GEOTECHNOLOGIEN EGIFF

EGIFF - Developing advanced GI methods for early warning in mass movement scenarios

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Abstract

There is a strong demand for analyzing mass movement scenarios and developing early warning systems to save lives and properties. However, hitherto the preparation of information and the analysis of hazards are still particularly critical links in the early warning chain. The responsible decision makers are usually confronted with huge amounts of structured and unstructured data. Thus the question arises, how they may be provided with a reliable and manageable amount of information to create the warning decision and to take preventive measures. In this article, objectives, concepts and results are presented, examining methods of an information system for the early recognition of geological hazards in mass movement scenarios. The simulation of landslides is executed on the basis of geotechnical, mechanically founded models. By coupling the simulation with GIS and advanced geo-databases, a better understanding of the corresponding geo-scientific processes is achieved. Additionally, the analysis of structured and unstructured data executed by statistical and linguistic methods, respectively, improves risk assessment and supports the early warning decision. Finally, a service-based 3D/4D geo-database manages selected data of a mass movement scenario.

Keywords: early warning, mass movement, geotechnical model, GI methods, 3D/4D geo-database, landslides, decision support system, learning system, finite element analysis.

1 Introduction and objectives

The number of geological events such as landslides (Glade and Dikau, 2001; Merritt et al., 2003; Bell and Glade, 2004; Dikau and Weichselgartner, 2005) has increased worldwide during the last decades. Thus, there is a strong demand for developing early warning systems to save lives and properties. The central components of an early warning system for natural phenomena are the recognition of the threats, the assessment and evaluation of the danger, the dissemination and communication of the warning, as well as the public reaction to the warning (Smith, 2009). The effectiveness of an early warning system largely depends on the transformation of the event recognition into the report for warning to the population. Obviously, the analysis and the preparation of information are particularly critical points of the early warning chain. However, they contribute significantly to the warning decision and to the risk estimate and the extent of the consequences caused by the natural event.

The objective of the GEOTECHNOLOGIEN joint project (Geotech, 2009) “Development of suitable information systems for early warning systems” (EGIFF) is to improve the early warning chain by the design and development of new methods to be integrated into appropriate components for early warning systems (Breunig et al., 2008).

2 Application areas

The methods of the EGIFF project are tested and evaluated with real mass movement scenarios. For this task, suitable application areas were selected. Main selection criteria were the availability of detailed data and sensor measurements, a coherent and comprehensive geology to verify the gained methodology in a generalized way and the potential risk for landslides. After the investigation of different landslide areas, in close cooperation with the Bavarian Environment Agency (LfU), a part of the Isar valley in the south of Munich, next to Pullach and Neugrünwald, has been selected for further studies. In this area the height difference of the slope is up to around 40 meters and endangered human infrastructure is located nearby the edge of the slope. Because of the risk potential, the area is observed by the responsible authorities. Inclinometer, extensometer, groundwater level measurements and geodetic surveys are available. These data include:

- Digital Elevation Model (DEM);
- topographic data (vector and raster format);
- orthophoto;
- geological and geomorphological data including drilling profiles and tearing edges;
- groundwater level measurements;
- deformation measurements;
- geotechnical properties.

Since the “Isarhänge Grünwald” application area and the available data appeared to be well suited for numerical simulation, but not for testing statistical methods and linguistic methods, we have decided to additionally use a second application area. Main reason was a larger size of the second application area, which is concentrated in Vorarlberg. The data of the second application area include:

- Digital elevation model (resolution 5 m), contour lines (50 m);
- topographic data (vector and raster format);
- orthophoto mosaic (resolution 1 m);
- geological data inclusively tectonics, geomorphology, drilling profiles, tearing edges (vector and raster format);
- risk maps for landslide hazards in various areas prepared by the Dept. of Applied Geology (AGK), University of Karlsruhe;
- measuring points for precipitation (since 1893);
- documentations of natural phenomena inclusively landslide hazards (since 1400);
- statistics of the Vorarlberg fire brigade (1997 – 2006).

Fig. 1: Application areas „Isarhänge Grünwald“ (Bavaria) and „Vorarlberg“ (Austria)

3 EGIFF system architecture

In this section the EGIFF components for the early recognition of geological hazards in mass movement scenarios are presented. While in the first component the coupling of GIS and modeling/simulation to support the evaluation of risks is examined. In the second component text descriptions are processed and spatial data mining is executed for the construction of hazard susceptibility maps. In the third component primary and secondary data are modeled and managed in a 3D/4D geo-database management system. The following subchapters provide an insight into the objectives and applied methods of the components.

EGIFF Component I: Development of an interconnected information and simulation system

System Architecture and data flow of the coupled system

At present, the application of the Finite-Element-Method (FEM) for the analysis and simulation of landslides is subject of research. Due to its complexity the corresponding simulation systems are predominantly used by experts and scientists. For disaster prevention and management, such tools are currently not available. An FE-analysis of presumably instable slopes requires detailed information about the subsoil structure, the occurring soil materials, the deformation history and the stress situation of the slope, etc. Therewith the configuration of the simulation input data is very complex and usually not sufficiently supported by the simulation system. Furthermore, simulation outputs are extensive and the interpretation of the simulation results is usually only weakly supported by the simulation system. For a broader use of simulation systems and for landslide susceptibility determinations, their handling should be more intuitive and user-friendly. GIS with their ability to store, manage and visualize geographical information provide a good basis for setting up the inputs of an FE simulation, analyzing and integrating the outputs to finally support a decision.

The interconnection between simulation system and GIS is schematically shown in fig. 2. The process starts with the selection of relevant parameters which are required for the analysis. The parameter transfer is controlled by the GIS. These parameters basically describe the model geometry, the subsoil structure and additional boundary conditions. Within the simulation system the modeling of the slope and the simulation of the landslide evolution are executed.

Fig. 2: Interconnection between simulation system and GIS.

After the analysis, the results are transferred to the GIS for visualization, assessment and for processing them into a form which is understandable for decision makers. Furthermore, i.a. stability indices and movement vectors can be calculated from the simulation results to assess the slope stability, the likely system behavior in future and the potential risk scenario. Uncertainties in the data used in the simulation and in subsequent processes should also be modeled and visualized in the GIS. In particular to support the user in the decision-making process, the uncertainties have to be recognizable, in order to allow the validation of the results by the user. Additionally, rule-based GIS components support the user in the decision whether to issue an early warning or not.

Operational modes of the coupled system

Comprehensive and exhaustive simulations are computationally intensive and can be too time-consuming in case of an early warning decision. Therefore two main operational modes of the coupled system with differing computational costs were identified (Ortlieb et al., 2009a).

a) Learning system mode for better understanding of landslides and
b) Decision support system (DSS) mode for prevention or reaction to a hazardous event.

Fig. 3: Architecture of the decision support and the learning system

The learning system enables the evaluation of consequences of various scenarios and allows a better understanding and prognosis of landslides. It can be used to analyze and to compare different simulations, which were performed under varying conditions or for different time intervals. Furthermore, the learning system enables to compare observed historical events with simulated ones. Thus, critical events can be determined (e.g. a critical flood discharge). This allows for the announcement of warnings at an early stage when the critical event is expected or forecasted (e.g. intense rainfall by the weather forecast). Another functionality of the learning system is the comparison of simulations with actual measured values. This enables the calibration and refinement of the simulations and supports the improvement of the understanding of the geotechnical characteristics of the slope. The results which were gained in the learning system are stored in the database. This allows either executing further analysis in the learning system mode or applying the DSS (see fig. 3).

In contrast to the learning system the DSS is used, if an acute danger exists and immediate action is essential. Examples are intense rainfall or an approaching flood wave, which may destabilize the slope causing a potential danger. This occurrence requires a fast decision whether to issue an early warning or not. Because in most cases there is no time for complex and comprehensive and therefore time-consuming numerical modeling of the slope and simulation of the system behavior, it is necessary that information is already available in the database from previous simulations for the actual case. If there has not been a simulation before, a new analysis has to be carried out. In this case a simplified FE-analysis is executed, because an exhaustive simulation would take too much time. How this simplified simulation is carried out with satisfying accuracy and significance is still under investigation.

Generation of geotechnical models and slope stability analysis

Before a slope can be analyzed in the simulation system, an appropriate model of the system has to be set up, which is able to reflect physical processes leading to slope failures, e.g. landslides. The generation of these geotechnical models (Trauner and Boley, 2009) is supported by the GIS. First the area of interest is selected within the GIS platform on basis of an orthophoto. Instead of an orthophoto various maps can be used, for example topographic maps or susceptibility maps, which may already indicate the necessity of further detailed investigations.

