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SCHEMATA – 3D CLASSIFICATION METHODS AND ARCHAEOLOGICAL IDENTIFICATION CRITERIA. AN INTERDISCIPLINARY COLLABORATION USING THE EXAMPLE OF ANCIENT TERRACOTTA STATUETTES

MARTIN LANGNER, ALEXANDER ZECKEY, LUCIE BÖTTGER

ABSTRACT | Both in the field of applied computer science and in disciplines dealing with material artefacts, three-dimensional objects with complex shapes are inadequately classified. Archaeologists are confronted with the problem that resemblance in shape can be recognized, but is difficult to adequately describe in words. Furthermore, archaeology has yet to make sufficient use of automated 3D shape recognition to differentiate the formal relationship of similar objects. A computer, however, has no problem recognizing identically shaped objects, though it has yet to learn our human perception and understanding of similarity. The goal of this project is therefore to develop procedures for automatically generating corpora using 3D pattern recognition, as well as to reflect on the associated schematizations and how they can be applied in the computer and visual sciences. This involves developing methods of object mining in 3D data. In close cooperation between computer science and archaeology, this experimental process leads to a substantial analysis of the concept of pattern recognition as a branch of the humanities. Based on 200 terracottas of the late 4th and 3rd centuries BC, which despite their similarity differ in various details, a classification system will be elaborated using digital methods and taking into account the complexity of the artefacts.

KEYWORDS | Archaeology, classification, cultural analytics, data mining, machine learning

Introduction: Connoisseurship and verbal description of the terracottas

It is well known that pictorial works act simultaneously. A multitude of visual impressions reach the recipient, who simultaneously absorbs and often unconsciously evaluates them. This evaluation is based on socio-cultural conditions, respective viewing habits and the visual stimuli generated in the picture. This large amount of information and its weighting is difficult to determine in linguistic terms, which is why experts in the appropriate field of knowledge have a certain connoisseurship. As a hermeneutical authority, the undoubted expertise of individuals has fallen into disrepute because its results can hardly be scientifically verified.[1]

At best, the reasons for the connoisseur's expertise are expressed through the medium of language, and archaeological databases annotate the images with verbal metadata. This, however, results in a double translation process, since each individual work of art must be translated into words in the form of detailed

22 JÜNGERE TYPEN.

1 Dumont-Chaplain, Les céramiques de la Grèce propre Taf. XXX. — h. 0,15 m.
b. Athen (Polytechnion 328 M. 298 und 1405). — h. 0,17 m. — Aus Tanagra.

2 British Museum 74 $\frac{11}{10}$ 107. — h. 0,15 m. — Aus Tanagra.
b. Louvre. Heuzey Taf. 25, 3. Kopf nach links gewendet, ohne Haube. Fächer in der linken Hand. — h. 0,22 m. — Aus Tanagra.
c. Paris, Musée Guimet. Nach vorn vorgebeugt, linkes Bein etwas weniger vorgestellt. — h. 0,13 m.
d. Berlin, Antiquarium 8593. Kopf abgebrochen. Ohne Basis. — h. 0,115 m. — Aus Priene.
Ähnlich: A. Athen, Centralmuseum 733. Der Mantel ist über den Kopf gezogen und fällt unten über die Kniee herüber, ähnlich wie bei der Figur S. 20 n. 3. — h. 0,19 m.
B. Ebenda 929. Ohne Haube. Nur Oberteil erhalten. — h. 0,09 m.

3 Louvre MNB 604. — h. 0,185 m. — Aus Tanagra.
b. Rouen, Coll. Bellon. Cartault, Terres cuites grecques Taf. VII 3. Kopf nach rechts gewendet, verhüllt und mit Hut. — h. 0,255 m. — Aus Tanagra.

