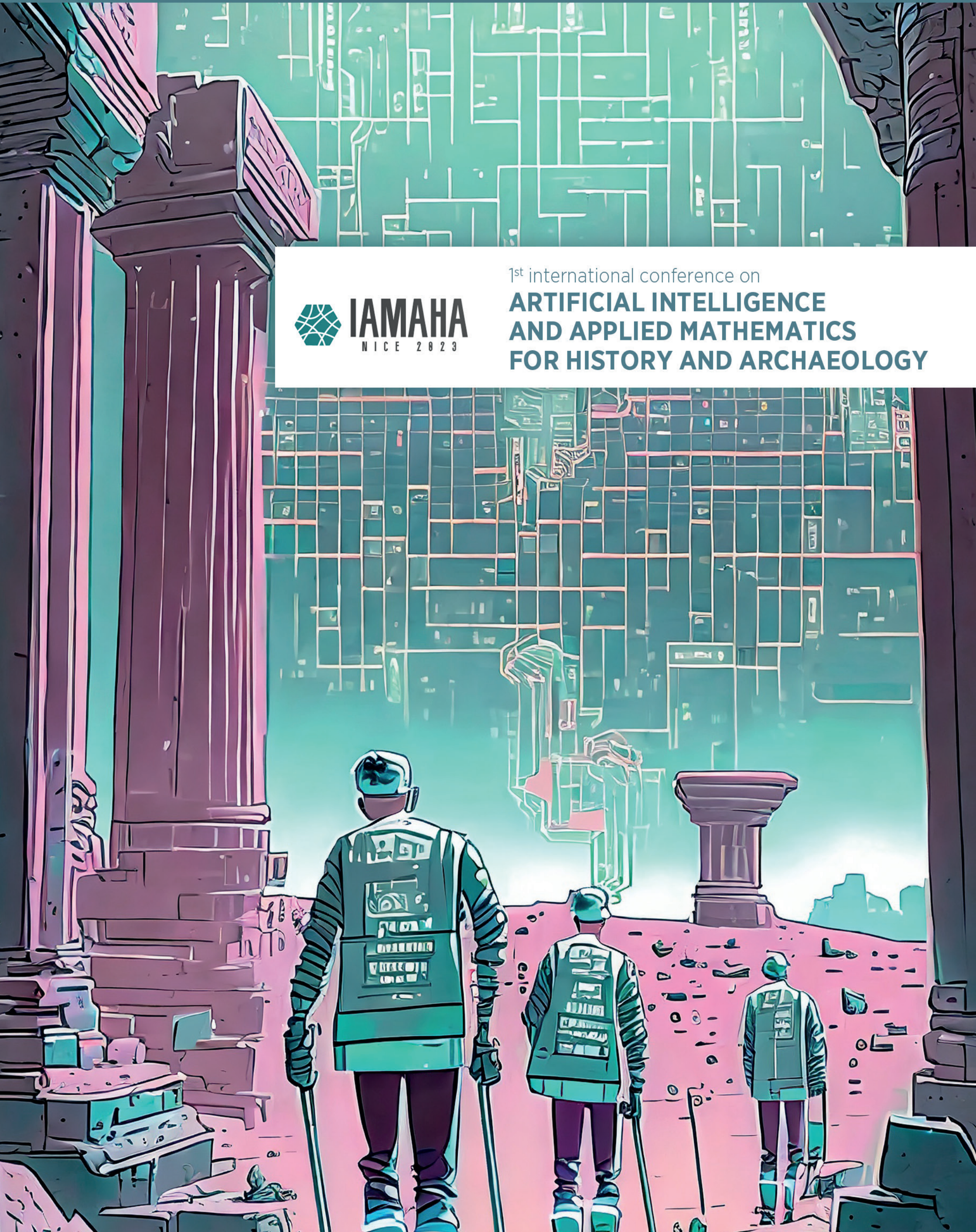
NICE, NOVEMBER 27-28 2023 – Théatre du Grand Château de Valrose



IAMAHA
NICE 2023

1st international conference on

ARTIFICIAL INTELLIGENCE AND APPLIED MATHEMATICS FOR HISTORY AND ARCHAEOLOGY

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IAMAHA

november 27-28 2023, Nice

SOMMAIRE

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PROGRAMME DÉTAILLÉ

Dans le programme, sont uniquement mentionné(e)s les auteur(e)s communiquant(e)s

LUNDI 27 NOVEMBRE

8h30 Welcome - Registration

9h00 Welcome speech

Session 1 : AI-AM FOR HISTORY AND PHILOLOGY
Session chair : Catherine Faron (Université Côte d'Azur, INRIA, Laboratoire I3S, Sophia-Antipolis, France)

9h30 AI-AM for history and philology
Keynote : Mathieu Aubry, École des Ponts ParisTech

10h30 *Coffee break*

10h45 Automatic Semantic Classification of Ancient Zoological Texts
Molka Tounsi Dhouib, Université Côte d'Azur, CNRS, Laboratoire I3S, Sophia-Antipolis, France

11h05 Computer Vision and Historical Scientific Illustrations
Fouad Aouinti, ISCD,SorbonneUniversité, Paris, France - **Zeynep Sonat Baltaci**, LIGM, Ecole des Ponts, Univ. Gustave Eiffel, CNRS, Marne-la-Vallée, France

11h25 Editing and Analysing Historical Astronomical Diagrams with Artificial Intelligence
Syrine Kalleli, LIGM, Ecole des Ponts, Univ. Gustave Eiffel, CNRS, Marne-la-Vallée, France - **Scott Trigg**, SYRTE, Observatoire de Paris - PSL, CNRS, Paris, France

11h45 *Flash talks poster session*, *see page 12*

12h15 *Lunch*

Session 2 : AI-AM FOR ARTS AND ARCHAEOLOGY OF BUILDINGS
Session chair : Luca Calatroni (Université Côte d'Azur, CNRS, Laboratoire I3S, Sophia-Antipolis, France)

14h00 AI-AM for arts and archaeology of buildings
Keynote : Aleksandra Pizurica, University of Ghent

15h00 *Coffee break*

15h15 Classification of ancient characters in mural paintings of the Alpine arc
Perrine Saillard, Université Côte d'Azur, CNRS, Laboratoire CEPAM, Nice, France

15h35 Detecting rock origin of blocks using surface roughness and colour : the case study of the ancient theatre of Orange (France)
Sophie Viseur, Aix Marseille Univ, CNRS, IRD, INRAE, CEREGE, Aix-en-Provence, France

15h55 µLIBS imaging and Artificial Neural Network for the characterization of heterogeneous materials: the case of lime mortars
Nicolas Herreyre, Univ. Lyon 1, Institut Lumière Matière, CNRS, Villeurbanne, France ; Univ. Lyon 2, Archéologie et Archéométrie, CNRS, MOM, Lyon, France

16h15 *Coffee break*

Session 3 : AI-AM FOR MATERIALS OF THE PAST
Session chair : Juliette Leblond (Université Côte d'Azur, INRIA, Sophia-Antipolis, France)

16h30 Archaeological Classification of Small Dataset Using Meta- and Transfer methods of Machine Learning Approach: An example using Hittite Stele Fragments
Deniz Kayikci, Universitat Autònoma Barcelona, Quantitative Archaeology Lab.

16h50 Astragalus bones identification via topological data analysis
Davide Adamo, Université Côte d'Azur, CNRS, Laboratoire CEPAM, Nice, France

17h10 Deep learning versus geometric morphometrics for archaeobotany
Vincent Bonhomme, Univ. Montpellier, ISEM, CNRS, EPHE, IRD, Montpellier, France ; Athéna, Lacamp, Roquedur, France – **Allowen Evin**, Univ. Montpellier, ISEM, CNRS, EPHE, IRD, Montpellier, France

17h30 From sherds to(wards) pots: advances on mathematical modelling of Neolithic pottery
Vanna Lisa Coli, Université Côte d'Azur, CNRS, Laboratoire CEPAM, Nice, France

18h00 *Poster session*

19h30 *Aperitif*

20h15 *Dinner*

MARDI 28 NOVEMBRE

8h30 *Registration*

Session 3 : AI-AM FOR MATERIALS OF THE PAST
Session chair : Didier Binder (Université Côte d'Azur, CNRS, Laboratoire CEPAM, Nice, France)

9h00 AI-AM for materials of the past
Keynote : Gabriele Gattiglia, University of Pisa

10h00 *Coffee break*

10h30 IA-SeReOs, an interdisciplinary project towards the automatic segmentation of CT-scanned ancient bone remains
Nicolas Vanderesse, Univ. Bordeaux, PACEA, CNRS, Pessac, France

10h50 Machine Learning vs frequentist statistics chemical data processing for dolerite archaeological artefact raw material origins.
Bernabeu auban Joan, Universitat de Valencia, Arqueologia i H. Antiga

11h10 Raman Spectroscopy of Flint and Artificial Intelligence: A Powerful Tool for Studying Fire Use by Hominins
Filipe Natalio, Kimmel Center for Scientific Archaeology & Department of Plant and Environmental Sciences, Weizmann Institute of Science, Rehovot, Israel

11h30 Thin Details Meet Large-scale 3D-reconstruction: Photometric Stereo for Cultural Heritage
Jean Mélou, IRIT, Toulouse, France – **Yvain Quéau**, Normandie Université, UNICAEN, ENSICAEN, GREYC, CNRS, Caen, France

11h50 Using statistical learning methods applied to stratigraphy and pottery to help establish periodisation in archaeology
Lise Bellanger, Nantes Université, Laboratoire de Mathématiques Jean Leray, CNRS, Nantes, France - **Arthur Coulon**, Université de Tours, CITERES, CNRS, Tours, France

12h10 Archaeological Classification and Machine Learning. Statistics, Bayesian Statistics and neural networks
Juan Barcelo, Universitat Autònoma Barcelona

12h30 *Lunch*

Session 4 : AI-AM FOR MODELLING OF SOCIO-ENVIRONMENTAL SYSTEMS
Session chair : Madalina Olteanu (Université Paris Dauphine-PSL, CEREMADE)

14h00 AI-AM for modelling of socio-environmental systems
Keynote : Andreas Angourakis, Rühr Universitat Bochum

15h00 *Coffee break*

15h15 Archaeology and Climate Change: New Perspectives of Agent-Based Modelling coupled with LPJmL agroecosystemic model for the Study of relationship between agricultural production and past societies
Nicolas Bernigaud, Univ. Montpellier, ASM, Montpellier, France

15h35 Explore the impacts of socio-environmental interactions on Gallo-Roman settlement dynamics: an Agent-Based experiment
Frédérique Bertoncello, Université Côte d'Azur, CNRS, Laboratoire CEPAM, Nice, France

15h55 Supervised and unsupervised classification of southern African wood and wood charcoals via their anatomical features
Marco Corneli – Elysandre Puech, Université Côte d'Azur, CNRS, Laboratoire CEPAM, Nice, France

16h15 Learning and inferring on Cochlear Shapes of Juvenile and Adult Fossil Hominins
Chafik Samir, Université Clermont Auvergne, LIMOS, CNRS, France

16h35 Mesolithic and Neolithic Niche Prediction Modelling with Bayesian Networks
Olga Palacios, Universitat Autònoma Barcelona, Quantitative Archaeology Lab.

16h55 Possibilistic models reveal trends, statis and contingent trajectories for plant and animal domestications
Cedric Gaucherel, Univ Montpellier, AMAP, CNRS, IRD, INRA, INRAE, CIRAD, Montpellier, France – **Allowen Evin**, Univ. Montpellier, ISEM, CNRS, EPHE, IRD, Montpellier, France

17h15 *Concluding remarks*

Session Flash Talks 1 [Lundi 27 novembre] : 11h45-12h15

11h45 Nouveaux outils d'apprentissage statistiques pour l'imputation et le pronostic en conservation sur les peintures
Shadé Alao Afolabi, UVSQ, IPANEMA, CNRS, MNHN, MC, Paris, France

Mark the way: Artificial Intelligence and Experimental Archaeology to better understand Bell Beaker pottery decoration
Gabriel Cifuentes-Alcobendas, University of Alcala, Alcala de Henares & Institute of Evolution in Africa, University of Alcala, Madrid, Spain

Evolution culturelle, IA et ritualités funéraires. Evaluation et Complémentarité de différentes méthodes d'approches
Eric Crubezy, Université Paul Sabatier, CAGT, CNRS & Institut Universitaire de France, Toulouse, France

Recognition of geometric patterns from Metal Ages: in search of mathematical markers within european ornate bracelets
Vincent Georges, Université de Bourgogne, Inrap, Artehis, CNRS, France

Extracting Structured Data from Historical Narratives Using the Running Reality Application in Combination with a Large Language Model
Garth Henning, Running Reality Organization, Garth Henning

A graph theoretical approach to depict Identity By Descent in ancient populations
Pierre Justeau, Université de Bordeaux, PACEA, CNRS, Pessac, France

Predicting Quaternary hominin climatic niches using faunal assemblages with random forest algorithms

Pierre Linchamps, MNHN, ISYEB, CNRS, UPMC, EPHE, Université des Antilles, Paris, France & UPVD, MNHN, HNHP, CNRS, Paris, France

One-class vs binary classification of ceramic samples described by chemical element concentrations

Dario Malchiodi, Università degli Studi di Milano, Dipartimento di Informatica, & Data Science Research Centre, Milano, Italy

Simulation énergétique intégrée des systèmes miniers médiévaux

Florence Maqueda, Sorbonne Université, IRD, UMMISCO, Bondy, France & UVSQ, LAPA - IRAMAT, NIMBE, CNRS

Deep image prior inpainting of ancient frescoes in the Mediterranean Alpine arc

Fabio Merizzi, University of Bologna, Italy & Université Côte d'Azur, I3S, CNRS, Inria, Sophia-Antipolis, France – **Perrine Saillard**, Université Côte d'Azur, CEPAM, CNRS, Nice, France

Domain Generalization for the Classification of Punch Marks in 14th–Century Italian Panels

Wallace Peaslee, Department of Applied Mathematics and Theoretical Physics, University of Cambridge

Artificial Intelligence Meets Archaeozoology: Using Deep Learning to identify archaeological faunal remains

Kaveh Yousef Pouran

Neuro-Symbolic Artificial Intelligence for epigraphy: Application to the Epicherchell project

Julien Seinturier, Université de Toulon, Laboratoire d'informatique & Systèmes, CNRS

RBS mapping treatment with AI to define the layering of ancient materials

Astrid Tazzioli, Ministère de la Culture, NewAGLAE, CNRS, France & Centre de Recherche et de Restauration des Musées de France, Ministère de la Culture, France & Institut de Recherche de Chimie, Paris, Ecole Nationale Supérieure de Chimie de Paris, Chimie ParisTech-PSL, France

On Roman small finds: a meta-analysis in archaeology

Alyssa Turgis, Université de Lyon, Lyon 2, ArAr & Université de Lyon, Lyon 2, ERIC CNRS, Lyon, FRANCE

RÉSUMÉS

Session 1
AI-AM FOR HISTORY AND PHILOLOGY

Speaker : Mathieu Aubry (École des Ponts Paris Tech)

Exposé : Computer Vision for Historians: examples

Préface : In this presentation, I will give an overview of recent projects my team did on Historical document analysis and outline the main associated challenges and approaches. Applications will include works artwork auction price prediction [1], historical document segmentation [2], historical watermark recognition [3], repeated patterns discovery in artworks [4,5,6], scientific illustration analysis [7], handwriting analysis for paleography [8]. I will discuss in particular methods to avoid relying on large-scale human annotation of the datasets - the use of synthetic data, weak supervision, self or unsupervised approaches - but also the importance of annotations to define tasks and for evaluation.

[1] Biased auctioneers, M Aubry, R Kraeussl, G Manso, C Spaenjers, Journal of Finance 2022
[2] docExtractor: An off-the-shelf historical document element extraction, T. Monnier, M. Aubry, ICFHR 2020
[3] Large-Scale Historical Watermark Recognition:dataset and a new consistency-based approach X. Shen, I. Pastrolin, O. Bounou, S. Gidaris, M. Smith, O. Poncet, M. Aubry ICPR 2020
[4] Discovering Visual Patterns in Art Collections with Spatially-consistent Feature Learning, X. Shen, A. Efros, M. Aubry, CVPR 2019
[5] Learning Co-segmentation by Segment Swapping for Retrieval and Discovery, X. Shen, A. Efros, A. Joulin, M. Aubry, ArXiv 2021
[6] RANSAC-Flow: generic two-stage image alignment, X. Shen, F. Darmon, A. Efros, M. Aubry, ECCV 2020
[7] Image Collation: Matching illustrations in manuscripts, R. Kaoua, X. Shen, A. Durr, S. Lazaris, D. Picard, M. Aubry, ICDAR 2021
[8] The Learnable Typewriter A Generative Approach to Text Line Analysis, Y. Siglidis, N. Gonthier, J. Gaubil, T. Monnier, M. Aubry, arXiv 2023

Automatic Semantic Classification of Ancient Zoological Texts

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Abstract. We present an approach to semantically annotate the paragraphs of the ancient zoological text Naturalis Historia (Pliny the Elder) according to the concepts in the domain thesaurus TheZoo.

Key words. Ancient Zoology, Semantic Classification, Thesaurus.

1 Introduction

This work is conducted in the context of the Zoomathia international research network studying the constitution and transmission of zoological knowledge from Antiquity to the Middle Ages. We combine methods from natural language processing, knowledge representation and machine learning to classify and automate the semantic annotation of ancient texts using the TheZoo thesaurus (Leyra et al., 2015). We address the following research questions: (i) What is the best vector representation of concepts and paragraphs that we can use as input for a classifier? (ii) What is the impact of taking into account the semantics captured by a thesaurus in the vector representations of concepts?

2 Proposed approach

We consider two approaches to automatically classify paragraphs of Pliny's *Naturalis Historia* on ancient zoology into one or more macro collections of concepts (i.e. "Places", "Anthroponym", etc.) from the TheZoo thesaurus: (i) **The baseline method** consists into training a Support Vector Machine for each collection separately. In more detail, for a given collection, a binary classifier is trained to label a paragraph with a 1 if one concepts from the collection appears in, 0 otherwise. Each paragraph is represented as a vector of 512 dimensions generated by the Universal Sentence Encoder (USE) (Cer et al., 2018). (ii) **The knowledge-based method** extends the baseline by using the hierarchical information extracted from the thesaurus. First, we compute the embedded vectors of each concept under the top concept of each collection. Second, we obtain the centroid of each hierarchical group based on the embedded vectors (Tounsi Dhouib et al., 202). Finally, we compute the cosine similarity between the vectors representing each centroid and each paragraph. As a result, each paragraph is represented by a vector of its cosine similarities with respect to the centroids of each group of concepts. We use these similarities to train a classifier.

3 Experiments and results

We evaluated the performance of our approach on the books 8 to 11 of Pliny's *Naturalis Historia.* These four books are divided into paragraphs, which are manually annotated by linguists with concepts from TheZoo. We count 765 paragraphs annotated with 10 collections from TheZoo. Since our dataset is not balanced for all the collections, we used oversampling methods to balance it, and we applied the train-test split procedure with 80% for train and

20% for validation/test. In order to evaluate the performance of the proposed settings, we reported the precision (P), recall (R) and F1 score. Based on the F1 score, we see that our domain Knowledge-based approach outperforms the baseline for some collections such as *Place*, *Zoological information*, *Zoonym*.

Collection	Baseline method (SVM)			Knowledge-based (level 1)			Knowledge-based (level 2)		
	P	R	1 F	P	R	1 F	P	R	1 F
Anatomy	0.630	0.615	**0.621**	0.625	0.604	0.613	0.626	0.615	0.619
Anthroponym	0.651	0.599	**0.619**	0.636	0.572	0.597	0.651	0.580	0.609
Environment	0.575	0.546	0.557	0.569	0.539	0.551	0.578	0.546	**0.560**
Ethology	0.550	0.543	0.545	0.557	0.559	**0.556**	0.547	0.548	0.546
Gen. descr.	0.562	0.529	0.543	0.566	0.525	0.543	0.559	0.532	**0.544**
Place	0.665	0.620	0.639	0.673	0.624	**0.645**	0.658	0.603	0.627
Rel. btw man and animal	0.450	0.383	**0.412**	0.446	0.383	0.410	0.439	0.381	0.405
Topic	0.559	0.375	**0.444**	0.645	0.550	0.356	0.532	0.361	0.425
Zoo. info.	0.524	0.383	0.439	0.651	0.532	0.405	0.522	0.402	**0.451**
Zoonyms	0.625	0.600	0.611	0.630	0.606	0.617	0.633	0.610	**0.620**

Tab. 1 : Classification methods performance.

References

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Computer Vision and Historical Scientific Illustrations

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https://vhs.hypotheses.org/

Abstract. The VHS project (computer **V**ision and **H**istorical analysis of **S**cientific illustration circulation) proposes a new approach to the historical study of the circulation of scientific knowledge based on new methods of illustration analysis. Our contributions in this paper are twofold. First, we present a semi-automatic interactive pipeline for scientific illustration extraction that allows and incorporated expert feedback from historians. Second, we introduce a new dataset of scientific illustrations from Middle Ages to modern era consisting of 11k illustrations validated by historians and a total number of 235k illustrations obtained from 405k corpora pages. We further discuss our current research for identifying series of related illustrations from this data.

