# INNER-MOUNTAIN CARTOGRAPHY - FROM SURVEYING TOWARDS INFORMATION SYSTEMS

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## Abstract

*Karst- and cave-systems are complex, 3-dimensional phenomena. Mapping and visualizing them represents a challenge to cartographers, morphologists and computer-graphics-specialists. Surveying and sketching of cave-maps as well as the construction of 3D-cave-models (incl. geology) are important parts of cave exploration and research. Besides supporting the efforts of speleologists, cave maps and 3D-models provide geologists and hydrologists with a better insight into the geological and tectonic structure of a given mountain range. This contribution deals with the computer-assisted generation of 2D cave maps and illustrates one possible implementation of a 3D cave information system. It is important to emphasize that neither a 2D-map nor a 3D-model is able to appropriately represent the complex structure of cave systems and their surrounding geology. In combination with observations in related disciplines (e.g. geology, hydrology, morphology, climate research, ...) they help to better arrange the "puzzle" of complex cave systems and understand their genesis.*

# Introduction

Karst is one of the major landscape types in the Alps. It contributes about 20 percent towards the overall area of both Austria and Switzerland. Roughly 50 percent of the Austrian population rely upon the water supplies of karst springs, including big cities such as Vienna, Innsbruck and Salzburg. In Switzerland, various communities and cities, such as Montreux, Vevey and La Chaux-de-Fonds directly depend on karst water. On all continents karst is a major landscape type. Due to various hydrological and geological factors, karst areas are highly vulnerable, especially if exposed to the stress of increasing hydrological, agricultural, touristic and urban use. Drainage systems within karst are mainly underground and therefore have not yet been researched thoroughly. These facts increase the significance of exploring and researching karst and its cave systems. Increasing knowledge on the various interdependencies of both environmental factors and human impact is of high relevance to the public.

The authors are active members of the Swiss and Austrian speleological societies and are collaborating with amateurs and specialists, in order to improve and complete the documentation and visualization of karst- and cave-systems. They are particularly interested in modelling terrain, geologic structures and underground features, in "inner-mountain" cartography and in establishing information systems for documenting karst- and cave features. Some of the software modules of the "Toporobot Family" - a suite of modules for terrain modelling and cave data management - have been developed by Martin Heller for more than 30 years. The development of a spatial information system for three-dimensional structures initially targeted karst research, but has the potential to be used for more general purposes as well.

## Definitions

In cave-mapping the terms "speleometry" and "speleography" can be distinguished, as introduced by Heller in 1980 [4]. Speleometry deals with surveying methods and processing of the derived data. Speleography deals with detailed topographic and thematic cave-mapping, and with 3D-visualization. Geodetic and cartographic data, together with other elements, form a complex database-driven "Cave-Information-System" (shortform CIS). CIS-elements include a cave-object's basic data (extent, height difference, length, etc.), verbal descriptions, directions and entrance descriptions, a site plan, photos and videos, trip reports, a chronicle of exploration, hints for trip planning and required equipment, 3D visualization and animation, geologic observations, flora, fauna and meteorologic monitoring, hydrology observations, findings and laboratory samples, documentation of human artefacts, bibliography and historical documents. The integrated "Cave-Information-System" is a synthesis of all available information on karst- and cave-objects and is the long-term objective of all efforts in documenting karst and related cave phenomena.

