# Direction-based Qualitative Locations

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## 1. Introduction

Qualitative spatial representation and reasoning are fundamental to many research fields, such as geographical information science, artificial intelligence (Cohn 1997, Skiadopoulos and Koubarakis 2004, Liu et al 2010), image analysis, spatial database, cognition science, etc. It aims at developing formal mechanisms to represent and infer commonsense knowledge about space using finite qualitative concepts. Qualitative locations specify the space by relating spatial objects to a frame of reference with qualitative relations, in which both the frame of reference and qualitative relations are familiar with people. Qualitative locations have three components: spatial objects which need to be located, a frame of reference in which objects are described, and the relations between objects and the frame. Traditionally, spatial locations are related to the Cartesian or spherical frames of reference. In the two coordination systems, spatial objects are composed of coordinates which are fine enough to describe most objects. However, human beings tend to locate objects by relating them to a frame of reference based on qualitative relations.

Topological relations have been considered as the basis of most qualitative spatial calculus as they are cognitive adequate, and thus dominate other relations as important components of qualitative locations. Recently, Klippel et al (in press) found that the Egenhofer-Cohn hypothesis, topology matters and metric (e.g. size, direction, etc.) refines, does not always hold, and in some cases other relations may be more important than topology. Mark (1999) also pointed out that topology are efficient for describing relations about non-disjoint objects, while for disjoint objects, direction and distance relations would be more useful.

For a long time, topological relations are used to describe the locations of spatial objects with respect to a frame of reference (Bittner and Stell 1998 & 2002), while there is a lack of direction-based qualitative locations. This study aims to developing a unitary representation of and reasoning about direction-based qualitative locations of spatial objects with respect to a frame consisting of disconnected points, lines, and polygons.

## 2. Direction-based Qualitative Locations

For different types of geometric objects, different models are used to represent direction relations. Direction-based spatial reasoning methods (Goyal 2000, Skiadopoulos and Koubarakis 2004, Liu et al. 2010) are designed only for polygons, but not for the hybrid of points, lines and polygons. This study will extend the cell-based representation of direction relations to handle the situation where a set of disconnected points, lines and polygons is regarded as a frame of reference and any hybrid of the three types of objects can be located.

Generally, one object $b$ can often be related to a set of reference object $A$ by direction relations. Let $A = \{a_i\}_{i=1}^{n}$ $(\forall a_i \subseteq U)$ be a set of disconnected objects (e.g. points, lines and polygons). Set $A$ is considered as a frame of reference. Each object in $A$ can divide $mbr(U)$ into cells according to the corresponding partitions methods varying with geometric type. For each object $a_i$ in $A$, its direction partitions are subdivided further by the MBRs of other objects. Therefore, if more objects are involved, the cell partition will be refined. For $n$ objects, the partition $CP(A)$ could be composed of cells (open sets) $\{c_{ij}\}_{i,j=0}^{nx,ny}$, horizontal segments $\{IY_{ij}\}_{i,j=0}^{nx,ny+1}$, vertical segments $\{IX_{ij}\}_{i,j=0}^{nx+1,ny}$ and corners $\{P_{ij}\}_{i,j=0}^{nx+1,ny+1}$, where $nx \leq 2n+1$ and $ny \leq 2n+1$ hold.

**Definition 1.** Let $U$ be a connected space, $A = \{a_i\}_{i=1}^{n}$ $(\forall a_i \subseteq U)$ be a frame of reference, and $b$ $(b \subseteq U)$ be a target object. Then the location of object $b$ with respect to frame $A$ is defined to be $loc_A(b) = \{\langle c_{ij}, \gamma(b, c_{ij})\rangle : \gamma(b, c_{ij}) \neq no\} \cup \{\langle IX_{ij}, \gamma(b, IX_{ij})\rangle : \gamma(b, IX_{ij}) \neq no\} \cup \{\langle IY_{ij}, \gamma(b, IY_{ij})\rangle : \gamma(b, IY_{ij}) \neq no\} \cup \{\langle P_{ij}, \gamma(b, P_{ij})\rangle : \gamma(b, P_{ij}) \neq no\}$, where $\gamma(\ \ )$ refers to the qualitative relations between object $b$ and elements in $CP(A)$.

