Virtual Reality in Medicine and Surgery

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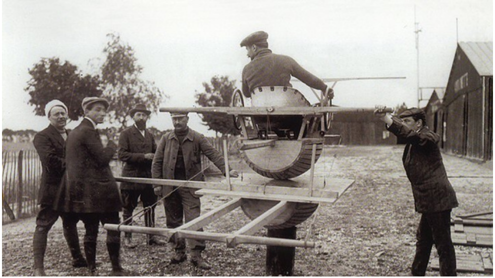
- A Brief History of Virtual Reality
- Techniques of Virtual Reality
- The Problems of Medical Virtual Reality

The History of Virtual Reality - 1615

"Then Don Quixote leaned forward and began to turn the pin in the horse's head. He fancied that he was rising in the air, and that he was sailing right up to the sky. "

The History of Virtual Reality - Flight Simulation



- 1909 Mechanical Simulators
- 1929 Concept for electronic simulators
- 1945 Point light source projection
  (simulating runway lights)
- 1955 Video Based systems

The History of Virtual Reality - 1960s

Motorcycle ride through Brooklyn

A Cinematographic Experience including:

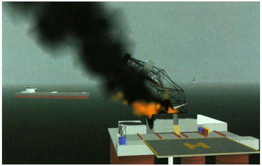
- 3D Imagary
- Contextual Smells
- Stereo Sound
- Vibration
- Wind in the hair

The History of Virtual Reality - 1970s

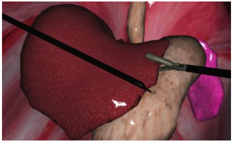
- Film Special effects
- Video arcade games
- Bend Sensing Glove
- Data Glove
- Polhemus Tracker

The History of Virtual Reality - 1980s

- See through head mounted display
  (Callahan (MIT) 1983)
- Commercial head-mounted displays
  (VPL Research and Autodesk 1989)
- Term ”Virtual Reality” coined
  (Jaron Lanier VPL 1989)
- SGI Reality Engine (1989)



The History of Virtual Reality - 1990s



- First Applications of Virtual Reality in medical teaching:
  - Colonoscopy Simulation
  - Upper GI tract endoscopy simulation
- Improved general purpose haptic devices (Sensable)
- First attempts at simulation of laparoscopy

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Types of VR Systems

- Window on World Systems
- Hands on Virtual Worlds
- Head Tracking Systems
- Immersive Systems
- Telepresence
- Mixed or Augmented Reality

Window on the World

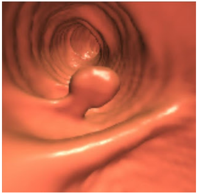
"One must look at a display screen, as a window through which one beholds a virtual world"

Ivan Sutherland 1965

- Conventional monitor
- Realistic Sound
- Special input devices

In reality just simple computer graphics, but still appropriate for many medical applications.

Window on the World



- Suitable for certain types of medical visualisation - for example virtual colonoscopy
- Given special hardware it can be used for simulating some medical procedures
- 3D systems with shutter glasses are a possible extension

Window on the World

One problem in creating windows on the world for surgery is designing realistic haptic devices.

They are expensive and are application specific.

Hands on Virtual Worlds

- Stereo displays can be constructed that allow the user to put his own hands into the virtual world,
- It is possible to interact with the image through a general purpose haptic device.
- These have been applied to simulating laparoscopic procedures.

Fish Tank Systems

Tracking a user's head position provides improved realism.

- Using simple stereo devices there is one correct position from which to view a scene.
- By tracking the user's head, and computing the stereo image pair accordingly a more accurate 3D image can be created.
- No major applications in Medicine as yet.

When applied to the limited space around a simple screen this is sometimes termed "Fish tank virtual reality"

Immersive Systems

Head mounted displays are an alternative to head tracking systems. They provide an immersive experience by blocking out the real world.

- There is no restriction on user movement.
- They are relatively inexpensive and can have good 3D visual quality.

