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Cover: Drawing of Jude Larkin, lead tape on a survey in Sistema Purificacion in Mexico by Linda Heslop of Victoria, B.C. Canada. It is based on a photo by Carol Vesely.

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CONTENT DEFINITION AND CONTROL FOR STAGE-4 CAVE MAPS

by

Fred L. Wefer

1. INTRODUCTION

In recent papers in this journal, Wefer (1989a, 1989b, & 1989c) introduced the concept of "stages" in the development of the computerization of cave mapping, presented the design of a 3D north/scale icon, and discussed viewing definition and control for Stage-4 cave maps.

A Stage-4 cave map is a map designed to be viewed on the computer graphics screen. The information content of the cave map is conveyed via lines, symbols, text, and polygons comprised of pixels on the screen. Extensive use is made of color. The content of the map can be changed at the option of the viewer. Any portion of the cave may be viewed in any 3D direction at any reasonable scale, all at the option of the viewer. Sequences of changes in both viewing and content can be defined interactively by the viewer and played back in a movie-like fashion. The hardware and software which make all this possible are integral parts of the map.

A computer program now called Interactive Cave Map (ICM) was used by Wefer et al (1983) to illustrate the application of interactive computer graphics to cave mapping. ICM is written in FORTRAN and makes extensive use of a Commercial Off The Shelf (COTS) software product called TEMPLATE (a graphics package based on the proposed CORE graphics standard). ICM has continued to be used by this author over the past eight years as a prototype for Stage-4 cave mapping.

A caver viewing a cave map can, of course, see only the information included on the map by the cartographer; however, with a Stage-4 cave map, so much information may be available that displaying it all simultaneously may merely create confusion. The caver needs to be able to control what is (and what is not) displayed at any point in time.

This paper discusses the definition of content and its interactive control for Stage-4 cave maps. It is assumed that the reader is familiar with the previous papers in this series. The north/scale icon discussed by Wefer (1989b) and the viewing options discussed by Wefer (1989c) were used in creating the illustrative examples of this paper.

2. CONTENT DEFINITION

The information content of a Stage-4 cave map is comprised of <u>content features</u>. Some examples of content features are: survey stations, passage walls, and streams. Each content feature is comprised of <u>marking elements</u>, i.e., lines, graphics symbols, text, and/or polygons. Interactive computer graphics can provide content control at almost any level of the information displayed, from the entire screen to individual line segments and their attributes. In general the lower the level at which control is provided, the more detail the viewer is required to provide in order to achieve that control. The level of content feature is an appropriate level at which to provide content control.

Content features of Stage-4 cave maps can be categorized by the kind of information they contain. There are four basic types, each of which is briefly discussed below.

- Traverse lines information,
- Passage walls information,
- Symbols information, and
- Auxillary information.

2.1 TRAVERSE LINES INFORMATION

By traverse lines information is meant the basic information obtained during the surveying process, viz: the stations, their identifying labels, and the straight lines connecting them. This information is "basic" in the sense that the placement on the map of all other information about the cave ultimately relies on it. This does not mean, however, that the viewer necessarily wants to see it on the screen. The traverse lines information comes from the left-hand (or numerical data) pages of the survey notes. When it is shown, the marking elements used to display it are: text for the station labels, graphics symbols for the survey stations themselves, and lines to connect successive stations. Most papers on computerized cave mapping to date have dealt solely with traverse lines information.

2.2 PASSAGE WALLS INFORMATION

By passage walls information is meant the information that provides a description of the morphology (shape or form) of cave passages. The survey data providing this information is the up/down/left/right distances recorded on the left-hand (or numerical data) pages of the survey notes combined with the drawings of the cross sections recorded on the right-hand (or sketch) pages of the survey notes. When it is shown, the marking elements used to display it are polygons for the cross sections plus lines and/or polygons connecting successive cross sections.

2.3 SYMBOLS INFORMATION

By symbols information is meant the symbols representing the objects inside (usually) the cave passages. The survey data providing this information is the sketches on the right-hand (or sketch) pages of the survey notes. This information is usually conveyed via cave map symbols, e.g., streams, stalactites, pools of water, breakdown on the floor, etc (see, e.g., Hedges et al (1979)). When it is shown, the marking elements used to display it are lines, graphics symbols, text, and/or polygons.

2.4 AUXILLARY INFORMATION

By <u>auxillary information</u> is meant information relating to the cave and/or the cave map, but not directly representing the cave itself. Some examples are: the north/scale, the cave name, the menus, the map legend, the topographic overlay, and various grids. The auxillary information may be further subdivided into two types, static and dynamic. <u>Dynamic auxillary information</u> moves on the screen when the viewing is changed, e.g., the north/scales and the topographic overlay. <u>Static auxillary information</u> does not move on the screen when the viewing is changed, e.g., the cave name and the map legend. When auxillary information is shown, the marking elements used to display it are lines, text, and/or polygons.

Content features can be structured so as to allow the caver to easily view logically connected pieces of information depicting the cave and associated objects. The logical connection might be that of similar interest, e.g., surveying, geology, or hydrology. In this case the caver might wish to view all survey stations in the cave, or all passage walls in the cave, or all streams in the cave, depending on what he is interested in.

Alternatively, the logical connection might be that of similar location. In this case the caver might wish to see all survey stations, passage walls, and streams, but in only a particular section of the cave.

3. BACKGROUND INFORMATION

Very little has appeared in the caving literature on the subject of content definition and even less has appeared on the subject of content control for computerized cave maps. The work of Wefer et al (1983), reported via video tape, contained some information but at a time too early in Stage-4 of the computerization of the cave map to be comprehended by most cave cartographers. That work is covered again in later sections of this paper.

Ganter (1989) touched upon the subject of content definition in his discussion of the use of AutoCAD in constructing Stage-3 cave maps. AutoCAD provides entities in the information display called <u>blocks</u>. Blocks can, in turn, contain other blocks. They can be used to display different types of information, e.g., traverse lines, passage walls, symbols, etc. Blocks can also be used to minimize the amount of information that needs to be stored for the display of the map. Ganter suggests that "...the area in which a cave lies could be 'tiled' with Blocks in a regular grid pattern...". The hierarchy in the information display suggested by Ganter might be represented as follows:

- CAVE MAP.
  - * BLOCK-A (SECTION-A OF THE CAVE)
    - \+ BLOCK-A1 (TRAVERSE LINES FOR PASSAGES IN SECTION-A)
    - \+ BLOCK-A2 (PASSAGE WALLS FOR PASSAGES IN SECTION-A)
    - \+ BLOCK-A3 (SYMBOLS FOR PASSAGES IN SECTION-A)
  - * BLOCK-B (SECTION-B OF THE CAVE)
    - \+ BLOCK-B1 (TRAVERSE LINES FOR PASSAGES IN SECTION-B)
    - \+ BLOCK-B2 (PASSAGE WALLS FOR PASSAGES IN SECTION-B)
    - \+ BLOCK-B3 (SYMBOLS FOR PASSAGES IN SECTION-B)

This type of information structure maps easily into the hierarchical graphics display list of a CORE based COTS graphics package like TEMPLATE. In computer graphics the top level entity is called a graphics segment, its subordinate entities are called Display List Subroutines (DLSs). DLSs can be nested up to five levels deep in TEMPLATE.

Blocks seem to be the Stage-3 equivalent (at least in AutoCAD) of the content features discussed in Section 2 above. The term content feature was chosen for use here for two reasons. Firstly, the adjective content makes it clear that the word feature does not refer to some capability of the software, rather it refers to a prominent part of the map. Secondly, content features can either overlap in space or not, at the option of the cartographer and/or the Stage-4 cave map viewer. The words block and tile have unfortunate 2D connotations, e.g., the tiles on your bathroom wall do not overlap.

In program ICM the hierarchy is physically more simple than the one shown above, but logically more complicated than the one shown above. It is more simple in that physically it has only two levels. The part of the hierarchy that physically corresponds to the above is as follows:

- SEGMENT CONTAINING THE DYNAMIC REPRESENTATION OF THE CAVE.
  - * DLS-T1 (TRAVERSE LINES INFORMATION)
  - * DLS-T2 (TRAVERSE LINES INFORMATION)
  - * DLS-P1 (PASSAGE WALLS INFORMATION)
  - * DLS-P2 (PASSAGE WALLS INFORMATION)
  - * DLS-S1 (SYMBOLS INFORMATION)
  - * DLS-S2 (SYMBOLS INFORMATION)

The logical structures accomodated in ICM by this physical structure are discussed in Section 7 below. How these information and display structures are constructed is the subject of future papers in this series. In the remainder of this paper we concentrate on techniques for controlling the content of the Stage-4 cave map after the structures have been constructed.

4. STAGE-4 REQUIREMENTS

The considerations that influence the interactive control of content are quite similar to those influencing viewing control. The three considerations are: (1) the content is changed frequently, (2) the user does not always know what he wants to see until he sees it, and (3) the user is not necessarily an expert in computer graphics.

Stage-4 cave maps are viewed on a computer graphics screen, typically an area of approximately 11 x 14 inches or smaller. In fact, this is the major distinction between Stage-4 and Stage-3 cave maps, the latter being designed to be viewed on paper. Some content features take up a lot of space, hence the user wants them displayed only while they are actually being used, and then removed so they do not interfere with other operations. This results in the content of the map being changed frequently. This in turn means that the user interface must be fast and efficient.

In some situations the caver does not know what he wants to see, so he experiments. In other situations the caver knows exactly what he wants to see. It should be easy to display the desired content features and only the desired content features. This means that control must be provided at a level in the information that makes sense to the caver. This also means that an overview of the information structure or "layout" of the map must be available so that the caver can determine "what is where".

Stage-4 cave maps provide the caver the opportunity to "explore" the cave by changing the map content. This is basically a trial and error process and is a natural part of exploring a cave on a computer. Because the content is changed frequently in this exploration, a minimal number of steps should be involved in getting to any desired content state, and the current content state must be easy to determine.

An example may make the last point more clear. Suppose the cave contains two layers of passages, one on top of the other, in different layers of limestone. If the caver is studying the passages in the bottom layer, he may want only that layer of passages displayed, but with all possible detail. If he is studying the relationships of the passages in the two layers, then he may want both layers displayed, but with much less detail in each of the layers.

The Stage-4 cave map must allow the cartographer the flexibility to include information in such a way that this kind of "exploration" is possible. The user interface must, in turn, provide the viewer the flexibility to explore the logical connections built into the map by the cartographer, and also to explore logical connections not anticipated by the cartographer.

Stage-4 cave maps are designed to be viewed by people who are not necessarily experts in computer graphics. This means that the user interface must be easy to understand, easy to learn, and easy to use. It should deal with entities that are natural to the caver vice entities that are natural to the graphics programmer. For example, it should be possible to display passages in a particular section of the cave without having to know in detail which graphics segment or display list subroutine contains that information.

The above discussed considerations result in the following seven requirements for the user interface for Stage-4 cave map content control:

- The user interface must be fast and efficient,
- It must provide control at an appropriate level in the information,
- It must provide the viewer with access to the information required to understand the map,
  - General information about the map,
  - What each content feature contains, and the
  - Attributes of the map,
- It must be possible to display the current content state,

- It must provide the cartographer with flexibility to support logical connections in the information displayed,
- It must provide the viewer the flexibility to explore logical connections in the information displayed,
- It must be easy to understand, easy to learn, and easy to use.

5. STAGE-4 DESIGN ELEMENTS

The requirements for the user interface for content control for Stage-4 cave maps are presented above. Exactly how these requirements are satisfied is the decision of the system designer. As with viewing, more than one solution exists. A list of design elements which, by experimentation via program ICM, have been found to satisfy the above requirements is shown below.

- Use the four content feature types defined in Section 2 above, viz:
  - * Traverse lines information,
  - * Passage walls information,
  - * Symbols information, and
  - * Auxillary information,
- Provide content control at the content feature level,
- Include an option to display the current content state,
- Provide content control via toggle operations,
  - * Individual control for all content features,
  - * In addition, provide global control of:
    - + Traverse lines information,
    - + Passage walls information,
    - + Symbols information, and
    - + North/scales in the cave,
- The content definition must allow the cartographer to:
  - * Select where information is contained, and
  - * Display/describe to the user "what is where",
- Provide two different interfaces for content control:
  - * A Command Language Interface (CLI),
  - * A Graphics Menu Interface (GMI), and
  - * Both interfaces provide the same functions.

