Geometric morphometric analysis of late woodland triangle point types from the Mohawk Valley, New York

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GEOMETRIC MORPHOMETRIC ANALYSIS
OF LATE WOODLAND TRIANGLE POINT TYPES
FROM THE MOHAWK VALLEY, NEW YORK

by

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ABSTRACT

Borrowed from the field of biology, geometric morphometric analysis has been recently applied to lithic assemblages with great success. This paper discusses the results of a 2D morphometric analysis of triangle points from the Mohawk Valley, New York, the staple point form of the late pre-contact period. This morphometric approach, which uses outline data extracted from high-resolution photos of the projectile points, leverages multivariate statistical analysis to visualize intra-type variation present in the collection. Change in shape (via length-width ratios) has been previously documented for this collection, but this new application of morphometrics results is a more nuanced look into the nature of change through time than that provided by traditional caliper-based methods. The result is a high-resolution examination of morphological variability that is able to demonstrate a bimodal distribution of types that conforms to the traditional typological classification system present in the region, that which archaeologists have qualitatively known but have thus far been unable to quantitatively demonstrate. As well, intra-type variability through time is explored and results demonstrate a pattern of increasing variability consistent with the array of sociopolitical changes that take place through the contact and into the historic periods. This study presents an example of an alternative technique that offsets the inherent drawbacks of coarse-grained typological approaches to projectile point characterization.
INTRODUCTION

Northeast North American archaeologists have for decades sought to supplement qualitative observations of projectile point form with useful quantitative observations. In studying Late Woodland Period triangle points, for example, traditional typological approaches have discriminated between the early Late Woodland Owasco Levanna point and the classical Iroquoian Madison point. In one such study, Kuhn (1996) analyzed 441 triangle points from the Mohawk Valley in an attempt to test the hypothesis that triangle point form exhibits linear change through time. Kuhn sought to determine whether the resulting patterns might facilitate intra-type temporal classification. This work was undertaken using traditional uni-dimensional metrics and ratios and revealed a weak temporal trend in length/width ratios, thereby presenting qualitative evidence for lithic technological change in the Late Woodland period.

Despite such advances, analysts are increasingly beginning to favour descriptions of the points as “triangle arrow points” (Snow 1995:53) in an abandonment of the two types Ritchie described (Ritchie 1971): Madison and Levanna. This shift in perspective is a consequence, in part, of ongoing frustration with the disconnect between methodological practice and the phenomenon under investigation. Put simply, lithic analysts have not had the right tools available to study the nature of or variability within projectile point assemblages in respect to overall shape. Conventional caliper-based metrics fail to consistently show what analysts seem to intuitively know, that these two types are not opposite ends of a continuum of form but instead represent different end-product goals that manifest themselves variably in the archaeological record.
The present study turns to the field of geometric morphometrics - commonly employed by biologists and physical anthropologists but relatively new to the field of lithic analysis as an alternate means of discriminating and characterizing projectile point types in a quantitative way. The outline-based geometric morphometric technique of elliptical Fourier analysis is here used to quantify and analyze 292 of the original 441 points from the collections of the New York State Museum that Kuhn examined in his study. When overall shape is examined, as opposed to isolated linear metrics, the linear pattern Kuhn described is not replicated. Instead, a bimodal distribution of point shapes is revealed, clustering temporally by cultural tradition. The results are consistent with the traditional typological framework, albeit exhibiting a greater range of variability than has been previously recognized.

Traditional caliper-based lithic analyses are beneficial in many contexts, but come with inherent drawbacks that limit interpretative potential. The benefits of elliptical Fourier analysis in lithic studies are numerous, in particular the objectivity of a landmark-free outline-based approach to shape characterization and measurement. Geometric morphometrics and other non-traditional methodologies are being shown to shift definitions upon which typological schemes are based away from isolated aspects of tool shape to behaviourally-meaningful descriptions related to maintenance, intent, and purpose (Iovita 2010). The present study approaches the typological problem of separating Late Woodland triangle points based on form using multiple dimensions of shape carried through the analytic process with the intent of serving as a more realistic and holistic way of looking at formal tool typology.
The results of this study are relevant to lithic analysts, in general, from a methodological perspective, and to Iroquoian scholars in particular, from a technological development perspective. The results end up showcasing the benefits and drawbacks of simplified typological approaches to artifact analysis by demonstrating a case where the material record does not fit neatly into the boxes archaeologists conceive for it.

Figure 1: Madison points from the Elwood site. Scale is 20x20mm

**METHODOLOGICAL BACKGROUND AND RELEVANCY**

Morphometry is the study of shape and size (or form) and the nature of change in such forms (Bookstein 1997; Lele and Richsmeier 2001). The study of form can be undertaken using uni-dimensional techniques, as in linear caliper measures of an object, with two-dimensional techniques employing landmarks and outlines, and in three dimensions with digital scans and triangle-mesh data (Neal and Russ 2012). Lithic analysts traditionally employ uni-dimensional morphometrics that describe formal tool
and debitage specimens and assemblages, although non-linear units based on weight, volume, or other analytics have been the subject of successful experimentation as well. These traditional morphometric studies include size measures of length, width, and thickness of various artifact features. Shape measures include ratios, often combinations of the above size metrics, as well as angles (Rohlf and Marcus 1993). Coupled with qualitative descriptions of artifacts, very successful analyses of inter- and intra-site assemblages can be created. The typological approach to formal tool classifications in Northeastern North America is based on these traditional metric measurements, as well as relevant qualitative descriptors.

Geometric morphometrics is a term in the literature that signifies an advanced stage of the study of form that typically includes computationally-intensive approaches able to analyze multiple dimensions of an object at once. The key difference between traditional morphometrics and their geometric counterparts is that the latter approach preserves the geometry of an object and carries this through all levels of analysis (Adams, et al. 2004). The term is meant to associate itself with the study of shape, defined by Slice as, “the geometric properties of an object that are invariant to location, scale, and orientation” (2005:3), and includes a wide variety of techniques meant to include and describe geometric structures and relationships between structures that define the measurements being taken. Listing a series of distances between points on an object, such as length, width, thickness, gives no information about the positional relationships of the various structural features of objects, key information when considering and studying form (Zeldich, et al. 2012). Variation in shape is mathematically separated from variation in size and can be studied in its own right, or in relation to size as its own separate
variable. Shape is inherently multivariate and this new series of methods is able to preserve the geometry of an object throughout the analytic procedure (Lycett and Von Cramon-Taubadel 2013).

This change in methodology was deemed revolutionary by Rohlf and Marcus (1993) as they argue that shape is more effectively captured with relational datasets and therefore statistical analyses carried out on the data are far more robust and powerful. Another advantage of this new series of methods is the ability to more effectively visualize changes in shape. Since the geometric information is retained, the analytic results can be turned back into shape form in order to be mapped and visualized in many ways that are simply not possible with traditional methods (Slice 2005). Instead of spreadsheets of synthesized data, charismatic and highly intuitive visualizations are available for explanatory purposes. These methodological advantages have led to the investigation of new research questions and the clarification of old issues in many fields.

In addition, advances in computing power have allowed geometric morphometric techniques to become widely accessible.

There are two approaches that comprise modern geometric morphometric methods: landmark and outline. The former began as a series of methodological advancements that aimed to describe the geometry of an object using landmarks taken as
coordinates. The position of these landmarks and how they change over different manifestations of the same object-type describe the geometry of an object. The result is that landmark positions are added into a multivariate analysis, a point that was lost in traditional approaches, though the landmarks may have been used to acquire traditional-type measures (Rohlf and Marcus 1993). Landmarks must be subjectively selected based on the nature of the dataset and the research question (Lele and Richtsmeier 2001). Over the collection of specimens, the landmarks are placed in homologous locations each time, forming the foundation for a comparative analysis. There are many types of landmarks, combinations of which can be used to answer a wide variety of research questions, and the background and specific mathematical theories that have gone into the creation of landmark-based geometric morphometrics have been studied in great detail (Adams, et al. 2004; Bookstein 1997; Kendall 1977; Kendall 1989; Lele and Richtsmeier 2001; Rohlf and Marcus 1993; Zeldich, et al. 2012). In biological applications, for instance, landmark placement is generally based on the perceived significance of the location, such as the intersection of tissues. Changes in these locations are thus assumed to be relevant to evolutionary or other research questions (Thulman 2012).

