corridors, and water and sewage systems) withstand ground disturbance. Areas of potential slope failure should be zoned as inappropriate for urban development unless prevention measures are taken. Another factor when zoning for seismic hazards is the sensitivity of the ground to disturbance. Buildings located on solid bedrock will require different structural design from those located on easily disturbed soils, such as sensitive clays.

Natural resources. The rapid increase in population and urbanization throughout the world has generated major concern about the sustainable development of natural resources. Natural resources can be nonrenewable such as minerals and fossil fuels, or renewable such as water, biodiversity, and agricultural resources. Urban geology provides information on the nature and location of underground resources such as aggregate materials (sand or stones used for fill or in concrete), ground water, and minerals, but regional planning relies on other sources of information for resources of nongeological origin, such as forestry or agriculture. Planning for natural resources implies the identification of all the natural resources in the urban and surrounding area, and development of plans and regulations to preserve, protect, and promote careful use of these resources.

Value of urban geology. The benefits of urban geology go beyond regulating regional planning and development since it has a net positive value to society, including government, the private sector, the academic sector, and the public. The prime users of earth sciences in the urban environment are engineering and environmental consulting firms that use the information in preliminary project planning and design work. Since site-specific investigations are expensive, urban geology maps and models are used to provide estimates of the work to be done and the problems to be anticipated, resulting in considerable savings to the private sector. Substantial savings are also reported by governments in planning highways, facilities, land use, and public servicing in the most appropriate locations based on the nature of soils and bedrock. Mitigation of natural hazards can also result in substantial monetary savings and prevent the loss of human lives. Educational and research bodies, especially universities, often use geoscience maps and models provided by urban geology for teaching or training purposes. The public is also a major user of regional geoscience information for safety and knowledge of the local environment.

For background information *see* CONSERVATION OF RESOURCES; ECOLOGY, APPLIED; ENGINEERING GEOLOGY; ENVIRONMENTAL MANAGEMENT; GEOGRAPHIC INFORMATION SYSTEMS; GEOMORPHOLOGY; LAND-USE CLASSES in the McGraw-Hill Encyclopedia of Science & Technology.   Robert Bélanger

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Visible Human Project

For centuries, the study and findings of anatomy have traditionally been recorded in anatomical atlases—books of two-dimensional pictures representing three-dimensional structures. The early atlases contained idealized illustrations of anatomical features to give the viewer some sense of their three-dimensionality. Many modern atlases use photographs of actual dissections. These often contain artist renderings in order to make the photographs more understandable. Still, all atlases rely on two-dimensional art forms to represent complicated three-dimensional structures.

Realizing the limitations of the printed page, David L. Bassett from 1948 to 1962 used a three-dimensional photographic technique, popularly known as View-Master® stereo pair transparency technology, to photograph his dissections. In this way, he was able to capture the depth and spatial orientation of the anatomical structures. However, the stereo pairs still limited the user to the orientation of the photographer at the time the picture was taken. There was no way to change one's point of view of the object, to view it from the side instead of the front, or to move in closer to see detail.
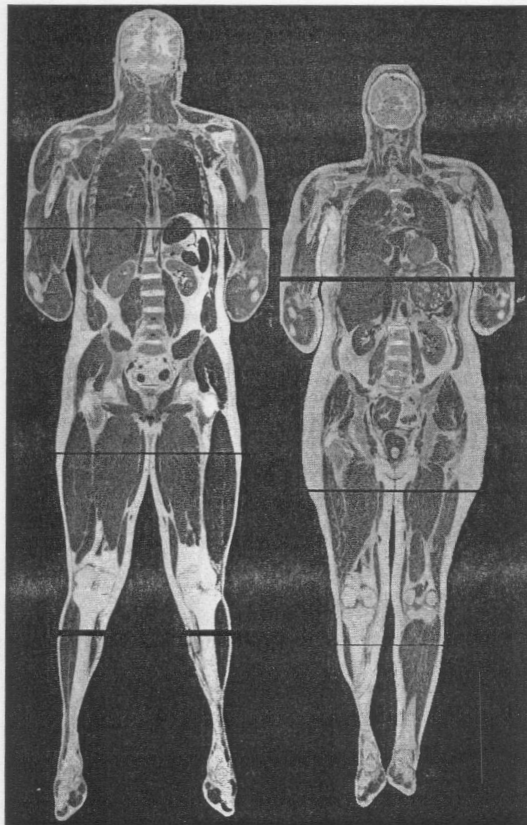

Fig. 1. Male and female frontal sections created by loading the Visible Human anatomy cross-section data into computer memory, aligning the sections in the memory, and then viewing the data as if a cut were made though the middle of the body from head to toe.

