University of Graz /Landesmuseum Joanneum
July, 2008

Methods in Ostracodology

Geometric Morphometrics

Angel BALTANÁS (UAM, Madrid)
Dan L. DANIELOPOL (ÖAW, Uni-Graz)

We have told each other so often
and with such force and such eloquence
of the uses to which
the study of ostracodes has been applied
that we have overlooked one startling fact:
almost no one uses ostracodes for anything

R.L. Kaesler (1983)

This is a course about

SHAPE

Why SHAPE?

… the Book of Nature is written in character of Geometry

(Galileo Galilei)

William Blake

Information on shape is used for many purposes (taxonomic, ecological, evolutionary,…) because shape resemblance between organisms is expected to reflect:

- ► the degree of relatedness (genetic /phylogenetic similarity),
- ► the existence of similar evolutionary responses to comparable selective pressures or
- ► the by-product of environmentally cued by physiological/developmental processes

But, how can we properly 'measure' shape in an operational way in order to link shape changes to causal cues (be they phylogentic, devlopmental or environmental)?

Aim of this module:

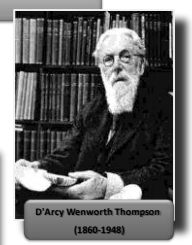
1) to introduce some of the methods available for shape analysis; and

2) to demonstrate that it is feasible to incorporate such morphometric approach into ostracodologists standard working procedures

Structure of this module:

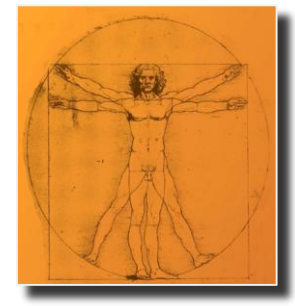
- Geometric Morphometrics *vs.* Traditional Morphometrics: a brief account of terms and concepts
- Some ideas about Landmarks Analysis
- When *landmarks* are not available: different approaches to Outline Analysis
- Practical sessions to work out some examples
- Questions and Discussion

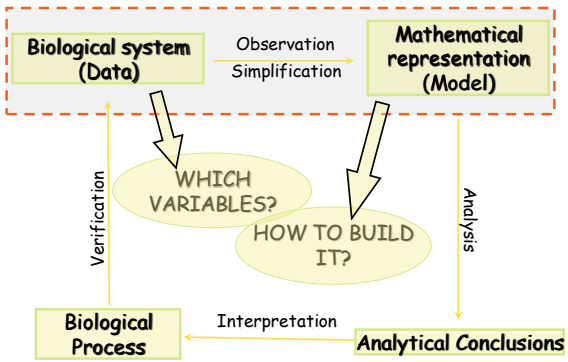
Shape has been a main issue to understand the organic world

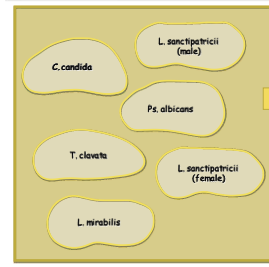


MORPHOMETRICS is:

the quantitative description, analysis and interpretation of shape and shape variation in biology

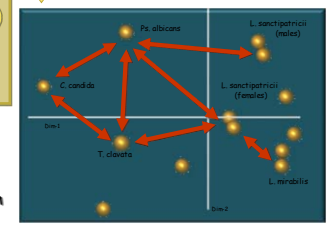






BIOLOGICAL OBJECTS

MORPHOSPACE



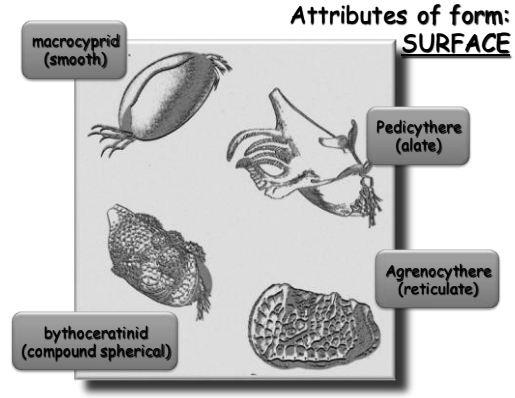
if we can describe a shape with numbers we will be able to use standard numerical techniques for comparing them

