

Visualisation: An introduction

What is it?
What is it good for?
How does it work?

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Outline

- Visualisation, what is it?
- Data types and characteristics. Volumetric data.
- General techniques, tools, technologies, standards.
- Exploiting characteristics of the human visual system: stereoscopy, immersion.
- Challenges for those working in the science visualisation field.

- Case studies from recent projects.

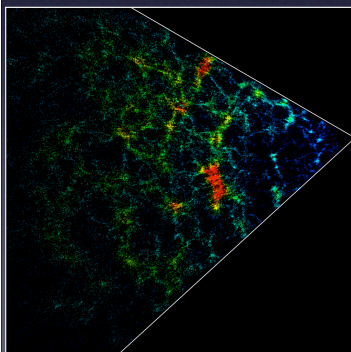
- Hands-on example: Volume visualisation using Drishti.
- Demonstration of hardware in the visualisation laboratory.
Stereoscopic projection, iDome immersion, holograms, tactile examples.

Data Visualisation: What is it?

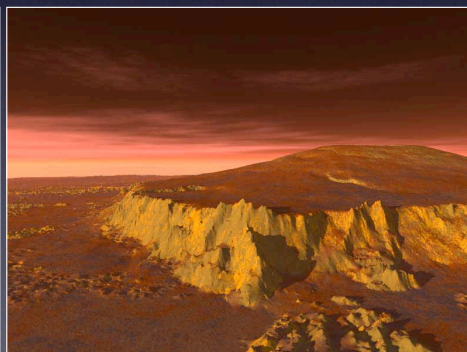
- Presenting data in an informative way using computer algorithms and computer graphics.
- Distinction between data and illustrative visualisation.
Illustrative visualisation: conveying a understanding of some principle without necessarily any real data being involved.
- Research orientated scientific data visualisation.
 - Finding relationships in datasets (Data sourced experimentally or from simulation).
 - Faster understanding of relationships in datasets.
- Not uncommon and valuable visualisation outcome is data checking and verification. Errors are also more obvious when seen graphically/visually.
- Differences in visual approach depending on the audience
 - Presentation to peers can often assume a discipline specific visual language.
 - Presentation to an expert audience.
 - Public outreach and education may require more engaging visuals or environments.

Data types/characteristics

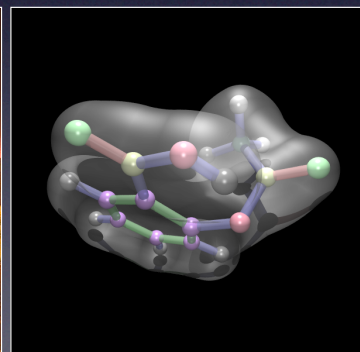
- Dimensionality, number of independent variables.
- Variable types: binary, scalar, vector. Discrete or continuous.
- Static vs dynamic data, single image vs movie, dynamic data vs camera animation.
- Geometric elements required to represent the data: Points, lines, surfaces, spheres, cylinders.
- Data sampling, regular grid in 2D (surfaces) or 3D (volumetric), or irregular sampling (common in simulation data).



Astronomy survey data



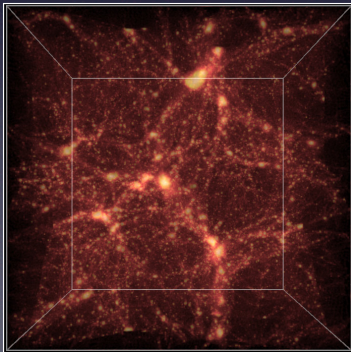
Terrain models



Molecules: sphere, tube, surface

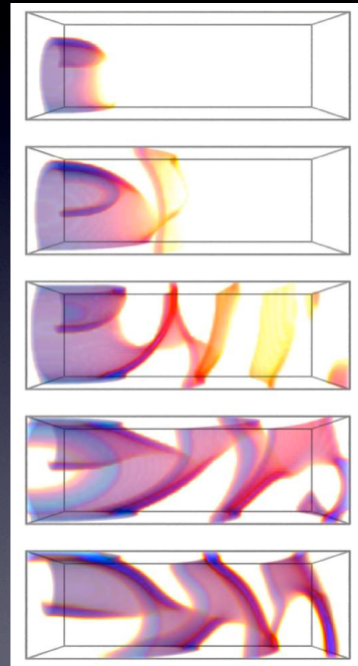
Volumetric data

- Volumetric data. 3D pixels = voxel.
- Generally a scalar (from 3D scanner) defined at every voxel but can be vector or even higher dimensional data type.
- Not always a regular sampling, but usually is.
- Has always been a challenge, as hardware capabilities have increased so has the size of the volumes researchers want to visualise. Increased volume resolution arising from both scanning technology and simulations from increased HPC capability.



