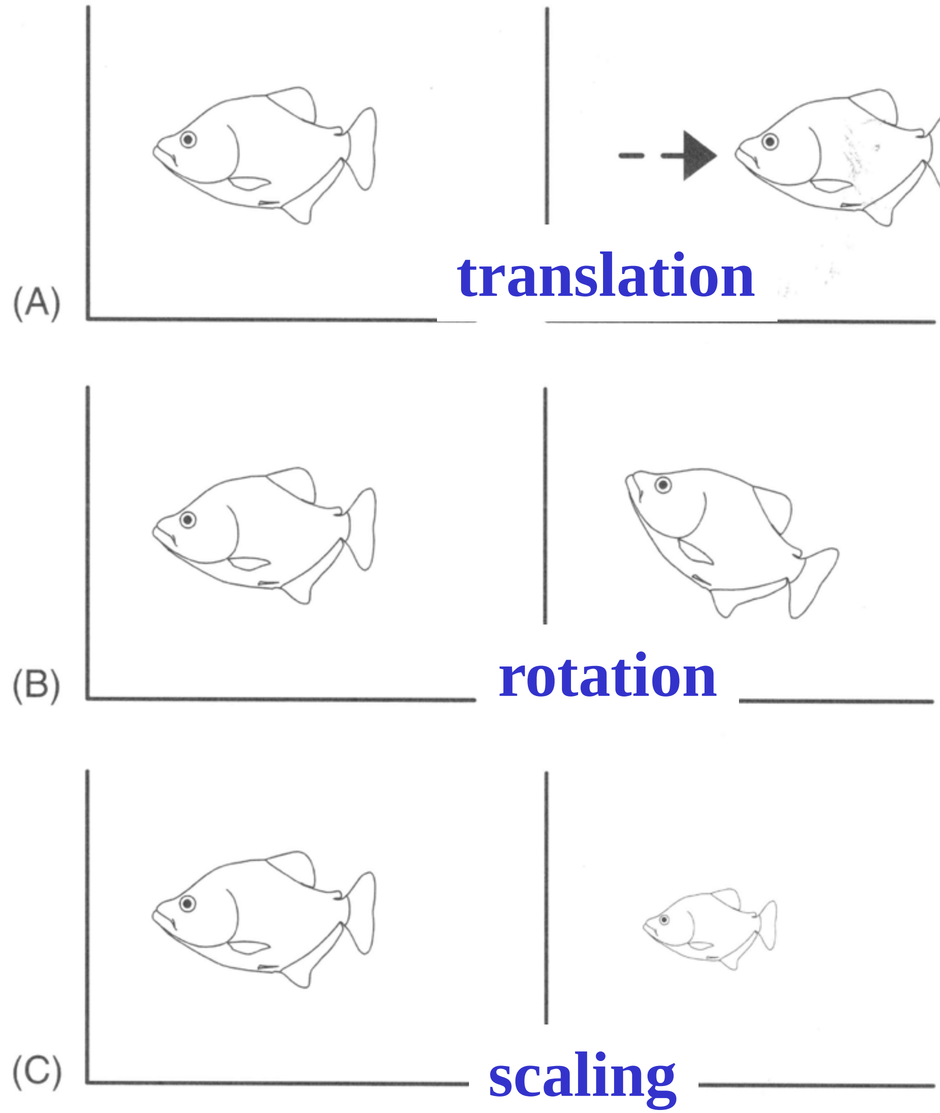
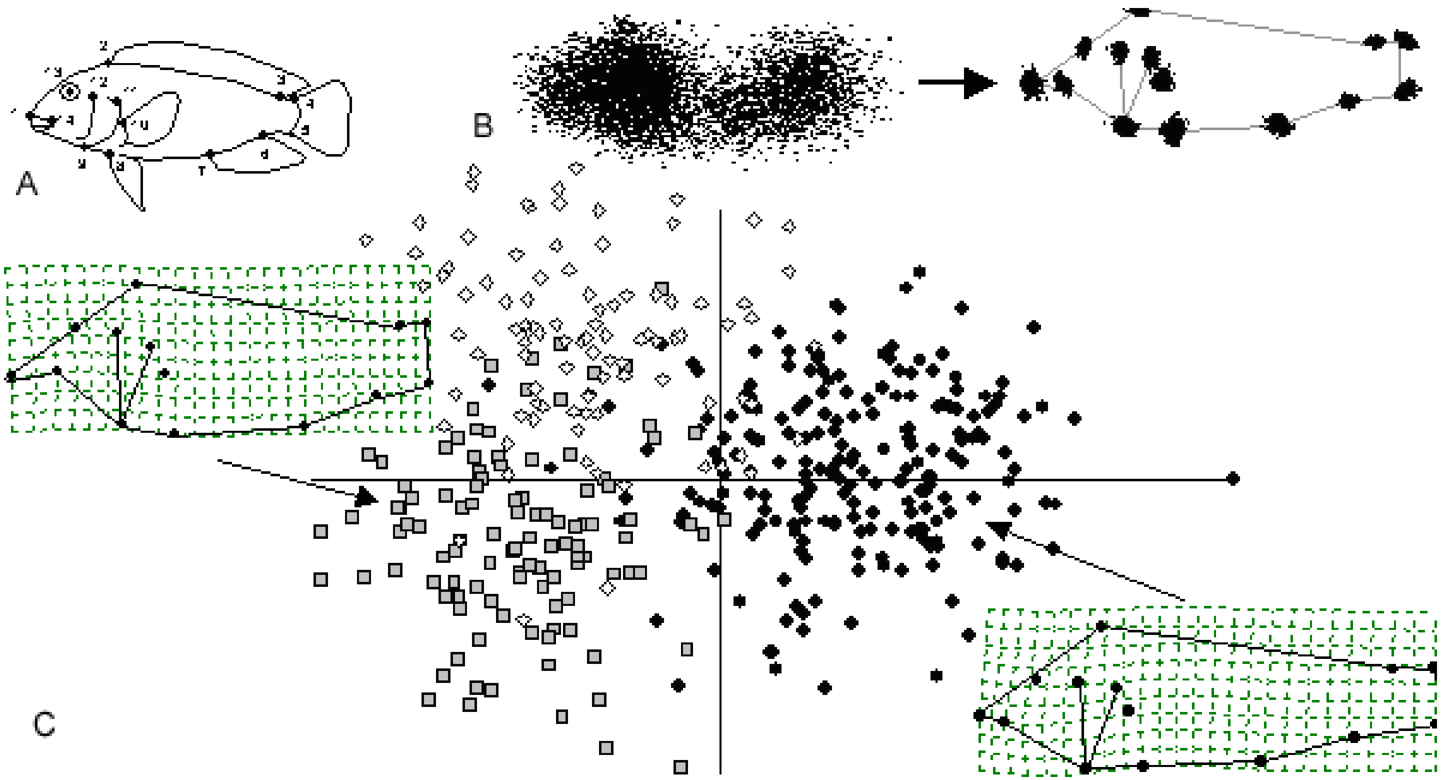
Geometric Morphometrics (New Morphometrics)

Shape:

Shape is all the geometrical information that remains when location, scale and rotational effects are filtered out from an object

David Kendall 1977

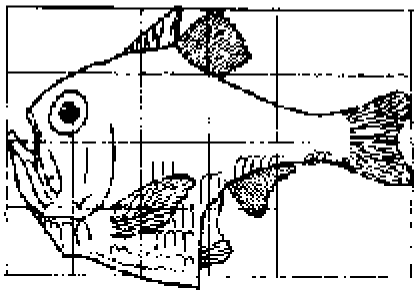




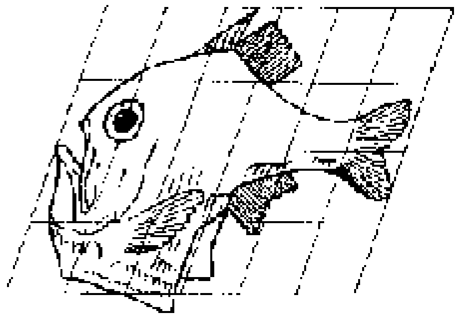
Graphical representation of the four-step morphometric protocol. A: Quantify raw data (landmarks recorded on body of cichlid fish), B: Remove non-shape variation (landmarks of 412 specimens before and after GPA), C: statistical analysis (CVA) and graphical presentation of results. Deformation grids for mean specimen for (right) *Eretmodus cyanostictus* and (left) *Spathodus erythrodon* (magnified by 3X to emphasize shape differences). Data from Rüber and Adams, 2001.

Adams D. C. et al., 2004, Ital. J. Zool. 71: 5-16.

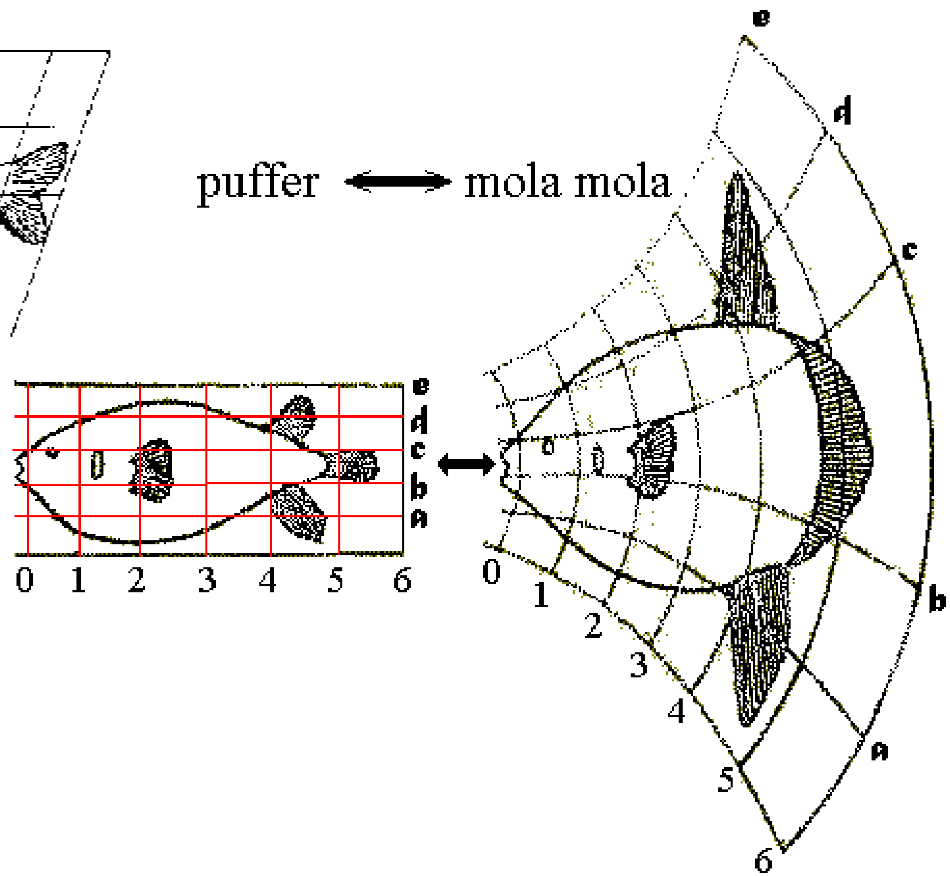
Geometric Morphometrics



Argyropelecus olfersi.



Sternoptyx diaphana.



Shape analysis

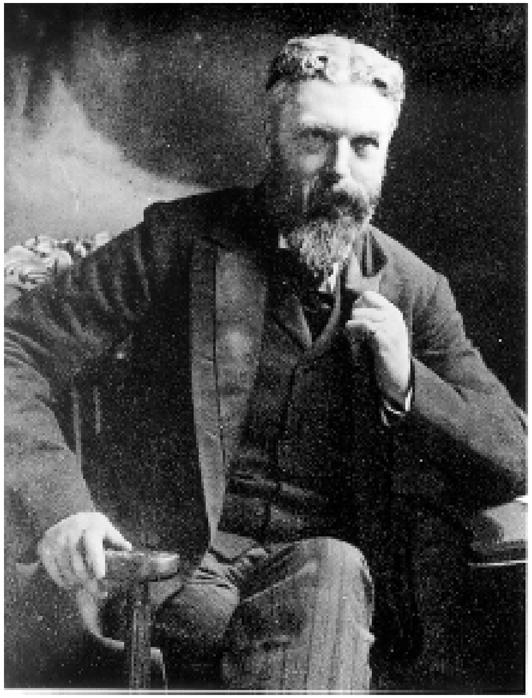
Thompson, A. W. 1917. *On growth and form.* Cambridge University Press, Cambridge.

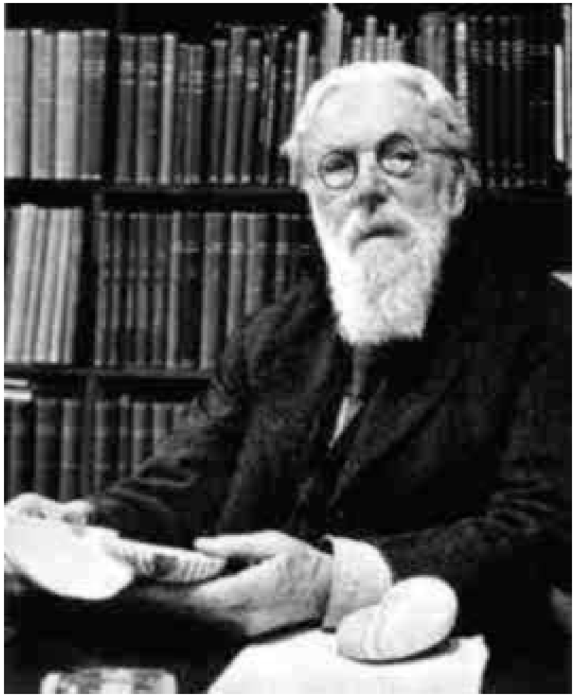
D'Arcy Wentworth Thompson

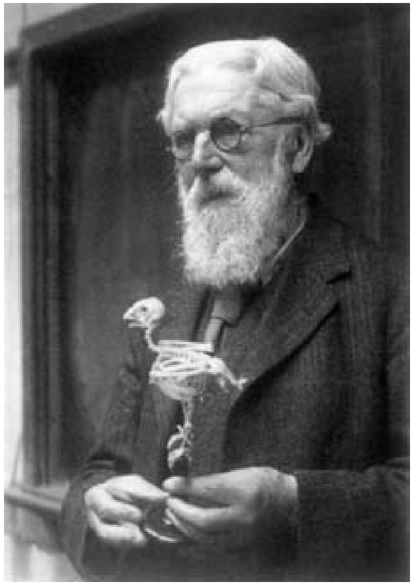
*** 2. 5. 1860 in Edinburgh, Scotland**

+ 21. 6. 1948 in St Andrews, Fife, Scotland

http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Thompson_D'Arcy.html





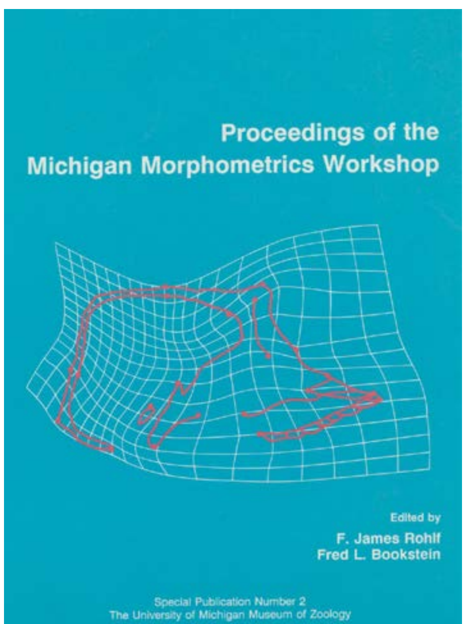


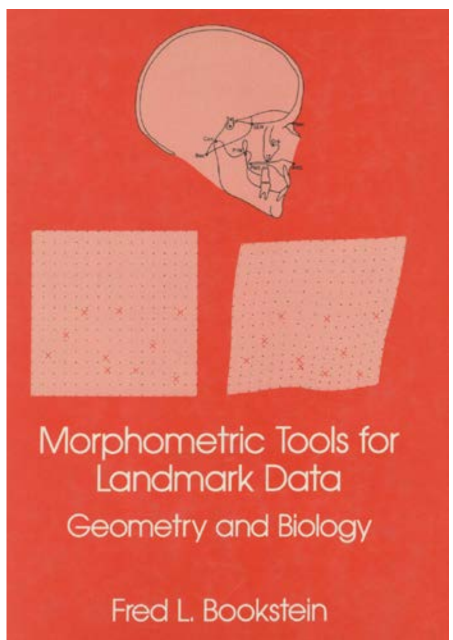
Rohlf, F.J. & Bookstein, F.L., eds., 1990. Proceedings of the Michigan morphometric workshop. *Special Publ. No. 2, The University of Michigan Museum of Zoology.* [Blue book]

