Classification of Archaeological Fragments using Profile Primitives[1)]

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Abstract:
We are currently working on a project that provides an objective and automated method for classification and reconstruction of archaeological pottery. The purpose of classification is to get a systematic view of the material found, to recognize types, and to add labels for additional information as a measure of quantity. Traditional archaeological classification is based on the so-called profile of the object, which is the cross-section of the fragment in the direction of the rotational axis of symmetry. This two-dimensional plot holds all the information needed to perform archaeological research. Therefore, our method of classifying and reconstructing archaeological pottery is also based on this profile. This paper shows how a two-dimensional profile can be formulated as functions (multiple splines) which segment the complete profile into relevant sub-parts used for classification.

1 Introduction

At excavations a large number of sherds of archaeological pottery is found. Since the documentation and administration of these fragments represent a temporal and personnel effort, we construct a documentation system for archaeological fragments to form the basis for a subsequent semi-automatic classification and reconstruction. Every fragment or pot holds the information about when, where, and for what it was made for and therefore, the task of pottery research is comparison. This means that pottery must be grouped in a way that facilitates a comparison.

When dealing with a collection of different objects it is natural to group similar items together, and separate them from the groups from which they differ. Pottery was made in a very wide range of forms and shapes. There are several different ways of classifying vessels: based on

[1)] This work was supported in part by the Austrian Science Foundation (FWF) under grant P13385-INF and by the European Union under grant IST-1999-20273.

their shape, rim form, the presence of handles or spouts, decorative motifs and so on.

Because the conventional method for documentation is unsatisfactory [27], we are developing an automated archivation system with respect to archaeological requirements [31, 21] that tries to combine the traditional archaeological classification with new techniques in order to get an objective classification scheme.

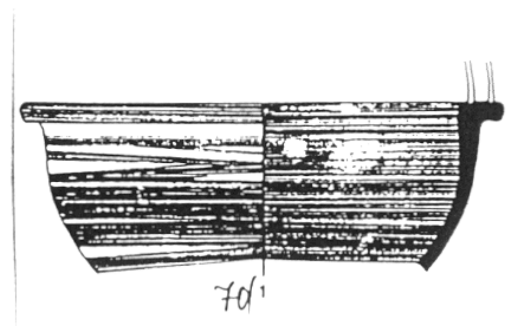

Figure 1: Drawing of a complete pot (from [22])

Archaeological finds are traditionally grouped by typology [14]. Defined forms and types of vessels form codes which simplify communication within the scientific field. A single example is illustrated which thereby represents all the others. Figure 1 shows such an example (taken from [22]) of a drawing of a pot, on the right hand side the profile is shown (black part of the figure, four parallel lines on the top show that there are rills on the top of the pot), the rest of the figure shows the decoration (rills) on the surface of the pot, its rotational axis and therefore also its diameter. Therefore, the important properties of such a drawing are outer and inner profile shape, diameter and surface characteristics.

Section 2 gives a short introduction into archaeological classification schemes. The most prominent relies on the segmentation of the profile shown in Section 3. Section 4 describes the mathematical formulation of the underlying segmentation and results of this approach are given in Section 5.

2 Archaeological Classification Goals

Traditional classification started 100 years ago (Draggendorff's classification of Samian ware [9]) and is still being developed (see [2, 1, 4, 7, 10, 13] or [34] for some approaches). The classification of the shape is descriptive - supported by the drawing - and defines first of all the shape of the vessel as well as the shape of the rim and lip [11, 17]. In most publications definitions of the terms shape, type and variant, are lacking. Subsequently a subdivision based on subjective aspects is produced. The description of shape is subject to the ideas of the author and are not standardized [5].

A more formal scheme of ceramic classification has been described by Gardin [12, 13]. Individual features like base, neck, rim, and so on are compared with drawn examples and appropriately coded. Another method of classifying pottery is to define types in terms of ratios of the principal dimensions. An overview of such classification systems can be found in Millet [26] and Orton [28]. In the course of a mathematical definition the description was omitted or was added secondarily.

Another approach is to use mathematical curves as a description of shape. There are different approaches like the sampled tangent profile [24], the B-spline technique [16] or the the two-curve system [15] to name a few, but it is not obvious how these methods can readily be used to compare complete profiles. Since ceramic vessels are, however, produced by hand and thus have an individual character, it is difficult to order them mathematically [29].