Keywords. historical document analysis; IIIF; illustration detection; deep learning

Introduction and context

Illustrations and their evolution in the scientific corpora of the Middle Ages and modern Western cultures have only been partially studied. More generally, the role of image in the construction and dissemination of scientific knowledge raise complex questions that remain historically delicate to grasp and for which adapted analysis' tools are lacking. To fill this gap, we aims to develop automated methods for extracting illustrations then analyzing their similarities, which will lead to the constitution of iconographic series that can be interpreted by historians. One major difficulty lies in the heterogeneity characterizing these corpora and the impossibility of carrying out large-scale annotations for every specific task. We thus develop approaches to handle the heterogeneity of historical data with limited annotation effort.

Various deep learning methods have been developed for visual analysis of historical documents. In this paper we focus on our dataset creation and illustrations extraction. We introduce the digital platform developed in order to allow historians to leverage deep learning methods, improve them by collaborative annotation, and historically analyze the results.

Dataset and illustration extraction

We started by building a platform to enable historians to upload 54 manuscripts and 704 printed volumes of interest in varying formats (IIIF manifests, JPEG, PDF), and the associated metadata. This resulted in 405,594 document images. To ease the work of annotating illustrations, we developed a two-stage workflow (Fig. 1). First, we exploited YOLOv5s (Jocher et al., 2020) trained on SynDoc (Monnier et al., 2020) and predicted illustrations bounding-boxed on a subset of 5788 representative images. Our platform then enabled historians to easily verify and if necessary use

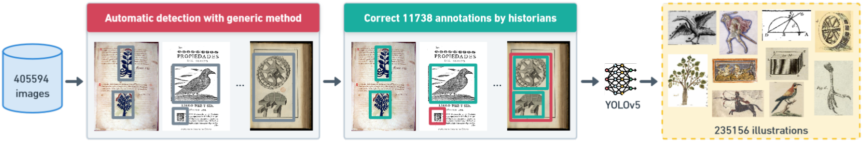

Fig. 1: Overview of our pipeline to refine illustrations detections in scientific historical documents.

Pre-training	Fine-tuning	Manuscripts				Prints			
		P	R	F-score	AP	P	R	F-score	AP
COCO	SynDoc	0.7	0.565	0.625	0.594	0.269	0.065	0.105	0.157
VHS	-	0.913	0.899	0.906	0.939	0.9	**0.701**	**0.788**	**0.797**
COCO	VHS	**0.96**	0.917	0.938	0.96	0.911	0.692	0.787	0.796
SynDoc	VHS	0.953	**0.93**	**0.941**	**0.964**	**0.916**	0.688	0.786	0.795

Tab. 1: Performance of YOLOv5s in precision (P), recall (R), F-score and average precision (AP).

SAS[1] to correct and complete these detections. We split this curated 'VHS' data into train (80%), validation (10%), and test (10%) sets and use it to fine-tune YOLOv5s. We will release this data upon publication. We tested different pre-training and fine-tuning strategies, and obtained a very significant boost over the network trained on synthetic data (see Table 1).We used the network pre-trained on SynDoc and fine-tuned on VHS to obtain 235,156 illustrations (including false positives) from our complete corpora.

Discussion

Based on this huge high-quality illustrations dataset, we work on developing similarity search algorithms and interfaces. We already obtained high-quality results using (Xi et al., 2021). Our next step is to equip the platform with tools that will enable historians to easily analyze and annotate the obtained image clusters, to assess their historical interest and to refine the developed similarity search tools, in a spirit similar to the one we have presented for illustration detection.

Acknowledgements

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Shen, X., Efros, A. A., Joulin, A., and Aubry, M. (2021) *Learning Co-segmentation by Segment Swapping for Retrieval and Discovery.* arXiv.

[1] https://github.com/glenrobson/SimpleAnnotationServer

Editing and Analysing Historical Astronomical Diagrams with Artificial Intelligence

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Abstract. The EIDA project explores the historical use of astronomical diagrams across Asia, Africa, and Europe. We aim to develop automatic image analysis tools to analyze and edit these diagrams without human annotation, gaining a refined understanding of their role in shaping and transmitting astronomy. In this paper, we present a method to detects lines and circles in historical diagrams, based on text removal, edge detection and RANSAC. We plan to compare this strong baseline with deep approaches. This work contributes to historical diagram vectorization, enabling novel methods of comparison and clustering, and offering fresh insights into the vast corpus of astronomical diagrams.

Key words. Astronomy; Diagrams; Line/Circle detection; Manuscripts; Vectorization.

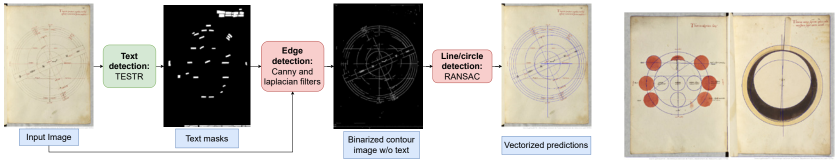
Context.

Astronomy flourished across premodern Eurasia as a means to understand the natural world and fulfill religious, ritualistic, and political needs. This knowledge primarily circulated in handwritten documents, which contained a rich diversity of diagrams and numerical tables alongside the texts. Building on the visual turn in the history of astronomy, we explore astronomical diagrams as visual heritage and as representations of, and support for, historical scientific reasoning. We aim to develop new image analysis tools that do not require previous human annotation to enhance the study and edition of diagrams (Jardine and Jardine, 2010). We present a computer vision approach to examine diagrams on a large scale independent of linguistic or cultural origin, enabling a deeper understanding of their roles in shaping and transmitting astronomy.

Methodology.

Line segment detection is a fundamental task in computer vision, commonly tackled using traditional methods such as Hough transform and more recently deep learning approaches. We propose a vectorization method that leverages RANSAC (Fischler et al. 1981) for line and circle detection after initial edge detection and text removal steps. RANSAC fits models to subsets of data iteratively, selecting the most consistent ones as the final result. Our edge detection is based on Canny (Canny, 1986) and we use TESTR (Zhang et al., 2022), a text-spotting transformer network, to effectively detect text, and experimentally validate the benefits of this step (see Tab. 1) on a set of 14 diagrams we annotated and will distribute.[1]

[1]https://imagine.enpc.fr/~kallelis/eida/visu/ransac_results.html



(a) Detection pipeline

(b) Detection examples

Fig. 1: **Fully automatic diagram vectorization pipeline.** Our workflow performs text and edge detection on a raster image, then performs RANSAC on the non-text edge pixels to obtain the line and circle proposals.

Experiment	Lines F-score ↑	Circles F-score ↑
ours with text removal	**0.483**	**0.496**
ours w/o text removal	0.366	0.281

Tab. 1: **Quantitative results.** We compare our RANSAC method with and without text removal over our annotated set of 14 diagrams. Detected lines and circles are considered true positives when they are within a marginal distance of ground truth annotations and false positives otherwise. Note that text removal significantly improves results.

Discussion and perspective.

Although it achieves satisfactory results, our proposed method has limited generalization capabilities and several failure cases. We believe a deep learning approach would allow for better generalization, however, this requires large amounts of data. Given their substantial scale and readily accessible ground truth, synthetic datasets offer an appealing alternative, which we will explore. Solving these problems will open new methods of comparison and clustering for astronomical diagrams, and prepare the stage for a fresh view of the huge corpus of astronomical diagrams.

Acknowledgements

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Session 2
AI-AM FOR ARTS AND ARCHAEOLOGY OF BUILDINGS

Speaker : Aleksandra Pizurica (Ghent University)

Exposé : Artificial Intelligence in digital painting analysis

Information processing in support of art investigation is an emerging and rapidly growing cross-disciplinary field of research. Museums are routinely digitizing their collections in multiple imaging modalities. Next to standard digital images of artwork, such as digital photographs, infrared and X-ray images, new sensing technologies are being developed and employed together with advanced techniques for analysing multimodal data. The progress in artificial intelligence (AI) and particularly in deep learning opens new, unprecedented possibilities for supporting technical study of art works, their conservation, and even the process of creation and interactive immersive presentation. AI-driven techniques are increasingly employed not only to authenticate artworks, but also to uncover their hidden details and connections to other works, to enhance viewing experience and to improve understanding of various layers of a masterpiece. In this talk I will present our results in the analysis of digitized paintings, and how they are employed to support art conservation and restoration, as well as art historical study. The focus will be on the case study of the Ghent Altarpiece and on the experience gained from a multidisciplinary collaboration in the framework of the recent major research and conservation campaign conducted on the Van Eyck brothers' masterpiece.

Classification of ancient characters in mural paintings of the Alpine arc

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Abstract. The attribution of wall paintings located in some medieval places of worships (15th-16th centuries) in the southern alpine arc is often debatable. The question of attribution is critical for the understanding of the artistic processes, transfers, and collaborations in such area. As a case study, we focus on epigraphic inscriptions to identify their authors by means of a simple classifier and using few (possibly fragmentary) labelled data. A preliminary study successfully distinguishes two painters with a 95% rate of paving the way for new studies and perspectives.

Key words. Supervised classification; painted characters; epigraphic inscription; wall paintings; southern alpine arc, Medieval art.

1. Historical and artistic context

In the southern alpine arc, the painted decors of medieval places of worship have mainly been realized during the second half of the 15th century and the early 16th century (Acquier, 2021). In this period, it was not systematic for an artwork to be signed by its creator. In some cases, some archive documents can be used to inform us about the painters' identity. When those data are not available, art historians have worked to identify the painters of unsigned and undocumented artworks based on stylistics studies. These attributions should be carefully discussed because: i) a same artwork may be attributed to multiple painters and ii) the realization date can often be arguable. A precise attribution study of the paintings in the area may be a valuable tool for better understanding artistic processes, transfers, and collaborations. *Painted* texts are frequent in the analyzed wall paintings. The use of textual content was privilege, often reserved to the master painter or to a painter copyist, either part of the workshop or independent (Acquier, 2021). In this contribution, we aim to refine some existing attributions of painted murals of medieval chapels in the south of the alpine arc by means of a supervised classification algorithm applied to scarce and fragmentary painted characters. In the long run, we hope to be able to distinguish painters by identifying their handwriting with the help of style classification techniques, as well as to study how epigraphic inscriptions may have been restored and/or modified, so as to identify the motivations behind these acts.

2. A preliminary case study and methods

As a case study, we focused our analysis on resized images of the painted character '*a*' for two identified painters: Giovanni Baleison and Tommaso Biazaci. They were the most prolific painters of the area under study and provided a significant amount of textual content in their painted images. Giovanni Baleison is indeed believed to have painted 12 places of worship, 4 of which were signed; Tommaso Biazaci is believed to be the author of the wall paintings of 15 chapels, 5 of which have been signed. The letters considered in our analysis came from the chapel *Sainte Claire* also called *Saint Sébastien* in Venanson, France, decorated by Baleison in 1481, and from the sanctuary of *Nostra Signora dell'Assunta* in Piani, Imperia, Italy, decorated by T. Biazaci in 1488. The dataset considered was composed by 42 and 47 images of the character 'a' for each painter. Roughly, 80% of the data was used to fine-tune several neural network architectures in combination with data augmentation techniques. In the end, a ResNet50 architecture (He et al. 2016) provided us with the best results comparable with those achieved by training a SVM on a similarity Gram matrix obtained via Stlye-GANs (Karras et al. 2019). The classifiers were tested on 18 letters and succeeded to correctly attribute them with a 95% rate of accuracy. A Grad-CAM visualization (Selvaraju et al. 2017) of the classified (test) characters is shown in Figure 1. It suggests a coherence of the classification results with respect to some stylistic differences between the two authors. Future work will focus on the use of this method to other letters/painters of our corpus. As a loss function we considered both a standard cross entropy (BCE) loss and a style loss function defined in terms of Gram matrices. Both choices show that despite the scarcity and the quality of the data, a simple classifier is able to successfully distinguish the two authors, see Table 1.

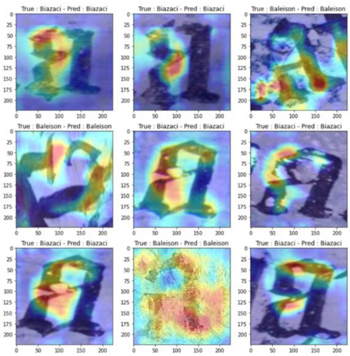

Figure 1: Grad-CAM visualization of a few correctly classified characters.

Model/loss	**Accuracy**
ResNet50/BCE	0.9444 (0.05)
SVN/Style Loss	0.9444 (0.08)

Table 1: Rates of accuracy on the validation data set (standard deviation in brackets)

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Detecting rock origin of blocks using surface roughness and colour : the case study of the ancient theatre of Orange (France)

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Abstract. The ancient theatre of Orange, one of the best preserved ancient theatres in the world, was built at the end of the first century BC. First geological analyses showed that different rock types, hence quarries, were used for its construction. Mapping the quarry origin of rock blocks is of paramount importance in archaeology to understand the construction history. However, manually mapping rock origin on all the theatre walls is a tedious task and not always possible with naked eye in humanly inaccessible building parts. Thus, we propose in this paper an approach for detecting block origin using roughness and texture descriptors. First analyses showed differences in colour and roughness according to facies types. These attributes can be then used in a segmentation algorithm to classify blocks. These results will be shown and discussed.

Key words. Ancient theatre; pattern recognition; roughness; texture; geology; facies ...

1 Data and proposed approach

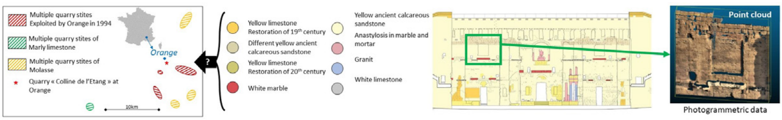

Fig. 1: Data and problematic: A) facies mapping of the inner theatre façade from [1]; B) map of potential quarries providing the block material; C) an example of a Lasergrammetic dataset showing two facies.

Previous studies have mapped different facies (rock type) on part of the theatre walls, such as the inner façade behind the stage (Fig. 1). Lasergrammetric acquisitions were also performed from different theatre façades and provided high-resolution point clouds with RGB attributes (Fig. 1). Interpreting rock types on all the walls and architectural elements of the ancient theatre of Orange is a daunting task. Moreover, in some places, it might be hard to distinguish facies with naked eye. Thus, the objective of this work is to facilitate the rock interpretation by, first, computing from point clouds descriptors that highlight rock characteristics, and second, using these descriptors to automatically classify blocks according to their rock type.

Beyond the chemical differences, facies may visually differentiate by their colour (Fig. 1), but also by their contents (e.g., fossiles, grains) considering their size (e.g., coarse or fine grains) and their organization (e.g., lamination), which leads to differences on surface roughness. Then, the proposed approach relies on the analysis of roughness and colour attributes.

Roughness analysis of natural rocks is not a novel issue and approaches were proposed to classify rock surfaces [2] using roughness descriptors. The proposed approach adapted these works to the present study objectives. Thus, an attribute α is first computed from the local surface variability using variogram computation. Second, the well-known Local Binary Pattern (LBP) descriptor [3] is calculated to decipher texture changes using different colour components (e.g., RGB, Lab, HSV). By combining these descriptors with a segmentation algorithm, it could be possible to map blocks sharing similar characteristics.

2 Results and perspectives

From preliminary tests, similarities and differences on histograms of the α attribute were observed from blocks stemming from, respectively, similar and different facies. The LBP attribute also shows different values depending on facies. Moreover, the LBP descriptor applied on the Hue of HSV reduces drastically the effect of shadows or highlights fire traces (Fig. 2) onto the block colour characteristics. The observed differences allow these descriptors to be candidates as input parameters for classifying blocks.

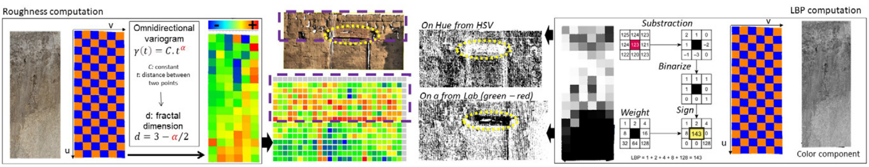

Fig. 2: Computation and results: left) α computation; middle) results, violet line corresponds to facies limit and yellow lines, fire traces; right) LBP computations.

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µLIBS imaging and Artificial Neural Network for the characterization of heterogeneous materials: the case of lime mortars

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Abstract.

Lime mortar was a building material widely used from antiquity to the Industrial Revolution. It is a complex mixture of lime and aggregates, with some components of the same chemical nature. That is mainly true for calcium carbonates, from different origins, which therefore need to be differentiated before any ^{14}C dating (Hayen *et al.*, 2017). µLIBS imaging (Laser Induced Breakdown Spectroscopy) for lime mortar characterization is a powerful newly used technique both in terms of sample requirements and mineral identification: it allows accurate differentiation of binder and calcareous and siliceous aggregates (Richiero *et al.*, 2022). However, material heterogeneity and the ever-increasing size of data sets (sometimes >1 million spectra) make spectral data processing difficult and time-consuming. Advanced statistical methods have become necessary to process these data, but most of them still require considerable expertise and are not suited to rapid data processing or high-throughput analysis. To address these issues, we have developed an artificial neural network (ANN) for processing LIBS spectral imaging data, in order to identify the different mineral phases in lime mortar (Herreyre *et al.*, 2023). The ANN have been trained to recognize the different phases in these complex samples by using over 1300 reference LIBS spectra, obtained from various pre-selected materials that may be present in mortars. ANN hyperparameters (data pre-processing, number of neurons and iterations) have been optimized to ensure the best recognition of mortar components. The results show fast, accurate identification of each component, especially for distinguishing the calcium carbonate of interest for dating. Using ANN seems to be an effective means of providing rapid, automated LIBS characterization of mortar, a concept that could be used for other complex and heterogeneous samples such as ceramics.

Key words. Lime mortar; mineral; characterization; LIBS; ANN.

1 Main text

Lime mortar is an almost ubiquitous material in buildings from antiquity to the Industrial Revolution around the Mediterranean Sea and Europe. It is of great interest for the study of construction phases in building archaeology, since it was produced for every phase. This also makes it a material of choice for dating of ancient buildings, as neoformed mortar calcite could by radiocarbon method (Labeyrie and Delibrias, 1964). Nevertheless, mortar is a complex and heterogeneous material composed of lime and aggregates, and besides neoformed calcite, it may contain other calcium carbonates that make dating false and are still impossible to separate from the neoformed one. Characterization is thus always essential before any dating attempt (Hayen *et al.*, 2017). In this framework, we aim to develop a method to extract neoformed calcite from lime by laser ablation based on its identification by Laser Induced Breakdown Spectroscopy (LIBS) imaging (Richiero *et al.*, 2022). The challenge of using this technique is in the large amount of spectral data, which are quite time-consuming and complex to process and interpret. To overcome this issue, we tested the use of a simple artificial neural network (ANN) structure to classify the main mortar components in a fast and automated way and thereby identify the right calcium carbonate for dating (Herreyre *et al.*, 2023).

We trained the ANN on reference spectral data obtained by µLIBS imaging (27 line intensities with wavelength from UV to near-IR, recorded by 3 spectrometers) from mineral and other raw materials (quartz, marble, limestone, shell, tile, charcoal…) as well as some mortars containing those materials. We have 1353 reference spectra with over 100 spectra for 8 different classes that may represent main families of mortar components. This corpus has been randomly divided into 2 sets for ANN training and validation.

We optimized ANN hyperparameters (data pre-processing, number of neurons and iterations) for the best classification model. The model was tested on whole spectral data from 3 mortars : 2 hydraulic mortars from Lugdunum aqueducts (Gier and Brévenne), and 1 pure lime mortar from the Angers Cathedral.

Results showed the ANN to be highly effective in rapidly processing and classifying data sets of over 500 000 spectra, with accurate identification for the 8 phases we have defined (e.g. Fig. 2). Our ANN has some minor problems in discriminating between the class of aluminosilicate minerals such as feldspars and the class of tile, due to the same chemical nature. However, the distinction between neoformed and geological calcium carbonates, which we are interested in for dating, is very effective.

For further tests, we will need to expand our reference corpus for more materials we might encounter, and indeed validate ANN selection of neoformed calcite by its radiocarbon dating.

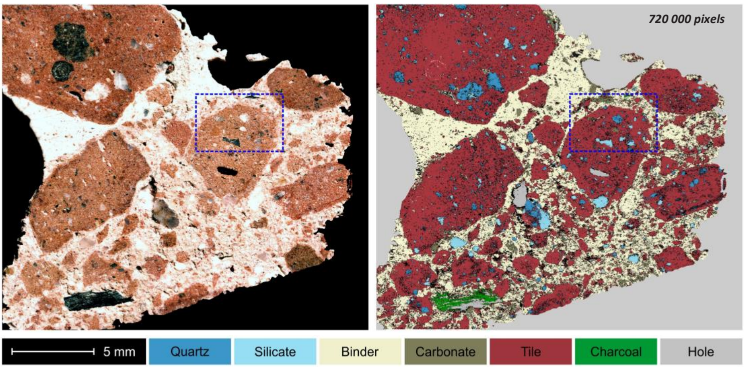

Fig. 1: Spectra classification by ANN on mortar from Gier aqueduct (Herreyre *et al.*, 2023).