The four content feature types defined in Section 2 above are employed for content definition and control. Surveyors are naturally interested in traverse lines information. The display of this information early in a project can be a great help in detecting problems in the data and targets for resurvey. When the map is complete, however, the display of this information is of less importance.

Passage walls information is unique in that it is a combination of the numerical data and the sketch data. Symbols information is primarily sketch data. It can be organized in several different ways, depending on the aims of the cartographer. Auxillary information should be sufficient for a caver who knows the user interface to determine everything necessary to successfully study the map, even if he is not familiar with the cave. Content control is provided at the content feature level within these four content feature types.

It is not always obvious to the user exactly what information is being displayed. For example, if the symbols representing hydrology are being displayed but the section of the cave on the screen contains no water, then no hydrology symbols will be visible. The appearance on the screen is the same as if this information were not being displayed at all. Because of this an option is needed to unambiguously display the current content state.

Toggle operations, i.e., on/off switches, are well suited for content control. A switch must be provided for each content feature. In addition, global switches are provided for: traverse lines information, passage walls information, and symbols information. Experience with ICM has shown that auxillary information is of such a varied nature that global switches make sense only for controlling the multiple north/scales.

During the map construction phase the cartographer needs to have the opportunity to decide where each piece of information will be contained, and to describe "what is where" in an auxillary content feature that the user can later display. Without this the map is easily understandable only to the cartographer who created it, and to him only as long as he remembers the structure of the map.

Two different interfaces were provided for viewing control (see Wefer, 1989c). The same two user interfaces must be provided for content control, else the operation of the Stage-4 map would be unnecessarily complicated. Because switches are so straightforward to implement and operate, both the Graphics Menu Interface (GMI) and the Command Language Interface (CLI) can easily provide exactly the same functions.

6. THE ICM IMPLEMENTATION OF CONTENT CONTROL

Forty-two ICM CLI toggle commands (and corresponding GMI options) are available for use in changing the content of the Stage-4 map. These commands function as toggle switches. ICM maintains a flag indicating the current state ("on" or "off") of each content feature. What the commands do when executed depends on the current state of the content feature as follows:

- If the content feature is currently "off" as indicated by its flag, turn it "on" and set its flag to "on" (i.e., if it is currently invisible, make it visible).

- If the content feature is currently "on" as indicated by its flag, turn it "off" and set its flag to "off" (i.e., if it is currently visible, make it invisible).

For details of the ICM implementation of toggle switches and some sample FORTRAN code, see Wefer (1985).

6.1 THE ICM GMI TOGGLE OPTIONS

The ICM function menu containing the GMI options for content control is shown in Figure 1 below. It appears in the lower-left corner of the screen. The two-character commands in this menu are placed three in a row and separated by "/"s. The user selects an option by placing the pick device cursor on either of the two characters and pressing the button. If the user places the cursor on a "/" and presses the button, nothing happens (or at user option a message is displayed in the alphanumeric window just above the device viewport at the top of the screen).

```
RC/SC
SP/RP/CS
SU/CF/ML
YW/PT/RL
MU/HL/CV
HP/NS/EW
FM/SG/VB
TO/NC/NP
TL/PW/SY
N1/N2/N3
N4/N5/N6
S1/S2/S3
S4/S5/S6
P1/P2/P3
P4/P5/P6
T1/T2/T3
T4/T5/T6
RV/CP/CM
TB/PS/CL
```

Figure 1. The ICM function menu is shown. It contains the forty-two GMI options for content control. The two-character options in this menu are separated by "/"s. The user selects an option by placing the pick device cursor on either of the two characters and pressing the button.

6.2 THE ICM CLI TOGGLE COMMANDS

Table I below lists the forty-two content control toggle commands divided into five groups: (1) static auxiliary content features, (2) dynamic auxillary content features, (3) traverse lines, (4) passage walls, and (5) symbols. Each of these is discussed below and illustrated via hardcopies of the Stage-4 cave map of Corkscrew Cave, the mythical cave used to illustrate viewing control in Wefer (1989c).

TABLE I. The forty-two ICM toggle commands are listed. The CLI command is shown followed by the command meaning. Underlined and capitalized characters in the meaning indicate the origin of the command name.

COMMAND	MEANING
-------	STATIC AUXILLARY CONTENT FEATURES
CF	toggle Content Features descriptions.
FM	toggle Fiducial Marks.
ML	toggle Map Legend.
MU	toggle graphics MenUs.
SC	toggle SCript portion of the graphics menu.
SG	toggle Screen Grid.
SU	toggle SetUp parameters.
TB	toggle Title Block.
-------	DYNAMIC AUXILLARY CONTENT FEATURES
EW	toggle East-West plane.
HP	toggle Horizontal Plane.
NC	toggle North/scales in the Cave globally.
N1	toggle North arrow number 1.
N2	toggle North arrow number 2.
N3	toggle North arrow number 3.
N4	toggle North arrow number 4.
N5	toggle North arrow number 5.
N6	toggle North arrow number 6.
NP	toggle North/scale Pinned on the screen.
NS	toggle North-South plane.
TO	toggle Topographic Overlay.
VB	toggle Viewing Box.
-------	TRAVERSE LINES
TL	toggle Traverse Lines globally.
T1	toggle Traverse lines number 1.
T2	toggle Traverse lines number 2.
T3	toggle Traverse lines number 3.
T4	toggle Traverse lines number 4.
T5	toggle Traverse lines number 5.
T6	toggle Traverse lines number 6.
-------	PASSAGE WALLS
PW	toggle Passage Walls globally.
P1	toggle Passage walls number 1.
P2	toggle Passage walls number 2.
P3	toggle Passage walls number 3.
P4	toggle Passage walls number 4.
P5	toggle Passage walls number 5.
P6	toggle Passage walls number 6.
-------	SYMBOLS
SY	toggle SYmbols globally.
S1	toggle Symbols number 1.
S2	toggle Symbols number 2.
S3	toggle Symbols number 3.
S4	toggle Symbols number 4.
S5	toggle Symbols number 5.
S6	toggle Symbols number 6.

6.3 STATIC AUXILLARY CONTENT FEATURES

Auxillary content features, as the name implies, provide help in understanding the cave depicted on the computer graphics screen, but they do not represent the cave itself. Static here means that they do not move on the screen when the viewing is changed.

Figure 2 below shows a hardcopy of a Stage-4 cave map with the setup parameters display, the fiducial marks, and the graphics menus toggled "on".

At a point early in the construction of the map a number of parameters specifying details of the map are input from a disk file. These parameters are of two types, run parameters and setup parameters. The run parameters can be changed interactively while viewing the Stage-4 cave map via command "RP" (not a toggle command). The setup parameters cannot be changed after the map is constructed. The setup parameters (toggled via command "SU") are displayed in the right-hand portion of the screen in Figure 2 below. The color index of the text and surrounding box, and whether or not the background of the surrounding box is transparent or opaque, are setup parameters.

Note: Colors in computer graphics are specified by color indices. While the numerical color index of a content feature may be a setup parameter, the actual definition of the color corresponding to that color index is a run parameter. This means that if a content feature is drawn in color index 4 (normally blue), and you later redefine color index 4 to be red, then everything drawn in color index 4 will instantly change from blue to red.

The fiducial marks (toggled via command "FM") are nine marks fixed on the screen and used for reference purposes. The central fiducial mark is at the center of the device viewport (see also Figure 8 below). Fiducial marks are useful for visually positioning the cave on the screen via viewing changes. The color index of the fiducial marks is a setup parameter.

The graphics menus (toggled via command "MU"), both the viewing menu discussed in Wefer (1989c) and the function menu containing the toggle options and other options as well (Figure 1) are shown at the lower-left corner of the screen. The size of the menus is a run parameter. The color index is a setup parameter.

Note the current content state displayed in the alphanumeric window just above the device viewport. This is updated by picking option "CS" (not a toggle option), but it is only updated when the option is picked. A "0" under the vertical two-character option name means that content feature is currently "off". A "1" under the option name means it is "on". A "2" means it is "off" and has not yet been constructed. Some static auxillary content features are not actually constructed until the first time they are toggled "on". All remaining figures in this paper show the content state at the time the hardcopy was made.

Figure 3 below shows a hardcopy of a Stage-4 cave map with the graphics menus, the script menu, the screen grid, and the content features descriptions toggled "on". The graphics menus were discussed above.

The script menu (toggled via command "SC") is used for creating and viewing movies, and is the subject of a future paper in this series. It uses the same color index and size as the viewing and function menus.

The screen grid (toggled via command "SG") is a square grid fixed on the screen. The grid spacing, the color index, and the line style (solid lines or dashed lines with a specified dash pattern) are all setup parameters.

The cave cartographer has considerable flexibility in constructing the Stage-4 cave map. Because of this it is not always obvious exactly what information is controlled by the traverse lines, passage walls, and symbols toggle commands. The content features descriptions (toggled via command "CF") tell the viewer what is where. They are displayed in the right-hand portion of the screen in Figure 3 below. The color index of the text and surrounding box, and whether or not the background of the surrounding box is transparent or opaque, are setup parameters. The Stage-4 cave map shown in Figure 3 has been constructed with an opaque surrounding box. A single setup parameter actually controls this detail for the setup parameters display, the content features descriptions, and the map legend (see below).

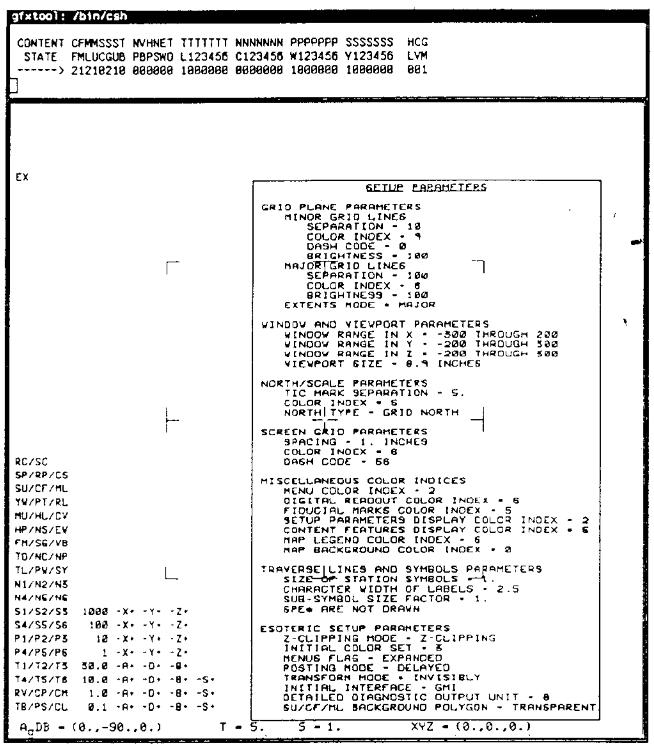

Figure 2. Hardcopy of a Stage-4 cave map with the setup parameters display, the fiducial marks, and the graphics menus toggled on.

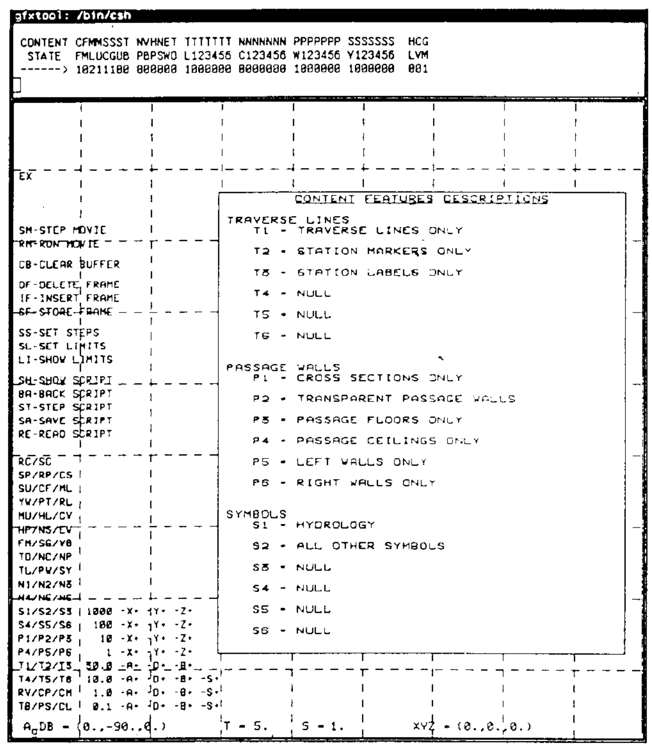

Figure 3. Hardcopy of a Stage-4 map with the graphics menu, the script menu, the screen grid, and the content features descriptions on.

