Order Number 1357288

From calipers to computers: Three-dimensional imaging in forensic anthropology

Ackermann, Rebecca Rogers, M.A.

The University of Arizona, 1994

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

FROM CALIPERS TO COMPUTERS:

THREE-DIMENSIONAL IMAGING IN FORENSIC ANTHROPOLOGY

by

Rebecca Rogers Ackermann

A Thesis Submitted to the Faculty of the

DEPARTMENT OF ANTHROPOLOGY

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF ARTS

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 9 4

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgement the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: ______________________

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Walter H. Birkby, PhD, D-ABFA — 11 April 94

Walter H. Birkby
Forensic Anthropologist

Date

ACKNOWLEDGEMENTS

I would like to thank Dr. Walter H. Birkby for allowing his students to share in his work, dedication, and enthusiasm.

I also wish to express my heartfelt gratitude to Dr. Jane E. Buikstra for her constant inspiration.

Additionally, I am incredibly grateful to Denice Warren at IPT for allowing me access to their systems hardware.

To Kurt

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABSTRACT

Forensic anthropology is an applied science sorely lacking in theoretical underpinnings, despite the fact that forensic anthropologists have unique, albeit usually fleeting, access to modern skeletal remains. By constructing a database of three-dimensional images, such remains can be accessed indefinitely. I have proposed a method for just such imaging, using Macintosh hardware and NIH *Image* software to digitally preserve remains using red-blue three-dimensional imaging techniques. Additionally, I address the qualitative and quantitative accuracy of these images. By creating this type of forensic database, anthropologists can then reformulate outdated methodologies that address issues like populational variance, thereby using modern forensic skeletal remains to better understand some of the fundamental theoretical issues within anthropology.

THE PROBLEM

Introduction

The study of humankind has intrigued intellectuals for centuries. From an early curiosity about 'self and others,' anthropology has developed into a subdivided academic discipline with specialties ranging from the linguistic study of language origins to the forensic analysis of human remains. Forensic anthropology, a relatively young field, began as pathologists with little osteological experience turned to local physical anthropologists for occasional consulting in legal investigations; it has since become a discipline in its own right, incorporated into physical anthropology Master's programs in universities around the globe.

However, as most forensic anthropologists situated in a non-physically-oriented anthropology department realize, some anthropologists maintain a pejorative view of the applied science of forensics. In fact, a split within anthropology between cultural and biological factions has never been wider than it is today.

> Anthropology has always been divided among those who use biological theories to illuminate the behavior of human societies, and those who take a more interpretive and descriptive approach. But the divide has become much more pronounced as biological anthropologists have become deeply involved with the latest tools of molecular biology and theories of evolutionary ecology, while many cultural anthropologists have become caught up in the wave of deconstructionist thinking that has been sweeping the humanities (Morell 1993).

To many, forensic anthropologists are just a bunch of "techies," no more academic than any average laboratory technician. In some respects they are not far off. We ourselves have promoted this view by relying heavily on applied empirical methods such as metrics and shunning more theoretical aspects of anthropology. We crave to be included in the "hard" sciences, but are not accepted there; we shun the social sciences as too "soft." This leaves us suspended over the growing chasm; our moorings are tenuous at best and threaten to give way altogether.

So, where exactly **do** forensic anthropologists reside--in the "hard" empirical realm of biology, in the "soft" philosophical realm of sociology, or in the purely applied realm of the technician? And what role does theory play in forensic anthropology? In order to address these questions, it is helpful to reflect on the history of science itself.[1]

Science in General, Forensics in Particular

Modern Western science began in earnest its separation from traditional Western philosophy in the 17th century. Before this separation, it was difficult to distinguish science from natural philosophy, largely because the Church dominated the world of ideas and the physical embodiment of

[1] I in no way claim to be an expert on this subject, nor can I profess an ability to address such a historically rich and complex task in this forum. However, the nature of critical reflection necessitates at least looking at scientific history.

those ideas, the university. In the 17th century, organized scientific societies, distinct from the church-controlled universities, formed, promoting exploration of new ideas of science and nature. These societies, coupled with the inventions of many monumental instruments (telescope, microscope, precision clock, thermometer, barometer) created an environment leading, as we shall see, to the birth of the experimental method (Westfall 1990).

Two prominent figures of this watershed era were Bacon in England and Descartes on the Continent, and a quick gloss over some of their thoughts will provide the groundwork we need for our discussion of modern science. Francis Bacon (1561-1626) is frequently considered the originator of the experimental method, due to his call for a direct examination of nature. Around the same time, Descartes' insistence on and elevation of experiment and mathematics helped delineate 'science' as a pursuit of knowledge via rational inquiry that contains a hard empirical core.

This scientific inquiry was one with a stated direction and purpose as well-- it had to be *useful* to man. As Westfall writes, "Science also contributed to a new ideal of the function of knowledge. Where knowledge had been considered an end in itself, and the quiet contemplation of truth the highest activity in which man can engage, the assertion was now made that the end of man is action and the end of knowledge utility" (Westfall 1990).

In his preface to The Great Instauration, Bacon emphasizes man's control over nature:

> That the state of knowledge is not prosperous nor greatly advancing; and that a way must be opened for the human understanding entirely different from any hitherto known, and other helps provided, in order that the mind may exercise over the nature of things the authority which properly belongs to it. (Bacon 1989)

The stated and proper end of the pursuit of knowledge is to enhance human comfort and convenience--a view that has been promoted by the social and economic climate since the 17th century. From Bacon, to Descartes' statement that we should "make ourselves, as it were, masters and possessors of nature" (Descartes 1980), the pursuit of useful knowledge that gives rise to powerful technology has become the prime mover of modern science, and simultaneously, of modern culture.

In light of this selfish purpose that drives scientific inquiry, many find that the equation of science with objective fact is hardly viable given our modern perspective, as all science is seen as part of a modern culture which relies heavily on prevailing ideologies of desire. All work that a scientist does is influenced by the culture he resides within, and cannot be entirely objective. By way of preface to the coming argument, we must acknowledge that to use 'fact' as a criterion for distinguishing 'science' from 'non-science' and, similarly, to distinguish various sciences from each other is problematic. Nevertheless, scholars insist on splitting the sciences into distinct 'types,' claiming that some are more 'scientific' than others.[2] For my purposes, I will follow this useful if imperfect distinction as my primary interest is in a historical reflection, not a critique of current scientific ideologies.

Mortimer J. Adler discusses the fact that in the 19th century, Auguste Comte, in his book Positive Philosophy, insisted that only the positive sciences-- those which study phenomena by means of empirical methods-- should be called "sciences" (Adler 1992). This conception, referred to as "positivism," is prevalent in today's attitudes. According to Adler, the various modern types of positivism share a common denominator. "All its current varieties seem to have this much in common: the identification of science with knowledge of fact, and further, the restriction of such knowledge to conclusions obtained and verified empirically. Whatever does not accord with this conception of science is either, like mathematics or logic, a purely formal discipline or, like philosophy and religion, it is conjecture, opinion, or belief-- personal, subjective, even wishful" (Adler 1992).

In other words, a discipline can be considered more scientific depending on the degree to which empirical methods

---

[2] As a budding scientist, I too am forced to distinguish between realms of science. For the sake of clarity, I will refer to distinctions between theoretical science (with philosophy as its applied science), and empirical science (with the technical sciences as its applied science).

are used to gather facts or data. We refer to the general process as the scientific method, although this is far from a neat recipe for science. In general, scientists explain their observations with hypotheses-- theories that are not yet proven. A scientist recognizes that these hypotheses are tentative; they are to be tested by experiment and are subject to change following the acquisition of new information. Through this process of creating, testing and recreating hypotheses, scientists ultimately prove and disprove theories. Grounded in experiment and empirical data, directed by an interest in utility, and shaped by a shared method, modern science has assumed its current form. For those who think in evolutionary terms, it might help to think of this as the most fit process to date. "That which is most useful in practice," Bacon writes, "is most correct in theory" (Bacon 1989). This approach epitomizes what it means to be a science in the modern world and it has served the sciences well.

Having taken a brief look at the underlying history and method of science in general, we get a broad sense of what we would call "science," how it works and why. Certainly forensic anthropology, like the sciences in general, is extremely useful in practice. By looking at the historical and methodological development of forensic anthropology against this broader background, we can more accurately assess its origins and position relative to the other sciences. We can then consider the place of theory in forensic anthropology.

Forensic anthropology is a young science, and therefore did not spring directly from natural philosophy as did most of the sciences in the 17th and 18th centuries. Rather, it grew out of the ensuing empirical and utilitarian ideologies of that time period, a second generation science, one might say.[3] In Europe (where much of the history of forensic science unfolded) in the late 18th and early 19th century, women and children were still being hanged for petty crimes, and more serious crimes were relatively scarce. Wilson, in Clues!; a History of Forensic Detection, speculates that the rise of crime in England (and London in particular) in the mid-18th century was caused by three factors: (1) new gin availability, (2) an increase in visiting sailors due to the increase of world trade, and (3) the separation of the classes due to a massive increase in England's wealth (Wilson 1991). This rise in crime ultimately led to the creation, in 1829, of the first police force.

However, it wasn't until 1889 that pathologist Jean Alexandre Eugene Lacassagne, a Professor of Forensic Medicine at the University of Lyon, succeeded in the first (recorded)

---

[3] In fact, forensic anthropology is in many ways the ultimate product of Bacon's philosophy of the servitude of science to humans; crime is very much a product of our selfish human culture, and therefore the investigation of crime uses science to fit our culturally created needs. This manipulation of science to fulfill cultural necessity is evident in the history of forensics.

identification of a decomposed body. Since then, the increase in suspicious deaths, and subsequent increase in the need for body identification, coupled with a reduction of the osteological knowledge imparted to pathologists, due to the tendency to stress soft tissue study in medical school curricula, has forced many forensic pathologists to turn towards outside consultants in body identification situations. As the same osteological skills that are frequently lacking in pathologists tend to be honed in physical anthropologists, it follows that forensic work has become incorporated into the realm of some anthropologists.

According to Ubelaker (1992), three eras have been identified in the history of forensic anthropology. From the mid-nineteenth century until 1939 is "viewed as the Dark Ages of the science as an instrument of law. Anatomists and physical anthropologists were consulted now and then on forensic remains, and sometimes they testified in court, but with very little visible impact on the academic development of their profession" (Ubelaker and Scammell 1992). The time period from the 1939 publication of W. M Krogman's "Guide to the Identification of Human Skeletal Material" until 1972 marks the second era of forensic anthropology--one in which both the legal and the anthropological community began to acknowledge the legitimacy of applied osteology in the medical-legal world. In 1972, the Physical Anthropology section of the American Academy of Forensic Sciences was founded, marking the start of the third historical era in forensic anthropology. "The new organization gave a legitimacy and rallying point for all the previously unconnected anthropologists who were scattered about in the field" (Ubelaker and Scammell 1992). By coming together, forensic anthropologists could unify to define the boundaries of their subdiscipline. These definitive boundaries within the field of anthropology as a whole are therefore not merely a product of a historical trend towards experimental and empirical approaches to science, but also contain historical strands born of the byproducts of these approaches-- the practical, the technical, and the useful.

Theory in Forensic Anthropology

So, having reflected on the historical development of modern science and the subsequent development of forensics, I now return to the question, "What is theory in forensic anthropology?" In its broadest literal sense, a theory is a postulate supported by facts. With this understanding, virtually everything academic-- every sort of research imaginable-- involves devising theories. Such a broad definition allows room for relatively straightforward (and easily provable/disprovable) hypotheses like 'it is possible to infer stature from the length of the fifth metacarpal.'

