THE HARRIS MATRIX COMPOSER - A NEW TOOL TO MANAGE ARCHAEOLOGICAL STRATIGRAPHY

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ABSTRACT:

The Harris Matrix - formulated by Dr. Edward C. Harris in 1973 - is the established way of representing the archaeological stratigraphy of an excavation. The Harris Matrix is a sequential diagram defining relations between stratigraphic units. It is an important method to document the stratification that is destroyed by the excavation process and hence a vital tool for analysis. Although the Harris Matrix has become a quasi standard of archaeological stratigraphy, only a few software tools exist to create and edit these diagrams. An evaluation of these tools showed that they do not completely comply with the theory or suffer from poor usability. Therefore we decided to develop a new application, called Harris Matrix Composer (HMC). Dr. Harris was involved in the evaluation of early prototypes to guarantee compliance with his theory. User tests were undertaken to address usability problems. The HMC provides a graph editor with an intuitive graphical user interface for editing a Harris Matrix throughout the entire excavation process. It supports valid Harris Matrix creation and indicates invalid units and relations. The theory has been extended to allow for temporal relations as well. Furthermore units can be grouped into structural entities called phases and into periods, assigning them to a historical epoch. A powerful interface to the GIS system ArcGIS will be developed to access layers for visualization and analysis by selecting units of the Harris Matrix. In this way the HMC becomes also a unique tool for the management and retrieval of digital archaeological data.

1. INTRODUCTION

1.1 Archaeological Stratigraphy

Every archaeological site is stratified and any archaeological stratification is unique. Stratigraphy, the description and interpretation of stratification, is the main key for any further analysis of archaeological finds. Excavation is both costly and destructive. The recording process, which takes place during excavation aims at dividing the stratification into its components, the units of stratification. This is done by removing single deposits in the reverse order to which they were formed. Any unit of stratification has to be destroyed as the excavation proceeds to the next one. It is therefore absolutely necessary to document each stratification unit by recording its physical and spatial properties and stratigraphic relations, while collecting finds and samples in relation to it as accurately as possible (Neubauer, W., 2007).

The stratigraphic excavation method, as defined by E.C. Harris (Harris, E.C., 1989) makes it possible to record the single units of stratification (i.e. deposits and surfaces) along with all its attributes and relations, and to create a stratigraphic sequence from this data. Such a sequence is known as Harris Matrix (Figure 1). As Harris points out, every unit of stratification is formed by material (deposits) and immaterial aspects (surfaces or interfaces) that have to be found and recorded by the excavating archaeologist.

In the first instance these two aspects are the main objects to be recorded on a stratigraphic excavation. Any finds, samples, or other information and observations have to be related to the deposits and surfaces, i.e. the units of stratification, for the subsequent analysis.

The Harris Matrix is the fundamental diagrammatic representation of time for an archaeological site. It displays all uniquely numbered units of stratification in a sequential diagram, which represents their temporal succession. It provides the relative calendar which is the testing pattern for any further analysis.

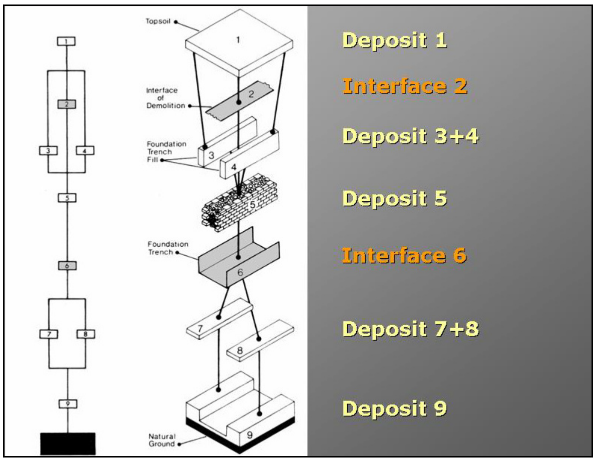

Figure 1: Creation of a stratigraphic sequence as defined by E.C. Harris 1989.

