Multi-Sketch Alignment in the Context of Volunteered Geographic Information

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INTRODUCTION

Sketch maps are an intuitive way of expressing geospatial information. They contain objects which represent real world geographic features, relations between these objects, and oftentimes symbolic and textual annotations (Blaser, 1998). These elements enable us to use sketch maps to communicate about our environments and to reason about our actions in those environments. In this way sketch maps provide an intuitive user interaction modality for some geospatial computer applications (Egenhofer, 1998). Especially with the advent of Volunteered Geographic Information (VGI) (Goodchild, 2007) sketch maps may be the key to removing the barriers imposed by the technical requirements of traditional Geographic Information Systems (GIS) (Schwering, 2010). In order to allow users to contribute and query geographic information using sketch maps an automated system must be able to analyze them and ground them in the real world (Wallgrün, 2010). Some sketch based geospatial query systems achieve this by extracting the spatial relations between objects in the sketch map and searching the database for a set of objects that share matching or similar relations. Two examples of this approach are Spatial-Query-By-Sketch (SQBS) (Egenhofer, 1998) and Qualitative Matching (Wallgrün, 2010) which I will refer to as QM in this paper.

One way to support users of sketch maps is by providing information about how different sketch maps compare with each other thereby allowing them to use several sketch maps in combination. This type of comparison involves sketch map alignment which is a process that aims at discovering structural similarities between a pair of sketch maps. In this paper we propose to extend existing sketch based spatial query methods for the alignment of sketch maps. First we demonstrate a scenario where automatic sketch alignment can become a critical tool, then we outline some drawbacks of using SQBS and QM directly for sketch alignment in a VGI context using QM as a working example, and finally we discuss how these limitations can be solved. In the remainder of this paper the terms sketch, map, and sketch map are used synonymously. We do so to differentiate contexts in which one of the notions “map as a cartographic artifact” and “sketch as a rough, inexact visual representation of an idea or thought” stands out from the specific concept of sketch maps with which this paper is primarily concerned with.

EXTENDING SPATIAL KNOWLEDGE WITH SKETCH MAPS

Sketch maps can be a useful tool for gathering environmental knowledge for research and practical applications (see e.g. Read, 2010; walking papers[1]). Our work is motivated by a scenario in which a user needs to plan actions in an unfamiliar urban environment using a collection of sketch maps from many different people. Examples of such scenarios include disaster response operations in which any information may become critical for saving lives and property. The use of crowdsourced crisis information after the January 2010 earthquake in Haiti demonstrates the importance of information acquired directly from the affected communities as well as from those working inside the affected areas (Heinzelman, 2010). In a first step field officers in the disaster response operation can collect sketch maps from residents to be digitized and stored in a sketch repository. In the second step the sketch maps can be aligned to each other and to metric maps, if available, providing vital information for tasks such as the assessment of damages or blocked paths and roads at a local scale. This second step is the subject of our investigation.

Our problem can be stated as follows: given a collection of sketch maps of sections of an urban environment one of which depicts a location known to the user, find that collection of sketch maps that best extends the initial sketch by providing more information for the immediate environment and

[1] http://www.walking-papers.org/about.php

connecting the environment beyond. At first it may seem that sketch based geospatial query methods can be used to perform the task described above by recursively querying the sketch map collection starting with the initial sketch map. But as will be seen in the next section this may lead to results that are difficult to organize in a comprehensible way.

REPRESENTATION OF SKETCH MAPS

This work considers a sketch map to be composed of a set of objects and relations among those objects over several aspects of space. In comparison, in Forbus et al. (2003) a sketch is composed of units called glyphs. Every glyph is associated with a conceptual entity which is its content and spatial relations in the sketch map are relations among the glyphs. Similarly, Kopczynski and Sester (2004) represent sketch maps based on their conceptual content. In their case, sketch objects form nodes of a so called conceptual graph. The nodes are associated with instances of concepts which represent geographic features and the edges are relations between those features. While these approaches are interesting, they restrict the representational units (to geographic concepts) so that some interesting details may not be accessible. In our approach sketch objects can be referred to without knowledge of their geographic feature type. Emphasis is placed on spatial relations and this provides a model which is well suited for sketch based query processing when little information about the objects is known.

