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Linking movement and environmental data: The need for representation

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ABSTRACT

In several domains, there has been an increasing interest in analysing moving objects due to the recent ubiquity of location tracking devices. These locations are commonly abstracted and stored as trajectories: a finite set of ordered in time geometries. Tracked objects tend to move in a certain environment that influences their movement behaviour. Time dependent environmental data are commonly abstracted and stored in grid/array structures that have different granularities and characteristics compare to the trajectory datasets. Movement analysis requires linking these two data types. However, little consideration has been given to the issues of integration in the moving objects databases that is primarily dealing with trajectory storage and analysis as well as in array databases dealing mainly with the storage and retrieval of grid structures. In this paper, we propose a database model that utilizes abstract data types for combining trajectories and time dependent environmental data. We introduce a set of spatio-temporal operations for interacting with raster data and integrating them with the moving geometries. We demonstrate how the integration operations can be used for manipulation and analysis of moving objects, using trajectories of tropical cyclone and environmental data, using sea surface temperature (SST) for the period from 1980 to 2009 as a case study. Since tropical cyclones generally gain strength over the warmer seas, the proposed operations are used to answer questions about genesis and movement patterns of tropical cyclones, in relation to the changing patterns of the SST.

1. Introduction

Recent data acquisition tools – such as remote sensing, sensor technologies, global positioning system (GPS) and mobile phones – have resulted in huge amounts of data that have spatial and temporal components. These tools track various moving objects such as people, animals, and cars. The moving object may have a spatial extent undergoing a change in its geometry during movement. Most applications abstract such objects to points by neglecting the spatial extent and even though the change of object's locations is continuous, most applications abstract the trajectories to a finite set of ordered observations. Each of these consists of an object location (in one, two, or three spatial dimensions), a time stamp, and a set of attributes.

The objects tend to move in an environment that influences their movement behaviour (Buchin et al., 2014) that changes over time too. For example, tropical cyclones generally gain strength over the warmer seas and movement of cyclones is affected by these changing patterns of Sea Surface Temperature (SST). Similarly, movement of birds and animals is influenced by meteorological conditions, such as temperature, wind, and rain. Such environmental phenomena are different from the trajectories in how they are observed and stored, as depicted on Fig. 1. Time dependent environmental data are commonly abstracted as raster/grid and stored in multi-dimensional array structures that have different granularities and characteristics compare to the trajectory datasets. Movement analysis requires the integration of these two data structures: trajectories data, with multidimensional arrays. Such integration provides opportunities to answer the "*Why*" beside well-known spatio-temporal questions (Turdukulov et al., 2010).

In some cases, movement analysis needs to consider the environmental data at different temporal and spatial scales. For example, to study the relations between the tropical cyclones trajectories and the SST, the experts need to consider the SST patterns over longer periods of time and over the larger areas such as the

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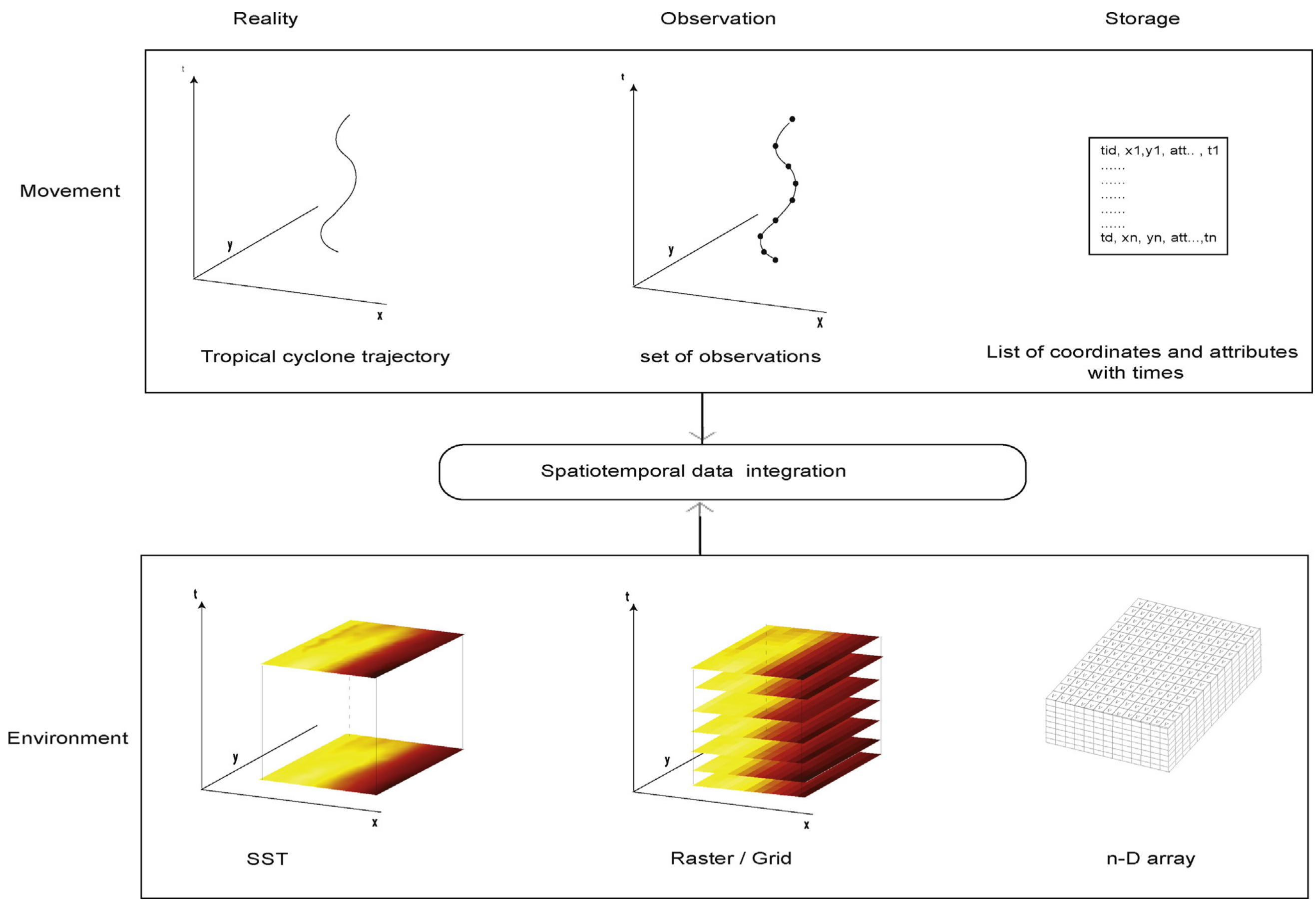

