Geometric morphometrics

An introduction

P. David Polly
Department of Geology, Indiana (Biology and Anthropology)
University, 1001 E. 10th Street, Bloomington, IN 47405, USA
pdpolly@indiana.edu
http://mypage.iu.edu/~pdpolly/

Rychlik, L., G. Ramalhinho, and P. D. Polly.
Course website
http://www.indiana.edu/~g562/
# Spring 2014 Syllabus

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Computers and *Mathematica®*

Laptops should be brought to class every week. The software we will use is compatible with both Mac and Microsoft operating systems.


**Mathematica®:** Most of our work will be done in the Mathematica which is a mathematical and statistical application that does efficient computations, is flexible for customized analysis, has powerful graphics capabilities, and is easy to learn (compared to R, for example, which is an equivalent application). You can purchase a student license for Mathematica 8.04 at the IU Stat/Math Center at 410 Park Avenue for $30 (cash or check only). They will provide licence code and download link for installation.
### Grading

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<td>Project proposal</td>
<td>10%</td>
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Projects

The focal assignment for the course is to carry out an original morphometric study that you will present as a written project paper. Ideally your project will be related to your broader research interests. During the first half of the course you will develop your study, with advice if you need/want it.

Project proposals are due mid semester. Proposals consist of a one to two page description of the aim and subject of your project, the source of your data, the question your study will try to answer, and the tools you’ll need to collect your data. Please feel free to consult me as you develop your proposal.

The final project report should be modelled on a scientific journal paper, with introduction to the problem, materials and methods, results, discussion, conclusion, references (cited properly in the journal format of your choice). Target length is 10-15 pages, including figures, tables, and references.
Supplementary texts


What are morphometrics?

Any quantitative measurement and analysis of morphological traits.
Geometric morphometrics

the quantitative representation and analysis of morphological shape using geometric coordinates instead of measurements
The Major Goal of Morphometrics: Measuring morphological similarity and difference
Types of geometric representation

Landmarks (2D or 3D)

Outlines (2D or 3D)
Semilandmarks, sliding landmarks

3D surfaces


Definitions

Landmark – any point described with cartesian coordinates \((x, y, z)\) used to represent the shape of a structure.

Landmark (2) – any point that can be placed on a biologically or geometrically homologous point on the structure.

Semi-landmark – a point that is placed arbitrarily using an algorithm, often by defining endpoints at biologically homologous points and placing a specified number of semilandmarks between them.
Landmarks

Landmarks are coordinate points used to represent a shape.

They are quantified as Cartesian coordinates (x,y[,z])

At least 3 are required (two points make a line)

Example analyses: Relative Warps (PCA of landmarks), Euclidean Distance Matrix Analysis (EDMA) of distances between landmarks.
Outlines

Outlines are perimeters delimited by many points

They are quantified as Cartesian coordinates \((x,y,[z])\), often converted to angles

Many points are required to represent a shape

Example analyses: Semilandmarks, sliding semilandmarks, Eigenshape (PCA of outline), Fourier analysis
Surfaces

Surfaces are the 3D surface of an object.

They are quantified as Cartesian coordinates \((x,y,z)\).

Many points are required to represent a shape.

Example analysis: Eigensurface (PCA of surfaces), sliding semilandmarks.

Advantages to geometric representation

Results can be presented visually as a “shape” than tables of numbers

Data are easily collected from digital photographs

Size is mathematically removed from the analysis to focus on pure shape
GMM results can be presented graphically

Difference in shape of mandibles of shrew and marmot

Two examples of graphically showing those differences

Vector Plot

Spline Plot
Traditional morphometrics mixes size and shape

The size of the animal affects all measurements so that primary morphometric difference between two taxa is size rather than shape.
Geometric morphometrics removes size by rescaling

Shapes are enlarged or reduced to achieve a standard, equal size

Coordinates of rescaled landmarks show difference in relative position only
Disadvantages of geometric representation

Size is completely absent from the analysis, and size may be biologically relevant.

