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Image data banks and geometric morphometrics

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Abstract — This paper examines the opportunities offered by recent advances in digital image processing to allow access to natural history museum collections without direct handling of specimens. It specifically refers to two- and three-dimensional data recording and analysis in the frame of geometric morphometrics.

Index Terms — geometric morphometrics, 2D and 3D image recording, landmarks, osteological collections.

1 Introduction

Osteological collections, especially skull collections, represent an ideal material for the study of morphological variation in both time and space in a variety of vertebrates. Its multiple functional properties (protection of the brain and sense organs, feeding and respiratory structures) make the skull a highly informative structure where both highly conservative and plastic characters coexist [1]. These qualities led to a rich production on the intra- and interspecific variation of vertebrates based on skull features [1] and to a precise coding of traditional quantitative characters [2]. The geometric morphometrics *revolution* in the '90s [3], [4] offered a new powerful tool to investigate the variation of biological forms, allowing the distinction between size and shape variation. Geometric Morphometric (GM hereafter) studies have found their elective applications in the analysis of osteological collections devoted to clarification of clarify phylogenetic and evolutionary patterns among vertebrates, [5], [6], [7], [8]. Basic data for GM are usually recorded either from 2D or 3D images. Taking advantage of the tremendous advances in digital technologies, museums can play a fundamental role for future GM studies by offering an easy and rapid remote access to their collections [9], [10].

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2 Geometric Morphometrics

GM uses sets of Cartesian coordinates, such as (semi-)landmark locations, outlines, curves, and surfaces, to capture the geometric information about biological structures and preserves that information throughout the analyses, including the multivariate treatments of data [4], [5], [11]. Most multivariate methods of GM are linearizations of statistical analyses of distances and directions in the Kendall's shape space. Each point in this shape space represents the shape of a configuration of points (landmarks) in some Euclidean space, irrespective of size, position, and orientation [5]. In shape space, scatters of points correspond to scatters of entire landmark configurations (specimens), not merely scatters of single landmarks, and differences among shape configurations are most often expressed as cord distances relative to a curved, generalized Procrustes space [4], [12], [13], [14], [15].

Configurations are described by either two (x,y) or three (x,y,z) Cartesian coordinates of homologous points (landmarks). The advantage of working with 2D landmarks is that these data are easily recorded from digital pictures through easily accessible and friendly software, e.g., TpsDig [16]. Meanwhile, studies using coordinates of 3D points are becoming standard in some fields, such as physical anthropology [17], [18]. A distinct advantage of the use of 3D coordinates is that the definitions of landmark points are often much less arbitrary in three dimensions than they are in 2D projections [5]. An historical disadvantage of three dimensional landmarks is that they can only be recorded directly from the objects by means of devices like the 3D Microscribe or Polhemus digitizers or gathered from 3D pictures obtained from very expensive scanners. Unfortunately, statistical methods for dealing with such additional data types (surfaces and volumes) are still in their infancy. Moreover, we also still lack effective methods for the visualization of genuinely 3D shape variation whether for points or more complicated data structures [5].

3 2D and 3D digital images for GM analyses

Datasets used for GM analyses can be derived from 2D and 3D digital images (Fig. 1). Digital imaging has undergone an explosive development in the last decade, allowing access to high resolution and low-cost devices, especially in the case of 2D pictures.

Digital images used to collect data for GM analyses have to comply with some basic requirements, as imaging systems include artifacts related to acquisition, storage, and display processes [7], [21], [22], [23], [24]. The use of high-quality optical equipment and caution in specimen position and distance from the camera will help to reduce the effect of these artifacts.

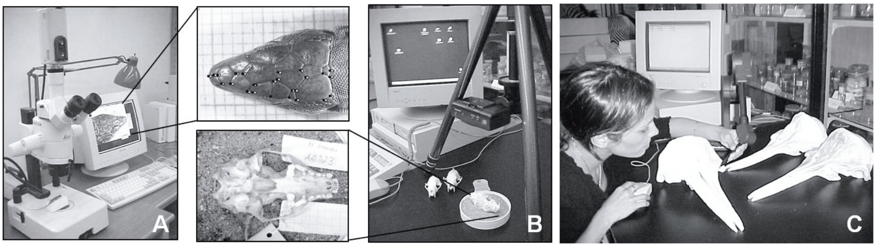

Fig. 1 – Devices used for 2D and 3D data recording for GM. **A**. Binocular microscope connected to a digital camera and a pc. **B**. Digital camera mounted on a tripod at a fixed distance from the skull. **C**. Microscribe used to get 3D coordinates directly from the skull.

The choice of digital camera should take into account resolution, accuracy, tonal range, color purity and accuracy, white balance, and image noise (see [23] and http://www.imaging-resource.com). Shadows and the reflecting surfaces of the object (bone surfaces often reflect a lot) may impede the view of important features like skull sutures. Lighting that maximizes the visibility of the whole object is recommended.

Once the equipment is calibrated, a standard protocol should be adopted for image recording that will retain all information needed for GM analyses (Fig. 2).

