Graphics and Rendering

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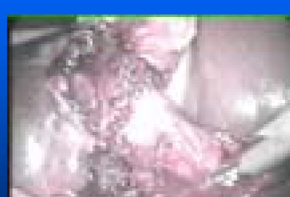
Overview

- Motivation
- Models for rendering
- Surgical effects
  - Cutting
  - Bleeding
  - Smoke

Motivation

- Visual feedback
  - Hand/Eye coordination
- Suspension of disbelief
- Integral part of surgery
  - Anatomical landmarks



Video by courtesy of ReachIn Technologies, Sweden.

Models for Rendering

- Ease of representation
- Ease of rendering

Models for Rendering

- Modeling at different levels
  - Whole organ
  - Tissue properties
- Modeling for different purposes
  - Haptic rendering
  - Visual display

Models for Rendering

- Different requirements at each level
- Visual rendering
  - Display hardware
  - Realism
  - Speed
  - Efficiency

Models for Rendering

- Not necessarily compatible with other modeling requirements
  - E.g. Polygonal vs. voxel representation

Modeling Elements

- Voxels
- Polygons
  - 2D surface-based
  - 3D volume-based
    - » Tetrahedral elements

Modeling Using Voxels

- [GIBSON98]
- Single representation for
  - Collision detection (trivial – occupancy map)
  - Deformation modeling [GIBSON97]
  - Cutting
  - Haptic rendering using density fields (e.g., [AVILA96])
  - Visual rendering using 3D texture maps [CABRAL95]

Voxel-based Modeling

- Shortcomings
  - Collision response difficult to handle
  - Visual details can be limited (lighting effects, texturing)
  - Realistic deformations (how to encode tissue properties?)
  - Rendering
    - » Cheap, fast, video cards assume polygons

Polygons

- Triangular 2D mesh/3D tetrahedrons
- OpenGl widely available
- Optimized in current rendering hardware
- Widely used

Animation by Yogendra Bhasin,
The Surgical Simulation Laboratory

2D Polygonal Mesh

- Problems
  - Cutting into a hollow shell
  - No interior structures
  - Difficult to model realistic deformations
  - Needs to be segmented from volumetric data

Animation by Sofia del Castillo
Uniformed Services University

3D Mesh

- Tetrahedral elements ties in well with other modeling requirements
- Ties in well with deformable modeling requirements

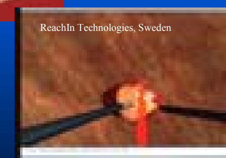
Surgical effects are dependent on underlying model representation

Surgical Effects

- Cutting
- Bleeding
- Smoke

[Bruyns02]

[Cakmak00]



ReachIn Technologies, Sweden

Cutting

- Very common surgical task
  - Surgery => cutting
- Not easy
  - Cuts can be made arbitrarily.
  - Depth and appearance varies with force, angle, location.
  - Wound “opening” after incision is made
    - » Deformation model must handle this
  - Need interactive, real time response

Challenges

- Change of topology affects methods for speeding up deformation computation
- Speed-up methods involving preprocessing can be invalidated
  - E.g. [COTIN99]
  - [BRO-NIELSEN96]

Cutting

- Methods used
  - Simply remove elements
- Pluses
  - Simple, Fast
- Minuses
  - Not visually pleasing
  - Cuts not precise

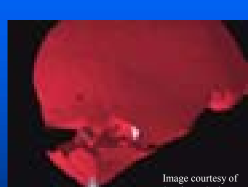


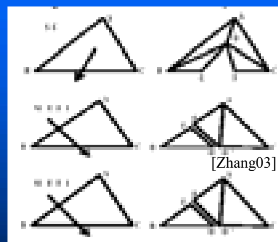
Image courtesy of Stephane Cotin

Cutting – Current Research Focus

- Making precise cuts
  - Split elements along cut line
- Progressive cutting
  - Splitting within a polygon

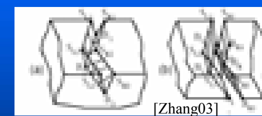
2D Mesh Cutting

- [Zhang03]
- Applied to 2D mesh models
- Track starting polygon
- Track when leaving and entering polygons
- Track ending polygon

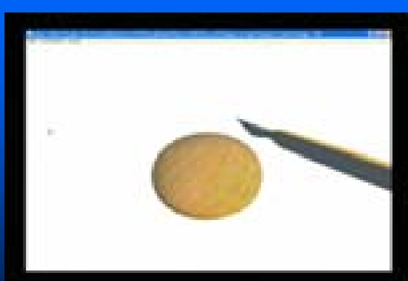


What About Cracks?