Figure 4 below shows a hardcopy of a Stage-4 cave map with the graphics menus, the title block, and the map legend toggled "on".

The graphics menus were discussed above. The title block (toggled via command "TB") is displayed at the center-top of the screen. It can be up to five lines long, with up to 76 characters in each line. The character size, text font, and color index are user settable for each line. These attributes can also be changed within a single line at the sacrifice of some characters in the text displayed on the screen for that line. This is illustrated in Figure 4 by the changes of text font near the middle of the second line. The title block, including both the text and its attributes, are run parameters.

The map legend (toggled via command "ML") is displayed in the right-hand portion of the screen in Figure 4 below. It provides the cartographer with up to 40 lines (of 40 characters each) of textual data for use in giving the viewer some background information about the cave and the map, e.g., who was on the survey crew and in what positions, the date of the survey, the location of the cave, other sources of data, and where to get additional information. The text, the text font, the color index of the text and surrounding box, and whether or not the background of the surrounding box is transparent or opaque, are all setup parameters.

6.4 DYNAMIC AUXILLARY CONTENT FEATURES

Dynamic auxillary content features move on the screen when the viewing is changed. Figure 5 below shows a hardcopy of a Stage-4 cave map with the horizontal plane, the north-south plane, the east-west plane, the viewing box, and the pinned north/scale all toggled "on". The graphics menus have been toggled "off", then the content state displayed via the CLI command "CS". Note the CLI prompt at the lower-left corner of the alphanumeric window, viz "ICM:".

There are three types of grid planes; the horizontal plane (toggled via command "HP"), the north-south plane (toggled via command "NS"), and the east-west plane (toggled via command "EW"). They are parallel to the XY, the YZ, and the XZ coordinate planes, respectively.

These grid planes contain two types of grid lines called "major" and "minor". The spacings, color indices, and brightnesses of major and minor grid lines are setup parameters. The line style (solid lines or dashed lines with a specified dash pattern) of the minor grid lines is also a setup parameter.

Also included in the setup parameters is an "extents mode" which indicates how the extents of the grid planes are to be determined. As the traverse lines data is read from disk files, ICM keeps track of the extreme station coordinates in the three coordinate directions. If the extents mode is set to "major", the grid plane is the smallest rectangle defined by the major grid lines which encloses the traverse lines data in that plane. If the mode is set to "minor", the grid plane is the smallest such rectangle defined by the minor grid lines.

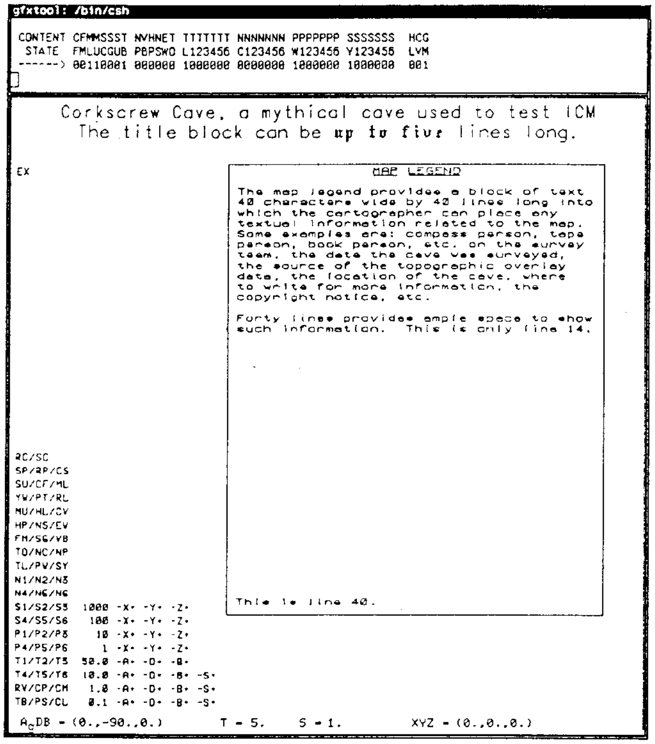

Figure 4. Hardcopy of a Stage-4 map with the graphics menu, the title block, and the map legend on.

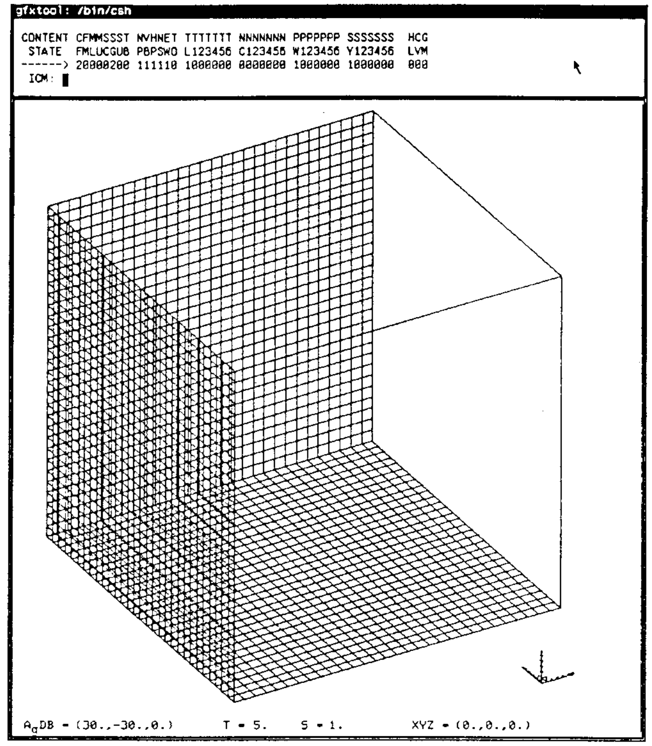

Figure 5. Hardcopy of a Stage-4 map with the horizontal plane, the north-south plane, the east-west plane, the viewing box, and the pinned north/scale all on.

The grid planes are initially displayed as follows: the horizontal plane is at the bottoms of the east-west and north-south planes, the north-south plane is at the west end of the horizontal plane, and the east-west plane is at the north end of the horizontal plane, as is shown in Figure 5. The x-coordinate of the north-south plane, the y-coordinate of the east-west plane, and the z-coordinate of the horizontal plane can be changed interactively while viewing the Stage-4 cave map via command "RP".

The viewing box (toggled via command "VB") is a transparent rectangular parallelepiped with faces parallel to the grid planes and with the same extents. Three of its faces initially coincide with the three grid planes discussed above. The viewing box color index and line style are the same as those of the edges of the grid planes, i.e., they are controlled by the extents mode.

The pinned north/scale (toggled via command "NP") discussed in detail in Wefer (1989b) is shown at the lower-right corner of the screen. The distance between tic marks and the color index are setup parameters. The coordinates on the screen of the pinned north/scale are run parameters.

Figure 6 below shows a hardcopy of a Stage-4 cave map with the graphics menus, the viewing box, the six <u>north/scales in the cave</u>, and the <u>topographic overlay</u> toggled "on".

The graphics menus and viewing box were discussed above. The <u>north/scales in the cave</u> (toggled individually via commands "N1", "N2", "N3", "N4", "N5", and "N6", and globally by command "NC") are identical to the pinned north/scale, except that they move with the cave as the viewing is changed. The coordinates of the north/scales in the cave are run parameters.

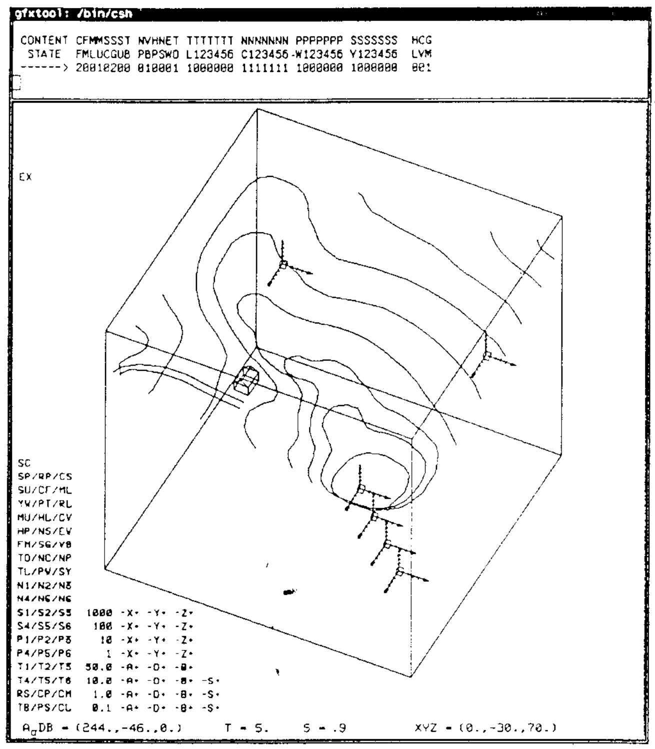

Figure 6. Hardcopy of a Stage-4 cave map with the graphics menus, the viewing box, the six north/scales in the cave, and the topographic overlay toggled on.

Program ICM maintains four global toggle flags and six individual subordinate toggle flags for each global toggle flag. What the global toggle commands (e.g., "NC") do when executed depends on the current state of the content features as follows:

- If the global flag is "on", make invisible any subordinate content feature whose individual flag is "on", set the global flag to "off", and leave the six individual flags unchanged.
- If the global flag is "off", make visible any subordinate content feature whose individual flag is "on", set the global flag to "on", and leave the six individual flags unchanged.

The subordinate toggle commands, for example "N1", work as follows:

- If the global flag is "on" and the individual flag is "on", make invisible the subordinate content feature, and set its individual flag to "off".
- If the global flag is "on" and the individual flag is "off", make visible the subordinate content feature, and set its individual flag to "on".
- If the global flag is "off" and the individual flag is "on", set the individual flag to "off".
- If the global flag is "off" and the individual flag is "off", set the individual flag to "on".

That looks confusing but it works just like the lights in your house. Subordinate toggle commands function as light switches while the global toggle commands function as circuit breakers. The switches only work when the circuit breaker is "on". When the circuit breaker is "off", changing the light switches has no effect. But when the circuit breaker is turned back "on", the existing light switch settings take effect.

The topographic overlay data (toggled via command "TO"), including the color indices and line styles of each contour line, are contained in and read by ICM from disk files.

6.5 TRAVERSE LINES

The traverse lines information (toggled via subordinate commands "T1", "T2", "T3", "T4", "T5", and "T6", and globally by command "TL") is contained in six content features. Some content features may, of course, be "null" (i.e., empty). In Figure 7 below, "T1", "T2", and "T3" are toggled "on", along with the graphics menus and the pinned north/scale. Refer to Figure 3 to see what is where. In Figure 8 the station labels have been toggled "off" and the fiducial marks toggled "on".

6.6 PASSAGE WALLS

The passage walls information (toggled via subordinate commands "P1", "P2", "P3", "P4", "P5", and "P6", and globally by command "PW") is contained in six content features. Again some content features may be "null". The map may not use any of them at all.

In Figure 9 below, "P1", and "P3" are toggled "on", along with the graphics menus and the pinned north/scale. Hidden line removal has been applied via command "HL" (not a toggle command). This is indicated in the content state display by a "1" below the letters "HL". In Figure 10 the cross sections have been toggled "off" via command "P1" and the walls of the passage have been toggled "on" via commands "P5" and "P6", then again hidden line removal has been applied.

