges of average velocity. Other examples could be thematic and topographic maps, satellite imagery, the raw FCD points or simply a digitized road network. Here it should be mentioned that this view on the data may only be a visualized layer and does not represent the original form of the data. Additionally we can show the original positioning points by dots colored by velocity ranges (in this case: instantaneous velocity).

With the visual detection of interesting places (points of interest) in a static traffic map, we can use a selection area for further inspection. There are many different options for the appearance of global views. Therefore Fig. 4 pictures two possible displays for a global view on FCD.

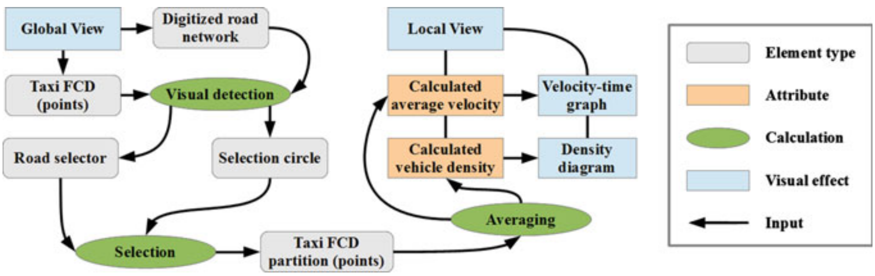


Fig. 3 Workflow of FCD inspection by selection areas and linked charts

Fig. 4 Examples for selection areas in a global view with **a** FCD records as points and **b** classified road partitions

Figure 4a shows the original dot representation of the used FCD and Fig. 4b a road network representation colorized by average velocity classes. The displays in Fig. 4 are showing the results for a test taxi FCD partition of 10 min in the global view. A selection of a bigger taxi FCD partition can be realized by queries on the spatial position of the introduced selection area. Afterwards it is possible to average and count FCD records for other time ranges.

4.3 *The Method for Defining Individual Time-dependent Selection Area Sequences and Its Visualization*

The proposed method for providing multiple successive selections structures as the following:

1. User defines polygons based on one selected point (POI) or on one line (selected road segment).
2. Sequence of user is recorded (ID, pol_ID, time, type, name).
3. Defined Polygons are enriched with average information on traffic states and travel times (with the option for different travel modes).

The deduced FCD information of the enriched polygons is visualized within a local view.

One example for a local view with linked displays is pictured in Fig. 5 with a road selector as selection area.

In Fig. 5 we test the selection area method on the Shanghai FCD set. As already mentioned, we follow with our approach the idea of a "Focus Map" (Zipf 2002), where the important areas of the map are displayed more dominantly then the others. In this example we investigate one FCD partition of one hour between 8 a. m. and 9 a.m. on a Wednesday in the center of Shanghai.

The visualized information about the average velocity and the vehicle density can be estimated with 10 min steps. Following the aggregation of movement is based on 10 min in time and the size of the selection area in space.

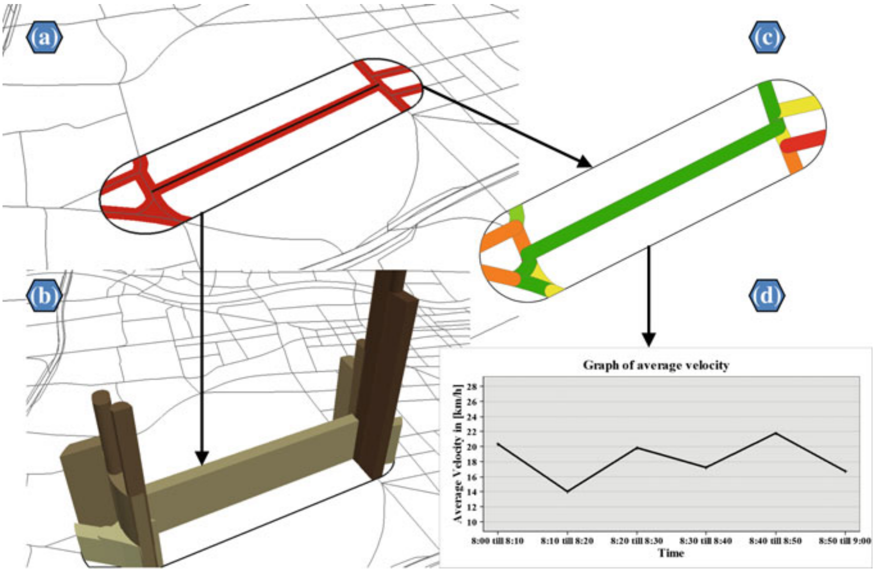


Fig. 5 Possible display of a global and local view on FCD with **a** road selector on road network; **b** extrusion of road segments based on taxi density; **c** coloration based on average velocity ranges and **d** associated graph of average velocity

The main selection steps consist of querying FCD by certain time windows and coordinate restrictions in space. This is included in the global view. The counting of the vehicle positions (for the vehicle density) and calculating average velocity values are the main calculation steps and part of the local view. Each of these steps is based on selected areas in the form of selection circles and road selectors.

Figure 5d shows the chart of the taxi average velocity by its variation in time, which is linked with the same selection area showing consistent time steps. Each time step includes a data partition based on time stamp selection. Similar to the mentioned data sets it is possible to link other spatio-temporal information and data sources as for example weather, social events or other changes in the environment. Interesting for personalized selections within location-based services (LBSs) are location-aware news feeds or user ratings of spatial items as additional data sources (Mokbel et al. 2011).

4.4 Defining Semantic, Topological and Temporal Relations of Multiple Successive Selections

Multiple successive selections are connected by semantic relations (between POIs in different selections), topological relations (same road network) and temporal relations (working hours).

Each selection area is product of personal interest ("personalized traffic information"). Depending on the type of averaged data within selection areas we can define semantic relations between certain selection areas. These semantic relations often result from temporal relations. One example might be the time when a user is leaving home and going to work. Resulting from the topological relations we know the usual travel time for the shortest path between the points in two different selection areas. Depending on the deduced traffic information from FCD we can estimate if a variation in travel time is possible or not.

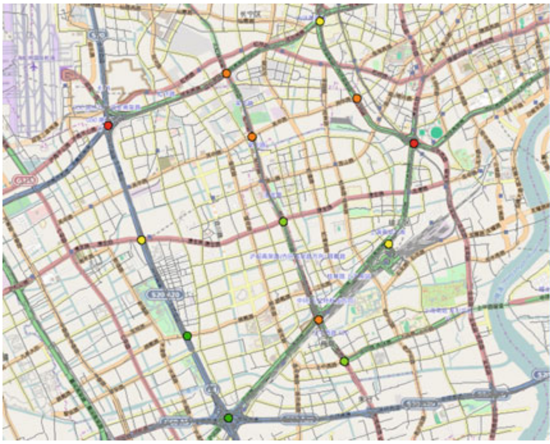
5 Results

By the use of combining a global and a local view on taxi FCD by selection areas it is possible to get insight into average velocity and absolute vehicle density values of the selected areas. The selection itself appears interactively within the global view, where raw FCD points, traffic base maps or simply the digitized road network are used for orientation.

In our case study we selected 13 prominent highway crossings in Shanghai for testing our approach on traffic congestion events, traffic states (slow or fast moving traffic) and travel times. The latter was calculated from historical taxi trajectories and recorded from the routing function of Google Maps. Traffic congestion was calculated from taxi FCD velocity records and the density of taxi positions. The traffic states were computed by average velocities and travel times from taxi FCD and recorded from the Google traffic layer.

Even if the inspected taxi FCD sets are from the year 2007, there are similar weekday-dependent traffic patterns comparing to the live and typical traffic classifications from Google traffic layer. The peak hours on weekdays, in particular from 8 to 9 a.m. and from 5 to 7 p.m. (Sun et al. 2009), that are characterized by heavy traffic congestion events are detectable in both data sets. Additionally there are only relatively small variations in comparing calculated traffic-aware travel times. For the latter case we used only the Google live traffic routing function respectively between the selected crossings in Fig. 6. We compared the traffic dependent shortest path of the life traffic of selected weekdays for the same times of the day.

Another interesting result is the traffic-aware routing for a given visiting order of the timestamped selection areas (see Fig. 6 on the right). Following the ascending order of selection area definition by a route delivers other travel times as the descending order of selection areas. This has the reason that the segments in between are associated with frequently changing traffic state information or travel time. Therefore differing starting and end points deliver different travel times for the same and in different directions driven routes. This factum shows the dynamically changing traffic situation on highways on workdays in Shanghai.



ID	Sel_area	Sel_lon	Sel_lat	Sel_ID
388	Wai Huan Hu Qing Ping Li Jiao Qiao	121.358094	31.183053	301
389	849 Hong Xu Lu	121.388660	31.193598	302
390	827 Zhong Shan Xi Lu	121.412212	31.205220	303
391	1885 Cao Bao Lu	121.367646	31.158105	304
392	1619 Gu Dai Lu	121.379107	31.136764	305
393	Xin Zhuang Li Jiao	121.389511	31.118375	306
394	708 Wu Zhong Lu	121.394401	31.180858	307
395	2 Wu Zhong Lu	121.421279	31.189230	308
396	71 Cao Xi Lu	121.436061	31.179283	309
397	688 Cao Bao Lu	121.403223	31.162119	310
398	Hu Min Lu Fu Lu	121.419189	31.148112	311
399	76 Liu Zhou Lu	121.429660	31.156339	312
400	710 Shang Zhong Xi Lu	121.418159	31.131703	313

Fig. 6 Selected crossings classified by quality of traffic congestion (5 classes) based on taxi FCD from Shanghai

6 Conclusion

The idea of introducing area polygons and circles as selection areas is helpful, as it was already used for visual analysis on different data sets (Tominski et al. 2012; Guo et al. 2011; Ferreira et al. 2013; Wang et al. 2013). Nevertheless, the extension to a user-driven selection process with establishing relations between individual selection areas is relatively new.

The proposed specified visualization methods are only examples of designing user-friendly visual analysis methods. One main issue of this testing may be the evaluation of the practical use of selection areas for getting insight into microscopic traffic patterns.

The 13 selected crossings in Fig. 6 are good indicators for detecting traffic variations on the highway network in Shanghai. We can connect averaged taxi FCD from various time windows with these selected areas. Especially in comparison with the Google traffic layer solution, colorized selection areas show a suitable and informative extension for commonly known interactive traffic maps.

There are several questions that result from the first tests of our analysis method. One of them implies the questioned usefulness of extending traffic maps with more interactivity. We cannot estimate the usefulness of our tool for daily commuters. One clear benefit of our user-based area selection method is the extension of the visual analysis process for FCD. Still, we need to detect the ease of use for a potential user by providing evaluations with individual selection areas. Defined preferences of selection areas are user-specific. Therefore, we need to respect the frequency of selection area inspections, which will be an addition to their order (temporal) and definition (local knowledge). This might be an initial point for the conception of a GUI for the visual analysis of FCD.

7 Outlook

All the presented visualization possibilities in Fig. 5 appear often trivial, since only highly generalized and averaged traffic information is visualized.

Future work may include the extension of 2D road networks into 3D representations of the entire vehicle transportation network of dense populated cities with the aim of expanding the possibilities for modelling vehicle traffic. Showing two variables of one feature is a good base for starting geovisual analyses. The linkage with the global view and estimated travel times and traffic states between user-defined areas can supplement this analysis, since we can detect dependencies in the typical or "usual" dynamics of vehicle traffic.

Another idea, which may include the use of the third dimension, is about representing different traffic situations on one and the same crossing visually. This may include the use of extrusion in 3D views with the vehicle density as the extruded value on the z-axis and additional coloration by average velocity for selected segments of the transportation infrastructure. Figure 7a pictures one imagined example for one hour of taxi FCD in one selected crossing in Shanghai. There are six partitions that appear different depending on the ratio of different vehicle driving directions. It should be mentioned that this appearance is highly dependent on the working times of traffic lights. This brings us to the favored linking of this kind of information, which is hard to detect but relatively simple to simulate.

In all of these cases the differentiation between times of the day, the certain weekday, and typical and averaged time windows is crucial for comparing results.

Another idea for further analysis and visualization of selection areas is the inclusion of spatial point interpolation and density estimation methods. This might be useful for cases of multiple or overlapping POI in the same selected area. One possibility is to introduce weightings for different POI as pictured in Fig. 7b. In this figure the points are weighted based on the Euclidian distances to one selected POI. Insight into weightings of POIs is important for applying and interpreting spatial interpolation methods and their results. In case of using kernel density estimation

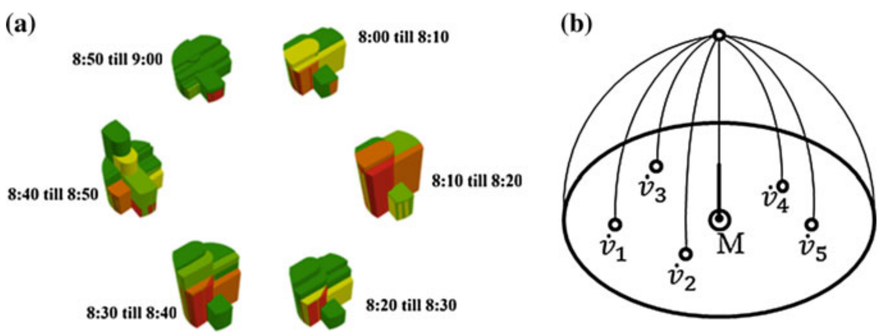


Fig. 7 Possible visual representations of **a** different traffic situations on the same crossing and **b** weighting of different POIs

(KDE) the views as in Fig. 7b are useful for selecting the kernel bandwidth. Another example for creating surface information out of spatial points is presented in Keler and Krisp (2015) by the inclusion of spatially interpolated PM2.5 values based on measurement from static monitoring stations. The connection between vehicle traffic and particulate matter is an important topic nowadays, especially since exceeded PM concentrations are a big problem in today's Chinese cities like Beijing and Jinan.

Acknowledgements The described taxi Floating Car Data set of Shanghai ('SUVnet-Trace Data'[3]) was obtained from the Wireless and Sensor networks Lab (WnSN) at Shanghai Jiao Tong University. We would like to thank the Laboratory for Wireless and Sensor Networks at Shanghai Jiao Tong University, especially Prof. Min-You Wu and Jia Peng, for providing access to this data.

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[3]http://wirelesslab.sjtu.edu.cn/taxi_trace_data.html.

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Spatial-temporal Modeling of Linguistic Regions and Processes with Combined Indeterminate and Crisp Boundaries

Johannes Scholz, Thomas J. Lampoltshammer, Norbert Bartelme and Eveline Wandl-Vogt

Abstract The paper elaborates on the spatial-temporal modeling of linguistic and dialect phenomena. Language Geography—a branch of Human Geography—tries to enhance the visual exploration of linguistic data, and utilizes a number of methodologies from GIScience, whereas publications focusing on analyzing linguistic data in GIScience are hard to find. This research work highlights the representation of language and/or dialect regions with combined indeterminate and crisp boundaries—i.e. frontiers and borders. Both boundary "types" are necessary in order to model the spatial-temporal dynamics of language phenomena. The article analyzes the emerging, ending, moving and merging of linguistic/dialect regions and phenomena with respect to space and time and the boundary types. In order to represent frontiers or indeterminate boundaries, fuzzy logic is employed.

Keywords Linguistic geography · Fuzzy logic · Geographic information science

1 Introduction

The intention of Language Geography—a branch of classical Human Geography (Delgado de Carvalho 1962)—is to enhance the usability of digital language and dialect databases and to foster the visual exploration of linguistic data. Currently,

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_9

linguistic phenomena are mapped in a static manner, which results in maps with dialect regions or isoglosses. Isoglosses define the geographic boundary of a linguistic feature, such as the pronunciation of a vowel, the meaning of a word, or use of some syntactic feature.

Due to the fact that language and dialect are dynamic phenomena per se, a digital representation should be able to model this fact. Hence, we apply the theory of fuzzy sets (Zadeh 1965) and indeterminate boundaries to Language Geography. Given the fact that language regions and isoglosses may move over time, boundaries between adjacent regions are not always crisp—but they can be crisp if, e.g., a natural barrier hinders the movement of people and thus the exchange of language. This is true for, e.g., mountain chains or oceans, which constrain the movement of people. The same can be said about barriers having been introduced in the late 19th and in the 20th century, when language became a major identifier for each country and there were more and more efforts to use political boundaries also for outlining cultural (and especially linguistic) domains. Nerbonne (2010) emphasizes that the change in dialectal spatial variation is gradual, thus supporting the argumentation of fuzzy linguistic boundaries.

In addition, language islands and regions may arise from scratch as well as existing language regions or islands may disappear over time—which has to be modeled accordingly. Globalization and urbanization fosters the creation of new language islands and regions within existing language regions. Hence, the regions have no crisp border, but share a certain part of space with fuzzy memberships of the involved linguistic regions (Burrough 1996; Worboys 1998).

The article covers the spatial-temporal modeling of language phenomena based on fuzzy sets, indeterminate boundaries and spatial-temporal change of spatial entities (Medak 1999; Hornsby and Egenhofer 1997, 2000). Hence, linguistic processes are analyzed regarding the implications on their according spatial-temporal entities and processes.

In this paper, we assume that boundaries between language phenomena may be fuzzy—with different degrees of fuzziness. Fuzzy boundaries represent the gradual transition zones between language phenomena. Nevertheless, the boundary may show an infinitely small transition zone, which classifies the boundary as crisp. We underpin this argumentation of fuzzy and crisp boundaries with an analysis of landforms and language boundaries.

In this article we do not cover the influence of media on language and dialect, due to the fact that this might have a more widespread impact on language itself, rather on merely its geographic extent.

2 Relevant Literature

In the following paragraphs, we highlight relevant literature for this article. We elaborate on publications from Geographic Information Science, Linguistics, Geolinguistics, and Dialectology.

2.1 Geographic Information Science

Literature from Geographic Information Science (GIScience) that contributes to Linguistics or Dialectology is very rarely found. There exist a handful of papers that are of relevance (e.g., Hoch and Hayes 2010; Silber et al. 2012; Scholz et al. 2008), which are discussed in Sect. 2.2. Relevant in this context is the theory of fuzzy sets from Zadeh (1965). Regarding Geographic Information Science, the publications by Burrough (1996) and Worboys (1998) cover the handling of objects with fuzzy boundaries and imprecise spatial data respectively. To model spatial-temporal dynamics in language and dialect regions, we refer to the work by Medak (1999), Hornsby and Egenhofer (1997), as well as Hornsby and Egenhofer (2000).

More recent publications deal with events and geographic phenomena, developing an algebraic theory to represent spatial-temporal events (Worboys and Hornsby 2004; Worboys 2005). Grenon and Smith (2004) developed a modular ontology for dynamic features that attempts to represent the real world. They rely on two concepts, which seem incompatible at first a glance: spatial-temporal snapshots of the universe of discourse and spatial-temporal processes in general. Both ontologies are designed in a way that they can interact with each other. Hornsby and Cole (2007) highlight an event-based approach to model moving objects. Based on the pattern of events of an object they try to create of semantics of events. Nixon and Hornsby (2010) extended the existing theory by adding geolifespans to objects—meaning that objects can be created, can vanish, can convert, merge, etc. In addition, the longevity of objects is modeled as geolifespan classes, where also transitions between the classes are possible.

2.2 Linguistics, Geolinguistics, and Dialectology

Classical language and dialectology atlases present their data with the help of point symbols or a thematic map (e.g., dbo@ema; REDE). Additionally, language boundaries are marked with isoglosses, a concept that has been critically discussed by Pi (2006), highlighting the concept of isographs.

An overview of contemporary mapping and visualization techniques in linguistics and dialectology is presented in the book edited by Lameli et al. (2010). Some researchers in linguistics advocate for using “honeycomb maps”—i.e., Delaunay triangulations or Voronoi diagrams—which are constructed around point observations (Goebl 2010; Nerbonne 2009, 2010). Rumpf et al. (2009) proposed a visualization of linguistic features using kernel density estimation. Subsequently, Rumpf et al. (2010) published a paper that elaborates on geographical similarities on area-class maps. In this paper, cluster analysis is employed in order to extract groups of similar structured maps.

It is a notable fact that in linguistics or dialectology, researchers use methods originating from GIScience to a certain degree, while publications on the analysis and mapping of linguistic data in GIScience are hard to find. Exceptions are the work of Lee and Kretzschmar (1993), Hoch and Hayes (2010) and Silber et al. (2012). Partly Bartelme and Scholz (2010) and Scholz et al. (2008) attempted to discuss the GIScience perspective of the project "Database of Bavarian Dialects electronically mapped" (Wandl-Vogt et al. 2008). Jeszenszky and Weibel (2015) propose four research questions to analyze the nature and behavior of linguistic boundaries. Generally, Nerbonne (2010) states that the theory of dialect continua indicates that the change in dialectal spatial variation is gradual.

3 Boundaries: Crisp Versus Indeterminate Boundaries?

Boundaries are present in everyday life. Thus, they are present in many ways in our mind and in reality and have different nature, properties, and dynamics. This section covers a definition of boundaries and highlights the spatial-temporal nature of borderland processes. In addition, it clarifies the terms border, borderland, and frontier, as well as it provides an introduction to fuzzy theory in relation to the afore-mentioned concepts. Additionally, we analyze linguistic boundaries and underlying landforms in order to evaluate if both, crisp and indeterminate boundaries, between language phenomena do exist.

3.1 Theory of Boundaries

Parker (2006) and Kristof (1959) list a definition of a boundary based on the Oxford English Dictionary, which defines boundary as something "that which serves to indicate the bounds or limits of anything" (Rankin and Schofield 2004, p. 2). This rather unspecific definition indicates that boundaries are unspecific divides that represent limits of any kind. Due to this generality, the term should be defined in a more precise way. For example, Kristof (1959) explains that the two words 'frontier' and 'boundary', although in everyday speech interchangeable, at a closer look show substantially different meanings. While a boundary is a line, a frontier is typically an area, part of a whole, specifically that part that is ahead of the hinterland. In German, the word 'Mark' comes close, in Slavic languages, the words 'Krajina' or 'Ukraina', which also have attained a geopolitical meaning. Parker (2006) even goes one step further, defining the terms 'boundary', 'border', 'frontier', and 'borderland'. He defines 'borders' as "linear dividing lines, fixed in a particular space, meant to mark the division between political and/or administrative units" (Parker 2006, p. 79). The term 'frontier' is defined as a region with interpenetration between two previously distinct objects (see also Kristof 1959). According to Parker (2006), such a zone could separate various types of political or cultural units and such regions could also be made up of empty areas without physical contact. A 'frontier' is seen in literature as a zone where a number of boundaries overlap and intersect—hence frontiers are made up of boundaries including, geographic, political, demographic, political, or cultural ones. The term ‘borderland’—as defined by Parker (2006)—represents the “region around or between political or cultural entities where geographic, political, demographic cultural and economic […] processes may interact to create borders or frontiers” (Parker 2006, p. 80). Following this definition, we can conclude that there are two types of boundaries that can be found in borderlands: borders and frontiers.

Boundaries and borderlands can be looked at in two opposite ways, either by paying attention to their separating role or by seeing them as a place where ideas—and also languages—meet and partly overlap or rather blend into each other. By emphasizing the chance to meet instead of only sticking to the separating aspects of boundaries, a deeper investigation of processes going on in such borderlands is highly interesting and rewarding. By the way, such a duality is quite common in GIScience, as for example in DIME (Dual Independent Map Encoding), which—for regions with crisp boundaries—defines two dual graphs that intertwine. DIME originated in 1967 at US Bureau of Census (http://www.ncgia.buffalo.edu/gishist/DIME.html). Here, this concept is being generalized to indeterminate boundaries.

According to Kristof (1959) and Parker (2006), there are several distinguishable types of boundaries. Generally, Parker (2006) lists five types of boundaries: Geographic Boundaries, Political Boundaries, Demographic Boundaries, Cultural Boundaries, and Economic Boundaries. Linguistic Boundaries—interesting in this respect—are a sub-type of Cultural Boundaries. The overview of boundary types is to be found in Fig. 1.

The nature of boundaries—either being border or frontier—is described in the following paragraph. Borders and frontiers are the opposite extremal points of the

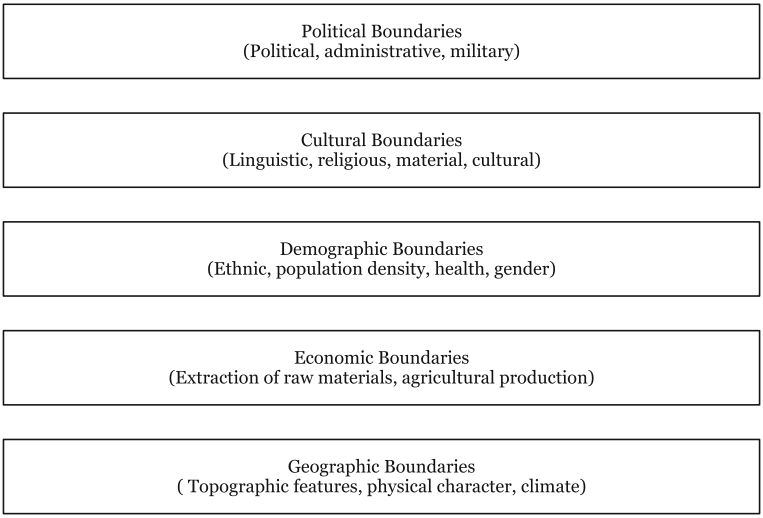


Fig. 1 Boundary types defined by Parker (2006)

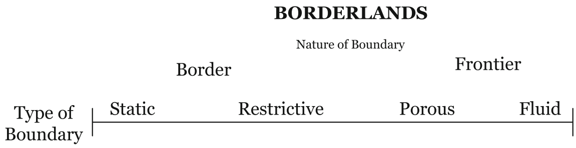


Fig. 2 Borderland continuum as defined by Parker (2006)

continuum of boundaries, where borders are hard, linear, and static, while frontiers are soft, fluid, and zonal. Figure 2 shows the interrelationships between borderlands, borders and frontiers, and boundaries. It is necessary to state that boundaries cannot be strictly classified as borders or frontiers. Hence, each boundary can be defined on the continuum between border and frontier.

There are several examples in Europe where all types of boundaries can be observed. The Karst region around the city of Trieste, as well as the adjacent Istrian peninsula offer a good base for testing all of the above statements.

3.2 Fuzzy Sets and Boundaries

As already discussed before, boundaries cannot be defined in a crisp way.

It would therefore be more appropriate to make use of the concept of zones. In consequence, the concept of boundaries is a fuzzy concept. While boundaries serve as clear separators between areas adjacent to each other, this model is an abstract one and the reality is a continuous space and not a discrete one. In addition, when descriptions such as 'large' or 'tiny' are used to describe the geographic extent of a region, a crisp and absolute quantification becomes impossible. Furthermore, specific descriptors of regions do not end at their boundaries. Intermediate 'in-between regions' reflect the decrease of an attribute of region A and the increase of another attribute of region B (Leung 1987). Ergo, alternatives to fixed quantitative descriptions are required. Fuzzy logic presents such a suitable alternative. While there is an on-going discussion whether fuzzy theory is applicable and acceptable in general (Zadeh 2008), it is fuzzy logic that enables computational approaches in areas of imprecise and incomplete information (Zimmermann 1978).

Let us elaborate on the concept of fuzzy logic by the use of a linguistic variable as show in Fig. 3. This variable in the context of granulation can be seen as a way to compress information of variables and system relations regarding input and output. In this case, the variable X can take values from U. If u is a value of X and u is precisely known, we refer to it as singular value, while in the opposite case, we refer to it as granular values of X (see Fig. 4).

For instance, let u be contained in an interval with the boundaries $[a, b]$, then $[a, b]$ is a value of X. In consequence, it can be stated that granular variables take granular values. In our case, the employed linguistic variable is a granular variable, which has linguistic labels assigned (Zadeh 2008).

Keeping these facts in mind helps to extend the concept boundaries beyond classical thinking regarding spatial planning, political strategies, and common

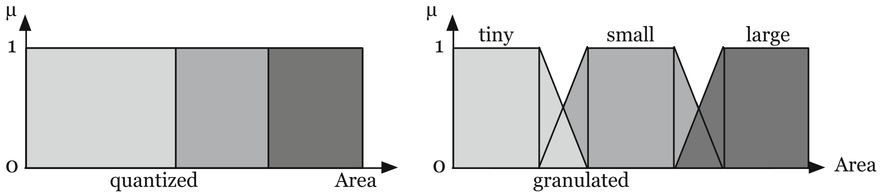


Fig. 3 Quantized versus granulated with fuzzy labels, adapted from Zadeh (2008)

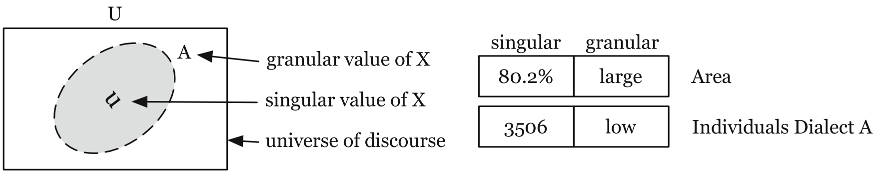


Fig. 4 Singular versus granular values, adapted from Zadeh (2008)

visualization, as well as their perception and interpretation (Allmendinger and Haughton 2009), which is necessary when working with linguistic boundaries.

3.3 *Fuzzy Boundaries as Linguistic Boundaries*

The definition of boundaries is necessary for linguistic processes. In addition to Nerbonne (2010), we investigate topographic landforms as physical objects that hinder or foster the exchange of language. Hence, boundaries that coincide with specific landforms may be regarded as crisp, whereas others indicate that a fuzzy boundary with a gradual transition zone exists. Furthermore, the authors explain why and how the term frontier coincides with linguistic boundaries.

An analysis of the boundaries of linguistic/dialect regions, mapped by the dboe@ema Project (Wandl-Vogt et al. 2008; Scholz et al. 2008) indicates that the boundaries of linguistic phenomena—discretized in linguistic/dialect regions—have both frontiers and borders (Bartelme and Scholz 2010). Therefore, Bartelme and Scholz (2010) analyzed the boundaries of dialect regions in the province of Styria (Austria) regarding their landform (see Figs. 5 and 6). The landform classes were determined based on the methodology published by Weiss (2001) and on SRTM90 data. The definition of landform classes is not subject to this paper; thus we refer to Weiss (2001) for details.

The results reveal (see Figs. 6 and 7) that boundaries of dialect regions are crossing plains and valleys as well as ridges. In detail, 19 % of the boundaries are crossing plains and 5 % valleys. 18 % of the dialect region boundaries cross midslope and high ridges and 49 % are overlapping with open and upper slopes.

Fig. 5 The province of Styria highlighted in *yellow color*, and the neighboring provinces and countries

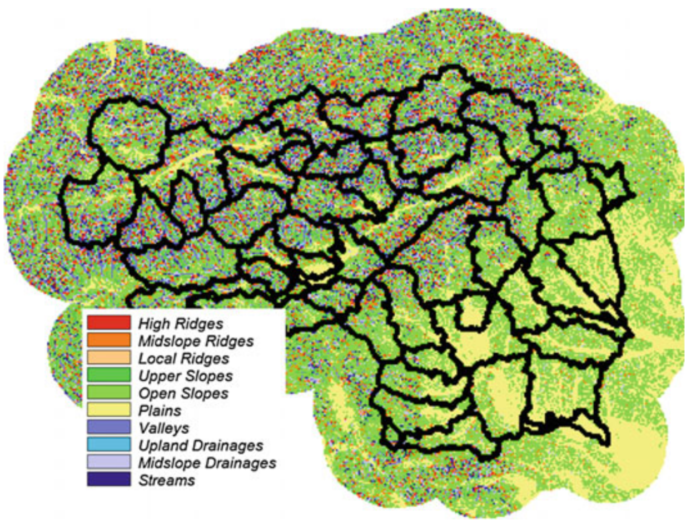
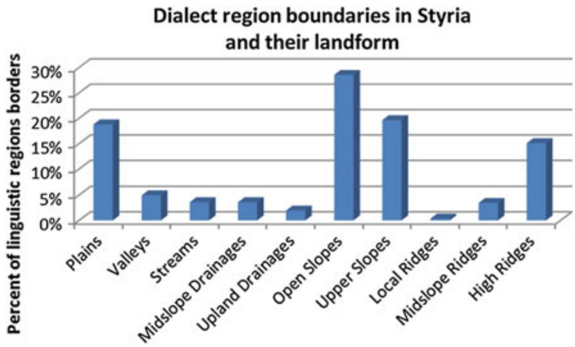


Fig. 6 Landform classes in the province of Styria with boundaries of dialect regions marked with *black lines*

If we assume that valleys and plains do not hinder the exchange of people and language in detail, we can conclude that such boundaries are *frontiers* in nature. The argument of fuzzy frontiers is also underpinned by the fact that linguistic/dialect boundaries are moving and not crisp—especially in plains and valleys. An example of such a fuzzy boundary is the boundary between the south Bavarian and the middle Bavarian dialect region. The boundary comprises a set of isoglosses

Fig. 7 Landform classes of the boundaries of dialect regions in the province of Styria



representing the boundaries of different language phenomena. Thus, the boundary is —depending on which isoglosses are chosen—not exactly defined.

On the contrary, the authors assume that high and midslope ridges are topographic phenomena, impeding the exchange of language. Thus, the boundaries are more static in nature, which leads to the conclusion that such boundaries are borders. An example for a static border is the boundary between the Alemannic and Bavarian dialect/language group. The Alemannic languages are dominant in the western part of Austria and Switzerland, whereas the Bavarian dialects are dominant in the eastern part of Austria. The boundary of the language regions is the Arlberg mountain ridge—a static border that remains fixed since 1900.

4 Linguistic Phenomena and Their Spatial-temporal Representation

The following section describes the linguistic phenomena and their spatial-temporal representation. Therefore, we utilize the theory of boundaries and fuzzy sets highlighted in the previous sections. In this section, we focus on the lifespan of a linguistic phenomenon (i.e., beginning and end), as well as moving and the merging of linguistic phenomena. The following sections are related to the publications of Medak (1999) and Hornsby and Egenhofer (1997, 2000). These publications list a number of operations that maintain or change object identity such as: create, destruct, reincarnate, issue, continue existence, continue, non-existence, spawn, metamorphose, merge, generate, mix, aggregate, compound, unite, amalgamate, combine, separate, splinter, divide, secede, dissolve, and select. A selection of these operations are depicted in Figs. 8 and 9 respectively.

The object identity operations highlighted here represent snapshots of processes. For the case of linguistic processes, which usually tend to span over several years or decades, snapshots are too coarse in terms of spatial-temporal granularity. Hence, the authors propose the modeling of linguistic processes with indeterminate boundaries—in order to represent the gradual change of linguistic phenomena.

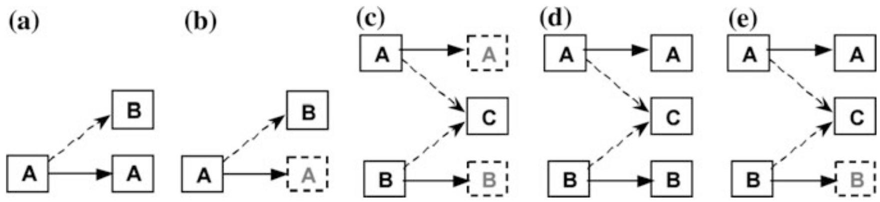


Fig. 8 Object identity operations on simple objects (Hornsby and Egenhofer 1997). **a** Spawn. **b** Metamorphose. **c** Merge. **d** Generate. **e** Mix

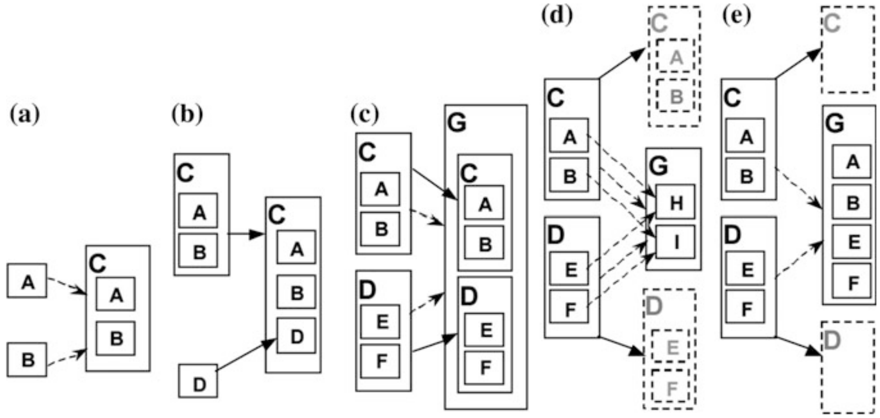


Fig. 9 Object identity operations on composite objects (Hornsby and Egenhofer 1997). **a** Aggregate. **b** Compound. **c** Unite. **d** Amalgamate. **e** Combine

4.1 Emergence and End of Linguistic Phenomena

Any linguistic or dialect phenomenon has a beginning and an end defined, with respect to the spatial-temporal dimension. The creation of a linguistic phenomenon has an origin, which can be regarded as point or geographical area. In order to model the beginning of a linguistic phenomenon, the authors propose to utilize static borders and fuzzy frontiers.

As linguistic phenomena are 'slow' processes in terms of the spatial-temporal dimension, the occurrence of a new linguistic phenomenon within a given linguistic region is a gradual process. Hence, the boundaries around a new linguistic phenomenon should not be represented by static borders but rather with fuzzy frontiers—if there is no natural barrier that hinders the exchange between people (see Fig. 10).

The situation is different, if natural barriers exist that hinder the exchange of people—and language as a result. Consider an alpine valley that is surrounded by high mountains, where exchange is only possible along the valley plain—that, e.g., connects with other (bigger) valleys. Then, the new linguistic phenomenon needs both frontiers and static borders (see Fig. 11).

New linguistic features may occur in cities where the (im-) migration of people may influence the language and dialect(s) spoken—due to introduced subcultures. Similar to topographic hinderings, the spreading of new ‘dialects’ in cities may face borders, which may be induced by, e.g., different social structure of neighboring areas, topographic features such as roads, rivers, or railway lines. Different social structures of neighboring areas impede the spreading of dialects due to the fact that people do not exchange too heavily.

The ending of a linguistic feature is similar to the new occurrence of a linguistic feature—but the process works in the opposite way. The linguistic phenomenon under review is gradually “soaked up” by other linguistic phenomena—i.e., a

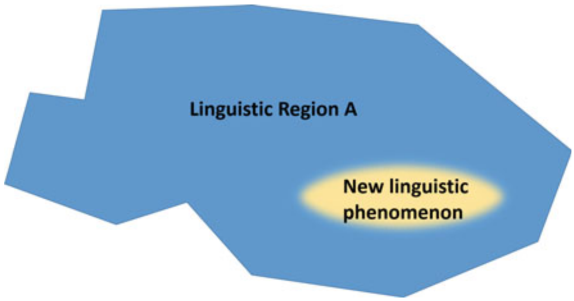


Fig. 10 Occurrence of a new linguistic phenomenon (marked in *yellow*) in an existing linguistic region—represented by the *blue rectangle*. The boundaries of the new linguistic phenomenon are fuzzy as the boundaries of a new linguistic phenomenon cannot defined in a crisp manner

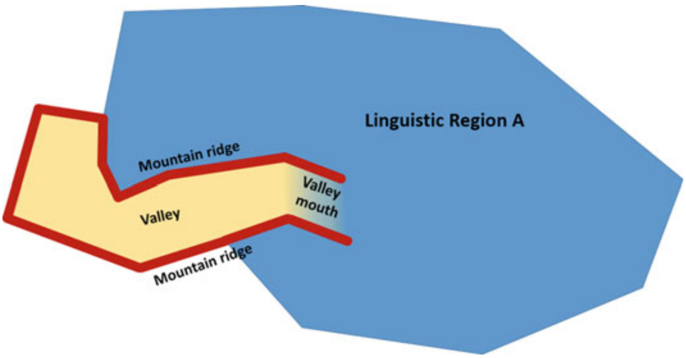


Fig. 11 Occurrence of a new linguistic phenomenon (marked in *yellow*) in an existing linguistic region—represented by the *blue rectangle*. The new linguistic phenomenon is occurring in a valley surrounded by a mountain ridge—marked with red lines—hence there are static borders. In the valley mouth exchange between the language groups can take place. Thus, the new linguistic phenomenon shows a fuzzy boundary—i.e., a frontier—there

dialect or phenomenon is not actively used by people living in that area. Hence, the boundaries are fuzzy and the space covered by the linguistic phenomenon under review gets gradually smaller, until the phenomenon disappears completely.

4.2 Moving Linguistic Phenomena

The movement of linguistic phenomena in space and time is a process that is dependent on the fact that people move and/or change their language and speaking "habits". Hence, it is obvious that those linguistic phenomena are not static in space and time. As stated above, a prerequisite for the movement of linguistic phenomena is the exchange of people and language. Due to the fact that natural barriers hinder the movement and exchange of people, whereas flat lands and valleys foster exchange, there is a need to model linguistic boundaries as static borders and frontiers (Fig. 12).

4.3 Merging of Linguistic Phenomena

If linguistic phenomena merge, we summarize under the term "merge" the following processes: mix, generate, and merge as described by Hornsby and Egenhofer (1997). Mix denotes a process where two regions unite and form a new type of region. Generate describes a process where two objects form an 'intermediate' (e.g., where they share a common border) object, whereas the original objects remain stable. Mix in the sense of Hornsby and Egenhofer (1997) denotes a situation where two objects form a new object type and one of the original objects is ending.

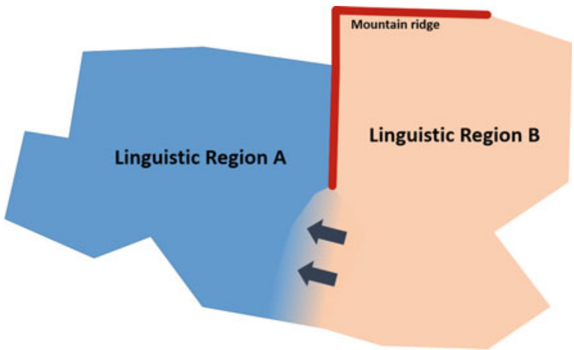


Fig. 12 Example of moving linguistic phenomena. The phenomenon B is moving into the region of the linguistic phenomenon A (marked with *black arrows*), where a fuzzy frontier exists. The mountain ridge—represented as *red line*—is hindering the exchange between the two groups, thus the boundary is of a static nature

Similar to the prior processes, the boundaries of linguistic phenomena are to be modeled as both static borders and fuzzier frontiers in order to represent linguistic processes accordingly. As 'merge' can only take place where two linguistic phenomena—i.e., the people—exchange, and have a common boundary, there are regions where such an exchange cannot take place. Hence, even parts of a common boundary of two linguistic regions are static, due to their nature of a natural barrier.

4.4 Modeling of Linguistic Phenomena with Crisp and Indeterminate Boundaries Over Time

To represent linguistic processes in a computer system, the authors attempt to model them in a functional manner. Thus, the definition is not aligned to a specific system or product. Here we utilize F# (Hansen and Rischel 2013) as functional language to describe boundaries of language phenomena.

In this paper, we restrict ourselves to selected parts of the code that foster the understanding of the modeling of crisp and fuzzy boundaries. First, boundaries of any two-dimensional linguistic phenomena are constructed as lines, which themselves consist of points. Subsequently, the boundaries of the polygons of linguistic phenomena consist of lines. If the line—as part of a boundary—has a fuzzy border, we add a polygon denoting the region of the transition zone—i.e., a fuzzy area. Clearly, the line has to be inside the polygon denoting the fuzzy area.

To model the transition zone between two neighboring language phenomena, two membership functions for each phenomenon are defined. These functions are applied to the two dimensional space with their x-axis perpendicular to the boundary line, and their y-axis showing the fuzzy membership value for each x value. In order to maintain a smooth transition, the fuzzy membership functions are normalized with respect to the maximum width of the transition zone, perpendicular to the boundary line. Hence, this allows the calculation of the membership value for each point within the transition zone. The membership value is then a function, depending on the normalized distance—of the evaluation point from the boundary line—and the fuzzy membership function. The underlying principle is depicted in Fig. 13.

To support the temporal dimension with this approach requires storing the polygons of each language phenomenon, the polygons of fuzzy transition zones, and the according membership functions for each time slice. Hence, genesis of linguistic processes can be analyzed.

5 Real-World Examples of Spatial-temporal Change of Linguistic Phenomena

In the previous sections, we have elaborated on spatial-temporal linguistic processes and their spatial-temporal representation. In detail we focused on the type of boundaries necessary for an accurate representation. In this section, we elaborate on

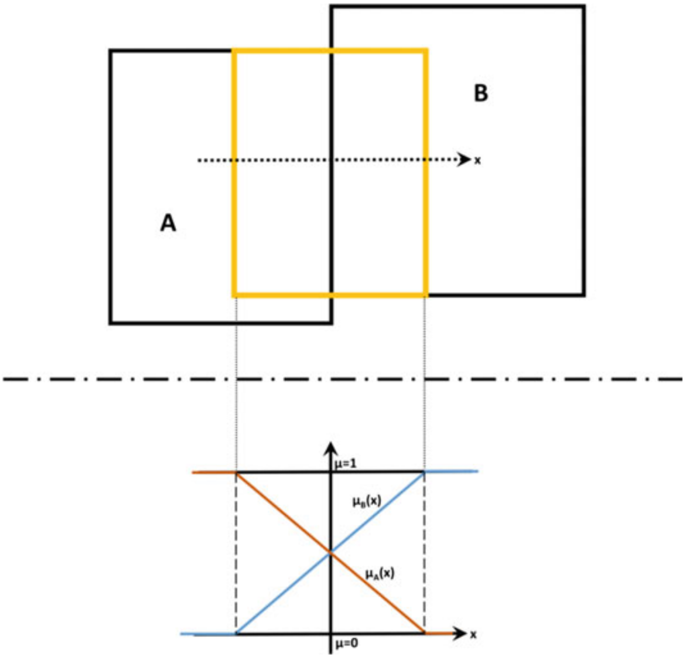


Fig. 13 Schematic graphic of the implementation of fuzzy boundaries. Here two linguistic phenomena A and B are mapped. The *yellow rectangle* denotes the transition zone between A and B. The fuzzy membership function for linguistic phenomenon A is denoted as function $\mu_A(x)$ in *red color*, and for linguistic phenomenon B as $\mu_B(x)$ in *blue*. The fuzzy membership functions are applied with their x-axis perpendicular to the border between A and B. The fuzzy membership value μ denotes the probability of the position to be either part of A or B

some real-world examples to stress the necessity for an accurate spatial-temporal representation with an appropriate boundary definition. These historical processes are not related to modern shifts in language phenomena—especially influences by mass media on language. Nevertheless, they underpin the fact that language is a dynamic process. Additionally, these examples show that language phenomena have both crisp and indeterminate boundaries.

The first example is located in the Paznaun valley. This valley is leading south-west from Pians (850 m) to the Bielerhöhe (2036 m), a mountain pass at the border separating the Austrian provinces of Vorarlberg and Tyrol. The example highlights the creation of a new language phenomenon, moving frontiers and the solidification of the boundary along the Arlberg mountain ridge (Wandl-Vogt 1997; Birlinger 1890). In the years 100–1350, Roman shepherds settled temporarily in the Paznaun, which is still recognizable by a number of roman remains in the dialect of that region. From 1350 until 1850, the Walser gradually moved from the west into the Paznaun, which moves the Alemannic-Bavarian language boundary to the east (across the Arlberg!) and brings an end to the roman dialects in the Paznaun. Around 1850 until 1900, the people in the region oriented their trade channels towards the east, which resulted in a vital exchange with Bavarian speakers (maybe induced by the opening of the transalpine Arlberg railway). Thus, the language in the Paznaun switched to Bavarian and the Alemannic-Bavarian boundary was moved ‘back’ to the Arlberg mountain ridge. From 1900 until today, the border is regarded as stable.

Migration processes often induce the end of a linguistic phenomenon, where people with another dialect/language settle in an area—similar to the Paznaun example mentioned above—but also due to political/administrative reasons. One example would be the historical region of Bohemia (today Czech Republic), where historically speakers of Bavarian dialects were found (e.g., Ehrismann and Carolinum 1996). Due to political and administrative reasons, which are not subject of this paper, the Bavarian dialect-speaking inhabitants disappeared, which results in the end of the language region.

Another example that we highlight in this paper are political heritages that are still visible in dialects today. Upper Austria, a province of Austria, was compiled of several princedoms over centuries (see Fig. 14).

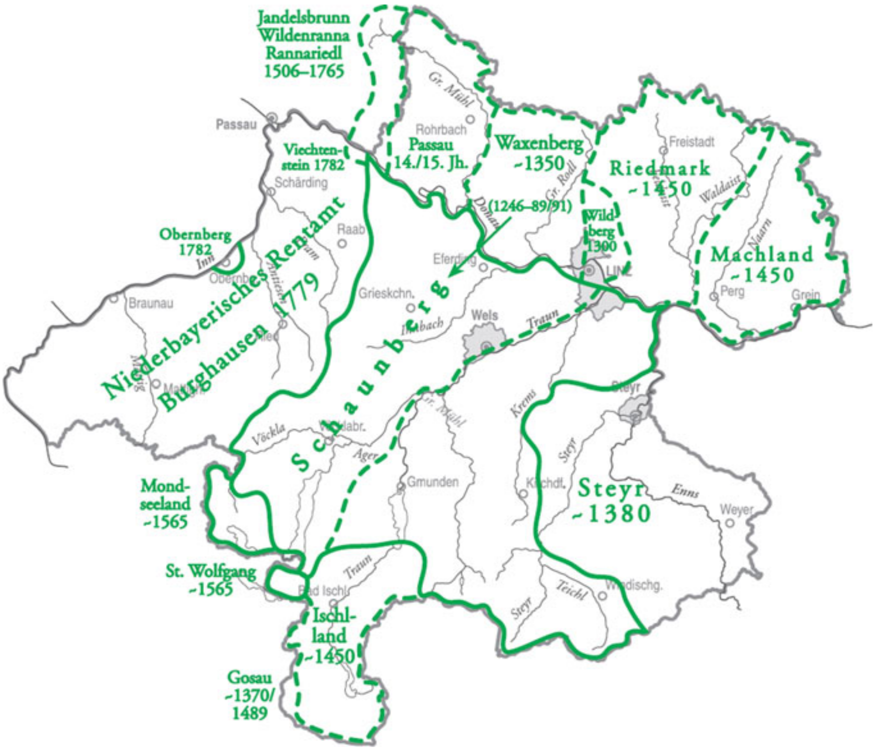


Fig. 14 Historical map of the princedoms of upper Austria and the year they “joined” upper Austria (Wiesinger 2001)

The linguistic distribution of the concept “last year” refers to the main linguistic types “fert”, “ferten” and “voriges Jahr”. In comparing more recent data (investigation ~70es) with data collections of the 30es an 60es there seems to be some correspondences with the political map (see Fig. 14; Geyer 2001) and shows some analogies with the historic map of Upper Austria (see Wiesinger 2001). Certain forms seemed to be significantly more used in certain administrative, political regions. This is still true for the recent data (70es) and this theory is strengthened by comparison with older data collections (e.g. Datenbank der bairischen Mundarten in Österreich).

Concluding, on this example it can be said, that the princedoms of Upper Austria seem to have relevant impact on linguistic distribution which is still recognizable in recent language. Based on more digital lexical resources, a subsequent spatio-temporal analysis, further research on the process of linguistic development over time and its social interconnections and dimensions are possible (Fig. 15).

6 Conclusion and Discussion

This paper analyzed the spatial-temporal behavior of linguistic/dialect regions and phenomena, and elaborated on the spatial-temporal representation of linguistic processes. In order to model linguistic regions and their spatial-temporal changes accordingly, the authors analyzed the term boundary with respect to the “application area” linguistics. Thus, a boundary can have a different nature—defined on the continuum between border and frontier. Borders and frontiers are the opposite extremal points of the continuum of boundaries, where borders are static, interrupt the exchange between people and separate two regions. Frontiers, on the other hand, are boundaries that have a porous character, and enable the exchange between neighbors. Due to the ‘openness’ of frontiers the exact boundary line cannot determined, and is of fuzzy nature. Hence, fuzzy theory can be employed to model the transition zone or borderland between two neighboring regions.

An analysis of the linguistic regions of Styria concerning their landform, collected by the dboe@ema Project (Wandl-Vogt et al. 2008; Scholz et al. 2008) shows that ridges, upper slopes as well as plains and valleys form the boundaries of linguistic regions. If we assume that natural barriers hinder the movement and exchange of people, we conclude that mountain ridges and upper slopes show characteristics of static borders. Due to the fact that people are moving through valleys and plains, they exchange language which leads to the conclusion that such landforms can be regarded as frontiers. Thus, the argument that a linguistic region or phenomenon may have both boundary types—borders and frontiers—is supported.

From an analysis of the spatial-temporal processes of linguistic/dialect regions or phenomena—i.e., emerging, ending, moving and merging—the authors argue that each process shows the necessity of modeling linguistic regions with borders and frontiers. Especially frontiers are an appropriate concept to represent the borderland where neighboring regions mix. In order to model the boundaries from a mathematical viewpoint fuzzy set theory (Zadeh 1965) seems appropriate.

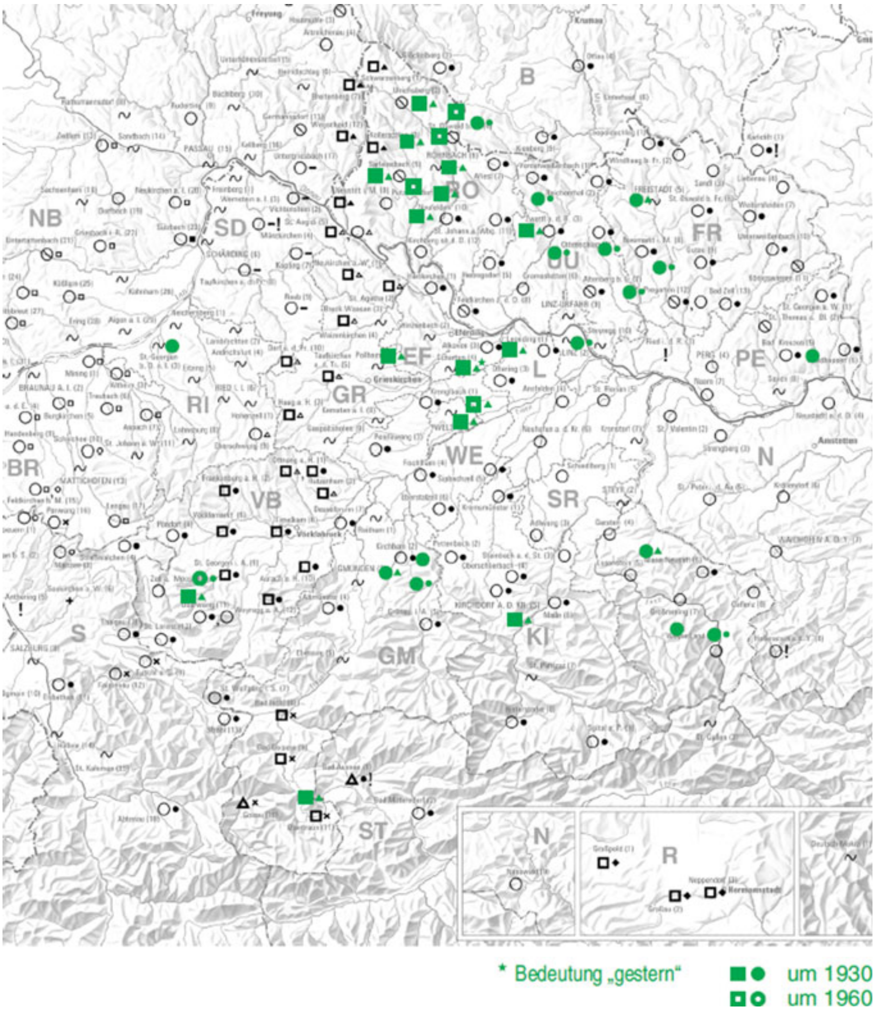


Fig. 15 Linguistic Map presenting the distribution of the word "fert" for "last year": *black symbols* show spatial distribution in the 70es of the last century, whereas *green symbols* present spatial distribution in the late 30es (*filled*) or the early 60es (*blank*) of the last century (Geyer 2001)

Future research items include a definition of the fuzzy theory covering borders and frontiers for the application area linguistic/dialect regions. As linguistic regions change slowly but constantly, there is a need to store the crisp/fuzzy boundary information over space and time, which is solved here with time slices and fuzzy membership functions within a defined transition zone. Furthermore, the approach needs a stronger integration with spatial-temporal processes of objects described by e.g. Hornsby and Egenhofer (1997, 2000) or Claramunt and Theriault (1996).

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Hybrid Approach for Large-scale Energy Performance Estimation Based on 3D City Model Data and Typological Classification

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Abstract This paper illustrates the results of a research project focused on the development of a Web 2.0 system designed to compute and visualize building energy performance large-scale maps. The workflow and the framework include: emerging platform-independent technologies such as WebGL for data presentation, an extended version of the EU-Founded project TABULA/EPISCOPE for building energy parameters estimation and a data model based on CityGML OGC standard. The proposed platform will allow citizens, public administrations and government agencies to perform city-wide analyses on the energy performance of building stocks. To evaluate the accuracy of the model, the simulation results were compared to real data of energy performance of the energy certificates available and the model uncertainties were analyzed.

Keywords CityGML · WebGL · Energy maps · TABULA · EPISCOPE · Web 2.0 · Geovisual analytics

1 Introduction

"Smart-cities" is certainly one of the current hottest topics in the information technology research area. Many definitions exist in current literature (Bowerman, et al. 2000); Fenger 1999; Giffinger 2007; Giffinger and Gudrun 2010; Washburn and Sindhu 2009) and all of them have a factor in common: the existence of an underlying ICT infrastructure that connects the physical infrastructure of the city with web 2.0 capabilities enabling innovative solutions for city management, in order to improve sustainability and the quality of life for citizens.

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_10

Urban metropolises, despite covering only 2 %, of the Earth's surface are the lead contributors of greenhouse gas production accountable for around 80 % of the oil, gas and coal world consumption. Therefore, energy consumption efficiency of residential houses is an important factor having impact on the overall city ecosystem and quality of life and it would greatly benefit from an ICT-enabled smart approach. In fact, increasing building energy efficiency would not only mean a cut-down in energy expense for citizens, but would also have an impact on the overall production of CO_2 at energy plants and also, even if less intuitively, on the city air pollution.

In this context, 3D city modelling can be an essential tool (Prandi et al. 2014) for energy planners and municipality managers, enabling them to perform accurate diagnostics of the existing building stock, and to plan low-carbon urban energy strategies. Indeed on top of that several smart services can be designed in order to support the increase of building energy efficiency and improve the city quality of life.

The paper will illustrate the concept and the development of smart services, which allow the assessment of the energy performance of all the residential buildings stock in a city, its validation and the easiest visualization in a format accessible to citizens and urban planning experts alike. The service leverages on geometrical and semantic data available at the city level providing a virtual 3D city model of the buildings and based on that calculate the energy demand of entire districts, cities and even regions.

The presentation of the energy maps in a 3D spatial-geographic framework, leveraging on interoperable OGC standards, allows citizens, public administrations and government agencies to evaluate and perform analysis on the building energy performance data, and provides a global perspective on the overall performance conditions of the residential building stock as well as on its fluctuations on the neighbourhood and block scale.

The development of these services is part of the scope of the SUNSHINE (2013) project (Smart UrbaN ServIces for Higher eNergy Efficiency, www.sunshineproject.eu), that aims at delivering innovative digital services, interoperable with existing geographic web-service infrastructures, supporting improved energy efficiency at the urban and building level. SUNSHINE smart services will be delivered from both a web-based client and dedicated apps for smartphones and tablets.

The SUNSHINE methodology is first designed and tested on the SUNSHINE pilot cities. The influence of the input data, not the same in all cities and regions, is studied. Then, the accuracy of the model is investigated, comparing the simulated energy performance of buildings with information data contained within energy certificates.

1.1 State of the Art

The current availability of relevant technologies and standards has encouraged the development of many research projects in the area of building energy performance estimation based on publicly available data with the aim of creating energy map (Strzalka et al. 2011; Nouvel et al. 2014). Virtual 3D city models, storing geometrical and semantic data of whole cities, have given a strong input in this context.

An example is described in (Nouvel et al. 2013a, b), where the City Geography Markup Language (CityGML) standard (Groeger et al. 2012) is used to semantically describe the set of objects that compose the urban environment, a building typology database is exploited to statistically estimate the energy performance properties of buildings and, finally, an Application Domain Extensions (ADE) to the CityGML model is defined to store the estimated information for each building. Some further examples of urban energy analysis based on virtual 3D city model have been realised at local scale for some city districts like in Berlin (Carrión et al. 2010; Kaden and Kolbe 2013).

The main challenge is however the quality of the data effectively provided for the whole city area. These are very variable, depending on the available public database (provided generally by the municipality), and the information data collected onsite. The quality of geometrical, meteorological, semantic and occupancy data influences uncertainty on the heating demand.

For example, building certificates, adopted by many of EU countries to describe building efficiency, can provide a very detailed insight on building energy properties, but on the other hand, these certifications are not mandatory for all the residential buildings and their availability is thus very sparse. Moreover, as they rely mostly on non-standardised data structures, they are with difficulty extensible to other cities or regions.

Typically publicly available data generally do not include all the information needed for the energy performance calculation, so one of the most common approaches to energy map creation is to estimate the missing information in a reliable way, using the basic input data that is typically available, such as building geometry, building use, construction year, climatic zone, etc. For the estimation of some of these parameters building typology libraries are essential.

These libraries can exist at a national level (e.g. in Germany: IWU 2003) or in the different European countries as outcomes of some EU initiatives (Project TABULA 2012) (Ballarini et al. 2012).

These approach, having to rely on typological databases to estimate the most of the energy parameters, yields a result that is typically not very statistically reliable at the building scale and is usually confined to residential buildings (where performance typologies are easier to define). Moreover, the overall software architecture is typically desktop based, so the access to the results is often limited to a small number of users with advanced GIS skills (Heiple and Sailor 2008). Another limit is related to the dissemination and exploitation activities of the computed results: for performance reasons, the visualization is commonly provided via a conversion to KML, where the link between the building performance data and its geometry is color-coded in each building-style parameter and the other information stored in the starting CityGML file is lost.

The work presented in this paper focuses on the results for the Building Energy Performance Assessment. The aim is to evaluate the accuracy and strength of a new approach that automatically calculates the heating demand of whole district areas, modelled in 3D. The proposed approach belongs to the typological one, but makes an effort to reduce the common drawbacks that have been delineated. As will be described in more details in the following sections, our approach is in effect hybrid, leveraging on the outcomes of project TABULA-EPISCOPE but limiting the use of building parameters estimated typologically.

The service provides an automatic large-scale assessment of building energy behaviour and the visualization of the results using the so called Energy maps which will be made publicly available via a 3D virtual globe interface based on WebGL (Marrin 2011).

2 SUNSHINE Approach

2.1 Energy Performance Map Calculation

The energy performance of a building is usually computed from a series of detailed information on building energy properties that are not available in general as public domain data. Publicly available data is usually limited to more basic information, such as building geometry, year of construction, number of building sub-units, etc.

The energy performance estimation approach developed in SUNSHINE is hybrid: it uses a deterministic approach for the geometrical properties, measured or computed, of the involved buildings and, a typological approach only for the estimation of the thermo-physical properties.

A fully typological approach has in fact the intrinsic limitation that the statistical significance of the performance estimation directly proportional to the scale at which the approach is applied, so very low at the scale of the single building. A hybrid approach that takes into account the real geometrical properties of the building makes the estimate of the building energy performance more accurate.

More specifically, the data necessary to the estimation are:

- **Geometrical data**: i.e. footprint, height, number of floors, etc. From these data, using specific geoprocessing procedures, other geometrical properties are derived, such as the building volume of the extent or the building wall surfaces shared with neighboring buildings.

- **Thermo-physical data**: i.e. period of construction, prevalent building use, refurbishment level. From these data, using a typological approach and leveraging on a sample of representative buildings for the different thermo-physical typologies, the thermal properties of each building are estimated, such as U-values of envelope elements and the percentage of windowed surface.
- **Climatic data**: i.e. the extent of the heating season and the average external temperatures. These data are derived from national and local directives.

The energy performance calculation is based on a simplified computation procedure based on ISO 13790 and ISO 15316 (international standard protocols for the energy sector). This, uses the geometrical, thermo-physical and climatic data to compute the following parameters are for each residential building:

- The energy need for heating;
- The energy need for heating and domestic hot water;
- The corresponding index for energy performance.

There are some considerations to highlight about this approach. The first is related to the fact that the building typological classification currently applies to residential buildings only and thus cannot be used to assess the energy performance of buildings with a predominant use that is other than residential (commercial, administrative, industrial, educational, etc.). As a consequence, the energy map itself will carry information only for residential buildings. This seems to us a reasonable compromise as residential buildings are among the major causes for energy consumption and air pollution (Fenger 1999).

A second important aspect is the use of thermo-physical typologies in order to estimate building properties that would be otherwise hardly obtainable on a large scale without employing a great deal of resources (money and time) and whose knowledge is instead necessary to determine an estimate of energy performance. The definition of these typologies is based on the results of project TABULA, integrated and extended to adapt to the specificities of SUNSHINE. Project TABULA defined a set of building typologies for each of the countries participating into the project, basing on 4 parameters: country, climate zone, building construction year, building size type (i.e. single family house, terraced house, apartment block, etc.). A building stereotype, described in all its geometrical and thermo-physical properties, is associated to each class, with the aim of representing the average energy behavior for buildings of that class. So, if the 4 parameters are known, than it is possible to associate the building to a specific typology class and thus to its estimated energy performance class.

A workflow for the automatic process for large-scale building energy performance estimation, has been implemented by using the following software:

- A relational database with spatial extension, where an input shapefile, structured in accordance with the input data model (i.e. Postreges/postGIS).
- An ETL tool for manipulating spatial data (i.e. GeoKettle, FME).

The logical structure of the workflow is the follow:

1. The workflow starts initializing the system;
2. For each building, all the data gathered in the input data model is used and, in addition, additional geometries parameters are computed such as area, perimeter, shared and exposed walls perimeter;
3. The building typology, according to the categories provided by TABULA, is estimated with the algorithm described in Fig. 1.
4. Using the previous estimated parameters, it is possible to query the TABULA database in order to obtain the set of U_VALUES in accordance with the climatic zone, typology, construction year and refurbishment level;
5. Having the set of U_VALUES and the real geometry proprieties it will be possible to estimate the Energy Performance Index (EPI) according with the EN ISO 13790 regulation.
6. An output shapefile extending the input data model with the new geometrical and thermo-physical data is produced. More details regarding the output data model will be provided in the next section.

The procedure implemented, is represented in Fig. 2.

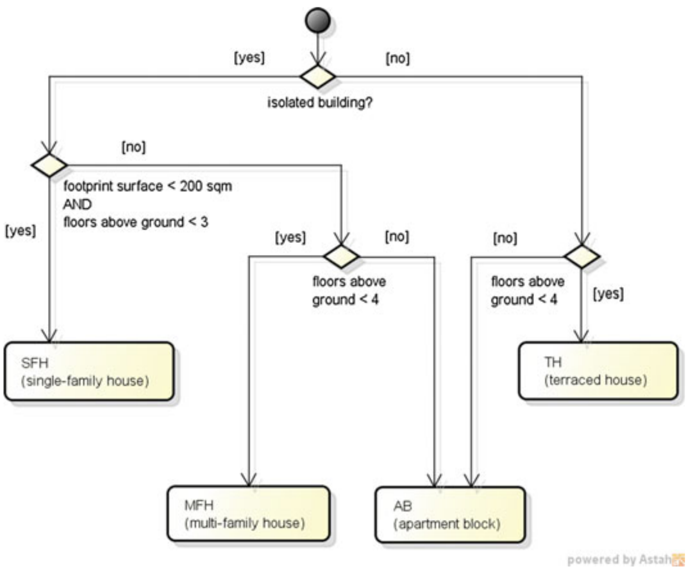

Fig. 1 Building type estimation

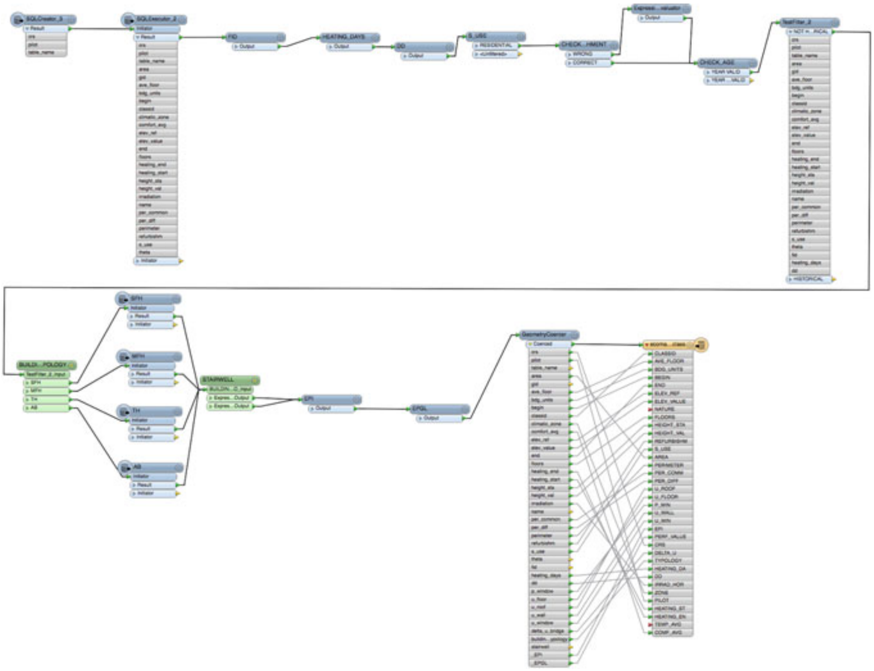

Fig. 2 ETL energy maps generation workflow

2.2 Input and Output Data Model

To ensure the extendibility of the energy performance calculation developed during the project across different EU countries and regions, which have different input data sources and building characteristics, it is needed to define an input data model in order to harmonize the possible different data sources.

The OGC Standard CityGML has been selected for the modelling of 3D building data. An advantage of CityGML compared to other 3D city model formats is its spatio-semantic model, which allows modelling even the specific semantic characteristics of the spatial features.

However the CityGML language core does not provide explicit attributes for modelling energy consumption of buildings, utility infrastructure distribution and capacities, and transmission coefficient. For this reason, an extension of the data model by energy specific contents is required, in order to allow inventorying, classifying, mapping and analytical processing of energy related values with strong reference to the related city object. Thus, the CityGML core needs to be extended by an Energy ADE. One goal of SUNSHINE is, together with other research groups, the definition of a coordinated and harmonized version of an Energy ADE (Nouvel et al. 2015). A working group, which is led by the Modeling Working Group of the Special Interest Group 3D (SIG 3D 2014), has been created for this purpose.

Due to the fact that a final version of the Energy ADE is not yet available, a simplified data model designed based on the ADE draft version has been used to model the workflow's output (Table 1).

To test and validate the methodology and algorithms a set of data related to the buildings in the pilot urban scenarios of Trento and Cles (Italy) has been collected and the SUNSHINE energy map estimation workflow has been executed on it. The results of this estimation then have been validated against the assessment retrieved on the energy performance certificates.

Table 1 Energy maps output data model

Attribute name	Type
Building identifier	string
Building geometry	geometry
Begin construction year	integer
End construction year	integer
Building height	real
Floors	integer
Average floor height	real
Refurbishment level	{no/standard/adv}
Use	string
Area	real
Perimeter	real
Shared perimeter wall	real
Exposed perimeter wall	real
U_roof	real
U_floor	real
P_win	real
U_wall	real
U_win	real
EPI	real
EPGL	real
CRS	string
Delta_U_bridge	real
Building_typology	int
Heating_days	int
Pilot_id	int
Irradiation	real
Climatic_zone_id	int

3 Analysis of Results

3.1 Energy Map Validation

Estimated energy performances, for residential building built after 1900 in the urban environment of Trento and Cles, has been validated comparing the obtained results with real energy certifications.

The logical validation process was composed by several phases with some constrains that have to be taken in account (Table 2).

General consideration: the SUNSHINE Workflow provides estimation based on the whole building geometry while energy certifications are based on thermal-zone and, the apartment position (ground floor/middle floor/last floor) influences the heat loss.

Through the SUNSHINE web portal, the user is able to analyse—in a local mode—the thermal situation taking into account the aforementioned general consideration. For this reason, the energy performance estimation workflow is refined as follows and performed for the three mentioned conditions. According by EN ISO 13790:

$$Q_{\mathrm{H,nd}} = 0.024 \cdot \left(Q_{\mathrm{H,tr}} + Q_{\mathrm{H,ve}}\right) \cdot t - \eta_{\mathrm{H,gn}} \cdot \left(Q_{int} + Q_{\mathrm{sol}}\right) \quad (1)$$

$$Q_{\mathrm{H,tr}} = H_{tr,\mathrm{adj}} \cdot (\theta_i - \theta_e) \quad (2)$$

$$H_{tr,\mathrm{adj}} = \sum\left(\alpha_i \cdot A_{env,i} \cdot U_{env,i} \cdot b_{tr,i}\right) + \Delta U_{tb} \cdot \sum\left(\alpha_i \cdot A_{env,i}\right) \quad (3)$$

With:

α_i = for walls and windows;
α_i = {0,1} for roof or floor;

In particular:

$\alpha_{whole\ building,\ i}$ = 1 for all elements;
$\alpha_{ground\ floor,\ i}$ = 1 for {walls, windows, floor}; $\alpha_{ground\ floor,\ i}$ = 0 for roof;
$\alpha_{middle\ floor,\ i}$ = 1 for {walls, windows}; $\alpha_{middle\ floor,\ i}$ = 0 for {floor, roof};
$\alpha_{last\ floor,\ i}$ = 1 for {walls, windows, roof}; $\alpha_{last\ floor,\ i}$ = 0 for floor;

Table 2 Logical validation processes and related constrains

Phase	Constrains
Building choice	Thermal zone
Outputs from SUNSHINE	Misalignments between stored data and real data, in particular the refurbishment level
Statistical elaborations	Degree of acceptability

In the first version of validation process (Giovannini et al. 2014), the simulation was performed for each of the three available apartment-position possibility (ground/middle/last floor) and outputs compared with the real value. The main problem related with this approach is that thermal-zone placements was originally unknown. In order to create a validation with the least number of uncertainties, the mode has been modified.

In the new validation approach the main parameter used is the S/V rate, where S—expressed in m^2—is area delimits indoor building from outside and V—expressed in m^3—is the heated volume. Selected buildings for the validation process are the one that have similar S/V value compared with real S/V.

The second phase concerns the acquisition of outputs from the SUNSHINE web portal for the selected buildings. Here the first issue to solve is related to the building construction year: several times it was identified a misalignment between SUNSHINE data and real certifications. For the model structure, this influences the thermal properties and so the final EPI value. Another important aspect regards the unknown refurbishment level and in particular way which external building envelope part was improved.

In order to solve these issues, the platform provides the possibility to update these data, and compute an updated analysis for the selected thermal zone. For the validation, SUNSHINE data of age are checked with real one and eventually changed locally.

Table 3 reports a subset of the whole set of buildings involved in the urban environment where the following information is reported:

Table 3 Validation results

ID	City	Year	Δ (S/V)	Real EPi	Est. EPi	Δ EPi	Δ EPi (%)
Building 1	TN	2013	0.015	35.44	49.88	14.44	41
Building 2	TN	1999	0.02	106.02	109.8	3.78	4
Building 3	TN	1960	0.041	54.8	45.61	9.19	17
Building 4	TN	1925	0.068	55.5	45.45	10.05	18
Building 5	TN	1992	0.059	73.4	61.64	11.76	16
Building 6	TN	1996	0	88.6	63.1	25.5	29
Building 7	TN	2002	0.047	14.94	39.8	24.86	166
Building 8	TN	2007	0.082	42.77	37.11	5.66	13
Building 9	TN	2002	0.096	124.4	80.5	43.9	35
Building 10	TN	1970	0.029	66.62	38.17	28.45	43
Building 11	TN	1962	0.054	75.23	75.97	0.74	1
Building 12	TN	2007	0.093	67.57	61.57	6	9
Building 13	CL	2011	0.035	32.57	61.72	29.15	89
Building 14	CL	2001	0.082	41.63	37.28	4.35	10
Building 15	CL	1960	0.094	62.2	42.79	19.41	31
Building 16	CL	1980	0.081	116.08	111.6	4.48	4

- Building typology, in according with the TABULA classification;
- City (TN/CL);
- Real Construction year;
- S/V rate difference between real and SUNSHINE data;
- Real EPI [KWh/(m^2 year)]: energy performance index provided by real certificates;
- Estimated EPI—whole building [KWh/(m^2 year)];
- Difference between real and estimated EPi.
- Absolute difference between real and estimated EPi.

Figure 3 reports the comparison of real (blue bars) and estimated (red bar) data on the whole dataset.

In the third phase we set up acceptability scale for the model. Looking at outputs, it is clear the impossibility to refer to the absolute difference between EPI and neither to percentage difference, because all depends on the baseline value, as it is refer in Table 4.

The solution was to use a mixed scale. It should be also considered that different software used to calculate the energy performance index produces similar, but not equals, results. These differences are variable and can reach up to 20 %, with an absolute difference between 20–30 KWh/(m^2 year).

The final acceptability scale is reported below:

ΔEPi < 20 %
ΔEPi > 20 % and ΔEPi < 25 KWh/m^2a

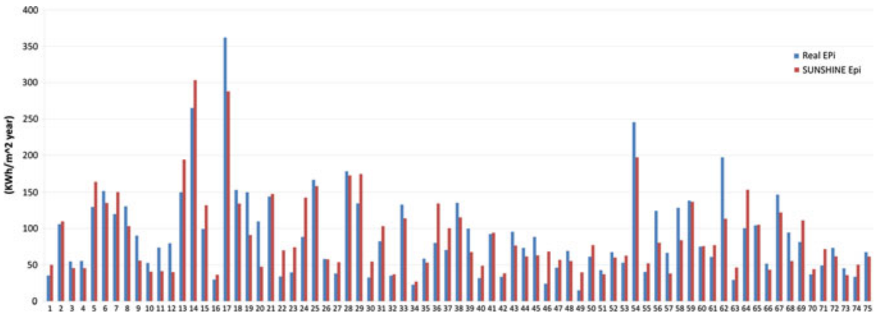

Fig. 3 Difference between estimated and real EPIs

Table 4 Samples of some result

Real Epi	Epi SUNSHINE	Absolute difference (KWh/m^2 year)	Percentage difference
362.01	287.98	74.03	20
95.61	76.72	18.89	20
90.3	56	34.3	38
34.02	70.04	36.02	106

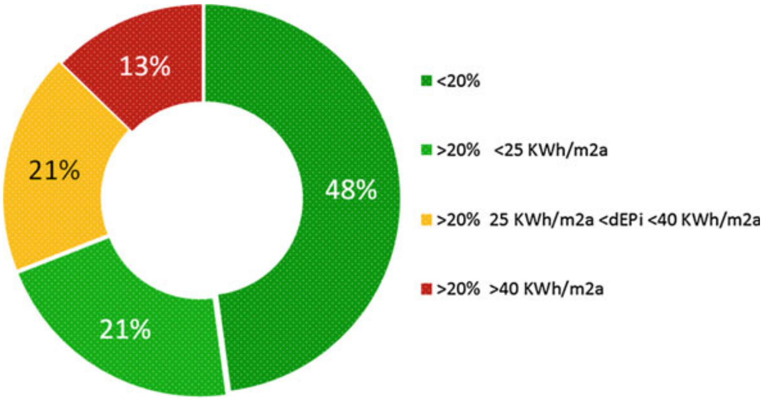

Fig. 4 Acceptability classes

ΔEPi > 20 % and 25 KWh/m2a < ΔEPi < 40 KWh/m^{2}a
ΔEPi > 20 % and ΔEPi > 40 KWh/m^{2}a

The model is acceptable if the average difference scale was in one of the first two classes.

Figure 4 represents the results in a pie chart. As it is possible to see, the average error between estimated and real data is near the 22 KWh/(m^2 year) and the percentage difference near to 30 %.

3.2 *Energy Map Visualization*

The final data model selected to host the 3D buildings and their data is CityGML at the LoD-1 level of detail that will be extended with a new Application Domain Extension (ADE) defined with the aim of describing the properties of the buildings in the energy domain.

Previous works already provided the visual representation of these outcomes in 3D GIS environment allowing more intuitive understanding of the building stock energy performance. However these systems was limited to specific GIS desktop tools or in such case in intranet client/server infrastructure.

In the new smart-city paradigm all the involved stakeholders (citizens, public administrations and government agencies) should be aware about the outcomes of the research and development activities and rely on that in order to provide feedback and take decision. For this reason, a paradigm shift on the client platform to access the information is fundamental. The system should be usable by the majority of users via web so the designing and testing phase, both mobile and desktop-based SUSNHINE web-client, requires a careful evaluation of the proposed solution.

To achieve the widest dissemination possible for the project's results, the emerging WebGL technology (Marrin 2011) has been employed, in conjunction with HTML5 elements, as the main component of the application layer. WebGL is a cross-platform royalty-free web standard for a low-level 3D graphics API based on OpenGL ES 2.0, exposed through the HTML5 Canvas element as Document Object Model interface.

Energy maps are generated merging geometry LOD-1 information from the CityGML of the displayed city with the output of the energy performance estimation procedure; however CityGML is designed to represent 3D city models, but not to present or visualise 3D city models directly (Soave et al. 2013).

In order to overcome this lack and to provide 3D geographic information via web the service is based on providing the geometrical information using a format more suitable for 3D visualization (i.e. KML) and the related semantic information

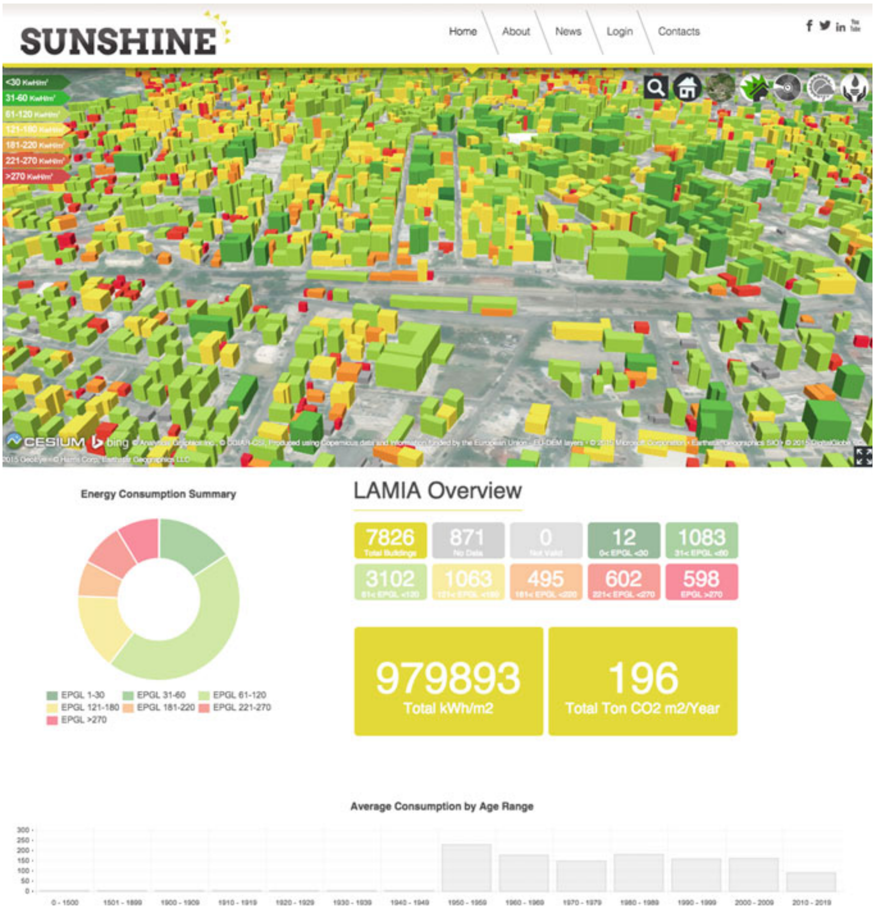

Fig. 5 Energy map visualization

using a WFS services. The reference between each building feature in KML file and the corresponding building in 3D CityDB is ensured by storing the unique GML UUID of the building in the KML polygon name property. By the use of a WFS web service it will then be possible to retrieve the energy-related parameters corresponding to the selected object and stored as semantic features of the CityGML.

Three interconnected parts compose the energy map visualizer

1. An HTML5 canvas that displays the WebGL virtual globe in which KML energy maps, based on CityGML LOD-1 geometries, are loaded (Fig. 5);
2. A classical HTML tab, displaying overall statistics for the selected ecomap. By the use of this interface, the user can estimate how many buildings belongs to a specific Energy Performance Index range, the total emission of CO2 etc.;

Fig. 6 Building analysis and simulation tool

3. A HTML console to refine the energy performance calculation for the selected building acting on the input data such as year of construction, refurbishment level or U values. This increase the energy performance index estimation accuracy also providing some information for the apartment-level estimation (position of the apartment: ground, middle, last: already discussed in the previous chapter) (Fig. 6).

