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A model for uncertain lines

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Abstract

The paper introduces a geometric model for uncertain lines that is capable of describing all the sources of uncertainty in spatial objects of linear type. We define uncertain lines as lines that incorporate uncertainties description both in the boundary and interior. These objects can model all the uncertainty by which spatial data are commonly affected and allow computations in presence of uncertainty without rough simplifications of the reality. The proposed model is an extension of the model for regions with a broad boundary and can be easily integrated into existing data models for spatial databases. We use the model as a basis for the study of topological relations between uncertain lines.

1. Introduction

The use of spatially related data has grown in many disciplines and therefore the definition of spatial ontologies [1–4] has become a main research issue in various research communities. Ontologies allow a better understanding of spatial data and are of prime importance for data modeling, GIS interoperability, geographical information sharing through the web, etc. Among all ontologies that describe different application domains, a particular emphasis has to be given to core spatial ontologies, i.e., concepts inherent to any spatial phenomena due to their geometric nature. Indeed, most of these core spatial ontologies are common to different

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applications and may be reusable for all spatially related domains. In this paper, we propose a spatial ontology for uncertain lines. An ontology of imperfection of spatial data has been proposed in [5], mainly with reference to spatial objects of the region type. The case of lines has received by far less attention in the literature.

The treatment of uncertainty in spatial data is a problem that has been studied from a theoretical point of view (notably, [6]). The various models have never been developed in enough depth to become operational and, till now, the management of uncertainty in current spatial database systems is not supported. Also the recent OpenGIS specification for SQL [7] is based on a geometric model that does not support uncertainty. An adequate modeling of geometric uncertainty in spatial data is essential for the assessment of data quality, and, consequently, for helping any process related to data set acquisition and integration [5,8–9].

The main goal of our approach is to record the information about uncertainty together with the data in order to be able to deal with it at each step of the data life cycle. In essence, a new geometric model is needed that overcomes the limits of the current models of spatial databases, which traditionally are a collection of lines (points, polylines and polygons). Many models are about the introduction of broad boundaries replacing crisp ones in the case of regions [10–14]. The geometric model takes into account a 3-valued indeterminacy of location {false, maybe, true}, where "false" means that the point is not in the location, "true" means that the point is in the location and "maybe" means either that the point is with some probability in the location or that the point belongs up to a certain membership value to the location. Therefore, the model does not make any further hypothesis on the internal structure of the broad boundary. There are other approaches that utilize fuzzy sets [15] or probability theory [16], which describe the internal structure of the uncertain geometry with membership functions or probability distributions, respectively. These other approaches require much effort to store data and also the operations become computationally expensive. The advantage of our approach is that it can be implemented on existing database systems at reasonable cost: the new model can be seen as an extension of existing geometric models. Based on the geometric models, then spatial operators applying to the new category of objects are needed. To this regard, topological relations between regions with a broad boundary have been defined in [11,17].

In this paper, we introduce a geometric model for uncertain lines that is capable of describing all the sources of uncertainty in spatial objects of line type. An advantage of our model is that the different semantics of the uncertainty of spatial objects do not influence the representation and management of the spatial objects themselves. Also, as a special case, we introduce a model for uncertain points. The paper is organized as follows. In Section 2, we propose various semantic interpretations of spatial objects with uncertainty of line and point type. In Section 3, we introduce the geometric model for objects with a broad boundary. Section 4, starting from the two most widely used models for topological relations, the 9-intersection [18] and the Calculus-Based Method (CBM) [19], proposes specific models for topological relations between uncertain lines and points. Section 5 discusses the integration of