Creating data representations for moving objects with extent from images

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Spatial entities or phenomena are often captured as time-ordered sequences of observations in the form of satellite or aerial images. Thus, to capture the spatio-temporal behavior of such entities, which may change location, orientation, shape, and extent continuously across time, and usually are referred to as moving objects, it is necessary to develop methods to model their spatial transformations between the observations. The aim is to obtain continuous representations that are as close as possible to the actual shapes and movements of the objects at all times.

Current solutions implemented in database management systems represent the spatial transformation of a moving object between observations using interpolation [1–3]. Each observation is represented by a 2D polygon, and the spatial transformations are modeled using analytical formulas representing the movement of the polygons' vertices or edges. These works have mainly focused on the definition and development of data models and query languages for moving object databases and the creation of movement data representations from observations has been covered only in few works.

The first attempt [4] to create movement data representations from observations introduces the so-called 'rotating-plane' algorithm to interpolate between consecutive snapshots of convex and non-convex polygons, yielding movement data representations that are compatible with the Secondo' spatio-temporal data model [1, 5]. Later, it was shown [6] that those algorithms can, in certain cases, yield invalid geometries during the transformation of the polygons. Thus, modified algorithms were proposed to rectify the shortcomings. These solutions assume that the polygons are represented in vector format and that the the rotation of the objects between observations is small. They are mainly focused on creating valid movement data representations at all times, and few considerations are made on qualitative features, such as the objects' deformation during the transformations. Experiments were limited to synthetic data sets. A subsequent study [7] presents a method to model the spatial extent and orientation of moving regions using only minimum enclosing boxes. Here, experiments were conducted with real-world data.

This talk aims to present and discuss a solution to the acquisition, transformation, and loading of moving object data, extracted from a sequence of aerial or satellite images, into spatio-temporal databases. The focus is on two main problems: (1) the matching problem, aiming at automatically determining the correspondences between the vertices of two polygons extracted from source images and (2) the vertex path problem, to represent the spatial transformation of the polygons across time. It will also present the results of a suite of experiments performed to evaluate and compare the quality of the continuous movement data representations using real-world data sets.

The case study concerns the representation of icebergs in spatio-temporal databases. This is of interest, because it requires the modeling of different kinds of spatial transformations, namely the translation, rotation, deformation, and splitting of icebergs. The source data are satellite images, obtained from three sources [8–10], that track icebergs with movement that was predominantly translation, rotation, or a mix of both. The time interval between observations was variable, making it possible also to study the influence of the frequency of the observations on the quality of the resulting continuous movement data representations.

The segmentation of the icebergs in the images was implemented using the *Java ImageJ API*. The resulting polygons were simplified using the *Douglas-Peucker* algorithm [11] to reduce the number of vertices and irregularities created during segmentation. Some polygons were improved using a tool developed for adding, moving, or deleting vertices manually. The goal was to create a reference data set to be used in the evaluation and comparison of automatic procedures for the acquisition moving object data.

The first challenge addressed in this work was the application of morphing techniques to establish a mapping between the vertices defining the shapes of two polygons. We have used the Perceptually-based Approach [12] that relies on the identification of a subset of the vertices, called feature points, that best represent the shapes of the polygons, and on the computation of algebraic measures describing each feature point. These measures are invariant under translation and rotation, which are important properties when dealing with moving objects. The mapping of feature points is given by a similarity function relying on the algebraic measures. The correspondences between the other vertices (non-features points) are obtained by interpolation of the indexes of the vertices. Experiments show that the application of this method to create the moving object data representations can often be improved by asking the users to enter the first pair of corresponding feature points manually. To decrease the need for user interaction, we implemented a preprocessing step to perform the alignment of the polygons. That information is used to define the correspondence between the first pair of vertices automatically.

The second challenge is the definition of the paths of the vertices to represent the spatial transformation of the objects between observations. Current spatio-temporal data models [1–3] use a single function to represent the transformation of a moving object. The translation and rotation of the objects are implicitly modeled by the movement of the vertices defining the shape of the polygons. We introduce an alternative approach to model the translation, rotation, and deformation of the objects separately, rather than using a single function. The basic principle is to perform a translation and a rotation of one of the polygons to find the best possible alignment with the other polygon and then perform an interpolation between them. The translation and rotation of the polygons are represented explicitly in the model, making it possible to use special-purpose methods to represent them. For example, it is possible to take into account information about previous observations or considering external factors such as maritime currents or wind velocity. The initial alignment also minimizes the distance between the vertices of the two polygons, which can decrease the deformation of the polygons during the spatial transformation. This approach was implemented using methods based on Cartesian and polar coordinates.

The evaluation and comparison of continuous movement data representations is also an open issue. Due to the lack of moving object data sets in adequate formats for representation in databases, the spatio-temporal data models and query languages proposed in the literature have not been sufficiently evaluated. Indeed, many evaluations were theoretical and were not validated using real case studies.

We have implemented an experimental framework to evaluate and compare the methods proposed in this work and in previous work. This framework considers several qualitative features, and we propose also a method to compute a similarity measure to compare the moving objects' shapes estimated using the movement data representations and the actual shape of the moving objects. Some experiments were oriented towards the evaluation of the continuous movement data representations as a whole, while others were focused on the evaluation of specific features, e.g., translation, rotation, or deformation, independently.

The results obtained for icebergs where the movement was predominantly translational were similar for all data representation models studied in this work. The quality of the movement data representations depends on the elapsed time between observations (this feature depends only on the data sources, and it is not related to the issues covered in this work) and on the mapping between the vertices of the polygons created during the vertex correspondences step. The representation of moving objects that rotate can be improved by modeling the translation, rotation, and deformation of the objects independently.

The experiments also show that it is possible to develop a semi-automatic procedure to create continuous movement data representations from a sequence of images that represent well the spatio-temporal behavior of real-world objects.

Acknowledgements

This work was partially funded by FEDER through the Operational Program Competitiveness Factors - COMPETE and by FCT - Foundation for Science and Technology in the context of the project FCOMP-01-0124-FEDER-022682 (FCT reference PEst-C/EEI/UI0127/2011).

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