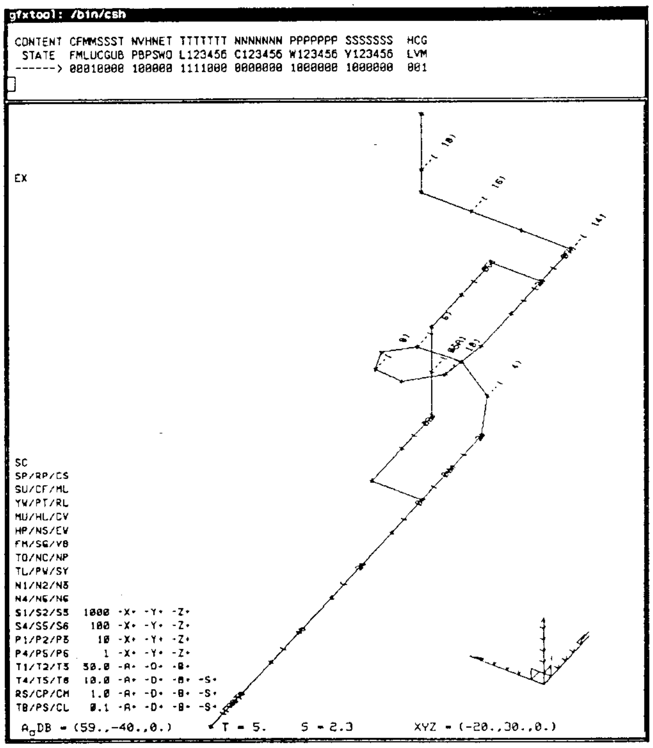

Figure 7. Hardcopy of a Stage-4 map with T1, T2, T3, NP, and the graphics menus on.

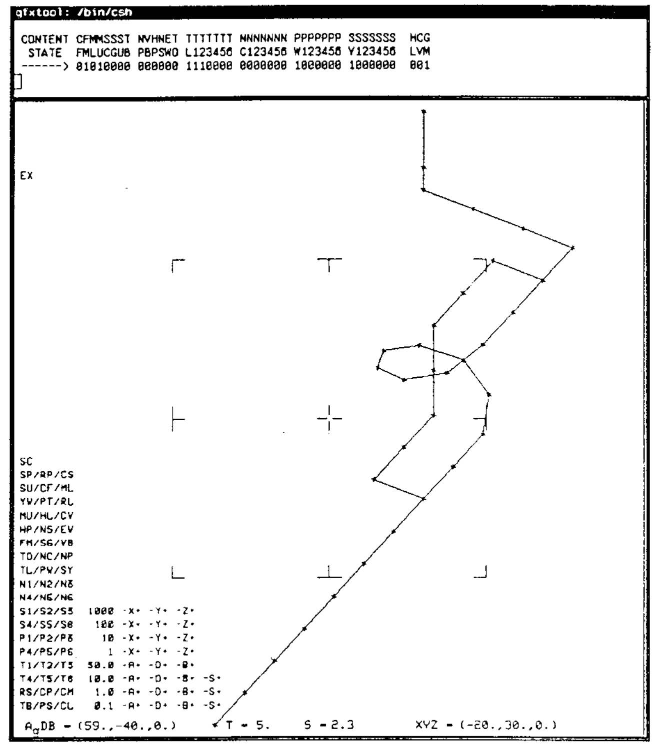

Figure 8. Hardcopy of a Stage-4 map with T1, T2, FM, and the graphics menus on.

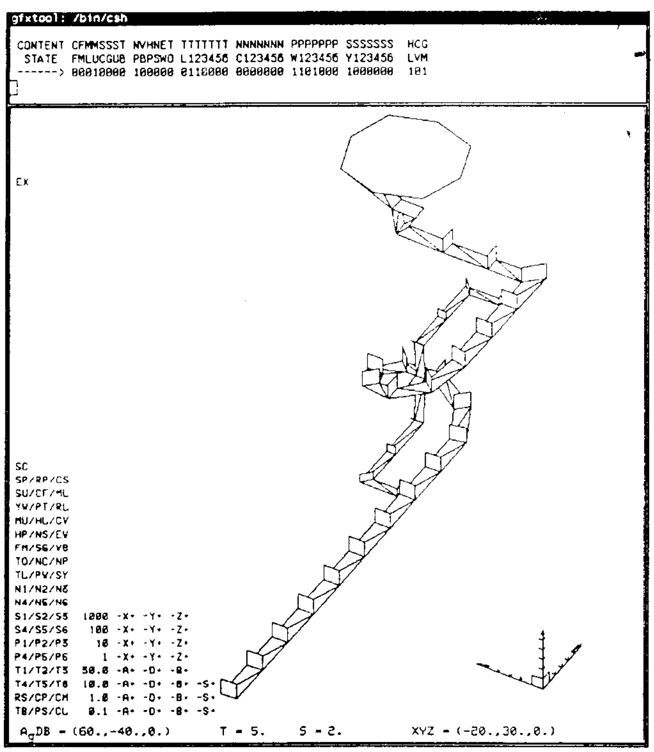

Figure 9. Hardcopy of a Stage-4 map with P1, P3, NP, and the graphics menus on.

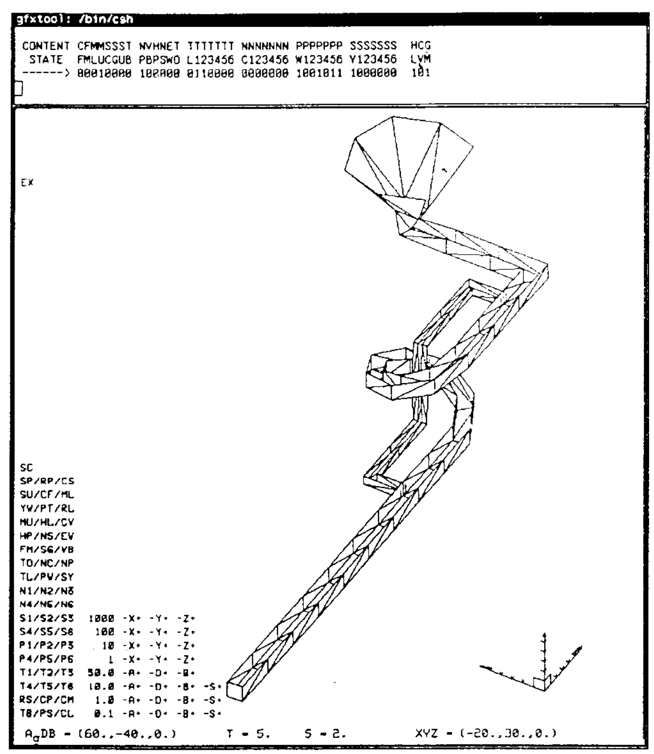

Figure 10. Hardcopy of a Stage-4 map with P3, P5, P6, NP, and the graphics menus on.

6.7 SYMBOLS

The symbols information (toggled via subordinate commands "S1", "S2", "S3", "S4", "S5", and "S6", and globally by command "SY") is contained in up to six content features. In Figure 11 below, "S1" (containing the symbols related to hydrology) is toggled "on" along with the pinned north/scale and the transparent passage walls. In Figure 12 below, "S2" (containing all other symbols) has been toggled "on". A large stalagmite and a caver are visible in the main passage of the cave.

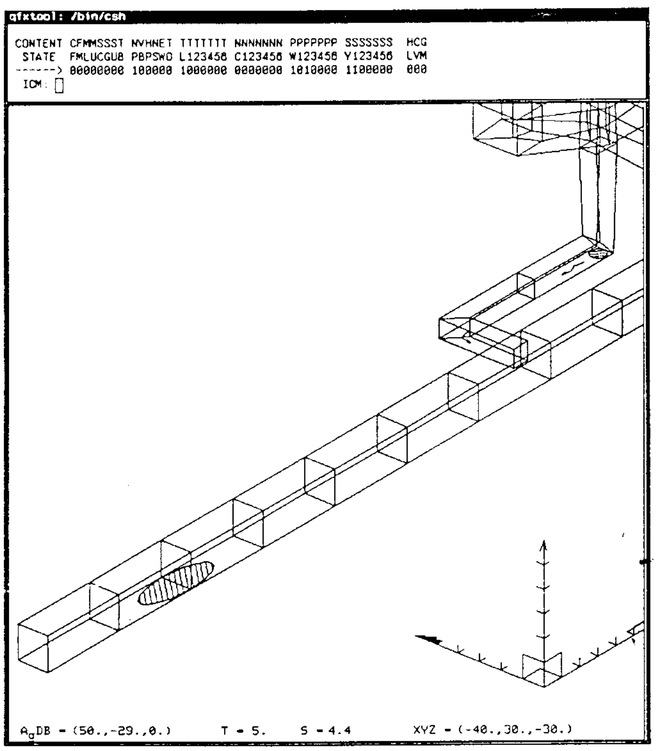

Figure 11. Hardcopy of a Stage-4 map with S1, P2, and NP on.

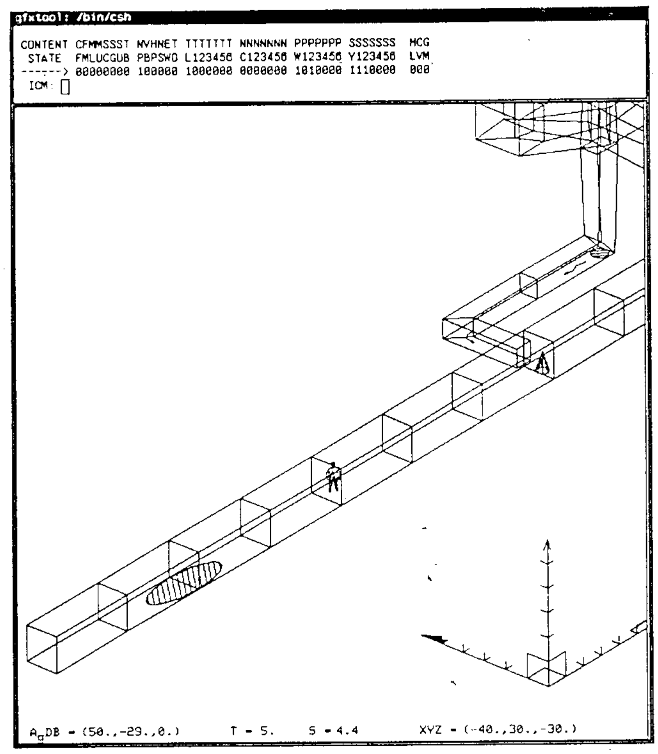

Figure 12. Hardcopy of a Stage-4 map with S1, S2, P2, and NP on.

6.8 NUMBER OF CONTENT STATES

In Figure 13 below, all content features for the Stage-4 cave map have been toggled "on". Figure 13 is included to make the point that not all content features are normally "on" at any point in time. And that brings up an interesting question. Considering only toggle options, how many meaningfully distinct content states are there?

The number of "meaningfully distinct" content states depends strongly on the organization of the Stage-4 cave map being viewed. To get an idea, suppose that all six traverse lines content features, all six passage walls content features, and all six symbols content features are being used. (This not uncommon situation has prompted me to consider adding another three of each.)

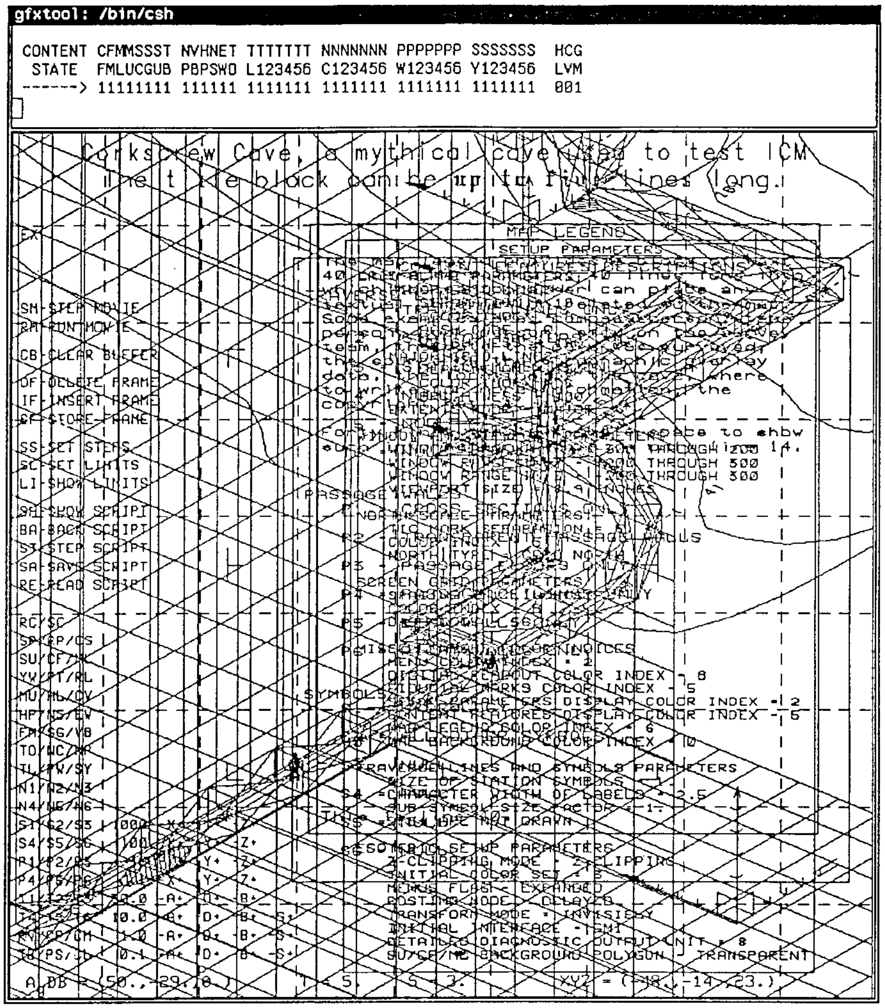

Figure 13. Hardcopy of a Stage-4 cave map of Corkscrew Cave will all content features toggled on.

