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Anthropology Takes Control of Morphometrics

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ABSTRACT

There has been a startling change over the last decade in the intellectual context of morphometrics. In the 1990's, this field, which has not altered its focus upon the quantitative analysis of biomedical shape variation and shape change, was principally centered around concerns of medical image analysis; but now it is driven mainly by the demands of researchers in human variability, physical anthropology, primatology, and paleoanthropology instead. This essay celebrates that change and tries to account for it by reference to cognitive and intellectual aspects of the new home.

Key words: *morphometrics, anthropometrics, multivariate statistics, shape coordinates, thin-plate splin, Partial Least Squares*

Introduction – From Ötzi to Procrustes

One day in September 1991, two hikers in the South Tyrol noticed a dead body at the edge of a glacier and ran to inform the Austrian police. Before it was permanently determined that the mummy was actually on the Italian side of the international boundary, Ötzi, the celebrated Iceman, had been sent to the CT scanner at the University of Innsbruck, and Horst Seidler, the sole professor of anthropology in Austria, had been summoned to oversee an international consortium of specialists working to learn all they could from this precious specimen.

The results of this first round of investigations were published quickly[1], and generated material samples that continue to be of great interest, but serious quantitative study of the CT scan was greatly delayed (so that, for instance, it was not until 2001 that the famous arrowhead was discovered embedded in the shoulder). Already in the early 1990's, Seidler had invited the Zumtobel Corporation to make a stereolithographic model of Ötzi's skull, so that he could run his eyes and fingers over it and generally assess its anthropological affinities. Beyond

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that technique of direct inspection, it was not at all obvious how to extract further information from the CT about the parts of the mummy that remained inaccessible.

Enter the late Dr. Leslie Marcus, who, upon meeting a Vienna colleague of Seidler's early in 1998, mentioned the recent developments (summarized in Marcus et al. 1996[2]) rendering the field of morphometrics relatively stable, so that data analyses, even in three dimensions, might be considered consensual, and arguments might be restricted mainly to scientific content instead of infecting the Methods section of papers as well. Marcus offered to organize a workshop for the Vienna anthropologists, and Seidler found the necessary funds (a generous grant from Zumtobel). The plan for the workshop was a staid parade of lectures and examples similar to what several of us invited faculty had been presenting for some years in similar venues (Madrid, Paris, Il Ciocco). Of the five days scheduled, day 1 was given over to review talks and an introduction to »data sets to be examined during the workshop – CT data and specially prepared [meaning: midsagittal] slices of Petralona, Atapuerca 5, Kabwe, Monte Circeo, and Bodo.« The teachers concentrated on the Procrustes methods, which were introduced and taught in the usual way for a couple of days.

Marcus's original syllabus for the meeting stated that »if Horst wants some short paper out of this stating the problem area, where we got with a solution, and why all of this is important, then a subset of Horst and two others should work on drafting something during the meeting.« In fact, Seidler's intention had been to produce a severe criticism of the Frankfurt superposition, which, he thought, was leading to misleading conclusions about all the comparisons among archaic *Homo* (as well as Ötzi). But instead the syllabus was mostly put aside as the meeting erupted in an unexpected creative ferment. Turning to those »specially prepared slices,« Hermann Prossinger showed a system of pseudolandmarks for frontal bone outlines in the fossils, to be treated by the usual Procrustes methods; but Bookstein immediately threw out the agenda in favor of a demonstration of the semilandmarks he had just published, to no acclaim whatever, in the medical literature. The computer program Edgewarp was imported and the midsagittal CT images formatted for it that same day. On Thursday Prossinger, sitting in front of a Silicon Graphics with his magnifying glass, heroically redigitized the entire data set; and by Friday we had the main findings and even a few text fragments for the manuscript about frontal bone invariances that actually appeared as Bookstein et al. (1999)[3] [which explains why the author's list for that is so long: it included most of the workshop instructors as well as the curators of most of the fossil specimens].

The thrust of this paper is instructive in its simplicity.