Attributes of Form

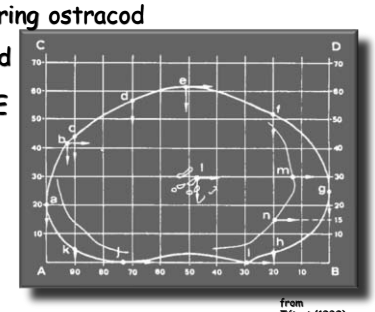
Form = [SIZE, SHAPE, State, Surface, Interior, Substance]

- State - solid, liquid or gas.
- Surface - is characterized with zero thickness and by two primary properties: texture and colour.
- Interior - in addition to texture and colour has thickness. It is normal everywhere to the surface of the form.
- Substance - based on physical properties (hardness, density, mass, elasticity, etc.)

Attributes of form: SURFACE



SIZE can be easily approached (for instance, by measuring ostracod carapace length and height), but SHAPE is a more elusive feature.



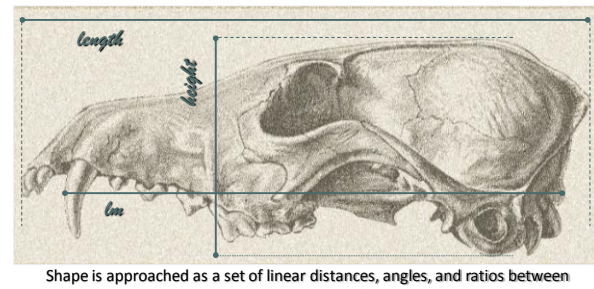
from Tétart (1982)

Indeed,
What is SHAPE?

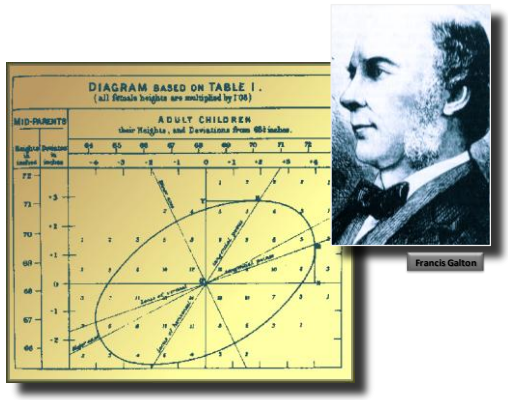
Shape is all geometrical information that remains when location, scale and rotational effects are filtered out of an object

Kendall (1977)

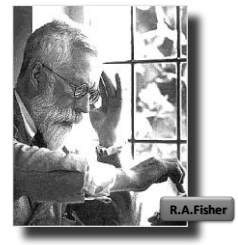
Traditional Morphometrics



Shape is approached as a set of linear distances, angles, and ratios between selected 'homologous' points

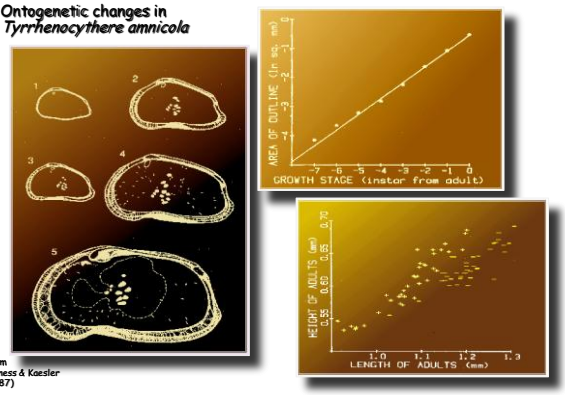


Regression analysis
Discriminant analysis
ANOVA
Path Analysis
Principal Component Analysis

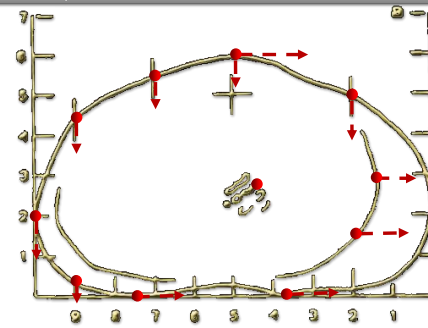


Karl Pearson
Harold Hotelling
G. Udny Yule
P.H.A.Sneath & R.R.Sokal

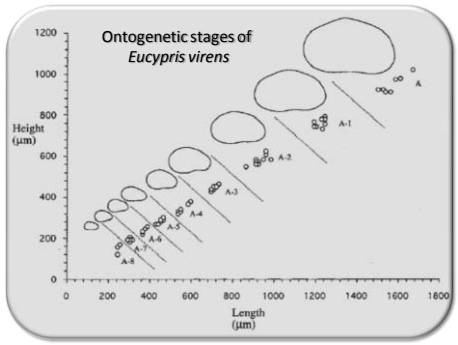
Ontogenetic changes in *Tyrrhenocythere amnicola*



from
Maness & Kaesler
(1987)



