Medical Science and Medical Informatics:
The Visible Human Project, 1986–2000

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Abstract

The Visible Human Project originated at the National Library of Medicine (NLM) in the late 1980s. The imaging of a human body was possible in a technical sense and was a project that could be appropriately funded by the NLM, falling within the library's mandate from Congress to disseminate information. The competition in 1990 to carry out the project was won by a consortium of medical centers in Texas, Maryland, and Colorado and led by a research team at the University of Colorado Health Services Center at Denver. The construction of an anatomical atlas required researchers to image a cadaver using computerized tomographic scans and magnetic resonance imaging; these images would then be correlated with photographic cross-sectional images of the body. The first complete anatomical database—taken from the body of a Texas convict—appeared on the Web in November 1994. Almost immediately commercial companies moved to take advantage of the data set. By the time of the First Visible Human Conference at the NLM in 1996, there were almost four hundred research groups in academic and industrial contexts using some aspect of the Visible Human database.

The genesis in 1986 of the Visible Human Project—the mapping of the human body through electronic imaging—lay in deliberations by a planning committee at the National Library of Medicine (NLM) that was formed to define NLM's role in medical informatics (National Library of Medicine, 1986, p. 6). More specifically, the project arose in clearer definition as the consequence of a meeting in June 1986 between Michael Ackerman, chief of the Educational Technology Branch at NLM, and Cornelius Rosse, professor and chairman of the Department of Biological Structure at the University of Washington. Ackerman was immensely impressed with advances in computer imaging in Rosse's laboratory (he later described them as "sensational") and predicted that there were grounds for fruitful collaboration between the NLM and the university (National Library of Medicine, 2001, pp. 12–13).

The Visible Human Project was then developed through the collaborative planning of institutions and agencies that were all involved in one way or another in research on computer graphics and medical informatics. Design and marketing of the Visible Human Project was undertaken by private business, university informatics research centers, and government agencies. The project won strong support from the medical community and its representative institutions, and it found its greatest success in enhancing and improving the curriculum at the nation's medical schools and colleges.

Conceptualization and Planning

At an early stage researchers in medical informatics could envisage a multitude of applications. By 1988 scientists at the University of Washington had already demonstrated how the body could be dissected in a virtual sense: electronic images could be rotated through several different axes to provide the student with various views of the body. Patient care was enhanced through electronic images; preoperative counseling could demonstrate a surgical operation on the computer screen and reveal it to be both less mysterious and less threatening. Surgeons and physicians could more effectively plan and organize treatment, especially if it were radically invasive, as with surgery or radiation therapy. Prosthesis design and engineering, consumer health education, forensic medicine, trauma modeling, and surgical simulation were possible avenues that could be opened up in the future by the new methods (National Library of Medicine Lister Hill National Center, 1988, p. 8). By 1990 the Visible Human Project had caught the imagination of a broader constituency. A total of twenty-five participants at an NLM meeting in 1990 on electronic imaging included representatives from private industry, most notably Parvati Dev, vice president of CEMAX, and Alvy Ray Smith from Pixar Inc. Important medical associations were interested in learning more about the new initiative: the American College of Physicians, the Association of American Medical Colleges, the National Board of Medical Examiners, and the Institute of Medicine—all significant actors in the area of medical education—sent their executive officers to the NLM meetings. Finally, many prestigious medical schools—the leaders of the profession—were now heavily involved in the discussions. Donald West King of the University of Chicago served as chair of the planning panel, and faculty from Cornell University, Johns Hopkins University, Yale University, the Mayo Medical School, and the University of Texas, among others, all attended regularly.

While the earlier discussions had focused on technical and practical issues, the 1990 meeting on electronic imaging adopted a more philosophical and theoretical approach: the 1990 planning panel attempted to frame the topic in a long-term and conceptual framework. In this sense the discussions of the members of the panel were informed by influential contributions from the pioneers of computer graphics. Smith identified the central problem associated with electronic imaging of the body as one of classification of the pixels to individual organs. Thus, for example, a sample that falls at the boundary of bone and muscle tissue may represent some combination of both tissue types. Classification techniques could identify the pixels as either bone or muscle tissue and thus could introduce inaccuracies at the boundary of different parts of the body. Smith was optimistic that a more efficacious application of sampling methods might resolve the problem, but for scientists in the early years of the decade, classification remained a thorny issue (Smith, 1988, p. 93).

