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Handling location uncertainty in probabilistic location-dependent queries

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Summary. Location-based services have motivated intensive research in the field of mobile computing, and particularly on location-dependent queries. Existing approaches usually assume that the location data are expressed at a fine geographic precision (physical coordinates such as GPS). However, many positioning mechanisms are subject to an inherent imprecision (e.g., the cell-id mechanism used in cellular networks can only determine the cell where a certain moving object is located). Moreover, even a GPS location can be subject to an error or be obfuscated for privacy reasons. Thus, moving objects can be considered to be associated not to an exact location, but to an uncertainty area where they can be located.

In this paper, we analyze the problem introduced by the imprecision of the location data available in the data sources by modeling them using uncertainty areas. To do so, we propose to use a higher-level representation of locations which includes uncertainty, formalizing the concept of uncertainty location granule. Intuitively, an uncertainty granule is a place or an area where an object can be located, together with a probability density function to know the likelihood that the object was in any point of this area. This extension allows us to consider probabilistic location-dependent queries, among which we will focus on probabilistic inside (*range*) constraints. In this context, we detected a lack of an in-depth formal study of this type of queries, along with an efficient processing approach, where uncertainty is also considered for the queried position (as it can be the position of moving object) and which does not assume the availability of indexes of moving objects. The adopted model allows us to develop a systematic and efficient approach for processing this kind of queries.

The main contributions of this paper are as follows:

- We formally analyze a type of query, that we call probabilistic inside query from the point of view of our extended location model. Our results are general enough to be applied to other models in the literature.
- We provide a method to solve these queries efficiently when the underlying probability density function is the uniform distribution over a disk. Note that, in fact, the uniform distribution is the case where the least information we have about the position of the objects, and it has been used in many previous works.
- We perform an extensive experimental evaluation where the efficiency of the described method for the uniform distribution can be appreciated. We show the feasibility of our approach even for mobile devices.