УДК 004.925.8

COMPUTER GEOMETRIC MODELLING OF N-DIMENSIONAL INTEGRATED DATA IN 3D SYSTEMS

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Abstract. Real-world phenomena have traditionally been modelled in 2D/3D GIS. However, powerful insights can be gained by integrating additional non-spatial dimensions, such as time and scale. While this integration to form higher-dimensional objects is theoretically sound, its implementation is problematic since the data models used in GIS (geo-information systems) are not appropriate. In this paper, we present our research on one possible data model/structure to represent higher-dimensional GIS datasets: generalized maps. It is formally defined, but is not directly applicable for the specific needs of GIS data, e.g. support for geometry, overlapping and disconnected regions, holes, complex handling of attributes, etc. We review the properties of generalized maps, discuss needs to be modified for higher-dimensional GIS, and describe the modifications and extensions that we have made to generalized maps. We conclude with where this research fits within our long term goal of a higher dimensional GIS, and present an outlook on future research.

Despite the GIS (Geographic Information Systems/Geospatial Information Systems) have been provided with several applications to manage the two-dimensional geometric information and arrange the topological relations among different spatial primitives, most of these systems have limited capabilities to manage the three-dimensional space. Other tools, such as CAD systems, have already achieved a full capability of representing 3D data. Most of the researches in the field of GIS have underlined the necessity of a full 3D management capability which is not yet achieved by the available systems.

Keywords: computer geometric modeling, GIS (geo-information systems, spatial model, simplicial network, simplicial network data model (SNDM)

Introduction. Data models, and especially integration and enterprise data models, support data and computer systems by providing a single definition and format for data. If this is used consistently across systems, then they can achieve data compatibility. An integration data model or enterprise data model provides the definition and format applications need in order to exchange and integrate data.

Each application knows how fields are to be used because of the way they are mapped to the integration or enterprise data model [1].

What is a data model for? Once upon a time a data model was simply an abstraction of the table and column structure of a database that showed how the tables related to each other. (Today we would probably call this a physical data model.) It was not long before the logical data model was introduced, which would be described as "fully normalized." However this type of data model would still be related to the contents of a single database. Another popular sort of data model is the conceptual data model. There are various thoughts about what this type of model is but typically it includes no or few attributes and might be described as being about the things the data represents, rather than about the data contained in it [2].

Theoretical support

Several spatial models have been proposed starting from the late 80s and each one shows aspects which make them more suitable for a specific field of application, from the terrain to the urban modelling. The selection of the appropriate model depends essentially on the typology of the geometric objects we're going to represent and on the complexity degree of the structure of spatial objects and theirs aggregations [3].

As underlined by Molenaar [4] and others one of the first classification of spatial models is based on the way the model represents the geometrical objects in the space: in the field-approach the real world objects are treated as a continuum in which the thematic classes of the spatial representations are linked directly to the geometric data and so the attributes are represented like a function of the position. This kind of models, in spite of the simple mathematical formulation, aren't capable to store explicitly the topological relationships. For this reason they are used mainly in the modelling of natural features where the geometrical objects doesn't have a value that can be described independently from the position in the space. This kind of features can be easily mapped through a direct association of the thematic attributes to the position in the space.

An example of field-based model is the cell-tuple model proposed by Pigot [5]. On the contrary in the object-structured approach the space is considered as an empty container in which the objects are represented with their geometric and thematic aspects. This approach can be considered as a formalization of the geometrical space in which objects are structured regardless of the dimensional and positional features. Each objects, stored independently with an unique identifier, is linked both with the thematic and geometric data. So, instead of a direct link between position and theme, in the object-structured approach the mapping of the thematic features is done through the object identifier. This identifier fulfil the purpose of storing the geometrical features independently from the position in the space clarifying the kind of geometry represented (lines, surface and solids for example are declared). It can also be used to store explicitly the topological relationship of the geometrical elements.

We can establish a general concept of an integrated data model based on irregular tessellation which may be useful for the study of multi-dimensional spatial information. In the different stages of the development, proceeding from TIN-based to TEN-based, both single-theme and multi-theme can be formalized. Theoretical support to this generalization is given by:

- the FDS (Formal Data Structure), which clearly represents relationships between the real world objects and how components of their representations are related in the spatial model;
- the simplicial complexes, which help simplify the spatial objects and systematically and consistently map them into the representations in the model;
- graph theory, which can be used to rigorously describe the representations, that is, the irregular network in this case.

