Development of a 3D GIS based on the 3D modeller Gocad

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Abstract

Large-scale mineral exploration studies or regional mapping campaigns often result in large and complex spatial models consisting of many geological objects. For those models it becomes difficult to determine the spatial, temporal, and structural relationships between the modelled geological objects and their consistency. This task requires tools for querying the model for those relationships, and methods to represent the query result graphical or using meta-data. So far, a set of topological and directional query tools, and a legend have been implemented as a prototype version in the Gocad 3D modeller.

1 Introduction

What means “Geo-Information System” in 3D? In geology, classical 2d/2.5d-GIS packages are extensively used in mineral exploration sensitivity studies or for general regional mapping campaigns. They are mainly employed to create, manage, query and analyse georeferenced maps [Bonham-C. 2000]. While real geological objects are essentially 3D, a map often represents just a cross-section through a 3D model with complex topology and geometry. For those, 2D/2.5D-GIS packages must fail to interrogate and analyse the geometrical and topological relationships and properties of the geological objects as they do not contain this information.

To solve this task, we have to use a model with true 3D topology and query it for those relationships and properties. As a result, one can obtain either a subset of the query argument objects fulfilling the search constraints or a boolean answer whether a given constraint is matched. The queries important for geological purposes are based on the topology, geometry, direction and attributes of model objects and associated meta-data. The different types can be logically combined to sub-sample data sets in order to constrain exploration targets or to test the conceptual geological model. To illustrate the vast application fields, here are some query examples:

- highlight all conjugate fault surfaces with an east-west strike and a gold anomaly in their 100m-vicinity
- which model regions are cut by a certain fault?

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- detect structural patterns using stereographic projection and cluster analysis, highlight the cluster in the 3D camera;
  show all parts of a fault network with a certain mean normal and tolerance
- highlight all model regions of Cretaceous AND sandstone AND with a certain permeability
- highlight all model regions with a certain f(pressure,temperature,time) property

As the base for this work the 3D modeller Gocad, version 2, has been used [Mallet 1997]. The topological kernel, the notion of region and geological information provide an excellent starting point for the development of functions querying 3D model objects. A requirement to all of them is that they do not change the model itself, store if possible nothing in memory, and give fast answers. In this work, a basic collection of such Gocad-based GIS tools has been implemented.

2 3D GIS-Tools - Overview of Functionality

Query tools acting on a 3D model can be conceptually distinguished in spatial, temporal and meta-data query functions and in query representation tools.

2.1 Spatial query functions

Spatial GIS functions can be defined as interpretative data exploration tools based on the geometry, topology, orientation and proximity of model objects. Spatial query functions can be used for the back-sampling of model objects to create object subsets. These functions can be classified as shown in Table (1). For the implementation, the current topological kernel of Gocad has been used. The queries can act on model-regions (e.g. “Layer”, “FaultBlock”) and on atomic objects (“Part”).

Topological queries must be carried out on each topological simplex of the queried objects. Let A and B be two discrete topological model-objects,we can define the following set of simple topological relationships if the following sufficient conditions are true (after [Breunig 2000]):

1. If all simplexes of A are disjoint with all simplexes of B ⇒ $A \cap B = \emptyset$
2. If all simplexes of A and B are by pairs equal ⇒ $A \equiv B$
3. If a boundary simplex of A touches a boundary simplex of B from the outside and if all other simplexes of A are disjoint to all other simplexes of B (neighbourhood) $\overline{A} \cap \overline{B} \neq \emptyset$
4. If a simplex of A intersects a simplex of B ⇒ $A \cap B \neq \emptyset$
5. If a boundary simplex of B touches a boundary simplex of A from the inside and if all other simplexes of B are inside A (A covers B) ⇒ $A \supset \overline{B}$
6. If a boundary simplex of B touches a boundary simplex of A from the outside and if all other simplexes of A are inside B (A covered-By B) ⇒ $\underline{\overline{A}} \subset B$
7. If all simplexes of A are inside the boundary simplexes of B ⇒ $A \in B$
8. If all simplexes of B are inside the boundary simplexes of A ⇒ $B \in A$