The Visible Human Project® of the U.S. National Library of Medicine (NLM) was designed to provide the sample-based data needed to reproduce in three dimensions any part of human anatomy down to 1 mm in detail (**Fig. 1**). To obtain the images that make up the Visible Human data sets, a male and a female cadaver were magnetic resonance imaging (MRI) scanned, then computerized tomography (CT) scanned, and finally frozen. Each frozen cadaver was filed down using a mill to produce a series of cross-sectional views of the body. Digital photographs were taken of the cadaver each time 1 mm was removed from the male and each time 0.33 mm was removed from the female to produce cross-sectional anatomy images.

The complete male data set contains 1871 cross-sectional anatomy images and is 15 gigabytes in size. The complete female data set contains 5189 cross-sectional anatomy images and is 39 gigabytes in size. Each anatomy image is made up of an array of dots (2048 dots wide and 1216 dots high), where each dot is one of 16,777,216 colors. Each CT image is 512×512 dots, where each dot is one of 4096 gray tones, and each MR image is 256×256 dots, where each dot is one of 4096 gray tones.

The new data acquired by the Visible Human Project, in conjunction with developing data manipulation technologies, have greatly increased our visual understanding of human anatomy.

Digital imaging. During the 1990s, it became clear that the digital computer could provide the missing technology needed to acquire, store, display, and interact with three-dimensional images. These computer images are reproduced by two fundamentally different methods: object-based and sample-based.

Object-based method. In this method, the picture is broken down into its fundamental geometric objects, such as a collection of polygons, whose shapes and surface qualities can be calculated by the computer to produce a likeness of a real-world object. The underlying representation is based on mathematical formulas for the geometric shapes that are combined to make up the complete object. The mathematics allows the computer to control groups of individual geometric components making up objects within the picture.

Sample-based method. This method is based on the acquisition, storage, and display of image samples taken of an original object. The pictorial data can be thought of as individual sample points (pixels) in a

