3D GIS, where are we standing

Jantien Stoter and Siyka Zlatanova
Delft University of Technology, The Netherlands
{j.e.stoter|s.zlatanova}@citg.tudelft.nl

Introduction

Since early '90 GIS has become a sophisticated system for maintaining and analysing spatial and semantic information on spatial objects. The need for 3D information is rapidly increasing. 2D GIS analysis have shown its limitations in some situations, e.g. noise prediction models (noise spreads out in three dimensions) (Kluijver and Stoter, 2003), water flood models, air pollution models, geological models (Van Wees et al., 2002). Other disciplines that have met the need for 3D geo-information are: 3D urban planning, environmental monitoring, telecommunications, public rescue operations, landscape planning, real-estate market (Stoter and Ploeger, 2003).
The breakthrough of 3D GIS seems not to come off. The developments in the area of 3D GIS are pushed by a growing need for 3D information from one side and new technologies on the other side. In (Zlatanova et al., 2002) the side of new technologies were addressed by discussing the current status of 3D GIS considering developments reported by vendors and researchers. This paper continues on that discussion and gives an extended overview on the status of 3D GIS in both research and practise.
We start with a description of technology developments in 3D GIS. Then we address the main complexities of 3D GIS: 3D object reconstruction, visualisation and navigation in 3D environments and the organisation of 3D data. We end with a discussion on where to go for a serious breakthrough of 3D GIS.

Technology progress

An important development is the improvement of 3D data collection techniques(aerial and close range photogrammetry, airborne or ground based laser scanning, surveying and GPS). Sensors are faster and more accurate than before. Other new techniques that push 3D GIS developments are hardware developments: processors, memory and disk space devices have become more efficient in processing large data sets. Furthermore elaborated tools to display and interact with 3D data are evolving .

GIS software-tools have also made a significant movement towards 3D GIS. Zlatanova et al., 2002present a survey on mainstream GIS software: ESRI (Esri, 2003), Imagine VirtualGIS (Erdas, 2003), PAMAP GIS Topographer (PCIGeomatics, 2003) and GeoMedia Terrain (Integraph, 2003). The paper concludes that major progress in 3DGIS is on improving 3D visualisation and animation. 3D functionality is still lacking such as generating and handling (querying) 3D geo-objects, 3D structuring, 3D manipulation and 3D analyses (3D overlay, 3D buffering, 3D shortest route). This is caused by the specific character of 3D data compare to 2D . Bottlenecks are still the 3D object reconstruction, the representation and navigation through large 3D models, editing and organisation of the data.

3D object reconstruction

3D GIS requires 3D representations of objects. 3D object reconstruction of real world is a relatively new issue in GIS, since generating 3D models used to be the work of CAD-designers. The 3D models created in this way were mostly industrial models designed for production purposes. Geo-applications nowadays require much more advanced functionality, e.g. linking information to the real-world objects and the possibility to identify individual objects in a 3D environment. 3D geo-objects should therefore be available as identifiable objects in a 3D GIS environment. This requires 3D object reconstruction. There are four approaches for constructing 3D models:

- bottom-up: using footprints and extrude the footprints based on laserscan data, surveying, GPS or photogrammetry data. Problem with this approach is that the detail of roofs cannot be modelled: the buildings appear as blocks in the model.
- top-down: using the roof outlines and project them on the surface level.
- detailed reconstructing of all details. The disadvantage of this approach is that it is very time-consuming.
- combination of all of them

There is not a universal automatic 3D approach. The optimal way of 3D reconstruction is often completed by manual methods. Since this is a time-consuming process, automatic or semi automatic methods are preferred. Also modelling details makes the 3D construction labour-intensively. Details should therefore be adjusted to the requirements of the application.
The approach of combining all the approaches above contains some risks since many data sources are used and combined, all with different scale and qualities. Using only few data sources gives more overview and it minimises quality risks. At the moment the manual approach is still needed to reconstruct 3D models, which is a bottleneck to model large urban areas in 3D. More research is needed to make the process of 3D construction (semi)automatic.