4 Sammlung Calvert, Dardanellen. — h. 0,18 m. — Aus der Troas (Tschamlydja).

5 Athen, 1876 im Kunsthandel. — Aus Tanagra.
b. Berlin, Antiquar. 7077. Griech. Terrakotten aus Tanagra und Ephesos Taf. 10. Ohne Haube. Kopf nach links und etwas nach vorn geneigt. — h. 0,19 m. — Aus Tanagra.
c. Berlin, Sammlung des Grafen Wilhelm Pourtalès. Kekulé, Griechische Thonfiguren von Tanagra Taf. VIII. Ohne Haube. Fächer in der linken Hand. — h 0,178 m. — Aus Tanagra.
d. Athen, 1876 im Kunsthandel. Mantel über den Kopf gezogen. — Aus Tanagra.
e. Petersburg, Ermitage. Furtwängler, Sammlung Sabouroff Taf. CI. Wie c. — h. 0,21 m. — Aus Tanagra.
f. Coll. Lecuyer Taf. A 3. Kopf scheint nicht zugehörig. — h. 0,20 m. — Aus Tanagra.
g. Froehner, Coll. Gréau 1891 n. 317 Taf. XIV 1. Kopf nach links, Fächer in der linken Hand. — h. 0,156 m. — Aus Tanagra.
h. Ebenda n. 279 Taf. XV 1. Kopf nach links gewendet, ohne Haube. Die Bewegung stärker. — h. 0,20 m. — Aus Tanagra.
i. Coll. Milani 277. 278. — Ohne Haube. — h. 0,15 und 0,16 m. — Aus Tanagra.
k. British Museum. Ohne Haube. — h. 0,18 m. — Aus Rhodos (Kamiros).
l. 1893 im Kunsthandel. — h. 0,23 m. — Aus Tanagra.
m. Athen (Polytechnion 948). Kopf gradeaus. — h. 0,19 m. — Aus Tanagra.
n. Winterthur, Sammlung Imhoof-Blumer.
Ähnlich: A. Odessa, Museum. E. von Stern, Das Museum der Odessaer Gesellschaft I Taf. II 1. Kopf mit Bindenkranz, gradeaus gerichtet, aufgesetzt, Gewand am Hals geschlossen. Ähnlich, nach v. Stern, eine Figur in der Ermitage 882 A. — h. 0,24 m. — Aus Olbia.
B. Madrid. Catálogo del museo arqueológico nacional I n. 3235. Wie A, aber ohne Kranz. — h. 0,20 m. — Aus Kyrenaika.

6 Louvre. Heuzey Taf. 27 1. Gazette des Beaux-Arts 1875 II S. 63. Monuments grecs 1874 S. 8 Taf. 1 D. — h. 0,155 m. — Aus Tanagra.
b. Athen (Polytechnion 812). — h. 0,16 m. — Aus Tanagra.
c. Athen, Akropolismuseum. Kopf und Unterschenkel abgebrochen. — h. 0,095 m. — Aus Athen.

7 Athen (Polytechnion 1258). Basis z. T. modern. — h. 0,185 m. — Aus Tanagra.

8 Athen (Polytechnion 826). — h. 0,18 m. — Aus Tanagra.

Vgl. die Figuren aus Unteritalien S. 28.

Figure 1. Franz Winter; Die Typen figürlicher Terrakotten; 1903; in: Winter, Franz. Die Typen der figürlichen Terrakotten: Die antiken Terrakotten III (Berlin: Spemann, 1903), 22.

Figure 2 a–e. after Violaine Jeammet; Origine et diffusion des Tanagréennes; 2003; in: Tanagra: Mythe et Archéologie, ed. Violaine Jeammet (Paris: Réunion des musées nationaux, 2003), no. 118–120. © Museum for Fine Arts Boston; Different grades of similarity in ancient terracotta figurines.

descriptions, which must then be converted into machine-readable numerical values. In some ways, the simultaneity of visual impressions even contradicts the verbal analysis of images, which must emphasize and weight details in the order of description. This is important for the respective understanding of the image, but is contrary to its specific character.

The corpus of the ancient terracottas

In the heyday of archaeological corpus formation at the end of the 19th century, scholars set out to create a corpus of ancient terracottas. However, they quickly recognized the difficulties associated with this undertaking, since the ancient clay figures were not individual works, but rather serially manufactured products taken from molds.[2] Franz Winter was commissioned to create more of a catalog than a corpus. It was to cover all relevant types of antique clay statuettes and be as complete as possible.[3] The resulting arrangement can be seen as an early form of archaeological pattern recognition, where the "types" were represented in simplified drawings.

Without resorting to verbal descriptions of the types or even naming the differentiated categories, the catalog relied on expert knowledge and an established method of visual identification (the so-called "Vergleichendes Sehen"). Each supposed repetition was listed under a figure schema that was defined solely by a drawing (fig. 1). These schemas were called types, but not in the sense of the strict terminology established in sculpture research.[4] Furthermore, Winter investigated neither the degree of similarity nor the relationship of the repetitions to each other and to the "type".

Degrees of similarity: the coroplastic type

Ancient terracottas resemble each other to differing degrees. These degrees of resemblance can be precisely defined by archaeologists and evaluated progressively using classification procedures with different levels of precision:[5] Firstly, there are the figures taken from the same mold, which therefore exhibit an exact match. Secondly, there are the figures taken from the same patrices, which differ from the source object only in size (fig. 2a, b, c). Thirdly, there are the figures, which despite also being taken from the same mold subsequently show a changed appearance due to later additions and modifications by hand, and which therefore no longer belong to the same type (fig. 2c). Then there are the terracottas which resemble each other very closely in posture and drapery of the costume, but which nevertheless do not originate from the same mold (fig. 2d). And finally, there are those terracottas in which the same figure schema occurs in various free configurations (fig. 2e). At the craftsmanship level, it can be stated that two terracottas come from the same production. If this is not the case, however, there are still no suitable criteria for determining the similarity and its gradations.