An important benefit of having a theoretical basis for the tessellation-based integrated data model as a basic standard is that the compatibility across different dimensions can be established, thus:

–It is more convenient for the user to decide what kind of data model to select; single-theme or multi-theme, and in what dimension. The user can instantiate a requirement as an input parameter to the generic data model and obtain the suitable model for the application. Users need not worry whether the databases at hand are based on or limited to a certain dimension. The generic data model makes possible the handling of data across different dimensions.

–The user can navigate in different databases from one dimension to another dimension via the compatible links in various network structures, for example, from body, tetrahedron, triangle, arc, node and coordinates, provided that other databases also adopt the generic data model. In this sense, the generic data model can be regarded as dynamic.

–The more efficient organizing, sharing and exchange of data and the elimination of disparity and redundancy lead to significant cost reductions. Avoidance of duplicate data collection is also feasible if the core database is widely accessible [6].

Prior to the design of the generic version of the integrated data model, a set of definitions must be introduced.

Definitions

We limit our consideration to geometric modeling and recall the mathematical description of spatial objects following the theory of combinatorial topology described by some scientists. This theory classifies spatial objects according to their spatial dimensions defining the spatial extent of objects. The simplest form of a geometric element for each dimension is called a simplex. For example, a node is a 0-simplex, an arc (a straight line consisting of two nodes) a 1-simplex, a triangle a 2-simplex, and a tetrahedron a 3-simplex.

Spatial position is defined by linking nodes to coordinates. Based on the concept of minimal objects and the notion that a minimal objects and the notion that a minimal object in a higher dimensions, the following definitions can be given.

Definition 1: The metric dimension is defined by the number of linearly independent axes denoted by the coordinate tuple [7].

For example, nodes are defined by coordinate pairs in 2-dimensional space, by (x, y, z) in 3-dimensioanal space, and by an n-tuple in n-dimensional space.

Definition 2: Any simplex of dimension n, called an n-simplex, is bounded by $(n+1)$ geometrically independent simplices of dimension $(n-1)$ [8] [9] [10] and $n+1$ simplices of dimension 0 (which are in fact the vertices of K_{n+1} complete graph).

For example, a tetrahedron (3-simplex, K_4 complete graph) is bounded by four triangle (2-simplies) and four nodes (0-simplies); a triangle (2-simplex, K_4 complete graph) is bounded by three arcs (edges of a triangle, 1-simplices) and three nodes; an arc (1-simplex, K_4 complete graph) is bounded by two nodes. Arcs are geometrically independent if they are not parallel and none of them is of length zero.

Definition 3: Confining analysis to an n-dimensional metric space, two n-simplices are always incident at a simplex of dimension $n-1$.

The above definition can be turned into a component relation that is being shared. For example, in 1-dimensional space $(x\neq 0)$, a node can be shared by at most two straight-line segments (whereas in two or higher dimensional space, a node can be shared by an infinite number of arcs); in a 2-dimensional space, an arc can be shared by only two triangles; in 3-dimensional space, a triangle can be shared by only two tetrahedrons. Similarly, in a 4-dimensional space, a tetrahedron can be shared by only two 4-simplices (see Figure 1 for graphic illustration).

Note that the above definitions only hold for simplices; they do not hold for complexes.

Given the above three definitions, a generic n-dimensional data model can be derived following the logic we observed when extending our model from 2D to 3D. Figure 2 illustrates the nD data model. The generic data model can be illustrated elegantly, and it has the advantage that objects of dimensions higher than three need not be given names. The term ‘simplicial network’ is, threrefore, introduced to refer to the nD network. The definition of a simplicial network can be given:

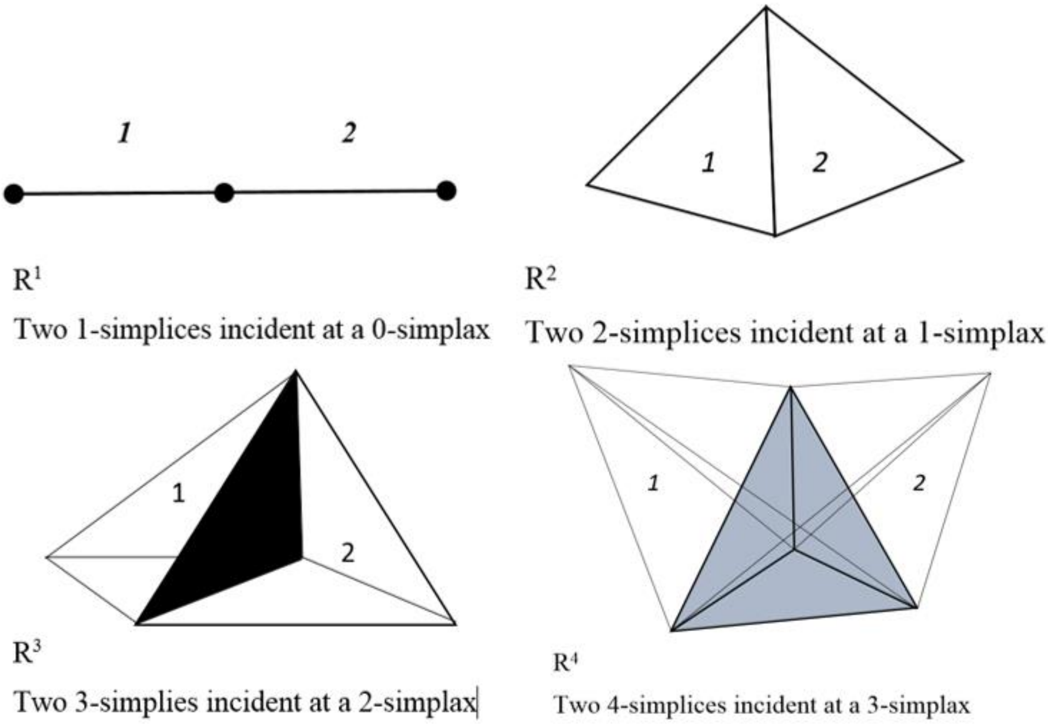

Figure *1.* – Examples of two n-simplices incident at an (n-1)-simplex in R^n

Definition 4: An n-dimensional simplicial network is a network of simplices of different spatial dimensions, ranging from *0* to *n*-dimensions.

Definition 5: a finite set of simplices constitutes a complex that represents a spatial object.

Definition 6: A simplicial network is composed of a set of complete sub-graph. The simplicial network itself need not be a complete graph. Either a simplicial network or each complete sub-graph can be, but need not be, a planar graph.

Single-theme and multi-theme

A feature of a data model with one topic is that an instance of an object type belongs to only one thematic class, and an instance of a geometric type (node, arc, triangle, tetrahedron) can be defined as part of only one instance. type of object (on the topic). For a multi-topic data model, an instance of an object type still belongs to only one thematic class, but an instance of a geometric type can be defined as part of one or more instances of an object type.

In the framework of a multifaceted concept, it is necessary to distinguish between two types of complexes. A homogeneous complex (feature) is a set of adjacent simplexes of the same dimension, all of which relate to only one topic. A heterogeneous complex (overlapping part) is a set of adjacent simplexes of the same dimension that are associated with more than one topic. A heterogeneous complex is part of two or more homogeneous complexes. Introducing homogeneous and heterogeneous complexes, we can solve the problem of “more to many” relations between geometric primitives and objects. A formal definition of a multi-dark integrated n-dimensional data model can be given.

Definition 7: A spatial object is represented by a complex. A complex is a finite set of simplices. Two or more complexes can overlap; in other words, their intersection yields a non-empty but closed and contiguous set of simplices that are embedded in the network structure.

Figure 2 shows the nD data model for the single-theme concept. Figure 3 shows the corresponding multi-theme data model.

