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SECTION 1 : THÉORIES ET MÉTHODES / THEORY AND METHOD

Colloque / Symposium 1.7

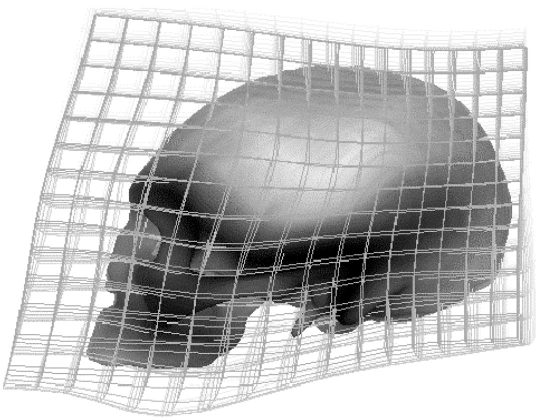
Three-Dimensional Imaging in Paleoanthropology and Prehistoric Archaeology

Edited by

Bertrand Mafart
Hervé Delingette

With the collaboration of

Gérard Subsol



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VIRTUAL ANTHROPOLOGY - THE HOPE FOR MORE TRANSPARENCY IN PALEOANTHROPOLOGY

Gerhard W. WEBER

Résumé: Au cours des dernières décennies, une grande quantité de fossiles d'hominidés a été mise au jour. Certains d'entre eux n'ont pas été encore étudiés et d'autres nécessitent d'être ré-étudiés avec des méthodes plus élaborées. Alors que le décompte des restes fossiles est en constante augmentation, il manquait jusqu'à présent une méthode d'inventaire permettant l'acquisition et l'archivage optimale des données de ces spécimens, dont une part est inaccessible à l'observateur comme les structures anatomiques internes. L'Anthropologie Virtuelle (VA) permet des explorations morphologiques tridimensionnelles grâce au traitement informatique des données numériques obtenues à partir des fossiles originaux.

Différentes méthodes comme les scanners médicaux, l'imagerie par résonance magnétique ou les lasers surfaciques, permettent l'acquisition des données tridimensionnelles qui peuvent être secondairement analysées avec des moyens informatiques. Ces données permettent aussi la réalisation de reproduction des spécimens par stéréolithographie. La recherche anthropologique tire un grand bénéfice de ces méthodes qui permettent la visualisation des structures internes. De plus, l'obtention de copies est un moyen de protéger les originaux de toute dégradation. Les analyses morphologiques, à partir de points remarquables ou de surfaces, produit de remarquables résultats grâce aux méthodes de morphométrie géométrique.

Ainsi, l'Anthropologie Virtuelle transforme la Paléoanthropologie en offrant la possibilité d'augmenter notre connaissance de la diversité morphologique des Hominidés, élément clef pour l'analyse des spécimens et l'élaboration des théories phylogéniques. Avec moins de restriction d'accès aux fossiles, une nouvelle étape devient possible : la création d'une base de données tri-dimensionnelles des fossiles récents et des hominidés fossiles qui soit à la disposition de tous.

Abstract: Within the last decades, a remarkable amount of fossil material was excavated, some of it still awaiting a detailed first analysis, some of it requiring re-examination by more developed methods. While the fossil record grew continuously, a methodological inventory evolved to extract critical information about fossilized specimens, most of it preserved in the largely inaccessible interior as unrevealed anatomical structures. Virtual Anthropology (VA) is designed to allow investigations of three-dimensional morphologic structures by means of digital data-sets of fossil and modern hominoids within a computational environment.

3D-data is acquired by different computer-necessitating processes, like CT, MRI, or surface laser scanning. This kind of data also permits the production of accurate 3D-hardcopies of specimens by stereolithographic modeling. Anthropological research profits substantially from methods enabling views to the interior of structures. Additionally, electronic preparation and re-assembly of fossils protects the originals from damage, and quantitative analysis of morphology based on 3D-coordinates of landmarks or surfaces produces biologically meaningful results using Geometric Morphometrics.

As a consequence, Virtual Anthropology is changing the daily routine of anthropological sciences, offering the possibility to extend our knowledge about diversity of hominoids, an imperative component for the assessment of specimens and construction of phylogenetic trees. For more transparency in paleoanthropology, there is the chance for a further step: The foundation of a digital 3D-data archive of recent and fossil hominoids and its opening for global use.

