

# Chapter 13

## Towards Automating Artifact Analysis: A Study Showing Potential Applications of Computer Vision and Morphometrics to Artifact Typology

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### Idea and Aims

First released in 1961, William A. Ritchie's *A Typology and Nomenclature of New York State Projectile Points* remains an influential resource for archaeologists working in the northeastern US. Ritchie examined a large and diverse sample of stone projectile points, but not all fit neatly into his typology. In this chapter, we propose that alternative approaches afforded by computer vision and morphometrics can shed light on this and other problems of traditional stone tool typology. With the advent of computer vision, we can now examine the entire morphological continuum of projectile points through statistical shape analysis. Following automated image capture, three analytical methods were evaluated using silhouette, outline, and landmark data. Biased free capture methods to record the form of an individual projectile point, together with using invariant shape descriptors to quantify the data, may result in more objective analysis than was possible in the past.

### Introduction

Archaeology is the study of the past that uses material remains to reconstruct human behavior. As archaeologists, we seek to understand the similarities and differences within and between groups, often over large distances in both time and space. Our attempts to understand the past are often framed by broad questions: how and when did human groups spread across the globe? What are the origins, and repercussions, of plant and animal domestication? Why did social complexity develop in some places and not others? The answers to these questions lie in the archaeological record of artifacts and features, the tangible remains of past human activities. However, the data set is far from complete. Many aspects of human behavior simply

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do not leave significant traces, while other clues to the past typically do not survive in the ground for centuries or millennia, such as fragile organic remains (e.g., objects made from animal or plant materials).

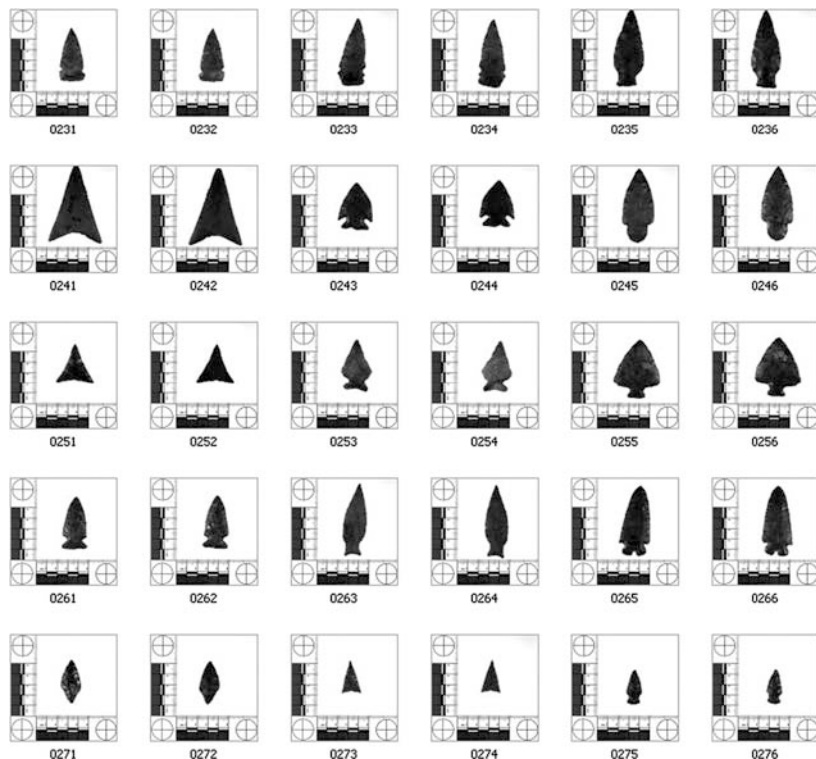
The most ubiquitous class of artifact found on archaeological sites worldwide consists of stone tools and the waste products from their manufacture. Chipped stone implements are found on sites left by some of our earliest hominid ancestors, and are still used today by some groups. Stone artifacts are frequently the only type of artifact recovered from archaeological deposits left by pre-ceramic peoples. Raw material for stone tool manufacture is found in most environments, and it is extremely durable, making it valuable not only for its original user but also for archaeologists.

Archaeologists working in the northeastern United States usually employ a system of three broad periods (Paleoindian, Archaic, Woodland) to divide the span of time between the first settlement of the region by Native peoples and the arrival of the European explorers and colonists in the sixteenth century. Although much fieldwork has taken place, many questions regarding the region's prehistory remain. Interpretation has been hindered by a lack of radiocarbon dates from prehistoric Native American sites. In the northeastern US, many prehistoric archaeological sites lack organic material suitable for direct dating using radiocarbon methods, largely due to very poor preservation in well-drained, acidic soils. Often this means that sites and components are dated solely on the basis of artifact (especially projectile point) styles. Projectile points are classified based on morphology (e.g., Justice 1987; Ritchie 1971), and the contexts from which they were recovered are then assigned the absolute dates that have been obtained for similar materials in the region. The resolution available with typological cross-dating is generally very broad and therefore not always adequate for sorting out remains into contemporary components or making comparisons among sites.