1.2 Stratigraphic Recording

Terrestrial laser scanners combined with digital imagery are the most effective tools for stratigraphic recording to date and provide the ability to reconstruct the excavated volumes and specific surfaces in 3D space (Neubauer, W., 2007; Doneus, M. & Neubauer, W., 2005a). Therefore, 3D recording of the top and the bottom surface of any single deposit, as well as the 3D recording of specific interfacial surfaces is necessary to reconstruct fully any part of a site destroyed during the process of excavation (Neubauer, W., 2008a).

Figure 2 (left) shows the terrestrial laser scanner Riegl LMS Z420i on scanner platform (Riegl, 2008) at 4.5 m height monitoring the stratigraphic excavation process at Schwarzenbach, Austria (Doneus, M. & Neubauer, W., 2005b). Figure 2 (right) shows the triangulated and textured virtual model of four successive top surfaces of excavated deposits and scatter of categorized finds spots.

During recording every single unit – surface or deposit – is given a unique number and documented by its boundary polygon, as well as its topography. The collected point-clouds from specific surfaces, the surfaces of deposits and the associated texture derived from digital photographs are the primary raw data and processed in a Geographical Information System (GIS). In that way the geo-referenced data is immediately available for on-site analysis (Neubauer, W. & Doneus, M., 2008).

Surfaces, the immaterial aspect of stratification, can therefore be captured in their entirety. By their nature, the material aspects of deposits can only be captured by sampling. For the stratigraphic record, each deposit, as represented by its top and bottom surface is reduced to a unique number in the Harris Matrix. It imparts this number to all of the portable finds and samples found within its volume. Their 3D position can be easily defined upon discovery or extraction. All additional attributable data, such as descriptions of surfaces and deposits and the finds database are integrated into the GIS.

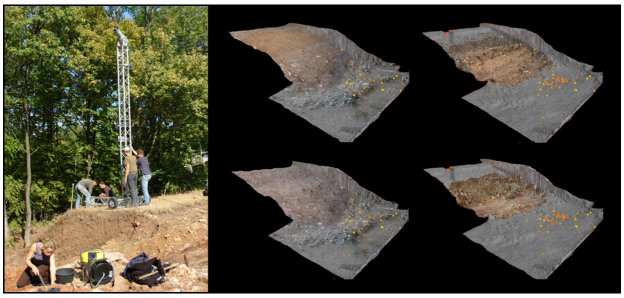

Figure 2: Recording of surfaces with a laser scanner.

1.3 Creating and Editing a Harris Matrix

As GIS provides the ability to store, visualise and analyse graphical information in combination with descriptive information, it is a perfect general tool for the visualization and analysis of excavation results. The outstanding value of a GIS is its ability to reproduce the complete record of a stratigraphic surface as well as any related descriptive information (Doneus, M., Neubauer, W., Studnicka, N., 2003; Harris, E.C., 2001).

The stratigraphic recording of an excavation as described above results in a vast volume of digital archaeological data. This data needs to be ordered by setting the correct stratigraphic relations. GIS do not provide such a feature. Usually it just allows arranging data sets into a tree-like hierarchy that has nothing to do with stratigraphic relations.

The Harris Matrix is de facto the standard method of defining stratigraphic relations. Thus a tool is needed that allows creation and editing of a Harris Matrix during stratigraphic recording. This tool can then be used to provide the GIS with the necessary stratigraphic relations and to manage digital archaeological data stored by it in a meaningful way for analysis.

Since no tool is available that completely complies with the theory of E.C. Harris (Harris, E.C., 1989), let alone provide an interface to GIS, we decided to design and develop a new one, which is called Harris Matrix Composer (HMC). This project paper describes the requirements on the HMC, the resulting design of its user interface and evaluation results.

2. REQUIREMENTS FOR A HARRIS MATRIX TOOL

Requirements have been acquired in close cooperation with archaeologists. Reported experiences with other tools have been taken into account (see next section). The practice of documenting stratigraphic relations by other means has been studied in the field, observing archaeologist on excavation sites. This revealed that a standardized method has not yet prevailed. People were filling lists of stratigraphic relations either with standard text editors or on printed templates. If these lists were later translated into Harris Matrices at all, it was done by using diagram editors or by pen and pencil, - a clear sign that an appropriate tool is still missing.

