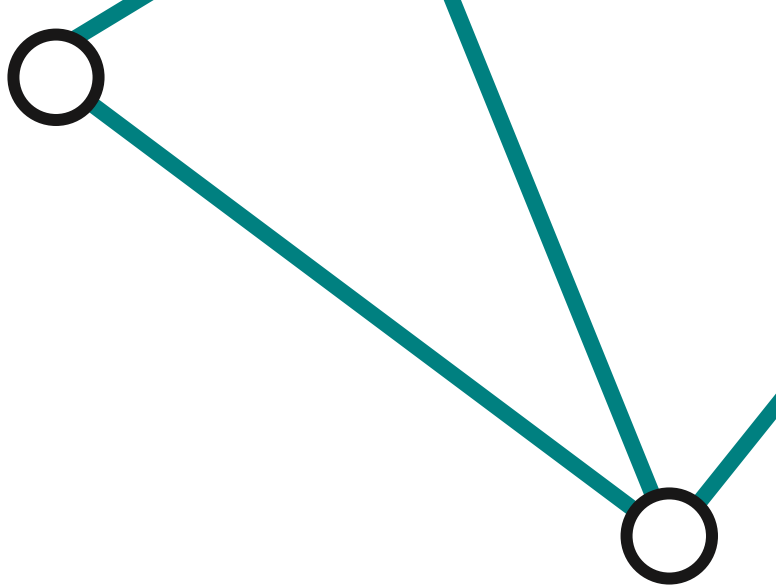


Geometric Morphometrics and Archaeology

(Workshop One)

Dr Christian Steven Hoggard (University of Southampton)

CSHoggard

#StayHomeButStudy

Welcome!

1. Find the workshop materials
   https://github.com/CSHoggard/-workshopjapan2020

2. Immediate feedback? **Zoom** (emojis and chat)

3. Questions? **Slack and Google Document**

#workshop01 ☆
38 | 1 | Add a topic

Details

#workshop01

@Atsushi Noguchi created this channel on April 18th. This is the very beginning of the **#workshop01** channel. Description: 第1回ワークショップのチャンネルです。情報共有・連絡・質疑応答・ディスカッションはこちらで!

This is the channel for the first workshop on GMM. (edit)

Add an app Add people

Saturday, April 18th

Atsushi Noguchi 3:29 PM
joined #workshop01.

Atsushi Noguchi 3:29 PM
set the channel description: 第1回ワークショップのチャンネルです

Yuichi Takata 3:29 PM
was added to #workshop01 by Atsushi Noguchi, along with 3 others.

Atsushi Noguchi 3:30 PM
set the channel description: 第1回ワークショップのチャンネルです。情報共有・連絡・質疑応答・ディスカッションはこちらで!

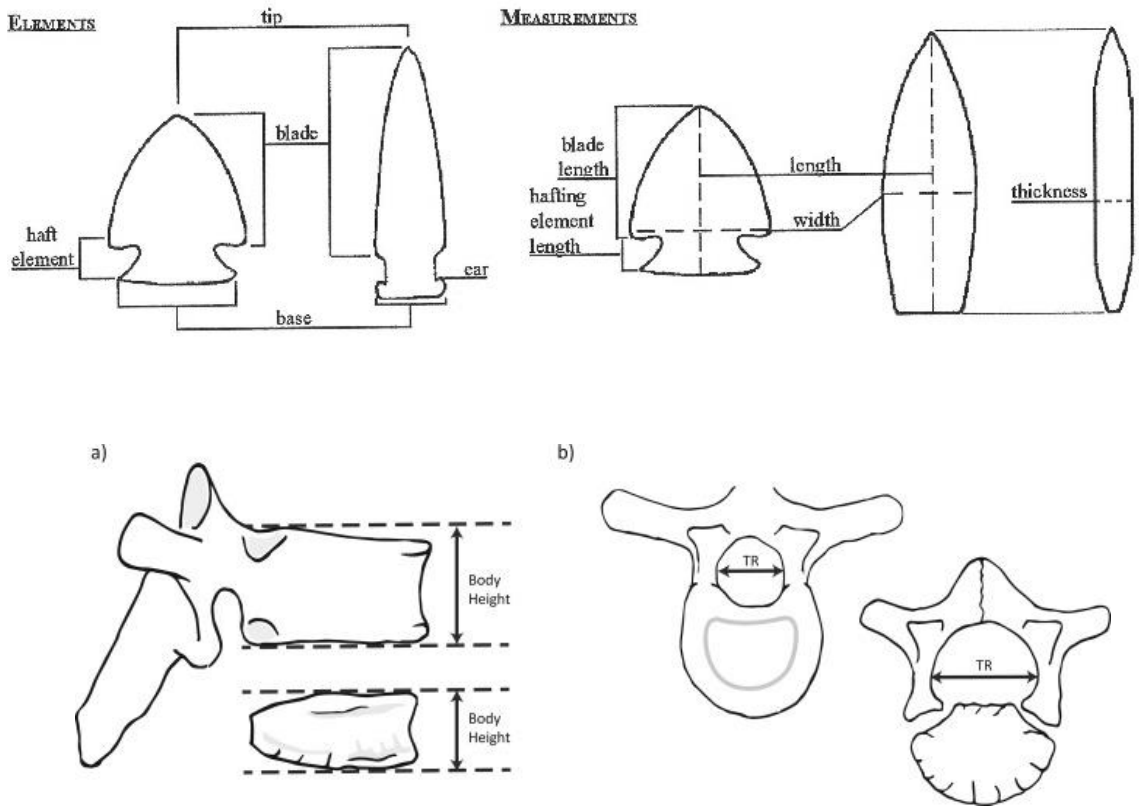
This is the channel for the first workshop on GMM.

Tomoki Iwasa 3:35 PM
joined #workshop01 along with 4 others.

taisei tokumori 3:43 PM
はじめまして

1 reply 1 day ago

Message #workshop01


Elements
tip
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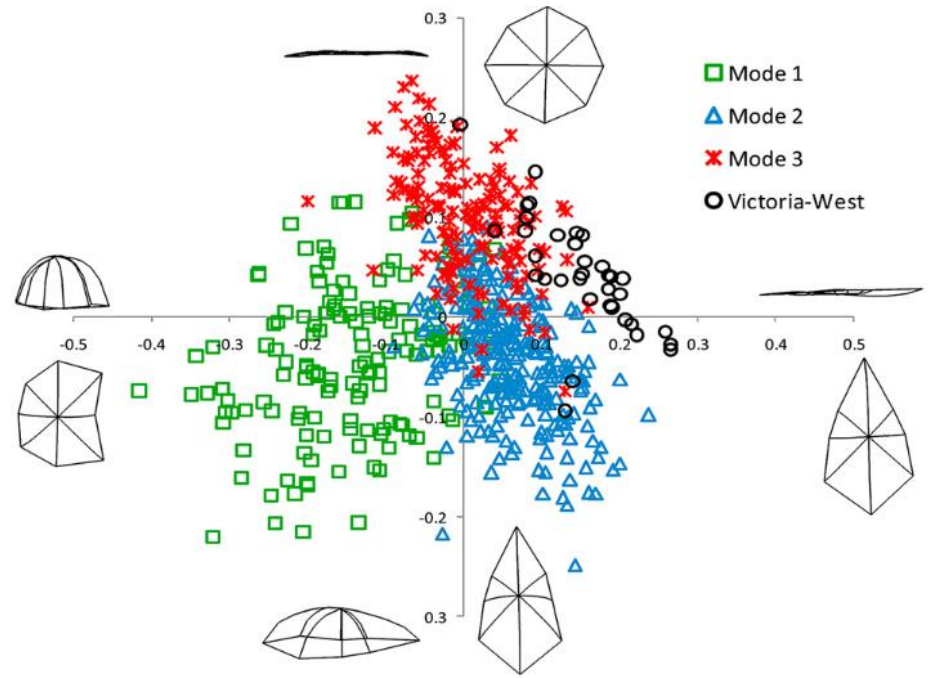
Mode 1
Mode 2
Mode 3
Victoria-West
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-0.4
-0.3
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0.4
0.5

What is shape?

