Adding Semantics to 3D Digital Libraries

Anshuman Razdan[1], Jeremy Rowe[2], Mathew Tocheri[3], Wilson Sweitzer[4]

Abstract

Many disciplines in academia and industry must deal with large numbers of 3D objects. There has been a recent push to organize multimedia content into digital libraries, and attention has now turned towards archiving 3D objects in an intelligent way. A 3D object representation in the most primitive form is a collection of space points connected via edges to form triangle faces. This representation has no semantics associated with it. Therefore, it is important that semantic information be included with the raw 3D data when creating searchable databases or digital libraries. Our work has focused on creating a patent pending process to create 3D digital libraries. There are several steps necessary to create and associate semantics with the content that are at least partially automated. We also conclude that there is a need for a discipline expert to assist and validate the process. We give an example of an Osteological 3D library and describe the steps of the process in this paper.

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[1] Dr. Anshuman Razdan, Director PRISM, MC 5906, Arizona State University, Tempe AZ 85287 USA (Corresponding author and presenter).

[2] Dr. Jeremy Rowe, Director Media Development, Information Technology, MC 0101, Arizona State University, Tempe AZ 85287, USA.

[3] Mathew Tocheri, Graduate Research Associate, PRISM & Department of Anthropology, MC 5906, Arizona State University, Tempe AZ 85287 USA.

[4] Wilson Sweitzer, Graduate Research Associate, PRISM & Department of Anthropology, MC 5906, Arizona State University, Tempe AZ 85287 USA.

1 Introduction

Several efforts have begun to archive 3D data in an organized manner and to create 3D Digital Libraries. An important challenge in creating an intelligent archiving mechanism is the problem of adding semantics to the original content. One of the most common representations of a 3D object is in the form of a triangle mesh, a collection of geometry (i.e. points (x, y, z) in space) and topology (i.e., how these points are connected to each other). There are many advantages of 3D models over 2D images as a great deal of information can be gleaned from the geometry and topology. For example: geometry gives us the size of the object in a coordinate system, volume, surface area, curvature distribution (where the object is highly curved and where it is flat, etc.). Topological information can give us clues about the genus of the object or if it has orientable manifold. Beyond that there are no semantics associated with the geometry and topology of 3D object.

Under the NSF funded 3D Knowledge Project (3DK), PRISM researchers have devised a patent pending process to add semantic content to a 3D digital archive [RAZD01; ROWE01a,b; SCHU01]. This is done by first applying our feature extraction and segmentation algorithm to divide a 3D object in to a set of bounded regions or features based on curvature. These regions can be manually edited with the Region Editing software if the discipline specific researcher is not satisfied with the region boundaries. Next, the regions are tagged with discipline specific nomenclature. In case of bones, it might be textually tagging the joint surfaces which have been automatically segmented. Many of the geometric properties about each region are also automatically created at this time. The object is then ready for archival. We have used XML schema for storing the semantic content about the different regions and their relationships to one another. The data is then archived in a database with both the XML and the raw 3D data stored together.

We have also developed a Visual Query system whereby this data can be retrieved, visualized and analyzed in 3D. Initially, plugins were developed for Netscape browser, but we have recently made the switch to Java3D to achieve platform independence. The paper details all aspects of the process including data acquisition, geometric modeling for adding semantic content, representation, analysis and visual query using osteological database as an example. In short, this paper describes the process of creating a 3D Digital Library.

2 Development of the Osteology 3D Digital Libary

One of the 3DK pilot projects addresses the need of physical anthropologists to acquire, analyze, and intelligently archive, manage, and query complex 3D bone morphology. Although physical anthropologists have always worked with three-dimensional objects, they have largely been unable to capture truly three-dimensional data. Consider how an osteologist describes the shape of a bony feature in traditional terms such as *deep, shallow, robust,* or *gracile*, and uses calipers to quantify complex shapes. There is a clear need to more effectively characterize the complexity, topology, and semantics of bones.

