Evaluation of Database Modeling Methods for Geographic Information Systems

Thanasis Hadzilacos
Computer Technology Institute
University of Patras
BOX 1122
GR-26110, Patras, GREECE
thh@cti.gr
tel: +30 (61) 274496
fax: +30 (61) 222086

Nectaria Tryfona*
Department of Computer Science
Fredrik Bajers Vej 7E
Aalborg University
DK-9220, Aalborg, DENMARK
tryfona@cs.auc.dk
tel: +45 (96) 358898
fax: +45 (98) 159889

Abstract

We present a systematic evaluation of different modeling techniques for the design of Geographic Information Systems as we experienced them through theoretical research and real world applications. A set of exemplary problems for spatial systems on which the suitability of models can be tested is discussed. We analyze the use of a specific database design methodology including the phases of conceptual, logical and physical modeling. By employing, at each phase, representative models of classical and object-oriented approaches we assess their efficiency in spatial data handling. At the conceptual phase, we show how the Entity-Relationship, IFO and OMT models deal with the geographic needs; at the logical phase we argue why the relational model is good to serve as a basis to accommodate these requirements, but not good enough as a stand alone solution.

Keywords: Geographic Information Systems, spatial requirements, spatial database modeling, conceptual geographic models, logical geographic models, Entity-Relationship Model, Object Modeling Technique.

1. Introduction

Geographic Information Systems (GIS) is but one of a large number of data-intensive application areas –often referred to as "non-standard"– including among others, architectural and VLSI design, robotics, image and voice processing, artificial intelligence, multimedia and knowledge-based systems. Modeling GIS has gained much attention and popularity over the last years firstly due to their increased use and, secondly due to the special requirements for their design and use.

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Peculiarities of GIS steam from the main difference between geographic and classical objects: their “position” in space. Two major different approaches have been adopted from the scientific community to capture the spatial dimension:

(a) the employment of the already existing data models; for example, [Oxborrow and Kemp, 1992] and [Worboys, et. al., 1990] use the Entity-Relationship (ER) and object-oriented models respectively, to represent spatial objects and,

(b) the extension of these models for the efficient handling of geoinformation; characteristic examples are [Benoit et. al., 1993] and [Scholl and Voisard, 1991] for the extension of O_2, [Pelagatti et. al., 1991] for the extension of ER, [OGIS, 1994] for the establishment of a common spatial data model based on object-oriented aspects for the communication among heterogeneous spatial systems.

Despite the significant research efforts, the result is not the expected one: GIS still lack portability, maintainability, scalability and sometimes even correctness. The reason is that they are built without any consideration to a particular methodology -usually they are developed in an ad-hoc way.

Our position is that GIS are special cases of Information Systems (IS) and spatial databases an indispensable part of them. By using well-known modeling techniques such as standard application design methodologies for IS, the resulting systems are -at least- easy to be extended and maintained. On the other hand, such methodologies should be extended to accommodate the particularities of spatial information.

From this perspective, for the analysis and design of spatial database design for geographic application we adapted a well-known methodology, which includes the phases of conceptual, logical, and physical organization of data. For the conceptual and logical phases we employed representative -already existing- models to capture the spatial aspects. Whenever it was desirable, we extended the provided modeling techniques for that purpose. We tested this approach in real world applications, such as network utility [UtilNets, 1994] [Tsironis, 1992], cadastral, and forest management systems.

In this paper we present an excerpt of the evaluation and comparison of the models we used during this research effort. The contribution of this work lies at exactly this point: by providing a comparative study about the modeling techniques that can be used for geographic data modeling, we help designers to choose the most appropriate models for this purpose, based on specific application requirements.

The models we compare are: (a) ER [Chen, 1976], as a representative of the conceptual models family, (b) IFO [Abiteboul and Hull, 1987], as a strong mathematical conceptual model, (c) the Object Model of the Object Modeling Technique [Rumbaugh, et. al., 1991], as a typical object-oriented model and, (d) the powerful and mathematically sound relational model. We focus on the more interesting and general points, leaving out modeling aspects concerning particular geographic environments (for example, special network modeling needs).

The rest of the paper is organized as following: in Section 2 we give a set of exemplary problems for spatial systems on which we test the suitability of each model. In Section 3 we discuss the criteria of the evaluation for a good spatial database model. Section 4 shows the evaluation of models: in §4.1 we discuss the ER, IFO and OMT models for the conceptual design of GIS, while in §4.2 we argue why the relational model is a good basis to serve spatial peculiarities at the logical level. We conclude in Section 5 with the comparative results.

