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The Use of a Metadata Repository in Spatial Database Development

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The Use of a Metadata Repository in
Spatial Database Development

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Abstract

Database schemas currently used to define spatial databases are deficient in that they do not incorporate facilities to specify business rules/integrity constraints[2]. This shortcoming has been noted by Günther and Lamberts [Günther & Lamberts, 1994] who commented that geographical information systems (GIS) do not generally offer any functionality to preserve semantic integrity. It is desirable that this functionality be incorporated for reasons of consistency and so that an estimate of the accuracy of data entry can be made. Research into constraints upon spatial relationships at the conceptual level is well documented. A number of researchers have shown that the transition from conceptual to logical spatial data models is possible [Firns, 1994; Hadzilacos & Tryfona, 1995]. The algorithmic accomplishment of this transition is a subject of current research. This paper presents one approach to incorporating spatial business rules in spatially referenced database schemas by means of a repository[3]. It is demonstrated that the repository has an important role to play in spatial data management and in particular automatic schema generation for spatially referenced databases.

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[2] User or business rules are a superset of integrity constraints. They include domains and triggering operations as well as entity integrity and referential integrity constraints.
[3] A place where design information may be stored, retrieved and manipulated by design tools.

1 Introduction

It is widely acknowledged that there are shortcomings associated with commercial spatial database management systems. These shortcomings lie in the following broad areas.

- Lack of appropriate query and data definition languages (DDLs) [Egenhofer & Al-Taha, 1992; Kim, Garza & Keskin, 1993]
- Poor integration between analysis/modelling tools, databases and geographic information systems (GIS) [Abel, Kilby & Davis, 1994; Chou & Ding, 1992; Dutton, 1993]
- No facilities for maintenance of database integrity/consistency [Dutton, 1993]
- Need for development of a spatial systems development theory in cognisance of mainstream non-spatial approaches [Aronoff, 1989; Benwell, 1994; Firns, 1994; Milne, 1993].

These shortcomings stem from the complexity of spatial data and the fact that systems have traditionally been developed to address specific requirements, in the geographical/land management disciplines, with little reference to traditional database design techniques. This approach is exemplified by Star and Estes [Star & Estes, 1990] in their statement:

"The first steps in developing the database for a geographic information system are to acquire the data and to place them into the system."

The study described here is an interdisciplinary one. The disciplines concerned are spatial/geographical information systems (SIS/GIS) and mainstream database system development. Many authors have noted the convergence of these two disciplines [Günther, et al., 1994; Hadzilacos & Tryfona, 1994; Medeiros & Pires, 1994; Worboys, 1994a:1]. Thus, it is accepted that there is a place for the application of traditional systems development methodologies and tools for the design of spatial information systems, and there is a growing body of literature in the area. There are many interesting problems associated with this process, but it is the specific problem of incorporating spatial business rules in data definition language statements, and then enforcing them in an active manner, which is of interest here.

Figure 1 illustrates the overall software engineering environment to which the repository is central. It mirrors the type of software engineering environment readily available for the development of non-spatial information systems. A few terms in Figure 1 warrant explanation.
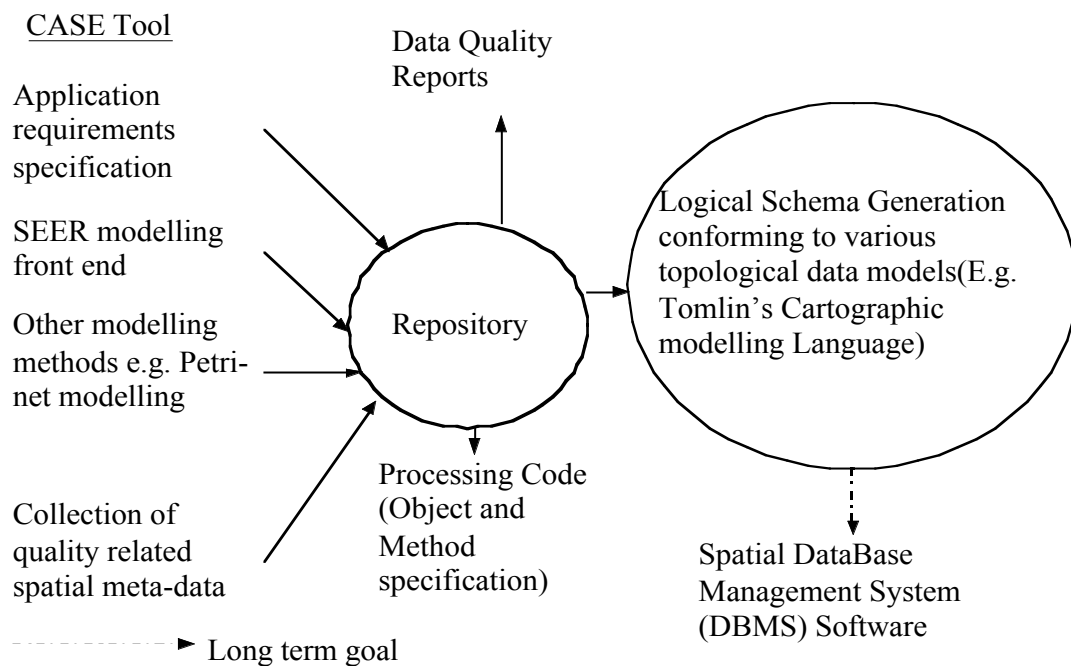
CASE Tool

