COUPLING GIS AND ENVIRONMENTAL MODELLING: THE IMPLICATIONS FOR SPATIO-TEMPORAL DATA MODELLING

Cheng Tao, Wolfgang Kainz, Robert A. van Zuidam
International Institute for Aerospace Survey and Earth Sciences (ITC)
350 Boulevard 1945, P.O.Box 6, 7500 AA Enschede, The Netherlands
e-mail: {cheng, kainz }@itc.nl

Commission III, Working Group 4

KEY WORDS: Environmental Modelling, Object-oriented Data Model, Spatio-Temporal GIS

ABSTRACT

This paper discusses spatio-temporal data model design for coupling environmental models with GISs. It is organized along three levels of data modelling, i.e., the spatial modelling level; the conceptual level and the logical level. Issues to be discussed include: whether an application-oriented or a system design-oriented perspective should be taken at the spatial modelling level; how the objects should be constructed at the conceptual level (geometric-based, temporal-based or attribute-based), if an object-oriented approach is selected; should it be the loosely-coupled or tightly-coupled method chosen for the logical implementation; and finally how environmental modelling can be implemented in objects. It is hoped that these discussions will contribute to the data model design for the integration of environmental models with GISs, and to the development of object-oriented concepts in GIS data modelling.

1. INTRODUCTION

In recent years, the integration of environmental models with GISs has attracted much research attention. The past experiences demonstrate that three levels of such an integration can be achieved, depending on the circumstances of the GISs and the environmental models:

a. A basic level of separated but interfaced system. At this level, environmental models communicate with GISs via data files. The GIS data are converted to the formats (or structures) required by the environmental models, or the way around, so that the data stored in the GISs can be used by the models, and the data generated by models can be represented in the GISs. Models and GISs are independent of each other.

b. An intermediate level of "seamlessly" interwoven systems sharing a common user interface. At this level, macro-languages provided by GISs are used to build a user interface, under which the GISs and environmental models are linked. Sometimes, the macro-language can also be used to develop part of the environmental models. The user interface provides menus to invoke the modelling process module and GISs functionality. So the gap between GISs and modelling processes may not be noticed by the users.

c. An advanced level of a fully integrated system. At this level, the environmental modelling is fully embedded in a GIS. The environmental models can directly read GIS data and the data produced by models can be directly managed and represented by the GIS.

Currently, most environmental models are integrated with GISs at the first level. Such GISs are used as a tool for preparing data input for environmental models, and for post-processing data output from environmental models. However, even this basic level of integration is normally made ad hoc, and a standardized procedure is yet to be created (Cremers et al., 1995). Given the fact that many commercial GISs provide macro-languages or other tools to facilitate applications in different fields, there are ample opportunities to achieve the second level of integration. However, the static and 2-D or 2.5-D features of current GISs may only allow the simple and static models to be easily integrated. Complex, 3-D and dynamic environmental models, which are important analytical tools in environmental studies, may be difficult. Most benefits of using GISs for environmental modelling can only be achieved by the fully coupled environmental modelling processes within a GIS framework. Whether or not such an objective can be achieved largely depends on what is offered by the GIS and what is required by the modelling process. One of the most important factors in this supply and demand relationship is whether or not the data structure of the GIS can support the data organization requirements of the modelling process concerned. That justifies the importance and the necessity of discussing the issues of the spatio-temporal GIS data model design for coupling GIS and environmental modelling in this paper.

According to Molenaar (1995), GIS data modelling has four steps or levels which represent the process of mapping the real world gradually into symbols readable by computers. These four levels include spatial modelling, conceptual modelling, logical modelling and physical modelling. As the physical modelling deals with the physical storage of data in computers, users and GIS designers normally pay their attention only to the first three levels and the relationships among them. Therefore, we will discuss how the data modelling at these three levels can support full integration.

2. SPATIAL MODELLING LEVEL - HOW TO DECOMPOSE THE REALITY

Users in different application disciplines pay attention to different phenomena. They will decompose the complex environmental issues into simpler ones. In the mean time several types of entities are selected and defined as the study objects to represent environmental issues. Later on, they use environmental models to describe the interrelationship and behaviours of these objects. The process of decomposing reality and selecting typical objects for a specific discipline is called spatial modelling. Therefore, a spatial model can be considered as the user understanding of the reality and the model is for them to describe the reality. It also implies a method to decompose the reality into representable entities.

