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QUANTITATIVE ANALYSIS OF THE SYMMETRY OF ARTIFACTS

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INTRODUCTION

The concept of symmetry has attracted virtually all domains of intellectual activity, archaeology being no exception. For example, symmetry has been at the focus of many Lower Paleolithic studies because it is one of the main shape characteristics of handaxes from Acheulian assemblages. Scholars investigating this period have often argued that the ability to perceive symmetric shapes, is meaningful in attempts to reconstruct the evolution of human cognitive, behavioral and technological capacities. For instance, Isaac (1986) saw the ability to conceive and produce symmetric shapes, as manifested in many Acheulian handaxes, as one of the indications of the higher complexity of this industry complex, compared to earlier traditions. Wynn (1985) even proposed a qualitative correlation between the *degree of symmetry* of the artifacts and the degree of intelligence of their makers. He used the ability to perceive bilateral symmetry, as manifested in typical Late Acheulian handaxes, as a major argument for relating a higher degree of intelligence to the makers of these tools compared to the degree of intelligence demonstrated by the earlier Oldowan industrial tradition.

Despite the central importance of the concept of symmetry in these and many other studies, it has usually been treated in qualitative rather than quantitative way, and sentences like '...these early handaxes are *roughly* symmetrical – none approaches the *fine* symmetry of later example...' (Wynn, 1985, p. 40 our emphasis) are often found in the literature. The need for objective means for symmetry measurement is the main motivation for the current study.

The concept and the methodology of symmetry content measurement, were developed in a recent series of publications (Zabrodsky & Avnir, 1995 and references cited therein; Avnir, et al., 1996 – a review) and applied successfully to a variety of symmetry related problems on the molecular and supra molecular levels (Buch, et al., 1995; Kanis, et al., 1995; Katzenelson, et al., 1996; Keinan, et al., 1996; Pinto, et al., 1996). This approach of Continuous Symmetry Measures (CSM), is general and not limited to the molecular scale.

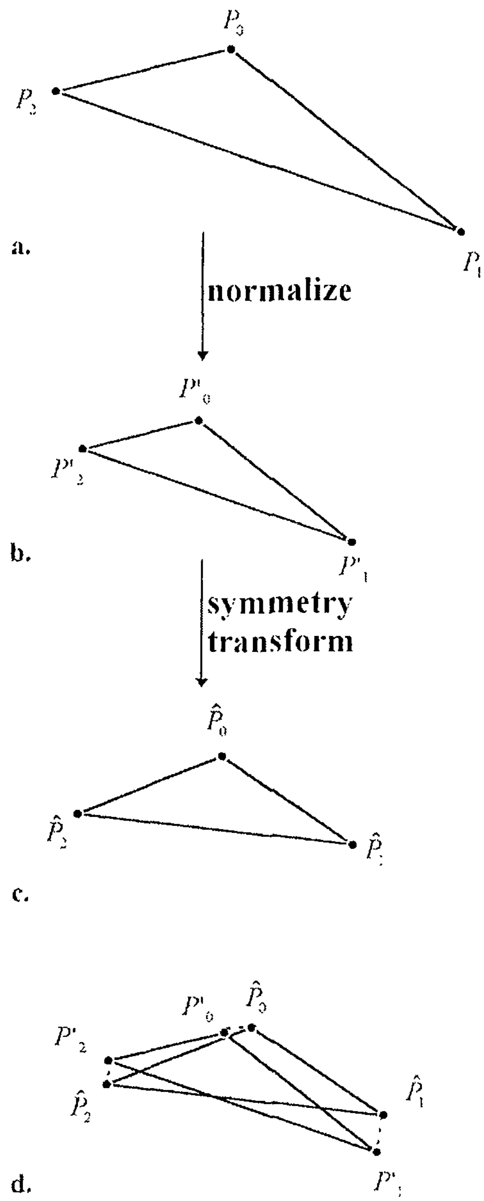
The main aim of this study was to test whether quantitative analysis of symmetry is applicable to archaeological research as an objective tool for assessment of shape through symmetry.

The general principles of the method are briefly described below, with special attention given to the details relevant for the archaeological research. The application of this method to the quantitative analysis of the symmetry of handaxes is described thereafter.

