Cardillo M. 2010. Some applications of Geometric Morphometrics to archaeology.
Morphometrics to Nonmorphometricians. (Lecture Notes in Earth Sciences). Edited by Ashraf M. T. Elewa.
Springer, 325-341

Chapter 15
Some Applications of Geometric Morphometrics to Archaeology

Marcelo Cardillo

Idea and Aims

This work explores some aspects of the application of geometric morphometric techniques in archeology, with a focus on lithic artifacts. We show that Elliptic Fourier Analysis and landmark/semi-landmark based methods can easily generate quantitative useful information relative to outline variation in lithic artifacts. This information can be used latter as raw data into univariate, multivariate analysis to explore mayor trends of morphological variation as well as relations between metric and morphological variation.

Introduction

As in other disciplines that used classification procedures, archeology depends heavily on classification to analyze and explain variation. However, as Gero and Mazullo pointed out (1984), many traditional typologies are based on an intuitive recognition of patterns, where types are defined as a series of idealized forms, broken down into subvarieties on the basis of some number of defining variables.

This selection criterion is often biased, and the analysis cannot be replicated by other researchers. Dunnell (1971) observed that common typological analysis based on invariable properties of artifacts, make difficult the study of change, and referred these to an essentialist typology, contrary to materialist one (see also Hiscock 2001). A materialist approach to variation emphasizes a statistical treatment and management of data. Classification and analysis in lithic technology is commonly based on discrete, qualitative traits. Often, the classes or types are generated cutting down continuous metric and morphological variation into varieties or subclasses. These divisions are at last, arbitrary actions, which increase intra-observer error among

M. Cardillo (✉)
IMHICIHU-CONICET, Saavedra 5th floor, Buenos Aires, Argentina
e-mail: marcelo.cardillo@gmail.com

A.M.T. Elewa (ed.), *Morphometrics for Nonmorphometricians*, Lecture Notes in Earth Sciences 124, DOI 10.1007/978-3-540-95853-6_15,

lithic analysts and impede or difficult the replication by other researchers (see extended discussion in Dunnell 1971, Hiscock 2001).

We believe that the geometric morphometric approach is related with a more materialistic view of technology where the focus is on continuous quantitative phenomena rather than qualitative. Also, a more integral approximation to artifactual variation result from using geometric morphometrics tools for description, classification, and analysis. In this sense, artifactual variation can't be seen as self-explained phenomena but linked to different factors in need to be explained in each case. According to Shott (1996) variation within a single class or artifacts may be related to random sources like individual variation, style, replicative error, raw material variation and measurement error. Also, other factors, like manufacture and performance criteria are related to function (sensu Dunnell 1978).

In archaeology, a traditional morphometrics (*sensu* Marcus 1990) approach to lithic analysis was implemented through linear measurements as length, width, thickness, ratios and angles (see Wynn and Tierson 1990, Crompton and Gowlett 1993, Franco et al. 2005 among others), also three dimensional scanning techniques were used (Grosman et al. 2008). A primary concern of this analysis was to measure within class variation or morphological changes due to use and reactivation of artifact edges (Hiscock 2003; Hiscock and Clarkson 2005; Buchanan 2006; Shott et al. 2007; among others). In recent years, morphometric techniques based on different geometric models became more common, although in very different ways. These disparate approximations prevent the development of a common language for shape studies in archaeology, and also discourage researchers who want to start using these techniques.

In one of the first systematic applications of geometric morphometrics in archaeology, Gero and Mazzullo (1984) used elliptical Fourier analysis (EFA) over closed forms of lithic flakes for different time periods in Peru. These authors found that different levels of variation in harmonics amplitude describe changes in flake detachment techniques and relative standardization, observed as a paulatine angularity reduction trough time. In a similar fashion, Saragusti et al. (2005) shows the potential application of Fourier descriptors to make account of shape variation related to deformation, symmetry, roughness, and surface of different artifacts. In another work Saragusti et al. (1998) applied mathematical equations to study changes in symmetry, showing a temporal trend to more symmetric artifacts in lower Paleolithic handaxes. In relation to the use of landmarks, Brande and Saragusti (1996) defined important methodological issues related to the application of a landmarks based method to the study of artifacts. This works develops a geometric model to study handaxes, focused on linear measurements taken at regular intervals and then transformed into shape coordinates. In a similar fashion, Lycett et al. (2006) explores three dimensional morphometrics of Pleistocene lithic cores. The author takes several measures with a special purpose caliper and transformed them into shape coordinates, and after that submitted it to multivariate morphometric analysis. The results reflect the mayor trends of variation in lithic nuclei, as general dilation compression and relative asymmetry (also see Brande and Saragusti 1999 for an early exploration with three dimensional landmarks).

One of the most paradigmatic artifacts in lithic analysis is the projectile point. This kind of artifact was used to explore change in subsistence practices, stylistic or functional change among other approaches. Shape change in projectile points were accounted for Cardillo (2006) and Castiñeira et al. (2009) and Franco et al. (2009) among others. The existence of variations in the design of stemmed bifacial projectile points using geometric morphometric analysis, combined with linear measurements and microwear analysis was assess Franco et al. (2009). Results suggest that shape variation in the stem section of projectile points are not related to hafting technique defined by microwear analysis or metrical variation. Also, morphological change referred to resharpening and reavivation of artifact edges was explored within scrapers with EFA technique (Cardillo and Charlin 2009) and semi-landmarks (Cardillo 2009). In both cases, we found that variation display as a continuum is best explained by resharpening intensity and raw material acquisition and exploitation. Also, this variation can't be explained with a common typological approach. A common element in these studies is a focus on capturing variation of contours at various levels, using different parameters. It is important to note that lithic artifacts have common smooth contours of curves and plane convex or plane concave sections in essentially a two-dimensional outline. For this reason, outline description was a primary focus of inquiry in these investigations.