One often-voiced criticism of using projectile point typologies for dating occupations is that the various point types do not necessarily represent discrete temporal periods (Filius 1989), and that many of the types were likely used for extremely long (thousands of years) periods of time. In addition, more than one type may have been used by the same cultural group at any particular time (Snow 1980:162). Thus there may be some degree of temporal overlap among many of the described point types, even in a relatively restricted geographical area. Despite these and other drawbacks (e.g., Hoffman 1983), projectile point typologies are indispensable tools for Northeastern archaeologists (McBride and Dewar 1981; Starna 1979).

## **Ritchie's Typology and Nomenclature for New York State Projectile Points**

Projectile points from northeast US archaeological sites are most often classified using the typology constructed by former New York State Archaeologist William Ritchie (1961, 1971), who during many years of research examined 10,800 artifacts from New York in addition to materials from a series of sites in coastal

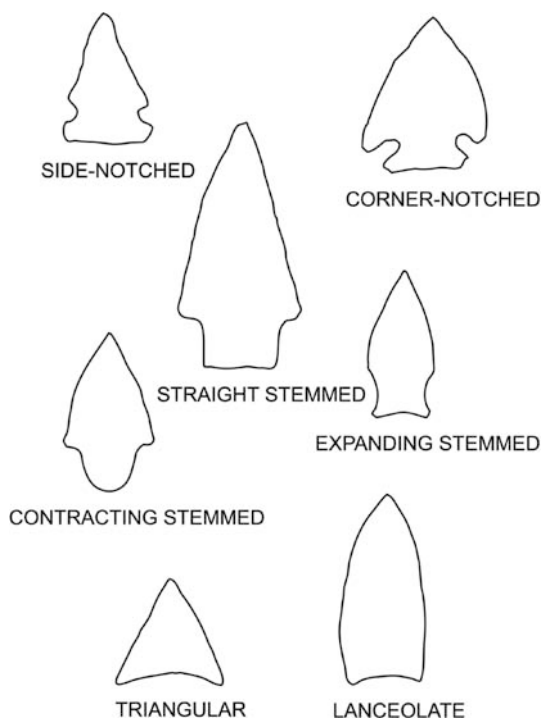


**Fig. 13.1** A small portion of the over 10,800 projectile points analyzed by William A. Ritchie for his 1961 publication *A Typology and Nomenclature for New York Projectile Points*

Massachusetts (Fig. 13.1). Points were placed into types using chronological, geographical, and most importantly, morphological (size and shape) data. Ritchie first defined major categories based on seven shapes: side-notched, corner-notched, straight-stemmed, contracting stemmed, expanding stemmed, triangular, and lanceolate (Fig. 13.2). Next, these categories were further subdivided into types, often named for the site where they were first identified or recovered in high frequencies (e.g., Madison (Fig. 13.3), Levanna, Beekman, and Squibnocket triangles). In all, 27 projectile point types were described by Ritchie's original study (Ritchie 1961), and another 10 types were added for the revised edition published in 1971.

Problems with Ritchie's typology were evident from the start. More than 900 of the 10,800 points could not be typed. Further, the subjective nature of the classification scheme has been noted by several researchers. For example, three well-known and respected northeastern US archaeologists were independently asked to identify the projectile point types from one Hudson Valley, New York archaeological site. Although there was agreement among the three analysts for some of the artifacts, in many cases, two or three different types were assigned to a single piece (Claassen 1995). Another fundamental problem in dealing with artifact morphology concerns

**Fig. 13.2** Primary morphological features presented by Ritchie (1961, 1971). Image reproduced with permission of New York State Museum



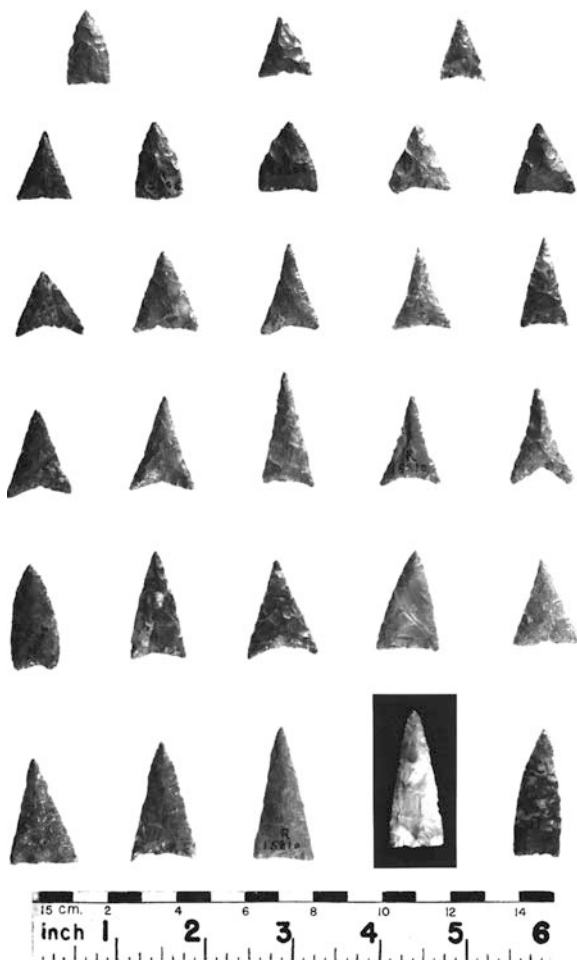
the use life of a stone tool. A projectile point is just one part of a continuum of stone tool technology that begins with raw material procurement and ends with eventual loss or discard, often with many stages of use and refurbishment along the way. Since making and recycling a stone tool is essentially a reductive process, a single piece may change shape as it diminishes in size over its use life (Frison 1968). This process, referred to as the “Frison Effect,” can confound artifact typologies.

