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Short Paper

Semi-automated Annotation of Repetitive Ornaments on 3D Painted Pottery Surfaces

S. Lengauer[1], A. Komar[1], S. Karl[2], E. Trinkl[2], I. Sipiran[3], T. Schreck[1], R. Preiner[1]

[1]Institute of Computer Graphics and Knowledge Visualisation, Graz University of Technology
[2]Institute of Classics, University of Graz
[3]Department of Computer Science, University of Chile

Abstract

The creation of drawings from the surface of painted pottery artifacts is an important practice in archaeological research and documentation. Traditional approaches include manual drawings using pen and paper, either directly on the physical surface, or from photographs, while more recent approaches are supported by photography or flattening of 3D digitized objects. Elaborate vase paintings, mostly showing figural scenes, often comprise ornamental decorations in secondary position or in the background, exhibiting repetitive patterns. We propose a tool supporting the creation of archaeological drawings with a semi-automatic extraction of ornamental surface sections, based on a combination of user-defined queries and self-similarity detection. Appropriate heuristics allow to detect the presence and positions of ornamental bands, a frequently occurring scheme, where ornamental primitives are evenly spaced along the tangential direction of a vessel's solid of revolution. Our interactive tool allows domain experts to efficiently select ornamental queries, and assess the quality of resulting similarity detections. First experiments with real world artifacts from ancient Greek and Peruvian cultures confirm the feasibility of the approach.

CCS Concepts

***• Human-centered computing** → Visualization systems and tools; **• Information systems** → Specialized information retrieval; **• Computing methodologies** → Image processing; **• Applied computing** → Arts and humanities;*

1. Introduction

Graphical annotation of vase paintings – drawing in archaeological terms (Fig. 1 bottom left) – is a crucial task in the research of ancient pottery. They improve the readability of a painting and enable its in-depth analysis and interpretation, such as the painter's style and used manufacturing techniques. Manual creation with tools like tracing paper requires access to the physical artifact and is oftentimes neither feasible nor allowed, due to the fragility of artifacts. Today, high resolution textured 3D models can be obtained from contact-less acquisition methods like *Structure-from-Motion* [WBG*12] or *Structured Light Scanning* [RZR17]. Computer-aided unwrapping methods, e.g. using the GigaMesh Software Framework (`https://gigamesh.eu/`), have considerably facilitated this task (Fig. 1 top), since they allow a domain user to annotate a painting directly on top of a digital planar surface representation. To date, the annotation is conducted mostly manually, for a domain expert is required to distinguish legit painting from various noise sources like fracture lines, signs of erosion, or worn off and missing surface parts. Therefore, a mere edge image of the planar surface will not be of help (Fig. 1 bottom middle). Still, manual annotation can take up to several hours, even for rather small vessels [KBMM19]. Consequently, repetitive ornamental patterns which oftentimes take up large portions of vase paintings are not annotated graphically but only described textually. Nonetheless, they are important cues for attributing a pottery object to a painter or workshop, and overall for dating the artifact. Generally, these patterns mentioned above comprise simple shapes like spirals, concentric circles, triangles, swastika, zigzags and meanders, or more complex ones like rosettes, palmettes, leaves and birds [Kun98]. These are either employed for filling the background of figural scenes or accompany the main image in form of ornament bands or friezes around the rotation axis of pottery objects. The latter are created by the painter while rotating the pot on the potter's wheel. Moreover, pots can even be decorated solely by repetitive ornaments (cf. the 'Geometric style' in Greek art).

We present a concept which greatly facilitates the graphical annotation of such ornamental bands using an interactive query-by-example approach, making it feasible for archaeologists to include them into surface drawings. To this end, we apply a similarity detection that leverages two constraints which commonly apply simultaneously to ornaments within an ornamental band: (i) an ornament is similar to a provided primitive and (ii) several of such occur at the same position along the object's rotational axis.

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Figure 1: *Top: 3D model of a Corinthian aryballos from the university of Graz with a spherical unrolling, bottom: archaeological drawing by domain expert (left), surface painting subjected to Canny edge detection (middle) and detection of multi-bar scribbles in two ornament bands with our method (right).*

2. Related Work

The creation of archaeological drawings is a common practice to extract valuable information about the scenes represented on cultural heritage (CH) objects' surfaces. In general, this task is a manual labor [KBMM19], which can be supported with the automatic analysis of repetitive patterns. In this section, we describe methods that exploit the use of repetitive patterns in CH applications.