An object mining approach analogous to text mining has yet to be tested in classical archaeology. This is the aim of the project SCHEMATA, which will adopt an application-oriented approach that also emphasizes methodological reflections. Its goal is not only to analyze procedures for automatically generating corpora using 3D pattern recognition, but also to reflect on the associated schematisations and their scholarly applications. The results will be evaluated and the procedures finely calibrated in a multi-step process. A systematic investigation of formal elements (and of the organization, identification, and interpretation of sensory information in general) could serve as a key to the development of a concept for the materialization of knowledge and visualization. Three questions being pursued in the project are of particular relevance: Can figure types be captured non-verbally using digital methods of pattern recognition and if so, to what degree of precision? To what extent is verbal reasoning terminology necessary as a means of distinguishing and differentiating between the types? Can the categories developed in archaeological style research for describing types also be used for digital procedures, or are new diacritical methods needed to replace them?

Possibilities of the third dimension: advantages of 3D acquisition

The archaeological interest in the categorization of terracottas goes hand in hand with an interest in the epistemological possibilities offered by 3D imaging and automated classification of terracottas. The acquisition, analysis and publication of historically relevant objects as 3D models offers numerous advantages for art historical and archaeological disciplines:[6]

In addition to global availability, simple and contact-free handling and unlimited replicability, the main advantage is that the perspective (obtained by rotating, zooming or juxtaposing the objects, for example) can be determined individually. Compared to common documentation methods (such as orthophotography or plaster cast), the objects become much more accessible for research. With this approach, researchers can also reproduce historical conditions (in the sense of an object biography), assign fragments to objects and reconstruct their positioning. As a result, traditional academic perspectives and analytical methods are not only enhanced, but even called into question, since the large-scale virtualization of objects in collections will generally have a significant impact on visual identification processes in historical and visual disciplines. On the one hand, the comparative visualization of similarity allows the results of formal analysis to be measured and thus objectified. On the other hand, the visual identification methods used by researchers in visual disciplines must adapt to new forms of visualization, which will lead to standardization processes grounded on new methods. Based on the methodological comparisons used in the project, the question of how archaeological research can be transformed using 3D models will be explored and captured in best practice examples.

Archaeological shape analysis and digital pattern recognition

Archaeology as a scientific discipline sees its task primarily in extracting patterns from the sum of the surviving remains of past societies, allowing conclusions to be drawn about the conditions of that time. For this reason, it has always used forms of pattern recognition to describe artifacts and images, although it has preferred the terms structural analysis, typology or seriation.[7] The question arises whether the methods of archaeological 'Formenanalyse' correlate with the corresponding methods of digital pattern recognition.

Figure 3. Acquisition of 3D-models of terracotta figurines at the Museum August Kestner, Hanover. © IfDH.

Therefore, archaeological concepts for describing similarity and machine learning techniques for classification need to be compared. The resulting discussion has two goals: On the one hand, archaeology is to be provided with non-verbal forms of description that make it possible to classify not only typological dependencies, but also other degrees of similarity, and which may provide a clearer view of the ancient perception of terracottas in terms of types, variants and motifs.

The second goal is to significantly improve the object mining process so that in the future a large percentage of the data on the objects in a collection can be automatically stored in databases. On the one hand, this will revive the somewhat deadlocked debate about types and schemas by adapting established shape recognition methods from the fields of mathematics and computer science. On the other hand, concepts of comparative visual analysis developed in visual disciplines will be applied in the field of shape recognition. This project will therefore investigate theoretical aspects of practical importance, such as a modified definition of the concept of similarity. What exactly does it mean when two shapes are similar?

Measurable characteristics of the terracottas

Form, workmanship, and function are closely related. However, traditional methods of archaeological form description and analysis, based on a summary collection of individual criteria, have proven inadequate. The degree to which identity of molds and similarity in shapes, as well as workshop traditions and tendencies of contemporary styles can be identified and distinguished from one another, is often unsatisfactory.[8]

