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Review

Another link between archaeology and anthropology: Virtual anthropology ☆

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ABSTRACT

Archaeology and *biological anthropology* share research interests and numerous methods for field work. Both profit from collaborative work and diffusion of know-how. The last two decades have seen a technical revolution in biological anthropology: *Virtual Anthropology* (*VA*). It exploits digital technologies and brings together experts from different domains. Using volume and surface data from scanning processes, VA allows applying advanced shape and form analysis, higher reproducibility, offers permanent availability of virtual objects, and easy data exchange. The six main areas of VA including digitisation, exposing hidden structures, comparing shapes and forms, reconstructing specimens, materialising electronic specimens, and sharing data are introduced in this paper. Many overlaps with archaeological problems are highlighted and potential application areas are emphasised. The article provides a 3D human cranium model and a movie flying around and through the virtual copy of a most famous archaeological object: the Venus from Willendorf, Austria.

1. Archaeology and anthropology

Biological anthropology represents one branch of anthropology that deals with the biological variability of us humans, our ancestors, and our closest relatives. This “natural history of mankind through time and space”, as Robert Martin defined it already at the beginning of the last century (Martin, 1914), involves a variety of disciplines such as functional anatomy, physiology, osteology, human evolution, primatology, molecular and population genetics, embryology, demography, systematics, life history, and many others. Frequently, biological anthropology is separated at universities from cultural anthropology (ethnography), linguistics, and archaeology, though all kinds of combinations exist (Stanford et al., 2009). However those teaching curricula and research units might be organised, there is no doubt that the relations between biological anthropology and archaeology are manifold. Let’s imagine a typical example: At a pre-historic excavation site, the archaeologist would take care for the stone tools, the pottery, or remnants of buildings, and involve the biological anthropologist to identify sex and age of individuals, or to assess the taxonomic classification of the hominin remains preserved at the site. They would then together draw a picture of the life and environment of this ancient population. Palaeoanthropology, osteology, and osteopathology are particularly important areas in biological anthropology that create overlap with archaeology.

Biological anthropology as an institutional science is an astonishingly young discipline given the fact that it revolves around our own species. Though many scholars, among them such famous individuals as Adrian von Spieghel (1578–1628), G.L. Leclerc Comte de Buffon (1707–1788), J.F. Blumenbach (1752–1840), often called the “father of anthropology”, or Carl Linnaeus (1707–1778), the founder of the binominal nomenclature, were studying human phenotypic variability and were partly aware of the diversity appearing within and between modern human populations, it was not before the middle of the 19th century when the first chairs and societies were founded (Knumann et al., 1988). The reason for this condensation of ideas and data into established structures might be quite simple. Focusing on biological variability of populations really makes sense if the idea of biological evolution, and connectedly, the changeableness of species and populations, is acceptable. Wallace (1858), Darwin (1859), Mendel (1866), and many others paved the way to depart from a religiously dominated picture of human origin, and consequently opened minds to understand our biological history. In the early days, there was much overlap of knowledge and research interests among comparative anatomists, ethnographers, archaeologists, and anthropologists.

Despite the alliances in history, other links between archaeology and anthropology are present, for instance, the methods employed during field work. The scrutiny of documenting excavation sites layer by layer, the analysis of the resulting stratigraphy, or the wet and dry sieving to detect the smallest fragments of evidence being just a few examples. The newer technologies such

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as remote sensing using satellite images in multispectral modes (Ch'ng et al., 2011) or using ground radar to detect potential sites (Goodman, 2009) connect the two disciplines as well as using mass spectrometry (Prat et al., 2011; Stevenson and Mills, 2013), or GIS (Conroy et al., 2008), or laser-based surface scanning for documentation of material and reconstruction of whole sites (e.g. Milojevic et al., 2005; Paquet and Viktor, 2005; Kampel and Sablatnig, 2006; Grosman et al., 2008; Barton, 2009; Niven et al., 2009; Du et al., 2010; Kuzminsky and Gardiner, 2012; Oliveira et al., 2012; Unver and Taylor, 2012).

The topic of this paper, however, is to demonstrate another field where the research approaches begin to merge and overlaps are becoming more and more visible: Virtual Anthropology – VA (Weber Bookstein, 2011a). Since the 1990s, this new interdiscipline emerged in biological anthropology. Only a few years later, Kirchner and Jablonka (2001) suggested a "Virtual Archaeology" using digital methods. Predominantly for documentation and demonstration purposes (e.g. Pollefeys et al., 2001; Gaitatzes et al., 2001; Guidi et al., 2006; Calori et al., 2009; Aguilera and Lahoz, 2010; Stanco et al., 2012; Trinks et al., 2012) digital data from sites and artefacts were used in the last decade. Nevertheless, the analysis of the object geometry, for instance, or the installation of accessible object data bases are still awaiting broader applications (but see some examples below).