However, in scientific inquiry questions frequently involve more fundamental concepts, such as the nature of matter or the mechanism of human evolution. Resulting theories not only address physical phenomena, but also why they exist. One might claim that the differences between these theories can be clearly distinguished, that a line can be drawn separating one from the other based on some criterion of content, scope, difficulty, or other measure. We can draw out and clarify these issues by considering the distinction between differences in degree or in kind. In other words, are differences between these two types of questions and between the corresponding modes of inquiry due to fundamental differences or rather to their placement on a continuum? I contend that while all theories in scientific inquiry are important, some are more important than others. However, all scientific theorization involves similar processes by employing the hypothetico-deductive method of inquiry.[4] Any measure of the relative scientific merit of a question forces one to draw an arbitrary line in the sand; the questions asked reflect differences in degree and not in kind.

Theories, too, display a difference in degree--they occupy different positions on the continuum which runs between basic problem-solving and those fundamental issues which concern the nature of nature itself. For example, a

---

[4] Ideally, scientific theorization should be the result of inductive reasoning, however, science is far from ideal, and is subject to the same forces that affect all humans in all matters of inquiry.

person theorizing about human evolution by examining hominid remains might analyze and describe neandertal remains and then theorize about whether a direct lineage exists from the neandertals to modern *Homo sapiens*. In this sense, there are two parts to theory formation-- one asks simply "what?," and the other asks "what does this tell us?." In forensic anthropology, we ask "what?" all of the time. "What is this bone?" "What sex is this skeleton?" However, we don't frequently ask "what does this mean?" True, a forensic anthropologist might ask "what does this Carabelli's trait on the molar tell us?" But, he or she is less likely to ask "what does this specific trait tell us about changing world racial distribution patterns?" Or, "what do changing world racial patterns tell us about the human condition?" Such probing questions reside on the 'highly theoretical' end of the theory continuum, as they address fundamental truths about science and humanity. Although many forensic anthropologists address such challenging issues within their other interests in physical anthropology, frequently these issues are kept distinct from their forensic work. The cases which pass through the hands of forensic anthropologists rarely escape the purely osteological and morphometrical applied realm to enter into the theoretical realm.

As we have seen, scientific thought developed from highly speculative pre-17th century inquiry towards highly empirical post-17th century science. 'Empirical' became the catch-word of the times, with 'applied empirical' gaining importance in a time when science became morally bound in servitude of humanity. So, having a historical legacy grounded in such scientific thought, forensic anthropology understandably occupies a niche in the farthest applied realms of empirical science. Perhaps it is best that forensics reside solely as an applied empirical science by becoming distinct from physical anthropology. However, if this is the case, forensic anthropologists cannot complain when others consider their specialty rather non-academic. After all, many would argue that a field which does not produce theory that contributes to meaning in scientific inquiry hardly belongs in academia. With no theoretical foundation, it is impossible to get a PhD, and it follows that PhD's are not offered in forensic anthropology; forensic anthropology as a distinct academic discipline simply does not have its own theoretical grounding. And as a specialty without a theoretical foundation, the tenuous suspension of forensic anthropology over the chasm within anthropology departments can do nothing but weaken, and the situation draws ever nearer to calamity.

Before proceeding further, I must make it clear that much of this introductory argument is based on commentary, from non-forensically inclined scholars, that I have gathered throughout the past few years. I certainly do not believe that forensic anthropology is worthless, or I would not be involved with it. I do, however, believe that many of its fundamental premises are in need of reworking. It is towards this goal that this paper now turns.

If forensics were to leave anthropology, as some would like, where would it go? Anatomy departments, a likely choice in academia, have turned towards microanatomy and away from macroanatomy in recent years.[5] Other choices, such as incorporation into law enforcement, would mean leaving the academic arena. In such a scenario, forensic anthropologists would definitely become technicians, and would forfeit the other academic research interests that they pursue. Anthropology departments appear to be the most likely places for forensic anthropologists to pursue their academic interests. However, if forensic anthropologists wish to remain within the academic environment where they now reside, this image as mere technicians needs to be dispelled. While the chasm in anthropology is between the more scientific physical anthropologists and the more philosophical cultural anthropologists, each side maintains a theoretical foundation. I believe that the dichotomy between non-theoretical forensic anthropology and these other two more theoretical areas of anthropology maintains this "merely technical" image, and may lead to the ousting of forensics

---

[5] While this is good for physical anthropologists in the sense that they now frequently get to teach gross anatomy, it reflects the dwindling interest in gross structure within anatomy departments--certainly not an attitude which favors the addition of gross structure specialists.

from anthropology as one of the few things upon which the two factions can agree-- forensic anthropology may very well become extinct, and it is not at all clear that this is not for the best.

Will DNA Fingerprinting Make This All Moot?

Some might say, "Okay, then, forensic anthropology is weak. Get rid of it--DNA technology will replace it soon anyway." While the vision of DNA technology as the panacea is an idyllic thought, it is far removed from reality. There are many problems inherent in knighting DNA technology as the ruler of biology, the savior of law enforcement, the king of forensics.

First, such a statement assumes that all that forensic anthropologists do is identify people. This is simply not true. Yes, our ultimate goal, particularly in very recent "fresh" cases, is to learn the identity of the individual, however, our job is not "to identify," but rather "to learn as much as possible from remains using applied skeletal biology." Forensic anthropologists attempt, to the best of their ability, to approach a subject inductively, so that gathered information is not tainted by prior knowledge.[6] In this sense, the actual identification of an individual is

[6] This is, of course, impossible, for as I mentioned before, all science is tainted to some degree with prior knowledge--a world-view, if you will.

secondary--merely a comparison of facts after all possible information has been collected and analyzed. Additionally, some forensic cases involve historic or prehistoric skeletal analyses that function as a sort of sieve to separate physical from forensic cases and therefore do not involve this final comparative identification process at all--some forensic cases turn out to be physical analyses. So, while forensic anthropologists frequently identify human remains, this result is the end product of highly specialized observation and information gathering.

A second problem with this interpretation of DNA as all-powerful is that it assumes that law enforcement will have access to a world-wide database of all humans. A database of DNA fingerprints of previous criminal offenders would, no doubt, encompass some percentage of the forensic anthropology cases, however a complete record of all human DNA would likely be necessary to cover the range of all casework. What is the use of DNA fingerprinting if you have NO fingerprint to match it with? Of course, the Human Genome Project promises the potential for universal DNA fingerprinting by facilitating rapid technological development to improve the efficiency and discriminatory powers of DNA fingerprinting. I must question such a lofty goal, as both practical and ethical implications of massive fingerprinting are foreboding; I am certainly not alone in these reservations--many have elaborated on such barriers and their implications

(Wills 1991; Lewontin 1991). Assuming, against many odds, that a universal DNA fingerprinting database is established, what can we learn from it? DNA fingerprinting is done by digesting highly polymorphic regions of the genome with cleavage enzymes and passing the now fragmented DNA through a gel which permits different length fragments of DNA to move different distances, thereby separating into bands on the gel.[7] This banding pattern is the DNA fingerprint, named so because proponents of this method claim that no two individuals have identical patterns, much like the fingerprint. DNA typing laboratories claim that the probability of two people having the same DNA fingerprint is 1 in 100,000, 1 in 100 million, or even 1 in 739 trillion (Lander 1992). As Lander emphasizes, such calculations are based on the questionable assumption that all bands, and therefore alleles, are statistically independent; additionally, the calculations do not account for clinical laboratory error rates which are estimated between 1 percent and 5 percent. These weaknesses clearly threaten the reliability of DNA fingerprinting for identification purposes in the legal world of 'proof beyond a reasonable doubt.' However, let us assume that DNA fingerprinting methods will be improved upon in the near future--so much so that their

---

[7] I am greatly oversimplifying this process--for a well-articulated, detailed look at the DNA fingerprinting process, see (Pena, Chakraborty et al. 1993).

reliability is unquestionable. What happens when a forensic DNA specialist is unable to retrieve non-degraded DNA from a body? DNA in tissue is virtually useless shortly after death, while even under the best of circumstances, DNA from bone may only be retrievable up to four weeks after death.[8] In such a scenario, all you could do is compare phenotypic characteristics of the deceased to a DNA data bank. However, DNA fingerprinting is based merely on fragmentary DNA lengths of largely uncoded DNA, not on specific coded regions. Therefore, retrieving useful genotypic data from DNA fingerprinting data is not possible. Only by sequencing every human's genome can we hope to locate areas that code for specific phenotypic and morphological characteristics. And, of course, sequencing every individual genome is significantly more expensive and unrealistic than DNA fingerprinting. And, even if done, genotype certainly does not determine phenotype--we are only beginning to understand the complex relationship that our genotypes have with the environment.[9] So, we are caught in a vicious circle--we have both not enough information and too much information; DNA fingerprinting is simultaneously useful and useless.

---

[8] See (Rankin 1994)--under the worst of circumstances, such as burned remains, buried remains, or skeletonized remains, high molecular weight, non-degraded DNA is virtually unretrievable.

[9] For instance, we could never determine things like height or age by looking at genomic sequences--their interaction with the environment is undeniable. And race--well, the social construction of this category drives the forensic anthropologist's need to use it--it is unlikely that social categorizations will be easy to locate on the genome.

The Human Genome Project is perhaps the most looked to sign of the potential of DNA applications. As the Human Genome Project progresses, it is likely that scientists will be faced with unfathomable amounts of information that they will not be able to understand.

> Science is a match that man has just gotta light. He thought he was in a room--in moments of devotion, a temple--and that his light would be reflected from and display walls inscribed with wonderful secrets and pillars carved with philosophical systems wrought into harmony. It is a curious sensation, now that the preliminary sputter is over and the flame burns up clear, to see his hands lit and just a glimpse of himself and the patch he stands on visible, and around him, in place of all that human comfort and beauty he anticipated--darkness still."
>
> H. G. Wells, 1891, as quoted in
> (Congress of the United States, 1988)

Surely after millions of years of evolution, the structure of our genome is complex beyond our abilities to decipher it in a virtual second of evolutionary time.

MY SOLUTION

What Computers Can Do For Us

So, although forensic anthropology is losing ground within the academic arena, the work that forensic anthropologists do is not being picked up by other research areas--certainly not by DNA fingerprinting. It seems that with the demise of forensic anthropologists, much of their science would also be lost. I do, however, believe it is possible to change this rather grim scenario. Forensic anthropology might have developed along certain historical lines, but it need not be constrained by the past. New tools leading to the collection of more extensive data, and the data leading to the development of well-reasoned theories can empower forensic anthropology to rise above the chasm and stand firmly on its own foundation.

Currently, when a forensic anthropologist receives a case, most of the analysis involves the application of standard rules for sexing, aging, racing, etc. This relatively straightforward data collection uses both sensory observation and quantitative measurement. The collected data is most often of a very specific kind and limited in scope, as the aim is to determine certain factors, with each individual case having a different set of these factors. Later analysis of this information by a researcher hoping to compile a broad and statistically significant set of data may or may not reveal the specific bits of information being sought--the measurement of some particular feature was perhaps not a required factor in the individual case, therefore the time was not taken to collect what was at the time perceived as extraneous data.

However, using simple computer imaging techniques to record, measure, and analyze these data would not involve a significantly longer amount of time or a more involved process. In fact, with computer imaging techniques, an impressive data set can be recorded in a mere fraction of the time it might take to do it manually. Thus, there would exist an enormous amount of data for all kinds of analyses involving both immediate and future research. Such data are significantly more complete than the information usually recorded during regular casework. Additionally, this immense information source can be stored indefinitely in computers, allowing future researchers to explore new paths of inquiry.