»Archaic and modern human frontal bones are known to be quite distinct externally, by both conventional visual and metric evaluation. Internally, this area of the skull has been considerably less well-studied. Here we present results from a comparison of interior, as well as exterior, frontal bone profiles from CT scans of five mid-Pleistocene and Neanderthal crania and 16 modern humans. Analysis was by a new morphometric method, Procrustes analysis of semilandmarks, that permits the statistical comparison of curves between landmarks. As expected, we found substantial external differences between archaic and modern samples, differences that are mainly confined to the region around the brow ridge. However, in the inner median-sagittal profile, the shape remained remarkably stable over all 21 specimens. This implies that no significant alteration in this region has taken place over a period of a half-million years or more of evolution, even as considerable external change occurred within the hominid clade spanning several species. This confirms that the forms of the inner and outer aspects of the human frontal bone are determined by entirely independent factors, and further indicates unexpected stability in anterior brain morphology over the period during which modern human cognitive capacities emerged.«

There is no mention of the notorious Frankfurt horizontal (even though, incomprehensibly, the article figured its raw data in that orientation) nor any argument about the new methods. The Procrustes toolkit is simply declared to be the method of the paper, without any justification, serving directly for nonstandard answers to standard questions about features and factors of evolutionary form change.

The reader should not think of this as a story about some visiting Americans and their intellectual imperialism. Rather, it is intended to illustrate a sudden change in the scientific setting of morphometrics: a discontinuity in its community of reference, which shifted from medical imaging into anthropology just about the time of this workshop, and, to a surprising extent, as a consequence of it. The scale of applications for geometric morphometrics in paleoanthropology was evidently larger than the scope of this or any other single workshop. Other activities first imagined in 1998 have continued and intensified since then – notably another workshop (in 2000) on the general topic of »missing data« in paleoanthropology, the construction of a permanent curriculum in morphometrics at the University of Vienna, and a steady stream of presentations year after year at both the European and American anthropology conventions – but the impact is actually much broader than that single Vienna venue. It is anthropology journals like *American Journal of Physical Anthropology, Journal of Human Evolution,* or this very *Collegium Antropologicum*, not biomedical imaging journals like *Medical Image Analysis* or *IEEE Transactions on Medical Imaging*, that publish Procrustes and thin-plate spline papers in nearly every issue; it is the anthropology meetings, not statistics meetings, that have extensive sessions on the future of morphometrics[4]. This essay speculates on the reasons that this energetic joint advance is shared between these two otherwise quite dissimilar disciplines.

Brief Sketch of the Standard Toolkit

The editors of this special section have asked us to incorporate a short overview of the core methods used by the community we will be discussing. It is convenient to report these under three headings: shape coordinate methods, visualization methods, and statistical methods.

Shape coordinate methods

What we mean by the »shape« of a set of labelled points (landmarks) is the information in such a figure after we ignore location and orientation and set aside scale as a separate scalar for later use (the quantity called Centroid Size). David Kendall (1984)[5] showed that sets of figures that are all »the same shape« in this sense can be treated as the separate points of their own geometrical space in which the distance between any two shapes should be taken as *Procrustes distance*, root-sum-square of the Euclidean distances between the landmarks when each configuration is scaled to sum of variances 1 and then one is superimposed over the other for least such sum of squares. Bookstein (1998)[6] is typical of the review articles specialized for biomedical applications, and for a standard text see Dryden and Mardia (1998)[7].

To any sample of shapes corresponds their average, the shape with the least summed squared distances to the shapes of the sample. There is a unique set of *Procrustes shape coordinates*, landmark locations after each configuration is fitted to their average by the best translation-scaling-rotation, and these shape coordinates serve as the *variables* that represent shape for most subsequent statistical maneuvers. Unusually for a branch of biometrics, it is this part of morphometrics, the actual generation of variable values, that is founded on fairly deep mathematical theorems (which in other application domains usually pertain only to the algebraic procedures by which measurements are combined or compared over samples). Nevertheless, those more standard mathematical maneuvers apply as well – all the conventional distributional assumptions of multivariate biometric analysis can be shown to reasonably apply to the shape coordinates once they have been converted to »Kent coordinates,« projections onto an auxiliary linear construction of Kendall's space that relates to it somewhat as a tangent plane relates to an ordinary ball. The extensions to these methods that handle curves and surfaces are thus far exploited mainly in anthropology, and will be discussed below when we return to our main theme.

