КУНСТКАМЕРА

РОССИЙСКАЯ АКАДЕМИЯ НАУК
МУЗЕЙ АНТРОПОЛОГИИ И ЭТНОГРАФИИ
ИМЕНИ ПЕТРА ВЕЛИКОГО (КУНСТКАМЕРА)
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при поддержке фонда
Династия

30 АПРЕЛЯ – 5 МАЯ 2012
САНКТ-ПЕТЕРБУРГСКИЙ СЕМИНАР ПО ГЕОМЕТРИЧЕСКОЙ МОРФОМЕТРИИ
ДЛЯ АНТРОПОЛОГОВ, БИОЛОГОВ И АРХЕОЛОГОВ

DR. GERMAN MANRIQUEZ. Lecture
"Basics of GMM (Shape and size, Morphospaces and Procrustes analysis, TPS function).

EXCELLENCE IN SCIENCE
THE ROYAL SOCIETY

PROYECTO ANILLO ACT-96
Programa de Investigación Asociativa de CONICYT

Geometric morphometrics: Internet resources

Morphometrics
at SUNY Stony Brook

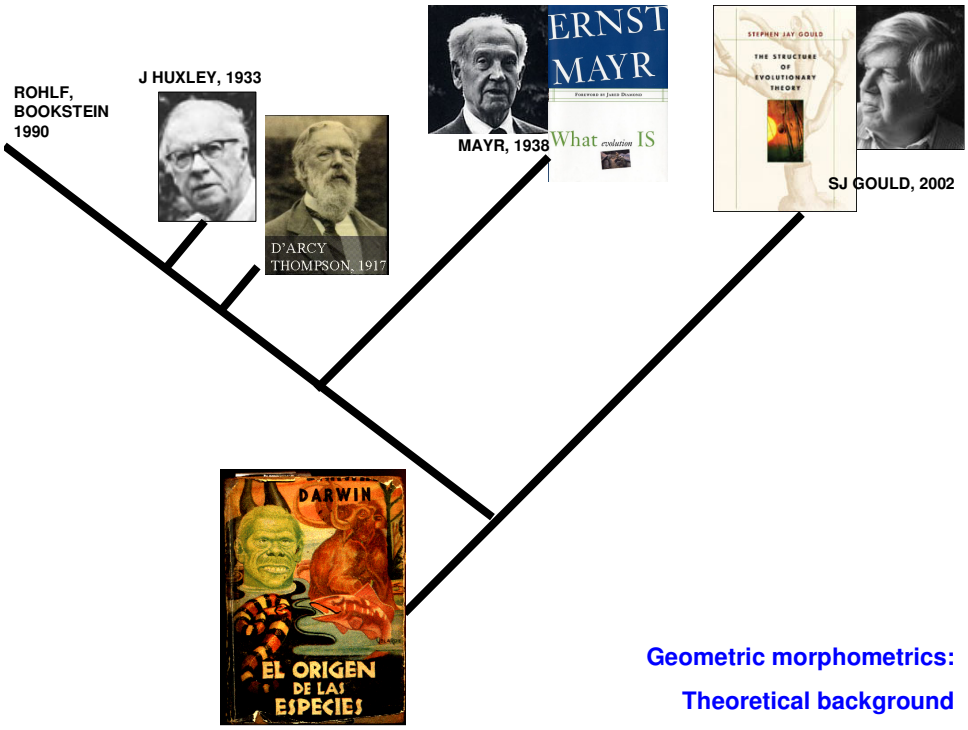
http://life.bio.sunysb.edu/morph/

- Meetings
- Softwares, Data adquisition
- Books
- Glossaries

Functional Morphology and Evolution, Hull York University, UK

http://www.york.ac.uk/res/fme/index.htm

- Paul O'Higgins Lab
- Research
- Morphologika download



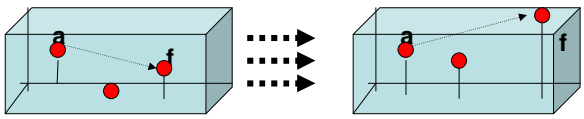
Geometric morphometrics:

Theoretical background

MAP FUNCTION IN MORPHOMETRY

Distance & homology

"Morphometric distances express the patterns of relative location among the parts of one organism in comparison with those of another" **("Distances" and distances, after Bookstein 1991 (Ch. 3)**



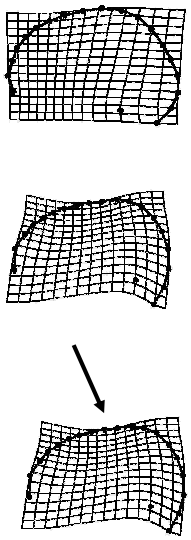
"What we are measuring is ultimately a matter not of shape but of homology. To pass from the biological to the biometrical context, homology must be considered as a mapping function, a correspondance relating points to points rather than parts to parts" (idem)

LANDMARK'S DEFINITION

LM= ***Discrete anatomical loci that can be recognized as the same loci in all specimens in the study"*** **(Zelditch, 2004, Ch. 2)**

LM= ***A specific point on a biological form or image of a form located according to some rule. Landmarks with the same name, homologues in the purely semantic sense, are presumed to correspond in some sensible way over the forms of a data set "*** **(Slice, Rohlf, Bookstein. Glossary…)**

LM= ***The points at which one's explanations of biological processes are grounded (…) the boundary points between organ and organ or between organism and organism, at which our epigenetic explanations adhere"*** **(Bookstein, 1991)**



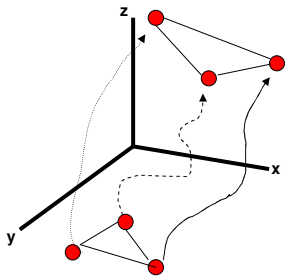
PROPERTIES OF LANDMARKS OF COORDINATES

Landmarks are anatomically /evolutionary, functionally, structurally, ontogenetically/ homologous (O'Higgins 2000)

For Mathematics biological change is interpreted as a deformation= a smooth mapping of one set of points to *corresponding* points in another form.

