Conceptual Design of Spatio-Temporal Applications: Requirements and Solutions

(Extended Abstract)

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1. Introduction

This work focuses on the conceptual modeling of spatio-temporal databases. While for classical applications -exemplified by the "suppliers-supply-parts" paradigm- the available set of models and tools for conceptual database design is complete and mature, this is not the case for spatio-temporal applications. These are characterized by a wide set of peculiarities stemming from the complex nature of spatial information and the intricate integrity constraints imposed by the temporal dimension. For these applications, the already existing constructs and modeling techniques are far from complete and efficient.

Our research is based on the analysis of the combined (unified) spatial and temporal requirements. We propose to augment the available semantic tools and models with the minimal set of mechanisms necessary for spatio-temporal handling, while maintaining the particular philosophy of each model. The contribution is twofold:

- the definition of the set of constructs necessary to represent spatio-temporal information at the conceptual level. And we argue that, by augmenting any semantic model with these constructs, results into a powerful tool for the full and non-redundant representation of geographic information over time. Here, we present an extension of the Entity-Relationship (ER) Model -the Spatio-Temporal ER- as a prototype; the designer can use any his/hers favorite model or tool enriched by the presented spatio-temporal mechanisms, and

- the ability to handle over time (a) field-based (such as the grid model) suitable for the representation of properties like "temperature" or "vegetation" and (b) entity- (or object-) based information which view spatial information in terms of identifiable ontologies.

We continue (Section 2) with a brief presentation of the spatio-temporal needs at the semantic level of design. Then (Section 3), by giving a small representative example, we show the way to handle them with the use of Spatio-Temporal Entity Relationship Model. We conclude (Section 4) with a discussion on the future research plans towards this direction.

2. Spatio-Temporal needs at the conceptual level of application design

The phase of conceptual database modeling refers to that level of abstraction which: (a) employs no computer metaphors, (b) is understandable to the user who has the domain knowledge of the application, and (c) is formal and complete, so that it can unambiguously be transformed into the logical data model without additional user input.

Our position is that the development of models and tools sufficient enough to handle geographic information varying over time at the conceptual level, should be based on:

a) the study of the requirements of spatial information,
b) the study of the requirements of temporal information, and
c) the combination of the requirement of the above two -leading probably to a refined set of them-, and the proposal of specific constructs to describe both types of requirements at a high level of abstraction.

2.1 Spatial Requirements[1]

Theoretical research as well as practical experience shows that at the conceptual level of geographic applications we need to model:

a) geographic objects *position* in space,
b) geographic objects' different *views* in space, e.g., "a landparcel as a region and/or as a point",
c) *spatial* attributes, e.g., "vegetation" or "soil_type",
d) *spatial relationships*, e.g., "a river passes through a landparcel".

2.2 Temporal Requirements

Temporal applications deal, mainly, with two kinds of time:

a) *valid time* of a fact, showing when a specific fact is true, e.g., "landparcel A belongs to John from 1995 to 1997",

b) *transaction time*, showing when an entity in the database is retrieved, e.g., "In March 1997 John sold landparcel A to George".

2.3 Spatio-temporal requirements

For the conceptual spatio-temporal applications design, the spatial part has the dominant role. It appears more demanding in new data types and modeling mechanisms, while the temporal part shows its complexity in the requirements of transaction mechanisms at the physical implementation. Therefore, combining the spatial and temporal requirements means that, starting from the spatial part, we add time to all the spatial components, i.e., time period of their existence. In other words, spatial entity sets, spatial attributes of entities and spatial relationships are recorded over time. Additionally, position of entities may change. We make the assumption that a geographic object is uniquely defined by its position. So, whenever the position changes, the object itself changes. In that case the existence period of position is the same with valid time of the identity of the object it belongs.

3. The Spatio-Temporal Entity-Relationship Model

By combining the aforementioned aspects, we form a set of constructing mechanisms to handle the spatio-temporal requirements. We enrich the ER [2] with these mechanisms, resulting into Spatio-Temporal ER (STER). The Geo-ER [4] and Time-ER [3], extensions of ER towards space and time respectively, contributed to the formulation of STER.