Fig. 4: Support of the generation of the geotechnical model in the GIS

The associated data for the ground and subsurface structure of the area of interest is obtained from the geo-database (see chapter ”Component III”) and preprocessed in the GIS. The ground surface topography is represented by a digital elevation model (DEM). For processing in the simulation system the DEM is transformed to a local coordinate system before it is imported in the simulation system (see fig. 4).

Additionally to the DEM the subsurface structure is needed to generate a wire-frame model, which represents the geometry of the ground for the selected area of interest in the simulation system (see fig. 5). This information is obtained from borehole logs, which are located in or around the selected area. Upon request the data can either be retrieved from the geo-database, if available for that area, or provided by the user.

Fig. 5: Wire-frame model for the area of interest

The wire-frame block model generated for the area of interest represents a part of the subsurface continuum. For FE-Analysis this continuum has to be discretized, i.e. a defined grid of points (nodes) is generated within the continuum and each node is connected to neighbors. These connections represent the edges of the finite elements. The structure of finite elements represents the geometry defined by the wire-frame-model and is called Finite-Element-mesh (FE-mesh). All characteristics or attributes of the material and actions are then assigned to the nodes or elements, respectively. Fig. 5 shows a FE-mesh based on the above mentioned wire-frame model assembled by tetrahedral elements (fig. 4).

Fig. 6: FE-mesh for the wire-frame model (fig. 5).

The set-up of the FE-mesh is supported by an external mesh-generator, since particularly geometric design conditions have to be followed to achieve satisfying performance for the numerical analysis. The mesh-generator is integrated into the simulation system, but any external tool could be employed within the modular system architecture, if favored.

On basis of the FE-mesh all locations and magnitudes of loads (forces are arranged on nodes, edges or surfaces of finite elements) or geometric modifications (action effects in general) are defined. In addition to the geometric description of the model represented by the FE-mesh, the behavior of the soil material due to changes in the primarily stress state, has to be described by constitutive equations. Based on these mathematical functions, deformations of nodes can be calculated, if the applications of loads or geometric changes cause the formation of a new equilibrium stress state.

When all information required for an FE-analysis is available, the data is put together in a single input file which is then basis for computation. This input file is compiled such that the computation program can directly process the data.

During the computation, the defined action effects are applied incrementally on the slope, e.g. the loads are not applied with their full magnitude at once, but stepwise. If finally the entire action effects are successfully applied and an equilibrium stress state is determined, the deformations of nodes or the degree of material utilization at different locations are obtained. If no equilibrium stress state for the slope is determined for the simulated scenario, the slope will fail and a landslide may occur. In this case, the latest possible equilibrium stress state defines the slope’s ultimate limit state, i.e. all loads greater than the ones applied during incremental loading, will result in failure of the slope. Although the computation will abort in this case, information on the expected deformations of the slope before its failure and the critical magnitude of action effects can be gained by these computations.

Relevant results from the analysis - in regard to the assessment of the endangering by possible landslides (e.g. deformations, degree of material strength utilization, etc.) - are written to an output file and transferred back to the GIS for further processing and visualization.

Preparation of the extensive simulation results in the GIS for decision support

Results of the simulation include several parameters (e.g. stresses, strains or deformations, degree of material utilization), which can be referred to the nodes of the FE mesh. In fig. 7 the result of a 3D simulation is shown. In this example the deformations of the FE nodes are visualized as deformation vectors. To identify the important parameters, namely the deformation direction und deformation length of the deformation vectors, the deciption has to be strongly enlarged. But therewith the overview of the whole slope will get lost.

Fig. 7: Visualized deformation vectors from a 3D analysis.

In the following paragraph a short abstract of a methodology, which allows for the user-friendly visualization of the complex simulation results is presented. The methodology is shown schematically on simplified 2D simulation results. For a more detailed version see Ortlieb et al., 2009b.

The length of the deformation vectors may indicate if the slope has to be categorized as susceptible to landslide. This length results directly from the loads, which were applied during the simulation. Usually, the stronger these impacting loads have been, the larger are the deformations of the FE mesh nodes and therefore the lengths of the deformation vectors. According to their lengths these deformation vectors can be divided into classes. Subsequently the deformation vectors are divided into direction classes. Afterwards clusters are detected, which include deformation vectors, belonging to the same deformation class and to the same direction class. The clusters are spatially adjacent.

The deformation vectors, which belong to a cluster, can be aggregated to one single deformation vector. For the aggregated deformation vectors, the area of validity has to be determined. Therefore the FE mesh can be used. Around the FE-nodes of the FE-mesh, which belong to a cluster, polygons are built (see fig. 8). Result of this method is a visualization, which presents the constitutive movement tendencies of different areas with a related deformation vector.

Fig. 8: Deformation vectors for different areas.

Besides the user-friendly preparation and visualization the complex simulation results can be enriched by additional data from any other resources in the GIS to support the decision-making process. The modeling area can, for example, be intersected with available digital topographical data (see figure 9) to determine the potential endangered human infrastructure (e.g. buildings and streets). This information can then be used to support the user in the decision-making process, whether to issue an early warning.

Fig. 9: Modeling area with overlain topographical data

EGIFF Component II: Analysis and valuation of fuzzy textual descriptions of geo-scientific phenomena to support and improve early warning systems

The objectives during the development of component II are the collection, pre-processing and analysis of relevant structured and unstructured data (numerical and textual measurements, observations and descriptions of specialists and laymen (citizens)) related to natural hazards (alpine mass movements). The focus is on the development and application of novel computational methods aimed at a combination of results obtained from analyses of heterogenic data sources, followed by a prototypical implementation as suitable components of an early warning system.

In the following the main working results concerning component II are described. They have been worked on collaboratively by FZI, IPF and disy Informationssysteme GmbH, Karlsruhe. The work in component II can be divided into a) Conceptual work (01.04.2007-31.03.2008) and b) Implementation/ technical realization (01.09.2007-)

Conceptual work

In the first year of the project, research into the application domain seen from the point of view of component II, followed by an investigation into previous work relevant to the objectives of component II, was conducted. The two main lines of work pursued by the project partners focused on (1) the investigation of statistical approaches to predictive modeling of landslide susceptibility/ hazard, including an investigation of model-free (geostatistical) and model-based statistical techniques/ pattern recognition methods (FZI), and (2) an investigation of approaches integrating natural language processing and knowledge representation for the task of an analysis of unstructured (i.e., textual) data relevant to the application domain (IPF).

Analysis of structured data

In the first year of the project, the first line of work (1) was followed by the selection of suitable methods combining GIS techniques and multivariate statistics/ pattern recognition, a comparative analysis, an application on regional scale, and a dissemination step (Gallus et al., 2007a; Gallus and Kazakos, 2008). The progress in (1) was the result of a contribution from a preliminary stage, involving the collection of structured data, data preparation, and a pre-processing step (IPF).

Fig. 10: a) Hazard map (Gaussian process model/ Laplace approximation) – prediction for study area Hochtannberg/ Arlberg (Vorarlberg), ArcGIS-postprocessing.
b) Hazard map (Gaussian process model/ Laplace approximation) – uncertainty of prediction for study area Hochtannberg/ Arlberg (Vorarlberg), ArcGIS-postprocessing.

In the second year of the project, further work was directed into research, conceptual work and development related to improvement in the performance of the chosen techniques (classification performance, computational complexity), and further enhancements. Towards the goal of improving classification performance, approximate inference techniques for Gaussian process model classification were investigated, with focus on (fast) analytical approximation techniques (PQL/Laplace, Expectation Propagation). As a second line of research, an investigation into established and emerging web service/ Geo-Data Infrastructure (GDI) technology standards (OGC web coverage service (WCS), and web processing service (WPS)) was launched, in order to facilitate integration of statistical computation procedures into existing software (desktop GIS systems). As a first step towards integration, a prototypical implementation (Java) was developed, allowing for flexible, TCP/IP-based access to statistical computation procedures from desktop GIS software.

Analysis of unstructured data

For the second line of work (2) the SOKRATES system (Schade and Frey, 2004), a system combining natural language processing (NLP) and knowledge representation techniques, was investigated. The system, which can be used to display events on a tactical map by means of limited automated interpretation of battle field reports, has been considered as a methodological basis for the envisioned system. However, an application of SOKRATES in component II was ruled out for several reasons, including the different application context, missing spatial and temporal concepts, and the missing consideration of uncertainties and fuzziness inherent in textual data. Instead, the open source framework GATE (Cunningham et al., 2002), used for all sorts of language processing tasks, including Information Extraction (IE) in many languages, was chosen. The IE module was realized with various gazetteers and JAPE grammars, in order to extract relevant information on different entities, including location and spatial relations, time, event, trigger, and damage/ consequence. As a starting point for the development of the prototype, historical data, including 1008 text excerpts were collected to generate a test corpus. Furthermore, an empirical survey was carried out investigating spatial descriptions of humans to support interpretation and locality modeling (Andrienko and Andrienko, 2001; Schuffert, 2009).

