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The Digital Darwins Project: 3-D Resources for Interactive Natural Science via the Internet

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Abstract

The Digital Darwins Web site is a pilot project to demonstrate: 1) the application of 3-D modeling and visualization to the study of museum objects, and 2) the viability of the Internet as a delivery medium for virtual museum material. Its concept envisions the electronic delivery of museum objects to K-12 classrooms around the country and the provision of hardware and software tools to those classrooms, to enable students to create their own digital models of specimens for comparison and interaction with the museum material. Thus, students may truly become scientists, and classrooms may become museums. The Digital Darwins project is an interdisciplinary effort conducted jointly by the BioVisualization of the Smithsonian Institution; the Office of Imaging and Photographic Services, National Museum of Natural History; and Mississippi State University. Charles Calvo, acting as Director of the S/ARC Digital Research and Imaging Lab (DRIL) supervised the Web site's creation (by two undergraduate students); its debut was scheduled to coincide with the Smithsonian's 150th anniversary. The site is the world's first three-dimensional Natural History Web site. The work represents a significant advance in the application of three-dimensional modeling and visualization to morphology and systematic biology, especially in areas such as feature identification, measurement and comparative study. The potential to create exciting, object based delivery of museum material to K-12 science classes via the Internet is demonstrated.

Introduction

The Digital Darwins project began last winter in a laboratory at the National Zoological Park in Washington, D.C. There, Dr. Alfie Rosenberger showed me his work done with a Laser Design scanner, fondly referred to as Huxley. Dr. Rosenberger, a leading expert on New World monkeys, was using Huxley to scan specimens ranging from individual teeth, which were a few cubic millimeters in volume, to entire primate skulls. Then, with the aid of a Silicon Graphics Workstation, Dr. Rosenberger was creating extraordinarily accurate 3-D models. On screen he was able to rotate the models any way he desired; take measurements no one had taken previously; cut sections that would have destroyed the original specimen; and enlarge tiny, all but invisible, details. Such capabilities were transforming his work in morphology and producing new insights almost daily. Dr. Rosenberger and I had been brought together by Cissy Anklam, Director of the Natural Partners Initiative of the Smithsonian Institution's National Museum of Natural History, to explore ways in which visualization technologies could aid the Initiative in its mission to use telecommunications technologies to make the collections of the Institution available to schools and classrooms around the country. Dr. Rosenberger and I talked about the potential of these digital specimens for both research and education as they were made available via the Internet. By the end of the afternoon, the Digital Darwins concept had emerged.

Imagine, we asked ourselves: A child in the seventh grade in Tishomingo County, Mississippi finds a small animal skull in her school yard. What is it? The encyclopedia requires that she perform a preliminary identification in order to read about it. Where can she take it to find out? The local Natural History Museum? The nearest one is hundreds of miles away. The scientists at the university? They would love to help but simply don't have the time to answer every question from every young person (and what common "skull language" would they share in order to converse anyway?). She takes it to her teacher, who thinks it is a rodent skull but is not sure. So teacher and student take it into their science classroom, use a small probe digitizer and digital camera to trace and photograph the surface of the skull, creating their own 3-D model on the classroom's desktop computer. Then they use the same computer to access the Smithsonian's Web site where they navigate to Digital Darwins. A few mouse clicks get them to a section on mammals, where they find a bat skull similar to their specimen. With a few more mouse clicks, they superimpose their model on the Smithsonian's and identify some important anomalies. They e-mail the Digital Darwins Webmaster and attach a file representing their model. A few days later, they get an e-mail back, this time from a mammology curator, saying that they appear to have found a new species of bat. Can they send the entire skull to the museum for a taxonomic study?

Our next stop was the Office of Imaging and Photographic Services at the National Museum of National History. There, Carl Hansen, Branch Chief, was experimenting with digital photography and Web-based research archives, and was anxious to apply QuickTime™ VR technology to his work. Carl had photographed a cast of an Australopithecus skull and asked if we could create a QTVR movie. With this work, we understood that 3-D modeling, together with QTVR and similar digital imaging, represented a powerful medium for research and education.

