Computational Bioimaging for Medical Diagnosis and Treatment

CHRISTOPHER R. JOHNSON

"THE future of radiology is not getting the data. We have plenty of data. The need is how to make use of all the data we have."
—*Dr. William Orrison, chairman, Department of Radiology, University of Utah, Salt Lake City*

The coming decades will experience an explosion in the use and scope of medical imaging, and the fuel for this fire will be computing and visualization. From Leonardo Da Vinci's anatomical drawings 500 years ago, to Wilhelm Roentgen's first X-ray of the human hand in 1895, to today's use of computer graphics and virtual reality to "fly through" 3D reconstructions of magnetic resonance imaging data, researchers have used visualization in their quest to understand human physiology. Each new visualization technique has brought them closer to capturing the complexity and beauty of human anatomy and physiology.

Though the complexity of the human body still outstrips the capabilities of even the most powerful computational systems—and will for some time to come—computer scientists working with surgeons and radiologists will produce higher and higher resolution and combine imaging modalities to create effective, interactive visualizations (see image).

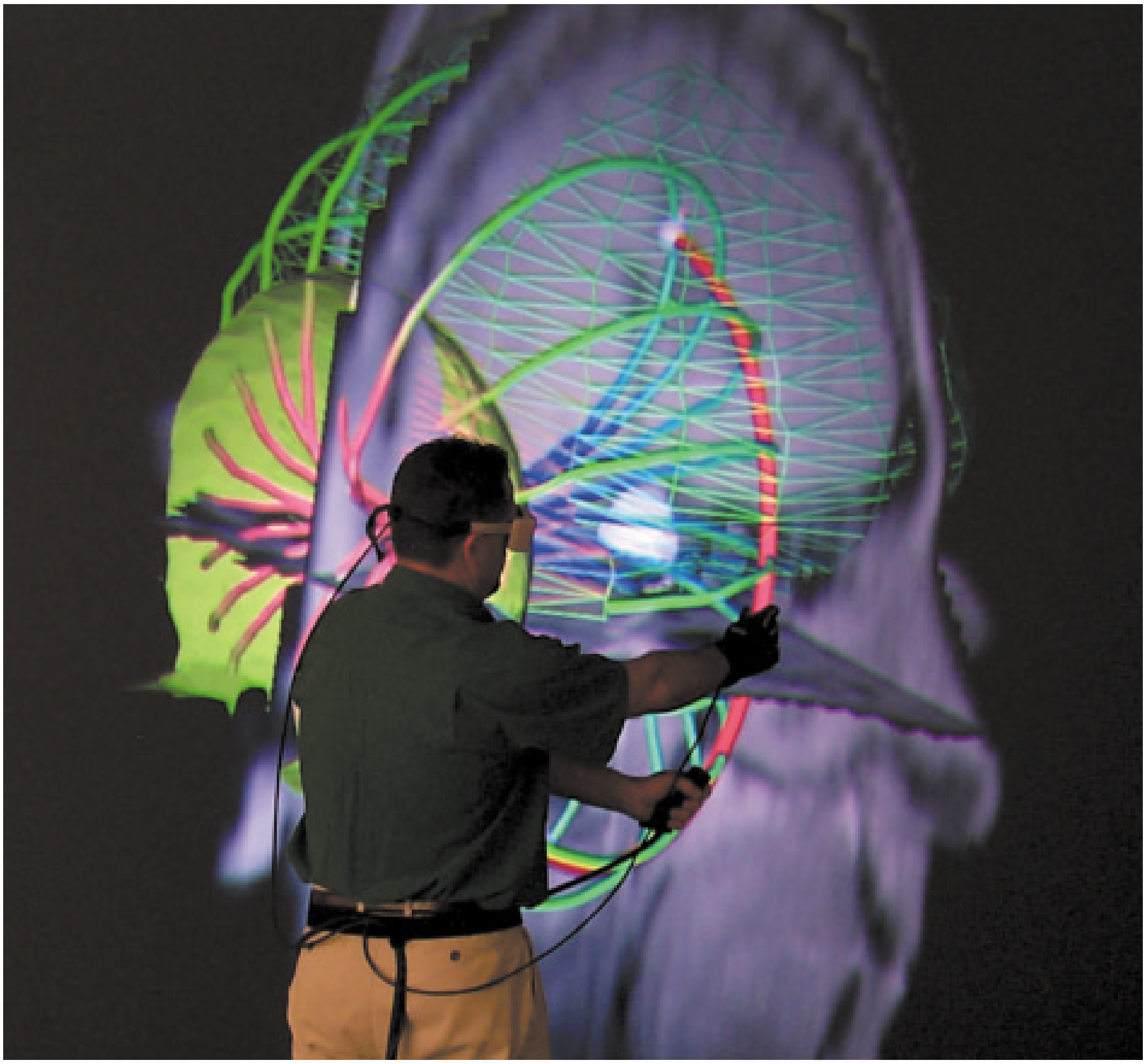
In particular, advanced, multimodal imaging techniques, powered by new computational methods, will change the face of biology and medicine. These imaging modalities will produce information about anatomical structure linked to functional data in the form of electric and magnetic fields, mechanical motion, and metabolism. This integrated approach will provide comprehensive views of the human body at progressively greater depth and detail, while the visualizations gradually become cheaper, faster, and less invasive. As a result, computer-assisted imaging will be more ubiquitous, in turn producing new scientific and clinical specialties that rely on special combinations of imaging, computer science, and medicine.