Application
requirements
specification

Data Quality
Reports

SEER modelling
front end

Logical Schema Generation
conforming to various
topological data models(E.g.
Tomlin's Cartographic
modelling Language)

Other modelling
methods e.g. Petri-
net modelling

Repository

Collection of
quality related
spatial meta-data

Processing Code
(Object and
Method
specification)

Spatial DataBase
Management System
(DBMS) Software

Long term goal

Figure 1: Integrated software engineering environment for
spatial information systems

The spatially extended entity relationship (SEER) model [Firns, 1994] is a conceptual level modelling technique proposed in an earlier study at the University of Otago. It is of interest because it incorporates a method of representing the *semantics* of spatial relationships in a way that is both easy to understand and forms the basis for spatial database design. It should be emphasised however that the repository will be designed in such a way that it would accept metadata[4] from a number of front end tools.

Tomlin's cartographic modelling methodology [Tomlin, 1990] comprises a data definition language and a data manipulation language. It has been implemented as part of the GRID module of Arc/Info, a widely used GIS. The methodology is of particular interest here because the way it handles location as an entity is a similar approach to that of the SEER model. Other interesting logical data models include the GeoRelational Data Model (GRDM) [Hadzilacos, et al., 1995] and spatial extensions to SQL [Egenhofer, 1994]. It should be noted that since a repository can be used to automatically generate logical level data models there is no reason why a number of such models should not be supported.

1.1 Metadata

The concept of metadata has evolved through several disciplines. At its simplest level metadata is additional information that is necessary for data to be useful. Henderson

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[4] Simply, metadata is 'data about data' - further explanation of the term is given in Section 1.1

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[Henderson, 1987] explained metadata as data that describes what the data in an organisation's databank are, and what they mean. She also classified metadata into *dictionary* descriptions describing characteristics, relationships and uses and *directory* metadata describing where the data is and how it can be accessed. In other words metadata can be divided into those describing the informational entity being stored and those which pertain to storage and use. Spatial metadata that reflects the quality, lineage or content of a dataset is currently an area of considerable interest to the GIS community. In the geographical information systems context a detailed set of metadata content standards have been laid down [FGDC, 1994]. However this type of data is distinct from design metadata required for logical schema generation. It is therefore considered to be beyond the scope of this work. The issue of quality metadata and the storage thereof will however be of interest once integrated spatial data management systems are implemented. As illustrated in Figure 1 the repository would facilitate the production of quality reports by storing this type of metadata about datasets in associated databases.

2 Deficiencies of Current Spatial Databases

As introduced in Section 1 there are a number of issues of concern in the literature with regard to spatial information systems development. These are discussed in the following sections.