Virtual Anthropology (VA) exploits digital technologies and brings together experts from different domains such as anthropology, biology, medicine, mathematics, statistics, computer science, and engineering. VA, as we define it at University of Vienna, mainly deals with the functional morphology of recent and fossil hominoids. Its methods can, of course, be applied in a much broader sense, e.g. for other primates, mammals, vertebrates and invertebrates, and even plants or tools. The most striking differences to classical approaches in anthropology are the fact that only virtual copies are used (which derive from digitisation processes such as computed tomography or surface scanning), and that they are analysed in 3D or 4D within a computer environment. The crucial advantages are:

(1) the accessibility of the entire structure, including hidden areas such as the braincase, the sinuses, the dentine of teeth, the medullary cavities of long bones, or the heart including its chambers,
(2) the permanent availability of virtual objects (24/7) on hard drives or servers,
(3) the possibility of obtaining high-density data across the whole geometry for powerful quantitative analyses of form and function,
(4) the great range of options for data handling, statistics, visualisation, and data exchange for increasing sample size, and
(5) the increased reproducibility of procedures and measurements, a fundamental requirement of science.

The raise of Virtual Anthropology came along with the computer revolution of the 1970s–1990s. Without the capability of processing vast amounts of data, it simply would be unthinkable. Also the development of the mathematical methods and statistics, which stand behind it, would have been impossible to realise without fast electronic data processing.

2. The six areas of Virtual Anthropology (VA)

Many methods and procedures developed in VA for studying biological remains of our ancestors or to compare living individuals or populations can be used 1:1 in a "virtual archaeology". The paper here will introduce some of VA's major features for the readers of this journal which hopefully will be inspiring for further applications in archaeology, and elsewhere.

We divide Virtual Anthropology into six operational areas:

1. Digitise—mapping the physical world
2. Expose—looking inside
3. Compare—using numbers
4. Reconstruct—dealing with missing data
5. Materialise—back to the real world
6. Share—collaboration at the speed of the internet

All six are described in detail in the first comprehensive textbook of this discipline (Weber and Bookstein, 2011a). A short introduction to each of the six areas will be given below.

2.1. Digitise

Working with virtual copies in a computer environment obviously requires the conversion of the real object at first. There are many technologies available today, some still expensive and sophisticated, others cheap and simple to use. The first question to ask is whether the surface of the object is enough to be analysed, or, if the whole volume of the object is needed. In biological anthropology, many traits such as the labyrinth of the inner ear, the maxillary sinus, the tooth roots or the trabecular structures carry important information with regard to interpretation of functional morphology and taxonomical assessment. Therefore, volume data is frequently required. In archaeology, we may find a lot of applications which would be satisfied using surface data, for instance, when the shape of stone artefacts is measured and compared. In this case, the inner composition might be less important or known, and for the sake of saving time and money, surface scans can be ideal.

For volume scanning, all kinds of "tomographic" procedures are in principle applicable. Computed Tomography (CT), a standard medical imaging procedure usually used for scanning living patients, Micro-Computed Tomography (μ-CT), an industrial imaging routine to examine materials in very high resolution, or Magnetic Resonance Tomography (MRT), a medical routine to image patients without ionising radiation, are common examples. The latter is good for capturing soft tissues but delivers no usable signals from the hard tissues such as bones and teeth. It is used to examine the brain, the heart, the cartilage in joints, and the like in living subjects. Its use for archaeology might be limited to very specific problems, e.g. using a special technique of MRT – Ultrafast Echo Time – for specific problems in mummy research (Siemens, 2008) or standard MRT for hydrated mummies (Shin et al., 2010). In contrast, CT and μ-CT can cope easily with dense and very dense objects like bones, teeth, ivory, antler, shells, stones, and pottery. Like any tomographic method, it delivers a stack of 2D images (slices) that are combined to a 3D volume. Images are based on x-ray technology which means that radiation is emitted by a tube, the rays are partly absorbed by the object which is penetrated, and the remaining x-rays are recorded at a detector behind the object. Since archaeology only deals with dead material, the radiation dose is of low interest here (it might, however, affect preserved DNA).

Each slice of the volume data consists of tiny elements, like those of an electronic image that you produce with your smartphone. While these elements in a 2D photo are called "pixels", we call elements of 3D volume data "voxels" because they get a third dimension, a thickness. Thus they carry information about their individual position in x, y, *and* z – plus a particular value for their colour or grey value. Since different densities of materials lead to differences in the grey values of the voxels, one can detect the inner composition of the scanned object. If that composition is to