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Symmetry in a Kaleidoscope 1

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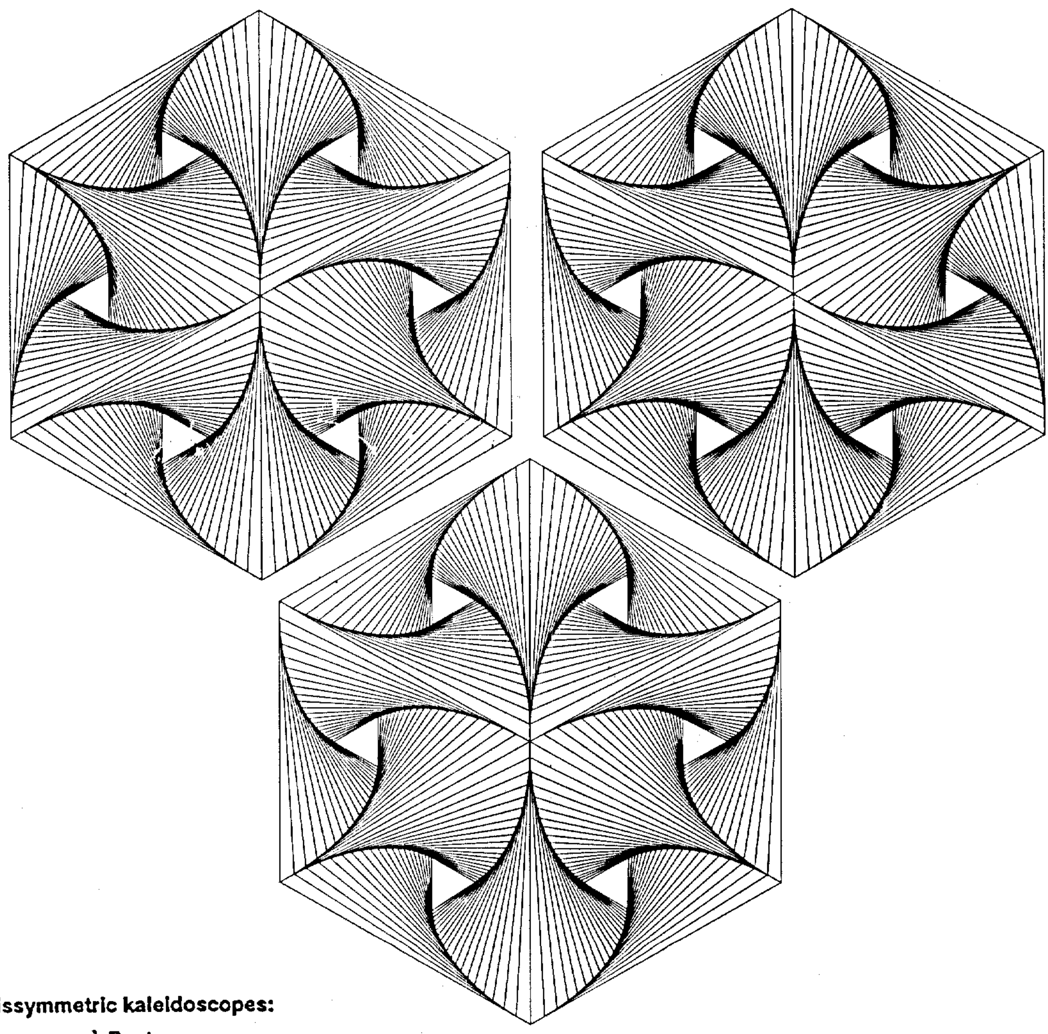

Dissymmetric kaleidoscopes:
Hommage à Pasteur

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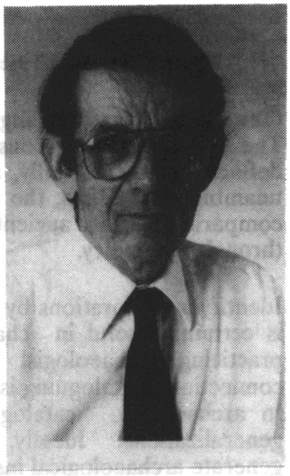
ON THE USE OF SYMMETRY AS AN ARCHAEOLOGICAL AND ANTHROPOLOGICAL TOOL

Bert Zaslow



(b. New York, N.Y., U.S.A., 1924) Educator, Chemist

Address: Department of Chemistry, Arizona State University, Tempe, AZ 85287-1604, U.S.A.