If the user and GIS designer can decompose the reality in the same way, i.e., GIS designers and users select the same entities to represent environmental issues, then the environmental models and GIS can be easily integrated with each other. The benefits can be seen from three points. Firstly, the users of the system can map their understanding of the environmental issues directly into GIS without paying attention to the geometric concepts such as points, lines and polygons. Secondly, the environmental models created outside GIS can directly accept the abstract data types described in GIS and the output of the environmental models can be directly accepted in GIS. In this case, the conversion between GIS and environmental models for the abstract data types will be reduced. Thirdly, the environmental models may be developed directly in a GIS as the abstract data types can be used to define the environmental models.

There are two ways to decompose the complexity, which will lead to different criteria and strategies for the development of the spatio-temporal GIS data model.

2.1 From the Data-Driven Perspective

Traditionally, the design of a GIS is not directly related to the requirements of its application. Most of the designs are started from the stage of conceptual level. Most available GISs take a system-oriented approach, i.e. they structure the data and design operations from the perspective of a data-driven system, formed according to different function modules, such as data input, data analysis, data management and output. The reality is decomposed into separated layers of space or time. So the environmental entities are forced to be segmented and represented in these layers. If the environmental models are integrated with the system, their form and nature have to be adopted as the representational basis of the GIS. This approach implies an essential adoption of geometrically-indexed methods for representing environmental models in a spatial context and forces compromises on most environmental modelling (Raper and Livingstone, 1995). They normally fail to directly map the users' conceptual schemata and analytical needs. Consequently, the GIS data structure can not satisfactorily support environmental modelling.

2.2 From the User Perspective

As the strong emphasis on technical aspects in the design of most GISs results in a significant drawback of application-specific data and system-confined operations (Yuan and Albrecht, 1995), some researchers suggested that the data structuring and operation design should take a users' perspective. The representational basis of the data model should be driven by the structure of the application issues. In such a way, the direct mapping from users' concepts to data objects can be provided (Yuan, 1995). It means that first level integration of spatial modelling can be achieved.

As structured design does not address the issues of data abstraction and information hiding, object-oriented analysis and design approach attract more and more attention of the experts of information system design. In this approach the system is decomposed according to the key abstraction in the problem domain, rather than decomposing the problem into algorithm steps, by which the objects are identified and derived directly from the vocabulary of the problem domain (Booch, 1993).

For environmental modeling, Raper and Livingstone (1995), among others, stated that the *traditional science paradigm* has been considerably modified in the last few decades in a number of ways which demands a more rigorous approach towards modelling, classifying and discritizing when studying environmental problems. Adoption of the object-oriented approach to spatial representation recognizes these priorities and enables solutions for some of the problems of environmental models coupled with GIS.

Therefore, we can see that the system design is transferred from a system-oriented perspective to an application-oriented perspective, and from a data-driven to an object-oriented approach. But ideally, GIS data models can better reflect the mental models of both the system designer and the user in order to best facilitate the communication between the GIS and the user. Any aspect that is overemphasized will result in a drawback of further development of GIS and its applications. If we only take the approach from the user's perspective, by applying an object-oriented approach, the system to be developed will only be useful for very specific cases, as the method and data are encapsulated in the definition of the object. Although Yuan (1995) put forward to generalize the user's conceptual schemata and analytical needs and try to implement them in a GIS, it is not possible to integrate the users' conceptual schemata and analytical needs of all specific application areas into a single commercial GIS. As the aim of geo-information theory analyses is to form design criteria and strategies that can be used by experts to support and advise users with the development of their applications (Molenaar, 1995), we believe that both the system-oriented and the application-oriented approaches have their points in the design of data models for coupling GIS and environmental modelling. In practice, there is a need to take both and a trade off between them. It can be shown in the case study In Section 6. In the study of geomorphology of the coastal zone (in Ameland, the Netherlands), the coastal zone is decomposed into landscape units according to the conceptual schemata of user and environmental models. These landscape units are represented as objects in the first level, described by three factors at the second level, while these factors are referenced by spatio-temporal data stored in the third level. The data at the third level can be structured and managed in different ways from that of the first and the second level. In this way, the third level of spatio-temporal database can also be used for other studies such as hydrological research in the same area, except that the first and second level definition of objects has to be adopted.

