# No News from Stratigraphic Computing?

Irmela Herzog

**Abstract** - What are the issues stratigraphic computing has to deal with? This is a personal view presenting the features of my program Stratify and highlighting trends and aspects that have been discussed in recent publications.
Each Harris diagram program has to store its data, either in a data base, or in dynamic structures like linked lists or resizeable arrays. Data storage is the basis of all stratigraphic computing, and with a data base, it is easy to perform simple queries, copy operations, etc.. Of course, the Harris diagram software must create a layout, it is desirable that it minimises crossings, and is capable of dealing with groups and phases. One may want to enter data in one's own data base and import it into the Harris diagram program later, and probably export the layout results. In my opinion, the most important aspect in Harris diagram computing is dating: The chronological relationships do not result in an unambiguous relative chronology, and therefore additional information must be taken into account to assist the reconstruction of the chronological sequence.

## Introduction

Stratigraphic computing has a long history. Only one year after the first publication of the Harris matrix concepts by Edward Harris (HARRIS 1975a), a computer program had already been developed which assisted the creation of the Harris diagram (BISHOP/WILCOCK 1976). At that time, Edward Harris was against the use of the computer for Harris diagram layout (HARRIS 1975b), but he later changed his opinion. In the 1980s, three new computer programs dealing with Harris diagrams were developed. There may be more, but these are the programs that came to my notice: GAMP (DAY 1987), Gnet (RYAN 1988), and Orpheus/Delilah (WILLIAMS 1989). Gnet was updated several times, the final completely reprogrammed version 4 was released in 1995, and therefore Gnet is included again in the list of newcomers in the 1990s, which comprises at least seven computer programs dealing with the layout of stratigraphic data: Harris (HERZOG/SCOLLAR 1990), Posar (SHARON 1995), Gnet (RYAN 1995), ArchEd (HUNDACK et al. 1998), Ade (ANCONA et al. 1998), P.E.T.R.A. (CRESCIOLI/NICCOLUCCI 1998), and Tempo (HOLST 1999). Some of these programs were part of an integrated excavation recording system (Ade, P.E.T.R.A.). ArchEd probably is still the most popular of these programs; the last update of ArchEd dates back to April 2003. In the current decade, another three programs arrived on the scene: Proleg Stratigraf (2001?), Stratify (HERZOG 2004a), and jnet/Strat (DAY et al. 2005). Considering the fairly constant rate of new programs per decade, it seems that there is a continuing interest in creating new stratigraphic software.
What are the issues stratigraphic computing has to deal with? I will give a personal view in presenting the features of my program Stratify (www.stratify.org) and highlighting trends and aspects that have been discussed in recent publications (Fig. 1).

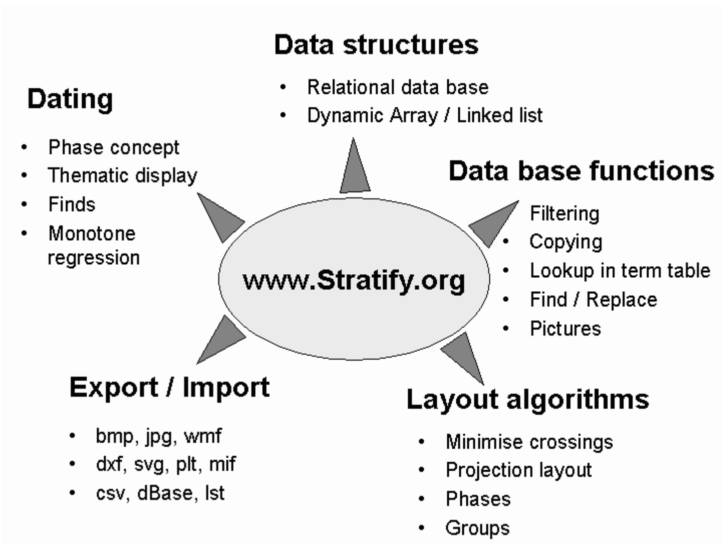


Fig. 1 - Mind map showing the main features of Stratify that are discussed in this paper.