Fields of Interest: Chemistry, Crystallography, Archaeology, Anthropology

Publications: The structure of V amylose dehydrate: A combined x-ray and stereochemical approach. (*Biopolymers*, 14, 1975 – co-author); Pattern mathematics and archaeology. (*Arizona State University Anthropological Research Papers* No. 2, Tempe, 1977 – co-author); Pattern dissemination in the prehistoric Southwest and Mesoamerica. (*Arizona State University Anthropological Research Papers* No. 25, Tempe, 1981); A botanical growth pattern depicted on a Hohokam bowl. (*Journal of the Arizona-Nevada Academy of Science*, 18, 1983 – co-author); Symmetry and contemporary Hopi art. (*The Kiva* 51, 1986), Part 1

QUESTION 1

what is symmetry?

Scholars, craftsmen and laypeople have long been fascinated by ornamental art. Such art might appeal to individuals for a variety of aesthetic or cultural reasons, or some underlying geometric principles that are on display might be of interest. Clearly, a symmetry component which is both striking and widely prevalent is found in anthropological and archaeological art; and in recent years attempts have been made to develop symmetry as an archaeological and anthropological tool.

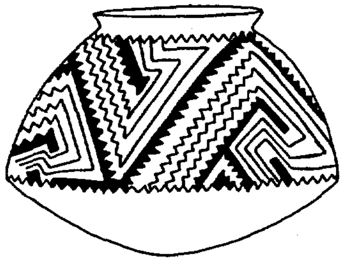
Figure 1: A reference pattern in a truncation sequence.

Figure 2: The second pattern. Note the cutoff in primary line work compared to Figure 1.

One can note that the language of symmetry is excellent for discussing geometric art. The symmetry operations of rotation, translation and mirror reflection can be defined mathematically, and the notation for symmetry elements is concise and unambiguous. Thus, the multitude of words that would otherwise be required in comparing various ancient and contemporary decorations can be greatly reduced through symmetry.

Identifying decorations by group or class within one of the metric symmetry systems is certainly useful in characterizing art of a particular culture. However, for a practicing archaeologist interested in developing temporal and geographical connections, cataloguing is simply a beginning step. In order to be more meaningful to archaeology, cataloguing should lead to correlations, and correlations to generalizations. Ideally, symmetry data would integrate with other data and generate archaeological insights.

As a physical scientist who has studied archaeological designs, I am often asked the question, "Were all possible groups employed by the peoples whose designs you examined?" Ancient people often tended to specialize within certain pattern classes. Even if all possible band groups or wall- paper groups are observed, this, in itself, is no proof that these peoples had formalized a unified theory of symmetry. In the pre-Columbian southwestern United States and Mesoamerica, designs were usually constructed in traditional ways, with changes over time and space providing a mathematical history for the archaeologist to follow and exploit. Making effective correlations depends more on reconstructing the methods the ancients actually used than on examining ancient designs by means of a formal contemporary approach.



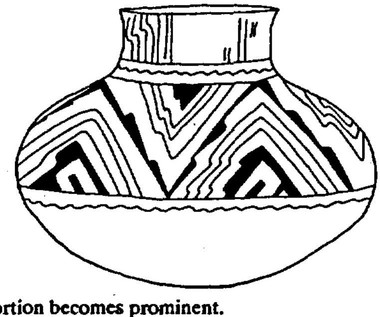


Figure 3: The third pattern. Distortion becomes prominent.
Figure 4: The fourth pattern. Further truncation is observed.

Consider the five decorated ceramics shown in Figures 1 through 5. These display Hohokam decorations from central Arizona dated approximately A.D. 1100 to A.D. 1220. Analysis of the decorations can be made by their transfer to a plane. After splitting and opening a decoration, distortion due to the ceramic surface is removed during the transfer process.

Figures 1 through 5 belong to a Hohokam decorative tradition whose primary line work derives from the line structures of Figure 6a. The individual line structures of Figure 6a exhibit glide symmetry and are positioned in regular order; and the neighboring line structures are mirror images of each other. Figure 6b shows the manner by which the line structures of Figure 6a are embellished. Again, glide symmetry is maintained. The decorations of Figures 1 through 5 are a sequence of patterns displaying truncation and distortion relative to their precursors.