3. CONCEPTUAL LEVEL - HOW TO STRUCTURE THE SPATIO-TEMPORAL OBJECTS

The last section discussed the view point for the selection or definition of entities to be considered in the spatio-temporal data model. This Section will investigate the format or structure by which the entities can be represented, i.e., "what structure in the environmental problem should drive the representational basis of the model?". In order to integrate GIS and environmental models fully, we should select a structure which can satisfy requirements of both of them. However, most of the existing GISs manage static and discrete data while environmental models deal with dynamic and continuous phenomena. GIS databases contain information on location, spatial distribution and spatial relationships while environmental models work on a basic currency of mass and energy transfer. Therefore dynamics and continuity should be added to spatial data and spatial interaction for the full integration.

There are two approaches to represent spatial data and related processes, field-oriented and object-oriented. The field-oriented representation takes the view that the environment is continuous. It is a locational-dependent representation, i.e., the thematic information of the entities is attached with their locations or geometric data. Thus, the data is structured according to their locations, representing "what exists at where" and "where" (specific locations) is assumed to be known or fixed first. This representation is fit for temporal analysis of thematic information related to fixed locations. The object-oriented representation considers that the world is made up of objects which are uniquely identified by their identifiers. The thematic data and the geometric data are linked together through the object identifiers (Ids). It assume that the object exists first, then the data is structured according to the object, describing "where is it and what thematic attributes it has". It is fit for the temporal analysis of the objects, which location and the thematic attribute may change in different ways.

As for many natural phenomena of continuous surfaces, they can be represented by field-oriented approach, and temporal analysis related to specific locations can also be easily implemented. E.g., the height change of terrain surface on several points (fixed horizontal locations). But the temporal analysis of the whole terrain surface of dune is not easy to be accomplished if the data is structured by locations. Firstly, the temporal analysis of the thematic information is not direct and convenient, as it can only be revealed after the accessing of the related locations; Secondly, as the spatial distribution (locations) are always changing, the thematic data attached with them have to be updated according to their changes. Therefore the field-oriented representation is not suitable to represent dynamic, natural phenomena, which position always changes, e.g. the developing dunes and transportation of polluted materials. In these cases, the geometric data can not be considered as a basis or a reference to link the thematic data. But the object-oriented representation will be able to deal with such situations.

The difference between field-oriented and object-oriented is coming from their perspectives of viewing the world, i.e., what exists first. In the field-oriented perspective, it assumes the space exists first, while in the object-oriented perspective, it assume that the object exists first, in the space with thematic attributes. For environmental issues, the object-oriented perspective seems more natural and acceptable to the user compared with the field-oriented one. However, for the real representation of these two perspectives, they don't have so much difference if we think both of them can be raster or vector based format. So, at the conceptual level behind the field-oriented and object-oriented representation, the representations for locational (geometric) aspects are same, i.e., raster-based and vector- based. Both of them can be adopted to represent the natural phenomena.

Furthermore, with object-oriented programming languages, the objects can be classified as abstract data types with associated methods determining the processes that happened to them. In this way, the physical process can be implicitly contained through the definition of methods adding to the data. At this level, by applying inheritance, encapsulation and aggregation of object-oriented concepts, the dynamics and continuity of natural phenomena can be represented. So a full integration can be achieved.

Therefore we would like to apply the object-oriented approach for the representation, as it poses rich semantics capable of representing knowledge of environmental problems in a realistic spatio-temporal context. The authors will discuss the representational basis of objects in the spatial domain and in the spatio-temporal domain.

3.1 Spatial Aspect of Object Is Over Emphasized

Most GIS studies emphasize modelling the spatiality of geographic phenomena. The emphasis on the spatial key and spatial property signifies the importance of locational concerns in spatial data handling. So the conventional GIS data models are designed in a way that reality is described according to locations. Furthermore, as the GIS is based on a visualization-oriented cartographic representational paradigm, the spatial GIS is formed from the concepts of points, lines, polygons and grids with a static map display. The overemphasis of the spatial aspect and visualization-oriented representation result that the object-oriented concept in GIS data modelling is often narrowed down to a spatial context with visualization function. Geometric-index GISs always require that the users adopt their understanding of the reality to match the concepts of geometric layer of points, lines and polygons. It is quite difficult for most of the users, e.g. the manager who doesn't have sufficient knowledge of GIS and can not understand the geometric concepts used in GIS. Consequently, the manipulation of the GIS is not convenient for the user and the user may be not willing to use the GIS. Therefore, the geometric-index paradigm limits the application of GIS.

