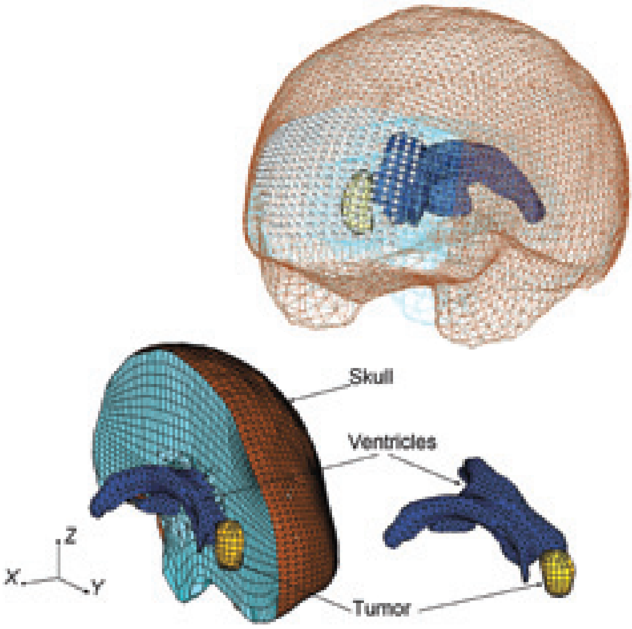
Brain power to transform the world's operating theatres

By Sally-Ann Jones

There is a fine line for surgeons between taking enough of a brain tumour out and leaving too much behind.

Now the world's most cited laboratory working in the field of brain biomechanics is set to revolutionise this surgery, to make the procedure easier and to improve patient outcomes.

UWA's Intelligent Systems for Medicine Laboratory is using biomechanics and computer science to transform risky soft-tissue surgery such as operations to remove brain tumours. The work is being trialled at clinical hospitals of Harvard Medical School in Boston.



Top: Geometry of the brain extracted from patient's MRI. Bottom: Patient-specific computational model of the brain

Lab Director, Winthrop Professor Karol Miller, is the editor of *Biomechanics of the Brain* (to be published soon by Springer), the first comprehensive book on the subject. He said the lab had been awarded substantial funding from the National Health and Medical Research Council, the Australian Research Council and the USA's National Institutes for Health.

Professor Miller explained it was essential for surgeons to know exactly how a soft organ, such as the brain, would change shape, or 'deform', during surgery. A pre-surgery magnetic resonance image (MRI) gives an accurate picture of the brain and the location of the tumour before the start of the operation, but during the operation the organ changes slightly and crucially, due to factors including anaesthesia, cerebrospinal fluid flow and interactions with surgical instruments.

"Traditionally, surgeons use 'mental projection' to estimate these changes, which can be up to 20 mm," he said. "Our work provides a patient-specific, very cost effective, very fast, very sophisticated intra-operatic guide that surgeons use while they are operating. Thanks to our algorithms working perfectly on graphics processing units, within 10 seconds one can get an accurate picture of the complexity of deformations from a basic computer.

"This means that neurosurgeons are more likely to feel confident cutting more of the tumour out, knowing they are leaving the healthy tissue behind," he said.

"We have attracted substantial grants because our methods of modelling the brain and computing deformities provide data that enhances neuro-navigation, already known to improve patient outcomes in other contexts such as treating epilepsy."

Professor Miller and his team use digitised models of a patient's brain that are developed from MRI. By segmenting 3D magnetic resonance volumes the neuro-images are transformed into geometric meshes or computational grids. They show, in different colours, the tumour, healthy tissue, and ventricles.

The images are then used for real-time computer simulation of the brain's deformation during surgery. The results can be viewed from every angle during the operation. The technology is so fast and easy to use that it does not interfere with a traditional operating surgery schedule.

"It is embedded in the clinical work-flow and is very useful in treating unpredictable pathologies and tumours of different sizes," Professor Miller said.

"At the moment, the brain models can be developed within a week of seeing the patient but we are improving it to the extent that it will soon be available within a minute. Instead of the mesh, we are working on meshless algorithms that work on 'clouds of points' which is much faster."

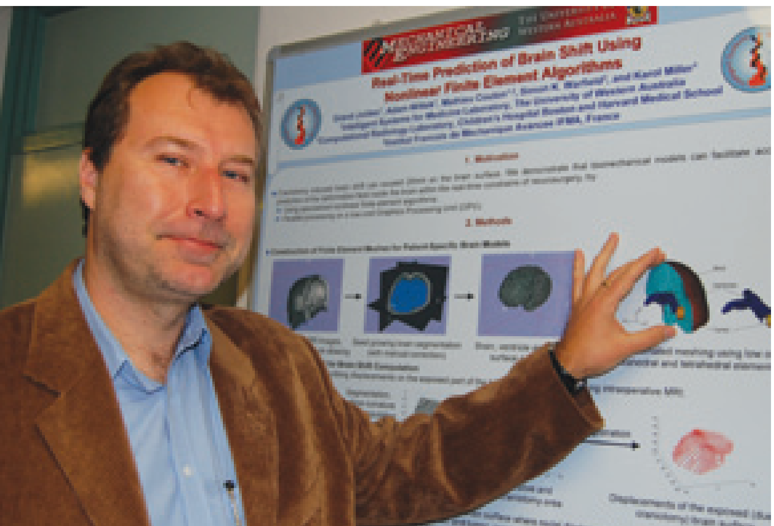
The system is not yet used in Australia, but is gaining traction around the world, particularly with American technology giant NVIDIA which is the major manufacturer of the graphics processing units (GPUs) used in computer games. Computer-simulation in medicine is fast gaining a major share of the market, Professor Miller said, with applications not only in patient treatment, but also in training surgeons.

