Generalized, Inaccurate, Incomplete: How to Comprehensively Analyze Sketch Maps Beyond Their Metric Correctness

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Abstract

Sketch mapping is a method to investigate a person's spatial perception and knowledge about the surrounding environment. While cartographic maps can be easily evaluated with respect to the represented features, map scale, and spatial accuracy, there still does not exist a comprehensive method to evaluate sketch maps. This paper aims to overcome this gap and proposes a sketch map analysis method that allows for analyzing the completeness, generalization and (qualitative) spatial accuracy of the sketched information in a three-step process. After describing the method, we illustrate how our computer-supported method performs in a use case with three sketch maps. Our approach may assist researchers in geography, psychology, and education to evaluate spatial knowledge in a systematic way independent of specific research questions and experimental scenarios.

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1 Introduction

Studying spatial knowledge of humans is a challenge that we face in many different settings in spatial cognition, e.g. when studying the participant's performance in spatial tasks, when studying the nature of cognitive processes, or when studying the effectiveness of different spatial representations or wayfinding assistance systems. We aim to explore how much of the presented information participants recall. Did they capture every detail? Did they focus on the important spatial aspects? What type of information did they consider important? What kind of knowledge did they acquire and how accurate is this knowledge?

Sketch mapping is a method with a long tradition to explore spatial knowledge and people's mental maps of their surroundings. Researchers have studied the elements of spatial knowledge [11, 26, 3], studied the distortions of size, distance and directions [19, 26], and

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studied factors influencing the sketch map quality [7, 2]. Sketching is commonly used to evaluate the spatial memorization performance in experiments [16]. Despite the fact that sketch mapping is a great method to capture the configuration of features in a two-dimensional map that reveals distance and directional relations between objects sketched, they suffer from the fact that to date there exists no comprehensive method to analyze sketch maps. In 2016, Montello claims that "Analyzing sketch maps is something of a notorious problem in research" [15, p. 174] and not much has changed since then. Researchers have been counting the number of sketched features, the existence of particular landmarks, and analyzing the properties of such features (distance, direction, shape). A successful approach is bidimensional regression [6, 9], which analyzes the spatial distortion between selected sets of points (e.g. a set of landmarks) ignoring the map layout (street network etc.) between these points.

A core problem in analyzing sketch maps in comparison to cartographic maps is the fact that human spatial knowledge is incomplete, generalized and schematic. So are sketch maps. To evaluate a sketch map, we need a method that can handle incompleteness, generalization and schematization while comparing sketched information to a base map which is considered as the "correct" ground truth. In this paper we present a comprehensive sketch map analysis method that analyzes the information content with respect to the

- degree of completeness: How many of the features in the base map are covered by a corresponding feature in the participant's sketch map? A participant with a more complete sketch map is considered to have a better memorization performance than participants with a less complete map.
- degree of generalization: How many features in the sketch map are represented at the same level of generalization as the base map? Do participants recall all details or do they recall the information at a more abstract level?
- qualitative spatial accuracy: How correct is the spatial configuration of skeched features? E.g. do participants place landmarks along the correct street segments which themselves are connected in the correct way?

It is necessary to analyze these three aspects within a single method for two reasons. First, it is impossible to determine one of them independently. The completeness analysis informs us about which elements should be considered in the generalization analysis. Qualitative correctness can only be analyzed if the alignment of generalized objects is done. Second, even small sketch maps easily become too complicated for humans to analyze as the number of spatial relations among the drawn features grows exponentially. Visual inspection of the accuracy of spatial relations is nearly impossible for human rater when generalization (example in Figure 1) and incompleteness (example in Figure 2) is involved. A consistent, computer-supported method is necessary to ensure a systematic evaluation.

2 Background

A cognitive map is a mental model that encompasses the internal processes that enable people to acquire and operate information about the physical environment [5]. Information in cognitive maps is not as it is in two-dimensional cartographic maps. "Instead, cognitive maps are complex, highly selective, abstract, generalized representations in various forms" [5, p. 18]. Human spatial knowledge in cognitive maps is incomplete and fragmented [8]. This is not only due to our limited memory capacity and the natural process of spatial knowledge fading out over time, but rather the result of our cognitive processes, using objects to establish a frame of reference for other objects to localize, relate and provide orientation. Capturing information at different levels of detail is not seen as a sign of memory failure, but as a

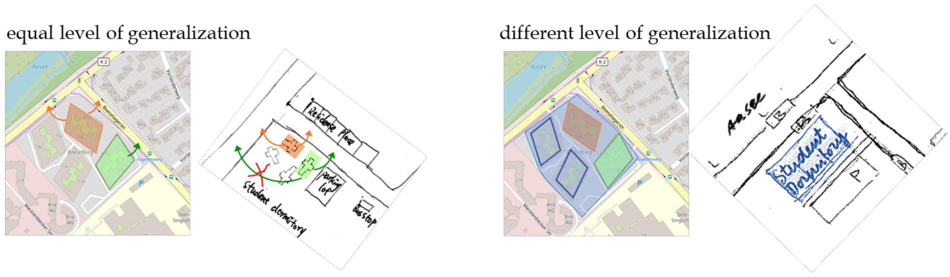

Figure 1 Challenge: Evaluating the spatial accuracy when generalization is involved. The student dormitory highlighted in orange is adjacent to two streets, while the student dormitory highlighted in green is not. To compare the spatial relations with a generalized visualization in the sketch map, we need to change the level of generalization in the base map. Similarly, the student dormitory highlighted in green has an adjacency relation to the parking lot, which is not present for the student dormitory highlighted in orange, but cannot be distinguished at a generalized level.

consequence of normal information processing. Spatial memory is organized in hierarchies and categories [26]. This leads to various effects of distortions well studied in Psychology since decades [24].

