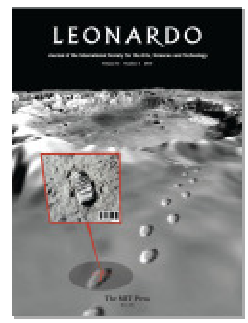
Emerging Congruence between Animation and Anatomy

O'Neill, Rob.

Leonardo, Volume 40, Number 2, April 2007, pp. 167-173 (Article)

Published by The MIT Press

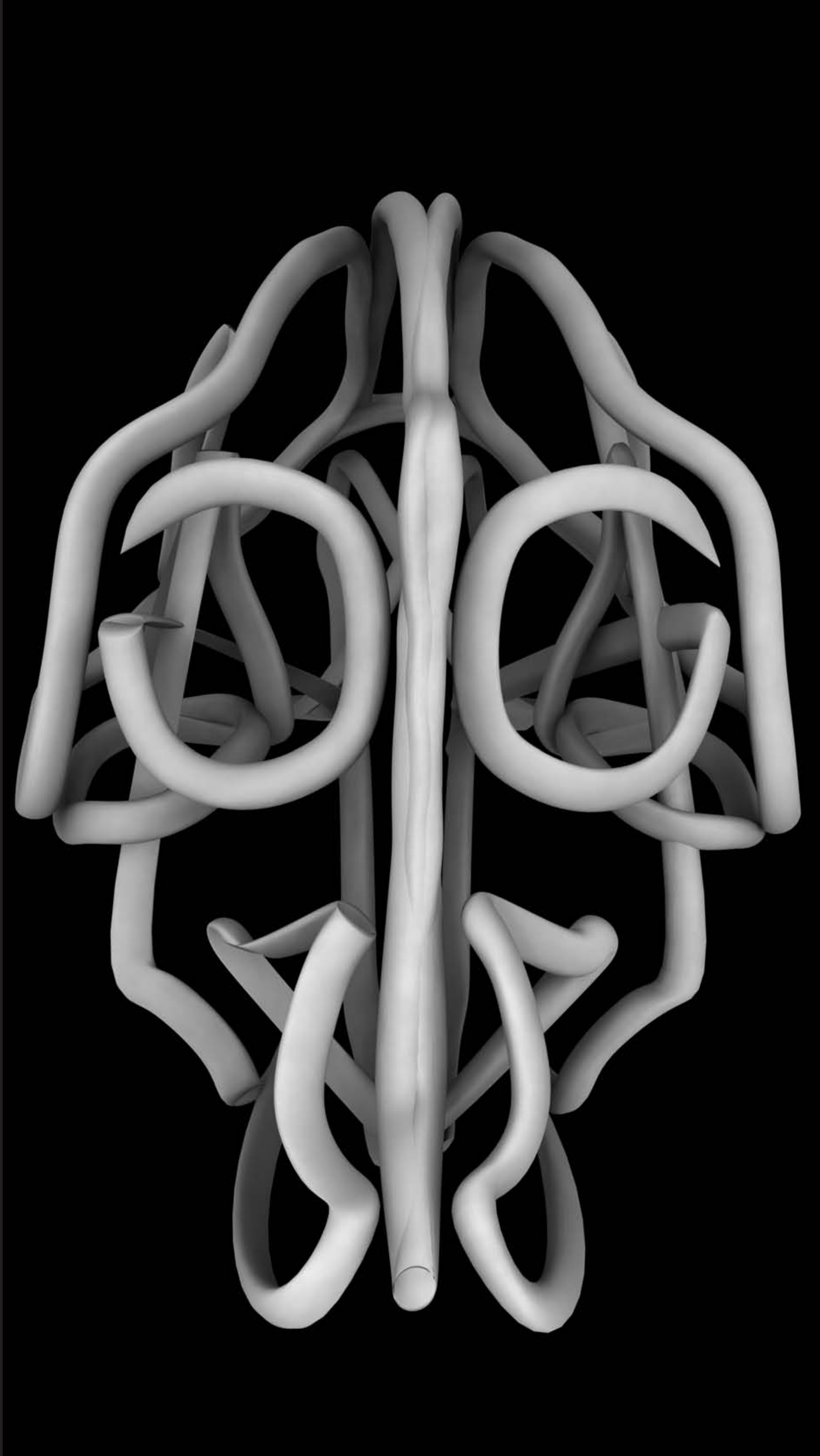


Special Section

ArtScience: The Essential Connection

Guest Editor: Robert Root-Bernstein

The seventh installment of a Leonardo special project exploring the work and writings of artistic scientists who find their art avocation valuable; scientifically literate artists who draw problems, materials, techniques or processes from the sciences; or others interested in such interactions.