- Mass-spring model pulls cut apart.
- Grow polygons to cover cut region
- Handles grooves and cut-through.

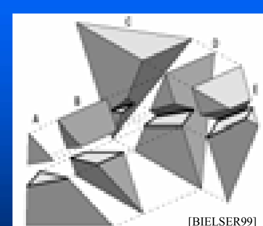


Animation



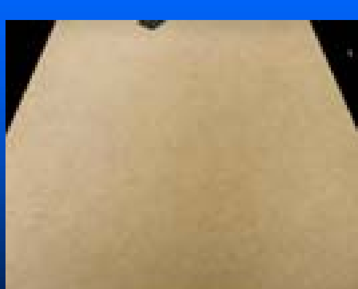
Video by courtesy of Hilary Zhang, School of Engineering Science, Simon Frasier University, Canada

3D Mesh Cutting



- [BIELSER99],[BIELSER02]
  - Five distinct cut types
  - Use intersected edges as an index into lookup table of split types
- Cut relaxation
  - Mass spring approach

Animation



Daniel Bielser, Computer Graphics Lab, ETH Zürich

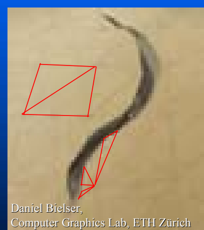
Shortcomings

- Increased polygon count
  - [Zhang03] 3-4 per cut polygon
  - [Bielser99] up to 5 pieces (not necessarily tetrahedrons)
- Incremental cutting exacerbates this
  - Cutting through tissue layers with repeated strokes

Shortcomings

- Poorly formed polygons (large angles and short edges)


[Zhang03]


Daniel Bielser, Computer Graphics Lab, ETH Zurich

Research Directions

- Minimize number of new elements created
- Rearrange vertices for more "balanced" polygons.
- Cutting along element faces
- Cutting same polygon twice

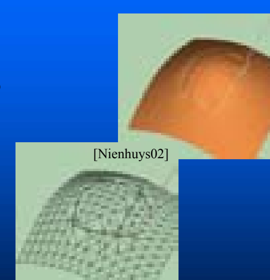
Minimizing Element Creation

- [MOR00], [MOR01]
  - Tetrahedral mesh
  - Reuse original points
  - New points at face/edge intersection.
  - 5 to 9 new elements
  - Problem with unbalanced elements
    - » Unstable during deformation modeling


[MOR01]

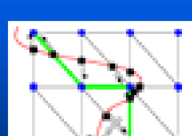
Create "Balanced" Elements

- [Nienhuys02]
  - Re-triangulate vertices to reduce large angles/short edges
  - Dynamically introduce/remove nodes during cut
  - 2D and 3D versions developed


[Nienhuys02]

"Cut" Along Faces

- [Nienhuys01a], [Nienhuys01b]
  - Distort tetrahedron so that face is along the cut.
    - » "Snap" closest nodes path onto path
    - » Duplicate nodes along cut path
    - » No other new nodes are created
  - Degeneracies can be a problem
    - » All three nodes of tetrahedron snap to path
    - » Not all degeneracies can be handled
  - Progressive cutting not addressed


[Nienhuys01b]

Create "Balanced" Elements

- [Serby01]
  - "Snap" nodes onto cut path
  - Redistribute surrounding nodes
    - » Treat vertices as nodes in a mass-spring system
    - » Use Lennard-Jones function as added internal energy term to "disperse" nodes
    - » Empirical description of behavior of rare gas molecules
  - Progressive cutting not supported

Bleeding

- Every surgical procedure involves blood
- At least three kinds of bleeding
  - Spurting
  - Flowing
  - Oozing

Bleeding

- Different approaches used for each type
- Navir-Stokes equation
  - Pooling
  - Flowing
  - Oozing
- Particle systems
  - Spurting
  - Flowing
- Ad-hoc

Navier-Stokes Equation (Incompressible Fluid Flow)

$$\nabla \bullet u = 0$$

$$\frac{du}{dt} = \nu\nabla \bullet (\nabla u) - (u \bullet \nabla)u - \frac{1}{\rho}\nabla p + f$$

- Navier-Stokes equation describes flow of fluids.
  - Water, blood, smoke.
- Extensive body of work available
  - See http://www.eng.vt.edu/fluids/msc/ns/nsintro.htm for an introduction

Height Field Approximation [KASS90]

- Model only liquid surface
- Use a height function over a 2D grid
- Simplifying assumptions
  - Ignore vertical component of fluid velocity, constant horizontal component
- Used to simulate blood flow over tissue surface [BASDOGAN99]

