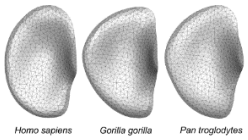
Course ME:130.742 Geometric Morphometrics



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Course Description: This course provides the foundations of geometric morphometrics which is the statistical analysis of biological shape. The course will cover theoretical underpinnings, background mathematics, as well as applied methodologies. Topics will include collection of landmark data, superimposition methods, statistical analyses and methods for visualizing shape variation.

Intended Learning Outcomes: By the end of the course, the student should be able to do the following:

- Use standard software for conducting a geometric morphometric analysis
- Collect and/or generate three-dimensional surface models of biological structures
- Collect landmark data and identify landmark types
- Explain and carry out alignment procedures for landmark data
- Explain and carry out appropriate statistical methods for GM analyses
- Create graphs / models to visualize results from GM analyses
- Formulate biological questions in terms of shape analyses and test these hypotheses

Grading: Grades for the course will be based on class participation (25%), problem sets/lab activities (25%) and a project (50%). The project will be composed of two parts, a conference-style research talk presented during the last class meeting (25%), and a paper written in the style of a journal manuscript submission or grant submission (25%).

Texts and Online Materials

Zelditch ML. 2012. Geometric Morphometrics for Biologists: a Primer. 2nd ed. Burlington: Elsevier Science. A.K.A the "green book"
This book is available to read online from the Johns Hopkins Libraries by following the link below and then clicking on the Online Access link (JHU.eblib.com)
https://catalyst.library.jhu.edu/catalog/bib_4279916

Bookstein FL. 1991. Morphometric Tools for Landmark Data: Geometry and Biology. Cambridge University Press. A.K.A the "orange book"

Slice DE. 2005. Modern Morphometrics in Physical Anthropology. Vol. 6. Springer Science & Business Media.
PDF version available for download from Johns Hopkins Libraries by following the link below and then clicking on the Online Acess link (SpringLink)
https://catalyst.library.jhu.edu/catalog/bib_3639739

Romans LE. 2011. Computed Tomography for Technologists: A Comprehensive Text. Wolters Kluwer Health/Lippincott Williams & Wilkins.

Matlab Primer. The MathWorks, Inc. 2015.
PDF version available from instructor (and can be found online).

MacLeod N. PaleoMaths 101: A collection of essays by Prof. Norman MacLeod, Natural History Museum, London. Hosted by The Palaeontological Association.
Available online for download:
https://www.palass.org/publications/newsletter/palaeomath-101

IDAV Visualization and Graphics Research Group. 2007. Landmark User Guide 3.6.
Available online for download:
http://www.idav.ucdavis.edu/research/projects/EvoMorph/supplement/LandmarkDoc_v3_b6.pdf

Some other important texts

Weber GW, Bookstein FL. 2011. Virtual Anthropology: A Guide to a New Interdisciplinary Field. Wien; London: Springer.

Lele SR, Richtsmeier JT. An Invariant Approach to Statistical Analysis of Shapes. 2001. 1 edition. Boca Raton, Fla: Chapman and Hall/CRC.

Marcus LF, Corti M, Loy A, Naylor GJP, Slice DE. 2013. Advances in Morphometrics. Springer Science & Business Media. A.K.A the "black book"

Rohlf FJ, Bookstein FL. 1990. Proceedings of the Michigan Morphometrics Workshop. University of Michigan Museum of Zoology. A.K.A. the "blue book"
Available online for download:
http://deepblue.lib.umich.edu/handle/2027.42/49535

Software

Matlab: This course will use Matlab for most of the data analysis. Matlab is a flexible objected-oriented programming environment that excels at large matrix operations (Matlab is short for Matrix Laboratory). It also has many standard statistical procedure and analyses, making it useful for general data analysis and visualization. It is, as software goes, relatively friendly and is a gentler introduction to the world of programming as compared to other packages (i.e., R). Furthermore, there is an enormous group of Matlab users around the world that contribute programs for others to use (for free) through a central website (Matlab Central). Chances are, if you have a problem to solve, someone has already written a program to do it. In addition, since it functions in many ways like R, skills you learn from programming in Matlab are transferable to other (free) software packages (e.g. R, ImageJ, SciLab). You can get Matlab free through Johns Hopkins University:
(http://www.it.johnshopkins.edu/services/software/matlab/).

Avizo (Amira): Software application that allows user to perform interactive visualization and computations on 3D data sets, including image segmentation, surface model editing, and landmark collection. This software is available on a few computers in the FAE.

