Drawing up cave surveys by computer: the Tunnel software suite

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Once you are back on the surface after a surveying trip, there are two main parts to the job of drawing up your survey. The first is a purely mathematical one, that of calculating the most probable positions of your stations based on the tape, compass and clinometer data (or whatever other combination of instruments you are using). This job is ideally suited to computer calculation, and many software packages exist to solve the problem, whose merits have been extensively debated in past Compass Points articles. Once this first task is done, the next task is more artistic: to take the centreline you have calculated, and draw in the walls and other passage details around it. This is harder to automate to quite the same extent as calculating the centreline. Nonetheless a dedicated software package can make the task much easier. This article describes one such program, "Tunnel", which was written largely by Julian Todd with the collaboration of Martin Green and the author.

It is, of course, possible to draw up surveys using any of the standard computer drawing packages, without using any cave-specific software. This approach works well for certain caves - particularly small, simple caves that are fully surveyed within a short period. However, these packages become extremely frustrating for larger, more complex systems, or for long-term surveying projects where a major loop closure can require the whole survey to be redrawn. The difficulties encountered in correcting the first sheet of the Red Rose Cave and Pothole Club's Easegill survey when one of the entrance locations was found to be in error demonstrate this. The aim of Tunnel is to make this process easier, in several main ways. One of the most important is that the drawn-up survey can be warped if changes are made to the centreline (for example, due to a changes in the distribution of loop closure errors). In this article, I aim to describe Tunnel's main features, and to provide a quick-start guide to drawing up a cave using Tunnel.

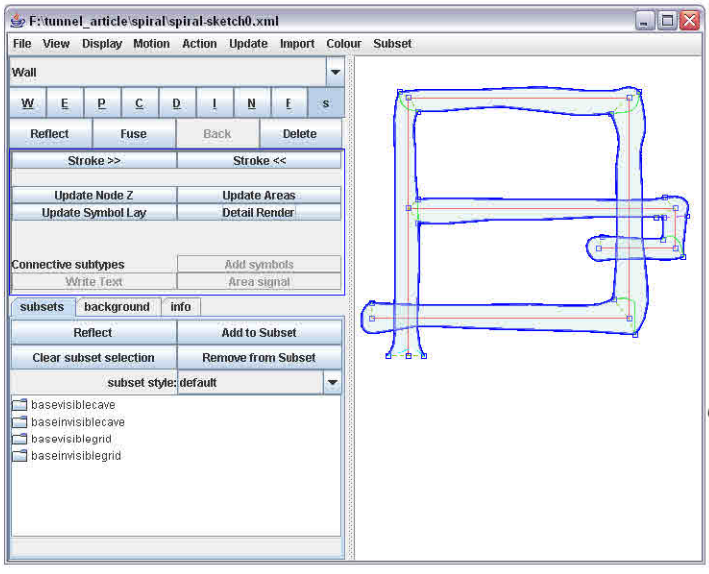
Importing your centreline data

Tunnel was designed to import centreline data in Survex's .svx format, but it can also import .TOP (Toporobot) and .PRJ (Walls) files; other import filters could be added if required. See [1] for a description of the Survex file format. When Tunnel imports a Survex file, it processes the data into its own format, which is based on XML. It also splits up the data into one file for each *begin/*end prefix block in the Survex file, which would typically represent one passage or survey trip (it is considered good practice to split your Survex files up in this way anyway) and puts each of these in a separate folder. Each of these folders will hold sketches and other files relating to this section of the cave. The advantage of using lots of small files is that it allows teams of people to draw up different parts of the same cave simultaneously, particularly when combined with versioning systems such as CVS [2].

Drawing a sketch

The core of Tunnel is its sketch drawing window, which allows you to draw in the walls of your cave using the mouse. We usually draw up each individual survey trip by hand around a print-out of the centreline. These sheets are then scanned and traced into individual Tunnel sketches. It is also possible to trace from scans of original underground survey notes, or even draw freehand; the latter requires some practice, but that is true for all computer drawing packages. What is shown in the sketch window differs from the final output, as different line types are highlighted in colour, but all labels and symbols are shown (unlike one of Tunnel's competitors, Therion, where labels are not visible until the final render, which makes accurate placement difficult – see [4] for a discussion of Therion's capabilities).

Tunnel supports a range of line types. Some of these are self-explanatory: a thick solid line for walls (dotted for estimated walls), a thinner line for passage detail, and the usual pitch and aven indicators with their tick marks. In addition, Tunnel calculates the two-dimensional shapes that these lines surround, so that it can work out which parts are inside the cave; by default, Tunnel shades in passages light grey in the final rendered output, to make them stand out against the white background (this is, of course, customisable). The two other main line types are invisible lines, which form the boundary of an area without having a line visible in the final output (so that, for example, areas of sand or mud can be defined), and connective lines, which are ignored in the area calculation and which serve to tie walls and other parts of the drawing to the centreline. Tunnel uses these connective lines to determine which areas should be drawn over or under others, based on the height of the centreline itself. They are also needed by Tunnel's warping algorithm used for loop closures. See Figures 1 and 2 for some examples of the area shading system.



