UKHEC

Scientific Examples of Virtual Reality and Visualization Applications

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Medical Applications

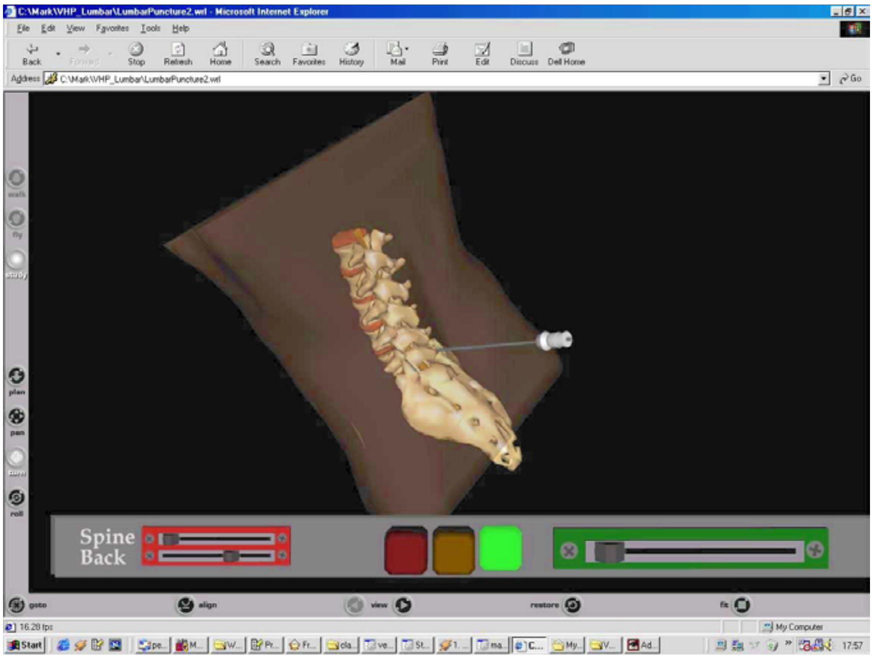
Medical scans now produce large 3D volumes of data. This data can be analysed by image processing techniques and then visualized to give surgeons an accurate 3D anatomical view of the inside of the patient non-invasively. This type of visualization can be used to aid a number of medical processes: diagnosis, quantitive measurement, surgical planning, surgical training and surgical simulation. Each type of application requires different VR technologies making it is a very diverse and popular area of research:

Medical Training

WebSET (http://www.hoise.com/vmwc/projects/webset/articles/websetHome.html) is a project to develop VR tools for surgical and physiological training. The project uses low-level VR technologies that can be accessed through the WWW. The tool has a collaborative interface, which allows trainers to assist trainees. A number of VR models are being developed both of physiological objects and surgical tools.

Surgical training works by the apprenticeship model, a trainee surgeon watches surgical procedures until they are thought to be suitably proficient, then they perform the procedure under supervision until they make the grade and qualify as a surgeon. Unfortunately there are several problems with the apprenticeship model:

- Learning the complexities of 3D anatomy is difficult and needs to be learnt by experience. The apprenticeship model requires this skill to be learnt from actual patients.
- It is difficult to assess the trainee's skills; there is no clear definition of "suitably proficient".

