

SEISMOGIS: A TOOL FOR THE VISUALIZATION OF EARTHQUAKE DATA

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ABSTRACT:

SeismoGIS is a GIS toolset developed for the Earthquake Observatory Bensberg of the University of Cologne. The system supports the analysis and visualization of current and past earthquake events measured by the seismometer station network. The Toolset consists of (i) an extension for ESRI's ArcGIS, developed in C#, (ii) an online GIS using the UMN MapServer software and (iii) a small PHP web application for dynamic KML data generation. The software parses dynamically the measured earthquake events from an ASCII file, which is supplied by the SEISAN / SEISNET software. For further use within the SeismoGIS, these parsed event datasets get stored in a MySQL database with 17 fields each. In this contribution we present an overview of the system architecture of SeismoGIS. In addition, the database design and the management of the GIS data, the single components e.g. the tools with its architecture, implementation details, and an overview of the provided functionality to the user are described. Finally a preview on considered future work is given.

ZUSAMMENFASSUNG:

SeismoGIS ist eine Zusammenstellung von drei Programmen, die für die Unterstützung der Analyse und Visualisierung aktueller und vergangener Erdbebenereignisse, für die Erdbebenstation Bensberg der Universität Köln implementiert wurden. Die Programme bestehen aus (i) einer in C# programmierten Erweiterung für das DesktopGIS ArcGIS von ESRI, (ii) einem WebGIS, welches die UMN MapServer Software nutzt und (iii) einer in PHP programmierten Webanwendung zur dynamischen Erstellung von KML-Layern. Die Software liest dynamisch die vom SEISAN / SEISNET System erstellten ASCII-dateien, mit den prozessierten Erdbebenereignisdaten ein. Diese Ereignisdatensätze werden in einer MySQL Datenbank mit 17 Attributen für jedes Ereignis gespeichert. Dieser Artikel beschreibt die Systemarchitektur des SeismoGIS. Neben der Datenbankstruktur und der Organisation der GIS-Daten werden außerdem die einzelnen Komponenten und verwendeten Werkzeuge hinsichtlich ihrer Funktionsweise und Implementierung erläutert. Zum Schluss wird ein Ausblick auf die geplante zukünftige Entwicklung des Systems gegeben.

1. INTRODUCTION

The seismological observatory of Cologne University in Bensberg is running a 40 station local network in the Northern Rhine area in Germany (Fig. 1) which belongs to the most active parts of Europe north of the Alps. The routinely observed seismic event data were not linked to a GIS environment before. The same counts for the complete instrumental earthquake database of the Bensberg observatory. Therefore SeismoGIS was developed in cooperation between the Earthquake Observatory Bensberg and the GIS- and RS-research group of the Department of Geography at the University of Cologne. It is designed and developed as a GIS tool for analysis and visualization of the basic parameters of current and past earthquake events. This paper gives an overview of the system architecture of SeismoGIS and describes the database design and the management of the GIS data. In addition the single components e.g. the tools will be described each with its architecture, implementation details and an overview of the provided functionality to the user. Finally a preview on considered future work is given.

1.1 The earthquake observatory and the seismometer network of the University of Cologne

The seismometer network of the Earthquake Observatory Bensberg provides measurements from 40 stations, (Fig1 1). The network covers the Lower Rhine Embayment (LRE), which extends over parts of western Germany, eastern Belgium and the southern Netherlands. The LRE is one of the most important areas of earthquake recurrences in Europe north of the Alps (Hinzen & Reamer 2007). Part of the network is a 20 station strong motion net (SeFoNiB) equipped with the latest strong motion seismometer technology (Hinzen & Fleischer 2007). The central station in Bensberg has remote access to all network stations. The data acquisition system is a development of Cologne University. Routin processing is on the SEISAN System (Havskov & Ottemoeller 1999), a software developed by the seismologists of the University of Bergen (Norway) in cooperation with the British Geological Survey. This system provides the processed attributes of the events measured by the seismometer station network, like coordinates of the epicentre, magnitude and time of occurrence. The naming of an earthquake event by the nearest settlement and the postal zip

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code area of the epicentre, is usual practice for locating events in the seismological sciences (Willmes & Weskamm 2007).