Different classes of spatial descriptions (Table 1) were distinguished according to Guo, Liu et al. (2008), and identified by means of GATE to further calculate coordinates and uncertainties. All named places, including also features like river confluences or road junctions, are being determined using the available Vorarlberg base maps, and feature generation will be done within a spatial database that stores these base maps as well as the text corpus and annotations of the information extraction process.

Table 1: Exemplary classes of spatial descriptions according to Guo et al. (2008).

There are existing various approaches to georeference locality descriptions, allowing methods to handle sources of imprecision and uncertainty resulting from an analysis of textual spatial references (Dilo, 2006; Guo et al., 2008; Hwang and Thill, 2005; Wieczorek et al., 2004). According to different classes of spatial description various approaches were investigated followed by an exemplary modeling using a fuzzy set approach (Schuffert, 2009).

Current work focuses on the evaluation and implementation of adequate modeling methods and the combination of analysis results from structured and unstructured data (1) and (2) (see fig. 11).

Fig. 11: Common workflow to integrate results obtained from analyses of structured and unstructured data.

In the context of spatial data visualization, characteristics of the data related to reliability and precision of spatial references will be presented in a way that they satisfy the requirements for adequate usability. In particular, previously established qualities like priority or urgency of information and their possible interpretations are major aspects to be considered. Also, scale-dependencies will play a special role.

EGIFF Component III: 3D/4D geo-database support for the geotechnical assessment of mass movements

In EGIFF component III, measured and interpreted geological data are modeled and managed in a service-based geo-database management system. Fig. 12 shows an example for data of the application area “Isarhänge Grünwald” managed by the geo-database management system, visualized with the GoCAD®[1] 3D modeling and visualization system (Mallet, 1992; Mallet, 2002).

Fig. 12: 3D database query example for data of the application area “Isarhänge Grünwald”

In this component the geo-database is used for archiving data and for providing fast and efficient access to geo-data. This enables the re-use of geo-data, e.g. for upcoming new hazards. In addition, the geo-database can also manage models and their results and even become active, e.g. by computing geometric intersection queries between a set of geo-objects.

The following three main topics have been identified:

1. 3D Geometric and topological management of measured and interpreted geological data including time sequences.
2. Development and implementation of geometric / topological and time-dependent geo-database operations.
3. Management of FE model parameters and their results for the use in geotechnical evaluations of mass movements.

For the first topic, selected measured and interpreted test data (e.g. extensometer data and profile sections) from the application area “Isarhänge Grünwald” have been examined and managed in the geo-database. The second topic consists of developing geometric, topological and time-dependent geo-database operations, which support the geotechnical analysis of mass movements. Not only simple range calculations between point geometries (as it is the case in classical 2D GIS buffer operations) are of interest, but also the movement/speed of complex 3D geometries and the direction of the movement have to be considered. The third topic concerns the management of the input data and results from 3D model calculations within the geo-database. During the FE model calculation a second kind of data interpretation takes place. The

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[1] GoCAD software is distributed by Paradigm.

management of modeling results in a geo-database creates new possibilities for their further use. Furthermore, the results of a larger number of model calculations can be stored in the geo-database and, on later demand, they can be compared and queried by different database views. For example, versions or scenarios of model calculations can be stored and compared with each other.

The geo-database has been tested in the early-warning scenario “Isarhänge Grünwald”. Hitherto the following heterogeneous data are managed by the geo-database:

- digital terrain model (resolution of 2m);
- drilling profiles (borehole data);
- approximated surface model in 3D space.

DB4GeO

To meet the requirements of the three topics, DB4GeO, a service-oriented geo-database core is used (Bär, 2007; Breunig et al., 2009a, Breunig et al. 2009b) which is based on our experiences gained from GeoToolKit (Balovnev et al., 2004) and geological modeling (Alms et al., 1998; Mallet 2002). DB4GeO is developed as an extensible toolkit for 3D/4D geo-database services. It provides suitable data types and geometric geo-database services to support data analysis by complex geo-database queries. Furthermore, combined thematic and spatio-temporal database queries are supported by its data model. The easy-to-use internet-based interface enables the direct service access and usage from other geo-tools. DB4GeO is embedded into a simple service infrastructure.

DB4GeO has been designed with a service-based architecture right from the beginning and is exclusively implemented in the Java programming language, i.e. its interface provides Java-based services. Presently, REST (Fielding, 2000) is used as communication platform. The system architecture of DB4GeO is presented in fig. 13. On the client side, GIS clients or mobile clients may access 3D data managed by the DB4GeO server. On the server side, DB4GeO may be accessed exclusively via its services, being divided into operations and version management.

Fig. 13: System architecture of DB4GeO

The central part of DB4GeO is its 3D/4D geo-database which is based on a geometry library and the R-tree based spatial access structure. The latest version of DB4Geo is implemented upon the free object-oriented database management system db4o.

Geometry library of DB4GeO

The geometry library of DB4GeO consists of geometric and analytic objects. The relevant classes are Vector3D, Line3D, Plane3D, Point3D, Segment3D, Triangle3D, Tetrahedron3D and Wireframe3D. The class ScalarOperator makes methods available to compare scalars with a given accuracy constant (space feature). All geometric comparisons are based on this principle to avoid errors due to imprecise representations of floating-point numbers. The class MBB3D defines a minimal bounding box of 3D objects.

Based on the geometry library, a geometric model was implemented (fig. 14). Its structure is symmetrical to the dimension of the geometric objects. Putting <Simplex> in place of the k-dimensional Point3D, Segment3D, Triangle3D or Tetrahedron3D, the model can be described as follows. The class <Simplex>Net3D has a number of <Simplex>Net3DComp components. The components have no topological coherence to each other. Each <Simplex>Net3DComp models the specific k-dimensional simplicial complex through an adjacent disjoint set of 3D elements, i.e. <Simplex>Elt3D objects. There are no isolated simplexes within those components, i.e. they are topologically connected. <Simplex>Elt3Ds are finally direct subclasses of the supported simplex types collected by the geometric library. A special case of the implementation is the support of solids. The hull representation is established by 2-dimensional simplicial complexes implemented in ClosedHull3D and ClosedHull3DComp. Those classes wrap around TriangleNet3D and TriangleNet3DComp. Area calculations are passed to these more simple classes and volume calculations are implemented in the wrapping classes.

Fig. 14: Geometric model of DB4GeO in UML notation (figure from (Bär, 2007))

“4D” objects in DB4GeO

Time dependency is one of DB4GeO´s key features. Thus beside the request of spatial data we offer the ability to access temporal data in a simple and effective way. “4D” objects in DB4GeO are structured into components, which have a unique sequence for every single geometry object, e.g. a triangle. A spatio-temporal component C consists of a set $C = \{seq_1, seq_2, ... , seq_n\}$ of sequences which temporal discretizations are all equal (fig. 15). The elements of C build a contiguous and topological invariant network.

A sequence $S = \{ste_1, ste_2, ... , ste_n\}$ consists of a series of n spatio-temporal states *(ste).* Every element ste_{m+1} is a continuation of the element ste_m ($1 \leq m \leq n-1$). The implementation is realized with the class Point4DTubes. Each of these tubes consists of n Point4D elements and describes one point of an n-simplex ($0 \leq n \leq 3$) in the specified time interval.

Fig. 15: Structure of 4D objects in DB4GeO

Semantic model for spatial data types

The “semantic” (thematic) model (fig. 16) implements the attributes, which may be attached to the geometric objects. The theme is defined by the class *ThematicObject3D* which implements the abstract class *Thematic3D*.

Fig. 16: Thematic model of the database objects, showed in UML notation

Geometric objects are members of a thematic group in which attributes are defined. Floating point numbers, integers, Boolean values, strings and vectors are supported. Likewise an indexed table can be defined in runtime to include a collection of datasets for thematic purpose.

DB4GeO services

Fig. 18 shows the approximate surface model of the application area (a) and the result when applying one of DB4GeO´s typical services, the so called “3D-to-2D service” to our application scenario “Isarhänge Grünwald” (b). This approximated surface model has been designed manually with the 3D modeling tool GOCAD®[2] and then stored in DB4GeO. The 3D-to-2D service computes the intersecting geometry between geologically defined surfaces and a vertical plane specified by the user. Internally the basic 3D database operators (intersects, isContained, boundingBox) are applied to the surface model.