Today, researchers and physicians in a number of advanced medical research specialities are moving toward using computer images and visualizations within highly interactive virtual and enhanced-reality systems for diagnosis, treatment, surgical planning, and surgery itself. Other visualization techniques are being used for medical training. With the assistance of computers, the medical community now verges on important breakthroughs in diagnosing, controlling, treating, even curing numerous life-threatening conditions, including heart disease and various cancers.

I can say with certainty that medical visualizations will play an ever greater role in medical research and practice and that medical researchers will use visualization and virtual/enhanced reality to work collaboratively despite being separated by great distances. My conversations with Robert MacLeod, co-director of the Cardiovascular Research and Training Institute and professor of bioengineering, and Dr. Orrison at the University of Utah's School of Medicine have inspired the following even more farsighted scenario.

Upon arrival at a hospital, patients will press their fingers onto sensors that identify them through DNA analysis, then move down a short corridor in which they are scanned by a number of imaging devices, before arriving in a waiting room (there will probably still be waiting rooms in our medical future). Together with their physicians, they will view fully registered, multimodal, high-resolution, interactive, 3D visualizations of

Interacting with a large-scale model of a patient's head within a stereo, immersive environment; the colored streamlines indicate the current from a simulation of epilepsy. Created by David Weinstein, Dean Brederson, and Chris Johnson, Scientific Computing and Imaging Institute, University of Utah, 2000.



their anatomical selves (structure) as well as their functional selves (electrical, mechanical, and chemical). Immediately highlighted will be possible abnormalities in structure and function. Physicians will then be able to manipulate and further analyze various suspect regions and simulate possible treatments, from drug and gene therapies to minimally invasive surgical reconstructions. In the far future, one could imagine "at home" imaging and analysis systems that communicate remotely with physicians to support patient diagnoses and treatments.

No matter when this scenario might be implemented, some of its elements exist today. We are fast approaching a revolution in medical imaging and visualization as computer science and medical researchers collaborate to advance the state of the art in visualization and integrated analysis tools for the medical profession. These tools will improve diagnosis and treatment while effectively decreasing medical costs.

However, as rapidly as these new tools emerge, the extent of their medical effectiveness and

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benefit will rely on the presence of a new kind of scientist who combines expertise in anatomy and physiology with a specific set of skills in physics, mathematics, bioengineering, and computer science. The result will be a person qualified in "computational bioimaging."

Educational training will emerge as the largest obstacle to such a revolution, as universities tend to lag far behind advances in technology, especially in multidisciplinary application areas. However, if we begin today to win the commitment of legislative and educational bodies throughout the U.S. and of their counterparts around the world to train researchers and physicians to use the latest technological resources, a revolution in diagnosis and treatment will soon be upon us. C

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Computers and Biology

JACQUES COHEN

Can we replace costly and possibly unethical animal experiments by computer runs? Can we have computer versions of ourselves that can be used for medical experiments, reducing the danger of risky trials? I believe will have some positive answers to these questions in the centuries ahead.

It is safe to infer the major role that computer science will play in molecular biology for future generations. Both deal with discrete structures (for example, four nucleotides, 20 amino acids, triplets representing codons) and both also deal with a flow of control that regulates the generation of proteins (for example, operons), much like semaphores dictate program execution. The growing interaction between the two disciplines is reflected in the recently coined term "bio-informatics."

During the last two centuries mathematics played a key role in physics because it provided the foundation for establishing new theories. Computer science will play a key role in biology in the centuries ahead because those mathematical theories are mostly unsuitable. For example, the human genome project would be unfeasible without computers, and that task is just a minuscule fraction of what remains to be accomplished to comprehend the behavior of a cell.

Computers will be essential to simulate cells both at the micro and macro level. In the micro stage, one studies structure at the atomic level and must learn how proteins fold and interact. Proteins are the building blocks of every living organism and they are generated from DNA in a machine-like manner. The unique 3D geometrical shape of a given protein