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Chapter XVIII

Extending UML for Space- and Time-Dependent Applications

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INTRODUCTION

In recent years, the need for a temporal dimension in traditional spatial information systems and for high-level models useful for the conceptual design of the resulting spatiotemporal systems has become clear. Although having in common a need to manage *spatial data* and their *changes over time*, various spatiotemporal applications may manage different types of spatiotemporal data and may be based on very different models of space, time, and change. For example, the term *spatiotemporal data* is used to refer both to *temporal changes in spatial extents*, such as redrawing the boundaries of a voting precinct or land deed, and to *changes in the value of thematic* (i.e., alphanumeric) *data across time or space*, such as variation in soil acidity measurements depending on the measurement location and date. A spatiotemporal application may be concerned with either or both types of data. This, in turn, is likely to influence the underlying model of space employed, e.g., the two types of spatiotemporal data generally correspond to an object- versus a field-based spatial model. For either type of spatiotemporal data, change may occur in discrete steps, e.g., changes in land deed boundaries, or in a continuous process, e.g., changes in the position of a moving object such as a car. Another type of spatiotemporal data is *composite data whose components vary depending on time or location*. An example is the minimum combination of equipment and wards required in a certain category of hospital (e.g., general, maternity, psychiatric), where the relevant regulations determining the applicable base standards vary by locality and time period.

A conceptual data-modeling language for such applications should provide a clear, simple, and consistent notation to capture alternative semantics for time, space, and change processes. These include point- and interval-based time semantics; object- and field-based spatial models; and instantaneous, discrete, and continuous views of change processes. Multiple dimensions for time (e.g., valid, transaction) and space should also be supported.

Although there has been considerable work in conceptual data models for time and space separately, interest in providing an integrated spatiotemporal model is much more recent. Spatiotemporal data models are surveyed by Abraham and Roddick (1999), including lower-level logical models (Claramunt, 1995; Langran, 1993; Pequet & Duan, 1995). Those models that deal with the integration of spatial, temporal, and thematic data at the conceptual level are the most relevant to this work and are reviewed here.

Several conceptual frameworks have been designed to integrate spatial, temporal, and thematic data based on Object-Oriented (OO) or Entity-Relationship (ER) data models that include a high-level query language capable of specifying spatiotemporal entity types. The data definition component of these query languages thus has some potential for use in modeling spatiotemporal applications.

Becker, Voigtmann, and Hinrichs (1996) and Faria, Medeiros, and Nascimento (1998) propose OO models based on extensions of ObjectStore and O2 respectively. Becker et al. consider both object- and field-based spatial models, defining a hierarchy of elementary spatial classes with both geometric and parameterized thematic attributes. Temporal properties are incorporated by adding instant and interval timestamp keywords to the query language. In Faria et al. spatial and temporal properties are added to an object class definition by associating it with pre-defined temporal and spatial object classes. This solution is not suitable for representing temporal or spatial variation at the attribute level, as the timestamp and spatial locations are defined only at the object component level. In addition, both Becker et al. and Faria et al. offer text-based query languages; the non-graphical query languages of these models reduce their suitability as conceptual modeling languages.

In a clear indication that the need for a spatiotemporal graphical modeling language has been well recognized, there have been several concurrent efforts to develop such a language recently reported in the literature. The MADS model (Parent, Spaccapietra, and Zimanyi, 1999) extends an object-based model with pre-defined hierarchies of spatial and temporal abstract data types and special complex data types to describe all of an attribute's properties, i.e., name, cardinality, domain, and temporal or spatial dimensions. The use of a non-standard, hybrid ER/OO model and the definition of new composite data structures to incorporate spatiotemporal properties, rather than exploiting existing features of the ER or OO models, increase the complexity of this model. The SpatioTemporal ER model (Tryfona & Jensen, 1999) adds temporal and spatial icons to entities, attributes, and relationships in the ER model to support timestamped spatial objects and fields (i.e., spatiotemporal variation in thematic attributes). Composite data whose components vary over space and relationships associated with their own spatial extents are not considered: instead, spatial relationships are used to represent explicit geometric or topological relationships between associated spatial objects, which could otherwise be derived on demand. Therefore, temporal relationships describe model structure (i.e., timestamps), whereas spatial relationships describe model integrity (i.e., constraints). Peceptory (Brodeur, Bedard, & Proulx, 2000) is a spatiotemporal model and CASE tool aligned with both geographic and object-oriented standards, based on adding spatial and temporal stereotypes to objects in UML. The focus is on spatial objects; spatial

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