Tétart, J. (1982)
Etude de la variation morphologique de la carapace chez Eucypris virens (Ostracode Cyprididé)
Arch. Zool. Exp. et Gén. 122: 341-351
Farkas, H (1974) / Kaesler, RL & Lohmann, KC (1976) / Maddocks, RF (2000)

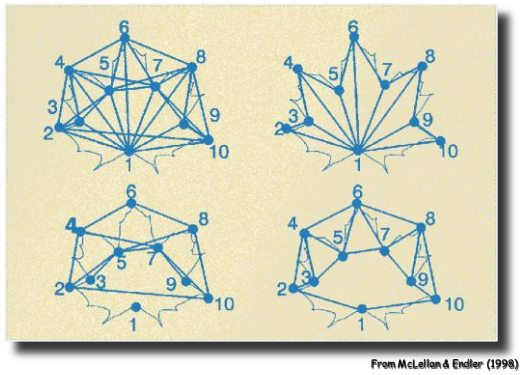


Smith & Martens (2000)

Limitations of the Conventional Metric Approach (=Traditional Morphometrics)

[Data: linear distances, angles, and ratios between selected homologous points]

(1) the choice of CMA contains a large subjective element;



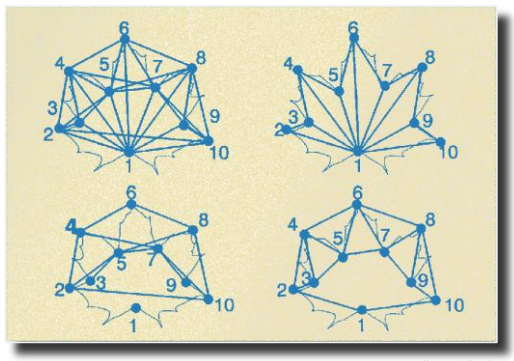
From McLellan & Endler (1998)

Limitations of the Conventional Metric Approach (=Traditional Morphometrics)

[Data: linear distances, angles, and ratios between selected homologous points]

(1) the choice of CMA contains a large subjective element;

(2) the use of CMA precludes the ability to subsequently visually reproduce the form;



From McLellan & Endler (1998)

Limitations of the Conventional Metric Approach (=Traditional Morphometrics)

[Data: linear distances, angles, and ratios between selected homologous points]

(1) the choice of CMA contains a large subjective element;

(2) the use of CMA precludes the ability to subsequently visually reproduce the form; and

(3) the use of homologous points in a CMA dataset represent a very small percentage of the information present in the biological form.

Conventional multivariate techniques

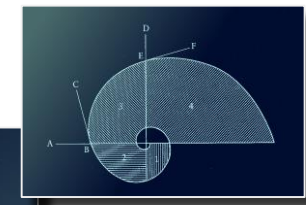
Graphical Analyses of form

Geometric Morphometrics

Landmark Methods (coordinate morphometrics)

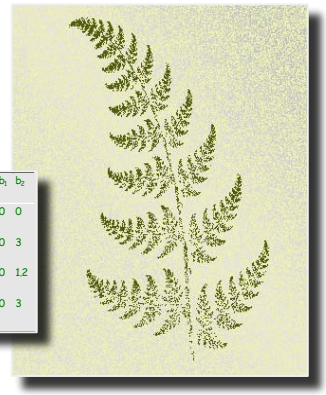
Outline analysis (boundary morphometrics)

On Growth and Form
D'Arcy Wenworth Thompson (1917)