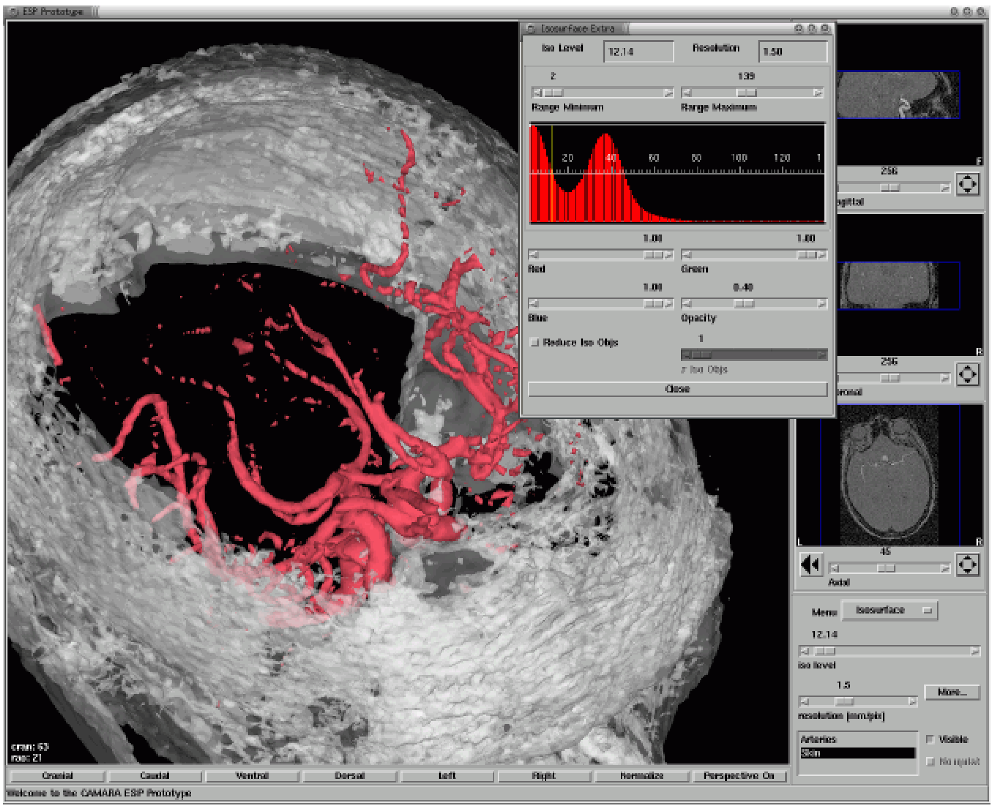


The picture shows the WebSET tool running through a web browser. This application is designed to aid lumber puncturing.

Medical Visualisation/Surgical Planning

Computer Augmented MRA System (http://www.man.ac.uk/MVC/research/camras/) aims to develop a clinically tested tool that will automatically select the optimal view of an aneurysm for the surgeon before surgery. An aneurysm is an area of blood vessel that is very thin, weak and prone to spontaneous rupture. Rupture is often fatal, treatment involves a small tube or catheter being inserted into the femoral artery in the groin and fed up into the brain and eventually into the aneurysm itself. A tiny flexible platinum coil is pushed through this tube into the aneurysm and the aneurysm is packed with platinum. The platinum promotes clotting and eventual healing of the aneurysm without the need for brain surgery. The risks and benefits of this endovascular coiling technique are currently being compared with standard surgical approaches. This tool assesses the shape, size and position of the aneurysm prior to the surgical coiling procedure.

The technique is based on non-invasive magnetic resonance imaging combined with state-of-the-art image analysis and visualisation to enable the operator to step through the entire operating procedure and take all essential measurements prior to the operation without risk to the patient.



The Endovascular Surgical Planning tool (ESP) provides a single interface for the different tasks needing to be accomplished.