Volumetric data example from cosmology

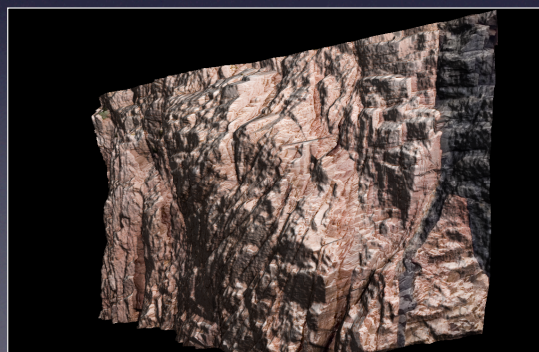
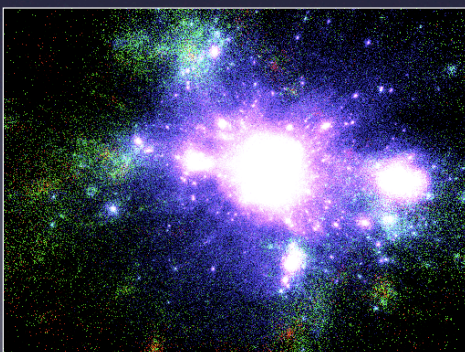
Velocity mapping - time varying



Data set size

- Often need to deal with very large datasets. Often larger than existing packages can handle, thus requiring customised solutions.
- May be too large to fit into memory.
 - Various strategies to deal with this, tend to be highly application dependent.
 - May need to use optimal data structures.
- May be too much data to transfer to graphics card for interactive frame rates. Techniques for dealing with this: Pre-culling, scenegraphs
More recent model: Server (HPC) based rendering and distribute the image frames.

5 million points per time step



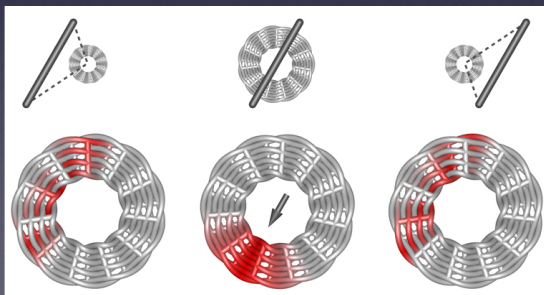
General techniques

- Mapping data objects geometric primitives. Sometimes a clear one-to-one correspondence, sometimes not.
- Mapping mathematics or abstract relationships to geometry.
- Mapping variables to colour, transparency, glyphs.
 - Discrete or continuous colour ramps.
 - Circular or unidirectional mappings (eg: circular colour maps for angles).
 - Consideration of the capabilities of the vision system and viewer variation.
 - Not always in RGB space, eg: HSV, YUV.
- Representation of data in different topologies or coordinate systems.

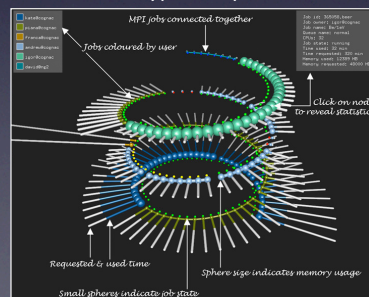
Colour ramps



Abstract mathematical model representation



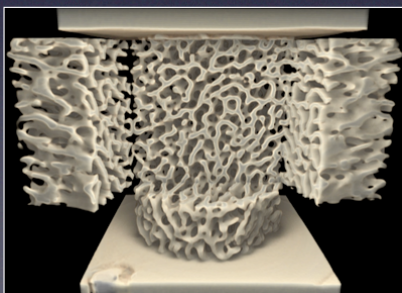
Glyph example



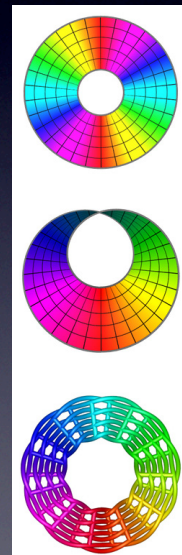
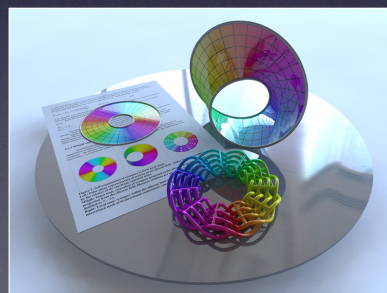
General techniques, continued ...

- Slicing/cutaway to see inside data, as well the use of transparency.
- Rendering quality: Simple lighting models for realtime APIs, to more realistic light simulations based upon raycasting, raytracing, and radiosity.
- File format conversion. Occupies a significant amount of time for those working in this field, lots of data file formats and generally poor conversions.
- Dimension reduction: projections, contours (3D->2D), isosurfaces (4D->3D).
- Realtime/interactive vs precomputed. Various hybrid methods exist to interactively explore datasets with precomputed elements.