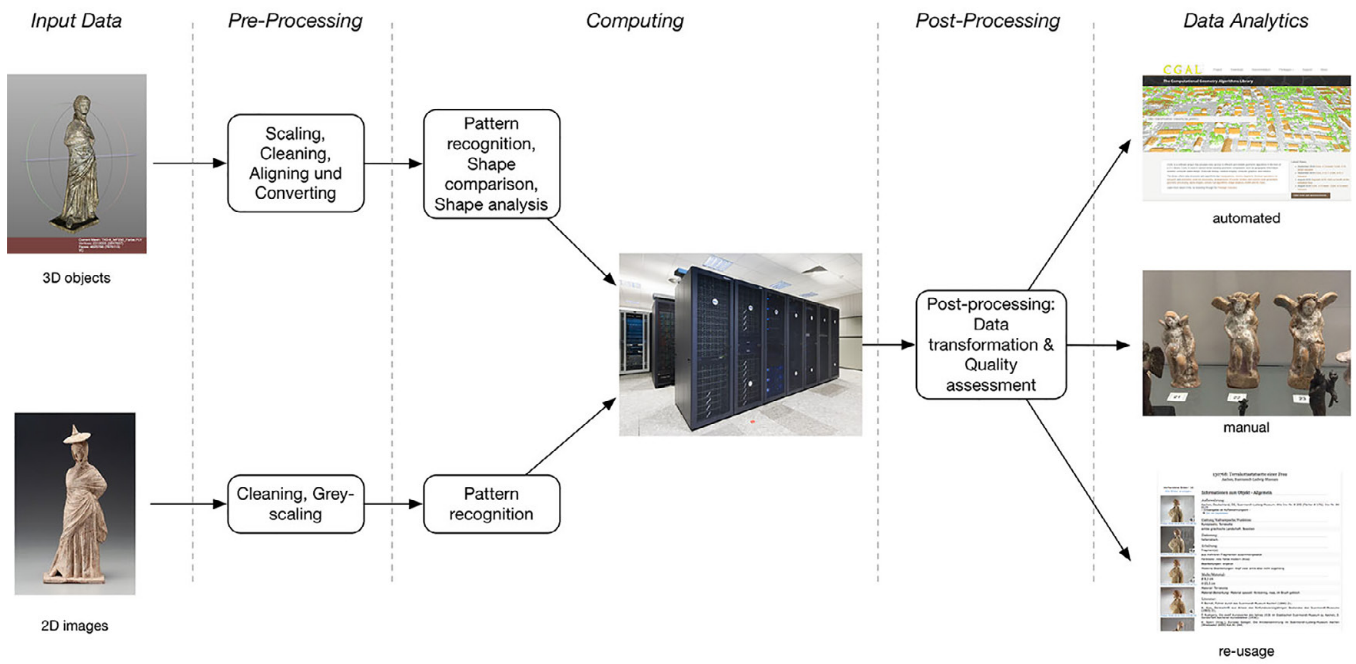

Figure 4. Data Pipeline. © IfDH.

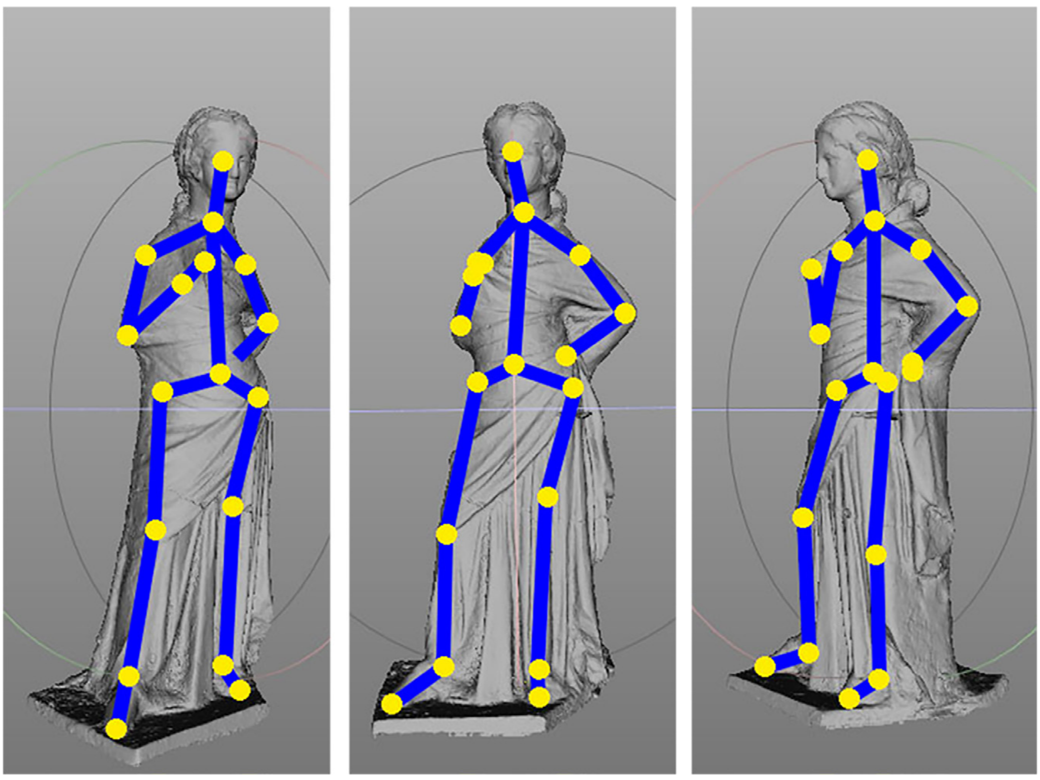

Figure 5. Ideal skeletons of a terracotta from the Göttingen collection. © IfDH.