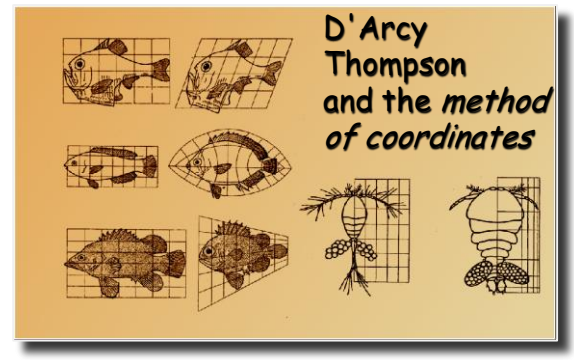


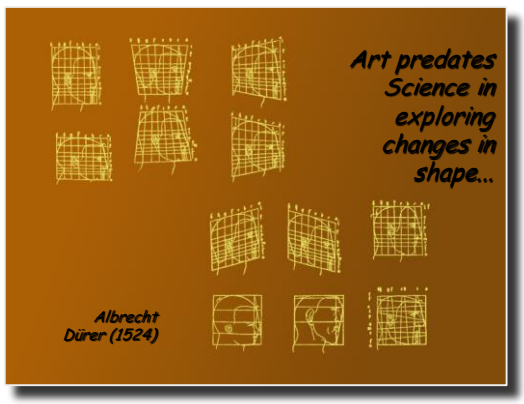
Complex forms may originate from simple principles...

... like the fractal fern



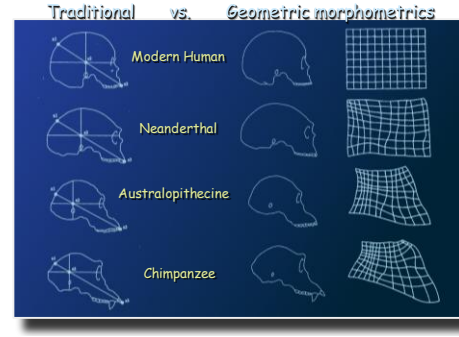
	a_{11}	a_{12}	a_{21}	a_{22}	b_1	b_2
f_1	0	0	0	0.17	0	0
f_2	0.8496	0.025	-0.025	0.8496	0	3
f_3	-0.1554	0.235	0.1958	0.1865	0	1.2
f_4	0.1554	-0.235	0.1958	0.1865	0	3





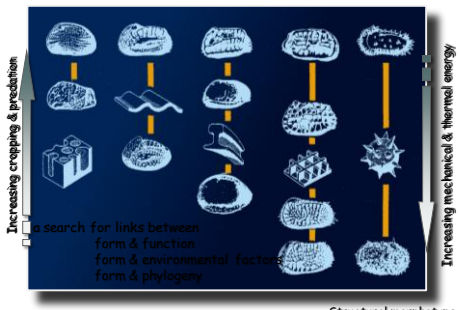
The Geometric approach focuses on comprehensive configurations of points emphasizing their geometric structure

Traditional vs. Geometric morphometrics



(from Oxnard 1984)

The Geometric approach has a long tradition in ostracodology
(Richard H. Benson, Roger L. Kaesler, Richard A. Reyment)



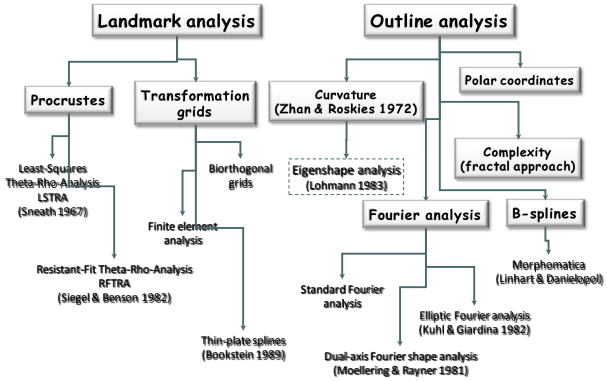
Structural morphotype distribution relative to depth in the sea (Benson 1975)

Two basic options:

- landmark analysis
- outline analysis

shapes are described as configurations of points (=landmarks) associated with the biological form in a meaningful way. Configurations are then compared through different techniques

a function is fitted to the outline of the object and the numerical parameters of the function are used for further analysis and comparisons



Landmarks

a *landmark* is a point of correspondence on each object that matches between and within populations.

[They are special points associated with the biological form in a meaningful way]

Landmarks do not define the form of any edge or surface: they merely provide points of reference on it.

