Qualitative Representations of Extended Spatial Objects in Sketch Maps

Sahib Jan, Angela Schwering, Malumbo Chipofya and Talakisew Binor

Abstract With the advent of Volunteered Geographic Information (VGI) the amount and accessibility of the spatial information such as sketched information produced by layperson increased drastically. In many geo-spatial applications, sketch maps are considered an intuitive user interaction modality. In sketch maps, the spatial objects and their relationships enable users to communicate and reason about their actions in the physical environment. The information people draw in sketch maps are distorted, schematized, and incomplete. Thus, processing spatial information from sketch maps and making it available in information systems requires suitable representation and alignment approaches. As typically only qualitative relations are preserved in sketch maps, performing alignment and matching with geo-referenced maps on qualitative level has been suggested. In this study, we analyzed different qualitative representations and proposed a set of plausible representations to formalize the topology and orientation information of extended objects in sketch maps. Using the proposed representations, the qualitative relations among depicted objects are extracted in the form of Qualitative Constraint Networks (QCNs). Next, the obtained QCNs from the sketch maps are compared with QCN derived from the metric maps to determine the degree to which the information is identical. If the representations are suitable, the QCNs of both maps should be identical to a high degree. The consistency of obtaining QCNs allows the alignment and integration of spatial information from sketch maps into Geographic Information Systems (GISs).

S. Jan (✉) · A. Schwering · M. Chipofy · T. Binor
Institute for Geoinformatics, University of Muenster, Münster, Germany
e-mail: Sahib.jan@uni-muenster.de

A. Schwering
e-mail: schwering@uni-muenster.de

M. Chipofy
e-mail: mchipofya@uni-muenster.de

T. Binor
e-mail: talakisew@uni-muenster.de

J. Huerta et al. (eds.), *Connecting a Digital Europe Through Location and Place*,
Lecture Notes in Geoinformation and Cartography, DOI: 10.1007/978-3-319-03611-3_3,

Keywords Qualitative representations · Extended objects · Sketch maps · Qualitative constraints networks · Qualitative alignment

1 Introduction

Hand-drawn sketch maps have extensively been used to investigate how humans memorize spatial knowledge. Cognitive maps and cognitive collages (Tolman 1948; Tversky 1993) have been suggested as metaphors to describe mental organization of geographic information. They relate the concrete and detailed spatial information from the physical environment to abstract and conceptual information stored in our brain (Casakin et al. 2000). Sketch maps are used to externalize the individual's mental image of the environment. They contain objects which represent real world geographic features, relations between these objects, and oftentimes symbolic and textual annotations (Blaser 1998). These spatial objects and their relationships 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 many geo-spatial applications (Egenhofer 1996; Nedas and Egenhofer 2008; Wallgrün et al. 2010). Especially with the advent of Volunteered Geographic information (VGI) (Goodchild 2007), sketch maps may be the key to contribute spatial information in Geographical Information Systems (GIS) without taking into account the technical barriers imposed by traditional GIS as noted by Goodchild (2007).

The information represented in sketch maps reflects the user's spatial knowledge that is based on observations rather than on measurements. However, Humans' cognitive maps are typically distorted, schematized, incomplete, and generalized, thus the information in sketch maps is equally distorted, schematized, incomplete, and generalized (Tversky 1992, 2003; Huynh and Doherty 2007). Cognitive errors documented in Wang and Schwering (2009), Schwering and Wang (2011) are neither random nor solely due to human ignorance. In sketch maps, people present a few significant objects and their configuration in terms of qualitative relations (Wang and Schwering 2009; Schwering and Wang 2011). In many GIS applications (Egenhofer 1996; Nedas and Egenhofer 2008; Wallgrün et al. 2010), these relations are used to represent and reason about spatial configurations between depicted objects. However, processing spatial information from sketch maps and making it available in information systems requires computational approaches to represent, align, and integrate the sketched spatial information.

During the last two decades, a series of qualitative spatial calculi have been proposed in the area of Qualitative Spatial Reasoning (QSR) (Freksa 1993), focusing on different aspect of space such as representations for the topological relations (Randell et al. 1992; Cohn et al. 1997), orderings (Allen 1983; Schlieder 1995; Osmani 1999), directions (Frank 1996; Renz and Mitra 2004), relative position of points (Moratz et al. 2000, 2005; Renz and Mitra 2004) and others. These representations provide general and sound reasoning mechanisms based on spatial configurations in terms of qualitative relations. Wang et al. (2010, 2011) identify a set of qualitative aspects in sketch maps throughout a series of experiments. These qualitative aspects represent spatial configurations between depicted objects in terms of relations. In our previous study (Jan et al. 2013), we propose a set of coarsened representations to formalize the ordering aspect of spatial objects in sketch maps.

This study extends our previous work on qualitative representations of spatial objects in sketch maps. In this study, we propose qualitative representations to formalize spatial configurations between extended objects such as containment (topology) of landmarks in city-block, their orientations, and the topology of city-blocks themselves. We identify these representations being robust against schematizations, distortions, and other cognitive effects (Tversky 1992, 2003; Huynh and Doherty 2007) found in sketch maps. Using the proposed representations, we extracted qualitative information of extended objects in the form of Qualitative Constraint Networks (QCNs) (Wallgrün et al. 2010; Chipofya et al. 2013). Next, the obtained QCNs from the sketch and metric maps are tabularized to evaluate the proposed representations. The evaluation is done by testing the accuracy of qualitative relations between landmarks and city-blocks from sketch maps with the qualitative relations of corresponding spatial objects in metric maps—generated from OpenStreet Map. The tested sketch maps (28 in total) are from two different locations (area about 1.04 and 2.10 km^2) in Münster, Germany. All the sketch maps are generated by different participants and most of them were holding an academic degree at University of Muenster, Germany. Though none of the participants were residents of the predefined locations, all of them were familiar with the locations by frequent visits by foot or vehicle. During the experiment, participants were asked to produce sketch maps of predefined locations as detailed as possible but only from memory.

The results of the evaluation show that the proposed representations are suitable to formalize the qualitative information of extended objects. They provide high accuracy of identical relations between objects from sketch and metric maps. The highly identical qualitative relations will allow users to align and integrate spatial information from sketch maps into geographic information systems (GISs) as VGI (Goodchild 2007).