Emerging Congruence between Animation and Anatomy

Rob O'Neill

ABSTRACT

The worlds of animation and anatomy have a long-standing connection based on both direct and indirect collaboration. The author surveys a number of projects in which anatomists have consulted on animation projects or animation techniques have been used for data gathering and analysis. The author describes his own work in light of this connection.

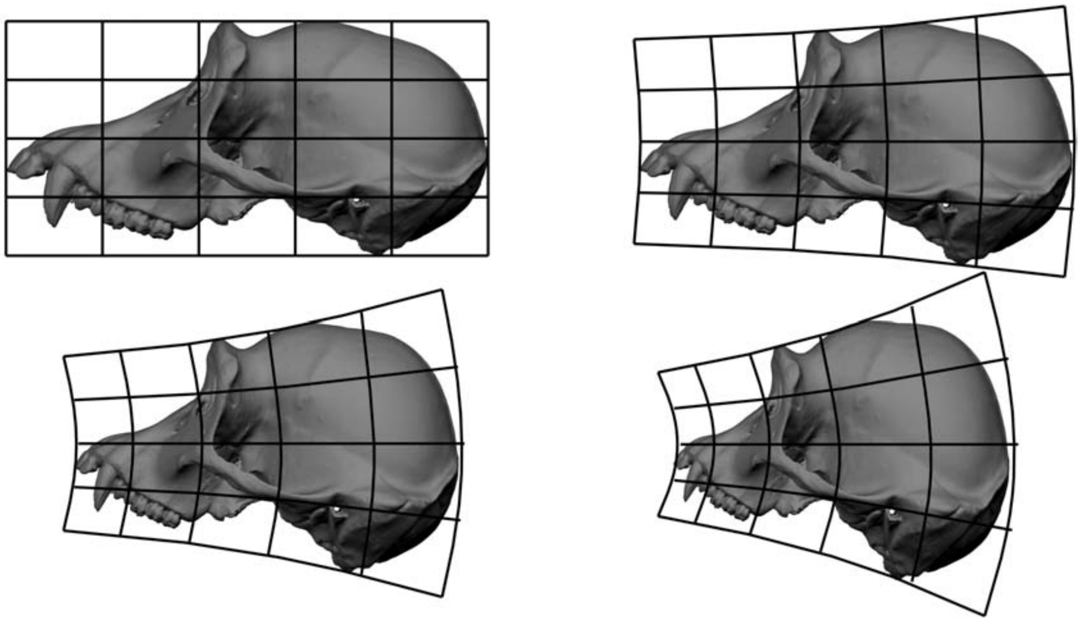
A long-standing connection exists between the worlds of animation and natural history, in particular in the studies of evolution and anatomy. This article addresses the use of natural history topics as inspiration for narrative elements in animation and the advisory work of scientists regarding the accuracy of images depicted. Conversely, I also discuss the influence of artists, designers and engineers upon the methods of scientists. One of the earliest examples of American animation (produced in Brooklyn, New York) was Winsor McCay's *Gertie the Dinosaur* (1914), in which the power of animation was used to represent an extinct entity and to portray it being "tamed" by a modern human, McCay himself.

Disney Studios encouraged animators to study anatomy, both by bringing live animals into the studio and by sending artists to visit zoos. The study of live animals and consultation with experts have been long-standing practices in the world of animation. The realistic grounding that the resultant knowledge brings is unparalleled and reflected in some of the best animation. Furthermore, as 3D animation becomes increasingly complex and often realistic, technical animators are turning to anatomy-driven systems to re-create and simulate the underlying structures (bones and muscles) that drive the look of these hyper-real characters. In doing so, they rely on the consultations of experts in the fields of anatomy and evolution. Similarly, the techniques used in animation and computer graphics are being increasingly used by researchers not only to visualize their data but also as a means of collecting new information from fossil skeletal material and living species. An interesting feedback loop has developed, in which anatomy and animation inform each other in order to achieve compelling results.