Of this different methods, we believe that landmark and semi-landmak approximations (Bookstein 1991, 1997) or EFA (Kuhl and Giardina 1982; Rohlf 1990), have more potential in the study of artifactual variation because they are based on easy to learn steps and comprehensive free software as Morpheus et al. (Slice 1998), Tps series (Rohlf 2002a), IMP series (Sheets 2003) Past program (Hammer et al. 2001), among others. Landmark semi-landmarks and EFA based approach are very flexible tools to describe and visualize shape change in an interactive manner as continuum phenomena, based on a sets of digitized x/y coordinates or x/y/z in a three dimensional case. These methods may prove useful to study, among others, change related with artifactual edge rejuvenation (reactivation or resharpening) and morphological variation due to functional or performance requirements. Here we show some of the potential of these methods with simple examples where geometric morphometrics are used as a tool to study lithic technology in a more quantitative and detailed manner. In this sense, we believe that a major potential in morphometric application in archaeology, is linked to visualization and numerical description of outlines and therefore, to the use of semi-landmarks, and the EFA method. This is because in the lithic analysis, only few landmarks (or homologous points) can be defined in the sense of Bookstein (1991).

In archaeology, the landmarks are according to "type two" landmarks of Bookstein (1991), which define them as points located in the maximum of curvature or extreme points in morphology (Bookstein 1991; Zelditch et al. 2004). Neverless in some cases, these can be difficult to establish, because artifacts can show variable morphological attributes due to random or functional causes, as mentioned above. But the location of landmarks when is possible, can be very useful to take account shape change due to reactivation of artifact edges or projectile point tips as observed by Castiñeira et al. (2009). On the other hand, semi-landmaks are used to incorporate information about outlines (Bookstein 1996/1997) defined as a set of points located at equal intervals along the curve. These points defined in terms of his relative position to other features (Zelditch 2004) in these cases, the entire outline are treated as a homologous unit. Therefore, relative variation to discrete semi-landmaks has no meaning per-se, and make sense when is studied as a whole. In relation of theoretical implications of the use of landmarks and outline descriptors, we consider that morphological features can be studied independently of homological information as common is used in biology (as Ferson et al. 1985 suggest, see also Bookstein 1996/1997). In fact artifacts not have biological homologies, but are the byproduct of recursive and standardized human technological practices, transmitted and maintained by cultural transmission and imitation (Cavalli-Sforza and Feldman 1981; Boyd and Richerdson 1995). However selection of outlines or discrete points must be related not only to research questions, but also to the particularities of each artifact topological feature as well as technical and morphological criteria, see also Brande and Saragusti (1996) and Lycett et al. (2006).

In this paper we focus on flaked lithic technology. Flaking artifacts from a piece of stone is a reductive process, where artifacts are made by removing flakes from a piece of parent lithic material. Different techniques as direct percussion flaking (striking the piece with a hammer) or pressure flaking (pressing a pointed instrument against the edge) are commonly used together to make different tools, from scrapers with steep-edge to knife with thinner edges and projectile points. Projectile points are only a part of more complex artifacts as throwing spears or bow and arrow technology. Also, lithic resharpening or reactivation practices that extend the use wear of lithic artifacts are reductive in nature. For this reason, reduction in size is a common byproduct that results in an allometric relation between form and size. Knapping processes themselves are subjected to random error related to rock texture, composition and grain, and also, knapper skills (Eerkens 2000; Eerkens and Bettinger 2001). For this reason, a different range of variation is expected even within the same kind of artifacts, variation being probably higher than the expectations, for example, in living organisms. Therefore, different types of artifacts will have a different rank of variation depending on the complexity of design, functional requirements or production techniques, and in the case of lithic artifacts the physical properties of the materials employed for knapping. For this reason, the potential discrimination between classes or subclasses of artifacts, or the power of multivariate analysis to explain the major trends of variation depends in some extent of the kind of artifacts analyzed and the selected methods to capture the morphological information. It is likely, that different kind of artifacts require different approaches, depending on their morphological features. In this regard, we believe that Fourier and landmarks and semi-landmarks based methods can give an efficient account of the shape variation in almost all cases.

To explore some applications of these methods in common lithic analysis and classification, we show three examples previously studied by Cardillo (2006), Scartascini and Cardillo (2009), and Castiñeira et al. (2009). The first two cases, use landmarks and semi-landmarks methods, and the third case, EFA approach.

Materials and Methods

First Case: Morphotype Variation in Simplest Outline: Line or Fish Weights

The line weight or net weight stones are artifacts commonly found in some areas in coastal north Patagonia (Sacartascini and Cardillo 2009) and are related to the exploitation of marine resources. Little archaeological information of fishing techniques exists, due to the fact that only weights were preserved. These artifacts were made with little modification of the original piece of stone, using pebbles from gravel deposits located near the sea shore (Scartascini and Cardillo 2009). Artifact manufacture was limited to knapping two notches in each extreme of the pebbles.

The sample is composed by 56 artifacts from three archaeological areas located along the north coast of San Matías Gulf, río Negro, República Argentina (Fig. 15.1a). Given the little energy investment in these artifacts, our primary interest was to obtain exhaustive characterization morphological variation relative pebble selection criteria. To that end, we measured metric variables as length, width, thickness and weigh, as well as the size of the notches in each of the ends, in order to explore correlations between shape and size.

Fig. 15.1 Geographical location of samples (**a**) north coast of San matías Gulf, río Negro, República Argentina, (**b**) República Oriental del Uruguay y (**c**) Puna of Salta, República Argentina

Second Case: Allometric Change in Paleoindian Projectile Points "Fishtail" from Uruguay

24 instruments classified as paleoindian Fishtail projectile points (around 11–10 years Ka B.P.) from surface collections of different localities in the República Oriental del Uruguay were analyzed. They are stored in public and private collections (Fig. 15.1b). Available radiocarbonic chronology (Nami 2007) supports the statement that the "Fishtail projectile point" morphotype is related to first human occupations processes in South America (during Pleistocene–Holocene period). In this case, we use geometric morphometric to make account to the allometric process of shape change related to blade rejuvenation of projectile points using centroid size of digitized images as a measure of size change.