MRI—proton density   MRI—T1   MRI—T2
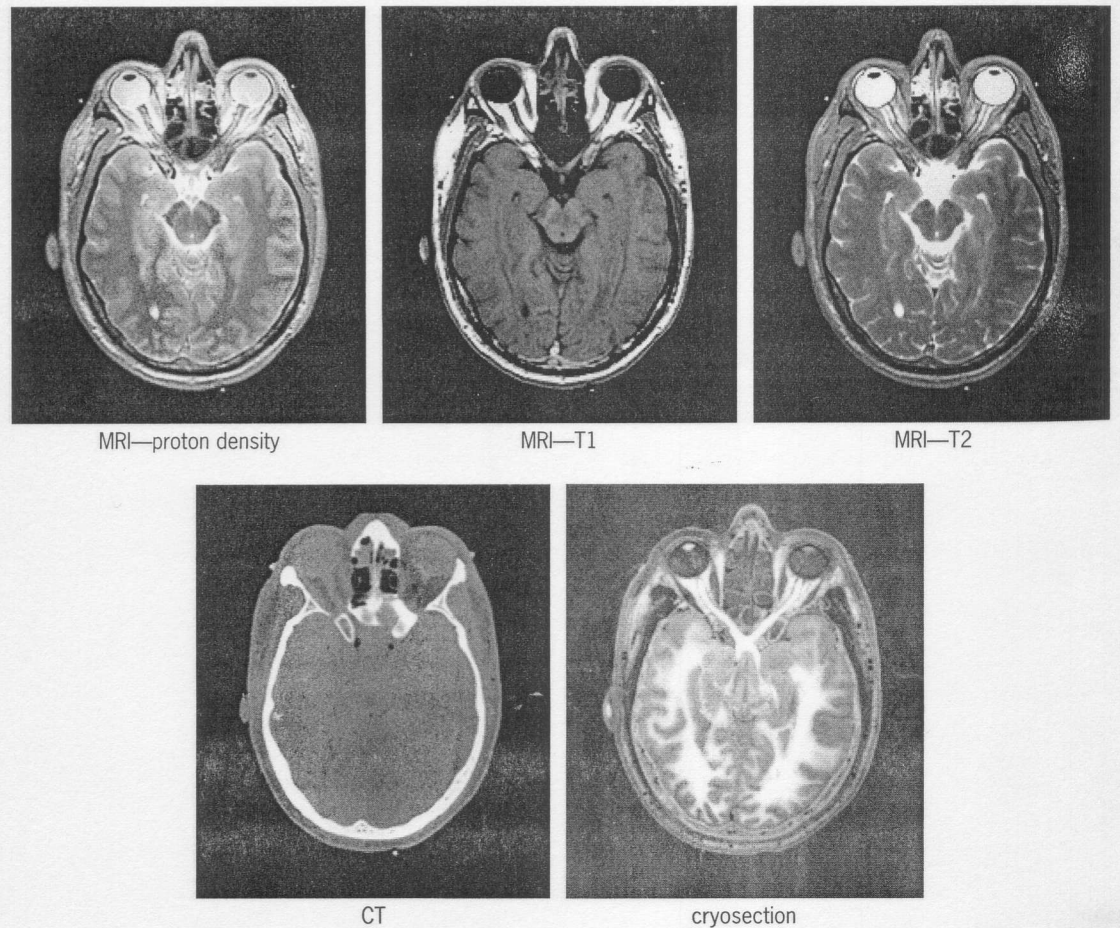
CT   cryosection

Fig. 2. Corresponding cross sections from the Visible Human MRI (various), CT, and anatomy (cryosection) data sets showing the nose, nasal sinuses, eyes, optic nerves, and brain.