Rob O'Neill (researcher, artist), Digital Arts Research Lab, Pratt Institute, ISC 101A, 200 Willoughby Avenue, Brooklyn, NY 11205, U.S.A. E-mail: <roneill@dal.pratt.edu>. Web site: <www.morphometric.com>.

Article Frontispiece. *dataProjections 003.* (© Rob O'Neill) The data, which has been processed as in Figs 2 and 3, here is mirrored to create a semblance of the source object (a female gorilla's skull). All skulls used in the *dataProjections* series are housed in the collection of the Division of Anthropology of the American Museum of Natural History. Data collected by Ken Mowbray.

Fig. 1. Stills from the animation *The Theory of Transformations,* a 3D rumination based on the work of D'Arcy Wentworth Thompson. (© Rob O'Neill) A 3D model is warped by a procedurally generated grid.



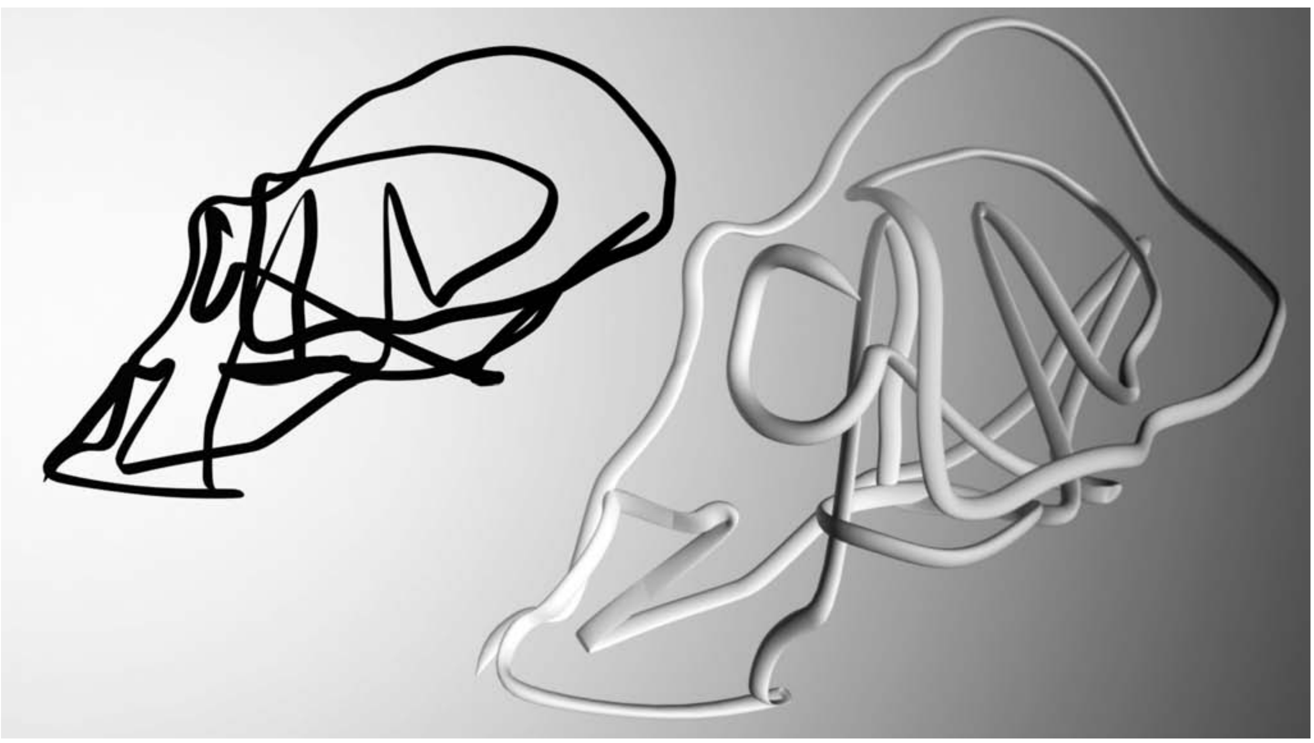
Anatomy for Animators

Scientists are often called in to consult on animation projects, and their work and advice is incorporated to varying degrees. Willy Ley, Wernher von Braun and Heinz Haber were consulted for the 1950s Disneyland space series that included *Man in Space* (1955), *Man and the Moon* (1955) and *Mars and Beyond* (1957). In these films, animators created characters and situations in outer space based on interviews with the scientists. Merian Cooper (on behalf of Willis O'Brien) consulted with the American Museum of Natural History for "gorilla specifications" [1] on *King Kong* (1933). *Greystoke: The Legend of Tarzan* (1984), although not an animated film, employed the knowledge of Roger Fouts, co-director of the Chimpanzee and Human Communication Institute, whose expertise in teaching chimpanzees human language in the form of American Sign Language for the Deaf was inverted when he was asked to guide human actors to act more like nonhuman apes [2]. The *Jurassic Park* film series, which featured 3D animated dinosaurs in a live-action film, benefited greatly from the consistent input of paleontologist James Horner, Curator of Paleontology at the Museum of the Rockies, acting as a technical consultant. Horner's input included a range of information, from skin texture and coloration to the mechanics of dinosaur movement. It has even been suggested that Horner was a partial inspiration for the original book and subsequent movie's lead character, Dr. Alan Grant. For the Pixar film *Finding Nemo* (2003), a 3D animated feature, the animators were treated to a special 12-lecture course on fish behavior and locomotion by Adam Summers, a professor in the Ecology and Evolution department at the University of California at Irvine. Summers was asked to discuss such topics as fish shapes and colors but in the end taught what he referred to as a "graduate-level ichthyology course" to the Pixar staff [3]. In all these examples, scientific accuracy was taken into account to some degree, but the end result can best be described as an artist's interpretation of this information.