Furthermore, it is not easy to decompose complex and dynamic natural phenomena into objects according to geometric characteristics because of their irregular shapes. E.g., for the study of dune geomorphology, it is not possible to simply divide a dune into geometric objects stored as different layers, represented by points, lines and areas. Moreover, the geometric-based structure is not appropriate when the major concerns of users are temporal characteristics of nonspatial attributes of the phenomena as the geometric-base structure is still the extending of field-oriented representation. Therefore the conventional geometric and visualization-based concepts have not only limited the development of object-oriented technology in GIS but also restricted the spatio-temporal data representations. Therefore a more general representative basis should be formed to deal with the spatio-temporal phenomena.

3.2 The Objects Can Be Set Up Based On Three Aspects

Most spatio-temporal data models are put forward as extensions of traditional GIS representations, i.e. a spatial aspect of the objects is the main factor to divide the space and to classify the objects. When we consider the objects in a spatio-temporal domain, the concepts of an object and its representative basis should be extended from the spatial domain. In a spatio-temporal domain, an object has three characteristics, i.e., geometry, temporal and nonspatiot-emporal attributes (Cheng et al., 1995). The temporal and nonspatio-temporal aspects can also be used as basis to construct objects. Some people have the opinion that time can not be used as a separated visualization factor, but it does not contradict to using time as a basis to organize information, e.g. we can organize objects according to events.

Some researchers suggested to organize the objects in a different way. The earlier work of the authors put forward a unified spatio-temporal model for 4-D GIS (Cheng et al., 1995). In such a model, the objects can be built based upon the spatial, nonspatio-temporal and temporal aspects. An event-based structure of the model was proposed to demonstrate how it works. Yuan (1995) thought less research on geographic semantics was done compared with spatial aspects. She proposed a conceptual design for the three domain models of semantic, location and time. Peuquet (1995) put forward a triad model, which is made up of object-based representation, location-based representation and time-based representation.

These three models are quite similar to each other. They all consider that an object contains spatial, temporal and nonspatio-temporal attributes (Figure 1). The geographic data can be organized according to these three aspects. They can be location-based (according to spatial aspects), event-based (according to time aspects) and attribute-based (according to nonspatio-temporal attribute aspect), and normally it can be implemented by applying vector-based, raster-based, or event-based approaches, respectively. The advantage of these models is that the information can be structured according to the requirements of analysis in an effective way. If information of changes relates to individual attributes, attribute-based (vector-based) models should be selected. If changes of individual locations and set of locations are be traced, location-based (raster-based) models should be applied. If the time-dependent changes are the important aspects of the objects to be represented, the time factor can be the key link to sufficiently organize all the information (Cheng et al., 1995).

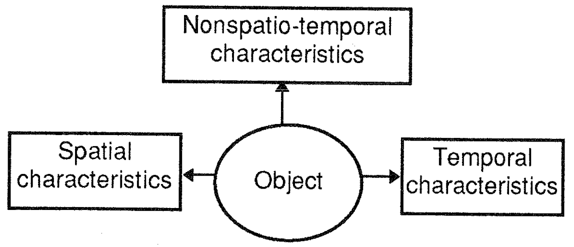

Figure 1: Three components of a spatio-temporal object

4. LOGICAL LEVEL- HOW TO IMPLEMENT THE SPATIO-TEMPORAL DATA MODEL

Logical modelling is the bridge to link the conceptual models and physical data models. One of the most important models at this level is the relational data model, which is used by relational database management systems to implement conceptual models in computerized databases. However, object-oriented database management systems attract more attention recently as they have advantages over relational data models.

This section will concern the implementation of data models by applying the object-oriented approaches proposed above. The paper distinguishes a loosely-coupled method and a tightly-coupled method. The three characteristics of objects are tightly linked in the first case. It means these three characteristics of an object are stored together under the same identifier. In the second case, the geometric, attribute and temporal characteristics of objects are loosely linked. They can be stored separately, e.g. in different files or in different DBMSs. The objects can be represented as random combinations of these three characteristics. The first approach provides a tool to extract the change of an object as a whole. It may not be easy to identify the changes happened to which of the three aspects. The second method is convenient to organize the objects which frequently change in all three aspects: i.e., the spatial, temporal or attribute aspects. It is not easy to quickly query the situation of a specific object. Several examples are given in the following section to illustrate these two approaches.