The National Library of Medicine, a component of the National Institutes of Health in Bethesda, Maryland, was the agency of the federal government principally involved in funding the research done in the Visible Human Project. As a consequence approval by the NLM Board of Regents was crucial for future progress: if the board expressed its commitment, federal research dollars would quickly flow to the academic centers around the country. Such approval was not automatic. For example, it was not clear to many members of the board how the electronic images were to be distributed, even if they were successfully created. It was conservatively estimated that imaging of the body would require 15 gigabytes. Given the capacity of most computers, that amount was clearly unrealistic: it would require a very long time to download and would require the storage space of approximately fifteen thousand floppy disks. Given such constraints, was it not unrealistic—even outlandish—to contemplate such a project? One member of the Board of Regents was more sanguine than most. Alvy Ray Smith, the executive vice president of Pixar, reassured the other members of the board that the technology might not yet be available but that in five years or less the problem would disappear: by the time the electronic imaging data had been collected, the technology would be available.

Smith, a graduate of New Mexico State University, had received his Ph.D. from Stanford in 1970 with a dissertation on cellular automata theory under the supervision of Michael Arbib. After teaching at New York University and the University of California, Berkeley, Smith worked at the New York Institute of Technology. Smith's academic research and his work in the Computer Graphics Laboratory at the institute served as excellent preparation for his subsequent work during the 1980s and 1990s.[1] In 1980 Smith moved to Lucasfilm as the director of Computer Graphics Research, where he oversaw all aspects of research and development, including the financing and production of feature film animation. He worked for Lucasfilm for six years during a period when the company was making an indelible mark on film production. In 1980 Lucasfilm released *The Empire Strikes Back*, a movie that eventually became the third largest-grossing movie of all time. The following year the company released *Raiders of the Lost Ark*, and in 1983 *The Return of the Jedi* appeared. Smith was a central figure at Lucasfilm, and in 1983 he supervised a reorganization of the company's computer division, giving the new division the name Pixar.

Along with his close colleague Ed Catmull, Smith engineered the spin-off of Pixar and its purchase by Steven Jobs in 1986. Smith was executive vice president of Pixar and responsible for computer software and hardware engineering, computer graphics research and production, and laser engineering. Under Smith's leadership Pixar recorded success after success: the company won an Academy Award for the animated film *Tin Toy,* and after Pixar teamed up with Walt Disney Pictures, Smith's

[1] On the New York Institute of Technology see Smith (2001).

research team won a series of Academy Awards and Golden Globes throughout the 1990s. It was evident to members of the Board of Regents of the NLM, therefore, that Smith's experience and knowledge of computer graphics was to be invaluable in assessing the feasibility of the proposed electronic imaging project.

On 18 January 1990 the regents met to consider the final report on electronic imaging. Elliot Siegel, assistant director for planning and evaluation at the NLM, briefly summarized the evolution of the project over the past five years, from the initial meeting of the Long-Range Planning Panel to the present. Dan Masys, director of the Lister Hill Center, followed his colleague with a detailed slide presentation that laid out the "opportunities for creating increasingly detailed and informative medical image banks made possible by large memory graphics computers, high-resolution displays, optical disk and other storage media capable of storing billions of bits, and high-speed computer networks for transferring this information over long distances." Masys was careful to list both the advantages and the hazards of the proposed project; everyone was mindful of a need to keep the regents fully informed of the NLM's plans. Thus Masys limned the various steps to be followed: the project not only had to acquire the raw data sets but also had to ensure that these could eventually be linked to "high-speed transmission networks" (Board of Regents, 1990).

