Eurographics Symposium on Geometry Processing (2018)
T. Ju and A. Vaxman (Editors) *Poster*

Using Mathematical Morphology to Simplify Archaeological Fracture Surfaces

H. ElNaghy and L. Dorst

Computer Vision Group, Informatics Institute, University of Amsterdam, The Netherlands
{hanan.elnaghy, l.dorst}@uva.nl

Abstract

It is computationally expensive to fit the high-resolution 3D meshes of abraded fragments of archaeological artefacts in a collection. Therefore, simplification of fracture surfaces while preserving the fitting essentials is required to guide and structure the whole reassembly process. Features of the scale spaces from Mathematical Morphology (MM) permit a hierarchical approach to this simplification, in a contact-preserving manner, while being insensitive to missing geometry. We propose a new method to focusing MM on the fracture surfaces only, by an embedding that uses morphological duality to compute the desired opening by a closing. The morphological scale space operations on the proposed dual embedding of archaeological fracture surfaces are computed in a distance transform treatment of voxelized meshes.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—Boundary representations-Geometric algorithms, languages, and systems

1. Archaeological Morphology

One of the goals in GRAVITATE H2020 project is to reassemble fragments of archaeological artefacts (http://gravitate-project.eu/). The artefacts have been scanned, resulting in 3D meshes with relatively little scanning noise. However, chipping and abrasion of the fragments over the ages have affected how well they can match, and should obviously inform the processing.

Within the GRAVITATE data collection, it is rare to have all fragments belonging to certain archaeological broken object. A pair of promising fragments, coming from same or different data collections, can be suggested for digitally gluing them at specified fracture surfaces. Our task within the system, is to accurately establish the pairwise alignment or to reject their initial suggestion for potential fit. Our computational approach focuses completely on the purely geometrical properties of archaeological fragments, ignoring clues given by patterns or color. We will assume that the fragments have not been deformed (our archaeological test case is on terracotta rather than metal), though they are likely to be abraded or chipped.

Verification and optimal pair-wise alignment are computationally much cheaper on simplified versions of the originally scanned fracture surfaces, organized in a hierarchy of increasing resolution. Accordingly, we need a representation where a coarser, simplified version of the fracture surface maintains its potential contact with a coarser, simplified version of the counterpart, and is sufficiently specific to detect non-fitting cases. Moreover, the representation should not be linearly sensitive to missing geometry: a local gap with the same surface outline but twice as deep should not make the local fit twice as bad.

The Mathematical Morphology (MM) framework [Ser83], though originally developed for image analysis, turns out to precisely enable such chipping-insensitive contact-preserving properties of shapes. Employing it for 3D mesh fitting appears to be new. It is easy to show that under exact complementarity (the ideal case), when one morphologically *closes* the gaps on one of the fitting surfaces, one must *open* them on the other, to retain complementarity of the fit. Therefore, we need to make dual opening and closing morphological scale spaces [JD96] for each pair of fracture surfaces suggested for potential fit. These will form the basis for stable morphological features, since it can be shown that MM scale spaces are insensitive to certain types of abrasion of the surfaces.

2. Fracture Morphology

Locally, whether two broken fragments can be refit depends on the shape of their fractures, so we need to design a method to constrain our MM operations to the fracture parts of the mesh. Those parts can be extracted by our faceting method proposed in [ED17]. The extracted fracture surfaces are piecewise plane-like (which makes sense for our terracotta artefacts).

According to such expected approximate planarity, the normal of the best-fitting plane to the fracture surface can be used as the