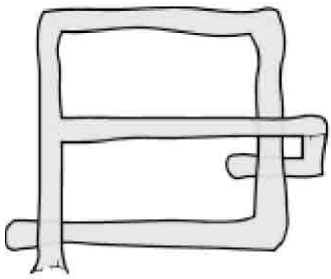


Figure 1: Here I have created a (rather contrived) example of a centreline that spirals downwards, with a side passage crossing over the main one then looping back under it. Tunnel automatically calculates which passages should be rendered above and below, based on the height of the centreline, to produce the output on the right. Note that the lower passages are still visible, as by default all passages are drawn slightly translucent; passages can be drawn opaque if desired, or made more transparent. The latter is useful for very complex surveys with many superimposed levels.

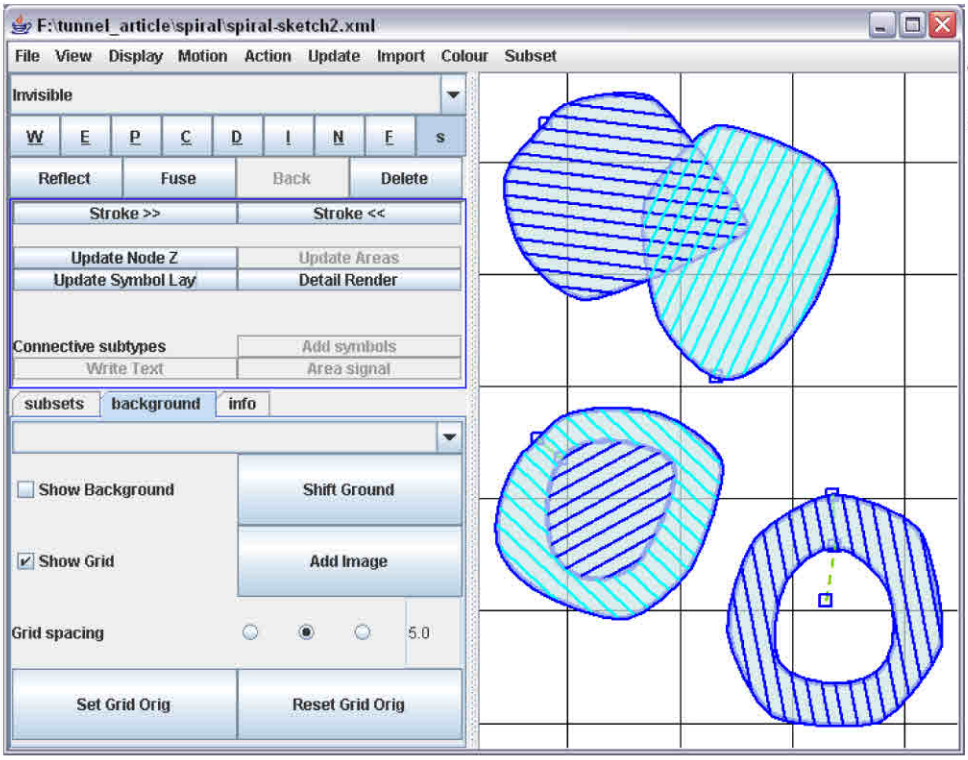


Figure 2: More examples of the area-detection algorithm. As Tunnel detects areas more or less by following walls, it assumes all areas are simply connected (that is, they have no "holes"). Areas may overlap, as in the first example, to allow for passages on multiple levels. Connecting two loops of wall with an invisible line, as in the second example, defines a ring-shaped area, but the central hole is also assumed to be passage; to draw a pillar, we also need to mark the inner area as rock, using a connective line with an "area signal".

Symbols

Tunnel allows a variety of types of symbols to be added to survey sketches. Some are added as single symbols (e.g. stream, slope and breeze arrows), but others are placed randomly to fill a specified area (e.g. sand, mud or boulders).

The algorithm for laying out random fields of symbols is a particular strength of Tunnel. It is actually a surprisingly difficult problem: how do you draw a realistic-looking field of random boulders? Placing them by hand is intolerably tedious. It is possible to draw a small section of reasonably random-looking boulders and tile this to cover the entire area, but this produces a rather odd effect, reminiscent of cheap wallpaper, as the eye recognises the similarities in the pattern. On the other hand, most genuinely random algorithms either produce lace-like patterns with numerous holes or perform poorly on areas of convoluted shape, or both. The algorithm Tunnel uses covers the area with a lattice, essentially approximating its shape with a bitmap, then places symbols at some random offset from each point of the lattice. This works remarkably well in practice (see Figure 3), especially when the size and alignment of the symbols is varied randomly at the same time.

The default set of symbols available within Tunnel covers most of those specified in the UIS standard [3], such as pools of water, various sizes of boulders and pebbles, stalactites and so on, but if this isn't enough, it is easy to design new ones: just create a new sketch in the "gsymbols" folder containing a drawing of the symbol, and add a line to the default style definition file specifying how it is to be laid out. The syntax of this file is quite complicated, but it is usually possible to just copy the code for an existing symbol that behaves in the same way.