Fig. 17: (a) Approximated surface model of application area “Isarhänge Grünwald” (b) Result of 3D-to-2D service

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[2] GoCAD software is distributed by Paradigm.

In DB4GeO, spatio-temporal geo-objects are accessed in a simple and effective way. But how do we get the geo-objects at a specified time step out of the database? To handle this request we have developed the "4D-to-3D service". With this service we offer access to the following queries:

- "Get one specified geo-object at a specified time step".
- "Get all geo-objects contained in a space4D at a specified time step".
- "Get one specified geo-object and all it's time representations in one response".
- "Get all geo-objects and all it's time representations in one response".

The REST requests of these four sample queries run as follows:

1. http://server/projects/p1/area1/object?getTimeStep(STEP)
2. http://server/projects/p1/area1/all?getTimeStep(STEP)
3. http://server/projects/p1/area1/object.gml
4. http://server/projects/p1/area1/all.gml

Fig. 18: Results of the 4D-to-3D service at different time steps

As we can see in fig. 18, the access to the temporal data is very simple and easy structured. With every request we get the 3D geometry of the object at the specified time step. The 4D-to-3D service has explicitly been designed to retrieve snapshots of moving 3D objects.

A typical *workflow*, i.e. geo-database session in this scenario is described as follows:

1) Export the 3D model from a 3D modeling tool and import it into DB4GeO.

2) Use the DB4GeO services (e.g. 3D-to-2D or 4D-to-3D service) for data retrieval and geometric computations.

3) Work with spatio-temporal client application analyzing the temporal change of landslides.

These spatial and spatio-temporal services are ready to support the analysis of landslides. To provide further early warning functionality such as "triggering" a client application when the content of the geo-database has changed, DB4GeO is being coupled with suitable services such as GeoRSS (http://georss.org).

Conception and prototypical implementations for using the thematic model of DB4GeO for the management of FE modeling parameters

The geometric representation of the Finite Element Model constructed in component I by the Abaqus® software, may be stored in DB4Geo, the only prerequisite is an ASCII export provided by Abaqus. To manage the geometry of the Finite Element Model in the 3D/4D geo-database, the ASCII export has to be sent to the database via HTTP protocol using the HTTP-Request method PUT. A puristic example call using a command line with cURL-Program (cURL program is used to transfer files without a browser) runs as follows:

```
curl -X PUT --header "Content-Type: text/plain" -s --url http://localhost/egiff/isarhang -
data-binary "@AbaqusGeometryExport.gz" --header "application/x-gzip" --header
"Content-Encoding: gzip"
```

Considering a "4D model" it is planned to use different geometric time-/modeling steps of the FE model to be managed in the 3D/4D geo-database for temporal analysis of mass movements. With the assistance of the introduced 4D modules/components the movement/speed of complex 3D geometries and the direction of movements will be considered.

DB4GeO's thematic model can be used for the management of geotechnical parameters for the material of the surfaces used by numerical modeling. Exemplary geotechnical parameters are:

density, dilatation, cohesion, and joint permeability factor. They can be retrieved in the geo-database by REST requests such as:

```
GET /egiff/isarhang/sandstone?getThematic(density)
```

Examples of thematic REST queries for some cells of a 3D geo-object are:

```
GET /egiff/isarhang/sandstone/componentID/elementID?getThematic(density<26)
GET /egiff/isarhang/sandstone/componentID/elementID?getThematic(cohesion!=10)
```

Adding single geotechnical parameters can be done by the following REST request:

```
http://server/egiff/isarhang/sandstone?addThematic(demsity=26)
```

If several geotechnical parameters shall be added to an object, an ASCII-text containing geotechnical parameters can be sent to the 3D/4D geo-database:

```
density=26
cohesion=10
joint normal stiffness=20
…
```

By extending the themes, it is possible to get information about different semantics of geometrically identical objects. This information is important for the numerical modeling. In this context we are also speaking of the "thematic coloring" of the model.

The data (Scalars and Vectors) calculated in the FE-model for every cell (2D-Simplex) can also be taken into account by extending themes in DB4GeO:

```
GET /egiff/isarhang/sandstone/componentID/elementID?getVector
GET /egiff/isarhang/sandstone/componentID/elementID?getScalar
```

The thematic model of DB4GeO can be used to attach 0D, 1D, 2D, and 3D simplexes, respectively. No close coupling of the geo-database with the FE model is intended by using DB4GeO's thematic model. The aim by using the thematic model is the documentation of the process (movement -/ deformation history), therefore the management of result geometries and their movements as well as the management of geotechnical parameters for the numerical modeling are provided.

4 Integration of the EGIFF components

One main challenge was to integrate the separate EGIFF modules in one coherent application in order to demonstrate how a user can interact with the separate services offered by EGIFF. In a first step the Text Annotation and Hazard Map Calculation was integrated (see Fig. 19). The basic idea is, that a user starts a given text, coming for instance from a current message, such as “land slide observed between village 1 and village 2”. Through the text analysis process developed within EGIFF the main annotations are extracted. Special emphasis is put on the spatial annotations, like names of specific locations and terms such as “between” (1). The service proposes a list of terms which are then extended by their geometries (2) though a Gazetteer. The text annotation is itself using a gazetteer for the annotations. The user now has a list with areas mentioned in the text and can zoom to one of the specific areas (3). In case a pre-calculated hazard map for the area is available, he can view the map by contacting the appropriate service (5). If now hazard map is available he can call the service calculating hazard maps (4). This service is using the statistical methods developed within EGIFF and provides the calculated hazard map. In case the calculation lasts longer, the service will publish the new map to a WMS-Server where the user can access this map.

Fig. 19: EGIFF service based integration of components

In the first step the process was developed without the use of Web services. An extension to Web services is currently under development. To do so we decided to use the reference Architecture by OGC using the Internet as a service bus and Web Processing Services (WPS), Web Feature Services (WFS) and Web Map Services (WMS) to demonstrate the application in a wider scenario.

The application itself was developed as a plug-in for the desktop GIS software disy GISterm, a Java-based software package widely used in environmental authorities in Germany and Austria. Fig. 20 gives some impressions of the current prototype.

Fig. 20: EGIFF samples: Integration of text-analysis and statistical methods

5 Cooperation with EWS joint projects and Geotechnologien main topics

The EGIFF project seeks cooperation with other early warning system (EWS) projects within the GEOTECHNOLOGIEN research program. For example, the EGIFF project maintains a close cooperation with the staff of the alpEWAS project (Thuro et al., 2007; Singer et al., 2008). The objective of this project is to design and implement an integrated early warning system for known (reactivated) and new landslides and mudflows. Innovative sensor measurement technology, comprising amongst others surface sensors (Global Navigation Satellite System), reflectorless tachymetric surveys and Time-Domain-Reflectometry systems promise the availability of large and accurate deformation data. Also the GIS/simulation coupling is interesting for the alpEWAS project as a tool to show and clarify failure mechanisms. Hence, sensors can be installed in crucial locations to obtain the most valuable data. The concepts and results of the EGIFF- and the alpEWAS-project have been discussed intensively in joint sessions (Schuhbäck, 2008; Trauner, 2008).

Furthermore, the EGIFF project was represented at the workshop “Transparenz schaffen, Synergien nutzen – Geodateninfrastruktur Komponenten und Sensor Observation Services” at Bonn University (Richter 2008). However, after the workshop the question remained open, if the early warning system projects within the GEOTECHNOLOGIEN research program really have the person power for an additional intensive training and sustainable use of standards and infrastructures for spatial information.

In future project phases we see realistic chances for EGIFF project cooperation with other joint EWS projects in the following fields:

a) Exchange of results gained from numerical methods and sensors developed for the analysis of mass movements

Data for surface and subsurface deformations, ground water level fluctuation and other additional information obtained from various sensor measurements are of great importance for numerical simulation models. These data is required to represent geometrical characteristics of a study area in a preferably realistic manner and to calibrate the models by adjusting/choosing appropriate material parameters as well as constitutive equations.

On the other hand results obtained from numerical analysis may be valuable to explain triggers of slope movements and deformations in detail, especially underground, which are often hardly visible on the slope surface. Providing this information to other EWS projects, the cooperation partners can select appropriate and best-suited sensors and install them in key-positions.

b) Methodological Exchange in the domain of quantitative assessment of landslide/ mass movement hazard/ susceptibility and beyond

In EGIFF component II, traditional and novel statistical classification methods have been selected, developed and evaluated against spatial data on regional scale. The techniques developed in this component can be used considering a “higher level” of hazard research. Research towards an integration of data analysis techniques in the framework of emerging GDI technology standards is considered a promising direction.