In Maths, Homology means correspondence point to point, in Biology instead, it means a correspondence among two or more structures (the region in between the points, but not the points themselves)

They are explaining the change ierarchically : Type I, Type II, Type III, sensu Bookstein. After Zelditch et al interpretation, they can be assumed as anchoring different amounts of biological spaces rather than logical explanations (implies forces acting onto them)



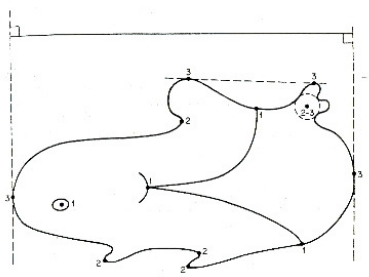


Figure 3.3.1. The three types of landmarks. Type 1: Juxtapositions of tissues. Type 2: Maxima of curvature. Type 3: Extremal points.

(Zelditch et al, 2005)

SUPERPOSITION METHODS

Bookstein shape coordinates

52 GEOMETRIC MORPHOMETRICS FOR BIOLO(

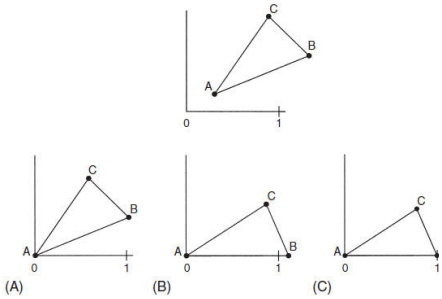


Figure 3.1 Three operations that do not alter shape, applied to a triangle: (A) trans (B) rotation; (C) rescaling.

$$SC_x = \frac{(B_x - A_x)(C_x - A_x) + (B_y - A_y)(C_y - A_y)}{(B_x - A_x)^2 + (B_y - A_y)^2}$$

$$SC_y = \frac{(B_x - A_x)(C_y - A_y) - (B_y - A_y)(C_x - A_x)}{(B_x - A_x)^2 + (B_y - A_y)^2}$$

SIMPLE SIZE AND SHAPE VARIABLES: BOOKSTEIN SHAPE COORDINATES 53

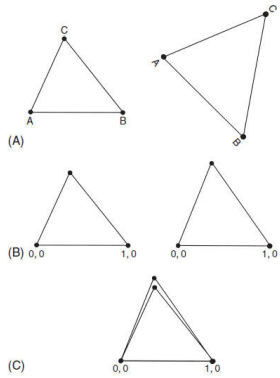


Figure 3.2 Two triangles whose shape difference is the subject of investigation: (A) the two triangles as initially recorded; (B) the same two triangles after being translated, rotated and rescaled by the two-point registration; (C) the same two triangles, superimposed.

Do these triangles differ in shape?

(Zelditch et al, 2005)

SUPERPOSITION METHODS

Bookstein shape coordinates

54 GEOMETRIC MORPHOMETRICS FOR BIOLOGISTS

any two points as the endpoints of the baseline (A and B); we will discuss how to choose them later.

1.	54.00000	306.00000
2.	223.00000	447.00000
3.	632.00000	300.00000

Now take the next three coordinate pairs, and draw that triangle:

1.	11	342
2.	251	520
3.	769	318

Now draw both triangles using the same baseline (with point A and B superimposed), and draw the vector extending between the one free (C_{xy}) landmark on both of the triangles. That vector is the shape variable describing the difference between the triangles.

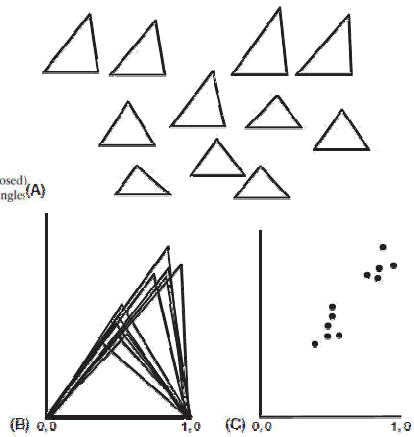
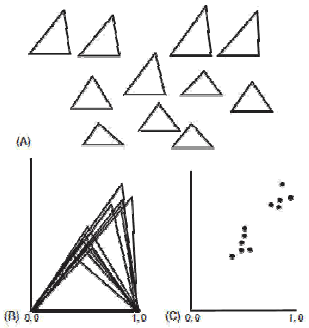


Figure 3.3 Comparing shapes of triangles: (A) the collection of triangles whose shape differences are the subject of investigation; (B) the same collection of triangles, put in a common coordinate system by the two-point registration; (C) scatter-plot depicting the location of the free landmark.