	Topological queries:	*Metrical queries:*	*Directional queries:*
Relationships: GObjxGObj->bool	intersection, inclusion, exclusion, equality, neighbourhood	spatial buffer	direction buffer, relative situation
Functions: GObj->real, GObjxGObj->real		(already implemented in Gocad 2:) *binary*: displacement, distance ; *unary:* length, surface, volume, curvature	*binary*: angle

Table 1: Classification of spatial query functions. (GObj = gocad object)

Since this can give different answers for the simplexes of an object (e.g. some overlap and some are contained) a superior topological relationships has to be determined: overlap > covers, covered-By, meet > contain, inside. Using these relationships, one can formulate and answer questions to model regions (e.g. “which are the neighbours of a region”, “is this region within our permit area”) or atomic parts (e.g. “which surface parts are cut by a fault surface”). For large geological models, a graph showing the topology of the model regions and faults could aid the understanding of the geological relationships but has not yet been implemented.

Directional buffer queries are useful for objects with a large 1D or 2D extension like fault surfaces and their map traces. Given a direction $D(\varphi, \delta)$ (e.g. azimuth and dip angle) and a confidence interval angle α, the task is to select all parts of a multi-part object whose mean extension lies within that direction interval (Figure 1). To determine the mean extension with spatial dimension *n* of a given discrete model-object *M*, one can compute either:

- the mean of the normals of the topological simplexes of *M* (e.g. triangles). In the case of *n*=2, the mean normal defines the mean plane of the node locations of *M*.
- compute the first (for *n*=1) or the first and the second (for *n*=2) greatest Eigenvectors of the variance-covariance matrix of the node locations of *M*. These define the space with the highest variability and thus, in the case of *n*=1 define the direction of a mean line, or in the case of *n*=2, define the mean plane.

Having calculated the mean extension, one can test whether it (if *n*=1) or its normal (if *n*=2) lies within the bi-conical space defined by the direction interval. Both methods have been tested and give similar results. A descriptive measure for the maximum curvature of the object should be given, as for example calculating the direction of a sphere is quite useless. If this measure is larger than the standard deviation of the simplex normals, or the norm of the third eigenvector, respectively, no trend will be computed.

In addition to directional buffer queries, the following tools for the analysis and visualisation of directional data are suggested for integrated structural geology investigations:

- stereographic projection (Schmidt net) of structural data. This includes pole, great circle, contour or rose plotting of points with direction property (e.g azimuth and dip, normal vector). Multiple