Stuart Sumida [4] is a paleontologist at California State University at San Bernardino who consults with animation and visual-effects companies. His specialty is comparative anatomy and biomechanics of vertebrates with regard to locomotion. Providing animators with an understanding of the underlying physiology of animals helps them to better understand the nuances involved in animating characters in a way that looks natural. Even on projects in which the character design is very stylized, the motion of a character still remains grounded in realistic biomechanics to some degree. This grounding is where animation often begins; from there the style of motion needed for the project is designed and the limits of motion, or lack thereof, are defined. Sumida's studio lectures interweave details of bone structure and muscle activity with species idiosyncrasies to illustrate topics such as animal posture and gait. These lectures are attended by animators as well as by artists who implement this information in the character's construction.

The position on modern productions known as the character technical director (or, more commonly, character rigger) takes all this information and builds the control rig that animators manipulate to pose the character in the manner needed for the shot. The skeleton inside drives the deformation of the digital sculpture. Much thought, sculpting and technology is put into how the character looks while undergoing every positioning of the joints by the animator. These motion and deformation systems are the foundation of all digital characters, and the character technical directors are the individuals who bridge anatomy and technology to create an intuitive animatable character rig for use in the project. An anatomy text is always on hand, and the position of every joint

Fig. 2. ***dataProjections 001*, digital print developed from scientist-collected morphometric data. (© Rob O'Neill) The simulated object on the right is the 3D polygonal structure created by the raw data collected from a male gorilla skull. The object on the left is the shadow produced by casting simulated light through the object on the right.**



in the character is scrutinized while static and in motion to achieve the desired look for the character. As noted above, the complexity of these characters is increasing at a dramatic rate, and most featured characters utilize some form of layered muscle system to deform the overlying geometry. The complexity and anatomical abstraction of these systems varies from studio to studio and from production to production, but the principles remain the same.

Consultation by experts in anatomy or the behavior of animals depicted varies depending on the film and the level of realism needed. Certainly, on films such as the *Jurassic Park* series and programs created for educational benefit, experts are brought in early to help define the motion of the creatures developed for the production. It is likely that we will see much more collaboration on this front in the future. Every animation student studies figure drawing [5] and the dynamic anatomical work of Leonardo da Vinci, but turning this information into something that moves over time often takes expert advice from those who study the intricacies of anatomy. Similarly, animators and computer-graphics programmers, as well as the techniques they have developed, are starting to find their way into research projects and work previously informed exclusively by scientific data.