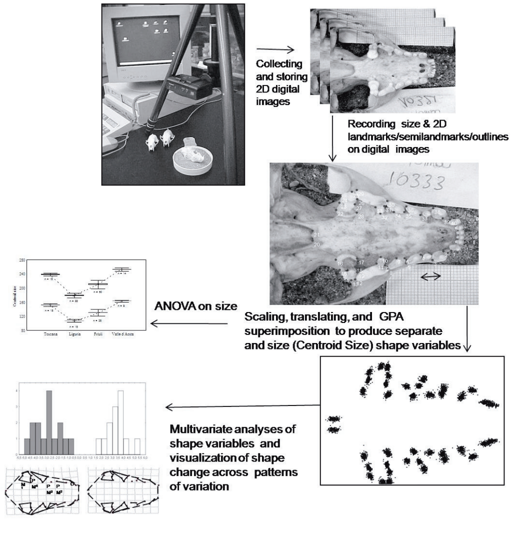

Fig. 2 – Flow chart of 2D data recording and processing for GM.

The protocol should closely adhere to the following recommendations:

1. Place the object on a soft and possibly dark substrate to allow the object to be placed exactly horizontal to the plane.
2. Images should always include a scale factor and the specimen label.
3. Keep the object as much as possible in the centre of the image, and place the camera at such a fixed distance that distortion effects do not occur at image margins [24].

Three-dimensional images are more complicated, both in their nature and acquisition. They can be volumetric data encoding some spatial property, e.g., x-ray attenuation (CT scans) or water content (MRI-Magnetic field and Radiowave pulses), or they may consist of coordinates of point clouds representing the surface of a specimen (preferably with texture information). The production of such images has been prohibitively expensive, but is becoming increasingly affordable and accessible. Micro-CT scanners with micron-scale resolution are appearing within universities (e.g.http://www.ucalgary.ca/mousegenomics/3DMorphometrics, http://www.ctlab.geo.utexas.edu/index.php, http://micro-ct.at/). Usable surface scanning devices are ever more affordable (e.g., http://www.nextengine.com/). Students at FSU last year built a working scanner for only 15.00 USD (http://www.david-laserscanner.com/). Just as with 2D images, though, care must be taken to calibrate and test the product of any 3D scanning modality, and this information should be made available along with the image.

4 Images databanks, museums and GM analyses

Museum's collections play a fundamental role in geometric morphometric studies. By creating specific digital image databanks, museums would greatly speed up the data collection of large samples, reduce the costs of the research, and minimize damage to collections due to specimen handling. They could also benefit from extra income, as access to images could be regulated and charged, and advice from specialists could rapidly solve diagnostic and systematic problems often posed by specimen labels. To be suitable to GM analyses, image data banks should meet some basic requirements, including standards for image recording, acquisition, storage, and analysis of morphometric information. A number of excellent image repositories exist today. These include:

- Morphbank (http://www.morphbank.net/),
- MorphoBank (http://www.morphobank.org),
- and eSkeletons (http://www.eskeletons.org/),

designed primarily for two dimensional images, and:

- Aves3d (http://aves3d.org/),
- DigiMorph (http://digimorph.org/), and:
- the Open Research Scan Archive (http://plum.museum.upenn.edu/~orsa/ORSA/),

for (mainly) CT-based 3D images.

Such web-accessible repositories are valuable resources for any study concerned with the anatomical variation of the archived material, but there is much that could be improved. None of these (nor any other) repositories have incorporated into their structure the capacity for the direct acquisition, storage, and analysis of morphometric information. Neither do any of these provide the ability to easily interface with other archives. What is very much needed is an interface standard that would allow the query and retrieval of material from multiple online archives. Perhaps more practical, and maybe even better, would be the development of a meta-interface that could map the idiosyncrasies of the individual archives to a common access tool. Scientific research would be greatly enhanced, then, with even the basic capacity to search for and download images

(2- or 3D) and associated data for local analysis with standalone morphometric tools. Better still would be the direct support of such morphometric tools within the common interface and a secure, quality-controlled extensibility to the root archives to support morphometric annotation, e.g., labeled point (=landmark) coordinates, curve descriptors, etc.

As the growing use of medical imaging has allowed the production of 3D images of extant and fossil specimens, the analysis and visualization of 3D data and the combination of (semi-)landmarks, outlines, and surfaces are expected to yield a better description of changes in biological complexes. 3D analyses are affording several new perspectives in the field of human paleontology and physical anthropology (see for example [19], [20]). Progress is also expected in the study of covariation between subsets of landmarks [25] and the extension of landmark-based morphometrics to the analysis of articulated structures [26]. This progress would be greatly facilitated by standards-based, online archives that either directly incorporate or otherwise support the acquisition, storage, and analysis of morphometric data.

References

[1] J. J. Hanken and K. Hall (eds.), *The skull. Functional and evolutionary mechanisms*. vol. 3. Univ of Chicago Press, 1993.