The creation of a Harris Matrix has in fact to parts. The first stage is the creation of a correct stratigraphic sequence. Units of stratification are either deposits or surfaces. Each excavation is enclosed between the top surface and the interface to geology, marking the start and end of the process. The first stage is based entirely upon the analysis of the topographical record and topology by defining the stratigraphic relations "above" and "below" or "none". The first stage is finished right after the excavation.

The second part is the division of the sequence into so called phases and periods. It depends on additional information based on structural (phase) and temporal (period) analysis of the stratigraphic record. The first stage can be done during the excavation and is not related to any find analysis. The Harris Matrix can be created without any respect to the archaeological finds. They have to be integrated in the second stage when the units of stratification are grouped according to structural or temporal arguments into phases and periods.

The creation of a Harris Matrix does not consider any temporal relations between units that might be deduced from related finds in the subsequent analysis. Stratigraphic relations imply temporal relations. But it is not possible to explicitly set temporal relations between stratigraphical unrelated units. So we proposed to extend the theory by incorporating the temporal relations "later" and "contemporary". This has been discussed with E.C. Harris and he liked the idea.

One of the most important requirements concerns usability. The tool should provide an efficient way of building up a Harris Matrix during stratigraphic recording. This implies a Graphical User Interface (GUI) that is intuitive and easy to comprehend. Familiar and well established paradigms of interaction as known from widely used drawing tools need to be considered.

The Harris Matrix is created by direct manipulation. Thereby the user should be freed from the task of doing a layout. The tool should automatically arrange the graph structure according to the theory. Most important is that the layering of units, which determines their vertical arrangement, reflects the stratigraphic sequence and thus their temporal succession. This means that all lines representing the relation “above” point from top to bottom connecting two units on different layers, which correspond to different time slots. The same is true for lines representing the temporal relation “later”, while lines representing the relation “contemporary” are bi-directional horizontal lines, because they connect units that are placed on the same layer, i.e. belonging to the same time slot.

Usually a Harris Matrix quickly becomes very large, so that sophisticated navigation methods are essential. It is necessary to zoom and pan efficiently but also provide a mechanism to jump and focus to a certain unit, phase or period. User tests with early prototypes revealed that a search function is desired. The tool should also be able to remember the locations in the matrix that has been most recently edited.

A pedagogical requirement has also been identified. The tool should support its users to create valid Harris Matrices that fully comply with the theory. Invalid relations, like cycles and invalid units, like those with missing relations are indicated and an explanation is given. This validation check helps students to better understand the concept and strengthens learning by doing. In that way it should also help to spread the method of stratigraphic excavation. The validation check is also an aid for professionals showing them mistakes or missing input. However it must not hinder users to proceed with building the stratigraphic sequence but just give them a hint that there is something to resolve to obtain a valid Harris Matrix.

The HMC needs to incorporate a direct interface to a GIS. The matrix then will be used as a GUI for the creation of composite maps and 3D reconstructions of phases and periods. Such reconstruction has often been impossible to achieve on most archaeological sites until the introduction of the Harris Matrix and the advent of GIS technology. So it is an important and valuable requirement to combine the Harris Matrix concept with GIS technology.

Concerning system requirements, the HMC needs to be computational efficient with a low memory footprint. This is because the tool will be mostly used in the field running on lightweight mobile computers. Despite that fact it must be able to handle the large graph structure of a typical Harris Matrix. It also needs to be robust and reliable. When the system crashes most of the data must be retrievable. Platform independence has been identified as desired property.

3. EVALUATION OF EXISTING TOOLS

One of the first Harris Matrix tools was included in the BASP package (Scollar, I., 1994; Scollar, I., 2008), a software bundle for archaeologist. The user interface is outdated. Stratigraphic units and their relations can only be defined by textual input. Then the tool draws a Harris Matrix with a suitable layout that can be controlled by some parameters.

Direct manipulation is not supported and so creation and editing becomes a tedious task because it is necessary to switch between the input mask and the visualisation. The tool was also restricted in the amount of data it can handle.
Because of those limitations the tool Arched was later developed based on the algorithms of the BASP Harris Matrix tool (Pouchkarev, I., Thome, S., Mutzel, P., Hundack, C., 1998; Hundack, C., Mutzel, P., Pouchkarev, I., Thome, S., 1997). ArchEd had a standard GUI and the Harris Matrix is created and edited by direct manipulation. It provides layout algorithms that can be configured.