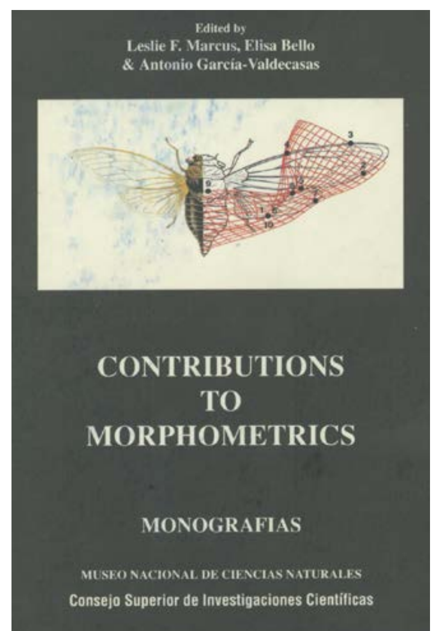
Bookstein, F.L. 1991. *Morphometric tools for landmark data: geometry and biology.* Cambridge University Press, New York. [Red book]

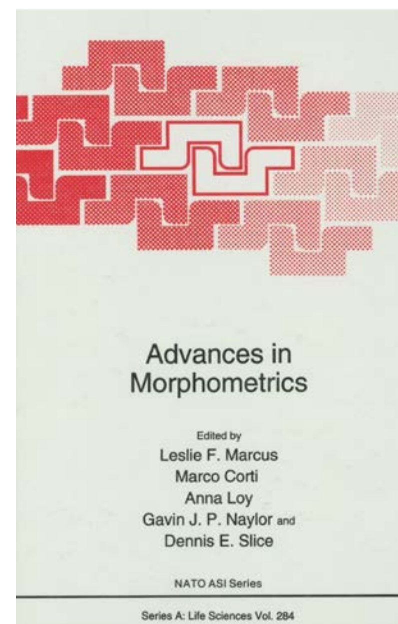
Marcus, L.F., Bello, E. & García-Valdecasas, A., eds., 1993. *Contributions to morphometrics.* Museo Nacional de Ciencias Naturales, Madrid. [Black book]

Marcus, L.F., Corti, M., Loy, A., Naylor, G.J.P. & Slice, D.E., eds., 1996. Advances in morphometrics. *NATO ASI Series A: Life Sciences* 284. [White book]









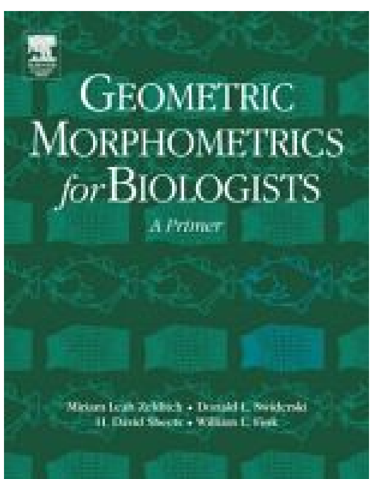
Dryden, I. L. & Mardia, K. V. 1998. Statistical shape analysis. John Wiley & Sons, Chichester, etc.

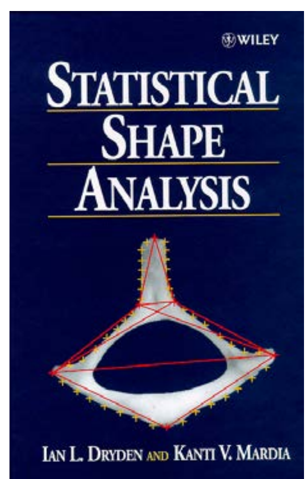
MacLeod, N. 2001. Landmarks, localization, and the use of morphometrics in phylogenetic analysis. *In* Edgecombe, G., Adrain, J. and Lieberman, B. (ed.). *Fossils, phylogeny, and form: an analytical approach*. Kluwer Academic/Plenum, New York, pp. 197–233. http://www.nhm.ac.uk/palaeontology/a&ss/nm/nm.html

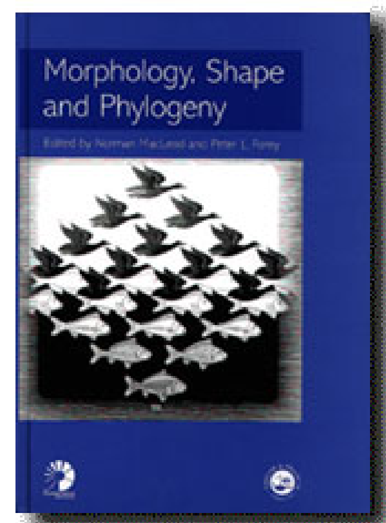
Macleod, N. & Forey, P. 2002. *Morphology, shape and phylogeny*. Taylor and Francis, London, New York.

Zelditch, M. L., Swiderski, D. L., Sheets, H. D. & Fink, W. L. 2004. *Geometric morphometrics for biologists*. Elsevier / Academic Press, Amsterdam, etc.

Macholán, M. 1999. Prokrustes, deformace a nová morfometrie. *Vesmír* 78: 35-39.





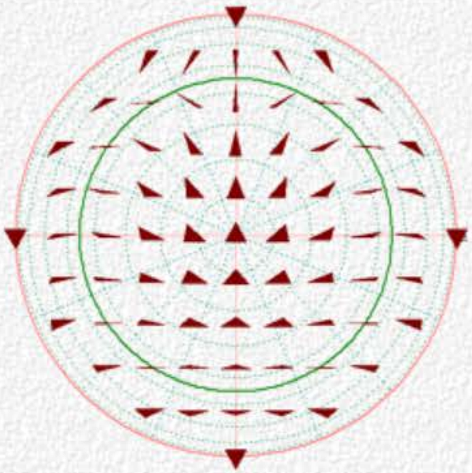


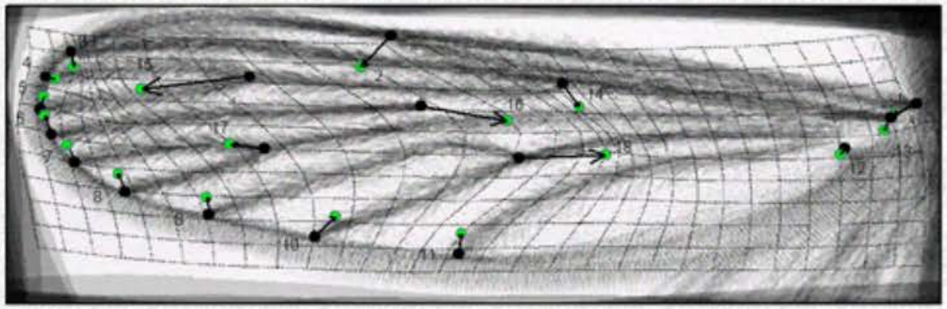
SB Morphometrics

(Was the site at life2.bio.sunysb.edu/morph)

Contents:

- Meetings, workshops, courses, etc. NEW
- Software
- Data
- Bibliography
- Glossary
- People
- Hardware
- Other sites
- Archive of meetings, workshops, & courses
- **Home**





https://www.sbmorphometrics.org/

SB Morphometrics

(Was the site at life2.bio.sunysb.edu/morph)

Morphometric software

The purpose of this directory is to make available programs useful for morphometric analysis. Contributions of additional software are welcome. Contact us with suggestions for improvements and with additional contributions to the morphmet archive. Click on the categories in the contents window (at the left) to obtain lists of available software. The platform required by each program (e.g., DOS, Windows, Mac, Unix) is indicated in red for each program. Note: Windows programs can sometimes be run using emulators on other platforms (e.g., Wine on Linux of Connectix Virtual PC on a Mac).

Would you like to have your software listed? Please send me an e-mail . .

Notes on downloading files

WWW browsers such as Netscape or Internet Explorer can download these files. Dates indicate the date of the last upload of the file to this server. For some programs there is a link to the *readme* file which may be selected to get additional information about the software.

There are also links to websites and directories on other servers (such as the anonymous FTP edgewarp directory on Bookstein's server. If you select an FTP site then a directory will be displayed from which you can select files to download via FTP. No dates are furnished with these entries since they can be updated independently.

- Files with types of "exe" are self-extracting archive files for the IBM PC.
- Files with a type of "zip" are IBM PC ZIP files that require the PKUNZIP, Winzip, or equivalent program to unpack.
- Note: DPMI = a DOS protected mode program that does not have the 640K limitation. Requires computer using 80386 or better CPU and appropriate software. These programs are less common because Windows provides the same function in a standard way.

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- **Home**

Publications

Publications relevant to geometric morphometrics.

Review	A general review of the field of geometric morphometrics in late 2002. By Adams, Rohlf, and Slice.
Books	A list of books, workshop proceedings, and similar documents concerned with geometric morphometrics.
Multivariate primer	A contribution by Richard Reyment containing a "Multivariate Statistical Primer for Geologists."
Glossary for morphometrics	A glossary of morphometric terms. It is based on the glossary in the NATO volume ("white book") by Marcus et al. (1996).
PalaeoMath	Newsletters that include introductory descriptions of geometric morphometrics and some of the statistical methods used. In both html and PDF formats. in By Norm MacLeod.
Fish Geometric Morphometrics	References on Fish Geometric Morphometrics. Available in HTML format. By Mauro J. Cavalcanti.
Bibliography	An extensive morphometric bibliography is now available agin at http://darwin.bc.asu.edu/refbase/. You will need to register and create a userid before you can use the site. The website allows searching, exporting (in various formats), and adding new references. The site is maintained by John Lynch.

This page was updated on 06-Oct-20 by F. James Rohlf

SB Morphometrics

(Was the site at life2.bio.sunysb.edu/morph)

Contents:

A Glossary for Geometric Morphometrics

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This glossary provides definitions for terms, concepts, and methods frequently encountered in morphometric literature and discussions. It includes entries for technical terms with more-or-less special meaning in shape analysis and biological morphometrics (e.g., preshape, warps, anisotropy) and some of the casual jargon that may be completely foreign to newcomers to the field (e.g., books of various color - Red, Blue, Orange, and Black). Many definitions provide the general idea behind each entry instead of a technically or mathematically rigorous treatment. As such, they are intended to give

Landmarks

Bookstein shape coordinates

Procrustes analysis

Thin plate spline

Outline analysis

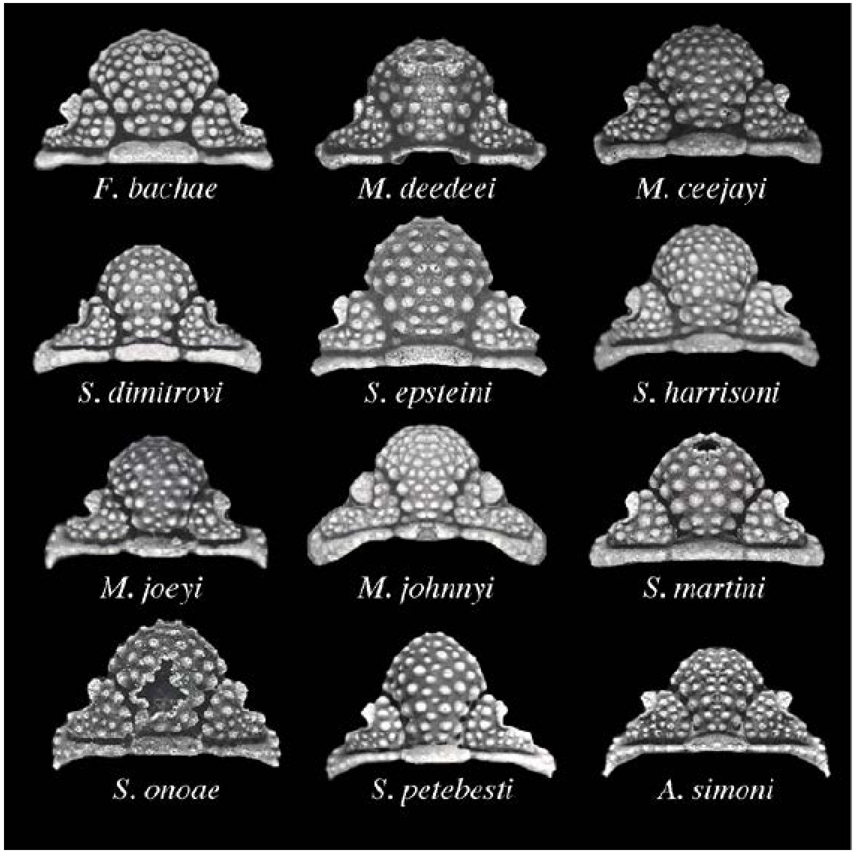
Geometric Morphometrics

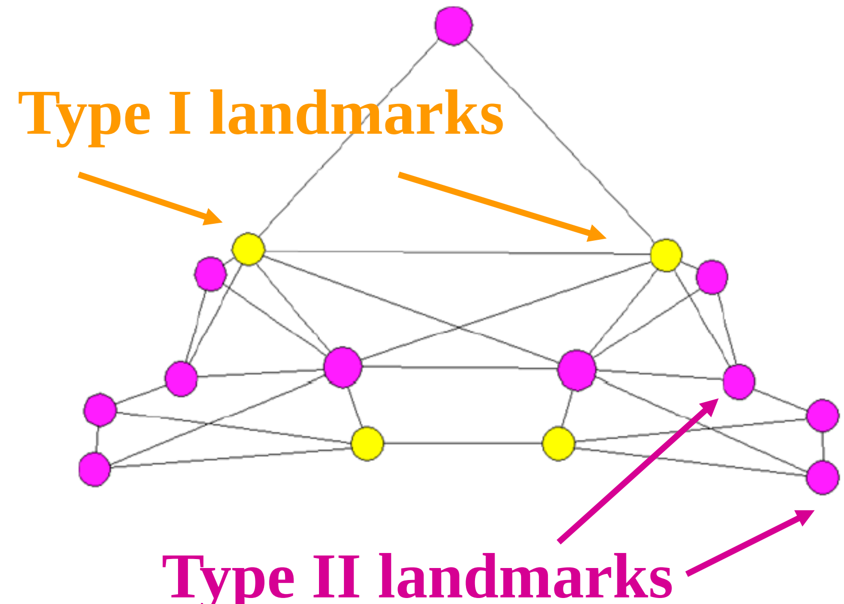
Landmarks

Type I landmarks represent points on an organism whose homology among different individuals of the same taxon or among different taxa is sufficiently demonstrably supported at the histological level.

Type II landmarks are points whose homology is supported only geometrically, but not histologically.

Type III landmarks (also known as pseudolandmarks or semilandmarks) represent, for example, points at the ends of an organ, structure, or organism.