Sketch maps, as externalizations of cognitive maps, reflect distortions and errors that are originated in cognitive maps. For example, distances between near spatial objects are considered relatively longer than distances between far away ones [9]. Ordinary buildings are judged closer to landmarks than the other way around [20, 14]. Routes with more turns and intersections [20] or more landmarks [25] are judged longer. Spatial information is also simplified in cognitive maps. For instance, angles tend to be perceived more rectangular, and curved features are perceived straighter [28]. There are other typical cognitive impacts found in sketch maps such as errors of quantities, shape, size, and inconsistent scales. Another phenomenon of human spatial knowledge is its generalization. The process of generalization can be found in cartography to represent the same spatial information at different levels of detail. In cognitive maps – or following Tversky better called cognitive collages [27] - this process of generalization happens in an inconsistent way. When externalizing such knowledge, this leads to different generalization levels integrated within a single sketch map produced by a single participant. Generalization of spatial information is a well-researched problem in cartography – although their generalization is consistently applied across the whole map. The generalization types suggested below are inspired by cartographic generalization, but are however differ since generalization is rather conceptual in sketch maps and applied inconsistently across the map.

Regarding the characteristics of sketch maps, there are two principles being followed in this paper: first, sketch maps contain invariant spatial information as a necessity for people to conduct any spatial behaviour in the physical environment; second, cognitive impacts should be taken into account when sketch maps are under analysis, because they cause inaccuracy in sketch maps.

Methods to evaluate Spatial Knowledge Acquisition. Experiments in wayfinding research may pursue very different targets – e.g. investigate human wayfinding strategies, the influence of different wayfinding instructions, or the effect of digital wayfinding assistance on wayfinding performance or spatial knowledge acquisition. While some studies focus on landmark knowledge acquisition, others study route or route network knowledge acquisition, configural or survey knowledge acquisition.

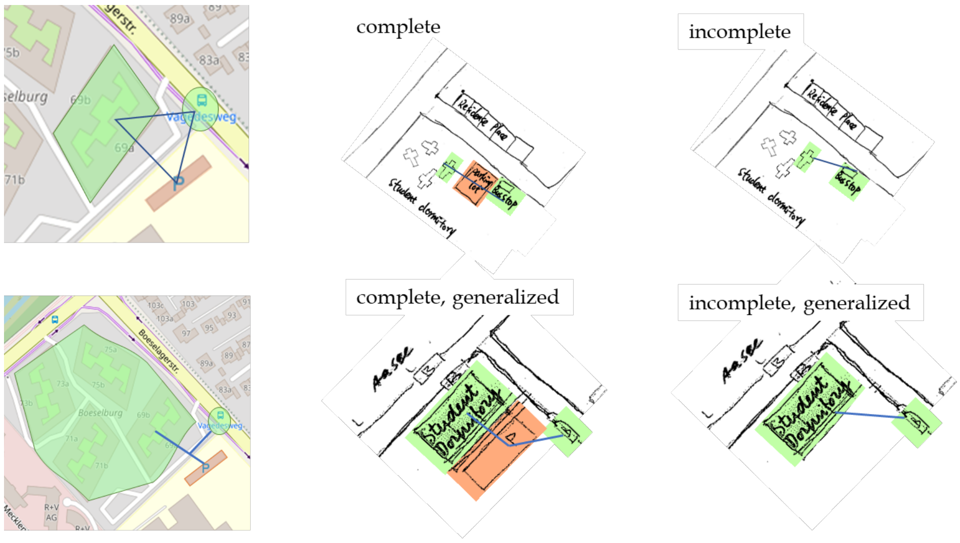

Figure 2 Challenge: Evaluating the spatial accuracy when incompleteness is involved. In the base map, the bus stop is in-between the dormitory and the parking lot. In the complete sketch maps, the spatial arrangement of bus stop and parking lot is wrong, while in incomplete sketch maps, the arrangement of dormitory, bus stop and street is (qualitatively) correct.

The probably simplest method to analyze spatial knowledge acquisition are recall tasks. Participants can be asked to mention verbally all features they recall or to select landmarks that they recall from a set of landmark pictures. To test their route knowledge, participants may be asked to order landmarks on the route correctly or to place them correctly on locations on a base map. Distance estimates are oftentimes combined with direction estimates where participants have to point in the direction of the landmark assuming that they are standing at a particular location. Ranking landmarks according to their distance and direction as well as placing them onto a two-dimensional map involve certain survey knowledge. To elicit spatial distance information between places but to avoid sketch mapping, experiments oftentimes apply the method of multidimensional regression.