The remainder of this chapter is structured as follows: In the following section, we briefly introduce related work. In Sect. 3, we introduce extended objects found in sketch maps. Representations are proposed to formalize the qualitative information of extended objects in Sect. 4, which are evaluated with respect to accuracy of qualitative information in Sect. 5. Section 6 concludes the chapter with an outlook on future work.

2 Related Work

In qualitative representations, everyday descriptions of distinguishing the relative direction (left, right), distance (near, far), and topology (disjoint, overlap) are used to identify associations or correspondences between scenes. During the last two decades, several approaches attempt to capture spatial configurations between objects qualitatively. Egenhofer (1996, 1997) propose Spatial-Query-by-Sketch to query spatial databases using a sketch-based interface. It focuses on specifying spatial relations by drawing them. The approach uses five types of spatial relations such as coarse, detail topological relations, metric refinements, and coarse and detailed cardinal directions relations to capture spatial configurations between depicted objects.

Forbus et al. (2003) develop a sketch understanding system, nuSketch, which is a battle-space search system that focuses on qualitative topological reasoning. The system uses both qualitative topological relations and quantitative information to construct spatial configurations between depicted entities. Nedas and Egenhofer (2008) propose a similarity measure to compare two spatial scenes by identifying similarities between (i) objects in the two scenes, (ii) similarity between the binary relations among spatial objects such as buildings and lakes, and (iii) the ratio of the total number of objects to the number of objects that has been matched—or equivalently, not matched.

Similarly, there are several approaches on how graph-like structure can be represented qualitatively. For example, Wallgrün et al. (2010) propose an approach for qualitative matching of geo-/non-referenced datasets using qualitative relations between spatial objects. In Chipofya et al. (2013), we propose a simple model for matching qualitatively described spatial scenes extracted from sketch maps. The qualitative direction relations over points in the plane depend on the angles formed by the points, where angles that yield the same direction relation belong to a common direction sector bounded by different angles.

There are two types of qualitative representations that allows for defining sectors with different angles: the STAR calculi (Renz and Mitra 2004) for absolute directions and $\mathcal{OPRA}$ calculi (Moratz et al. 2005) for relative directions. In STAR calculus, the direction sectors are same for every point p in the plane, while the sectors in $\mathcal{OPRA}$ depend on the orientation of p. Lücke et al. (2011) propose a qualitative approach for navigating in the street-network. They use Oriented Point Relation Algebra ($\mathcal{OPRA}$) (Moratz et al. 2005) together with Klippel's turn directions (Klippel and Montello 2007) for navigating in the street-network. Renz and Wölfl (2010) use STAR calculi (Renz and Mitra 2004) for representing direction sectors in order to have a consistent sector arrangement for every intersection node in the route-network.

All the above cited approaches use the method of representing spatial configurations with some abstract qualitative relations. They share motivation with our work and use similar methods of representing spatial configurations in sketch maps. However, they did not consider the influences of human spatial cognition and the effects of cognitive distortions (Tversky 1992, 2003; Huynh and Doherty 2007) in the qualitative representation and alignment of spatial objects. Since spatial objects' outlines in freehand sketches are imprecise, the qualitative representation of spatial objects with imprecise boundaries leads to different qualitative relations when compare with relations in geo-referenced maps.

In this study, a set of plausible qualitative representations is proposed to formalize topology and orientation information of extended objects in sketch maps.

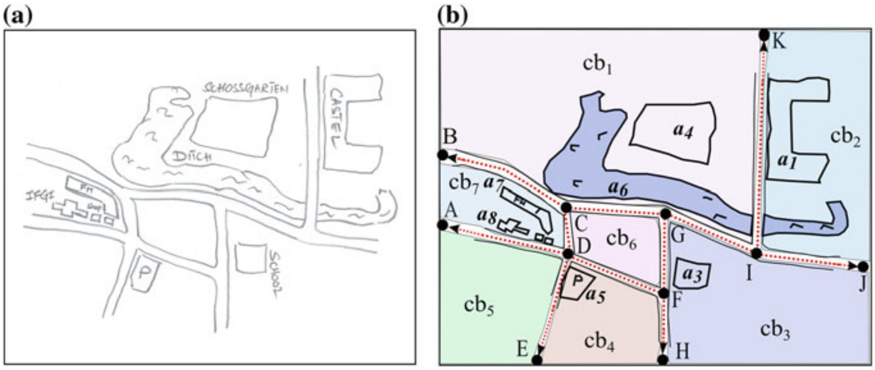

Fig. 1 **a** The unprocessed sketch map with depicted street segments and landmarks. **b** Street segments, landmarks, and city-blocks in the processed sketch map

3 Extended Objects in Sketch Maps

3.1 Landmarks

According to Blaser (2000), landmarks and road entities are the most frequently depicted spatial objects in the sketch map. In freehand sketches, landmarks are vectorized and approximated by polygons. They are represented as multiple intersecting or non-intersecting strokes. Sketcher considers main street segments that lead to frequently visited or important landmarks and few side street segments which contain landmarks along them (Huynh and Doherty 2007). In sketch maps, landmarks represent spatial entities such as water bodies, buildings, and parks (see Fig. 1a).

3.2 City-Blocks

City-blocks are important areal features for sketch map alignment. We define city-blocks as the smallest area, completely surrounded by street segments. In our representation, a city-block plays the role of a container for other spatial objects such as buildings, water bodies, and parks (see Fig. 1b). People do not always sketch complete city-blocks. They may sketch a network of the streets without any loop because they have omitted other street segments, in particular at the edge of sketch medium. Therefore, sketch maps do not contain many closed city-blocks. In order to maximize the number of city-blocks, we consider them as areas bounded not only by the street segments, but also by the medium-boundary. Therefore, all incomplete street segments with endpoints towards the medium-boundary are extended. This is done until either the medium-boundary or other street segments extension is encountered (see Fig. 1b).