Drishti

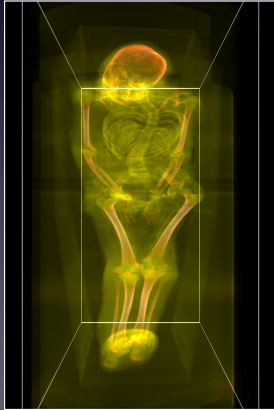


Environment maps and radiosity



Industry standards, packages, and file formats

- General visualisation software: OpenDX, VTK, AVS Express, IRIS Explorer, AMIRA,
- Discipline specific software: APS++, RasMol, Vis5D, VMD, ...
- APIs: OpenGL, DirectX/3D.
- File formats: HDF, NetCDF, FITS, DICOM “hundreds” of others.
- Researchers often dream up their own formats, sometimes appropriate, sometimes not.

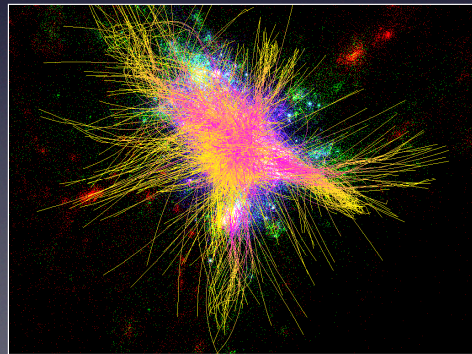


Direct rendering



Isosurfaces

“Standards are good, lets have lots of them.”

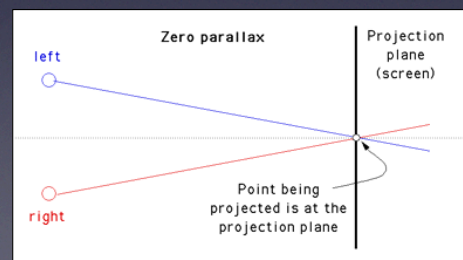
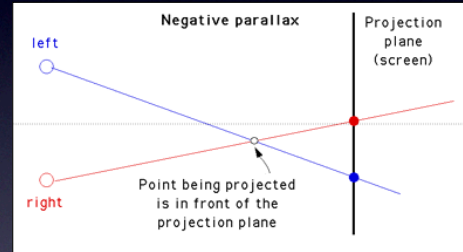
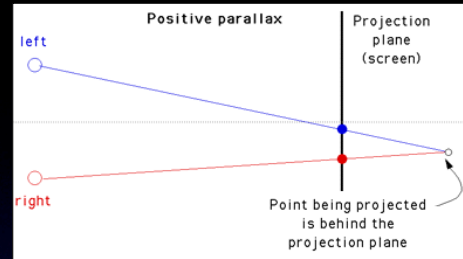
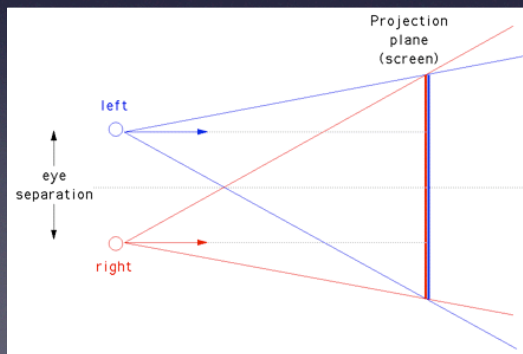


Exploiting the human visual system

- Visualisation is primarily about the visual system one wants to use it to maximum benefit.
- Often dealing with 3 or more dimensions so important to convey depth cues.
 - perspective.
 - motion cues.
 - shadows, surface properties, light shading.
- Stereoscopy, sense of depth from parallax arising from our brain receiving two slightly different images from each of our two eyes.
- We have a wide peripheral vision both horizontally (almost ± 90 degrees horizontally, and about 120 degrees vertically). Gives rise to a sense of immersion.
- Resolution (spatial and temporal) of our visual system is higher than many of our display technologies.

Stereoscopy

- Both IVEC & WASP have stereoscopic projection systems although based upon very different technologies.
- Proven usefulness for visualisation of multidimensional data due to enhanced depth perception.
 - Finding new spatial relationships.
 - Appreciating relationships faster.
 - Engaging for exhibition and public education.



Stereoscopy, continued ...

- Irrespective of which stereoscopic technology is used the underlying requirement is that correctly formed left and right images are independently presented to each eye.
- Technologies: Active (usually monitors), passive (WASP), Infitec (IVEC), autostereoscopic.
- Autostereoscopic displays are available but they still have problems in terms of resolution and viewing positions.
- Holography. Many 3D technologies call themselves “holographic” without actually being holographic.