Acknowledgements

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Session 3
AI-AM FOR MATERIALS OF THE PAST

Speaker : Gabriele Gattiglia (University of Pisa)

Exposé: Managing AI in Archaeology: opportunity and challenges

The advent of Artificial Intelligence (AI) applications within archaeology has brought incredible opportunities but also significant challenges. Only a few years ago, Machine Learning algorithms and Neural Networks were concepts unknown to archaeologists; now, AI has been applied to many archaeological fields, from the detection of archaeological sites, the recognition and reassembling of archaeological pottery, the mining of text from historical documents and epigraphs, the study of human remains, the identification of murals and graffiti, and even robotics. AI has great potential to create a better comprehension of shared archaeological heritage. In general, archaeology benefits from AI when a large amount of data must be analysed and when complex, highly specialised and time-consuming activities are required. However, despite popular perception, one of AI's most problematic aspects is not the algorithm's development but the creation of the dataset used to train it.

Therefore, together with a thorough knowledge of technical aspects, a more profound understanding of which archaeological research questions could be addressed, the availability and creation of the data upon which this research relies, the ethical, epistemological and hermeneutics side of the challenges that AI poses, and the lack of access to the necessary resources to undertake this work and its sustainability deserve more in-depth discussion and exploration.

Archaeological Classification of Small Dataset Using Meta- and Transfer methods of Machine Learning Approach: An example using Hittite Stele Fragments

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SHORT ABSTRACT. In recent years, the application of deep learning techniques in the field of archaeology has gained significant attention. Classification of archaeological artifacts poses a significant challenge due to the limited number of labeled samples available for each class. Our goal is to accurately predict the provenance of Hittite engraved stelae fragments from a small dataset containing only 136 fragments from 4 ancient Hittite cities: Alacahoyuk, Aslantepe, Karkamış, and Sakçagozu. For this classification task we explore the use of deep learning convolutional neural networks using a transfer learning approach on a pre-trained ResNet-18 model. Preliminary results are further compared with a meta-learning alternative model.

Key words Hittite Steles, Small Datasets, Image Classification, Transfer Learning, Meta Learning, Few Shot Learning (FSL)

The Method. Transfer learning has proven to be a powerful technique for various tasks in computer vision, where a model trained on a large-scale dataset, is fine-tuned to perform well on a target task with limited samples. In this study, we leveraged a pretrained ResNet-18 model and adapted it to the Hittite stelae classification problem by modifying its final layers to account for the four-class problem.

To prepare the dataset for training, the images are resized to 224x224 pixels and normalized using the mean and standard deviation values specific to the ImageNet dataset. We removed the data augmentation step, which included random horizontal flipping and rotation, to reduce variability in the results and ensure the reproducibility of our experiment. For the meta learning method to be applied, 4 Classes were created, each representing a Hittite city, 28 support and 6 query samples were assigned to each class (Totaly 112 support /24 query, Homogenius dataset 1500x1000 pxs). The research was conducted with Pytorch-Torchvision library using Google Collaboration.

The pretrained ResNet-18 model was fine-tuned on the support dataset using the stochastic gradient descent (SGD) optimizer with a learning rate of 0.001, weight decay of 0.0005, and a momentum of 0.9. A total of 2500 epochs were used to train the model, and the model's performance was evaluated on the query dataset. To address the random fluctuations in the accuracy, the model was trained multiple times with different random seeds, and the average performance was reported. After the fine-tuning process, the model's classification performance is evaluated on the query dataset, and the classification accuracy is calculated as the percentage of correctly classified samples out of the total number of samples in the query dataset. The proposed transfer learning approach using a pretrained ResNet-18 model achieved quite promising results on the Hittite stele classification task, with a mean accuracy of 91.6% of the training set.

Initially, the Model-Agnostic Meta-Learning (MAML- Model Agnostic Meta Learning) algorithm alongside a simple convolutional neural network (CNN) was proposed as a potential solution. MAML, a popular meta-learning approach, is designed to facilitate rapid learning from limited examples by optimizing the model for quick adaptability to new tasks. In the context of our problem, the MAML algorithm helped to adapt the simple CNN model to the task of classifying Hittite stele fragments with a small amount of training data. İn this method the support dataset is used for inner loop updates, while the query dataset is used for outer loop updates to validate the model's adaptation. After trying different parameter values, the result couldn't go beyond 50% success. However, upon further analysis, a transfer learning approach using a pretrained ResNet-18 model was found to be much more suitable for the given problem.

This study highlights the effectiveness of advanced machine learning approaches, like the transfer learning method, in tackling classification problems in archaeology affected by the small number of training data samples. Our investigation is also open to further exploration of other meta-learning algorithms and alternative transfer learning techniques, investigating additional data augmentation and preprocessing strategies to improve model performance on such tasks. The findings from this study contribute to the growing body of literature on the application of deep learning techniques in the field of archaeology and pave the way for future research in few-shot learning for artifact classification.

	Simple CNN + MAML (FSL)	**Pre-Trained Resnet18**
Num. Of Epochs	2500	2500
Learning Rate	0,001	0,001
Weight Decay	0,0005	0,0005
Momentum	0,9	0,9
Optimize Results	**%50**	**%91,6**

Tab. 1 : Comparison of Methods

Acknowledgements

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Torchvision documentation: https://pytorch.org/vision/stable/index.html

Hittite civilization: https://www.britannica.com/topic/Hittite

ImageNet dataset: http://www.image-net.org/

Astragalus bones identification via topological data analysis

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Abstract. Archaeozoology is a discipline that documents human-animal relationships in the past based on faunal remains found in archaeological contexts. One of the main challenges in this field is to distinguish morphologically close species through archaeological bones. Often, some species belonging to the same family or genus share common morphological features that are difficult to differentiate. We propose a novel approach using topological data analysis (TDA) on the 3D models of astragalus bones of the Caprinae's family. By analysing the geometric information of the bones, including connected components, cycles and holes, we are able to identify interspecies morphological features that can help distinguish closely related species. We then compare the performance of our methods with PointNet, a state-of-the-art method for 3D object classification.

Key words. Topological data analysis; Machine Learning; 3D models; Archaeozoology.

1 Model explanation

Traditional approaches used by the archaeozoological community for species identification are based on anatomical and biometric criteria, observed and measured from known and well-documented archaeological and modern osteological collections. In our case, we consider a 3D modern dataset (Vuillien 2020) consisting of 44 astragalus bones, divided into four species: chamois, goats, mouflons and sheep. We aim at classifying the bones at the species level by considering only the geometric structure of the bones. The final challenge is the prediction of the species of an archaeological bone.

1.1 Topological data analysis

TDA (Edelsbrunner and Harer 2022) is an emerging field that uses algebraic topology tools to extract topological information from the data. It relies on concepts of simplicial homology, homological algebra, and persistent homology. In this study, we present two methods for constructing simplicial complexes and calculating persistent homology from bone meshes and point clouds. These methods use two distinct filtration processes. The first one adopts Alpha filtration (Rouvreau 2015), a commonly employed filtration dealing with point clouds. The second method, called curvature-based filtration (CBF), has been introduced with the goal of emphasizing, during the filtration process, the appearance of morphological features used by the archaeozoologists for the identification of such species. The main idea behind CBF it to make appear the vertices/faces of the simplicial complex in a decreasing curvature order over the points of the shape. At the end of the

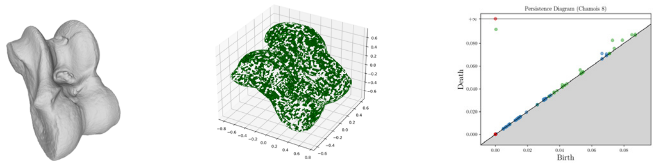

Fig. 1: From left to right: example of bone (mesh); corresponding Alpha complex at fixed radius; final PD.

filtration process, we collect the information in the so-called persistence diagrams (PDs), Figure 1.

1.2 Experiments and results

TDA allowed us to compare the bones through their respective PDs. After some experiments, we decided to calculate the Wasserstein distance between two-dimensional PDs thus obtaining a distance matrix between the 44 bones. The similarity kernel associated with the distance matrix was then injected into a Support Vector Machine for classification. Moreover, we fine-tuned PointNet (Qi et al. 2017) on our dataset, after training the network on ModelNet10. The results reported in Table 1 show that TDA outperforms PointNet in terms of accuracy, demonstrating its potential as a valuable tool for archaeozoologists working with complex morphological datasets.

Model	Training acc.	Test acc.
Alpha & SVM	1.000	0.730 ($\pm$ 0.065)
CBF & SVM	1.000	0.602 ($\pm$ 0.080)
PointNet & SVM	1.000	0.455 ($\pm$ 0.145)

Tab. 1: Comparison in terms of model accuracy.

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Deep learning *versus* geometric morphometrics for archaeobotany

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Abstract.

The taxonomic identification of archaeological fruits and seeds is of paramount importance for any archaeobotanical study. We compared the relative performance of deep learning and geometric morphometrics in identifying pairs of plant taxa using their seeds and fruit stones, which are the most abundant recovered organs in archaeobotanical assemblages and whose morphological identification, mainly between wild and domesticated types, allows the documentation of their domestication and biogeographical history. We used existing modern datasets of four plant taxa (date palm, barley, olive and grapevine). On these datasets, we compared the performance of a deep learning approach, here convolutional neural networks (CNN), with that of a geometric morphometric approach, here shape analysis using Elliptic Fourier transform (EFT). The results show, quite unexpectedly, that CNN outperforms EFT in most cases, even for very small data sets. We discuss the potential of CNN for archaeobotany, why outline analyses and more widely morphometrics have not yet said their last word by providing quantitative descriptions, and how archaeobotanical and more generally bioarchaeological studies could embrace both approaches, used in a complementary way, to better assess and understand the past history of species.

Key words. CNN, Convolutional Neural Network, Elliptic Fourier Transform, fruit stone, fruit grain, carpology

From sherds to(wards) pots: advances on mathematical modelling of Neolithic pottery

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Abstract. Pottery building techniques are important markers for the identification of ancient cultures and practices. The characterisation of the forming sequence allows to retrieve the technical traditions of the past and to identify communities of practice. In this talk, some advancements on the mathematical characterisation of forming sequence on selected regions inside pottery vessels are presented, representing an incremental step for the pottery technology analysis of complete archaeological pots.

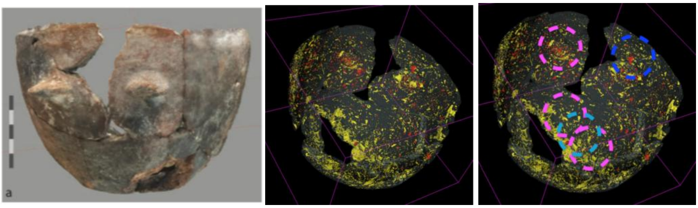
Key words. Pottery technology; Early Neolithic; Microcomputed tomography; 3D imaging; Image processing; Hough transform

1 Introduction

In a recent paper, a protocol applied to pottery sherds' tomographic data and based on the application of the 3D Hough transform to segmented porosity was proposed to discriminate between coiling technique and the Spiralled Patchwork Technology (SPT, Coli et al., 2022). The latter are among the major techniques implemented for pottery forming during the early stages of the north western Mediterranean Neolithic; coiling technique and SPT are keys for identifying communities of practice and, further, diffusion routes through the Mediterranean and Europe (Gomart et al., 2017, 2022a, b). In this exploratory work, a shift in the volume and complexity of data is proposed, coupling macroscopic and microscopic examination. Regions of interest (ROIs) are selected by experts within the internal structure of complete pots and analysed. This analysis is a test in the perspective of the treatment of large datasets of complete archaeological pots.

2 Material and methods

The archaeological pots come from the Pendimoun rock shelter (*Impressa* Neolithic; Early sixth millennium BCE, Binder et al. 1993, 2022) in Castellar (Alpes-Maritimes, France), whose ceramic assemblage technological analysis led to the first identification of the SPT fashioning sequence. In the present work, the pots that showed clear diagnostic macrotraces of the SPT were selected for micro-CT in order to correlate the macroscopic evidence with the vessels' internal microstructure. The investigation protocol consists of pore segmentation (semi-automatic, using Moment thresholding function) and visualisation, segmentation of the non-plastic inclusions (user-defined thresholding) and visualisation, followed by the region of interest (ROI) selection by experts. This intermediate step is crucial to orient the future analysis towards the entire volume of complete pots. The ROIs are selected according to pore and inclusion distribution patterns that are likely to correspond to a spiral patch (visualised in pink in Fig. 1, b), to superimposing patches (in clear blue in Fig. 1, b) or a region with no apparent pattern (in dark blue in Fig. 1, b).



(a) (b) (c)

Figure 1. (a) Pot AP001; (b) segmented porosity (yellow) and inclusions (red); (c) ROI selection

A progressive threshold based on pore size (volume) is applied on each ROI to highlight patterns designed by fine elements, which could be masked by larger elements. Large porosity elements can inform on the localisation of the interface between forming elements, or on the addition of vegetal fibres in the clayey material, while fine pores can be related to the form of the basic components assembled during the preforming stage. At present, this interpretation relies only on macroscopic observation and microscopic 2D petrography. The 3D Hough transform is applied to the segmented objects and the results between the different types of ROI are compared and interpreted at a macroscopic scale.

3 Discussion

Data visualisation via micro-CT and 3D imaging gives access to the high complexity of the considered pottery material. During the talk, an exploratory approach, aiming to highlight characteristic patterns of SPT, will be presented for several archaeological vessels. The multiscale analysis enables to broaden the point of view of the considered quantitative approach based on the 3D Hough transform, previously focused on local analysis of sherds, which still has to be improved for the processing of entire vessels. Moreover, the visualisation of different types of elements (both pores and non-plastic inclusions) inside the complete vessels enables a finer level of analysis, though at present it relies on experts' interpretation. Perspectives on future works include automatic classification of pore elements based on shape recognition and the search of invariants between ROIs to characterise the basic elements of the forming technique.

Acknowledgements

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IA-SeReOs, an interdisciplinary project towards the automatic segmentation of CT-scanned ancient bone remains

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Abstract. We present a project shared by biological anthropologists and computer scientists aimed at developing a deep learning method for the analysis of ancient bones scanned by X-ray microtomography. The IA-SeReOs project builds upon previous work by two of the co-authors that proposed a segmentation convolutional neural network, presenting the particularity to enforce the preliminary recognition of bone regions vs sediment rich regions.

Key words. Osteology; CNN; Image segmentation; Microtomography.

1 Context

Computed microtomography (micro-CT) has become a widely used characterization technique of ancient materials. Its non-destructive nature allows for producing 3D volumetric images of the inner structure of the specimens under investigation, with intensity levels provided by the local density of the material. The processing of CT scan data usually involves a segmentation step aimed at extracting a region of interest prior to further analysis. In the case of ancient bones, this operation can be complex due to the presence of extraneous material such as sediment and mineral grains. Indeed, these appear in the image as textured zones, infiltrated inside the specimen with intensity values overlapping with that of bone (Fig. 1).

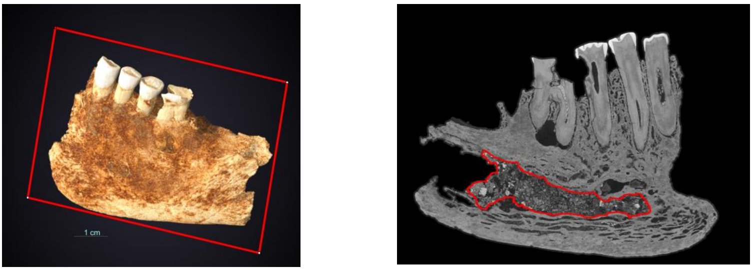

Fig. 1: *Homo sapiens* mandible fragment (bronze age, North of Spain) imaged by CT scan. 3D rendering (left) and virtual slice (right) highlighting the presence of sediment.

In these instances, a manual outlining of the bone, possibly assisted by semi-automatized region growing methods, is often the only workaround. This approach can be tedious and often depends on the expertise of the scientist, which can introduce bias and error into the segmentation process. The IA-SeReOs project (*Intelligence Artificielle pour la Segmentation 3D de Restes Osseux*) aims at developing a deep learning approach for segmenting bone material, both human and faunal, from soil and sediments in CT images.

2 Materials and methods

The team members in this project each present distinct expertise for the various aspects of the problem. In particular, a custom model was proposed recently by two of them (Yazdani et al., 2020), the "*Discriminative Sparse Regularized Deep Network for µ-CT segmentation*". This network processes patches extracted from the 3D image. It comprises two parallel convolutional layers followed by a U-Net model. The parallel layers aim at computing an intermediate representation of the patches according to their bone/sediment content (*discriminative*). The representation features are then passed to the U-Net model that performs the pixel-wise segmentation task. The discriminative layers are jointly optimized each with its own custom loss function, that comprises penalty terms (*regularized*) emphasizing the dominant character of the patch while excluding the other. An additional term is added to the sediment detecting loss function to reduce the number of weight parameters (*sparse*). This particular structure has the ability to promote the mutually exclusive segmentation of the bone and the sediment.

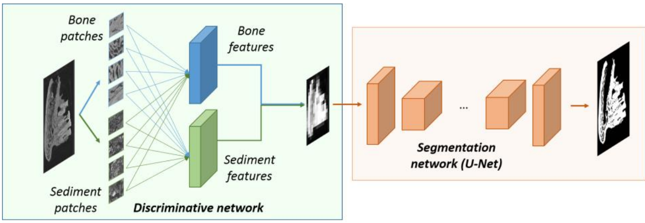

Fig. 2: Architecture of the proposed model.

3 Results and perspectives

The model has been previously trained and tested with several specimens with various sediment content and morphology and shows promising perspectives in terms of robusticity and ease of use for non-expert users (Fig. 3). The goal now is to upscale it to a wide range of specimens with different morphologies and preservation conditions.

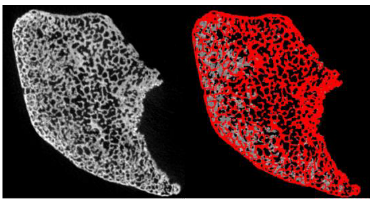

Fig. 3: Segmentation of a *Homo sapiens* bone with the model.

Acknowledgements

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Machine Learning vs frequentist statistics chemical data processing for dolerite archaeological artefact raw material origins.

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Key words. Arcaheochemical analysis; Polished stone tools; Neolithic; raw matherial clasification;

An non-destructive apporach to chemically characterize dolerite lithic artefacts, found in Neolithic-Chalcolithic sites and possible related outcrops, in the Westearn Mediterranean region of the Iberian Peninsula, has been developed employing portable energy dispersive X-ray fluorescence spectroscopy (pXRF). The elemental data obtained from the lithic materials, were processed using different algorithms and comparative studies using Machine Learning (ML) algorithms. Supervised and unsupervised ML implementation, to categorize and trace the origin of the raw material present in archaeological dolerite tools, have been carried out. In unsupervised learning the goal is to identify group patterns within the dataset. On the other hand the Supervised learning predicts the origin of the tools. We divided dolerite tools data into two official parts: validation and training. A training dataset is used to calibrate the parameters of the algorithm while a validation dataset is used to test the performance of the algorithm.

We will also crossed the results with those obtained from classic statistic classification methods. The results showed the potential of ML as a statistical tool to predict stone tools raw material origins.

Raman Spectroscopy of Flint and Artificial Intelligence: A Powerful Tool for Studying Fire Use by Hominins

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Abstract.

Pyrotechnology was critical in developing hominin adaptations, society, technology, and biological evolution. Fire identification in archaeological sites primarily relies on visual identification of altered sediments, lithics, and bones (e.g., soil reddening, discoloration, pot lids, warping, cracking, shrinkage, darkening, or calcination). Other complementary analytical techniques extensively used to identify heat exposure of clay sediments, lithics, and bones include magnetic susceptibility, Fourier-transform infrared spectroscopy (FTIR), thermoluminescence, and micromorphology.

In this talk, I will present two archaeological case studies where we combined Raman spectroscopy and artificial intelligence to build a thermometer to estimate the temperatures to which different flint/chert lithics were exposed. Our first case study was performed in lithics excavated from the Deep Shelf layer of the archaeological site of Qesem Cave (Israel), dated about 320,000 years ago (Agam *et al.*, 2021) where we found a relation between heating temperatures and lithic typologies. The second case study focused on the lithic assembly from the open-air site of Evron Quarry (Israel) about ~1 million years ago with no apparent signs of fire use (Stepka *et al.*, 2022). These two case studies highlight that AI-Raman spectroscopy tool can be used to identify fire use by hominins and that these behaviors can be more widespread
than previously thought.

Key words: Fire, pyrotechnology, flint/chert, stone tools, materials, artificial intelligence, deep learning

Acknowledgements

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Thin Details Meet Large-scale 3D-reconstruction: Photometric Stereo for Cultural Heritage

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Abstract. This talk will discuss the 3D-digitization of two cultural masterpieces: the Chauvet cave and the Bayeux tapestry. Both of these cultural heritage treasures are exceptional in their size and their fine-scale details, which raises the challenge of correctly reconstructing both the low and the high geometry frequencies. We will discuss two ways to extend the classic photometric stereo technique, which excells at recovering the thin structures. First, we will show how to combine it with multi-view stereo, in order to get a rough 3D-reconstruction of the whole cave. Then, we will put forward a deep learning-based solution for creating a 2.5D panorama of the tapestry.

Key words. 3D-reconstruction; cultural heritage; photometric stereo.