Digital Darwins is a collaborative effort to develop an artifact-based learning and knowledge exchange environment which may be accessed and navigated electronically. It is a set of Web resources built around three-dimensional computer representations of museum artifacts relating to natural history, specifically to the origins of humanity and human culture. The project's principal investigators are: Dr. Alfie Rosenberger, Director of the BioVisualization Lab at the Smithsonian Institution; Carl Hansen, Branch Chief, Office of Imaging and Photographic Services, National Museum of Natural History; and Charles Calvo, Director of Research, School of Architecture, Mississippi State University. Together, this collaboration represents expertise in Anthropology, archival photography and digital documentation, and three-dimensional computer visualization. The Digital Darwins Web site <digitaldarwins.sarc.msstate.edu> was a pilot project which debuted to coincide with the Smithsonian's 150th anniversary in August 1996. The Web site demonstrates: 1) the application of 3-D modeling and visualization to the study of museum objects; and 2) the viability of the Internet as a delivery medium for virtual museum material.

Digital Darwins Goals

The appeal and potential impact of three-dimensional libraries is represented by a simple analogy: the museum. It is often difficult to engage students in the study of history or archaeology when material is presented in the abstract as text, dates, or unknown, unseen locations. However, the museum, which presents the same subject matter, remains a popular and powerful informal education resource. Students (and parents) are engaged by the ability to view actual objects presented in a context which provides connections to other objects, images, and supporting material. As these same museums provide opportunities for visitors to interact directly with material, they expand the capacity to learn through object-based experiences. Three-dimensional computer models of museum artifacts, delivered with tools which allow for their manipulation and comparison, have that same power, and are truly capable of turning the classroom experience into a museum experience. Through creating such a classroom experience, the Digital Darwins project and its spin-offs seek to:

- apply new understandings about the potential of electronic archives of museum artifacts, and especially 3-D artifacts, to engage students in a quest for knowledge;
- use technology as a means of opening doors to knowledge by inspiring students to ask questions, make comparisons and connections;
- develop the Internet as a resource for the exploration of natural science, including archaeological, historical and cultural material;
- create an environment where students and teachers can contribute to the Internet resources available and interact with the researchers and scientists generating the material; and
- provide a means by which students and teachers may communicate with their counterparts in other parts of their region, country and the world regarding the material they are exploring and generating.

The overall goal of Digital Darwins is to leverage visualization technology together with the Internet to increase interest in and learning of science, technology, and natural history among students, in both formal and informal learning environments. Digital Darwins is accomplishing this goal through the creation of a science, technology and natural history education environment that is:

- graphically-based: able to engage students immediately without language hurdles;
- asynchronous: allowing the student to proceed through material at his/her own pace;
- project and discovery oriented: providing the means for students to make their own connections and develop their own insights;
- collaborative: enabling students to communicate their finds with others and to share in common discovery based activities, and
- open-ended: able to be continuously expanded and updated, both by the project developers and by the students themselves.

Skulls, bones, and other remains; archaeological material like pottery, arrowheads, and jewelry; historical material like patent models, cultural artifacts or icons; and ultimately archival material like drawings of unbuilt or ruined engineering works, all serve as resources from which visualizations are created and for which background information is being prepared. Thus a student will be able, for example, to:

- view a QTVR movie of Martha, the last American passenger pigeon, which may be rotated so she may be viewed from any position, or enlarged to show the feathers in more detail, and learn about her life and death, the extinction of passenger pigeons, and the problems of species loss worldwide;
- view a simulation of the process of flint knapping to produce stone tools recreated with actual flint nodules, each stage of which may be viewed from any position around the nodule, and learn about the people, on this continent and others, who used such tools, what they hunted, how they lived and died;

- view a wolf head, which may be rotated or enlarged, and from which the fur can dissolve away to reveal the musculature and finally the skull; compare the wolf skull with a dog's or fox's, and learn about the reintroduction of Canadian wolves into formerly native habitats, and the accompanying debate about species affiliation;