## Data Structures and Data Base

Let us look at these aspects in more detail: A data base can store, sort, copy, and query or filter data. It is very comfortable for the programmer that these features are readily available "off the shelf". Stratify is based on the free data base system that is part of the Delphi development environment. Unfortunately, this data base system is fairly slow, and therefore I had to switch to dynamic arrays and linked lists in some crucial parts of the layout algorithm. These data structures are less flexible but very fast. The bottleneck now is the time needed to read out the data from the data base and to store the results.

Recent developments in the new Stratify version 1.4 are data base functions to set a default value for a specific field, and to search and replace field entries. These two new features were suggested by Andrew Wilson (Oxford), they are useful in the phase construction process: Firstly, all contexts are assigned to a default phase ("none"), then the units belonging to the first phase are identified starting at the bottom of the diagram, and so on. If it becomes apparent that an additional phase is needed before a certain phase, phases can be renamed so that the numerical sequence of the phases remains intact.
In addition, it will be possible to establish a link to digital photographs or other images which can then be shown in the Stratify environment.

## Layout

The layout of the Harris diagram is of course the eye-catcher. The layout can be subdivided into three tasks: Assigning level lines to the contexts, sorting the contexts within the level lines, and adding the relationship lines. The first job can be done easily, but the result might not comply with the true chronological sequence – I will return to this issue later. The most popular algorithm for sorting the contexts within a level line is the Sugiyama method (KAUFMANN/WAGNER 2001, 103-104) also known as the barycenter heuristic. This algorithm attempts to reduce the number of crossings of the relationship lines since the diagram can best be understood when the number of crossings is low. It is well-known that there is no algorithm that can find the optimal solution to this problem within reasonable time, therefore heuristic methods such as the Sugiyama method have to be applied. An alternative is the PQ-tree layout (DI BATTISTA/NARDELLI 1988) used in my previous Harris program (HERZOG/SCOLLAR 1991). The latter ensures that the diagram is drawn without crossings whenever possible. I am tempted to add the PQ-tree layout to Stratify as an alternative. An additional method for reducing the number of crossings is the edge concentration technique (KAUFMANN/WAGNER 2001, 110-111) which is similar to the H-structure detection described in HERZOG (1993). For example, in Fig. 2, group G6, the three contexts 241, 242, and 243 are all later than 244, 245, and 246. The picture would become more readable if a point was included below 241, 242, and 243, to which the relationship lines from above and below are connected. This technique has the disadvantage that an additional level line has to be inserted for each concentrated relationship bundle. Moreover, it is then no longer possible to show different types of relationships with different styles, a feature which might be included in a future version of Stratify. To me, it appears to be more important to improve diagram readability, so the edge concentration technique is on my agenda for Stratify.
Both the Sugiyama method and the PQ-tree layout determine only the sequence of the contexts on the level lines. The location of the contexts on the level line is calculated by an algorithm suggested by SANDER (1996), which includes an iterative balancing procedure. This balancing procedure is fairly slow because it

still relies on data base functions, therefore I restrict the number of balancing iterations; more iterations would certainly produce a more satisfying result. Finally the relationship lines are positioned, and I am aware that there are some imperfections in this part of the layout.