# Data Acquisition

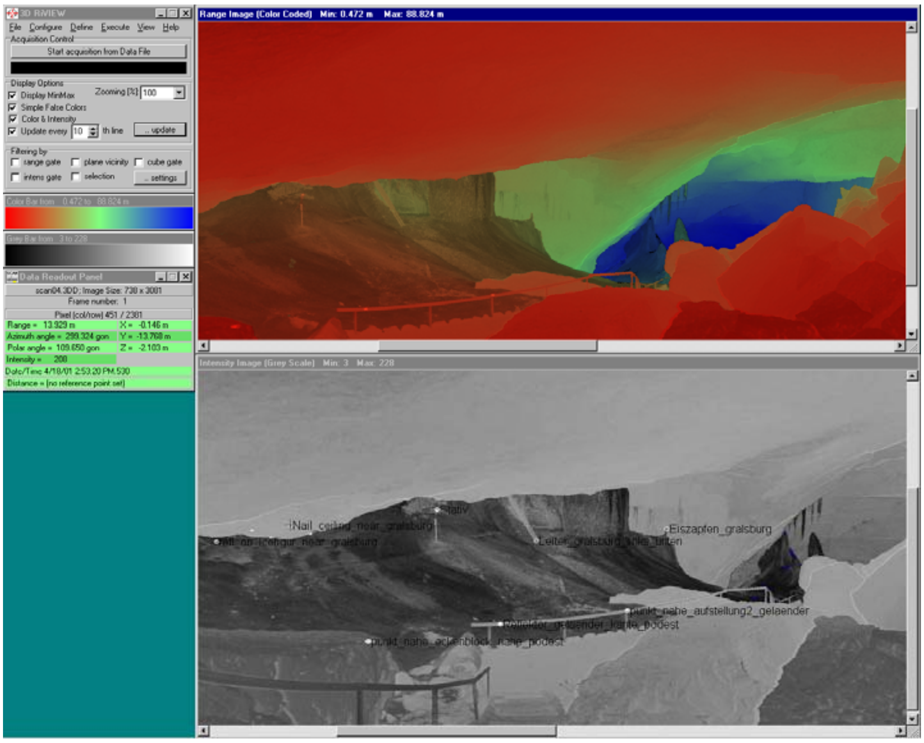
## Traditional Survey Approaches

### Current techniques

Caves are usually surveyed with quite simple methods, like compass, tape and clinometer. A reasonable price-performance ratio is thus ensured, along with good operability of the instruments, even in adverse conditions. In Europe, compasses and clinos produced by the Finnish "Suunto" company are most widely used [13]. The ultimate accuracy of such compasses is specified by the manufacturer with 1/6 degree, in practical use, however, the range is rather 1 to 5 degrees. In order to survey main passages with higher accuracy, cavers also used theodolites and tachymeters. Examples in Europe are passages of the "Hoelloch-Cave" in central Switzerland, and some of the main passages of the Dachstein "Mammut-Cave". Theodolites and GPS systems are frequently used for surface surveying of karst formations and cave entrances.

### Difference to land surveying

Unlike regular land surveys that typically result in well-defined, dense triangulations, the traverses of underground surveys are loosely intertwined. Thus, the resulting error-equations are only slightly overdetermined. The required accuracy for cave surveying is not very high though. Due to surveying conditions which frequently are most unfavourable, the number of serious blunders is usually quite high. The primary goal is therefore to efficiently detect and remove them, or to arrange for a specific re-survey. For a brief description of possible error sources in traditional cave-surveying see [7] and [12].



scan04.3DD; Image Size: 730 x 3001
Frame number: 1
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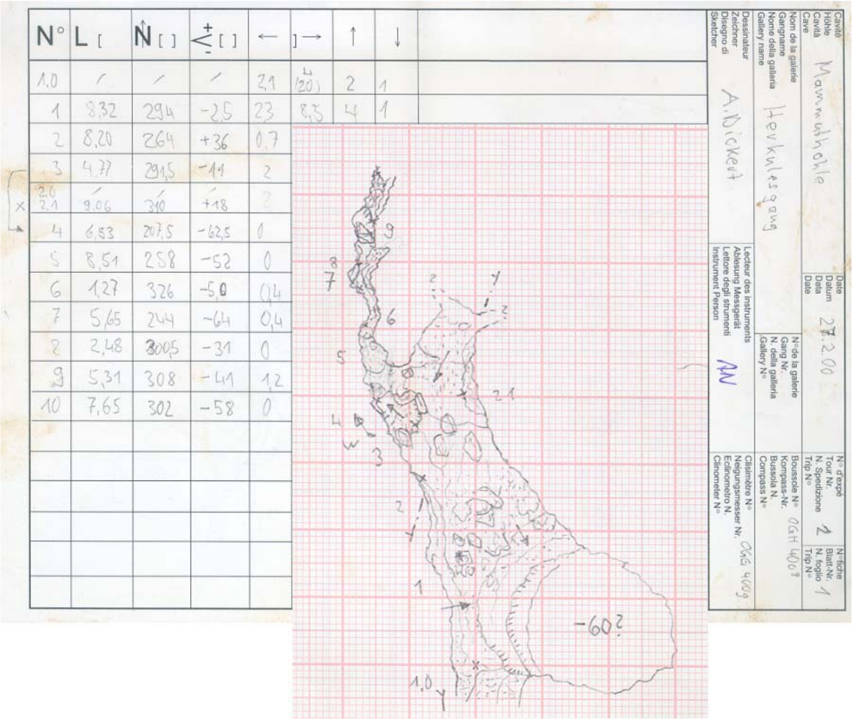
*Figure 1: Screenshot of the Riegl Scanner Application 3DRiview with a combined range and intensity image and labeled reference points.*

## New survey approaches

As electronic surveying instruments are getting more widely available, cavers use laser distometers, electronic compasses and clinometers more frequently. In recent efforts distometers, compasses and clinometers are combined into one single electronic device. For a technical description of such devices, see the projects webpages at [7], [12]. For some pilot-projects, especially in show-caves and historically interesting caves, surveyors began to use new methods, such as photogrammetry and 3D-laserscanning. The authors had the opportunity to test a scanner from the Riegl company [11] within the Dachstein Ice-Cave. This scanner has a range from 2 to 400 meters (depending on reflectivity) and a field of view of 340 by 80 degrees. Angle step-width is 0.24 degree and measurement resolution  2.5 cm. Resulting are two images representing the intensity of the received signal and the range color coded with the spectrum colors (see Figure 1). If good lighting conditions are available, an additional digital true-color image may be recorded that can be used for texturing. Surveyors are able to generate polygonal meshes from the raster images and export them to common 3D-graphics formats.

## Sketching

Usually a cave-survey-team consists of two to three peresons who complement each other when undertaking scouting and equipping climbs, surveying, and sketching. The sketching person is usually responsible for the documentation process and establishes a tentative draft of the cave-map on-site within the cave. He keeps sketching plan views, extended profiles and characteristic cross-sections. Depending on the targeted scale, he includes the surveyed traverse and survey-stations, the gallery outlines, the soil structures (clastic sediments, sinter, debris, blocks and rock structures), ledges, pits and ceiling-structures, relief and rock representation, special symbols and alphanumerical signatures, hydrology, snow and ice, finally observations on geology and tectonics. Typical scales used for a detailed cave-map include 1:200, 1:500 and 1:1000. The sketcher needs a good spatial perception, skills in estimating distances and most importantly must be talented in recognizing and understanding morphological features.