Visualization methods

We need not just to measure but also to *see* scientifically relevant trends or distinctions of shape. For this purpose there is another standard tool of the new morphometrics, the *thin-plate spline*, that comes in formulations for 2D data and for 3D data. In 2D, let U be the function $U(\vec{r}) = r^2 \log r$, and consider a reference shape (in practice, a sample Procrustes average) with landmarks $P_i = (x_i, y_i)$, $i = 1,\ldots, k$. Writing $U_{ij} = U(P_i - P_j)$, build up matrices

$$K = \begin{pmatrix} 0 & U_{12} & \ldots & U_{1k} \\ U_{21} & 0 & \ldots & U_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ U_{k1} & U_{k2} & \ldots & 0 \end{pmatrix},$$

$$Q = \begin{pmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ \vdots & \vdots & \vdots \\ 1 & x_k & y_k \end{pmatrix}, \qquad L = \begin{pmatrix} K & Q \\ Q^t & O \end{pmatrix},$$

$$(k+3) \times (k+3),$$

where O is a 3×3 matrix of zeros. The thin-plate spline $f(P)$ having heights (values) h_i at points $P_i = (x_i, y_i)$, $i = 1,\ldots, k$, is the function $f(P) = \sum_{i=1}^{k} w_i U(P - P_i) + a_0 + a_x x + a_y y$ where $W = (w_1,\ldots,w_k, a_0, a_x, a_y)^t = L^{-1}H$ with $H = (h_1, h_2,\ldots, h_k, 0, 0, 0)^t$. Then we have $f(P_i) = h_i$, all i: f interpolates the heights h_i at the landmarks P_i. Moreover, the function f has minimum »bending energy« of all functions that interpolate the heights h_i in that way: the minimum of

$$\iint_{\mathrm{R}^2} \sum\sum_{i,j} \left(\frac{\partial^2 f}{\partial x_i \partial x_j} \right)^2 .$$

This integral is proportional to $W^tH = H_k^t L_k^{-1} H_k$, where L_k^{-1}, the *bending energy matrix*, is the k×k upper left submatrix of L^{-1}, and H_k is the corresponding k-vector of »heights« $(h_1, h_2,\ldots, h_k)$.

For morphometric applications, where the sample Procrustes average supplies the coordinates P of the reference shape, the algebra here is applied separately to each Cartesian coordinate H of vectors that illustrate specific biologically meaningful entities: for instance, the shape coordinates of of each organismal specimen in turn. In 3D, $U = |r|$, O is 4 × 4, and Q is k × 4.

Statistical methods

Most of the tools that evolved for earlier multivariate morphometric studies apply to shape coordinates with at most small modifications. Principal components, for instance, apply to shape coordinates without any change in formula (though once computed they are typically displayed by splined grids rather than by lists of coefficients); linear models such as regression or analysis of variance go forward meaningfully whenever the variance components being decomposed are taken as squared Procrustes distances or their restrictions to specific useful subspaces; allometry is displayed by thin-plate splines of the regressions of all the shape coordinates on Centroid Size.

But the geometric symmetries of the shape coordinate formalism are a fertile domain for exercising a third core technique of the morphometric toolkit, Partial Least Squares (PLS). PLS is a statistical technique remedying the absence from the classic toolkit of a least-squares equivalent for canonical correlations analysis. PLS represents low-dimensional linear relationships between two or more high-dimensional measurement blocks by adapting the singular-value decomposition (SVD) for cross-block covariance matrices. Suppose there are k landmarks or semilandmarks, and thus pk Procrustes shape coordinates, $p = 2$ or 3, in some data set of images, and also m organismal measures, such as behaviors, titres, grouping variables, environmental measurements, or another set of shape coordinates. Write X_i for the i^{th} shape coordinate variable, $i = 1,..., pk$, and Y_j, $j = 1,..., m$ for the j^{th} z-scored exogenous score. PLS produces pairs A_1, B_1, A_2, B_2,... of singular vectors, the A's, having pk elements, and the B's, having m elements. With each pair will be associated a scalar singular value d_i. The A's are orthonormal (perpendicular and of unit length), and likewise the B's.

The *latent variables* $LV_X = \sum A_{1i}X_i$ and $LV_Y = \sum B_{1j}Y_j$ have covariance d_1, and this is the greatest covariance of any such pair of linear combinations with coefficients of unit length. Successive pairs (A_2, B_2), (A_3, B_3), etc. satisfy the same properties contingent on the constraint that each A_i be perpendicular to all previous A's and each B_i to all previous B's. When the X's are shape coordinates, these successively most predictable aspects of shape are usefully drawn as thin-plate splines. Statistical significance is tested by permutation tests (not distribution-based statistics), usually pivoting on those d's, at all levels of study design from two-group comparisons on upward.