2. Desiderata for the geographic database design of geographic applications

In this section we give a set of exemplary problems for spatial systems on which the suitability of a model will be tested. Practical experience [UtilNets, 1994], [Tsironis, 1992] as well as theoretical research [Tryfona and Hadzilacos, 1995a], [Tryfona, 1994] reveal the following issues as the most important and critical peculiarities of geographic databases:

- Object's **position** in **space**.

In the real world, objects have a position, which is the object's link with space. In information systems we are only interested in position for *some* objects: these are the *geographic* or *spatial* objects of the application. The position of an object includes its *location* (centroid), *shape*, *size* and *orientation.* Position has a fixed meaning: it is a function on all and only on geographic objects and returns for each geographic object *a part of space*.

There is also the need to capture space in order to locate objects in it. Space is a set. The elements of space are called *points*. Any set will do for space. A very important intuition and interesting theories come-up from non-standard spaces; however for practical reasons, in current spatial applications, space is modeled as a subset of R^2 or R^3.

- **Views** of geographic objects.

Geographic objects may have more than one views in space, e.g., a land parcel can be seen as a *point* or as a *region*, depending on the current *scale* of the application.

The need for modeling different views of the same excerpt of the real world does not only steam from the fact that scale changes (multi-resolution representations), but also from the requirements of the spatial database, e.g., the user wants to be able to see and refer to a *land parcel* either as a *point* or as a *region* or both. Apart from issues dealing with assessing consistency among these different perspectives, we are also invited to integrate all different views in one single conceptual schema as well as to preserve uniformity of successive results when dealing with them; for example, how is defined the distance between two land parcels when these are captured (a) both as points (b) one as a line and the other as a region?

- **Space-depending** attributes.

A fundamental peculiarity of spatial information systems is that some properties of interest do not properly belong to any particular object. For example, *soil_type* in a cadastral application. Although one application view may regard the *soil_type* of the land parcels as an attribute of the parcel, it is clear that: (a) it is defined whether or not a land parcel exists at that position in space, and (b) when a land parcel is moved, it will not keep the value of "its" attribute; rather it inherits new values from the new position. These attributes are called *spatial* or *space-depending* attributes.

Informally, space-depending attributes are properties of space which indirectly become properties of objects situated at some position in space. Overlapping objects share the same values for these attributes. *The value of a space-depending attribute depends on position only*, and not on the object itself. Formally, a *space-varying attribute* is a function whose domain is space and range is any set. Under this perspective, *soil_type* needs to be modeled as a function from space to the set {*sand*, *clay*, ...}. Space-depending attributes can be found in the literature also as *thematic maps* or *layers*.

- **Spatial** relationships.

Dealing with geographic objects means dealing with relationships among them, e.g., *the Limfjorden traverses the city of Aalborg*. Relationships among geographic objects are actually conditions on object's positions and are called *spatial* or *geographic* relationships. Spatial relationships are translated into spatial integrity constraints of the database. Conceptual geographic models should lead to straightforward solutions for explicitly storing topology in the logical and physical levels -a common practice despite topology being derivable from object positions [Hadzilacos and Tryfona, 1992].

- **Complex** geographic objects.

Constructing complex geographic objects from "simpler" ones involves their position; that "a network is an (ordered) set of network segments" differs from "a class is a set of students" in that the former grouping has a spatial dimension as well: the position of the network is the geometric union of the positions of its constituent segments -whereas nothing of this sort holds in the second case.

- **Retrieval** of geographic aspects.

There is the need to access geographic objects, their attributes as well as thematic maps or layers. For example *two land parcels may be merged* or *the soil_type of a land parcel changes*. Methods are the only means to access these "components" of the database. Three types of basic methods on geographic databases exist:

(a) those which manipulate objects and act only on descriptive attributes; for example, *change the name of a river,*

(b) those which manipulate objects and act on objects' position; for example, *retrieve the distance between two buildings,*

(c) those which manipulate layers (space-depending attributes); there are four types of this category [Delis, et. al., 1995]: ATTRIBUTE DERIVATION, SPATIAL COMPUTATION, OVERLAY, and RECLASSIFICATION. For example, *overlay the soil_type and the erosion map*.

Methods of types (b) and (c) are called *geometric* or *geographic methods* or *operations*. The database must keep track of these changes which constitute its dynamic aspect.

3. Criteria for a "good" geographic database model

For the evaluation of geographic data models, we used five criteria as guidelines to test their suitability. Some of these criteria can be applied to conceptual models, while some others to logical ones. All of them are "general", in the sense that they can be used for the evaluation of any "classical" modeling technique. But when they are applied to spatial systems they gain additional meaning as they "measure" the models' ability to deal with the spatial peculiarities described in Section 2. The five criteria are:

(a) **Expressiveness.** The more expressive a model is, the more close to the real world application will be, the more semantics will capture. Semantics play an important role in geographical systems as it is common in spatial applications to find different objects with the same semantics as well as same objects with different semantics.