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| 1.0 | / | / | / | 2,1 | 4<br>(20) | 2 | 1 |
| 1 | 8,32 | 294 | -2,5 | 23 | 8,3 | 4 | 1 |
| 2 | 8,20 | 264 | +36 | 0,7 | | | |
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| 2.0<br>2.1 | /<br>9.06 | /<br>310 | /<br>+18 | 2 | | | |
| 4 | 6,53 | 207,5 | -62,5 | 0 | | | |
| 5 | 8,51 | 258 | -52 | 0 | | | |
| 6 | 1,27 | 326 | -5,0 | 0,4 | | | |
| 7 | 5,65 | 244 | -64 | 0,4 | | | |
| 8 | 2,48 | 300,5 | -31 | 0 | | | |
| 9 | 5,31 | 308 | -41 | 1,2 | | | |
| 10 | 7,65 | 302 | -58 | 0 | | | |

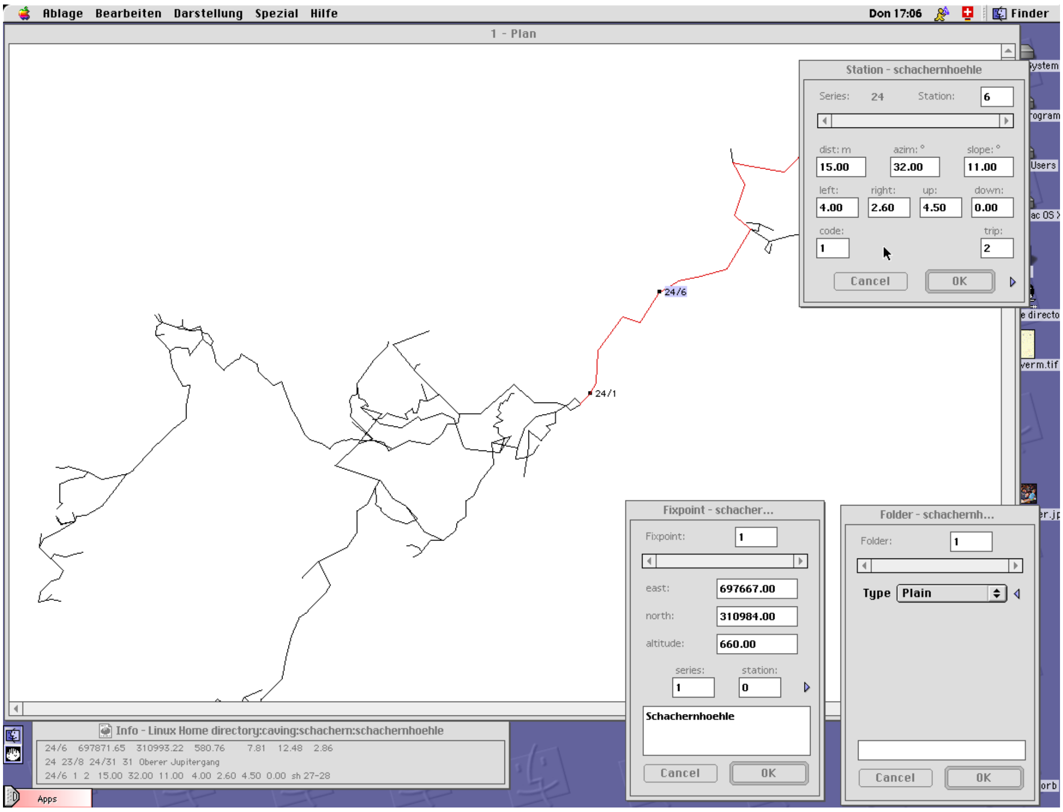
Cavité / Höhle / Cavità / Cave: Mammuthohle
Date / Datum / Data / Date: 27.2.00
N° d'expé / Tour Nr. / N. Spedizione / Trip N°: 2
N° fiche / Blatt-Nr. / N. foglio / Trip N°: 1
Nom de la galerie / Gangname / Nome della galleria / Gallery name: Herkulesgang
N° de la galerie / Gang Nr. / N. della galleria / Gallery N°:
Boussole N° / Kompass-Nr. / Bussola N. / Compass N°: OGH 4007
Dessinateur / Zeichner / Disegno di / Sketcher: A.Dickert
Lecteur des instruments / Ablesung Messgerät / Lettore degli strumenti / Instrument Person: AW
Clisimètre N° / Neigungsmesser Nr. / Eclinometro N. / Clinometer N°: OGG 4009

*Figure 2: Example of a survey page and a sketch of a plan view.*
*Source: A. Dickert, Mammuthoehle, Austria.*

# Data Processing - Speleometry

Various software packages for managing cave survey-data acquired by traditional compass and tape survey are available on different platforms. Toporobot, a comprehensive suite of tools for terrain and cave modelling developed by Martin Heller, is widely used world-wide. Its core module "Limelight" (see Figure 3) assists cavers in processing, managing and visualizing survey data. While developing the Toporobot-software, Martin also conceived a particular approach to surveying: a set of survey guidelines that help to structure complex cave-systems and enable 3D-visualization. Toporobot exports 2D and 3D-data into many graphics-formats, including Adobe-Illustrator, SVG, DXF, VRML, 3DMF, etc. It also handles loop-closing and error detection, consistency checks, structuring according to chronological, morphological and hierarchical entities, and a number of analysis functions.