- view and interact with a reverse engineered model of the original Morse telegraph, and learn about other forms of long distance communication which preceded the Internet, like the semaphore towers of France, or hear a message transmitted in Morse code;

- see and move through a bridge design by a 19th century railway engineer and learn about the role of the railroads in the opening of the American West; and

- draw such connections as how the Morse telegraph aided the rail-based expansion, the impact of that expansion on Native American populations, the results of settlement and ranching on local wolf population, and ultimately on the extinction of such species as the passenger pigeon;

and in each case these students may communicate with their peers around the country about their common discoveries through e-mail, or through the construction of their own Web sites describing their own local correlates to what they have seen and learned.

Digital Darwins Technology

Current technology for three-dimensional computer representation provides a powerful tool for researchers concerned with the specimens of natural science and history, and provides an equally powerful means to engage students in the study of human history, culture and diversity. The development of three-dimensional libraries of the artifacts of natural history and human culture and the development of software tools to compare and manipulate those artifacts will provide researchers and students with opportunities for knowledge development and exchange not heretofore possible. Because of their tangibility, and because of the potential for students to experience manipulating the simulated object directly, these representations offer students the opportunity to engage in a hands-on study of the processes and products of natural science, barely one step removed from fieldwork itself. In the study of the natural history, there can be little doubt that a continuous, intuitive, multi-sensory, interactive experience is more appropriate and empowering than the abstraction of information and rote memorization.

The world of three-dimensional computer imagery is no longer limited to the movie screen or to high-performance workstations. Effective development of three-dimensional models and animations is possible on desktop computers through such technologies as VRML (Virtual Reality Markup Language), QuickDraw3D, and QuickTime™ VR. Similarly, networked communication is no longer limited to universities and research institutions. The Internet has become a popular and effective means of transmitting text, graphics, video, voice, and other data; however, the combination of 3-D visualization and the Internet, while possible, presents some challenges.

Three-dimensional computer representations of common objects may be presented in one of two ways. First, actual 3-D geometry may be described, often as a series of triangular surfaces, which may be processed by the computer in order to create a shaded image of the object. The appearance of the surfaces may be enhanced through the description of textures or through the application of texture maps—in effect, decals of photographs of material wrapped onto the computer model. Second, an array of photographs may be created, representing the object from all sides in high levels of detail. Moving a mouse or pointing device instructs the computer to display images in sequence, creating a simulation of rotating or moving the actual object. Apple's QuickTime™ VR is the most common version of this approach.

Three dimensional geometry has the advantage of simulating the actual object, creating in effect a virtual specimen or artifact that can be measured, sliced through, or viewed from any point, inside or out. It has the disadvantage of requiring processing power to generate each and every image. File sizes for geometry depend on how finely the geometry is described. Arrays of photographs do not require processing power, only display, but require large amounts of storage. Indeed, storage requirements increase—often dramatically—with the level of detail or resolution required, as one photograph must be stored for each simulated viewing position. Both forms of data may be transmitted via the Internet; geometry usually results in smaller file sizes but requires software and processing power to visualize; arrays of photographs may be visualized very easily but are often measured in megabytes of file size and are therefore slow to deliver.

A variety of means are used to generate the data for 3-D visualizations. A 3-D laser scanner, capable of sampling up to 150 points per square millimeter, records geometry, form, and volume. High resolution digital photographs record surface textures, colors, and fine detail. Similar technologies are available, providing lower levels of resolution and correspondingly lower prices. Digitizers include electromagnetic, acoustic stylus, and rigid and servo-mechanical devices, and start at less than $3,000. Laser light stylus, single and multiple point devices can cost up to $80,000. Digital cameras also range in price, from a few hundred dollars to close to $20,000 for museum quality. A classroom may be reasonably equipped with a probe digitizer and digital camera for under $3,500.