Shape as…

"In general terms, the shape of an object, dataset
or image that can be defined as the total of all information is invariant under
translation, ***rotation***, and ***isotropic rescalings***"

Small (1996: 6)

Small, C. (1996). *The statistical theory of shape*. New York: Springer.

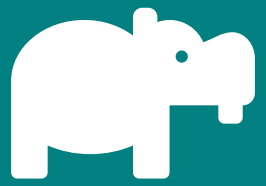
Size as…

The…

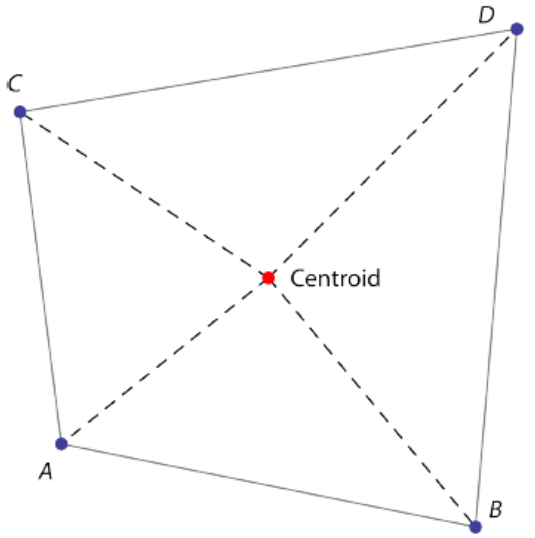
Length of an object?

Weight of an object?

Volume of an object?



Centroid size: square root of the summed squared lengths of the dashed lines



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. *Hysterix, the Italian Journal of Mammalogy*. pp. 59-66.

Shape + **Size** = **Form**

Morphometrics 101

- First coined by Professor of Zoology (UCD) Robert Blackith in 1957
- Quantitative study of shape, shape variation and shape covariation
- Two types of morphometric studies:
  - **Traditional morphometrics** (length measurements, angles, ratios…)
  - **Geometric morphometrics** or **GMM** (landmarks, outlines, curves, surfaces…)
- Note: Geometric Morphometrics $\not\succ$ Traditional Morphometrics

GMM advantages

Powerful method of
documenting shape change

Less information is lost in comparison
to traditional measurements

Can easily be collected from a variety of methods
(e.g. photographs and 3D models)

Abstraction and registration method
permits an analysis of exclusively shape

GMM disadvantages

Size is often removed
which may be of biological importance
(can be reintegrated)

Skill competency: often requires
specific technical software and knowledge

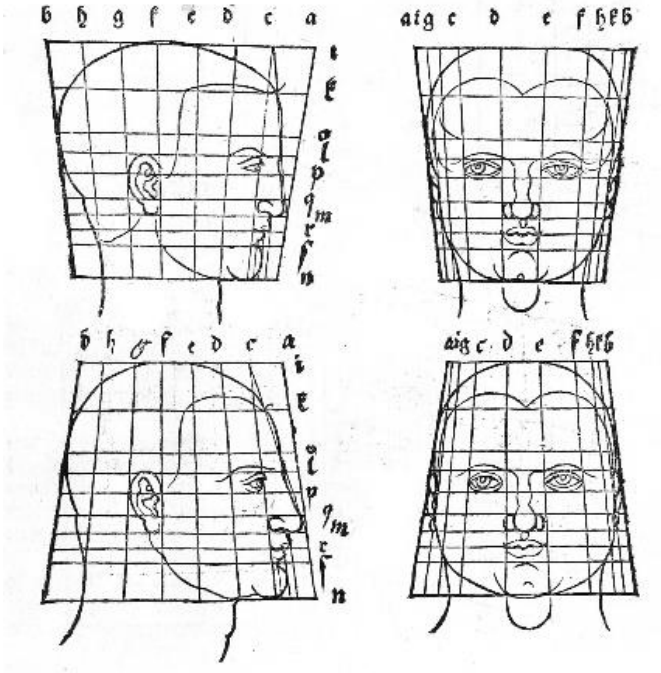
We can use GMM to determine…

1. Whether two assemblages are different in terms of their shape?
2. How is shape related to…
   size? time? raw material? hominin?
3. Whether differences correspond to a hypothesis or a model?
4. On an assemblage level:
   what is the mean or median shape?
5. With respect to size:
   is there an allometric relationship?
6. Over a series of sites:
   Is a network-based model of artefact production pertinent?

A short history of geometric morphometrics…

Albrecht Dürer (1471-1528)

- Painter, printmaker and theorist
- Founder of descriptive geometry working on helices, conchoids and epicycloids
- Investigated the Delian Problem (doubling the cube)
- Use of shape transformations in studying morphological differences in the human head



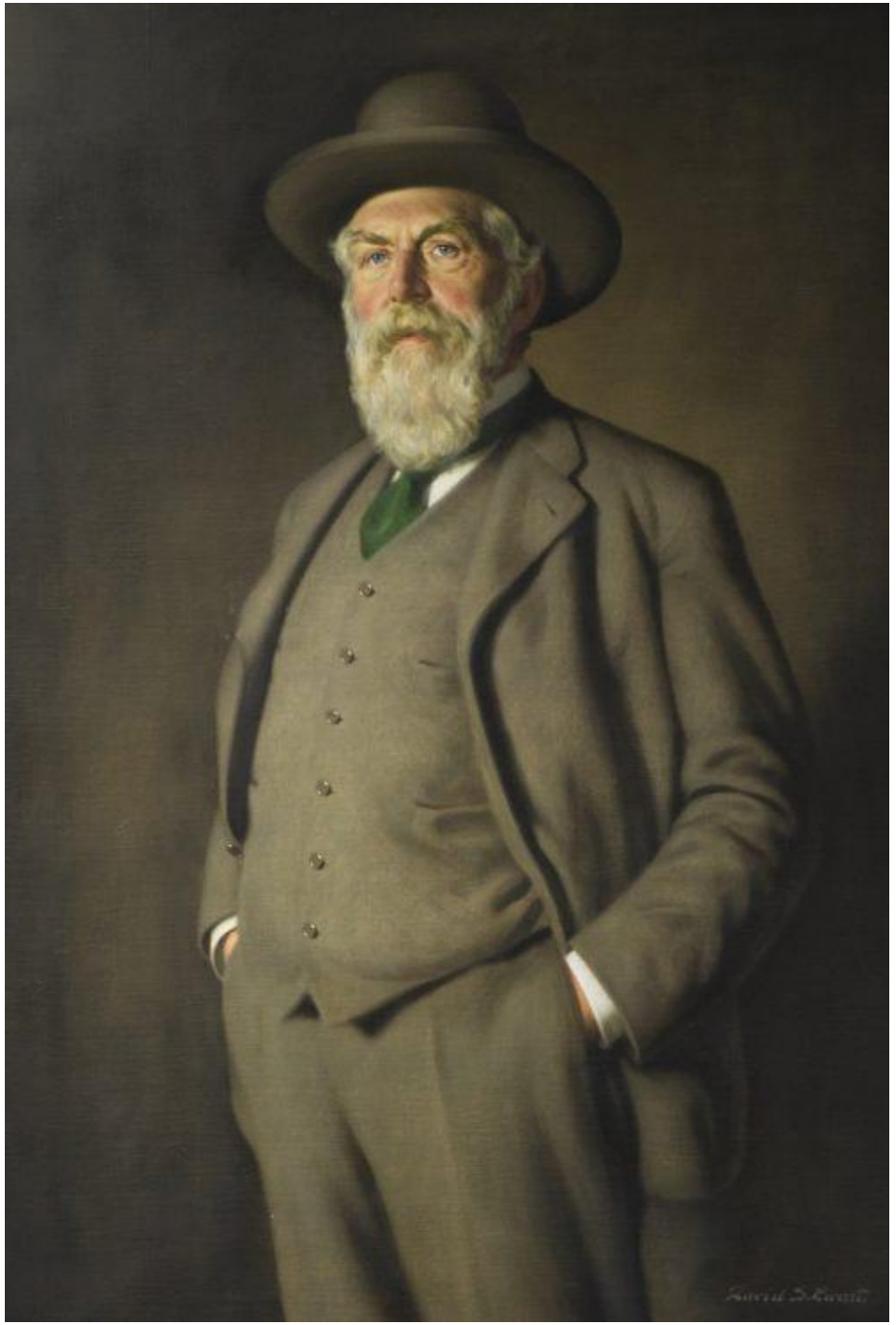
Dürer, A. (1528). *De Symetria Partium in Rectis Formis Humanorum Corporum Libri*, German edn. Patav. Nuremberg: Parisiis Curvi ac recti proportio.