2.1 Querying and Data Definition Languages

Shortcomings in query and data definition languages have been noted by many researchers. Aronoff commented that 'The urgent need for operational spatial data handling in computer-based GIS applications has outstripped the ability of the research community to develop the needed spatial database theory and practical spatial database systems' [Aronoff, 1989:183]. Egenhofer asserted that 'The usage of standard query languages for spatial data handling has been hindered by the lack of appropriate language support for spatial data' [Egenhofer, et al., 1992]. This was reiterated by Kim et al [Kim, et al., 1993] who stated that there was no commercial database system at that time that directly supported spatial data management, and in particular, data definition and query facilities for spatial data. This situation is now being addressed with advances such as HHCODEs in multidimensional Oracle [Oracle, 1995]. It is anticipated that the work presented here will make a contribution to the body of research on data definition languages for spatially referenced databases.

2.2 Integration

There are two major concerns regarding integration; the integration between elements of a GIS and integration between different GIS software. Chou et al [Chou, et al., 1992] cited the need for a methodology for the efficient design of integration between spatial analysis/modelling and GIS and suggested the data dictionary as a vehicle for this integration. Dutton appears to support this view and introduced the notion that inconsistencies are commonplace in current spatial database systems: *'While digital cartographic exchange standards such as FIPS 173 (STDS) enable databases to feed one another - perhaps losing information, perhaps not - data remains multiply represented in autonomous archives, with all their overhead inconsistencies and*

hassles' [Dutton, 1993:157]. Abel also pointed to problems with current GIS from the point of view of integration *'current GIS have basic weaknesses as components of integrated systems and many researchers have argued that fundamental extensions to GIS are needed to achieve effective integration'* [Abel, et al., 1994].

2.3 Database Integrity

Many authors suggest that improved data consistency can be achieved by means of integrity constraints [Günther, et al., 1994; Günther & Riekart, 1993; Hadzilacos & Tryfona, 1992; Hadzilacos, et al., 1994]. This is an issue that will be expanded upon in Section 3.

2.4 Recourse to Mainstream Data Management Approaches

This issue was introduced in Section 1, where it was noted that the conceptual modelling of spatial data and its representation in accepted logical (implementation) data models have typically received little attention in the development of spatial data management systems. The focus of database design in disciplines associated with spatial information systems has been the acquisition of data. Benwell [Benwell, 1994] contended that spatial systems are similar to information systems in general. The subtle difference, in his opinion, is the fact that spatial systems are not yet supported by large digital databases. This fact has diverted attention away from system development to data collection. Spatially referenced databases are usually developed for use with spatial information systems, to meet specific output requirements. By contrast, in the area of non-spatial databases data modelling is an important aspect of contemporary system development methodologies. It has been found that a rigorous approach to system specification leads to systems that are more flexible and maintainable [Jordan & Machesky, 1990]. A number of conceptual spatial data models have been proposed [Calkins & Marble, 1987; Feuchtwanger, 1993; Goh, 1988, Hadzilacos, 1995 #239; Laurini, 1990; Wang & Newkirk, 1988; Worboys, Hearnshaw & Maguire, 1990] however, they have yet to be widely adopted commercially.

Many researchers have highlighted the loss to the spatial information systems industry resulting from this focus on data collection. Systems have traditionally been developed to address specific requirements, in the geographical/land management information systems disciplines, with little reference to traditional database design techniques. Milne [Milne, 1993] suggested that the spatial information systems industry has traditionally ignored mainstream database developments. This opinion was supported by Firns who suggested that the reason for this is that *"Developments in spatially referenced databases have taken place more or less independently of those in general (textual) database design, hence those people involved with spatially referenced databases have not been experienced in, and may not have recognised the need for, formal methods of database design"* [Firns, 1994:14]. However, mainstream database systems are not appropriate in themselves for handling spatial data. Medeiros et al [Medeiros, et al., 1994:107] pointed out that *'the data that must be integrated into GIS ... requires specialised analysis and output formatting operations not available in commercial database systems'*.

3 Spatial Business Rules and Integrity Constraints

The inability of current spatial information systems to provide integrity constraints, and suggestions for addressing this inability, are recurring themes in the database and GIS literature. Existing SIS do not incorporate facilities for ensuring the integrity of data actively at data entry. For example a road could quite readily be digitised as running through a lake. By contrast in mainstream DBMS integrity can quite readily be maintained by means of an active data dictionary or repository. This concept is further described in Section 4.2.1. For example the repository would automatically prevent a negative value being entered for a person's age in a personnel database or a withdrawal amount being entered that is larger than the balance in a banking system.