4.1 A Tightly-Coupled Approach

A time-based approach is selected to implement a unified and tightly-coupled spatio-temporal model in (Cheng et al., 1995). The following steps are proposed for the physical implementation of the conceptual model:

(1) Set up lists to store the identifiers of objects existing at time t1 (assuming t1 is the base state), according to different object classes (i.e. body, surface, line and point);
(2) Set up a "history-list" for each object, keeping the temporal topology for each object;
(3) Set up dynamic linked list to represent the spatial composition of the object, keeping spatial topology at the same time.

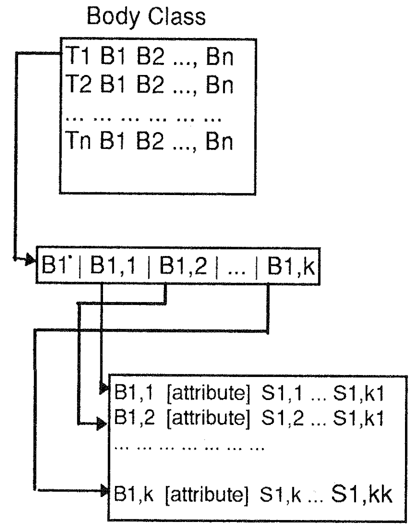

Figure 2: A tightly-coupled approach

The structure of the data model can be illustrated in Figure 2. Such a data structure will have the following characteristics:

(1) It is a unified representation of spatial, temporal and attribute information of 4-D geographic objects;
(2) The geometric and temporal topological relationships are explicitly recorded. It is convenient for topological queries about spatial and temporal aspects within and between objects;
(3) The changes of the objects are recorded explicitly, which makes it easy to detect changes along time.

Using the tightly-coupled approach, however, it is not easy to reduce the data redundancy for both geometric and attribute aspects. The model shown in Figure 2 provides an effective storage for geometric data while it might have high redundancy in attribute aspects.

4.2 Loosely-Coupled Approach

Yuan (1995) put forward a spatio-temporal data model to manage wildfire information. It has three domains of semantics, time and space. The data model is shown in Figure 3. The semantic domain consists of wildfire's concrete or abstract concepts of aspatial and atemporal properties, such as names of individual fire events, fire intensity, fire types, or forest stands. The temporal domain consists of temporal objects of points and lines, which represent instance time and time intervals respectively. The temporal domain supports analysis and reasoning, such as fire frequency or fire cycles. The spatial domain is composed of spatial objects of points, lines, polygons, cells, and volumes. Each of them represents zero-, one-, or three- dimensional spatial units. It was suggested that each domain could have its own database management system (DBMS) for data storage, maintenance, and operation (Yuan, 1995). However, how to define and to link the semantic object, temporal objects and spatial objects and how to reduce the redundancy of the (unchanged and changed) data are not discussed in her paper.

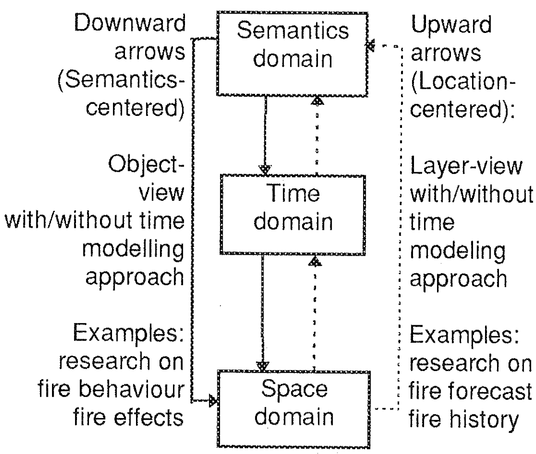

Figure 3: The three domains model (Yuan, 1995)

Peuquet (1995) set up a triad representation framework illustrated in Figure 4. The object-based representation includes four types of attributes, i.e., the generalized locational indicator, temporal intervals, nonspatio-temporal data and higher-level knowledge about known spatio-temporal phenomena. In the event-based model, an event is stored as an observation in the time-based view. Each event and the attributes describing it are stored in their chronological order of occurrence. The attributes might include the time of change, the locations of change and types of objects. The location-based representation is a raster based snapshot. Some relationships exist among the data in these three models, but how to organize the data effectively to reduce the data redundancy is not discussed in her paper. E.g., different events have different objects, the location and nonspatio-temporal description may be the same among several objects.