Although ArchEd is a good approach and a clear improvement to the BASP tool, it misses to meet some of the requirements described in section 2, which are:

- It does not distinguish between the two types of stratigraphic units, surfaces and deposits.
- The top surface and interface to geology, thus the start and ending point of any valid Harris Matrix are not considered.
- Stratigraphic units cannot be assigned to phases and/or periods.
- Temporal relations are not represented in the graph structure but only as text indicators in symbols of units.
- Validity of the Harris Matrix is not checked.
- It has no interface to a GIS.

The last version of ArchEd (v1.4) was released in 2004 and since then development has been frozen. We first considered building upon ArchEd and implementing missing features. But analysis of the requirements convinced us that it is better to start from scratch. We also decided to use a professional Java library for graph drawing enabling us to develop an intuitive GUI in reasonable time.

Another well known Harris Matrix tool is Stratify by Irmela Herzog (Herzog, I., 2008). Its major drawback is that direct manipulation is not supported and display methods based on graph theory is emphasized (Herzog, I., 2004; Herzog, I., 2006). Units and their relations have to be inserted into lists from which a Harris Matrix is created. Layout techniques are sophisticated, making it possible to arrange the Harris Matrix in a way that omits or minimizes crossing of lines. Grouping of units to an arbitrary depth is supported. However, we have not identified this as an important requirement and it can easily be confused with phases and periods, which seems to provide sufficient hierarchical ordering.

Stratify focuses on chronologic relation alone. So it does not distinguish between stratigraphic and temporal relations. This is confusing because the first are established by the excavation alone and the second by analysis of the stratigraphic record. The software also seems to misinterpret the meaning of phases. It defines phases by vertically separating units, i.e. assigning them to different layers. This however is characteristic for periods, whereas phases are a structural combination of units. Phases can be contemporary with each other and then they lie on the same layer. On the other hand Stratify allows colour coding units according to the period they belong to.

Beside that Stratify does not meet some of the key requirements. It also does not distinguish between surfaces and deposits. Hence the top surface and interface to geology are not considered. And it does not provide an interface to a GIS.

4. DESIGN OF THE HMC

4.1 The Graph Editor

The heart of the HMC is the graph editor, where the Harris Matrix is composed (see Figure 3). It starts with a minimal but valid Harris Matrix, consisting of the top surface, the interface to geology and a special unit called “Unexcavated” that represents the unexcavated archaeological stratification. As long as this unit cannot be deleted without invalidating the Harris Matrix the stratigraphy is not finished.

Users add either deposits or surfaces by choosing the appropriate tool from the toolbar and clicking somewhere on the background of the graph editor. The new units automatically move to the top layer and build a sequence there, like birds on a wire. This is because their final position depends on their stratigraphic relations, which have yet to be set. Each unit of stratification except the preset top surface and the interface to geology must be set in stratigraphic relation with at least one unit above and at least one below it to be valid. As long as these relations are not set these units are marked as invalid.

To set stratigraphic relations the users draw a line with an arrow head between two units. This line represents the relation “above” and means that the unit where the line starts lies above the unit where the line points to. There is no extra tool for the relation “below” because for that the line only needs to be drawn in the opposite direction. Most invalid relations are recognized as they are drawn and declined, for example if a user tries to set a unit above the top surface. An explanation is then given in the status bar.

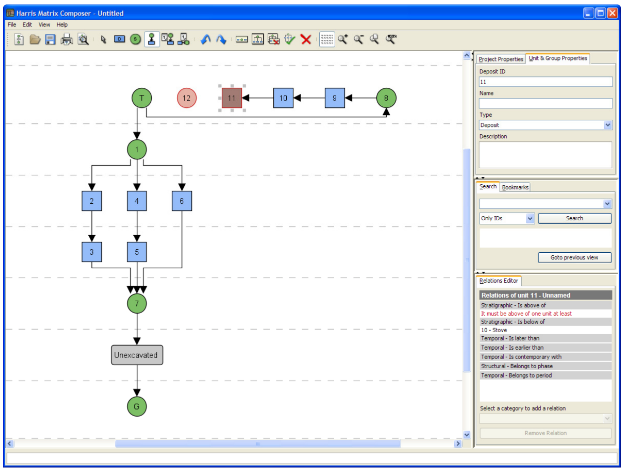

Figure 3: Composing of a Harris Matrix with the graph editor.