Donald West King, the chair of the NLM Planning Panel on Digital Image Libraries, had originally been lukewarm toward the creation of a "visible human"; his reservations centered on the reluctance of medical schools to adopt new ideas. As King put it at that afternoon's meeting, "medical schools are notoriously independent and loath to adopt methods and curricula developed elsewhere." A reading of the minutes indicates that even as late as 1990 King was still hesitant to endorse the project wholeheartedly. He believed that the project was valuable, but only because "individual parts of the project would be enthusiastically embraced by medical educators . . . thus it is worth doing." Smith was less cautious; he urged the regents not to pass up this "rare opportunity to make an important contribution in an important field—the development of a digital 'Adam and Eve.' " Only the NLM had the ability to carry off such a project now; the technology was "exclusively American at this time." Smith was most persuasive in sketching the future capabilites of high-speed computers: in a few years it might be possible to develop image sets based on the Visible Human that "are disease-oriented, concerned with growth and development, [and] embryology." Smith's arguments at the meeting were persuasive, and the Board of Regents voted unanimously to adopt the plan (Board of Regents, 1990).

The suggestion for an anatomical atlas was a clear consequence of the efforts of several university laboratories throughout the 1980s to create anatomical computer maps of distinct parts of the body, most notably in such areas of research as the knee or the central nervous system. No single university, however, possessed either the technology or the funding to create a finely detailed atlas of the entire human body. Dan Masys remembered that the fragmented state of research and its attendant difficulties obtained cogent expression at the 1990 NLM conference: "No one had sufficient resources to complete millimeter and submillimeter resolutions . . . Most were working on specifics . . . and couldn't take on the whole human" (Richardson, 1990, p. 12). The task was, at least in theory, relatively simple once the funding and technology had been secured: the techniques of imaging volumetric data and translating the images into mathematical data—techniques that enabled scientists to project X, Y, and Z coordinates and to translate them into three-dimensional graphics on high-powered machines—had been learned successfully in several laboratories but only for limited and distinct areas of the human body.

The construction of an anatomical atlas for the entire body required researchers to image a cadaver through both computerized tomographic (CT) scans and magnetic resonance imaging (MRI) technology. Both methods would be necessary because each technique images different parts of the body: CT scans generate cross-sections of the body, highlighting bones, while MRI is sensitive to tissue and organs. Ackerman envisioned that the researchers chosen by the NLM to carry out the project would take an image of each of two thousand sections of a cadaver, each section being one millimeter thick. Scientists would analyze the information in each section and assign numbers that corresponded to the colors in the tissues of the cadaver: "the computer can manipulate the range of numbers from black to white and establish a grid pattern for the range of gray" (National Library of Medicine, 2001). After assigning numbers to the data on a white-to-black spectrum, scientists would translate the figures to correspond with red, green, and blue or spectral colors. The data obtained by photographing cross-sections of the body at one-millimeter intervals would be correlated with data obtained by the CT scans and MRI. Eventually the information scientists aimed to put all three sets of data into a computer and construct a series of voxels (volume pixels, or the smallest distinguishable box-shaped part of a three-dimensional image) and, by stacking voxels on each other, thus create an anatomically correct image of an organ or body part.

Even at this early stage, when the NLM project was merely a concept that had yet to take tangible form, there was great enthusiasm among other federal agencies for the NLM initiative. Thus the National Aeronautics and Space Administration (NASA) saw the anatomical database as an aid to medical education. According to Daniel Winfield, a senior research engineer at NASA's facility in Research Triangle Park in North Carolina, the space agency expected NLM's database would allow NASA to "test things that you can and can't do in space." Similarly, engineers at the Goddard Space Flight Center in Greenbelt, Maryland, expected to be able to use the anatomical atlas to "develop more accountable models of how the human skeletal system operates. That translates to how humans work with machines like space vehicles" (Richardson, 1990, p. 69).