It is important that the -up to now- disjoint conceptual model classes of object-based (for the representation of spatio-temporal ontologies) and field-based (for the representation of spatio-temporal properties, e.g., "temperature") techniques are integrated under this rationale.

The following example describes an excerpt of the conceptual design of a cadastral database by using STER; it represents a landparcel as a geographic object related to others - such as a river- in time and space.

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[1] In this report we present only the spatial requirements which gain special interest when they are related to time; for the full set of spatial requirements and their semantics the reader should refer to [4].

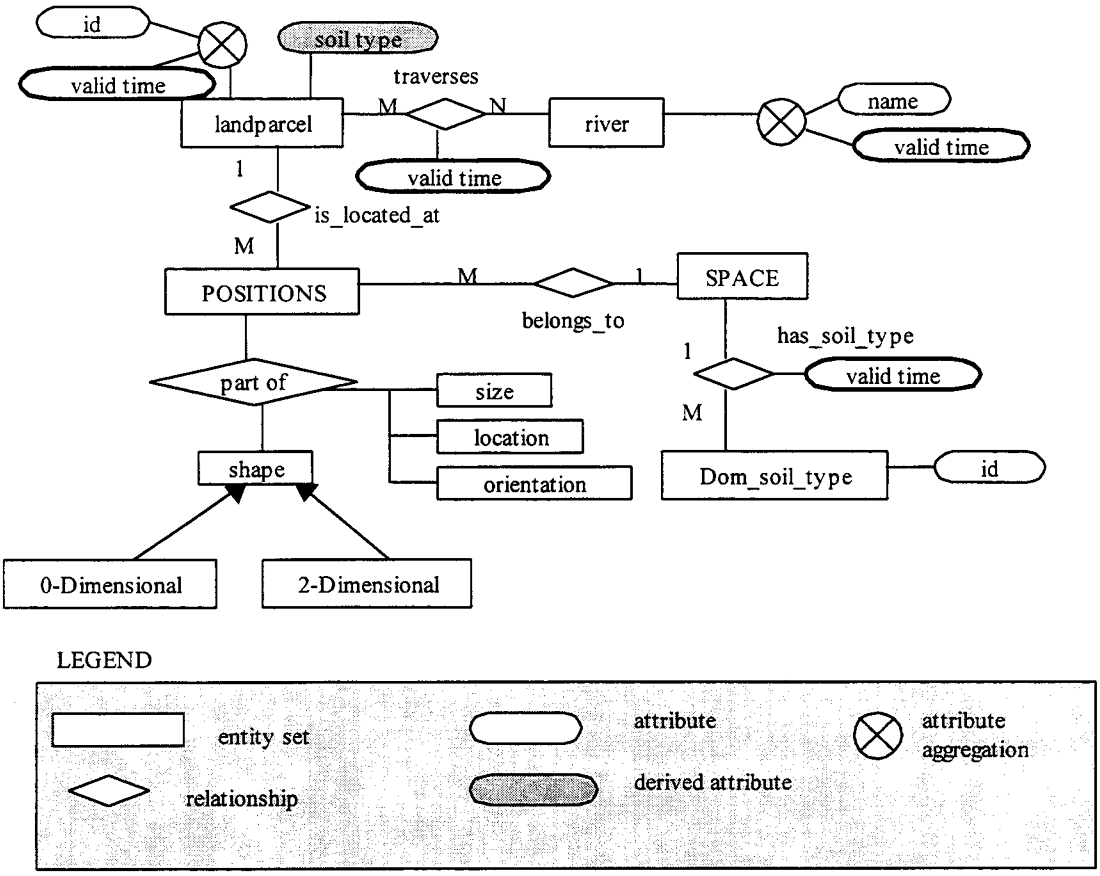

Figure 1: An excerpt of the conceptual design of a spatio-temporal application in STER.

The following modeling needs are handled:

- Geographic objects' position and different (multiple) views of objects in space and time.