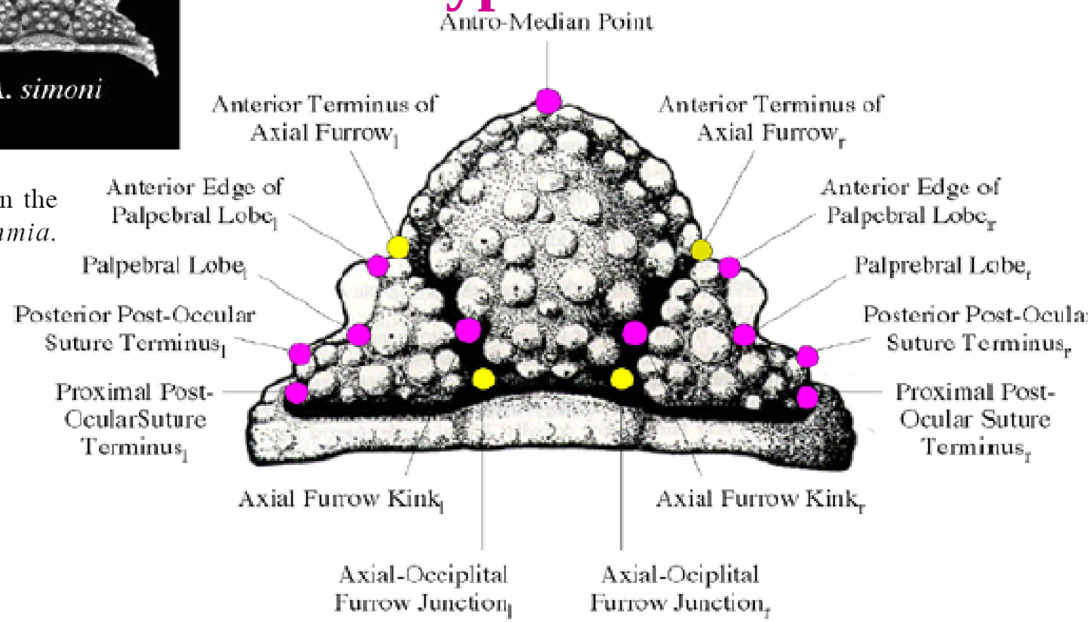
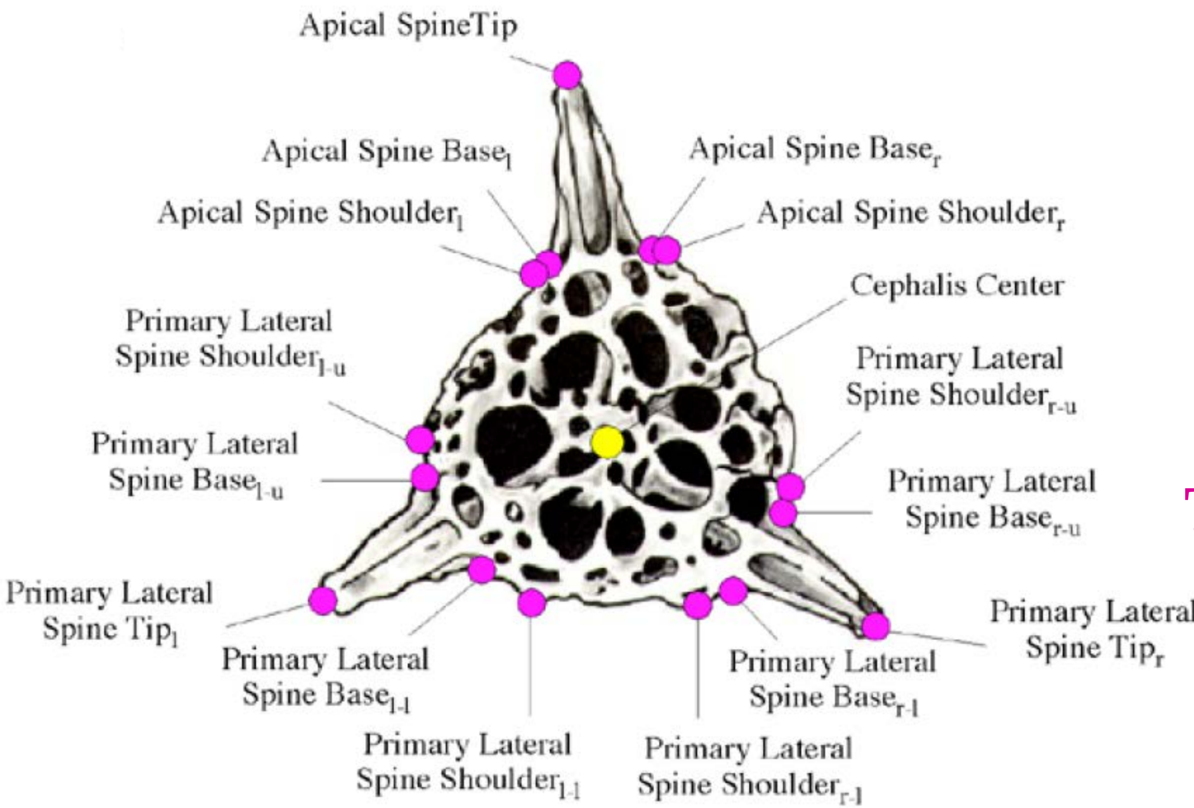


Figure 1. Representative trilobite cranidia from species in the genera *Struszia*, *Mackenziurus*, *Avalanchurus*, and *Fammia*.

Adrain, JM, and Edgecombe, GD. Silurian encrinurine trilobites from the central Canadian Arctic. Palaeontographica Canadiana 1997;14:1—109.

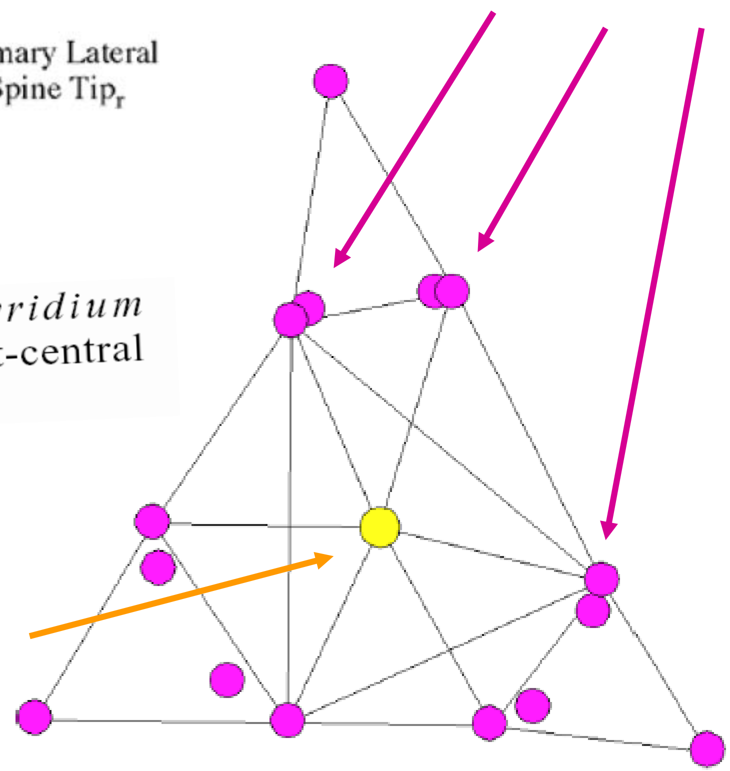
MacLeod (2001)



MacLeod, N. Lower and Middle Jurassic *Perispyridium* (Radiolaria) from the Snowshoe Formation, east-central Oregon. Micropaleontology 1988;34:289—315.

Type II landmarks

Type III landmarks



MacLeod (2001)

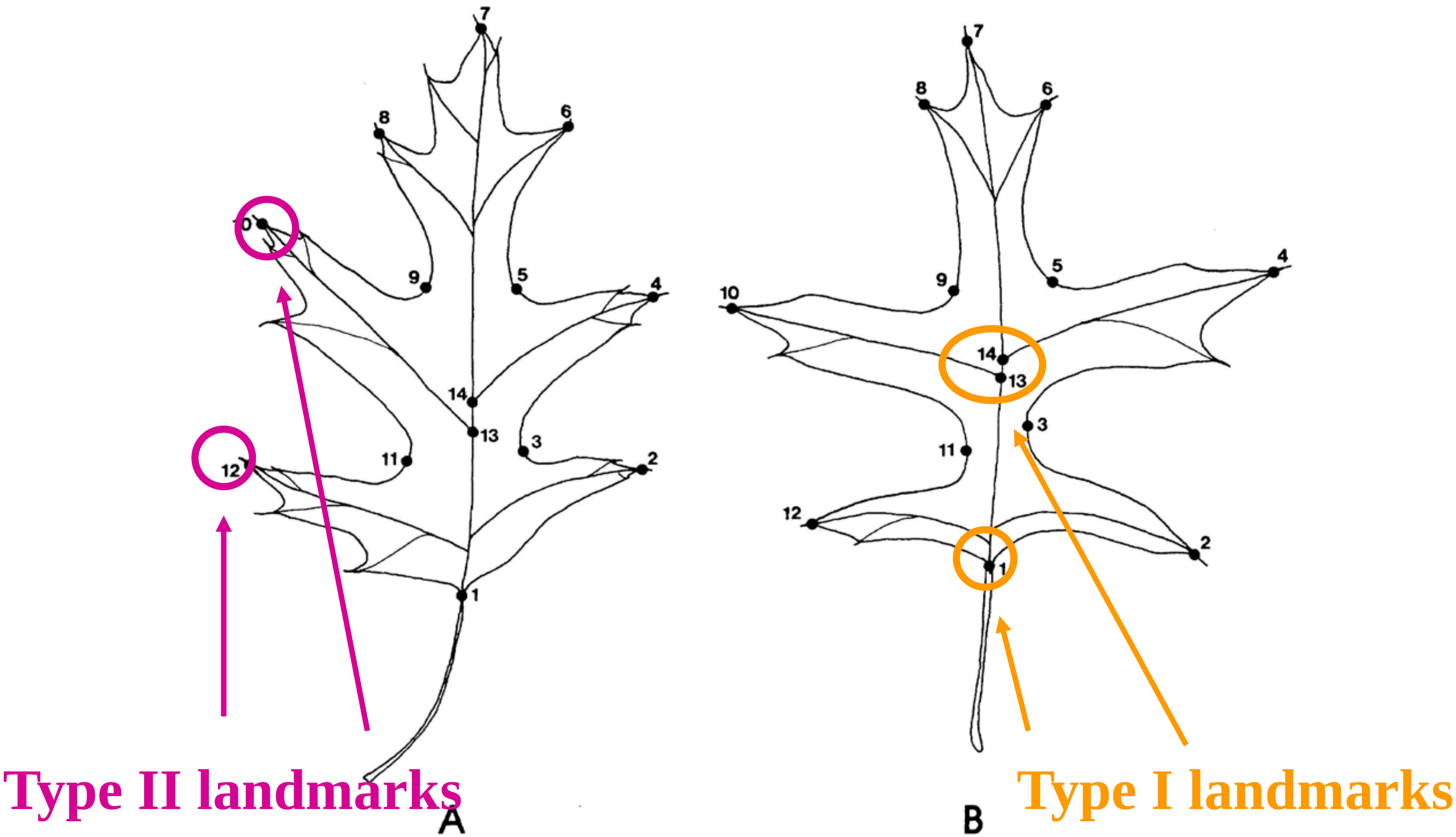


Fig. 1. Leaves of (a) black oak and (b) pin oak illustrating the landmarks chosen for analysis.

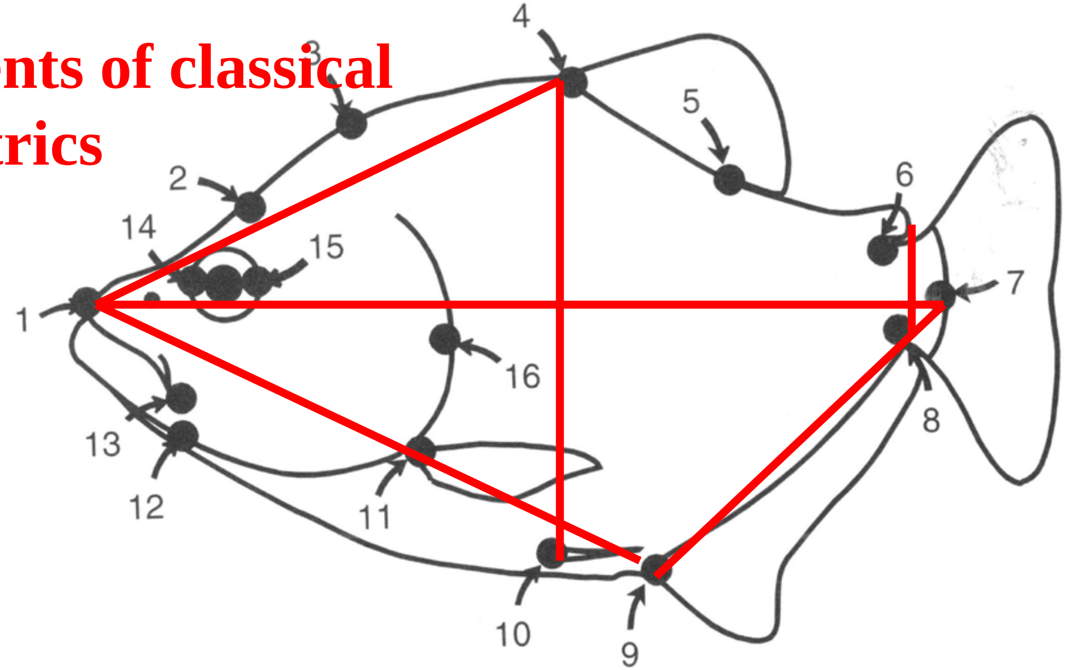
Amer. J. Bot. 77(10): 1279–1293. 1990.

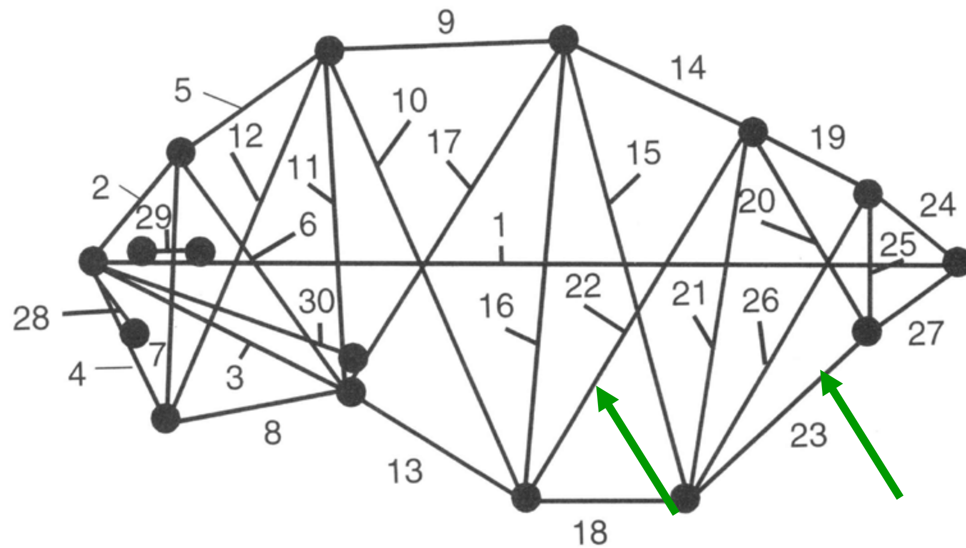
DETECTING SHAPE VARIATION IN OAK LEAF MORPHOLOGY: A COMPARISON OF ROTATIONAL-FIT METHODS[1]