Figure 1 shows a cell partition of a set of points, lines and polygons and the locations of objects with respect to a frame of reference. The reference set is composed of five reference objects, i. e., $A = \{a_1, a_2, a_3, a_4, a_5\}$. Objects $b_1, b_2, b_3, b_4$ are target objects, which do not take part in the cell partition. Both the reference and target objects can be located in the cell partition $CP(A)$. $loc_A(b_1) = \{\langle c_{46}, po\rangle, \langle c_{47}, po\rangle, \langle c_{57}, po\rangle, \langle IX_{47}, po\rangle, \langle IY_{57}, po\rangle\}$, $loc_A(b_2) = \{\langle c_{43}, po\rangle, \langle c_{44}, poo\rangle, \langle c_{45}, po\rangle, \langle IX_{44}, poo\rangle, \langle IX_{45}, poo\rangle\}$, $loc_A(b_3) = \{\langle c_{63}, in\rangle\}$, $loc_A(a_4) = \{\langle IX_{42}, fo\rangle, \langle P_{42}, nof\rangle, \langle P_{52}, nof\rangle\}$, $loc_A(a_6) = \{\langle P_{61}, fo\rangle\}$. In the examples, $po$, $in$, $poo$, $nof$, and $fo$ are qualitative relations.

It is clear that direction-based location can locate any type of target objects in a frame. Not only the target objects, but reference objects can be located in the cell partitions. Accordingly, the cell-based location is a unitary representation because it can accommodate points, lines and polygons as both target and reference objects.

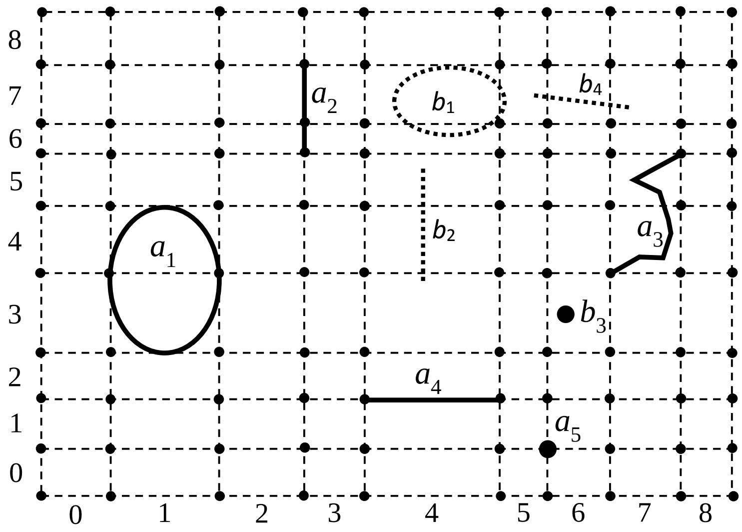


Figure 1. Cell partitions and qualitative locations

## 3. Location-based Spatial Reasoning

Existing qualitative spatial reasoning methods mainly focus on relation-based reasoning. That is, given two known relations, the third new relations can be derived. On the other hand, most direction-based spatial reasoning methods (Skiadopoulos and Koubarakis 2004, Liu et al. 2010) only are designed to handle polygons or points. Moreover, different models are use to describe and infer direction relations for different types of spatial objects. The unitary representation can handle the direction relations between any types of objects. The direction-based locations further locate objects in the frame by qualitative relations. Similarly, if two qualitative locations of two objects with respect to the same frame are given, topological relations between two objects can be derived directly. The rules will be presented to derive topological relations from two locations.

Location-based topological reasoning can obtain topological relations between objects from their locations. Since reference objects in $A$ are disconnected, the topological relations between them need not to be derived. Furthermore, both target and reference objects can be one of the three types of geometry, thus six kinds of relations can be derived, such as point-point, point-line, point-polygon, line-line, line-polygon, and polygon-polygon.

There are three types of direction relations, such as that between target objects, between reference objects, and between target and reference objects. For each type of direction relations, six kinds of relations can be derived, such as point-point, point-line, point-polygon, line-line, line-polygon, and polygon-polygon. Since cell partition $CP(A)$ is generated in terms of the direction partitions of reference objects, the direction relations concerned with reference objects can be exactly computed from the locations, while the relations between target objects can only be derived approximately. The rules and infer algorithm would be the core to derive the relations between target objects.

## 4. Conclusions

This study presents unitary representation of and reasoning about direction-based qualitative locations for points, lines and polygons. The presented model can locate any type of spatial objects in a frame of reference composed of points, lines, and polygons, and thus can derive topological relations and direction relations of any pairs of objects from the locations in a unitary method.

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