DOI: 10.2312/sgp.20181179

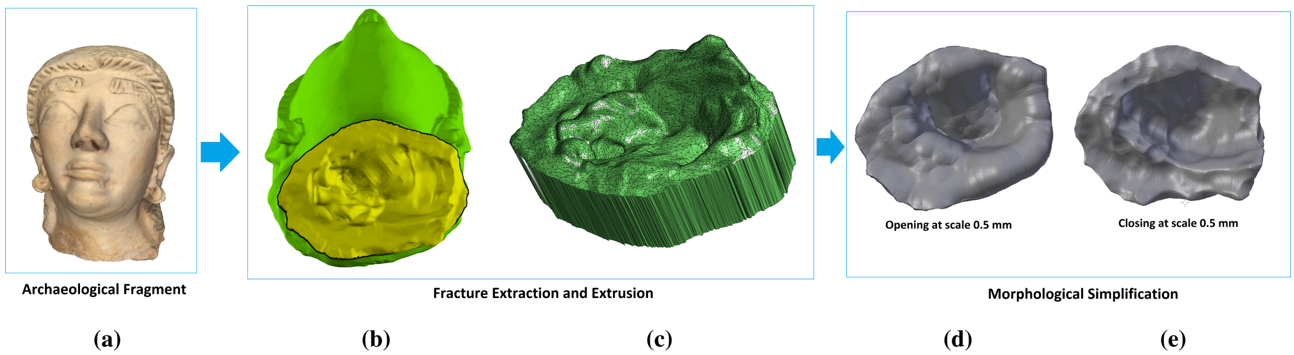

Figure 1: *Morphological Simplification of Archaeological Fracture Surfaces*

principal breakage direction along which the fracture is almost a depth function. This geometrical intuition suggests to generate a thickened fracture volume by extruding the surface along the breakage direction. Such an extrusion effect is equivalent to making two copies of the fracture surface bounded by a generalized cylinder: one with original (non-inverted) normals and one with inverted normals (see Fig. 1c). The outward propagation of the copy with non-inverted normals is the fracture mesh dilation, while the propagation of the one with inverted normals is the erosion. By a subsequent inward propagation, by the same amount, one then retrieves the closing and the opening of the fracture.

Intuitively, morphologically closing the entire extruded volume is equivalent to rolling a ball on the fracture surface from both sides. The upper rolling is equivalent to the closing effect, while the lower is equivalent to the desired opening effect on the fracture surface.

3. Distance-Transform based MM implementation

Since we are interested in isotropic surface propagation using ball-like structuring elements, the euclidean distance transform is used for computing the MM operations. For generating our distance field, the method proposed by [MQRM03] is employed, which calculates the euclidean distance transform in linear time on binary voxelized representation of the object.

We convert the extruded fracture mesh to binary representation by embedding it in a 3D voxelized grid of a well-chosen resolution. The generated grid is padded with an empty region sufficient to contain the maximally dilated versions of the fracture surfaces.

4. Coarser is Simpler

We compute the closed and the opened fracture surfaces at increasingly coarse scales (i.e. with larger rolling balls). The resulting surfaces are simpler in form than the fracture they represent: they tend to be hierarchically composed of fewer, larger and more dispersed spherical caps. In fact, the centers of the balls to which these spherical caps belong, are medial axis points of the complement of the extruded fracture mesh volume [ABE09]. With increasing scale, the ongoing morphological simplification can be characterized in terms of these distinctive feature points that can be weighted by the significance of their area contribution to the simplified surfaces. Such point-like landmark MM features are expected to be stable enough for guiding and structuring the next phase in our work: optimal pairwise alignment (possibly by using the Kabsch algorithm).

5. Discussion

We have presented a morphological representation for simplifying archaeological fracture surfaces based on their scanned 3D representation, which is the structural step to enable our ongoing-work for fitting broken artefacts. Using the MM framework in this manner provides contact-preserving simplification of shapes that is highly robust to missing information in a non-linear way. Such a representation should indeed lead to cheaper well-structured hierarchical testing of possible fits of archaeological objects at interactive speed.

Our current research focuses on quantifying the applied simplification by the medial axis feature points. Clearly this necessitates studying the voxelization effect together with the noise sensitivity of the resulting scale space representation.

6. Acknowledgement

This research was funded by GRAVITATE project under EU2020-REFLECTIVE-7-2014 Research and Innovation Action, grant no. 665155. Datasets are from GRAVITATE data collection.

References

[ABE09] Attali D., Boissonnat J.-D., Edelsbrunner H.: *Stability and Computation of Medial Axes - a State-of-the-Art Report*. Springer Berlin Heidelberg, Berlin, Heidelberg, 2009, pp. 109–125. 2

[ED17] ElNaghy H., Dorst L.: Geometry based faceting of 3d digitized archaeological fragments. In *The IEEE ICCV Workshops* (Oct 2017). 1

[JD96] Jackway P. T., Deriche M.: Scale-space properties of the multiscale morphological dilation-erosion. *IEEE PAMI Transactions 18*, 1 (Jan. 1996), 38–51. 1

[MQRM03] Maurer C. R., Qi R., Raghavan V., Member S.: A linear time algorithm for computing exact euclidean distance transforms of binary images in arbitrary dimensions. *IEEE PAMI Transactions* (2003), 265–270. 2

[Ser83] Serra J.: *Image Analysis and Mathematical Morphology*. Academic Press, Inc., Orlando, FL, USA, 1983. 1