A lot of profound and interesting papers were published within the last years concerning the three-dimensional analysis of paleontological data. In this short contribution, not a specific scientific analysis shall be our focus. Rather I would like to bring a topic of science politics to your attention and introduce a certain perspective of Virtual Anthropology (VA) that can be indeed a hope for paleoanthropology in the future, apart from all the scientific advantages in a narrower sense.

Virtual Anthropology, computer-assisted anthropology, or however else one may call it, is designed to allow investigations of three-dimensional morphologic structures by means of digital data-sets of fossil and modern hominoids within a computational environment. In general, anthropology touches one of the four primary philosophic questions: What is the human being? In asking so, the study of human evolution represents one of the frameworks of our discipline, and thus a potential field of application for VA.

Within the last decades, a remarkable amount of fossil material was excavated, some of it still awaiting a detailed first analysis, some of it requiring re-examination by more developed methods. Morphology and DNA-studies are the main sources of information to distinguish between paleospecies, but variation is often poorly known. Partly, because there are so few specimens, but partly because it can be also very difficult to gain access to the existing fossils record.

What are the main goals of Virtual Anthropology?

1. Acquire new qualitative traits, especially so far inaccessible ones (e.g., endocranial traits, sinuses, medullary cavities, etc.).
2. Measure and compare quantitative traits (exo & endo) with high accuracy and reproducibility, and to study variation
3. Provide digital 3D-data of recent and fossil hominoid material and the relevant methods of analysis.

A main issue for paleoanthropologists is the definition of a paleospecies. Fundamental is a profound knowledge of variation and the inclusion of a multitude of traits. Of course, also those structures that are hidden should be studied. When a scientist has a new idea for a comparative analysis, it can be really troublesome to gather all the material of the comprised specimens that are physically stored around our planet. If this idea involves traits of hidden structures too, the only way to investigate them is to use Virtual Anthropology anyway. Perhaps, once you were tempted to think about checking a measurement done by another author in his recent paper? You'll have fun flying to Johannesburg, Nairobi, or Beijing.

Once a specimen is CT-scanned, the resulting virtual objects have a great advantage: They are resting on the disk of your personal computer, waiting there 24h a day, 365 days a year. No more applications for access are necessary. You just have to login and start your software. Virtual objects can be rotated, scaled, moved, cut or imaged. The comparison of a real object with its virtual copy shows that there is only a negligible difference (Hildebolt et al., 1990; Richtsmeier et al., 1995; Feng et al., 1996; Weber et al., 1998), except a lack of texture information.

There is also the possibility to bring back virtual objects to reality. Such "stereolithographic models" are of significant importance for the investigation of morphology (Seidler et al., 1997). But sometimes, their relevance is misunderstood. They are not meant as a substitute for traditional casts, they are an addition. They provide some advantages over traditional casts like the possibility to produce a model in parts and to look at the structure of cavities, a task that is not grantable with usual casts. Moreover, there is the possibility to produce parts of anatomical structures on an enlarged scale, let us say the orbit or the maxilla on a scale of 1:10, and to produce electronically casted cavities also as physical objects, like the labyrinth or the frontal sinus.

Virtual Anthropology is THE gateway to hidden anatomical structures and allows to penetrate into the last corner of a specimen. In Figure 1 are just a few examples, like an endocast of a frontal sinus, including volume computation, the study of the tooth roots of an *A. robustus* specimen, or an example of computing thicknesses along the surface of a single bone and graph them as topographical thickness maps (Weber et al., 2000).

For the comparison of the shape of organisms it is necessary to utilize quantitative methods. The traditional morphometry mainly uses distance and area measurements, whereby the original shape is not recoverable from the usual matrices of measurements, even if multivariate statistical methods are used. Geometric morphometric methods are using coordinates, and are permitting to distinguish between shape- and size-variation as well as to analyze which structures were changing or remaining constant (Bookstein et al., 1999). Traditional orientation problems (e.g., Frankfurt plane) are eliminated by superimposition methods, for example procrustes. Finally, thin plate spline (Figure 2) can visualize the change of the position of landmarks as deformation grid. Each analyses can start from the original CT-scans because landmark coordinates are extractable from this kind of data.

Fossils undergo a series of processes along their way from biosphere to lithosphere and can be embedded into sediments or have calcite incrustations. In each case, the anatomical investigations are affected and a preceding preparation is unavoidable. Virtual Anthropology offers the possibility of electronic preparation which is reversible and avoids physical contact with the original specimen. In some cases, the incrustations have a different gray value than the bone and their elimination is quiet easy by setting the appropriate threshold. In other cases, there is an overlap in the density profiles of the incrustations and the bone. In such a case, more sophisticated methods, involving various filter algorithms and manual processing of each CT-slice (Prossinger et al, 1998), are needed but can be worth the effort if one obtains an electronically cleaned specimen that allows subsequent analyses of its endocranial morphology.