The Toporobot-approach consists in modeling the cave as a set of galleries. Each is represented by a series: a sequence of cross-sections spanning a tube. The series typically abstract morphological entities. Virtual series may also be used to geographically reference objects and observations in space and to represent traverses or profiles on the surface. A cross-section is approximated by a rectangle (left, right, up and down-values) in the direction of the bisecting angle of the adjacent survey shots. These rectangles may be substituted by elliptical approximations. Toporobot works in close collaboration with Geo3D, a QuickDraw3D-Viewer written by Stefan Huber [6]. Geo3D features very good navigation controls, picking and linking, rotating, viewpoints, scripting and recording, options for renderer and lighting, grouping and hiding, display of coordinate planes and axes, and many more useful functions. Toporobot and Geo3D communicate by AppleEvents and are able to control each other.



Series: 24 Station: 6
dist: m 15.00
azim: ° 32.00
slope: ° 11.00
left: 4.00
right: 2.60
up: 4.50
down: 0.00
code: 1
trip: 2

Fixpoint: 1
east: 697667.00
north: 310984.00
altitude: 660.00
series: 1
station: 0
Schachernhoehle

Folder: 1
Type Plain

Info - Linux Home directory:caving:schachern:schachernhoehle

```
24/6   697871.65   310993.22   580.76     7.81   12.48   2.86
24  23/8  24/31  31  Oberer Jupitergang
24/6  1  2   15.00  32.00  11.00   4.00  2.60  4.50  0.00  sh 27-28
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*Figure 3: Screenshot of Toporobot, a system for cave survey-data management.*

## Dataformats

As an integrated information system, Toporobot serves as a hub providing links to specialized programs (e.g. visualization, databases and 3D-graphics). One major task is to exchange data with other cave-surveying software. Currently there is an ongoing effort to establish an XML-based exchange format for cave-survey-data. XML is a rapidly evolving text-based standard with strong support in the Open Source community as well as in the industry. It is human readable and extensible for integrating new features. Its strict separation of data, syntax description (DTD, Schema) and formatting and presentation allows different views of the same dataset, simply by introducing rules on how to process and display the data. Toporobot and other cave-survey software packages are currently in the way of turning XML into their native format. Despite of all its advantages, it is still a major challenge to integrate the different surveying philosophies into one unified format. The envisaged approach is to start with a modest solution integrating the most common requirements, and then gradually extend the format to encompass particular features as well. For the current CaveXML-discussion see [10].

## 2D Cave-Mapping

Traditionally, various cartographic products are produced for karst- and cave documentation purposes; so far, most of them manually. The master thesis of Andreas Neumann proved that computer-aided generation of detailed 2D-cave-maps looks like a reasonable and realistic goal [9]. For this purpose, he focused on prototyping tools to assist cavers in creating 2D maps that compare favourably with their manually made counterparts. He wrote VisualBasic macros to tap the capabilities of CorelDRAW, enhancing it's existing graphical