Only single rigid structures can be easily analyzed.
Size is biologically important and it may be of interest in a morphometric analysis.

- Log body mass (kg)
- Log metabolic rate (O²/hr/g)

Data from Eisenberg, 1981
Size and shape may behave differently
Size or shape data may be appropriate for different analyses

Only single rigid structures can be represented with geometric morphometrics.

- **Okay**
- **Not okay**
A short history of geometric morphometrics....
Albrecht Dürer (1471 -1528)
D’Arcy Thompson (1860-1948)

*On Growth and Form, 1917*
Francis Galton (1822-1911)

1891: starts biometric laboratory at University College London

**Biometric approach to genetics:** regression & correlation

**Composite portraiture:** photographs of different subjects combined (through repeated limited exposure) to produce a single blended image

**Anthropometry & differential psychology:** quantitative analysis of fingerprints
Modern Geometric Morphometric Methods (GMM)

Development of landmark geometrics was driven by Fred Bookstein (long of University of Michigan, now Washington and Vienna)

Joined very productively by F. James Rohlf (Stony Brook)

Ian Dryden, Kanti Mardia, Les Marcus, and Dennis Slice have been important names in developing techniques and theory.

Bookstein was originally intent on creating a truly quantitative way of producing d’Arcy Thompson transformation grids.

(After Thompson 1917.)
Steps in a geometric morphometric study

- Study design
- Data collection
- Data standardization
- Analysis
- Results interpretation
How do you choose landmarks (or outlines, or surfaces)?

1. The data must reflect a hypothesis
2. The data must represent the shape adequately
3. Landmarks must be present on all specimens

Measurement Error and Sample size

1. Measurement error (ME) always exists in any collection of data, but ME doesn’t matter if it is substantially less than the differences you want to measure.

2. Sample size required for a particular study depends on the within-group variation relative to differences between groups.
How many specimens do I need?

• Depends on the question being addressed

• Depends on the error in your data

• You need more specimens when the differences you want to measure are small compared to the variation within your group (natural or due to error)

• For sexual dimorphism in skulls of humans or other primates, 10 individuals of each sex might be enough

• For differences in genetic strains of mice where the mutation doesn’t obviously affect the skeleton, 50 individuals of each strain is more realistic

• For species that belong to different families or orders, 1 specimen per species is almost always sufficient
What morphometrics can’t answer for you..

- Morphometrics does not tell you what ‘large’ or ‘difference’ or ‘shape’ mean. (These are definitions you must supply and your results depend upon them)

- Morphometrics does not tell you whether you unwittingly have two unrecognized groups in a single sample. (Although comparison with known groups may help such an endeavour)

- How to identify cladistic characters. (For the first two reasons combined)
Examples of available software

Digitizing landmarks and outlines:  tpsDIG, ImageJ

Superimposition:  Morpheus (plus integrated in some below)

Outline analysis:  Eigenshape, PAST

MANOVA:  Statistica, PAST

Discriminant functions, CVA:  Statistica, PAST

Principal components analysis of landmarks:  tpsRELW, PST

Construction of trees:  PHYLIP, PAUP, NTSYSpc, PAST

Simulations:  Mathematica, R

Links and downloads at SUNY Stony Brook morphometrics site:
http://life.bio.sunysb.edu/morph/
Equipment: 2D outlines and coordinates

High-quality digital cameras

(resolution doesn’t matter as much as the possibility of lens distortion: test your camera first by photographing a piece of graph paper and looking for “fish eye” distortion)

Calipers or scale bar
Equipment: 3D outlines and coordinates

Reflex Microscope for collecting three-dimensional landmarks, outlines and measurements (good for objects the size of a cat skull down to things about 2-5 mm long)

Microscribe robotic arm for collecting 3D landmarks and measurements (good for objects the size of a human skull down to a rat skull)
3D surfaces

Microscan Laser scanner for scanning surfaces (good for objects the size of a cat skull down to ones about 2-3 cm long)

NextEngine laser scanner (good for objects the size of a horse skull down to a single tarsal bone)