[2] O. Thomas, "Suggestions for the nomenclature of cranial length measurements and the cheek teeth of mammals" *Proc.Biol.Soc.Wash.,* vol. 18, pp. 191-196, 1905.

[3] F. J. Rohlf and L. F. Marcus, "A revolution in morphometrics". *T.R.E.E,* vol. 8, pp. 129-132, 1993.

[4] F. L. A Bookstein, "Hundred years of morphometrics". *Acta Zool. Acad. Scient. Hungar.*, vol., 44, pp. 7-59, 1998.

[5] D. C. Adams, F. J. Rohlf and D. E. Slice, "Geometric Morphometrics: Ten Years of Progress Following the 'Revolution'" *Ital. J.Zool*., vol. 71, pp. 5-16, 2004.

[6] D. E. Slice (ed.), *Modern Morphometrics in Physical Anthropology*. Kluwer Academic/Plenum, 2005.

[7] P. L. Forey and N. MacLeod (eds.), *Morphology, shape and phylogeny*. Syst. Ass. Sp. Vol. Ser. 64. London: Taylor and Francis, 2002.

[8] F. J. Rohlf "Geometric morphometrics and phylogeny". In: P. L. Forey and N. MacLeod (eds.), M*orphology, shape and phylogeny*. Syst. Ass. Sp., Vol. Ser. 64. London: Taylor and Francis pp. 175-193, 2002.

[9] A. Loy, "Morphometrics and theriological collections. Homage to Marco Corti". *Hystrix- It. J. Mammal*., vol. 18, pp. 115-136, 2007.

[10] S. Elton and A. Cardini, "Anthropology from the desk? The challenges of the emerging era of dat*a* sharing*". J. Anthr.Sci.*, vol. 86, pp. 209-212, 2008.

[11] F. L. Bookstein "Size and shape spaces for landmark data in two dimensions". *Stat. Sci.,* vol. 1, pp. 181-222, 1986.

[12] D. E. Slice, "Landmark coordinates aligned by procrustes analysis do not lie in Kendall's shape space". *Syst. Biol.,* vol. 50, pp. 141-149, 2001.

[13] D. G. Kendall, "Shape-manifolds, Procrustean metrics and complex projective spaces". *Bull. Lond. Math. Soc*., vol 16 pp. 81-121, 1984.

[14] D. G. Kendall, "Exact distributions for shapes of random triangles in convex sets". *Adv. Appl. Prob*., vol. 17, pp. 308-329, 1985.

[15] F. L. Bookstein, *Morphometric tools for landmark data: geometry and biology*. Cambridge University Press, Cambridge, 1991.

[16] F. J. Rohlf, *tpsDig ver. 2.10*. Ecology and Evolution at SUNY Stony Brook, 2006.

[17] D. E. Slice, "Geometric morphometrics". *Ann.Rev. Anthr.,* vol. 36, pp. 261-281, 2007.

[18] P. Mitteroecker and P Gunz, “Advances in Geometric Morphometrics”. *Evol.Biol.* vol. 36, pp. 235-247, 2009.

[19] P. Gunz, P. Mitteroecker and F. L. Bookstein, “Semilandmarks in three dimensions”. In: D. E. Slice (*ed.)*. *Modern Morphometrics in Physical Anthropology,* Kluwer, 2005.

[20] P. Gunz and K. Harvati, “The Neanderthal “chignon”: Variation, integration and homology. *J.f Hum. Evol.* vol. 52, pp. 262-274, 2007.

[21] F. J. Rohlf and F. L. Bookstein (eds.), *Proceedings of the Michigan morphometrics workshop*. Sp. Publ. N. 2. Univ. of Michigan Museum of Zoology, Ann Arbor, 1990.

[22] J. M. Becerra, E. Bello and A. Valdecasas “Building your own machine image system for morphometric analysis: a user point of view”. In: L. F. Marcus, E. Bello, A. Valdecasas (eds.), *Contribution to Morphometrics*, Monographias 8, Museo Nacional de Ciencias Naturales, pp. 66-92, 1993.

[23] A. Garcìa-Valdecasas, “Two-dimensional imaging: an update”. In: L. F. Marcus, M. Corti, A. Loy, G. J. P. Naylor and D. E. Slice (eds.), A*dvances in Morphometrics*, NATO ASI Series A: Life Sciences vol. 284. Plenum: New York: 71-81, 1996.

[24] M. L. Zelditch, D. L. Swiderski, H. D. Sheets and W. L. Fink, *Geometric Morphometrics for biologists: a primer*. London: Elsevier Academic Press, 2004.

[25] F. L. Bookstein, P. Gunz, P. Mitterocker, H. Prossinger, K. S Chafer and H. Seidler, “Cranial integration”. In *Homo:* singular warps analysis of the midsagittal plane in ontogeny and evolution. *J.Hum. Evol*., vol. 44, pp. 167-187, 2003.

[26] D. C. Adams, “Methods for shape analysis of landmark data from articulated structures”*. Evol. Ecol. Res*., vol. 1, pp. 959-970, 1999.