Title: GIS/CAD Integration

Subtitle: Large-scale 3D Geo-information

Why is GIS/CAD integration important? Why is GIS/CAD integration so difficult? What are the possible directions for finding solution? These challenging questions were pinpointed
at the Bentley First Geospatial Research Seminar held on May 23, 2004, as part of BE Conference 2004. The seminar was organised in co-operation with the authors. They provide a state of the art overview of answers and issues concerning GIS/CAD Integration.

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The border between GIS and CAD is fading. CAD software has been designed to deal with large-scale models of small regions, without maintenance of attributes and geographic coordinates systems. In contrast, GIS has been designed to manage small-scale models of large regions, and to maintain attributes and a variety of geographic coordinate systems. As CAD has developed towards Architecture Engineering and Construction (AEC), integration of large-scale geo-information becomes of interest for both CAD and GIS users. CAD and GIS share one major characteristic; both deal with data of spatial nature and thus with geometry and topology. However, they used to differ in many aspects.

Table 1 summarizes the main differences.

	CAD	**GIS**
Mathematical description	Single complex objects in 3D (e.g. free-form curved surfaces) with high accuracy	Large numbers of objects in a common embedding
Coordinate system	2D and 3D orthogonal world	Many different coordinate systems model the spherical (ellipsoid or geoid) world
Coverage	Small areas	Large areas (the whole Earth)
Representation	Mainly 3D	Mainly 2D
Timescale	'Project' basis (lifecycle maintenance is a fairly recent issue)	Very long period of data collection and maintenance (almost an endless lifecycle)

Table 1, *Differences between CAD and GIS*

Why Bridging the Gap?

GIS and CAD are increasingly integrated. This is because both provide information on and deliver representations of the same real-world objects in each phase of the lifecycle. The need for an integrated approach is illustrated by applications as plan development and visualisation, data collection, Location Based Services (LBS), and Virtual and Augmented Reality (VR & AR). The design of large infrastructures, such as roads, railways, bridges and tunnels, needs both CAD and GIS information; CAD for engineering and construction, GIS for initial planning and lay-out. Plan presentation and data interaction often require different 'views' of the data:

- *2D plan view* for initial context analysis (GIS-like)
- *2.5D model view* for creating and evaluating the different design concepts (mixed CAD/GIS-like)
- *3D world view* for realistic visualisation of the subsequent design (CAD-like).

3D Data Collection
3D objects can be modelled from different data sources. Many 3D reconstruction techniques have been developed from the 2D and 3D GIS perspective. However, the resulting data set looks often more like a CAD model. This is especially true for 3D building model reconstruction. Alternative solutions include:
- Map-based by extruding existing footprints with a given height
- Image-based by using close-range, airborne or satellite images
- Point cloud-based, where the point cloud results from active sensors like laser scanning.

Surveying and mapping for GIS applications generally differs from those for the CAD community. Often CAD designers need data which are not of particular interest for GIS applications, such as trees, bushes, and traffic signs.

Geo-Semantic and Ontology
Lack of interoperability is a major problem of combined CAD and GIS use. Applications usually use different terminologies and representations and when the same terminology is used, they often refer to different semantics. Sets of shared concepts and labels (ontologies) enable description of the semantics of terminology, relevant for CAD and GIS. There are at least two ontology-based solutions:
- Standardization; all applications share a common ontology
- Use of a reference ontology, which requires translators from/to the different software applications. This solution is suitable for non-restricted heterogeneous domains

Both thematic and spatial aspects require an ontology. The semantics of spatial data can be specified in many ways. Ontologies, therefore, should have the form of a common data standard. The mainly 3D character of CAD representations and the mainly 2D character of GIS representations forces us to go beyond today's standards.

Data structures in GIS and CAD
Boundaries of real-world objects are usually visible and measured. As a result, boundary representations (B-reps) are popular in CAD and GIS; the 3D object is represented by its bounding elements: vertex/node, line/edge and polygon/face. Also rendering engines are based on B-reps. Typical weaknesses of B-reps are non-uniqueness and complex constraints: in 3D a boundary element can 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 (connectedness).