Regarding increasing extreme weather situations relatively simple and fast methods are required for landslide hazard and risk assessment, also to provide people or decision makers with useful information to reduce hazards. Therefore, site specific quantitative methods based on extensive data and formal analysis can contribute to assessment of mass movement risk.

Furthermore, historical frequency-magnitude analyses supply valuable information, whereby linguistic methods can play an important role. Exemplary the ILEWS subproject (Glade et al. 2007) develops/investigates methods for monitoring frequency and magnitude of landslides through history in the Swabian Alb and South Tyrol region to integrate historical analysis into early warning systems. However, spatio-temporal distribution of past landslide events is incomplete. Nevertheless, all existing data including historical information stored in archives should be provided for an adequate reconstruction of time series. This is the first step to make conclusions regarding risk zones and expected distributions of future events. These methods could also be transferred to reconstruct previous historical volcanic eruptions (Hort et al., 2007; Exupéry, 2008).

c) Software exchange and discussion of standards, infrastructures for spatial information, and web-based GIS

As impact of the workshop “Transparenz schaffen, Synergien nutzen – Geodateninfrastruktur Komponenten und Sensor Observation Services” at Bonn University in April 2008 and further discussions in the status meeting at Osnabrück in October 2008, it should be further examined what the effort is to achieve a more homogeneous software use in the EWS projects. Web-based GIS and Sensor Web Enablement (SWE) seem to be suitable “candidates” to start this process. Also the effort for using and further developing or extending standards and infrastructures for spatial information should be further examined. However, the different priorities of the projects such as different application areas, different data types, different methods, and different software environments have to be taken into account.

Regarding software and data interoperability, in the EGIFF project the GML data exchange standard is used. The most promising cooperation partners in this field seem to be the ILEWS project (Glade et al. 2007), the SLEWS project (Arnhardt et al. 2007, Fernandez-Steeger et al. 2008), the AlpEWAS project (Thuro et al. 2007, Singer et al. 2008), and the TRANSPORT project (Hohnecker et al. 2008) These projects are using modular software environments that could be used in more general EWS software architectures. Finally, the service-based 3D/4D geo-database access via Internet realized in the EGIFF project could be interesting for other EWS projects. Finally, the plug-in techniques used by our commercial project partner disy Informationssysteme GmbH, Karlsruhe, could also contribute to further integration of EWS projects in future.

Additionally, requirements of specific visualization and presentation methods should be exchanged between our project and the projects ILEWS (Glade et al. 2007) and SLEWS (Arnhardt et al. 2007), because advanced 3D/4D visualization techniques should be used for all mass movement scenarios.

Last, but not least, the EGIFF project has maintained close cooperation with two other Geotechnologien main topics: the main topic “Technologies for safe and permanent storage of the greenhouse gas CO_2” and the closed main topic “Sedimentary basins: The largest resource of humanity”. In both main topics EGIFF is cooperating with the group of H.-J. Götze / Sabine Schmidt / Andreas Thomsen (Working group Geophysics and Geoinformation, Christian-Albrechts-Universität zu Kiel. These “trans-disciplinary connections” provide interesting insides into the need of GI technologies and data integration methods in the geosciences. Clearly, the GI methods needed are transferable to the EWS program.

6 Conclusions and outlook

In this article, objectives, requirements, and results of the GEOTECHNOLOGIEN joint project “Development of suitable information systems for early warning systems” (EGIFF) have been presented. In our work, the focus has been set on the design and implementation of new methods and on the combination of methods from the fields of simulation, GIS, spatial data mining, geo-databases and linguistics. The simulation of mass movements is executed on the basis of geotechnical, mechanically founded models. Thus a better understanding of the geological processes is achieved. The decision for early warning is supported by coupling simulation of mass movements with GIS. Furthermore, methods for the statistical analysis of structured data and linguistic examinations of unstructured data have been presented. Finally measured and interpreted data have been managed by an advanced 3D/4D geo-database to support the analysis and early warning of mass movements. The presented work is a first important step on the way to efficient recognition and early warning of mass movements. However, establishing operative early warning systems from the scratch needs more time and future research.

Acknowledgements

The funding of the research project “Development of suitable information systems for early warning systems“ (Entwicklung geeigneter Informationssysteme für Frühwarnsysteme) by the German Ministry of Education and Research (BMBF) by grant no. 03G0645A et al. within the framework of the Geotechnologien initiative (http://www.geotechnologien.de) is gratefully acknowledged. We also thank the Geotechnologien office for their support. Finally, we thank the Bayerisches Landesamt für Umwelt (LfU, www.lfu.bayern.de) and the Bayerisches Landesamt für Vermessung und Geoinformation (LVG, www.lvg.bayern.de), for providing data for the application area.

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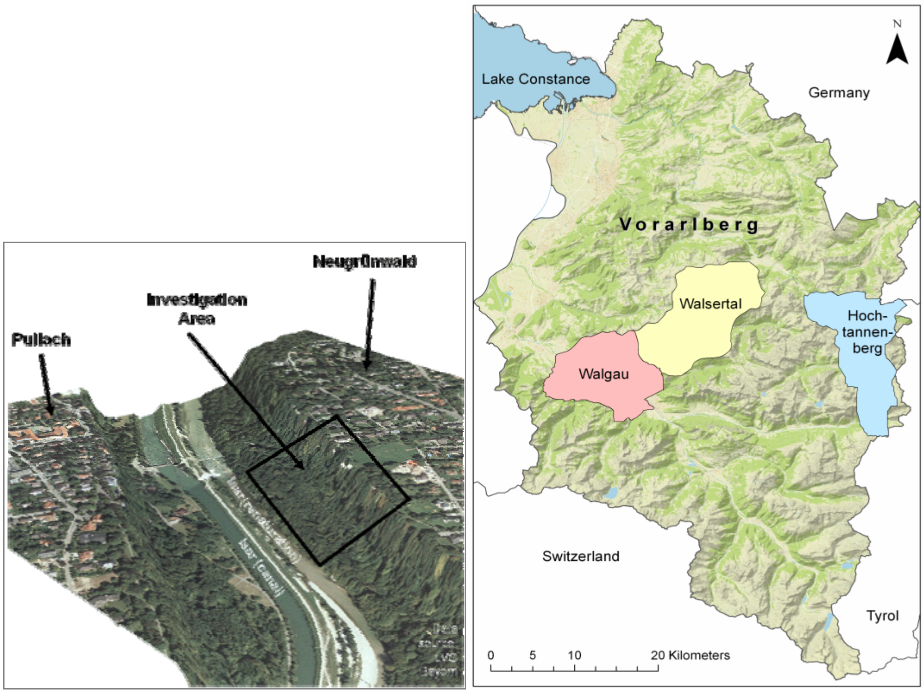
FIGURES:



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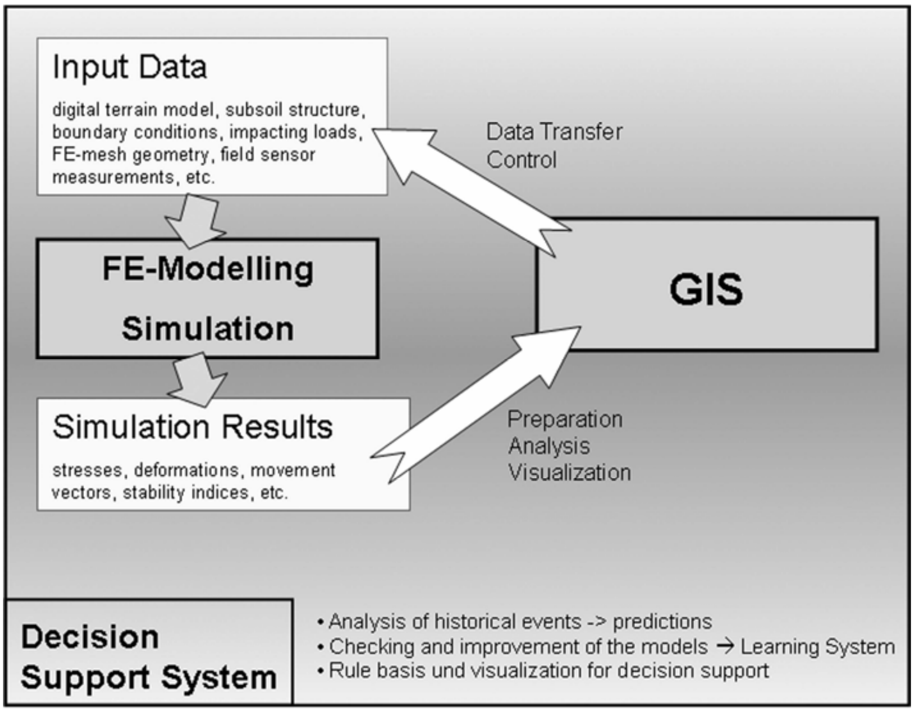

