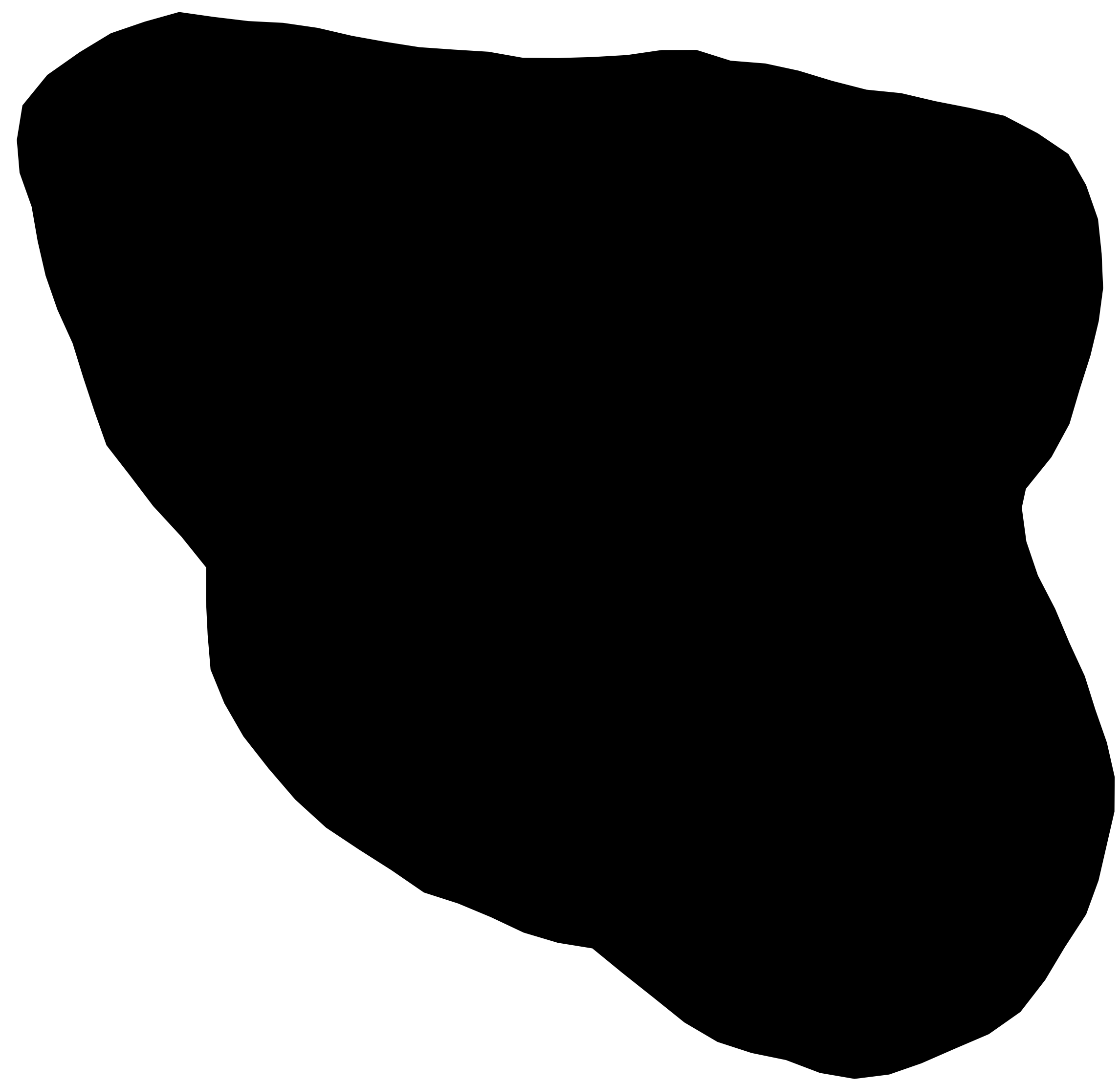
Analysis of Outlines

Semilandmarks, Sliding semilandmarks, Fourier, and Eigenshape



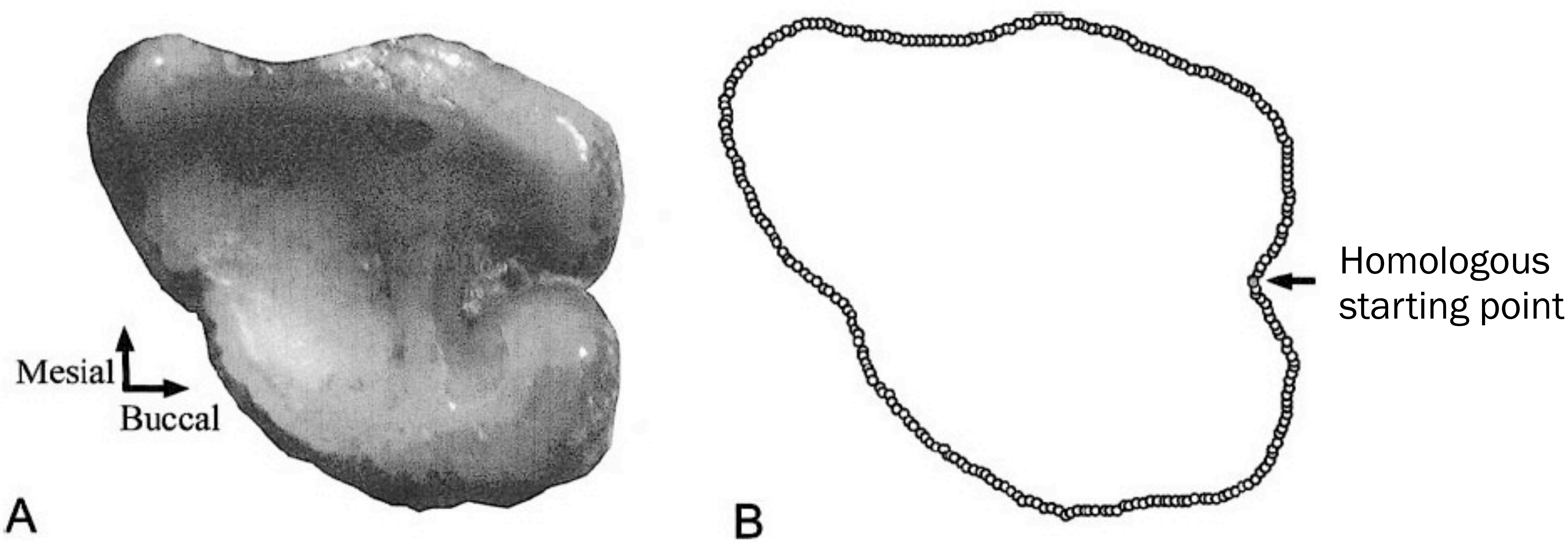
Lower third molar of *Marmota caligata*

Department of Geological Sciences | Indiana University

Outline coordinates

XY coordinates of points spaced along an open or closed curve

Also known as semilandmarks

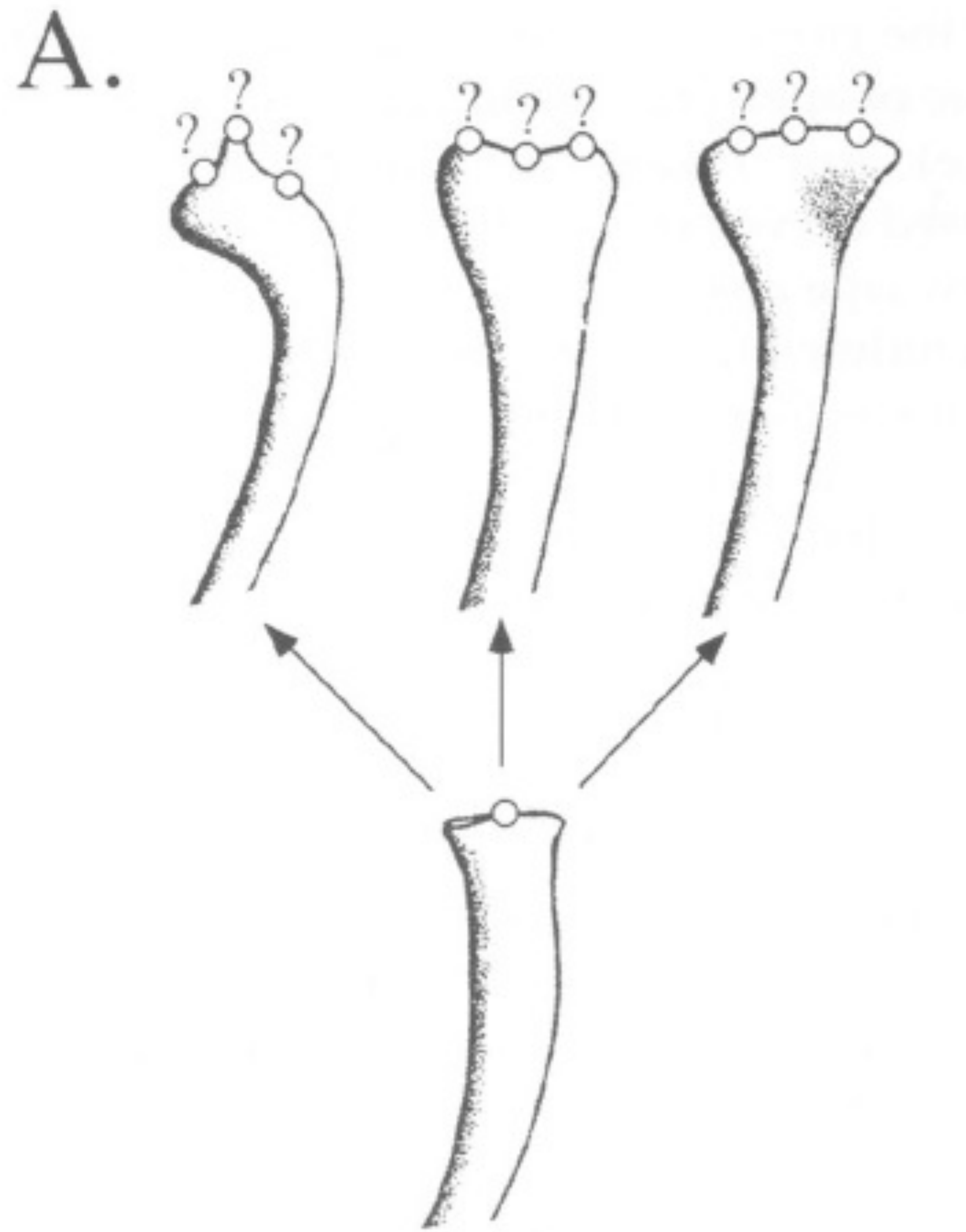


Polly, 2003. *Journal of Mammalogy, 84: 369-384.*

Uses of outline analysis

Useful for structures that are generally homologous (in biological sense) or comparable in the geometric sense, but where individual homologous landmarks are difficult to pinpoint

Examples: tooth perimeters, leaf shapes, mollusk shells, stone tools, floor plans, footprints



MacLeod, 1999. *Paleobiology*, 25: 107-138.

Types of outline or curve analysis

Fourier analysis - uses Fourier decomposition to produce “harmonics” that describe the positions of the points along the outline. The harmonics can be converted into shape coordinates and ultimately into principal components.