In this paper, we propose that alternative approaches afforded by computer vision and morphometrics can shed light on these and other problems of traditional stone tool typology. With the advent of computer vision, we can now examine the entire morphological continuum of projectile points through statistical shape analysis. Following automated image capture, three analytical methods were evaluated using silhouette, outline, and landmark data. Biased free capture methods to record the form of an individual projectile point, together with using invariant shape descriptors to quantify the data, may result in more objective analysis than was possible in the past.

## Materials and Methods

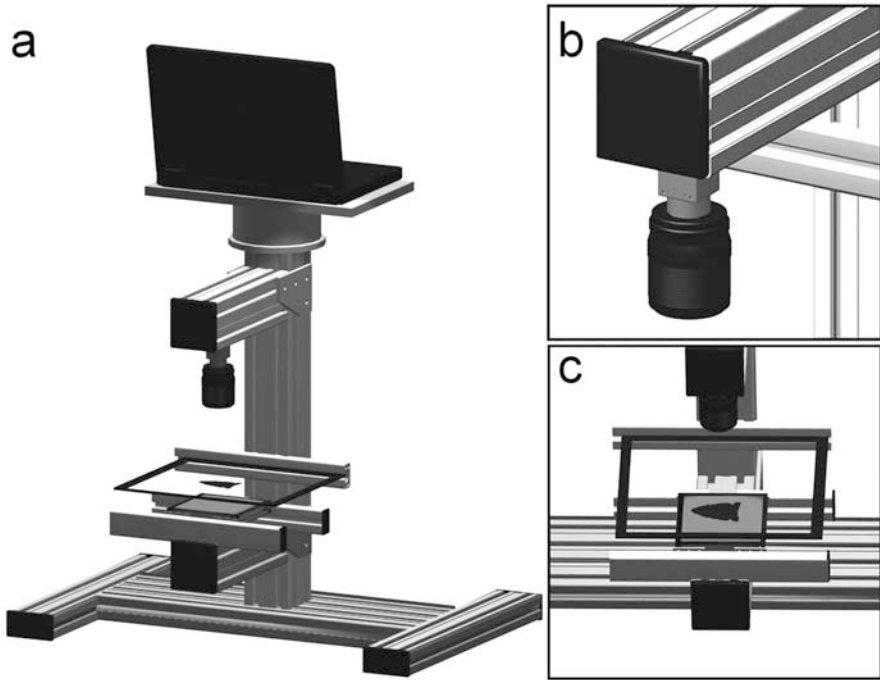
A combination of custom and off-the shelf hardware and software was used to create a flexible image capture system (Fig. 13.4). The goal was to design a system

**Fig. 13.3** Madison projectile points (Plate 16) in Ritchie's typology. As is evident in this example, a particular type as defined by Ritchie sometimes encompasses a high degree of shape variation (e.g., here these *triangular* points are lumped as a group despite having sides that are concave, convex, and straight). A number of hypotheses could potentially explain this problem: more than one point type is actually represented in this grouping, shape variations are due to unknown functional differences, or cultural reasons (e.g., importance of shape standardization). Image reproduced with permission of New York State Museum



well-suited for fast, efficient data collection for statistical analysis of hundreds, if not thousands, of projectile points. The following five criteria were important for achieving this goal:

- (1) the system should have a high speed image capture rate without compromising accuracy,
- (2) be flexible in case any requirements changed,
- (3) be modular, so it could be dismantled and transported to other research institutions,
- (4) limit overall cost due to economic realities, and
- (5) optimize the system workflow, in terms of image and data processing, to be as fully automated as possible without sacrificing any camera control, image



**Fig. 13.4** Camera and laptop computer setup (a) used to capture projectile point images at high speeds without sacrificing shape or measurement accuracy. Detail of camera and telecentric lens with deeppass filter (b), and glare-free artifact stage, light-control filter, and LED backlight illuminator (c). Approximate capture rate is 70 projectile points per hour

processing capabilities or compromising the quality of data necessary for robust statistical shape analysis.

## Hardware

Industrial structural aluminum framing was used as the main construction material for its rigidity and light weight (Fig. 13.4). The modular nature of the aluminum framing is ideally suited for the camera setup because it allows for the flexible mounting of equipment (e.g. lights, power boxes) and cable management. More importantly, precise adjustments required for different fixed and adjustable focal length lens and cameras can be made.

Three digital cameras are currently being evaluated for use with this setup: two Firewire (IEEE 1394a, DCAM 1.31 compliant) cameras, and an 8.0 megapixel Olympus digital SLR camera controlled by computer via tether. The choice of camera used for this kind of research is influenced by the method of imaging being

performed. For example, the setup described here consists of a camera, lens, filter and illumination optimized to capture accurate 2D shape silhouettes from 3D projectile points (see below).

