GIS Functionality in Multimedia Atlases: Spatial Analysis for Everyone

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Abstract

Modern multimedia atlases offer both a high cartographic quality and a user-friendly interface yet they still lack the functionality to perform advanced spatial analysis. This paper presents a new approach, which explores the possibilities of integrating analytical GIS functions with multimedia atlases. In order to realize this approach, the software AGAIS was developed by extending a multimedia authoring system with additional GIS functions implemented as a C++ shared library. AGAIS contains a set of applicable GIS functions that are easy to use, reliable and fast. Using this software, thematic and topological Boolean database queries can be performed without prior SQL knowledge. In addition, the values of the attributes in the database can be reclassified in a hierarchical reclassification tool. Moreover, graphical and geometrical overlay can be performed. The line intersection process of the geometrical overlay is rendered transparent to the user by drawing the intersection points on the map, in order to reduce waiting time. Finally, histograms and contingency tables can be displayed to visualize statistical distribution and correlation. The results of this study show that GIS functions in multimedia atlases cannot be simply adopted from common GIS, but have to be redesigned in order to foster meaningful use by non-expert atlas users.

Introduction

Geographic Information Systems (GIS) are required in order to analyse spatial data. These systems are becoming increasingly user-friendly, but technical training and expert knowledge are still needed for operation. On the other hand, multimedia atlases are easy to operate, but they lack advanced spatial analysis functions. The present study investigates how GIS analysis functions can be integrated with a multimedia atlas system, and how these functions can be rendered accessible to a broad range of non-expert users.

Currently, three apporaches exist towards integrating GIS with multimedia. The first is referred to as “Multimedia in GIS” (Bill, 1998; Craglia and Raper, 1995) and entails extending commercial GIS software with additional multimedia elements. The essential advantage of this approach is that GIS functions, as well as structures for storing geometrical and attribute data, are already built in the system. This strategy is favoured by GIS developers to produce urban and environmental decision-support systems (Blat et al., 1995; Moreno-Sanchez et al., 1997; Olenderek et al., 1996). Similarly, some national multimedia atlases are also based on this approach, e.g. the PC-Atlas of Sweden (Ögren, 1997; Wastenson and Arnberg, 1997). However, the second approach, called “GIS in Multimedia”, favours development of high standard multimedia atlases. It attempts to integrate GIS functionality with multimedia authoring systems and is more flexible. The graphic user interface can be designed independently of a GIS system. Moreover, cartographic and GIS functions can be individually adapted to meet the specific needs of non-expert atlas users. Despite these important advantages, several shortcomings prevail. Initially, this approach is very labour-intensive. Secondly, it does not support data structures that equally provide for high cartographic quality and GIS functionality. As a matter of fact, most modern multimedia atlases, e.g. the national atlases of Austria (Kelnhofer et al., 1999), Germany (Lambrecht, 1999), and the USA (Wright, 1999), do offer high visualisation quality yet they lack such GIS functionality that would go beyond simple measuring, database query and graphical overlay. To overcome these drawbacks, Bär and Sieber (1999) suggested a third approach especially designed for the development of multimedia atlases: “GIS and Multimedia Cartography”. Its new cartographic data structure not only allows for optimal cartographic visualisation, but also offers cartographic and elementary GIS functions. This approach was followed when developing the first edition of the ATLAS OF SWITZERLAND (2000).

In the following section we suggest a new approach, which extends the "GIS and Multimedia Cartography" approach with additional analytical and more complex GIS functions. It is called "GIS Analysis for Multimedia Atlases". Subsequently, we illustrate how this approach can be put into practice by developing the software AGAIS (**A**nalytical **G**eographic **A**tlas **I**nformation **S**ystem). The purpose of this software is to complement the second edition of the ATLAS OF SWITZERLAND. The research questions are as follows: 1. Which GIS functions are applicable to multimedia atlases? 2. How should the user interface be designed? 3. How can these functions be technically integrated within a multimedia atlas environment?