4 Conclusions and Future Works

In this paper we have presented the results of the SUNSHINE project.

3D city models combined to reliable TABULA building typology database offer a good base for large-scale energy performance estimation. However correctness of results is strongly influenced by the quality of input data.

Reasonable energy performance estimation error of around 20–25 KWh/(m^2 year) can be accepted. The final assessment demonstrates that the model is valid, with about 70 % of the estimated energy performances belong to the acceptable class. Furthermore the possibility for the end user to recreate a local simulation was a basic instrument to improve the simulation where basic input data can be wrong.

Future improvements will be focused on refurbishment in order to separate the different element and year of restructuring; in this way it will be possible improve the estimation quality.

Building energy performance assessment using 3D city models offers opportunities to simulate energy scenarios, that could support municipal managers in the development of long-term urban energy strategies.

Accurate data collection to retrieve missing input data and to validate the existing ones are the major challenges for the 3D city model use. Several approaches including crowd sourcing could be exploited in order to reduce time and costs of these data collection and validation.

Moreover, the use of the emerging WebGL technology ensures the largest available audience in terms of devices, both desktop and mobile, avoiding the development of device-dependent custom clients for 3D city map visualization.

Future improvements will be focused on increasing the quality of the geometry displayed, making it possible to render buildings based on CityGML LoD-2 level of detail and on the development of more detailed building typologies estimation procedures.

Acknowledgements The project SUNSHINE has received funding from the EC, and it has been co-funded by the CIP-Pilot actions as part of the Competitiveness and innovation Framework Programme. The authors are solely responsible of this work, which does not represent the opinion of the EC. The EC is not responsible for any use that might be made of information contained in this paper.

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Part III
Cartographic Technologies

Atlas of Switzerland Goes Online and 3D—Concept, Architecture and Visualization Methods

René Sieber, Marianna Serebryakova, Raimund Schnürer and Lorenz Hurni

Abstract Interactive atlas systems are products of high cartographic quality and user-targeted functionality. The main challenge for future digital atlases will be to incorporate the new trends of 3D mapping, online and mobile applications into atlas design. The Atlas of Switzerland, an example of a mature digital atlas, tries to advance these trends together with existing atlas functions in its next version. Starting with the concept of an online 3D atlas, this article explains the architectural implications of an atlas based on a virtual globe engine. By embedding the globe in a modern graphical user interface and implementing cartographic 3D visualizations, it is intended to strengthen the position of the atlas against other online mapping services.

Keywords National atlas · Web cartography · 3D visualization

1 Introduction

During the last two decades, numerous interactive atlas and mapping systems have been developed. With the rise of high-speed Internet connections, online atlases appeared (e.g. Atlas of the USA, Atlas of Canada, ÖROK Atlas, Atlas of Belgium) facing the challenge of streaming map data with good performance. One trend goes

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_11

towards service-oriented online atlases (e.g. National Atlas of the Netherlands, WebAtlasDE), which act as visualization front-ends of the National Spatial Data Infrastructure. In parallel, touch-based online atlases for mobile devices have been created (e.g. National Geographic World Atlas, Barefoot World Atlas, Statistical Atlas of Switzerland). All these systems offer mainly statistical 2D map types like choropleths, point symbols and charts, and partly some 3D map types like panoramic views and block diagrams (e.g. Swiss World Atlas). They also include a bundle of atlas functionalities for spatial and temporal navigation, map visualization, and layer handling. Nevertheless, all kinds of online atlases have to compete with freely available map services (e.g. OpenStreetMap, Google Maps), geoportals (e.g. INSPIRE, geo.admin.ch), and virtual globes (e.g. Google Earth, Cesium). At the same time, the popularity of geodata and geo-related applications enables digital atlas products to activate new user groups and to animate them for collaboration. Thus, also the development of atlases has to strive for new horizons.

A detailed survey on current geovisualization products points out that the majority of up-to-date applications are dedicated and conceived for 2D web and mobile use (Hurni et al. 2011). Web-based applications are rather heterogeneous concerning content handling and cartographic quality. The attractiveness of these applications is primarily based on the immediate benefit in everyday life and on the actuality of the data. In addition, the survey reveals that 3D maps in atlases are nearly inexistent. However, applications using 3D concepts and virtual globes are persuading users by their intuitive navigation and their spatial clarity (Bodum 2002). Regarding atlas cartography, map and atlas authors should be engaged in the 3D application discussion to determine and establish viable visualization rules (White 2012). They have to know the weaknesses of 3D symbolization and interpretation, but first of all, they have to investigate in and demonstrate possible solutions for 3D maps. Although there is a tendency towards 3D representations in cartography, many questions on their effectiveness (e.g. of 3D charts) and their usefulness (e.g. of extruded polygons) remain unsolved and disputed (Harrower 2009; Bleisch et al. 2008). Scientific research has proven that 2D overrules 3D symbolization in terms of accuracy estimation of chart sectors and height, or in comparing different charts (e.g. White 2012; Wilkening and Fabrikant 2013). Attempts have been made to improve 3D symbolization, for instance the cartography-oriented design of 3D visualization (Semmo et al. 2015), the evaluation of graphic variables for 3D use (Häberling et al. 2008) or the definition of the appropriate levels of abstraction depending on viewing distance (Pasewald 2012). For quantitative interpretation of 3D symbols, there are already approaches to use tools like reference grids or scale bars (Bleisch 2011).

To summarize, the main challenge for future digital atlases will be to merge the big trends of *online mapping*, *mobile mapping* and *3D mapping* with cartographic design and atlas-specific functionality. Thus, research and development should focus on cartographic 3D visualization and interactivity for different user groups and applications. In the upcoming version of the *Atlas of Switzerland*, we try to follow the proposed strategies.

2 Project Background

The *Atlas of Switzerland* (*AoS*) is mandated by law by the Swiss Federation to visualize themes from different fields, such as socio-economy, ecology, traffic, and energy, in an ongoing long-term project (Hurni et al. 2015). Since its beginning in 1961, the Swiss national atlas offered cartographically sound maps in combination with additional information to the general public in order to visualize visible and hidden structures and processes.

A first printed version with over 600 maps has been produced and published until 1997. These maps show the whole range of thematic cartography, including various kinds of charts, and even 3D symbolization (www.atlasofswitzerland.ch/portfolio). From 2000 to 2010, three interactive versions of AoS were published on CD-ROM/DVD (Figs. 1 and 2).

The last edition, AoS 3, contains about 2000 maps with additional time series in 2D maps and 3D mode (block diagrams, prism maps, and panoramic views). It offers

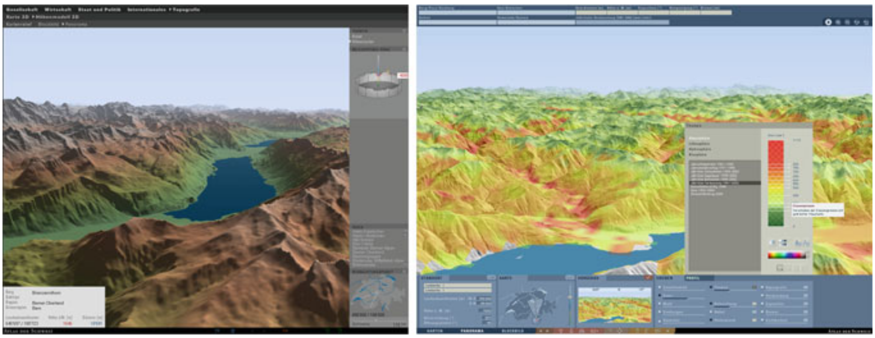

Fig. 1 Atlas of Switzerland—interactive series: AoS 1 (2000; *left*), AoS 2 (2004; *right*)

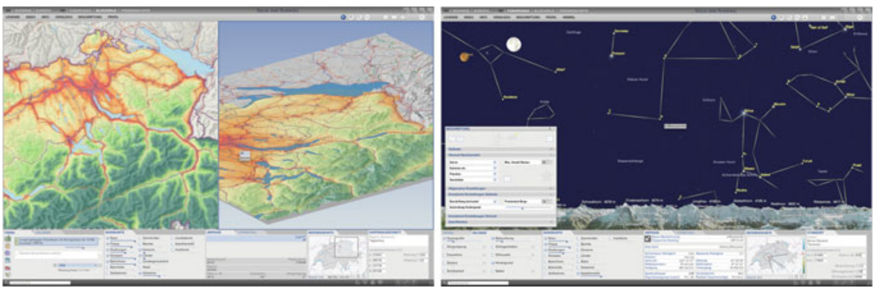

Fig. 2 Atlas of Switzerland 3 (2010): 2D map/block diagram (*left*), *Starry sky* with settings panel (*right*)

a multitude of tools and map functions, including a sky tool, terrain analysis tools, data and map comparison tools, smart legends, and many more (Sieber et al. 2009).

The series of interactive AoS was a big success: overall, more than 23,000 copies were distributed during this decade. The interactive AoS versions can be characterized as stand-alone GIS in a Multimedia approach (Bär and Sieber 2007), where map visualization, atlas tools and GUI are fully developed in-house by the AoS team. Main achievements were the integration of various map types (point symbols, charts, lines, choropleths, and grids), a graphically appealing map design, adaptive map layers, and tailor-made functionality. The drawbacks of this approach were that the atlas was developed as a closed single application with proprietary data formats, too many tools and features, no smooth transition between 2D and 3D map mode, and nearly no online connection.

To sum up, the AoS product cycle has reached the stadium of a mature desktop-based atlas system, and only a total conceptual rethinking would push the project to meet current user needs.

3 New Concepts

The next generation of the Atlas of Switzerland focuses on online cartography with real-time 3D visualization of geographic data. Thus, the concept of a *3D-based cartography* will be pursued, where a 2D map is considered as a special case of a 3D map setting (Sieber et al. 2013). The basic idea is to combine 2D and 3D by allowing the user to choose a conventional 2D map view, but also to detect additional information in a 3D map view. Within this 3D environment, new rules, interactive methods and user-friendly tools for 3D navigation in space and time, map graphics and layer handling, and explorative analysis will be developed.

The 3D atlas should stand for a *world of experience and discovery*, inviting people to explore its thematic content, and interrelations (Vozenilek 2015). Hence, the functionality of the atlas has to start with basic functions of navigation and information retrieval (Häberling et al. 2007). In detail, the 3D atlas functionality consists of *spatial navigation* (3D navigation, place search, geolocation, home extent), *temporal navigation* (time points and periods), *thematic navigation* (map search/menu; related/popular maps), *information* (query, legend, theme description, multimedia elements), *visualization* (2D/3D mode; layer interaction), *import* (WMS, GPX) and *export* (PDF, permalink). The functionality will be augmented stepwise according to user needs, that is, the user's vote is essential to develop new tools and actions.

Map themes of the new AoS will be grouped into ten thematic categories: Portrait of Switzerland, History and Future, Nature and Environment, Landscape and Space, Tourism and Leisure time, Society and Culture, State and Politics, Economy and Energy, Traffic and Communication, and finally, Switzerland International. In the first edition, each category will contain only a few maps. These maps are selected according to the following principles: popularity (e.g. Swiss records, beer map) as a door opener for other more serious topics, "classical" themes (like geology, population) as a must-have in every national atlas, and data suitability for 3D representation (c.f. Chap. 6). It will also be forced to present well-known themes in a new way, for example by approaching the historical origination of Switzerland on a commune level. Although the main part of the thematic content spatially focuses on Switzerland, the use of a virtual globe also allows integration of European and worldwide map themes (e.g. international flights).

Conceptual considerations are also dedicated to the *Graphical User Interface* (*GUI*) of the 3D atlas (Sieber et al. 2015): the GUI should work for desktop and mobile applications, and consider reduced feature and layout complexity as well as responsive design. Further graphic-oriented concepts and techniques concerning the GUI are described in the next chapter.

4 Atlas System Architecture

As a basic framework for future AoS products and affiliated atlases, the *Atlas-Platform-Switzerland* (*APS*) has been propagated and prototypically implemented (Fig. 3).

On the back-end, map-editors can import attribute, vector, and raster data to a PostGIS database with the *APS Editor*, a plug-in for QGIS. The *APS Editor* facilitates composing map layers, adding multimedia elements (e.g. images in

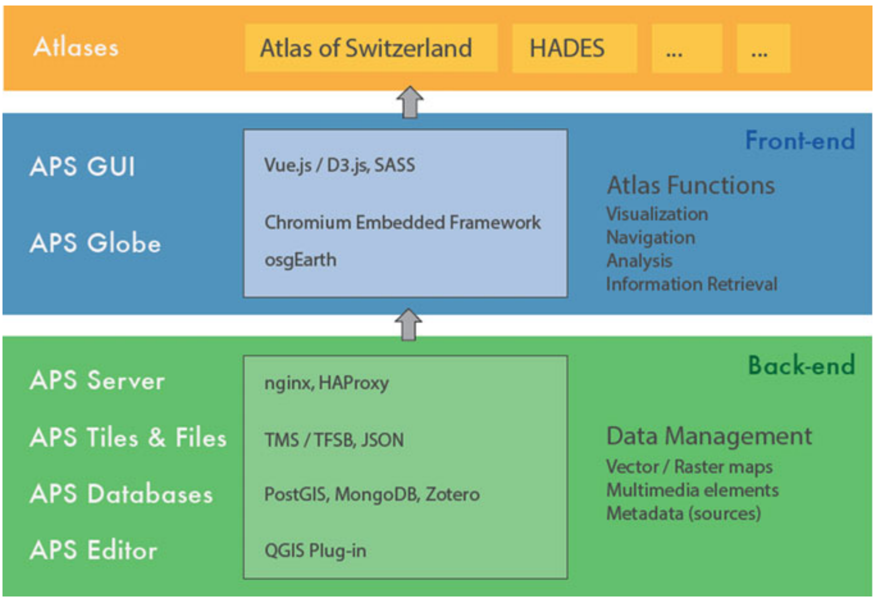

Fig. 3 System architecture of the Atlas-Platform-Switzerland (APS)

MongoDB), and annotating map metadata (e.g. text sources in Zotero). In addition, tile caches (TFS for vector data, TMS for raster data) can be created which split maps into smaller parts at different levels of generalization. Once a map is ready to be published, metadata is exported from the database to JSON documents, which are—together with the map tiles—hosted on a scalable web server (nginx). A load balancer (HAProxy) mediates the HTTPS requests for map tiles and metadata.

The APS front-end architecture consists of a desktop application, at which the Chromium Embedded Framework (CEF) combines the web-based atlas user interface with the *APS Globe*. The *APS Globe* extends the 3D visualization engine osgEarth whose dedicated virtual globe offers near real-time rendering and navigation, high geodetic quality, dynamic streaming of large data sets, and a multi-resolution terrain representation. It also supports overlaying custom imagery, manifold GIS formats and web services. This enables, amongst others, the interactive data exploration in AoS, such as combination of a base map and thematic maps, interactive adjustment of transparency of thematic maps, and query of the map elements.

Currently, the APS is in use for two thematic atlas products, the *Atlas of Switzerland—online* and the *Hydrological Atlas of Switzerland* (*HADES*).

The GUI for the atlas platform has been established with methods of interaction design (IxD) in the four following steps (Sieber et al. 2015): (1) investigation phase, (2) rough design phase, (3) detailed design phase, and (4) implementation phase.

After investigating existing atlas GUIs, use cases, and possible GUI layouts, interaction designers deepened into sketching the appearance of the atlas. At the rough design stage, they used wireframe techniques to create a storyboard, whereas moodboards set the main design direction of the GUI. During the detailed design phase, interaction designers created and specified all layouts, icons, tools, and actions. Finally, web application engineers implemented the GUI with Java-Script frameworks (e.g. Vue.js, D3.js) and a CSS preprocessor (SASS).

The final GUI consists of two main screens: the start screen and the map screen (Fig. 4). A transition between the two screens is initiated by clicking on a map tile,

Fig. 4 GUI design of the Atlas of Switzerland—online: Start screen with main categories (*left*) and map screen with layer and tool bar (*right*)

a search result, or an icon at the top left corner. It is possible to combine up to three thematic atlas maps and three external maps atop of a base map. Controls for spatial 3D navigation, a time slider for animating map layers, and elements for thematic navigation (i.e. a quick and an advanced search for places and themes, a hierarchical menu, and panels for related and combinable maps) help users to explore the atlas contents. Following Shneiderman's (1996) information seeking mantra—overview first, zoom and filter, then details on demand—user may obtain additional information on maps by displaying multimedia elements, inspecting metadata, and measuring distances and areas in separate panels. The GUI is designed to be responsive for tablets, laptops, and desktop PCs as well as to be extensible for new functions.

5 Cartographic 3D Visualization

The APS aims to provide eye-catching and well-readable 3D visualizations to raise the interest of the public. The third dimension has the advantage to depict an additional variable, but at the same time, it has the disadvantage that depth cues lead to misinterpretation of size. Furthermore, although we perceive the world in three dimensions, reading a map may be puzzling when trying to interpret 3D visualizations with too many graphical variables. This information overload can be partly avoided by using generalization methods like selection, decluttering, etc.

Depending on the source data type, the APS includes cartographic 3D representation techniques like solid charts and billboards for point data, curved lines for trajectories, extrusion for areas, and terrain modelling for volumes. Considering the interaction of thematic layers with terrain, the LOD behavior, the performance, as well as possible occlusions need to be taken into account. The challenging part is to make an intuitive visualization both in 2D and in 3D: Map-readers should get an overview from the birds-eye perspective and more details when tilting the globe.

Cartographic 3D visualizations are driven, but sometimes also restricted by the underlying technology. In the *APS Globe*, the terrain surface is generated by a uniform triangle mesh (regular grid), which is simpler to store and manipulate than an irregular triangle mesh (Luebke et al. 2003). Terrain and maps are stored in tiles and loaded in a quad-tree graph so that data sets can be transferred in little chunks and at a convenient resolution. Maps are either draped as textures on the terrain or tessellated in case of vector data. During the rendering process, the virtual globe engine has to solve tasks like intersections, ordering of map features, avoiding artefacts from projections and at tile borders, shading of 3D features, and opacity of different layers (Cozzi and Ring 2011).

Below are examples of the 3D visualization methods that have been implemented in the new version of the Atlas of Switzerland.

5.1 Point Features

Basic visualization methods used in AoS for point features are translation, billboards, 3D solid charts, 3D symbols, and labels.

Translation can be applied to the point data, as it was done to represent the population of Switzerland (Sieber et al. 2013). The result of such a combination is a point cloud map (Fig. 5). From an orthogonal view, the point cloud densifies to a choropleth-like map; population peaks are visible from a tilted view. As height-depending scaling of features is quite cost-intensive, the behavior of the map when zooming in remains an open issue. The initial loading time of the map, on the other hand, was reduced by creating tiles with a limited number of point features.

A common representation of point data is a *billboard.* In a 3D space, a billboard rotates always to the direction of the camera, as draping 2D symbols on the terrain would distort them. Billboards can contain both images (e.g. PNG) and vector data (e.g. SVG), the latter however are rendered into a texture due to performance reasons. This technique was used, for instance, to visualize different types of mountain cableways (Schnürer et al. 2014), such as cable railways, funiculars, or shuttle cableways (Fig. 6, left).

Another example of using a billboard, implemented by Schnürer et al. (2014), is a 2D wing chart showing how many passengers travel at the airport at certain time slots (Fig. 6, right). Wing colors represent the time of day, and the radius of each sector the number of passengers. The angle stays the same to enable users to compare the areas of different sectors correctly. 2D wing charts can be used with absolute values. A still open cartographic question concerns the display order when

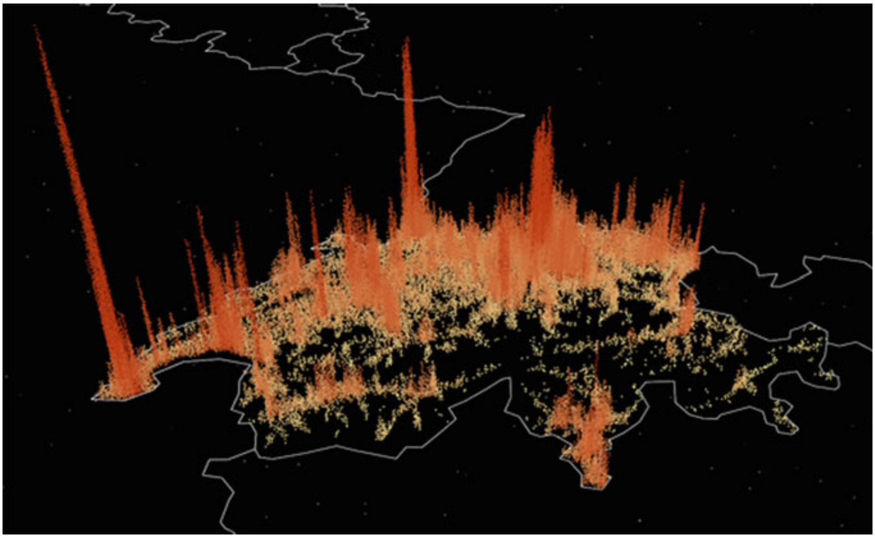

Fig. 5 Point cloud map: Population distribution in Switzerland

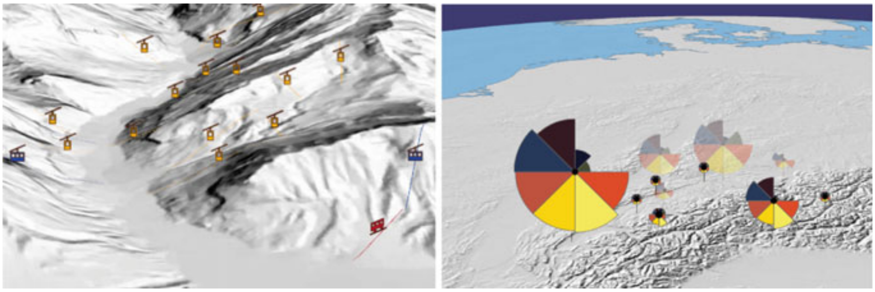

Fig. 6 Billboards: Mountain cableways (*left*). 2D wing charts: number of airport passengers at different times of day (*right*)

billboards intersect each other: Shall the nearest, the smallest or the most important feature be displayed the foremost? In our map, the nearest feature to the camera is visible, whereas intersecting features are minified and faded.

The atlas also contains maps with *3D charts*, for example stacked pyramid frustums (Fig. 7). The frustums show population counts of European countries from 1960 (bottom layer) to 2010 (top layer) with changes over decades, displayed by differences in square of upper and lower planes of every single frustum. Thus, top and bottom surface areas represent thematic variables at sequent points in time. From an orthogonal view, however, this kind of visualization hides the temporal dimension and displays only one variable at a point in time. Compared to 2D bar charts, which are also suitable for population counts, stacked pyramid frustums imply the metaphor of a population pyramid. As charts are 3D features, it is possible to query individual chart parts. Yet, the rendering of edges and line joins needs to be further improved so that outlines are visible from all distances (Schnürer et al. 2015).

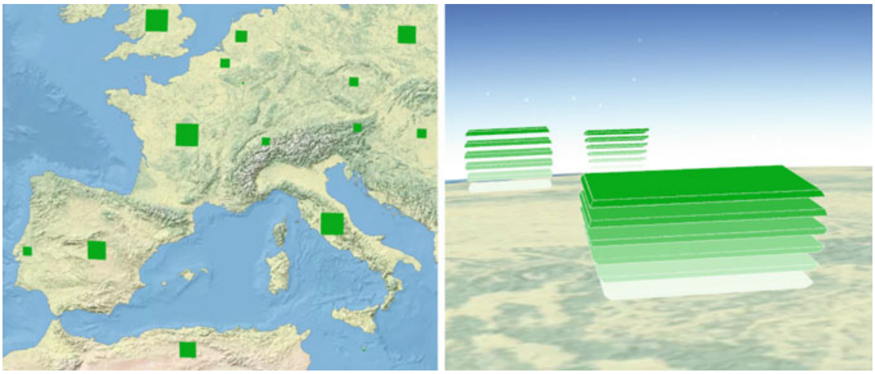

Fig. 7 Stacked pyramid frustums: population in European countries. Orthogonal view (*left*) and tilted view (*right*)

Point features can be depicted on a more realistic level by *3D symbols,* such as castles, airports, volcanoes, and types of houses. Those may replace billboards on some maps in future since they may serve as landmarks for the map-reader.

Beyond, point information can be conveyed as *labels*. An example of this representation type is a map of worldwide appearances of the term ‘Schweiz’ (German for Switzerland), because some names of small mountain chains and regions in different countries contain this word fragment.

5.2 Line Features

3D curved lines are a technique to visualize paths between a starting point and an end point. With this kind of visualization, a “focus” effect can be achieved by setting a common starting point. It is much easier to identify the destination points. An additional attribute can be mapped to the height of the path, for instance the approximate flight height, and parameters for a finer or coarser line tessellation can be set. An addition would be the implementation of arrows at the line endings to indicate directions. This type of visualization is applied for the flight routes of the main airports in Switzerland (Sieber et al. 2013, Fig. 8). Darker shades of pink represent a bigger number of passengers, and lighter shades indicate a lower number.

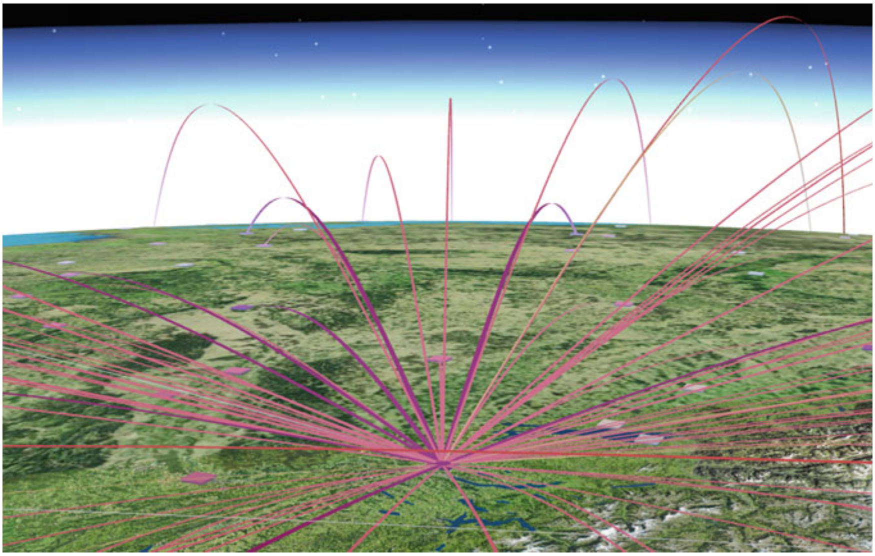

Fig. 8 *Curved lines* Direct flights from Zurich airport

Linear objects bound to the ground in AoS are usually rendered by means of *GPU clamping* mechanism, which is fast, generally well-suited to lines and causes no jags at the edges, as if it would happen when draping linear features (Pelican Mapping 2013). In the atlas, natural gas pipelines are displayed with the GPU clamping technique. To avoid the problem of Z-fighting of intersecting lines, altitude offsets have been introduced for pipelines with different diameters.

5.3 Area Features

Vertically extruded polygons are implemented in AoS to assist in visualizing quantitative data or to simply embed them appealingly into 3D space. Challenges for this technique are intersections of larger extruded polygons with the terrain, that can be avoided by a finer tessellation. Extruded grid cells were applied, for example, in a precipitation map, where the third dimension demonstrates the amount of rain. Another example is the conversion of building footprints into 3D building areas in the settlement development map (Fig. 9), where extrusion intensifies the built-up area connotation (Chesnokova et al. 2015). Together with the color-coded time component—the darker the older—the user gets a vivid impression of the urban development.

In contrast to lines, polygons can easily follow the terrain by means of *draping*, which is the process of rendering features into a texture and projecting them onto the surface of the terrain (Pelican Mapping 2013). Despite possible jagged artifacts

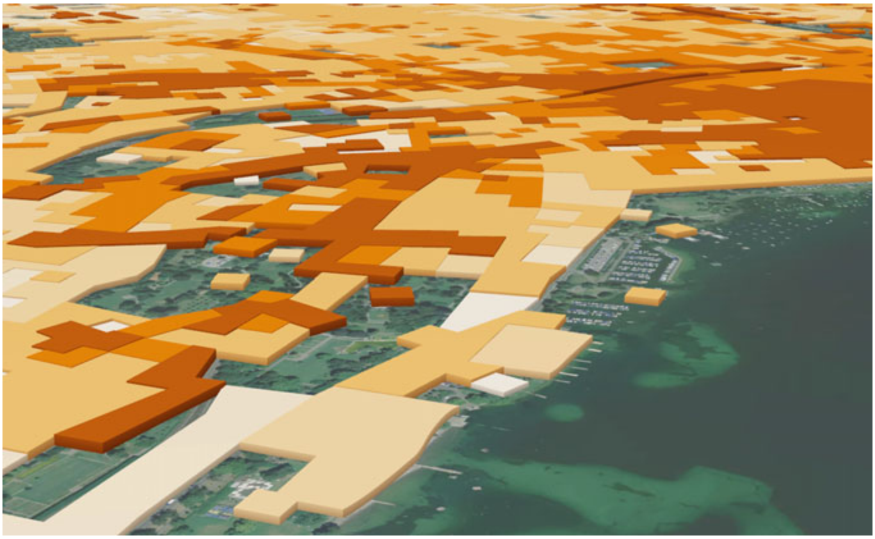

Fig. 9 Extruded polygons: Settlement development

(which are mostly visible when tilting the globe), areal features benefit from draping, as they fully match the terrain, and the resolution is preserved. Since draped polygons are always displayed at the bottom level, thematic choropleth maps will not cover all base map elements (e.g. rivers), what is not desirable from a cartographic perspective.

5.4 Volume Features

To depict volumes in 3D, two techniques were applied. The first type is represented by *terrain volumes* and is used, for instance, in the Swiss last glacial maximum map (Fig. 10). The DEM appears here as a variable that represents the height of an ice shield. When applying this technique, it is possible to combine the former ice shield with the situation today. Thus, the user can locate different known places and compare the thickness of the ice.

The other type of volume visualization implemented in AoS is *polyhedral surfaces* like airways, airspaces, and geological layers. Map-readers can fully explore the dimensions of those 3D volumes in a virtual globe, what would not be possible on a 2D map, where height information is lost. In a 3D environment, however, it is likely that the map-reader loses orientation when diving into a transparent 3D volume. Therefore, the atlas needs to provide additional aids, for example an overview map including the current altitude.

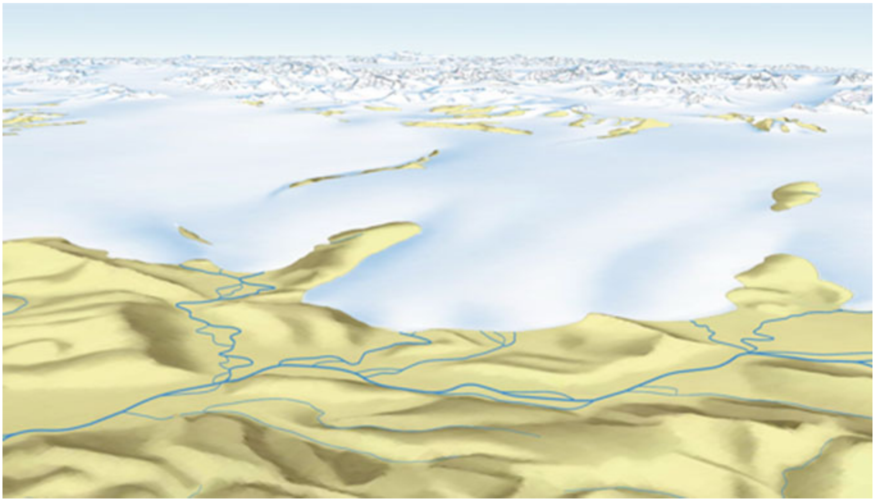

Fig. 10 Terrain volumes: Last glacial maximum in Switzerland

6 Outlook

The launch of the new product line *Atlas of Switzerland—online* is scheduled in spring 2016 as a desktop version for Windows. In the upcoming years, the functionality and content of *AoS—online* will be enriched and completed with an OS X Mac version. A version for tablets, *AoS—mobile*, is also planned. Both versions will offer a broad range of thematic maps, visualized with 3D techniques, giving professionals and inexperienced users the opportunity to combine different geospatial phenomena in a modern atlas user interface.

Conceptually, more storytelling aspects will be included in the next versions to deliver the atlas contents to users easier. Accompanying usability studies will evaluate the user experience and may reveal further user needs for the GUI and globe. To ensure a good performance for many users, a private Cloud infrastructure is currently being developed, as the speed of rendering 3D maps is a crucial factor for user satisfaction. Internal workflows for creating new maps and for updating existing maps in the atlas are continuously optimized and automated by geoprocessing scripts and GIS tools. Lastly, it is planned to make map metadata available for search engines and to introduce some animated 3D visualizations.

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Development of a Web-Browser Based Interface for 3D Data—A Case Study of a Plug-in Free Approach for Visualizing Energy Modelling Results

Jochen Wendel, Syed Monjur Murshed, Akila Sriramulu and Alexandru Nichersu

Abstract This research explores the usage of freely available open-source resources for the deployment of a plug-in free web-application interface for 3D geospatial data to visualize energy related modelling and simulation results. Such plug-in free web mapping applications will be essential for future cartographic web applications as forthcoming web browsers will no longer support the usage and installation of those plug-ins used in the past. As a proof of concept, a 3D city model of the city of Karlsruhe in Germany consisting of over 87,000 buildings is used as a case study. This data set was compiled using OpenStreetMap data and outputs from energy simulation models. The CityGML format is used for data storage of this multi-domain data set. In order to ensure independence from browser plug-ins, HTML5 and freely available JavaScript libraries are used for the creation of this application. Multiple analytical cartographic and geospatial functions such as cartographic classification, attribute selection, descriptive statistics, spatial buffer analysis and the retrieval of modelling results from a PostgreSQL and PostGIS data infrastructure are implemented in this interface. This paper further discusses some case studies, future enhancement opportunities of the proposed interface and experiences gathered during the interface development process that would help other cartographers and GIScientists in developing future native 3D web mapping applications.

Keywords 3D web mapping · Geovisualization · WebGL · Web mapping API · Energy analysis

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_12

1 Introduction

The visualization of urban energy modelling and simulation results is a crucial part in energy research as they act as the main communication tool among scientists and decisions makers. Results from energy modelling and simulations are usually directly linked to spatial objects such as buildings or city furniture. 2D visualisation techniques have been implemented since many years but with the recent emergence of detailed 3D urban data models and their advantages in energy modelling, the visualization in 3D plays a significant role. In some cases, the results are usually not aggregated by the building object but at a finer scale such as building surfaces. This requires a higher grade of visualization and therefore 3D becomes a necessity (Nouvel et al. 2014). Furthermore, the presentation of energy simulation results in 3D enables the decision makes and users to better explore and comprehend outcomes from multiple perspectives (Bahu et al. 2014).

Recently, numerous 3D web Application Programming Interfaces (API) ranging from GoogleEarth[1] to Unity's Game Engine[2] have evolved, but most of the web-mapping services that visualize 3D data are either based on browser plug-ins and require the users to install one or more programs locally on their computing devices. The installation of those plug-ins is often cumbersome and raises compatibility issues with different web browsers. Furthermore, browser plug-ins, especially those that do graphically represent information such as Adobe Flash or Java are prone to security issues (Barth et al. 2010; Soltani et al. 2010). In the future, new releases of major web browsers from Apple, Google, Mozilla and Microsoft will no longer support any plug-ins. This is particularly important to cartographers and GIScientists as many of those 2D and 3D web mapping applications still rely on plug-ins. In addition to those functional limitations, most proprietary web browser plug-ins do not provide a wide range of custom functionalities specific to the application area of urban energy analysis (Wendel and Nicerhsu 2015).

This research focuses on the development of a plug-in free 3D web mapping application for the display of different energy related simulation and modelling results at the urban scale (Fig. 1). The focus is thereby on the usage of free and open software libraries that can be natively run in any web browser. Given the complex multidisciplinary nature of energy related modelling data sets commonly differ in spatial and temporal resolution, data structure or data storage format that requires an intensive data integration workload. A major obstacle in this process is the current proprietary nature of major commercial software packages (Wendel and Nichersu 2015). The lack of interoperability among software packages makes it difficult to share and further process research results. Therefore, all data sets can be stored in an open source data infrastructure that is based on a PostgreSQL database and PostGIS, for spatial capabilities (Simons and Nichersu 2014). A major requirement of this research is the connectively to a PostgreSQL databases and the usage of open-source Geographic Information Systems (GIS) functionality with PostGIS directly from the interface.

[1]https://www.google.com/earth/.

[2]https://unity3d.com/.

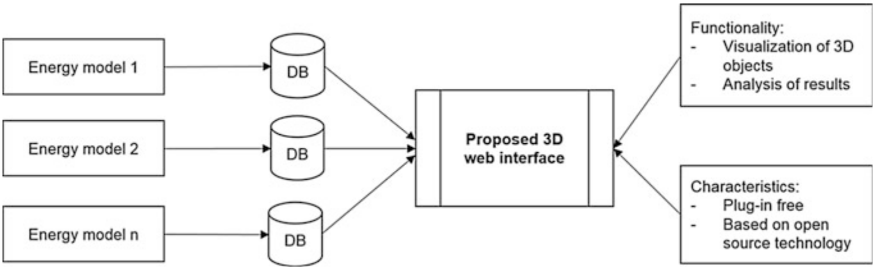

Fig. 1 Proposed 3D web interface for visualization and analysis of different energy related simulation and modelling results

In addition to the interface development, this research further focuses on the lessons learned from this experiment as well as gives an outlook in the field of open-source 3D web mapping interfaces.

In the following section, the evolution of different web-mapping technologies for the visualization of 3D data are summarized. Sections 3 and 4 describes the data and technologies used to develop the web-mapping platform. The methodology and the description of the interface are illustrated in Sects. 5 and 6. Finally, a discussion and future direction of such a plug-in free 3D web visualization are explained in the Sect. 7.

2 The Evolution of Related Research

The visualization of spatial 3D information has experienced multiple popularity peaks during the last two decades. These peaks were tightly coupled with major breakthrough in technological enhancements (Peterson 2015). In establishing visualization technologies, 2D data visualization developments were always on the forefront before this trend was adopted to the visualization of 3D cartographic displays such as the development of HTML and VRLM. Figure 2 highlights major breakthroughs in 2D and 3D web mapping applications and technologies ranging from early GIS desktop systems (Goodchild 1991; Dix et al. 2004) and web mapping applications such as Xerox PARC MapViewer (1993), GRASSLinks (1995), MapQuest (1996) and TIGER Map Server (1997), that mostly provided static displays, to web technologies such as Web Feature Service (WFS), Web Map Service (WMS) and Web Coverage Service (WCS) that made the distribution of geospatial data on the web easier and thus helped to increase web-based 2D mapping applications drastically. These web mapping services provide static image tiles of maps or XML (Extensible Markup Language), using Open Geospatial Consortium (OGC) web-service standards, formatted feature details and coverage data in GML (Geography Markup Language) format, respectively. While Fig. 2 does not show all milestones on 2D and 3D visualization technologies it clearly highlights the trend to web technologies that can visualized both, 2D and 3D.

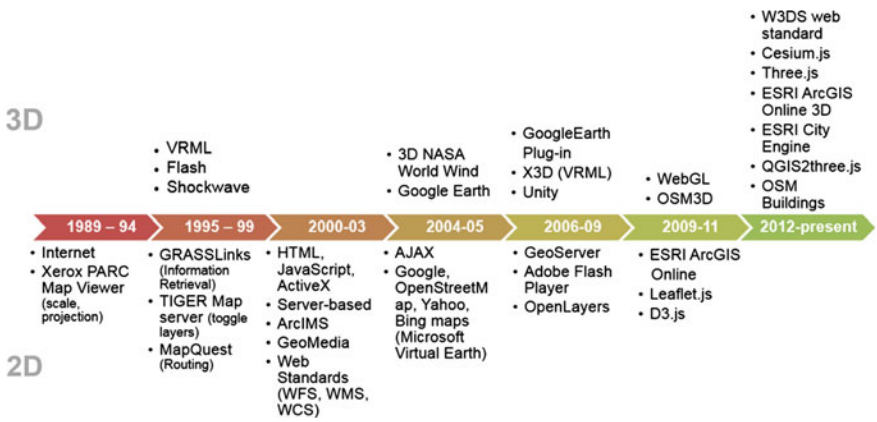

Fig. 2 The evolution of 2D and 3D web mapping milestones

On the visualisation front, all the above mentioned services were limited to displaying static geographic data, with exception to browser plug-ins such as Flash, Shockwave and VRML. After 2005 the adoption of these plug-ins for geospatial data (e.g. Google Earth plug-in) and X3D, the successor of VRML was observed. However, due to the lack of native graphics processing (GPU) support, VRML X3D was unable to handle larger amount of data (Ming 2008). Since 2010, with the emergence of OpenStreetMap (OSM), several 3D research projects such as OSM3D Globe[3] (University of Heidelberg), OSM Buildings,[4] etc.[5] have been initiated at experimental stages which demonstrate the popularity of 3D city models. With the advancement in graphics technology these plug-ins have evolved to display 3D objects or models that were exported from specialised 3D Desktop software (Fig. 2). Recently the adoption of Unity's powerful gaming engine towards the usage of 3D geospatial data in web mapping applications have been demonstrated (Raghothama and Meijer 2015; Jenny et al. 2015). Although Unity provides a preformat way to visualize large quantity of data, it is still reliant on web browser plugins in its current version.

With the support of webGL in all major web browsers, many new libraries were developed in the last few years. For example, the open source library project Cesium.js, based on webGL and not reliant on any browser plug-in gained

[3]http://osm-3d.org/home.en.htm.

[4]http://osmbuildings.org/.

[5]http://wiki.openstreetmap.org/wiki/3D_Development.

increased popularity among cartographers and web developers. For example, the Sunshine project made use of an early adoption of cesium.js for cartographically displaying urban services and energy consumption at the urban scale (Giovannini et al. 2014).

3 Data Sets for 3D Visualization

The generation of 3D city models can be costly and time extensive process (Thiele et al. 2013; Döllner et al. 2006; Huber et al. 2003). Currently, many major cities such as New York, Berlin or Lyon started to provide detailed 3D models of their cities which could be used by any cartographer for visualization and analysis purposes. In addition, OSM provides building data as building footprints and often additional height information, mainly for public buildings. However, the availability highly varies among regions. Out of 5.5 million mapped buildings in Germany, only 5 % have the height information tagged in OSM data, only 7 % of the buildings have the number of floors and 2 % have roof type information specified (Goetz and Zipf 2012).

In this research, the city of Karlsruhe in Germany is considered as a case study area. Karlsruhe is a medium sized city of 300,000 inhabitants located near the Franco-German border in the southwestern part of Germany. The city does not provide any public access to its 3D spatial data. Although building footprints were available for the whole city, the height information was missing or unusable for the objective of this experiment. Instead, the height information of each building was estimated by the number of floors of each building obtained from areal imagery. In total 86,000 buildings were generated at a Level of Detail 1 (LoD1). For each floor, a standard height value in meters, depending on the building type, is used to estimate the total height of a building that provided higher accuracy levels of 92.4 % within a 95 % confidence interval for the whole data set (Saed and Wendel 2015).

Due to interoperability requirements with energy simulation models, the data set is stored in a PostgreSQL database using the CityGML standard.[6] A benefit of using the CityGML standard over other geospatial data formats is that semantic information of each surface or element of a building or object can be stored. This would be particularly interesting to cartographers when designing multi-scale cartography data bases for the definition of cartographic visualization rules across multiple scales (Brewer and Buttenfield 2007).

[6]CityGML is an open data model standard developed by the OGC (Open Geospatial Consortium). See: http://www.opengeospatial.org/standards/citygml.

Table 1 Resources used in interface development

Technologies	
WebGL	3D web standard
HTML	Functional control of web page
JavaScript	Control of elements and data conversion
Python	Database and server connection
Structured Query Language (SQL)	Data base queries
Data exchange format	
GeoJSON	Data transfer to WebGL
Software libraries/APIs	
EXT JS	Interactive web applications
Three.js	3D visualization
D3.js	Conversion of geographic coordinates
D3-ThreeD.js	Link Three.js with D3.js

4 Technological Requirements

The process of designing and implementing a 3D web mapping application that natively runs in any web browser requires the exploitation of different technologies, software and programming APIs. Table 1 summarizes the resources, technologies, software libraries and data formats utilized in this study.

4.1 Technologies

The implementation of the 3D web interface and visualisation requires different technologies and software such as WebGL, HTML, JavaScript, Python and SQL, in a client and server side configuration. HTML and CSS are used for the functional aspect of the front-end of the interface, while other components that interact with data and provide functionality of the web pages, are controlled using scripting languages, namely JavaScript and Python. JavaScript is used to control all the elements in the interface and to manipulate the data which is in the JSON format that constitutes the client-side processing in this application. In contrast, Python and related adapter such as psycopg[7] are used to access functions in PostgreSQL through scripts, to query the database, and to run energy simulation scripts. Regarding the display of 3D data, the WebGL standard is used. It enables the implementation of 3D graphics directly in the web browser without the use of any plug-ins.

[7]http://initd.org/psycopg/.

4.2 Data Exchange Formats

The GeoJSON format is applied for encoding a variety of geographic data structures and for interchanging geospatial data that is based on JSON (Butler et al. 2008). JSON enables easy access and manipulation of objects not only with JavaScript, but also SQL and Python. In addition, it is also advantageous to use this format since it is possible to convert GeoJSON to and from many other spatial data formats such as KML, GML and ESRI shapefiles. For example, using GeoJSON, ViziCities9, an open source project inspired by the massive online multi-player game SimCity, aims to visualize the entire world in 3D.

4.3 Software Libraries/APIs

Several software libraries are utilised to develop the visualisation interface. Ext JS is used for designing the user interaction of the web mapping interface. It is a pure JavaScript application framework for building interactive web applications and is developed by Sencha.Inc.[8] It leverages HTML5 features to provide pre-defined web page elements such as button, text field panels and layouts that can be customised and used in building cross platform web applications. Some advantages of using this API are its Model-View-Controller (MVC) architecture, theming and styling using CSS and SASS, extensive documentation and support (Suderaraman 2013).

Three.js handles the entire 3D visualisation part in this interface. It is a relatively new open-source JavaScript library (released in 2010) that uses the WebGL capability of a browser to create, display and animate 3D objects with a very low level of complexity (Doob 2010). Apart from native geometries such as line, sphere or cube, this library also supports visualization of 3D models exported in JSON format from other software such as Blender, 3D Max and hence supports interaction with GeoJSON. Although Three.js is employed mainly for interactive games development, it has been recently demonstrated to be useful in geographical data representation and web mapping applications (Sandvik 2013).

D3.js is a JavaScript library for manipulating documents based on data using HTML, SVG and CSS and has been used in many web mapping applications (Ledermann and Gartner 2015; Bostock 2011). It combines powerful visualization components and a data-driven approach to Document Object Model (DOM) manipulation. D3.js has a module called *Geo* that can convert the geographic coordinates between 12 major projection systems. It is used in this research for converting geographic coordinates to screen coordinated.

[8]http://www.sencha.com/products/extjs.

d3-ThreeD.js a small library of functions that aims to link Three.js with D3.js (Sutherland 2012). The ability to transform SVG path from D3.js to Three.js object is offered by one of the functions provided by this library. It is used in facilitating the extrusion of the building footprints within the interface.

5 Interface Development and 3D Data Handling

This section describes the methodology of the interface development process as well as the handling of 3D data and their visualization challenges. The interface development process can be further divided into design of interface architecture, interface workflow and interface visualisation. Furthermore, a detailed description of the geometric transformations from 2D to 3D and resulting challenges are described in this section.

5.1 Interface Architecture

A typical client–server (e.g., PostgreSQL database) is used for the architecture of the interface (Bell 2005). Using WebGL, all visualization and rendering processing are performed on the client side while data storage and analytical capabilities are executed on the server side. While the complexity of WebGL is higher than propriety plug-in based environments such as Microsoft Silverlight or Adobe Flash, support and performance of 3d spatial data is more efficient, interactive and responsive (Resch et al. 2014).

5.2 Interface Workflow

In order to visualize and analyse data from the PostgreSQL database, several steps are required. Figure 3 highlights the detailed flow of process between the interface and the database. For data input (Fig. 3 (1)) multiple Python scripts are used depending on the data type. All data Processing (Fig. 3 (2)) is done on the server side. When the request from the interface is sent to the server with the required connection parameters, the data is processed based on the query and sent back to the interface in the GeoJSON format. The spatial coordinates and attributes are retrieved by using the ExtJs functions and subsequently visualised using functions from the Three.js library.

Data processing and visualization is handled on the server and client side. The connection to spatial data sever is established by a Python script using the ‘psycopg’ adapter and then an SQL query is executed. The SQL query performs the necessary manipulation of the data through PostGIS extension functions. For instance, *ST_AsGeoJSON* converts the resulting rows from the PostgreSQL to GeoJSON file and *ST_Transform* function converts the spatial coordinates to WGS84 (defined by EPSG:4326) adopted in the interface (Fig. 3 (3)).

The data infrastructures presented in Fig. 3 is particularly of interested when developing an interface to visualize multi-domain datasets. The PostgreSQL database with the PostGIS functionality enables the merger of results from energy model outputs and spatial data. Furthermore, by strictly using a Python environment each independent energy model can be extended and visualized further by directly using PostGIS functions in the PostgreSQL database.

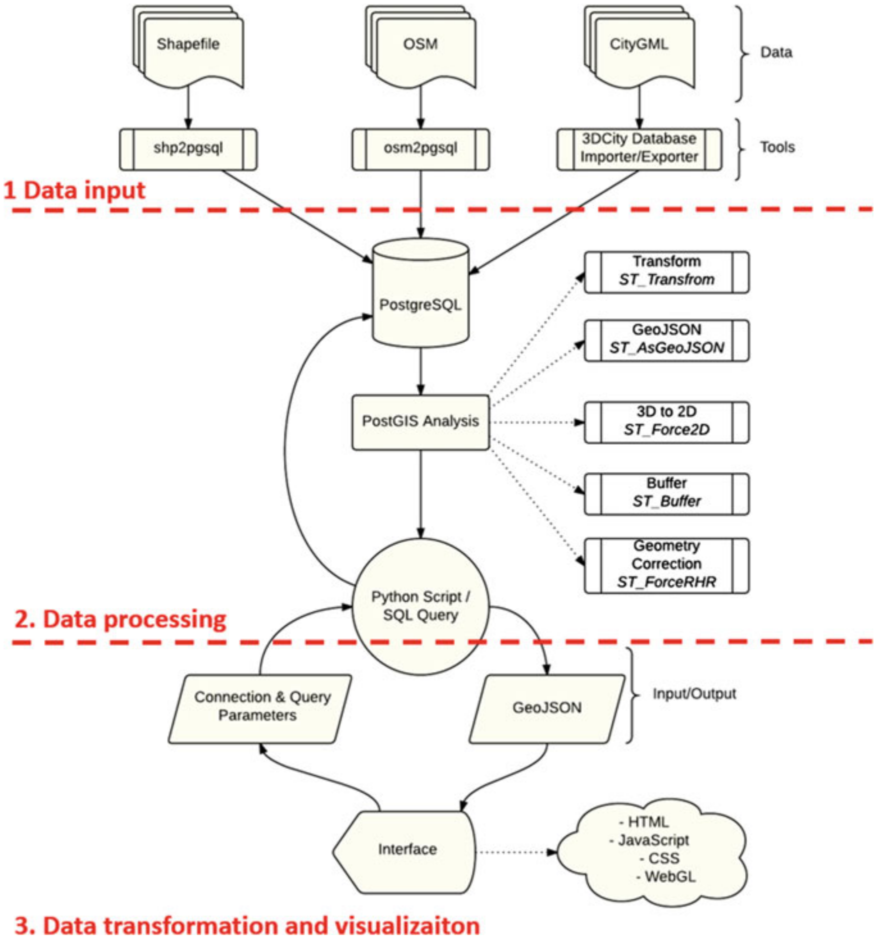

Fig. 3 Detailed interface workflow illustrating data input, data processing, data transformation and visualisation steps

5.3 3D Data Handling and Visualization Challenges

The transformation and handling of spatial 3D data is a major challenge in this research since no out of the box programming libraries that could handle the technical requirements to natively display urban energy data, such as Cesium.js, were available at the start of this experiment. Therefore, coordinate conversion and extrusion had to be handled by custom implementation. The majority of objects in the Karlsruhe 3D city model that are displayed in the interface are buildings, natural features and roads. While the former two can be stored as polygons (Polygon or MultiPolygon), roads are usually stored as lines (LineString or MultiLineString) in a GeoJSON file. Hence, the basic flow of data from PostgreSQL to Three.js for both buildings and roads is common but the handling of these two data types for visualisation is different from each other. The flow of data conversion undergone by a polygon feature footprint is as shown in Fig. 4.

Once retrieved from the database, the coordinates are used to generate an intermediate SVG path using the D3.js library function. This path is then converted to a 3D object. In the scope of Three.js, each object added to the 3D scene is called a *mesh*. In order to be rendered on screen, a mesh requires two parameters namely, THREE. Material and THREE.Geometry, whereas the latter is provided by the building footprints. The *transformSVGpath* function from the d3-threeD.js library converts the path generated by d3.geo object to a Three.js 2D path (THREE.Shape) object. An arbitrary extrusion value is applied to each of the meshes to make them three-dimensional. No extrusion value is applied for the objects representing natural features so that they appear flat and an even lower value of 1 or 2 is applied for water bodies so the water-type polygons overlapping the natural features polygons appear above. An arbitrary extrusion value of 10 (determined through testing) multiplied by the number of floors is applied to the building meshes to give them the required 3D perspective. All the extrusion values are following the Three.js coordinate system.

Several challenges have been encountered when displaying spatial 3D objects natively in a web browser. For example, in the process of converting building objects from a GeoJSON file to SVG using the D3.js library, it was found that the building footprints were not displayed as expected due to their polygon winding order (Grünbaum and Shephard 1990; Neumann and Winter 2001) In order to allow efficient data handling on the client side, the order of coordinates must be reversed directly in the PostgreSQL database before the conversion into a GeoJSON object takes place. Another challenge appeared while displaying line features. For example, in the database road features are stored as LineStrings in the GeoJSON file where each vertex of the line segment is a pair of latitude and longitude coordinates. If converted to SVG, the ends of the line segments are connected resulting in a polygon. In trying to overcome this limitation, the coordinates are directly converted to screen coordinates using *d3.geo* object and passed to the Three.js function to create a *THREE.Line* object. However, this line object, if extruded, will result in a wall rather than a road (Fig. 5, left). Therefore, a rectangular shape was chosen (Fig. 5, right) and extruded along the line object created to build a road. A detailed discussion about line extrusions for WebGL web mapping applications can be found in McNamara et al. (2000) and Deslauriers (2015).

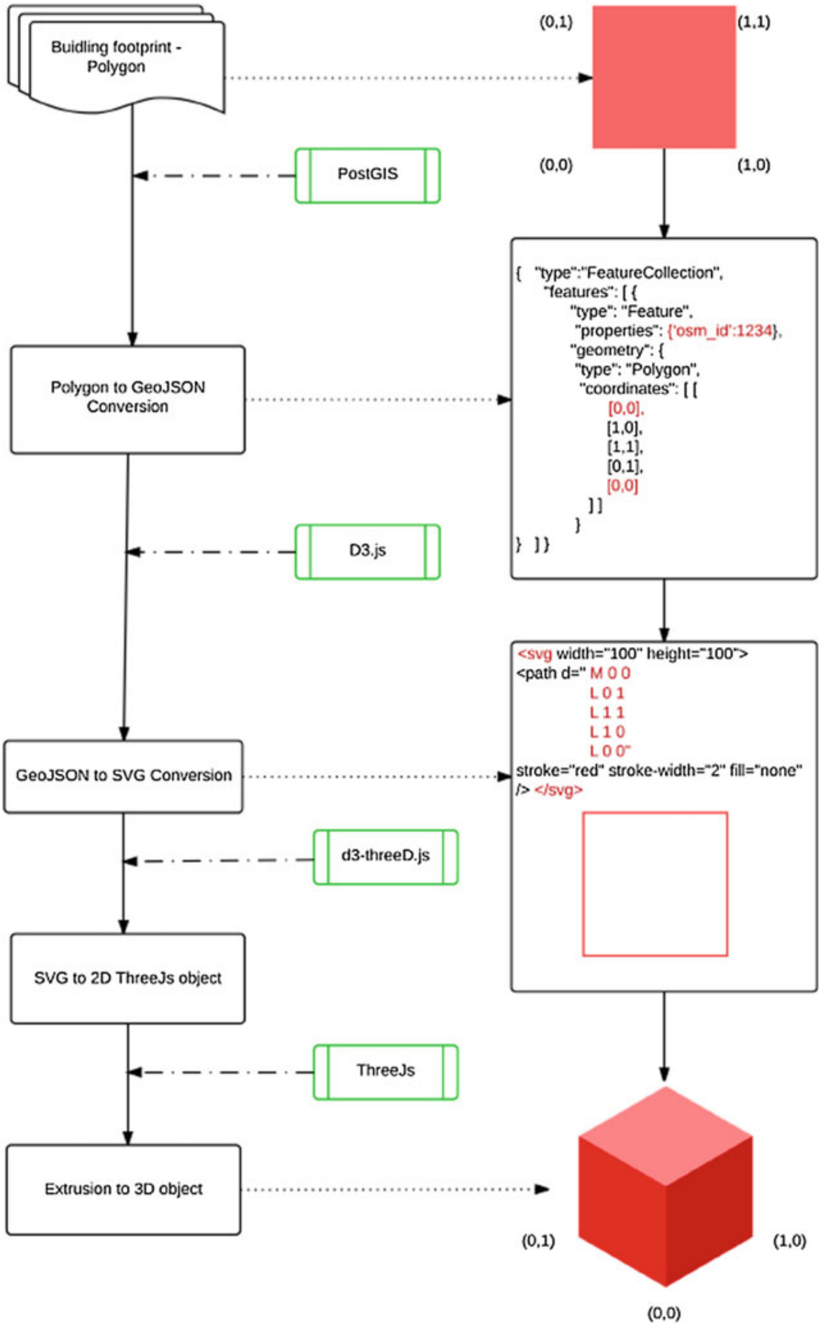

Fig. 4 Dataflow and processes required to extrude 3D features natively in the web browser

Fig. 5 Extrusion of road features: direct extrusion (*left*), shape extrusion (*right*)

5.4 Interface Visualization

The main focus of this research lies in the usage and implementation of open-source libraries for a plug-in free 3D browser based visualization. Therefore, the user interface that has been implemented in the research, has not been gone through user testing or design adaptation phases. However, common Human-Commuter Interaction (HCI) guidelines, for example layout by Dix et al. (2004) were considered in the design process. The main components of the interface layout are:

1. Viewer window
2. Navigation controls
3. Toolbar
4. Action panel
5. Information windows

Furthermore, the interface is divided into front-and back-end. The front-end includes elements such as buttons, windows and message boxes, and the appearance of the interface, whereas the back-end includes the general organization of the files containing the code so that the application remains readable and expandable. Figure 6 shows the buildings and natural features layers directly derived from the PostgreSQL database displayed in the interface while the action panel shows classification options of the data.

6 Interface Functionality and Case Studies

The proposed interface not only allows cartographic visualisation of the 3D features, but also supports the exploration of the results from energy simulation with several functionalities such as layer navigation, feature selection, information retrieval, visibility control, data classification and spatial buffer functions. These functionalities are made accessible through a toolbar available at the top of the browser window (Fig. 6). In this way, scientific cartographic visualisation such as well-defined symbols, harmonious use of colour through ColorBrewer.org (Harrower and Brewer 2003) of spatial data derived from energy modelling is ensured. Moreover, several case studies consisting of the outcomes of energy modelling and simulations are integrated into the interface as a proof of concept.

Fig. 6 A 3D web interface layout consisting of Viewer window (*1*), Navigation controls (*2*), Toolbar (*3*), Action panel (*4*), and Information windows (*5*)

6.1 Retrieval of Information

The user can select and retrieve basic information and energy model outcomes of particular features such as buildings from the database via the interface. When a client request is executed data, in form of a database table with the requested information is loaded from the PostgreSQL server on to the interface and the information is saved in the browser's cache memory. The geometry details of the loaded features get stored in the *THREE.Mesh* object of the Three.js library and the attributes are programmed to be stored as an *Ext.data.JsonStore* object which acts as a local database at the client-side. On selecting or deselecting a building, the *osm_id* of the building is accessed by id of the mesh and added to or subtracted respectively from an array. This id serves to access the type of a selected feature, retrieve corresponding entry in the Ext.data.JsonStore previously constructed and display them in grid format provided by ExtJs (Fig. 7). The Ids stored in the array can be later used for further analysis such as creating charts or buffer.

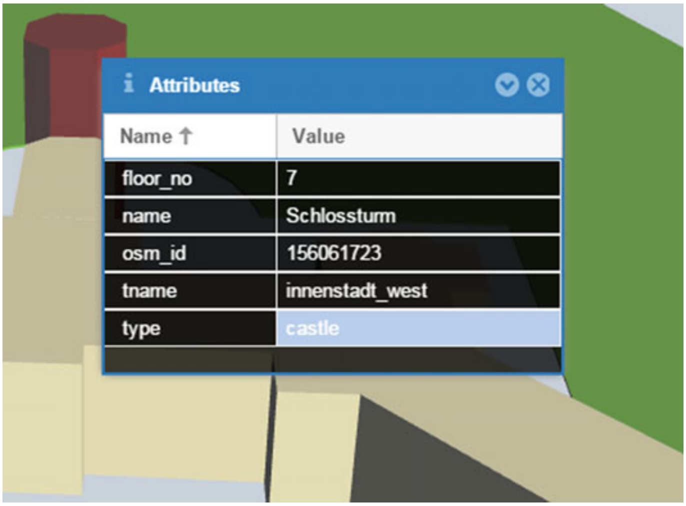

Fig. 7 Retrieval of sample information displaying building attributes

6.2 Cartographic and GIS Functionality

Several visualization and spatial functions have been implemented as a proof of concept. As an initial proof of concept for visualization functionalities, the classification of building attributes are demonstrated by the 'Equal-interval' method has been implemented (Slocum et al. 2009). A corresponding legend displays the harmonious colour code while the corresponding class intervals are based on building classification (Fig. 6). Color schemas were derived from the recommendation of ColorBrewer[9] and the symbols were drawn on the screen using the *Ext.draw.Sprite* object from the Ext Js library. This powerful library allows several other built-in cartographic representations of 3D objects.

As a proof of concept for spatial functionalities, buffer analysis has been implemented to identify buildings or any other feature, within a certain search radius of another feature or to find the extent of impact of any phenomenon around points or lines or polygons. 3D buffers enable further explorative analysis, such as noise emission mapping and emergency route planning (Zipf 2010), costs and risks of urban networks (e.g. district heating networks), dynamic air flow analysis (Autodesk Ecotect Analysis 2010), spread or visibility analysis, fire exposure or explosion and are commonly represented as a polyline feature with extruded z-values. In energy research, 3D buffers can be exploited such as to identify the coverage of street lights in order to optimally plan their setting. The implementation of buffers in this research are created by using PostGIS functions and the results are saved back to the PostgreSQL database (Fig. 8).

[9]http://colorbrewer2.org/.

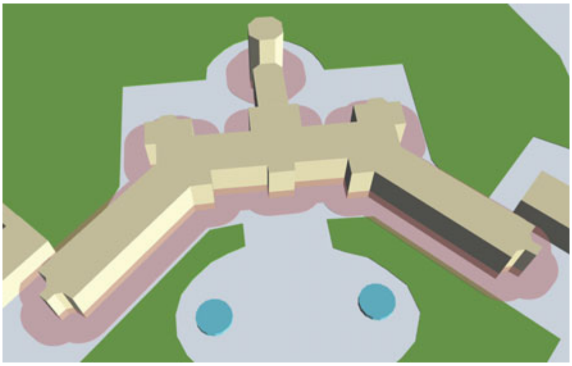

Fig. 8 Line buffer function showing a 10 m 2D circular buffer around a building

6.3 Case Studies

Several energy simulation and modelling results are incorporated into the interface platform in order to test the capability of the interface in terms of technical feasibility, visualization and explorative analysis of results. The outcomes of these energy models are generally stored in a different database and the interface was able to successfully connect to them. In the first case study, the modelling of vertical solar radiation potential of LOD1 and LOD2 buildings facades resulted in a set of values as attributes of a building and building surfaces (Wieland et al. 2015). This included six fields which are comprised of beam and diffuse solar radiation on building surfaces with clear and overcast sky conditions in kilowatt hour (kWh) for each month of a year. Since the values are distributed over certain time intervals line charts are well suited to visualise the distribution and are hence demonstrated in this application (Fig. 9). Charts can be saved and exported into multiple formats as well. Further case studies are tested for example, by incorporating the socio-demographic energy behaviour research on energy consumption for the city of Karlsruhe (Saed and Wendel 2015) and an energy balance model to calculate heat losses from LoD1 and LoD2 buildings (Simons and Nichersu 2014).

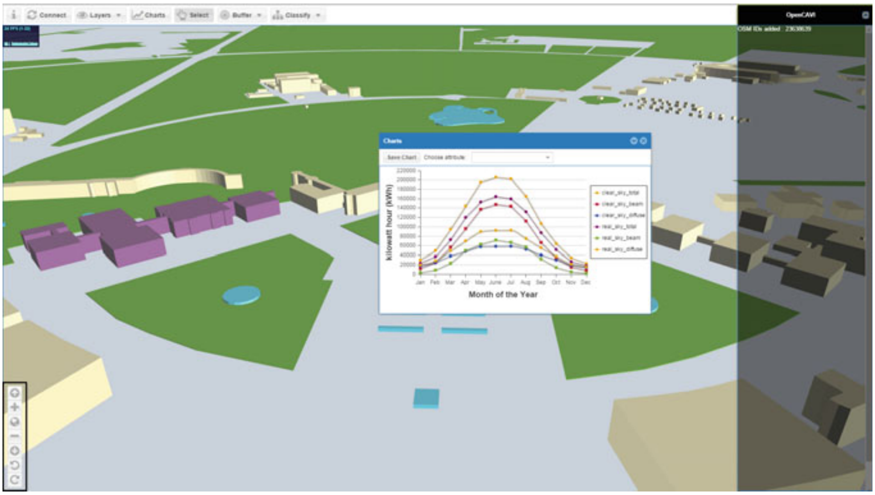

Fig. 9 Visualization of energy modelling results in charts and colour codes

6.4 Performance of the Interface

The interface represents the usage of various software technologies, large number of 3D objects, cartographic functionalities, and data from several energy model. Moreover, powerful computer systems (e.g., client, server, and network) have been exploited to load and to display the 3D objects in real time. Therefore, the performance of the interface and its capabilities need to be tested to evaluate its performance.

Generally, three types of the testing strategies such as functional testing, non-functional testing and acceptance testing are conducted for a web application (Liang 2010). The functionalities listed in the earlier section are forms of functional testing. The non-functional testing includes the usage of memory space in the browser, the time required to load the data on the interface and the frames per second (FPS) value of the renderer measure the performance of this interface (Table 2). This test is particularly of interest when developing an interface for displaying buildings as it sets the threshold of how many 3D objects can be

Table 2 Comparison of the performance of the interface in standard browsers

Browser	With 1874 building parts		With 14,000 building parts	
	Memory (MB)	FPS	Memory (MB)	FPS
Chrome	~200	35–45	~400	7
Firefox	~240	57–60	_~940	3
Safari	~273	25–40	~1.73	9–15
Internet explorer	~350	24–38	~960	6–10

Benchmark was run a regular laptop, running Windows 7 64bit (Core I5-4310U, 8 GB DDR3 Ram, Samsung PM851 256 GB SSD, Intel HD 4400 graphics) displayed simultaneously in the interface. Furthermore, the acceptance or benchmarking tests defines target level scales for visualization of 3D as well as 2D data. A comparative assessment of the performance of the interface with varying number of building parts are performed. The memory and FPS required by some standard browsers are displayed in Table 2. It is important to note that the FPS are monitored by the Three.js library's stats object when one or more datasets of buildings are loaded on to the interface.

Googles' Chrome browser provides the best support for visualisation with higher FPS and lower memory because of its compatibility with the WebGL, compared to the Firefox and Safari browsers. Internet Explorer browser indicated difficulty to run the interface because of its limited compatibility with WebGL. However, it indicates better FPS after implementing the *Detector.js* object which is provided by the Three.js library. This object identifies whether the web browser is able to run WebGL and in case of its absence, *THREE.CanvasRenderer* is used, however, results are then displayed in lower graphics quality. The performance assessment helps to identify the best suitable browser and the limited capability of certain browsers, ascertains the optimal number of buildings or parts to be displayed.

7 Discussion of Results and Future Direction

The process of developing the 3D web mapping interface led to the identification and explanation of different resources, technologies, data exchange formats, libraries, and APIs. Moreover, during different implementation stages, the potential, limitations and opportunities in the field of current 3D web mapping technologies are explored systematically. From these experiences, cartographers and GIScientists could gain a comprehensive overview of current web mapping technologies as well as gain lessons to implement similar application.

Along with the visualization of basic 3D data, several functionalities, such as buffer analysis, and classification of data are integrated into the interface. The suitability of the interface has been demonstrated by integrating several energy research related case studies such as 3D solar potential assessment and visualization of the energy consumption per building. Finally, a comparative assessment on the performance of the interface has been tested in several web browsers. The interface would allow users and energy policy makers not only to visualize different data and modelling results but also enable to use the interface as a tool for analytical and explorative purposes. As the developed open-source data infrastructure of the interface allows flexibility for extensions, other models and simulation such as results from urban simulation or environmental modelling could be shown in the interface.

It is observed that the developed interface for the LOD1 building model, though functional and adequate in certain application areas, demonstrated that the depiction of the real-world on a computer screen is a tedious process and leaves opportunities for further research and enhancement. For instance, improvements in computing power such as computer graphics to handle the implementation of textures as well as standardization (OGC and W3C) to obtain building height information are especially subject to further development. While new implementations in 3D web mapping such as cesium.js has seen an increase in performance for visualizing 3D objects in a higher resolution than LoD2, WebGL is still reliant on the performance of the client side computer system. To overcome this major bottleneck some 3D web mapping services that do visualized high detailed and textured spatial data, such as CyperCity3D[10] are based on streaming services. Thereby, the rendering of all 3D objects is done on the server side and content is streamed to the client. However, the interactive remote visualization of 3D graphic data in a web browser remains a challenging issue due to latency (data volume) and the adoption of heterogeneous networks (Lavoué et al. 2013).

Moreover, the lack of standardization in data models and data-exchange was a major obstacle in this development process. For example, the user must know how data is structured if the data source is unknown. It was observed during the retrieval of data for the chart (Fig. 9) that the SQL query contained the exact field names of calculated energy modelling related output attributes. This will not be an issue if a standardized naming convention such as conventions from the INSPIRE initiative or the CityGML Application Domain Extension (ADE) Energy is followed for the attributes of a building. Furthermore, data formats and tools have to be constantly modified to suit changing technology. For example, O3D[11] is a free API for generating 3D graphics built basically as a plug-in for desktop and web browsers. Recently, this API was re-built to suit the growing interest in WebGL. It is the same case with X3D[12] which is an open standard for 3D graphics. X3D files can be incorporated into web pages by Applets which is a type of plug-in. Due to WebGL, a X3DOM[13] JavaScript library was developed to include 3D graphics without plug-in. These changes are however reasonable considering that most of the APIs were built predominantly for gaming or CAD applications and not necessarily for geographic data.

Open standards do exist for 2D geographical data services such as WFS and WMS where the request for information is returned in formats such as GML, SVG and images, respectively. However, such standards for 3D geodata (e.g., W3DS, Web 3D service) are still in a draft versions and need to be further defined. W3DS will however, be the standard portrayal service for 3D geodata such as landscape models, city models, textured building models, vegetation objects, and street furniture (Open Geospatial Consortium 2010).

The variety of data sources and in particular the storage of this data for 3D visualization showed that the adoption of open-standards is a promising solution to interoperability, scalability and to harvest the maximum benefit from a 3D

[10]http://www.cybercity3d.com/#!streaming/r2pa2.

[11]https://code.google.com/p/o3d/.

[12]http://www.web3d.org/x3d/what-x3d.

[13]http://x3dom.org/.

web-based GIS interface not only for data models (e.g. CityGML and X3D) but also for data distribution services such as W3DS across different platforms and visualization (WebGL).

Future enhancements of this interface will include further cartographic functionalities such as integration of map tiles from 2D mapping services such as OSM or other topographic map providers, integration of a Digital Elevation Model (DEM) for terrain visualization and incorporation of textures as well as shading of buildings. Furthermore, at the time of the development of this interface, libraries such as Cesium.js weren't fully available to use and future development should be focused in incorporating these recent technologies. In addition further benchmarking will be undertaken with a focus on user experience such as browsing (panning) of 3D models as well as a comparison of the performance of different implementation strategies such as the usage of different open-source APIs versus proprietary plug-in based approaches by using the same 3D data set and spatial extent.

Acknowledgements The authors would like to extend sincere gratitude towards the two anonymous reviewers for improving the paper. Furthermore, the authors would like to thank their colleagues at EIFER and EDF SINETICS for valuable support during the implementation process as well as EDF for funding this research.

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Modern Methodology and New Tools for Planetary Mapping

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Abstract The paper describes a workflow of planetary mapping using the newest remote sensing data and modern GIS technologies. We present the newly developed tools for planetary surface analysis based on cartographic measurements. The data management and design approaches for planetary mapping are described, and the main results of implementation of tools and methods are presented, including new planetary maps.

Keywords Planetary cartography · GIS · Spatial analysis · Cartographic design · Data model · Geoportal · Web-mapping

1 Introduction

Nowadays the rapid development of GIS and web-technologies as well as terabytes of data obtained from different planetary missions provides big opportunities for study of extraterrestrial territories by cartographic methods. The representation by maps and GIS-analysis of the planetary remote sensing data are the most common and sometimes the only possible way for people's visual recognition of surfaces of the other planets and their satellites due to a high cost or technical impossibility of contact studies. We can explore the surface of celestial bodies by creating maps from remote sensing data thereby learning the land and converting it from *terra incognita* into a well-studied territory.

Here we present the modern workflow for mapping of the Solar system planets and their satellites based on results of photogrammetric image processing and

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_13

spatial analysis of the newest remote sensing data received by various missions (Fig. 1). The planetary cartography includes the following scientific and technologic tasks: to estimate the fundamental geodetic parameters and establish the coordinate system based on photogrammetric image processing; to study and

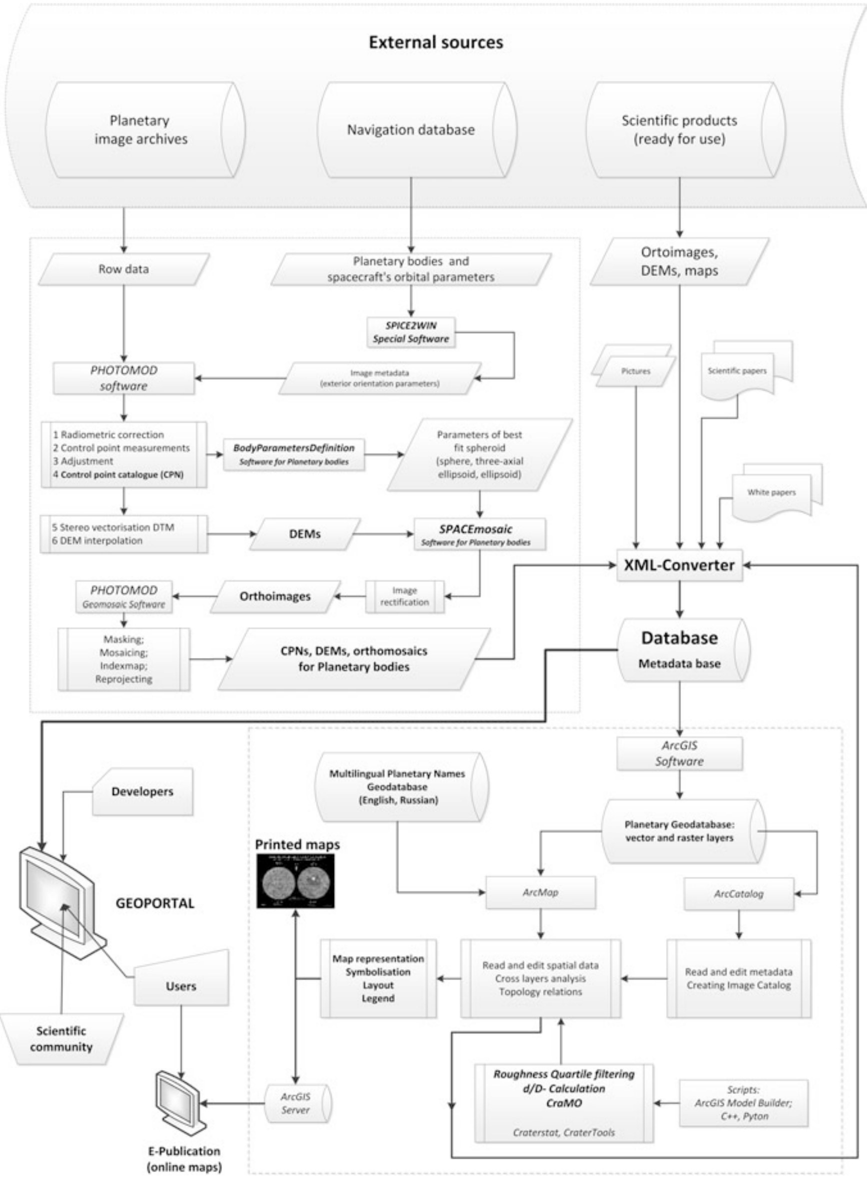

Fig. 1 The flowchart of mapping of celestial bodies based GIS and web-techniques

analyse the planetary surface based on GIS-tools; to create and publish maps using modern approach like distributed cloud environment.

Our workflow combines all steps of processing and using data for analysis and mapping of planetary surface. Through the photogrammetric bundle block adjustment orbital data are improved, which leads to an increase in the accuracy of the maps. As a result of such processing we obtain the orthomosaics and digital elevation models (DEMs) that provide basic coordinate system for the celestial bodies or for local regions of interests (ROI).

Planetary data from different sources could have different formats and metadata, therefore for their standardisation we use the specially developed converter based on XML, which enables upload of any product in the GIS. After the processing we create the geodatabase for studied celestial body with referenced images, DEMs and catalogues of features as a starting point for further analysis and thematic mapping.

The important part of research of extraterrestrial territories is interpretation of images and analysis of relief of the study area. Using DEMs in GIS provides many possibilities for measurements with cartographical methods. They produce various types of data: slopes, roughness, steepness, etc., which makes possible the deeper complex analysis of the studied planetary surface and could be published as final maps. Modern technologies offer opportunities of publishing maps either as hard copy or in a digital form as online maps. Access to data via the developed planetary data geoportal opens new opportunities for presentation of the results of the cartographic studies and its usage for further analysis through online tools and intelligent search system.

2 Coordinate Systems of Celestial Bodies

The basic data for planetary mapping are control point networks (CPN), which provide accurate coordinates for surface objects, DEMs and orthomosaics, derived from photogrammetric image processing (Fig. 1). The production of the CPN for different celestial bodies is based on bundle block adjustment of coordinate measurements by least squares analysis techniques using large numbers of overlapping stereo images (Nadezhdina and Zubarev 2014). The CPN generation is complicated by irregular shape of many celestial bodies, which should be better approximated by 3-axial ellipsoids. This requires an individual approach for the special projection for small bodies (Bugaevsky et al. 1992; Nyrtsov et al. 2014) and implementation of special tools (http://geocnt.geonet.ru//en/3_axial) supporting a 3-axial reference surface. In addition, information about shape and size of planets and their satellites is being constantly updated, which affects the best-fit ellipsoid parameters. For example, for Phobos mapping and 3D-modelling (Fig. 2) we used recently updated new shape (Oberst et al. 2014); for Galilean satellites of Jupiter (Zubarev et al. 2015) we used spheres with refined radii different from previously recommended by IAU (Archinal et al. 2011).

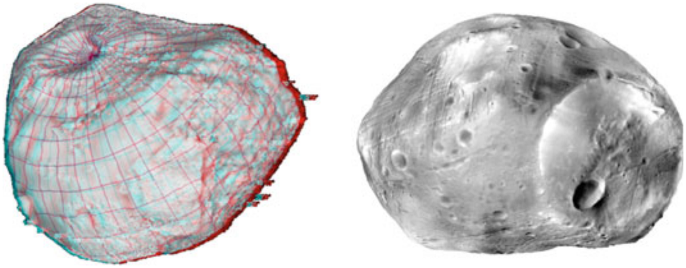

Fig. 2 Phobos shape model presented as an anaglyph (*left*) and 3D model based on new shape parameters (*right*) derived from new control point network

3 Cartographic Research Method for Surface Studies and Morphological Analysis

The results of photogrammetric processing of high resolution stereo images—orthomosaics and DEMs—provide basic information for detailed study of small relief features including quantitative morphometric analysis based on cartographic measurements.

3.1 Crater Measurements

Impact craters are the most common objects on the surfaces of the Solar System's solid planets and satellites. The spatial catalogues of craters are the keys to geomorphological studies. The catalogues usually are created with special GIS tools (Kneissl et al. 2011; CraterTools: http://hrscview.fu-berlin.de/mex4/software/cratertools/CraterTools(v2.1).zip). The catalogues not only register location and spatial relationships of craters; they also can include various parameters, which are used for various goals: geomorphological analysis (Basilevsky et al. 2014), surface dating with CraterStats tool (Michael et al. 2012; http://hrscview.fu-berlin.de/mex4/software/craterstats2/craterstats2.zip), or calibration of the result of automated detection of relief features (Salamunićcar et al. 2013).

To ensure the statistical validity of the morphometric measurements, our catalogues include up to several thousands of objects. For automation of morphometric calculation of such data amount the special algorithm has been developed using on ArcGIS Model Builder (Fig. 3). The algorithm calculates crater's depth as difference between the mean height of the crater rim and the lowest point near the geometric center of crater. This approach avoids wrong depth calculation for small craters located at slopes that sometimes have absolute heights along the rims lower than their geometrical center. The algorithm yields data for crater dating through craters' stage of degradation deduced from their depth to diameter ratios.

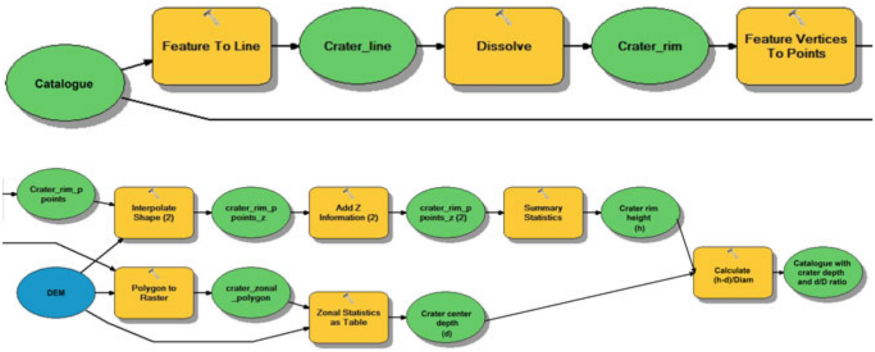

Fig. 3 Model of crater depth calculation in ArcGIS software

The developed technique was applied to comparative analysis of morphometric parameter of lunar craters in low latitudes and polar areas, which showed that the craters at the poles differ from those in the other highland areas, specifically, the polar craters were found to be systematically shallower than craters at lower latitudes. This is one of important lines of evidence of the actual presence of water ice or, possibly, organic volatile materials in the polar areas (Kokhanov et al. 2015). This result could be used, for example, for assessment and choice of sites for prospective lunar sample probe return missions. Another study, cartographic measurements of recently discovered interesting objects on Mercury, flat-floored craters and hollows, gave us the possibility for estimation of the thickness of the regolith, an upper disintegrated layer of the surface (Zharkova et al. 2015).

Massive automated measurements facilitate and improve the expert analysis of the crater shapes and morphological parameters, which previously was carried out manually by geologists and geomorphologists with photo-visual techniques. Results of cartographic measurements are used for the comparative studies of different planetary bodies (Fig. 4).

3.2 Roughness Calculation

Statistical characteristics of topography are a useful tool for morphological study of surface. Topographic properties could be described by the set of parameters: slopes, aspect, curvature, roughness, etc. Study of statistical characteristics would reveal the surface structures that are obscured on the physical maps. Roughness is one of important characteristics, which shows the relative height variation within studied area.

