University of Graz /LandesmuseumJoanneum
July. 2008

Methods in Ostracodology

Geometric Morphometrics

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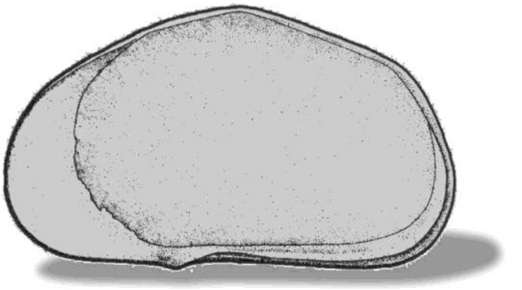
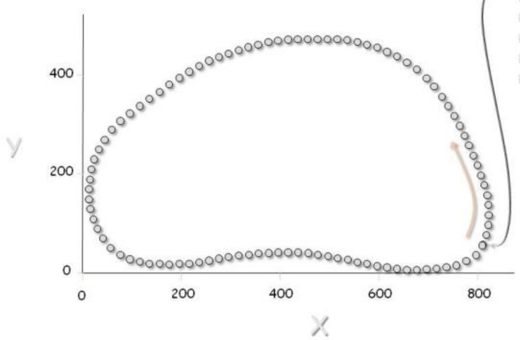
When Outline Analysis is the option



Having the x,y coordinates we can easily plot the outline but is that enough for comparing different outlines?

x	y
807	61
814	81
818	101
819	121
818	141
816	161
...	...
...	...
...	...



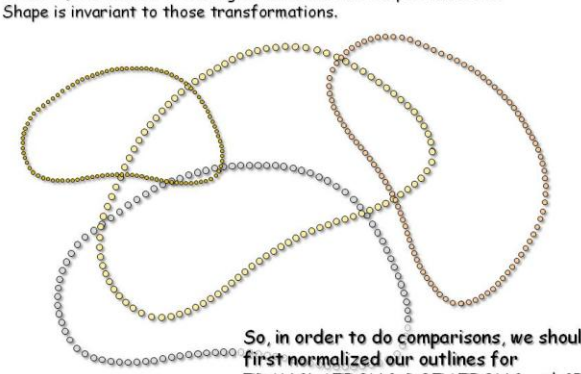
REMEMBER

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

Kendall (1977)

Superimposition might seem a reasonable option for comparing the outlines, but the right solution is not so straightforward ...

Rotation, translation or scaling do not make two shapes different. Shape is invariant to those transformations.

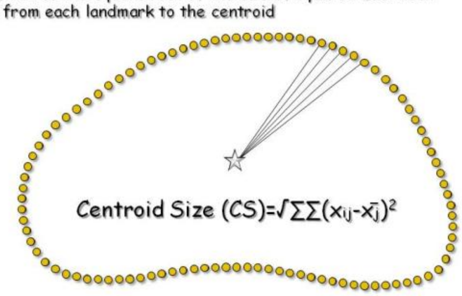


So, in order to do comparisons, we should first normalized our outlines for TRANSLATIONS, ROTATIONS and SIZE

Normalizing for TRANSLATIONS is easy!
Centre all the outlines on their centroid

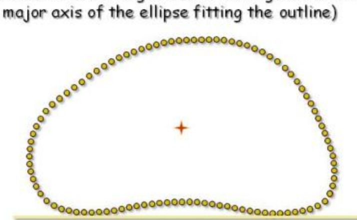
2) Normalizing for SIZE. That's easy too! Re-scale all the outlines according some measure of size (e.g. total length, outline area, centroid size, …)

Given an outline which is described by k-points in m-dimensions, centroid size is defined as the square root of the sum of squared Euclidean distances from each landmark to the centroid