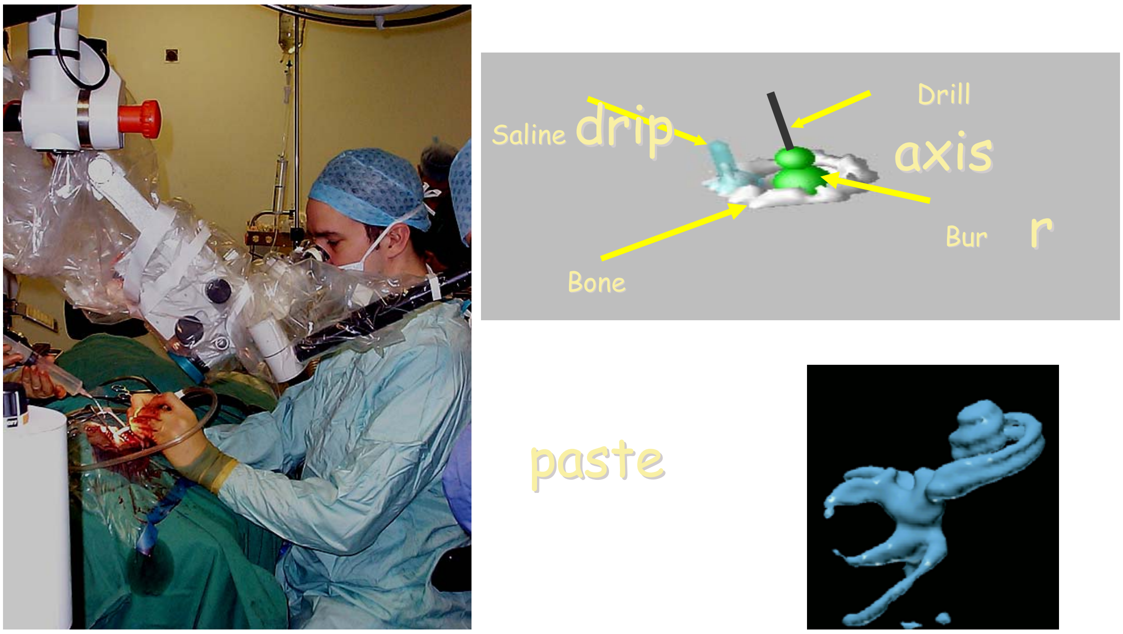
Surgical Simulation

IERAPSI - An Integrated Environment for Rehearsal And Planning of Surgical Interventions (http://www.hoise.com/vmwc/projects/ierapsi/articles/ierapsiHome.html) is a project similar to WebSET but using more advanced technologies so that it can be used to simulate actual operations with haptic feedback on data derived from the patient scans. It is aimed at specific surgical procedures that involve dissection of the petrous bone (the bony lump behind the ear) for mastoidectomy, cochlear implantation and acoustic neuroma. More exactly the tool functionality is:

- Image review and analysis tools to allow the surgical review of CT, MRI and angiographic examinations in an interactive 2D and 3D manner.
- An integrated suite of image segmentation and visualisation tools intended to allow rapid and accurate identification of individual structure based on their imaging characteristics.
- A physics based surgical simulation system with visual and haptic feedback for training surgeons to perform operations on individual patient data.

This surgical simulation involves:

- Initial Bone Exposure
- Drilling/Burring
- Instruments used for cleaning (e.g. irrigation and sucker); visual and (possibly limited) haptic representations
- Instruments used for hooking (e.g. thin bone), probing (e.g. manual testing for dura or bone) and peeling (e.g. neuroma tissue); visual and haptic representations
- Instruments used for special purposes (e.g. diathermy – standard probe and hoop; facial stimulator); visual and haptic representations
- Materials used for soaking or coagulation (e.g. *Surgicel* mesh or swab representations); visual only



The surgeon drills away bone to reveal the inner structure of the cochlea.

Augmented reality is another similar technique that will also be useful in assisting surgery in the future. Often modern surgery uses fibre optics or microscopes to make the site of the operation visible to the surgeon. These systems stream images to the surgeon and form the reality part of augmented reality.

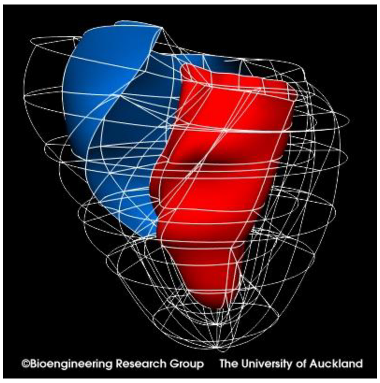
Before surgery appropriate radiological data can be taken of the patient and important anatomical features can be extracted and geometric models made, for example of nerve fibres. At the start of the operation the patient’s anatomy is registered to the radiological data. Now it is possible to calculate where the extracted nerve fibre lies in real space and virtual space. The position of the camera and surgical tools can be found by measurement or tracking systems. The geometrical shape of the nerve fibre can be precisely located and added to the image streamed to the surgeon. The surgeon now has the location of the nerve fibre clearly visible, augmenting the surgeons view so that the nerve fibre is more easily avoided.

Virtual Tissues

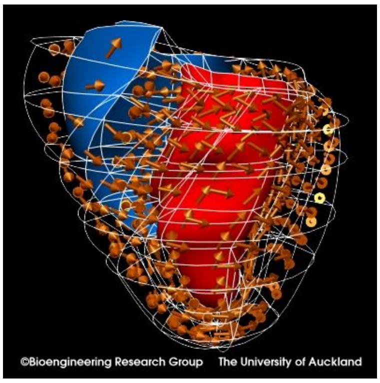
The bioengineering research group at Auckland University specialise in models of cardiac activation (http://www.esc.auckland.ac.nz/Groups/Bioengineering/). This has required them to develop a number of computational models of the heart, which in the future may be used in virtual reality.

