ArchAIDE: Archaeological Automatic Interpretation and Documentation of cEramics

Holly Wright[1][0000-0002-3403-4159] and Gabriele Gattiglia[2][0000-0002-4245-8939]

[1] University of York, The King's Manor, York, YO1 7EP, UK
[2] University of Pisa, Via Trieste 38, 56126 Pisa, Italy
holly.wright@york.ac.uk

Abstract. The ArchAIDE project (archaide.eu) is funded by the European Union's Horizon 2020 research and innovation programme and has developed a new app that aims to improve the practice of pottery recognition in archaeology, using the latest automatic image recognition technology. Every day, archaeologists are working to discover and tell stories around objects from the past, investing considerable time, effort and funding to identify and characterise individual finds. Pottery is of fundamental importance for the comprehension and dating of archaeological contexts, and for understanding the dynamics of production, trade flows, and social interactions. Today, this characterisation and classification of ceramics is carried out manually, through the expertise of specialists and the use of analogue catalogues held in archives and libraries. The goal of ArchAIDE is to optimise and economise this process, making knowledge accessible wherever archaeologists are working. ArchAIDE supports the classification and interpretation work of archaeologists (during both fieldwork and post-excavation analysis) with an innovative app for tablets and smartphones, designed to be an essential tool for archaeologists. Pottery fragments are photographed, their characteristics sent to a comparative collection, which activates the image recognition system, resulting in a response with all relevant information linked, and ultimately stored, within a database that allows sharing online. The system currently supports shape-based recognition of Terra Sigillata and Roman Amphorae, and decoration-based recognition of Majolica of Montelupo, as proof-of-concept.

Keywords: Archaeology, Pottery, Ceramics, Image Recognition, 3D Modelling

1 Overview

The ArchAIDE project [1] is funded by the European Union's Horizon 2020 research and innovation programme and has developed a new app that aims to improve the practice of pottery recognition in archaeology, using the latest automatic image recognition technology [2]. Every day, archaeologists are working to discover and tell stories around objects from the past, investing considerable time, effort and funding to identify and characterise individual finds. Pottery is of fundamental importance for the comprehension and dating of archaeological contexts, and for understanding the dynamics of production, trade flows, and social interactions. Today, this characterisation and classification of ceramics is carried out manually, through the

expertise of specialists and the use of analogue catalogues held in archives and libraries. The goal of ArchAIDE is to optimise and economise this process, making knowledge accessible wherever archaeologists are working. ArchAIDE supports the classification and interpretation work of archaeologists (during both fieldwork and post-excavation analysis) with an innovative app for tablets and smartphones, designed to be an essential tool for archaeologists. Pottery fragments are photographed, their characteristics sent to a comparative collection (which is meant to show typical pottery types and characteristics, against which pottery to be identified by the user is compared), which activates the image recognition system, resulting in a response with all relevant information linked, and ultimately stored, within a database that allows sharing online. This goal has been implemented through the following practical elements:

- a digital comparative collection for multiple pottery types has been created, incorporating existing digital collections, digitised paper catalogues and multiple photography campaigns;
- an automatic-as-possible workflow has been built to accurately digitise paper catalogues and improving the search and retrieval process;
- a multilingual thesaurus of descriptive pottery terms has been created, mapped to the Getty Art and Architecture Thesaurus and including French, German, Spanish, Catalan, English and Italian;
- an app has been created using the digital comparative collections to support archaeologists in recognising potsherds during excavation and post-excavation analysis, with an easy-to-use interface and efficient image recognition algorithms for search and retrieval based on either characteristics of shape or decoration;
- the app can also be used as a tool for learning about pottery identification, either for students or when specialists are not available;
- once a sherd has been recognised, the app can be used to automatically populate information about the sherd into a virtual assemblage for a site, including the generation of an identity card as a formatted, digital or printable document;
- the underlying technologies developed for the app have also been implemented as a desktop application, which is a web-based, real-time data visualization resource, to improve access to archaeological heritage and generate new understanding;
- the comparative data will be available from an open access archive ensuring it is available for re-use beyond the ArchAIDE project, contributing to our sustainable, common heritage.

ArchAIDE has entered its third and final year, and has successfully implemented nearly all of the practical elements. A beta version of the app is currently being presented and promoted to stakeholders, allowing feedback to be incorporated into its ongoing development.