(b) **Power of abstraction.** (For the conceptual models). One of the criteria to evaluate conceptual (or semantic) models is their ability to represent real world in a highly abstract way. Being able to understand and attribute objects' structure without including details allow us to come closer to objects' semantics and their role in the application.

(c) **Complexity.** This appears to be one of the most crucial issues in selecting a database model. The usual trade-off between expressiveness and complexity exists. The more expressive a model is, the more complex appears to be.

(d) **Friendliness.** Friendliness and ease of adaptation/use of a model relates to its complexity. It is considered important, as a powerful -in terms of expressiveness- model may result in a useless model in terms of usage. Model's friendliness is connected to both user and designer: at the phase of conceptual modeling the user -who is considered as the person who has the domain knowledge of the application- checks the conceptual schema and verifies the correctness of the application design, while at the phase of logical modeling the designer translates the conceptual schema into the logical one. In both cases, it is critical to deal with an easy model.

(e) **Extendibility.** Another important issue is how easily a model can be extended; the general trend for new application areas modeling -such as multimedia, image and voice processing, geographic systems- is to build methods and techniques on top of well-known data models in order to make use of the already existing knowledge from the classical areas.

4. Using different models for the design of geographic databases

Through theoretical research and real world applications, we experienced the use of models and tools for the design and development of geographic applications at: (a) different levels, and (b) different approaches in the same level.

(a) At the phase of conceptual geographic database modeling we used:

- new approaches, such as the object-oriented one, with representatives the Object Modeling Technique (OMT) [Rumbaugh, et. al., 1991], and Kappa System [Intellicorp, 1993],
- classical approaches, with the use of the Entity-Relationship (ER) [Chen, 1976], the IFO model [Abiteboul and Hull, 1987], the Semantic Data Model (SDM) [Hull and King, 1987], and the General Semantic Model (GSM) [Abiteboul et. al., 1995],
- new (specialized or extended) models within certain approaches. In order to capture the peculiarities of GIS we augmented models such as the ER, IFO, OMT, and Kappa with the spatial dimension, resulting in the GeoER [Hadzilacos and Tryfona, 1996], GeoIFO [Tryfona and Hadzilacos, 1995a], GeoOMT [Tryfona et. al., 1997].

In this work we show the evaluation of ER, IFO and OMT: ER, as it is undoubtedly the most popular and easy to use semantic model; IFO, because of its complete and sound mathematical background; and OMT as a representative of the Object-Oriented family. We present the way we handle the six geographic peculiarities of Section 2 by using (extending or specializing) each one of these three models[1].

(b) At the phase of logical geographic database modeling we extended [Hadzilacos and Tryfona, 1994] the mathematically sound relational model with the aspects of geometry and time. Here, we argue why the relational model is good to serve as a basis for an extended model to accommodate spatial needs, but not good enough as a stand alone solution.

4.1 Evaluation of conceptual data models for geographic applications

The conceptual modeling phase 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.

4.1.1 The models ER, IFO and OMT

(a) ER [Chen, 1976] is arguably the first conceptual model that appeared in the literature. Its main advantages are the ease of use that provides and the minimum set of supported constructs. Its basic elements are the: (a) *entity sets*, which represent autonomous ontologies (objects), (b) *attributes* of entity sets, which capture their properties; properties associate a value from a domain of values for that attribute with each entity in an entity set, and (c) *relationships* among entity sets, defined as an ordered list of these sets. Relationships can be 1:1 (one to one), 1:M (one to many), N:M (many to many). *ISA* is a special kind of relationship which is used to model an entity set as a subset on another one; the subset inherits all the properties of its ancestor.

(b) IFO [Abiteboul and Hull, 1987] has become a standard conceptual data model due to its precise mathematical specification rather than its widespread use in practice. An IFO schema is a directed graph with vertices and edges. The vertices represent object classes, which may be *atomic* (further divided into abstract, printable and free) or *complex* (recursively built from atomic through aggregation and grouping). An abstract atomic data type models an object class whose underlying structure is irrelevant to the application and can not be printed. A printable atomic type corresponds to simple predefined objects that can serve as input or output. A free atomic type represents objects obtained via ISA relationships. Edges represent functional dependencies. *Aggregation* refers to a form of abstraction that formally composes a new object class from previously defined ones by forming a Cartesian product. *Grouping* denotes the collecting of elements of an already existing (atomic) class to form a set. *ISA relationships* in are distinguished in generalization and specialization.