There are more than 10 ways of roughness calculation (http://gis4geomorphology.com/roughness-topographic-position/), no one being universal; their applicability depends on analysis purposes. For study planetary topography we suggest filtering

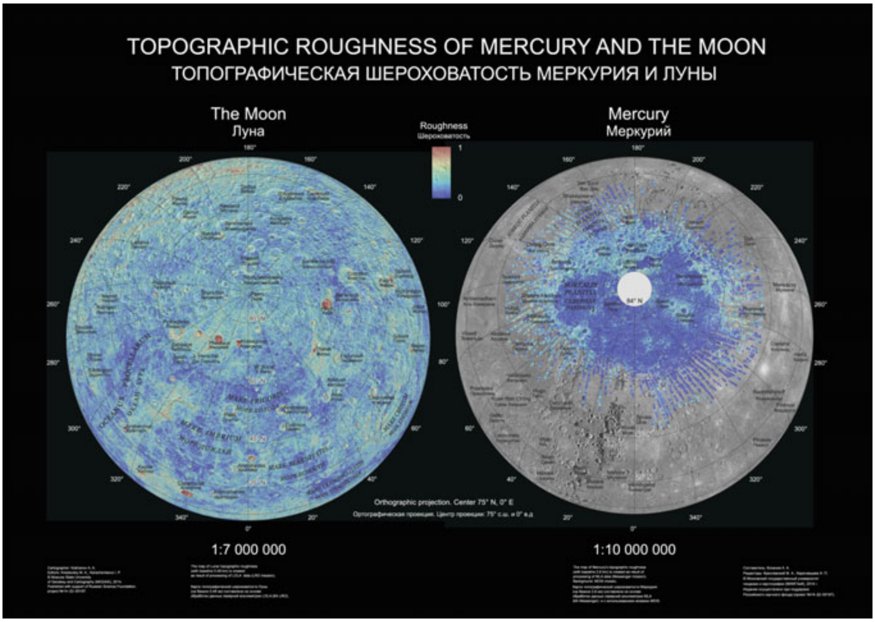

Fig. 4 Comparative map of the topographic roughness of Mercury and the Moon

algorithms using the interquartile range of the first and second derivatives of the topography, which provide scale-defined stable results. For visual presentation, the roughness calculation results can be displayed in different ways, as grayscale (Fig. 5a, c) or color images (Fig. 6).

For many types of geological studies, the greyscale image presentation with brighter shades representing a rougher surface and darker shades representing a smoother surface is the most convenient. Topographic roughness depends on spatial scale. To characterize this dependence, the roughness calculations at different baselines were used for Mercury mapping (Fig. 6).

This approach highlights peculiar properties of relief structures at various levels. The comparative analysis of lunar (Kreslavsky et al. 2013) and mercurian (Kreslavsky et al. 2014) topographic roughness at different baselines, calculated by

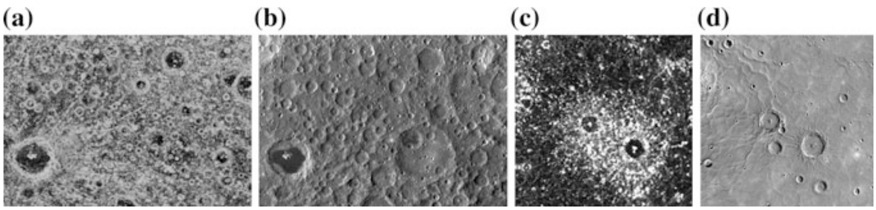

Fig. 5 Example of typical rough relief features in the grayscale rendition (**a** Moon, **c** Mercury) in comparison with image of surface (**b** Moon, **d** Mercury)

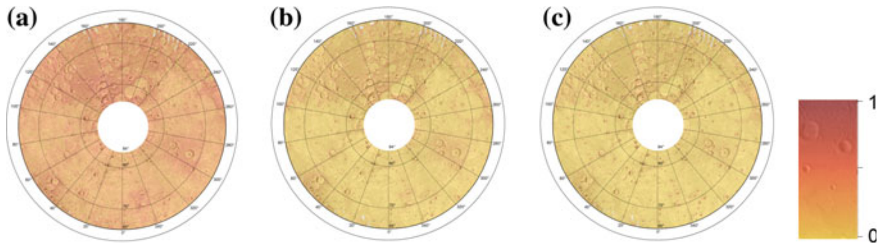

Fig. 6 Mapping of Mercury roughness (northern hemisphere) at different baselines: **a** 0.7 km; **b** 2.8 km; **c** 11.2 km. The color scale indicates type of surface: *1* high roughness, *0* smooth plain

individual laser altimeter tracks, showed the similarity of these celestial bodies in their high contrast between rough terrains (intercrater plains on Mercury, highlands on the Moon) and smooth terrains (smooth plains on Mercury, maria on the Moon) (Fig. 4).

Studying the lunar surface at different levels of detail, we examined various local measures of roughness, including spatial distribution of heights and slopes, second derivatives of heights, etc.

To map the surface topographic roughness, the interquartile range of Laplacian was chosen as a roughness measure. This is justified by a higher tolerance of this method to errors of the original DEM in comparison with other methods of roughness calculation. The Laplacian filtering algorithms were applied to the DEM derived by photogrammetric methods. To exclude the effect of map projection distortion when mapping the entire Moon surface, we introduced the following restriction: linear distortion in the entire surface should not exceed 10 %. To meet this condition, for the equatorial region (±60°) we used the equidistant cylindrical projection along the meridians from original DEM. Length distortions along the parallels in a selected for the mapped surface projection are calculated using the formula: $n = \cos \varphi_k \sec \varphi$, where φ_k is the central latitude, and φ is the latitude, where the distortion is calculated.

Estimations show that for keeping the distortion within 10 %, the size of the area should not exceed 40° along a meridian, when the central latitude is 0°. Based on these conditions, the original DEM was cut into separate fragments (Fig. 7). For the two large regions bordered by 20° N and 20° S, where the original projection is not changed, the linear distortions are up to 6.4 %. In the polar areas above 60° latitude, the stereographic azimuthal projection of the original DEM also was not changed, as its distortion up to 60 parallel are in the range up to 7.2 %, which meets the condition imposed. This approach ensured that the conditions for permissible edge length distortion are in certain range. As a result, an accurate map of roughness of the Moon has been created (Fig. 8).

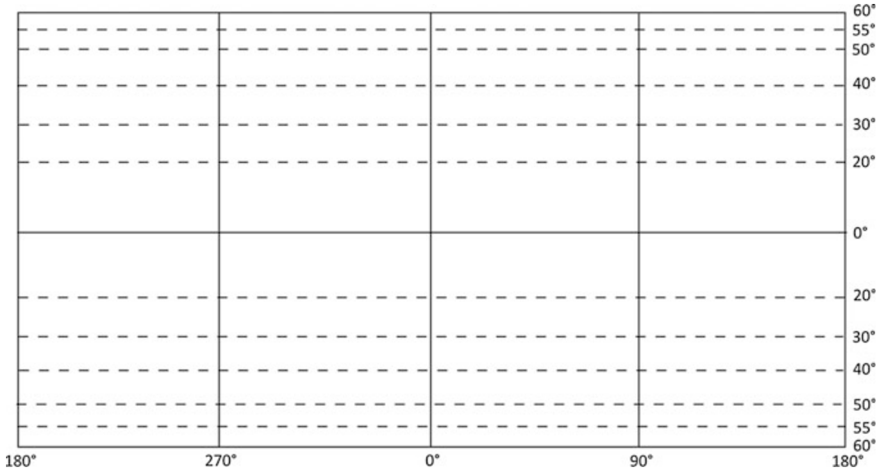

Fig. 7 Scheme of DEM segments, used for roughness calculation of the Moon

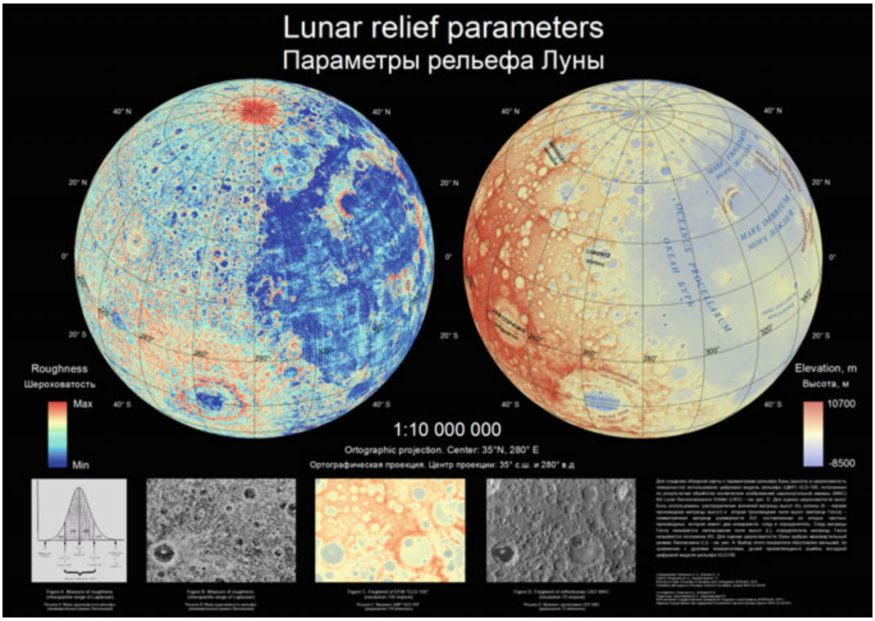

Fig. 8 Map of lunar relief parameters

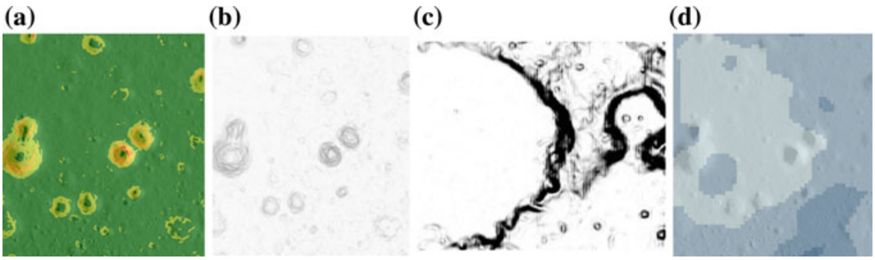

Fig. 9 Content of special thematic maps for the Lunokhod 2 area: **a** slopes map at the 5 m *baseline*, **b** roughness map at the 2.5 m *baseline*, **c** roughness map at the 100 m *baseline*, **d** map of small crater density

4 Special Maps for Landing Site Selection

Special planetary maps for support of the planned space missions are aimed to characterize safety for spacecraft landing. It is necessary to estimate various topographic parameters within the ROI which may affect the operation of the landing module. The characterization of selected potential site was carried out using special software developed based on critical criteria of safety for landing module for future missions (Karachevtseva et al. 2015a): the absence of slopes steeper than specified; visibility of the Earth; the Sun illumination, sufficient for lander operations; the absence of boulders and fresh small craters, which could be dangerous for the landing.

The special maps allows us to estimate the parameters of the ROI using cartographic measurements at the scales, comparable to the lander's size, and at the overview scales; they will help to detect the smoothest areas safe for landing.

For testing our methods of landing site characterization we studied a reference area, Lunokhods' 1 and 2 operation region (Fig. 9) on the Moon. Involvement of historical data and comparison with modern remote sensing data allowed evaluating the plausibility of the results and extrapolating their application to new ROIs on the Moon, e.g. in the prospective polar areas. We used the comprehensive approach based on the evaluation of a set of various parameters of the relief in accordance with the proposed criteria for future Russian (Slyuta et al. 2010) or European missions (De Rosa et al. 2012).

5 Planetary Data Modelling

As the volume of remote sensing data on celestial bodies increases, it is necessary to provide management and unified organization of spatial information. For these purposes, a general planetary data model has been developed (van Gasselt and Nass 2011) that described the basic elements, in particular, relationship between

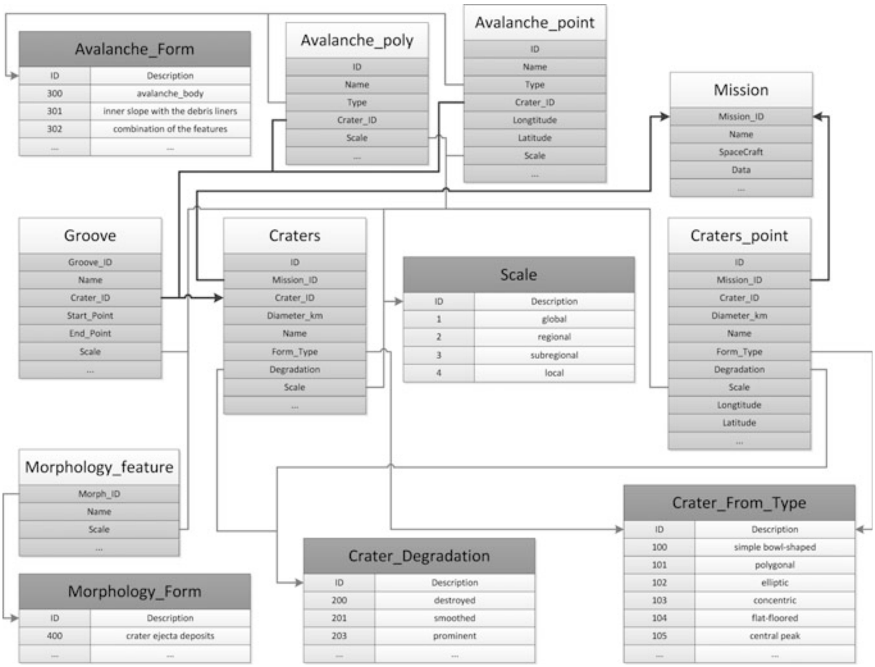

Fig. 10 A scheme of the logical model data implemented for Phobos, indicating feature properties and their relations

planetary features and their representation. The extension of the model for geologic mapping, including geochronology, has been described in Nass and van Gasselt (2013).

To meet demands of planetary mapping derived from our research and workflow (Fig. 1), we designed a logical model for implementation of the proposed approach (Fig. 10).

The main model features are standardization of vector and raster data obtained after different types of processing, and representation on maps. In addition, the model is optimizing the work with the spatial component through various scales, or level of detail (LOD). This function allows a user to perform automatic generalization of large data sets (management of cartographic representation of objects on the map at a minimum cost of computer resources). For example, in the lunar data model, there are 4 LOD for Moon surface representation:

1. Global level: map scale less than 1:5000,000. Spatial coverage—the entire surface of the Moon;
2. Regional: for displaying extended regions of the Moon, such as the polar territories or extensive lunar basins, scale 1:1000,000–1:5000,000;
3. Sub-regional level: presentation of some large areas of the lunar surface at a scale of 1:100,000–1:1000,000;

4. Local level: displays small ROI, including landing sites of soviet lunar missions and traverses of lunar rovers Lunokhod 1 and 2 (map scale less than 1:100,000), as well as potential landing sites for future missions.

To describe the various classes of spatial objects the model presents the definitions, rules for data sets and relationships between them, and includes topologic constrains and domains for attribute values. Object-oriented approach allows the use of metadata inheritance from the original raster image to the derivative, processing of various information types (vector, raster, descriptive), and domains. Moreover, editing one object causes changes in associated objects.

Besides data management, the modelling provides automation of symbolic representation in GIS, e.g., the planetary symbols based on Federal Geographic Data Committee geospatial data standards (http://www.fgdc.gov/index.htm) were implemented in ArcGIS environment (Nass et al. 2011). Using this approach and based on results of morphological analysis of Phobos surface (Karachevtseva et al. 2015b) we have extended the model (Fig. 10), and suggested new symbols for planetary mapping, based on new classifications of relief features, e.g. morphological types of impact craters (Fig. 11), or grooves: gutters (seen as simple linear depressions), chains of the overlaying funnels and chains of separated funnels (Phobos Atlas 2015).

Our logical model was applied for automation of planetary map designe (Fig. 12). It is constantly updated by adding new object classes with new properties, e.g. the small features at high LOD (lunar rilles, sulcī, pyroclastic deposits), whose symbols for are not yet included in list of Planetary geology features in FGDC standard (http://ngmdb.usgs.gov/fgdc_gds/geolsymstd/fgdc-geolsym-sec25.pdf).

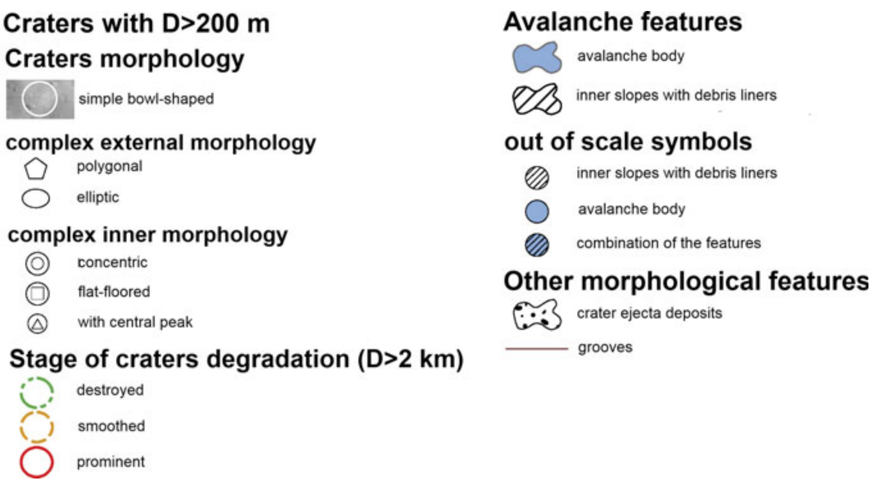

Fig. 11 An example of legend for geomorphologic map, based on the extended logical model for planetary features

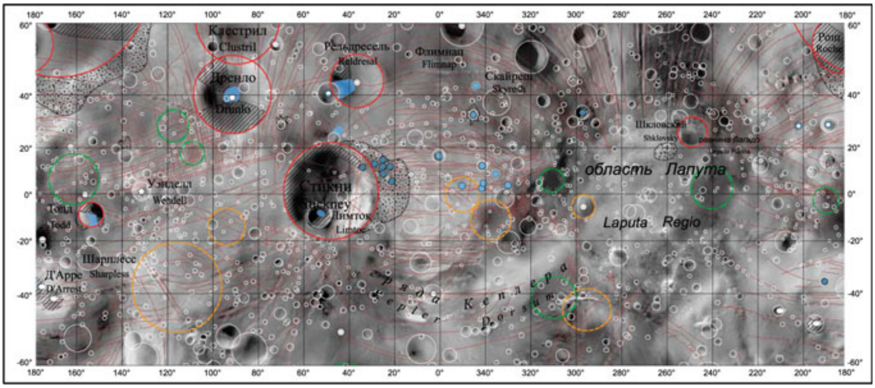

Fig. 12 New geomorphological map of the Phobos craters (central belt) (Phobos Atlas 2015)

6 Planetary Map Design

Designing the maps, we combine modern GIS-tools with the traditions of Russian cartographic school (Shevchenko et al. 2016). These include special approach for color scales, including stages of hypsometric scales (Fig. 13) and nonstandard layout for map elements (Fig. 14, Phobos).

Fig. 13 Part of hypsometric map of the Moon (Rodionova et al. 2015)

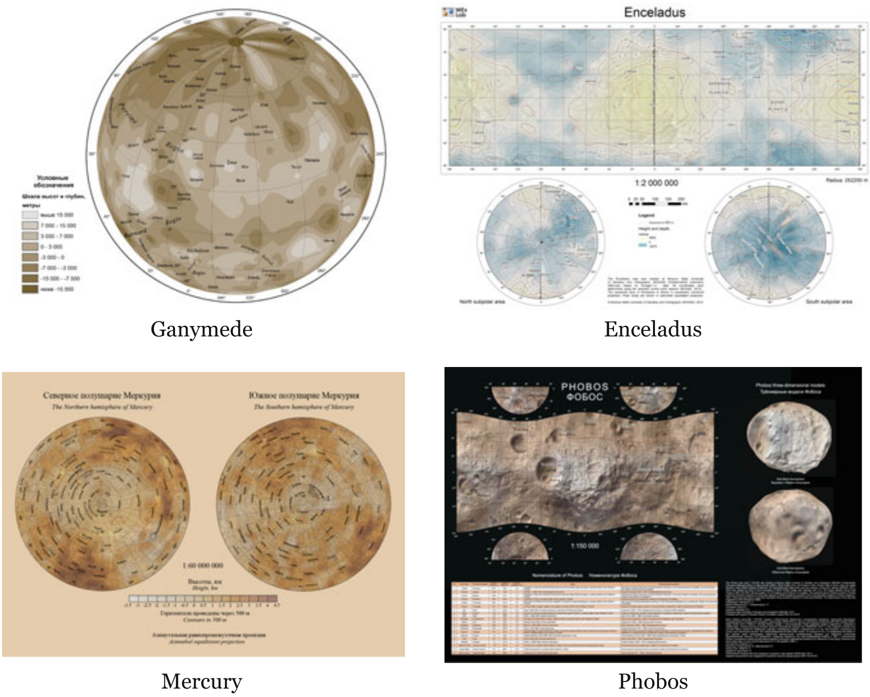

Fig. 14 Examples of map design for extraterrestrial maps of planets and satellites

Hypsometric and topographic maps should give a user the possibility to perform relief measurements with certain accuracy. For these goals on our planetary hypsometric maps contours and elevations are used (Fig. 13). The map, fitted with hypsometric step scale and contours provides information about height in the any point of the map. The hypsometric scale is specially developed for our map of the Moon with unequal intervals. This feature allows highlighting of surface characteristics: the smooth plains and deep craters, hills. In contrast, a map with gradient color scale (Hare et al. 2015) without contours shows distribution of heights stepless and allows assessment of relative and absolute heights only approximately.

Besides, for the best representation, the color scheme of a map should be close to the natural color of the mapped surface, therefore, it is better to develop the hypsometric scale individually for each of planetary body (Fig. 14). Here Ganymede is presented in brown colors due to dark areas of surface, Enceladus—as an icy body with high albedo, Mercury is traditionally shown in warm colors due to its neighbourhood to the Sun, color scheme of Phobos is based on the multispectral images from Mars Express (Neukum et al. 2004). Developing these maps we also try to keep the traditional design from the Terrestrial planets map series (Shingareva et al. 2005).

7 Published Planetary Maps and Products

Using described approaches, tools and workflow implementation we have compiled and printed new planetary cartographic products, namely, Phobos Atlas and Mercury globe (Fig. 15). The Phobos Atlas (Phobos Atlas 2015) contains 43 global and local maps of this martian satellite and summarizes modern knowledge about this unique body. Atlas includes four chapters describing the results of Phobos studies that are shown on the maps. Three different scales are used for the maps. Global topographic and thematic maps of Phobos are presented in scale 1:250,000; this choice is defined by the size of the body and format of the atlas (25 × 35 cm). One of the global maps presents the result of new geomorphologic study of Phobos grooves. Analyzing individual images of Phobos, obtained from Mars Express, and orthomosaics of images we have created the new GIS-catalog of the grooves, which included new, previously not identified objects. The map represents the spatial distributions of the grooves detected, their classification (Fig. 10) according to morphological types and orientation. The identified morphological regions are shown. The obtained results of study are consistent with the grooves being surface expressions of deep cracks in the Phobos body. The low bulk density of Phobos is possibly related to its high porosity, the presence of voids inside the satellite; the groove-forming cracks may play a role of such voids.

Beside the global maps, we compiled a large-scale Phobos topographic map (1:75,000), which is divided into 8 sheets according to proposals suggested for planetary cartography (Greeley and Batson 1990). Another multi-sheet map (1:1200,000–1:150,000) represents the crater distribution on Phobos sub- and anti-Mars sides, leading and trailing sides, and both polar areas. Some large-scale maps (1:60,000–1:45,000) in oblique azimuthal projection describe several Phobos regions in more detail as these are based on images of a higher resolution and limited extent (Fig. 15b).

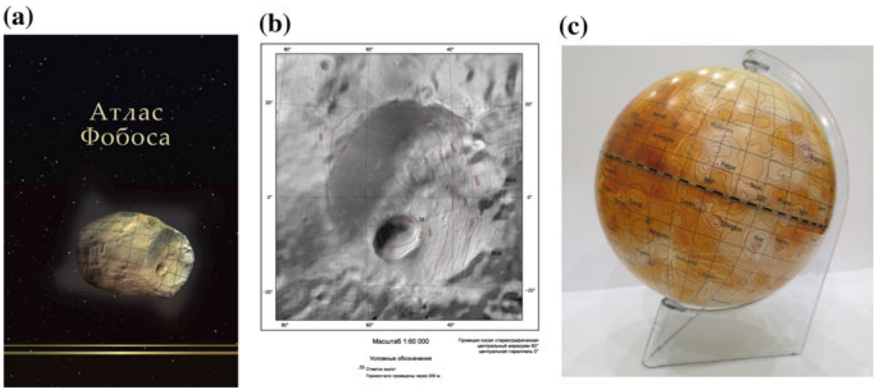

Fig. 15 New planetary cartographic products: **a** the of Phobos atlas, **b** map of crater Stickney (1:60,000) from the Phobos atlas, **c** hypsometric globe of Mercury

The other cartographic product is the first hypsometric globe of Mercury (Fig. 15c). The topography of the planet is based on global DEM derived from limb measurements of new MESSENFER images (Elgner et al. 2014); elevations are shown by contours in 500 m and with color hypsometric scale in 16 intervals. The elevations are referenced to the sphere with radius 2 439 700 m recommended by IAU (Archinal et al. 2011). On the Mercury globe are shown Caloris Montes, the longest scarp Enterprise (822 km) and other major objects, including multiring basins, crater ray systems, smooth plains and all large craters (diameter >100 km). Names of relief features are given according to the Mercury's nomenclature approved by IAU.

8 Geoportal and Web Mapping

Data usage in geospatial research critically depends on availability of maps for convenient retrieval. The Internet not only provides the easiest way to spread information; it also organizes a "platform" to work with it. We use modern spatial and web-based technology to store and distribute the results of various planetary missions, including past Soviet Lunar program in a form of the planetary geodatabase (Fig. 16) with access via geoportal (http://cartsrv.mexlab.ru/geoportal). It is the practical implementation of the previously proposed concept of a thematic node, which provides access to geodetic and cartographic results of planetary research (Shingareva and Leonenko 2003). Using this original idea we have developed a spatial information system using SQL database.

8.1 Data Storage and Processing Subsystem

The developed information system includes storage, visualization, and processing (import/conversion) subsystems that fulfil data collection from a predefined set of sources. It also performs data transformation, which brings the data to chosen standard presentation, suitable for visualization and external access. For standard representation we selected typed XML-presentation of data based on the established Open Geospatial Consortium standards (http://www.opengeospatial.org/standards). Typed XML means that for every data object, corresponding description in form of XSD-schema is available. Web Feature Service (WFS) specification is used for spatial data queries, GML—Geography Markup Language is used for presentation of results of these requests (Fig. 16). Beside the spatial information, the results can include some metadata extracts from and references to local or remote databases (DB), for example, the external archives of the NASA Planetary Data System (PDS, https://pds.nasa.gov/), that provides data in original pds-format.

At the software level, data processing subsystem consists of a set of software components, grouped around two key modules—*conversion module and user*

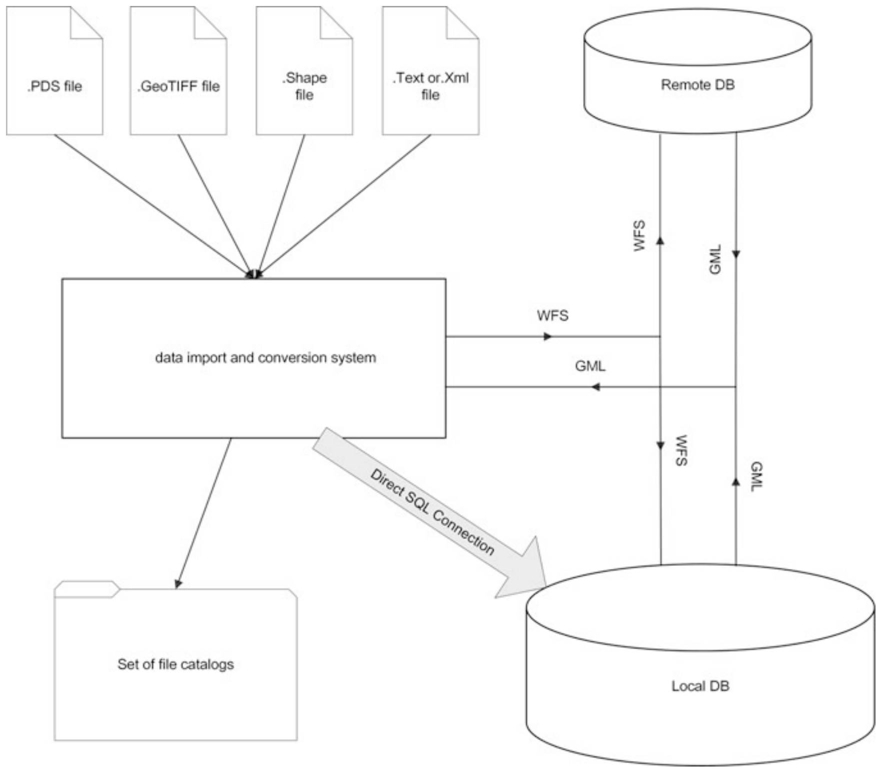

Fig. 16 Functional scheme of spatial information system for storage of planetary spatial data

interface module. *Conversion module* actually executes data conversion with optional load to the Database. This module can work in autonomous mode without operator intervention. *User interface module* provides operator's access to conversion module settings and parameters. Besides, it provides an operator with possibility to perform ad hoc data conversion. This module is implemented as Windows-application "MExLab ConverterUI". Several instances of *Conversion module* can be used in parallel (when installed on different computers), and be managed by operator via single Converter UI program. *Conversion module* is fully DB-independent and can operate with or without any access to SQL database.

8.2 Geoportal: Present and Future

Geoportal provides user interface to local planetary geodatabase based on 2D-visualisation and the ability of spatial queries to the contents of available data sets (http://cartsrv.mexlab.ru/geoportal). Users can obtain the quantitative and qualitative characteristics based on metadata of the objects. Geoportal provides public access to the products of different processing levels: DEMs and orthomosaics of Phobos, Mercury, Moon, Ganymede, catalogues of relief objects for studied celestial bodies, results of roughness calculation, control point networks, etc.

The planetary data geoportal is used as an external node of a distributed online resource for educational and scientific organizations in the frame of PRoViDE project, Planetary Robotics Vision Data Exploitation (http://www.provide-space.eu/), that supports a major portion of the imaging data gathered so far from planetary rover missions on Mars and the Moon (Morley et al. 2014), including access to the lunar archive panoramas received by Soviet Lunokhods (Kozlova et al. 2014).

Using online planetary maps (http://bit.ly/Lunohod_1) prepared with ArcGIS-online tools we are developing the web-service for intellectual data search based on methodology of Local-Based Service. Spatial and semantic context of map objects provide the new information about planetary features based on the API-services of data storages of the national space agencies (ROSKOSMOS, NASA, ESA, JAXA). The service will support search for newest images, scientific publications, news about planetary mission results based on localization of the studied objects like craters, rover, etc. (Garov et al. 2015a). The order and the number of references received by each query will depend on the weights, which are automatically assigned to the attributes of objects, according to its importance to the user. In

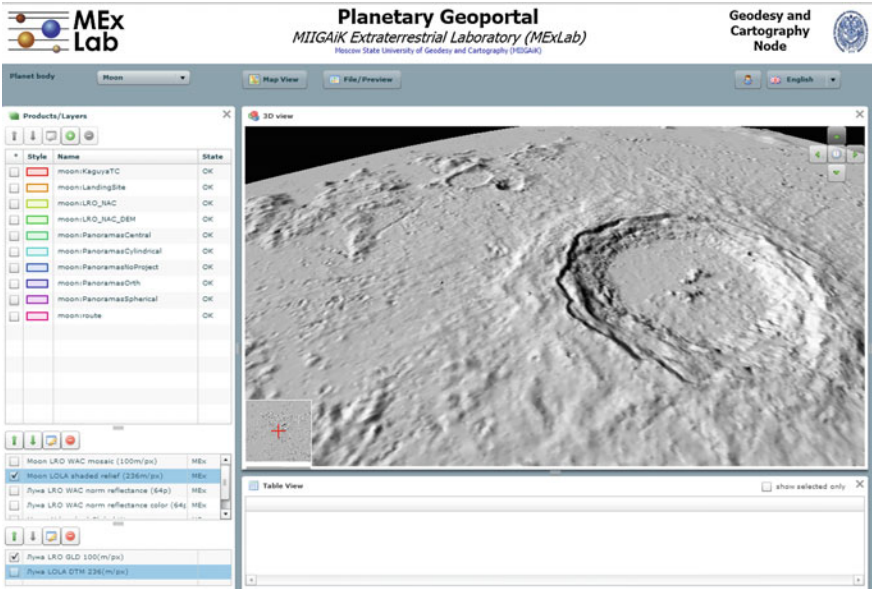

Fig. 17 A screenshot example of updated version of Geoportal in three-dimensional regime for the Moon

priority are the attributes that precisely describes objects, which user selected on the online map. Parameters that complement the data about the object (e.g. description criteria such as belonging to certain mission, research area, celestial body, etc.) could be assigned a lower rank.

For extension of the geoportal functionality, we use cloud and network solutions for developing a new 3D web-GIS (Fig. 17), which will provide possibilities for online processing of spatial data, including relief modelling, morphometric measurements, co-registration of images by combining spatial data geometries, etc. Based on conception of "online laboratory" we are developing interactive GIS-tools, which can be widely used in planetary studies: landing site selection for planning of future missions and collaborative research of international scientific community, using joint online meeting within common spatial context to share and discuss observations and results of cartographic measurements. For the further development of geoportal as a new system based on distributed environment, the network libraries that allows telecommunication between remote users within a joint spatial context have been adapted (Garov et al. 2015b).

9 Conclusion

We developed a methodology for mapping celestial bodies using a new innovative approach based on GIS- and web-techniques, which includes various stages from raw image processing to surface analysis, online maps and planetary data geoportal. To extend the capabilities of geoportal, the concept of 3D-web-GIS as online laboratory was proposed that includes not only access to and visualization of spatial information, but also three-dimensional modeling, joint analysis by remote scientific groups and intelligent data search based on spatial context on the map.

The modern cartographic methodology that combines the developed tools, design approach and online access was applied for planetary studies of various planets and satellites. As a visual representation of the research the planetary maps were created, including Phobos atlas, topographic and geomorphologic wall maps of Phobos, basemaps of Ganymede, global hypsometric Enceladus map, global and local maps of the Moon, including special maps for lunar landing sites. The results of cartographic measurements, presented on maps, are useful for Solar system research, planning future missions, fundamental studies of planetary surfaces, etc.

Acknowledgment This work was carried out in MIIGAiK and supported by Russian Science Foundation, project "Study of fundamental geodetic parameters and relief of planets and satellites", No. 14-22-00197. The authors would like to acknowledge M. Kreslavsky for the advice and careful reading. We thank anonymous reviewers for their helpful comments.

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SDI4Apps Points of Interest Knowledge Base

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Abstract The SDI4Apps project has collected a large number of points of interest (POIs). The Smart Points of Interest (SPOI) represents a seamless and open resource of POIs covering all the world. Its principal target has been to provide information for cycling as Linked data together with other data sets containing road network. But the current version can be used for any purposes related to tourism. The article presents the data model for POIs as a basis for harmonization of external data sources into this data model. The current version of the SPOI data set includes a harmonized combination of selected OpenStreetMap data, GeoNames.org, experimental geo-ontologies developed at the University of West Bohemia and local data. The data model follows the recommendations for RDF data sets, semantic data, and Linked Data as well as the data model published in Points of Interest Core. The SPOI knowledge base complies with the 5-star rating system of Linked Open Data. The data model re-uses several important, respected and standardized formats and vocabularies such as XML, XML Schema, RDF, RDFS, SKOS (Simple Knowledge Organization System), GeoSPARQL or FOAF (Friend of a Friend).

Keywords Point of interest · Linked data · Data model · SDI4Apps · Data set · Spatial data modelling

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_14

1 Introduction

SDI4Apps (sdi4apps.eu) is an EU-funded project (European Union's ICT[1] Policy Support Programme as part of the Competitiveness and Innovation Framework Programme) coordinated by the University of West Bohemia in Plzen, Czech Republic. SDI4Apps seeks to build a cloud-based framework with open APIs (application programming interfaces) for data integration focusing on the development of six pilot applications. The project draws along the lines of INSPIRE (INfrastructure for SPatial InfoRmation in Europe; inspire.ec.europa.eu), Copernicus (copernicus.eu) and GEOSS (Global Earth Observation System of Systems). The SDI4Apps development process started with data integration and harmonization, including semantic annotation and Linked Data interconnection. Data are collected based on requirements of the six pilot activities, which represent the first users, testers and feedback providers of the whole SDI4Apps solution.

This chapter describes the Smart Point of Interest (SPOI) dataset as a specific set of POIs (specific point data that could be useful or interesting for particular purposes) which are useful for potential customers of applications developed in the SDI4Apps project, above all in the Open Smart Tourist Data pilot. "POI provide an essential data source for a wide range of location-based applications. Having emerged from in-car navigation systems the classic POI are often linked to an address and relate to businesses such as petrol stations, garages, shopping centers, or common sense information, such as the church, police station or hospital in a city" (Andrae et al. 2011). Various POI datasets are implemented into popular applications for traveling and tourism such as Trip Advisor or navigation tools such as Waze. There are also two US Patents mentioning the role of POIs in on-line advertisement (Jakobson and Rueben 2013a, b).

There are a lot of resources providing POI data. First of all, it is necessary to mention OpenPOIs (openpois.ogcnetwork.net) by Open Geospatial Consortium. This database contains more than 9 million POIs, which are available through an API. Other POI data are offered by various web pages such as POIplaza, POI download, GPS Data Team, Pocket GPS World or the POI service provided by Flemish government. Data are also provided by several producers of navigation tools. These resources contain various types of POIs and POIs and are downloadable in in different formats (usually in a format that can be processed by navigation tools).

The SPOI data set is created as a combination of global data (selected points from OpenStreetMap/openstreetmap.org/ or GeoNames.org) and local data provided by the SDI4Apps partners or data available on the web. The final version will represent an open and seamless solution which will be able to be "a data fuel" for location-based and navigation services and applications. The added value of the SDI4Apps approach consists in implementation of linked data. The current version contains several links to external resources (see the Sect. 3.1 "SPOI as Linked

[1]Information and Communication Technologies.

Data”). Interconnections to other data will be added, including transformation of all used code lists into RDF (Resource Description Framework) vocabularies.

There are several disadvantages of contemporary POIs data sets (such as those mentioned above), which prevent their integration and further re-use. These disadvantages include:

- using proprietary formats or specific formats for geographic information systems,
- download based on topics or geographical regions (for example countries),
- common absence of standardized services or querying,
- charge for data.

The main goal of this text is to introduce the SPOI base, above all the development process and the data model. The SPOI data are compared with the similar solution OpenPOIs in order to check the compatibility between both POI datasets for further reuse in various applications.

The chapter is structured as follows. Section 2 describes the used methodology including fundamental pillars of the design and development of the SPOI base. This includes theoretical backgrounds as well as inspiring data sets and models (as the overview of state-of-the-art). The methodology also contains a short description of the comparison of the SPOI base and OpenPOIs. Section 3 presents the SPOI data set, its data model and relation to the Linked Data approach. The last section (except Conclusions) includes a discussion on further steps of the SPOI development.

2 Methodology

The reason for the development of another dataset of POIs emerged from the needs of users (tourists, tourist service providers as well as developers of applications focused on tourism). There was a lack of a complex set of POIs which would not be territory specific (for example limited to particular countries, regions or national parks), would be open and not limited to one data resource (usually OpenStreetMap). The SDI4Apps SPOI team composed of experts from the Czech Republic and Latvia, developed a seamless open database of POIs which will be distributed as 5-star Linked Open Data (Berners-Lee 2009) to be accessible for all users.

Even though the data modelling of POIs (as features with simple point geometry, identifier and several descriptive attributes) seems to be very trivial, authors did an extensive research of existing data models and literature. The development of the SPOI data model was based on seven fundamental pillars:

1. Classical studies and books focused on spatial (or geographical) data modelling such as Goodchild (1992), Shekhar et al. (1997), Longley et al. (2001) or Tomlinson (2007). These resources gave a basic framework of SPOI data model.
2. Several research dealing with publication and modelling of spatial data as RDF triples (for example Auer et al. 2009; Janowicz et al. 2012 or Kritikos et al.

2013) was taken into consideration and implemented, because RDF has to be the principal format to store data.
3. General principles of development for Linked Data as they are published in Bizer et al. (2008, 2009), Heath et al. (2008) or Hausenblas (2009). There is also a lot of publications focused on Linked Data on the geographical domain such as Auer and Lehmann (2009), Atemezing and Troncy (2012) or Kuhn et al. (2014).
4. The data model of POI as it is published in the W3C Editor's Draft Points of Interest Core (Hill and Womer 2012; this document was originally created by the W3C Points of Interest Working Group that was transformed into OGC as the Points of Interest Standards Working Group) as well as in the presentation Framing a Geo Strategy for the Web with Points-Of-Interest Data by Singh (2012).
5. Data models of existing POI datasets (for example POIplaza or POI download).
6. Existing standards, formats and vocabularies such as RDF, RDFS, SKOS, OWL, FOAF, GeoSPARQL or WGS84 Geo Positioning.
7. Experiences of data modelling from existing solutions and projects such LinkedGeoData (linkedgeodata.org), DBpedia (dbpedia.org), GeoNames.org or SmartOpenData (smartopendata.eu).

The reasons for selecting particular classification systems, coordinate systems and other parts of the data model are explained in the next section.

The POI data model is open and flexible. The essential core of the model (ID, coordinates, label and categorization) was extended by several attributes which are integral components of some original data and could be helpful for tourist purposes (for example contact information, opening hours or accessibility for handicapped visitors).

The contemporary version of the SPOI base is populated by several free software components (for example Osmconvert or Osmfilter) and XSLT templates [several examples of using XSLT transformations in spatial data domain are published in Čerba (2010) or Čerba and Čepický (2012)]. The XSLT template contains procedure of harmonization, data models' mapping, including transformation rules of classification systems.

3 SPOI Knowledge Base

3.1 SPOI as Linked Data

SPOI corresponds with the 5-star rating system of Linked Open Data published by Berners-Lee (2009) and described in Janowicz et al. (2014). Table 1 shows how particular criteria are satisfied by the SPOI data.

3.2 Data Model

The current version of the SPOI data model (November 2015)[2] has eight basic components:

1. Identification—each POI is identified by a unique ID expressed as URI. The original ID (URI of the product and a unique code generated by XSLT script) was replaced by a more readable form providing some information such as country and category. The new identifier is composed of URI (http://www.sdi4apps.eu/spoi), ISO 3166-1 alpha-2 country code, category of POI according Waze navigation data and coordinates.
2. Description—each POI is described by a label (name). In several cases, there are more labels differentiated by the xml:lang attribute. POIs can contain a longer textual descriptions in various languages if they are available.
3. Geometry/Localization—each POI is localized by two coordinates (latitude and longitude) of World Geodetic System (WGS) 84. WGS84 represents the most used, respected and universal system, which is usually transformable to local systems and cartographic projections. Coordinates were originally published according to the Basic Geo (WGS84 lat/long) Vocabulary (Brickley 2006). But due to better compatibility with the Virtuso engine, all the coordinates were transformed to GeoSPARQL standard. The latitude and longitude are written as WKT (Well-Known Text).
4. Classification—the categorization of POIs is realized through three various parameters—classification based on GPS-based geographical navigation Waze and two OpenStreetMap categories (key and value). The Waze category is primary, mandatory and used for visualization in the SPOI map client. The classification system used in Waze is quite short, clear and simple to visualize as well as differentiate, because it contain 10 well-defined categories. The Waze categories are connected to data as URIs to self-standing RDF vocabulary. Since majority of data originate in OpenStreetMap, two types of classification from OpenStreetMap are used. The authors tested other nomenclatures used in various products (data, services, applications) such as Trip Advisor, Yelp!, USGS Geographic Names Information System or Ordnance Survey POI classification scheme. But the Waze scheme is the most appropriate for the purposes of the POI database developed in the SDI4Apps project. Mapping rules between the Waze nomenclature, the OpenStreetMap classification and categories used in other source data are kept in the transformation XSLT file.
5. Contact information—several POIs contain contact information such as address, e-mail, homepage, fax or phone number. The authors didn't want to create new properties and decrease the interoperability with other data. Therefore existing vocabularies (for example FOAF—Friends of a friend) were used.

[2]The data model scheme is not included in this text, because it is very large. It is available on the SPOI web page (gis.zcu.cz/spoi).

Table 1 SPOI and 5-star rating system of linked open data

Stars	Description	SPOI
1	Data is available on the Web under an open license	Data objects are provided to download on the Web through the SPARQL endpoint The data will be provided under the Open Database License (ODbL)
2	Data are available as a structured data	SPARQL endpoint is able to provide data in many structured formats, including JSON, XML, CSV or various serialization of RDF
3	Data uses a non-proprietary format	Majority of output format offering in Virtuoso SPARQL endpoint are classed as non-proprietary formats
4	Particular objects have URI as identifier	Data uses unique identifier based on URI based on http://www.sdi4apps.eu/poi
5	Data is linked to another data	Several object are linked by properties *skos:exactMatch* and *owl:sameAs* to equivalent elements in DBpedia and GeoNames.org All objects are interconnected via topological property *sfWithin* to relevant countries as they are expressed in DBpedia and GeoNames.org The main classification of POIs is accessible through URI

6. Common (touristic) information—includes information such as opening hours, cuisine, access to the Internet, code of airports or accessibility.
7. Links—all POIs include one or more of three types of links to external data—(1) links to external non-linked data resources such as photos, Wikipedia or Wolfram|Alpha; (2) links to an equivalent object in DBpedia or GeoNames.org; (3) links to relevant countries (in DBpedia and GeoNames.org) containing the POI. The last type of links is mandatory for each object.
8. Feature metadata, which contain basic information on data, for example the origin of data, the identifier, rights or the date of embedding into the SPOI data set.

4 Future Steps

The current version of the SPOI base is useful, but the base as well as the data model or vocabularies haven't been completed yet. The SPOI developers together with partners of the SDI4Apps project and other users are discussing many proposed changes and improvements. They could be divided into two groups—(1) modifications of the data model and (2) other further steps related to populating, visualization or maintenance.

The possible changes of the SPOI data model include implementations of:

- a property for preferred label (for example *skos:prefLabel*), because the SPOI base contains more than one label (in one language) for several features.
- transformations of classifications to RDF structure to be re-usable in other data and applications.
- changes of string values (for example addresses or opening hours) to several semantically rich values, for example based on the INSPIRE specifications (for example the INSPIRE Data Specification on Addresses), vCard or the ISA Core Location Vocabulary for addresses.
- new attributes important for tourism.

Other further steps are related to population of the SPOI base (searching of new data resources and its processing, removing errors and shortcomings in data, massive and automated adding links to other resources), refining data (eliminations of duplicities), providing data (export to other formats that are supported by navigations tools, improvements of map portal, generalization), updating (questions of persistent URIs or processing of changes in source data) and improvements of a presentation of the product (social media).

There are also important questions related to SPOI cartographic visualization, because especially in several regions SPOI data has a character of "big data". The character of "big data" is related with development of modification of methods for data harmonization, storing, uploading of visualization. These open questions consist in a design of view pyramids preventing presentation of huge tangle of POIs, which will be very complicated for users' perception. It is connected with switching layers based on categories implemented in SPOI. An efficient filtering of POIs also contributes to faster drawing of data.

5 Conclusion

There are many ways how to describe the Smart POI data set (for example quality of data or maintenance and updating). With respect to the limits of this document, it is not possible to mention all question or problems connected to SPOI. This chapter introduces the data set of Points of Interest developed in the SDI4Apps project. This data set is a seamless and open resource of POIs that will be available for other users to download, search or use in applications and services.

The data model of SPOI is based on literature review, existing data (for example OpenPOIs), recommendations of W3C and OGC and user requirements. The current version of the data set has been created as a harmonized combination of selected OpenStreetMap data, GeoNames.org, experimental ontologies developed in the Section of Geomatics of the University of West Bohemia and local data provided by several partners of the SDI4Apps project (for example Uhlava region, Czech Republic). The transformation was realized by fitting open-sources applications and XSLT templates. Data is stored in the Virtuoso tool as RDF triples. SPOI is published via SPARQL endpoint which enables comfortable, efficient and standardized querying of data. All the information on SPOI (including the links to the map client, the data model or the SPARQL endpoint) is available at sdi4apps.eu/spoi.

The added value of the SDI4Apps approach is in reflecting other similar solutions, implementation of linked data, using standardized and respected datatype properties and in development of the completely harmonized data set with uniform data model and common classification (not only a copy of original resources).

The authors believe that the selected approach to develop an open data base of POIs is promising, especially from the following reasons:

- implementation of many external data resources can provide a multi-level view on POIs, including corrections of shortcoming and gaps,
- Linked data enables more efficient way how to combine and re-use data,
- the combination of global data and data provided (or edited) by concrete users (municipalities, local and regional authorities, subject running a business related to tourism or volunteers) can form very interesting complex of spatial data,
- open data can generate an interesting business effect such as local advertising or development of applications.

The authors welcome other remarks and comments how to improve the SPOI data set, its model, content as well as the interconnection to other data.

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Licences and Open Data in Cartography

Alena Vondrakova and Vit Vozenilek

Abstract Cartographic production and publishing are related to many aspects including data availability and legislative requirements. They are highly relevant to the map making process from its beginning to the possibility of extending the final step. The modern trends of Open Data have a significant impact on the development of cartography and its essential part—knowledge of licences. Intellectual property is crucial in the era of the information society. Unfortunately, the debate over the appropriate scope of intellectual property protection for spatial data and geo-databases mostly ignores the role of cartography and spatial data uniqueness in the setting of the rights. The law essentially requires the authorization to apply the right to use a work (licence) to another person. There are possible arrangements and licensing agreements where no such authorization is needed (open licences), in some cases is it also possible to use authors work in situations prescribed by law. In most instances it is, however, necessary to know licensing rules to allow practical work with data sources and work disclosure. Knowledge of licensing becomes essential for the process of contemporary cartographic production. Spatial digital data are often under copyright protection as geodatabases. Due to the territoriality of copyright protection, it is very important to know the specific licence terms and conditions. The uniqueness of spatial data compared to other information, is that it is often necessary to combine different data sources. Moreover, it is the combination of the various data sources that often cause a problem because of the requirement for separate licences.

Keywords Licences · Copyright law · Cartography · Data

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_15

1 Introduction

Copyrights relate to all the creative activity that is objectively perceivable by human senses. Copyright and legal issues in the visual arts are mostly respected (Goldstein 2001), but in Cartography and GIScience it is much neglected, both on the legislative side and at the level of education of professionals and the public (Vondrakova 2011).

Open Data is one of the phenomena of present Cartography and GIScience. Development and expansion of geovisualized products are linked to spatial data availability. That is why the Open Data became a boom that begins to form "geoinformation society"—society dependent on the applications working with spatial data approximately 15 years after the formation of "information society".

At the beginning of the 21st century, data was the main "assets" of each cartographic publishing house. However, now it is not difficult to obtain almost any data, and it was clearly shown that free availability of the spatial data causes the development of other spatial-based applications. Open data mean that data are freely available to everyone to use and republish as they wish, without restrictions (Vozenilek 2002). There are various "openness levels" of data—from "data availability only" in a particular format, and for non-commercial use only, to "really open data", which are fully free available to anyone, without any restrictions from copyright, patents or other mechanisms of control. In fact, open data also complement the existing range of open source, open hardware, open content and open access. Together with these tools, open data provides enormous opportunities in Cartography and GIScience—for any data processing, cartographic production, and other applications. Open data has become a valuable tool for creating geoinformation policy states (Reichman et al. 2011).

The authors are studying copyright issues in Cartography and GIScience in the cooperation with the experts in law. The paper presents the specific illustrative examples in which the conflicts with the legal protection of copyright works are demonstrated. Based on the definition of national matters a brief analysis of problems in the protection of copyright in Cartography and GIScience was implemented.

2 International Context

Copyright legislation has originated in various countries around the world simultaneously, but it differed according to the concept of implementation. This issue was addressed in detail for example by Taylor (1998). In the U.S.A., a monism of property rights has been applied until 1988 that involved a common approach to the application of the principles of ownership to immaterial things and a transferability of all rights to this matter. European legislation introduced dualistic principles of the division of rights into two main groups—exclusive personality rights and exclusive property rights. Copyright is a territorially defined it means that all countries have their legislation affecting copyright, even though they may be based on uniform internationally applied directivities.

The Berne Convention and the Rome Convention for International Copyright are the most relevant international agreements on intellectual property rights. The Paris Convention, the Madrid Agreement, the Nice Agreement, the Lisbon Agreement, the Madrid Protocol, the Trademark Law Treaty, the Patent Cooperation Treaty and the Convention on the Grant European Patents are the most respected legal documents for industrial property rights (regulated by MIT, 2009). The TRIPS Agreement is crucial for international trade, although it can be applied to the global projects including Cartography and GI Science.

The World Declaration on Intellectual Property and the Universal Declaration of Human Rights are the most important global conventions of protecting copyright that form the framework for all other agreements, guidelines, and conventions. The World Intellectual Property Organization (WIPO) manages the international multilateral conventions. It is the agency of the United Nations (UN) founded in 1967 with its headquarters in Geneva, Switzerland.

Although the level of the copyright protection in the developed countries is on the very similar level, a significant impact on this issue has the regional specifics. It is therefore always consistently ensure compliance with all procedures and rules, depending on which country the cartographic or geoinformatic product is carried out (Vondrakova 2011).

3 Licences

If anyone other than the author is going to use the author's work, it is always necessary to enter into a licence agreement (there are statutory exceptions). The licence is a legal document that contains legally enforceable conditions specifying the rules for the use of the work (e.g. cartographic products, GIS software, and spatial databases). A legal copyright licence authorizes the right to use the work, and the assignee is required to use the licence. The agreement with entering into the licence agreement may be expressed by the utilization of the work, for example during the software installing. The legal copyright licences are not registered in most of the countries. There are internationally-used licences, which are clearly defined, and the authors can publish their works immediately with their launching. The licences differ for the use of geoinformation technologies (geographic information systems) and cartographic products.

The licence agreement may be made in various ways—such as the extensive legal texts, such as the oral agreement confirmed by a handshake, as well as the talks from which it is clear that somebody agree with a certain use of the work. Basic types of licences are the public licence (completely open licence) and "full" copyright (most restrictive licence). There are also often used predefined licence agreements with an open circuit users—the best-known are Creative Commons (CC) or Open Data Commons Open Database Licences (ODbL).

3.1 Copyright

The copyright licence can be interpreted as all rights reserved. If the user handles any product under *copyright* concerning the use of the work under the copyright law, he/she has to contact the author (or the copyright owner) and to obtain its approval (Fig. 1). However, any author work is protected automatically without explicit stating any licence agreements or a reference to the legislative protection. The copyright symbol © lost its importance; nevertheless, it is still used as a warning to the user that the product is subject to the copyright protection and that it refers to the law executor. The use of the copyright symbol is highly recommended because it clearly defines the owner of copyright rights.

3.2 Creative Commons

The Creative Commons licence means that some rights are reserved. These are certain predefined licences, in which the author through a specifically selected licence (designation) closes the contract with all potential users of the works. The contract has to be on the basis that the authors give the users some of their rights to use the work while they retain the other rights. The user of the Creative Commons work does not need to contact the author of the original work when he/she use it in some procedures, since itself licence already frees some rights. The most commonly used licences are shown in Fig. 2.

The Creative Commons licences allow an easy way to provide permission to use the author works, including the cartographic works. Under this licence, any text, presentations, images and videos may be disseminated. For GI Science, it is important that Creative Commons licence support and protection of databases since

Fig. 1 Copyright protection—according to the Berne Convention there is no need of registration and "full" copyright protection is applied

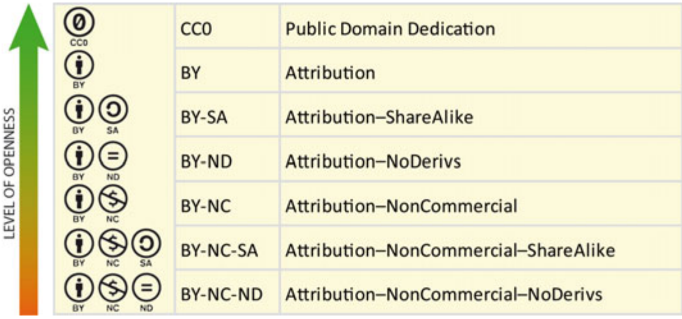

Fig. 2 Most used creative commons licences

version 4.0. The Creative Commons licences protect, for example, mapping services (the tiles) Open Street Map.

Creative Commons is also the name of the US non-profit organization for the management and promotion of the use of Creative Commons licences. The latest Creative Commons 4.0 version was released in 2013. They are also translations into other languages, which are crucial for many institutions. The Open Data Commons Open Database Licences (ODbL) are highly suitable for protecting various types of databases; however, they are less usable because of missing national translations (for example to the Czech language). Missing translations are caused mostly by conflicts between Anglo-American and continental legal systems.

The user expresses the Creative Commons licence through the pictograms, or font combinations. On the internet, they use so-called Machine-readable versions that can be generated on creativecommons.org. Here is a simple one-page summary of the user rights and obligations, called the Commons Deed. It provides all the essentials of what is possible to manipulate the work and what is not. The Commons Deed texts are understandable to the laymen. The full texts of the licence agreements are included in Creative Commons version 3.0 licences in various national versions modified to follow the national legislation in the details. The Creative Commons 4.0 is only one international licence version, and the language versions are the simple translations.

It is necessary to distinguish between the versions of Creative Commons licences because they are different, though usually only in details, which a common user does not notice. The very latest version 4.0 has brought so far the largest number of changes in the history of Creative Commons. A significant change is the ability to use Creative Commons licences for database and licensing of its rights. Newly the author also may request removal of his/her name during the next use of the work, for example if he/she disagrees with the way of use. Also new is the fact that the licence violation may not directly mean the extinction of the licence agreement because there is the thirty-day period to remedy the violations detected. Fig. 3 illustrates the use of Creative Commons licence.

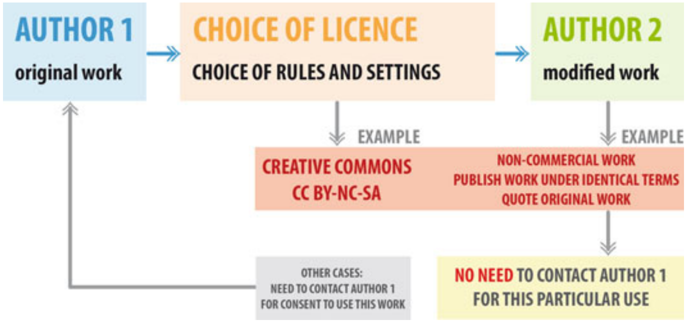

Fig. 3 Use of creative commons licence

3.3 Licences Compatibility

Licence compatibility is an issue that arises when licences applied to copyrighted works can contain contradictory requirements. For example, share-alike licences require derivatives of the licensed work to be released under the same licence as the original—but when there are combined two different data sources, it is often impossible to combine content from such data sources in order to create new ones, because it is impossible to meet the requirements of two different licences.

Spatial data have a specific characteristic: in many cases we get the additional value by their combination and subsequent analysis. Therefore, licences compatibility is crucial for effective work. Relevance and compatibility problems of licences are a hot topic, especially with the growing policy of Open Data—many open licences are not compatible. Figure 4 is an example of the most common types of licences and their mutual compatibility.

	PUBLIC DOMAIN	CC0	CC BY	CC BY-SA	CC BY-NC	CC BY-ND	CC BY-NC-SA	CC BY-NC-ND
PUBLIC DOMAIN	✓	✓	✓	✓	✓	✗	✓	✗
CC0	✓	✓	✓	✓	✓	✗	✓	✗
CC BY	✓	✓	✓	✓	✓	✗	✓	✗
CC BY-SA	✓	✓	✓	✓	✗	✗	✗	✗
CC BY-NC	✓	✓	✓	✗	✓	✗	✓	✗
CC BY-ND	✗	✗	✗	✗	✗	✗	✗	✗
CC BY-NC-SA	✓	✓	✓	✗	✓	✗	✓	✗
CC BY-NC-ND	✗	✗	✗	✗	✗	✗	✗	✗

Fig. 4 Licences compatibility comparison

3.4 Specifics of Licences in Cartography

The authorship in cartography results from knowledge, ability and fine art skills of individuals or group of experts in modelling spatial data and in their generally accepted graphic presentation (Birin and Posloncec-Petric 2009). Specifics of licences in cartography and geoinformatics are essentially related to the specifics of spatial data. Cartographic production is associated not only to legal aspects, but also the ethical aspect (Vondrakova 2013). In the cartographic processing, it is often difficult to decide in which case it is merely a technical procedure and when it is the author's work. "*There is no foundation in law for the argument, that because the same sources of information are open to all persons, and by the exercise of their own industry and talents and skill, they could, from all these sources, have produces a similar work, one party may at second hand, without any exercise of industry, talents, or skill, borrow from another all the materials, which have been accumulated and combined together by him. ... But it is just as clear, that he has no right, without any such surveys and labors, to sit down and copy the whole of the map already produces by the skill and labors of the first party*..." (Id. at 1037-38. Cf. Blunt v. Patten, 3 Fed Cas. 762, 763—No. 1579, injuction granted, 3 Fed. Cas. 763–65—No. 1580, C.C.S.D.N.Y. 1828 in Whicher 1963). This quote is very old, but the problem of determining the degree of authorship in cartography is a considerable problem today as well.

Any special copyright licences are not available for cartographic production. It is important the nature of the work and licence has to focus what to be protected—data or the resulting visualization. Important is also proper consideration of copyright income. Therefore, it is important in cartography and GISc&T not only to ensure correct identification of the licences but also to ensure that licences are granted by real owner of copyrights.

The Creative Commons licences are especially suitable for printed cartographic production, since version 4.0 they are also suitable for geodatabases and datasets. Suitable for digital cartographic products and datasets are also Open Data Commons licences—Open Data Commons Open Database License (ODbL), Open Data Commons Attribution License and Open Data Commons Public Domain Dedication and License (PDDL).

Copyright protection is also listed under 'Cartography and Visualization', one of the core knowledge area in the UCGIS Body of Knowledge. The issue is thus given considerable attention of experts. Specific issues dealing with copyright in GIScience are focused by many authors—for example copyright issues for spatial databases are described by Yeung and Hall (2007), standardization of licences is described by Van Loenen and Welle Donker (2010), copyright protection of vector maps are described by Kitamura et al. (2001) etc.

4 Open Data

Open Data is a global trend that is at the forefront of cartographers and GI experts. The benefits from open data are crucial, and they range from the efficiency and supervision improvement of public administration, through the citizens involvement in decision-making processes, to the support of the economy and the increase of the work efficiency with data in general. The issue of open data closely relates to the copyright issues, because the copyright law relates to a broad range of databases and data files. Knowing copyright issues, licensing and related rights are essential to the right "data opening". The copyright and open data issues are an extremely topical subject of current research and practical use in Cartography and GI Science.

In general, open data is the idea that some data should be freely available to everyone (Vozenilek 2009). Open data can be used or republished without restrictions from copyright. The main aim is similar as in the case of open-source software or open hardware—to involve as many people as possible to data processing and to enable the best possible development. Open access to scientific data was institutionally established with the formation of the World Data Center system, in preparation for the International Geophysical Year of 1957–1958 (Committee on Scientific Accomplishments of Earth Observations from Space, National Research Council 2008). The concept of open data has been associated with a number of areas, including the participation of citizens in public administration to the issue of climate change: "*International programs for global change research and environmental monitoring crucially depend on the principle of full and open data exchange, i.e., data and information are made available without restriction, on a non-discriminatory basis, for no more than the cost of reproduction and distribution*," (On the Full and Open Exchange of Scientific Data, National Research Council 1995).

There are many initiatives for opening data at regional, national and transnational levels. It is the current trend in data policy, which can have a fundamental impact on the development of geospatial applications and cartographic visualization.

5 Case Study

Efficient, fast and precise handling spatial data support the security of the state and citizens—the productive spatial data processing maximizes the use of technological knowledge and supports the latest developments. A coordinated approach towards ensuring national security requires the effective, fast and practical use of the information, the vast majority of this information is spatial. Also, all preventive measures are based on detailed spatial analysis, in which entering spatial data from different data sources and different institutions. It is, therefore, necessary draft procedures and arrangements to ensure efficient work with spatial data in national security, dealing with emergencies and working in crisis management.

Analysis of the assumptions, preventive measures, operational procedures and revitalizing activity events related to internal security of the state, with natural and anthropogenic emergencies and crisis situations require flawless and legislative procedures and measures. The synergy of experts involved in the analysis and creation of legislative procedures and action is the basis of a global space for the effective operation of the competent authorities, organizations, constituents and people in emergency and crisis situations. To reduce the risk of threats to lives and health of the population and destruction of the environment, a new geoinformatic approaches (such as spatial models and simulation, network analysis, and querying spatial databases) and geoinformation technologies (GIS, GPS, map servers, drones, and mobile applications) play the irreplaceable role.

Geoinformation technologies are integrated into traditional processes and datasets. Therefore, their efficient use contributes to the internal security of the state. Over the last 20 years of active development of geoinformatics and geoinformation technologies in fields dealing with natural and anthropogenic disasters, particularly preference problems of crisis management, improved the quality of datasets, methodologies, calculations and map visualizations. To protect the population, public health, infrastructure, integrated rescue system and for the sustainable development of the whole society in all developed countries of the world are spatial analysis one of the key determinants.

Nowadays, unfortunately, many institutions and organizations involved in crisis management and ensuring the safety of citizens and the state seem not work effectively with spatial data, which are nevertheless the basis for successful crisis management, analysis, and the resulting measures. The effort of many projects in separate states or unions is to solve this situation by the design of appropriate procedures that will lead to the proper publishing and distribution of spatial data and their subsequent efficient use.

The European Union establishes a program of education in modern methods of crisis management through workshops, seminars and pilot projects. The Observation Centre was established for this purpose (EU Monitoring and Information Centre). The common communication and information system for emergency cases was established. The detection and alerting system, the support system in public transportation use, the support and cooperation system in consulting assistance for EU citizens were founded. This framework, based on the foundations in the end of 2013, has to connect to a modern information platform, existing and used not only by the headquarters of the EU, but also its Member States within the 2020 strategy.

The first initiatives and cooperation between the countries in the spatial data exchange and continuity goes back to the beginning of the 1990s. Nowadays European Directive INSPIRE (Infrastructure for Spatial Information in Europe) is crucial for cross-border cooperation. Its implementation solves most problems of spatial data continuity, even from a legislative perspective and semantic harmonization. INSPIRE aims to create a European legislative framework for building a European spatial data infrastructure, and it also establishes the general rules for the establishment of a European spatial data infrastructure to support environmental policies.

If any national platform should be successfully bound to the European structure and on its completion in the UN (via UNOCHA), all methodical, scientific, instrumental and real means must be used to support the prevention against crisis situations caused by natural and human factors.

The authors were involved in the publishing of two methodologies that are the input key to solving the problems of copyright in the Czech Republic. The authors also develop activities to the copyright applications in security research. Figure 5 shows an example of the practical importance of the open data and licences availability in crisis management. State institutions publish data with different licenses—some datasets are open, some are partially open (for example under Creative Commons licence) and some are available under individually formed licences. During data processing, it is really difficult to combine this data so that it meets all licensing requirements. In fact, it is possible to use only selected data, which is very limiting. Restrictions may also be caused on the side of the underlying (topographical) data. If there were all licenses at the same level of copyright protection and would be compatible, it would be possible to perform more analyses and create much more new cartographic works. Crisis management needs to use all the data sources that are available at all institutional levels. It is, therefore, necessary to unify all data licences in the future.

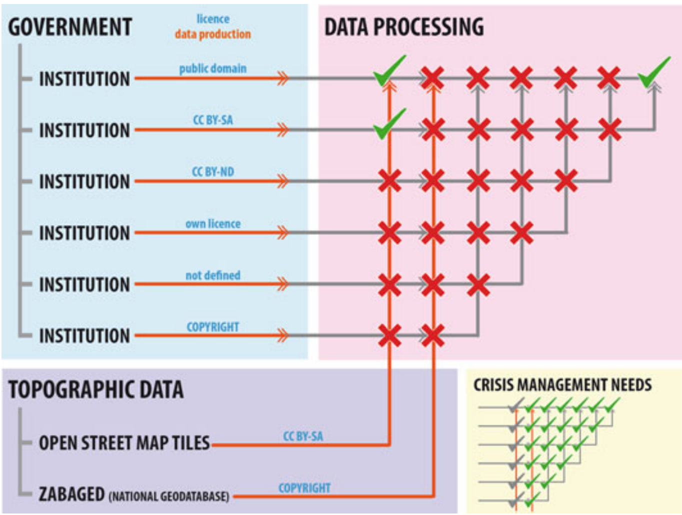

Fig. 5 Illustration of relations between different data licences

6 Conclusion

Intellectual property is crucial in the era of the information society. Often the debate over the appropriate scope of intellectual property protection for spatial data and geodatabases ignores the role of cartography and spatial data uniqueness in the setting of the rights. The law essentially requires the authorization to apply the right to use a work to another person, but there are possible arrangements and licensing agreements where no such authorization is needed and open data are trend in contemporary society. Therefore, knowledge of licensing becomes essential for the process of contemporary cartographic production.

Due to the territoriality of copyright protection, it is crucial to understand the specific licence terms and conditions. The uniqueness of spatial data compared to other information, is that it is often necessary to combine different data sources. Moreover, it is the combination of the various data sources that often cause a problem because of the requirement for separate licences.

The availability of data and their use is important in any area of human activity. Mostly this issue is addressed in the context of crisis situations. In the crisis management, the availability of accurate spatial data is essential. It is important that data can be used efficiently for finding the right solution. Accessing data under definite, open and mutually compatible licence is the best possible step for the future.

Acknowledgment This contribution was implemented within project “Increasing of effectiveness of copyright protection in cartography and geoinformatics” TD020320, co-financed by Technology Agency of the Czech Republic. The authors also gratefully acknowledge the support by the Operational Program Education for Competitiveness—European Social Fund, project CZ.1.07/2.3.00/20.0170 of the Ministry of Education, Youth and Sports of the Czech Republic.

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Part IV
Projection, Cartographic Heritage and Education

Some Remarks on the Question of Pseudocylindrical Projections with Minimum Distortions for World Maps

János Györffy

Abstract The chorographic world maps cannot go missing from the atlases for the general public and for schools. Among other requirements, their map distortions are usually expected to be minimal. In the aphylactic projections both the angular and area distortions can be reduced by the principle of "balance of errors". Equations for the mapping functions help us to search pseudocylindrical projections showing minimum distortions according to the Kavrayskiy criterion, while the outline shape of the mapped Earth is monitored. Some of the best solutions are demonstrated in this paper.

Keywords "Minimum-error" projection · Aphylactic projection · Pseudocylindrical projection

1 Introduction

The small-scale planar representation of the known world, the "Oekumene" means a problem of mathematical cartography for two thousand years in retrospect. These days such maps also appear in the atlases for the general public and for schools. The traditional expectations which were set up in the course of the history of cartography—let the representation be symmetric, similar to the curved Earth surface, and have small map distortions (Klinghammer 2015)—resulted in numerous solutions. Small-scale world maps are not appropriate to measure the size of various map objects—lengths, angles and areas—because of the occasional strong *map distortions*, as their main target—to illustrate some geographic phenomena—is unfavourably influenced by them.

To select the projection for a world map, the most important characteristics are its *distortion* and *graticule* features. The oldest distortion requirement is to preserve the distances as much as possible; this is an optional aspect for the chorographic

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_16

world maps in our days (Gott et al. 2007), though some Google global map services underplay its importance. The distortion property of *equivalency* and *conformity* turned up far later, and mainly the previous one occurs in thematic world maps (Gede 2011). If none of them is required, but both are allowed, we turn to *aphylactic* (neither conformal nor equal-area) projections. From the point of view of the map graticule, on the basis of other cartographical considerations, the *pseudocylindrical* projections (where the map graticule consists of parallel straight lines as lines of latitude, and some arbitrary lines as meridians) have a decisive importance.

2 The Reduction of the Distortions

2.1 The "Balance of Errors"

Let us investigate the minimizing of distortions of the aphylactic pseudocylindrical projections. We disregard from the minimization of linear distortions, and apply the principle of "balance of errors" (Airy 1861). It prescribes the simultaneous decreasing of area and angular distortions, starting from the fact that these distortions can be eliminated separately, but decreasing either of them causes increasing the other, and conversely. The "error" means distortion, and the phrase "balance of errors" should be read as balance of distortions. That is, if the quotient between sizes of the correspondent planar and earth object equals 1, then the measure of deviation turning up in the course of mapping equals zero, and this distortion rises together with the measure of both magnification and reduction of the object.

It is not sufficient to determine this distortion in some allotted points of the map. The *mean distortion* of the points of the territory to be represented will be minimized (principle of *variation*).

If both area and angular distortions can be moderated in accordance with the "balance of errors", the linear distortions will be diminished too, because both distortions contribute to it (see the note in Sect. 2.2). Moreover, as both distortions deform the shape of Earth objects—the equivalency by stretches, and the conformity by areal disproportions—their reduction assists the *similarity* of the map. The other aspect of similarity refers to the outline of the mapped Earth as a whole. A world map should have to reflect its spherical shape, where the way of the pole representation has an importance, too. If the pole is mapped as a single *point* ("pointed-polar projection"), then the Earth can be represented in an oval contour, which is nearer to the view of geography. On the contrary, the projections picturing the pole as a line ("flat-polar projection") can be described mathematically mostly more simply, they are more favourable from the point of view of the aggregate distortions, but the interpretation of the map needs some abstraction, and the shape of the outline less reminds us of the Earth sphere.

The types of pseudocylindrical projections that can be taken into account here, differ in the local linear scale *along the parallels*. By the generally used ones this local linear scale does not vary as we are running mentally along the map parallels (property of *equidistancy*). Note that the parallels of equal-area pseudocylindrical projections should be inevitably equidistant, and what is more, the great majority of aphylactic ones possesses this property. (A counter-example is the Baranyi IV projection applied in many Hungarian atlases and other maps, where the distances along the map parallels with the same longitude differences decrease according to a given function while we are rolling away from the midmeridian, so the distribution of local linear scale along the parallels has the same pattern for every lines of latitude.) Moreover, a pseudocylindrical projection with parallels of varying local linear scale on different ways can be theoretically imagined too, but such a projection does not occur in practice.

2.2 The Calculation of Distortions for Pseudocylindrical Projections

We applied the Kavrayskiy version of the principle of "balance of errors" for the investigation of aphylactic pseudocylindrical projections, denoted the mapping functions ("projection equations") by $x(\varphi, \lambda)$ and $y(\varphi)$, which assign the map coordinates x, y to the geographical coordinates φ, λ of the Earth points. (The coordinate y does not depend on the longitude λ because of the parallel straight lines for the lines of latitude.) According to this, the maximal and minimal local linear scale a and b (Canters 2002) will be utilized, which can be calculated in every point of the map prepared in pseudocylindrical projections by the following formulae, using the partial derivatives of the projection equations:

$$a = \frac{\sqrt{\left(\frac{\frac{\partial x}{\partial \lambda}}{\cos\varphi}\right)^2 + \left[\left(\frac{\partial y}{\partial \varphi}\right)^2 + \left(\frac{\partial x}{\partial \varphi}\right)^2\right] + 2\cdot\frac{\frac{\partial x}{\partial \lambda}\cdot\frac{\partial y}{\partial \varphi}}{\cos\varphi}} + \sqrt{\left(\frac{\frac{\partial x}{\partial \lambda}}{\cos\varphi}\right)^2 + \left[\left(\frac{\partial y}{\partial \varphi}\right)^2 + \left(\frac{\partial x}{\partial \varphi}\right)^2\right] - 2\cdot\frac{\frac{\partial x}{\partial \lambda}\cdot\frac{\partial y}{\partial \varphi}}{\cos\varphi}}}{2} \tag{1}$$

and

$$b = \frac{\sqrt{\left(\frac{\frac{\partial x}{\partial \lambda}}{\cos\varphi}\right)^2 + \left[\left(\frac{\partial y}{\partial \varphi}\right)^2 + \left(\frac{\partial x}{\partial \varphi}\right)^2\right] + 2\cdot\frac{\frac{\partial x}{\partial \lambda}\cdot\frac{\partial y}{\partial \varphi}}{\cos\varphi}} - \sqrt{\left(\frac{\frac{\partial x}{\partial \lambda}}{\cos\varphi}\right)^2 + \left[\left(\frac{\partial y}{\partial \varphi}\right)^2 + \left(\frac{\partial x}{\partial \varphi}\right)^2\right] - 2\cdot\frac{\frac{\partial x}{\partial \lambda}\cdot\frac{\partial y}{\partial \varphi}}{\cos\varphi}}}{2} \tag{2}$$

(They give the semi-major and semi-minor axes of the Tissot indicatrix on the other hand.) From this quantities the local overall distortion ${\varepsilon_K}^2$ can be got by the formula established by Bayeva (1987)

$$\varepsilon_K{}^2 = \frac{\ln^2(a/b) + \ln^2(a \cdot b)}{2}$$

where the changes in angles are characterized by the quotient

$$a/b$$

and the area scales p are characterized by

$$p = a \cdot b;$$

furthermore, the angular and area distortions are given one after the other by

$$\ln^2(a/b)(\geq 0) \quad \text{and} \quad \ln^2(a \cdot b)(\geq 0)$$

It is well-known from the general theory of the map distortions (Canters 2002) that in case of conformity or equivalency in the first and second term of the numerator in the formula of the local overall distortion $\varepsilon_K{}^2$, the following formulae come true one after the other:

$$a/b = 1\,(\text{conformity}) \quad \text{or} \quad p = a \cdot b = 1\,(\text{equvivalency})$$

so

$$\ln^2(a/b) = 0 \quad \text{or} \quad \ln^2(a \cdot b) = 0.$$

In the points where both area distortion and change in angles occur, both terms are positive, but their sum is not necessarily greater than the sum in points possessing the property of conformality or equivalency, where one of the addends equals zero. The quantity local overall distortion $\varepsilon_K{}^2$ is twice as much as the quantity given by the Airy-Kavrayskiy index number of distortion (Kavrayskiy 1958)

$$\frac{1}{2} \cdot \left[\ln^2(a) + \ln^2(b)\right]$$

(Note: the local linear scale l at any point of the sphere surface in a particular direction can be calculated by the formula

$$l = \sqrt{a^2 \cdot \cos^2 \upsilon + b^2 \cdot \sin^2 \upsilon} = \sqrt{p \cdot a/b \cdot \cos^2 \upsilon + \frac{p}{a/b} \cdot \sin^2 \upsilon}$$

where υ is the angle between the direction of the maximal local linear scale and the direction in question on the Earth surface. The second expression shows the dependency of the local linear scale l on both the area scale p and the quotient *a/b* characterizing the changes in angles, beyond the dependency on the direction υ.)

The average ${E_K}^2$ of the local overall distortions (the mean overall distortion) is usually calculated in the representation of the Earth territory T by the formula

$${E_K}^2 = \frac{1}{\mu(T)} \iint_T \varepsilon_K^2 dT$$

(the so called *Airy-Kavrayskiy criterion*, Frančula 1971), where the surface integral represents the aggregated local overall distortions ${\varepsilon_K}^2$ depending on the mapping functions $x(\varphi, \lambda)$ and $y(\varphi)$, too, and the division by the size (surface area) of the territory T denoted by $\mu(T)$ means the averaging. A projection is considered to be the best ("minimum distortion") in a family of map projections, if its Airy-Kavrayskiy criterion ${E_K}^2$ is minimal. In the case of world maps the spherical Earth will be mapped, therefore the surface integral in the Airy-Kavrayskiy criterion goes to a double integral, and the distortions of points in a 5° environment of poles on the spherical Earth is not taken into account (Frančula 1971). So the final formula for the ${E_K}^2$ is:

$${E_K}^2 = \frac{1}{2 \cdot \sin 85^\circ} \cdot \int_{-85^\circ}^{85^\circ} \int_{-180^\circ}^{180^\circ} \varepsilon_K^2 \cdot \cos\varphi \, d\lambda \, d\varphi$$

Through calculating the Airy-Kavrayskiy criterion for more world maps constructed in different projections, these projections can be compared in respect of their mean overall distortion.

2.3 The Minimization of Distortions for Pseudocylindrical Projections

Let us denote by f the function $\varepsilon_K^2 \cdot \cos\varphi$ to be integrated, and additionally introduce the following denotations for the partial derivatives of mapping functions $x(\varphi, \lambda)$ and $y(\varphi)$:

$$y_\varphi = dy/d\varphi, \; x_\varphi = \partial x/\partial\varphi \quad \text{and} \quad x_\lambda = \partial x/\partial\lambda.$$

According to a theorem of the calculus of variations (see e.g. Gelfand and Fomin 1963), if the ${E_K}^2$ criterion for a projection given by the functions x and y is minimal, then the so called Euler-Lagrange differential equations

$$-\frac{d}{d\varphi}\left(\frac{\partial f}{\partial y_\varphi}\right) = 0 \tag{3}$$

and

$$-\frac{d}{d\varphi}\left(\frac{\partial f}{\partial x_\varphi}\right) - \frac{d}{d\lambda}\left(\frac{\partial f}{\partial x_\lambda}\right) = 0 \tag{4}$$

will be satisfied by the functions $x(\varphi, \lambda)$ and $y(\varphi)$, where the characteristics of the function $f = \varepsilon_K{}^2 \cdot \cos\varphi$ were taken into consideration, too. (The validity of these equations is a necessary condition of the minimality.) So we can look for the projection equations x and y providing the best pseudocylindrical projection according to the Airy-Kavrayskiy criterion by solving the equations above.

2.4 The Solution of Eq. (3) for the Mapping Function y(*φ*)

As the function y, and consequently also y_φ does not depend on the longitude λ, Eq. (3) can be investigated on $\lambda = 0$, that is $x = 0$. Then $x_\varphi = 0$ comes true, so the expressions under the square root are completed squares.

The derivative of function $\partial f / \partial y_\varphi$ equals zero, thus

$$\frac{\partial f}{\partial y_\varphi} = const \tag{5}$$

Let us denoted by h the local linear scale along the parallels:

$$h = \frac{\partial x}{\partial \lambda} \cdot \frac{1}{\cos\varphi},$$

then the numerator of the derivative of function $f = \varepsilon_K{}^2 \cdot \cos\varphi$ with respect to y_φ is:

$$2 \cdot \left[\ln\left(\frac{|h + y_\varphi|}{2} + \frac{|h - y_\varphi|}{2}\right) \cdot \left(\frac{|h - y_\varphi|}{2} \cdot (h + y_\varphi) + \frac{|h + y_\varphi|}{2} \cdot (y_\varphi - h)\right)\right.$$
$$\left. + \ln\left(\frac{|h + y_\varphi|}{2} - \frac{|h - y_\varphi|}{2}\right) \cdot \left(\frac{|h - y_\varphi|}{2} \cdot (h + y_\varphi) - \frac{|h + y_\phi|}{2} \cdot (y_\varphi - h)\right)\right] \cdot \cos\varphi$$

It equals zero in both cases of $h \geq y_\varphi$ and $h < y_\varphi$ if

$$y_\varphi = 1,$$

so the constant in Eq. (5) equals zero. Thus the solution of this equation satisfying the projection requirements is:

$$y = \varphi,$$

which means the *true scale midmeridian*, irrespectively of the function $x(\varphi, \lambda)$ and the territory to be represented. (The direct method applied to the minimizations supports this solution.)

This result, whose analogy for cylindrical projections was demonstrated earlier (Györffy 1990), seems trivial and corresponds with the several hundred-year old consensus of the practical cartography from Apianus on, since the generality of aphylactic pseudocylindrical projections uses this projection equation y. However, there are some projections differing from this model applied in practice: e.g. the Eckert III and V

$$(y = 0.844476 \cdot \varphi \quad \text{and} \quad y = 0.8820255 \cdot \varphi),$$

Robinson [in the approach of Beineke (1991)]

$$\left(y = 0.96047 \cdot \varphi + 0.00857 \cdot |\varphi|^{6.41} \cdot sign(\varphi)\right),$$

or Baranyi IV (Baranyi and Györffy 1989)

$$(y = -0.001639406 \cdot \varphi^9 + 0.01560242 \cdot \varphi^7 - 0.0538964 \cdot \varphi^5 + 0.073880 \cdot \varphi^3 + \varphi).$$

We can state that these projections are not qualified as one of "minimum distortions" according to the "balance of errors" on the basis of the information mentioned above.

2.5 Approximative Solution of Eq. (4) for the Mapping Function x(φ, λ)

The solution of the second order differential Eq. (4) is even numerically lengthy. Therefore, we acted upon a procedure that directly minimizes the criterion by determining of the parameters of relatively simple approximative functions.

The starting point is a pseudocylindrical projection with true scale midmeridian, and we might use its projection equation x as the product function

$$\left[1 - \left(\frac{2 \cdot |\varphi|}{\pi}\right)^{c_2}\right]^{\frac{1}{c_3}} \cdot \lambda$$

where the coefficients c_2 and c_3 regulate the running down of the meridian arcs on the map. It results in equidistant parallels and a true scale Equator. (Specifically the case of $c_2 = 2$ and $c_3 = 2$ gives the extension of the well-known Apian II projection with elliptic meridians which is just acceptable in respect of its distortions, but it is more favourable in the view of the similarity of the Earth.) In addition two modifications were put in:

(a) This product function can be multiplied by an even degree polynomial of the geographic latitude φ in order to reduce the value of the criterion. (b) A further multiplication of the product by an even degree polynomial of the geographic longitude λ allows a varying linear scale along the parallels.