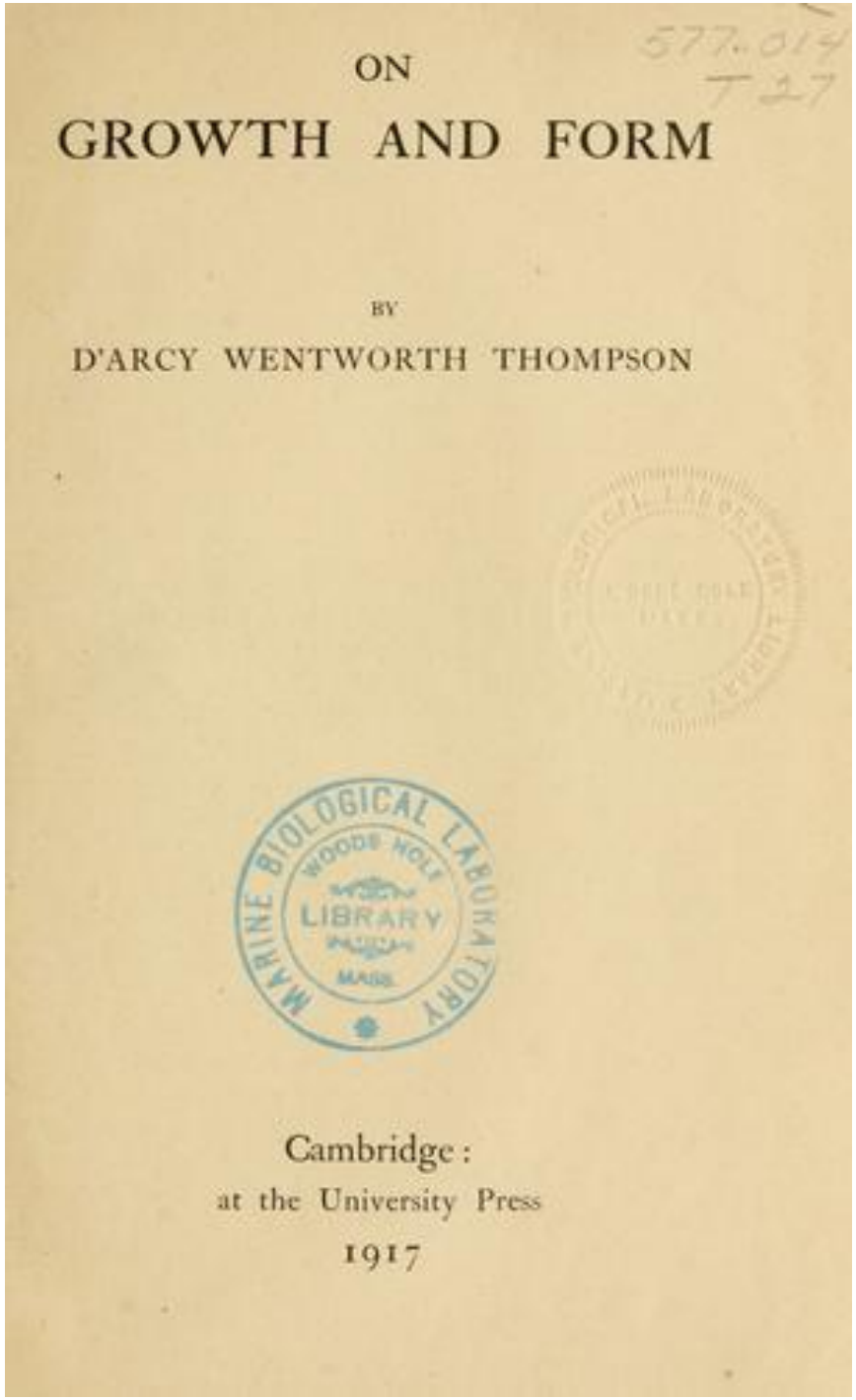
Sir D’Arcy Wentworth Thompson (1860-1948)

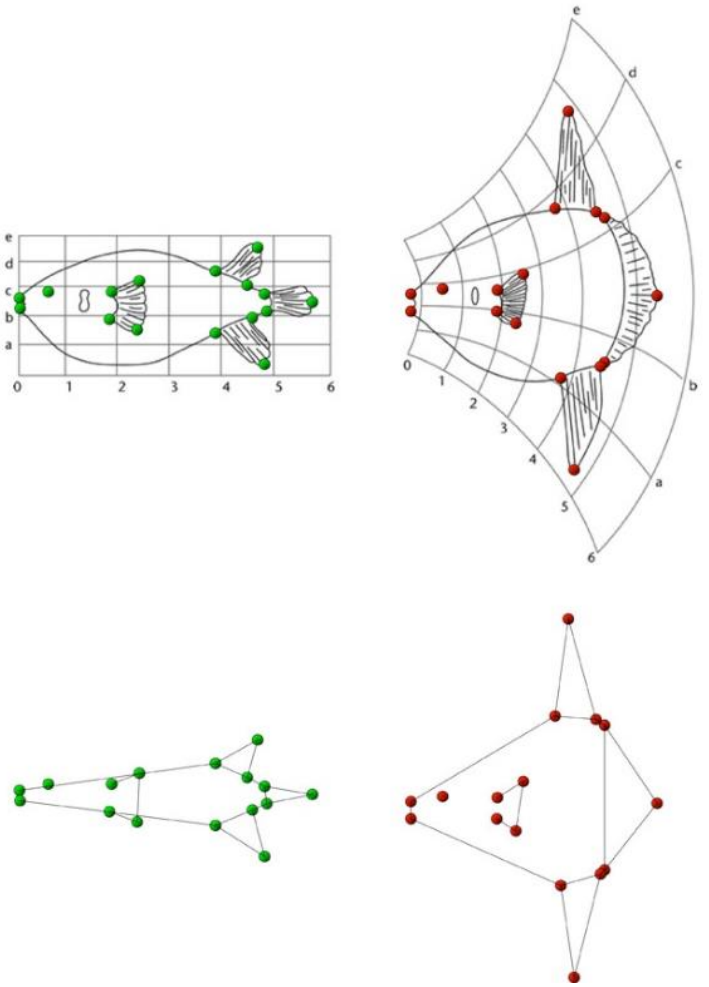
- Biologist, mathematician and classics scholar
- Famous for his quotes on the mathematical beauty of nature (inspiring Huxley, Turing, Lévi-Strauss and van der Rohe)