Methods to analyze the information content in sketch maps. Approaches to analyze sketch maps include simple counting approaches (e.g. counting streets, landmarks, other particular features) or verifying the existence of features with a particular interest for the experiment. This method has been used in many studies, however Billinghurst and Weghorst (1995) was the first to name this method as "completeness". There are different variations in measuring completeness such as counting nodes, paths drawn in sketch map etc. Since, this method does not have any spatial relevance, it is usually accompanied by "map goodness". "Map goodness" [1] is measured by asking experts to rate sketch maps based on certain criteria such as "how useful the sketch maps are for navigation purpose?" etc.

The best known quantitative approach is bi-dimensional regression [6, 9]: It analyzes the degree of shape and scale distortions between reference points in the map. These are collectively called quantitative approaches as they only capture the metric aspect of sketch map such as scale, angle etc.

Qualitative approaches give some guidelines how to analyze qualitative aspects of sketch maps. The Qualitative Matching approach developed in [4] represents a sketch map as a set of qualitative constraint networks (QCN) one for each aspect of space. This approach supports only limited number of qualitative relations and was never extensively tested in the context of sketch map evaluation analysis.

Spatial Scene Similarity by Nedas [17, 18] proposed a similarity measure to compare two spatial scenes that takes into account (i) the similarity between objects in the two scenes; (ii) the similarity between the binary relations among objects in the two scenes; and, (iii) the ratio of the total number of objects in both scenes to the number of objects that have been matched – or equivalently, not matched. This approach goes into a promising direction, although it was never applied and tested in the context of sketch map evaluation.

Last but not least, there is our SketchMapia approach [22], analyzing different sketch aspects to align sketch maps and metric maps. A set of sketch aspects were identified that are used to compare sketch maps with a base map. So far, the approach was only applied to sketch map alignment, not sketch map evaluation. However, the set of spatial sketch aspects identified in [28] is useful for this approach, because it describes spatial relations between drawn objects, which - if the relations in the sketch map are not identical to the relations from a topographic map - should be considered as erroneous in the sketch map. The invariant sketch aspects are further described below.

3 The Research Gap

The related work in section 2 demonstrates that different approaches have been applied to separately detect completeness and spatial accuracy. We believe, that spatial accuracy cannot be analyzed without a systematic approach to capture generalization and generalization cannot be analyzed without having determined missing objects. A comprehensive sketch map analysis method therefore has to address all three aspects jointly. However, completeness, generalization, and spatial accuracy are not always easily separable. Sometimes missing a feature leads to a generalization of other objects which would have been separated if the missing feature was drawn. Generalization might affect the spatial relations that can be determined in a map. For example, grouping several objects into one such as in Figure 1 changes their spatial relation to the streets: while the dormitory area is adjacent to both streets, the single buildings are not.

Thus, the first challenge we address is the integration of the three aspects into one formalized and structured procedure applicable to different sketch maps. While simple counting methods will suffice to measure completeness, we aim to build upon our previous work on generalization types in sketch maps [12, 13] and apply it to the context of spatial knowledge evaluation. For determining the spatial accuracy, we will build upon the sketch aspects we identified for sketch map alignment [22, 28] to detect spatial configurations which should be considered as erroneous. Note that within this approach a geographically inaccurate location along the correct street segment is not considered an error.

4 A comprehensive sketch map analysis method

Our comprehensive sketch map analysis method can be useful for sketch maps in various experimental set-ups, e.g. for sketch maps drawn directly from memory, after prior exploration of the scene with or without assisted wayfinding, or for sketching as a recall task after a learning phase. We first describe how data for the sketch map analysis method might be acquired and afterwards explain, how each aspect is captured by our comprehensive method.

Data Acquisition in an Experiment. Experiments in wayfinding research may pursue very different goals. We may investigate wayfinding strategies, the influence of different wayfinding instructions, or the effect of digital wayfinding assistance on wayfinding performance. In spatial learning tasks, the spatial knowledge acquired might tell us about the memorability of different communication formats or the nature of different cognitive processes. Sketch mapping is commonly applied to learn more about a participant's spatial knowledge, e.g.:

- what features did the participant remember,
- at which level of abstraction did the participant recall objects,
- was the participant able to recall them in the correct spatial configuration.

Based on the research question that shall be answered, the experimenter has to decide what information they want to extract from sketch maps, i.e. which landmarks and streets the participants are expected to recall in a 'perfect' (i.e., best possible) sketch map. Next, the experimenter digitizes the base map of the experimental area and the sketch maps collected throughout the experiment.

Sketch maps may also include additional features. These may be additional features from the real world that are not captured in the base map or additional features made up by the participant. As our base line for comparison are only features digitized in the base map, we do not consider such additional features in the sketch map analysis.

