Geometric morphometrics

Introduction

Manuel F. G. Weinkauf

Univerzita Karlova, Prague, Czech Republic

26–27 August 2022

Section 1

Who am I and why do I teach this?

My way in life

2003–2010	Dipl.-Geol.: Freie Universität Berlin, Germany
2011–2015	Dr. rer. nat.: Eberhard–Karls Universität Tübingen, Germany
2015	Postdoctoral researcher: Universität Bremen, Germany
2015–2019	Research Associate: Université de Genève, Switzerland
since 2020	Academic Researcher: Univerzita Karlova, Czech Republic

My work in applied morphometrics

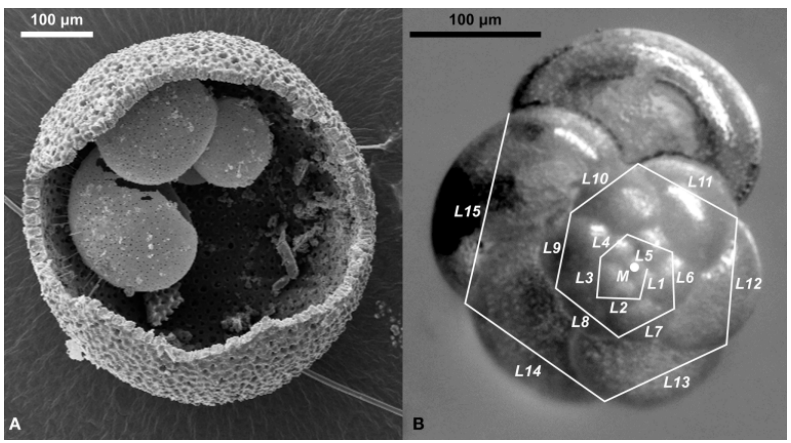
frontiers in
ECOLOGY AND EVOLUTION

ORIGINAL RESEARCH ARTICLE
published: 14 October 2014
doi: 10.3389/fevo.2014.00064

Disruptive selection and bet-hedging in planktonic Foraminifera: shell morphology as predictor of extinctions

Manuel F. G. Weinkauf[1,2]*, Tobias Moller[1], Mirjam C. Koch[1] and Michal Kučera[2]

[1] *Micropalaeontology, Department of Geosciences, Eberhard-Karls University, Tübingen, Germany*
[2] *Center for Marine Environmental Sciences, Micropalaeontology-Palaeoceanography, University Bremen, Bremen, Germany*



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Disruptive selection and bet-hedging in planktonic Foraminifera: shell morphology as predictor of extinctions

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[2] Center fo

PLOS ONE

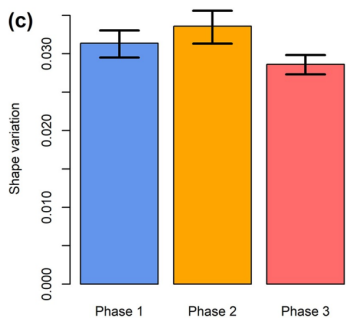
RESEARCH ARTICLE

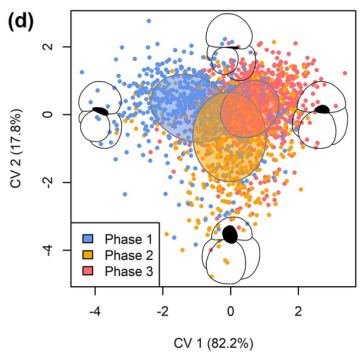
An extinction event in planktonic Foraminifera preceded by stabilizing selection

Manuel F. G. Weinkauf[1,2,3]*, **Fabian G. W. Bonitz**[1¤], **Rossana Martini**[3], **Michal Kučera**[2]

1 Department of Geosciences, Eberhard–Karls Universität Tübingen, Tübingen, Germany, **2** Center for Marine Environmental Sciences (MARUM), Universität Bremen, Bremen, Germany, **3** Department of Earth Sciences, Université de Genève, Genève, Switzerland

¤ Current address: Norwegian Research Centre, Bjerknes Centre for Climate Research, Bergen, Norway
* Manuel.Weinkauf@unige.ch





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PLOS ONE

RESEARCH ARTICLE

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Marine Micropaleontology 114 (2015) 19–35

Contents lists available at ScienceDirect

Marine Micropaleontology

journal homepage: www.elsevier.com/locate/marmicro

ELSEVIER

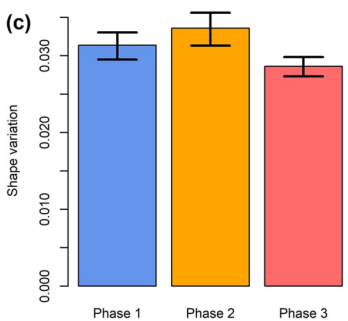
Research paper

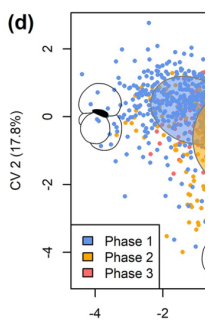
Genetic and morphometric evidence for parallel evolution of the *Globigerinella calida* morphotype

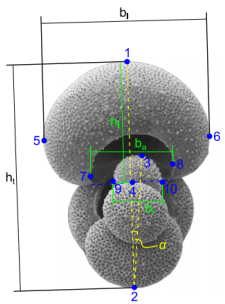
CrossMark

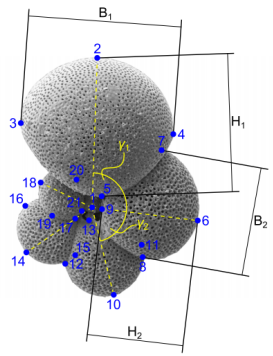
Agnes K.M. Weiner [a,*], Manuel F.G. Weinkauf [a], Atsushi Kurasawa [b], Kate F. Darling [c,d], Michal Kucera [a]

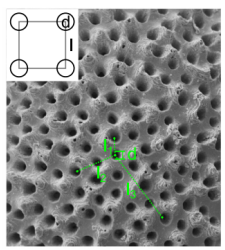
[a] MARUM Center for Marine Environmental Sciences, University of Bremen, Leobenerstrasse, 28359 Bremen, Germany
[b] Research and Development Center for Global Change, Japanese Agency for Marine Earth Science and Technology, Natsushima-cho 2-15, Yokosuka 237-0061, Japan
[c] School of GeoSciences, University of Edinburgh, Edinburgh EH9 3JW, UK
[d] School of Geography and GeoSciences, University of St Andrews, Fife KY16 9AL, UK











$h_{total} = h_t\ [\mu m]$
$\alpha = \angle 123$
$E_l = \frac{h_l}{b_l}$
$PS = b_i \in b_a\ [\%]$

$E = \frac{\sum_{i=1}^{n} \frac{H_i}{B_i}}{n}$
$E_L = \frac{H_1}{B_1}$

$\gamma = \frac{\sum_{i=1}^{n-1} \gamma_i}{n-1}$

$\bar{d} = \frac{\sum_{i=1}^{n} d}{n}$
$\bar{l} = \frac{\sum_{i=1}^{n} l_{min}}{n}$