On Growth and Form (1917)

- Fundamental book documenting the process of body structures formed in plants and animals
- Emphasis on mathematical structures accounting for biological diversity







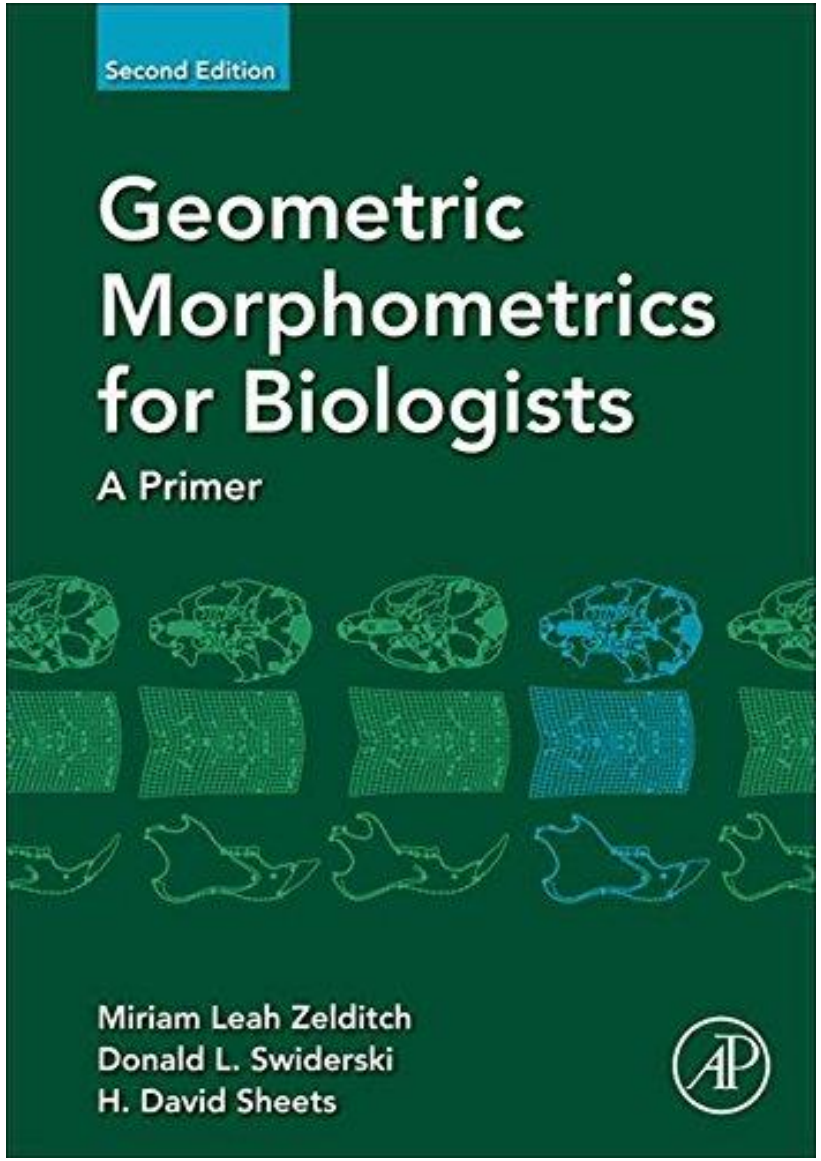
"The harmony of the world is made manifest in Form and Number, and the heart and soul and all the poetry of Natural Philosophy are embodied in the concept of mathematical beauty."

Thompson, D.W. (1917). *On Growth and Form*. Cambridge University Press.

Towards a statistical framework

From the 1960s onwards...

- Fred Bookstein (founder of modern-day GMM)
- Dennis Slice
- Miriam Zelditch
- Norman MacLeod
- Ian Dryden and Kanti Mardia
- James Rohlf



10 Minute Break

Questions? (Slack and Google Document)

I’ll answer them following the break!

How do we ‘do’ GMM?

Stage 1: Dataset creation

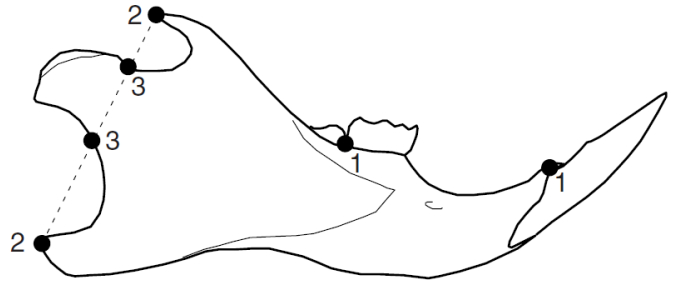
Methods include…

- **CT scanning**
- **Photogrammetry** and **structure from motion** (**SfM**)
- **Microphotogrammetry**
- **Microscribe**
- **3D scanners** (e.g. NextEngine)
- Data obtained from **drawings** and **photographs**

Note: Considered the error associated with each technique!

Stage 2: Landmark choice

- Central to geometric morphometrics are landmarks
- **Landmark**: coordinate point used to represent a shape and/or a homologous point on a structure
- Quantifiable as Cartesian coordinates (x , y / z coordinates)
- Variety of different ways of approaching what type of landmarks are necessary
- Can be treated as individual points or converted (using various techniques) into curves and outlines

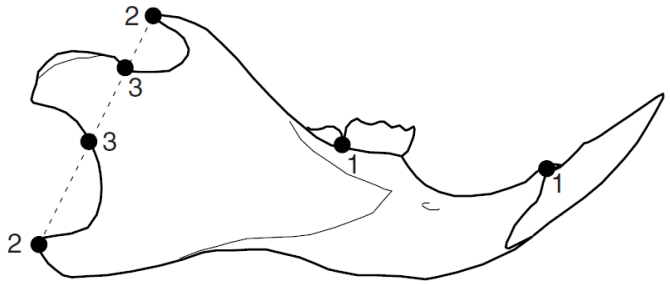


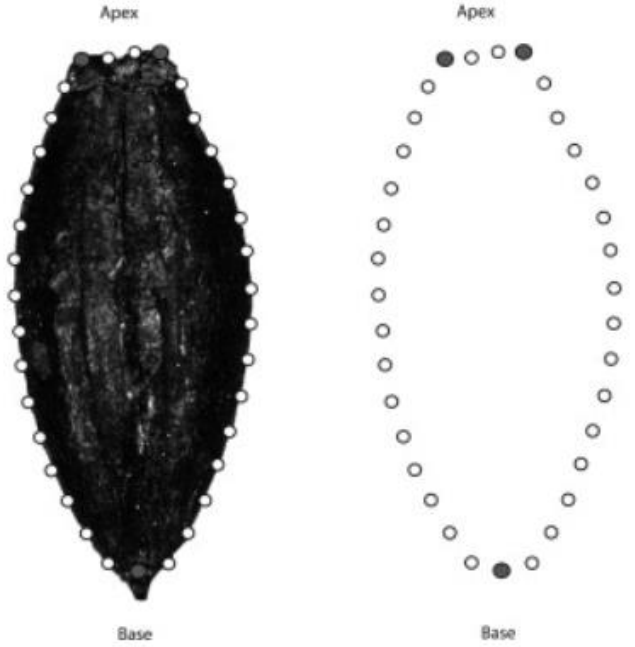
Claude, J. (2008). *Morphometrics with R*. Springer Publishing.