Note that the global toggle commands (TL, PW, SY, and NC), while they are quite useful, do not really provide content states which could not be set by toggling "off" each individual subordinate content feature. We should probably also eliminate from the calculation the commands which control static auxillary content features, since they are not directly related to displaying the cave (CF, FM, ML, MU, SC, SG, and SU).

The remaining thirty-one toggle commands provide the Stage-4 cave map viewer with 2^{31} content states. That's more than 2 billion. Compare this with a traditional cave map (or even a Stage-3 cave map) which provides the viewer with exactly 1 content state.

From Wefer (1989c) we know that each of these content states has perhaps 65,000 meaningfully distinct viewing states. If you made a hardcopy of each distinct state (combined viewing and content) you would end up with a stack of paper more than five million miles high! Yes, more than 5,000,000 miles high! Each sheet of paper in this stack would be a different Stage-3 cave map.

Instead of killing all those trees, suppose we simply view the distinct states on the screen. Assuming that we can display a new state once every second (a good graphics workstation can actually do this), how long would it take to view all the combined content and viewing states for our Stage-4 cave map? The answer is more than 44,000 centuries!

The point here is that ICM gives the caver lots of options. While each state is "meaningfully distinct", the vast majority of them are not helpful in understanding the cave being displayed. It is up to the Stage-4 cave map viewer to provide the intelligence to determine which are helpful and which are not.

7. LOGICAL DISPLAY STRUCTURES

The physical structure of a portion of the ICM display list was discussed in Section 3. This physical structure accomodates a number of logical structures that can be employed by the cartographer in representing the cave. For example, the logical structure might be the same as that suggested by Ganter (1989), viz:

- STAGE-4 MAP OF THE CAVE.
  - section-a of the cave
    - DLS-T1 (TRAVERSE LINES INFORMATION)
    - DLS-P1 (PASSAGE WALLS INFORMATION)
    - DLS-S1 (SYMBOLS INFORMATION)
  - section-b of the cave
    - DLS-T2 (TRAVERSE LINES INFORMATION)
    - DLS-P2 (PASSAGE WALLS INFORMATION)
    - DLS-S2 (SYMBOLS INFORMATION)

The levels represented by lower case letters in this display hierarchy (and in the ones shown below) are logical levels only, there are no physical entities in the display list that correspond to them. There doesn't need to be if the toggle switch mechanism is fast enough.

Alternatively, the logical structure in ICM might look like this:

- STAGE-4 MAP OF THE CAVE.
  - traverse lines information in the cave
    - DLS-T1 (TRAVERSE LINES)
    - DLS-T2 (STATION LABELS)
  - passage walls information in the cave
    - DLS-P1 (PASSAGE WALLS)
    - DLS-P2 (CROSS SECTIONS)
  - symbols information in the cave
    - DLS-S1 (HYDROLOGY SYMBOLS)
    - DLS-S2 (FORMATION SYMBOLS)

Since in ICM there are actually six content features of each type, the logical structure might even be:

- STAGE-4 MAP OF THE CAVE.
  * section-a of the cave
    + traverse lines information in section-a of the cave
      - DLS-T1 (TRAVERSE LINES)
      - DLS-T2 (STATION LABELS)
    + passage walls information in section-a of the cave
      - DLS-P1 (PASSAGE WALLS)
      - DLS-P2 (CROSS SECTIONS)
    + symbols information in section-a of the cave
      - DLS-S1 (HYDROLOGY SYMBOLS)
      - DLS-S2 (FORMATION SYMBOLS)
  * section-b of the cave
    + traverse lines information in section-b of the cave
      - DLS-T3 (TRAVERSE LINES)
      - DLS-T4 (STATION LABELS)
    + passage walls information in section-b of the cave
      - DLS-P3 (PASSAGE WALLS)
      - DLS-P4 (CROSS SECTIONS)
    + symbols information in section-b of the cave
      - DLS-S3 (HYDROLOGY SYMBOLS)
      - DLS-S4 (FORMATION SYMBOLS)

The cave cartographer has considerable flexibility in constructing the logical display structure. He uses the content features descriptions (see Figure 3) to describe the logical display structure to the Stage-4 cave map viewer.

8. SUMMARY AND DISCUSSION

Content control in computer graphics is a subject which is fairly easy to understand. The constraints imposed by: the content being changed frequently, the user not necessarily knowing what he wants to see until he sees it, and the caver not being an expert in computer graphics, all must be taken into account. The requirements for the user interface for content control for Stage-4 cave maps have been defined.

The ICM graphics menu interface and its corresponding command language interface make content control easy to perform. These interfaces are: fast and efficient, involve a minimal number of steps, and are easy to understand, learn, and use.

Figure 1 above includes several menu options that are used for neither viewing control nor for content control. The next paper of this series discusses these miscellaneous but important options for Stage-4 cave maps.

9. SOME TECHNICAL NOTES

This section is included for readers familiar with the terminology and technical details of CORE. Visibility can be controlled in CORE by changing the visibility attributes of graphics segments. This technique is employed in ICM in the case of the pinned north/scale, the map legend, and several other content features.

TEMPLATE also provides DLSs within graphics segments, and these can be used to control visibility by swapping the DLS containing the actual content feature information with an empty DLS. This is employed in ICM for all dynamic content features: dynamic auxillary content features, traverse lines information, passage walls information, and symbols information. Employing this technique means that the viewing of the entire cave can be changed via a single 3D segment image transformation. This is the key to the smooth dynamics apparent in the video tape of Wefer et al (1983). The interested reader is referred to Wefer (1985) for more details.

Content control is made more efficient by adaptive coding. Some display devices perform posting and image transformations in hardware. For others these graphics operations are performed in software. ICM has two posting modes: immediate (for hardware operations) and delayed (for software posting/image transformations). In addition, in ICM two segment image transform modes are available: visibly (transform with the segments visible) and invisibly (used with delayed posting as follows: make the segments invisible, post, perform the transformation, then make the segments visible again). The posting mode and transform mode setup parameters allow ICM to perform content and viewing changes in the most efficient manner possible on the display device.

ICM maintains existence flags for the individual content features subordinate to commands "TL", "PW", and "SY" and uses these to optimize content control. If, for example, content feature "P4" is "null", then executing command "P4" results only in the visibility flag being changed. No time is wasted posting since it can have no effect on the screen.

10. REFERENCES

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Cave Visualization Using Voxels - an Alternative to Commercialization

by Richard L. Breisch

The Scene. This was the first time the caver had ever been at the controls of a helicopter. He purposefully crisscrossed the sinkhole plain looking for a good sinkhole - one that had a cave entrance. The first several sinks he landed at had no enterable passage, so his guide. who had been here before, suggested he check out a large sink which had a stream flowing into it. The new pilot landed the helicopter at the edge of the sink. All the passengers then descended the slope of the sinkhole into the mouth of a cave. They moved slowly through the twilight zone; as their eyes adjusted to the darkness, they detected a passage leading on.

The group inched cautiously down the passage. As they rounded a corner, the blackness indicated they were entering a large room with large stalactites hanging down from the ceiling. The caving party split up to explore the room. The lights of each person weaved in and out behind breakdown and columns. A shallow stream trickled across the floor. One person peered into a quiet pool and spotted a cave fish. There was a disturbance on the water surface, and the fish swam away. Another caver discovered bacon rind Speleothems and held his light behind them so the others could view the multi-colored bands in the translucent calcite. After a while the cavers extinguished their lights and turned on a portable black light. The fluorescent minerals radiated greenish light. The trip leader found delicate crystals an one wall and moved closer to get a better look. Momentarily forgetting good conservation practice, he reached out to touch the crystal. He felt a smooth wall. The cave scene was a projected, onto the inside of a large, white dome!

Image-Generation Technology. This scenario is fictional, but the technology to create it will soon be available. The visual imaging field is now employing methods to create images which were not conceivable only a few years ago. Until recently, realistic computer generated scenes could be generated only by employing polygon-based databases. For example, to generate the image of a sinkhole plain, a map or aerial photograph would be used to precisely identify points to be incorporated in the database. Each point is represented using 3-dimensional cartesian coordinates. The landforms are represented by polygons which are approximately flat. The flat portion of the sinkhole plain is composed of relatively few polygons. Features with greater relief, such as sinkholes, are represented with many more polygons.

Polygons are useful for images of city streets, man-made structures, and other objects having flat planes or smooth surfaces. It is not unusual today to have a computer picture of a automobile which uses an the order of 50,000 polygons. The computer graphics literature has hundreds of articles describing how to convert the "wire-frame" images into a smooth, realistic picture of the object.

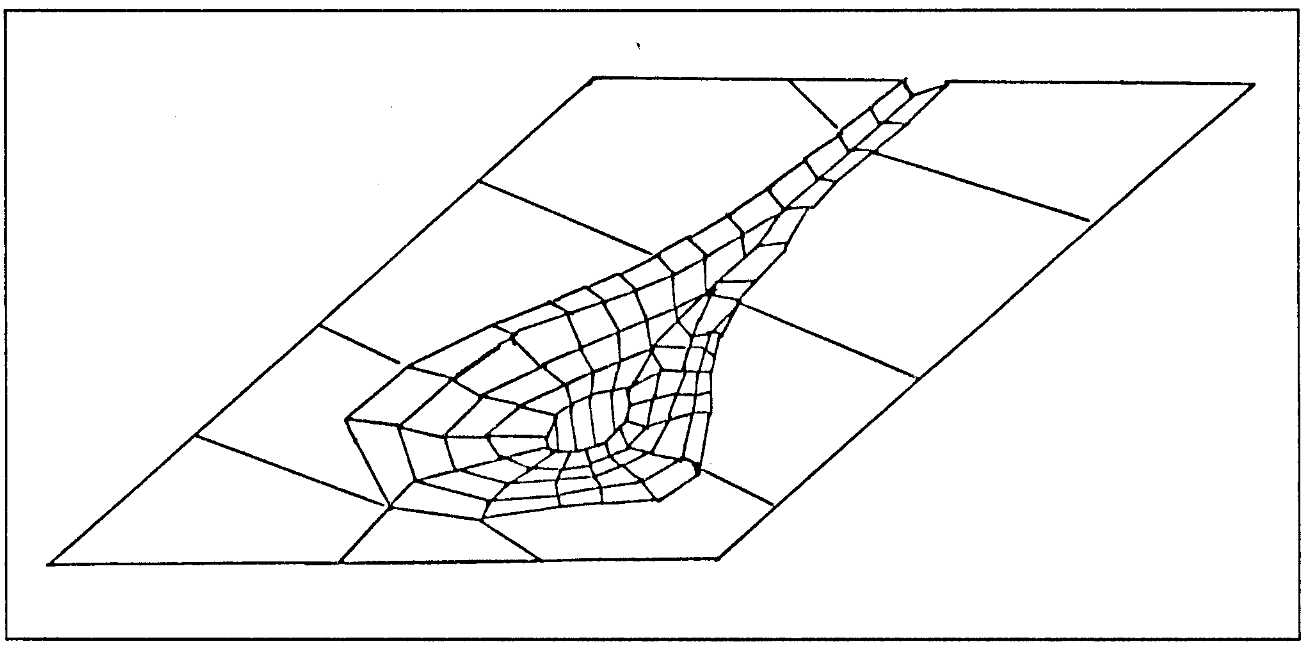

Figure 1: Polygons used to Represent a Sinkhole Plain.

