Science Visualisation

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Contents

- What is science visualisation?
- Illustrative vs data visualisation.
- Workflow and data types.
- Volume visualisation.
- Visualisation in humanities.
- Presentation media.

- Demonstration in VisLab.

What is it?

- Presenting data in an informative (insightful) way using computer graphics.
- “Visualisation” is a term that is used in a large number of fields to refer to the general notion of using images/diagrams to give insight into underlying data or process.
- Aims of scientific data visualisation in research:
  - Allow researchers to learn something new about the data.
  - Allow researchers to more quickly understand the data.
  - Identify errors or unexpected effects in the data.
- Audience for science visualisation:
  - Used by scientists as part of their research.
  - Used by researchers to convey research outcomes to their peers eg: conferences, papers, seminars.
  - Used to educate a non expert audience eg: public education/outreach.
- Data sources:
  - Experimental data, for example 3D scanning, surveys, photogrammetry, etc.
  - Simulation data, for example finite element analysis, cosmology simulation, etc.
- Involves a combination of programming - algorithms - computer graphics - art.

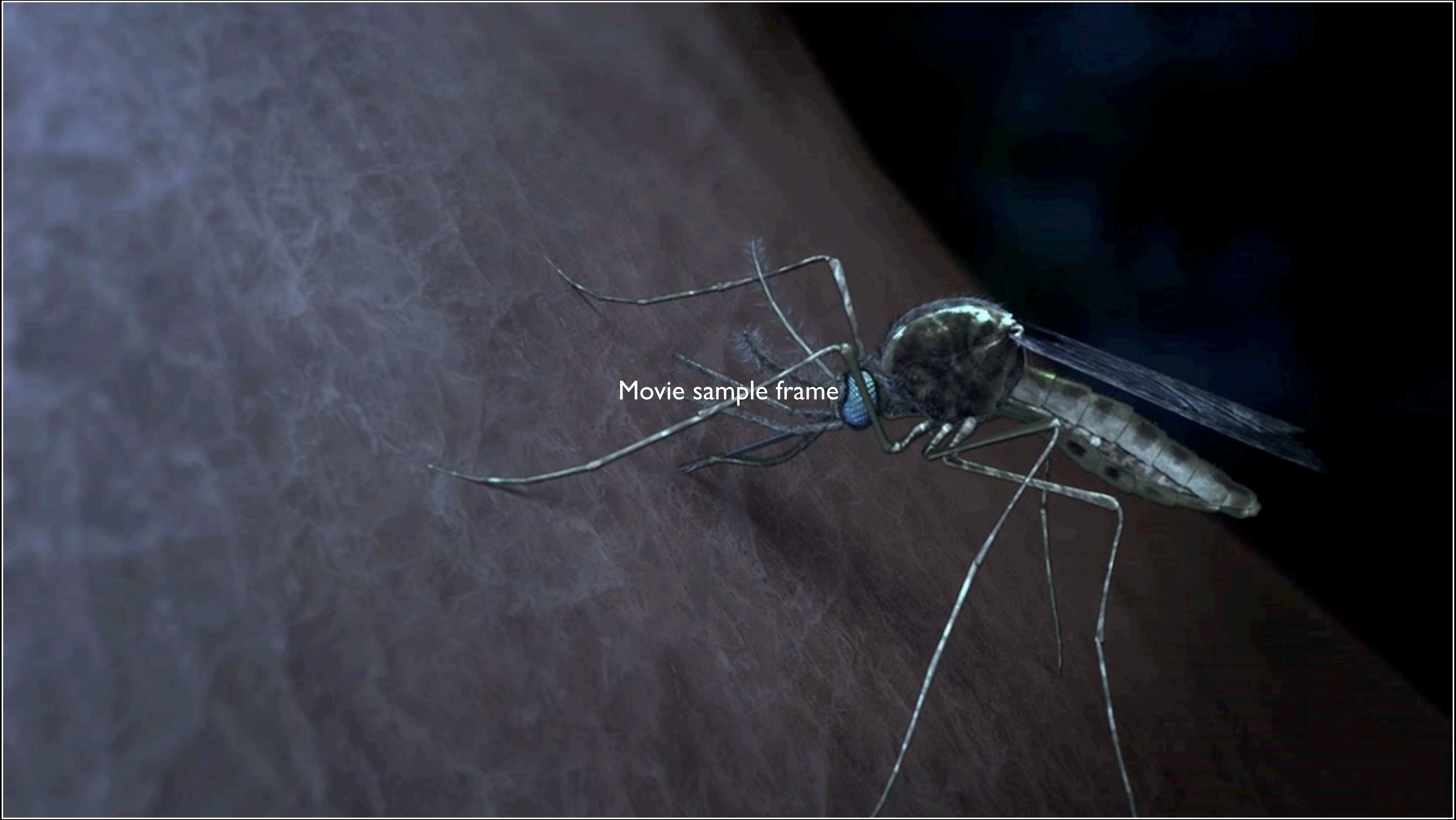
Illustrative vs data visualisation

- Will draw a distinction between illustrative visualisation and data visualisation.

- Illustrative visualisation
  - Generally performed by an animator in conjunction with a domain expert.
  - Usually intended to convey insight into a process rather than necessarily being an accurate representation.

- Data visualisation
  - Based upon actual data, either from experiment or simulation.
  - Generally no scope for changing the underlying data, only how it is represented.

Example: Illustrative visualisation

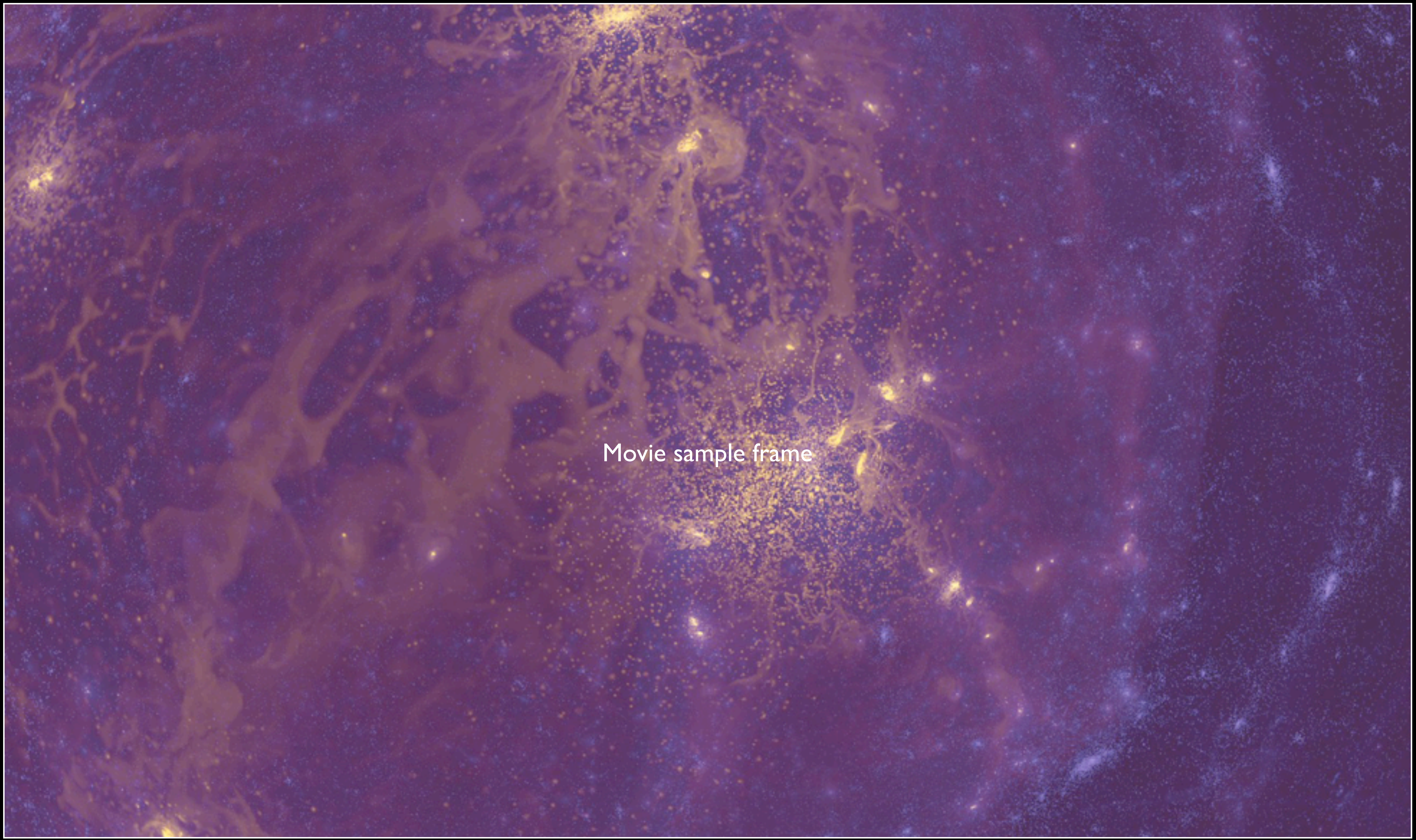


Courtesy Drew Berry, WEHI

Example: Data visualisation (medical)

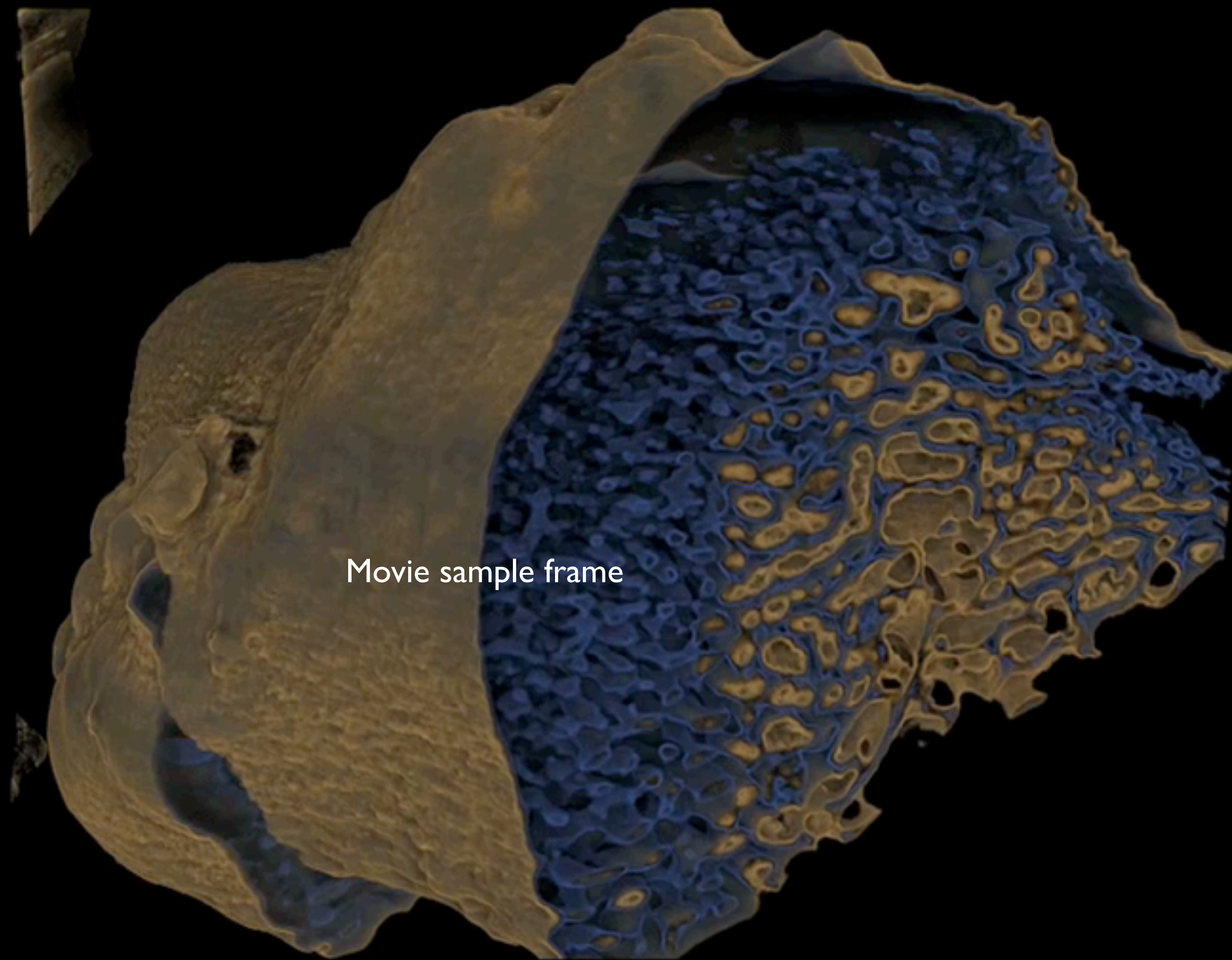
Courtesy Ajay Limaye, ANU

Example: Data visualisation (astronomy)



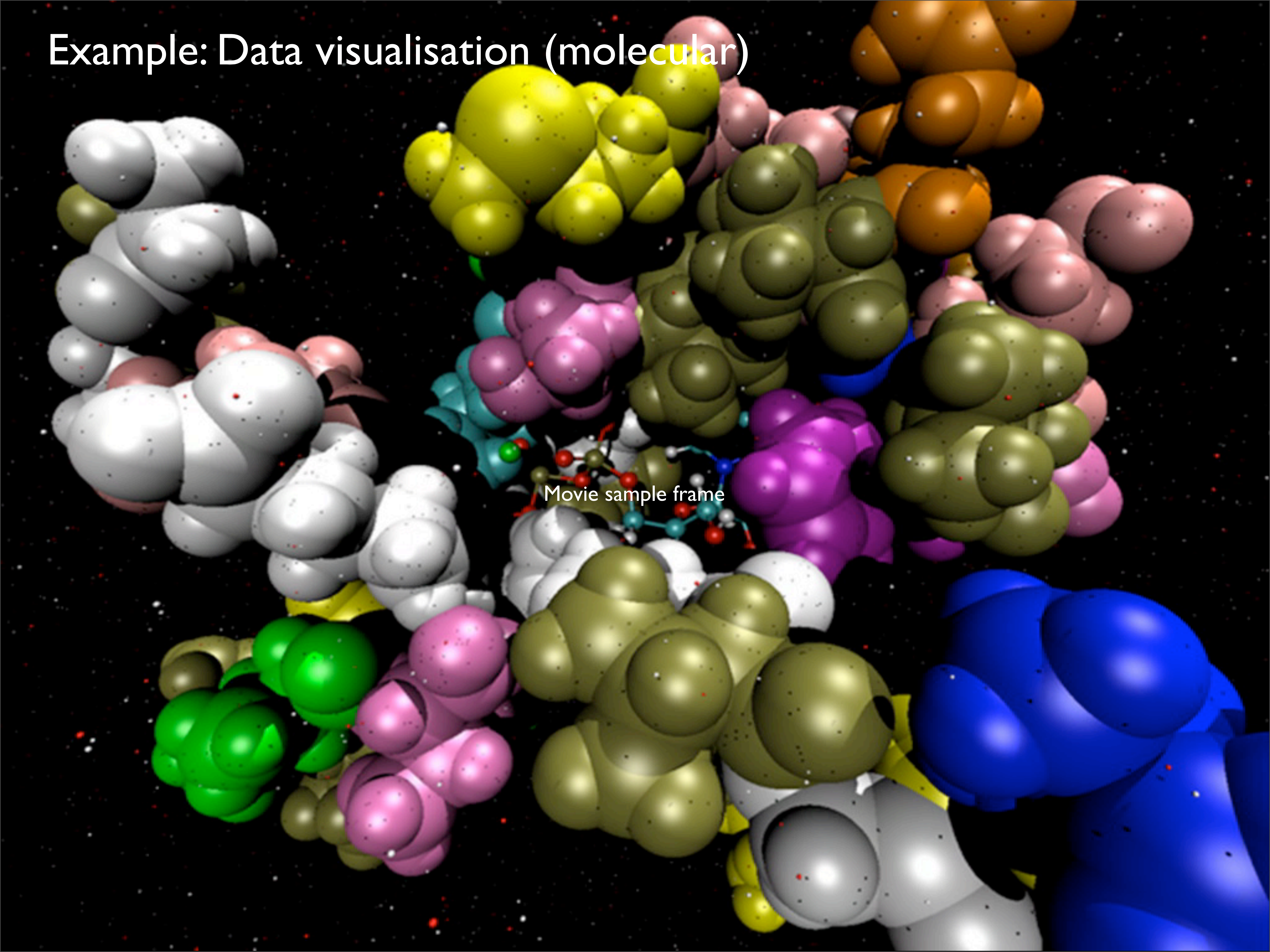
Galaxy formation simulation visualisation

Example: Data visualisation (geology)

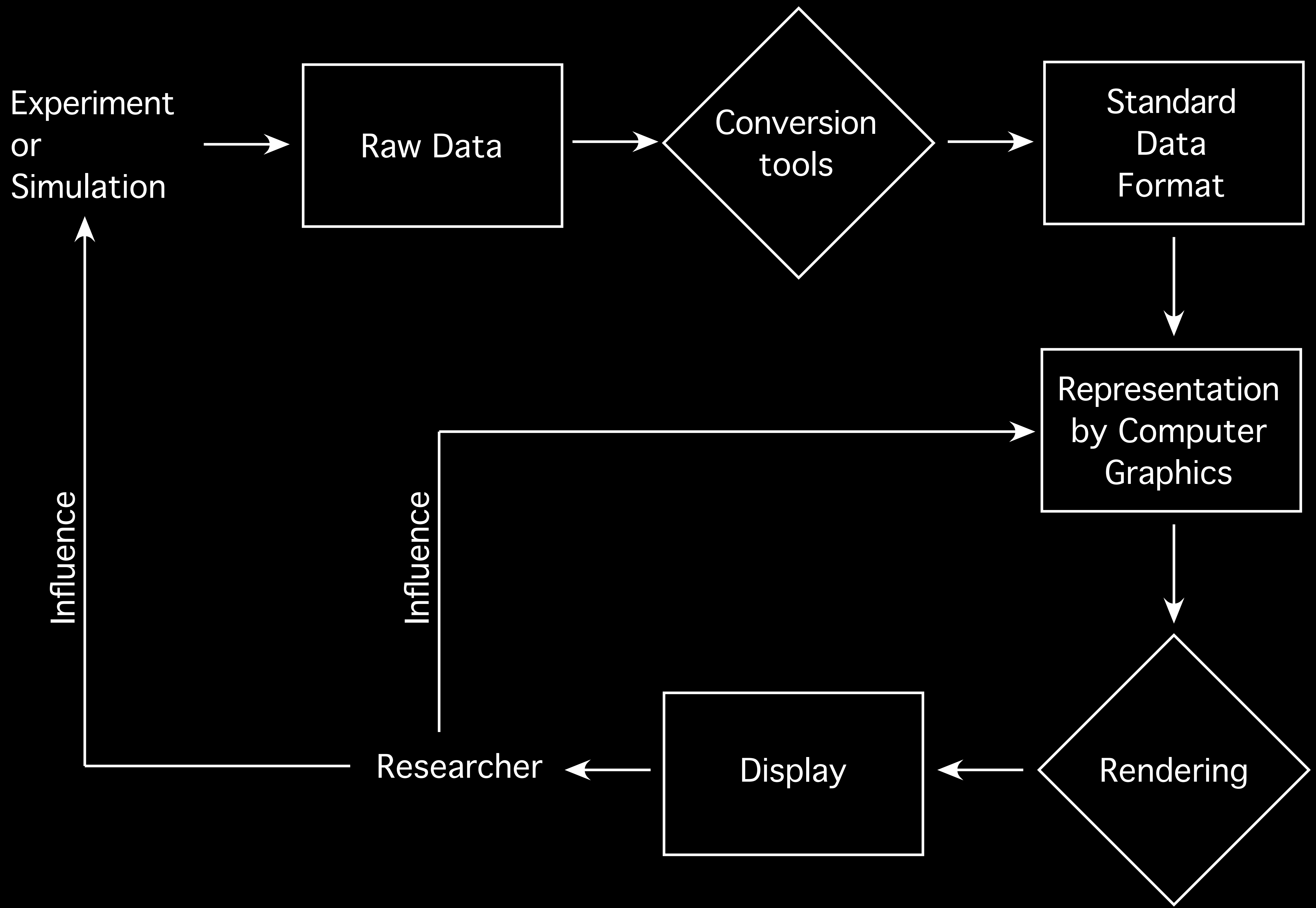


The upper tooth plates of the placoderm show several rows of teeth.

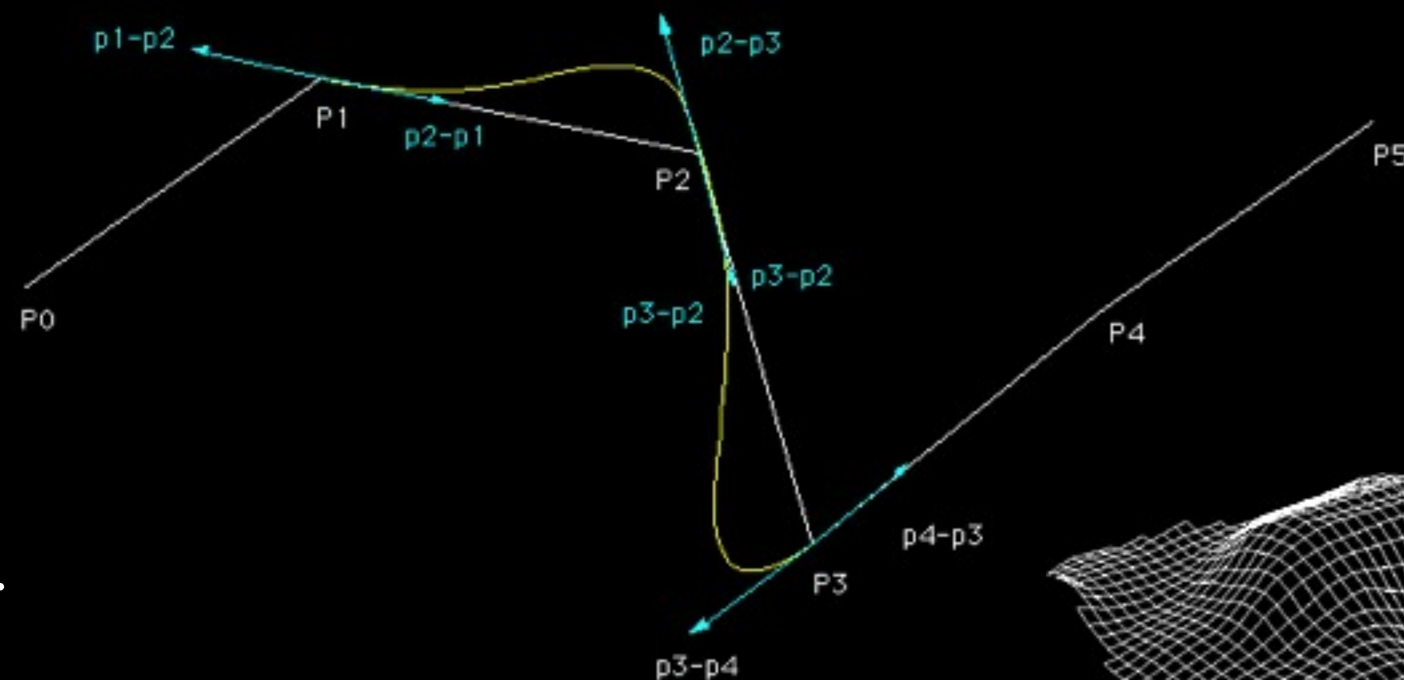
Example: Data visualisation (molecular)



Typical Workflow



Data considerations

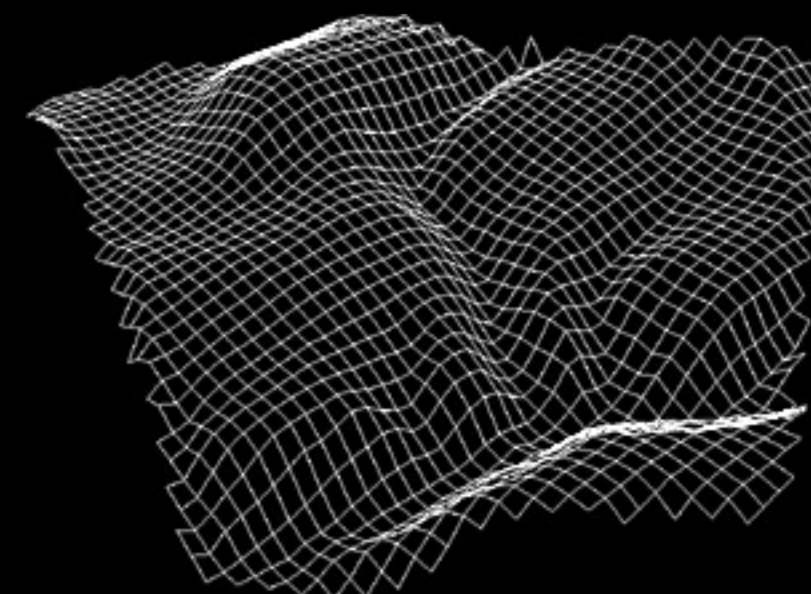


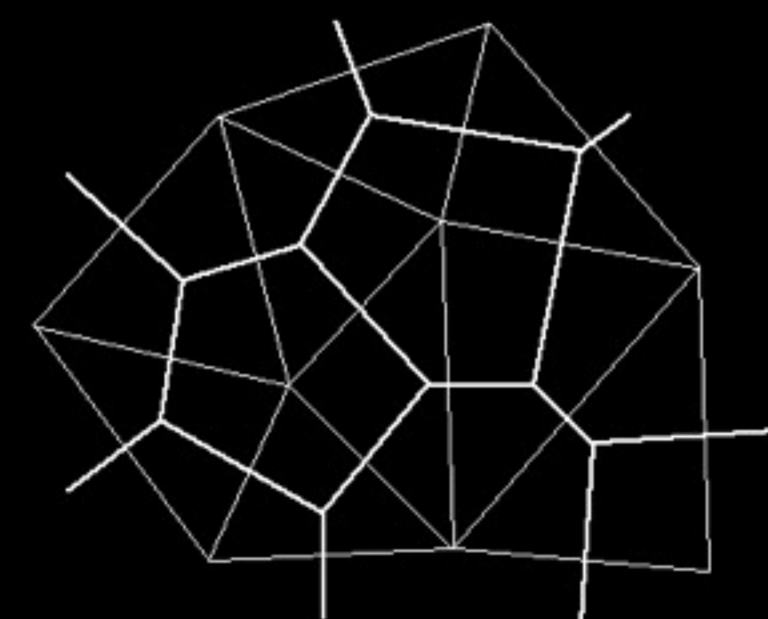
- Topology:
  - Points.
  - Lines/Curves.
  - Regular grids.
  - Unstructured mesh.
  - Volume.

- Static or time varying.

- Dimensionality.
  - The number of independent variables.
  - Dimensionality of the variables: scalar, vector, matrix ....

- Discrete, category, or continuous variables.

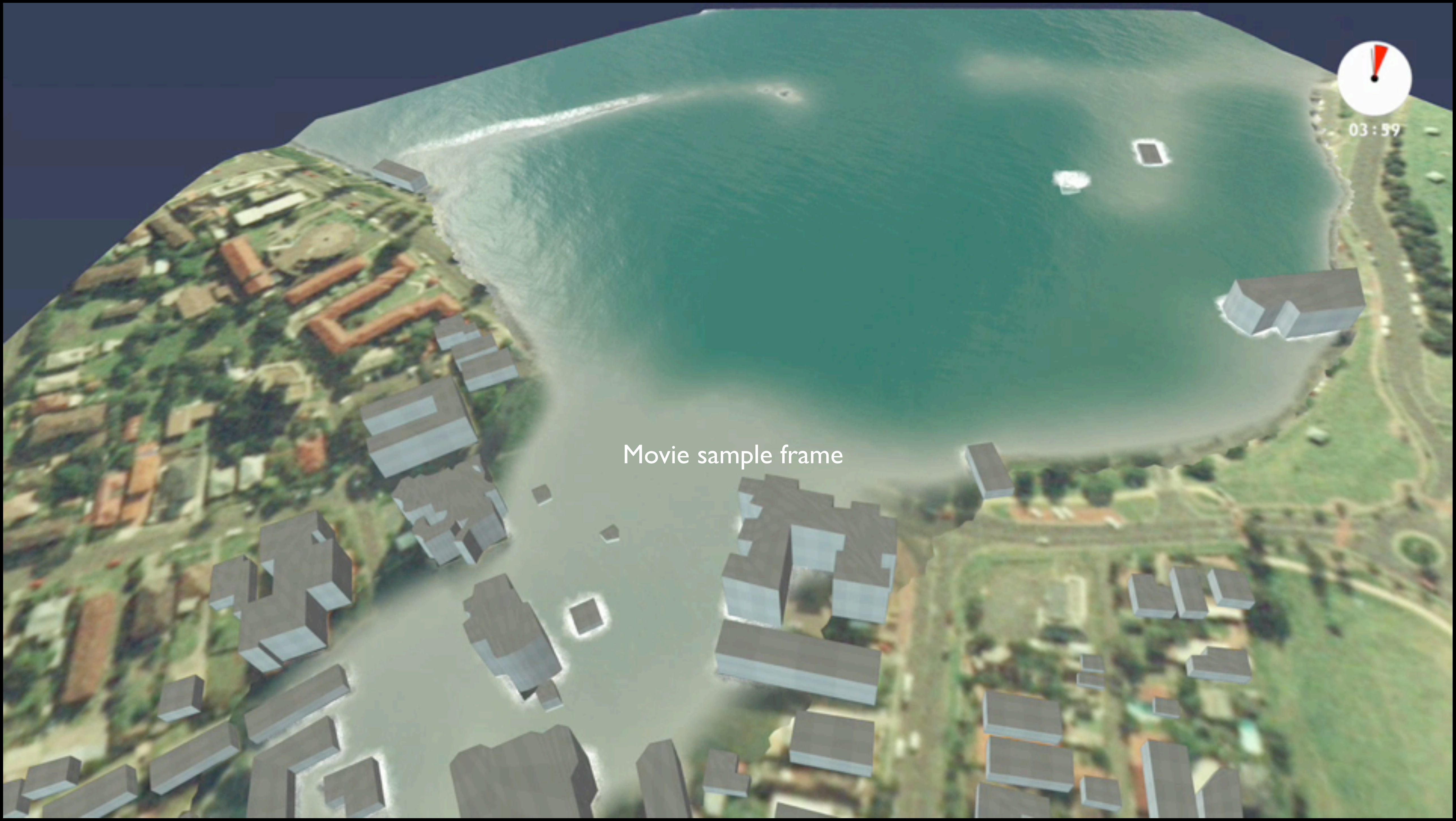




Mapping data to geometry

- Visualisation is concerned with the mapping between data variables and images/geometry using computer graphics.
- In some cases the mapping is very obvious, for example a mesh describing a landscape.
- In some cases the mapping is familiar, for example ball and cylinders to represent atoms and bonds.
- Often there is no obvious relationship between the data and a geometric entity, one can then choose an informative geometric or visual representation.
- Common to map variables to colour maps/ramps.
- Common to use “glyphs” to represent variables. In this context a glyph is usually a 3D object made up from units each of which is a mapping from a data variable.
- Often reduce the dimensionality by
  - Isosurfaces (equivalent of contours in 2D)
  - Clipping planes

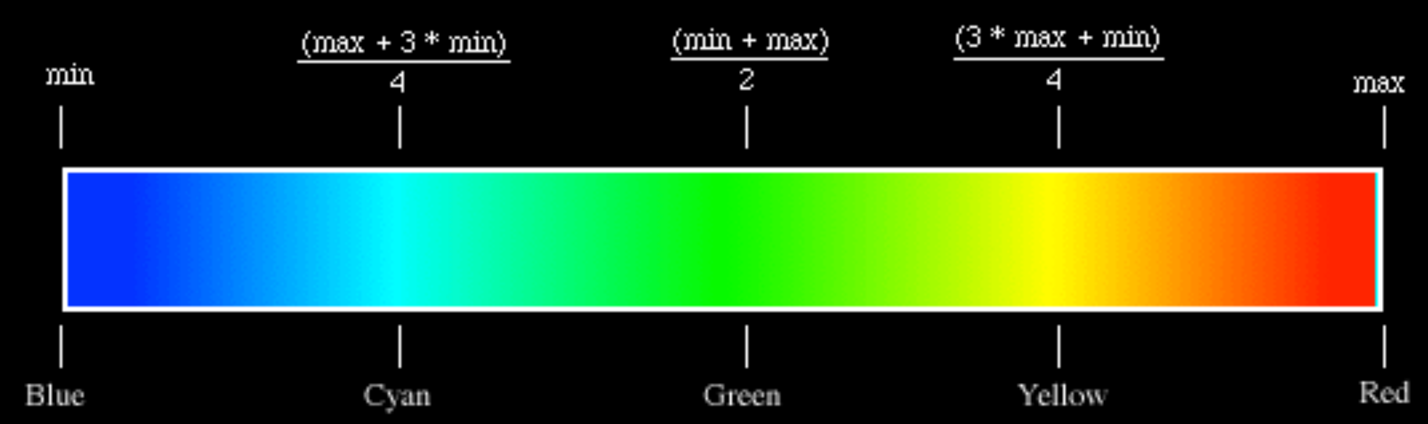
Example: Obvious mappings



Courtesy Drew Whitehouse and Geoscience Australia

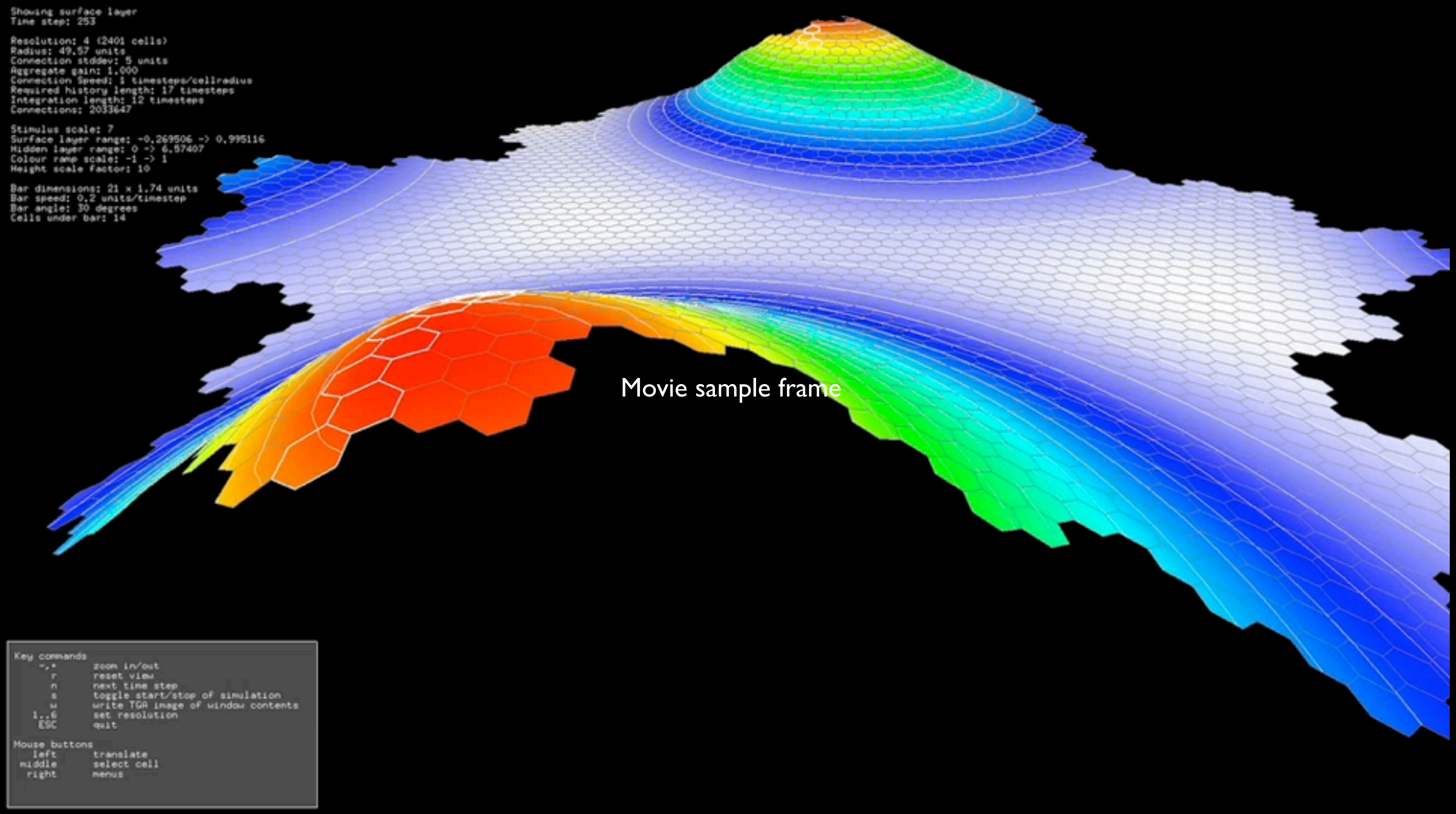
Colour ramps

- Involves mapping a variable range onto a series of colours.
- Be warned there is a lot of contention around the best or most appropriate way of doing this.
- Hot to cold colour ramp is very common (although not necessarily the best).
  Blue=cold, green=medium, red=hot.



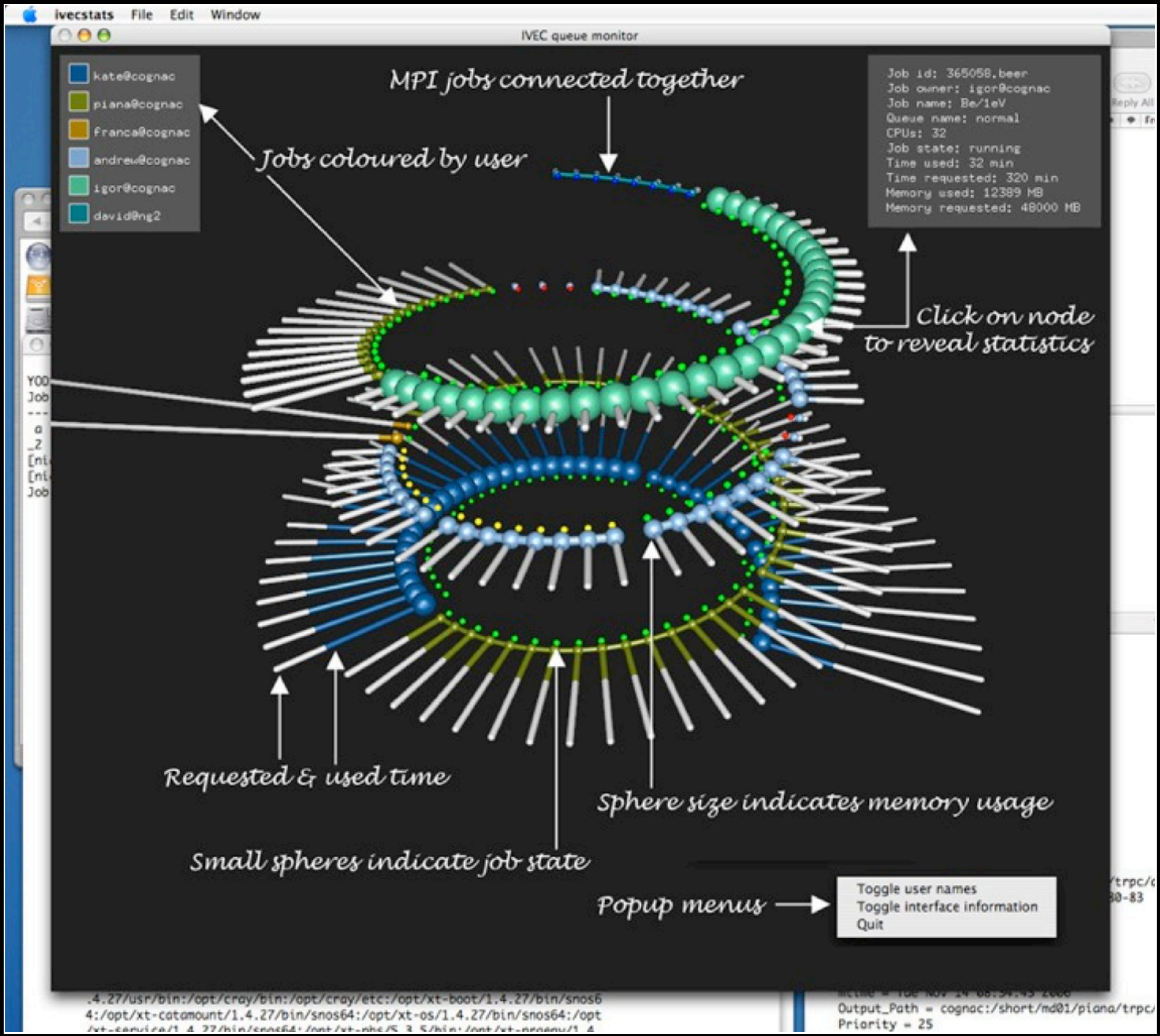
- Some variables (eg: angles) are circular, colour ramp can reflect that.

Example: Surface visualisation



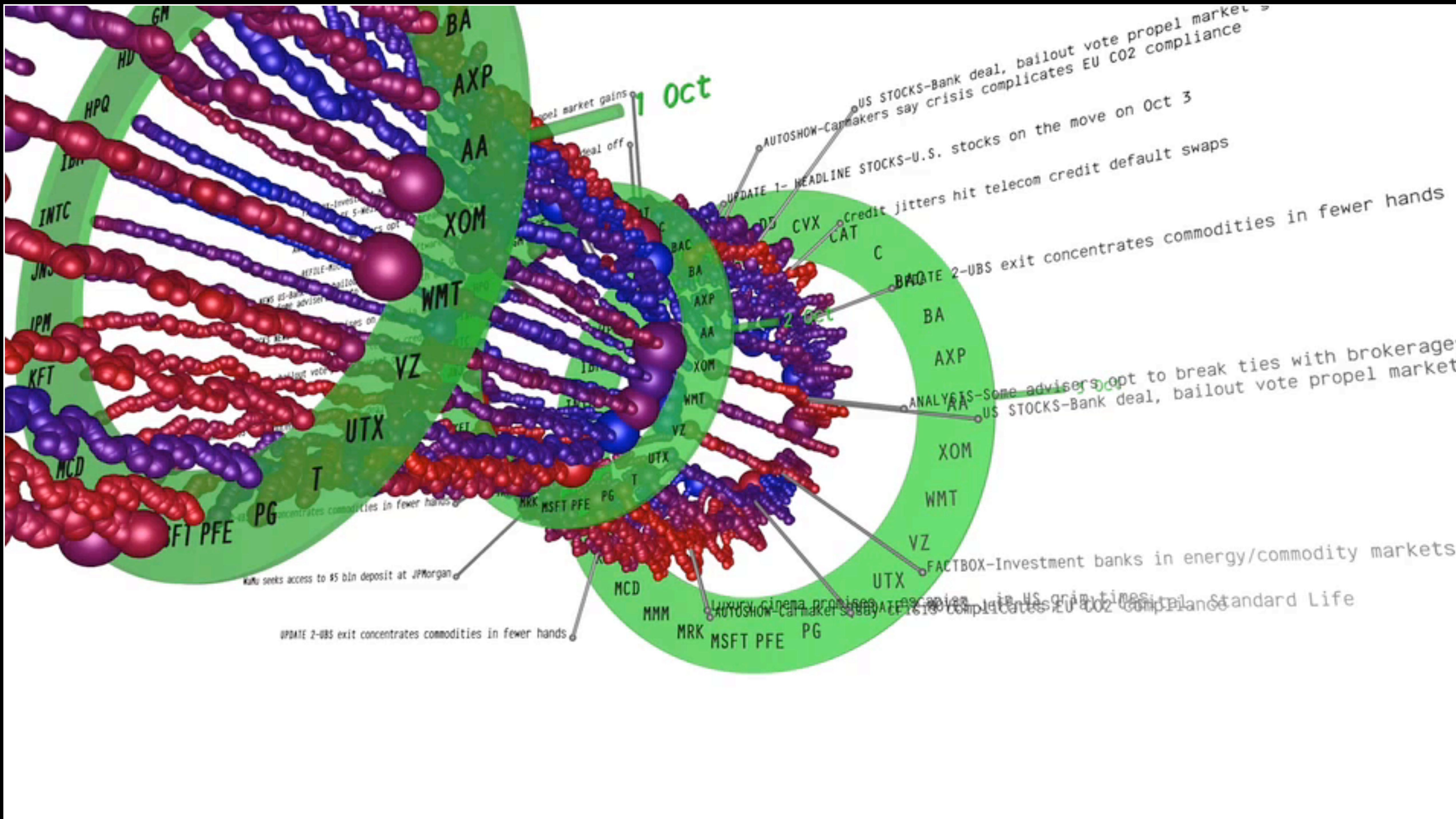
Movie sample frame

Example: Glyphs



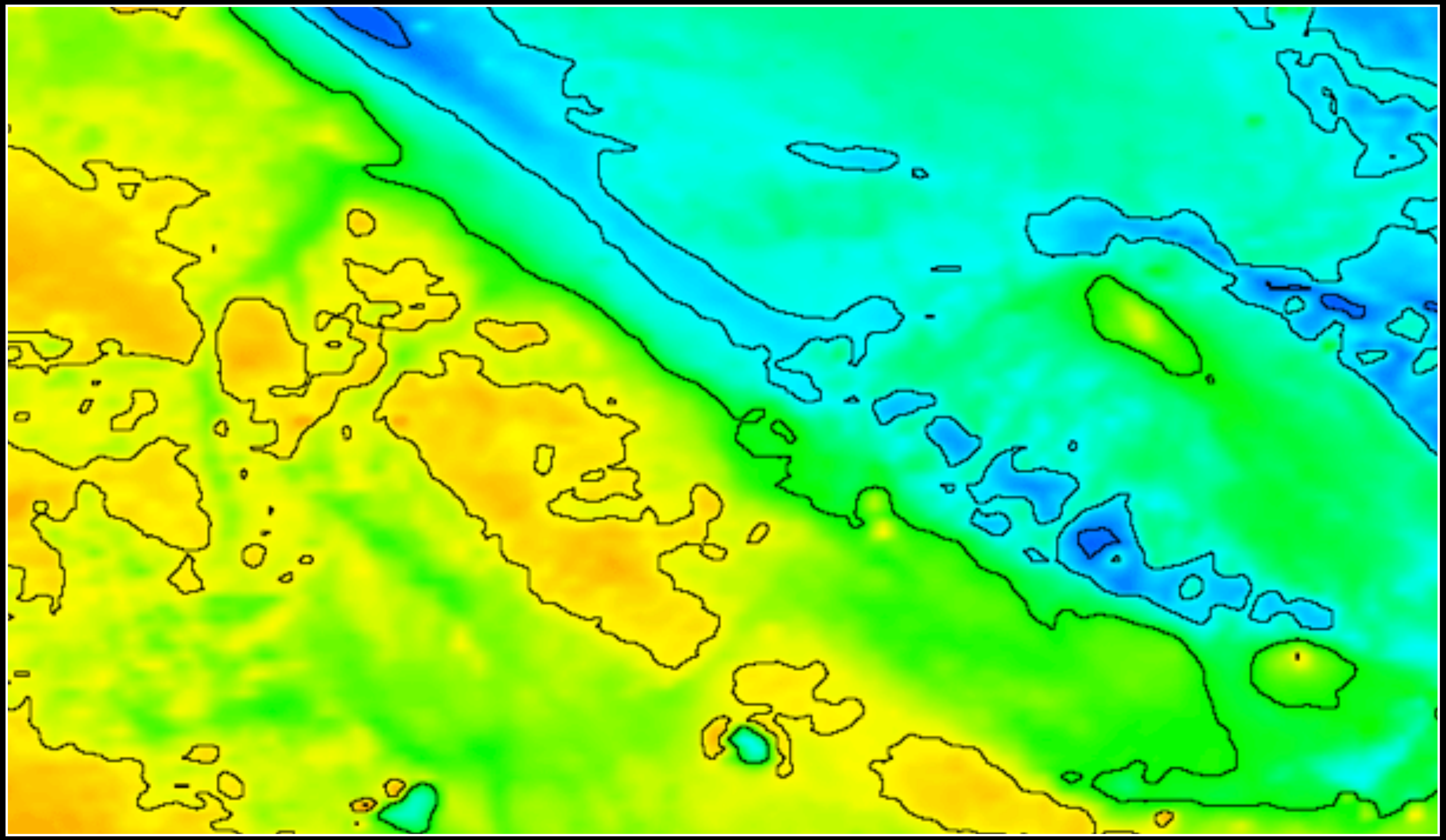
Example: Glyphs (Visualisation of Australia stock exchange data)

Movie sample frame



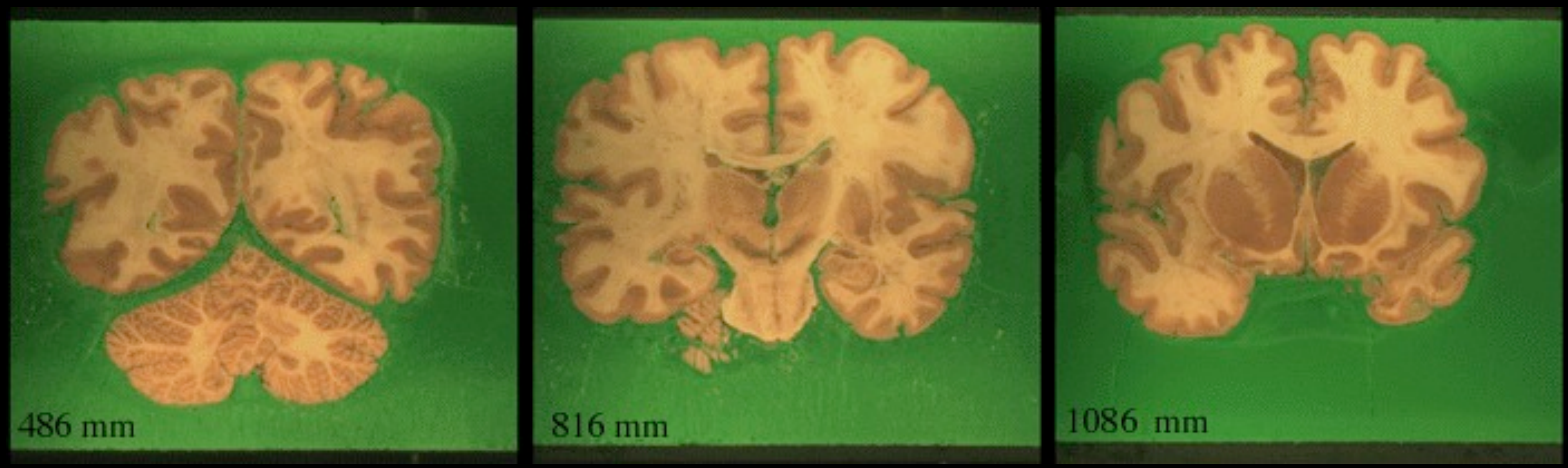
Contouring (2D)

- Most of us are familiar with contours, for example from:
  - Isobars on weather maps.
  - Terrain maps.
- A contour curve shows where "height" of a surface has a particular value.
- Dimension reduction: This has turned a surface (3D) into a curve (2D).



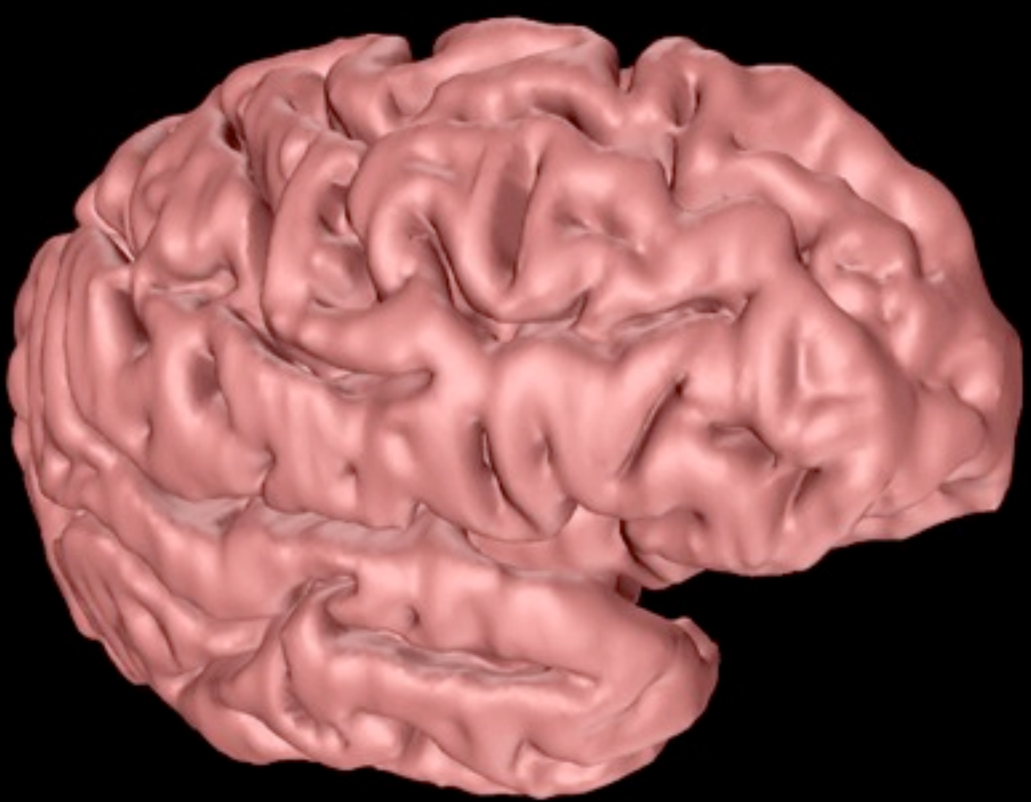
Isosurfaces (3D)

Input slices



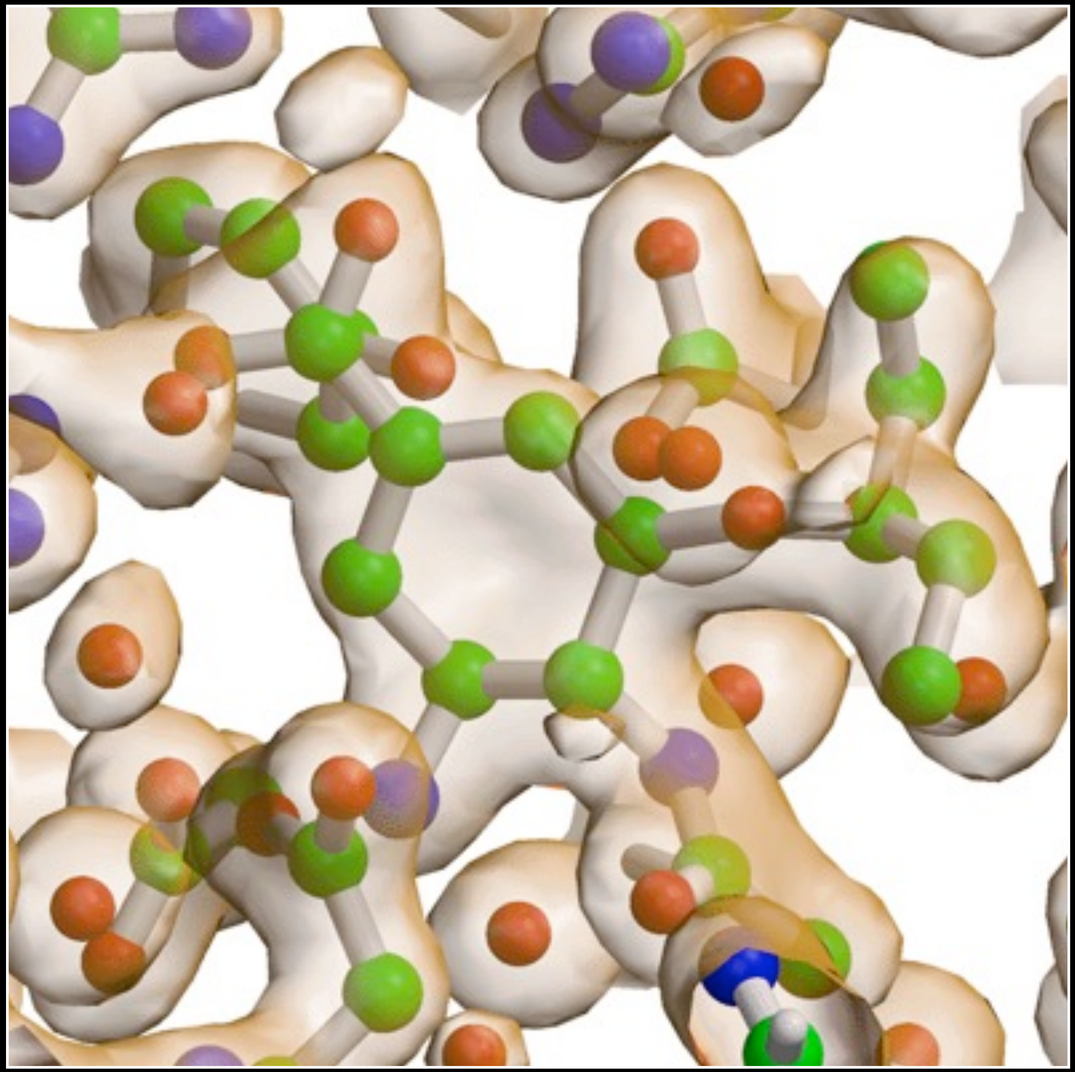
Extracted contours

Final 3D isosurface

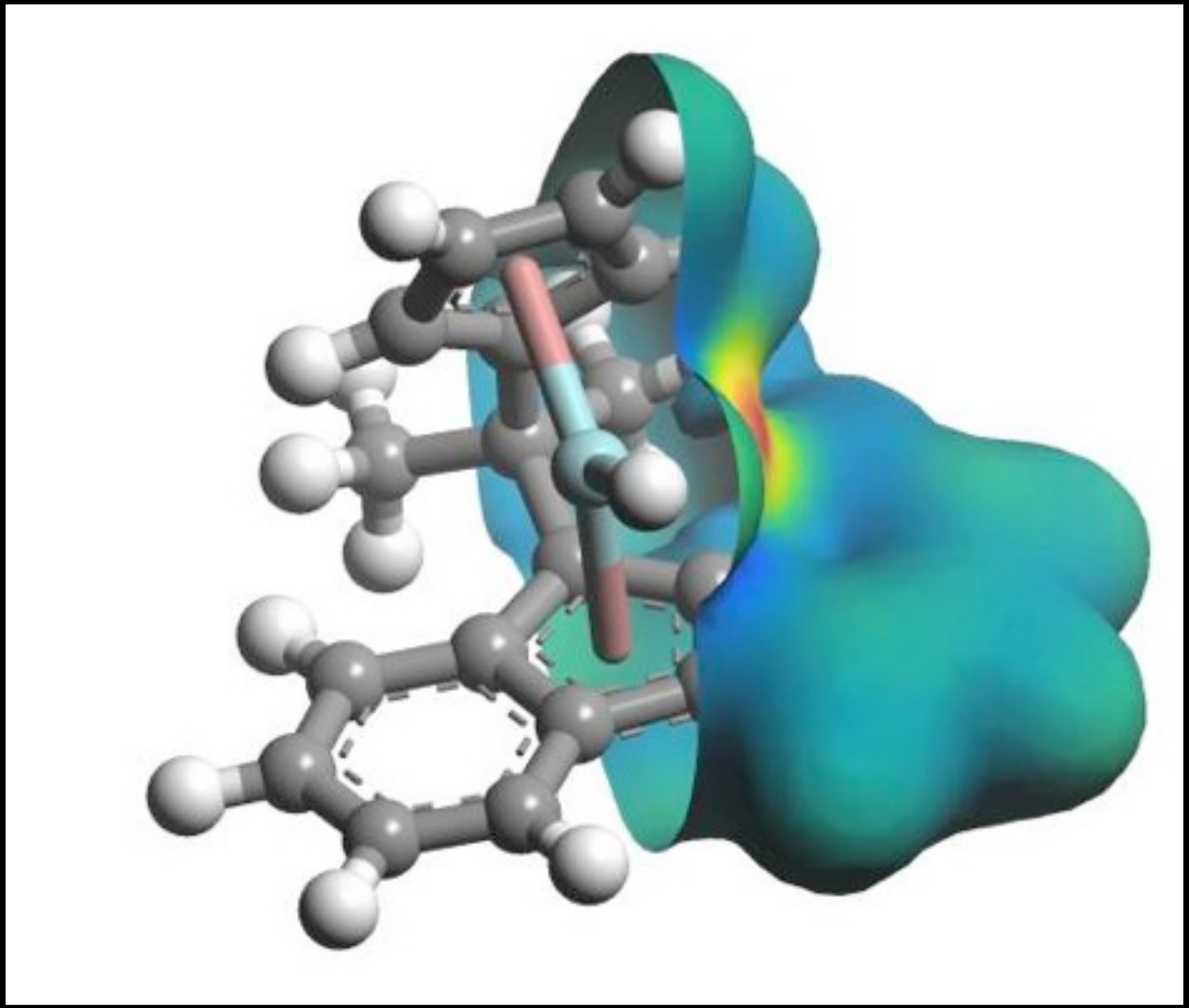


Isosurfaces (3D)

- An isosurface represents points within a volume that have equal value.
- Commonly used algorithm is called "marching cubes".
- Dimension reduction: Reduces a volume (4D: x,y,z,value) into a surface (3D).



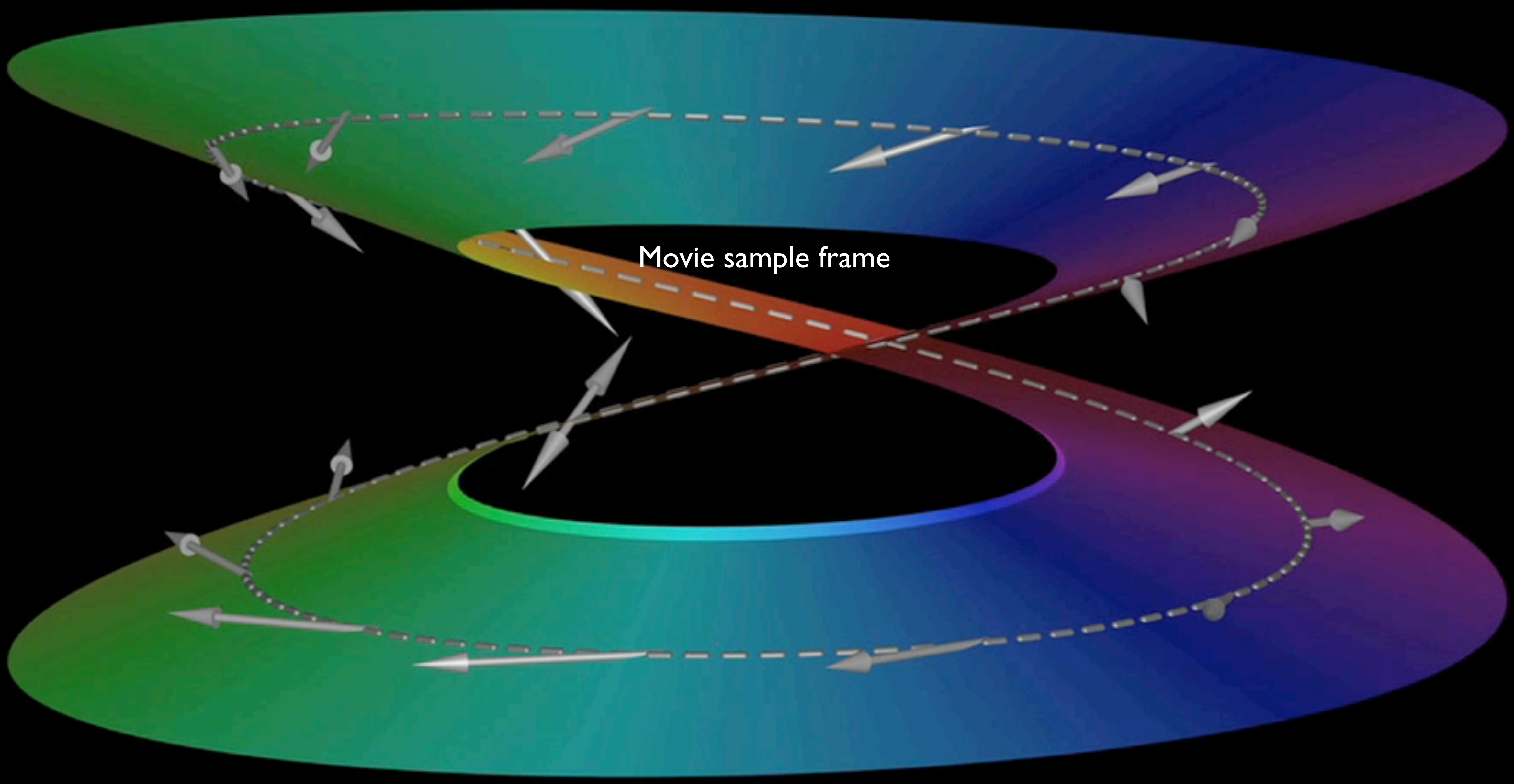
Isosurface of molecular potential



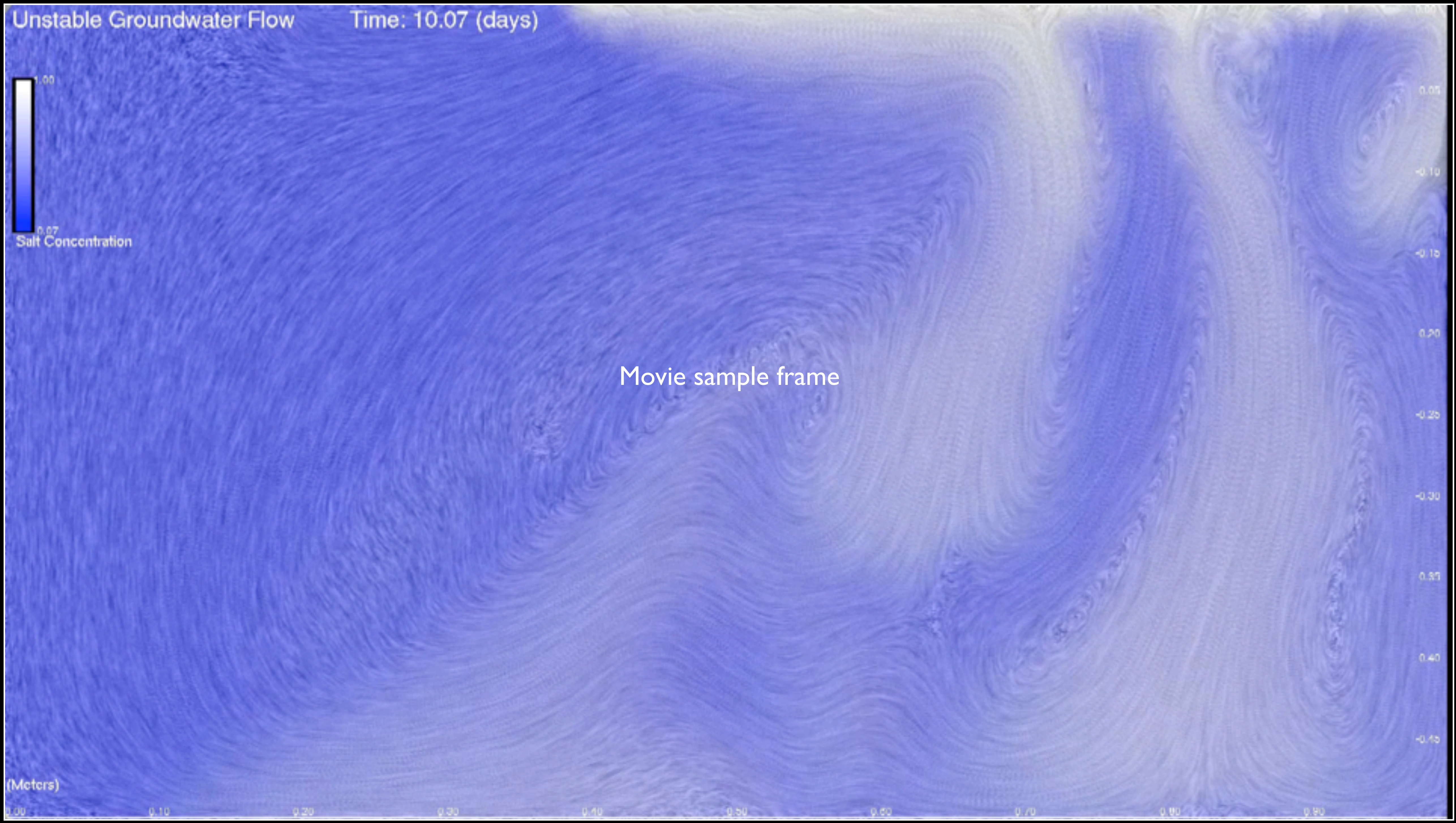
Zirconocene molecule, credit: Accelrys

Visualising flow

- Vector fields or flow is a common time dependent datatype.
- Arrows are an obvious choice.

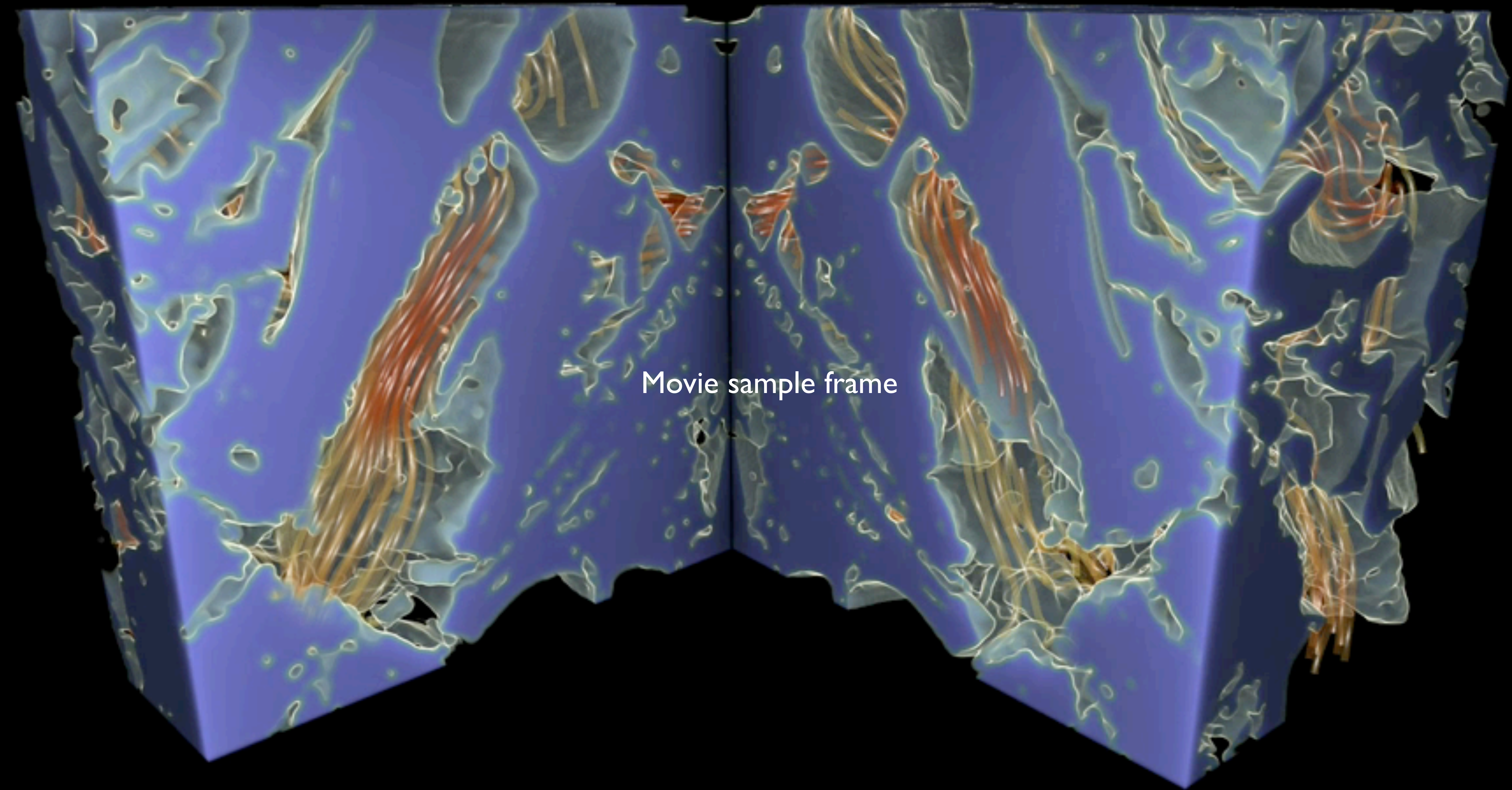


Visualising flow



Courtesy Queensland University of Technology

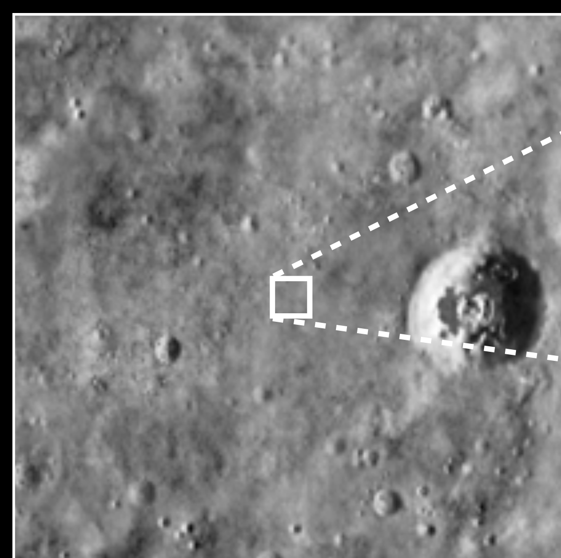
Visualising flow

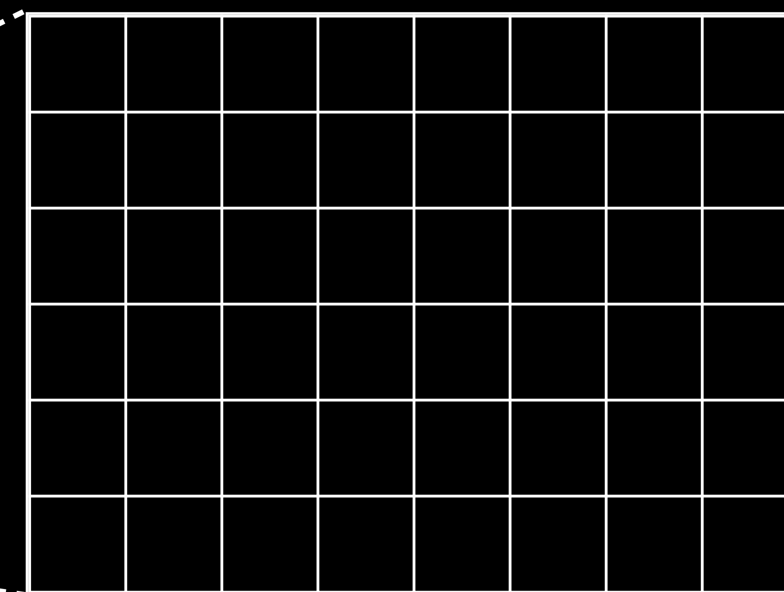


Courtesy Ajay Limaye, ANU

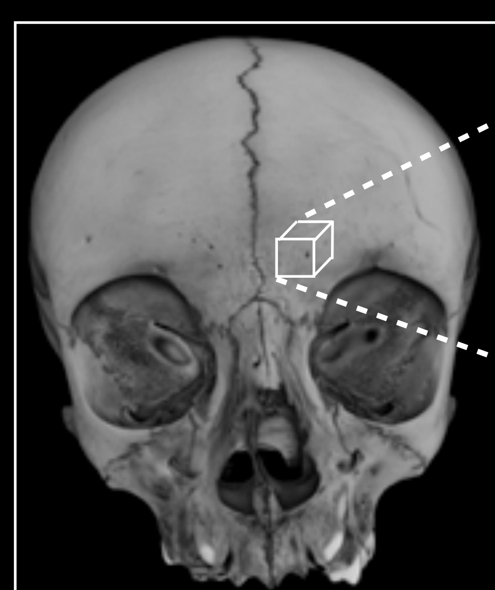
Volumetric data

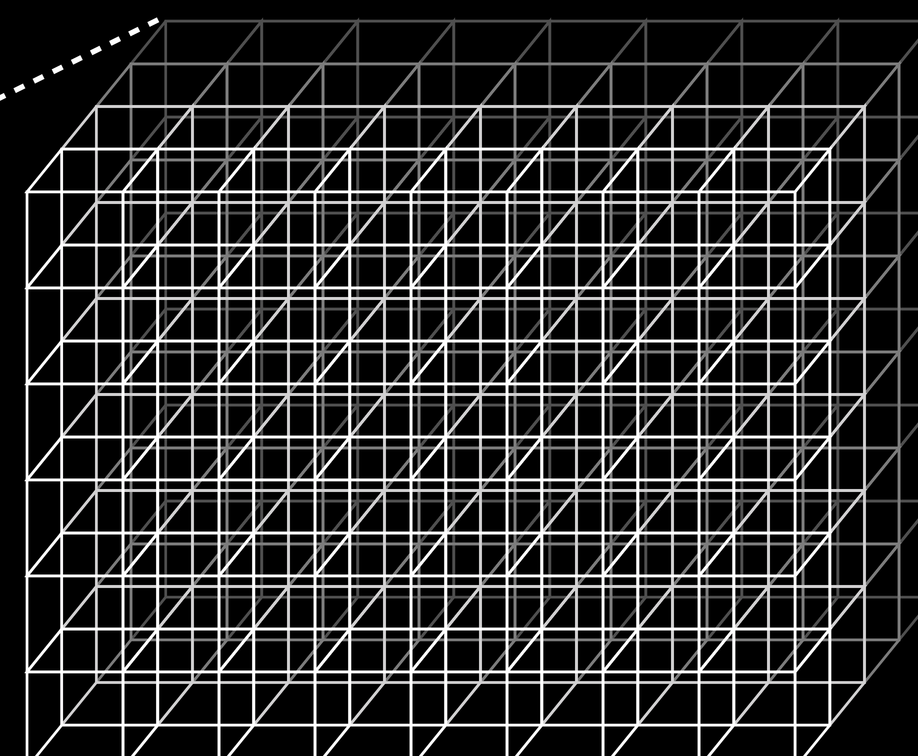
- A digital image contains some quantity sampled on a regular grid on a 2D plane.



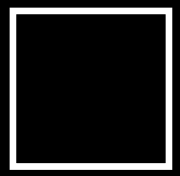


- In a volumetric dataset there is some quantity sampled on a regular 3D grid.

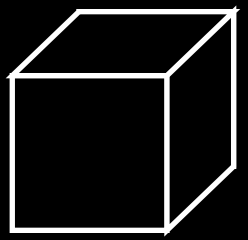




Terminology



- In a 2D image the fundamental unit of measure is a "pixel".
  The quantity represented by the image is sampled at each pixel.

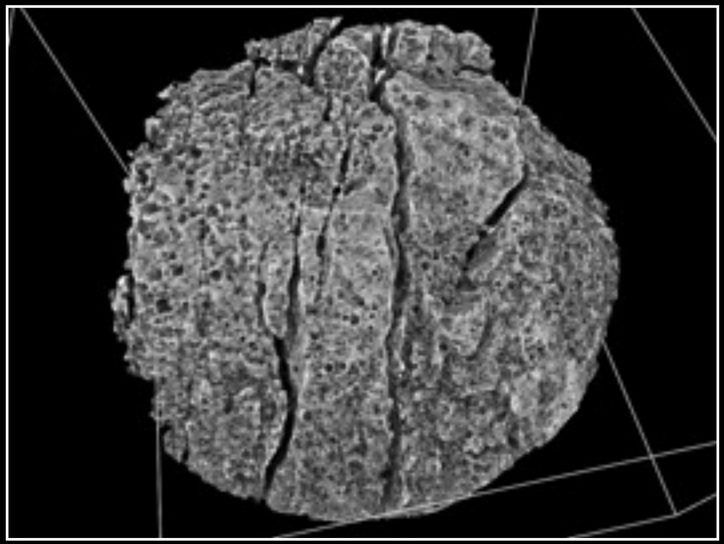


- In a volumetric dataset the fundamental unit of measure is a "voxel" (VOlume piXEL).
  The quantity represented by the volume is sampled at each voxel.
- The resolution of a 2D image is defined as the number of pixels horizontally and vertically. The resolution of a volumetric dataset is defined as the number of voxels in width, height, and depth.
- Image pixels are usually but not always square. Voxels are sometimes cubic (simulation)but generally not (experimental data), for slice based data the resolution within the slices is often very much greater than that between the slices.
  Note that some volumetric data (eg: finite element simulation) can have variable voxel sizes.
- Depends on who you talk to and their area of research but generally
  - A "small" volumetric dataset may be < 200 voxels on each side.
  - A volumetric dataset is considered "large" if it is > 1000 pixels on each side.
- Another important characteristic is the dynamic range of the data at each voxel. Most commonly a single byte, integer (2 or 4 bytes), or floating point. May even be vectors, multivariate, and so on.

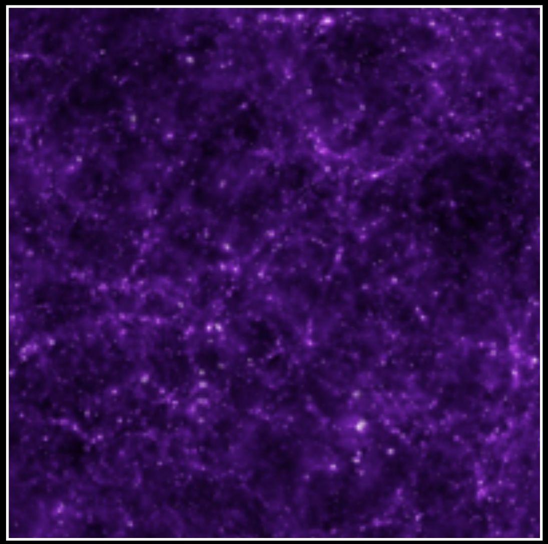
Volumetric data in research

- Volumetric datasets have been a common data type in many areas of science for some time.
- Traditionally one thinks about medical data, for example MRI.
- Other scanning and 3D imaging technologies include CT (MicroCT) and CAT scans. There are many others.
- Volumetric data also arises from numerical simulations.
  Quite common in astronomy and engineering (finite element calculations).
- In scanned volumetric datasets the quantity per voxel depends on the scanning technology. For example: MRI essentially gives water content, CT gives density.
- For volumetric datasets derived from simulation there can be multiple variables per voxel.

Medical research (MRI)



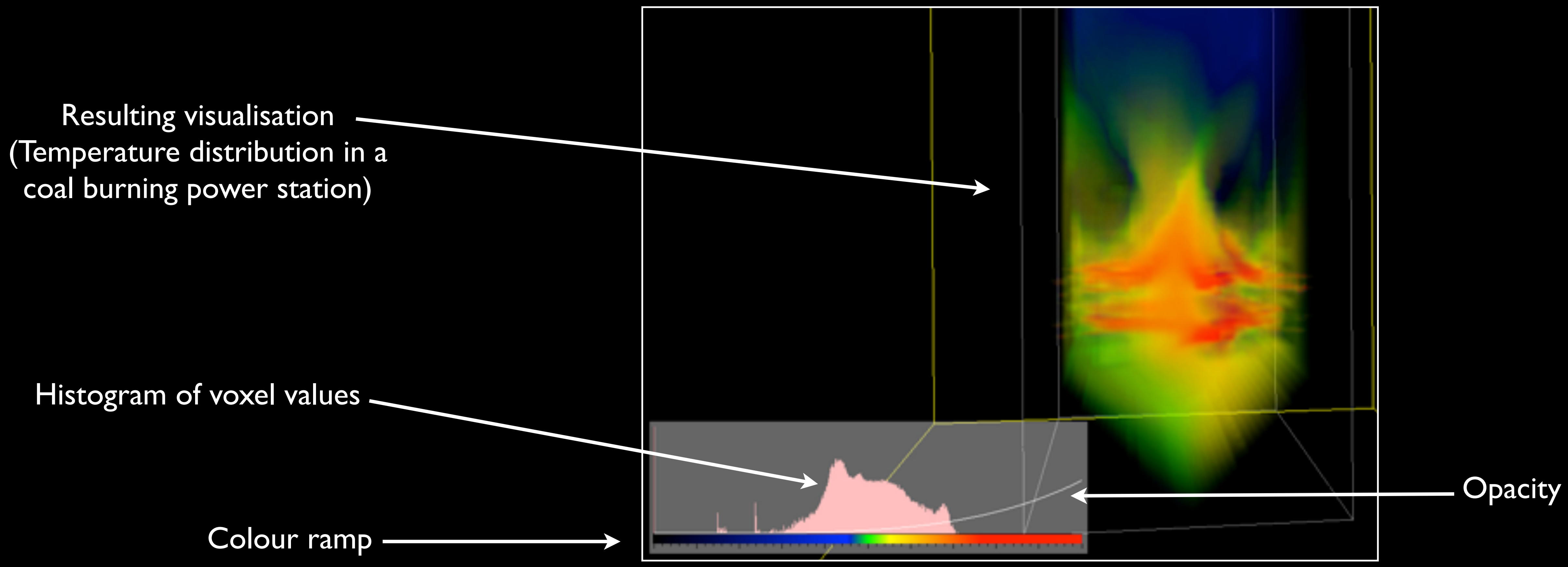
Geology (CT)



Physics (Simulation)

What is volume visualisation?

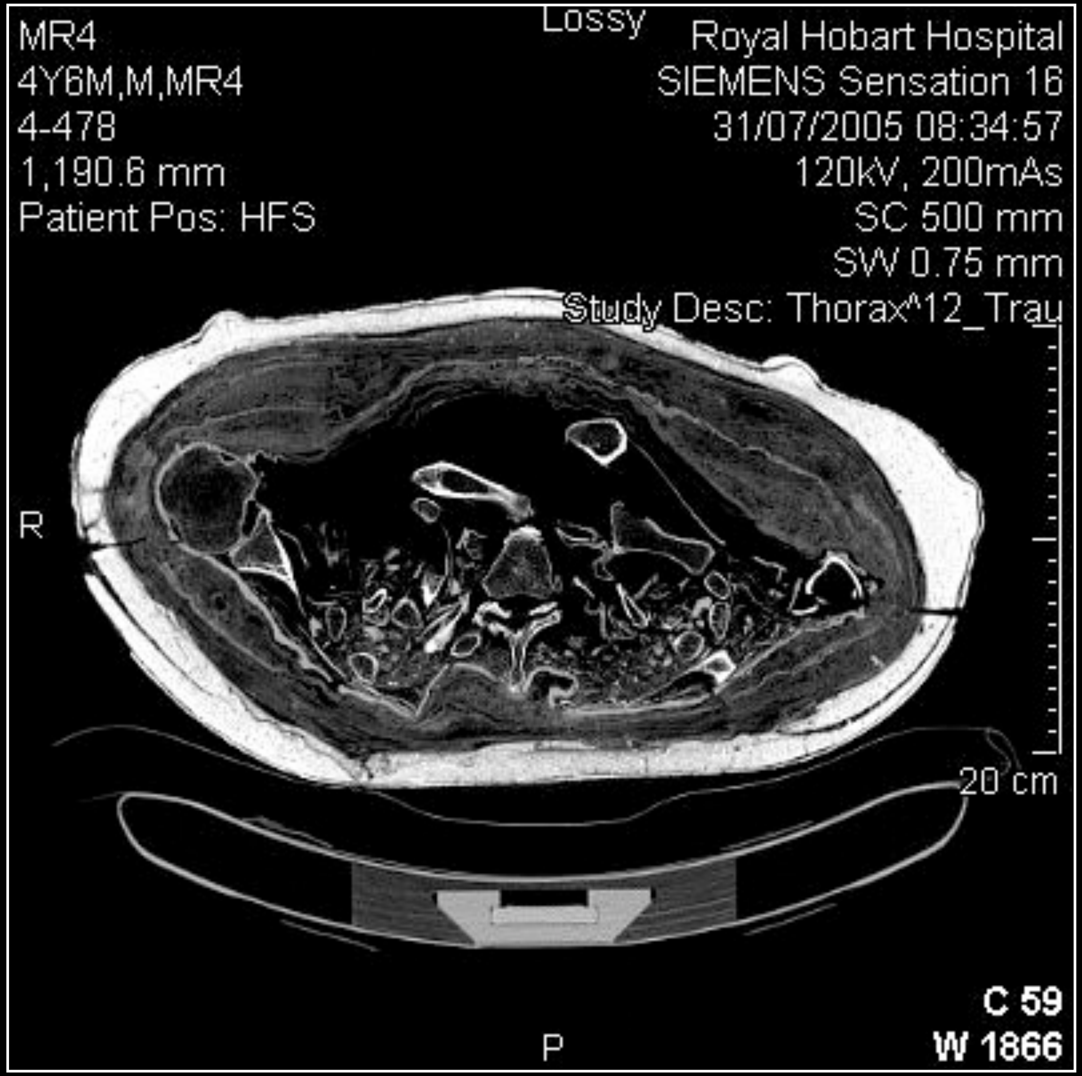
- The process of exploring and revealing the structure/interior of a volumetric dataset.
- The general approach involves a mapping between voxel values and colour/opacity.

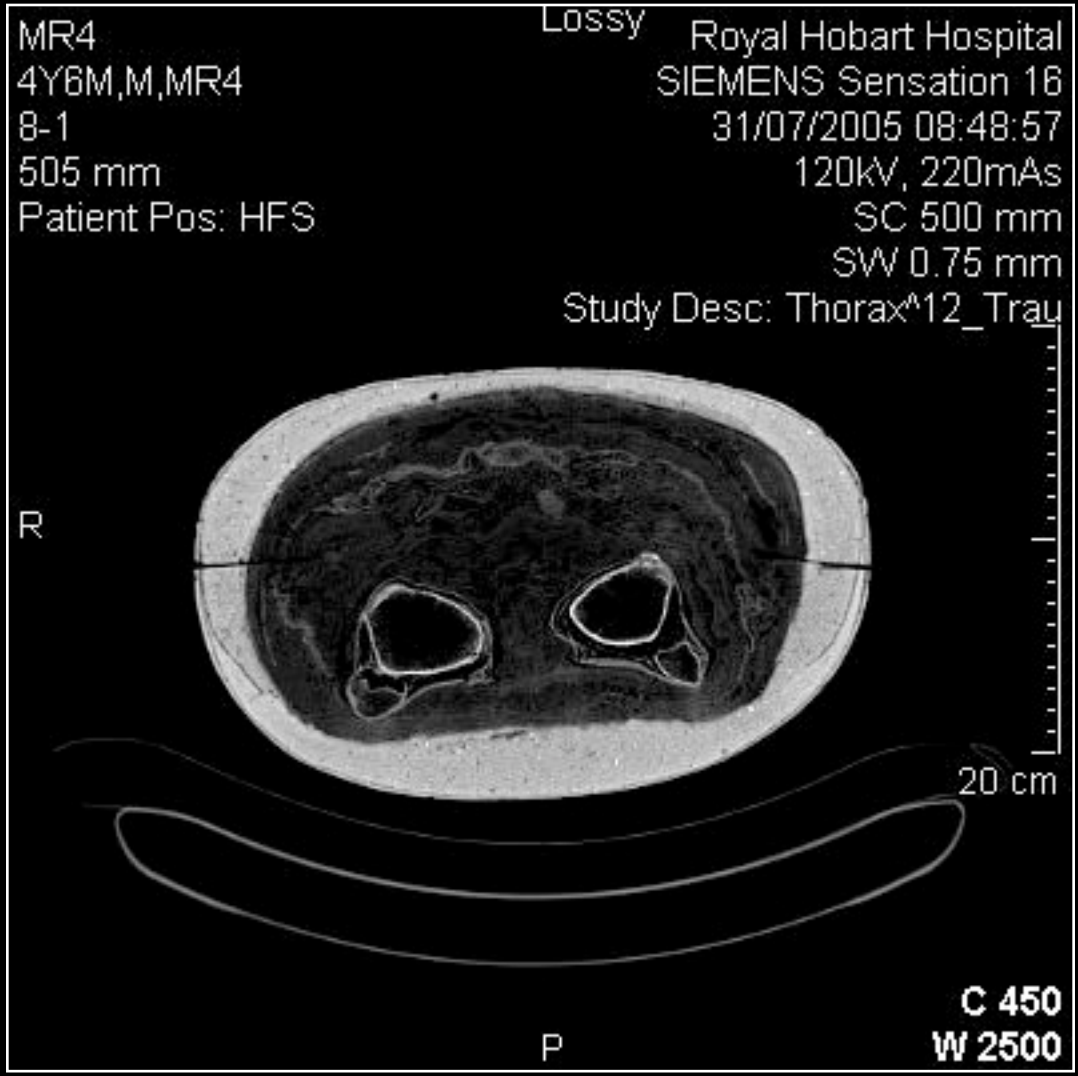


- Today most volume visualisation that runs in realtime is performed on the graphics card.
- The limit on the volumetric resolution for realtime performance is generally the amount of memory on the graphics card.

Example: Egyptian Mummy (MRI)

- MRI essentially gives a volume where each voxel value is proportional to water density.
- In this case the interslice resolution is 1mm, the between slice resolution is 1.5mm.
- Dimension reduction: slicing converts 3D volume into 2D images.
- Volume visualisation provides a mapping from grey scale value to colour/opacity.





Example: Egyptian Mummy (MRI)

Movie sample frame

Courtesy MONA (Hobart)

Example: Egyptian Mummy

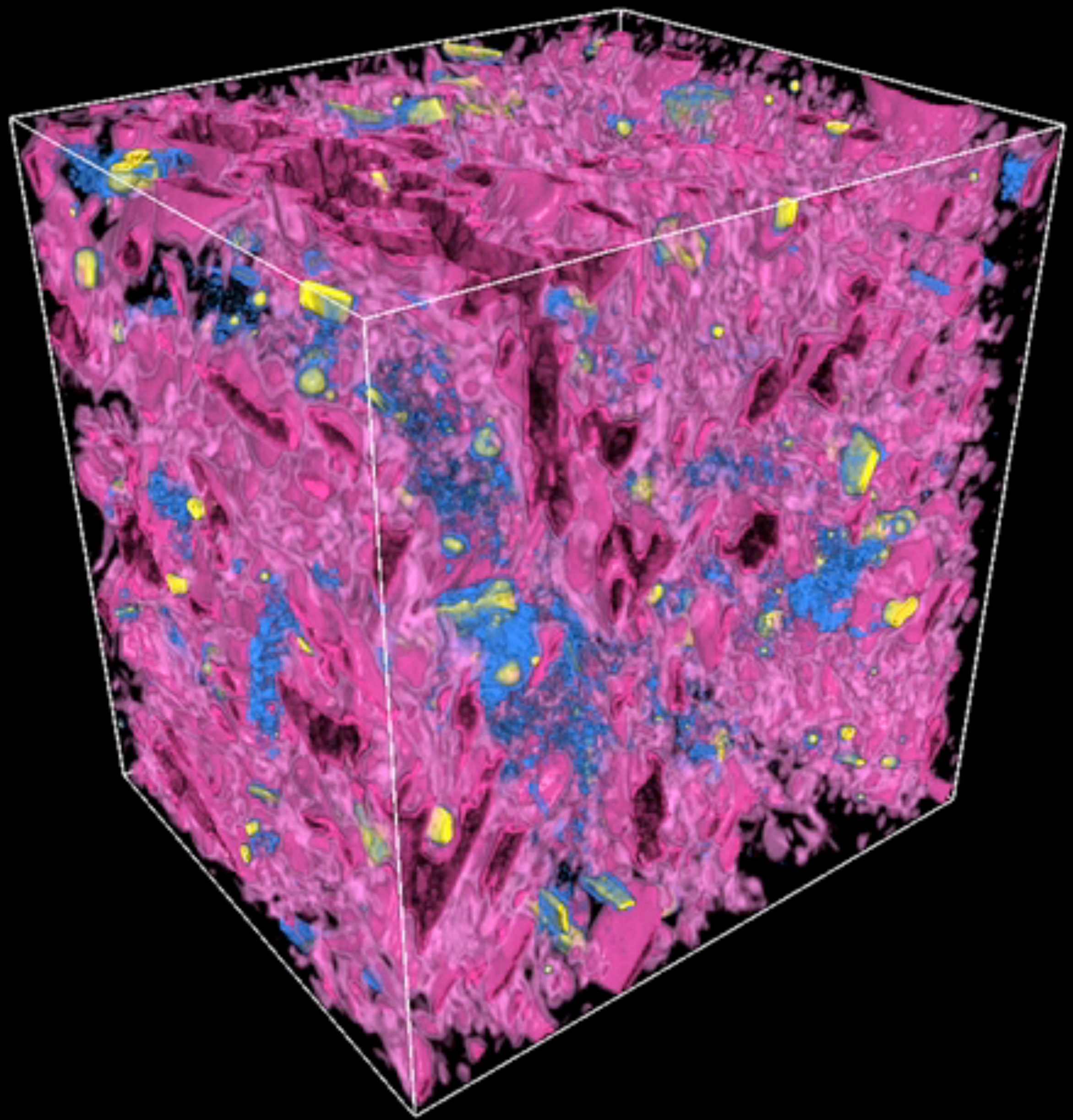
Courtesy MONA (Hobart)

Example: Geology (Volcanology)

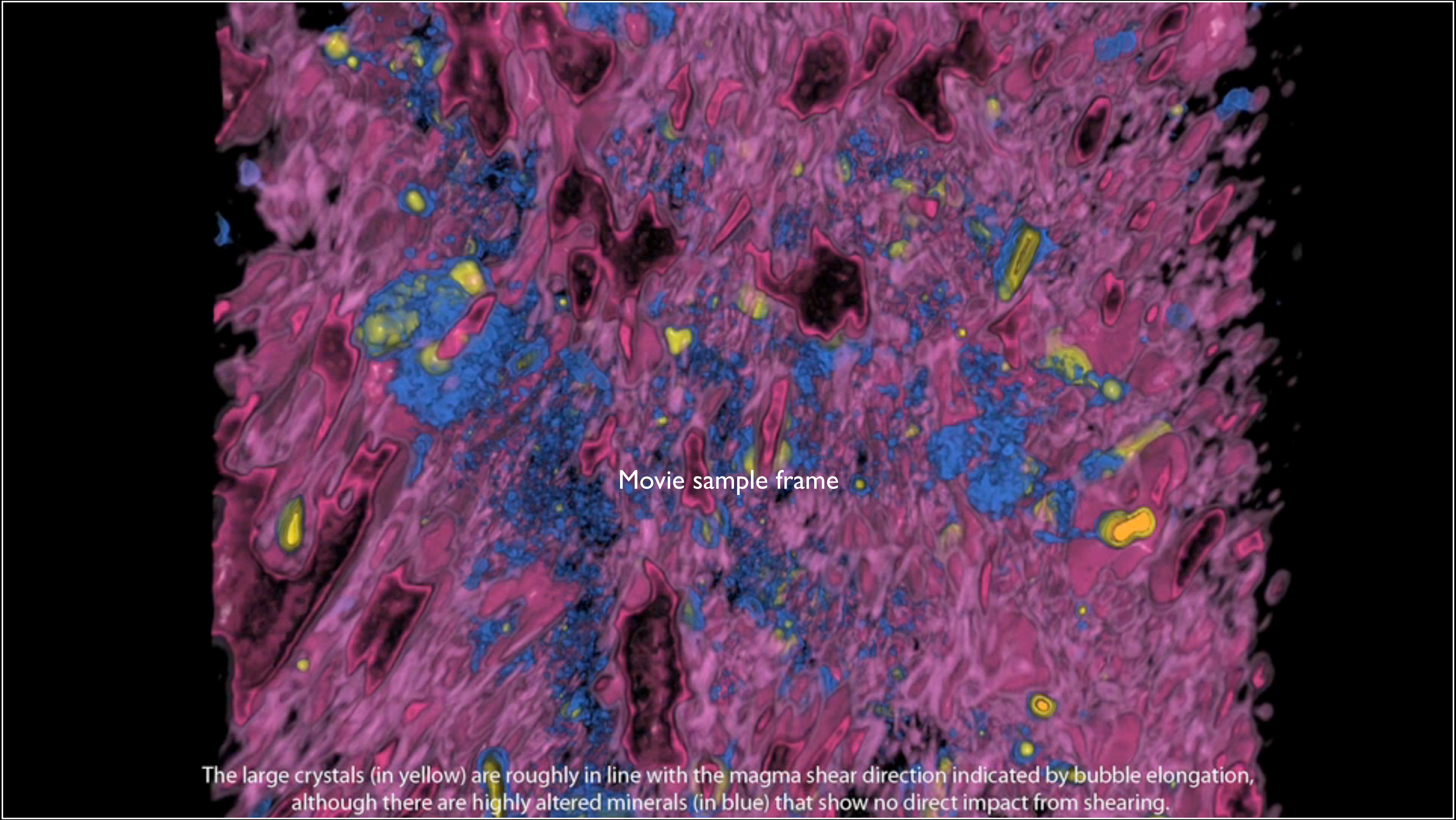
Volcanologists are most interested in how bubbles are deformed and coalesce, or join with neighboring bubbles, at depth (they are highlighted in dark pink).

The regions surrounding the open voids are very low density, indicating the presence of small or partially collapsed bubbles, which are also of great interest in terms of understanding how gas is transported within and away from magma before it solidifies (rendered in light pink).

If we look at the large crystals in each sample (yellow and blue), we can get a sense of the timing of magma deformation relative to the growth of each crystal type.



Courtesy Leslie Almberg


Movie sample frame
The large crystals (in yellow) are roughly in line with the magma shear direction indicated by bubble elongation,
although there are highly altered minerals (in blue) that show no direct impact from shearing.

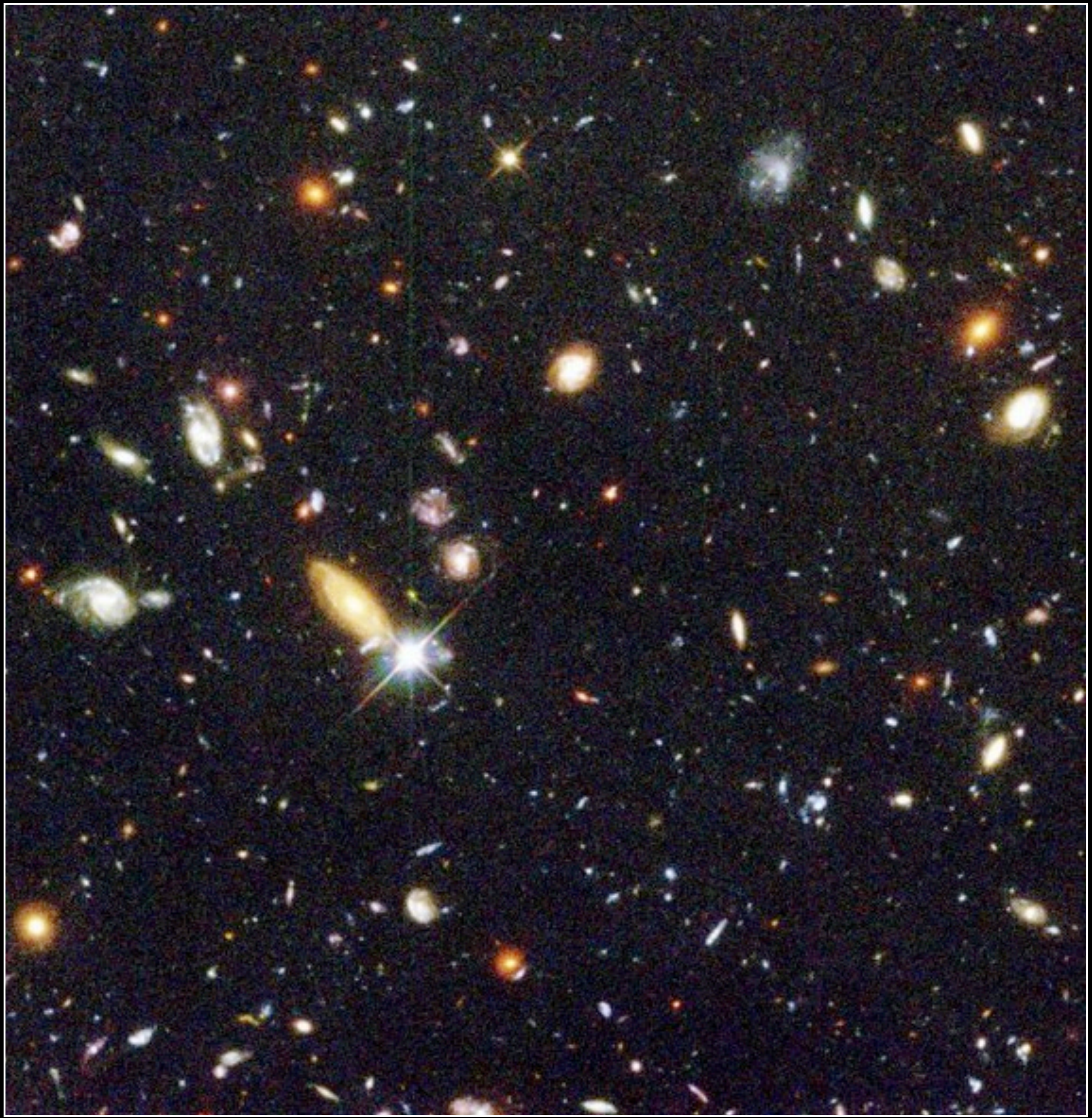
High resolution image data

- Tiled photography is a trend that spans a wide range of disciplines.
- Hubble space telescope - landscape - archaeology - microscopy.

100,000 x 80,000 pixels

6400 x 5120 pixels

Example: Hubble deep field



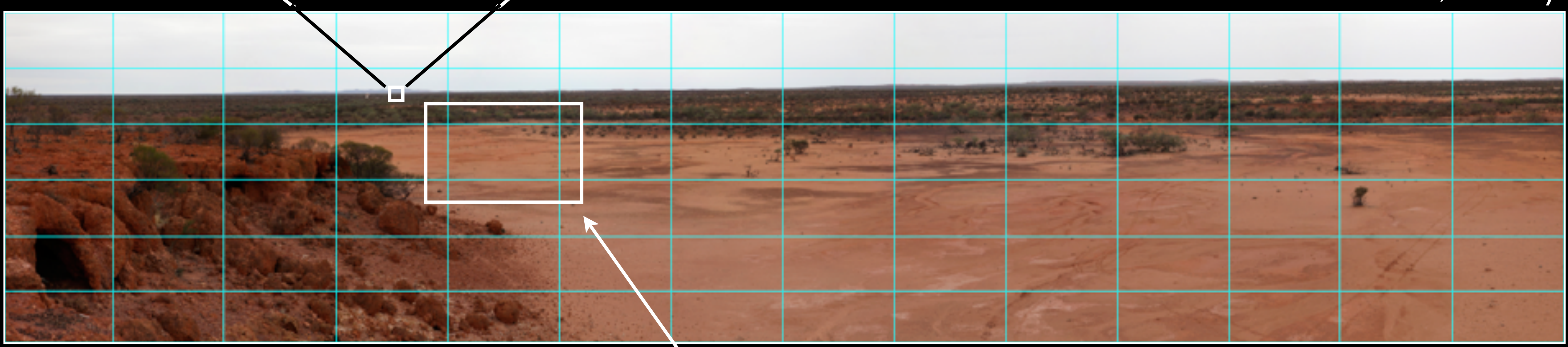
Hubble deep field, 340 images.

Example: ASKAP site

First ASKAP dish

Canon EOS 5D MkII camera
and gigapan mount

ASKAP site, Boolardy



21 MPixels, Canon EOS 5D Mk11

Total: 1.5 GPixels

Example: Microscopy

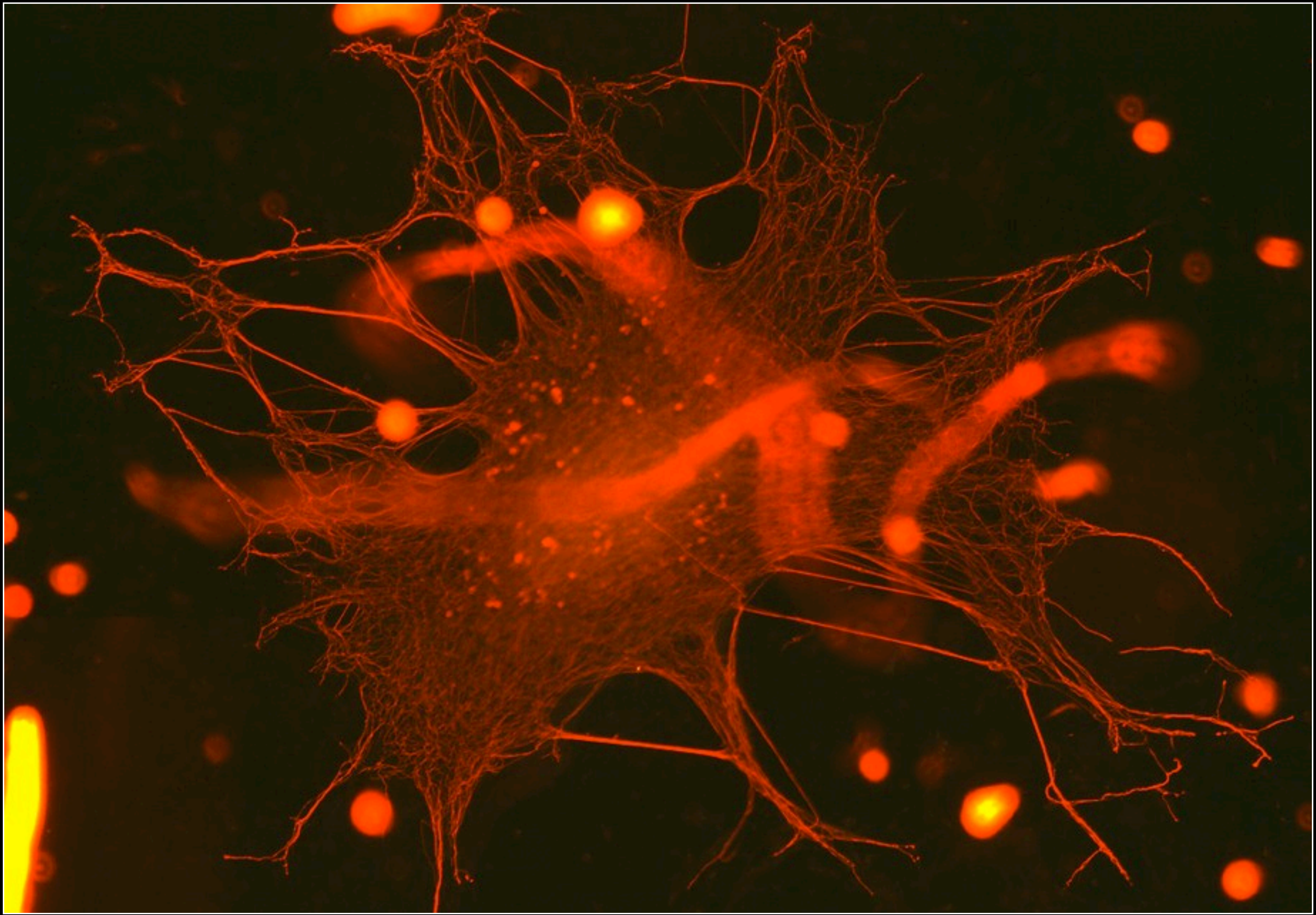


Image courtesy CMCA, UWA

11,000 x 8,000 pixels

Example: archaelogy

Left eye image

40,000 by 20,000 pixels

Hurleys darkroom, Mawsons hut (Antarctica), courtesy Peter Morse.

Visualisation in the humanities

- Cultural heritage: providing insight into a past time and/or culture.
- Often involves special photographic techniques and 3D reconstruction.
- Often uses novel interactive methods of presenting the experience.

Example: Place Turkiyé

- Recording stereoscopic panoramas and 360 video of places and cultural events across Turkey.

42,000 pixels x 12,000 pixels

Left eye

Right eye

Ephesus. Courtesy Sarah Kenderdine, Jeffrey Shaw

360 video

5400 x 2700 pixels

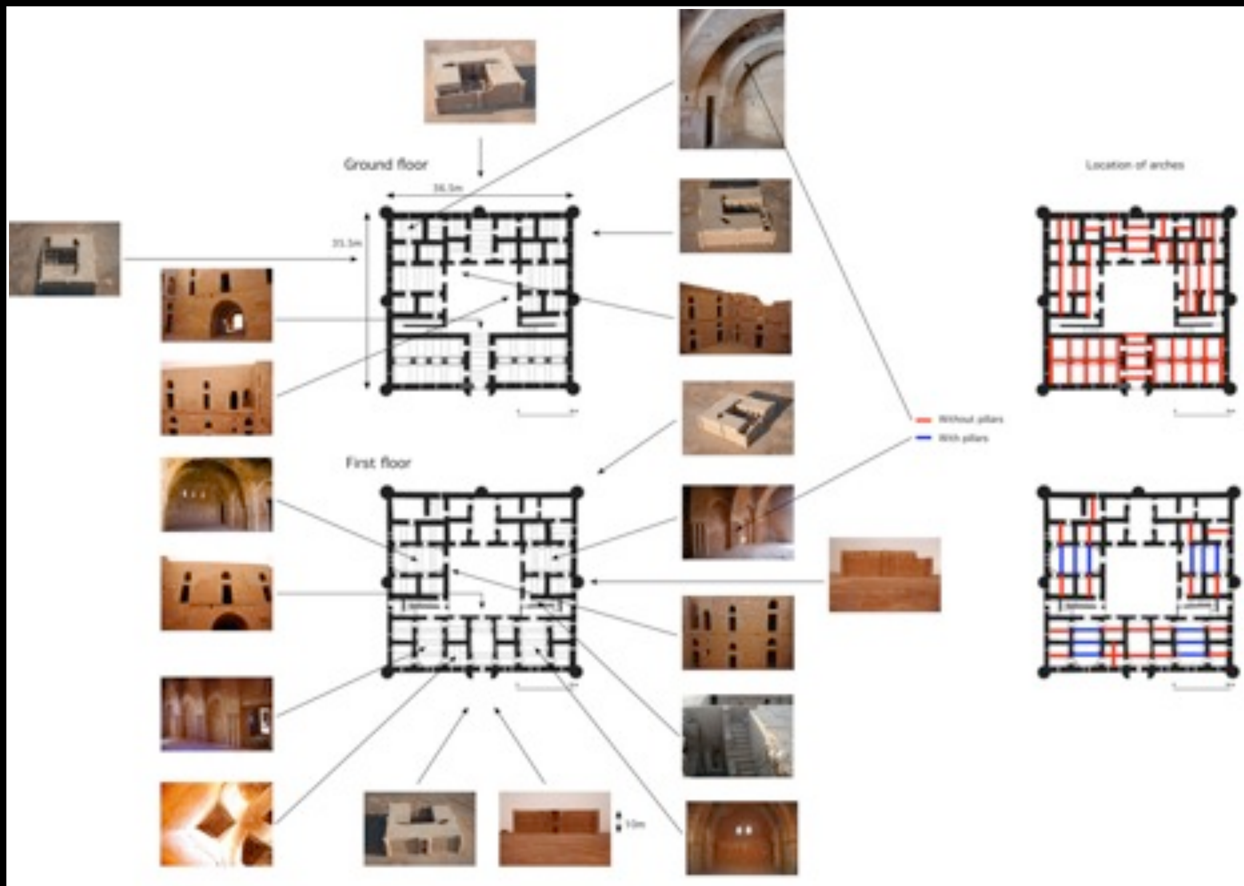
Whirling Dervishes, Orient Express train station

Presentation

3D reconstruction and visualisation in archaeology

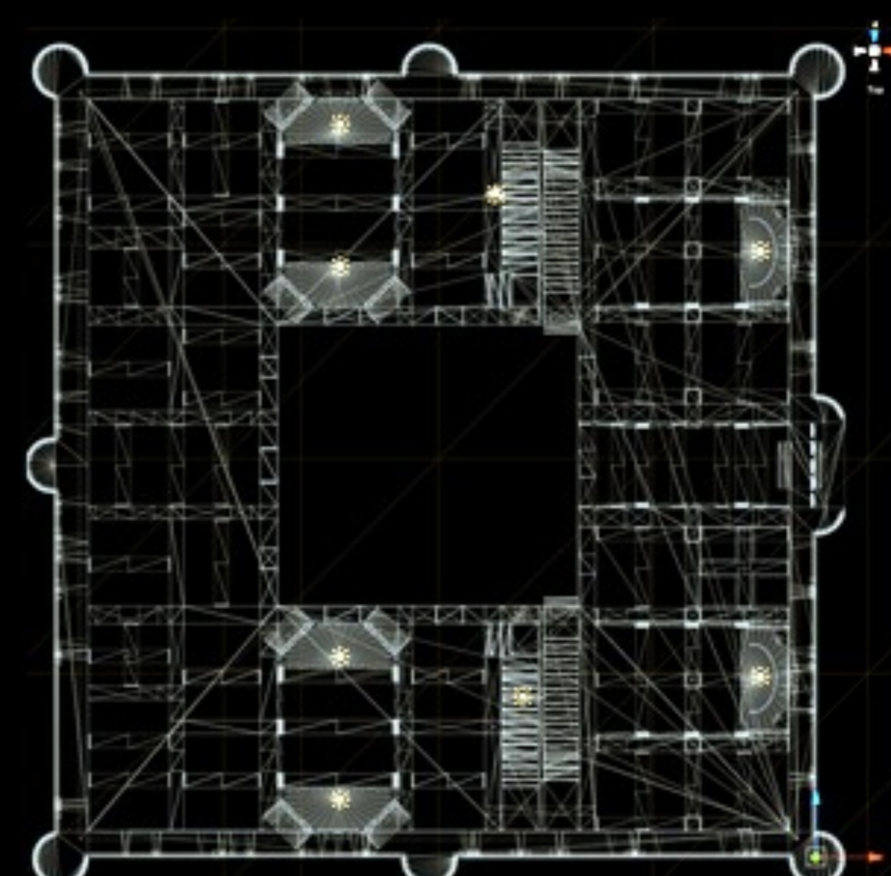
- Reconstruction from diverse range of sources.
  - Descriptive, stories.
  - Plans, often with variations due to error or changes in time.
  - Photographic sources.
  - Paintings, sketches.

- Presentation of 3D interactive environments through game engines: "Serious Gaming".

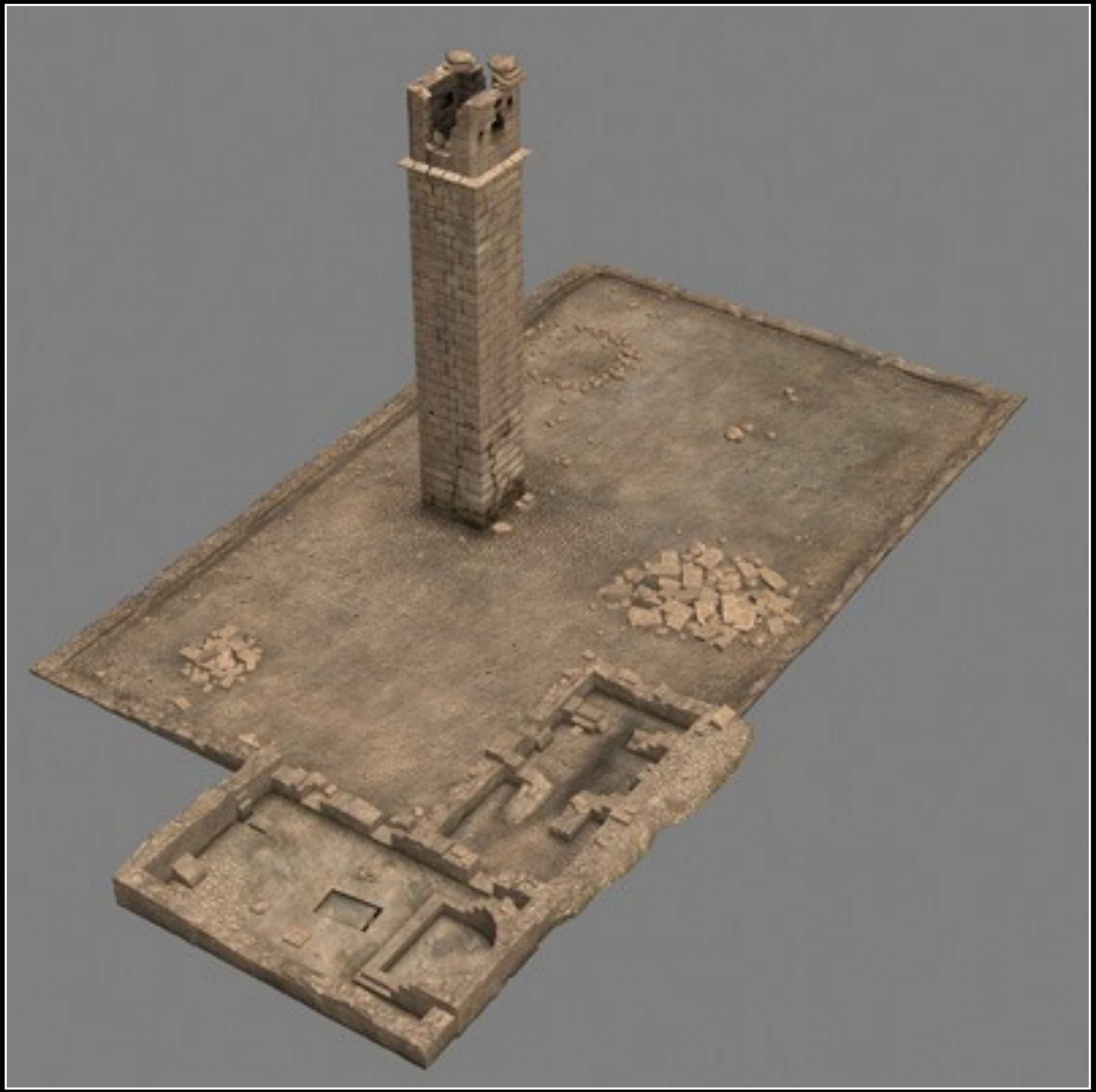


Qasr Kharana

Interactive Virtual Environment



Example



Reconstructed model

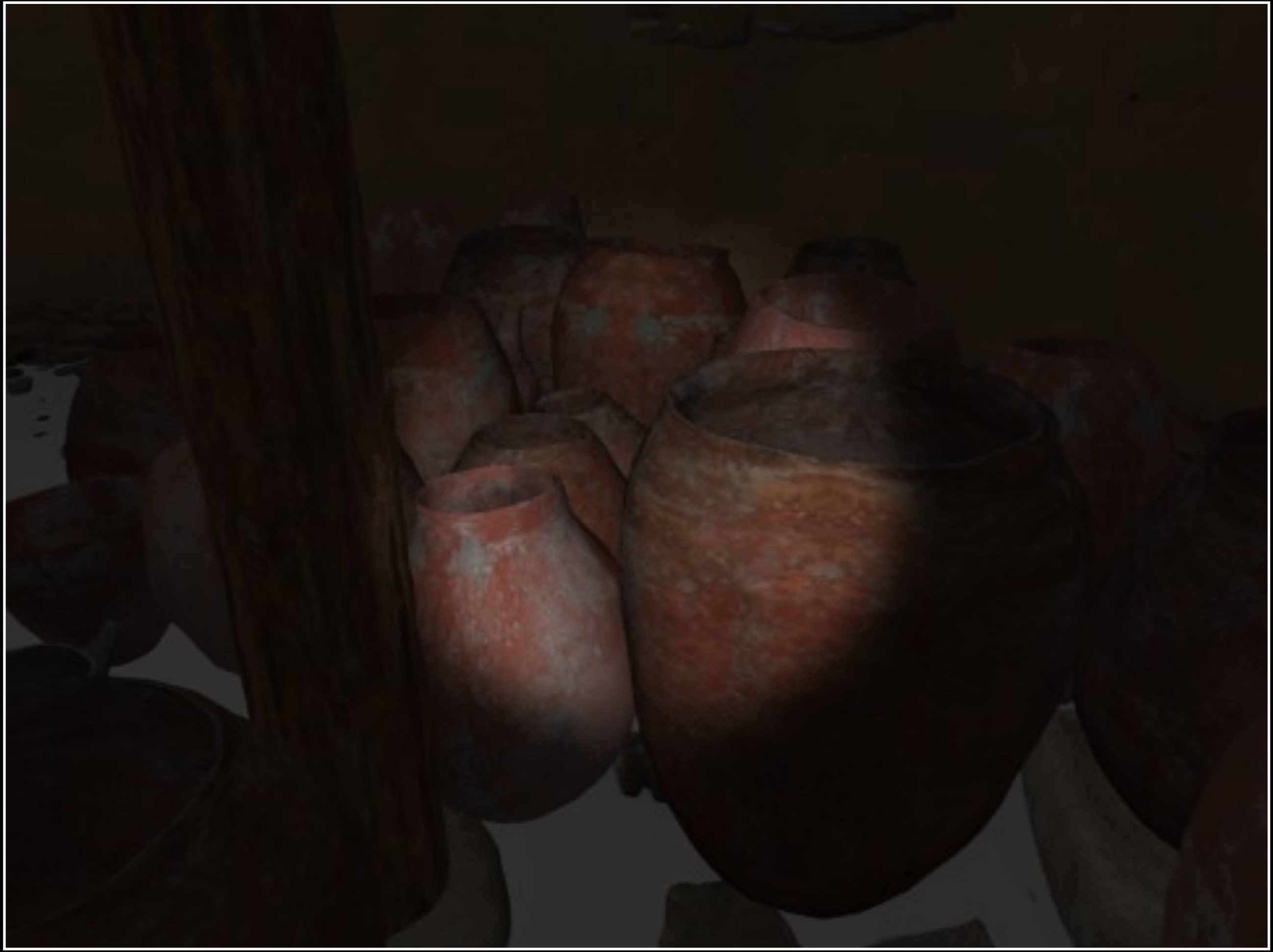
Um er Rasas

Google Earth

Example: Unity3D

Umm er Resas

RoundHouse



Courtesy Mat Dalton

Support for standard displays, stereo3D displays, dome/planetarium, cylinders, multiple walls, online through a browser, iOS devices (iPhone, iPad, etc), Android, Nintnedo (PS3 and Xbox 360 coming).

Presentation to our brain

- Visualisation is largely concerned with the human visual system, that is, presenting information to our brain through our sense of sight.

- There are abilities of our visual system that are not normally engaged when using a standard flat panel display.

- Stereopsis.
  - Our brain receives two images from horizontally offset eyes.
  - Gives rise to the depth perception we experience in real life.

- Peripheral vision.
  - Our field of view is almost 180 degrees horizontally and 120 degrees vertically.
  - Gives us a sense of immersion, "being there".

- Visual fidelity and dynamic range.
  - Eyes (mostly) have higher resolving power than displays, real world is continuous.

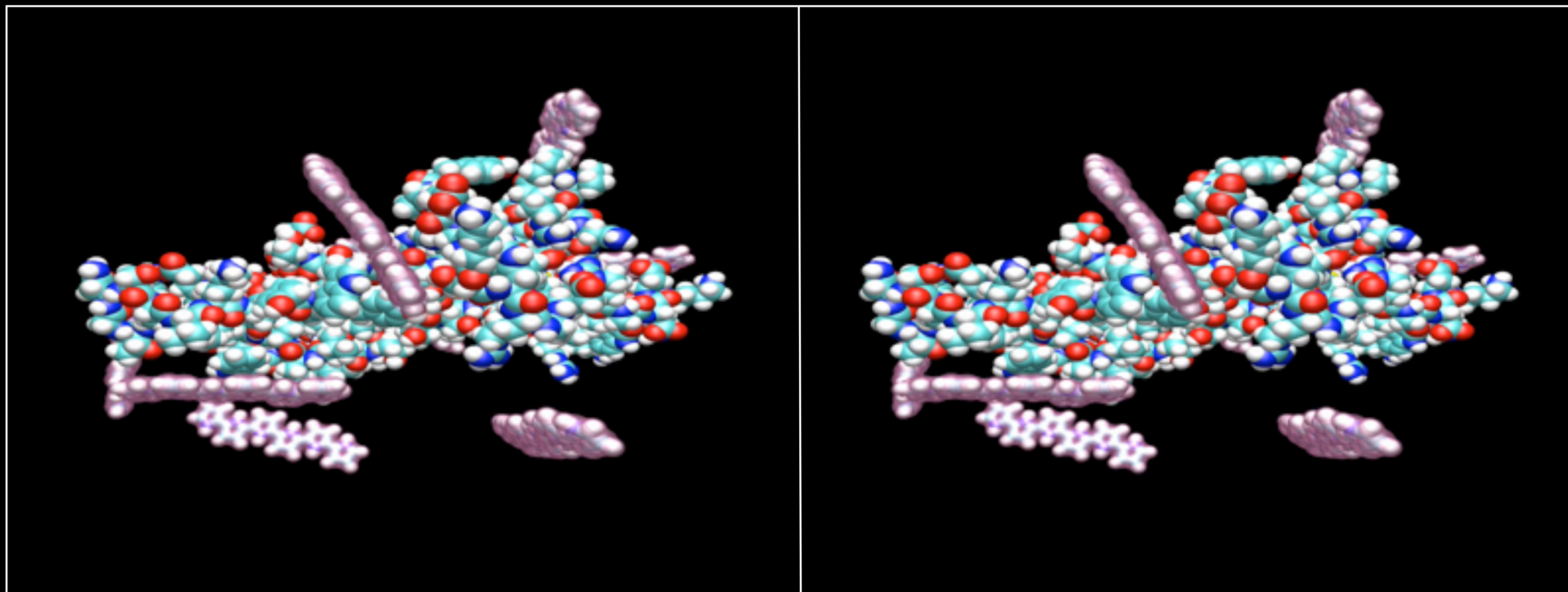
- Display technologies that leverage our visual system are useful in the visualisation process and have applications to public outreach and engaged learning.

  [Demonstration of facilities after this presentation]

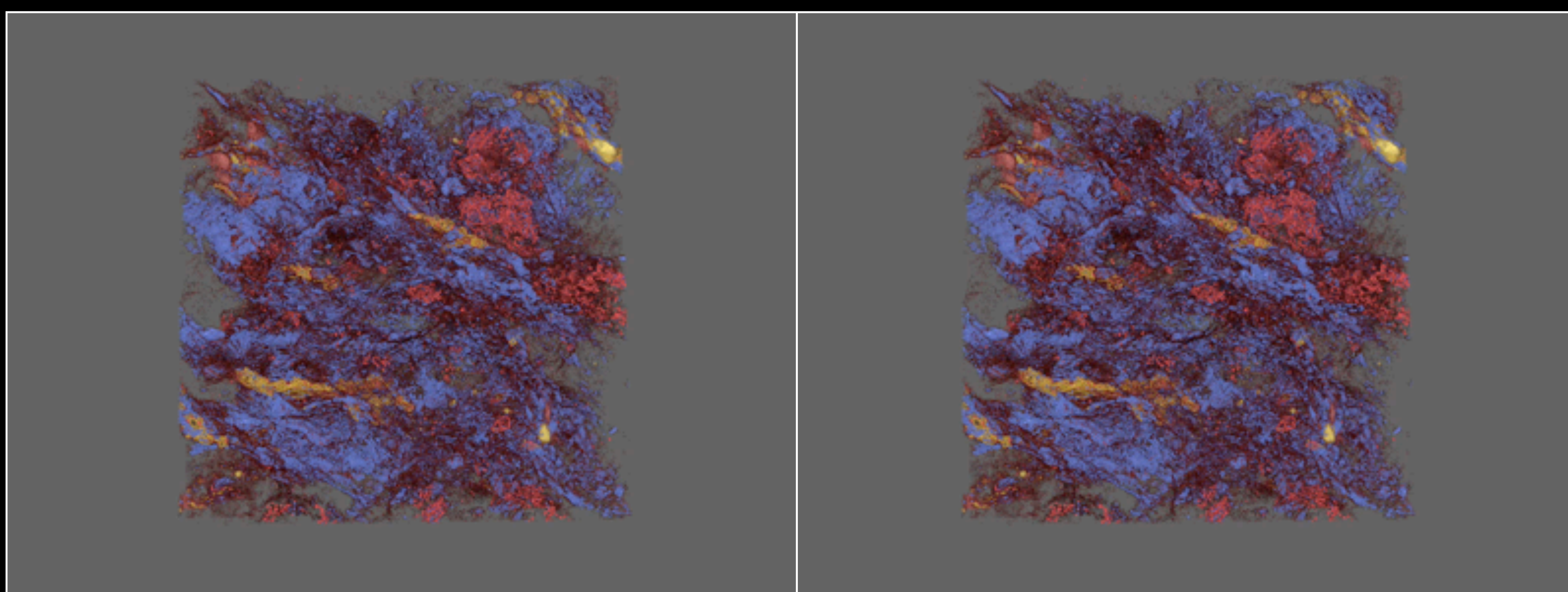
Stereoscopic 3D

- Proposal: Exploring geometrically complicated datasets can be assisted if we use our sense of depth perception.
- Irrespective of the stereoscopic system used the goal is to present two correctly formed images independently to each eye.
- Technologies include shutter glasses, polaroid filters, Infitec.
- Glasses free systems are being developed but generally still low resolution and have viewing constraints.

Examples: Stereoscopic 3D



Left eye Right eye



Courtesy Florian Fusseis

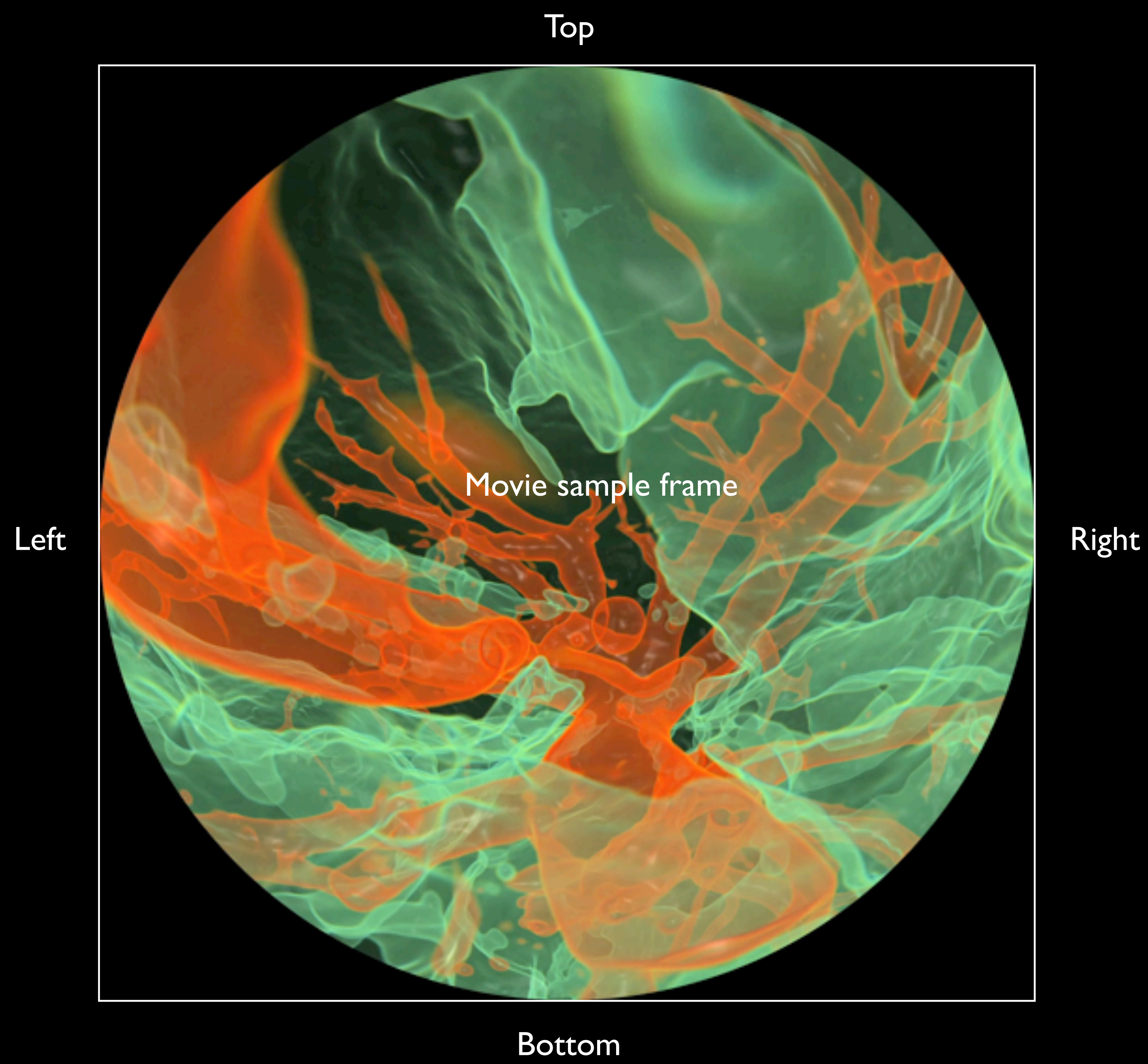
Peripheral vision

- Many geometries have been used, eg: cubic rooms (CAVE), partial room (WEDGE), cylindrical displays (AVIE).
- Peripheral vision is credited with a sense of "being there", otherwise known as "presence".
- Ideal for placing a person inside the data rather than the traditional outside looking in.
- Often provides strong depth cues due to the visual system not seeing the frame.
- Another option is a hemispherical surface.
  UWA has an iDome, Perth has the Horizon Planetarium.

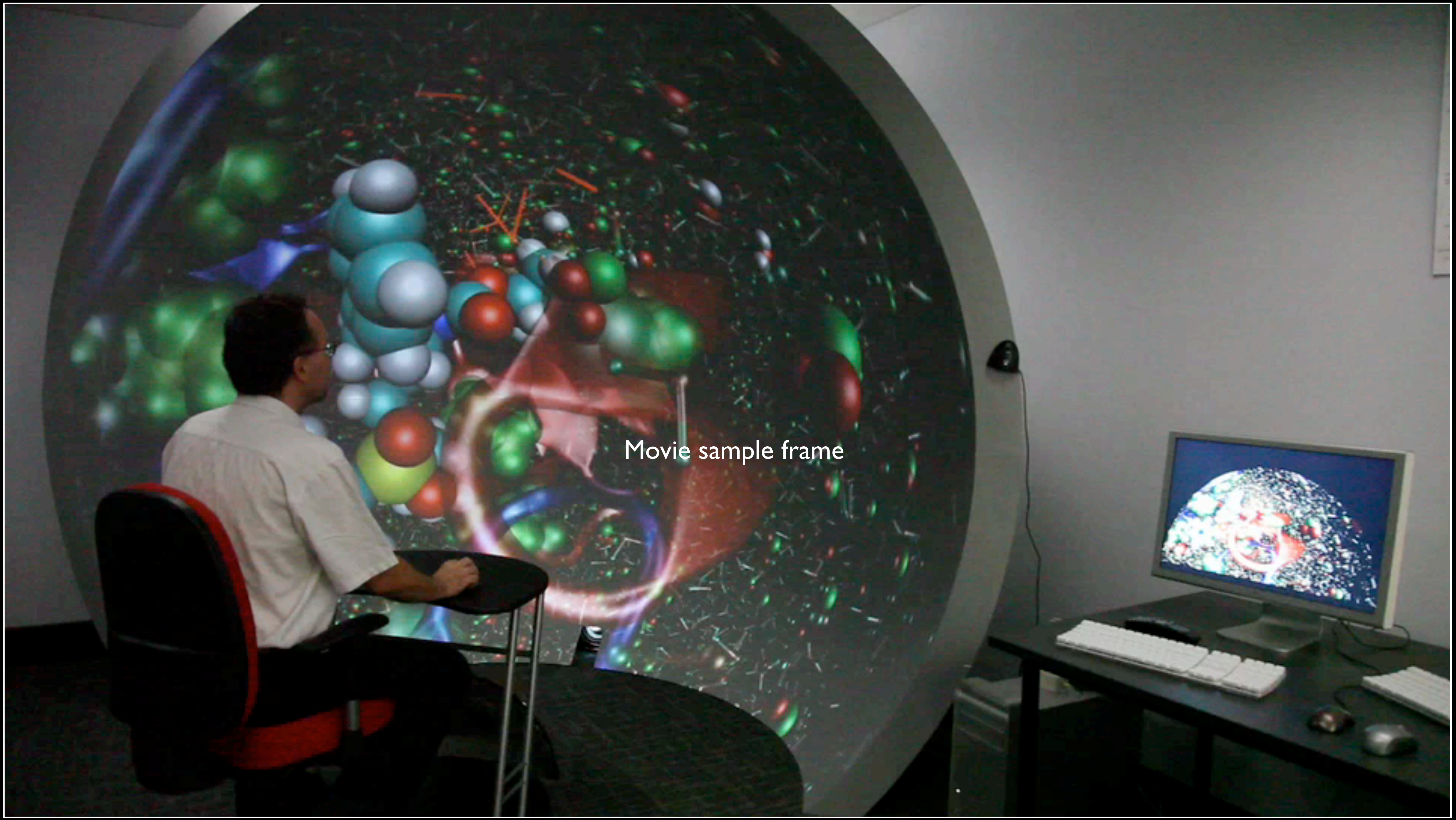
iDome at UWA

Example: Fisheye projection

- Fisheye projection is the natural format for a hemispherical viewing environment.



Example: Molecular simulation



High resolution displays

- Standard resolution displays can be non-optimal for
  - High resolution images.
  - High density data.
- For high resolution images one is forever zooming in to see details (lose the context) or zooming out to see the context (lose the details). The "Google Earth" effect.
- For high density data there simply may not be enough pixels to differentiate the details in the data.
- A standard monitor may be HD resolution (1920x1080), images of resolutions 10,000x10,000 pixels (and much larger) are increasingly common.
- Three approaches
  - Tile a number of standard data projectors. Very hard to get high resolution and end up with a high cost of ownership system.
  - Tile a number of high resolution (4K) projectors. Costly, require lots of space.
  - Tile a number of commodity LCD panels.

Tiled Displays

- The highest resolution panels (readily) available are 2560x1600.
  UWA system has 8 units resulting in 33MPixels.
  6400 pixels horizontally by 5120 pixels vertically.

- Bezels are a disadvantage but accounted for in the viewing software for a similar experience to looking through a window frame.

- By far the lowest cost per pixel option for high resolution.

- Physically move closer to see detail, stand back to see the context.

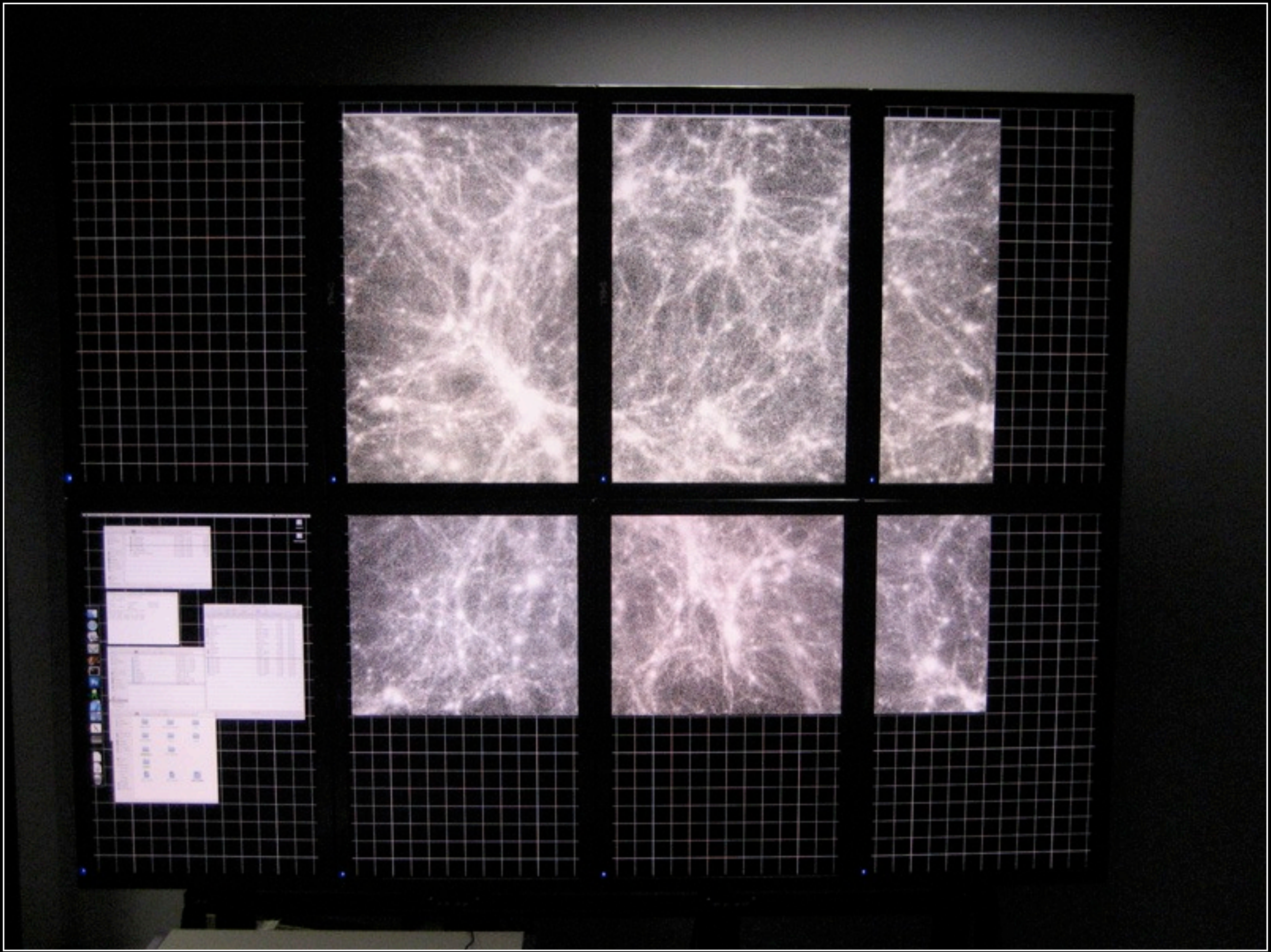
Courtesy Hubble Space Telescope

Courtesy CMCA, UWA

Tiled displays and high resolution imagery

Google Earth

Tiled displays and high density data



Cosmology simulation data

Holography

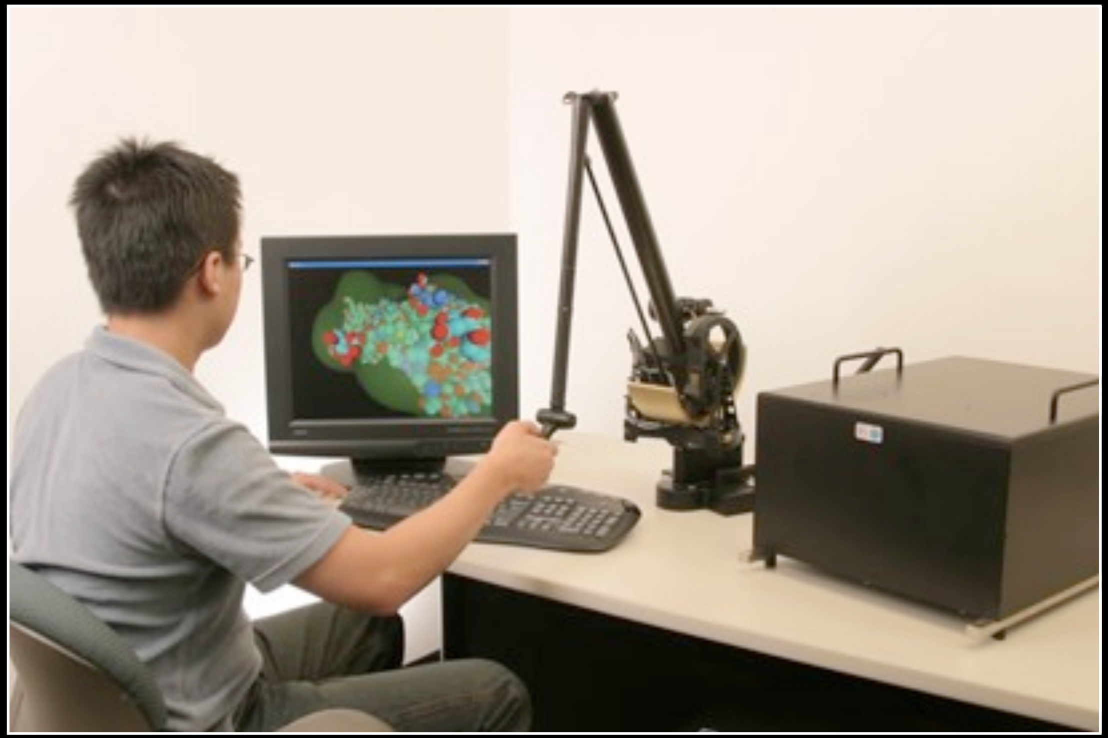
- The ultimate form of 3D display would be a hologram.
  Technology does not exist yet for (useful) realtime holography.
- Note that there are lots of technologies being proposed that use the word "hologram" and very few are holograms in the true sense of the word.
- A true hologram encodes the interference pattern of light from an object with a reference beam. Upon illumination of the hologram the light field is reconstructed by a process called diffraction.
- A discrete approximation to a hologram has been developed for printing and called a "holographic panoramagram".

Placoderm jaw and "teeth"

Other senses

- Sonification.
  - Turning data into audio/music.
  - Well known example is a Geiger counter for measuring ionizing radiation.
  - Another example are hospital machines for heart rate monitoring.
  - Mapping of data values to frequency, amplitude, tempo, instruments.
  - Often used in support of visuals, often too imprecise by itself.

- Touch.
  - For example Braille.
  - Haptic user interfaces with force feedback allow one to “feel” data.
  - Rapid prototyping creates physical objects from data.



Phantom from SensAble Technologies

Tactile Visualisation - Rapid Prototyping

- A number of technologies exist that will allow one to automatically build a physical object from a computer model. Essentially 3D printing.
- Each technology has certain advantages and disadvantages. For example: degree of post production, strength of material, cost, colour fidelity, etc.
- Designed mainly for the mechanical engineering fields and component/product design. Also well established in the medical area for pre-surgery planning and implant design.
- Allows one to explore data in the same way as we explore objects in our everyday experience.

Tactile Visualisation - Crystal Engraving

- Rapid prototypes can only practically be used for a small number of connected parts.
- Crystal engraving (usually found in tourist shops) allows disjoint or even point based datasets to be captured as a physical object.

MRI Mummy dataset

Human heart

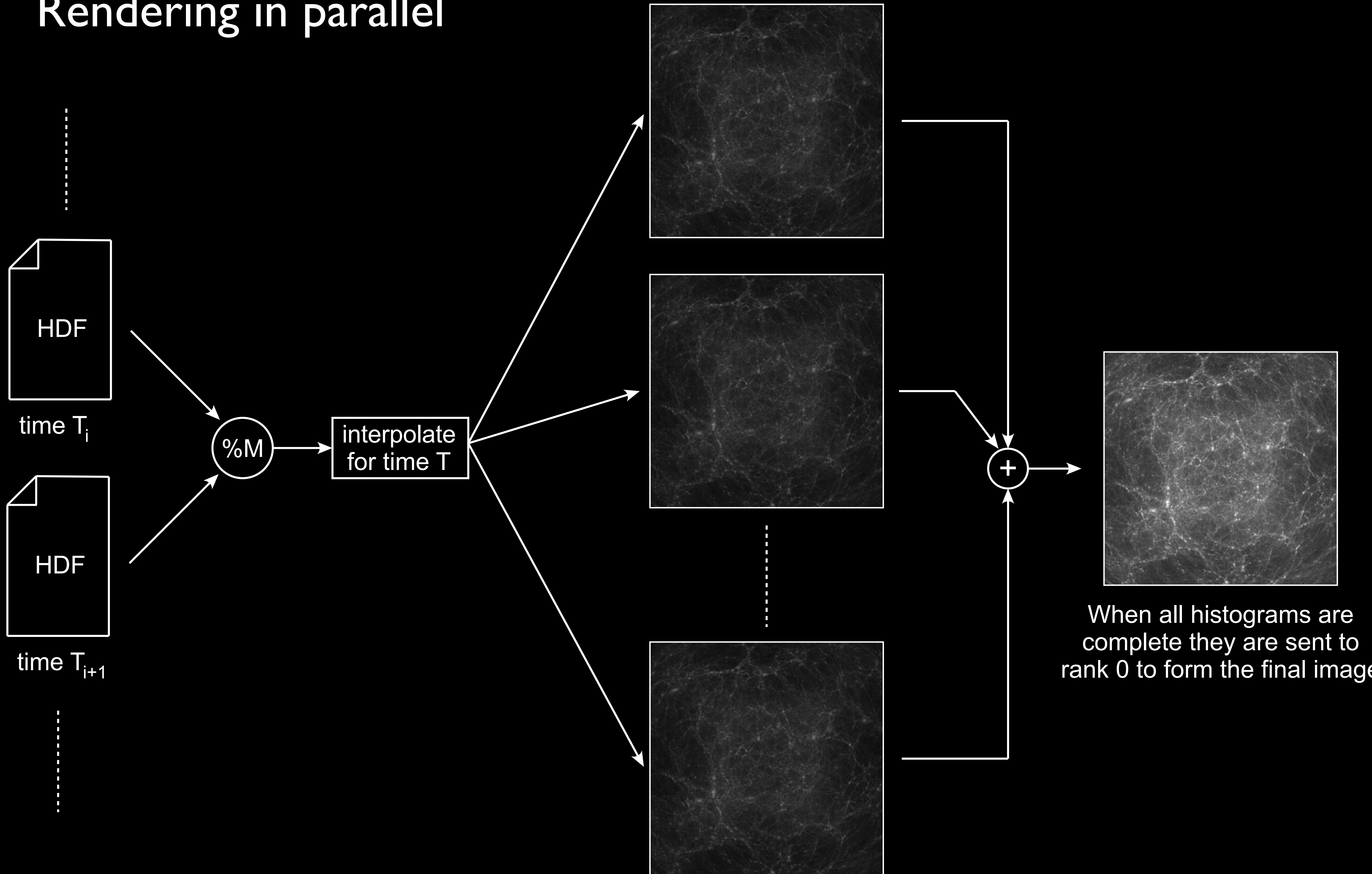
Main challenges

- Datasets are getting larger as instrument resolution improves.
- Datasets are getting larger as compute resources grow allowing higher resolution simulations.
- The size of datasets from 10 years ago that were difficult to visualise can now be handled in real time on commodity hardware. But the datasets of today have simply grown to be just as problematic.
- Often need to deal with datasets that cannot fit into memory on one computer or cannot fit into graphics card memory.

Example

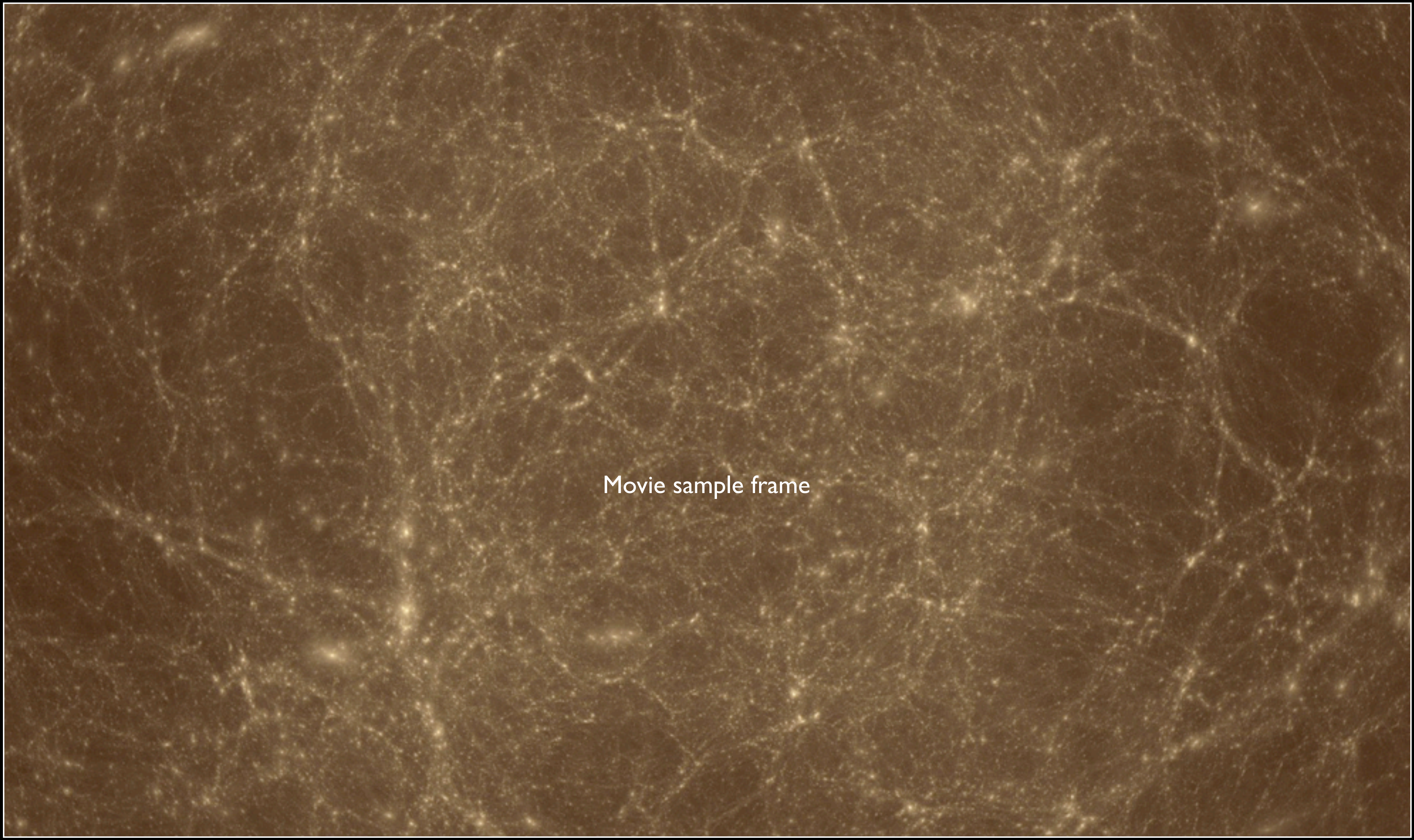
- Simulation within a cubic region (periodic bounds) of the Universe just after the Big Bang.
- 600 million light years on each side of the cube.
- Shows dark matter collapsing over 14 billion years of cosmic time, forming filaments and collapsing haloes of the Cosmic Web.
- Original simulation computed on vayu (NCI).
  Used 1024 cores, 2.8TB RAM, took 19 hours (~20,000 CPU hours)
- There are 1 billion particles, the final image is essentially a histogram formed on the projection plane. The visualisation movies were produced at 3000x3000 pixels, if the whole dataset is in shot and if it were uniform then there would be 100 points per pixel.
- Need position + velocity + mass for each particle = 7 floating point values = 28GB per time step. Need two time steps for smooth time interpolation!
- Visualisations like the simulation are computed in parallel using MPI.

Rendering in parallel



N = 10^6 points each timestep

M independent MPI processes each working on 1/N of the data and each generating a histogram


Movie sample frame

Trends

- Compute - data - visualisation “in the cloud”.
  Development of tools that compute visualisation remotely from remotely located data.
  - Key solution to large data volumes which may not or cannot be local.

- Realtime visualisation generated on remote servers through a range of technologies similar to VNC, screen sharing, etc.
  - Removes the need for (often expensive) software licences.
  - Removes the need for high-end workstations.

What I can offer during your internship

- Advice on any/all aspects of computer graphics and geometric algorithms.
- Advice on file formats and data conversion.
- Access to novel presentation technologies.
- Access to high end graphics workstations (128GB Ram, top-of-the-line graphics cards).
- Access to loan hardware such as high resolution cameras, projectors, ...

Questions?

Move to VisLab for demonstration.