Selection of landmarks in non-biological archaeological contexts is inherently subjective and reminiscent of traditional morphometric approaches that measure various distances and ratios of objects. However, Rohlf and Marcus here describe the difference between this approach and traditional morphometric measurement techniques: “Rather than having to decide beforehand exactly which variables should be measured, the analyses are designed to indicate directions of maximum variation and hence may suggest which conventional variables one should emphasize in verbal descriptions of the results”
(1993:130). While the subjective placement of landmarks for study is ever-present, and indeed traditional data can be extrapolated by reducing the landmark data into unidirectional measures, a geometric approach to data collection works backwards from this approach by evaluating a great deal of landmark data and from this, important changes in shape can be gleaned. Multivariate approaches to analysis are inherently obligatory.

Outline approaches to geometric morphometrics gather a different type of data, though they still include the geometric information in analysis and are able to display it as such. Outline data represent the two-dimensional boundary of an object (Lele and Richtsmeier 2001). Information is collected about the outside of an object at equally spaced intervals and subjected to varying types of analyses. This approach is ideal for samples where no meaningful landmark points can be taken, such as along a curve (Adams, et al. 2004). The points are fitted to a mathematical function or else analyzed in some standardized way, and are then submitted to multivariate analyses. These data can then be used to recreate and visualize the object’s outline. This approach is distinct from landmark data as the data points taken are not subjectively placed at perceived key locations, nor can information about the interior of objects, relational or otherwise, be included in analysis. Data of this type has the ability to represent curved objects with a higher degree of reliability (Baylac and Friess 2005; Lele and Richtsmeier 2001). The most common types of outline study are Eigenshape analysis and Fourier harmonics analysis.

Eigenshape analysis relies on equally spaced landmark data that traces the outline of an object using angles measured between the points (Polly 2012). After digitization,
one homologous landmark must be chosen on each specimen to mark the beginning of angle measurement. Using these angles, principal components analysis can be performed. In practical use, eigenshape analysis is often used in tandem with landmark-based approaches in order to analyze a greater portion of geometric data found in different types of specimens (MacLeod 1999). This flexibility has allowed for application to a variety of research areas.

Fourier harmonics analysis, or Fourier shape descriptors analysis, provides another outline-based method of studying object geometry. This particular set of mathematical functions is part of a grander series of Fourier analytics covering a wide array of applications. Classic Fourier harmonics analysis, as is relevant here, is performed
on simple closed-outline shapes and creates a series of sine and cosine functions based on angles relative to the centroid of the object. These functions represent the outline and are the foundation for subsequent multivariate analyses. An object must not have an outline that curves in on itself (i.e. having no one point stemming from the centroid to the outline that crosses the outline more than once) or this procedure will not work. To put this in terms relative to lithic analysis, a radius stemming from the centroid of a notched projectile point to the outline of the object may cross the outline more than once if running through the noted inlet. Fourier harmonics analysis is therefore limited in its application to lithic studies to specimens with simple outlines.

Kuhl and Giardina (1982) developed a variation on the Fourier approach known as elliptical Fourier analysis, or EFA, that solves the problem of complicated shapes. The present study employs this outline-based approach for the study of shape using elliptical Fourier harmonics generated via EFA. This variation on the Fourier approach remains the most popular of the series across many disciplines (Iovita 2009). EFA turns all curves of an object into sine and cosine functions based on a simple ellipse generated relative to the original object. The first harmonic describes this ellipse while the subsequent ones add detail to the outline representation.
As a result, EFA has the ability to orient objects based on the position of this first harmonic, or the primary ellipse (Baylac and Friess 2005; Kuhl and Giardina 1982). However, various applications of EFA can standardize their orientations prior to analysis. In other words, EFA measures and mathematically describes the difference between the first ellipse and the original shape (Brophy, et al. 2014). Each harmonic produces four descriptors - sine and cosine descriptors for each $x$ and $y$ coordinate present. Based on the Kuhl and Giardina (1982) method, these coordinates are generated via chain code, a method of representing outline retaining directional and positional data. EFA produces twice as many descriptors as would a classic Fourier analysis. EFA can also be performed on user-selected landmark data that describes the outline of a shape in a robust way (Brophy, et al. 2014; Iovita 2009, 2010). Theoretically a disadvantage, doubling the data being analyzed is not in fact given much thought as calculation complications are...
effectively subsumed by modern computing capabilities. EFA also removed the requirement for equally spaced intervals along the outline, and the ability to reconstruct complicated shapes allows this application of Fourier descriptors to cover a larger range of two-dimensional shapes (Lestrel 1997).

EFA represents a curve-fitting approach to geometric morphometrics useful for describing characteristics of form that are not dependent on homologous points and not reliant on finding an object’s centroid (Lestrel 1997). This theoretical technique was first applied in a biological context, and two classic studies exemplify early advancements. Rohlf and Archie (1984) investigate mosquito wing shapes using a number of Fourier techniques, concluding that EFA produces the most desirable results. Ferson et al. (1985) study the shapes of mussel shells using EFA to discern between two populations. Their study takes advantage of some of the properties inherent in EFA such as invariance related to changes in size and orientation in order to isolate the shape variable and describe intra-sample variation. These two studies were important in showcasing the unique strengths of EFA in its early adoption by research communities.

Research Applications of Geometric Morphometrics

Geometric morphometrics have been used to address a wide array of research questions in many fields. Biologists have long used geometric morphometric data to address issues specific to their discipline. Research questions within the field of biology motivated many morphometrics advancements in the previous century as the field of biology shifted from a descriptive to a quantitative one (Adams, et al. 2004). Therefore, much of the range of computational power and applicability of geometric morphometric data has been described in terms of its biological applications. Based on the nature of
biological data, landmark techniques are favoured as these relate to the available data and represent it quite well. There are many resources available for the biologist that delve into the specifics of landmark approaches and their utility (Bookstein 1997; Lele and Richtsmeier 2001; Marcus, et al. 1996; Slice 2005; Zeldich, et al. 2012). For the purposes of comparative study of biological form, the study of shape is often conflated to a series of landmarks, and that is how much biological morphometric data is taken (Zeldich, et al. 2012:77).

The field of physical anthropology has already benefited from geometric morphometric advancements; these techniques are commonplace but have not yet filtered into common archaeological practice. Orientation protocol of biological materials allows for landmark data to be easily taken and manipulated in ways that biologists have found successful. The ability to visualize and study allometry is a key strength of these approaches. Studies of premodern humans, primates, and related paleozoological materials have benefitted from the use of geometric morphometric approaches in exploring questions surrounding evolution, development, and function.

Outline analysis fills a different niche regarding materials studied. Specifically, its ability to represent curved outlines has strengthened morphometric investigations of objects like skulls, and its capacity to quantify complicated shapes like crenulated objects allows for analysis of a greater range of 2D objects. Baylac and Friess (2005) have shown how EFA more accurately represented and categorized patterns of skull deformations, covering changes in shape more precisely and leading to fewer group misclassifications. Botanists have studied leaf outlines using EFA to reduce noise in shape caused by such phenomena as seriation or size, and to examine inter-species variation and evolutionary

The SHAPE software package used in the present study to perform EFA has been employed by biologists for a variety of research questions. SHAPE is a series of programs that processes 2D images of objects, records contours, creates EFA descriptors, and performs a principal components analysis on the series of images (Iwata and Ukai 2002). It is designed to be accessible and user-friendly, and has already been employed by scholars from a number of fields. Thus far, however, and to the best of the author’s knowledge and investigation, the present study marks the first archaeological application of this specific software package and the first complete chain-code-based application of EFA to an archaeological assemblage.