4 Qualitative Representations of Extended Objects

4.1 Topology of Landmarks in City-Blocks

It is common to use lines or extended objects as basic entities in topological reasoning and points as basic entities in positional reasoning (Freksa 1993; Moratz et al. 2000, 2005). The topological constraints on landmarks and city-blocks together allow us to partially constrain the possible locations of the landmarks. For topological relations between extended objects, the region connected calculus RCC (Randell et al. 1992; Cohn et al. 1997) is perhaps the most well-known topological formalism. RCC supports the definition of two spatial relation algebras, i.e. the RCC5 and the RCC8. These two algebras make a small number of five and eight topological distinctions between regions.

For the topology of landmarks in the city-blocks, we analyze different qualitative representations that support extended objects as entity types such as region connected calculus RCC (Randell et al. 1992; Cohn et al. 1997) and string based topological representation (Li and Liu 2010). In sketch maps, city-blocks are non-overlapping regions, while landmarks may overlap several city-blocks (see Fig. 2a). Since spatial objects' outlines in freehand sketches are imprecise, the distinction between overlapping and disconnected boundaries becomes less important when landmarks are involved. Similarly, for the topology of landmarks with respect to city-blocks, the distinction between completely inside and sharing boundaries become less important. Therefore, we propose RCC5 to capture the topological relations between landmarks and city-blocks. RCC5 base relations consists of DR ("discrete"), PO ("partially-overlap"), PP ("proper-part"), PPi ("proper-part inverse"), and EQ ("equal"). The RCC5 provides topological relations at an abstract level, which overcomes the effects of schematization and distortion of landmark's boundaries in qualitative representation and alignment.

Figure 2a shows, the landmarks and detected city-blocks (delineated by street segments and page-boundary) in the sketch map. Using RCC5, the topology about landmarks with respect to city-blocks are represented as follows: landmarks a_1 is *proper-part* of the city-block (cb_2), landmark a_2 *partially overlaps* on city-blocks (cb_1 and cb_2), and landmarks a_4 is *proper-part* of the city-block (cb_1), while landmarks them self are disconnected from each other. Figure 2b shows the constraint network for topological relations between landmarks with respect to city-blocks in the sketch map.

4.2 Topology of City-Blocks

Triangulation of City-blocks. In freehand sketches, the city-blocks are mixed (concave and convex) regions surrounded by street segments and medium-boundary. The qualitative representation of these mix regions increases topological relations

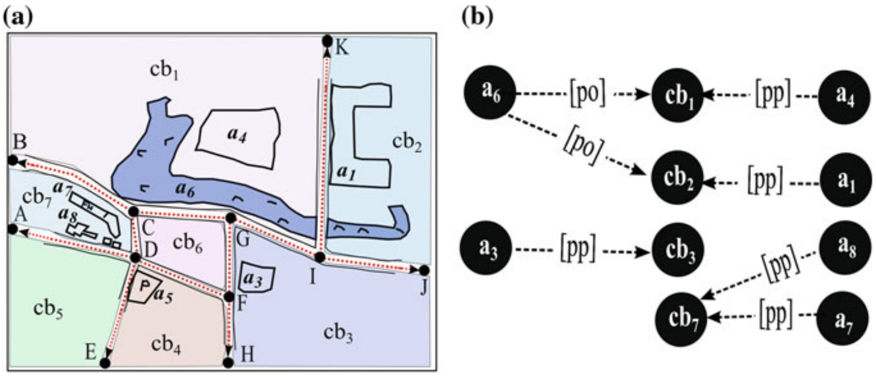

Fig. 2 **a** Landmarks and city-blocks in the sketch map. **b** QCN for the topological relations of landmarks with respect to city blocks using the RCC5 representation

significantly because there are many uncountable topologically different regions in the plane (containing infinite holes and connected components).

However, we need to restrict our representation of city-blocks to specific regions, such as simple regions (homomorphic to a closed disk), convex regions or rectangles. In many practical applications, arbitrarily shaped spatial objects are approximated by their convex hulls. Randell et al. (1992) represent the problem of representing qualitative relations of concave objects with the help of their convex hulls. Bennet et al. (1998) consider regions as the union of convex polygons. However, the qualitative representation using convex hulls of approximated city-blocks lead to different topological relations when compared with the relations of city-blocks in corresponding metric maps.

For the qualitative representation of city-blocks, we restrict ourselves to convex regions. Convexity plays a central role in computational geometry, geographical information science, and several other disciplines. For qualitative representation, concave city-blocks from sketch and metric maps are detected using an algorithm and decomposed them into a set of triangles (convex regions), known as a triangulation (Eberly 2002). In triangulation, concave polygon of n vertices is decomposed into $n-2$ triangles with the help of the ear-clipping algorithm (Eberly 2002). For example, we have concave city-blocks cb_1 and cb_3 in sketch map; the vertices of bounded street segments are used to decompose them into sets of triangles (see Fig. 3b).

Formally, the decomposition of concave city-blocks can be described as follows: A city-block A is a region surrounded by street segments and medium-boundary. It is divided into a set of triangles, called parts, such that the union of all parts constitutes A itself (Eq. 1), and all parts are mutually exclusive (Eq. 2).

$$\mathrm{A} = \bigcup_{\mathrm{i}=0}^{\mathrm{n}} \mathrm{A_i} \qquad \text{With } \mathrm{n} \geq 1 \tag{1}$$

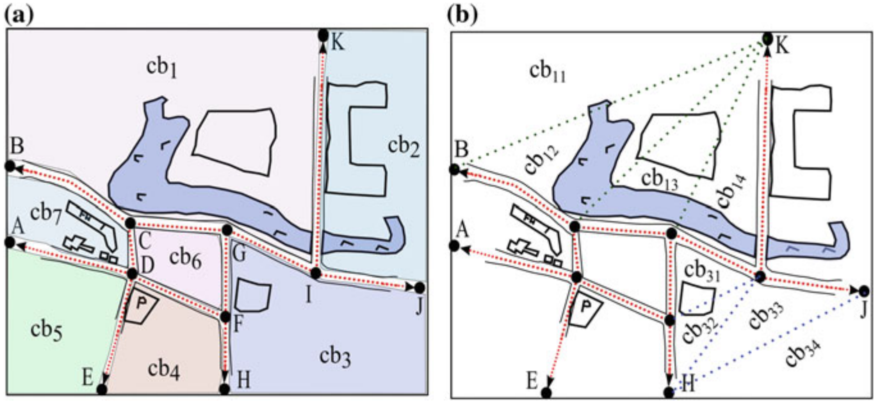

Fig. 3 **a** Concave city-blocks cb_1 and cb_3 bounded by street segments and page-boundary. **b** Decomposition of the city-blocks into sets of *triangles*

