Arothron: an R package for virtual anthropology to build endocast and to perform digital reconstruction

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Description: Arothron is an R package [1] containing brand new tools for geometric morphometric analysis. The package comes with examples pertaining to the field of virtual anthropology, yet it is addressed to the entire audience of geometric morphometricians. The functions embedded in the package allow aligning disarticulated parts belonging to a single specimen (i.e. broken skull fragments), to build internal cavities such as endocasts, and to reproduce and analyse the shapes of three-dimensional objects. Arothron functions import and export landmark coordinates and 3D paths into 'landmarkAscii' and 'am' format files.

Digital Alignment Tool (DTA): The Digital Tool for Alignment (DTA) is a landmark-based methodology which allows aligning two or more portions of a 3D mesh (i.e. a disarticulated model, DM) by using a reference sample or model (RM) for comparison. To run DTA, a set of anatomical landmarks is defined on two separated portions of the DM. Each point of the landmark sets is moved to the nearest vertex of the triangles. This way, each landmark is identified by a number corresponding to a row of the vertex matrix of the mesh and its position is tracked on the 3D models moved in the Cartesian coordinate system. The second step is the alignment via Generalized Procrustes Analysis (GPA) of each part of the DM on each RM of the comparative sample, where the same landmark configuration as with the DM has been previously defined. The items of the reference sample are previously scaled to the mean of the single scale factors calculated for each half of the DM, separately, and symmetrized via reflection and relabelling, thereby producing a perfectly symmetrical, bilateral, and scaled landmark configurations (to avoid alignment error as introduced by asymmetry). The last step consists in the quantification of the morphological (Euclidean) distances between each part of the DM and the corresponding landmark configurations on each item in the RM set.

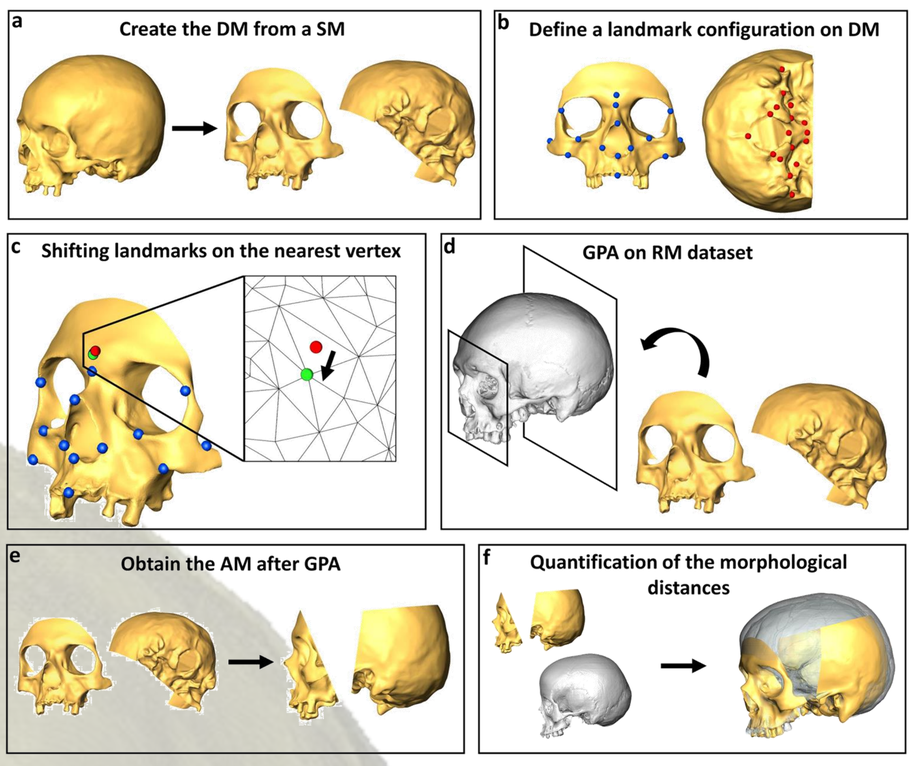

Figure 1. DTA methodology explained step by step. (a) Definition of the Disarticulated Model (DM) from a starting model (SM). (b) Definition of a landmark configuration on both face com-plex and cranial base of DM. (c) Shifting landmarks of DM model (in red) on the nearest vertex of the mesh (in green). (d) Compute a General Procrustes Analysis (GPA) of the facial complex and the cranial base on each reference model (RM). (e) Alignment of the two halves of the DM after the GPA. (f) Quantification of the morphological distance between the aligned configuration and the reference model dataset.