features. One macro, for instance, imports the processed survey data from Toporobot and attaches attribute-data to the graphical elements, such as a series name, the number of stations, etc. Figure 4 shows the framework of CorelCAVE and its modules. The macros are partially implemented in an object-oriented manner to use encapsulation and to render the code more reusable. They are based on the Corel Type-Library to access graphical objects, create and manipulate them. Classes include object-data management, mathematical calculations and list manipulations not provided by Visual Basic. Further they offer graphical-primitives such as point, line, polyline and polygons implemented as objects and some simple geometrical methods. Executable scripts, called modulesc combin the classes. For triggering macro execution, we use GUI-components, shortcuts and global events. Currently there are modules to import data, manage layer and object-data, to create graphical objects (symbol placements, raster generation, etc.) and to draw grids and scale bars.

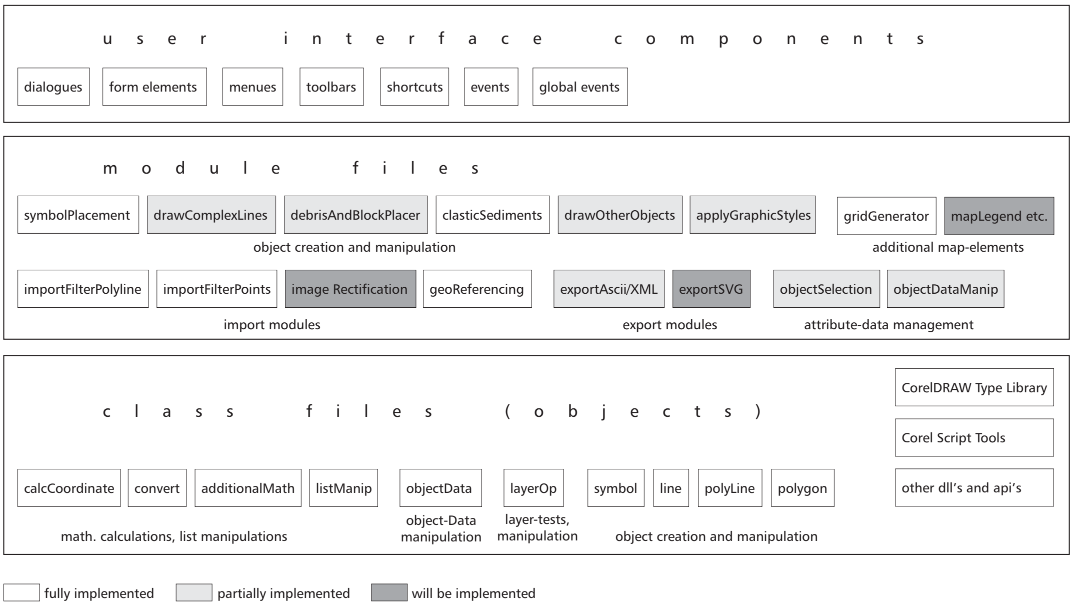


*Figure 4: Framework and Modules of CorelCAVE*

Several test caves and the entire Dachstein ice-cave have been successfully mapped using CorelCAVE. The program is not yet released for general use, it only suits for beta-testers who are rather proficient in Visual Basic and are not afraid to experiment. There are still various features missing, such as modules to rectify scanned sketches, and enhanced SVG and XML-export. Macro-features are primarily designed to meet the specific needs of alpine and ice-caves, which means that additional symbol libraries and functions need to be added for other types of caves. When comparing drawing software with CAD-software, we became convinced that graphic design software leaves more artistic freedom to the sketcher than the more technically oriented CAD-systems. Pressure-sensitive tablet devices and digital airbrushes simulate a natural sketching experience. It is thus possible to produce hillshadings emphasizing block-edges and terrain-structures (see Figure 5). We use calligraphic line-effects to draw lines for rock-structures and block-edges in a more subtle style (see Figure 6).

Requirements that determine the choice of a particular drawing or CAD-software package include ease of use, price, reliability, handling of large data amounts, graphical features and effects, printing capabilities, import- and export filters, extensibility with macros and/or plugins, ability to attach attribute data and documentation. It is quite clear, that no software satisfies all of these requirements. We decided to base our experimental prototypes on CorelDRAW, mainly because of its ease of use, moderate price, the rich set of features and easy scriptability via VBA-integration. A potential alternative would be Adobe Illustrator. We did not choose a CAD-system, with despite its technical and constructive strentghs, because we estimated the creative aspects higher and wanted to find out whether the shortcomings of a drawing software could be overcome by specific macros. Our approach was designed to complement other projects for computer-assisted detailed cave-mapping: "CAD fuer Hoehlen" - a macro-library built on AutoCad, is probably the most advanced tool today, having been developed for about 10 years now [2]. Another project - "Therion Cavemapping" - provides a framework and a data-format based on Tcl/Tk, VTK and LaTeX for the use on platforms which support those technologies. This project is at an early stage.

