Tactile Visualisation: Feel your data!

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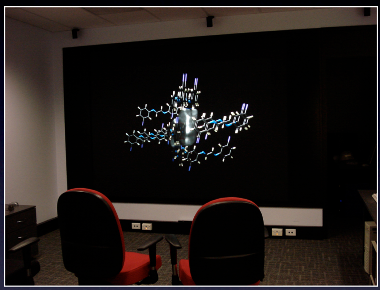
- Motivation
- Technology
- Discussion

Acknowledgement: Joe Sandon, CSSE, UWA

Visualisation - Vision centric

- Science visualisation: Present data in such a way as to assist in the understanding of the underlying principles/processes.
- Data may be sourced from experimental measurement (acquisition), simulation, or mathematics.
- Traditionally only employs our visual system.
- May include stereoscopic techniques to exploit our depth perception.
- May use immersive environments to exploit our peripheral vision.
- May use virtual reality (head tracking, 3D interface devices, etc) to increase the observers engagement with the data.

What about our other senses?



Smell / Taste

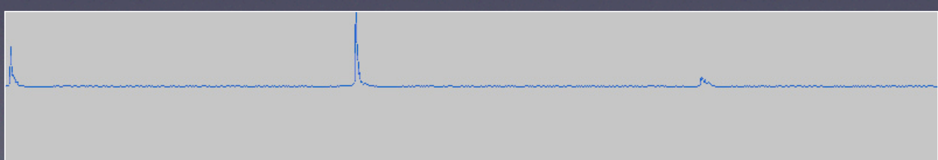
- Difficult to imagine an informative mapping between data and smell/taste.
- Unable to (reliably) synthesis odors.
- Not a precise sense.
- Highly subjective, significant variation between individuals.
- Has a high degree of habituation, we subconsciously block out continuous or unpleasant odors.

- Note the reverse has been attempted, visualising odors using visuals or music.

Hearing

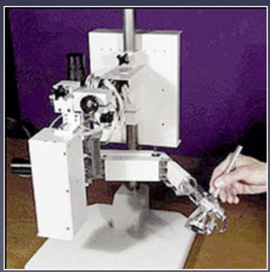
- Sonification : Generation of audio from data (excludes speech).
- Simplest examples are the Geiger counter and medical monitoring (machine that goes "ping").
- Volume mapping (soft to loud), pitch mapping (low to high frequency), instrument mapping (eg: midi).
- Generally a very loose/imprecise relationship to the data except for time series.
- Potential for representing spatial relationships.
- Sonification most commonly used to enhance a visual experience.
- Most common in support of scientific visualisation for exhibitions and movies.

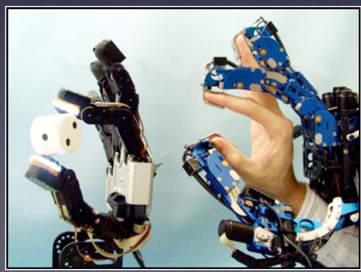
Pulsar example



Touch: Haptic / force feedback

- Application of forces to give a sense of touching (hitting) a virtual object.
- Quite a coarse sensation, usually limited to a single point of contact.
- Most commonly used as a human-computer interface, eg: teleoperation.
- Employed in gaming, eg: force feedback joysticks and steering wheels.
- Some experiments have mapped data to temperature.
- Vibrator pads can give a sense of surface properties (eg: roughness, hardness).
- Still a very different sensation to holding and feeling objects in real life.





Touch

- We regularly explore objects during our everyday life by using our hands, usually in conjunction with our eyes.
- We hold objects and turn them around with our hands to see/feel different sides.

  Can we do this to datasets?
- We are already familiar with the conversion of data into geometry which is then rendered for our visual sense.

  Can we take the additional step of turning data into a physical object which can then be explored with both our sense of touch and vision?