3D visualisation, navigation and editing of large data sets

Specific aspects that come with visualising 3D data compared to 2D data are projections, readability of data (realism), and selecting and editing 3D elements. Also interacting in 3D environments (exploring 3D models) asks for specific techniques. 3D models usual deal with large data sets, requiring efficient hardware and software. Different levels of detail (high detail when objects are close by and low detail when objects are further away) in a model improve efficiency of navigating through a model (Kofler, 1998). Different representation of objects can be stored in the DBMS or created on the fly.
To make a view realistic one can add illumination, shade, fog, textures, colour and material to the geometry.
For 3D GIS new elements need to be organised in the database compared to 2D data. Not only the spatial and non-spatial representation of the object is needed but also characteristics such as physical properties of objects (texture, colour) , behaviour (e.g. on-click-open) and different Levels Of Detail representations.

Virtual reality and augmented reality

The link between 3D geo-data and VR (Virtual Reality)/AR (Augmented Reality) improves visualizations of the 3D geo-data (Verbree et al., 2000), e.g. putting textures on objects and facilitating navigating through the 3D environment.
Virtual reality is a realistic representation of data (2D, 2.5D, and 3D), which means that details and physical properties are represented together with sounds and behaviours of the objects. Manipulation and interaction in the views can take place by mouse click, animations, navigation and exploration. All kind of devices are nowadays available to support visualisation in VR environments:

- devices for 3D display: Head Mounted Device, workbench, panorama, CAVE, Cockpit
- devices for tracking the position and orientation of the user: wire and wireless devices (gyros, accelerators), GPS
- devices for sensing the movements of the user (Power Glove)
- hardware for acceleration of input-output operations

The research on spatial querying and 3D visualisation using VRML (Virtual Reality Modelling Language) and X3D (Extensible 3D) has resulted in a few prototype systems (Coors and Jung, 1998; Lindebeck and Ulmer 1998; Zlatanova, 2000; Stoter et al. 2003).

Organisation of 3D data

3D representations

For modelling 3D objects, several 3D abstractions are possible. 3D objects can be modelled in constructive solid geometries, in which 3D objects are represented by solids. Solid modelling has its origin the CAD world. The basic primitives in constructive modelling are spheres, cubes, and cylinders and they are used with varying parameters. Set operations are applied to the basic primitives to construct 3D bodies, such as union, intersect en difference.

The advantages of CSG that they are good in computer-aided manufacturing: a brick with a hole drilled through it is represented as "just that". The disadvantages are that relationships between objects might be very complex and that real world objects may get very complex.

A second type of 3D representation is the voxel representation. A voxel is a volume element (3D "pixel"). A 3D object is represented as a 3D cubical (or spherical) array, with each element holding one (or more) data values (boolean or real). Voxels are very appropriate in modelling continues phenomena such as geology, soil etc. Voxels are also very regular in modelling: the basic unit of the model is the same. A disadvantage of voxels is that high resolution data requires large volume of computer space. Another disadvantage is that surface is not regular by nature: it is always somehow "rough".

A third method for representing 3D data is a boundary representation. The 3D object is represented by bounding low-dimensional elements (vertex (0D), line (1D), polygon (2D), polyhedron (3D)), which are organised in various data structures. This can be either simple boundary representations such as planar faces and straight edges or complex boundary representations such as curved surfaces and edges. The main advantage of boundary representations is that it is optimal for representing real-world objects. The boundary of the objects can be obtained by measurements of properties that are visible (i.e. "boundaries"). Furthermore most of the rendering engines are based on boundary representations (i.e. triangles). Disadvantages are that boundary representations are not unique and that constraints (rules for modelling) may get very complex. For example in 3D a boundary element could be a face (topologically described), a triangle or a polygon (geometrically described), with constraints such as planarity, number of points and arcs, the order of edges and nodes, relation with neighbours etc. . Constraints in 3D are even more complex: open space, neighbours, planar faces etc.