With this in mind, picture the following scenario: a forensic anthropologist wants to research modern trends in stature among various races by looking at the femur. In order to do this project, she needs to collect data from a rather large sample of femora from various races of people to produce statistically significant results. There are three possible ways to complete this project: 1) the researcher can spend many years collecting forensic sample data from cases that pass through her lab, 2) she can travel to one of the few modern collections of human skeletons with known attributes (such as sex), or 3) she can reject the goal of performing a modern analysis in favor of a historic or prehistoric analysis of skeletal materials housed in many departments around the country. The first solution involves an exorbitant amount of time and effort. The second solution is rather costly and labor-intensive. Additionally, such modern collections are, in fact, not large enough nor racially diverse enough to support research on modern trends involving racial distribution of characteristics. Therefore, the researcher is likely to opt for the simplest--the third--solution. Obviously, much of the research objective would be sacrificed through such a decision. Although historical and prehistorical analyses are important in their own right, such an analysis would no longer involve the realm of forensic anthropology because it fails to address modern remains. Also, historic/prehistoric collections tend to deal with single-race populations that do not necessarily reflect populational variance and admixture within the modern world.

In short, a substantial, populationally representative modern collection of osteological remains does not exist.[10]

However, this in no way means that it should not exist. The computer technology necessary to digitally preserve such remains does exist, however, the rapidly advancing field of

---

10 I mean the term population in the broad sense--a continent-wide or world-wide geographic group--not in the sense of small endogamous groups. Therefore, a populationally representative collection would be one that thoroughly samples the diversity within large geographic regions.

computer science has been embraced by conspicuously few anthropologists-- a remarkable fact considering anthropology is a field that depends upon interdisciplinary research. Although methods and techniques developed in the arena of computer science could also be useful within anthropology, anthropologists continue to rely on traditional methods. Considerable advances within the field of forensic anthropology in recent years have focused on various techniques for determining age, sex, race, and stature of skeletal remains, and while these techniques are extremely insightful and helpful, their narrow focus is rapidly becoming so minute as to become trite. (For instance, [hypothetically] measuring stature from the length of the fifth metacarpal.) The underlying tedium that gives rise to such an analysis of minutia emphasizes the fact that we have done as much as possible with the tools available to us. In other words, human observation and metric tools such as calipers have achieved their potential; the time has come to investigate new techniques made possible by computer technology in order to eliminate the stagnancy so prevalent in forensic anthropology and build a database for present and future study.

Compared to other biological sciences, physical anthropology has been slow to delve into computer technology, while as a whole, the scientific community has taken advantage of this technological tool in an effort to further itself. For example, today's non-invasive medical imaging technology such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) have helped shine a light on the often invisible world of the internal human body. Currently, it is possible to build three-dimensional models from these CT and MRI cross-sectional images so that doctors can have a better picture of gross anatomical structures. The benefit of such a display of data is intuitive; most humans, as creatures who largely perceive our environment with stereoscopic vision, learned early on to analyze the world around us in three dimensions. Therefore, three-dimensional data presentation works in harmony with our natural instincts and abilities.

It is curious, then, that physical anthropologists who are so intimately connected with the biological sciences have not also adopted computer technology.[11] Certainly the type of materials with which many physical anthropologists deal readily lends itself to computer imaging. Forensic anthropologists deal with human remains in particular, which are inert and therefore ideal for such computer analysis. There must be other, more subtle, factors that help maintain

---

[11] I do not mean to suggest that NO physical anthropologists utilize modern technology, simply that the field as a whole has been slow to adopt computer technology. For good examples to the contrary, refer to (Haglund and Fligner 1993; Pickering, Conces et al. 1990; Conroy 1988).

the separation between forensic anthropology and computer technology.

Perhaps dwindling funding contributes to the lack of enthusiasm for incorporating computer technology into forensic methodology. However, while it is true that computer equipment can be costly, established trends of falling prices and rising computational power make suitable hardware and software ever more accessible. Also, scientific grants today tend to favor technological proposals--particularly interdisciplinary ones-- making it easier to receive outside funding for such research. Particularly where the National Science Foundation is concerned, "...'cross-disciplinary' has become the watchword of the day" (Holden 1993). Therefore, it seems unlikely that funding, while an obstacle of sorts, is the crucial factor keeping forensic anthropologists from adopting high-tech tools.

Perhaps the prevalent stereotype that computers are not only difficult to master but are also unnecessary impedes the incorporation of useful technology. This view of computer technology as 'impossibly hard to use' is incorrect in today's world of "user-friendly" software. True, much technological understanding requires years of training, but forensic anthropologists can effectively utilize advanced computer technology without specialized learning; unless you are involved in programming or other such knowledge-intensive areas within computer science, using today's computer hardware and software requires a surprisingly small amount of specialized knowledge or training. But are computers unnecessary? No doubt the power of human observation is incredible, however, computer technology can greatly reduce work time and increase quantity of data collected without compromising quality.[12] In spite of the validity of these concerns, I believe that it is not this factor, nor the cost factor, which prevents forensic anthropologists from embracing technology. Rather, the critical factor is a fundamental failure to understand the degree to which computers can be beneficial for anthropologists.

Having recently spent time working with some of today's technology, I have come to understand computers and the insight they can provide for forensic anthropology and anthropology as a whole. What follows will not be a technical description of computer imaging-- that is something better left to the experts in the field such as programmers and statisticians (Palamidese 1993). Rather, the analysis of technology in this paper is from the standpoint of the consumer. As a user of this technology, I wish to describe the following: (1) the nature of the work being done in computer imaging, (2) how this can be used by forensic

---

[12] For an anthropological study showing that computer results can be quick, easy to obtain, and accurate, refer to (Hildebolt and Vannier 1988).

anthropologists, and (3) the insight such use can provide and the advance that will follow.

I will critically assess these points by first addressing the positive aspects of objective computer analysis rather than subjective human analysis. Next, I will look at computer technology which is currently being used in the medical sciences. Following a discussion of my initial research, I will propose an alternative, and, I believe, superior method for the digital preservation of human remains. Finally, I will present a test study of the use of three dimensional imaging in forensic anthropology.

The Limitations of Human Observation

Until recently, human observation in forensic anthropology has been largely confined to the eye. The complexity and acuity of the human eye exceeds that of even the most sensitive computer visualization system. Our eyes commonly and easily obtain information concerning size, shape, and structure. However, although major patterns are easily noticed, frequently more subtle optical information is missed. In other words, while the human eye is a phenomenal tool for observation, it does have certain fundamental weaknesses.

One of the weaknesses of the human eye centers on its limited capacity for quantitative assessment. For example, imagine judging the length of two femora simply by looking at them. When side by side, it may be easy to tell that they are about one centimeter different in length. However, if you look at one femur and then take it away and look at the other, it becomes difficult to recognize this length difference, let alone quantify it. This inability to measure from memory is a weakness which in the past has been compensated for with caliper use and data recording. Although there is nothing inherently wrong with manual measuring and recording, it is rather time consuming and exhausting. Computer imaging eliminates the need for manual measurement and recording because all of the necessary data exists within the image and is easily accessed.

The human eye also falters in the comparison of complex interrelationships such as variation, angles, or torsion. Conversely, the computer can easily analyze such relationships and provide quantitative comparative assessments of the phenomena. Also, the computer can handle large quantities of data, which aids the analysis of such complex relationships.

This is not to say that computer imaging does not have its own unique drawbacks. Understandably, relying on computers rather than the naked eye for the visual acquisition of data makes some people nervous, and to some degree justifiably so. And, although through artificial intelligence research the computer is slowly coming to resemble the human brain, the computer cannot yet parallel the complexity of our brains. Pattern recognition is one of the areas currently being developed to help the computer match the acuity of the human brain. Such a technological ability would help to make processes like the one which I will describe fully automated, thereby eliminating the need for extended human involvement in the data-collection phase and freeing the anthropologist to focus on the analysis.

The Image

Using the computer, we wish (in the best scenario) to capture information similar in detail to the acuity of the human eye, and preferably superior in detail. The desired computer image should mimic our human visual image at the very least, in order to display an image sufficient for subsequent human analysis. Therefore, before beginning a discussion of computer imaging techniques, it is important to first understand exactly what the properties are of the image that needs capturing. Forensic anthropologists strive to gather as much information about the osteological remains being studied as is physically possible. This includes the analysis of basic elements such as length, width, and shape, as well as more specialized components such as pathology, anomaly, and pattern (symphyseal face pattern or rodent gnaw marks, for example). For such analyses, **more** data is definitely **better**.

For most osteological analyses, surface information, rather than internal structure, is of primary interest; the majority of important osteological data can be obtained by looking at the surface of bones (except perhaps for studies involving osteon counts and related areas). Such an approach eliminates the need for cross-sectional imaging like the types most frequently used in biological/medical imaging today, as we will discuss further.

In short, the three-dimensional surface rendering necessary to digitally preserve human remains is truly closer to two-dimensional imaging in its simplicity. In somewhat simplified mathematical terms, when forensic anthropologists analyze an object, they need consider only the surface of that object, the area of which is proportional to the square of its dimensions, rather than the volume, which is proportional to the cube of its dimensions. This external surface analysis (rather than internal) greatly reduces the storage space necessary for data collection (the difference between x-squared and x-cubed) and allows for the use of simpler equipment, thereby reducing both hardware and software costs.

<u>Computer Imaging Technology</u>

Computer imaging is at the forefront of technological advancement and offers precise, reliable measuring capabilities, unlike the more qualitative assessment possible through human visual systems. Such technology facilitates the collection, preservation, and interpretation of data by producing a wide range of highly accurate and very specific information from one image, thereby enabling numerous kinds of studies and further analyses from a single scanned object.

This is not to imply that computer technology is foolproof (yet). On the contrary, there is still much to be learned about the technology as well as about the human brain which it strives to match. The field of computer science is constantly growing, changing, and diversifying. This complex environment can be likened to an ecosystem in the grip of a massive, exploding speciation--an adaptive radiation of sorts. There are endless niches needing habitation, and the fate of each species is tenuous.

Following this metaphor, three-dimensional imaging technology is like one of these new and uncertain species, and, as a species, it utilizes many methods for approaching problems. For instance, each species has unique ways for observing and analyzing information in its environment. Similarly, computers utilize various methods for data collection and data analysis. So, in order to best understand computer imaging we must first examine how computers look at space, and then examine different technologies and their methods for collecting data.

Computers can look at, and thereby represent, space in different ways. Currently, there are three commonly used techniques for the visualization of volume data: surface-based techniques, binary voxel techniques, and volume-rendering techniques (Fuchs, Levoy et al. 1990). Although I will not attempt a detailed description of these technical programming methods here, I consider it necessary to briefly summarize them.[13] The surface-based technique "applies a surface detector to the sample array, then fits geometric primitives to the detected surfaces, and finally renders the resulting geometric representation" (Fuchs, Levoy et al. 1990). The most common technique involves edge tracking of the features of interest. The contours of adjacent slices that this tracking produces are then connected by a 'mesh' of polygons. The relative simplicity of this method--through the use of primitive geometric objects (i.e., simple, like 2-D triangles)--allows for minimal storage space and easy manipulation. Binary voxel[14] techniques, on the other hand, "begin by thresholding the volume data to produce a three-dimensional binary array" (Fuchs, Levoy et al. 1990),p.141.