To get the Airy-Kavrayskiy criterion $E_K{}^2$, the Earth sphere was divided into geographical quadrangles of $1° \times 1°$, and the local overall distortion $\varepsilon_K{}^2$ was calculated in the intersection points of this network. The double integral of the function $f = \varepsilon_K{}^2 \cdot \cos\varphi$ was approximated by the Simpson's rule. The numerical values for the coefficients c_i of the projection equation x were obtained with the help of the downhill simplex minimization method.

The outline of the mapped image of the Earth is disadvantageous from the aspect of similarity, if its *curvature* (the reciprocal of the radius of the osculating circle) varies extremely in the environment of the poles, therefore it was checked in course of reduction of $E_K{}^2$, too. Because of the choice of $y = \varphi$, the projection equation $x(\varphi, \lambda)$ can be considered a function of y and λ. In case of $\lambda = \pi$ the function x depends only on y, and its graph provides the eastern outline. Then the formula for the curvature κ of the outline depending on y, known from the differential geometry:

$$\kappa = \frac{\left|\frac{\partial^2 x}{\partial y^2}\right|}{\left[1 + \left(\frac{\partial x}{\partial y}\right)^2\right]^{3/2}}$$

The resulted parameters of the projection equations, their Airy-Kavrayskiy criterion and the curvature limit κ of the outline in the neighbourhood of the poles were calculated for several increasingly difficult types of projections and the preferably decreasing criterion values.

3 Numerical Results

The following features and results concerning the reviewed minimum-distortion projections are collected hereinafter: projection equations and their parameters, the distortion character of the parallels, the mean overall distortion $E_K{}^2$ according to the Airy-Kavrayskiy criterion and the curvature κ of map outline of the Earth in the pole and in the point having the geographical latitude of 85°. Furthermore some favourable projection graticule variations are displayed on figures with the distribution of area scales p:

$$p = a \cdot b$$

and maximum angular deformations 2ω:

$$2\,\omega = 2 \cdot \arcsin\left(\frac{a-b}{a+b}\right) = 2 \cdot \arcsin\left(\frac{a/b-1}{a/b+1}\right)$$

(The latter often characterizes the change in angles instead of *a/b*.)

0. Apianus II projection with elliptic meridians

The projection equations:

$$x = \sqrt{1 - \left(\frac{2 \cdot \varphi}{\pi}\right)^2} \cdot \lambda$$

$$y = \varphi$$

The parallels are equidistant.

$E_K{}^2 = 0.21609$

$\kappa_{\pm 90^\circ} = 0.159$, $\kappa_{\pm 85^\circ} = 0.181$

1. keeping $c_2 = 2$ and $c_3 = 2$ in the general x, and multiplying it by a polynomial of φ (Fig. 1)

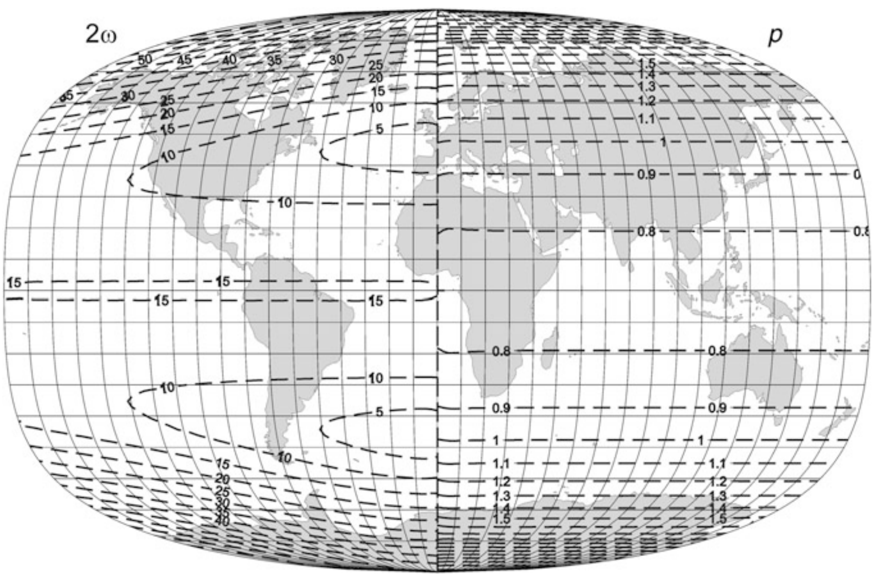

Fig. 1 The isolines of the maximum angular deformation 2ω (°) and the area scale *p*

The projection equations:

$$x = c_1 \cdot \left(1 + c_5 \cdot \varphi^2\right) \cdot \sqrt{1 - \left(\frac{2 \cdot \varphi}{\pi}\right)^2} \cdot \lambda$$

$$y = \varphi$$

where c_1 = 0.768, c_5 = 0.170
The parallels are equidistant.
$E_K{}^2$ = 0.13522
$\kappa_{\pm 90°}$ = 0.134, $\kappa_{\pm 85°}$ = 0.221

2. **keeping c_2 = 2 and c_3 = 2 in the general x, and multiplying it by a polynomial of φ and an other polynomial of λ**
   The projection equations:

$$x = c_1 \cdot \left(1 + c_5 \cdot \varphi^2\right) \cdot \sqrt{1 - \left(\frac{2 \cdot \varphi}{\pi}\right)^2} \cdot \left(\lambda + c_4 \cdot \lambda^3\right)$$

$$y = \varphi$$

   where c_1 = 0.734, c_4 = 0.0052, c_5 = 0.160
   The parallels are divided according to the same pattern.
   $E_K{}^2$ = 0.13339
   $\kappa_{\pm 90°}$ = 0.137, $\kappa_{\pm 85°}$ = 0.223

3. **varying the exponent c_2 and keeping c_3 = 2 in the general x, and abandoning the true scale property of the Equator**
   The projection equations:

$$x = c_1 \cdot \sqrt{1 - \left(\frac{2 \cdot |\varphi|}{\pi}\right)^{c_2}} \cdot \lambda$$

$$y = \varphi$$

   where c_1 = 0.760, **c_2 = 4.39**
   The parallels are equidistant.
   $E_K{}^2$ = 0.13665
   $\kappa_{\pm 90°}$ = 0.125, $\kappa_{\pm 85°}$ = 0.210

4. **varying the exponent c_2, keeping c_3 = 2 in the general x, and multiplying it by a polynomial of λ** (Fig. 2)
   The projection equations:

$$x = c_1 \cdot \sqrt{1 - \left(\frac{2 \cdot |\varphi|}{\pi}\right)^{c_2}} \cdot \left(\lambda + c_4 \cdot \lambda^3\right)$$

$$y = \varphi$$

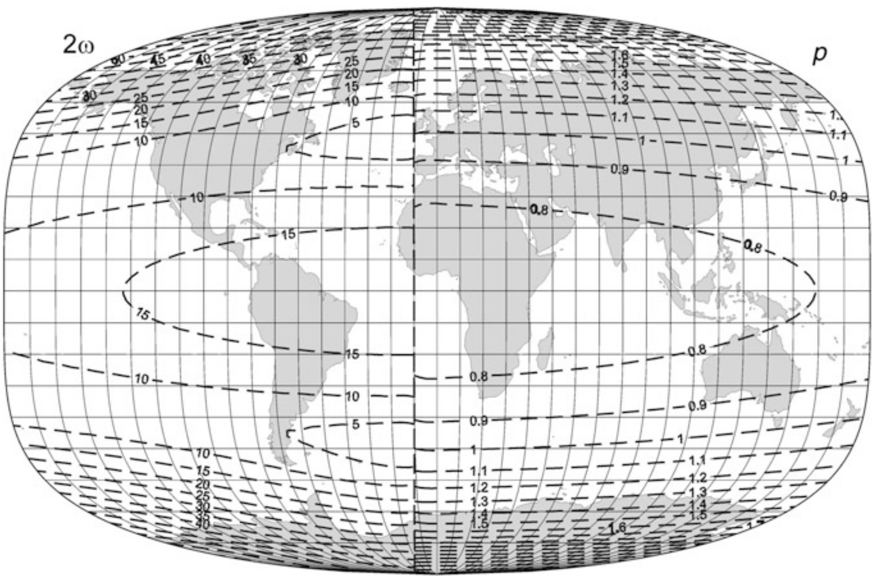

Fig. 2 The isolines of the maximum angular deformation 2ω (°) and the area scale *p*

where $c_1 = 0.731$, $\boldsymbol{c_2 = 4.21}$, $c_4 = 0.0046$
The parallels are divided according to the same pattern.
$E_K{}^2 = 0.13510$
$\kappa_{\pm 90^\circ} = 0.129$, $\kappa_{\pm 85^\circ} = 0.211$

5. **varying each of the exponents c_2 and c_3 in the general x, and abandoning the true scale property of the Equator**
The projection equations:

$$x = c_1 \cdot \left[1 - \left(\frac{2 \cdot |\varphi|}{\pi}\right)^{c_2}\right]^{1/c_3} \cdot \lambda$$

$$y = \varphi$$

where $c_1 = 0.779$, $\boldsymbol{c_2 = 1.70}$, $\boldsymbol{c_3 = 5.13}$
The parallels are equidistant.
$E_K{}^2 = 0.12432$
$\kappa_{\pm 90^\circ} = 0.0$, $\kappa_{\pm 85^\circ} = 0.738$

6. **varying each of the exponents c_2 and c_3 in the general x, and multiplying it by a polynomial of λ** (Fig. 3)

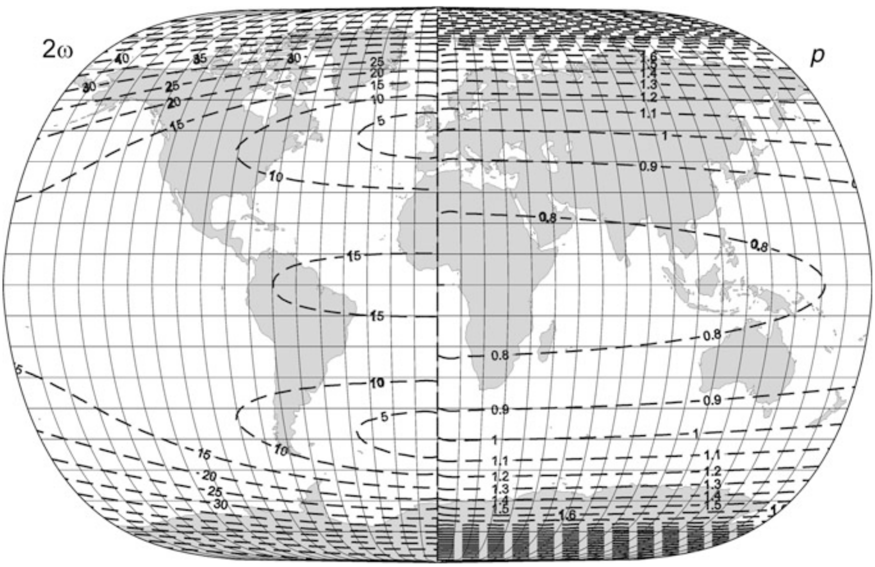

Fig. 3 The isolines of the maximum angular deformation 2ω (°) and the area scale *p*

The projection equations:

$$x = c_1 \cdot \left[1 - \left(\frac{2 \cdot |\varphi|}{\pi}\right)^{c_2}\right]^{1/c_3} \cdot \left(\lambda + c_4 \cdot \lambda^3\right)$$

$$y = \varphi$$

where $c_1 = 0.762$, $\boldsymbol{c_2 = 1.67}$, $\boldsymbol{c_3 = 5.18}$, $c_4 = 0.0026$
The parallels are divided according to the same pattern
${E_K}^2 = 0.12379$
$\kappa_{\pm 90^\circ} = 0.0$, $\kappa_{\pm 85^\circ} = 0.745$.

4 Conclusion

World map representations demanding neither conformity nor equivalency: e.g. global physical or political maps, or maps demonstrating linear phenomena not expanding to the poles (air and ocean currents, transportation) can be found in almost every atlas.

The minimum distortion aphylactic pseudocylindrical projections as demonstrated above always have a true scale midmeridian, and—in connection with the value of c_1—its Equator is diminished by about one-fourth. The changes concerning c_2 and c_3 or the transformation (a) as mentioned above reduce the

Airy-Kavrayskiy criterion ${E_K}^2$ in a significant degree, from 0.216 to about 0.13, and the parallels remain equidistant.

The transformation (b) means the abandonment of the equidistancy of parallels. Because of $c_4 > 0$ the distances with the same longitude differences increase somehow along the map parallels when rolling away from the midmeridian. Meanwhile the mean overall distortion only slightly decreases, and the route of isolines of the area scales marginally alters.

The last projection above have the smallest mean overall distortion, but the outline shape of the mapped Earth can be barely distinguished from an outline of a world map in a flat-polar projection (Snyder 1985). It is caused by the zero curvature limit in the pole and by the strong variance of the curvature in its environment. The other calculated projections are a bit more distorted, but they are more similar to the wanted oval shape.

Summarized: if their distortion and outline properties are taken into consideration, all the projections listed here can be used expediently in the atlas cartography for world maps enumerated above.

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A Semi-automatic Approach for Determining the Projection of Small Scale Maps Based on the Shape of Graticule Lines

Ádám Barancsuk

Abstract Knowing a map's projection is of essential importance, particularly when using them as a source for creating derivative works or dealing with them in a GIS environment. However, (especially on older maps), projection information is often absent or partially present. Our objective is to develop a semi-automated approach for determining the projection of a small-scale map, based on the shape and secondary properties of its graticule lines—as outlined in the hierarchy published by Érdi-Krausz (Studia Cartologica 1:194–270, 1958). To this end, a web-based tool is created, explicitly designed to be usable by a non-professional audience. Drawing tools are provided for manually tracing graticule lines on pre-uploaded raster maps. Given the approximate traces, we employ a number of algorithms to determine the shape and secondary properties (e.g. equidistancy, concentricity, angles of intersection etc.) of graticule lines. Having computed these properties, one can fit the projection into Érdi-Krausz's system.

Keywords Projection analysis · Cartometry · Curve fitting

1 Introduction

Mix-and-matching already existing source maps and combining them to create derivative works is everyday practice in contemporary cartography. This was not always possible: historically, differences between projections among source works often posed major obstacles to such practices. The situation has improved substantially with the advent of GIS and computer-aided map design, that equipped cartographers with tools that now allow them to freely transform source material (both vector and raster datasets) into their projection of choice.

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_17

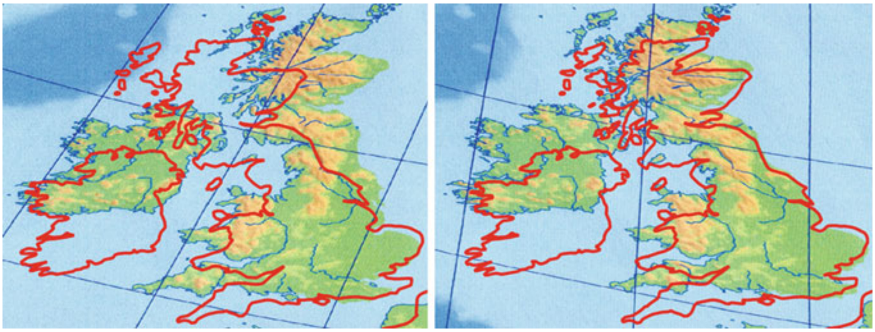

Fig. 1 Suboptimal results of georeferencing using different (global vs. local) interpolation techniques (*left* first order polynomials, *right* thin plate spline rubbersheeting)

How does one integrate datasets with different projections into one's cartographic workflow? This problem is dealt with in a number of different ways in cartographic practice. The most common solution involves ignoring the question of projections and using ground control points (with known coordinates in both a geographic and the dataset's own coordinate system) to associate the dataset with its location in geographic space. This method is called *georeferencing* and is very broadly used.

Georeferencing works by transforming points of the original dataset to new positions, while relying on the position of the ground control points as aid. Thus, georeferencing always involves a form of interpolation (either global or local), the precision of which is heavily dependent on the number and position of ground control points placed by the user. This method, if used improperly, can introduce gross transformation errors (see Fig. 1) that can render badly georeferenced datasets unsuitable for further use as described by Havlicek and Cajthaml (2015).

Another way to deal with the problem is taking the question of projections into account. This method assumes knowledge of both the *original* and the *target* projection to transform the dataset from/into. Compared to ground control point-based georeferencing which relies on points with known geographic *and* projected coordinates, this provides us with a *function* in a mathematical sense which, when applied to the original coordinates of each point, computes its coordinates in the target coordinate system. Such a method thus avoids interpolation and the errors associated with it, often leading to better precision.

However, information on the *original* projection of source works is often absent or only partially present. This is particularly true when using relatively old, printed maps as a source: while digital cartographic data are usually accompanied by metadata including a projection definition, paper-based maps seldom provide such information with sufficient level of detail. (Note, that for the purpose of using maps in a GIS environment, not only the type of projection but also its exact parameters should be known to the user.)

To overcome the problem of determining unknown cartographic projections, this study proposes a semi-automatic approach for making educated guesses regarding the projection of a small-scale map. Our guess does not only serve as an aid for more precise georeferencing but can also provide metadata that might be useful when digitizing and cataloguing cartographic documents in a library.

The method we describe primarily builds on the work of *György Érdi-Krausz* who proposed a system for determining a small-scale map's projection by examining its graticule (geographic grid). This system was first outlined in a study concerned with the analysis of cartographic projections (Érdi-Krausz 1958) then later refined by Györffy (2012). Érdi-Krausz's study describes an algorithm for determining an unknown projection which is modeled as a *decision tree*. The algorithm starts at the tree's root node, ascends the tree by repeatedly branching based on different properties (such as the shape, position, intersections and spacing) of the map's graticules lines, then arrives at one of the leaves containing a specific type of projection.

While Érdi-Krausz's study also describes projection-specific methods that allow the user to compute projection parameters, our research in its current state has a narrower but more practical focus: First, we utilize applied mathematical methods to try and implement Érdi-Krausz's decision tree algorithm on computer. Second, we build a web-based application that helps people determining the projection of a small scale map, who otherwise lack deeper knowledge of cartographic projections.

2 Related Work

Many online tools are available for georeferencing maps, but none of them deals with the question of projections. This may be mainly due to the fact that the problem of determining the projection of maps, then using the resulting information for the purposes of georeferencing has not been studied in great depth historically. Such analysis would have required abundant computing resources that were unavaliable even a couple of decades ago. In the recent years however, several approaches were developed that allow us to make educated guesses about unknown cartographic projections.

According to the author's knowledge, there are three methods that actually solve the problem of determining unknown projections of maps. The first one is an application developed by Snyder (1985). The main focus of Snyder's work is to allow data transfer between two maps in different projections. His algorithm is similar to the one described in this paper in that it also uses a decision tree mechanism to determine the projection type. The list of recognized projections includes the most commonly used ones from every major class (azimuthal, cylindrical, pseudocylindrical and conic) and also includes a second-order polynomial approximation of the projection as a last resort. Unlike our method which works on graticule lines, Snyder's program only takes nine points as its input, which should reside along three meridians and three parallels. Given this information, the program performs a number of measurements on the graticule: it checks whether graticule lines are straight or curved, the spacing of meridians and the concentricity of parallels. Because of it only relies on nine known points, Snyder's algorithm provides a more rudimentary view on the form of the graticule (e.g. it cannot differentiate between different curves). Compared to our approach, however, his program also provides the exact parameters for the projection.

The other two methods are MapAnalyst (described thoroughly by Jenny and Lorenz 2011), and Detectproj, which is developed by Bayer (2014) and seems to provide the most comprehensive solution to the problem to date.

These latter methods, while they differ in important aspects of their implementation, view the problem in a roughly similar way:

- Consider a predefined list of projections and a set of control points (and possibly other, higher dimensional features such as lines and polygons) with coordinates both known in geographic space and the unknown map's own coordinate system.
- Iterate through the list of possible projections. For each projection:
  - Iterate through a range of different projection parameters or apply numerical optimization to traverse the parameter-space towards the best fit:

    Transform the set of control points (and possibly other features) from geographic space into the current projection and parameter set.
    Assess the difference between the set of freshly-transformed features and the set of features on the unknown map.
    Compute some measure that quantifies the goodness of fit (transformation parameters) between the two sets.

- Having found the projection with the highest goodness of fit, report that as the most likely projection for the map.

Our method takes a different approach:

- Consider a set of graticule lines on the unknown map, each defined by an ordered set of its points.
- Traverse the decision tree by on-demand computation of the following properties of the graticule:
  - Best fit **curve type** for the given graticule line (in its current state, our algorithm can distinguish between straight lines, circles, generic ellipses, parabolas and hyperbolas);
  - Position, spacing and angle of intersection at **intersection points**;
  - **Concentricity of the curves** representing graticule lines;
  - **Representation of poles** (lines or points);
  - **Closedness of curves**.

These differences result in a number of advantages and disadvantages when compared to the former two algorithms:

- We found the decision tree traversal method to be faster (5–10 s for the whole graticule) than Detectproj iterating through a set of projections (couple of minutes). This may also be due to the fact that our method of choice for numeric optimization takes derivatives into account which results in faster convergence.
- Our method in its current form is unable to take different aspects and projection parameters into account. While this lets us focus on a subset of projections that are of actual cartographic importance (without having to deal with existent, but rarely used variants), it also severely narrows the feasibility of our method. This also means we cannot easily quantify the goodness of fit of our solution or offer multiple possible choices sorted by that measure.
- To extend our method with new projections, one has to fit the given projection into Érdi-Krausz's system. This is possible but far from straightforward. To be extended, the previously discussed methods only require the projection's mathematical formulation to be known.

3 Mathematical Foundations

As mentioned above, the primary goal of our research is to automate the computations needed to traverse the decision tree of Érdi-Krausz's system. As an input, the algorithm takes a set of line strings (ordered set of points) that represent a graticule line. In its current state, the application requires the user to manually trace the graticule lines on the previously uploaded raster map.

3.1 Homogeneous Coordinates

Throughout the application we use *homogeneous coordinates* to represent points. Homogeneous coordinates are coordinate vectors used in projective geometry. One advantage of homogeneous coordinates is that they allow us not only to represent points of Euclidean spaces but also points at infinity. They are also widely relied upon in computer graphics as they allow formulas of affine (or more generally, projective) transformations to be represented as matrix operations. We use them because they allow us to formulate relationships between points and curves of our graticule more easily than it would be possible with Euclidean coordinates.

Given a point (x, y) on the Euclidean plane and for any $z \in \mathbb{R} \setminus \{0\}$, the homogeneous coordinate-vector of the point can be written as (xz, yz, z).

3.2 Curve Fitting

Traces of graticule lines drawn by the user inherently has a small amount of error introduced by the limited accuracy of the original maps and also the tools provided for drawing. This means that no straight line, conic section or other mathematically representable quadratic curve can be fit to these points exactly.

Both curve fitting problems we consider in this section can be formulated as the solution of a system of N equations in the form of

$$f(x_i, \boldsymbol{p}) = 0$$

where $x_i (i = 1 \ldots N)$ are coordinate vectors of the points to be fit and $\boldsymbol{p} \in \mathbb{R}^M$ is the unknown vector of parameters of the curve in question. Such a system is said to be *overdetermined* when $N > M$, meaning it consists of more equations than the number of unknowns. This is usually the case when fitting user-drawn traces of a couple dozen points to lines or conic sections defined by either 3 or 5 parameters.

The above mentioned two circumstances makes curve fitting an optimization problem. As such, we have to find a method that provides an approximate solution to our problem, characterized by some minimal measure of error.

A possible definition of error is a vector of corrections (or deviations) $\boldsymbol{r} \in \mathbb{R}^N$ such that, when applied to the original system $f(\boldsymbol{x}, \boldsymbol{p}) = 0$ it is transformed into $f(\boldsymbol{x} + \boldsymbol{r}, \boldsymbol{p}) = 0$, which now has an actual solution. Thus our goal is to find some vector $\boldsymbol{p}$ for which the error measure $\boldsymbol{r}$ is minimal. As is customary in statistics, we choose to optimize the square of errors which leads us to the optimization problem:

$$\min \sum_{i=1}^{N} \|r_i\|^2$$

This is the method of *least squares*, that is the most frequently used method in regression analysis for finding approximate solutions to overdetermined systems.

In our application we utilize a two-pass least-squares fitting algorithm to try and fit straight lines and conic sections to the points of traces drawn by the user. This algorithm is run on each graticule line separately. First, the algorithm tries to fit a straight line to the given set of points (see Sect. 3.2.1). If the error of this fit is lower then a predefined numeric tolerance, the fit is accepted and the line is considered to be straight. The second, conic fitting stage (see Sect. 3.2.2) is only performed if straight line fitting fails (the error is higher than the given tolerance). After conic fitting is performed, the goodness of the second fit is again compared to another numeric tolerance. If both stages fail (both errors are above the respective tolerances), the application considers the graticule line to be of an unknown curve type and excludes it from further processing (i.e. no secondary properties are computed on these lines). If either of the fitting passes succeed, the result is a parameter vector of the best fit straight line or conic section, that is associated to the graticule line.

The later stages of our program only use these parameter vectors to represent the graticule lines.

Theoretically, a single-pass fitting algorithm would also be possible, because a straight line is just a special (degenerate) case of a conic section. However, fitting degenerate conic sections proved to be numerically unstable in practice.

3.2.1 Line Fitting

On the Euclidean plane, a line may be formulated as $y = ax + b$ (the so-called slope-intercept form). This form however does not allow us to represent vertical lines which are ubiquitous when dealing with map graticules. To overcome this limitation, we use the line equation from projective geometry, $ax + by + c = 0$ which can also be represented with the three-element homogeneous coordinate-vector (a, b, c). Note that in the two dimensional projective space, the same coordinate-triple may be used to represent either points or lines. This leads to the notion of *duality* in projective geometry.

Given the line $\boldsymbol{l} = (a, b, c)$ and the point $\boldsymbol{p} = (x, y, 1)$, said point lies on the line when it satisfies the equation $ax + by + c = 0$ of the line. This can also be written using homogeneous coordinates as $\boldsymbol{pl} = 0$.

Our goal is to find a line that fits best to the points of the user-drawn trace of a graticule line. Given N trace points this yields a system A of N linear equations in the form mentioned above.

$$A = \begin{pmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ \vdots & \vdots & \vdots \\ x_N & y_N & 1 \end{pmatrix}$$

Given the above the problem of line fitting in projective two-space can be formulated as the equation $A\boldsymbol{x} = 0$ where $\boldsymbol{x} \in \mathbb{R}^3$ represents the coordinate triple of the solution line.[1]

To obtain the solution we consider the singular value decomposition (SVD) of the matrix A. The singular value decomposition is a factorization in the form

$$A = U\Sigma V^T$$

which can be proven to exist for all real matrices $R \in \mathbb{R}^{N\times M}$ (Bast 2004). The product on the right hand side consists of the unitary matrices $U \in \mathbb{R}^{N\times N}$ and $V \in \mathbb{R}^{M\times M}$ (called the collection of left and right singular vectors), and the $\Sigma \in \mathbb{R}^{M\times N}$ rectangular diagonal matrix, the elements of which are all zeroes except for

[1]Every homogeneous linear system A is satisfiable by the trivial solution $\forall x \in \boldsymbol{x} = 0$. They have non-trivial solutions only if $\mathrm{rank}(A) < N$.

the values $\sigma_1 > \sigma_2 > \cdots > \sigma_n > 0$ in its main diagonal. The vector composed from the biggest elements of the right-singular vectors

$$\boldsymbol{x} = \left\{ V^T_{m,1}, V^T_{m,2}, \ldots, V^T_{m,n} \right\}$$

can be proven (Tomasi 2013) to be the least-squares solution for the system A. In our case, $N = 3$, thus the solution is a vector $\boldsymbol{x} \in \mathbb{R}^3$, which is the parameter vector of the best-fit line in projective space.

3.2.2 Conic Section Fitting

Given

- A number of points in projective 2-space $P = \{p_i\}$ where $p_i = (x_i, y_i, 0)$,
- A group of conic sections $C(\boldsymbol{a})$ where $\boldsymbol{a} \in \mathbb{R}^5$ is the vector of parameters for the conic section,
- And some distance measure $\delta(C(\boldsymbol{a}), x_i)$, describing the distance between $\boldsymbol{x}$ and $C(\boldsymbol{a})$

our aim is to determine the vector of parameters $\boldsymbol{a}_{min}$ for which the least-squares measure of error

$$\epsilon^2(\boldsymbol{a}) = \sum_{i=1}^{n} \delta(C(\boldsymbol{a}), x_i)$$

is minimal.

This problem is well-researched in the field of computer vision and graphics. For an overview of methods for solving it, see Fitzgibbon and Fisher (1995). Most of the techniques consider only a certain type of conic sections (e.g. ellipses, parabolas or hyperbolas), but our use case requires a method that is agnostic on the type of the conic section.

Conic fitting methods can also be characterized based on their choice of distance measure. The most easily computable form of distance is *algebraic distance*. A conic section can be defined as the quadratic form

$$C(\boldsymbol{a}) = a_1x^2 + a_2xy + a_3y^2 + a_4x + a_5y + a_6 = 0.$$

Algebraic distance then can be formulated as

$$\delta(c(\boldsymbol{a}), \boldsymbol{x}) = \boldsymbol{x}^T A_Q \boldsymbol{x}$$

where

$$A_Q = \begin{pmatrix} a_1 & \frac{a_2}{2} & \frac{a_4}{2} \\ \frac{a_2}{2} & a_3 & \frac{a_5}{2} \\ \frac{a_4}{2} & \frac{a_5}{2} & \frac{a_6}{2} \end{pmatrix}$$

The problem with algebraic distance is that it often results in geometrically (visually) inaccurate fits. Therefore, we choose to optimize *orthogonal distance* which is believed to be the most natural choice (Ahn 2004).

Computation of orthogonal distances between points and a general conic is possible, but can be numerically instable. This can either be overcome by using properties that are specific to a type of conic such as rotation, position of the center etc., or by using the method described in Wijewickrema et al. (2010).

To be able to compute the orthogonal distance between a point $\boldsymbol{b}$ and the conic C, the authors choose to solve the system

$$\boldsymbol{x}^T C \boldsymbol{x} = 0$$
$$\boldsymbol{x}^T D \boldsymbol{x} = 0$$

where

$$D = c_1 a_1^T - c_2 a_1^T$$

is another conic section that represents the relationship between C and $\boldsymbol{b}$. Solving the system yields two intersection points. We consider the one closer to $\boldsymbol{b}(\boldsymbol{x})$ to be the orthogonal point of $\boldsymbol{b}$ on C (Fig. 2). The solution of the system leads to a quartic formula. To evade numeric instabilities that emerge when solving the formula, the authors instead choose a method that relies on finding a degenerate conic:

$$C_d = \boldsymbol{l}\boldsymbol{m}^T + \boldsymbol{l}^T\boldsymbol{m}$$

then decomposing it into two straight lines **l** and **m** which allow us to compute the intersection points between either line and the original conic C. This results in two possible intersection points. As mentioned above, we choose the point closer to **b** and consider the distance between **b** and that point to be the orthogonal distance between **b** and C. Having computed the orthogonal distance $\delta(C(\mathbf{a}), \mathbf{b})$, we have to solve the optimization problem

$$\min \sum_{i=1}^{n} \delta(C(\boldsymbol{a}), \boldsymbol{b}_i)$$

for which purpose we choose the Levenberg–Marquardt method as recommended by Wijewickrema et al. (2010). This iterative method requires the calculation of the Jacobian matrix for each step which makes the process robust but more

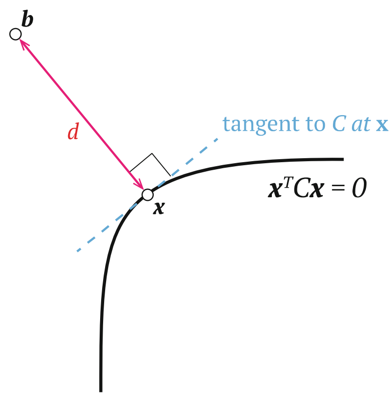

Fig. 2 Orthogonal distance between a conic section and a point

computationally expensive compared to other methods. Reliance on the Jacobian also makes the method insensitive to the choice of initial parameter vector, therefore no prior fitting is required.

3.3 *Curve Intersections*

Having computed the best fit curve for all graticule lines, we also have to obtain the position and angle of their points of intersection. Based on this information we can differentiate between certain members of projection families. (As an example, one might consider either (pseudo)cylindrical or azimuthal projections. In both cases, the change in spacing between lines of latitudes towards the map contour is indicative of distortion conditions.)

3.3.1 Intersection Points

Currently we only consider intersection points between one line of latitude and one line of longitude (but not two lines of latitude or longitude). The remaining two cases always fall into either one of the following categories:

1. The **intersection of two straight lines** defined by their projective coordinates (a_1, b_1, c_1) and (a_2, b_2, c_2) can be found by computing

$$(a_1, b_1, c_1)^T \times (a_2, b_2, c_2)^T$$

2. Assuming that both input triples describe lines that are not in the infinity, the Euclidean coordinates of the intersection point can be inferred from the resulting triple of projective coordinates.

3. The **intersection of a straight line and a conic section** can be computed by first computing the antisymmetric matrix of the line **l**:

$$L = \begin{pmatrix} 0 & -l_3 & l_2 \\ l_3 & 0 & -l_1 \\ -l_2 & l_1 & 0 \end{pmatrix}.$$

Given the above

$$D = L^T CL$$

is a degenerate conic, which represents the intersection points between C and **l**. One can decompose D to obtain these intersection points.

3.3.2 Intersection Angles

The angle between two homogeneous lines is given by

$$\Theta = \cos^{-1}(l_1 m_1 + l_2 m_2)$$

whereas to compute the angle of intersection between a straight line and a conic section, one first has to calculate a tangent line to the conic at the intersection point. This is given by

$$l = Cp^T.$$

Having computed the tangent line, one might obtain the intersection point by intersecting the tangent with the other straight line.

3.3.3 Intersection Spacing

To distinguish between projections with different distortion conditions, the spacing between intersection points also has to be computed. In its current state, the application only considers distances between intersection points lying on a straight line of graticule. Positions of intersections along this line may be characterized by the homogeneous vector-parametric equation of that line:

$$\boldsymbol{P} = \boldsymbol{P}_0 + t\boldsymbol{r}$$

where $\boldsymbol{P}$ is the graticule line, $\boldsymbol{P}_0$ is an arbitrary point along that line, $\boldsymbol{r}$ is the directional vector of the line and $t \in \mathbb{R}$ is a scalar indicating the position of $\boldsymbol{P}$ along the line relative to $\boldsymbol{P}_0$.

Given our lines with the homogeneous triple (a, b, c) and also taking vertical lines into account:

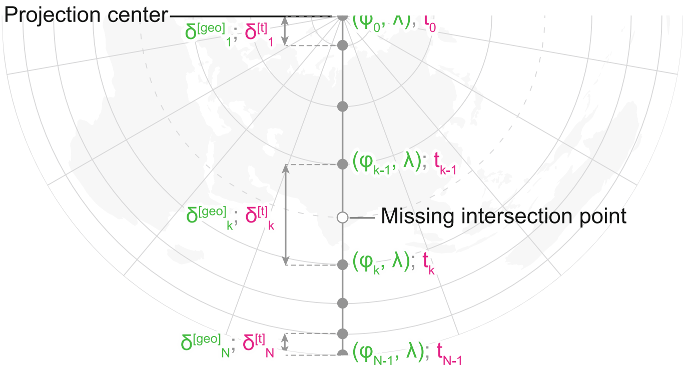

Fig. 3 Computation of the intersection points

$$\boldsymbol{P}_0 = \begin{cases} \left(-\frac{c}{a}, 0\right)^T & \text{if } a \neq 0 \text{ and } b = 0 \\ \left(-\frac{a}{b}, -\frac{c}{b}\right) & \text{otherwise} \end{cases},$$

the directional vector is:

$$\boldsymbol{r} = \begin{cases} (1,0)^T & \text{if } a = 0 \text{ and } b \neq 0 \\ (0,1)^T & \text{if } a \neq 0 \text{ and } b = 0 \\ \left(-\frac{a}{b}, -\frac{c}{b}\right) & \text{otherwise} \end{cases}.$$

and the relative position of the intersection point along the line can be obtained by solving the system defined by the vector parametric equations for t.[2]

To be able to assess how the spacing of intersection points change when moving along a straight graticule line from the projection center towards the map contour, we have to compare changes in geographic coordinates ($\boldsymbol{\delta}^{[\text{geo}]}$) with planar distances (that is, changes in intersection point positions $\boldsymbol{\delta}^{[\text{t}]}$).

One might expect that comparison of values of the parameter t for different intersection points would also be sufficient, but that would rely on the implicit assumption that graticule lines are geographically equally spaced (e.g. every 10°). This is not the case when graticule lines are more densely spaced in an area of the map than in another. The assumption might also be incorrect in a number of other cases. Such an example might be when the curve fitting algorithm fails on a user-drawn trace for some reason, thus intersection points along that curve cannot be computed (Fig. 3).

[2]In the application's current implementation, the solution is obtained by using the '\' (backslash) operator in Julia which is based on a form of QR-factorization (see http://docs.julialang.org/en/release-0.4/stdlib/linalg/#Base).

For obtaining the planar distances we compute:

$$\boldsymbol{\delta}^{[geo]} = \left\{\kappa_j - \kappa_i | \forall i, j \in [1, N] \,\text{and}\, j = i + 1\right\}$$

as well as a vector of changes of the geographic coordinate:

$$\boldsymbol{\delta}^{[t]} = \left\{t_j - t_i | \forall i, j \in [1, N] \,\text{and}\, j = i + 1\right\}$$

where N is the number of intersection points and κ is the respective geographical coordinate (λ when measuring spacing along a line of latitude and φ when measuring spacing along a line of longitude). To compare the two, we look at the geographic differences normalized by planar distances:

$$\boldsymbol{\delta} = \left\{\frac{\delta_i^{[geo]^2}}{\delta_i^{[t]^2}} - i \in [1, N]\right\}.$$

This yields distances that are independent from the geographical spacing of graticule lines on the map. To assess the equidistancy of the intersection points, we compute the coefficient of variation of δ:

$$c_v = \frac{\sigma}{\mu}, \text{ where } \sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \delta_i - \mu^2} \text{ and } \mu = \frac{1}{N}\sum_{i=1}^{N} \delta_i.$$

The coefficient of variation measures the variation of the distribution of the normalized distances, irrespective of the distances' actual values. The spacing of intersection points is considered uniform if c_v is lower than a predefined numeric tolerance.

3.4 Concentricity

To assess whether certain curves of graticule are concentric, one should compute the position of their center points. This helps us differentiate between pseudoconic projections, where curves of latitude are concentric and polyconic projections, where they are not.

Computation of the center point is only done in case of ellipses and hyperbolas. The center point of a generic conic section lies where the gradient of the quadratic form of the conic (see Sect. 3.2.2) vanishes:

$$\nabla C = \left(\frac{\partial C}{\partial x}, \frac{\partial C}{\partial y}\right) = (0, 0).$$

By substituting the partial derivatives into the quadratic form C, we obtain

$$\begin{cases} \frac{a_4}{2} + a_1 x + \frac{a_2}{2} y = 0 \\ \frac{a_5}{2} + \frac{a_2}{2} x + a_3 y = 0 \end{cases}.$$

If the determinant of this system is non-vanishing (i.e. the conic is either an ellipse or a hyperbola), the Euclidean coordinates of the center is given by (x, y) (Wylie 2011). To assess whether conic sections representing graticule lines share the same center, the standard deviation of centers is computed. A numeric tolerance for this value is defined, which, when not exceeded by the standard deviation, indicates the concentricity of graticule lines.

3.5 Representation of Poles

There are a number of ways to determine how poles are represented on the map. For the sake of simplicity, we expect the user to also trace poles when they are represented by lines on the map. In case poles are mapped to points, another drawing tool is provided on the user interface that allow the user to trace these points. When curves of latitude with a coordinate value of $\phi = \pm 90^\circ$ are present, poles are considered to be lines. When points are present, poles are considered to be points. When none or both of the above is true, representation of poles is assumed to be undefined and the property is ignored when traversing the decision tree.

3.6 Closedness

Again, for the sake of simplicity, closedness of curves is computed as the norm of differences between the positions of the first and last point of the corresponding trace along the x and y axis of the viewport coordinate system on which tracing was done.

3.7 Decision Tree

After computing all necessary properties, we can traverse the decision tree to obtain the type of projection (Fig. 4). In its current form the decision tree is implemented as a series of nested conditional branches of program code. This is hard to maintain and is planned to be reimplemented such that projection definitions can be specified declaratively.

When traversing the tree, decisions are often made based on properties of a *group of objects* at once (e.g. "Which type of curve fits best to *all* of our latitude lines?") As the inherent error of user-drawn traces may affect the precision of our algorithms (as seen in Sect. 5.1), they may provide bogus results for certain

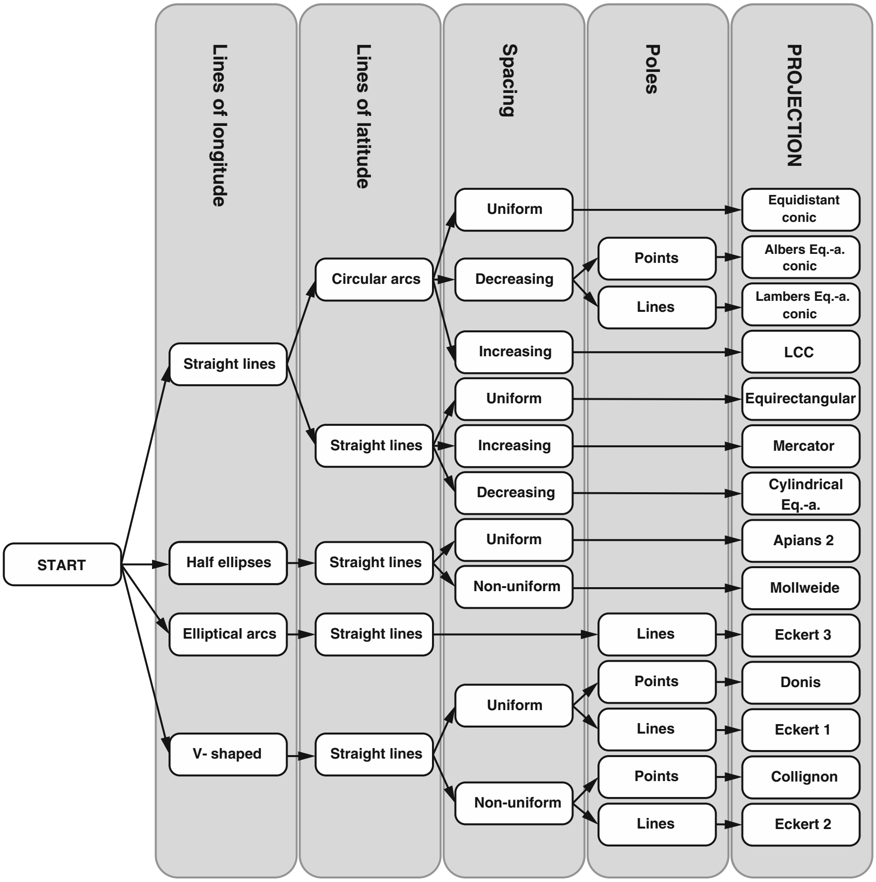

Fig. 4 Excerpt from the decision tree used for categorizing projections (some levels are omitted for clarity)

graticule lines. To compensate for this situation, when inferring a property of a group of objects we calculate said property on each object, then assume the most frequent value in the dataset to be the answer. This allows us to proceed even when one of our algorithms fail for a graticule line.

4 Application

To test the algorithms outlined in Sect. 3, we developed a web-based application. The two-tier architecture (Fig. 5) of the application allow us to separate business logic from user interface concerns and forces us to explicitly specify means of data transfer between these two layers.

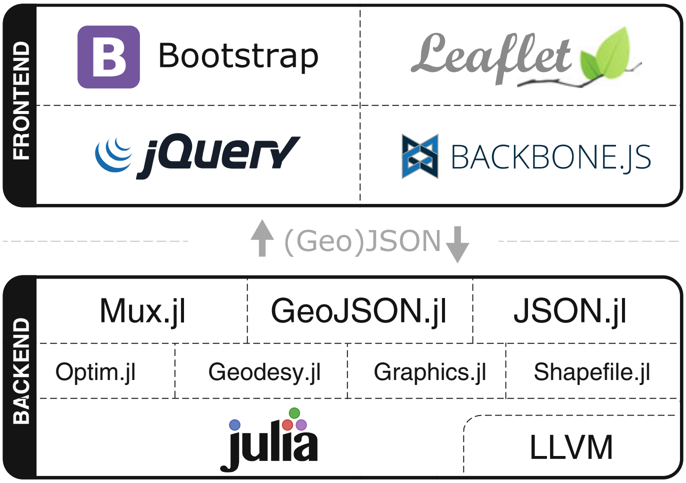

Fig. 5 Application architecture

4.1 *Backend*

The application's backend where the previously discussed algorithms run was developed using the Julia programming language. Julia[3] is a high-level, high-performance dynamic programming language created for the purposes of technical computing. Its user-facing characteristics roughly resemble those of other popular technical languages as Matlab and R, however Julia also provides a powerful just-in-time compiler based on the LLVM compiler architecture that makes it possible to write highly performant applications. With its Git-based package management system, Julia was easily extendable for our purposes. For example the packages `JSON.jl` and `GeoJSON.jl` handles data (de)serialization between the server and the client, `Optim.jl` contains an implementation of the Levenberg–Marquardt method we use for curve fitting, while `Mux.jl` provides an HTTP server implementation for communicating with the client.

4.2 *User Interface*

The user interface is based on widely used contemporary web technologies. We chose to implement a web-based interface for our application because we believe the web is the most widely accessible platform that is available independent of the operating system and other architectural differences between devices.

[3] http://julialang.org.

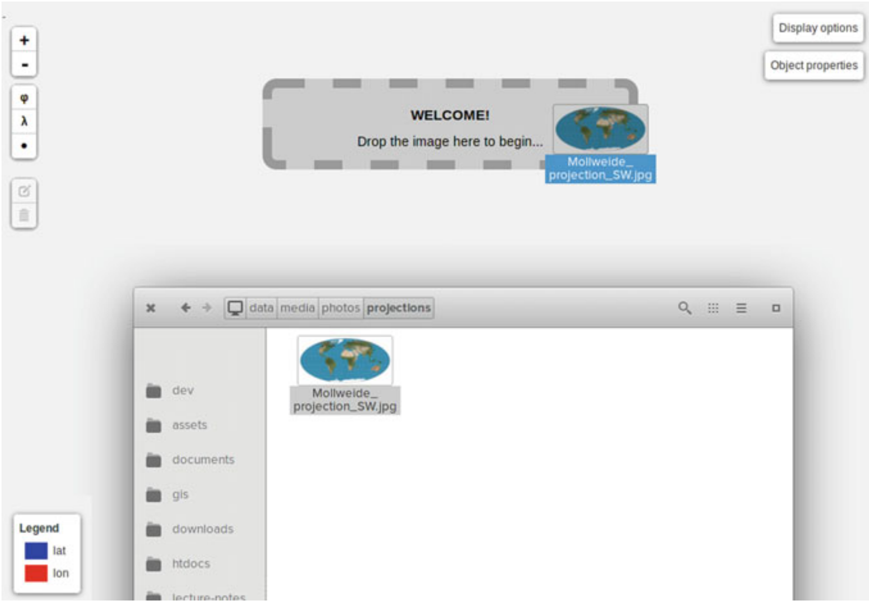

Fig. 6 Uploading a raster map for processing on the user interface of the application. Tools for tracing graticule lines and poles can be seen in the *upper left* corner

The application consists of a map view into which raster maps can be uploaded by the user (Fig. 6). An uploaded map, its graticule lines and the result of backend algorithms together form a *project* that can be saved, then restored at a later time. After uploading, the user is advised to manually trace the graticule of the map using a number of tools that are provided. The interface resembles that of widely used web based mapping applications to maintain a familiar feel.

After tracing each graticule line the user should input the value of the geographic coordinate associated with the freshly drawn curve. When all lines are traced, backend processing can be started. At this point, all traces are uploaded to the server where assessment of graticule properties and traversal of the decision tree to determine the projection is automatically done.

When finished, results of the backend processing are presented to the user in a table. The guessed projection, processing times as well as resource usage are also reported.

The user interface also features a sidebar where common operations such as saving/loading projects and setting application parameters (such as numeric tolerances) can be invoked. Also provided is a panel for modifying how graticules are displayed. The user can choose between displaying graticule lines based on their coordinate type (latitude/longitude), curve type (straight line, ellipse, parabola etc.), equidistancy of their intersection points or closedness.

5 Testing and Results

5.1 Synthetic Testing

We first tested the application by programmatically generating graticules for widely used projections.

The algorithm for graticule generation takes the following parameters:

- **Projection type** (p)—For testing purposes we included a number of projections in the application by implementing their projection equations. We tested the algorithm with projections from each major projection class (azimuthal, cylindrical and conic).
- **Graticule interval** (n)—Controls the density of the generated graticule. By gradually decreasing this value, processing time increases with the number of generated graticule lines. Having a lot of graticule lines also helps in testing other algorithms such as intersection point finding.
- **Scale** (s)—All projections implemented for testing purposes are computed as if they were on a unit sphere. For display purposes and to avoid numerical problems, an up-scaling factor had to be defined.
- **Noise** (σ)—As mentioned in Sect. 3.2 user-drawn traces are inherently noisy. In order to simulate this, we added a configurable pseudorandom noise modifying the position of the graticule lines' points. For the sake of simplicity, we assumed the noise to be normally distributed: (μ = 0, σ). This allowed us to define the amount of noise by specifying its variance σ.

Given these parameters we could generate our synthetic graticules by computing

$$P_\Lambda = \left\{ \left(\begin{bmatrix} x_p(arc\,\Lambda, arc\,\phi) \\ y_p(arc\,\Lambda, arc\,\phi) \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \end{bmatrix} \right) * s \,\middle|\, \begin{matrix} \phi \in \{\phi_{min} \le x \le \phi_{max} | x \bmod n = 0\} \text{ and} \\ \epsilon_{1,2} \sim \mathcal{N}(\mu = 0, \sigma) \end{matrix} \right\}$$

and

$$P_\Phi = \left\{ \left(\begin{bmatrix} x_p(arc\,\lambda, arc\,\Phi) \\ y_p(arc\,\lambda, arc\,\Phi) \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \end{bmatrix} \right) * s \,\middle|\, \begin{matrix} \lambda \in \{\lambda_{min} \le x \le \lambda_{max} | x \bmod n = 0\} \text{ and} \\ \epsilon_{1,2} \sim \mathcal{N}(\mu = 0, \sigma) \end{matrix} \right\}$$

for every Λ and Φ where they are an exact multiple of n. For lines of longitude, P_Λ are the set of points generated for the line where the longitude equals Λ degrees. x_p and y_p denote the projection equations for the chosen projection p, $\epsilon_{1,2}$ is the pseudo-random noise generated from the normal distribution $\mathcal{N}(\mu = 0, \sigma)$, and s is the up-scaling factor defined earlier. Points in P_Λ are generated such that Λ stays constant, while ϕ is a parameter moving from λ_{min} to λ_{max} sampled at the chosen interval defined by n.

The same is true for lines of latitude (P_Φ) when exchanging Λ with Φ and λ with ϕ respectively. For certain projections (e.g. the Mercator projection), graticule boundaries (ϕ_{min}, ϕ_{max}, λ_{min}, λ_{max}) should be limited so as to avoid generating graticules lines which lie at infinity.

Testing our algorithms with these synthetically generated graticules proved our implementation to be quite robust. Increasing the graticule density did not seem to have a significant effect on processing time. On the other side, we saw that increasing the amount of noise resulted in significantly worse accuracy during curve fitting. As curve fitting is the first step in the row of our algorithms, erroneously recognizing a curve means all subsequent steps would fail and projection recognition might either become impossible or—worse—give an incorrect result.

By comparing synthetically generated test data with graticule lines traced by humans we empirically came to the conclusion that errors introduced by manual tracing fall into an order of magnitude best approximated by setting the synthetic

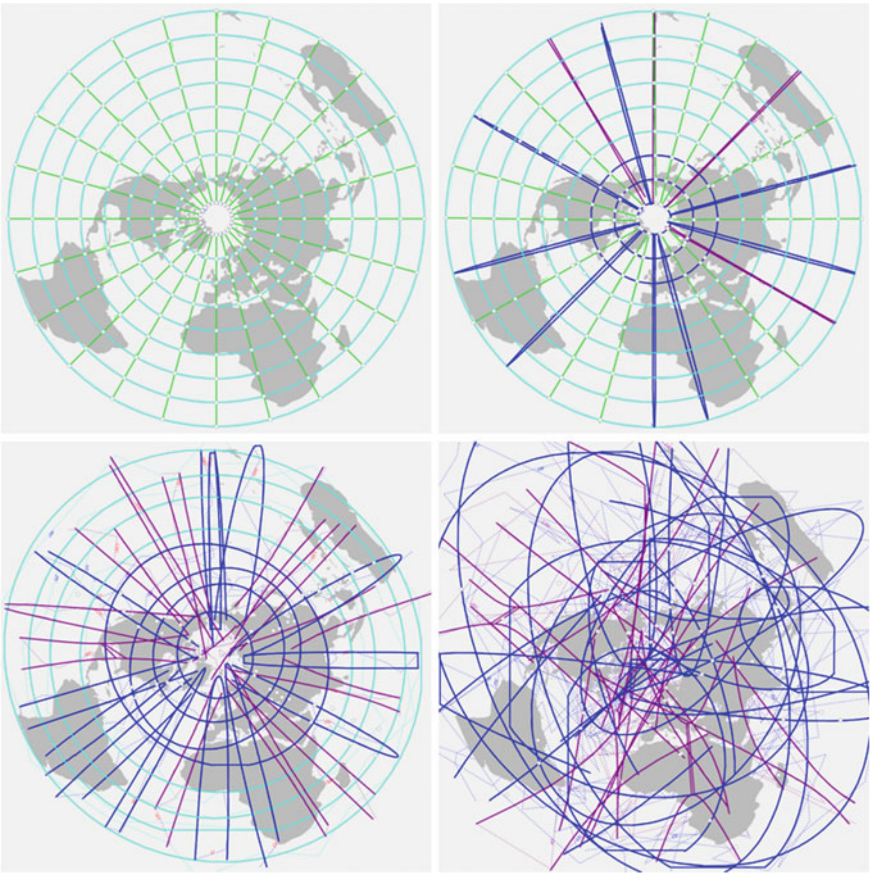

Fig. 7 The effect of pseudo-random noise with differing variance on the accuracy of curve fitting (azimuthal equidistant projection)

noise variance to $\sigma = 10^{-2}$. As it can be seen on Fig. 7, errors of this magnitude are relatively well handled by our algorithm, thus it remains suitable for practical use.

The success of curve fitting and a number of other steps are also dependent on user definable numeric tolerances. In its current state, the application relies on the user to set these values before computations, however empirically established defaults are also provided in the configuration file which should work well most of the time.

5.2 Testing on Real Maps

For the purpose of testing the algorithm on real maps we used maps from the geographic atlas *Teljes földrajzi atlasz* (Complete Geographic Atlas) a collection of maps from the beginning of the 20th century, authored by Hungarian cartographer and publisher Manó Kogutowicz, that—besides geographic themes—also includes thematic maps in a variety of cylindrical and pseudocylindrical projections (Kogutowicz 1902).

Due to the rather limited scope of these experiments, the results should only be considered as a proof of our concept, not a comprehensive suit of tests. Even so, trying out our algorithms on real maps already yielded some interesting results. When applied to one of the maps in *Teljes atlasz*, the application correctly identified its projection as being Mollweide. However, longitudes of ±80° were identified as circles instead of ±90° as should be the case for a map in the Mollweide projection (Fig. 8).

This calls attention to the problem of the inaccuracy of hand drawn maps. We expect to encounter this problem frequently as we deal with historical cartographic documents that might not have a solid geodetic and geometric basis. This is a problem that needs to be dealt with in a future version of the application.

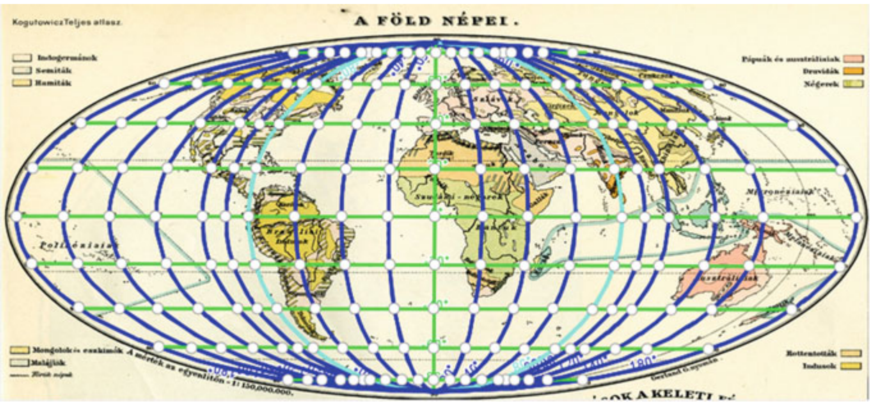

Fig. 8 An interesting result: longitudes of $\lambda = \pm 80°$ (instead of ±90°) are identified as circles on a map in the Mollweide projection (*Green* lines; *blue* ellipses; *cyan* circles)

5.3 List of Recognized Projections

Having implemented the algorithms presented in the previous sections, our application can distinguish between the following types of projections on small scale maps:

Cylindrical 1. Equirectangular 2. Mercator 3. Lambert Cylindrical Equal-area	**Conic** 16. Equidistant Conic 17. Lambert Equal-area Conic 18. Albers Equal-area Conic 19. Lambert Conformal Conic
Pseudocylindrical 6. Apian's 1/2 (Ortelius) 7. Sinusoidal 8. Mollweide 9. van der Grinten's 3 10. Eckert 3–6 11. Kavrayskiy 1–2, 6–7	**Azimuthal** 20. Lambert Azimuthal Equal-area 21. Azimuthal Equidistant 22. Stereographic 23. Gnomic (polar/normal aspect)
	Other 24. Hammer 25. Aitoff 26. Pseudoconic

6 Conclusion

In our study we examined the possibilities to implement Érdi-Krausz's decision tree system for determining the projection of small scale maps on a computer. We presented the mathematical foundations for the work and gave an overview of the accompanying web-based application that has been developed to aid non-professional users in the process of determining unknown projections on raster maps. We tested our algorithms both with synthetically generated graticules and on real maps. Both set of tests found the algorithm to be generally useable in practice, however a number of problems were revealed which might serve as a basis for further research.

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A Forgotten Atlas of Erwin Raisz: “Atlas de Cuba”

José Jesús Reyes Nuñez

Abstract The “Atlas de Cuba” was published in 1949 by the Institute of Geographical Exploration at Harvard University. This atlas is result of collaboration between Erwin Raisz, the American cartographer born in Hungary and a Cuban geographer and cartographer, Gerardo Canet. Using Canet’s words in the Introduction, the atlas is “a living picture of Cuban Geography as far as possible in 64 pages”. A total of 34 themes were represented by maps and graphics, presenting the history of the country, its’ physical geographical characteristics, the major parameters to describe the society (standard of living, health, social composition, government, etc.) and the national economy. The atlas is the rich combination of maps with pictures, charts and text. The authors not only wanted to create an atlas for scientists and specialists with the different topics represented in the maps: their intention was to make all this information available and easily understandable for the public in general. The atlas joined two peculiar cartographic styles: the delicacy of the drawing ability of Erwin Raisz and Canet’s interest to represent the broader spectrum of data collected by him, using all the graphic tools at their disposal to make the atlas more attractive. This little masterpiece of the mid-twentieth century constitutes a gem intentionally ignored by the current Cuban cartography.

Keywords Atlas · Raisz · Canet · Cuba

1 Introduction: The Authors

1.1 Erwin Raisz

Erwin Josephus Raisz (1893–1968). He was born in 1893 in the city of Levoča of the former Austro-Hungarian Monarchy (Hungarian name: Lőcse, now in the East

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_18

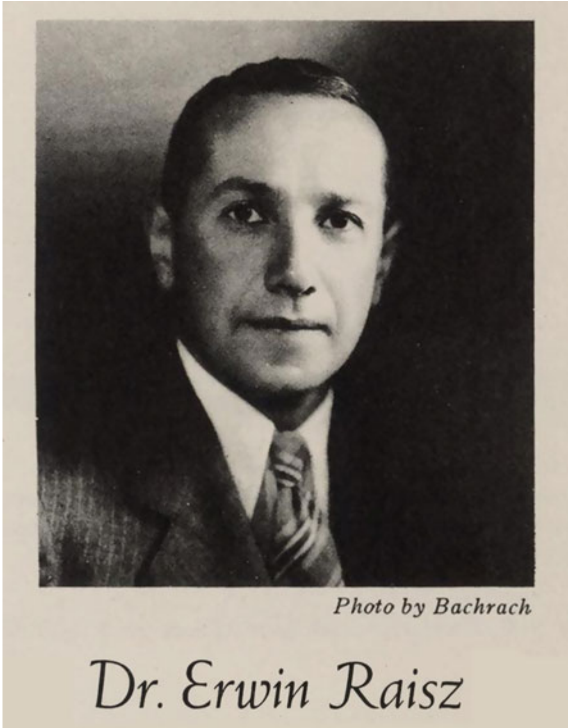

Fig. 1 Portrait of Erwin Raisz from the atlas of global geography (Raisz 1944). ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

region of current Slovakia) and obtained a degree in Civil Engineering and Architecture at the Royal Polytechnicum in Budapest in 1914 (Karsay 2009). After the 1st World War, in 1923, he emigrated to the United States and began to work simultaneously for the Ohman Map Company and Columbia University in New York. At this university he obtained a degree of Master of Arts in 1923 (McMaster and McMaster 2002). He was the first professor to organize and teach a course on Cartography at Columbia, which at same time was one of the first such courses in the country (Anonymous 2012). In 1929, he obtained his Ph.D. in Geology, presenting a dissertation entitled "Scenery of Mount Desert Island: its origin and development", which can be considered the first research work related to the creation and posterior development of his physiographic method for the representation of landforms (Fig. 1).

In this period he had his first contacts with the Cuban Geography, meeting the Cuban geographer and professor Salvador Massip at Columbia University. Raisz told him about a new method for the representation of relief that was developing and later known as physiographic method. They decided to make together the Physiographic diagram of Cuba (Original title: *Diagrama Fisiográfico de Cuba*) applying the new method developed by Raisz. They finished the map of 125 × 30 cm and printed in two colors in 1929 (Fig. 2), the same year when Massip is elected President of the Pan American Institute of Geography and History

Fig. 2 *Diagrama Fisiográfico de Cuba* with two detailed fragments (Raisz and Massip 1929). ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

for a period of three years. The map title and colophon reads in Spanish: "Physiographic Diagram of Cuba, designed by Dr. Erwin J. Raisz, Mapping instructor at Columbia University, New York, under the direction of Dr. Salvador Massip, Professor of Geography at the University of Havana, 1929".

The importance of this map is emphasized by Raisz at the end of his article entitled "*The physiographic method of representing scenery on maps*" (1931), when listing the maps made with the physiographic method for the representation of relief to date. He wrote:

> The lack of detailed physiographic maps from which information can be taken is a more serious question. Very little has yet been done in this field. The United States and Europe have been worked out by Professor A. K. Lobeck. For Asia we expect soon to have the map of Professor F. K. Morris. New Zealand has been worked out by C. A. Cotton (not yet published), and **Cuba by the author (E. J. Raisz: Diagrama fisiográfico de Cuba, Havana** 1929)… (Raisz 1931: 304)

According to his own words, the "*Diagrama fisiográfico de Cuba*" published in 1929 can be considered the **first map** entirely worked out by Erwin Raisz using his physiographic method.

In 1931 he left the Columbia University and followed his research and teaching activities at the Institute of Geographic Explorations of Harvard University. Here published his "*General Cartography*" in 1938, which was the first textbook on Cartography published in the United States and the only one book written in English on this subject for the next fifteen years (McMaster and McMaster 2002). After the closure of the Institute of Geographic Explorations in 1951, continues teaching at Clark University in Boston until 1961. From 1957 until his death he worked at the University of Florida, where he published his book entitled "*Principles of Cartography*" in (1962). In his long professional career he was the author of numerous maps, but only three Atlas: Atlas of Global Geography (Global Press 1944), *Atlas de Cuba* (Atlas of Cuba, Harvard University Press 1949) and Atlas of Florida (University of Florida Press 1964).

1.2 Gerardo Canet

Gerardo Canet (1911–2011) was a geographer and economist who obtained a title of Doctor in Pedagogy and later of Philosophy at the University of Havana (Fig. 3). He also earned a Master of Arts at Harvard University in the United States. He worked as a regular teacher at the Normal Pedagogical School of Havana and served as Professor of Geography at the Institute of Víbora (Sarausa 1957). Between 1945 and 1949 he obtained a grant within the Program for Latin America and the Caribbean of the John Simon Guggenheim Foundation, in the area of Social Sciences—Geography and Environmental Studies (http://www.gf.org/fellows/2224-gerardo-a-canet). He worked as assistant professor in the Department of Cartography of the Institute of Geographic Explorations at Harvard University, under the tutelage of Erwin Raisz. In this period he published "Atlas of Cuba" and attended as chairman of the Cuban delegation to the 3rd Congress of Geography and History held in Buenos Aires in 1948. At the time of publication of the atlas was a national representative on the Commission on Cartography of the Pan American Institute of Geography and History, and later became president of the Panamerican Committee of Charts and Special Maps of the same institute.

After returning to Cuba continues teaching at the Institute of La Víbora in Havana in the decade of 1950, collaborating as cartographer in the publication of different scientific and textbooks. His work transcended Geography and made maps for books published in other fields of science such as History.

From 1954 Canet and his wife (Isabel Pérez Farfante de Canet, a renowned biologist who specialized in the study of crustaceans) began to oppose the dictatorship of Fulgencio Batista, who had taken power after a military putsch in 1952.

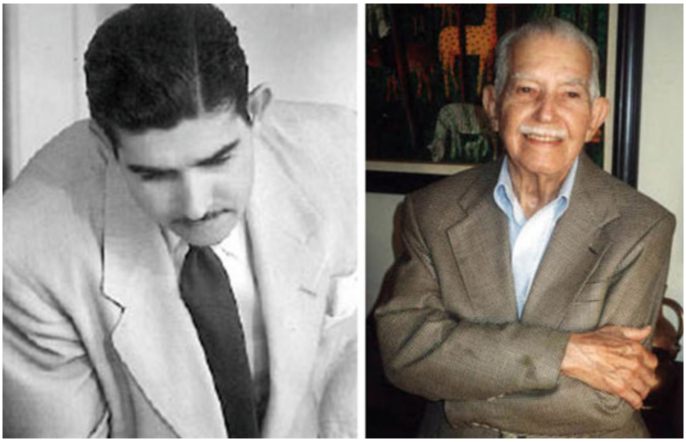

Fig. 3 Gerardo Canet in the decade of 1950 and beginning the 21st century (*Sources* Journal of Crustacean Biology 2010 and University of Miami Library 2012). ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

Canet becomes a member of Montecristi Association, a group formed mainly by intellectuals who were dedicated to raising funds for the support of revolutionary activities against Batista. In 1959 support the nascent Cuban Revolution led by Fidel Castro, being Canet appointed Vice-President of the Agricultural and Industrial Development Bank of Cuba and member of the Board of Tourism Development (Diario de la Marina 1959). Shortly thereafter arise and sharpened the differences of opinion and discussions with government representatives. Because of these contradictions, Canet and his family decide to leave the country and emigrated to the United States in 1961. Bauer (2010: 346) described this crucial moment of Canet's life in the Obituary dedicated to the memory of his wife, Isabel Pérez Farfante de Canet: "…Isa and Gerardo's names appeared on a secret government blacklist (revealed to them by a friend in the government), which meant that their days in Cuba were numbered… They sent their two young sons to the United States on a pretext and then, a month later, went to the airport without reservations, bought a ticket, and flew to the U.S. They carried with them only a single suitcase, leaving home, possessions, and their careers in Cuba behind."

2 The "Atlas de Cuba", 1949

2.1 General Characteristics of the Atlas

In 1945, following the advice given by his professor Salvador Massip, Gerardo Canet decided to spend the grant obtained from the Guggenheim Foundation under Erwin Raisz's orientation. The publication of the Atlas of Cuba in 1949 (Fig. 4) was the final result of his 5-year stay in the Institute of Geographic Explorations at Harvard University, which was funded by the grant obtained.

In the Introduction of the atlas, Canet made special mention of his professor Salvador Massip: "The inspiration was provided by the distinguished Cuban geographer, Professor Salvador Massip, with whom the idea for such an atlas originated and on whose advice the author went to Harvard University to complete his cartographic studies and to undertake the project" (Canet and Raisz 1949: 3). Canet also acknowledges the grant from the Guggenheim Foundation and the work developed by Erwin Raisz: "The award of a Guggenheim Fellowship made it possible for the author to remain at Harvard University, where the work was carried on, in close collaboration with the well-known cartographer, Dr. Erwin Raisz." (Canet and Raisz 1949: 3).

A total of 34 themes were presented in the atlas, which can be structured into five main groups (excluding Index and Bibliography):

1. Introduction: Cuba, center of the Americas; The world around Cuba
2. History: Discovery, conquest and colonization; Colonial Cuba; Revolutionary Cuba
3. Physical Geography: Climate; Hurricanes; Magnetism, gravity and earthquakes; Oceanography; Geology; Geomorphology; Soils; Forestry; Fisheries; Vegetation

Fig. 4 Fragment of the cover of “Atlas de Cuba” (Canet and Raisz 1949). ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

4. Society: Population; Standard of living; Health; Social composition; Government; Tourist trade; Education
5. Economy: Agriculture; Sugar; Minerals; Tobacco; Coffee; Winter vegetables; Fruits; Other crops; Livestock; Industries; Communications; Import and Export.

It should also make special mention of a map annexed to the atlas. This map was entitled “*Mapa de paisajes de Cuba*” (Map of Landscapes of Cuba), scaled at 1: 1,977,896 and whose first version was published in 1945. This map of 151 × 57 cm (60 × 24 inches) was catalogued by Canet as “*a new experiment in cartography*” (Canet and Raisz 1949: 3), using colors to make difference between “*land types: cultivated fields, pastures, mountains, swamps, valleys,* etc.” Colors are completed with the use of symbols. They counted with the official support of the Cuban Navy, which organized a series of flights over Cuba for Canet and Raisz. After these flights Raisz updated the geographical data represented on the “*Diagrama Fisiográfico de Cuba*” of (1929) (Fig. 5). Canet wrote in the Introduction that the map is the result of “*a series of flights over the Island and the analysis of numerous color photographs taken from the air*” (Canet and Raisz 1949: 3).

Their aims when creating the atlas are described in detail in the first sentences of the Introduction: “*This Atlas is more than an attempt to describe Cuba. Our aim is*

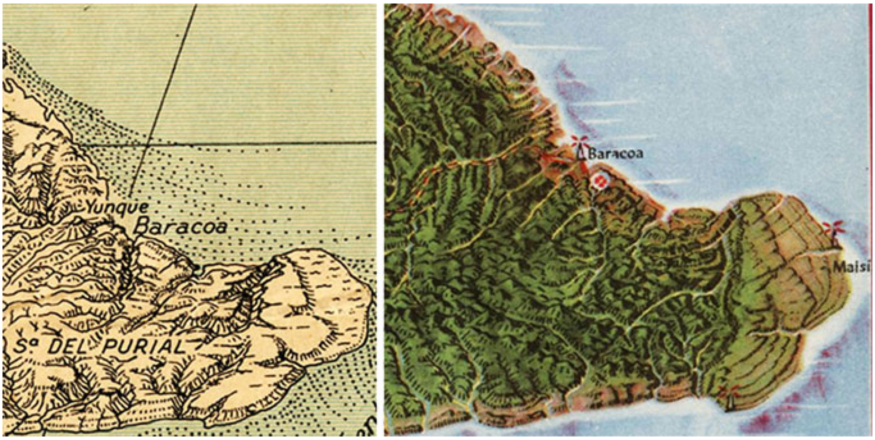

Fig. 5 Comparison of the Eastern region of the island in the "Diagrama Fisiográfico de Cuba" of 1929 (*left*) and in the "Mapa de paisajes de Cuba" of 1945 (*right*). ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

not only to present the setting in which the drama of Cuban life is played but to show how his life itself changes its own setting, creating new problems and new adjustments to them. This dynamic element is usually absent from the impersonal atlases produced by governments, societies and publishing houses, which merely give a graphic report of a given moment of time." (Canet and Raisz 1949: 3)

2.2 The Maps of the Atlas

Seventy one maps can be found in the 64 pages of the atlas (excluding the annexed "*Mapa de paisajes de Cuba*"). The number of maps by theme is as follows in descending order:

- 14 maps (1 theme): Climate
- 6 maps (2 themes): Hurricanes; Magnetism, gravity and earthquakes
- 5 maps (1 theme): Discovery, conquest and colonization
- 3 maps (3 themes): Colonial Cuba; Revolutionary Cuba; Communications
- 2 maps (4 themes): Tobacco; Other crops; Population; Imports and exports

The remaining themes included only one map each. They were drawn with larger scale between 1:5,900,000 and 1:2,220,000, with much more detailed information on their respective themes than the 48 maps mentioned above. In the theme entitled "Standard of living" they used a map at scale approximated to 1:2,000,000, but the Western and Eastern ends of the island were left out of the page. The scale of the maps was calculated according to the graphic scales given in 21 of the 71 maps.

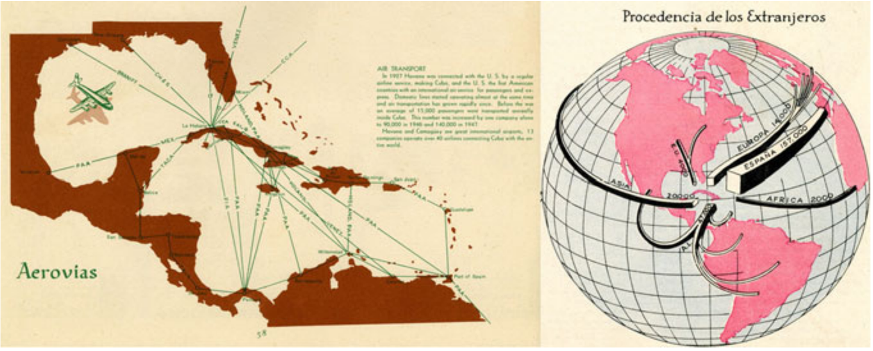

Fig. 6 Maps representing not only Cuba in the atlas. ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

The majority of maps, a total of 65 were printed using only two colors, while 6 maps and the annex were printed in full colour. 56 maps represented only the Cuban territory: the island of Cuba, then island of Pinos (currently island of Youth) and the major adjacent archipelagos formed by small islands. Moreover 10 regional maps (representing the Caribbean area), 2 maps representing the Western hemisphere on a globe (America), 2 world maps and 1 map of Havana and surroundings can also be found in the atlas (Fig. 6).

2.3 *Graphic Solutions Representing Statistical Data*

A special characteristic of this atlas is the rich combination of maps using innovative methods to represent data with pictures, charts and text. The explanative texts were written in Spanish and English to make the information more accessible for a broader number of specialists and interested people. The authors intended to create an atlas that can be used not only by the scientific community, but by the general public too, being their premise to make easily understandable the information represented with maps and graphics (Canet and Raisz 1949: 3):

> We have presented the results of our labor in graphical form. An old Chinese proverb says: 'A picture says more than a thousand words'. Moreover by visual representation the most complicated problems may be brought within the understanding of the layman. Everyone should know the geography of his own country, and in the case of Cuba this need is imperative, since few countries have such clear-cut dependence on location, climate and soil. Cuba's internal problems of adjustment and interdependence with the rest of the world demand a high degree of understanding from its citizens.

The authors appealed to different solutions to make the data represented in the atlas more understandable. In this manner there were born cartographic representations as we can see on page 5 of the atlas: an easy and original map to make sense of the approximated distances between Cuba (drawing Havana in the center point of the

Fig. 7 The world around Cuba (Canet and Raisz 1949: 5), wage distribution (Canet and Raisz 1949: 31), number of women employed in different types of jobs and distribution of places where Cubans live (Canet and Raisz 1949: 35). ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

world map made using an azimuthal orthographic projection) and other regions of the world. Furthermore, they also used purely graphical solutions or different types of diagrams that effectively complement the maps of the atlas (Fig. 7).

An specialist can discover the remarkable influence exerted on authors by the isotype based visual school created by Otto Neurath in Vienna (Austria), as well as in the Institute of Visual Education in Oxford, which was created by Neurath after leaving Austria. This graphic method of visualization became very popular in the first half of 20th century and currently remains an unavoidable reference point for scholars and users of graphic visualization. In the "*Atlas de Cuba*" we can see numerous examples of using isotypes (English abbreviation of "International System of Typographic Picture Education"), many of them located around the maps, illustrating and complementing the explanations offered in bilingual texts (Fig. 8).

Other characteristic to be mentioned apart is that the authors avoided the use of charts on the thematic maps. The diagrams can be found situated around the maps to complete the information represented in them, but also are located independently of the maps to illustrate the texts. Many of them are illustrated with pictorial motifs related to the represented topic (Fig. 9).

Fig. 8 Sample pages of the atlas using the method of isotypes developed by Neurath (Canet and Raisz 1949: 35, 57). ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

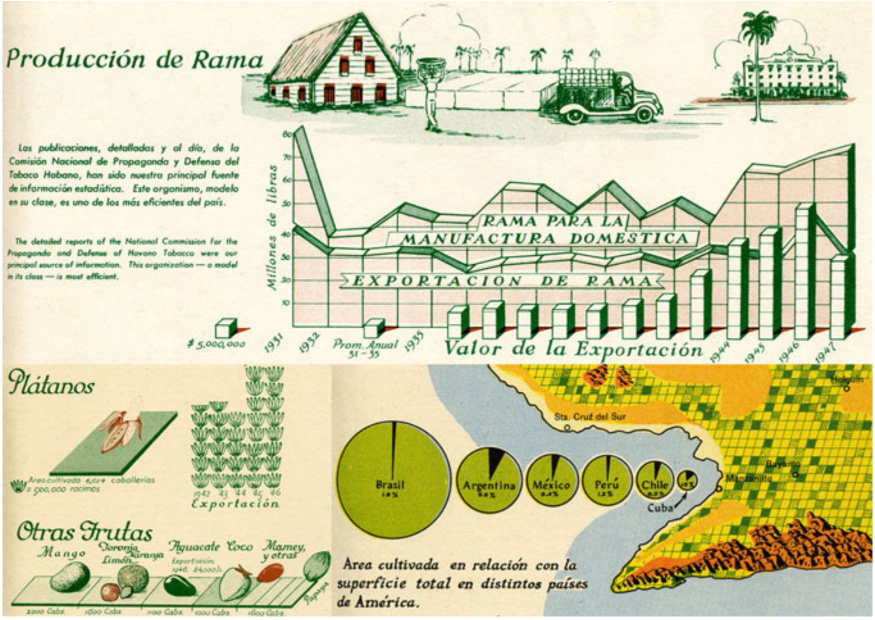

Fig. 9 Charts used in the atlas (Canet and Raisz 1949: 43, 49, 51). ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

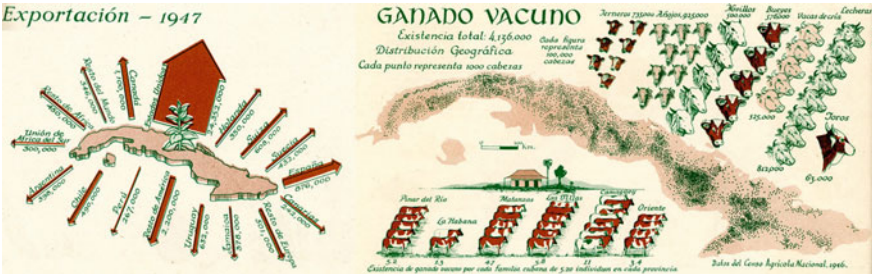

Fig. 10 Examples of flow map (Canet and Raisz 1949: 49) and dot map completed with the isotypes of Neurath (Canet and Raisz 1949: 54). ATLAS DE CUBA by Gerardo Canet, in collaboration with Erwin Raisz, Cambridge, Mass.: Harvard University Press, Copyright © 1949 by Gerardo A. Canet. Copyright © renewed 1977 by Erwin Raisz

Only in few maps were used different versions of diagrams of columns, some of them represented by a symbol, while three thematic maps were made using dots and four maps using flows (Fig. 10).

This atlas (the second atlas of Raisz, who had previously published the Atlas of Global Geography in 1944) is a unique combination of two very peculiar styles: the personal "carto-artistic" style and delicacy of the drawing ability of Erwin Raisz, which skilfully used to illustrate profusely (but very clear and understandable) the scientific interest of Gerardo Canet to offer the broader spectrum data of the Cuban nation using all the graphical and technological tools at their disposal.

3 First National Atlas of Cuba … or Not?

In a presentation of this atlas is impossible to elude the fact that this work is practically unknown to the new generations of Cubans born after the triumph of the Revolution of Fidel Castro in 1959. This atlas has been mentioned or simply used as bibliographic reference in very few articles and scientific studies written by researchers and other specialists living and working in Cuba during the last more than 45 years. Even its existence is (perhaps unknowingly) omitted in some articles, e.g. in the detailed study entitled "*La obra del Dr. Salvador Massip Valdés y su contribución a la Ciencia Geográfica y su enseñanza en Cuba*"/The work of Dr. Salvador Massip Valdés and his contribution to the Geographical Science and its teaching in Cuba/(León Méndez y Valdés Roja n.d.), which can be accessed on the Web and in which the "*Diagrama Fisiográfico de Cuba*" is mentioned. Both authors also refer to the research that later Salvador Massip developed with Raisz and Meyerhoff in Cuba:

> The research developed by him in his country at that time is very important: within them, the work carried out along the country along with the American professors Howard A. Meyerhoff and Erwin J. Raisz. Due to the lack of effective source material for research as reliable topographic and geologic maps, aerial photographies and other media in those years, he was the first specialist to organize aerial travel for the study of all the geographical landscapes in Cuba.

In the same article the authors indirectly ignored the publication of the Atlas of Cuba in (1949), stating:

> … Almost time to celebrate his 80th birthday, he/Massip/departed to Moscow in 1969 and worked tirelessly, checking each page of the National Atlas of Cuba. His work, in this **first geographic atlas of the Cuban state**, was also a notable contribution that he made not only to geographical sciences, but also to their teaching.

The most detailed reference that I found was made by Dr. Armando A. Domech González in his study entitled "*La cartografía de atlas en Cuba: situación actual y perspectivas en el siglo XXI*" ("Cartography of atlases in Cuba: current situation and perspectives in the 21st century"). The chapter dedicated to this atlas is entitled "Atlas of Gerardo Canet" and begins with the following words: "*The first atlas published in Cuba that we know, but not being really a national atlas—mainly because of its modest presentation and represents the efforts of an isolated author in an adverse environment from the point of view of scientific work–, is the atlas published by the Cuban geographer Gerardo Canet in 1949.*" (Domech 2000: 6)

Before reacting to this opinion given by the President of the Cuban Association of Geography beginning the 21st century, I would cite some widely accepted definitions of national atlases, which have been internationally recognized first in the 20th century and today too:

- Konstantin Salishchev (Russian geographer and cartographer, 1960): "*A national atlas is a multiobjective basic atlas of a country in particular, which contains a summarized representation of contemporary scientific knowledge of the country in the field of Physical Geography, Economics and Politics. It is usually an official publication, or at least sponsored by the government and includes all the wealth of information available about the territory.*" (Domech 2000)
- National Geographic Institute (Instituto Geográfico Nacional), Spain: "*A National Atlas is a complex and fundamental geographic atlas containing a summary and generalization of contemporary scientific knowledge in the field of physical, economic, cultural and political geography of the country concerned. It serves as a reference tool to offer substantial value for the public servant, and to provide knowledge of different aspects that characterize a territory in business activities; in turn, is an educational point of reference for the public in general*". (IGN 2014)
- Menno Jan Kraak, Ferjan Ormeling and others: "*National atlases present a synthesis of the spatial knowledge that characterizes a country. They contain comprehensive combinations of spatial datasets represented by maps that each completely covers a country, with an added narrative function. All information in national atlases refers to the same area, the national territory.*" (Kraak et al. 2009: 9)
- Encyclopedic Dictionary of Cartography in 25 languages: "*An Atlas which depicts different aspects of one country*". (Neumann 1997: 471)
- Erwin Raisz: "*Atlases that usually contain, besides the topographical pages, a rich assortment of special maps that almost all informative or statistical data concerning the country can be conveniently obtained.*" (Raisz 1948: 217)

> They/National Atlases/are published either by government agencies or by private concerns subsidized by the government or business firms. Besides their topographical pages, they contain maps dealing with climate, population, economics, social conditions, and other topics.
>
> (Ena L. Yonge, National Atlases: A Summary, Geog. Rev., vol. 47, 1957, pp 570–578. Cited by Raisz 1962: 100–101)

Any of the cited definitions made mention and the least fixed a range of number of pages or the level of printing quality as a condition to consider an atlas national or not. By this reason, the "*modest presentation*" cannot be a serious argument to consider. The second argument is that the atlas was the result of the efforts of "*an isolated author in an adverse environment*", which is refuted by Canet in the Introduction writing his thanks to all the entities, personalities and colleagues that made possible the publication of the atlas.