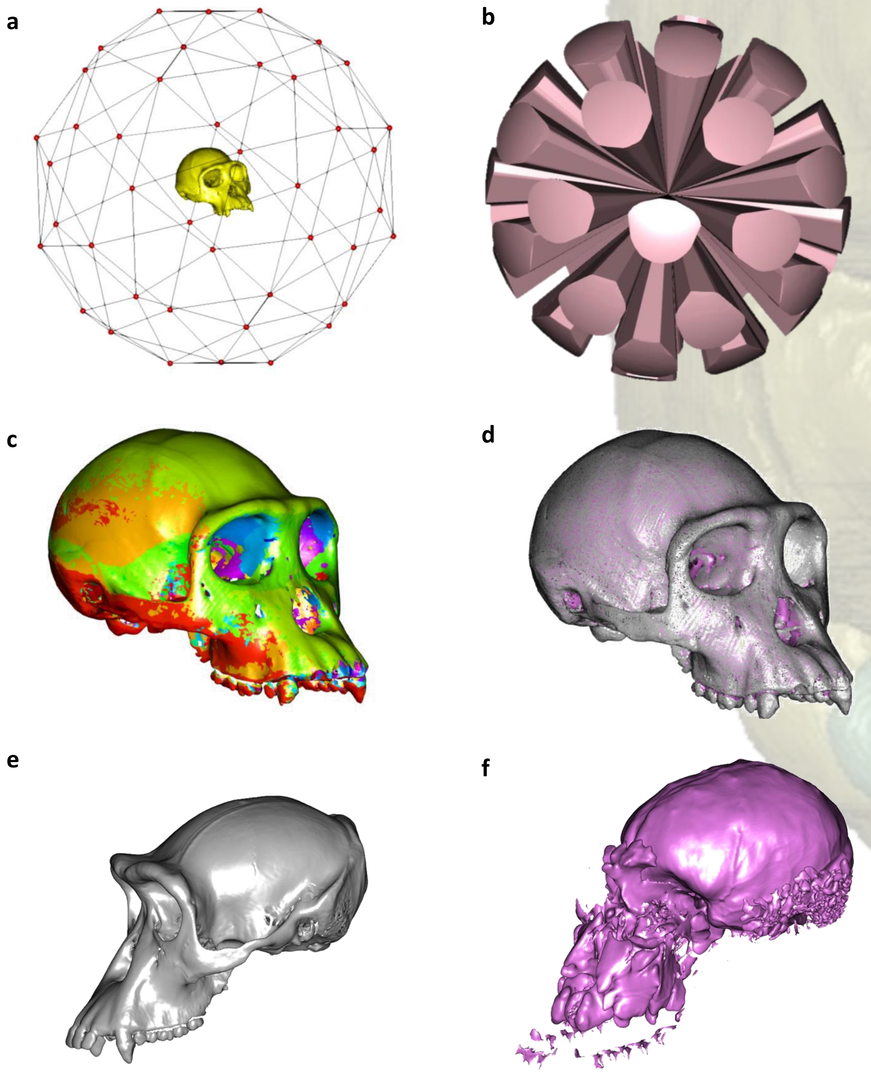

Figure 2. CAL-SE and AST-3D methodology explained step by step. (a) Definition of a set of points of view (POV). (b) Spherical flipping applied from each POV. (c) Merge of the vertices visible from each POV. (d) Pruning of the starting model into two 3D models: a mesh formed by visible triangles (e) and a mesh defined by not visible triangles (f).

Computer-Aided Laser Scanner Emulator (CA-LSE) and Automatic Segmentation Tool for 3D objects (AST-3D): CA-LSE and AST-3D are two new tools designed for the reconstruction of virtual cavities and external shapes [2]. CA-LSE provides the reconstruction of the external portions of a 3D mesh by simulating the action of a laser scanner. AST-3D performs the digital reconstruction of anatomical cavities as endocasts. Both tools use the definition of points of views that can be placed externally to the object (CA-LSE) or inside the object (AST-3D). In the Arothron R package, we supplied three examples of reconstructing: the dental pulp cavity within a deciduous Neanderthal tooth, the network of blood vessels within a human malleus bone, and an endocast of a human skull. The tools could be used in virtual anthropology application.