A monochrome CCD-based Firewire camera was chosen for this study because it produces crisper edges than a comparable color camera (Steger et al. 2008). This is due to differences in the internal sensor array layout between monochrome and color charge-coupled device (CCD) sensor arrays. The color camera has an alternating array of red, green, and blue (RGB) light sensitive “wells” known as a Bayer pattern. Monochrome CCD sensors differ in that each well measures light intensity, not color. Silhouettes captured by monochrome CCD sensors have more edge fidelity than RGB color units (Russ 2002).

A telecentric lens was chosen for the camera because it eliminates common types of distortion that plague many compound lens systems such as parallax, pincushion, and barrel distortion. There are two caveats in using a telecentric lens effectively: 1.) the lens diameter has to be at least as large as the object being photographed, and 2.) a matching telecentric illumination source should be used in conjunction with this type of lens (Steger et al. 2008). Due to economic constraints, a partial telecentric lens was used (Computar Tec 55). The level of lens distortion was tested using a standard ISO 12233 slanted-edge measurement target and software designed to measure parameters such as the modulation transfer function (MTF). The MTF measures the spatial frequency response of the camera and lens system as a whole. The chosen lens was found to be sufficiently free of distortion for the purposes of this study.

The final elements of the system constitute the illumination system, probably the most difficult and counter-intuitive part of the entire system to design. The illumination required five specialized parts to work: an illumination source, a constant current source, a separate voltage supply, a specialized piece of light control film, and a specific lens filter mounted to the camera.

The illumination is provided by a red LED backlight (660 nm wavelength), driven by a constant current source and separate voltage supply to provide flicker-free operation. As stated above, monochrome cameras produce sharp silhouette images due to the internal layout of the CCD sensor array. The red color illumination was employed because CCD is most sensitive to this particular wavelength (Russ 2002). Telecentric lenses require telecentric illumination, which can be cost-prohibitive. Telecentric illumination consists of a large diameter compound lens which provides straight light rays in the same manner as collimated light sources used for microscopy. As mentioned earlier, the lens size has to be at least as large as the object being imaged, which equates to a telecentric illuminator costing many thousands of US dollars. Industrial engineers specializing in computer vision applications have developed an effective lower cost solution called light control films (personal communication, Daryl Martin, 2008). These plastic films have micro-louvers that block reflected light at known angles effectively creating a telecentric LED panel.

The last piece of the puzzle is the lens filter. Since it is desirable for the telecentric lens to capture only the straightened light produced by the red LED backlight, a deep red bandpass filter was used to eliminate all ambient light and just allow the 660 nm + 40 nm wavelengths through. According to one engineer (personal communication, Daryl Martin, 2008), this system may be capable of obtaining accuracies close to 1/1000 inch (0.025 mm) based on similar systems used in industry, though this has not yet been verified with the projectile point study.

### Software

The software used for automated image acquisition and processing is VisiQuest from AccuSoft Corporation. VisiQuest employs a visual data flow programming paradigm that encapsulates blocks of code as “glyphs.” The first glyph in the upper portion of Fig. 13.5 represents the image source (e.g., a camera) or from a directory of image files. The image data is then pipelined through a series of glyphs which represent a range of standard image processing (e.g., edge detection shown in the

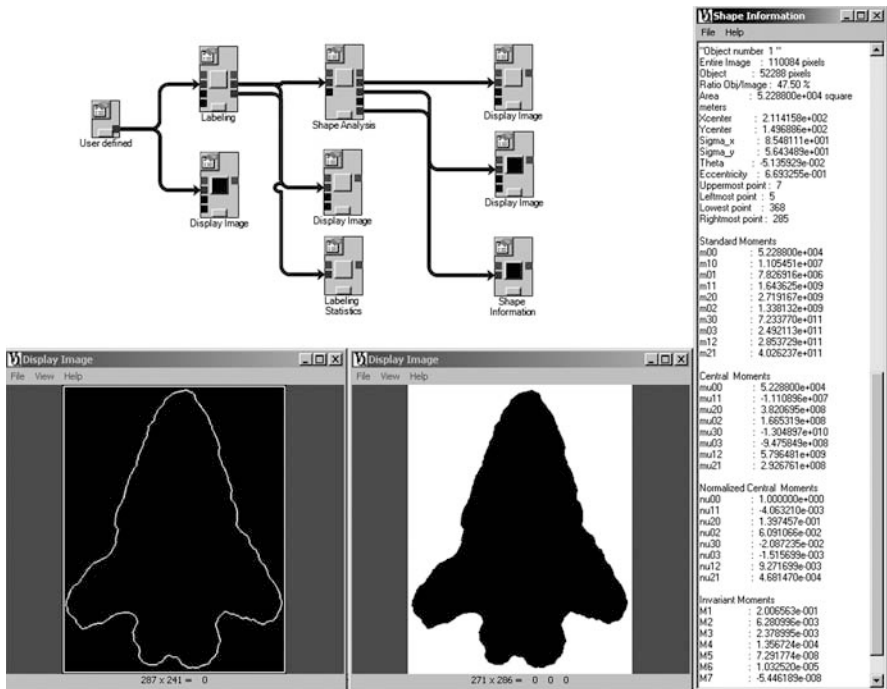


Fig. 13.5 Computer vision software (VisiQuest from AccuSoft Corporation)



lower left of Fig. 13.5, with corresponding statistical data to the right), morphological, and statistical tasks. The VisiQuest software is programmable with custom algorithms, but most applications can be found among the library of approximately 500 available functions.