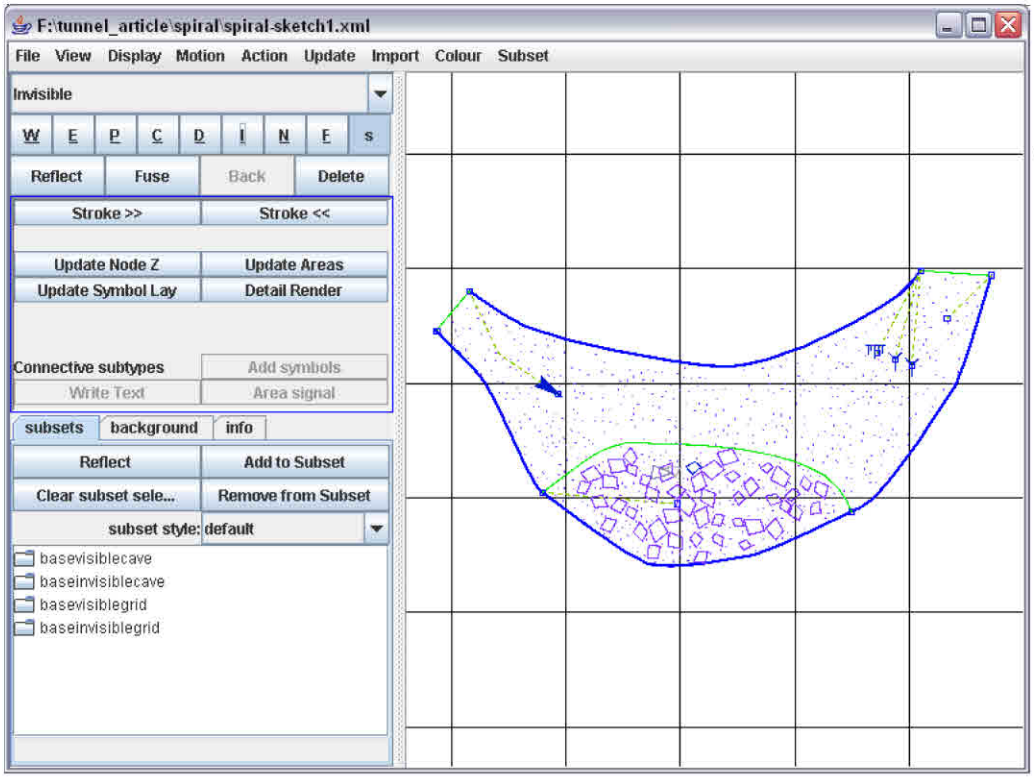


Figure 3: An example of laying out symbols in Tunnel. Notice the invisible line defining the area that contains the boulder symbols (this will not be shown in the final output).

A similar method based on connective lines is used to add text, although here the situation is simpler, as there is no need to spread text randomly across a specified area. Font sizes and colours are controlled by a system of font styles, so for example you might have a style for pitch depth labels, allowing you to easily change the appearance of the entire class of labels in one go (or even hide them entirely, if you want to produce a small scale version of your survey).

Joining it all together: The Import Sketch command

Having created sketches for the individual parts of the cave, the Import Sketch command allows these sketches to be combined into a single master sketch. This is somewhat analogous to the Therion concept of "scraps" [4]. However, unlike Therion, Tunnel has a multi-layer hierarchy: you can combine sketches A and B into a new sketch C, and then import C and another sketch D into a higher-level sketch E. This makes the task of joining your sketches together into a finished survey rather less intimidating, as you can combine bottom-level sketches of individual passages into a complete sketch of a particular area, then join this to other area sketches later.

When importing sketches, Tunnel automatically warps them to fit the centreline of the new sketch. This enables you to draw up sections of a large loop without the distortion induced by the loop closure. When you then import these sections into a sketch which includes the whole loop, it will bend them to take into account the loop closure error (see Figure 4). This figure simulates a case where a new loop closure somewhere else in the cave has forced the top right branch to be moved northwards, while the top left branch is fixed, perhaps as it is connected to something else. The left-hand side shows the original sketch; the right-hand side is the version warped to fit the new centreline. Note that the actual calculations of the station positions in the warped version were done with Survex, and imported into Tunnel; what Tunnel handles is bending the wall shapes to fit the new centreline. In practice, it is unlikely that a survey would need to be warped as grossly as this – this degree of misclosure would suggest a serious blunder in the surveying – but it serves to demonstrate the concept.