3.1 The Implications of Omitting Integrity Constraints from Spatially Referenced Databases

Worboys et al [Worboys, 1994b] acknowledge that the majority of GIS implementing the relational model use a hybrid architecture where attribute data is maintained in a conventional DBMS, but spatial data is organised and manipulated using conventional file handling techniques. They note that one of the implications of failing to maintain an entire map base within a single DBMS was the inability to provide basic DBMS functionality such as integrity control.

Gunther et al [Günther, et al., 1994] also noted that geographic information systems lack the functionality to preserve semantic integrity. By contrast in non-spatial DBMS it is commonly possible to maintain consistency according to user-defined constraints.

Medeiros et al [Medeiros, et al., 1994] cited issues of spatial integrity constraints and spatial query processing as one problem that originates from the existence of a spatial dimension. They emphasised that, in their opinion, there would never be a general all encompassing database for GIS because the different families of applications demand distinct types of database support.

Hadzilacos et al [Hadzilacos, et al., 1994] defined a Geographic Relational Data Model that incorporated topological integrity constraints. They did not address the concept of incorporating layers or topological integrity constraints in relational theory. Neither did they address the automatic transition from conceptual to logical models, although this was cited as a subject of research.

4 The Use of a Repository to Incorporate Integrity Constraints in Database Schemas

4.1 Approaches to Incorporating Integrity Constraints in Database Schemas

There are four types of business rules [Hoffer & McFadden, 1994]:

- Entity integrity : Each instance of an entity type must have a unique identifier (or primary key value) that is not null
- Referential integrity constraints: Rules concerning the relationships between entity types

- Domains: Constraints on the valid values for attributes - e.g the valid range of ages as exemplified in Section 3.
- Triggering operations: Other business rules that protect the validity of attribute values - the withdrawal example from Section 3 would be implemented as a trigger.

In the spatial domain Gaede et al [Gaede & O.Günther, 1995] are particularly interested in integrating constraints into database systems by means of queries. Queries can be interpreted as a kind of constraint, each query predicate representing a constraint that the objects in the result have to satisfy.

4.2 The Repository Approach

Currently available spatial data management systems usually require application programmers to manage the consistency and currency of linkages between spatial and non-spatial data.

One of the advantages of a well designed data base management system is that it removes the need to specify data structures in application programs. In addition mechanisms are provided for the management of relationships between data items as well as the implementation of integrity constraints. This is done by means of a repository. Hoffer et al [Hoffer, et al., 1994] stated the advantages of incorporating business rules in the repository as follows:

- faster application development
- reduced maintenance effort
- faster response to business changes
- facilitate end user involvement in system development
- consistent application of integrity constraints
- reduces time and effort to train application programmers
- promotes ease of use of database

Various researchers have suggested the repository as an integration tool for spatial analysis and modelling. The focus of their work was often specific implementations of spatial information systems rather than spatial information system design in general [Chou, et al., 1992; Robinson & Sani, 1993]
Business rules are generally incorporated in a repository in the form of domains, referential integrity constraints, and triggering operations [Hoffer, et al., 1994].

4.2.1 What is a repository?

According to Cheng et al. [Cheng, Bouziane, Rattner & Yee, 1991], the purposes of a repository include applications development in a CASE environment, enterprise information resource management and information processing and management at a global level within the enterprise. Its contents comprise metadata that model both data resources and knowledge [Henderson, 1987]. 'Data dictionary' is a somewhat narrower term, describing computer software that records, stores and processes descriptions of an organisation's data resources. This term is often used in the