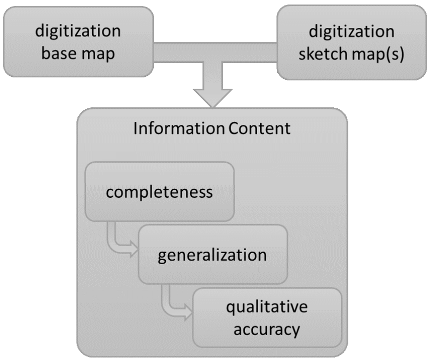

Figure 3 Procedure of the Sketch Map Analyzer: To evaluate the information content of a sketch map, we need to compare it to a base map.

Further, we distinguish between analyzing its information content and the type of the map: The information content is analyzed in a sequential order with respect to the completeness of the sketch map, the degree of generalization of sketched features and with respect to the qualitative accuracy.

Sketch Map Analysis Step 1: Completeness. The sketch map's completeness tells about the ratio of features captured in the sketch map with respect to all base map features. Depending on the design of the experiment, the sketch map's drawn features may be compared to the (very large set of) features in the corresponding map section of a topographic map or to a subset of features selected by the experimenter. We identify all features that have not been sketched. All other features – independently of whether they are drawn at the same level of generalization or in an accurate way, are counted for the number of drawn objects. We interpret the amount of recalled features as an indicator for more or for less comprehensive spatial knowledge acquisition.

Sketch map completeness is the first step of the analysis process, because it determines the set of features in the base map that need to be aligned to (generalized or non-generalized) features in the sketch map.

Sketch Map Analysis Step 2: Generalization. The degree of abstraction, respectively the detailedness, is considered as an indicator for the level of abstraction of spatial knowledge. The degree of generalization of a drawn object says something about a person's perception of the environment and thus about the mental model[2]. Generalization is the second step of the sketch map analysis process in which we establish alignment between features: This may be a one-to-one alignment (i.e. no generalization involved). If generalization is involved, we distinguish between group-to-one alignment and group-to-group alignment. In the first case, several detailed features in the base map are aligned with one abstract feature in the sketch map. In the latter case, several objects are drawn in the sketch map to indicate a particular pattern but not concrete features. The alignment is established at a generalized level, e.g. the houses at the side of a street are represented by a set of houses in the sketch map while not every single sketched house can be aligned to a particular house in the base map.

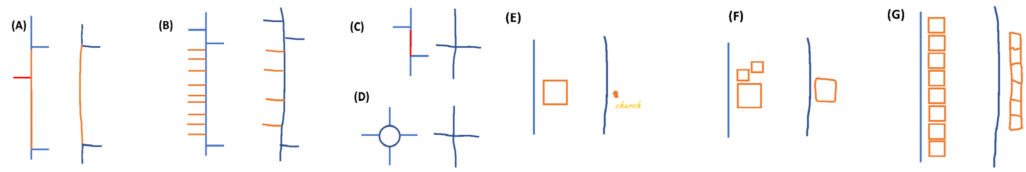

Figure 4 Seven generalization types: geometric merging for streets (A), abstraction to show existence for streets (B), junction merge (C), roundabout collapse (D), collapse for buildings (E), amalgamation for buildings (F), abstraction to show existence for buildings (G).

Figure 4 visualizes the different generalization types that we proposed in [13] based on an extensive analysis of sketch maps. Generalization type (A) and type (C) are a result of an incompletely drawn sketch map. In generalization type (A), a side street was left out and thus two street segments are merged into one. In generalization type (C), the missing street leads to a junction merge which eventually also effects the spatial accuracy of the street segments, because a new street pattern occurs. Generalization type (B) and (G) are examples of group-to-group alignments. While in the base map each feature matches one feature in the reality, the set of side streets or the set of houses do not refer to a specific streets or houses in reality; but only indicate the existence of a set of streets and houses, respectively. In generalization type (D) and (E), the extended feature in the base map is represented by a feature of lower dimensionality: The junction is collapsed into a junction, and the polygon representing the footprint of a building is collapsed into a point. Generalization type (F) amalgamates a multi-complex building to one single building.

The procedure of highlighting missing and generalized objects in a base and a sketch map was tested in [12]. Five raters received annotated the same set of 30 sketch maps which systematically differed in their degree of generalization and completeness. Out of the total of 416 features coded by the 5 participants, 53 features were generalized, 275 features were non-generalized, 82 features were not drawn (out of which 24 resulted in merging of segments due to omission of streets). Once, the color-coded data was ready, we used the Light's Kappa index [7] of the irr package in R to calculate the agreement. The overall agreement score among the participants was kappa = 0.889 with p = 0.056.

[2] Every spatial representations, not only the sketch map but also the topographic map, results from an abstraction process. Simlarly to completeness, the experimenter decides for the degree of generalization (s)he expects.

Sketch Map Analysis Step 3: spatial accuracy. The third step aims to determine spatial accuracy of a sketch map. It operates on the generalized feature alignments, i.e. in case a feature is generalized, the detailed features are replaced by the generalized one. The spatial relations are calculated also based on the generalized one. Since sketch maps are distorted and schematized due to the cognitive processes underlying the formation of a cognitive map, we strongly believe that a quantitative regression measure has only limited meaning. In our previous work [28, 22] we have investigated invariant aspects in sketch maps, i.e. (qualitative) spatial relations among sketched objects which are typically not distorted in the sketch map.