(c) The Object Model Technique [Rumbaugh et. al., 1991] is based on a software development tool for object-oriented analysis and design. It became very popular the last years as it is both powerful and affordable with many of the features of a CASE (Computer Aided Software Engineering) tool. The Object Model of the OMT contains object diagrams whose nodes are object classes and whose arcs are relationships among classes. Its basic elements are the: (a) *object classes*, which represent a set of autonomous ontologies (objects) and show their internal structure. The symbol representing a class has three areas: The upper area contains the class name, the middle area its attributes, and the lower area its operations (methods), (b) *attributes* of object classes, which capture their properties, (c) *associations* among object classes, which are

[1] For a thorough description of this work the reader should refer to the corresponding citations.

used to model relationships, (d) *generalization* hierarchy, which is a "is-a" association. Attributes and associations of the supertype are inherited by the subtypes, (e) *aggregation*, which is a "part-of" association and is related to the construction of complex object classes.

4.1.2 Handling spatial needs at the conceptual level

Next, we show how each one of the above described models handles the spatial needs discussed in Section 2. For reasons of convenience and better presentation, we combine logically these spatial peculiarities, without following the order in §2.

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

For that purpose, we need to represent *space*, object's *position*, *connect* position to space (position is a part of space) and show *different representations* of position. We introduced -in all three models, ER, IFO, OMT- special object classes (entity sets)[2] and functions:

(i) a special object class SPACE,

(ii) the special object classes POSITIONS, "size", "shape", "location" and "orientation", which represent object's position in space; POSITIONS is determined fully and non-redundantly as an aggregation of "size", "shape", "location" and "orientation" [Tryfona and Hadzilacos, 1995b],

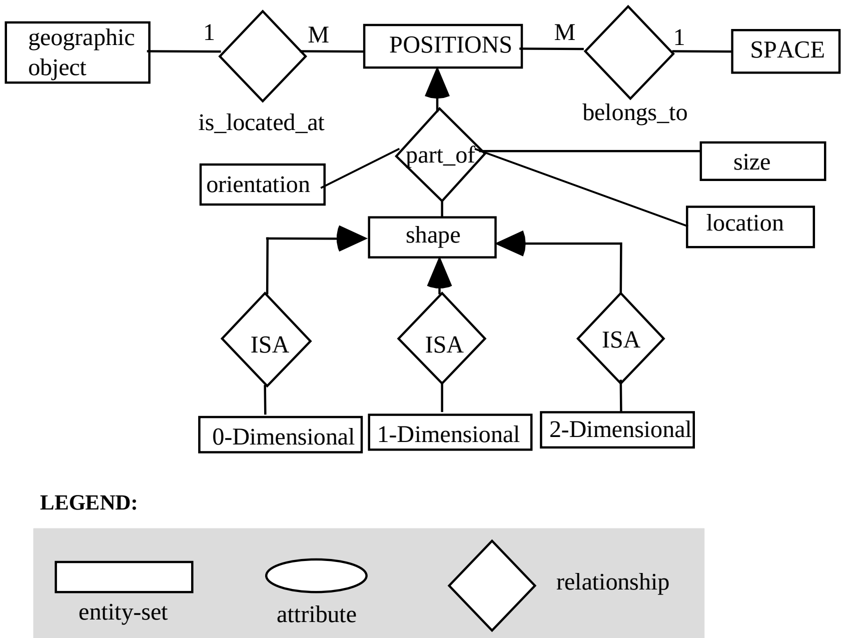
(iii) a special function "is_located_at" (1:M), which connects the geographic object to its position (one object may have more than one positions in different spaces),

(iv) a special function "belongs_to" (M:1) between POSITIONS and SPACE,

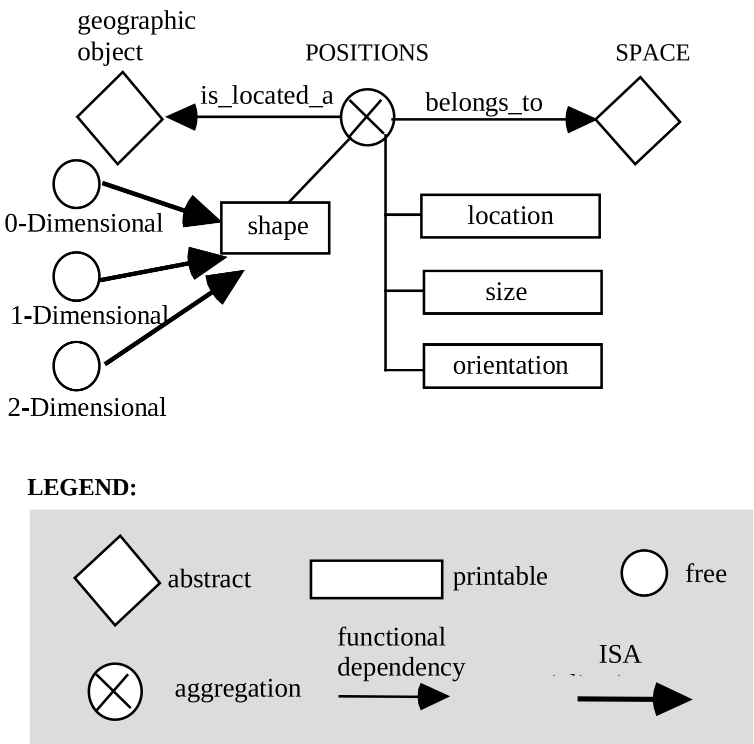
(v) the special object classes "0-Dimensional", "1-Dimensional" and "2-Dimensional", which are "shape"(s) of geographic objects; whenever these classes appear simultaneous they represent different views of the same object.

