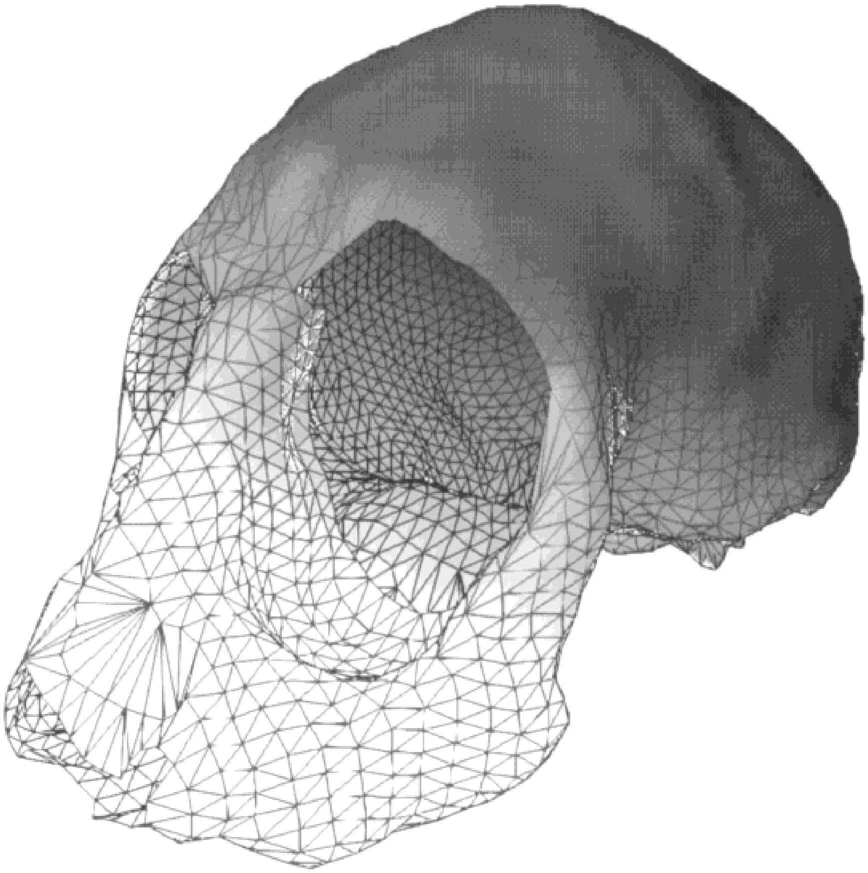
Digital Morphology: The Smithsonian's BioVisualization Lab



Computer-based visualization is revolutionizing many fields of science by suggesting new questions, creating new forms of data, presenting new ways to publish results, and increasing accessibility to the public through the World Wide Web. There are numerous examples of the alluring power of this three-dimensional (3-D) technology as it can objectively capture meaningful information and produce novel images of scientific specimens.

The Smithsonian BioVisualization Lab was established to produce research-quality digital (virtual) specimens for scientific study and education. One of our principle objectives has been to adopt a technology that could produce highly accurate digital files for taking exact measurements and for creating accurate computer-generated images of specimens. Researchers at the BioVisualization Lab have worked in collaboration with the Digital Research and Imaging Lab of the Mississippi State University to develop approaches and to establish Internet access that will enable others to share work and specimens on-line.

The beginning of the Smithsonian BioVisualization Lab grew out of proof-of-concept experimentation with laser scanners and digital data conducted at other facilities in the late 1980s. The apparatus for magnetic resonance imaging and scanners for computer-assisted tomography and positron emission tomography are among the better-known examples of the types of tools used to create 3-D imagery (for reviews, see Hartwig and Sadler,[1] and Dean.[2]) These tools have been shown to have interesting applications to anthropology, such as the reconstruction of skulls from multiple pieces.[3]

The centerpiece of the BioVisualization Lab is a high-resolution laser digitizer, a point-scanning instrument. The device generates an array of x, y, z co-ordinates that record the geometry of an object as it spins or translates below the laser beam. The data array becomes a series of parallel contour lines that are later translated into a more refined polygonal geometry. Data collection is automated by setting various machine parameters such as point interval and laser beam focus, and by setting protocols that define a target window and calibrate the vertical distance between a point on the target surface and the laser head. When the laser fires, it triggers an internal reading of each point in an x, y plane. The reflection of the laser beam is simultaneously registered on a pair of charge-coupled device (CCD) sensors to enable triangulation of the height measurement (z coordinate value) of each datum.