This is a world-respected group that are part of the virtual human project (also known as the physiome project). The aim of this project is to construct a computational model that reproduces the physiological function and anatomical structure of the human body. It is a vast and ambitious project with a wide range of scales - from whole body to organ to cell to protein - and processes - mechanical, electrical and biochemical.

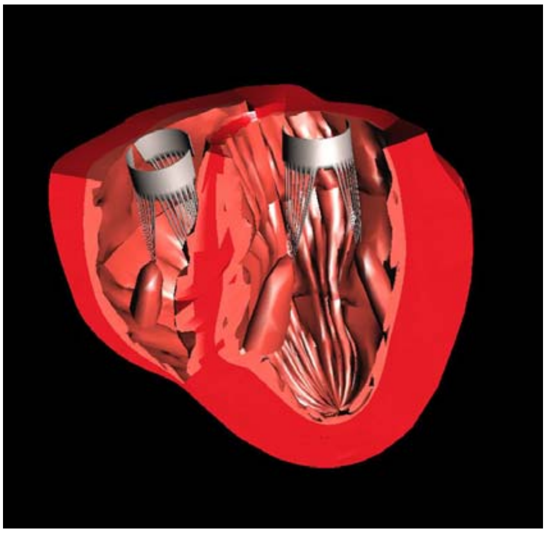
The group run their models on high performance computers but they are also strong on graphics with up to one quarter of their group working in graphics.



Finite element model is based on prolate spheroidal coordinates and uses linear Lagrange and cubic Hermite basis functions.



Fitted muscle fibres shown on with arrows in the volume of the heart mesh.



Details of endocardial trabeculations, heart valves and chordae tendinae.

Computational Fluid Dynamics (CFD)

Computational fluid dynamics have been used to design aeroplanes, cars and other vehicles. This is a commercially important sector since combining CFD modelling and VR prototyping they have drastically reduced their development time while improving the aerodynamic quality of the new vehicle.

For these reasons, companies that design planes and cars have been at the lead of CFD visualization. They have defined standard methods to visualize vector field flow for example by streamlines, glyphs or partial advection. One of the most important features of field flow is detection of vortices and some surface based methods like isosurfacing have been used to detect these. CFD examples normally have empirical data that needs to be compared against theoretical/simulated data. Comparative visualization allows errors to be detected in both observational or simulation data.

It is not only engineers who wish to use CFD, scientists who are trying to understand fluid flow in oceans or hurricanes may use similar techniques. The Proudman Oceanographic Laboratory (http://www.pol.ac.uk/) is new to VR but they have found 3D visual analysis very useful. They have recently developed a number of AVS/Express applications to examine their data and are applying for grants to get high-end VR hardware so they can work more interactively and collaborate more efficiently.