Lengauer et al. [LKL*19] introduced a method to retrieve similar motifs by segmenting and comparing the shape context of the relevant shapes against potential candidates. Also, Gilad-Glickman and Shimshoni [GGS16] took advantage of the repetitive pattern in the depiction of CH objects to restore the color of degraded items. Similarly, Moscoso-Thompson and Biassoti [MB19] proposed a variation of the local binary pattern method to describe color patterns in CH objects and perform a similarity search. In Rodriguez and Song [RS16], saliency features were used to retrieve similar 3D ornamentations. Visualizing the features by a feature map also supports the identification and comparison of local ornament elements. Many methods leverage a self-similarity approach to search for repetitive structures in 3D surfaces. Gal and Cohen-Or [GCO06] proposed a way to detect and describe salient regions based on the curvature information. This method also proposed the construction of a hashing index to accelerate the search of similar geometric patterns. Similarly, Mitra et al. [MBB10] devised an intrinsic approach to detect repetitive geometric patterns when the surface undergoes a near-isometric transformation.

In the context of cultural heritage applications, Itskovich and Tal [IT11] applied a partial matching algorithm to search similar geometry given a query. In the same direction, Leifman and Tal [LT13] combined the local description approach with machine learning to validate the search of a given motif. Also, Harary et al. [HTG14] used heat diffusion descriptors to find similar patches in a shape and use the obtained results to repair the surface of damaged objects. In a recent effort to study the problem of retrieval and recognition in surfaces with recurrent geometric patterns, several datasets and methods have been evaluated with promising results. Biasotti et al. [B*18] proposed a benchmark and performed evaluations to recognize 3D objects using the geometric pattern over the surface. More recently, Moscoso-Thompson et al. [MT*20] described a different benchmark and compared classical geometric methods and deep learning-based approaches. It is worth noting that descriptions based on local binary patterns (edge-LBP [MB18] and mesh-LBP) have proven to be suitable for this kind of problem.

3. Concept

Our approach takes as input a textured 3D model of a painted vase and outputs an image of an unwrapped projection of the object surface (henceforth referred to as *canvas*) exhibiting a binary depiction of all extracted ornament groups. The group-wise detection and extraction is supported by a user operating on an interactive depiction of the projected vessel surface. We choose a projection that widely minimizes both distance and angular distortions [PKBS18], which closely resembles the surface as it would be drawn by an archaeologist. This also allows for robust similarity detection in surface areas of high curvature.

In our proposed workflow, the following four steps, depicted in Fig. 2 are executed repeatedly, until all self-similar ornamental element candidates are extracted: (1) the user selects one well preserved ornament primitive from an ornamental band with a scalable selection rectangle; (2) a self-similarity detection (Sec. 4), yielding a set of candidates, is computed in the background; (3) false positives are discarded by the user before a binarized representation of the refined selection is written to a separate canvas; (4) the displayed vessel surface is updated by removing surface parts containing the remaining selection. The canvas resulting from the extraction of all repetitive ornaments can be used as a basis for a complete annotation of the painting showing several figures.

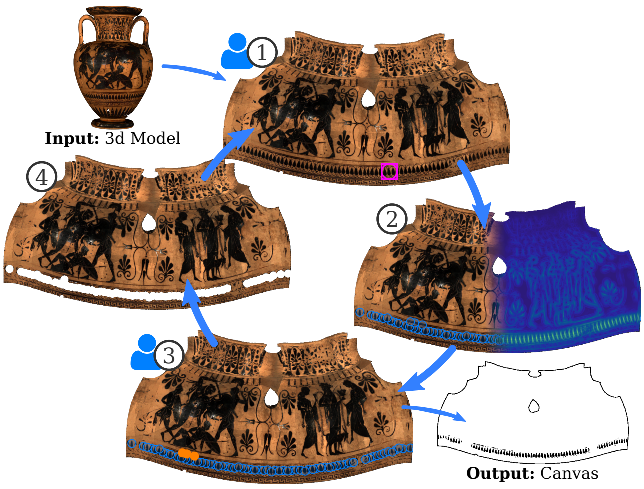

Figure 2: *Workflow overview with a 3D model of an Attic black-figured amphora (Kunsthistorisches Museum, Vienna) as input, a canvas as output and the iterative steps of (1) query selection, (2) self-similarity detection, (3) result refinement and (4) surface subtraction. A blue symbol indicates steps requiring user interaction.*

