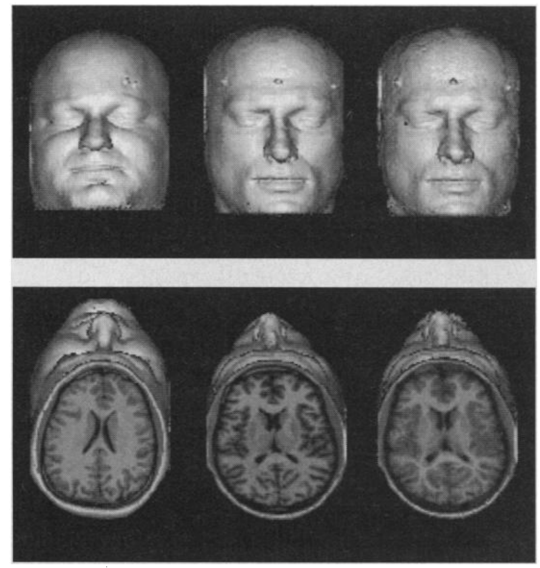
IMAGING SCIENCE

Computer Processing Gives Imaging a Sharper View

ARGONNE, ILLINOIS—One hundred years ago this autumn, the Prussian physicist Wilhelm Conrad Roentgen made the first x-ray images—one of them a picture of the bones in his wife's left hand. "An absolute avalanche" of techniques for seeing the invisible in medicine, materials science, and other fields has followed, notes Robert Beck, director of the Center for Imaging Science at the University of Chicago and Argonne National Laboratory. Most, like Roentgen's original demonstration, have exploited some new wave or particle to probe matter—everything from photons to particle beams to radionuclides to ultrasound. But 100 years after Roentgen, Beck and his colleagues agreed at an imaging conference* here last month, the most powerful imaging medium of all is turning out to be the computer.



Real meets ideal. A computer algorithm transforms a reference image *(left)* to match an individual *(center)*, imaged by MRI. The result is a new reference image *(right)* matching the individual in almost every detail.

Now that imagers have exploited seemingly every usable wave and particle to collect imaging data, says the University of Chicago's Chin-Tu Chen, "more and more, the analysis aspects will take over." Agrees Jay K. Udupa of the University of Pennsylvania Medical Center, "Image processing will dominate." At the conference, some of the ways in which it might do so were on view: strategies for combining information gathered separately into a single image, ways to gauge image quality without an independent measure of the object, and methods for computationally refining an image. While most of these techniques are being developed for medical imaging, biologists, materials scientists, and astronomers are all likely to benefit. As image-processing researcher Gary Christensen of the Washington University Medical School in St. Louis puts it, "To me, it's just an image. It doesn't matter what's in there."

Christensen and his colleagues—Michael Miller of Washington University, Ulf Grenander of Brown University, Richard Rabbitt of the University of Utah, and several others in St. Louis—are developing computer programs that can stretch, squeeze, and rearrange a brain image. The goal is to transform an image made, say, by magnetic resonance imaging (MRI) to match a standard "atlas" of a normal or diseased brain—or rearrange the atlas to match the image. Features and boundaries from the atlas can then be mapped onto the original image, giving doctors a powerful tool for planning radiation therapy for cancer and objectively measuring brain structures such as the hippocampus, whose volume and shape can be markers for schizophrenia.

Doing this kind of mapping by hand "takes a long time and is very variable," says Christensen. Some researchers trying to automate the procedure have developed computer algorithms that treat brain images as a "linear elastic" material, which can be computationally stretched and shrunk but not cut. That approach preserves the brain's basic topology, but the elastic restoring force often distorts key details. Instead, in an approach that Chicago's Chen says is "leading the field," Christensen and colleagues treat the images as a viscous fluid. On a supercomputer with 16,000 separate processors operating in tandem, the team allows an image to "flow" until it matches the atlas. The viscosity preserves the topology of the brain, and the absence of a restoring force minimizes distortions and allows each brain region to be transformed independently of other regions.

The technique not only makes it possible to identify anatomical features in an individual brain, says Christensen; it should also open the way to merging images from several different people for a sharper view of, for example, brain function. The transformations needed to map the brains onto a common image could be worked out with a high-precision imaging technique, such as MRI. The same mapping could then be applied to images of the identical brains made by positron emission tomography—a grainier, lower resolution technique that records brain activity.

But image processing can improve even an isolated image by applying "constraints"—known features of the object. In some objects, for example, all internal boundaries should form loops, because they outline organs or tumors; other objects have no sharp boundaries at all. Such prior knowledge cuts down on the number of ways to interpret noisy image data. Henry Stark of the Illinois Institute of Technology in Chicago, for example, showed how image data sets could be refined by comparing them with a series of hypothetical data sets, consistent both with some constraint and with the original data. The method "gives you a tremendous amount of liberty" to sharpen an image, says Stark.

The danger, as Harrison Barrett of the University of Arizona pointed out at the conference, is that such refining will eliminate crucial features of the image. To underscore his point, Barrett showed two images of the same brain, one image crisp and sharp and the other noisy and unattractive. "Clearly one image is very good and the other is almost worthless," said Barrett, who then turned the tables by noting that only the noisy image revealed the presence of a cerebral infarct. The "beauty" of scientific or medical images has to be defined in terms of a specific task, said Barrett, rather than simply their appearance.

Barrett went on to outline his group's procedure for judging how good an image is for a particular task and whether or not applying constraints will actually improve it. His group has developed algorithms that estimate all sources of noise in the image—due to detector inefficiencies, limited numbers of imaging particles or photons, object jitter, and so on—and then incorporate the noise into hypothetical images of the feature being sought, such as a tumor hiding within the folds of a brain. These images amount to realistic expectations of what the imaging system can deliver; by calculating the maximum amount of information an observer could extract from the images, Barrett comes up with a measure of the image quality for a given task—finding the tumor, say. He can then repeat the procedure for constrained images to see whether they are better or worse than unaltered images at revealing the target feature.

He warns, however, that the approach is "extremely computer-intensive." Those three words could become as familiar to imagers over the next 100 years as the bones in Mrs. Roentgen's hand have been for the last.

–James Glanz

*Theory Institute on Large-Scale Medical Imaging, held at Argonne National Laboratory on 25 August. Organizers: Man Kam Kwong, P. T. Peter Tang, Robert Beck, and Chin-Tu Chen.