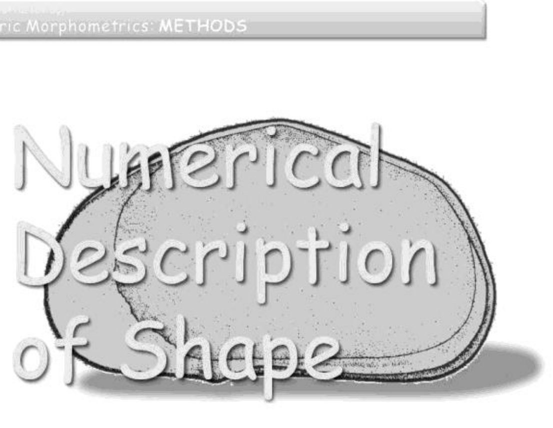


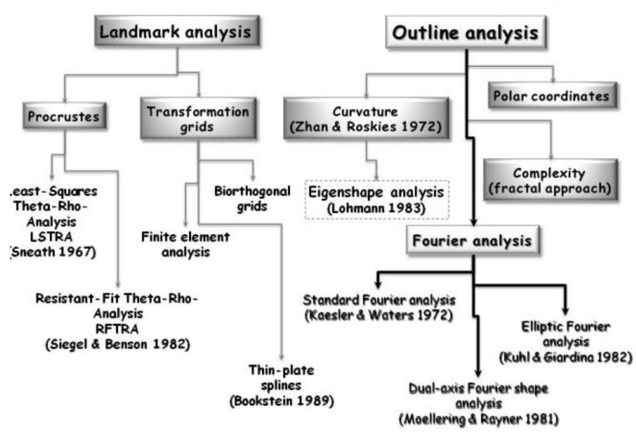
Normalized CS=CS/$\sqrt{k}$

3) Normalizing for ORIENTATION
That's a little more complicated but not too much!
All we need is a kind of base-line recognizable in all specimens so that we can orientate the outline accordingly. That reference line might be the one connecting two landmarks in the organisms or some geometrically derived feature (e.g. the major axis of the ellipse fitting the outline)



Now, it's clear that all the original outlines have indeed the same shape





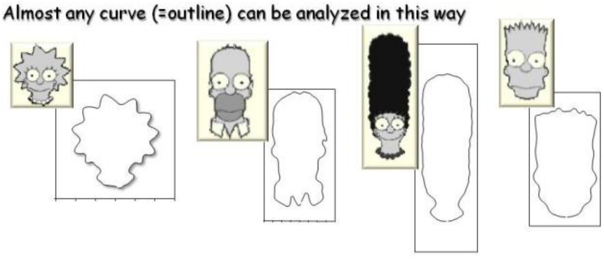
Elliptic Fourier Analysis

Jean Baptiste Joseph Fourier (1768-1830)

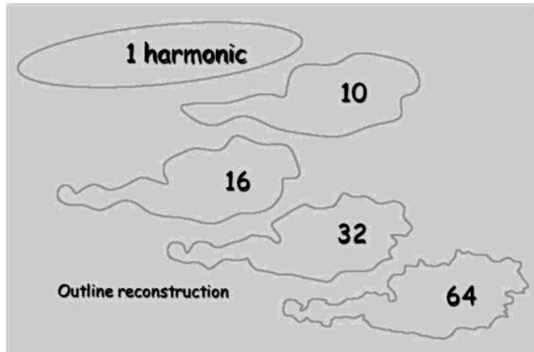
Fourier analysis is a mathematical way of reducing complex curves into their component spatial frequencies

$$x(t) = A_0 + \sum_{n=1}^{N} a_n \cos nt + \sum_{n=1}^{N} b_n \sin nt \qquad y(t) = C_0 + \sum_{n=1}^{N} c_n \cos nt + \sum_{n=1}^{N} d_n \sin nt$$

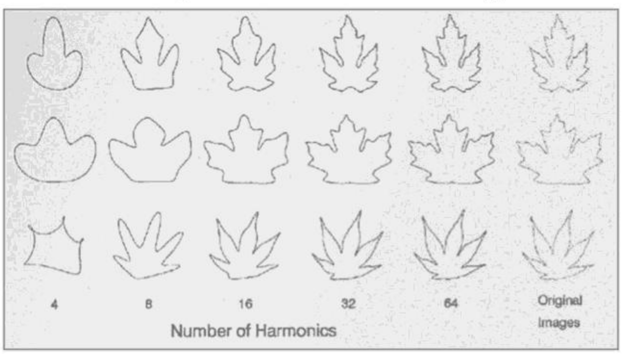
Almost any curve (=outline) can be analyzed in this way