Landmark Editor: Free software developed by scientists at the Institute for Data Analysis and Visualization (IDVA) and the University of California, Davis working in collaboration with researchers at the American Museum of Natural History. The software allows importation of standard 3D surface models and collection of landmarks (single, curves or patches).
Software and Manual available online for download:
http://graphics.idav.ucdavis.edu/research/EvoMorph

MorphoJ: Free integrated software package for doing geometric morphometrics. Includes functions for doing Procrustes, principal component analysis, partial least squares, and mapping shape variables onto a phylogeny.
Available online for download:
http://www.flywings.org.uk/morphoj_page.htm
Online user guide:
http://www.flywings.org.uk/MorphoJ_guide/frameset.htm?index.htm

R and geomorph: R is a free statistical computing and graphics software package and programming environment. Because the software is open source, there are many free add-on packages for carrying out different statistical procedures. This includes the geomorph package by Adams and Otarola-Castillo which provides functions GM analyses.
R are the geomorph package are available online for download:
https://cran.r-project.org/

Students with disabilities

All students with disabilities who require accommodations for this course should contact Catherine L. Will, Disability Services Coordinator for Graduate Biomedical Education (cwill@jhmi.edu or 410-614-3781) at their earliest convenience to discuss their specific needs. Please note that accommodations are not retroactive.

Week 1: Introduction to Geometric Morphometrics

Readings:

Zelditch: Chapter 1

Rohlf JF, Marcus LF. 1993. A revolution morphometrics. Trends in Ecology & Evolution 8:129–132.

Adams DC, Rohlf FJ, Slice DE. 2013. A field comes of age: geometric morphometrics in the 21st century. Hystrix, the Italian Journal of Mammalogy 24:7–14.

Mitteroecker P, Gunz P. 2009. Advances in Geometric Morphometrics. Evol Biol 36:235–247.

Additional readings:

Richtsmeier JT, Burke Deleon V, Lele SR. 2002. The promise of geometric morphometrics. Am J Phys Anthropol 119:63–91.

Adams DC, Rohlf FJ, Slice DE. 2004. Geometric morphometrics: Ten years of progress following the "revolution." Italian Journal of Zoology 71:5–16.

Webster M, Sheets HD. 2010. A practical introduction to landmark-based geometric morphometrics. In: Alroy J, Hunt G, editors. *Quantitative Methods in Paleobiology Paleontological Society Papers*. 163–188.

Week 2: Matlab, MorphoJ and Landmark Editor

Readings:

Matlab Primer: Chapters 1, 2, 5 (Sections 5-9 to 5-12)

Landmark 3.6 Manual: p.7-14

Additional readings:

Klingenberg CP. 2011. MorphoJ: an integrated software package for geometric morphometrics. Molecular Ecology Resources 11:353–357.

Week 3: Collecting 3D Data

Readings:

Friess M. 2012. Scratching the Surface? The use of surface scanning in physical and paleoanthropology. J Anthropol Sci 90:7–31.

Romans: Chapters 1 and 3

Additional readings:

Scherf H, Tilgner R. 2009. A new high-resolution computed tomography (CT) segmentation method for trabecular bone architectural analysis. Am J Phys Anthropol 140:39–51.

McHenry K. 2008. An Overview of 3D Data Content, File Formats and Viewers. [Esp. section on PLY files].

Week 4: Landmarks

Readings:

Zelditch: Chapter 2

Bookstein: Chapter 3

von Cramon-Taubadel N, Frazier BC, Lahr MM. 2007. The problem of assessing landmark error in geometric morphometrics: theory, methods, and modifications. Am J Phys Anthropol 134:24–35.

Additional readings:

PalaeoMaths 101: Articles 14 & 15.

Landmark User Guide: p. 15-19

Week 5: Superimposition methods

Readings:

Zelditch: Chapter 3

Rohlf FJ, Slice D. 1990. Extensions of the Procrustes Method for the Optimal Superimposition of Landmarks. Systematic Zoology 39:40–59.

Additional readings:

Noback ML, Harvati K. 2015. Covariation in the Human Masticatory Apparatus. Anat Rec 298:64–84.

PaleoMaths 101: Article 16

Slice: Chapter 1 p11-21

Week 6: Shape

Readings:

Zelditch: Chapter 4

Rohlf FJ. 2014. Shape Statistics: Procrustes Superimpositions and Tangent Spaces. J of Classification 16:197–223.

Slice DE. 2001. Landmark Coordinates Aligned by Procrustes Analysis Do Not Lie in Kendall's Shape Space. *Systematic Biology*, 141–49.

Additional readings:

PaleoMaths: Article 17

Week 7: Principal components analysis

Readings:

Zelditch: Chapter 6 (Skip the part on between-group PCA until next time).

Gunz P, Ramsier M, Kuhrig M, Hublin J-J, Spoor F. 2012. The mammalian bony labyrinth reconsidered, introducing a comprehensive geometric morphometric approach. J Anat 220:529–543.