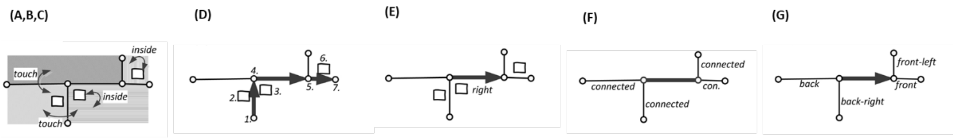

Figure 5 Seven sketch aspects to determine the qualitative correctness [22]: topological relations between landmarks (A), regions (B), and between street segments (C), linear order of features along the route (D), left/right relation of landmarks with respect to the street (E), connectivity of street segments (F), and orientation of street segments (G).

Figure 5 illustrates the six sketch aspects taken into account for calculating the qualitative accuracy. The first sketch aspects refer to topological relations: In our implementation, we calculate topological relations jointly for landmarks and regions (A, B), and separately the topological relations between street segments and landmark/regions (C). Sketch aspect (D) describes the linear ordering of landmarks and junctions along a route. A route is defined as connected street segments. Sketch aspect (E) describes whether the landmark is left or right located with respect to its nearby oriented street segments. Sketch aspect (F) describes whether two street segments are connected to each other. Sketch aspect (G) describes the binary directional relations of two street segments that coincide in at least one junction point.

In various studies [10, 21] we investigated the reliability of these sketch aspects in alignment scenario to determine at which level topological relations, ordering relations and direction relations should be distinguished to provide a reliably and accurate measurement. This challenge is highly connected to the problem of defining which factors influence a sketch map quality: Which distortions in sketch maps do we consider correct and which ones false. In our experiments we could show that the methodology of capturing qualitative relations with the abovementioned sketch aspects is feasible and demonstrates a high accuracy of >99%, but further studies with systematically varied sketch maps will be necessary to empirically validate our treshhold when a distortion is supposed to be considered as an error or not.

5 Use Case demonstration

For the demonstration of our sketch map analysis method, we simulate a wayfinding study in which participants follow a route given by wayfinding instructions which indicate which street to follow, which turns to take and refer to landmarks for better orientation. Our research aims at investigating how memorable our route instructions are. Thus, we decide to consider only features that are mentioned in our route instructions for our evaluation.

Figure 6 shows our study area. Our wayfinding instructions refer to 11 landmarks (all buildings or complex buildings) and 22 streets (12 of them form the route). Afterwards, participants are instructed to draw a sketch map on a blank piece of paper. They shall remember as many streets and landmarks mentioned in the route instructions as they can.

Figure 6 Experiment route with landmarks and streets referred to in route instructions (solid blue line), streets part of the route (dotted red), and the start and end location.

We collected a set of sketch maps out of which we will analyze three examples following the above described methodology. Figure 7 visualizes step 1 (completes) and step 2 (generalization) for sketch map 1.

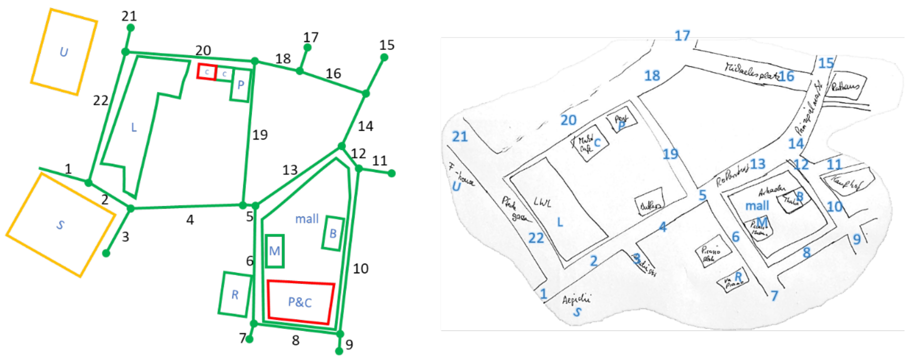

Figure 7 Sketch map 1 (right). The base map on the left indicates which features are missing (red), generalized (yellow) and which features can be one-to-one aligned with the sketch map (green).

Sketch map 1 is of very high quality: It misses only very few features: The two missing landmarks do no effect the level of generalization of the street network. In sketch map 1, nearly all objects are at the same level of abstraction as in the metric map. Only landmarks S and U were collapsed to a single label in the sketch map not specifying the footprint of the landmark (generalization type (E) in Figure 4. There are only minor qualitative errors. For example, landmark U is alongside street segment 21 and 22 in the base map, but in the sketch map landmark U is collapsed into a label and the label is only adjacent to street segment 21.

Sketch map 2 is much simpler than sketch map 1 (c.f. Figure 10 in the appendix). Many street segments are missing such that the network structure is mostly reduced to the route of the experiment. Missing street segment lead to a high generalization in the street network. Many landmarks are missing as well, however if they are drawn, they are not generalized.