Currently most CAD systems can make a conversion between representations like CSG, Voxel, and Raster. By default they provide export to B-reps often as triangular meshes. The number of primitives in CAD is much richer compared to GIS and the precision requirements are much higher. Most of the CAD and GIS data modelling solutions have to be analyzed in view of their suitability to be used as an integrated GIS/CAD reference model.

Topology
Although topology today is more visible in GIS applications, it is equally important in CAD. However, commercial database software in the GIS field restricts topological data management to 2D (or 2.5D) only. CAD operates also with 2D topologies but on closed surfaces. Critical in closing the gap between CAD and GIS is sharing of representations of spatial objects and handling consistency by different software

environments. Although progress is being made in the definition and nomenclature of spatial primitives, a major inhibitor of consistency concerns the representations used to implement these primitives.
Research on vector representation has focused on developing the mathematical model. However, the digital implementation of the mathematical model is less well understood. New approaches for representing topology have to be looked for.

Integrated CAD/GIS framework

A true solution for an integrated CAD/GIS framework concerns formal and shared semantics and integrated data management. The development of formalized semantics is crucial to achieving the true CAD/GIS integration. First, the semantics of geometry and other information within a domain need to be formalized, that means a domain ontology has to be developed. Next, these domain ontologies have to be matched for exchanging information meaningful. This can be realized through an integrated and defined ontology covering the CAD and GIS concepts in one framework.
After having solved the semantic differences, the next step is to create an integrated model that can serve multiple CAD and GIS purposes. Different views may be defined on this representation. Management of the integrated model enables maintenance of consistency during inserts, deletes and updates. So, the same model is used as the foundation for planning, design, construction, management, analysis, presentation, and so on. Shared data management renders conversions and all the accompanying problems superfluous. This is because everyone taps from the same source. DBMSs also offer other well-known advantages such as multiple user support, transaction support, and security. Island automation will be abandoned, as company-wide –(CAD/GIS) information management becomes a reality.

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Further Reading

- Kolbe, T.H., Plümer, L., 2004, Bridging the gap between GIS and CAAD: geometry, referencing, representations, standards and semantic modelling, GIM International, vol. 18, nr. 7, July, pp. 12-15
- S. Zlatanova and D. Prosperi (edt.), 2005, *Large scale 3D data integration: problems and challenge,* CRC Press (Taylor & Francis), to be published, with contributions form T.Bittner, O.Custers, M.Donnelly L.Hui, E.Jansen R.Lattuada, P.van Oosterom, J.Stoter, V.Tao, C.Reed, R.Thompson, S.Winter, Z.Qing and S.Zlatanova

Biography of the Authors

Dr. Sisi Zlatanova graduated as a surveyor in Sofia, Bulgaria in 1983 and obtained her PhD degree on 3D GIS for urban modelling at the Graz University of Technology, Austria in 2000. After having worked as a software designer at the Bulgarian Central Cadastre (1984-1989), as an assistant-professor at UACG (1989-1995) and as a researcher at the ITC, The Netherlands (1995-1999) she joined in 2000 the section GIS Technology, OTB, Delft University of Technology. Her research interests focus on 3D GIS.

Prof.dr.ir. Peter van Oosterom obtained a MSc (ir.) from Delft University of Technology in 1985 and a PhD degree from Leiden University in 1990. An updated version of his Ph.D. thesis has been published by Oxford University Press in 1993 under the title *Reactive Data Structures for GIS*. After having worked as a computer scientist (1985-1995) at TNO-FEL laboratory, The Netherlands, and as senior information manager at the Netherlands' Kadaster (1995-2000), he joined the Delft University of Technology as head of the section GIS Technology OTB. His research themes are spatial DBMS, GIS architectures, generalization, spatial analysis, querying and presentation, Internet/interoperable GIS and cadastral applications.

Figure Captions

Figure 1, *3D real-world objects look like CAD objects*

Figure 2, *Arial photograph (left) and a 3D model reconstructed from a single satellite image (right) (Courtesy V. Tao)*

Figure 3, *Architecture of Virtual Geographical Environments (Courtesy L.Hui and Z. Qing)*

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