Three approaches to statistical shape analysis were evaluated in this study: silhouette, outline, and landmark. The silhouette analysis was undertaken with a custom-written program developed by Holly Rushmeier and Andreas Glaser of the computer graphics group based in Yale University's Computer Science Department. Outline analysis was done using VisiQuest. Landmark data analysis was investigated using tpsDig2 (Rohlf 2008), tpsSmall (Rohlf 2003), MorphoJ (Klingenberg 2008), and PAST (Hammer 2008).

## Analysis

As discussed above, among the goals of this pilot study was to evaluate various methodologies for analyzing data extracted from images in either silhouette, outline, or landmark form. Rather than immediately attempting to replicate Ritchie's typology study with 10,800 projectile points, we limited our sample size for each evaluation. This way, we hoped to limit any wasted effort in case one technique was deemed ineffective or found to be totally inappropriate.

The type of archaeological research proposed here has the potential to amass a very large amount of data, with sample sizes in the thousands, due to the high image capture rate possible using the camera setup described in detail above (with an average capture rate of 60 to 90 seconds per image). Further, this will be an ongoing multi-year data collection effort. The image capture camera system was designed to be disassembled for transport in order to image projectile point collections located at other museums, universities and archaeology laboratories.

## Silhouette Based Methods

The first analytical method evaluated deals with silhouette data. Silhouettes were derived from raw image data by threshold and segmentation algorithms to create black and white bitmap images of each side of 100 specimens. The bitmap data were then subjected to geometric harmonic analysis that uses diffusion distances to organize data (similar to Isomaps used in cluster analysis). These methods create a shape space defined by the group of objects themselves. The original bitmaps were scaled and plotted as data points in such a shape space (Fig. 13.6). We inadvertently included images of both sides of each projectile points, which explains the pairings evident in Fig. 13.6. This actually may provide a useful statistic for ascertaining and quantifying effects of symmetry/asymmetry within a sample (as defined by a vector between specimen centroid pairs).

**Fig. 13.6** Organization plot based on natural basis functions. This plot was generated by custom programming code written by Dr. Holly Rushmeier and Andreas Glaser of the computer graphics group based at Yale University

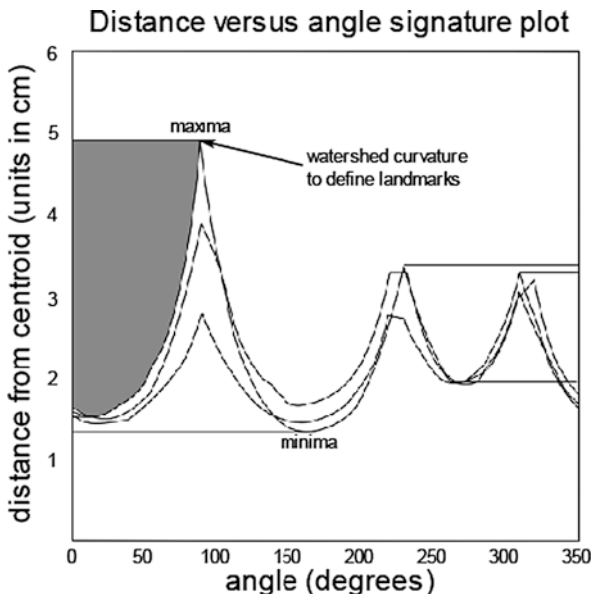


## Outline Based Method

After an object has been imaged and converted to a bitmap silhouette, an accurate outline may be obtained by using a variety of edge detection algorithms commonly used in the image processing field. The outline can then be converted to a series of  $x$ - $y$  coordinates by placing a grid over the outline and “cutting” out points. The  $x$ - $y$  coordinate pairs then are averaged to determine the centroid of the outline. If measurements are taken from the centroid to the object outline at known angles (polar coordinates), a signature plot of the object can be created (Gonzalez et al. 2004). While this method is useful for a variety of tasks (e.g., Optical Character Recognition and pattern/template matching), by itself it is not a robust statistical shape analysis technique for our research needs because it fails with certain projectile point shapes (personal communication, Holly Rushmeier, 2006). For example, taking measurements from the centroid of a corner-notched projectile point (Fig. 13.2) will result in more than one intercept on the outline near the point’s base from a given polar coordinate, invalidating the data.

Signature plots may still prove useful for mathematically determining geometric landmark data. This is accomplished by using a so-called “watershedding” algorithm, in effect filling the troughs of the signature plot graph, whereby the minima/maxima points can be used to place objective (mathematical) landmarks on an amorphous set of shapes, thus overcoming the problems presented by irregularly shaped projectile points (Fig. 13.7).

