Some conceptual issues on 3D Urban GIS

The development of 3D Urban GIS is not only a technological issue but also a conceptual one. The evolution to multi-dimensional systems still have to overcome strong inertia: the 2D way of thinking in spatial representations. The true 3D conceptual approach adopted here, provides a solution to representing some 3D spatial objects in a new 3D data structure.

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Introduction

There is always strong resistance to global changes and innovations. A technical development or a new system must overcome a strong inertia. This phenomena is even more critical as 3D information is concerned. Moving to the third dimension is not only a technical challenge but also a conceptual evolution. Conceptual evolution in geo-information aspect means that people have to give up the traditional 2D representation in favour of a true 3D representation and 3D reasoning of space.

For many years, the scientific community and the GIS industry have explored and developed 3D GIS for discrete objects for specific purposes (facility management, environmental issues, etc.). Most commonly, the researches and developers focus on technical aspects: how to acquire 3D data; how to manage and handle 3D information; how to query and analyse it. The knowledge on 3D data acquisition grows continuously: classical topographic techniques, GPS, photogrammetry (aerial and satellite), laser altimetry techniques are already available and largely in use for reconstructing 3D models. 3D GIS infrastructures are flourishing and many commercial solutions for 3D visualisation are being available. The practical limitations to the use of 3D information decrease and still in most of the cases (especially in urban context), the evolution to real 3D geo-objects is rather slow. Apparently, moving to 3D GIS is more than technical developments; it is a conceptual step forward. In this paper, we present some issues on 3D Urban GIS. First we will take a closer look to the 3D objects of interest. Then we will present a new data structure based on a spatial model dedicated to 3D objects.

There are two important issues to be considered. Firstly, 3D GIS must present real advantages compared to the current 2D solutions. Investing in 3D systems is rather costly. It is well understandable that people are reluctant to change just for the sake of having 3D applications. 3D Urban GIS (or even 4D, including time changes) tend to better render the complexity of the real world and therefore is expected to provide more efficient simulations and space analysis. Secondly, 3D GIS have to preserve 2D analysis and ensure the production of conventional 2D maps. The process should not be more complex than producing 2D maps from 2D GIS.

3D objects of interest

Types of Geo-object

When discussing 3D urban objects, people generally think of terrain, buildings and vegetation. People familiar with underground urbanism, naturally consider also underground infrastructures (sewer, pipes, tunnel, etc.). But objects of interest in the urban environment go far beyond. Let's go back to a general classification of real objects. One can distinguish four basic groups of real objects, i.e. juridical objects (e.g. individuals, institutions, companies), topographic objects (e.g. buildings, streets, utilities), fictional objects (e.g. administrative boundaries) and abstract objects (e.g. taxes, deeds, incomes). Since all these objects have semantic characteristics, the geometric characteristics of real objects are the leading criterion of the grouping. Therefore, there are objects with either: 1) non-complete geometric characteristics (i.e. only location); 2) complete geometric characteristics and existence in the real world; 3) complete geometric characteristics and fictive existence; and 4) without geometric characteristics.

According to this classification, the 3D topographic objects are basically the 3D spatial objects currently maintained (or intended for maintenance) in a variety of information systems. The need for 3D fictional objects is usually not that transparent. While it seems normal to evolve from a 2D representation of building to its 3D representation (because this is the reality), this is not the case for fictional object (municipality unit, statistical unit, or other fictional phenomena).

3D fictional objects

Cadastre supplies very good examples of fictional objects, e.g. cadastral parcels, unmovable properties. A compromise about the 3D nature of property exists. Without considering technical constraints and present solutions, it seems obvious that the best-fitted solution for a property is to model it in 3D (figure 1). 3D cadastral units (instead of 2D) should be the only (or at least the best in most of the case) solution to represent it. The primary reflex when upgrading the present 2D cadastral model may be to keep the 2D object's definition and add some 3D extensions. Even if the result is satisfactory, the approach is incomplete and limitative. The opportunity of working with 3D data allows us to consider the 3D world in which many objects can significantly evolve.