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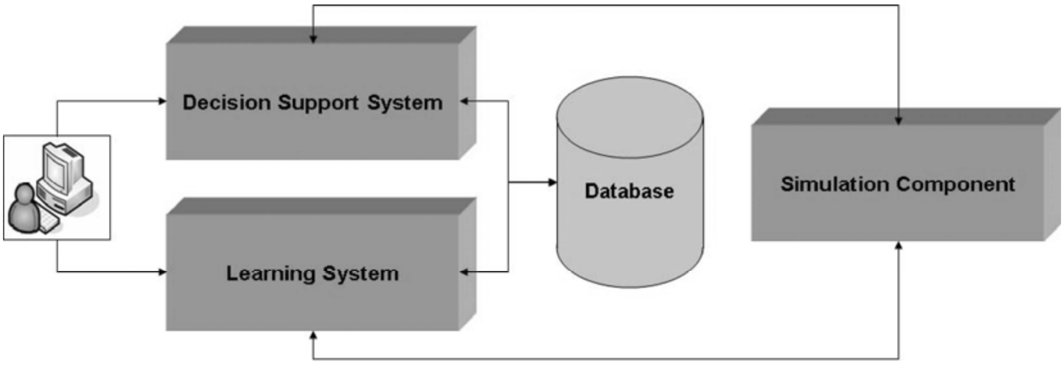

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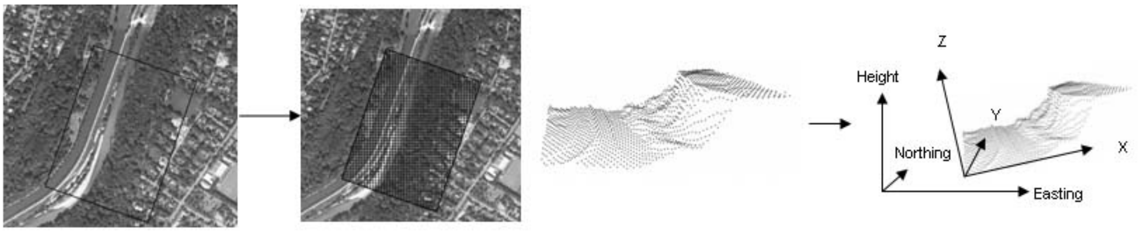
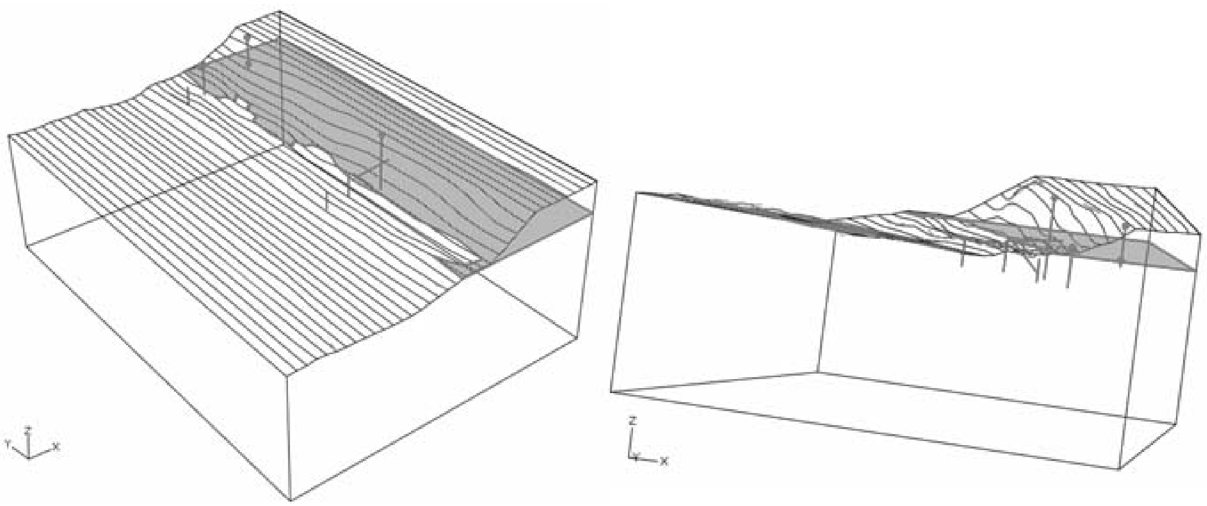


Selection of an area of interest

Digital elevation model for the selected area of interest

Transformation in a local coordinate system

Fig. 4



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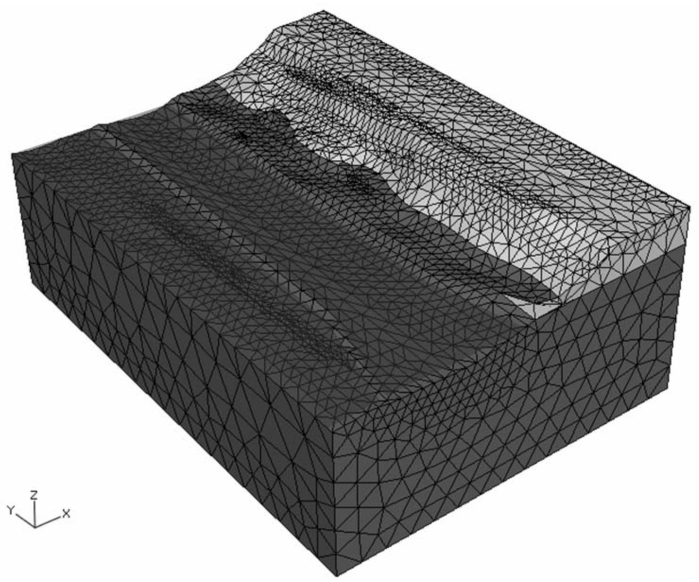

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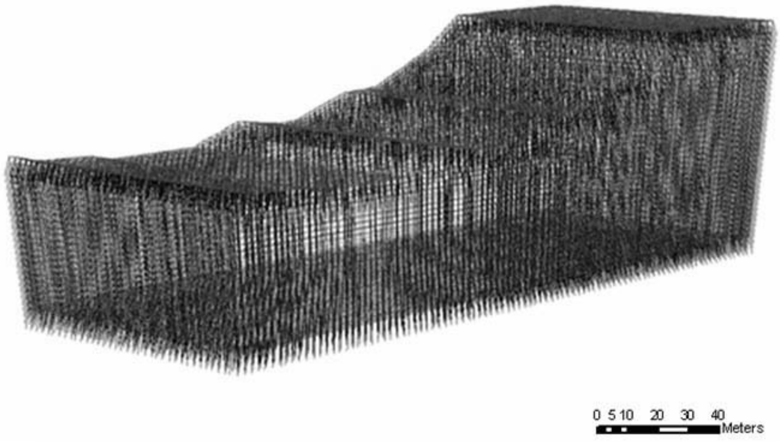

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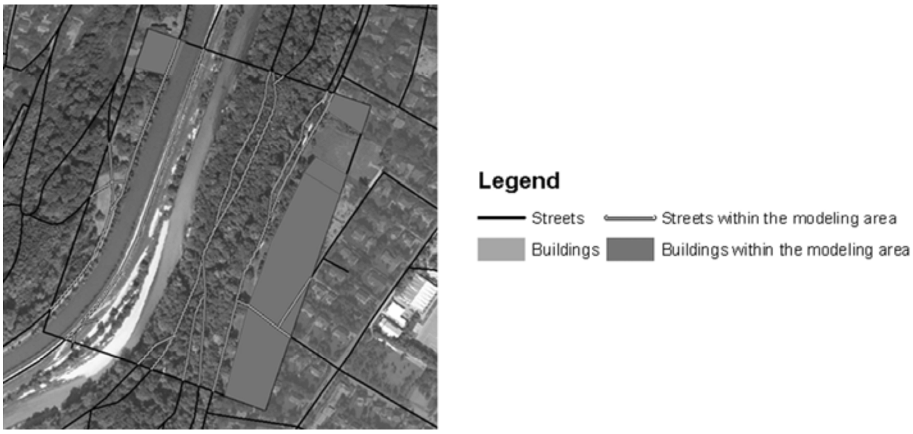
Fig. 8