For many of the early supporters of the NLM project, however, the most immediate applications of the Visible Human Project, as it came to be known, lay in medicine and medical research. In medical therapeutics physicians anticipated that the anatomical body, when seen on the computer screen, would help researchers develop new surgical procedures, ease routine medical operations, and help patients understand more easily the procedures they would undergo on the operating table. Medical students would no longer have to dissect a cadaver to gain an understanding, say, of the physiology of the heart but instead could go to the computer terminal for an almost effortless understanding of the cardiovascular system. Michael Ackerman anticipated that a student could practice open-heart surgery on the computer before seeing his or her first cadaver: "The database will contain every millimeter of the body, so any way you slice it, the computer will show you what the inside of the portion that has been cut looks like. That way the doctor will know what types of obstacles he may encounter in the course of surgery" (Baerson, 1991, p. 3). Postoperative procedures could also be better explained to the patient to help him or her comprehend the necessary steps to regaining complete health.

Constructing the Database

In June 1990 the NLM invited proposals from university medical research centers to bid for the contract to carry out the first stage of the Visible Human Project. Much to the NLM's surprise, interest in participating in the project was expressed by over one hundred medical schools in the United States. Within a short time the principal contenders for the contract had grouped themselves into six consortia, each of which put in a bid for the project. Ackerman and his colleagues at NLM narrowed the field down to three consortia and asked each group to provide pictures of slices, taken one millimeter apart, from the abdomen of an animal or human body. After judging the submissions, the NLM Board of Regents chose a consortium of institutions from Colorado, Texas, and Maryland (Brown, 1999). The University of Colorado Health Sciences Center in Denver—the lead institution in the winning consortium—regarded its successful bid as validation of the research work of CU medical scientists. Both Victor Spitzer and David Whitlock, the principal investigators at CU, had spent their careers in the study of medical imaging. Spitzer had graduate degrees in nuclear engineering and physical chemistry and had taught radiology, anatomy, and structural biology at CU for many years; Whitlock was a professor of anatomy at the University of Colorado School of Medicine. As a first step in the Visible Human Project the Colorado team needed to obtain an appropriate cadaver. Whitlock and Spitzer hoped to find a male cadaver in good physical condition, preferably between twenty and sixty years old, under six feet tall, neither overweight nor undernourished, and without surgical scars or traumatic injuries. Yet, as they soon discovered, such a request was not easy to fulfill (Bylinsky, 1993).

NLM's criteria were even more demanding. The library required that the Colorado team find and compare at least three bodies, all fulfilling the necessary criteria, of each sex. The source of the bodies was to be the state anatomy boards in Colorado, Texas, and Maryland, which are the recipients of corpses donated each year for purposes of medical research.

Even though an annual total of some three thousand bodies thus became available to the Colorado team, it still proved difficult to select the six cadavers, not least because they had to be free from communicable infections, such as hepatitis or tuberculosis, diseases that might threaten the scientists. Bodies of elderly individuals, even if they were free of signs of trauma, were not suitable since their body shape was far from the ideal that Spitzer and Whitlock hoped to approximate.

Not until August 1993 did an appropriate cadaver appear. Joseph Paul Jernigan, a high school dropout from a small town in Texas who had been dishonorably discharged from the army after using drugs, had gradually drifted into a life of petty crime after failing to hold down a series of menial jobs. In July 1981 Jernigan, realizing that he had been seen carrying out a burglary, caught up with his witness, a seventy-five-year-old man, and first stabbed and then shot his victim. Convicted of murder, Jernigan sat on death row through a series of appeals that consumed twelve years of court hearings. Jernigan had, by the date of his execution in August 1993, reached an accommodation with himself, if not with the victim's family, for as he told a wire-service reporter in a death-row interview shortly before his execution: "I know I did wrong . . . I have no one to blame but myself." A few days later Jernigan was dead, killed by chemicals passing into his body through a catheter attached to his left hand (Wheeler, 1996, p. 7; Laytner, 1995).