Immersive Systems

However, they have rarely, if ever, been used for any serious medical or surgical purpose because of many drawbacks:

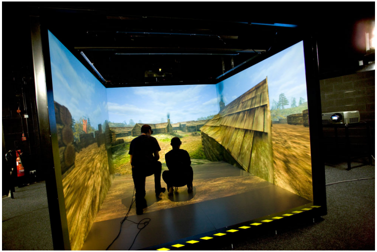
- Restricted field of view with no peripheral vision
- Unnaturally close image
- Isolation and fear of real world events
- Uncomfortable to wear

Immersa Desks

- These devices are essentially fish tank displays, but are scaled up and have other features.
- Some have drafting capabilities, and are well suited to applications in architecture.
- They have not been used widely in medicine.

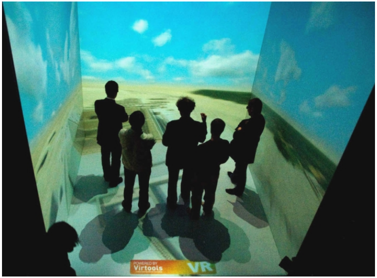
Cave Installations

- A room with projection on the walls floor and ceiling.
- Provides complete visual immersion.
- Driven by a group of powerful graphics engines.



Cave Installations

- Provides high resolution and large field of view with light weight shutter glasses for stereo viewing.
- Real and virtual objects can be mixed.
- A group of people can inhabit the space simultaneously.



Medical applications could include simulating operating theatre dynamics, but this has not been tried.

Cave Installations

Cave installations are unlikely to be used extensively in medical applications because of various drawbacks which are:

- they are very expensive (approximately 1 million pounds);
- they require a large amount of permanent physical space;
- the projector calibration must be maintained;
- real physical objects cannot be easily incorporated with the graphical objects.

Telepresence

Sensors and manipulators are remotely controlled by a human operator.

Some spectacular success, such as the exploration of the Titanic.

Applications include fire fighter robots and unmanned military vehicles.

Proposed for endoscopic or robotic surgery, but not really required in practice.

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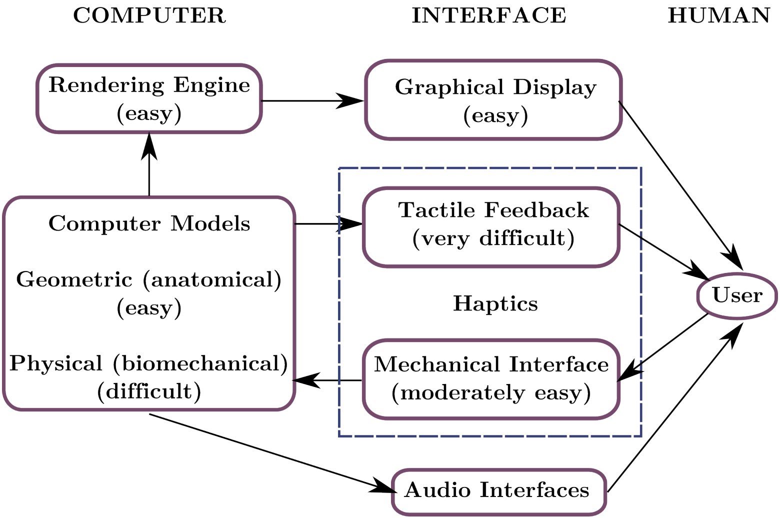
Applications of VR in Medicine and Surgery

- Training
  Popular and feasible
- Assessment and Certification
  Gaining acceptance, feasible
- Telepresence (Interaction with remote environments)
  Popular but not very useful