Other invalid or impossible relations are only recognized by analysing the whole Harris Matrix, which does not work in real time. This especially concerns transitive and cyclic lines. Users can trigger a validity check whenever they like. The Harris Matrix is then analysed using methods from graph theory. Transitive lines are automatically removed, i.e. if unit A lies above unit B and B above unit C then the relation “A above C” is transitive and redundant.

Cycles represent a physically impossible stratification because when unit A is above unit B and B above C then C cannot be above A. Cycles are detected by the validity check and the corresponding lines are marked as invalid (see Figure 4). This is a clear composing mistake and needs to be resolved by the user since the application cannot know, which line in the cycle the wrong one is. An exception are loops to the same unit, which are declined in real time and cycles between two units, in which case the direction of the line is reversed, i.e. when A lies above B and the users draws a line from B to A then this line is kept and the one from A to B is automatically removed.

The Harris Matrix can be set into a layout that complies with the theory. All units are then moved to the layer that corresponds with their stratigraphic relations. This means that all lines are vertical lines pointing from top to bottom as one would assume for the lines representing the relation “above” (see Figure 5). The layout algorithm can only be applied to a valid Harris Matrix. It cannot resolve invalid units that have missing relations or cyclic lines. Therefore validity check and layout are combined to one function.

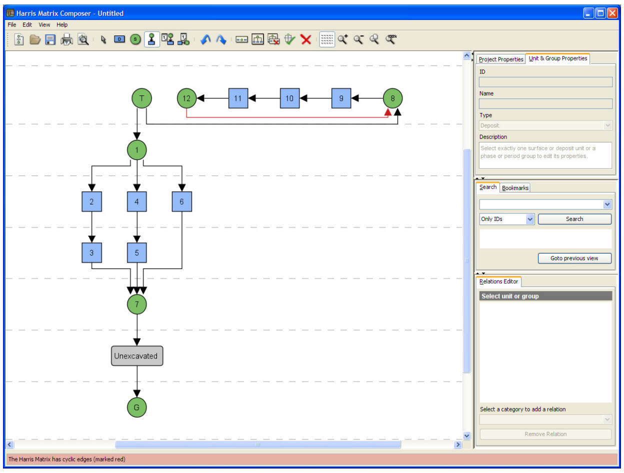

Figure 4: A cycle has been detected by the validity check and marked red.

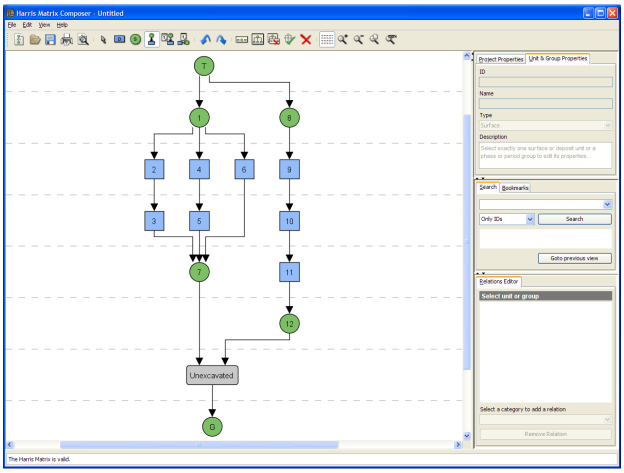

Figure 5: A valid Harris Matrix in the correct layout.

4.2 Temporal Relations

As mentioned in section 2 we extended the theory to allow explicit temporal relations. Stratigraphic relations imply temporal ones. But analysis of the stratigraphic record might yield additional, non topological arguments to define extra temporal relations between units. Users can either set a source unit to be later than a target unit or set both units as contemporary. The relation "earlier" is obtained by drawing a "later" line in the opposite direction.