Introduction. Digitizing cultural heritage artifacts such as the Chauvet cave (see Fig. 1, left) or the Bayeux tapestry (see Fig. 1, right) is of major interest for both the general public, archeologists and curators. However, it is difficult to reconstruct all their fine-scale details, in view of the exceptional size of these marterpieces. For small-scale scenes, the thin details can be reconstructed using the well-established photometric stereo technique, which is an active 3D-reconstruction method where multiple images are acquired from a fixed viewing angle, yet under varying illumination. In this work, we propose to extend this technique to the multi-view setting for digitizing the Chauvet cave, and with a 2.5D panorama generation pipeline for digitizing the Bayeux tapestry.


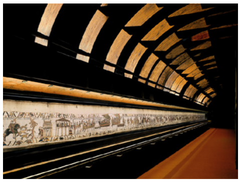

Fig. 1: Left: “Horses pannel” at the Chauvet cave. Right: the Bayeux tapestry.

Digitizing the Chauvet Cave The Chauvet cave is a treasure of palaeolithic art. The quality of conservation of the rock art makes it an invaluable witness to this period of prehistory. In the interests of preservation, access to the cave is very restricted, making the digitization of the cave a tool of major scientific interest for archaeologists. Because of the sheer size of the panels, photogrammetry was the technique of choice for digitizing the cave. However, palaeolithic artists also expressed themselves through very fine engravings on the wall or by digitized tracings that erase the thin brown clay deposit and reveal the white of the limestone wall (see Figure 2), which cannot be recovered using photogrammetry. Moreover, the analysis of the antero-posteriority of the engravings merges with the different phases of creation of the paintings or of the animal activity is of great interest to archaeologists. This means that it is necessary to be able to easily separate the relief from the color during the study. Photometric stereo meets both these needs. However, digitizing the entire cave using photometric stereo is out of the question because of the time required to capture the images. We are therefore proposing a combined approach, in which the entire cave is reconstructed using photogrammetry, and certain areas of interest are reconstructed more precisely using photometric stereo.

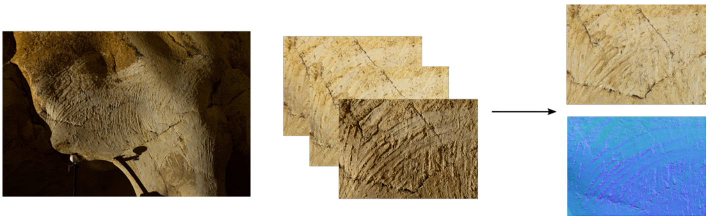

Fig. 2: Chauvet cave: “Panneau des Mammouths raclés” (left), zoom on three images (among fifteen) under different lightings (center), and estimated albedo and normal map (right).

Digitizing the Bayeux Tapestry The Bayeux tapestry, shown in Figure 1, is 70 metres long and 50 centimetres high *embroidery* exhibiting fine-scale wool strings on a woolen canvas. It has already been fully digitized in 2D under daylight[1], and we now aim at converting this panorama to 2.5D using deep learning techniques. To do so, a dozen of scenes from the tapestry were reconstructed using the photometric stereo technique, which provides us with a database of (RGB image, 2.5D normal map) associations (see Fig. 3, left and center). A GAN-like neural network was then trained on this dataset to convert an RGB image of the tapestry into a normal map. It was then applied to the full RGB panorama to obtain the 2.5D panorama (see Fig. 3, right).

Fig. 3: Bayeux tapestry: A scene of the tapestry under different lighting (left), photometric stereo-based decomposition of this scene into reflectance and 2.5D normals (center), and full 2.5D normal map panorama obtained with a generative adversial network (right).

[1]https://www.bayeuxmuseum.com/la-tapisserie-de-bayeux/decouvrir-la-tapisserie-de-bayeux/explorer-la-tapisserie-de-bayeux-en-ligne/

Using statistical learning methods applied to stratigraphy and pottery to help establish periodisation in archaeology.

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Key words. Statistical Learning Methods; unsupervised clustering; supervised clustering; archaeology; pottery; stratigraphy;

1 Context and objective

The development of archaeo-statistical analysis methods is essential for the detailed study of large datasets of artefacts (pottery, objects, glass, etc.). Through a long-standing interdisciplinary collaboration, initiated first for the city of Tours, then for the Middle Loire Basin (Husi dir., 2022) and currently for the city of Angkor Thom (Cambodia), we have developed various analytical tools (Bellanger et al., 2012; Bellanger et al., 2021a, Bellanger et al., 2021b). The aim of this paper is to present an original approach that contributes to the periodisation of stratigraphic sets (chrono-functional units: domestic levels, dumps, fills, etc.) from different archaeological sites, sometimes spatially distant, on the basis of the pottery assemblages that constitute them. In other words, the aim is to present a methodology for defining pottery facies and their rhythm, one of the essential tools for establishing the periodisation in archaeology, in this case of Angkor Thom (Cambodia), capital of the Khmer Empire between the 9th and 15th centuries (Gaucher, 2004).

The approach is divided into 2 main stages using statistical learning methods (Hastie et al., 2009). The first stage, compromised clustering (Bellanger et al., 2021b), identifies pottery facies based on the most reliable sets from a chronostratigraphic point of view. The second stage, supervised clustering, assigns less reliable stratigraphic sets to one of the previously constructed pottery facies. This archaeo-statistical approach is essential for the construction of a chronological model of the city, one of the main objectives of the ANR ModAThom project, since pottery are the main material excavated at Angkor.

The tools developed have been implemented in an R `SPARTAAS` package (Coulon et al., 2023).

2. Material and methods

2.1 Materials

Two dialectically linked sources of information are mobilised here: stratigraphy (over/under relationship; after/before) and pottery assemblages (number of sherds per pottery category and per stratigraphic set). Our approach is based on the creation of two datasets:

- A reference dataset consisting of 120 stratigraphic sets selected for their chronostratigraphic reliability and the quality of the pottery assemblages.
- A supplementary dataset consisting of 121 stratigraphic sets considered less reliable, with pottery assemblages more disturbed by residual material.

2.2 Methods

2.2.1 Compromised hierarchical clustering (hclustcompro)

Consider a set of n objects and denote $\mathbf{D}_1$ (respectively $\mathbf{D}_2$) the normalised dissimilarity matrix $n \times n$ associated with the first (respectively second) information source. The principle of the hierarchical clustering by compromise (hclustcompro) method (Bellanger et al., 2021) is based on the application of a clustering algorithm to the following convex combination of curves:

$$\mathbf{D}_\alpha = \alpha \mathbf{D}_1 + (1 - \alpha)\mathbf{D}_2$$

where $\alpha \in [0; 1]$ is a fixed parameter that weights each dissimilarity matrix. Once α is fixed, the clustering dendrogram can be constructed using any of the aggregation strategies satisfying the formulation of Lance and Williams (1967). Thus, the key point of this approach is the choice of α. The determination of α depends on a criterion ($CorCrit_\alpha$). The criterion measures the fidelity with which a dendrogram preserves the initial dissimilarities of the two sources (Sokal and Rohlf, 1962; Everitt et al., 2001). In our case, the two sources of information available for each set are its pottery assemblages and its position in the stratigraphy.

2.2.2 Supervised clustering

The aim of this second stage is to integrate the supplementary sets into the periodisation while preserving the notion of uncertainty associated with them. To do this, we use statistical learning methods (Hastie et al., 2009) to predict the facies to which they belong. The reference sets that actively contributed to the construction of the facies in the clustering by compromise, stage are used again to select and train the supervised clustering model that assigns the sets judged to be less reliable to a given facies. Several supervised clustering models adapted to our archaeological data are possible. We used the R package ecosystem `tidymodels`[1] to train, develop, test and compare the models. We compared four models, namely: K-NN, Logistic Regression, CART Decision Tree and Random Forest.

3 Results and discussion

This work enabled 4 main pottery facies to be identified from the 120 reference stratigraphic sets. A further 121 sets were then assigned to one of these 4 facies using a supervised clustering model. The periodisation of the city of Angkor Thom can thus be clarified.

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ARCHAEOLOGICAL CLASSIFICATION AND MACHINE LEARNING. Statistics, Bayesian Statistics and Neural Networks

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In this paper, we present how to use a supervised Machine learning approach to archaeological reconstruction. Classical Multivbariate Statistics, Bayesian Probabilistic networks and Feed Forward neural networks are used to build an associative memory where complete pottery vessels are represented and we use it to associate different fragments to the most probable complete form they may come from.

Because the objective of the paper is basically theoretical, we use a simulated data base where pottery shapes are represented using six quantitative measurements (diameters and heights) and six qualitative attributes (decoration, surface characteristics). Simulated fragments are represented using the same measurements and attributes when available, and as missing values when the sherd appears to be too small to measure. Statistical classification and numerical taxonomy methods are used in a preliminary step, and results are compared with different algorithms of neural networks. Finally, the concept of induction and generalization is critically debated.

A key aspect in our approach is a critical evaluation of the very idea of object similarity: Two entities are similar because they have many properties in common. According to this view (Medin 1989):

- similarity between two entities increases as a function of the number of properties they share;
- properties can be treated as independent and additive;
- the properties determining similarity are all roughly the same level of abstractness;
- these similarities are sufficient to describe a conceptual structure: a concept would be then equivalent to a list of the properties shared by most of its instances.

The problem is that fragments are not "similar" in shape, even though they come from the same pot or from pots with the same general shape. We need a form of supervised learning, because some known instances of a particular fragment-to-complete shape relationship should be used. In this paradigm, an agent learns to classify fragments as members of generalized shapes through trial and error with corrective feedback (prior knowledge) (Baxter 2006, Barceló 2009). Known examples of a particular input-output mapping may be experimental replications and/or ethno-historical data. In other words, the idea is to look for common features between positive examples of the fragment-to-pot relationship to be predicted, and common differences between its negative examples. For best generalization, we need an algorithm able to match the complexity of the hypothesis with the complexity of the function underlying the data. If the hypothesis is less complex that the function, the resulting model will be underfitted. If the hypothesis is too complex, or the data is not enough to constrain it, we will end up with a bad hypothesis. If there is noise, the resulting model will be overfitted because it is not only based on the underlying function but also on the noise in the data. In such a case, having more examples, or known instances helps but only to a certain point (Alpaydin 2004).

Neural networks are a special kind of algorithm able to learn non-linear and non-monotone input-output relationships. They have three main characteristics that have contributed to the wrong idea that they mimic the way the human brain operates: they work in a distributed and parallel way; they are also the result of adaptive process of learning. 'Distributed' means that calculations are decomposed into thousands of basic calculations between some basic computational units. ‘Parallel’ means that all those calculations are made simultaneously and all of them contribute to the final solution. ‘Adaptive’ means that they learn through reinforcement of rewards in successive ‘evolutive’ steps.

The most known learning algorithm to solve this kind of problem was invented in 1986 by David Rummelhart, Geoffrey E. Hinton and others, and it is called Backpropagation (Rumelhart et al. 1995; Kishore, Kaur 2012). Once learned, a neural network can be used as associative memory, and therefore it assigns to new unseen inputs, the output that probably corresponds. It is a distributed representation of scientific knowledge because causal and other explanatory associations are stored throughout all the connections in the network, and because one set of connections can store several different associations. After learning, when using the network to categorize a new input, if the associative mechanism runs properly, then the pattern of activation in the output neurons will be the pattern that was originally associated with the cue pattern.
An artificial neural network for multi-label classification predicts the probabilities of each output node independently of all other nodes. In this way, it allows information to be simultaneously classified into multiple categories, which distinguishes this classification algorithm from others, such as discriminant analysis, because the neural network does not compute the probabilities of outputs in conjunction with or in opposition to any other output (Lin 2021).
The advantages of this way of learning what archaeological elements may be – the concept to which they probably belong – are obvious. First of all, the relationship between input and output, between description and explanation can be non-linear, when classical statistical classifiers are limited by the intrinsic linearity of distinctions they can reproduce. Second, qualitative attributes can be added to quantitative ones. Parametric assumptions, normality or symmetry are not required.

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Session 4
AI-AM FOR MODELLING OF SOCIO-ENVIRONMENTAL SYSTEMS

Speaker : Andreas Angourakis (Rühr Universitat Bochum (RUB))

Exposé : Simulation, Machine Learning, and their Synergy in Addressing Past Socio-Environmental Systems

Simulation and machine learning are two powerful approaches to understanding complex phenomena. Simulation modelling, including but not only system dynamics and agent-based modelling, is to design models to reproduce patterns and trends in empirical data as outcomes of postulated mechanisms under controlled conditions. Machine learning is a family of data-based or descriptive approaches that involve the creation of models able to recognize patterns and make predictions based on large datasets. Despite their shared background and fundamental relationship to AI, they differ in several aspects, among which the most essential is how causality is considered. More recently, both epistemological and pragmatical differences between these approaches have contributed to the unfortunate distancing between communities of practice, particularly accentuated in the study of past complex systems.
However, acknowledging these differences also reveal an opportunity to combine them and bring a more powerful paradigm to light [1]. Simulation can be used for machine learning (generating training datasets and hypotheses sets, serving as learning algorithms, validating final hypotheses) and, conversely, machine learning can be used for simulation (model generation, selecting and processing input data, detecting patterns in simulation output, calibrating parameters, serving as a simulation model component). Deep learning, and particularly the latest generations of large language models, bring the potential of mixed workflows to a new, unforeseen level.
This lecture will present an epistemological outline of simulation and machine learning and emphasize the potential of hybrid methodologies to address complex socio-environmental systems. Although there are still a few examples of deliberate applications, I will overview a selection of explored and unexplored use cases, including insights from previous and current work in modelling ancient agriculture and foodways [3,4,5].

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Archaeology and Climate Change: New Perspectives of Agent-Based Modelling coupled with LPJmL agroecosystemic model for the Study of relationship between agricultural production and past societies

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Abstract. Appearing in the 1990s in the United States to analyze the rise and fall of Amerindian societies, agent-based modeling applied to archaeology has been developing for about fifteen years in Europe. In the field of Distributed Artificial Intelligence, ABMs offer the possibility of simulating the processes at work in the transformations that affect ancient societies by mobilizing multiple entities that interact with each other and with their environment, thus generating a dynamic. Simulations make it possible to test hypotheses concerning these processes to understand the trajectory of ancient societies, whose changes perceived by archaeologists and historians are interpreted by mobilizing different concepts (crisis, mutation, reorganization, etc.).

Regardless of the results produced by these models, ABMs also have great heuristic virtues. The development of conceptual models and the computer implementation of these socio-environmental systems require a rethinking on the complex interactions between social processes and natural phenomena, on the different types of data to be integrated, on their articulation and the relevance of the parameters selected: this requires a close dialogue between human and social sciences, environmental sciences and computer sciences.

In this communication we will present in more detail the ROMCLIM and ROMPIRE-LPJmL models developed in RDMed and the recent ANR MICA projects to analyze the evolution of settlement, agricultural production and agrarian landscapes at different scales (southern Gaul, Roman Empire) between the Iron Age and the end of Roman antiquity, in relation to climate change.

Key words. ABM; Climate Change; Agricultural Productivity; Roman Empire; Roman Climate Optimum, Late Antique Little Ice Age

1 Agent-Based Modelling, Archaeology and Climate Change

ABMs make it possible to model socio-cultural systems and environmental dynamics and to observe the results of their interactions. Different hypotheses on the endogenous and exogenous causes of the rise and fall of ancient societies can thus be tested by multiple simulations.

In Europe, the recent growing number of articles and books testifies in recent years to the heightened interest of archaeologists in agent-based modeling, inspired by the Anglo-Saxon works. While ABMs have aroused the interest of prehistorians and protohistorians, they are now also beginning to develop in the field of more classical Roman studies. These are now opening to the modelling approach, particularly in the Netherlands and England.

In general, the ABMs developed in the United States and Europe respond to various archaeological and historical issues concerning different chrono-cultural periods between Prehistory and late Antiquity, or even the beginning of the Middle Ages. For most of these models, environmental changes do not appear to be considered (perhaps because of a still insufficient involvement of paleoenvironmental specialists in these projects). Models simulating climate variations and their impact on ancient societies are still few, although agent-based modeling appears particularly well suited to this type of problem, which is part of the complexity of human-environment relations.

2 Impact of Climate Change on Roman Empire

The evidence of a warming climate between the 3rd century BCE and the 2nd century CE based on various continental and oceanic paleoclimate proxies has led to questions about its impact on ancient societies. While the beneficial role of this Roman Climate Optimum (RCO) on agriculture in the Roman Empire has recently been evoked, as well as the negative effect of the Late Antique Little Ice Age, it is still difficult to measure with certainty the effects of these climatic fluctuations on agricultural yields and the economy based on textual and archaeological sources alone, which are often very scanty and incomplete or difficult to interpret.

2.1 Use of ABM

The application of agent-based model to archaeology, which provides a new exploratory tool, now makes it possible to overcome these difficulties. It is indeed possible to test multiple hypotheses on the interactions between societies and their environment, independently of the quantity or quality of the data available. In archaeology, this type of modeling has been used for some years to deal with questions related to the demography of ancient societies, agricultural strategies, carrying capacity, and settlement dynamics.

What impact did the Roman Climate Optimum (RCO) and the Late Antique Little Ice Age (LALIA) have on the rise and fall of the Roman Empire? The agent-based modeling (ABM) approach is developed to evaluate the impact of climate change on the profitability of vineyards, olive groves, and grain farms which were the main source of wealth in the roman period. These ABM simulate an agroecosystem model which process potential agricultural yield values from paleoclimatic data. The model calculates the revenues made by agricultural exploitations from the sale of crops whose annual volumes vary according to climate and market prices. The potential profits made by the different agricultural exploitations are calculated by deducting from the income the operating and transportation costs.

2.1 Results and discussion

We conclude that the warm and wet climate of the Roman period may have had an extremely beneficial effect on the profitability of wine and olive farms between the 2nd century BCE and the 3rd century CE, but a more modest effect on grain production. Subsequently, there is a significant decrease in the potential profitability of farms during the Late Antique Little Ice Age (4th-7th century CE). Comparing the results of our model with archaeological data enables us to discuss the impact of these climatic fluctuations on the agricultural and economic growth, and then their subsequent recession in west roman empire from the beginning to the end of antiquity.

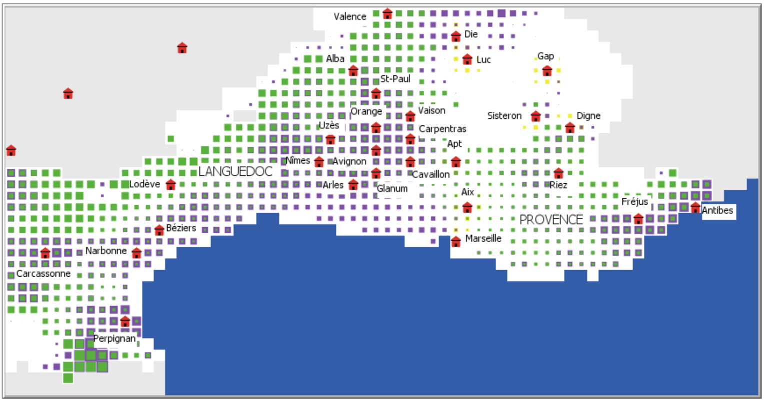

Fig. 1 : Potential benefits for wineries (purple squares) and olive groves (green squares) according to climate data of the 1st c. AD in Southern Gaul.

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Explore the impacts of socio-environmental interactions on Gallo-Roman settlement dynamics: an Agent-Based experiment

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Abstract. Complexity theory provides useful concepts for archaeological issues related to the understanding of past societies and their environment. More specifically, Agent-Based Modelling is a relevant tool to explore scenarios and to test hypotheses about the impacts of complex socio-environmental interactions on the transformations of ancient settlement systems evident in archaeological records. After a short historiography of complex systems modelling in Archaeology, the presentation will focus on the main issues of the ModelAnSet model and its first results. In this case Agent-Based Modelling is used to explore the respective impacts of environmental and social factors on the settlement pattern and dynamics during the Roman period in South-Eastern France. The model aims at simulating the impact of the climatic and macro-economic conditions on the behaviour of Gallo-Roman landowners. According to the profit they derive from their farms and/or villas, which depends both on natural and socio-economic factors, the landowners can decide to maintain without change, improve, enlarge or abandon their holdings or to create a new one. The potential yield of each holding is calculated using the LPJmL agro-ecosystem model adapted to Ancient agriculture and to paleoclimatic data reconstructed for the Roman period. Through the repeated landowners decision-making, the ABM simulates a changing macro-level settlement pattern, in terms of number, type and location of the settlements. The first results of this work will be presented and opened to the discussion.

Key words: Agent-Based Modelling; Archaeology; Settlement pattern; Roman Empire; Agricultural production; Paleoclimate

1. Introduction

Research carried out over the last thirty years in southern and central France has shown that the Roman conquest resulted in great variability in the density, form and structure of the settlement in the conquered provinces, tempering its supposed homogenising effect on the settlement patterns (Van der Leeuw et al. 2003, Bertoncello et al. 2012, Ouriachi and Bertoncello 2015). Within the same region, some areas are intensively and permanently settled, while others are more sparsely and ephemerally occupied. Dwellings types and the spatial and hierarchical organisation of the settlement also vary. For pre-industrial societies, the settlement pattern and dynamics result from a complex interweaving of environmental factors (topography, soil quality, hydrology, climate) which define the potential and limitations to the occupation and exploitation of an area, and social factors (social structure, degree of technical sophistication, intensity of trade, economic power, etc.) which enable to increase the exploitation of resources while reducing the impact of environmental constraints. In order to explore the interactions between these different factors on the settlement pattern, we developed an Agent-Based Model (ABM) to simulate the behaviour of Gallo-Roman landowners regarding their agricultural holdings, which were the main components of the Ancient settlement system.