$$\forall A_i, j | i \neq j: A_i \cap A_j = \emptyset \tag{2}$$

Qualitative Representation. In order to formalize topological relations among city-blocks, we analyze region based qualitative representations (Randell et al. 1992; Li and Liu 2010). Since street information is incomplete in sketch maps, we find aggregated city-blocks covering larger areas quite often. Using RCC8 (Randell et al. 1992), we find the topological relations such as disconnected (DC), externally connected (EC) between city-blocks very often. In sketch maps, city-blocks are externally connected by street segments or connected diagonally at junctions. Using RCC8 (Randell et al. 1992), the relation EC represents the connectivity of the city-blocks without differentiating their connectivity by street segments or junctions. For example, the city-block cb_6 is EC with city-blocks cb_1, cb_7, cb_4, and cb_3 by street segments (see Fig. 3a). It provides the same EC relation for the connectivity between city-block cb_6 and cb_5 which are connected diagonally at junction D. The aggregation of street segments in the sketch map leads to different topological relations among city-blocks when compare with topological relations between corresponding city-blocks in metric map. Therefore, it is important to make the distinction between these two types of externally connected scenarios when city-blocks are involved.

We propose the qualitative representation known as a model for topological relations between convex regions (Li and Liu 2010). Using representation, the atomic topological relation between two convex regions can be uniquely represented as a circular string. It provides a complete classification for topological relations between regions. Using circular string, two configurations are topologically equivalent if they have the same string representation. If we have two non-equal convex region (a, b), the topological relations $\alpha_{a,\,b}$ between interiors (°) and boundaries (∂) of a and b is represented by a circular string over {u, v, x, y}. If a region $a \neq b$ and a is not contained in the interior of b, each maximally connected component (mcc)

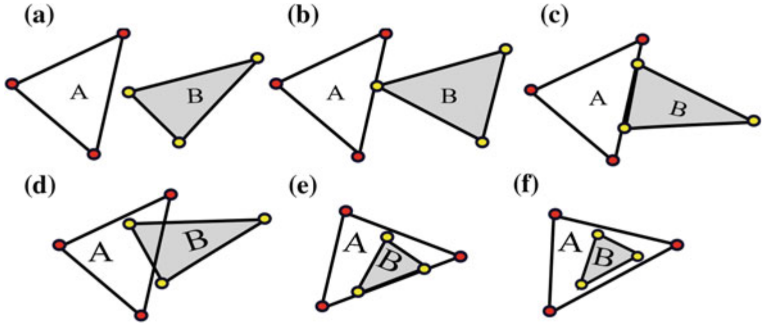

Fig. 4 Topological relations between convex regions using the *circular* strings {ε, u, v, x, and y}. **a** A (ε)B, **b** A(x)B, **c** A(y)B, **d** B(uxvx)A, **e** B(vy)A, **f** B(u)A

of $a^\circ \cap \partial b$ or $\partial a \cap b^\circ$ is homomorphic to the open interval (0,1) and each mcc of $\partial a \cap \partial b$ is single point or line (Li and Liu 2010). The circular string represents following possible intersections.

u represents mcc of $\left(a^\circ \cap \partial b\right)$
v represents mcc of $\left(\partial a \cap b^\circ\right)$
x represents 0—dimensional mcc of $(\partial a \cap \partial b)$
y represents 1—dimensional mcc of $(\partial a \cap \partial b)$

The circular strings {(ε), (**u**), (**v**), (**x**), (**y**)} represent the atomic topological relations DC, NTPP, NTPP^{-i}, and two refine sub-relations for the EC of RCC (Randell et al. 1992). The refine sub-relations for EC distinguish the topological relations between regions which are externally connected by lines or points. Similarly, the combinations of strings represent PO, TPP, and TPP^{-i} of RCC (Randell et al. 1992). Figure 4 shows, the possible topological relations between two regions using circular strings.

As shown in Fig. 3b, we have two concave city-blocks cb_1 and cb_3 in the sketch map. The decomposition of these concave city-blocks provide sets of triangles $cb_1 = \{cb_{11}, cb_{12}, \ldots, cb_{14}\}$ and $cb_3 = \{cb_{31}, cb_{32}, \ldots, cb_{34}\}$, which are basically convex sub-regions of the given concave city-blocks. If A_i and B_i represents a set of triangles in the city-block cb_1 and cb_3, then the topological relations between city-blocks can be inferred using the possible topological relations between triangles.

If the boundary of at least one triangle in A_i intersects with the boundary of B_i and the intersection of the interiors of A_i and B_i is empty, then the boundary–boundary intersection between two city-blocks is non-empty (Eq. 3). Similarly, if the boundaries and interiors of all triangles in A_i and B_i have empty intersections, then the intersection between city-blocks is also empty (Eq. 4).

$$\partial \bigcup_{i=0}^{n} A_i \cap \partial \bigcup_{i=0}^{n} B_i = \neg\emptyset \wedge \bigcup_{i=0}^{n} A_i^{\circ} \cap \bigcup_{i=0}^{n} B_i^{\circ} = \emptyset \rightarrow \mathrm{A} \cap \mathrm{B} = \neg\emptyset \tag{3}$$

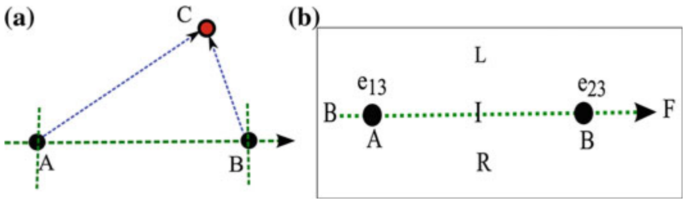

Fig. 5 **a** The orientation information of C with respect to oriented line going through A and B. **b** The basic relations of $\mathcal{LR}$ where A $\neq$ B

$$\partial \bigcup_{i=0}^{n} A_i \cap \partial \bigcup_{i=0}^{n} B_i = \emptyset \wedge \bigcup_{i=0}^{n} A_i^{\circ} \cap \bigcup_{i=0}^{n} B_i^{\circ} = \emptyset \rightarrow \mathrm{A} \cap \mathrm{B} = \emptyset \tag{4}$$

Using constraints among interiors and boundaries of triangles, we formalize the set of possible topological relations between aggregated city-blocks in the sketch maps and relations between city-blocks in the metric maps. These relations can be used to infer new knowledge and can be combined for more than two parts such that $\mathbf{R_i} \otimes \mathbf{R_j} \otimes \mathbf{R_k}$ derive the relation between two pairs of adjacent regions (Tryfona and Egenhofer 1997).