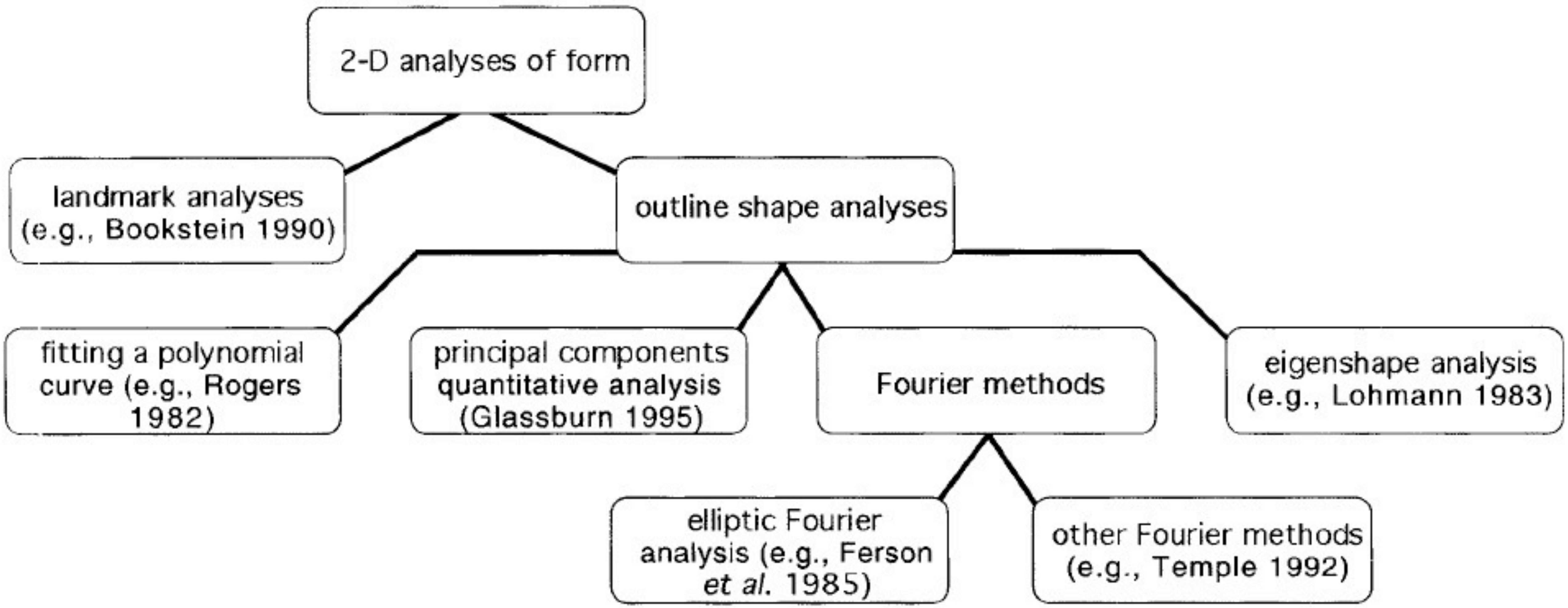
Semilandmark analysis - semilandmarks are the points along a curve. If strategically spaced, they can be submitted to Procrustes analysis and analyzed just like ordinary landmarks.

Sliding semilandmark analysis - The position of semilandmarks can be optimized by sliding them along the outline curve as part of Procrustes analysis to provide the best fit between shapes.

Eigenshape analysis - a different approach to outline coordinates where the standardization is not done with Procrustes, but by calculating angles between points to provide map around the curve. Principal components scores are derived from the angular data.

Extended eigenshape analysis - Same as eigenshape, but a series of homologous landmarks are used to pin the outline at points along the perimeter of an object.

Classification of outline analysis



Crampton, 1995. *Lethaia*, 28: 179-186.

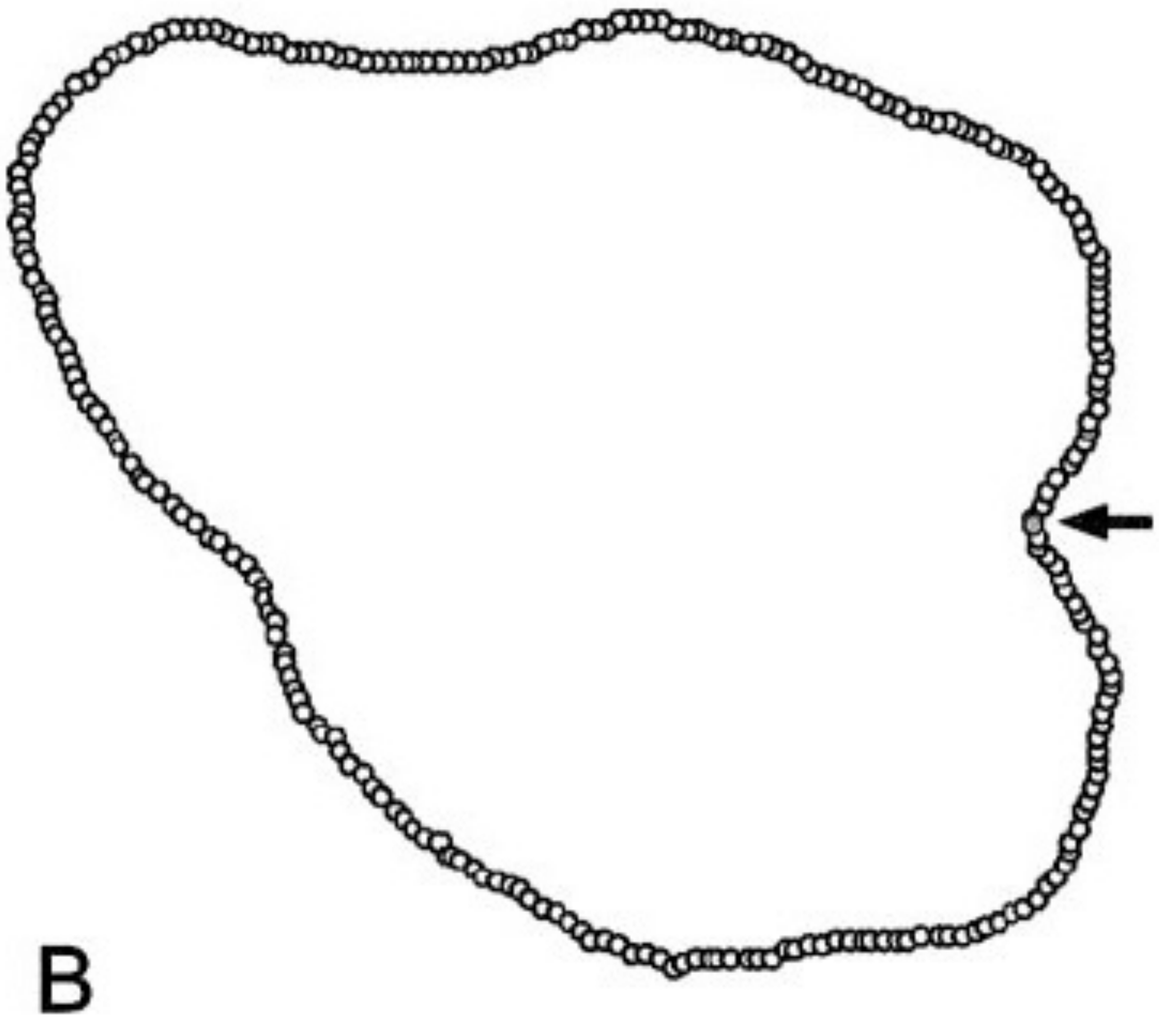
Typical data

Series of points along a closed or open curve

Each object usually has the same number of points, points are usually equally spaced

