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Abstract:
The work of archaeologists is generally based on the classification of archaeological artefacts. Amongst all observable intrinsic descriptors (material, decoration, fabrication mode/chaine opératoire, etc.), the shape is often considered as the most important feature, giving clues to study chronological, social, religious or cultural aspects of ancient populations. Although ceramic classifications are well elaborated nowadays, they are sometimes considered as being subjective, ambiguous and hard to implement. The main goal of the project is therefore to bridge the gap between archaeology and recent developments in mathematics, statistics and 2D/3D imagery, in order to (semi-)automatize the process of ceramic classification and attribution. We hope that the project will bring a normative and standardized solution, allowing to overcome the linguistic, temporal and spatial limitations. We hope that this solution will be possible to be easily generalized and adopted to study other kinds of archaeological artefacts (axes, brooches, swords, etc.).

Keywords:
ceramics, classification, La Tène, Iron Age, morphometrics

Introduction
For my doctoral research, I have chosen to study several aspects of Hrazany – one of the most important archaeological sites in Central Europe. The site was occupied between the 2nd and 1st centuries BC by the Celts, who built an oppidum – fortified structure – which is considered to be the political, economic and religious centre of the territory. The huge amount of archaeological artefacts unearthed by L. Jansová during several excavation campaigns (1951-1963) gave rise to three monographs and several other articles concerning various related topics (e.g. Horáková-Jansová 1952; Jansová 1959, 1960; 1986; 1988; 1992). Nevertheless, Second Iron Age research has largely developed since that time and new questions and approaches as well as new methods of responding to them have appeared.

The excavations by L. Jansová have brought to light a huge quantity of artefacts. Nevertheless, the comprehension of more complex phenomena (exchanges, strategies of production organization) associated with Celtic society cannot be studied from a corpus collected at only a single site. For these reasons, the corpus studied was augmented by objects from other zones in Central Europe (Central Bohemia, Moravia and Silesia), as well as from other European regions (Burgundy and the oppida of Manching in Germany and Bibracte in France). The particular focus of the present project will be laid on the study of ceramics.

The choice of ceramics is quite evident: it is the most abundant material found by archaeological excavations – it is almost omnipresent. As ceramics first emerged in Prehistory, they bear not only information about chronology, technical and stylistic evolution, but also information about human relations. Contrary to precious artefacts intended for elites, ceramics are used and touched by all social strata. They reflect not only the cultural entities to whom they belong but also more intimate features – their personal preferences. By quantifying their intrinsic characteristics (form, decoration, technology of fabrication) and by observation of their spatial distribution, we, as archaeologists, are capable of modelling the socio-economic dynamics of ancient populations (Orton et al. 1992).

Despite their informative qualities, ceramics suffer from strong post-depositional degradation caused by climate, soil acidity, etc. We are estimating that almost 95% of all ceramic objects have disappeared over time and, from that highly-reduced quantity, only 10 to 20% of fragments possess information about the original form. At the same time, traditional typological techniques used for the treatment of residual information suffer from recurrent problems: they are subjective, often ambiguous and take too long to
be implemented, while their adaptation to another spatial or temporal window is rather delicate (e.g. Hodson et al. 1966).

Confronted with similar problems, biologists and palaeontologists (following the works by mathematicians and statisticians) have developed methods of analysing forms, generally named “geometric morphometrics” (e.g. Bookstein 1997; Kuhl and Giardinet 1982; Lestel 1989; Zelditch et al. 2004). These methods are based on the study of open (Discrete Cosine Transform – DCT, b-splines, Orthogonal polynomials) or closed outlines (e.g. Elliptic Fourier Analysis – EFA, Wavelet analysis) or on observation of differences in constellations of so-called “homologous points” (Procrustes Analysis, Thin-Plate Spline, etc.). These techniques allow treatment of huge amounts of data. Morphometric approaches are objective, fast and reproducible, and largely generalized, to be used to treat a large variety of objects. They offer graphical tools allowing condensation of complex information into a two- or three-dimensional space. For example, it is possible to graphically represent a large corpus of ceramics in only one diagram – e.g. a morphospace (Fig. 1) - in which structuration of individuals into groups may be directly observed. Contrary to discrete traditional typologies, the morphospace is continuous by its nature and therefore allows vast application of statistical methods, including validations – thus means which are not available with traditional approaches.

Fortunately, these methods have recently been applied in archaeology, but in spite of good will, the creation of an efficient technological transfer between mathematics and archaeology is not always a simple task - due to “isolation” between interlocutors – in terms of differences in nomenclature, goals, methods, knowledge or even mental representation of concepts (the problem of the so-called “Third culture” - Brockman 1995).