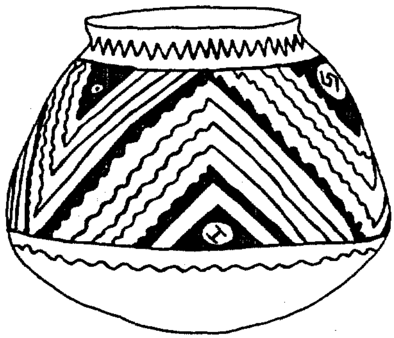


Figure 5: The fifth pattern. Transition from a wall-paper group to a band group is almost complete.

It is helpful to imagine the patterns of Figures 1 through 4 as extending above and below the field of view. Figure 6c demonstrates the initiation of primary line work at the top of the decoration of Figure 1, and the arrow locates the cutoff at the bottom of the decoration. One complete line structure and parts of two adjacent line

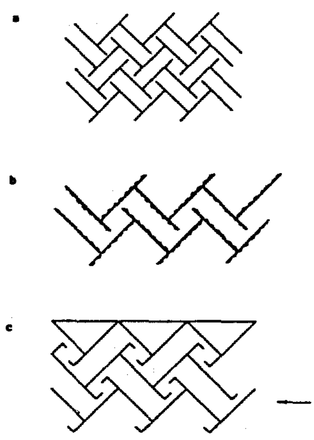
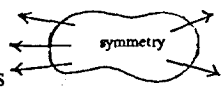


Figure 6: Analyzing Figure 1
a. Primary line work of Hohokam precursors to Figure 1. The pattern of line work belongs to symmetry group pgg.
b. The method of adding elaborative detail to the line structures in Figure 6a.
c. Initiation and cutoff levels of Figure 1.

structures are displayed in Figure 1, which serves as a reference pattern. The decoration is essentially undistorted. Figure 2 reveals more truncation at the bottom of the decorations than Figure 1. Relative to Figure 2, truncation in Figure 3 is extreme enough to force much distortion to occur in positioning the primary line structures. Finally, in Figure 5, a single band or strip results. Embellishment was added to the primary line structures according to the glide format employed in the more ancient patterns of the pgg decorative tradition, even though glide symmetry is distorted in the decorations of Figures 3 and 4.

The Hohokam people were dedicated to their crafts, and how symmetry was generated and lost is important in understanding their decorations. Banding mechanisms for creating wall-paper groups were regularly employed by the pre-Columbian inhabitants of the southwestern United States in constructing ceramic decorations; a discussion of this topic has been presented by Zaslow (1977, pp. 27, 31-36). However, it is not necessary for a person to have had formal training in symmetry to become adept in making decorative correlations. Jernigan (1986), who was educated in fine arts, correctly sorted decorations from Chaco Canyon, New Mexico according to their antisymmetry or color counterchange properties, and arrived at some interesting insights using a "craft" approach. He developed the ability to deal with symmetry by copying and drawing all of the ceramic decorations that he studied. In this way his thinking could parallel the thinking of the potter-artists who inhabited Chaco Canyon from about A.D. 900 to A.D. 1150.

QUESTION 2



Some mathematical scholars view symmetry in ornamental art as the first use of sophisticated mathematics by early man. However, there is evidence from the American Southwest that weaving preceded ceramic manufacture and ceramic art. Weaving displays even more sophisticated symmetry than ornamental art, because weaves exist in three space dimensions, whereas ornamental art is a surface phenomenon.

Even the early American ethnologists recognized that weaving exerted an influence on ornamental art. Thus, the line constructions of Figure 6a are visible on the surfaces of twill weaves. The analysis of archaeological decorations serves to attract attention to a general use of symmetry in prehistory; and it seems logical, for example, to examine the symmetry properties of simple weaves. How symmetry restricted and affected man's early development is a matter of broad anthropological interest, for symmetry is involved in motion and transportation, hunting and tracking, the building of houses and furniture, weaving and sewing, the design of tools, and so on. Man clearly had to possess symmetry skills to enhance survival in prehistoric times.

Weaves are three-dimensional objects which show translations in two independent directions. They are a macroscopic counterpart to crystallographic layers, and can be analyzed by means of layer groups. During the process of weaving a mat or a fabric, the weaver will actually perform the symmetry operations of translation, rotation and mirror reflection. Twills are weaves that employ a simple over, under construction, as illustrated in Figure 7. Contemporary manufacturers of fabrics produce weaves that possess various desired mechanical properties.