RICHARD J. JENSEN

Department of Biology, Saint Mary's College, Notre Dame, Indiana 46556

Measurements of classical morphometrics

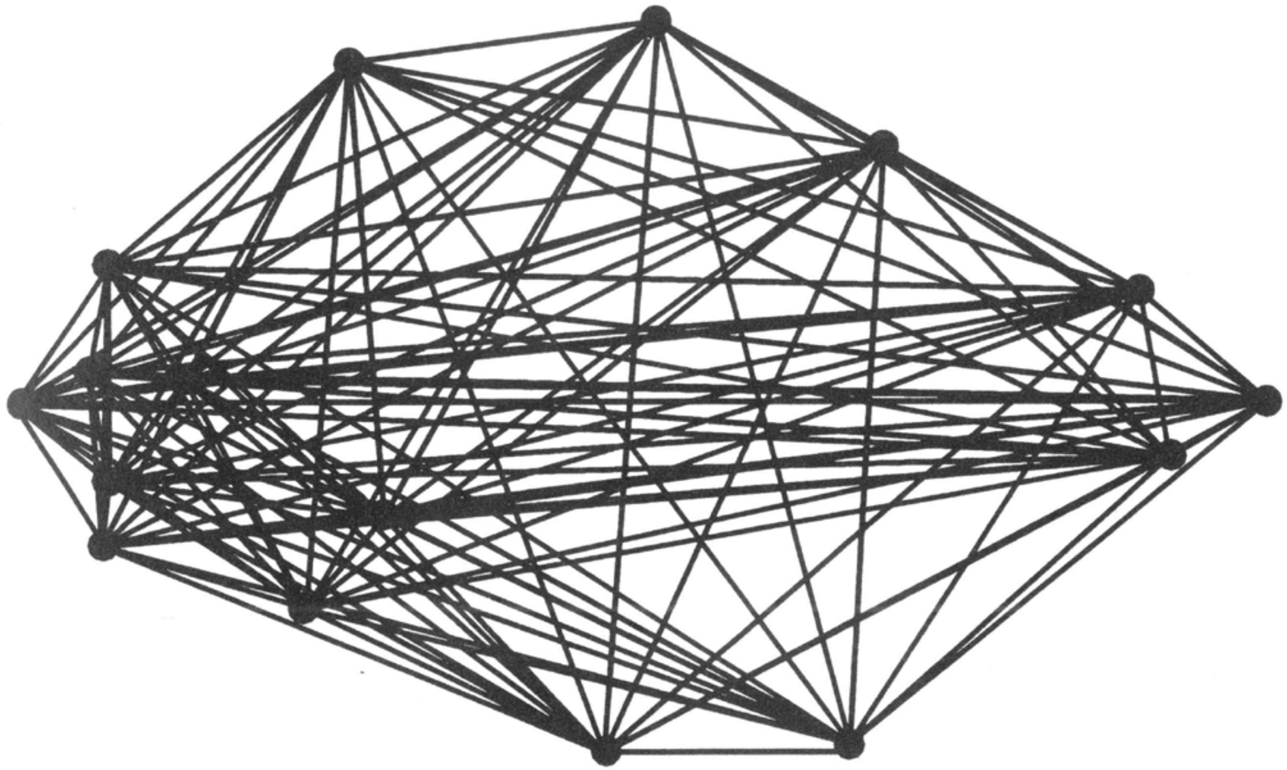




trusses

Strauss & Bookstein 1982

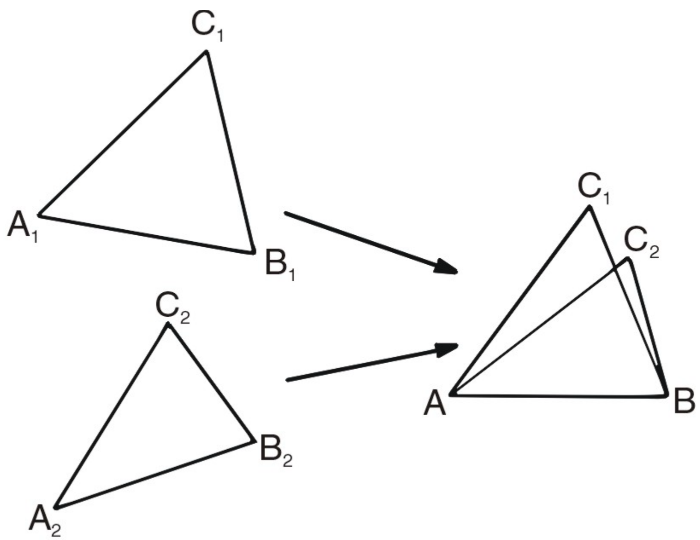
Zelditch et al. (2004)



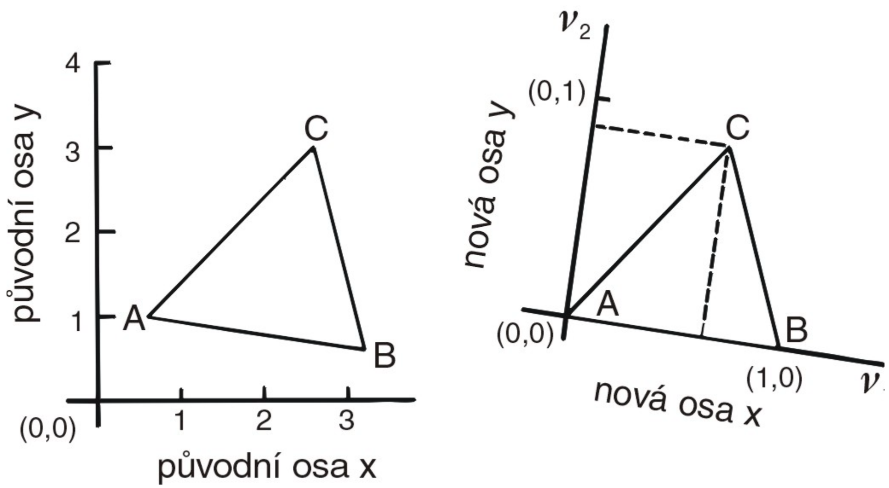
Distances between all homologous points – 120 measurements – an impractical alternative.

Zelditch et al. (2004)

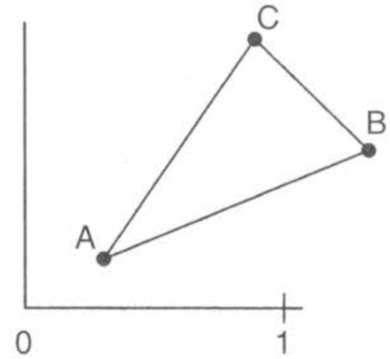
Direct comparison of landmark coordinates using the so-called Bookstein shape coordinates

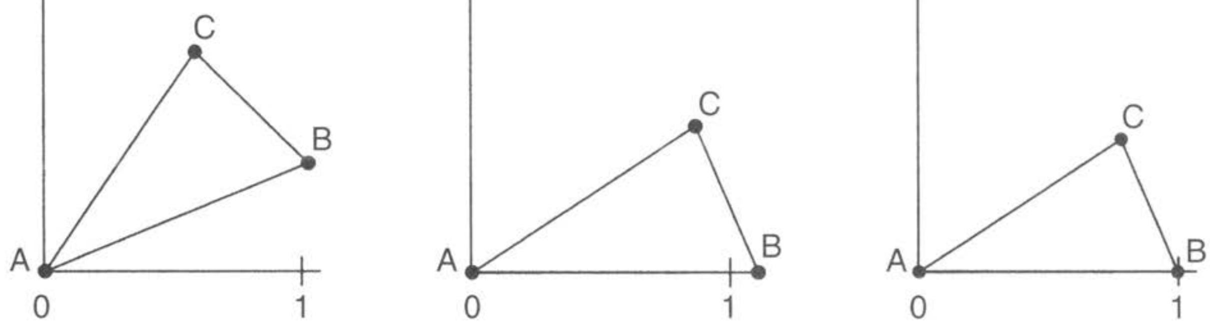


For each object with *p* landmarks, whose coordinates were recorded on a plane, we obtain 2 (*p* – 2) values, which can be further evaluated using multivariate methods.



Calculation of the coordinates of point C in the new coordinate system.



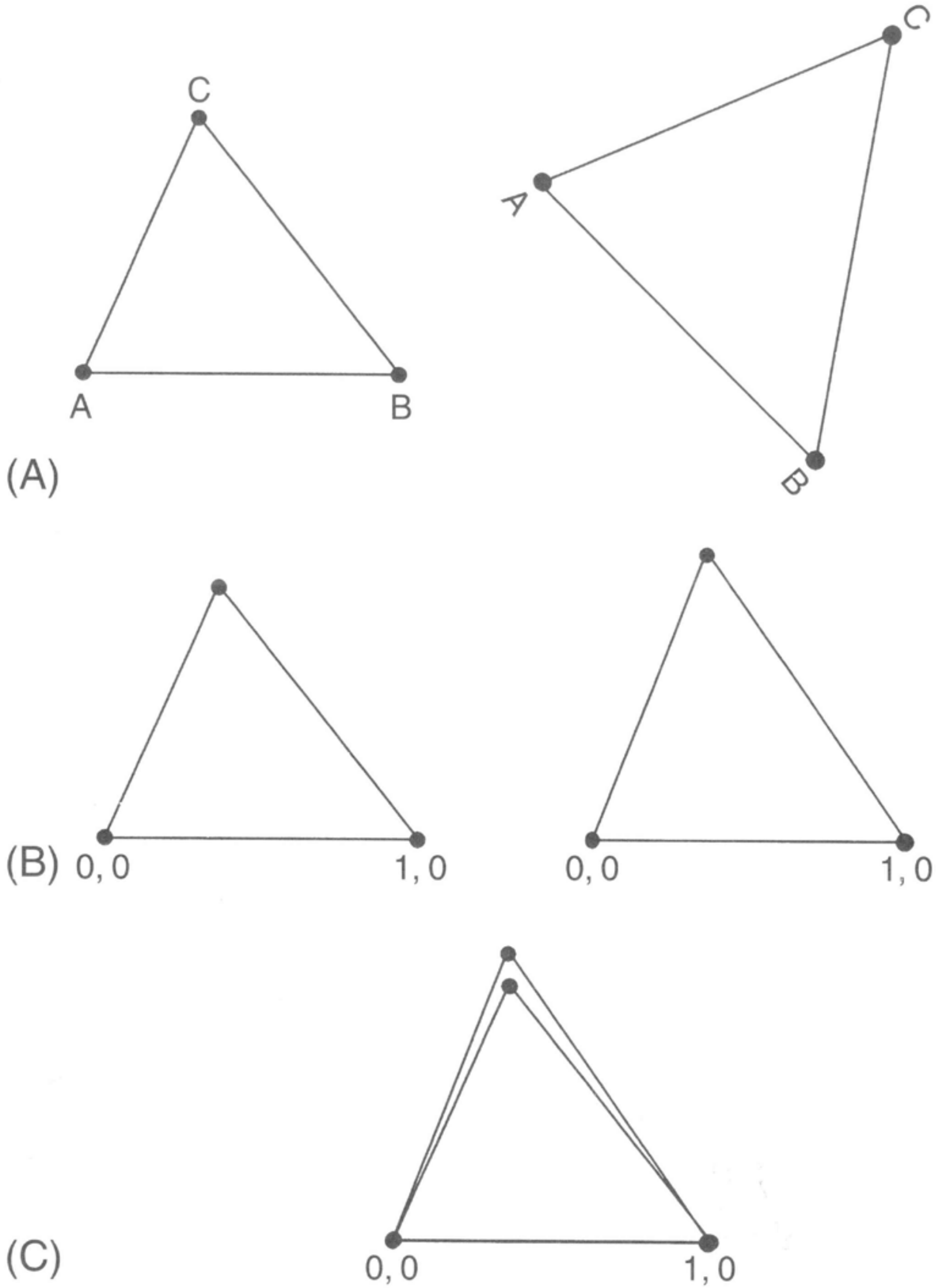


$$SC_x = \frac{(B_x - A_x)(C_x - A_x) + (B_y - A_y)(C_y - A_y)}{(B_x - A_x)^2 + (B_y - A_y)^2}$$

„shape coordinates“
of the point C

$$SC_y = \frac{(B_x - A_x)(C_y - A_y) - (B_y - A_y)(C_x - A_x)}{(B_x - A_x)^2 + (B_y - A_y)^2}$$

Zelditch et al. (2004)



original triangles (shapes)

original triangles after translation, rotation and scaling

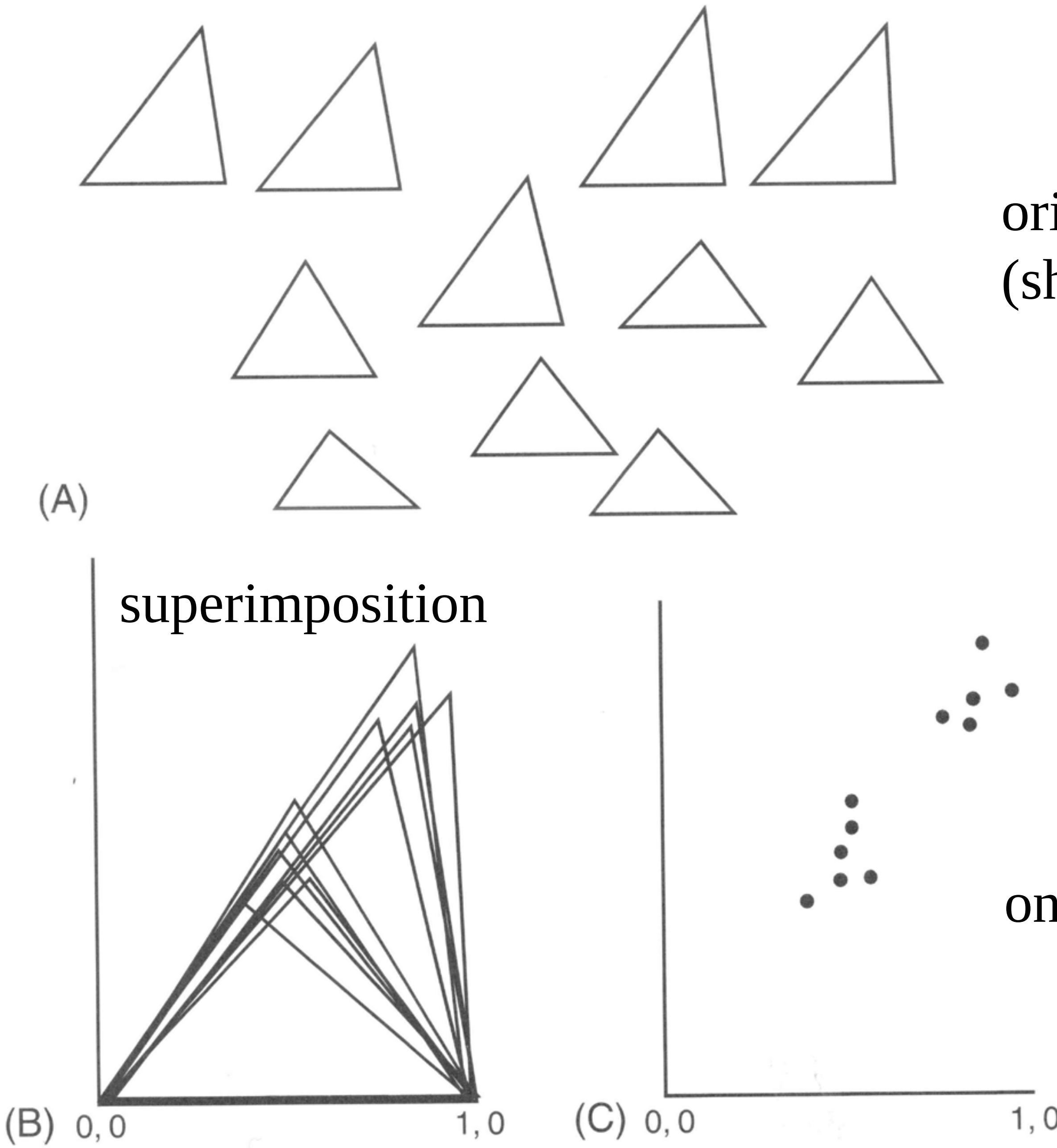
superimpositiona

Zelditch et al. (2004)