Outputting your finished survey

When you have finished drawing up your survey, there are various ways to export it. Tunnel can of course print directly to any printer supported by the operating system, at any scale; if the survey is larger than the paper size, it can be split between several pages with printed guides for cutting and pasting the result together. Alternatively, sketches can be exported to SVG (Scaleable Vector Graphics) format, which can be read directly by most drawing packages (and by the Firefox web browser; the Tunnel developers are working on the possibility of producing SVG-based interactive surveys with hyperlinks to text descriptions, photographs and so on). Finally, you can export to a bitmap file in TIFF, BMP or PNG format (although this is not ideal for print-resolution output, as the files tend to be unmanageably large). Most print shops should accept SVG files; the 600dpi A0 colour printout of the Cambridge University Caving Club (CUCC) Steinbrückenhöhle survey that was displayed at Hidden Earth 2005 was printed by this method, exporting an SVG from Tunnel and importing this file into Adobe Illustrator 10 on the print shop's computers.

Advanced formatting: the subset styles system

Over the last few years, much of Tunnel's development has been to support CUCC's survey of Steinbrückenhöhle in Austria. This cave system was discovered in 1999 and is now 11km long. Its complex layout includes six major planes of horizontal development corresponding to beds of rock sloping at differing angles and interconnected by numerous shaft series. As there are points where four or five passages in different levels cross over each other, the resulting survey is visually confusing if drawn up in the usual way. In drawing up the 2004 survey, Martin Green developed a system using multiple colours and transparency. This is implemented in Tunnel using a flexible system of "subset styles".

This works by grouping parts of the cave into subsets, which typically (but not necessarily) correspond to individual passages or survey trips (there is a command which automatically creates subsets based on the *begin/*end prefix hierarchy, which can then be fine-tuned by hand, or you can create your subsets from scratch if you prefer). A style definition file then organises these bottom-level subsets into a flexible hierarchy, which could (for example) correspond to the cave's main geographical areas or horizontal planes. It is then easy to specify how these areas are to be rendered, so one might choose to have the top level shown with a pale red background, the middle level in green, and the lowest level in blue with no symbols and pitch labels in italic; or any other choice of colours and styles that is needed. The style definition files are written in an XML-based format, which is immensely flexible but has the disadvantage of being difficult to edit; the Tunnel developers are currently working on ways to simplify the syntax without having to lose features.

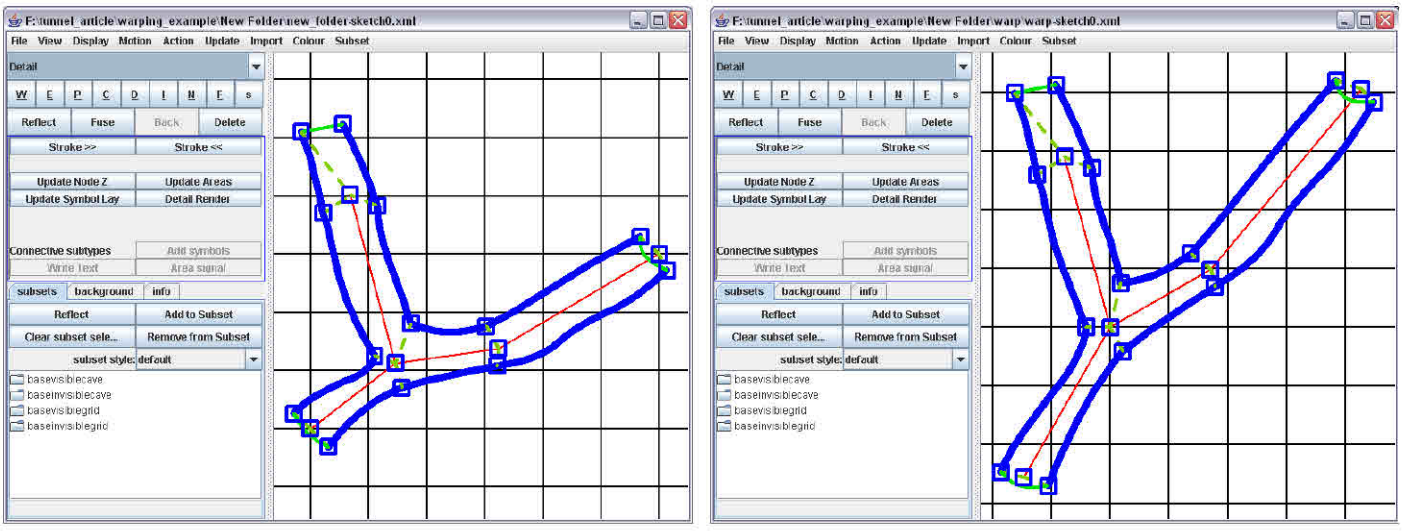


Figure 4: Example of warping a sketch following changes to the centreline due to loop closure adjustment (left is original, right is warped).

Future directions

At present, the main sketch-drawing interface of Tunnel has reached a reasonably stable state: further major changes in functionality are not contemplated at present, and current development is focussed on weeding out the few remaining bugs and making the interface somewhat easier to use – parts of it are rather haphazard, and the documentation is out of date following the substantial development effort that accompanied the drawing-up of over 30km of survey of Er Wang Dong and San Wang Dong for the Hong Meigui Cave Exploration Society's expedition to Houping last year. Features that are under development include a "necklace" algorithm for placing symbols along a line, allowing one to draw chains of slope or stream arrows, or a barrier of boulders terminating a passage.