Once data has been collected, visualizations may be created in several ways. The scanning software which accompanies Huxley, Dr. Rosenberger's laser digitizer (like most digitization devices) was developed for industry rather than natural science. While it is able to locate points on the surface of an object with remarkable accuracy, recreating the full object requires intimate knowledge of the relations between points. These relations define the surfaces and also require significant human intervention in the interpretation of the scanned data. Skulls, with their complex convolutions, demand careful editing by persons with some familiarity with anatomy. While a probe digitizer would not require the same level of editing, it would also not deliver anywhere near the level of accuracy of the laser instrument. Once an accurate model is created, textures may be assigned to simulate surface qualities, and the geometry rendered. By creating views and storing images from around the object, QuickTime™ VR movies may be produced. By converting the geometry into other formats, the file may be transferred to other software to create, for instance, a VRML or QuickDraw3D model.

QuickTime™ VR movies are also created through digital photography. The object is carefully mounted and placed against a color background, and recorded with a digital camera which stores images electronically and allows those files to be downloaded to a computer. The images are edited (e.g., removing the mounting mechanism, cleaning up the background, and increasing contrast or brightness and adjusting color balance as appropriate). The images may then be scaled down, or compressed if required for the transfer medium, and combined to create a QTVR object movie.

The Digital Darwins project has been experimenting with the capabilities of Apple's QuickTime™ VR format in order to expand the potential of this medium to create interactive experiences. The QuickTime™ VR object format is essentially a two dimensional array of images, where a conventional movie is one dimensional. Work done at MSU's Digital Research and Imaging Lab in the School of Architecture exploited this two-dimensional structure to look at buildings. We found that we could, for example, use one dimension—the horizontal movement of the mouse—to navigate around a building, while we could use the other—vertical movement—to zoom in for a closer look. Similarly, we created QTVRs where we could move around a university campus and change the time of day to see the pattern of shadows created from any position, or could move through a model of the restored galleries of the National Museum of National History with the ability to look left or right at any point in our journey. These experiments convinced us that we could apply these two dimensions of freedom to significant benefit with the Digital Darwins material. While these applications have just begun, they include the ability to morph between two specimens, as well as the ability to pass a plane through a specimen to reveal its cross-section at various points. Work in development includes showing the sequence of flint flaking used to produce Neolithic tools; dissolving the fur and musculature away from a mammal head to reveal the skull or, similarly, building up the musculature and skin on a hominid skull to recreate the face of an early ancestor.

In addition, we have been experimenting with stereo imaging. Various strategies exist for simulating the appearance of depth by projecting slightly different images to each eye. Like the creation of 3-D simulations themselves, these methods may use processing power, or may rely on pre-processed imagery. In either case, images are developed or recorded, representing the view seen from each eye, in effect with cameras separated by an average interoccular distance. In order to develop the means to deliver stereo imagery over the Internet, we have looked at two forms of image delivery to the eyes: alternating left and right eye images, and red/blue anaglyph stereo pairs. As alternating left and right eye images require synchronizing the computer monitor with a pair of goggles—the monitor projects alternating images up to sixty times a second and the goggles alternately occlude each eye—and therefore still demand somewhat sophisticated software, we have, for the moment chosen to develop red/blue pairs. This form of stereo projection recalls the B-movie genre of the 1950s, but is extremely economical: glasses cost less than $0.50 each in small lots.

As Digital Darwins embraces both research and education, various strategies for transmission of 3-D visualizations are being actively explored. Research quality files can be quite large. Digital photographs recorded at 600 dots per inch and 24 bit color resolution requires a megabyte or more of storage depending upon format. Compression schemes can reduce file size, but can also result in some data loss. Geometry files, especially when recording data at densities of 150 points per square millimeter, can result in file sizes which rapidly bring all but the most powerful workstations to their knees. Because of the demand placed on networks when exchanging such extremely large data sets, we are experimenting with alternative network solutions. Currently we have an ATM (asynchronous transfer mode) network testbed up and running between the Smithsonian and several sites around the country. This network is capable of carrying 145 mega-bits per second, three times greater than current technology. Plans for Internet 2, and the vision articulated by the President in his State of the Union address, suggest that our present work with research quality material will be well supported by next generation networks. At the moment however, the Internet still serves a valuable role beyond 3-D file transmission.