EFA is an information preserving technique

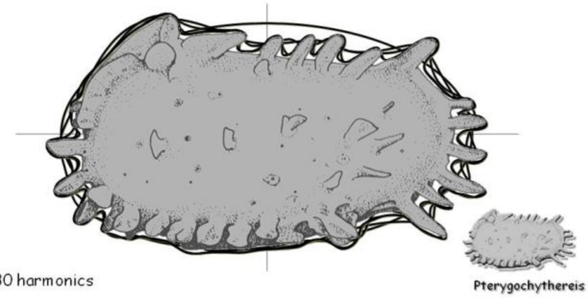


Reconstructing outlines for three different *Acer* spp. leaves



Each of the basic frequencies in which a complex curve is decomposed is called a harmonic. The more complex the outline is the higher the number of harmonics we need to adequately describe it.

[higher order harmonics → higher frequencies → finer details]

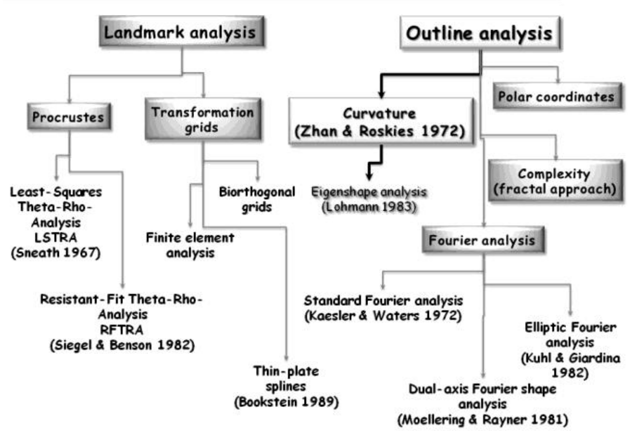


The overall shape of most non-marine ostracods can be properly described with just 10-20 harmonics (=40-80 coefficients)

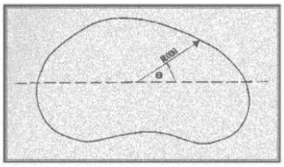
Fourier COEFFICIENTS

	A_1	B_1	C_1	D_1	...
specimen 1	0.732	0.0451	0.569	0.321	
specimen 2	0.265	0.231	0.633	0.597	
specimen 3	0.368	0.789	0.012	0.469	
...	...	...	...	...	

to standard numerical analysis



Polar coordinates



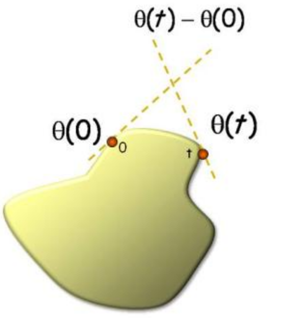
$R(\theta)$: radius vector
θ : polar angle from arbitrary reference line
i : harmonic order
c_i : amplitude of i – th harmonic
θ : phase angle

$$R(\theta) = \overline{R} + \sum_{i}^{n} c_i \cos(i\theta - \theta_i)$$

Zahn & Roskies Algorithm (1972)

$$\phi(t) = \theta(t) - \theta(0)$$

$$\phi^*(t) = \phi(t) - t$$



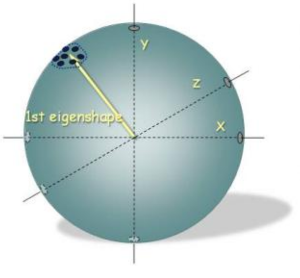
$$\phi^*(t) = A_0 + \sum_{n=1}^{\infty} A_n \cos(nt - \alpha_n)$$

Amplitude $= A_n$

Phase angle $= \alpha_n$

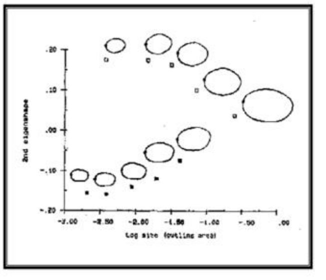
(1) the form of an individual's outline is described in terms of phi-star (ϕ^*) function measured at n ponts;

(2) columns in the dataset containing the values of ϕ^* associated with a single individual are standardize to unit variance;



(3) the matrix of covariances among the standardized ϕ^* shape functions is decomposed to its eigenvectors:

The first eigenshape summarizes the general or shared shape; subsequent eigenshapes represent contrasts in shape.