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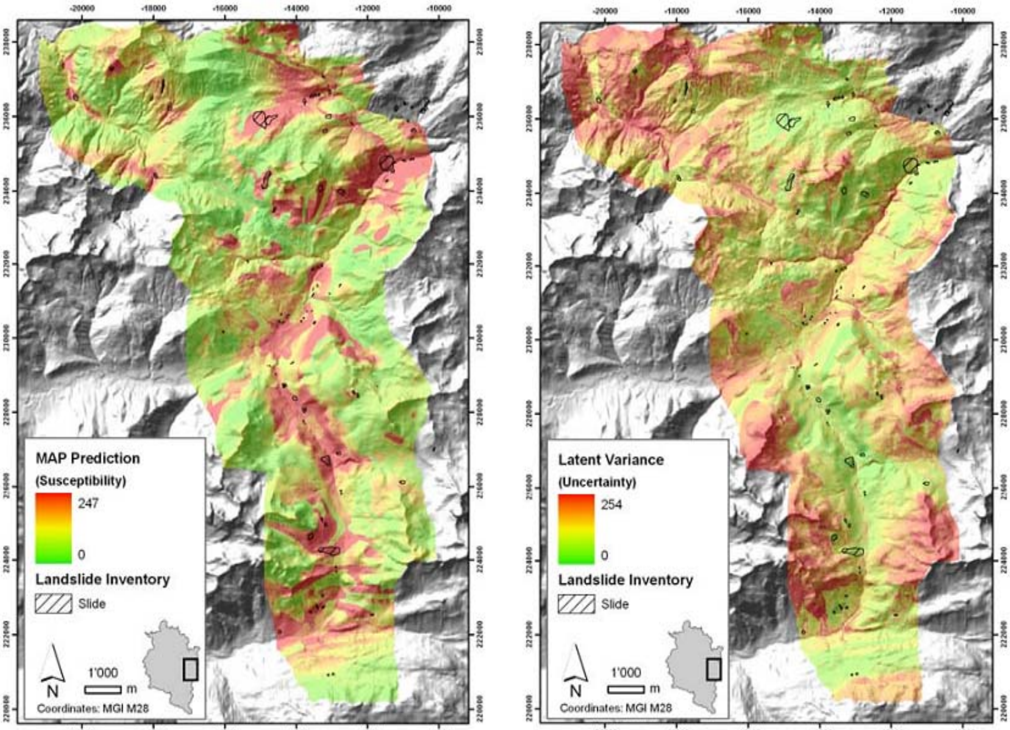

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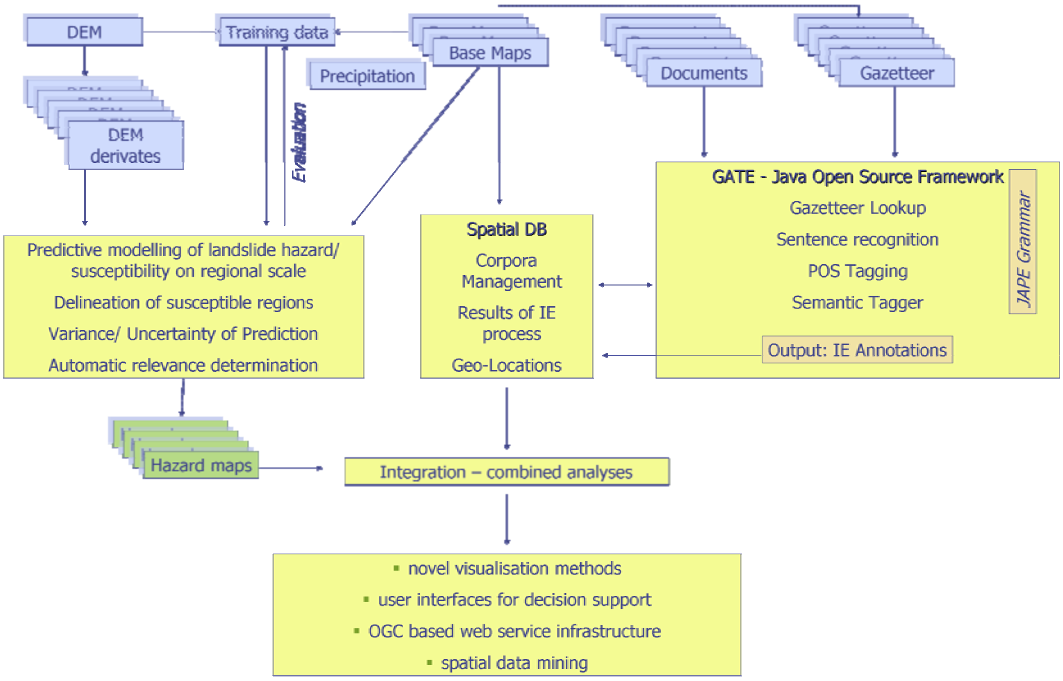

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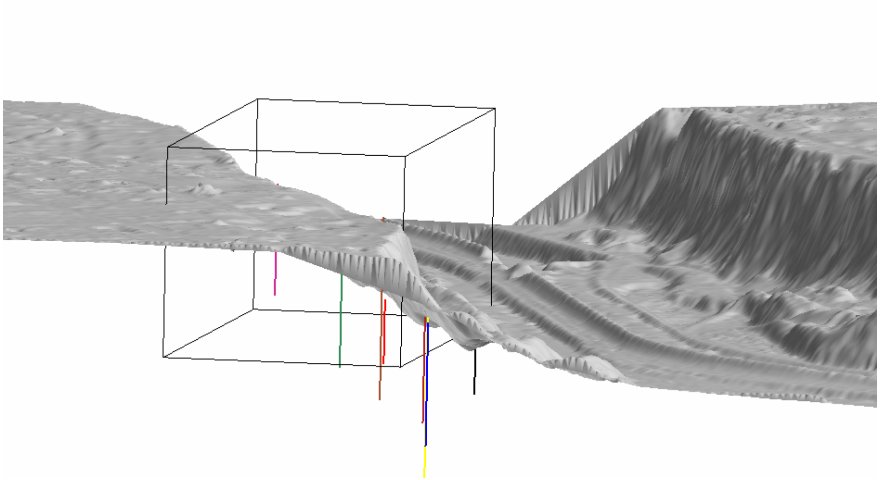

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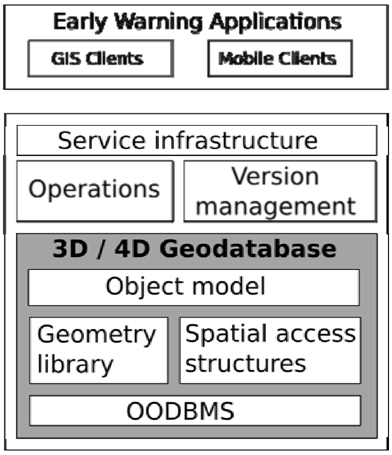

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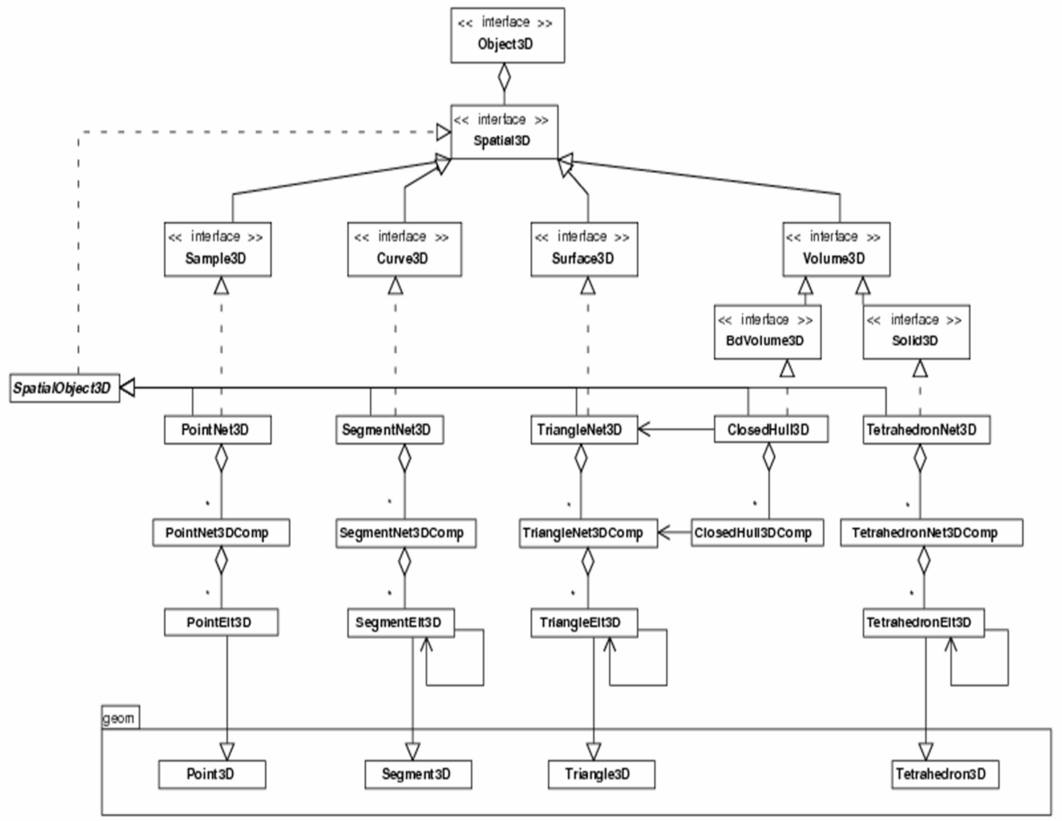