---

[13] For a more detailed analysis of this information, please refer to expert opinions (Fuchs, Levoy et al. 1990),(Palamidese 1993)

[14] A voxel is basically a three-dimensional pixel. In other words, it is a three-dimensional fundamental graphic unit.

These techniques give a "sugar-cube" appearance by treating voxels as if they are either opaque or not. Volume-rendering techniques are a variant of binary voxel techniques where each individual voxel participates in volume rendering through partial transparencies and color. However, these techniques do not make a binary classification of data.

There are numerous problems with using these techniques for digitally preserving human bone (Fuchs, Levoy et al. 1990). The contour-following mechanisms of the surface-based techniques tend to go astray when tackling complex forms. The 'sugar-cube' effect achieved through binary voxel techniques requires that users 'smooth out' the surface, thereby eliminating much necessary surface detail. Additionally, both the surface-based and binary voxel techniques involve binary classification[15] which makes capturing small, detailed images nearly impossible without creating visual artifacts such as spurs or holes. Although volume rendering techniques eliminate the need for binary classification, it is considerably more costly in terms of storage space and still does not render extremely fine features. Also, all of these techniques utilize cross-sections of the analyzed material in order to create the surface images. For the preservation of osteological surface features, gathering data on internal

[15] binary classification--i.e. black and white only (no shades of grey)

structure is, as previously mentioned, not only unnecessary but is also expensive in both dollars and storage space.

With so many faults, one might ask why such scientific visualization is necessary at all. Probably the key reason why scientists have turned towards visualization techniques is because such techniques present an opportunity for exploration without altering the subject in any way. Imaging makes it possible to evaluate materials in a non-invasive, non-destructive manner. Visualization also allows scientists to rapidly communicate large amounts of information--a goal not as easily achieved through the use of tables and statistics. Additionally, scientific imaging technology excels in both qualitative and quantitative image analysis. Image manipulation is used for general purpose image processing such as contrast adjustment, image rotation, or image enhancement. With such manipulation, the quality of images can be greatly improved. Conversely, image evaluation allows for the analysis and measurement of scientific data, improving the accuracy of quantitative evaluation.

After exploring how computers look at three-dimensional data, it is necessary to examine possible methods for collecting these data. Current applications of these scientific visualization techniques span a multitude of sciences, including the computer sciences, physical sciences, and biological sciences. In the field of computer science, these visualization techniques are widely applied in the subfields of optics, engineering, and artificial intelligence. The physical sciences use this technology for modelling properties of wave motion or structures of molecules (to name a few) (Simmons and Koskela 1990). It is, however, the technology of the biological sciences which most closely approximates the imaging needs of the physical anthropologist. In the search for non-invasive diagnostic procedures, the medical field has developed an impressive array of imaging technology. The scientific visualization applications in medicine which resemble the type of imaging necessary for preserving skeletal remains include computed tomography (CT) scans, magnetic resonance imaging (MRI), positron emission tomography (PET), and ultrasound. It seems plausible that if forensic anthropology imaging needs can be fulfilled using currently existing techniques, the processes would likely involve these well-established medical imaging methods.

Computed Tomography (CT) scans create a map of opacity using X-ray technology. Because this medical technique utilizes radiography, bone structures tend to show up quite well, although soft tissue does not. One of the largest problems with CT scans is that only a limited number of 'slices' can be radiographed due to the dangers of large X-ray doses. Brodlie, *et al* (1992), approximate 25 slices/each 256 one-byte values (pixels) squared, which does not allow for precise three dimensional reconstructions. In such a scenario, the spaces between slices are simply 'filled in' by the computer--a technique which can eliminate small detail.[16] Some people are attempting to reduce this poor inter-slice resolution in medical imaging, however, the technique remains inaccurate (Chun, Lee et al. 1991). Of course, inert materials such as dry bones do not suffer from the dangers of radiation, so this is not nearly as much of a problem for forensic anthropologists as it is for medical doctors working on live patients. Another problem with CT scans is that blurring around the mouth can occur due to X-ray scattering caused by the metals in amalgam fillings, as well as by other prosthetic work (Brodlie, Carpenter et al. 1992). This is definitely a concern for forensic anthropologists who work predominantly with recent materials that often exhibit dental reconstructions of many kinds. Additionally, 3-D reconstructions from bony CT data can be problematic because is is difficult to determine the threshold distinguishing bony and soft tissues, thereby leading to inaccurate quantitative evaluation (Mankovich and White 1992). Hildebolt noted the imprecision of bony measurement utilizing

---

[16] As an example, I had the opportunity to view CT scans of an Egyptian mummy and to watch the skull reconstruction process which utilized volume rendering techniques to analyze the scans. This is acheived when the operator selects for the bony area of the CT scan to represent the outermost surface, and then 'stacks' these images on top of each other to create the final image. Due to the finite number of slices that can be taken, the surface of this three-dimensional skull reconstruction closely resembles the steps of a Mesoamerican pyramid. In order to eliminate this ragged appearance, the image is "smoothed out." Although such smoothing is fine for uses like facial reconstruction, it tends to eliminate any fine surface data for other, more detailed analyses.

CT scans in a quantitative pilot study (Hildebolt, Vannier et al. 1990). There is one last problem that, although it is not a large one for the heavily funded field of medicine, is a huge problem in the field of anthropology. The equipment necessary for CT scans is very expensive, as is the maintenance required for their upkeep. Few anthropology departments get the funding necessary to invest in such equipment to use on a regular basis[17].

A second commonly used technology in the medical field today is magnetic resonance imaging (MRI). This type of imaging solves many of the problems encountered by CT scans. Rather than using X-rays, MRI uses a magnetic field to excite hydrogen atoms and then records their rate of decay. Because it is not harmful, it can take a large number of slices of the designated area. Unfortunately, although the soft tissue resolution is quite excellent, the bone resolution is not great. Because of this, it is difficult to identify bony structures, making it a poor candidate for the preservation of osteological remains.

Positron emission tomograpy (PET), as the name suggests, functions by recording positronic emissions. Accordingly, this technique produces good data for areas of physiological activity. Unfortunately, it is weak in areas of low

---

[17] And few anthropology departments are engaged in the interdisciplinary relationships necessary for borrowing the equipment from more heavily endowed disciplines.

physiological activity and exhibits poor localization (Brodlie, Carpenter et al. 1992). While this technique is good for analyzing areas such as the heart, it does not produce clear bony images. Similarly, ultrasound is good for monitoring activity (such as a fetal heartbeat), but has poor resolution. Both techniques are inadequate for detailed osteological analysis.

The above technologies, while well-suited to many areas within the biological sciences, exhibit fundamental shortcomings for application to forensic anthropology. Perhaps by combining these techniques in some manner (like CT and MRI), a non-invasive, non-destructive technique that can illuminate both bone and soft tissue equally well can be created (Hu 1989). Possibilities also exist for combining such technology with analytical techniques being developed in the rapidly expanding field of artificial intelligence. Currently, identification of landmarks on these images occurs through a human operator. With pattern recognition, an area of artificial intelligence now being researched, processes such as landmark identification could be fully automated, greatly reducing operator intervention time and increasing accuracy. Technology that exists today, while incredibly impressive, is merely the tip of the iceberg compared with the possibilities for technological advancement in the future. However, technology such as this remains rather expensive and is still more than is needed in forensic anthropology.

My exploration of imaging technology began at a logical place--by looking at technology that already exists in the biological sciences to determine the viability of such methods in physical anthropology. The analysis of these methods led to the conclusion that while they are ideal for capturing volume data, they are less than ideal when applied to surface data, and each has critical flaws that are apparent when applied to specific forensic anthropological problems. Additionally, combining these medical imaging techniques does not currently overcome these flaws. So, not only is such technology insufficient, but should it become sufficient, it still utilizes unnecessary amounts of memory and money. With this in mind, I had to look elsewhere for techniques that can fulfill my specific imaging needs.

THE PLAN

What Imaging Will Work Best?

My approach was a simple one. In the Jurassic, the large, impressive dinosaurs went extinct, while the small, seemingly insignificant mammals went on to dominate the earth. Similarly, I attempted to look beyond the impressive medical imaging, towards simple, less obvious (at least in the biological and anthropological fields) imaging techniques. It is possible to achieve the goal of imaging bones using relatively simple computer technology which is currently available. As was stated before, most of the visualization equipment used in biological imaging is significantly more complicated and expensive than is necessary for osteological surface imaging. For these reasons, I believe that more simple computer technology utilizing hardware that captures two dimensional images and software that converts these images into three dimensions is the simplest solution to these imaging needs.

I began by exploring methods for the digital preservation of human remains in order to develop the increasingly useful and accessible tools of computer imaging technology for applications in the field of physical anthropology. Specifically, I planned to successfully digitize femora through three-dimensional scanning, and to test these images for quantitative accuracy by comparing linear measurements of the digital image with known data regarding the metrics of the human skeletal remains. I chose the femur for several reasons. First, its large size demands that the problems of scale and accuracy be addressed in the conversion to a three-dimensional image. Second, the femur is a relatively dense bone, and is therefore frequently recovered in whole or in part during excavation. Third, the abundance of knowledge that can be gained from the femur (sex, race, stature) provides a wealth of possibilities for further demographic studies.

The largest milestone in this project was to identify the type of equipment that could best suit my needs. I needed to capture surface detail while utilizing equipment that is relatively easy to use and inexpensive. The NEC CCD camera is a simple NTSC video camera with a relatively low quality zoom lens. This camera produces a composite video signal which is digitized by the PC Vision Frame Grabber. The frame grabber is a hardware interface board for the IBM PC which converts a standard video signal into binary data for the computer to further manipulate. This board is actually capable of capturing color data, however, the camera I worked with was only monochrome. Image Action Software works in conjunction with the frame grabber to allow the display and manipulation of the captured image data. It is a fairly simple package capable of a wide range of image processing. All this is used in conjunction with a basic IBM

PC. This equipment works together to create a relatively simple method for capturing images digitally.

Various steps exist in this process of digitally preserving bones. First is the image data acquisition itself. Using CCD cameras and a framegrabber makes this process quite easy because the image captured by the camera is automatically converted into digital form for storage within the computer. The second step involves the reconstruction of the two dimensional images into three-dimensional ones. This step is certainly the most complicated one, and will be discussed in more detail momentarily. Third, throughout this process, software for manipulation of the images is essential. Qualitative analysis and manipulation can be achieved using conventional software like the type mentioned previously. Finally, a storage device is imperative for accommodating the large file sizes of the images; in order to develop a significant data base of forensic information, a large storage system is crucial. Equipment such as a 5.25" rewritable magneto-optical disk drive and 5.25" magneto-optical disks (600MB or more capacity each) should be used for storage. This aspect of the process is probably the most expensive and the most necessary.

Stereographic techniques for reconstructing two-dimensional image into three dimensions seem most appropriate for three-dimensional surface rendering because of the principle that underlies their development; these techniques strive to imitate human stereoscopic vision. Obviously, the incredibly complex human optical system creates nearly 'perfect' renditions of three-dimensional objects for the brain to interpret. Likewise, such a stereoscopic method of data accumulation allows for complex and accurate three-dimensional digital representation and easy identification and interpretation of this data by the user.