The project therefore entails fundamental work on the standardization of acquisition processes. All information contained in an object, such as size (length, width, height, weight and mass), shape (geometry and contours, surface, volume), composition of individual elements, texture (roughness, waviness and position) and visual appearance (color variations, brightness, reflectivity, etc.) are systematically measured, documented and analyzed using computational methods. This requires collaboration between archaeologists and computer scientists to optimize the speed and smoothness of the acquisition process, as well as the accuracy and quality of the 3D models for subsequent processing by both parties. Ultimately, a corpus will be created that is as usable as possible for a wide range of applications. Until then, the 3D scans will be made accessible in a viewer that will accompany the acquisition process.

The “New Winter” as 3D Repository

Because Franz Winter’s book has established itself as a reference work, the terracottas depicted there will be used as a point of departure. In order to limit the quantity of material used in the project to a suitable amount, the project will be confined to standing female figurines of the so-called Tanagra style from early Hellenistic times.[9] Terracottas of this period were made with two or more molds and became popular burial goods. They have therefore survived in large quantities, in good condition, and in a wide variety of forms.

For our study, 200 terracotta statuettes were selected, not only because of their particular suitability due to their similarity and easy accessibility, but also because they will also provide a sufficient material basis for the ensuing investigations. To obtain suitable 3D-scans, a number of museums will be visited. The data acquisition will be carried out using a structured light scanner, which provides high-resolution 3D scans of the terracottas (fig. 3). Parallel to the data acquisition, we have begun to question the theory of the concept of type and its validity. A further sharpening of the spectrum of methods is to be expected, particularly in dealing with the theoretical discussions in other (non-classical) archaeologies.[10]

Object mining in computer science

The economic mass digitization of 3D artifacts is still an unsolved problem. Although the semantic enrichment of 3D data itself is challenging, methods of using the geometry of the 3D shape[11] for data mining are an active research area.[12] But a fast partial decomposition into simple geometric shapes[13] has so far been insufficient. Instead, suitable pattern recognition methods[14] have to be developed that link the degree of simplification and abstraction to the human way of recognizing and distinguishing patterns. Therefore, the classification of unknown objects must be evaluated and calibrated step by step. The 3D pattern recognition of the main components shape, size and color must therefore go hand in hand with suitable forms of machine learning. This is implemented in the form of a data pipeline (fig. 4), in which various procedures are developed and fine-tuned to suit the case study. This is a method which is widely used in the field of data analysis, and which is also used for Big Data applications. An input element is processed piece by piece in a series of processing steps. The data processing steps to be dealt with include pre-processing, computation, and post-processing. The goal is to extract data sets that can be used to categorize the similarity of historical art objects.[15] A repository can then be created based on the information obtained. These data can be used to find new categorizations or to link them to existing humanities categorizations as additional digital investigations.

Up to now these methods have seldom been used for the automated acquisition of artifacts, although experiments with curve recognition, for example, have already been conducted on archaeological objects. The reasons for this are, on the one hand, that there is not a sufficient number of images available as 3D models to test the applicability of these methods to any significant extent. On the other hand, works of art (as opposed to components or plants, for example) represent a great challenge to any computer-aided classification due to their high variability. The assignment of a specific instance to a more general class is much more difficult in this case, since they can differ considerably from each other in shape, size and color.

2D method: analysis of the outer contour

In the context of 2D comparisons, there are already established methods for calculating equality or, in part, similarity. These are used to calculate and compare distributions and patterns in binary and grayscale images. The 2D pattern recognition uses automated methods or manually trained data sets to find identical or similar features. For this purpose, Multiview Convolutional Neural Networks[16] are used to break down the complexity of the 3D model into the second dimension using virtual cameras. These generated 2D data are supplemented by existing object photos. In this way, for example, the outer contours of the objects can be analyzed via their geodesic distance, their depth – represented by different brightness values – or their surface distribution.