$P = \frac{\frac{\pi}{4} \times \bar{d}^2}{\bar{l}^2}$

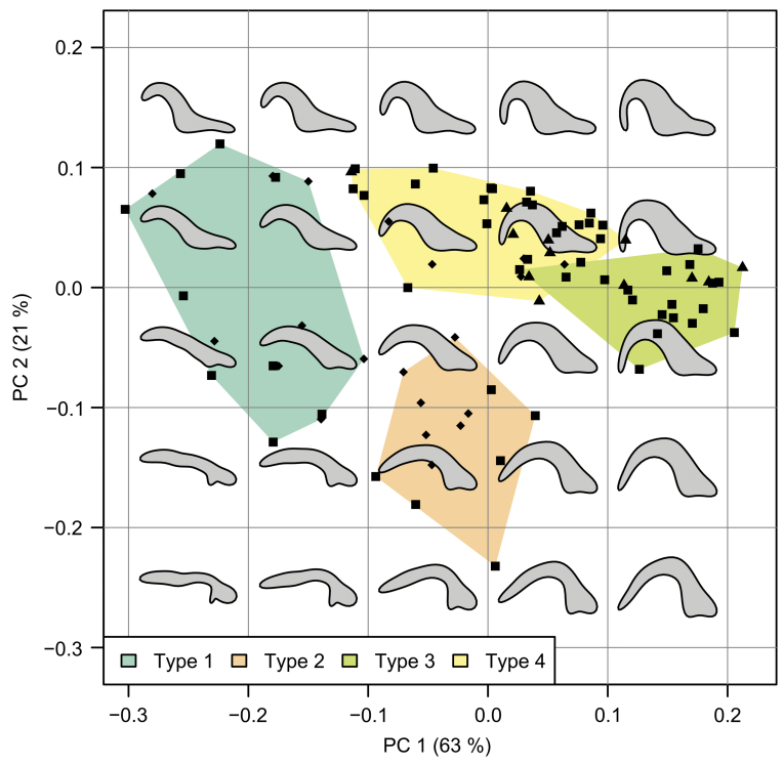
My work in applied morphometrics

Paleobiology, 43(2), 2017, pp. 304–320
DOI: 10.1017/pab.2016.44

PALEOBIOLOGY
A PUBLICATION OF THE Paleontological SOCIETY

Grasping the shape of belemnoid arm hooks—a quantitative approach

René Hoffmann, Manuel F. G. Weinkauf, and Dirk Fuchs



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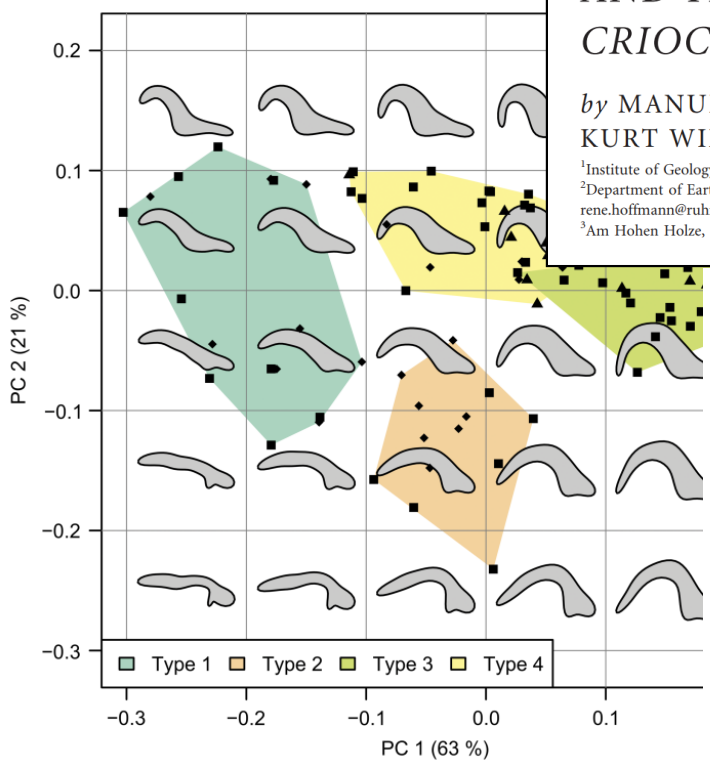
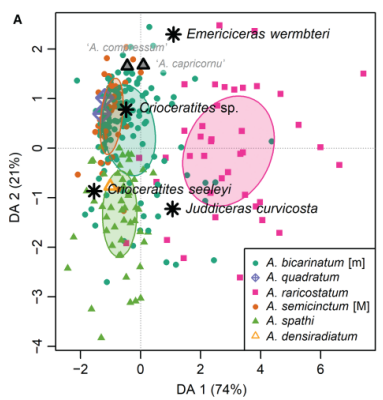
[Papers in Palaeontology, Vol. 7, Part 4, 2021, pp. 2113–2139]

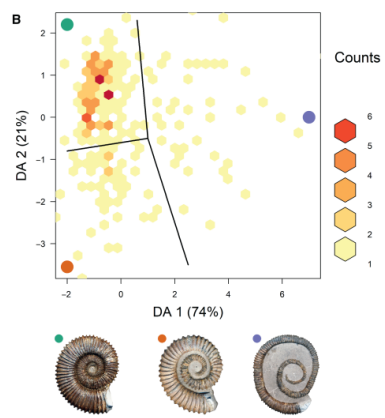
EVOLUTIONARY–PHYLOGENETIC PATHWAY OF THE CRETACEOUS AMMONITE GENUS *AEGOCRIOCERAS* AND ITS RELATIONSHIP TO *JUDDICERAS* SPP. AND *CRIOCERATITES* SPP.

by MANUEL F. G. WEINKAUF[1], RENÉ HOFFMANN[2] *and* KURT WIEDENROTH[3]

[1]Institute of Geology and Palaeontology, Univerzita Karlova, Albertov 2038/6, 128 43 Praha, Czech Republic; weinkaum@natur.cuni.cz
[2]Department of Earth Sciences, Institute of Geology, Mineralogy and Geophysics, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany; rene.hoffmann@ruhr-uni-bochum.de
[3]Am Hohen Holze, 30823 Garbsen, Germany







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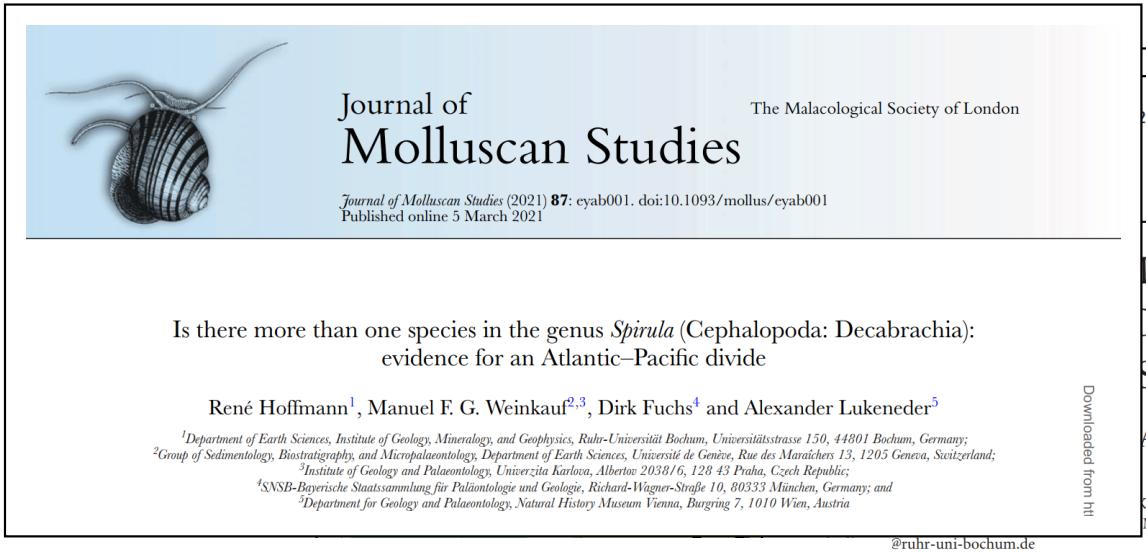
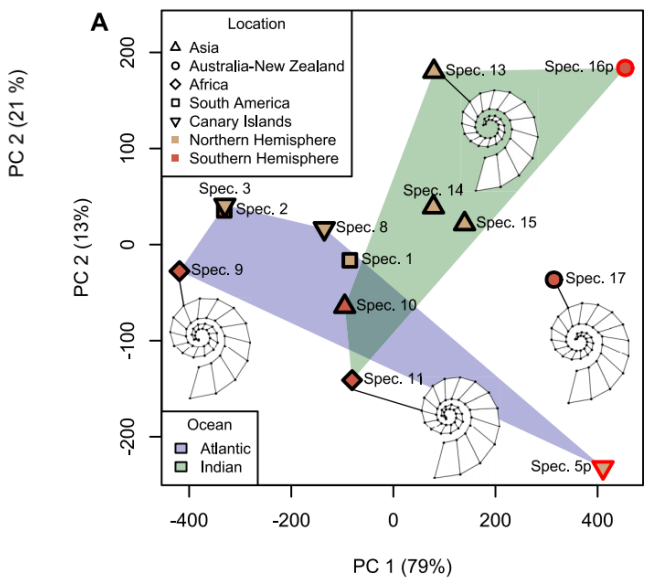


Journal of Molluscan Studies
The Malacological Society of London
Journal of Molluscan Studies (2021) **87**: eyab001. doi:10.1093/mollus/eyab001
Published online 5 March 2021

Is there more than one species in the genus *Spirula* (Cephalopoda: Decabrachia): evidence for an Atlantic–Pacific divide

René Hoffmann[1], Manuel F. G. Weinkauf[2,3], Dirk Fuchs[4] and Alexander Lukeneder[5]

[1]*Department of Earth Sciences, Institute of Geology, Mineralogy, and Geophysics, Ruhr-Universität Bochum, Universitätsstrasse 150, 44801 Bochum, Germany;*
[2]*Group of Sedimentology, Biostratigraphy, and Micropalaeontology, Department of Earth Sciences, Université de Genève, Rue des Maraîchers 13, 1205 Geneva, Switzerland;*
[3]*Institute of Geology and Palaeontology, Univerzita Karlova, Albertov 2038/6, 128 43 Praha, Czech Republic;*
[4]*SNSB-Bayerische Staatssammlung für Paläontologie und Geologie, Richard-Wagner-Straße 10, 80333 München, Germany; and*
[5]*Department for Geology and Palaeontology, Natural History Museum Vienna, Burgring 7, 1010 Wien, Austria*



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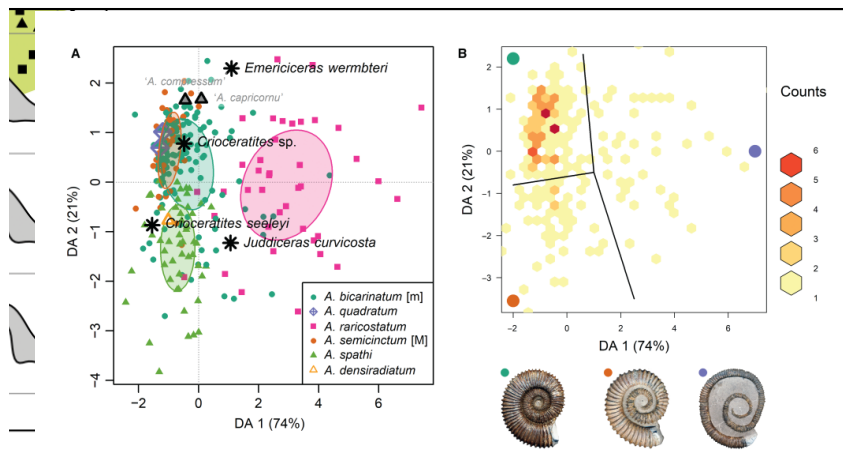


Section 2

A brief history and applicability of morphometrics

Earliest stages

Size and shape for information transfer

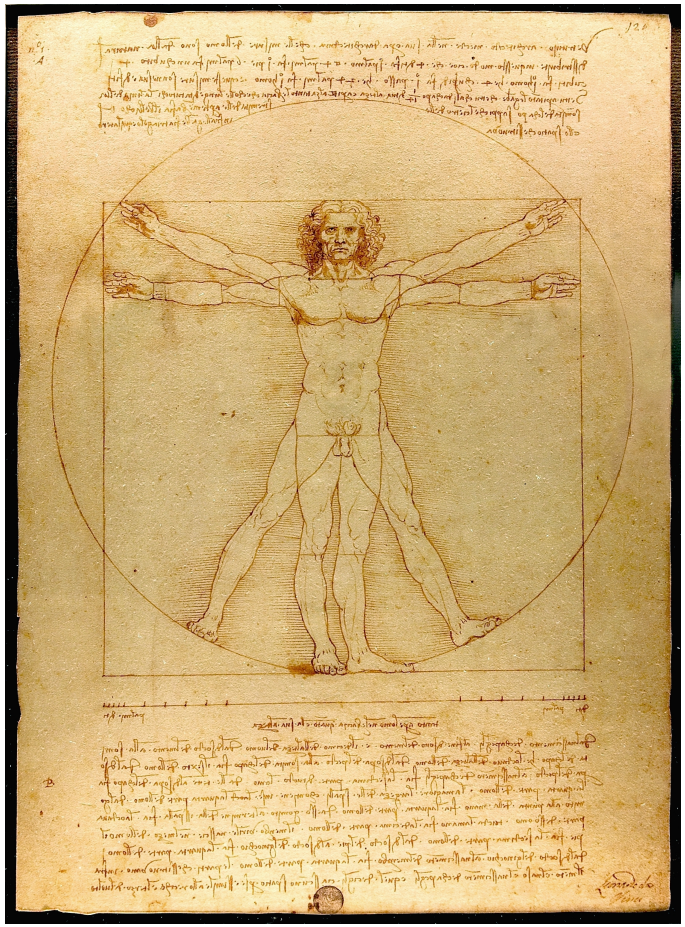
- In art from the Middle Ages, size and shape was used to symbolize importance and rank