2. The model components and dynamics

The model simulates the creation, maintenance, enlargement, improvement and abandonment of agricultural holdings by the landowners according to their economical power and the profit (economic and symbolic) that they derive or expect to derive from their holdings. This benefit varies according to the type of environment, whose fertility is impacted by climate change, and according to the macro-economic context. Although there was a great diversity of Gallo-Roman landowners, and as modelling imposes to simplify reality, we only consider three types of agents with different socio-economic status: the farmers, the big landowners, and within this group, the aristocrats, meaning magistrates who played a political role in the city. We implemented behaviours to each agentset of landowners. To do so we used the Belief Desire Intention (BDI) architecture which allows the agent to take decisions based on a set of beliefs and desire which are confronted with the simulation. Two strategies of the landowners are tested. The first one is a profit-oriented strategy while the second aims to secure income and consolidate the main holding. Two types of agricultural holdings have been designed based on historical and archaeological data: farms and villae. The potential yield of each holding is calculated using the Lund-Potsdam-Jena-managed-Land (LPJmL) agro-ecosystem modelling (Bondeau et al. 2007, Fader et al. 2015) adapted to Ancient agriculture (Contreras et al. 2018, Contreras et al. 2019, Bernigaud et al. 2021) and to paleoclimatic data reconstructed for the Roman period (Guiot and Kaniewski 2015). The model was instantiated in a specific spatio-chronological context which is the territory of the Roman colony of *Forum Iulii*, the actual Fréjus in South-East of France, where archaeological and palaeoenvironmental studies have been conducted for over 20 years. This instantiation helped defining some model parameters and will also allow to evaluate the simulation outputs. Through the repeated landowners decision-making, the ABM thus simulates a changing macro-level settlement pattern, in terms of number, type and location of the settlements. The model includes feedbacks between agents behaviour and the properties of their environment, as they can improve land productivity but also degrade it by over-exploitation.

3. Results

The results are still in process. We are creating a plan of experiment on the OpenMole platform to test all the combinations of the three parameters to identify patterns and confront our hypothesis to a sharp protocol of calibration and sensitivity analysis. The models outputs will be confronted to archaeological settlement distribution maps in the Fréjus area, in order to test the relevance of the simulated processes. We outline the fact that models, and ABM in particular, are powerful heuristic tools for archaeologists: the aim is not to reproduce past reality, which is out of reach, but to use simulations results to select within our hypothesis which ones are the most plausible or the least inconsistent with archaeological observations.

1.2 Figure

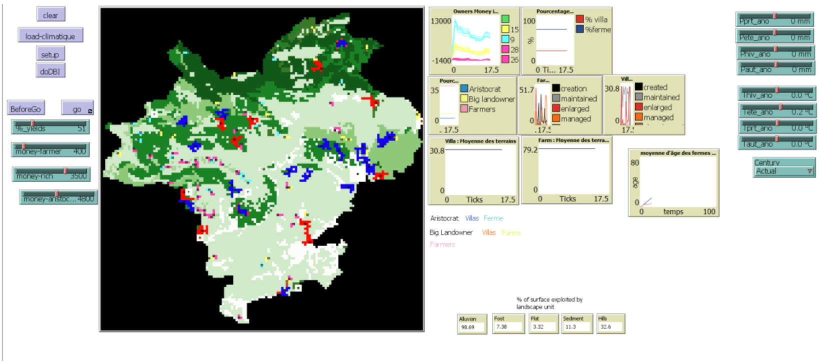

Fig. 1: The GUI of the ModelAnSet ABM while running a simulation.

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https://ccl.northwestern.edu/netlogo/

https://openmole.org/

Supervised and unsupervised classification of southern African wood and wood charcoals via their anatomical features

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Abstract. The identification of archaeological wood charcoals is carried out by anthracologists based on the comparison of the wood anatomy observed under microscope with dedicated modern reference collections. In particular, in species-rich regions, the identification process is long and tedious, due to both taxonomic diversity and anatomical variability. InsideWood is the largest online database of wood descriptions relying onto the anatomical features defined by the International Association of Wood Anatomist (called the IAWA list). InsideWood is commonly used to obtain a first clue on the taxonomic identification of an unknown archaeological specimen, before delving into the available collections and the specialized literature. This work focuses on the anatomical description of specimens of southern African woods and charcoals, based on a modern collection available for the region on InsideWood. In order to bring some light into the identification routine, we firstly report the results of a co-cluster analysis of the specimens and their anatomical features. This analysis aims to detect groups of features that would be relevant for discriminating certain taxa at the family and/or genus level with respect of the region studied. We secondly train several classifiers on the collection with the aim (in the long run) of automatically identifying the taxa of new archaeological specimens based on their features.

Key words. Antrhacology; wood anatomy; InsideWood; IAWA features; co-clustering; supervised classification.

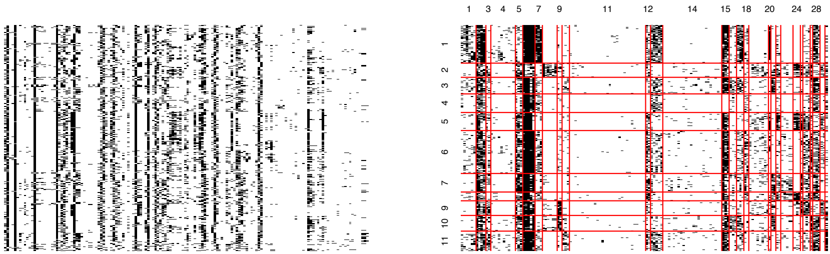
1 The dataset

Anatomical descriptions of around 2000 wood and charcoals specimens from southern Africa are used for this study. They are from three different modern collections: the largest online database InsideWood[1] as well as two published and unpublished physical charcoal collections. In total, 148 anatomical wood features defined by the International Association of Wood Anatomist [Wheeler et al., 1989] have been adapted to charcoals and homogenised for the entire dataset.

2 Data mining and learning

The binary dataset that we consider (a.k.a. *incidence* matrix) is made of $N = 526$ rows (specimens) and $D = 148$ columns (the IAWA features). The entry (i, j) of the incidence matrix is either 1 if the

[1]https://insidewood.lib.ncsu.edu/search?1



(a) Original incidence matrix.

(b) Reorganised incidence matrix.

Fig. 1: On the left hand side (Figure 1a) we see the original incidence matrix : a pixel location (i, j) looks black if the j-th feature has been observed for the i-th wood specimen. White, otherwise. On the right hand side (Figure 1b) the rows/columns of the matrix have been permuted in such a way make emerge dense regions.

j-th feature was observed for the i-th specimen, 0 otherwise. Each specimen from the original IAWA dataset is labelled by its Latin taxonomical name (species, genus and family) corresponding to one or several taxa, sometimes with old botanical name and sometimes accompanied by other botanical information as vernacular names. In order to harmonise the taxa nomenclatures we extract the taxa part from the taxonomical names with a regular expression to align them with the open source dataset available on the Plant Of The World Online website[2]. Only the taxa with an "accepted" status and native from southern Africa are kept and used. First, we fit the latent block model [Keribin et al., 2012] to the incidence matrix matrix to co-cluster specimens/features in order to form coherent botanical groups with respect to relevant anatomical wood characters (Figure 1). Then, several classifiers including Support Vector Machines [Pisner and Schnyer, 2020] and Random Forersts [Biau and Scornet, 2016] were trained on part of the incidence matrix in order to predict a specimen's taxa based on its IAWA features. All the experiments as well as the results will be carefully presented and commented in the talk.

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Learning and inferring on Cochlear Shapes of Juvenile and Adult Fossil Hominins

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Abstract. We study the cochlear spiral-shaped cavity in the temporal bone's petrous part, which poses unique challenges related to shape and sex differences from early and modern fossil hominins, especially in juvenile. We use statistical learning models on Riemannian manifolds to classify cochlear shapes efficiently.

Key words. Prediction; Fossils hominins; Gaussian process; Cochlear Shapes.

1 Context and Objectives

In this work, we have a finite set of cochlear shapes denoted $\{\mu_j\}_{j=1}^{J}$ and defined on $\mathcal{I} = [0,1] \subset \mathbb{R}$ with values in $\mathbb{R}^3$. Our main objective is to classify them based on sex differences. We consider a discretized version of $\mathcal{I}$ with $\mathbf{X} = (x^1, \ldots, x^N)$ which leads to $\mu_j = \mu_j(\mathbf{X})$, where $\mu_j \in \mathbb{R}^{3N}$. Hence, each population (class) is characterized by its optimal reparametrization as a local distribution of the shape. This distribution is given by the Cumulative Distribution Function (CDF): F unknown and need to be estimated. We formulate the problem as finding the most likely class by solving the corresponding binary posterior probability [2].

Fig. 1: A μ-CT image (left) and the extracted surface with cochlear curve (middle). An illustration of two different populations of spherical observations with their associated Fréchet means μs in green and tangent spaces $T_\mu(\mathcal{S}^\infty)$ (right).

All cochlear curves are extracted from micro-computed tomography (CT) images and are represented using $N = 200$ points (see Fig. 1 for an illustrative example). We use real dataset to first learn a Gaussian process classifier and then infer on sex differences, distinguishing between female and male from juvenile and adult individuals [1].

2 Methods

We remind that a CDF F is a non-decreasing and differentiable function defined from $\mathcal{I}$ into itself. The space of CDfs is given by $\mathcal{F} = \{F : \mathcal{I} \to \mathcal{I} \mid \dot{F} > 0 \text{ and } (F(0), F(1) = (0,1)\}$. Let $\beta : \mathcal{I} \to \mathbb{R}^3$ be a parametrized curve. We define its Square Root Velocity Function (SRVF) by $\mu(x) = \frac{\dot{\beta}(x)}{\sqrt{\dot{\beta}(x)}}$. This representation insure invariance to translation, uniform scaling and rotation [3]. We now focus on a more challenging problem: invariance to reparametrization of $\sqrt{\dot{F}}\mu \circ F$. We define a new regression model by

$$\mu_j = \sqrt{\dot{F}(\mathbf{X})}\mu^k \circ F(\mathbf{X}) + \nu_j; \quad j = 1, \ldots, J; \quad k = 1, 2$$

where $\mu^k : \mathcal{I} \to \mathbb{R}^3$ denotes the underlying shape of the k-th class and ν_j represents noise. The posterior that μ_j belongs to the k-th class is given by

$$p\big(k|\mu_j\big) \propto p(k) \int_{F \in \mathcal{F}} p(\mu_j|F, k)p(F|k)dF,$$

where the likelihood is given by $p(\mu_j|F, k) \propto \exp(-||\mu_j - \sqrt{\dot{F}(\mathbf{X})}\mu^k \circ F(\mathbf{X})||_2^2)$ and the prior as $p(F|k) \propto \exp(-d_{\mathcal{F}}^2(F, id)) = \exp(-d_{\mathcal{S}^\infty}^2(\sqrt{\dot{F}}, 1))$. We note $d_{\mathcal{S}^\infty}(\psi_1, \psi_2)$ the geodesic distance on $\mathcal{S}^\infty$ based on the isometric map between $\mathcal{F}$ and the infinite-dimensional Hilbert sphere $\mathcal{S}^\infty$. Let $\hat{F}^k$ be the resulting Maximum Likelihood Estimation (MLE) of F. We write

$$\hat{F}^k = \underset{F \in \mathcal{F}}{\operatorname{argmin}} ||\mu_j - \sqrt{\dot{F}(\mathbf{X})}\mu^k \circ F(\mathbf{X})||_2^2; \quad k = 1, 2.$$

Once we have estimated the k-th optimal CDF, it becomes possible to approximate the posterior as $p\big(k|\mu_j\big) \approx p(\mu_j|\hat{F}^k, k)p(\hat{F}^k|k)p(k)$. The classification is performed when choosing the most likely class maximizing the posterior probability: $\hat{k} = \operatorname{argmax}_{k=1,2}\, p\big(k|\mu_j\big)$.

3 Results

Fig. 2 shows the optimal CDFs (left) and their corresponding Fréchet means from the class of females in blue and males in red (right).

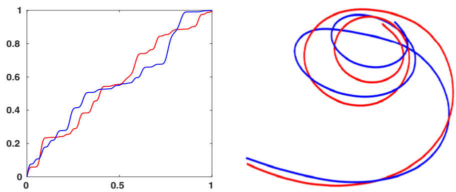

Fig. 2: Examples of CDFs $\hat{F}^k$ (left) and their corresponding Fréchet means $\hat{\mu}^k$ (right).

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Mesolithic and Neolithic Niche Prediction Modelling with Bayesian Networks

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Abstract.
There is a long-standing tradition in archaeological settlement prediction studies of placing considerable importance on the environmental characteristics for defining subsistence strategies. However, that does not seem to agree with the archaeological record as there were Mesolithic settlements that continued being occupied during the Neolithic and adopted agropastoralism.

In this study, we will quantify the influence of landscape on Mesolithic and Neolithic settlement location in the Iberian Peninsula. We will explore the differences in location of Mesolithic and Neolithic settlements and whether early Neolithic settlements built ex novo were located in different sites than the ones already present in Iberia. To achieve this, we have learned a Bayesian Networks model from 121 Mesolithic sites and 145 Neolithic sites (116 ex novo, and 29 with continuity from the Mesolithic period). Results suggest the non-restrictive nature of landscape on settlement location and the importance of social co-evolutionary transformations of the environment.

Key words. Settlement prediction, Mesolithic, Neolithic, Iberian Peninsula, Bayesian Networks

1. Introduction

The debate concerning the differences in settlement location of Mesolithic and Neolithic sites in the Iberian Peninsula has a long trajectory. The underlying assumption is that communities lived in the most suitable landscape for their subsistence strategy, foraging for Mesolithic and agropastoralism for Neolithic groups. However, this is difficult to sustain due to several reasons. First, the identification of more Mesolithic settlements has evidenced their continuity of occupation during the Neolithic and, also, the overlapping of ecological niches (Vidal-Cordasco & Nuevo-López, 2021). Second, early Neolithic communities not only consumed agropastoral resources, but hunting, gathering, and fishing foodstuffs as well, with different intensities and variances (Ahedo et al., 2021, Antolín and Saña, 2022, Tarifa-Mateo et al., 2023). Therefore, a linear model between diet and location is difficult to explain Mesolithic and Neolithic communities. In this study, we will explore two questions:

Q1. Can we identify different ecological niches between Neolithic and Mesolithic sites?

Q2. Are ex novo Neolithic sites located in different ecological niches than Neolithic sites that were already occupied during the Mesolithic?

2. Materials and Methods

A total of 121 Mesolithic sites and 145 Neolithic sites (116 ex novo, and 29 with continuity from the Mesolithic period) have been collected. We have used two different paleoclimatic models, Beyer (Beyer et al., 2020), and Krapp (Krapp et al., 2021) for recording ecological variables of every settlement with the aim to characterise their ecological niches (Tab. 1).

Independent variables		**Dependent variables**
Nearest river	Precipitation driest month	Type of settlement * **
Elevation	Coef. Variation precipitation	Previously Mesolithic? **
Slope	Precipitation wettest quarter	Phase *
Annual mean temperature	Precipitation driest quarter	Nearest Mesolithic site
Temperature seasonality	Precipitation warmest quarter	Nearest any site
Max. Temperature warmest month	Precipitation coldest quarter	
Min. Temperature coldest month	Net primary productivity	
Temperature annual range	Biome	
Mean temperature wettest quarter	Leaf area index	
Mean temperature driest quarter	Rugosity	
Mean temperature warmest quarter	Topographic wetness index	
Mean temperature coldest quarter	Ungulate carrying capacity	
Annual mean precipitation	Herbivore biomass	
Precipitation wettest month		

Tab. 1: Variables considered in the models. Outputs for every model are indicated as * for Q1 and ** for Q2, the rest of the variables are the model inputs.

We have built a different model for addressing every question. We have used Bayesian Networks (BN), a supervised machine learning algorithm that employs conditional probabilities for designing the model (Koller and Friedman, 2009). With BN, we have obtained two kinds of results: the correlation between every independent variable with dependent variables and, the prediction of the potential settlement depending on the ecological niche.

3. Results and Discussion

Our preliminary results indicate that Mesolithic and Neolithic settlements are generally located in similar niches, near water sources, in lowlands and avoiding extreme weather (medium index of temperature and precipitation). Therefore, Bayesian Network models were not able to distinguish between the two periods in most cases. For instance, it was expected to identify differences concerning the Net primary productivity of the soil (NPP) since it has traditionally been said that this variable would have been crucial for agropastoral communities for producing resources (e.g., Verhagen, 2007).

However, our results indicate that the NPP of Mesolithic and Neolithic settlements were similar (Fig. 1).

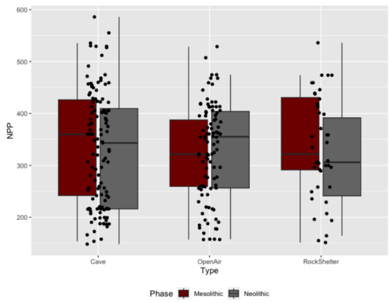

Fig. 1: Net primary productivity of soil (NPP) of Mesolithic and Neolithic settlements and distribution depending on the type of settlement (Model Q1).

Concerning Q2, our results suggest that Neolithic sites that were a continuation from the Mesolithic period are distributed in more diverse landscape characteristics. For example, we observed the dispersion of these settlements when we compared the herbivore biomass values with ex novo settlements (Fig. 2).

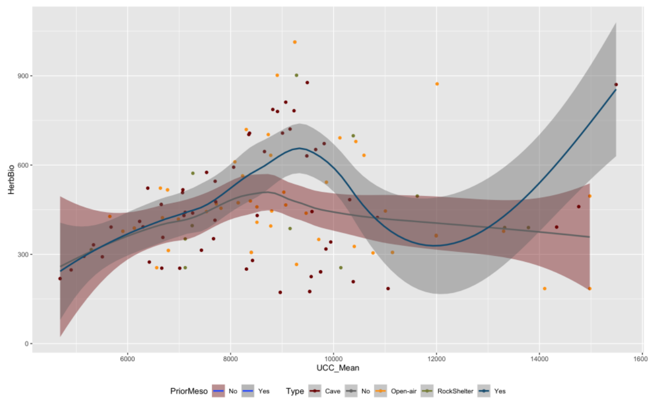

Fig. 2: Distribution of the herbivore biomass (HerbBio) and ungulate carrying capacity (UCC mean) values of Neolithic settlements that are occupied since the Mesolithic period and the ones found during the early Neolithic. We observe more homogeneity in ex novo settlements concerning biomass availability.

In this study, we have quantified the relationship between landscape characteristics and settlements, evidencing that there is no clear-cut differentiation. That does not imply that the environment was not important for communities, but it was not restrictive. This goes in agreement with research approached within the framework of the Niche Construction Theory (Laland et al., 1996), which considers the dynamism and co-evolutionary transformations resulting from human decisions in face of human transformations in the environment. In this contribution, we would also like to discuss the suitability of the Bayesian Networks in comparison to other quantitative and machine learning methods to explore socio-ecological systems in the past.

Acknowledgements

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Possibilistic models reveal trends, statis and contingent trajectories for plant and animal domestications

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Abstract.

The development of agriculture depends on the emergence, selection and dispersal of domestic plants and animals. The transition from hunter-gatherer communities to farming societies correspond to major transition in human history. The different steps and sequences are only partially known. Through the use of, deliberately simple, possibilistic models (from the EDEN framework) and the establishment of qualitative rules representing the interactions between domestic and wild plants and animals as well as human societies, we provided a set of trajectories for farming development in a core domestication centre. We explored three models of increasing exploitation of resources. As a central result, we provided possible scenarii for the emergence and development of farming, and generated alternative hypotheses regarding the beginning and appearing order of plant and animal domestications. Possible ecosystem development with over-exploitations of resources highlights the importance of wild resources for sustainable (modern) societies. This first rigorous and yet parsimonious approach demonstrated the interest of a possibilistic formalism to address bioarchaeological questions.

Key words. bioarchaeology, theory, discrete event models, socio-ecosystem, resources overexploitation, farming, agriculture

FLASH TALKS

Nouveaux outils d'apprentissage statistiques pour l'imputation et le pronostic en conservation sur les peintures

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Abstract.
Conservateurs et restaurateurs doivent faire face à diverses dégradations observées sur les peintures à l'huile sur toile de l'époque contemporaine (blanchiment, clivages de la matière, craquelures...). Ils constatent de nombreuses similitudes d'altération de peintures parmi les différentes collections. Le partage de données entre professionnels de ce secteur aiderait grandement à l'amélioration des protocoles de restauration et de suivi de ces œuvres. Cependant, du fait du marché de l'art, le partage de ces données est rendu problématique par le caractère confidentiel de certaines informations, de l'hétérogénéité des données collectées sur les œuvres et de la non uniformité des formats utilisés. Le professionnel fait face à un problème avec jeu de donnée *creux*, ou une part très significative des données est manquante. Le projet Méthodes d'Intelligence Artificielle pour l'Imputation des Altérations ($M(IA)^2$) s'attache à exploiter les méthodes de l'intelligence artificielle pour développer un outil d'aide à la décision pour les spécialistes de la conservation. L'outil consiste en trois couches; à sa base l'extraction des données issus de formats variés (PDF, images, XML tous issues de base documentaires); organisation des données dans un SGBD déjà établi; à son sommet, génération de représentation synthétiques assistées par l'IA pour aider le restaurateur dans son travail de pronostic et de préconisations.