In addition, physical anthropologists face a number of hurdles in their research and teaching efforts. Gaining access to data samples with appropriate depth and breadth is often a resource-expensive endeavor. Research collections are spread throughout the world and frequently contain limited breadth and depth, inadequate for a variety of research questions. Preservation concerns and repatriation issues may further limit the value of important collections. Furthermore, specimen catalogs and specimen-related data are often not computerized, requiring time-consuming legwork. The scope of this last problem is evident from the following email exchanges. We queried a number of important biological collections during June 2002 asking:

> *"I am a researcher interested in primate hand and wrist bones. Could you please send me any appropriate information regarding the number of disarticulated samples you have in your collection? Thank you for your time."*

The following are quotes from the responses:

> *"I am afraid our database is not very helpful in answering your questions directly. There is no way to know from our computer records which of our skeletons have hand bones, and which do not." – National Museum of Natural History*
>
> *"We have only a small part of the collection databased so getting the information you requested is somewhat a challenge." – Academy of Natural Sciences of Philadelphia*
>
> *"Unfortunately, we do not have an inventory of the material that would allow me to tell you what is articulated and what is not." – Field Museum of Natural History*
>
> *"I don't have exact counts of which forearms and wrists have been disarticulated." – Cleveland Museum of Natural History*
>
> *"I can xerox a copy of our taxonomic cards that will show you our holdings of the material you requested. I'll send it along in the postal mail to you this week." – Harvard Museum of Comparative Zoology*

It is clear from these responses that new approaches to archival and management of biodata are needed. Not only do these problems hinder individual research efforts, but they also tend to discourage data sharing among scientists.

2.1 Data Collection

Researchers at PRISM have begun to address the needs of physical anthropologists by developing an osteological 3D digital library. The current collection includes over 850 specimens of primate hand, wrist, and forearm bones from the National Museum of Natural History and the Cleveland Museum of Natural History and 24 pubic symphysis casts used by forensic researchers to determine the age at death of unidentified human skeletal material [BROO90].

This collection was acquired using laser scanners. At PRISM we use four different laser scanners depending on the resolution desired and the size of the scanned object. The raw data, commonly referred to as a point cloud, consist of points (x_i, y_i, z_i), i = 1, …, n which lie on the surface of a bone. For meaningful analysis, these point clouds must be modeled. A convenient surface model is a triangle mesh consisting of a set of faces containing loops of edges terminated by vertices stored to retain geometry and topology. For example, eight points, twelve edges, and six (four-sided) faces can describe a cube. These meshes can also be shaded to assist in the visualization of the object. See Figure 1 for an example of the stages of the modeling process for a human trapezium (a bone in the wrist). The triangle mesh is the most common representation method for 3D objects. Another popular mathematical representation is NURB[5] [FARI01,02] surfaces. Approximating the scanned data with NURB surfaces [RAZD98, STEI98] requires extra work but can be useful for

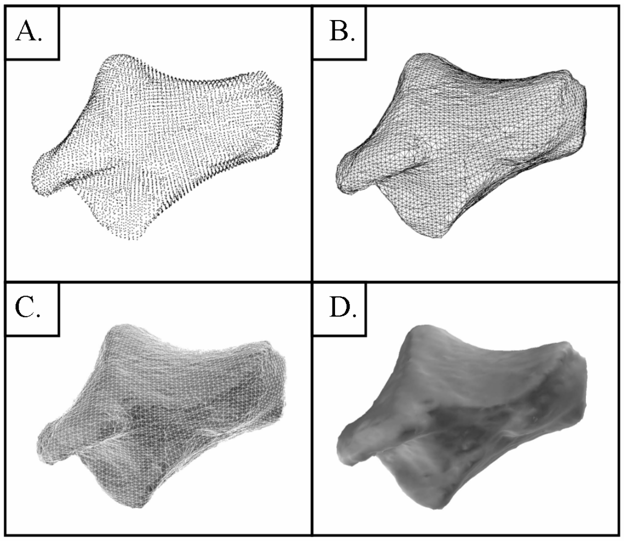

Figure 1. Example of 3D data: 3D point cloud from laser scanner (A); wireframe of triangular mesh (B); flat-shaded model (C); smooth-shaded model (D) of a human trapezium.

