# A New Dimension For Diagnosis

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Imagine the skilled surgeon being assisted by a precision robotic scalpel, guided with input from a CT scan. The idea seems quite possible, judging from University of Pennsylvania researchers who are developing a machine that will aid physicians and surgeons tremendously. By converting CT scans into detailed three-dimensional (3-D) computer images, generated at the speed of fifteen per second, the machine facilitates clinical diagnosis and surgical planning.

The research, headed by Dr. Samuel Goldwasser, assistant professor of Computer and Informational Sciences, is conducted in the General Robotic and Active Sensory Processing (GRASP) Lab in the Moore School. Corporations such as the National Science Foundation, the National Institute of Health, IBM, RCA, Digital Equipment Corporation, the Army and the Air Force provide the main funding for the GRASP lab, thus indirectly supporting the research project.

Modern medical imaging systems include computed tomography (CT scans), magnetic resonance imaging (MRI), positron emission tomography (PET) and ultrasound. CT scans are used to examine anatomy, as is ultrasound, which is based on the reflection of high frequency sound waves. The newest technique, MRI, permits the physical and chemical analysis of soft tissue, and PET examines the physiological processes of the body. All of these devices generate large quantities of 3-D information, usually in the form of a series of two-dimensional (2-D) slices representing cross sections of the body. A 3-D representation is obtained by stacking these 2-D slices. However, under Dr. Goldwasser's supervision, a student team is developing a system, known as the Voxel Processor (VP) that has much more flexibility in medical applications. The research team consists of Anthony Reynolds, who was responsible for the original algorithms, and Larry Ashery, Ed Walsh and Andrew Wolff, who designed the current prototype. Several other students involved in the digital hardware design and software applications and implementation include Ted Bapty, David Baraff, Ned Batchelder, Erica Liebman, John Summers, Dave Talton and Chris Warren. "Compared to 2-D slices, the system is light years

different. This technology will take off and in a few years will be as common as CT scans," Dr. Goldwasser said, during a recent demonstration of the VP. He is hoping that its effect on medical technology will be analogous to the transition from X-rays to CT scans.
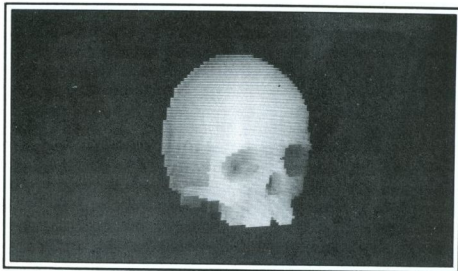

A dimensional image of a human skull.

The fundamental difference between the VP and its competitors is its unique, real-time, three-dimensional display and interaction. It generates 15 new pictures per second, over 500 times the speed of the fastest software-based techniques and roughly 20 times the speed of competing hardware technology. Thus, the operator receives instant feedback as he rotates and slices the object. The capability of the VP to manipulate grey-scale densities further enhances the operator's interaction with the object. One can view skin contours, then change the density map and strip away tissues of a different density to view the internal passages.

Another feature of the VP is that it displays dynamically changing objects but still allows for operator interaction. By displaying multiple frames of data quickly, the VP can simulate motion. For example, a beating heart can be displayed, and one can rotate and slice the heart while it is still beating.

Such a feature would not be possible without mass quantities of data, collected as large arrays of integers or voxels. A voxel is a 3-D cubical volume element. A number called the density is associated with the region of space represented by a voxel. In modern medical imaging devices (CT, MRI or PET) this scalar property may be radiological density, proton density or radiopharmaceutical concentration respectively. In the VP, the density values are available at all stages of the computation — permitting complex shading of the image. Using a recursive back-to-front time-ordered sequence, the VP performs volume rendering by mapping 3-D object space into 2-D image space. Voxels can be ordered (without sorting) and read out in a sequence so the hidden surfaces are correctly achieved.
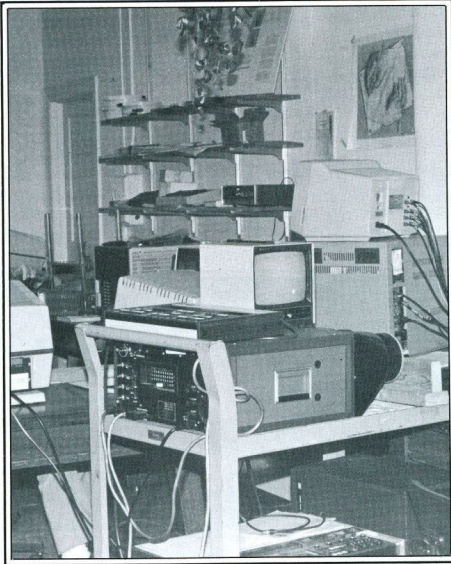
The General Robotic and Active Sensory Processing (GRASP) lab in the Moore School.