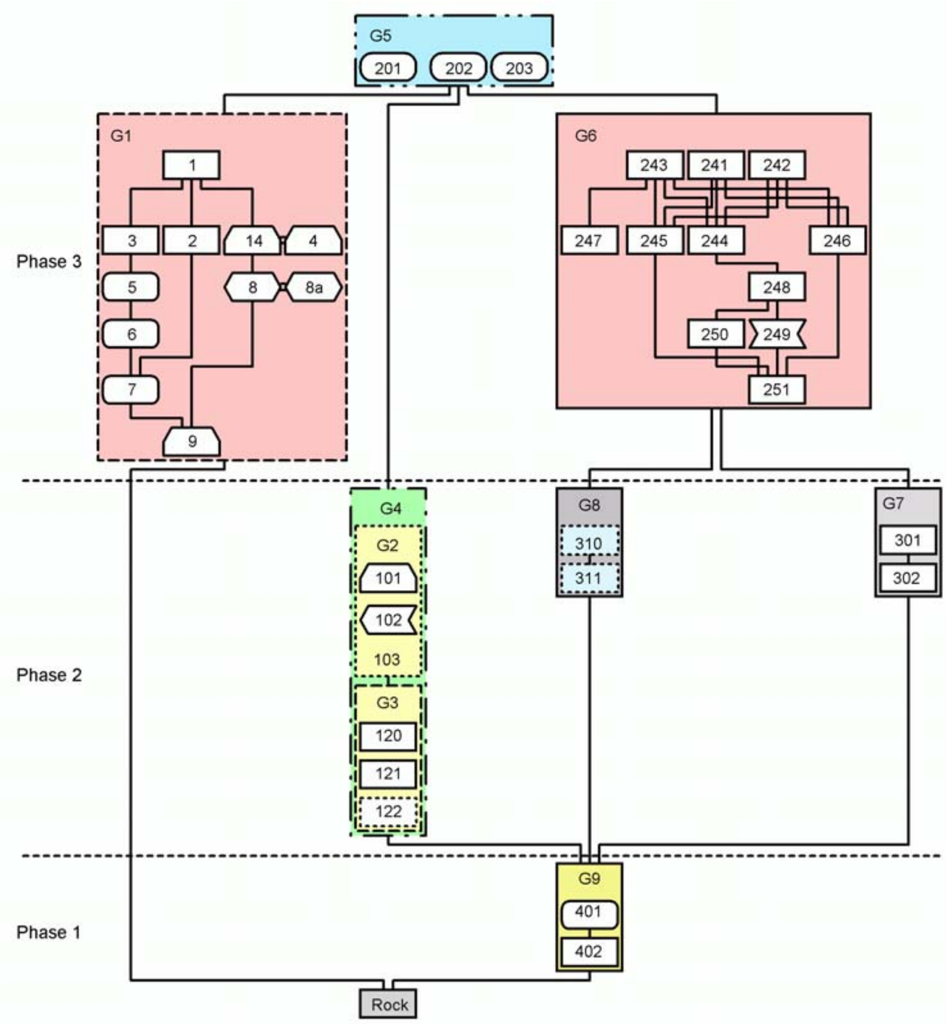


Fig. 2 - Sample Harris diagram with groups and phases. Several border styles for different context types are shown.

A further layout technique is based on the centre coordinates of the contexts. These context centres are projected onto a plane which corresponds to a section of the excavation, and the projected context centres determine the horizontal sequence in the Harris diagram (HERZOG 2001). So the layout takes the physical position of the contexts into account as is done when laying out the diagram manually. My experience with simulated data shows that this layout is more compact than the Sugiyama layout.

An alternative to automatic diagram layout is manual positioning of the context boxes with a graph editor. As far as I am aware, the first program supporting this feature was an early version of Gnet (RYAN 1988). Arched allows the user to position the layers manually in the data entry phase, but can also create an automatic layout. The disadvantages of the graph editor approach were discussed in another paper (HERZOG 2001). Using Arched, it is possible to position a layer above a later layer, so that the relationship line points in a direction opposite to that in a normal Harris diagram. The two layers connected with a “later than”-relationship may be set on one level line as well, without any warning from the Arched program.

Applying such a graph editor one can never be sure that the resulting diagram complies with the stratigraphic relationships. In Arched, only automatic layout ensures that a proper Harris diagram is generated. Then however, the contexts' horizontal positions entered by the user are not retained. Nevertheless, the success of Arched suggests that users like to have some control over the positioning of the contexts in the diagram. It is possible to include restrictions concerning the horizontal sequence of the contexts in the layout procedure. The use of such constraints has been discussed in the graph layout literature for more than 40 years (PAULISCH 1993, p. 45-53) but has not yet been applied for automatic Harris diagram layout.