Temporal relations are represented by dotted lines in a different colour. Lines meaning "later" point to the unit that is earlier than the one the line originates from. Contemporary is a bi-directional relation shown by lines with arrows at both end points (see Figure 6).

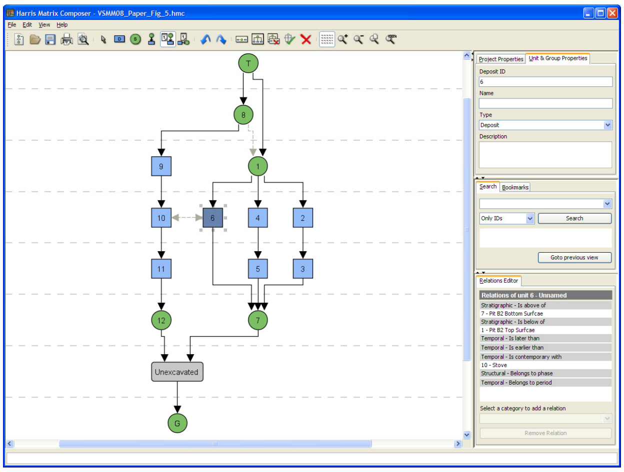

Figure 6: A Harris Matrix with temporal relations "later" and "contemporary".

Temporal relations are considered for validation and layout. They can be transitive with respect to themselves but also with respect to stratigraphic relations. Any stratigraphic relation "above" also implies the temporal relation "later". Temporal relations that are transitive in one or the other way are removed by the validity check. For example when unit A is above B and B above C then the relation "A later than C" is redundant and removed.

The temporal relation "later" has similar effects on the layout as the stratigraphic relation "above". It positions units on appropriate layers so that these lines always point from top to bottom. In contrast contemporary units are placed on the same layer so that the lines representing them are horizontal.

Like with transitivity, cycles can be caused by temporal lines with respect to themselves and to stratigraphic lines. For example if unit A is above B and B above C then C cannot be later than A. To be consistent first stratigraphic relations are checked independently and then temporal relations are checked considering also stratigraphic ones. Temporal lines can also be hidden by the user so that only stratigraphic relations are seen. In that case they do not affect validity checks or the layout.

4.3 Phases and Periods

During analysis of the stratigraphic record units might be assigned to a structure and/or to a period as described in section 2. User can select units and group them into a phase, which represents a structural entity, for example post-holes remaining from an ancient dwelling. Phases cannot be nested but can belong to periods.

Periods represent a certain historical epoch. Units and phases are assigned to a period by selecting them in the Harris Matrix and use the appropriate grouping operator. Periods cannot be nested and encompass units that lie on different layers since the vertical position also has a temporal meaning. In the current design neither phases nor periods can have any relations. They are solely defined by the stratigraphic units they contain.

Both phases and periods appear as boxes that encompass the items grouped into them (see Figure 7). These boxes can be collapsed one by one or all at once to make the Harris Matrix more compact. When collapsed their content is not shown and the group appears as small box with a label (see Figure 8). Of course each collapsed group box can be expanded again.

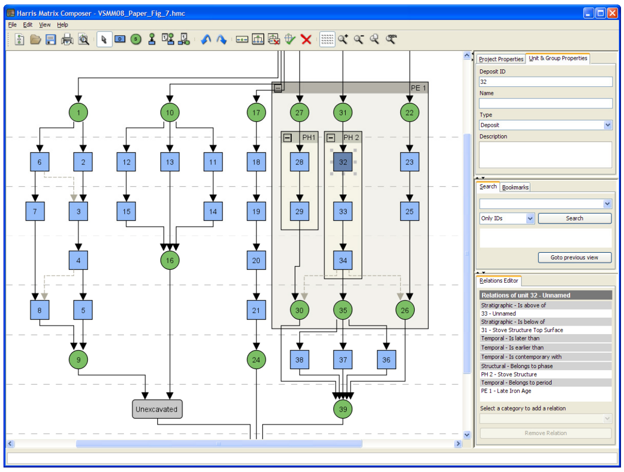

Figure 7: A Harris Matrix with phases and periods.