4.3 Orientation of Landmarks

A person's ability to establish his or her location in an environment is termed spatial orientation (Correa de Jesus 1994). From the cognitive point of view, the spatial orientation is considered as the capability to form a cognitive map (Golledge et al. 1996). Human beings always distinguish between spatial objects ahead of them or behind their back, spatial objects on their right and on their left-side, when they proceed along the path (Scivos and Nebel 2004).

To formalize the orientation information about adjacent landmarks with respect to street segments, different qualitative representations for relative orientations are investigated such as $\mathcal{LR}$ calculus (Scivos and Nebel 2004), Single Cross Calculus (SCC) (Freksa 1992), and Double Cross Calculus (DCC) (Freksa 1992). We exclude the DCC as it is not closed under composition and permutation and there exists no finite refinement of the base relations with such a closure property (Scivos and Nebel 2001). We propose $\mathcal{LR}$ calculus (Scivos and Nebel 2004), an enhanced and refined version of the FlipFlop Calculus (Ligozat 1993). The $\mathcal{LR}$ calculus deals with point type entities in the plane R^2. It describes the position of a point C with respect to two other points A (the origin) and B (the relatum) as illustrated in Fig. 5a.

For configurations with A $\neq$ B, the following base relations are distinguished using $\mathcal{LR}$ calculus: C can be to the *left* or to the *right* of the oriented line going through A and B, or C can be placed on the line resulting in one of the five relations *inside, front, back, start* or *end* (see Fig. 5b). The $\mathcal{LR}$ calculus (Scivos and Nebel

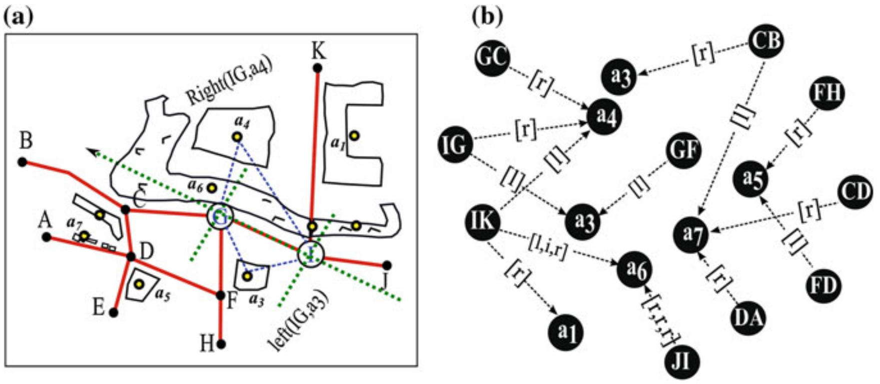

Fig. 6 **a** Orientation of landmark a_4 and a_3 in the sketch map using the $\mathcal{LR}$ calculus, **b** QCN for relative orientation of the adjacent landmarks with respect to street segments

2004) introduces relations *dou* (A $=$ B $\neq$ C) and *tri* (A $=$ B $=$ C) as additional relations. Overall, the $\mathcal{LR}$ calculus provides nine relations. The orientation relation of an object using $\mathcal{LR}$ is represented as A, B (reILR) C.

For positional reasoning, it is common to use points as basic entities (Freksa 1993; Moratz et al. 2000). To fulfill the requirements of proposed representation, landmarks are approximated by the centroids of their minimum bounding boxes. The landmarks which are stretched over multiple city-blocks, the centroids of their sub-regions in each city-block are considered. For example, landmark a_6 is a water body that stretched over city-block cb_1 and cb_2 (see Fig. 6a). We have three approximated points, one point for each sub-region and a point on the street segment that intersects the landmark. The start-and end-junctions of street segments are used as origin and relatum points and the orientation information about adjacent landmarks is extracted. The $\mathcal{LR}$ calculus provides the orientation information of landmarks at an abstract level, which overcomes the effects of schematizations and distortions of reference street segments in the relative orientation of adjacent landmarks.

For example in Fig. 6a, we have street segments with their start- and end-junctions such as JI, IK, and IG. The orientation information about adjacent landmarks with respect to oriented street segments is represented as $r(I, G : a_4)$, where relation r represents the orientation of the landmark a_4 with respect to a street segment IG. Similarly, the orientation information about landmarks a_6 (water body stretched over multiple city-blocks) is represented as $l, i, r(I, K : a_6)$. The qualitative relation left (l), inside (i), and right (r) represents the relative orientation of a_6 with respect to reference street segment IK. Figure 6b shows the orientation of landmarks with respect to street segments in the form of QCN.

5 Evaluation

In this section, the proposed representations are evaluated by aligning aforementioned 28 sketch maps with corresponding metric maps. The sketch maps are generated by different participants at University of Münster, Germany. Spatial aggregation is ubiquitous in the sketch maps world. Particularly, street segments and city-blocks are highly aggregated spatial features (see Fig. 7a). After our participants have completed drawing the sketch maps, we asked them to describe and indicate the spatial objects on the metric maps. We also asked participants to indicate the corresponding street segment for every sketched street segment, thus we got information on how streets were aggregated. As city-blocks are delineated by street segments, these street segments are used as reference objects to identify corresponding city-blocks in metric maps on an aggregated level.

