e-Skeletons: The Digital Library as a Platform for Studying Anatomical Form and Function

John Kappelman *Principal Investigator*
Myriam Zylstra *Post Doctoral Project Supervisor*
Timothy M Ryan *Graduate Research Associate*
Marat Maga *Graduate Research Associate*

University of Texas at Austin

Introduction

I would like to take this opportunity to thank the organizers of this conference for making it possible for all of us to meet here this week, and especially Carl Lagoze of Cornell and Dianne Martin and Steve Griffin of NSF for all of the hard work that they have put into this conference.

Today I will update you on the status of our ongoing digital library project, “eSkeletons”

One of the important goals of educators is to attempt to ensure that all of our students have the best possible access to the resources that form the foundation of their learning experiences.

The study of the anatomy is one of the key topics that underlies many fields within the biological sciences and medicine but has, historically, been critically dependent upon the availability of actual skeletons for study.

Although much of this study is based on either black and white or color photographs and drawings, studying actual skeletal elements is an essential component because it is in this way that the two-dimensional experience is elevated to the three-dimensional .The quality of the learning experience is therefore controlled in large part by access to the skeletal material. Some institutions have excellent skeletal collections, with some schools having enough extra material that students can check out a skeleton for home study, while other institutions have no teaching material at all. In the latter case, students are forced to base their study of the three-dimensional form and function of the skeleton on two-dimensional pictures from their textbooks. Clearly, there is little comparability between these two learning experiences.

PROBLEM:
Uneven access to the critical laboratory materials used in teaching skeletal anatomy

GOAL:
To provide 1) the raw materials needed for the study of skeletal anatomy in

2) a user-friendly learning interface

First, I will discuss the various techniques that we are using to acquire the raw data that is used to construct the library; and second I will present the current status of our web interface.

Data Acquisition

Advances in three-dimensional data capture, display and software learning interfaces now make it possible to build a digital library of the skeleton that will serve to even out the disparities that exist among the learning experiences of students from different institutions.

There are numerous methods now available for digitizing both the external and internal surfaces of three-dimensional objects. Some of the most useful technologies for digitizing skeletal materials are three-dimensional laser scanning and high resolution X-ray computed tomography. Both technologies are ideally suited for this task because of their noninvasive and nondestructive natures. These technologies are presently available at the University of Texas, Austin.

Laser Scanning

Some of the most recent advances in automated 3-D imaging incorporate a laser to capture the surface topography of a specimen.

Operating costs are much lower than CT because laser scanners use standard electric current, have very low maintenance costs, and do not require a licensed operator.

The laser scanning technology that we use to capture the surface geometries of the skeletal elements uses what is known as adaptive scanning and is manufactured by Digibotics, Inc. of Austin, Texas. This system tightly focuses a laser beam and uses this single point of light and a triangulation algorithm to measure the exact x and y coordinates of each point on the surface of the specimen at a fixed z coordinate level.

The x, y, z data can be exported to a variety of software programs for wiremeshing , shading and animation. For the purposes of our Digital Library project, long scans are usually run overnight or on the weekend, and we have now completed scans of every element of the human skeleton. We are now completing scans of the chimpanzee and baboon.

High Resolution X-Ray Computed Tomography

The development of X-ray CT began as a medical diagnostic tool in 1971 and witnessed a wide number of applications in physical anthropology. Computerized tomography differs from conventional radiography in that the X-rays are restricted to a plane and the intensities of the beam, before and after it passes through the specimen, are measured. Conventional CT typically has a resolution of 1-2 mm thickness.

High resolution X-ray CT, also known as industrial CT, offers several advantages over conventional medical CT. First, HRXCT uses a range of higher energy sources (typically 125-450 kV) than those available in medical CT, which makes the instrument capable of penetrating much denser objects including rocks and very heavily mineralized fossils.

Second, the X-ray detectors are modular, and these can be switched between linear and area detector arrays, which increases the resolution of the instrument. The combination of modular sources and detectors produces a CT system that can scan a variety of specimens across a wide range of resolutions.

For example, currently the best resolution available on a medical CT is 1000 microns, while a micro CT can scan as low as 10 microns. This increase in resolution means that much smaller objects or structures such as trabecular bone can be clearly imaged.

The images shown here are those of our recent Hi res X-ray CT of a human cranium.

3-D Hardcopy Output

Many of the digitizing technologies discussed above come directly from the fields of computer-aided engineering and manufacturing. In fact, many laser scanners are specifically designed for reverse engineering and computer-aided manufacturing (CAM). Once these skeletal elements are digitized, it is useful to think about the remaining option of outputting these data back into three-dimensional models for study by a range of students who would not otherwise have access to the materials.

Automated milling and stereolithography are two of the best known techniques.

Laser sintering, a process invented by DTM, Inc. is the newest addition to this line-up of technologies. This process uses a laser to sinter or fuse nylon or plastic powder into the first layer of the object, which in turn is sintered to the next layer, and so on, until the 3-D printout is completed.