The "GIS Analysis for Multimedia Atlases" approach

Suitability of GIS functions
In order to evaluate the suitability of GIS functions for multimedia atlases, we need to classify them first. According to Goodchild (1990) GIS functions can be subdivided into data entry (e.g. digitizing), manipulation (e.g. editing), analysis (e.g. overlay) and output functions (e.g. map making). In contrast to GIS, where users can carry out all of these four main functions, users of multimedia atlases should be preoccupied neither by data entry nor by data manipulation. In fact, atlas users are rather meant to concentrate on data analysis and presentation. Since data presentation is not part of this study, we are concerned with data analysis functions. Albrecht (1996) presents a set of twenty GIS analysis functions covering the full range of analytical capabilities of current GIS. These functions are independent of data structures, they do not require any knowledge of abstract spatial concepts, and they are readily apprehended. Therefore, they are a priori suited for multimedia atlases. In practice, however, some of them have to be excluded, e.g. buffer and corridor functions. They do not make sense in small scale maps of a national atlas. Multivariate statistical functions have also to be excluded because they are too complex for non-expert atlas users. Below, we present a set of seven GIS functions, which we consider suitable for multimedia atlases, and which we have implemented in AGAIS:

- *Database queries:* thematic Boolean queries, topological queries, reclassification
- *Spatial analysis:* graphical overlay, geometrical overlay (by line intersection)
- *Uni- and bivariate statistics:* distribution, correlation

User interface
When designing the user interface for the GIS functions listed above, the following criteria have to be taken into account (Schneider, 1999): First of all, functions should be *simple*, that is intuitively understood by expert and non-expert users without extensive explanation. Second, the authors must control actions and settings to a certain degree to prevent users from obtaining incorrect results. In other words, functions have to be *reliable*. Finally, tasks must be *fast*, i.e. performed within a short time.

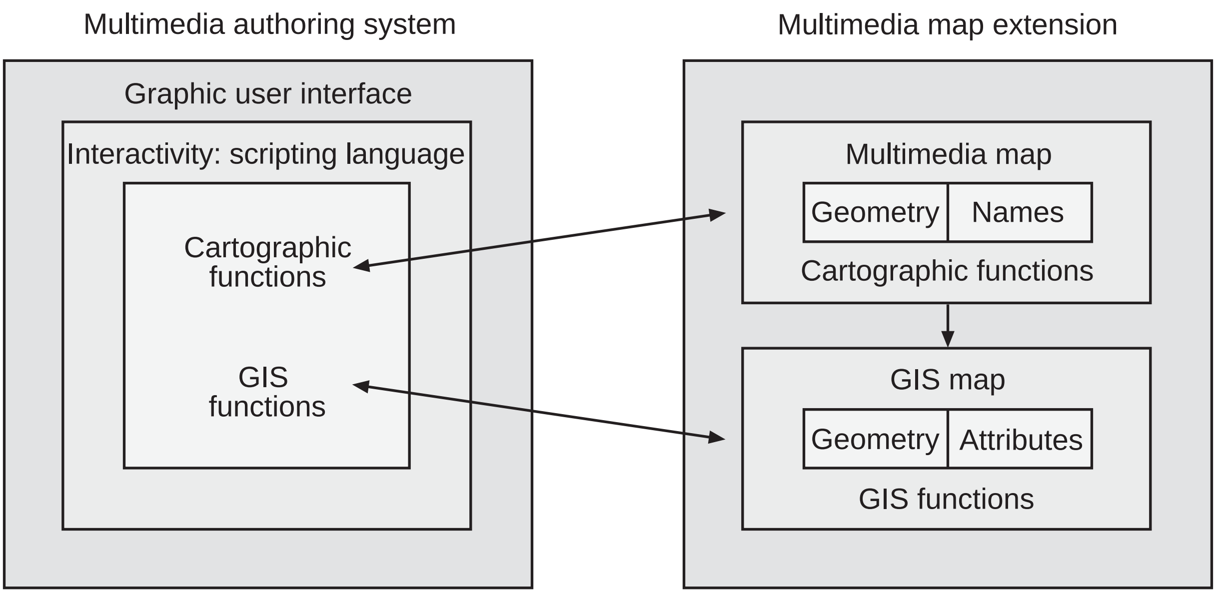

Figure 1. Technical implementation of the "GIS Analysis for Multimedia Atlases" approach.