Rapid prototyping technology

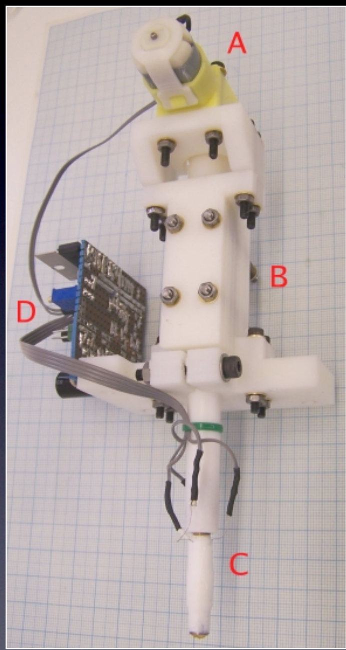
- “Rapid prototyping”: the automatic construction of physical objects.
- Intended primarily to speed up the model making cycle for new products and components. The term “rapid” is relative, generally rapid compared to a human tool maker or sculptor.
- The vast majority of the techniques are referred to as additive fabrication, that is, the 3D model is built up by thin layers.
- Three main technologies: selective laser sintering, fused deposition, stereolithography. There are others but they are more exotic and outside the scope of this discussion.
- Considerations
  - resolution, accuracy
  - requirement for self supporting structures
  - durability
  - support for colour and/or transparency
  - ability to create both rigid and flexible models
  - support for multiple materials within a single model
  - operating environment

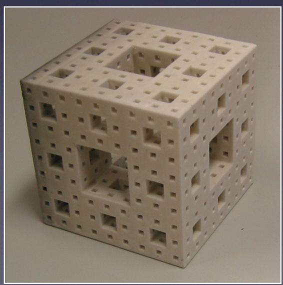
Selective Laser Sintering

- Uses a high power laser to fuse small particles together, layer by layer.
- There are a variety of materials that can be used: plastics, powders, ceramics, metals, etc.
- Because of the wide range of materials it is often capable to creating final products rather than just prototypes.
- Very similar to the ZCorp process (see later) except it uses a laser rather than glue.
- There is an inverse process call Selective Laser Melting that removes material from a solid block.

Fused Deposition

- A nozzle squirts a (melted) plastic or metal wire.
- While in theory the nozzle (extrusion head) can have 6 degrees of freedom (any position and orientation), most commonly the model is still created in layers.
- Some machines can use multiple materials to form one model. This can also be used to create water soluble (for example) support structures when necessary.
- See the “RepRap project” (Opensource), the goal is to create a machine that can manufacture all of it’s own parts.





Illustrate the problem of supporting structures

Stereolithography

- Uses a liquid polymer that solidifies on contact with a UV laser beam.
- Polymer/resin level slowly rises as the layers are traced by the laser.
- Main limitation is the need for supporting structures and limited support for colour.
- Quite popular for medical applications, custom implants, prostheses, and pre-operative planning.

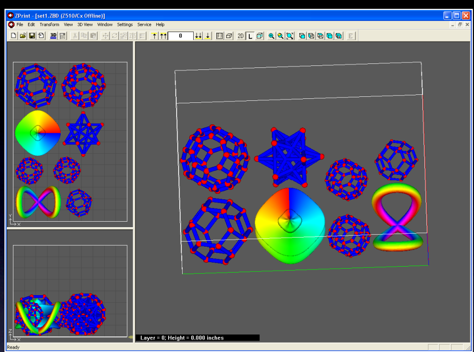
ZCorp rapid prototyping machine

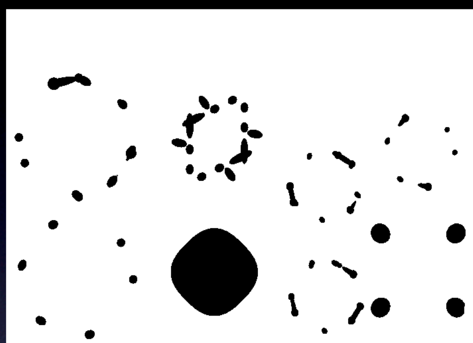
- Glorified ink jet printer.
- Deposits binding agent (glue) instead of ink over layers of fine powder.
- Simple extension to deposit coloured binding agent.
- Spectrum Z510, 3 colour and clear binding agent.
- Main advantage over other technologies is the ability to create non-self supporting structures. The powder acts to support new structure.

CSSE, UWA

- Will restrict the remainder of the discussion today to the evaluation of the ZCorp Z510 printer located in CSSE, UWA.
- Result of a ARC Linkage Infrastructure, Equipment and Facilities (LIEF) grant by M. Bennamoun et al. Titled "3D Scanning and Printing Facilities (3DSPF)"