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[5] Non Uniform Rational BSpline

many applications. We save both the triangle mesh as well as the NURB representation (bicubic) of the joint surfaces. NURB representation smoothes out noise and makes it easier to compute accurate curvatures of the joint surfaces. NURB fitting first requires segmentation of the data which we explain in the next section. Yet another popular methodology in representation of triangle meshes is called Subdivision surfaces [AMRE02], an area we plan to explore in the future.

2.2 Segmentation and Feature Extraction

To raise the level of abstraction of the data (i.e., to be able to describe the object in terms of its various parts), the triangle mesh must be segmented into distinct regions or features. This is an important step for adding semantics to the data. In the case of bones, this step involves identifying osteological features of interest, such as joint surfaces and muscle attachments, which can then be quantitatively described and cataloged along with the 3D model. Feature extraction and segmentation is accomplished with a watershed-based hybrid segmentation algorithm developed at PRISM [PULL02; RAZD02]. The algorithm is based on the principle of a watershed as used in geography; by identifying local maxima and minima the program defines regions roughly analogous to drainage basins. The maxima and minima are based on the curvature of the vertex. In general the regions identified by this algorithm are too small to be biologically meaningful. Therefore, the user can increase the watershed depth, the equivalent of adding more water so that drainage basins overflow into one another. In this way, the user can let the program define regions at various resolutions. Figure 2 illustrates this process. The initial segmentation of human trapezium (top left) identified a number of very small regions, but when the watershed depth threshold was increased, the algorithm segmented out the joint surfaces for the first metacarpal (bottom left, left image), trapezoid, and scaphoid (bottom left, right image).

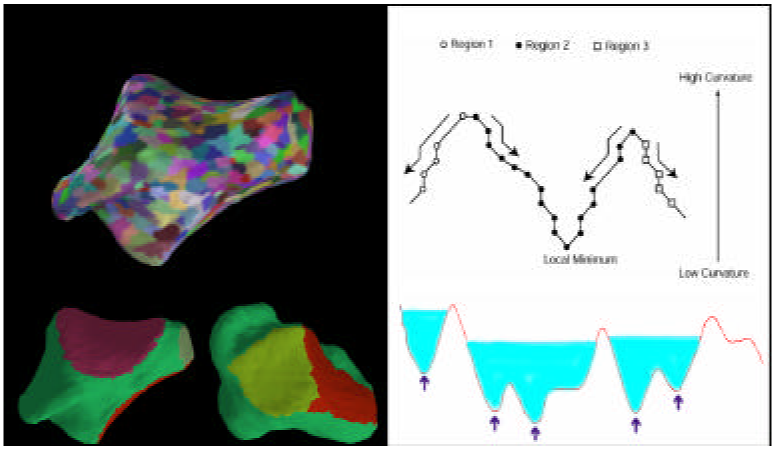


Figure 2. Before (top left) and after (bottom left – two different views) merging similar regions on a human trapezium by changing the watershed depth threshold (illustrated at right). Note the clear segmentation of joint surfaces in the after images.

The algorithm is independent of the underlying data and only relies on the geometry and topology embedded in the data. Hence, it has no inherent knowledge of whether a region is a meaningful feature or not. This is both a plus and a minus for the algorithm. Building discipline specific intelligence defeats the purpose of developing a generalized algorithm like this. On the other hand, this is applicable to a vast variety of data and is highly automated. We deal with the issue of discipline specific semantics and feature editing in the next section.

2.3 Feature Editing and Adding Textual Semantics

In some cases though, the user may still need to define features manually. For instance, a stray data point on a surface affects the curvature values of the data points around it. This type of error could confound the watershed algorithm. To combat this problem, the Region Editor software enables the user to merge and split regions by manually identifying the vertices of interest.

After the features of interest are segmented, these defined regions are then tagged by the researcher. This additional information, or semantic content, can include contextual and 3D data. Using a human trapezium as an example, contextual items such as biographical data (age, sex, population, etc.), data collection information (researcher names, scanner and software settings, etc.), and anatomical names of segmented features, and 3D data, such as curvature values, surface areas, spatial relationships between features, and custom measurements, can all be added to the original bone model. These metadata are recorded using Extensible Mark-up Language (XML) schema.

