MEDICAL IMAGE COMPUTING (CAP 5937)

LECTURE 18: Medical Image Visualization

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Outline

• Volume Rendering
  – Shading, illumination, …

• Example Applications
Goal

• Realistic Image Synthesis
• Improved Scene Perception
Introduction

- 2D visualization: slice images (or multi-planar reformation: MPR)
- Indirect
  3D visualization: isosurfaces (or surface-shaded display: SSD)
- Direct
  3D visualization: direct volume rendering: DVR
Motivation
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4Vs of Big Data as defined by Gartner Group [Marc Streit]
Scenes/Structures → Rendition

**Scene-based:** Display object information directly from scenes.
- Slice mode
- Surface mode
- Volume mode

**Object-based:** Represent object information first as hard/fuzzy structures, then display them.
- MIP
- Surface rendering
- Volume rendering
Surface Reconstruction from Segmented Objects

• Binary pictures
  – **Pros**: natural geometric form for bio-medical data; simple to operate on
  – **Cons**: blocky boundary; costly to store or visualize (particularly in 3D).
Geometric Form

• Continuous forms
  – Defined by mathematical functions
  – E.g.: parabolas, splines, subdivision surfaces

• Discrete forms
  – Disjoint elements with connectivity relations
  – E.g.: polylines, triangle surfaces, pixels and voxels
Boundary Representation

- Polylines (2D) or meshes (3D) that tile the object boundary
  - Smoother appearance
  - Less storage (no interior elements)
Iso-contours

Digital image  Binary picture  Boundary curve

\[ f(x, y) \]
Good Approximations

• Marching Cubes
• Shell-rendering
Direct Volume Rendering
Ray-Casting

*Image order approach:*

For each pixel {
  calculate color of the pixel
}
Ray Casting

How do we determine the radiant energy along the ray?

- Physical model: emission and absorption, no scattering

\[ I(s) = I(s_0) e^{-\tau(s_0, s)} + \int_{s_0}^{s} q(\tilde{s}) e^{-\tau(\tilde{s}, s)} d\tilde{s} \]
Transfer Functions (TF): Classification

Assign optical properties: define the “look” of the data

- Which parts are transparent?
- Which parts have what color?
1D Transfer Functions

texture = scalar field

resampling

scalar value $S$

$T(S)$

RGBA

transfer function texture = [Emission RGB, Absorption A]
1D Transfer Functions
Pre/Post Classification

Pre-interpolative vs. post-interpolative classification

pre-classification

post-classification

same TF, same resolution, same sampling rate
Pre/Post Classification

Pre-interpolative vs. post-interpolative classification

pre-classification
post-classification

same TF, same resolution, same sampling rate
2D Transfer Functions

1D transfer function
• Horizontal axis: scalar value
• Vertical axis: number of voxels

2D transfer function
• Horizontal axis: scalar value
• Vertical axis: gradient magnitude

[Kniss et al. 2002]
2D Transfer Functions

1D transfer function
- Horizontal axis: scalar value
- Vertical axis: number of voxels

2D transfer function
- Horizontal axis: scalar value
- Vertical axis: gradient magnitude

[Kniss et al. 2002]
Volume Shading

Local illumination vs. global illumination

- Gradient-based or gradient-less
- Shadows, (multiple) scattering, ...
Colon Unfolding

- Polyp detection
- Entire mucosal surface at a glance

Visualization Techniques for Virtual Endoscopy [Anna Vilanova]
Cardiac Artery Disease Visualization

- **Coronary Artery Disease**
  - Collection of diseases with obstructed coronary arteries
  - Lack of blood supply kills heart muscle tissue
  - Ischemia, chronic infarction, acute infarction, ...

[Susan Standring, editor. *Anatomy of the Human Body*]
Unfolding the Myocardium
Visual Analysis for Needle Pathway Planning
Circle of Willis (CoW)-Visual Analysis


Figure taken and modified from http://en.wikipedia.org/wiki/File:Circle_of_Willis_en.svg
Standardized Visualization-CoWRadar

Preprocessing → Vessel Extraction → Vessel Modeling → Visualization

Labeled vessel graph → CoWRadar
CoW Radar Sectors

Preprocessing → Vessel Extraction → Vessel Modeling → Visualization

Subtrees → Sectors
CoWRadar Sectors

Preprocessing → Vessel Extraction → Vessel Modeling → Visualization

Segments → Nodes
CoWRadar Branching Points

Preprocessing → Vessel Extraction → Vessel Modeling → Visualization

Branching points → Edges
Semantic Driven Illustrative Rendering

- If penetration depth is low and distance to focus is low, then skin-style is transparent white.
- If penetration depth is high or distance to focus is high, then skin-style is pink.
- If distance to plane is low, then skin-style is transparent blueish and glossy green is low.
- If distance to plane is high, then skin-style is opaque pink and glossy green is transparent.
How do we measure hemodynamics? (Blood Flow Visualization)

