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Original article

Spatiotemporal data as the foundation of an archaeological stratigraphy extraction and management system

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Transforming relations between stratigraphic units of an archaeological excavation to a formal model like the Harris Matrix is a challenging task. Especially when the number of stratigraphic units is large or when spatiotemporal relations are complex, such models are difficult to generate. This paper describes a novel procedure for the automated construction of Harris Matrices involving the use of open source database software programs and tools. The procedure is based on an algorithm for the detection of spatial relations between stratigraphic units. For each stratigraphic unit (represented by commonly available 2D polygons), all possible top-down spatial relations are defined. These large series of relations are then iteratively validated, retaining a limited number of topological coherent sequences. These relations are required for the definition of stratigraphic sequences. To facilitate the presentation of resulting sequences, a stratigraphic diagram is incorporated into a graphical user interface on top of a geodatabase management system and web feature service (WFS). This interface is supplemented with attributes of each stratigraphic unit and with a virtual representation in an embedded 2D map viewer and 3D viewer. The link between sequences and cartographic representations of stratigraphic units by the underlying system enables interactions between various elements of the dataset while taking into account 2D and 3D spatial information, stratigraphic relations and attribute displays. Three theoretical datasets are used to develop and test the workflow. Furthermore, a reference dataset is used to validate this workflow. We find that expert knowledge remains indispensable for the interpretation and validation of both data sources and results. Nevertheless, the robustness of the results of this study illustrate the potential of the proposed procedure for use in automated Harris Matrix construction based on sequences of stratigraphic unit polygons. In employing this procedure, systems may facilitate the management of archaeological (spatiotemporal) data in cost- and time-efficient research infrastructures.

1. Research aims

This paper elaborates on the transformation of 2D polygons of stratigraphic units to a formal representation. An automated procedure for the construction of Harris Matrices serves as a clear overview of an archaeological excavation while retaining spatiotemporal complexities of a site. While manually composing Harris Matrices for stratigraphic sequences is common practice, it is a time-consuming and challenging approach. The proposed procedure should overcome this issue through the iterative top-down validation of all possible spatial relations between each stratigraphic unit. Furthermore, the integration of a formal site model with cartographic, semantic and virtual representations of each stratigraphic unit will facilitate the interpretation of various features and phenomena of excavations as well as generating a stronger understanding of scenes as a whole.

To summarize, the main goals of this research study are:

- to develop a methodology for the automated reconstruction of Harris Matrices based on a series of 2D polygons of stratigraphic units;

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- to define a set of validation rules for the evaluation of candidate relations between different stratigraphic units;
- to implement a user interface on top of an open source geo-database management system and web feature service (WFS) to facilitate interactions with and visualizations of the formal model.

2. Introduction

As archaeological excavations are destructive by nature, detailed and accurate documentation involving the use of rapid registration techniques is of paramount importance. An emphasis on data recording has been reinforced on one hand by the rise of contract archaeology and by its associated time pressures [1] and by the widespread use of digital recording and 3D acquisition systems on the other [2,3]. This form of data recording affects future interpretations of excavations [4], which are mainly designed to reconstruct site formations through the removal of soil components [5,6]. These components, which can be identified via observable discontinuities in shapes, colours, textures, etc. [6–8], form a "temporal trajectory" [8]. Such components are recorded not only semantically and topographically but also topologically using spatial relations (e.g., "above", "below", "none" and "equal") [6,9,10]. These spatial associations are respectively translated into the following temporal topological relations: "younger than", "older than", "unknown" and "contemporaneous". The latter allows for the creation of stratigraphic sequences, which are typically graphically depicted via the Harris Matrix [10]. This analysis tool first employs information recorded in the field and then removes all superfluous information (e.g., exact locations and redundant relations) to arrive at a directed graph that represents a chronological succession [10,11].