4. Self-similarity Detection

With a sliding window approach we compute the pixel-wise correlation of a query patch, given by the user's selection, and an equal-sized patch of the projected surface. The resulting confidence map can be employed for making proposals (candidate regions similar to the query). Due to the binary colorization of ancient Greek pottery [LKL*19] and the locally varying lighting conditions of the scanned vessel surface we compute the correlation over the binarized surface and query, which is obtained from the locally adaptive thresholding method by Sauvola et al. [SRS*12] (Fig. 3 top left). The detection has to be rotation-invariant, for relevant ornaments can occur in a rotated manner, either due to alternating orientations in an ornament band, or due to distortions caused by the preceding surface flattening step. This invariance is achieved by calculating the confidence for a set of K queries, with the k-th query exhibiting a rotational transformation equal to an angle of $2\pi k/K$. With $C \in \mathbb{R}^{m\times n\times K}$ as the map of confidences over a $m \times n$ surface image and $[C]_{ijk}$ as the confidence at pixel (i, j) and radial bin $k \in [1 \,..\, K)$, the resulting sliding window confidence $C_{sw} \in \mathbb{R}^{m\times n}$ (Fig. 3 top middle) is given by the pixel-wise maximum confidence $[C_{sw}]_{ij} = max_{k\in[1..K)}[C]_{ijk}$. The step of obtaining a set of candidate regions thereof is a low level computer vision task referred to as Non-Maximum Suppression (NMS), which conducts a local maximum search after discarding all pixels below a threshold. The result of $nms(.)$ is a set of filtered candidate regions, marked with blue circles with orientation indication in Fig. 3 bottom right.

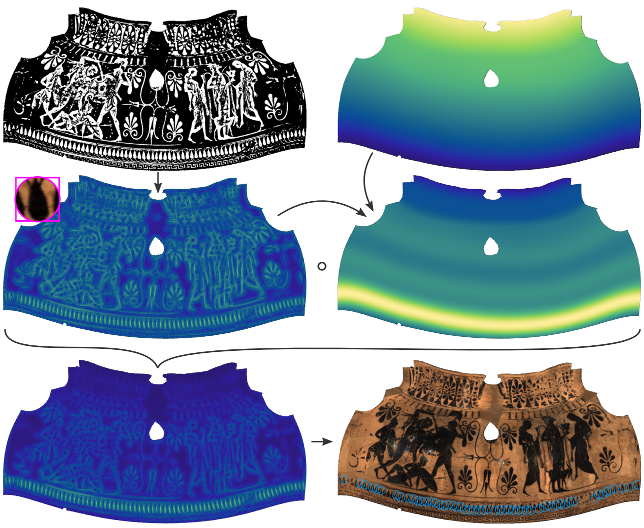

Figure 3: *From left to right, top to bottom: Amphora surface after locally adaptive thresholding, isohypses map I_z, sliding window confidence C_{sw} for a blossom shaped query, isohypses confidence C_z, combined confidence C and resulting candidates $nms(C)$.*

4.1. Refinement with Isohypses Map

Simple queries like the blossom shape in Fig. 3 top middle result in several high-confidence peaks strewn around across the whole confidence map. Due to its simplicity, similar patterns appear infrequently in various parts of the vessel surface, resulting in numerous false positives after the NMS. We refine the capability of our repetitive ornament detection by leveraging the assumption that repeating ornaments are arranged in ornamental bands around the rotational axis of the solid of revolution. With a mapping between the pixels of the flattened surface $S \in \mathbb{N}^2$ and the vertices of the 3D model $V \in \mathbb{R}^3$, we can derive the position of a surface point $p \in S$ along the rotational axis (z-axis) of the solid of revolution. With $I_z : \mathbb{N}^2 \rightarrow \mathbb{R}$ as the map of z positions of the surface pixels we are able to determine surface areas of equal height (isohypsal areas, Fig. 3 bottom left). An isohypsal confidence map C_{ih}, of the same dimensionality as C_{sw}, determines the probability that a surface region is part of an ornamental band exhibiting the query ornament. To this end, we multiply the isohypsal mask $H_z = \mathcal{N}(z, \sigma^2)$ of a normal distribution around a specific z (with $\sigma^2 = \text{const.}$) with $\phi_z = \sum_{i=1}^{|nms(H_z)|} conf(nms(H_z)[i])$, a value related to the number and confidence – $conf(.)$ returning a candidate's normalized confidence – of candidates occurring in the masked region. The isohypsal confidence $C_{ih} = \sum_{z=1}^{|M|} H_z\phi_z$ (Fig. 3 bottom middle) is given as the accumulation of the masked confidences for individual z positions, with $M = \{0, 2\sigma^2, 4\sigma^2, \cdots, 1\}$ as the set of mean values. The (element-wise) combined confidence $C = C_z \circ C_{sw}$ (Fig. 3 top right) was used as the basis for the NMS in all subsequent experiments.