The value of the Internet as a communication and information delivery medium is that it is constantly changing. Participants in chat rooms may sign on and leave at any time, e-mail may be accessed from various sites, Web pages can be updated, added to or modified at will. This medium is well suited to the delivery of background, context, and related information to support the three-dimensional objects and specimens. This material can undergo expansion and refinement as students, teachers, researchers and scientists add new links, references, curricular material, and data. More importantly for Digital Darwins, the Internet may be used to deliver software tools (through JAVA for example) or to provide access to processing power—as demonstrated by the Fusion 3-D component of the Digital Darwins project which allowed users to request customized visualizations created on the site's server.

The Internet may also serve as an effective medium for evaluation of certain aspects of project effectiveness. Web sites may contain simple devices such as counters to indicate the number of 'hits' the site receives, or may contain questionnaire sections, allowing a user to sign on by answering a series of questions designed to gather pertinent information. Users may be tracked and surveyed at different points to assess changes in knowledge, perception, and attitude as the result of interaction with the material. Students and teachers will be able to communicate with their peers (as well as with science experts) through e-mail, chat-rooms and, as the project grows, through desktop video conferencing. At the Smithsonian Institution, for example, Web delivery of objects will be integrated with "scientists in the classroom" discussions via the Natural Partners Initiative Electronic Classroom.

Benefits

Digital Darwins will provide access to museum collections, knowledge- and discovery-based learning to students in districts which traditionally struggle to encourage learning in the sciences, technology, and natural history. Classrooms in Digital Darwins schools will be able to become museums, and Digital Darwins students will operate as researchers and scientists.

The need for stimulating students about science in the early years of their education is clear. The 1983 report *Educating Americans for the 21st Century* identified as a goal that:

> By 1995, the Nation must provide, for all its youth, a level of mathematics, science, and technology education that is the finest in the world, without sacrificing the American birthright of equity and opportunity.

Fourteen years later, the evidence suggests that this goal has not been achieved. In a comparison of mathematics and science achievement scores internationally it has been found that U.S. students rank below those of most other industrialized nations. In science in particular, average

> achievement of U.S. 9-year-olds is not significantly lower than that of any other nation, and is significantly higher than the achievement of Slovenia and Ireland. Among the 13-year-olds, however, the average science achievement of U.S. students is not significantly higher than any country and is significantly lower than the achievement of Korea, Taiwan, Switzerland and Hungary.[1]

These findings are supported by data from the National Assessment of Educational Progress (NAEP) which indicates that

> (a)verage proficiency scores in science fell in the 1970s, then began to rise after 1977 for students at ages 9 and 13. By 1990, the average scores of students in both of these age groups had returned to their 1970 levels. Scores for students at age 17 continued to drop until 1982—a 22-point drop over the period—then regained some ground. Their scores in 1990 remained still significantly below the 1970 level.[2]

Education reform efforts have identified a number of elements leading to increased learning—especially of advanced or higher-level skills, enhanced student motivation, and self-concept. These include student exploration, interactive modes of instruction, extended blocks of authentic and multi-disciplinary work, collaborative work and performance-based assessment. Studies of the use of instructional technologies have shown that, when used in ways that are compatible with these elements, "technology supports exactly the kinds of changes in content, roles, organizational climate, and affect that are at the heart of the reform movement."[3]

When used for exploratory learning, technology allows students to direct their own assimilation of facts, concepts, and procedures through a process of discovery. Exploratory learning technologies have included electronic databases, computer-based exploratory applications and video exploratory applications. Three problems in particular have been identified in the development of exploratory applications: 1) Scarcity: they have been expensive to develop, so few are available; 2) Low return: they are difficult to match to the curriculum of enough schools to establish a broad market base; and 3) Time limited value: they tend to have a short shelf-life as students learn the lessons of the material and desire to move on. Digital Darwins is applying exploratory technology to develop students' learning, motivation and interest in science, technology, and natural history with particular attention to the three problems identified above.