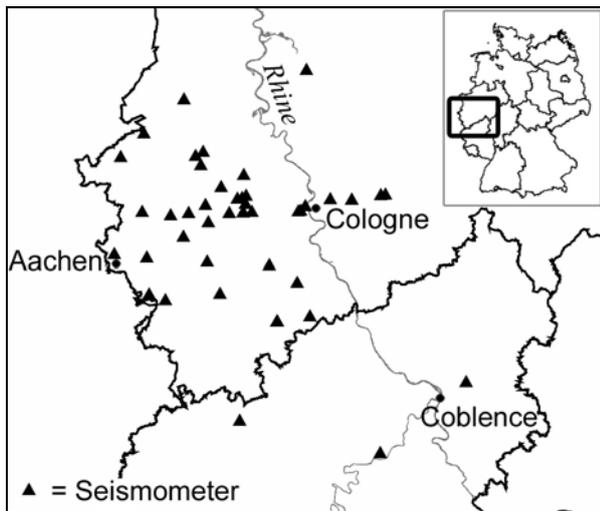


Figure 1. Station network (SeFoNiB).

The naming was so far done on the basis of analogue information like topographical maps and postal zip code area maps. Locating the events was done considering the error ellipses parameters, which are processed by SEISAN and provided as X and Y measuring error (minor and major axis of the ellipse), the epicentre and the angle of orientation.

1.2 The seismic situation in the Lower Rhine Embayment

More than 20 damaging earthquakes have happened in the past 300 years in the LRE, a young sedimentary basin with typical intra-plate seismicity (Hinzen & Reamer 2007). The strongest instrumentally recorded earthquake in the region occurred in 1992 near Roermond, with a local magnitude of 6.0 [Richter] and a hypocentral depth of 17 km. Studies of historical earthquakes such as Vervier (1692) and Düren (1756) estimate macroseismic magnitudes of 6.8 and 6.4 [Richter], respectively. The border faults of the Roer Valley Graben and the seismotectonic setting in the LRE including more than 400 km of active surface fault traces has a potential for producing earthquakes with magnitudes up to approx. 7 (Hinzen & Reamer 2007).

1.3 The aim of the SeismoGIS

The intention of SeismoGIS is to support the daily routine task of the earthquake station with automation of processes, which are mainly the tasks of naming and locating actual measured earthquake events. Especially the task of naming an event by postal zip code and nearest settlement is provided automatically by this extension. A second objective is to visualize, document and publish the earthquake data to the public. Additionally it provides a comfortable management of the geological, seismological and topographical data, which helps to support the analysis of the earthquake data.

2. ARCHITECTURE

The first version of SeismoGIS (Willmes & Weskamm 2007) was developed with Visual Basic 6 programming language as a

Component Object Model Dynamic Link Library (COM DLL) implemented as an ArcMap extension.

Due to reasons of better software design and support of the Microsoft .NET infrastructure the tool was ported from Visual Basic to C#.

The extension is implemented using the ArcObjects libraries provided by ESRI to build custom components, which can be integrated in the ArcGIS environment. The ArcObjects library provides interfaces to connect to ArcGIS applications. In this case the DesktopGIS application ArcMap is used as environment in which the SeismoGIS extension is anchored. ArcObjects was used because it is a “set of platform-independent software components, written in C++, that provides services to support GIS applications on the desktop in the form of thick and thin clients and on the server” (ESRI Developer Network 2008a). ArcObjects utilizes COM, which is often thought of as simply specifying how objects are implemented and built in memory and how objects communication is established. “COM also provides a solid infrastructure at the operating system level to support any system built using COM. On Microsoft Windows operating systems, the COM infrastructure is built directly into the operating system” (ESRI Developer Network 2008b). This architecture provides the advantages of creating interfaces to the rich GIS functionality of the ArcGIS environment. By using COM, the processes take place on a very low level of the operating system, which gives performance and stability benefits. Another reason for using this approach is to embed the self developed relatively small set of highly customized and specialized functionalities into the established environment of ArcGIS.

2.1 System overview

The SeismoGIS consists of three independent tools (see figure 2), (i) the ArcMap Extension, (ii) the KML-Tool and (iii) a WebGIS (see figure 2).