Fig. 1. Moving object data integration with the environmental data.

local basin or even at the global scale. In addition, environmental data are often collected at daily or even hourly intervals. This requires processing data at multiple granularities and computing various spatio-temporal lags. For example, analysing relations between tropical cyclones movement and changing patterns of the SST needs aggregation of environmental data to the predefined time intervals, such the monthly, yearly, or (maybe) decadal averages for SST as well as aggregation to several ad-hoc time intervals such as before, during, or after tropical cyclones passage.

Trajectory and remote sensing data have experienced unprecedented growth in the last decades, increasing in both size and complexity. To efficiently retain and provide uniform access to these datasets, users commonly opt to store them in a database management system (DBMS). Trajectories are commonly stored in a relational DB and deviation of those specifically for moving objects are called moving objects databases (MOD). MOD are databases supporting time dependent and continuously changing geometries (Güting et al., 2010). MOD provides a comprehensive framework using a set of data types and operations to handle the continuous object movement. This database technology allows the user to model, store, retrieve, and query the objects changing over time (Schneider, 2009). Two main abstractions are used to represent the trajectories: moving point and moving region. The moving point and moving region are defined as functions of time represented as curve and polyhedral shapes in continuous 3-D (2-D + time) space respectively.

On the other side, array DBMS are used to store time dependent environmental data in multi-dimensional arrays (Misev et al., 2012). Such databases defined the multidimensional array by a spatial domain specified by the lower and upper bound of each dimension to describe the data dimensionality and a base type to describe the data content. They incorporate time as one of the array dimensions forming essentially a multi-dimensional array with discrete and often arbitrary set of time stamps corresponding to the actual observations. For example, the domain of STT dataset is a set of finite points in 3-D (latitude, longitude, and time) and its base data type is DOUBLE.

However, little consideration has been given to the issues of integration in the moving objects databases community that is primarily dealing with trajectory storage and analysis as well as in array databases community dealing mainly with the storage and retrieval of grid structures. A database model that supports this integration framework and efficient querying of both data types is needed for movement analysis. In this paper, we present such database model, consisting of data types and operations on them, for combining trajectories and time dependent environmental data.

We introduce *TRaster* data type to represent the time dependent environmental data and to integrate it with the moving data types. We also introduce a set of spatio-temporal operations for interacting with raster data changing over time and linking them with the moving geometries. This model provides the user with a standard query language (SQL) that allows robust set of queries as high-level functions. We demonstrate how the integration operations can be used for manipulation and analysis of moving objects, using trajectories of tropical cyclone and environmental data, using sea surface temperature (SST) for the period from 1980 to 2009 as a case study. Since tropical cyclones generally gain strength over the warmer seas, the proposed operations are used to answer questions about genesis and movement patterns of tropical cyclones, in relation to the changing patterns of the SST. Since our primary aim is to illustrate how to use the proposed data types and functions to