Week 8: Partial least squares and between-group PCA

Readings:

Zelditch: Chapter 7

Rohlf FJ, Corti M. 2000. Use of two-block partial least-squares to study covariation in shape. Syst Biol 49:740-753.

Mitteroecker P, Bookstein F. 2011. Linear Discrimination, Ordination, and the Visualization of Selection Gradients in Modern Morphometrics. Evol Biol 38:100–114.

Week 9: Visualizing shape variation and the Thin Plate Spine (TPS)

Readings:

Zelditch: Chapter 5

Klingenberg CP. 2013. Visualizations in geometric morphometrics: how to read and how to make graphs showing shape changes. Hystrix 24: 15–24.

Additional readings:

PaleoMaths 18 & 19

Bookstein FL. 1989. Principal warps: thin-plate splines and the decomposition of deformations. IEEE Transactions on Pattern Analysis and Machine Intelligence 11:567–585.

Week 10: Hypothesis testing with morphometric data

Readings:

Zelditch: Chapter 8

Klingenberg CP, McIntyre GS. 1998. Geometric Morphometrics of Developmental Instability: Analyzing Patterns of Fluctuating Asymmetry with Procrustes Methods. Evolution 52:1363–1375.

Kowalewski M, Novack-Gottshall PM, Alroy J, Hunt G. 2010. Resampling methods in paleontology. Quantitative methods in paleobiology (J Alroy and G Hunt, eds) The Paleontological Society Papers, The Paleotological Society, Chicago, Illinois:19–54.

Additional Readings:

Adams DC, Anthony CD. 1996. Using randomization techniques to analyse behavioural data. Animal Behaviour 51:733–738.

Week 11: Sliding semilandmarks for curves and surfaces

Slice: Chapter 3

Gunz P, Mitteroecker P. 2013. Semilandmarks: A Method for Quantifying Curves and Surfaces. Hystrix 24:103–109.

Ivan Perez S, Bernal V, Gonzalez PN. 2006. Differences between sliding semi-landmark methods in geometric morphometrics, with an application to human craniofacial and dental variation. J Anat 208:769–784.Green book 123 – 126

Week 12: Application: Fossil reconstruction

Senck S, Coquerelle M, Weber GW, Benazzi S. 2013. Virtual Reconstruction of Very Large Skull Defects Featuring Partly and Completely Missing Midsagittal Planes. *The Anatomical Record* 296 (5): 745–58. doi:10.1002/ar.22693.

Gunz P, Mitteroecker P, Neubauer S, Weber GW, Bookstein FL. 2009. Principles for the Virtual Reconstruction of Hominin Crania. *Journal of Human Evolution* 57 (1): 48–62. doi:10.1016/j.jhevol.2009.04.004.

Week 13: Application: Ontogeny, Allometry and Phylogeny

Readings:

Frost SR, Marcus LF, Bookstein FL, Reddy DP, Delson E. 2003. Cranial allometry, phylogeography, and systematics of large-bodied papionins (primates: Cercopithecinae) inferred from geometric morphometric analysis of landmark data. Anat Rec 275A:1048–1072.

Caumul R, Polly PD. 2005. Phylogenetic and Environmental Components of Morphological Variation: Skull, Mandible, and Molar Shape in Marmots (marmota, Rodentia). Evolution 59:2460–2472.

Gunz P, Neubauer S, Maureille B, Hublin J-J. 2010. Brain development after birth differs between Neanderthals and modern humans. Current Biology 20:R921–R922.

Additional readings:

Mitteroecker P, Gunz P, Windhager S, Schaefer K. 2013. A brief review of shape, form, and allometry in geometric morphometrics, with applications to human facial morphology. Hystrix 24:59–66.

Singleton M. 2015. Functional Geometric Morphometric Analysis of Masticatory System Ontogeny in Papionin Primates. Anat Rec 298:48–63.

Week 14: Application: Functional geometric morphometrics

Bookstein FL. 2015. The Relation Between Geometric Morphometrics and Functional Morphology, as Explored by Procrustes Interpretation of Individual Shape Measures Pertinent to Function. Anat Rec 298:314–327.

Sylvester AD. 2013. A Geometric Morphometric Analysis of the Medial Tibial Condyle of African Hominids. Anat Rec 296:1518–1525.

Smith AL, Benazzi S, Ledogar JA, Tamvada K, Pryor Smith LC, Weber GW, Spencer MA, Dechow PC, Grosse IR, Ross CF, Richmond BG, Wright BW, Wang Q, Byron C, Slice DE, Strait DS. 2015. Biomechanical Implications of Intraspecific Shape Variation in Chimpanzee Crania: Moving Toward an Integration of Geometric Morphometrics and Finite Element Analysis. Anat Rec 298:122–144.

Additional readings:

Cooke SB, Terhune CE. 2015. Form, Function, and Geometric Morphometrics. Anat Rec 298:5–28.