Building a 3D Virtual Museum of Native American Baskets

Volkan Isler
Department of Computer Science
Rensselaer Polytechnic Institute
Troy, NY 12180
isler@cs.rpi.edu

Bradford Wilson
Computer Science Division
University of California, Berkeley
Berkeley, CA 94720-1772
bwilson@berkeley.edu

Ruzena Bajcsy
Electrical Engineering and Computer Science
University of California, Berkeley
Berkeley, CA 94720-1772
bajcsy@eecs.berkeley.edu

***Abstract*— In this paper we report our progress in building a system for the acquisition, analysis, and visualization of a collection of Native Californian baskets from the Phoebe A. Hearst Museum of Anthropology. Our project differs from existing cultural heritage applications in terms of its focus: to build tools and techniques for visualizing and studying a large number of related objects – in this case, baskets. We present our progress in the following system components: (i) laser-scanning of baskets, (ii) construction and processing of 3D models, and (iii) building virtual exhibits. We conclude the paper with our experiences and a summary of challenges we anticipate in building a completely automated system for processing and analyzing a large set of models – such as might be encountered when digitizing a large museum collection. Efficient retrieval and visualization of artifact collections are important to a number of communities, including anthropology researchers, Native American tribes, and the general public.**

I. Introduction

Advances in three dimensional data acquisition, processing, and visualization technologies enable new methods for not only preserving our cultural heritage but making it vastly more accessible to both researchers and society alike.

In this paper, we report our experiences and progress in building a virtual exhibit for the Phoebe A. Hearst Museum of Anthropology. Home to an estimated 3.8 million objects, the Hearst Museum has extensive collections devoted to Native California peoples, including a unique research collection of California Indian baskets which it has been gathering for nearly a hundred years. In addition to being the largest collection of its type in the world, with approximately 9,000 baskets, the collection's remarkable breadth – there are representative specimens from almost every tribe in California – make it a particularly attractive, and heavily used, resource for study.

As is common with managing research collections of this size, providing access to scientists and the public is a continual problem for museums. Due to space limitations in its crowded quarters, the Hearst Museum must house its collection of California Indian baskets in an off-site storage facility. Physical access to the collection is strictly controlled, since handling of the often fragile objects hastens their deterioration. Before researchers can gain access to the baskets, they must first make an appointment to visit the storage facility, during which museum staff must be on hand to supervise and handle the artifacts, a less than efficient arrangement. Researchers who must travel great distances around the globe to visit collections are necessarily limited in the access they can afford by the size of their research budgets. The general public has even less access than do researchers, as the museum's gallery space is quite small in comparison to the size of its holdings. Typically, only a handful of baskets are on permanent display. Occasionally, larger numbers are displayed during special exhibits, but space restrictions make it impossible to display more than a small percentage of the entire collection at any given time.

Fig. 1. A Yurok indian basket from the California ethnology collections of the Phoebe A. Hearst Museum of Anthropology. Top left: outside surface of a hat basket. Top right: inside surface of same hat. Weaving proceeds in either a clockwise or counter-clockwise direction from the large central knot. Bottom row: close-ups of top row images show central knot and weaving detail.

Yet another audience for which access to this collection is important are native Californians, a number of whom still practice the traditional forms of basket weaving represented in the collection. In recent years, cultural institutions with significant holdings produced by native peoples have begun to reach out to indigenous communities, not only to increase the value of collections by gathering contextual annotations from their traditional owners, but in some cases to extend access to sacred and historically significant objects as part of repatriation agreements. The Smithsonian National Museum of the American Indian has begun to build a collaborative information technology framework for just this purpose [1]. Sadly, in the case of our Native Californian collection, some artists and tribal elders with an interest in examining the baskets are denied access simply because they are unable to travel to the museum.

Given the need for access to these artifacts, and to explore the potential benefits that a virtual access capability could provide, we set out to build a virtual museum. In this paper, we report on our experiences in building the initial prototype of our virtual museum. Before we start with a description and overview of our project in section III, we present an overview of related work in the field.

II. Motivation and Related Work

The issue of 3D digital preservation of cultural heritage and museum artifacts has received a lot of recent attention. For example, the aim of the European Consortium ARCO [2] is to develop a comprehensive system for acquisition, representation, and searching of cultural objects. Similarly, in the Ikeuchi Lab of University of Tokyo [3], researchers are acquiring models of large objects such as Buddha statues. The Digital Hammurabi Project [4] at the Johns Hopkins University is aimed at scanning and visualizing high resolution, three dimensional models of cuneiform tablets. A comprehensive natural history research library containing both 2D and 3D high-resolution X-ray computed tomographic images can be found at the University of Texas' Digital Morphology library project [5]. Other projects aimed at cultural heritage preservation are ViHAP3D Consortium [6], Columbia 3-D database of Medieval French Architecture [7] and the University of Pennsylvania Museum's project to create an underground image of a Pre-Inca city [8], [9].