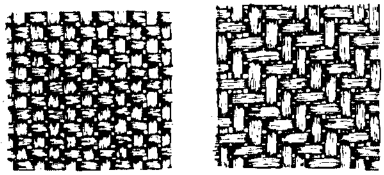


Figure 7: Twills.
a. A section of an over-1, under-1 twill with identical horizontal and vertical weaving elements. This twill belongs to the centrosymmetric layer group p4/nbm.
b. A section of an over-2, under-2 twill. The layer group is pbaa.

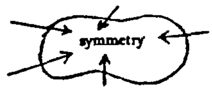
Twill weaves from the pre-Columbian southwestern United States, that were intended for heavy usage, have constructions: over-1, under-1; over-2, under-2; over-3, under-3, etc. Rarely encountered are twills with the following constructions: over-1, under-2; over-1, under-3; over-2, under-3, etc. Mats which functioned as surfaces for pounding and shaping clay and caliche, and sleeping mats, fall into the category of heavy usage; mats with floating weaving elements that generate decorative designs are not included in this category. It is interesting that the symmetry properties of the commonly occurring constructions differ from the symmetry properties of the rarely encountered constructions. The over-n, under-n types have centrosymmetric structures, while the over-n, under-m constructions, where n does not equal m, are non-centrosymmetric (Zaslow 1987). The correlation holds when vertical weaving elements are identical to horizontal weaving elements, and also when vertical and horizontal weaving elements differ, as in wickerwork. There appears to be a mechanical advantage in the utilization of centrosymmetric twills, or they would not have had so preponderant a distribution. Possibly the mechanical advantage may simply be a resistance to unraveling.

In a similar fashion, consider the knots illustrated in Figure 8. Figure 8a is a square knot, while a false or granny knot is shown in Figure 8b. The square knot exhibits a 2-fold rotation axis perpendicular to a mirror plane and a center of symmetry. In the conformation of Figure 8b, the false knot displays three mutually perpendicular 2-fold rotation axes and lacks a center of symmetry. The two knots differ only in the orientation of the second loop relative to the first loop, yet the centrosymmetric square knot exhibits a resistance to unraveling, while the non-centrosymmetric false knot readily unravels.

a — a. A square knot
Figure 8: Knots
b — b. A false knot

Chemists have long known that what appears to be a small structural change can have profound implications. The difference between edible starch and indigestible cellulose is not one of chemical composition; different configurational arrangements exist around one of the carbon atoms in the repeat unit. A few anthropologists are now beginning to show concern about the way that mathematical restrictions can affect anthropology. In this regard, examining the symmetry of the structure of cultural materials might yield some new surprises.

QUESTION 3



Depending on one's training and experience, symmetry means different things to different people. A typical chemist looks at symmetry in terms of the reproduction of objects or figures in space. The three-dimensional point groups which characterize molecules, and the crystallographic space groups with translations in three independent directions, are central to the chemist's thinking about symmetry. Mathematicians have a considerably broader outlook that includes not only geometric symmetry, but also algebraic symmetry and duality (Nering 1987). Within these categories are topics such as combinatorial symmetry, Galois Theory, linear algebra and analytic duality. A close look at some of the mathematical techniques that come under this broader perspective of symmetry, with the purpose of furthering applications towards chemistry, ought to stimulate some new areas of research.

Whereas chemists rapidly adapt to new innovations and ideas, archaeologists generally tend to move more slowly. Field archaeologists in the American Southwest often have to deal with tens of thousands of decorated sherds from a single excavation. It is not surprising, then, that many of these workers think in terms of design fragments rather than whole ceramic designs. By tradition, archaeologists have focused on design elements, e.g., scrolls, flags, hachuring, rather than on how these elements are placed together to form a total composition. Furthermore, although archaeologists generally acknowledge the presence of symmetry in ornamental art, symmetry analysis is sometimes viewed only as a methodology for studying whole decorations. In reality, symmetry is fundamental in nature and an integral part of man, and can be observed in sherd data as well as in whole ceramic designs.

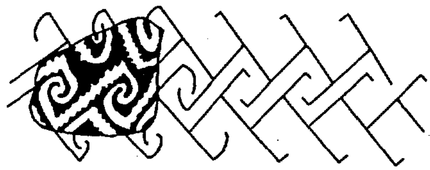


Figure 9: A single sherd with sufficient detail to allow pattern reconstruction.