The series of points starts at the same landmark position on each object

The series of points may be broken into subseries anchored by landmarks



Polly, 2003. *Journal of Mammalogy, 84: 369-384.*

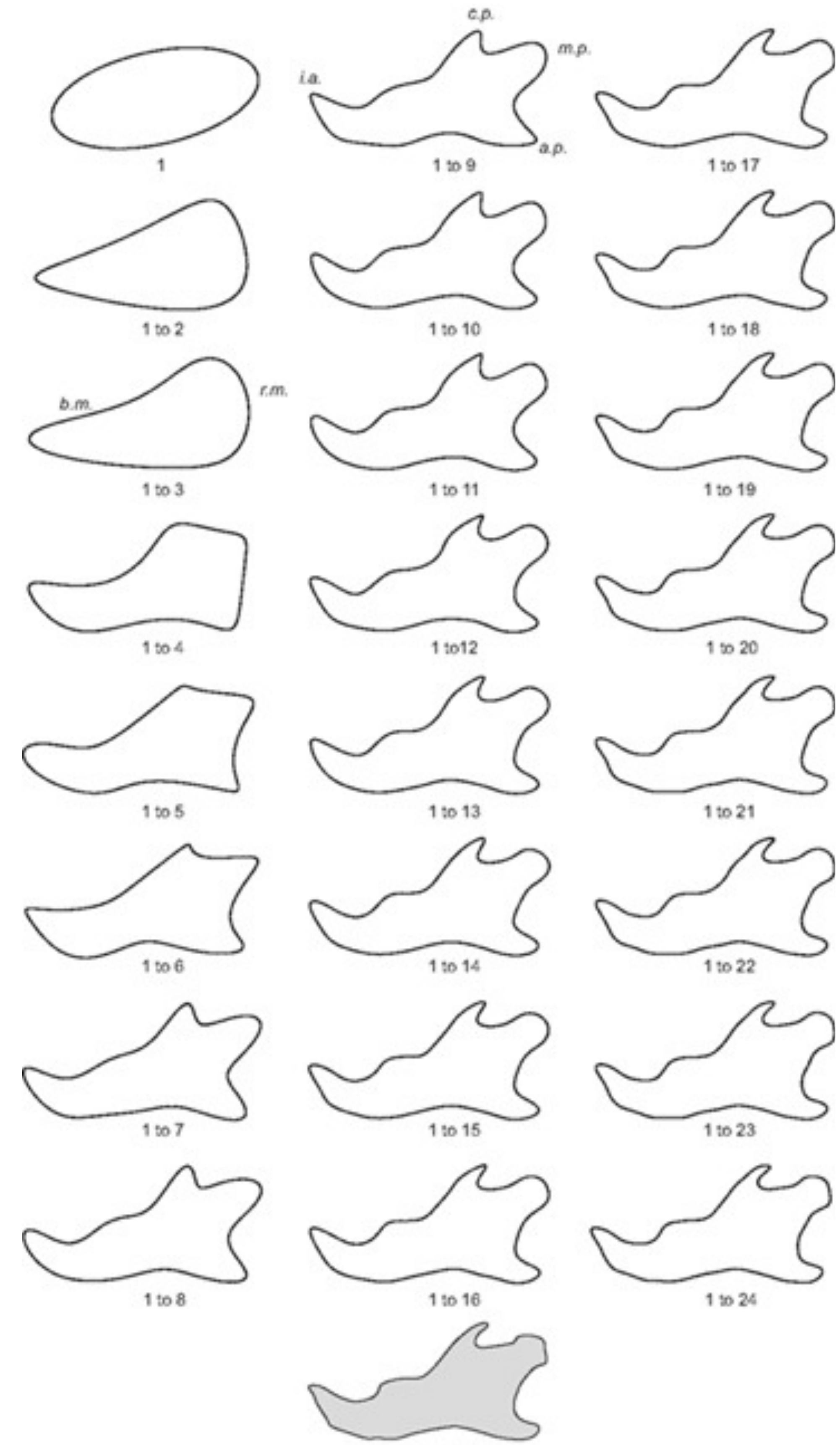
Elliptical Fourier Analysis

Uses Fourier harmonics to describe shape of outline

Harmonics are trigonometric sine and cosine waves, the first of which describes a simple ellipse

Higher harmonics add detail to the outline, the number of which depends on the complexity of the shape

Harmonic coefficients can be decomposed into shape variables, and ultimately used to derive a principal components morphospace

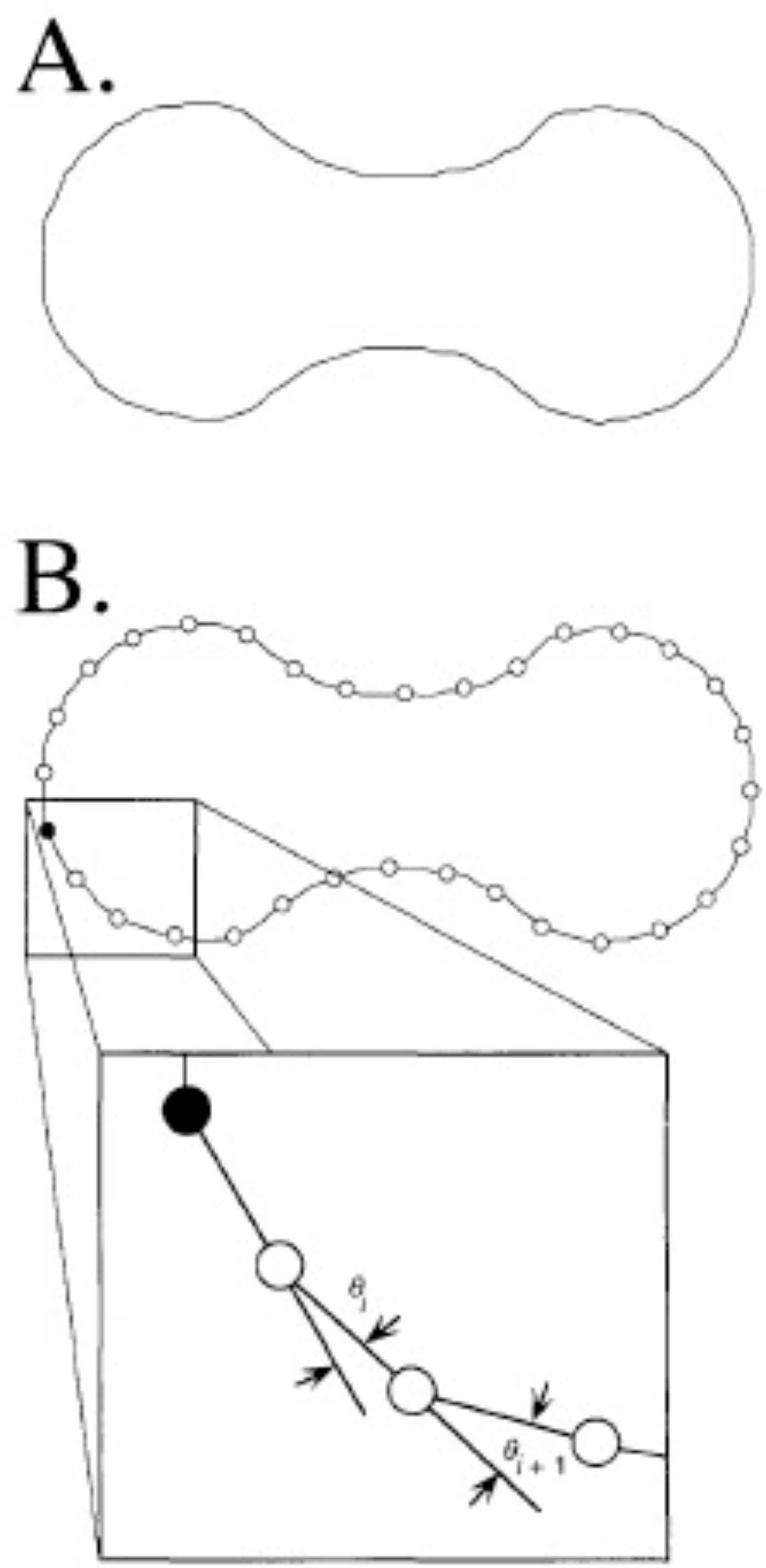


Bornert et al., 2011.