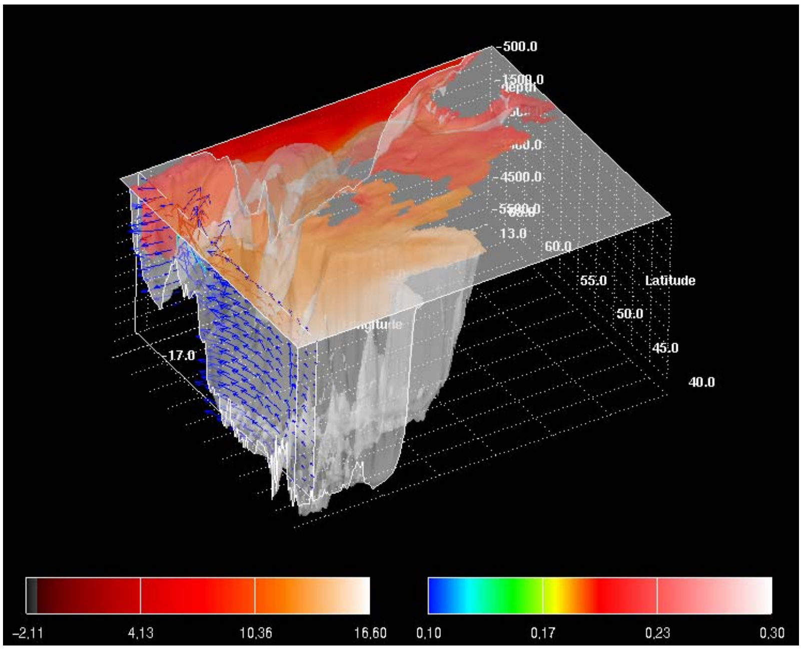
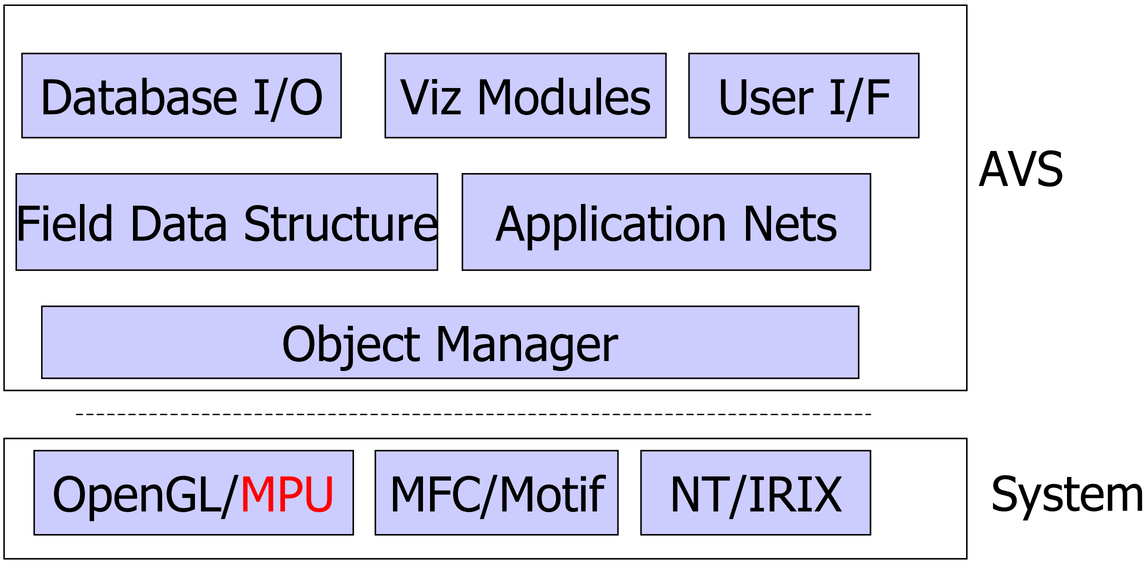


Image showing the currents in the North Sea: the data was produced by computational simulation at the Proudman Oceanography Laboratory Coastal Ocean Model POLCOMS.

Many applications like this would not be possible if products like AVS/Express Multi-Pipe Edition had not been developed. AVS/Express Multi-Pipe Edition is a product from Advanced Visual Systems with the multipipe renderer being developed at the Manchester Visualization Centre where the International AVS Centre is sited (http://www.iavsc.org/general/news/mpu.html).

The goal was to create a new rendering environment for any AVS/Express visualization application so it could take full advantage of parallel, large-scale immersive graphics facilities that use the SGI Multi-Pipe systems.

AVS/Express MPE software allows rapid construction and tuning of immersive applications, without involving a detailed understanding of the low-level multi-channel graphics programming. The structure of AVS/Express has been altered as little as possible, there is an internal switch embedded in AVS/Express that can change the renderer from OpenGL to multipipe. A user need not understand any internal details of the system can access this switch. The data visualization toolkit allows users to interactively visualize data in a full 3D stereo immersive display environment.



The structure of AVS/Express has been left intact but a MPU rendering engine has been put along side the old OpenGL one.

The AVS/Express Multi-Pipe Edition runs on Silicon Graphics® Onyx2® multi-pipe high performance workstations. Each pipe may have several display channels and projectors, for large screen or smaller Immersive desk stereo systems. The MPE software will also operate on any SGI IRIX system, in 32-bit or 64-bit modes.