Third Case: Projetile Point Change in Archaic Period in Salta. Puna Region

The sample was obtained from surface and sub-surface contexts in the Ramadas site, located in San Antonio de los Cobres valley, Puna of Argentina (Fig. 15.1c). The temporal span is between 6000 B.P. and 4000 B.P. The technological sequence of this site is similar to others recorded in the dry and salty Puna, for example in sites as those from Quebrada Seca and Inca Cueva 4 (Martínez 1999)

We selected a sample of ten morphotypes (or morphological variants); nine of them correspond to the samples collected in the studied zone, but one of these (the selected outgroup -OG- that dates from 6000 B.P.) proceeds from the site Quebrada Seca 3 excavated by Carlos Aschero (Aschero 1988; Aschero et al. 1993, 1994). The selected morphotypes are well represented in the archaeological sequences of very different sites with also good chronological information (see Ratto 2003; Martínez 1997). These authors suggest that metric variation was related with the use of different hunting weapons (spear-thrower weapon or more weighty hand thrower spears).

The main focus was to explore the temporal trends of change within this artifactual class, as well as the relation between metric and shape change.

In all cases, images were taken with an eight megapixels digital camera and no more than 30 cm of focal distance. Given that the analysis focused mainly on the contours of the artifacts, the images were taken in grayscale on a contrasting base to increase edge resolution. Before that, we used a variable number of sampling points around the outline using tpsDig (Rohlf 2002a) program using the automatic outline detection mode. All artifacts were recorded in a standard orientation, previously defined according to morphological and technological criteria (Fig. 15.2).

In the first case, where the artifacts show a considerable variation we use 100 closely spaced points, and the outline tracing began at the most distal point (Fig. 15.2a). In the second case, two landmarks and 22 semilandmarks was used. Landmarks were located at the tip and the base of specimens (Fig. 15.2b). Using the program Make Fan (Sheets 2003) equally angle spaced point were located using only a half portion of each artifact, in order to avoid information related to the

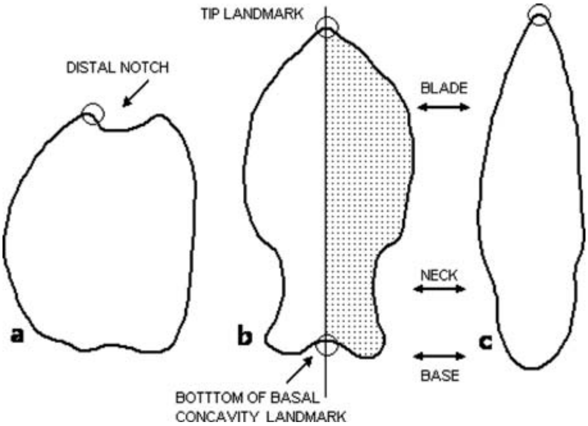

Fig. 15.2 The three examples presented in this work. (**a**) stone weight, (**b**) Fishtail projectile points (**c**) lanceolate projectile points. In (**a**) and (**c**) the *open circles* show the point were automatic digitalization begins in (**b**) the *open circles* indicate the location of the landmarks used, the shading area indicates the half portion selected to put semilandmarks

asymmetry. In this case we use Partial Least Square method (Rohlf and Corti 2000) to explore covariation between set of metrical attributes and shape using TpsPLS (Rohlf 2002a) as maximum length, thickness, width, and centroid size of specimens. Centroid size is the square root of the summed squared distances of each landmark form the centroid of the landmark configuration, and is obtained from the images in the process of superimposition. Correlation of shape change and centroid size is a good method to explore allometric change, as expected in the case of reactivation as in the case that Shott et al. (2008) shows.

Once a set of points around the outlines was digitized, landmarks and semilandmarks were processed using a generalized Procrustes analysis (Rohlf 1999), Also, in order to reduce de effect relative to the they arbitrary position, semilandmarks were aligned using bending energy minimization criteria (Bookstein 1997). To explore mayor trends in morphological variation, the resulting shape coordinates were submitted to relative warp analysis using TpsRW program (Rohlf 20002a) that are principal components of the partial warp shape variation at different scales (Rohlf 1993). An important aspect of relative warps is that the results of statistical analysis can be expressed as an intuitive deformation grid diagram of each case with respect to the mean form or reference.

In the third case, we use 100 equally spaced points along one smooth curve (Fig. 15.1). Digitalization was also made with automatic outline detection utility in tpsDig program. In this case, digitalization begins at the tip of projectile. Resulting coordinates were submitted to EFA using the program Past (Hammer et al. 2001). EFA method fitting successive sine and cosine terms (harmonics) these harmonics decreasing in amplitude to the first (lower) to higher harmonics. These harmonics describe components of shape at different scales (Rohlf 1990). In this case the first 20 harmonics were then using in principal component analysis to reduce dimensionality. Also the first principal component axes that explain mayor trends of morphological variation in outline are used as new variables in regression analysis.

Also, to explore grouping patterns and historical relations between projectile points we use the neighbor joining method (NJ). This method was proposed by Saitou and Nei to analyze distance data (Saitou and Nei 1987). This procedure, generate phenetic trees from continuous data like morphological multivariate data. NJ tree is an unrooted tree, but can be rooted like parsimony based methods. The input data to NJ procedure was the Fourier coefficients or harmonics obtained for each case. The earlier morphotype was use as outgroup to polarize the resulting phylogram. The likehood of resulting tree was computed by bootstrap (1,000 times). NJ method and bootstrap were performed using the program Past (Hammer et al. 2001). Also, general statistics, as principal component analysis, mixture analysis and regression were performed with the same software. Mixture analysis is an advanced maximum-likelihood method for estimating the parameters (mean, standard deviation and proportion) of two or more univariate normal distributions, based on a pooled univariate sample (Hammer et al. 2001).

Analyses

First Case

The RW analysis using semilandmarks show that the first component explains about 81% of shape variability, while the second 7, 48% (Fig. 15.3).