One of the most challenging tasks for VA is the reconstruction of fragmented fossils and the reversal of deformations. Missing features can be re-created by mirroring pieces or by completing with pieces from similar specimens. The production of such a composite fossil does not affect the precious original, and the electronic manipulations are easier to reproduce than physical ones. But most of the reassembling experiments still rely more on the "morphological eye" of the scientists than on empirical standards. Statistical information on the distribution of homologous landmarks, ridge curves, and other surface properties is indispensable. We are currently working on the development of parameterized skull models (Weber & Neumaier, 2001) which will allow to reconstruct parts to a certain degree of reliability.

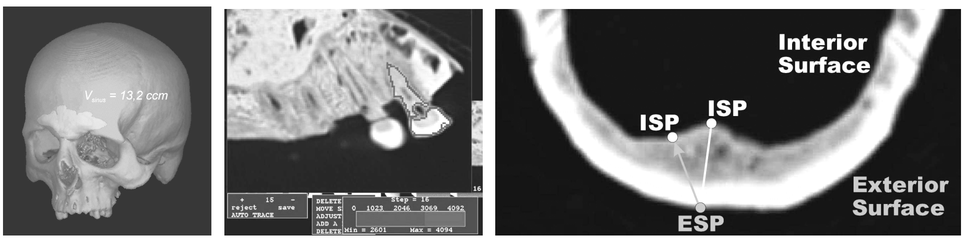

Figure 1 - Visualization and computation of volumes (left), study of tooth roots (middle), semiautomatic thickness measurements (right)

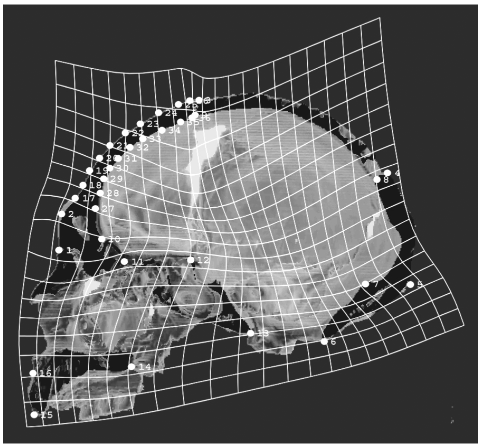

Figure 2 - Thin-plate spline deformation grid (*Homo sapiens* ⇒ *Homo heidelbergensis*)

Figure 4 - The first CD-ROM with 3D-data of a fossil hominid

In Figure 3 an example for a simple, non-linear model based on conic triangles is shown. We use traditional measurements, Cartesian coordinates and differential-geometric data, whereby the latter and semi-landmarks can only be obtained on the virtual object and not on the physical one.

Undoubtedly we made a big step forward in paleo-anthropology within the last decade. But something is still unsatisfactory. **WHAT IS IT?**

The number of fossils is growing rapidly, the potential to analyze the material is growing too. But the access to the fossils is still very limited. I think it is time to implement a democratic process for paleoanthropology. I call this idea a “Glasnost” in paleoanthropology (Weber, 2001), a Glasnost, if all the discovered fossils would be easily accessible. It is increasingly obvious that knowledge about diversity is the key for the assessment of specimens and the constructing of phylogenetic trees. But how can morphologic diversity be studied on a large scale if access to fossil specimens is restricted by time, by distance, or simply by the benevolence of curators? Of course, the latter have the responsibility to protect their treasures and are alarmed by the increasing number of applications for access. In some cases, conventional distance measurements are taken for the umpteenth time, always risking micro-destructions due to contact with sharp instruments. That can be easily avoided using digital data.