In order to evaluate the proposed representations, the topology and orientation information of extended objects is extracted. The qualitative information is derived from the geometric representations of sketch and metric maps manually. Since, the proposed representations for the topological relations are binary and the representation for the orientation of landmarks is ternary, we extracted both binary and ternary qualitative relations in the form of QCNs.[1]

Next, the obtained QCNs from the sketch maps are compared with QCNs derived from the metric maps to determine the degree to which information is identical. If the representations are suitable, the QCNs of sketch maps and metric maps should be identical to a high degree. In order to align depicted landmarks and city-blocks, we identify the possible pairing of nodes from one QCN with those in the other QCN. The hypothesis of matching city-blocks and landmarks are generated based on a visual analysis, where we consider all depicted landmarks and city-blocks from sketch maps and identify their corresponding spatial objects in metric maps.

5.1 Topology of Landmarks in City-Blocks

As proposed above, the qualitative representation RCC5 is used to formalize the topological relations between landmarks and city-blocks. The QCN derived from sketch maps are tabularized and compare with the corresponding QCN derived from metric maps. From a visual analysis of the tabularized QCNs, we find that the qualitative constraints using the RCC5 have an average accuracy rate of 99.87 % (see Table 1). While using the RCC8, we have an accuracy rate of 99.02 % for both locations. In sketch maps, most of the landmarks are depicted correctly with respect to city-blocks. However, we fine some mismatched topological relations using the RCC8, because

---

[1] Complete QCN comparison files and images are available at http://ifgibox.de/s_jan001/QualitativeRepresentation_ExtendedObjects/.

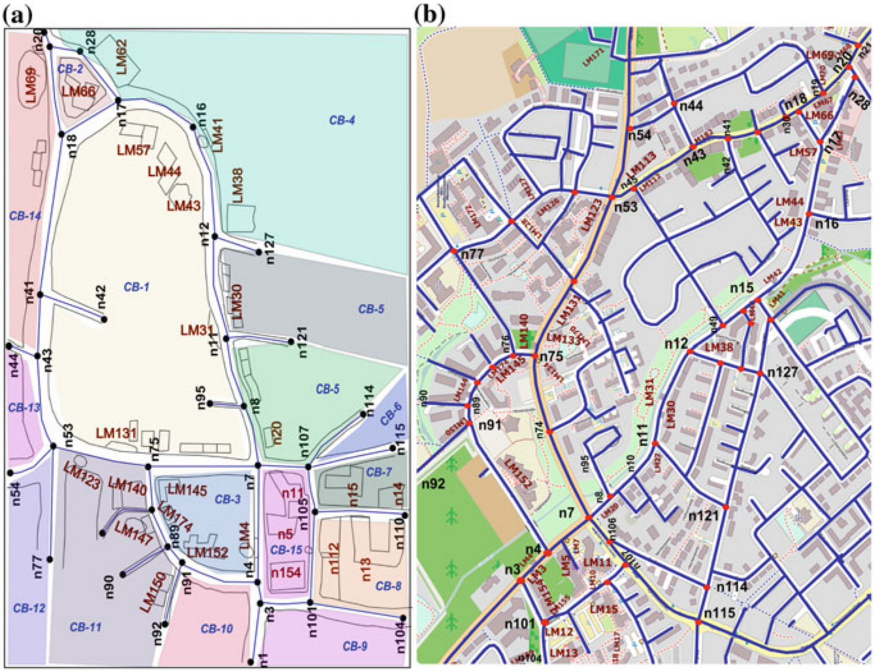

Fig. 7 **a** Landmarks and city-blocks in the sketch map. **b** Corresponding spatial objects in the metric map of the location-II

Table 1 Accuracy of topological relations between landmarks and the relations of landmarks with respect to city-blocks in the sketch and metric maps using the RCC5 representation

Sketch maps (28)	Total # of QCNs	Mismatched QCNs	Accuracy (%)
Location-I	3543	2	99.96
Location-II	22275	24	99.78
Average			99.87

topological relations such as EC, DC, TPP, and TPP^{-I} in RCC8 require precise boundary information of landmarks, which is not possible in freehand sketches.

Table 2 shows the inconsistent topological relations between landmarks and city-blocks from sketch and metric maps using the RCC8. For example, the landmark LM66 is disconnected with LM67 in the sketch map (SM_7), while the same landmarks are externally connected with each other in the metric map. Similarly, the landmark LM42 is *tangential proper-part* with respect to city-block (C10) in the sketch map. The same landmark is *non-tangential proper-part* with respect to corresponding city-block in the metric map.

The high accuracy of topological relations indicates that the proposed representation overcomes the effects of schematizations and distortions of landmark's boundaries in qualitative representation and alignment.

Table 2 The comparison table showing topological relations between the landmarks (LMs) and city-blocks (Cs) from the sketch map (SM$_7$) and metric map (MM). Using RCC8, we find six mismatched topological relations between the landmarks and city-blocks

MM		C61	C23	C24-C35	C48-C52	LM66	LM67	LM70	LM69	LM84
	SM$_7$	C9	C2	C10	C12	LM66	LM67	LM70	LM69	LM84
LM42		**dc**	**dc**	***NTPP***	**dc**	**dc**	**dc**	**dc**	**dc**	**dc**
	LM42	dc	dc	*TPP*	dc	dc	dc	dc	dc	dc
LM66		**NTPP**	**dc**	**dc**	**dc**	**eq**	***ec***	**dc**	**dc**	**dc**
	LM66	NTPP	dc	dc	dc	eq	*dc*	dc	dc	dc
LM67		**NTPP**	**dc**	**dc**	**dc**	***ec***	**eq**	**dc**	**dc**	**dc**
	LM67	NTPP	dc	dc	dc	*dc*	eq	dc	dc	dc
LM70		**dc**	**dc**	**dc**	**dc**	**dc**	**dc**	**eq**	***dc***	**dc**
	LM70	dc	dc	dc	NTPP	dc	dc	eq	*ec*	dc
LM69		**dc**	**dc**	**dc**	**NTPP**	**dc**	**dc**	***dc***	**eq**	**dc**
	LM69	dc	dc	dc	NTPP	dc	dc	*ec*	eq	dc
LM85		**dc**	**dc**	**dc**	**NTPP**	**dc**	**dc**	**dc**	**dc**	***ec***
	LM85	dc	dc	dc	NTPP	dc	dc	dc	dc	*dc*

Table 3 The accuracy rate of topological relations between city-blocks using the string based topological representation

Sketch maps (28)	Total # of QCNs	Mismatched QCNs	Accuracy (%)
Location-I	1210	40	96.94
Location-II	3631	42	98.65
Average			97.79

5.2 Topology of City-Blocks

To formalize the topology of the city-blocks, we use string based representational model (Li and Liu 2010). For both locations, the string based topological relations between city-blocks are extracted in the form of QCNs and compare with QCNs derived from the metric maps. We find the string based topological relations between city-blocks have an average accuracy rate of 97.79 % for both locations (see Table 3). While using the RCC8, we have an accuracy rate of 98.75 %. Since the EC relation of the RCC8 loses the important distinction of external connectivity, the proposed string based representation seems a promising way to formalize topological relations between city-blocks.