Extension of the Tools for Anthropology

These are the basic tools[2] of contemporary morphometrics across a wide range of applications. Here in 2004, it is plain that the *depth* of these applications is much more profound in physical anthropology than in most of the other domains (systematic biology, medical image analysis, cognitive psychology) in which it has been put to use. Evidently the preceding three techniques are fairly technical, and yet their penetration into anthropology is more engaged – more fundamental, less just a matter of convenience of formalisms – than the corresponding uses in fields otherwise far more technical, such as computer science or algebraic image analysis, and, complementarily, the field of morphometrics now responds to demands from anthropologists with greater alacrity and pertinence than to demands arising outside.

Specific developments illustrating this general point are easy to come by in the pages of JHE or AJPA and in the syllabi of our workshops and courses at Vienna.

Symmetry

The analysis of symmetry in biological data, especially bilateral symmetry, has a history spanning centuries. Yet the first paper bridging the biotheoretical study of fluctuating and directional asymmetry to the language of contemporary biometrics[8], centered on two anthropometric data sets, and the only refinement of that decomposition over the intervening four years is a dissection of the space of directional asymmetry (into components such as bilateral size difference or midline bending) that was presented first at the AAPA 2003 meeting[9]. From this anthropological foundation, these techniques are making their way into overlapping disciplines such as genetics of development[10,11] and into the sociobiological studies of mate choice[12] that had been hobbled since the 1980's by the older morphometrics of single variables. These new studies use Procrustes analysis and thin-plate splines, two of the components of the current toolkit.

Integration

The topic of morphological integration erupted briefly into the biomathematical literature in the 1950's[13] but then faded, mainly for reasons of a mismatch between multivariate statistical tactics and underlying biological theory. Recently all three elements of the current toolkit have been combined[14] in a re-engineered approach to the same themes. Integration is interpreted as a statistical shape pattern fitted across multiple regions of a shape coordinate scheme, extracted by Partial Least Squares and visualized by thin-plate splines that correspond to integrative factors.

Allometry and heterochrony

Another classic problem left behind in recent decades is the study of the relationships between size and shape introduced by Huxley in the 1930's and last formalized by Gould and colleagues in the late 1970's. The construct of *Procrustes size-shape space*, an algebraic possibility mentioned in passing in the mathematical theory of Procrustes work[7] has just now seen its first practical application: in Mitteroecker, Gunz, and Bookstein, (2004)[15,16], it is applied to systematize the wide variety of methods emerging since the 1980's for extracting »factors« of allometry from multivariate data. The paper shows how all the main current multivariate approaches arise as alternative visualizations of one single shared ordination in this new statistical space.

Semilandmarks

This technique, already mentioned in connection with the frontal bone study of 1998, had been introduced to the algebraic image analysis community but had not previously played any role in a scientific argument prior to its appplications in anthropology. Semilandmarks are a joint extension of the Procrustes and spline tools of the toolkit whereby data about curves and surfaces can be directly be used in multivariate analyses and their visualization right alongside conventional landmark points. As of this writing, the principal software product in which this formalism is computed is the University of Michigan program package Edgewarp, the latest release of which highlights the extension of this useful notion to semilandmarks in three dimensions (points sliding on anatomical surfaces). The installation in Edgewarp lags by some years the implementation by two authors of this paper (PG, PM) in the course of their dissertation research in anthropology at the University of Vienna, and the initial applications[15] are extended arguments in paleoanthropology and human evolution. Figure 1 shows how many previously unquantified shape features can be incorporated in the analysis