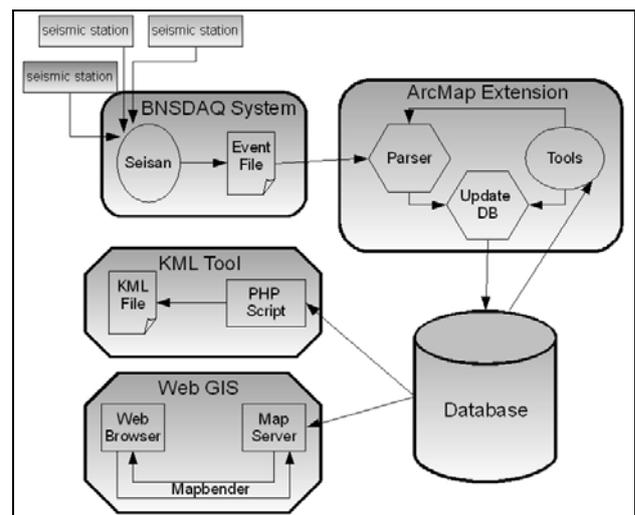


Figure 2. SeismoGIS system overview.

The SeismoGIS tools are based on the event data stored in the MySQL database. One of the key components of the extension is the parser. It parses the data, acquired from the SEISAN system, into a MySQL database, to make the data available to

the GIS environment. The parser can be triggered manually or by automatic checking if a specified event file has been updated by the SEISAN system.

The resulting database provides the seismic event data for any component of the SeismoGIS. This event database grows approx. by three earthquake events per day (Willmes & Weskamm 2007). These are added to the already approx. 5000 archived seismic events in the database, which consists of the comprehensive earthquake event archive of the Bensberg observatory. The main tool, which provides the interface between the measured and processed earthquake event data generated by SEISAN is the ArcMap extension. In this extension, all the functionality for visualizing and analyses, like drawing of error ellipses and automatically naming and locating the events within the desktopGIS application ArcMap is implemented.

The KML Tool generates KML layers directly from the event database. KML is an XML based geographic content exchange format and stands for "Keyhole Markup Language". It is an OGC standard since early 2008. (Wilson 2008). The user can make different queries on several attributes of the events as well as spatial queries to select a subset of events from the database, of which the KML layer will be generated.

The online GIS within the website of the earthquake observatory (<http://www.seismo.uni-koeln.de>) shows the content of the event database in an interactive WebGIS GUI. It provides interactive spatial and attribute matching queries on

the database content, to give the user a wide variety of functionalities to visualize the earthquake data.

2.2 The SEISAN format parser

The parser is one of the key components of the SeismoGIS. This parser reads the values of an earthquake event from ASCII files provided by the SEISAN system in a "nearly static" SEISAN format (see figure 3). The SEISAN format describes the arrangement of the attributes in each record set in the event ASCII file. These record sets are stored as blocks of data which are constructed as followed. The first four lines of an event record (Fig. 3) are static. These values are always on the same character positions in a particular line of the ASCII dataset. The lines from four on are non-static, because they depend on the number of involved measuring stations of the particular event. In contrast to that, the number of involved stations is given in the static part of the dataset in line one. With this information it is possible to develop an algorithm that parses the data below line four dynamically. For each earthquake event 17 attributes, like coordinates, date and time of occurrence, magnitude etc., get parsed and stored in the database.

Internally all attributes of an event get handled in a user defined datatype (UDT). This UDT is implemented as an object of a class which encapsulates and manages the parsed values. This design gives the advantages of passing sets of events between database, processing, analysing and visualization functionality easily as collections of these event objects.

