Geophysical Research Abstracts, Vol. 7, 05732, 2005
SRef-ID: 1607-7962/gra/EGU05-A-05732

A 3D geological information system framework

M. Apel

Dept. of Geosciences, TU Freiberg, Germany,
http://www.geo.tu-freiberg.de/∼apelm

1 Introduction

Geoscience Information Systems (GIS) provide a means to create and analyse models of real world geological situations based on data. In contemporary two-dimensional (2d) GIS, geological objects are represented as map objects in two spatial dimensions. "Spatial" extensions of common 2d GIS are at present not applicable for 3d geological applications as they are not capable of representing 3d spatial geological relationships and properties with 3d spatial variation. 2d GIS and so-called 2.5d GIS represent the altitude values z of geoobjects as a continuous function of the geographical coordinates: $z = f(x,y)$. That way such systems cannot model 3d geological objects whose boundary geometry features multiple z-values for a x,y-value and non-manifold topology, like faulted horizons.
On the other hand, 3d geomodeling software provides data models and functionality to represent sophisticated geological situations in three spatial dimensions as geomodels. Geomodeling systems are widely applied in the petroleum and mining exploration industry, geological surveys, and academic science departments. Such systems are commonly based on 3d discrete topological data models and interpolation methods like Discrete Smooth Interpolation (mallet). In a sense, 3d geomodeling software can be regarded as core 3d GIS user applications.
The increase of digital geodata and the possibility to create detailed regional 3d geomodels results in new, specific needs for geodata management, and new opportunities for geodata query and analysis. However, both fields are underdeveloped in existing 3d geomodeling environments. This becomes obvious especially when comparing geomodeling software with mature 2d geographical information systems.
The objective of this research project was the development of geologically sensible

query functionality for geometrical, topological and geological properties, and the integration of 3d geological modelling and data management system components in a generic framework.

2 Data model for 3d GIS

An integrated data model for geological data need to account for both primary observation data and geomodels. A geomodel is an abstract digital representation of a part of the Earth subsurface. Such models are derived by interpolation of data observed at points and can represent geological situations in 3d space. Geophysical models may be used as additional constraints.
Two main approaches exist to partition the space into a set of mutually exclusive and collectively exhaustive volumes: discrete geoobject-based models and grid models. In order to create a digital geological model using the object-oriented approach, the subsurface space is discretized into spatial regions based on a chosen parameter, like stratigraphy or lithology. In practice, a complete geomodel is composed of both a unique structural model representing the topology and geometry of the subsurface geoobjects, and a property model providing a mechanism to model the material properties of each geoobject. Several data models exist which allow to represent primary geological field observations (for example, NADM soller99) and 3d geomodels (for example, tesselated Weiler boundary representation weil88, Generalized Maps gmaps).
Several database-supported 3d GIS have been proposed (see, for example, breunig00). These concepts have in common that they are not based on a data model which consistently integrates 3d geomodels and primary geoscience data. Such an unified data model is required in order to create reproducible, maintainable 3d geomodels and make primary geological data accessible in a user-friendly way. Analogous conceptual data models have been proposed for geological maps (for example, NADM soller99).
In this work, a data model for observation data based on the NADM model has been integrated with the tesselated Weiler boundary representation data model for 3d geomodels. This data model allows to represent sophisticated geological situations and is, for example, implemented in the popular 3d geomodeling software Gocad. The OpenGIS consortium standard Geographic Markup Language (GML version 3.1.x, gml) is largely compatible with this data model. If possible, standards (UML, XML Schema and GML) were used in order to provide maximum flexibility, interoperability, and long-term usability.
The approach proposed here distinguishes between discrete model cells (for example,

vertices) which support a smoothly interpolated geoobject and cells which represent primary observation data. Such cells store a pointer to a XML document (for example, an outcrop description) in the observation database and can interactively be queried. Thus from one consistent observation database a set of different models can be derived and maintained.

3 Spatial geoscience queries

One primary concern of this work is to develop novel query functionality based on geological, geometrical and topological properties and relationships in 3d space. The investigation of 3d models of large and complex geological situations using queries may lead to new insights and may allow the systematic search of exploration targets. To illustrate possible geoscience queries in a GIS, here are some examples:

- *"Select the set of fault surfaces with given mean normal direction AND a given geochemical anomaly within a certain distance."* This query may be used for exploration sensitivity studies for hydrothermal ore deposits.
- *"Select the set of geoobjects with a certain permeability AND which have given faults as their boundaries."* This type of query can support the understanding of fluid movements.
- *"Select the sets of geoobjects which occur in a given stratigraphic succession."* This can be used to detect stratigraphic patterns.