anatomy
cross section

CT cross
section

anatomy
reconstructed
side view

CT
reconstructed
side view

combined
CT and anatomy
front view

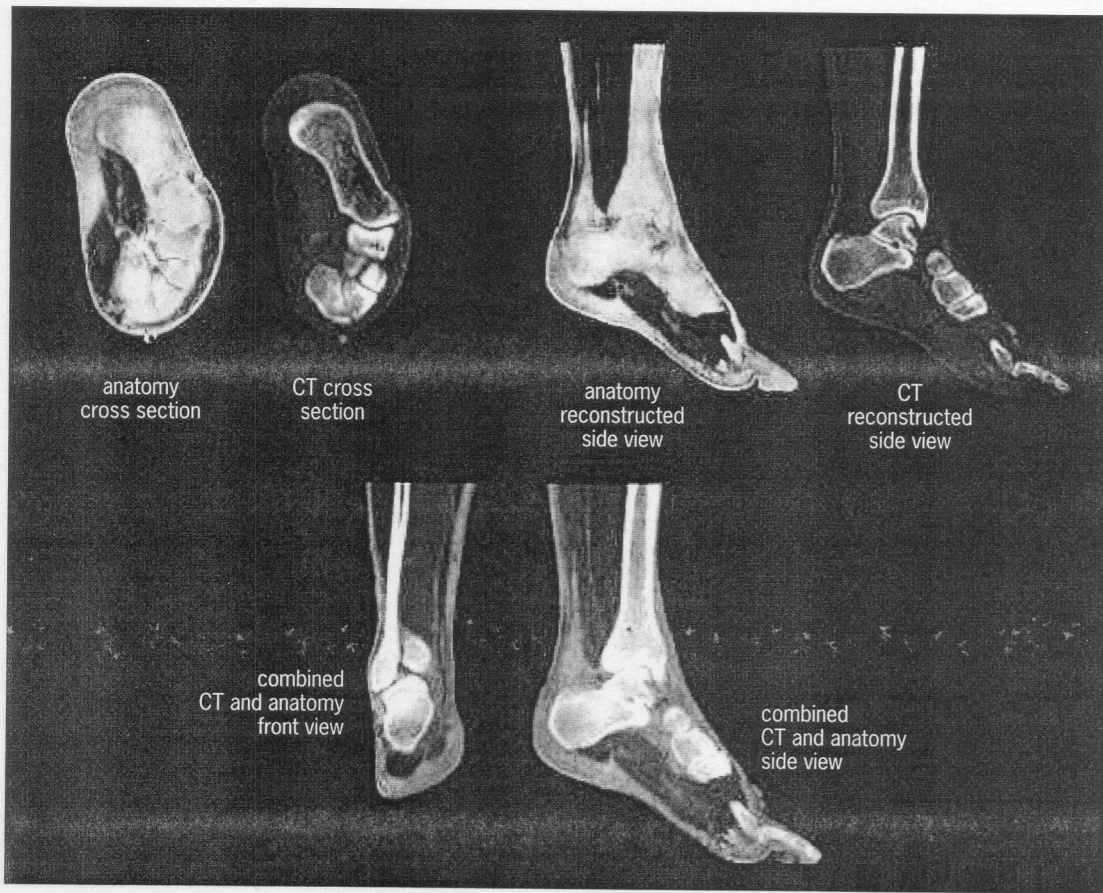combined
CT and anatomy
side view

Fig. 3. Reconstructions of the Visible Human male foot, as seen from the front and side, made from the CT and anatomy data sets to demonstrate the absolute coincidence between them.

large two-dimensional field which, when displayed together, create an object that is a representation of the original object. There are no mathematical formulas in this scheme, so the computer cannot control any of the objects within the image.

Image acquisition. The distinction between the object- and sample-based methods in terms of acquiring, storing, and displaying a digital picture is crucial to computer-based biomedical imaging. Most clinical images acquired with techniques such as magnetic resonance imaging and computerized tomography use the sample-based method. Thus, varying black, gray, and white patterns are displayed such that a physician can interpret them as various anatomical structures. But to the computer, the components of the image are not manipulable as independent structures (for example, lung, heart, or bone), except to the extent that some tissues share a unique gray-tone level (for example, bone). For perception of each element within a complex medical image, the identification of objects and object boundaries within the images is essential.

The need for anatomical, CT and MR images is based on the fact that physicians view radiological images but are expected to interpret and treat anatomy. Anyone who has seen an x-ray photograph will immediately understand that the image seen on an x-ray is very different from the anatomy itself. The same is true for anatomy seen on CT or MRI photographs. In fact, anatomy viewed on a CT photograph looks different from the same anatomy viewed on an MRI photograph.

Computerized tomography. Computerized tomography is an x-ray-based technique. Tomography is a technique by which only a single selected cross section through a three-dimensional object is photographed. Using a CT scanner, the radiologist obtains consecutive and equally spaced x-ray cross sections through a region of a patient's anatomy. Typical spacing between the cross sections is 3 mm for clinical use. The cross sections are then computer-assembled to create a three-dimensional scene.

Unexposed film is transparent, so it looks white. When film is exposed to light or x-rays, it becomes opaque and looks black. When x-rays pass through the body, they are reflected by hard tissue (for example, as bone) but are transmitted through soft tissue (for example, muscle). Therefore, on an x-ray photograph or a CT image, bone appears gray and white, and muscles generally appear black. There is no color, just shades of gray from black to white.

Magnetic resonance imaging. The basis of this technique is that water molecules have very weak but detectable magnetic properties. If living tissue is put

into a very strong magnetic field, sensors will detect the interference to the magnetic field caused by the water molecules in the tissue. Using sophisticated computer techniques, this effect can be interpreted as sequential cross-sectional pictures of a patient's anatomy. Typical spacing between the cross sections is 5 mm for clinical use. As for CT images, these cross sections can also be reassembled by a computer to create a three-dimensional scene.