Eigenshape analysis

Measures curve as series of angles between semilandmarks

Curve is digitized, equally spaced points found, angles calculated



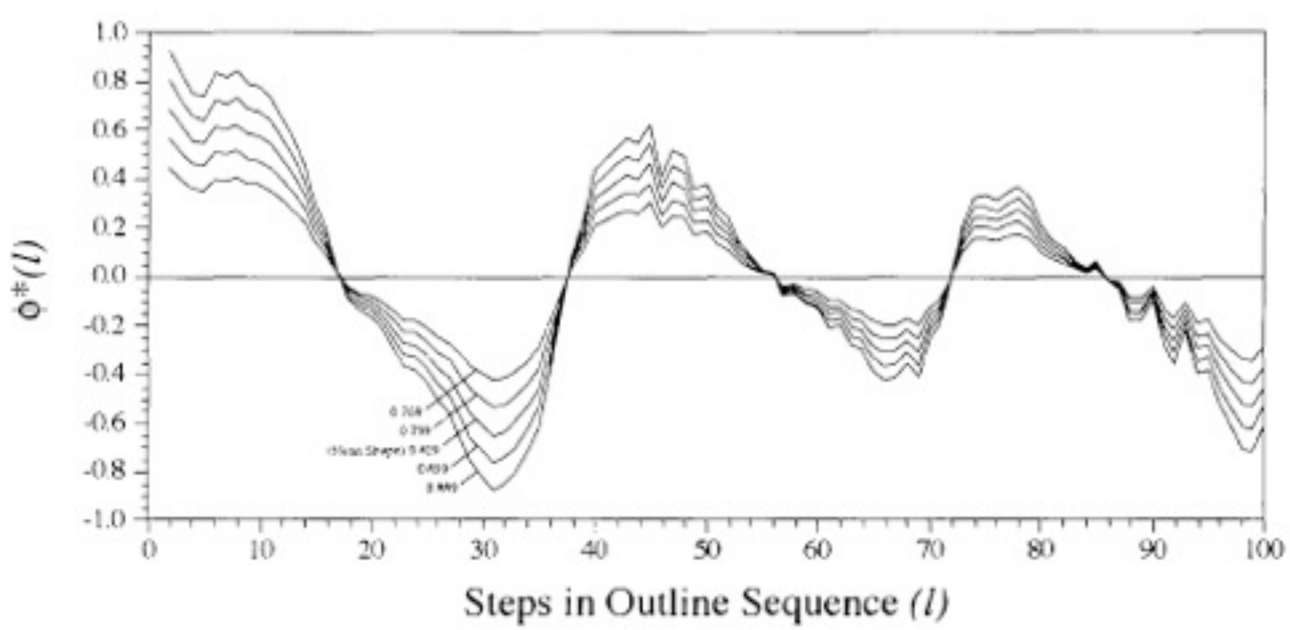
MacLeod, 1999. *Paleobiology*, 25: 107-138.

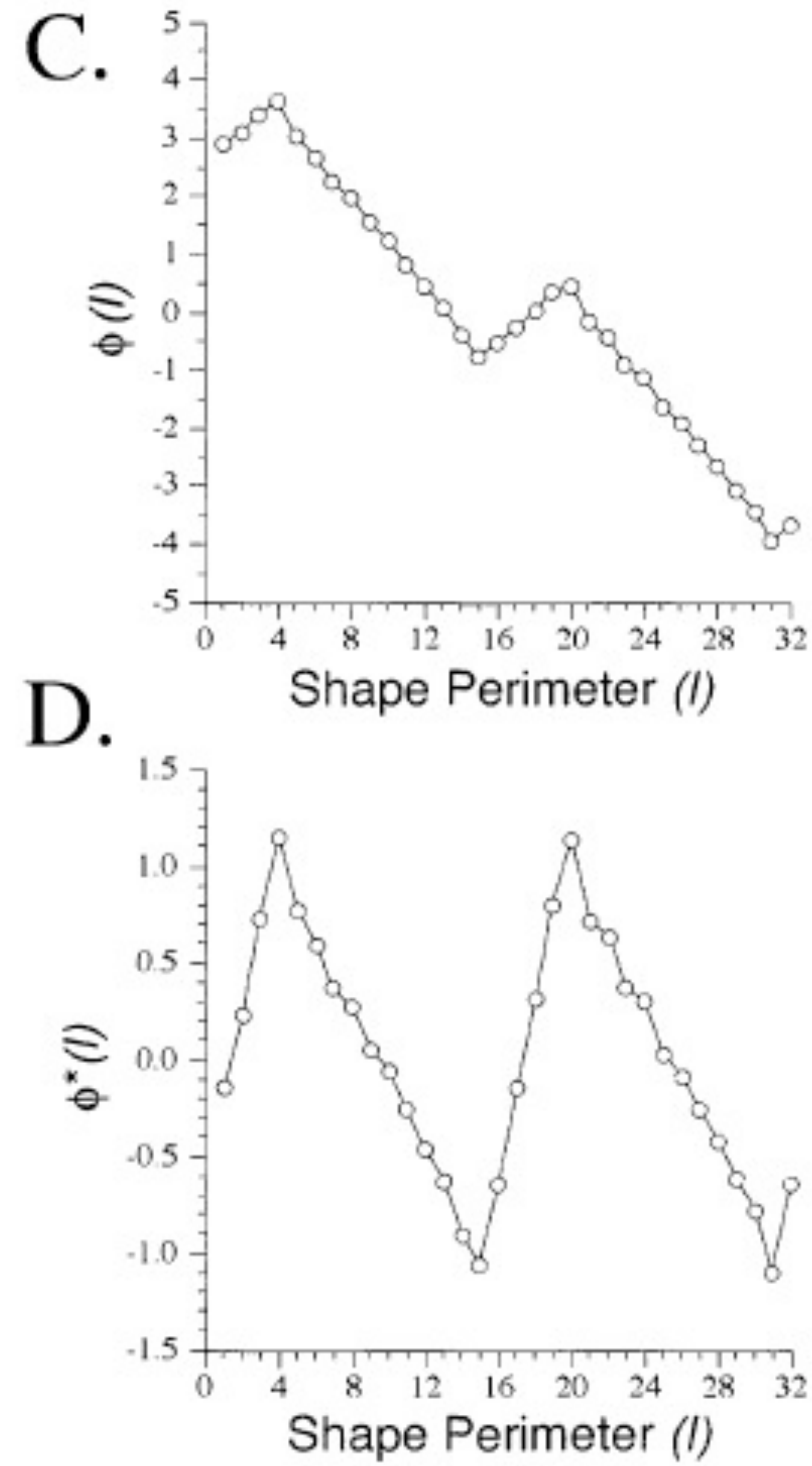
Eigenshape (cont.)

Series of angles between points is known as Phi function (Zahn and Roskies shape function), describing the direction the curve turns at each step

Phi function can be normalized as deviation from a circle, or as deviation from the sample mean