5. Experimental Results

With our prototype implementation we conducted an evaluation of the self-similarity detection (Sec. 4) on our amphora object. To this end, we selected five queries of ornaments with varying size and complexity (Fig. 4 left) whose detected similar surface parts are drawn to a canvas (Fig. 4 right). It can be observed that even without a user discarding false positives (Step (3), the combination of sliding window and isohypsal confidence values resulted in several correct ornament detection in every case. Also, it was established that the similarity detection capabilities decline with increasing query complexity and decreasing number of present repetitions as it is the case with blue colored ornament in Fig. 4.

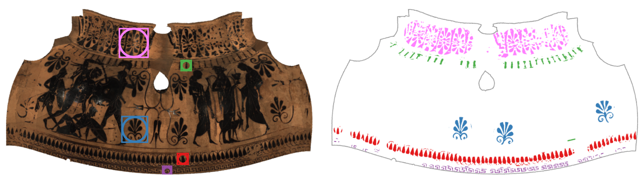

Figure 4: *Flattened amphora surface (left) with different ornament selections marked by colored circles and the resulting drawing on the canvas (right) with the same color coding.*

Even though our approach is optimized for vessel surfaces exhibiting a binary colorization, e.g. Greek pottery, it is also (to some degree) applicable for colored surface paintings, observable on pottery surfaces of other ancient civilizations. Fig. 5 shows the outcome of the similarity detection for two pre-Columbian pots from the Josefina Ramos de Cox museum at Lima, Peru. While our method works well for the first object where all of the ornament repetitions are detected, it reaches its limits for the second object with a success rate of approximately 50% and also some false positives. Nonetheless, the presence of multiple ornamental bands containing the query ornament are visible in the isohypsal confidence map, allowing to discard many of the false positives present in the sliding window confidence map.

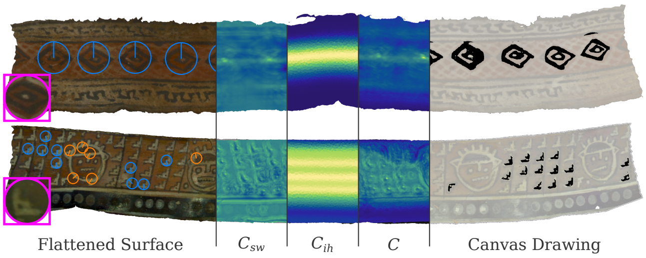

Figure 5: *Filtered candidates of the similarity detection (blue circles for true positives and orange circles for false positives) for provided queries on two Peruvian pots and illustrations of the sliding-window confidence C_{sw}, isohypscal confidence C_{ih}, their combination C, and the resulting extracted ornament drawings.*

6. Application, Limitations and Future Work

As it is noticeable in Fig. 4, our basic matching approach of correlating the binary surface is only applicable if the surface painting can be sufficiently well approximated by a binary representation, and struggles for larger and more faceted ornaments. To this end, we want to implement more sophisticated matching algorithms, invariant towards scaling and non-rigid transformations, which can be done without changing the rest of our system. Additionally, we want to subject the whole of our workflow to a rigorous usability testing with domain users to evaluate the practical applicability of our approach. This requires further post-processing of our output, in order to support SVG export, which can be readily achieved by fitting splines to the edge image of the canvas. The iterative ornament extraction is not only applicable for generating surface drawings, but also for a grouping of ornaments [KBMM19]. This grouping can be employed for analysing the variability of a group's ornaments as well as reconstructing missing parts of ornamental bands if alignment and distribution patterns can be derived.

7. Conclusion

Our approach supports the semi-automatic drawing of simplistic repetitive ornamental elements of surface paintings with an iterative self-similarity detection, based on a query-by-example method. Experimental evaluations show that the majority of occurrences of an ornamental pattern can already be recognized. The workflow is meant as support for creating repeatable and unambiguous parts of a drawing, while disputable or incomplete sections still require the expertise of a domain researcher. Our approach focuses specifically on repetitive ornaments which can be supported sufficiently well with computer-aided methods while the automatic annotation of complex scene depictions remains an open research objective.