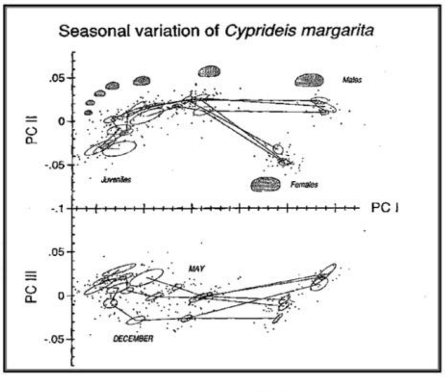


Ontogeny in the fossil ostracod *Cavellina*

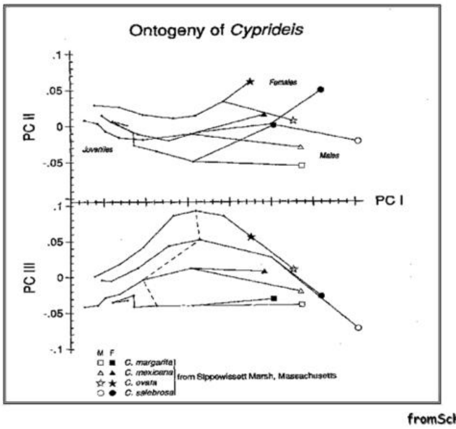
from Schweitzer, Kaesler & Lohmann (1986)

Shape measured as the ϕ^* function of Zahn&Roskies

Shape variation analysis based in eigenshape analysis (with modifications)

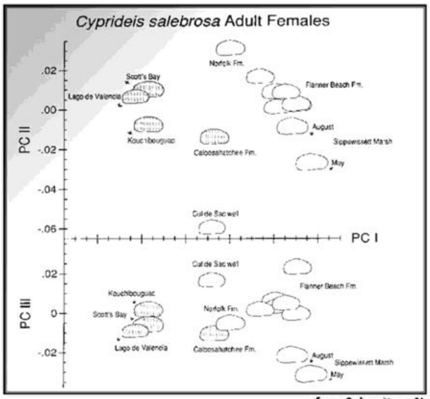


from Schweitzer & Lohmann (1990)



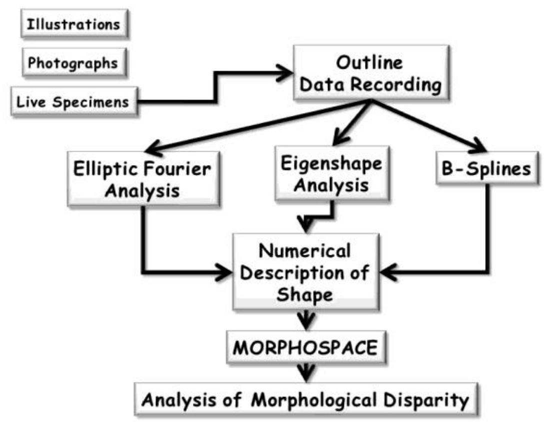
from Schweitzer & Lohmann (1990)

Geometric Morphometrics: EIGENSHAPE ANALYSIS



fromSchweitzer&Lohmann (1990)

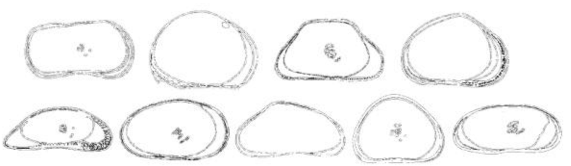
Geometric Morphometrics: METHODS



Geometric Morphometrics: EXAMPLES

Morphological disparity within the Cypridoidea

Morphological disparity: the overall morphological variety within a taxon regardless of the rank of that taxon