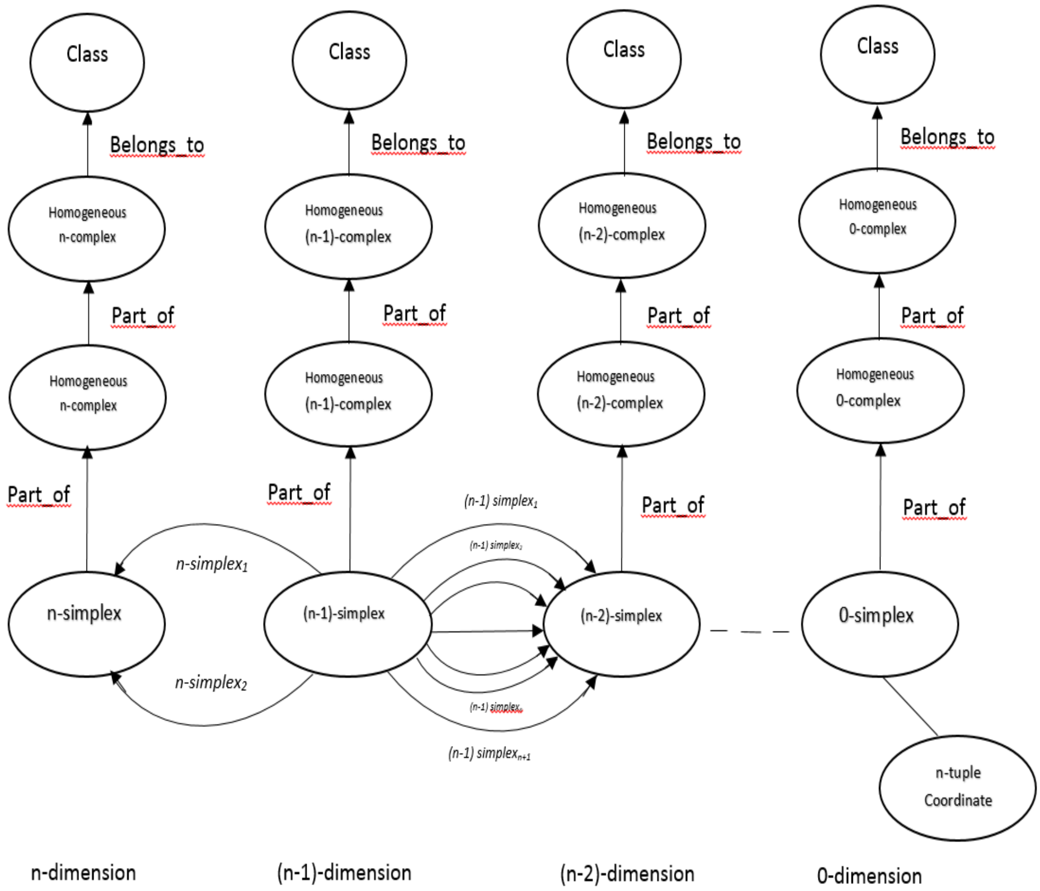

Figure *2*. – A generalized *n*-dimensional data model for single-theme

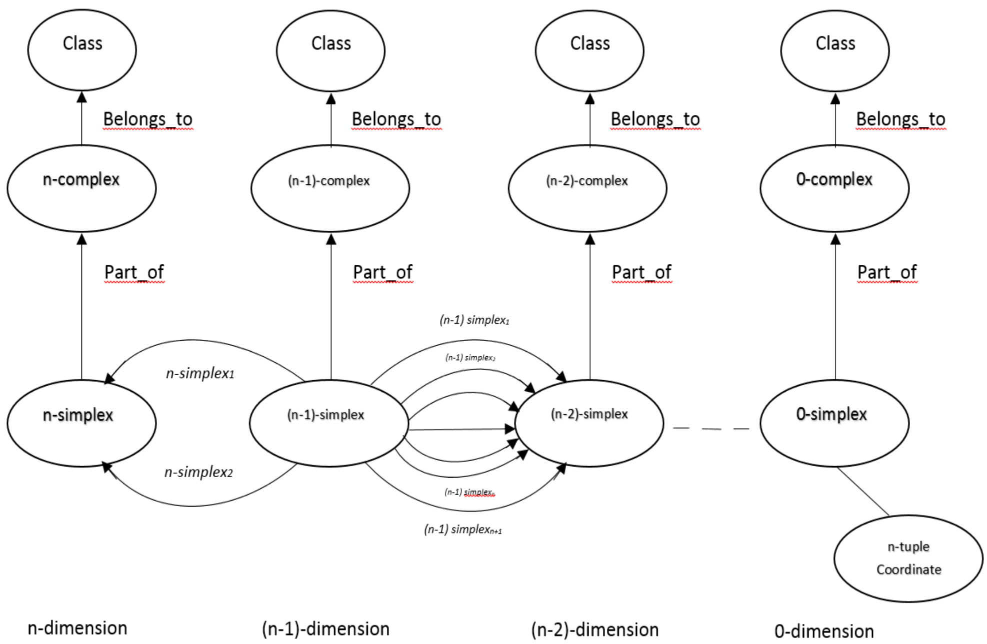

Figure 3. – Generic multi-theme data model for n dimensions

The multi-theme data model can be seen as an extension of the single-theme data model, as it accepts objects that share the same spatial region. This extension means two or more objects can have overlapping parts (body, surface, line, point). A typical example is of layers of soil and a volume of ground water sharing the same spatial region.

Conclusion

In contrast, the metric information surveyed is usually organized and structured for use by architects and engineers in creating their restoration projects. This implies a shift from an approach to managing spatial data for architectural heritage to managing spatial data on an urban scale. This is due to differences in the semantic display of data and the representation of geometric objects. A three-dimensional view of the construction of spatial information management is assumed in fact, while a three-dimensional GIS is still open to research. On the other hand, the semantic display of constructing geometric information is not yet the standard obtained through best practices.

The spatial model allows you to integrate two types of real-world objects into one database: deterministic and indefinite spatial objects and their components. This integration allows you to better represent the spatial relationship between the two types of features. Defined features – features with distinguishable boundaries, such as buildings and roads – can be represented directly by model elements. Uncertain spatial features – features with incorrect boundaries such as soil layers, temperature, and mineral deposits – require an indirect representation.

To contribute to the development of three-dimensional GIS architecture based on structural integration, the design of an integrated data model and the development of a method for constructing a spatial model were carried out. The simplicial network data model (SNDM) is the result of conceptual design. SNDM provides general concepts valid for spatial models ranging from 2D to nD.