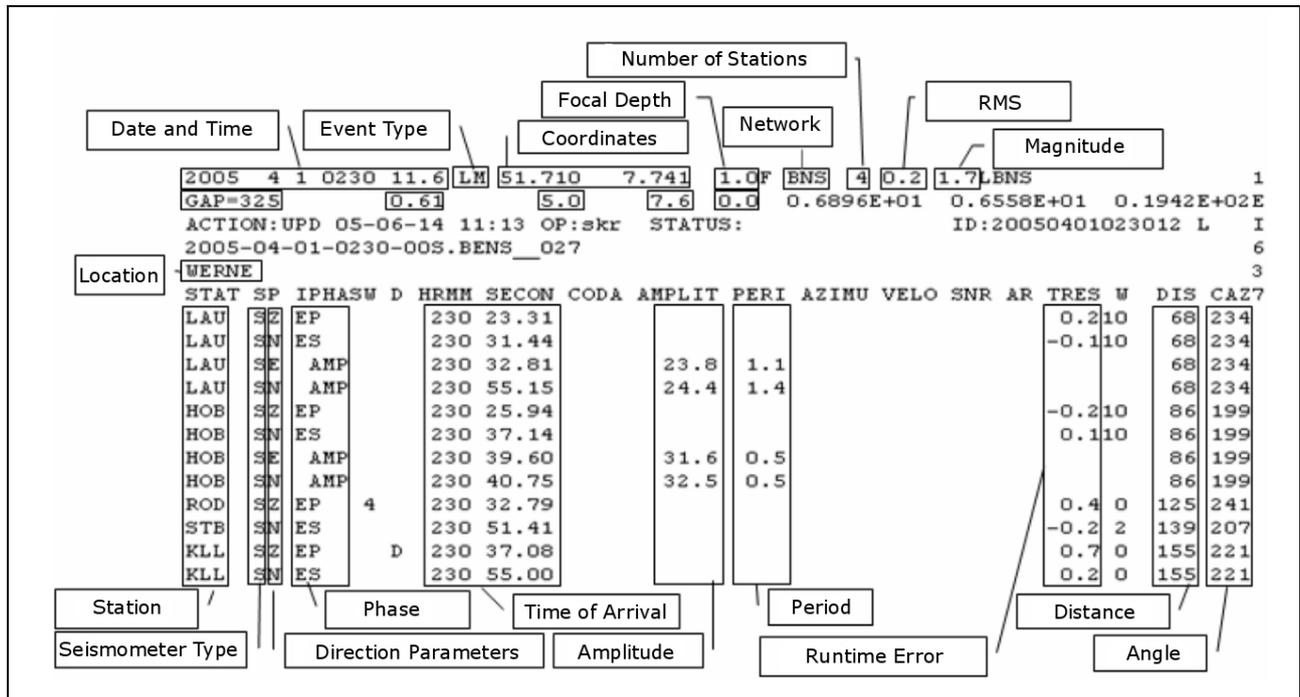


Figure 3. SEISAN format event recordset (Willmes and Weskamm 2007).

2.3 Database design

In the MySQL database the events are stored in one table with one row per event. Every event has a nearly unique timestamp by which it is identified internally. This timestamp gets generated from the date time of the event occurrence. The

measured date time has a resolution of 0.1 seconds. So it is possible to get two events occurring on the same tenth of a second time interval, which would be considered as one and the same. But the probability of the occurrence of two events in the same tenth of a second is very little, therefore this method of identification was considered good enough to use. To

implement spatial queries in the KML tool, two additional tables with information about the relationships between postal zip code areas and governmental units' areas were created. The first table stores the governmental units for each postal zip code area, in particular community (german: *Gemeinde*), county (*Kreis*), state (*Bundesland*) and country (*Staat*).

Hence a spatial query is implemented as a matching between the postal zip code area of the event and the postal zip code areas of the governmental unit. The second table stores the postal zip code areas of each governmental unit. A further matching between the returned set of zip code areas from each governmental unit is necessary for the implementation of the spatial queries. The postal zip code based spatial queries are not implemented by geometries, like bounding boxes or polygons, instead it is implemented by a simple attribute matching and saves from computing spatial intersections geometrically.