Initially, three methods for obtaining and analyzing three-dimensional surface data seemed promising: Moire fringe topography, stereophotogrammetry, and rasterstereography. Moire fringe topography involves the illumination and visualization of objects through a grating placed close to the surface to be analyzed[18]. This technique, however, has numerous drawbacks, including mechanical restrictions (Elad and Einav 1990) and considerable computation time (Frobin and Hierholzer 1981). Additionally, "an interpretation of a Moire topogram in terms of (nearly) equidistant parallel contour planes is possible only for special geometries of the Moire apparatus which must be carefully maintained" (Frobin and Hierholzer 1981). This is in stark contrast to the arbitrary geometry that can be utilized in the other two

---

[18] Moire topography, which utilizes a grid, is reminiscent of the Cartesian grid frequently used in morphometric analysis. Ultimately, morphometric techniques could be incorporated into osteological imaging for comparitive analysis as well as analysis of ontogeny and phylogeny. For a good overview of such morphometric research, refer to (Reyment, Blacklith et al. 1984), (Rohlf and Bookstein 1990), and (Bookstein, Chernoff et al. 1985).

techniques. In stereophotogrammetry, the desired object is photographed simultaneously by two CCD cameras in two separate positions. The stereo analysis of the data is based on matching identical points from the two images and using triangulation principles to create the three-dimensional surface. The computational procedure used in this method-- direct linear transformation (DLT)-- is a relatively old and well established procedure developed by Abdel-Aziz and Karara in 1971 (Abdel-Aziz and Karara 1971). Unfortunately, because this method is highly accurate (involving precise measurements and fine resolution), it consumes large amounts of memory (Elad and Einav 1990). In order to create a simpler process for capturing three-dimensional surface data, researchers have developed a slightly altered, and thereby simplified, technique-- rasterstereography.

Rasterstereography is similar to the stereophotogrammetric method, except that one of the cameras is replaced by a projector. A pattern of lines is projected onto the object of interest from a given angle, and the resulting image is captured by a camera mounted at a different angle at a distance from the projector. By reducing the data input to a single image, less computer memory is utilized. Additionally, this technique can use the well established photogrammetric model reconstruction and calibration techniques with few modifications (Frobin and Hierholzer 1981). This method is also good for both smooth and rough surfaces, because it creates landmarks of its own using the projector. Other methods, such as stereophotogrammetry, are dependent on surface landmarks to match up images from two cameras[19]. Rasterstereography, then, using relatively inexpensive equipment such as the kinds I described earlier, is capable of capturing and storing three-dimensional osteological surface data for endless future analysis.

In many ways, rasterstereography is superior to the high-end medical imaging techniques such as CT or MRI. It is an incredibly simple method-- using only a basic computing system along with a CCD camera and a projector (Rosenberg, Zeltser et al. 1990). Additionally, all of this equipment is inexpensive, and therefore feasible for low-funded departments such as anthropology. As a whole, this simple, inexpensive technique fulfills the role of the 'mammal' quite well, and potentially could overtake the niches of the hulking dinosaurs currently so prevalent in computer imaging technologies.

<u>A Test Study:</u>

<u>Methods:</u>

To begin this project, I took various femora from the skeletal collection of the Human Identification Laboratory

---

[19] This is crucial when you consider the lack of surface landmark data on some bones such as those of the cranium.

over to the Electrical and Computer Engineering Department to familiarize myself with the imaging equipment. I was specifically concerned with the quality and accuracy of the image. I quickly learned that the image produced by the CCD camera is remarkably detailed, even with a relatively low resolution camera such as the one I used--that took care of qualitative accuracy. As for quantitative accuracy, it soon became apparent that the weaknesses of this system were not with the CCD camera, but rather with the software. It was, of course, possible to include a ruler in the image for calibration with computer distances (for example, 15 pixels = 1 centimeter). However, the IBM software necessary for the subsequent image manipulation is not particularly user-friendly, and, I believe, will therefore be rather difficult to 'sell' to anthropologists.

Subsequently, I discovered a wonderful, free program for the Macintosh-- NIH *Image*.[20] The same equipment--a CCD camera and framegrabber-- can interface with any Macintosh computer with at least 4MB of memory and a monitor with the ability to display 256 colors or shades of gray[21]. For my test study,

---

[20] NIH *Image* is a public domain image processing and analysis program for the Macintosh written by Wayne Rasband (wayne@helix.nih.gov) at the National Institutes of Health, USA. I used versions 1.52 and 1.54.

[21] An ideal new technology has surfaced--digital cameras such as the Fotoman-- where the camera is used just like any 35mm camera and is plugged into your computer for direct interfacing. In this manner, the framegrabber is eliminated from the necessary system hardware. However, when I used this technology, I discovered that it has a few glitches that need to be ironed out. First, the image resolution is lower than that of the CCD video cameras. Second, it does not allow the operator to adjust parameters-- for each image it automatically adjusts things

because I did not have unlimited access to the CCD camera and framegrabber hardware, I took black and white 35mm camera images of osteological remains and sent them to a photo CD lab for conversion into digital images. For all practical purposes, the product is the same as that obtained through a CCD camera and framegrabber--it simply bypasses hardware costs[22].

To create three-dimensional images, I took the premises of stereography and further simplified them. The ultimate purpose of stereo imaging is to mimic the stereo vision of the human eye. Rather than taking images from two separate cameras and imposing them, or taking a single image of a landmarked bone, I have used a simpler, more traditional method for creating three-dimensional images-- red/blue 3-D superimposition.[23] I rotated the samples on a turntable with graduation marks in order to photograph pair images from slightly different angles, much like what is done with the human eyes [see Figure 1]. When these digital images are superimposed and one is colored red and the other blue, they can be viewed through 3-D glasses as three-dimensional

---

like contrast and lighting . Due to these problems, the images that I produced were not uniform in contrast and were frequently saturated. However, this is relatively new equipment, and with time and improvement, will be ideal for the kind of imaging that I propose.

22 However, due to out-of-pocket processing costs, it has also limited the size of my test study.

23 I am tremendously grateful to Denice Warren and others at Image Processing for Teaching (IPT--an NSF-funded project headquartered at the Universiy of Arizona) who not only gave me access to their hardware, but also helped me become familiar with the software and think through this imaging method.

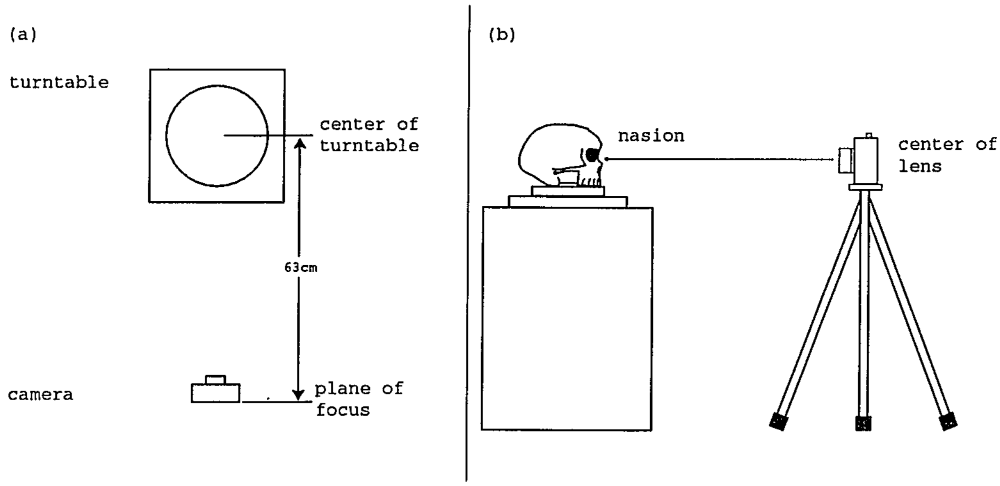

FIGURE 1, The imaging set up. (a) plan view; (b) lateral view

images. By photographing these pairs at equal intervals all of the way around the bone, I was able to use *Image* to stack them into a single image--this rotating three-dimensional image can be measured quantitatively (I calibrated the scale to millimeters) and can be manipulated in a multitude of ways (contrast, zoom, etc.).

For my test study, I imaged five individual crania (skulls without mandibles), some of which have unique qualities that could challenge the capabilities of this technique [see Figure 2]. Because problems of scale and resolution seemed negligible from the previous work with femora, I decided that it would be useful to tackle the complexities of the cranium (overall size, diverse surfaces, etc.). Additionally, I could thoroughly assess the quantitative accuracy and usefulness of the imaging by comparing established caliper measurements of the skulls with computer measurements. Also, the cranium is central to the issue of human variation-- a subject that I will tackle in the next section.

Results:

Qualitatively, the imaging process that I used was excellent. It is possible to visualize fine details on the crania, including fissures within the eye orbits [see Figure 3]. I specifically included two trauma cases in my sample to see how well the imaging worked when dealing with darkened and damaged crania; while the blackening of Cranium 2 did negatively affect the image resolution, this effect was slight and caused only minor contrast problems. The resolution and contrast on Cranium 4 remained excellent. An additional bonus with this method is that the images are stored on the CD in five different resolutions--the quality of the image is only truly limited by the amount of memory in the hardware set-up.[24]

Quantitatively, there are some minor problems with absolute measurements which I believe are solvable. TABLE 1 shows a comparison of cranial measurements taken with both calipers and the computer. The only point which I was unable to locate on the computer image was basion, which could be

[24] Although I was only able to use the second to lowest resolution (due to memory constraints) the image was still quite clear.

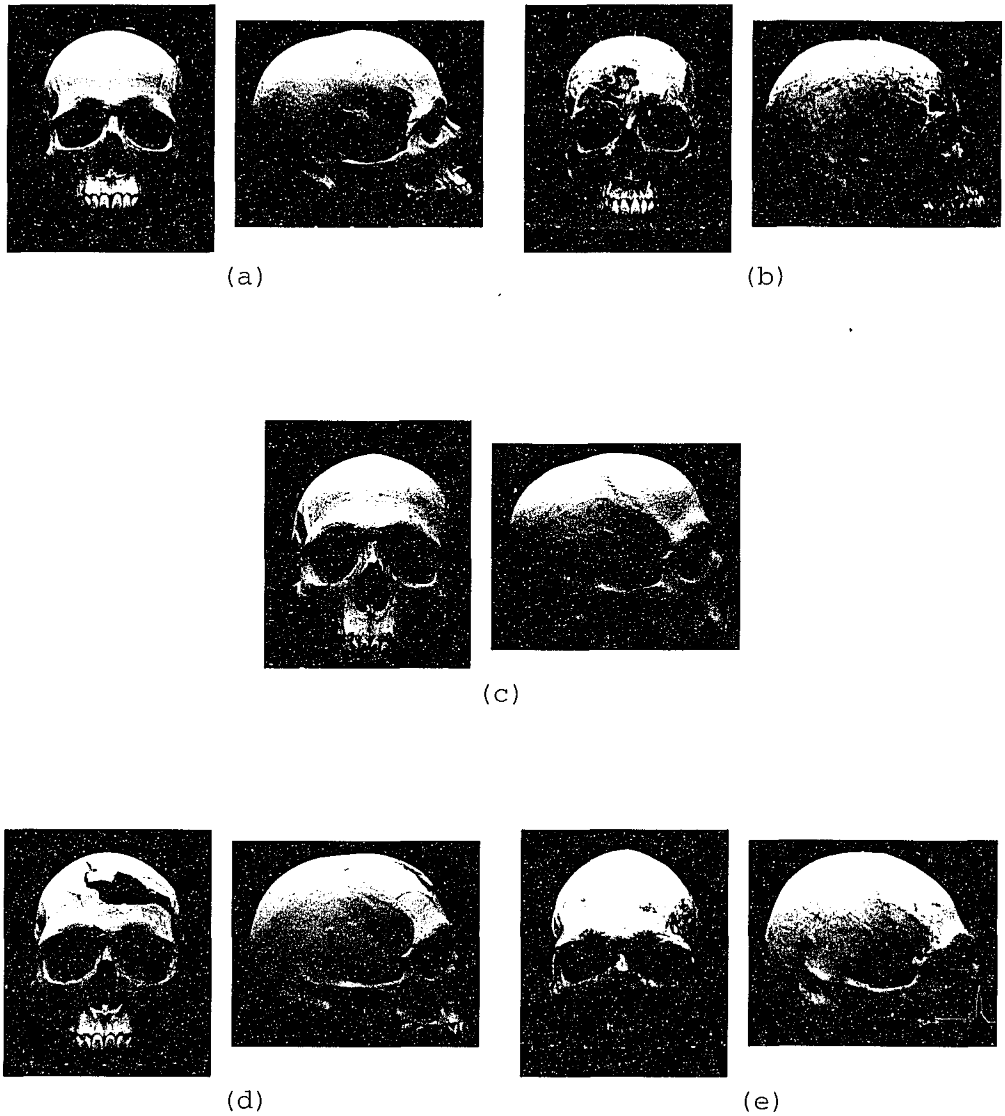

FIGURE 2, The test sample. Note that these images were generated digitally, not photographically.