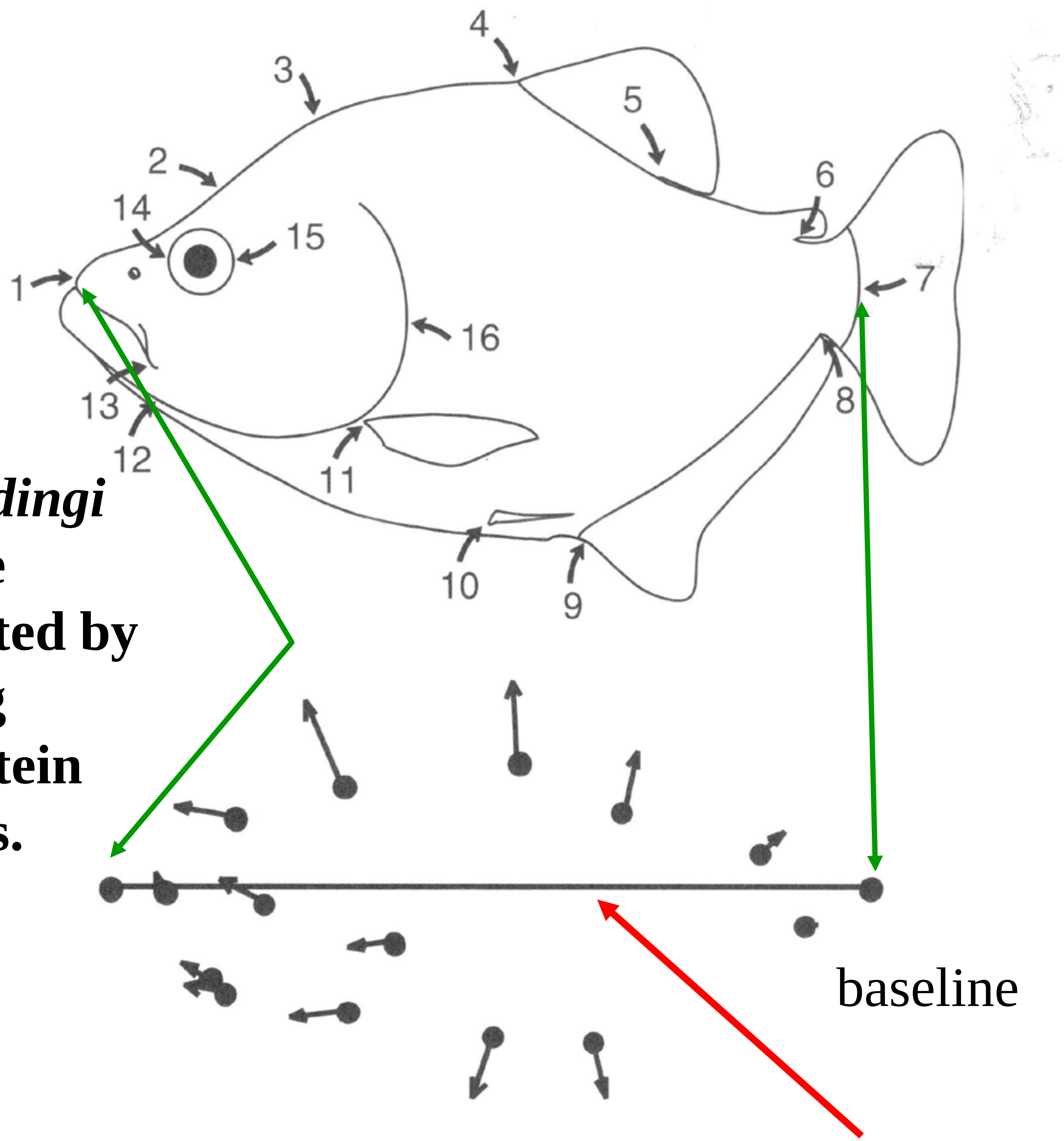
original triangles
(shapes)

superimposition

only landmarks



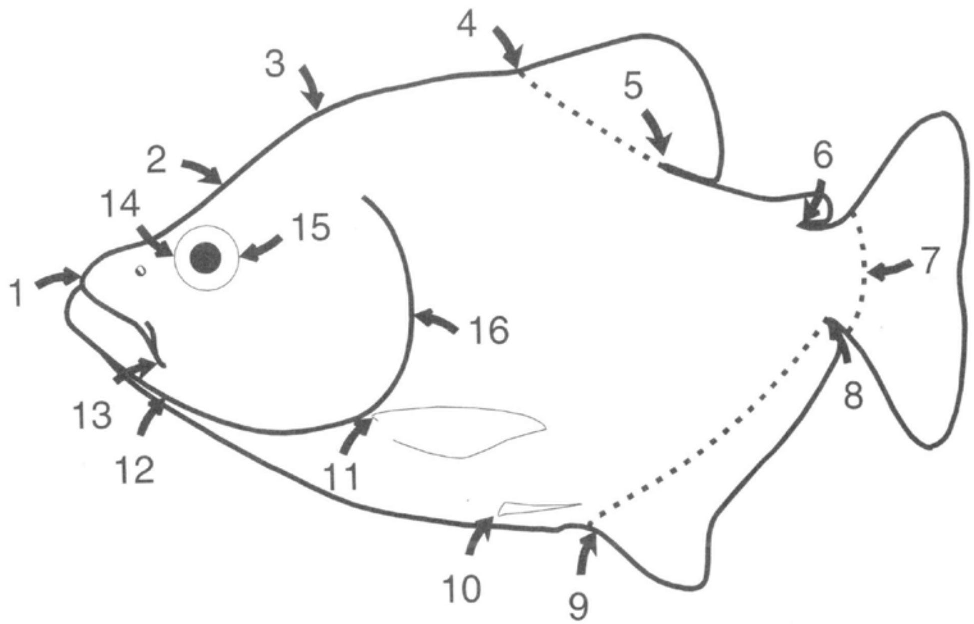
Zelditch et al. (2004)

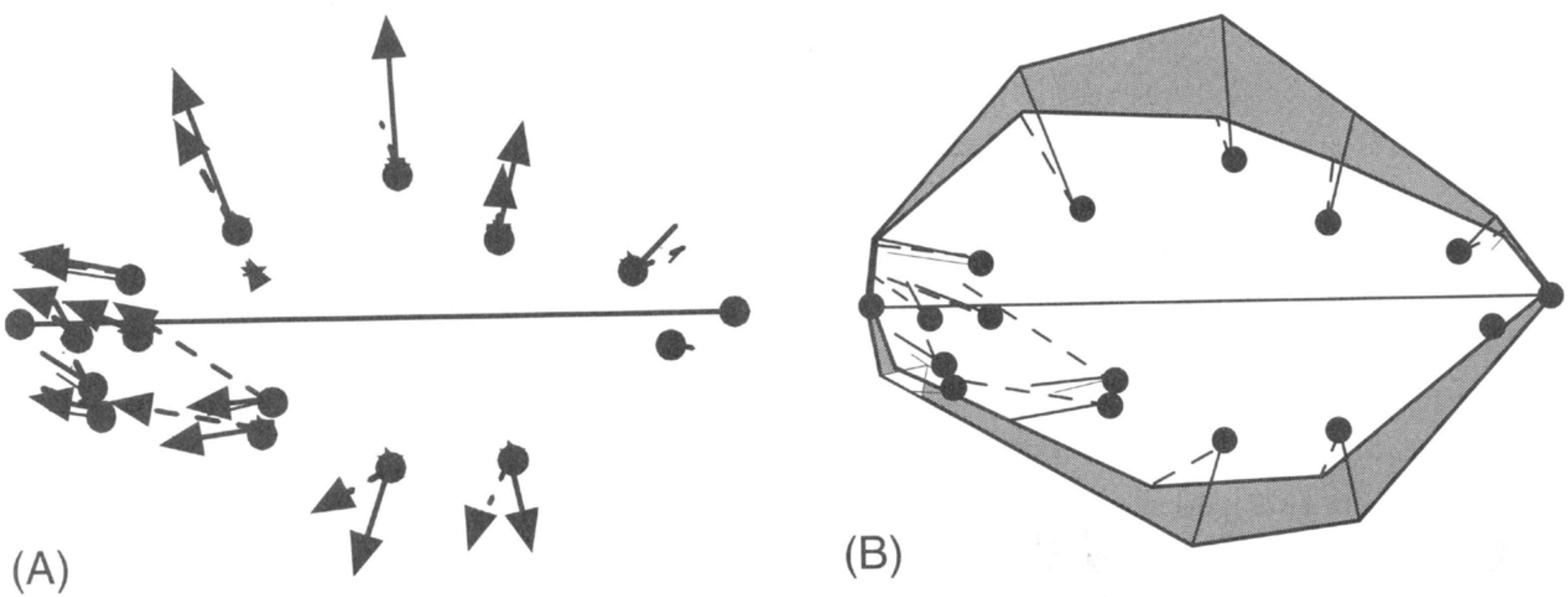


Serrasalmus gouldingi **ontogenetic shape changes represented by vectors indicating changes in Bookstein shape coordinates.**

Zelditch et al. (2004)

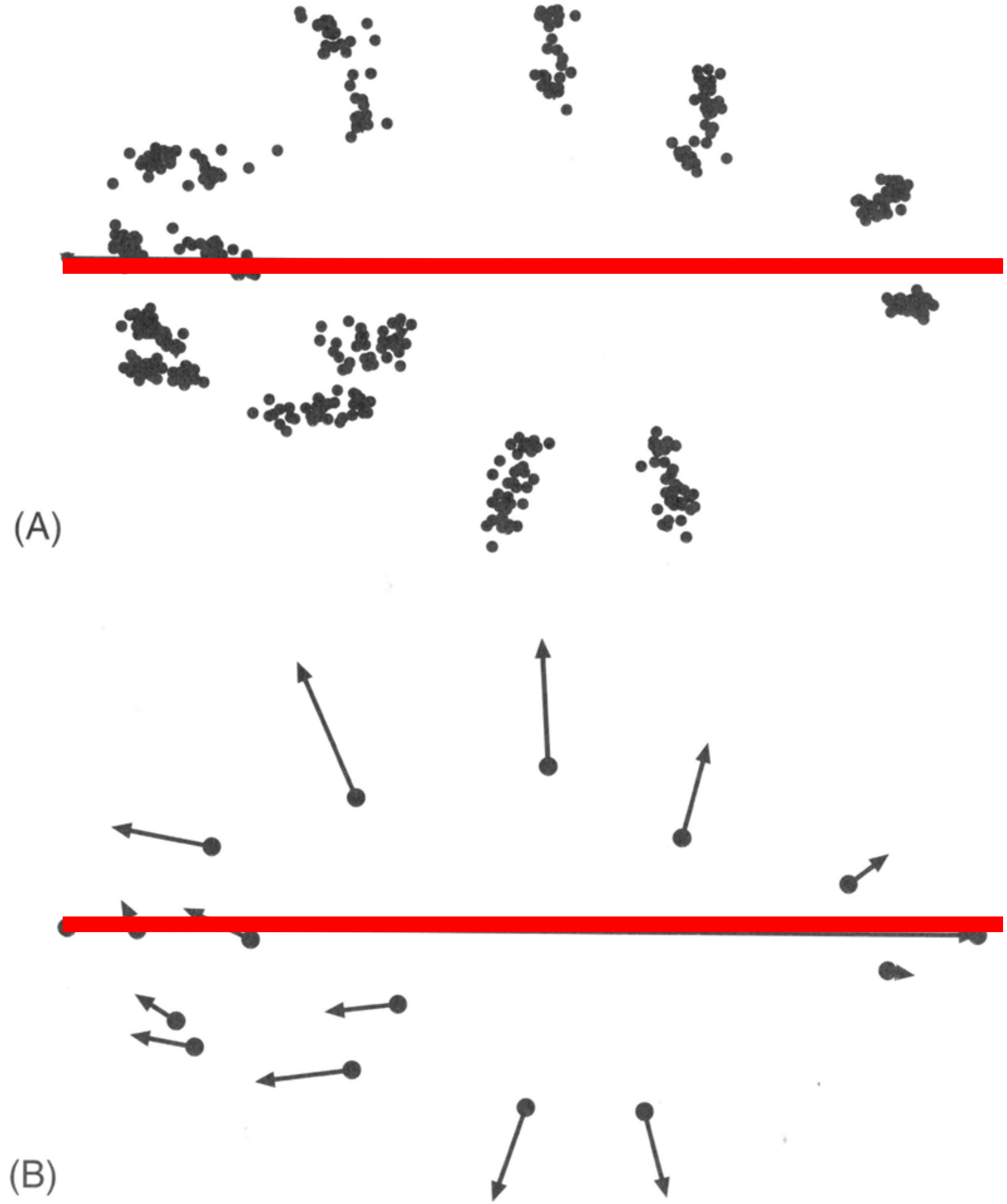
Comparison of ontogeny of the two species *Serrasalmus goulgingi* a *S. elongatus*





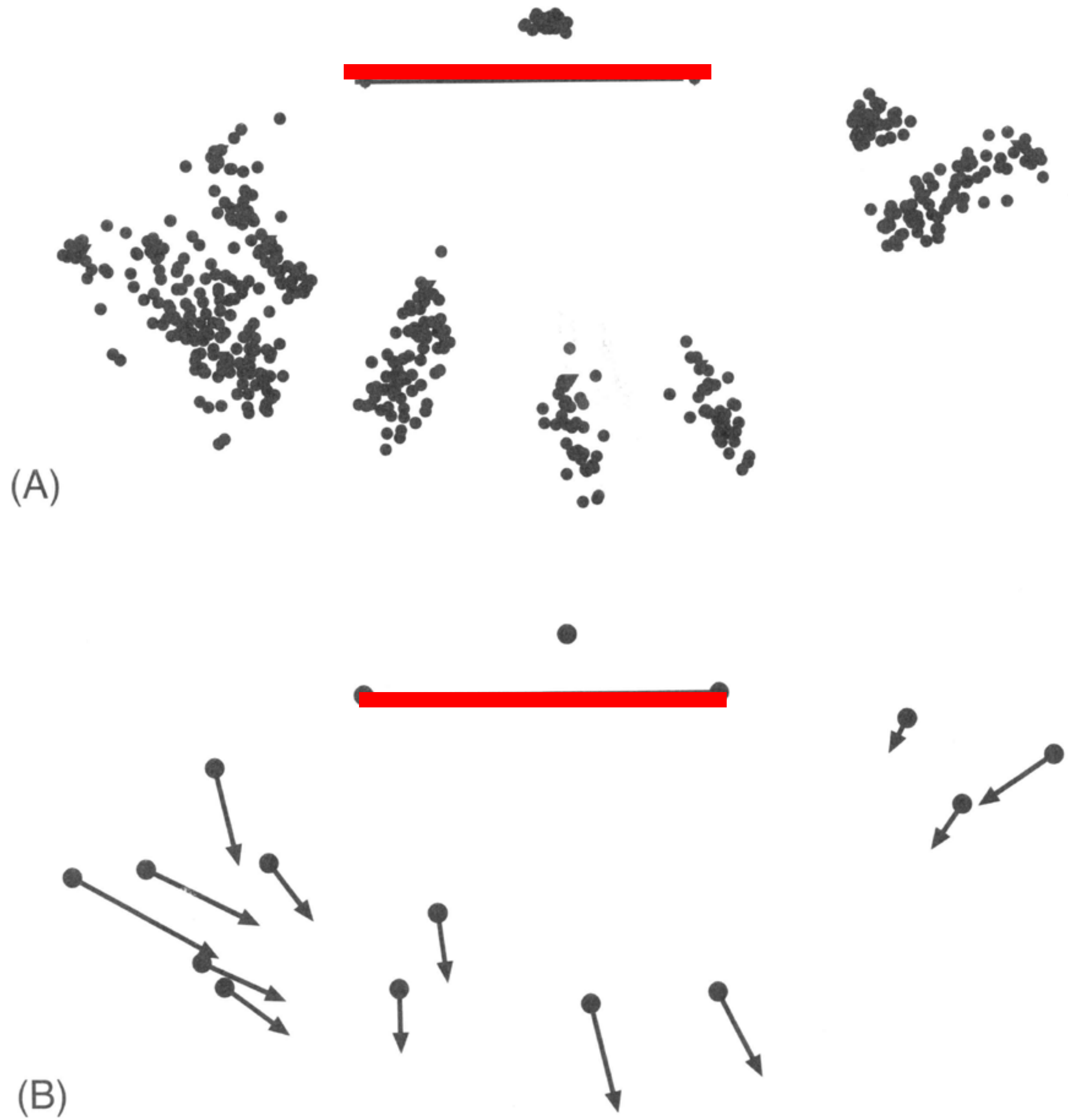
Zelditch et al. (2004)

Comparison of the ontogeny of the species *Serrasalmus goulgingi* changibg the landmarks that define the baseline.



