A new 3D morphometric method based on a combinatorial encoding of 3D point configurations: application to skull anatomy for clinical research and physical anthropology

E. Gioan[1,2,3,4], K. Sol[1,2], G. Subsol[1,2,3,8],
Y. Heuze[5], J. Richtsmeier[5], J. Braga[6,8], F. Thackeray[7,8]

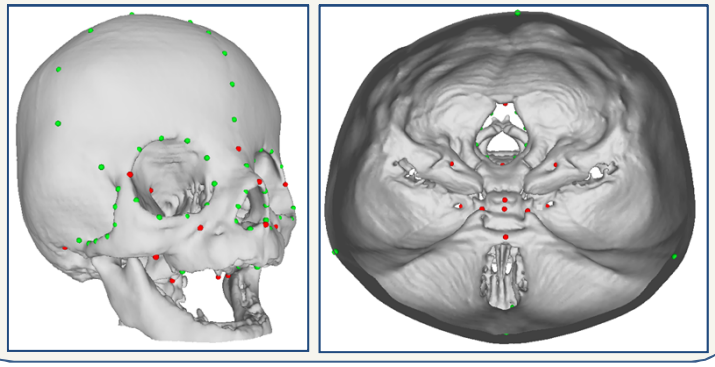
Limit of metric-based methods

Geometric Morphometrics is usually based on metric parameters to characterize the deformation of landmark configurations. Though potentially important to biological interpretations, variations of landmark coordinates may not emphasize the "structural" differences.

Example: **a**: "concave" / **b**, **c** "convex" not differentiated by PCA.

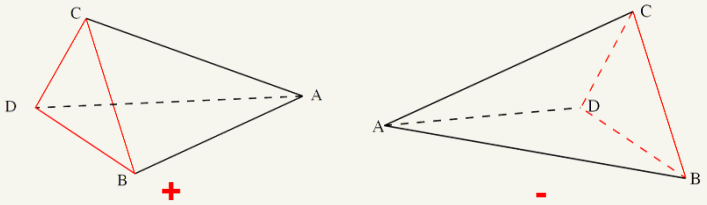
Data

- 3D CT-images of 40 children (0.1 – 19.9 months) with craniosynostosis, i.e. premature fusion of cranial sutures
- visual evaluation and classification into 3 categories by a clinician:
  - BCS (*bicoronal*): fusions of both lateral sutures (15)
  - LUCS (*left unicoronal*): fusion of only left-side suture (8)
  - RUCS (*right unicoronal*): fusion of only right-side suture(17)
- 133 landmarks defined by an expert:
  41 anatomical landmarks / 92 curve semilandmarks.



A new 3D morphometric method

In 3D, each set of 4 landmarks A, B, C, D, can be associated with a sign depending on the orientation of the tetrahedron ABCD.



For a configuration composed of *n 3D* landmarks, we consider $t = \frac{n!}{(n-4)!\cdot 4!}$ tetrahedra and get a vector of *t* signs (+ or -) that encodes the "shape" of the configuration.

This vector defines a *combinatorial mathematical structure* called an ***Oriented Matroid.***

[Björner, Las Vergnas, Sturmfels, White, Ziegler. "Oriented Matroids". Cambridge University Press. 1999]

x	y	z
17.45	26.36	13.7
14.51	26.93	11.5
15.93	26.94	12.36
17.11	26.94	13.63
18.69	26.98	14.67
19.50	27.03	15.03
15.75	29.67	10.89
14.96	29.08	11.07
…		

Landmark configuration

Each tetrahedron gets 1 sign

+
-
+
+
-
+
-
+
…

x	y	z
16.75	25.86	13.38
15.13	27.33	11.93
15.35	22.54	10.46
16.34	25.34	13.45
19.49	26.23	14.53
19.53	25.97	13.53
15.45	30.42	10.65
14.56	29.68	10.76
…		

+
-
+
+
-
+
-
+
…

Combinatorial distance between 2 individuals

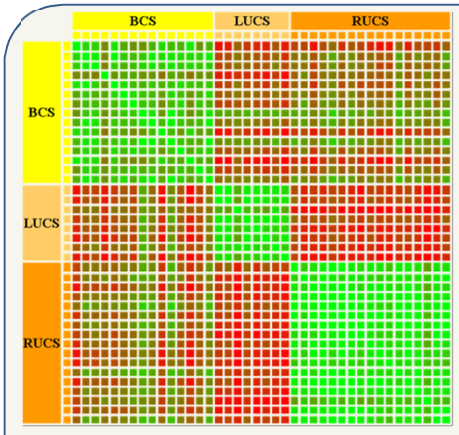
(e.g. number of different signs)

Automatic classification of the set of all individuals

→ The method has to be assessed w.r.t. to current GM methods;

→ Applications in anatomy (human and primate comparison) and paleo-anthropology (analysis of fossils).

Preliminary results



Inter-individual combinatorial distance matrix

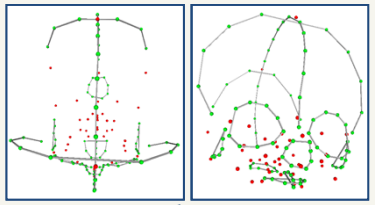
14% 40%

number of different signs / total number of non-constant signs

Visually, the distance matrix correlates quite well with diagnosis.

Automatic classification

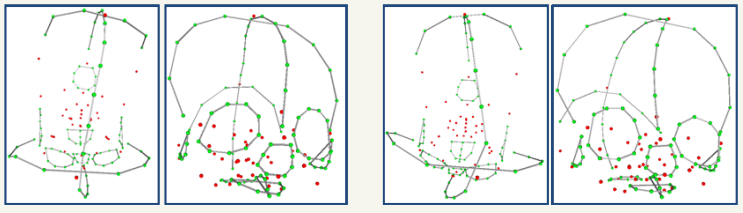
Cluster analysis by K-means criterion / algorithm using this combinatorial distance.



Cluster 1
BCS: 15
LUCS: 0
RUCS:0

Cluster 2
BCS: 0
LUCS: 8
RUCS:0

Cluster 3
BCS: 0
LUCS: 0
RUCS:17



Mathematically, K-means clustering based on this combinatorial distance provides classification matching diagnostic categories.

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