(a) Cranium 1—caucasoid, male, sub-adult;
(b) Cranium 2—caucasoid, female, sub-adult, burn trauma;
(c) Cranium 3—mongoloid, male, adult;
(d) Cranium 4—caucasoid, male, sub-adult, blunt force trauma;
(e) Cranium 5—mongoloid, male, adult, alveolar resorption.

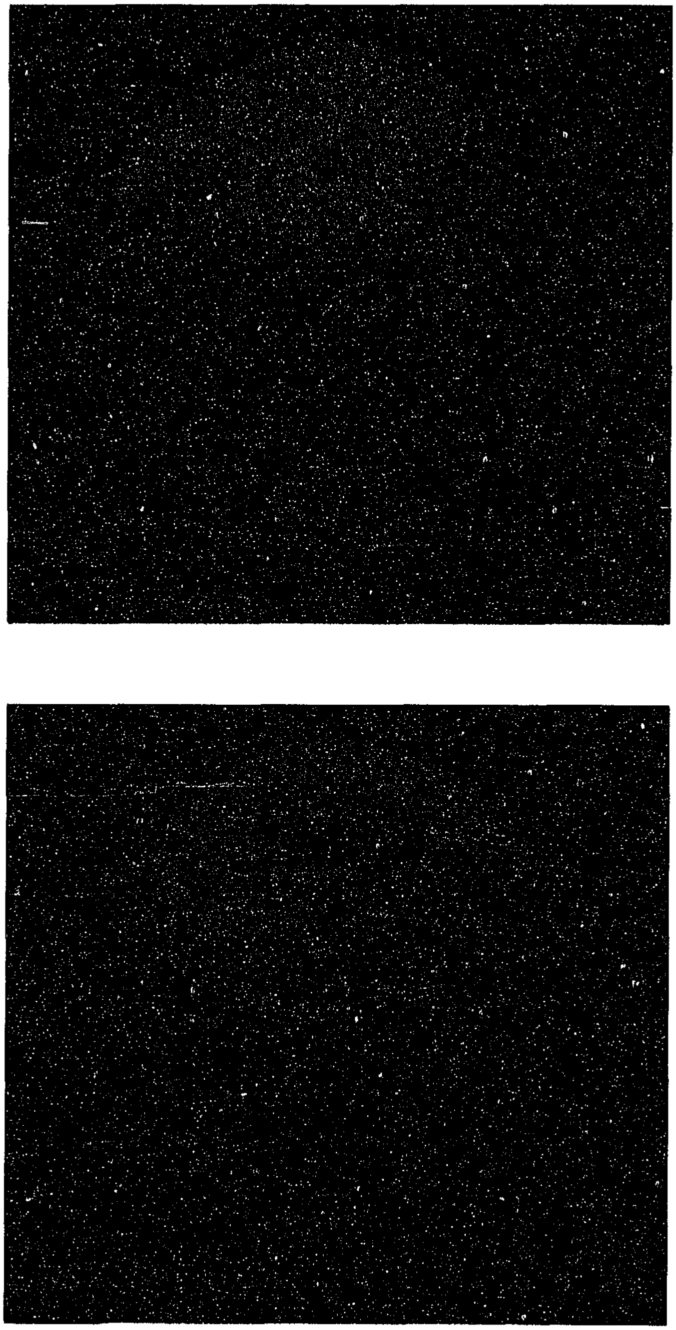

FIGURE 3, Examples of red-blue three-dimensional images.

rectified by rotating the skull in the perpendicular plane--therefore any measurements which include basion are marked "N/A." I knew that because I was using crania, depth and breadth might cause some measurement difficulties. Therefore, when my initial computer measurements did not exactly duplicate the caliper measurements, I performed a crude calibration to see if it was possible to reduce the error. Making the assumption that the caliper measurements on cranium 1 are accurate, I determined the pixel/mm value for each linear measurement of cranium 1, and used these dividers to convert the measurements for each of the other four crania to millimeters. These values are as follows: Glab-Opis, 4.50 pixels/mm; Eur-Eur, 4.54 pixels/mm; Zyg-Zyg, 4.77 pixels/mm; Prosth-Na, 4.52 pixels/mm; Ala-Ala, 5.36 pixels/mm; Mastoid length, 5.27 pixels/mm. The final calibrated measurements are reported in TABLE 1. I have determined that in order to further reduce these measurement inaccuracies, a Macro program for calibrating the measurements based on a somewhat spherical shape needs to be created.[25] This type of calibration which is generally used to correct data distortion is called a geometric transformation and is a generally accepted technique for working with two-dimensional data sets on three-dimensional objects (Brodlie, Carpenter et al. 1992). Even without such

---

[25] A Macro program is a program that will automate a complex procedure or complex calculation.

calibration, the crude calibration technique which I have used has brought most of the measurements below the allowable inter-observer error amount of 2mm. [26]

Depth and breadth are larger considerations when dealing with crania than with any other bones of the body. However, while they have caused slight measurement inaccuracies, these do not appear to be insurmountable and should not invalidate

	CRANIUM 1	CRANIUM 2	CRANIUM 3	CRANIUM 4	CRANIUM 5
	caliper/comp	caliper/comp	caliper/comp	caliper/comp	caliper/comp
Ba-Prosth.	102.0/ N/A	96.0/ N/A	102.0/ N/A	98.0/ N/A	104.0/ N/A
Glab-Opis.	177.0/ 177.0	178.0/ 179.8	186.0/ 186.0	193.0/ 189.2	191.0/ 190.3
Eur-Eur.	135.0/ 135.0	126.0/ 126.6	153.0/ 153.8	138.0/ 140.6	140.5/ 139.6
Ba-Breg.	137.0/ N/A	135.0/ N/A	146.0/ N/A	139.0/ N/A	147.5/ N/A
Ba-Nas.	103.0/ N/A	100.0/ N/A	112.0/ N/A	104.0/ N/A	110.0/ N/A
Zyg-Zyg.	120.0/ 120.0	114.0/ 113.5	140.0/ 136.6	134.0/ 132.0	132.0/ 128.6
Prosth-Na.	65.5/ 65.5	68.0/ 67.1	76.5/ 76.6	72.5/ 71.3	66.0/ 65.0
Ala-Ala.	26.0/ 26.0	21.5/ 22.4	25.5/ 25.4	26.0/ 25.1	23.5/ 23.5
Ext.pal.br.	62.0/ N/A	N/A	62.5/ N/A	65.0/ N/A	56.0/ N/A
Mastoid len.	23.7/ 23.7	23.0/ 22.9	25.0/ 25.1	26.0/ 28.1	28.0/ 27.2

TABLE 1, Calipers vs. computers. A comparison of calibrated cranial measurements. The measurements taken are defined by (Hooten 1946) and used by (Giles and Elliot 1962), and are expressed in millimeters. The measurements for cranium 1 are absolutely accurate because it was used to determine the calibration dividers.

---

[26] This is, of course, assuming that caliper measurements are exactly accurate--I'm sure that user error causes ranges of accuracy in even the most finely calibrated calipers. It is important to note that both calipers and computers are incredibly accurate tools--they lose their accuracy in application.

the use of imaging processes for storing and analyzing human remains. However, even with the slight inaccuracies, the measurements I took are still useful for comparative quantitative assessment, say, to look at variance of characteristics between specimens. Additionally, the ability to see a specimen in three-dimensions on the computer has many benefits when compared to some current methods of archiving skeletal data that simply store huge data pools of measurements.

For example, the University of Tennessee, Knoxville, has assembled an extensive database of osteological measurements. The measurements are largely cranial, with about 75 caliper measurements taken per specimen, although there are also some postcranial data. As of 1989, this database contained over 850 records of forensic cases, 60% of which have documented histories (sex, age, and race); today the number is probably closer to 1000 (Moore-Jansen and Jantz 1989). But what happens if an investigator wants to research measurements that were not recorded? This data bank would then be useless. And what if a researcher wants to correlate measurements with non-metric traits, or wants to focus solely on non-metric traits? The type of imaging I have presented will capture shading, texture, detail (such as fissures and minute foramina), pathology, trauma, and other such individually distinctive features with excellent quality.

This type of information is not retrievable from a database of measurements. Additionally, the quality of these images far exceeds that of traditional reconstruction techniques that utilize CT data or laser scanning, at a significantly lower price using much less processing time and memory [see TABLE 2].

It is also important to note that this technique for imaging skeletal material will build on and could incorporate information collected in databases like the one at the University of Tennessee. Once this process incorporates geometric transformation techniques for data correction and is further calibrated for increased quantitative accuracy, it will equal (or surpass?) the accuracy of such databases for

	MINIMAL	OPTIMAL
Hardware	LCIII w/ 4MB RAM, 120MB HD; $1500	Quadra 840; $3000 32MB RAM; $1400 1.0GB; $1000
Monitor	13" 8-bit color; $300	21" 24-bit accel. color; $4000
Storage/Communications	Syquest 44MB; $250 [$65/44MB cartridge=$1.20/MB]	CD-writer; $4000 [$25/600MB disk=$0.04/MB] 28.8kbaud modem; $400
Information Capture	FotoMan Plus; $650	High-res. digital camera; $2000
	TOTAL= $2700+ cartridges	TOTAL= $15,800+ disks

TABLE 2, System costs. These prices are rounded up from pricings in commercial magazines as of April 1994--academic pricing is usually slightly lower. For comparative purposes, refer to (Bower 1994), where the hardware costs are estimated at $700,000.

measuring continuous traits. It will, however, also offer accurate analysis of discontinuous traits, providing this and other important qualitative data that a merely numerical database cannot. Further, the quantitative measurements possible are not limited by previously established standard measurements (like the 70+ craniometric measurements in the University of Tennessee database); measuring any points of interest is possible (providing these points have been imaged). Additionally, digital images, such as my technique produces, can be shared via electronic networks (like the Internet), making national and international collaboration possible and practical.

Intra- and Inter-observer Variability

Intra-observer and Inter-observer variability are important concerns when investigators are performing repeat measurements on skeletal material. By taking repeat measurements of each cranium, I have demonstrated that this imaging technique yields low ranges of intra-observer variability [see TABLE 3]. Additionally, with automation using pattern recognition techniques, computer measuring offers the opportunity to eliminate inter-observer variability by consistently taking the same measurements, although this development is several years from being practically available. This is particularly significant when a system relies on multiple sources for its data, such as the

University of Tennessee database does, and as this data collection system proposes to do.