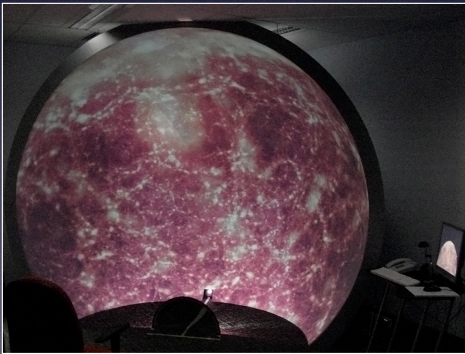
Twin projectors, one for each eye image



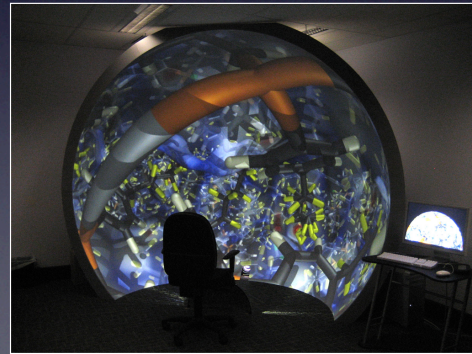
Rear projection screen to avoid blocking light

Peripheral Vision

- iDome, an experimental environment based upon a dome. A whole hemisphere is visible.
- Peripheral vision is identified as enhancing the sense of “being somewhere”.
- Target visualisation problems where it may be useful to be inside the model, a situation that is often difficult for stereoscopic viewing.
- The alternatives
 - zooming and panning around on a flat display, this loses the relationship to the whole.
 - applying projections (eg: fisheye) on a flat screen, this distorts the geometry.



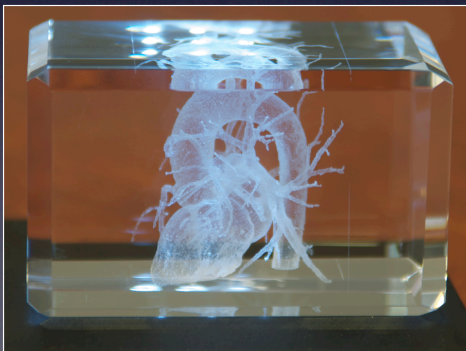
Cosmological simulation



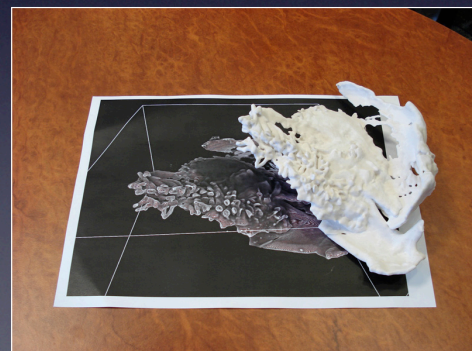
Synthetic crystal design

The other senses

- Sonification: turning data into audio or sounds.
A less precise sense so generally only used in support of visuals.
- Tactile: force feedback and haptics, generally used as interface devices but can be used for data exploration.
- “Printing” physical representations of datasets. Allows one to explore data representations in the same way as we generally explore objects in everyday life.
See example later from rapid prototyping machines and 3D crystal engraving.