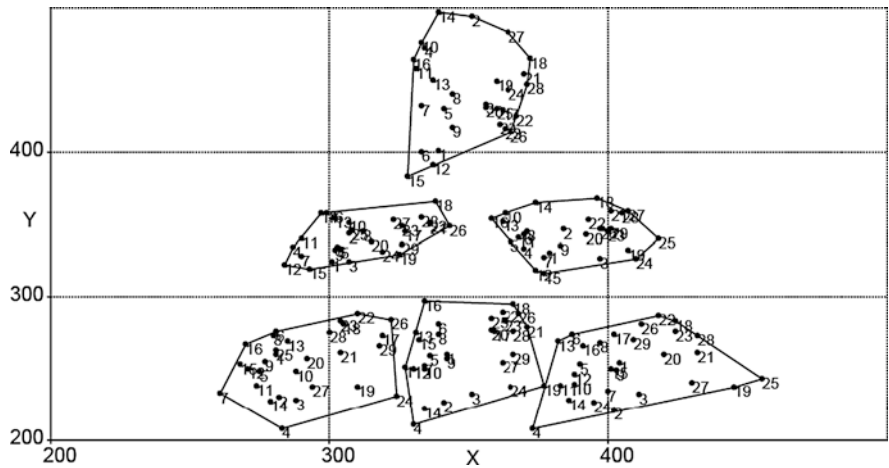
**Fig. 13.7** Signature plots of three projectile points representing the outline of each specimen. Landmarks may be determined using a watershed algorithm to find minima/maxima locations on the plots



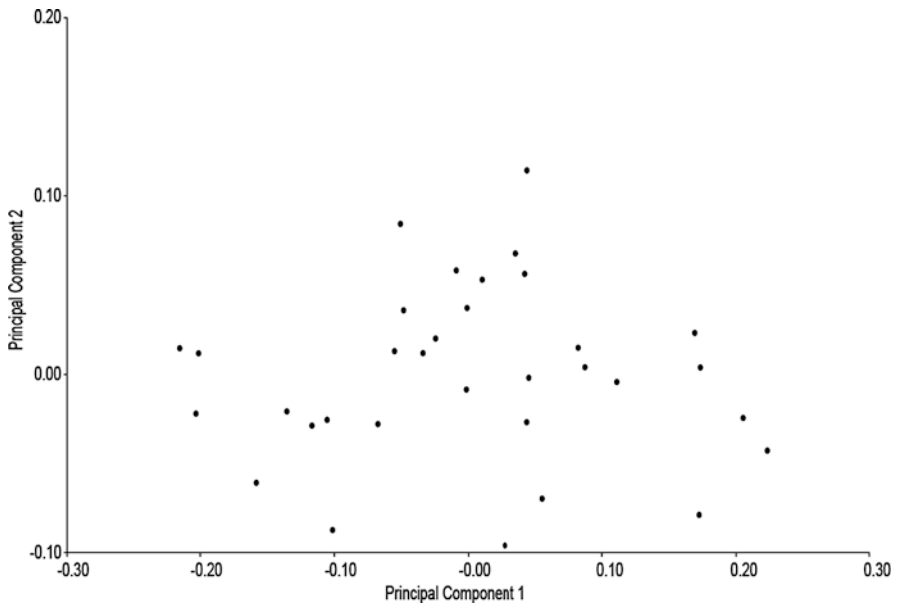
## Landmark Based Methods

A small sample ( $n=33$ ) of triangular projectile points was digitized manually using *tpsDig2* (Rohlf 2008). The points were previously classified by Ritchie as Levanna and Madison (Fig. 13.3) types. In this pilot study, landmarks were not rigorously determined, but rather they were subjectively placed in an attempt to describe features normally noted by archaeologists (e.g., height relative to width, curvature of the sides). Six landmarks were located on each of the 33 specimens. The first (landmark 1) was placed at the presumed top of the projectile point. The remaining five landmarks were then recorded counterclockwise from the first: two were placed at the remaining corners (landmarks 3 and 5), and three were placed at the midpoints along each side (landmarks 2, 4 and 6) to reflect the degree of concavity or convexity of each side (Fig. 13.8). Principal component analysis was performed on the data (Fig. 13.9; Tables 13.1, and 13.2), followed by generalized Procrustes analysis (GPA). While the choice of landmark location and number could be made more objectively in future research, the six landmarks chosen here were sufficient to differentiate two distinct projectile point types in a robust fashion (Figs. 13.10, and 13.11).