Given the focus on global description of morphological variation, the analysis proceeds with the uniform component, this describes the overall trends in compression/dilation or stretch of shape (Zelditch et al. 2004). For this reason the first RW shows that the greater variation is explained by big scale compression dilation patterns while the second RW shows that variation on asymmetry of pebbles used as weights. Also correlation was carried out between the first three RW and length, width, thickness, weight, but not significant correlations was observed in any cases.

The clustering distribution of cases inside the morphospace (concentration of the cases in two different clusters) of the first two RW, suggest a morphological gap or discontinuity. Finally, we use mixture analysis on the first RW in order to explore if that pattern can be best explained by the existence of two different distributions. The results show that the two group's hypotheses have the best likehood score (Fig. 15.4).

Results suggest that a different selection pattern of pebbles was carried out by humans, although no relation between shape and size variation was observed. It appears that, morphological variation responds first to performance requirements of these artifacts related to hydrodynamic requirements. Due to little modification, metric variation in natural outcrops of lithic deposits, may explain much of the morphological variation observed here.

Second Case

The RW analysis shows that the first component explains 56% of shape variation (Fig. 15.5). Variation was explore with and without the uniform component (Rohlf

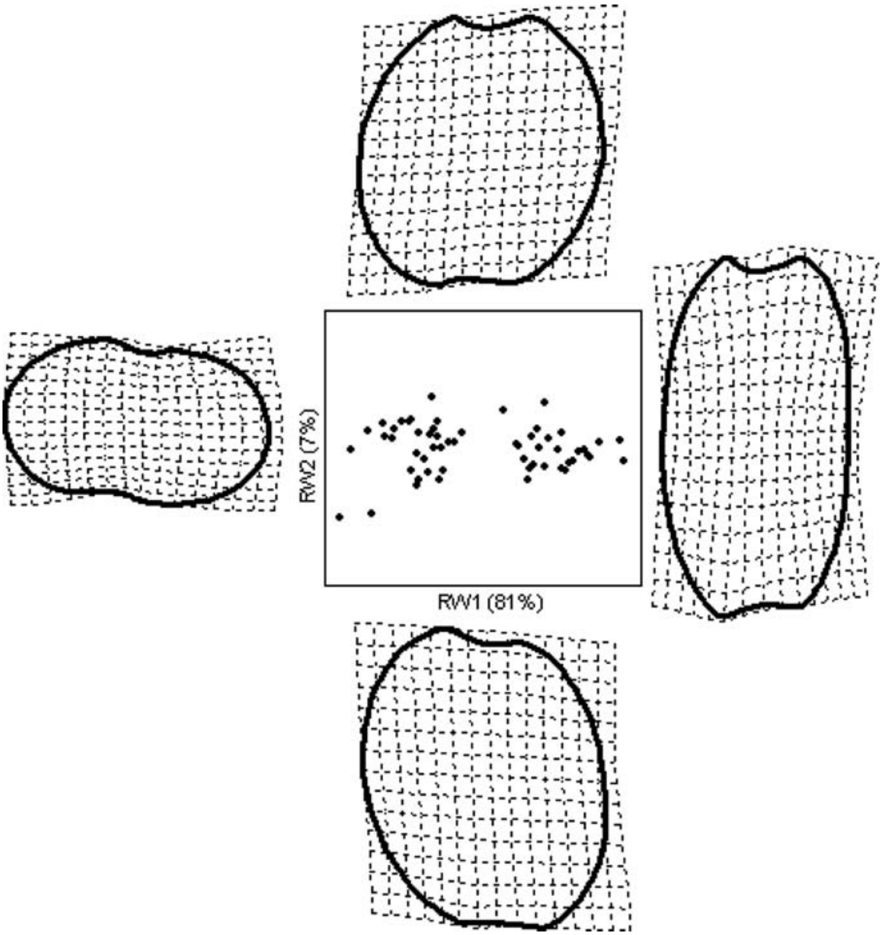

Fig. 15.3 First two axes of RW analysis of stone weights

and Bookstein 2003) and employing a variable weight to partial warps at different scales Rohlf (1993) alpha = 0 (gives equal weight at different spatial scales), and alpha = 1 (that gives more emphasis to variation at larger spatial scales). In all cases we got similar results.

The first axes of RW analysis shows the relative dilation/compression of blade and neck of projectile points. Also no discontinuities are observed in the first morphospace distribution; this pattern suggests a continuum of morphological change. To explore if this pattern was related reactivation/rejuvenation of blade a multiple regression using different variables was carried out, including the uniform component with partial least square method. Through this analysis is observed a significant correlation ($r = 0.65$, $p < 0.05$) between the centroid size and blade shape which indicates an allometric relationship between shape and size (Fig. 15.6).

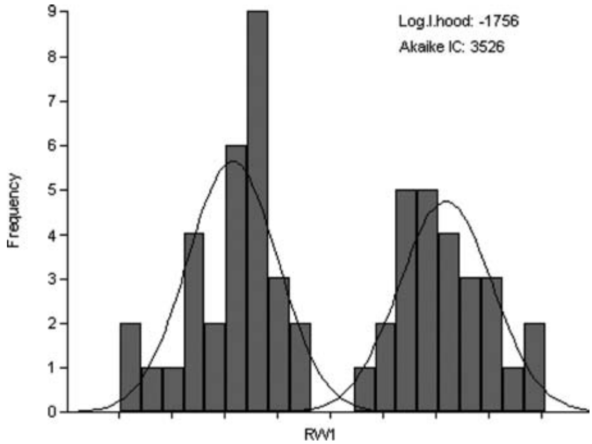

Fig. 15.4 Mixture analysis plot showing two slightly overlapped distributions using the first RW