This difference can be seen in the bar charts in Figure 8 (right side): while the degree of detailedness is 100% for landmarks, it is only 30% for street segments. For detailed data from the bar charts refer to Tables 1 and 2 in the appendix.

There are several qualitative errors. For example, in the base map landmark R and P&C are right/left at the opposite side of the street segment. In the sketch map, you first pass landmark R on the right side and afterwards you pass landmark P&C on the left side. This leads to wrong spatial ordering relations of landmarks on the route (Figure 9). Furthermore, street segment 22 is connected to street segments 2 in the base map, while in the sketch map segment 22 is too short (c.f. Figure 10).

In our third example (sketch map 3 is shown in Figure 11 in the appendix), less streets and landmarks are missing than in sketch map 2. This leads to a lower degree of generalization (respectively higher level of detailedness) in the street network (Figure 8). Several landmarks are placed incorrectly in the sketch map: Landmark M is supposed to be located next to street segment 6 within the mall. Landmark R is supposed to be next to street segment 6. The spatial relation between the two landmarks M and R is correct. Furthermore, landmark S is placed inccorectly. In the base map, it is adjacent to street segment 1 and 2, while in the sketch map it is adjacent to street segment 2.

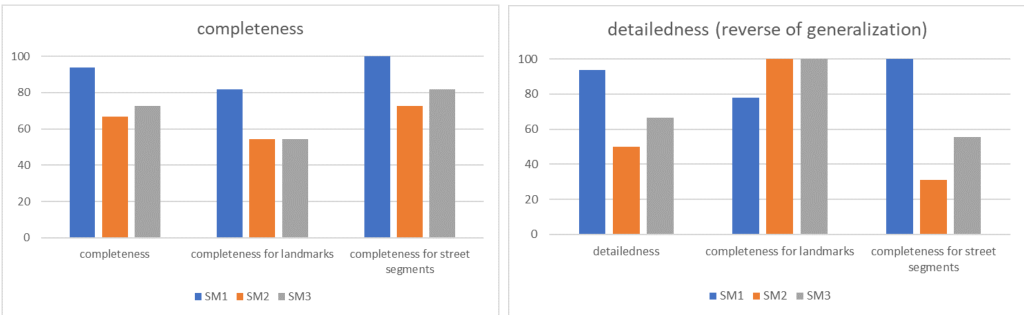

Figure 8 Results for step 1 and 2 of the sketch map analysis method: Completeness and degree of detailedness (the reverse of generalization) for all three sketch maps.

Figure 8 compares the completeness and the detailedness for all sketch maps. The missing streets lead to a high degree of generalization in sketch map 2. The charts clearly show, that completeness does not necessarily go together with a low degree of generalization. Missing streets oftentimes lead to generalization in the street network, but the degree of generalization differs.

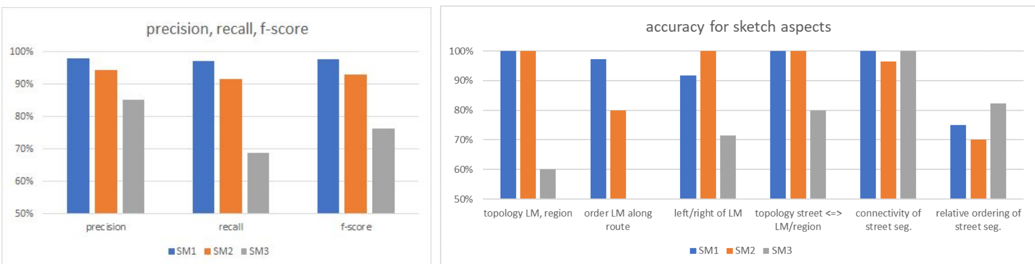

Figure 9 Results for step 3 of the sketch map analysis method: Spatial accuracy for each sketch map (precision, recall and f-score of spatial relations on the left) and the individual accuracy values for each sketch aspect (right).

For analyzing the spatial accuracy in step 3, we calculate the spatial relations for each feature and sketch aspect (c.f. Table 1 in the appendix for all relations in sketch map 1). Even for a small map such as sketch map 1, these relations easily sum up to a large number of relations which cannot be manually computed anymore. We analyse them using the precision, recall, and f-score values. Precision is the proportion of elements that are correct; recall is the proportion of information (correct or not) that was included in the sketch map; and f-score is the harmonic average of the two (their relative weight can be adjusted). Recall of spatial relations should not be confused with the completeness of features. The whole process is supported by our software implementation (screenshots in the appendix, at `http://www.sketchmapia.de` you find our open-source tool).

Sketch map 2 and 3 are missing about 50% of the landmarks, but those landmarks sketched are placed correctly in sketch map 2 and incorrectly in sketch map 3. Figure 9 shows that sketch map 1 has the highest qualitative accuracy, but also sketch map 2 – despite of the higher incompleteness, has a high precision, recall and f-score. For sketch map 3 we see a low recall, i.e. the number of correctly represented spatial relations in sketch maps compared to the number of spatial relations in the base map is relatively low. Sketch map 3 scores only 100% with respect to the connectivity of street segments, since the errors are introduced by wrong placement of landmarks.