When comparing computer-assisted methods with manual approaches, we are able to report the following: The quality of digital output is already quite high, which of course is limited by the printing-system. Digital cave-drawings, however, still do not match good traditionally produced maps, which is particularly true for cliff-drawing, clastic sediment-structures and block representation. As for today, computer-assisted cave-mapping does not yet save any time to cartographers. Including the initial effort towards getting familiar with the software and the input devices, next to finetuning the workflow with various macros, this process takes about the same amount of time as the manual approach. Hard- and software expenses are still high, especially large format output devices. Computer assisted cave-mapping still is a long-term investment. The development of sophisticated data-formats for exchange and archiving is essential to success.

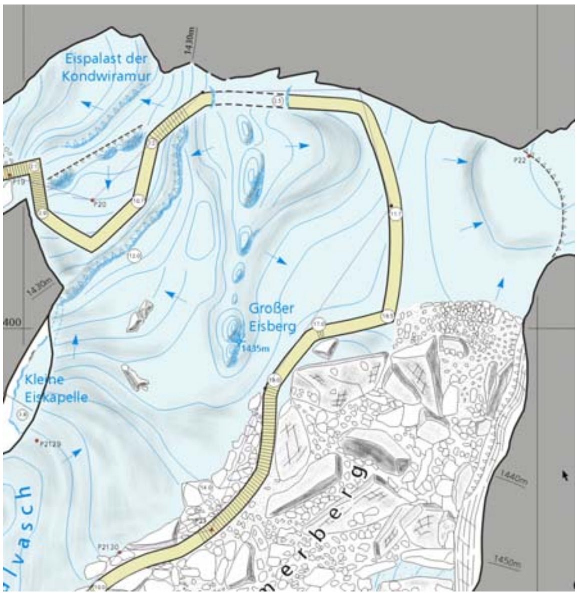


*Figure 5: Clipping of the Dachstein Ice-Cave Map, note the use of block and ice-shading.*

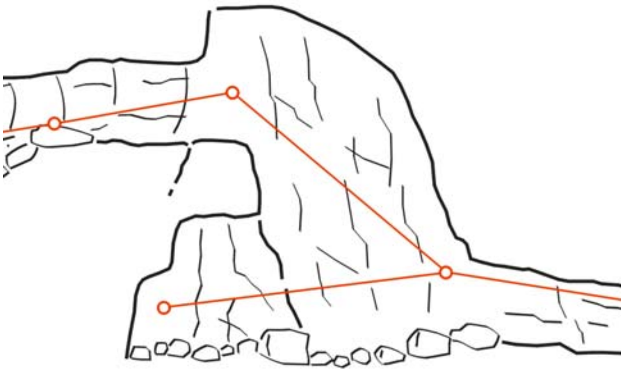


*Figure 6: Use of calligraphic line-effects to get more natural-looking rock-structures and blocks.*

On the other hand there are obvious advantages to digital cave-mapping: simplified maintenance and map revision, the ability to create different versions (layers), the ability to change scale within a limited range, the easier lettering of map elements, consistent look and feel through the use of styles and symbol libraries, no reproduction loss through copying, the management of attribute-data and the good integration with other (digital) media, e.g. multimedia and web-presentations.

## 3D Visualization

Due to the three-dimensional nature of karst- and cave-systems, 3D-representations have always been popular. The first cave-maps may even be considered as perspective views (e.g. the perspective view from Taubenloch in 1747, [3]). With the rise of computer systems at the beginning of the seventies, along with their ability to quickly calculate perspective projections, it became possible to view cave-systems from different angles. Toporobot started out in 1972 with simple three-dimensional visualizations of the traverse-lines, being able to color and group them. Since 1978, Toporobot is able to produce vector-based visualizations with rectangular cross-sections and hidden line removal (see Figure 7). This was of particular interest, because the first available output-devices had been vector-based. In 1981 the first shaded 3D-representation of a cave-system had been achieved [5], which led to high-quality "Renderman-shadings" (see Figure 8, Figure 9 and Figure 10)at the end of the eighties. This allowed cavers and geologists to build, verify and refine models of the geological situation.