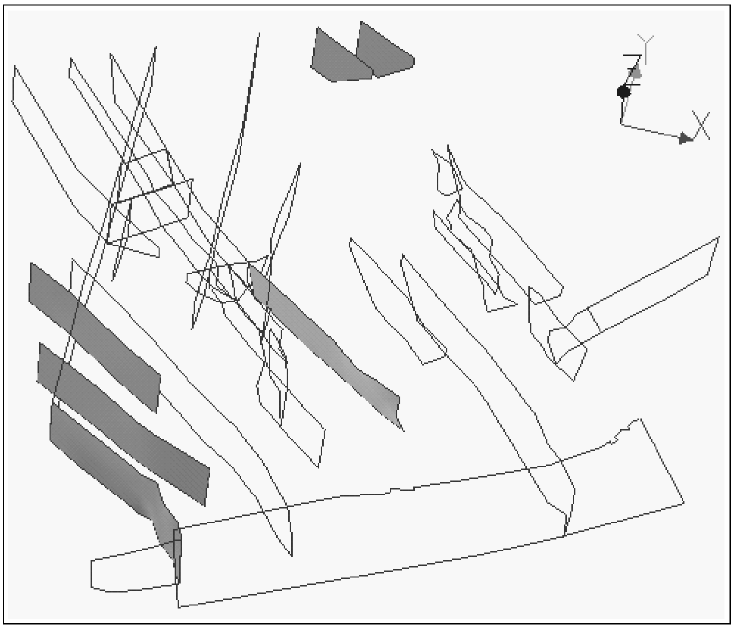
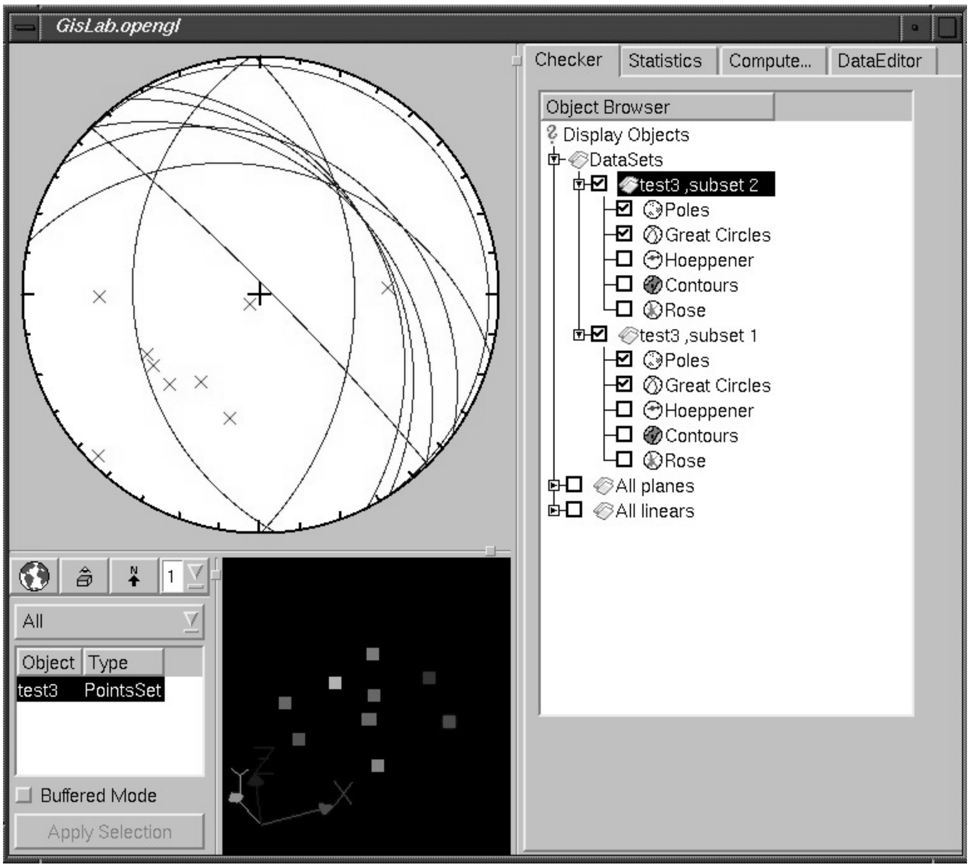


Figure 1: Direction query “highlight all faults with a trend north-west $\pm 10 deg$” applied to a fault network. The faults which are not within the buffer are transparent.

data-sets can be handled, and selected subsets may be highlighted in the plot window and in a Gocad 3D camera. This linking allows simultaneous exploration of structural trends and spatial situation of the model objects. Another integrated dialog allows the computation of structures (e.g. plane intersection), and direction statistics. The next steps will be the implementation of (i) cluster analysis, (ii) the projection of poles, circles and contours on a 3D-sphere, and (iii) strain calculation and visualisation. A first prototype of a generic “structural analyser” is available in a Gocad plug-in (Figure 2) as well as an standalone program with data import facility. (source available at www.ensg.inpl-nancy.fr/~apel/StrucAnal.tar.gz).

2.2 Temporal query functions: The Legend

In most well-known earth modellers including Gocad, the model objects are accessed via a list of the physical objects (e.g. Surfaces,Voxets,...) - which is not the syntax geologists are used to communicate. Geological objects are commonly referred to by their age. The age can be described in three ways: (i) stratigraphic age, (ii) absolute age, and (iii) relative age. The stratigraphic age and absolute age can be stored with the model objects. A legend provides in addition to the object browser a generalised hierarchical graph representing consistently the age relationship of all geological features. The idea of a legend is nothing new - geological maps are usually handled this way. But in a 3D modeller a legend can provide even more functionality: The Legend is query-able. For example one can show “all Cretaceous objects”, “all objects between two discontinuities with certain ages”, “all faults of a certain age” in the 3D camera. This approach - in combination with spatial queries - allows conceptual questions to be answered like: Do Cambrian unconformities intersect Permian lime-stones? If they do, there is either a problem