2.4 XML Schema for Bones

Figure 3 illustrates an example of an XML scheme used for the trapezium. An XML structure is a hierarchy of classes. Each of these classes contains data and/or subclasses. There are two basic data types in this archival scheme: contextual and 3D data. The branch labeled Data_collection_info is an example of a contextual data class; it would contain metadata associated with the acquisition, processing, and archival of a particular trapezium. The branch labeled Model_data is an example of a 3D data class; it would contain raw data (triangle mesh), as well as calculated data (feature information, surface area, etc.) derived from the original model. The data is then ready for archival using any off-the-shelf database software. Potentially, these

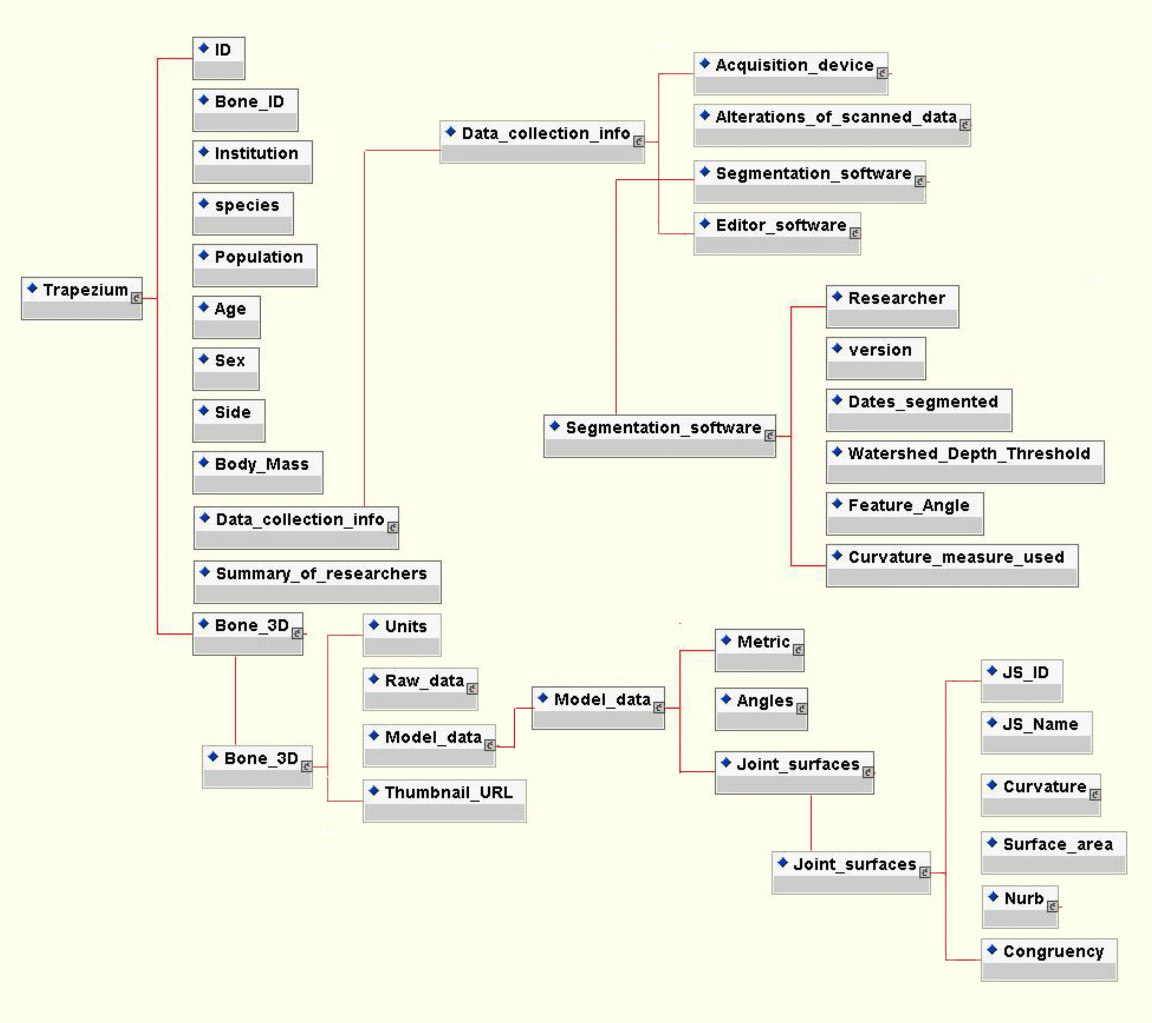


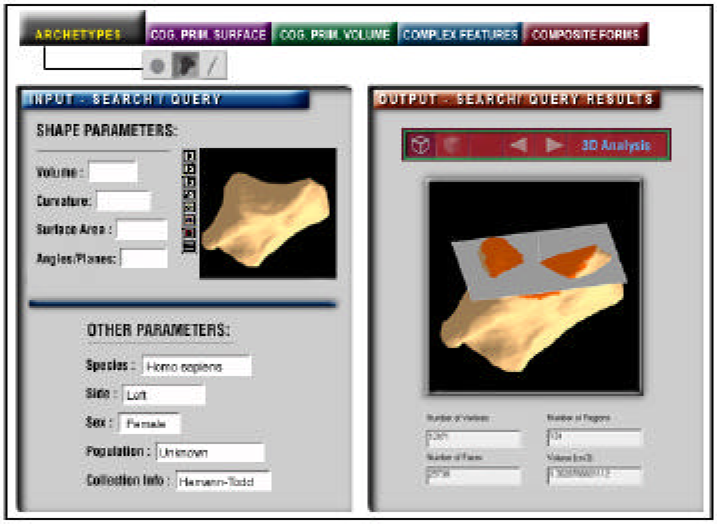
Figure 3. An example of how contextual and 3D data associated with a bone specimen (i.e., metadata) are archived using XML.

databases could be linked as a collection of federated databases and systems [HSIA92].

3 Visual Query

Currently, most osteological research collections can only be queried by contacting the collections manager (as we did) or through simple text-based online interfaces. Aside from issues of convenience, these types of queries are limited in their utility. Bones are 3D objects, and only a fraction of the information they contain can be described textually.

This is why the 3DK visual query system is designed to support a variety of modes including text, vector graphics, and interactive 2D and 3D models [ROWE01a,b]. Figure 4 is the visual query interface. In addition to traditional textual inputs, the interface includes fast interactive surface and volume visualization capabilities for inputting 3D search criteria. The results interface combines display of raw data and supplemental semantic data from the XML archives with quantification tools to extract additional 3D data directly from the search results. We are implementing 3D compression techniques [TAUB98] for faster delivery of 3D data to the client/user.



SHAPE PARAMETERS:

Volume :

Curvature:

Surface Area :

Angles/Planes:

OTHER PARAMETERS:

Species : Homo sapiens

Side : Left

Sex : Female

Population : Unknown

Collection Info : Hamann-Todd

Figure 4. Web-based visual query interface for an osteological 3D digital library.

4 Conclusions

3D digital libraries are in their infancy, but steadily gaining popularity. The need to acquire, view, and manipulate 3D data is forcing researchers and industry to look seriously at the archival process. Several 3D catalogs are currently available, but much of the library creation process in terms of shape description remains manual. We cite the work at Princeton (http://shape.cs.princeton.edu) as an important step in the direction of automating the process. As with any other digital library, we have to constantly maintain and update it. Data acquisition and processing can be time consuming, generally requiring an hour or more per object. Currently, we use local experts at Arizona State University to segment the bones (or other objects). It is important to note that such data is still subject to qualitative interpretations. For this reason, we also make the raw data available from the database so that other researchers can download it and verify the results or apply a different set of algorithms.

Already, this approach to digital archiving and analysis of 3D objects shows great promise for research in physical anthropology and other fields [TOCH02a, b and c]. The tools provided here allow researchers a way to back their qualitative results with quantitative data, improve reproducibility, and efficiently share data between researchers.

Many of the algorithms used here are at an early stage of development, especially compared to text and image based digital libraries. In our experience, the effort to organize a 3D digital library is far greater than for text and image libraries. It also requires development of sophisticated geometric modeling and computer graphics tools that are currently not standard, although there is progress in that area with X3D organization (www.x3d.org).

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