Architecture of a Medical VR System

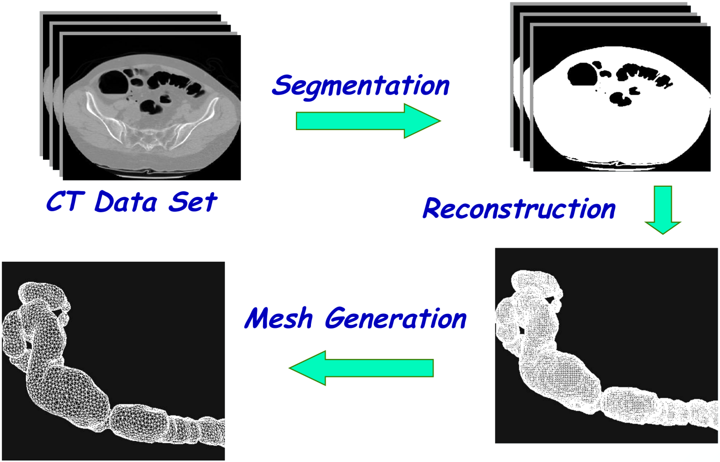


Geometric (Anatomical) Modelling

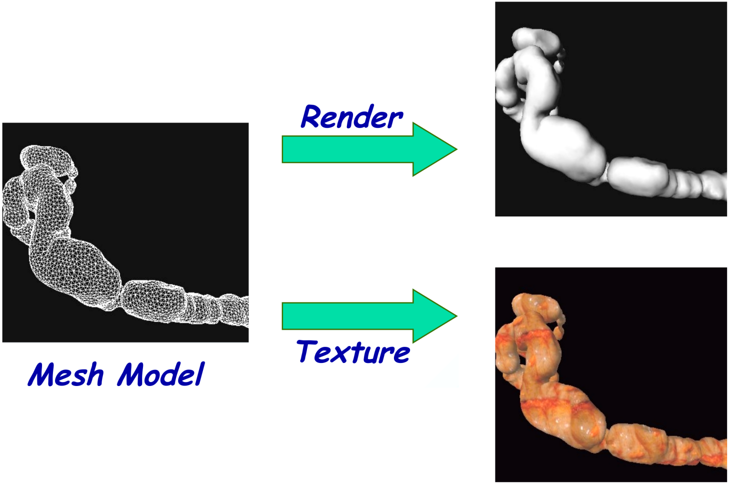
- Geometric modelling can be used to reproduce views of patient anatomy.
- It is used to create walk-throughs of the peritoneum, lungs colon etc.
- Geometric models can be derived from scan data.

As an example let's look at virtual colonoscopy.

Extracting the Colon Geometry

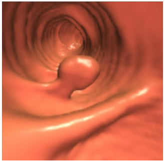


Creating the walk-through



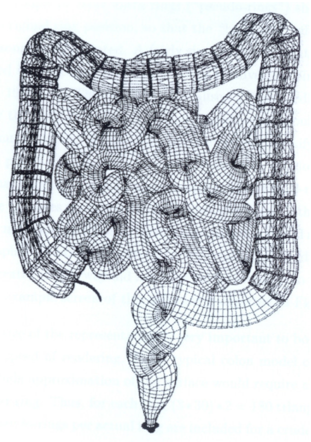
Walking Through

The images are very pretty:



However the texture colour and shading are fake, and there are reconstruction errors:

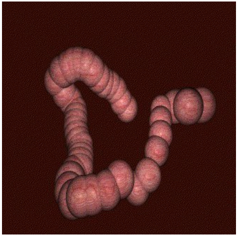
Limitation of Geometric Models



- Triangulated models are easy to obtain, but are difficult to deform.
  (large number of triangles)
- They are suitable for rigid structures.
  (larynx, lung, trachea etc)
- They are unsuitable for animating deformable organs.
  (colon, GIT, gallbladder etc.)

Quadratic Gometric Models

- The colon can be effectively modelled by a quadratic (sphere) model, which offeres many advantages:
  - Compact representation
  - Faster to render
  - Easy to deform to simulate spasm and inflation
- However they are a less accurate representation of real anatomy.



Higher Order Geometric Models

- Cubic patch surfaces are good for representing complex smooth shapes
- The shape is controlled by a small number of control points (or knots) which can be moved to create animations.
- However, they are harder to match to real anatomical data.