The challenge of 3D GIS is to support analysis between all kinds of real objects. If 3D GIS incorporates only 3D topographic objects and no 3D fictional objects, some analysis would be simplified or even truncated. Such simplification may also have the effect of a strong brake to the evolution of 3D GIS. The real world is very complex. Even if some generalisation can still be done, the up-growing technical tools should in a near future allow us to work in complex virtual representation of the world where all the kind of objects could be represented and managed. Figure 2 gives a general idea of the different potential objects of such a system.

3D data structure

In our investigation, we have also tried to tackle the problem of 3D data structure looking from a new 3D geographic-information point of view. The intention is to escape from the classical understanding of GIS as a system maintaining topology. Instead, we consider our perception for 3D objects, urban needs and activities.

The Dimensional model that we have developed is not a topological one, since the basic mathematical space is different. The commonly used mathematical spaces to represent real world are the set-based space, topological space, metrical space and Euclidean space. For example, the topological models are defined on the basis of the topological space. Our model is the first one defined in the affine space. This mathematical space is very appropriate for 3D data abstractions because it allows definition and utilisation of convexity properties of objects.

There are many 3D data structures ranging from boundary representation (B-rep) to voxel and CSG. B-rep has been widely accepted as the most suitable representation for 3D urban data. The definition of the Dimensional model relies on the B-rep approach (i.e. the objects are represented by their boundaries) and constructing rules derived from the theory of affine spaces and convexity properties. This data model can be used for two purposes: as a spatial data model and as a framework for representing spatial relationships between the objects.

The major benefit with respect to storage of data is the possibility to maintain a minimum amount of data needed to retrieve the geometry of an object. For example, if two cubes touch each others like in the figure 3, there is no deterioration of the original cube faces. This contrasts the traditional topological approaches that require subdivision of intersecting faces. For example, the red cube would have 7 faces. The “touch” relationship is explicitly stored outside the object description. Such an organisation of objects ensures precise spatial analysis to be carried out (see Billen for further details). This approach is very appropriate for integrated storage of fictional and topographic objects, since the factual objects would not partition the topographic objects.

Furthermore, 3D visualisation is greatly facilitated. Since the objects are represented with the minimal set of composing elements, the time needed to extract the geometry of the objects (or other geometrical operations) is significantly reduced (compare to topological representations) and approaches the speed of geometric models.

The model can be used to represent spatial relationships. Similarly to the topological approach, dimensional element are introduces and investigated for their interrelations. On the basis of these interactions a conclusion on the type of relationsips between the objects is made. The approach is similar to the approach adopted from the OpenGIS specifications (i.e. the 9-intersection model) but allows larges set of relationships to be detected. Since one can take into consideration different dimensional elements (e.g. only 3D, or 3D and 2D), the approach can be easily fitted to the needs of a particular application. Further details can be found in Billen et al 2002.

The conceptual developments are validated in a prototype system. The prototype has been implemented in Oracle 9i in the GIS technology Section of the TU Delft. Specific spatial analysis modules have been developed in PL/SQL (high level SQL language of Oracle).

Conclusion

The will of thinking in 3D has brought us to a new approach of 3D data model, which can be see as a mean term between topological structure and a CAD structure. Going to multi-dimensional systems is a true revolution in terms of reasoning, representing and structuring of our world. The technological constraints are not the issue anymore, but a deeper redefinition of 3D concepts is necessary for this advance in the geographic information science. The proposed 3D fictional objects and the new data structure are just outcomes of such a conceptual approach.

Further reading

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Acknowledgements

We thank the Belgian National Scientific Research Foundation (FNRS) for the four-year research grant dedicated to this topic. We acknowledge the expertise of Section GISt, Delft University of Technology in the development of the prototype. A special thank goes to Bernard Cornélis for his constructive comments.