Stage 2: Landmark choice

- **Various types of landmarks**
  - **Type I:** Homologous biological structures
  - **Type II:** Geometric definition e.g. greatest curvature
  - **Type III:** Point with reference to another point

- A special example: **semilandmarks**
  - Placed using an algorithm
  - Equidistant and placed between one or two end-points
  - A special **Type III landmark**
  - See also sliding semilandmarks



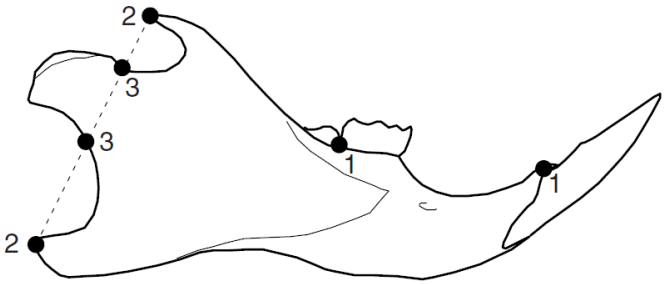


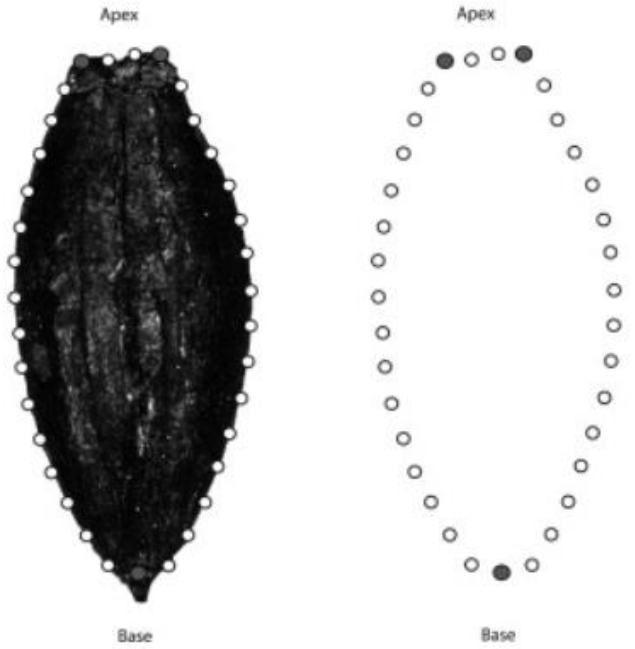
Claude, J. (2008). Morphometrics with R. Springer Publishing.

Ros, J., Evin, A., Bouby, L. & Marie-Pierre, R. (2013). Geometric morphometric analysis of grain shape and the identification of two-rowed barley (Hordeum vulgare subsp. distichum L.) in southern France. Journal of Archaeological Science. 41.

Stage 2: Landmark choice

- Landmarks should sample aspects which are of archaeological interest
- Landmarks should be repeatable and identifiable on all examples (if possible)
- Landmarks should cover as much of the shape as possible
- Sufficient as to not increase the ‘weighting of areas’
- Landmarks should always be plotted in the same order (otherwise the math wouldn’t work!)





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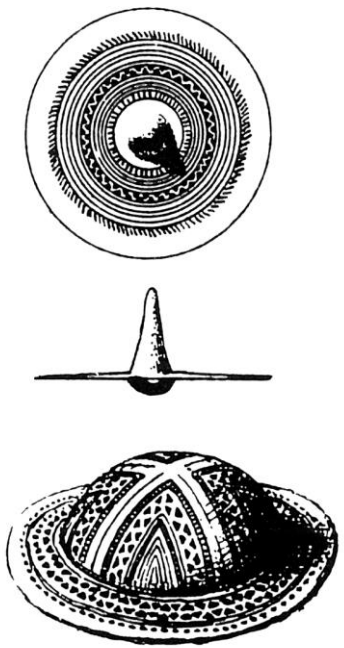
Ros, J., Evin, A., Bouby, L. & Marie-Pierre, R. (2013). Geometric morphometric analysis of grain shape and the identification of two-rowed barley (Hordeum vulgare subsp. distichum L.) in southern France. Journal of Archaeological Science. 41.

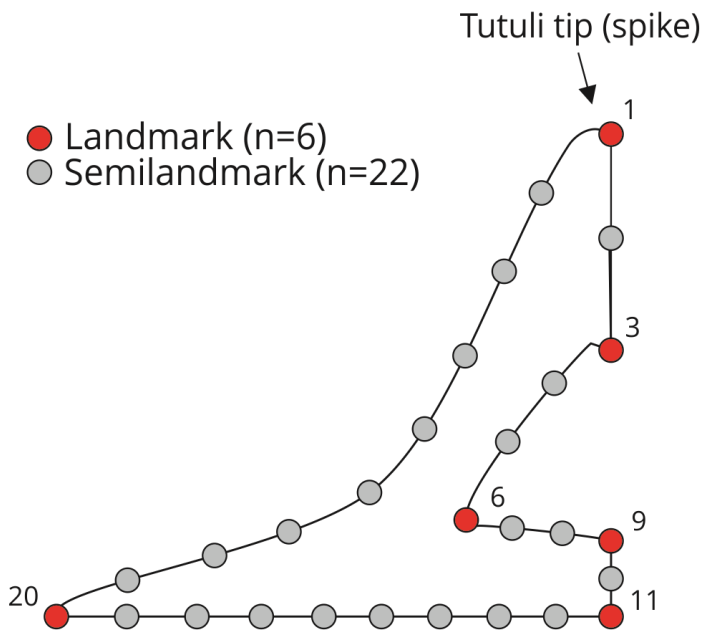
Stage 2: Landmark choice (some observations)

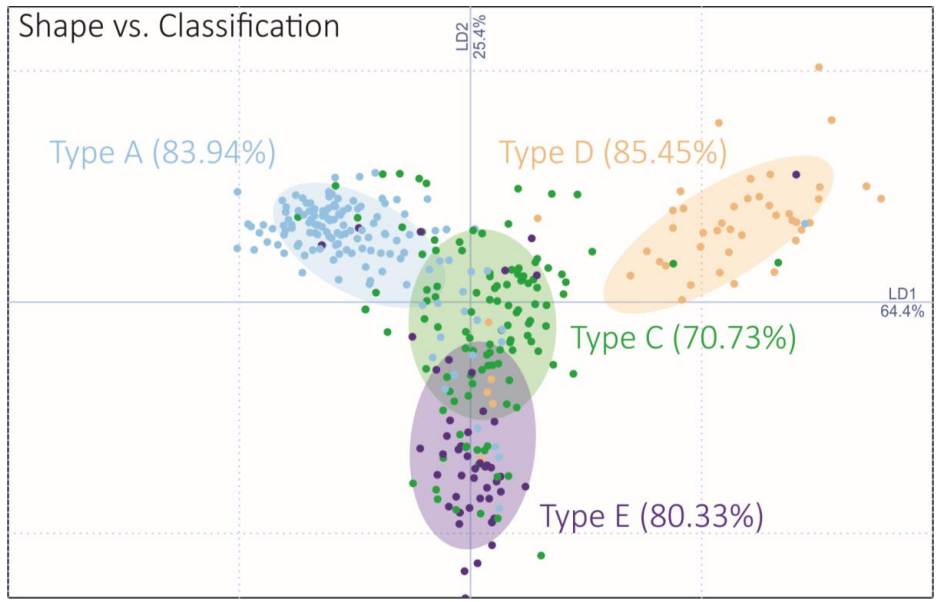
- For Bioarchaeologists…
  - Greater number of points of morphological correspondence on specimens
  - Easier to study three-dimensional shape (orientation is less of an issue)
- For Archaeologists studying non-biological material…
  - Greater creativity and thought is needed in orienting specimens and placing landmarks
  - Fewer case studies to compare geometric morphometric methodologies
- For all archaeologists…
  - Fragmentation and sample size (representation of a population) need to be considered

A Novel Geometric Morphometric (GMM) Application to the Study of Bronze Age Tutuli

Christina Vestergaard[1,3] and Christian Steven Hoggard[1,2]







Stage 3: Landmark digitisation

Variety of different programs including:

- TPS Suite (*TpsUtil* and *TpsDig2*)
- R Packages (*geomorph*, *StereoMorph*, *shape* and *GUImorph*)
- Landmark Editor (IDAV)
- SlicerMorph
- PhyloNimbus

Variety of different output files created including:

- .tps*
- .nts
- .csv
- .txt

GMM in the R Environment

- With an increasing number of packages for creating, manipulating and analysing shape coordinates, and a more code-literate discipline, R is the ideal environment for archaeologists.
- Permits a transparent, repeatable and reproducible GMM workflow.
- Note: you may find certain stages easier to process outside of the R environment e.g. digitisation (and that is fine!)