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ПРИМЕНЕНИЕ МЕТОДОЛОГИИ DEEP LEARNING В БИОМЕДИЦИНСКОЙ СЕГМЕНТАЦИИ ИЗОБРАЖЕНИЯ

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Аннотация. В статье рассмотрены реальные явления, которые традиционно моделируются в 2D / 3D ГИС. Однако мощные системы обработки можно получить, интегрируя дополнительные внепространственные измерения, такие как время и масштаб. Хотя такая интеграция для формирования многомерных объектов теоретически обоснована, ее реализация проблематична, поскольку модели данных, используемые в ГИС (геоинформационных системах), не подходят. В этой статье мы представляем наше исследование по одной возможной модели/структуре данных для представления наборов данных ГИС более высокой размерности: обобщенные карты. Он формально определен, но не применим непосредственно к конкретным потребностям ГИС-данных, таким как поддержка геометрии, перекрывающиеся и несвязанные области, отверстия, сложная обработка атрибутов и т. д. Мы рассматриваем свойства обобщенных карт, обсуждаем необходимость модификации для многомерных ГИС и описываем модификации и расширения, которые мы сделали для обобщенных карт. Мы заключаем с тем, где это исследование вписывается в нашу долгосрочную цель более высокомерной ГИС, и представляем взгляд на будущие исследования.

Несмотря на то, что ГИС (географические информационные системы/геопространственные информационные системы) были обеспечены несколькими приложениями для управление двумерной геометрической информацией и организация топологических отношений между различными пространственными примитивами, большинство из которых эти системы имеют ограниченные возможности для управления трехмерным пространством. Другие инструменты, такие как CAD-системы, уже имеют достигнута полная возможность представления 3D-данных.

Ключевые слова: компьютерное геометрическое моделирование, ГИС (геоинформационные системы), пространственная модель, симплициальная сеть, МДСС (модель данных симплициальной сети).