It is shown that a landparcel has a geographic position and can be viewed as a point or a region. We represent *space*, object's *position*, *connect* position to space (position is a part of space) and show *different representations* of position. For this reason, we introduced in ER special object classes (entity sets) and relationships:

- the special object class SPACE,
- the special object classes POSITIONS, "size", "shape", "location" and "orientation", which represent object's position in space; "0-Dimensional", "1-Dimensional" and "2-Dimensional", are "shape"(s) of geographic objects: whenever these classes appear simultaneously they represent different views of the same object,

- the special relationship “is_located_at”, which connects the geographic object to its position, and “belongs_to” between POSITIONS and SPACE.

Additionally, we record existence of objects in time by connecting them to valid time[2,3]. For this reason we introduce a new construct, namely the *aggregation*, represented by , to build complex attribute types. Formally speaking, an aggregated attribute A is defined as:

$A = at_1 \times \ldots \times at_n$, where $at_1, \ldots, at_n$ are attributes.

Informally speaking, an aggregated attribute is an ordered set of the component attributes.

In the same way, we can keep track of the existence of any attribute of an entity set by aggregating it with valid time.

- Spatio-temporal attributes (layers), such as "soil_type".

Spatial attributes are functional dependencies from SPACE to specific domains. In that way we assign to each part of space a specific value of the attribute. We modeled them as entity sets connected to SPACE via the relationship “has_<spatial_attribute_name>”. By connecting geographic classes to POSITIONS (via the special relationship “is_located_at”, see previous figures) and POSITIONS to SPACE (via “belongs_to”) objects are related to the space-depending attributes. In other words, spatial attributes of entities are derived properties of space. Valid time is added as attribute to the relationship “has_<spatial_attribute_name>" to record changed of spatial attributes over time.

- Spatial relationships, such as "a river traverses a landparcel".

We represent spatial relationships as functions or special kind of relationships among entity sets. By adding valid time as an attribute we record changes over time.

4. Discussion

We present a brief overview of an on-going research effort, focusing on the spatio-temporal requirements at the conceptual level of database design, the ontological foundation

[2] Since the Entity-Relationship Model captures the static information of an application, we record only the valid time of the database components. Adding transaction time at the conceptual level of design can be a valuable technique for the designer to facilitate the transition to the consequent logical design phase. However this approach is outside the scope of this report

[3] In case of a complex identity, its parts are aggregated in one and the later is aggregated with valid time.

of the environment, and the description of a minimal set of constructs to accommodate them. We argue that these constructs are generic, i.e., they are applicable to a variety of conceptual models, resulting to tools sufficient enough to represent geographic information varying over time. Here we show the applicability into the ER model; an extensive study of its semantics and syntax has been done.

We see this modeling rationale and techniques as a part of a design methodology for geographic systems; moreover the STER (graphical and textual representation) as an intermediate step in the definition of a tool for the semi-automated transition from the conceptual to logical modeling.

We are currently working on applying the same technique to other semantic models (IFO [1]) and commercial tools (Object Modeling Technique [5]) in order to test its applicability. Both of them serve satisfactory the spatio-temporal needs after their extension. Finally, we intend to test the applicability and efficiency of this proposal with small prototypical examples.

5. References

[1] Abiteboul, S., and Hull, R., 1987. *IFO: A Formal Semantic Database Model.* ACM TODS, 4, pp. 525-565.

[2] Chen, P.S., 1976. *The Entity-Relationship Model: Toward a Unified View of Data.* ACM TODS, 1, pp. 9-36.

[3] Gregersen, H., and Jensen, C., 1997. *Conceptual Modeling of Time-Varying Information.* Working paper.

[4] Hadzilacos, Th., and Tryfona, N., 1997. *Extending the Entity-Relational Model to Capture Spatial Semantics*, SIGMOD RECORD (Sept).

[5] Rumbaugh, J., Blaha, M., Premerlani, W., Eddy, F., and Lorensen, W. 1991. *Object-Oriented Modeling and Design.* Englewood Clifs, NJ:Prentice-Hall.