Previous applications of SHAPE can shed light on the utility and functionality of this software package and the chain-code-based EFA results that it produces. Duarte-Neto, et al. (2008) study dolphin sagittal otolith shape as a means of differentiating between two populations. The study uses SHAPE and EFA, and compares its ability to discriminate between groups to other types of shape descriptor such as perimeter, circularity, and fractal dimension. It is argued that EFA is the most robust method for discriminating between groups, and their results indicate two populations of dolphin off the Brazilian coast. Elise Huchard et al. study sexual signaling in primates (Huchard, et al. 2009). Shape has previously been an overlooked attribute of sexual swellings. The EFA performed on photographs of two primate populations is here shown to characterize differences in shape within and between populations, useful for studying possible species and individual recognition. Huchard’s study takes advantage of the lack of need to
standardize rotation and alignment of objects within photography, as photos were opportunistically taken in the field. Carlo, et al. (2011) specifically take advantage of the ability of EFA to quantify complex shapes when they study sclerites (calcified exoskeleton parts) using 60 harmonics that very accurately track the crenulated shape of these objects, though a mere 16 harmonics were deemed sufficient to discriminate between species. Like the field of lithic analysis, sclerite studies have so far been restricted to qualitative descriptions or traditional ratio-based morphometrics. Carlo et al. praise the utility of EFA to quantify and study shapes that do not readily lend themselves to a landmark-based approach.

**Geometric Morphometric Lithic Analysis**

Unlike the field of physical anthropology, archaeological applications of geometric morphometrics are not yet as common as may be expected when considering their utility. However, this is changing as computational software becomes more readily available and analysts are creating dialogue that is more accessible to scholars with a wider background of training than that found in the jargon-heavy earlier seminal works. These advances make analysis and results interpretation an achievable goal for a wider scholarly audience.

Where biologists create specimen-specific landmark schemes over areas of perceived biological significance, the archaeologist will place artifacts' landmarks over areas of perceived cultural or technological significance. The following landmark-based studies navigate the intricacies of this approach, taking advantage of the robust analytic power of geometric morphometrics while at the same time managing landmark schemes that are intended to represent those culturally or technologically appropriate aspects of
material culture assumed to reflect the research questions at hand. So far, the vast majority of lithic geometric morphometric applications have been to North American Paleo-Indian collections and Old World Acheulian technologies as only a small handful of researchers employ these techniques. Case studies that are deeply prehistoric, this collection of literature very effectively showcases the range and applicability of geometric morphometric analytics.

Some of the first applications of geometric morphometrics to lithic studies were undertaken by Buchanan on North American Paleo-Indian projectile points. This series of explorations uses geometric morphometric analyses to address a number of questions about early formal tool technology. His works were strictly landmark-based and address questions related to manufacture and rejuvenation technology and tool use. Folsom points from Texas and New Mexico were analyzed to investigate questions related to resharpening as a factor of distance from raw material source (Buchanan 2006). Buchanan assigned each point 32 homologous landmarks and subjected the coordinate results to a univariate ANOVA analysis in addition to describing the variations of a number of interrelated landmark variables. This work was combined with a principal components analysis as related to size and shape allometry in order to describe the nature of resharpening. This study and application of morphometric landmark data rejected the null hypothesis of resharpening as being correlated with distance to material source, but rather related it to a fixed-in-haft cyclical-use resharpening model instead. Here, landmark data were used to address questions of technological organization and resharpening (ibid: 185). Buchanan and Hamilton (2009) employed a nearly identical method of gathering landmark data and used an appropriate array of multivariate
analytics to study early Paleo-Indian points from across the continental United States in order to test the Morrow and Morrow neutral drift hypothesis for stylistic change. The relevance of this study lies in their results showing how early Paleo-Indian points remain technologically unaffected by local environmental variation across the continent. Instead regional change exhibited in various point forms is attributed to the biological notion of genetic drift first posed by Morrow and Morrow. Their analogy of projectile point shape attributes to genetic features using this landmark data is particularly poignant. Using the same system of 32 homologous landmarks, Buchanan and his colleagues investigated hafted Clovis points, questioning the hypothesis that the hafting process constrained base shape, allowing blade design to manifest itself more variably (Buchanan, et al. 2012). The results of their study showed how this model is inaccurate – not one base and blade shape characteristic was statistically more variable than any other. The authors speculated on technological scenarios that would produce these results, overall questioning hafting models that only result in constrained base shape and producing a wider array of possibilities.
Two varying constellations of landmarks.
Using a differently structured system of equally-spaced landmark data, Buchanan and Collard (2010) studied Clovis, Folsom, and Plainview points from Oklahoma, Texas, and New Mexico to compare blade shape in order to be able to distinguish between the types. Here, the structure of their landmark data is fitted to accommodate their research question of shape differentiation and they subject their points to a Procrustes fit in order to account for size differences within the collection. Using MANOVA, ANOVA, thin-plate spline deformations, and a discriminant functions test, they found that Clovis points are distinguishable from the others; however, Folsom and Plainview exhibit too similar a blade shape to be distinguishable from one another and therefore they have a possible co-evolutionary history. This particular study and its structure is also relevant for theories of lithic reduction because, as the authors noted, misclassification of point types occurred at the same rate for large points as it did for smaller ones. The authors used these results to advocate for repeating previous studies of lithic reduction using geometric morphometric techniques and multivariate analyses to strengthen results, as previous methods are argued to have been “insufficiently precise” (Buchanan and Collard 2010:357). Another question Buchanan has investigated using geometric morphometric landmark data is hunting practices and how different hunting goals affect point form (Buchanan, et al. 2011). Using an American Southwest dataset of Clovis and Folsom points associated with mammoth and bison kill sites, the authors compared the size and shape of points based on a series of landmarks visualized on a thin-plate spline deformation grid. Intertype results based on prey showed a statistically significant difference between assemblages, though intra-type Clovis analyses are not differentiated, suggesting that the
Clovis type was used to kill both mammoth and bison whereas Folsom was strictly for bison.

As well, David Thulman (2012) grapples with Paleo-Indian lithic typologies and the shape attributes traditionally used to define different types. He used digitized landmark data to distinguish between Suwanees, Simpsons, and Transitional Side Notched points from Florida. This is a pioneer study about distinguishing between types using landmark-based geometric morphometrics that robustly and vividly explains how base shape, not blade shape or overall shape, is the most important discriminating factor between types. The results of this study have direct and immediate applicability to daily archaeological practice.

Though not considered exhaustive, these studies by Buchannan, Thulman, and colleagues show a wide array of lithics-related research questions that can be addressed using applications of geometric morphometrics. By rearranging the nature of the landmark data being taken, each study can more accurately address specific questions about the nature and complexity of Paleo-Indian projectile point technology. The structure of Buchanan’s landmark placement in the first three studies is modeled after a traditional morphometric approach and represents the type of data a biologist may collect on their assemblage of specimens. While this collection of landmarks may appear to be representative of traditional metrics taken on points, the geometry is preserved through analysis and the statistical power and computational variety of approaches is quite evident. The final two research studies, whose landmarks are placed spatially and are not based on any perceived characteristics of the points aside from three primary landmarks at specific homologous locations on the points, are more divergent from the traditional
approach in that they do not use landmarks representative of typical measurements. By doing so, the data collected is better situated to answer the desired research questions, specifically in situations where traditional metrics have been insufficient. In these ways, the flexible nature of this approach is showcased. As the authors admit directly in the conclusions of much of their research, their methods are specifically able to show correlations and relationships between assemblages where traditional metric analyses fail. Buchanan uses each of these works to advocate for morphometric applications to lithic studies.

Geometric morphometric methods are being applied to Paleolithic Old World lithic assemblages with great success, allowing archaeologists to learn more about this most ancient prehistoric time. Radu Iovita studies European Middle Paleolithic handaxe reduction trajectories using outline data analyzed with elliptical Fourier harmonics and by doing so brought EFA into the field of lithic studies (Iovita 2008; Iovita 2009). Assemblages from three different technocomplexes of different hominids - Micoquian, Mousterian of Acheulian, and Quina Mousterian - are compared using nine harmonics. Iovita analogizes tool resharpening to biological ontogenetic trajectories (i.e. life histories). Functional implications of maintenance are explored when Iovita uses the harmonics data, correlating it to size, to extract reduction strategies as a unit of use and function with the goal of creating phylogenetic relationships of tool types independent of this continued maintenance. The result of separating maintenance from function results in a clearer understanding of the phylogenetic relationships among these ancient technocomplexes.
Iovita (2010) again addresses rejuvenation when he employs EFA to treat resharpening trajectory as a classificatory metric for types rather than as a source of variability and thus error. He defines a resharpening trajectory as the relationship between the geometric shape and the size of a tool, thus making this trajectory the regression between EFA coefficients and the size. In this way, the use-life of a tool can be traced through the resharpening process, adding it in as a variable that helps include behaviour, use, and purpose in a typological analysis. Iovita (2011) shifts his focus to Aterian tanged tools and explores the possibility they were used as projectile weaponry. By using traditional morphometrics and EFA subjected to principal components analysis, he concludes that Aterian points show edge reduction strategies consistent with use as cutting and scraping implements rather than projectile weapons— they were retouched in-haft with a focus on edge retouch rather than point-tip refreshment. Iovita’s works here represent a departure from the common use of the typological approach that equates type with shape. Instead type is related to intended purpose and behaviourally-based artifact life histories of continued reuse. This end-goal was achieved using a metric accurately able to represent shape throughout vigorous multivariate statistical processes.