Animation for Anatomists

There are a number of cases emerging in which scientists are delving into the world of animation and computer graphics not only for the purposes of data visualization but also for data collection and analysis. Four research projects conducted in the last few years are worth exploring. The first is that of Stephan Gatesy [6] of Brown University and the "Scientific Rotoscoping" technique. Rotoscoping is an animation technique in which the motion of the animated character is created by the tracing of live-action reference footage. This is a common technique in both traditional 2D animation and modern digital 2D/3D animation. Walt Disney even used rotoscoping on such classic films as *Snow White* (1937), for which he filmed an actress acting out the role and then provided the film to his animators as a 2D baseline of realistic motion from which they could begin work. The motion derived from this method has a very realistic and controlled look when compared with that done without this frame-by-frame reference. Gatesy and his team are creating accurate 3D animations of the locomotion of animals (often birds) by filming them on treadmills and in wind tunnels with an X-ray camera. These X-ray movies are then imported into 3D animation programs in which hierarchical models of the bones, which have been meticulously sculpted (or scanned), are match-moved on a frame-by-frame basis to re-create the motions and thus create accurate animated 3D models of the motion. Scientists are now using what Disney and many others have relied on for years to re-create and study motion.

Similarly, the modern-day analogue of rotoscoping is motion capture, often derided as "The Devil's Rotoscope" (reflecting the perception that it is "cheating" and not true animation), in which markers are placed on a performer in a multi-camera calibrated space. The motion of these markers is then converted to 3D point positions, thus re-creating the motion of the performer. This technique is used by John Hutchinson [7] of the Royal Veterinary College of the University of London where, as in Gatesy's work, the motion of extant species such as elephants and other large animals is captured and compared to information collected from dinosaur anatomy (without the benefit of motion capture). This is done to gauge what generalities about large animal stance and gait emerge from comparisons of these different lineages. Problems with motion retargeting, the transformation of one creature's proportions to those of another, and differences in anatomy prevent a direct transfer of joint angles from elephants to dinosaurs, but the connections gleaned from traditional and emerging biomechanical analysis tools have shed an innovative light on the subject. These two researchers are working intensely with animation techniques and methodologies on various research endeavors to inform their analysis and to visualize their results with great success. They are also discussing the limitations and restraint needed in making assumptions based on animation techniques. Merely animating the bones does not amount to a scientific analysis and results in a vast number of possible solutions for the position of bones from frame to frame. Evaluating these multiple possibilities has been an eye-opening experience, and Hutchinson and Gatesy are employing strict constraints and innovative techniques to narrow the realm of possibilities [8] and shed some light on how these methods can develop into documented analytical techniques.

> *Animators and computer-graphics programmers are starting to find their way into scientific research projects*

While scientific rotoscoping takes a cue from animation techniques, a collaborative project between paleontologists at the American Museum of Natural History and computer scientists at the University of California at Davis takes its lead from classic computer graphics techniques, in particular morphing. Morphing is the transformation of one shape into another. The work being carried out, labeled "Evolutionary Morphing" [9], is actually the interpolation of shape transitions between extinct and living primate species in an attempt to mathematically fill in the gaps in the fossil record. With the advent of 3D laser-scanning technologies, the ability to capture, at high resolution, the shape and detail of anatomical specimens is changing the way data are collected and analyzed. Databases of specimens can be stored and compared using methods that rely not on the resolution of the scan but on the shape of the specimen. Work with anatomical landmarks is also changing. Anatomical landmarks are defined anatomical locations typically used for measurement and are denoted by skeletal features such as the nasion, which is the midline point where the two nasal bones meet the frontal bone (forehead). These markers can now be identified visually by the investigator (as they have been traditionally) or, increasingly, by software via algorithmic analysis of the surface. In addition, the use of semi-landmarks or interpolated landmarks placed by the software between true landmarks is becoming more prevalent as these markers are used to define shape and drive analytical morphing from one species to another. The power and, I would say, artistry of this technique allow researchers to investigate the hypo-