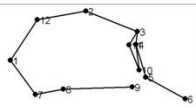
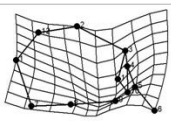
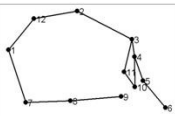
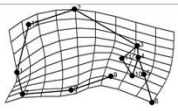
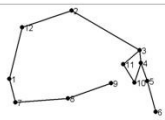
(Zelditch et al, 2005)

Bookstein shape coordinates limitations: they do not answer to the question how do landmarks change during the transformation of the objects?



Thon-plate spline function allows to describe visually the changes occuring during the transformation

(Manríquez, 2009)

				
Pan troglodytes adulto	Energia de torsión= 1.17	*Pan troglodytes* juvenil	Energia de torsión= 0.33	*Homo sapiens* adulto

SHAPE AND SIZE

Procrustes fitting

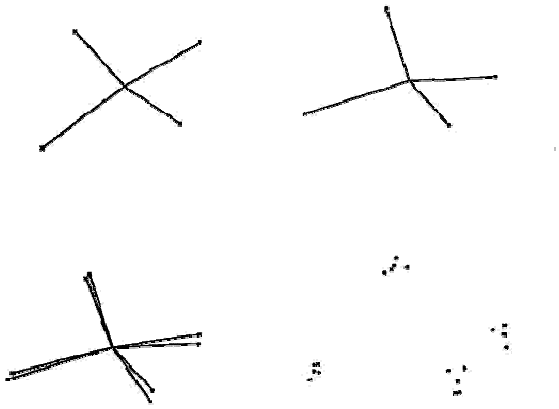


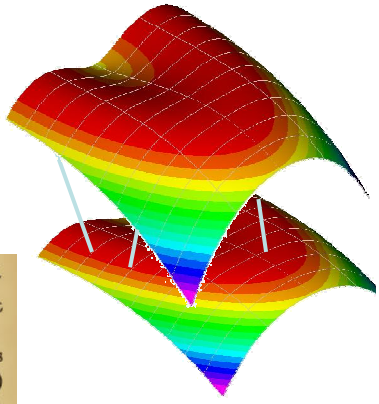
Figure 1. Geometry of Procrustes fits. Upper row: Two forms with four landmarks. Center row: Each form is scaled to unit Centroid Size (sum of squared distances from the centroid to the landmarks). Lower left: The centroids are superposed and then one form is rotated over the other to a position of least squared differences between the homologues. Lower right: If the fixed form is a sample average shape (see text), vectors of displacement in Procrustes space, shown here as four scatters around the average (dots), serve as one set of shape coordinates for the sample of forms. These coordinates total eight (four sets of two), which is four in excess of the actual dimension of the shape space of a quadrilateral.

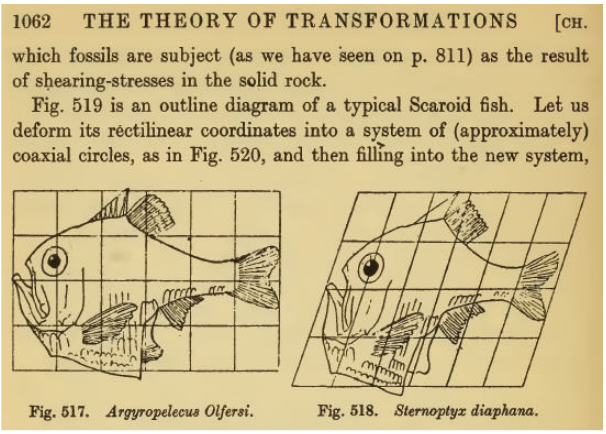
(Zelditch et al, 2005)

The model: the thin-plate spline

The parameter: Shape changes

The variable: Bending energy. It's the mean value of the local vectors's change in magnitude and direction when they are superposed to the homologous landmarks located on a new object





1062 THE THEORY OF TRANSFORMATIONS [CH.

which fossils are subject (as we have seen on p. 811) as the result of shearing-stresses in the solid rock.

Fig. 519 is an outline diagram of a typical Scaroid fish. Let us deform its rectilinear coordinates into a system of (approximately) coaxial circles, as in Fig. 520, and then filling into the new system,

Fig. 517. *Argyropelecus Olfersi.* Fig. 518. *Sternoptyx diaphana.*

¿Qué es una deformación?

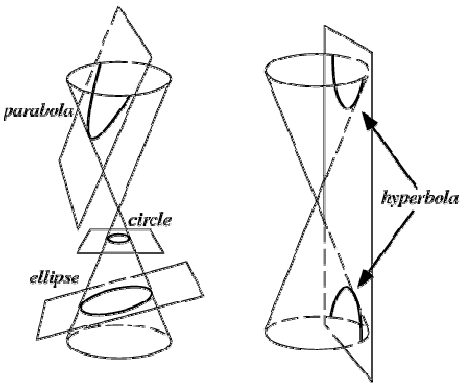
Es una función que mapea hitos en una forma que se corresponden con los hitos uicados en otra forma, es decir, una función tal que posee continuidad geométrica

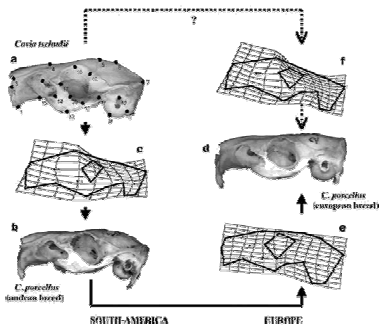
Las cinco secciones de un cono como cinco versiones diferentes de una misma forma