However, we have some long-term plans. So far development has concentrated on drawing plans, as the convoluted nature of CUCC's Austrian caves means that elevations are formidably difficult to draw and, once drawn, are frequently incomprehensible. But we believe that it may be possible to use Tunnel to intelligently combine small sketches of extended elevation survey to produce larger extended elevations of whole caves or parts of them, or even to produce an approximation to a projected elevation by foreshortening the elevation sketches.

How to draw up a simple cave in Tunnel

This walkthrough describes the process of drawing up part of a real cave explored and surveyed by CUCC: Hauchhöhle, number 1623/234 in the Austrian Geological Survey catalogue. The starting point for the drawing-up process is a set of .svx files giving the centreline data, and scans of the original surveyors' drawings.

Step 1: Installing Tunnel

Tunnel can be downloaded from the SourceForge website, at `http://sourceforge.net/projects/tunnelx/`. Download a copy of the latest build from the tunnelx CVS repository. (The name Tunnel-X is something of an anachronism, as it was introduced to distinguish the main graphical Tunnel project from a very old DOS-based ancestor just called Tunnel, which no longer exists). Tunnel is written in Java, so it should work on any Java-supported platform (it has been tested under Windows, Macintosh, and various Unix variants). You will also need to download the Java Development Kit (JDK), available from the Sun website at `http://java.sun.com/`. The Tunnel directory contains a README.txt file which gives instructions on how to compile and run Tunnel.

Step 2: Importing Survex data

The first step in drawing up a survey is to import the centreline data and process it into Tunnel's XML-based format. To do this, use the "Open svx" command, then "Set XML dir" and "Save XML dir" to create the XML files. If the cave contains complex loops you will also need to tell Tunnel the final station positions calculated by Survex. To do this, process your survey with Survex in the normal way, use 3dtopos to create a .pos file, and place this .pos file in the top level of the new XML folder hierarchy; you need to close Tunnel and re-open it after this step.

Step 3: Creating a new sketch

The left-hand panel in the Tunnel window now shows a tree-style view of the *begin/*end prefix hierarchy of your .svx file (Figure 5). In our example, this is only one layer deep, but it can be divided up into as many levels of hierarchy as you need. Let's have a look at Left-Hand Passage, which is marked with the prefix "lefthand".

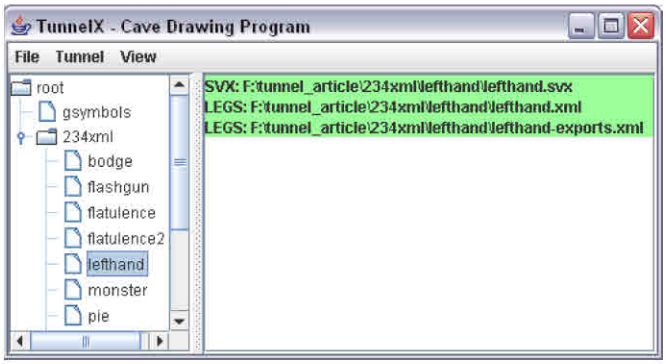


Figure 5: Tunnel window showing the survey hierarchy.

We want to add a sketch of this passage, which can be done by selecting "New Empty Sketch" from the Tunnel menu. This creates a new file called "sketch0.xml", and opens up the sketch editing window. Before we can draw anything else, we need some centreline data: select "Import Centreline" from the Import menu. The result is shown in Figure 6.

To get the hang of the interface, try drawing a few lines. The controls are based entirely on combinations of mouse clicks and modifier keys: if you click anywhere in the picture, it will start a line; you can add more points onto the line by clicking again, or Shift-click to finish the line. If you Ctrl-click on an existing point, the line you are drawing will snap to that point, or if you're not currently drawing a line it will start a new line based there. To select a line, right-click on it; you can then change the line type (the menu of line types is at the top left; "Detail" is the default line type), or press Ctrl + Delete to get rid of it. You can add new points in the middle of existing lines by selecting them and then Ctrl + Shift + clicking somewhere along the line. To scroll around your image, press Shift and drag with the middle mouse button (the wheel); Ctrl + middle mouse button zooms in and out. This interface based entirely on modifier keys and mouse clicks is a bit counterintuitive at first, but in practice it is far faster than having to pick different tools off a toolbar. If you don't have a middle mouse button, pressing the two buttons simultaneously should have the same effect. The only serious problem with this interface seems to be that most Macintosh computers have single-button mice; the developers are prepared to implement a workaround for this if anyone asks for one.