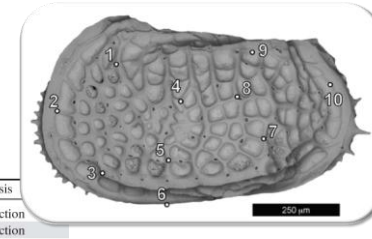
Types of landmarks

(1) anatomical (eye tubercles, sutural junctions): landmarks located at the site of homologous features; or

(2) extremal (most dorsal point, etc.)

Configurations of landmarks

The full set of lanmarks recorded for each specimen



No.	Landmark basis
1	Ridge intersection
2	Ridge intersection
3	Ridge intersection
4	Ridge intersection
5	Ridge intersection
6	Pore location
7	Ridge intersection
8	Ridge intersection
9	Ridge midpoint
10	Pore location

Left valve of *Poseidonamicus pintoi showing location* of 10 landmarks used in morphometric analysis

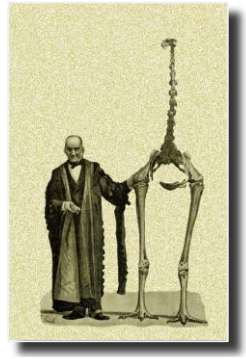
Hunt (2007)

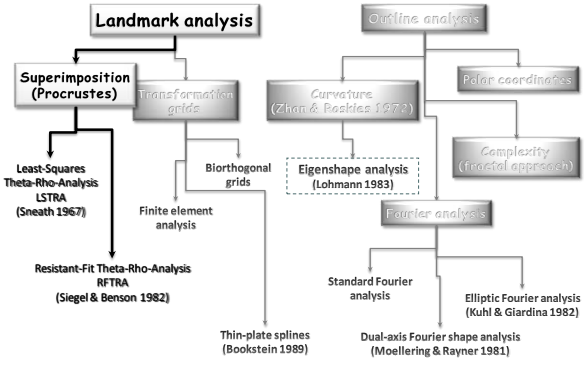
HOMOLOGY

⇨ Point homology (mathematics): landmarks that stand in one-to-one relationship across specimens of the same class.

⇨ *the same organ in different animals* (Owen 1848)

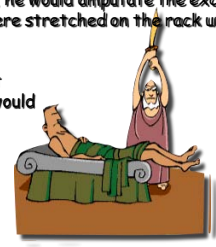
⇨ *resemblance due to inheritance from a common ancestry* (Simpson 1961)



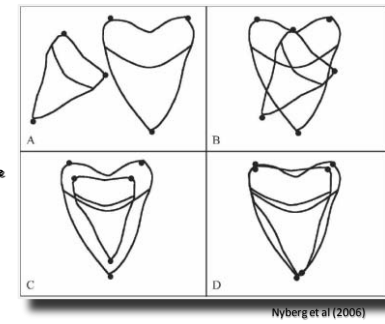


PROCRUSTES (the stretcher),
is a figure from Greek mythology (and possibly the world's first plastic surgeon). He was a bandit from Attica, with a stronghold in the hills outside Eleusis.
There, he had an iron bed into which he invited every passerby to lie down. If the guest proved too tall, he would amputate the excess length; victims who were too short were stretched on the rack until they were long enough.

Nobody ever fit in the bed because it was secretly adjustable: Procrustes would stretch or shrink it upon sizing his victims from afar.

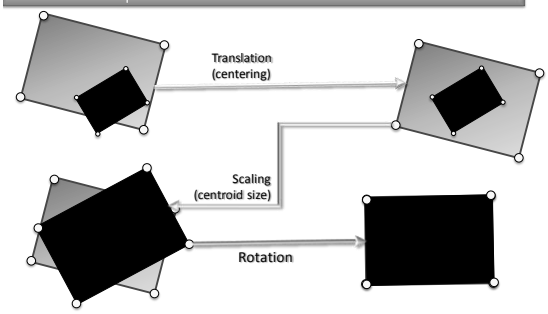


Conventional Procrustean methods allows the analysis of morphology through the superimposition of one morphology onto another using the positions of landmark points