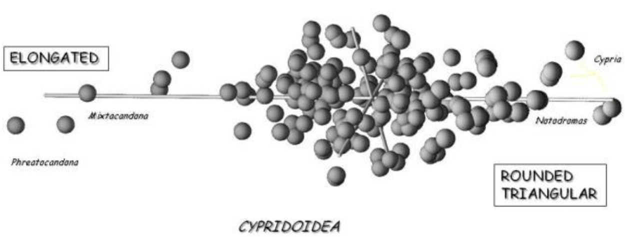
from Sánchez-González et al. (2004)

Geometric Morphometrics: EXAMPLES

Study area

Geometric Morphometrics: METHODS

TheCypridoidean morphospace



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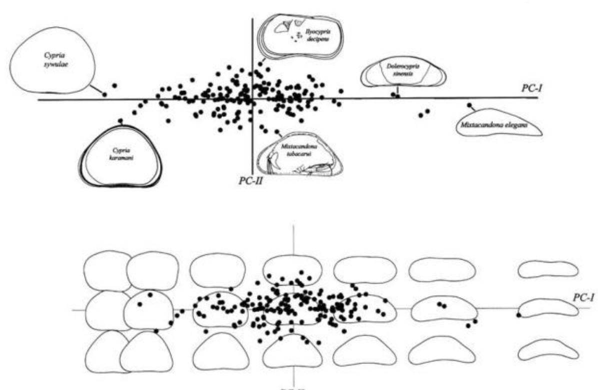
Geometric Morphometrics: EXAMPLES



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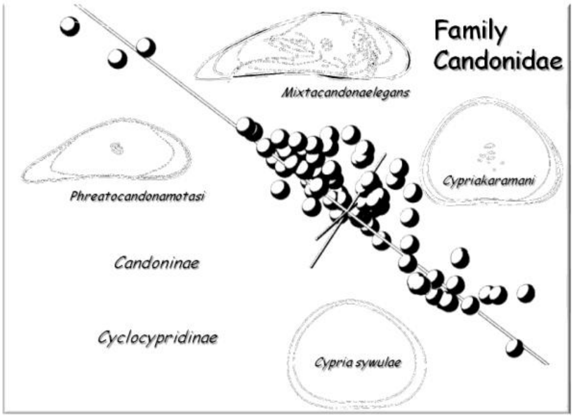
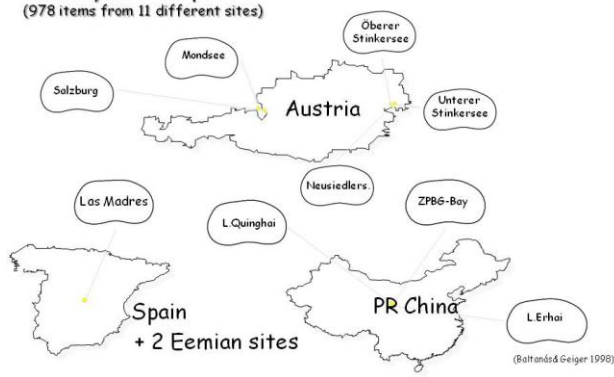
Geometric Morphometrics: EXAMPLES

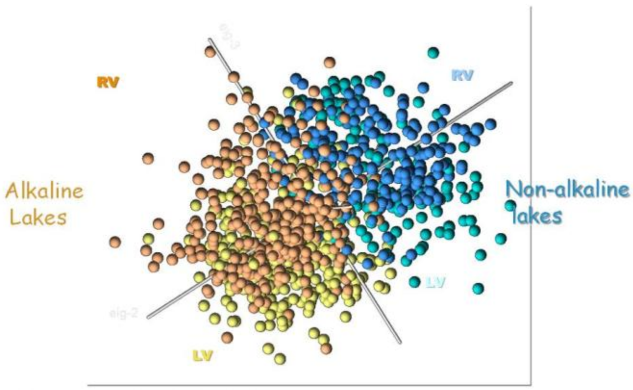


Geometric Morphometrics: EXAMPLES

Limnocythereinopinata
(978 items from 11 different sites)