[2] For the rest of the paper, we shall use only the term "object class" as equivalent to the term "entity set". Furthermore, in the following figures, for reasons of simplicity, we use the term "object" instead of "object class".

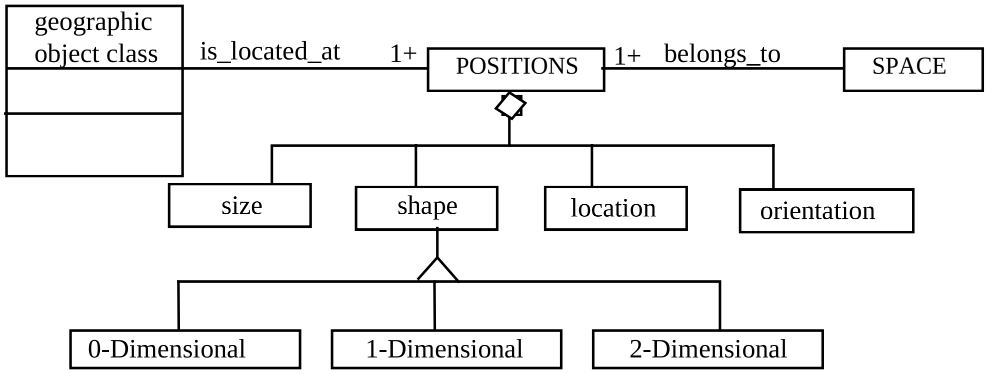
(a) ER


geographic object
1
M
is_located_at
POSITIONS
M
1
belongs_to
SPACE
part_of
orientation
size
location
shape
ISA
ISA
ISA
0-Dimensional
1-Dimensional
2-Dimensional
LEGEND:
entity-set
attribute
relationship

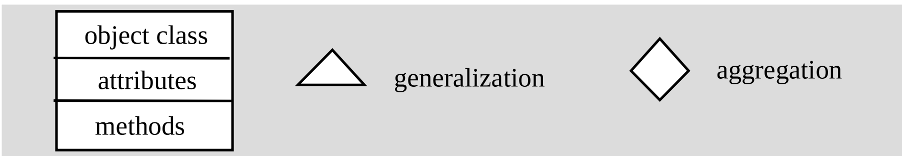
(b) IFO


geographic object
POSITIONS
SPACE
is_located_a
belongs_to
0-Dimensional
shape
location
1-Dimensional
size
orientation
2-Dimensional
LEGEND:
abstract
printable
free
functional dependency
ISA
aggregation

(c) OMT



LEGEND:



Discussion

♦ as IFO and OMT provide (mathematically) the construct of aggregation, we model POSITIONS as an aggregation of the four components ("shape", "size", "location" and "orientation"); none of them can be null in order to fully define POSITIONS; ER does not provide this option,

♦ in ER, we connect "shape", "size", "location" and "orientation" to POSITIONS via the "part-of" relationship. Although this helps us to represent the constructs of POSITIONS, the four component-classes don't have any attributes and the design decision seems redundant and not elegant enough,

♦ in IFO, the four components of POSITIONS can be shown as printable objects, i.e., they can be represented in a computer system. Although this is a logical organization aspect (and conceptual modeling is independent of implementation issues) it is important for the designer to be early aware of what kind of information he has to implement and how easily this can be done,

♦ in IFO, the object classes "0-Dimensional", "1-Dimensional", and "2-Dimensional" are specializations of "shape" and not just ISA hierarchies. This adds more semantic information as "shape" pre-exists and the three classes represent different roles of it,

♦ in all three cases it was easy for us (the designers) to specialize the models towards the spatial aspects and for the user to follow it.