SKETCH BASED GEOSPATIAL QUERY EVALUATION

The central concept of sketch based queries is similarity. Both SQBS and QM begin by attempting to match query and database objects based on properties assigned to query objects such as feature type or name. For those query objects that were not matched in the first step, a match is made by assigning them database objects with relations to other matched object pairs that are similar to the relations of the query object with those matched pairs. A query evaluation therefore involves the comparison of qualitative spatial relations from the sketch with qualitative spatial relations from the database. Spatial relations are represented using formal qualitative spatial knowledge representation methods (Cohn, 2001) which support maintaining consistent associations between the sketch and the solution (Wallgrün, 2010), measurement of relation similarity using the conceptual neighborhood (Cohn, 2001), and constraint based reasoning using composition tables (Cohn, 2001).

Sketch Alignment Based on QM

Figure 1 below shows a generalized flowchart of the query evaluation process based on QM as it would be applied to sketch maps. The process *InterpretSketch* interprets, for each sketch map s_i, the qualitative information for a given aspect of space a into a representation $Q_{C_a}(s_i)$ of the corresponding spatial calculus C_a. $Q_{C_a}(s_i)$ is a constraint graph (Kumar, 1992) also called the Qualitative Constraint Network (QCN) whose vertices V correspond to objects of s_i. The objects of s_1 and s_2 in figure 1 are matched pairwise by the process *MatchObjects* which leads to $\frac{n!}{(n-l)!}$ possible alignments if s_1 and s_2 have n and l objects respectively, $l \leq n$. If the matching is restricted by some constraints then the number of potential matchings is less.

Each combination of object pairs found in the last step is called a *matching* and can be represented using as a QCN, $Q_{C_a}(m)$, in which the variables corresponding to matched object pairs are constrained by the identity relation of C_a and the remainder are initially constrained by the universal relation of C_a. A matching m is said to be admissible if the constraints of the combined consistent QCN $Q_{C_a}(m)$ are consistent with constraints of both $Q_{C_a}(s_1)$ and $Q_{C_a}(s_2)$ (Wallgrün, 2010). *FindOptimalMatches* uses an evaluation function to find the set of optimal matches $M_{optimal}$. Optimal matches are those matches that maximize the size of the matching and the number of representations for which the matching is admissible. The optimality can be considered as a component of a measure of quality for the alignment. Therefore, for a collection of k sketch maps the results of the $\binom{n}{2}$ pairwise alignments can be ranked to obtain the best alignments with respect to this measure of quality.

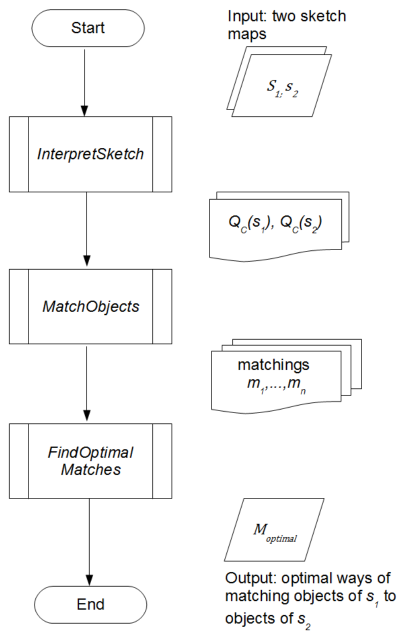
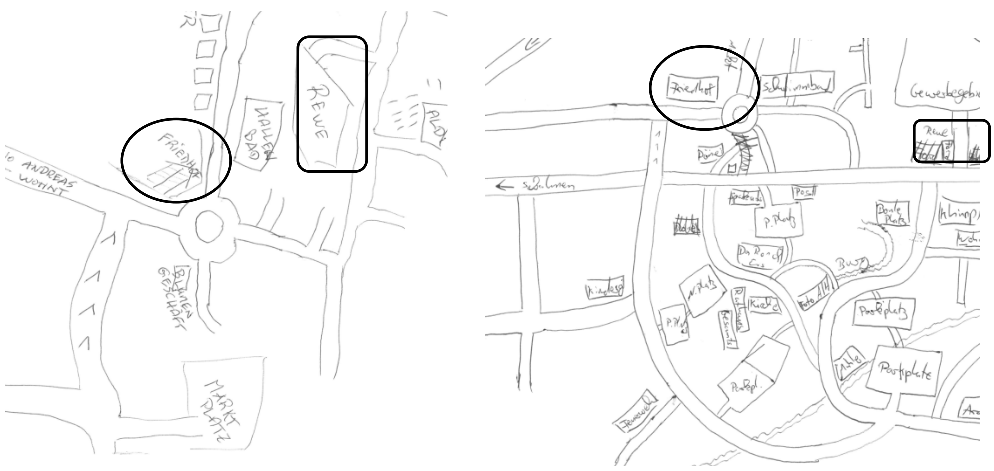


Figure 1: Stages in the alignment of two sketch maps based the query evaluation process of QM.