Human heart

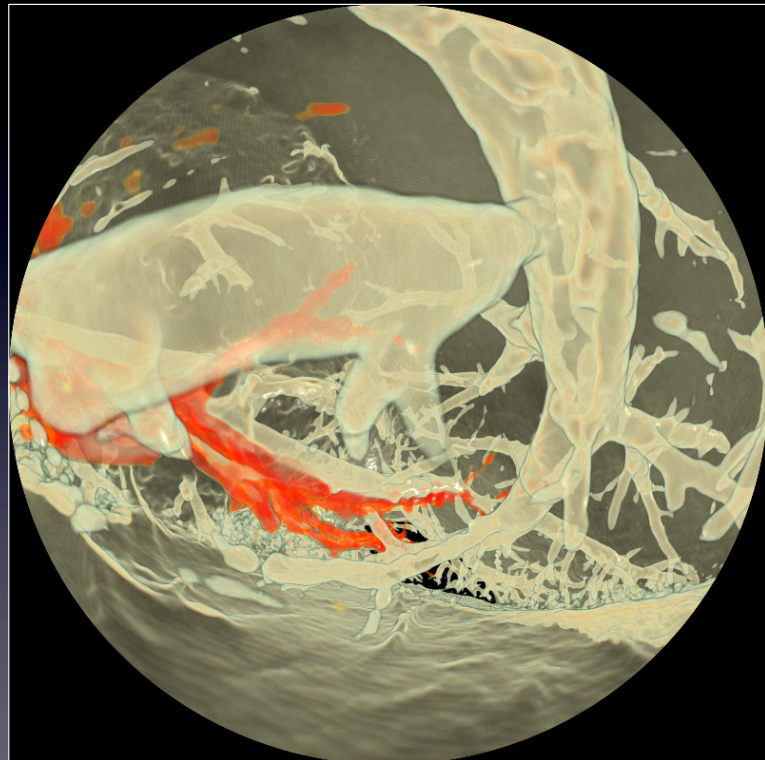


Placoderm fish vertebra

Challenges

- Datasets are growing in spatial and temporal resolution:
 - data acquisition devices are improving, for example: microCT scanners.
 - computing advances allow researchers to perform larger simulations.
- Use of clever data structures to cope with insufficient RAM to hold the data if stored in less efficient formats. Availability and speed of RAM does not seem to be advancing at the same rate as compute performance or data storage.
- Development of techniques that provide means of trading off interactivity with visual quality.
- Expectations of realtime interactive graphics and performance is increasing mainly due to hardware acceleration of GPUs.
- Increased network bandwidth from HPC to the desktop for remotely generated time varying visualisation. In particular for direct driving of simulations.
- Improved projection hardware to support/represent higher resolution visuals.
- Desire of users to be able to work on personal desktop machines and in their office rather than going to special laboratories with high end or specialised infrastructure.
- Expectations of higher visual quality from users (particularly the public), competing with gaming and Hollywood for visual impact.

Case study: Immersive volume rendering



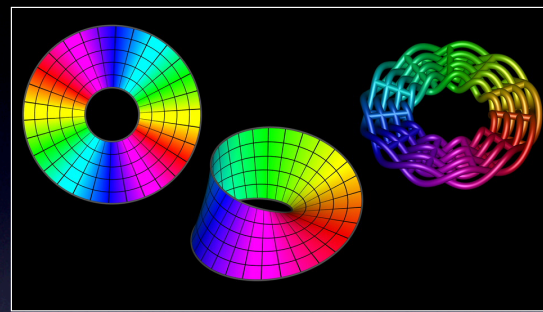
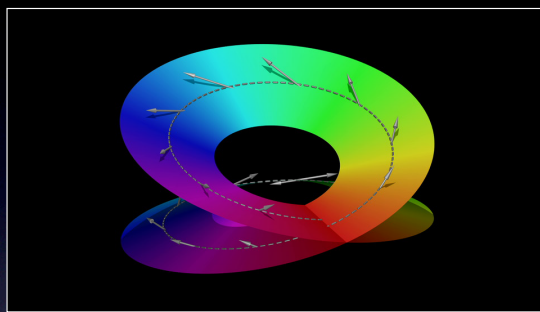
Volume rendering of a CT scan of a rabbits liver. Support now added to Drishti to render projections suitable for this environment.

Case study: ASKAP site visualisation

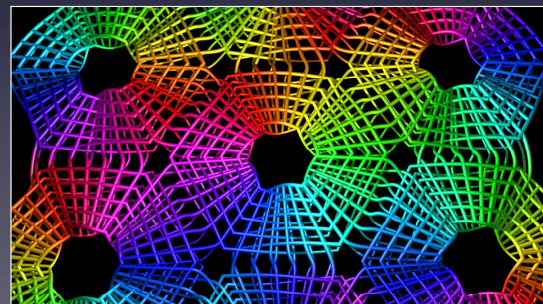
ASKAP (Australia Square Kilometer Array Pathfinder) site at Boolardy station. Collection and presentation of high resolution aerial and ground back panoramic imagery. Employ the Unity game engine to give an interactive walk-about the proposed site.



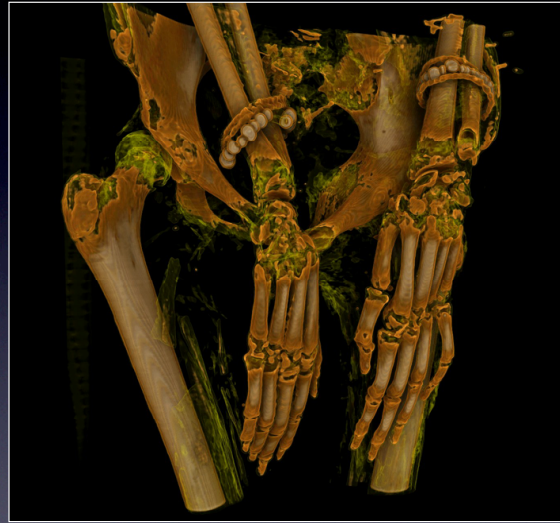
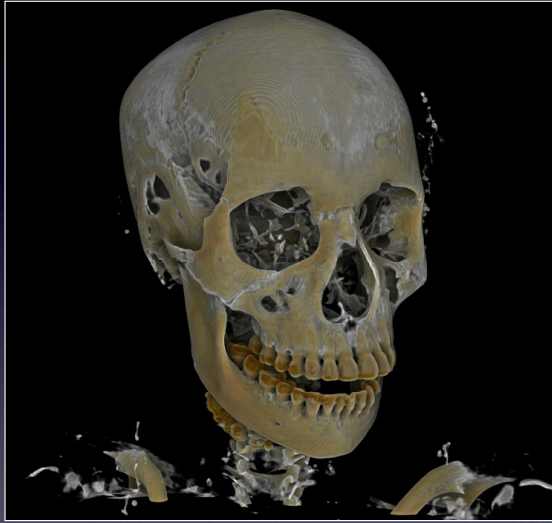
Case study: Mathematics in Vision research