5.3 Orientation of Landmarks

We use $\mathcal{LR}$ calculus (Scivos and Nebel 2004) to formalize the orientation information about the adjacent landmarks. The street segments are used as reference objects to localize nearby landmarks. Nearness is defined via the distance in a Voronoi

Table 4 The accuracy of orientation information about landmarks with respect to street segments in the sketch maps using the $\mathcal{LR}$ calculus

Sketch maps	Total # of QCNs	Mismatched QCNs	Accuracy (%)
Location-I	272	2	99.43
Location-II	719	13	98.27
Average			98.85

diagram (Aurenhammer 1991). A landmark is considered adjacent, if its footprint is in the Voronoi diagram of the reference object. For both locations, the orientation information about landmarks is extracted from the sketch and metric maps. The orientation information about landmarks using $\mathcal{LR}$ calculus has an average accuracy rate of 98.85 % (see Table 4).

We compare these results to QCNs obtained from the Single Cross Calculus (SCC) (Freksa 1993). Using the SCC, the average accuracy rate drops to 93.67 %. Therefore, the $\mathcal{LR}$ representation is suitable to formalize the orientation information of landmarks in sketch maps.

6 Conclusion and Future Work

Sketch maps represent the physical environment in a highly schematized and therefore distorted way. To formalize the topology and orientation information of extended objects, we analyze the existing qualitative representations in the area of Qualitative Spatial Reasoning (QSR). We propose a set of qualitative representations that are robust against cognitive distortions. The proposed representations are evaluated by comparing the QCN matrices derived from the sketch maps and corresponding metric maps. Overall evaluation shows that the representations are suitable to extract high degree of identical information, and thus are reliable for the alignment of spatial objects from sketch maps with geo-referenced maps. This way, the additional sketched information such as information on the usage of the buildings, bakeries, and completely un-mapped information about landmarks and areas can be transferred to the geographic information system as volunteered information.

In the present study, we handle the aggregation and detection of city-blocks manually. So, the future work comprises, in part, the automatic detection of the city-blocks and the methods for handling aggregations. In evaluation, we use the sketch maps of an urban spatial structure. In the future, we will investigate the relevance of the proposed representations for the alignment of sketch maps from the rural areas. We evaluated proposed representations by comparing QCNs manually. The problem of QCN matching is ongoing research work. Evaluation of the representations using the matching model is a part of our future work.

Acknowledgments Research for this chapter is based upon work supported by the Deutsche Forschungsgemeinschaft (DFG) under grant for the SketchMapia project (584820).

References

Allen JF (1983) Maintaining knowledge about temporal intervals. Commun ACM 26:832–843

Aurenhammer F (1991) Voronoi diagrams: a survey of a fundamental geometric data structure ACM computing surveys. ACM Comput Surv 23:345–405

Bennett B, Isli A, Cohn AG (1998) A system handling RCC-8 queries on 2D regions representable in the closure algebra of half-planes. In: Proceedings of the 11th international conference on industrial and engineering applications of artificial intelligence and expert systems IEA-98-AIE Benicàssim, Castellón, Spain, 1–4 June 1998

Blaser A (1998) Geo-spatial sketches. Technical report. Department of Spatial Information Science and Engineering and National Center for Geographic Information and Analysis, University of Maine, Maine, USA

Blaser A (2000) A study of people's sketching habits in GIS. Spat Cogn Comput 2:393–419. doi:10.1023/A:1015555919781

Casakin H, Barkowsky T, Alexander K, Christian F (2000) Schematic maps as wayfinding aids. In: Freksa C et al (eds) Spatial cognition II. Lecture notes in computer science, vol 1849. Springer, Berlin, pp 54–71

Chipofya M, Schwering A, Binor T (2013) Matching qualitative spatial scene descriptions 'a la Tabu. In: Proceedings of the 12th Mexican international conference on artificial intelligence, MICAI 2013, Mexico City, Mexico, 24–30 Nov 2013

Cohn A, Bennett B, Gooday J, Gotts N (1997) Qualitative spatial representation and reasoning with the region connection calculus. GeoInformatica 316:275–316

Correa de Jesus S (1994) Environmental communication: design planning for wayfinding. Des Issues 10:32–51

Eberly D (2002) Triangulation by ear clipping. Magic Software, Inc 2002

Egenhofer MJ (1996) Spatial-query-by-sketch. In: Burnett M, Citrin W (eds) IEEE symposium on visual languages, vol 96. IEEE, Boulder, Colorado, pp 60–67

Egenhofer MJ (1997) Query processing in spatial-query-by-sketch. J Vis Lang Comput 8:403–424

Forbus K, Usher J, Chapman V (2003) Qualitative spatial reasoning about sketch maps. In: Proceedings of the fifteenth annual conference on innovative applications of artificial intelligence, Acapulco, Mexico, 12–14 Aug 2003

Frank AU (1996) Qualitative spatial reasoning: cardinal directions as an example. Int J Geogr Inf Syst 10:269–290. doi:10.1080/02693799608902079

Freksa C (1993) Dimensions of qualitative spatial reasoning. In: Carreté NP, Singh MG (eds) Proceeding III MACS-international workshop on qualitative reasoning and decision technologies—QUARDET'93, Barcelona, 1993

Freksa C (1992) Using orientation information for qualitative spatial reasoning. In: Frank AU, Campari I, Formentini U (eds) Theories and methods of spatio-temporal reasoning in geographic space. Lecture notes in computer science, vol. 639. Springer, Berlin, pp 162–178