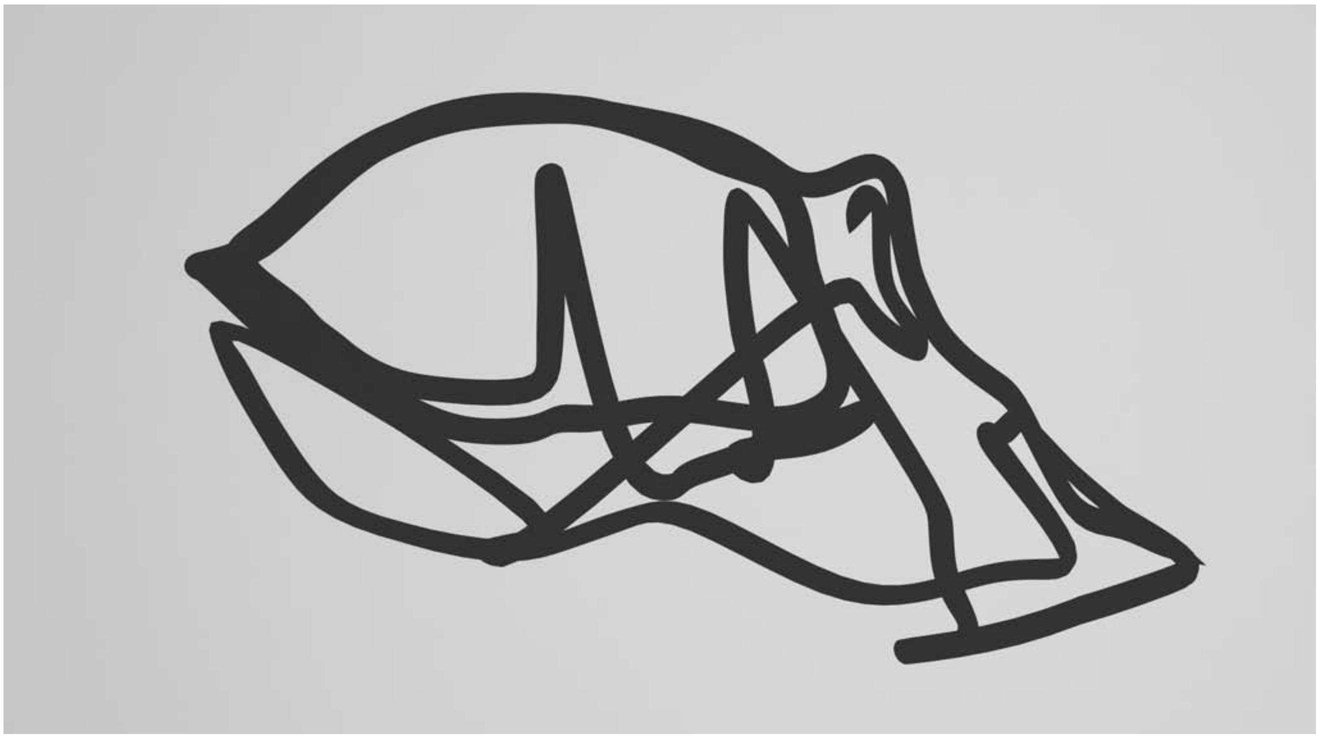


Fig. 3. ***dataProjections 002.*** **(© Rob O'Neill) As in *dataProjections 001*, the object depicted is the simulated shadow of the object created, in this case a female gorilla's skull.**

thetical shapes (and thus hypothetical species) interpolated in between them. While most morphing operations are linear—the points of shape A are moved in a linear manner to their corresponding position on shape B—the evolutionary morphing technique (encapsulated in software called Landmark) bases its morphing on the biometric mathematical underpinnings of the work of F. James Rohlf of the State University of New York at Stony Brook. This leaves the work informed by the database of shapes and the principles of biometry and geometric shape analysis.

A step closer to the world of computer graphics, and also approaching those of anatomy and natural history, is the software Dinomorph [10]. It is essentially a biomechanical simulator through which scanned anatomical elements are articulated and simulated in a physical environment. This allows a researcher to interactively hypothesize the mechanics of an extinct species with the intent of gaining a better sense of stance, posture and motion. The physics of many motions, in animals ranging from long-necked sauropods to modern giraffes, can be simulated and explored from a biomechanical point of view. These are the subtle details that are difficult to discern from raw anatomical study and will ultimately help bring extinct species to life by the hand of the animator.