Research into the human visual system gives rise to mathematical models of how the cortex is wired and how waves propagate across and between layers of the cortex. These models attempt to explain one of the more baffling experimental results known as orientation preference.



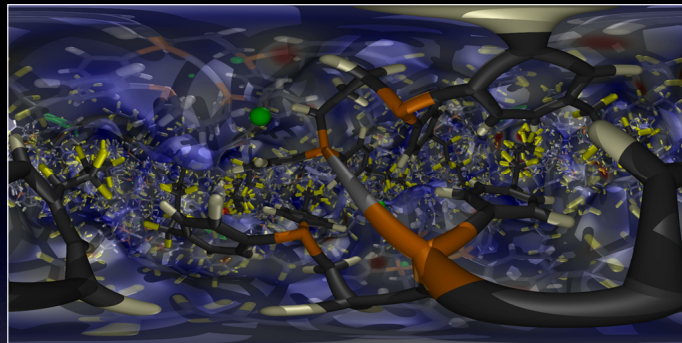
Case study: Egyptian mummy



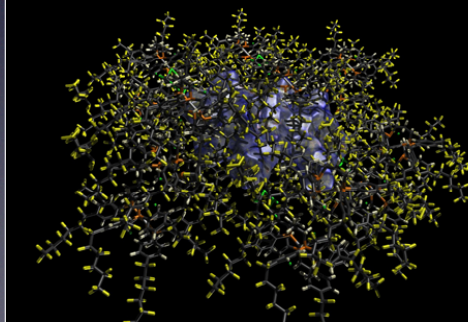
Volume visualisation of an egyptian mummy (4th century BC) located in a new Hobart museum. The casket with mummy was CAT scanned at the Royal Hobart hospital. Questions of interest include the cause of death and the nature of some of the jewelry.

Case study: Molecular

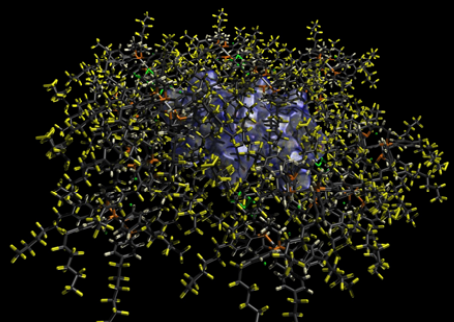
Study in using two novel displays in an exercise to judge their relative merits and effectiveness in presenting molecular (crystal) datasets. Rendering full spherical projections allows high quality renderings to be presented in the iDome in a semi-interactive way.



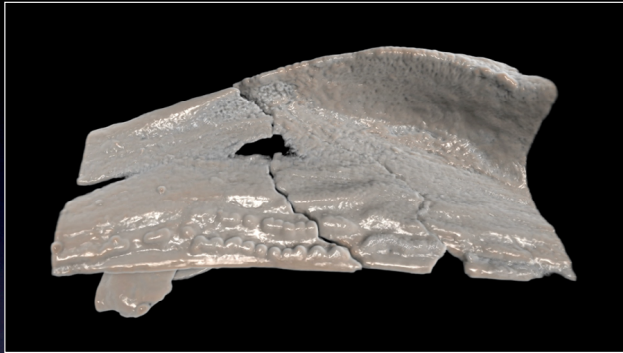
Left eye image



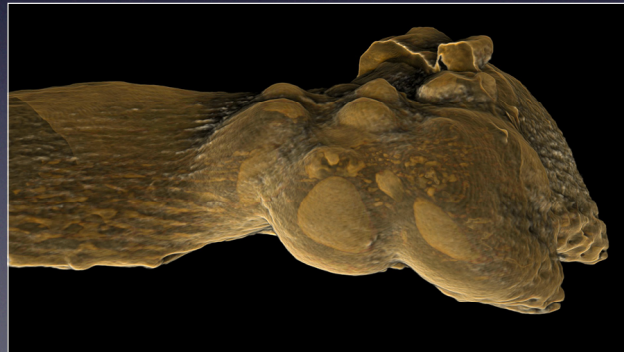
Right eye image



Case study: Fossil CT data



Volume rendering of CT and micro-CT scans of small fossil samples. Samples from placoderm fish (circa 400 million years old) and one of the questions involves research into the earliest evolutionary evidence for teeth.