Maksymiszyn (2013) Medieval Art (https://michalsgraphicblog.blogspot.com)

Earliest stages

Size and shape for information transfer

- In art from the Middle Ages, size and shape was used to symbolize importance and rank
- In the Renaissance, a more scientific approach was adopted that tried to understand proportions in organisms

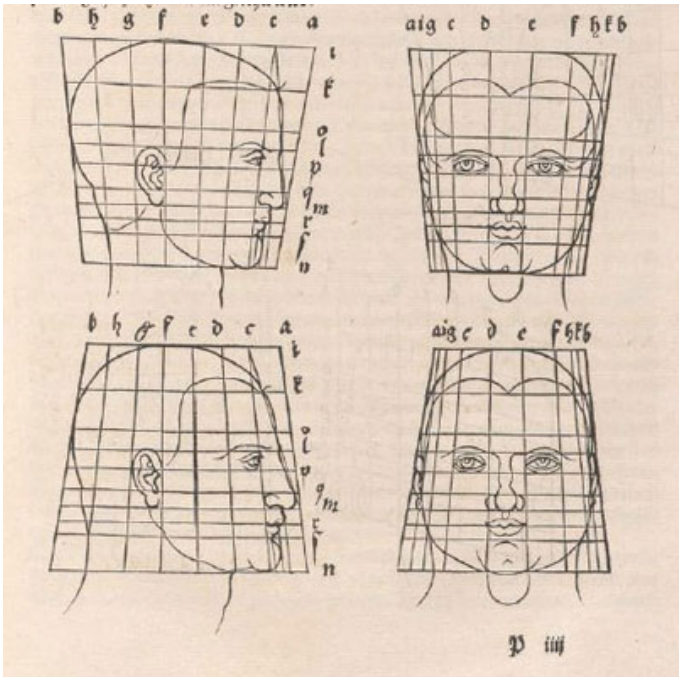


da Vinci (c.1490) Le proporzioni del corpo umano secondo Vitruvio

Earliest stages

Size and shape for information transfer

- In art from the Middle Ages, size and shape was used to symbolize importance and rank
- In the Renaissance, a more scientific approach was adopted that tried to understand proportions in organisms
- This culminated in early experiments with deformation grids by Albrecht Dürer

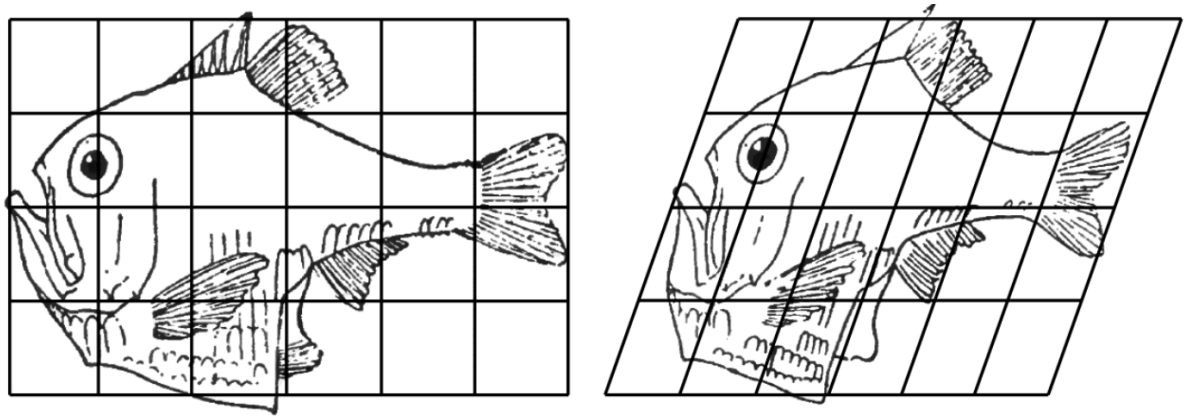


Dürer (1528) Vier Bücher von menschlicher Proportion

Deformationists vs. statisticians

Deformation: The school of D'Arcy Wentworth Thompson

- Biological shape can be constructed by the deformation of corresponding or topologically homologous points
- Complex morphological transformations are result of simple geometric deformations ⇒ **evolutionary approach**

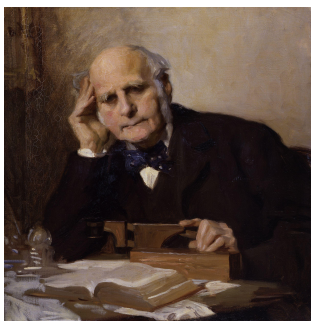


Thompson (1917) On Growth and Form (Cambridge University Press: Cambridge)

Deformationists vs. statisticians

Description: The statistician's school

- Quantification of biological shape provides information about mean values and variation in populations and taxa
- Morphological data can be interpreted as statistical summaries of form similarity and difference ⇒ **descriptive approach**



Sir Francis Galton
*1822, †1911

Karl Pearson
*1857, †1936

Sir Ronald A. Fisher
*1890, †1962

Calyampudi R. Rao
*1920

Coining the term ‘Morphometrics’

- ‘Morphometrics’ was first used by Robert E. Blackith in **1957** during his work on polymorphism in locusts

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Coining the term ‘Morphometrics’

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- The term was widely established in **1971** by the book ‘Multivariate Morphometrics’ by R. E. Blackith and R. A. Reyment
- Since the **late 80s/early 90s**, the field of morphometrics is rapidly expanding and advancing

What is morphometrics good for?

- Offer an **objective** and **quantitative** (reproducible) assessment of morphology of populations and species to
  1. Objectively distinguish taxa and ecophenotypes (**systematics and ecology**)

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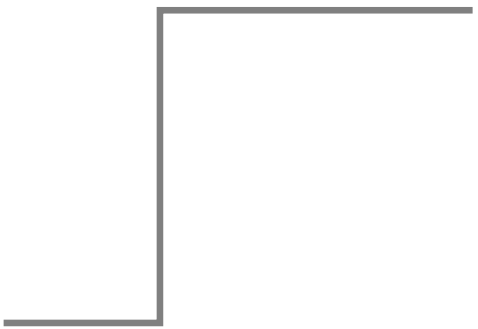
What is morphometrics good for?

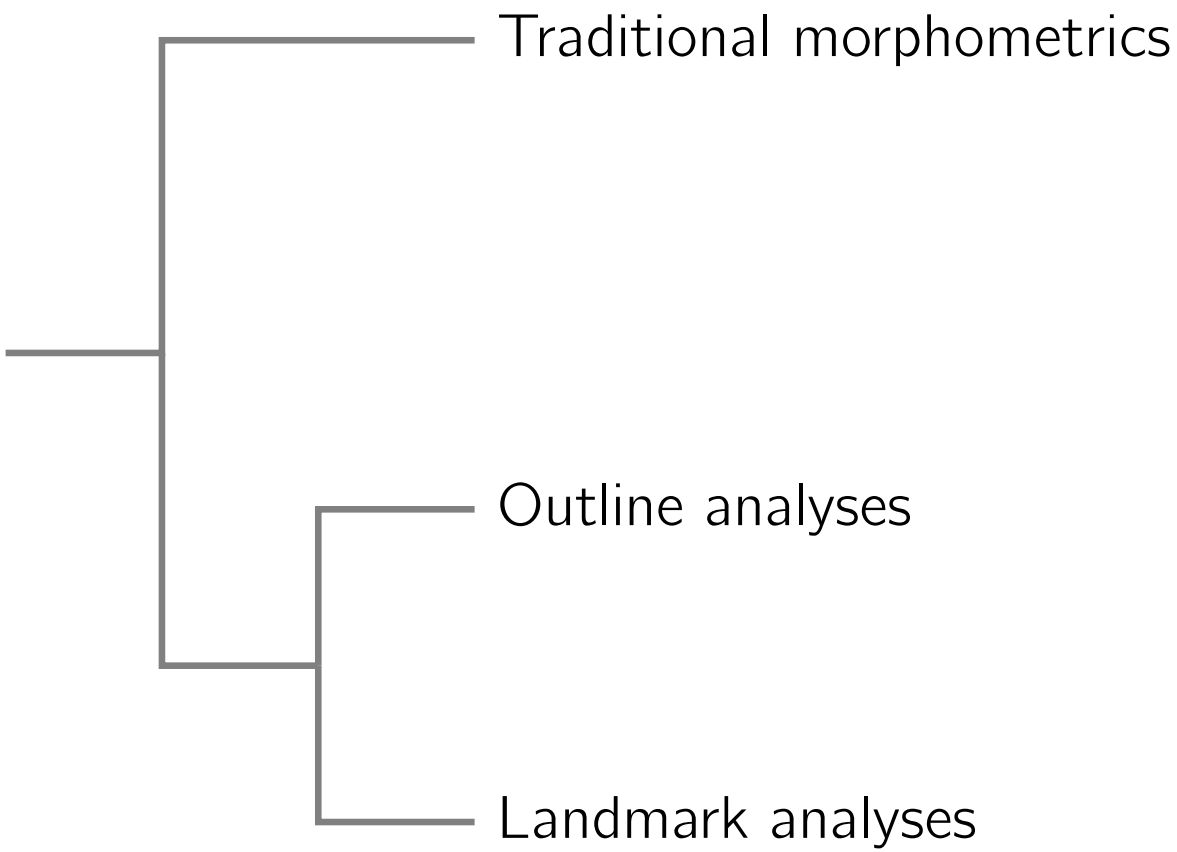
- Offer an **objective** and **quantitative** (reproducible) assessment of morphology of populations and species to
  1. Objectively distinguish taxa and ecophenotypes (**systematics and ecology**)
  2. Evaluate the impact of the environment on morphological developments during growth (**evo-devo**)
  3. Reconstruct morphological changes during phylogeny (**evolution**)