Digital Darwins is a pilot program intended, in part, to demonstrate how the resources of the nation's museums may be made available electronically, in cost effective ways. Several numeric indicators are worth noting. The National Museum of Natural History contains some 120,000,000 objects, of which only about 1 percent are on display at any time. Costs to dismantle an exhibit and reconstruct a new one in order to display new material run up to $500 per square foot. Traditional museum display, as the sole means of access to museum collections, is extremely expensive. Two-dimensional digitization projects have demonstrated the economy of this method of preservation and information exchange. Harvard University, for instance, has converted some 80,000 posters from its Judaica holdings at a cost of about $2.00 each. It is estimated, based upon actual work such as Digital Darwins, that the time involved in preparing a 3-D visualization file of a moderately sized object can be reduced to as little as an hour and no more than one person-day, and that the costs of preparing background material for Web publication are equivalent to any other publication form, while the actual costs of publication, revision and distribution are much lower.

Value (cost) may be better calculated by examining impact. In this case, the cost of the program might be reasonably compared with the cost of transporting a rural student to a science, technology, or natural history museum. Though not intended as a substitute for such a trip, Digital Darwins provides a powerful supplement as its materials are available to the student, in his/her classroom (or home), at any time.

The problem of curriculum match and market base results in part from the elaborate and specific nature of many simulation-based exploratory technologies. In its full development, Digital Darwins will not be one large simulation, but a collection of small simulations each with multiple links allowing it to be tied to existing curricula in various ways. In addition, it is intended to be effective enough in cost and delivery to allow market development in manners not dependent on curriculum, for instance through the school library or home markets. Finally, Digital Darwins value will not be time limited. Two means exist inherent in the structure of the project to allow constant re-energizing of the material. First, the project envisions the addition of 3-D visualizations to the collection at regular intervals. Second, the Web-based support system provides a means by which new tools, background, context and related material can be made available to enrich and enliven existing 3-D collections.

Conclusions

The Digital Darwins project is unique in that it applies technology with clear value to basic research to develop a body of materials and resources for use in K-12 classrooms and informal education settings around the nation. The teaming of researchers with students, through a common database of archival material and a common set of tools for investigating and adding to the archive, is a model for collaborative work which engages young people in real research and in real problems. There is no question that our youth are fully capable of making significant contributions to research and knowledge if only given the opportunities and tools. Projects involving Digital Darwins partners, such as EarthVision and work at the Bergen County Academy for the Advancement of Science and Technology (a New Jersey magnet school), are powerful demonstrations of their capacity. The model of using 3-D computer technology for the representation, investigation and distribution of important material may be applied to subject matter ranging from archaeological artifacts, to biological specimens, to manufactured objects, as well as to the history of art. The Web interface being developed is a model for utilizing the Internet as a significant tool for education and the exchange of knowledge which supplements traditional curricula and publication.

Publication of museum material (archaeological material, for example) is constrained by the cost of publication. Researchers working with original material are not able to publish full collections, and researchers or students seeking information about collections are not able to find full visual documentation. Research and learning is further constrained by problems of access to specimens. Important materials are often fragile and precious, and cannot easily be lent. Traditional publication processes mean it is often years between the time of the discovery of important information and its publication, and therefore its general availability.

Limited availability of images and information about artifacts not only compromises the advancement of knowledge directly, indirect compromise results as well. One cannot imagine the number of artifacts—pottery shards, stone tools, figurines, etc.—which have been lost to the study of the evolution of human culture because those who found them had neither context nor means by which to identify them as something of scholarly or other value. The production of libraries of three-dimensional computer models of archaeological and museum artifacts, especially when those libraries represent current work in the field, offers researchers a means of generating and exchanging new knowledge. Through the teleconferencing breakthroughs of the Natural Partners Initiative, Digital Darwins is an opportunity to provide students and researchers with access to expeditionary discoveries as they are being made. The digital archive will become a repository of scholarly material in the form of a new medium for students—not just text or images, but objects, representing important knowledge of artistic, scientific and cultural value.

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