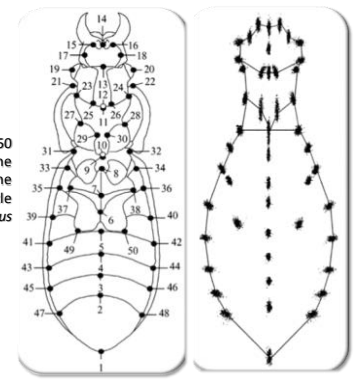
Nyberg et al (2006)

Coordinates in the superimposed specimen (u,v) are transformed (without distortion*) to fit the base specimen by the following.
$u' = T_1 + T_3u - T_4v$
$v' = T_2 + T_4v - T_3v$
T_1 - horizontal translation;
T_2 - vertical translation;
T_3 (= S □ cos□) & T_4 (= S □ sin□) - scaling and rotation
[*- affine or uniform transformations]



Criterion: until the sum-of-the-squared residuals (=distances) between corresponding coordinates in both configurations is minimized
[in other words, this is a least-squares fit]

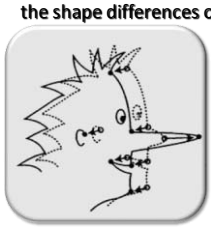
Location of 50 landmarks on the ventral view of the ground beetle *Carabus*



Result of the generalized LS superimposition for the 322 landmark configurations of *Carabus auronitens*

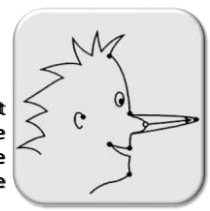
Alibert et al (2001)

The lest-squares (LS) fit provides a vector field that distributes the shape differences over all landmarks.



Nice, except when strong differences occur at one or a few points... the Pinocchio effect!

Under such circumstances, a resistant fit algorithm (based on the computation of medians) is more appropriate

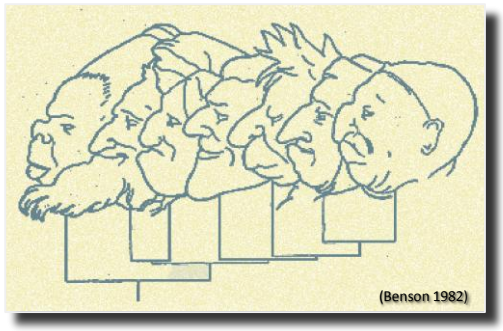


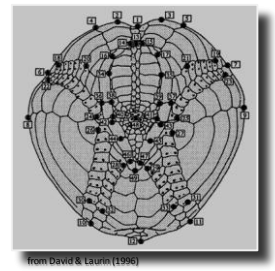
Resistant-Fit Theta-Rho-Analysis
RFTRA
(Siegel & Benson 1982)
Localized change

Least-Squares Theta-Rho-Analysis
LSTRA
(Sneath 1967)
Not localized, general change

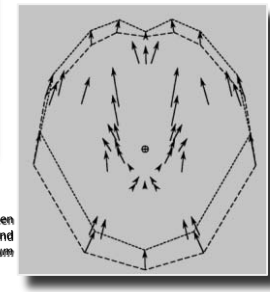
from Chapman (1990)

Resistant-Fit Theta-Rho Analysis
application to the caricatures of Leonardo da Vinci





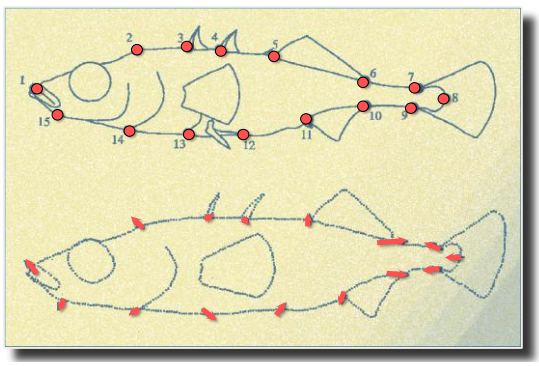
Shape analysis using
Procrustean methods of the sea
urchin *Echinocardium*



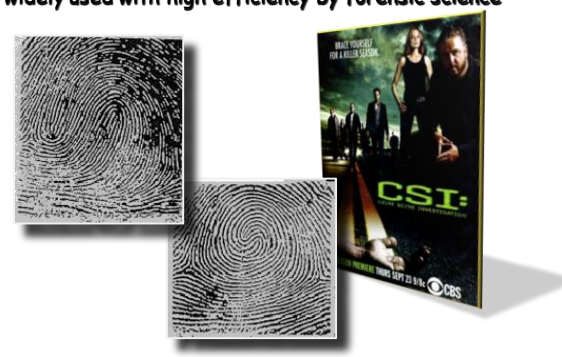
LSTRA analysis of the transition between
52-mm *Echinocardium penatifidum* and
49-mm *E. cordatum*