The systematics of morphometrics

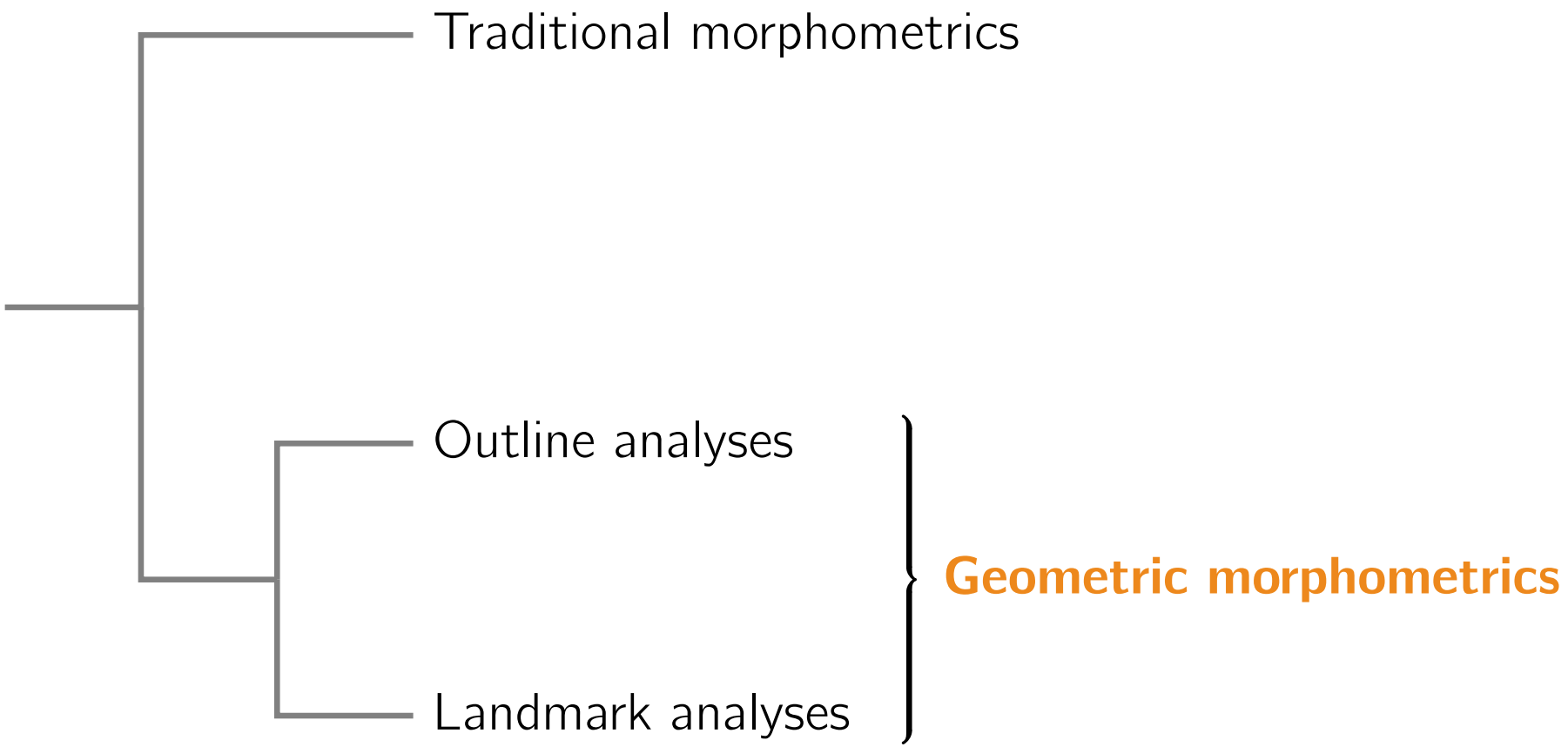


Traditional morphometrics

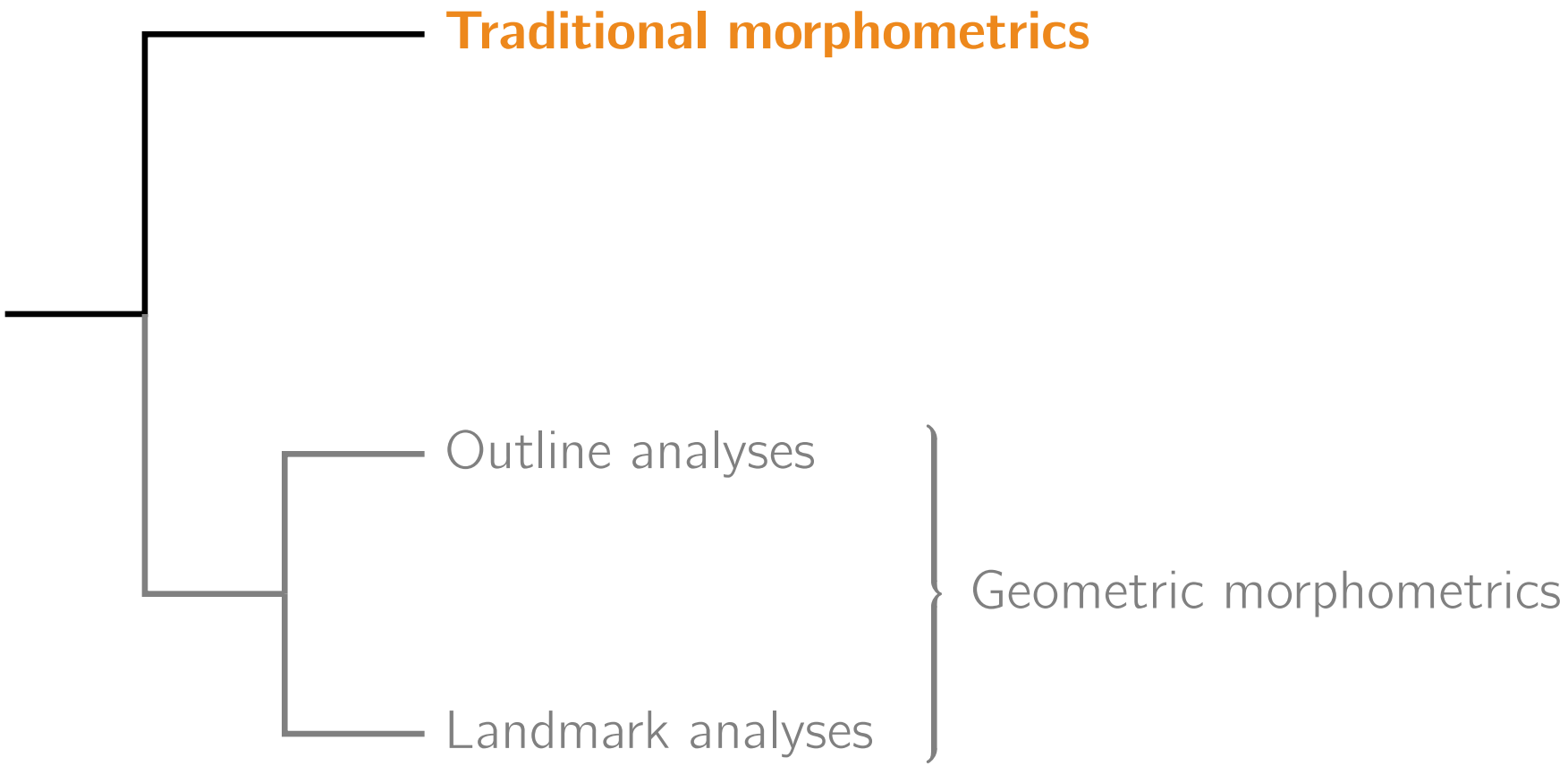
The systematics of morphometrics



The systematics of morphometrics



The systematics of morphometrics



Traditional morphometrics

A set of individual, linear measurements

Traditional morphometrics

A set of individual, linear measurements

Skull length = 34 cm

Traditional morphometrics

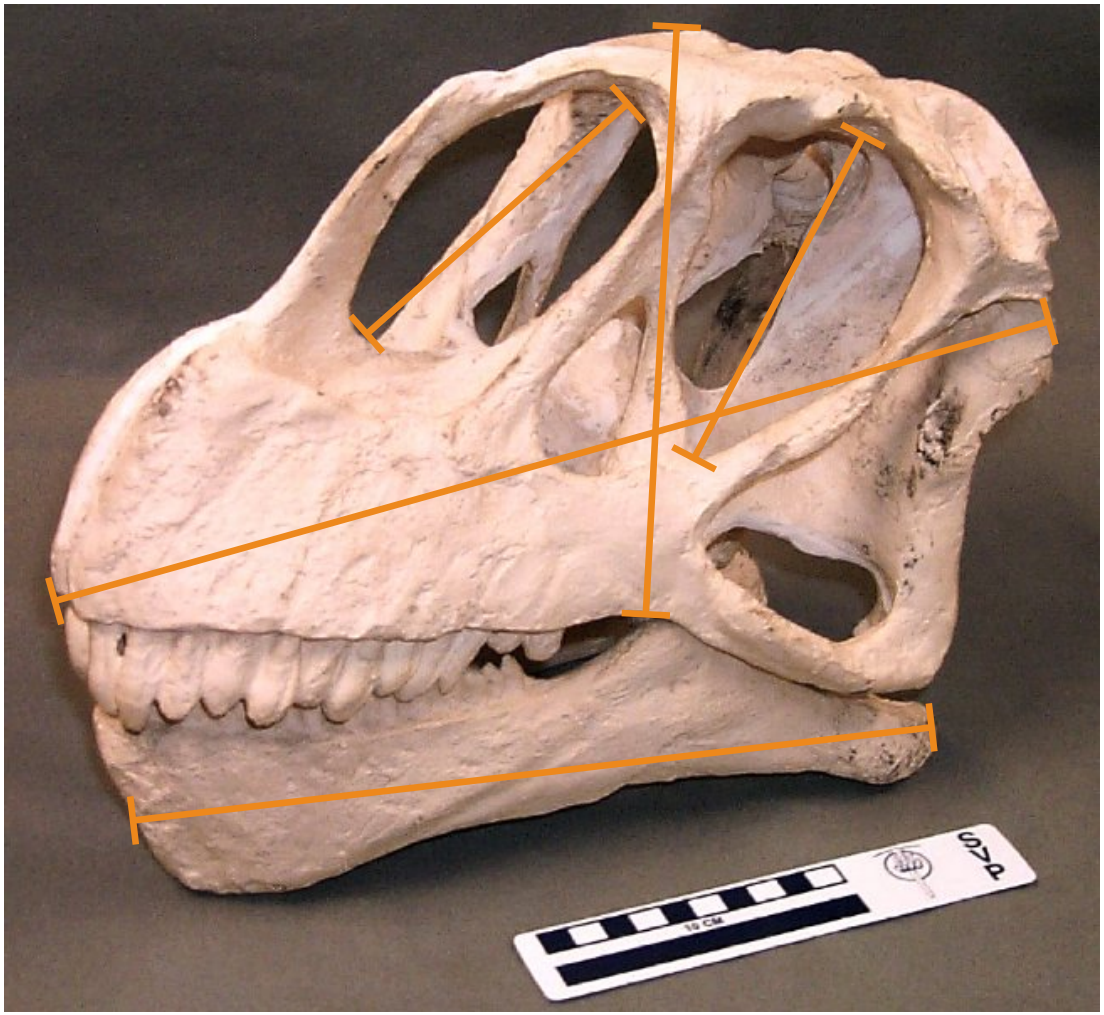
A set of individual, linear measurements