Professor Miller has been named NVIDIA GPU Computing Champion and he is Moderator of the NVIDIA-sponsored Computational Biomechanics on-line research community, and a winner of an Outstanding Achievement Award from the Simulation Industry Association of Australia.

His students have also achieved acclaim. Stephen McAnearney is a Fulbright Postgraduate Scholar about to study for a MSc at Columbia University in New York. Seven years ago another ISML alumnus Stuart Munro was a Rhodes Scholar at Oxford.

Professor Miller's book, *Biomechanics of the Brain,* is the first comprehensive reference in this area of research. It covers topics from brain anatomy and imaging to methods of modelling brain injury and neurosurgery, as well as cutting-edge methods in analysing cerebrospinal fluid and blood flow.

Along with colleagues at UWA and Harvard Medical School, his lab collaborates with AIST and Keio University in Japan, ETH in Zurich, ICES at the University of Texas at Austin, Wayne State University in Detroit, Swansea and Cardiff Universities in Wales,



Winthrop Professor Karol Miller

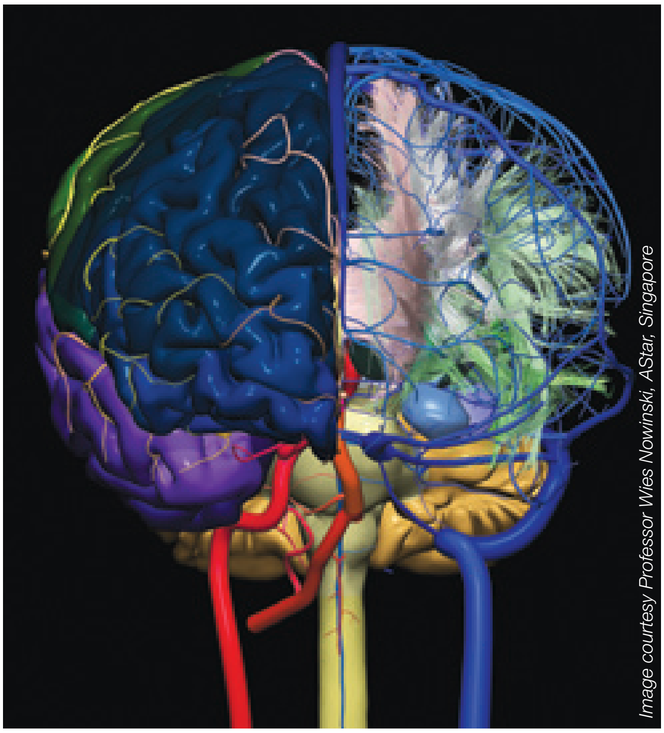


Image courtesy Professor Wies Nowinski, AStar, Singapore

the Institute of Heat Engineering at Warsaw University of Technology and the BioMedical Lab of the CSIRO in Sydney.

Professor Miller completed a Masters in Applied Mechanics and a PhD in robotics at Warsaw University of Technology before undertaking post-doctorate work in Japan in 1994.

"At that time, nothing was known about the mechanics of the brain or any soft organ, such as the liver or the prostate, that doesn't have mechanical, or load-bearing, function," he said.

He received a Doctorate of Science from the Polish Academy of Science in 2003. He is the Editor of the *Australian Journal of Mechanical Engineering* and a member of the editorial boards of the *Journal of Biomechanics* and the *International Journal for Numerical Methods in Biomedical Engineering*.

Along with applications in medicine, the laboratory's work has potential in mining. "Using our algorithms on GPUs can potentially allow computing large, highly non-linear problems between 500 and 5,000 times faster than using commercial software on standard computers," Professor Miller said. "Close-to-real-time interactive use of Finite Element Method computations for design seems to be within reach. (FEM is the most common computer analysis method in engineering.) This can be achieved on computing hardware costing around $10,000.

"Types of problems that we are able to efficiently tackle using our methods are large-deformation, non-linear solid mechanical problems. Such problems emerge for example in open-pit and underground mine design, mining and tunneling in squeezing and high deformation conditions, mining-induced seismicity research, fragmentation and explosion.

"General large nonlinear engineering computations that are currently most often subcontracted to specialised consultancies will be possible on desktop computers (such as the Tesla Supercomputer). Design engineers will be able to run simulations of their design concepts interactively, greatly increasing the number of cases they are able to consider.

UWA has started commercialisation of the algorithms. The Office of Industry and Innovation is talking with Dassault Systems, Rolls-Royce, Simpleware and others. So far the GPU-based FEM has been licensed to Kitware, USA.