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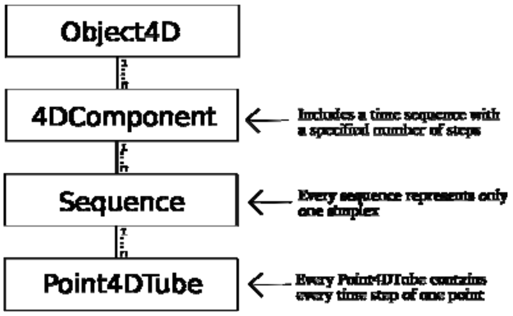

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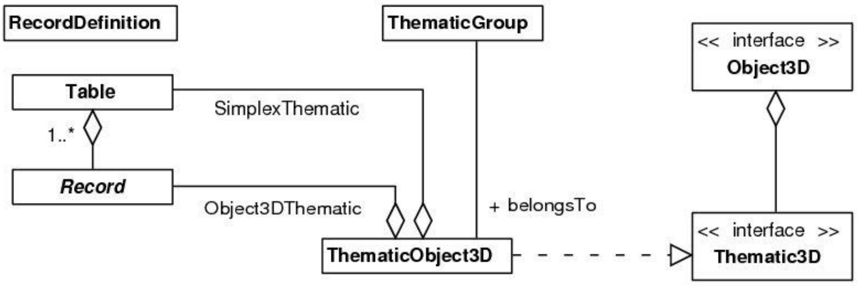

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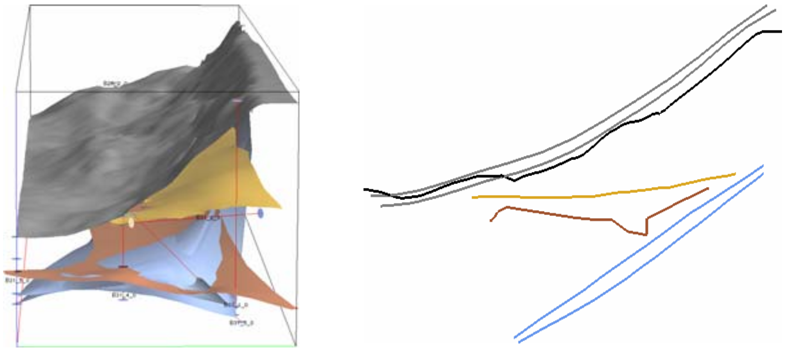


Fig. 17 a)
b)

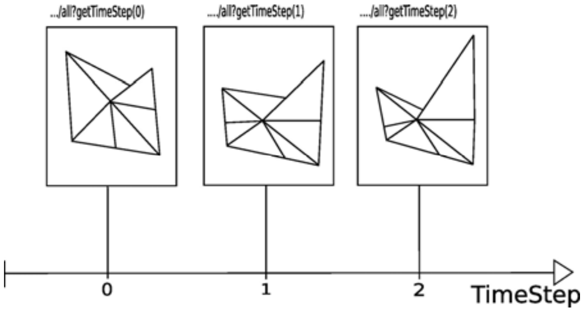


Fig. 18

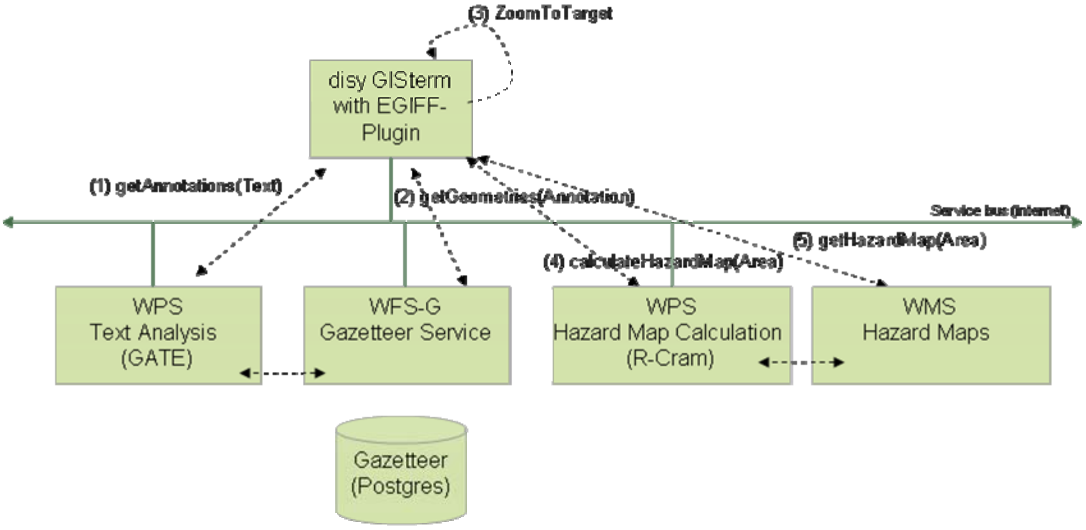
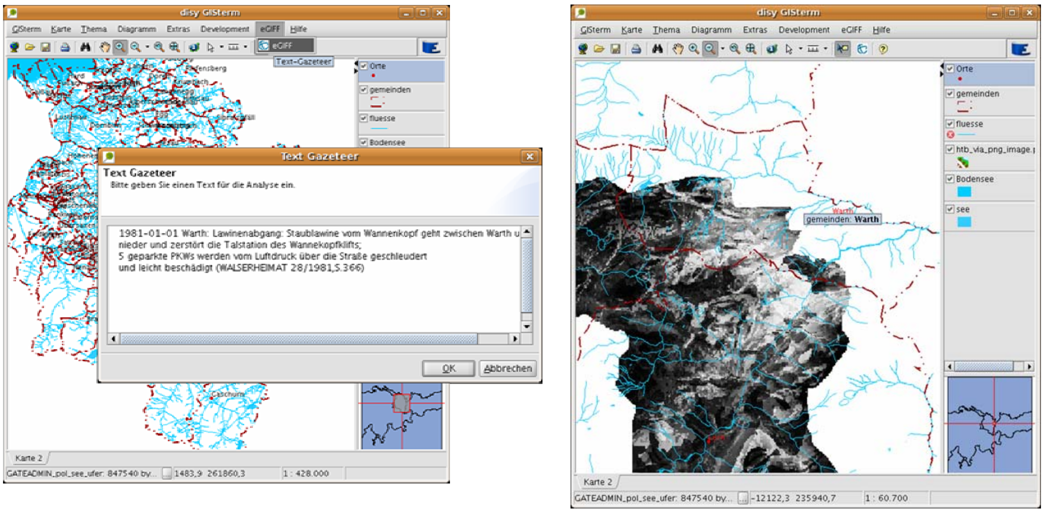


Fig. 19



Text Gazeteer

Bitte geben Sie einen Text für die Analyse ein.

1981-01-01 Warth: Lawinenabgang: Staublawine vom Wannenkopf geht zwischen Warth u
nieder und zerstört die Talstation des Wannekopfklifts;
5 geparkte PKWs werden vom Luftdruck über die Straße geschleudert
und leicht beschädigt (WALSERHEIMAT 28/1981,S.366)

GATEADMIN_pol_see_ufer: 847540 by... 1483,9 261860,3 1 : 428.000

GATEADMIN_pol_see_ufer: 847540 by... -12122,3 235940,7 1 : 60.700

Fig. 20

Description	**Example**
Feature	Bregenz
Path or linear feature	Isar, A5, along the road
Between features or paths	Between Lech and Warth
Near a feature or path	near Bregenz
Junction	Confluence of Loisach und Isar
Subdivision of a feature or path	Northern Italy
Offset from a feature (or a path) at a heading	5 km N of Bregenz
Heading from a feature, no offset	W of Karlsruhe
Offset from a feature, no heading	5 km of Bregenz

Table 1