- Display Objects
  - DataSets
    - ☑ test3 ,subset 2
      - ☑ Poles
      - ☑ Great Circles
      - ☐ Hoeppener
      - ☐ Contours
      - ☐ Rose
    - ☑ test3 ,subset 1
      - ☑ Poles
      - ☑ Great Circles
      - ☐ Hoeppener
      - ☐ Contours
      - ☐ Rose
  - ☐ All planes
  - ☐ All linears

Object	Type
test3	PointsSet

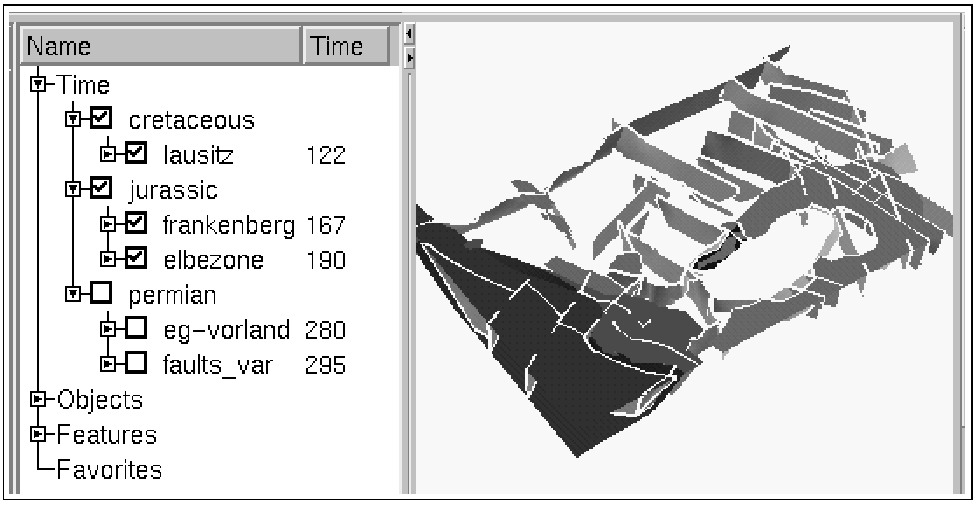
Figure 2: Example of structural analyser integrated with Gocad.

in (i) the Gocad-model, (ii) the age information associated with the model objects or (iii) the geological meaning of the supposed unconformity (example by Eric de Kemp/ NRCan Ottawa). Finally, if a legend graph becomes extended to a stratigraphic column containing the graphic object symbol in a look-up table, it can also be attached to model screen-shots as an explanation. Concerning the implementation, access to the geological information associated with the model objects has been integrated with the object browser (Figure 3). However, this is not sufficient as often a more detailed stratigraphic classification is necessary. Therefore, classification schemes for stratified model objects (e.g. “super-group-group-formation-member-?user defined?” depending on required level of detail) and for unstratified model objects (e.g. lithodemic ranks, tectonic division) should be created and be made accessible in a legend graph.

2.3 Query result representation options

The result of spatial, temporal or attribute queries can be represented:

- graphical by using a distinct symbolisation in the 3D camera or in a 2D projection view (e.g. stereographic projection). This is the most important method, as it is transient and does not change the model object itself. The way it becomes symbolised depends on the object type and the query type.



Name	Time
Time	
☑ cretaceous	
☑ lausitz	122
☑ jurassic	
☑ frankenberg	167
☑ elbezone	190
☐ permian	
☐ eg–vorland	280
☐ faults_var	295
Objects	
Features	
Favorites	

Figure 3: Example for object access using geological information: “show all but Permian”.

In theory, changes in transparency, shape, size, colour, thickness, continuity, or texture of symbol graphics are possible. The most applicable and obvious technique is to make the complement of the query result transparent (Figure 4); a boolean value indicating whether a simplex belongs to the result is stored as a temporary property and linear interpolated. For structural observations, the visualisation of orientation properties attached to nodes is important and can be realized e.g. using tablets or disks indicating the orientation of a plane. This provides visual queues to extend local structures. In addition, other object properties can become components controlling the 3D-symbols size or colour; like a tablet indicating the orientation with a size controlled by an element abundance. This makes it possible to visualise relationships without sophisticated queries and statistical analysis.

- by changing the model objects themselves. Using the standard Gocad libraries, one can create persistent new regions, properties or objects from a the query result.
- by creating meta-data. With respect to a discrete model, meta-data can be defined as data attached to a model as a whole and not to each cell. Thus, data like "geological age", "bounding box" of a discrete object can be treated as meta-data.