In taking into account intensifying time pressures, computer tools can assist in the time-efficient documentation of archaeological stratigraphy [2,3,12]. Tools that document archaeological stratigraphy have been created since the Harris Matrix was first developed in the 1970s [6,11,13,14]. Most tools start from textually recorded stratigraphic relations between deposits and interfaces. Graph editing techniques in combination with consistency checks form the main features of these applications. Although spatial data on stratigraphic units are recorded during excavation [5] and constitute the primary information source for the creation of the Harris Matrix, it is surprising that they are not used or linked to in any of these tools. As a result, both the automated construction of the Harris Matrix and explicit correlations between the matrix and excavation plans are absent in current practice. An exception is the Harris Matrix Composer developed by Traxler and Neubauer [6], who created a GIS link to allow for the management of digital archaeological data for analysis. Another link between spatial information and the Harris Matrix can be found in the management system developed by Stal et al. [12] for the Greek site of Thorikos. In this system, a static Harris Matrix constitutes an interaction link between user and management features including 3D reconstruction models, map interfaces and metadata [12]. These two studies illustrate the advantages of using a combination of stratigraphic and spatial information. Furthermore, this integrated approach facilitates the further management and analysis of archaeological information.

This paper determines how spatial relations can serve as the basis for the automatic creation of a Harris Matrix and how this automated process can be incorporated into a user-friendly management system. In the remainder of this paper, the requirements of a stratigraphic management system are outlined. The proposed methodology is presented in section 4, and then the results are presented and discussed in Sections 5 and 6, respectively. The paper is concluded in Section 7.

3. Requirements of a user-friendly archaeological stratigraphic management system

As a variety of Harris Matrix tools have been developed, it is necessary for the management system proposed in this paper to incorporate all functionalities that have proven to be promising while preventing or even ameliorating drawbacks. Therefore, an outline of the requirements of an archaeological stratigraphic management system is given, partly based on requirements listed by Traxler and Neubauer [6] and based on parameters of the evaluation of the system developed by Stal et al. [12].

The composed Harris Matrix must first be pursuant to theory. This has implications on both layout and validity outcomes. In regards to layout configurations, Harris Matrixes depict the archaeological stratigraphy along a vertical axis, where the uppermost and thus newest layer is placed on the top of the diagram directly underneath the upper surface and where the geological interface forms the bottom layer [6]. Stratigraphic units that are contemporary are placed on the same vertical level, where equal layers are connected by a double horizontal line. The 'later than' (and equally 'earlier than') stratigraphic relation is transitive and irreflexive [13], resulting in the need to remove superfluous relations and to prevent cycles, respectively. The 'contemporary with' relation is transitive, symmetric and reflexive [13]. Properties of these relations must form the bases for a validity check of the created Harris Matrix in the proposed tool.

To facilitate user interactions with the system, direct diagram manipulation is preferred [6]. However, the layout, including validity checks and based on conventional symbology, should be constructed by the system. Furthermore, a user should be able to zoom and pan to navigate the Harris Matrix [6]. Due to the geographical nature of archaeological data, a connection with GIS should be made available to support a spatial overview of the matrix while enabling spatiotemporal analyses [3,5,15]. In turn, the system can function as a simplified variant of a 4D archaeological GIS. Furthermore, a dynamic overview map and linkage to an excavation database may facilitate the management of information while improving insights gained [12].

A final feature of the tool involves the facility to assign stratigraphic units to phases and periods, which are structural entities and historical epochs, respectively. These manipulations of the initial Harris Matrix, which is only based on topographic and topologic information [10:115], are produced from additional information on artefacts or from more detailed structural or temporal analyses [6,10:115].

4. Methodology

To determine whether spatial relations can support Harris Matrix creation, four theoretical examples of various complexity are used, as presented by Harris [10:39] (Fig. 1) and Bibby [16:106] (Fig. 2). In this study, it is assumed that every stratigraphic unit is topographically recorded during excavation and that each is given a unique identifier [6]. Furthermore, Barceló et al.'s [8] method is adopted to strictly consider spatial information of the upper plane of the stratigraphic unit, as the stratigraphic unit is at the bottom bounded by another stratigraphic unit. In turn, the four examples are digitalized, where contemporary polygons are stored within the same layer.

As this paper focuses on the use of spatial information in the creation and management of stratigraphy, a geodatabase is used as a central element in the proposed tool. According to De Roo et al. [15], this database allows for extendibility towards a complete archaeological data management, research and policy infrastructure. Given growing demands for cost-efficient recording, free and open source