Technical implementation

In figure 1, the technical implementation of the "GIS Analysis for Multimedia Atlases" approach is illustrated. The multimedia authoring system provides all necessary elements for designing the graphical layout of an atlas. It also contains a built-in scripting language to control interactive user input by means of buttons, sliders, menus, etc. Cartographic and GIS functions, however, are externally stored as a shared library, which communicates with the built-in scripting language. Basically this external shared library, called *multimedia map extension*, consists of two modules. The first module controls cartographic functions, like intelligent zooming and drawing Bézier curves, and elementary GIS operations like georeferencing, scrolling, and simple querying. The second module is based upon the first and provides the additional GIS analysis functions.

We have used the commercial multimedia authoring system Macromedia Director and its scripting language Lingo for developing the AGAIS software. The *multimedia map extension* is written in C++ and has been programmed by the authors themselves.

Data

Data sets

In our approach, we refer to environmental vector data sets like soil, climate, geology, or land cover. This kind of data usually consists of polygon vector geometry linked to a database containing ordinal or nominal attributes. For the development of AGAIS, we used the digital soil-suitability map of Switzerland 1:200'000 (© Swiss Federal Statistical Office, SFSO). Its attribute table contains information about soil types and soil properties like water retention capacity, nutrient retention capacity, permeability, soil depth, etc. We also recurred to the relief of Switzerland 1:1 million (© Swiss Federal Office of Topography), to the map of average annual precipitation 1:1,5 million, and to maps of administrative borders (cantons and districts, 1:1 million, © SFSO).

Data structure

Geometrical data is stored as *multimedia map file*, a file format particularly developed to represent cartographically updated GIS data in a dynamic multimedia environment (Bär and Sieber, 1999). Its data structure is based on a spaghetti data model featuring no topology. This model is very efficient for cartographic display and for simple GIS operations, but it is not an optimal solution for more complex operations affecting the geometry of the polygons (e.g. line intersection). The file format can be imported and handled by the *multimedia map extension*. Attribute data is imported from standard DMBS and stored in an internal structure of the extension.

Practical implementation of the "GIS Analysis for Multimedia Atlases" approach

In this section, we intend to demonstrate the practical implementation of the "GIS Analysis for Multimedia Atlases" approach by presenting a discussion of AGAIS's own set of seven GIS functions. We also illustrate to what extent these functions differ from those found in common GIS so that untrained users can understand them by intuition.

Thematic Boolean queries

In GIS, Boolean database queries require at least some knowledge of SQL (Structured Query Language) expressions, using *and*, *or*, *not*, etc. As soon as several queries are combined, these expressions get increasingly complex and nested. The following SQL syntax would be required to select all the "Cambisol" and "Gley" soil types with a good "water retention capacity": *Select ("Soil type" = "Cambisol"* ***or*** *"Soil type" = "Gley")* ***and*** *"Water retention capacity" = "good"*. For AGAIS, we developed a query form that enables the users to build complex Boolean queries without any knowledge of SQL. In addition, the structure of the query window prevents the users from performing queries that lead to a useless or empty result. The query window displays all the attributes and their values at a glance (see figure 2). The main soil types "Cambisol" ("Braunerde") and "Gley" are selected, which corresponds to a logical *or*. The query is then additionally narrowed by a logical *and* expression: "water retention capacity" ("Wasserspeichervermögen") = "good" ("gut"). Note that all those values of the attributes appearing in grey cannot be selected because this would lead to an empty result.