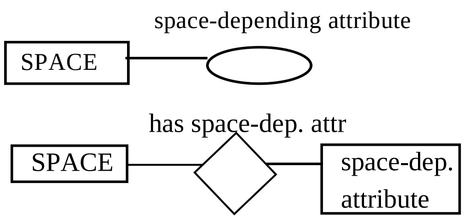
- **Space-depending attributes and methods on them**

Space-depending 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 either as:

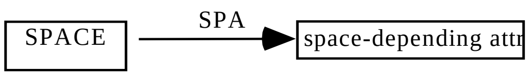
(i) attributes or entity-sets connected to SPACE via the relationship “has space-depending attribute” (in ER); the two approaches are equivalent as the first results from the second.
(ii) functional dependencies (in IFO), or
(iii)object classes (in OMT).

By connecting geographic object 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.

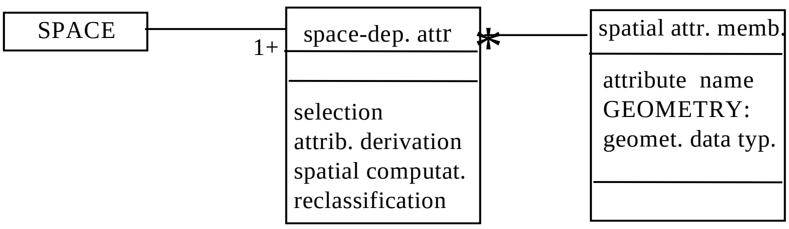
(a) ER



(b) IFO



(c) OMT



Discussion

♦ as IFO is function-oriented, it gave us more flexibility in representing space-depending attributes the way they are: as dependencies (SPA) from SPACE to specific domains,

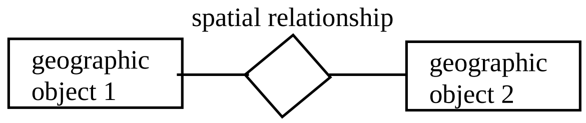
♦ with OMT we had even more freedom and modeling flexibility: we created an object class “space-depending attribute” and connected it to space with the function SPA. This object class shows actually a layer (coverage) which represent the property. The third part of this class has all the operations (methods) we can apply on this layer: “select an area with a specific value on this attribute”, “reclassify based on this attribute”, etc. A layer is a “group of” parts of space with specific attribute values. For example, a layer representing *soil type* includes subareas with *clay*, *sandy*, etc. *soil type*. For that purpose we represent “space-depending attribute” as a grouping (*) of “spatial_attr_member”. Each subarea (“spatial_attr_member”) is distinguished by its specific geometric type (point, line, region, or a combination thereof) which is captured by the attribute GEOMETRY[3],

♦ OMT appears difficult to follow it due to the complex constructs it provides.

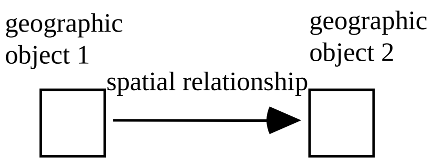
- **Spatial relationships**

In all the three models we represent spatial relationships as functions or relationships among object classes. In all cases the resulting schema appears easy to follow it.

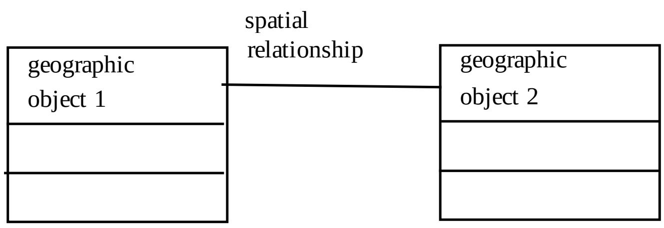
(a) ER



(b) IFO



(c) OMT



- **Complex geographic objects – extension with “spatial member of” and “spatial part of” constructs**

We extended all three models with two new constructs; for IFO and OMT we extended the constructs of aggregation and grouping, while for ER the “part_of” and “member_of” relationships. Each one of these mechanisms has specific properties [Hadzilacos and Tryfona, 1996]:

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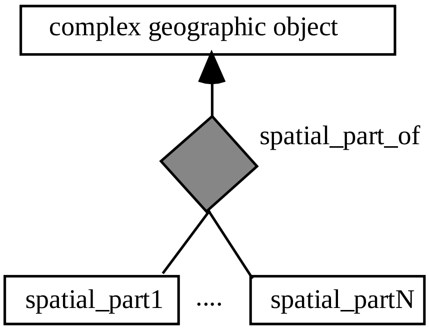
[3] A detailed description of this approach is described in [Tryfona, et. al., 1997].