Polygons are not as useful in creating realistic images of natural objects, since the created objects often look very "boxy". Objects in nature often have a great deal of irregularity and hence cannot be accurately represented by polygons. Some people have attempted to create more realistic objects by increasing the number of polygons by, say, a multiple of ten. This works if the application can be created off-line and the picture is viewed from a single direction. It does not work well if the scene is to be generated in realtime from a constantly changing viewpoint such as a helicopter in flight.

Voxels. A new method for storing image data uses voxels which stands for volume elements. These can be thought of as a generalization of pixels or picture elements, which are the smallest displayable elements of an image on a computer monitor. On the simplest type of voxel, a flat surface is represented by a square grid of data. Each square grid may have several attributes associated with it such as height and color. See Figure 2.

More complicated forms of voxels divide 3-dimensional space into a myriad of cubes. Each point is space belongs to one of these cubes. The voxel is denoted by its 3-dimensional coordinates, and it may have many attributes such as color, translucence, reflectivity, material type, fluorescence, or any other descriptive noun which would be used to categorize the objects of the image. Each attribute could have anywhere from two to many values. For example, color might be selected from a palette of 256 or more colors, and translucence might have 8 levels.

Until recently voxel representations have been mainly used in university research projects. In the medical field, CAT scans have been used to create 3-dimensional images of a skull or an injured limb. The doctors could then rotate the image to learn more about the body part. For instance, by changing the color of the image of a tumor tissue and then examining the body part from many angles, a surgeon could determine the best way to operate to remove all of the tumor while doing the least damage to healthy tissue. In meteorology, voxels have been used to show how storm cells develop during time. Whatever the meteorologist is most interested in temperature, wind speed, turbulence, or humidity - can be artificially color-coded to enhance human understanding.

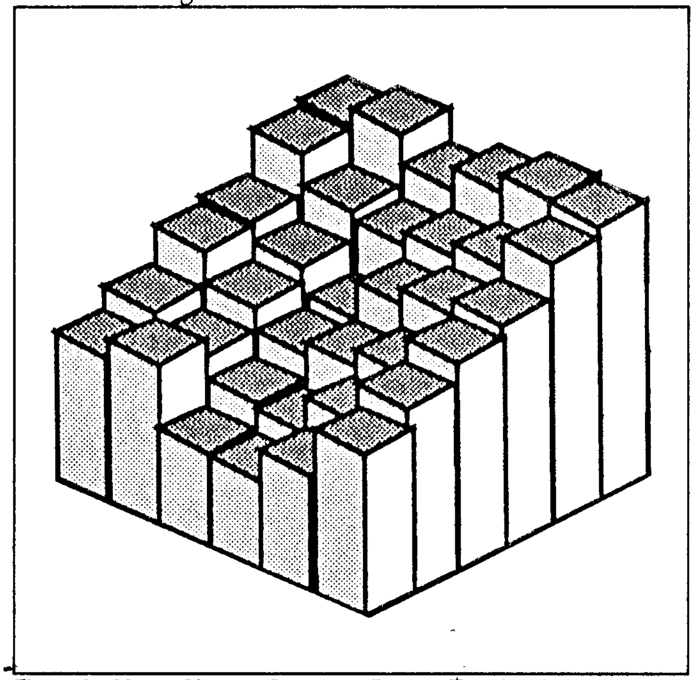

Figure 2: Voxels Used to Represent Rugged Terrain. In this example, height is an attribute of voxels on a 2-dimensional grid.

Computer graphics landform images are now being created rapidly by at least two companies, Hughes Aircraft Corporation in Long Beach, California, and Image Data Corporation in Pasadena, California. These companies can use topographic maps to generate data for the voxel database. Alternatively, stereoscopic pairs of aerial photographs can be used to obtain the data. From the photographs, each voxel is assigned attributes of position, color, texture, material, vegetation, etc. I have seen voxel-based imaged created from aerial photographs which were then "flown" at altitude levels appropriate for a helicopter or a propeller airplane. Most people would think these scenes were taken with a movie camera - not originally based on two aerial photographs. The resolution of features is on the order of 0.1 meter to 10 meters depending on the quality of the aerial photographs, the size of the database, and the requirements of the application. The resolution of the data does not have to be the same throughout the database. The area of primary interest may have a resolution many times greater than areas an the fringe of the scene. There is no reason other than computer memory to limit the fineness of the resolution.

If the aerial photos do not provide as much detail as desired in certain regions, other methods can be used to give the detail.
Additional details for buildings or vehicles can be generated from street-level photographs, architectural or engineering drawings, or an artist's imagination. Trees, shrubs, eroded terrain, and other natural features can be created using the mathematics of fractals. Any of these objects are then placed in their own voxel database to be duplicated and repositioned as the image designer wishes.

The viewer can shift his position so that he can best view between the leaves of a fractal tree. If he is looking at a building, he can look between the leaves of a tree to peer through a window to see inside - assuming the interior walls have been recorded in the database and the windows are transparent.

Voxels and Cave Visualization. What does this have to do with cave scenes? The technology now exists, or will within a year or two, to create a simulation which performs all of the features described in the beginning of this article. The karst landscape could be generated using existing products of Hughes or Image Data. Flying a helicopter through a voxel scene in realtime is, to the best of my understanding, not quite possible in January 1990 but could be possible by the end of the year. The control of position and attitude are easy to implement since similar technology exists, and its fidelity ranges from that of a video game to that of a flight simulator.

Creating the voxel database of cave scenes could be done with stereoscopic photography, which has been used in caves since the beginning of the twentieth century, if not before. Several NSS members have used these cameras in caves. Extracting 3-dimensional coordinates from stereo cave photos should not be too different from extracting 3-dimensional coordinates from aerial photographs.

Figure 3 shows how voxels, which fill 3-dimensional space, would be used to represent the speleothems. Each voxel has a color and a degree of translucency attached to it. All other voxels in the vicinity of this speleothem are null, i.e., they have no color or mineral attributes and hence are transparent. Transparent voxels are ignored when the image is created by the computer. Translucent speleothems would not be hard to incorporate in the voxel database. Aragonite bushes might be too complicated to portray realistically in 3 dimensions if the data were based upon photographs. This is one place where it might be easier to use fractals to capture the essence of the object rather than using photographs of the real object.

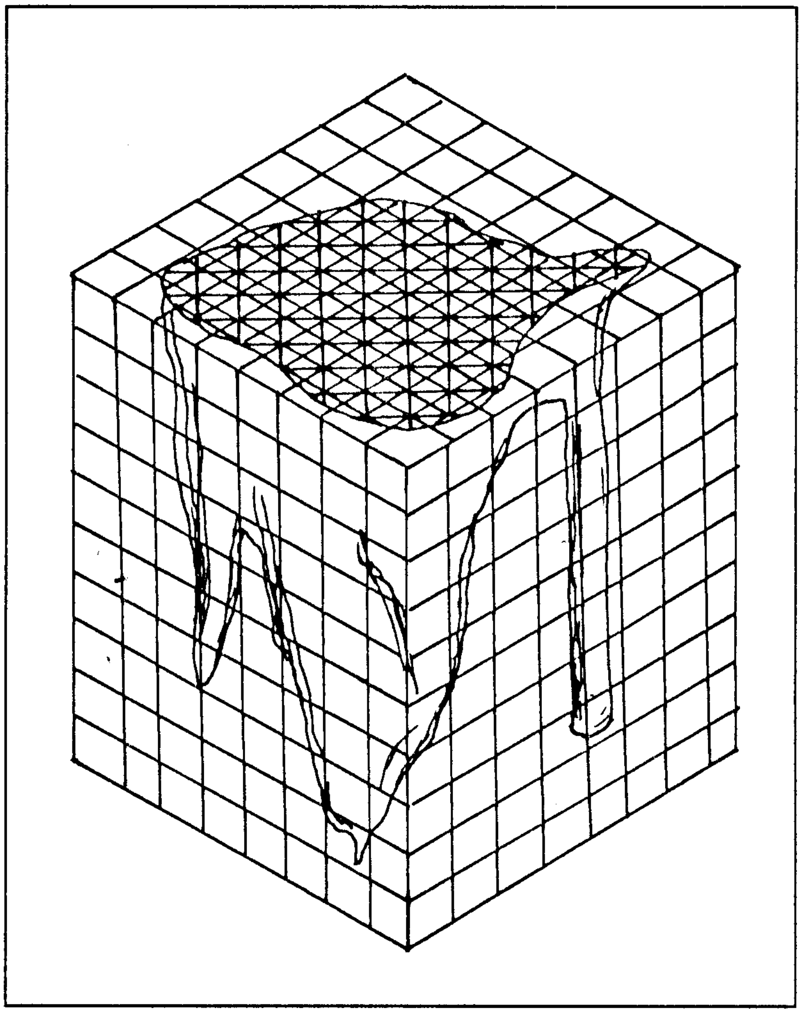

Figure 3: 3-Dimensional Voxels Used to Represent Stalactites.

Flowing water may be simulated by changing texture patterns of the voxels which represent water. Large computer imaging systems using voxels often have the capability to move specified objects. A darting cave fish is within the realm of possibilities.

I doubt that mineral fluorescence has been used in existing applications of voxels. The data could be derived from photographs taken using black light. This is the least important feature of the hypothesized cave scene, so it could easily be eliminated.

Size of the Voxel Database. For purposes of estimating the magnitude of a voxel database, I have estimated the number of voxels necessary to create a scene of a sinkhole plain and a large cave room. The estimates are meant only to give a crude approximation of the number of voxels. Several assumptions were made. The most important is that it is not necessary to have the same resolution throughout the cave. At least Hughes' image generation system does not require the same resolution for all features in the database. In fact their system only processes the data down to the resolution observable by the viewer. For example, their data base might have voxels which have a dimension of I meter. If the viewer is so far from some object in the scene that his eye can only resolve objects at least B meters on a side, then the image generation scheme only processes the data down to 8 meters.

Figure 4 approximates a cave room as a right cylinder 20 meters in diameter and 20 meters high. Table I gives estimates of the number of voxels needed to represent the room. In this hypothetical cave, features which can be seen up close, such as speleothems an a cave wall, were given a resolution of I millimeter. Features on a high ceiling of a dark cave need much less resolution. In addition, it was assumed that somewhere in the cave room is 100 square meters of speleothems which require the highest resolution. The sinkhole plain was estimated at a square 5 kilometers on a side, and the sinkhole itself fits into a square 200 meters on a side. For some applications, it might not be necessary (or maybe impossible) to show the cave floor.

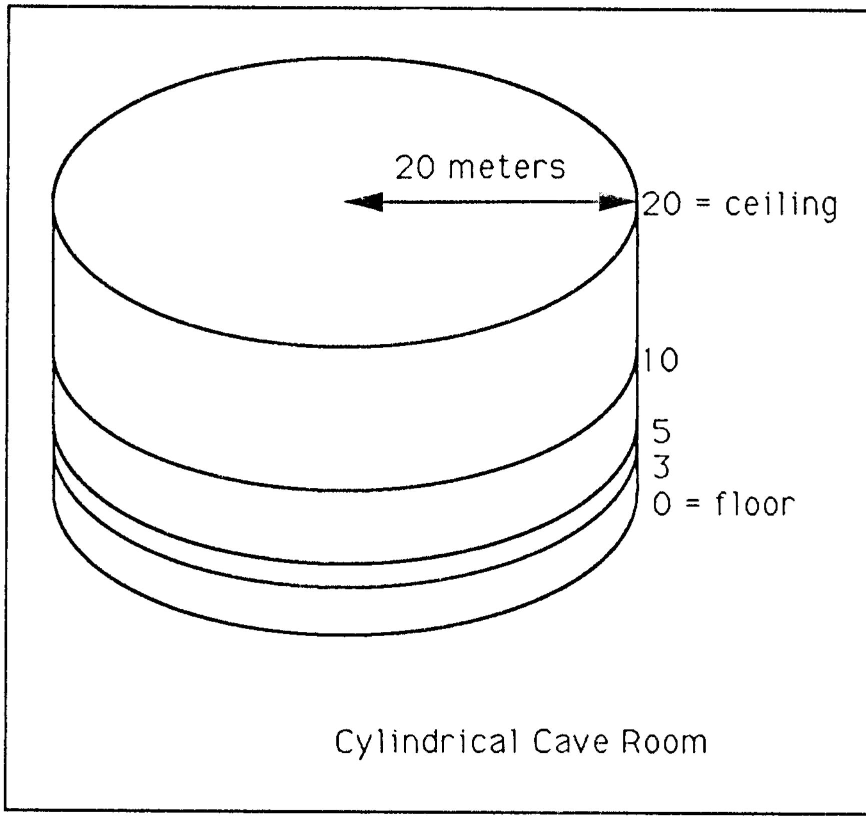

Figure 4: Right Cylinder as Model for a Cave Room.