Today, with the use of animations and a trend towards real-time-visualization, based on QuickDraw3D and OpenGL, cavers can virtually explore the caves, discover potential continuations or connections, and try to understand the complex structure of large cave-systems. Toporobot exports to the most popular 3D-graphics formats like Renderman, QuickDraw3D, VRML, OpenInventor, DXF, and Povray, thus enabling the use of popular open-source and commercial 3D-modelling and visualization tools. For exporting cave-passages, triangular meshes and indexed-facesets are used. Realtime-rendering-tools based on QuickDraw3D and VRML allow the use of interactive techniques like picking, different walk, fly and examine navigation modes, hyperlinking, multimedia-integration, sensors, etc. For the Macintosh we currently recommend the "Geo3D" viewer mentioned above [6], for PC and Unix the OpenInventor-Viewer or several available VRML-viewers like Cortona, VRMLView, Polyworks, Blaxxun, Cosmo-Player, etc., depending on the amount of interactivity required.

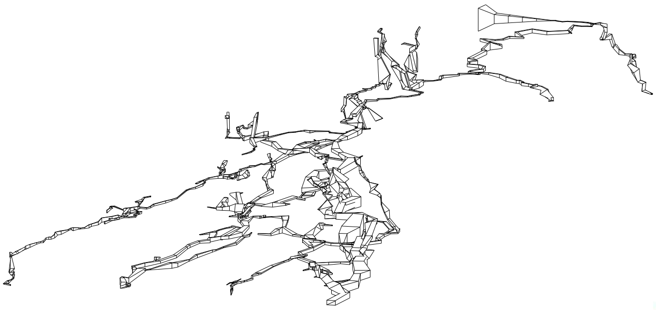


Figure 7: Perspective vector-represenation with hidden-line removal, Haglaetsch-Cave, Bernese Alps.

Figure 8: Renderman shading of the same cave with the use of bump-mapping.

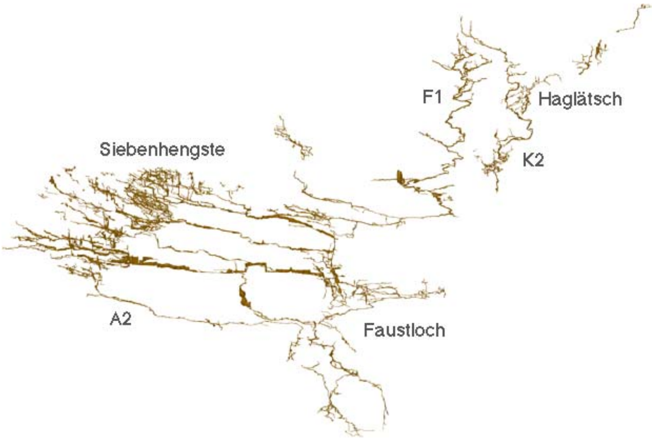


Figure 9: 3D Renderman-Image of the Sieben-Hengste-Area, Bernese Alps.

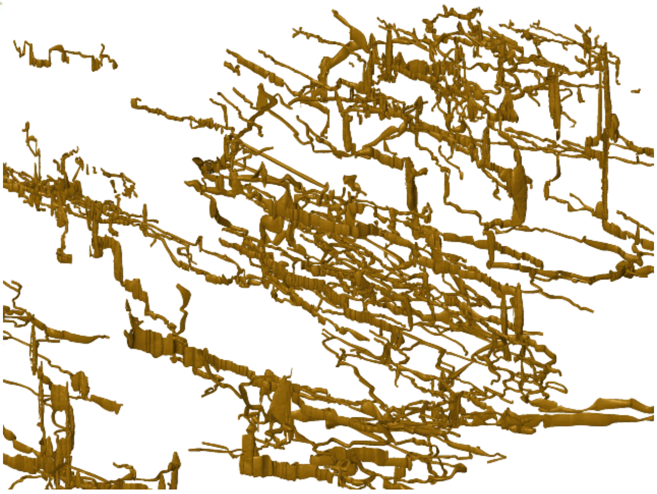


Figure 10: Closeup of the same cave-system.

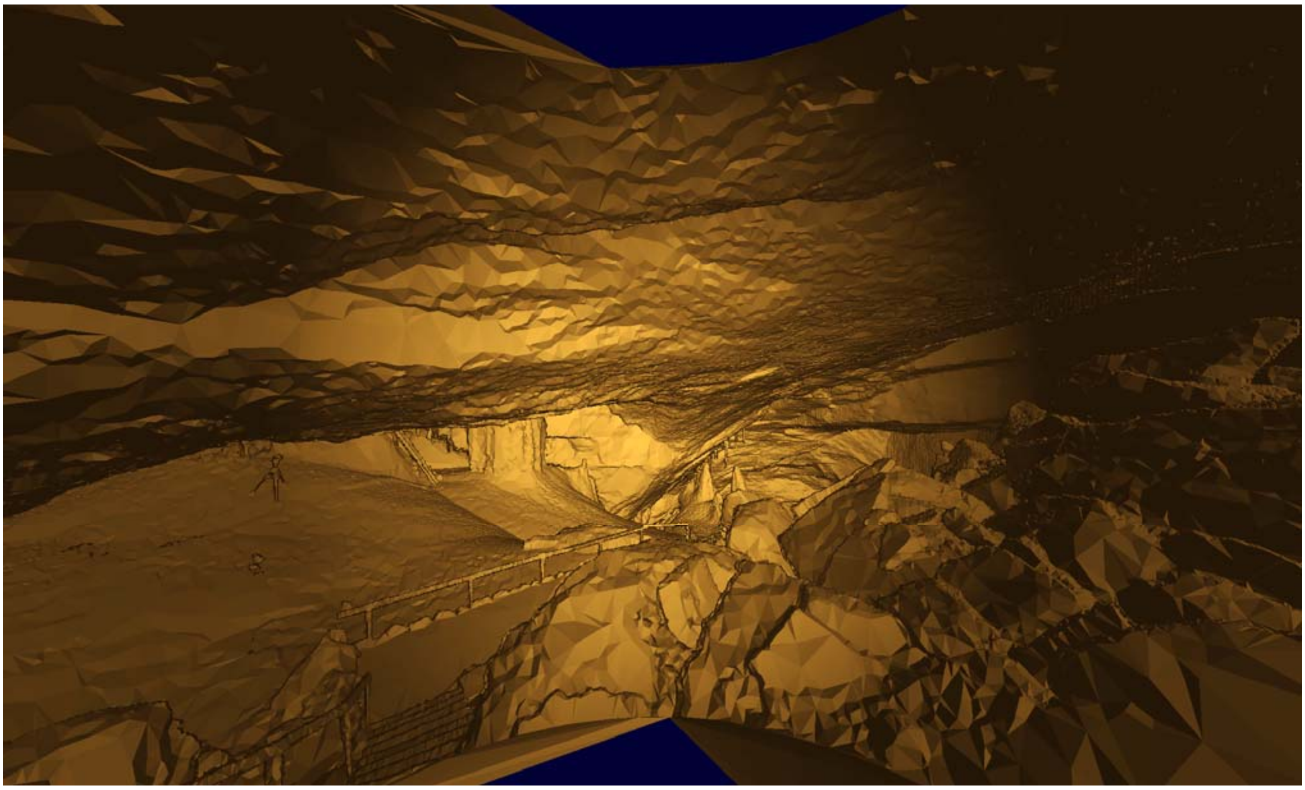


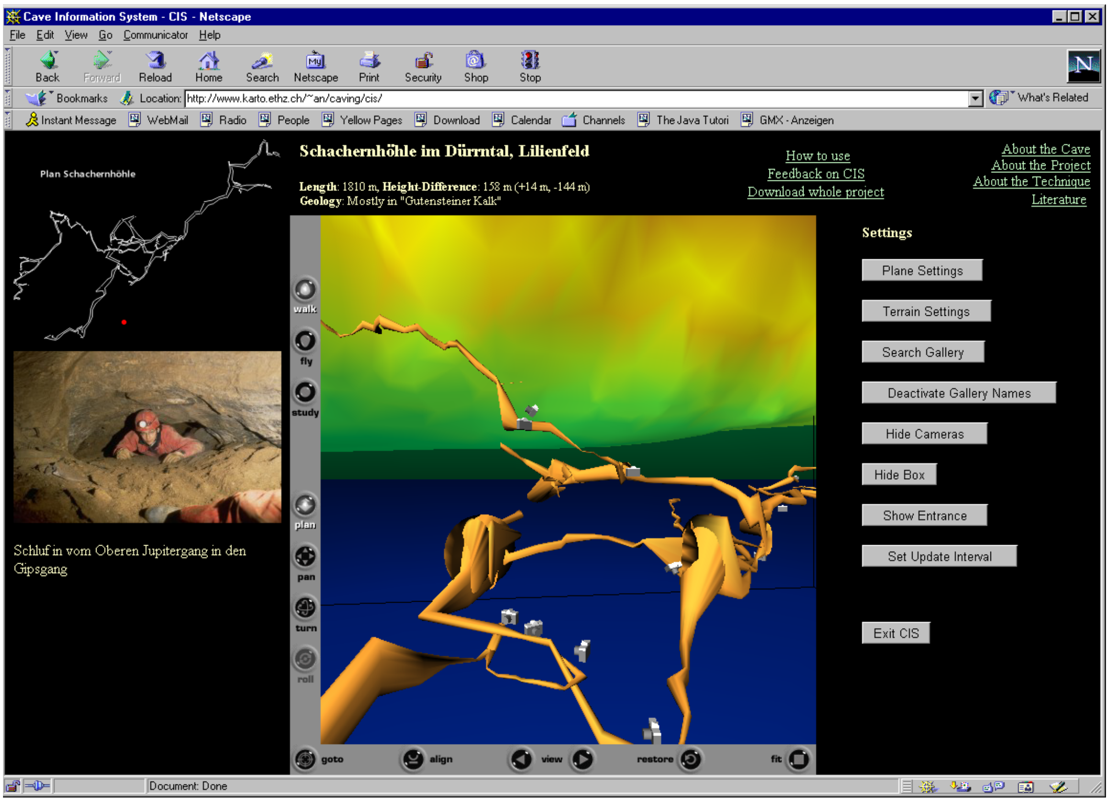
Figure 11: First result of a single laser-scanning scene, filtered with Martins modified TIN-Filter.

We already mentioned the 3D-laser-scanning devices as a tool for rapid surveys of cavities in great detail. Due to the very complex shape of typical caves, however, it is unrealistic to model an entire cave-system with the help of this approach. Already survey of one single room requires scans from several vistapoints, in order to reach all corners and niches. Handling of the vast amount of resulting raw data (several million points per scan) is not a trivial task at all. We have used the 3DRiScan [11] software of the scanner-manufacturer Riegl in combination with Polyworks and our own software. The overall goal of data modelling is to merge individual scans into one scene, which adequately represents the cavity while keeping the number of facets reasonably low. This requires three steps: First the coordinate-systems of the scenes need to be spatially correlated by using reference-points visible in two or more scenes. We have used 3DRiScan to interactively match a few initial pairs. On this basis, Polyworks is able to merge scenes, using a sophisticated adjustment process.

The resulting very large number of 3D-points needs to be filtered while taking into account the heterogeneous precision of the measurements. The result rendered by commercial packages was not totally satisfactory, taking into account the characteristics of our data. We have therefore fine-tuned Martin Hellers adaptive TIN-filter for this purpose. We extended it to handle spherical coordinates and have experimented with various ways to detect discontinuities and to handle unisotropical noise in the data.

## Towards Cave-Information-Systems

Caves can provide direct insight into the geological situation. Modeling caves also serves as a good prototype towards modeling geological structures. This requires sophisticated analysis tools as well as exploratory visualization. As spatial algorithms are getting better and more powerful and computer-graphics systems more affordable, we have tried to complement traditional maps with an interactive cave information system. Ideally, such as system would be used in a distributed network environment with many users and differentiated access-rights. A centralized database with web-access would provide the most recent data to all researchers in a karst- and cave-region, as a basis for online visualization. Version Control Systems (such as CVS) would help to store and extract different versions of survey- and attribute-data, so that different stages of exploration may be reconstructed.