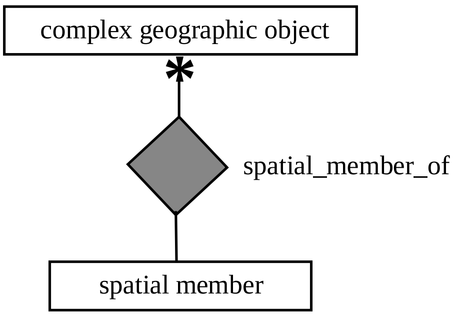
(i) the components of “spatial_part_of” are not necessary all spatial; the position of the composed object is the union of the positions of its geographic components, while

(ii) the components of “spatial_member_of” are all spatial and have the same geometric type.

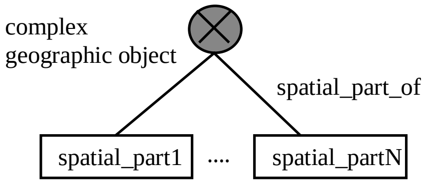
In the following figures the extensions (new constructs) are highlighted.

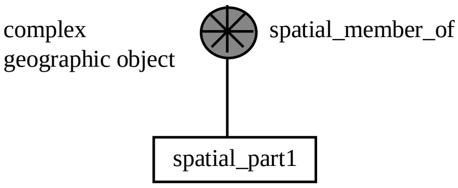
(a) ER



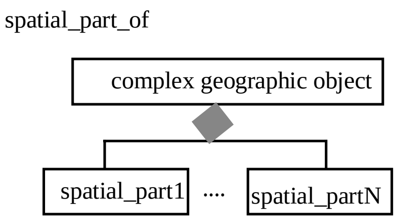


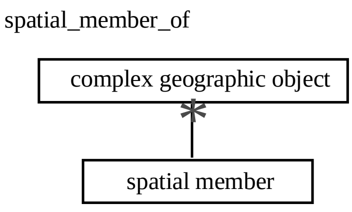
(b) IFO





(c) OMT



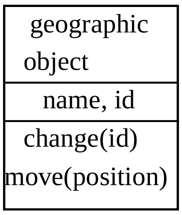


- **Methods on geographic objects and attributes**

Properties of databases are categorized in: (i) static, which characterize the objects of the database such as “the identification number (id) of a land parcel” and (ii) dynamic, which access on static ones, like “change of landparcel's id”. Both static and dynamic properties form *objects’ behavior*. ER and IFO capture only the static properties. OMT captures the dynamic ones also. In the graphic representation of objects by using OMT, the symbol has three areas: the upper area contains the class name, the middle area its attributes and the lower area its operations (dynamic properties).

In the following example, the geographic object has a *name* and an *id* and we can *change* the *id* and *move* object’s *position*.

OMT



4.2 Evaluation of the relational model for geographic applications

The modeling phase that follows the conceptual in the adapted design methodology us the logical one. Here, the conceptual schema –which is the graphical representation of the application- is transformed into a formal, system independent, yet system implementable description.

4.2.1 Handling spatial needs at the logical level

The standard data model for logical database design is the relational. It can be used for geographic applications and has extensively been used so, even at the low level of describing polygons and other geometric features [Burrough, 1986]. The question is why is the relational model not good enough for spatial applications -while it is still a good basis from which to build one.

The power and elegance of the relational model stems from the fact that it uses a single construct: the relation. Five fundamental closed operations are defined on relations (union, difference, selection, projection and Cartesian product, all others being simply notational shorthands, see [Ullman 1988]. For spatial applications, however, the resulting representation is inadequate. For example, if layers (maps representing space-depending attributes) are represented with plain relations, operations such as overlaying and reclassification cannot be derived from the fundamental relational ones [Delis et. al., 1994].

What usually happens when the relational model is used for logical modeling of geographic applications is that these operations are hidden in the physical level. As a result important information is lost and the system is tied to some specific implementation. Thus relations are inadequate as the sole modeling construct for geographic applications.

A fundamental requirement for spatial database design is the ability to model space-depending attributes (Section 2). Spatial applications deal with two, orthogonal, generalizations of spatial properties. One is associations of the whole of space with one attribute, and the other is associations of sets of attributes with a geometric feature (point (0-Dimensional), line (1-

Dimensional), region (2-Dimensional) or combination there of). The former is modeled with concepts like layers whereas the latter is modeled with concepts oriented towards objects. [Couclelis, 1992] offers an insightful view on the orthogonallity of the two approaches.