6 Summary

Analyzing sketch maps is a common methodology to evaluate human spatial knowledge. Researchers have developed analysis methods specifically adjusted to the research question and set-up in their experiments, but to date, no methodology exists that allows for a comprehensive analysis of sketch maps. Montello outlined the key challenge: "one piece of good advice is that you should figure out what kind of information you want to get from the sketch maps, based on what research questions you want to address" [15, p. 174].

Based on previous work by the authors on analyzing sketch maps, this paper proposes to combine different analysis approaches to a three-step comprehensive sketch map analysis method accounting for the typical characteristics of cognitive maps, namely incompleteness, generalization and schematization. In step 1, completeness of the map is determined by identifying missing features in the sketch map. All remaining features will be investigated in step 2: In the generalization, we identify features that cannot be directly aligned to a single feature in the other map. We analyze the type of generalizations which end up in a one-to-group or group-to-group alignment. The third step analyzes the spatial accuracy by comparing the qualitative spatial relations among features in the base map and corresponding features in the sketch map. A software suite is implemented to support this systematic analysis.

While we are aware that the overall evaluation of the method is still to be done, we believe that – having shown the evaluations for completeness, generalization and spatial accuracy separately – we are able to demonstrate with our extensive use case that the methodology is sufficiently generic to be useful in different settings assisting researchers to analyze sketch maps in experiments in a comprehensive way. Comparisons across different experiments become possible, as the method is systematic, standardized and not research question specific.

Future Steps. Human spatial knowledge is classified into three types [23]: landmark knowledge, route knowledge, and survey knowledge. Our sketch map analysis method comprises components that evaluate different types of knowledge. For example, completeness of landmarks, generalization of landmarks and bidimensional regression relate to landmark knowledge. Street segment completeness, generalization of street network, linear ordering of landmarks along the route as well as left/right relations along the route relate to route knowledge. Topological relations of landmarks and regions, connectivity of spatial relations leading to cycles in the graph, and the topology of street segments and regions relate to survey knowledge. As a next step, we aim to evaluate the quality of landmark, route, and survey knowledge based on the different components of our analysis method.

One open challenge is determining how individual measures obtained by our toolset correlate with each other. This way we could avoid situation in which one error in a sketch has a cascading effect on multiple measures computed by the toolset, and results in much lower scores, e.g., because it invalidated a very large number of qualitative relations. Simultaneously, other errors may have disproportionally small effect of the final scores only because they occurred in an area of a sketch map less sensitive to the problem of correlated measures or because the specific qualitative relation being wrong is less correlated with other relations.

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A Appendix

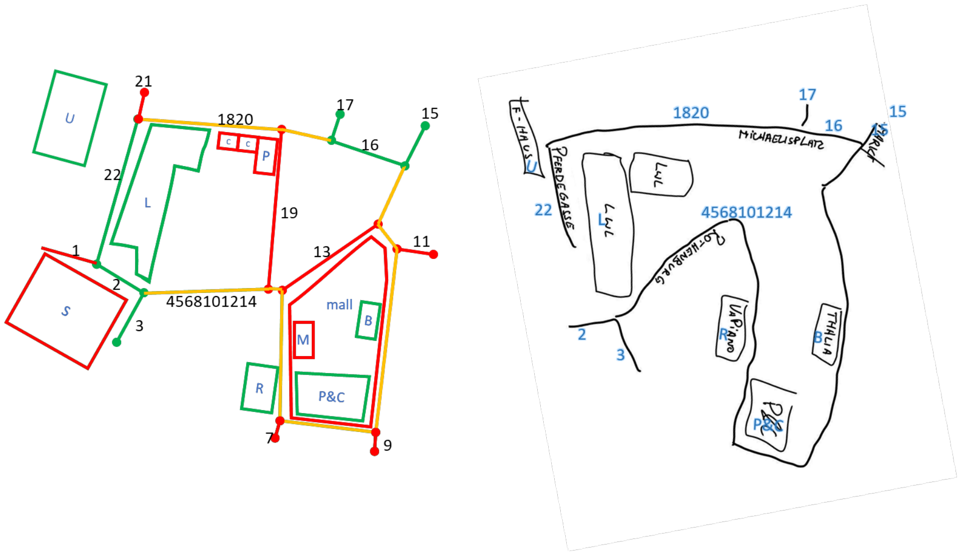

Figure 10 Sketch map 2 (right). The base map on the right indicates which features are missing (red), generalized (yellow) and which features can be one-to-one aligned with the sketch map (green).