Archer and Braun (2010) examine Acheulian bifacial variation in Middle Pleistocene handaxes using a 3D configuration of 33 landmarks (\(x, y, z\) data gathered for all points) subjected to a PCA. They compare the results of this geometric morphometric approach, a novel application of 3D data collection, to results of a traditional morphometric analysis. The results of the study demonstrate a specific reduction strategy associated with these tools where resharpening occurs at the biface tip. In a related study, Iovita and McPherron (2011) analyze the shape and size of Mousterian handaxes and
Lower Paleolithic Acheulian handaxes, this time with respect to inter-type manifestations of variability. Using elliptical Fourier analysis and traditional morphometrics, resharping trajectories in the different industries are compared. Contrary to previous assumptions about the level of skill manifest in Mousterian and Lower Paleolithic assemblages, the Mousterian collections are as variable as those of the Lower Paleolithic. As Archer and Braun (2010) concluded, classic Acheulian reduction strategies are consistently tip-down. Using EFA they demonstrate that Mousterian strategies are just as nuanced, yet occur around the tool to preserve its shape. These two cases demonstrate the flexibility of geometric morphometric applications of both landmark and outline approaches and the necessity to consider the research question at hand when constructing methods.

In a study thematically related to the present one, Costa (2010) studies plan views of bone and stone Acheulian handaxes to ascertain whether the same shape was desired in the creation of each assemblage. At present, Costa’s study is the singular instance of eigenshape-based outline analysis applied to lithics, and is used alongside a Procrustes fit and PCA to determine whether there is significant variation between the shapes of the two assemblages. Using a MANOVA to test for significant differences between assemblages, results indicate that the outline shapes are too similar to be discriminated, leading Costa to conclude that the end manufacturing goal of a preferred 2D shape was the same for each type of material used. Costa employed this outline technique as an objective analysis of form needed to possibly discern shapes between groups and it showcases the effectiveness of outline approach to questions of overall shape.
Lycett advocates for the inclusion of rigorous geometric morphometric techniques in the study of Paleolithic technology, citing their dependability and flexibility to the research at hand (Lycett 2009). His research takes similar 3D landmark data as used by Archer and Braun to assess the perceived shape relationships between various Acheulian technologies (Lycett, *et al.* 2010), and to investigate which morphological parts of handaxes manifest themselves most variably (Lycett and Von Cramon-Taubadel 2013).

In summary, applying principles of geometric morphometric analyses to Old World Paleolithic technologies has proved a fruitful avenue able to gather information in a way where comparison within and between groups evidences nuances of change, and where industries can be compared anatomically. The following are studies performed on other lithic traditions that have proven useful and continue to represent the relevancy of this kind of research.

A landmarks-based approach to studying shape was used by Soledad de Azvedo on stemmed points from Southern Patagonia (de Azvedo, *et al.* 2014). Landmarks were chosen to discern between the life histories and resharpening trajectories of two different weapons systems that manifest themselves in similar ways in the archaeological record. This landmarks data and subsequent analytics show that points with different uses exhibit different maintenance patterns relative to their respective weapons system - arrows or spears. Retouch patterns and life histories are detangled from original design to showcase adaptation to demands via artifact shape.

In what appears to be a foreshadowing of the advent of a wave of morphometrics research in archaeology, two chapters of the book *Morphometrics for Nonmorphometricians* (Elewa 2010) are dedicated to archaeological applications of
morphometric research. Specifically, they have the goal of explaining geometric morphometric techniques and their utility for archaeologists. Cardillo (2010) summarizes and synthesizes three applications of geometric morphometrics to flaked stone tool technologies from South America. He compares between two studies that use landmarks and semi-landmarks and one that uses EFA. All three studies show how the shape data that results from these analyses have a better ability to represent gradual changes in shape than do traditional morphometric approaches or qualitative descriptor data. Clustering algorithms are useful to represent specimens and their relations given sample sizes remain small. This synthesis of South American scholastic work in geometric morphometrics in a variety of research contexts effectively showcases visualization tools available to archaeologists using outline and landmark analyses.

The final study of note directly relates to the present research. Lenardi and Merwin (2010) discuss applications of computer digitization and geometric morphometrics and their ability to objectively quantify projectile point shape data in order to better understand and utilize the typological approach to artifact analysis. As a test case that showcases the applicability of a geometric morphometric approach to archaeological research, they cluster 33 triangular projectile points of Levanna and Madison type. Six landmarks are chosen based on their ability to robustly differentiate between types. The results are clustered and some of the points are reclassified based on their shape relationships to the other points in the sample. The study investigates intra-user variability when it comes to typing projectile points and how these types of computer-based applications can aid archaeological research daily by limiting or removing subjective bias. The majority of their landmark positions effectively replicate
locations where traditional morphometric data is taken, though the added position and morphological information carried through analysis allows for the robust clustering study. In spite of the small sample size, this exploratory investigation is successful in introducing and demonstrating the inherent problems within the typological framework and how they can be addressed using a rigorous data collection method less prone to human subjectivity.

Applications of geometric morphometric approaches to shape analysis are becoming more common, though they remain limited in practice to a handful of scholars. Advocates of geometric morphometric approaches in the archaeological sciences are now trying to address the problem of scholarly availability. So far, it has been observed that technical and mathematical frameworks hinder use (Slice 2005:vii-viii). However, manuals, user-friendly software, and a jargon-lite approach to dialogue and explanation are all proving effective, to which the existence of the present study can attest.

Benefits for Lithic Analysis

Having described issues of technique and application, it is clear that both landmark and outline based geometric morphometrics have a wide array of advantages for the lithic analyst. The previously discussed applications of these methods have served to demonstrate this applicability; a synthesis of strengths and weaknesses of the approach is in order.

Summarized above are a number of applications of landmark-based methods for studying shape. These approaches to questions in lithic studies have been fruitful; however, it is important to note that homologous landmarks placed on points of assumed cultural or technological relevancy rely on the same subjective biases of a traditional
measurement-based morphometrics analysis. A length/width ratio taken over a number of artifacts will rest upon what appears to be an important distance found on the shape of the artifact. This bias remains in a fully homologous-landmark study, where places of assumed cultural relevancy are being measured.

Anchoring homologous landmarks alongside equally-spaced ones that represent outline is one such way taper off some of this bias, and a fully outline-based approach will remove any pre-existing ideas about what sorts of shape attributes are reflective of cultural processes. Despite this, multivariate approaches resting on such landmarks-based geometric data have the benefit of answering previously unexplored questions that caliper data was not able to achieve because of the geometric data being carried through the analytic process. As such, these landmark approaches are (and are demonstrated above to be) perfectly valid if instigated by the research question at hand.

Intra- and inter-observer error has been an issue for archaeological artifact analysts to consider in their own research. The more of the analytic process that is done by hand, the more possibilities for human error are included in research design. Caliper-based metrics come with a specific set of considerations in this regard (Lyman and VanPool 2009). Digitized landmarks are possibly subject to a similar array of perception errors, though the specifics of this have not yet been investigated. However, one of the goals of a geometric morphometrics approach is to increase objectivity in the analysis of artifact form (Costa 2010). Often, geometric morphometric methods are based on standardized photography, which can reduce error from the caliper-measuring process. Artifact alignment can be processed digitally and standardized to a degree superior than what is capable with a cumbersome artifact in hand. Homologous points on artifacts may
be calculated digitally as well. In all these ways, added digitization of artifacts makes more objective data collection possible.

It is here worth considering the theoretical benefits that EFA brings to lithic studies. Studying lithic artifacts in this way is a departure from the traditional caliper based metric analyses so pervasive in lithic studies. As an outline-based approach, it is completely free of subjectively-placed landmarks and their assumptions of culturally important shape characteristics. The present study endeavours to demonstrate that EFA at a moderately high resolution of harmonics is particularly apt at characterizing and describing nuanced changes in form such as patterns in the curves of a point shoulder or tip.