Feature	Dimensions in meters	Resolution in millimeters	Number of Voxels in millions
Floor	diameter = 20	2	314.
Wall	0 to 3	1	376.
Wall	3 to 5	4	15.7
Wall	5 to 10	16	2.5
Wall	Over 10	32	1.2
Ceiling	diameter = 20	64	0.3
Details	100 sq. meters	1	100.
Subtotal for cave			810.
Surface	5000 x 5000	512	95.4
Sinkhole	200 x 200	128	2.4
TOTAL			900.

Table 1. Estimate of Number of Voxels for Cave Room and Sinkhole Plain

The calculations illustrate a way to size the database. Better estimates could be obtained if the cave visualization were to be based on a specific cave of known dimensions. 900 million voxels in the example given above are a lot of data, but it is small compared to some of the projects of the companies mentioned above. They are used to having voxel databases of several billion voxels (gigavoxels).

The room for the projection is another aspect of cave visualization. I suggest a hemispherical dome which are often used in aircraft flight simulators. Large hemispherical domes are used in Omni-Max theaters. Although far from common, these theaters are located in several cities in North America and are designed so the audience views the image which has been projected onto the dome. Admittedly these theaters show movies filmed with very wide-angle lenses and do not project computer-generated imagery. Imagine, if you will, instead of viewing a movie as filmed by a cinematographer, you, the audience, could direct the areas of a cave which you wished to examine. This would provide a new level of audience participation in theaters.

Using Omni-Max-like theaters would allow people in many locations to view a specific cave. One theater could have several cave scenes in its computer database library. Each cave could be called up as requested by the audience.

Possible sites for Computer Generated Cave Scenes. Because of the very high cost in generating voxel databases, processing the data, and then projecting the data onto a screen, the proposed cave visualization method is only feasible for a few very special caves. Each of these is a national treasure where the public's desires to view the cave far exceeds the cave's capacity to withstand the onslaught of tourists. In two of the suggested sites, tourism has been shown to damage the cave so severely that the public in now prevented from entering the cave. In the third example, proposed development could easily destroy the cave's features.

La Cueva de Altamira in northern Spain has some of the finest prehistoric cave art in the world. The cave was discovered in 1879, and was the first cave ever recognized as having prehistoric paintings. In August 1975, 29,000 tourists viewed the art in Altamira. As with many commercialized caves, public use of the cave changed the conditions of the cave environment until the conditions caused deterioration of the cave's features. In Altamira the carbon dioxide and heat from tourists' respiration, fungi, and bacteria caused flecks of paint to flake from the ceiling. Realizing that their cave was being destroyed, the Spanish authorities closed the cave to all tourists and began conducting extremely detailed studies of the cave, its atmosphere, and the prehistoric paintings. In 1986 when I visited the cave, 35 people per day were permitted to view the cave art. The visitors were divided into seven groups of 5 visitors and a guide. Each group was given a 15-minute tour of the room with the cave art. For me this was the highlight of a tour of prehistoric art caves in Spain. However, each day many busloads of tourists went to Altamira, but were only permitted access to the museum. One room of the museum had full-sized photographs of the art glued to the flat ceiling of the room. The tourists who saw this depiction of the famous paintings of bulls could not appreciate the 3-dimensional relief of the paintings where the bison were painted on rock projections of roughly the shape of the animals depicted.

Lascaux Cave is France's most famous prehistoric art cave. The cave was discovered by modern man (actually four teenage boys) in 1940. After World War II, it was made into a tourist attraction. By 1960 it was showing signs of deterioration. Lascaux was closed entirely to the public for many years, but now five people per day are allowed to see the prehistoric art. The French authorities have partially satisfied the tourists's desire to see the cave by building a replica of the cave in an abandoned limestone mine near Lascaux. The mine has been reshaped to the shape of Lascaux and artists have made copies of the famous prehistoric painting on the walls and ceiling of the mine. Development of a voxel database for Lascaux might be relatively easy since stereoscopic color photographs are already being routinely taken every 6 months to assess deterioration in the cave. A microtopography map of one wall was made to study the relationship between the prehistoric paintings and the shape of the wall.

In the United States, one cave stands out as being so beautiful that many people would like to see it yet is off limits to many of these people. Lechuguilla Cave in Carlsbad Caverns National Park was considered a small cave until 1985 when a group of cavers dug open a new area. Since then the cave has been explored to over 66 kilometers of passage and is now the second deepest known cave in the USA. After many newspaper and magazine articles were written about Lechuguilla, the development interests of the city of Carlsbad asked the National Park Service to develop the cave for tourists [In my opinion, this development pressure would not exist if the people leading the exploration had been discreet about their discoveries and had not sought publicity and glory outside the caving community; but alas, it is too late to act wisely about publicity for Lechuguilla.] If the cave were developed, it would require roads, trails, elevator shafts. All these "improvements" would come at great financial expense and would have deleterious effects on the cave environment. Probably ninety-five per cent of the tourists who would like to see Lechuguilla Cave would be satisfied with viewing the cave using cave visualization as I have outlined in this paper.

Conclusions. For a few, very special caves where the demand to visit the cave is high, but the cave is very fragile, cave scenes projected onto a dome might be an attractive alternative to commercialization. The scenes would be computer images based on a voxel database. A single member of the audience could control which sections of the cave to explore and which features to examine in detail. To the audience, the images would look realistic in every way.

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DISCUSSION OF WEFER'S "THE COMPUTERIZATION OF THE CAVE MAP" AND "A NORTH ARROW AND SCALE FOR STAGE-4 CAVE MAPS"

by John Ganter

In a couple of recent articles Wefer (1989a, b) traces the development of cave "maps" through four stages, and presents a "north/scale" device for what he calls Stage-4 Cave Maps. While this conceptual overview is welcome, I believe Fred leaps over some important distinctions between traditional maps and what might be better termed "models" or "representations."

More Stages

Wefer's (1989a) theme is the distinction between what he terms Stage-3 and Stage-4 maps. Stage-3 maps are what we have traditionally drawn: ink or other physical stuff adhering to a surface of mylar, paper, etc. Stage-4 maps are similar, except they are what Moellering (1984) might call "virtual maps." They are visible as pixels on a computer screen, and thus can be manipulated easily since this involves only algorithms operating on stored data. We can change variables like color and fill pattern with ease. This takes us most of the way down Wefer's Table 1 (p. 10), and I have no argument with it. These are the sort of things one can do with a paint or drawing package on any PC, MacIntosh, etc.

Under Content in Table 1, the distinction is between fixed content in Stage-3 vs. Stage-4 where "content can change, disappear, and reappear, at the option of the viewer." On the surface this seems reasonable. But how computerized is this cartography? Let me pose this question: what if we wanted to instantly change our Stage-4 map so that it used AMCS instead of NSS symbols? It wouldn't work. The reason is that Wefer's Stage-4 map has a "surface structure" of symbols (lines, polygons, etc.) but no "deep structure" of features (walls, mudbanks, breakdown, pools, etc.) We would have to go through and redraw every symbol.

This deep and surface structure can be a huge problem in some contexts. For example, the US national mapping program wants to store digital data that can be accessed by many agencies, each of whom have their own desires for symbols or "surface structure." This is a big problem, and a lot of work has been put into it (e.g. NDCDSC 1988).

So maybe there should be another stage or substage in Wefer's scheme. This would include "maps" that have a more extensive database containing information about the features in the cave. When the map was displayed, these would be linked to other stored information which would supply the chosen symbol.

The other comment that I have concerns the Viewing heading in Table 1. So far, we have been talking about Stage-4 "flat" maps, albeit virtual ones that may have symbols drawn on various "layers" corresponding to certain passages or perhaps elevation. If you attempt to transform these maps in 3-dimensional space, they project to lines. But Wefer says there is more to Stage-4, that they can "viewed" in any 3D direction. They can apparently represent volume.

It seems to me that at least one stage has been skipped completely. We have "paint maps" on a PC, and "draw maps" with AutoCAD or FreeHand, and solid or volume models all dumped into Stage-4. There are some big differences here.

Wefer's 1983 video was of a line plot in 3D space. It did not really have any "symbols," although the lines were colored according to their elevations. There were no walls or floors or stalactites or mudbanks. As I have suggested before (Ganter 1989b), line plots are not really "maps" because they only have one symbol.

But then Wefer (1989b, p. 11) shows us a most interesting "Stage-4 cave map" which is a digital sculpture! It is in 3-space, and obviously encloses a volume with not polygons but polyhedra. What happened to symbols? That thing is not a map, it is what I would call a "representation" (Ganter 1989a). It is mimetic. It looks like what it represents. Wefer has left symbolism and thus mapping.

The reason he has is that caves really are not that well-suited to symbolization. They are not a country or a state -- they are human-scaled. We represent caves the way an architect draws a house, not the way a cartographer maps a house. This is why I have always been so bored by the perennial "Standard Cave Map Symbols" wars. I don't draw symbols, I draw caves. Semi-symbolically.

What will happen if Fred decides to show features inside his cave? Will he use realistic or abstract symbols? (Figure 1, from Ganter 1986). Let's say he chooses the popular 'Y' for a stalactite. Will it be converted to a sort of 3D funnel so that it looks right when viewed from any angle?

The obvious alternative (or next step) is for it to be drawn realistically. In this case we will truly have left mapping and entered representation. We will also need the skills of a painter and sculptor. Stereo viewing will be helpful as well. (Try to construct a common object in AutoCAD Release 10 or Swivel 3D on the MacIntosh).

So I think there really have to be some more stages added to Wefer's classification. There are big differences between digital representations and digital maps, even though they all appear as pixels on graphics screens, etc.

The User Chooses

In his design for a "north/scale" Wefer (1989b), reviews various bar scales and north arrows. As his examples illustrate, the variation is large. In most cases, these devices are identical only in regional reports (e.g. books) where one mapper has done the work, or a small group has worked together.

In his listing of "characteristics of good" north arrows and scales (p. 3-4), Wefer neglects to mention their other roles. These devices are part of the distinctive style, the signature, of every mapper. This is important. It helps the viewer to identify the mapper. It also reflects the "art" in cartography, the need to make expressive statements. I can spot a Fred Wefer map, from 1968 or 1990, from a mile away. While I, like Fred, favor austerity in design, I see no need to prescribe what others do.

People like to customize their tools and their products. Every Mac or workstation "desktop" is set up differently by the user. Newer software is allowing the user to customize further. Wefer has designed an excellent default "north/scale." If ICM were to leave the lab and be used by the community, it would be natural to allow customization.

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Rivalry Error in Two-eyed Suunto Sightings

by Roger V. Bartholomew NSS 9349

In an article "Use One Eye With the Suunto", Compass & Tape,V.6, #2, Fall 1988, Pgs. 16-20, I presented data and an explanation of the origin of a systematic error which several cave surveyors had observed when the Suunto compass was sighted with the two-eyed method and I proposed the following name for this error: rivalry error.

The purpose of this article is to present additional experimental results gathered in the early summer of 1989 which support and further clarify my earlier conclusions. These results were presented at the Survey and Cartography Session at the 1989 N.S.S. Convention in Sewanee, TN.

If two eyes are used to sight the Suunto compass as the manufacturer recommends, "so that the hairline [seen by one eye] is superimposed on the target" [seen by the other eye] there will always be, with only one exception, what I shall call a rivalry error in the azimuth reading. The only exception occurs when the target is about 2 feet from the Suunto at the exact location of the virtual image of the hairline caused by the Suunto eyepiece lens.

Normally, each eye converges to the same object which is at about the same distance from each eye. In most two-eyed Suunto sightings, the human binocular vision system is forced to superimpose images of two different objects, hairline and target station, each located at different distances from the eye. This causes a rivalry over which eye's image will control the convergence angle of the optic axes of the eyes. This is because each eye tends to make the other eye converge to the same point on which it is focusing. This misuse of the human binocular vision system causes rivalry error because the compass has to be rotated slightly off the correct bearing to superimpose the target and the hairline.