3D model is "printed" slice by slice

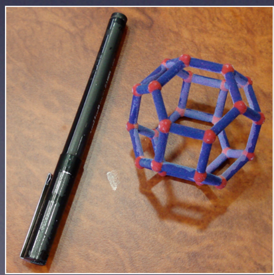




Two representative slices

Limitations / Specifications

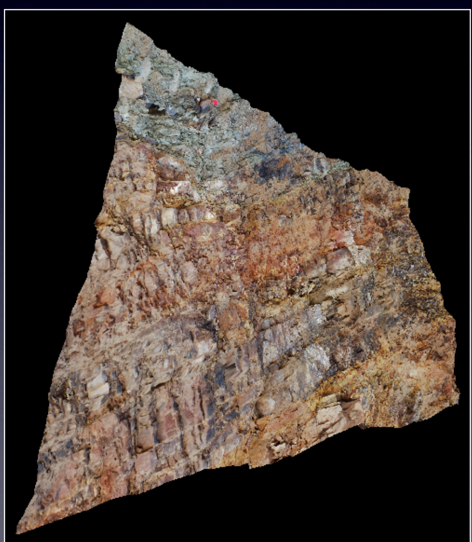
- Only solids can be printed, must have an “inside” and be of finite thickness.
  This is a common problem with trying to print existing models with single polygon facets.
- The final models can be quite strong, after being infused with Supa-glue.
  The most likely cause of breakage is while extracting the model from the powder.
  Main limitation is on the thinnest structures that will survive extraction.
- Structures also need to be capable of being self supporting after being extracted and before infusion. One solution is to infuse parts of the model while it is being extracted but while still supported by the powder.
- Seems to be some colour fidelity issues, variation in colour depending on the orientation of the surface. [Still requires investigation to see whether it is inherent or an issue with the machine we have.]
- Maximum build dimensions: 250 x 350 x 200 mm.
- Maximum theoretical resolution: 600 x 540 dpi.
- Some models require a significant manual post processing stage.



Close to the minimum thickness ~ 4mm

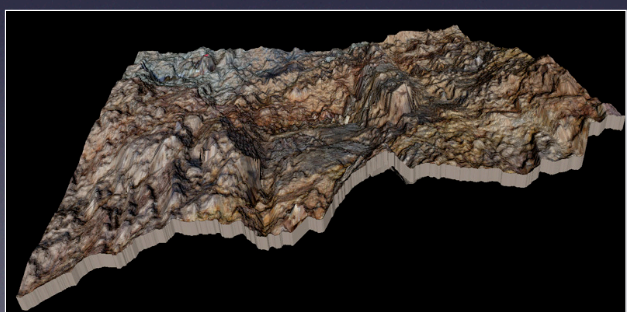
Standard tricks: infinitely thin surfaces

- Single polygonal faces are extruded to have a finite thickness.
- Can be preformed by most modelling software packages as well as in custom code.
- Extrude along each polygon normal or the average surface normal (example shown here).



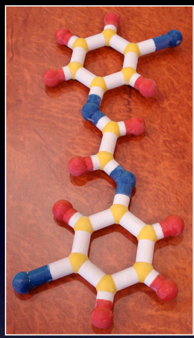
2D textured mesh, no thickness

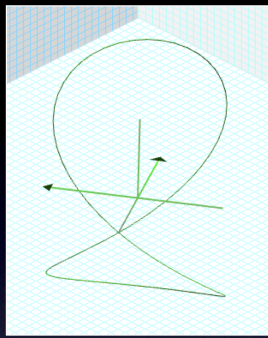
Extruded model ready for printing



Standard tricks: lines and curves

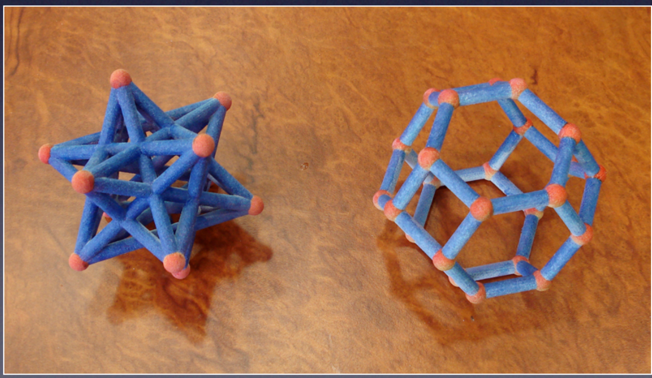
- Lines turned into cylinders of finite radius.
  - For example: for molecule bonds.
- Parametric circle sweep along a curve.