Finding the Middle Ground

As an observer of all these projects (and a consultant on the Evolutionary Morphing project), as well as a character technical director, graphics programmer and artist, I am intrigued by these relationships and the results emerging from them.

A great influence on my work, as well as that of many others in the field, has been the writing and illustrations of D'Arcy Wentworth Thompson in his 1917 volume *On Growth and Form* [11]. The book outlines some early principles in biological morphology, or the study of shape. Thompson found geometry and pattern in the natural world and introduced Cartesian morphs (grid-based geometric deformations of 2D surfaces) to the thinking of biologists. Thompson essentially applied the idea of morphing to biological structures and thereby plotted the profiles of various species, warped them to look like other species, and generated deformed grids based on the results to illustrate the difference. His illustrations were compelling at the time of their publication and continue to be a source of inspiration. In my work as an artist I have always returned to this volume, which has challenged me to undertake experiments that compare the shapes of biological objects. A connection between this influential volume and my work is my series entitled *The Theory of Transformations* (named for a chapter of *On Growth and Form*) (Fig. 1), composed of 3D interpretations of Thompson's work in animated and print form. In many ways, these ruminations on shape represent a direct animation of Thompson's work and have been a seminal exploration in my work.

dataFace is a multi-component work that I created to undertake simple experiments with a large morphometric data set. The data set is one collected by W.W. Howells (1908–2005, professor of anthropology at Harvard University) between 1968 and 1980 and now maintained by the University of Tennessee. The data set contains 82 craniometric measurements from over 3,000 human skulls housed at various museums. I have been fascinated by this data set since discovering it as an anthropology major at Brooklyn College. Over 10 years later and after much time studying computer graphics and animation, I have begun to generate software and art pieces using it. The first piece in this series is a simple tower of measurements in which each bizyomatic breadth (essentially the full width of the face) is generated as a line that is added to a stack of lines representing each member of the data set. The column of data is then printed to scale so that the widths are accurate representations of the measurements. In a second iteration of this piece, I programmed an animated line that moves through the data as an act of meandering across the width of all the faces in much the same way that the eye would track across faces. In these pieces the line reveals nothing but the variation in the data set. Taken a step further is a data-generated face sketch based on many of the data points plotted on a 2D plane, illustrated by animated points that are drawn procedurally to give an impression of the face of the individual (Color Plate A). This procedure is carried out for each of the individuals in the data set. I am captivated by the idea that all these collected numbers reflect the person that they were collected from.

The Morphology Project is a series of artistic ruminations on these data with the intention of bringing some life to the cold numbers that were so meticulously, I would venture to say artistically, captured. The gestures required to capture these measurements entailed a great deal of discipline and precision, and the data were collected for hours, days and months on end at various anatomical collections at museums all over the world. Where in the past, measurements were collected with a wide array of apparatuses—such as calipers, protractors or hand-made measuring boxes—much of today's data is collected with digital tools such as 3D point plotters. The data collected by these devices provide a 3D coordinate point cloud of the same landmarks that were used to capture distances. Once these landmarks are captured in 3D space, a large number of measurements can be calculated from them. Many of these measurements would be impossible to record on a physical specimen due to the position of and angles between the landmarks. In this use of 3D landmark data collection, what emerges is the path traveled by the data collector. The points are stored as a linear data set of the number of the points collected, followed by the x-y-z coordinates. By reading these points in and drawing a line from one to the next, one follows the hand of the researcher and ends with another example of the artistic gesture of data collection. *Data Projections 001* is an example of work created from this exploration of scientific data collection. The shape procedurally drawn is that of a gorilla skull—the shape data was collected via a 3D point plotter, in this case an Immersion MicroScribe, and modeled using custom tools in Autodesk Maya. A 3D surface is generated, and the object's shadow is then projected onto another surface, producing a flat, almost graffiti-like graphic image (Fig. 2) representing an analysis and presentation of data as a study in how hypotheses are generated by projecting the data into hypothetical spaces (Fig. 3 and Article Frontispiece).