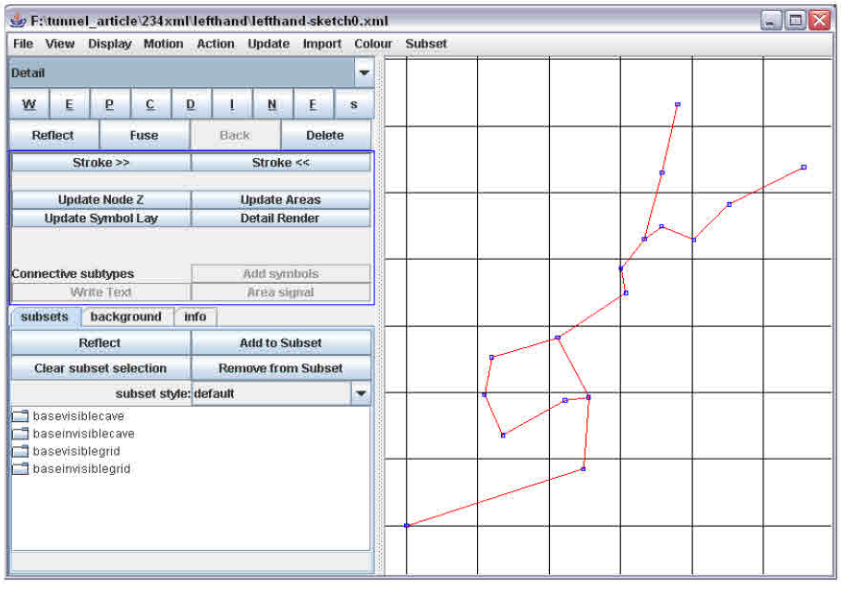


Figure 6: Imported centreline in the Tunnel window.

Step 4: Importing scanned drawings

Before we do any serious drawing, we need to import the existing drawn version of the survey, in order to trace over it. Click on the "Background" tab at the bottom left of the screen, make sure "Show Background" is ticked, and click on "Add Image". This will display the scan behind the image. Now you can move it around to fit the centreline: just draw a line from a point on the background image to the corresponding point on the centreline and click the "Shift Ground" button to move the first point onto the second one. To rotate and scale the background, draw a line with three points; this will move the second point to the third one while keeping the first one fixed. This should enable you to line up the red centreline with the centreline from the imported sketch. The result should look something like Figure 7.

Step 5: Drawing in the walls

The next stage is to draw in the walls. Select the "Wall" line type and draw a line around the wall of the part you want to draw. When you've drawn in the walls themselves, "seal up" the ends (where exploration stopped, or bits that are on a separate survey) with invisible lines. Click on "Update Areas", and it will work out what is cave and what is rock. Unfortunately, in my example "Update Areas" gets it wrong: it mistakes the loop in the passage for two chambers, one above the other. This can be corrected with an area signal, as shown in Figure 2 above.

You can just leave it at that if your survey is a simple one, but if the survey is complicated, you need to tell Tunnel a bit more about how the walls relate to the centreline, so that it knows which bits of wall to draw above and below others if they cross over, and so it can warp the drawing intelligently if there is a loop closure. To do this, add points along the walls every now and again, and join these to the centreline stations with connective lines. (There is an example of how to do this in the main article, in the discussion of warping). How conscientious you need to be at this stage depends on how much you think you are likely to need the layering and warping features, but at the very least you should have one connective line joining each segment of wall to the centreline.

Step 6: Adding labels and symbols

The original drawing shows a floor of boulders for this passage, so let's draw that in. First, use invisible lines to divide up the passage so sections with different symbols in them are in different areas. Then, for each area you want to add a symbol to, select a point on the boundary of the area and draw a connective line leading into the area, click "Add symbols", and select a symbol from the list. In the example in Figure 8, I have added boulders and pebbles to most of the survey, except the loop on the left, which has a bare rock floor, and the passage at the top, which is floored with mud; and I have put in some arrows for slopes and draughts. (The line attached to the draught is somewhat convoluted, as the symbol is actually not inside any area, but the connective line always has to start off heading *into* an area, so Tunnel knows which area to associate it to for layering purposes). To add text, we add a connective line in the same way, but use the "Write Text" button; there are various predefined text styles for question marks, pitches, passage names and so on, which can be customised if required. (Notice that I've turned off "Show Background" in the figure to make it easier to see what's going on.)

Step 7: Combining your sketch with the rest of the survey

Let's suppose we have another sketch into which the rest of the survey has been already imported, and we want to join our Left-Hand Passage sketch onto this. Open this master sketch in the sketch editing window, then flip back to the file list window and select the other sketch we've just drawn. Now go back to the sketch editing window and select "Import Down Sketch" from the Import menu. This will bring in the Left-Hand Passage sketch, and you can zoom in and do the fine work of stitching together the two (Figure 9).

This can be done semi-automatically: if you have two wall lines, one from each sketch, you can fuse them together – just draw a line from one to the other and click "Fuse".