The GeoRelational Data Model [Hadzilacos and Tryfona, 1994] is an extension of the relational. It provides a language for the definition of relations (used for non-spatial entities and relationships); of layers (to represent space-dependent attributes); of object classes (to represent geographical entities that have characteristics from more than one layer); and of constraints among objects or layers (used for topological and other spatial relationships). An excerpt of its Data Definition Language follows:

DEFINE RELATION rel_name
(attr_name$_1$, Domain$_1$, <KEY>),...,(attr_name$_k$, Domain$_k$, <KEY>)
<TIME_POINT attr_name$_j$>

DEFINE LAYER n <layer_name> <TEMPORAL>
ATTR (attr_name$_1^n$,Domain$_1^n$,<UNIQUE>),...,(attr_name$_{m_n}^n$, Domain$_{m_n}^n$, <UNIQUE>)
GEOMETRIC TYPE Geometric_type <POSITIONING Coordinate_system>
<CONSTRAINT topological_condition >

DEFINE OBJECT CLASS obj_class_name
<GEOMETRIC TYPE Geometric_type> <SUBTYPE OF sup_obj_class>
<ON LAYERS layer_id$_1$,...,layer_id$_k$> <WITH ATTRIBUTES attr_name$_1$,...,attr_name$_m$>
<CONSTRAINT composite_constraint_name>

DEFINE CONSTRAINT constraint_name ON {object_class_name | layer_id}
AMONG{obj_class$_1$,...,obj_class$_k$ | layer_id$_1$,...,layer_id$_k$} AS condition_specification

5. Discussion - Results

We present an evaluation of classical and Object-Oriented modeling approaches for geographic database design based on spatial peculiarities handling. The whole research effort is under the perspective of the use of a specific methodology for the analysis and design of spatial applications; it is also governed by the idea that GIS are special Information Systems. For the conceptual geographic database modeling we test the ER, IFO and OMT tools. All of them need to be firstly specialized and then extended to handle efficiently spatial needs.

- ER is easy to be extended, but the result is not expressive enough for the spatial semantics. Sometimes it appears to be too naive, with no elegant solutions. It can be easily followed by the user.
- IFO is easy to be extended, the resulting schema appears to be more complex but still can be followed by the users. It provides sophisticated and semantically rich mechanisms to deal with space.
- OMT provides high level of expressiveness, is more understandable than IFO and can be easily extended. The result is semantically rich enough to represent space. The ability to capture dynamic properties of geographic objects is one of its major advantages, as spatial databases are mainly characterized by changes of objects' behavior.

The following table summarizes the results.

	expressiveness	**complexity**	**friendliness**	**extendibility**
ER	low	low	high	high
IFO	medium	medium	medium	high
OMT	high	medium	medium	high

At the logical level, the relational model provides a good basis for adding the aspects of geometry and time for GIS handling.

Next step in our research plans is to incorporate temporal aspects in the phase of conceptual modeling of spatial applications. The extendibility and friendliness of the selected models will play an important role as time-varying spatial information is a complex issue in terms of semantics and representation.

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Biographical Sketches

Dr. Thanasis Hadzilacos is a senior researcher and a member of the Board of Directors at the Computer Technology Institute (CTI), in Patras, Greece, where he is in charge of the Research Unit for Applied Information Systems. His long-term research line is large-scale information systems in non-standard application areas. His current work is in the design of Geographic Information Systems, Multimedia Applications and Informatics for Education. He has published over 25 articles in books, international journals and conferences on Database and Object Base Transaction Processing, Geographic Application and Database Design, Educational Software Design, and Multimedia Systems. He studied Computer Science at Harvard University where he received his BA and MS in 1976. He received his Ph.D. from the University of Patras in 1984 for research in Database Concurrency Control, working with Prof. Christos Papadimitriou. He has worked in the computer industry in Greece, and taught at the Department of Computer Engineering and Informatics of the University of Patras and the Department of Spatial Planning of the University of Thessaly.

Dr. Nectaria Tryfona is assistant professor in the Department of Computer Science at the University of Aalborg, Denmark. Her expertise and current research interests and activities are focused in the area of Database Modeling, Geographic Information Systems Design and Spatio-Temporal Information Systems and Interoperability of Spatial Systems. She is the author of various articles in books, journals and conference proceedings. In addition to the aforementioned research activities, she taught courses of Database Design and Information Modeling in the Department of Spatial Information Science and Engineering of the University of Maine and the Department of Computer Engineering and Informatics of the University of Patras and the gave lectures about Geographic Information Systems at the Department of Spatial Planning of the University of Thessaly. She has received her Dipl. Eng. and Ph.D. from the Department of Computer Engineering and Informatics of the University of Patras (Greece) in 1991, and 1994, respectively. During her graduate studies she held a Graduate Research Fellowship from the Computer Technology Institute and was a teaching assistant at the University of Patras. Upon graduation from the University of Patras she joined the National Center of Geographic Information and Analysis at the University of Maine in USA as Post Doctoral Research Associate (until 1997) and was involved in research projects aiming at the assessment of geographic information consistency at multiple levels of detail.