Repeat for each object in the data set



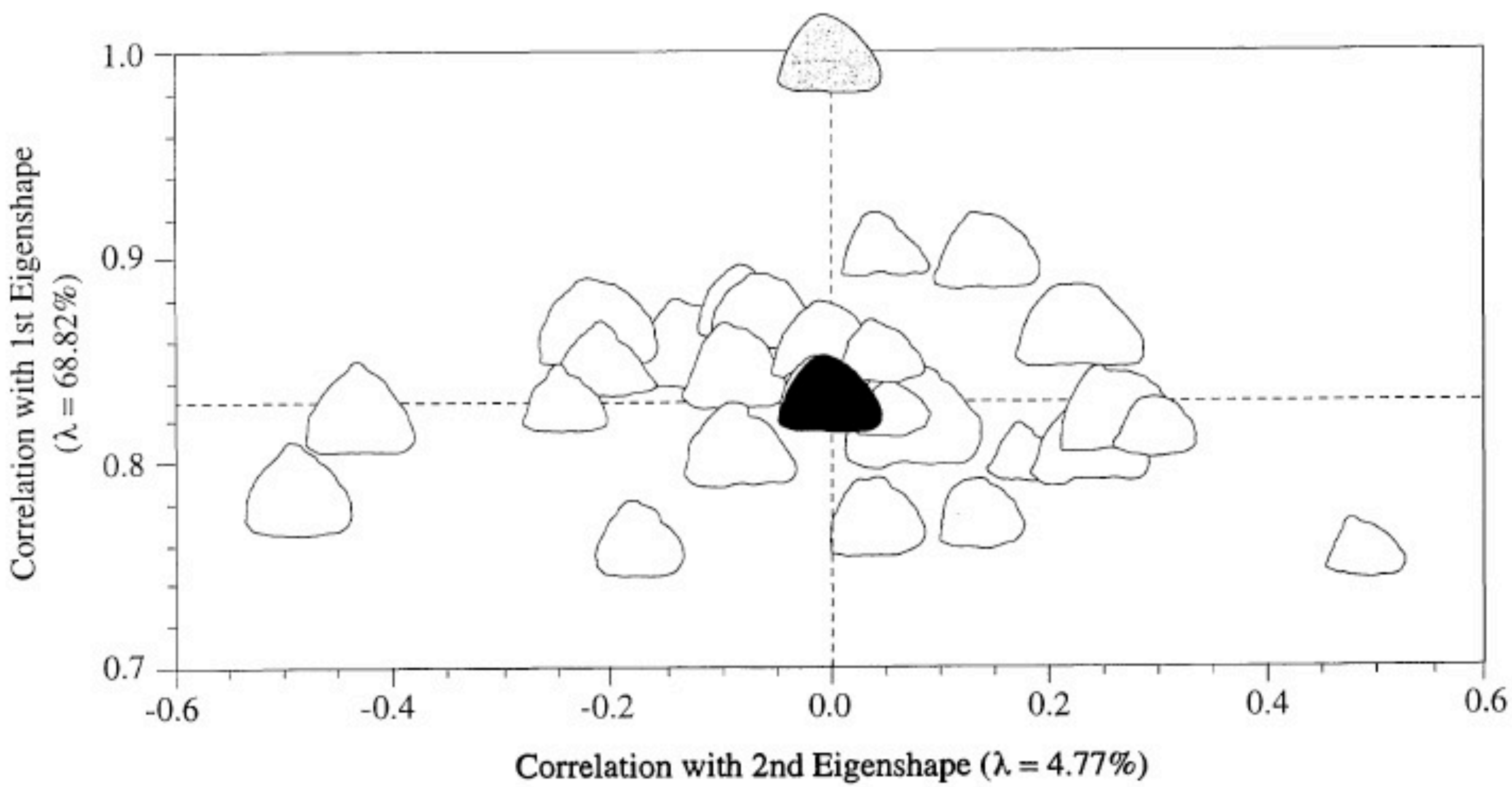


MacLeod, 1999. *Paleobiology*, 25: 107-138.

Eigenshape (cont.)

Principal components (eigenshape) space is a morphospace like ones based on landmarks, one for which shape models can be built using eigenvectors and eigenvalues (albeit with extra twist related to reversing the phi functions)

Eigenshape space centered on either sample mean shape or on perfect circle



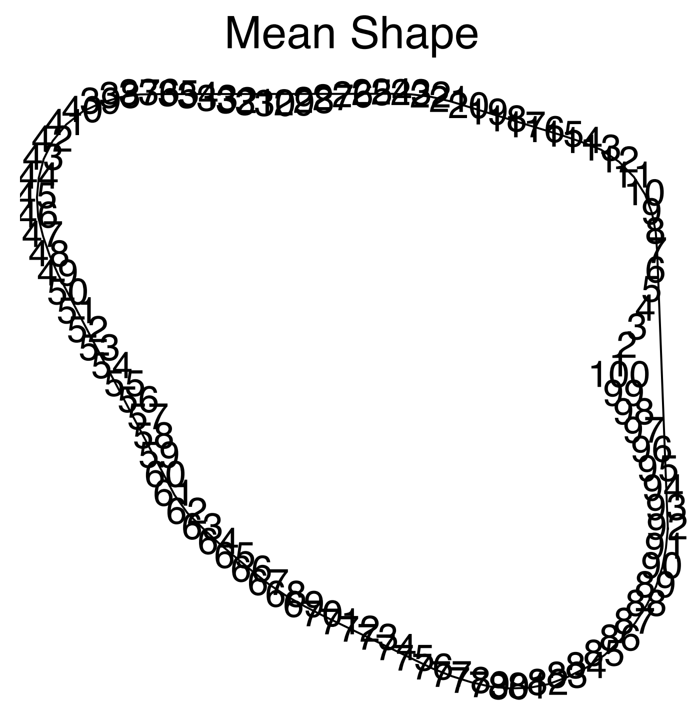
MacLeod, 1999. *Paleobiology*, 25: 107-138.