3D analysis of posture: voxelization and skeletonization

One possible approach to the analysis of 3D data, beside other methods, is a voxel-based approach, where the 3D model is compared using a logical array and different skeletonization methods (fig. 5). This is where drawn posture schemes come into play. The skeletons extracted from the object are compared with these posture schemes. This step is not only interesting for comparing the objects, but also for clarifying the difference between human and computer-based perception. After all, the manually generated comparison data in the data memory are not necessarily the only ones, since new models are to be created automatically and loaded into the data memory. Subjective influences and preferences of the researchers are removed, so that only the most numerous schemata remain, the ones also more likely to have a certain significance.

Currently, medial-axis-transformation methods are used, in which the model is reduced to its mean minimum. Also currently in progress are studies on extraction using Voronoi diagrams and topological and geometrical analyses. Such analyses use feature points and constraints in the model to determine the skeleton. Some of the results obtained so far are already useful for comparison, but have not yet reached their desired final state. The method needs to be further improved, since the figures, which are usually heavily wrapped in fabric, make it difficult for the computer to clearly recognize the corresponding body features. To compare the skeletons, procedures in the 2D and 3D range are used and supplemented by further analyses specifically used for this purpose. One of these is a backtracking search, in which the individual edges of the two skeletons to be compared are gradually compared for size ratio and angle. With this method, the different postures of the terracottas can be compared without elements of interpretive perception on the level of form alone.

Combination of different methods

In summary, various existing methods are currently being developed and evaluated in the field of shape recognition procedures, and extended primarily by means of posture comparisons, a 3D-to-2D unwrapping and a custom system with automatic extension and a weighting procedure. Thus, although all data that can feasibly be extracted are to be collected, their interpretation has to be restricted according to those weighting parameters optimized by investigation in order to obtain a suitable threshold value for defining similarity. In this way we are working on a way to determine and evaluate the degree of similarity.

Interdisciplinary collaboration: archaeological object mining

The goal of the computer science section can only be achieved in close cooperation with archaeologists.[17] In order to find suitable parameters for the algorithms to be tested, a constant review of the results by the humanities is necessary. For this purpose, joint experiments are conducted in which the framework of digital and comparative vision is checked. The aim is to determine whether or not the technical extraction of the object's features can be assigned to existing or newly developed archaeological typologies.