Heterophoria, a biological condition, can cause another type of azimuth error which may increase or decrease rivalry error but heterophoria is not the cause of rivalry error. The manufacturer's caution about heterophoria errors is correct but no mention is made of rivalry type errors in the two-eyed method.

Dominance of one eye in controlling convergence will also increase or decrease rivalry error but dominance is not the cause of rivalry error.

In the following graph, the zero error line represents the compass reading made by the one-eye method of sighting the Suunto. The solid lines represent the two-eyed sighting method recommended by the manufacturer where I tried to obtain a relaxed superimposition of the two images. Each point on the zero error line and on the solid line represents the average of about four readings. For all measurements the Suunto was tripod mounted.

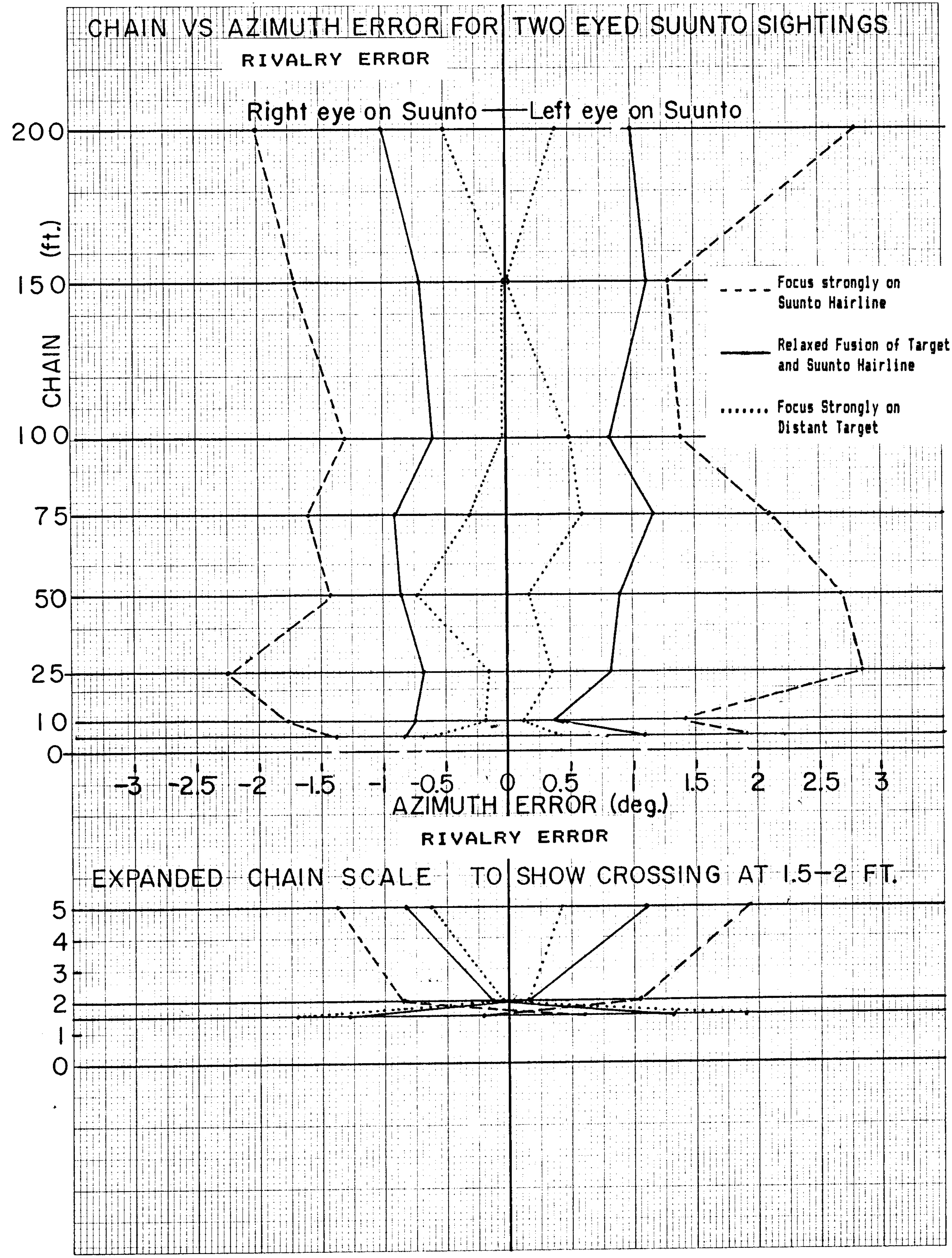
At each chain distance I could deliberately cause a wider range of rivalry errors by abandoning a relaxed fusion of target and hairline and either focusing stronger on the target (dotted line) or stronger on the Suunto hairline and scale (dashed line).

The rivalry error reverses when the chain is below 1.5 to 2 feet, the location of the virtual image of the Suunto hairline, because the target is closer to the Suunto case than the virtual image of the hairline.

With my left eye on the Suunto, a greater rivalry resulted than with my right eye on the Suunto which may indicate that my left eye is dominant. This may indicate that dominance can slightly effect rivalry error but it is not the cause of rivalry error.

It can be concluded that when the target is not about 2 feet from the Suunto all two-eyed sightings of the Suunto will always have a systematic rivalry error. If the left eye is on the Suunto, the rivalry error will cause the compass to be pointed to the right of the target which causes the bearing to be greater than it should be. If the right eye is an the Suunto, the rivalry error will cause the Suunto to be pointed to the left of the target which causes the bearing to be less than it should be. The magnitude of the error will be from 1/2 to 1 degree for relaxed two-eyed sighting. But the more strongly one focuses on the Suunto scale the greater will be the rivalry error. During hand held sightings where the scale is not well illuminated and the eye has to focus more strongly on the scale more rivalry error may be introduced.

One practical result of a rivalry error graph would be to correct the far extreme of a loop or a line survey. Rivalry error will cancel out around a loop, but it causes the far extreme of the loop to be in error. Suppose a surface survey from one cave entrance to another was made with a transit, Brunton or a Suunto sighted with the one eye method which causes no rivalry error and suppose the cave survey was made with a Suunto sighted with the two-eyed method and it was known what eye was used on the Suunto. If the instrument man measures the rivalry error for that eye at each chain distance used in the survey, these could be used to correct the cave survey for the systematic rivalry error. Then a loop-closure routine can be used to further refine the survey.


CHAIN VS AZIMUTH ERROR FOR TWO EYED SUUNTO SIGHTINGS
RIVALRY ERROR
Right eye on Suunto — Left eye on Suunto
CHAIN (ft.)
200
150
100
75
50
25
10
0
Focus strongly on Suunto Hairline
Relaxed Fusion of Target and Suunto Hairline
Focus Strongly on Distant Target
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
AZIMUTH ERROR (deg.)
RIVALRY ERROR
EXPANDED CHAIN SCALE TO SHOW CROSSING AT 1.5–2 FT.
5
4
3
2
1
0

Past Medal Winners of the NSS' Cartographic Salon

compiled by George Dasher

Year	Convention	Cave	Medal Winner
1978	New Braunfels, Texas	Natural Bridge Caverns, Texas	Orion Knox
1979	Pittsfield, Massachusetts	Williams' Cave, Virginia	Ward Fueller
1980	Saint Paul, Minnesota	Hoya de Quital, Mexico	Peter Sprouse
1981	Bowling Green, Kentucky	Grotte de Reclere, Switzerland	Remy Wagner
	(International Congress) (tie)	Natural Bridge Caverns, Texas	Orion Knox
1982	Bend, Oregon	No Medal Awarded	
1983	Elkins, West Virginia	Nikki Anada, New Guinea	Carol Vesley
1984	Sheridan, Wyoming	Nambawan Ananda, New Guinea	Carol Vesley
1985	Frankfort, Kentucky	Corinth Church Cave, Kentucky	John Ganter
1986	Tularosa, New Mexico	Sotano de San Marcos, Mexico	Peter Sprouse
1987	Sault Saint Marie, Michigan	Buckeye Creek Cave, W. Virginia	George Dasher
1988	Hot Springs, South Dakota	Dunco Springs Cave, Jamaica	Mike Futrell
1989	Sewanee, Tennessee	Cave Spring Cave, Virginia	Tom Spina

Surveying Tips and Techniques

by Tom Kaye

Cave surveying, I find, has many local variations in technique. There are many ways of handling the problems we encounter, even though the basic equipment we use is the same. There is a lot that is controversial, we all know. There is also a reluctance to adopt the surveying ideas of others; this is euphemistically called the NIH problem; 'not invented here'. Despite these little problems, I want to share a few minor techniques I have seen and used. Hopefully, some of you will be willing to share some of your tips and techniques with the rest of us for publication in upcoming issues of the Compass & Tape.

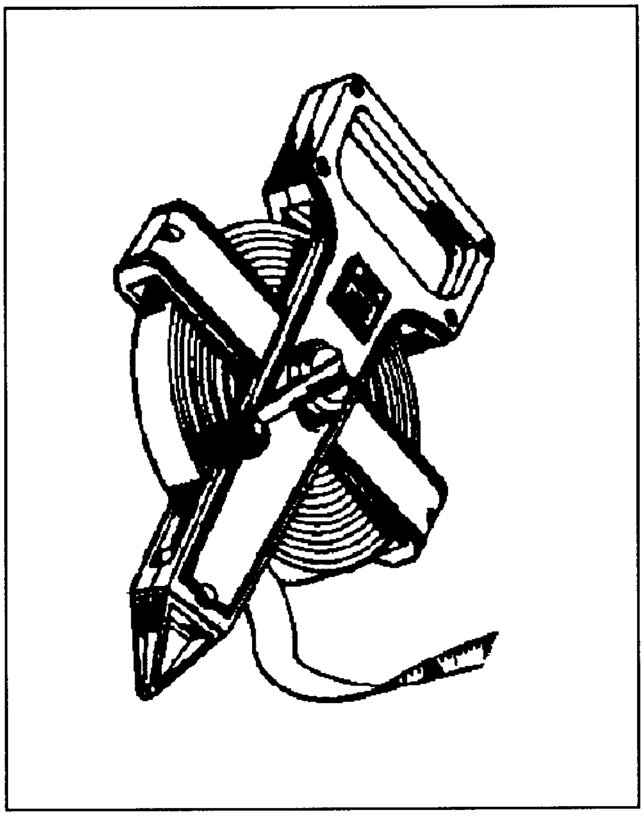
1. Station marking - we use lumber crayon. It is sold in country hardware stores and looks like a fat hexagonal crayon. I think its composition is some kind of hard wax. The favorite color among us is red. The yellow has been tried, but it is surprisingly much less visible in a cave, even by a colorblind person. The crayon marks appear to have a far more limited lifespan than carbide station marks. In a cave we surveyed a few years ago, I looked for our station markings. I only saw one or two, and they were almost completely dispersed. The stuff seems to break up into minute pieces, spread out, and fall off. (It is probably being bio-degraded by something.) Carbide marks from another group several years before that are still plainly readable. Another advantage is that a lumber crayon affords much more writing control than a carbide lamp; you can get by with much smaller stations. I hate those gross four- inch circles that some people make with carbide!

2. Yellow rubber covers for Suuntos (and Sistecos). These are not cheap, but they allow you to get rid of those pesky snap cases. What an improvement! By the way, if you use the snap cases, put the hole for the cord in the bottom of the case instead of the top.

3. Silicone those suuntos. Even if you only go in dry caves, the dust gets in and sticks to the glass inside. Use clear bathroom silicone caulk on both the lens and the window of the instruments. Excess can be rubbed off the glass with a jacknife and q-tip, so don't worry about that. I usually clean most of the excess off about 2 hours after application when the consistency is favorable. I once made the mistake of forcing 409 cleaner into a Suunto to clean it. It cleaned it well, but also cleaned the ink out of the sighting hairline!

4. Colored sighting lights. We tried a little L.E.D. with a 9-volt battery for placing on a station as a target. It was neat, but the deep red light was somehow not conducive for sighting. A much better trick is to put a slip of red or pink ordinary survey ribbon behind a Techna light's lens. You never have to ask "well, which light is it?" with one of these on station!

5. Magnetic inspection. Check all unfamiliar glasses and penlights for magnetic problems before going into a cave. Most penlights need calibration as to the minimum distance they must be from the compass when in use.



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