Queries important for geological purposes are generally based on the topology, geometry, and non-spatial geological properties (for example, age and material properties) of geomodel objects. Spatial and non-spatial query operators may be combined with logic expressions in order to provide a powerful query language. Applications of such a query language are the selection of sub-sets, spatial operators, or model consistency checks.
For this purpose, an algebraically sound geospatial query language based on the theory of generic spatial queries paredaens and XQuery (standard XML query language, xquery) has been developed and implemented as a plug-in for the geomodeling system Gocad. It particularly covers geometrical queries on discrete geomodel objects based on shapes, directions, properties and relationships, topological queries for connectivities, relationships, and queries for non-spatial properties and geological semantics. As the data model is a topological one, the computation of topological queries is very

efficient. Built on top of a 3d geomodeling system, such GIS-like query functionality can be regarded as a step towards a 3d geoscience information system.

4 Geodata management

For common 3d geomodelling projects a large amount of geodata needs to be stored and served to multiple users for a long time. Often geological databases need to be maintained for decades. Therefore, for 3d GIS projects it is essential to have an efficient and reliable data management. Currently, no appropriate solution for the integrated storage and query of primary geological data and 3d geomodels exists. The 3d GIS proposed in this article features a:

1. client-server architecture, where geomodelling applications act as clients of a database server for geomodels and primary observation data.
2. XML-based storage and query, including 3d-spatial queries.

The coupling of a professional 3d geomodelling software and a DBMS in a component- oriented framework can provide a 3d geoscience information system offering comprehensive spatial and geological query capabilities. In order to realize the proposed system, the extensible standard XML query language has been extended by 3d geometrical and topological operators. Moreover, an application server frank03 has been developed in order to cope with computationally demanding spatial queries. The system has been implemented in a generic way and can be used with various XML-supporting databases and applications, including geomodeling systems and internet browsers.

5 Results and Conclusions

As a novel result, a 3d GIS framework has been created. Similar to common 2d GIS, the 3d GIS framework is not a single-component application. Instead it is a system integrating several software components and based on a novel data model incorporating both geomodels and geological observation data. The 3d GIS framework characterized by the following features:

- an integrated data model for geological observation data and 3d geomodels. This allows to store observation data and geomodels as valid XML documents in a XML database. The current XML Schema data model includes geological observation points and tesselated Weiler Boundary Representation geomodels. Additional data types may be added, for example wells and grids.

- functionality for querying observation data and 3d geomodels based on their 3d geometrical, topological, material, and semantical geological properties were developed and implemented as plug-in for a 3d geomodelling user application.
- for 3d spatial database queries, the standard XML query language has been extended with 3d spatial operators and an application server for spatial query computation has been developed. The spatial database query operations are computed using a XML application server which has been developed for this specific purpose. This technology allows sophisticated 3d spatial and geological database queries. Data can be retrieved by geomodelling software or other applications via the internet by non-spatial or 3d spatial XQuery requests.

This 3d GIS framework is designed to support the data management and data analysis of 3d geomodelling projects which usually incorporate large sets of geological observation data and 3d geomodels. Currently, the system is being tested in several geological situations, partly in collaboration with the Geological Survey of Saxony. An interesting topic for further research is the development of a spatio-temporal paleogeographic GIS, which could benefit from the result shown here.

References

[Breunig (2001)] Breunig, M. 2001: On the way to component-based 3D/4D Geoinformation Systems. LNES No. 94, Springer Verlag. 179 p.

[Frank (2003)] Frank, T. 2003: Design and Implementation of a 3d XML application server. Unpubl. M.Sc. Thesis, University Freiberg, 97 p.

[GML (2003)] OpenGIS Geography Markup Language (GML) Implementation Specification v.3 2003, http://www.opengis.org.

[Lienhardt (1994)] Lienhardt, P. 1994: N-Dimensional Generalized Combinatorial Maps and Cellular Quasi-Manifolds. Journal on Computational Geometry and Applications, volume 4, p. 275-324

[Mallet (2002)] Mallet J.-L. 2002: Geomodelling. Oxford University Press Monograph.

[Paredaens (1994)] Paredaens, J., Van den Bussche, J., Van Gucht, D. 1994: Towards a theory of spatial database queries. Extended abstract, Proc. 13th Symp. on Princ. of Database Systems, Minneapolis, p. 279-288.

[USGS (2004)] North American Geologic Map Data Model Steering Committee, 2004, NADM Conceptual Model 1.0 - A conceptual model for geologic map information: U.S. Geological Survey Open-File Report 2004-1334, 58 p.

[Weiler (1988)] Weiler, K. 1988: The radial edge structure: a topological representation for non-manifold geometric boundary modelling. Geometric Modelling for CAD Applications, Elsevier Science Publish., p. 3-36.

[XQuery (2003)] XQuery 1.0: An XML Query Language, W3C Working Draft, http://www.w3.org/TR/xquery.

[XML (2003)] Extensible Markup Language (XML) 1.0. W3C Recommendation 6/2000, http://www.w3.org.