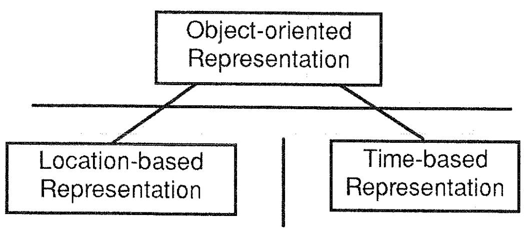

Figure 4: The triad representation framework (adopted from Peuqeut, 1995)

Furthermore, in the two models of Yuan and Peuqeut the objects exist dependent on nonspatio-temporal attributes. However, some objects at different locations may share the same attributes and the value of the nonspatio-temporal attributes may changes at a specific location. So a Rich Spatio-Temporal Data Model (RSTDM) is proposed (Roshannejad, 1996), wherein a object is uniquely defined by its identifier (ID), which is the only unchanged thing keeping the trace of the object. The object is independent from their spatial and attribute representations. While relationships between objects and its spatial and nonspatial attributes are recorded as another type of object. In this way, the representations can be shared by multiple objects so that a considerable amount of space in the database can be saved. However, only a few man-made objects have been implemented in the RSTDM, such as building, roads and wells, which changes suddenly and obviously. How to adopt the model to natural phenomena with irregular shape and gradual changes is not discussed in the thesis. Moreover, the three dimensional case is not discussed in the model.

4.3 The General Spatio-Temporal Data Model

The authors propose a general model, wherein an abstract data type of object, unique and defined by the user, is indicated by its identifier. All the information related to the objects will be linked to it through references.

There are two ways to build the temporal reference of the spatial and nonspatial attributes to these phenomena. One is to link the temporal reference tightly (or explicitly) to the spatial data and nonspatial attribute data, i.e. when the object has which kind of thematic attributes at which places (see Figure 5(a)). Another way is to set up two historic lists to show the relationships of the object with its properties, i.e. one shows when the object has which kind of thematic attributes, another one shows when the object is where (see Figure 5 (b)). In this case, the first level stores the information about the objects, which can be managed by an object-oriented database management system (OODBMS); while the real content of the object, i.e., the location, the temporal information and nonspatio-temporal characteristics as well as the processes related to the objects are stored in the second level, which can be maintained by an OODBMS or a relational database management system (RDBMS).

5. TOWARDS FULL INTEGRATION

The object-oriented approach discussed so far concerns only how to describe the objects in a spatio-temporal environment. More important, to capture its development, is the major concern of environmental models. If the objects can not only carry the information on the spatial, temporal and attribute characteristics of the environment, but also its development, then we come close to the stage of fully coupling the environmental models with GISs. As discussed in Section 2, the objects can be defined from the view point of application and the users perspectives, e.g. from the behavior of the phenomena, then such aim can be achieved.

The development process of the environment is described by environmental models, tracing the major factors for development. Suppose that the objects can be constructed based on these major factors, we have enough reasons to state that, in such a case, the environmental models are better to be included in the objects to describe the development processes of the objects. Therefore, there are two strategies here to combine the spatial, temporal and attribute characteristics of an object with its development processes (in the form of environmental models) into a single object: one is to organize objects according to their geometric, temporal and nonspatio-temporal characteristics, building operation on them based upon environmental models. Another one is to organize the objects according to the requirements of environmental models, assigning the spatio-temporal references to them. As the first case is not easily to integrate the environmental models, the second strategy provides the possibilities to fully embed environmental modelling into a spatio-temporal GIS data model.

6. CASE STUDY

One of the Dutch barrier islands, Ameland, has been selected as a test area for research. At certain locations of the island, severe (marine) erosion happens, while at other places accretion or accumulation occurs. To be able to predict which process will dominate for a certain location in future, it is necessary to know the various processes, the interaction of these processes and the governing factors concerning the sediment transport on the land-sea interface. Such information is also quite important for optimizing the coastal defense works, e.g. beach nourishment or planting grass, which require high investments.