2   Partnership

The ArchAIDE partnership has representation from the academic and industry-led ICT domains, and from the academic and development-led archaeology domains. The archaeological partners of the consortium are the MAPPA Lab at the University of Pisa (coordinator) which has relevant experience in mathematical and digital applications in Archaeology, and archaeological communication; the Material Culture and Archaeometry research unit at the University of Barcelona, which is focused on promoting studies of material culture, especially on archaeological ceramics, and archaeometric approaches; the Digital Archaeology Laboratory at the University of Cologne, which manages ARACHNE, a highly structured object database in partnership with the German Archaeological Institute (DAI); and the Archaeology Data Service (ADS) at the University of York, which is a world-leading digital data archive for archaeology.

The consortium also includes two companies carrying out preventive and development-led archaeological investigations: Baraka Arqueólogos S.L., which has particular expertise in the study of archaeological ceramics, and Elements S.L which is experienced in the application of digital technologies related to ceramic studies. Finally, the consortium's technical ICT partners are the Visual Computing Lab at CNR-ISTI, an institute of Italian CNR devoted to research on Visual Media and Cultural Heritage; the Deep Learning Lab at the School of Computer Science at Tel Aviv University, which focuses on document analysis, image textual description, and action recognition; and the private software company, Inera s.r.l, which has experience in the field of protocols and web apps.

3   Lessons Learned

It quickly became evident that the quantity and quality of comparative data required to create the image recognition algorithm was far greater than estimated during the planning of the ArchAIDE project. This meant that together with the digitisation of paper catalogues, whose acquisition was at an advanced stage, photos would need to be taken of many more sherds. Specifically, developing the appearance based similarity training was more complex than expected, and to ensure accurate results were returned, recognition based on appearance (decoration) had to be separated from recognition based on shape (profile), requiring the building of two different algorithms. As a result, the archaeological partners invested considerable effort in photographing new pottery sherds to train the algorithms. The system currently supports shape-based recognition of Terra Sigillata and Roman Amphorae, and decoration-based recognition of Majolica of Montelupo, as proof-of-concept for the two main diagnostic criteria used by archaeologists.

In order to gather sufficient examples to train the algorithms, partners undertook photographic campaigns of collections in a variety of locations in Europe, along with help from volunteers and students at additional sites. This included more than 10,000 images of Majolica of Montelupo collected by partners at the University of Pisa, a large photo campaign and the creation of a typology of medieval and post-medieval pottery by the partners at the University of Barcelona, ongoing work by Baraka and Elements in locating sherds of Roman Amphorae and Terra Sigillata from

a range of their archaeological excavation work. Partners from the University of Cologne are also currently undertaking a very large photo campaign of Roman Amphorae and Terra Sigillata in Austria to improve the shape-based algorithm.

There was much discussion with partners at Tel Aviv University about how best to approach training the algorithms. For the appearance-based recognition (decoration), it was decided to create an algorithm based on combining classic machine learning tools with neural networks that were trained on general image classification tasks. Following a testing phase on a huge dataset of images, the functionality was incorporated into the ArchAIDE app, and classification is now available to archaeologists. Early testing indicated that (a) the performance of the classification differs with different lighting conditions, and this can be improved by simulating further lighting conditions while training the system; (b) the recognition achieves better accuracy on the "common" classes, compared to more "rare" classes, and this can be fixed by giving a weight to each input in the training, to simulate an equal number of inputs from each class.

As for shape-based recognition, the system was designed to produce "synthetic sherds" (3D shapes available on the computer) to train the system, starting with the pottery profiles that are extracted from the catalogues, in combination with work carried out by partners at CNR-ISTI. Early in the project, CNR-ISTI carried out a variety of experiments around automated generation of 3D models from traditional archaeological pottery profile drawings, which proved very successful. Not only was it possible to generate a 3D model, it was possible to automatically identify the different diagnostic parts of ceramic object, allowing objects to be 'virtually broken' to create a wide range of synthetic sherds [3]. After being trained and test on Amphorae synthetic sherds, an algorithm was developed by partners at Tel Aviv University based on a standard convolutional neural network (CNN). As ArchAIDE is training on large numbers of classes, there was also experimentation with curriculum training (gradually introducing more classes during the training process) and custom loss functions, to make the network converge. Presentation of the difficulties encountered, results achieved and opportunities for feedback have been carried out through organising workshops and training days in the UK, Italy, Germany, Spain and participating in national and international conferences.

During the first two years of the project exploitation strategies were analysed and discussed, resulting in a better understanding of the potential market has led the project to a promising approach: a free ArchAIDE mobile app as a vehicle to commercialise digitised versions of the pottery catalogues. The idea is to show copyright holders the added value of digitising paper catalogues, as they can then be used dynamically in a digital environment like the ArchAIDE app. The work of the copyright holders can then be shown how their work becomes more accessible, and more useful than in a traditional paper publication. While the long-term goal for archaeological data is to be open access, for those copyright holders who are not able to do so, a commercial exploitation model will be developed. ArchAIDE app users will be able to buy a specific catalogue (i.e. Conspectus) from the app itself as an "in-app purchase", the proceeds of which are paid to the copyright holder for use of their resource. For a user, buying a catalogue means having the possibility to browse and search the types contained in it and display all the available information, including multimedia object and eventually 3D models generated by ArchAIDE team. Whether

any copyright holders choose to participate or not, this exploitation model will serve as a strong proof-of-concept for making paper catalogues more useful and accessible, within a commercial environment, but copyright remains an open challenge.