La línea como círculo de radio infinito: $x = \infty$ sea un punto en el círculo, $x = +\infty$ and $x = -\infty$ sean idénticas

El cambio de la forma no es una deformación cuando dicho cambio se concentra en un sólo hito…

La grilla es un gráfico que describe el desplazamiento de los hitos discretos en deformación





(Spotorno et al, 2007)

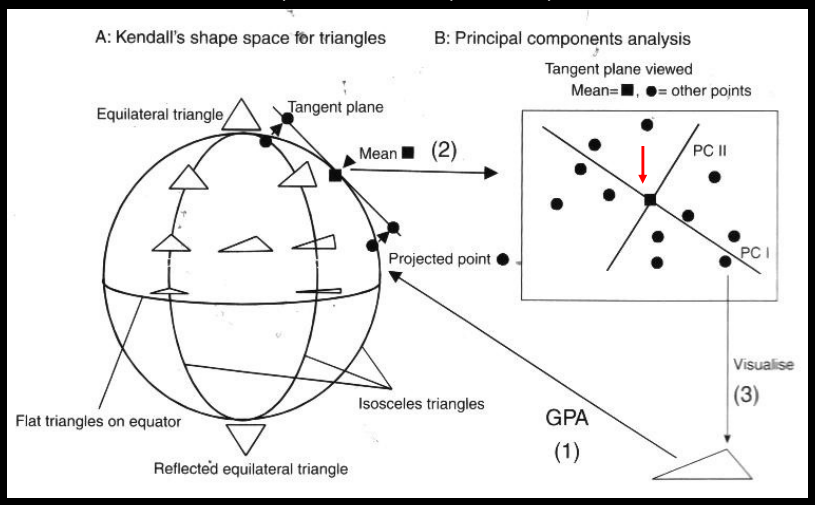
Remoción de diferencias de escala, rotación y traslación (Análisis de Procrustes generalizado)

Obtención de configuración de consenso

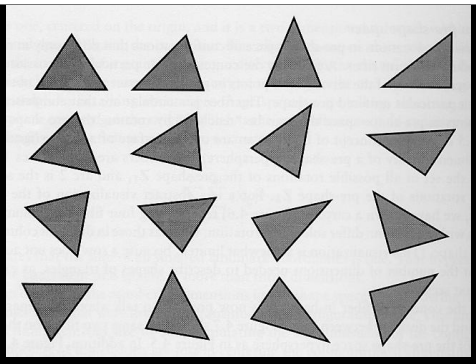
Proyección ortogonal de matrices alineadas (Relative warp analysis)

Función de placa delgada para interpolar los datos de la variación no uniforme.

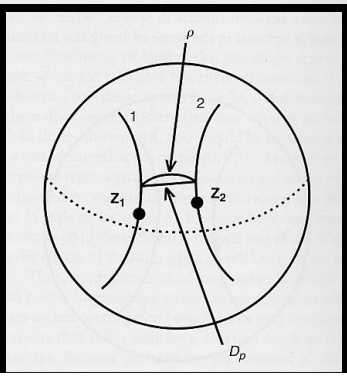
Sus componentes son los partial warps

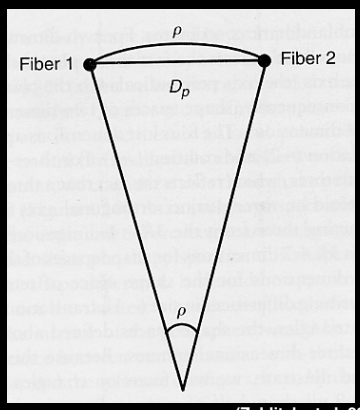


O'Higgins, 2000



pre-shape space





(Zelditch et al, 2005)

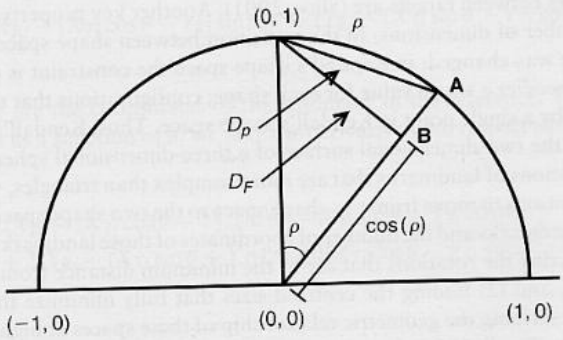


Figure 4.10 A slice through part of the space of aligned triangles at unit centroid size, showing the relationships among the distances between the reference shape (at 0, 1) and A. The semicircle is a cross-section of the space, which is a hemisphere of radius one. The length of the arc is the Procrustes distance (ρ), the length of the chord is the partial Procrustes distance (D_ρ), and the shortest possible distance (obtained by relaxing the constraint on centroid size, producing the configuration B) is the full Procrustes distance (D_F).

(Zelditch et al, 2005)

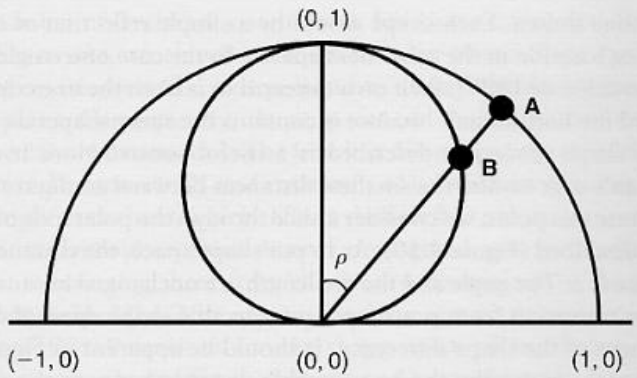
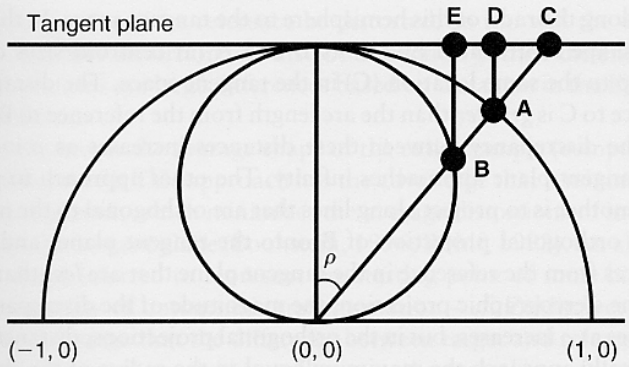


Figure 4.11 The relationship of Kendall's shape space to the space of aligned triangles scale unit centroid size. The outer semicircle is the cross-section of the space of aligned triangles sc to unit centroid size, as in Figure 4.10. The inner circle is a cross-section through Kendall's sl space, which is the sphere of aligned triangles scaled to cos(ρ). Kendall's shape space has a radii one-half. Points A and B represent the same shape at $CS = 1$ and $CS = \cos(\rho)$, respectively.

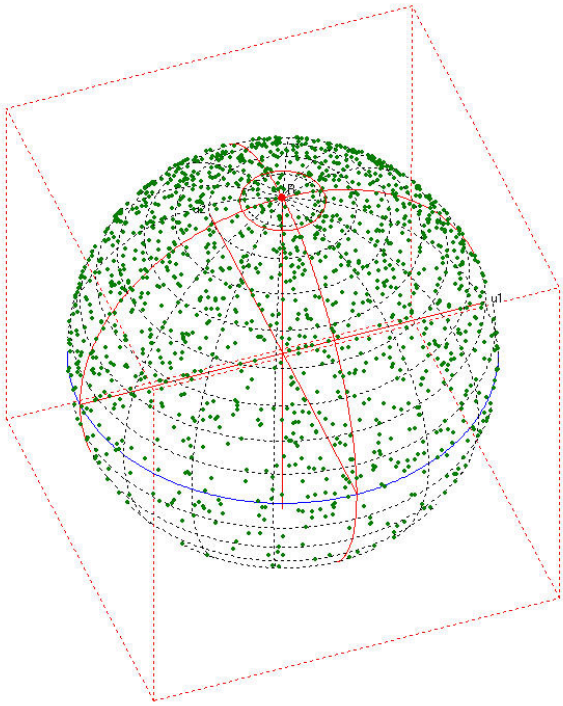
(Zelditch et al, 2005)

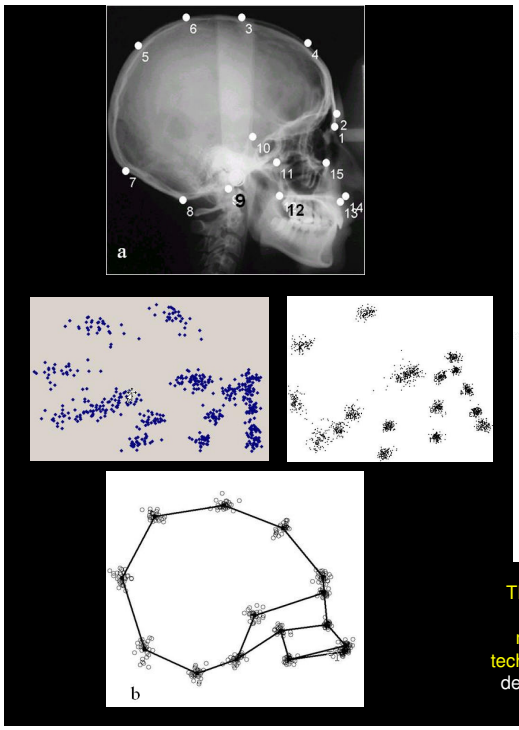


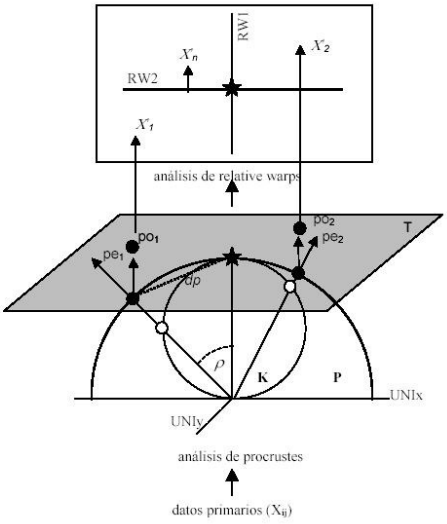
re 4.18 Tangent space to shape spaces of triangles and projections onto the tangent space. As gure 4.11, the outer hemisphere is a section through the space of centered and aligned shapes d to unit centroid size, and the inner circle is a section through Kendall's shape space of centered aligned shapes scaled to cos(ρ). The plane is tangent to the sphere and the hemisphere at the t of the reference shape. The configuration at point B represents a triangle in Kendall's shape e; A is the same shape scaled to unit centroid size. C is a stereographic projection of B onto the ent plane. D is the orthogonal projection of A onto the tangent plane, and E is the orthogonal ction of B onto the tangent plane.

(Zelditch et al, 2005)

Population character of GM data





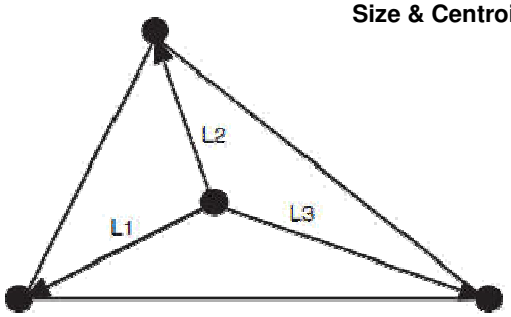


The methods: In order to avoid these limitations and to know the pattern of skull shape variation, geometric morphometric methods and craneofacial radiographic technics were applied on non deformed and intentionally deformed samples of Arica's archeological populations.

(Manríquez, 2006)

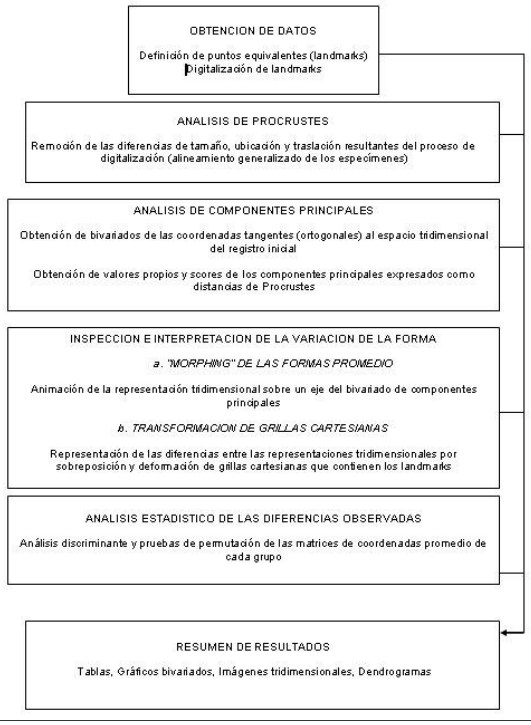
FORMA Y TAMAÑO EN MORFGEOM

Size & Centroid size



Cálculo del tamaño del centroide (centroid size):
-calcular el centroide, ubicado en el punto medio de las coordenadas. Corresponde al promedio de las coordenadas en X, y al promedio de las coordenadas en Y (X, Y)
-Para
(0, 0), (1, 0), (0.3, 0.8)
(X, Y)= (0.433, 0.267)
-Luego, se calcula la distancia cuadrática de cada coordenada al centroide: (Xi – X)^2 + (Yi – Y)^2
(0 – 0.433)^2 + (1 – 0.433)^2 + …
-Se obtiene una medida del área. Se lineariza obteniendo la raíz cuadrada de ese valor cuadrático, y tenemos el valor del tamaño del centroide (raíz cuadrada de la suma cuadrática de las coordenadas de cada hito respecto de las coordenadas del centroide)

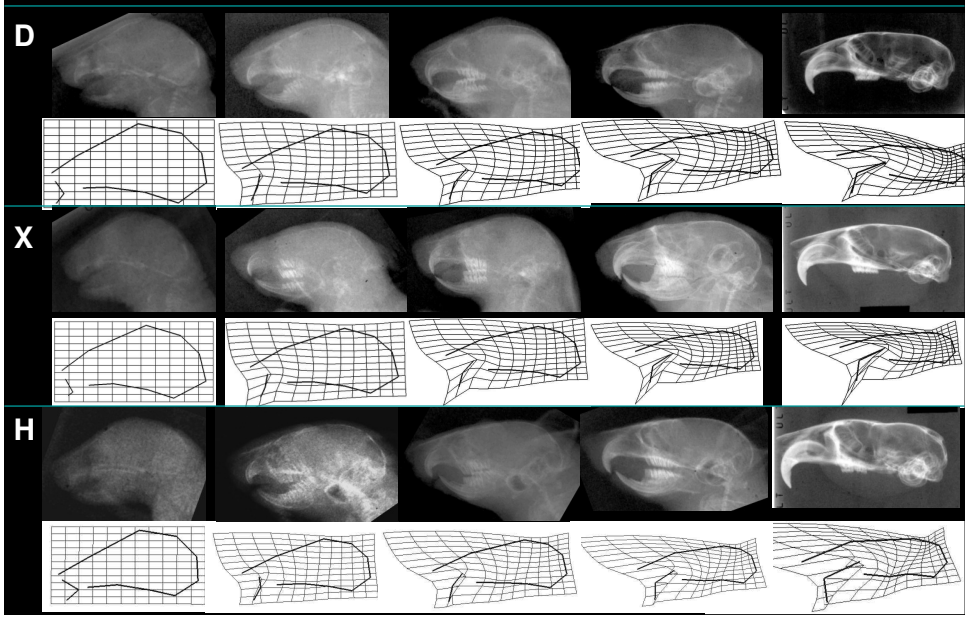
tpsDIG



(Manríquez, 2006)