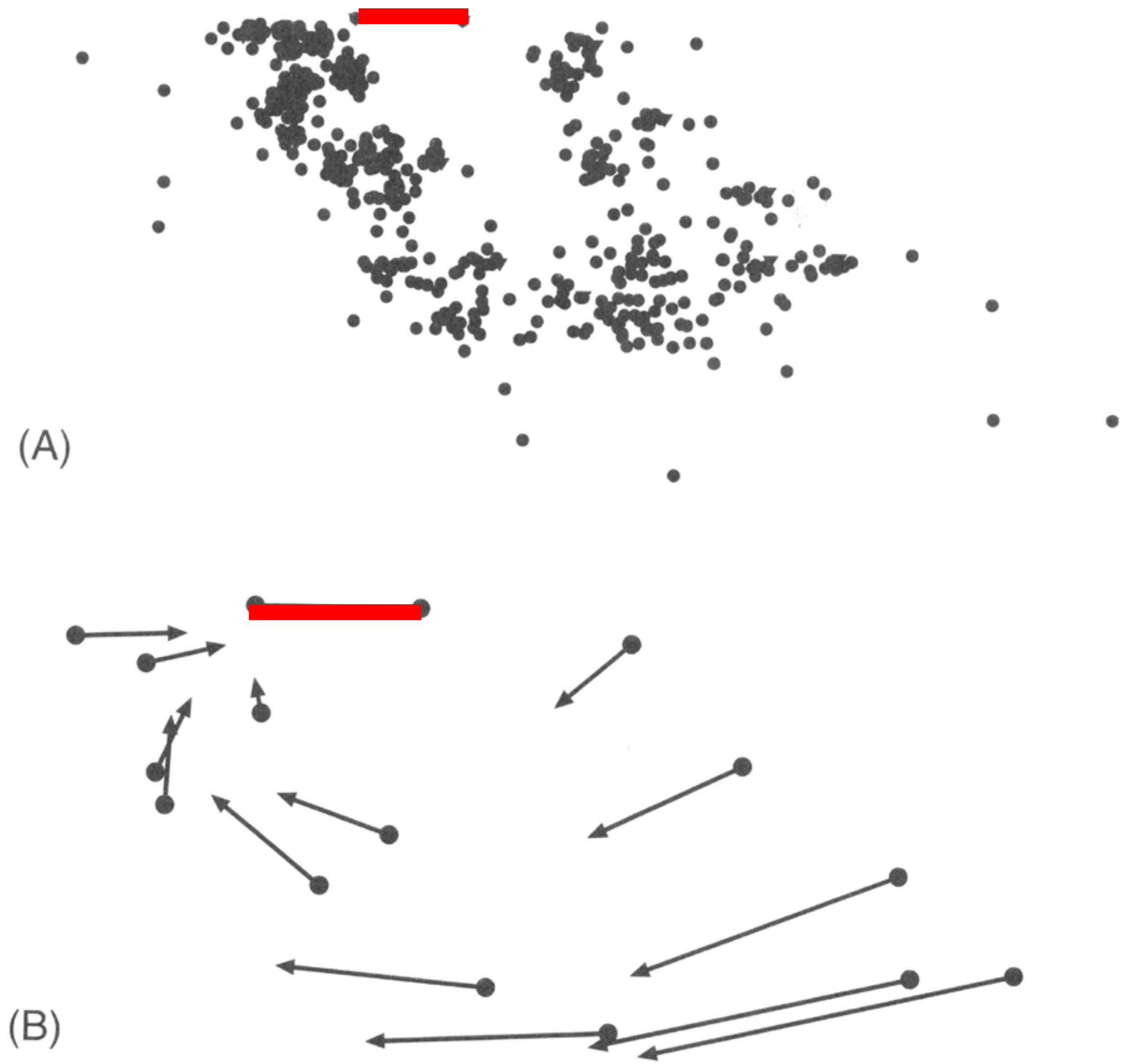
Zelditch et al. (2004)

Comparison of the ontogeny of the species *Serrasalmus goulgingi* changibg the landmarks that define the baseline.



Zelditch et al. (2004)

Comparison of the ontogeny of the species *Serrasalmus goulgingi* changibg the landmarks that define the baseline.



Zelditch et al. (2004)

Procrustes superimposition

Procrustes superimposition of objects (shapes) involves translation, scaling, and rotation of objects in such a way that the distances between corresponding landmarks, expressed as the sum of the least squares, are minimized.

All landmarks are considered equivalent, thereby eliminating the subjective weighting of two specific landmarks, as is the case with Bookstein shape coordinates.

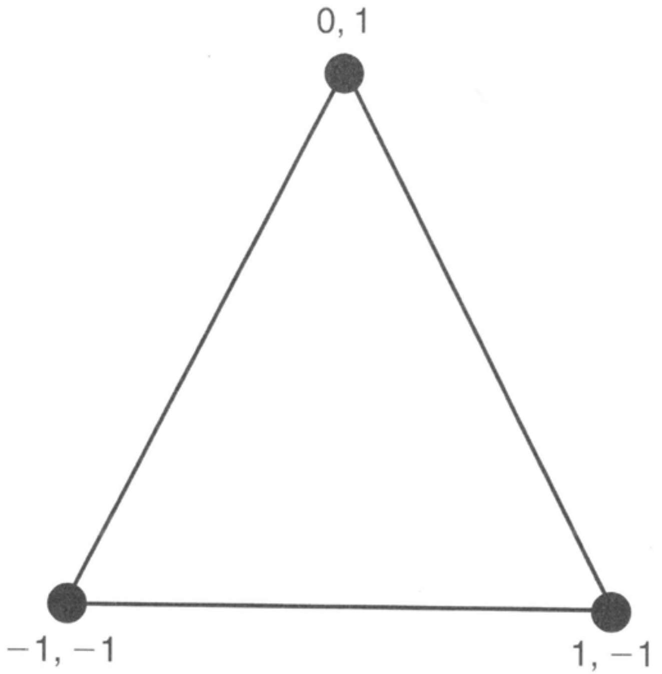
Configuration matrix – the complete configuration of landmarks

It is a K × M matrix – the coordinates of K landmarks in M dimensions (on M axes).

Each of the K rows represents the coordinates of one landmark.

The matrix can also be expressed as a vector
$\mathbf{X = [X_1\ Y_1\ X_2\ Y_2\ X_3\ Y_3\ ]}$
i.e.

$\mathbf{X = [-1\ –1\ 1\ –1\ 0\ 1]}$



Zelditch et al. (2004)

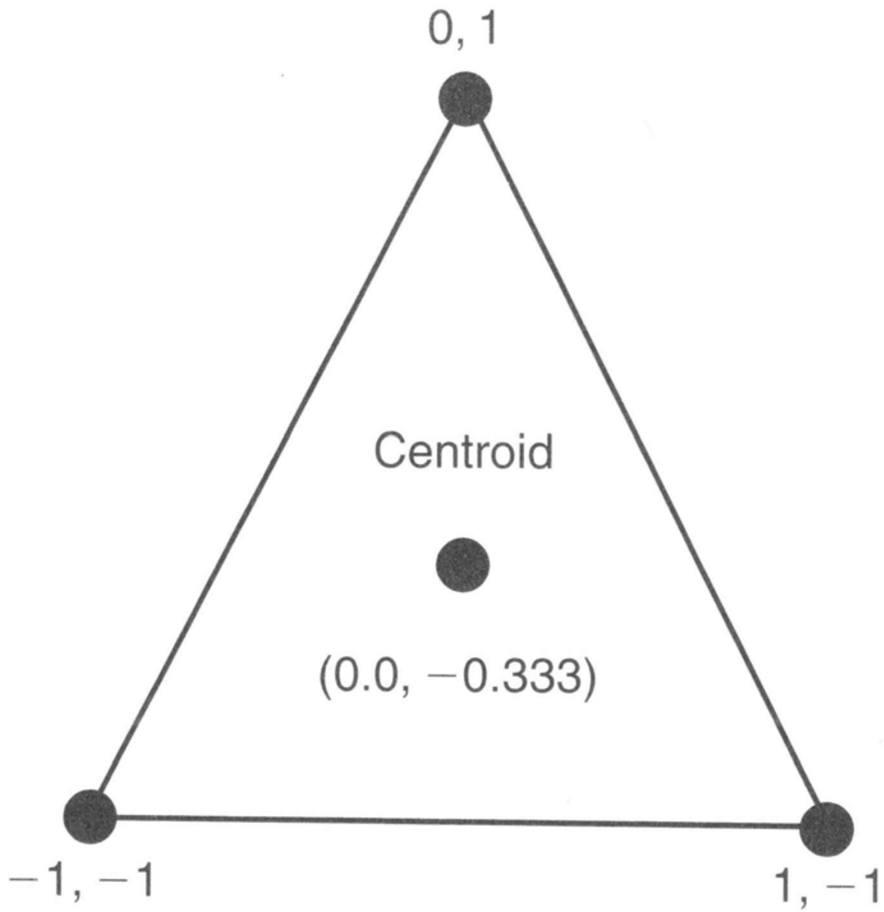
Configuration space – a set of potential matrices that describes all possible sets of configurations of landmarks for K landmarks and M dimensions.

A 16 × 2 configuration space is the space of all possible configurations for 16 landmarks in two dimensions.

The position of the configuration space is determined by the placement of the centroid of the K × M matrix.

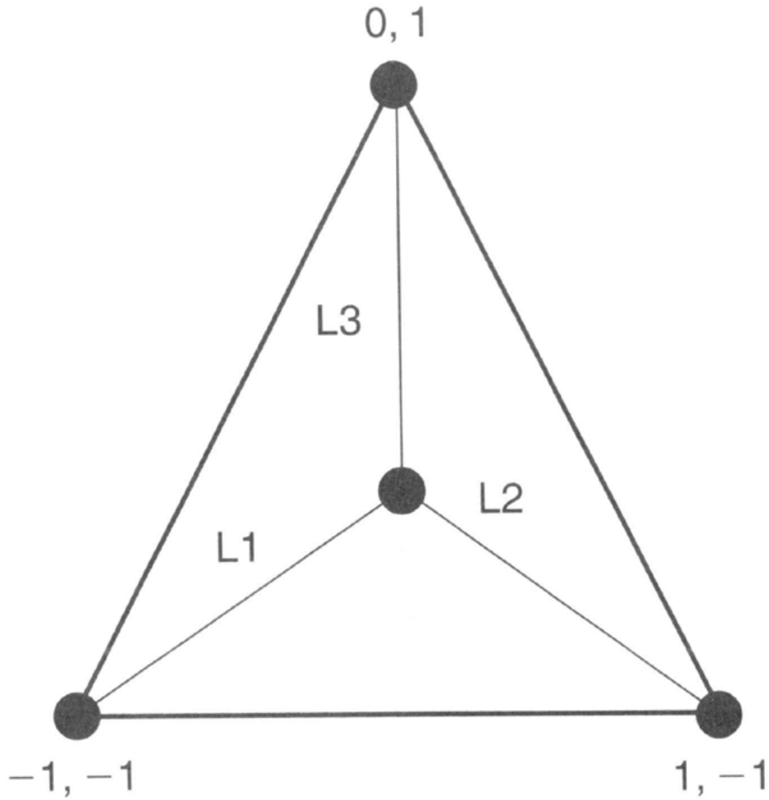
$$X_C = \frac{1}{K}\sum_{j=1}^{K} X_j$$

$$Y_C = \frac{1}{K}\sum_{j=1}^{K} Y_j$$



Centroid je m-rozmerný vektor, v prípade dvoch rozmerov ide o vektor, ktorého komponenty sú priemernými hodnotami X a Y súradníc všetkých významných bodov

Zelditch et al. (2004)



Centroidová veľkosť trojuholníka (konfigurácie) – druhá odmocnina súčtu druhých mocnín L1, L2 a L3

Zelditch et al. (2004)

Pre-shaped space

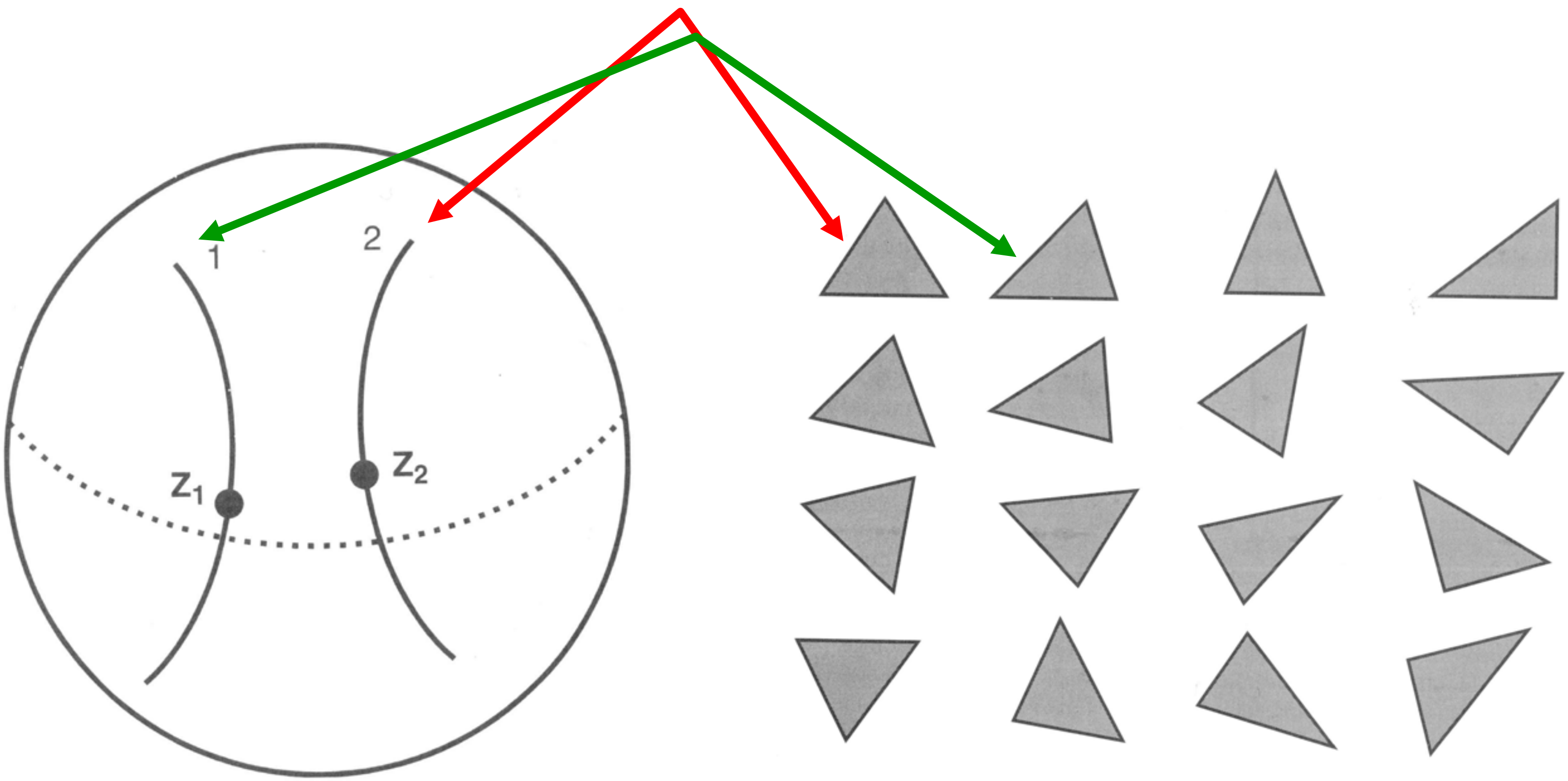
Each configuration of K landmarks with M coordinates can be considered as a point in a space with K × M coordinates.

Some configurations in this space differ only in their centroid size, while others differ only in their position.

We can define a subset of these configurations where, for each matrix, it holds that it is centered and its centroid size equals 1 (translation and scaling).