Chemistry and Molecular Modelling

Visualisation by MAVIS

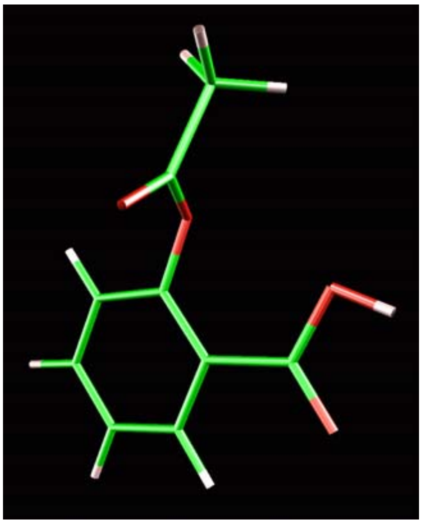
MAVIS, the Molecular Animation and VIsualization System (http://www.man.ac.uk/MVC/research/MAVIS/MAVIS.shtml), is a Molecular Graphics display and manipulation package designed specifically to interface to many popular Computational Chemistry codes. It is based on the widely available visualisation package AVS/Express and as such can be run on high performance graphics systems like the CAVE or Reality Centre.

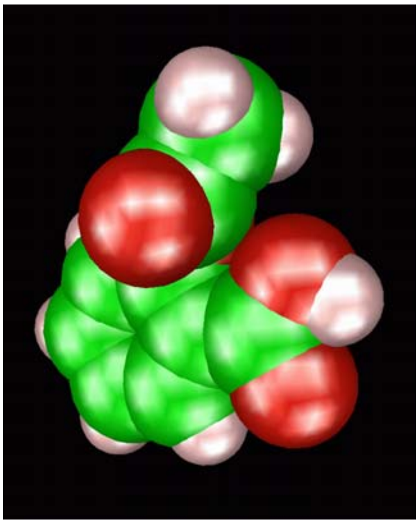
Interaction

- The package is designed to enable users to build and study complex molecules from both individual atoms and residues through the user interface.

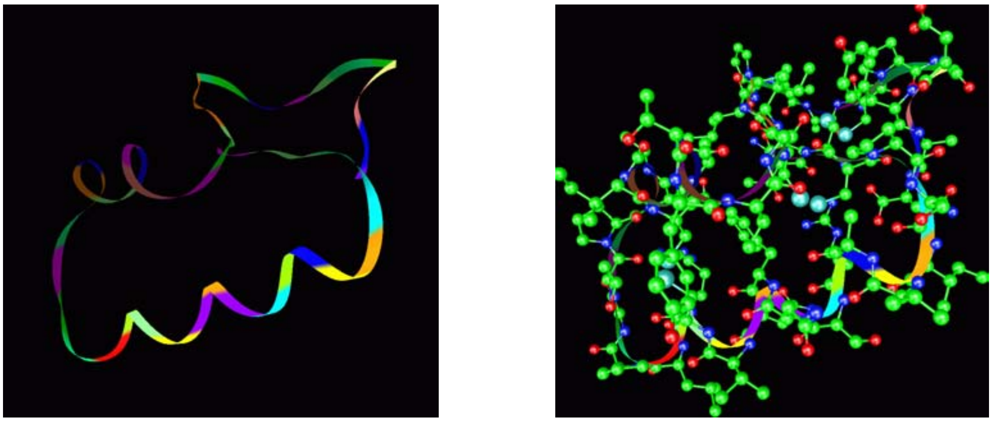
- It is capable of reading and writing many different file formats and has clear and consistent interfaces to many popular computational codes including MM2/MM3, Amber, MOPAC and Gaussian.

- The output structures can be viewed in any number of display styles, for both bonds and atoms, for small molecules through to large proteins.





The asprin molecule: the one on the left is rendered as a stick model while the one on the right is a space-filling model.



Protein molecules: the one on the left is rendered as an alpha chain while the one on the right also shows a ball and stick model.