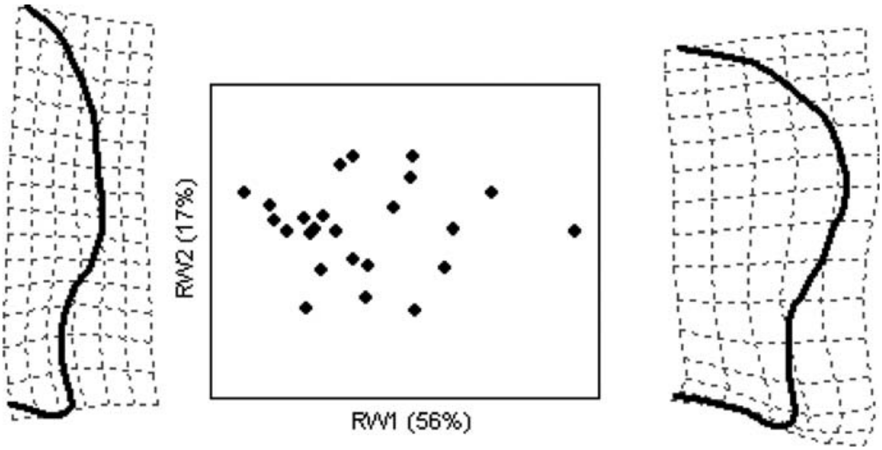

Fig. 15.5 Two first RW showing thin plate spline, including uniform component and alpha = 0

The analysis suggests that projectile points became more rounded while the geometric size decreases. At the right of Fig. 15.6 shows the shape relative to smaller artifact as deformation grids (a) and also display them as by vectors of relative landmark displacements (b). In both cases we can see the pattern and direction of allometric change in witch the blade is contracted in relation to the expansion of neck, also affected by reactivation. Results suggest that morphological change is related to rejuvenation of Fishtail projectile points, resulting in allometric patterns as Shottt et al. (2007) observed in Folsom Points.

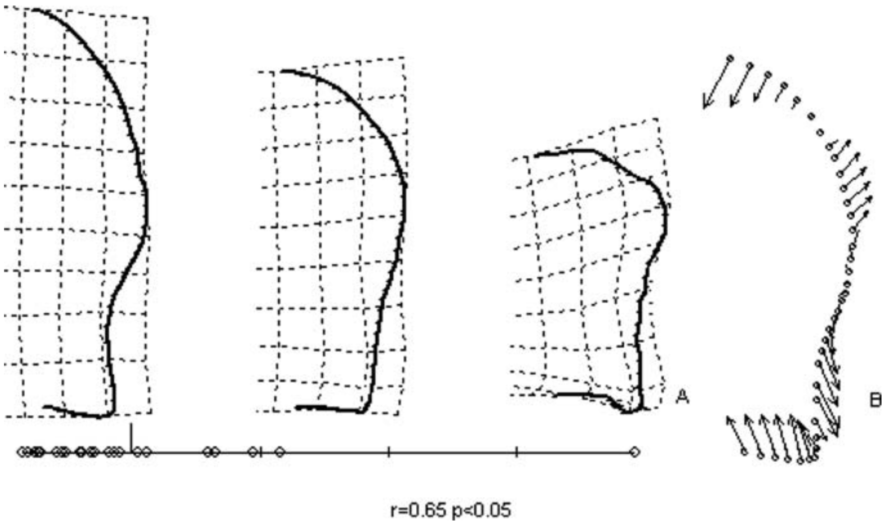

Fig. 15.6 Correlation between shape and centroid size. More exhausted or reactivated projectile points are toward the *right* of the figure variation (Fig. 15.6)

Third Case

The results of PCA over 20 harmonics shows that the first component explains an 88% of the total of the variance, while the second a 5.81%. The first PCA axis shows the general rounding or elongation of shape, while the variation of the remaining components is linked to relative asymmetry and shape change in more local scales. To explore how this change is related with an allometric pattern between size and shape, we made a regression analysis between weight (log) and the first PCA. Regression shows a positive correlation of $r = 0.66$ $p = 0.03$, in which more elliptical shapes are more light than elongated oval ones (Fig. 15.7).

To explore the pattern of morphological change from the oldest known morphotype, we use NJ method two perform a phylogram using the 20 harmonics as input. The results suggest a gradual trend of morphological change (Fig. 15.8), a same result can be seen in the first two axis of PC analysis (at the right, above)

Discussion

In the first case, results suggest that semi-landmarks based techniques are useful to capture the main trends of morphological variation, even in cases of highly variable shapes. We can also see potential discontinuities in the morphospace that may be related to statistical subclasses in Dunnell's (1971) sense. These subclasses can be explored with different statistical methods as mixture analysis or clustering

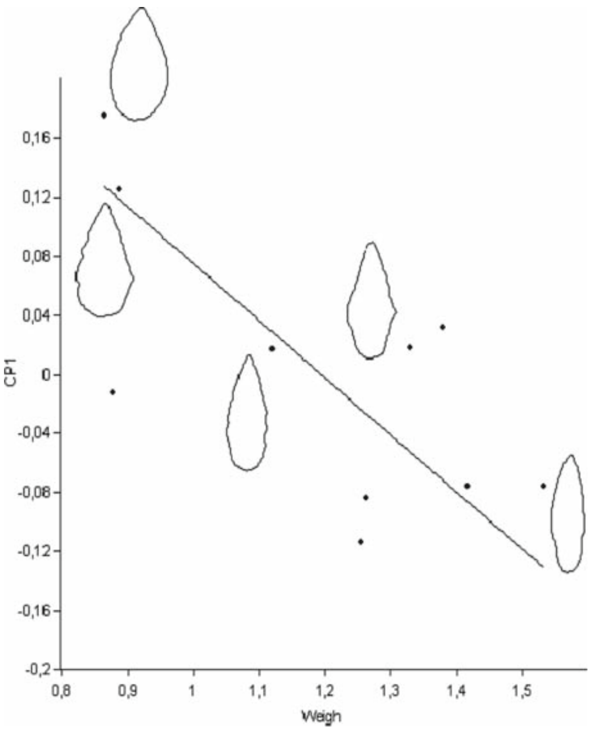

Fig. 15.7 Regression between the weigh and the first PC axis of EFA coefficients

algorithms, as K-means. Also, we observed that particular morphotypes of relative symmetric pebbles was preferred. This selection criterion can be explored for example, dividing each case in the middle and then performing two separate morphometric analysis and shape versus shape regression with partial least square.