Spitzer, informed of Jernigan's death by medical colleagues in Texas, chartered a Lear jet to bring the corpse back to Denver, where the Colorado team worked around the clock to get the different sets of images of the cadaver through X rays, MRI, and CT scans. These scans were designed first to ensure that the body was undamaged internally and second to provide images that could complement the photographs—to be taken at a later date—of the cross-sections of the body. Once the initial sets of scans had been successfully completed, the Colorado team froze the body in a block of gel at –70°C and then sawed it into four sections. The body was not so much sliced as milled: beginning at the feet, a milling machine would take off one-millimeter slices, and an array of three cameras would film the cross-section of the body after the pass of the milling machine. The work was painstakingly slow, requiring four months to create almost two thousand cross-sections. Each new surface, which needed to be uniform in color with the preceding section, was cleaned with compressed air and sprayed with alcohol to prevent extraneous variations from appearing. Victor Spitzer emphasized the necessity to preserve a continuity between succeeding cross-sections: "The rhythm was very important . . . We wanted the top to be the same temperature every time we took a picture" (Wheeler, 1996, p. 7). The following year Spitzer began the second half of the Visible Human Project when he received the cadaver of a fifty-nine-year-old woman from Maryland who had died of a myocardial infarction (Roylance, 1995). Before her death the woman and her husband had decided to will their bodies to scientific research, but her identity was never released in order to guard the family's privacy. Although the woman's body was far from perfect (she had, after all, died of a heart attack), her suitability for the project became obvious once investigators found that her muscles and bony structures were well developed and that her reproductive organs—the cervix, uterus, vagina, and cardinal ligaments—were intact. The body had a subcutaneous and generalized fat deposition but that was to be expected and of little account to the research team. One significant drawback to using a female subject who was well into middle age came from restrictions on using a postmenopausal cadaver; thus obstetrical studies using the anatomical data provided by the Visible Woman would be limited, although medical researchers had predicted that they would be able to gain control over the musculature to simulate human prolapse (Whitaker, 1995).

For the Colorado scientists their experience the previous year in milling and filming Joseph Jernigan's body had enabled them to refine their techniques. Whereas the milling machine had ground down the tissue at a depth of one millimeter for the male, for the female subject, the depth was only 0.33 mm, thus providing three times as much detail ("CU Researchers Ready," 1995; McNamee, 1995). The process took considerably longer for the Visible Woman, approximately ten months for the milling and filming of over five thousand sections (Brown, 1999). Officials at the NLM believed the additional effort was eminently worthwhile. The NLM's director told the annual gathering of the Radiological Society of North America that "we demanded more of our technology and ended up with a significantly higher resolution for the Visible Woman than we achieved for the Visible Man. . . . Medical professionals can study the Visible Woman data to learn about female anatomy, perform better surgical planning, continue training and conduct research." Spitzer pointed out that scientists would also be able to interact with and manipulate smaller parts of the Visible Woman, in particular, smaller nerves and blood vessels (Whitaker, 1995, pp. 8, 9). The completion of the Visible Human Project represented a triumph of the first order both for the leaders of the NLM and for the team of scientists at the University of Colorado. Michael Ackerman remembered that when the project was first conceived in the 1980s any number of obstacles stood in the way of its realization, not least the primitive state of computing. In 1987 computer software still came on floppy disks, not CD-ROMs; modems ran at the glacial pace of 2,400 baud (compared with the typical 28,800-baud modems in computers in 1994); and storage problems seemed insoluble. The anatomical atlas data might take up, according to the best estimates, 15 to 20 gigabytes at a time when a home computer had only 60 megabytes of hard drive.

Indeed the project seemed so visionary or far-fetched, or both, that private-sector computing companies were reluctant to take on the task, fearing that the costs would be too high and the rewards either too low or indeed nonexistent. Nor did anyone even at the NLM anticipate there would be much demand for the anatomical data produced by the Visible Human Project. Given that it might take as long as a year merely to download the Visible Woman, library officials expected that the project would interest perhaps "half a dozen medical publishers" (Peltz, 1998). As with other research activities at the NLM, the success of the Visible Human Project illustrated the continuing tension between the public and private sectors. Research carried out with public funds and disseminated by the NLM at little or no cost was, in the eyes of some observers, being appropriated unfairly by commercial companies, which reaped windfall profits, while the NLM and by extension the federal government received comparatively little.

