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Poster

Towards Crowd-Sourced Collaborative Fragment Matching

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(a) (b) (c)

Figure 1: Web-based 3D environment visualizing fragments of an archaeological artifact for virtual reassembly (a). Matching a fragment with already joined stones (b). Other users can up- and downvote joins (c).

Abstract

Many artifacts of our archaeological heritage are preserved only in fragments. The reassembly of these parts to their original form is therefore an essential task for archaeologists. Our project aims at incorporating the intellect of many participants from the broad public in the solution of this complex task. To this end, we develop a web-based 3D environment, in which users can interactively and collaboratively reassemble virtual fragments of real-world artifacts, supported by computer-aided methods. Our primary research focus lies on identifying how to best design and setup such a system in order to maximize the collaboration efficiency. By participating in this open reassembly process, users can gain valuable insight into the archaeological task, thus raising awareness for our common cultural heritage in a multitude of people.

CCS Concepts

• Human-centered computing → Empirical studies in collaborative and social computing; Collaborative and social computing systems and tools; • Applied computing → Archaeology;

1. Project Context

As most archaeological finds are only preserved in a broken and often incomplete state, their remaining fragments first need to be tediously matched before they can be studied and interpreted by archaeologists. To support this complex reassembly task, several computer-based algorithms that work with *digitized fragments* exist [RN20, LWN*21, YCT*21], but they are not robust enough to provide correctness guarantees, nor can they be applied to any given set of fragments without parameter tweaking. This is due to fragment reassembly being an ill-posed problem, as even in the case of an ideal fragment digitization, erosion of fracture surfaces of the real-world artifacts leads to potential false matches among their virtual counterparts. An alternative approach to pursing a fully automatic computer-based approach is to utilize the human intellect for highly complex puzzle-solving problems. Previous work mainly focused on *virtual reassembly systems* to be used by single expert users [KA10]. In our project, we aim to engage a *large number of collaborating users* from the broad public in the problem-solving process in a playful manner. This goal relates to the fundamental question in citizen science, namely how to most efficiently benefit from the collective intellect of many individuals when collaboratively solving a problem [VB14]. We address the following

Research Questions: (RQ1) How to measure collaborative reassembly efficiency in the first place, (RQ2) finding the ideal number of participants working on the same task with respect to their problem-solving efficiency, and (RQ3), to which degree algorithmic aids, such as automatic fine registration and snapping of nearby fragments, can improve or even hinder the problem-solving progress and user motivation, respectively.

2. Methodology

To answer these questions, we create a web-based 3D environment that makes the digitized fragments accessible to multiple remote users who can collaboratively *interact*, and *move* and *join* fragments with the aim of finding matches, and reconstructing the original artifact (Section 3). In our study we use a collection of 97 fragments of an early Christian mensa slab made of marble, set up as a 2D puzzle (Fig. 1(a) shows approximately 70% of all fragments).

Approach. To address the stated research questions, we distribute participants into different virtual *rooms* with identical sets of stone fragments. Within each room, we track the current *connectivity graph* between already joined fragments, which indicates the current solution progress over time. Given the known ground-truth connectivity, we will measure the current solution progress by the number of correct edges in the graph (RQ1). To investigate the solving efficiency between different group sizes (RQ2), virtual rooms will differ in the maximum permitted number of participants. The influence of algorithmic assistance (RQ3) will be assessed by further dividing rooms into three levels of automatism: (A) automatic fine registration only when joining stones, (B) automatic snapping proposals as users move stones, (C) automatic random proposals of matches by the system, with users only rating the joins.

Evaluation. During the time in which the finished system will be online, and users will be able to participate in the virtual artifact reassembly, we will conduct the study by tracking the progress data for the various room setups. Subsequently, we will examine the data collected for each room to analyze the influence of the parameters on the solution efficiency.

3. Implementation

Our conceptual prototype features the following building blocks:

Manual Interaction. Users can freely navigate through the scene, interact with individual stones or partial assemblies, and move and rotate them interactively in 2D (Fig. 1(b)). If a feasible match between fragments is found, they can be joined (Fig. 1(c)).

Visual Aids. Fine surface details such as working traces on the stones can give important hints for possible fragment matches. In the real world, archaeologists would therefore investigate these stones under various lighting directions. Analogously, we allow users to interactively adjust the virtual light direction to emphasize these crucial surface features. Moreover, match quality, measured by the residuals of a geometric fit, will be visualized along fragment surfaces using color coding.

Computer-Aided Geometric Fitting. A fine registration of joined fragments is performed in order to reduce accumulating fitting errors over multiple matches in the assembled artifact [RL01]. Depending on the active level of automatism in each room, stones may also automatically "snap" to nearby stones where a good match is found by the underlying geometry-calculation framework.

Collaboration. To support collective opinion sharing in a standardized, non-offensive way, any join between two stones is subject to up- and downvotes by other participants, using interactive user-interface widgets (Fig. 1(c)). We explicitly opt for placing *no restrictions* on the user interactions: joins can be undone at any time, independent of their associated votes.

4. Expected Results

By collecting multi-modal data on the solution progress, interaction events, matching attempts, and user votes during the online study, we will generate a rich dataset that will allow us to derive statistically significant statements about suitable parameters (e.g., the number of users per room, or the levels of computer-assistance) of an efficient collaborative reassembly system, and identify problems, and potential improvements for the collaborative solution process. Once the user study is finished, the dataset of stone fragments digitized for this project will be made available publicly. We also plan to use our platform to solve the reassembly of other comparable artifacts, for which the correct solution is not yet known. Finally, through this project, we aim to raise awareness of the importance of our common cultural heritage in the broader public.

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References

[KA10] KIMIA B. B., ARAS H. C.: HINDSITE: A user-interactive framework for fragment assembly. In *2010 IEEE Computer Society Conference on Computer Vision and Pattern Recognition-Workshops* (2010), IEEE, pp. 62–69. doi:10.1109/CVPRW.2010.5543532. 1

[LWN*21] LIU B., WANG M., NIU X., WANG S., ZHANG S., ZHANG J.: A Fragment Fracture Surface Segmentation Method Based on Learning of Local Geometric Features on Margins Used for Automatic Utensil Reassembly. *Computer-Aided Design 132* (2021), 102963. doi:10.1016/j.cad.2020.102963. 1

[RL01] RUSINKIEWICZ S., LEVOY M.: Efficient Variants of the ICP Algorithm. pp. 145–152. doi:10.1109/IM.2001.924423. 2

[RN20] RASHEED N. A., NORDIN M. J.: Reconstruction algorithm for archaeological fragments using slope features. *ETRI Journal 42*, 3 (2020), 420–432. doi:10.4218/etrij.2018-0461. 1

[VB14] VUCULESCU O., BERGENHOLTZ C.: How to Solve Problems with Crowds: A Computer-Based Simulation Model. *Creativity and Innovation Management* (2014), 121–136. doi:10.1111/caim.12059. 1

[YCT*21] YAO W., CHU T., TANG W., WANG J., CAO X., ZHAO F., LI K., GENG G., ZHOU M.: SPPD: A Novel Reassembly Method for 3D Terracotta Warrior Fragments Based on Fracture Surface Information. *ISPRS International Journal of Geo-Information 10*, 8 (2021). doi:10.3390/ijgi10080525. 1