Salishchev's definition is the only one to put as condition the sponsorship by a government, therefore it must not be considered a decisive factor when assessing whether an atlas may or may not be considered national. The participation of government in the publication of a national atlas is primarily driven by the need to be responsible at least of a portion of the financial costs involved in the publication of an atlas of this type, as well as that a governmental scientific institution (e.g. Academy of Sciences) coordinate the participation of those state research institutes collaborating in the project. In the decade of 1940, the research and work developed by Canet counted with the support and collaboration of personalities and institutions of the government and from the private sector, as well as the then Cuban scientific community (headed by Prof. Salvador Massip as promotor of the atlas), as stated in the Introduction (Canet and Raisz 1949: 3): "*…to the constant encouragement received from the Instituto de La Víbora, from which he was granted an extended leave of absence in order to devote his time and attention to the project; special recognition is due his associates of the geography department, and in particular his distinguished colleagues Leví Marrero and Fernando Portuondo. Likewise to the Cuban Navy which, through Officers Oscar Riverí and Guillermo Driggs, provided the facilities for an aerial reconnaissance of the Island, on which the author was accompanied by Dr. Raisz.*"

Moreover, on the first page of the atlas can be read: "*Preparado en el Instituto de Exploraciones Geográficas de la Universidad de Harvard y publicado en cooperación con el* ***Ministerio de Agricultura de la República de Cuba***" (Made at the Institute of Geographical Explorations Harvard University and published in cooperation with the **Ministry of Agriculture of the Republic of Cuba**). However, the governmental support was not limited to the Ministry of Agriculture, counting Canet with the collaboration of numerous personalities of then government, as he wrote in the English version of the Introduction: "*Thanks are also given to all the people who have contributed in so many ways to the solving of the various problems involved and to the successful completion of the work, among whom should be mentioned specifically His Excellency, the President of the Republic/* Carlos Prío Socarrás*/; also Germán Alvarez Fuentes/*Ministry of Agriculture 1944–1946*/, Miguel and Augustín Guitart, Guillermo Belt/*Cuban ambassador in USA, Cuban representative in the Directing Council of the Pan American Union*/, Francisco P. y González Muñoz, Antonio Calvache/*Director of the National Geographic Institute in 1948*/, and César Lugones; as well as Jesús F. de Albear, Hermano León, and many others.*"

Some years before (exactly in 1946) the Cuban geographer Leví Marrero also acknowledged the collaboration provided by the Cuban Navy in scientific activities, writing in the first pages of his textbook entitled "Elements of Geography of Cuba": "*A considerable number of aerial photographs were taken by Donnadieu Lieutenant of the Cuban Navy, who accompanied the erudite doctor Erwin Raisz from Harvard University and his assistant Dr. Gerardo Canet, during their flights over Cuba in 1944. We thank the Chef of the Cuban Navy, Commodore José Aguila Ruiz, his permission to use these photos, and also his invitation to accompany the doctors Raisz and Canet in part of their exploration.*" (Marrero 1946)

In the Introduction of the atlas, Canet gave his opinion about those "*impersonal atlases produced exclusively by government, societies and publishing houses, which merely give a graphic report of a given moment of time*" (Canet and Raisz 1949: 3). Based on these words it can be deduced that Canet made the atlas just during his fellowship in Harvard—counting with the personal collaboration of Erwin Raisz as international recognized and experimented cartographer—to ensure his personal capacity of decision in the determination of the content and the editing works. Although in the pages of the atlas "*are collected in a rather simple way the main aspects of the Geography of Cuba*" (Domech 2000), the collection of the data represented on the maps only could have been successful if he also counted with the collaboration of government and private scientific institutions.

In 1962—eight years before the publication of a new National Atlas of Cuba in collaboration with the Soviet Union, considered by the Cuban government as the first National Atlas of the country—, Raisz also made mention of the atlas within the "*National Atlases*" topic in the chapter entitled "*Private Maps*" of his book "*Principles of Cartography*", referring to the publication of national atlases all around the world: "*Almost every country of Europe, in addition to Mexico, the Central American republics,* ***Cuba****, Brazil, Argentina, the French colonies, Morocco, Tunis, the Congo, Egypt, India, Japan, China, Australia, Tanganyika, Ghana,* etc. *published such atlases.*" (Raisz 1962: 101) This statement reflects the objective traced by both authors of creating an atlas that could be considered the first national atlas of the country.

If a very strict evaluation of the Atlas of Cuba is made, then it should be recognized that the number of maps and the detail of presentation of the different topics is lower than other national atlases made in the first half of the 20th century. At the same time, it is worth carefully read the definitions of national atlas offered by one of the most prestigious institutions in the area of the Spanish Geography, the National Geographic Institute in Madrid, as well as renowned researchers from different areas of Cartography as are Ferjan Ormeling and Menno-Jan Kraak. In both definitions are emphasized as fundamental characteristics of a national atlas first the map content and second its value as a reference tool at different levels, adding the importance of educational reference and narrative function. I leave the reader to consider whether the Atlas of Cuba of 1949 fits or not the approaches of these definitions.

The atlas had a second edition in 1965, which was also published by the Harvard University Press, Cambridge, USA.

4 Epilogue

In the late 1920s, when Erwin Raisz began to work with Salvador Massip, he could not suspect that this meeting would link him very directly to the geographic and cartographic research activities developed in the young Republic of Cuba. This personal cooperation is manifested in different ways during the next twenty years, being the "Atlas de Cuba" of (1949) the master piece of this collaboration, undoubtedly the most important work of the Cuban cartography in the first half of the 20th century.

Let me conclude this article reaffirming other ideas related to the Atlas of Cuba. As noted in Chap. 3.5, the extension, design and format of the atlas differs markedly from the usual format of traditional national atlases. At same time the methods used for the graphic representation of information also differ from the methods of representation used in national atlases published in those years. It also differs from all those national atlases that could be considered more "conservative" or "traditional", because they remained faithful to the guidelines and style of edition followed by the National Atlas of Finland (*Atlas of Finlande*) in 1899. This effort of both authors to create an "atypical" atlas makes the Atlas of Cuba to be considered an exception and at same time a multifaceted example of the use of "traditional multimedia" in a cartographic work: a combination of text, graphics, illustrations and maps to make more understandable the information represented for all sectors of the population, but without losing its scientific value. The atlas was ahead of its time, being a predecessor of atlases using different multimedia resources that would have their heyday beginning from the 1970s.

Whereas the Academies of Sciences of then Soviet Union and of Cuba (founded in 1962) began the edition of the National Atlas of Cuba only more than 15 years after the publication of the Atlas of Cuba, it is undeniable that the atlas of Canet and Raisz was worthy of being recognized as a meritorious work of the national cartography in the period 1949–1969. It was the only atlas summarizing the most characteristic aspects of the country (which may also be and has been considered a national atlas) with a degree of detail and scientific rigor according to the level of the Cuban scientific development at that time.

Since 1961 this place was and even today, 15 years after having begun the 21st century, is denied by Cuban scientific and politic authorities with the deliberate official ignorance of its existence, causing that it is an unknown work for the new generations of Cubans.

Paradoxically the international valuation of the atlas has grown over the years. Currently, it constitutes not only a seemingly mute testimony to the Cuba anterior to 1949, but also an extremely valuable and rare piece of universal cartography, because of the participation of Erwin Raisz in its creation and the small number of copies that have stood the test of time.

With this article I want to make a modest contribution to give a more complete picture of a specific chapter of the development of Cuban geography and cartography in the first half of the 20th century. This development was directly or indirectly related to Erwin Raisz, one of the most important cartographers of the century. I could only consider that this aim was at least in part achieved, if this work can be a source of inspiration and can constitute the starting point for further research on this topic.

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Who Needs *Mitteleuropa* Old Maps? Present-day Applications of Habsburg Cartographic Heritage

Marco Mastronunzio and Elena Dai Prà

Abstract The historical Habsburg Tyrol was extensively mapped from the 18th to the 20th centuries, since it represented the "south of *Mitteleuropa*". These historical maps have their main *foci* on the southern boundaries and rivers network: measuring the Empires as a form of practical geopolitics through state "sponsorship". In this mainly methodological paper a cartographic time-series was considered as a data-set, one which starts after the First Military Survey (not including the Tyrol): from *Kriegskarte* by von Zach (1798–1805, 1:28.800), to the Third Military Survey (1869–87, 1:25.000). Faced with cartographies composed of hundreds of map-sheets, with a good positional accuracy and mainly not georeferenced, it is necessary to place them in a common reference system (ETRF89 UTM), in order to compare with present-day reference maps for geospatial analysis and dissemination purposes: each map-sheet needs to be localizable avoiding a massive initial georeferencing/mosaicking process onto the whole data-set. Thus, our current work centres on developing a methodology for regional purposes, using a map-sheets overview (index map-sheet), often neglected in a GIS-framework. Using archival documents alongside maps and contemporary literature, the native reference systems were investigated. The 4-step map-to-map workflow is: (a) assign to index-maps the native (or comparable) reference system; (b) shift from Ferro to Greenwich (longitude rotation); (c) perform the geographic datum transformation to WGS84; (d) reproject in ETRF89 UTM. The first results are georeferenced index-maps that readily provide the 4-corner coordinates of each map-sheet for subsequent georeferencing, assigning the corner coordinates (from index-map) to corresponding corner-points (onto a single sheet) without identifying landmark/control points on old and reference maps.

This paper is the result of a collaborative effort by Marco Mastronunzio and Elena Dai Prà, who are responsible for paragraphs 1, 3, 4, 5, and paragraphs 2 and 6 respectively.

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_19

Keywords Historical maps · Archival research · Geodetic reference system · Georeference · Habsburg empire · Military survey

1 Introduction

Since the 18th century, the Cassini triangulation method has provided us with a "mapped" Europe and, in a number of cases, "connected" through a triangle chain-network: a geometrical skeleton rather than a true map. To begin with, large basis triangulations were executed to give reference points for subsequent detailed triangulation to enable large scale mapmaking, earlier (after France) in the Austrian Empire. In other words, state-scale surveying for "national" geographies and national mapping, the so-called "systematic mapmaking", to provide a meridian triangulation (Adler 2003; Brotton 2012; Favretto 2014). This was carried out, in the case of France and Austria, at the same scale factor: the well-known 1:86.400 and its enlargements/reductions. A map-production frequently carried out along with early cadastral surveys,[1] also in this case previously in France and in Napoleonic *Royaume d'Italie* (surveyings from 1809 to 1814; Mastronunzio and Buffoni 2014; Repele et al. 2011) and then, starting from the *Grundsteuerpatent* ("land tax edict") of 1817, in the Austrian Empire (Abart et al. 2011; BEV 1967; BEV 1983; *Instruction […]*[2] 1824; Lego 1967). French scales for Habsburg mapping: measuring the Empire(s) as a form of practical geopolitics through direct state "sponsorship".

At that time in Europe, France has its own prime meridian (Paris), Austria also (Ferro), and so on following other national longitudes of origin. The vast Chinese Empire of Ming has one—and only one—prime meridian, measured and centred in Beijing by the Jesuit missionary Martino Martini in the first half of the 17th century (150 years earlier), represented in his *Novus Atlas Sinensis* included by Joan Blaeu in the *Theatrum orbis terrarum* of 1655 (Dai Prà and Mastronunzio 2015).

Contrary to the latitude of origin, the prime meridian has always been, from a historical point of view, conventional and a strictly politically-based question (e.g., Paris, Ferro, Rome, Pulkovo). First and foremost, *Élisée Reclus* in the *Nouvelle géographie universelle, la terre et les hommes*, in the volume concerning the Austrian Empire (*Tome III: L'Europe centrale*, 1878) among hundreds of maps (from chorographical maps to urban plans) only a couple report the Ferro prime

[1]The authors would like to thank Dr. Dino Buffoni (Head of the Geodetic Office of the Autonomous Province of Trento's Cadastre Service) for his kind help with all issues regarding cadastral survey and mapping.

[2]Accessed on the manuscript translated into Italian for former Tyrol territories, *Istruzione per attivare la misurazione dei territorj […]*, conserved at the Cadastre Museum of the Autonomous Region Trentino/South Tyrol. More significant, in terms of the relationship between the cadastral and topographical survey, is the manuscript *Instruction über die Reduzierung der Katastermappen und die hiernach zu verfertigenden militärischen Aufnahmssektionen*, conserved at the *Kriegsarchiv* (Vienna). The latter dates from 1821, earlier than the *Instruction* which is from 1824.

meridian, Austria's "own" prime meridian; conversely, both the Paris and the Greenwich prime meridian are used.

2 Current Research and Source-Maps

The historical Habsburg region of Tyrol (nowadays *Land Tirol* and, in Italy, *Trentino-Südtirol* Autonomous Region) was extensively mapped from the late 18th to early 20th centuries since it represented the "south of *Mitteleuropa*".[3] These historical maps have their main *foci* on southern boundaries (security and fortifications) and the rivers network (resources, transport).

Our research group in historical geography at Department of Humanities of University of Trento (Italy) is currently mainly involved in two research projects on Trentino historical boundary line(s) and on historical change detection concerning the River Adige (*Etsch*). Our work involves a very large data-set of Habsburg cartographic heritage (following the above-mentioned two mapping topics, boundaries and rivers), as a source for present-day issues (boundary disputes on the one hand and river restoration on the other). In both research projects we use source-maps as geodata/geoinformation for an interdisciplinary research landscape, working with archaeologists, historians, geologists, environmental engineers and cadastral surveyors.

Concerning the first project ("Cartography and boundaries of the Trentino historical region", funded by *Trentino-Südtirol* Autonomous Region in partnership with the Cadastre Service of the Autonomous Province of Trento), it should be stated that the thorny issue of boundaries in the Trentino area is due to a political boundary which shifted between a number of sovereign states throughout the centuries (the Republic of Venice, the Habsburg Tyrol and the Kingdom of Lombardy-Venetia and the former Kingdom of Italy). Thus, as previously mentioned, boundaries are one of the main features represented in the historical cartography of Trentino. At present time this boundary (an administrative one) is faced with disputes between the neighbouring provinces over several sections. There is a clear need for a precise setting and geo-localization of boundary lines with a geohistorical approach. The research on historical maps is integrated with geospatial analysis in order to extract different boundary lines so as to provide a time-series analysis from the first half of the 18th century to the present day and relevant geovisualization tools. Notably, the historical maps (boundary maps, Habsburg and Napoleonic cadastral maps, "pre-cadastral" maps, topographic maps) are conserved in Austrian archives (in Vienna, Innsbruck), in Venice and in local archives (*Südtirol*, Lombardy). The methodology focuses on a number of case-studies (following specific boundary disputes) and uses a double approach:

[3]The German term *Mitteleuropa* (literally "Middle Europe") refers to historical "Central Europe", intended here with the Austrian Empire connotation from a cultural and intellectual point-of-view which partially corresponds to the former Austrian Empire.

firstly, the census, the classification and the study of historical cartography (also with a critical cartography approach); secondly, the analysis of geometric accuracy of maps and the development of an historical GIS for geospatial analysis and thematic-boundary maps production. Finally, this will result in the creation of a web geo-browser for visualizing historical maps as a source and related metadata, geospatial analysis results and maps showing differences in boundary-lines.

The second project ("ETSCH2000", funded by the Autonomous Province of *Bolzano/Südtirol*), concerns a different issue yet has something in common with the above-mentioned project, one which plays a significant role in using historical maps as source material. Most large rivers in Italy and Europe have been significantly altered by human activities throughout the centuries. The overall goal of ETSCH2000 is to reconstruct the morphological adjustments of the River Adige between the *Südtirol* and *Trentino* over the last 2000 years, and to put it in relationship with the history of relevant direct pressures (e.g., channel rectification) and indirect ones (e.g., variation in hydrological and sediment regimes), anthropic and climatic alike. The project proposes an interdisciplinary approach that integrates geo-historical investigations, geomorphological analysis and mathematical modelling that will provide a morpho-historical reconstruction of a large river system at large spatial (150 km) and time scales, furnishing a modern view on the concept of reference conditions for such a highly modified river system.

In this mainly methodological paper which follows an idiographic approach, a cartographic time-series was considered as a data-set, one which starts after the First Military Survey (1763–87, scale 1:28.800, not including Tyrol): from the *Kriegskarte* by Anton von Zach (1798–1805, a survey of Venetian territories which shared common boundary lines with Trentino); then with the Lutz map of the Tyrol (1806, 1:28.800) and its *Reambulierung* (updating) by Reininger-Geppert (1816–21, 1:28.800), both of which were included in the Second Military Survey (1806–69, 1:28.800); to the Third Military Survey (1869–87, 1:25.000). All the maps are conserved in Vienna (the *Kriegsarchiv*-KA, and the *Kartographische Archiv* of *Bundesamt für Eich- und Vermessungswesen*-BEV)[4] and Innsbruck (*Tirolerlandesarchiv*-TLA).

3 Map Accuracy and Methodology

We are therefore faced with cartographies composed of hundreds of map-sheets,[5] with a good positional accuracy since these are maps produced in the late 18th century (Zentai 2013), but this is also after a planimetric/positional analysis on

[4]The authors would like to thank engineer Heinz König (former Head of the Department of International Affairs and State Boundaries, BEV-*Bundesamtes für Eich- und Vermessungswesen*, Vienna) for his kind help with all issues regarding BEV map-production.

[5]Digitized using a flatbed cold-light scanner in multi-resolution format (bit depth RGB 24 bits, TIFF master files 600 dpi, JPEG 300 dpi and 72 dpi for web).

sample sheets (e.g., Dai Prà and Mastronunzio 2014). The positional accuracy appears significant for maps at this scale, notably for earlier ones at larger scale (at least 3 times the graphic error, up to approximately 10 times). However, it ought to be highlighted that these maps present certain anisotropic deformations over the course of 200 years (as with other case-studies, e.g., Monti et al. 2009). Moreover, regarding map accuracy, it is well-known that the distortions generated by mapping an ellipsoid into a reference plane can be reduced by selecting the most appropriate map-projection/standard parallels and that the effects of distortions are increasingly avoidable from small-scale towards topographical to fine-scale maps (Triplat Horvat and Lapaine 2015). This, in theory, matches to our regional purposes, due to our data-set composed only of large scale maps. However, in practice our case is quite difficult for a number of maps: the problem is not *whether* an ellipsoid was mapped to the projection plane, rather that *no* ellipsoid was used.

Although a geodetic basis was used since the Second Military Survey—Zach 1809 or Bessel 1841 ellipsoid, Vienna Datum 1806 or Hermannskogel Datum 1871—as well as different projections such as Cassini (or Cassini-Soldner modified) or the Gauss-Krüger projection (Buffoni et al. 2003; Mugnier 1999, 2004; Timár 2004; Timár et al. 2006), other previous or contemporary to early survey campaigns of the Second Military Survey (*Kriegskarte* by von Zach of Venetian territories, Lutz map of Tyrol) have no fundamental geodetic survey, being produced using only triangulation with plane tables[6] and theodolites, starting from a central meridian (crossing astronomical observatories) with latitude/longitude (from the Ferro prime meridian) of the surveying points astronomically determined.

With the exception of a number of case-studies (e.g., Dai Prà and Mastronunzio 2014) such maps are not yet georeferenced. However, it is necessary to place them in a common reference system (ETRF89) in order to compare with present-day reference maps (Google Map, Open Street Map and official topographic basemaps) for both geospatial analysis and dissemination purposes. In other words, each map-sheet needs to be localizable, avoiding a massive initial georeferencing/mosaicking process onto the whole data-set., as well as avoiding merging sheets with graphic software and the subsequent georeferencing of large areas composed of several map-sheets.

Thus, our current work centres on developing a methodology for regional purposes, using a map-sheet overview (index-map sheet)[7] provided alongside the maps (if any) and often neglected in a GIS-framework. The original reference systems were investigated by merging these data with archival documents and contemporary literature.

The 4-step map-to-map (warping) workflow is: (a) assign to index-maps the native reference system; (b) shift from Ferro[8] to Greenwich prime meridian with

[6]The so-called "Marinoni table", *Messtisch* in German.

[7]*Übersichtblatt* or *Skelett* in German.

[8]Ferro was the most common classical prime meridian of Habsburg mapmaking from the late 18th century onwards and, in the Republic period, until the 20th century. Moreover this is clear from evidence in several index-maps ("*östl. L. v. Ferro*").

longitude rotation; (c) perform the geographic datum transformation to WGS84; (d) reproject in the ETRF89 UTM system.

Generally speaking, the first step (a) is the most difficult, since investigations into "imperial geodesy" are characterized by a certain lack and/or sometimes by inconsistency of information recoverable from archival documents along maps and contemporary literature, as highlighted below in the case-studies presented (furthermore these are in 18th and 19th century German so quite time-consuming). For this reason, given the poor information regarding native reference systems, we also used a "comparative cartography" approach (Harley 1968), due to the geometric accuracy of suitable comparable maps and since these maps cover the same area using a comparable scale. As well as the methodology, which was the same for both case-studies, the initial results were also quite similar.

4 Case-Studies

4.1 The Third Military Survey (1869–96) Index-Map: A Map as a Tool

Alongside the Third Military Survey (1869–96),[9] at a scale of 1:25.000, the relevant index-map was given providing both the map-sheets overview of such a Survey, as well as the map-sheets overview of the *Spezialkarte*[10] (1872–1944) at a reduced scale of 1:75.000. The Third Survey was mainly based on the most common classical imperial datum, the so-called *Militärgeographisches Institut* (MGI) Datum of 1871, and on the Bessel ellipsoid of 1841 (Molnár and Timár 2009), although at a very early stage (1869–71) the previous Vienna Datum of 1806 was still used (Mugnier 2004). In our case, however, regarding map-sheets of the current Trentino-South Tyrol region produced in 1871, the MGI Datum was used.

The first problem in our case-study is the ellipsoid. The original Bessel ellipsoid was in *Klafter* (fathom, *toise*), with the semi-major axis a = 3272077,14 fathom, but which one: the *Wiener* or *Fortifikations Klafter*? The latter has the same length of the *toise de Paris* (also termed *Pariser* or *französische Klafter* in German).[11] As well as other historical anthropometric measures (Dai Prà and Mastronunzio 2016), the Bessel-fathom is also uncertain. So we have used the values of the ArcGIS library for Bessel-1841:

[9]German title: *Dritte Landesaufnahme* (or *Franzisco-Josephinische Landesaufnahme* or *Neue Aufnahme*). Index-map and map-sheets used in the present case-study are conserved in the Archive of BEV (*Bundesamt für Eich- und Vermessungswesen*, Vienna). For an overview of this map, see Abart et al. (2011).

[10]Complete German title: *Übersichtsblatt zur Militär-Landesaufnahme und zur Spetialkarte der österr.-ungar. Monarchie.*

[11]*Wiener Klafter* = 1,896484 m (from 1871, previously 1,896614 m), *Fortifikations Klafter* = 1,94903 m (Rottleuthner 1883; Savart 1825).

a = 6377397, 155 m (semi-major axis); 1/f = 299, 1528128 (inverse flattening).

Yet the problem is not fully solved—it would appear that the original ellipsoid definition is in *Fortifikations Klafter*—since such a value represents a weighted mean of values from several authors but did not account for differences in the length of the various fathoms (US Army Map Service Technical Manual 1943, quoted in ArcGis library and *ArcGis Guide*). However these values remain the most easy-to-use ones and the most quoted in current literature (Mugnier 2016, 2004, 1999).

Other uncertainties come from the Datum. The fundamental point of MGI Datum *is* Hermannskogel, but this is also another Datum from 1871 therefore the two-systems are almost the same. Moreover, in the ArcGis library, Hermannskogel is not properly referred to Ferro and the Datum selectable as "Hermannskogel" refers to former Yugoslavia, *not* to Austria. The last inconsistency for the MGI-Datum is represented by different longitudinal coordinates of the Hermmanskogel fundamental point between current literature (Mugnier 2004)[12] and the ArcGis library. Hence the values of the ArcGIS library for MGI-Datum (Ferro, Hermannskogel point) were used:

Lat = 48° 16′ 15.29″N; Long = 33° 57′ 41,06″E of Ferro.

Thus, according to the proposed 4-step workflow (a map-to-map warping methodology), we assigned the Bessel 1841 ellipsoid as mentioned before; in the same way, the aforementioned Datum MGI-Ferro—the only one originally referred to Ferro—was assigned in order to use the transformation parameters to WGS84 already implemented in ArcGis and quoted in the relevant literature (Mugnier 2004), without new computation. Subsequently, well-distributed corners (representing the 4 corners of each map-sheet) from the index-map were selected, assigning the relevant lat./long. coordinates, which were easily readable (both on paper as well as on the raster one) in the index-map (as well on each map-sheet, but without georeferencing these sheets), thus finally obtaining our index-map referenced in its native geographic (not projected) reference system. Since the most accurate way is to reference a map in its native system first, in this case (the index-map) such a system is projectionless, even if during the second half of the 19th century the Gauss-Krüger projection was adopted.

The following step consists of the application of the longitude rotation method, from "non-Greenwich" (Ferro, in our case) prime meridians to Greenwich. Having obtained the Third Military Survey index-map referenced in MGI-Greenwich system (geographic, not projected) we then performed the geographic datum transformations from MGI-Greenwich to geocentric WGS84 datum using the Position Vector 7-parameters methods. As mentioned above, in this case, parameters are already provided in the ArcGis library (the same were reported by Mugnier 2004), as follows[13]:

[12]Long. 33° 57′ 27,08″ E of Ferro.

[13]dx = x axis translation (m); dy = y axis translation (m); dz = z axis translation (me); rx = x axis rotation (arc-sec); ry = y axis rotation (arc-sec); rz = z axis rotation (arc-sec); ds = scale difference (ppm).

dx = 577, 33 dy = 90, 129 dz = 463, 92 rx = 5, 137 ry = 1, 474 rz = 5, 297 ds = 2, 4232.

Finally, once transformed into the WGS84 geographic reference system, the index-map of the Third Military Survey (and of the *Spetialkarte* too) was easily projected into the ETRF89 UTM planimetric reference system.

4.2 Kriegskarte *(1798–1805) Index-Map: A Map in-Between*

Like the First Military Survey (1763–87)[14] carried out without a fundamental geodetic survey (no ellipsoid, no datum), but using the Liesganig triangulation and then executed graphically with plane tables and theodolites (namely: a topographic/trigonometric surveying; von Nischer-Falkenhof 1937), the *Kriegskarte*[15] by von Zach was performed using the "von Zach triangulation" at the same scale (1:28.800) and without a geodetic base. A map "in-between" the First and the Second Military Survey (1806–69)[16] was thus produced, the latter characterized by the early imperial geodetic survey, using in its middle stage the Zach ellipsoid[17] of 1809 and the Vienna Datum-1806[18] with *St. Stephan Turm* as the fundamental point (Mugnier 1999, 2004; Timár 2004; Timár et al. 2006),[19] both of them

[14]German title: *Erste Landesaufnahme* (or *Josephinische Landesaufnahme*).

[15]Title: *Topographisch-geometrische Kriegskarte von dem Herzogthum Venedig […] 1801–1805 aufgenommen […]*. Nowadays stored at the *Kriegsarchiv* (Vienna). The most valuable and comprehensive study on this map is the book by Rossi (2005).

[16]German title: *Zweite Landesaufnahme* (or *Franziszeische Landesaufnahme)*. Note that the archival title of the *Kriegskarte* is the same as the Second Military Survey: *Franziszeische Landesaufnahme Venetien.*

[17]The Zach-Oriani hybrid ellipsoid (1810) was later used for cadastral survey (Buffoni et al. 2003). Both ellipsoids have the same 1/f = 310, but a different semi-major axis: a = 6376480 m (Zach-1809); a = 6376130 m (Zach-Oriani-1810). Originally, the Zach-1809 has a = 3362035 *Wiener Klafter*, but with the *Wiener Klafter* length prior to 1871 (see above, note 11).

[18]As argued (Timár 2009), the Second Survey regarding the Tyrol was performed using a different Datum, centred in Innsbruck (the same used later for cadastre); such analysis considers, for the Tyrol, the Reininger map of 1816–21 (stored at *Kriegsarchiv*, Vienna). However, the first survey of the Tyrol was the Lutz map *finished* in 1806 (also as *Originalaufnahme*, stored at the *Tiroler Landesarchiv*, Innsbruck) and it represents the first survey ever "within" the Second Survey, whereas the Reininger map represents its *Reambulierung* (updating). This means that the Lutz map could not have had a geodetic basis as it predates the Vienna Datum and the Zach ellipsoid. The Lutz map and *Kriegskarte* share this "in-between" feature, otherwise defined, for the Tyrol, as "Survey Number One and a Half" (Timár 2009).

[19]There are some inconsistencies between the *St. Stephan Turm* coordinates of the Vienna Datum-1806. Mugnier (2004) and Timár et al. (2006) report Lat. 48° 12′ 31, 5277″N, Long. 16° 22′ 27, 3275″E of Greenwich (originally 34° 02′ 13, 3275″E of Ferro, following the Albrecht-deviation of 17° 39′ 46″ used throughout the Empire); instead Mugnier (1999) and Timár (2004) report Lat. 48° 12′ 34″N, Long. 16° 22′ 29″E of Greenwich (34° 02′ 15″E of Ferro).

developed after the *Kriegskarte*. Thus, von Zach started his surveying from 1798 (Rossi 2005).[20] The first ellipsoid ever was the Laplace one of 1802, considered suitable also for Italian territories, and the second one, contemporary to the Zach one, was the Bohnenberger ellipsoid of 1809 (Timár and Molnár 2013), also partly used for the Second Survey (Mugnier 2004).

Another contemporary "hypothesis" ellipsoid (without its own name) was developed for Italian territories by von Babel and von Scheppler with inverse flattening 1/f = 334 (von Zach 1803b, von Babel and von Scheppler 1803), but in some cases this latter and the Laplace one was considered not suitable—in brief, some contemporary literature present, for a large number of northern Italian cities, several lists of lat./long. coordinates (*Verzeichnis*; von Zach 1803b), considering the Laplace ellipsoid (von Zach 1803c) or "Babel-Scheppler" ellipsoid. On the contrary, and within the same literature sources, the ellipsoid effects were not considered, thus complicating things further.

This means that, in contemporary documents and literature, we are clearly able to find only information regarding triangulation, such as surveying methods, topographical instruments and calibration, notably about the setting-up of baselines (*Verifications-Basis* and *Versicherungs-Basis*). In particular, for the Tyrol, it is possible to find information about surveying metrical inaccuracy (e.g., in difficult to access mountain areas on the border with Venetian territories, due to a certain lack of survey-points useful for a precise triangulation; von Zach 1803a). Finally, the "von Zach triangulation" was centred in Padua (Italy), in the astronomical observatory (as usual and with lat./long. astronomically determined from the Ferro prime meridian), with a *central* meridian: the "Padua meridian" (*Paduaner Meridian*) and its related parallel (*Paduaner Paralel Zirkel* or, simply, the *Perpendikel*), which is not really a *prime* meridian but merely the meridian to start the triangulation and set-up 3-trigonometric-baselines (*Standlinien*), as well as the coordinates which were not a datum fundamental point but only the lat./long. of the Padua observatory[21] (von Zach 1803a).

Thus, since the *Kriegskarte* has no geodetic basis (or has, at this stage of investigation, an unknown one), but its mesh of map-sheets on index-map appears to fit well enough (at least for our purposes, see final remarks below) with the one of the above-analysed Third Military Survey, we applied the same procedures accordingly to the proposed methodology: (a) Datum MGI-Ferro and Bessel 1841 ellipsoid selection, as well as well-distributed corners assigning the relevant lat./-long. coordinates (representing the 4 corners of each map-sheet) from the index-map, to obtain *Kriegskarte* not in its native but in a comparable (and easy to manage) geographic reference system (geographic coordinates are generally reported on the index-map but in detail on each map-sheet); (b) longitude rotation

[20]Contrary to von Nischer-Falkenhof (1937) and contrary to the map title, from 1801.

[21]Moreover, von Zach was the first to introduce (and invent) the false origins method to obtain only positive length values: false easting was the *fingierte Meridianer* and false northing was the *Perpendikel* (von Zach 1803a).

application, from Ferro to Greenwich; (c) geographic datum transformations, from MGI-Greenwich to WGS84, using the Position Vector 7-parameters methods (with the same parameters); (d) ETRF89 UTM projection.

5 Initial Results and Final Remarks

What results is a georeferenced index-map that readily provides the 4-corner coordinates of each single map-sheet for subsequent georeferencing (Fig. 1), assigning the corner ETRS coordinates (from index-map) to corresponding corner-points (onto single sheets) without identifying landmarks/control points both on old and current reference maps.

The positional accuracy is considerably better for maps with a geodetic basis (the Third Military Survey) and in flatlands, with increasing inaccuracy in relief areas (the Tyrol-Venetian border in the *Kriegskarte*) and without a geodetic basis (*Kriegskarte*). Moreover, from 1 to 3 additional landmarks/control points are needed to align (zero-order transformation) the old map to the current target one (Fig. 2), but avoiding a massive selection of control points in both historical and reference maps required for a standard method and in the whole data-set.

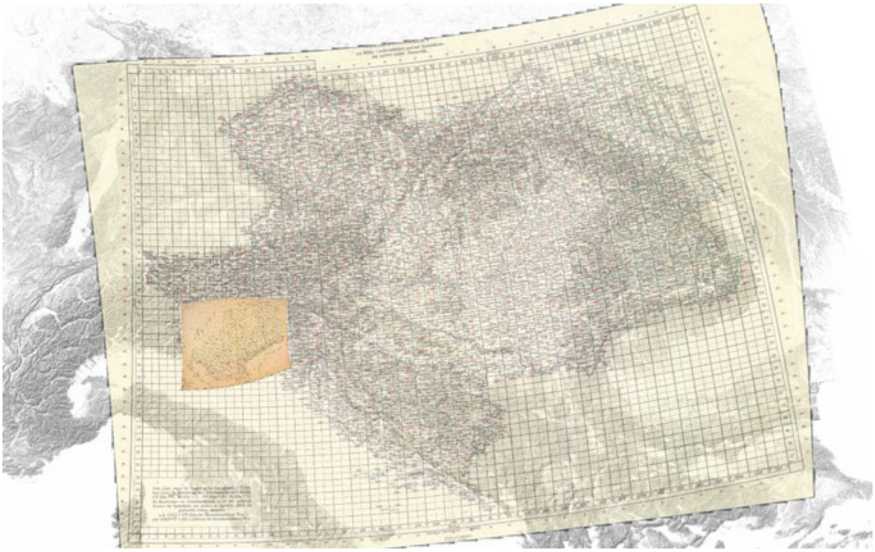
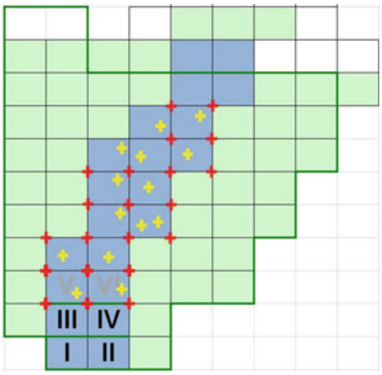


Fig. 1 Index-map of third military survey (larger) and index-map of *Kriegskarte* (smaller) overlaid on a shaded DEM (adapted by the authors from sources: BEV-Vienna for the third military survey; the *Kriegsarchiv*-Vienna for *Kriegskarte*; the WORLD OSM WMS for shaded DEM, developed, hosted and provided via WMS by the University of Heidelberg, www.osm-wms.de)

Fig. 2 Map-sheets XI.6–7 and XI.10 of the *Kriegskarte* (*right-side*) and map-sheet 5546–4 of third military survey (*bottom-left*; aligned, see text) georeferenced with proposed methodology (adapted by the authors from sources as Fig. 1)

Regarding the shift between the two graticules as represented in Fig. 2, it is necessary to point out that this does not mean incorrect datum settings (since the *Kriegskarte* simply has no datum), rather it should be read as an outcome of the presented "comparable-reference-system" method. Despite the inaccuracy (but fairly suitable for dissemination purposes), fewer control points of a standard rectification might be used: 6 corner-points for 2 sheets, 10 corner-points for 4 sheets, 22 corner-points for 10 sheets and so on (if the sheets are in one column or row), also applying a few additional points (Fig. 3). For instance, in the case of a data-set of 43 non-georeferenced map-sheets, with a standard georeferencing approximately

Fig. 3 Framework of proposed methodology: 6 corner-points for 2-map-sheets, 10 for 4-sheets, 22 for 10-sheets and so on; representation of additional points (inside sheets)



10 GCP per map-sheet are probably required, for a total amount of 430 GCP. Indeed, with the "corners georeferencing" approximately (it depends on the sheets schema, in columns or rows, or with a different arrangement, e.g., 16 corners for 8 sheets in a different schema) 71 corners-points might be used, adding a mean of 2 GCP per sheet (tot. 86 GCP) for shifting (with a zero-order transformation), making a final total amounting to 157 GCP.

If inaccuracy (for each map-sheet, not for small scale index-maps) represents a weakness, the overall gain of the proposed methodology could be, as mentioned, the application of procedures directly onto the index-map, avoiding significantly time-consuming procedures on each map-sheet. Furthermore, in general, referencing an old map in its native (or, as in the first case-study, comparable) reference system, could avoid the introduction of distortions generated by a georeferencing process directly applied in a present-day reference system.

Finally, it is possible to obtain a data-set of points coordinates (for the second case-study this was undertaken both for the Third Military Survey and *Spetialkarte*) in the most common European planimetric reference system (e.g., official topographic base maps), as well as easy to reproject in Web Spherical Mercator (e.g., Google Maps, OSM).

6 Further Research

In conclusion, while the proposed methodology has to be refined, it could nevertheless provide a useful means of using maps as a tool for non-GIS-oriented fields and might therefore be considered suitable for further research in digital humanities, notably in spatial humanities.

Further research must be carried out towards an improvement of the proposed methodology. First of all, more in-depth investigation about early Datum and ellipsoid needs to be undertaken to reach a native reference system, since for these Datum and ellipsoid, the transformation parameters are not provided and the rototranslation parameters have to be calculated using pairs of control points derived from comparable maps.

Secondly, if arriving at native systems proves difficult then truly best-fitting procedures (Livieratos et al. 2011) ought to be applied and not only a generic comparison approach as presented here.

Furthermore, the different pixel resolution between index-map corner-points and map-sheets corners have to be "merged" (due to the difference between the small scale of index-maps, on the one hand, and the large scale of map-sheets, on the other).

Finally, the correct procedure should be the vectorization and automated generalization of a mesh of index-maps, but at the current stage this represents a future issue: vector-based GIS frameworks deal with geoinformation, whereas raster-based ones deal with cartography, with maps as data-sources for geoinformation itself.

In this sense we are at an early stage: not the vectorization but the digitization. However, the common starting point is always to make sense of the "geo" prefix put before "information", through a suitable georeferencing process.

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GEOTHNK: A Semantic Approach to Spatial Thinking

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Abstract Spatial thinking has lately been acknowledged as an important ability both for sciences and for everyday life. There is a clear need for enhancing spatial thinking in education and engaging both educators and learners in more critical, inquiry-based teaching and learning methods. In this context, GEOTHNK project is a European effort to propose a scientifically grounded, technologically sustainable, and organizationally disruptive framework for the development of learning pathways for enhancing spatial thinking across education sectors and learning environments.

Keywords Knowledge structure · Inquiry-based learning model · Geospatial thinking · Formal and informal education

1 Introduction

Spatial thinking uses the properties of space as a means of solving problems, finding answers, and expressing solutions (National Research Council—NRC 2006). In other words, it uses space for structuring problems, seeking answers, and formulating possible solutions associated with space in science, in workplace and in everyday life. It also includes the ability to review and analyse space, which is essential to educated citizens for decision-making.

According to Booth and Thomas (2000), spatial thinking includes cognitive skills related to map reading and making, processes involving representation, scale,

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_20

transformation, production and recall of symbolic information, recognition and understanding of spatial projections, coordinate systems, geometric configurations, formulation of verbal instructions as well as navigation and orientation based on observation and instruments handling. In education, though, other forms of thinking such as verbal, metaphorical, hypothetical, and mathematical, have supplanted spatial thinking.

Spatial thinking is defined as a constructive synthesis of three components: (a) concepts of space, (b) tools of representation, and (c) processes of reasoning (NRC 2006). The geospatial domain presents an excellent opportunity towards achieving a meaningful connection between theoretical, higher-level concepts and tools of representation and their application in everyday life such as locating one's home or following directions to an unknown place. For example, to identify areas vulnerable to flooding due to sea level rise, learners should grasp spatial concepts such as location, distance, proximity, and elevation, use representation tools such as maps and terrain models, and be able to perform reasoning processes, such as combining maps to evaluating multiple criteria (e.g., location of settlements) and making inferences about environmental consequences. These components are also helpful in understanding many other georeferenced phenomena, such as the spatiotemporal change of countries and their boundaries due to historical events.

However, research proves that the three components of spatial thinking are not treated equivalently in education; low-level spatial concepts are given priority relatively to higher-level ones and spatial representations, whereas higher-order cognitive skills are rarely prompted (Injeong and Witham 2009). Furthermore, geospatial knowledge is usually static and independent from other knowledge, impeding critical thinking and understanding of complicated interactions among entities, events, and phenomena in space.

The NRC Report marked the need for a major turn in education towards the enhancement of spatial thinking: "fostering spatial literacy can be achieved only by systemic educational reform" (NRC 2006). In Europe, however, there is not a declared official priority in this area yet.

In this context, the GEOTHNK Project is a European effort for a scientifically grounded, technologically sustainable framework for the development of learning pathways for enhancing spatial thinking across education sectors and learning environments. The Project takes a methodological approach that accounts for several conceptual, pedagogical, and developmental premises such as (a) spatial thinking notions and dimensions, (b) the formation of spatial perception during one's lifetime, and (c) knowledge structure for facilitating intuitive thinking.

The paper is organised as follows: Sect. 2 reveals different aspects of spatial thinking and how they apply to education and Sect. 3 presents several educational initiatives worldwide that focus on spatial thinking and knowledge. Section 4 exposes the GEOTHNK approach to spatial thinking teaching and learning, while Sect. 5 discusses insights gained by the project thus far, and finally Sect. 6 indicates that way forward.

2 Spatial Thinking; Basic Notions and Aspects

Before we begin by exploring notions relative to spatial thinking, a discussion on scale is necessary. Montello (1993) divides space into four classes, depending on the projective size of space relative to the human body and, judging from the cognitive processes needed for the understanding of spatial dimensions. This classification divides three-dimensional space into:

- Figural space; perceived in all its properties, without requiring locomotion by humans
- Vista space; includes the human body, is relatively as large or larger than that and comprises a room or a town square
- Environmental space; larger than the human body, comprising semantic information, is variable and hardly perceptible without moving into it, comprises of buildings, neighbourhoods, cities and, finally,
- Geographical space; much larger of the human body and cannot be understood directly even by human movement. Conversely, it can be perceived through representations, such as maps or schematic models.

Therefore, which type of space GEOTHNK deals with? To answer this, it should be pointed out that the term “geospatial” refers to environmental and geographical scales according to the previous classification and it is used in literature for representation and analysis of geographic phenomena (Golledge et al. 2008). Geographers in the traditional curricula deal with geospatial phenomena and refer to environmental and geographical space; GEOTHNK focuses mostly on these two but incorporates knowledge related to figural and vista space as well.

Furthermore, spatial abilities include the following (Golledge 1992):

- thinking geometrically;
- imaging complex spatial relations at various scales, from urban systems to interior room designs or table top layouts;
- recognizing spatial patterns in distributions of functions, places and interactions at a variety of scales;
- interpreting macro-spatial relations such as star patterns;
- giving and comprehending directional and distance estimates as required by navigation, or the path integration and short-cutting procedures used in way finding;
- understanding network structures used in planning, design and engineering; and,
- identifying key characteristics of location and association of phenomena in space.

Finally, the distinction between knowledge of space and knowledge about spaces made by Eliot (2000) is significant; he suggests that the former is phenomenal, while the latter is intellectual.

3 Spatial Thinking Initiatives in Education

As the importance and amplitude of spatial thinking in various scientific and everyday tasks has been acknowledged, several efforts are currently made towards its effective development through education, some of which are outlined in what follows.

3.1 TeachSpatial

TeachSpatial[1] (2011) is an environment for browsing several hundreds of teaching and learning resources annotated with spatial concept terms. To date the initiative: (a) lists 129 spatial concept terms grouped in 10 categories derived from the National Science Education Teaching Standards (NRC 1996), (b) gives links to reference publications related to spatial cognition, spatial teaching and learning, and spatial literacy, and (c) provides stakeholders with collaborative tools for sharing views and experience.

3.2 Geographic Information Science and Technology Body of Knowledge (GIS&TBoK)

The Geographic Information Science and Technology Body of Knowledge (AAG 2006) by the American University Consortium for Geographic Information Science (UCGIS) attempts to draw an outline of the concepts and skills pertaining to GIS, GIScience, remote sensing, satellite navigation systems, and cartography. The intention was to serve as resource for curriculum design and curricula mapping and comparison, for educational assessment and accreditation, and professional certification. GIS&TBoK is hierarchically structured, composed of 10 Knowledge Areas, further divided into 73 Units and 329 Topics. Each topic includes a list of 5–10 educational objectives corresponding to varying levels of knowledge and skills.

Currently, GIS&TBoK is being revised in the context of the BoKOnto project,[2] which will transform the initial body of knowledge into an ontology for the field of GIScience and Technology.

Following a very similar context, GI-N2K[3] constitutes the European answer to GIS&TBoK envisioning to establish its European counterpart. Twenty-five

[1]Undertaken by the Center for Spatial Studies, University of California, Santa Barbara, while supported by the U.S. National Science Foundation.

[2]http://gistbok.org/#.

[3]http://www.gi-n2k.eu/.

countries participate in the project with 31 partners from the academic and non-academics sectors, the GI industry and GI associations of professionals and experts.

3.3 Schools Online Thesaurus—ScOT

Schools Online Thesaurus website—ScOT (2014) provides a controlled vocabulary used in schools in Australia and New Zealand; it includes terms (concepts and topics) of various thematic areas, as described by the countries' formal curricula.

Terms (concepts) contained in this thesaurus, are structured hierarchically. For some concepts, there exists a structure of multiple inheritance; they are subconcepts of more than one concept, which actually means that they belong to more than one topic of the curriculum. An example is coordinates, which belongs to two knowledge areas, Science and Mathematics shown in Fig. 1.

The thesaurus contains over 10,000 concepts, of which only a small part has spatial dimension. It is worth noting that the majority of these "spatial" concepts are part of the vocabulary of two out of ten Knowledge areas (Mathematics and Science), which provides evidence of the close relation between spatial thinking and STEM disciplines. To a lesser extent, spatial concepts can be found in other Knowledge areas such as Arts, Society, and Technologies.

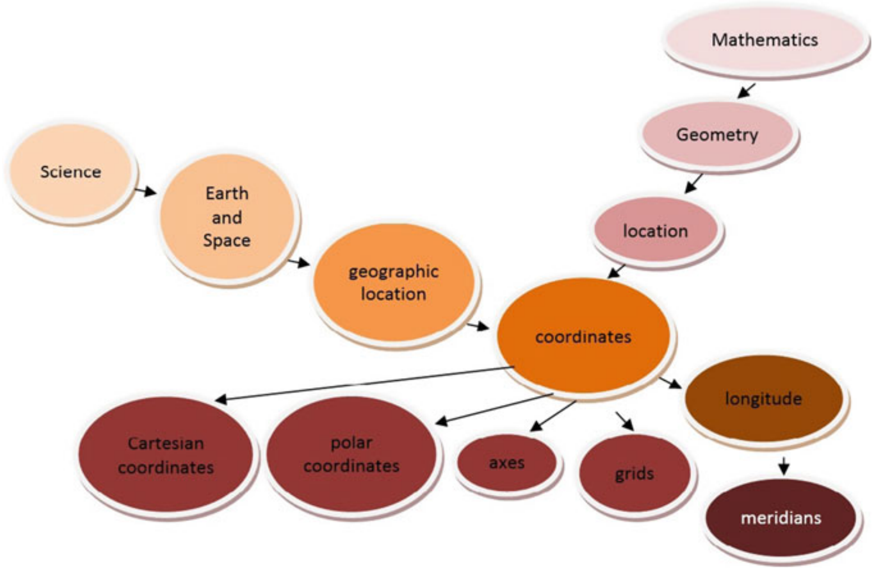

Fig. 1 The complete schematic representation of coordinates in ScOT

3.4 ITS Education Asia

The website ITS Education Asia (2013) developed by a group of private schools and enterprises, aims primarily at students in the fields of economics, literature and language, science and psychology. This website is a collaborative effort between a number of private schools in Asia to help pupils of secondary education, early university students, and school teachers in understanding and teaching the aforementioned courses.

Dictionaries are developed for various knowledge areas, among which the Geography Dictionary and Glossary (Harrington 2014) which contains over 1500 terms all cross-referenced and linked.[4] Advantage of the Geography dictionary is that a number of definitions contain links to online resources in an attempt to facilitate understanding of the underlined concepts.

A close inspection of the Geography dictionary reveals that it lacks a great deal of "geospatial concepts" directly defined and therefore not included in the glossary as distinct entries. They, nonetheless, are indirectly included in existing definitions; from the example of longitude, a number of spatial concepts can be identified. Browsing the Mathematics dictionary (Halliday 2014), several "spatial" concepts are defined therein (e.g. distance), another proof connecting spatial thinking to STEM disciplines.

4 Geospatial Thinking Building Blocks in GEOTHNK

The European project GEOTHNK[5] aims at: (a) enhancing spatial thinking through an innovative ICT-based approach and an open, collaborative educational environment and (b) offering a methodological approach that allows the interdisciplinary organization and semantic linkage of knowledge.

The GEOTHNK approach goes beyond the provision and organization of resources. An innovative learning and teaching environment has been developed for the semantic linkage of geospatial concepts, representation tools, and reasoning processes in between and across other domains that may also provide relevant and meaningful contexts (e.g., Environment, Earth Sciences, Social Sciences, etc.). As mentioned, "spatial thinking is a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning" (NRC 2006) and GEOTHNK follows this premise.

GEOTHNK Community of users cover diverse target groups; teachers, university students, science center educators, and adult learners which address different

[4]An example is the definition of longitude (http://www.itseducation.asia/geography/l.htm#Longitude), where underlined words indicate lemmas in the dictionary and the user is prompted to look up another reference as well by following a url.

[5]GEOTHNK Website, http://www.geothnk.eu/.

levels of education; schools (primary and secondary), higher Education, and adult education in two distinct educational environments; formal (schools and universities) and informal (science centers/museums). Moreover, since GEOTHNK constitutes a European project, its content is generated in six European languages: English, Bulgarian, Dutch, German, Greek, and Romanian.

To accomplish the project's objectives, the pedagogical methodology adopted in GEOTHNK follows the Inquiry Based Learning Model (IBLM) as formulated over the years by various researchers and perspectives (Collins 1986; DeBoer 1991; Rakow 1986), and has been officially promoted to pedagogy for improving science learning in many countries (Hounsell and McCune 2002; NRC 2000; Rocard et al. 2007). Five essential features characterise IBLM when applied in classroom; learners: (1) engage themselves in scientifically oriented questions, (2) give priority to evidence in responding to questions, (3) formulate explanations from evidence, (4) connect explanations to scientific knowledge and (5) communicate and justify explanations.

The IBLM is implemented by the GEOTHNK authoring tool and community,[6] which gives educators and learners an open, collaborative environment for developing learning pathways based on the three components of spatial thinking; users are prompted to add to their scenarios concepts, representation tools, and reasoning tools. A Learning Pathway describes the organization and coordination of various individual learning resources into a coherent plan so that they become a meaningful learning activity for specific target audiences in a specific learning environment. The GEOTHNK Community allows users to revisit, revise and continually develop pathways, or even use pathways created by others for creating their own new versions, in a process reflecting social learning in the community.

4.1 Concepts

The set of GEOTHNK concepts is formulated based on a thorough analysis of existing vocabularies, which have been presented in Sect. 3. GEOTHNK includes 342 concepts, both spatial (e.g., coordinates, altitude, and distance) and non-spatial (e.g., natural resources and alternative energy), concepts referring to tangible objects (e.g., city and canal) and concepts referring to abstract notions (e.g., form and connection). Spatial concepts are considered important not only for understanding relative disciplines such as Mathematics and Geography, but they are either directly or indirectly related to other disciplines as well such as History and Social Sciences. Each concept is described by three elements: (a) a term, (b) a definition, and (c) links to useful educational on-line resources to facilitate

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[6]GEOTHNK Authoring Tool and Community, http://portal.opendiscoveryspace.eu/community/geothink-community-400866.

Fig. 2 The concept "planning" in the GEOTHNK authoring tool

understanding of concepts (770 in total collected by the consortium); Fig. 2 shows a characteristic example.

The set of GEOTHNK concepts was developed according to the following principles: (a) interdisciplinarity, (b) transversality and, (c) semantic linkage of concepts.

4.1.1 Interdisciplinarity

Interdisciplinarity, among the major innovative elements of GEOTHNK, is accomplished through the inclusion of three kinds of concepts:

- General concepts not particularly focused on any specific discipline, such as class, accuracy, analysis, and analogy but rather cross-cut different disciplines,
- Specific concepts relevant to particular disciplines such as Geography, Earth Sciences, Environment, and Mathematics. For example, the concept continent is mainly relevant to Geography, deforestation to Environment and interpolation to Mathematics.

- Interdisciplinary concepts relevant to several scientific fields that function as a bridge for linking these and for developing multifarious scenarios. For example, the concept city may be used for several pathways dealing with a variety of subjects, such as urban planning, population distribution, urban evolution through history and urban sprawl. Each one of these pathways deals with the concept city from a different perspective, associates it with different other concepts, and triggers different aspects of spatial thinking.

The motivation for selecting such a diverse set of concepts is the integration of knowledge from different disciplines. GEOTHNK does not aim at imposing a single, specific view of concepts that users should adhere to, but to provide a wide, flexible range of views on these. In that way, users may develop different pathways for the same concept or topic reflecting diverse views or interests.

4.1.2 Transversality

Geospatial thinking varies according to various factors (age, background knowledge, etc.) and therefore cannot be treated uniformly for all target groups. The transversal character of GEOTHNK concepts, i.e., their adaptation to the needs of all target groups is reflected in the three elements that describe the concepts: (a) terms, (b) definitions, and (c) links to useful resources. Terms and definitions are derived from WordNet (2014), which provides alternative terms for each concept and comprehensible definitions with example sentences that meet the needs of GEOTHNK's target groups.

However, the transversal character of GEOTHNK concepts is mainly reflected in the links to useful resources that describe each concept. For each concept, a range of resources with varying degrees of difficulty is offered for fitting the needs and background knowledge of the user groups, as shown in Fig. 2. In general, a teacher needs more simplified explanation of concepts; a university student needs a more elaborate description, while an adult learner usually needs a more general one.

4.1.3 Semantic Linkage of GEOTHNK Concepts

Equal importance as the development of the GEOTHNK set of concepts is given to the establishment of interrelations among them. Concepts are organised in a three-level hierarchy that reflects clusters of basic notions and subject areas such as geometric primitives, spatial relations, space-time primitives, geography etc.

The concepts have been further analysed based on WordNet's large lexical database for discovering relations among them. GEOTHNK concepts are not linked only through strict taxonomical relationships such as hypernymy/hyponymy but also through other relations such as meronymy/partonomy and association. In this

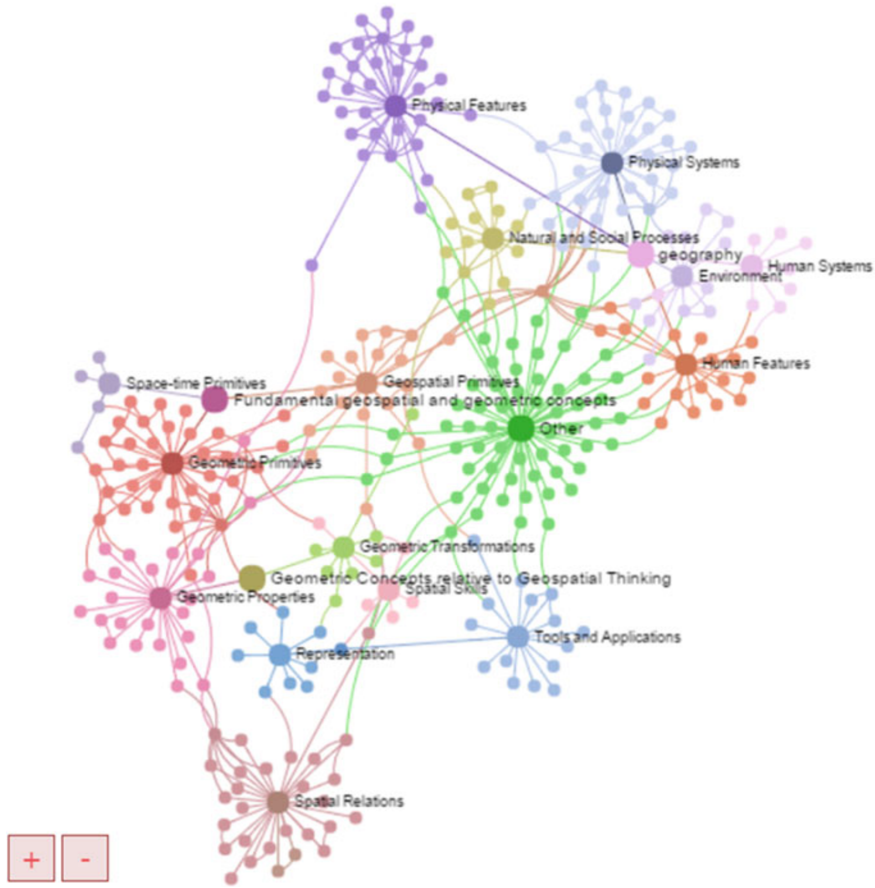

Fig. 3 GEOTHNK semantic network

way, GEOTHNK does not enforce a specific view regarding concepts and their relations but allows flexibility during the development of pathways. To ensure semantic linkage, GEOTHNK concepts form a semantic network (Fig. 3), of a total 802 taxonomic relations, developed initially in English and further translated into the languages of the Consortium. Users are able to browse it to find out the structure of geospatial knowledge. Furthermore, once a pathway is created, the platform enables its overview in graphical form, that is, it highlights the concepts involved in the pathway, and the relations between them. In Fig. 4, the excerpt of the semantic network that corresponds to a particular learning pathway represents the conceptual structure of the pathway, which reflects the creator's conceptions of the subject matter.

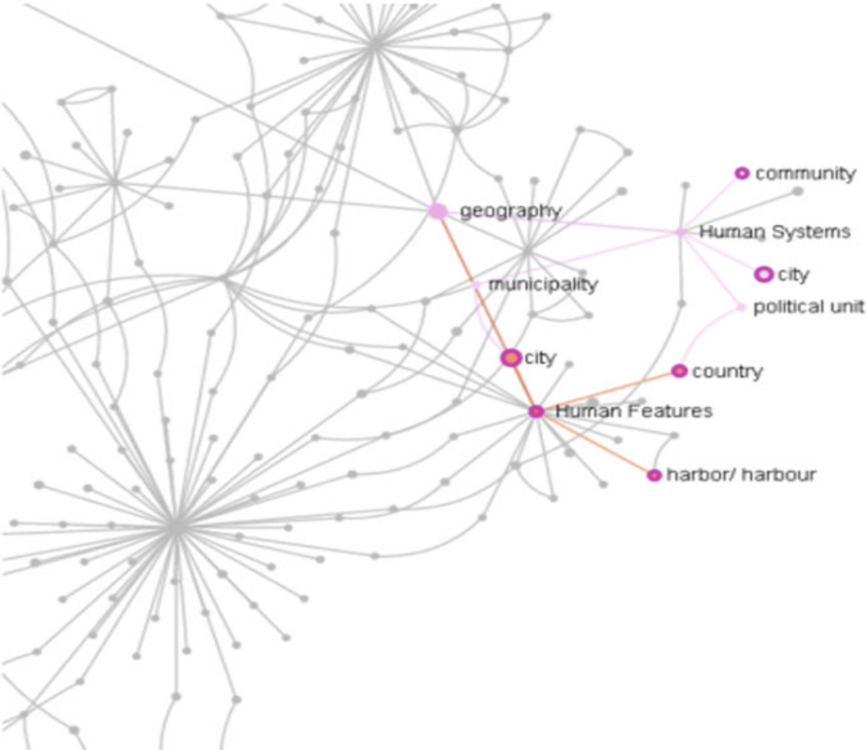

Fig. 4 The semantic network of an individual pathway (First world war: the conflict of ideologies)

4.1.4 Instances

"Putting on the map" learning pathways is an important functionality—and innovation—of the GEOTHNK educational platform which aims at: (a) connecting the conceptual/semantic to the geospatial/cartographic information as to a better understanding of geospatial concepts and geographic space, and (b) supporting an additional search mechanism, i.e., the map-based search of learning pathways. This is achieved through concepts' instances and the extraction of their geographic coordinates from gazetteers. In particular, certain concepts referring to real entities, natural (e.g., rivers, mountains, etc.) and man-made (e.g., cities, towns, etc.) are populated with instances extracted from GeoNames geographical database.[7] Instances play a dual role; (a) they serve as examples to help clarify the meaning of concepts (e.g. many pathways developed for explaining the notion of flood or the concept of sea level rise use the Netherlands as an instance of the concept country)

[7]http://www.geonames.org/.

Fig. 5 Putting GEOTHNK learning pathways on the map

and (b) their positions on a map (by their coordinates) support map-based search of pathways as shown in Fig. 5.

4.2 Representation Tools

Representations, either internal or external, serve as an effective reasoning tool and trigger complex reasoning processes and abilities (NRC 2006). The ability to create and use spatial representations is a necessary process towards spatial thinking. Representations, which include maps, models, diagrams, and graphs help in making the most abstract concepts understandable (Mathewson 1999). According to Newcombe and Huttenlocher (2000) symbolic representations of spatial location, either in language description or in the various kinds of optical displays serve the transmission of information obtained. On the other hand, science and technology are developed through exchange of information and data and a large part of these are presented as diagrams, illustrations, maps, schematics, which summarize information and contribute to their understanding by the wider public (Mathewson 1999). Representations also “help us remember, understand, reason, and communicate about properties of and relations between objects represented in space, whether or not those objects themselves are inherently spatial” (NRC 2006).

Additionally, Uttal (2000) found out that the use of maps and thinking about them can help children understand abstract concepts of space and gain systematic thinking about spatial relations with which they have not come into direct contact. In addition, the “exposure” to maps can help children think the numerous spatial relationships that may exist among locations.

Representation tools vary in terms of the following: (a) media (tangible, digital, auditory, etc.), (b) form (static, dynamic, interactive), and (c) level of detail (from abstract graphs to detailed aerial photographs or satellite images). Representations may depict geospatial entities and phenomena at different scales such as oceans, landforms, water bodies, cities, forests, industrial areas, buildings, etc. They may also depict entities and phenomena beyond environmental and geographic scales (Montello 1993), both at the micro scale e.g., DNA maps and macro scale, e.g., maps of the universe. Space and spatial representations are also used as a metaphor for creating the so-called spatializations.

To support the development of multifarious pathways, GEOTHNK provides links to various categories of representation tools (links to 55 online representation tools added by the consortium):

- Maps, Map Viewers, and Map Making; includes online maps and web mapping applications for map viewing (e.g., Google Maps, Bing maps, OpenStreetMap, etc.) and map making (e.g., MapMaker Interactive).
- Country Maps; includes maps from GEOTHNK partner countries to support users from different countries in pathway development.
- Atlases; includes mainly educational resources for world maps accompanied with other useful information such as geopolitical, social, religious, statistical etc.
- Historical maps; provided from digital Libraries may be used for the development of pathways that deal with the evolution of geospatial entities through time.
- Virtual globes; includes web-based 3D applications that display geographic data on spherical representations of the Earth.
- Satellite and Aerial Imagery; includes aerial photographs and satellite images provided mainly for educational purposes. Figure 6 shows the NASA Earth Observatory featuring the Image of the Day as an example of a repository of satellite imagery that GEOTHNK provides link to.
- Data Visualizations[8]; tools and resources for viewing, exploring, and creating data visualizations, such as graphs, charts, mind maps, tree maps heat maps etc., not necessarily representing geospatial data but any kind of data.
- Models; includes 2D and 3D geometrical models, which are commonly used for supporting STEM education.

[8]Examples include spicynodes (http://www.spicynodes.org/) and biggeplate (http://www.biggerplate.com/).

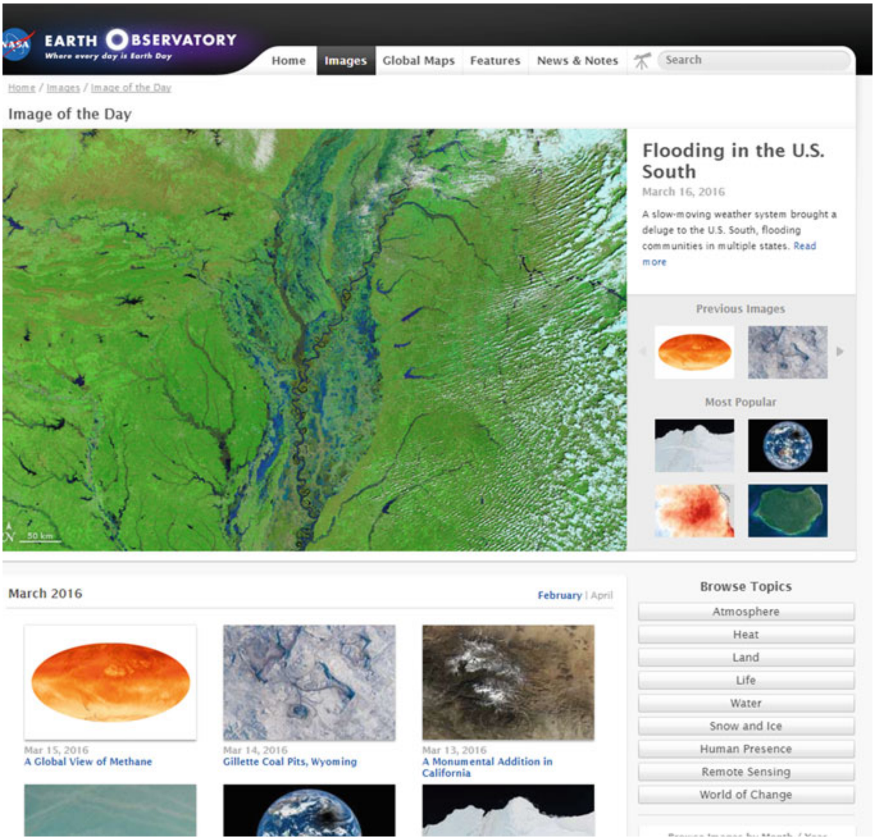

Fig. 6 The NASA earth observatory, image of the day repository, http://earthobservatory.nasa.gov/IOTD/

4.3 *Reasoning Tools*

Thinking is a cognitive process, while reasoning is considered an important cognitive ability (Presseisen 2001). Marzano and Pollock (2001) identified six general reasoning skills: (1) identifying similarities and differences, (2) problem solving and fault detection, (3) argumentation, (4) decision making, (5) hypothesis testing and scientific research, and (6) the use of logic and reasoning. Furthermore, studies by Holyoak and Morrison (2005) and Presseisen (2001) recognized that reasoning process covers cognitive processes, such as analysis, hypothesis, problem solving, and generalization.

Reasoning processes, therefore, are cognitive processes that allow the combination of spatial knowledge and representations to achieve problem solving and decision making through analysis, classification, hypothesis, generalization, and evaluation. The idea is that defining spatial thinking as an operating procedure facilitates the development of spatial literacy.

A reasoning tool may be any kind of tool (educational game, learning activity, interactive application, etc.) that may facilitate the understanding of a concept or pathway and prompt reasoning processes. The reasoning tools on the GEOTHNK educational platform are classified into two types:

1. Reasoning tools for understanding a specific concept. For example, for teaching the concepts distortion and projection, Google Mercator Puzzle[9] represents such a choice.
2. Reasoning tools for understanding or implementing a learning pathway. For example, for implementing a pathway for urban planning, an educational game such as Plan It Green[10] may be used.

Reasoning tools are not predefined, since they are pathway-specific. For this reason, the platform allows users to add new reasoning tools relevant to their needs and objectives.

5 Feedback and Insights Gained from the GEOTHNK Community

Users contribute to the repository by either: (a) creating new educational objects or pathways, (b) reusing pathways developed by other users, (c) tagging educational resources, and (d) creating new reasoning tools.

To date, there are 700 registered members in the GEOTHNK Community. These have added or reused 427 on-line resources (144 educational objects and 283 pathways), have created 68 reasoning tools, and have introduced over 4000 tags on resources.

It is important to point out that the content is implemented in six different languages. Regarding learning pathways, several have been developed in more than one language, since their contributors have showed an interest in helping the community and addressing a bigger audience with their contribution, fact that raises the number of pathways to 415.

The partnership has been monitoring the quality of the uploaded content throughout the project's life cycle, which led to the identification of 40 exemplary pathways. These represent the best examples of content created on the platform in terms of the overall approach (use of all three components of spatial thinking, meaningful allocation of resources, and adoption of the Inquiry Based Learning Model). They have been especially indicated on the platform as exemplary scenarios so that users can assess them easily and have a clear image on how to

[9]http://gmaps-samples.googlecode.com/svn/trunk/poly/puzzledrag.html.

[10]http://www.planitgreenlive.com/en/build-your-own-city.

develop coherent learning pathways that follow the GEOTHNK approach to its fullest. Indicative examples of such pathways consist: (a) perceptual image of an urban environment,[11] (b) Milky Way—the back-bone of night,[12] (c) the injectivity, surjectivity, bijectivity properties of functions—graphical recognition,[13] and (d) Volcanoes and Plate tectonics.[14]

Concerning the relation of added resources to education levels, the great majority of resources addresses formal educational contexts; 119 for primary, 294 for secondary, and 77 for higher education. However, regarding target audiences, 42 resources have been added for science centers educators for any educational context, and 73 resources for adult learners. These numbers indicate that GEOTHNK has succeeded in meeting the various target groups' needs as formulated in the beginning of the project.

Another interesting finding is the connection of GEOTHNK resources to curriculum subjects as these have been defined by the community members. The vocabulary provided to the Community for connecting resources to the curriculum comes from Open Discovery Space (ODS),[15] a multilingual open learning platform for sharing eLearning resources, in the context of which a vocabulary of subjects for several European curricula has been formulated. Table 1 gives solid evidence of the strong relation between spatial thinking and STEM disciplines; as expected, Science comes first, and following downward the hierarchy of the ODS vocabulary, Geography and Earth Science Mathematics appear in the list as well as Environmental Education, Physics, and Astronomy, while ICT is also present in the list of subjects. Table 1 gives also some insights on the relation of spatial thinking to Humanities, with the presence of English teaching and History subjects in the list of most chosen disciplines.

A closer look in the subjects included in the general area of Geography and Earth Science, reveals 21 resources developed for Maps and plans, 19 in the context of GIS, 9 for Cartography and 6 for Spatial Transformations, to name a few relevant to the overall thematic area of Mapping and Cartography. While examination of the general area of Mathematics, exposes, 34 resources relevant to Geometry, 10 to Graphical Display of Data and 7 to Transformation, which can also be considered related to Mapping and Cartography.

Another inspection on the Community analytics provides interesting facts about content of the resources added by the users. Regarding GEOTHNK Concepts included in user-generated learning pathways, Table 2 shows the twenty most used

[11]http://portal.opendiscoveryspace.eu/edu-object/perceptual-image-urban-environment-830235 created by a Greek postgraduate student.

[12]http://portal.opendiscoveryspace.eu/edu-object/milky-way-backbone-night-834098 developed by a Bulgarian university professor for pre-service Astronomy teachers.

[13]http://portal.opendiscoveryspace.eu/edu-object/injectivity-surjectivity-bijectivity-properties-functions-graphical-recognition-830247 contributed by a secondary education Romanian teacher.

[14]http://portal.opendiscoveryspace.eu/edu-object/platentektoniek-en-vulkanen-834837 uploaded by a Dutch science center educator.

[15]http://opendiscoveryspace.eu.

Table 1 GEOTHNK resources and curriculum subjects

Curriculum subjects	Resources
Science	221
Geography and Earth Science	197
Mathematics	52
Environmental Education	41
Physics	13
Astronomy	9
ICT	32
English teaching	27
History	25

ones, with the predominance of the concept map being undisputable giving evidence on how the use of maps in education can be a powerful tool for enhancing spatial thinking abilities of learners. High on the list are the concepts Representation, scale, and mapping finding that also indicates the strong relation of spatial thinking teaching and learning and Cartography-related notions.

Spatial thinking interdisciplinary character is given also evidence upon variety of pathways developed including the same concept. For instance, 38 scenarios include the concept scale, as indicated in Table 2, which relate to a diversity of curriculum subjects; Cartography, Astronomy, Physics, Mathematics, Geography, Earth science, geology, Mapping etc.

During the GEOTHNK Project, both the overall approach and the GEOTHNK Authoring Environment have been validated. The validation instruments and feedback tools especially developed for the needs of the project have proven to be effective as they both worked perfectly with different target groups participating.

Teachers and teachers' trainers admitted that school students found it feasible to follow the GEOTHNK activities and that they enjoyed using reasoning tools that were suggested by GEOTHNK. Moreover, they declared that their students' spatial thinking skills have been improved and that the educational framework (Inquiry Based Model) was the most appropriate pedagogical approach for communicating geosciences. Finally, they were familiarized with tools that were new to them after admitting that they did not use such tools in class before.

On the other hand, university students stated that being taught via GEOTHNK could help them do better in their studies apart from mentioning that they found the experience interesting. Also, they answered that GEOTHNK platform was important for their improvement and that the use of reasoning and representation tools suggested by the platform is fundamental and at the same time beneficial for the preeminent teaching of geospatial issues. In the very same perspective, they agreed that GEOTHNK educational pathways eased the teaching of geosciences. Overall, they replied that geosciences issues became more attractive for them after the use of GEOTHNK.

Meanwhile, science centre educators noticed that visitors of science centres and museums found their involvement with GEOTHNK enjoyable and it was feasible

Table 2 Twenty most used GEOTHNK concepts in user-generated learning pathways

Concept	Occurrences
Map	*109*
Location	90
Geography	85
City	75
Representation	*70*
Spatial relations	59
Area	54
Distance	52
Methods and abilities	51
Island	48
Fundamental geospatial and geometric concepts	44
Geographic information systems	42
Geometric concepts relative to geospatial thinking	42
City	39
Scale	*38*
Spatial relation	38
Time	37
Physical systems	36
Mapping	*35*
Tools and applications	35

for them to follow GEOTHNK activities. They also stated that adult learners enjoyed the use of representation and reasoning tools and that in this case they contributed to the development of problem-solving skills of the adult learners. Most importantly, they declared that geosciences' issues became more attractive for adult learners after the use of GEOTHNK. They finally admitted that through the development of spatial thinking their problem-solving skills are also empowered.

6 Conclusions

To support spatial thinking in formal learning environments, it should be incorporated into the general education system including educational practices, curricula, teaching support materials, and assessments. In Europe, no such priority is yet formulated, which presents a challenge for projects such as GEOTHNK to turn into policies and trigger educational policy reform in the long term.

Our experience from the GEOTHNK Community has shown that there is more to spatial thinking than meets the eye. GEOTHNK groups of users have a wide, multidisciplinary conception of spatial thinking that cross-cuts different subjects and levels of education More specifically, regarding teachers in the community, these vary in terms of the discipline they practice; there can be found English, Math, even

Art teachers that constitute a multifarious audience that blends with Geography teachers and give strong evidence that spatial thinking cross-cuts the curriculum and should be dealt with accordingly.

GEOTHNK has proven very successful in reaching its initial objectives. It has raised awareness among educators of different education levels in Europe towards spatial thinking and how it can be taught inside and outside the classroom. Future steps include among others, tracing spatial thinking across the curriculum, which is a challenging task since it cross-cuts curriculum subjects. Furthermore, we envision directly addressing the learners; to date GEOTHNK focuses on educators and how these can be encouraged in including spatial thinking notions into their teaching, while it would very valuable to assess how the GEOTHNK approach can actually enhance learners' spatial thinking skills. Finally, discussion from the previous section has indicated that spatial concepts relate somehow to the international trend and discussion about crosscutting concepts in education, thus a step further would be to showcase how crosscutting concepts such as scale, pattern, and system may be explicated using real-case examples from the spatial or geospatial domain connected to spatial thinking skills.

Acknowledgements Research conducted and presented herein is partially funded with the support of the Lifelong Learning Programme of the European Union in the framework of the GEOTHNK Project (Pr. no 543451-LLP-1-2013-1-GR-KA3-KA3MP).

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Thematic Cartography: A Key Course in Geospatial Engineering

Chrysoula Boutoura, Alexandra Kousoulakou and Angeliki Tsorlini

Abstract In this paper a new revised undergraduate course on Thematic Cartography (TC) is presented as a 5 ECTS compulsory core course of the 300 ECTS undergraduate curriculum of a relevant European University engineering School leading to a five years engineering degree, comparable to the MEng degree, after the submission of the diploma dissertation. The paper presents the underlying philosophy for the course design, respecting fundamental criteria of university education and considering the fact that this TC compulsory course is the basis of a series of other nine cartography plus GIS related elective courses available in the curriculum, oriented in various engineering disciplines (geodesy and surveying, cadastre and photogrammetry, infrastructure engineering, including road construction, transportation, hydraulic works, environmental engineering). This course is focused not only on the theoretical issues of TC but also on implementation in terms of a web-based course, targeting at the familiarisation of the students with a series of relevant free software applications in relation with the mining of relevant data from the EUROSTAT free provider, in order to develop modularly a TC project. It is shown how this key course covers the educational and student needs of a spectrum of other courses that follow in the engineering curriculum and raises an overall interest of engineering students for cartographic science and technologies.

Keywords Thematic cartography · University education · Geospatial engineering curriculum

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_21

1 Introduction

The presentation here of the rationale and the implementation strategy followed in developing a new compulsory Thematic Cartography (TC) base-course refers to a five-years/ten-semesters curriculum of university studies in geospatial- and infrastructure-related engineering in Greece, leading to a MEng degree at the level of 300 ECTS.[1] The engineering degree in this particular field defines a long historical track of studies and profession with solid roots in the country's early 20th century higher education system and even older, having the relevant studies, offered first at the military academy in 1829 and establishing them in the 1830s after the foundation of the modern Greek state.

Cartography in Greece is traditionally treated among the core subjects of the studies and research in the two geospatial- and infrastructure-related university engineering schools in Athens and Thessaloniki,[2] covering the whole spectrum of the field in the sense of the issues treated in the international scientific and professional bodies of, at least, the ICA, IAG, ISPRS and FIG.[3] Both schools offer education and research to satisfy the requirements of a discrete engineering degree, with strong relevance and ties with geodetic, surveying, cartographic, photogrammetric, remote sensing, cadastral and geoinformation related matters focused on the engineering points of view and definitely beyond. Cartography in Thessaloniki was treated at a privileged level, mainly since the early 1980s after the relevant Chair of *Higher Geodesy and Cartography* was first established in 1979.[4] From the first

[1]The issue refers to the new TC course developed and implemented at the School of Rural and Surveying Engineering at the Aristotle University of Thessaloniki (AUTH), Greece (http://www.topo.auth.gr/main/index.php/en/studies-atm-2/undergraduate-studies), one of the seven independent Schools of the Engineering Faculty providing 300 ECTS engineering degrees at the MEng level. This School was established in 1962 third, after Civil Engineering (1955) and Architecture (1957). It consists of three Departments: Geodesy and Surveying; Cadastre, Photogrammetry and Cartography; Transportation and Hydraulic Engineering, all providing undergraduate and postgraduate teaching and research. The AUTH School and its counterpart at the National Technical University of Athens, offer the MEng level degree in "Rural and Surveying Engineering" leading to the professional engineering State license, after a legal examination, and to the enrolment at the Technical Chamber of Greece, the official technical adviser of the State.

[2]Definitely engineering-born and historically related to engineering higher education development (Livieratos 1993), also because, in contrast to other European countries (including the neighbouring countries), the geography higher education studies started very late, only in the mid-1990s.

[3]ICA: International Cartographic Association (http://www.icaci.org); IAG: International Association of Geodesy (www.iag-aig.org); ISPRS: International Society of Photogrammetry and Remote Sensing (www.isprs.org); FIG: International Federation of Surveyors (www.fig.net).

[4]Headed by Prof. Evangelos Livieratos, who since then (1979) and for the next 36 years dedicated efforts, energies and resources in developing cartographic teaching and research in Thessaloniki. TC was taught for the first time in Greece by E. Livieratos, at the National Technical University of Athens in 1978; his text-book *General Cartography and introduction to Thematic Cartography*, Ziti Editions, Thessaloniki (2nd ed. 1989), is a basic reference, in Greek, for teaching introductory cartographic courses.

three cartographic courses introduced at that time: *General Cartography, Thematic Cartography, Mathematical Cartography,* all backed by relevant lecture-notes, the current curriculum of geospatial- and infrastructure-related engineering at Thessaloniki counts nine "pure" cartography-based undergraduate compulsory and elective courses for a total of 38 ECTS, to which a number of GIS relevant courses should be also considered, as parts of subjects relevant to geodesy, surveying, photogrammetry and remote sensing, cadastre and geoinformation as well as in the post-graduate courses. Thus, it is not a coincidence that some cartographic institutions were founded and operate in Thessaloniki: the *Hellenic Cartographic Society* (HCS),[5] the *National Centre for Maps and Cartographic Heritage,* now *Archives of Cartographic Heritage*,[6] together with the seats of other international cartographic activities as it is e.g. the ICA Commission on *Cartographic Heritage into the Digital* (2006–2019) and the international web journal *e-Perimetron*, since 2006.[7]

Having such a background, the approach to a Thematic Cartography (Arnberger 1966; Imhof 1972; Dent 1996; Slocum et al. 2005) key undergraduate compulsory course is a highly demanding and challenging issue for our overall educational and training process, taking into account the synthetic and multidisciplinary profile of the engineering degree which combines a very strong geodetic-geospatial engineering component with a component related to the multifold issues of the engineering of infrastructures.

2 Thematic Cartography as a Basic Engineering Course

2.1 The General Picture

Thematic Cartography (TC) is a basic course in most geospatial/geomatics engineering and geography related curricula of tertiary education in Europe and worldwide. Our TC course (Course ID 20052253) is compulsory in the list offered at the 4th semester programme of undergraduate studies under the general course description, reading as: "The object and history of TC; thematic data and classification; the issue of scale and projection in thematic maps; standards, rules and practices in the graphic and image representation of thematic information; acquisition, process and representation of thematic data; symbolism of qualitative and

[5]The HCS is since 1995 a member of the International Cartographic Association; before its establishment the AUTH Department of Cadastre, Photogrammetry and Cartography was an affiliate member of the ICA.

[6]Established in 1997 and operated as independent public legal entity under private law to 2013, when was merged in the General State Archives of Greece operating since then as its distinct section.

[7]Commission website: cartography.web.auth.gr/ICA-Heritage; e-journal on sciences and technologies affined to the history of cartography and maps, website: www.e-perimetron.org.

quantitative information; the issue of ordering information; classes of thematic maps—choropleths, isarithmic contouring, topologic maps, atlases; statistics in TC; graphics and design in TC". This general description reflects the TC impact to the content of other cartography-related courses coming next in higher semesters, as electives i.e. the courses of map use, map production, cartographic visualisation and non-conventional cartography and other courses focused on GIS (Table 1). A team of two academic staff members, assisted by two external volunteers, and a senior student, guide the class, supported online by a networked researcher based abroad, who contributed in the initial development of the new TC course.[8]

The TC course is backed by a dedicated web page,[9] which is the on-line reference of the students for downloading the exercises and get general and targeted information about the course and relevant student activities, also with links to relevant sites.

2.2 *Motivation and Strategy*

The challenge of designing a compulsory TC course for students in engineering was based on the fact that the design should follow the fundamentals of the engineering education, namely:

- The *structural* (analytic and synthetic) and the *modular* approach to knowledge, rather than the "integral", "in-one-shot" approach, which is mainly the case of non-engineering or engineering education which follow the track of the 180 ECTS level curricula.

Engineering education at a 300 ECTS level of studies should prepare the student:

- To construct *his own synthetic solution,* according to the theoretical background of TC accounts, basis of any *analysis*, especially in the perspective of facing and solving the highly demanding ad hoc situations often appeared in the engineering practice.
- To develop *synthetic systems* based on *modular* tools.

Following the content of the TC course, the series of class lectures are combined by the series of computer-assisted exercises with which the students meet for the first time the cartographic mapping topics. The basic educational strategy is based on:

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[8]Respectively: Profs. Chrysoula Boutoura and Alexandra Kousoulakou the academic staff; Dr. Maria Pazarli and cand. Dr. Nopi Ploutoglou, the external volunteers for the Archives of Cartographic Heritage by the General State Archives of Greece; dipl. Math. Filippos Makris, the senior student; Dr. Angeliki Tsorlini, post-doc fellow at IKG-ETH Zurich, winner of the 2015 "Prix Carto—digital" of the Swiss Society of Cartography for the product OCAD 12 ThematicMapper with the IKG ETH Zurich and the OCAD AG firm.

[9]The TC course web site: http://cartography.web.auth.gr/Thema_Carto.