THE CONTINUOUS SYMMETRY MEASURE APPROACH

The Continuous Symmetry Measure (CSM) approach is based on the notion that quite often, it is natural to evaluate "how much" of a given symmetry there is in a structure rather than treating it as a "more" or "less" property. Consequently, this implies treating symmetry as a structural property of a *continuous* behavior, the quantity of which should be evaluated by a measurement tool. The design of a measurement tool involves some degree of arbitrariness, in the sense that one has to decide on issues such as how should the zero-reference level be set, what should be the maximal value, what should be the actual measurement yard-stick, what normalization procedures should one employ, and so on. Any such decision is open to debate. Keeping this in mind, the symmetry measure is based on a definition which is minimalistic as one could practically get. Our proposed answer (Zabrodsky & Avnir, 1995) to the question "How much of a given symmetry is there in a given structure?" has been:

Find the minimal distances that the vertices of a shape have to undergo, in order for the shape to attain the desired symmetry.



In a formal way:

Let G be a given symmetry group.

Let $P_{i=1\ldots n}$ be the vertices of the original configuration and $\hat{P}_{i=1\ldots n}$ the corresponding points in the nearest G-symmetric configuration then

$$S(G) = \frac{100}{n} \sum_{i=1}^{n} \left\| P_i - \hat{P}_i \right\|^2 \qquad (1)$$

expresses the amount of symmetry in the original configuration.

If a shape has the desired symmetry, $S(G) = 0$. A shape's symmetry measure increases as the shape departs from G-symmetry and it reaches a maximal value. As seen above, eq. (1) is normalized to the number of vertices (n) defining the object's outline.

Eq. (1) is general and allows one to evaluate the symmetry measure of *any* shape relative to *any* symmetry group or element. In order to avoid size effects, the size of the original structure is normalized, enabling the comparison of the degree of symmetry of shapes of different size.

Figure 1: The basic features of the Continuous Symmetry Measure (CSM): In order to evaluate how much bilaterality (mirror symmetry) is there in the triangle (a), its size is normalized (b), and the mirror symmetric structure (c) which is nearest to (b) is found using the symmetry transform described in the text and in the Appendix. (d): The $S(\sigma)$ value is calculated from the minimal distance between (b) and (c), using equation (1). In this case, $S(\sigma)$ =4.96

An important feature of the CSM approach, is that no pre-selected specific reference shape is assumed at the beginning of the analysis, though it is obtained as an end outcome. The nearest set of $\hat{P}_i$'s, i.e., the set of coordinates describing the nearest symmetric shape is computed with an algorithm, described in detail in Zabrodsky and Avnir (1995). The algorithm thus also provides one with the shape of the nearest symmetric object (Fig. 1). An additional important feature is that the $S(G)$ values are on the same scale, so that one can ask, for example which member of a set of polygons is the closest to being symmetric (having the lowest $S(G)$ value), or the farthest (having the highest value).

BILATERAL SYMMETRY ANALYSIS OF HANDAXES

As a part of a research which aims to analyze changes in the symmetry of handaxes over time, samples of handaxes from three Lower Paleolithic sites in Israel (Ubeidiya, Gesher Benot Ya'aqov and Mayan Barukh) were used as a test-case, through which we were trying to test the applicability of the method presented above to the archaeological research.

In the archaeological literature the term "symmetry" has been usually limited to bilateral symmetry, namely to symmetry around a mirror that bisects the body, also known as *achirality.* Many other symmetry operations (e.g., symmetry of rotation, tetrahedral symmetry and so on, which may be of relevance for other archaeological problems as well) are treatable by eq. (1), but we limit our discussion here to bilateral symmetry, to which we continue to refer in this report as simply "symmetry". The meaning of eq. (1) is then, the minimal distance of a given shape from exact bilateral symmetry.

Also in the current study we limited ourselves to the analysis of the two dimensional (2D) symmetry of the plan view of the artifacts. In the archaeological research, the 2D presentations of plan view and various cross sections of the 3D handaxes are standardly considered to represent reliably the morphological features of the artifact, including its symmetry features. The plan view is the one most commonly used for shape evaluation of handaxes, although the degree of symmetry of longitude and latitude cross sections maybe of interest as well.