Topological queries

In a common GIS, several independent steps are required in order to combine thematic and topological queries. In AGAIS, this combination is achieved in a simpler way and in one single window. By opening an additional panel on the bottom of the query window (see figure 3), users can perform supplementary topological queries. They can search for soil units lying within one or several administrative borders (cantons or districts). Additionally, they can choose whether the polygons should lie only partially or completely within these borders.

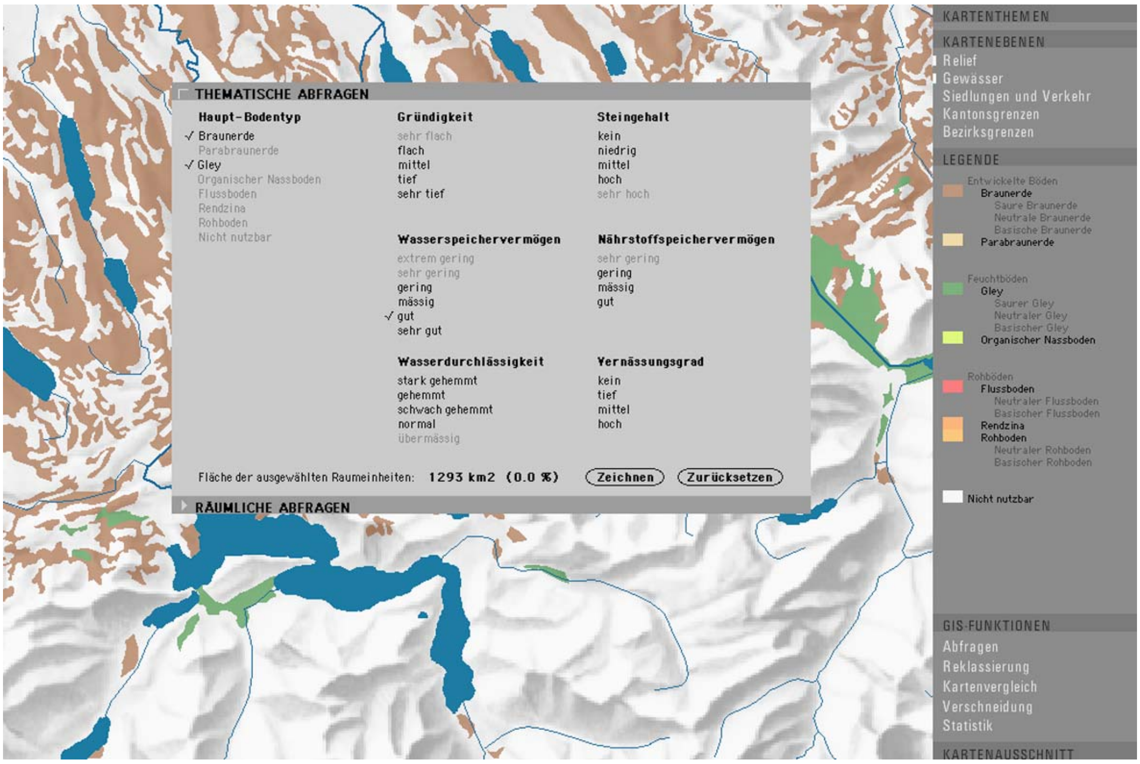

Figure 2. Thematic Boolean query of the attributes "main soil type" ("Haupt-Bodentyp") and "water retention capacity" ("Wasserspeichervermögen").