The morphodynamically active areas will be selected as testing places. On Ameland the geomorphologic processes can be distinguished through the interpretation of remote sensing data in various landscape units, particularly, the shoreface, beach, dunes, saltmarshes and tidal flats.

We choose the landscape units as our mapping units. In this way the data can be structured according to environmental units, which make that the integration of environmental modelling will be relatively easy.

We use three levels to represent the geomorphology of this island. The first level is the landscape units as foreshore, beach and foredune, which are the concepts used by geomorphologist and each of them can be described by three factors as forms, process and materials. These three factors can be considered as objects at second level. The spatio-temporal data to describe these factors are stored as objects in the third level. The environmental models are set up as another class of objects, described by their environmental factors such as sea, wave, wind and vegetation, etc. These factors can also be classified as objects with spatio-temporal references. The environmental models are embedded into the description of the landscape units through the process associated with these units. Such structure is shown in Figure 6.

7. CONCLUSION

Several aspects concerning how to design data models for coupling environmental models with GISs are discussed in this paper, i.e. (1) whether an application-oriented or a systemdesign-oriented perspective should be taken for designing the spatial model; (2) how the objects should be constructed (geometric-based, temporal-based or attribute-based), if an object-oriented approach is chosen; (3) should the loosely-coupled or tightly-coupled method be chosen for the physical implementation of the conceptual model; and finally (4) how environmental models can be integrated into objects. A general spatio-temporal data model is proposed and a case study is given as an example of full coupling of environmental modeling in GIS. It is hoped that the discussions in this paper will theoretically contribute to the data model design for the integration of environmental models within GISs, and to the development of object-oriented concepts in GIS data models.

References

Booch, G., 1993. Object-Oriented Analysis and Design with applications, Second edition, The Benjamin/Cummings Publishing Company, Inc.

Cheng Tao, Van Zuidam, R.A. and Kainz, W. 1995. A Unified Spatio-Temporal Data Model For 4-D GIS, Proceedings of GIS/LIS'95 Annual Conference and Exposition, Nov. 12-16, Nashville, USA, pp. 967 - 976.

Cremers, N.H.D.T., Wouters, W.J.C., Roo, A.P.J. de, Wesseling, C.G., Burrough, P.A., and Van Deursen, W.P.A., 1995. Integratie GIS en Dynamic Modellen "Definitiestudie", Survey Department, Directorate-General for Public Works and Water Management (MD-GAG-NR. 9503), -pp.34.

Molenaar, M. 1995. Spatial Concepts as Implemented in GIS, Geographic Information Material for a Post-Graduate Course, Vol.1: Spatial Information, Edited by Frank, A.U., Department of Geoinformation, Technical University Vienna, pp. 91-154.

Peuqeut, D.J., 1995. It's about time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information Systems, Temporal Data in Geographic Information Systems, complied by Frank, A.U. Kuhn, W. and Haunold, P., pp.149-170.

Raper, J. and Livingstone, D., 1995. Development of a geomorphological spatial model using object-oriented design, INT. J. Geographical Information Systems, Vol. 9, No.4, pp.359-383.

Roshannejad, A.A., 1996. The Management of Spatio-Temporal Data in a National Geographic Information System, Ph.D. Thesis (to be published).

Yuan, M., 1995. Wildfire Conceptual Modeling for Building GIS Space-Time Model, Temporal Data in Geographic Information Systems, complied by Frank, A.U., Kuhn, W. and Haunold, P., pp.47-56.

Yuan, M. and, Albrecht, J., 1995. Structural Analysis of Geographic Information and GIS Operations from a User's Perspective, Lecture Notes in Computer Science 998, Spatial Information Theory - A Theoretical Basis for GIS, Proceeding of the International Conference of COSIT'95, Semmering, Austria, Sept. 21-23, Eds. Frank, A.U. and Kuhn, W., pp. 107-122.