CSM analysis requires that the shape of the object to be analyzed be represented by a set of n vertices or boundary points. For the purpose of this pilot study, we scanned hand-drawings of the handaxes outlines into a PC and then automatically traced these outlines, resulting in sets of x, y coordinates, each set of which served as the desired boundary points.

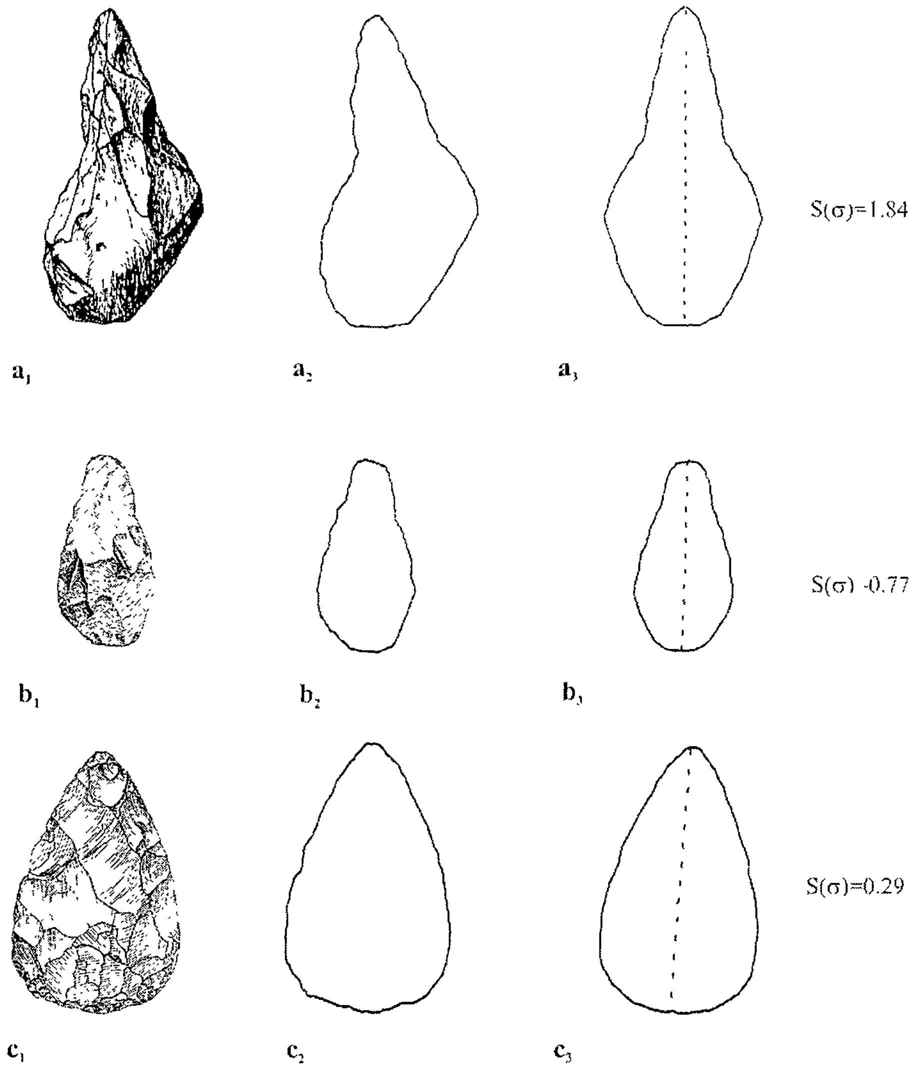


Figure 2: Handaxes samples from the three sites: a - Ubeidiya (Bar-Yosef & Goren-Inbar, 1993); b - Gesher Benot Ya'aqov and c - Ma'ayan Barukh (Stekelis & Gilead, 1966); Original drawings: a_1, b_1, & c_1; Outlines redrawn, using x, y coordinates: a_2, b_2 & c_2. The nearest symmetric shapes, their $S(\sigma)$ values and the mirror lines: a_3, b_3 & c_3.