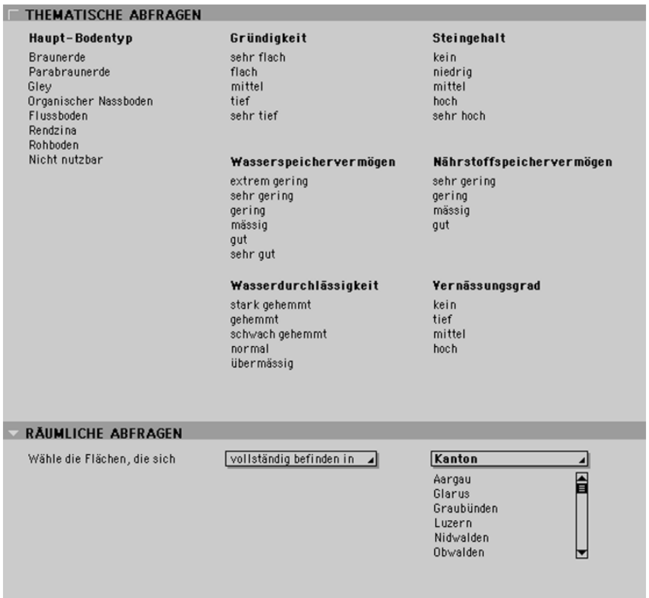

Figure 3. Extended query window where thematic and topological queries can be combined.

Reclassification

By reclassifying nominal map attributes, the database is modified. Experts only should perform this action. For this reason, atlas authors need to restrict the range of possibilities for reclassification. They even have to determine which attributes can be reclassified in which sense. As for AGAIS, we developed a hierarchical reclassification tool for the attribute "soil type". According to the desired level of detail, soil types can be regrouped or subdivided to predefined classes. In figure 4, the values of the attribute "main soil type" ("Haupt-Bodentyp") are regrouped into superordinate classes. After reclassification, the map and the legend are redrawn according to the new values of the attributes.