2.4 Geodatabase of the GIS

The SeismoGIS uses different datasets for the visualization of the earthquake events. Most of these datasets first had to be edited and converted in order to get a unique and satisfying visualisation. A geological map in a scale of 1:1,000,000 is used to cover whole Germany with petrographic, stratigraphic and genesis information. A script was written in the VBA programming language (Visual Basic for Applications), to colourize the different polygons of the primarily uncoloured map with the help of an included data table. This table contains the necessary CMYK colour information and also the ID of each polygon, so that this information could be automatically connected to the vector graphics of the map. Besides this, different geological maps in a scale of 1:200,000 are used as vector graphics to give more detailed information on the geological situation. A DLM (Digital Landscape Model) is also used to provide the user with the necessary topographic information in a scale of 1:250,000. Additionally, topographic raster maps are going to be used in different scales to serve standardized views of the topographic information e.g. with signs and symbols. The VG250 datasets are used to visualize the administrative boundaries of a region. As already mentioned, vector data of postal ZIP code areas are included in the geodatabase of the SeismoGIS, not only for visualization, but mainly for determining the zip code of the locations of near earthquake events. Digital elevation data of the SRTM (Shuttle Radar Topography Mission) are also included and used as raster images in the SeismoGIS. Georeferenced satellite images, obtained by the Landsat-7 ETM+ satellite through the USGS (United States Geological Survey), complete the geodatabase.

The whole geodatabase of the SeismoGIS is saved as a mapdocument (.mxd) in ArcMap. It contains the arrangement of the different layerfiles, their colourisation, symbology and labelling. With the option of saving the map document with relative paths, the whole data basis can be moved without losing the linked information.

3. THE TOOLS

3.1 The ArcMap extension

The extension for ArcMap forms the interface between the earthquake data generated by the SEISAN system from the measurements of the station network and the composed geodata of the GIS for the earthquake analysis (see figure 2).

It is the key component of the SeismoGIS, because it manages the editing of event features and the updates of new and edited events into the database. For post editing of the data, it is possible to edit all attributes of the earthquake events with the "edit events tool" of the extension and update the edited changes into the database.

The main functionality of the extension is, the implementation of the SEISAN parser and the possibility to import new event datasets into the database. This makes it possible to select the actual SEISAN output file via network as the automatically checked file. So the tool can read the actually measured events directly into ArcMap.

The ArcMap extension provides also several functionalities like visualization of the error ellipses, estimating of the spatial context like nearest town, postal zip code etc., or automatic generation of printable maps and statistic reports of selected seismic events, as well as the export of the event layer as a whole or a selectionset of events as a KML file for viewing in an Virtual Globe application like Google Earth. Placemark features of the events are exported by this KML export function including a HTML table generated from the event attributes information within the description tag of the KML Placemark feature.

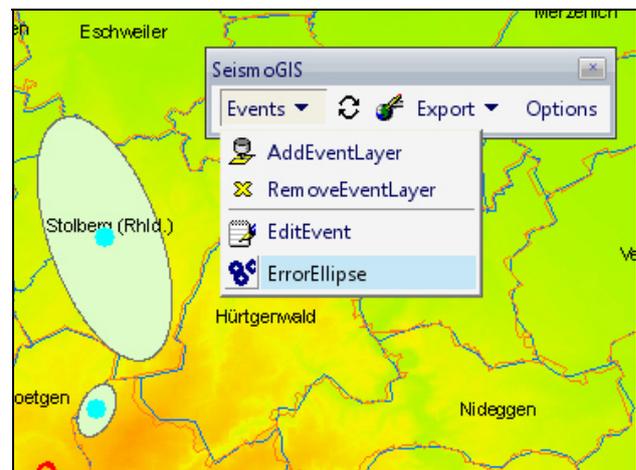


Figure 4. Screenshot of the SeismoGIS extension toolbar.

Figure 4 shows a screenshot of the extension in action.

One of the main features of the extension is the visualization of the error ellipses. The ellipses are drawn as polygons calculated by the parameters of X error, Y error, angle of orientation and the epicentre coordinates, which are processed by the SEISAN system and parsed as attributes for each event. This is a significant improvement for the quality of the event naming and locating process: As mentioned above, previously the seismologist on duty considered the fault ellipses in mind from the given parameters. Hence, this is an evaluation tool in terms of precision of the measurement.