Skull length = 34 cm

Jaw length = 26 cm

Traditional morphometrics

A set of individual, linear measurements



Skull length = 34 cm

Jaw length = 26 cm

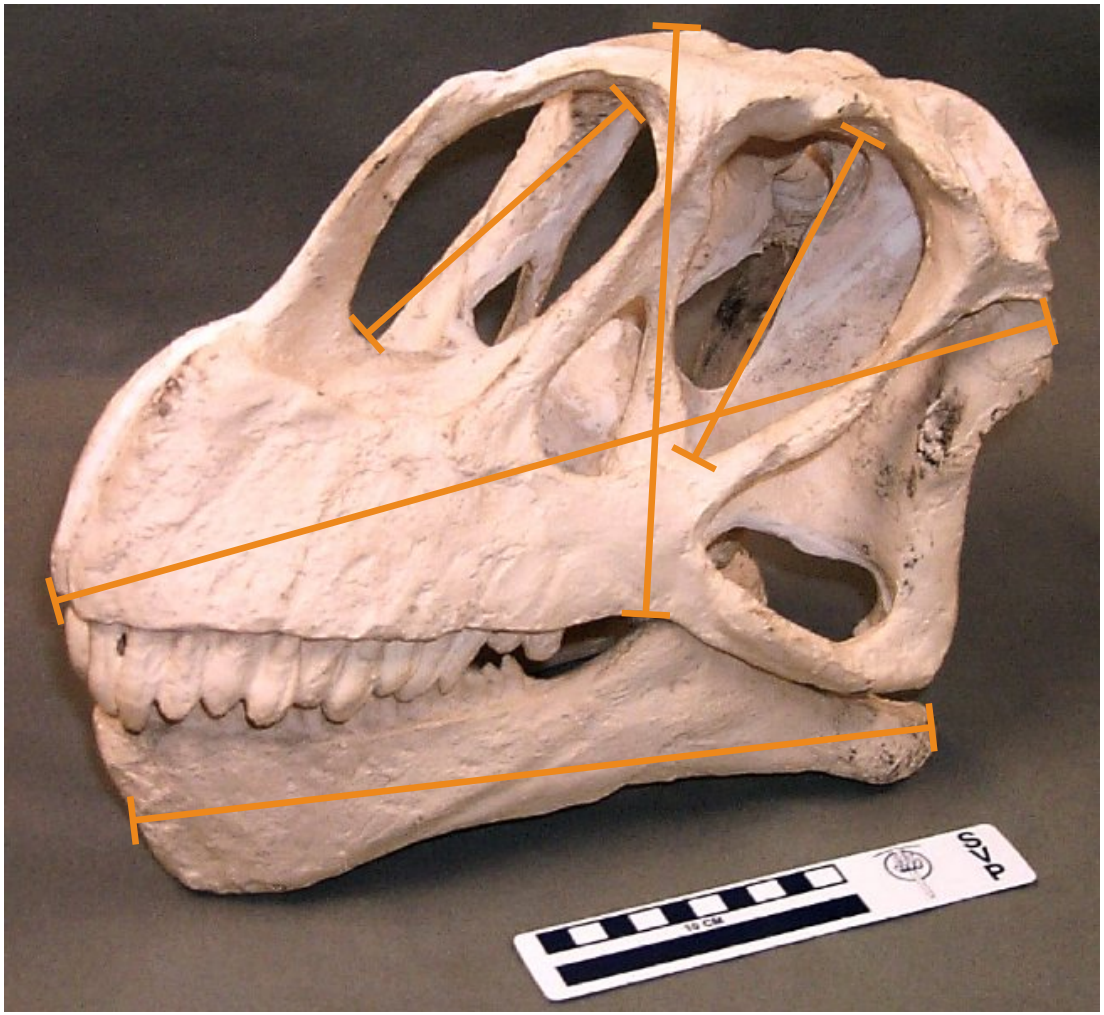
Skull height = 19 cm

Nose height = 12 cm

Eye height = 12 cm

Traditional morphometrics

A set of individual, linear measurements



Skull length = 34 cm

Jaw length = 26 cm

Skull height = 19 cm

Nose height = 12 cm

Eye height = 12 cm

We end up with a set of univariate morphological measurements

Traditional morphometrics

Pros and cons

Pros

- Easy to measure
  - Just a linear length
- Easy to store
  - Simple tabular data
- Easy to understand
  - Intuitive quantity with direct meaning

Traditional morphometrics

Pros and cons

Pros

- Easy to measure
  - Just a linear length
- Easy to store
  - Simple tabular data
- Easy to understand
  - Intuitive quantity with direct meaning

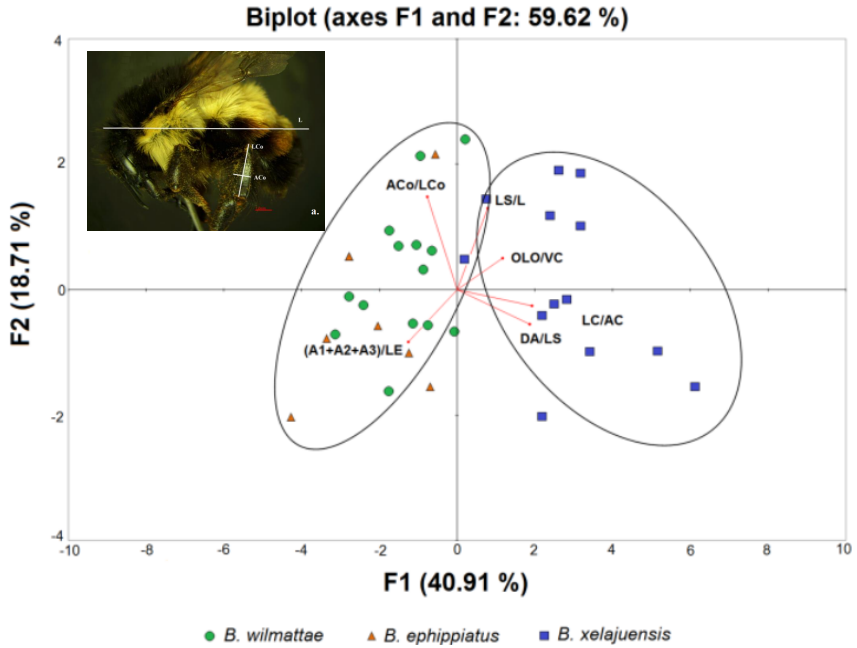
Cons

- Measures only sizes
  - Just a linear length
- Derived shape parameters
  - Shape from e.g. ratios
- Shape and size intermingled
  - How to separate size from shape?

Traditional morphometrics

Multivariate solutions

- Multivariate analyses are often employed to separate size and shape information

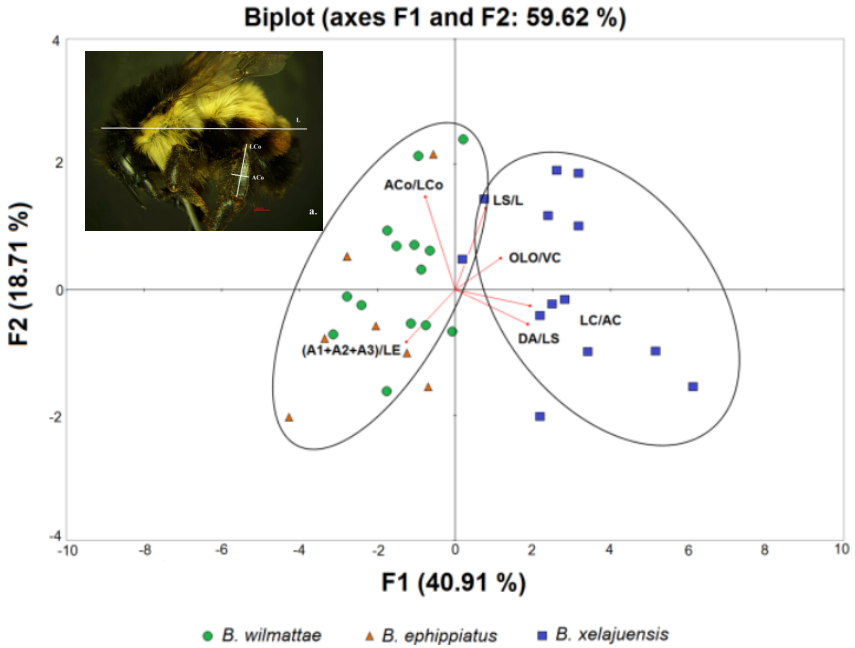


Dardón et al. (2020) Int. J. Sci. Res. Biol. Sci. 7 (2): Article 114

Traditional morphometrics

Multivariate solutions

- Multivariate analyses are often employed to separate size and shape information
- **Caution:** This is only true under very specific circumstances
- Adaptations of principal component analysis where devised to deal with this problem, e.g. Somers (1986) Syst. Zool. 35 (3): 359–368