Stage 3: Landmark digitisation

Ask yourself…

Do all my specimens have the correct number of points?

Are all my landmarks in the correct order?

Are the ID labels correct?

Are they to scale? (For size-integrated analyses)

```
LM=28
66.00000 340.00000
72.00000 318.00000
75.00000 297.00000
78.00000 274.00000
84.00000 253.00000
86.00000 232.00000
88.00000 209.00000
83.00000 187.00000
80.00000 166.00000
76.00000 155.00000
75.00000 147.00000
57.00000 144.00000
37.00000 146.00000
34.00000 155.00000
33.00000 166.00000
32.00000 187.00000
32.00000 209.00000
30.00000 231.00000
30.00000 253.00000
30.00000 274.00000
33.00000 296.00000
37.00000 318.00000
46.00000 340.00000
50.00000 350.00000
52.00000 357.00000
57.00000 361.00000
61.00000 355.00000
63.00000 350.00000
IMAGE=Abri_Mannlefels_R.png
ID=Abri_Mannlefels_R
SCALE=0.105240
```

An example of a .tps file

10 Minute Break

Questions? (Slack and Google Document)

I’ll answer them following the break!

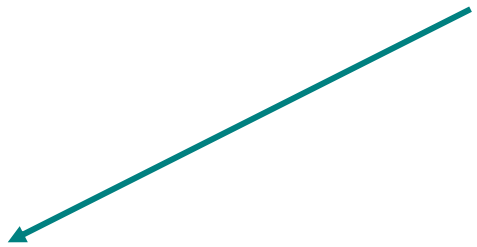
Different forms of shape analysis

1. **Landmark Analysis**

2. **Outline Analysis**
   - Semi-landmark Analysis
   - Fourier-based Analysis
     - Radial Fourier Analysis (RFA)
     - Elliptic Fourier Analysis (EFA)
     - Discrete Cosine Transform (DCT)
   - Eigenshape Analysis

3. **Other methods** e.g. Polynomial Curve Fitting

Workshop Two!



Generalised Procrustes Analysis (GPA)

Also known as…

- Procrustes Superimposition
- Procrustes Analysis
- Procrustes Fitting
- Generalised Least Squares

Procedure to isolate shape from a number of sometimes related variables, specifically ***rotation***, ***size*** **and** ***translation***

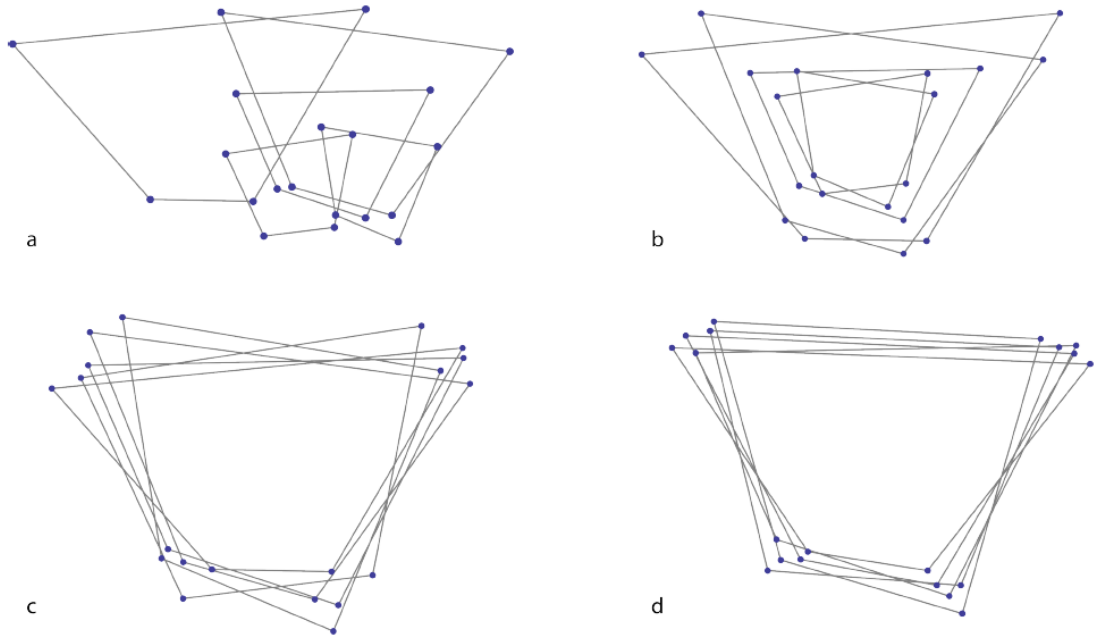
Generalised Procrustes Analysis (GPA)

The raw coordinates are…

- Translated to a common centroid **(A-B)**
- Scaled to the same centroid size **(B-C)**
- Rotated to minimise the summed square distances between landmarks **(C-D)**

Outcome: **Procrustes coordinates**

The Procrustes coordinates = shape *per se*



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Who was Procrustes?