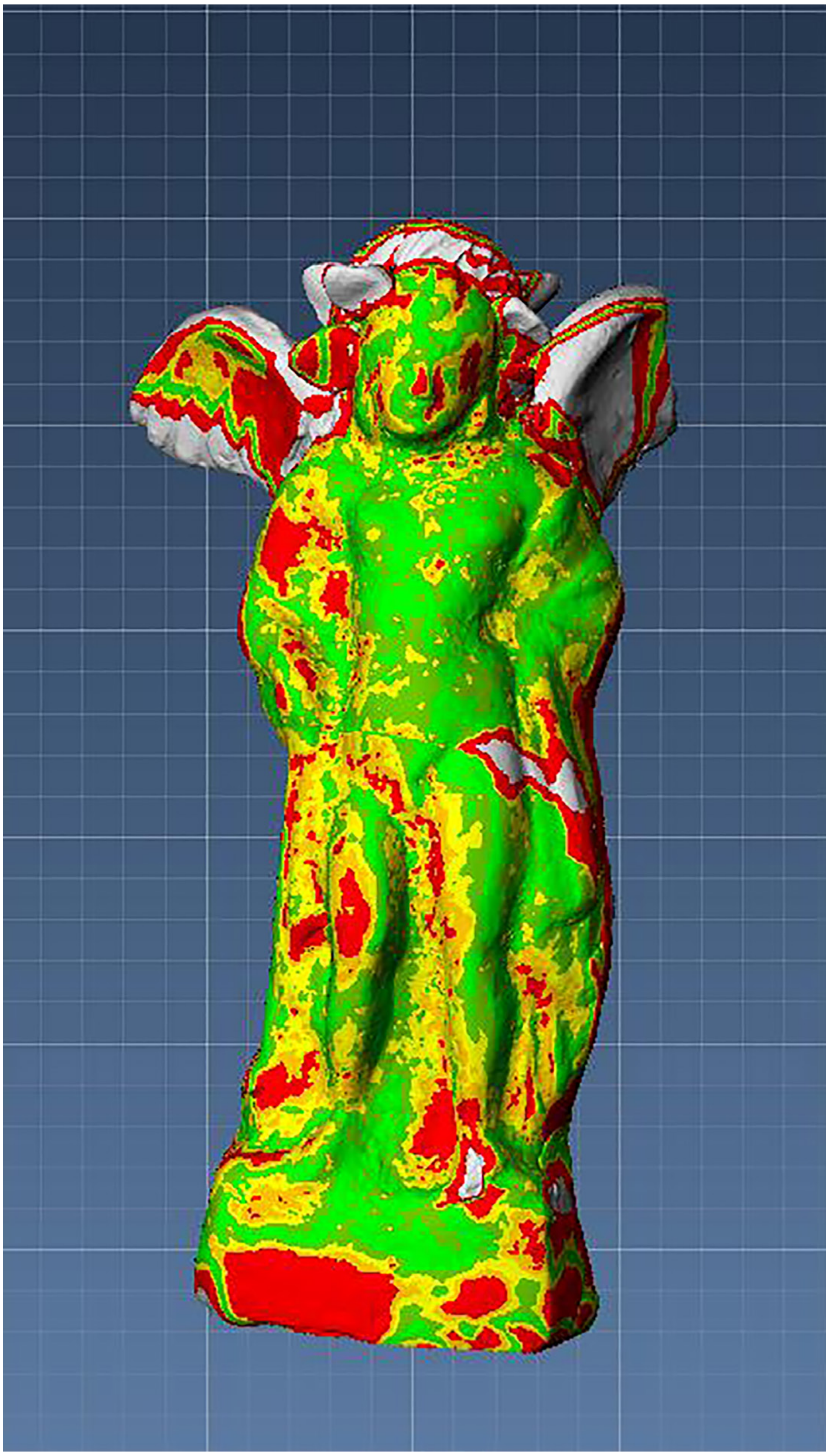

Figure 6. Best Fit Example of two terracottas from the Göttingen Collection. © IfDH.

The parameters of the algorithms are then adjusted and recalculated to improve the result using constant tuning. This includes checking to identify the extent to which the automatically extracted pattern recognition features are suitable for comparison or to determine whether or not these technical procedures will be able to match archaeological photo comparisons in the foreseeable future. This is achieved by a continuous, joint reflection of the methods on the informative value and by examining the objectivity of the algorithms. In this way it should be possible to automatically provide data for archaeologists to describe the body of an artifact, whereby the accuracy of these data must always be achieved by validating the results. In doing so, the computer science side will learn to use and improve existing methods for the automatic analysis of 2D and 3D data and to develop ideas for new ways of handling such data.

The measurement data must be checked, and standard deviations must be taken into account in order to relativize the degree of objectivity of the various methods. These must be further developed accordingly, or critically examined for their suitability. Overall, the objectivity of the methods is of great importance throughout the project. Finally, there should be object mining that automatically compares different degrees of similarity and determines the category and subcategory (or type) to which the respective artifact belongs. In archaeological and informatics analyses new similarity criteria will be defined and evaluated in both disciplines.

In addition, further considerations will take place regarding the objectivity of all the methods used in order to prove their usefulness for further procedures in the field of 2D and 3D data processing. Finally, the questions arise: Is the potential of the tools being fully exploited? Or will there be further possibilities for data extraction by analyzing the objects created from this work? Does the degree of objectivity of a technical data analysis also apply to complex works of art? Are these ultimately useful, superior or unsuitable for further investigation? And is their granularity sufficient to interpret works of art? These questions must be answered within the context of the project in order to achieve a better understanding of the possibilities of these procedures.

Semantic similarity

To classify the type of a figure, it must be divided into the three components posture, garment, and surface design. When creating a sustainable typology,[18] however, not all attributes should be treated in the same way, since their meaning may depend on individual characteristics. The semantic meaning of the figure is often determined by details such as hairstyle, attributes and headgear, which changes the meaning of the terracottas even if they come from the same mold.

These features must therefore be extracted separately. The result is a catalog of features that can be used in a statistical analysis to determine both the frequency of certain features and the popularity of their combination. On the formal level, it becomes clear which characteristics are particularly relevant for the perception of a type as a carrier of meaning. When is it a rare variant of the same motif and when is it already a new type with a different meaning? The archaeological interest in the typological classification of terracottas goes hand in hand with the interest in the research possibilities offered by 3D recording and automated classification of terracottas.

When working with the 3D models and the dimensional comparisons according to Best Fit[19] (fig. 6), impulses for methodological reflection are self-evident, since we may initially be surprised or dissatisfied with the first results. However, these impressions should be systematized and discussed together in order to analyze the consequences of their use. The main focus should concentrate on answering the following questions: To what extent is the 3D model superior to the photo series? How high is the scientific applicability of the 3D models and algorithms and how can the expressive potential of the digital tools be exploited? How does archaeological work change when forgoing a normalized view of the artifact in favor of examining the 3D model in different positions and also visual distortions? How can a standardization of the scientific documentation nevertheless be achieved? What degree of (apparent) objectivity do the 3D scans achieve? How can this be measured and challenged on a case-by-case basis?