Academic and Commercial Applications

Once the anatomical database had appeared on the Internet in November 1994, there was a veritable stampede of software companies rushing to download the images and repackage them for sale. Gold Standard Multimedia, Inc., a company in Gainesville, Florida, created by Jonathan Seymour, a twenty-seven-year-old doctor, expected that the Visible Human Project would "do for medicine what flight simulation had done for the airline industry" (Gerlin, 1996, Section B, p. 1). Gold Standard Multimedia was one company that saw its future success linked to immediate access to the research emanating from Spitzer's laboratory at the University of Colorado. In return for a monthly payment of $35,000 from the company, the Colorado research unit, now known as the Center for Human Simulation, provided Gold Standard Multimedia with exclusive rights to a new database, one in which the body organs and structures were detailed and labeled. With this information Seymour planned to sell a three-dimensional "virtual reality" anatomy atlas for around $150. Gold Standard Multimedia also promised to pay the Center for Human Simulation 50 percent of the royalties from derivative applications (Gerlin, 1996).[2]

Other companies were also rushing to sell versions of the database. Knowledge Adventure, Inc., in Glendale, California, had previously produced anatomical software and, using the NLM data, was adding a full-body tour to its "3-D Body Adventure" CD-ROM for sale in stores for about $35. Visible Productions, Inc., a company based in Fort Collins, Colorado, planned to sell a "Bone Box" CD-ROM that would allow users to replicate motions of the skeletal system on a screen. HT Medical, a division of a company based in Rockville, Maryland, called High Techsplanations, Inc., planned to develop entertainment software for children based on the Visible Human and marketed like Nintendo games.

In reply to critics who charged that such companies were making profits from publicly supported research, the answer came back that the companies had made, and were continuing to make, substantial investments before they could realize a profit. Thomas McCracken, vice president of Visible Productions, Inc., acknowledged that the company paid no license fees either to the NLM or to the University of Colorado yet claimed that Visible Productions had already invested several million dollars in its educational series of CD-ROM packages: "We've pretty much based all of our research and development on the Visible Human Project. . . . I have no doubt that this is a revolution in anatomy and medicine" (Gerlin, 1996, Section B, p. 1).

Most observers readily perceived that the commercial companies were using public information that differed less in kind from the printed word than it might at first appear. True, some entrepreneurs were making quick and easy profits for no appreciable effort. Tim Helton, for example, a mechanical engineer from Florida, had produced a "Visual Man" CD-ROM that, as he boasted to a reporter, repaid his initial investment in fifteen minutes. Yet how did this differ from a best-selling novelist making millions from research based on collections at the Library of Congress? Since most of the CD-ROMs and other ventures based on the Visible Human Project were clearly produced for educational purposes, it seemed that the private sector was at least using the databases in a positive manner. Victor Spitzer, head of the Colorado research team, was both sanguine and stoical about the commercial uses of his research. The commercial use of his work was part of an American pattern of enterprise and initiative: "I expect there will be a few companies

[2] On corporate funding for the research at the University of Colorado see Hicks (1995).

built as a result of these data . . . and the government will make a lot of money from taxes" (Gerlin, 1996, Section B, p. 1).

Speculation in the popular media imagined a variety of commercial uses for the Visible Human Project data set. However, it was evident from the first conference at the NLM that brought together the users and researchers of the Visible Human (held at the Lister Hill Center in October 1996) that the more interesting and significant developments would come principally from university research centers. Participants presented research on simulation and modeling, segmentation, navigation, visualization, and data manipulation, but the dominant concern at the conference was, as one might expect from an academic community, still the uses of the Visible Human in medical education.

Researchers from Duke University gave some idea of how the Visible Human Project had already, in the few short years from 1993 to 1996, transformed the teaching of anatomy for medical students. At the beginning of the decade it was apparent that gross anatomy was inadequately taught at the Duke Medical School; the course was one of the shortest of any medical school in the United States, and the medical faculty was apprehensive that adding a formal course on cross-sectional anatomy would be both inadequate and difficult. The teaching materials—largely a collection of old CT scans—were hopelessly outdated, and the school's access to clinical images, particularly those from MRI, was limited.