Geo-DBMS

GISs used to be organised in a dual architecture in which a GIS consists of separated data management for administrative data on the one hand and spatial data on the other hand, caused by the different nature of alphanumerical data and spatial data. In dual architecture (figure 1a) the two parts are connected with each other via links (unique id's). In dual architecture consistency of the data is hard to manage, for example if an object is removed from the spatial part, the object should also be removed from the non-spatial part.

The solution to this was a layered architecture in which all data is maintained in a single DBMS, but knowledge about spatial data types in middle ware (figure 1b). In this case the DBMS itself does not support spatial data types. This solution requires data transport from the DBMS to middle ware and consequently queries cannot be implemented optimally. The next step was the integrated architecture in which all data is maintained in one DBMS. The DBMS support spatial types and spatial functions (figure 1c).

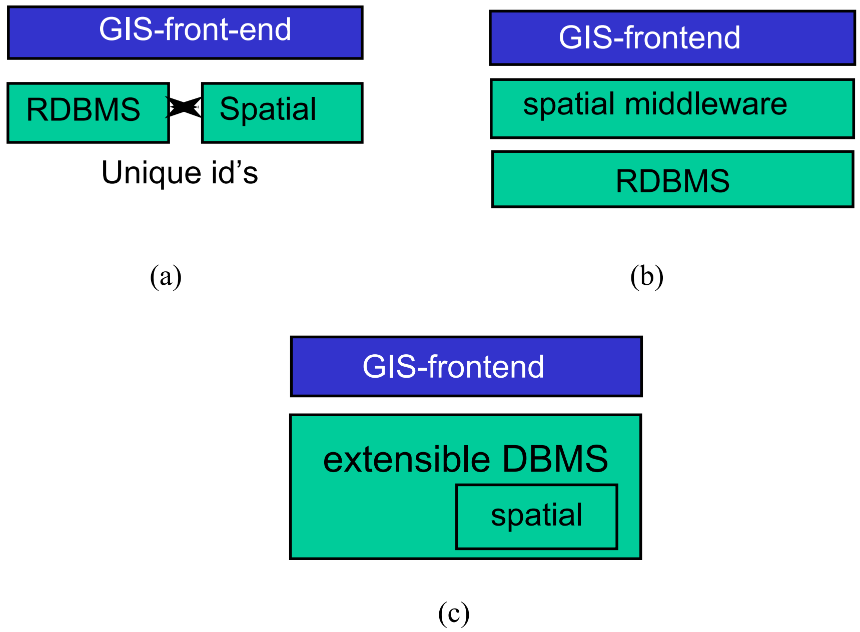

Figure 1: development of GIS from dual architecture, through layered architecture to integrated architecture

In mainstream DBMS spatial data types have been implemented according to the OpenGIS consortium specifications for SQL (OGC, 1999). The implementations are purely 2D and based on the geometrical model. Recently topology has been implemented (LaserS can Radius, 2003; Stoter et al. 2003 (2)) based on the geometrical model in Oracle Spatial 9i (Oracle, 2001). Current DBMSs do not support 3D objects, although z-coordinates can be used to store 3D objects. The only 3D functionalities in 3D that are available in DBMS are length and perimeter in 3D (PostGIS, 2003; Mapinfo, 2002) and spatial indexing in 3D (for example 3D R-tree in Oracle).
(Stoter and Zlatanova, 2003) describes how 3D objects can be organised in a DBMS within current techniques both in the geometrical model and the topological model. (Arens et al. 2003) implemented a true 3D primitive (polyhedron) as an extension on the geometrical model in Oracle Spatail 9i, which included operators to validate the 3D objects and 3D operators such as distance in 3D and point-in-polyhedron.
In conclusion, research results have been achieved to organise 3D objects in DBMS, however DBMS vendors still have not made the step to implement 3D objects in their geometrical model. Reasons for this may be that OGC still woks on the specifications for 3D features and consensus on a 3D topological model has not been achieved yet.

Where to go

GIS applications, which use true 3D functionalities other than 3D visualizations, do hardly exist. Also GIS and DBMS vendors are not matured towards full support for 3D. It seems that practice is waiting for vendors to make the step to 3D and that vendors are waiting for an extensive request for 3D information from practice. In this respect, the role of the researcher pursuing new 3D solutions is very critical.
In order to mature 3D GIS in the coming years the geometrical model in 3D should be developed based on OpenGIS specifications for 3D features, which still have to be completed.