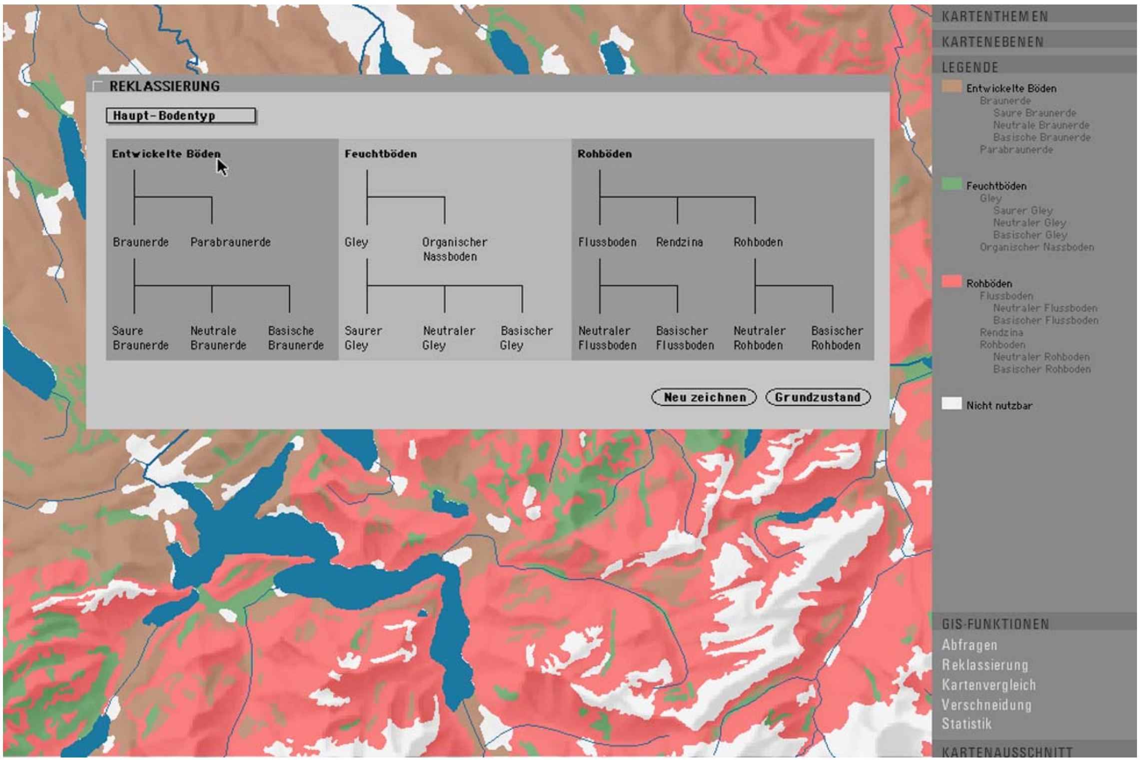

Figure 4. Reclassification: the values of the attribute "main soil type" ("Haupt-Bodentyp") are regrouped into superordinate classes.

Graphical overlay

The graphical overlay of two transparent map layers can lead to a very unaesthetic result if too many colour combinations meet. Atlas authors should thus preprocess the layers by reducing the number of classes and by attribut-

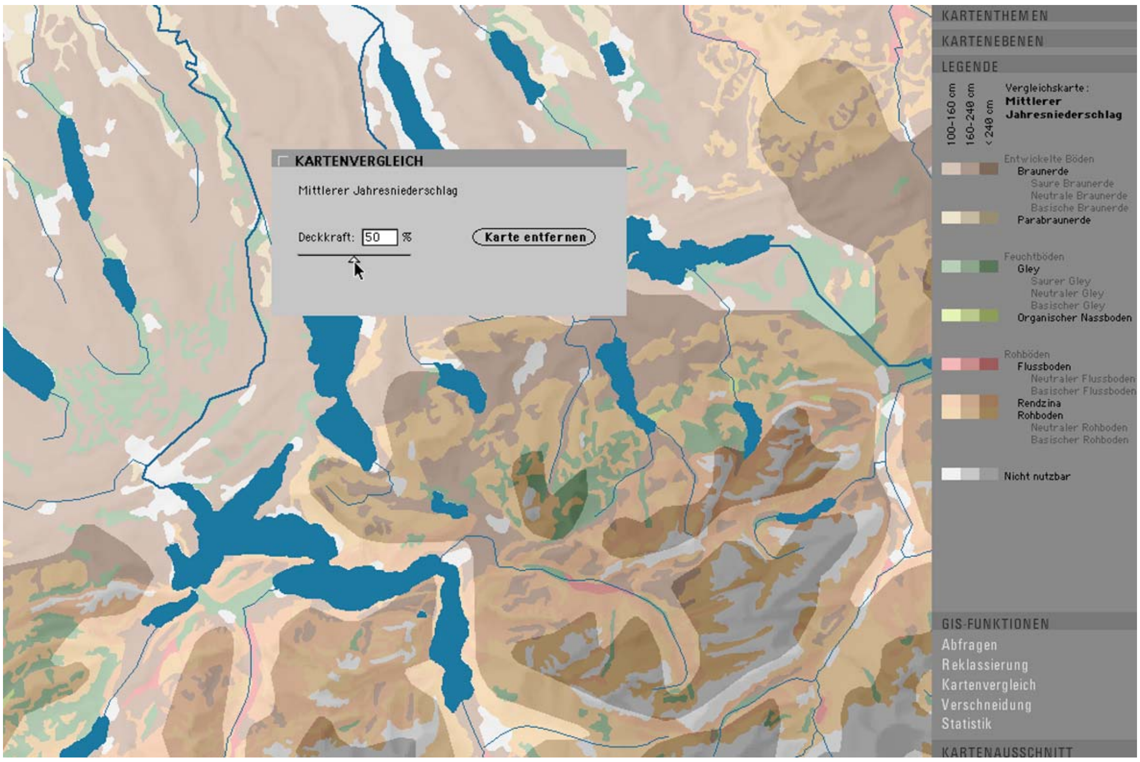

Figure 5. Graphical overlay: the opacity of the second layer, "average annual precipitation" ("mittlerer Jahresniederschlag"), can be adapted by moving a slider. It is currently set to 50 %.

ing appropriate colours. In figure 5, the colour classes of the second layer ("average annual precipitation" = "Mittlerer Jahresniederschlag") have been reduced to three grey scale values, while those of the main layer ("soil type") remain unchanged. The opacity of the second layer can be individually adapted by moving a slider. It is currently set to 50 %. In order to facilitate the identification of colours on the map, the legend has been rendered two-dimensional. The corresponding legend box flashes when the mouse moves over the map.