In the second case, employ landmarks and semi-landmarks together, general trends of change was captured, but no discontinuities in morphospace were observed. That can be related as a continuum of shape change inside the same basic design. Also, the observed allometric relations between centroid size and shape change, (almost located in the blade and neck areas), suggest that morphological change is related at last some extent, with reactivation processes (Castiñeira et al. 2009).

While not shown here, in the first and third cases we use the previously aligned points to perform Principal Component Analysis on EFA coefficients and RW analysis. The resulting coordinates of EFA and RW ordinations for fish weights and lancolate points were compared by means of procrustean superimposition using PROTEST (Peres Neto and Jackson 2001) through 10.000 permutations (results, $m12 = 0.87$ $p < 0.001$ in the first case and $m12 = 0.88$ $p < 0.001$ in the second one). These results suggest that similar ordinations or clustering patterns between cases could be obtained by means of both methods. While our these results are very crude, we found that both EFA and landmark/semi-landmark based methods give similar

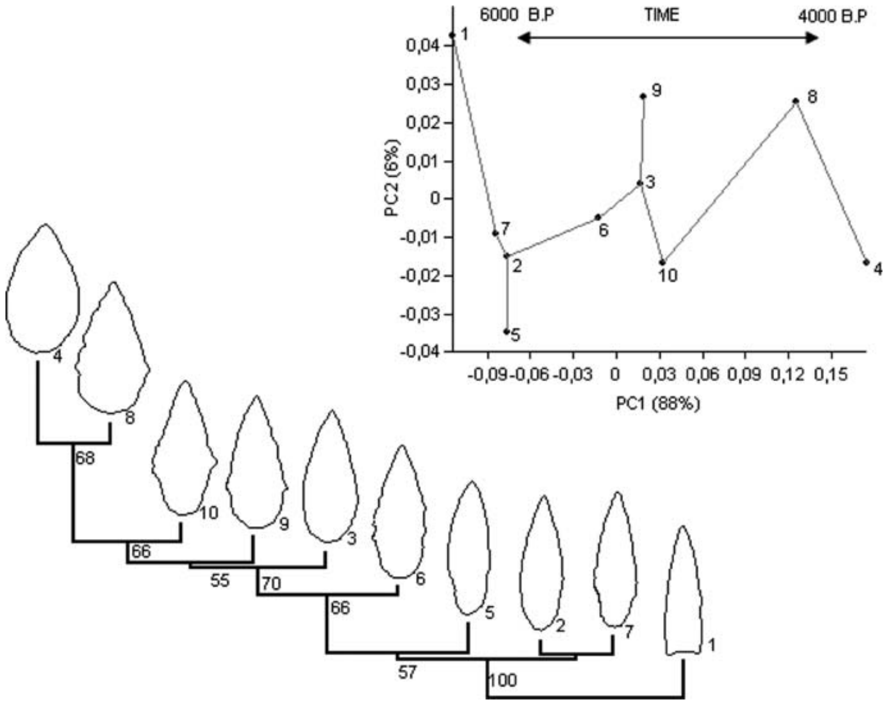

Fig. 15.8 Phylogram showing the clustering pattern of ten morphotypes. Numbers display de bootstrap support or each node only one case (2 and 7) was lower than 50%. At the *upper side* of figure we display scatter plot from PCA, cases were connected by a minimum spanning distance. *Arrows* shows the temporal trends

results in capture mayor trends of variations in two dimensional outlines taken as a whole, according to Sheets previous results in biological shapes (Sheets 2006).

Fourier harmonics (Rohlf 1998) or partial warp scores (Rohlf 2002b) can be used into clustering algorithms to explore morphological patterns (in witch some selected morphology or mean morphology can be used to rooting the tree). Also the morphospace generation and visualization with Thin Plate Spline or other methods can be use as a heuristic tool to explore variation patterns in different scales (Bookstein 1991). After that, different correlation/regression routines can be made, to pursuit the proximate causes of shape variation.

Because limited points can be used as landmarks in lithic artifacts, it appears that the common rule is a larger number of semilandmarks than landmarks. For this reason in almost all the lithic analysis the semi-landmarks have more weight in the results, as Sheets (2004) shows (see also Zelditch et al. 2004 for more complete discussion of this issue). One possibility is to divide morphology into a set of modules based on morphological of technological criteria. Correlation patterns between these modules (for example between the blade and de neck/base of a projectile point) can be related to functional integration of different sections of artifacts.

On the other hand, partitioning morphology into modules allows reducing the effect of sections with greater number of semilandmarks and therefore, more potential weigh in the results, as Sheets (2004) suggest. Also bounded regions of morphology and open outlines (as we show in the second case) can be more easily explored by landmark/semi-landmarks methods (see Franco et al. 2009) although some Fourier derived techniques can be used for open outlines as well.

Maybe one useful way to select between EFA or landmark methods depends on the nature of the data. The first method is better for complete outlines, and when scarce or no landmarks can be recognized or used. The landmarks/semilandmarks approach can be used for bounded regions of morphology, open or closed outlines, in this last case, with similar results.

Another important factor that we see is related with curation and reactivation of artifacts. This is a very common factor that can be expected to alter size and shape, result in allometric deformation, which is best explained as big scale shape deformations and uniform component related variation (compression/dilation and shear). Also we found that small scale variation along the outlines was related to roughness of lithic artifact as flaking or retouching of edges and microfractures due to taphonomic history (pot-depositional processes as trampling, abrassion, and weathering) of artifacts. These processes are taken into account when changes in roughness in one of the focus of analysis (see Gero 1984; Saragusti 2005) for this reason variation in local scale along the outline may be less informative than macro-scale variation. Small scale morphological change can be observed in some cases. But there is not a one single method for all possible cases, and much more work will be done with different kind or artifacts.