My future projects will involve mapping the aforementioned 2D Howells distance measurements as 3D landmark points to visualize historic data through modern means. Concurrently, I am developing genetic algorithms to treat the data as a population and cause it to evolve. In the end, my true goal is to collaborate with scientists and to develop functional crosstalk between the fields of art/animation and research. Current developments in animation, biomechanics and morphology suggest a number of potential collaborations. As artists become more technically oriented and scientific analysis of large data sets is increasingly performed graphically, the possibility of collaboration increases. For example, I am working on the above-mentioned Evolutionary Morphing project to develop geometric techniques to "fix" 3D scans of geologically deformed fossil specimens so that they can be analyzed. This work is currently a mix of graphics-tools development, animation technology and digital sculpture. For me, all of these threads are paths that lead to personal artistic output in the form of animations, prints and sculptural installations that emerge from collaborations with scientists and from following published research. The work is typically personal rumination on the scientific process, but it often leads to the development of software that could be used for research. I plan to release the software to researchers, as the algorithmic processes that I use to analyze the data are very similar, if not identical, to the processes utilized in research-specific tools. Much of this software will be available via open-source distribution.

Looking forward, collaborations with scientists and data gleaned from research are important for me as a working artist in addition to my work in developing tools for character-animation technology. This is merely the beginning of uncovering and fostering the balance between anatomists impacting animation production in a meaningful way and the tools and techniques of animation evolving into truly accurate and usable tools for scientific research.

References and Notes

1. Tom Huntington, "King Kong: How the Greatest Special-Effects Movie Was Made with the Simplest Technology," *American Heritage of Invention & Technology* **21**, No. 3, 21–31 (Winter 2006).

2. "Biology of King Kong," panel, 2006 Tribeca Film Festival, New York (6 May 2006).

3. "The Making of Finding Nemo," CG Society, <http://features.cgsociety.org/story_custom.php?story_id=1389>.

4. Stuart S. Sumida, <www.stuartsumida.com>.

5. See, for example, Kimon Nicolaides, *The Natural Way to Draw: A Working Plan for Art Study* (Boston: Houghton Mifflin, 1941).

6. Stephen M. Gatesy, <www.brown.edu/Departments/EEB/gatesy>.

7. John R. Hutchinson, <www.rvc.ac.uk/SML/People/jhutchinson.cfm>.

8. John R. Hutchinson and Stephan M. Gatesy, "Beyond the Bones," *Nature* **440** (16 March 2006) pp. 292–294.

9. David F. Wiley et al., "Evolutionary Morphing," *Proceedings of IEEE Visualization 2005,* 23–25 October 2005, Minneapolis, Minnesota, <http://graphics.idav.ucdavis.edu/research/EvoMorph>.

10. Dinomorph, <www.dinomorph.com>.

11. D'Arcy Wentworth Thompson, *On Growth and Form,* Rev. Ed. (Cambridge, U.K.: Cambridge Univ. Press, 1942).

Glossary

character rigger (or character technical director)—a person who merges anatomy with computer graphics to create a character rig for animated films.

landmarks (or anatomical landmarks)—defined anatomical locations typically used for measurement, ideally denoted by features on skeletal elements.

motion capture—a technique of digitally recording movements for entertainment, sports and medical applications. In general, markers are placed on a performer and tracked, in real-time, in a multi-camera space.

motion retargeting—adaptation of an animated motion from one character to another to compensate for differences in size or limb proportion.

rig—the architecture of a modern digital 3D animated character that defines how it moves and how it appears when in motion.

rotoscoping—an animation technique wherein the motion of the animated character is created by the tracing of live-action reference footage.

Manuscript received 9 May 2006.

Rob O'Neill is a researcher, animator and programmer in New York City. He is a research associate in the Digital Arts Research Lab and faculty in the Department of Digital Arts at Pratt Institute. Formerly, he was the studio technical director at Eyebeam, where he continues to consult on projects. Prior to that he was a character technical director at PDI/Dreamworks and a researcher in Cultural Resources at the American Museum of Natural History. He holds a BA in anthropology from Brooklyn College and an MFA in digital design and technology from Parsons School of Design.