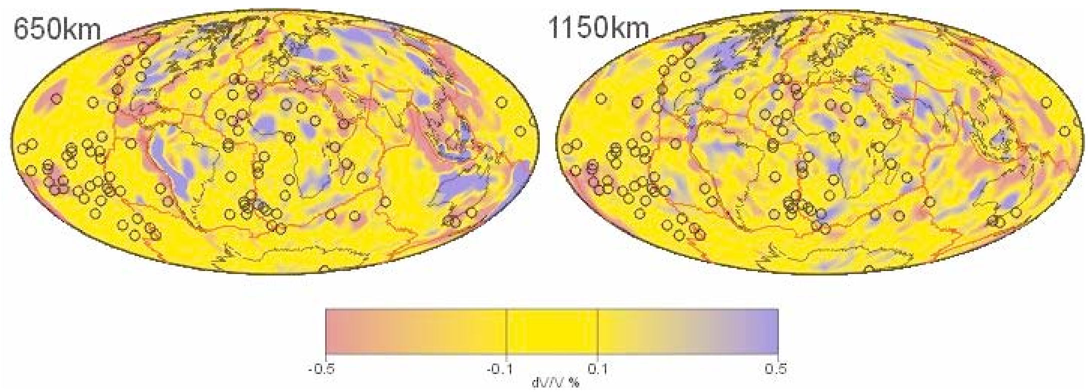
Earth Sciences

Many computational simulations are run on problems to do with the physics of the Earth on the surface, in the mantle or in the core. There is particular interest in this area because of its importance for the financially important oil and gas exploration industries. There are several common problems with VR of geosciences data:

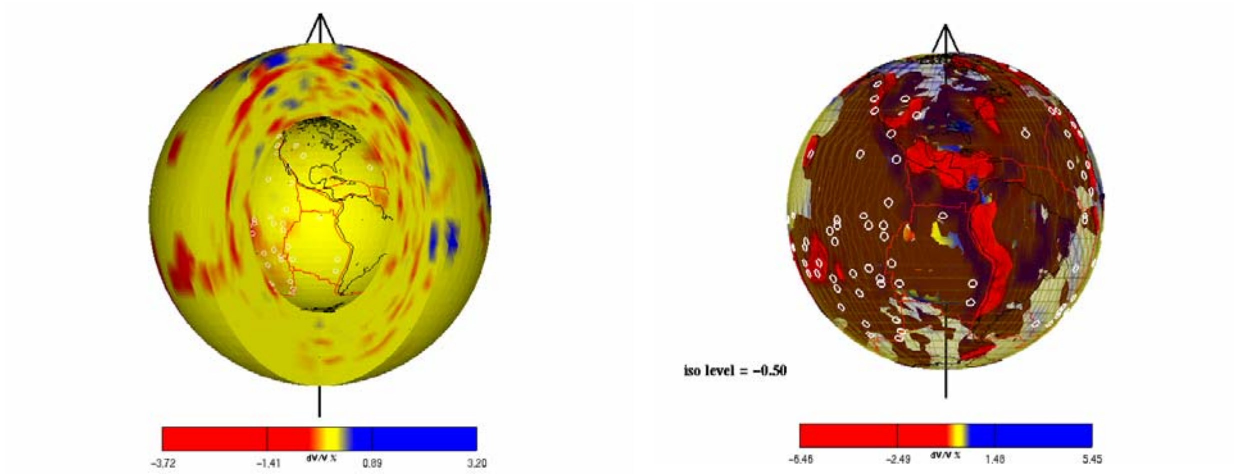
- The data sets are large and often cell based.
- There is an implicit curvature in the data because the Earth is a sphere and for large problems the data may be defined in spherical coordinates.
- Reference data needs to be registered to the model to make the underlying physics easier to understand.
- The data sets need to be explored collaboratively.

Using a high-end solution best solves these problems, a reality centre can deal with large volumes of data in stereo and can allow up to 30 people to explore the data together. The model may well be complex and need a graphics expert to develop the model and make sure it runs efficiently.

A UKHEC funded case study looked at the problems encountered by one geosciences group that runs their simulations on the CSAR service. The Terra group based at the University of Liverpool are investigating currents within the Earth's mantle. They were examining data as a series of 2D projections but this meant they could not fully understand the 3D nature of his data. A graphics expert helped them to build several applications that allowed them to examine his data new ways. The applications are designed so they can examine either low or high-resolution data depending on the capacity of the workstation they use.



2D projections of the data – the original method of visual data analysis.



3D visualizations of the same data in the 2D projection – on the left a segment is cut out of the Earth's mantle and on the right an isosurface shows the San Andreas fault.

Oil Extraction

The underlying physics of oil extraction is also an area of research. A research group at Queen Mary and Westfield (http://www.chem.qmw.ac.uk/ccs/) run simulations to try and find the best way to extract the most oil from rock. To do this they need to explore the parameter space of the problem and investigate the areas of parameter space that give the best solution. Analysis of each computational run is carried out visually by use of high-end visualization hardware.