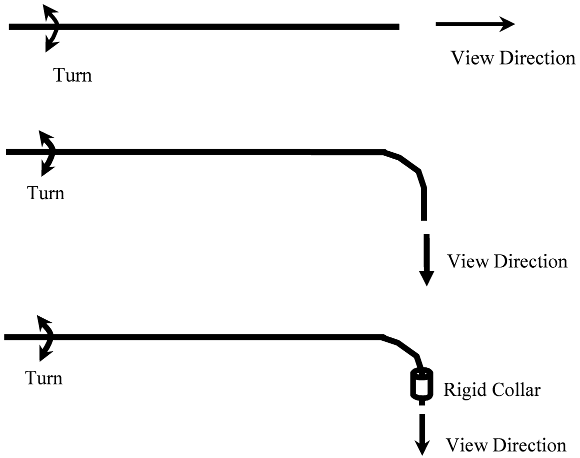
Overall there is a trade off:

- Polygon surfaces (linear) can match anatomical geometry accurately, but are hard to deform.
- Quadratic and cubic surfaces are easy to deform and manipulate, but are anatomically less accurate.

Building a Simlation

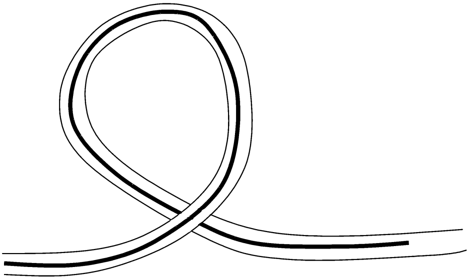
- Geometric models can achieve high accuracy, but they are only one part of a simulation system.
- Typically in a medical application the user needs to manipulate the underlying geometry - for example in colonoscopy or laparoscopy.
- There are major difficulties in simulating both the mechanicl behaviour of the medical instruments and the interaction with the human organs.

Modelling a flexible colonoscope



The Flexible Colonoscope in the Colon

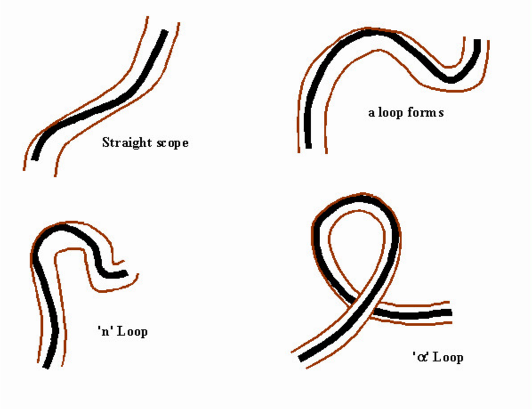
In practice it is not uncommon to find a colonoscope configured like this:



Does twisting the shaft tighten the loop or rotate the image?

Variety is the Spice of Life

Unfortunately a colonoscope can end up in many configurations:



Problems in modelling Colonoscope Physics

- What happens when you push the colon wall?
- What dynamic properties does the endoscope have?
- What frictional forces are acting?
- The colon is surrounded by the small intestine which is also deformable, but how does it deform?
- etc.

Behavioural modelling in Colonoscopy

However, one major factor works in favour of colonoscopy simulation:

You cannot see how the colon is being deformed by the colonoscope.

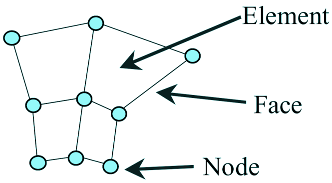
This means we can use behavioural instead of physical models:

- Consultants can describe behaviours that often occur in colonoscopy (paradoxical behaviour)
- Simulating the behaviour is easier than simulation the underlying physics.