	CRANIUM 1	CRANIUM 2	CRANIUM 3	CRANIUM 4	CRANIUM 5
Glab-Opis.	798.55	810.80	836.56	851.34	855.96
	797.43	807.46	837.42	852.76	856.40
	796.23	808.87	837.02	850.37	856.13
Eur-Eur.	586.04	552.00	668.00	610.36	606.30
	585.03	549.00	666.36	610.55	605.03
	585.01	547.23	668.03	610.02	606.21
Zyg-Zyg.	573.03	539.18	648.08	632.06	613.24
	572.00	544.21	656.01	631.13	614.21
	572.00	541.33	651.11	626.00	613.18
Prosth-Na.	295.49	300.57	343.12	323.01	293.25
	296.74	303.73	346.07	322.90	293.75
	295.78	305.84	348.86	320.81	293.75
Ala-Ala.	139.00	117.04	136.01	136.06	125.00
	140.13	122.15	137.03	133.00	126.19
	139.09	121.00	136.13	134.01	126.06
Mastoid length	123.02	119.44	132.50	146.56	145.97
	124.48	122.25	135.96	147.05	141.03
	126.49	120.07	128.88	151.40	142.43

TABLE 3, Intra-observer variability. The measurements are expressed in pixels, with approximately 4-5 pixels equaling one millimeter.

WHERE DO WE GO FROM HERE?

Obviously, imaging technology is feasible and shows great potential in the world of forensic anthropology. Yet, most of the research into this imaging technology has occurred within the biological and computer sciences. Although physical anthropology is widely considered to be a biological science (at least by anthropologists), technologically, physical anthropology more closely resembles the social sciences-- an academic area strangely lacking in computer technology advancements. Because forensic anthropology is an applied science caught within the world of social science, it also lags behind in the technological realm. Why does this gaping technological hole exist? It exists because anthropologists have not yet realized the extent of the potential of a merger between computer technology and anthropology.

Accurate imaging processes have many interesting and useful applications in physical anthropology, and specifically forensic anthropology. Because Native Americans are reclaiming ancestral remains, the skeletal teaching collections around the country are rapidly disappearing. A method for digital preservation of such remains prior to repatriation could be invaluable. Furthermore, once the information is in a digital format, additional analyses can be performed by later individuals without rescanning, thus providing a much-needed new source of highly-accurate raw data for continuing research. The process would also be applicable in forensic anthropology; once the technique is refined, unknown skeletal remains could be input for identification purposes in criminal investigations, and one could imagine the possibility and potential of national and international databases of such images. We live in a constantly changing population amidst a constantly changing world, yet many of the osteological charts forensic anthropologists use for case analysis are decades old. A modern imaging data base of skeletal material could help to keep such charts current.[27] These are but some of the practical applications of computer imaging technology.

In spite of the fact that these conclusions may be compelling enough reasons to incorporate computer imaging technology into forensic anthropology, they are but practical reasons. The beginnings of this paper raised fundamental issues concerning the past, present, and future of forensic anthropology. Playing "Devil's advocate," I then concluded that the discipline was on a road to extinction, and that perhaps in the opinion of many this would be best. It was also apparent that if forensic anthropology were to be delivered from this fate, it must have firm theoretical foundations upon which to stand. The ensuing discussion of

---

[27] These imaging techniques would also be beneficial in computer engineering, particularly in developing areas such as robotics, to improve digital modeling techniques for further research, and in moving the fields of engineering closer to meaningful applications in biological sciences and biomechanics.

computer technology offered some practical solutions to real problems, as I noted in the above paragraph, but this technology also presents the opportunity to solve the fundamental crisis of theory.

Theories ultimately stand upon empirical data. Using present forensic methodology, collected data is too erratic, incomplete, and scant, to support or refute theories at the "more theoretical" end of the theory continuum. By compiling a database of digitized casework, forensic anthropologists can access a complete and consistent set of data from each case. Statistically significant amounts of data could be accessed for research on many fronts. As one example, a computerized method of calculating and preserving such statistics would be very helpful in the determination of population characteristics as well as human variability. In fact, it could ultimately provide the means to accurately assess the enormous range of variability on this globe. In such a scenario, anthropologists could build substantial theories about topics such as the disappearance of racial categories through admixture. Such speculation concerning modern trends would provide the wherewithal for hypothesis and revision to ultimately form a meaningful theoretical presence within forensic anthropology.

Allow me to further elaborate upon this example. The process of dividing people into distinct races originated in 18th century thought along with the process of classification.[28] Such division was based largely on phenotypic characteristics such as hair type and skin color. Today, the concept of race is a tenuous one. Many anthropologists (particularly cultural ones) deny the existence of race altogether. However, in revolting against the idea of "inferior" and "superior," there is a tendency to deny the idea of difference in lieu of the notion of equality. But how do we then explain real biological variation? How exactly can you explain to the average person that those groups that they see quite easily don't exist? Rather than denying the existence of race, I believe that it is beneficial to understand exactly what a 'race' is. As a physical anthropologist, I consider 'race' to reflect social categorizations based on real biological variation. This biological variation, however, is far from 'neat'; it cannot be cleanly divided into categories. Instead, it reflects a clinal distribution of gene frequencies--a statistical concept--where the populational areas of increased frequencies of certain genes are classified as races.

Such a definition can account for modern genetic concepts such as the acquired data that suggests that only 15% of human individual genetic variation occurs between the three groups that we classically consider races. Therefore,

---

[28] This merely refers to the formal process approbated by scientists such as Linneaus and Buffon--historically, we have been dividing ourselves into groups (particularly 'self' and 'other') virtually since the beginning of civilization.

the 85% that occurs within the races shows the tremendous amount of individual variation in these culturally construed categories. So do races exist genetically? Well, there is a higher frequency of certain genes that we like to lump together, so in this sense, yes. But it is important to remember that not only are such genes present in other 'races' (just in smaller concentrations), but that the grouping of these genes is culturally construed.[29]

However, as a forensic anthropologist, I typologically categorize people into social categories as part of the human identification process. Many of the characteristics used for this classification were originally studied on historic and prehistoric skeletal collections--hardly accurate reflections of today's rapidly mingling gene pool. However, law enforcement as well as the general public insists on carving populations into races, so we continue to abide. Forensic anthropologists, through this process, have a unique perspective on racial categorization. While we understand the arbitrariness of racial divisions, we are not afraid to address their existence. We also have a unique opportunity to contribute to studies on racial groupings--we are constantly in contact with modern human skeletal remains; "Police work might just be a source for invaluable data about

---

[29] It would make just as much genetic sense to pick a different characteristic, say, eye color, and group people with different eye colors in separate races.

present populations that was unavailable from ancient sources" (Ubelaker and Scammell 1992).

Computer imaging is an ideal method for archiving these modern remains in a format for exploring human variation. Consider the test study discussed in this paper, for example. While the imaging technique provides decent absolute measurements, it is ideal for relative measurements (such as ratios and other such comparative measurements)--just the sort of measurements we should be making with reference to human variability. Comparative measurements could quantify human diversity in terms of ranges and overlap rather than in terms of averages and divisions, as is commonly found in the anthropological literature.

Giles and Elliot ('62) produced a chart which divided individuals into three races (white, Negro, American Indian) based on cranial measurements. This method is still commonly being used (in whole, part, or modified) by forensic anthropologists around the country. I would like to question the theoretical validity of this study, and propose three-dimensional imaging techniques as a way to re-formulate studies on race to fit the modern world.

While Giles and Elliot seem to realize some limitations to the usefulness of their study with regards to its application in other populations (Giles 1966), they do not appear to acknowledge the extent of these limitations. The description of their statistical analyses, done before the advent of covariant analyses, reads as follows:

> "The actual calculation of the discriminant functions involves first the computation of a correlation matrix for all the variables, and then the determination of the proper numerical weights for each of the variables. These numerical weights, which constitute the formulas given below, are so calculated that when the measurements from white and Negro skulls are weighted by them, the numerical results for the Negroes tend to cluster around an arbitrary, previously chosen point and the results for the whites tend to cluster around a different arbitrary point. The weights are calculated to make the number of specimens getting into the wrong cluster as small as possible, so the chance of placing a white skull, say, in the Negro or Indian population is minimized" (Giles and Elliot 1962).

Additionally, when describing the skeletal populations, they state that "the Negroes in this series are "Negro" by cultural standards, not genetic ones" and that the Indian Knoll sample is "...from archeological deposits radiocarbon dated approximately 3450 B.C. ..." (Giles and Elliot 1962). So, in other words, the three populations on which their formulas are based are not only not representative of U. S. Native American populations, as Birkby argued in his 1966 paper analyzing 104 American Indian and Labrador Eskimo crania, but stand upon weak theoretical foundations and circular reasoning.

Giles and Elliot make *a priori* assumptions about what constitutes a race. While they claim that their samples are of known race, they also state that "It seems reasonable to assume that any person showing any phenotypic evidence of

Negroid admixture was considered a 'Negro'" (Giles and Elliot 1962). What does that mean? Any person can have black admixture from 1% to 100% and still be considered black? In fact, this sort of typology is common--people who span this whole range of admixture are frequently classified by society as blacks--a typology based on cultural classifications. How can such an incredibly variable group be clumped into one category? And, knowing that this group is so variable, how can Giles and Elliot focus on within-group similarities and between-group differences. Today's genetic data, as mentioned earlier, suggests that the focus should be just the opposite--on within-group differences and between-group similarities. By taking *a priori* notions about what constitutes a race and formulating equations to divide crania into these pre-made categories, all they are saying is that society typologically divides people into categories and that it is possible to create equations that will then further separate these categories so that, most of the time, we can then typologically divide people into cultural categories. Assumptions about people are used to generate data to make assumptions about people.

This argument is not only relevant to the black population. The population commonly characterized as "white" consists of a hugely diverse mixture of people. Even a "predominantly British" sample, as Giles and Elliot claim theirs was, no doubt has an indeterminable mix of other ethnic groups. It is likely that the most homogeneous population, the Indian Knoll population, is easily distinguishable phenotypically because they lived in a relatively isolated population with little admixture--a reality that bears little similarity to today's overcrowded world. So, Giles and Elliot base their equations which claim to distinctly divide modern populations into groups on crania of indeterminate ancestry and those from a population that is not representative of modern populations.