database context. A data dictionary is described as holding detailed information about objects within a database including the tables and views, and the columns within those tables and views. With the advent of CASE the term 'data dictionary' was replaced with 'encyclopedia'. The major difference between the two terms is that the encyclopedia allows more sophisticated queries, and queries across CASE tool components. In addition they allow graphical depiction of the dictionary's contents. The narrowest term is the metadatabase. This is commonly used in the field of GIS and has been described as a catalogue of existing data sets [Everett, 1994]. Such a catalogue has also been developed in [Everett, 1994].
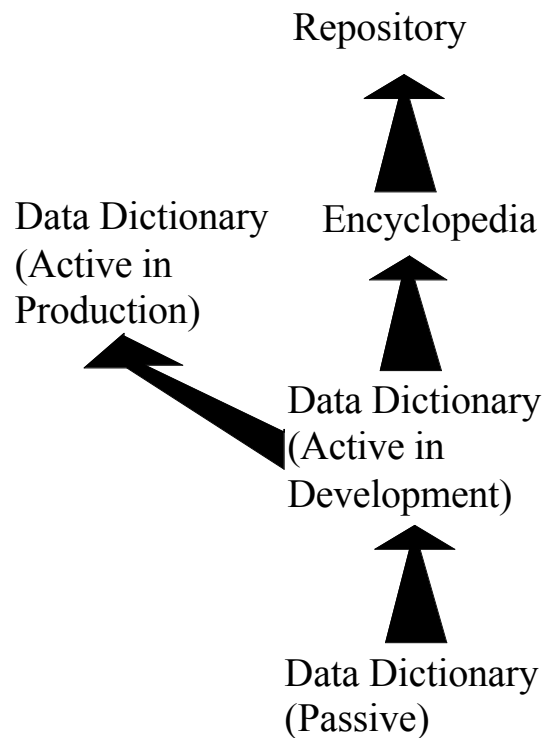
Repository

Data Dictionary (Active in Production) Encyclopedia

Data Dictionary (Active in Development)

Data Dictionary (Passive)

Figure 2: The evolution of the repository

The role of a repository has also been described as 'to manage datasets' [Shoshani, 1994]. The implication of this is that the datasets have already been collected and the database must 'fit around them'. Tannenbaum [Tannenbaum, 1994] defines the repository with reference to the evolution of CASE. In her definition the repository supersedes the data dictionary and the encyclopedia in terms of functionality. Each succeeding generation of the data dictionary, in the evolution of CASE tools, incorporated all the functionality of the last (see Figure 2).

For the purposes of this work the chosen definition is 'A repository is a place where design information may be stored, retrieved and manipulated by design tools'. This reflects the fact that metadata held in repositories are definable, loadable and retrievable in an integrated environment regardless of the originating tool. In addition, given the evolution described by Figure 2 it is assumed that the repository will be active in production.

4.2.2 Schema generation

Some non-spatial database management systems (DBMS) incorporate Computer Aided Systems Engineering (CASE) front-ends. These allow schema designs to be specified graphically using, for example, entity relationship modelling methods. Syntactically correct native SQL is then generated from entity relationship schemas through the use of a repository. Similarly, CASE tools and 4GLs have also been designed to complement each other, while 4GLs may be linked to particular DBMS through data dictionary systems.

The value of CASE tools when used with DBMS is derived from the fact that conceptual modelling methods, such as entity relationship modelling, complement database models [Cockcroft & Firns, 1994]. CASE tools provide modelling methods for the specification of system design. The automation of modelling methods within CASE environments enables the derivation of database schema definition language from graphical representations of data requirements (ie the derivation of logical schemas from conceptual schemas). It is contended that this is a desirable situation with respect to the development of spatial information systems, as shown in Figure 1.

5 Methodology

It is accepted that current GIS do not have the functionality to preserve semantic integrity. The effect of this is that integrity is compromised and we have very little idea of the accuracy of data in a given dataset. It is proposed that business rules can be incorporated in database schemas by means of a repository which is active in production. This theory will be tested by designing and implementing a spatial metadata repository. Test data will then be entered, both with and without the aid of a repository, and the quality of the resultant data sets evaluated.

6 Conclusion

It is suggested that spatial constraints analogous to 'business rules' in non-spatial databases can be incorporated into database schemas. The vehicle for storing and managing these business rules is the repository. The constraints will be implemented by means of data definition language statements, thus making a contribution to the body of research on spatial data definition languages. This goes some way towards addressing the problem of spatial data consistency by enforcing constraints on data entry, update and deletion. One outcome of this research will be a measure of the feasibility of incorporating spatial semantics and spatial data under the same architecture. That is, a move away from the present file processing approach to spatial data handling towards an extended relational approach.

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