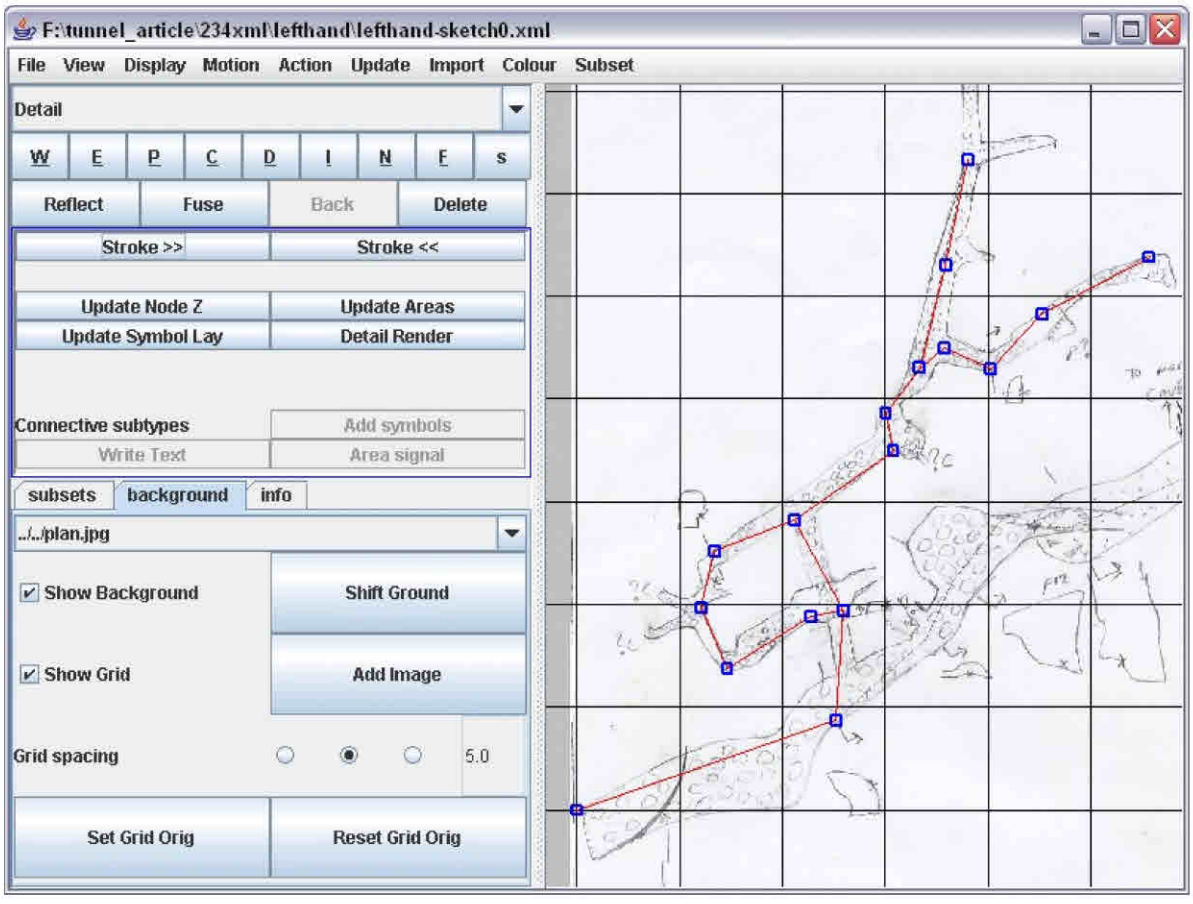


Figure 7: A survey sketch aligned with the centreline.

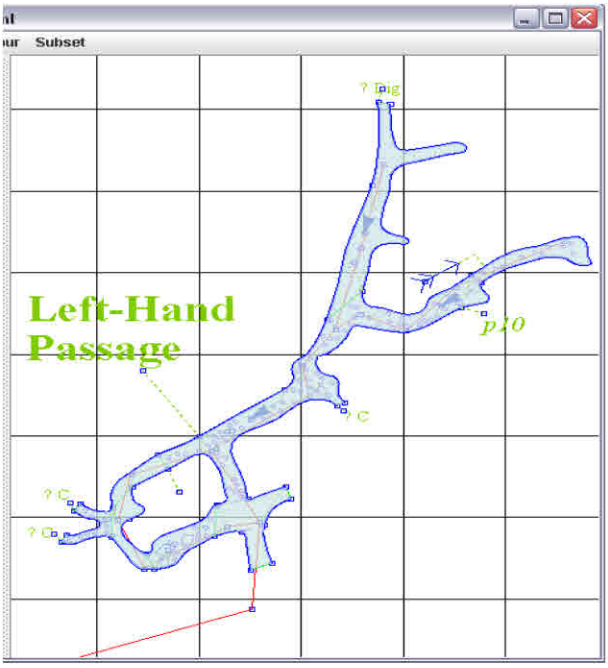


Figure 8: Survey segment with walls traced from the original sketch and passage details added.

