Representation of movement and contextual data: the need for integration

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Recent data acquisition tools such as global positioning system (GPS) and mobile phones have resulted in huge amounts of data with spatial and temporal components. They can be collected by tracking various moving objects such as humans, animals, cars, iceberg, and hurricanes. Understanding the behaviour of these moving objects is very important in various domains such as meteorology, sociology, transportation planning, urban planning, and land use. These moving objects are not isolated: they move in a certain context that influences and often explains their behaviours. To study the behaviour of moving objects we need to consider the relationship among moving objects and the context in which they move (Andrienko, Andrienko, & Heurich, 2011). Therefore, there is need to integrate movement data and contextual data that may be discrete or continuous. This integration increases the complexity of movement analysis and requires combining object and field representations. Humans and hurricanes are two domains of the moving objects where the context intensely influences the movement behaviour. Hurricane propagation is affected by sea surface temperature, humidity, vertical wind shear, global temperature, and sea level pressure. Human movement is also affected by context elements such as activity, infrastructure, socio-demographic characteristics, and climate.

Besides the integration with contextual data, human and hurricane movement analysis share number of challenges regarding movement representation, dataset size, and granularities. Although the real trajectories of movement are continuous, most existing applications abstract them to a finite set of ordered observations `X,Y,T,Object ID` at regular or irregular temporal intervals. These ordered observations are not sufficient to query and analyse the moving object behaviour especially due to the vast amount of collected movement and contextual data. In addition, movement and contextual data are often collected at different granularities. For example, human movement can be recorded on minute intervals with meters distances, whereas temperature data might be recorded on daily rates with 1km pixels size. The interaction between these multiple granularities will be critical to the analysis of movement behaviour.

Study of movement behaviour requires the ability to answer complex queries such as spatiotemporal behaviour queries and spatiotemporal relationship queries. Spatiotemporal behaviour queries retrieve information about how the behaviour of single phenomenon change in space and time (Yuan & McIntosh, 2002). These queries provide summarizes of spatial and temporal characteristics and patterns. For example: ‘Has the frequency of intense hurricanes increased in the past few years over the Atlantic?’ Spatiotemporal relationship queries extend the behaviour queries by involving the interaction among phenomena (Yuan & McIntosh, 2002). For example: ‘How has the proportion of intense hurricanes varied and changed with changing sea surface temperature?’

To be able to allow efficient query and analysis of the movement and the contextual data, an efficient spatiotemporal representation is needed. This computer representation should allow integrating both movement and contextual data, and overcome the aforementioned challenges. Time is still problematic despite the efforts over the past two decades to add it into GIS. Many spatiotemporal data models have been proposed in literature to incorporate time into GIS. For example, snapshot model, space-time composite model (STC), three-domain model, event-based spatiotemporal data model (ESTDM), objected-oriented spatiotemporal model, history graph model, hybrid spatiotemporal data model and structure (HST-DMS), ROD arrays model, and extended dynamic GIS (EDGIS) model. Nevertheless, the existing models exhibit weaknesses in various aspects.

The first goal of this paper is to review aforementioned spatiotemporal data models for finding the most promising model(s) that is able to represent objects and fields along with their changes through time. The strengths and weaknesses of these models are depicted. This review classifies them into four categories: location-based models, time-based models, object-based models, and combined models. Despite the relative merits of these models, no existing data model can fulfil all needs of spatiotemporal data. A critical weakness of existing spatiotemporal data models is that each of them deals with few common characteristics found in specific applications such as the land use. Therefore, the model applicability to different situations fails on spatiotemporal behaviours not expected by the application used for the initial model development. Most of these models cannot integrate both object and field data or represent moving objects. Some of these models suffer from data redundancy and low performance on large spatiotemporal datasets. This review results in two data models that are able to integrate the object and field representations; namely, ROD arrays (McDowall, 2006) and EDGIS (Pultar, Cova, Yuan, & Goodchild, 2010) data models.

The second goal of this paper is to critically evaluate ROD arrays and EDGIS data models using two use cases; namely human and hurricane movement. In this evaluation, we look at the most important issues such as model aptness for large datasets, model ability to integrate object and field representations, model ability to represent multiple granularities, model ability to represent the movement, and model performance with regard to different type of spatiotemporal queries. This evaluation results in both models cannot overcome human and hurricane challenges. The ROD arrays data model represents the space as regular cells with histories to store the sea surface temperature and hurricanes names. EDGIS organize the hurricane case as three tables: theme, feature, and space-time points. The space-time point table stores the spatial and temporal components of hurricane movement and sea surface temperature. The characteristics of these data models lead to low performance on large datasets. In addition, both models allow representation of multiple granularities of hurricane movement and sea surface temperature but with large data redundancy. Both models exhibit limited efficiency of different spatiotemporal queries. ROD arrays and EDGIS data models are efficient at location based and object based queries respectively. On the other hand, their data organizations are not sufficient for others types of queries. Both of them are inefficient at complex spatiotemporal queries such as spatiotemporal behaviour and spatiotemporal relationship queries.

Finally, a prototype has been implemented to study the performance of both models along with a set of spatiotemporal query functions. This prototype has been used to represent hurricane movement and sea surface temperature datasets. Improving different aspects of both models is needed in order to represent human and hurricane movements in an efficient manner. This will encompass integration of object and field data with multiple granularities and minimizing data redundancy. In addition, improving query performance in large datasets will be required due to the large amounts of data in the selected domains. In addition, to represent human and hurricane movement we will need to support some moving objects aspects. For example, presenting the uncertainty of spatial data and performing accessibility analysis (space-time prisms) as well as the ability to implement temporal topology and support different visualization techniques such as space-time cube. These improvements will result in an integrated spatiotemporal model able to get over the challenges of the selected domains.

Keywords:

Spatiotemporal representation, dynamic GIS, change, moving objects, contextual data, object-field data integration.

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