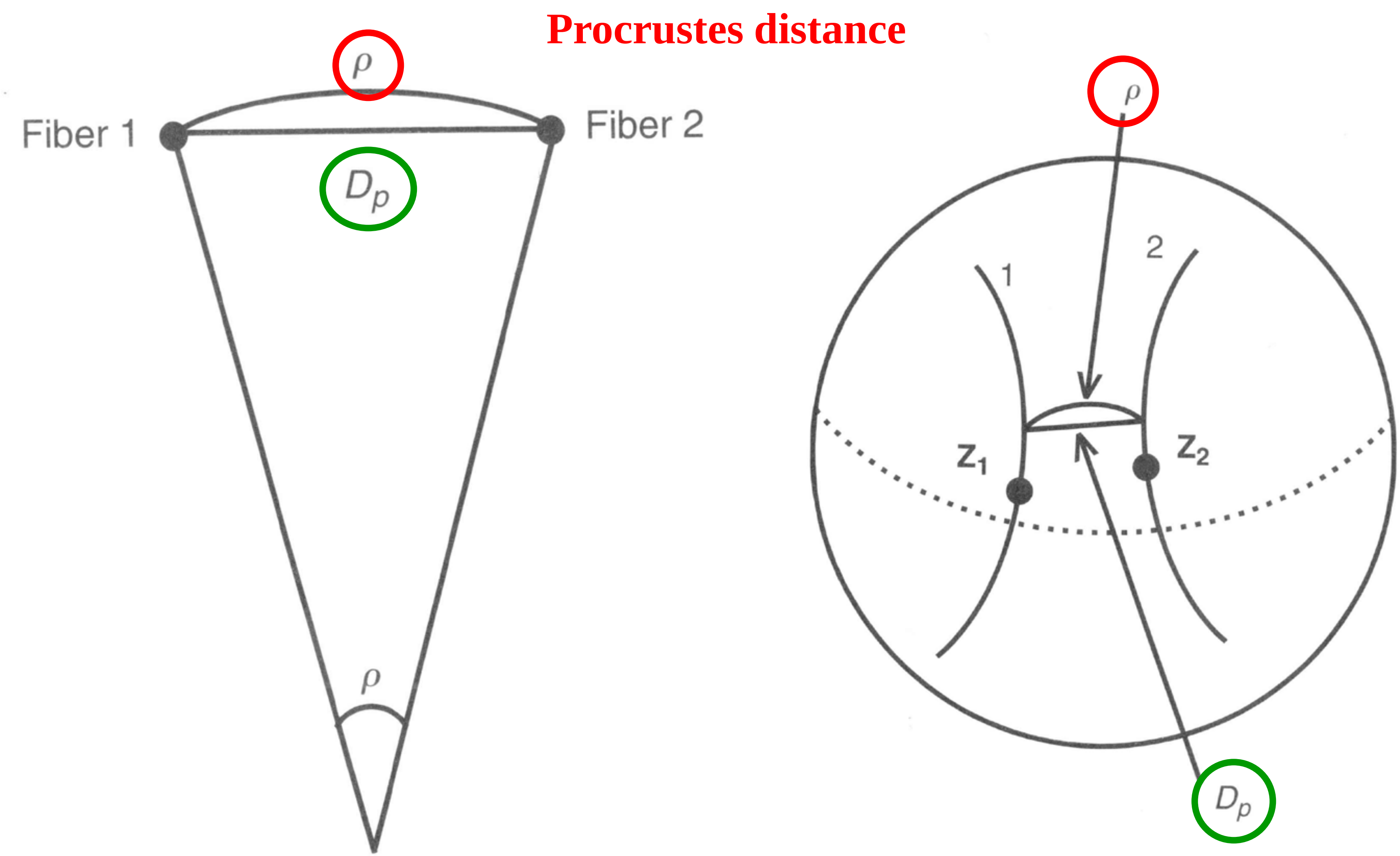
In two-dimensional space, this pre-shaped space will represent a circle centered at (0,0) with a radius of 1. In three-dimensional space, it will correspond to the surface of a sphere, and so on.

This process eliminates M dimensions through centering and one additional dimension by fixing the centroid size to the value of 1.



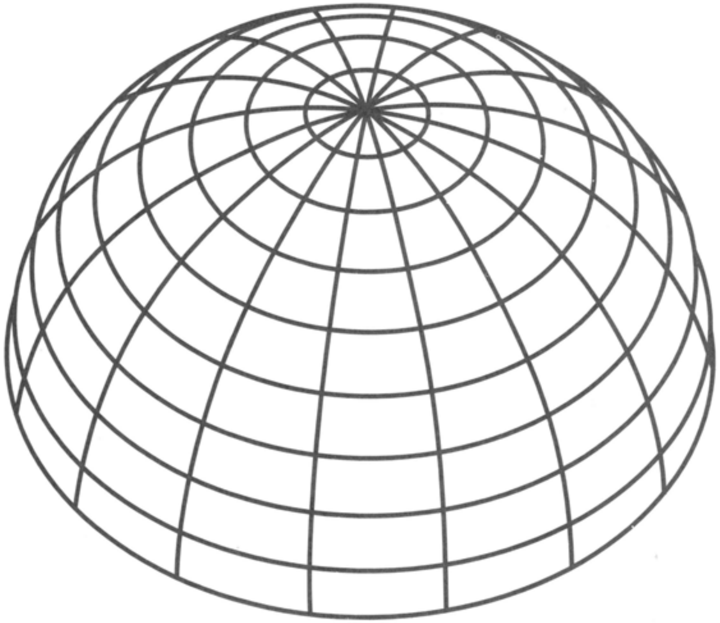
The "fiber" on the surface of this hollow sphere represents configurations of landmarks that differ only by rotation.

Zelditch et al. (2004)



partial Procrustes distance

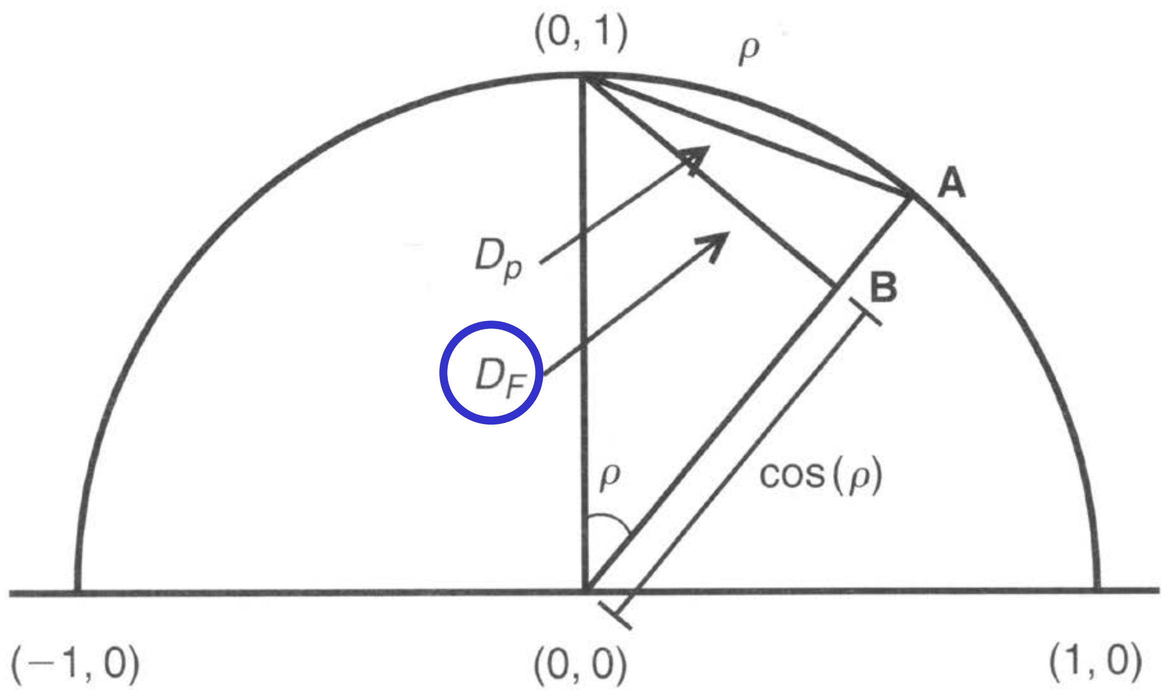
Zelditch et al. (2004)



ρ is not the shortest distance between configurations; that is the full Procrustes distance.

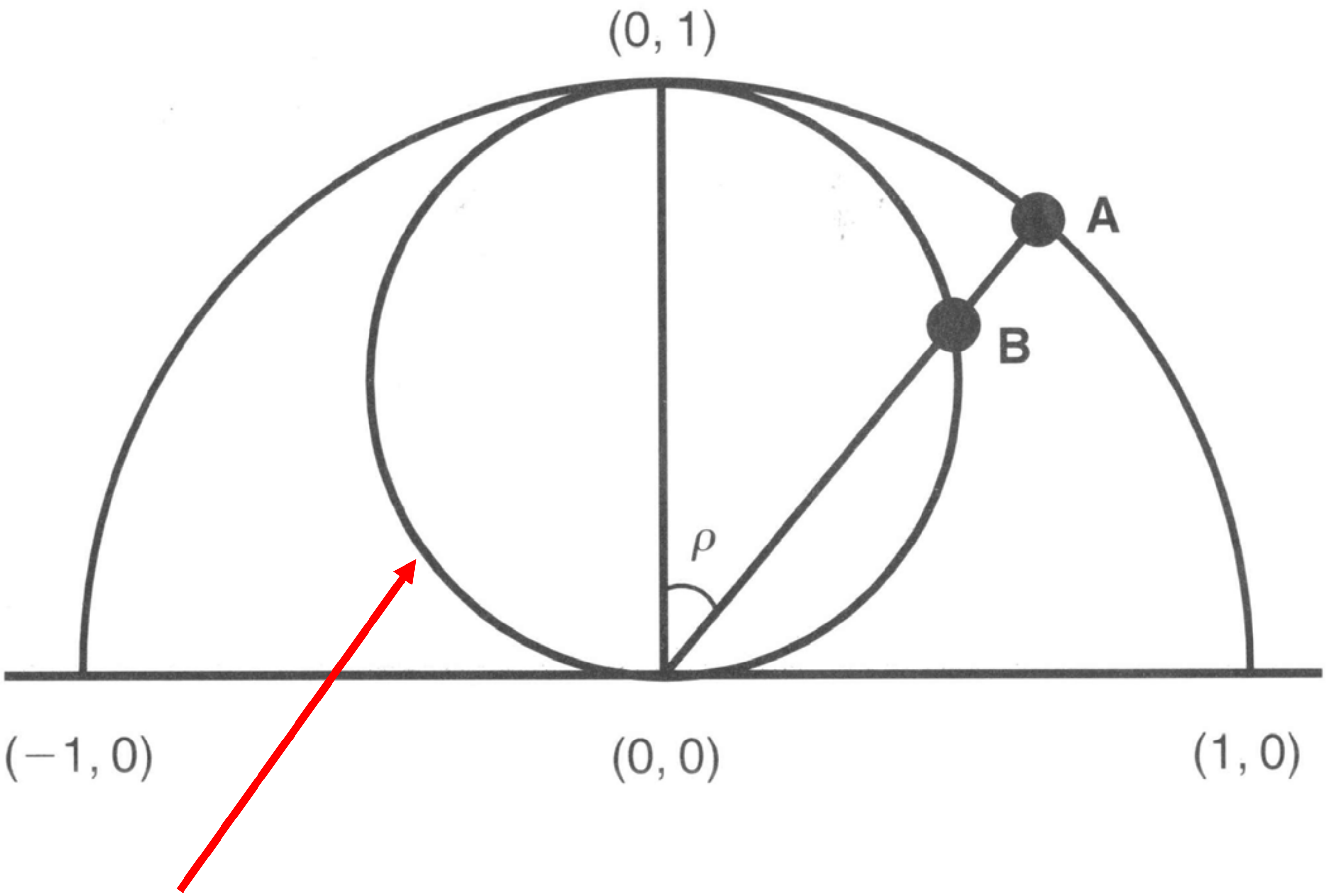
For the reference object, scaling to centroid size is preserved, and for the compared object, the distance is minimized.

Full Proscrustes distance



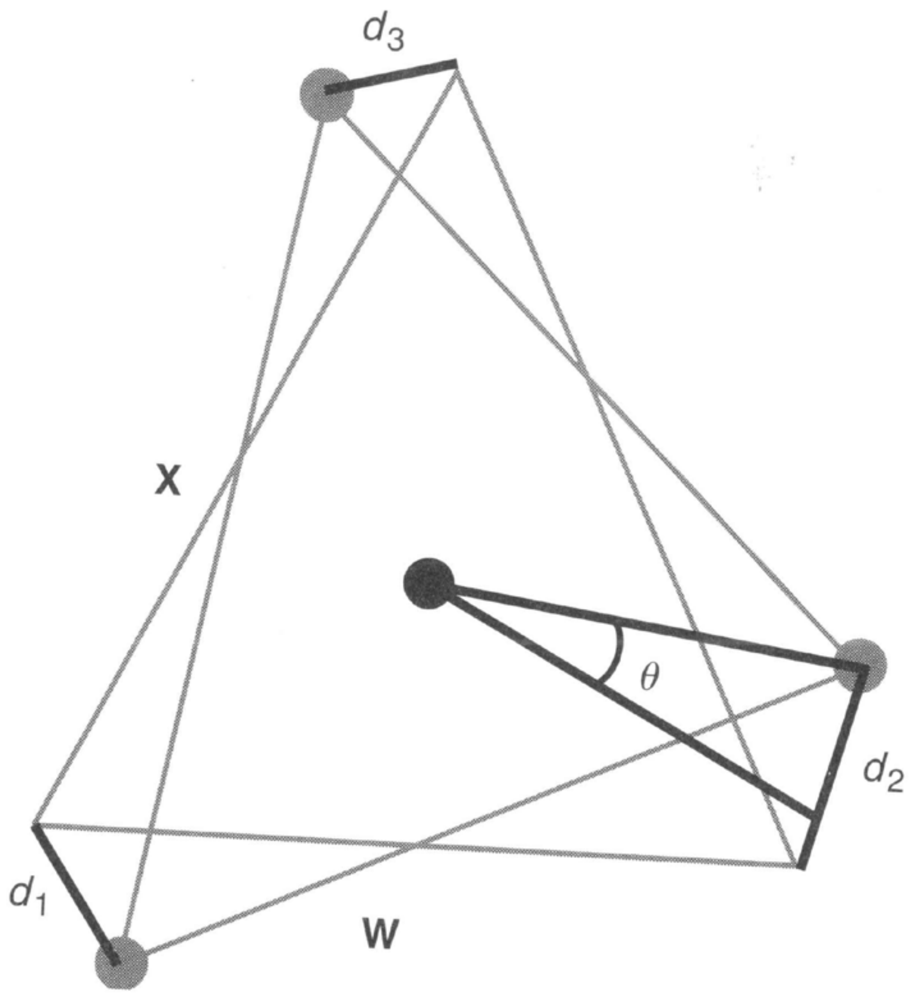
Zelditch et al. (2004)

B = shape scaled to *cos*(ρ)
A = shape scaled to a unit centroid size



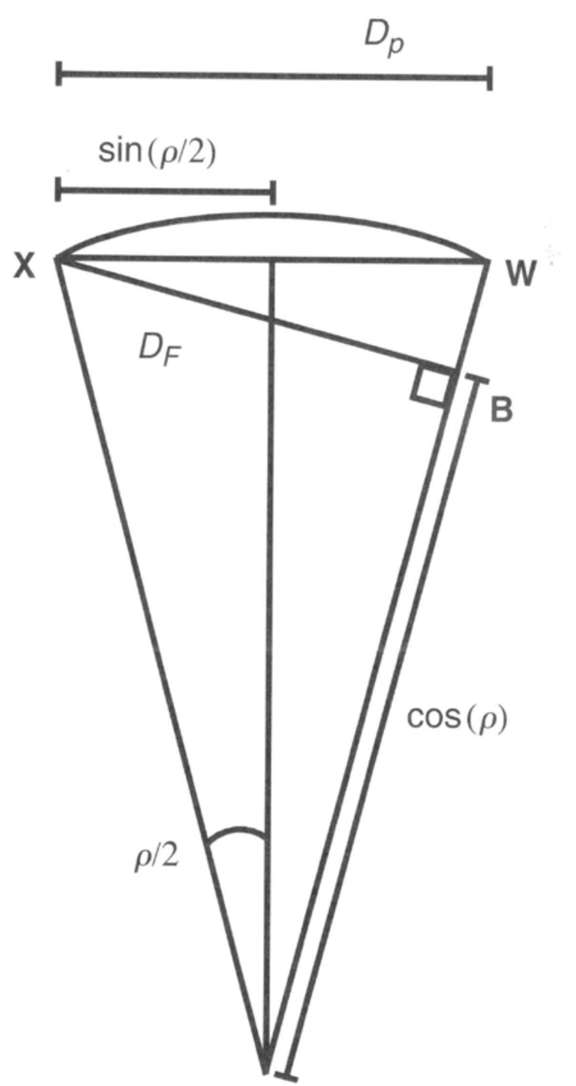
Kendall's shape space minimizes the distance from the reference shape.