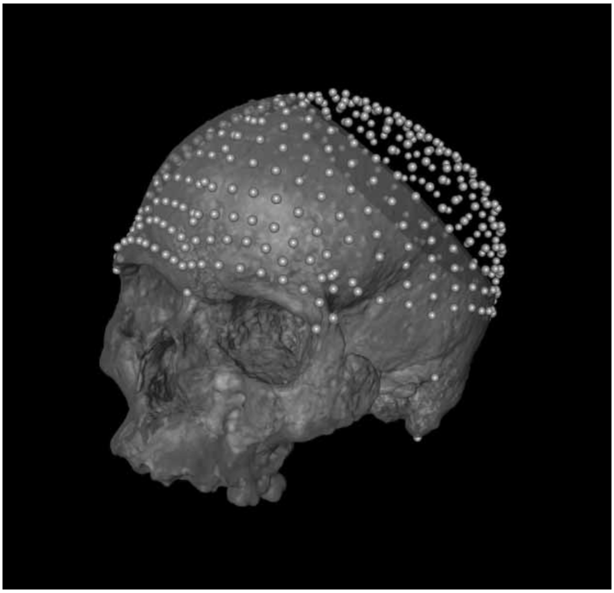

Fig. 1. CT scan of a fossil H. sapiens cranium with semilandmarks on the neurocranium. Combining the tools of virtual anthropology and geometric morphometrics allows one to capture and analyze shape information in previously inaccessible regions. The calvaria is cut to access the interior of the Mladec I skull (Weber et al., 2004)[29]. The spheres show landmark and semilandmark coordinates on the exterior cranium. These points are geometrically homologous and can be used for multivariate statistical analysis.

by using semilandmarks on the neurocranium.

Rethinking the classic ontology of landmarks

The very word »landmark« came to morphometrics from anthropology, and the semilandmark constructions reviewed in the previous paragraph originated as attempts to capture for morphometrics the information that anthropologists were already gathering from curves and surfaces[17]. The anthropological literature has always been more advanced than others in its awareness of the dependence of point definitions on artifact[18], or the emphasis on fixed orientations such as the notorious Frankfurt horizontal in order to lead to reproducible comparisons across specimens). Recently morphometric language has changed in order to acknowledge the origins of many of the useful punctate constructions in terms of the curves and surfaces that serve as original data. Thus new landmark point types may arise from anthropologically familiar constructions such as the midplane of a symmetric form, the midcurve of a slightly nonsymmetric form, or the ridge curves that for decades have characterized the description of archaic *Homo*. The new discussion of semilandmark-aware landmark point types is being opened for the first time at the 2004 AAPA annual meeting[15].

Why is This Happening Here? Why Now?

The shape coordinate techniques first appeared in the statistics literature in 1986. If one had asked then to which sorts of biometrical applications they would likely be most profitably directed, the answer would surely not have been »paleoanthropology.« Rather, the early applications were to praxes like orthodontics or reconstructive facial surgery, and the next round of findings ran to neuroanatomy and image-related studies in psychiatry. Nevertheless, here in 2004 we find that physical anthropology, specifically the evolutionary part, is now the major driving force behind advances in the computational and statistical tools shared by all the users of shape coordinates and splines. It would be nice to have some explanation of this striking intellectual-sociological phenomenon, preferably (but not necessarily) one that flatters the anthropologist without deprecating the statisticians, mathematicians, computer scientists, and other quantitative biologists whose collaboration has been essential to these advances. In formal presentations (e.g. Bookstein, 2002[20], a plenary address at the European Anthropology Congress in Zagreb, Croatia), in symposia (e.g., Slice, 2004[4]), and in diverse conversations over the last several years, we are finally beginning to understand some of the reasons this unusually close interdisciplinary collaboration has come to pass.

History of multivariate pioneering in anthropology

A first reason is by way of intellectual history. There is a close collaboration between anthropology and statistics today partly because there has always been such a collaboration. The ori- gins are manifold, and not always praiseworthy: anthropometrics in the service of European racism in the mid-1800's[21], transformed into multivariate approaches by the Galton-Pearson school of eugenics in the early twentieth century. Francis Galton himself invented twopoint shape coordinates (»Bookstein coordinates«), and at the very end of his life Pearson almost got the rest of multivariate morphometrics in the course of his study identifying the mummified head of Oliver Cromwell by matching its landmarks to the corpus of portraits and busts[6,22]. More respectably, during the initial surge of multivariate methods into statistics in the 1930's, Fisher's variance decomposition ideas were complemented by the anthropometric techniques of Mahalanobis distance applied to racial and other anthropological classifications at about the same time. These techniques continued to be developed right up through the mature work of W. W. Howells (1973)[23]. In our view, the reinvention of anthropometrics in collaboration with the current turn to the shape coordinate methods may be the most important development in biometrics in half a century, inasmuch as it demonstrates to other user communities how it is possible to use biomathematics in the course of generating actual measured data, not merely in combining those measurements once they have been made.