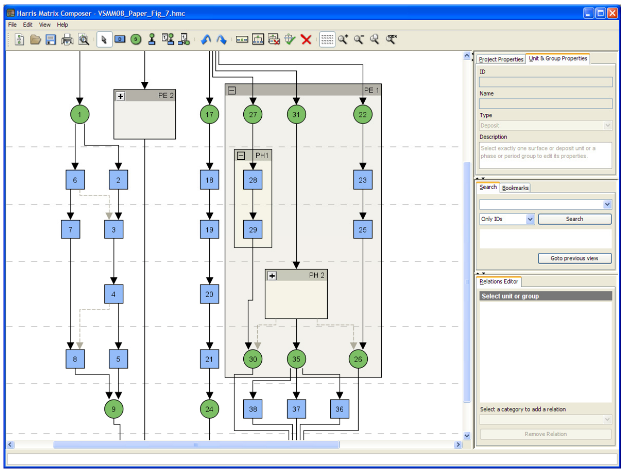

Figure 8: Collapsed phase and period boxes.

4.4 Navigation

A typical Harris Matrix is rather large. Hence efficient and convenient navigation techniques are important. There are two types of navigating through the graph structure, by direct manipulation of the graph view and by searching for units and jumping to bookmarks.

Direct navigation is achieved by panning and zooming. Panning works by dragging the mouse, which is analogue to shifting a sheet of paper with the hand. Zooming is done by the mouse wheel. Users can rapidly change to a completely different view by resetting the zoom factor so that the whole Harris Matrix is shown and then use a tool to draw a frame around that part, which should be magnified to the window's size.

A full text search can be initiated by the search panel. All the data associated with units can be searched, i.e. its id, name and description. A list of results is shown and when clicking on an item the view of the graph smoothly changes to the found unit, so that it appears in the centre in normal size.

A view can also be bookmarked and later looked up in the bookmark panel. In this way users can store interesting points or locations that are currently edited and efficiently jump between them.

4.5 The Properties Panel

The project properties editor of this panel allows naming the project, writing a description and referring to the excavation site. When a unit is selected in the Harris Matrix the panel automatically shows the unit properties editor. Here the unique identifier of units can be changed. It is set automatically while composing by using consecutive numbers. The application refuses to change the identifier if it is not set to a unique alpha-numeric value. This is important because it is used for the interfaces to GIS or external database.

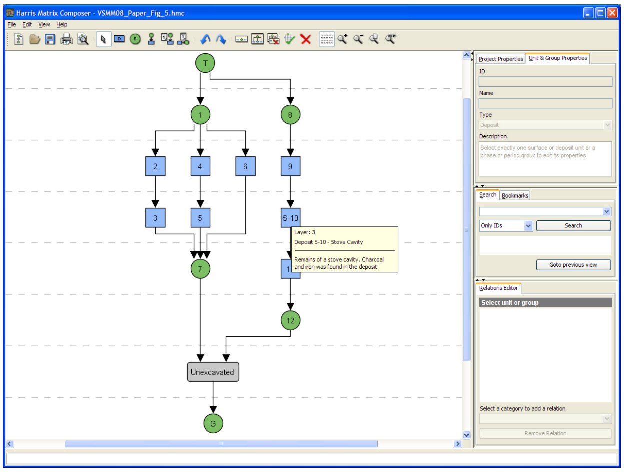

Figure 9: Properties set in the properties editor are shown in a pop-up balloon, when the mouse is moved over a unit.

Other properties for units are a name, a description and its type, namely either deposit or surface, which can also be changed by this editor. The unique id appears as label of the graphical representation of units in the graph editor. All other properties appear in a balloon when moving with the mouse over a unit (see Figure 9). Phases and periods can also be assigned a unique id, a name and a description by selecting them and using this editor.

4.6 The Relations Editor

This panel lists all relations of the selected unit, phase or period (see Figure 10). It provides an additional view beside the graph structure in form of a list. Beside the relation "above" it shows also the relations "below", which is defined implicitly, i.e. when A is set to be above B then B is implicitly set to be below A. In addition it also lists all temporal relations including "earlier" as complement to "later" and "contemporary". If the selected unit belongs to a phase and/or period then they are also shown.
The relations editor provides an alternative way to set relations. For each relation category a unit can be chosen to establish the corresponding relation between the selected unit and the chosen one. The corresponding line is then immediately drawn in the graph editor. It is also possible to delete relations in which case the corresponding line is removed. The selected unit can also be assigned to an existing phase or period by choosing it from the drop down list.

