Chapter XVIII
Spatio–Temporal Object Modeling

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ABSTRACT

Integrating spatial and temporal dimensions is a fundamental yet challenging issue in modeling geo-spatial data. This article presents the design of a generic model within the object-oriented paradigm to represent spatially-varying, temporally-varying, and spatio-temporally-varying information using a mechanism, called parametric polymorphism. This mechanism allows a conventional data type (e.g., string and integer) to be enhanced into a spatial, temporal, and/or spatiotemporal collection type, and so an ordinary attribute can be extended with spatial and/or temporal dimensions flexibly. An associated object query language has also been provided to support the manipulation of spatio-temporal information. The design of the model as well as the query language has given rise to a uniform representation of spatial and temporal dimensions, thereby offering a new option for the development of a spatio-temporal GIS to facilitate urban/environmental change tracking and analysis.

OVERVIEW

Spatio-temporal databases are a subject of increasing interest and the research community is dedicating considerable effort in this direction. Natural as well as man-made entities can be referenced with respect to both space and time. The integration of the spatial and temporal components to create a seamless **spatio-temporal data model** is a key issue that can improve spatio-temporal data management and analysis immensely (Langran, 1992).

Numerous spatio-temporal models have been developed. Notable among these are the snapshot

model (time-stamping layers, Armstrong 1988), the space-time composite (time-stamping attributes, Langran and Chrisman 1988), the spatio-temporal object model (ST-objects, Worboys 1994), the event-based spatio-temporal data model (ESTDM, Peuquet and Duan 1995) and the three-domain model (Yuan 1999). The snapshot model incorporates temporal information with spatial data by timestamping layers that are considered as tables or relations. The space-time composite incorporates temporal information by timestamping attributes, and usually only one aspatial attribute is chosen in this process. In contrast to the snapshot and the space-time composite models, Worboys's (1994) **spatio-temporal object model** includes persistent object identifiers by stacking changed spatiotemporal objects on top of existing ones. Yuan (1999) argues that temporal Geographic Information Systems (GIS) lack a means to handle spatio-temporal identity through semantic links between spatial and temporal information. Consequently, three views of the spatio-temporal information, namely spatial, temporal, and semantic, are provided and linked to each other. Peuquet and Duan's ESTDM (1995) employs the *event* as the basic notion of change in raster geometric maps. Changes are recorded using an event list in the form of sets of changed raster grid cells. In fact, event-oriented perspectives that capture the dynamic aspects of spatial domains are shown to be as relevant for data modeling as object-oriented perspectives (Worboys and Hornsby 2004; Worboys, 2005).

Despite these significant efforts in spatio-temporal data modeling, challenges still exist:

a. Object attributes (e.g., lane closure on a road) can change spatially, temporally, or both spatially and temporally, and so facilities should be provided to model all of these cases, i.e., spatial changes, temporal changes, and spatio-temporal changes;

b. Object attributes may change asynchronously at the same, or different, locations.

As an additional modeling challenge, object attributes can be of different types (e.g., speed limit is of the *integer* type and pavement material is of the *string* type). To overcome these challenges, a spatio-temporal object model that exploits a special mechanism, ***parametric polymorphism***, seems to provide an ideal solution (Huang, 2003).

PARAMETRIC POLYMORPHISM FOR SPATIO-TEMPORAL EXTENSIONS

Parametric polymorphism has been extensively studied in programming languages (PL), especially in functional PLs (e.g. Metalanguage, ML). In general, using parametric polymorphism, it is possible to create classes that operate on data without having to specify the data's type. In other words, a generic type can be formulated by lifting any existing type. A simple ***parametric class*** (type) can be expressed as follows:

```
class CP<parameter>{
    parameter a;
    …
};
```

where parameter is a type variable. The type variable can be of any built-in type, which may be used in the CP-declaration..

The notion of parametric polymorphism is not totally new, as it has been introduced in **object-oriented databases** (OODBs) (Bertino *et al.*, 1998). This form of polymorphism allows a function to work uniformly on a range of types that exhibit some common structure (Cardelli and Wegner, 1985). Consequently, in addition to the basic spatial and temporal types shown in Figure 1, three parametric classes, *Spatial<T>*, *Temporal<T>***,** and *ST<T>* are defined in Huang and Yao (2003). Here, *T* is defined as a spatial type that contains the distribution of all sections of *T*

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