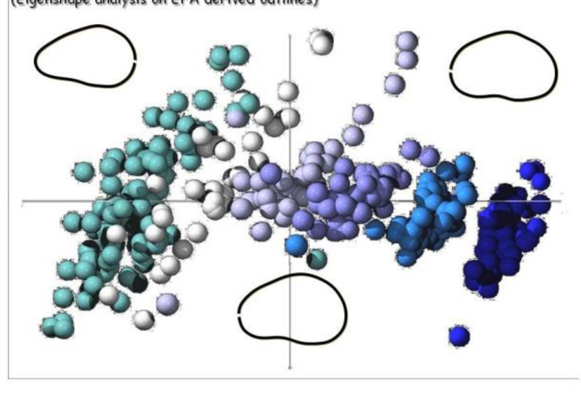
Geometric Morphometrics: EXAMPLES



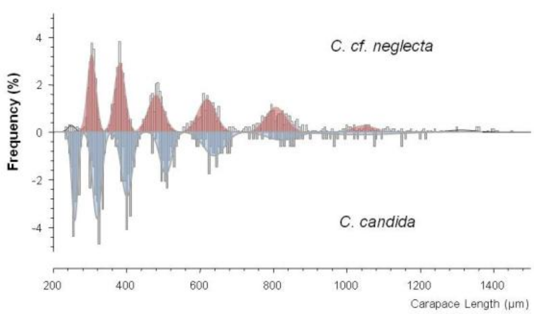
Eigenshapeanalysis on EFA derived outlines

Geometric Morphometrics: EXAMPLES

Eucyprisvirens- Ontogenetic stages
(Eigenshape analysis on EFA derived outlines)

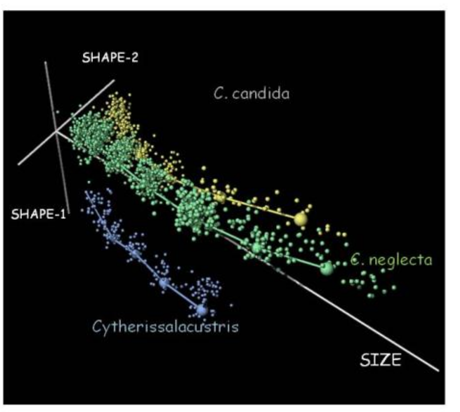


Geometric Morphometrics: METHODS



from Danielopol et al. (2008)

Geometric Morphometrics: EXAMPLES



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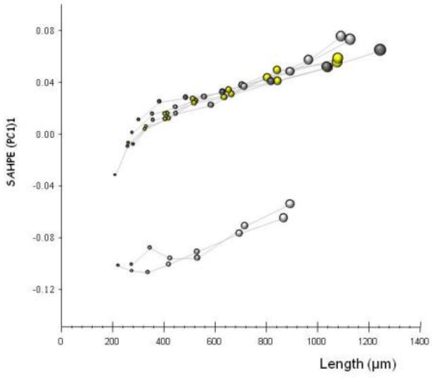

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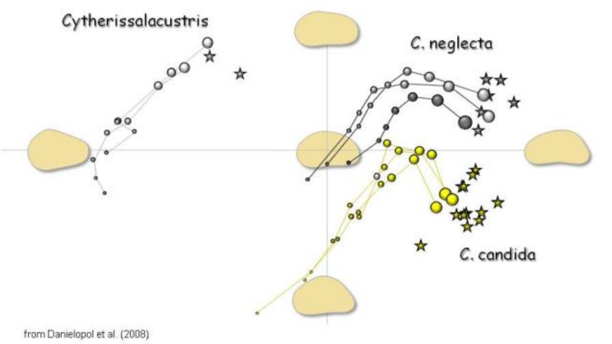
Geometric Morphometrics: EXAMPLES



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