Another feature of the extension is the automatic estimation of the zip code area of the event and provision of suggestions for naming the event by a settlement name. The zip code area is simply determined by an intersection of the epicentre with the zip code area polygon. In the first place the system suggests the name of the community which area polygon intersects with the epicentre. In case of a larger extent of the error ellipses, a settlement with higher population in the area should be chosen for naming tasks. Using the name of a small settlement in this

case would implicate a precise estimation of the epicentre, which would be misleading. If the extent of the error ellipse is relatively small because of a precise estimation, it is appropriate to choose a smaller settlement for naming the event. The naming algorithm just generates suggestions: the final decision is still made by the seismologist. However it is planned to implement an algorithm which can estimate an appropriate settlement for naming the event by error ellipse size and population of the settlements in a calculated distance (radius) of the settlements from the estimated epicentre.

3.2 The KML-tool

Since the KML standard (Wilson 2008) is a widely accepted interchange format of geographic content, especially for web based applications, a tool to give the users of the earthquake observatory website the opportunity of visualizing the earthquake event data in a Virtual Globe like Google Earth or NASA WorldWind by KML is implemented. The tool facilitates this by a small dynamic PHP application, which generates KML layers from the events database.

The user can request a KML file dynamically by querying several attributes of the events. In detail, attributes like the time interval of occurrence, a selection by magnitude, for example all events with a magnitude greater than X or all events between magnitude X and Y, as well as spatial queries defined by a bounding box of coordinates or by a geographical region can be visualized. The geographical region is defined by a political unit with clearly defined boundaries like a state, a province or county, down to postal zip code areas. The matching of the postal zip code areas was described in section 2.3 "database design". In the case of a spatial query by a bounding box, a simple test if the X and Y coordinates are between the given coordinates of the bounding box corners delivers the intersecting events.

The user applies his request through an HTML form. By submitting that form, a PHP script is triggered which gets the data, defined from the user input by attribute matching rules or spatial intersections, from the MySQL database in combination with the mentioned matching algorithms and creates an KML file with the requested content as a reply to the user request. The different queries can be combined with each other, so that the user has relatively detailed selection opportunities of the given data for the generation of the KML layers.

The generated KML layers can be viewed in the mentioned virtual globe applications or the most web mapping service applications (like Google Maps, OpenLayers or Virtual Earth). The KML files are provided as a temporally URL of the generated KML layer file. The user can choose to download the layer to his local computer or display the layer directly from the web server using the provided URL in one of the mentioned web mapping applications as data source.

3.3 The WebGIS

An online GIS is implemented by using the open source UMN MapServer software. The MapServer generates WFS services for the WebGIS from shapefiles which are generated automatically and manually by the observatory based on the event database.

For the configuration by the earthquake observatory staff, the software Mapbender is used. Mapbender acts as a geo content

management system to orchestrate different WMS and WFS data sources into an online GIS (Mitchell et. al. 2008). Applying that tool the observatory staff is able to change the set of tools which are accessible to the user for online browsing the data, and also to change the composition of the data layers of the GIS, as well as the appearance of the interface.

4. CONCLUSION AND FUTURE WORK

The SeismoGIS is a toolset for supporting the staff of the earthquake observatory Bensberg on their daily routine work. The task of locating and naming the events measured by the seismometer station network is significantly improved by this application. In general the System acts as an interface between the SEISAN system, where the parameters of events get processed, and the desktop GIS ArcGIS. Consequently, every working group which is using SEISAN could apply SeismoGIS for the described functionalities. Consequently, the SeismoGIS users are now able to analyse the event data in the desktop GIS environment, which support the research on issues like calculating of seismological risk area maps.

Another aspect of the SeismoGIS is the visualization, publication and documentation of the data, which is acquired and archived by the earthquake observatory. For publication the historical and actual earthquake event data on the website, a WebGIS and an application for generating KML layers out of the earthquake database are implemented.

For the automatic naming of the events by a settlement name, an improvement of the quality by using a centrality factor will be considered for future development of the SeismoGIS. This centrality factor will be estimated from a combination of economic and sociological status factors, which has to be defined and the number of inhabitants of the considered settlement.

As an additional functionality, it is planned to integrate a 3D geological subsurface model into the SeismoGIS data basis. This would allow to implement geostatistic functionality based dynamically on the regularly updated data basis of the measured earthquake events and support seismic hazard analysis. The processing of macroseismic data, recent and historic will eventually be included as well.

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