- The *in situ implementation* using on-line data (e.g. the freely provided EUROSTAT data).
- The proper setting of requirement for thematic map design in terms of point, linear, areal (surface) and 3d data.
- The *modular-wise* familiarisation with a series of basic software tools (preferably freely available), offering flexibility for synthetic solutions.
- The use of *purposely selected* simple tools to get the students familiarised with: the *underlying theory* of TC, the *technical requirements*, the often need to *combine software* in more cartography-dedicated interdisciplinary engineering applications in order to construct quality maps in terms of *both* the geometric and thematic contents.
- The postulate that students should *NOT be just users* of available integrated, all-in-one professional tools ("great", but not meant for a student's first compulsory educational acquaintance with TC).
- The consideration of students as *NOT stream-users* of just one "in-one-shot" software tool, usually expensive and sometimes rather questionable for student use.
- The educational principle that university students, future engineers, must learn to create maps complete and correct in both their *geometric-projective* and *thematic* components, according to the rules of the internal and external map reading (Bertin 1967), ready to be used in many types of applications, at the worksite or in office, printed ad hoc in few copies (in the RGB mode) or in printing house in many copies (in the CMYK mode).
- The planning for the deepening in TC issues, both theoretical and practical, in cartography and GIS related courses to come next according to the curriculum of studies (Table 1).

As required and expected in an educational process, the main didactic effort for the consolidation of knowledge in a complex field like TC, requires implementation strategies and practical experience, the imposing theoretical background apart, is to focus on an efficient plan of exercises targeted at the advancement of the students efficacy in approaching integrally a TC project. Following this principle, we per-formed recently a reform of the TC exercise–practical student work, focusing

Table 1 Purely cartography-related courses (*C* compulsory and *E* elective) in the engineering oriented curriculum of 300 ECTS level studies

Semester	Course	Type
3	- Introduction to Cartography	C
4	- **Thematic cartography**	C
7	- Computer assisted cartography - Map use	E
8	- Map design and production	E
9	- Non-conventional cartography - Cartographic visualisation - History of cartography	E
10	- MEng thesis	C
Plus the relevant GIS courses (C, E)		

on the gaining of online experience in the chain of data acquisition, processing and cartographic representation. The basic idea is the in situ implementation of an integrated project by the students, using on-line a European institutional web provider of thematic data, familiarising themselves with a series of software applications for data analysis, vector- and raster-wise graphic design, image processing etc., all assembled in a workflow.

3 Steps and Targets

3.1 The Data Provider

The main concern of this plan in the TC teaching strategy for engineering students is to make them aware of the great importance of the linking with the underlying geospace of the ordered data coming either from the physical (natural) world or/and from the human world, all data requiring a TC referenced mapping and visual monitoring. This is achieved perfectly using e.g. a data provider as it is EUROSTAT (2015a), selected for its prestige, institutional authority and validity of data, which attracts the interest and the attention of the students from the very beginning of the process (Fig. 1).

The EUROSTAT (2015b) website gives the possibility to students to meet and browse the huge crowd of geospatial information collected over time and to familiarise themselves with the ordering of spatial units, which is a basic concept in TC (Fig. 2). This gives the students the direct view and understanding about the European geospatial arrangement distributed in areal units for the better classification and management of information.

The examples of good practices, including proper cartographic visualisation and the contexts of thematic issues treated, concerning the demographic, social, political, cultural and economic situation in Europe, easily retrievable and downloadable from the EUROSTAT (2015c) provider, familiarise students with the themes and show them the importance of organising properly the geospatial data in tabular and/or pictorial media the latter in terms of diagrams, cartograms and maps helping thus them to consolidate the theoretical teaching and to draw “real life” conclusions on the spatial distribution of phenomena.

The use of the EUROSTAT portal as the basic on-line provider of real and updated spatial thematic data, which are already represented on existing maps (used thus in the teaching process as examples of good or bad cartographic practice, if it is the case) or suitable to be represented in a new TC project carried out by the students. These data satisfy in multipurpose way the teaching strategy and work in the class, helping the in situ concentration of the students’ interest and self-acting but also the growth of the group work in testing and discussing alternatives. More,

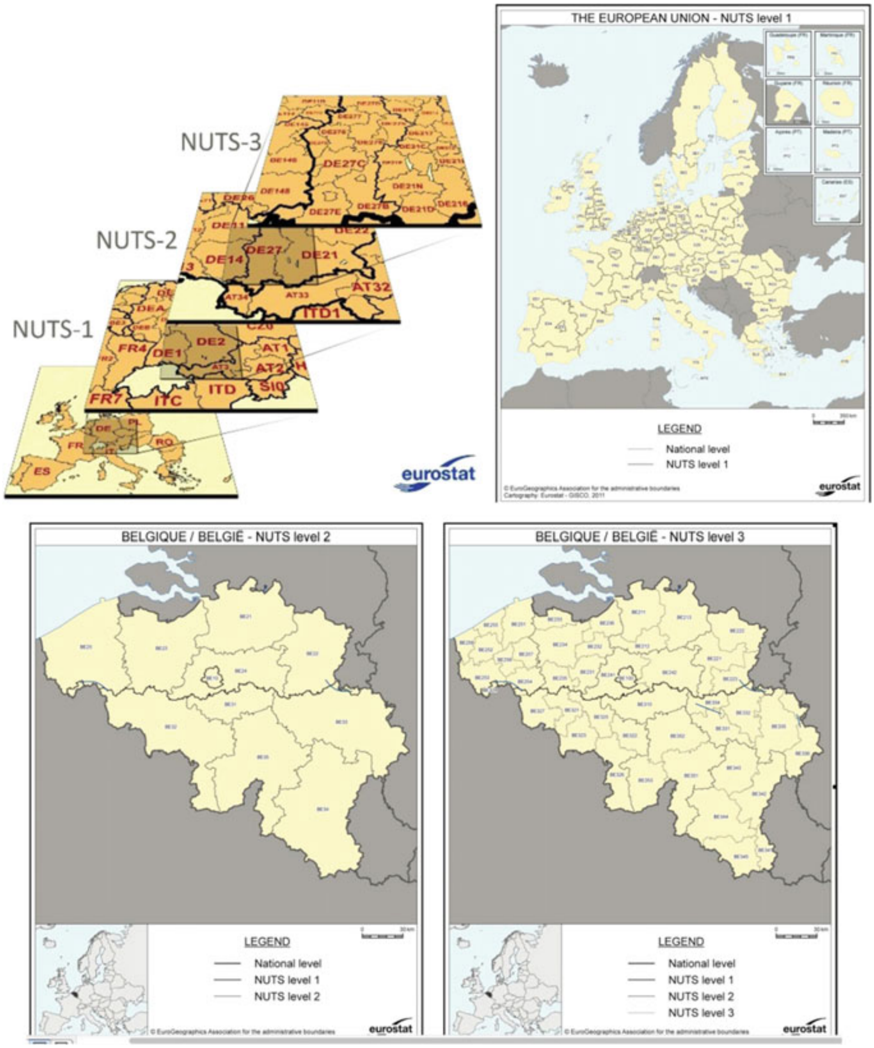

Fig. 1 The NUTS classification (Nomenclature of territorial units for statistics) as a hierarchical system for dividing up the economic territory of the EU (*Source* EUROSTAT portal)

the students are encouraged to think different approaches for the treatment and representation of the available data and to learn to criticise constructively the solutions adopted by the EUROSTAT staff. This is achieved in class by elaborating and depicting the relevant data and the associated spatial distribution in students' own alternative way, enriching this way their cartographic knowledge and training impact.

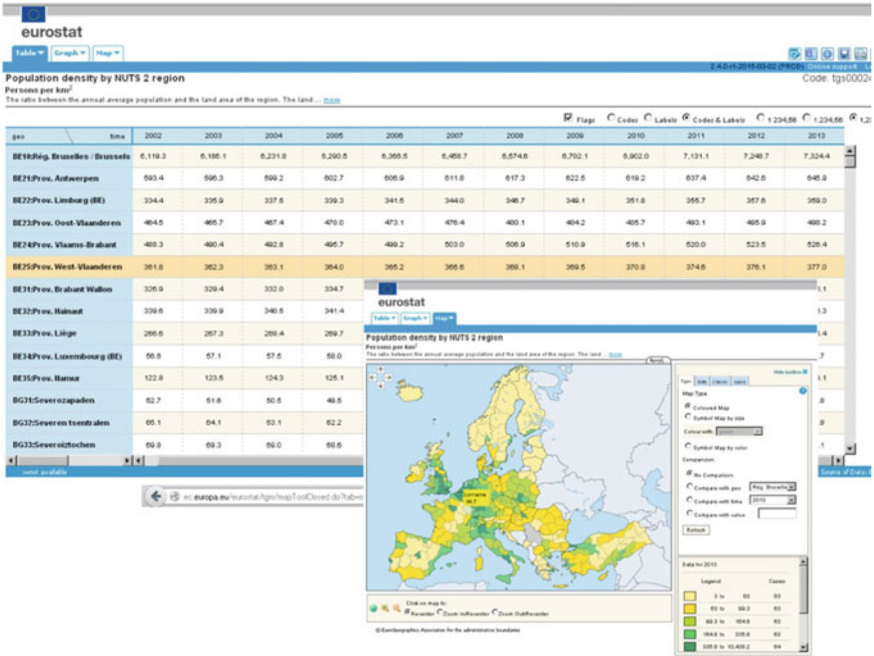

Fig. 2 Online thematic map directly associated with the database (*Source* EUROSTAT portal)

3.2 The Cartographic Implementation

The next step in the student work and the interaction with the tutor is the use and proper implementation of the TC rules for the preparation of own thematic maps using the available basic software applications. Thanks to the plan and the modular approach, students are trained to use a range of software applications for the mathematical and graphical management of spatially related information.

The applications are used in a sequential mode, following the combined use and learning procedure in order to prepare thematic maps properly representing point, linear, surface and volumetric data. Applications like “Jasc PaintShop Pro”, “Microsoft Office Excel”, “ColorBrewer”, “GoldenSoftware Surfer” and other less known supportive software are used in a chain-wise flow for a *best* thematic mapping of data downloaded from the EUROSTAT portal in the EU regional spatial levels according to the EU countries administrative division (Figs. 3, 4, 5, and 6).

Following this logic, the students are not more stream-users of just one dedicated software application for the construction of a thematic map (Dorling et al. 2006, Sandvik 2008), since the dedicated software is constrained upon a predefined typology from those taken among the very few existing for this purpose or as those in GIS applications.

On the contrary the students learn how to be unconstrained to just one possibility and constructive in combining a number of relevant software applications (usually

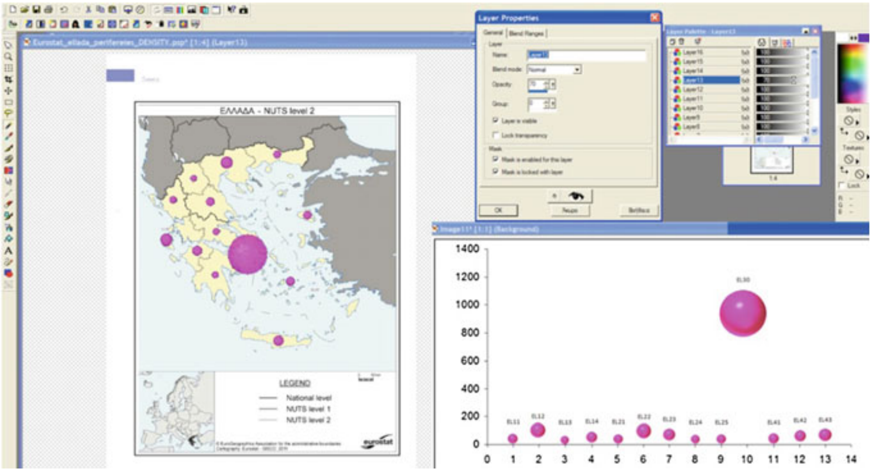

Fig. 3 Preparing a thematic map with proportional point symbol using “MS Office Excel” and “Jasc PaintShop Pro”

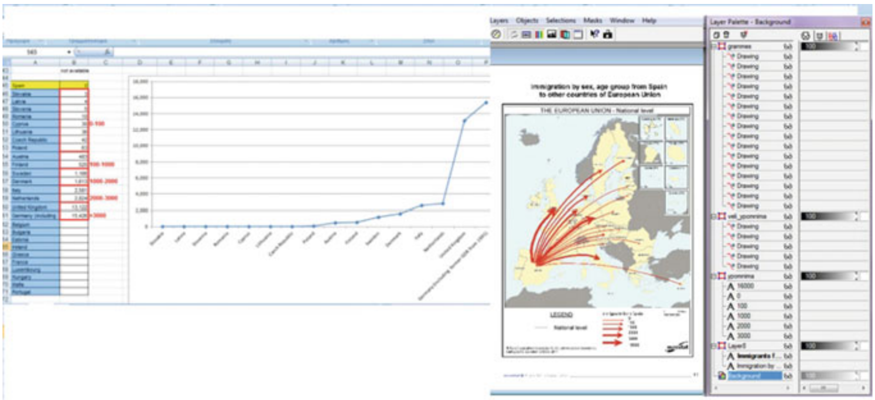

Fig. 4 Preparing a thematic map with linear data depiction. The choice of optimal breaks classification using “MS Office Excel” and “Jasc PaintShop Pro”

easily available) becoming thus flexible *smart-users* having understood first the procedures and the rules for the best possible solution, according to the problem and the effective ways to its implementation.

3.3 *The Final Project*

The project on thematic mapping followed in the TC class is based on free online software, namely “Indiemapper” (2010), one of the few available for free, fuelled,

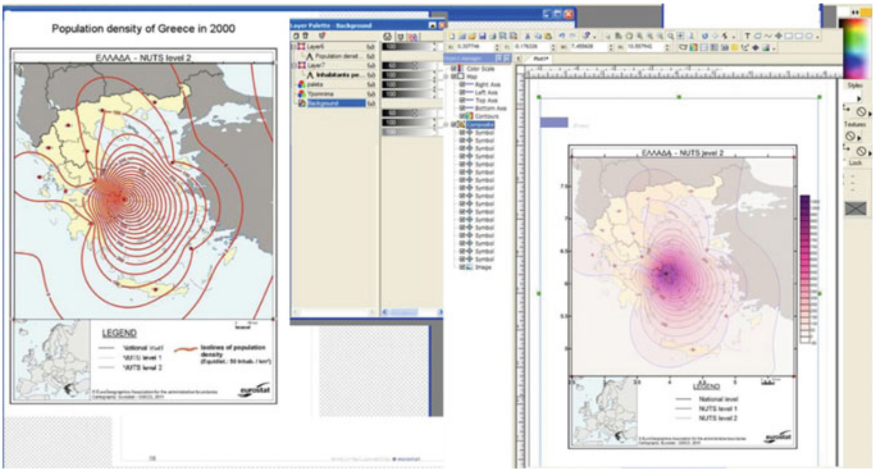

Fig. 5 Compiling an isarithmic thematic map using “MS Office Excel”, “JascPaintShop Pro” and “GoldenSoftware Surfer”

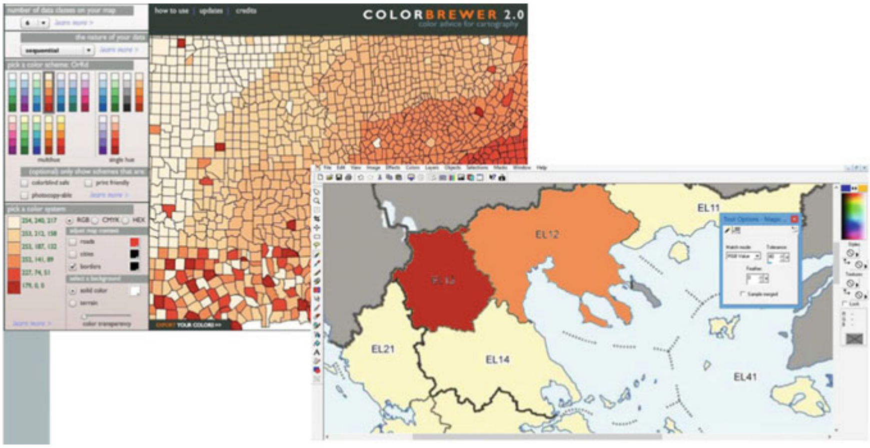

Fig. 6 Implementing the “ColorBrewer” utility

in our case, by data downloaded (equally for free) from the EUROSTAT portal (Fig. 7). After the experience gained with the use of a number of supportive software applications, the students are using an online available main application to construct a series of thematic maps. Having now the gained experience they can judge and face any gaps and imperfections to fill in the automation of such complex and multifaceted process, as it is the preparation of a thematic map, in order to satisfy the preset objectives, i.e. the effective visualisation and transmission of geospatial information, concerning especially issues like a properly designed title,

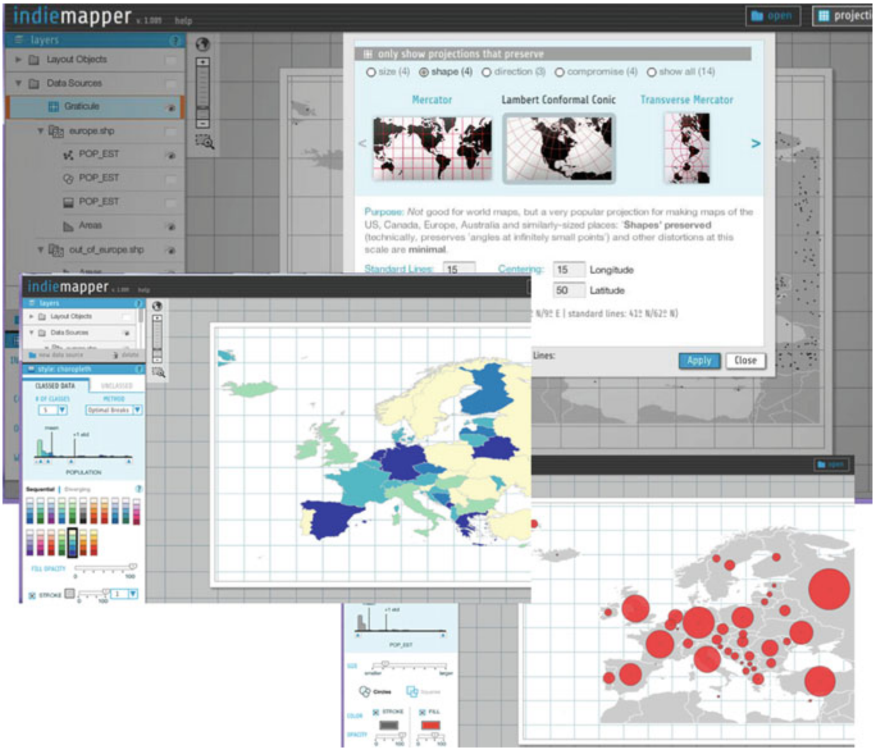

Fig. 7 Example of online thematic mapping, using the “Indiemapper” free software

legend, scale bar etc. which complete and enable the reading of the map. Almost always the map is further elaborated in other image processing or graphics editor software such as “Jasc Paintshop Pro” mentioned before, “Adobe Illustrator” or “Adobe Photoshop”.

The concept of this practical work is to make the students thinking and acting in preparing a thematic map, not only as simple users having got a surface contact on what TC is all about from the lectures-part of the course, but also as “first step cartographers”. This means that the students should be capable enough to decide, e.g. on the choice of the adequate map projection system, the selection and implementation of classification (optimal breaks, quantiles, equal intervals, manual classification etc.) as well as on the design of a complete and functional legend. Considering in addition, that the students follow an engineering curriculum, they should be able to conceive, plan, organise, install and apply integrated processes for the production of a specific product output: a thematic mapping project.

This approach concerns especially the engineering perspective since, by definition, the students are dealing with multitasking thematic data concerning a variety of geo-related issues such as the environment, the transportation, and infrastructures, the cadastre and land registry, the geo-positioning of natural resources and other affine themes from the worlds of physical and human activities and interactions.

Some examples (Figs. 8, 9, and 10) of student-exercises, following the chain flow presented in this paper, illustrate the result of the process and the work done in the TC class. The maps were prepared using the online free software (Indiemapper) and finalised using additional image and graphics processing software.

3.4 Evaluation

The new revised teaching strategy and implementation in teaching TC, as presented here, is developing since the academic year 2011–2012. The results are spectacular for an engineering class of a hundred students developing their own project, all attending the course in situ, each with a laptop or serviced by desktop computer facilities in a wi-fi backed environment.

Other benefits for the students were: the rapid familiarisation with all software available (the tendency to learn many software applications is popular among

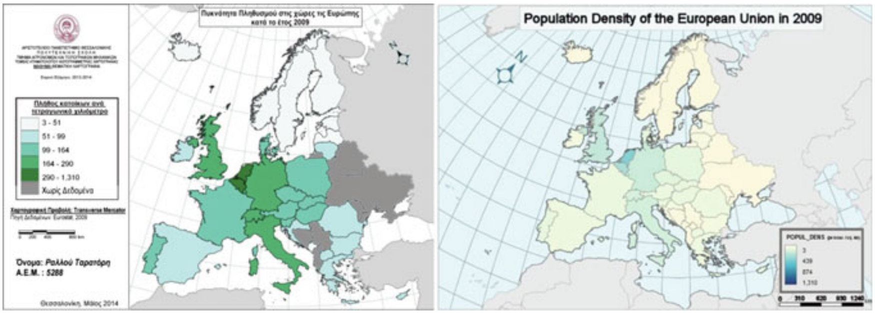

Fig. 8 Student exercise: two graphic approaches to European population density

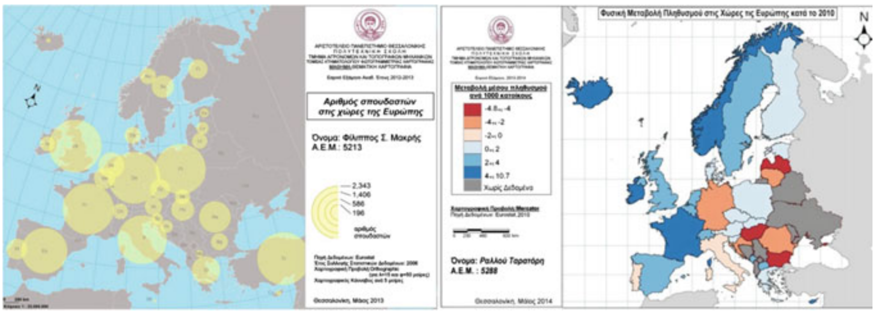

Fig. 9 Student exercise: student population (*left*); population variation (*right*)

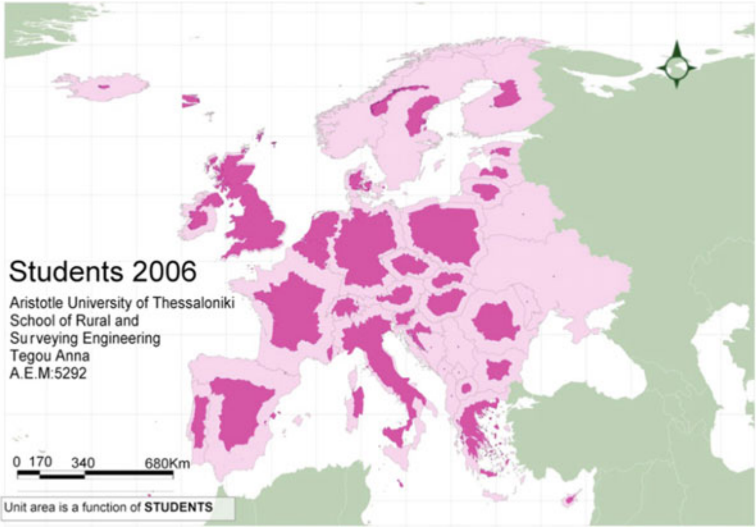

Fig. 10 Student exercise: European countries according to student population; a *cartogram* onto a map

engineering students, especially when this is done in an real-life application environment, as it is the TC project); the consolidation and digest of the theoretical teaching given almost simultaneously with the preparation and guidance of any new step of the practical work; the understanding of TC as a key issue in a variety of many other study courses throughout the entire curriculum. Students are using the first simple packages (i.e. "PaintShop Pro", "Excel", "Surfer") in a modular way. They learn how to use them in combination, taking advantage of the strong points of each package. Here, e.g., are some of the advantages of the modular cognitive approach:

- "Excel" helps students better understand in practice how they can build *thematic classes* according to the method of *natural-optimal breaks*, based on the *cumulative frequency graph* of the data distribution, produced by the package.
- Concerning the construction of *isolines* one has to recall that no cartographic package, suitable for education, provides so far an isoline module. The use of "Surfer" is a convenient and effective tool solution for students, suitable also for use in other courses requiring the tracing of *contours*, like e.g. in geodesy (geoidal studies, gravimetry, gradiometry, altimetry, etc.), in topography and photogrammetry projects. "Surfer", although a rather general purpose software, gives a good understanding to a novice user of how the isolines are created, step by step: it provides a "hands on" work starting from a *random point distribution* over an area and gradually understanding the formation of contours for the representation of ordered *continuous reliefs*.

- "Indiemapper" is a package for TC, very efficient from many points of view, especially for education. It is built following the cartographic theory, which is operational in its various components, as are e.g., the selection of the proper *projection system*, the *data classification* methods, the *colour scheme structure* with the "ColorBrewer" utility (Brewer et al.,2013), the design of *legend* and the overall *map layout*. More, well-written and directly accessible *educational texts* are available during the process reminding the proper underlying theory. In this way, the students implement cartographic theory in an optimal way, coming back to it whenever they want, while making a map.
- In a broader context, a fact that was made clear during these years that the course is running, is the lack of suitable software for TC, oriented to educational purposes and suitable for thematic map production following cartographic theory and rules as taught in class. The only exception till now has been "Indiemapper", which is a skillful package, apparently made by people having knowledge and appreciation of TC, as a proper field of study and research and probably of educational procedures. This lack of cartographic software among the cartographic community is perhaps the reason that GIS-like packages currently available on the web might be considered suitable for use in any educational context; this elusive impression is actually created by the technical facilities provided by such tools, a fact that does not necessarily mean that the results are good from a cartographic point of view. In fact, the user has to already know the cartographic rules, in order to take advantage of the easily combinable technical tools that are offered. Therefore, such tools are useful for knowledgeable cartographers but they are not necessarily suitable for use in the class and definitely not suited for teaching students how to implement the principles of TC in their maps. There is thus a clear need within the carto-community for the development of TC-dedicated software as some promising examples in this direction have recently been developed.

Last, but not least, students look to appreciate getting direct free access to the numerical, textual, pictorial and map database of a major European institution, as it is EUROSTAT, portraying all data referred to the real social, political, economic and cultural life and activities of the EU member states.

It is, finally, worth to report that, as a result of this didactic type of approaching TC, it was soon visible the active interest and involvement of students concerning both the class labour and the homework. The raise of students' interest for Cartography in general, with TC as the vehicle, was evident and measurable: e.g., the increasing student enrolment in elective cartography courses, coming next to TC in the curriculum setting and the participation of students (Fig. 11) in scientific communal activities—national and international—promoted by cartographic organisations,[10] are distinct evidences favouring the case and future of Cartography.

[10]A high number of students, attended the new TC course, participated in the 2014 National Cartographic Conference of the Hellenic Cartographic Society and in 2015 the Conference on Digital Approaches to Cartographic Heritage, organised by the relevant ICA Commission.

Fig. 11 Students, following the TC course, participated in the ICA 10th International Conference on *Digital Approaches to Cartographic Heritage* Corfu 27–29 May 2015. Here the students in educational visit at the Historical Archives of Corfu examining maps and plans from the Venetian, French and British rule in the Ionian Islands

4 Conclusion

Thematic Cartography is a fundamental course in any cartography related education and in the relevant map production. The theoretical part of TC teaching is a rather straightforward approach based on the important literature available. On the other hand, the practical part of teaching TC is a much more complicated issue demanding a strategy of selecting the didactically proper software tools, among the many dedicated or general software available in the market, which can be used either as *integral* tool or as *modular* tools, for the design and production of thematic maps. The choice depends upon the special characteristics and demands of the TC course with respect to the type of the curriculum, the field of studies and the level of the degree.

Our approach in designing and implementing a TC course is addressed to a ten (10) semesters' curriculum in geospatial and infrastructure engineering at the 300 ECTS level MEng type degree. Following the standards of engineering university education, concerning the structural and modular approach of knowledge and the content distribution of other cartography-related courses in the curriculum, we opted for the modular tooling instead of integral tools. Thus, the TC student-projects are developed using a number of rather simple and mainly freely available software packages in implementing TC theory for the production of thematic maps in a structurally synthetic way. In this way, engineering students are approaching closely each of the specific components of a TC project, a procedure which supports better understanding of the thematic map production. This approach proved to be effective, by providing students, among other advantages, the ability to handle effectively the integral software tools in a later stage of their studies in the elective cartography courses and the MEng thesis.

The implementation of the re-designed TC course in the last four academic years showed that the introduced modifications and improvements, as described here, have been so far successful. The involvement of students and the quality of projects, compared to previous years, is concrete evidence together with the students' increased interest for cartography. Furthermore, the students seem to appreciate the fact that they are provided with a multitude of software tools in order to carry out their exercises, despite some inevitable initial complaints. They seem to quickly understand that the variety of modular tools they have to use for their exercises reflects a real-world situation and they rapidly appreciate and master the different software packages they are asked to use in a synthetic manner.

Additionally, some feedback from students of the first academic year that the new TC course was implemented (and who are now almost at the end of their studies) seems to enhance this point; not only they appreciate in retrospect, but they also seem to develop an increased interest for cartographic and geographic topics, compared to previous years. This is manifested not only in the dense and enthusiastic participation to national and international cartographic events, but also in the increasing (compared to previous years) number of students who in the last two years follow the cartography related elective courses, from the seventh semester onwards. Hopefully this will set a trend for the future; in this context the TC course is already an *example of good practice*.

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Part V
Cartographic Applications

A Review of Research Investigations Related to User-Centred Design for Geo-Information Products

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Abstract This article is based on our participation in the workshop "Envisioning the Future of Cartographic Research," one of the ICC 2015 pre-conferences. In order to answer the question posed to the workshop participants—"How can we best develop a systematic understanding of the intersection between human abilities (perception, cognition, affective), design decisions (graphic and interactions), and map use context?"—we realized that from the results of some of our research projects, it may be possible to build a systematic understanding of human abilities, design decisions, and map use context under the assumption that the design of a geo-information product could be developed in agreement with the user-centred design (UCD) approach. This article aims, then, to present some results of our research projects, the main goal of which is to develop investigations that are defined based on the relationship between geo-information solutions and the theory of cartography and geoscience. Those projects have been in development for the last 10 years, and here we describe six of them: two at the doctoral level and four at master's level.

Keywords User-centred design · Geo-information product design · Map use context

1 Introduction

We understand that improvement of the user-centred design (UCD) approach for geo-information products can be achieved when we seek knowledge related to the intersection of the following concepts: human abilities, cartographic design decision, and map use context (Fig. 1). This article describes some investigations that are being developed in the research group called Cartography and Geo-Information

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_22

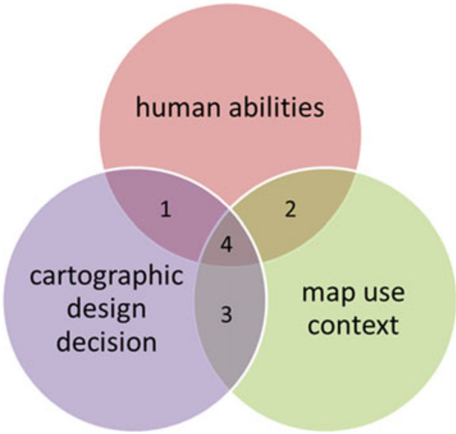

Fig. 1 Intersections between human abilities, map use context, and cartographic design decision

Systems (in Portuguese, *Cartografia e Sistemas de Informações Geográficas*) <dgp.cnpq.br/dgp/espelhogrupo/7239248197975667> that, we believe, are examples of how to build knowledge related to those intersections. Those investigations were developed as two Ph.D. dissertations and four master's theses.

Our research approach takes into consideration two important premises: *map* is a broad concept that can include different kinds of geo-information products, and *cartographic design* is the design of a product. Moreover, the success of a geo-information product is dependent on the abilities of the cartographer, or geo-information expert, to take into account the needs of the users in each product design decision.

When we refer to map use context, we mean a geo-information product use context, such as the context of use of an interactive map or a geo-information system (GIS). In our research discussions, we also understand any cartographic product, including a map, as a particular kind of information system. Consequently, cartographic design decision is understood in a broader sense than map symbol design. The design of a cartographic product encompasses decisions about every characteristic of a geo-information system, including the geo-information, the geovisualization and the geodatabase components (Sluter et al. 2015).

We also understand that the intersections illustrated in Fig. 1 are defined by the relationship between the research problem, the research hypothesis, and the discussion of the research results. For intersection 1, the research problem concerns visual perception and cognition, and in the discussion of the results, we could acquire some knowledge that can be used to improve map symbols design. In intersection 2, the research problem is related to visual cognition and knowledge schemata, and the results are discussed in the VGI use context. In intersection 3, the research problem involves defining map use context based on requirements engineering, and the results discussion aimed to improve the design decisions for geo-information systems. And there are two investigations of which the research problem, the hypothesis, and the discussion of the results involve those three concepts; thus, they are included in intersection 4 (Fig. 1). These intersections are the topics of this article.

2 Intersection Between Human Abilities and Cartographic Design Decisions

The first intersection takes place when the research problems are related to understanding visual perception elements in detecting, identifying, and recognizing the map symbols, and the results of the investigations are discussed in order to improve the map design decisions. These investigations are designed in order to understand better the Gestalt laws of figure-ground and prägnanz (Koffka 1975) that are embedded in the symbol detection, the visual unities that result from visual grouping by similarity and proximity (Marr 1982), and the Gestalt laws of continuity and closure that are part of the map symbol identification and recognition (Marr 1982). Prägnanz is related to the simplicity, visual unity, clarity, and visual balance of the figure. The visual unity is mainly dependent on the organization, harmony, and balance of a visual composition. Thus, the visual elements that form an image are perceived by the visual relations between them (Arnheim 2011).

Specific cases of this first intersection are the investigations of research problems related to the perception of form (Arnheim 2011) of map symbols. Two investigations of this specific kind of case were developed by our research group, and the research problems were related to the visual perception of point and line symbols (Santil 2008) and pictorial symbols (Andrade 2014). Some important conclusions of those investigations are the following:

- Proximity (Koffka 1975; Arnheim 2011) is an essential element in seeing groups of symbols, but similarity (Koffka 1975; Arnheim 2011) is the element that imposes the unity of symbols (Santil 2008).
- The design of a pictorial symbol must result in a semantic relationship between the symbols and their referents (Andrade 2014).
- The mimetic level of the pictorial symbol and the figure-ground relations must not drive people to an ambiguous interpretation (Andrade 2014).
- The picture (drawing) of the symbols must be balanced and visually simple (Andrade 2014).
- When a pictorial symbol is near to other symbols, it is more difficult to discriminate it from those that are close to it (Andrade 2014).

Some results of the users' tests are that there are three locations on the map where the symbols were more easily seen: in the central part, in the main group of symbols (number of symbols), and near to this group of symbols. The results of the users' tests related to the symbols located in the optical centre of the map agree with MacEachren (1995) in that the features in the centre of the map are more easily seen than those at the periphery. Therefore, when it is important to emphasize map symbols in the periphery, these symbols should be enlarged. Moreover, the results confirmed the hypotheses related to the mimetic level of a pictorial symbol and that the symbol drawing must be simple.

3 Intersection Between Human Abilities and Map Use Context

Intersection 2 (Fig. 1) happens when the scientific investigation is developed in order to comprehend the semantic relations between the information represented on a map and its correspondent in the real world, as well as the way these relations are mentally reproduced and processed by humans while accomplishing map-reading tasks (Ooms et al. 2015; Hochmair and Frank 2001; Tversky 1991). Consequently, the results of some research works related to this knowledge intersection are discussed mainly to allow researchers to understand how the mental abilities of humans influence the way people read maps in a broader sense (Ooms et al. 2015; Fabrikant and Löbben 2009), as well as to improve map design decisions.

In this context, the investigation could be defined from a research problem that is related to spatial cognition and knowledge schemata applied to spatial reasoning, and the results could be discussed within the realm of volunteered geographic information (VGI) use context. As we pointed out before, we consider map use context as the context of use of any geo-information product or system. Therefore, the definition of map use context is fundamental to the design of the investigation because it determines the kind of map-reading tasks related to the research problem.

One of the master theses that has been developed in our research group was based on the following research problem: "How does the human mental processes for acquiring spatial knowledge influence the perceived reliability of volunteered geo-information?" (Bravo 2014). In this case, the map use context was restricted to VGI, and the map design is embedded in VGI use context. The "human abilities" are related to the human mental processes of acquiring spatial knowledge.

The map-reading tasks definition (Board 1978) was the focus of the research design because the results have been discussed in accordance with the map use context. The map-reading tasks comprise a set of events that individuals perform while using geo-information products. In this specific case, we have designed scenarios within the VGI platform called Wikimapia (http://wikimapia.org/) where the individuals performed map-reading tasks such as searching, identifying, describing comparing, verifying, recognizing, and preferring. Because we have investigated the "perceived reliability" of VGI content, we have added a task that allowed us to identify the individuals' trust on VGI ("to trust"). The tasks designed to verify how much the individuals trust VGI were necessary because, in the Web 2.0 applications, the users can also produce data besides searching for some information.

The possibility of producing geo-information can make the reliability in VGI to decrease (Flanagin and Metzger 2008; Budhathoki et al. 2008).

Additionally, this intersection is built when the results discussion has to help researchers understand the users' spatial reasoning during the map use context. By using the example from our research group (Bravo 2014), we have verified the following hypothesis: Assuming that the human mental categorization process is influenced by the knowledge schemata, the human mental categories drive the geospatial knowledge used in deciding the perceived reliability of VGI. Therefore, for this research work, we considered the mental categorization as the main characteristic of the human's cognition that influences the "perceived reliability." We tested individuals who provided semantic information—categories—about touristic places. We classified the data produced in the tests according to the level of abstraction that generated the semantic classes of categories (Rosch et al. 1976). We also have classified the type of reasoning used by the subjects based on the taxonomic and partonomic structures of reasoning (Tversky and Hemenway 1984). The results showed us that the individuals who reached more successful results in their map-reading tasks often used basic-level categories, as well as partonomic reasoning (Tversky and Hemenway 1984). Again, basic-level categories were more effective in making the individuals rely on the data produced at this level of abstraction. The results of our investigation agreed with Rosch (1973), Rosch et al. (1976), and Tversky and Hemenway (1984) in that the individuals preferred basic-level categories and partonomic processes to describe the features and to use the information (Bravo 2014).

In general, the results of this example led us to comprehend that the "perceived reliability" in the VGI use context is dependent on the way the features are described in a VGI system—mental categorization. This might lead the user to decide about his confidence on the data represented in a map. Then, we may conclude that mental categorization and partonomic and taxonomic processes triggered, somehow, the "perceived reliability" judgment of individuals. Therefore, by using research results as example, it is possible to comprehend the way human abilities and the map use context have influenced the way the people read and trust VGI. Additionally, it is necessary to highlight the importance of designing research works within this intersection—"human abilities" and "map use context"—based on a restricted map use context due to the variability of possible "human abilities" encompassed in each one of the scenarios, tasks, and map use contexts.

4 Intersection Between Cartographic Design Decisions and Map Use Context

Interaction 3 is defined between a geo-information product use context and its design decision. On one side, the use context is determined in accordance with requirements engineering methods. On the other side, the decisions about the product design are based on users' requirements. To understand in detail, the requirements for the geo-information product, we adopt the techniques and methods developed in Requirements Engineering (Sluter et al. 2015).

In the first, and current, phase of the investigation, we aim to determine how the requirements engineering theory, methods, and techniques can be adopted for the design of geo-information systems, and how to consider the geo-information characteristics in the system requirements definition. In the second phase, our investigations will be based on research problems related to understanding when and how the characteristics that define the different use context can interfere with the establishment and application of requirements engineering methods for geo-information products. In both phases, we will be applying requirements engineering theory and expertise for the design of geo-information systems.

The investigations hypotheses are based on the proposition that a geo-information solution will achieve the desired goals, providing correct results for the defined use context, when users' requirements are elicited in accordance with the techniques and procedures of requirements engineering (Sluter et al. 2015), and when the geo-information systems are built based on those users' requirements and needs.

The process of requirements engineering is here divided into four stages, following the literature, and adapted to the characteristics of geo-information systems (Kotonya and Sommerville 1998, Sluter et al. 2015). In the first stage, which is requirements elicitation, information about the users is collected, including their needs and goals, the context of use of the system, and its application domain. The elicited information is analyzed and negotiated with the system stakeholders. At this stage, the goal is to eliminate or minimize ambiguities, conflicts, and misinformation. Moreover, the geo-information system requirements will be grouped in functional (characterizing system functionalities or what the system should do) and non-functional requirements (representing the use restrictions of the system or how it will achieve the desired goals). From these results, the next stage will be the official documentation of the requirements survey. Documentation standards, for example, ISO, IEC, and IEEE (2011) are used as a foundation for the requirements document for the geo-information system for land value capture policies, taking into account the geo-information peculiarities. The main topics of the documentation are shown in Fig. 2.

The topic called introduction describes the initial information about the system to be built. The system's purpose and scope are stated together with the use context, functionalities, and stakeholders' characteristics. It also introduces the definitions needed for the correct understanding of the specification. This item is followed by the list of the material referred to in the specification. The main body of the document is Sect. 3, which groups all the requirements gathered for the system to be built. This item divides the requirements according to their type and role in the system. The main contribution we aim to achieve is the analysis of the geo-information within those requirements, and how to treat it in the requirements documentation. The verification section is compared with the system requirements

Fig. 2 An example of system requirements specification outline (ISO, IEC, and IEEE 2011)

- **1. Introduction**
  - 1.1 System purpose
  - 1.2 System scope
  - 1.3 System overview
    - 1.3.1 System context
    - 1.3.2 System functions
    - 1.3.3 User characteristics
  - 1.4 Definitions
- **2. References**
- **3. System Requirements**
  - 3.1 Functional requirements
  - 3.2 Usability requirements
  - 3.3 Performance requirements
  - 3.4 System interface
  - 3.5 System operations
  - 3.6 System modes and states
  - 3.7 Physical characteristics
  - 3.8 Environmental conditions
  - 3.9 System security
  - 3.10 Information management
  - 3.11 Policies and regulations
  - 3.12 System life cycle sustainment
  - 3.13 Packaging, handling, shipping and transportation
- **4. Verification**
  - (parallel to subsections in Section 3)
- **5. Appendices**
  - Assumptions and dependencies
  - Acronyms and abbreviations

section, for an evaluation and qualification of the requirements. Section 5 presents the additional information applicable to the system requirements.

The initial investigation we have developed in our research group (Ramos 2016) refers to a requirements survey and documentation for a geo-information system applied to land value capture policies. Land valuation capture represents the return to society of undue/unfair land valuation resulting from public investment in infrastructure. For this return, we studied betterment taxes, a tribute charged specifically on valuated lands. The calculation and application of this tribute are based on location and proximity to the public investment. Therefore, the geo-information used must be correctly analyzed and applied.

From the elicited information on land valuation capture, and according to stakeholders' needs, we were able to determine the users' activities required to achieve the desired goal. This allowed us to identify the geo-information elements to be considered in the design of the geo-information systems for this specific use. From that, we proposed system interfaces better suited to achieve the desired objective of tribute calculation and application.

From this research, we aim to determine the relationship between users' requirements and geo-information systems characteristics in order to establish a sound methodology for requirements elicitation and documentation, for the construction of geo-information systems interaction interfaces. Since we focus on users' interactions, other studies are needed to complete the requirements survey, covering all the users' requirements. Moreover, the follow-up investigation can bring us further knowledge on the application of requirements engineering for the design of geo-information products.

5 Intersection of Human Abilities, Cartographic Design Decisions, and Map Use Context

At the intersection of the three concepts: human abilities, cartographic design decisions, and map use context, the research problem remains centred on cognition's processes and the users' knowledge schemata. And the results discussions are related to a map use context. The map use context is understood and described in accordance with the tasks that the users have to fulfil in order to accomplish their professional duties.

The users are experts in some knowledge field, such as urbanists (Yamada 2015) and soil scientists (Bueno 2007). That means the knowledge schemata have been structured by the users along their professional education and career. Therefore, they already have mental maps that they use to deal with their educational and professional duties. In this context, the users' expertise prepares them to accomplished some defined tasks using maps. However, sometimes the cartographic products are not suitable for fulfilling the users' needs. Usual problems with those maps can be related to geo-information classification, the level of generalization, and representation.

In order to illustrate the intersection of human abilities, cartographic design decisions, and map use context, we describe how the investigation about urbanists' mental schemata was proposed, and some of its results. The research problem was established in order to understand the urbanists' mental schemata when they define, describe, and represent urban public spaces. And the related hypothesis was based on the assumption that if the urbanists define and describe public spaces by their professional experiences (repetitive processes) at a precognitive and global level (Pinker 1999), their knowledge schemata of public spaces should lead to some categories relationships that represent a particular understanding of the urban landscape. Moreover, the public spaces definition, description, and consequently representation should be mutually equivalent and based on the same categories (Yamada 2015).

To verify our hypothesis, we developed our investigation in the following three steps: Identify the propositional schema, identify the image schema, and relate these results to the usual representation of urban public spaces in maps. First, we interviewed the subjects; then we extracted from their answers the information related to the definition, spatial structure, landscape elements, or description of public spaces. In the second step, we prepared some maps, orthoimages, and a questionnaire based on the results of the first step. And for the third step, the main goal was to compare the propositional and image schema with the cartographic representation of urban public spaces (Fig. 3).

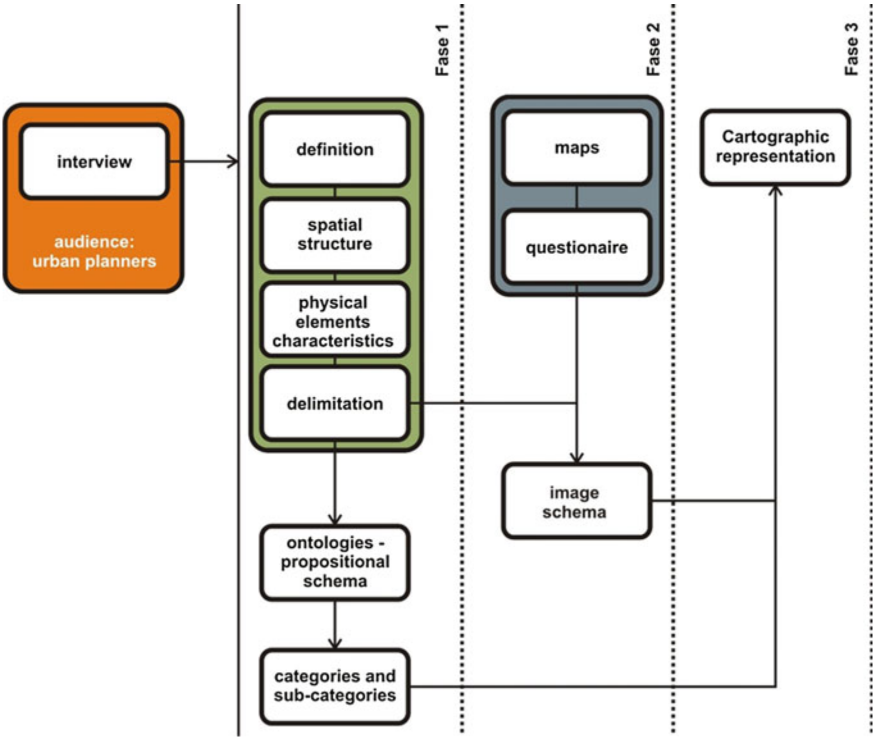

Fig. 3 The steps of the investigation

Based on the achieved results, we first represented the subjects' propositional scheme. Figure 4 illustrates the general propositional scheme about urban public space of the 11 urbanists who were our research subjects. For all of them, we could detect three main concepts that compose urban public spaces: space itself, urban land use, and urban morphology. From these three main concepts, we could figure out the concepts related to them. For example, for them, the land use related to urban public spaces can have characteristics of freedom, urban services, pedestrian, urban transportation, and so on.

The next step was to identify the urban public spaces using maps and the construction of the users' image scheme. At this moment, one important conclusion of this investigation is that the subjects (urbanists) described more elements about urban public spaces than those that can be seen on maps or orthoimages they use when proposing an urban plan. When comparing these results with the thematic maps used and presented in urban planning, there are some divergences. In the subjects' propositional schemata, there is a stronger influence of public spaces and vegetation areas than public services places. However, in the thematic maps they use, the public services places are more emphasized. It is thus possible that the level

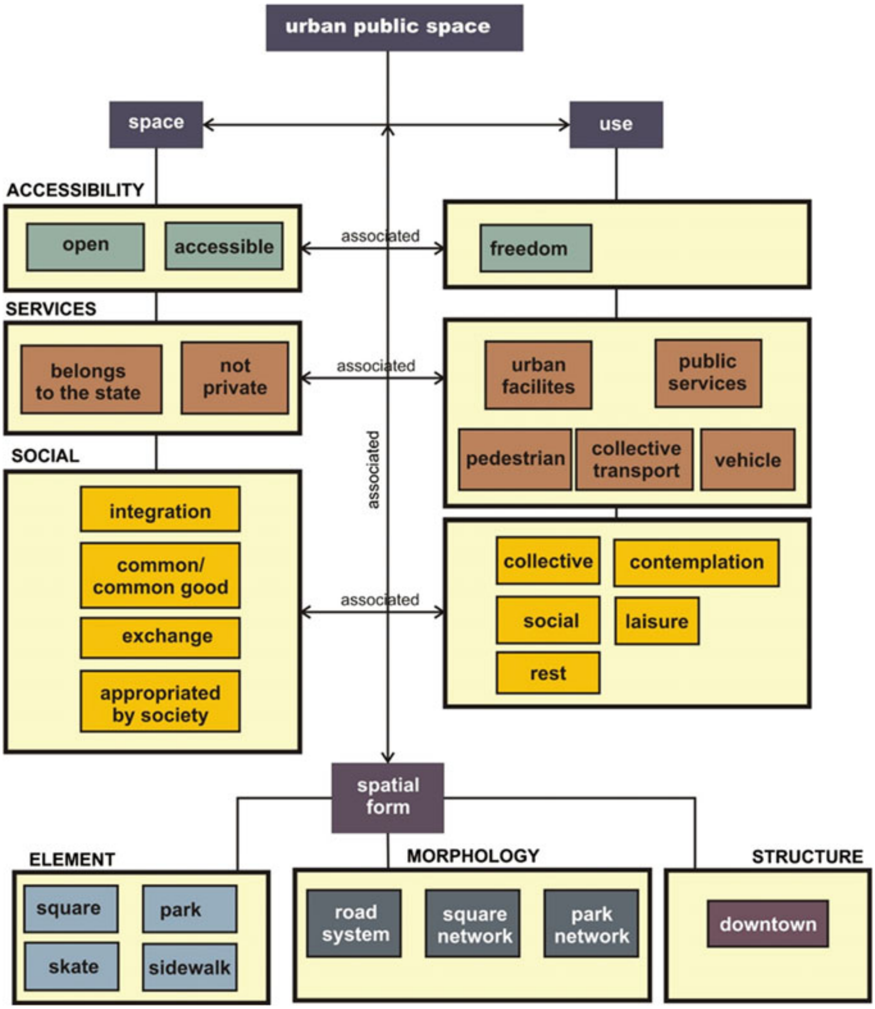

Fig. 4 The general propositional scheme of urban public spaces of the research subjects

of semantic simplification of public spaces concepts on maps leads to an inefficient result in urban planning.

Therefore, one important issue that we could figure out from the results of this investigation is: how the knowledge about the users (experts) propositional schemata can help cartographers to define better, classify, and visually represent (symbols) geo-information to generate more efficient maps? Understanding the users' context, their needs, and uses, allows the cartographers to represent the information needed and to represent better it.

6 Conclusion

Our main purpose in developing these investigations is to design and build better geo-information products. The geo-information product design is a process that begins with knowing the map users, including their characteristics, needs, goals, and requirements, and ends with the product validation by the users. That means that we adopt the UCD approach.

This article describes some investigations that are being developed in our research group that we believe are examples of how to acquire knowledge related to those intersections. The results of the research investigations that define the intersection between human abilities and map design can be applied to UCD when the cartographer uses them to design maps. Moreover, these results show the influence of the symbols on the map to the users' visual attention. Although we cannot change a symbol location on a map, those results can be used by cartographers to decide on the relationship between point symbols and the level of map generalization (map scale).

The research investigation defined in the intersection between human abilities and map use context is useful to geo-information solution design based on UCD because it can help cartographers classify the geo-information depicted on the maps based on users' mental categorization. Moreover, if the mental categorization of the map users can be understood and thus defined by the cartographers, the cartographer can design the map based on the level of categories abstractions. For example, if the users' mental categorization of a geographic feature matches a concrete category, the map symbol must be more iconic than abstract.

The UCD approach is very clear in the investigation described in Sect. 4 of this article. The investigation was defined based on the intersection between the design a geo-information solution as an information system (cartographic design decision) and the system characteristics that are defined based on users' requirements (map use context). Our main purpose in developing these investigations is to design and build better geo-information products that today we understand as systems. The criteria we use to qualify the product are efficiency, efficacy, and user satisfaction.

In the last investigation described in this article, we can clearly understand the relationship between human abilities, cartographic design decision, and map use context. The human abilities are related to the knowledge mental schemata of urbanists, the map use context is defined for urban planning activities developed by urbanists and some important elements of the research problem, and hypotheses were discussed based on cartographic design decisions. The relationship among these three concepts allows us to learn and understand that the maps and cartographic products some urbanists currently use in Brazil to make decisions about urban public spaces are not efficient.

Our view of building a systematic understanding of some important issues related to cartographic design and production is to define a systematic approach to cartographic design that is composed of a set of steps, and for every step to define and describe the knowledge background that is needed for making design decisions.

In doing so, we may be able to identify our difficulties to make such decisions and the lack of knowledge that causes those difficulties. Then, every research result can be related to the cartographic product design that is established in a systematic way. Now we have to propose some methods that can be used to build better geo-information products based on the results of our investigations.

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Interoperable Volunteered Geographic Information Empowering e-Governance Processes: Case Study for Land Use Dataset in the City of Zagreb

Tomáš Kliment, Vlado Cetl and Marcel Kliment

Abstract Spatial data resources have become very important phenomena in Europe within the last few decades. They are especially important in large cities due to the urbanisation trend. The expansion of urban areas due to the rise in the population and economic growth is increasing demand on natural resources, thereby causing land use changes. It is expected that by 2040, more than 60 % of the world's population will live in cities. In order to manage sustainable development and support e-governance processes, the efficient integration of relevant spatial data is needed. Land use data deliver an asset for local governments to develop better strategy for urbanistic planning, in order to manage land in a sustainable way. This work presents the methodology used to collect VGI observations for land use area definition based on the LUCAS (Land Use and Cover Area frame Survey) fieldwork methodology, HILUCS (Hierarchical INSPIRE Land Use Classification System), and reference topographic dataset. The practical research work was performed in June 2014 during the GIS Summer School in the city of Zagreb, in a dual collaboration between the Faculty of Geodesy, University of Zagreb and Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra. The results try to offer and verify a suitable proposal for fieldwork methodology and updating a land use database in line with the INSPIRE directive applicable at the local spatial data infrastructure level.

Keywords VGI · Land use · INSPIRE · Strategic planning · e-governance · Local SDI

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_23

1 Introduction

Today's large wave of urban development is a major change taking place globally. It can be seen as a gift to human society if it is controlled, coordinated and planed (Mohan et al. 2011). However, this development causes many ecological, economic and social problems. It is increasingly difficult to manage in a sustainable way (FIG 2010). Cities are complex, networked and continuously changing social ecosystems, shaped and transformed through the interaction of different interests and ambitions. Ensuring employment, sustainable development, inclusion and quality of life are important concerns. There is no doubt that, in these challenges, spatial data play a crucial role.

The INSPIRE (Infrastructure for Spatial Information in the European Community) Directive defines principles for the harmonization of spatial data in the European Community, including data themes related to urbanist issues. INSPIRE provides guidelines on how to transform datasets into common data models, but it does not cover the process of data collection and updating. Evaluation of the Land Use dataset derived from remote sensing products complemented by fieldwork has been carried out since 2006 by Eurostat within the LUCAS (Land Use and Cover Area Frame Survey) project at the European level.

Local spatial data infrastructure level (LSDI) covers data management in local administrative units (municipalities and cities). LSDI can also be seen as a tool to empower e-governance processes defined for strategic planning at the local level. It should be also emphasized that the local level is specific, because there spatial data are the most detailed, in the biggest scales, and therefore the most expensive to collect and update. In 2009, the city of Zagreb administration (capital of Croatia) recognized the importance of LSDI development, and established coordination for creating the Information System of the City of Zagreb's Spatial Management, with the main goal of setting up the Zagreb Spatial Data Infrastructure (ZSDI). In the City of Zagreb, many bodies of the city administration office use and create various sets of spatial data and services in their daily work (Cetl et al. 2012).

The most important area of the ZSDI is urban planning. This is a complex task requiring multidimensional urban information (spatial, social, economic, etc.). The need for assistance in performing urban planning tasks has led to the rapid development of urban information systems, especially 'e-Planning' systems, with the support of government policies and emerging information and communication technologies (Wang et al. 2007). One important dataset required for local planning is data on land; land use by type (residential, commercial, industrial, recreational and open space, institutional, etc.) by density/intensity, by ownership, by land supply/demand, and by development potential (Nedović-Budić et al. 2004). Land use (LU) and Land cover (LC) are core information layers for a variety of scientific activities and administrative tasks (e.g. hydrological modelling, climate models, LU planning, integrated land management, and agricultural crop mapping) usually covered by state public agencies. In the last decades, LU coverage change has become an additional, irreplaceable observation feature, not only in Europe, but across the globe. LU and LC mapping products are mandatory baseline datasets, usually required for large areas, with different levels of detail. For their proficient use, they should be provided in an interoperable way, by applying harmonized, reliable, effective and efficient methods. To ensure this, space and aero remote sensing techniques, integrated with field information collected by citizen sensors, are gaining ground against large scale statistical surveys based on in situ observations (Manakos and Braun 2014). In the last decade and even longer, we have been witnessing the availability of more and more spatial data collected by citizens. Thanks to rapid technological developments, e.g. ICT, GNSS, smart phones etc., today almost everyone is able to collect and share spatial data in an easy, user-friendly way. Citizens are becoming sensors and sensors are everywhere. This has given rise to a new phenomenon called Volunteered Geographic Information (VGI), which involves the widespread engagement of citizens in the creation of, or interaction with, geoinformation (Goodchild 2007).

This chapter describes the application of LUCAS observation methodology concepts through the collection of VGI and INSPIRE land use categories definitions. The main idea was to investigate employing VGI to collect and maintain land use information in the city area usable for a local SDI. A practical exercise was carried out during the summer GIS school held in Zagreb in July 2014. The work performed consisted of INSPIRE LU categories collection, processing, verification and publication. The Materials and methods chapter defines the study area details and reference input datasets provided by the city of Zagreb. Information about the methodology used during fieldwork, the software used for data processing, and publication is described next. The results chapter reports the basic statistics, final product developed and a comparison with existing land use data produced in 2011 available in ZSDI. Individual problems discovered during the newly developed dataset life cycle are discussed, and conclusions drawn.

2 Land Use/Cover Classification

Land is an essential natural resource. It can be divided into two interlinked concepts:

- Land Cover (LC) refers to the bio-physical coverage of land (e.g. crops, grass, broad-leaved forests, or built-up areas)
- Land Use (LU) indicates the socio-economic use of land (e.g. agriculture, forestry, recreation or residential).

There are several initiatives that try to harmonise and classify LC and LU data; in this chapter INSPIRE HILUCS and Eurostat LUCAS were chosen and tested.

European Directive 2007/2/EC establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) entered into force on 15 May 2007. The main objective of the Directive is to establish an infrastructure for spatial information in Europe to support Community environmental policies. INSPIRE addresses 34 spatial data themes organized in three groups, reflecting different levels of harmonization efforts expected and a staged phasing (Cooper et al. 2011). Groups I and II focus on reference data, while Group III focuses on data for environmental analysis and impact assessment, including the LU data theme defined as the use and functions of a territory, according to its current and future planned functional dimension or socio-economic purpose (e.g. residential, industrial, commercial, agricultural, forestry, recreational). The Hierarchical INSPIRE Land Use Classification System (HILUCS) is a multi-level classification system developed for application to existing and planned LU. Essential idea is to ensure that the spatial data infrastructures of the Member States are compatible and usable in the European Community and trans-boundary context. The INSPIRE Directive requires that common Implementing Rules (IR) or components are adopted in a number of specific areas (Metadata, Data Specifications, Network Services, Data and Service Sharing and Monitoring and Reporting) (Cetl et al. 2009).

The European statistical office Eurostat carries out a survey on the state and dynamics of changes in LU and LC in the European Union called the LUCAS survey (Eurostat 2013). The aim of the LUCAS survey is to gather harmonised data on LU/LC and changes over time. In addition, the survey provides territorial information facilitating the analysis of interactions between agriculture, the environment and the countryside. The surveys are performed every three years. LUCAS surveys are carried out in situ; this means that observations are made and registered on the ground all over the EU. From a LUCAS survey, three types of information are obtained:

- elementary data in its most disaggregated form (in situ microdata)—(land cover, land use and environmental parameters associated with single surveyed points, including transect information)
- point and landscape photos in the four cardinal directions
- statistical tables with aggregated results by land cover and land use at the geographical level.

Land cover and visible land use are classified according to the harmonized LUCAS LC and LU nomenclatures, which is similar to INSPIRE's HILUCS nomenclature. The LUCAS survey provides harmonised and comparable statistics on LU and LC across the whole of the EU's territory, a total area of just under 4.5 million square kilometres (km^2) for the 28 EU countries. LUCAS points belong to the intersections of a 2 km grid that includes around a million points throughout the EU. During the LUCAS 2012 survey, 270,000 points were visited on the spot by 750 field surveyors (Eurostat 2013).

3 Study Area and Methodology

The central part of the city of Zagreb was chosen as the territory for the LU dataset definition, with the River Sava taken as a natural boundary for the allocation of survey zones. The selected area of Zagreb was divided into six survey zones (Fig. 1) with various characters of land usage. Zone 1 is characterized by recreational and sporting facilities. Zone 2 is mainly residential. In Zone 3, there are administrative and commercial centres, with a distinctive urban character. Zone 4 has a varied distribution of agricultural, industrial and natural environments. Zones 5 and 6 are characterized by residential-commercial use with a high proportion of recreational areas.

The reference spatial data was a topographical layer provided by the City of Zagreb Office for Strategic Planning and Development of the City. The total study area was 1825.4 ha, while the overall number of polygons representing different features in the reference topographic dataset was over 11,000. The original LU classification consisted of 23 categories according to the Croatian national topographic model CROTIS (DGU 2014).

The geographical representation of the input dataset is displayed in Fig. 2 and the basic statistical distribution of CROTIS categories are presented in Table 1.

LU mapping has been already the subject of many scientific works, always depending on the context of use. For instance, in the agricultural sector, for land consolidation projects and the impact on the visual scenery of a landscape (Muchová and Petrovič 2014), for soil bonitation and land valuation (Streďanská et al. 2013), or for determining soil erosion and modelling (Lackóová et al. 2013; Urban et al. 2013). However, mapping in urban spaces is applied in a different way, e.g. remote sensing data are more difficult to use, and additional fieldwork is required.

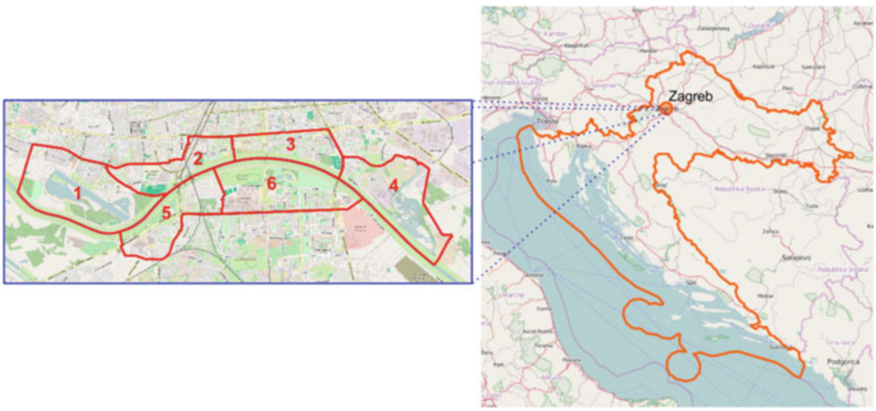

Fig. 1 Study area divided into 6 surveying zones (*Source* OpenStreetMap)

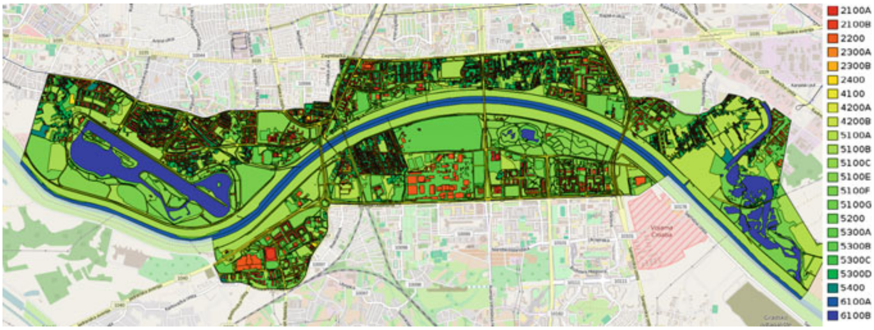

Fig. 2 Geographic distribution of usage categories areas in input dataset (*Source* Topographic dataset provided by the city of Zagreb Office for strategic planning and development of the City and OpenStreetMap base layer)

The Trimble Juno 3B mobile GIS device, with an integrated high sensitivity GPS receiver with a real-time measurement accuracy of 2–5 m and an integrated 5Mpix camera, with pre-installed ESRI ArcPad mobile GIS software, was used for the fieldwork. A customised form for creating and editing feature attributes was developed using the ArcPad Studio utility (Rusmore 2002) and attached to the dataset created for observation points within each surveying group (Fig. 3).

Attributes such as HILUCS (Benner et al. 2013) LU and LUCAS LC codes (Gallego and Bamps 2008), with cardinal direction photographs, were implemented in the data model for the field observations dataset. Surveying groups took observations for each accessible polygon present in the reference input topographic dataset (without obstacles to direct access, allowing unambiguous LU identification), evaluated the possible aggregation of topographical features in a new LU polygon feature based on HILUCS category definitions, and decided on the representative location of observation points for this purpose.

For each observed point, one photograph in each cardinal orientation (North, West, South and East) was taken. The photographs aimed at capturing the observed areas in the best possible way, to identify the existing land use of the locality by providing a broader picture (Fig. 4).

The main tool used for data processing was a desktop GIS Quantum GIS (QGIS), which is the most advanced open source GIS editor, described by Tsou and Smith (2011). QGIS is freely downloadable and is distributed under GNU General Public License, with many custom modules for integrating, topological cleaning and processing data of various types. To perform an update of the topological dataset with the newly collected LU code attributes, it was necessary to match the observed characteristics from the survey points and merge them with the source polygon features. Merging the attributes of topological and observation layers in the target LU dataset was performed by joining the attributes of features by location. The joining algorithm was based on the rule that a polygon, which did not contain a point, would take an attribute from the nearest point. However, the rule of taking attributes based on distance weighting would not have reflected the actual situation observed in the field,

Table 1 Categories of land use derived from the CROTIS original topographic database nomenclature and related spatial objects available within the study area, with information about areas in hectares, percentage of the whole study area, number of features, and average area of a single feature

CROTIS code	Original nomenclature (CROTIS)	Area (ha)	Part from whole area (%)	Feature count	Average area of feature (ha)
2100A	Residential and combined structures	74.76	4.10	3751	0.02
2100B	Public structures	13.48	0.74	213	0.06
2200	Commercial structures	45.87	2.51	844	0.05
2300A	Cultural and historical structures	0.01	0.00	1	0.01
2300B	Religious structures	0.43	0.02	12	0.04
2400	Other structures (e.g. storehouses)	15.7	0.86	2543	0.01
4100	Road transportation	121.02	6.63	449	0.27
4200A	Rail transportation	3.2	0.18	6	0.53
4200	Public transportation—tram	6.07	0.33	29	0.21
5100A	Arable land	119.44	6.54	74	1.61
5100B	Grassland	416.09	22.79	1349	0.31
5100C	Orchards and vineyards	17.75	0.97	44	0.40
5100E	Parks	229.13	12.55	654	0.35
5100F	Forests	98.97	5.42	20	4.95
5100G	Shrubland	40.72	2.23	43	0.95
5200	Barren land	3.69	0.20	6	0.62
5300A	Public built-up areas	246.15	13.48	689	0.36
5300B	Commercial built-up areas	47.13	2.58	30	1.57
5300C	Transportation built-up areas	0.17	0.01	1	0.17
5300D	Yards	117.46	6.43	306	0.38
5400	Areas of intense commercial activity	6.27	0.34	11	0.57
6100A	Water streams	84.05	4.60	13	6.47
6100B	Backwater	117.84	6.46	23	5.12
Total		**1825.4**	**100.00**	**11,111**	**0.16**

so the joining algorithm was reserved only for polygons that contained a specific point. Before this process, each of the six working groups verified the accuracy of the observed points and additionally adjusted or discarded the points from the next round of data processing. Topological checking functionality provided by a custom QGIS module was used to verify the accuracy of topological relations among newly created polygon features according to predefined rules.

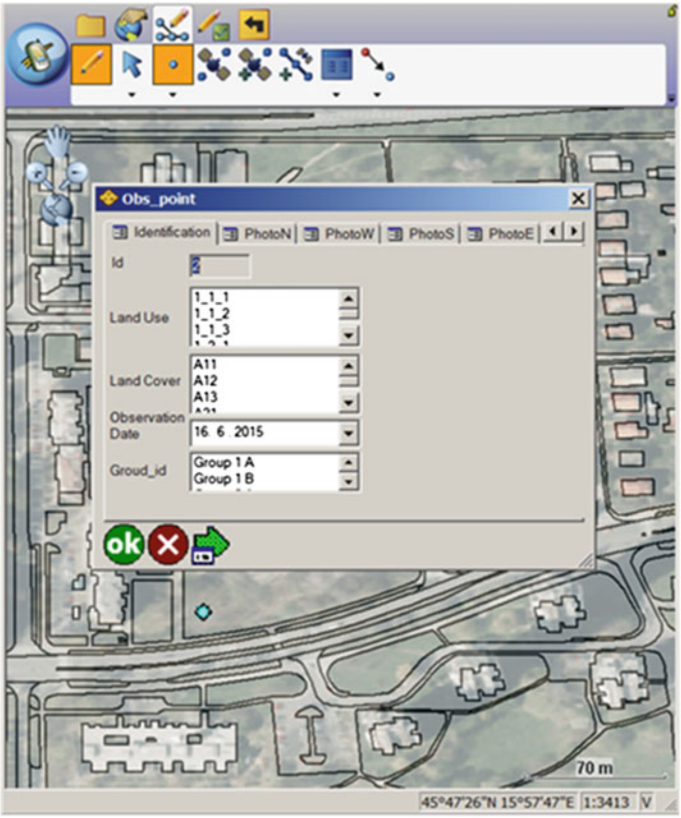

Fig. 3 Snapshot of the form for creating and editing feature attributes to the observed field measurement

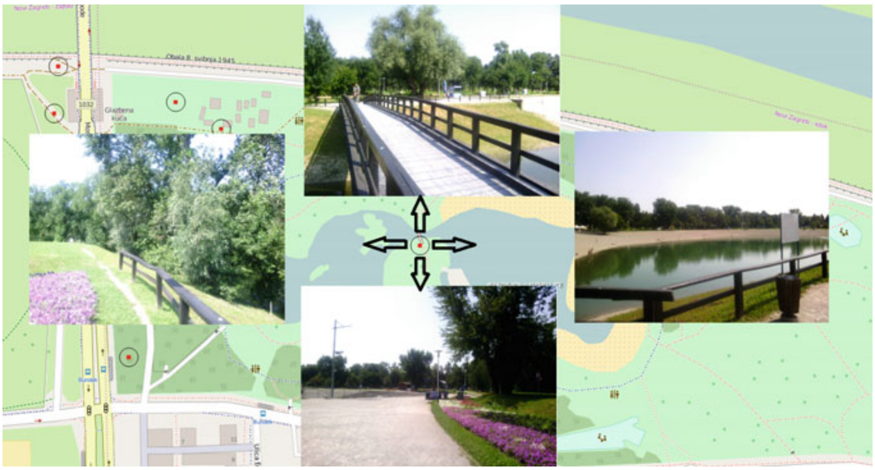

Fig. 4 Sample set of four photographs taken in each main cardinal direction from the observed point

4 Results and Discussion

The fieldwork lasted four days and resulted in a total number of 1755 observation points collected by six working groups, each covering a selected zone within the study area (Fig. 1). In comparison with the LUCAS methodology reported in Gallego and Bamps (2008), the density of survey points was not predefined. However, a recommendation was made to observe each polygon available from the original topographic dataset, or aggregation of a group of polygons identified by observation point, with photographs taken at the site. Observations depended on the variability of LU distribution and density, as well as the accessibility of polygons. Initial verification of observations during the data processing phase filtered a set of 132 points that were not used for further processing due to multiple and/or outlier measures. The results of automatic attribute joining by location of observations with the reference topographic dataset resulted in 1099 features, which represent less than 10 % of the source dataset feature count (Table 1). The total area classified by HILUCS codes covered 1259.12 ha, which represents 68.98 % of the entire area of interest). Additionally, 566.4 ha of LU (31.02 % of features) were determined manually in order to update the entire area of interest. In the source topographic dataset, the average area of available polygon features represented 0.16 ha for CROTIS land usage categories, which after data processing became 1.06 ha, due to the number of features, which was originally more than 11,000, but after processing, 1721. The final number of polygon features (LU classes) was reduced about 6.5 times. The distribution of HILUCS LU categories classification in the final dataset is presented in Figs. 5, 6 and 7, divided into three groups as follows:

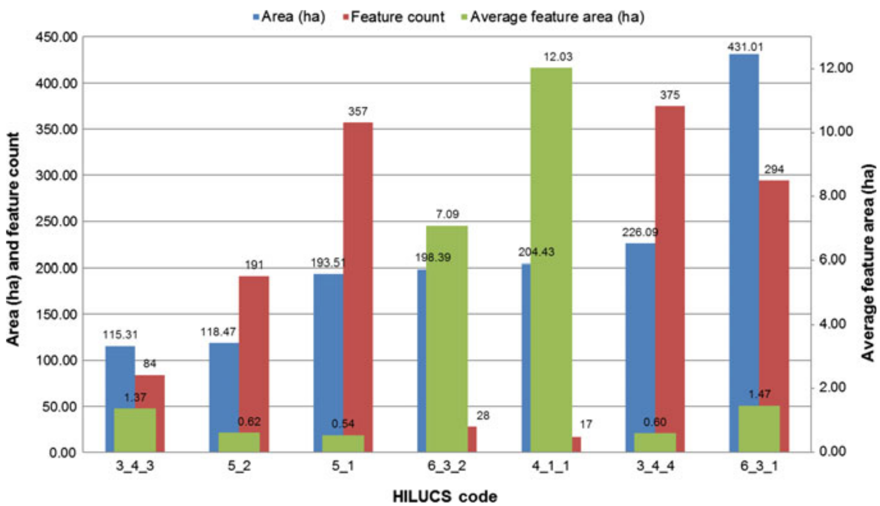

Fig. 5 Distribution of HILUCS Land Use categories in the final dataset—calculated areas greater than 100 ha

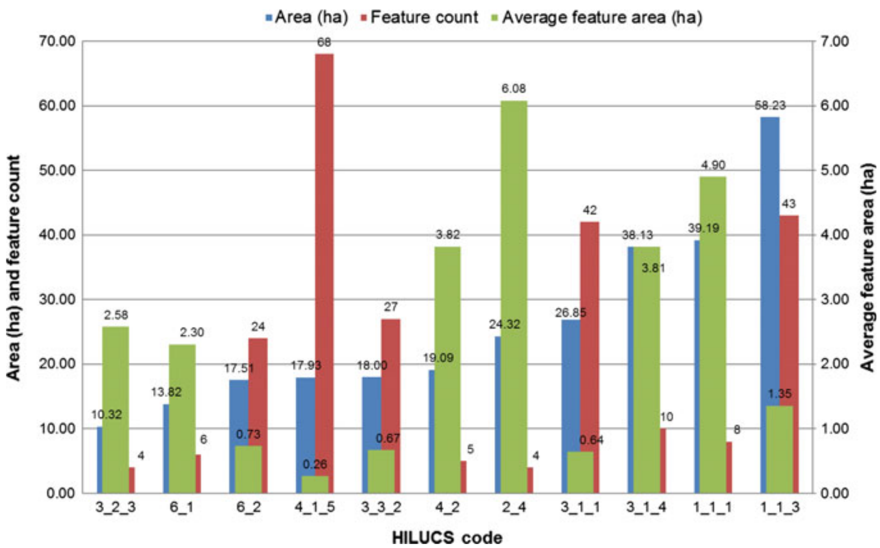

Fig. 6 Distribution of HILUCS Land Use categories in the final dataset—calculated areas between 10 and 100 ha

Fig. 5 represents INSPIRE LU categories where the sum of areas was greater than 100 ha. This group covered a total area of 1487 ha, which represents almost 82 % of the entire study area (1825.4 ha). Figure 6 characterizes the group of categories where the sum of the areas was between 10 and 100 ha, while Fig. 7 shows the distribution of areas between 1 and 10 ha. Areas smaller than one ha were not reported, since they represented less than 0.3 % of the study area.

The geographic distribution of individual INSPIRE LU zones identified in the developed dataset is depicted in Fig. 8; the colour map was based on a recommendation defined in the technical guidelines for the INSPIRE data theme on Land Use (EC 2013).

In order to verify the data quality for INSPIRE LU zones definitions based on the geometry derived from the topographic dataset and HILUCS codes assignment, based on field observations, the reference land use dataset (Fig. 9) developed in 2011 and available from ZSDI was applied.

For comparison analysis, we developed a mapping table between the ZSDI LU nomenclature, which for the study area consisted of 31 categories, and the newly developed LU dataset categorized by INSPIRE HILUCS nomenclature, covering 31 LU categories (excluding those smaller than 1 ha) (Table 2). Based on the proposed mapping, we calculated the areas in the existing land use from ZSDI and newly developed areas defined by HILUCS code. The resulting comparison is represented in the chart in Fig. 10.

Based on the statistics reported in Fig. 10, and the geographic distribution of the LU categories available in both ZSDI and newly developed HILUCS datasets mapped to the parent ZSDI, we will move on to discuss the comparison analysis.

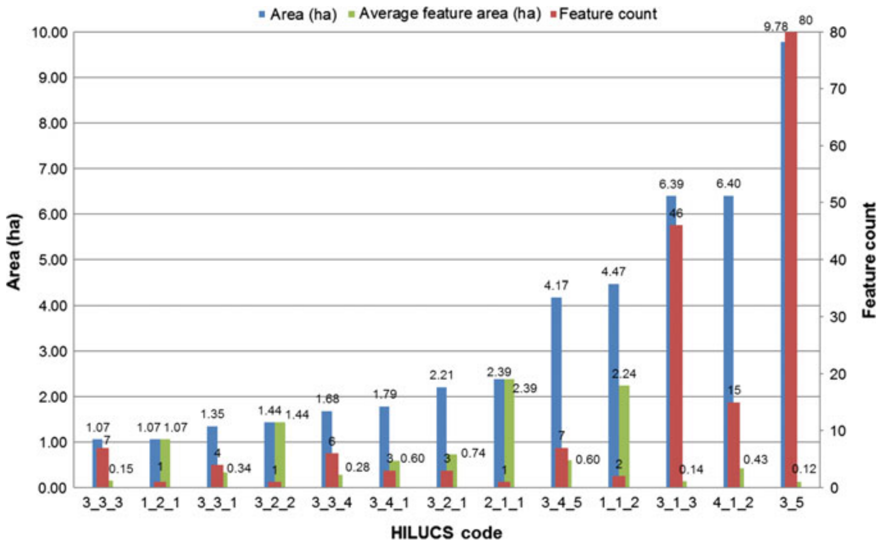

Fig. 7 Distribution of HILUCS Land Use categories in the final dataset—calculated areas between 1 and 10 ha

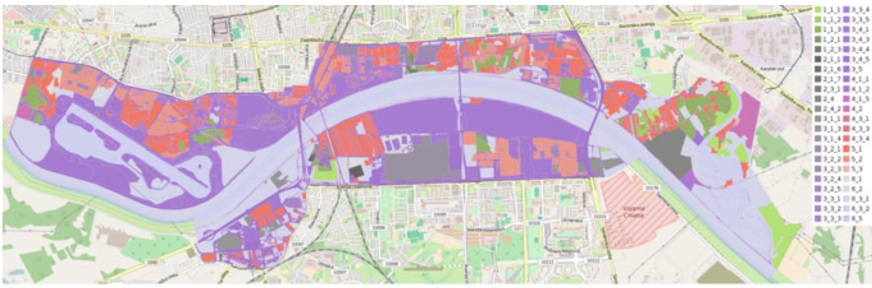

Fig. 8 Land Use dataset developed from the topographic dataset and VGI observations performed by students during the 2014 Summer School

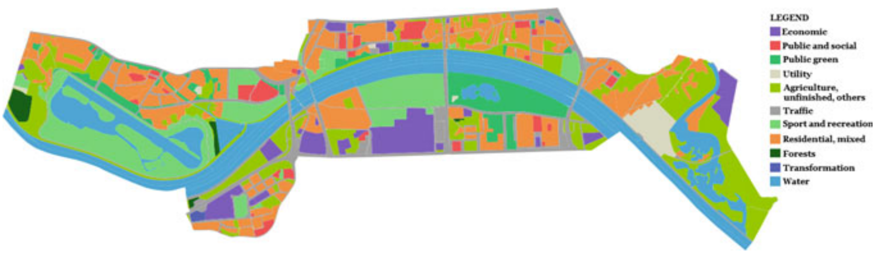

Fig. 9 Land Use dataset available from the local SDI of City of Zagreb published in 2011

Table 2 Mapping table between INSPIRE HILUCS and ZSDI nomenclatures' categories and the parent category used for comparison analysis

HILUCS Code	HILUCS category	ZSDI category	Parent category
6_3_1	Land areas not in other economic use	Poljoprivreda, neuređeno, ostalo	Agriculture, unfinished, other
3_4_4	Open air recreational areas	Sportsko rekreacijska namjena—bez gradnje	Sport and recreation
		Javne zelene površine	Public green spaces
4_1_1	Road transport	Prometne površine	Traffic
6_3_2	Water areas not in other economic use	Vode i vodna dobra—pod vodom	Water
		Vode i vodna dobra—povremeno pod vodom	Water
5_1	Permanent residential use	Stambena namjena	Residential and mixed
5_2	Residential use with other compatible uses	Mješovita namjena	Residential and mixed
3_4_3	Sports infrastructure	Sportsko rekreacijska namjena—bez gradnje	Sport and recreation
		Sportsko rekreacijska namjena—s gradnjom	Sport and recreation
1_1_3	Agricultural production for own consumption	Poljoprivreda, neuređeno, ostalo	Agriculture, unfinished, other
1_1_1	Commercial agricultural production	Poljoprivreda, neuređeno, ostalo	Agriculture, unfinished, other
3_1_4	Other commercial services	Gospodarska namjena	Commercial
3_1_1	Wholesale and retail trade, vehicle repair and personal and household goods	Trgovački kompleksi—gospodarska namjena	Commercial
2_4	Energy production	Komunalna infrastruktura (objekti i površine)	Utility
4_2	Logistical and storage services	Prometne površine	Traffic
3_3_2	Educational services	Predškolska—javna i društvena namjena	Public and social
		Osnovnoškolska—javna i društvena namjena	Public and social
		Visoko učilište i znanost—javna i društvena namjena	Public and social

(continued)

Table 2 (continued)

HILUCS Code	HILUCS category	ZSDI category	Parent category
4_1_5	Other transport networks	Benzinska postaja	Traffic
		Parkirališta	Traffic
		Trgovi	Traffic
6_2	Abandoned areas	Transformacija u tijeku	Transformation
6_1	Transitional areas	Poljoprivreda, neuređeno, ostalo	Agriculture, unfinished, others
3_2_3	Information and communication services	Poslovna—gospodarska namjena	Commercial
3_5	Other services	Poslovna—gospodarska namjena	Commercial
4_1_2	Rail transport	Željeznica	Traffic
3_1_3	Accommodation and food services	Ugostiteljsko turistička—gospodarska namjena	Commercial
		Poslovna—gospodarska namjena	Commercial
1_1_2	Farming infrastructure	Poljoprivreda, neuređeno, ostalo	Agriculture, unfinished, others
3_4_5	Other recreational services	–	Sport and recreation
2_1_1	Manufacturing of textile products	Poslovna—gospodarska namjena	Commercial
3_2_1	Financial and insurance services	Poslovna—gospodarska namjena	Commercial
3_4_1	Cultural services	Kulturna—javna i društvena namjena	Public and social
3_3_4	Religious services	Vjerska—javna i društvena namjena	Public and social
3_2_2	Professional technical and scientific services	Poslovna—gospodarska namjena	Commercial
3_3_1	Public administration defence and social security services	Socijalna—javna i društvena namjena	Public and Social
1_2_1	Forestry based on short rotation	Šume	Forests
3_3_3	Health and social services	Zdravstvena—javna i društvena namjena	Public and social

The water areas from the ZSDI LU dataset decreased by more than half (from 401.82 to 198.39 ha). On the other hand, the rather wide, general category covering 'Agriculture, unfinished, and other' almost doubled (from 304.93 to 546.73 ha). The main reason was that in the original nomenclature of the land, areas around the river bank were defined as water areas, whereas in the newly developed dataset they were identified as land areas *not in other commercial use*, which were mapped to

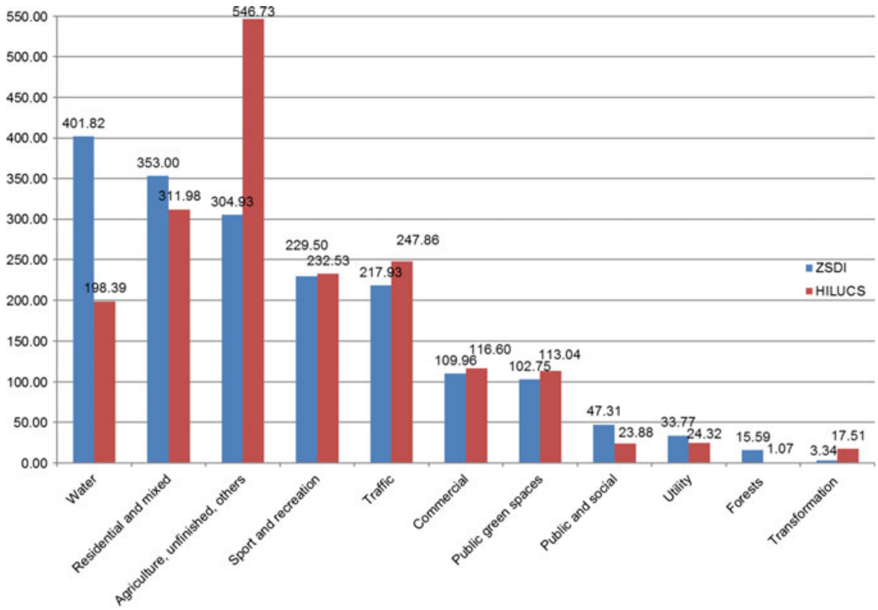

Fig. 10 Comparison of areas calculated for the areas grouped in the ZSDI land use dataset nomenclature parent categories

the parent ZSDI category 'Agriculture, unfinished and other'. The reason for identifying these areas as not belonging to the part in other commercial use was based on the INSPIRE registry definition: "Areas which are in natural state, e.g. woodland, shrubland, grassland, wetland, bare land, which are not in any other socio-economic use." And while investigating these areas via digital orthoimagery provided by the Croatian State Geodetic Administration as WMS service (DOF 2012), it was evident that they were natural, while at the same time, they had no social or commercial use. In addition, Bundek Lake, an area of more than 8 ha, was generalized to the category of open-air recreational areas in the new dataset, while being identified as a water category in ZSDI.