When placed into a PCA, each generated principal component is a non-linear metric that represents patterns of form inherent in the sample assemblage. These metrics can be visualized and studied as directed by the research at hand. A PCA will also filter out data noise based on the nature of idealized lithic outlines possibly being compromised by the flintknapping process. EFA, as performed in this study, is invariant to previous artifact alignment (McPherron and Dibble 1999; Wynn and Tierson 1990). Here, alignment is standardized based on a function within the analytic mathematical process and not on a user-based protocol subject to error. It is strictly based on inherent properties of the object as determined by the same measurement process that is analyzing the shape as a whole. User-alignment is possible within this approach, if necessary. Results demonstrate patterns of shape change found within the assemblage using techniques that do not assume the nature or quality of said change beforehand. This approach removes the need to rely on traditional distance measurements that we perceive as important but
may not, in fact, be as significant to the characterization of form as archaeologists have come to believe.

One goal of Lenardi and Merwin’s pilot investigation was to demonstrate that geometric morphometrics can be applied to pre-existing lithic collections in museums and universities (Lenardi and Merwin 2010). Their interest is in showcasing new methods for studying collections of artifacts already excavated and curated in the same manner as a physical anthropologist may reanalyze a sample of crania seeking to create data for a new research question. In this way, novel morphometric research becomes one way that encourages further non-destructive archaeological study – both in terms of fieldwork and individual artifact preservation. As ancient material culture is a non-renewable resource, this is seen as a huge advantage for the field overall.

Evidenced in the cases above is one downside to a geometric morphometrics approach. Unlike a traditional morphometrics analysis where lists of synthesized data can be included directly in chapters and articles, the raw data gathered from a geometric morphometric investigation is not easily transferrable via publications, only through results. An assemblage’s PCA results cannot be directly compared to another separate PCA in the same way that averages of distance and ratio data can. Comparative study and reuse of data becomes much more difficult in the traditional sense. That being said, the present ease of digital data sharing permits relatively facile exchange of such datasets and should not discourage collaboration, though careful attention to methodology must be paid as there are a greater number of ways the methods used can be tailored to the given research question in cases such as these.
One final point on the subject of utility that was briefly mentioned earlier is the
ease in which these operations can now be performed. Software and user manuals are
widely available, free, and applied on a standard personal computer. The majority of the
studies above were performed using downloadable “freeware” programs, and many
authors praise their utility (see Thulman (2012) in particular). Said software calculates
the tricky math that would have been cumbersome, time-consuming, and preventively
intimidating even a couple decades ago. As well, computation time is now a non-issue
for increasingly larger and more detailed samples. Statistical software packages like R
and SPSS can run a plethora of standard multivariate analyses as well as platform
creative arrangements of tests for the more discriminating analyst. Data visualization
tools have become quite effective at effortlessly generating charismatic visual aids, a
particular bonus given the nature of geometric morphometric analyses. The present study
serves to illustrate all these benefits, especially so when considering the relative lack of
mathematical savoir-faire on the part of its author. As archaeological literature on these
morphometric analyses increases and diversifies, there will be less need to cite the classic
mathematics papers; a solid framework for interpretation of data results will be present.
Such is the case in the biological sciences and it is hoped that the present study
encourages such a pattern for future archaeological investigations.

OVERVIEW OF ASSEMBLAGE AND PREVIOUS INVESTIGATION

As mentioned earlier, this study is a re-examination of the collection of triangular
points Robert Kuhn used in his statistical analysis of Mohawk Valley projectile point
assemblages (Kuhn 1996). The original study presented the results of a descriptive
statistical analysis on 441 points from Owasco and Mohawk sites, comparing the results
to nearby Onondaga sites for the same time period – AD 1000-1700. The Onondaga Iroquois projectile points’ data included in Kuhn’s study come from previously published sources for 12 sites (the number of points per site is unspecified). The Owasco Mohawk Iroquois projectile points’ data for the 12 sites used were gathered by the author at various collection locations including the New York State Museum.

Kuhn’s original purpose for analyzing projectile point metrics was to assess whether Mohawk Valley Iroquoian triangle points fit a previously suggested model of linear change through time established for the nearby Onondaga Iroquois triangle points (Bradley 1987; Kuhn 1996; Tuck 1971). The interpretive purpose of this model was to create a “temporal order for Mohawk sites [that] can be used to cross-date the Mohawk and Onondaga site chronologies.” (Kuhn 1996:27). Kuhn measured length, width, and thickness of all points to the nearest half millimetre, and recorded data on base shape and side shape (Kuhn 2013). For the maximum length, width, thickness, and the ratio of length to width, he calculated the mean, range, standard deviation, and coefficient of variation on all Mohawk sites. The coefficient of variation was used to assess relative homogeneity within the sample, with a score of 20.0 as a maximum score indicating a homogeneous group.

Of the investigated metrics, only the length/width ratios exhibited a temporal trend described as, “generally increasing over the course of Mohawk prehistory and then decreasing during the historic period.” (Kuhn 1996:30). Another conclusion of note is the relative homogenization of samples through time based on coefficient of variation (save for thickness of artifact, which varies a great deal in all assemblages). This trend is
thought to indicate that thickness was not a functionally important characteristic and/or was a particularly difficult aspect of tool production for the knapper to standardize.

To bring the former conclusion into the wider arena of Iroquois triangle point analysis, Kuhn compares mean length/width ratios by site and time period to ratios from 12 previously published Onondaga Iroquois site assemblages of the same periods in order to demonstrate the spatial and temporal continuity of this trend and to fulfill his goal of attempting to cross-date Mohawk and Onondaga site chronologies. Kuhn (1996) writes an example of how this conclusion can be applied to interpretation when he briefly discusses the apex of the length/width ratio occurring during the Garoga phase for both cultural traditions - at the Mohawk site of Garoga and the Onondaga site of Barnes. He explains this could very well be evidence that the two sites are contemporaneous. Thus the ratio becomes a relative dating technique.

With both spatial and temporal pattern similarities in length/width ratio patterns between Onondaga and Mohawk Iroquois groups, Kuhn concludes that there must have been a fluid interaction sphere between Iroquois men during this time, and that this analytic metric of length/width ratios could be an effective way to cross-date Iroquois sites of a larger range than a comparative ceramic attributes analysis may show (Kuhn 1996:31). The above has been a summary of the previous analyses and interpretations of this particular collection of triangle points.
This study makes use of completed projectile points from all 12 of the Mohawk sites Kuhn included in his study, though it is restricted to 292 of the 441 points originally measured. This sampling change is caused by fluctuating collections materials at the New York State Museum between the years 1996 and 2013. Kuhn was gracious to make available museum catalogue numbers for six sites, and in these instances many of the original points used were guaranteed to be identical as the museum had kept a great deal still in collections (Kuhn 2013). Each time period with the exception of the Oak Hill (AD 1300-1400) phase is represented in this study; Kuhn’s study did not have a representative Mohawk site for this period; he used only two Onondaga assemblages for later results.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Site</th>
<th>1996 Study</th>
<th>2013 Study</th>
</tr>
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<tbody>
<tr>
<td>Owasco AD 1000-1300</td>
<td>Beekman Flats</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Nahrwold No. 1</td>
<td>37</td>
<td>21</td>
</tr>
<tr>
<td>Chance AD 1400-1500</td>
<td>Garooga</td>
<td>24</td>
<td>21</td>
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<tr>
<td></td>
<td>Getman</td>
<td>33</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Elwood</td>
<td>33</td>
<td>13</td>
</tr>
<tr>
<td>Garooga AD 1500-1550</td>
<td>Otstungo</td>
<td>51</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Cayadutta</td>
<td>60</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Garooga</td>
<td>52</td>
<td>29</td>
</tr>
<tr>
<td>Protohistoric AD 1550-1600</td>
<td>Klock</td>
<td>69</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Smith</td>
<td>46</td>
<td>28</td>
</tr>
<tr>
<td>Historic AD 1600-1700</td>
<td>Rice's Woods</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Martin</td>
<td>17</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Cromwell</td>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>441</strong></td>
<td><strong>293</strong></td>
</tr>
</tbody>
</table>

Table 1
comparison. As such, there is an unrepresented 100-yr temporal gap which may affect interpretation. Despite this, Kuhn’s work did not show a gap in the length/width trend he discerned and thus the temporal gap is not of great concern.