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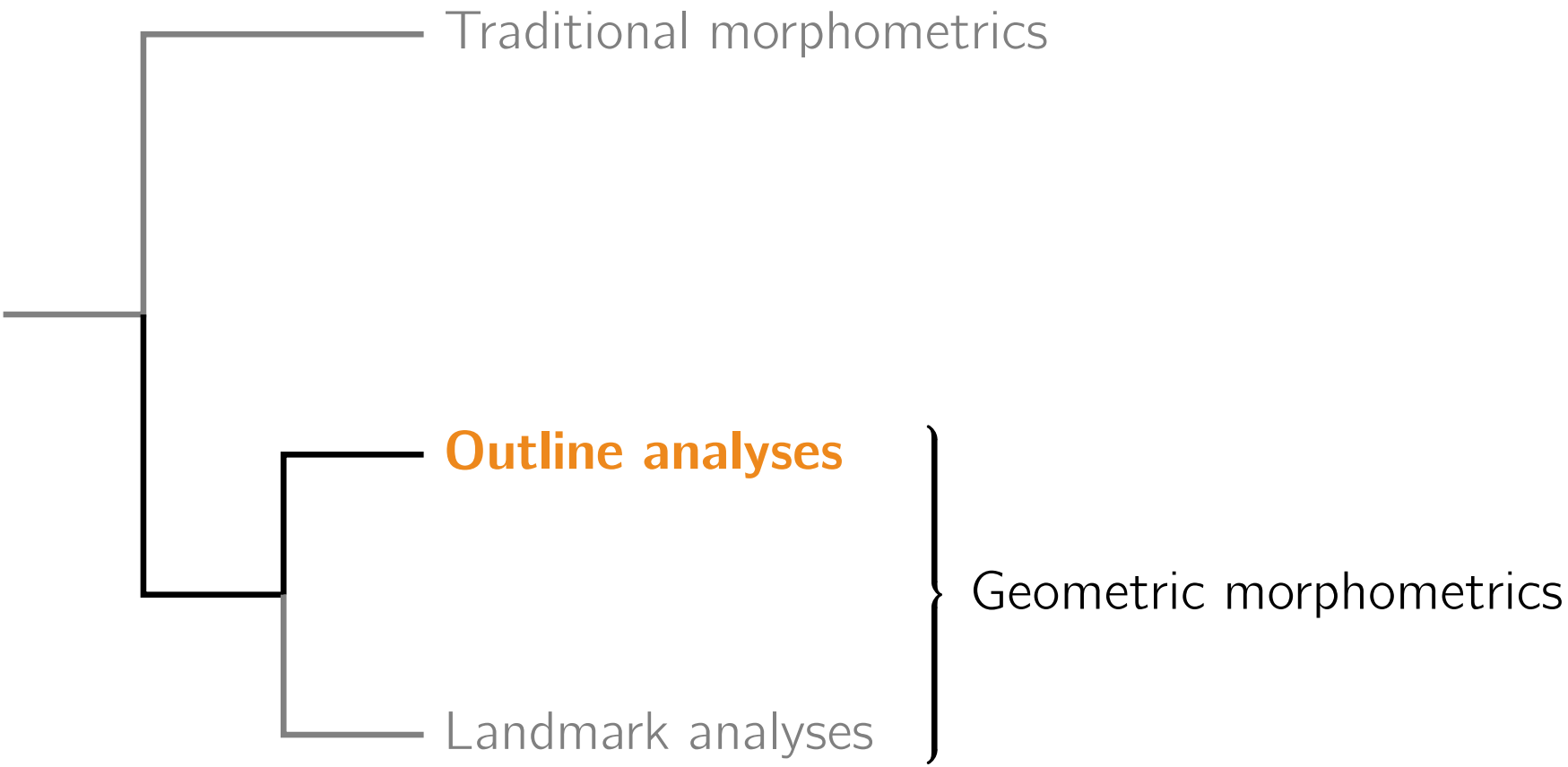
The systematics of morphometrics



Outline analyses

A mathematical description of the structure's perimeter

- Ideal for structures with little internal characteristics

Carcharadontosaurus saharicus

http://www.fossilmall.com

Outline analyses

A mathematical description of the structure's perimeter

- Ideal for structures with little internal characteristics
- Identify the object of interest in the image

Carcharadontosaurus saharicus

http://www.fossilmall.com

Outline analyses

A mathematical description of the structure's perimeter

- Ideal for structures with little internal characteristics
- Identify the object of interest in the image
- Extraxt x- and y coordinates along outline
- The first outline point is mostly a **well defined homologue structure**

Carcharadontosaurus saharicus

http://www.fossilmall.com

Outline analyses

Pros and cons

Pros

- Automated extraction
  - Outline is well defined and computer-findable
- Pure shape data
  - Size is eliminated by mathematical transformation
- Easy to analyse
  - Standard statistics work without modification

Outline analyses

Pros and cons

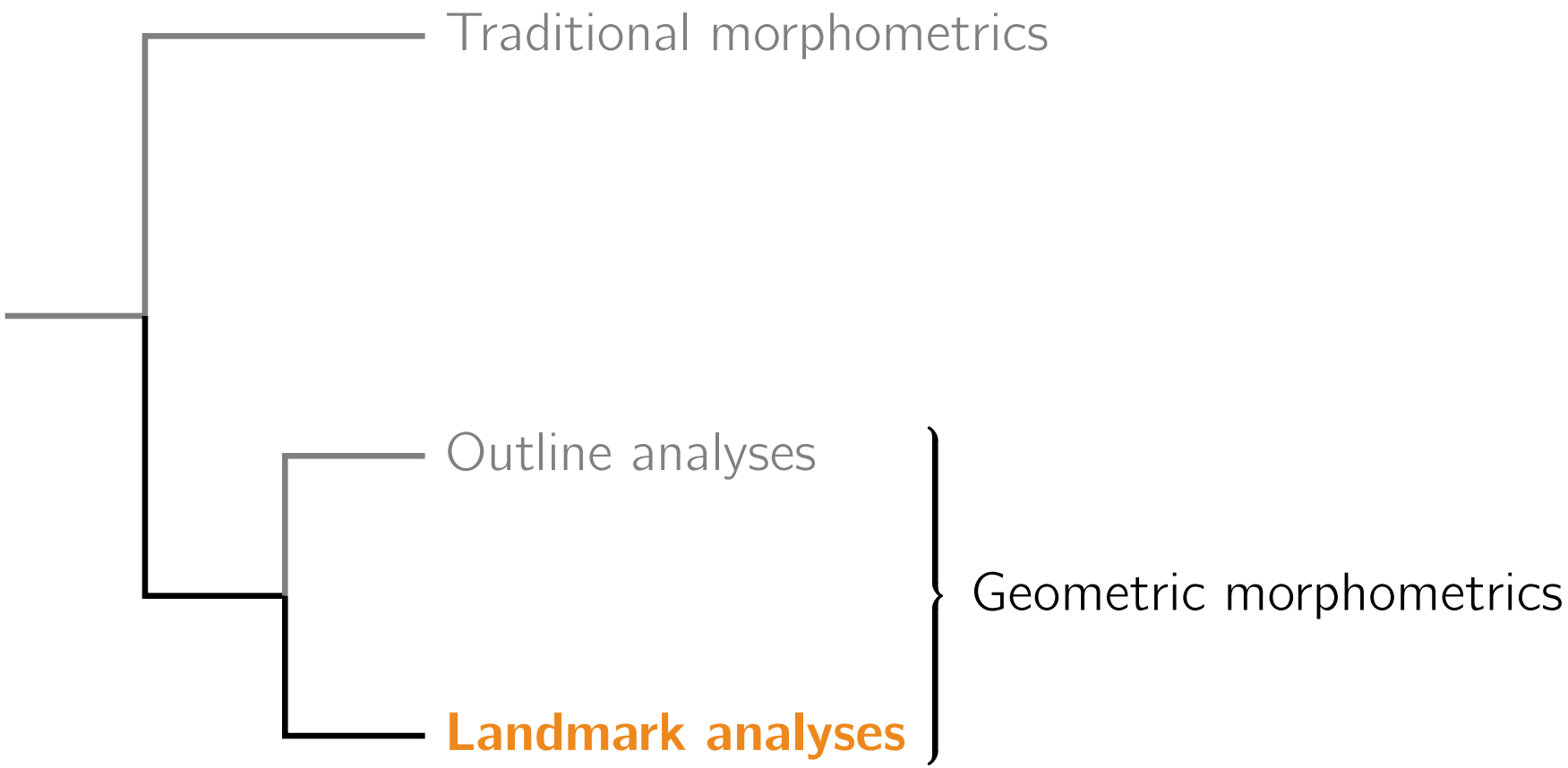
Pros

- Automated extraction
  - Outline is well defined and computer-findable
- Pure shape data
  - Size is eliminated by mathematical transformation
- Easy to analyse
  - Standard statistics work without modification

Cons

- Difficult to analyse
  - Only starting point is comparable
- Derived shape parameters
  - Complex mathematical re-description of shape information
- Limited information
  - No structure-internal information

The systematics of morphometrics



Landmark analyses

The relative position of homologuous structures

Landmark analyses

The relative position of homologuous structures

Landmark analyses

The relative position of homologuous structures

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The relative position of homologuous structures

Landmark analyses

Pros and cons

Pros

- Pure shape data
  - Size is eliminated by superimposition
- Easy to understand
  - Landmark coordinates have direct meaning
- Detailed information
  - Structure-internal information provided

Landmark analyses

Pros and cons

Pros

- Pure shape data
  - Size is eliminated by superimposition
- Easy to understand
  - Landmark coordinates have direct meaning
- Detailed information
  - Structure-internal information provided