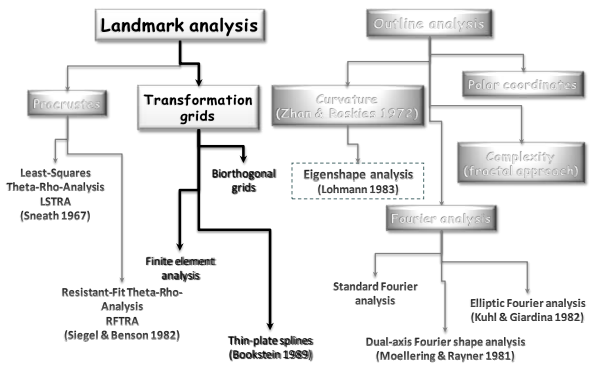
Ontogenetic Allometry of
Gasterosteus aculeatus

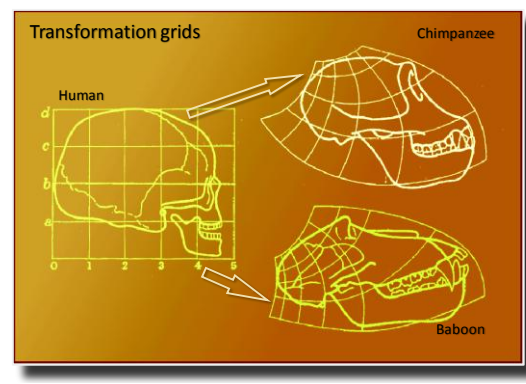
Procrustes superimposition
General Resistant Fit



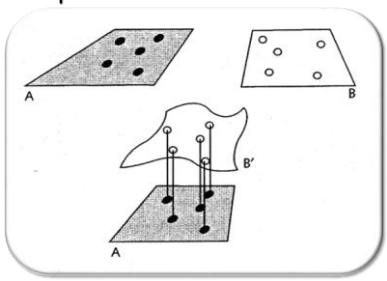
Superimposition (Procrustean) methods have been widely used with high efficiency by forensic science







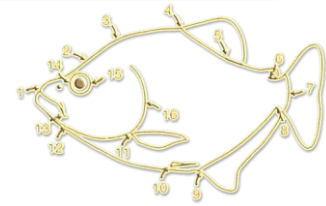
Thin-plate spline



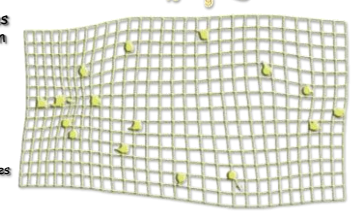
(from David & Laurin 1998)

Configuration B is warped into B' to fit A
The bending energy necessary to achieve the fit of B on A can be measured

Transformation grid-based methods have been applied in many fields too

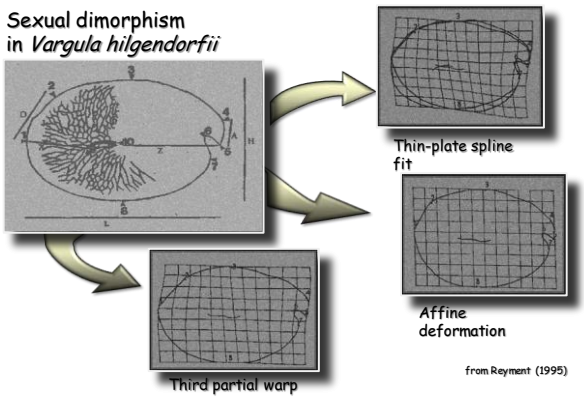


The thin-plate spline visualizes shape change as a deformation over the entire form



Ontogenetic changes in a piranha species (from Zelditch et al. 2004)

Sexual dimorphism in *Vargula hilgendorfii*



from Reyment (1995)

However, when there are no landmarks in our organisms (or they just have few of them which are not easy to work with) …

…well, Outline Analysis is the option