4   Open Challenges

As expected, when the shape-based algorithm was first tested with real archaeological pottery sherds for the first time, the system did not operate well. Furthermore, as the network was trained on sherds generated from profile drawings, the classification was not robust enough to handle small variations that can be seen in sherds observed in practice. Both problems are currently being addressed in the research carried out by partners at Tel Aviv University. Currently, the process for appearance-based recognition is totally integrated in the mobile app, whereas the process for shape-based recognition is still undergoing improvement, but already permits the automated extraction of a profile from the image of a sherd.

As mentioned in the previous section, there are considerable challenges with regard to open licensing and intellectual property rights. As the project has progressed it has become evident that the comparative data necessary to the implement the ArchAIDE app must be derived from a variety of sources, each with different advantages and restrictions. For example, the online comparative collection *Roman Amphorae: A digital resource*, held by the Archaeology Data Service, or an analogue equivalent might be a particular comparative paper catalogue for Majolica of Montelupo. In the first example, while the data creators retain copyright, the comparative collection is already freely and openly disseminated online via a deposit agreement between copyright holder and the Archaeology Data Service, and can therefore be incorporated into the ArchAIDE app without needing to derive further permissions from the copyright holders. This is not the case for the paper catalogue described in the second example, where conversion into a dynamic digital resource was never envisioned.

While useful tools to help digitise the paper catalogues necessary to show the technical proof of concept of the ArchAIDE app have been developed by CNR, this does not mean the ArchAIDE project necessarily now holds copyright to the newly digitised, remixed data (although the metadata created as part of this process by the ArchAIDE project can be argued to be new data, for which the project can claim copyright). Whether this data can be made available outside the proof of concept would need to be negotiated with each copyright holder, which represents a major logistical and (potentially) financial difficulty. This becomes even more complicated if the ArchAIDE app is monetised in any way. The issue cannot of course be solved by ArchAIDE, but instead provides another important proof of concept opportunity by the project. By showing the potential of digitising paper catalogues in a way that demonstrates how their content can be actively re-used, allows ArchAIDE to now open discussions with publishers and other data providers around the importance of making their resources available in new ways with a concrete example (seeing their data in use within the app), furthering the long-term discourse around making research data open and accessible.

5　Tools

While the full range of tools described in this paper will be freely and openly available by the completion of the ArchAIDE project (subject to copyright), the following aspects are already completed:

Mobile App: The following features are currently functional within the mobile app:

- the appearance-based recognition workflow (i.e. the automatic recognition of pottery through the decoration) is complete
- the shape-based recognition system allows for the correction of the white balance (automatically and manually), scaling of the image using a ruler (automatically and manually), the extraction of the profile of a potsherd (semi-automatically)
- the information contained into the reference database can be searched and visualised
- a personal profile can be created within which archaeologists can store data related to assemblages of sherds from their own excavations

Desktop App: The following features are currently functional within the web-based, desktop app:

- the information contained into the reference database can be searched and visualised, in particular the geolocation of the origin and the occurrences of each pottery type, 3D models of each pottery type that can be interrogated, the relationships between different sherds (for instance) types and stamps
- the appearance--based recognition tool (i.e. the automatic recognition of pottery through the decoration)

Data: The following data is currently available by request from the authors:

- the multilingual thesaurus of descriptive pottery terms is available in JSON format. The terms are mapped to the Getty Art and Architecture Thesaurus and include French, German, Spanish, Catalan, English and Italian.

References

1. Home - ArchAIDE. http://www.archaide.eu/.

2. Gualandi ML, Scopigno R, Wolf L, Richards J, Buxeda i Garrigos J, Heinzelmann M, Hervas MA, Vila L, Zallocco M (2016) ArchAIDE-Archaeological Automatic Interpretation and Documentation of cEramics. In: EUROGRAPHICS Workshop on Graphics and Cultural Heritage. The Eurographics Association. doi:10.2312/gch.20161408

3. Banterle F, Dellepiane M, Evans T, Gattiglia G, Itkin B, Zallocco M (2017) The ArchAIDE Project: results and perspectives after the first year. In: EUROGRAPHICS Workshop on Graphics and Cultural Heritage. doi:10.2312/gch.20171308