(Manríquez, 2004)

Trayectoria ontogénica del cráneo de *P. darwini* (D), *P. xanthopygus* (X) e híbridos (H)



tpsRelWarp

OBTENCION DE DATOS

Definición de puntos equivalentes (landmarks)
Digitalización de landmarks

ANALISIS DE PROCRUSTES

Remoción de las diferencias de tamaño, ubicación y traslación resultantes del proceso de digitalización (alineamiento generalizado de los especímenes)

ANALISIS DE COMPONENTES PRINCIPALES

Obtención de bivariados de las coordenadas tangentes (ortogonales) al espacio tridimensional del registro inicial

Obtención de valores propios y scores de los componentes principales expresados como distancias de Procrustes

INSPECCION E INTERPRETACION DE LA VARIACION DE LA FORMA

a. "MORPHING" DE LAS FORMAS PROMEDIO

Animación de la representación tridimensional sobre un eje del bivariado de componentes principales

b. TRANSFORMACION DE GRILLAS CARTESIANAS

Representación de las diferencias entre las representaciones tridimensionales por sobreposición y deformación de grillas cartesianas que contienen los landmarks

ANALISIS ESTADISTICO DE LAS DIFERENCIAS OBSERVADAS

Análisis discriminante y pruebas de permutación de las matrices de coordenadas promedio de cada grupo

RESUMEN DE RESULTADOS

Tablas, Gráficos bivariados, Imágenes tridimensionales, Dendrogramas

(Manríquez, 2006)

tpsRelWarp
tpsReg

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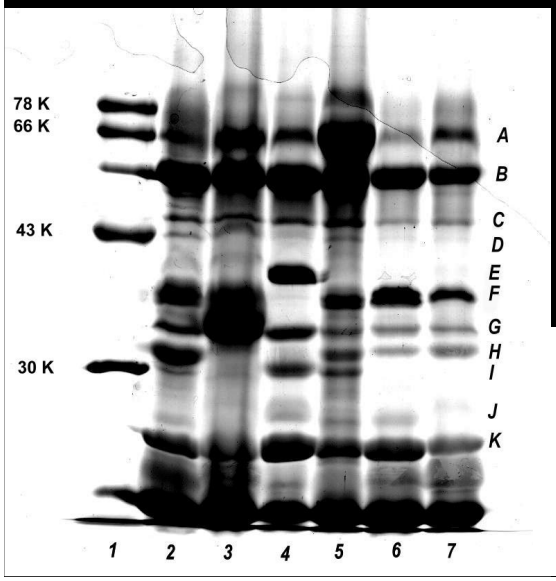
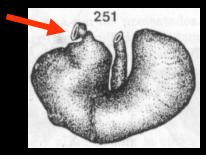
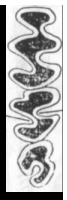
(Manríquez, 2006)

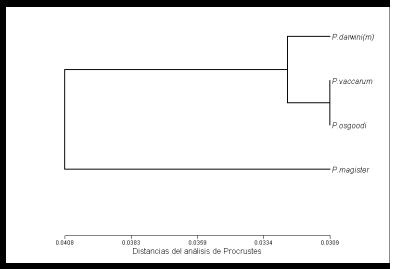
Hipsodontía y herbivoría progresiva debieran tener un correlato funcional, y no sólo anatómico (hipótesis *ad-hoc*, análisis *a posteriori*)

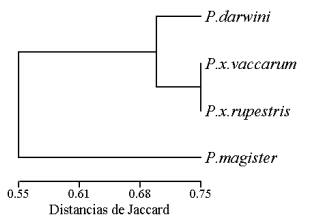
(Manríquez, 2004)