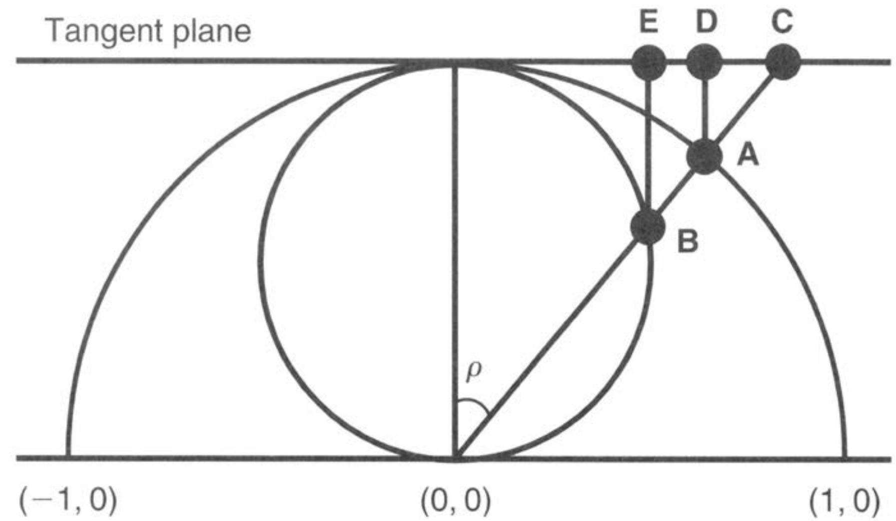
Zelditch et al. (2004)



Zelditch et al. (2004)

B = projection onto Kendall's space
A = shape scaled to unit centroid size





The outer hemisphere is a cross-section through the space of centered and aligned shapes scaled to a unit centroid size.
The inner circle is a cross-section through Kendall's shape space of centered and aligned shapes scaled to cos(ρ).

Zelditch et al. (2004)

Procrustes superimposition using the GLS method (generalized least squares)

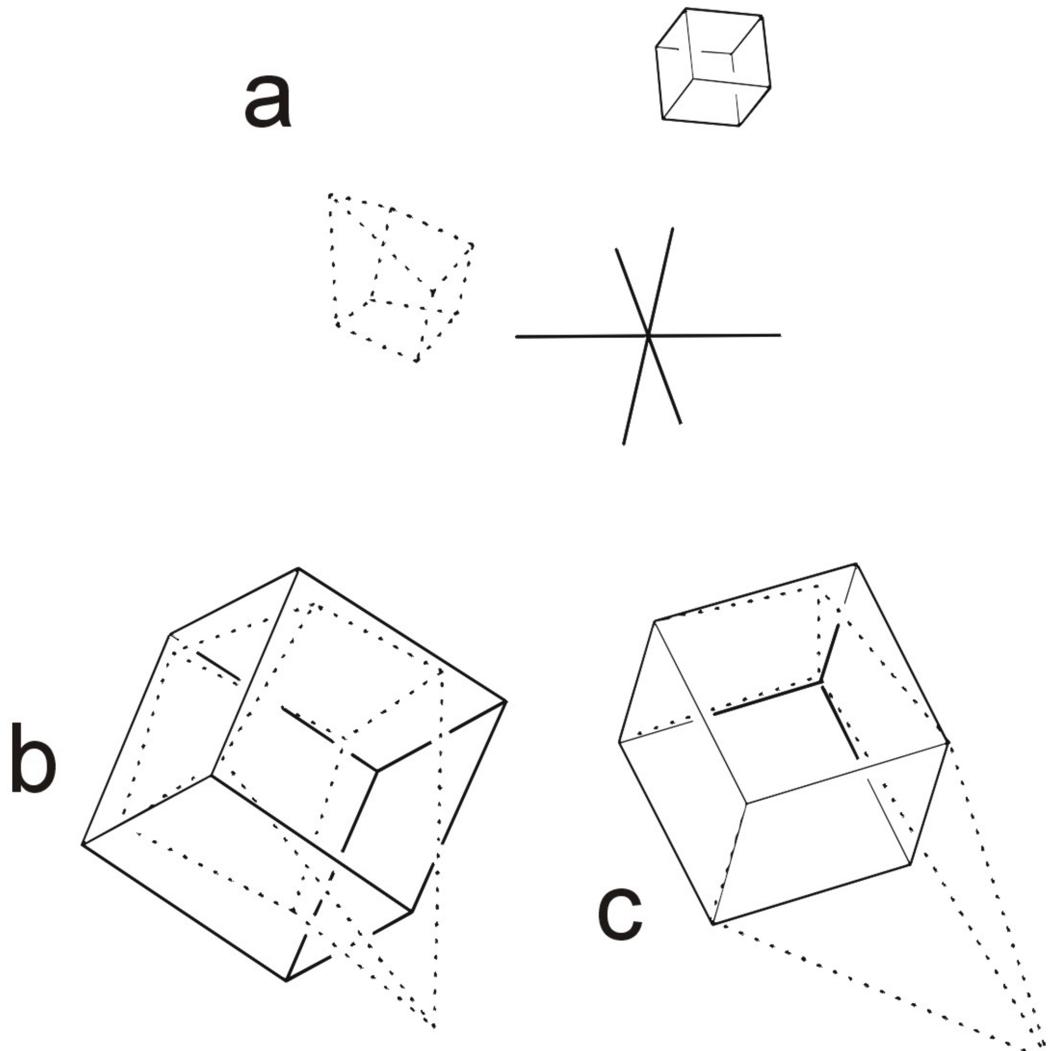
1. **Center each configuration** of landmarks by subtracting the centroid's X and Y coordinate values from the X and Y coordinates of each landmark. This is a translation step, where the landmark coordinates now express their deviation from the centroid.

2. **Scale the configurations** to a unit centroid size by dividing each coordinate of every landmark by the centroid size of that configuration.

3. **Select one configuration as the reference** and rotate the other configurations to minimize the sum of squared deviations between homologous landmarks.

Pinoccio

Procrustes superimposition

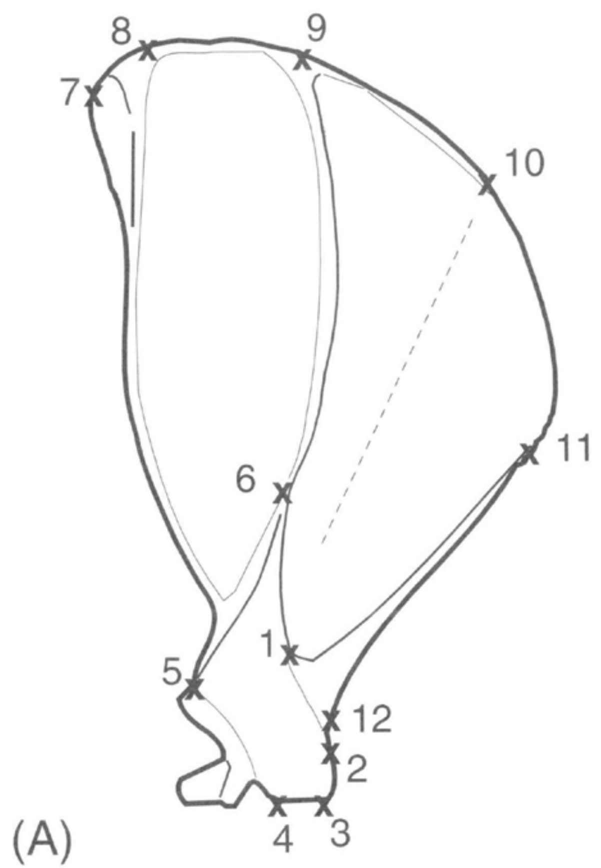


a – Consensus configuration is shown with a solid line, while individual objects are represented with dotted lines.

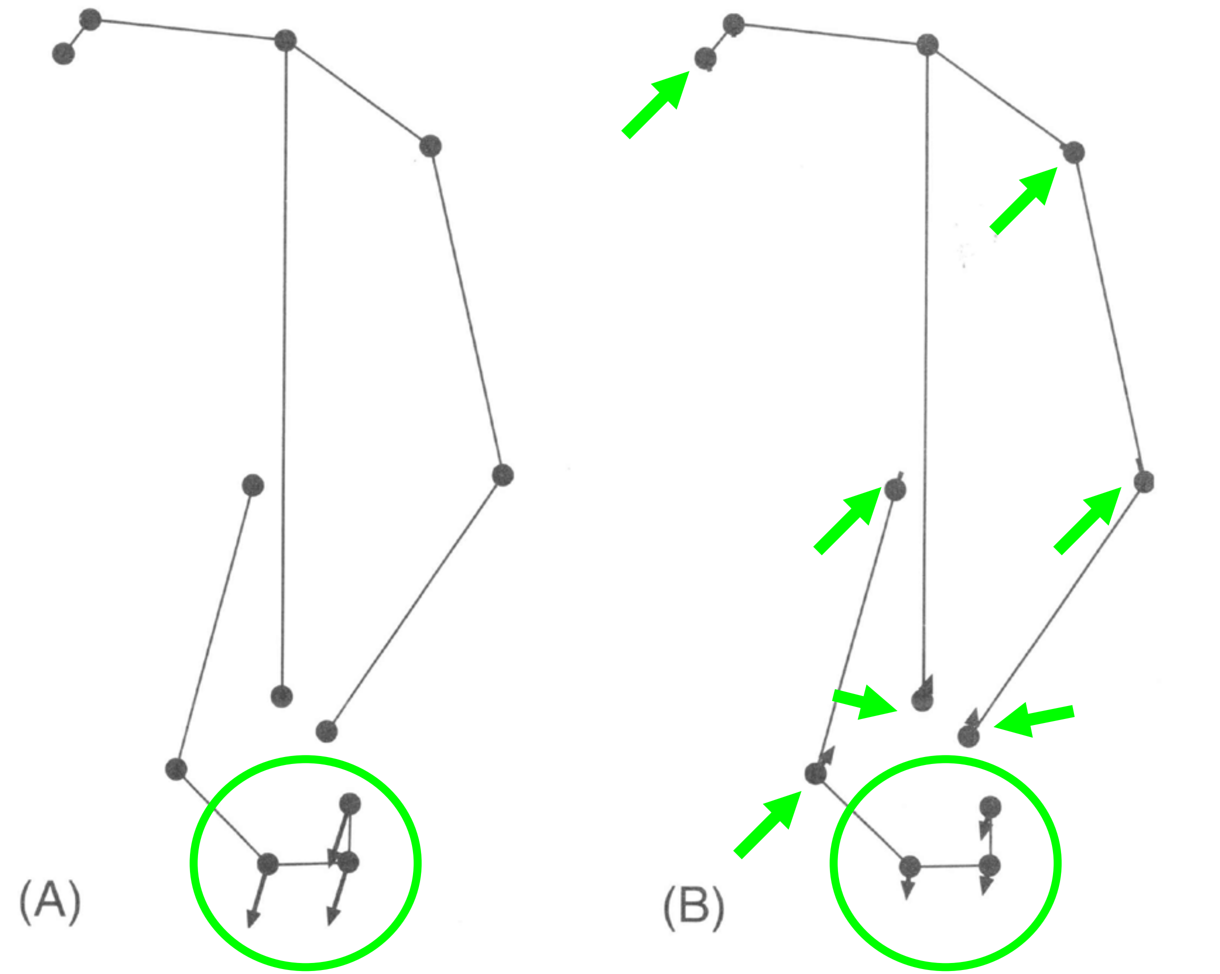
b – Superimposition using the GLS (generalized least squares) method, where differences in the positions of corresponding landmarks are comparable.

c – Superimposition using the method of resistant fitting.

From this, we obtain an m × m matrix of distances between m objects.



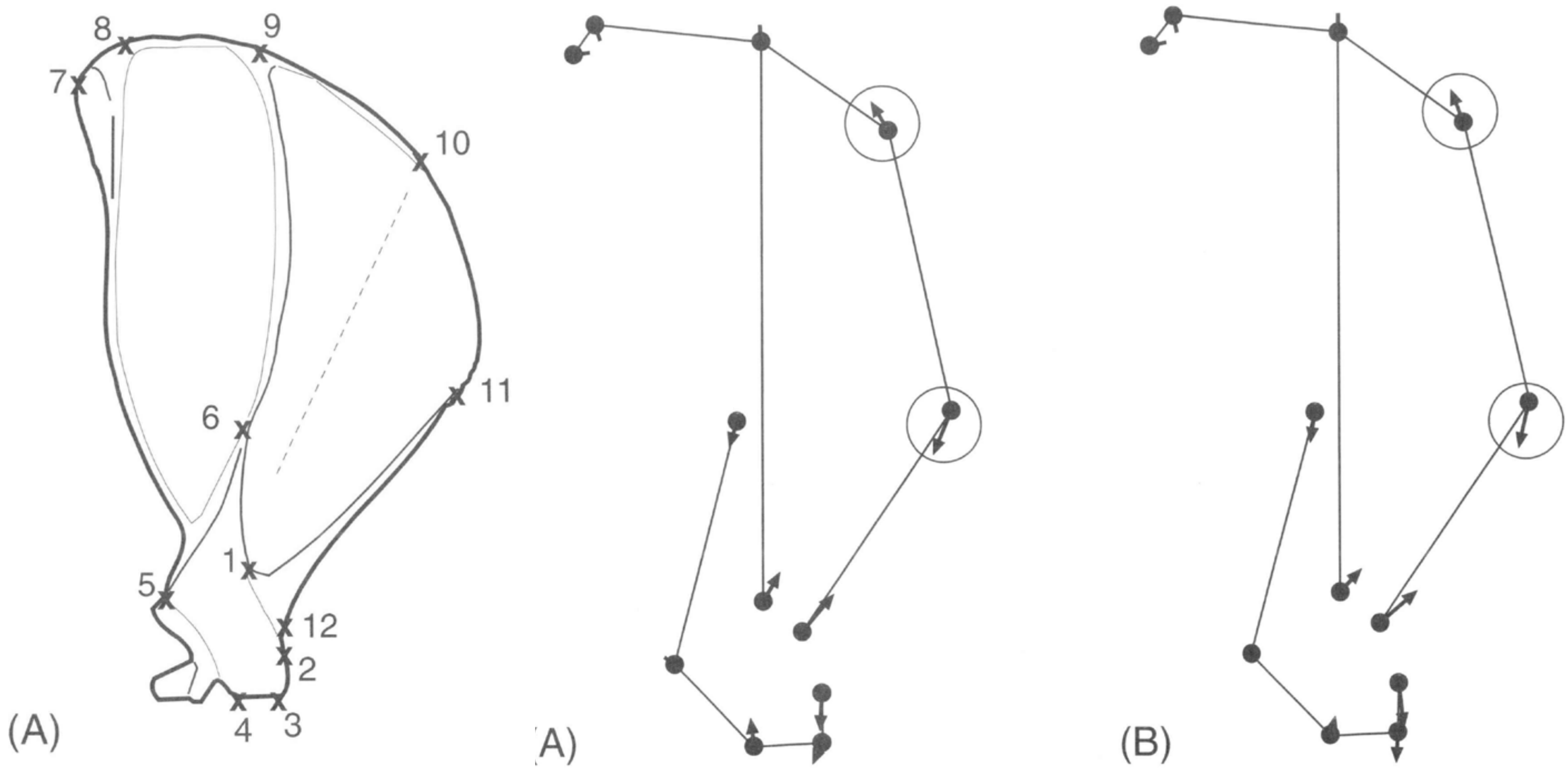
Squirrel scapula



Pinocchio effect present: A – resistant fit method,

B – GLS (generalized least squares) method

Zelditch et al. (2004)



Pinocchio effect absent: A – resistant fit method, B – GLS method

Zelditch et al. (2004)