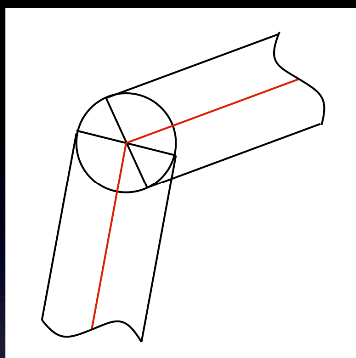
Polyhedra edges/nodes

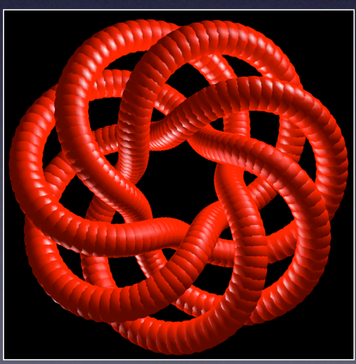
Box curve: circle sweep

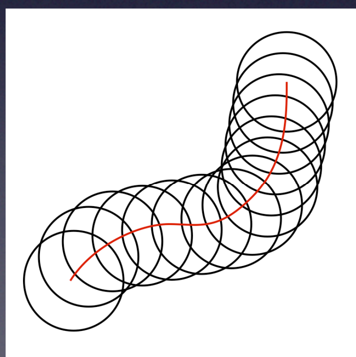


Standard tricks: lines and curves

- Curves turned into lots of spheres or cylinder/sphere pairs.
- Former can add additional surface texture, the more spheres the smoother the result.
- Inefficient especially for STL (no sphere primitive) but often acceptable for VRML.

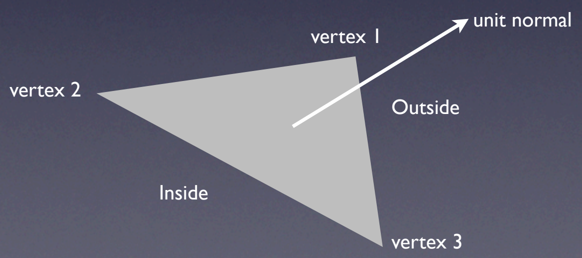






File formats: STL

- STL: literally STereo Lithography
- Extremely simple to create
  - Defines nothing but triangles [3 vertex facets]
- Normal determines what is inside/outside (if provided), otherwise determined by vertex ordering.
- Assumes right hand coordinate system for cross product determination of the normal.
- Exists as a binary and ascii (human readable) format



STL example

```
solid objectname
  facet normal -9.49 1.87 -2.51
    outer loop
      vertex -1.42 5.22 8.09
      vertex -1.78 3.37 8.09
      vertex -1.85 3.40 8.34
    endloop
  endfacet
  facet normal -9.49 1.87 -2.51
    outer loop
      vertex -1.85 3.40 8.34
      vertex -1.48 5.22 8.34
      vertex -1.42 5.22 8.09
    endloop
  endfacet
  :
  :
  :
endsolid
```

File formats: VRML

- Virtual Reality Markup Language.
- Not specifically a rapid prototyping format but adopted as a standard 3D format by the industry.
- Also a text/human readable file.
- Required if colour is necessary, also supports texture, see earlier terrain model example.
- I can supply some standard functions for C to assist in data to VRML conversion.
  WRLHeader();
  WRLSphere();
  WRLCone(); // Also for cylinders radius1=radius2
  WRLFace();

VRML example

```
#VRML V2.0 utf8
WorldInfo {
 title "Polyhedra"
 info [ "By Paul Bourke" ]
}
Transform {
 translation 0,0,1
 children [
  Shape {
   appearance Appearance {
    material Material {
     diffuseColor 1 0 0
    }
   }
   geometry Sphere {
    radius 0.103366
   }
  }
 ]
}
  :
  :
  :
```

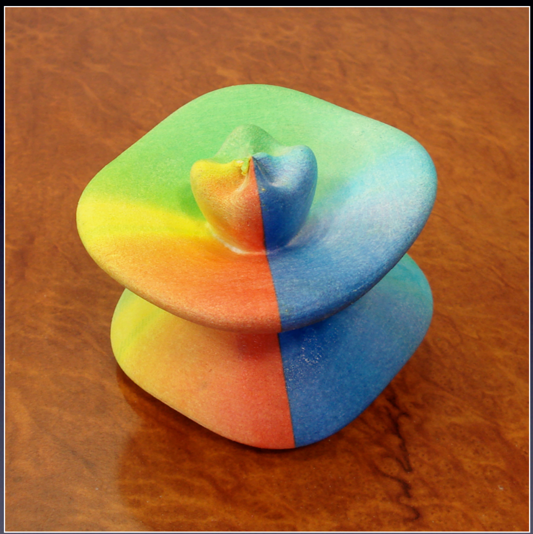
Summary

- Rapid prototype hardware exists and is relatively affordable.
- There are clearly defined limits on what geometric forms can be created.
- The value of tactile visualisation for public outreach and education seems obvious.
- The value for researchers and peers is likely to depend on the application/discipline.