Respect for precious specimens

Anthropologists have *always* pushed statistical methods to maximize information content in order to convert scarce specimens into the even scarcer inferences that really matter about human variation and human origins. Anthropology has emphasized multivariate studies because the originally primary research data (dried skulls) have always had more potential features of measurement than there were specimens for analysis. The modern morphometric emphasis on keeping quantitative features of *all* parts of the form in focus at the same time, and the possibility of multivariate tests of association that permit a greater number of variables than cases (such as the PLS methods already noted, or the replacement of most Gaussian models by permutation tests), meet specific needs of the classical anthropologist, and were welcomed for that reason.

The importance of multivariate analysis in anthropology is not only in respect of the efficiency with which it gathers intentionally redundant information from scarce specimens. It also speaks to the prophylaxis for that redundancy, namely, the strong role played by principal components analysis, canonical variates analysis, and the other techniques explicitly searching for optimal *combinations* of those measurements. Contemporary morphometrics has supplied equivalents for all of the classic anthropometric summaries – for distances, the techniques of Procrustes distance ordination and its specializations for shape space and for large-scale features; for large-scale proportions, the uniform component and the first few partial warps; for studies of allometry, the explicit construction of a rigorous replacement for the classic »principal component 1« studies[15,16] that encapsulates the direct measurement of size change right alongside the geometric modeling of its effect on form.

Ceaseless attention to features at multiple scales

Anthropologists have always been catholic in their choice of the data patterns that are to be explained. The feature of a form that might account for its evolutionary or functional importance might be a muscle size, a lever arm, or a small detail of local remodeling in the form of a facetted joint or the position of a foramen. There resulted the demand that morphometrics, also, respect this range of scales. The language of landmarks and semilandmarks responds explicitly to this demand, as also does one possible »dead end« in geometric morphometrics, the technique of *edgels* (landmarks with directional information attached), introduced early in the 1990's, that has not yet found its compelling application[24].

Corresponding to this respect for the data at multiple scales is a need for precision of data gathering that is likewise quite unusual in the sciences of form. One of the reasons anthropologists use geometric measurements is that accuracy to the submillimeter level in forms at a scale of meters is often crucial to explanatory contrasts in a way that accuracy to, say, grams is only rarely crucial to explanations at the level of kilograms. The distances, angles, and ratios that preceded shape coordinates for representing variability of form were obsessively accumulated and tabulated well before there were any sensible statistical methods to handle the information in them[18]. The contemporary efforescence of methods for semilandmarks, in turn, responds to the need of the anthropologists for geometric measurements at even closer spacing than discrete landmarks, but still accessible for multivariate summary sensitive to signals at any scale. The expectation of precision of course exploits the central histological fact of osteology, namely, that bones are typically much more well-delineated than other tissue boundaries characterizing anatomical variation. (This is a different merit from the equally helpful observation that bones and teeth survive longer than other materials postmortem.)

Historically tight coupling between variation and explanation

No good anthropological study is restricted to one explanation at a time. Specimens vary by species, age, sex, ecotype, and evolutionary level, and usually by most or even all of these. Anthropologists have always needed to keep multiple explanations in mind simultaneously, meaning, in quantitative practice, allowing multiple factors to affect data covariance patterns simultaneously. The resulting emphasis on higher-dimensional data displays actually antedates all of contemporary morphometrics (see Oxnard, 1973[25], for instance, or the comment by Bookstein and Rohlf, 2004[26]). The distinction between evolutionary and ontogenetic explanations, in particular, drives the contemporary morphometric exegesis of allometry[27], which requires that multivariate techniques explicitly proffer explanatory factors for growth and for evolution in precisely the same coordinate system. No other field known to us reviews applied multivariate findings so strictly, nor searches so assiduously for confounding factors.

The experience of physical anthropology under this rubric can usefully be contrasted with the situation in closely related fields, such as medical image analysis, in which the principal subject of concern is the single form or its relationship to what is »normal.« In this somewhat different context, the most important statistical models are not of variation but of noise (meaning instrumentation noise). In anthropology, there is measurement noise (signal corruption) as well, but modeling it is of far less importance. The principal source of interesting variation is covariation, intended to inform about causes or effects. Scientifically, it is covariance that is far more useful, informative, and suggestive.