First blood-flow pressure measurement

Stephen Hales
1727

Courtesy of Roy van Pelt
Motivation: Hemodynamic Information
Simulations vs Measurements

Simulation
- Model assumptions
- Numerical approximations

Measurement
- Artifacts, noisy
- Limited resolutions
- Limited contrast

Research in FlowVis

Recent Vis Research
Blood Flow Measurements

spatial resolution: 150x150x50 voxels
temporal resolution: 25 phases

0.5% of all velocity vectors
Temporal Maximum Intensity Projection (T-MIP)
Direct visualization of the data does not convey flow patterns

$\mathbf{v}_x$  $\mathbf{v}_y$  $\mathbf{v}_z$

$||\mathbf{v}||$  $||\mathbf{v}||$  $tMIP$
Flow Visualization Techniques

Particle tracing techniques:

Simulate the trajectory of a particle released inside the blood flow

CFD simulations [Cebral et al. 2011]

Flow measuring with 4D PC-MRI [Meckel et al. 2008]
Particle Tracing - Streamline

Streamline – steady flow – vector field fixed on time
Numerically solve the following equation:

\[ \vec{v}(x) = \frac{dp(s)}{ds} \]

\[ p(s) = \int \vec{v}_i(p(s))ds \]

\( p(s) \) trajectory
\( \vec{v}(x) \) vector field value at position \( x \)
Particle Tracing - Pathline

Pathline – Unsteady flow – Vector field changes on time
Extension of streamlines for time-varying data

Pathline

Streamlines
Anatomical Context (from Segmentation) + Flow

Semitransparent

[Lawonn et al. VMV 2013 ]
Visualization of Diffusion Imaging

- Glyph Visualization
  
  A **glyph** is a geometric object whose shape, size, orientation, and color conveys the data

- Common for diffusion tensors: **Ellipsoid**

  Axes
  - aligned with eigenvectors
  - scaled with eigenvalues

  Implicit Equation:
  \[ x^T D^{-2} x = 1 \]
Visualization of Diffusion Imaging

• Glyph Visualization

  • Ellipsoids suffer from visual ambiguities:

  • Superquadric Glyphs greatly reduce them:
Motivation for Superquadratic Tensors

- **Ellipsoids** are transformations of the sphere
- **Superquadrics** smoothly interpolate between sphere, cylinder, and box
• Packing glyphs densely reduces occlusion and enhances perception of continuous structures

Grid-based Layout  Glyph Packing
Medical Image Fusion

Pixel-based fusion is performed on a pixel-by-pixel basis. It generates a fused image in which information associated with each pixel is determined from a set of pixels in source images [...]. “

Pixel level fusion

Straight forward:
- Checker board, Linear Blending

http://itk.org/

Osirix, Enterix Dataset
Pixel level fusion—On the Fly

Information theoretic approaches (Haidacher et al 2008)

Pixel level fusion– On the Fly

Information theoretic approaches
(Bramon et al 2013)

“Feature-based fusion at feature level requires an extraction of objects recognized in the various data sources. It requires the extraction of salient features which are depending on their environment such as pixel intensities, edges or textures. These similar features from input images are fused.”

Feature Fusion

“Features”
- Edges, regions with similar characteristics, ...
- Segmented objects

Pipeline
- Extract features from each dataset — offline or online
- Treat features as objects and represent them in one scene
- And/or use features to influence rendering pipeline
Feature Fusion

The Classics


Feature Fusion

Challenge: Correctly render mixed scenes containing Volume Data and transparent geometry

- Depth Peeling
- A-Buffer
- Depth Complexity Histograms

Figure 9: Fused visualization of hybrid data for the purpose of neurosurgical planning. The scene is particularly complex in areas where the DTI fibres converge towards two main bundles. (a) Full scene, (b) zoomed view and (c) the depth complexity histogram (DCH, log scale) of (d).

Feature Fusion

“Decision-level fusion consists of merging information at a higher level of abstraction, combines the results from multiple algorithms to yield a final fused decision. [...] The obtained information is then combined applying decision rules to reinforce common interpretation.”
Virtual Autopsies

From body bag to bones in a minute Real-time full body rendering (10 GB volume)
Virtual Autopsies Workflow

Multi-Resolution Volume rendering

Multi Touch Technology

User Interface Design

A NEW WAY OF WORKING WITH MEDICAL DATA
Touch Technologies in Clinical Training

- Different cases
  - Real dimensions, real pathologies
  - real patients
  - simulated surgery
- Different training programs
  - radiology
  - surgery
  - general medicine
  - residency
Summary

• Realist Volume Rendering
  – Radiology applications
• Example Applications
Slide Credits and References

- Markus Hadwiger
- Eduard Groller
- Anna Vilanova
- Katja Buhler
- Thomas Schultz
- Anders Ynnerman