Soft Tissue Deformation

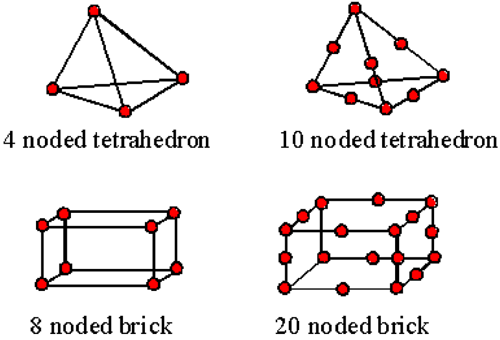
Considerable effort has gone into modelling soft tissue deformation over the last 30 years. Most approaches are based on the finite element method.

A complex shape is epresented by a small number of simple elements, in 2D:



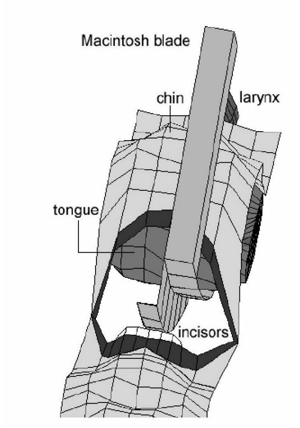
Soft Tissue Deformation

There are a variety of elements that can be used for 3D analysis:



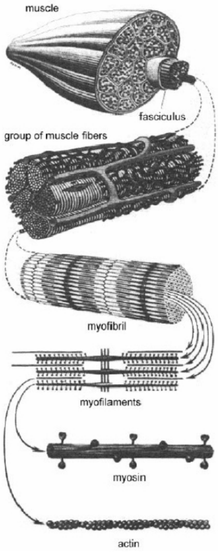
Finite Element Modelling of Laryngoscopy

- Geometry must be extracted from scan data.
- Boundary conditions must be defined. (attachment points and rigid parts)
- Material properties must be specified.



Material Properties of Soft Tissues

- The finite element method was designed for engineering applications where the materials have known uniform properties (eg steel structures).
- Soft tissue cannot be characterised in this way, though good approximate models have been developed.



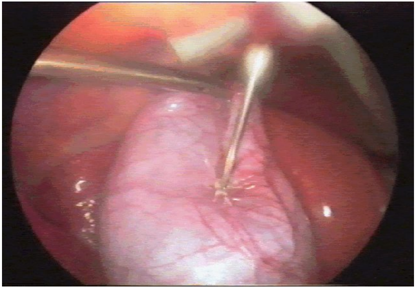
More difficulties in soft tissue modelling

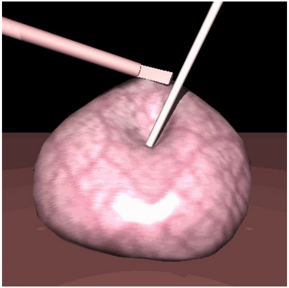
- Data on soft tissues deformation often comes from cavadars. This data does not represent the *in vivo* behaviour.
- Other effects come into play. For example when compressing the tongue initially the blood is squeezed out. After that the muscle becomes considerably less compressible.
- More accurate finite element models cannot be used in real time animation.

Laparoscopic Surgery Simulation

- Laparoscopic surgery simulation has attracted great commercial interest over the last 20 years. It is perceived as the most important application of virtual reality in surgery.
- Unfortunately however it poses the hardest modelling challenges:
  - Interaction of several systems:
    BILE $\Leftrightarrow$ GALL BLADDER $\Leftrightarrow$ SURROUNDING ORGANS
  - Cutting tissue, bleeding, flowing bile &c.
- Although it is possible to create plausible graphics does this really represent the real proceure?

Visually Appealing Laparoscopy Simulation





Summary

The modelling problems cover a wide spectrum:

from: No deformation (easy)

- Bronchoscopy
- Colonoscopy
- Upper GI endoscopy
- Other endoscopic procedures
- Laryngoscopy
- Laparoscopic Cholecystectomy

to: Large and Complex Deformations (very difficult)

Validation Issues

- Creation of convincing simulations is now possible, but there is no real way of assessing how accurately they reproduce the real procedures.
- On the one hand we know that the underlying modelling must be approximate, and it is possible that using computer simulation might induce bad habits
- On the other hand as training methods for manual skills they could be just as effective - if not better - than older methods