Challenges of Sketch Map Alignment Using Sketch Based Query Methods

The first problem of the approach outlined above is that it fails to account for the cognitive aspects of environmental knowledge. On the one hand sketch maps schematize, they simplify and distort information (Tversky, 2002). The schematization and distortion inherent in sketch maps renders some aspects of space unsuitable for this type of alignment. For example in figure 2 below, the orientation of the object labeled *Rewe* (inside rectangular outlines) with respect to the object labeled *Friedhof* (inside oval outlines) in figure 2 (a) is different from the orientation of respective objects with same labels in figure 2 (b). As a result alignment may produce many or even only suboptimal solutions (i.e. with low measures of similarity).



(a) (b)

Figure 2: Distortions and variations in levels detail for two sketch maps of the same part of Brugger city in Germany.

On the other hand an analysis of patterns of map sketching shows that people tend to cluster objects around areas of interest in several subsketches (Blaser, 1998). In addition because mental representations of geographic environments are simplified abstractions (Tversky, 2010), people draw sketch maps with varying levels of detail as can be seen in figure 2. And the amount of detail may vary widely even within a single map, for example, a sketch may have one object representing a house, one representing a town, and one representing a road that connects the house to the town (Blaser, 1998). The challenge of matching such variations in detail lies in the fact that the correct object matching according to the intentions of the people who drew the sketch maps may not be one-to-one or even complete (e.g. whole-part correspondence). And since there is no prior knowledge about the real world object that a sketch object is referring to, it is difficult to determine when a one-to-many matching would lead to a better alignment of the corresponding sketch maps. This is certainly important in a VGI context where users create information at different levels of detail.

The second problem is that the approach does not provide a way for relating more than two sketch maps directly. Multiple sketch representations can be matched together using the QM approach but there is no clear method for determining whether a result is optimal. There needs to be a way of computing the goodness of the result of an alignment and isolating sketch maps that contribute highly to making a result suboptimal. As such one challenge in this task is the definition of the measure of goodness itself and the design of appropriate methods for computing it. Another challenge is in the resolving of conflicts which are likely to occur when comparing multiple sketch maps. In the present approach a conflict in the information of two sketch maps that spans all of the representations used in the alignment will cause the solution to be discarded. However it may be desirable to allow a conflict between the facts of one sketch map and those of another to persist just in case removing one of the sketch maps leads to a worse off solution than keeping it.

SOME SOLUTIONS TOWARDS AN AUTOMATED ALIGNMENT OF SKETCH MAPS

The problems outlined above are not an exhaustive list of the issues involved but they represent some important steps towards an automated sketch map alignment process. In particular, schematization and variations in the level of detail in sketch maps prevent 'high quality' results from emerging during alignment (Wang, 2009). In order to resolve these problems the influence of human cognitive tendencies needs to taken into account. We believe that resolving these issues also leads to significant improvement in the process of aligning multiple sketch maps.

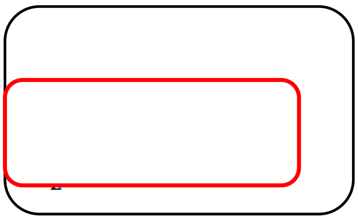
Schematization and Distortion

Wang et al. (2009) have studied the effects of schematization and distortions in sketch maps on qualitative sketch representation. They have suggested using salient aspects that are more or less invariant under schematization such as the order of objects along a street segment. In (Wang, 2010) they present a model for aligning sketch maps of urban environments to metric maps that uses the street network to define city blocks which are used to constraint the locations of objects by evaluating their topological, directional, and ordering relations with respect to the city blocks and among themselves. Based on this previous work, we propose to extend the process evaluating the optimality of a solution of an alignment in two ways. The first is to weight the contribution of each aspect based on the extent to which it is likely to be distorted. In figure 2, for example, a low weight for orientation based on cardinal directions would be preferable because this aspect is distorted. The determination of such a weight could be done in an empirical investigation or by incorporating learning capabilities into the system. This way we ensure that aspects that are likely to be distorted make a lower contribution to the overall measure of alignment. Secondly, we propose to take a hierarchical approach to the alignment process, so that partial alignments that are locally optimal and complete with respect to certain aspects can contribute to a solution that is globally optimal with respect to other aspects.