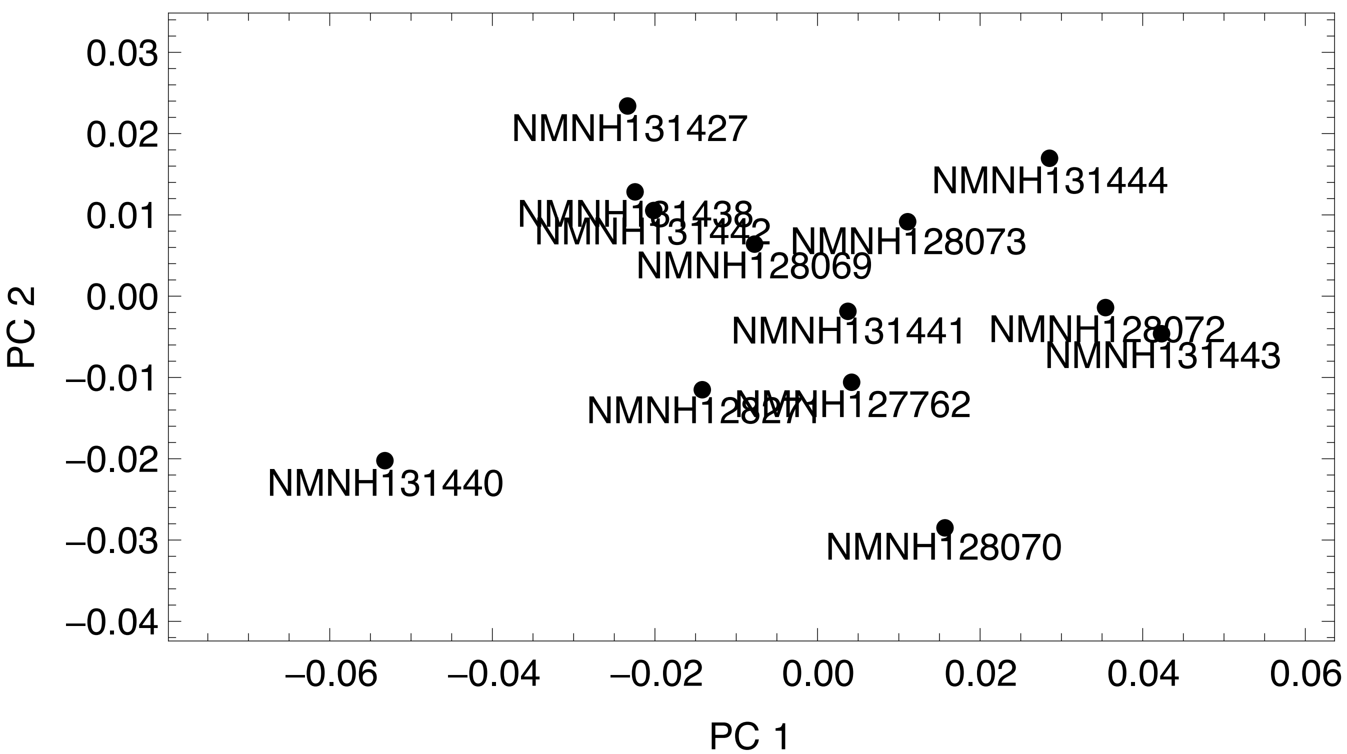
Semilandmark analysis

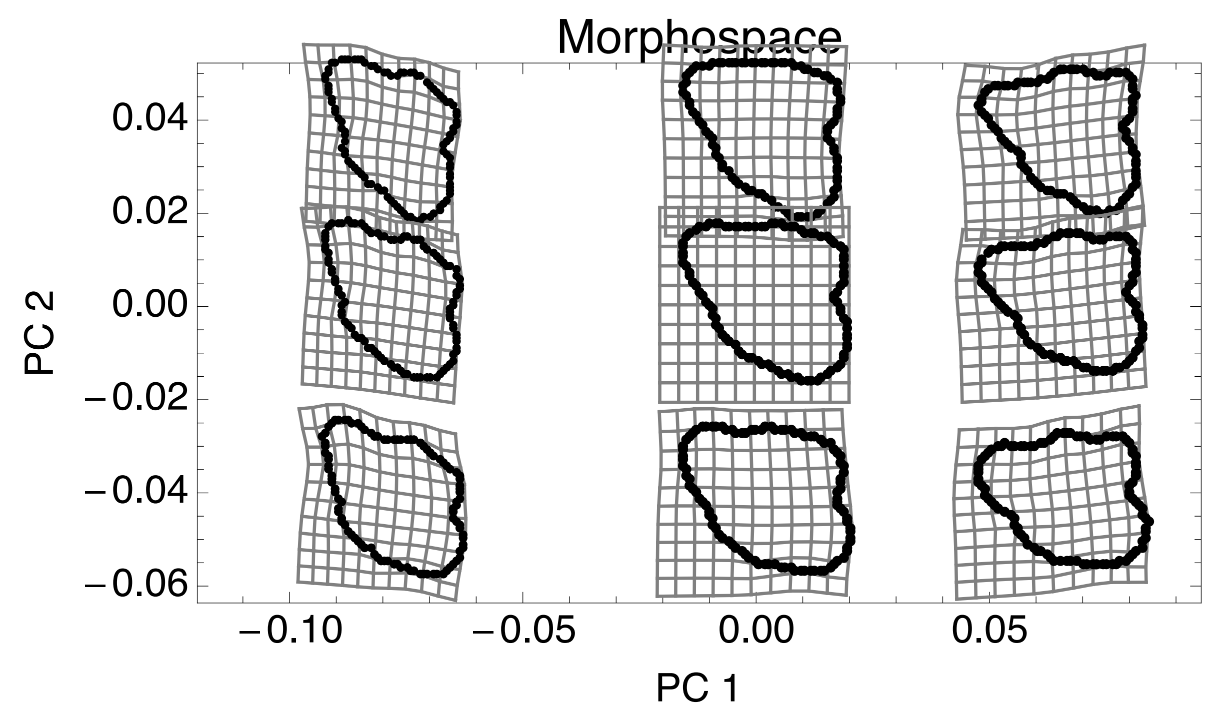
Treats semilandmarks as ordinary landmarks

Removes size, translation, and rotation using Procrustes

Follows ordinary landmark procedures





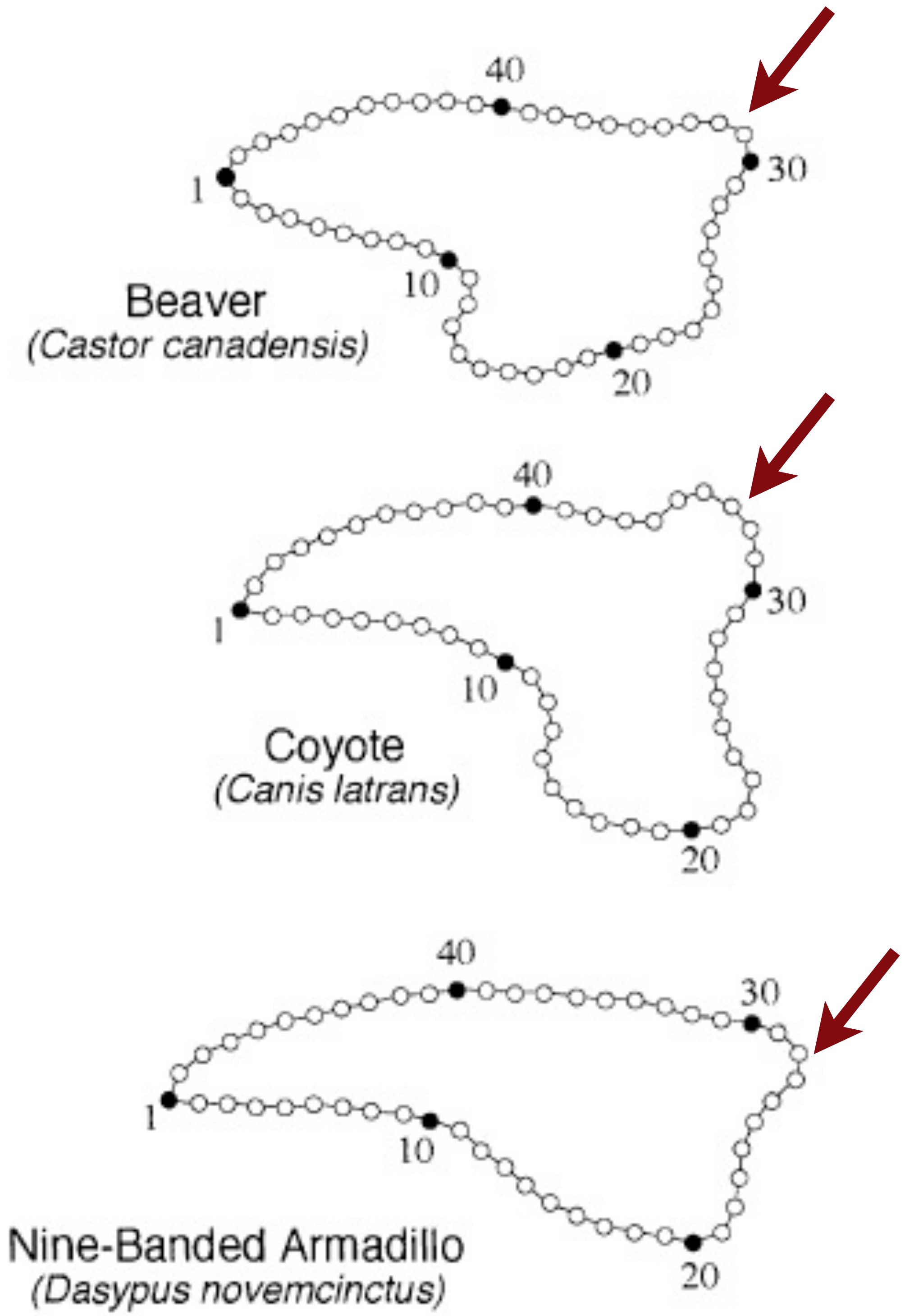


Issues with outline analysis

Individual semilandmarks don't necessarily correspond to the same homologous point on the shape, except at the starting point of the outline

This (usually) doesn't affect assessment of similarity and difference in overall shape…

…but it can have complicated consequences for which part of the shape drives the similarity and difference



MacLeod, 1999. *Paleobiology*, 25: 107-138.

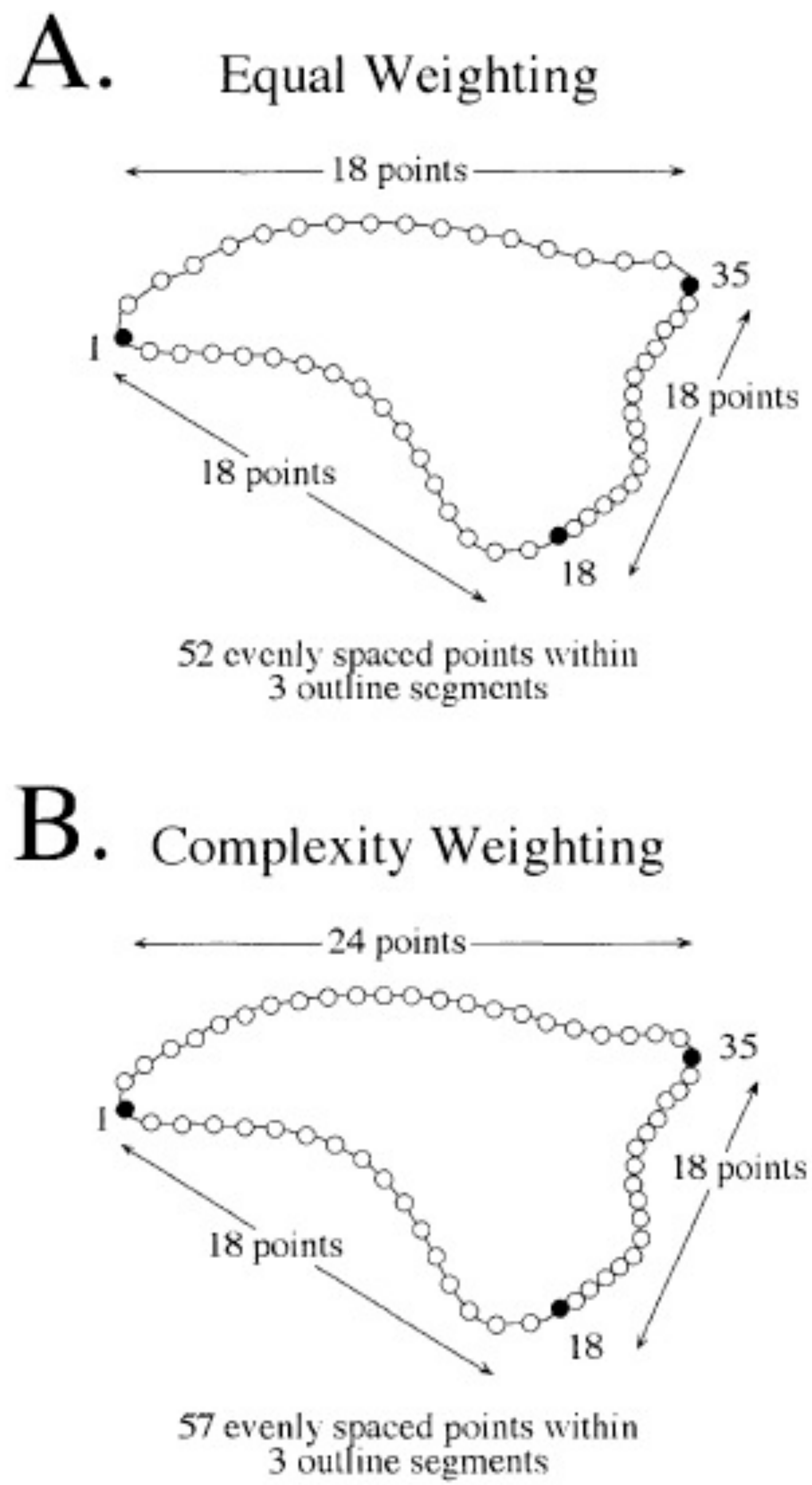
Extended eigenshape

Uses landmarks on homologous points and semilandmarks between them

Number of semilandmarks can be equal in each segment, which places an equal weight on each segment in the analysis