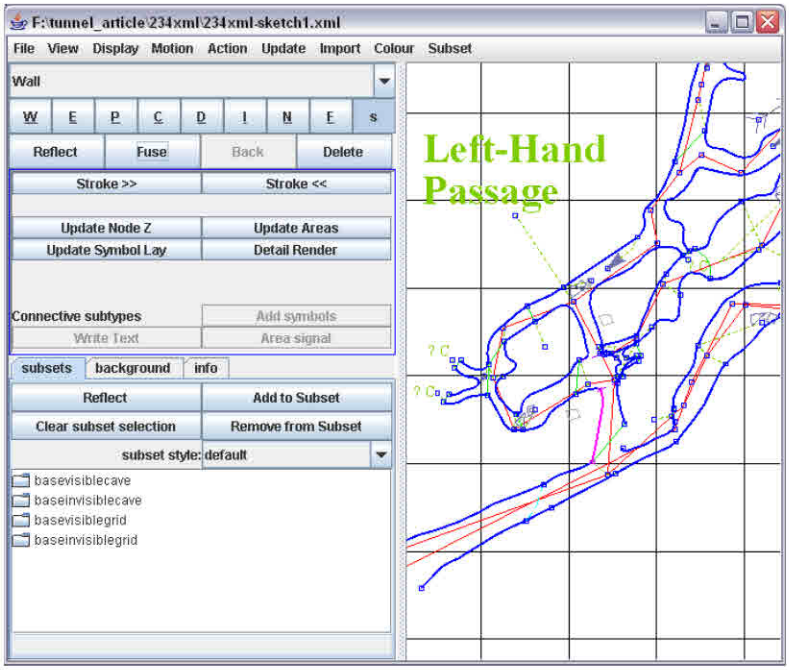


Figure 9: Joining two survey segments together.

Step 8: Rendering and exporting your sketch

When you are happy with the join between the imported sketch and the master, select "Update Everything" from the Update menu, which calculates the node Z coordinates, updates the areas and updates the symbol layout. Now your survey is ready to be printed, or exported as SVG or bitmap, using the File menu. The entrance area of Hauchhöhle ends up as shown in Figure 10.

Conclusion

The developers hope that Tunnel has achieved at least in part its aims of providing a system that allows complex cave surveys to be drawn up on a computer, and that it overcomes some of the disadvantages inherent in drawing up surveys using general-purpose drawing packages. If you have a survey to draw up, we encourage you to give Tunnel a try. More information about how to obtain and use Tunnel is available from the Tunnel website [5]; alternatively, please feel free to contact Julian (julian@goatchurch.org.uk), Martin (mjg54@cam.ac.uk) or myself (dave@cucc.survex.com).

References

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[3] Survey and mapping working groups of UIS informatics commission, online at: http://www.uisic.uis-speleo.org/wgsurmap.html

[4] Wookey (2004). Therion – state of the art cave-drawing software, *Compass Points*, 33, 5-12.

[5] TunnelX – Index to information, online at: http://www.goatchurch.org.uk/tunnelx/

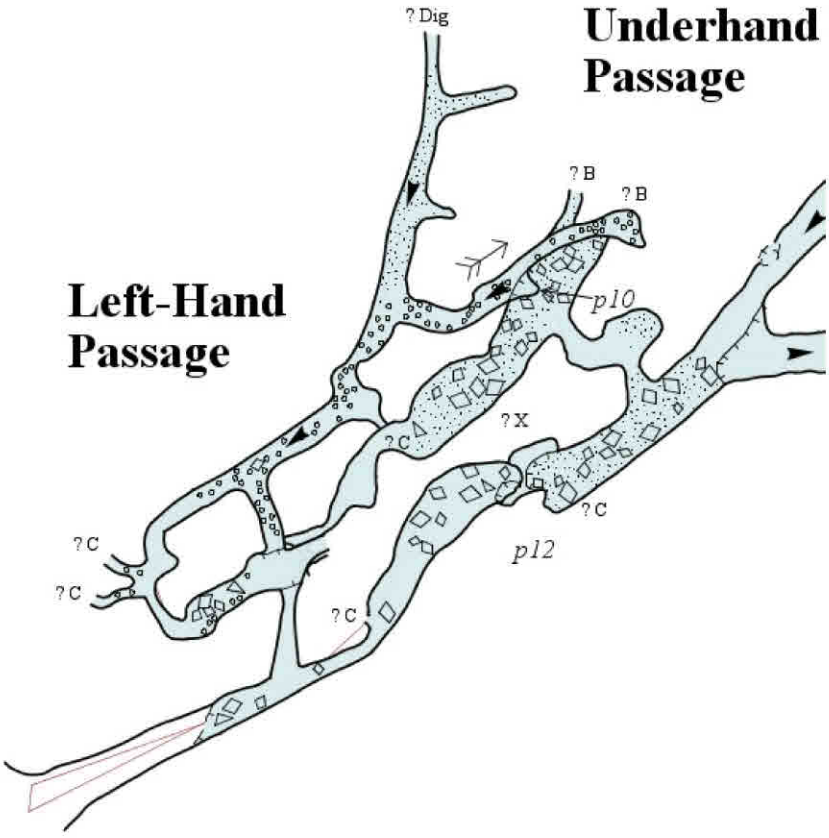

Figure 10: Final version of the Hauchhöhle entrance survey.