Experience shows that design elements lacking a mirror plane are often identifiable in one or both mirror forms in an assemblage of decorated sherds, and such data has the potential to yield archaeological information (Zaslow 1980). Sometimes a single sherd or ceramic fragment can be found from which a whole pattern can be deduced, as seen in Figure 9. The primary line construction in Figure 9 is shown extending from the sherd; this is the same construction illustrated in Figure 6, but from an earlier time period. Clockwise as well as counterclockwise interlocking scroll elements can be detected in Figure 9, and are positioned as required by pattern class pgg. When more than one sherd from the same decorated ceramic vessel is recovered from a site, it may be possible to reconstruct the whole decorated surface, even though the sherds may not fit together. The four ceramic fragments of Figure 10 were obtained from a closed context, where a fire and roof collapse had occurred; a side view is shown of one of the sherds, indicating that it comes from a shoulder of a jar. From the shapes of the vessel fragments of Figure 10, and with the truncation sequence of Figures 1 through 5 as a reference, the vessel decoration shown in Figure 11 could be reconstructed. The ability to relate the fragments of Figure 10 with the truncation sequence roughly dates not only the decorated vessel, but also other ceramics excavated from the same room.

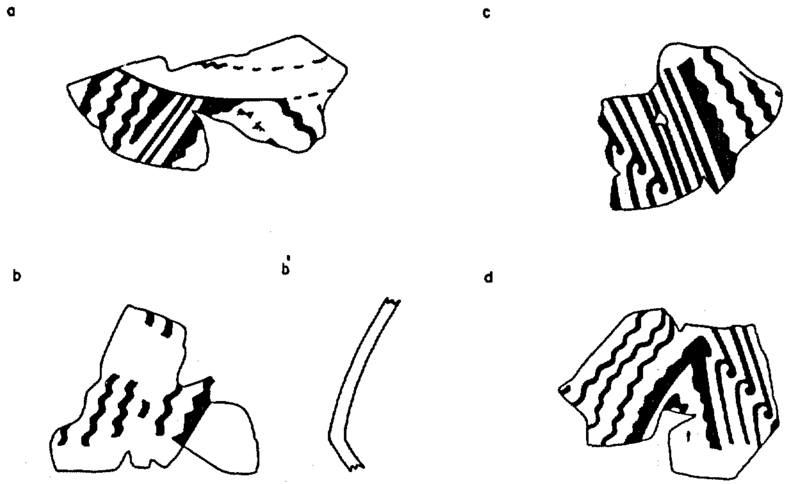


Figure 10: Four decorated fragments from the same ceramic jar.

The symmetry inherent in whole and fragmented decorations is an archaeological resource waiting to be more extensively utilized. Assistance from the mathematicians and physical scientists who are attracted to ancient ornamental art is surely welcome; but in order to be helpful to the conventional archaeologist, communication is necessary. Mathematical scholars should not present their work too abstractly, if they want archaeologists to read their results. Examining a given data set from both an archaeological (or anthropological) perspective and a mathematical perspective has been accomplished in the past under various circumstances. An archaeologist can become an expert in symmetry (Washburn 1977), direct collaboration between an archaeologist and a physical scientist is possible (Zaslow and Dittert 1977), and separate but parallel studies by symmetry specialists (Donnay and Donnay 1985) and an anthropologist (Hanson 1985) can also occur.

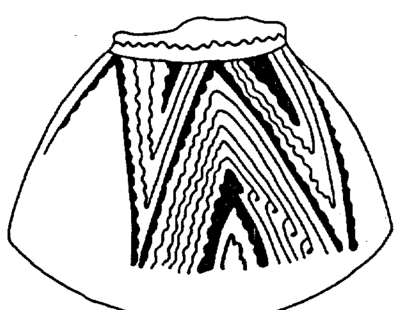


Figure 11: The decoration synthesized from the fragments of Figure 10.

What kind of an overview should an archaeologist have about symmetry? I believe that archaeologists ought to be at least as proficient with symmetry as the peoples whose art and culture are under study; otherwise, their records will be incomplete. Symmetry needs to be recognized as a part of an anthropological package; it is not an abstract methodology of limited utility. Finally, a broad historical outlook is ever important, and a general alertness to change and asymmetry should be maintained.

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