Golledge R, Klatzky R, Loomis M (1996) Cognitive mapping and wayfinding by adults without vision. In Portugali J (ed) The construction of cognitive maps. GeoJournal Library, vol. 32. Springer, Netherlands, pp 215–246

Goodchild MF (2007) Citizens as sensors: the world of volunteered geography. GeoJournal 49:211–221

Huynh NT, Doherty ST (2007) Digital sketch-map drawing as an instrument to collect data about spatial cognition. Cartographica Int J Geogr Inf Geovisualization 42:285–296. doi:10.3138/carto.42.4.285

Jan S, Schwering A, Wang J, Chipofya M (2013) Ordering: a reliable qualitative information for the alignment of sketch and metric maps. In: Proceedings of the IEEE 12th international conference on cognitive informatics and cognitive computing (ICCI*CC13), New York, USA, 2013

Klippel A, Montello DR (2007) Linguistic and nonlinguistic turn direction concepts. In: Winter S, Kuipers B, Duckham M, Kulik L (eds) Spatial information theory. Lecture notes in computer science, vol. 4736. Springer, Berlin, pp 354–372

Li S, Liu W (2010) Topological relations between convex regions. In: Proceedings of the 24th AAAI conference on artificial intelligence (AAAI-10), Atlanta, Georgia, USA, 11–15 July 2010

Ligozat G (1993) Qualitative triangulation for spatial reasoning. In: Frank AU, Campari I (eds) Spatial information theory a theoretical basis for GIS, European conference, COSIT'93. Lecture notes in computer science, vol 716, Marciana Marina, Elba Island, Italy. Springer, Berlin

Lücke D, Mossakowski T, Moratz R (2011) Streets to the OPRA—finding your destination with imprecise knowledge. In: Renz J, Cohn AG, Wölfi S (eds) IJCAI workshop on benchmarks and applications of spatial reasoning, vol 27. Barcelona, Spain, pp 25–32

Moratz R, Dylla F, Frommberger L (2005) A relative orientation algebra with adjustable granularity. In: Proceedings of the workshop on agents in real-time and dynamic environments (IJCAI05), Edinburgh, Scohtland, 2005

Moratz R, Renz J, Wolter D (2000) Qualitative spatial reasoning about line segments. In: Horn W (ed) Proceedings of the 14th European conference on artificial intelligence (ECAI'00), Berlin

Nedas KA, Egenhofer MJ (2008) Spatial-scene similarity queries. Trans GIS 12:661–681

Osmani A (1999) Introduction to reasoning about cyclic intervals. In: Imam I, Kodratoff Y, El-Dessouki A, Ali M (eds) Multiple approaches to intelligent systems. Lecture notes in computer science, vol. 1611. Springer, Berlin, pp 698–706

Randell DA, Cui Z, Cohn AG (1992) A spatial logic based on regions and connection. In: Proceedings of the 3rd international conference on knowledge representation and reasoning. Morgan Kaufmann, San Mateo, 1992

Renz J, Mitra D (2004) Qualitative direction calculi with arbitrary granularity. In: Zhang C, Guesgen HW, Yeap WK (eds) PRICAI-04. Lecture notes in computer science, vol 3157. Springer, Berlin, pp 65–74

Renz J, Wölfl S (2010) A qualitative representation of route networks. Frontiers in artificial intelligence and applications (ECAI), vol 215. IOS Press, Amsterdam, pp 1091–1092. doi:10.3233/978-1-60750-606-5-1091

Schlieder C (1995) Reasoning about ordering. In: Frank AU, Kuhn W (eds) Spatial information theory: a theoretical basis for GIS, international conference COSIT '95, semmering, Austria, 21–23 Sept 1995

Schwering A, Wang J (2011) SketchMapia: a framework for qualitative mapping of sketch maps and metric maps. In: Las Navas 20th anniversary meeting on cognitive and linguistic aspects of geographic spaces. Las Navas del Marques, Avila, Spain, 4–8 July 2010

Scivos A, Nebel B (2004) The finest of its class: the natural, point-based ternary calculus LR for qualitative spatial reasoning. In: Freksa C et al (2005) Spatial cognition IV. Reasoning, action, interaction: international conference spatial cognition. Lecture notes in computer science, vol 3343. Springer, Berlin, pp 283–303

Scivos A, Nebel B (2001) Double-crossing: decidability and computational complexity of a qualitative calculus for navigation. In: Montello DR (ed) Spatial information theory, COSIT 2001. Lecture notes in computer science, vol 2205. Springer, Berlin, pp 431–446

Tolman EC (1948) Cognitive maps in rats and men. Psychol Rev 55:189–208

Tryfona N, Egenhofer M (1997) Consistency among parts and aggregates: a computational model. Trans GIS 1:189–206

Tversky B (1993) Cognitive maps, cognitive collages, and spatial mental models. In: Frank AU, Campari I (eds) Spatial information theory: a theoretical basis for GIS, proceedings COSIT '93. Lecture notes in computer science, vol 716. Springer, Berlin, pp 14–24

Tversky B (1992) Distortions in cognitive maps. Geoforum 23:131–138. doi:10.1016/0016-7185(92)90011-R

Tversky B (2003) Structures of mental spaces: how people think about space. Environ Behav 35: 66–80

Wallgrün OJ, Wolter D, Richter K-F (2010) Qualitative matching of spatial information. In: 18th SIGSPATIAL international conference on advances in geographic information systems, ACM, USA, 2–5 Nov 2010

Wang J, Muelligann C, Schwering A (2011) An empirical study on relevant aspects for sketch map alignment. In: Proceedings of the 14th AGILE international conference on geographic information science (AGILE 2011), Utrecht, Netherlands, 2011

Wang J, Mülligann C, Schwering A (2010) A study on empirically relevant aspects for qualitative alignment of sketch maps. In: Proceedings of the sixth international conference on geographic information science (GIScience). Zurich, Switzerland, 2010

Wang J, Schwering A (2009) The accuracy of sketched spatial relations: how cognitive errors affect sketch representation. Presenting spatial information: granularity, relevance, and integration. workshop at COSIT 2009, AberWrac'h, France, 21–25 Sept 2009