Our work differs from this impressive body in an important aspect: our focus is on creating a database of a large number of highly related objects such as the California Indian basket collection. This allows us to develop techniques for extracting different aspects of these objects automatically. Traditionally, anthropology researchers manually extract many geometric attributes [10] such as dimensions, curvature etc. Our short term goal is to fully automate this process. The Partnership for Research in Spatial Modeling (PRISM) project at Arizona State University has done work in this area with collections of ceramic vessels, bones and lithics [11]. They found that the accuracy of measurements computed from their acquired 3D models met or exceeded the measuring capacities of traditional 2D tools such as calipers and rulers [12]. In the long run, we are aiming at developing high-level algorithms which can have a bigger impact on the anthropology research. Let us demonstrate this idea with an example. There are many different types of symbolic weaving patterns (e.g. sun, zig-zag, bear-claw) on the baskets. However, not every pattern is suitable for every type of basket; a particular type of pattern can be appropriate for, say, a cup but not for a hat. We are interested in developing algorithms that discover such correlations. Note that this requires not only understanding the type of the basket but also the meaning of the pattern as well.

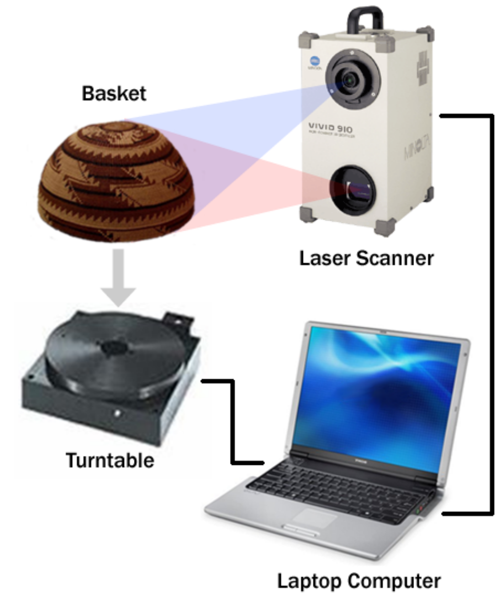

Fig. 2. A schematic representation of the scanning setup

III. Project Overview

In this section, we present an overview of our project. The details of individual components will be given in subsequent sections.

The first component is *Data Acquisition* (Section IV). The purpose of this component is to obtain a 3D model of a basket using a laser scanner. A schematic representation of the laser scanning process is shown in Fig. 2. Our laser scanner, the Konica Minolta VIVID 910, can acquire a partial model of a basket which contains the set of points visible from a single viewpoint. To cover the entire object, we obtain multiple scans using a turntable. These partial scans are then registered and merged into a single object (Section V).

In the *post-processing* phase, we remove parts of the model that do not belong to the object (Section VI). We also apply texture blending to smooth the texture.

The 3D models are then utilized in two independent components. In the *visualization* component, we are building a collaborative tool within the Croquet [13] environment that enables users to build and explore virtual exhibits. The collaboration software allows for geographically remote users to interact (Section VIII). In the *data analysis* component we are building tools for analyzing geometric and textural properties of individual baskets. We are also investigating applications of machine learning techniques to discover common properties of groups of baskets (Section VII).

(a) Cup (b) Hat (c) Mush Bowl

Fig. 3. Representative examples of the three types of Yurok baskets in our sample. We are able to classify baskets based on slight differences in mouth diameter and shape profile in the models.

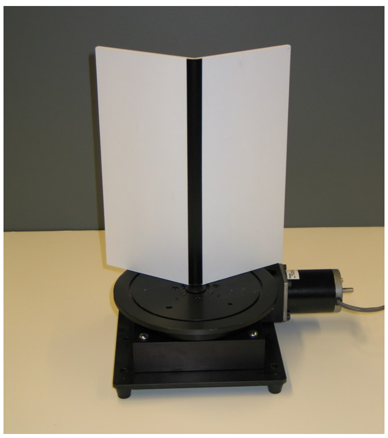

Fig. 4. Computer-controlled turntable and calibration chart used in laser scanning.