The third way of classifying pottery is based on the examination of the methods of manufacture by describing the steps taken to produce a vessel rather than classifying the finished product. Everything produced in the same way, that falls within the variations of shape that the particular technique permits, can be classified as one type [32]. The classification is a decision tree based on the traces left on the inner surface during manufacturing. Figure 2 shows the inner side of a fragment on the left, its left side (broken surface) in the middle, and the profile section generated automatically on the right (Figure 1 shows the same fragment drawn by hand). The profile shown in Figure 2 was computed using a laser system and a shape from structured light technique described in [23].

Figure 2: (a) Archaeological fragment - (b) site of fracture and - (c) profile section

3 Profile Segmentation

Segmentation of the profile is done for three reasons: to complete the archive drawing, to classify the vessel and to reconstruct missing profile parts.

As already mentioned, the profile has to be segmented such that drawings like Figure 3 (b) can be derived automatically. These drawings indicate the beginning and end of defined shape features. In the left half of Figure 3 (b) these lines indicate the structure (i.e. traces and rings) on the inner surface. The right half of Figure 3 (b)shows the shape features defined by archaeologists. They depict the borders of certain parts of the vessel like rim, lip, shoulder and wall in this example. By classifying the parts of the profile, the complete vessel is classified, missing parts may be reconstructed with the expert knowledge of the archaeologist.

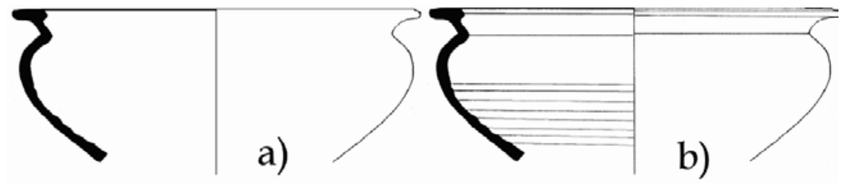

Figure 3: Automatic documentation after orientation (a), desired documentation (b).

Following this manual strategy, the profile should first be segmented into its parts, the so-called *primitives*, automatically. Our approach to do so is a hierarchical segmentation of the profile into rim, wall, and base by creating segmentation rules based on expert knowledge of the archaeologists and the curvature of the profile. Therefore, the determined profile has to be converted into a parameterized curve [33, 18] and the curvature has to be computed [3, 25]. Local changes in curvature [30] are the basis for the required rules for segmenting the profile into its primitives: rim, wall, and base. The three primitives are then subdivided into part-primitives, the base for example is divided into flat- and ring-base.

In order to standardize the classification, which is based on the fragment's structure stored in a database, it can be divided into two main parts, shape features and properties. Details on the complete classification process can be found in [20], this paper deals with the shape classification based on the profile.

4 Multi Spline Processing

The input data for the estimation of the profile is a set of points produced by the acquisition system [23]. A function fitting this set should be constructed and later on processed to find the extrema points necessary to classify the original fragment.

Many methods exist to construct such a function, they are quite different in nature and each one has distinctive advantages and drawbacks. We will give here a brief summary in order to justify our choice. Two main approaches exist: interpolation and approximation. Naturally, classical interpolation methods tend to be disturbed easily by the inherent noise associated with each set of points and they usually do not create a smooth function but rather a very fragmented one. This is very unsuitable for further processing as we will end up with a high number of non significant extrema points (or first derivatives). So, the nature of the set more naturally lends itself to approximation methods. A plethora of them can be found in the current literature[19]. A good compromise between accuracy, efficiency and smoothness is given by approximating splines [6]. The one we propose is based on B-splines or *bell-shaped splines*. As an example, consider the cubic interpolatory spline S on the five nodes x_0, x_1, x_2, x_3 and x_4 for a function f defined as:

i) S is a cubic polynomial, denoted by S_j, on $[x_j, x_{j+1}]$ for $j = 0, 1, 2, 3$,

ii) $S(x_j) = f(x_j)$, for $j = 0, 1, 2, 3, 4$,

iii) $S_{j+1}(x_{j+1}) = S_j(x_{j+1})$, for $j = 0, 1, 2$,

iv) $S'_{j+1}(x_{j+1}) = S'_j(x_{j+1})$, for $j = 0, 1, 2$,

v) $S''_{j+1}(x_{j+1}) = S''_j(x_{j+1})$, for $j = 0, 1, 2$,

vi) One of the following boundary conditions is satisfied:

   a) Free boundary condition: $S''(x_0) = S''(x_4) = 0$,

   b) Clamped boundary condition: $S'(x_0) = f'(x_0)$ and $S'(x_4) = f'(x_4)$

Our cubic spline differs from the above interpolatory spline in that both sets of boundary conditions in *(vi)* are satisfied. This requires the relaxation of the conditions in *(ii)* through *(v)*. Since the spline must have two continuous derivatives on $[x_0, x_4]$, we delete from the description of the interpolatory splines two of the interpolation conditions. In particular, we modify condition (ii) to:

$$S(x_j) = f(x_j) \quad \text{for} \quad j = 0, 2, 4$$

The choice of the subset of points that will be used to construct the spline is very important. Many of the methods proposed so far, used the simple approach of dividing the original set of points into equidistant intervals [8]. This method suffers from many drawbacks as the part of a profile with higher curvature cannot be interpolated sufficiently by the splines which are fit to areas with lower curvature. We assume that in parts of the curve with higher curvature there is sufficient data between the knots (more precisely, Schoenberg-Witney condition is satisfied). Our system orientates the extracted profile in a way that the upper part of the profile has higher curvature. The majority of the points (at least 60%) is assumed to be located in this area. Figure 4 shows an orientated profile and resulting splines of the inner and outer profile.

The complete profile is divided into intervals, so that for each interval the profile is a function. Then the spline approximation is used to compute part-splines. The starting point for the subdivision is defined as the left most, upper most point. The begin- and end points of each interval are based on the first derivatives of the profile line, detected in the acquired profile. Figure 5a and b show multisplines which can be subdivided into 9 and 7 part-splines

Figure 4: (a) acquired profile - (b) spline (c) smoothed spline

respectively. Experiments have shown that the number of part-splines ranges between 5 and 12 depending on the curvature of the profile.

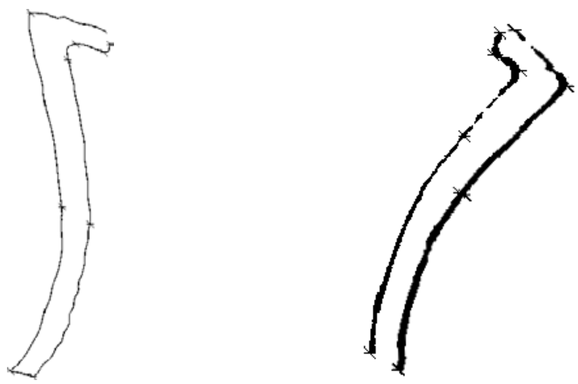

Figure 5: Multisplines:intervals for spline approximation of two different profiles

5 Results

The functions obtained from the profile in the previous section are fundamental to classify the sherds. The classification scheme devised by the archaeologists taking part in our multi-disciplinary project works by the exploitation of so called 'extrema points' or points of variance (usually first and second derivatives). Using these points the relative ratios and distance of characteristic parts of the sherds can be measured and check if they fit with a general classification scheme. It is clear now, why the spline should be as smooth as possible in order to omit any redundant point of inflection (or a cloud of such points), while preserving the structure of the profile.

A first result that corresponds with archaeological classification is shown in Figure 6. The multispline shown in Figure 5a is combined and segmented such, that rim and wall are separated due to archaeological rules: the separation between rim and wall has to be performed at the local minimum of the outer spline with respect to the axis of rotation. Figure 6 (b) shows the rim primitive for the example, Figure 6 (c) shows the wall primitive. A quantitative

Figure 6: (a) Complete profile represented by multisplines (b) rim primitive (c) wall primitive

evaluation of the results is rather complicated, since a ground truth is not available due to the fact that all the segmentation rules are designed manually. We are currently performing tests on a wide range of archaeological fragments. The segmentation into primitives depends on the orientation of the sherd, therefore a unique segmentation is difficult, if the orientation of the sherd cannot be computed correctly (ie. the sherd is too flat or too small). Future work goes towards further classification into primitives like base or bottom and the development of a database for profile primitives.

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