Cluster analysis was performed on the small sample of projectile points ( $n=33$ ) using PAST software (Hammer 2008). The tree was created using the unweighted pair-group method using arithmetic averages method UPGMA (Sneath and Sokal 1973) with the similarity measure set to use Euclidean distances. The cophetic correlation coefficient was 0.9132. Four of the points (specimens 0, 30, 31,



**Fig. 13.8** Landmark data before being subjected to generalized Procrustes analysis (GPA). As this was a pilot study, only six landmarks were used (three at each corner and three at the midpoint of each side) on a small sample (n=33) of triangular projectile points



**Fig. 13.9** Principal component analysis of 33 triangular shaped projectile points. PC1 (73.55%) and PC2 (13.90%) account for 87.45% of the shape variation within an unclassified sample of Madison and Levanna points. See Tables 13.1, and 13.2 below

**Table 13.1** Eigenvalues. Principal components 1 through 8

Eigenvalues	% Variance	Cumulative %	
1	0.01137	73.547	73.547
2	0.00215	13.899	87.446
3	0.00099	6.425	93.871
4	0.00035	2.266	96.137
5	0.00028	1.807	97.944
6	0.00013	0.84	98.784
7	0.00012	0.802	99.586
8	6.4E-05	0.414	100

**Table 13.2** Principal components analysis

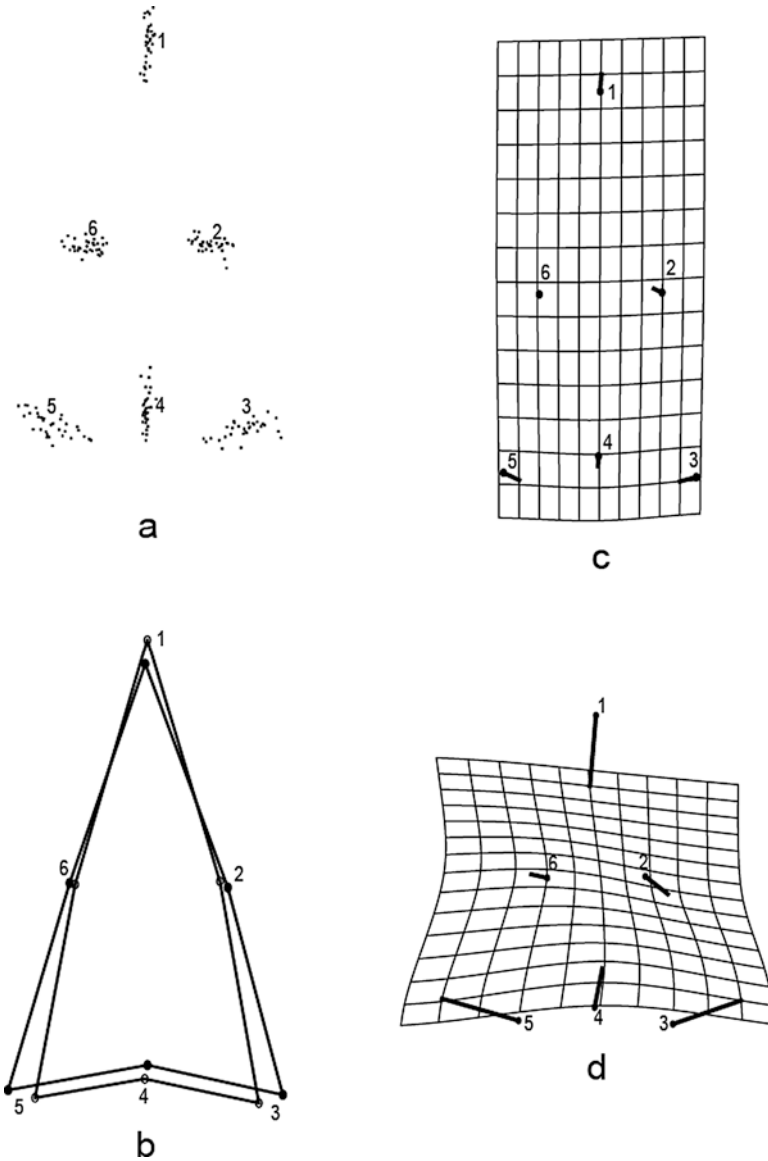
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
x1	0.02294	0.03831	-0.0993	-0.3215	0.40159	0.01424	-0.3508	0.1365
y1	0.40364	0.1915	0.09103	0.1826	0.29034	-0.2418	0.18443	0.01971
x2	-0.2454	-0.5554	0.33308	-0.0936	-0.1464	-0.0605	0.50789	0.05397
y2	0.06558	-0.168	-0.3092	-0.522	-0.4613	-0.1621	-0.2282	0.28729
x3	-0.558	0.23608	-0.2143	0.29778	0.05767	0.18084	-0.1595	0.27183
y3	-0.1163	-0.1473	-0.267	-0.2313	0.57376	0.17295	0.3238	-0.1146
x4	-0.0044	-0.0047	0.08788	-0.0914	-0.0171	-0.3468	-0.2996	-0.7264
y4	-0.2469	0.43693	0.66814	-0.1471	-0.0598	-0.0761	-0.0406	0.15251
x5	0.55272	-0.2209	0.20057	0.25025	0.04502	0.13551	-0.1883	0.35405
y5	-0.1558	-0.1902	-0.253	0.56852	-0.1132	-0.4171	-0.0617	0.0073
x6	0.23213	0.50666	-0.308	-0.0415	-0.3408	0.07678	0.49026	-0.0899
y6	0.04977	-0.1229	0.06999	0.14932	-0.2298	0.72419	-0.1777	-0.3522

and 32) clustered on the branch farthest left had all been previously classified as Levanna points by Ritchie (1961, 1971). One previously identified Levanna point (specimen 1) was reclassified as a Madison point by the cluster analysis.