1. Research objectives

At the first stage, it is therefore necessary to bridge the gap between recent developments in mathematics, statistics, 2D/3D imagery, 3D printing etc., and archaeology (and more especially in the field of material culture).

The first goal is to propose a new procedure allowing attribution of a fragment to the complete form, based on the probabilistic approach. It is sure that the quality of output will depend largely on fragment quality. Nevertheless, the multiplication of individuals treated in this way will largely augment the spectra of known types of vases. More techniques, recently developed in Computer Vision and robotics, seem suitable to fulfill this task – as for example the Iterative Closest Point algorithm (ICP) - an algorithm which is unexploited in archaeology, but which is used in numerous domains requiring the 3D algorithm (ICP) - an algorithm which is unexploited in archaeol -

The second objective of the project is dedicated to the study of the spatial management of the Celtic period in Central Europe. Once types of objects are defined by statistics and morphometrics, the tools of Geographic Information Systems (GIS), will serve to reconstruct schemes by which archaeologica objects circulated from their producers to their consumers. These methods will render more visibly the material and cultural exchanges between ancient populations.

Using GIS will serve to delimitate zones of producers’ economical impact, to trace more precisely passages and ancient commercial roads, to define relations between rural and urban space, or at a more intimate scale between « neighbours » occupying the same sites.

Merging results from all these methods, the objectives of the project are: (i) definition of ceramic productions for each period of the Second Iron Age; (ii) identification of their origins and geographical limitations of their distribution; in order to (iii) identify social and economic interactions and dynamics between cultural groups; and to (iv) define zones of their influences.

These aspects, observed at different scales – either “microscopic” (sites, micro-regions) or “macroscopic” (region, country) – will contribute to better understanding of the territorial organization, technological and stylistic evolution of production as well as socio-economic implications.

2. First results

The project started in September 2013. The methodological part already carried out may be briefly summarized:

1) For the studied zone and period, no archaeological database containing information about ceramics existed. At the first stage, almost all well-published sites from the zone were entered in the database. At this moment, the database contains information of circa 1,500 accurately geo-localized sites, 2,500 structures (graves, houses, pits, ditches, trenches) and 36,000 archaeological objects (including 27,000 ceramic entries with 10,000 individuals – e.g. rims – which are morphometrically exploitable).
2) The chronological sequence based on seriation of archaeological structures containing well-dated artefacts (brooches, jewellery, belts) was established.

3) Before the beginning of the analyses, it was necessary to make sure that the choice of methods, which at that time were only rarely applied in archaeology, were appropriate to the studied goals. For that reason, two morphometric methods (EFA, DCT) were applied to the corpus of 154 complete vases from the contemporary oppidum Bibracte (Burgundy). The approaches served: (i) to identify the most appropriate method of visualization and morphometric standardization of vases, (ii) to test whatever morphometrics match two traditional classifications of ceramics, and (iii) to show their pros and cons. Results showed that all morphometric approaches are reliable and coherent with traditional typologies. Nevertheless, it was demonstrated that morphometric methods yielded results which are not achievable by classical typologies (see Wilczek et al. 2014 and above for more details).

4) To prove that the strength of morphometrics is neither limited only to ceramics, nor chronologically limited, the analysis of Bronze Age flanged axes was performed. The goal of the study (Wilczek et al. 2015) was to propose the new flanged-axe classification based on the combination of morphometrics (EFA) and statistics (SOM, Model-based Clustering and Discrimination analysis). This new classification, validated geo-statistically (Multinomial Scan Statistics) and by spatial distribution (Kernel density) revealed complex relations between several flanged-axe productions. It is worthy of mention that the classification obtained by these methods is fully automatic, i.e. “on its own” and allows individuals of unknown membership to be classified (e.g. newly found artefacts).

Conclusion
The main goal of the project is to adapt and develop morphometric methods to study archaeological ceramics. From a methodological point of view, we hope that it will bring a normative and standardized solution, which will overcome the linguistic, temporal and spatial limitations, already evoked in archaeological literature. The approach can easily be generalized and adopted for other kinds of artefacts, to study the level of production standardization and the evolution of shape over space and time, and to provide information about material and cultural exchanges. Applied to a corpus of several thousand Central European ceramic vases dated to the Second Iron

Figure 1: Projection of 32 ceramic plates from the Bibracte oppidum (Burgundy, France) in a PC2 vs PC1 morphospace. The morphospace is given by a PCA performed on the first 20 harmonics obtained by Elliptic Fourier Analysis (EFA) performed on the profile outlines (J. Wilczek).
Age, we hope that this project will considerably contribute to better understanding of archaeological sites and interaction mechanisms between Celtic populations.

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References