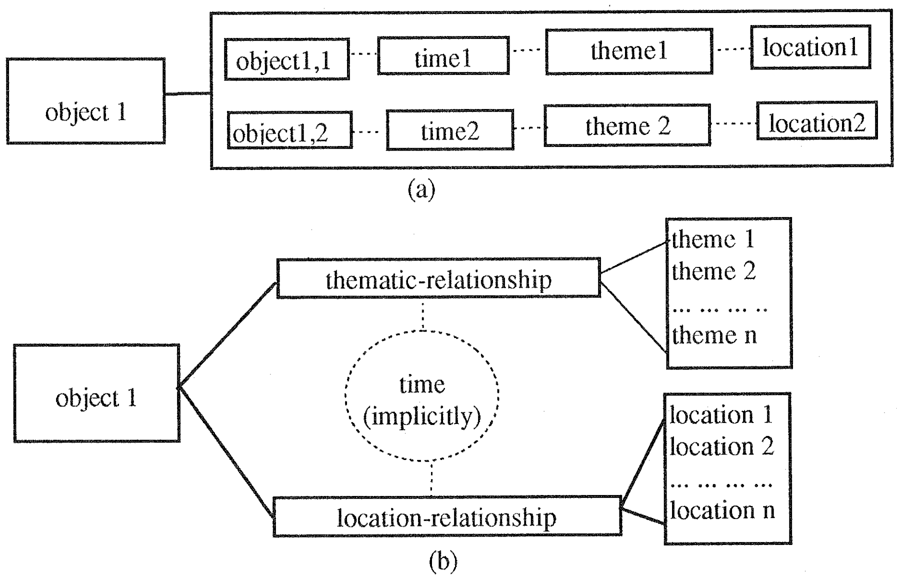

Figure 5: Links between the objects with its spatio-temporal references

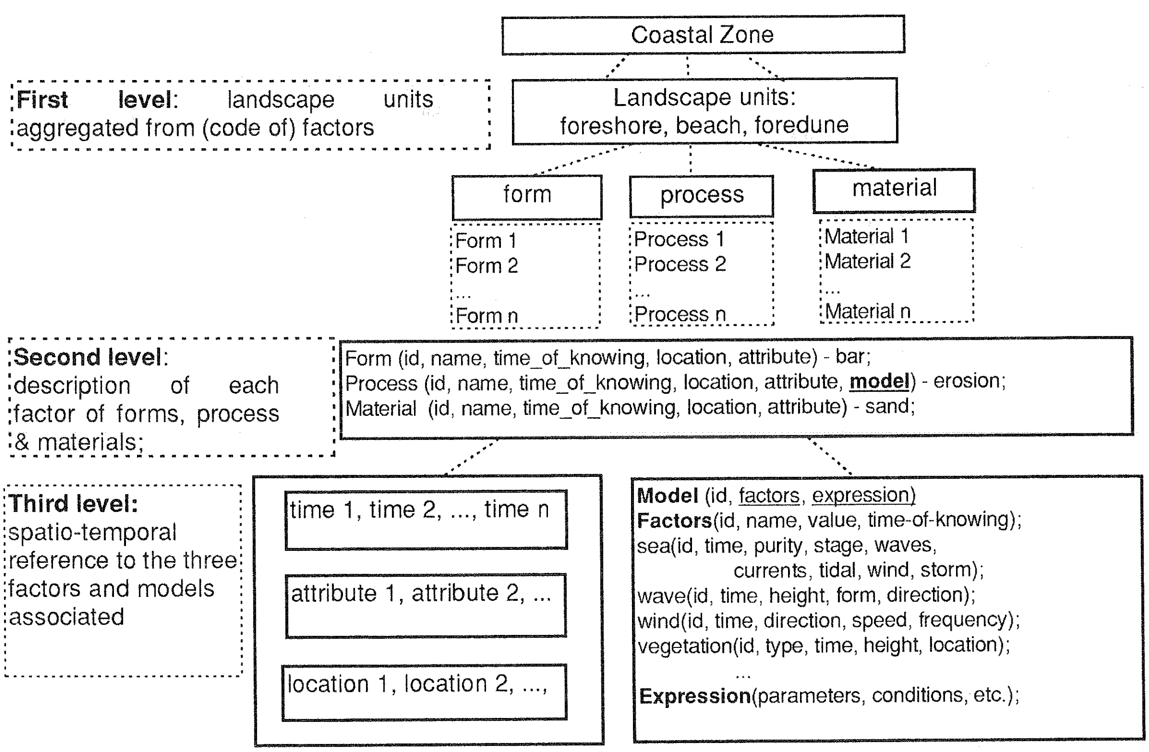

Figure 6: Data model for the study of the geomorphology of coastal zones