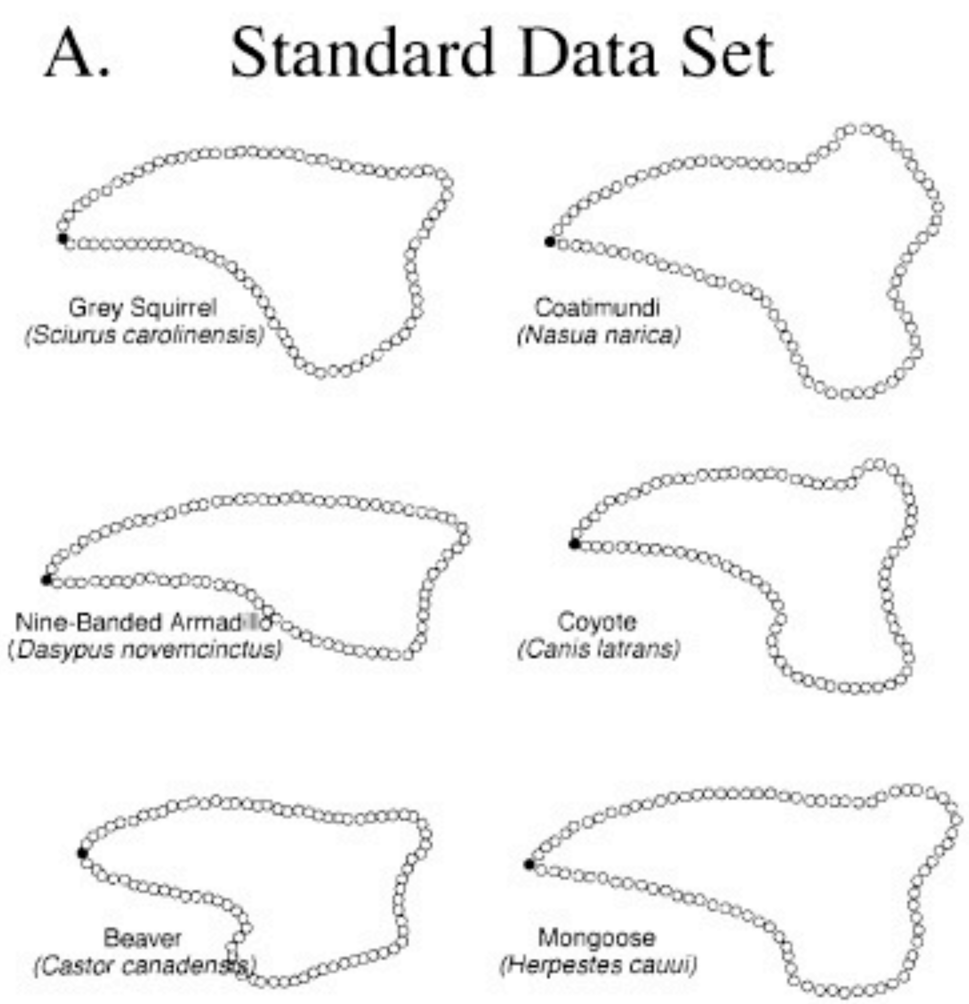
Number can be varied according to complexity of the segment, which puts higher weight on more complicated parts of the morphology

(each landmark or semilandmark contributes equally to the overall variance, so placing more points on a structure increases its contribution to the outcome)



MacLeod, 1999. *Paleobiology*, 25: 107-138.

Comparison by MacLeod



MacLeod, 1999. *Paleobiology*, 25: 107-138.

Comparison by MacLeod

Landmarks make variation in shape more comparable, so more variance is concentrated on first PC axis

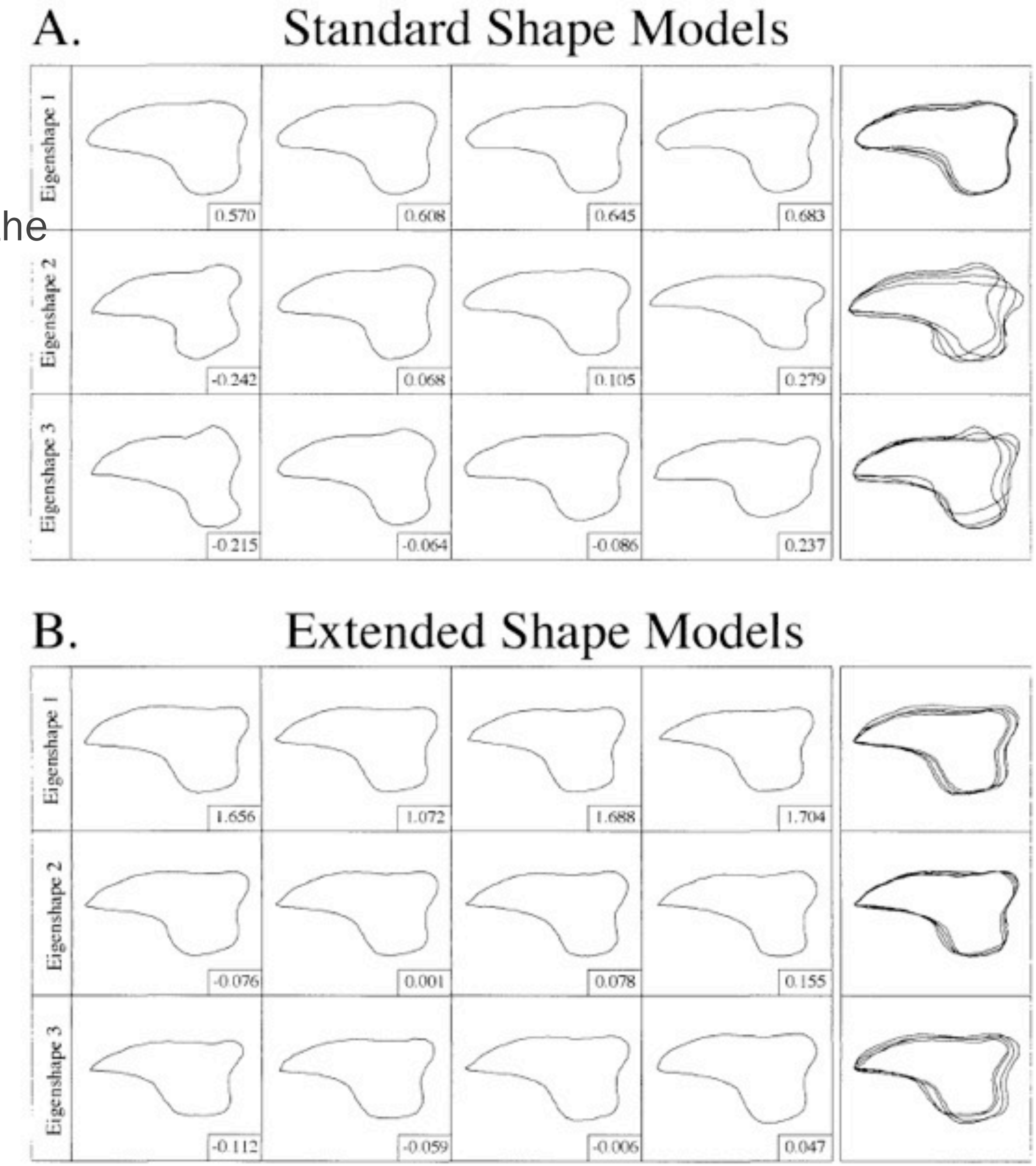
TABLE 1. Eigenvalues.

Eigenvectors	Eigenvalues	Total variance (%)	Cum. variance (%)
Standard eigenshape method			
1	2.291	82.293	82.293
2	0.262	7.244	89.537
3	0.151	5.421	94.958
4	0.069	2.463	97.421
5	0.045	1.606	99.026
6	0.027	0.974	100.000
Extended eigenshape method			
1	16.855	97.426	97.426
2	0.190	1.098	98.524
3	0.118	0.682	99.206
4	0.061	0.351	99.557
5	0.046	0.240	99.797
6	0.035	0.203	100.000

MacLeod, 1999. *Paleobiology*, 25: 107-138.