Video courtesy of Yogendra Bhasin

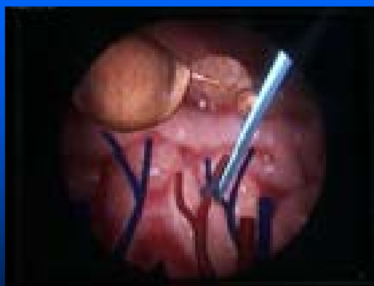
Related Research

- [FOSTER96]
  - Practical treatment of liquid animation
- [STAM99]
  - Unconditionally stable numerical model
- [FOSTER01]
  - Splashing effects
  - Combines Navier-Stokes eq. with other methods.

Particle Systems [REEVES83]

- Model fluids as large collection of particles
- Particles behave according to physical laws
- Particles can also interact with each other
- Stochastic processes increase realism
- Simulate liquids
  - Spurting, flowing

Example



- Karlsruhe Laparoscopic Simulator

Particle Systems

- Pluses
  - Easy to understand
  - Simple to animate
- Minuses
  - Need lots of particles for realism
  - But see animated textures

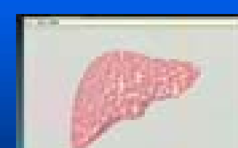
Ad-hoc Methods

- Video overlays
  - [OPPENHEIMER01]
- Video from actual/simulated bleeding
- Superimposed on 2D plane perpendicular to view direction

[OPPENHEIMER01]

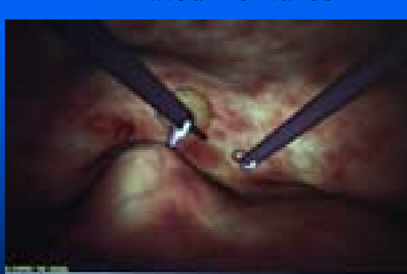
Ad-hoc Methods

- Animated textures
  - Visual overlay onto unchanging surface (e.g. [NEYRET02])
- Pluses
  - Fast, decent realism, can be used for other effects (e.g., bruising)
- Minuses
  - Limited to surface effects
  - Less realistic when viewed stereoscopically or at shallow angles



Video courtesy of Fabrice Neyret, iMAGIS - GRAVIR / IMAG

Combining Particle Systems with Animated Textures



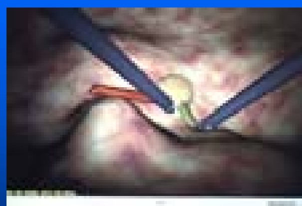
Surgical Science LapSim

Bleeding Effects

- Surgeons use a variety of methods to stop bleeding
- Coagulation
  - Change from fluid to solid
  - No work being done on this
  - [TERZOPOULOS95] did work on melting

Smoke

- Cutting and coagulation done using
  - Electricity
  - Ultrasound
  - Heat
- Smoke and steam from (localized) burning tissue



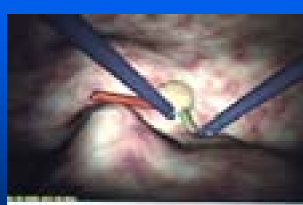
Surgical Science

Current Methods

- Texture based
- Fluid dynamics
  - Solve Navier-Stokes equation

Texture-based Methods

- 2D methods
  - 2D smoke puff texture
  - Map texture onto plane
  - Change plane orientation (billboard)
- Smoke trail
  - Overlapping series of puffs
  - Increase size and transparency of puffs

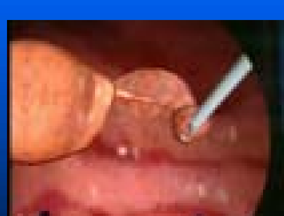


Generating Smoke Textures

- Perlin noise function [PERLIN85], [PERLIN02]
  - Method for generating coherent noise
  - Function varies smoothly
  - Sum of white noise at various scales

Generating Smoke from Textures

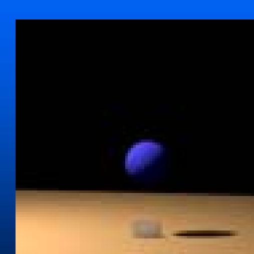
- [CAKMAK00]
- Rising smoke simulated by changing texture coordinates



Source: Forschungszentrum Karlsruhe

[FEDKIW01]

- Efficient Navir-Stokes implementation
  - 2D version in real-time.
  - Simplified version on PocketPC system.
- Compensates for dissipation
  - Persistent vortices
- Interaction with objects in smoke-stream



http://graphics.stanford.edu/~fedkiw/

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