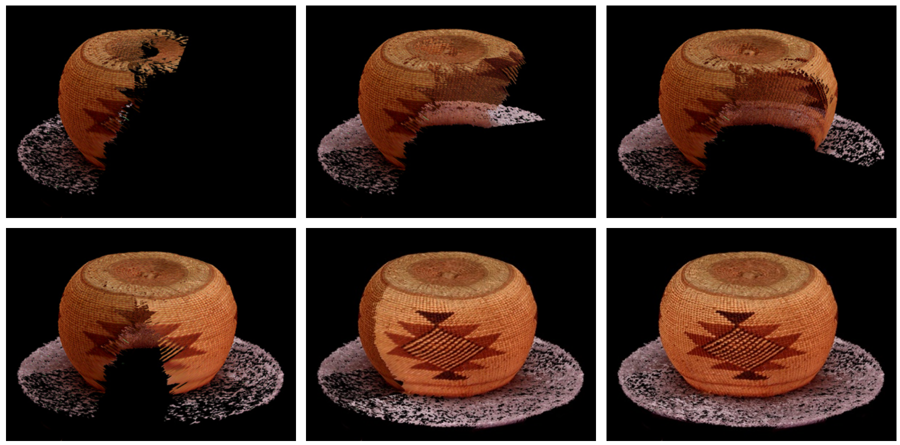

Fig. 5. Construction of a complete model of a cup basket from six separate partial model scans. The turntable is automatically rotated 60° after each scan.

IV. Data Acquisition

The primary component of our acquisition system is the Konica-Minolta VIVID 910 laser scanner. The VIVID 910 casts a laser onto a surface using a rotating mirror whose intensity is observed by a camera. The depth values are obtained by triangulation. The scan-range (i.e. depth) is between 0.6 and 2 meters but the optimal measurements are obtained for depth values around one meter. According to the manufacturer's specifications, the scanner can have a resolution up to ± 0.1mm.

In order to acquire basket models, we used a 14mm lens which allowed us to obtain depth values for all points which are visible from the camera and lie within a 148 to 618mm in Y (up) direction, 198 to 823mm in X direction. This way we could get an approximately 120° slice of a basket. To obtain the full image, the basket was placed on a computer controlled turntable (Fig. 4). We obtained six partial scans per basket, rotating the turntable 60° between scans (Fig. 5).

There are two main advantages of using a turntable. First, rotating a basket with a turntable is significantly faster than the two alternatives: rotating the basket manually and relocating the scanner. This drastically reduces scanning time. Second, the rotation axis of the turntable (with respect to the scanner's reference frame) can be easily obtained by scanning a calibration pattern (Fig. 4) which allows for simple, accurate registration of partial scans into a complete model.

To scan an initial set of baskets, we made an appointment to visit the Hearst Museum's secure off-site storage facility. Our team consisted of two freshmen and a post-doc and was supervised by the collection's manager. Since the baskets are covered with preservatives, they can not be touched by naked hands and must be placed on a layer of special foam to prevent contamination. This caused an additional difficulty in scanning. Normally, the turntable is covered with a black cloth. Due to the fact that black does not reflect laser light well, the cloth is not acquired by the scanner. However, since the protective foam is white, the scanner acquired the foam in addition to the basket (Figs. 5, 7).

For each basket we acquired eight scans. In addition to the six rotation images, we took two high resolution scans of the bottom of the basket – one from the outside and one from the inside (Fig. 1). The bottom of the basket contains valuable information for research purposes. For example, the sizes of various types of knots are important characteristics of the weaver. The weaving orientation (clockwise and counter-clockwise) varies across different tribes and basket types.

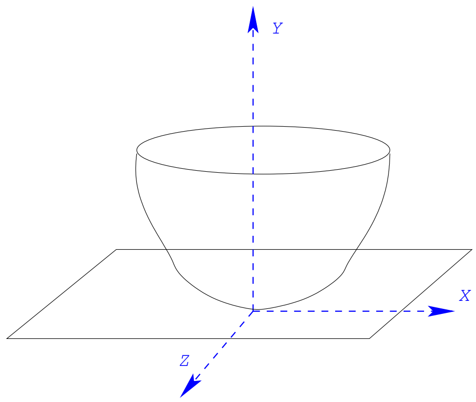

Fig. 6. Canonical orientation of a basket.

Even though taking a single scan takes only a few seconds, scanning a single basket took around 10-15 minutes including the time to position the basket (three times: one on the turn table and two for the close-ups), transferring the scans to the computer and saving the full model. Combined with the time to select the baskets, setup the equipment and adjust the lights, we were able to scan around 30 specimens (27 plus a few corrupted ones) in a single day. In selecting the baskets, we picked representative samples from a single tribe (Yurok) which included three different types of basket objects: mush-bowls, cups and hats (Fig. 3). Techniques for automatic classification of basket types are described in section VII.

V. Model Building and Registration

As described in the previous section, we acquired eight partial scans for each basket which need to be merged to form a complete model. Six of these partial scans were obtained using the turntable, each corresponding to a sixty degree rotation of the turntable.

Since we can also obtain the rotation axis of the turntable using a calibration chart, merging these six partial scans were relatively easy. In fact, we were able to use a utility program that was available as a part of Konica Minolta's utilities for VIVID 910 to merge these six partial scans.