**Schachernhöhle im Dürrntal, Lilienfeld**

**Length**: 1810 m, **Height-Difference**: 158 m (+14 m, -144 m)
**Geology**: Mostly in "Gutensteiner Kalk"

Schluf in vom Oberen Jupitergang in den Gipsgang

*Figure 12: CIS - Interactive Cave Information System based on VRML.*

Current cave-data management software, such as Toporobot, already offers quite sophisticated query tools and grouping features. Individual series and groups can be hidden or symbolized with different colors and materials. It further provides for the calculation of approximated volumina, shortest paths, etc.

To web-enable most of the functionality, we experiment with current web-techniques, such as XML, SVG, VRML, Javascript, Java, etc. First prototypes demonstrating the interactive use of VRML integrated in web-projects can be seen at [1] and [8] (see Figure 12). The Browser window is split up into different sections, such as information, GUI, Short-Info, overview-map (supports navigation) and main section for 3D-visualization. Functionality includes general information on the cave, picking of gallery names and survey data, querying and highlighting galleries, linking of photos and camera-positions in 3D-space, show/hide of 3D-elements, simple draggable geologic planes with the ability to set dip and fall. A second version adds a flight-recorder, an enhanced plane-tool and a more sophisticated group and gallery-navigator, to work like a file-manager. Both versions are still prototypes and are not yet produced directly by the standard export filters of Toporobot.

## Conclusion

Cave-mapping is a challenging part of cartography, with topics ranging from surveying and sketching, 3D modelling and visualization, up to detailed 2D mapping in various scales, depicting complex 3D-geomety. The need for an integrated and interactive 3D-analysis tool is obvious. We have created such a system by providing the cave-specific functionality and trying to tap the potential of general purpose packages, such as GIS, 3D-modeling, rendering, databases and web-applications.

While various software packages already do support cave survey data-reduction, computer-assisted cave-mapping is still in its infancy. Before most cave surveyors will use it, much remains to be done. Some of the major issues that need to be resolved include semi-automated loop-closing of existing detailed cave-maps, simple generalization algorithms for limited scale-changes, sophisticated exchange and archiving formats, methods to deal with huge amounts of 3D-data (laserscanning) and finally the overall-goal of establishing and refining easy-to-use "Cave Information Systems". Fortunately the web has intensified worldwide collaboration and many groups contribute their various skills and their know-how. Considering that most of the work in this field is undertaken by volunteers, the overall progress is already quite outstanding.

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