Sensibility regarding missing data

Among the themes that have not yet made it into morphometrics are several that anthropology is still demanding. One of these is the ubiquity of missing data, meaning whole broken-off substructures. As we write this, Gunz et al. (2004)[28] are experimenting with the completion of certain classic fossil skulls (the Taung child, as well as STS71) by joint exploitation of semilandmarks, thin-plate splines, and integrative statistics. If these methods succeed in promulgating persuasive reconstructions, they will lead to a change in the way morphometrics applies in its *other* application domains (for instance, inferring invisible boundaries in images by deformation of a template), whereby regressions and other sources of ancillary information can be used to characterize the post-hoc uncertainty of what has been inferred.

Work at Other Sites

We do not mean to imply that all the work in this new tradition goes forward inside the city limits of Vienna. Many other centers of anthropological research are adapting many of these techniques to a wider range of hypotheses or data sets. Among these additional nuclei of innovation are the group under Eric Delson at the American Museum of Natural History[30,31], considerable work on comparative ontogeny from Paul O'Higgins's group at University College London[32,33], and contributions from the Zurich group[34], Rosas's group in Madrid[35], and the group at the national Museum of Natural History in Paris[36]. Many more papers in this spirit are cited in the chapters of the collection of papers that just appeared under the editorship of Dennis E. Slice (2004)[4].

Fascinated Publics, Fascinated Patrons

We have reviewed several thrusts of anthropology that either have prodded morphometrics or are about to do so – symmetry, integration, allometry, landmarks and semilandmarks, regionally systematic missing data – and we have explored several historical or cognitive reasons why they have taken root in anthropology, such as the Euro-American history of racial studies and racism, scarcity of specimens, the multifactorial and multiscale nature of explanations, and the sheer precision of data collection that the smoothness of bony surfaces makes possible whether pre- or postmortem and, if the latter, regardless of how long.

But there is one additional factor in anthropology not shared by any other science of form: the weight of public fascination with human variation and human origins. For centuries the West has had museums and imperial collections (like the 35,000 skulls in the Naturhistorische Museum in Vienna), and topics of variation and origins are discussed ubiquitously in popular books and in the popular media. Human variation is irreducibly quantitative – anthropology must clothe itself as anthropometrics to make any progress on this topic – and the study of human origins became quantitative more than a century ago, in the hands (ironically) of Galton and Pearson, whose scientific theories would immediately be refuted by the studies their own tools made possible.

Morphometrics makes anthropologists better scientists; thin-plate splines allow displays to use the same visual apparatus exploited since Dürer for communication of caricature; debates about the driving forces of hominization (upright posture? freed upper arms? bipedal motion? large brain? droughts?) fascinate readers from every walk of life, and morphometrics gives anthropology more authority in speaking to all of these issues. The correlation techniques that led Pearson to his racism, and that are so badly abused throughout today's social and psychological sciences, have finally, in modern anthropology, found their proper role. Combined with shape coordinates for (semi)landmarks and with visualizations of form and of deformation in dynamic 3D and 4D, the rich data arrays of modern physical anthropology and the elegant rhetoric it has evolved for dealing with multiple explanations of the same non-experimental material at the same time render it the scientific community most central to public understanding of the scientific method in the new century.

For at least the last two hundred years, the science of anthropology has proceeded under the banner of the Enlightenment belief that, in Pope's words, »the proper study of Mankind is Man.« Horst Seidler – scholar, colleague, citizen, and friend – has certainly lived his career in light of that belief. If humankind is the central object of academic scholarship, then regarding the permanent physical traces of that subject of study, the best methodology that has yet been devised is the contemporary morphometric toolkit. Its predominance in contemporary anthropometrics can be directly laid to Seidler's efforts in organizing and encouraging this Vienna group, and it is to him that this essay is fondly dedicated.

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ANTROPOLOGIJA PREUZIMA NADZOR NAD MORFOMETRIJOM

SAŽETAK

Tijekom zadnjih desetljeća došlo je do velike promjene u intelektualnom pristupu morfometriji. Tijekom 1990-ih primarna zadaća ovog polja bila je usmjerena na kvantitativne biomedicinske analize varijacija i promjena oblika i primjeni u analizi slikovnih prikaza koji se primjenjuju u medicinskoj dijagnostici. Danas je cilj prvenstveno usmjeren zahtjevima istraživanja na područjima varijabilnosti čovjeka, fizičke antropologije, primatologije i paleoantropologije. Ovaj rad obilježava tu promjenu i pokušava ju smjestiti u njenom intelektualnom i kognitivnom okruženju.