### Dimensions

The projection layout discussed above ignores the height coordinates, the line levels are calculated by the traditional method. Projection layout is based on three-dimensional data, the centre positions of the contexts without heights and the line levels. This raises the question as to the dimensions of the Harris diagram. Most importantly, the aim of stratigraphic analysis is to create a relative chronological sequence, time is the first and foremost dimension (HARRIS 1975a, p. 113). Those who claim to add the temporal dimension to the matrix might not have understood the method at all (Proleg Matrixbuilder 2005: “Proleg MatrixBuilder builds the stratigraphic sequence adding the temporal dimension to the matrix.”). According to HARRIS, BROWN III, and BROWN (1993, p. 198), there are four dimensions in the matrix: the 3D context and its chronological level. But the traditional Harris matrix is drawn as a 2D graph on a sheet of paper. As 3D comes closer to 4D there have been attempts for quite a time to add at least one dimension to the traditional Harris diagram.

Indeed, the earliest reference to combining 3D recording and stratigraphic data I know of dates back to 1989 (ALVEY 1989). 3D recording becomes more and more popular and most archaeologists believe that stratigraphic relationships can be deduced from the 3D model: “Once a model of the excavation has been obtained, then we can use the model to obtain an stratigraphic matrix in 3D, which gives much more information than standard approaches.” (BARCELO et al. 2001). “The capability for automatically generating Harris Matrices ... from 3D stratigraphy data lifts the stratigraphic component from being a purely visual instrument to being an integrated research tool.“ (GREEN 2001). In my view, it is not quite as easy as these quotations suggest to reconstruct the stratigraphic sequence from the 3D model. I will deal with this point in more detail when considering GIS (below). David BIBBY (2001) called for as system that includes three elements: CAD, data base, and Harris diagram software, integrated in such a way that a change or insertion of a context is immediately visible in all three elements. He presented a system (ArchaeoCAD) which consists of an archaeological CAD application linked with a data base, and the relevant data base fields can be exported to ArchEd; the graphic output of this stratigraphic software is then reimported into the ArcheoCAD environment. Recently, a working group including Nick Ryan came to the conclusion that the Harris diagram and the 3D recording provide different, but complementary, benefits in the analysis of an archaeological excavation (DAY et al. 2005). This working group presented a first attempt to link the Harris diagram with the 3D recorded contexts.

Another way to deal with the 4D stratigraphic data was proposed by RYAN in 1988: He suggested a method using three-dimensional stratigraphic diagrams, with the x- and y-coordinates representing the position of the centre of the context, whereas the z-coordinate is provided by the relative position in the stratigraphic sequence. Here 3D boxes would be drawn rather than 2D rectangles. I am not aware of any publication which uses this approach, but the idea was taken up by Bogdan BOBOWSKI in his paper presented at the CAA Conference in Tomar, Portugal (2005). His working group is creating software showing the 3D stratigraphic diagram with standard VRML techniques. One disadvantage of this approach is that the 3D diagram cannot be printed but has to be attached in digital form to the excavation report. The recommendation is to use this technique only for small portions of the diagram, as things become increasingly confusing as the 3D diagram gets larger.

### GIS and stratigraphic diagrams

For the last couple of years, one of the most popular subjects in computer archaeology has been geographic information systems (GIS). So it comes as no surprise that archaeologists try to combine GIS and stratigraphic computing. Edward Harris himself pointed out at the 2001 Vienna Workshop that with GIS methods it is possible "to reconstruct the landscape history and topographical evolution of any site" (HARRIS 2001). A disadvantage is that most GIS systems are not yet capable of dealing with 3D data adequately. In his presentation Harris focused on the importance of surfaces. However, when looking at the examples given in the papers dealing with 3D recording combined with stratigraphy, no interfaces or surfaces are explicitly shown, although stratigraphic units of this type account for a significant proportion of a proper stratigraphic data set. Only DONEUS and NEUBAUER (2004) point out the importance of these features in a GIS environment. Since interfaces or surfaces can be represented as digital terrain models (i.e. curved 2D objects), they can be more easily recorded in a GIS environment than can true 3D solid layers.
In my view, the most fascinating combination of GIS and stratigraphy was presented by Peter JABLONKA (2000, 2003): He assumes that all the contexts on a Harris diagram level were created simultaneously and shows them in one plan. Starting at the earliest level, a sequence of plans for each level shows the development of the site, and the resulting film helps to detect errors in the reconstructed chronology of the contexts.