Like medical professors in other schools, the Duke faculty found that most printed cross-sectional atlases were awkward to use and overwhelming in their amount of factual detail. Invariably there was an absence of exact correspondence between clinical images and body sections in anatomical atlases, a discrepancy that made comparison cumbersome and inefficient. Last but not least, students could not be tested on fine anatomical detail because of the poor quality of the images available to the medical examiners.

In other words, the anxiety felt by Cornelius Rosse many years previously that anatomy would eventually give up its place as a preeminent medical science seemed, to the Duke researchers at least, to be fully justified. Their ability to remedy the situation was, moreover, severely limited. Teaching of anatomy could be most effectively undertaken in 1992 with small groups of students, but this demanded large amounts of faculty teaching time. The Nasco Life/form abdomen images, commercially produced by a company in Wisconsin, was one way of teaching cross-sectional anatomy, but such images did not include correlated CT scans or MRIs. Annoyingly, the images were from an "elderly male individual with poor muscular development and some significant pathology, including a missing kidney" (Bushyhead, Bouvier, & Benson, 1996).

The discovery in 1993 by the Duke professors of the NLM's Visible Human Project was clearly an epiphany for the medical teachers. The Visible Human was everything that the Nasco images were not: for a start there were many thousands of body levels available; amazingly, there were no royalties to pay or copyright restrictions to avoid; the images were provided with correlated CT scans and MRIs; and the images showed no signs of disease, having been taken from a healthy and well-developed individual. Less than two years after they had first learned about the Visible Human images, the Duke team had implemented a new program, called the Cross-Sectional Anatomy Tutor, into the medical school curriculum. In many ways it served as a model and as an example of the work conducted in many other medical schools both within the United States and abroad. The Anatomy Tutor program enabled students to grasp orientation quickly while viewing body sections, CT scans, and MRIs; correlation of different sets of images was facilitated; and the inclusion of case studies provided a clinical context.

Other participants at the NLM conference could also testify to the impact of the Visible Human Project on the teaching of medicine. David Dean and Thomas Herbener from Case Western Reserve University praised the "Visible Human image collection [with its] high contrast images with virtually *in vivo* tissue colors. These cross-sectional tissue images are nearly perfectly correlated to a set of high resolution radiographic CT and MR grayscale images." The success of the Visible Human Project brought with it a new set of issues. The team at Case Western noticed that the sheer quantity of images was itself a problem: "Sorting through these thousands of images for relevant structures is a daunting task for first- and second-year medical students." Accordingly, Dean and Herbener proposed the creation of a Cross-Sectional Human Anatomy Atlas that would contain some two hundred cross-sectional images based on the Visible Human data set to enable beginning medical students to "develop sufficient comfort with cross-sectional images" (Dean & Herbener, 1996).

By the time of the first Visible Human Conference at NLM, knowledge of the project had spread like wildfire not only within the United States but also throughout the world. There were almost four hundred research groups in academic and industrial contexts employing some aspect of the Visible Human database. The uses of the Visible Human were, even in the early years, extraordinarily diverse: it was being used as the basis for models of radiation absorption and therapy; for models of crash injury; for ergometric design; and for the planning of surgical techniques (Spitzer, Ackerman, Scherzinger, & Whitlock, 1996; Spitzer, 1997).

The Visible Human Project had melded the research of university medical scientists initially involved in creating electronic images of discrete parts of the human body with the financial resources of a federal agency—the National Library of Medicine—preoccupied with the extension of medical informatics. Medical applications drove the Visible Human Project forward. By 1990 important medical institutions had grasped the significance of the research, and by the mid-1990s electronic images of the human body were being incorporated into medical school curricula. The Visible Human Project had succeeded. Its success was a consequence both of cooperation among government, industry, and academe and of an awareness of the benefits of information technology for medical research and medical education.

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