Geometrical overlay by line intersection

Polygon overlay by line intersection is one of the most complex GIS operations and is therefore numerically intensive and time consuming. For atlas users, however, computing time has to be reduced to a minimum. This can be achieved by using an efficient topological data structure. Unfortunately, the multimedia map file does not support topology to the effect that every single line segment is stored twice. In order to overcome this drawback, map geometry was first generalized by reducing vertex points. Second, the intersection process is made transparent to the users in order to subjectively reduce waiting time. Intersection points are thus progressively marked on the map (see figure 6). Afterwards, new polygons are constructed and simultaneously drawn. As a result, users are able to comprehend this complex process by taking an active part in it, without even noticing time passing.

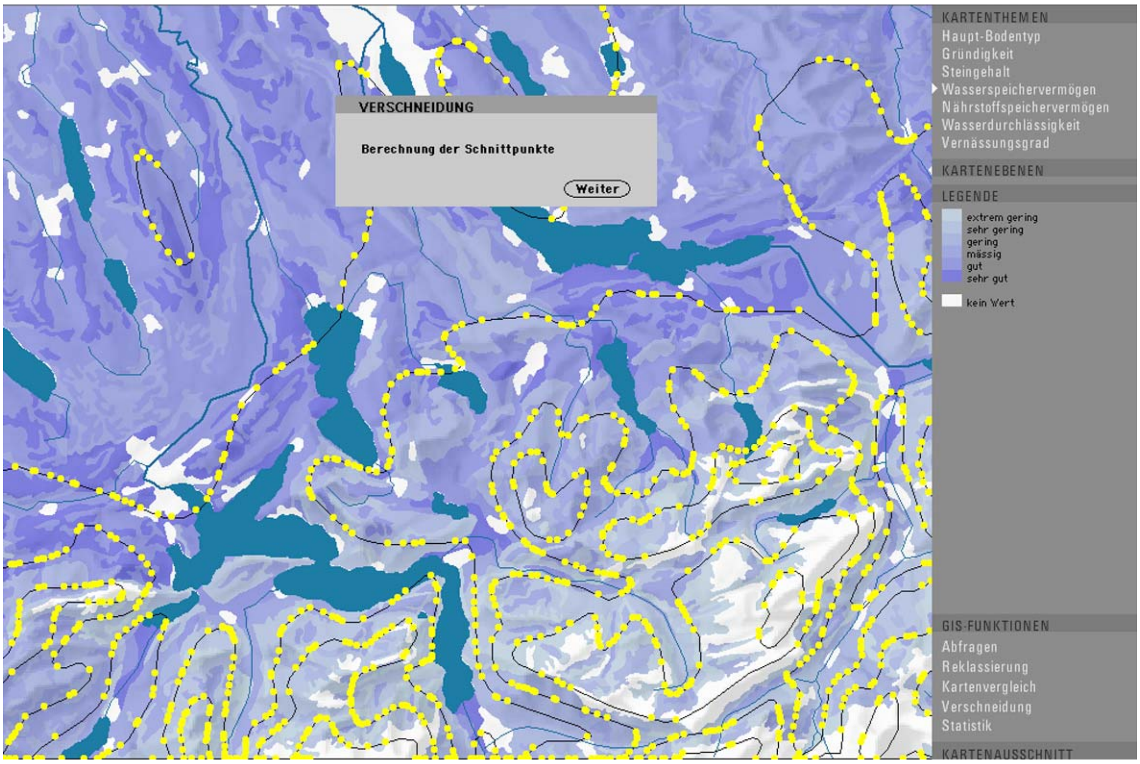

Figure 6. Geometrical overlay of the soil and the precipitation layer. While line intersection points are calculated, they are marked on the map at the same time.