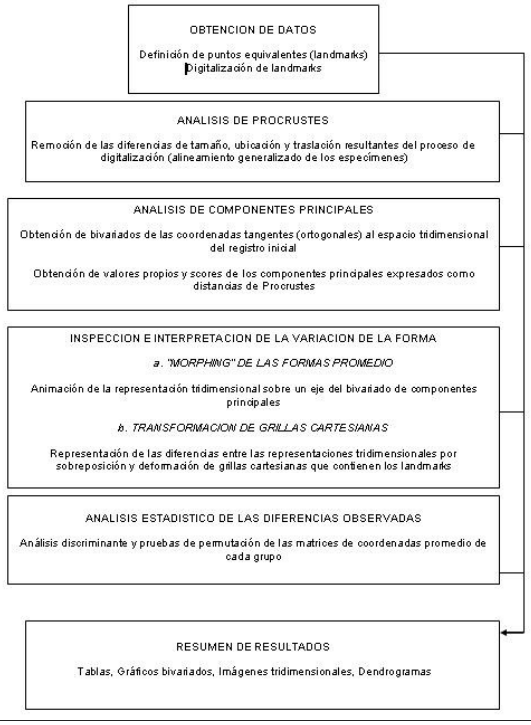






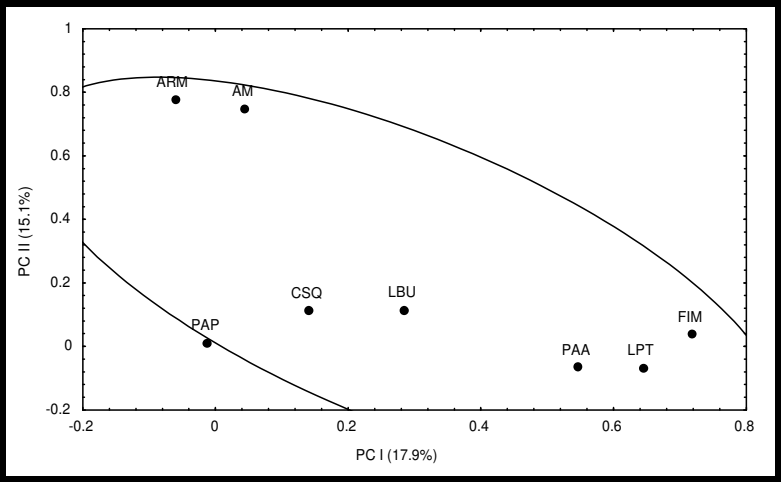
tpsRelWarp

tpsReg



(Manríquez, 2006)

Eigenloads for variables explaining main variation of masticatory apparat (FIM, ARM, AM1). They are also trhe less asymetric.



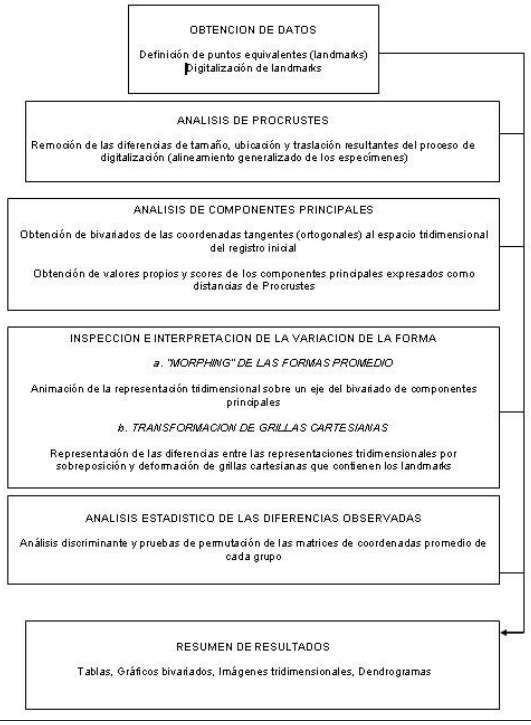
CANALIZATION OF THE STRUCTURES OF THE MASTICATORY APPARAT?

(Manríquez, 2004)

tpsReg

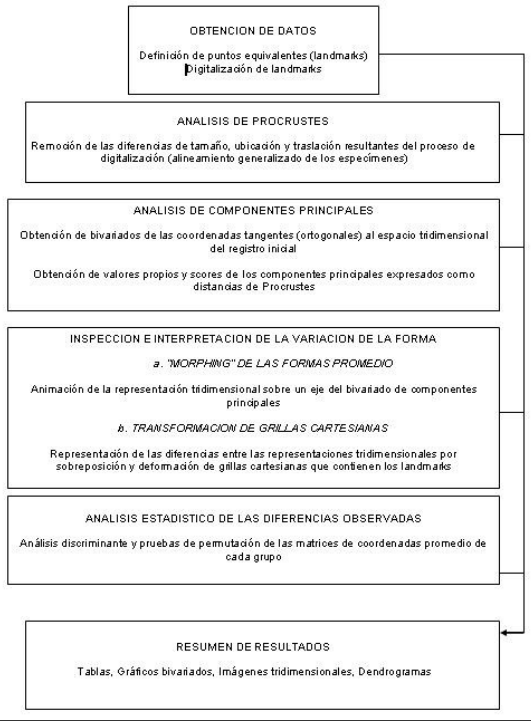
tpsSmall

SPSS, SAS, Statistica, etc



(Manríquez, 2006)

Tps,
Morphologika



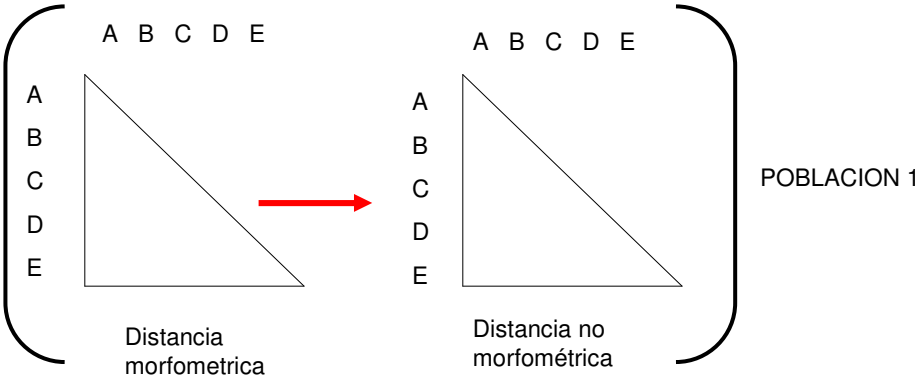
(Manríquez, 2006)

La concordancia taxonómica como función de mapa

Concepto de matriz de distancias (matrices rectangulares

Uso de matrices de distancias de Procusto y configuraciones de consenso en análisis de concordancia (tpsRelwarp tpsSmall)

Puesta a prueba de hipótesis con Mantel-test



+ Mantel-test (pruebas de permutación)

(Manríquez, 2009)