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References

[B*18] BIASOTTI S., ET AL.: Recognition of Geometric Patterns Over 3D Models. In *Eurographics Workshop on 3D Object Retrieval* (2018), The Eurographics Association, pp. 71–77. 2

[GCO06] GAL R., COHEN-OR D.: Salient Geometric Features for Partial Shape Matching and Similarity. *ACM Trans. Graph. 25*, 1 (Jan. 2006), 130–150. 2

[GGS16] GILAD-GLICKMAN D., SHIMSHONI I.: Color Restoration of Scanned Archaeological Artifacts with Repetitive Patterns. In *Proc. of the 14th Eurographics Workshop on Graphics and Cultural Heritage* (Goslar, 2016), GCH '16, Eurographics Association, p. 105–108. 2

[HTG14] HARARY G., TAL A., GRINSPUN E.: Context-Based Coherent Surface Completion. *ACM Trans. Graph. 33*, 1 (Feb. 2014). 2

[IT11] ITSKOVICH A., TAL A.: Surface partial matching and application to archaeology. *Computers & Graphics 35*, 2 (2011), 334 – 341. 2

[KBMM19] KARL S., BAYER P., MÁRTON A., MARA H.: Advanced Documentation Methods in Studying Corinthian Black-figure Vase Painting. In *Proc. of the 23rd Int. Conf. on Cultural Heritage and New Technologies 2018* (Vienna, 2019), Museen der Stadt Wien – Stadtarchäologie. 1, 2, 4

[Kun98] KUNISCH N.: *Ornamente geometrischer Vasen. Ein Kompendium.* Böhlau, Cologne, Weimar, Vienna, 1998. 1

[LKL*19] LENGAUER S., KOMAR A., LABRADA A., KARL S., TRINKL E., PREINER R., BUSTOS B., SCHRECK T.: Motif-driven Retrieval of Greek Painted Pottery. In *Eurographics Workshop on Graphics and Cultural Heritage* (Switzerland, 2019), Eurographics Association, pp. 91–98. 2, 3

[LT13] LEIFMAN G., TAL A.: Pattern-Driven Colorization of 3D Surfaces. In *2013 IEEE Conference on Computer Vision and Pattern Recognition* (2013), pp. 241–248. 2

[MB18] MOSCOSO THOMPSON E., BIASOTTI S.: Description and retrieval of geometric patterns on surface meshes using an edge-based LBP approach. *Pattern Recognition 82* (2018), 1 – 15. 2

[MB19] MOSCOSO THOMPSON E., BIASOTTI S.: Retrieving color patterns on surface meshes using edgeLBP descriptors. *Computers & Graphics 79* (2019), 46 – 57. 2

[MBB10] MITRA N. J., BRONSTEIN A., BRONSTEIN M.: Intrinsic Regularity Detection in 3D Geometry. In *ECCV 2010* (Berlin, Heidelberg, 2010), pp. 398–410. 2

[MT*20] MOSCOSO-THOMPSON E., ET AL.: SHREC 2020: Retrieval of digital surfaces with similar geometric reliefs. *Computers & Graphics 91* (2020), 199 – 218. 2

[PKBS18] PREINER R., KARL S., BAYER P., SCHRECK T.: Elastic Flattening of Painted Pottery Surfaces. In *Eurographics Workshop on Graphics and Cultural Heritage* (2018), The Eurographics Association, pp. 165–168. 2

[RS16] RODRIGUEZ-ECHAVARRIA K., SONG R.: Analyzing the Decorative Style of 3D Heritage Collections Based on Shape Saliency. *ACM Journal on Computing and Cultural Heritage 9*, 4 (2016), 20:1–20:17. 2

[RZR17] RIEKE-ZAPP D., ROYO S.: Structured light 3D scanning. In *Digital Techniques for Documenting and Preserving Cultural Heritage*. Arc Humanities Press, Leeds, 2017, pp. 247–251. 1

[SRS*12] SINGH T. R., ROY S., SINGH O. I., SINAM T., SINGH K., ET AL.: A new local adaptive thresholding technique in binarization. *arXiv preprint arXiv:1201.5227* (2012). 3

[WBG*12] WESTOBY M., BRASINGTON J., GLASSER N., HAMBREY M., REYNOLDS J.: 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology 179* (2012), 300 – 314. 1