At the same time, the 'Residential and mixed category' areas decreased in area by 41.02 ha, due to the fact that lower priority roads and parking lots mostly located between blocks of buildings and near the sport facilities were not included in the ZSDI dataset, whereas they were included in the newly developed dataset. In addition, the green areas located between blocks of buildings were also generalized to the residential category, while in the new dataset they exist as public green areas. This is reflected in the increase of the public green space category by more than 10 ha.

On the other hand, the 'Forest' category almost disappeared from the newly developed dataset (Fig. 11—zone 1), therefore the photographs taken in the field were used to identify the wrong category assignment, which was indeed a forest, rather than land areas not in other commercial use, as initially observed.

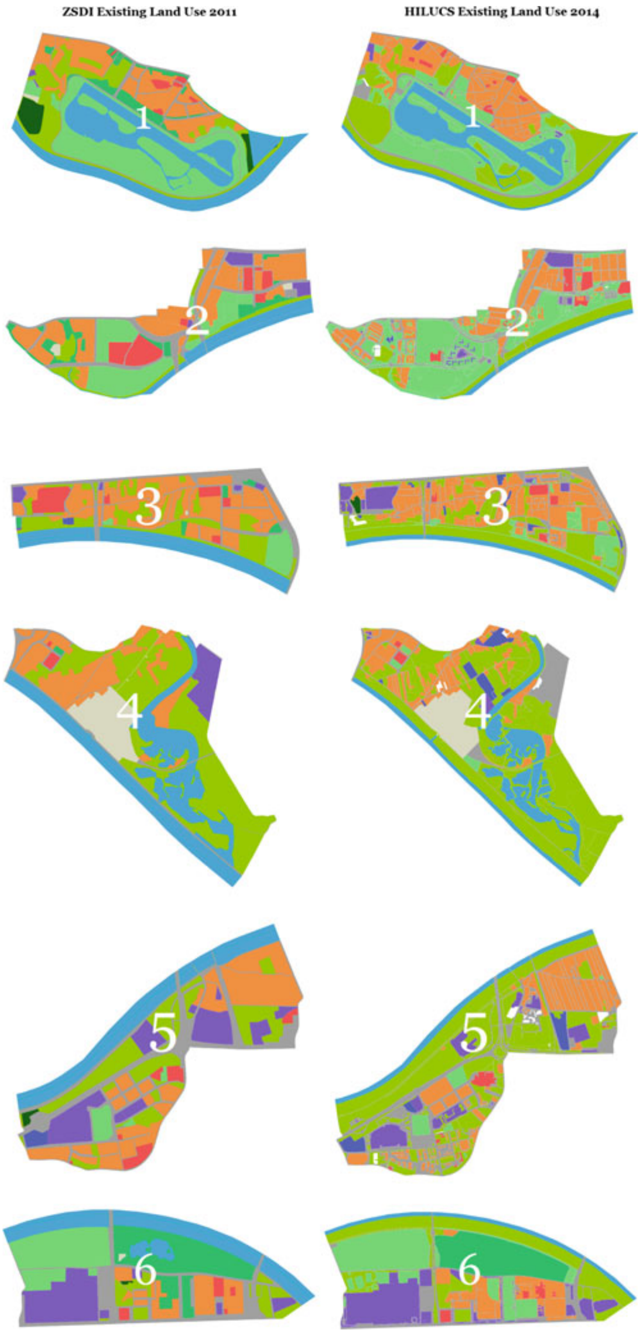

Fig. 11 Comparison of land use areas defined by ZSDI and newly developed HILUCS dataset mapped on ZSDI parent categories for 6 zones within the study area

Another alarming figure was the halving of public and social services, where the categories assigned related to commercial and information services, e.g. the student dormitory (Fig. 11—zone 2) and the Croatian National Television premises. In case of the television areas (*Hrvatska radiotelevizija*) the category assigned was information and communication services, which according to the INSPIRE Registry definition, “Publishing, sound recording, TV-programme, motion picture, radio broadcasting, post and telecommunication, computer and data processing services”, might be correct. On the other hand, national television, which is funded from the state budget, might be categorized as a public and social service.

In addition, the ‘Utility’ category decreased by almost 10 ha, prompting a detailed investigation into the reason. One reason was that four buildings out of six occupied small areas (<1 ha) and thus were not represented in the comparison analysis. The representative object in this category was the heating plant and its surface area covering more than 30 ha in the ZSDI dataset, while in the new dataset; it was divided into three categories, energy, transportation for the rail infrastructure, and land areas not in other commercial use (Fig. 11—zone 4).

Another example was identified in Fig. 11—zone 4, a 15 ha area located in the northeast corner of the zone. The category identified for this polygon in the field was ‘Logistical and storage services’, which is described by INSPIRE registry as “Areas used for separate (not linked directly to industries) storage services and logistical services”. Therefore, it represents the traffic category in the new dataset, but commercial use in the original ZSDI dataset.

5 Conclusion

Time brings about change and awareness of the need to understand the interdependencies of environmental and social phenomena. Today, the mere availability of spatial data is not enough city employees or ordinary citizens. They want and need more. The more spatial data we have, the more we see the need for sophisticated processing and analysis models that can turn data and information into insight and intelligent action. This is the way to support and empower e-governance processes implementing strategic planning.

In this chapter, we have presented the process of using Volunteered Geographic Information (VGI) resources to collect and maintain land use information at the local SDI level, relevant to a city’s strategic planning. Research was performed with students in the city of Zagreb in Croatia. The surveying groups collected point features with the following data type attributes: Land Use codes defined by HILUCS and optional Land Cover codes defined by LUCAS classification. In addition, photographs representing the observed areas were collected by cameras embedded in mobile GIS platforms. An update of the original topological layer was performed and Web GIS components for sharing the newly developed datasets were implemented. In addition, the newly developed dataset was compared to the one available in the ZSDI created in 2011. Based on the results, we can conclude that there is a problem regarding the simultaneous existence of several nomenclatures representing different views on land use category definition. It is very important to understand the differences between categories of similar type, which very often vary only in small details, in order to provide valuable data for European, national and local governments. Based on the research, it was confirmed that land use data are not available in the expected quantity, quality and update frequency. Therefore, the methodology reported in this chapter may improve the situation, by providing a suitable proposal for fieldwork and updating land use database in line with the INSPIRE directive, applicable anywhere at a local spatial data infrastructure level. However, it is very important to mention that for e-governance in a city, existing land use and time series represent just one part of the essential dataset, while planned land use with its time series covers this set of geospatial information resources, and is vital to effective and efficient workflow processes in strategic planning.

The data collected in this work were made available for e-Planning and further developments in the selected area of the city of Zagreb. The approach described in this document is novel and could be extended to other contexts. These datasets could form the starting point for future investment and extension in the city of Zagreb's spatial urban planning.

Acknowledgments The GIS Summer School 2014 received funds from the project entitled "Development of international cooperation with the aim to transfer the results of research into the educational programs", Number of the project: ITMS 26110230085.

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7 2007–2013) under grant agreement no 291823 Marie Curie FP7-PEOPLE-2011-COFUND (The new International Fellowship Mobility Programme for Experienced Researchers in Croatia—NEWFELPRO). This manuscript has been prepared as a part of a project "Bolegweb" which has received funding through NEWFELPRO project under grant agreement no. 3.

In addition, this work was supported by the Croatian Science Foundation as part of the 7714 "DEMLAS" project.

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Mapping a City's Activity. A Project of Volunteered Geographic Information Using Mobile Mapping Collection

Giuseppe Borruso and Viola Defend

Abstract The work done deals with the concept of Volunteered Geographic Information and is based on the use of a mobile mapping collection tool to retrieve geographical data from an urban fieldwork. The research has been carried on during the academic year 2014/2015, involving students from the course of Geography of Networks within the post graduate degrees in 'Economics' and 'Business' of the University of Trieste (Italy). The intent was testing the potential of crowdsourcing in retrieving data using a bottom up approach, relying on a set of trained and aware 'urban sensors' as data collectors. This allowed us to derive first-hand geographical data concerning a particular topic and analyze its spatial distribution by means of Geographical Information Systems and spatial analytical tools. The topic studied was represented by the urban 'movida', the analysis of the areas of the city that are more or less active during the days and during the week. This major aim was also coupled with an ancillary one, as the coverage of Wi-Fi hotspots and networks over the urban area of Trieste. It is known that many Italian cities still do not allow a very wide coverage of wireless networks to access the Internet. The city of Trieste, on the border between Italy and Slovenia, is suited with a certain degree of coverage, particularly in main roads and squares, thanks to free Wi-Fi coverage managed by the municipality and an academic network of Eduroam system, quite spread over European and world cities hosting universities and research centers.

Keywords Volunteered geographic information · Citizens as sensors · Smart cities · GIS · Mobile data collection

The paper derives from the joint reflections of the two authors. However, Viola Defend realized paragraphs 2, and 5, while Giuseppe Borruso wrote paragraphs 1, 3, 4 and 6.

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_24

1 Introduction

The current debate on Smart Cities is running on the impact of the ICT (Information and Communication) in fostering sustainability of our urban environment and, in a broader sense, in improving the quality of our lives (Toppeta 2010; Schuurman et al. 2012). The debate is often split in two main fronts On one side we find particularly hardware and software vendors, promoting ICT out-of-the-box solutions, aimed at managing and controlling cities through big operation centers, mainly hosted by local authorities, in terms of traffic, security and other form of 'smart', top down remote control of the different aspects of a city (IBM 2011). On the other side, many authors follow a bottom up approach in which inputs and instances come from citizens and city users as active participants in highlighting issues and possible solutions at urban level, helped by new technologies and tools. The debate is between top down—techy—solutions and bottom up approaches integrated into an urban planning process (Townsend 2013; Murgante and Borruso 2013, 2014, 2015).

In such sense, citizens are becoming more and more data producers, both unawares and knowingly. In the former case, citizens can be unaware of the amount of data they create, by being connected to smartphones with geolocation functionality on and registered to the most popular apps and social networks and media, making it possible to private companies as mobile phone and services providers to rely on a wealth of data from which deriving spatial patterns of movements and occurrences of some phenomena. In the latter case, citizens can be aware 'urban sensors' and deliberately collect data for some purpose, using the mobile devices nearly everybody of us to-date have access to and few skills for data collection (Goodchild 2007).

Scope of the present paper is to present how citizens can be involved in projects dealing with the collection of data with a spatial reference on urban issues, therefore playing a role of 'urban sensors' and provide scholars with original data to work on. The paper is focused on urban issues and on the process of data acquisition, visualization, analysis and representation made possible by combining the citizen science approach of citizens as urban sensors, the implementation of mobile data collection tools by means of low cost solutions, and the opportunities offered by free and open source GIS platforms to perform analysis and cartographic visualization and representation.

The paper is organized as follows. In paragraph 2 the concepts of Volunteered Geographic Information, Neogeography and Citizen Science are briefly presented, included an overview of the cartographic implications of this process. Paragraph 3 is more focused on the role of users in collecting data in a field work, acting as sensors in a bottom up approach in a smart city scenario. In paragraph 4 the methodology adopted is followed, including the workflow made, that concerns the setup of the project, the data collection process and the successive analysis and visualization of the results made through GIS packages (online and desktop) and visualization software. The different tools developed and the software, as well as the analysis on the data after their collection and the visualization chosen are presented. Paragraph 5 deals with the case study: the choice of the mobile data kit to collect data, the volunteers and sensors to engage, open issues. Conclusions and future developments are can be found in paragraph 5.

2 VGI, Neogeography, Public Participation, Citizen Science

The rationale behind the project presented deals with a particular case of Citizen Science where geographical element is essential: Volunteered Geographic Information. It configures not only as a mere data collection plan, but a way to increase awareness and engagement of participants in the community through new technologies (Publications Office of the European Union 2014). This phenomenon of Volunteered Geographical Information (VGI), coniated by Goodchild (2007) sees, as a particular case of Neogeography (Turner 2006, 2007; Graham 2009; Warf and Sui 2010; Eisnor 2006; Elwood 2006, 2008; Fischer 2008a, b, 2009; Ghosh and Dasgupta 2015), the involvement of citizens in collecting geographical data as a particular case of user-generated content (Neis and Zielstra 2014; Hudson-Smith and Crook 2008).

Together with these two characteristics—that are the engagement of private citizens without formal qualification and the creation of geographic information—in Goodchild's definition of VGI we can find other main points:

- A voluntary contribution to the projects;
- A level of uncertainty in the accuracy of collected data;
- It's being a "dramatic innovation" affecting GIS and geography in general.

The scientific data collection in the last century has become an expensive process due to the increased costs related to the high-end equipment and technologies. However, when referring to data acquisition aimed at geographic information retrieval, analysis and representation, nowadays low cost solutions are available, allowing practically everyone to make geographic information.

Mapping procedures and the way spatial information are made and transmitted, have been widely changing over the last years. Communication systems are upgrading quickly, adapting to new technological discoveries. These facts, merged with the new mobile internet and computing devices like personal computers, allowed the switch from printed maps to web and digital one. New kinds of mapping technologies flexible and dynamic way of presenting spatial data to a mobile user based on his context and his profile (Reichenbacher 2001).

The need of a mobile cartography was born from the need of adaptation and customization. New kinds of mapping technologies present in a flexible and dynamic way spatial data to a mobile user based on his context and his profile

(Reichenbacher 2001). That regards many aspects of geographic data processing and transformation into information—and possibly knowledge (Longley et al. 2011).

Data collection is made simpler, faster and low cost to-date. First-hand geographical data can be easily collected by means of portable devices fitted with GNSS—GPS receivers. The GNSS receivers installed inside our portable digital devices are in fact powerful and allow reaching a decent level of precision, spanning from 2–3 m in good conditions to a worse case of 10 or more meters in adverse multipath situations (Pesyna et al. 2015; GPS.gov 2015), typical of cities, where 'urban canyons' effect can cause distortions to the signals received by the satellites. That allows virtually everyone to become an amateur geographical data gatherer or a map-maker and participate to mapping local or global projects. Examples can be found in OpenStreetMap (http://openstreetmap.org) and Wikimapia (http://wikimapia.org), where maps are made completely by users, as results of a 'democratization' of GIS (Goodchild 2007). Other examples include the use of citizens over specific projects over a certain amount of time or the use of finalized user groups to target some specific issues (e.g. former Nokia, Here Maps, maps.here.com). This is because citizens are the stakeholders par excellence and represent the part that actually lives the urban environment and should—for that—be engaged to collect and use shared geographic information.

More in general, talking about citizen science and the involvement of citizens in scientific projects, the role played by citizens can be different depending on the task considered, both in cases it regards data acquisition and in cases it deals with data analysis. Projects concerning a various range of topics have been made, and participants are asked more observation skills than costly equipments. Three main types of public participation in scientific research can be identified, providing different models (Bonney 2009):

- Contributory;
- Collaborative;
- Co-created.

The first one reckons on scientists as designers of projects and public contribute to data collection. Collaborative projects see instead the involvement of citizens also in various phases, from planning, analyzing and diffusion of results. The extreme level of public participation is in the third model, the co-creation of projects between public and scientists in most of the steps of scientific process (Shirk et al. 2012).

Easiest ones relies on the computing power of computer, as in the case of SETI@home (e.g. http://setiathome.berkeley.edu), while in others cases an analysis of data is required to participants (e.g. Planet 4 Terrain, http://planetfour.org). In the last cases, scientists may give some basic or more specific information in scientific methodology: this way, an impressive number of 'researchers' can be a part of the data collection, with a higher level of training. Sensors can give a little help, but most of the work lays on the analysis and interpretation of all the data collected.

In the case of SETI@Home the need was the mere power of the personal computer, but in more recent projects the need switches to the sensing of a human and his capacity of analysis. In the panorama of Citizen Science there are also projects interely designed by citizens: a model of 'science by the people' or Participatory Action Research' (Cooper 2015) and kinds of 'do it yourself science' (European Union 2014).

Citizen science, Volunteered Geographic Information and neogeography have some things in common: people willing to be included in the scientific research, no formal skills—or a very limited training over the cartographic and data acquisition process—, a passion for a topic and the dissemination of these activities. It is interesting to underline that there is an exchange of knowledge between the two sides; that depends according to the effort needed.

The only requirement is an Internet access or a smartphone app: mobile connectivity allows also more closeness between scientists and citizens. The motivations can vary over places and types of projects, but the initial participation is due to personal interest, self-promotion, self-efficacy and social responsibility (Rotman et al. 2014).

On the other side, many firms and companies tend to refuse using data collected through VGI because of the difficulty of evaluating quality, and so does a large part of academic environment, questioning information and source credibility due to the involvement of the public and not only experts. However, many researches (Haklay 2010; Girres and Touya 2010; Cipeluch et al. 2010) show that these data have a relatively high quality:, even if not collected by specialists: for this reason, a lot of participatory projects are considered interesting, mostly if there is a strong need toto involve a wider community, like in the case of Geo-Wiki Project (e.g. http://geo-wiki.org) in which the aims are the geospatial cover validation and improvement of global maps (Fritz et al. 2009; Perger et al. 2014). The fact that these data are collected mostly by non-experts or little trained and qualified volunteers lead to mine for some their credibility (Haklay 2010; Flanagin and Metzger 2008). This is not true in every case: from surveys conducted on OSM users there is evidence that more than 50 % of respondent was not entirely "new" to the world of GIS, geography, geomatics, urban planning, informatics (Neis and Zielstra 2014).

Applications of this particular case of user generated content are rising in many field, from the public utility projects on environmental or social issues, to humanitarian ones. These latter motivations are particularly interesting as many free and open source projects and platforms have been developed. This fact, coupled with the widespread use of smartphones and tablets and Internet connection, allows easier and faster data collection and sharing.

The ways of interaction and participation of citizens in the urban scenario are, in some ways, filled by a technological layer. A 'smart citizen' should not only be involved in the proposals of administrations, but also wish to be a part of a system to improve the city. In this scenario stands our project about the urban movida and the Wi-Fi coverage in the urban area or Trieste (Italy), thanks to the help of a particular category of citizens: students.

3 The Role of Users/Citizens in Collecting Mobile Data

In the recent literature concerning Smart Cities, a significant element is put onto the importance of citizens as the sensors who actively participate to a city's life and activities related to its good operation. As Murgante and Borruso recall (2013, 2014, 2015), citizens as 'urban sensors' can be put among the three 'pillars' sustaining a (smart) city. According to these authors, in fact, a Smart city can be thought as an urban system sustained by three main elements (the pillars) that includes citizens as urban sensors, data, in terms of both open and big data, and a network, or a set of connections among places and people. These elements are organized by an urban governance setting a limited set of rules concerning the interaction in the urban environment. Citizens and urban users can participate publicly to a city's life and build and realize their own services and activities, meeting needs they often know better than the final decision and policy makers. New technologies are of course strengthening such a process, thanks to the possibilities mostly given by the Internet, social networks and portable devices. However, the enhancement given as citizens by such technologies in terms of extension of our capability of sensing the city around us (Batty 2013), must face the still limited use that we do of them. Still to-date, the vast majority of people uses smartphones and portable devices for playing games, social networking, web browsing and professional communications (corporate emails), often blurring private and professional uses but still limiting the use of more advanced functions. In reminding this, still Murgante and Borruso (2014, p. 747) point out how "Our smartness as citizens should therefore be that of using the potential of such devices to exploit our interaction with the city to monitor it and highlight both positive and negative aspects and help its better management".

An important element in setting up a project of urban citizen science is therefore represented by the kind of users that are involved, acting as real sensors of the phenomenon under exam, and on the level of knowledge, awareness and (technical) skills they have to show. As Haklay (2013) points out, different can be the categories of citizens involved.

The 'classic' citizen science involves amateurs in traditional scientific activities; a second category is made by amateurs engaged by the science community in measurement and analysis to set action plans. A third flavor is represented by the citizen cyberscience, where users rely on the capabilities offered mainly by portable devices as smartphones and tablets, now fitted with positioning systems as GPS—GNSS receivers and network connection (Wi-Fi, Bluetooth, GSM—3/4G). Still with Haklay we can find volunteered computing, i.e. citizens download data, perform analysis locally and then send them back to a server; volunteered thinking, where citizens perform classification works, and participatory sensing. This latter involving applications centered on mobile phones capabilities.

In the present research, we relied on citizens as urban sensors in the 'citizen cyberscience' category, as a set of users was trained to install a mobile data collection app on their smartphones and then use it for an urban fieldwork, therefore with a certain degree of autonomy and participation to the project aims and ideas.

4 The Methodology

In this research the aim was to examine an urban phenomenon from data collection to visualization, to analysis to the interpretation of results, as the presence of people in different times of the day and places of the city, to try understanding the patterns of 'movida' in the city of Trieste and also the presence of free Wi-Fi coverage in such areas.

After deciding the topic of our research, we first started with the quest for an adequate mobile application to collect data that needed to be free and easy to use and to set up and allowing a set of different questionnaires to be loaded. That drew us to focus our attention on GeoODK system of data collection and aggregation (Ghosh and Dasgupta 2015; GeoODK Tutorial http://geoodk.com). It is an environment for collecting data via mobile devices and storing them onto a remote server allowing performing of field data surveys. GeoODK Collect is an app, developed for Android operating systems devices, capable of hosting forms and questionnaires, and suitable for collecting a wide set of data, including georeferenced ones. Such an application, whose forms for data collection are fully customizable, can be linked to a remote server where georeferenced data can be stored and processed. GeoODK is based on the ODK—Open Data Kit—environment for data collection, gathering, managing and analysis, with more fitted-for-purposes functionalities from the geographical point of view.

GeoODK can be fully implemented by means of questionnaire and survey forms. That was made possible using a tool named XLSForm, that allows creating forms using a MS Excel spreadsheet and then converting them as XForms, a format usable in platforms for mobile data collection as the ODK—Open Data Kit environment (http://opendatakit.org).

In parallel with the use of an app (GeoODK) and the realization of a form for collecting data, a web-form was also implemented, both to allow users of other devices to collect data (i.e., iOS and Windows phone), and a digital entry of data from a desktop or laptop pc, an useful feature also as for editing already inserted data. The survey form created using XLSForm was then made available also through a web-form as Enketo Smart Paper, a web form usable on portable devices and desktop or laptop pcs to collect data. Enketo Smart Paper is a part of the ecosystem of ODK and OpenRosa community, developed and implemented as a standardized open-source form format (http://enketo.org).

A successive step implied the definition of a set of users to be involved in the data collection campaign and their training. Our initial idea was to involve common citizens in the project, hopefully students and young people in general, potentially more prone to using apps and similar technologies on portable devices and to be involved in project dealing with a matter of interest for them, as the areas of free time and leisure (pubs and bars) and the presence of free Wi-Fi hotspots, both public and private. To do so, a dissemination campaign has been carried on among authors' acquaintances in the city, students of some university courses (Geography of Networks in the post graduate degrees in Economics and Business) and local groups on popular social networks. We realized a training by means of videos and slideshows both presented in seminars and broadcasted through social networks. An important aspect was in fact considered also exploring the potentiality of crowd-sourcing and retrieve useful data for public utility purposes.

Further steps involved the analysis and visualization of the data obtained. As an aggregation server we used a cloud based Ona, as that provided by Ona, a platform provided by a social company that has been developed to host data collected from fieldwork by means of forms and questionnaires on apps on mobile devices or through web forms (http://ona.io/home).

The platform allows also visualization, cartographic representation, editing of the data collected, as well as the realization of statistics and reports. It allows also exporting the collected data in popular formats, as spreadsheets and geographical formats. There are free services but also more complex solutions available through payment of a fee. Different levels of privacy can be set on the data server, so that each project can be shared with mobile data collectors at different levels of security. Although a certain level of visualization and reporting is possible through Ona, we needed to test different modes of cartographic representation and further analysis. This was done by means of GIS packages, as QGIS (http://qgis.org) and also visualization software as CartoDB (http://cartodb.com). In particular scatterplots were used to represent the dataset, as well as 'heat maps', also in their dynamic version.

The analysis on the spatial distribution of point data was done using basic point pattern analysis techniques as scatterplots, and using the more refined Kernel Density Estimation (KDE), a spatial function that allows the transformation of point events in space in a continuous density function over the a region, resulting a pseudo—3D surface that shows a concentration of point features.

The Kernel Density Estimation function creates an estimate of point events' distribution in space, within a searching radius, according to the distance to the point where the intensity is being estimated (Bailey and Gatrell 1995).

$$\hat{\lambda}(s) = \sum_{i=1}^{n} \frac{1}{\tau^2} k\left(\frac{s - s_i}{\tau}\right)$$

$\hat{\lambda}(s)$ is an estimate of the intensity of the events' spatial distribution, measured at location s; s_i is the ith events, k (.) is the kernel function and τ is the bandwidth, or searching radius. Changes in the size of the searching radius allow obtaining more or less smoothed surfaces: wider bandwidths oversmoothe the estimate including distant events, while a narrower ones overemphasize local variations in the events' distribution, this allowing the analysis of the phenomenon at different scales

(Levine 2004). One of the most desirable advantages of using this function, particularly in terms of the representational aspects, is given by the fact that it spreads all over the study region, therefore assigning to each point (or cells, as the study region is 'gridded' for an easier computation) an estimate of the density value (i.e., events per square kilometer) or as probability estimates.[1]

5 The Case Study

5.1 The Choice of the Mobile Data Collection Kit—GeoODK App

As the project was developed as an applicative part of an academic course, one of the most important element was the search for low cost and low skill requiring solutions, in order to be used for a research involving students and with a minimum effort in programming and customizing IT component, the aim being on focusing on the social aspects of the project and therefore leaving us time and resources to concentrate over the kind of data to be collected. We took into consideration many mobile applications, but most of them were limited in terms of number of submitted surveys per day or devices per project.

After several trials (Table 1) we approached the Open Data Kit (ODK) environment, appreciating its structure and application. The ODK Collect app was therefore tested as a tool for mobile data collection, given the high possibilities of customizing its content according to different projects. We decided to use an advanced version of ODK, as GeoODK, open source platform created by the University of Maryland and International Institute of Applied System Analysis that is composed of two main parts. On one side there is the mobile application, GeoODK Collect, that runs on Android smartphones and can be also used in offline mode. On the other side we have an "aggregate" web platform (examples are Formhub, ODK Aggregate and Ona). This web platform, based on html pages, aggregates data, lets you visualize on the screen the map of data, modify or delete data or export data in CSV, KML or XLS files. In addition, for those who do not have a smartphone or have a different operative system running (such as iPhone-users or Windows-users) and cannot use GeoODK Collect, the web system allows to retrieve data using Enketo Smart Paper, a web form of the survey (e.g. http://enketo.org).

The key element, and the element bringing added value to any data collection project, is represented by type of questionnaire or form used for collecting the data.

[1]For a more in depth overview of the Kernel Density Estimation and its characteristics see Diggle (1985), Levine (2004), O'Sullivan and Unwin (2003), Silverman (1986).

Table 1 Comparison between mobile data collection tools tested for the research project

Pros	Cons	Characteristics
ODK collect		
Free	Runs only on Android devices, no iOS, nor Nokia/Windows phone	Open Data Kit (ODK) is based on an architecture of an app for smartphone, a collection server and a set of trained individuals to work on the results
Easy to customize		http://opendatakit.org/use/collect
Allows creation of a form/questionnaire using an excel spreadsheet		
Allows multiple data types and formats		
Store point data		
GeoODK Collect		
Free	Runs only on Android devices, no iOS, nor Nokia/Windows phone	Geo Open Data Kit (GeoODK) is based on an architecture of an app for smartphone, a collection server and a set of trained individuals to work on the results
Easy to customize		Based on ODK Collect architecture
Allows creation of a form/questionnaire using an excel spreadsheet		http://geoodk.com
Allows multiple data types and formats		
Store geographical data as points, lines and polygons		
Kobo Collect		
Free	Runs only on Android devices, no iOS, nor Nokia/Windows phone	Kobo Collect is based on an architecture of an app for smartphone, a collection server and a set of trained individuals to work on the results
Easy to customize		Based on ODK Collect architecture
Allows creation of a form/questionnaire using an excel spreadsheet		http://kobotoolbox.org
Allows multiple data types and formats		
Store point data		
GIS Cloud—Mobile Data Collection		
Easy to customize	Free version limited to one device	Integrated with GIS Cloud platform
Allows creation of a form/questionnaire using an easy interface		http://giscloud.com/apps/mobile-data-collection
Allows multiple data types and formats	Fee for multiple devices	
Store point data		
Integrated with the GISCloud development environment		
EpiCollect		
Free; Easy to customize	Seems to be not adequately supported or developed at present	Web and mobile app for the generation of forms (questionnaires) and freely hosted project websites for data collection
Runs on Android and iOS operating systems		http://epicollect.net

Source Mobile data collection tools site

Table 2 Structure as structured in our project with the full list of questions

Type	Name	Label
Datetime	data_ora	Data e ora della rilevazione
Geopoint	Geolocalizzazione	La tua posizione GPS
Text	nome_evento	Nome dell'evento a cui partecipi o locale in cui ti trovi
Text	indirizzo_evento	Ci puoi dire l'indirizzo o la zona dell'evento?
Image	immagine_evento	Carica una tua foto dell'evento!

An example of the form, contained in the first worksheet of the Excel file "survey"

In this case, the form or survey form could be realized setting up different kind of data to be stored and registered, spanning from text, to numbers and to multi-media contents.

The design of the form is made through an Excel file composed by two standardized worksheets: one is 'survey' (Table 2) and the other is 'choices' (Table 3). In the first worksheet there is the list of questions: for everyone it is to explicit the kind of input required: text, media (photographs, audio, video) numbers, multiple choice questions, GPS or Polygon coordinates, date, time and barcode.

In the other worksheet, one has to specify the options for multiple-choice questions. One, with little more practice, can also add rows to create cascading selects, grouping and nesting questions, skipping questions add hints (http://geoodk.com/xlsform_format.php).

After loading the file in the aggregation server (http://Ona.io), the form is converted to Xform. To start collecting data through GeoODK Collect one has to

Table 3 Second worksheet, "choices", as structured in our project with the list of multiple choices questions

List name	Name	Label
si_no	Si	Si
si_no	No	No
affluenza_evento	Scarsa	Scarsa
affluenza_evento	Discreta	Discreta
affluenza_evento	Buona	Buona
affluenza_evento	Ottima	Ottima
nome_wifi	Eduroam	Eduroam
nome_wifi	Triestefreespots	TriesteFreeSpoTS
nome_wifi	Retelocale	La rete wifi del locale in cui mi trovo
nome_wifi	Nonrilevate	Non rilevo alcun free wifi
intensita_segnale	Scarsissima	1
intensita_segnale	Scarsa	2
intensita_segnale	Media	3
intensita_segnale	Discreta	4
intensita_segnale	Buona	5
intensita_segnale	no_reti	Non rilevo alcun free wifi

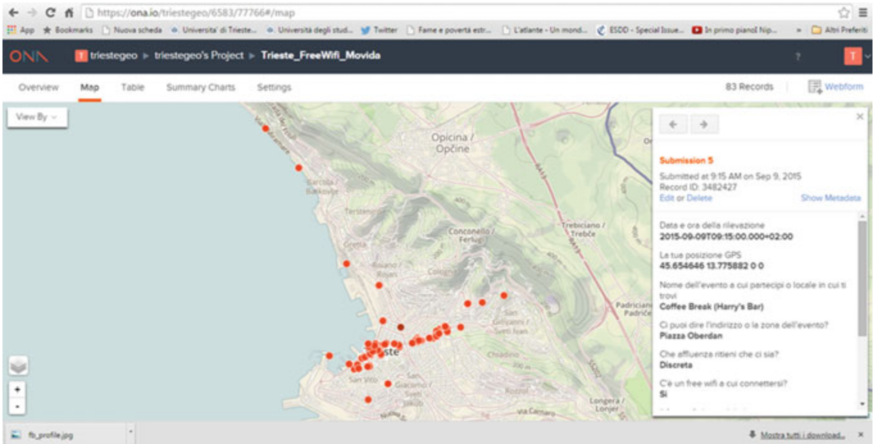

Fig. 1 First analysis of the data collected, available on http://ona.io/home

set the app settings, just for the first time: the procedure requires inserting the URL of the aggregation platform and then downloading the needed form. It is interesting to note that Ona.io allows not only visualizing the data both as a table and as points on a map (Fig. 1), but also to have a first analysis of the data collected and export them in multiple formats for further elaboration.

The use of GeoODK Collect is quite intuitive and does not require particular effort. As portrayed in Fig. 2 the main screen of the app is quite easy to use and present a limited set of options for collecting, editing, mapping and sending data to the aggregation server. Among the possible and interesting characteristics of the

Fig. 2 Main screen of GeoODK collect app and map visualization

GeoODK collect app, is the capability of capturing point events and correct them, in their geographical and attribute data, on the portable device, other than on the server side of the aggregation kit. This can prove to be very useful in cases of difficulties in getting a good GPS location in urban contexts and a need to correct the data already during the campaign.

5.2 The Choice of the Volunteers and Sensors. Students from Post Graduated Courses

In starting our project we had different options available to start the mobile data collection campaign and acquire a number of first-hand data. We had the idea to involve citizens and students in particular and incentive them to download an app and 'check in'—as in many popular social networks—in the different places of the city where they go, checking for the number of people located there—and therefore estimating their number—and also for the coverage of the Wi-Fi network, public or private. A second option was that of relying on a small, selected group of sensors citizens that, after a short training on the device and application's characteristic, would go and collect data in the urban environment.

Initially we tried to follow the first path, advertising the project via social networks and media, particularly within the University of Trieste students' community. However, such option did not prove to be particularly effective, with a limited number of people downloading the application and following the instructions on how to perform 'urban citizen science' tasks.

Our choice therefore felt on the second category of sensors, as that of aware and trained people over topics as 'smart cities', 'urban geography', 'GIS and mobile data collection'.

During the course of "Geography of networks", within the post graduate degrees in 'Economics' and 'Business' of the University of Trieste (Italy), students were given the opportunity to interact with people of the local administration to give some ideas to improve the city and city services. As this study of the "city's activity" emerged as an applicative example of this collaboration, we decided to involve the student of this course, suitably trained by the authors through a small presentation to use the mobile application or the web form, as well as on basic GIS and Cartography, as part of the topics covered in class.

Students were a suitable choice to collect these kind of data—urban movida and Wi-Fi, especially in a city, Trieste, where there is almost a 30 % of people over 65 years old (Adnkronos 2013) in a population of around 210,000 inhabitants, and the University students' community alone counts for nearly 20,000 people (including residential and non-residential students). This project wanted to be a way to show the places of activity of the city and have the opportunity to provide some sort of evidence to extend the free Wi-Fi coverage.

In addition to the engagement of this group of students, an advertising campaign on Facebook was made, together with the creation of a Facebook page "Data collection about movida and free Wi-Fi in Trieste". The data collection campaign took place during the summer period and involved volunteers in mapping places in the city of Trieste, stating the presence of public or private Wi-Fi network, as well as he level of affluence in the considered venues. These two elements could be interesting for further studies, in order to map places where people actually move in different days and times of the year, as well as understanding the level of coverage of the Wi-Fi network. These elements were useful both for experimenting visualization techniques and to provide local authorities with a set of information on where to address investments in Wi-Fi development and coverage according to the presence of users.

5.3 Visualization

After exporting data in *.csv or *.xls formats, they can be uploaded in various types of both online and desktop version of GIS software. We used CartoDB (http://cartodb.com) and ArcGis in its online and desktop versions, as well as QGIS.

A simple scatterplot of the data shows only a point in correspondence of every survey (Fig. 3): a more interesting map is made with heat map (Fig. 4)—realized by a density estimation—, which shows—as explained in the methodology—with a different colour the presence of overlying data.

This basic visualization gives us an initial idea of the spatial distribution of the locations mapped. An initial observation refers to the presence of locations particularly in the city center of Trieste, in proximity of the 'Piazza Unità d'Italia' and the 'Rive'—major corridors along the sea—and in some main pedestrian streets in the inner city.

Using a heat map (Fig. 4) on CartoDB there is evidence of a concentration of data collected in two main parts of the 'urban movida': Piazza Unità d'Italia, the main square of the city, and Viale XX Settembre, a street where many bars and restaurants are located and open until late hours. These reasons make them

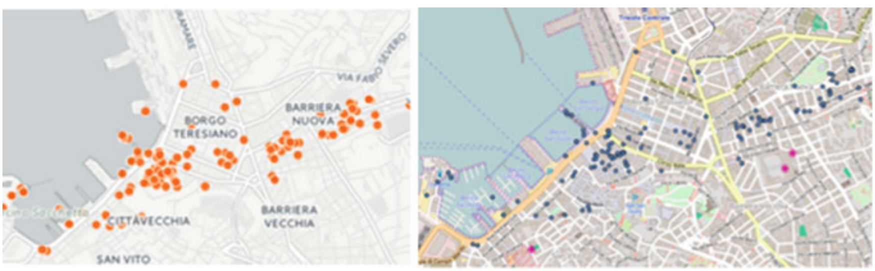

Fig. 3 A scatterplot of the data collected. The survey data in *orange* on the *left* in a CartoDB elaboration; in *blue*, on the *right*, in a QGIS elaboration

Fig. 4 Heat map of data on CartoDB. Data are concentrated in some parts of the centre of the city

frequented during evenings and nights and this is also compatible with the presence of high number of locations registered by the urban sensors involved in the project. The heat map has been realized according to a bandwidth of nearly 400 m, generally considered a good approximation for urban areas analysis, as it generally approximates a 5 min walk, a distance generally easily walkable by people.

Using the torque heat map instead, one can have a temporized map that shows a dynamic data population over time: in Fig. 5 a screenshot of four different moments of the data acquisition campaign are portrayed.

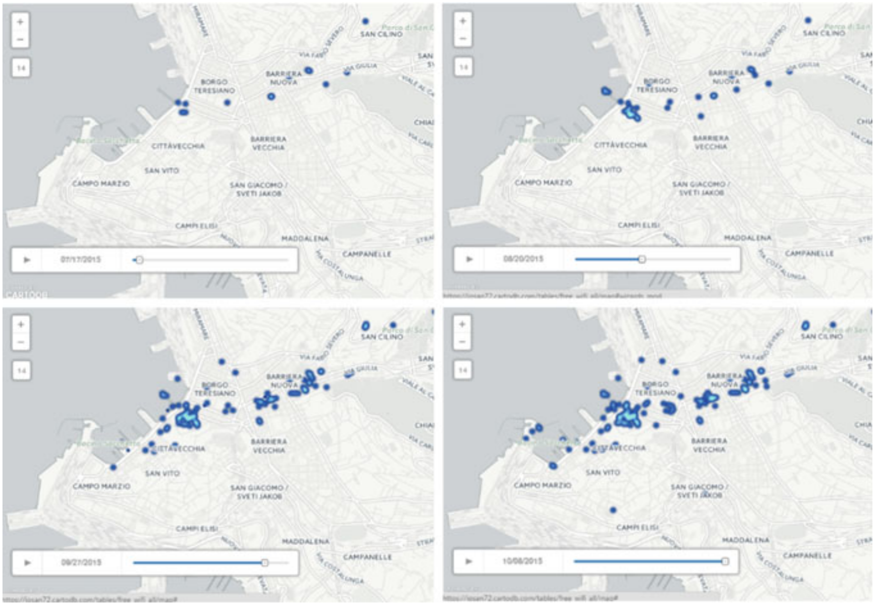

Fig. 5 Torque map of data population over time (*Top left*, 17 July 2015; *Top right*, 20 August 2015; *Bottom left*, 27 September 2015; 8 October 2015). CartoDB elaboration

The dynamic torque map gives us an idea of the data acquisition process that started during the summer time and had its peak at the end of September 2015 and beginning of October, with the mapping of a set of events that took place in the city and that helped in registering the affluence of people and coverage.

5.4 Analysis

The analysed data involved a total of 225 point events: 150 georeferenced data from our project about urban movida were merged with 75 referring to two particular events, Trieste Next 2015, conference and exhibition that took place on 25–27 September 2015, and Fuoriregata, a series of events held on 2–11 October 2015 as a 'backstage' of the more popular sailing race 'Barcolana' and the related activities on the sea shore.

As said before, we were interested about presence of people at places on a 'normal' week and in case of special events organized by the local administration. Data showed that in the 71.43 % of cases there was a discrete or optimal presence (3 or 4 on a scale of 4) to an event or in the bar/restaurant where the survey was taken and only a 9.82 % of poor affluence.

Users were asked to give information about the availability of free Wi-Fi, marking if public or private. In Fig. 6 red dots indicates the absence of a free Wi-Fi: considering that the places near Barriera Nuova are very crowded, this can point out the need of new hotspot in this area; more can be done so behind Piazza Unità

Fig. 6 Users reported *blue dots* indicating availability of free Wi-Fi. *Red dots* points with no free Wi-Fi. CartoDB elaboration

d'Italia. It is evident as some popular places among city-users are still not covered by free—public or private—Wi-Fi network.

5.5 Open Issues

We surely can say that the GeoODK solution we tested in our project was adequate because of its easiness to use and customize. It uses a XML standard working on many platforms, app and servers are free and the app allows to export data in multiple geo data formats.

On the other side, as in many similar projects of Citizen Science, we had a general problem in effectively engage people in the project. In our case, given the tight period of collection, we used a server side "ready-to-use": at first we started with Formhub aggregator (http://formhub.org) but due to problems of overcapacity and maintenance of the site we had to switch to another solution, Ona.io (http://ona.io/home). We had to download the file with already collected data from the Formhub server, but we could not merge it to the already started project on Ona.io. In any case this operation was possible in post-processing and elaboration in QGIS and CartoDB.

This solution was considered interesting by local administration and associations: the University and the team of Fuoriregata asked us to customize the app creating a survey form to retrieve data. During Trieste Next 2015 conference and exhibition, an academic and scientific event connected to the university, GeoODK was used to present two activities: one aimed at creating a digital map of the provenience of the visitors, the other to collect data about urban accessibility. In addition, the research group of the University of Trieste was asked to customize the application to retrieve data about the affluence to the activities and events proposed at Trieste Next. The same thing was asked by the team of FuoriRegata (www.fuoriregata.org), which was about to start a series of events "land side" preceding the well-known Barcolana, an international regatta.

After the activity of mapping with the urban accessibility (presented at Trieste Next), the research group is collaborating with LabAc, a Laboratory of Accessibility that involves University, Province and Municipality of Trieste (Italy), as well as associations of people with disabilities. The project is aimed at mapping walkways and pedestrian nodes in the area in the City of Trieste, where people with disabilities can move freely.

6 Conclusions and Future Developments

In this research, we applied some of the concepts related to Citizen Science and Volunteered Geographic Information to analyze and represent an urban phenomenon and to examine the opportunities given by geographical mobile data collection.

On one side, the attention can be drawn on the use of portable devices as smartphones and tablets and ad hoc apps to collect data “on the move” and on specific locations in a given territory. This can be done relying on the standard tools installed in such devices, as a GNSS receiver, wireless network connection systems, camera, video and audio recorders as well as QR code reader and other tools. Such elements can be integrated into apps that allow collecting georeferenced data of different sources relying on them and on the data input by the user. Our research was aimed at experimenting such integration and the use of free or low cost apps capable of transforming normal devices as mobile data collection ones. For that, we explored the ODK environment and particularly the GeoODK Collect app customized for collecting data and map them both on the device and on the server. The app and the overall environment, including a form input set up and a data collection server were considered very useful as allowing a high level of customization of the form or questionnaires for the data entry and collection, and also very promising for further development. This particularly in term of the kind of geographical data that can be collected, as the ODK collect apps (as KoBo collect and ODK Collect) can only store point events, while GeoODK allows to collect, edit, manage and store polyline and polygon data, de facto allowing a high level of variety on the data type. Also the combination of a standard device and free of charge app and environment allow users to focus just on the content and structure of the data they need to collect, therefore with a limited need for a training.

From another point of view we need to focus on the choice of the ‘citizen scientists’ and therefore on the category of users to be involved in a data collection campaign. A first lesson learnt deals with the difficulty in involving a wide range of people in a project, concerning mapping the most popular parts of the city during events or regular days according to the users’ experience and knowledge, as well as observing the availability of the free availability of a Wi-Fi network in the urban environment. A campaign just based on a limited social network advertising and a ‘word of mouth’, although supported by detailed instructions on how to install the app and customize it in order to collect easily urban data, did not prove to be particularly effective. On the contrary, it was more effective creating a selected group of knowledgeable users, in this case among the students of the course of “Geography of Networks” in the Postgraduate Degree in Economics and Business, where topics as ‘smart cities’, ‘VGI’ and basics of GIS and urban geography were introduced. Students were prepared about the topics throughout the term and during the final part were involved in the research project involving data collection. That allowed relying on a narrower but more focused network of participants in the data collection process.

A third set of conclusions deal with the results of the research area. The results portrayed some levels of clustering of ‘urban activity’ in some areas of the city, as the city centre in the area around the main square of the city (“Piazza Unità d’Italia”) and a major axis along a main walkable road (“Viale XX Settembre”). Both are parts of the city with a high presence of activities at night and during the free time (“movida”), in the second area particularly frequented by students. In addition, some other areas along the coastline were highlighted. The research was also useful in helping highlighting some hotspots in correspondence of some major events happened during the period considered—as the Science and University fair "Trieste Next" and the "Barcolana" sailing race.

We also experimented different modes of cartographic representation and further analysis, using both standard GIS packages for the analysis done—QGIS—and some visualization software as CartoDB for dynamic mapping. Also, a relevance for cartographic matters is given by the level of control on the accuracy of data collected that can be performed relying on trained user groups.

From the lessons learnt from the research, some plans for future research activities can be done. We plan to extend the capabilities of GeoODK and of the aggregation component of the server side. It is in fact our aim to explore the possibilities offered by the app of collecting polyline and polygon data other than the 'standard' point data as we experiment in such research. Also working on the server side is an aim of future research and development. Relying on platforms as Formhub or Ona.io were practical and did not imply so many computational skills, but we faced in some cases instability of the platforms and a slow reaction time in some moments of the day in loading data. In addition, many of this cloud data storage server are not suitable for managing polyline and polygon datasets, so the idea is to implement a local ODK aggregate server in order to have access and control over the data before further elaborations and analysis. The plan is also to set up an adequate campaign of promotion and communication of the future projects involving a bottom up mobile data collection process, in order to allow potential users and data collectors to be and feel more involved in the different parts of the project. This way we want to allow them to participate to the different steps of the project and observing the progresses done. Use of social media and networks as well as other forms of dissemination—working groups and conferences—will be carried on in order to inform about the project, the use of the apps and the state of the research. Also the use of expert users will be enhanced, in this case involving people—as students of the courses more active on the 'smart city' and mobile data collection issues—from the beginning and therefore relying on an audience capable of evolving, training, understanding the issues at stake and learning the functionality of the system as well as the importance of the research activity.

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Contextual Adaptability of Navigational Spatial Descriptions: A Pragmatic Comparison

Farid Karimipour, Negar Alinaghi, Paul Weiser and Andrew Frank

Abstract Different forms of spatial descriptions are used to communicate information in the context of navigation in urban environments. When generated by computers, such descriptions are combinations of map features in a predefined way. Unlike computers, however, people are capable of flexibly generating navigational spatial descriptions by taking into account a wide array of different contextual factors, e.g. a user's prior knowledge and the structure of the environment. This paper deploys the notion of pragmatics to compare formal addresses, route descriptions (generated either by computers or humans), and destination descriptions in terms of their adaptability to contextual factors in order to identify the means to creating more cognitively sound information systems.

Keywords Spatial descriptions · Addresses · Route descriptions · Destination descriptions · Navigation · Pragmatics

1 Introduction

Spatial descriptions are frequently used for navigation in urban environments. For example, they can take the form of an address or a route description, both of which are expressions that uniquely refer to a destination or to a route toward a location through a set of spatial features and relations (Paraboni et al. 2007).

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_25

Today's information systems provide these two forms of spatial descriptions as a combination of map features (e.g. street name and district number) in a predefined way (Schmidt and Weiser 2012), but offer no way to adapt to different users and environments (Hirtle et al. 2010, 2011). In contrast, in a spatial communication setting between humans, navigational descriptions are more flexible in the sense that factors like a user's prior knowledge and the structure of the environment shape the communication. For example, instead of using a formal address, you may describe a travel destination to a taxi driver by referring to features of the environment assumed to be known to both of you. Or a friend may direct you toward a location while considering your prior shared knowledge of the environment and its structure, which results in a generalized route description that includes only the relevant references to spatial features, e.g. buildings, junctions, subway stations, etc. (Dale et al. 2005). Although these different types of spatial descriptions refer to the same location, or provide instructions on how to navigate to it, their contextual meanings are quite different. In fact, they do not only depend on the user (i.e. interpretant) who may differ in prior knowledge and assign different meanings to the same expression, but also on the environment and situation (i.e. the same user may differently interpret the same expression in different environments and situations).

In this paper, we compare the potential for adaptability of contextual meaning of formal addresses, route descriptions (generated either by computers or humans), and destination descriptions in the context of human navigation in urban environments. The notion of pragmatics is deployed for the intended comparison. Assuming that cartography is the study of interaction between the user and map features, navigational spatial descriptions—as combinations of map features that communicate spatial information—can be partially considered a cartographic task (Fig. 1). Therefore, similar to the concept of map semiotics (MacEachren 1995; Zarycki 2000), we can talk about the semiotics of spatial descriptions in order to study their syntactics, semantics and pragmatics.

Here we understand pragmatics as the relation between spatial descriptions and description-using agents. While there already exists considerable work on pragmatic aspects of spatial descriptions (Dale et al. 2005; Denis 1997; Frank 2003; Paraboni et al. 2007; Raubal and Winter 2002; Richter 2007; Tomko and Winter 2009; Weiser and Frank 2013; Giannopoulos et al. 2014), a comprehensive comparative study is missing. It has not been investigated how different types of navigational spatial descriptions allow handling pragmatic aspects (e.g. redundancy and relevancy), as well as prior knowledge and the structure of the environment in order to provide the adequate level of detail (LoD) of the information for a specific user in a certain environment. We also argue that understanding the effect of context on navigational descriptions will affect the perceived usefulness of Web routing services. In particular, it will help to identify the means to creating more cognitively sound information systems.

This paper is further structured as follows: in Sect. 2, the concept of adaptability of navigational spatial descriptions is discussed in more detail and related work is introduced. Section 3 presents a review of three particular cases of navigational

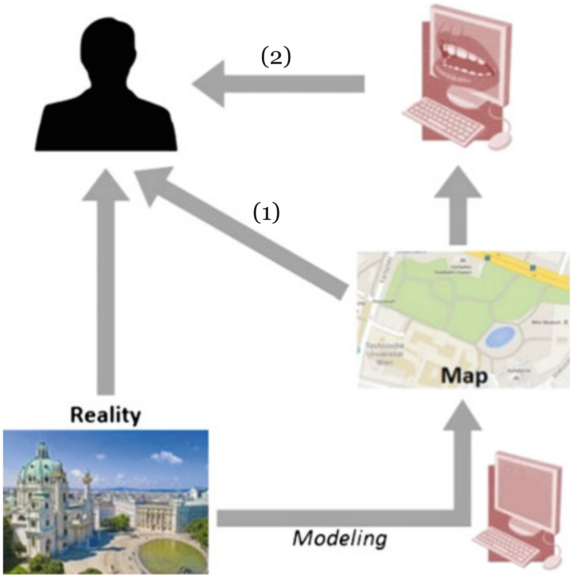

Fig. 1 Maps may either directly communicate spatial information to a user (*arrow #1*) or through generating spatial descriptions (*arrow #2*) as combinations of map features

spatial descriptions studied in this paper and discusses their related issues that allow a comparative study of their potential for contextual adaptability under the notion of pragmatics in Sect. 4. Finally, Sect. 5 discusses the findings of our research and concludes the paper.

2 Adaptability of Navigational Spatial Descriptions: State-of-the-Art

People use various forms of spatial descriptions to communicate navigational information effectively. They may specify a destination by providing a formal address, or describe its relations to the surrounding and (assumed) known features. Equally, people may navigate to a desired destination by using a computer-generated route description—which consists of structured turn-by-turn instructions that include street names as well as distance and time information. Alternatively, human-generated route descriptions are often generalized instructions omitting unimportant or obvious parts and emphasizing landmarks to identify turning points (Dale et al. 2005).

Although different types of spatial descriptions may all refer to the same location or provide instructions on how to navigate to it, their information content for an interpreting human agent is quite different. For example:

- Someone who is not familiar with the environment may have difficulties finding a formal address on a map, while someone who is familiar with the environment may be easily able to do so, even without using some components of the address (e.g. if she already knows the street, she does not need the district number).
- A (turn-by-turn) route description generated by a computer contains essential information for someone who is unfamiliar with the environment to navigate to a desired location, while containing redundant information (i.e. too many details) for someone who knows the environment (Frank 2003).
- A route communicated between two humans with an at least partially shared knowledge of an environment leaves out details, or refer to features and concepts that both know and understand (Weiser 2014). However, it may still contain redundant information for a more knowledgeable person (because of too much detail), or it could be useless to someone with less knowledge (because it contains information that they cannot interpret). The same is true for a destination described by its spatial relations to nearby features (Tomko and Winter 2009; Tomko 2007).

People tend to adapt navigational spatial descriptions by adding/removing information that is essential/unnecessary for a specific user in a specific situation. They may also adapt their descriptions by considering the structure of the environment, or by referring to elements that are assumed to be priorly known to a specific user, in order to ease the navigation process. The discussion could be generalized under the aspect of “successfulness”: All of the spatial descriptions above refer to a unique location or route; the success of constructing such a unique reference for human users corresponds to the adequacy of LoD of the information provided by the description, which in turn depends on user and environmental contexts. Nevertheless, different forms of navigational spatial descriptions allow for different levels of contextual adaption, which, among other things, depends on their structure.

In order to better understand this point of view, consider the following example: To navigate to the location marked in Fig. 2, you may enter its formal address (item #1 in Table 1) into, say, Google Maps, and in turn receive a turn-by-turn description similar to item #2 in Table 1 (dotted path on Fig. 2). In contrast, a Viennese may describe this location by its relations to the spatial features of the region (boxes on Fig. 2) like item #3 in Table 1; or they may instruct to navigate to this location as in item #4 in Table 1. Each of the above descriptions can successfully make a reference to the desired location or route for a human user, if it has adequate LoD based on the user and environmental contexts. While the formal addresses and the turn-by-turn descriptions allow for less adaption due to being pre-structured and having a fixed LoD, the LoD of the destination and route described by humans can be flexibly adapted based on the prior shared knowledge of the communicating parties as well as the structure of the environment.

There has been considerable research on adaptable navigational spatial descriptions. For example, Klippel et al. (2003) and Richter (2007)’s approaches provide means to generalize route descriptions (i.e. adapt the LoD) based on the

Fig. 2 A destination and spatial features around it (*yellow boxes*); the formal address of this destination matched on the map (*red* sign); and a machine-produced route description toward this destination (*blue dotted* path) (*Source* http://maps.google.com)

Table 1 Different types of spatial descriptions to refer to the location marked in Fig. 2 or to provide instructions on how to navigate to it

Item	Type	Expression
1	Formal address	Gusshausstrasse 28, 1040 Vienna
2	Computer-generated route description	… Turn right onto Rennweg; walk for 190 m; turn left toward Schwarzenbergplatz; walk for 160 m; turn right onto Schwarzenbergplatz; walk for 56 m; turn left onto Gusshausstrasse, walk for 500 m; destination will be on your right
3	Destination description	In the 4th district, near the Karlsplatz, next to the Paulanerkirche, in front of the new buildings of TU Vienna
		Near the Karlsplatz, next to the Asia Pavillon
4	Human-generated route description	Go to the Karlsplatz; take Karlsgasse to the end; turn right onto Gusshausstrasse; it is on your right
		Take Favoritenstrasse up to Paulanerkirche; turn left onto Gusshausstrasse; it is on your left

structural properties of the environment. However, this adaption does not consider any user context such as prior knowledge of the environment. On the other hand, Lovelace et al. (1999) evaluated the quality of route descriptions in familiar and unfamiliar environments with focus on psychological, linguistic, and geographical aspects. They suggested the inclusion of spatial elements e.g. *landmarks* and spatial relations e.g. *after* and *in front of* in route instructions. Another work with the same approach focused on natural language processing in generating automatic route descriptions (Dale et al. 2005). Although these efforts tend to consider human factors in computer-generated route instructions, they hardly consider individual characteristics, which may differ from user to user. Considering *humans* spatial thinking, they introduced landmarks instead of e.g. distance or time of travel in order to identify the decision points. However, humans are rarely all the same in either their characteristics or their particular spatial thinking and behavior. For example, one object may be considered a landmark by some, but not by others (Raubal and Winter 2002).

Such issues are considered by Frank (2003) who introduced the concept of *pragmatic information content*, which relates the information content of a route description to its users and assesses it based on how it helps a specific user reach her destination. He suggested that different messages can have the same effect on a user, while the same message may have different effects on different users. For example, two different computer-generated route descriptions may result in the same actions for a user, while a generalized route description may be interpreted differently by two users due to different levels of familiarity with the environment. This user-dependent assessment of information content corresponds to the users' prior knowledge of the environment. Tomko (2007) studied the way people with a shared knowledge of an environment communicate a destination through its relations to the surrounding features (e.g. item #3 in Table 1), which allows the user to flexibly use the most *relevant* features (e.g. landmarks, path, district) in the generated descriptions. Finally, Weiser (2014) and (Weiser and Frank 2013) proposed a pragmatic communication model for way-finding instructions, which models how people negotiate a mutually understood set of route instruction through the use of linguistic signals.

3 Navigational Spatial Descriptions: The Case Studies

This section reviews the concepts of addresses, computer- and human-generated route as well as destination descriptions, and discusses their characteristics. This is required for the pragmatic comparative study of their potential for contextual adaptability, introduced in the next section.

3.1 Addresses

An address is a specification that refers to a unique location on Earth (Longley et al. 2011). It is expressed as a combination of certain components with addressing value (e.g. district number, street names, postal codes) and their relations. They usually follow a hierarchical subdivision to first approximately refer to a place, and then include a linearly oriented second part to accurately specify the destination.

In most countries, addresses are expressed in the form of structured addressing systems, i.e. the components as well as their order are predefined, which often correspond to social and cultural aspects (Davis and Fonseca 2007; Davis et al. 2003). Nevertheless, they vary in the addressing concepts used. For example, in

Europe, roads and spatially ordered building numbers are among the standard addressing components; whereas in Japan and Korea, an address is a sequence of hierarchical subdivisions named by alphabetical or numerical codes. In addition, buildings are not consecutively numbered along a road, but the ordering is based on the date the buildings were constructed (Kim 2001). Structured addresses are easily comprehended by computers. A computer that knows the structure of such an address can easily decompose it to its components, and automatically interpret and match the components on a map. However, there are also countries where no standard addressing exists; instead, people freely express addresses in their natural language based on their spatial mental representations (a term coined by Tversky (1993) to refer to a “cognitive map”). Several concepts with addressing values may be deployed in such *descriptive addresses*. For example, a name assigned to a building can have addressing value, and thus may appear in addresses.

An example of descriptive addressing is Iran, where a sequence of spatial elements (e.g. streets, squares, landmarks, etc.) is used, starting from a known element and gradually navigating to the destination (Karimipour et al. 2014). For example, in Fig. 3 the address of point ***A*** based on route #1 is “Shariati ave., after Zafar st., Pabarja st., no. 12”. Such addresses are not unique, and people may generate different addresses based on individual characteristics and in different situations. For example, point ***A*** in Fig. 3 may be referred to as “Shariati ave., before Bahar st., Pabarja st., no. 12”. Even worse, the same place could also be referred to by a completely different route, e.g. based on route #2 as “Shahrzad blvd., Pabarja st., no. 12”, because different starting points or spatial elements may be used by another person. In other words, descriptive addresses depend on the user and environmental contexts. This makes them very difficult (if not impossible) to use for automated interpretation.

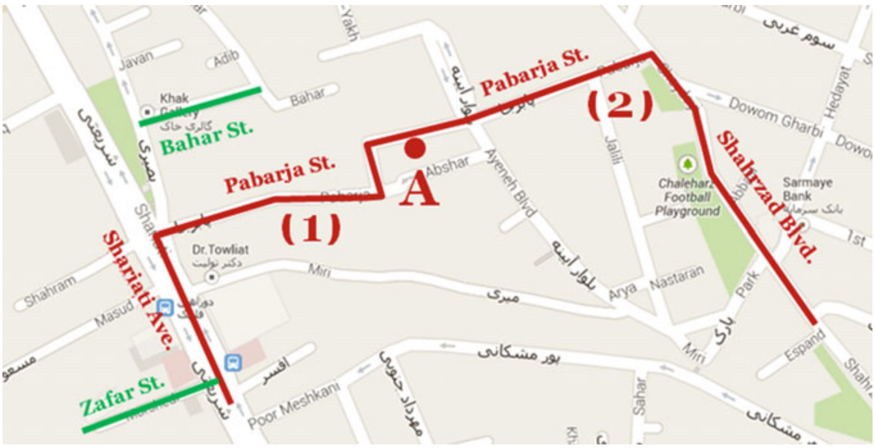

Fig. 3 Point **A** is referred to in two different ways using different starting points and spatial elements (*Source* http://maps.google.com)

3.2 Route Descriptions

Route descriptions are verbal instructions that tell one how to go from one place to another. When generated by computers, route descriptions are simply turn-by-turn instructions that include street names as well as distance and time information. Such computer-generated instructions stand in stark contrast to how humans would generate route descriptions. For example, there has been research on generalizing such descriptions based on the structural properties of the route in order to reduce redundancy (Klippel et al. 2003; Richter 2007). In addition, there exists a considerable body of work on different aspects of route descriptions, from assessing their quality (Dale et al. 2005) to establishing alternative navigation systems based on such descriptions (Burnett 2000; Denis et al. 1999; Streeter et al. 1985).

Human-generated route descriptions are expressed in natural language by describing the relations of landmarks and visible features to the environment. Humans also generalize the instructions by omitting steps that are considered obvious or unimportant, which depends on the individual and the situation, i.e. user and environmental contexts. In other words, it is a spatial discourse between parties who may not have the same prior knowledge of the environment. Particularly when a person asks someone else how to get to a specific place, a spatial communication setting may construct a mutually understood set of instructions that is negotiated between the parties (Weiser and Frank 2013).

3.3 Destination Descriptions

A destination description is “a referring expression uniquely describing a place …, consisting of a hierarchically ordered set of references to prominent spatial features of various types” (Dale 1992). The word was coined by Tomko (2007) as a “route description focusing on the *where* of the destination instead of the *how* to reach it”. Destination descriptions specify the destination through its spatial relations to features that are known to the addressee (for example, referring to “Luisenstrasse” as “in the city center, next to the opera house, off Rathenaustrasse”, cf. Tomko and Winter 2009).

Like addresses, destination descriptions refer to a location in the environment by describing its relations to the surrounding spatial features; but they also act as route descriptions, as they instruct the user how to reach the destination, based on a serialized hierarchy with varying granularity in elements. The selection of references is a critical issue here. Since the basis of a destination description is the parties’ shared knowledge of the environment, the most influential parameter while selecting a spatial feature as a reference in such descriptions is its importance and familiarity for the addressee. In other words, the selected reference may not be located along the road to the destination, or may not be as salient as other popular references (e.g. landmarks) of the environment, but it may still be appropriate for the user as long as she can easily recognize it due to some of its individual characteristics. Such a description is designed to be understood against the common ground shared between speaker and addressees, e.g. their common experience or expertise. For example, if a particular café is a well-known place for both parties, it can be used as a reference in order to find a destination even if its salience is not as high as other landmarks.

4 Pragmatic Comparison of Adaptability of the Navigational Spatial Descriptions

This section compares navigational spatial descriptions based on their potential for contextual adaptability. The notion of pragmatics is deployed for the intended comparison, as a general functional perspective on our spatial language, i.e. as an approach to spatial language which takes into account the full complexity of its cognitive, social, cultural and individual function (Verschueren 1999).

Pragmatics as the relation between description and description-using agents or interpreters is the main concern in this section. At the most elementary level, pragmatics can be defined as the study of the use of language from a viewpoint of its usage properties and processes. Various aspects are deployed in such pragmatic studies. For example, *redundant* information may be intentionally added to communication to make sure that the message is correctly transferred, to reduce the cognitive workload, to provide the recipient with more confidence, or to prevent unexpected failures. On the other hand, communication may contain terms that are only *relevant* for the communication parties but not for others. More generally, *cohesion* corresponds to the terms that are only understandable for a group of people. In addition, people shape their utterance in a way that it is *coherent* based on a *common ground* (i.e. shared knowledge) between the communication parties. Finally, a speech may carry the intentions of the speaker to affect the act of the hearer, which is called *speech act*.

If pragmatics looks at spatial language as a form of action anchored in a real-world context, or what is perceived as such, one of the most important consequences is that it must pay attention to types of meaning that go beyond what is *given* by the description itself, or what is literally *said*. In other words, a range of meaning emerging from the contextually embedded character of speech becomes the inevitable topic of investigation (Verschueren 1999). In particular, we intend to study how the above pragmatic aspects may shape spatial descriptions used in the context of navigation (i.e. what types of contextual meanings a spatial description may have) and compare navigational spatial descriptions based on their potential of such contextual adaptability.

The pragmatic dimension of human communication has been mostly studied and conceptualized within speech act theory (Bach 1994; Liu et al. 2012). Here we consider spatial descriptions as linguistic descriptions (i.e. a spatial description is our linguistic unit in this research) and introduce some other common topics of linguistic pragmatics such as redundancy, relevancy, cohesion, coherence, context, and common ground within the spatial descriptions studied in this paper.

4.1 Redundancy

Humans have invented effective forms of coding information so that it can handle high complexity. “Redundancy is a property of languages, codes and sign systems which arises from a superfluity of rules, and which facilitates communication in spite of all the factors of uncertainty acting against it” (Cherry 1974). Particularly, redundancy implies an over-determination of meaning in order to make utterances easy to understand. It has been claimed that “logically redundant information tend to be included when their inclusion fulfills one of a number of pragmatic functions, such as to indicate that the information is of particular importance to the speaker” (Paraboni et al. 2007).

In the case of spatial descriptions, *redundancy* refers to that part of the description which is not necessary in the decision-making process but will enable better understanding (Frank 2003). Strictly speaking, all the information added beyond what is required to uniquely identify a place is redundant. Nonetheless, such redundancy may be useful either to respond to unexpected situations like missing street signs, or to make the description easy to identify, especially in the case of a user’s unfamiliarity with the environment.

Structured formal addresses usually contain some levels of redundancy. For example, in “Gusshausstrasse 28, 1040 Vienna”, 1040, which refers to the 4th district of Vienna, is redundant as street names are unique in Vienna, i.e. there is only one “Gusshausstrasse” in the entire city of Vienna. Users who already know the street usually do not employ the district number. However, this information will help users who do not know Vienna or the street with an approximation on the location, and can e.g. make it easier to identify on a map. Nevertheless, providing redundant information is not flexible here due to the fixed structure of such addresses: it is neither possible to provide less knowledgeable users about the environment with more redundant information, nor is it possible to drop redundant information from the address for more knowledgeable users. The same is true for route descriptions generated by computers. For example, they may contain elements unimportant to humans (e.g. they may tell you to keep going straight when there is no turn in the first place) but may make the user more confident that she is on the right path. However, once the description is designed to be produced with a specific level of redundancy, there seems to be no opportunity to change it based on the user and environmental contexts.

In case of descriptive addresses, as well as human-generated route descriptions and destination descriptions, redundant information could be flexibly employed and adapted based on the users and environmental contexts. For example, consider the following example from Paraboni et al. (2007):

- 968 Lewes Road, Moulsecoomb area
- 968 Lewes Road
- number 968

The first two of these addresses refer uniquely to the same place. The third one is still unique due to the fact that "Lewes Road" is the only street in the area which is long enough to have numbers above 900. For someone who knows this fact, the first two addresses contain redundancy; though they help to reduce the cognitive load. As another example (see Fig. 3), in "Shariati ave., after Zafar st., before Bahar st., Pabarja st., No. 12", the "after Zafar st." is redundant but provides an approximation of the location of "Pabarja st."; and "before Bahar st." is redundant but makes the user more confident by limiting her spatial domain search.

4.2 Relevancy

The messages exchanged during communication contain the information necessary to make referents unique; and people receiving this information should be able to interpret the conveyed meaning. A spatial description is relevant if it connects with contextual assumptions to provide a better understanding of it (Tomko and Winter 2009). Many elements of varying relevance may be mentioned in a description, but humans select the most relevant ones in the given context. The relevance of possible referents is evaluated by the speaker, and the referent that is evaluated as the most relevant in the given situation (based on the speaker's knowledge of the hearer), is selected to be contained in the description. The interpretation of the meaning of that description is left to the hearer, who tries to interpret the utterance in a manner most relevant to her. Tomko (2007) suggested quantitative measures to evaluate the relevancy of different types of spatial elements (i.e. landmarks, paths, and districts). The concept of *relevancy* should not be misinterpreted as *saliency*, since for example a landmark may be salient due to its size, color and structure (Ganitseva and Coors 2010) but not relevant for a specific user in a specific situation. In other words, saliency is examined on a semantic level (Klippel and Winter 2005; Nothegger et al. 2004), while relevancy is an issue of pragmatics.

With regards to the above discussion, structured formal addresses and computer-generated route descriptions would not allow relevancy adaption due to their predefined structure and format. On the other hand, descriptive addresses, human-generated route descriptions, and destination descriptions flexibly allow relevancy adaption on both sides: the speaker can select the most relevant referents to be included in the description based on her prior knowledge of the environment as well as the addressee; the addressee, on the other hand, can interpret the description in a manner most relevant to him, and can even start a negotiation to provide clues for the speaker to improve her selection of referents based on his context. This negotiation continues until both sides agree on referents relevant to both sides, i.e. the speaker chooses exactly the most relevant referent for the addressee. Nevertheless, in case of descriptive addresses and human-generated route descriptions, there still exist an opportunity to choose salient referents to be included in the descriptions instead of predefined elements, but that is a semantic issue and is not the concern of pragmatics.

4.3 Cohesion

The word "cohesion" has the dictionary meaning of the effect of a group of people/things as a whole. In linguistics, *cohesion* is "the *grammatical* and *lexical* linking within a text or sentence that holds a text together and gives it meaning". In our approach, grammatical and lexical cohesions are respectively considered as the structural content of the description and the background knowledge. Grammatical cohesion monitors the structural content of a description to be correct in order to prevent generating meaningless descriptions like "next to the in front of *X*", which is not grammatically correct. Lexical cohesion, on the other hand, can be referred to as the background knowledge of the speaker and hearer that is mostly inferred from public knowledge. Although public belief is not always precise enough, "[its] frequency in the language suggests that they are easily produced and readily understood" (Tversky 1993). In some cases, cognitive errors may pervade human spatial descriptions; for example, if people refer to a direction as *north* while it is not really representing north, it would not affect the process of way-finding as long as people use this direction as *north* in their descriptions (Burns 1998). An example is the Yadegar highway in Tehran. It is known to be north-south in direction by the public, and even though in reality it certainly is not (Fig. 4), it is referred to as Yadegar-north and Yadegar-south in people's spatial communications. This even goes as far as a sign reading "Yadegar-west" at the upper entrance of this highway being taken down because it confused people! This is inherent in human spatial thinking in terms of the effect of public belief. This effect can be thought of as the background knowledge which speakers and hearers should be aware of during communication.

Grammatical cohesion is not of interest in automated route descriptions, as computers are designed so that they do not generate meaningless descriptions. However, such descriptions along with the structured addresses are not capable of considering lexical cohesion. More accurately, they are lexically cohesive, but this is achieved by taking public susceptibility into account when such descriptions and addresses are initially designed. They cannot be adapted to changes in public spatial beliefs due to many factors like social and geographical issues.

Assuming people do not generate meaningless route descriptions, they are always grammatically cohesive. But since such descriptions are generated by humans, everything related to their spatial thinking and behavior from cognitive errors to public susceptibility would also make the description lexically cohesive. For instance, when someone unfamiliar with the environment asks for a route description, she may receive some piece of information that may geographically be

Fig. 4 The Yadegar highway in Tehran (highlighted in *red*) is known to have a north-south direction by the public, even when it is actually (globally seen) west-to-east (*Source* http://maps.google.com)

wrong (e.g. the "north" example), but as long as people believe this as a referring fact, it is still helpful for navigation.

The same is true in the case of descriptive addresses. Some addressing concepts that are of common use in descriptive addresses, like direction, are prone to environmental contexts such as topology, slope, distance, etc. People's beliefs about the direction, the saliency of landmarks, etc. would heavily affect the shape of the spatial mental representation of an individual, which in turn reflects on their spatial descriptions and addressing.

4.4 Coherence

Coherence in linguistics is defined as what makes the text semantically meaningful. Here we consider the two different levels of *semantic coherence* and *pragmatic coherence* (Sanders 1997). On a semantic level, different parts of the description have a logical relation with each other which is obvious to everyone who can easily interpret the description as a whole, albeit with different levels of familiarity with the environment. In contrast, pragmatic coherence needs both communication parties to have a shared prior knowledge of the environment.

Structured addresses are pragmatically coherent as they illustrate the relations between different spatial elements, but prior knowledge is essential to interpret and understand them. For example, in “Gusshausstrasse 32/8/12, 1040 Vienna”, one needs to already know that 32, 8, and 12 are respectively the house, block, and door numbers, and that 1040 refers to the 4th district; only then can one infer that Gusshausstrasse is located in the 4th district of Vienna, and so on.

Destination as well as route descriptions produced by humans are semantically coherent since they are expressed in natural language, and thus relations between their components are logically managed. This helps the addressee to readily understand them without any prior knowledge. Similarly, in automated route descriptions and descriptive addresses the relations can easily be understood by the interpreting agent as they are spatially consecutive, and therefore semantically coherent.

4.5 Context

With context, here we mean all the factors (either from the user or environment) that form the setting of a description and are necessary for it to be fully understood. In spatial descriptions, factors related to the user like age, gender, carrier, culture, and background geographical knowledge are examples of user context; among environment contextual factors are topology, slope, distance, landmarks, direction (Javidaneh and Karimipour 2014).

Structured addressing systems and automated route descriptions seem to be less flexible in assimilating both individual and environmental contexts, as they are designed to be a standard. However, there have been efforts of incorporating contextual parameters in automated route descriptions (Klippel et al. 2003; Richter 2007) and location-based services like navigational systems (Chon and Cha 2011; Mokbel and Levandoski 2009; Zhu et al. 2010). Nevertheless, they hardly consider context as individual characteristics, which may differ from user to user.

In contrast, human-generated route descriptions and destination descriptions are highly dependent on both user and environmental context. Generating such descriptions from the first stages of referent selection and deciding on the optimum LoD for its spatial sequence and configuration is mostly based on user and environmental contexts.

Descriptive addresses have considerable flexibility when it comes to taking into account contextual parameters. The addresses presented in Sect. 3.1 based on Fig. 3 consider the user context in terms of her prior knowledge (i.e. different LoDs of the addresses), as well as her current position (i.e. the third address starts from “Shahrzad blvd.”, which assumes that the user is currently in that area). If however the address to, say, a local pizza delivery service were to be provided, it might start from “Pabarja st.” as it could be assumed that there is only one such street in the context of the delivery person (there could be a street with the same name in other parts of the city, but we would not expect a pizza to be delivered to that a far location). As another example, the use of terms such as “after” and “before” in the address must be clarified by direction: considering your direction or the fact that you are driving a car, or may be on the upward slope of the street would help figure out the exact relation of “after” or “before” a place. In the current example, “slope” of the “Shariati st.” plays the role of environmental context and implicitly indicates that “after” is meant to be along the slope where elevation increases.

4.6 Speech Act

The concept was first introduced by the philosopher Searle (Searle 1969). This theory analyzes the role of utterances in relation to the behavior of speaker and hearer in interpersonal communication. It is not an *act of speech*, but a communicative activity, defined with reference to the intentions of speakers while speaking, and the effects they have on listeners. Considering the spatial description as an utterance, the *act* or the effect on the addressee can be defined as how easy she can interpret the description and how it helps in performing spatial tasks.

In the case of structured addresses, the agent would need prior knowledge of the components and structure of addressing as well as the environment. Consider this example from the discussion on coherence in Sect. 4.4: “Gusshausstrasse 32/8/12, 1040 Vienna”. An agent who is unfamiliar with the structure of the Austrian addressing system may not be able to interpret some components (e.g. 1040 as referring to Vienna’s 4th district), and thus the process may fail at an early stage of the interpretation phase. In contrast, an agent who knows this addressing structure but has never heard of “Gusshausstrasse” can only correspond this address up to the district level. Furthermore, even if she knows the structure and can interpret the components correctly, the address would not give her a clue on how to reach there from her current position.

All descriptions produced by humans like destination descriptions, route descriptions, and even descriptive addresses can be easily understood by humans, and would effectively assist them through way-finding task owing to their flexibility in all the pragmatic aspects. Even automated route descriptions, despite their usual redundancy in information, would be understood by humans and thus help them navigate through the space.

4.7 Common Ground

Common ground is “the mutually recognized shared information in a situation in which an act of trying to communicate takes place” (Stalnaker 2002). Considering spatial description as a conversational language unit, common ground can be thought of on two levels: before and during the conversation. First, common ground is inferred from what both communication partners can assume to be known by the other, based on available evidence such as e.g. the knowledge that both partners are from the same city, speak the same language, or are located at the same place where the communication takes place. Second, the interactive process of meaning negotiation would also contribute to the development of a common ground: the progress of the conversation indicates whether some negotiated statements get added to common ground (Weiser 2014; Hahn and Weiser 2014).

Except for the structured addresses and automated route descriptions, whose fixed and predefined structure prevents significant flexibilities, common ground could be considered as the pulling engine for all of the above pragmatic parameters in the case of human-generated spatial descriptions. Establishing common ground is the first step to providing a user with a cohesive and coherent descriptive address/destination description/route description that contains enough redundancy and relevant information, and fulfills the user and environmental contexts. Both parties of the communication would first infer the common ground from their prior knowledge of each other, and would then gradually improve it during the negotiation. Once they reach a common ground and agree on the LoD, they can generate the optimum description.

5 Discussion and Concluding Remarks

We compared spatial descriptions for navigation in urban environments based on their potential for adaptability to user and environmental contexts (i.e. factors). We especially focused on formal addresses, route descriptions (generated either by computers or by humans), and destination descriptions, as the three common forms of spatial descriptions used in urban navigation. We compared them through the aspects of pragmatics to see how they allow users to take into account the user and environmental contexts. Formal addresses and computer-generated route descriptions are usually pre-structured, while human-generated route descriptions, as well as destination descriptions (as the way two people may describe a destination through relations to surrounding known features) are freely produced by humans in natural languages. There are also countries where no standard addressing system is employed and people convey addresses in natural language.

Those spatial descriptions that are expressed in natural language and directly made based on human spatial thinking might be seen as global among human beings. Such descriptions are among those forms of spatial description where the basic formations are the same everywhere around the world: in order to give efficient route directions, one should select some elements that are referred to as *good* on the levels of both semantics and pragmatics. There are some elements that seem to be appropriate and salient for making a significant impact on *human* spatial activities. For example, it has been claimed that for people who are unfamiliar with the environment, landmarks closer to the road will make better references (Lovelace et al. 1999). On the semantic level, the goodness of such elements is evaluated by *human beings as a concept*; while on a more detailed level, even the relevancy of the assumed-to-be-good elements may differ from one person to another. In such a case, all the parameters related to the context of that person will be taken into account, which requires us to consider *humans as individuals*. In summary, from a semantics point of view, human-generated route descriptions and destination descriptions are not limited to geographical or cultural constraints as long as their utilization is tied to human spatial thinking in general. However, considering individual differences remains a concern in both.

In contrast, although addresses are among the most commonly used spatial descriptions, their structure, and consequently their semantic and pragmatic considerations, show geographical differences. Different addressing systems around the world fundamentally differ even on the syntactic level. Some countries have declared a strict structure for addressing, from the type of the selected elements to their order of appearance, which does not fully correspond to our spatial thinking. But there also exist descriptive addressing systems, in which addresses are expressed in natural languages and thus treated like human-generated spatial descriptions.

Structured addressing systems are basically formalized to make the geocoding process more performable for computers, and thus do not necessarily support human spatial thinking. Nevertheless, humans use these addresses in their everyday life and deal with them, which may have impacts on their cognitive needs in the long term.

Semiotic issues, especially pragmatic considerations, can heavily affect the analysis of the actual interactive communication process that occurs between two humans. This could make for a research platform for designing machines and services that are more compatible with humans and extend human-human interactive communication to human-computer communication. For instance, it could be of interest to adapt a computer-generated route description to consider the context of a certain user in a specific situation. On the other hand, it would also be very useful if a user could simply type a destination description into a computer and the destination would be shown on the map. Such capabilities surely require an interpretation of contextual meanings of spatial descriptions.

The above theoretical results must be further verified by empirical testing. There are many linguistic, cultural, and cognitive issues to be taken into account, which may thoroughly affect the findings. However, it remains unclear still how to impart differences in spatial cognition caused by external factors.

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User Requirements Analysis for a Mobile Augmented Reality Tool Supporting Geography Fieldwork

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Abstract The combined use of mobile Augmented Reality (AR) and various visualizations has a potential to support geography fieldwork. Central to the development of a usable mobile tool is adopting the principle of User-Centered Design (UCD), the first phase of which is identifying user requirements. This research first establishes the current situation of using (mobile) AR in education based on a literature review. At the same time, in a real educational human geography fieldwork executed in China, through a survey, observation and interviews, we have investigated how teachers and students currently conduct the fieldwork, what difficulties they experience and their expectations and suggestions for a future mobile tool. It was found out that it will be practical to make use of a new mobile AR tool in geography fieldwork. In the fieldwork in China, students used their mobile phones to mainly collect data and browse digital maps of the fieldwork area, with the purposes of completing the fieldwork tasks and assisting them to geographically understand the fieldwork area, respectively. They also experienced some difficulties, e.g., the time required for and troubles in switching between different mobile applications and the data collected in the field lacking locational details. Both teachers and students, as users, expressed their expectations of a future mobile tool and indicated some basic key requirements, e.g., labeling geo-locations of all field collected data, making notes, recording voice data and field walking routes and optionally viewing various materials (maps, satellite images, etc.) of the fieldwork area.