### Phases and Groups

At the very beginning in the very first Harris diagrams published (HARRIS 1975a, p. 117), phase separations, i.e. horizontal lines across the Harris diagram, were shown, but even today one finds stratigraphic software that cannot handle phases. I have presented a concept for phases in another paper (HERZOG 2004a). In addition, I consider constructing an intelligent "phase-guesser" that helps in assigning phases to contexts on the basis of some model contexts with phase specifications.

Stratify supports the layout of groups of contexts (Fig. 2), i.e. contexts that belong together are shown in one rectangular frame. I have presented the method before (HERZOG 2004a), and I am aware that there are more refined methods for creating group layout. However, most of the other programs available for stratigraphic computing do not provide a group layout capability at all.

### Export / Import

In summer 2004, I spent some time creating graphic export formats and learned a lot in the process. Shortly afterwards, Andrew Wilson suggested using shapes other than just rectangles, so I added hexagons, rounded rectangles and some other shapes (examples are shown in Fig. 2). But then I had to go back to my export formats to adjust them accordingly. Scalable vector graphics (SVG) and MapInfo Interchange Format

(MIF) are fairly simple formats, Hewlett Packard Graphic Language (HPGL) and AutoCAD DXF required more effort. The basis of my AutoCAD export was the AutoCAD 2002 documentation on the Internet (Autodesk 2001) and some introductory web pages dealing with the DXF format. As I was not willing to buy AutoCAD just to test the output, a free viewer program (www.bravaviewer.com) was used. After the release of Stratify 1.3 which provides DXF export, a user told me that AutoCAD was not able to import this format, though MapInfo could import the DXF format created by Stratify. Hopefully this problem will be fixed in the new version, and after the new version has become available, nearly every user can export the layout result to a format which is readable by his or her preferred graphic software.

Currently, there are two user groups: University based archaeologists use the program for data entry whereas the staff of excavation units normally have their own recording data bases and want to import their data into Stratify. For the latter group I added options for importing dBase and csv files. So I hope that with the new version Stratify user Julien Denis' prophecy (sent in a very long mail full of suggestions in June 2004) will come true: "the more the people will be able to import their own data in Stratify, the more they will use it". Double stratigraphic input will no longer be necessary and most of the descriptive information is available in the program used for stratigraphic analysis, as David BIBBY (2001) requested.

### Dating

Some archaeologists believe that the Harris diagram is the unambiguous, logically consistent solution to the problem of reconstructing relative chronology. But as early as 1980, Clive ORTON (p. 67) pointed out that the Harris diagram is a visualisation of a partially ordered set. As the expression *partially ordered* implies, the stratigraphic relationship network does not establish a unique relative chronological sequence. Therefore, Orton discussed possibilities to add find information to the diagram (chapter "The Relationship between Stratigraphy and the Finds", p. 74-80). Edward HARRIS coined the term *multilinear stratigraphic sequences* in 1984, alluding to the fact that several parallel strands of contexts are present in a Harris diagram which has no fixed chronological sequence. At the Vienna Workshop in 2002 David BIBBY discussed the immense number of valid chronological sequences for a stratigraphic data set. So dating is a very important issue in stratigraphic computing: It is necessary to fix the multilinear stratigraphic sequences in time.

Several methods can be applied to ensure that the Harris diagram reconstructs the true historical sequence as exactly as possible. I already referred to the phase concept which is used to introduce additional knowledge about the chronology in the diagram. Tentative phases can be shown via thematic display (HERZOG 2001). Thematic diagrams may also highlight other aspects, for example context types like deposits or surfaces, or the physical altitude of the contexts.