The topological model will require more time and it will take at least 6-7 years until it will be fully supported in DBMSs. Once the two models are maintained by geo-DBMS, a robust set of converting functions has to be provides. Editing of the 3D models has to be further elaborated: instead of editing only individual elements (triangles, or lines), the front-end have to be able to preserve the topology of the 3D object.
The implementations of Constructive Solid Modelling and maintenance of primitives in DBMS will even take longer, since the discussion on this has not even started yet.

References

Arens, C., J.E. Stoter and P.J.M. van Oosterom 2003, Modelling 3D spatial objects in a GEO-DBMS using a 3D primitive, AGILE conference, April 2003, Lyon, France

Coors, V. and V. Jung, 1998, Using VRML as an Interface to the 3D Data Warehouse, Proceedings of VRML'98, New York

ESRI, 2003, url: http:\\www.esri.com

ERDAS, 2003, url: http:\\www.erdas.com

Integraph, 2003, http:\\www.integraph.com

Kluijver, H., de and J.E. Stoter, 2003, Noise mapping and GIS: optimising quality and efficiency of noise effect studies, In: Computers, Environment and Urban Systems (CEUS), 2003, Volume 27, no. 1, January 2003, pp.85-102 ISSN: 0198-9715

Kofler, M., 1998, R-trees for the visualisation of large 3D GIS Database, Ph.D. thesis, Technical University, Graz, Austria, 1998

LaserScan 2003, Laser-Scan Radius Topology, url: http://www.radius.laser-scan.com/

Lindenbeck, C. and H. Ulmer, 1998, Geology meets virtual reality: VRML visualisation server applications, In: *Proceedings of WSCG'98*, Vol. III, 3-19 February, Plzen, Czech Republic, pp. 402-408

MapInfo, 2003, url:http:\\www.mapinfo.com

OGC, 1999, OpenGIS Simple Features Specification for SQL. Revision 1.1, OpenGIS Project Document 99-049.

Oracle, 2001, Oracle Spatial User's Guide and Reference Release 9.0.1 Part Number A88805-01, June 2001.

PCIGEOMATICS, 2003, http:\\www.pigeomatics.com

PostGIS, 2003, url: http:\\ postgis.refractions.net

Stoter, J.E. and H.D. Ploeger, 2003, Registration of 3D objects crossing parcel boundaries, FIG Working week 2003, April, Paris, France

Stoter, J.E., E. van Nieuwburg and M.E.deVries, 2003, paper submitted to ACM-GIS conference, New Orleans, USA, November 7-8, 2003.

Stoter, J.E., C.W. Quak and T.P.M.Tijssen, 2003 (2), Topology in DBMSs, paper submitted to ACM-GIS conference, New Orleans, USA, November 7-8, 2003.

Stoter, J.E. and S. Zlatanova, 2003, Visualising and editing of 3D objects organised in a DBMS, EUROSDR workshop: Rendering and visualisation, January 2003, Enschede, The Netherlands.

Verbree, E., G. van Maren, R. Germs, F. Jansen and M. Kraak, 1999, Interaction in virtual views-linking 3D GIS with VR, International Journal Geographical Information Science, vol. 13, no.4, pp. 385-396.

Wees, J.D. van, R.W. Versseput, H.J.Simmelink, R.R.L. Allard and H.J.M. Pagnier, Netherlands Institute of Applied Geoscience TNO-National Geological Survey, Geo-informatiedag, 2002, February, 2002, Ede, the Netherlands

Zlatanova, S., A. Rahman, M. Pilouk, 2002, 3D GIS: current status and perspectives, in: Proceedings of ISPRS, 8-12 July, Ottawa, Canada, CDROM, 8p.

Zlatanova, S., 2000, 3D GIS for urban development, PhD thesis, ITC publication 69, Enschede, the Netherlands, 222 p.