I think it is alright for forensic anthropologists to typologically classify as long as we understand that these racial classifications are socially determined. However, in today's rapidly changing world, even these social categorizations are becoming fuzzy. What constitutes a race for the average person? Physical attributes? Geographical origin? Culture? Language? I am willing to bet that many people would call a dark-skinned Eastern Indian person 'black,' while forensic anthropologists consider them 'white.' If we are going to follow societal patterns, we need to acknowledge differences in opinion, which makes this sort of classification quite difficult. If we choose to follow biological patterns, we need to sample modern skeletal populations in a rigorous, uniform manner, in order to understand diversity and variability instead of only emphasizing similarity. It simply does not make sense to talk about modern world "races" or "ethnic groups" or whatever you want to call them when we are classifying these groups using 30-year-old charts based on even older populations. Even with their pre-determined sample, Giles and Elliot admit that "The three racial groups overlap to some degree in all of the measurements" (Giles and Elliot 1962). If you make all of the symbols on their scatter plots the same (and remember, this is after they have already weighted the characters), it is remarkably difficult to distinguish between the three groups. I think this in itself says something about the overall diversity of our species and the arbitrariness of racial divisions.[30]

This is exactly why a three-dimensional forensic database is so important. We simply need to sample the modern population so that forensic anthropologists can escape from some of these old theories based on outdated assumptions. For example, in the five crania I imaged, the computer calculated bizygomatic breadths ranged from 113.5mm to 136.6mm. Throwing out the female, the numbers are 120.0mm, 128.6mm, 132.0mm, and 136.6mm. By sampling this characteristic across modern world populations, we could build a histogram that would likely be fairly continuous. After doing this with numerous skeletal measurements, these measurements could be plotted in terms of concentric circles or bell curves, or other such overlapping objects, so that we

[30] Giles and Elliot's footnote in reference to an anomalous white man classified strongly as black also lends credit to this.

can begin to understand how these traits are expressed (and to what degree) in different populations. Only then could we delineate areas socially considered different races, ethnic groups, or populations, and only then could we truly understand the criteria for these typological classification systems that human create. In many ways, this would mesh forensic anthropology with the world of populational studies (a good thing, I think, since we work intimately with individual remains that come from various populations), which would force us to identify a skeletal race in terms of statistical probabilities. Perhaps the legal system won't like this, but I believe that jurors probably understand that things are not as "cut and dried" as the legal system would like. Take DNA fingerprinting, for example--while lawyers would like to say that 'only one in a trillion people have this fingerprint,' 'one in one thousand' is usually good enough for the average person (and cases tend to rely on more than one piece of evidence anyway). We should look at forensic anthropology in a fresh light, by reworking studies on morphological characteristics so that they reflect the modern population, which is full of range, variability, and overlap. Ideally, scientists hope that by collecting data, they can inductively reason to create new theories; establishing a modern three-dimensional data base could afford forensic anthropologists just such an opportunity.

IN CONCLUSION

In constructing this paper, I wanted to show the logical flow of ideas that have shaped my inquiry into what ails forensic anthropology. First, it was important for me to understand the position of forensic anthropology within physical anthropology. By tracing the history of science in general and forensics in particular, I found that forensic anthropology is ultimately the product of highly empirical, highly applied science. But has it gone to the extreme? I think it has; in developing such a highly applied discipline, we have split from the arena within which we reside. Is it meaningful science to strive for technical refinement of identifying remains with little context for doing it? Of course identifying human remains is incredibly important, but we are not using this unique experience to develop a broader understanding of modern populations, we merely categorize them. In order to understand these populations and bring forensic anthropology forward as a meaningful science, we need to access large, diverse forensic collections, and in order to have permanent access to these often fleeting materials, we need to preserve the osteological data. To this end I have proposed a database of three-dimensional images of osteological remains as the best way to collect and permanently preserve a modern representational skeletal collection.

Having made such a proposal, I addressed some of the practical questions it rouses. In particular, I explored which type of imaging would work best to generate the data for this database. Certainly there are plenty of promising techniques, particularly in the biological sciences, but as I found, these do not best fulfill the needs of forensic anthropologists. Stereographic methods appear to be ideal for collecting surface data, and their premise of mimicking human vision is perfect for those anthropologists who want to see the bones rather than just look at lists of measurements. Having found probable answers to some of the practical questions, I set up a brief experiment to test these findings for myself using some of these stereographic techniques to image five crania and determine their qualitative and quantitative accuracy. As I have shown, it works--it is possible to image osteological remains with low cost and little memory (approximately 1 megabyte per rotating image). The practical questions do have answers.

But how do these answers finally affect the position of forensic anthropology within physical anthropology, or of theory within forensic anthropology? If forensic anthropology is to come forward as a more meaningful science, it must bring more relevant contributions. By being able to image forensic remains, anthropologists in general will have the opportunity to work with large, diverse, modern samples of skeletal remains, enabling them to reevaluate analytical approaches currently being used by forensic anthropologists. In considering the more relevant contributions to science, I chose to look at race identification, which, as argued in this paper, is a perfect example of an approach needing reevaluation. My inquiry found that we are still dividing populations that are becoming increasingly difficult to divide, when we should be trying to understand morphological ranges of characteristics and their populational affinities and overlaps. We simply need to rework old typologies using new technologies, and forensic anthropology is uniquely poised to do just that.

This example is but one possibility among a multitude, and it is easy to see how theory in forensic anthropology could transcend the merely technical to assume a central position among the sciences. In the beginning of this paper I considered the split that divides anthropology. This split follows a recent splintering trend among many sciences in which increasing specialization isolates scientific disciplines from one another. Instead of excluding other fields, a forensic anthropology which rests upon solid theoretical foundations could reverse this trend by becoming inclusive. This inclusive trend could incorporate areas as diverse and numerous as human evolution, population demography, human variability, human adaptability, health and nutrition, medicine, human anatomy, growth and development, and even such fields as biomedical engineering, artificial intelligence, and robotics.

Forensic anthropology grew out of an intellectual environment that emphasized empirical analysis for the good of humankind. It has remained a field that serves the medico-legal world, despite the fact that it resides within the academic arena of anthropology. In light of this tenuous position, I have offered a possible solution which can help forensic anthropologists contribute fundamental theory to academia. Just because the historical development of forensic anthropology has limited it to what is merely practical and useful, does not mean that this is all it is capable of achieving. New tools empower the field to set new goals. It behoves academics as a group to discover ways of using modern technology to overcome fractious trends and rebuild foundations. In this particular instance, I think it rather ironic that by embracing the technologies of computer imaging, forensic anthropologists can escape from the stigma of being glorified technologists. Yet, it is somehow poetic.

REFERENCES

Abdel-Aziz, Y. I. and H. M. Karara (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrametry. ASP/UI Symposium on Close-Range Photogrametry, Urbana, Illinois, American Society of Photogrametry.

Adler, M. (1992). Great Ideas: A Lexicon of Western Thought. New York, Macmillan Publishing Company.

Congress of the United States, Office of Technology Assessment, Ed. (1988). Mapping Our Genes: Genome Projects: How Big, How Fast? Baltimore, The Johns Hopkins University Press.

Bacon, F. (1989). New Atlantis and The Great Instauration. Arlington Heights, Hatlan Davidson, Inc.

Birkby, W. H. (1966). "An Evaluation of Race and Sex Identification from Cranial Measurements." Am. J. Phys. Anthrop. 24: 21-28.

Bookstein, F. L., B. Chernoff, et al. (1985). Morphometrics in Evolutionary Biology. Ann Arbor, Braun-Brumfield Inc.

Bower, B. (1994). "Fossils on File." Science News. 145: 186-187.

Brodlie, K. W., L. A. Carpenter, et al., Eds. (1992). Scientific Visualization: Techniques and Applications. New York, Springer-Verlag.

Chun, K. W., M. S. Lee, et al. (1991). Directional 3-D interpolation technique for volume rendering. IEEE Nuclear Science Symposium and Medical Imaging Conference, Santa Fe, New Mexico.

Conroy, G. C. (1988). "Alleged synapomorphy of the M1/I1 eruption pattern in robust australopithecines and Homo: evidence form high-resolution computed tomography." Journal of Physical Anthropology 75: 487-492.

Descartes, R. (1980). Discourse on the Method for Rightly Conducting One's Reason and for Seeking Truth in the Sciences. U. S. A., Hackett Publishing Company.

Elad, D. and S. Einav (1990). "Three-dimensional measurement of biological surfaces." ISPRS Journal of Photogrammetry and Remote Sensing 45: 247-266.

Frobin, W. and E. Hierholzer (1981). "Rasterstereography: a photogrammetric method for measurement of body surfaces." Photogrammetric Engineering & Remote Sensing 47: 1717-1724.

Fuchs, H., M. Levoy, et al. (1990). Interactive visualization of 3D medical data. Visualization in Scientific Computing Eds. G. M. Nielson and B. Shriver. Washington, IEEE Computer Society Press. 140-146.

Giles, E. (1966). "Statistical Techniques for Sex and Race Determination; Some Comments in Defense." Am. J. Phys. Anthrop. 25: 85-86.

Giles, E. and O. Elliot (1962). "Race Identification from Cranial Measurements." J. Forensic Sci. 7(2): 147-157.

Haglund, W. D. and C. L. Fligner (1993). "Confirmation of human identification using computerized tomography (CT)." Journal of Forensic Sciences 38(3): 708-712.

Hildebolt, C. F. and M. W. Vannier (1988). "Three-dimensional measuremnt accuracy of skull surface landmarks." Journal of Physical Anthropology 76: 497-503.

Hildebolt, C. F., M. W. Vannier, et al. (1990). "Validation of skull three-dimensional computerized tomography measurements." Journal of Physical Anthropology 82: 283-294.

Holden, C. (1993). "New life ahead for social sciences." Science 261: 1796-1798.

Hooten, E. A. (1946). Up From the Ape. New York, Macmillan.

Hu, X., et al (1989). Volumetric rendering of multi-modality, multivariable medical imaging data. Chapel Hill Workshop on Volume Visualization,

Lander, E. (1992). DNA Fingerprinting: Science, Law, and the Ultimate Identifier. The Code of Codes: Scientific and Social Issues in the Human Genome Project Eds. D. Kevles and L. Hood. Cambridge, Mass., Havard University Press. 191-210.

Lewontin, R. C. (1991). Biology as Ideology: The Doctrine of DNA. New York, Harper Perennial.

Mankovich, N. J. and S. C. White (1992). The appearance of bony lesions on 3-D CT reconstructions: a case study in variable renderings. Medical Imaging VI: Image Capture, Formatting, and Display, Newport Beach, California, SPIE--The International Society for Optical Engineering.

Moore-Jansen, P. H. and R. L. Jantz (1989). Data Collection Procedures for Forensic Skeletal Material. The University of Tennessee, Department of Anthropology, Knoxville, Tennessee.

Morell, V. (1993). "Anthropology: nature-culture battleground." Science 261: 1798-1802.

Palamidese, P., Ed. (1993). Scientific Visualization: Advanced Software Techniques. New York, Ellis Horwood.

Pena, S. D. J., R. Chakraborty, et al., Eds. (1993). DNA Fingerprinting: State of the Science. Boston, Birkhauser Verlag.

Pickering, R. B., D. J. Conces, et al. (1990). "Three-dimensional computed tomography of the mummy Wenuhotep." Journal of Physical Anthropology 83: 49-55.

Rankin, D. (1994). Restriction Fragment Length Polymorphism (RFLP) Analysis on Forensic-Use DNA from Human Compact Bone.

Reyment, R. A., R. E. Blacklith, et al. (1984). Multivariate Morphometrics. London, Academic Press.

Rohlf, F. J. and F. L. Bookstein, Eds. (1990). Proceedings of the Michigan Morphometrics Workshop. Ann Arbor, The University of Michigan Museum of Zoology.

Rosenberg, N., R. Zeltser, et al. (1990). "Simplified remote measurement of three-dimensional surfaces: application for biomedical engineering." Photogrammetric Engineering and Remote Sensing 56(9): 1273-1280.

Simmons, M. and R. Koskela, Eds. (1990). Performance Instrumentation and Visualization. New York, Addison-Wesley Publishing Company.

Ubelaker, D. (1990). "Importance to forensic science of permanent curation of museum collections." Journal of Forensic Sciences 35(2): 513.

Ubelaker, D. and H. Scammell (1992). Bones: A Forensic Detective's Casebook. New York, HarperCollins Publications.

Westfall, R. S. (1990). The Construction of Modern Science: Mechanisms and Mechanics. Cambridge, Cambridge University Press.

Wills, C. (1991). Exons, Introns, and Talking Genes; The Science Behind the Human Genome Project. New York, Basic Books.

Wilson, C. (1991). Clues! A History of Forensic Detection. U. S. A., Warner Books.