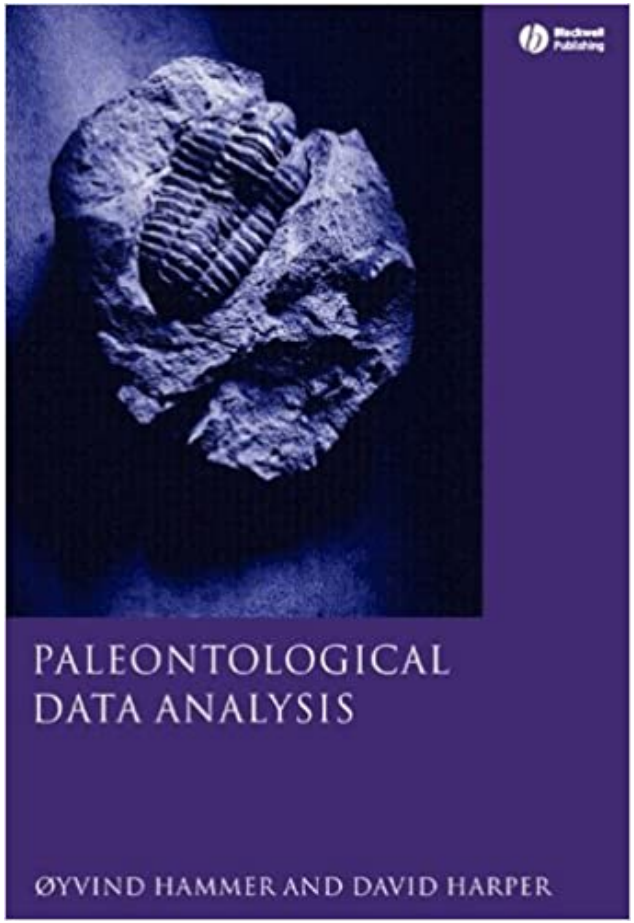
Cons

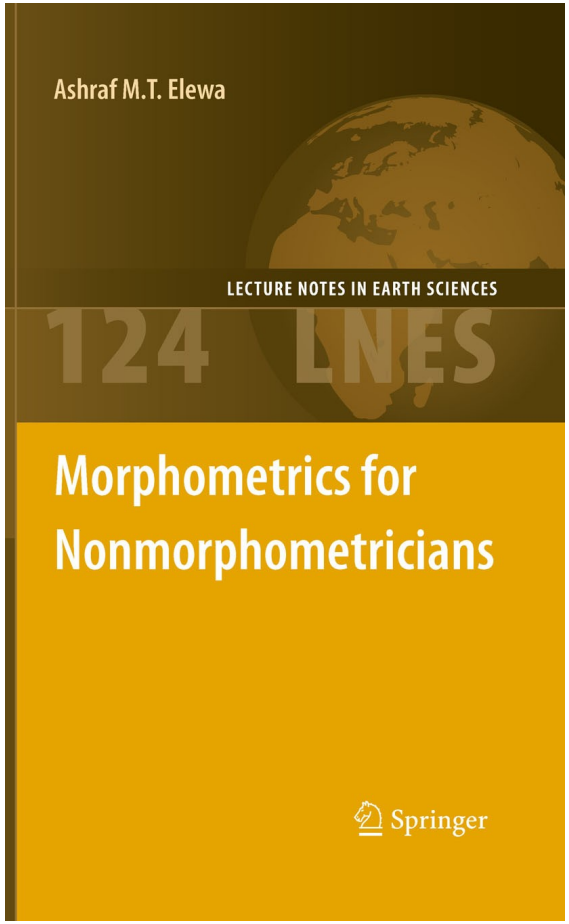
- Difficult to extract
  - Manual or using machine learning
- Difficult to analyse
  - Standard statistics must be modified
- Limited applicability
  - Requires homologous morpho-structures