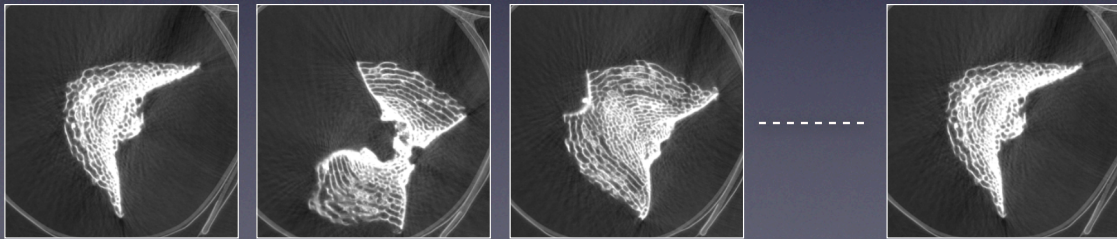


Hands on example: Volume rendering

- Drishti is an example of a volume visualisation application. Developed in Australia by Ajay Limaye at the ANU (Canberra).
- In a volumetric dataset we know some quantity at each voxel (3D pixel) within some rectangular volume.
- Generally (but not always) the volume is regularly sampled. Most volume rendering packages only support regular samplings.
- Data can come from 3D scans or simulations (see cosmology volume in the iDome).
- For example MRI scans give essentially water content throughout the volume, CT scans give density. Simulations can have a much wider range of variables at each voxel.
- Key is the mapping between voxel values and colour/transparency.
- Drishti has the additional capability to map local gradient to colour/transparency. This can greatly enhance the visual effect and reveal information on the surface slope.
- Drishti provides interactive volume visualisation by exploiting the graphics card, loads a 3D texture to the card and renders it using shaders.

Data example: Parasphenoid

- Data courtesy of Kate Trinajstic, geology UWA.
Bone from the back of the skull from a 350 million year old fish fossil.
- Original CT scan volume dimensions: $1030 \times 688 \times 904$.
Reduced version for this exercise of $514 \times 344 \times 452$.
- The volume here has already been pre-processed from individual slides into a “raw” data volume. The format consists of a header describing the dimensions of the volume followed by the voxel data, each a 2 byte unsigned integer.
- Usually the first stage of any visualisation process is to convert the data into a format suitable for the application being used. Drishti supports 1 byte per voxel so the first stage is to remap the values from 0 to 65535 to the range 0 to 255. This remapping is often crucial in order to maximise the dynamic range and minimise the discretisation.



Data import / remapping / export

- Run Drishti and use the import tool.
- Open the raw data file provided.
- Explore voxel mappings and volume subsets.
- Save the volume as a “.pvl.nc” file, this is the format the Drishti renderer expects.

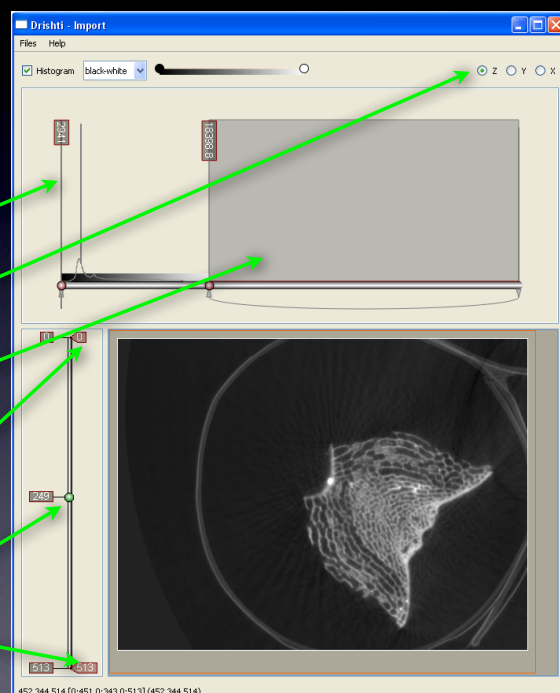
Voxel density histogram.

View different cross sections.

Remap voxel values.