Dans la phase initiale, cette recherche s'appuie sur les données du projet NOIRœS (Nouveaux Outils Interdisciplinaires pour la Restauration des œuvres de Soulages, mené par Pauline Hélou-de La Grandière) traitant de la restauration des œuvres de Pierre Soulages de 1958 à 1960.

Cette communication s'attache en premier lieu à expliciter la structuration des données et le développement d'une interface de saisie agrégeant des informations sur les œuvres d'art développé lors du projet MIB NOIRœS. Ces informations regroupent pour chaque peinture la description de la technique de l'artiste, l'historique des expositions et des emplacements, et des informations liées à leur état de conservation. La problématique de l'extraction de données sera abordée et différentes techniques telles que l'OCR et l'HTR seront présentées pour y remédier.

Key words. Intelligence Artificielle, Données manquantes, Base de données, Peinture

1 Main text

1.1 Contexte / Objectif

En France, le ministère de la culture recense « plus de 1.200 musées de France, 82% relèvent des collectivités territoriales ou de leur groupement, 13% de personnes morales de droit privé (associations ou fondations) et 5% de l'État ». Depuis la loi du 4 janvier 2002, les musées de France doivent réaliser un recollement décennal et de nombreux outils de gestion de collections ont vu le jour avec des pratiques très variées. Cette grande diversité a rendu, pour l'instant, impossible l'exploitation globale de la masse de données ainsi collectée. En particulier il semble que le croisement de ces documentations permettrait d'assister les professionnels de la conservation et de la restauration ainsi que le personnel des institutions dans leur recherche pour la préservation des biens culturels. Partant de cet attendu, la thèse $M(IA)^2$ (Méthode d'Intelligence Artificielle pour l'Imputation des Altérations) développe un outil d'aide à la décision avec une approche ascendante en prenant appuie sur un domaine patrimonial bien focalisé: les peintures à l'huile sur toile de l'époque contemporaine, en commençant par les œuvres de Pierre Soulages.

Mais avant de proposer des algorithmes d'exploitation des données, trois vérous doivent être dépassés par le projet $M(IA)^2$. Le premier, exposé *supra*, est celui de l'hétérogénéité des sources, des formats utilisés, des pratiques et de la natures des données collectées. Le second vérou est le caractère sensible et confidentiel de données qui peuvent très fortement faire fluctuer la côte des œuvres qui s'échangent sur le marché de l'art. Le dernier vérou est le croisement de données venant des trois domaines de documentation accessibles, à savoir la technique de création, les informations historiques d'état de conservation, et l'histoire sociale de l'œuvre. Ce croisement est rendu particulièrement difficile car les jeux de données accessibles sont *creux*, la majorité des informations sont manquantes et seule une petite fraction en est exploitable. C'est dans ce contexte que nous adoptons une démarche *bottom-up* en construisant une première expérience sur un corpus d'étude très précisément défini et documenté puis, une fois les outils développés, en caractérisant leur comportement sur un corpus plus large, plus générale mais, par conséquent, moins bien défini et plus faiblement documenté.

1.2 Matériaux / Méthodes

Le corpus d'œuvre sur lequel le projet s'appuie ne contiendra que des peintures sur toile contemporaine, plus précisément du XX° et XXI° siècle. Ces caractéristiques sont basées sur le cas d'école étudié qui sont les peintures de Pierre Soulages réalisées entre 1958 et 1960. En effet ces oeuvres forment le corpus étudié par Pauline Hélou-de La Grandière pour son doctorat NOIRœS ainsi que par d'autres projets connexe avec pour effet la production / génération de multitudes de données. Parmi ces projets, le projet MIB NOIRœS (Méthode d'Interface et de Base de données pour le projet NOIRœS) a été l'occasion de formaliser et structurer l'ensemble des informations accessible sur le corpus, structure schématisée en figure **??**. MIB NOIRœS s'est également attaché à proposer des interfaces ergonomiques tant pour la saisie que pour la représentation des données capturées de sorte que son alimentation puisse également être effectuée par les musées, fondations, collectionneurs privés, galeries ou encore vers les salles de vente. En effet chacune de ces institutions peuvent pour divers besoins avoir réalisé des constats d'état, des fiches de suivi, des photographies de l'œuvre ou divers types de rapports de conservation / restauration. Dans cette étape de capture et d'agrégation de documentation, de nombreuses sources d'informations sont sous forme non structurée, il n'existe pas de norme concernant leur rédaction. Un exemple en est donné en figure **??** avec la *fiche de santé* d'une œuvre de Pablo Picasso tel qu'établie par le C2RMF et archivé par le centre de documentation du Carrousel. Un des objectifs de $M(IA)^2$ est de mettre en place les outils permettant d'extraire des informations structurées depuis ces ensembles documentaires. Pour cela nous déploierons des techniques d'OCR (Optical Caracter Recognition) et de HTR (Handwritten Text recognition), en nous appuyant sur les infrastructures ouvertes déployées dans le cadre du projet CREMMA[1], et qui permettent la transformation des documents (images /pdf) en document texte lisibles par un ordinateur. Cette première étape permettra de concevoir des expressions régulières reconnaissant les informations importantes relatives au modèle de données MIB NOIRœS qui seront croisées avec le glossaire visuel des altérations sur les œuvres d'art et les objets de musées mis en ligne par le Québec couplé au thésaurus créé par Pauline ainsi que celui mis en ligne par l'Institut National du Patrimoine. L'ensemble de ses données formeront alors un jeu de données d'apprentissage permettant d'entraîner les algorithmes d'IA pour automatiser l'exploitation de constats d'état quel qu'en soit leur source (conservateur du patrimoine, restaurateur, régisseur. . .) et leur objectifs (pre/post restauration, transport et prêt d'œuvre, mise en vente. . .).

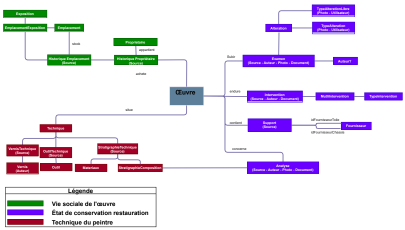
1.3 Résultats et perspectives

Le premier résultat de ce projet sera la construction d'un ensemble de données d'apprentissage pour des IA en vue de l'extraction des informations contenue dans les constats d'état. À travers un travail réflexif nous décriront également la méthodologie qui a permis d'obtenir ce corpus d'apprentissage avec la double visée de qualifier au mieux le jeu d'apprentissage, et par conséquent les biais qu'il peut éventuellement renfermer et transmettre aux IA qui l'exploiterai, et de simplifier la généralisation de l'approche à des corpus d'œuvres connexes.

Une fois cette première étape réalisée, deux processus seront menés de front. L'un centré sur la constitution d'IA permettant d'assister, voir d'automatiser, cette extraction d'information structuré de document hétérogènes, l'autre centré sur l'exploitation des données structurées elles-mêmes en vue de fournir une assistance aux professionnels de la conservation. Il s'agit là de croiser des méthodes d'apprentissage statistiques et des représentations dynamiques des données pour permettre la mise en évidences des informations les plus pertinentes dans des cadres d'exploitation précis, comme par exemple l'importance de certains aspects de la technique du peintre quand il s'agit de préconiser un système de transport d'une œuvre.

[1]https://cremmalab.hypotheses.org/

Figures

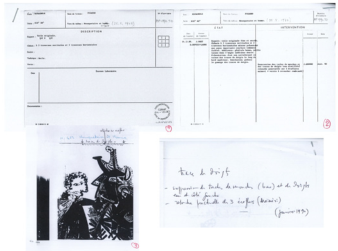


(a) Diagramme de classe du projet MIB NOIRœS

Technique du peintre correspond à la description des outils utilisés par l'artiste lors de la création de l'œuvre ainsi la description des différentes couches stratigraphiques et des matériaux présents sur la toile

Vie sociale d'une œuvre correspond aux différentes appartenances de la peinture, aux lieux d'exposition et de stockage de l'œuvre

État de conservation est l'ensemble des données décrivant les altérations observées lors d'un examen de la peinture, les analyses, le support ainsi que les restaurations réalisées par les spécialistes



(b) Fiche de santé l'œuvre *Mousquetaire et enfant (25/05/1972)* de Picasso issus du C2RMF

Page1 est une description du support de l'œuvre

Page2 est une brève description de l'état de l'œuvre ainsi que la liste des interventions réalisées

Page3 correspond à une image de la peinture contenant des annotations relatives à une intervention

Mark the way: Artificial Intelligence and Experimental Archaeology to better understand Bell Beaker pottery decoration.

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Abstract. The technique used to produce Bell Beaker decorative patterns in ceramics has been a topic of debate among the scientific community. Two different variants are analysed in this paper: incision and impression. An experimental reference collection of ceramic plaquettes decorated with both techniques was created to train the image classification model. The reference collection consisted on 72 plaquettes being marked several times by two different artists using impression and incision. Preliminary results show high accuracy (98%) in the distinction between incision and impression, and a higher-than-expected accuracy (85%) when differentiating between the marks produced by the two different artists. These results help to support the importance that Artificial Intelligence can have as a tool to better analyse and study aspects of human behaviour and culture that are not possible to analyse otherwise.

Key words. Image Classification; Computer Vision; Deep Learning; Bell Beaker Culture; Ceramics; Experimental Archaeology.

1. Rationale and objectives

The Bell Beaker phenomenon could be considered one of the first to have a pan-European sphere of influence during Prehistory. Nevertheless, this apparent homogeneity in ceramic shapes underlies a great heterogeneity in the styles and decoration techniques, where multiple decorative patterns may appear at the regional scale. One of these different styles is the so called ‘incision-style’ and its regional variants, which are characterised by decorations in the form of grooves that were made by dragging a pointy tool on the surface of the clay. Still, in recent years, some scholars (Garrido-Pena, 2000) have questioned the real nature of these purported incisions, arguing that these grooves were in fact made by imprinting the tool in the clay. This uncertainty has led to the creation of a new term, ‘incision-impression style’, that tries to accommodate these regional variants that are still under scientific scrutiny.

2. Materials and Methods

2.1 Computer Vision approach

Image-based classification algorithms have proven to be highly successful in other areas of archaeological research (Cifuentes-Alcobendas and Dominguez-Rodrigo, 2021). Since the problem at hand is dependent on correct classification, an approach using Convolutional Neural Networks (CNNs) aimed at classifying images through supervised learning seemed like the best possible fit. To test the viability of Computer Vision for this specific task, we used state of the art models that excel at image classification, such as VGG19 (Simonyan and Zisserman, 2015); ResNet50 (He et al., 2015); DenseNet (Huang et al., 2017); EfficientNet (Tan and Le, 2020). We used transfer learning to benefit from the previous training of these models and get better results at feature extraction from our relatively small training sample. Different combinations of optimizers were tested, including Stochastic Gradient Descent (SGD), Adagrad and Root Mean Square Propagation (RMSProp). After training the models on our own sample, we used Gradient-weighted Class Activation Mapping to check what were the most relevant features that the algorithms were using to make a classification.

2.2 Experimental sample

The experimental sample consisted of 72 clay plaquettes, marked using a special wooden tool similar to what is expected to have been used by Bell Beaker potters. Half of the sample was marked using the incision technique and the other half using the impression technique. Furthermore, these two groups were also sub-divided in half to be marked by two different researchers. The plaquettes where then left to dry and fired in an open fire pit, similar to ceramic ovens documented for the period. Work still needs to be done to document these plaquettes, but we estimate the total number of images to be around 5.760.

3. Preliminary results

Our first tests for these classification problems were conducted using a sub-sample of the total collection (n= 808 images). These first tests yielded high accuracy for the distinction between marks created by incision or impression techniques. The accuracy records for the four models tested are: ResNet50, 98%; VGG19, 96%; DenseNet, 93%; and EfficientNet, 85%. SGD was used as optimizer for these tests.

When classifying both decorative techniques and artists (*i.e.* 4 groups), the results were as follows: ResNet50, 84%; VGG19, 72%; DenseNet, 72%; and EfficientNet, 52%. Another test was conducted using ResNet50 and Adagrad as optimizer, achieving 85% of correct classification and a more stable learning curve. The low performance of EfficientNet in both tests may be explained to the nature of the model architecture, which is optimised to work with thousands or millions of images, and our little sample collection probably falls short to get the most out of this model properly.

4. Conclusions and Future Prospects

This study, although still preliminary, shows the potential of deep learning as a tool to address classification problems from the archaeological record. It has been shown that the problem described at the beginning of the paper can successfully be addressed using these new methods. Furthermore, the possibility of identifying artist agency has also been proven, which gives a new insight into further research looking for artisans craftmanship. The next step should be expanding the sample reference collection to the total of the experimental one to be able to make more supported assessments.

Knowing which specific decorative techniques were used is not a trivial matter, as it could be used as a first step to get our research closer to the idiosyncrasy of people that created these artifacts. This will allow us to know if the same techniques were being used in all the regional variants, or if specific techniques are linked to specific regions, providing a clearer picture of the cultural differences of the purportedly homogeneous Bell Beaker group.

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Evolution culturelle, IA et ritualités funéraires.
Evaluation et Complémentarité de différentes méthodes d'approches

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Abstract. Archaeology studies sites of different natures, state of preservation and diachrony. Archaeologists use a variety of sciences to trace their evolution and place them in context. However, interpreting sites and their evolution poses the challenge of combining heterogeneous and diachronic data. To gain a better understanding of past societies, we are examining funerary ensembles that offer precise chronologies and information on kinship links. Funerary rites, both conservative and innovative, are influenced by factors such as group pressure and economic or societal changes. We approach cultural evolution and transmission processes using methods combining artificial intelligence, linear discriminant analysis and phylogeny. Two examples of funerary ensembles are presented: a Xiongnu necropolis in Mongolia with cultural elements and information on kinship, and a predynastic funerary ensemble in Egypt with 500 well-preserved tombs and a detailed chronology. These methods reveal modes of cultural transmission in ancient societies, changing our perception of their evolution.

Key words. Cultural evolution; Cultural transmission; Machine learning; Factorial analysis; Phylogeny

1 Main text

1.1 General guidelines

Contexts and objectives

Based on the study of graveyards and funerary rites, our goal is to study cultural evolution in terms of rupture or continuity and to characterise the factors responsible for this evolution.

Materials and methods

We studied two funerary complexes. The first is the cemetery of Adaïma in Upper Egypt, which dates from the Predynastic period (fourth millennium BC). It contains more than 500 intact tombs with a chronological development that begins in the middle part of the Predynastic period and continues until the Fourth Dynasty. On the other hand, the Tamir cemetery in Mongolia dates from the Xiongnu period, from minus 100 to plus AD 100, and contains 47 tombs for which kinship links between subjects are known.

We compared classical statistical analyses (linear discriminant analysis) with several artificial intelligence algorithms (KNN, RFC, GBC, SVM, ANN, GNN), and finally, we looked for the factors responsible for this evolution with a Branch and Bound cladistic analysis.

Results

On the large Adaïma dataset, we support the results of conventional statistical analyses by specific artificial intelligence algorithms, particularly Random Forrest Classifier or RFC. Conversely, we use artificial intelligence to identify missing data. Phylogenetic analyses are necessary to analyze factors and differentiate between those responsible for horizontal cultural transmission (social or group pressure) and vertical transmission (specific to the funerary complex, for example). At Tamir, artificial intelligence algorithms can quantify what appeared to be 'impressions' by revealing an underlying structure that can easily interpret a posteriori.

Discussion

Our analyses reveal the power and weaknesses of these methods, which require a large dataset to be effective and appropriate coding. Only an increase in the number of studies will make it possible to determine the value of any particular algorithm. However, to date, the random forest is the most appropriate.

Recognition of geometric patterns from Metal Ages: in search of mathematical markers within european ornate bracelets

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Abstract.

This paper deals with the development of a model for automatic recognition of geometric ornaments fond in the Metal Ages. From digitized images of ornamented bracelets, the model describes describe the similarities between these decorations. A web module is able to redirect users to the graphbz.eu database entry sharing the most similarities with data provided by the user. This input data is in image format and can come from digitized ornamented bracelets, but also from other types of digitized supports. The heart of the model delivers algebraic markers within a matrix of results that precisely discriminates the ornamentation. This mathematization of the archaeological data contributes to revisit the subject of the ornamentation of bracelets, and even beyond, within the socio-economic organizations specific to the societies of the Metal Ages.

Key words. Artificial intelligence model; deep learning; classification; mathematical markers; geometric graphics; Bronze Age; Iron Age; ornaments

1 Main text

1.1 General guidelines

This study focuses on deep learning aimed at designing an artificial intelligence (AI) whose algorithm is inspired by a biological cognitive system. Image recognition problems typically employ a class of neural network called Convolutional Neural Network (CNN). The source code behind the AI model and its user module is available on the digital platform **github**[1]. A module runs on the web in a **dedicated digital space**[2] linked to the **graphbz.eu**[3] website.

The projected model aims at establishing similarities and dissimilarities on images of geometric constructions. Ornamented bracelets are used here as analogous to clothing adornments, from the Bronze Age to the later Iron Age periods of Northern Europe (1700 BC-500 AC). The training and validation data of the model are based on 4400 occurrences. The graphbz.eu website references more than 6000 occurrences of continental origin, in contact with the Aegean sphere. Major European trends lend themselves to evolutionary spatial readings (Georges 2020). The identification of typo-chronological criteria classically occurs in closed sets, essentially tombs or deposits. Groups of transformations have since been described using orthogonal planar projections (Opp) of geometric graphics (Georges 2015, 2017, 2020).

The training and validation datasets of the model are freely available on the graphbz.eu website. Divided into 46 object classes, the extensive Opp's have been retained to document the deep geometrical structures of the sceneries (fig. 1). The learning process consists in making

[1] https://github.com/ArnaudCrl/motif_archeo_heroku_flask
[2] Beta version: https://ai-geometric-ornaments.herokuapp.com
[3] https://graphbz.eu/spip.php?article6038

sure that the AI can associate a set with a class as well as possible. To do this, the neural network is presented with a series of pairs of backgrounds and expected response (training data).

The model outputs a matrix composed of 46 indicators with values between 0.01 and 0.99 relating to degree of confidence attributed by the model that the input corresponds to a particular class. The algebraic results give a very precise translation of the graphical data and can be exploited in graph theory.

In parallel to the output of this matrix, we include an additional module on a web page[4]. It shows the 3 classes for which the model has assigned the highest probability of matching the input data. The three predictions are ranked in descending order and provide the general orientation of the answer with hyper-text links associated with maps of Europe[5] and archetypal decorative forms represented in banners. The modus operandi guarantees the progressiveness of the analysis of the decoration, from broad-spectrum sets to targeted observations. In fact, the field of analysis potentially extends to all geometric graphics for clothing use.

1.2 Figure

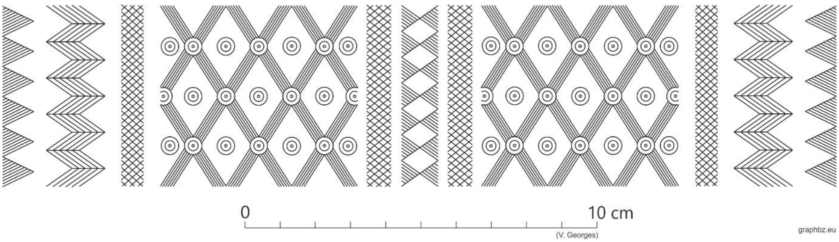

Fig. 1: An example of orthogonal planar projection used inside the model[6]

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[4] See 2.
[5] Example of map: https://graphbz.eu/spip.php?article6269
[6] https://graphbz.eu/spip.php?article3230

Extracting Structured Data from Historical Narratives Using the Running Reality Application in Combination with a Large Language Model

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Abstract. Digital history tools use structured data to create models of historical environments, but a very large fraction of historical data is in narrative format. Building a large set of structured data requires identifying individual factoids from within historical narratives. Recent advances in Artificial Intelligence and Machine Learning (AI/ML) have led to innovative neural networks known as the Large Language Models (LLMs) that can follow a train of thought in written work and then answer questions about that work. The Running Reality digital history desktop application has been upgraded with an experimental feature to interface with LLMs to import data from narrative text. Running Reality breaks up the text into single-topic sections, provides the section to the LLM, then asks the LLM a predefined set of questions. Running Reality has predefined sets of questions for text whose subject may be a city or a person, to determine if the text contains basic data such as founding or birth dates, alternative names, as well as locations over time. The OpenAI ChatGPT version 3.5 LLM is able to work with text within a 4096 token (or approximately 3000 word) look-back attention buffer, so Running Reality tries to keep section text to within this limit. The results of the experimental feature show that a combination of Running Reality and an LLM promises to be able to build large structured historical datasets.

Key words. Digital history tooling, machine learning, structured data, data extraction, world history model;

A graph theoretical approach to depict Identity By Descent in ancient populations

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Abstract.