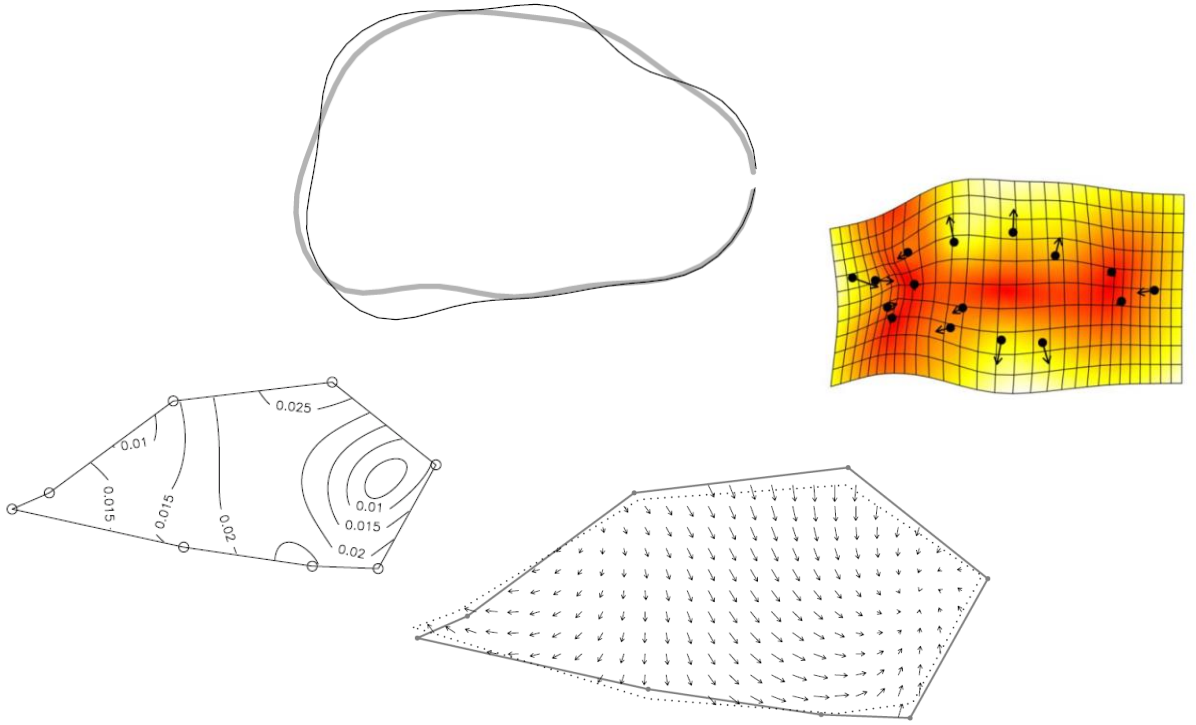
In Greek Mythology…

- Procrustes was a son of Poseidon and lived on a sacred way between Athens and Eleusis.
- There he had a bed, in which he invited every passer-by to spend the night, and where he set to work on them with his blacksmith's hammer, to stretch them to fit.
- In later tellings, if the guest proved too tall, Procrustes would amputate the excess length; nobody ever fitted the bed exactly.
- Procrustes continued his reign of terror until he was captured by Theseus, travelling to Athens along the sacred way, who "fitted" Procrustes to his own bed!

What can we do with these coordinates?
#1: Visualising shape change

Represent shape change as…

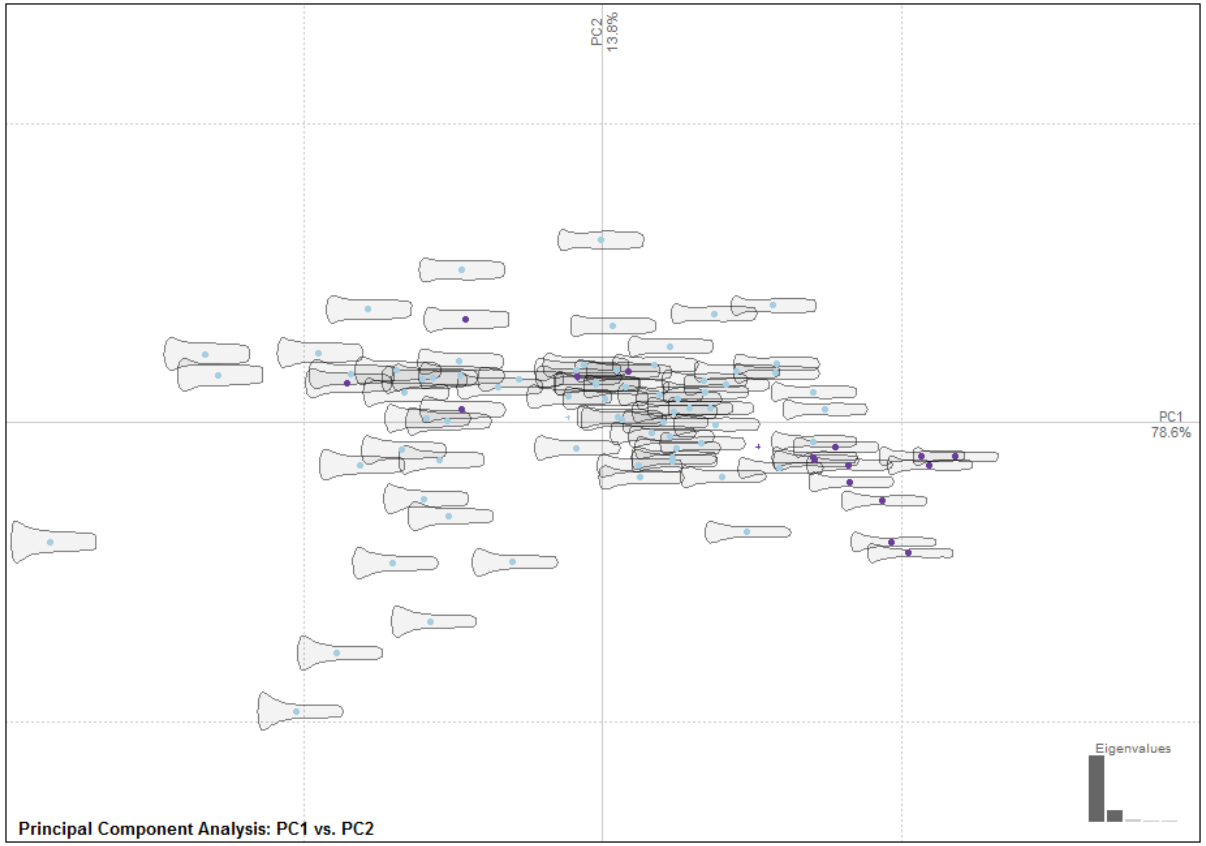
- Deformation grids
- Principal strains
- Lollipop sticks
- Vectors
- Contours



Claude, J. (2008). *Morphometrics with R*. Springer Publishing.

What can we do with these coordinates?
#2: Explore differences in shape through a PCA

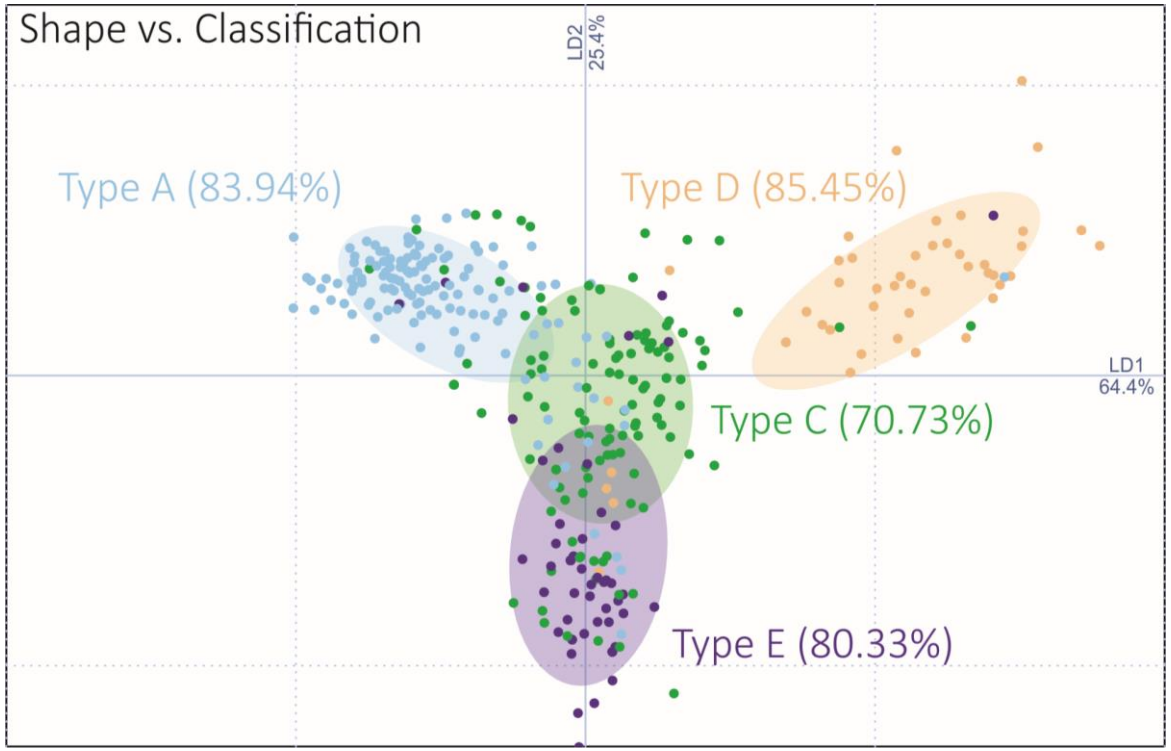
- PCA = Principal Component Analysis
- Often the first method of analysis
- Every point = landmark configuration
- Mean shape = axis origin
- Principal axes = sources of theoretical shape change
- The scores produced are often used for further analysis