The Owasco and Mohawk Iroquois sites included in this analysis have all been radiocarbon dated, thus the projectile points themselves are not being used as a relative dating tool for site analysis but come from horizons that have been subject to absolute dating techniques (Kuhn 1996; Snow 1995).

As Kuhn matched Mohawk temporal patterns to those exhibited in Onondaga assemblages, it is possible to investigate patterns found here among the Onondaga point assemblages. Such an exercise is considered beyond the scope of what the present study is trying to accomplish. However, this paper concludes by speculating upon some possible examinations engaging with Onondaga material culture in this way.

When it becomes necessary to engage with the classic typological breakdown as found in Ritchie’s classification scheme, two types are described here (Ritchie 1971). For the purposes of this study and Kuhn’s, the Levanna point represents the proto-Iroquois point form, that which reaches and becomes commonplace in New York around 900AD, though it is present in assemblages earlier as well. Snow describes the points from the Nahrwold #1 site as being, “of the typical Owasco-Iroquois triangular form” (Snow 1995:74). This “typical” form of the Owasco sites is called Levanna and that is how the present research treats with this material. Generally, this type is larger and more equilateral than the later Madison point, which is associated with later Iroquois groups, including the Mohawk and the Onondaga. Ritchie describes the Madison point as being “the distinctive Iroquoian form” (Ritchie 1971). Both are described as being arrow points.
The above-outlined research by Robert Kuhn does not strictly operate within Ritchie’s typological framework; though he mentions the two types by name he does not treat them separately in any way (Kuhn 1996). This study engages with its sample collection in ways that are both outside and within Ritchie’s typological framework. The purpose of this is to investigate differences in type that are lost when describing assemblages strictly using caliper-based analytics.

METHODS

Sampling and Images

292 points were collected from the New York State Museum collections department based on the sites Kuhn (Kuhn 1996) included in his prior study. Like the original study, only completed points were selected and, for the sites Klock, Garoga, Beekman Flats, Getman, Smith, and Nahrwold L, the majority of the points were guaranteed to be the identical specimens used courtesy of recorded museum catalogue numbers (Kuhn 2013). Completeness was judged qualitatively via an absence of breakages not attributable to the flintknapping process, and the points were subjectively discriminated based on those that did not appear to have been retouched into other distinctive tools, such as drills. Thus retouch is a possible reason for variation within the collection, but the overall standard of implement was uniform in these two ways. Points of various knapping quality were all included, and although most were of locally-made chert, possible variants exist in the sample.
Digital images were made using an Olympus Stylus 1050SW at f/5.0 | 1/640 | ISO 100, dimensions 2736 x 3648, at a distance of approximately 20cm using a backlit light table with additional side lighting to minimize shadow. These camera settings and lighting conditions were optimized in order to increase the contrast between artifact and background and maximize the accuracy of outline information data gathered. Each artifact was photographed individually at the centre of the frame in order to decrease the effects of aspect ratio distortion as part of the digital photographic recording process (McPherron and Dibble 1999; Neal and Russ 2012). By standardizing the photography procedure in this way, error caused through digitizing the artifact was reduced. A scale of 20x20cm was included in each photograph as recommended by Iwata and Ukai (Iwata and Ukai 2002), though this inclusion did not affect analysis. Points were aligned in the same direction, though specific care was not taken to create a more detailed alignment as the harmonics process standardizes alignment of shape later on via calculation of the longest artifact radius from centroid to outline, which normalizes alignment, size, and rotation (Kuhl and Giardina 1982). Object size in the photograph was standardized in
order to create a thorough environment for analysis, though it is not a major concern because of the harmonics normalization procedure outlined below, which makes distance-to-object irrelevant, as long as image quality is not compromised (Huchard, et al. 2009).

The side of the point with the least amount of museum catalogue numbering on it was chosen to face upwards during the photographing process. It was not possible to tell in most cases which side was the dorsal and which was ventral; this method reduces noise when the photographs are then digitized into the SHAPE software package. As a few of the points were asymmetrical, bias in symmetrical sampling becomes a possible source of error.

Figure 7: A photograph of a projectile point and the binarized image created by SHAPE.
Elliptical Fourier Analysis

All images were converted from Jpeg to Bitmap type using widely-available photo management software. These Bitmap files were imported into the SHAPE software series of programs which generated elliptical Fourier descriptors via creation of a chain code. This chain code process uses the binarized picture produced by the software and encircles the object in question counter-clockwise, creating an x and y sequence of ordered points beginning at an arbitrary point along the object (Huchard, et al. 2009; Iwata and Ukai 2002).

SHAPE creates elliptical Fourier descriptors (EFDs) based on this chain code using the procedure described by Kuhl and Giardina (1982). Twenty harmonics (each with four EFDs) were calculated with alignment based on the longest radius from the centroid of the artifact to its outline – for this collection it was always the point tip. In this way, alignment is standardized. Twenty harmonics accurately represents the artifact’s shape when taking into consideration the resolution of photographic digitization as well as the flintknapping process itself. Notably, EFA has been shown to poorly represent sharper angles of objects at lower numbers of harmonics (Kuhl and Giardina 1982). The present study relies on EFA to mathematically represent particularized nuances of shape, and as such a higher number of harmonics was needed to study this aspect of morphological variation. The software has the option of creating standardized alignment based on longest radius of the object, which was thought to be an accurate and objective method of standardizing alignment for the selected assemblage. The longest radius occurs from the centroid of the artifact to its outline, which in all but three cases matched the point tip. The three equilateral points not conforming to this method were aligned
manually. By having the program calculate alignment, artifacts were standardized based on a mathematical function inherent in their shape and in this way subjectivity was further reduced.

From these EFDs, the SHAPE software program PrinComp calculated 80 principal components and scored each point along these lines. The original EFDs are not used as direct shape characteristics because it is difficult to interpret shape from them (Huchard, et al. 2009). These principal components are created using the variance-covariance matrix of the EFDs and are what is used to contribute to further multivariate investigation. Principal components analysis works by creating a first component of variables that accounts for the greatest amount of variability in the data while at the same time reducing variability around it. The second component will be uncorrelated to the first component and perpendicular to it, and will account for more variability. This process is repeated until all the variability is accounted for by new principal components, all components orthogonal to previous ones and representing smaller amounts of data variability. The number of components generated will be less than or equal to the original number of variables.

Statistical Analysis

The software element PrinPrint is used to visualize the first five components (see Figure 8). Here, the principal components thus represent linear dimensions of shape variability and are functions of the EFDs that went into the PCA. Multivariate analyses were then calculated on the resultant principal component scores. Each of the 292 points has a score for all 80 components. In the succeeding steps, all 80 components were included in analysis in order to take account of all nuances found within the elliptical
Fourier results, despite the fact that the majority of the 80 components account for less than 1% of the variability. The results section takes advantage of both qualitative and quantitative analysis of the results from the following analyses.

The statistical software package R was used for the proceeding analyses (R Core 2012). The first three principal components scores (which comprise 86.9% of the variation) were visualized using a series of box plots and scatter plots to assess whether any of these principal components create the same distribution over time as Kuhn’s
original study of length/width ratios showed a similar pattern of shape relationships between the time periods (Kuhn 1996).

Kuhn’s study showcased the subjectivity of the two triangle point types – multiple dimensions of shape do not correlate over time and another exhibits unimodal linear change. In order to test the null hypothesis that there is no significant difference/modality in artifact shape between earlier Levanna-type points made by proto-Iroquoian groups and later Madison points made by Mohawk groups, a discriminant functions test was performed for the two groups. This test is unlike that of the PCA in that it takes into account prior group membership. This membership was defined temporally and by site reports (Kuhn 1996; Snow 1995). As there were only two groups, the discriminant functions test creates one linear discriminator function used to separate the groups. The number of discriminant functions is equal to either the number of groups minus one or the number of predictor variables, whichever is the smaller (Manly 2005). Here, there is one discriminant function and it is used to separate the two groups.

This test of discriminant function was performed twice: once using all 80 principal components and another which omits the first and strongest component in order to assess the relative importance of that component during the group discrimination process.