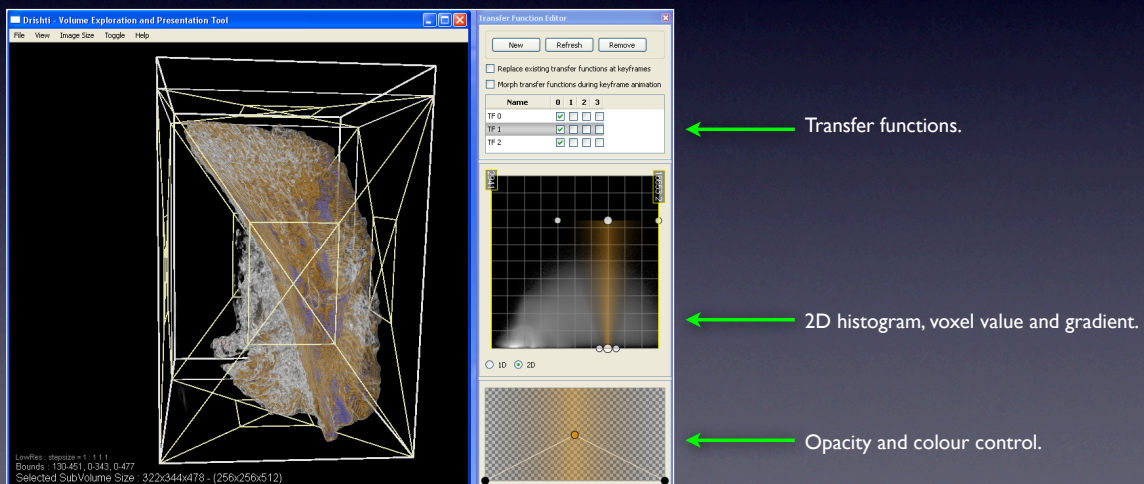
Optionally choose a subset of the volume.

Inspect the slices.



Rendering

- Run the Drishti rendering tool.
- Open the “.pvl.nc” volume from previous step.
- Create a number of mappings of different colour and located at different position on the histogram.



Subset of useful keyboard/mouse actions

Within 3D volume window

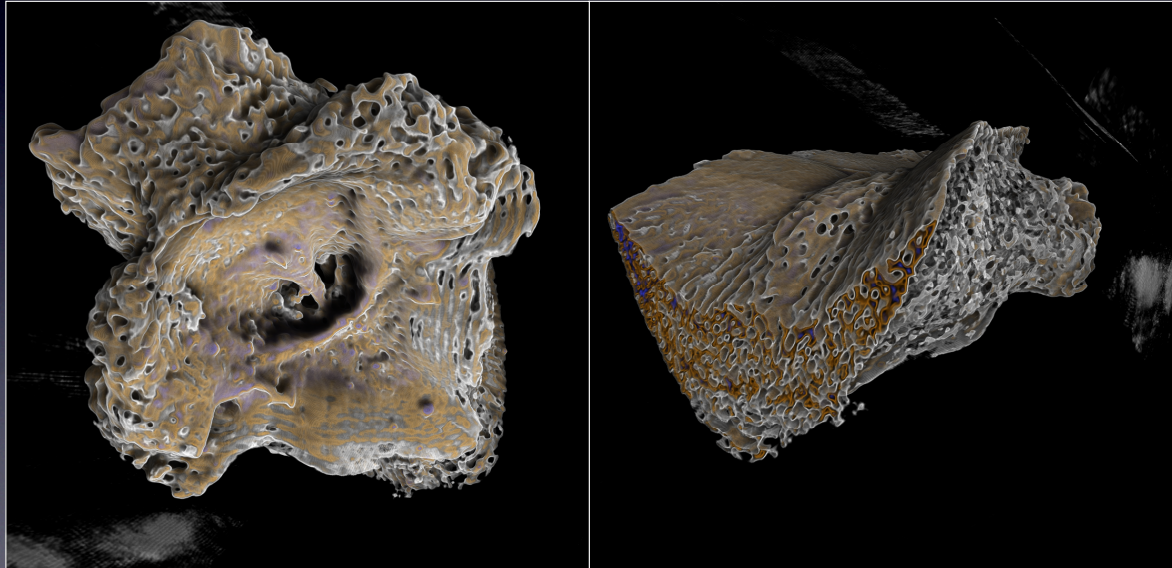
- left mouse button - Rotate camera.
- right mouse button - Translate camera.
- middle mouse button - Zoom camera.
- f2 - Toggles between high resolution and preview modes.
- l - Toggles between shading mode (only from high resolution mode).
Incorporates lighting model, shadows, etc.
- alt s - Create a snapshot of the current window contents.
- c - Add a clip plane.
- v - Toggle visibility of clip planes.
- b - Toggle bounding box
- ? - Toggle volume informational text.

Within transfer function windows

- left mouse button - Add, move a node.
- shift left button - Move node with constraints.
- right mouse button - Remove node.
- double click - Open colour selector for node.

Images prepared earlier ...

- See stereoscopic results in the visualisation laboratory.



Visualisation Laboratory Demonstration

Tactile visualisation examples

Hologram examples

Stereoscopic display

iDome