To reduce the problem of real-time display of 3-D objects to manageable proportions, it is necessary to partition either the input or output space or a combination of both. In multiprocessor implementation, partitioning input space avoids image memory access conflicts, which is necessary since a substantial amount of data reduction occurs in projection from 3-D to 2-D space. The current VP prototype is limited to a maximum object (input) size of 64 by 64 by 64 degrees, which means it can display 256,000 data points every fifteenth of a second.

Dr. Goldwasser envisions the next step as handling a 256-cube or larger object space, hence displaying a volume containing 16 million or more data points fifteen times a second, producing an image with much higher quality. He
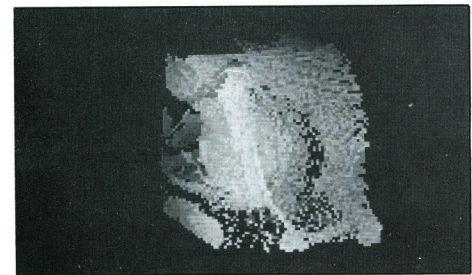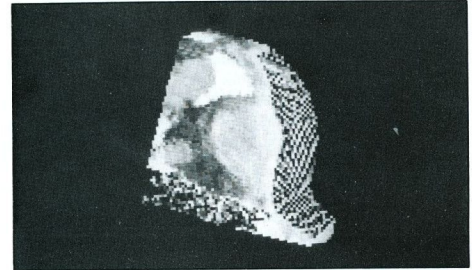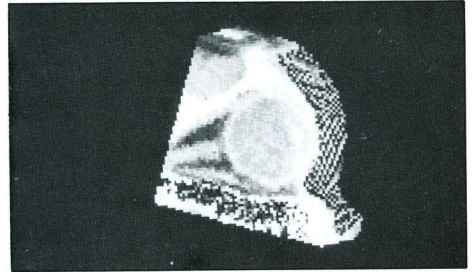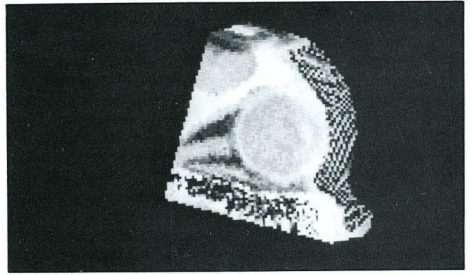
A rotating image of an eye, produced by Dr. Goldwasser's 3-D X-ray technique.

said his team is striving to "design an image equal in quality to the best software designs, while still retaining the same interactive capabilities." Matt Dunham is working to create even greater interaction with the display by developing a trackball, similar to the joystick used in video games, which would allow the physician to use the electronic scalpel to chisel away at the 3-D image on the screen, planning specific incisions. As for other improvements, Dr. Goldwasser said, "My fantasy is to have the whole skeleton stored on the system and have each of the joints move independently. Actually it's not a fantasy anymore, but a definite possibility. The basic theory has already been developed. All that's needed is more time and effort."

Dr. Goldwasser's system is the fastest in the world, and although the competing system generates a new frame every second, he feels the difference is significant. "Interacting in real time is much, much different. The 'jerky' motion of one frame per second as opposed to our continuous motion is like the difference between watching a slide show and watching a movie," he said. He believes real time display provides important cues to depth perception and visualization. With the ability to separate bone soft tissue or liquid, one can strip away obstructions and find otherwise hidden abnormalities and tumors. All of these enhanced capabilities contribute to a better medical diagnosis.

Clinical surgeons, especially orthopedic and plastic surgeons, make up the majority of the market for the Voxel Processor. Dr. Goldwasser refers to it as "a tool to make it much easier for the surgeon to visualize physical structures." Dr. Gabor Herman, chief of the medical imaging section of

radiology at the Hospital of the University of Pennsylvania, believes the device is quite useful to a clinical physician who has not been trained to read 2-D slices. However, he is quick to point out that, although the VP is an important medical breakthrough, it will never replace doctors in the diagnostic process. But Dr. Herman agrees that it could be an important learning instrument for medical students.

The VP has applications in other fields besides medicine, including geophysics — topographical analysis for oil exploration, mechanical engineering — visualization of 3-D solid modeling, defense — simulation of missile attacks and "not to mention the potential for 3-D video games," Dr. Goldwasser added. The ways of modern technology! ◣

A view of the equipment.