Uni- and bivariate statistical functions

Users are able to choose between two different statistical functions. They can choose a histogram displaying the area sum of each value in order to visualize the distribution of one single attribute. The correlation between two attributes, however, is best displayed in a contingency table. In order to identify the correlation pattern at a glance, we assigned colours to the boxes of the table, according to their area proportion. In figure 7, the variables "nutrient retention capacity" ("Nährstoffspeichervermögen") and "soil depth" ("Gründigkeit") appear to correlate positively:

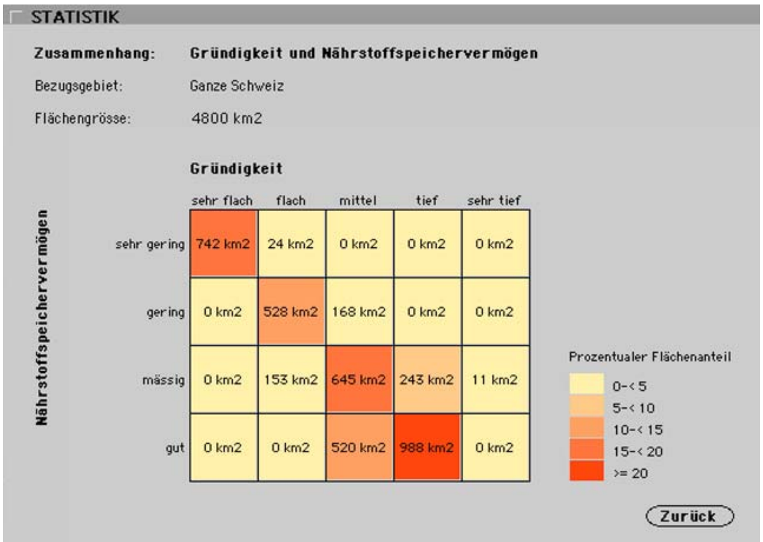

Figure 7. Correlation between the variables "nutrient retention capacity" ("Nährstoffspeichervermögen") and "soil depth" ("Gründigkeit").

Conclusions and Outlook

The integration of GIS functionality offers new perspectives to multimedia atlases and extends their field of application. Complex spatial analysis, so far mainly performed by GIS specialists, is now also available to a broader range of users. People who neither have a GIS technical education nor do dispose of spatial data sets and GIS systems will have the possibility to analyse spatial data, gaining insight into environmental processes and their interactions. The results of the present study show that GIS functions can be integrated with a multimedia atlas environment. These functions, however, must be carefully chosen, considerably adapted and simplified so that atlas users can understand them by intuition. Therefore, the user interface cannot be adopted from common GIS, but has to be redesigned according to the needs of atlas users.

Although the GIS functions of AGAIS have been developed using soil and precipitation data, little additional effort is needed to adapt them in a way to make them suit other environmental data sets. Before these functions can be implemented in the second edition of the ATLAS OF SWITZERLAND, soil and precipitation maps have to be accorded to a common scale of 1:500'000. Otherwise spatial analysis on these data does not make much sense. Future improvements need to focus on the data model. Certain functions (e.g. line intersection) should be conducted more efficiently. In addition, the "GIS Analysis for Multimedia Atlases" approach, which has been designed for a single medium (CD-ROM), should be extended to other media like the WWW. To meet these requirements, a new XML based topological data model for distributed geographic and atlas information systems is planned for future editions of the ATLAS OF SWITZERLAND (Hurni et al., 2000). Further developments on GIS functions in multimedia atlases have to focus on point data (e.g. interpolation), raster data (e.g. terrain modeling), and 3D functions.

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