3 Next steps - discussion of perspectives

The following facilities are proposed to be developed in the near future in order to create a comprehensive GIS-environment on top of Gocad:

- A work-flow-like arrangement of the set of tools is necessary to facilitate logical combinations of different queries and user-friendly access and its implementation is already in progress. The following structure is proposed:

  1. “Use previous query result” || “reset previous query result”

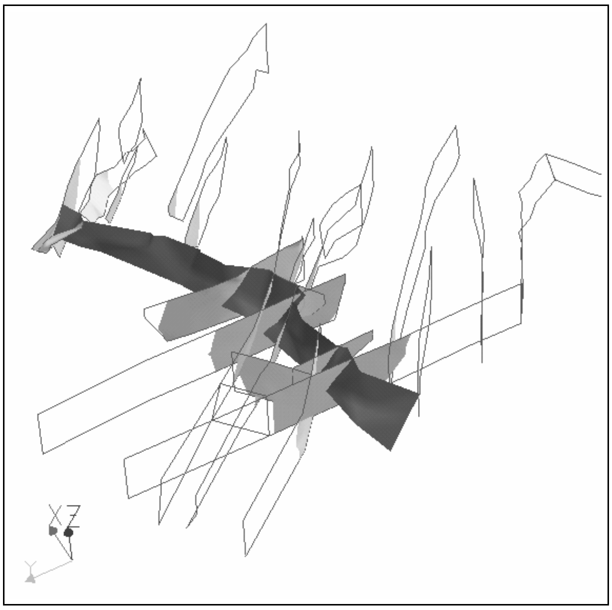


Figure 4: Highlighting the fault parts falling within a distance buffer of another fault

2. “Choose objects” (e.g. “Model3D”)
3. “Choose queries” (e.g. topological, directional, meta-data query with logical combination)
4. “Choose result representations”
5. “Apply” || “start querying again” || “OK, reset all” || “OK, store meta-data”.

The inter-operability with other means of data analysis has also to be developed. For example, spatial queries can be combined with statistical analysis of the object properties for further discrimination of target regions. Especially multivariate statistical tools are useful in this respect, like principal component analysis [Lafferiere 2000].

- This work focused on tools acting on the objects of a transient Gocad model. For very large models where handling in memory becomes difficult like large grids, one can move the data filtering process to a CORBA-accessed object-oriented database [Breunig 1999], which allows for retrieval of the persistent objects based on spatial index tree queries using R-Trees or object query language (OQL, www.odmg.org) for querying non-standard data-types. Because the change to persistence using object databases is an expensive and intrusive process, the possibilities of XML/RDF for search queries on persistent objects will be explored. The development of XML/RDF representations for spatial objects and meta-data conforming with the OpenGIS standard (www.opengis.org) provides the possibility of a data interchange platform with other applications and a better meta-data management.
  XML/RDF provides - in contrast to the relational or object data models - the possibility for user defined data schemas because XML documents are self-describing. This can be useful for meta-data as the requirements are different for different sites. For example, a mining exploration project might want to store descriptive core data with the well object whereas a petroleum production well

object might require a description of the well perforation. Having the possibility to access this meta-data via the net and using it to search objects with certain criteria using an XML query language (e.g. XML-QL, www.w3c.org/TR/NOTE-xml-ql) can provide a convenient “data-mining” framework. As discrete data as they are used in 3D geo-modelling can lead to to very large datasets, XML documents can become very large and slow to handle. For common queries, these discrete elements should be declared as unparsed sections like binary objects. Only information valid for the whole model object like bounding box, age data, coordinate system will be stored in XML and be available to queries.

- Topological queries can also be implemented using GMaps [Lienhardt 1994]. Preliminary tests have been made using the GMap-based research-kernel “TopoLab2” [Levy 2000] and will be developed further. This kernel allows arbitrary data-types to be attached to any type of cell, which could be used in the query work-flow to facilitate queries on complex property types.

4 Conclusion

Within this work, a set of 3D-GIS tools encompassing a variety of query types have been developed. Though they are not yet complete and lack inter-operability, they can already be used to answer questions concerning simple topological, directional and age relationships of 3D model objects.

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