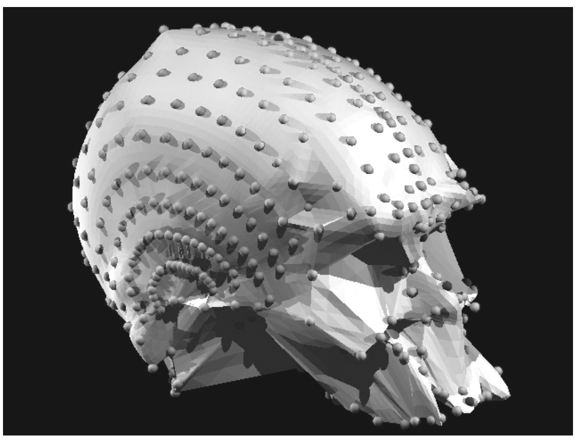

Figure 3 - Example of a simple parametric skull model (conic triangles)

Hominoid fossils are the heritage of all mankind. The digital 3D-data of all fossils should be freely accessible for global use. Electronic archives, on the Internet or on CD-ROM, are accessible at any time from the desktop. We made a beginning in this direction by publishing the first CD-ROM with 3D-data of a fossil (Figure 4), the Bodo cranium, in 1999 (Seidler et al.), and we are planning to publish more specimens. For the internal use at the institute, currently we run a trial version of an electronic archive of modern hominoids, and clearly, we are not alone. Others also have such parts of a global archive on their servers. Much work needs to be done to organize and administrate such an archive, for example, the quality standard, the distribution mode, or the financial aspect have to be worked out. But I hope that more people will realize the advantages for our field of science, including the chance to present a new picture of our science to the public. My suggestions for discussion are:

- We should start with the foundation of a global electronic archive for skeletal morphology of fossil and recent hominoids, comparable to the Human Genome Project.
- All fossils should be digitized with standardized methods. If an author wants to publish the description of a new fossil she or he should be obliged to publish the 3D-data too. If a fossil is announced but not officially published within a certain time limit, it should be scanned and the data also be published in the archive.
- The electronic archive should be opened.

High resolution CT-scans using m-CT enlarge the spectrum of potential investigations (Thompson & Illerhaus, 1998) and could be the future standard. Of course, the computational costs are enormous and at the moment, only a few institutes can afford to work with this technology. But with the steady increase in computer power this should not be an insoluble problem for a long time. With such a volume data set, a

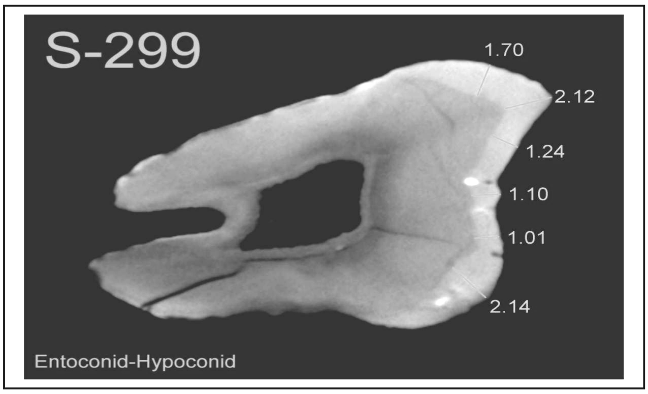

Figure 5 - Measurement of the enamel thickness; resolution is 60 μm (with the help of Dr. Bernhard Illerhaus, Bundesanstalt fuer Materialforschung und –pruefung, BAM-Berlin)

scientist can decide, after having explored the 3D surface properties of the cranial vault, for example to measure the volume of the hypothalamic pit and determine the radii of the semicircular canals, or to study dental enamel thickness or even perikymata structures of the teeth. In Figure 5 you see a m-CT of a third molar of an *A. afarensis*, done with the help of the BAM in Berlin on their self-constructed scanner. The exact measurement of enamel thickness is easy to perform, which leads at the end to hard numbers and not to descriptions like "thin-enameled" or "thick-enameled" which you might find in most of the literature.

Finally, another aspect: There is a gigantic NIH-project with the goal to provide anatomical data for all universities in the United States ONLINE. Our institute is the first test site outside the USA, being invited to contribute the development. The data is based on the Visible Human Project, a 47 GB data volume of kryosections. The coming user of the developed software will be able to explore the complete body in three dimensions online via Internet. Support will be given by descriptions of anatomical structures that appear after pointing at them. All kinds of measurements will be possible. Within the next two years, the development should be completed.

Meanwhile, we anthropologists should also think about the opportunity to use such a tool for a new way of teaching the morphology of fossil specimens because the software is easily adaptable for this kind of application. Students would have online access to fossils to train evolutionary anatomy – certainly also a contribution to more transparency in paleoanthropology.

Author's address:

Gerhard W. Weber
Institute for Anthropology
University of Vienna
Althanstr. 14, A-1090 Vienna
Austria
http://www.anthropology.at

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