Novel physical representations for the visualisation of science data and mathematics

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Visualisation

- The application of computer graphics and advanced algorithms to enhance the understanding of data, to provide insight.
- Key senses employed are the sense of vision (hence visualisation), hearing (sonification), touch (haptics).
- Often leverage key characteristics of the human visual system: fidelity (high resolution), depth perception (stereoscopic 3D), and peripheral vision.

6000 pixel wide, stereoscopic,
large scale display.
UWA VisLab.

Game engines

- There are lots of discipline and problem specific software, much of it very expensive.
- We have been interested in the application of commodity / consumer products for the visualisation of scientific data.
- For example, visualising data in SecondLife.
  Leveraging the considerable graphics effort in that and other consumer software.
  In this case not successful from the perspective of adding value to the visualisation process.
  Limitation around import limitations.

Evaluating Second Life as a tool for collaborative scientific visualisation.

Game engines

- Have recently been basing many data visualisation projects on the Unity 3D game engine.
- Extremely powerful environment with options for distribution on multiple platforms.
- In conjunction with products such as getreal3D and MiddleVR these add stereoscopic 3D support as well as head tracking and support for various input devices.
- Clearly adds value and saves local development investment.

Unity3D operating with head tracked stereoscopic viewing. UWA VisLab.

The problem

- Traditional visualisation hardware tools are often problematic to use outside the laboratory.

  - High cost, can have insurance implications

  - Delicate, while suited to use by researchers may not be suitable for the public

  - Require training, for example user interface (software and hardware)

  - Portability, often equipment is fixed or problematic/expensive to relocate

  - Health and safety, for example stereo glasses and particularly head mounted displays

- These may limit the applicability of the hardware at conferences, public spaces, museums, art galleries or the classroom.

Solution

- Will present three technologies being evaluated for data visualisation.

  3D printing - Crystal blocks - Lenticular prints

- These are normally used for more frivolous activities.

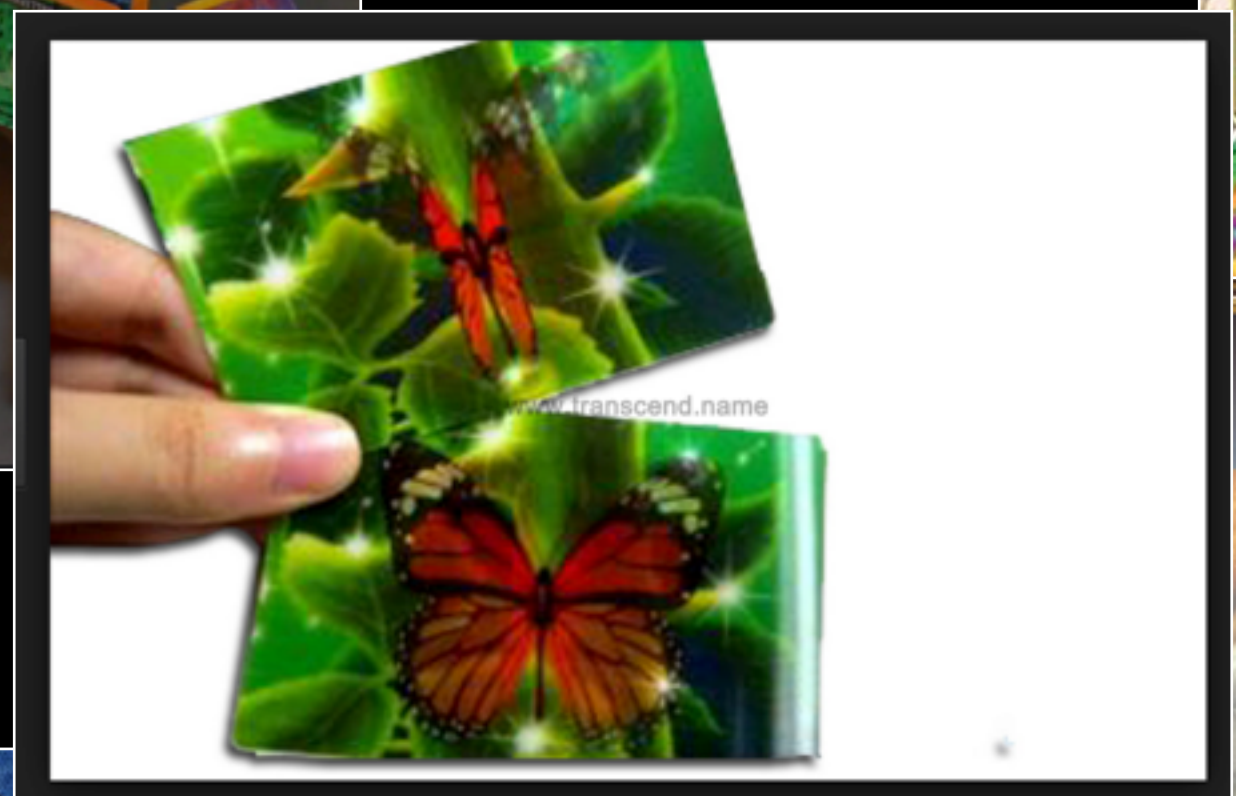
  - Biggest online market for 3D printing is jewellery.
    Printing game characters is second.

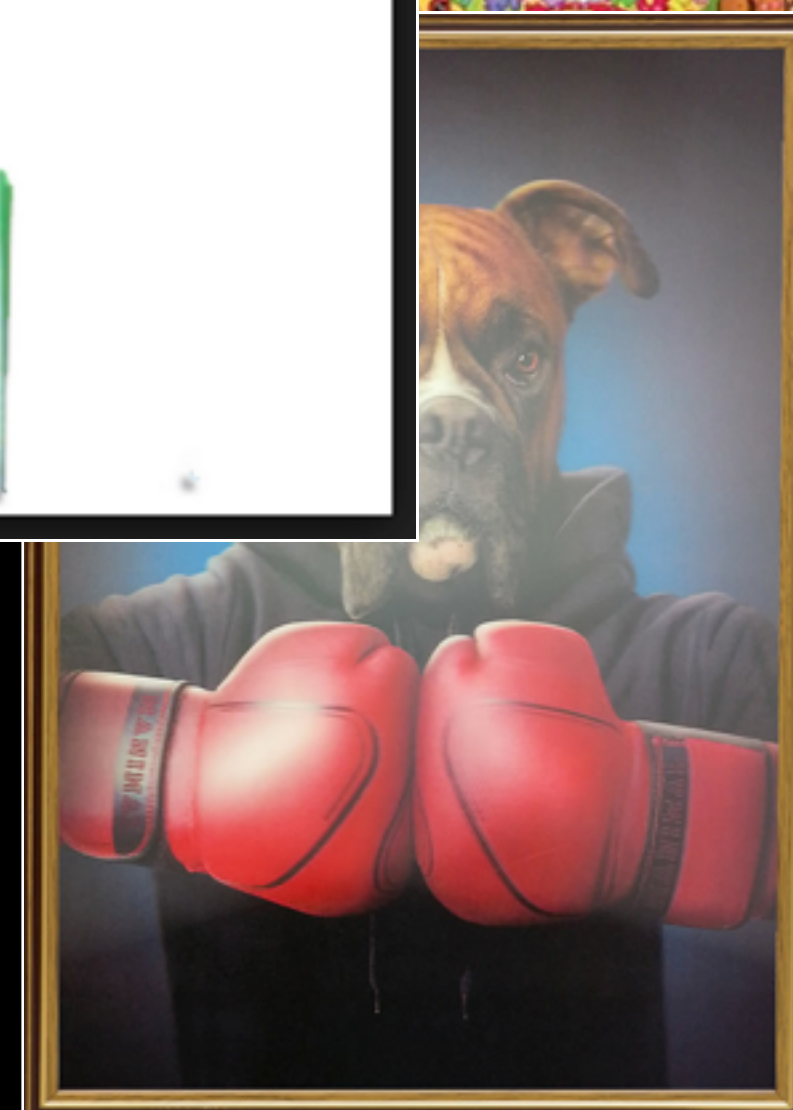
  - Crystal blocks are used for company branding and 3D face prints.

  - Lenticular prints used for marketing, for example game packaging.

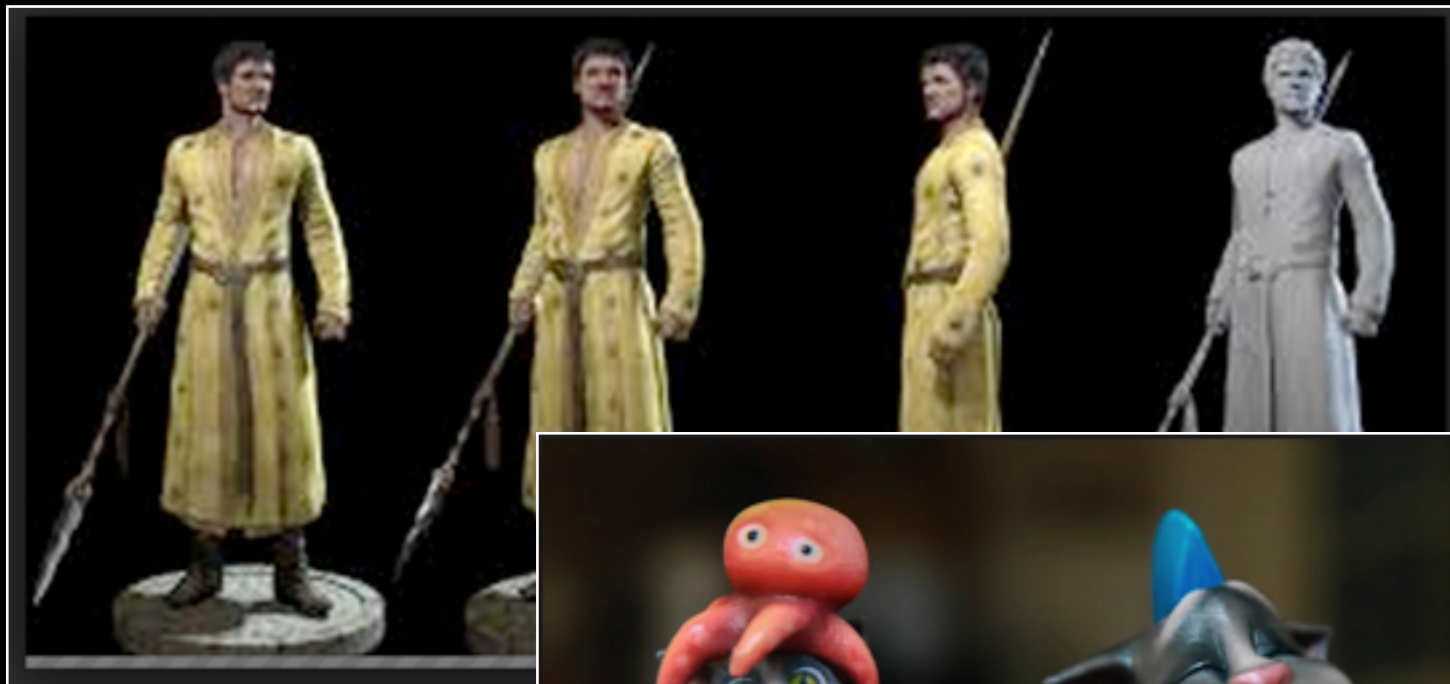
Crystal engraving

Lenticular prints





3D printing



Research

- Determining which data sets are most suited to each representation.
- How to optimally create material for each representation.
- How to convert existing data types into suitable formats.
- Evaluating which representations bring value to the visualisation process.

[As an aside they are also finding value as merchandise, promoting science research]

Lenticular prints

- A means of creating stereoscopic images that engage our depth perception.
- Unlike most stereoscopic displays these do not require glasses nor other viewing hardware. Just a print!
- Brief history: Barrier strip
  - 1692 the French painter G. A. Bois-Clair created paintings consisting of a pair of images with a grid of vertical slats in front.
  - Photographic possibility was discussed by Auguste Berthier in 1886.
  - First evidence of actual barrier strip construction was by Frederic Ives in 1901.
- Brief history: Lenticular
  - One-dimensional arrays of cylindrical lenses patented by Walter Hess in 1912.
  - Popular from the 1940s to create "flip animations" in the advertising industry.
  - Popularised again in the 1960s, for example, cover of the Rolling Stones: "Their Satanic Majesties Request".
  - 2002: Sharp manufactured switchable 2D/3D displays barrier strip displays.
  - Lots of autostereoscopic displays peaking around 2008.
  - Philips created the WOWvx screens in 2009.

Lenticular prints

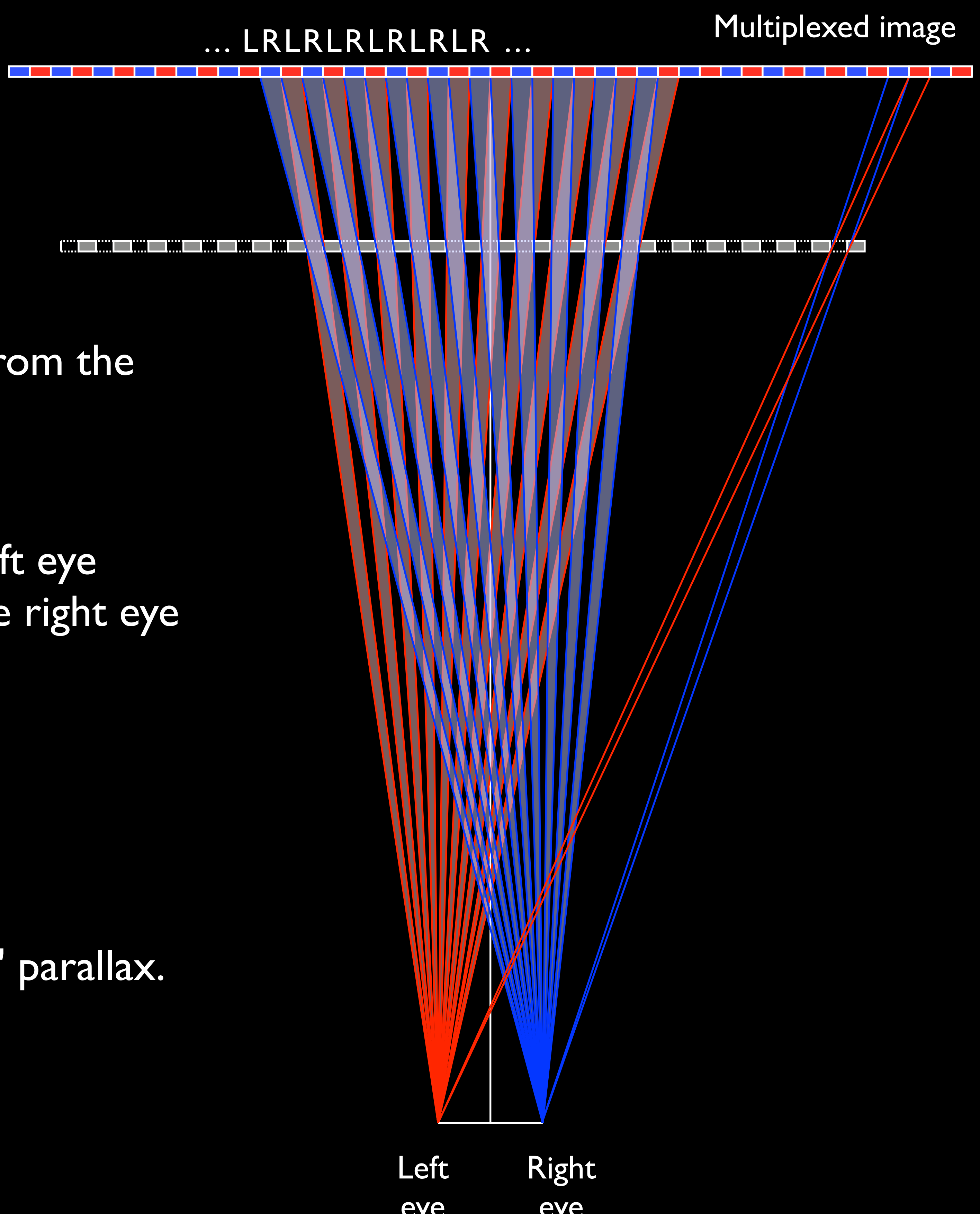
- Give researchers the ability to present work at conferences and exhibitions as autostereoscopic prints. Similar to how researchers experience the data in the laboratory.
- Avoiding the need to take display hardware to conferences for poster sessions.
- Avoids the high cost (factor of 10) of holographic panoramagrams investigated in 2009-2010 (http://paulbourke.net/miscellaneous/hologram/).
- Do not require special lighting.
- Generally have better colour reproduction than laser based holograms and even better than holographic panoramagrams.
  eg: Geola or Zebra prints.
- Personal motivation:
  Like the idea of employing commodity technologies normally used for "frivolous" marketing for more serious activities.

- As with all stereoscopic images, the requirement is to independently present a (correctly formed) image to each eye.

Lenticular prints: Multiplexed image

- Multiplexed image consists of alternating columns from each image.
- In this case just two images (for barrier strip prints), but could be a larger number of images (for lenticular prints).

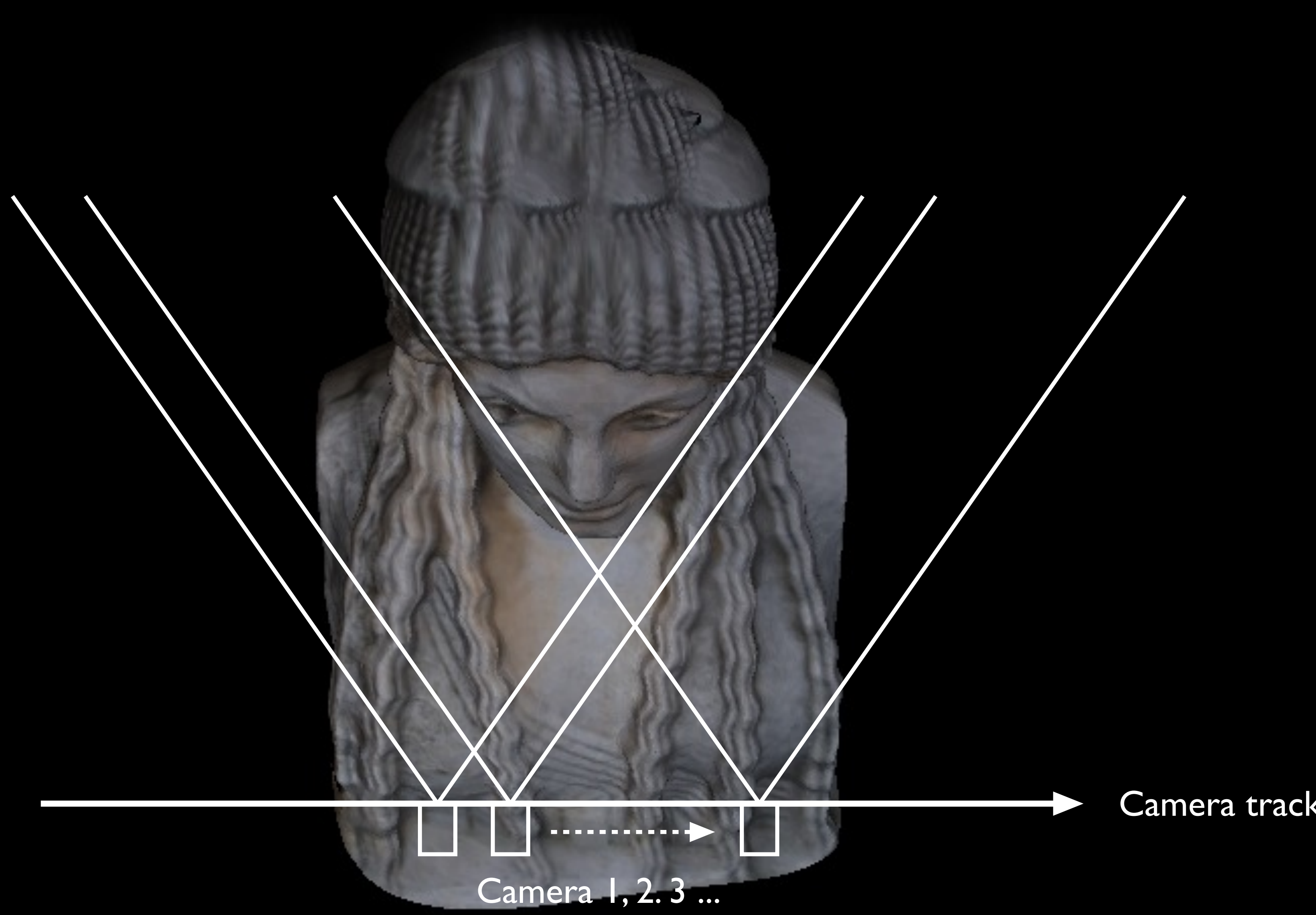
Lenticular prints: Barrier strip



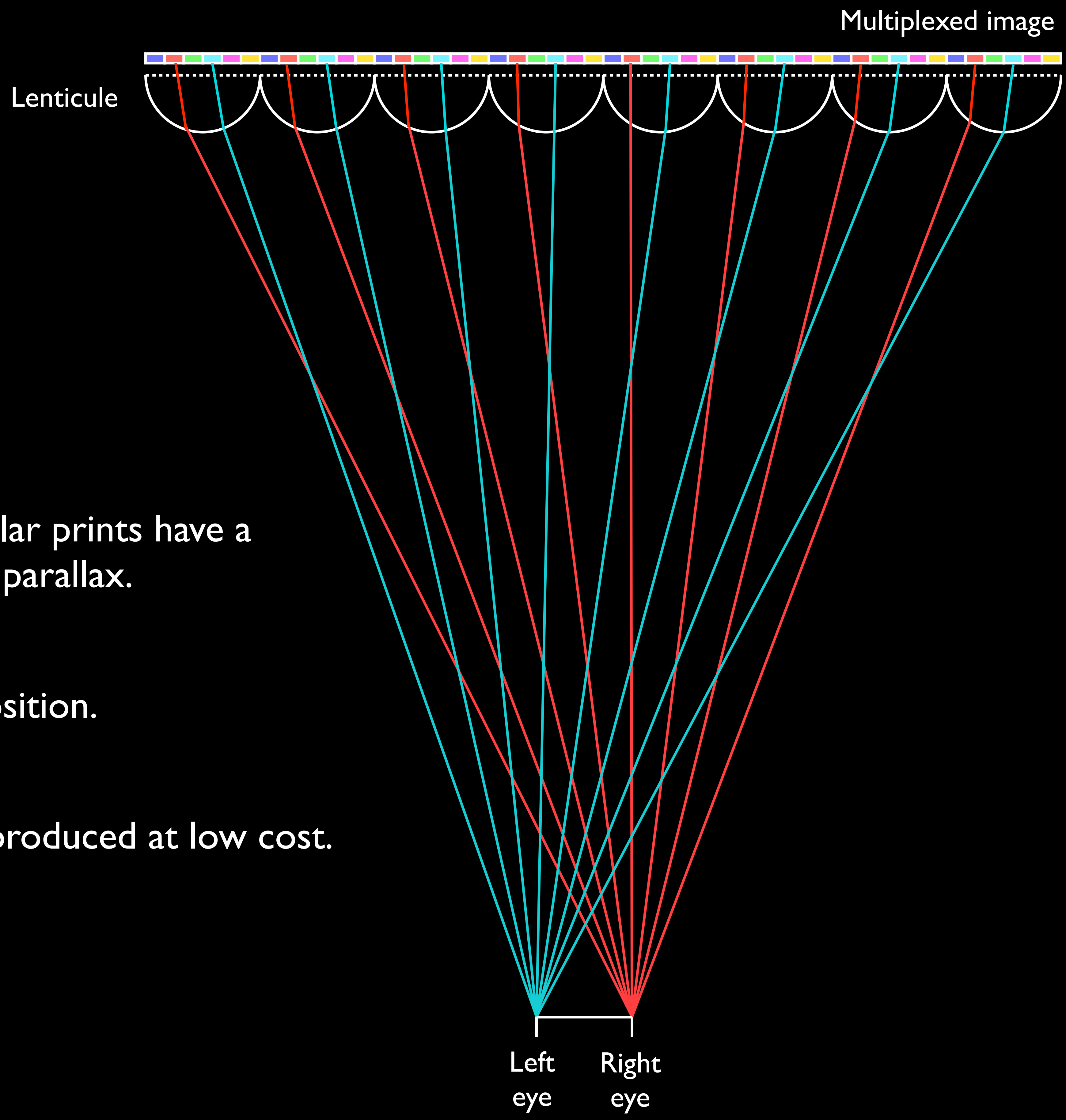
- Barrier placed at just the right distance from the multiplexed image.
- Constrains the left eye to see only the left eye columns and the right eye to see only the right eye columns.
- Characteristics
  - Very precise viewing position required
  - Very precise printing process
  - Depth perception but no "look around" parallax.

Lenticular prints: Camera path

- Camera shots taken along a linear path with the camera perpendicular to the direction of travel.
- Any and all pairs of cameras are a valid stereo pair of variable eye separation.



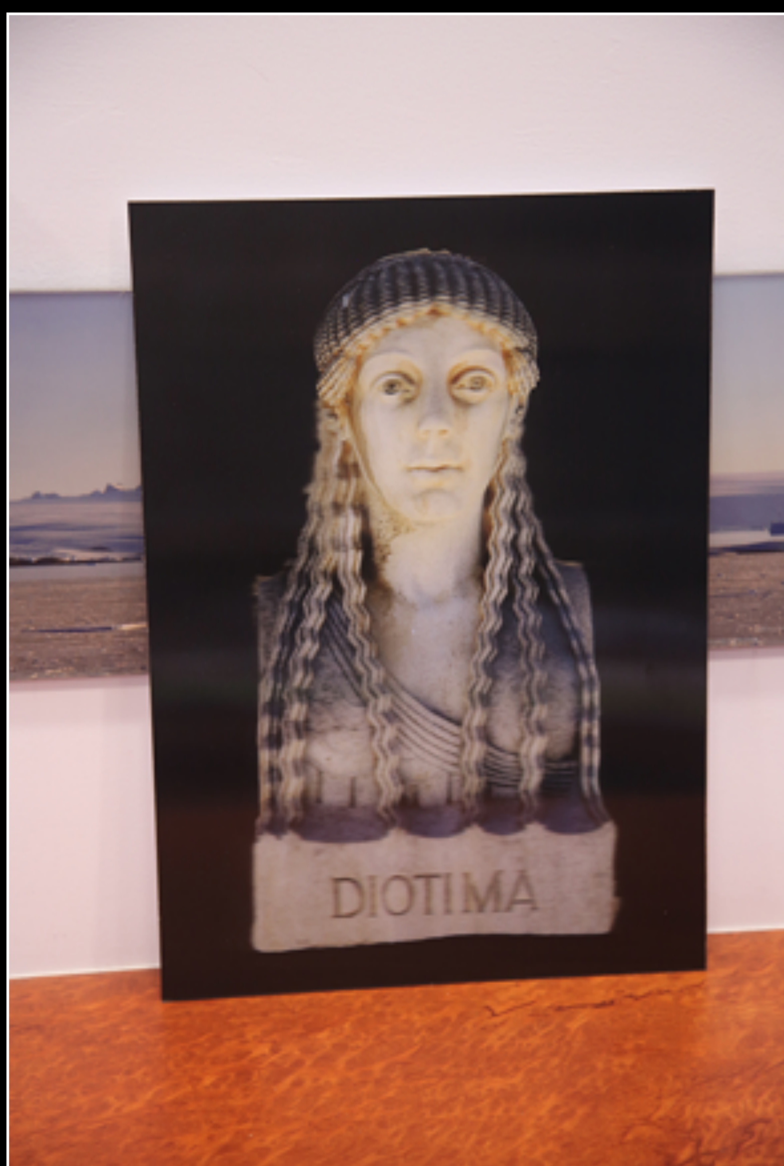
Lenticular prints: Lenticules



- Unlike barrier strip, lenticular prints have a viewing zone, look-around parallax.
- Less sensitive to viewer position.
- The lenses are able to be produced at low cost.

Lenticular prints: parallax

- Two photographs of the lenticular print from three different positions.
- Note the parallax difference, sides of objects visible in one photograph and not the other.



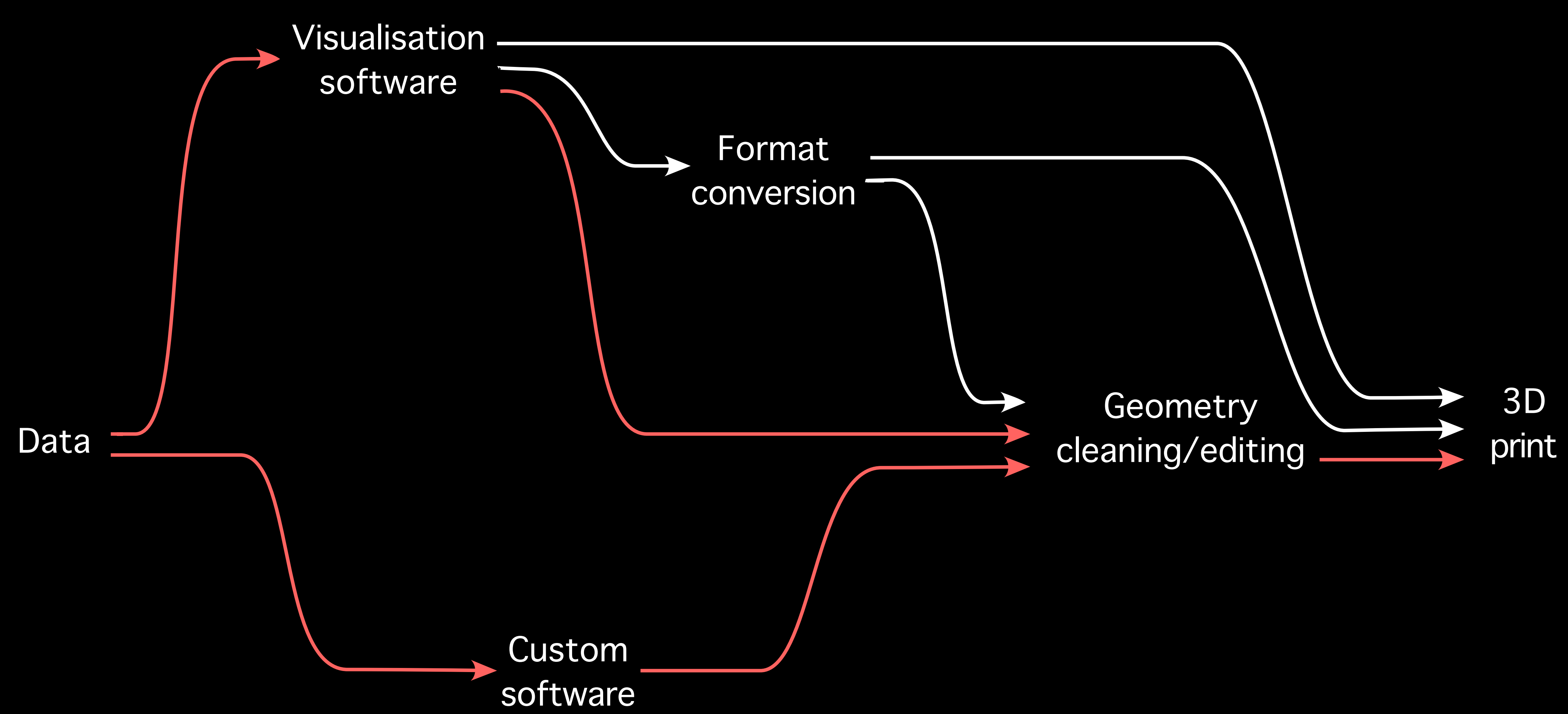
3D Printing

- Proposition: Insight into the geometry / structure of an object can be assisted if we study it in the same way as we explore objects in real life.
- 3D printing generally refers to additive processes where successive layers are laid down to form the model, but there are other technologies.
- Distinct from computer controlled milling or lathes (and others) where material is removed.
- Current limitations of machines at the high end of the market include
  - Poor colour support. Traditionally ZCorp and sandstone material.
    Currently some plastic printers are delivering continuous colour, still low saturation.
  - Finest structures limited to around 1mm diameter.

3D Printing: Details

- File formats:
  - STL (STereoLithography) for monochrome models.
    Easy to create in code.
  - OBJ (Wavefront) for textured models.
    Easy to create in code, shared vertices so fewer numerical issues.

- Pipelines

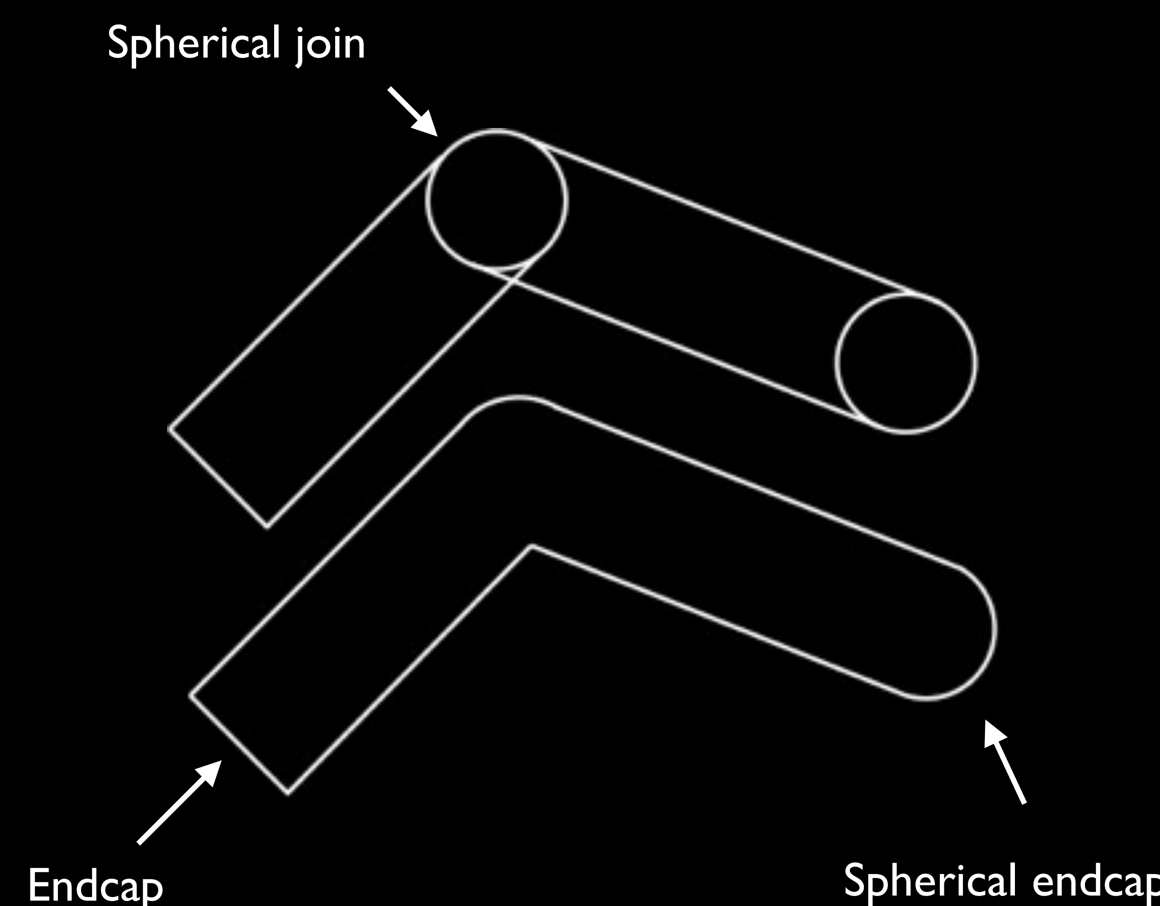


Red shows the most common workflows in our experience.

3D Printing: Lines and curves

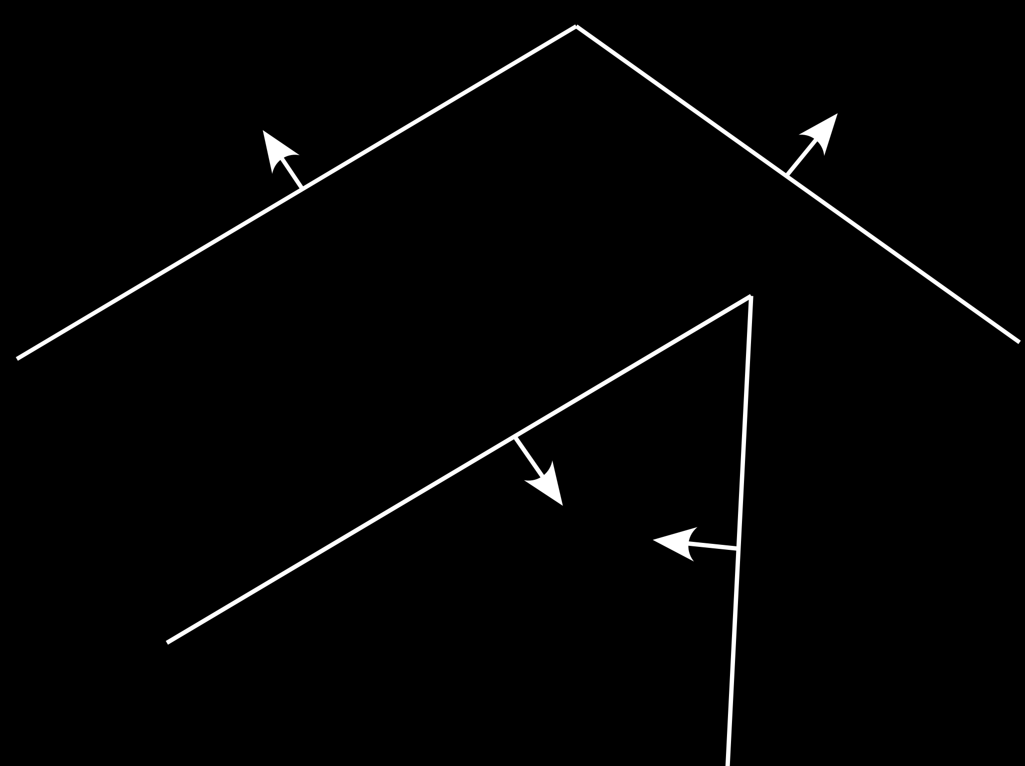
- The main challenge is dealing with the limitations of the machines. Structural integrity, formation order, finest constructable dimensions, accuracy ....
- Lines and curves are infinitely thin, cannot be physically realised.
- Need to be represented as meshes, collections of facets (triangular bounded plane sections).
- Approach is to turn lines into cylinders and seal them with spheres or endcaps.

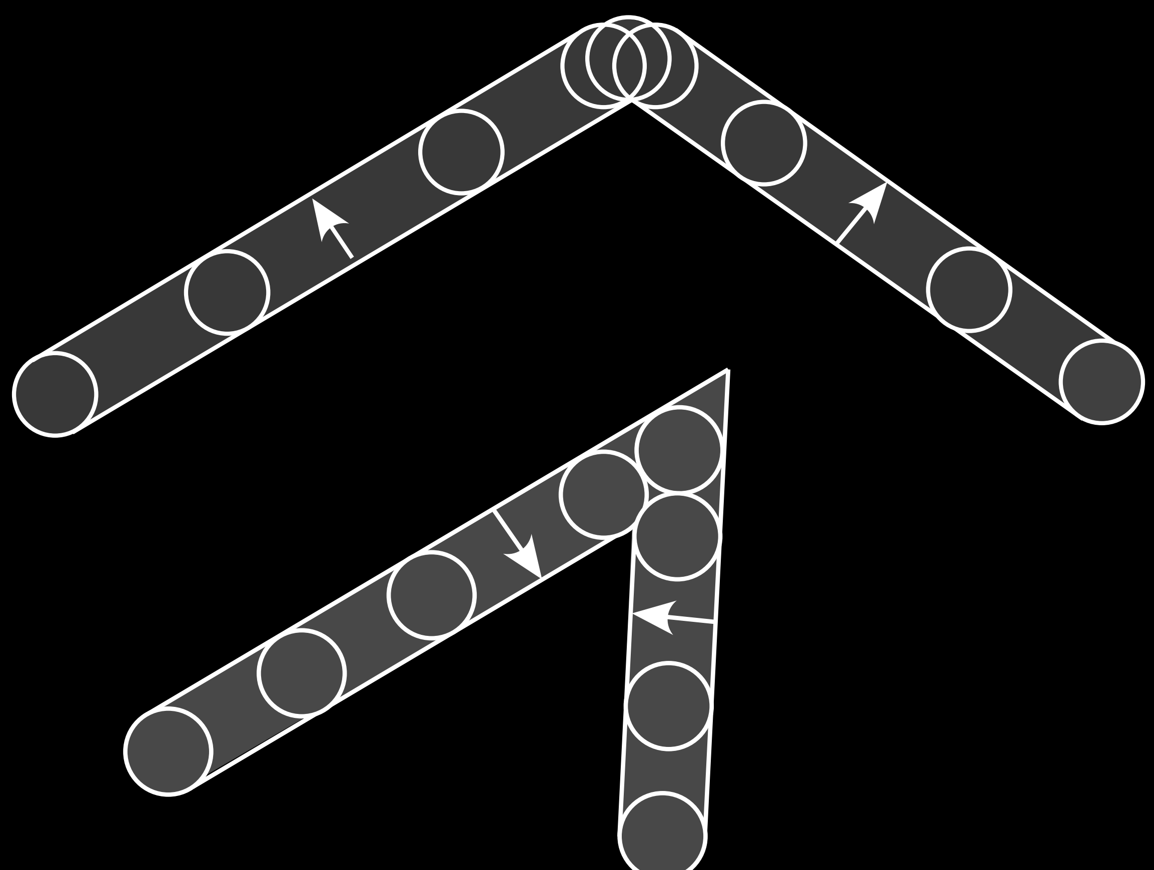
Model for connectivity in the visual cortex.



3D Printing: Surfaces

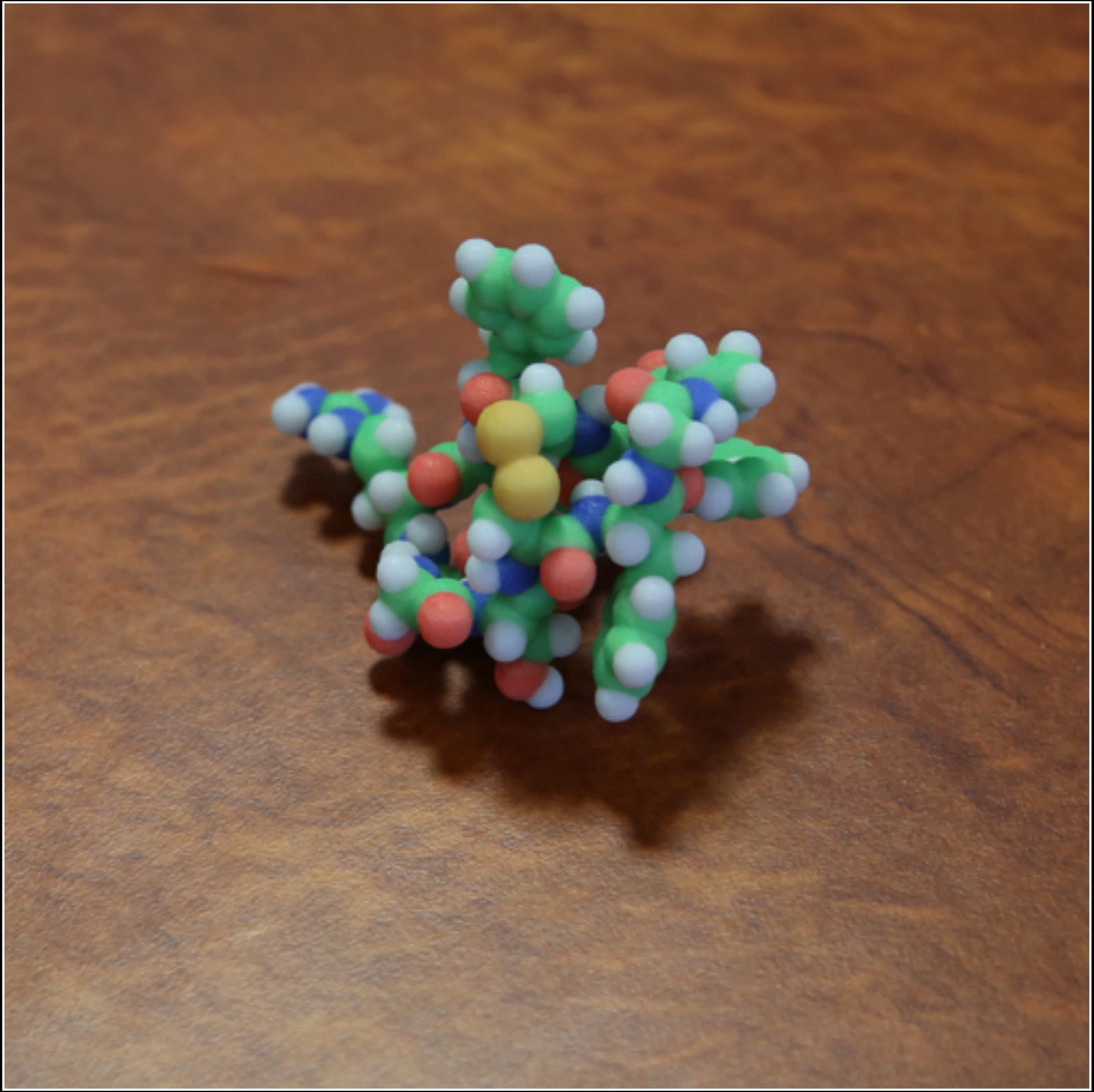
- A surface / mesh in 3D computer graphics, like an idealised point or line, is infinitely thin. As such is unrealisable physically.
- A triangle/quad/mesh needs to be "thickened" to some minimal thickness in order to be printed.
- One might imagine the solution is to extrude the triangles making up the mesh along their normals. This simple approach can have issues for areas of high curvature.
- Solution is called "rolling ball" thickening.
- Imagine a ball rolling across the surface, form an external mesh along the ball path.





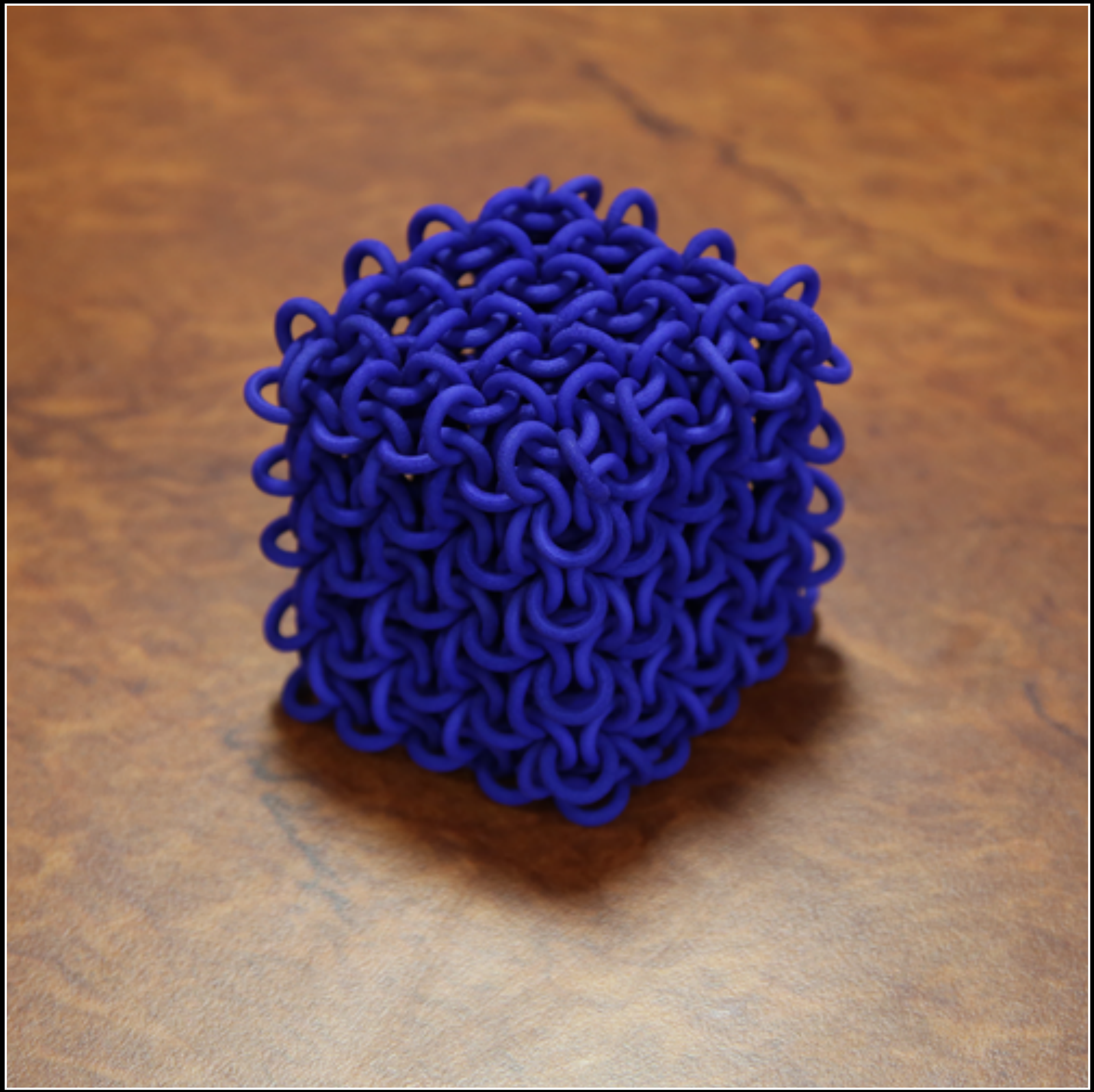
3D Printing: Examples

- Chemistry models.
- In this case the researchers determined a characteristic of these peptide not otherwise noted from computer based (and stereoscopic) representations.



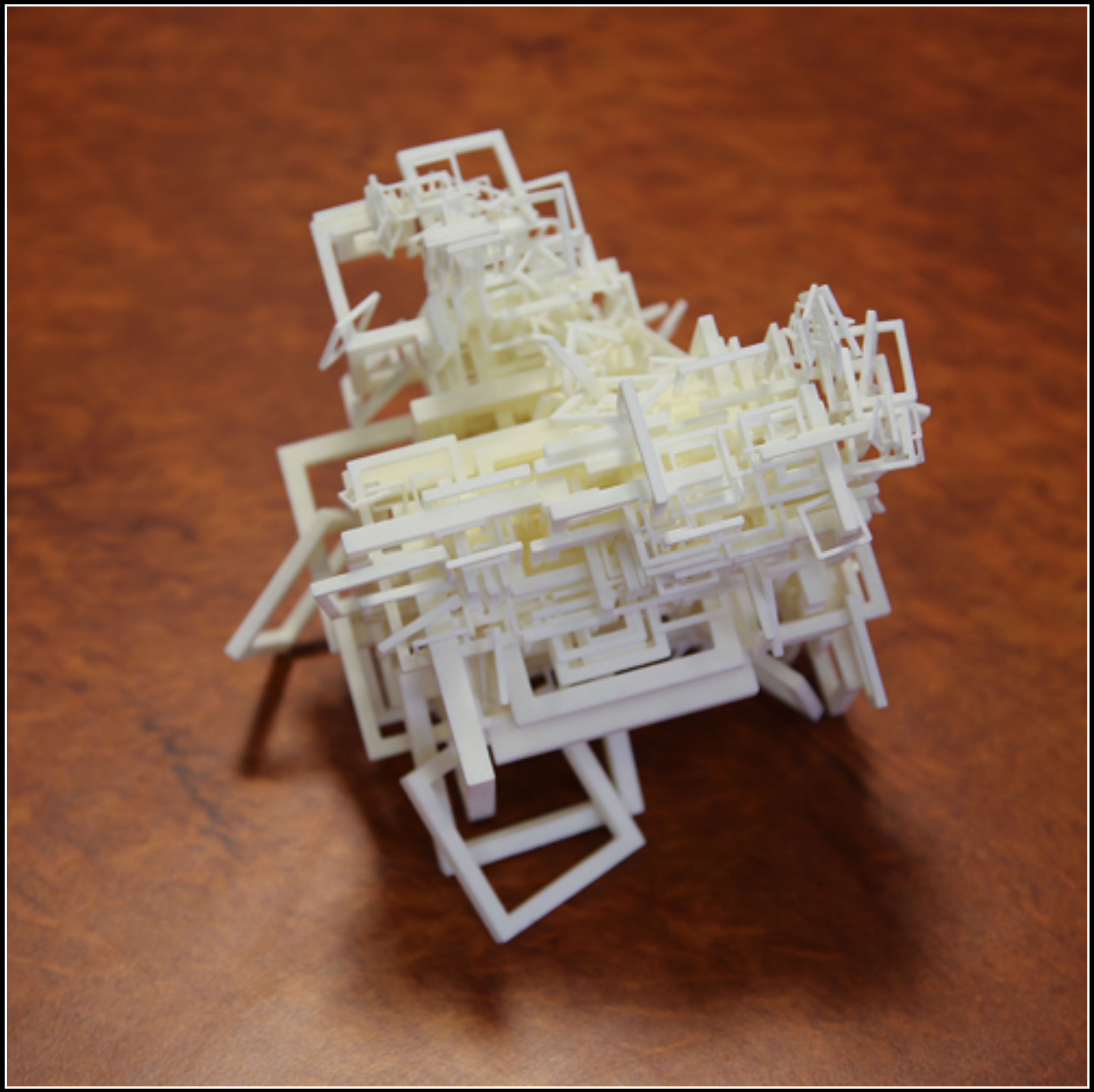
3D Printing: Examples

- Example from packing theory.
- Geometry that could not otherwise be made physical.



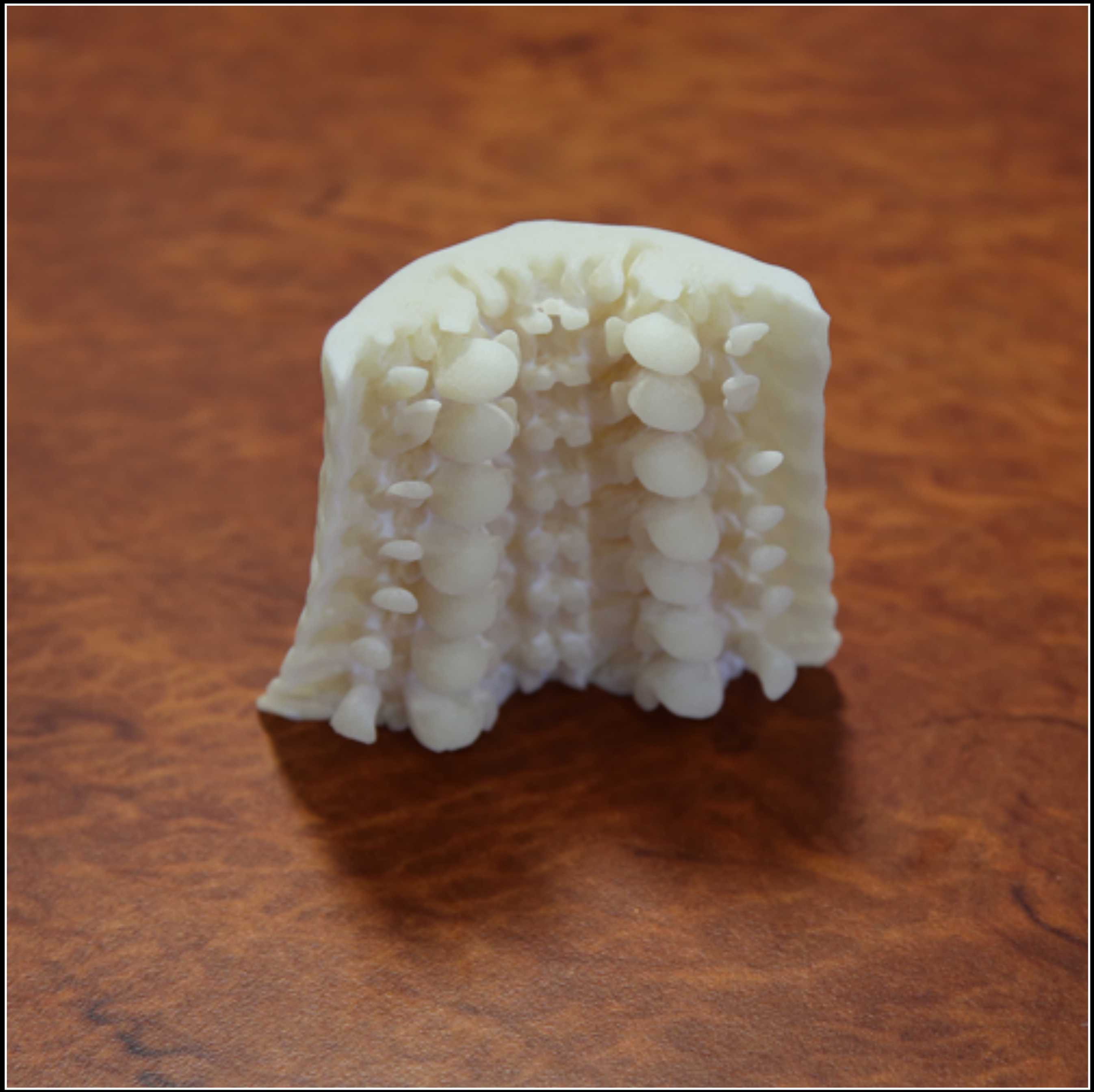
3D Printing: Examples

- Example from packing theory.
- Physical model also use to determine if object is connected.



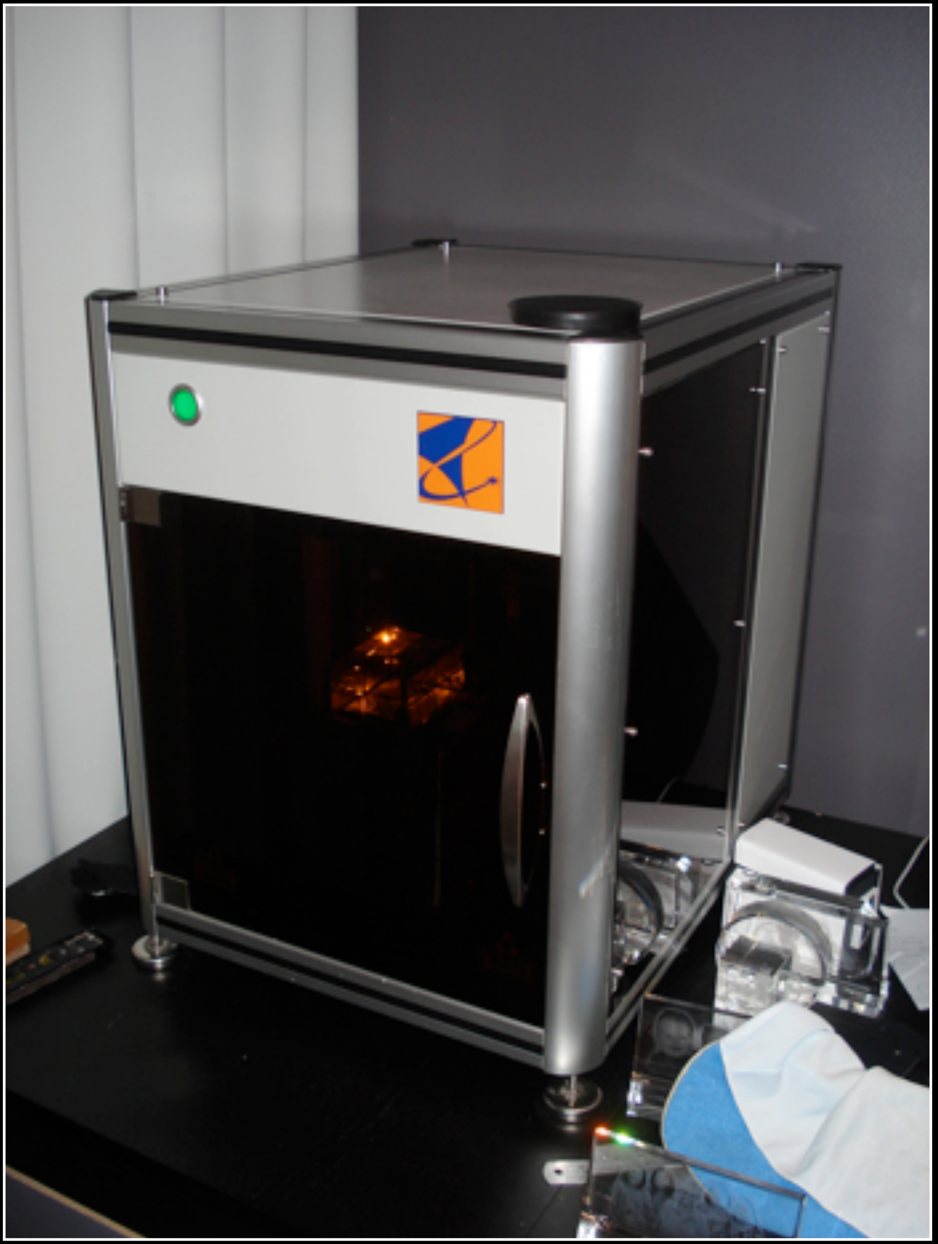
3D Printing: Examples

- Radula of ancient snail.
- Appreciation of the structure demonstrably more powerful than non-touching digital versions.



3D Crystal Prints

- 3D printing is most suited to single connected objects.
- Sub Surface Laser Engraving (SSLE) involves focusing a laser beam at precise locations within a crystal block, a small bubble forms representing one data point.
- Very high resolution, each bubble easily 1/100mm.
- Models can created very quickly, even for millions of points.
- Limitations
  - Monochrome only.
  - Bubbles are fixed size so size cannot readily be used to encode density.
  - Limits on bubble density, high density can cause cracking.
  - Too few points and the object is indistinct.
  - Block size rare above 15cm.



Example of machine

3D Crystal Prints: Point cloud

- Computer science and geometry question:
  "How to best represent different datasets as a point cloud?".

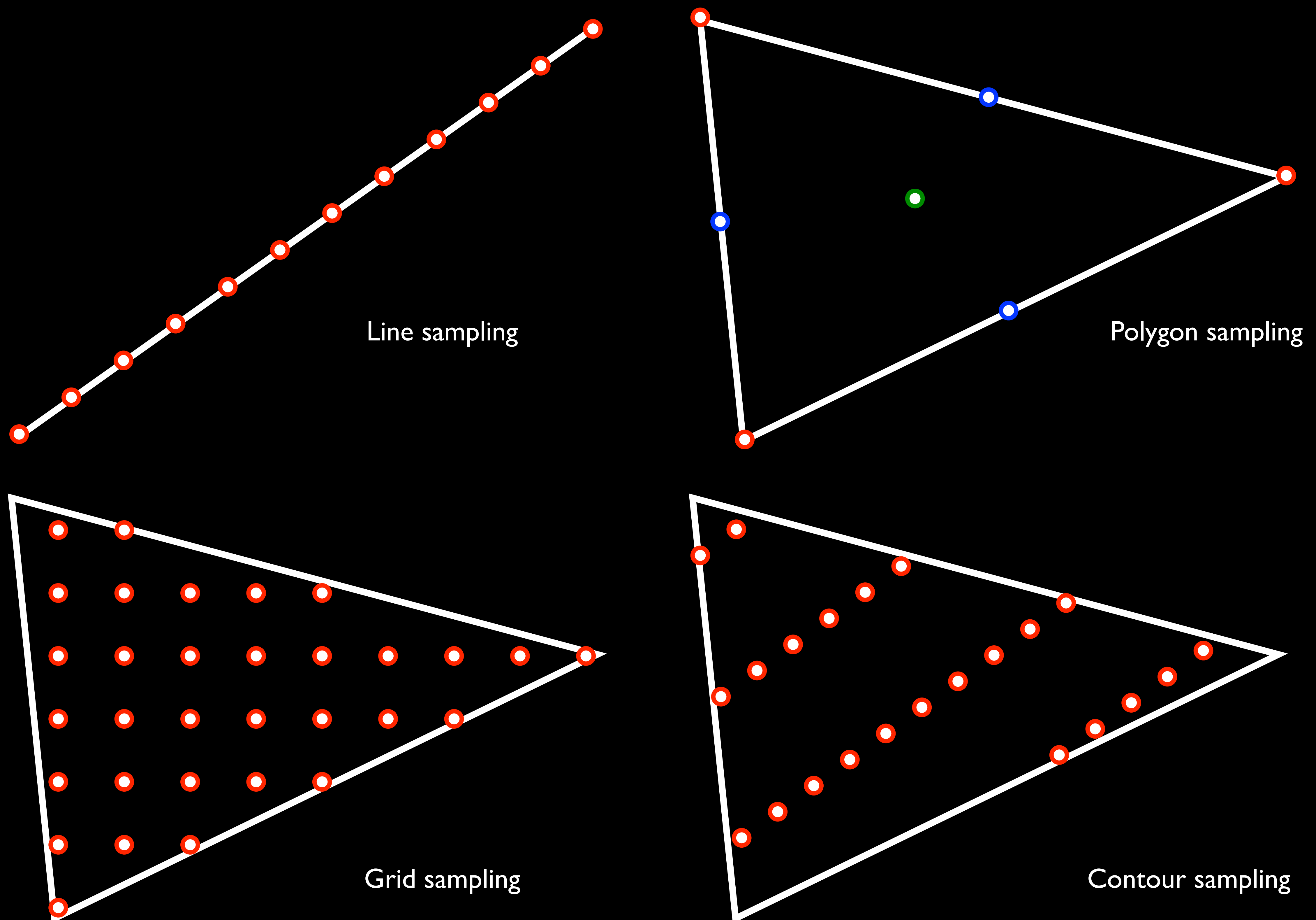
- Volumetric data (density at each point in a 3D volume, eg: from MRI or CAT scan).
  - Create a point at positions in the volume if the voxel value at that position lies within some range, the isosurface.
  - Create isosurface mesh from the volumetric data and sample the mesh.

- Polygonal (mesh surfaces).
  Only add a point to the final point cloud if the point is at least some minimum distance from any other point.

Mummy: Volumetric data

ASKAP disk: polygonal data

3D Crystal Prints: Triangle sampling options



3D Crystal Prints: Examples

- Examples from MRI (volumetric) data sets.
- Left: sampling isosurface, right: sampling volume directly.

Egyptian mummy, CT scan

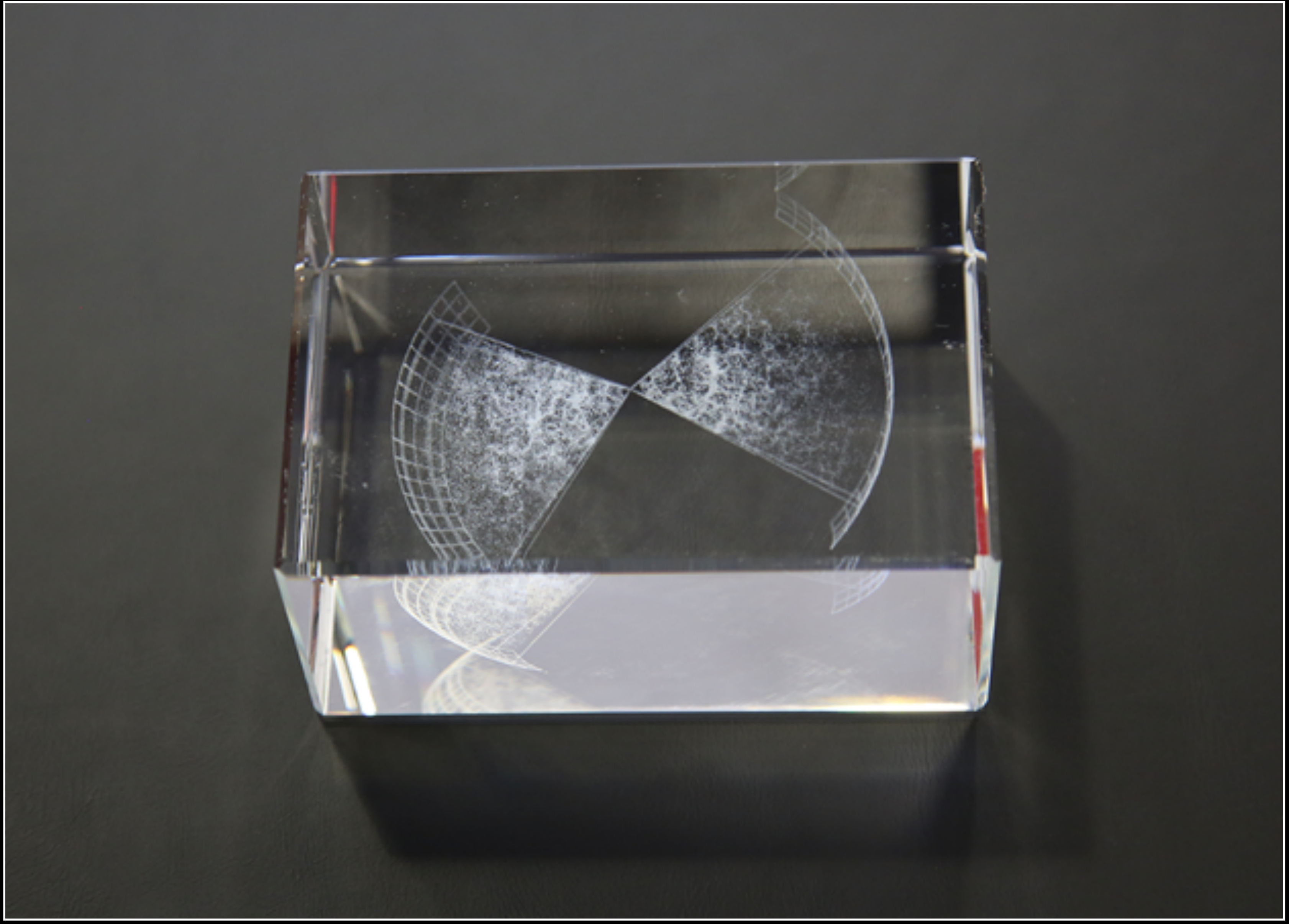
Human heart, MRI scan

3D Crystal Prints: Example

- Example from astronomy, 2dF galaxy survey data.
  The data itself is a point cloud.

- 250,000 points, each one represents a galaxy in 3D space.

- Obviously cannot 3D print or result would be a collection of dust on the table.



Conclusion

- Presented 3 technologies more commonly encountered in areas of merchandise and marketing but which are suited to more serious applications, in particular, the representation and visualisation of data from science and mathematics.

- All three technologies result in actual physical objects and can be produced at relatively low cost making them suited to use where more specialised digital displays or other hardware would not be possible or would be prohibitively expensive.

- The applications, while using technologies many of the public will have encountered, have not generally been applied to the visualisation of scientific data and can therefore be viewed as novel and thus give rise to an increased engagement.

- Visualisation is generally performed using only the sense of vision, the tactile aspect of the rapid prototypes and crystal blocks utilises another of the human senses. The multimodel aspects of printed 3D models has proved to have benefit.

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Questions

Additional related reading by the author

- Poster: Autostereoscopic lenticular prints for data visualisation. OzViz 2014
  http://paulbourke.net/papers/OzViz2014/
- Lenticular prints. August 2014
  http://paulbourke.net/papers/lenticularslides.pdf
- Workshop: 3D printing and data visualisation. August 2014
  http://paulbourke.net/papers/ecu2014a/
- Seminar: 3D printing and data visualisation: A technology brief. February 2014
  http://paulbourke.net/papers/3dprint2014/
- Report: Data visualisation in crystal
  http://paulbourke.net/miscellaneous/crystalengraving/
- Report: Autostereoscopic lenticular images
  http://paulbourke.net/stereographics/lenticular/
- Experiments in Rapid Prototyping, 2005
  http://paulbourke.net/miscellaneous/rapidprototype/