The growth of ancient DNA (aDNA) data allows us to expand what can be achieved to better understand the cultural-historical events of the human society using bioinformatic tools. A new software called ancIBD, which detects long DNA sequences shared between pairs of samples known as Identity By Descent (IBD), offers the possibility to infer relatedness up to the sixth degree. It's a novel way to investigate close and large-scale geneaological relatedness within and between past human groups. We propose to test ancIBD on published Eurasian samples dated from the transition between Neolithic and Bronze periods and display the results using a network. To this end, graph offer a powerful visualization strategy that allows to capture all the variation in relatedness within a single network. This approach offers the possibility to visualize both kinship within an archaeological site (local scale) and genetic relatedness across different sites (large scale) to potentially give us a new insight into the dynamics and dissemination of the "Steppe-related" ancestry in Western Europe.

Key words. aDNA, IBD, graph, kinship, migration

1 Main text

1. 1 Backgound

High-throughput DNA sequencing has revolutionized the field of aDNA by making feasible the characterisation of ancient nuclear genomes (since Rasmussen et al. 2010). This development has allowed the growth of aDNA studies over the last 20 years (Schaefer and Shapiro 2019) and has resulted in the availability of over 6442 ancient human genomes worldwide to date (Allen Ancient DNA Resource, version 50). This post-genomic era of aDNA therefore provides large and complex genomic datasets from human remains, thus expanding the limits of what can be achieved using bioinformatics analyses to help to address questions in anthropology and archaeological sciences.

To date, most aDNA analyses can be divided in approaches targeting large *vs*. local scale. At a large scale, standard multivariate analyses (Principal Component Analysis), clustering methods (ADMIXTURE) and F-statistics frameworks are commonly used to represent genetic affinities, and to model population ancestry associated with admixture processes. These analyses help to document major cultural events of human societies. At the scale of a local archaeological site, methods to detect genetic relatedness between individuals deposited in common or different burials are commonly used to identify kin groups and deduce some aspects of the community's social organisation. The methods used in this context can confidently detect genetic relatedness up to second-degree relationships (Lipatov et al. 2015, Kuhn et al. 2018). However, the probability of detecting this degree of kinship between individuals from geographically and chronologically distant archaeological sites is low, thus restricting this kind of analysis to the level of the community.

However, by identifying long segments of DNA between pairs of samples, ancIBD is able to detect biological relatives beyond the second-degree and thus between more distantly connected individuals found in distinct archaeological sites (Ringbauer et al. 2023). Such algorithm offers a powerful way to identify, for the first time in a single analysis, close biological relatives to better understand the social structure of communities based on kinship within a community (local scale) and distant biological relatives to document regional cultural-historical events (large-scale - Ringbauer et al. 2023).

1.2 Objectives

For this communication we propose to use ancIBD to detect IBD segments shared between published Eurasian samples from the transition between Late Neolithic and Early Bronze (Ringbauer et al. 2023). To model and analyse the degree of relatedness among these samples, we will use a graph theoretical approach where each node in the graph represents the degree of relatedness identified within the archaeological site (local scale), and a weighted edge can connect them according to the number and the length of the IBD segments shared between each sample from different archaeological sites (large scale). Then, by using algorithms for community detection, we will identify clusters based on the degree of relatedness within and between archaeological sites. Finally, we will plot the network of communities on a map to visualise how the kin groups are organised within an archaeological site and which of them are connected with communities from other archaeological sites. By mixing local and large scales in a single graph, such an approach will allow a better understanding of the dynamics of migration associated in Western Europe with the advent of the "Steppe-like" ancestry.

1.3 Methods

The algorithm of ancIBD is based on a Hidden Markov Model (HMM) that runs for each pair of individuals a forward-backward algorithm (Durbin at al. 1998) to compute the posterior probabilities of having an IBD state at each loci (Ringbauer et al. 2023). Then, based on this posterior probability matrix, ancIBD calls IBD segments and classifies them according to their number and their length (from 8 to 20 centimorgan) to infer relatedness potentially up to six-degree. Then, we will define the graph community using the Louvain algorithm for community detection (Blondel et al. 2008, Lambiotte et al. 20014), an iterative process permitting to define all potential communities. To keep the more reliable combination, the algorithm retains the partition that maximises the number of edges inside communities (density) while minimising the number of edges between them. The Louvain community's algorithm can also consider weighted edges to define more precisely the communities. In our context, weighted edges will be equal to the total number of pairs samples that share the same length of an IBD divided by the maximum number of all possible pairs of links between communities. Then, the graph will be plot on a map with the plugins Map of Countries and Geo Layout in Gephi (Bastian et al. 2009).

1.4 Expected results

We expect to identify highest degree of kinship within than between archaeological sites. Based on the communities detection, we can identify a subset of kin groups within the archaeological site which are connected with communities from other sites to infer migratory patterns. We could also identify if such groups have common funeral practises when comparing among archaeological sites. Finally, the fine scale of the network approach could allow us to identify new links between groups, potentially not perceived and discussed in the previous studies (Ringbauer et al. 2023).

1. 5 Perspectives

In addition, it will also be possible to combine the networks produced from the genomic data with archaeo- anthropological data such as funerary practices, cultures or artefacts for each of the samples to obtain a more detailed archaeogenetic graph integrating potential genetic and cultural transmissions across geographical areas/archaeological cultures and communities.

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Predicting Quaternary hominin climatic niches using faunal assemblages with random forest algorithms

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Abstract. Climate fluctuations throughout the Quaternary have had significant effects on African landscapes and faunal communities. This period coincides with important events in human evolution. Understanding the relationship between human evolutionary history and Quaternary climate shifts is therefore crucial in human origins research. Rodents and bovids have been used extensively in palaeoecological reconstructions; however, they are often analysed separately in the analyses for they have specific modes of accumulation and preservation of their remains. In this study, we developed a novel approach to retrodict past climate conditions in major African hominin-bearing sites using the composition of the rodent and bovid palaeocommunity. We utilized random forest algorithms for robust predictive modelling. Our models were trained on a dataset combining bioclimatic variables and modern species distribution maps. The distribution maps of rodents and bovids were overlaid on climatic raster layers, and the presence or absence of each species in 10x10 km cells was recorded as a binary variable. We used various taxonomic ranks as explanatory variables for predicting climate variables independently, accommodating fossil lists with different levels of taxonomic resolution. The models were validated through geographical cross-validation and evaluated using unseen modern mammal surveys, demonstrating high predictive performance. Combining both clades as predictors yielded the highest accuracy for predicting climate variables. We investigated the impact of sampling/preservation bias and taxonomic indeterminacy on palaeoenvironmental reconstructions by introducing false absences in the training data and measuring the loss of accuracy with increasing numbers of undetermined or unseen taxa. We compiled published lists of rodent and bovid fauna from major hominin-bearing fossil sites in Southern and Eastern Africa. The dataset included localities with only rodents, only bovids, and mixed assemblages. Applying our models to these associations will enable us to reconstruct climate parameters for each locality, allowing us to explore the climatic variability and tolerance ranges for different hominin taxa.

Key words. machine learning, palaeoclimates, palaeoenvironments, hominins, Africa, random forest (RF), Quaternary, faunal communities

1 Main text

1.1 Introduction

The Quaternary period (2.58 MYA - today) has been characterized by a series of abrupt climatic fluctuations and a global trend of cooling and aridification (DeMenocal, 1995; Ravelo et al., 2004). In Africa, these changes had substantial impact on landscapes and led to shifts in faunal communities (Vrba, 1995; Bobe and Behrensmeyer, 2004), which resulted in the gradual establishment of present-day faunas. The Early Pleistocene also coincides with major events in the hominin evolution, including the emergence and diversification of the genera *Homo* and *Paranthropus* (Maslin et al., 2014), the development of new lithic technologies (Braun et al., 2019; Semaw et al., 1997), and the adoption of new food and resources acquisition strategies (Bunn et al., 1986). Therefore, understanding the intricate relationship between the human evolutionary history and the environmental and climatic shifts of the Quaternary period is a fundamental focus within the field of human origins research.

For palaeoenvironmental reconstructions based on terrestrial vertebrate faunas, two clades of mammals have historically received great attention: rodents and bovids. Both provide useful ecological information, yet they are rarely used simultaneously for palaeoenvironmental reconstruction as they have specific modes of accumulation and preservation of their remains.

In this contribution, we developed a novel approach for retrodicting past climate conditions of several African hominin-bearing fossil sites from the Early Pleistocene based on the composition of the rodent and bovid palaeocommunities, using random forest (RF) algorithms (Breiman, 2001) for robust predictive modelling.

1.2 Material and methods: bioclimatic and species distribution data, random forests

We trained our models on a dataset constructed by aggregating bioclimatic variables (using the Worldclim set of 19 bioclimatic variables) with modern species distribution maps from scientific literature. The climatic raster layers were overlaid with distribution maps of rodents and bovids, and the occurrence of each species in a 10x10 km cell was documented as a binary variable with value of 0 (for absence) or 1 (for presence). We generated supraspecific distribution information (using genus, tribe, subfamily, and family levels), and eventually used all taxonomic ranks as explanatory variables for predicting each climate variable independently. This method allows us to use fossil lists with heterogeneous levels of taxonomic resolution for predictions, including lists with few identifications at the species level.

Several machine learning algorithms that perform regression were examined. After validation of the models through a geographical cross-validation phase (Dormann et al., 2007) and evaluation of the model's performances, the random forest (RF) models emerged as the most effective. We ultimately used unseen modern mammal surveys to assess the high predictive performances achieved by our trained models.

1.3 Quality of the fossil record and implications for palaeoclimate analyses

We were able to compare the accuracy of each faunal group for predicting several climate variables, and obtained the highest predictive performances when combining both rodent and bovid communities as predictors. In order to empirically measure the impact of sampling/preservation bias and taxonomic indeterminacy on palaeoenvironmental reconstructions, we generated two types of false absences in the data used for training, and measured the loss of accuracy as a function of the number of undetermined or unseen taxa.

1.4 Expected results: predicting Quaternary hominin climatic niches

Eventually, we compiled several published lists of rodent and bovid fauna retrieved from major hominin-bearing fossil sites in Southern and Eastern Africa. The fossil dataset includes 15 localities that yielded only remains of rodents, 45 bovid-only localities, and 15 localities that yielded mixed (both bovids and rodents) assemblages.

Application of our models to these mammal associations will enable us to reconstruct various climate parameters for each locality, allowing to explore the climatic variability and tolerance ranges for each hominin taxon.

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One-class vs binary classification of ceramic samples described by chemical element concentrations

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Abstract. We tested a one-class classification algorithm on a dataset of pottery fragments described in terms of nine chemical elements, and compared its performances with those of standard binary classification algorithms. The obtained results show that one-class classification attains a similar accuracy, meanwhile improving the performance in terms of sensibility and specificity.

Key words. Machine learning; one-class classification; ancient pottery classification.

1 Context and Objectives

Pottery classification based on chemical composition characterization through non invasive analytical techniques is a well-known method typically adopted to solve the problem of pottery provenance attribution [Idjouadiene et al., 2019]. If an hypothesized provenance is to be validated, an algorithm that is trained to recognize just the elements belonging to one class could be more adequate than a binary or multi-class classifier. One-Class Classification (OCC) algorithms [Khan and Madden, 2014] are trained only on positive examples of the class to be learned, and can be tested on positive and negative examples in order to evaluate their generalization capability in case of object recognition and outlier detection.

2 Materials and Methods

We focused on the classification of 27 pottery fragments of Etruscan *depurata and bucchero* pottery, from the archaeological excavation at Pian della Civita in Tarquinia (Italy), dating from the VIII to the IV century B.C., considered as local production, and 6 pottery fragments of black varnish fine pottery of non local origin. Each fragment was measured more than once. The dataset contained 112 examples, each one consisting of the relative concentration of 9 chemical elements (K, Ca, Ti, Cr, Mn, Fe, Zn, Rb, Sr). As different examples of the dataset can correspond to a same physical fragment, the hypothesis of independence among observations might be violated. For this reason, data stratification was done on physical fragments rather than on measures. We tested the SV OCC algorithm [Schölkopf et al, 1999], based on finding the smallest sphere in a feature space that contains most of the training points.

3 Experiments and Results

The classification performances of SV OCC were compared with those of several algorithms for binary classification [Ruschioni et al., 2023]. All the algorithms were trained by a nested cross validation technique. Comparisons were done on the same dataset according to different performance metrics. The list of considered algorithms and metrics is shown in Table 1, alongside their performances.

Model	**Kernel**	**Accuracy**	**Sensibility**	**Specificity**	**F1-score**
SV OCC		0.96 ± 0.03	0.94 ± 0.03	0.98 ± 0.04	0.95 ± 0.04
Support Vector Machines	Linear	0.96 ± 0.05	1	0.78 ± 0.22	0.97 ± 0.02
	Polynomial	0.93 ± 0.06	1	0.78 ± 0.22	0.97 ± 0.02
	RBF	0.96 ± 0.04	1	0.81 ± 0.21	0.98 ± 0.02
Logistic Regression		0.89 ± 0.07	0.93 ± 0.11	0.69 ± 0.32	0.92 ± 0.06
Decision Tree		0.85 ± 0.09	0.87 ± 0.08	0.73 ± 0.28	0.9 ± 0.06
Multi Layer Perceptron		0.89 ± 0.07	0.93 ± 0.11	0.69 ± 0.32	0.92 ± 0.06
Random Forest		0.9 ± 0.06	0.92 ± 0.08	0.82 ± 0.21	0.93 ± 0.05
kNearest Neighbours		0.96 ± 0.03	0.99 ± 0.02	0.86 ± 0.21	0.98 ± 0.02
Linear Discr.Analysis		0.9 ± 0.09	0.99 ± 0.02	0.61 ± 0.4	0.94 ± 0.05
Naïve Bayes		0.98 ± 0.04	1	0.88 ± 0.22	0.99 ± 0.02

Tab. 1: Comparison results. (RBF: Radial Basis Function)

4 Conclusions

It can be noted that binary classification algorithms scoring good accuracy and sensibility exhibit a bad specificity. SV OCC can be considered an improvement, since it attains a good overall performance in terms of accuracy, meanwhile showing a good behavior both on positive and negative examples.

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Simulation énergétique intégrée des systèmes miniers médiévaux

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Abstract. The exploitation of mineral resources for the production of metals over historical times is a complex industrial and social system. Each stage of material transformation can be associated with a cost, which is largely the cost of the energy required. In addition, there are indirect costs, such as the cost of dewatering. An interdisciplinary approach between the human sciences and digital modelling is essential if we want to be able to propose a model of this complex system that can be used to simulate its operation. Here we will focus on one sub-system of our subject: the link between the extraction and preparation of ore (mineralurgy) and dewatering. We will be working from two archaeological sites that were exploited during the 15th century and for which we have archaeological and written data.

There are two levels to the modelling of the mining and metallurgical production system. The first one is a detailed approach to each step in the operational chain. It enables us to understand both the transformations of matter and the energy consumed in these transformations. This modelling is based on three parts: applied physics, experiments and historical data. The second level is to simulate the complex system. We rely on the creation of a digital twin of the production system from mine to ingot. To do this, we use Matlab's Simulink module. In order to compare the evolution of the same operation over time, or synchronous operations, it is necessary to define a functional unit. At the heart of our study, the functional unit is a mass of ore ready to be smelt once it has been prepared.

For certain mining sites and for certain periods of operation, it is also possible to determine the energy-financial cost proxy. This data, combined with energy consumption, allows the energy and financial costs of producing the functional unit to be combined. In this way, they provide a better understanding of the socio-economic context of the system. This initial study will make it possible to calculate the energy costs of the various technical solutions for dewatering the mine, extracting the ore and obtaining the prepared ore. This approach opens up a new field for integrating the exploitation of mineral resources into the economic and ecological environments of different human groups. It can be used to simulate the consequences of specific events on operation, such as wood depletion, ore scarcity or the introduction of new techniques.

Key words. Mine, énergie, système complexe, jumeau numérique

1 Contexte et objectif

L'exploitation des ressources minérales aboutissant à la production des métaux pour les périodes historiques nécessite des systèmes industriels et sociaux complexes qui enchaînent les procédés industriels depuis l'extraction jusqu'à l'obtention d'un objet fini, combinant de nombreuses phases de transformation réalisées par des systèmes mécaniques et thermodynamiques. À chaque stade peut être associé un coût, qui, en grande part, est le coût de l'énergie qu'il faut engager pour réaliser l'étape correspondante. Il s'y ajoute des coûts indirects, comme le coût de la mise hors d'eau (« exhaure »), l'entretien des installations, l'acheminement des matériaux, etc.. Tout est relié dans un système complexe conduisant à des interrogations historiques et archéologiques en même temps qu'épistémologiques et logistiques. À ces interrogations, l'interdisciplinarité entre sciences humaines et modélisation numérique s'impose afin d'être en mesure de proposer un modèle de système complexe permettant de simuler le fonctionnement de ces ensembles.

Repenser les systèmes de production anciens en fonction de la transformation et de la quantification de l'énergie produite autant que dépensée permet de s'affranchir des lacunes propres aux données archéologiques et historiques relativement aux outils de production. La quantification de l'énergie et l'usage d'une unité fonctionnelle permettent alors une intercomparaison inédite des systèmes dans leur globalité.

Ici nous nous intéresserons principalement à un sous-système de notre sujet : l'articulation entre l'extraction et la préparation du minerai (minéralurgie) ainsi que l'exhaure, souvent nécessaire au maintien de l'extraction. La mise hors d'eau de la mine peut se faire par élévation de l'eau ou par le creusement d'une galerie d'exhaure assurant une évacuation gravitaire. Nous nous appuyons sur deux sites archéologiques exploités notamment au XVe siècle où la décision a été prise de creuser une galerie d'exhaure après la mise en place d'un système de treuillage : Pampailly dans les Monts du Lyonnais et Castel-Minier dans les Pyrénées ariégeoises. Ces deux ensembles ont œuvré pour la production d'argent et nous disposons pour eux de données archéologiques et archivistiques contrôlées.

2 Méthodes

La modélisation du système minier et de production métallurgique opère à deux niveaux. Le premier consiste en une approche détaillant chaque maillon de la chaîne opératoire. Elle permet à la fois de comprendre les transformations de la matière ainsi que l'énergie consommée pour ces transformations. Cette modélisation se base sur un triptyque : la physique appliquée, l'expérimentation et les données historiques (textes et archéologie). Dans le cas de l'exhaure, l'énergie dépensée lors de l'utilisation du treuil peut être modélisée par de la mécanique, tandis que la modélisation du creusement de la galerie d'exhaure nécessite des expérimentations archéologiques. Pour la question minéralurgique, les textes et l'iconographie viennent compléter notre approche.

Le second niveau de simulation est celui du système complexe. Nous nous appuyons sur la création d'un jumeau numérique du système de production de la mine jusqu'au lingot. Après avoir compris le fonctionnement des éléments de la chaîne opératoire, il est nécessaire de les lier entre eux. Pour ce faire nous utilisons le module Simulink de Matlab. Ce type de simulation numérique par blocs, tout en aidant à la création de la chaîne opératoire, facilite sa compréhension. Il permet notamment de comprendre le choix entre les techniques existant à l'époque considérée, ici le XVe siècle dans la partie occidentale de l'Europe. Dans l'optique de pouvoir comparer l'évolution d'une même exploitation sur le temps long, ou des exploitations synchrones, il est nécessaire de définir une unité fonctionnelle. Au centre de notre étude, l'unité fonctionnelle est une masse de minerai bon à fondre à l'issue de la préparation de celui-ci, mais elle aura pour vocation à s'étendre jusqu'à l'obtention d'une masse d'argent métallique couvrant ainsi l'ensemble du modèle depuis l'extraction jusqu'à l'affinage.

On peut alors à l'aide de la simulation connaître l'énergie dépensée pour obtenir cette unité fonctionnelle pour un site d'exploitation de ressources minérale. Puis dans un second temps, comparer ces données d'énergie entre les sites. La quantification de l'énergie permet cette comparaison à l'instar du calcul d'un coût financier.

Par ailleurs, à travers les textes, il est possible de connaître le proxy *énergie - coût financier* pour certains sites miniers et à certaines périodes de leur exploitation. Ces données couplées avec la consommation d'énergie autorisent l'association des coûts énergétique et financier de la production de l'unité fonctionnelle et donc permettent de mieux comprendre le contexte socio-économique du système.

3 Résultats attendus

Cette première étude permettra de calculer les coûts énergétiques pour les différentes solutions techniques permettant la mise hors d'eau de la mine, l'extraction et l'obtention du minerai préparé. Nous y associerons le coût financier grâce à la connaissance des proxies coût énergétique et coût financier.

Par exemple, ces données fourniront des éléments de compréhension des choix techniques mis en place dans le cas de l'exhaure. Dans le cas d'un système d'élévation d'eau le débit pouvant être extrait est une forte contrainte. De même la hauteur sur laquelle l'eau peut être élevée en est une autre. Ces limites mécaniques sont autant d'éléments de choix dans la méthode d'exhaure qui interviennent en plus du coût financier et énergétique.

L'articulation entre l'extraction et la préparation, notamment avec l'usage d'un moulin à minerai donnera une première estimation de l'efficacité de cette machinerie au regard du système ancien de broyage manuel et de celui qui lui succédera, sans nécessairement le remplacer, le bocard.