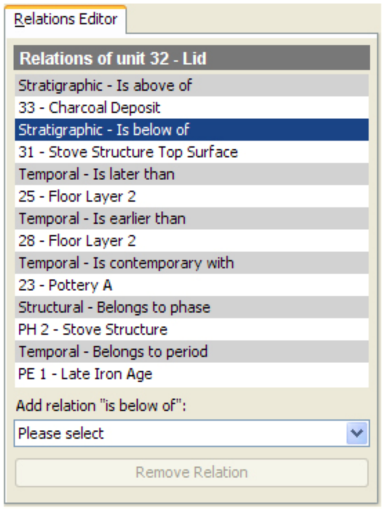

Figure 10: The relations editor showing all relations of the selected unit.

4.7 Management of Digital Archaeological Data

The HMC needs an interface to a GIS to select digital strata for visualisation and analysis. There are two ways of realising this feature. One solution is to use the HMC directly. On demand of the user it communicates with the GIS, sending selected units to it. The GIS then selects the corresponding data for visualisation.

Another solution is to derive a plug-in from the HMC that directly runs in the GIS to access digital archaeological data. It then provides an alternative to the common tree view. In that case it first loads a Harris Matrix composed by the HMC. The plug-in provides features for navigation and selection but does not allow manipulating the Harris Matrix.

5. IMPLEMENTATION AND EVALUATION

The HMC is a Java application and hence platform independent. We decided to use the very powerful Java library "yFiles" from yWorks (yWorks GmbH., 2008). It provides methods for graph editing and visualization including various layout techniques. Special classes have been designed and derived from yFiles classes to implement all the required Harris Matrix functions.

The HMC was developed by rapid prototyping. That strategy alternates between development and evaluation in several cycles. Every new version of the prototype is evaluated in user tests and the analysis of these tests guides the next phase of development. Because of our project consortium we were able to test even early prototypes on target groups, professional archaeologists and archaeology students. This was especially important to improve the usability of the tool.

One of the prototypes was also demonstrated to Dr. E.C. Harris in a small workshop in September 2007 in Bermuda, where he resides. We were glad that Dr. Harris liked our prototype very much and recommended to protect the software, which we did. We had the pleasure to discuss and refine theoretical aspects of the Harris Matrix together with its inventor. This especially concerns the extension for temporal relations, and the grouping of units into phases and periods. So the HMC fully complies with the outcome of this discussion and the theory of Dr. Harris.

The first beta version of the HMC was evaluated in a field trial for a real excavation project in Schwarzenbach, Lower Austria (Neubauer, W, 2008b). It was also used for a lab course on archaeological stratigraphy at the University of Vienna. Both tests brought new insights and revealed usability issues, which have been addressed in the following development phase.

A free trial version (beta 1.1) is available for download at the HMC website "www.harrismatrixcomposer.com". This free version is restricted to 50 stratigraphic units. Not all designed features are yet implemented. A full version will be available in November 2008.

At the time when this paper was submitted (June 2008) approximately 400 users have downloaded the free trial version. We already received valuable feedback from them, which helps us to further improve the HMC. Beside that a next large field trial is planned.

6. CONCLUSION

With the HMC a new tool for the composing and editing of a Harris Matrix has been introduced to the archaeological community. We are glad about all the positive feedback and the constructive comments we received so far. The strength of the HMC lies in its full compliance with the theory, which has been achieved in collaboration with its inventor Dr. E. C. Harris.

Another aspect is its usability, which was evaluated from the very beginning by successive user test on early prototypes. The interface to GIS makes the HMC to the ideal application for the management of digital archaeological data and thereby closes a gap in the software toolbox for archaeologist. The HMC will be directly used to access data in the GIS for visualization and analysis by selecting stratigraphic units in the Harris Matrix.

Further feedback of users and field trials will improve and extend the HMC so that a reliable and robust tool emerges. We hope it will gain high acceptance in the archaeological community. We also think that it is very well suited for the training of students in courses and labs. If so, it will foster the practice of stratigraphic excavation.

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