- If you have potential applications then using the facilities at CSSE is relatively painless.

Examples

Knots, polyhedra, curves



Solution to Laplace equation in spherical coordinates

Examples

Asteroids, Eros and the "dog bone"

Example

Geology / fossils

Examples

Topology arising from research in human vision.

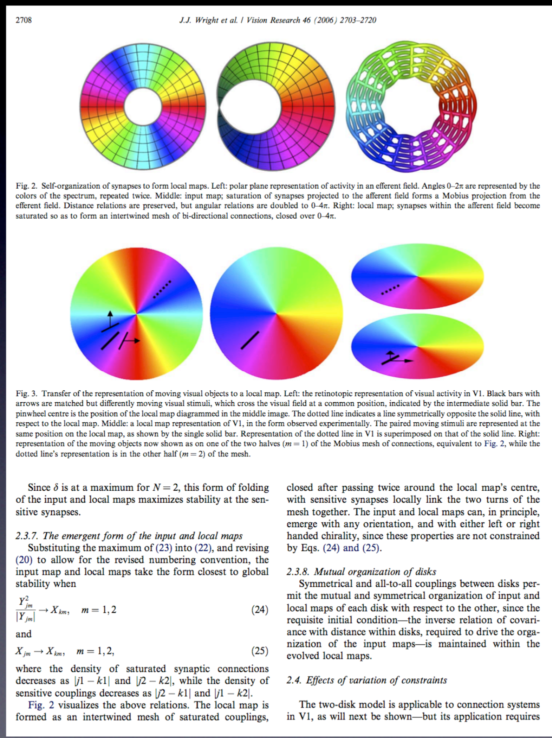


Fig. 2. Self-organization of synapses to form local maps. Left: polar plane representation of activity in an efferent field. Angles 0–2π are represented by the colors of the spectrum, repeated twice. Middle: input map; saturation of synapses projected to the afferent field forms a Mobius projection from the efferent field. Distance relations are preserved, but angular relations are doubled to 0–4π. Right: local map; synapses within the afferent field become saturated so as to form an intertwined mesh of bi-directional connections, closed over 0–4π.

Fig. 3. Transfer of the representation of moving visual objects to a local map. Left: the retinotopic representation of visual activity in V1. Black bars with arrows are matched but differently moving visual stimuli, which cross the visual field at a common position, indicated by the intermediate solid bar. The pinwheel centre is the position of the local map diagrammed in the middle image. The dotted line indicates a line symmetrically opposite the solid line, with respect to the local map. Middle: a local map representation of V1, in the form observed experimentally. The paired moving stimuli are represented at the same position on the local map, as shown by the single solid bar. Representation of the dotted line in V1 is superimposed on that of the solid line. Right: representation of the moving objects now shown as on one of the two halves ($m = 1$) of the Mobius mesh of connections, equivalent to Fig. 2, while the dotted line's representation is in the other half ($m = 2$) of the mesh.

Since δ is at a maximum for $N = 2$, this form of folding of the input and local maps maximizes stability at the sensitive synapses.

2.3.7. The emergent form of the input and local maps

Substituting the maximum of (23) into (22), and revising (20) to allow for the revised numbering convention, the input map and local maps take the form closest to global stability when

$$\frac{Y_{jm}^2}{|Y_{jm}|} \to X_{km}, \quad m = 1, 2 \tag{24}$$

and

$$X_{jm} \to X_{km}, \quad m = 1, 2, \tag{25}$$

where the density of saturated synaptic connections decreases as $|j1 - k1|$ and $|j2 - k2|$, while the density of sensitive couplings decreases as $|j2 - k1|$ and $|j1 - k2|$.

Fig. 2 visualizes the above relations. The local map is formed as an intertwined mesh of saturated couplings, closed after passing twice around the local map's centre, with sensitive synapses locally link the two turns of the mesh together. The input and local maps can, in principle, emerge with any orientation, and with either left or right handed chirality, since these properties are not constrained by Eqs. (24) and (25).

2.3.8. Mutual organization of disks

Symmetrical and all-to-all couplings between disks permit the mutual and symmetrical organization of input and local maps of each disk with respect to the other, since the requisite initial condition—the inverse relation of covariance with distance within disks, required to drive the organization of the input maps—is maintained within the evolved local maps.

2.4. Effects of variation of constraints

The two-disk model is applicable to connection systems in V1, as will next be shown—but its application requires

Discussion ... Questions?