To the untrained eye, MRI photographs look similar to CT photographs. This is illustrated in **Fig. 2**. In an MRI, soft tissue (for example, muscle) contains more water than hard tissue (for example, bone), so soft tissue causes more interference to the magnetic field. In the MRI photograph, this effect is represented as a lighter area. In a CT, hard tissue is denser than soft tissue and therefore reflects x-rays with greater efficiency. In the CT photograph, this effect is represented as a lighter area.

MRI technology is more sensitive to differences in soft tissue, while CT technology is more sensitive to difference in hard tissue. Clinically, CT is best for broken bones, and MRI for pulled muscles. In CT photographs, bones appear from gray to white depending on the bone density, while in MRI photographs bones generally appear black. In MRI photographs muscles appear from gray to white depending on the muscle mass, while in CT photographs muscles generally appear black. The physician must know how to interpret each of these imaging formats in order to relate them to a specific patient's anatomy.

Teaching aid. The Visible Human data sets contain coincidental CT, MRI, and anatomical images of the same cross section. These can be overlaid by the computer so that one can see the relationships between MRI and CT photographs and interpret their respective anatomical data (**Fig. 3**).

The consecutive cross-sectional nature of the Visible Human data sets also allows any part of the human body to be reconstructed by computer. The reconstructed organ can be rotated up or down and right or left, zoom in for a closer look at details and, given the proper software, even zoom inside. One can construct a reusable virtual cadaver that can be used indefinitely for the study and appreciation of anatomical complexity.

Outlook. In the near future, it will be possible to apply the techniques learned in building this virtual cadaver to build a personal virtual cadaver for each of us based on our own CT and MRI data. The National Library of Medicine, though a continuation of its Visible Human Project, will be working on computer-based software tools and Web-based methods to bring this futuristic dream into reality.

[This article was written by the author in his private capacity. No official support or endorsement by the National Library of Medicine is intended or should be inferred.]

For background information *see* ANATOMY, REGIONAL; COMPUTER GRAPHICS; COMPUTERIZED TOMOGRAPHY; MAGNETIC RESONANCE; MEDICAL IMAG-

ING; RADIOLOGY in the McGraw-Hill Encyclopedia of Science & Technology.   Michael J. Ackerman

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Water decontamination

For 1.5 to 2.5 billion people in the world, lack of clean water is a critical issue. It is estimated that by the year 2025 there will be an additional 2.5 billion people who will live in regions already lacking sufficient clean water. In the United States today, it is estimated that 90% of citizens live within 10 mi of a body of contaminated water. Large numbers of point (single, identifiable) and nonpoint sources having low flow volume [50 gal (190 L) per minute or less] contribute significantly to these water contamination problems. These sites pose a major unsolved problem because they also can be intermittent, reducing the cost effectiveness of many current mitigation technologies. The northeastern United States—with its large population, concentrated residential areas, industrial sites, livestock confinement operations, and the like—has many such sites where low-volume-flow water runoff and discharges need to be treated. In addition, it is estimated that there are approximately 500,000 abandoned hard-rock mine sites in the United States, many of them located in or near watersheds where acid mine drainage may release heavy metals into thousands of public drinking-water systems.

Decontamination systems. There are many technologies used today to remove contaminants from water, including reverse osmosis, synthetic resins, activated carbon, sand filtration, and inorganic substrates. Several of these technologies are very effective but can be expensive. Low-cost filtration systems are needed to remove an array of pollutants such as heavy metals, pesticides, herbicides, and other toxic chemicals; bacteria; particulates; nutrients; phosphorus; oil and grease; and nitrogen. Research has shown that lignocellulosic (plant-derived) resources such as wood and agricultural residues (for example, stalks, nut shells, and grasses) have ion-exchange capacity and general sorptive characteristics derived from their constituent polymers and structure. The polymers include extractives (those chemicals removed by solvent extraction), cellulose, hemicelluloses, pectin, lignin, and protein, which are adsorbents for a wide range of solutes, particularly divalent metal cations.

Lignocellulosic materials. Lignocellulosic materials are very porous and have a very high free-surface volume that allows accessibility of aqueous solutions to