4 Perspectives

Nous souhaitons ainsi pouvoir modéliser l'intégralité de la chaîne de production de l'argent. Fort de cette modélisation, il devient possible de traiter efficacement un système de production indépendamment de la période considérée (avant l'usage de la poudre noir en mine) Cette approche ouvre un champ nouveau pour l'intégration de l'exploitation des ressources minérales dans les environnements économiques et écologiques des différents groupes humains. Elle permet de simuler les conséquences d'événements particuliers sur les exploitation (par exemple, l'épuisement du bois comme ressource locale). Enfin, au-delà de notre approche spécifique au monde minier, la réflexion portée sur le coût énergétique des machineries anciennes permettra une transposition aisée dans l'ensemble des domaines de production impliquant l'usage d'appareils, le cas du moulin en étant une parfaite illustration.

Deep image prior inpainting of ancient frescoes in the Mediterranean Alpine arc

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Abstract. Deep neural networks have revolutionized image reconstruction approaches in various fields, including digital humanities. Among them, the so-called Deep Image Prior (DIP) can be effectively used to reconstruct ancient frescoes with no reference-data by progressively updating an untrained convolutional neural network. Compared to other methods, DIP-based inpainting reduces artifacts, adapts better to contextual information, thus proing to be a valuable tool for art historians. In this work, we applied this approach to highly corrupted digital images of medieval paintings, and integrate visible and infrared information for identifying and reconstructing damaged regions.

Key words. inpainting; deep image prior; ancient frescoes; southern Alpine arc; medieval art

1 Introduction

In many studies, the synergy between art history, mathematical image processing, and artificial intelligence has allowed to gain a deeper understanding of medieval wall paintings and their evolution over time. In this study, we are interested in investigating the murals found in medieval chapels in the southern Alpine arc, dating primarily from the second half of the 15th century to the early 16th century. In particular, we apply a digital reconstructing procedure known as *inpainting* to digitally restore elements of the murals that have been degraded or obscured over time [2]. Inpainting is a useful tool capable to provide a coherent visual experience for the viewer to better comprehend and interpret the damaged artwork. This can be done by making use of the visibile information only or in combination with spectral imaging, so as to reveal hidden layers in the murals. Our analysis covered seven religious buildings with works by Giovanni Baleison, Giovanni Canavesio, and Tommaso and Matteo Biazaci. The image dataset used in this project was collected as part of the PhD thesis of O. Acquier [1] and of the ongoing PhD thesis of P. Saillard.

2 Methods

We consider a Deep Image Prior (DIP) inpainting approach [3]. Compared to standard handcrafted inpainting methodologies requiring either a careful model/parameter tuning, such approach is based on the progressive update of parameters of an untrained convolutaional network which generates plausible contents within the region to be filled in. Compared to supervised deep learning methods relying on often unavailable large datasets of examples, the proposed approach is fully unsupervised and performs reconstruction based only on the available, incomplete, image and on

(a) Top row: original image (left) and inpainting mask (right). Bottom row: DIP (left) and patch-based (right) results.

(b) Top row: original IR (left) and IR with mask (right). Bottom row: original image (left) and result by DIP (left).

Fig. 1: Inpainting results by DIP using visible and infrared (IR) information.

the segmentation of the region to be filled-in. The proposed pipeline is applied directly on the visible image to reconstruct missing contents (image information, text characters) and combined with infrared information for the the study of the transformation/retouching process the artworks have been subject to.

3 Results

Results in Fig. 1a show that inpainting based on Deep Image Prior (DIP) outperforms standard methods based, e.g., on patch-based approaches in terms of visual quality. DIP-inpainted images are less likely to exhibit artifacts and do not require any training on large datasets. In Fig. 1b we show how infrared (IR) images providing a segmentation of the region to restore can be used to extract the inpainting mask for effective inpainting.

Inpainting methodologies can be utilized within the realm of digital representations of ancient frescoes, enhancing the presentation of the original artwork and facilitating its appreciation.

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Domain Generalization for the Classification of Punch Marks in 14^{th}–Century Italian Panels

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Abstract. Punch tools have been used to mechanically make decorative impressions–called punch marks–on gold ground paintings, becoming particularly widespread in Italy during the 14^{th} and 15^{th} centuries. Punch marks can be valuable for painting attribution and other art-historical investigations, especially because punch tools were frequently used across multiple paintings and were sometimes shared between workshops. So, accurately classifying punch marks used in panel painting becomes a crucial task, enabling comparison with other paintings and their punch marks as extensively documented by art historians/conservators Erling S. Skaug and Mojmir Frinta over the course of several decades. Deep learning methods excel at classifying punch marks in seen paintings but can falter when confronted with unseen paintings, a challenge that remains largely unexplored in this field. We have delved into the realm of domain generalization methods, which demonstrate remarkable improvements in accuracy for unseen panels. In the first exploration of its kind, our preliminary experiments offer compelling evidence of the profound significance of domain generalization in this context.

Key words. Computer Vision, Classification, Domain Generalization, Machine Learning, Supervised Learning, Panel Paintings, Punch marks.

1 Introduction

A Brief History of Punchwork. Late-medieval Italian panel paintings typically have gold backgrounds imprinted with decorative punch mark patterns, created by hammering a punch tool with a particular pattern on one end.These punch tools were frequently used across multiple paintings or even shared across workshops, making them valuable for attribution and other art-historical investigations. Punches have been the subject of decades-long studies, especially by art historians/conservators Erling Skaug (Skaug, 1994) and Mojmir Frinta (Frinta, 1998), which index thousands of types of punch marks. None of the original medieval tools survive.

Punch Classification & Domain Generalization. Traditionally, classifying a punch (e.g. determining its index as assigned by Skaug or Frinta) requires manually comparing side-by-side photographs or using at-scale tracings. Only recently have computational methods been applied, with the first use of supervised deep learning approaches introduced by (Zullich et al., 2023). However, a significant and largely unexplored challenge is the ability to generalize to unseen paintings. We introduce domain generalization (DG) and its profound impact on punch mark classification with a proof-of-concept study demonstrating substantial improvement an unseen artworks (domains).

2 Methods

ART-DGCP: Art-based Domain Generalization for the Classification of Punch marks. We adopt domain generalization methods identified and justified by Gulrajani and Lopez-Paz (2021). For a comprehensive comparison, we evaluate classification accuracies of vgg-11, vgg-19, ResNet-18, ResNet-50, DenseNet-121, and DenseNet-161, with and without standard data augmentation.

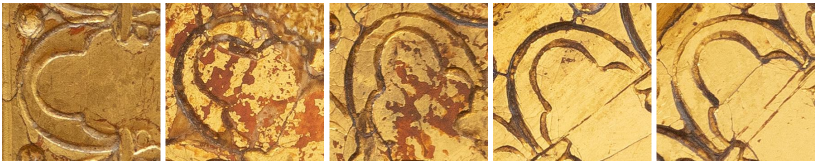

Fig. 1: Five punch marks (Skaug 72) from three panels in the Zullich et al. (2023) data set.

Dataset Description. Zullich et al. (2023) introduced a data set of 3815 images from four panels with 19 punch classes (see Figure 1). We divide the data into four domains. Images from one panel are reserved for a testing domain, while the remaining images are split into three training domains. We gain further insight with a novel data set of images from Simone Martini panels currently at the Fitzwilliam Museum, The University of Cambridge, and the Wallraf-Richartz Museum in Cologne, Germany.

3 Results & Discussion

We find that some domain generalization techniques drastically improve performance on unseen panels (domains). In particular, with early stopping, some domain generalization techniques can achieve overall accuracies above 70%, greatly exceeding methods like ResNet and DenseNet, which do not exceed 40% accuracy (See Figure 2). These results imply that domain generalization methods are crucial for punch mark identification on unseen panels. They also demonstrate potential to assist art historians and conservators identify these punches on new paintings.

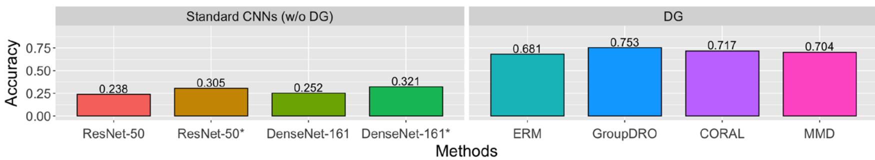

Fig. 2: Accuracy of standard and DG methods on a test domain; (*) indicates data augmentation.

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Artificial Intelligence Meets Archaeozoology: Using Deep Learning to identify archaeological faunal remains.

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Identifying archaeological faunal remains is crucial to understanding human-animal interaction through the pre-history. Zooarchaeology by mass spectrometry, or ZooMS for short, is a novel methodology for identifying archaeological faunal remains based on the characteristics of their collagen amino acid sequences (known as peptide mass fingerprint). The collagen peptide fingerprints are presented as the mass spectrometry results (plot of the mass-to-charge ratio, or m/z, versus intensity). Peptides, similar to the other metabolites, interact with each other in a complex pattern, which makes the conventional polynomial modelling approaches unfit for automated species separation. Therefore, the identification process usually follows a manual comparison with referential spectrometry. The manual identification process is time-consuming and prone to erroneous judgement, especially when the result of the ZooMS is noisy. Here we propose the use of deep learning to automate the identification process. In the present study, spectrometry data were first converted to images and normalised to the unit size (256x256 pixels) and propagated through the TensorFlow neural network (in Python). Deep learning is a machine-learning technique (a variation of the artificial neural network) with three or more layers. These neural networks learn the truth (e.g. mass-spectral characteristics of different species) from a large amount of data (which is called training data) by simulating the brain's behaviour. In the present study, the design of the learning process can be streamlined as follow: Our network consisted of nine sequential layers of neurons. In the context of deep learning, neurons are the core processing units holding the relevant values (e.g. pixel values of the spectrometry images). The input training data (also called labelled data) were propagated to the first layer of neurons, consisting of 196608 neurons, which conveniently is called the input layer. The input layer was fed to a convolutional 2D (Conv2D in TensorFlow) with 16 filters with the size of 3x3 pixels, a stride of 1, and the ReLU activation function. The second layer was chosen as a down-sampling layer (MaxPool2D in TensorFlow), which takes the maximum value for each input channel over a given input window to downsample the input. The next layer was chosen as a convolutional 2D (Conv2D in TensorFlow) with 32 filters with the size of 3x3 pixels, a stride of 1, and the ReLU activation function. Similarly, the next layer was a down-sampling layer (MaxPool2D in TensorFlow). The subsequent two layers were a convolutional 2D (16 filters) and, again, a down-sampling layer (MaxPool2D in TensorFlow). The seventh layer was a flattener, the eighth layer was a dense layer with 256 units, and the ReLU activation function, and the 9th layer (the output layer) was a dense layer with 77 units (number of labels) and the softmax activation function. The sequential model's loss function was chosen as the sparse categorical cross-entropy, which was minimised using the Adam optimiser. The presented design could successfully separate species with 96% accuracy. It was concluded that besides speeding up the identification process, deep learning helps to alleviate noisy ZooMS data, making the identification process more reliable.

Neuro-Symbolic Artificial Intelligence for epigraphy: Application to the Epicherchell project

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Abstract. This work presents a Neuro-Symbolic Artificial Intelligence-based approach to epigraphic study for automated inscription annotation. Over the years, digital corpora of inscriptions have been proposed, paving the way for the use of computer-assisted techniques to aid their study. Among the most recent proposals are the use of Deep Learning by neural networks for text transcription and restoration, and Computer Vision for detecting inscriptions within images. Although these methods give encouraging results and enable large amounts of data to be processed in a short space of time, they suffer from two drawbacks. The first drawback is that training Deep Learning models requires a large amount of pre-processed data, which represents a large amount of work. The second drawback is that these methods do not use all aspects of expert epigraphist knowledge, as systems based on Machine Learning or Computer Vision do not support inference, a characteristic of human reasoning, nor the management of complex, heterogeneous knowledge. On the other hand, works in Knowledge Representation and formalization enables complex knowledge to be represented, inferred and the coherence of a corpus to be managed, such as Ontology-based formalisms or Expert Systems, but these are generally unable to work on large quantities of data. To benefit from the advantages of previous works while minimizing their drawbacks, we propose in this work a neuro-symbolic approach to epigraphic study. This relies on the processing capabilities of Deep Learning and neural networks to handle large volumes of data, while integrating the knowledge of domain experts formalized through ontologies. The proposed approach aims to automate epigraphic studies by first detecting an inscription on an image, then extracting a transcription and finally associating historical information such as its origin or probable dating. The use of knowledge in the process not only makes it possible to explain the system's choices in a way that can be understood by a human being, but also to manage possible inconsistencies by pointing out their origin in a comprehensive way. This work is illustrated by presenting a collaborative software platform for automated inscription annotation using data from the EpiCherchell corpus of Latin epigraphy.

Key words. Archeology, Epigraphy, Artificial Intelligence, Knowledge Representation, Computer Vision, Neuro-Symbolic, Ontologies;

1 Context and objectives

Epigraphic study is a major field of archaeology. Over the years, generations of researchers have worked on the study of large numbers of inscriptions and have built up large corpora of annotated inscriptions. Recently, epigraphic corpus digitization projects have emerged, such as EpiCherchell[1] or Epigraphic Database Heidelberg[2], opening the door to automated interrogation and processing. In particular, work based on computer vision and machine learning can now process large numbers of inscriptions to help specialists with symbol detection

[1] http://ccj-epicherchel.huma-num.fr/fr/le-projet-epicherchel/
[2] https://edh.ub.uni-heidelberg.de/

like Garz, Liwicki & Ingold (2015), transcription and restoration from Assael et al. (2022). Computer technologies have also made it possible to set up storage and exchange standards enabling researchers from all over the world to work on homogeneous data and share their work. Among these projects we can cite Epidoc, which extends the Textual Encoding Initiative (TEI) format to epigraphy, or the projects to extend the CIDOC-CMR standard to epigraphy.

The aim of the proposed approach is to extend automatic solutions for processing epigraphic corpora to optimize their operation. The first is to provide the community with a tool for annotating images of inscriptions from corpora, to train Deep Learning models to detect and classify symbols, words and expressions.

2 Collaborative annotation

The use of Machine Learning such as Deep Learning requires a large amount of base data (e.g., images of inscriptions) but also a large number of annotations for the training phases. As we have already mentioned, the emergence of online epigraphic corpora has addressed the problem of lack of basic data, but the more data available, the greater the amount of work involved in annotation, which can no longer be supported by a research team.

The path followed in this work is to multiply the number of annotators by creating a collaborative platform for epigraphy annotation. This platform enables interested parties (researchers, teachers, students, the general public, etc.) to propose annotations via a simple, didactic interface. The user chooses an image to annotate, is offered the transcription and can mark symbols, letters, words or expressions on the image. Once the annotation is complete, it joins a database from which a learning model can be trained.

3 Formalization and integration of expert knowledge

The proposed approach integrates expert knowledge by formalizing it using ontologies. Ontologies enable complex knowledge to be represented using a formalism based on related concepts and properties, as well as expressing inference and consistency checks in logical form. These two aspects open the possibility of managing heterogeneous and sometimes incompatible knowledge (expert non-consensus), as well as inferring on a set of facts. In this work, machine learning is used to populate the ontology. The inference rules integrated into the ontology make it possible to check the consistency of the result (and to point out the relationships leading to inconsistency) and to explain the processing result by detailing the inference that produced it.

4 Conclusion et perspectives

The aim of the proposed work is to develop a methodology and a platform for using Neuro-Symbolic Intelligence for epigraphy. Based on Deep Learning and Ontologies, it has the advantage of being able to process a large amount of data, while allowing non-computer experts to understand and interact with the results obtained.

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RBS mapping treatment with AI to define the layering of ancient materials

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Abstract. RBS mapping treatment is far from being instantaneous and needs constraints to give reliable layering. Until now, RBS mappings were processed pixel per pixel. It takes too much time to be routinely used. The use of artificial intelligence for mapping clustering and spectral processing would automate data treatment and make it less time-consuming.

Key words. NewAGLAE; IBA; mapping; artificial intelligence.

Since the installation of the Accélérateur Grand Louvre d'Analyse Elémentaire, the ion beam analysis techniques used in the laboratory have evolved in conjunction with the needs of researchers. The implementation of the NewAGLAE Equipex enabled the automation of the beamline, the design and development of a PIXE multi-detector as well as the development of systematic chemical imaging. These measures are both non-invasive and non-destructive. Among them, RBS (Rutherford Backscattering Spectroscopy) provides stratigraphic analysis. Nevertheless, its treatment is not trivial because the same spectrum contains correlated and multiple information concerning the composition, number and thickness of these layers. PIXE (Particle Induced X-ray Emission) gives a more global composition of the sample. Combining the results of these two techniques would provide a basis for processing RBS spectra. In addition, the materials studied are often inhomogeneous, so it is necessary to map these samples. Unlike the processing of PIXE maps, which has already been automated in New AGLAE thanks to the development of software for visualizing, manipulating and quantifying these maps (Pichon et al., 2015), the processing of RBS imagery has not yet been studied. Processing PIXE mapping is a first step to accelerate global treatment since it gives a scale of elemental composition for RBS. One idea is to cluster PIXE and RBS mappings to identify parts with the same features (composition, thickness) thanks to artificial intelligence tools (machine and deep learning). Then RBS spectra with the same features would be processed following PIXE composition. The communication will present the methodology and the state of design of this new PIXE-RBS imaging tool which aims at providing information on layered objects. The first results obtained on datasets acquired on test pieces will also be presented.

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On Roman small finds: a meta-analysis in archaeology

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Abstract. Proof of concept combined with meta-analysis of research data seems a promising starting point for the analysis of Roman artefacts. These objects are highly variable in form and material, and are as much markers of the material culture of a social group as they are clues to the occupation of a site. They would therefore seem to be ideal candidates for exploring the question of artificial intelligence applied to archaeology. Can methods such as machine learning help archaeologists go beyond the limits imposed by their discipline and the nature of their subject? What are the prerequisites for such analysis? What are the pitfalls and how can they be avoided?

Key words. roman small finds; meta-analysis; machine learning; material culture; characterisation of social groups

1 Context and objectives

Today, archaeologists have a considerable amount of data at their disposal, which only increases as excavation commissions are awarded (Djindjian 2021). This observation raises questions about our research practice: why create new data when we have an abundance of information to (re)process? In light of this question, the practice of meta-analysis of archaeological research data is essential to move beyond the simple framework of the archaeological site.

The study of Roman small finds is a young discipline compared to ceramology but it hasn't escaped these epistemological questions. It therefore seemed interesting to examine the entire corpus of non-ceramic Roman small finds (late 1st century BC - late 3rd century AD) in Gaul and Germania through the prism of data science methods. This thesis will therefore be carried out in a multidisciplinary environment where archaeology, history, sociology and computer science will be mixed together.

2 Method

This thesis is intended to be a proof of concept for meta-analysis in archaeology, and therefore not an exhaustive treatment of any particular topic: what can the corpus of Roman small finds tell us when studied as a whole? One of the pillars of this thesis is the manipulation of a large amount of data, i.e. several tens of thousands of objects. Two lines of research structure this problem: the question of the characterisation of populations and that of archaeological sites.

Characterising populations means looking at the differentiation that may have taken place in relation to biological sex, age or the individual's place in the social hierarchy of their group. Funerary contexts seem to be the best place to try to highlight these variations using tools such as machine learning. Through the concepts of 'sociology of assemblages' and 'sociology of practices', it is possible to glimpse the different social interactions between members of the same group, as well as the processes of evolution of mentalities and populations over time (Marion 2015). Several syntheses on objects in funerary contexts have already highlighted recurrent patterns of presence/absence and/or assemblage of objects according to geographical area and age of the deceased. The use of an artificial neural network system or the k-nearest neighbors algorithm on structured data from published sites seems interesting in that each object is associated with a structure and a unique deceased (e.g. object A from tomb 1 containing the remains of a 25-year-old woman). By supervised machine learning we hope to be able to derive predictive models or highlight new patterns that we were unable to detect in the amount of data available, such as the presence of this or that type of object in relation to a person of this or that age or sex.

With regard to the characterisation of archaeological sites, the initial hypothesis is based on the idea that there may be sets of objects that are characteristic of an archaeological context or even a type of occupation. These considerations are in line with those made in recent decades on the functional distinction of archaeological spaces and sites. However, the methodological innovation proposed by this proof of concept may allow us to renew our interpretation of the assemblages. By using supervised learning on contextualised data, we hope to be able to qualify current hypotheses. For example, it is now accepted that the presence of a large number of the same object in a structure is a sign of a cultic gesture (cf. the corpus of objects discovered in sanctuaries such as Les Bolards in Nuits-Saint-Georges, FR). By associating the type of context with the type of object found, and by applying the same methods as those mentioned above, it will be possible to refine and quantify these impressions.

All this work will only be possible once a substantial, structured and homogeneous corpus of work has been built up in accordance with the FAIR principles; this is a real problem today, as not all data are easily accessible and the terms used by specialists are not the same from one study to another. However, this thesis has developed a method for building the data in several steps: scanning and OCR recognition of the texts, extraction of the metadata describing the small finds, conceptual modelling of the metadata, and creation and loading into a database.

3 Conclusion and perspectives

Researchers and young researchers are encouraged to open up their research data, but also to become part of a research ecosystem that is governed by principles such as accessibility, interoperability, re-use and sharing. The present work is therefore intended to be in line with these recommendations and with a new practice of archaeological research (Marlet et al. 2021). The understanding of ancient populations and land-use dynamics can be improved through the use of such tools. The results of this meta-analysis, whether they are positive or negative, will allow us to revise our preconceptions about archaeological data and the way in which we study small objects. In the long term, we plan to apply this method to preventive data as well, in order to deal with the immense amount of data that increases with each excavation prescription.

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