As the coordinate points record the geometry of the object's surface, software is used to reconstruct and display the object from the data. The resulting three-dimensional digital models can then be manipulated, edited, and measured on-screen. For example, virtual specimens can be positioned in an x, y, z space that mirrors the anatomical planes and orientations used with actual specimens. It is then possible to take linear measurements of the digital model just as a real specimen would be measured by hand. Landmarks can be highlighted as measuring points with the click of a mouse and linear spans calculated instantly on command. However, the greatest benefit of the technology is that it enables measurements of specimens that are too small, too large, or too geometrically complex to perform manually. For example, the surfaces of joints, the occlusal tables of molars, the extent of individual cranial bones, or regions of the brain's external surface can all be demarcated and their perimeters or areas calculated. Volumes can be computed from a scanned endocranial cast or the cavity of an eye socket.

This comprehensive form of data collection has far-reaching implications for solving classical problems in evolutionary morphology. Visual inspection and traditional quantification have well-known limitations, ranging from the semantic characterization of form that results from the "eyeball approach" to the inadequacy of a topological description typically taken with calipers. Digital morphology has the potential to unify and enhance both data collection and description. In addition, 3-D data bases provide robust descriptions of form encompassing a variety of measures and relationships, including volume, shape, slope, surface area, curvature, and linear dimensions. Moreover, they enable interactive visualization and comparison.

As part of the National Museum of Natural History's electronic outreach initiative, the Natural Partners Program, and in the hopes of encouraging the development of a digital-morphology community, we have mounted a World Wide Web site that displays some of our work (http://www.digitaldarwins.sarc.msstate.edu). Included are 18 3-D solid models or QuickTime Virtual Reality (QTVR) movies of skulls, dentitions, endocranial casts, stone tools, clay figurines, and other artifacts from museum collections, with background information on each subject (Fig. 1). The site demonstrates how this material can be manipulated interactively on-line. In QTVR mode, which uses an array of still images to simulate 3-dimensionality, objects can be rotated around a prefixed axis or axes, under mouse control. The 3-D digital models can be freely rotated, translated, and scaled to different sizes on-screen.

Two other visualization features of the DigitalDarwins Web Site are being designed specifically to increase the research value of these models. Both features are currently under development, but examples are available at the site. The first presents 3-D models as stereo images. It uses two techniques. One involves a red-blue shift to display the stereopair and inexpensive glasses for viewing, like the 3D viewers used in 1950s movies. The other technique presents alternating right-eye and left-eye views to produce the stereo effect. It requires special goggles to synchronize with the display on the monitor.

The second feature is an experimental engine, Fusion 3-D. When fully implemented, this tool will allow the user to request customized visualizations of multiple specimens for comparative purposes, such as side-by-side or nested views of two skulls. Many of these customization capabilities are already available, allowing the user to send a unique request, via the server, to a powerful graphics computer. Although the current implementation is a modest one, it demonstrates the notion of using networking and visualization technology to explore comparative morphology.

What these technologies hold for the future of science is no longer a matter of fuzzy visions. For example, the Protein Data Bank, created by a worldwide effort to define the three-dimensional shapes of proteins, archive them, and deliver visualizations and raw data over the Web, will contain about 1,600 sequence families by the end of 1997.[4] This on-line "protein museum" is a resource equivalent to the best natural history collections in the world, but is uniquely available for research and discovery at any instant. Moreover, some individuals believe that analysis of quantized libraries of protein shape and morphology, which barely existed a decade ago, will surpass the value of the amino acid sequences for deciphering deep phlyogeny.

Physical anthropology, which has always been a visual science fundamentally dependent on archived specimens, can benefit tremendously from digital morphology. Measuring, visualizing, modeling, and disseminating anatomy in usable form is not only possible and replete with potential insight, but it is also necessary in today's fast-paced scientific environment.

REFERENCES

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