Ensembles in graves as a source of ancient perception

The division into figure types is important not only as a method of object recovery, but also as a classification criterion for archaeological research. However, our typologies do not reflect the perception of objects in ancient times: terracottas were not made separately by type, nor were they used in groups by type. Likewise, ancient viewers used basic information such as shape, posture, and surface design to identify objects and explain the function of the figurines.[20] For this reason, the next step is to reconstruct ancient perceptions of terracottas. In order to get a clearer overview of this, it is necessary to examine the numerical popularity of certain pictorial works. The question of which connotations were associated with which types and variants remains an unfulfilled research desideratum in classical archaeology.

In the case study of this project, burial contexts with two or more similar female terracottas are understood as ensembles in which the individual figures enclosed as a set semantically complement each other. Contextual analysis of the range of variation can reveal the extent to which two similar figures in the same grave represent different aspects of the overall message of the burial inventory. Accordingly, types and variants can also be separated contextually. To this end, we have selected nearly 80 burials from excavation publications. There are about 200 terracottas in northern Greece and about 100 in Taranto which can be assigned to these burials. From their analysis, conclusions can be drawn about the special meaning of the individual figures. Thus, formal and semantic results of archaeological research, which up to now have been investigated separately, merge with each other at this point.

The impact of code-based epistemic methods on archaeology

The final analysis will again reflect the possibilities of creating archaeological typologies with digital methods, especially using 3D models and image recognition algorithms. The epistemological possibilities of working with 3D models and algorithms will come to the fore when we discuss the implications for cultural history research in general: How can meta- and paradata be meaningfully prepared and how can they be produced in such a way as to be available to the community? What is the relationship between form and content and how can we define it when working with digital models? How can the meaning of dimensional comparisons and similarity relations be determined without reintroducing structuralism and its deceptive authority through the back door? How can this proposal of objectivity be relativized and how can digital structures be extended to include historical components that can be evaluated?

Since the objects of archaeological study are digitized representations of the artifacts and not the artifacts themselves in their original material form, the question arises as to what extent code-based epistemic methods such as the object mining yet to be developed have categorically prejudiced the research question and analysis. How has the structure of technical processes influenced archaeological analysis and vice versa? And what opportunities for obtaining further knowledge through the focus on the digital and the ensuing need for algorithmic stringency remain untapped?

NOTES

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MARTIN LANGNER After studying Classical Archaeology and Classical Philology, Martin Langner received his doctorate from Cologne in 1997 with a thesis on ancient graffiti drawings. In 2012 he completed his habilitation at the Free University of Berlin on the chronology, decor and function of late red-figure vases from Athens. In 2012/13 he headed the Cologne Digital Archaeology Laboratory at the University of Cologne, before accepting the professorship for Classical Archaeology and its digital methodology at the Georg-August-Universität Göttingen in 2013. Since 2019 he has been Professor of Digital Image and Artefact Science at the Georg-August University of Göttingen and Director of the newly founded Institute for Digital Humanities. His main research areas are contextual image analysis and image pattern recognition, 3D digitisation and analysis of ancient sculpture as well as virtual museums.

Correspondence e-mail: martin.langner@uni-goettingen.de

LUCIE BÖTTGER is a research associate at the Department of Digital Humanities at Georg-August-Universität Göttingen. She studied Classical Archaeology at the Department of Archaeology at Georg-August-Universität Göttingen, where she completed her bachelor's and master's degree. During this time she worked as a student and research assistant, i.a. in the fields of collection and museum work and teaching. She also participated as an assistant in various archaeological excavations. After completing the master's program, she was accepted as a doctoral candidate at the GSGG, Georg-August-Universität Göttingen with the PhD topic "Classifications and Categorisations with Digital Methods: Consistency and Variation in the Shapes of Hellenistic Terracottas of Women" and has been working in the DFG-funded project SCHEMATA in the DFG Priority Program "The Digital Image".

Correspondence e-mail: lucie.boettger@uni-goettingen.de

ALEXANDER ZECKEY is a research associate at the Department of Digital Humanities at Georg-August-Universität Göttingen. He completed his bachelor's degree in Applied Computer Science (Embedded Systems) at Fulda University of Applied Sciences before transferring to Georg-August-University Göttingen for his master's degree. There, he continued his education in the fields of medical and neuroinformatics before choosing the specialization Digital Humanities, completing his master's degree. During this time and afterwards, he worked as a student and research assistant at the SNds Campus Laboratory Digitization, focusing on the 3D digitization of archaeological artifacts. He was accepted into the GAUSS program with the PhD topic "3D Shape Analysis of Similarities: Contributions to automated Object Mining", while now working in the DFG-funded project SCHEMATA in the DFG Priority Program "The Digital Image".

Correspondence e-mail: alexander.zeckey@uni-goettingen.de