## Discussion and Conclusions

Traditional artifact typology, although an indispensable tool for archaeologists and potentially imbued with cultural meaning, is limited by problems as illustrated with Ritchie's (1961, 1971) classification system for New York State projectile points. The bias free data capture methods made possible by computer vision, together with statistical methods that analyze shape in terms of invariant descriptors, may offer some solutions. Other archaeologists using this or similar approaches include Bradbury and Richmond (2004), Buchanan (2005), Cardillo (2006), Crompton (2008), Gero and Mazzullo (1984), Lohse et al. (2004), Pinkerton (1979), Saragusti et al. (2005), and Wei et al. (2007).

A computer based system, which relies on clearly defined geometric rules and algorithms, has the potential to limit the amount of subjective bias in classifying



**Fig. 13.10** The six landmarks shown clustered after generalized Procrustes analysis (a), wireframe connecting landmarks of PC1 (narrow *triangle*) over average shape of the sample (b), transformational grids (c and d) showing variation within two classified groups: Madison (c) and Levanna points (d). Note that the larger variation in Levanna points (d) is most likely due to the small sample size ( $n=5$ )

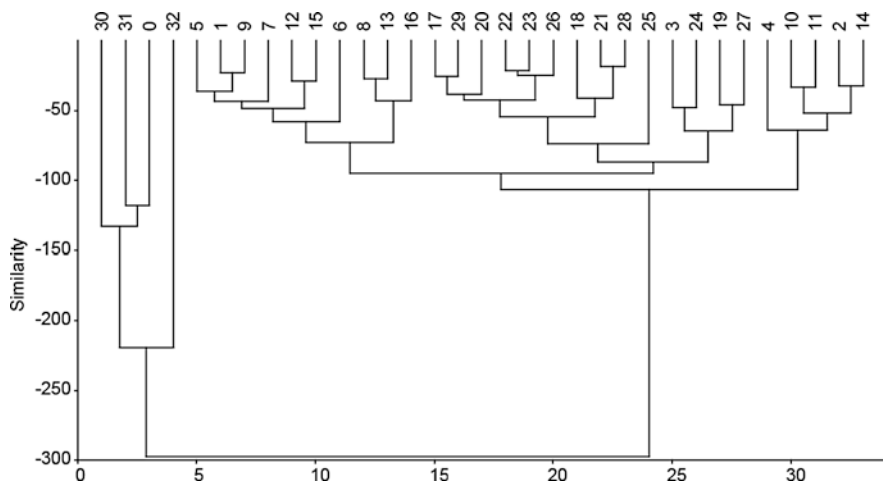


Fig. 13.11 Cluster analysis of 33 triangular projectile points

artifacts such as projectile points. Another benefit of using computer vision is fast, efficient, and accurate data capture, and is thus well-suited to documenting large artifact assemblages. We describe three analytical methods (silhouette, outline, and landmarks) that may be used to quantify artifact shape variables, and allow us to compare projectile points with one another in the context of a shape continuum as well as a discrete point type.

## Research Potential of Museum Collections

It is generally recognized that the majority of museums and other data repositories often exhibit only a fraction of their collections. Especially in the case of material recovered from an archaeological site, once an artifact has been cleaned, cataloged, and curated, it may only infrequently be re-examined, if at all. This has significant consequences for contributing to our knowledge and understanding of the past (Cantwell et al. 1981).

Perhaps among the most valuable products of the high speed data capture method described in this paper is that it will result in a digital photographic record of large collections of projectile points which could potentially be repurposed to answer a range of research questions. The ability to visually query a database, as well as extract useful shape and metric data directly from images of artifacts, has significant research potential and will likely lead to new perspectives on common archaeological problems. For example, by recasting the projectile point from a discrete and fixed “type” to instead as one stage in a continuum (from raw material procurement, through manufacture, use, resharpening, to loss or discard), we may be able to reconstruct a fuller view of ancient human behavior. Projectile

points may also be considered as part of a continuum of shape variation that changes in multiscalar dimensions due to a variety of mechanisms such as cultural data transmission (O'Brien 2008), need-based functional changes in morphology (e.g., changes in prey animals and hunting strategies), or simply the summation of divergent variations and characteristics which accumulated over time as groups of human populations spread out over the landscape, divided by natural physiographic or invented cultural boundaries. Linking artifact shape data with Geographical Information System (GIS) datasets is likely to reveal how the sources of variation within the morphometric data are distributed in both spatial and temporal dimensions.

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Our appreciation also goes to Dr. Holly Rushmeier and Andreas Glaser at the computer graphics group based in Yale University's Computer Science Department, who programmed custom software used to perform shape organization projectile point silhouettes based on geometric harmonic analysis and natural basis functions. Assistance with the engineering required for the high speed camera setup was gladly accepted from the following: Daryl Martin at Advanced Illumination Inc. (LED backlighting and deeppass filter), Linda Thalhuber at 3 M Optical Systems Division and Harvey J. Gibson Jr. Product Support Specialist at Edmund Optics (3 M light control films), and Dr. Jonathan Kane Computer Optics Inc. (telecentric lenses). William J. Schuler provided additional engineering expertise and invaluable assistance in fabricating the camera stand.

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