Chapter 25
Working Group III – Modelling – Position Paper:
Modelling 3D Geo-Information

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3D geo-information can be thought of in several ways. At the simplest level it involves a 2D data structure with elevation attributes, as with remote sensing data such as LIDAR. The resulting structure forms a simple 2-manifold. At a slightly more advanced level we may recognise that the earth may not always be modelled by a planar graph, but requires bridges and tunnels. This 2-manifold of higher genus may still use the same data structure (e.g. a triangulation) but certain assumptions (e.g. a Delaunay triangulation) no longer hold. Finally, we may wish to model true volumes, in which case a triangulation might be replaced by a tetrahedralisation.

Each of these structures may be thought of as a graph - a set of nodes with connecting (topological) edges or links. Most workers in computational geometry, for example, would think in this way. However, because of the usual very large volume of geo-information the emphasis here has often been on (relational) data bases and their associated modelling techniques. More work is clearly needed on the integration of these two approaches. The discussion here uses the graph approach.

An example of a potential major application area is disaster management. This has become particularly relevant in the last few years, and the GIS response to this is very recent, as the 3D structures are not in place in commercial products. Latuada's (1998) paper on 3D structures for GIS and for architecture, engineering and construction (AEC) provides a solid summary of available structures and their different requirements. Briefly, there are surface or volumetric models and he suggests methods for combining 2D triangulations and 3D tetrahedralizations. Lee's (2001) PhD thesis correctly distinguished between the geometric and the (dual) topological structures necessary for building evacuation planning, but did not produce a unified

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data structure. Meijers *et al.* (2005), Slingsby (2006) and Pu and Zlatanova (2005) discussed the structuring of the navigation graph (using the skeleton or dual of the geometric graph) and the classification of the building 'polygons' (temporary walls, doors etc.)

While this research is very new, a few things emerge. Firstly, both primal and dual graphs are required. Secondly these graphs need to be modifiable in real-time (and in a synchronized fashion) to take account of changing scenarios. This implies a joint data structure (not a hybrid) where the two are fully combined. Thirdly, the structure should not be restricted to buildings (which have relatively well-ordered floors) but should apply to overpasses, tunnels and other awkward objects. The same model would apply to queries about fire propagation and flammability, air duct locations and air flow, utility pipes and cables, flooding and other related issues, where data is available. The model would also apply to other 3D applications such as geology, since the algebraic system expresses all adjacency relationships for complex 3D objects. While it is always technically possible to calculate a dual from its primal graph, it must be emphasized that this is often not ideal. Coordinates and other attributes may be lost, and the navigation in the one space will be easy, while in the dual it will become complex. The integration of the primal and the dual within the one data structure simplifies the number of element types necessary, permits the development of an appropriate 'edge algebra' (as is the case of the Quad-Edge in 2D - see Guibas and Stolfi, 1985) allows verifiable navigation, and assignment of appropriate attributes. (For example, the question: 'How do I get from this room to the next?' directly becomes: 'Give me the properties of the dual of this relationship - of the intervening wall or door.')

GIS is the integrating discipline/system for geo-spatial data from many sources for many applications. It is the natural context for various types of disaster management, route diversion, and flood simulation problems. It is basically a 2D system. Traditionally static, it may permit route modelling, and often include terrain models (TINs). It is a natural 'hub' for the import of various geographically-distributed data types - roads, polygon data, property boundaries, rivers etc. A major emphasis is on querying the attribute and geographic information.

While a good foundation, it does not include proper 3D structures - only 2D terrain models with associated elevations. Full 3D structures are needed for bridges, tunnels, building interiors etc. (N.B. recent work on extending TINs - the Polyhedral Earth (Tse and Gold, 2004) - has allowed bridges and tunnels, but only to give an exterior surface representation - not building interiors. This has been extended in Gold *et al.* 2006.) Thus in the long run, in an operational setting, 3D structures would need to be integrated within a commercial GIS. Zlatanova and Prosperi (2006) discuss the ongoing convergence between GIS and AEC, including the need for topological structures, as do Zlatanova *et al.* (2004)

The core requirement for volumetric models is the development and implementation of an appropriate 3D data structure so that the application may be run in the GIS context. The objective, as given above, is to have a real-time modifiable 3D data structure that integrates the primal and dual graphs, along with their attributes. This should be mathematically verifiable (an algebra) and implementable.

We may classify 3D data models into: Constructive Solid Geometry (CSG); boundary-representations (b-rep); regular decomposition; irregular decomposition; and non-manifold structures (Ledoux and Gold, 2006). Of these, b-reps and irregular decomposition models are the most relevant. B-reps model the boundaries of individual 2-manifolds (surfaces) as connected triangles, rectangles etc. but do not model the interiors. Well known b-rep data structures are the half-edge (Mantyla, 1988); the DCEL (Muller and Preparata, 1978); the winged-edge (Baumgart, 1975) and the quad-edge (Guibas and Stolfi, 1985). The quad-edge is distinctive in that it directly models both the primal and the dual graph on the 2-manifold, and may be expressed as an algebra. (It is often used to model Voronoi and Delaunay cells in the plane.) Irregular decomposition models (e.g. for constructing 3D Delaunay tetrahedralizations) may be constructed with the half-face data structure (Lopes and Tavarez, 1997); G-Maps (Lienhardt, 1994) and the facet-edge data structure (Dobkin and Laszlo, 1989). Half-edges and G-maps do not directly reference the dual structure (a property we need), and the full facet-edge structure appears never to have been implemented. Ledoux and Gold (2006) have proposed the Augmented Quad Edge (AQE) as a navigational structure, but construction operators are not yet fully defined.

These are all graph storage structures from Computational Geometry. Within the GIS community most emphasis has been put on identifying feature elements and specifying their storage in a database. The actual topological connectivity would usually be established after their retrieval into memory (Zlatanova *et al.*, 2004). A possible approach to direct storage of graph structures is suggested in (Gold and Angel, 2006), where they use a form of Voronoi hierarchy to store edge structures in 2D, with the proposed extension to 3D.

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