An other important factor that must be taken into account is that in archaeology, sample size are commonly small in relation to the number of variables as Fourier descriptors or semiladmarks; witch in turn can impede the use of some statistical methods, as canonical variation or discriminant analysis. One good possibility is using the first PCA axis of EFA series or first RW of partial warps (in this case, only the mayor portion of all variation selected). This axes can be used in univariate regression with independent variables (as weight of specimen) or in common correlation routines, as we show in the examples.

Finally, geometric morphometrics has many applications that go beyond shape analyses of lithic technology, different kind of archaeological data can be studied, and other variables can be used as well. Also, it would be useful to increase de interaction between researchers working on morphology through special purpose workshops and congress. This would help to the development of a common language morphometrics in archeology.

Conclusions

We think that geometric morphometric is a fertile ground to archaeology and can be part of a common protocol lithic study. This method brings us to powerful tool to explore and analyze variation, also implies theoretical and methodological approximation to more materialistic approach to variation. In the case of lithic analysis, this allows quantitative description of variation of shape and more objective and testable results. Also numerical treatment of data can be used to explore design and performance hypothesis as well as temporal and spatial patterns and live history of artifacts.

Acknowledgments I specially want to thank Judith Charlin, Carola Castiñeira and Federico Scartascini, they allowed me to use information of our previous and current investigations. I also want to thank Luis Alberto Borrero and Roberto Pappalardo who provided valuable comments that improved this paper. This research was made with support of CONICET (Concejo Nacional de Investigaciones Científicas y Técnicas)

References

Aschero CA (1988). El sitio ICC4: un asentamiento precerámico en la Quebrado de Inca Cueva (Jujuy, Argentina). Estudios Atacameños 7

Aschero CA, L Manzi and AG Gomez (1993–1994). Producción lítica y uso del espacio en el nivel 2b4 de Quebrada seca 3. Relaciones 19. Sociedad Argentina de Antropología. Buenos Aires

Bookstein FL (1991) Morphometrics tools for landmarks data. Geometry and biology. Cambridge University Press. NY

Bookstein FL (1996/1997) Landmarks methods for form without landmarks: morphometrics of group differences in outline shape. Medical Image Analysis. Oxford University press. 1(3) 225:243

Brande S and I Saragusti (1996) A Morphometric model and landmark analysis of acheulian handaxes from norhern Israel. Advances in morphometrics. Edited by LF Marcus, M Conti, A Loy, GJP Naylor and DE Slice. Plenum, New York

Boyd R and PJ Richerson (1995) Culture and the evolutionary process. University of Chicago Press. Chicago

Brande S and I Saragusti (1999) Arti-Facts Graphic visualization of Handaxes and other atifacts. Near Eastern Archaeology 62(4) 242:245

Buchanan B (2006) An analysis of Folsom projectile point resharpening using quantitative comparisons of form and allometry. Journal of Archaeological Science 33:185–199

Cardillo M (2006) Explorando la variación en las morfologías líticas a partir de las técnicas de análisis de contornos. El caso de las puntas de proyectil del holocenomedio-tardío de la Puna de Salta (San Antonio de los Cobres, Argentina). Werken 7, 77:88

Cardillo M and J Charlin (2009) Tendencias observadas en la variabilidad de los raspadores de norte y sur de Patagonia. Explorando las interrelaciones entre forma, tamaño e historia de vida. Arqueometría Latinoamericana 2do. Congreso Argentino y 1ro Latinoamericano. Vol. 2, 351–359. Buenos Aires. Argentina

Cardillo M (2009) Variabilidad en la manufactura y diseño de artefactos en el área costera patagónica. Un enfoque integrador Doctoral dissertation. Facultad de Filosofía y Letras. Universidad de Buenos Aires. MS

Castiñeira C, M Cardillo, J Charlin, J C Fernicola and J Baeza (2009) Análisis morfométrico de cabezales líticos "cola de pescado" de la Rep Oriental del Uruguay. Arqueometría Latinoamericana. 2do. Congreso Argentino y 1ro Latinoamericano. Vol. 1, 360–366. Buenos Aires. Argentina

Cavalli-Sforza L and MW Feldman (1981) Cultural transmission and evolution: a quantitative approach. Princeton University Press. Princeton

Crompton RH and JA Gowlett (1993) Allometry and multidimensional form in Acheulian Bifaces from KilombeKenya. Journal of Human Evolution 25, 175:199