Inspired by Kuhn’s use of the coefficient of variation in his analysis of ratios, and in an effort to showcase the utility of elliptical Fourier analysis for lithic studies, a Levene’s test was performed on the four temporal classifications classically exhibiting Madison points. The purpose of this test is to examine intra-type shape standardization through time. This test separated the four temporal groups Chance, Garoga, Protohistoric,
and Historic, and examined whether there was a significant difference in projectile point shape variability amongst these time periods. Assemblage variability is assessed by measuring the Euclidean distance from each projectile point to a hypothetical average projectile point created for each temporal category. Results are visualized in a box plot (Figure 16) and subject to the Levene’s test of homogeneity of variance. To further investigate the nature of variance between populations, t-tests were performed upon pairs of the groups separately.

RESULTS

Principal Components Analysis

![Figure 9](image-url)
The elliptical Fourier descriptors for each projectile point generated 80 principal components scores, of which the first 7 account for over 95% of the cumulative variance, and the first 10 over 97% (see Table 2). The SHAPE program provides visualization of each of the major principal components, depicting their mean and 2 standard deviations range. While at first glance it may appear that each principal component reflects one type of common shape description, such as specimen width or basal concavity, it is important to remember that these visualizations are multivariate averages of coordinates for 80 harmonic descriptors – 4 for each of the 20 harmonics. Therefore, they are to be treated as individual metric clusters unique to this particular dataset.
By plotting the first three principal components grouped and coloured by temporal period and delineated with a convex hull (Figures 12 and 13), patterns in the data can be visualized qualitatively. Differences in the distribution are evident in the changes in median and overall range. In the scatter plot arrangements, where Figure 12 represents a total of 76.6% of the total shape variance, the Owasco points cluster in a different position from the other temporal periods. In addition, box plots (Figures 9-11) of the first three principal components show how Levanna specimens from the Owasco period score differently from later period samples. As well, it appears that the Owasco Levanna points have a wider range of shape variation in certain principal components than do the Iroquoian Madison points, the latter having tighter centre clusters, though all exhibit a wide range of outliers.
Discriminant Functions

A discriminant functions test of the PCA results separated by type indicates bimodal distribution of the two point types (Figure 14). Overlap between the groups represents variable nature of these two types, where manifestations of shape may be interpreted at-first-glance as either Madison or Levanna. Removing the first principal component blurs the groups together somewhat, however, the distinction remains (see Figure 15). These results suggest a significant amount of shape variation is represented by the remainder of the principal components, which account for 39% of the overall variation. The distribution here indicates that there are subtle differences in shape within the other shape descriptors that are still relevant enough to separate between groups.

### Table 2

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<th>Eigenvalue</th>
<th>Proportion (%)</th>
<th>Cumulative (%)</th>
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</thead>
<tbody>
<tr>
<td>PC1 1.03E-02</td>
<td>61.7972</td>
<td>61.7972</td>
</tr>
<tr>
<td>PC2 2.46E-03</td>
<td>14.7862</td>
<td>76.5834</td>
</tr>
<tr>
<td>PC3 1.71E-03</td>
<td>10.3072</td>
<td>86.8905</td>
</tr>
<tr>
<td>PC4 5.45E-04</td>
<td>3.2779</td>
<td>90.1684</td>
</tr>
<tr>
<td>PC5 4.50E-04</td>
<td>2.7028</td>
<td>92.8712</td>
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<tr>
<td>PC6 2.66E-04</td>
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<td>PC7 2.26E-04</td>
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</tr>
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<td>PC8 1.22E-04</td>
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</tr>
<tr>
<td>PC9 1.05E-04</td>
<td>0.6296</td>
<td>97.1925</td>
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<tr>
<td>PC10 5.80E-05</td>
<td>0.3487</td>
<td>97.5413</td>
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</table>
Though there is a difference in sample size between the Levanna points \( (n=36) \) and the later Madison points \( (n=257) \), each bin is still sufficiently large to provide robust DFA results. Larger sample sizes are always preferred, of course, but the sample of 36 Levanna points provenienced from two separate sites is sufficiently large to exhibit representative morphological variability.
Levene’s Test of Homoscedasticity

The four Iroquois time periods exhibit assemblages of Madison points that are significantly heteroscedastic through the Protohistoric period and into the historic period with a p-value of 0.0498. The significance here is without direction because of the Levene test is only capable of detecting significant differences in variation between multiple groups without describing the nature of that variation. Nevertheless, it is possible to describe that variation to some degree.

The Levene test creates centroids of theoretically-average points representative of each time period. The test calculates principal coordinates for each point, and the first two are visualized in Figure 17, with red centroids featuring predominantly. The distance of each point to its group’s average is shown in box plot Figure 16, which visualizes the differences here to be of increasing variation into the historic period, as demonstrated by the increased median variance. T-tests run between each group (see Table 3) intended to further discern the nature of that variability are mostly inconclusive, save for a significant difference in variability between the years 1500-1550 and 1600-1700. Malleability of results here may be a result of relatively low sample sizes within each time period. As such, further investigation of these patterns is warranted.

### Table 3

<table>
<thead>
<tr>
<th></th>
<th>1500-1550</th>
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<th>1600-1700</th>
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<td>1400-1500</td>
<td>0.5153</td>
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<td>1500-1550</td>
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<tr>
<td>1550-1600</td>
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<td>0.4185</td>
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When two shape variables are plotted against each other along with a visual representation of the Euclidean distance between each point and it’s group average, it can be seen that the four centroids are very similar to each other (see Figure 17). As this is a measure of overall shape, it is demonstrated that the average Madison point remained very similar throughout Iroquoian prehistory and into the historic period as well.

As demonstrated by the PCA visualizations, the Levanna points were quite variable, though the present dataset does not permit inference or examination of temporal trends from the Owasco period assemblages as was possible for the Iroquoian.

**DISCUSSION and CONCLUSIONS**

This geometric morphometric study presents data that supports what archaeologists have known for decades: Late Woodland triangular points manifest in
The results of this study indicate a bimodal distribution of point shapes separated temporally, ostensibly reflecting cultural differences of some kind, that which differentiates the Owasco and Iroquois Late Woodland periods.

Traditional metric analyses of points have confused the issue on account of uni-dimensional shape and size measurements failing to quantitatively distinguish between point types. Dean Snow writes of Late Woodland triangular points: “Research has shown there is no clear trend from larger to smaller triangular points over time ... the data indicate that triangular points might have become narrower and shorter over time, but
As there was no quantitative data to justify separating the point types, sometimes the assemblages of points would be called simply “triangular,” abandoning type naming altogether. Kuhn’s work has at its foundation the assumption of a linear continuum of triangle point shape change, where one measure of form followed a linear trajectory of temporal change through the historic period. At one end of the spectrum was the Levanna point, of equilateral shape and indicative of the Owasco time period, and at the other, the isosceles Iroquoian Madison point. The change from equilateral to isosceles does not occur in one fell swoop; instead points gradually morph from one to the next with plenty of variability manifested by individual specimens. At no time does he indicate where the change in type occurs and there is the assumption that this pattern is unaffected by the Owasco/Iroquoian cultural transition in the Mohawk Valley. Based on this analysis,
whatever occurred culturally at this transition did not affect the pattern of change that the triangular points were following.

The length/width ratio is a metric that does not take size into consideration; it is independent of the overall size of an object as it showcases the relationship of one measurement to another. Multiple sizes of artifact may exhibit the same ratio if this relationship is the same. Kuhn’s study specifically demonstrated that length, width, and thickness, all measures of size, do not exhibit any linear temporal trend during this time. Importantly, as this is an inter-type study, the implications of this are such that there is no traditional size metric that distinguishes between what are often decided as Levanna and Madison points in the literature and for practical analytic purposes.
As such EFA is particularly relevant here in that, in and of itself, it is not a measure of size. An EFA will strictly measure the relationships of shape objects take independent of their size. In a situation such as Kuhn (1996) describes for the Mohawk
Valley series of triangle points, an application of EFA is uniquely relevant because of this predefined acceptance of size irrelevancy. The following analysis is set up in a way that is not dependent on measurement subjectivity, but takes a collection of points and evaluates the shape they manifest first without considering prior group membership (PCA) and then distinguishes groups (DFA).