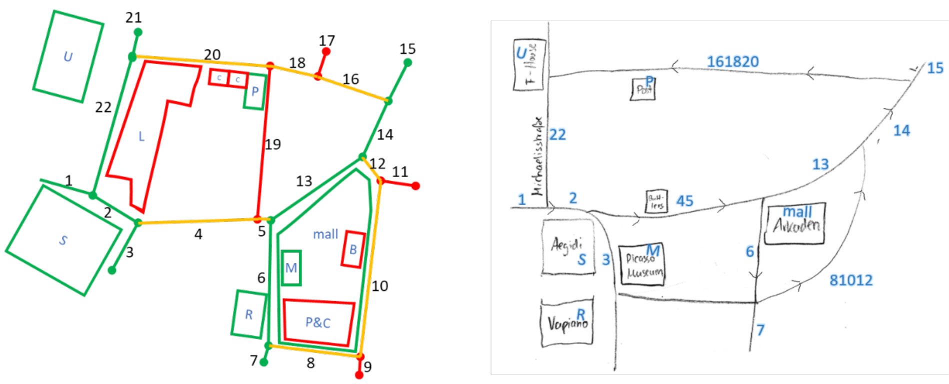

Figure 11 Sketch map 3 (right). The base map on the right indicates which features are missing (red), generalized (yellow) and which features can be one-to-one aligned with the sketch map (green).

Table 1 Sketch map 1: accuracy for each type of qualitative relation.

	base map	sketch map	correct	wrong	missing	accuracy
topology LM, region	36	36	36	0	0	100%
order LM along route	36	36	35	1	0	97%
left/right of LM	28	24	22	1	5	92%
topology street <=> LM/region	198	198	198	0	0	100%
connectivity of streets	231	231	231	0	0	100%
relative ordering of streets	36	36	27	9	0	75%

Table 2 Sketch map 2 and its completeness and generalization values for each feature.

ID	com	gen	ID	com	gen	ID	com	gen
B			1	√		12	√	merge
C1			2	√		13	√	
C2			3	√		14	√	
L			4	√	merge	15	√	
M	√		5	√	merge	16	√	merge
mall	√		6	√		17		
P	√		7	√		18	√	merge
P&C			8	√	merge	19		
R	√		9			20	√	merge
S	√	collapse	10	√	merge	21	√	
U	√		11			22	√	

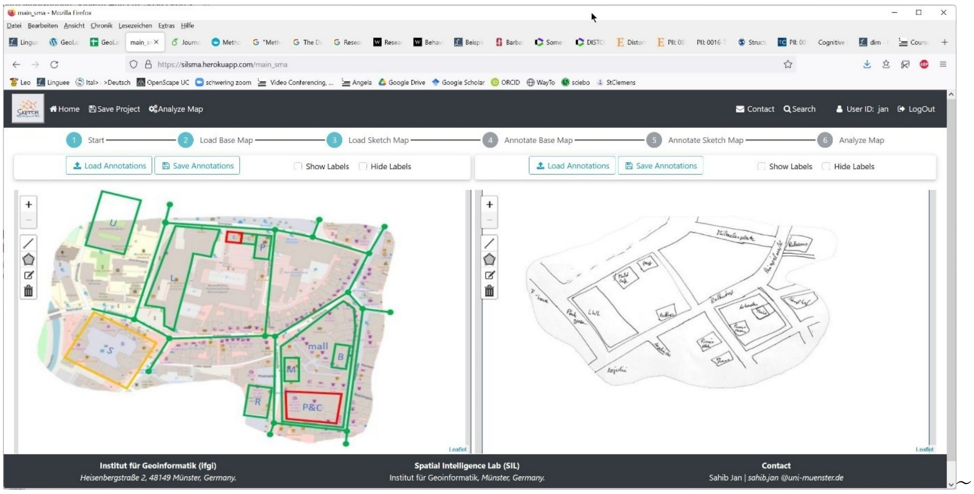

Figure 12 Screenshot 1: Annotation of incomplete, generalized and non-generalized features.

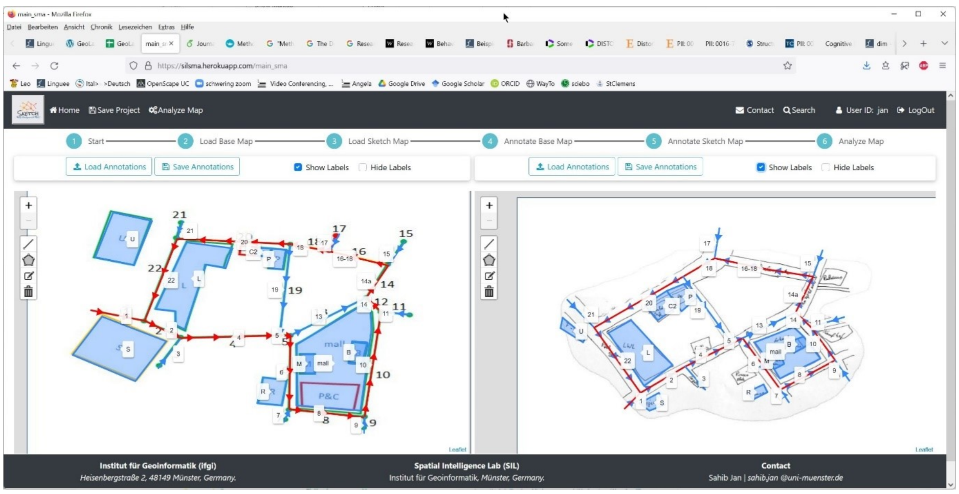

Figure 13 Screenshot 2: Digitization of base and sketch maps, indicating the route (street segment in red), and alignment via labels.