Keywords Augmented reality · User-centered design · User requirements · Human geography fieldwork · Cartographic visualizations

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_26

1 Introduction

Geography fieldwork, a geographical educational activity in the real world, is essential to increase the learners' understanding of the geography of a certain area (HMI 1992). Traditionally, fieldwork techniques have normally made use of visualizations, like paper maps, to provide basic geographical information of the fieldwork area. Nowadays, geography fieldwork has seen the increasing use of Information and Communication Technologies (ICTs), especially geospatial ICTs such as Global Positioning Systems (GPS) and Geographical Information Systems (GIS). This provides learners with opportunities to have a better view of the geographical space by facilitating visualization, collection and analysis of geo-features of the real world (Muñiz Solari et al. 2015). However, the learning technology should be properly designed with specific functions that are relevant to the fieldwork learning (Meek et al. 2013). Therefore, the questions are how to, with the use of ICTs, conduct a better geography fieldwork and improve the learners' geographical understanding while in the field. Because the utilization of ICTs in geography education always inevitably integrates with various (cartographic) visualizations (e.g., maps), researchers in the area of geography (fieldwork) education are trying to develop more productive educational methodologies by optimally integrating the latest technological potentials with visualizations to facilitate better geographical knowledge construction (Hedberg 2014; Chaffer 2015), which is, in fact, not only a geographic pedagogic issue but also a cartographic concern.

Regarding the latest ICTs, one of the most promising technologies is Augmented Reality (AR), which, as the very name suggests, augments the real with the virtual. AR enables real-time location-based interactions (Azuma 1997) with additional device-generated contextual information (i.e., augmentations) embedded within the real world (i.e., reality). Therefore, AR can deliver immersive experiences through unique interfaces. Here, the digital devices could be special wearable glasses, personal computers (PCs), or smartphones and tablets, and the contextual information could be texts, objects, audios, videos, photos, maps, or even data from social media (like Facebook, Twitter). Education is asserted as one of most promising application domains of AR (Wu et al. 2013).

In recent years, thanks to the availability of smart mobile devices equipped with GPS, camera, compass, accelerometer and other built-in sensors, the application of AR on mobile devices has a vast potential to make a difference in scientific disciplines (Specht et al. 2011). In the geography domain, mobile- or desktop-based applications could realize innovative geographic information visualizations (Hedley et al. 2002; Dunleavy et al. 2009; Asai 2010) with unique AR interfaces. And in geography education, particularly in geography fieldwork, AR on mobile devices could be used as a "cognitive tool and pedagogical approach" (Dunleavy and Dede 2014) to realize location-based learning and teaching. Yet, till now, few mobile AR has been applied in geography fieldwork, especially human geography fieldwork. The previous research work of Wang et al. (2015) demonstrated the necessity to implement AR in geography fieldwork, based on both geography fieldwork leaders' positive attitudes and the proven usefulness of AR in two recent cases of fieldworks in other domains, ecosystem fieldwork (Kasahara et al. 2014) and cultural science fieldwork (Ternier et al. 2014).

Following this current status, there appears to be a need to integrate AR in a mobile tool that can also provide additional visualizations (such as maps) to assist learning/teaching and gaining geographic understanding in an educational geography fieldwork. There is a wide range of existing mobile AR applications [such as Layar (https://www.layar.com/ Accessed 18-12-2015), Wikitude (https://www.wikitude.com/ Accessed 18-12-2015) and Junaio (http://www.junaio.com/ Accessed 18-12-2015)] with various user interfaces that are available to choose. However, the usability of them is still unknown and has not been compared. Furthermore, several AR development tools [such as ARToolKit (http://www.hitl.washington.edu/artoolkit/ Accessed 18-12-2015), Metaio Mobile SDK (http://www.metaio.com/ Accessed 18-12-2015)] empower a mobile AR tool to deal with not only simple visualizations and interactions (Schall 2012), but also broader functionalities, such as data collection (Kamarainen et al. 2013; Dunleavy and Dede 2014). Consequently, it will be a challenging task to successfully make use of mobile AR in geography fieldwork, due to issues of various user interfaces and multiple functionalities. To meet this challenge of developing a usable mobile AR tool, the principle of User-Centered Design (UCD) should be adopted. The first phase of such a UCD approach is identifying user requirements (ISO 13407:1999 1999) and it is hypothesized that identifying the actual user requirements for a mobile AR tool may, in the end, better support geography fieldwork.

This research is focusing on human-oriented geography fieldwork with the objective of learning about the spatial structure of the fieldwork area. Driven by this focus and the above hypothesis, and to formulate the basic user requirements for a potential mobile tool in which an AR application and visualizations are integrated, empirical investigations were conducted in a real educational undergraduate human geography fieldwork executed in China.

In this paper, we first present the theoretical background of the UCD approach, and establish the current situation of the design and use of (mobile) AR in (out-of-classroom) education. Thereafter, we describe the execution of the field study in terms of scenario, users, methods and procedure. Then we analyze the collected data from the survey, interviews and observations as results and discussions. Finally, we will list the main outcomes as summary.

2 Theoretical Background

UCD is a fundamental concept for designing interactive systems (or products or applications or tools), which emphasizes putting users at the center of design. The paramount purpose of applying a UCD approach in design processes is to increase the usability of an interactive system to be developed (Thimbleby 2008). To achieve the goal of improving usability requires, firstly, profiling potential end users and eliciting user requirements, and then trying to satisfy the user requirements during the later design process.

In fact, ISO 13407:1999 (1999) about human-centered design processes of interactive systems has already released a standardized description of UCD. More recently, this standard has been updated with some revises as ISO 9241-210 (2010). According to this new standard, the UCD lifecycle includes five key stages, namely, (1) plan the user-centered design process, (2) understand and specify the use context, (3) specify user requirements, (4) produce design solutions, and (5) evaluate the design. The interrelations among those design activities are illustrated in Fig. 1.

The need for the UCD of a new mobile AR tool was already proposed. Having in mind optimal usability of such a tool, the first thing is to plan the whole process of designing the mobile AR tool. In this paper, usability is defined in terms of effectively and efficiently supporting human geography fieldwork in a way that satisfies the potential users. Obviously, here, the context of using the tool is human geography fieldwork. As fieldwork involves both teaching and learning, the (potential) users are both teachers and students. And understanding and specifying user problems, expectations and needs in a current geography fieldwork will give a picture of what the user requirements are towards a future mobile AR tool.

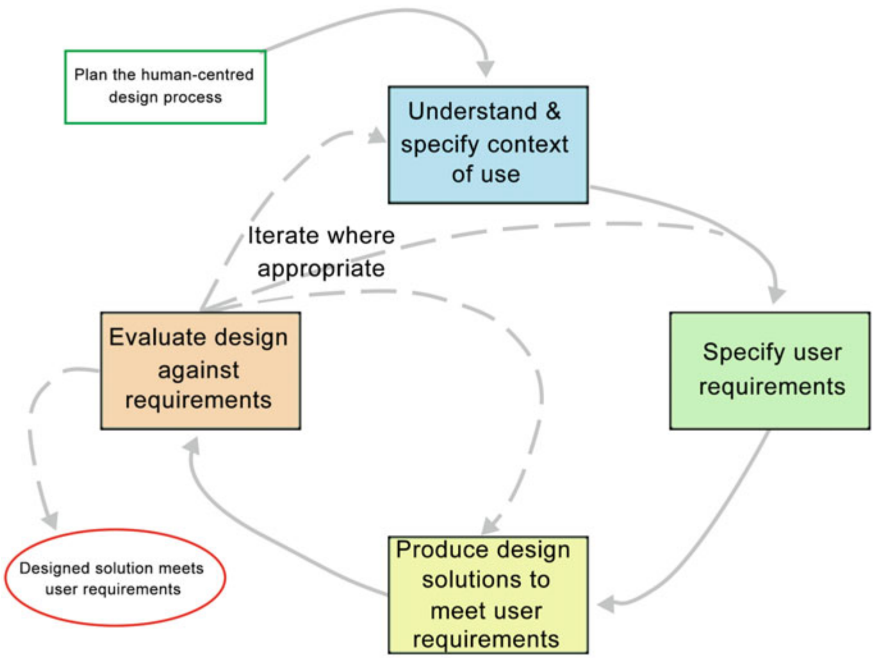

Fig. 1 The lifecycle of UCD. *Source* ISO 9241-210 (2010)

3 Related Work

In the scientific domain and beyond, AR-based technology has been visible for quite some time already since around half a century ago when Sutherland (1968) developed a Head Mounted Display system to present changing virtual images and objects with users' movements in reality. Because of AR's extraordinary immersive interfaces and unique real-time interactions between real and virtual scenes, AR has served as a transformative tool in fields such as tourism (Kounavis et al. 2012), entertainment (Juan et al. 2011), urban planning (Anagnostou and Vlamos 2011), medical surgery (Cristancho et al. 2011) and education (Yuen et al. 2011). Particularly in the domain of education, AR can offer cognitive support to learners (Bower et al. 2014). Furthermore, because one of the key pedagogical affordances of AR is the ability to overlay contextual information on reality, the use of AR can support situated learning in the real world (Bower et al. 2014). Increasing amounts of both scientific educational research in AR and AR-related application projects indicate that AR has already gained much attentions in educational research and applications. Several studies have summarized the current status and future directions of the use of AR in education (Yuen et al. 2011; Kesim and Ozarslan 2012; Wu et al. 2013; Dunleavy and Dede 2014; Bower et al. 2014; Bacca et al. 2014).

Normally, the educational contexts can be categorized into two basic areas: (1) formal classroom-based education, (2) informal out-of-classroom-based education. As the geography fieldwork in this paper is in the latter category, in the following, we will briefly review existing literature on the use of (mobile) AR in informal educational settings from the perspectives of the purposes, the ways, and outcomes of using it.

Around two decades ago, the first mobile AR was introduced by Feiner et al. (1997) who created an AR system on a see-through head-worn display with the main purpose of assisting users to explore the university campus with real-time labelling building information and overlaying imagery and navigation information. Although the initial intention of this mobile AR was not for education, this study opened possibilities of using mobile AR to support outdoor educational activities. More recently, considerable empirical studies have already been executed that explored the use of mobile AR in the context of informal education, such as learning and teaching in the settings of museums (Damala et al. 2008; Chang et al. 2014), historical sites (Vlahakis et al. 2001; Epstein and Vergani 2006), zoos (Perry et al. 2008), parks (Sotiriou and Bogner 2008) and certain outdoor fields (Liu et al. 2009; Sommerauer and Müller 2014). In detail, examples include teaching and learning local history in a city walking tour (Epstein and Vergani 2006), interpreting geological features in a rural area (Meek et al. 2013), instructing museum art appreciation (Chang et al. 2014), retaining mathematical knowledge in a mathematics exhibition (Sommerauer and Müller 2014), supporting ecosystem and cultural science fieldwork (Kasahara et al. 2014; Ternier et al. 2014). Regarding the AR platform used in out-of-classroom scenarios, smartphones are increasingly preferred in comparison to other electronic devices. The main reason is because it is relatively easy to take advantage of the high capacities of portable smartphones as well as their wide ownership (Höllerer and Feiner 2004).

Particularly, in terms of the augmentations in the above fieldwork cases, the personalized AR learning system for ecosystem fieldwork in the case of Kasahara et al. (2014) provided the functionalities of a basic location-based information overlay as well as field learning content recommendations. These two functionalities were implemented through retrieving stored information from pre-built databases. The databases included textual, graphical and geographical information about animals and plants within the fieldwork area as well as the users' browsing and manipulating history. The AR user interface of this system overlaid annotations and graphical information of animals and plants on the real landscape based on the user's current location.

In the study of Ternier et al. (2014), the mobile ARLearn tool for cultural fieldwork was built on the Google Maps API and the Google Sites Data API. Therefore, the ARLearn presented location-based digital "narrator" objects and enabled taking notes (texts, voices and pictures) on a map view (Google Map interface).

In human geography fieldwork, no similar AR has been used as an assisting tool up till now. To contribute to a broader vision on mobile AR for educational fieldwork, the prototype interface of our mobile AR learning tool will make use of the AR interface to overlay digital information that the fieldwork will need, based on the user's current location on the map view, reality view, as well as satellite imagery view, for the purpose of providing the overall structure of the field area to learners in human geography fieldwork.

Qualitative and quantitative study outcomes of using mobile AR out of the classroom have shown its advantages as an assisting tool. The benefits are, for instance, enhancing the students' learning motivations (Pribeanu et al. 2009; Liu et al. 2009; Tarng and Ou 2012; Kasahara et al. 2014), developing scientific literacy skills (Squire and Jan 2007), training skills, such as field data collection and conducting field research (Ternier et al. 2014), improving spatial skills (Sánchez Riera et al. 2015), and, more importantly, facilitating subject knowledge acquisition and promoting learning outcomes (Liu et al. 2009; Tarng and Ou 2012; Sommerauer and Müller 2014).

Despite the above positive aspects, like many other ICT potentials, integrating AR in education involves both opportunities and challenges. As Wu et al. (2013) indicated, the educational values of AR are not only related to the use of AR itself, but also closely subject to "how AR is designed, implemented, and integrated into formal and informal learning settings". Höllerer and Feiner (2004) and Bower et al. (2014) have indicated the potential technological, pedagogical and contextual benefits of the successful use of AR in education. On the other hand, Kerawalla et al. (2006) found negative educational effects of using AR, such as the students' low engagements. This might be even more true for the use of AR on mobile devices in fieldwork educational settings, because mobile learning might bring a heavy cognitive load (Liu et al. 2012) and the novelty of the context of fieldwork might distract the learners' attentions during the one-time field experience (Orion and Hofstein 1994).

However, the pedagogical paradigm of "design-based learning" (Papert and Harel 1991a, b) would deal with these potential issues and promote learning when applying educational innovations. Similarly, but more recently, for the use of AR, the concept of "learning by design" was presented by Bower et al. (2014) to better support education. There is already some research that has proposed guidelines for designing mobile AR, such as the mobile AR interaction design of of Kourouthanassis et al. (2013). With respect to design requirements, Kerawalla et al. (2006) extracted the requirements for classroom-based AR applications. But, till now, design requirements for mobile out-of-classroom-based AR have not been suggested yet.

In summary, it appears to be promising to successfully make use of a mobile tool which integrates AR and other visualizations to support human geography fieldwork (as an informal educational setting), provided that such a tool could be well designed by adopting the principles of UCD, the basis of which is the design requirements of the actual users, which are still invisible from existing literature.

4 Scenario, Users, Methods and Procedure

The main objective of this study is to explore the user requirements of a mobile AR tool to support human geography fieldwork. Here, the "support" includes assisting learning/teaching tasks and the students' geographic understanding. To this end, this study was conducted by attending an undergraduate human geography fieldwork (the objective of which includes learning the spatial structure of the fieldwork area) to collect data for user requirement analysis.

4.1 Scenario and Users

In this study, the scenario for the investigation of the user requirements was a human geography fieldwork for undergraduates that was executed within the town Dongshan in the city of Suzhou in Jiangsu province, China in July 2015. The participants were teachers (6 in total) and 3rd-year undergraduates (100 in total) from Beijing Normal University and East China Normal University, and the students were divided into 6 groups. Therefore, the users in this study were both teachers and students.

This fieldwork was affiliated to the human geography course. The overall objectives of the fieldwork were: (1) to learn about the spatial structure of Dongshan, and (2) to investigate the relations between the natural environment and human activities by conducting group field research within Dongshan. Students' pre-fieldwork activities were learning on their own through an online fieldwork website (http://210.31.68.1:8080/field-trips/human/human_comprehensive/ Accessed 18-12-2015). This website was established by Beijing Normal University, but now it is only accessible from the campus. The activities in the field lasted for two days. The first day was a so-called horizontal fieldwork. Students toured with the teachers while teachers gave lectures in the field to explain the geography, history, architecture, etc. of the town and students observed and made notes. Besides, students conducted group research work, i.e., field investigations on their topics. The second day was a so-called vertical fieldwork in which a mountain was explored. Students learned about the vertical distribution of vegetation through observation and teachers' explanations during climbing the mountain. Besides, students continued to conduct group work in the field. After the two days in the field, on the third day, students worked in groups on the field research report and presented it.

4.2 Methods and Procedure

The early requirements can be elicited by employing the methods of observation, questionnaires and interviews, as was done by Yovcheva et al. (2013) in similar future usage scenarios. The results are a requirement summary of how users currently perform to achieve certain goals, what difficulties users currently experience, as well as expectations and preferences for a future alternative product.

For analyzing user requirements towards the development of a new tool, the first part is to know the general user profile, i.e., the basic characteristics of potential users. In this research, questionnaires were used in the stage of pre-fieldwork to establish the students' basic information (gender, age, major, etc.), the use of mobile phones and tablets, cartographic background (use of paper and digital maps, the difficulties and the preferences of using them) and knowledge about AR. The questionnaires were translated into Chinese and then were distributed to all the students one day before the actual fieldwork. Before handing out the questionnaires, a brief introduction about the research work and the purpose of the questionnaire survey were given to all the students and teachers there.

The method of observation was used in all three stages of the fieldwork, aiming at observing how teachers and students perform the teaching and learning activities with a focus on the use of (cartographic) visualizations, as well as the difficulties of using them.

The main approach of gathering the observation data were writing field notes, together with taking photos and videos. For examples, when teachers used the paper map to explain the current location and geographical features, field notes and photos were taken to indicate the type of visualization (here was the paper map) and the purpose of using it (showing current location).

To formulate what difficulties were experienced when using the existing cartographic visualizations and mobile devices in the fieldwork, as well as to justify how an alternative tool could possibly be applied in future, students and teachers were also interviewed during and after the fieldwork. 9 students and 4 teachers were randomly chosen to attend the semi-structured interviews. Teachers were interviewed after they completed the field teaching tasks, while students were interviewed after the post-fieldwork task. Table 1 shows examples of questions that

Table 1 Examples of questions included in the interviews

Category	Questions
The use of cartographic visualizations (For teachers and students)	• What cartographic visualizations did you use before, during and after this fieldwork? • Why did you use these cartographic visualizations? • In your opinion, in which stage of geography fieldwork, the use of cartographic visualizations is more important in helping to improve geographical understanding of the fieldwork area? Before, during or after the real fieldwork?
The difficulties of using cartographic visualizations and mobile devices (For teachers and/or students)	• Did you experience some difficulties when using these cartographic visualizations during the fieldwork? What were those difficulties? (For students and teachers) • Did you experience some difficulties when using your mobile devices during the fieldwork? What were those difficulties? (For students)
The expectations and basic requirements for a future tool (For teachers and/or students)	• Do you have any ideas about how to use cartographic visualizations on mobile phones that could help to improve geographical understanding of the fieldwork area? (For students and teachers) • Do you have any ideas about how to use cartographic visualizations on mobile phones that could help to complete the teaching tasks? (For teachers) • Do you have any ideas about how to use cartographic visualizations on mobile phones that could help to complete the field learning tasks (processing data, visualizing your findings, etc.)? (For students) • What do you think about the possibility to develop a mobile augmented reality tool combined with the use of cartographic visualizations for fieldwork use? Do you have basic requirements (functionalities, interfaces, etc.) towards such a tool? (For teachers and students)

were asked during the interviews with teachers and students. The interview conversations were in Chinese and the interview data was recorded as audios through using a voice recorder on a tablet.

5 Results and Discussions

5.1 Students' Background and Experience

In total, 93 out of 100 students responded to the questionnaires. The students were doing a major in four different geo-related domains: geography science, GIS, urban planning and land administration. All students had attended cartography and GIS courses.

Among the 93 responses, only 5 students have heard of AR and gave relatively precise descriptions about what AR is. Some of those descriptions were:

- "Combining the reality with virtual world, e.g., Google Glass";
- "Adding real-time object information in the reality".

In terms of ownership of smartphones and tablets, it was found that all students had their own mobile phones, while half of them owned tablets. 64 % of the mobile phone operating systems was Android and 32 % of them was IOS. Students used their phones and tablets for various activities. 80 out of 93 students responded that they had ever used the phones and tablets for learning geography specifically. Among those 80 responses, 56 % said they learned geography through both websites and applications. Therefore, it became clear that it is practical to make use of a mobile learning tool in geography fieldwork. To be more specific, the mobile devices should be mobile phones instead of tablets and the tool should support the two main kinds of operating systems, i.e., Android and IOS.

5.2 *Current Use of (Cartographic) Visualizations and Mobile Devices*

From questionnaires, observations and interviews in the geography fieldwork, information could be derived on how cartographic visualizations and mobile devices are currently used in the three stages of this human geography fieldwork. It was found out that users (mainly students) used traditional maps, digital maps in mobile map applications, satellite images, and photos and videos of reality during this fieldwork.

- Maps

Regarding the use of paper maps, as well as digital maps on mobile phones and tablets, students used digital maps on mobile phones more frequently than using them on tablets and using paper maps. In terms of the preferences of using paper maps or digital maps on mobile devices, 58 % of the students preferred to use maps on their mobile phones or tablets, and only 18 % preferred the traditional paper maps. The remaining 24 % had no special preferences.

A number of traditional 2D maps were used, like an administrative map and a land use map of the fieldwork area and also maps with the fieldwork route and landmarks which were visited later during the fieldwork. Besides browsing them on the fieldwork website (http://210.31.68.1:8080/field-trips/human/human_comprehensive/ Accessed 18-12-2015), some of these maps were also used as printouts or stored on a computer or in portable devices. For the digital maps they used, Baidu Map (http://map.baidu.com/ Accessed 18-12-2015), Gaode Map (http://ditu.amap.com/ Accessed 18-12-2015), Google Maps and Google Earth were mentioned quite often. Others, like IOS Maps, OpenStreetMap and Bing Maps were also mentioned.

Students also used digital maps in mobile phone map applications to mark some key sites (Fig. 2a). From the interviews with students and teachers it could be derived that all these maps were used before the actual fieldwork with the purpose of giving a basic geographical understanding of the fieldwork area. During the outdoor fieldwork itself, students used printed paper maps to find their current location (Fig. 2b). Sometimes, students also checked their current location by using their mobile map applications [e.g., Baidu Map (http://map.baidu.com/ Accessed 18-12-2015)] in the field. Teachers also used printed paper maps to assist them to teach students about the geography of the fieldwork area and to show their current location.

After attending field lectures and group investigation activities in the field, students were required to present the investigation results of the group research topics (e.g., the distribution of public utilities of the fieldwork area). In order to complete the post-fieldwork tasks, students used maps in their presentations to demonstrate the field survey sites and to visualize their findings (Fig. 2c). Generally, they used existing maps as basic layers to make their own maps in GIS software. For example, they mapped the land use of the fieldwork area in ArcGIS (Fig. 2c). Or, they just simply added some thematic elements on an existing map.

All in all, it could be concluded that maps are used a lot in this fieldwork. And according to the interviews with students and teachers, among all visualizations, maps are the most useful and important to assist them to complete the fieldwork learning/teaching task and to increase the geographic understanding of the fieldwork area, especially during the stage of learning and teaching in the field.

Fig. 2 Maps used in different stages of the fieldwork

- Satellite images

The satellite images used in this fieldwork are from two sources: the fieldwork website and the switchable satellite image layers of desktop or mobile digital maps (e.g., the "earth" layer of Google Maps). In this fieldwork, satellite images were mainly used before and after the actual fieldwork. Before going to the field, satellite images were used to give a general aerial view of the fieldwork area and the planned fieldwork route (Fig. 3). In the stage of post-fieldwork activities, satellite images were used with the same purpose as using maps, i.e., as layers for post-fieldwork mapping. In general, using satellite images is a supplement to using maps, as satellite images encompass more geo-reality compared to the abstract information of maps.

- Photos and videos of reality

Photos were used in all three stages of this fieldwork, while videos were used only before the fieldwork. A lot of photos of reality are available on the fieldwork website for pre-fieldwork use, and videos as well. Before going to the field, students browsed the photos and videos of the fieldwork area. From the teachers' perspectives, these photos and videos were offered and used because they statically and dynamically illustrate the landscape of the fieldwork area. During the students'

Fig. 3 Satellite images used before the fieldwork. The *yellow line* is the fieldwork route

activities in the field, they used their mobile phones to take photos of the field landscape. And some of these photos were selected for use in the post-fieldwork presentations. Students also mentioned that the use of photos is necessary to complete the fieldwork tasks, but few of them indicated the purpose of increasing the geographic understanding of the fieldwork area.

All in all, it was found out that students and teachers currently use more traditional cartographic visualizations (e.g., maps) on different platforms, like mobile devices, computers, or paper. At the same time, the reasons of using them are not the same in every stage of the fieldwork. But the interviews demonstrated a consensus of students and teachers that it is more useful and more important to use these cartographic visualizations (especially maps) during the stage of the execution of fieldwork.

In addition, how students used their mobile phones during the whole fieldwork was also observed and interviewed. It was found that students used their mobile phones to collect field data (photos, notes, voices, etc.) and browse digital maps of the fieldwork area, with the purposes of completing fieldwork tasks and assisting their geographic understanding of the fieldwork area, respectively. This should be the starting point for personalizing a mobile AR tool in this research, i.e., better combining and fulfilling these two purposes.

5.3 Current Difficulties of Using (Cartographic) Visualizations

About the difficulties of using maps on mobile phones and tablets, more than half of the students experienced different levels of difficulties. 7 % of them always and 48 % of them sometimes experienced difficulties. These difficulties included inaccuracy of positioning and map contents, out of datedness, low resolution, unavailability of offline maps, complicated operation and unfamiliarity with the operation. However, all students have a cartographic education background (obtained in the past three years). Therefore, it is assumed that students themselves do not have fundamental problems with using mobile map applications.

Some of the difficulties were again mentioned during the interviews, e.g., one of the students said that "the Baidu Map is not that precise". Next to the map issues, another major problem is that both students and teachers found that the collected data (photos, voices, notes) lack spatial connotation. One of the teachers pointed that "now, the data collected is so messy and it is very easy to mix the data together and forget where the data was collected". Similarly, a student indicated that "after the fieldwork, I forgot where the photos belong to, because some of them look very similar." Besides, a teacher and a student mentioned a problem of switching between different mobile applications. It is time-consuming and troublesome to use different mobile phone applications at the same time.

Therefore, firstly, the mobile AR tool to be designed should be with accurate maps of the fieldwork area and easy to operate. All the difficulties that students and teachers are currently experiencing give a mental picture of what aspects should be paid attention to when designing the prototype of a new mobile AR tool to support the fieldwork. Those difficulties should be tried to be avoided and (or) solved when developing that new mobile AR tool. Secondly, it became clear that, despite the students' cartographic education background, both simple operation training on how to use the tool and an introduction about AR are needed before they can use it in the field.

5.4 Expectations and Requirements Towards a Future Mobile AR Tool

During the interviews, after briefly introducing what a future alternative mobile tool could look like, some expectations and requirements were expressed by students and teachers. In general, they were enthusiastic about using such a tool for assisting geographic understanding and completing the field learning/teaching tasks. Most of them believed that it would be helpful to use such a tool to assist fieldwork. However, some basic key requirements from teachers and students, as users of the alternative mobile tool, should be considered. Analysis of these requirements can suggest initial priorities for the functionalities of the prospective tool.

First of all, there is a strong need of labeling the geo-locations of all collected data, i.e., they would like to find the various data collected on the interface of a map within this tool. A teacher expressed this need in this way: "put all notes, voice recordings and photos in different locations, and at each location, a folder could be found to store all those data". Similarly, another teacher wanted students to create "a small working station" to collect photos, videos, voices, etc. in the field on their mobile phones. And there was a student who indicated a similar need. She said: "I just hope that one (mobile) application could complete all the data collection, and do not want to switch between different applications". It was not surprising to learn about this requirement because it was in line with the major difficulty of the lack of locational details that the students and teachers experienced during this fieldwork.

In terms of requirements of cartographic visualizations in a mobile tool, teachers and students wanted to optionally view various maps (up-to-date), satellite images and historical geography visualization materials of the fieldwork area. A teacher pointed out that the overlay of different cartographic visualizations is important, but also that these various materials (maps, satellite images, etc.) of the fieldwork area may be viewed optionally. Besides, students wanted to be able to see a 3D street view of the fieldwork area because they thought this could improve their geographical understanding of the fieldwork area.

Students also gave some suggestions regarding the needs of collecting data with the prospective mobile AR tool, like making notes, recording voice data and field walking routes.

In addition, some other requirements were listed, such as group interactions, automatic recommendations and readable materials on the screens of mobile phones. For example, both students and teachers mentioned that they would like to have interactions within the group, reporting the current investigation situations and sharing photos, etc. A student expressed the requirement that this tool should "recommend something based on the current location". One of the teachers said that the contents (like photos and videos) in the tool must be suitable to be viewed on the small screens of mobile phones.

6 Summary

It appears to be promising to make use of a mobile tool in which AR with map displays and various visualizations are integrated to support geography fieldwork as long as such a tool will be designed based on the requirements of the actual users. The investigations in a real human geography fieldwork in this research demonstrated that it will be practical to make use of such a tool in human geography fieldwork. The results of the investigations on how the fieldwork is currently conducted, what difficulties users currently experience as well as what the expectations of users are, can be used to formulate the basic user requirements of such a tool for supporting human geography fieldwork. All in all, teachers and students, as users, expressed their high expectations of a future mobile AR tool for fieldwork use and indicated some basic key requirements.

In summary, these requirements towards a mobile AR tool include: (1) collecting various field data (notes, voice, field walking routes); (2) labeling geo-locations of those field collected data; (3) optionally viewing various visualizations (maps, satellite images, 3D street view, etc.) of the fieldwork area; (4) group interactions; (5) location-based content recommendations; (6) showing readable contents on the screens of mobile phones. These user requirements also suggest the basic functionalities of a future mobile AR tool to be used in human geography fieldwork.

The next step in this research can now be the conceptual user-centered design of a prototype of a mobile AR tool based on the user requirements.

Acknowledgements Firstly, the authors are very grateful to the organizer of the human geography fieldwork, part of the Beijing Normal University Teaching Construction and Reform Project (14-07-01), for the acceptance to attend the fieldwork. The authors are also very thankful to all the teachers and students in the human geography fieldwork for their helpful answers in the questionnaires and interviews.

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Landmark-Based Pedestrian Navigation Using Augmented Reality and Machine Learning

Pouria Amirian and Anahid Basiri

Abstract The prevalence of smartphones and tablets featuring various kinds of sensors and the improvements in computation capabilities of those devices, have led to an acceleration of using geospatial data in many domains. The large number of sensors deployed on the devices has made it possible to detect user's location, heading and orientation as well as getting contextual information from various sources of online data. Combining the stream of data from positioning and orientation sensors with camera, has also made it more feasible to deploy practical Augmented Reality (AR) applications on mobile devices. This paper, explains a system and its related study that provides a view of the navigation experience which composed of the AR view as well as continuous personal feedbacks about the relative location of the user in relation to the closest landmarks. In the system, navigation and path finding are based on landmarks. Relative position of the user with regard to landmark is determined using GPS sensors as well as image processing algorithm for finding distance from a landmark. In addition, feedbacks for navigation instructions are customized for each user based on his/her movement profile and use of continuous tuning of a machine learning algorithm. Experiment of using the system showed a significant improvement in acquiring of spatial knowledge for the users in comparison with turn-by-turn systems.

Keywords Augmented reality · Landmark-based navigation · Pedestrian

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_27

1 Introduction

The prevalence of smartphones and tablets featuring various kinds of sensors such as positioning and orientation and the improvements in computation capacities of the mentioned devices, have led to an acceleration of geospatial information use in the many applications. These advanced mobile devices have allowed detection of a user's location, as well as his/her heading and orientation, and they have incorporated that data into their display systems. These data have been used massively in Location Based Services (LBS). Within the large number of services in LBS, navigation services, has been one of the most widely used services. In context of pedestrian navigation, most current pedestrian navigation systems on smartphones, provide visual or audio interactions using map-based turn-by-turn instructions. This interaction mode suffers from ambiguity, its user's ability to match the instruction with the environment, and it requires a redirection of visual attention from the environment to the screen (Giannopoulos et al. 2015). The map-based interaction concept requires the user's attention to be directed to the screen which can cause problems when the visual attention is required in the environment, e.g., to avoid obstacles, other pedestrians, or the surrounding traffic (Rümelin et al. 2011). Auditory navigation systems (Hazzard et al. 2014), as an alternative to maps, are not an adequate solution since the noise of an urban environment may be disturbing. In summary, distractive nature of the interaction model of pedestrian and the navigation app is the main problem with the turn-by-turn map-based interaction. In this paper we describe a pedestrian navigation system with following contributions:

- Image-based positioning based on images of landmarks which replaces or complements the satellite positioning
- Navigation instruction based using Augmented Reality (AR)
- Customized navigation instructions based on movement profile and machine learning

In this research project, a landmark based pedestrian navigation app is developed that provides a combined view of the navigation experience which composed of the AR view as well as continuous personal feedbacks about the relative location of the user in relation to the closest landmarks. The app was mainly designed for people who are not familiar with an environment (like tourists). The application also provides more friendly instructions based on personal and continuous feedbacks of movement sensors. As part of the research, an experiment was conducted in Oxford, UK, with 20 participants who weren't familiar with the Oxford city. The application was compared with widely used turn-by-turn navigation apps on devices. The result of the experiment indicated a significant improvement in acquiring local knowledge of users in comparison with turn-by-turn map-based navigation systems.

2 Related Works

In recent years, researchers have tried to overcome the redirection of visual attention issue by using different approaches and tools. In haptic interaction models user has to wear or take a gadget like vibro-tactile waist belt (Erp and Veen 2005), or a vibrating smartphone (Pielot et al. 2012; pielot and Boll 2010) in order to get haptic feedbacks about navigational instruction. While these systems are visually non-distractive, they suffer from a rather high ambiguity and may require a long learning phase, since the user needs to map the characteristic of the haptic feedback (vibration) to a way finding instruction. Ambiguity in pedestrian navigation, can lead to incorrect decisions and increase uncertainty, which in turn leads to insecure navigators not being able to validate their decision (Giannopoulos et al. 2015). One way to overcome many of the above mentioned problems is to use human gaze as the way for proactive interaction between user and navigation app.

Utilizing human gaze can provide easy, fast and natural ways of interaction (Tanriverdi and Jacob 2000) and (Smith and Graham 2006) leading to gaze-based pedestrian navigation systems that can avoid the problem of ambiguity and minimize the interaction with the device. In their recent work, Giannopoulos, Kiefer, and Raubal, implemented a gaze-based pedestrian navigation system called GazeNav (Giannopoulos et al. 2015). They utilized the user's gaze to inform the user if she or he has to take a turn at the street at his or her direction of looking. In the system ambiguity is removed through the direct mapping of gaze to navigation feedback. In addition, through proactive nature of the interaction, visual attention always stays on the environment during navigation to the destination.

For many pedestrians (especially tourists) navigation to the destination is not the ultimate goal rather getting to know the points of interest and potentially getting more information about them is far more important. In this context, using Augmented Reality (AR) can be more useful than gaze-based navigation. With AR it is feasible to dynamically superimpose computer graphics and information onto objects in the representation of real world. AR has been used as a new visualization method on mobile devices, in various fields such as games (Lv and Halawani 2015; Astrid et al. 2012), education (Cheng and Tsai 2013; Wu et al. 2013), retail (Rashid et al. 2015), shopping (Cuomo et al. 2015) and social media (Zook et al. 2015). In the context of pedestrian navigation, stream of data from positioning and orientation sensors can be combined with data from camera in order to superimpose wayfinding objects for facilitating pedestrian navigation (Amirian et al. 2015). In this case the user is not distracted if he or she always looks at the screen of the device. Looking through the smartphone or tablet seems frustrating but with the availability of 3D glasses and VR glasses, it is feasible to project the screen of the smart phone on the screen of the glasses and make use of the AR capabilities. In addition, with availability of many cheap DIY toolkits (like many Cardboard toolkits) it is possible to turn a normal smartphone to the AR viewer.

Huang, Schmidt and Gartner, studied the influence of different interface technologies (mobile maps, AR, and voice) on spatial knowledge acquisition in a field test in an urban environment. The field test showed that the landmark recognition task, route direction task and landmark placement task can differentiate ‘familiar’ and ‘unfamiliar’ participants. The field test also showed that in terms of spatial knowledge acquisition, the difference among the three interface technologies was not significant (Huang et al. 2012). In this study we will show that AR interface provides significant improvement on spatial knowledge acquisition especially for tourists which are mostly unfamiliar with the environment.

In the context of AR, most of the current navigation applications use geospatial data only to display positional information as a point in their AR view, forcing the user to switch from an AR view to a conventional 2D map view in order to receive continuous information that covers the user’s entire path. In this case most users prefer to resort to the conventional map view instead of using AR view to make sure that they are on the right direction or path to their destination. This has the same issue with turn-by-turn map-based interaction model. The app of this research, provides both views however the map view is provided as a small addition to the main AR view for sake of completeness.

In addition, many of the currently available navigation systems provide users with turn-by-turn navigational instruction, in which directions are associated with distances, e.g. “turn right after 340 m”. Such navigational strategy works very well for machine/robot navigation or for driverless car, as sensors sense and measure distances and headings. However, people give navigational instructions in a slightly different format. People associate directions with visual cues and personal experiences, such as “turn left right after the gas station” or “go straight ahead for almost 10 min and you will see the pharmacy”. The personal experience for navigational instruction is another contribution of this paper. In this paper we describe how the app uses personal movement data to provide customized navigational instruction for each user using a continuously adapting machine learning algorithm. The mentioned visual (and temporal) cues (or landmarks) utilize easy-to-recognize and unique features, objects and human-centric experiences. This strategy also is more attuned to the interests of pedestrians, since they move with relatively lower speed therefore they can notice visual landmarks easily. In addition, such unique and easy-to-recognize landmarks help people to remember the path they have taken and also results in better spatial knowledge acquisition, especially when they are exploring unfamiliar environments. Landmarks are highly desired additions to navigation services. They are top feature request of users. Using prototypical research systems, landmarks were found to improve users’ performance and satisfication with such systems in both car and pedestrian navigation (Richter 2013).

Landmarks constitute an essential basis for a structural understanding of the spatial environment. Therefore, they are crucial factors in external spatial representations such as maps and verbal route descriptions, which are used to support wayfinding. However, selecting landmarks for these representations is a difficult task since the selection task is highly dependant on how people perceive and remember landmarks in the environment. Kuttunen, Irvankoski, Krause and Sarjakoski, investigated the ways in which people perceive and remember landmarks in nature during different seasons (Kettunen et al. 2013). In this research we use the findings of their work. In addition, we introduce a novel approach for calculating the position of user using images of landmarks.

3 Landmarks in Navigation

A landmark can be defined as any object or feature, which is easily recognizable, such as a monument or a building. Landmarks are one of the interests of tourists, most often due to notable physical features, cultural references or historical significance. People often use landmarks for casual navigation, such as when giving directions verbally or when sketching a route map. In urban studies as well as in geography, a landmark is furthermore defined as an external point of reference that helps orientation in a familiar or unfamiliar environment (Lynch 1960). As noted above, landmarks are also used in verbal route instructions. These two properties of landmarks (i.e. being used as references to orient objects and being used in verbal route instructions) are very important and potentially helpful in providing more desirable navigation services.

Landmarks may have distinct geometric shapes, and they may include additional information (e.g., in the form of attached writings, bar-codes, QR codes and geo-tags). In general, landmarks have a fixed and known position, relative to which users can localize themselves. In this research, landmarks used for image-based positioning, way finding and for providing navigational instructions. Thus landmarks in this study, had to be carefully chosen to be easy to identify. A feature, which has significant contrast to the background, is a good option to be considered as landmark since its image would be easily recognizable to users as well as easier to detect by image-based positioning algorithm. Such objects have to possess a certain saliency, which makes them remarkable and distinctive. So the surrounding area determines the characteristics a point must have to be perceived as a landmark (e.g. a shopping Centre may not be very outstanding in urban areas, but becomes a salient landmark when being situated in a rural village). Since this research is about pedestrian navigation, the following are focused on role of landmarks in pedestrian navigation.

In general, a pedestrian can have several possible navigational strategies to find a desired goal (Redish 1999):

- The individual has no information and is forced to search randomly (random navigation)
- The individual moves towards a visible cue which leads to the arrival point (taxon navigation)
- The individual follows a fixed motor program (praxic navigation, e.g. "turn left after 200 m, then turn right after 150 m")
- The individual associates directions with visual cues (route navigation, e.g. "turn left at the church")
- The individual forms a mental representation of the surroundings and is able to plan routes between any locations within the area (locale navigation)

Landmarks have an important role in random navigation, taxon navigation, route navigation and locale navigation. Several researchers in the field of spatial cognition assert that navigating humans rely on three forms of spatial knowledge: landmark, route and survey knowledge (Siegel and White 1975; Werner et al. 1997). When exploring an unfamiliar environment, pedestrians first notice outstanding objects or structures at fixed locations. These unique objects and/or features are easy to recognize and can be kept in memory without difficulty (Schechtner 2005) thus improve the spatial familiarity with the environment. They are essential in route navigation and locale navigation strategies. Landmarks become more recognizable and therefore helpful for navigation when people move slowly, which is the case for pedestrians. The importance of landmarks for pedestrian navigation and wayfinding instructions is proved by many studies (Michon and Denis 2001; Denis 2003; Basiri et al. 2016a; Raubal and Winter 2002; Basiri et al. 2014; Basiri et al. 2016b).

With adequate images of landmarks, it is also possible to use landmarks for image-based positioning. Positioning is one of the most important components of any navigation system. Often Global Navigation Satellite Systems (GNSS) provide a good and reliable position. However, where GNSS signals are not available, use of alternative technique is necessary. For pedestrian navigation, using landmarks is considered as one of the best options as alternative way of positioning.

In general, two main categories of positioning techniques, can use landmarks as reference points: image-based and non-image-based techniques. As the name implies, in an image-based technique an image of the landmark or specific part of it is taken and then the image or the data in the image, is used for determining the position of the landmark. Some examples of image based landmark positioning are Quick Response (QR) positioning and photo-based positioning. In non-image-based techniques, information about the position of the landmark can be stored in a passive or active digital gadget and attached to the landmark. Examples of non-image-based positioning are Radio Frequency Identification (RFID) and Bluetooth network positioning. Unfortunately, RFID tags and Bluetooth networks are not available ubiquitously, therefore hardware needs to be embedded and installed both on users' handheld devices (e.g. RFID readers) and also on the landmarks (e.g. RFID tags). This means extra costs for both service provider and users. This research focuses on image-based landmark positioning techniques. Image-based positing has many advantages over non-image-based positioning. In image-based positioning approach the computation and processing phase is done on the server side therefore lower power consumption is achieved in comparison with Bluetooth positioning and similar techniques where users need to keep their smart phones' Bluetooth on all the time. In addition, many landmarks are registered as tourist and/or historic features. Consequently, it is almost impossible to install or affix a tag or any signal transmitter for positioning purposes. Moreover, landmarks can be huge objects, therefore a single tag or transmitter cannot represent its accurate location.

In an image-based positioning approach generally there are two main steps; image processing to identify the landmark and finding scale and rotation for finding the relative position of the user. In this context, user first takes a photograph of a preregistered and previously stored landmark and then sends/uploads the photograph for image processing and landmark matching service on the server. The landmark matching service on server can extract and identify the landmark from the uploaded photo. In this procedure, different techniques from machine learning, image processing and signal processing are applied. Then scale and rotation (tilt) of the photograph can be calculated, since the absolute sizes of different façades of the landmark have been already stored in a database or can be measured from the images in the database. The calculated scale and rotation then are used to calculate the user's relative position with respect to the landmark. Since absolute positions of landmarks are available in the database (at server side), the absolute position of the user can easily be calculated and then used in path finding and navigation services.

As it mentioned before, landmarks can be used as decision points in way finding for pedestrian. In general way-finding algorithms solve optimization problem to minimize the cost function which is traversed distance or length of time of travel. In pedestrian navigation the shortest path and the fastest path algorithms usually have similar outputs, as there is generally no traffic factor for pedestrians and they move with almost same speed. In case of tourists, users want to see specific monuments and landmarks, which may need deviation from the shortest path. A landmark-based path-finding algorithms provide a more attractive and, at the same time, more reliable path. Since users see more landmarks on the way, they get less bored and they are also more certain that they are taking the correct route.

As it mentioned above, landmark-based way-finding identifies the path which traverses the least distance to get to the destination while passing the most landmarks on the way. So landmark-based path-finding algorithms are tries to find a path which maximizes the result of the following formula.

$$\sum_{i=1}^{n} \frac{Ni}{Li} \tag{1}$$

N is Number of landmarks on an edge and L is length of the edge.

In summary, in landmark-based algorithm the above reward function must be maximized. At the other hand, in shortest path problem, the summation of weights of edges constitute the loss function and the loss function must be minimized. For sake of simplicity, the shortest path algorithm with inverse of the above function was used for finding the optimized landmark route. Once the route is found, it is possible to provide users with navigational instructions, which includes personal distance measurements.

As mentioned previously, landmarks can help to make navigational instructions more intuitive and closer to the instructions that people give in their daily conversations. One of the best ways to use landmarks in navigational instruction is to provide images of landmarks as a part of the instructions at or near key points, such as turning points and important cultural or heritage features (landmarks). In this research there is no need to provide the image of the landmark since the landmark is being seen by the user. In this context, for each key point in the calculated path (which can be a junctions or a landmark to be seen), the direction (d) between the current key point or user's position (indexed i) and the following one (indexed i + 1) is calculated using following equation.

$$d = \pi/2 - \arctan_2(lat_{i+1} - lat_i,\ lon_{i+1} - lon_i) \quad (2)$$

Direction between sequence of points.

Then, the image with the closest camera position from the key point 'i' and the closest heading from 'd' is retrieved using rear camera of the device. The landmark database is queried to retrieve a sequence of landmarks (position of camera when images had been taken is stored in the database) from the desired path in the direction the user should take to reach the destination. Then based on these points, the key points are augmented by overlaying a directional arrows pointing at the following direction to take, helping the user to visually interpret his or her position and get the bearings.

As it mentioned, for each point of the calculated path, the direction d between the user's current position (indexed i) and the following key point (indexed i + 1) is calculated using Eq. 2. Then, the image with the closest camera position from the point 'i' and the closest heading from 'd' is retrieved. To find the mentioned image, a score value s is calculated using location and heading from the Euclidean distance, which can be between 0 and 1. A sigmoid function is used to set to a score close to 0 for near images and 1 for the others. A trigonometric function is used to get a similar score for the heading based on the following formula:

$$s = \left(1 - s_{pos}\right)(1 - s_{head}) \quad (3)$$

Score function for images.

In the above formula, the S_{pos} is the score given by the Euclidean distance p between the position of the point and the position of image which can be calculated using the following formula:

$$s_{pos} = 1/\left(1 + e^{(-2.25(p-15))/5}\right) \quad (4)$$

S_{pos} formula.

The constants of the above sigmoid function are set experimentally, representing the threshold distance from which it is possible to exclude the results as they are too far away and cannot be a match. Figure 1 shows a plot of this function. The higher the distance p is, the higher the cost is.

The heading score S_{head} is calculated by following equation:

$$s_{head} = |\sin(h_{cam} + d)| \quad (5)$$

Heading score.

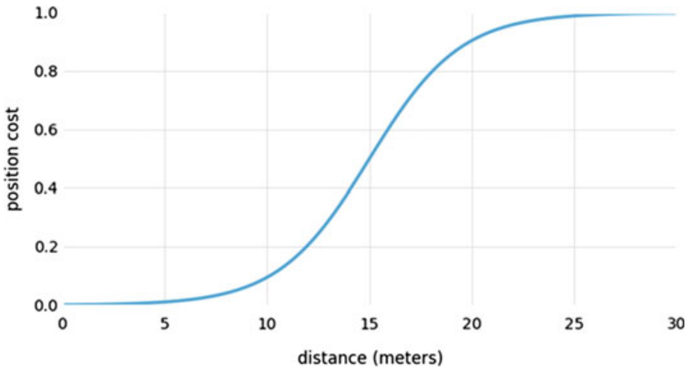

Fig. 1 Position cost function where p is the Euclidean distance between the point positions (in the path) and the image camera position

Given the relative location of user to the closest landmark (and known locations of landmark at server side), landmark-based wayfinding minimises the travel time and maximizes the number of landmarks during path.

The landmark along the calculated way can be used for producing navigation instructions. In order to provide a navigational instructions speed of the user and length of way (or a part of it to the next landmark) is needed. In most pedestrian navigation apps, the speed of pedestrians assumed to be fixed. However, this is not the case for all users. For better results, it is possible to calculate the travel time based on speed of device and recalculate the speed in constant time intervals (like every five minute). In this case, the speed of movement can be used to provide the number of steps and time of arrival to destination (again using fixed step length). However, in this study we found that the device speed is not a good enough for providing the personalized navigational instruction mainly due to low speed of travel of pedestrians. In addition, user's speed might change based on several variables like time of day, total length of journey (non-stop), total length of journey (with stops in same day), weather condition and even day of the week which has a direct influence on personalized navigation instruction. For example, some people tend to walk faster before lunch on Mondays but the same people walk slower before lunch on Fridays. For personalizing navigation instructions, data about previous movements (movement profile data) of the user was used to predict the current speed of movement for reaching to destination (or next landmark). More specifically the data about movement of the user is stored on the device and is used for training/validating a machine learning algorithm which predicts the current speed of movement of the user. The current speed of user then can be used to calculate the number of steps and time of arrival to the next landmark for each user given that the length of each step is calculated for each user (using pedometer sensor). This current speed of movement is more accurate than assuming fixed movement speed for all pedestrians or use the device speed to recalculate the movement speed every 5 min.

In contrast to most pedestrian navigation apps, in this research all the storage, training and retraining the prediction of the machine learning model is done on the device and not on server-side.

In prediction of speed of movement, it is possible to use many learning models (from linear, to ensemble models to deep learning models) however use of simpler models seems to be more reasonable. The simpler models like penalized linear regression (such as Ridge, LASSO and LARS) provides good accuracy and at the same time they are faster in training than more accurate and highly complex models. This is very important for two reasons; firstly, the model need to be retrained continuously to provide accurate prediction as the user keeps traveling. In this case penalized regression models are one of the fastest models for training. Secondly the complex models (like Random Forest) need more processing power and time for retraining and therefore use more battery life than the simpler models.

Since the movement profile might change (the user might give his/her device to another person; or the user might get tired) while user walks the movement profile data is continuously recorded and stored on the device. After user starts walking previous known speed of movement (or fixed speed of movement if the user uses the app for the first time) is used to provide the navigational instruction. After few minutes the model has enough data (first generation data) for training/validation process. The model uses the data for finding the best tuning parameters for predicting the current speed. Then the parameters that provide higher R-squared (higher accuracy) are used for prediction. As the user moves, more data will be available for the model (second generation data, third generation data and so on). So the app, regularly (every 5 min or after a long stop) retrains the model and finds the best parameters again and finally uses those parameters to predict the speed of movement. It is worth noting that each generation of data have its own weight in the training process and as data gets older, the weight of that generation will be reduced. By default the app stores up to 80 generations of data and deletes the old generation data as the new generation become available (in first in first out manner).

4 Implementation and Experiment

The landmark-based navigation system with AR, was designed to provide navigation services to pedestrians in some parts of Oxford city containing Oxford University main campuses for tourists. After designing the system and with some tests, an image database for landmarks was created. In this step both geometrical and non-geometrical characteristics of each landmark are stored in the spatial database along with position of camera at the time that those images taken and some other measurements for determining the scale of photo. Buildings and important features, such as statues, historic monuments and buildings with unique architecture were stored in the spatial database as landmarks. For each landmark at least four

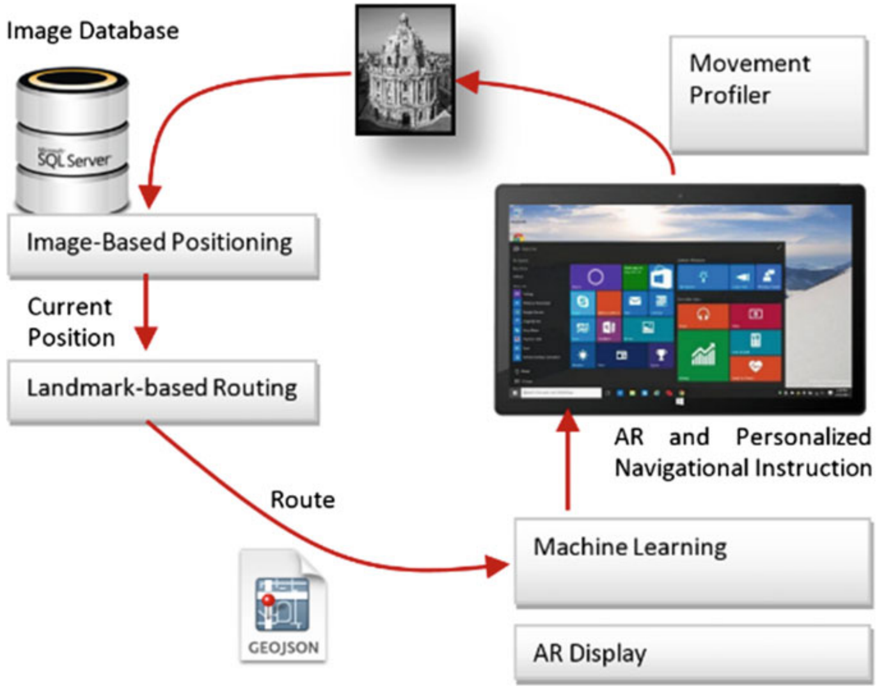

Fig. 2 High level architecture of the system

photographs from different points of view but with almost the same distance and tilt were captured. Attributes such as name(s), age, feature category and some descriptive information were also collected and stored in the database. All image-related data were stored in an instance of Microsoft SQL Server 2012 at server side. High level architecture of the system is illustrated in Fig. 2. Components for image-based positioning and landmark-based routing were developed in C#. These two components provide web API interfaces for uploading a photo (taken by a tourist) and delivering the route in GeoJSON format respectively. At client-side (device), the returned route from landmark-based routing components is fed to AR display component. The AR display, is responsible for generating and positioning of 3D arrows and other augmented objects on the main display as well as showing the route and position of the user on map view. In addition, the AR navigation display component, displays the personalized navigation instruction which are calculated by ML (Machine Learning) component. The machine learning component gets its needed data from Movement Profiler component which records all movement data of users. All the components at client-side were developed using C# and based on Universal Windows Platform (UWP) project type which was introduced with Windows 10. The UWP provides a common app platform on every device that runs Windows 10 which enables a single app package to be installed onto a wide range of devices.

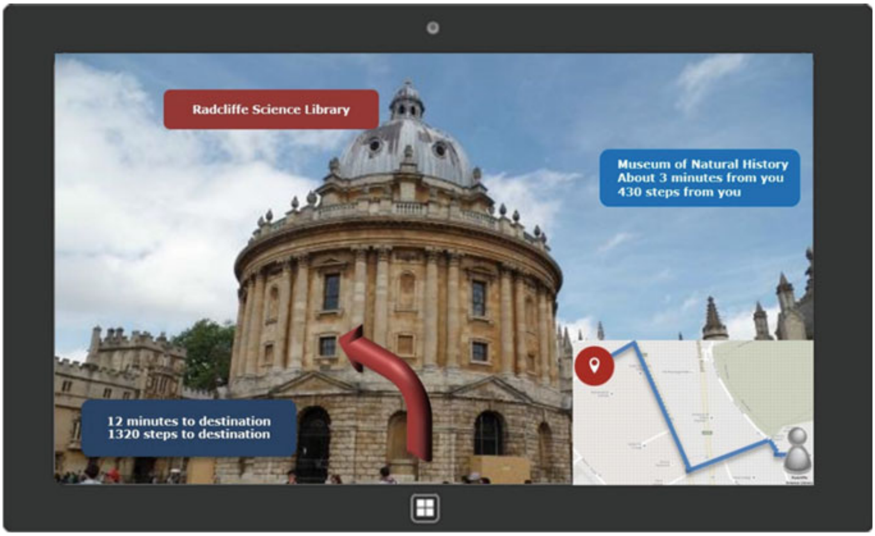

Fig. 3 The implemented system uses landmark based navigation to instruct the user. It shows close landmarks and the overview of the route with continuous feedbacks. Also the instructions are calculated based on more friendly unit (steps) and speed which is calculated based on movement profile of the user. The route is between Radcliffe Science Library and Radcliffe Observatory in Green Templeton College of the University of Oxford

The Movement Profiler and AR Display components use GPS sensor in the device to record the user's movements and refresh the user's position respectively.

In Fig. 3, display of a tablet (Surface Pro) is shown. The navigational instructions contain some information about landmarks, which can be seen from the user's point of view, this approach may be more compatible with tourist navigation applications. In addition, users feel that it is less likely that they may get lost, since they are being provided with the complete path information on map view (bottom left frame). So they are reassured that they are on the right path.

The system seems to provide better spatial knowledge acquisition than the turn-by-turn map-based navigation. To test this claim we designed a study with the following hypothesis: With AR and personalized navigation instruction users will acquire better local spatial knowledge about the environment than users of turn-by-turn map-based instructions.

To test the hypothesis we performed a user study to compare two pedestrian navigation systems, AR pedestrian navigation (the system we developed) and a map-based turn-by-turn instructions approach, that served as the baseline since it is one of the most widely used navigation systems on devices.

20 people who have never been to Oxford, participated in the study. The participants has a variety of professional backgrounds (computer scientist, social scientist, geographer) with average ago of 34.3 years.

4 different routes were used with both systems. First couple of routes (short routes) composed of 5 and the remaining routes composed of 9 landmarks (long routes) as decision points. The participants were told to use both navigation systems (one at a time for a short route and a long route) and navigate through the environment, trying to find the target destination as fast as possible.

Immediately after reaching to destination, participants were given a set of 20 images of the landmarks (5 and 9 were correct for short and long route however they could see 2 and 4 other landmarks during their navigation) and asked to choose the images which they saw during navigation and also place them on a printed map of the all two routes.

All participants in all routes reached the destination without a significant time difference. However, for the analysis of the spatial knowledge acquirement, the results showed a significant difference between the two tested systems. Using the turn-by-turn map-based systems (which is widely used in current device) participants could just select on average 1.8 and 3.7 correct images for short (min = 1, max = 3) and long (min = 2, max = 5) routes respectively. At the other hand participants who used the AR system of this research could select 3.05 and 5.95 on average correct images for short (min = 2, max = 5) and long (min = 4, max = 8) routes respectively. This difference was analyzed using t-test as well as Mann-Whitney U test, showed a significant difference between the two approaches. This was also the case about selection of incorrect images. In summary the result of the study showed that AR navigation system of this paper provides significantly better results for the spatial knowledge acquiring.

5 Conclusion

This paper described the result of a research project about use of augmented reality and landmarks for pedestrian navigation. In this research an app was developed on Windows 10 platform. The landmarks in this research were used for three purposes; image-based positioning, way finding and for providing navigational instructions. For providing navigational instructions, augmented reality was used to superimpose the navigational objects on the images of the landmarks. In addition a machine learning algorithm was used to provide personalized navigational instruction. Finally a user study between widely used turn-by-turn map-based navigation system and the developed system was conducted in Oxford, UK. Users of the system, was quite happy and excited about the system. More importantly, result of the study showed that using the system developed in this research provide significant improvement in acquiring local knowledge. In its current form, the system is just tested on a tablet which requires a redirection of visual attention from the environment to the screen. Testing the system on a smart phone (using a Cardboard) is the next step for this research. Also, at the moment all the movement profile is just used on the device. With proper design and using compression technique it is possible to send the data to the central storage and get useful insight from movements of potentially many tourists in a city. The large amount of data from many tourists is a valuable source of data however it needs a big data management techniques (Amirian et al. 2014; Amirian and Alesheikh 2008) as well as efficient way of sharing models and handling uncertainity(Amirian et al. 2010, 2013, 2015; Karimzadeh et al. 2011; Basiri et al. 2012). In other words, methods, techniques and technologies for handling large volume of movement data in the context of a smart city framework is the future direction for this research.

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The Role of Service-Oriented Mapping in Spatial and Regional Sciences

Markus Jobst and Tatjana Fischer

Abstract By now geoinformation is available everytime and modern maps rule our daily life. Whenever we leave our homes, we have made plans where to go to. If it is a new route we have generally used a map (application). We plan the way that we need to take or evaluate the transport network and its connections. If we feel lost, we take another look in the map and/or try to find reference semantics which will bring us back to our geospatial imagery—our individual mental picture of the world. At the same time, in our cross-linked world, we produce tons of unstructured data that describe the way we use our environment (nature, things and people). For example: when do we need electricity? For what actions? How much do we consume to what time of the day or in which situation? Does this electricity usage change with our age, education, employment—or any other demographic value? What is the impact of the surrounding topography on our electricity needs? All these questions can be answered by data that we leave in space with our actions and devices in addition to existing geospatial core data. In order to make use of unstructured data, we have to ask questions which allow for a first requirement analysis and lead to the primary model of data: a first data structure considering our questionnaire requirements. These models are worth distributing because a lot of questions are similar and variety of people could make value out of it. Information about validity, lineage, purpose of creation, recording method, and so on are needed to evaluate the data for specific use cases. This contribution describes a work in progress on the role of Service Oriented Mapping in spatial and regional sciences by means of a use case in health geography. Therefore it follows the thesis that specific requirements for the analysis, regional investigation and knowledge transmission in regional sciences exist. These specific requirements could be

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G. Gartner et al. (eds.), *Progress in Cartography*, Publications of the International Cartographic Association (ICA), DOI 10.1007/978-3-319-19602-2_28

extensively supported by the specific structure of Service-Oriented Mapping. Some requirements of regional sciences as well as the offers of Service-Oriented Mapping will be exemplified on the basis of a case study “health geographies”. Future tasks for the field of Service-Oriented Mapping and its communication issues could be elaborated from this first requirements analysis and a main future perspective of “Service-Oriented regional sciences” could be formulated.

1 Service-Oriented Mapping

Any analysis and transmission of spatial related information could be enhanced by its visualization in form of maps or cartograms. The access to distributed data sources for this communicative purpose supports a more objective processing but also comes along with challenging issues. The map production with distributed sources, real-time data collection and in a highly automated way can be described as Service-Oriented Mapping. Service-Oriented Mapping offers the creation of maps and complex geoinformation analysis by the use of a Service-Oriented Architecture paradigm, which covers specific information technology characteristics (Bieberstein et al. 2008) in a decentralized network. Decentralized networks, which may also contain centralized components, help to access more diverse data sources, support flexible production flows and enhance storage needs as well as processing power if appropriate standards, interfaces and connections are established. In a world of continuous data flows and increasing recordings (Borgman 2007) a successful system structure needs to embed collaboration and practice a parallel resource allocation. The advantages in data access, actuality, replication and scalability are accompanied by disadvantages in maintenance complexity and standardisation dependency for the network of included nodes.

A central processing of geospatial data sources may offer the advantage of “single node management” from an IT architectural viewpoint (Moser and Bayr 2005; Hanschke 2009), but also comes along with enormous disadvantages for data handling: (1) the replication of geospatial sources, which may be very huge, takes some time and therefore the processed data are not that actual anymore. This processing delay mainly effects sensor data and their unstructured data flows. For structured “non-real time” data, it may lead to redundant datasets, which are not appropriate anymore when we keep data growth and diversity in mind. (2) The scalability of single processing nodes is restricted. Processing infrastructures at one single node could be oversized at a specific moment in time, but may lack of power in near future. This depends on the growth of processing demand. Supercomputers are massively oversized for most of today’s processing demand, but for future applications they are restricted in their expandability (VSC1 2016; VSC2 2016). Therefore map production networks and the concepts of software as a service (SaaS), both following the Service-Oriented architecture paradigm, offer possible solutions for more flexible and powerful expansions in future (Lee et al. 2015; Nabeeh et al. 2015; Nazir et al. 2015).

SOA is the main working principle for spatial data infrastructures (SDI), which are the human- and machine accessible catalogues for geographic information. So to say SDI are the publication and search portals for geospatial content (de Kleijn et al. 2014). In order to support automated search in a data source evaluation process, semantic modelling, appropriate search algorithms and search prospection is needed. Semantic data models and their ontologies will help to create contextual meaning for the computer processing mechanisms. Appropriate search algorithms allow for finding the right data in terms of a geospatial communication aim and a use case. The search prospection may allow for a result forecasting and proposing relevant sources. An important step in improving the data discovery and binding is a semantic enhancement and linking of geospatial and non-spatial content (Vockner and Mittlböck 2014). This enriching of resource descriptions with "domain expanding" sources in form of synonyms, toponyms or multilingual terms expands searchability. The main fundaments are multilingual thesauri and ontologies. As result repositories that differ from the initial language and the context of a user or dataset can be accessed and included in search procedures.

Due to growing data collections and the diversity of data sources, an automation of geoinformation processing is needed. It follows aspects of data integration, data interpretation (Sester 2014), data "semantification" (adding multilingual and—contextual meaning and importance to data) and data transmission preparation (in terms of efficient communication for information handlers). Service-Oriented Architecture (SOA) is the main paradigm to connect and explore everything (Hendriks et al. 2012). Metadata are the key to publish available structured data and their accessibility. The access to unstructured information is not well published nowadays and often its access does not follow standardized interfaces. Persistent Identifiers (PID) connect metadata, data, functionality and their registers in a sustainable way (Paskin 2005; Askitas 2010). It is the glue within an SDI and is even used to relate to single features (and not only to datasets) for a linked data approach (Bizer et al. 2009).

At the moment we can observe three generations of SDI, which highlight the shift from product-centered solutions to user-centric SDI approaches (Rajabifard et al. 2006; Hennig and Belgiu 2011). In first generation of SDI product-based and centralized geoinformation (GI), repositories were opened for small groups of GI experts. In a following second generation a top-down approach enabled the link of metadata, data and organisations which allowed for the management and accessibility of additional information. The third generation tries to follow a bottom-up approach, where the system focuses on user requirements. This user-centric SDI follows the main standardization and development of the Internet, with a specific focus on faster data interfaces and more efficient user interaction (Craglia and Annoni 2007). This user-centric paradigm allows a wider audience, beyond geoinformation experts, to make use of SDI and to leave technical barriers behind.

SDI enabled Service-Oriented Mapping may enhance an expressiveness of spatial models for regional sciences due to its wide data accessibility, its content actuality, an enabled investigation and the appropriate scaling. More accessible data allow to intensify geospatial statistical models. A higher content actuality enhances time quality and even allows for historicized analysis. “Enabled investigation” allows for detailed requirement analysis and the selection of appropriate sources. Appropriate scaling supports dynamic combinations of data sources. All aspects may lead to a more consistent geovisualization that directs opinion formation as well as political decisions in an objective manner.

2 Spatial and Regional Sciences

Geovisualization is a cognitive-semiotic toolbox to transmit geographic information, construct spatial knowledge and support mental geo-imageries (MacEachren 2001). Many approaches focus on modification of the transmission process in terms of geocommunication (Brodersen 2008), which means an assistance of human perceptive reading, human cognitive processing (Raubal 2008), context based linguistics and building of spatial knowledge (Kettunen et al. 2015), all of which help to understand relations, their spatial scenario and a future development.

Spatial and regional sciences discuss spatial scenarios and their developments. Resulting from this discussion, indication and statistical evaluation a specific course of action is recommended. At the municipal level in an urban or rural context a variety of decisive stakeholders are embedded in the discussion process.

Spatial and regional sciences observe non visible phenomena in relation to its spatial environment and try to deviate rules. The consequential idea is to support influence on these phenomena. Therefore a successful spatial communication across different expert groups, based on well-understood semantic reference geometries, is needed. The main aim is to transmit any knowledge of observed phenomena and explain its political, regional and structural consequences.

Regional and spatial planning is a cross sectional oriented discipline which holds a key position because of its future- and forehandedness orientation. The main duties arrange, develop, protect and design are partly contradictory and lead to challenges in optimizing decisions for collective demands in predefined regions. The aim are sustainable solution statements considering the area of conflict between requirements and political possibility. It has to be stressed that the cross-sectional tasks of spatial planning must not only focus on favoured subgroups within the populations or a defined territory, but has to consider all stakeholders within the population based on the paradigms of equivalence and equal opportunities.

Research within the field of spatial planning does not end with an analysis of findings or its interpretation. In addition to analysis results, solutions have to be provided for political decision makers at different spatial levels. In literature this requirement is often described at an abstract-strategic level (Born et al. 2004). Walsh et al. (2012) point out that “…due to the small-scale nature of the research, and the diverse contextual factors of place and the heterogeneity of the rural older population, it is not possible to generalise our findings to other rural settings…” (p. 9). This argument hints at specific requirements and even difficulties for using

Service Oriented Mapping for spatial research of rural older population if the quality of data sources differs too much.

There exists one strategy that apparently evolved as cure-all in the past decades in order to consider as many stakeholders as possible: participation. From a spatial science perspective, participation is on one hand seen as political duty with the purpose to consider the diversity of demands and lifestyles within the democratic system. On the other hand participation is understood as individual and democratic right of attendance, contribution and composition of social life. It is politically defended as important element of quality of life. According to the Austrian development concept (2001) "…intensified participation in planning processes increases acceptance and a successful implementation of planning processes…". In this Austrian general orientation for spatial development "participative planning" is used as synonym for striking, successful, integrating and regional significant planning. In short this describes "intelligent planning" (ÖROK 2011).

According to Reuter (2006) participation is not only an ethical and democratic aspect, but also an epistemological one: including knowledge of many others reduces probability to be faced with unwanted consequences, which may call the planners to account. Therefore communication and agreement supersede the straight scientific fundamentals and information. The role of planners changes: it advances from classical technicians to moderators and mediators (Reuter 2006).

The discussion and development in regional and spatial planning shows that maps gain more importance due to the communication in a broad audience. Considering more different aspects and viewpoints in a planning project may result in the need for more diverse data, references and analysis. GIS systems provide the central toolbox for analysis, SDI allow for searching and accessing appropriate sources and the map results in a most efficient transmission of involved information, viewpoints and an exchange of mental geo-imageries.

3 General Requirements

Generally spatial knowledge in regional sciences structures itself in statistical models that embed all kinds of available geospatial sources. These sources are selected according to a requirements analysis based on planning issues and the questions to be clarified in the communication process. In addition possible consequences for a region/structure are derived on the basis of these (spatial) models. If the model is restricted in its expressiveness any recommended consequences may be wrong and therefore misleading political, regional and structural decisions could occur. Therefore it becomes more and more important to precisely define the main questions, the relation of space and planning issues, embed more data sources, automatise analysis and perform a discussion-centric map production.

Main investigation questions follow a detailed regional planning assessment, which defines a planning area and topic, explores available data and their fitness for purpose, discovers required surveys and observations and formulates a proposed decision support. The planning area and topic delimits the scope and helps to focus on important issues. This focus is especially needed to generate a questionnaire and to avoid rhetorical and manipulating questions (Kroeber-Riehl and Esch 2004), which distort the results of investigation. Any direct investigation with questionnaires needs to be related to geospatial components, where the components cover geospatial features in form of reference core data or core data as well as thematic data or statistics. SDI help to find published datasets, evaluate their licenses and terms of use and accentuates the owner and point of access. Actually very few cases allow for an evaluation of fitness for use in their lineage metadata. A specific geospatial data assessment determines an actual state of fitness. Furthermore the regional planning assessment expresses use cases and their aim of investigation. This collection leads to the requirements for surveys to undertake and the key attributes, which will be asked for in the questionnaire. The formulation of a proposed decision support lists possible outcomes and prepares for an effective communication design. Often detailed questions aim at establishing infrastructure facilities, specifying their catchment areas or defining supply capacities of infrastructure facilities for a given planning horizon. Spatial-thematic relations, development of spatial behaviour and awareness-building of (spatial) qualities form further topics of investigation in regional planning.

In general regional studies follow a national-economic approach with sustainable long-term estimation. This estimation is a demand- and stable-oriented approximation of observed key-values in context with the specified focus on a thematic content. In fact demographic forecasts can only base on the observation of spatial and demographic development. Any derivation of consequences comprises a rate of uncertainty that depends on quality of data collection. The change of socio-economic as well as socio-demographic structures can not be always directly observed but has to be collected in direct or indirect surveys (Eyles and Woods 2014). Main topics cover aging, emerge of poverty, changing mobility behaviour, migration decisions and so on. The orientation of research spans from provisioning science, which answers what kind of infrastructure to provide, to regional sciences, which creates knowledge by spatial change observation.

The socio-economic and -demographic forecasts may get better, the more comparable historic datasets exist. Comparison of datasets includes persistent references in space over time. Administrative units, which are often referenced in these topics, change from time to time. Therefore their comparability ends with the time of change. Independent references, like spatio-statistical rasters, could help to tie values to spatially defined areas in a sustainable way (Wonka 2010). Wonka (2010) states that several statistical data are stored in databases in a way that no data evaluation on basis of spatio-statistical rasters is possible, because these data are bound to the administrative units. In some cases disaggregation into a raster helps to gain improvement of spatial distribution within the map (Wonka 2010, p. 61).

For most of the topics a consistent investigation has to consider varieties of settlements, transport networks, topography, mobility and so forth within the given spatial extent. Urban settlements with their dense population come up with other characteristics and specifics than rural areas. Furthermore data quality and response density to questionnaires may differ enormously in rural regions. Economically-underdeveloped- and infrastructure-poor rural regions consist of macro-chore attributes, socio-demographic-economic indicators, settlement- and infrastructural characteristics and stakeholder-based attributes (Fischer and Peer 2013). Macro-chore attributes cover topographic exposition, large political-based administrative units, location in space and distance to (small-)regional hubs and lacking reachability of supraregional hubs. The socio-demographic-economic indicators consist of a tendency of aging, shinkage of principal resident numbers, selective migration of young and well educated population, high number of commuting ratio because of missing employment markets, high percentage of secondary residents and the thinning of social networks in the region. Settlement- and infrastructural characteristics consider small permanent settlement areas, low population densities, dispersed habitats, long distant routes to territorial subareas and thinning of local supply infrastructures and public transport offers. Stakeholder-based attributes describe increasing heterogeneity of stakeholder groups with decreasing basic population.

The indicators of infrastructure-poor rural regions in the previous paragraph highlight an extensive need of different geospatial reference core data as well as statistical, agricultural, economic and demographic datasets. Some of them can be found in nowadays SDI with tendency growing. In order to prove a pragmatic dimension of SDI for one simple use case in health geography the following exemplary first steps were gone. The main question behind these steps is: do actual SDI help to collect and evaluate needed data in a more efficient way?

4 Exemplary First Steps in a Use Case of Health Geographies

The authors selected a topic of health geography as use case. The reason of this topic is its apparent independence from environmental and land administration issues, which are a big focus of the actual SDI implementations (INS 2016) and therefore distort applications fields beyond and the evaluation of an extensive pragmatic usage of SDI. On the other hand spatial sciences in health geographies develop towards a more location-sensitive discipline (Andrews 2002) that should make use of SDI and also deliver its results to SDI as part of statistical data collections (GapM 2016). This recursive procedure could help to establish value adding findings, enhance data quality and bring in higher statistical relevance with manifold data sources.

The topic of aging population has impact on society (participation, health issues and social relationships) and economy. It deals with questions of nursing work, housekeeping, home care and the infrastructure of nursing homes (Liaschenko 2001). Especially structural weak areas face new challenges related to a demographic change: population decline and the increasing heterogeneity of the aging

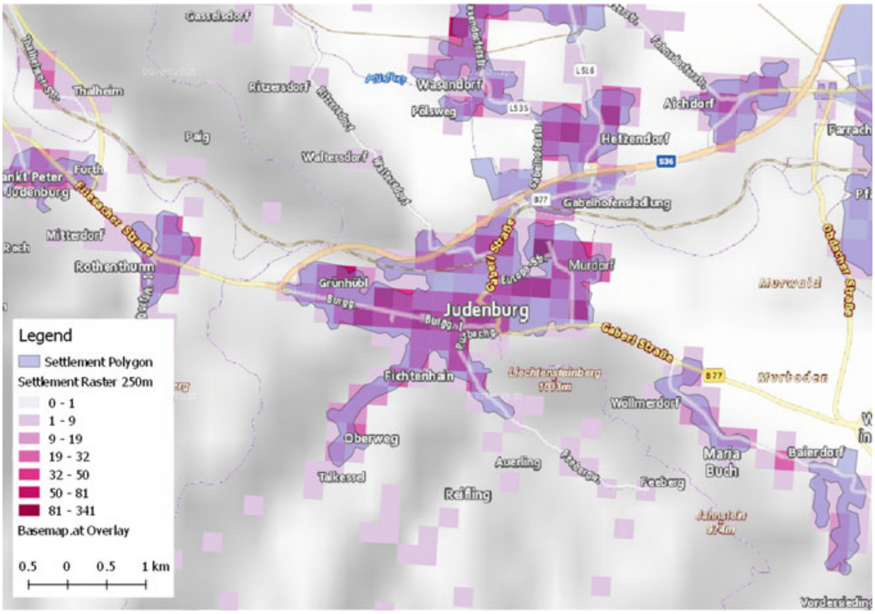

Fig. 1 Raster cells versus polygons—achieving persistent comparability

population. So the main challenges for structural weak rural municipalities will be the stabilisation of the amount of primary dwellers among the older generation and matching various requirements of an aging population in change. At the same time the financial opportunities decline. Therefore the migration behaviour at old age is of high interest. Is there willingness to move/stay to specific places for growing old? An answer of this question and the amount of future demanders allows to design infrastructure solutions and to evaluate alternative supply structures of goods and services at the municipal level. The migration behaviour is a result from specifics of spatial behaviour, spatial perception, social inclusion and political participation.

The source material in our use case of health geographies is a questionnaire that was send out to all public nursery homes in Austria. 800 of the directors responded to questions concerning indicators like level of urbanisation, reachability with public transport, individual transport and its facilities as well as walking distance, visiting regulations, significance of visitors and future development plans for the infrastructure, living, care and visitor models. These subject-specific data of the questionnaire call for quality improvement in terms of the standardized location judgement. Geospatial core data are needed to evaluate and standardize statements of urbanisation and reachability. A location aware assessment requires further geospatial data to calculate exposition, heights, solar radiation, lighting or wind regimes. The thematic intense evaluation needs a bulk of statistical data that is generally needed to embed and to relate to more common indicators.

In addition to the thematic data collection needed for quality enhancement, these source data structures need to be comparable to others (Wonka 2010). Each single topic may have its specifically used features (point, line, polygon, …), location and spatial extensions, which are not directly comparable nor stay persistent through time and space. By establishing comparability, for instance with regional-statistical rasters, analysis in depth can be performed for the standardized set of raster cells. In our use case the level of urbanisation was validated and intensified by counting the amount of addresses per raster unit of 250 and 100 m (Fig. 1). The raster units are standardized according to the European statistical grid systems (POPSTAT 2016). The dataset of Austrian addresses is provided by the Austrian Address Register as part of the public sector initiative with unrestricted rights of use when considering the property right in all following derivations. Further geospatial data that are identified for analysis are the Austrian height model with 10 m cell size, the European height model with 25 m cell size, a transport network of the intermodal traffic-reference system, settlements, buildings and different land use areas. All data sources are building blocks for further analysis, a geospatial logical processing (as done in GIS systems or Web Processing Services (WPS 2016)), that will support the indicators, and geospatial communication to inform decision makers. The collection of all used data sources are result of a SDI investigation. The way of selection, needed evaluation steps, existing coverage and comprehensive descriptions lead to main observations and indicate an answer if actual SDI help to access data sources in a more efficient way.

5 Main Observations

Surveys and comprehensive investigations are often financially underestimated, because the effort of data acquisition is restricted to either thematic datasets (indicator collection) or geospatial ones (reference collection). Due to the high effort of questionnaires and their analysis, topographic references and -indicators may suffer and vice versa. Therefore a comprehensive approach for a financial implementation planning is needed as a basic requirement. Financial planning issues are not a topic of this contribution, but had an impact on the data selection observations: we focused on the availability of open data for our use case, although the availability and quality of commercial products was observed as good as possible.

The main observations to evaluate the actual role of Service-Oriented Mapping for regional and spatial sciences resulted in some critical aspects that have to be solved in order to establish efficient production workflows.

5.1 Geospatial Coverage

When specific topics for a cross-regional use are requested the quality, data interface and -structure may differ among federal states. Looking at the European level this diversity exists for federal states and nations. Even regional diversities occur especially when specific regional investigations were done. Some results and data of these regional investigations were brought back to SDI's. One result that could be observed was that SDI build up from a large collection of single use cases (e.g. investigations) with a restricted regional extend. In most cases the content and data quality did not match with neighbouring regions. In that case it could not be used for cross-regional investigations without massive effort of data-, quality- and interface homogenisation. Directly usable data sources in SDI were found from federal agencies or cross-regional organisations (e.g. European Environment Agency EEA), which take the effort of homogenisation for their use cases and legal compliance.

5.2 Semantic Heterogeneity

In order to find appropriate sources, well documented metadata are needed. "Well documented" means that on one hand the metadata schema can be validated as common understood online resource (e.g. by use of a registry portal) (INS-REG 2016) and on the other hand the content of metadata is semantically usable. The usage of metadata distinguishes between geospatial content (geospatial data and services) and thematical content (tables, documents and so forth). Geospatial content generally follows standardized structured metadata as proposed by ISO 19115:2003/2006, ISO 19119:2005 and ISO 19139:2007 with slight variations according to regional legislation. It includes spatial references and spatial quality indicators. In contrary thematical-, non-spatial content follows different requirements and standardisation. Statistical data and tables make use of SDMX (Statistical Data and Metadata Exchange) which was approved as ISO standard ISO 17369:2013 in 2013. SDMX is used to exchange metadata on statistical sources and allows for data linkage in terms of linked data with the help of a RDF data cube vocabulary (SDMX 2016). For other documents that are shared on the Internet, especially in use of libraries, the Dublin Core schema defines a small set of vocabularies to describe a document. The Dublin Core Metadata Element Set is endorsed for example by ISO 15836:2009 (ISO-DC 2016) or NISO Z39.85 (NISO 2016).

In our use case we had to deal with three different metadata structures that did only have basic definitions in common. A cross-domain search was not possible. It needs to overcome semantic heterogeneity of metadata in order to support a cross-domain investigation. Even among geoportals semantic heterogeneity has been observed. The homogenisation of a geospatial search function has been defined for the legislation of the European spatial data infrastructure and its geoportal (Lutz et al. 2009; Smits and Friis-Christensen 2007). A possible approach to establish cross-domain recherché is a semantic enhancement by linking different metadata structures and embedding recommenders (Vockner and Mittlböck 2014).

5.3 Interface Heterogeneity

Independent from any data portal and its metadata structure, the possible access to data sources differs. It spans from complex data services to simple file downloads. This distribution format is additionally advanced by different file formats, application profiles or service types and therefore results in interface heterogeneity. According to the interface, different possibilities of the further processing or license restrictions exist, e.g. when proprietary formats call for proprietary software products. Encapsulated files, e.g. in ZIP files, cannot be accessed directly via a service but need to be extracted. The file format description is often not clear in the metadata description, because both information is needed: the format description of the embedded data as well as the compression format. Otherwise an appropriate use is not possible. Interface heterogeneity can be reduced by the usage of standardized, digital archivable formats (Beinert et al. 2008).

5.4 License Heterogeneity

After overcoming semantic- and interface heterogeneity a difference of licenses complicate a productive usage of the data sources. In the worst case a different license for each data source has to be fulfilled. Legal certainty is of great importance for the data combination, its analysis and the transmission/communication of results (LGDS 2004). Reduction of licence variety should be one aim for the future in order to support pragmatic cross-domain investigations in regional and spatial sciences.

From our observations point of view SDI evolve into a more efficient access for data sources in regional science investigations, but it is not there already. At the moment the authors have the impression that domain specific approaches are defined, but cross-domain support remains out of consideration. This leads to different kinds of heterogeneities preventing from an automatic workflow, which is needed in Service-Oriented Mapping.

From a regional science application point of view the main requirements are consistent and persistent relations between features and time-invariant, comparable features of different domains. Both are needed to investigate as well as predict the development of space, population and infrastructural needs.

The main challenge of spatial planning is to enhance public participation on informal planning processes. In order to develop participative processes in structural weak rural municipalities it is of great importance that the impact of infrastructural and regional changes can be communicated beforehand. All deficits and missing adjustments have to be clearly addressed, which will help to keep disappointment low. Additionally the difference between primary dwellers and multilocal mobile residents leads to heterogeneous aging structures and various infrastructural demands. This development is noteworthy and leads to various political elaborations, assisted by appropriate regional investigations and geovisualization.

Our observations show that Service-Oriented Mapping and SDI are an important step towards an efficient and objective regional investigation. Further developments for the main components in cross-domain SDI are needed in order to support the main requirements of comparability, prediction and Service-Oriented Mapping. The next steps in our ongoing work on the use-case of health geographies are the development of cross-domain quality algorithms, an establishment of SDI-supply-profiling and a more precise requirements definition for cross-domain investigations in regional sciences with a focus on participative geocommunication. Cross-domain quality algorithms will allow for an automated survey normalization in context with the geospatial situation. A SDI-supply-profiling establishes an assessment of data quality according to their lineage, usability, applicability and information depth. The requirements definition for cross-domain investigations in regional sciences will explicitly focus on the needs of geovisualization and the support of participative processes.

6 Conclusion

With this contribution we can conclude that future perspectives of "Service-Oriented regional sciences" definitely exist. The approaches within the geospatial, statistical and other domains support the general requirements of regional investigation even though some problems need to be solved for cross-domain investigations. Linking data and resources establish collaborative surveys and may generate more objective insights. The cross-domain requirements of regional sciences need further investigation and more sharpening in terms of geospatial expectations and geocommunication. Therefore further exploratory, consensual steps of methods in regional sciences and GIScience/cartography are needed.

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