The results of this study contradict Kuhn’s model of unilinear clinal change. The point shape that Owasco knappers had as their goal is perceptibly different from that which Iroquoian knappers had as theirs. Each of the first four principal components visualized by box plots shows that Levanna type points skew differently than do Madison, and the DFA that includes all principal components is able to demonstrate this bimodal variability as well, even as it manifests in only 39% of the quantified shape. Each of these time periods evidences two knapping trajectories of culturally relevant idealizations of shape. Owasco and Iroquoian knappers had different goals to meet, albeit very similar goals in a relative sense. Whether the differences in shape are based on technological requirements (e.g. hafting techniques) or less tangible ideological conceptions of appropriate form, it is unclear. However, it is here important to recognize that, based on these results, the two types should not be conflated into one triangular type subject to linear clinal change.

Those who advocate for and use a typological approach to analysis ought to find satisfaction in the results of this study. David Thulman writes of this phenomenon, “Frequently, an analyst can see differences in morphology but cannot find the appropriate measures to define that difference in a way that allows for statistical analysis.” (Thulman 2012:1606). That which analysts may perceive as difference has so far been
immeasurable. Here is a method that can robustly discern between types. Type, form, is perceptible to the discerning archaeologist, but when an analyst summarizes measured attributes and ratios, dimensional nuances are lost and this has implications for interpretation.

The results of the Levene’s test of homoscedasticity are key to interpreting why the original metric data led to the conflation of types. As well, the results shed light on a technological issue of energy expenditure. The first point to note involves examining the assemblages’ centroid, or the theoretically average point shape of each temporal assemblage. As noted earlier, this point is created for the test as a standard upon which all the points in the assemblage shall be measured against. When plotting all the points and their Euclidean distances to this centroid, it is noted that, for the four Iroquoian temporal periods, this theoretically-average point remains very much the same. In other words, as EFA takes into consideration multiple dimensions of shape variability, when averaged, all of these dimensions do not exhibit significant temporal change. This is very much evidence for a stable concept of idealized point form, or technologically-constrained point form, during the Iroquoian period (e.g. the Madison point).

Building upon this conclusion, it is demonstrated that manifestations of this point type become increasingly variable through time and into the historic period. Kuhn mentioned that he expected the results of his coefficient of variation metric to demonstrate increasing variation. His theory anticipated assemblage heterogeneity as the Mohawk lithic tradition declined in the proto- and historic periods with the advent of European trade goods (Kuhn 1996:30). However, his metric of coefficient of variation failed to detect such results. Here, variation in shape as discerned via outline analysis is
able to pick up on this change and demonstrate that Kuhn’s initial expectation was correct, though the results do not clarify the specific reasons for this change. It is possible that contact-induced change is being evidenced here. The theory behind this conclusion can be interpreted using Jeske’s model of energetic efficiency (Jeske 1992).

In this model, energetic expenditure (i.e., time spent creating tools) is strongly influenced by social organization. Changes in energy used to create tools serve as a litmus test for social change. He writes, “It is suggested that a shift in the allocation of energy as an adaptive response to changes in social organization caused the widely noted decline in formals tool types and stone-tool refinement in the late prehistoric periods in eastern North America.” (Jeske 1992:467) He applies this theory to two Upper Mississippian tool types, one earlier model exhibiting a higher degree of standardization and knapping quality than the other. This theory can be seen manifesting itself in the situation at hand here, where there was less energy placed into achieving the idealized Madison type as things became more complicated for the Mohawk Valley residents at this time due to warfare beginning in the first half of the 16th century and contact-induced change in the second half through the 17th century (Kuhn 2004).

Jeske’s theory places stone tools and the flintknapping process into a wider framework of adaptive response where manufacture is seen as a draw on human energy, thus it is reflective of the amount of energy a population will give to the creation of lithic technologies. Here it is suggested that the initial confusion regarding type differentiation was caused by a reduction in this energy, leading to increased variability and the blurring between two types that were already rather similar to start. Energy expenditure in this way will manifest itself not only in the 2D outline-shape of points, but in the knapping
quality and other qualifiers as well. The results here demonstrate the application of this theory over one variable, and the others are certainly worth exploring in the future.

Based on the aforementioned observations, it is concluded that a more-or-less defined concept of ideal or suitable point form existed in the Late Woodland period, although this goal does not appear to have been sought after with as much rigor as in earlier periods. As well, that defined concept changed with the Owasco and Iroquoian tradition and through the Iroquoian period it remained steady. As the Late Woodland types represent a small component of a typological schema meant to discern between all types created over many millennia, it is not surprising that these two types are often conflated in analysis given they are, in essence, two expressions of one simple form – the triangle. Knappers at this time existed in different social and political environments than their forebears and thus their time was subject to different pressures. With this theoretical framework in mind, lithic technology becomes an indicator of energetic efficiency and possibly a weathervane for social change. Projectile point form alone cannot fully explain the factors that influence change, but it can help to guide future inquiry towards likely sources of said change.

Applying an outline-based geometric morphometric approach to the study of shape has its benefits and drawbacks. Examining the full outline of a structure does not mean analysis is limited to those parts of an object the analyst assumes to be meaningful. That being said, it cannot tell you the culturally salient features of objects either. The centroid of each temporal period may represent the average achievement of each knapping effort, but shape is influenced by culture, mechanics, technological achievement and many other things besides. This method does not make it possible to
ascertain which attributes of a point type are those that were aimed for, such as a concave base or relative narrowness. Looking at the PCA box plots and their related visualizations, shape characteristics can roughly be discerned. However, these principle components are not linear measurements and each one represents multiple dimensions of variation. Note the first principal component. Initially, it may seem as though width is driving the representation of variation here; however, note also that the concavity/convexity of the blade changes along with it. 80 harmonics went into the creation of these principal components, and the first handful of components represents a great deal of those harmonic changes. Nuances of change such as this may be a reflection of sampling bias as much as cultural intent, and it is fallacious to attempt to segregate the two based on the nature of the present dataset.

This study does not attempt to undermine Kuhn and others’ attempts to create cross-dated site chronologies for Iroquois sites. Indeed, this data does not invalidate an attempt to cross-date sites based on average ratios of length/width as metric assemblages manifest. This study merely treats shape data in a different way that does not result in a continuum of linear temporal change, but rather a bimodal distribution that confirms the existing typological schema. Here, new multidimensional variables are thrown into the mix in order to derive stronger, more robust significances needed to shed light on the complicated issue of type and what it means to be labeled as such.

In a few ways, this study highlights the problematic nature of typological frameworks. Here studied are two point types which display differing statistical signatures of shape. However, because of various technological and/or social phenomena, these point types cast blurry shadows on the wall as it were, shadows that overlap to a fair
degree. What makes a type, then? Defining one type against the other - larger or smaller, wider or narrower (Snow 1995:53) - is fallacious and leads to problematic interpretation. This work does not attempt to solve this problem. However it is here argued that it is still appropriate to call or to refer to assemblages of specimens by their typological name as a way of referencing a distribution of a population. It is correct and also conceptually useful to call assemblages of points from sites by their traditional type name if the site has been conclusively dated to these time periods. By doing so, the archaeologist represents the cultural association of the type. Under this framework, Madison points go from being treated as a triangle of a certain quality to being the triangle of the Iroquois Period, a triangle shown to manifest itself quite variably including with overlap from the previous cultural period that exhibited a different distribution signature. Typological frameworks are inherently limiting, even when intra-type variability is recognized, typically described in synthesized lists of traditional metric data taken as canon. This is the manner in which Late Woodland triangle points must be treated, as this is how they fit into a typological framework.

Interpreting the technological implications of the results of this study is beyond the scope of the present work. Something is driving a change in shape between these two time periods and it remains to be seen just what is – technological, cultural, or both. If more work is done in this regard, it is possible to clarify the issue at hand here. However, until that time, reasons behind the need for different types of point is as yet unclear.

The terms as defined by Ritchie (1971) are still useful over populations of points, though perhaps less so for “typing” individual specimens taken out of their
archaeological context. Save for dramatic outliers, many triangular points must simply remain triangular in everyday archaeological practice.

In closing, this study demonstrates how elliptical Fourier analysis represents a novel method of investigating inter- and intra-type variability that is capable of objectively assessing the validity of typological approaches and can help create more nuanced perspectives about wider array of societal phenomena. It is hoped that lithic enthusiasts everywhere are interested in adopting novel methodological approaches like the one demonstrated here into their analyses in the future.
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