Hoggard, C.S., Lauridsen, L. and Witte, K.B. (2019). The Potential of Geometric Morphometrics for Danish Archaeology: Two Case Studies. *Arkæologisk Forum*, 40: 30-42. (http://www.archaeology.dk/16738/Nr.%2040%20-%202019). OSF: https://osf.io/en5d2/

What can we do with these coordinates?
#3: Explore group differences through DA

- DA = Discriminant Analysis (or Canonical Variate Analysis)
- Examine the success with which *a priori* classifications can be distinguished through maximum-group separation.
- Landmark configuration vs. PCA scores.
- Creation of a training dataset to test unknown knowns.
- Initial percentage = separation success on group data
- Jack-knifed percentage (leave-one-out cross validation)
    - Determines success with which an artefact can be categorised solely on its shape



Vestergaard, C. and Hoggard, C.S. (2019). A Novel Geometric Morphometric (GMM) Application to the Study of Bronze Age Tutuli. *Danish Journal of Archaeology*, 8: 5-28.

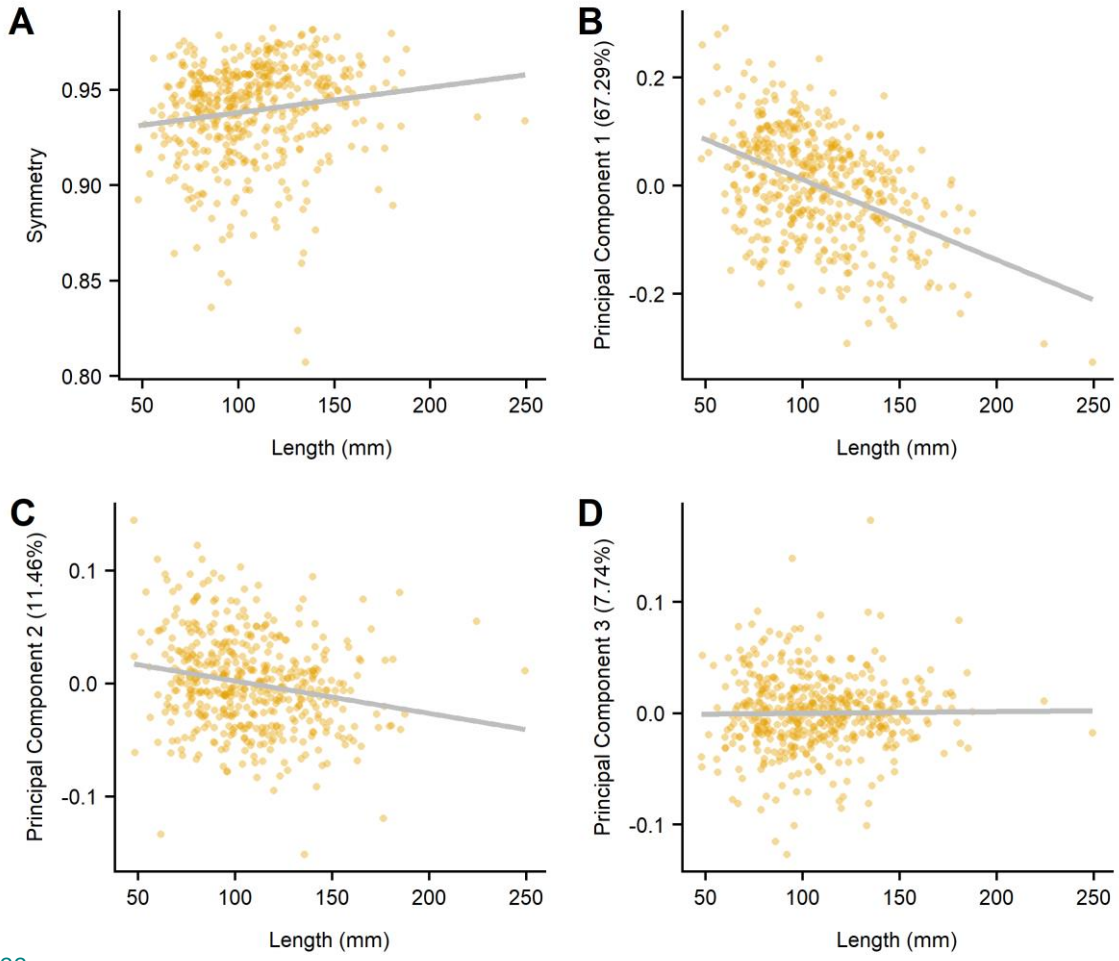
What can we do with these coordinates?
#4: Conduct a Procrustes ANOVA / MANOVA (statistical exercise)

- PCA and DA act as exploratory devices for looking at shape difference
- MANOVA and Procrustes ANOVA provide a statistical framework for examining shape
- Procrustes ANOVA: performed in *Geomorph* (with landmark data)
- MANOVA: performed in *Momocs* (with landmark and outline data)
- Null hypothesis: same populations / shape

What can we do with these coordinates?

#5: Perform correlation and regression analyses

- Useful for examining shape hypotheses involving quantitative data for example size.
- Other possible variables:
  - Symmetry
  - Latitude
  - Response (logistic regression)
- PCA scores can be fed in using the base::lm() function.



Hoggard, C.S., McNabb, J. and Cole, J.N. (2019). The application of elliptic Fourier analysis in understanding biface shape and symmetry through the British Acheulean. *Journal of Paleolithic Archaeology*, 2 (2): 115-133,

What can we do with these coordinates?

#6: Perform cluster-based analyses

- A useful method for examining *a posteriori* classifications.
- Utilises Principal Component scores (generated from the PCA!)
- A variety of different cluster analyses are available.
  - Momocs: Hierarchical Clustering
  - Rphylip: Parsimony / Maximum Likelihood (computationally intensive!)

Ivanovaite, L., Serwatka, K., Hoggard, C.S., Sauer, F. and Riede, F. (2012). All these fantastic cultures?
Research history and regionalisation in the Late Palaeolithic tanged point cultures of Eastern Europe. *European Journal of Archaeology*.

A quick note on outline-based analyses

- Useful for when homologous landmarks are difficult to place on a structure e.g. handaxes.
- Advantages over landmark analysis (for certain outline methods):
  - Do not need the same amount of points for each artefact (many more will be necessary for more complex objects).
  - Do not need to start at exactly the same position.
- One of the main outline-based methodologies**: Elliptic Fourier Analysis (EFA)**:
  - Semilandmarks are fed through a series of parametric equations (grounded on sine and cosine functions) to produce coefficients which create curve.
  - Coefficients are examined similarly to the Procrustes Coordinates

Workshop 2: R Demonstration (through Elliptic Fourier Analysis)

Concluding Remarks: Future Directions

1. **Greater application** of GMM in a variety of new (non biological) archaeologies
2. **Methodological applications**: automisation (recording and landmarking)
3. **Coding developments:** towards a replicable, reproducible and Shiny GMM…
4. **More powerful analytics**: e.g. Bayesian and Machine Learning techniques

Thank you for attending!