Fig. 2 shows that redrawing of the outlines with these coordinates preserves the information and the redrawn outlines are very close to the original ones. The symmetry values of each of the outlines was computed according to eq. (1), using the sets of coordinates. The output is the minimal $S(\sigma)$ value, namely, the minimal distance between the original outline and the *nearest* mirror-symmetric shape. An additional output is, as explained above, the coordinates of the symmetrized shape and the position and inclination of the mirror line, σ (Fig. 2).

Preliminary results of this research have shown that the overall symmetry of handaxes generally increases over time, and that the variability decreases. Although this tendency is commonly mentioned in the archaeological literature, we provide here – to the best of our knowledge for the first time – quantitative demonstration of this phenomena. These preliminary results and a more extensive discussion of this issue can be found elsewhere (Saragusti, et al. 1998).

CONCLUSIONS

Our starting point was the prevailing situation where symmetry often serves as an approximate descriptive 'language' in archaeological studies. We proposed that while it is true that an imprecise language helps grasp complex situations and identify first order trends, there is always a danger of missing the full picture because of vagueness. Thus, it has been our aim here to provide a method for a quantitative evaluation of symmetry in archaeology. This method, when used to evaluate the degree of symmetry of handaxes, was found to be sensitive enough for measuring observed differences in symmetry. The CSM method may, therefore, be applied as a means to achieve a quantitative, objective and more accurate description of an important global shape feature of artifacts in archaeological research.

REFERENCES

Avnir, D., Katzenelson, O., Keinan, S., Pinsky, M., Pinto, Y , Salomon, Y. & Zabrodsky Hel-Or, H. (1996). The Measurement of Symmetry and Chirality. In: D. H. Rouvray, Ed., *Concepts in Chemistry* Somerset: Research Studies Press, pp. 283-324.

Bar-Yosef, O. & Goren-Inbar, N. (1993). *The Lithic Assemblages of 'Ubeidiya, A Lower Palaeolithic Site in the Jordan Valley.* Jerusalem: The Hebrew University of Jerusalem.

Buch, V , Greshgoren, E., Zabrodsky Hel-Or, H. & Avnir, D. (1995). Symmetry Loss as a Criterion for Cluster Melting, with Application to (D2) 13. *Chemical Physics Letters* 247, 149-153.

Isaac, G. L. (1986) Foundation Stone: Early Artefacts as Indicators of Activities and Abilities In Bailey, G. N. and Callow, P. Eds. *Stone Age Prehistory.* Cambridge: Cambridge University Press, pp. 221-241.

Kanis, D. R., Wong, J. S , Marks, T. J., Ratner, M. A., Zabrodsky, H , Keinan, S. & Avnir, D. (1995). Continuous Symmetry Analysis of Hyperpolarizabilities. Characterization of Second Order Non-Linear Optical Response of Distirted Benzene. *Journal of Physical Chemistry* 99, 11061-11066.

Katzenelson, O., Zabrodsky Hel-Or, H. & Avnir, D. (1996). Chirality of Random Supramolecular Structures. *Chemistry European Journal* 2. No 2, 174-181.

Keinan, S., Zabrodsky Hel-Or, H. & Avnir, D. (1996). How Much Chiralıty was there in Pasteur's Tartrate? The Quantitative Evaluatıon of the Chirality of Crystals. *Enantiomer* 1, 351-357.

Pinto, Y., Zabrodsky Hel-Or, H. & Avnır, D J. (1996). Continuous Chirality Analysis of Interconversion Pathways of the Water-Trimer Enantiomers. *Journal of the Chemical Society, Faraday Transaction* 92, 2523 - 2527.

Saragusti, I., Sharon, I., Katzenelson, O. & Avnir, D. (1998). Quantitative Analysis of the Symmetry of Artifacts: Lower Paleolithic Handaxes. *Journal of Archaeological Science* 25, No. 8, 817-825.

Stekelis, S. & Gilead, D. (1996). *Ma'ayan Barukh - a Lower Paleolithıc Site ın Upper Galilee.* Jerusalem: Israel Prehistoric Society.

Wynn, T. (1985). Piaget, Stone Tools and the Evolution of Human Intelligence. *World Archaeology.* 17, No. 1, 32-43.

Zabrodsky, H. & Avnir, D. (1995). Continuous Symmetry Measures. *Journal of American Chemical Society* 117, 462-473.