Dunnell, RC (1971) Systematics in prehistory. Free press, NY

Dunnell RC (1978) Style and function: a fundamental dichotomy. American Antiquity 43, 192:202
Eerkens JW (2000) Practice makes whithin 5% of perfect: the role of visual perception, motor skills, and human memory in artifact variation and standardization. Current Anthropology 41, 663:668
Eerkens JW and RL Bettinger (2001) Techniques for asseing standardization in artifact assemblages. Can we scale material variability? American Antiquity 66(3) 493:504
Ferson S, FJ Rohlf and R Koehn (1985) Measuring shape variation of two-dimensional outlines. Systematic Zoology 34, 59:68
Franco NV, M Cardillo and LA Borrero (2005) Una primera aproximación a la variabilidad presente en las puntas de proyectil denominadas "Bird IV". Werken 6, 81:95
Franco NV, A Castro, M Cardillo and J Charlin (2009) La importancia de las variables morfológicas, métricas y de microdesgaste para evaluar las diferencias en diseños de puntas de proyectil bifaciales pedunculadas: un ejemplo del sur de Patagonia continental. Magallania 37(1) 99:112
Gero J and J Mazzullo (1984) Analysis of artifact shape using Fourier series in closed form. Journal of Field Archaeology 11(3) 315:322
Grosman L, O Smikt and U Smilansky (2008) On the application of 3-D scanning technologyfor the documentation and typology of lithic artifacts. Journal of Archaeological Science 35, 3101:3110
Hammer Ø, DAT Harper and PD Ryan (2001) PAST: paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4 (1) 9. http://palaeo-electronica.org/2001_1/past/issue1_01.htm
Hiscock P (2003) Early Australian implement variation: a reduction model. Journal of Achaeological Science 30, 239:249
Hiscock P (2007) Looking the other way. A materialist/technological approach to classifying tools and implements, cores and retouched flakes. Tools versus Cores? Alternative approaches to Stone Tool Analysis. Edited by S. McPherron. Cambridge Scholars Publishing: 198–222
Hiscock P and C Clarkson (2005) Experimental evaluation of Kuhn's Geometric Index of Reduction and the flat-flake problem. Journal of Archaeological Science 32:1015–1022
Kuhl FP and CR Giardina (1982) Elliptic Fourier features of a closed contour. Computer Graphics and Image Processing 18, 236:258
Lycett SJ, N von Cramon-Taubadel and RA Foley (2006) A crossbeam co-ordinate caliper for the morphometric analysisof lithic nuclei: a description, test and empirical examples of application. Journal of Archaeological Science 33, 847:861
Marcus L F (1990) Traditional morphometrics. Proceedings of the Michigan morphometrics workshop, Edited by FJ Rohlf and FL Bookstein, Special Publication Number 2. The University of Michigan Museum of Zoology. Ann Arbor. Michigan. 77:122
Martínez JG (1997) Estrategias y Técnicas de caza. Análisis tipológico-tecnológico de proyectiles arqueológicos. Trabajo Final de la Carrera de Arqueología. Facultad de Ciencias Naturales e Instituto Miguel Lillo. Universidad Nacional del Tucumán. MS
Martínez JG (1999) Puntas de proyectil, diseño y materias primas. En los tres reinos: prácticas de recolección en el Cono Sur de América. Edited by Por CA Aschero, MA Korstanje and PM Vuoto. Magna Publicaciones. Universidad Nacional del Tucumán. Argentina. 61:69
Nami H (2007) Research in the middle Negro river basin (Uruguay) and the paleoindian occupation of the southern cone. Current Anthropology, 48 164:174
Peres-Neto PR, and DA Jackson (2001) How well do multivariate data sets match? The advantages of a Procrustean superimposition approach over the Mantel test. Oecologia (Berl.). 129: 169–178
Ratto N (2003) Estrategias de caza y propiedades del registro arqueológico en la Puna de Chaschuil (Dpto de Tinogasta, Catamarca, Argentina). Doctoral dissertation. Facultad de Filosofía y Letras. Universidad de Buenos Aires. MS
Rohlf FJ (1990) Fitting curves to outlines. Proceedings of the Michigan morphometrics workshop. Special Publication No. 2, University of Michigan Museum of Zoology, AnnArbor 167:178

Rohlf FJ (1993) Relative warp analysis and an example of its application to mosquito wings. Contributions to Morphometrics, Edited by LF Marcus, E Bello and A Garcia-Valdecasas, Museo Nacional de Ciencias Naturales (CSIC). Madrid. Spain. 8 131:159

Rohlf FJ (1998) Review of "Fourier descriptors and their applications in biology". Bull. Math. Biol. 60:604–605.

Rohlf FJ (1999) Shape statistics: procrustes superimpositions and tangent spaces. Journal of Classification 16, 197:223

Rohlf FJ and M Corti (2000) The use of partial least-squares to study covariation in shape. Systematic Biology 49 740:753

Rohlf FJ (2002a) tps software series. http//life.bio.sunysb.edu/morph/

Rohlf FJ (2002b) Geometric morphometrics in phylogeny. In Morphology, shape and phylogenetics. Edited by P Forey and N Francis and Taylor. London. 175:193

Rohlf FJ and FL Bookstein (2003) Computing the uniform component of shape variation. Systematic Biology 52, 66:69

Saitou N and M Nei (1987) The neigbor-joining method: a new metod for reconstructing pylogenetic trees. Molecular Biology and Evolution 4(4) 406:425

Scartascini F and M Cardillo (2009) Explorando la variabilidad métrica y morfológica de las "pesas líticas" recuperadas en el sector norte de la costa del golfo de San Matías. Arqueometría Latinoamericana. 2do. Congreso Argentino y 1ro Latinoamericano. Vol. 1, 162–175. Buenos Aires. Argentina

Saragusti I, I Sharon, O Katzenelson and D Avnir (1998) Quantitative analysis of the symmetry of artifacts: lower Paleolithic handaxes. Journal of Archeological Science 25, 817:825

Saragusti I, A Karasik, I Sharon and U Smilansky (2005) Quantitative analysis of shape attributes based on contours and section profiles in artifact analysis. Journal of Archaeological Science 3 841:853

Sheets HD (2003) IMP-Integrated Morphometrics Package. Department of Physics, Canisius College, Buffalo, New York. http://www2.canisius.edu/~sheets/morphsoft.html

Sheets HD, K Kim and CE Mitchell (2004) A combined landmark and outline-based approach to ontogenetic shape change in the Ordovician trilobite Triathrus becki. Morphometrics applications in biology and paleontology. Edited by AMT Elewa. Berlin. Springer. 67:82

Sheets HD, KM Covino, JM Panasiewicz and SR Morris (2006) Comparison of geometric morphometric outline methods in the discrimination of age-related differences in feather shape. Frontiers in Zoology 3:15

Shott MJ (1996) Innovation and selection in prehistory. A case study from the American bottom. Stone tools theoretical insights into human prehistory. Edited by G Odell, Plenum Press. New York. 279:309

Shott MJ, DA Hunzicker and B Patten (2007) Pattern and allometric measurement of reduction in experimental Folsom bifaces. Lithic Technology 32(2) 203:217

Slice DE (1998) Morpheus et al. Software for morphometric research department of ecology and evolution, State University of New York. Stony Brook. NY. http://www.morphometrics.org/morpheus.html

Wynn T and F Tierson (1990) Regional comparison of the shapes of later Acheulian handaxes. American Anthropologist 92, 73:87

Zelditch ML, DL Swiderski, DH Sheets and WL Fink (2004) Geometric Morphometrics for Biologist. A Primer. Elsevier. Academic Press. NY