Comparison by MacLeod

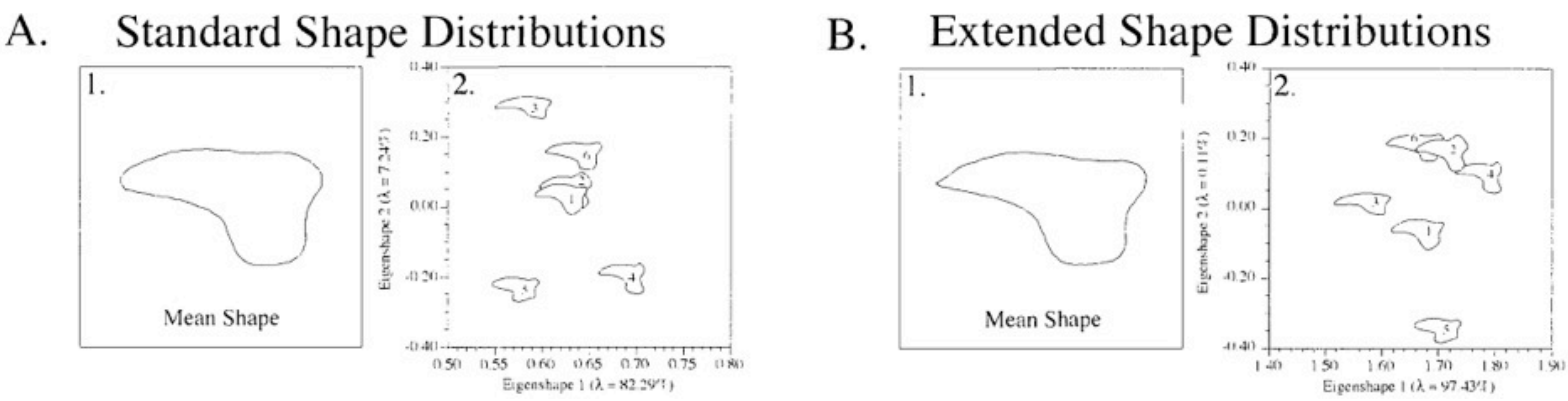
Landmarks provide anchors that make the shape models more intelligible



MacLeod, 1999. *Paleobiology*, 25: 107-138.

Comparison by MacLeod

By concentrating more of the variances on the first PC, landmarks change the apparent distribution of the shapes on a two-dimensional shape space plot



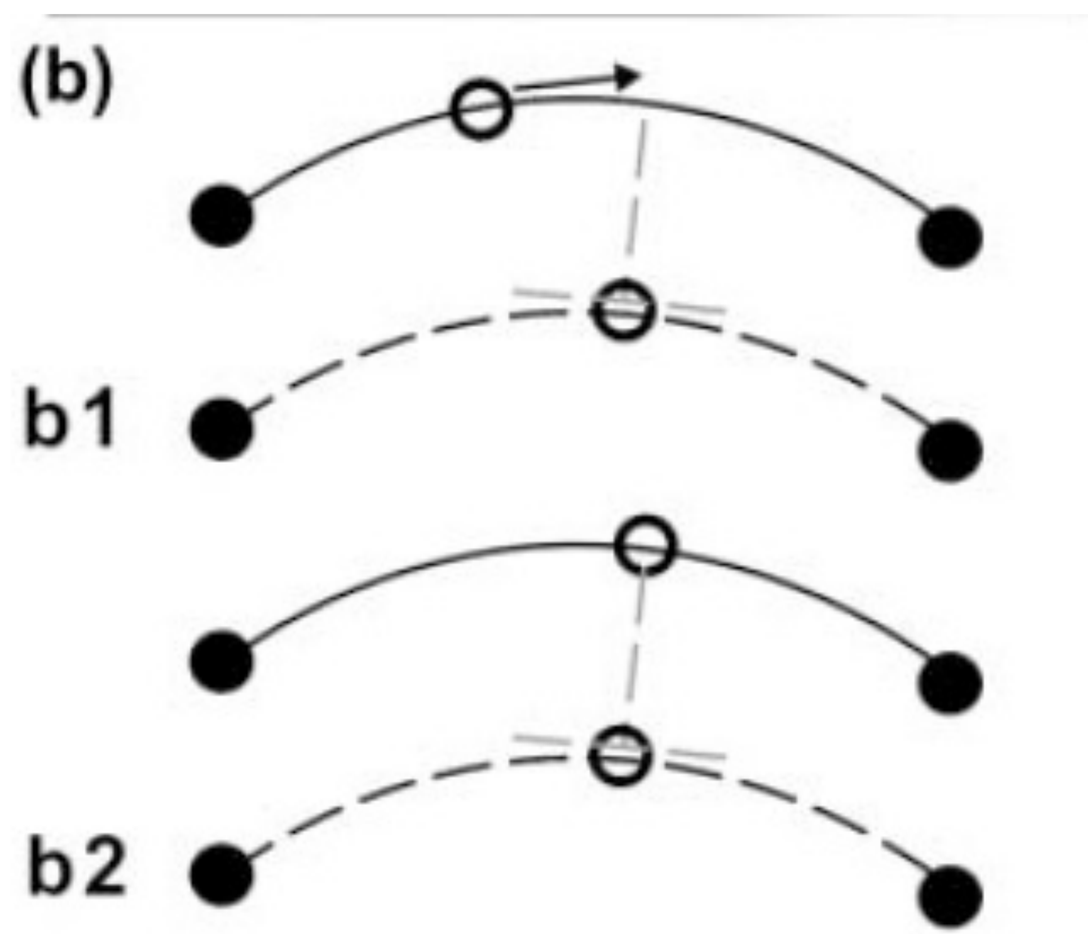
MacLeod, 1999. *Paleobiology*, 25: 107-138.

Sliding semilandmarks

Semilandmarks are iteratively moved along the outline to find the point of best correspondence as part of the superimposition process

Ensures that differences between the shapes are minimized (important as part of statistical assumptions)

May not make a huge difference to results, depending on data set

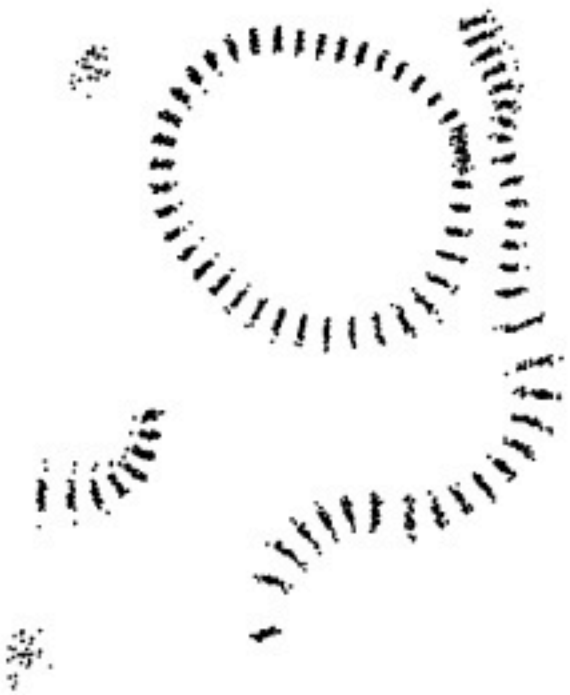


Perez, Bernal, and Gonzalez, 2006. Journal of Anatomy, 208: 769-784.

Consequences of sliding semilandmarks to superimposition

Ordinary semilandmarks

Sliding semilandmarks
(minimize bending energy)



Sliding semilandmarks
(minimize Procrustes distance)

Perez, Bernal, and Gonzalez, 2006. Journal of Anatomy, 208: 769-784.

Further analysis with outlines

Use any method to derive principal components scores

Use PC scores for further statistical analyses, just like with landmarks: MANOVA, regression, etc.

Classic papers on outlines

Fourier analysis

Rohlf, FJ and JW Archie. 1984. A comparison of Fourier methods for the description of wing shape in mosquitoes (Diptera, Culicidae). *Systematic Zoology*, 3: 302-317.

Ferson, S., FJ Rohlf, and RK Koehn. 1985. Measuring shape variation of two-dimensional outlines. *Systematic Zoology*, 34: 59-68.

Eigenshape

Lohmann, GP. 1983. Eigenshape analysis of microfossils: a general morphometric method for describing changes in shape. *Mathematical Geology*, 15: 659-672.

MacLeod, N. 1999. Generalizing and extanding the Eigenshape method of shape space visualization and analysis. *Paleobiology*, 25: 107-138.

Sliding semilandmarks

Bookstein, FL. 1997. Landmark methods for forms without landmarks: localizing group differences in outline shape. *Medical Image Analysis,* 1: 225-243.