Recent visualization hardware has such good rendering capacity that for many applications the visualization bottleneck has moved from the renderer back into the visualization pipeline. Many visualization systems are now developing parallel strategies for their visualization processes. VIPAR, Visualization In PARallel (http://www.man.ac.uk/MVC/research/vipar/) was a proof of concept research project that tried to put parallelisation into the visualization pipeline in a portable way. It was aimed at high-level visualization packages like AVS and Data Explorer because they already had many users and good visualization functionality. At the other end its portability was aimed at connecting to a number parallel libraries.

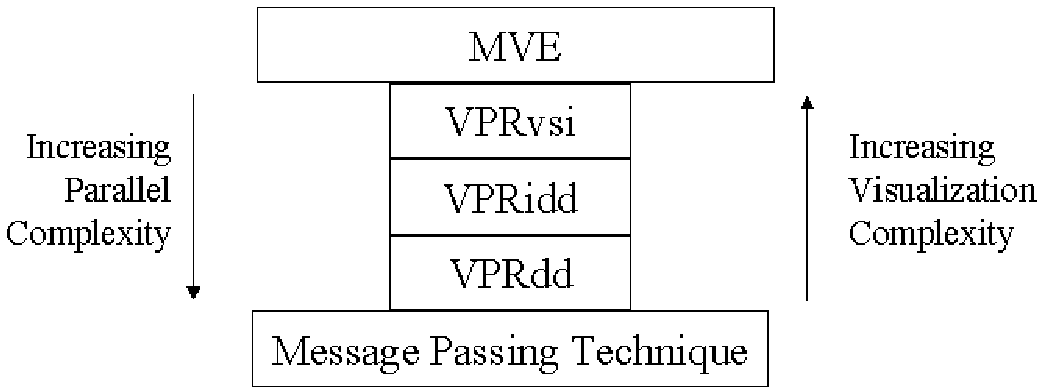
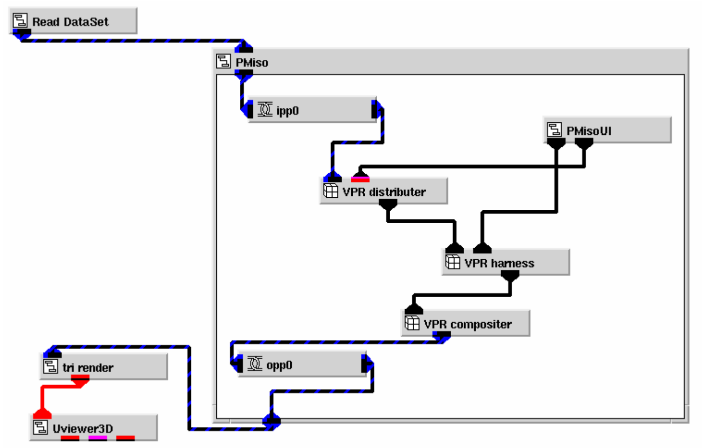
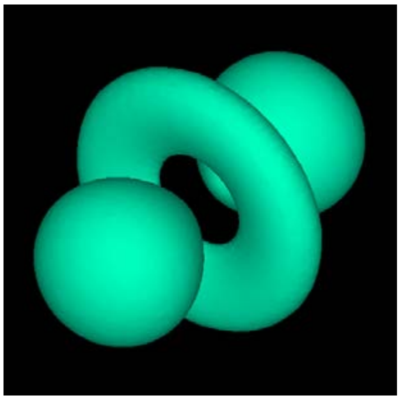


Diagram to show the complexity of VIPAR – the core VPR libraries are the same for all VIPAR applications while the MVE (Modular Visualization Environment) connects to different visualization systems and Message Passing Technique may also change. Both these features add portability to the system.

VIPAR is a project that has been recently reopened so it can benefit the researchers at Queen Mary and Westfield by improving the speed of the visualization pipeline within AVS/Express. The aim is to take VIPAR out of research and to make a stable product that can communicate through a portal to other machines and parallel libraries. Not only would this improve the performance of VIPAR but would enable computational steering and reuse of computational functions within the visualization system.





A VIPAR application developed in AVS/Express: The network on the left produces the associated isosurface on the right.