Traditionally, archaeologists analyse finds to date features, either using some sort of typology, or refittings or other knowledge. I still hesitate to add a finds data base to the Stratify data structures, and would like to discuss this issue with users (HERZOG 2004b). In the past several approaches were published to include finds information in the chronological sequence, and it depends on the data set which of these is applicable. ORTON (1980) discusses three problems in connection with the inclusion of finds in the stratigraphic analysis: "The possibility that finds may be residual" (p. 74), "some layers will simply not contain enough finds […] for a statistical approach to be valid" (p. 78), and "differences in function of different parts of the site could mask the chronological pattern” (p. 78). In my view, there is no generally applicable solution to these problems. Individual examination of the stratigraphic data set will be necessary to identify the appropriate method for including finds in the stratigraphic analysis.

When refitting stone tools and flakes to a core, a small Harris diagram can be created that reflects the chronological sequence of tool and flake production: The outer pieces were knapped off first, while the core is deposited at the very end of the process. When dealing with such data sets, the stratigraphic relationships induced by the knapping-sequence should be embedded in the total stratigraphic relationship set. Again, inconsistencies in the relationship network must be resolved.
Sherds from one pot found in different contexts suggest that either these contexts are contemporary or residual material is present in some of the contexts.

Monotone regression is a method that works with absolute dates or date intervals. It calculates new dates that are as close as possible (in a least squares sense) to the initial dates and makes sure that the new dates do not contradict the stratigraphic sequence. The algorithm is able to handle missing values and can be calculated iteratively, but does not always result in the optimal solution. The error has however been fairly low in initial experiments. The method has been adapted by Jürgen HANSOHM (2004) for archaeological data, but additional test data is needed to evaluate it properly.

Constrained correspondence analysis (CCA) may be applied in another situation: If only few stratigraphic relationships are recorded and most of the contexts can be considered as seriatable assemblages, CCA calculates a seriation result that takes stratigraphic relationships and absolute dates into account (GROENEN/POBLOME 2003, POBLOME/GROENEN 2003).

Another approach involving the inclusion of additional dating information in the stratigraphic analysis was presented by Caitlin Buck. She applies Bayes statistics to combine stratigraphic data with radiocarbon dating (BUCK et al. 1996, 190-192) and claims (2004, p. 1) that the “[Bayesian statistical] framework was ideally suited to the integration of chronological information – in particular stratigraphic sequences and historical or absolute dating evidence”. The papers cited in connection with this quotation were all co-authored by Buck, and it seems that no other working group took up this method. The Bayesian approach is mathematically and computationally complex, and this deters me from using Bayesian methods for the time being.

Dating has some other aspects that can be investigated further: HARRIS (1975a, p. 113) stated that each layer represents an event in time. When the duration of the event is short, the context in the Harris matrix can be considered as a point in time and this is often done in practice. In fact there are time spans involved, therefore Carver suggested in 1979 a sequence diagram with the length of the boxes representing the relative time of the contexts (according to ROSKAMS 2001, p. 264). This way of displaying the results of stratigraphic analysis is mainly used for the “land use diagram” which shows groups of contexts in a black box display, i.e. the contexts within the groups are omitted.
Mads Kähler HOLST (2004) proposed to analyse both the creation and end event for each context. These two events can be represented by separate context boxes, and some users of the Harris diagram have applied this method in cases when the time spans involved had been long, though they did not create a

formal framework for this kind of event. Holst created such a formal framework which is based on 15 types of relationships between two contexts, taking their creation and end event into account. For example, a relationship of the “directional continuity” type means that the creation event of one context is contemporary with the end event of the second context. According to Holst, after introducing the new relationships chronological sorting becomes an NP-complete problem, i.e. there is no efficient algorithm to calculate the optimal sequence, instead heuristic methods like simulated annealing have to be applied.

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