Although laser sintering is relatively expensive at present, it is likely that at some point in the future, this technology will offer a valuable means for getting replica specimens of rare, fragmentary, or fragile, or even those of endangered species, into the hands of students.

The Learning Interface

Archiving skeletal objects themselves as raw data to the web with no informative or comparative context may prove useful to some advanced users, but a software interface that serves to teach identifications, comparative morphology, and anatomical function will certainly serve to extend the benefits of these data sets to a much larger number of users across all educational levels. This is the introductory page for our site.

We have designed an interface that uses an image of the skeleton as a "map" and organizes the skeletal material by anatomical region.

This site is constructed with Java script.

Each region includes color images of each skeletal element taken from the six standard anatomical views. Each skeletal element has color overlays of muscle origins, insertion, morphological features and articular surfaces that can be turned off and on by the user. Higher levels of detail will include selective micro CT scans of particularly important anatomical features or elements.

Up to this point the software interface bears a very close resemblance to what the typical student would encounter in a hard copy printed book. Where this digital library begins to depart from the typical anatomy book is with its emphasis on the three-dimensional presentations. Each skeletal element has both QuickTimeÆ and VRML animations. The former animations are preset and include rotations around the standard anatomical axes, while the latter files provide the user with complete control over the anatomical materials. The VRML files require a more powerful CPU than do the QT animations and can probably only be accessed by advanced users.

If you are interested, I'll be showing the QuickTimeÆ and VRML animations after this session back in the breakout room.

For the purposes of comparative study, chimpanzee and baboon skeletons will also be posted to the web site. The interface is constructed in a way that will easily accommodate other species as well, and we anticipate that, in future years, the site will be expanded to include other mammalian species as well as other vertebrates.

An integral component of the user program interface will include self-evaluation. Virtual anatomy tests will draw from the full range of materials provided via the 2D and 3D images, as well as database content. They can be presented to the to the student in the form of multiple choice, matching, and interactive problem solving questions. Grades can be automatically calculated and reported as the last screen of the exam for immediate feedback to the student.

The primary audience that the eSkeleton project is aimed toward is that of college and university students, but we anticipate that the full range of K through university, or even K through grey learners, will use the web site. There has, however, been a great deal of interest expressed by potential users at the high school and middle school levels. In order to respond to this population, we have designed a parallel user interface that is aimed more directly at the middle school student. This portion of the web site uses the same basic anatomical data but has a more "kid friendly" interface. It will also include a number of classroom exercises that instructors can print out for class activities.

Delivery Issues

One of the critical issues that has to be addressed is how to handle the delivery of large datasets to users. One solution utilized in the design of this project is an emphasis on client-side storage and interactivity. When the user chooses an element, all views and overlays for that particular bone are downloaded at once. This results in a brief download delay initially, however after these images are stored, the speed of user interactivity is maximized.

Another possible solution that we are investigating is a CD-web hybrid interface that posts the program instructions to the web site and delivers the raw data files to the user via a CD ROM. This delivery system would alleviate unacceptably long download times across low speed networks. In addition, a separate CD that includes the same information as the web site will permit the user to access the anatomical data when they do not have web access. It would also permit updated postings to the web that utilize the same raw data from the CD.

Incompatability between Web browsers has also presented a problem for data delivery and access for users. At present, we are not aware of an effective solution to this issue but will probably have to build separate interfaces for each of the two most popular browsers.

When we started this project we relied on Macromedia's program Authorware, a program that we had used to produce virtual laboratories on CD-ROM. Authorware is not database-friendly over the web, and we switched to using web authoring software. If anyone knows of any fixes for Authorware, I'd be very interested in hearing about it.

Being able to quickly search the site for specific information is another topic that we could use some assistance with re. how to most effectiveley use metadata.

With continued agency support, the e-Skeletons project could increase the content of the database to include detailed information about the skeleton that would greatly increase its utility. For example, topics such as diseases of bone, age and growth related changes, forensic applications, techniques, and case studies and an enlarged archive of comparative taxa.

Moreover, additional high resolution micro CT scans of a wider variety of skeletal elements would provide an unparalleled resource not only for scientists in the fields of anthropology and palaeontology, but medicine as well.

Current web-hosting and address archiving costs will be on the order of $500-$1,000 per year without any maintenance or updating. We foresee three options:

1) It may be possible for the home university to cover these costs.

2) The web site could be migrated to CD-ROM and distributed by a publisher (who may or may not wish to maintain the web site).

or

3) ADVERTISING!

CONCLUSION

Archiving anatomical materials to a digital library will have wide ranging educational implications because it will make a broad range of study and research materials available to students of anatomy hailing from a wide number of disciplines, across the K-12 to graduate school levels as well as life-long learners. Providing broad access to critical materials that are otherwise unavailable to students is one of the central goals of a national digital library.

Thanks to NSF (IIS and DUE), and the University of Texas for the support of this project, and Drs. Carl Lagoze (Cornell), Dianne Martin (NSF DUE) and Steve Griffin (IIS) for inviting us to this conference.