Merging the other two scans (bottom zoom from the inside and outside) turned out to be very difficult, if not impossible. Note that the union of six rotations contain the outside zoom but the resolution is lower. At first, it may seem like there

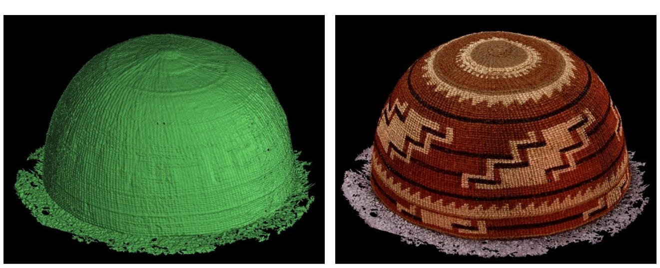

Fig. 7. Captured model of a Yurok hat basket. Note the outliers produced by the layer of protective white foam placed on the turntable prior to scanning.

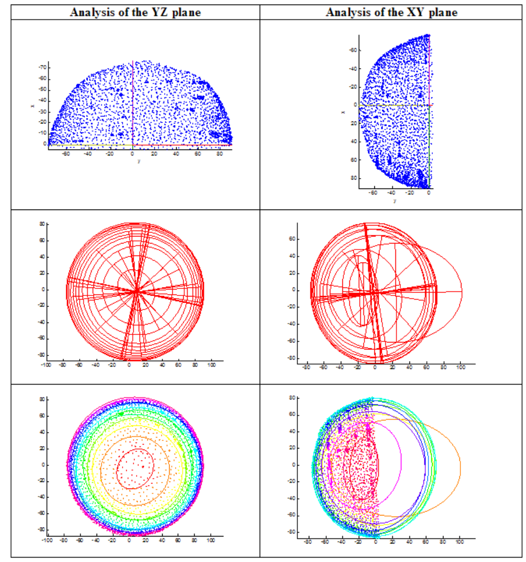

Fig. 8. Geometric analysis of a basket. Once transformed to the canonical orientation, the curvature of a basket can be obtained by taking slices along the x-y and y-z planes and fitting ellipses to the slices.

is at least a single-degree rotation ambiguity for registering the outside zoom onto the complete model. Nevertheless, we were hoping that each basket would contain enough fine details to resolve this ambiguity. Unfortunately, this was not true. Therefore at the moment, we are utilizing these two scans separately from the merged model.

VI. Postprocessing

After merging the six partial scans into a complete model, the model is postprocessed to:

- put the model in a canonical orientation, and
- clean-up data points that do not belong to the model.

To facilitate easy extraction of geometric features and comparisons between different baskets, we defined a canonical orientation for each basket (Fig. 6). In the canonical orientation, the y-axis is aligned with the rotation-of-symmetry of the basket and it increases toward the mouth of the basket. The x-z plane is perpendicular to the axis-of-symmetry and it passes through the point with lowest y-value. Ideally, the x-z plane would be parallel to the plane that contains the mouth of the basket.

As noted earlier, the baskets were put onto a white protective sheet during scanning. Most of the merged models contained (unwanted) points from this sheet which were acquired along with the basket (Fig. 7). We will refer to these unwanted points as the *residue*. The following procedure simultaneously computes the canonical orientation and cleans the residue: First, we treat the model as a point cloud and compute the three principal components of the data. One of the principal axes is a good estimation for the axis-of-symmetry (the y-axis) but it is not perfectly aligned mainly due to the residue. To find out which one, we shoot three rays each originating from the center of the data in the direction of the three principal

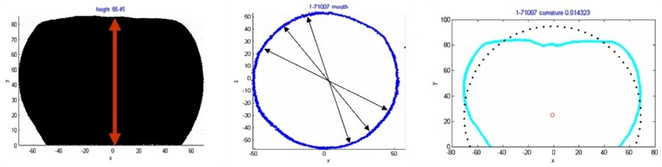

Fig. 9. Geometric properties used in clustering basket types include basket height, mouth diameter, and curvature.

axes. Two of these rays (x and z) intersect the model twice. The one that intersects the model only once is chosen as a good initial estimate of the y-axis. We choose the orientation of the y-axis so that the y values increase toward the mouth. Next we transform the coordinates of the data onto this new coordinate frame. We can now clean up the residue: we choose points with the highest 1% y-values and fit a plane to them. It turns out that all the residue points are very close to this plane and we remove them using a small distance threshold. After the residue is removed, we perform a second PCA to get the axis of rotation and compute the orientation of the y-axis.

Once we have the canonical orientation, we can easily compute many geometric properties such as dimensions, mouth diameter, and curvature. For example, the curvature can be computed by taking different x-z and y-z cross-sections of the data and fitting ellipses to the cross-sections (Fig. 8).

An additional post-processing was applied to smooth the texture. Ideally, one would use a uniform light source during scanning. Since this was not available, the texture of the merged model exhibited sharp discontinuities during the transition from one partial model to another. To reduce this unpleasant behavior, we have applied standard image smoothing techniques to the texture of the merged model. It is interesting to note that since we know the basket geometry precisely, it may be possible to use estimates of the basket albedo and the location of the light source to eliminate the light effects. We plan to investigate this technique further in the future.

VII. Data Analysis

As mentioned, our baskets are sampled from a collection containing approximately 9,000 specimens. To efficiently retrieve interesting subsets from a database of this size, such as might occur when comparing specimens or selecting objects for a virtual gallery, a flexible classification and indexing scheme is necessary. Though it is possible to index objects based on expert manual annotation of individual artifacts, this is a time-consuming process, and the relevant classification data are sometimes incomplete or unavailable. What we really need is an automated technique for indexing the objects.

The sample of Yurok artifacts we are working with represent three different functional basket types: cups, hats, and mush bowls. (Fig. 3). To the casual observer, these basket types are not always easy to discern, though trained ethnologists can discern them, as can members of the Yurok tribe. For example, cups are generally smaller than the other types, while bowls, though similar in size to hats, tend to have more rounded shape profiles and smaller mouth (rim) diameters than do hats. Symbolic pattern motifs woven into the basket also give clues as to the baskets function. We have considered the following possible avenues for automatic classification and indexing of baskets: clustering of basket types from geometric characteristics, analysis of gross pattern motifs, and fine-texture analysis using the MPEG-7 homogeneous texture descriptor [14], [15]. The first of these will now be described. The latter two are in progress and briefly described in section IX.

After data acquisition, registration, and postprocessing, each basket is represented by a tesselated model of its outer surface, along with one or more full-color texture maps. To analyze the geometric properties of our models, we extracted their mesh vertices, which typically number around 500k, and from this we compute height, mouth diameter, and curvature.

Computing basket height is a simple matter of finding the difference in y-coordinates between the highest and lowest vertices in the model, which after postprocessing can be obtained from the canonical orientation. Basket mouth diameter is computed as the mean of eight separate diameter measurements. First, the lowest 1% of the vertices (with respect to the y-axis) in the inverted model are selected as

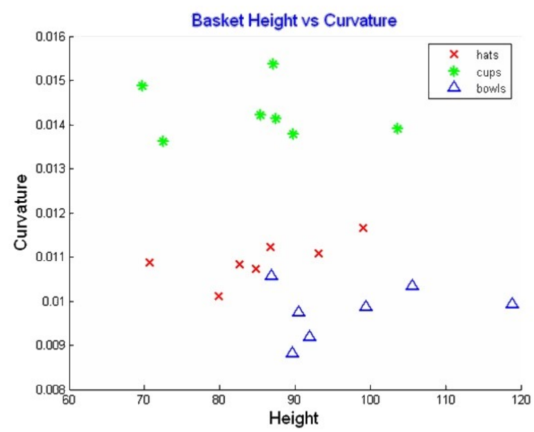

Fig. 10. Clustering based on height and curvature. Cups are easily identified, but hats and bowls exhibit similar curvature and are more difficult to classify.

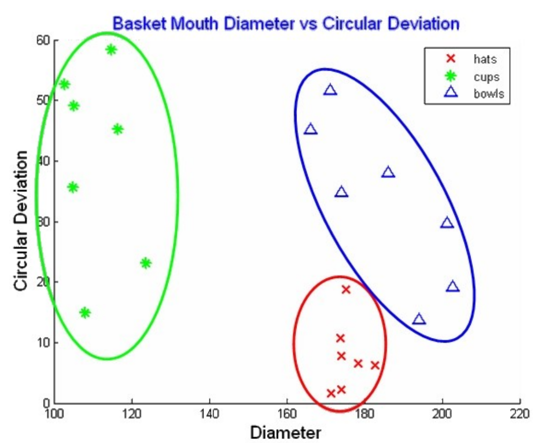

Fig. 11. A better clustering result based on mouth diameter and circular deviation.

the basket rim. When projected in the x-z plane, most basket rims appear roughly circular, though some are a bit lop-sided. From the vertices in the rim, the 1% of vertices closest to the x-axis are selected to calculate the rim's diameter along the x-axis. Approximately half of these vertices will lie to the left of the z-axis (have negative x-value) and the other half will lie to the right. To reduce the effect of noise which may be introduced into the model in the area where it rests on the turntable, diameter is calculated as the difference in x-value between vertices with maximal negative x-value and minimal positive x-value, respectively. The model is then rotated half-way around the y-axis in $\pi/8$ increments to yield eight separate diameter measurements, from which the mean mouth diameter is computed.

To compute curvature, a measure of the roundness of the baskets sides, we took slices along the x-y plane (1% of vertices closest to z-axis), and along the z-y plane (1% of vertices closest to x-axis.) In each slice, the best-fit circle in the plane is found using a nonlinear least-squares solver (we used the *lsqnonlin* function in MATLAB's Optimization Toolbox.) Basket curvature is then computed as the mean of the inverse radii of the best-fit circles. In our baskets, curvature itself was not particularly diagnostic as a clustering parameter (Fig. 10), but a related quantity, which we call circular deviation, was. Circular deviation in this case is the mean of the distances of each vertex in a slice to its best-fit circle. Our best clustering result is obtained by plotting mouth diameter vs. circular deviation (Fig. 11).

VIII. Visualization

We have developed the CITRIS Digital Gallery Builder [16], a software application designed to allow researchers in the humanities to interact with three-dimensional artifacts and related digital content inside of a collaborative virtual space. Based on HP Labs open-source Croquet environment [13], Gallery Builder is a powerful tool for presenting many kinds of media in a spatial order far beyond two dimensions, and can be used to construct virtual galleries which emulate real-life museum exhibitions. Media types supported include pictures, video, audio, 3D primitives, VRML models, and point clouds.

The task of integrating the third dimension into our mostly 2D computing environments is always a challenge. Gallery Builder does this in a rather natural way by using the metaphor of the gallery. 3D data are arranged in 3D space, and 2D data are placed on walls and other structural elements. The gallery metaphor helps on the one hand to organize the infinite 3D space, a prerequisite for orienting the user, and on the other hand to serve as the ordering principle of the presented data.

Gallery visitors find themselves in a 3D virtual space composed of various rooms populated with artifacts. Visitors are represented by avatars, with which they can navigate through, and interact with, the virtual environment. Several users may be present in the same space simultaneously, in which case they can interact with each other as well as with the gallery. Unlike objects in a real museum, virtual museum objects can be looked at from any direction and be interactively explored and examined in detail by moving or rotating them (Figure 13). Other examples of interaction include discussion, adding hyperlinks to artifacts, as well as introducing new items into the gallery and modifying the layout of the gallery, its lighting, and contents.

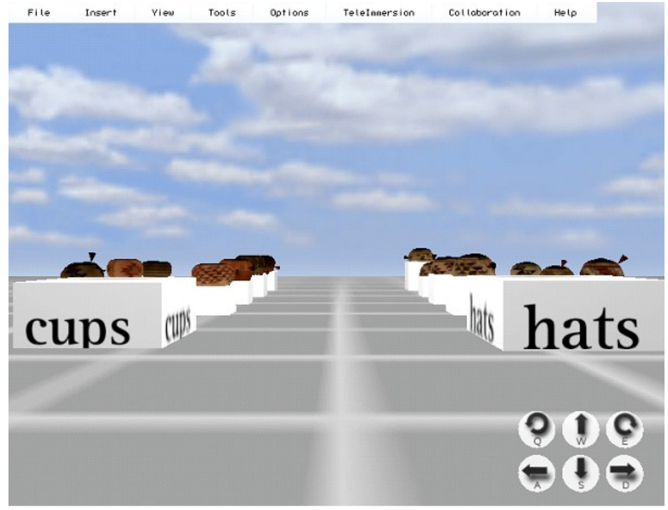

Fig. 12. A demonstration of CITRIS Gallery Builder running in the Croquet environment. This sample gallery contains 14 Yurok baskets imported as VRML models.

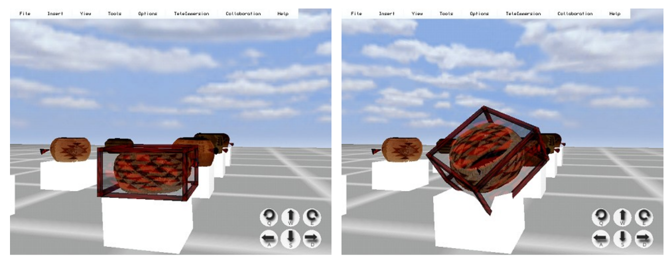

Fig. 13. A basket object is selected and manipulated inside the virtual gallery.

The system can be used in a traditional authoring mode, where one or more researchers curate the gallery, creating a space for exploration by later visitors. It can also be used as a purely collaborative 3D wiki, where everyone who visits is free to modify the space. In the second approach, curating itself becomes the learning experience. In the current version of Gallery Builder, gallery content is created by importing individual media files. Future versions of the software will include the ability to query a database for artifacts and then visualize the results.

The Croquet environment in which Gallery Builder operates is a 3D collaborative distributed computing platform incorporating the ideas of not only replication of data, but replication of computation [17]. Its creators envision massively multi-user applications able to span many machines. Though Croquet is still very much an experimental system (Gallery Builder is built on the 'Jasmine' release of Croquet) and many of its networking components are still in development, it holds much promise as a platform for building our virtual museum. For example, in Croquet terminology, a gallery is an instance of

Fig. 14. Close-up of hat basket model texture map, showing an instance of a repeating weaving pattern.

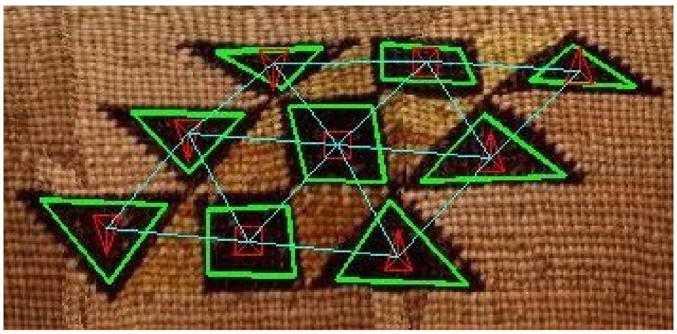

Fig. 15. The same weaving pattern instance, overlayed with detected geometric shapes (green) which have been identified and grouped into a pattern graph (nodes are red, edges are light blue.) Variations in symbolic design motifs across tribes and among weavers are of interest to anthropologists.

a *space*. 3D spacial connections, called *portals*, can be used to link spaces, even across machines. When two spaces are connected by linked portals, it is possible to view from one space into another space, much like looking through a doorway into an ajoining room. By linking individual spaces together with portals, it becomes possible to link virtual galleries together to become virtual museums.

IX. Discussion: Challenges and Ongoing Work

In this section, we present an overview of our ongoing work. At the moment, our focus is on two general problems: analyzing weaving patterns on the baskets using image processing techniques and analyzing weaving characteristics using the 3D geometry of the basket surface.

As mentioned previously, the patterned design motifs woven into the baskets typically have symbolic meaning, such as sun, snake, frog hand, bear claw, etc. An interesting feature of these patterns is the following: tradition dictates that not every pattern is appropriate for every type of basket. This feature can be used to determine the authenticity of a basket. Further, variances of these patterns among weavers and across tribes is of interest to anthropologists. Our strategy for analyzing the patterns is to identify basic geometric shapes (e.g. triangles, parallelograms) and then to group them using a template library where each template is represented by a graph whose nodes correspond to geometric primitives. There is an edge between two nodes if the corresponding shapes share a vertex or an edge. Even though we have made progress identifying basic geometric shapes (Figure 15), detecting full patterns is still in progress.

We are also exploring a method of similarity retrieval and additional clustering by extracting Gabor texture features [14] from basket images. This is accomplished by first subdividing cylindrical projections of the basket surfaces into 64 by 64 pixel tiles, and then passing each tile through a Gabor filter with parameters set to 4 scales and 6 orientations, yielding a feature vector of length 48. This technique has been shown to produce good results on satellite imagery [15]. We are currently exploring methods to extend them to our data.

A second line of research is to identify weaving characteristics at the bottom of the basket. This involves finding the location and dimensions of the central knot (shown in Figure 16), weaving direction (clockwise/counter-clockwise) and collecting statistics on the dimensions of individual, smaller knots – all of which are characteristics of the weaver. Computing these values from local geometry information turned out to be very challenging. At the moment, we are exploring global methods to collect these statistics. This, in turn, may allow us to identify baskets that are made by the same individual.

X. Conclusion

In this paper, we reported our progress in building a system for the acquisition, analysis, and visualization of a collection of Native Californian baskets from the Phoebe A. Hearst Museum of Anthropology. The focus of our project is to build tools and techniques for visualizing and studying a large number of related objects (baskets) which distinguishes our project from existing cultural heritage applications. So far, we have made progress in: (i) laser-scanning of baskets, (ii) construction and processing of 3D models, and (iii) building virtual exhibits. Our ongoing work includes developing algorithms for analyzing basket geometry and woven symbolic pattern motifs. We are also planning to increase the number of baskets in our sample. Once completed, our system will serve a number of communities, including anthropology researchers, Native American tribes, and the general public, by allowing efficient retrieval, analysis and visualization of artifact collections.

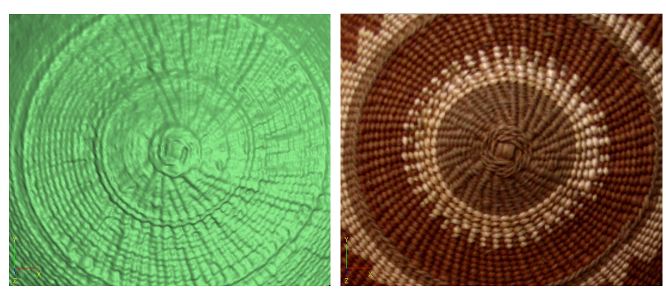

Fig. 16. Identical views of a hat basket model's bottom region showing central knot and weaving detail. Right image is texture-mapped. Computing weaving direction (clockwise/counter-clockwise) and statistics on individual smaller knots from local geometry information turned out to be very challenging. We are exploring global methods of collecting these data.

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REFERENCES

[1] J. Hunter, R. Schroeter, B. Koopman, and M. Henderson, "Using the semantic grid to build bridges between museums and indigenous communities," in *Proceedings of the GGF11-Semantic Grid Applications Workshop*, June 10, 2004, pp. 46–61. [Online]. Available: http://metadata.net/filmed/pub/GGF11%5FSemanticGrid.pdf

[2] "ARCO – augmented representation of cultural objects." [Online]. Available: http://www.arco-web.org/

[3] "3D digital preservation of cultural heritages," ikeuchi Lab: University of Tokyo. [Online]. Available: http://www.cvl.iis.u-tokyo.ac.jp/gallery_e/

[4] "Digital hammurabi," the Johns Hopkins University. [Online]. Available: http://www.jhu.edu/digitalhammurabi/

[5] The digital morphology library. The University of Texas at Austin. [Online]. Available: http://www.digimorph.org/

[6] "ViHAP3D – virtual heritage: High-quality 3D acquisition and presentation," visual Computing Lab, ISTI - CNR, Italy. [Online]. Available: http://vcg.isti.cnr.it/projects/projects.htm

[7] "3-D database of medieval france bourbonnais architecture." [Online]. Available: http://www.learn.columbia.edu/bourbonnais/

[8] "Computing and retrieving 3D archaeological structures from subsurface surveying." [Online]. Available: http://www.upenn.edu/pennnews/article.php?id=733

[9] X. Zabulis, A.Patterson, and K.Daniilidis, "Digitizing archaeological excavations from multiple views," in *Fifth International Conference on 3D Digital Imaging and Modeling (3DIM 2005)*, 2005, pp. 81–88. [Online]. Available: http://doi.ieeecomputersociety.org/10.1109/3DIM.2005.32

[10] L. M. O'Neale, *Yurok-Karok Basket Weavers*. Phoebe Apperson Hearst Museum of Anthropology, 1995.

[11] J. Rowe, A. Razdan, and A. Simon, "Acquisition, representation, query and analysis of spatial data: a demonstration 3D digital library," in *JCDL '03: Proceedings of the 3rd ACM/IEEE-CS joint conference on Digital libraries*. Washington, DC, USA: IEEE Computer Society, 2003, pp. 147–158.

[12] J. Rowe and A. Razdan, "A prototype digital library for 3D collections: Tools to capture, model, analyze, and query complex 3D data," in *Museums and the Web 2003*, D. Bearman and J. Trant, Eds. Toronto: Archives & Museum Informatics, 2003, pp. 147–158. [Online]. Available: http://www.archimuse.com/mw2003/papers/rowe/rowe.html

[13] D. A. Smith, A. Kay, A. Raab, and D. P. Reed, "Croquet – a collaboration system architecture," in *First Conference on Creating, Connecting and Collaborating through Computing (C5 '03)*, 2003, pp. 2–11. [Online]. Available: http://doi.ieeecomputersociety.org/10.1109/C5.2003.1222325

[14] P. Wu, B. S. Manjunath, S. D. Newsam, and H. D. Shin, "A texture descriptor for image retrieval and browsing," in *IEEE International Conference on Computer Vision and Pattern Recognition: Workshop on Content-Based Access of Image and Video Libraries*, June 1999, pp. 3–7.

[15] S. Newsam, J. Tesic, M. El-Saban, and B. Manjunath. MPEG-7 homogeneous texture descriptor demo. [Online]. Available: http://faculty.ucmerced.edu/snewsam/demos/demos.htm

[16] CITRIS digital gallery builder. Center for Information Technology Research in the Interest of Society. [Online]. Available: http://www.citris-uc.org/hosted/projects/ith/gallery

[17] D. A. Smith, A. Raab, D. P. Reed, and A. Kay, "Croquet: A menagerie of new user interfaces," in *Second International Conference on Creating, Connecting and Collaborating through Computing (C5 '04)*, 2004, pp. 4–11. [Online]. Available: http://doi.ieeecomputersociety.org/10.1109/C5.2004.1314362

[18] E. G. Nicoletta Di Blas and P. Paolini, "3D worlds and cultural heritage: Realism vs. virtual presence," in *Proceedings of Museums and the Web 2005*, D. Bearman and J. Trant, Eds. Toronto: Archives & Museum Informatics, Mar 2005, pp. 183–194. [Online]. Available: http://www.archimuse.com/mw2005/papers/diBlas/diBlas.html

[19] "Princeton 3D model search engine," princeton Shape Retrieval and Analysis Group. [Online]. Available: http://shape.cs.princeton.edu/search.html

[20] T. Igarashi, S. Matsuoka, and H. Tanaka, "Teddy: a sketching interface for 3D freeform design," in *SIGGRAPH '99: Proceedings of the 26th annual conference on Computer graphics and interactive techniques*. New York, NY: ACM Press/Addison-Wesley Publishing Co., 1999, pp. 409–416.