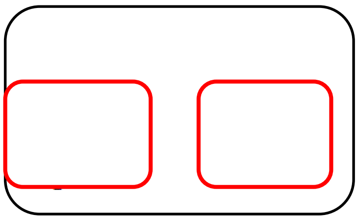
A Relative Level of Abstraction

As pointed out in the section on challenges above, dealing with variations in the level of detail in the context of sketch alignment is a challenging task because object correspondences are not immediately available. This requires the ability to match objects in a many-to-many, one-to-many, and whole-to-part fashion. Wallgrün et al. (2010) observe that an extension of their approach which allows such correspondences to be expressed is essential for different types of applications. We propose that these types of matching must be modeled within the realms of the language of representation (i.e. the spatial calculus) because they are the carriers of the semantics of the relations. Additionally there is a need for inference mechanisms for reasoning about the how spatial relations change under certain abstraction operators such as aggregation and generalization (Timpf, 1999). These inference mechanisms can then be used to define functions that simulated the process of abstraction for a given operator allowing the comparison of information at different levels of detail. For example, consider a function $Aggr$ that takes any finite number of objects and returns an object that satisfies all the constraints the input set of objects. The function $Aggr$ simulates a spatial aggregation operator. In figure 3 for example $(Aggr(a_1, a_2) \sim b_1, a_3 \sim b_2)$, where $\sim$ is read as 'is matched with', would be admissible with respect to both topology and cardinal directions. The question that needs to be answered here is how do we determine that an aggregate object satisfies all the constraints of the individual objects and vice-versa?

The next question would then be what criteria must be used to select candidate objects for applying the aggregation function? In fact, for any abstraction operator, the system needs to know the 'when, what, and how' for selecting a set of objects to be compared. A first step to achieving this is by processing all the maximum solutions (i.e. there is no solution with more matched objects). However this approach assumes that only maximum solutions can be improved under the abstraction operators. An analysis of the different abstraction mechanisms may lead us to a set of basic criteria for this purpose.



(a)



(b)

Figure 3: Two similar spatial configurations for which applying the function $\mathbf{Aggr}(*)$ can lead to a higher measure of similarity.

Multi-sketch Alignment

Comparing multiple sketch maps involves simultaneously evaluating multiple sets of constraints on multiple inputs. Isolating a pair of sketch maps that are introducing inconsistency in the QCN may be difficult due to the interdependencies of constraints (Kumar, 1992). A different approach would be to model the problem as a coherence problem (Thagard, 2002). (Thagard, 1998) have presented several methods for computing the coherence of a set of statements using constraint satisfaction. We propose two alternative approaches for adapting this idea to our problem. In the first each sketch map becomes an element of the problem and its pair-wise alignment with each of the other sketch maps represent the constraints of the coherence problem. This approach has the advantage of highlighting sketch level relationships while allowing us to consider all sketch maps at the same time. However lower level details about object interactions may not be accessible for use in the computation. The other approach considers sketch objects as elements of the coherence problem and the consistency of their constraints with other objects as the constraints for coherence. The problem with this approach is that it is possible that no alignment will be achieved because the constraints are at a very high granularity. In both cases, mutually consistent sketch objects will be grouped in one set while mutually inconsistent ones will be grouped in another. During this partitioning of the set of sketched objects, consistent and inconsistent constraints are counted per sketch and globally to keep track of the goodness of the alignment and the contribution of each sketch map to this goodness. The solutions suggested here are not complete but provide a case for exploring coherence as a basis for performing multi-sketch alignment. As the name suggests coherence provides us a way to judge the goodness of fit of the set of sketch maps being aligned. We believe that combining the approaches mentioned above can lead to an optimal solution for the multi-sketch alignment problem.

CONCLUSIONS

The problem of sketch map alignment can be modeled using sketch based geospatial query methods. Our proposed approach seeks to extend these methods by accounting for the schematizing effect of cognitive processes and the relative level of abstraction between different sketch maps. We note that these can be dealt with by employing simple techniques that consider the salience of these effects over different aspects of space. In the second section of this paper we presented a scenario in which automated multi-sketch alignment can be useful and we presented here a proposal for performing it. The problems reviewed in this paper represent what we view as some of the critical questions that must be answered to realize a truly automated sketch alignment procedure. Our approach is based on qualitative spatial information and therefore inevitably involves some information loss . However such losses are compensated by the fact that qualitative information is more akin to the way humans represent spatial knowledge (Cohn, 2001).

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