Case-studies: DTA tool is efficient in find ideal alignments of broken pieces. It could be applied as the first step in virtual reconstruction on human fossil specimens that often consist of a disarticulated fragments such as BOU-VP12/130 (*Australopithecus garhi*), AL-442 (*Australopithecus afarensis*), OH5 (*Paranthropus boisei*), ATD6-15 and ATD6-69 (*Homo antecessor*), Amud 1 (*Homo neanderthalensis*), Le Moustier 1 (*Homo neanderthalensis*). The easily and quickly use of the Arothron R package to build virtual cavities may provide a new means largely applicable in virtual Anthropology. We test DTA on Amud 1 and we compared the result with the original reconstruction performed by Suzuki (1970) [3]. CA-LSE and AST-3D address the increasing need for automation in virtual anthropology. AST-3D could be applied to build virtual cavities as endocast and maxillary sinuses. CA-LSE is useful to prune a surface in two components. Here, CA-LSE was applied to isolate the complex network of blood vessels of a human malleus bone.

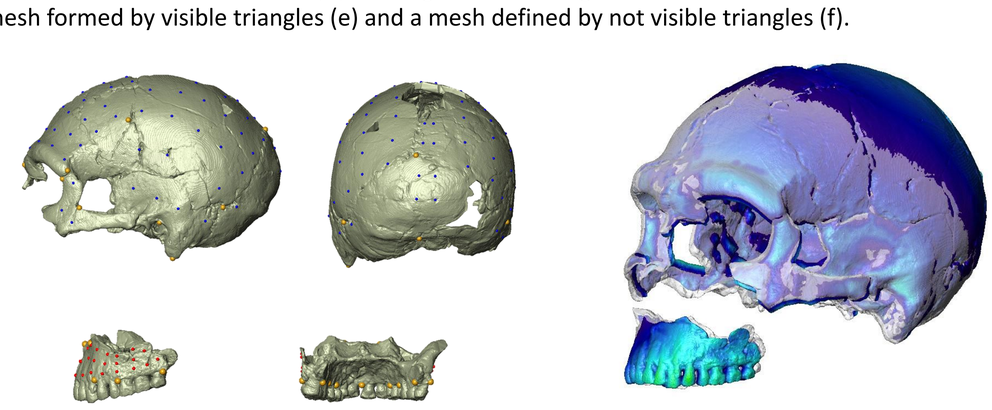

Figure 3. DTA applied on Amud 1 (*Homo neanderthalensis*) using La Ferrassie 1 (*Homo neanderthalensis*) as reference model. On the right the comparison with the original reconstruction performed by Suzuki (1970).

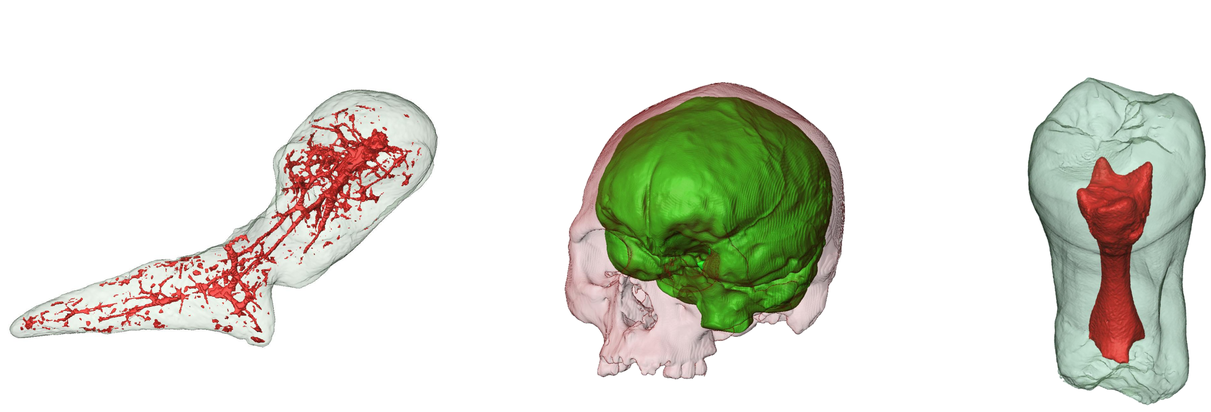

Figure 4. CAL-SE applied on a human malleus bone and on a Neanderthal deciduous tooth: in red the network of blood vessels and the dental pulp. AST-3D applied on a human skull in order to extract its endocast (in green).

References:

[1] Profico, A., et al. (2018a). Arothron: R Functions for Geometric Morphometrics Analyses. R Package Version 314 (1.1).

[2] Profico A., et al. (2018b). Reproducing the internal and external anatomy of fossil bones: two new automatic digital tools. American Journal of Physical Anthropoly, 166: 979-986.

[3] Suzuki H, Takai F. (1970). The Amud man and his cave site. Academic Press of Japan.

Video tutorial: