Three-Dimensional Scanning of Archeological Objects for Research, Outreach, and Specimen Archiving: Potentials and Responsibilities.

Christian Petersen, Robert Schlader, Ralph E. Chapman, Linda T. Deck, Nicholas Clement, Richard Heydt

Idaho Virtualization Laboratory
Idaho Museum of Natural History and Idaho State University
Pocatello, Id, USA
petechri@isu.edu

Abstract

Modern technology has progressed to the point where high quality three-dimensional scanning equipment is now affordable. This technology has significant applications in research, outreach, and the archiving of specimens. By scanning specimens and archiving the digital files thus generated, we can retain a great deal of information contained by those objects, thus extending our ability to study an object beyond the specimen's lifespan. Along with this technology, however, comes a series of responsibilities and concerns. The files generated by this technology can have both academic and commercial value. Prior to scanning any object, written agreements should be established between the owner of the object and the organization doing the scanning, research, and archiving. Finally, any movement or handling of museum collections should be governed by a set of Handling Protocols. Such protocols serve to maximize the information gathered from specimens while minimizing the risk of loss or damage to them.

1 Introduction

Over the last 20 years, the price of three-dimensional (3D) scanning technology has decreased to the point where it has become accessible to the academic community through a small number of laboratories widespread among universities across the world. The Idaho Virtualization Laboratory (IVL http://ivl.imnh.isu.edu/index.htm) at Idaho State University is one such entity with the means to capture 3D data using either in-house laser scanners or data from CT or related systems. The IVL was created with one basic goal: to apply this technology to natural history objects in order to carry out research, facilitate education, and archive these fragile objects. Because of the intellectual value of these specimens, and the fact that it only takes one mistake to irreparably damage them, one of the first basic steps taken by IVL staff was to create a set of Handling Protocols—designed to maximize the information gathered (i.e., the amount per specimen and the throughput of specimens) while minimizing the risks to the objects being scanned. The IVL is especially concerned with ownership of the information gathered and that the rights of all units participating in the virtualization process are recognized. In a content-hungry world, this information can have very real monetary value in addition to the intellectual potentials. This value should be exploited to provide funding to support both the object owner and the laboratories performing the virtualization; the owner of the scanned object has a significant investment in the acquisition, upkeep, and exhibition of the objects, and virtualizing (creating virtual, or digital, models) specimens takes long hours of work and expensive equipment. Explicit permission and contractual agreements must be obtained before scanning can begin.

2 Why Bother Virtualizing a Specimen?

Virtualizing artifacts has several major advantages over having the physical object alone. This is found in all areas of use of these specimens—measurement and other research aspects, all areas of outreach, and in the long-term conservation of the information provided by the specimens.

Measuring these objects, which are often quite complex three-dimensionally, can be done more accurately in a virtual environment than with using the real specimens. Many measurements that might be useful are either impossible to take with real specimens or require very specialized and odd equipment to do so—witnessed by the many odd medieval-looking devices that have been developed by physical anthropologists through the years to measure human bones. In the virtual environment, taking these measurements can be a piece of cake. Further, the process of measurement can be destructive to specimens (e.g., caliper grooves can develop very quickly) and the act of measurement also increases the chance of accidental damage (Chapman et al. 1999, 2002, 2003).

Once an object has been virtualized, it becomes very useful for outreach. Even though the files created by the various scanning methods are often quite large, they are still very easy to transmit over e-mail at whatever resolution matches the need. The file can also be "printed out" with a rapid prototyping system and at any scale that will be useful; very large specimens can be miniaturized and very small ones can be enlarged. These methods allow researchers to share virtual objects with colleagues around the world. The digital nature of these files also makes them relatively easy to include in educational material through a variety of media devices, printed or online. The IVL is also currently working on perfecting the texture mapping of digital photographs onto the surface of our digital specimens. This adds another level of information to the object, making the result more archival and taking the final product from a nice looking point-cloud to looking exactly like the original object. While nothing will ever replace physically holding an object while learning about it, the virtual object makes education and research available to those who cannot actually travel to the institution where the object is reposited.

As useful as virtual objects can be to research and outreach, the archiving of these files is also useful in the conservation of our valuable and temporary artifacts. Specimens get handled in excavation, curation, research, and teaching. Each time an artifact leaves the relative safety of the cabinet there is the risk it will be damaged or lost. The digital file is not a complete replacement for the actual object but, compared with an original that is badly damaged or deteriorated, it is a tremendous insurance policy on most of the information relevant to that specimen. It is a reasonable surrogate for the object in many research and educational situations and if the object is stolen, damaged or lost, the file will still allow much research to be done (Andersen et al. 1999; Chapman et al 2004, 1999; Deck et al. 2004).

3 Methods and Technology for Specimen Virtualization

The IVL has developed a series of steps that we feel captures as much information from an object as possible while exposing it to the least amount of risk. The steps in the process remain the same whether we are scanning a series of lanceolate projectile points or the skeletal remains of *Bison latifrons*.

The virtualization process starts with a physical inventory. The presence of all components that are part of a specimen is noted as well as any damage these items may have received, any anomalies, and any other special details of interest. During or immediately after the inventory each object is digitally photographed. Generally, six reference photographs are taken of each object, though more or less can be taken depending on the complexity and geometry of the object being photographed. The photographs are for general reference and are included in the final set of files generated for each object or set of objects. These files—photographs and scanned images—become part of the permanent collections data for that specimen (Chapman et al. 2003).

While the inventory and photographs are being generated, the most appropriate scanning methods are discussed. There are a number of different scanning technologies available and each type has a different utility that might be relevant and useful (or not) for different objects. The needs of the researcher for whom we are scanning the object are, of course, taken into consideration—although this is done to make sure extra steps are not necessary. If time and effort is taken to scan a specimen in the first place, then a basic set of scanned data should always be captured. The physical nature of the objects is taken into account before a digitizing process is chosen; the goal is to maximize the amount of information gathered from an object while minimizing the impact on the object (Andersen et al. 2003).

Once the object has been inventoried and photographed, the scanning process can begin. The details depend on which technology is being used. However, the general process includes digitizing the object, making sure the files are edited and cleaned up, and that all the necessary information is present. Depending on the technology used, as well as the complexity of the object being scanned, this step could take a few hours or a few days. The goal is to end up with a set of files that is as complete and as accurate as possible.

After the scans are complete, a texture map can be applied to the object (Figure 1). In essence, this involves adding surfaces to the object as we see it using detailed, high-resolution imaging. This process starts with the reference photographs but will typically include additional photos as they become necessary to make the final product look just right. Not all scanned objects will be texture mapped as it is a time consuming process.

After all of the work has been done to create the final scanned image and all associated files, the information is moved to a database held on a large capacity storage unit. The information in the database includes all available for the object as well as all the images generated. At the IVL we are currently using a one terabyte storage device, although it is becoming obvious that in order to digitize even a fraction of the collections of a small museum, much more than a terabyte will be needed. Depending on the agreement worked out with the agency that has legal custody of the artifacts, several more steps are taken. The agency that has legal ownership of the object(s) will always get a copy of the information on compact disk, DVD or whatever media type is requested. Also, if requested, the IVL is currently willing to archive data onsite as well as having a back-up copy at another secure location – the IVL has backups on CPU-based storage devices as well as on DVD's in multiple locations.

As noted earlier, archaeological objects can vary greatly in shape and any system for capturing these shapes should allow for this variation to be captured and studied. Fortunately, there are a number of ways to virtualize a solid object like a projectile point. The specific technology used really depends on what the specific research, education, or archival goals happen to be.

One of the simpler approaches to virtualization is the Point Digitizer—typically based on some sort of articulating arm system (Figure 2). When active, the program that controls the device keeps constant track of the point of the stylus on the arm in 3D space. When asked, using a button or foot-pad, the current position of the stylus is put into an active program such as a spreadsheet. As points are recorded these can be visualized in real time by some software packages. Taking coordinate data rather than using calipers or tape measures is the most efficient way to do basic measurements on an object. The distance between any two points can be calculated using a three-dimensional Euclidean distance (= Pythagorean distance in three dimensions) and angles can be calculated as well. In this way, objects can be measured much more quickly and for many more dimensions than with just calipers or other devices. The system at the IVL—a Microscribe—has a resolution of about 0.3 mm.

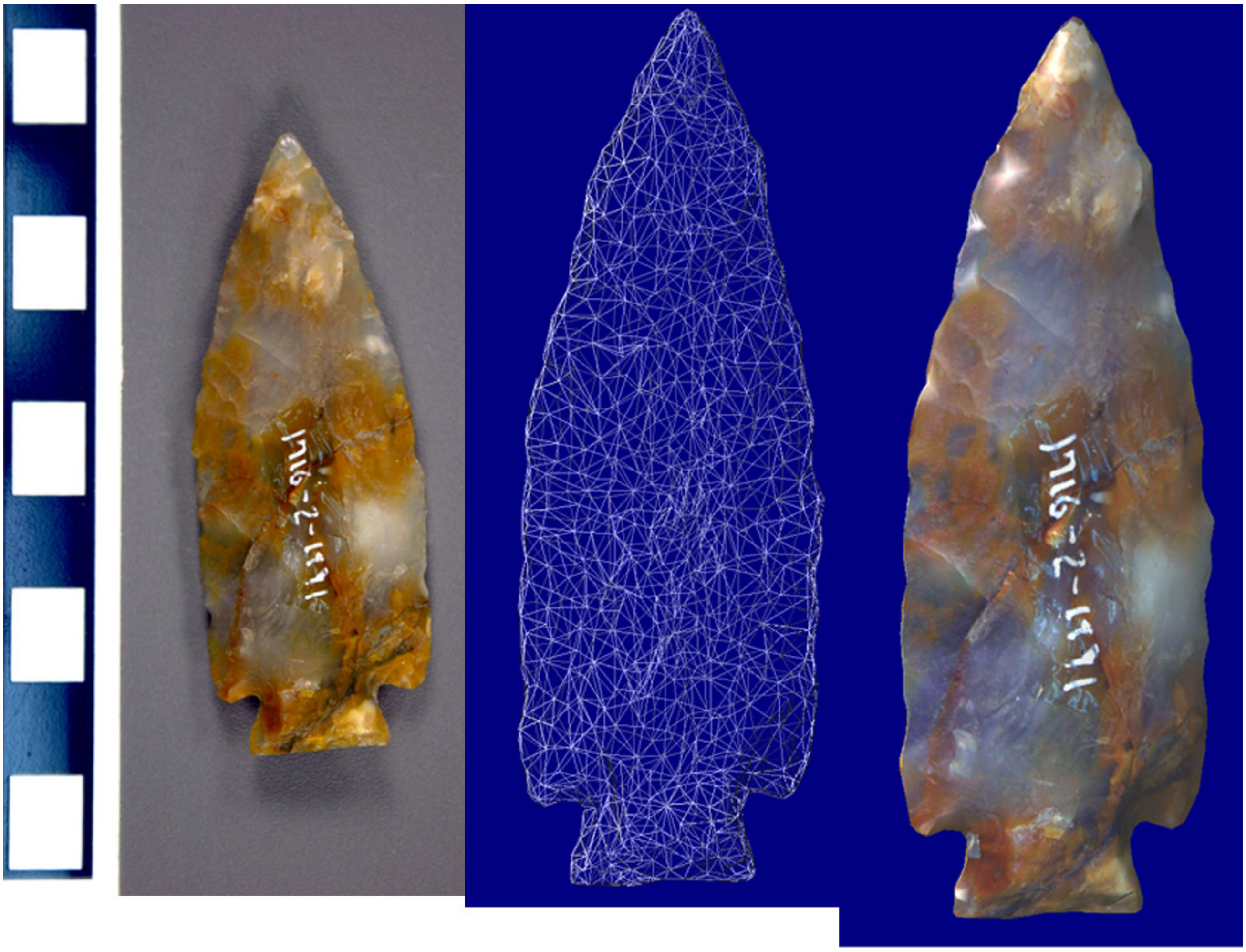

Figure 1. Texture map of a projectile point. From left to right: reference photo, wire mesh, and textured mesh.

Surface scanners, on the other hand, use radiant energy to measure the distance between the emitter and the object scanned by measuring the time it takes for the "light" to leave the emitter, hit the object and bounce back to the collector (Figures 3 & 4). While the process of scanning the object and editing and merging the files created takes more time than with other methods, this technology gathers a great deal of information about the objects, allowing for a huge variety of applications after-the-fact. Such scanners have sub-millimeter accuracy and can create a point cloud containing hundreds of thousands or even millions of points for a single small- to medium-sized object. Like the point digitizer, these various points can be used to create very complex sets of measurements. However, the surface scanner can create a file with a thousand-fold increase in the information gathered for a specimen. When the Smithsonian's National Museum of Natural History scanned a six-foot long *Triceratops* skull, the final model had in excess of twenty million data points in the point cloud (Chapman et al., 2003).

A Computed Tomography (CT) device uses a series of X-rays to create a slice through a specimen. These very thin slices are combined into a 3D representation of the subject being scanned—like putting together a series of irregularly-shaped poker chips to form the shape of the object being studied. This 3D file not only captures the surface detail of the specimen, like the surface scanners, but the internal structure can be captured as well (with some exceptions, depending on the material). This provides a much more complete virtual copy of the item than by just capturing the surface alone, but the process is almost always a lot more expensive to do. Large CT scanners, like those typically used in medical applications, have an accuracy approaching, but not equal to, that of a surface scanner. However, the micro-CT scanner, while only able to handle objects little larger than a Cottonwood Triangular Projectile Point, can have an accuracy to below ten microns. While this level of detail exceeds the surface scanners, accessing time on a CT scanner can be very expensive. Due to the cost of this kind of equipment, the surface scanner is more than adequate for most scanning needs for archeological material. CT systems are a tremendous asset to this type of work, however.

4 Archiving the Information Gathered

When archiving digital information there are two important issues to keep in mind. First, the files created by these digitizing methods can be very large. The average size of a file for a single projectile point digitized with a surface scanner is around 25 megabytes. Files as large as 50 megabytes are easily obtained for projectile points with complex shapes.

Figure 2. Immersion Microscribe Point Digitizer.

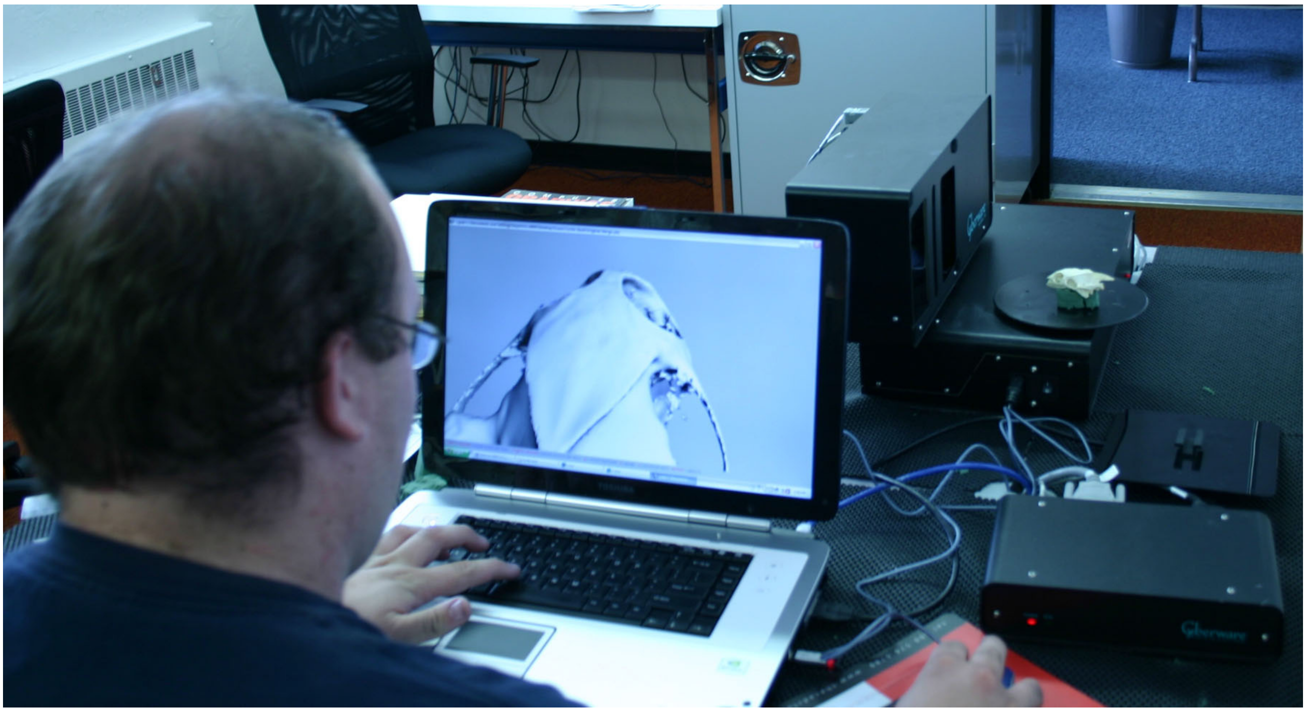

Figure 3. Cyberware Desktop 3D Scanner (Model 15).

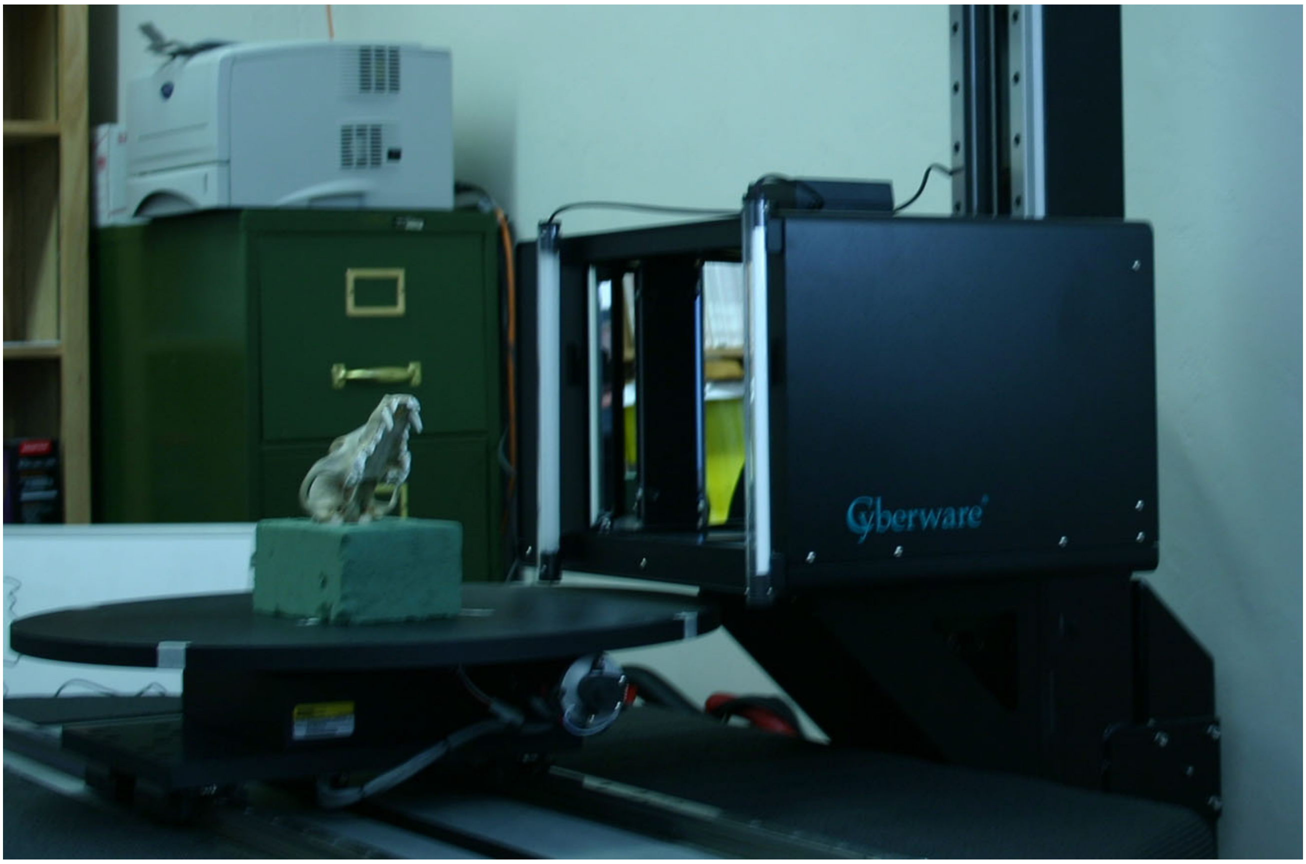

Figure 4. Cyberware Model Shop Color 3D Scanner.

Since many collections run into the thousands of projectile points—or other archeological specimens—having sufficient storage space for these files can become a problem very quickly. Deciding which items are to be digitized and which ones will not is always a first step; usually not every item in every collection needs to be digitized. With the price of digital storage going down all the time, however, storage devices with capacities larger than a terabyte are very affordable and will be ultimately necessary. Also, as with any other valuable digital information, back-up copies are always required.

While storage space is a vital problem, file security is just as important an issue. Many collections are not owned by the museum or university that houses them. The agency that owns the projectile point also will have legal interest in, if not actual ownership of, the digital files. Just like the physical objects in the collection, the files generated from these objects must also be very carefully protected. Digital files are uniquely vulnerable to theft in our increasingly networked world. This uniqueness comes from the fact that digital assets (text files, images, 3D files) are not physical, and can be stolen without loss of the original and this can easily go undetected. The object in question (the digital file) still remains in the owner's possession, while uncontrolled copies can be distributed, prototyped, and otherwise utilized without reference to and/or compensation to the original owner. These files, with a minimum of work can be inputted into a rapid prototyping machine to create what is essentially a cast of the original object. The file can be used over and over again, the only limit being the hardware available and usable materials for the prototype. This type of theft is very difficult to prove, making the various inventories, digital photos and solid file security particularly important. It is especially important to have an explicit agreement with all users of generated files as to what they can and cannot do with the data and, especially, the files. Otherwise, people who borrow a file for research or other use might decide to prototype a copy for themselves. This should only be done with explicit permission as marketing copies of artifacts is a major potential funding source.

5 Legalities

With the ability to rapidly scan artifacts and share the information, we can greatly facilitate educational and research opportunities. This ability allows people from around the world access to artifact collections well out of their reach prior to the development of this technology. However, there are important legal questions that must be addressed. This technology has developed more rapidly than the laws have been able to follow. While the ownership of the actual object is not usually in question, the ownership of the scanned, edited and archived files can be a more complicated question. In academia, you often find the idea that pure research shouldn't be fettered with base, monetary concerns. "Information," it has been said, "should be free to all." However noble the initial sentiment may seem, free information does not support research and it certainly does not buy supplies and equipment for the classroom or pay for the housing of the original specimen. Another common idea is that in creating and editing these files, enough alteration has been introduced to render the file a unique creation of the person who scanned the object, thus transferring rights to that file to the person who made it.

While the answer to the second point is far more ambiguous than the first, we at the IVL feel that the file is part of the object, and that the owner of the scanned object retains primary control over all the files generated from that object. In the same way that a photograph of a painting cannot be sold without the express permission of the artist who created the painting, or the owner of the copyright if the artist has transferred the rights, the files should be under the control of the owner of the originating object or their agent. We are also working with legal counsel to draft the documentation necessary to avoid any problematic legal entanglements.

However, the people who scan and edit files also invest considerable time and effort into the process and also need to be compensated for this effort. Everyone involved in a project that generates funds should receive compensation for their work and this can only happen with explicit agreements. We would strongly suggest that the entities involved in this process be flexible and acknowledge the contributions made by all involved and that any funds generated be shared amongst these entities in a fair way to promote further work.

6 Digitizing Protocols

When starting a complex act such as the virtualization of specimens, many of which are very fragile and/or one-of-a-kind, it is important to develop a series of protocols that cover the whole process. Protocols serve many purposes. First, they provide a series of established rules that grease the wheels—they optimize the throughput of material while making sure the specimens are protected as much as possible. If specimens cannot be digitized relatively rapidly, not many will be taken through the process and this will greatly restrict those available for archiving, research, and outreach. As archiving is one of the major reasons for going through these steps, any process that does not minimize damage to specimens is self-defeating. Many of the protocols are quite obvious and it may seem wasteful to state them (e.g., do no eat or drink near the specimens) but stating the obvious can sometimes avoid stupid mistakes, and all humans seem to have the ability to make stupid mistakes. Protocols form a strong basis for optimal organization—making sure all the steps are taken by everyone going through them. Laboratories such as the IVL always have new people coming in and stated protocols help in the training process. The protocols used in the IVL were mostly established right from the beginning during the winter of 2005 by Petersen and Chapman, and have been modified and perfected since. The basic rules of use from the collections program at the Idaho Museum of Natural History were added whenever an established protocol did not already cover a rule. This mostly included the more obvious rules. Basically, protocols err on the side of protection for the specimens/artifacts, and this is appropriate given the importance of the objects studied in natural history (Chapman et al. 2005).

The following are examples from our protocols. To view the protocols in their entirety, you can find them at the following url: http://ivl.imnh.isu.edu/pdf/CurrentHandlingProtocols.pdf.

1. Determine the ownership of the specimen and arrange with the owner to do the scanning, as well as make any necessary agreements on file usage and storage. Consider the potential for generating funds from the process right away and include this possibility in the written agreement.
2. Examine the specimen to assess the quality of the material and ascertain if any material may require extra care, even beyond the procedures outlined herein. If extra care is required, the IVL will coordinate with the owner of the specimen in order to add the required precautions to the regular handling protocols. Good communications among the entities involved is essential.
3. Determine the basic purpose of the scanning. This should be obvious but this might save a lot of time by removing specimens that do not need to be scanned.
4. Photograph the specimen to be scanned in multiple views to record data on the original external morphology of each element, as well as provide supporting data for working on scanned versions.
5. Transfer all appropriate specimen data to the specimen database to be linked with the photographic and scanned image data. Information pertaining to specific locality data, or any other information determined to be inappropriate or not for general distribution by the curator in charge or the Collections Manager, will not be included.
6. Determine the scanning method(s) to be used.
7. Scanning procedures are to follow the basic specimen handling protocols of the IMNH, or the parent institution owning the specimen.
8. The moving and transport of a specimen is an especially critical time and special considerations need to be taken to ensure that damage or theft does not occur during this process.
9. Specimen security is of extreme importance and must be considered during all actions with specimens. This includes wearing the appropriate protective gear, especially gloves, during handling and not eating, drinking, smoking, rough-housing, or doing any other problematic activities near the object. We call this the avoidance of stupidity protocol. Also, keep unnecessary people away during the scanning process.
10. Once a specimen is imaged and scanned, the resulting files are valuable and must be treated as such. These should be moved onto an archive server as well as having a backup copy on another CPU. A backup copy on DVD media is to be made and kept with the library of DVD's maintained by the laboratory. A second DVD copy is to be made and deposited at an external back-up location. Finally, copies will be sent back with the borrowed objects to the owning institution.

11. Access to data files is only available to the laboratory personnel and the relevant collections/administrative staff of the institution that owns the specimen. Other access is only under permission of those entities that control file access as negotiated in item #1 above.
12. In the event that a specimen is damaged, destroyed, lost, or stolen, the laboratory will work with the agency or individual in ownership to make sure the object is repaired, retrieved, or, if possible, replaced.

7 Conclusions

Three-dimensional virtualization methods were not originally invented for archiving, research, and outreach on natural history objects. However, the technology has a great deal to offer in these areas. Scanning an object, such as a projectile point, a fossilized long bone, or a ceramic vessel allows the digital likeness to be used in research, including allowing very complex sets of measurements to be taken. This can include measurements that are normally impossible to take with just the physical object. This "virtual handling" also prevents the inevitable damage that repeated handling and measuring tends to cause, as well as creating a virtual copy that will remain when access to the object is no longer possible due to damage, theft, or loss. The many catastrophic events of the past few years has reminded us of the dangers that are always possible to specimens and this technology is a major resource for making sure we always have most of the information contained by these objects (Deck et al. 2004).

There are a number of challenges inherent in this kind of technology, however. Because of the various digitizing methods and technologies available, the scanning needs of the specific researcher coupled with the requirements of the item to be scanned must be addressed before the work can begin. The storage and security of the resulting files must also be addressed. These files can be very large all by themselves, without even including the digital photographs, texture maps, inventories, and photo logs that also are usually generated. A large capacity digital storage device is highly recommended and essential. Security is also a primary concern because the nature of these files allows them to be stolen without the loss of the original file—so the act may not even be noticed by the owner. As many of the objects are owned by state and government agencies, poor security can lead to the loss of access to these collections or worse. Finally, a legal framework for dealing with digital ownership issues and intellectual property rights is still being created in the United States. The technology of virtualization has outpaced the creation of laws to deal with the process. The Idaho Virtualization Laboratory holds the position that all digital images of an object are part of that object and thus controlled by the owners of that object; any research, education, or archiving done by the IVL is with express permission of the owners. Toward these ends the IVL has created a set of Handling Protocols designed to maximize information output while minimizing handling and the risk associated with research. These protocols are also a valuable means of training people new to the lab as well as preventing the "stupid mistakes" that we all make in our daily lives

Acknowledgements

We would like to thank Dr. Robert Wharton, the Vice President for Academic Affairs, Idaho State University (ISU), and Dr. Lawrence Ford, Interim Director of the Office of Research (ISU) for administrative help and support. Funding for this work comes from the Department of Education and the Institute for Museum and Library Services to the Idaho Virtualization Laboratory. We would like especially to thank Art Andersen of Virtual Surfaces, Inc. for a long history of discussions related to these issues.

References Cited

Andersen, A. and Chapman, R. E. 1999. Conserving the data in natural history collections: approaches for automatic scanning and digitizing. In**,** *Program and Abstracts, Annual Meeting of the Society for the Preservation of Natural History Collections*, pg. 19. Washington, D.C.: Society for the Preservation of Natural History Collections.

Andersen, A., Chapman R. E., and Wilcox, B. 2003. Three-dimensional techniques for capturing and building virtual models of complex objects for use in scientific and industrial applications, data archiving, and the entertainment industry. In, *Stereoscopic Displays and Virtual Reality Systems X. Proceedings of SPIE – IS&T Electronic Imaging, SPIE*. Vol. 5006. A. J. Woods, M. T. Bolas, J. O. Merritt, and S. A. Benton, eds., pp. 461- 468. International Society for Optical Engineering.

Chapman, R. E. and Andersen, A. 1999. Conserving the data in natural history collections: using technology to minimize wear and damage on specimens during research. In, *Program and Abstracts, Annual Meeting of the Society for the Preservation of Natural History Collections, (Washington, D.C.)***.** Pg. 24. Society for the Preservation of Natural History Collections.

Chapman, R. E., Matthews, N. A., Schweitzer M. H., and Horner, C. C. 2002. Applying 21st century technology to very old animals. In, *Dinosaurs: The Science Behind the Stories.* J. G. Scotchmoor, D.A. Springer, B.H. Breithaupt and T. Fiorillo, eds., pp. 137-144. Society of Vertebrate Paleontology, The Paleontological Society. Alexandria, VA: American Geological Institute.

Chapman, R. E. 2003. Digital measurement and capture of images. In*, The Guild Handbook of Scientific Illustration, Second Edition.* E.R.S. Hodges, ed., pp. 40-43. New York: John Wiley & Sons, Inc.

Chapman, R. E., Andersen, A., and Deck, L. T. 2004. Virtualization of fossils and artifacts for conservation and research. *Journal of the Idaho Academy of Sciences* 39(2)/40(1):11.

Chapman, R. E., Andersen, A., and Wilcox, B. 2003. Studying extinct animals using three-dimensional visualization, scanning and prototyping. In, *Stereoscopic Displays and Virtual Reality Systems X. Proceedings of SPIE – IS&T Electronic Imaging, SPIE*. Vol. 5006. A. J. Woods, M. T. Bolas, J. O. Merritt, and S. A. Benton, eds. pp. 469-477. International Society for Optical Engineering.

Chapman, R. E., Deck, L. T., Andersen, A., Petersen, C., and Schlader, R. 2005. Protocols for the three-dimensional digitizing of specimens for research, outreach, and specimen archiving. *Journal of Vertebrate Paleontology* 25(3) Supplement: 43A.

Deck, L. T., Chapman, R. E. and Andersen, A. 2004. Conservation of vertebrate fossils and collections data using virtualization. *Journal of Vertebrate Paleontology* 24(3) Supplement: 51A.