Section 3

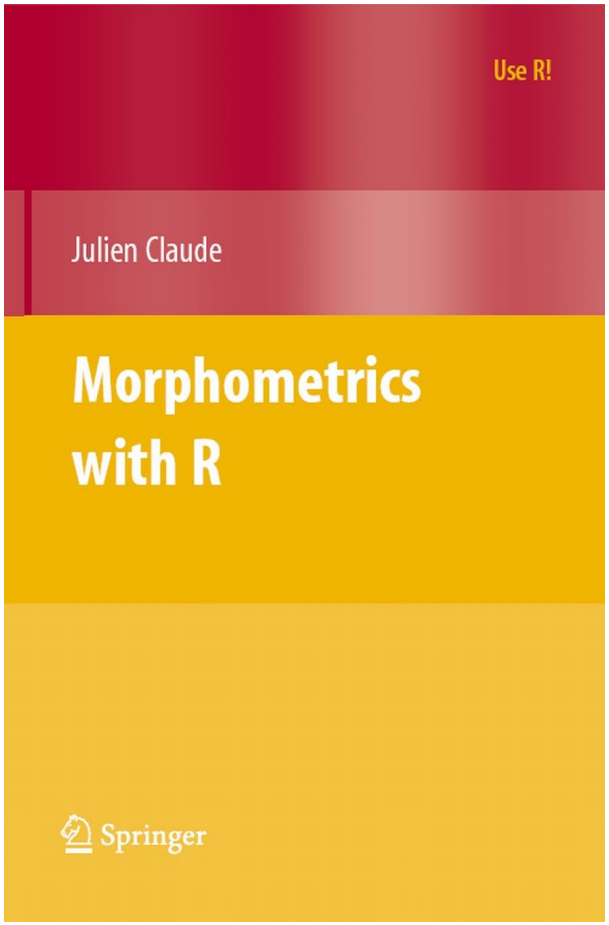
Literature and tools

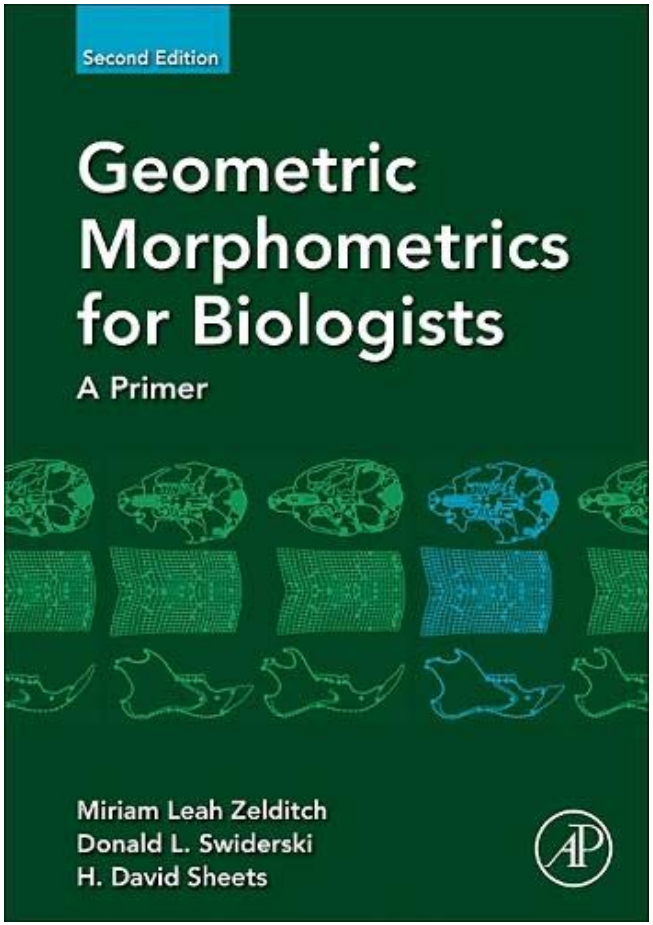
Light introductory literature



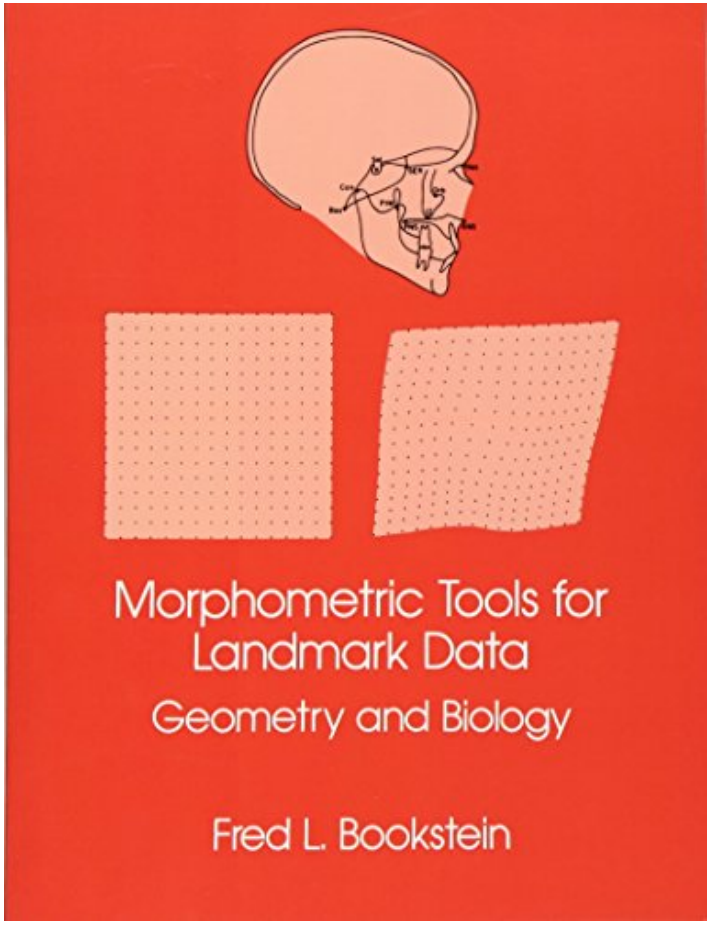


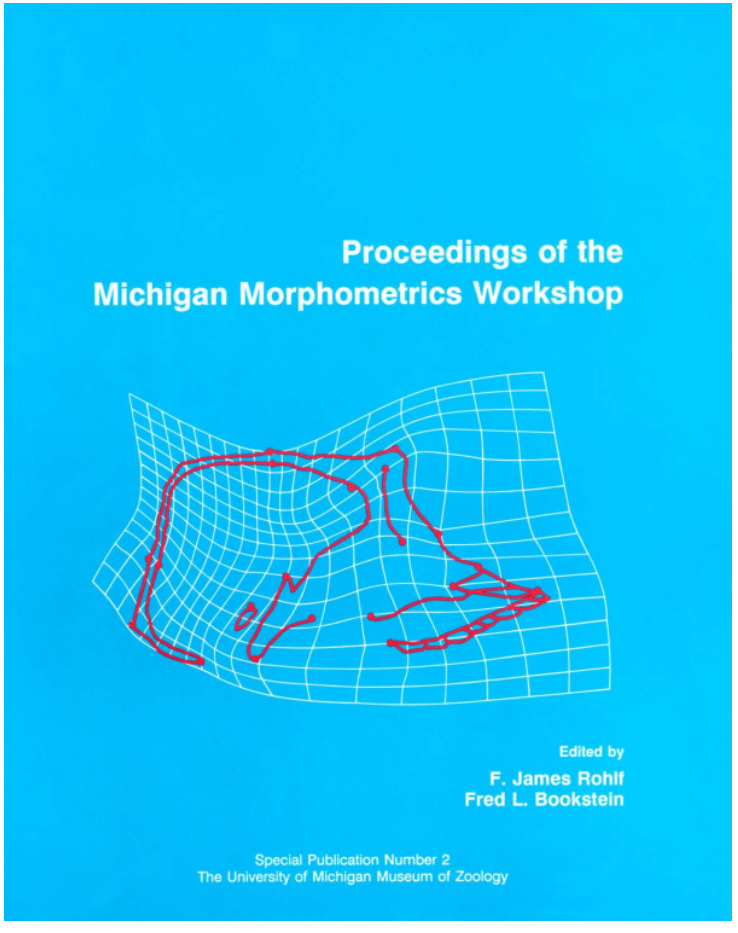
Practical hands-on guides



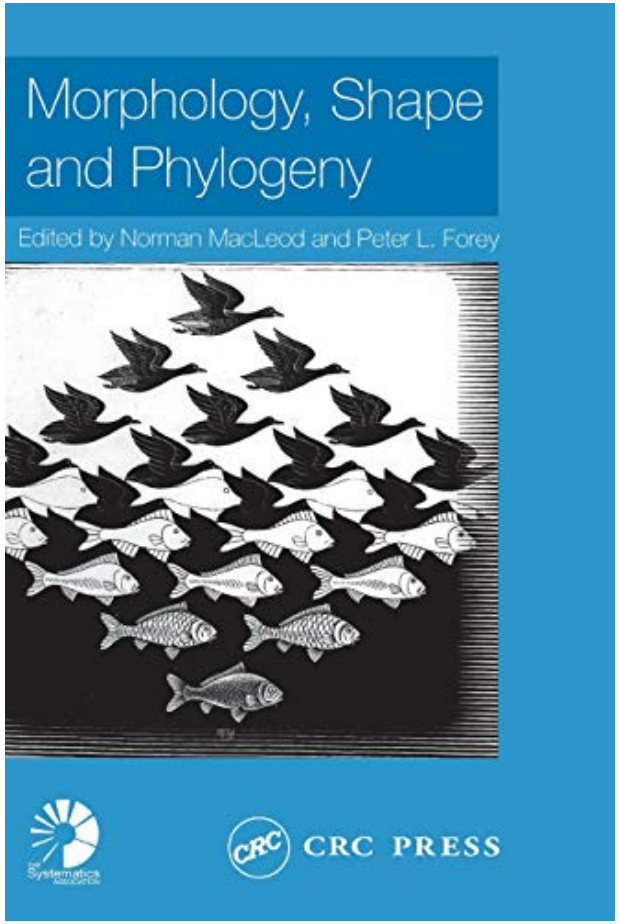


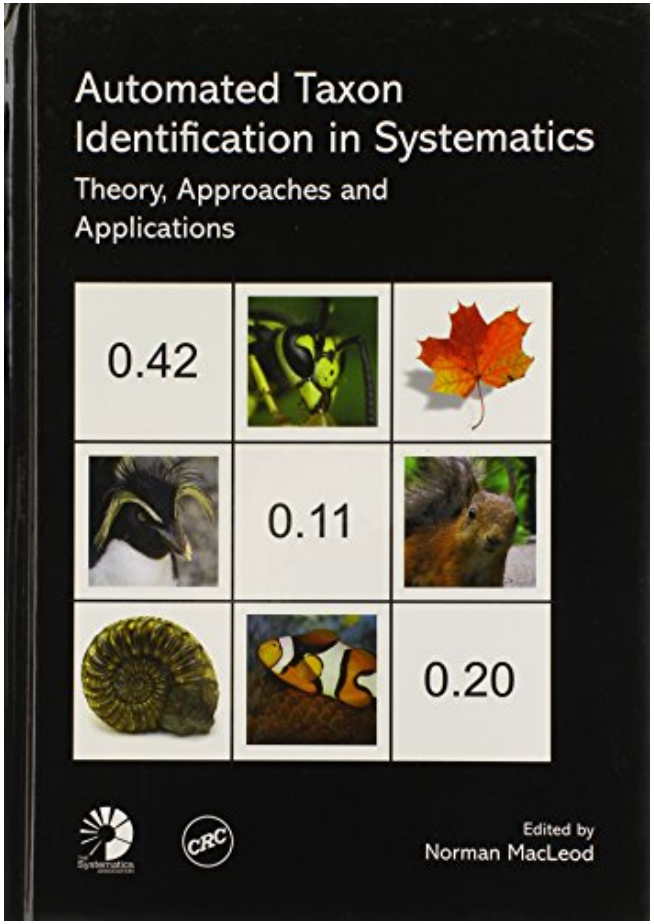
In-depth methodological books



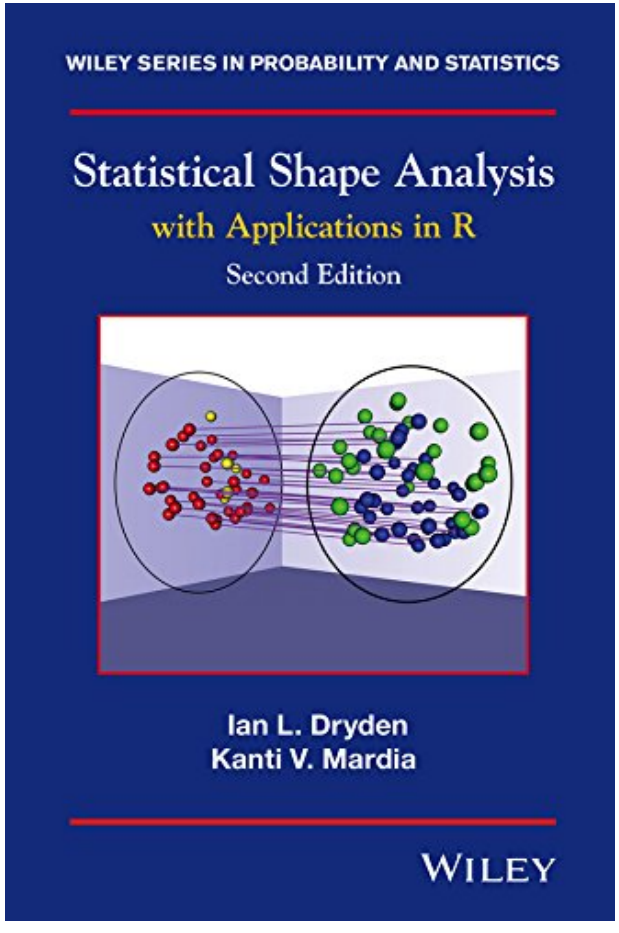


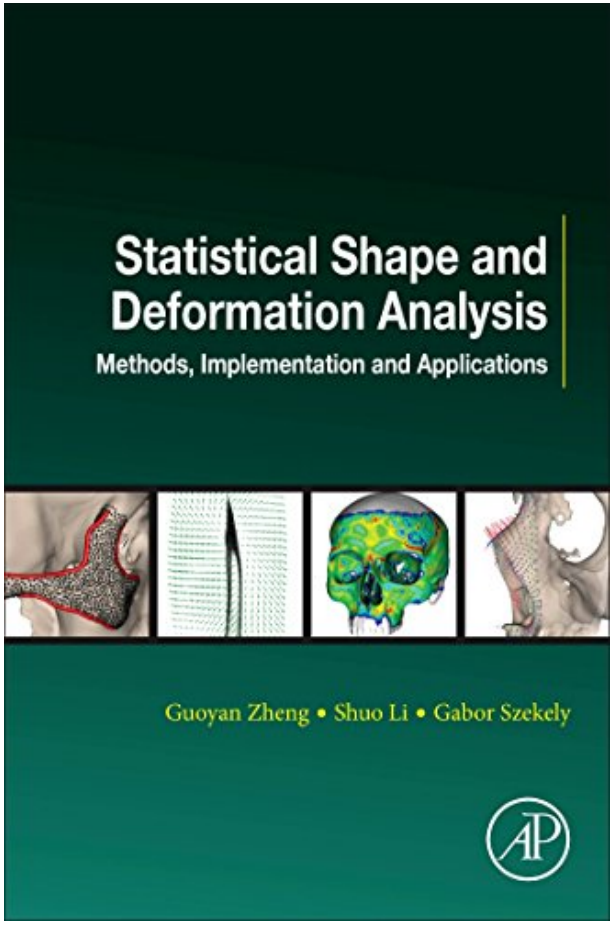
In-depth methodological books





In-depth methodological books





Hardware

Camera

Hardware

Camera

Microscope

Hardware

Camera

Microscope

Surface laser scanner

CT scanner

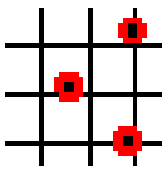
Software

Data extraction

FIJI

Scientific image analysis program

`https://imagej.net/software/fiji/`



tpsDig 2

Geometric morphometrics program

`http://sbmorphometrics.org/soft-dataacq.html`

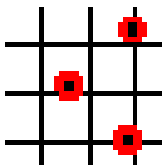
Software

Data extraction

FIJI

Scientific image analysis program

`https://imagej.net/software/fiji/`



tpsDig 2

Geometric morphometrics program

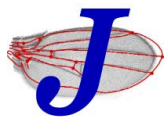
`http://sbmorphometrics.org/soft-dataacq.html`

Data analysis

PAST

General statistics program

`https://tinyurl.com/52ema3f4`



MorphoJ

Landmark analysis program

`https://morphometrics.uk/MorphoJ_page.html`

Software

- Integrated work environment in R
- Allows data extraction and advanced data analysis in a unified framework
- Several available packages:
  - `geomorph`: 2 D/3 D landmark extraction, manipulation, and analysis
  - `shapes`: Landmark analysis
  - `Momocs`: 2 D morphometrics (traditional, outlines, landmarks)
  - `Morpho`: Morphometric deformation analyses
  - `hangler`: Fast Fourier Transform for outline analyses