Feature Emphasis and Contextual Cutaways for Multimodal Medical Visualization

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Preface

CT scan with embedded Ultrasound data

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Visualization Scenario

- Poking needles
  - Liver biopsy
  - Radio frequency ablation

- Procedure:
  - Patient has CT scan
  - Needle path is planned
  - Uses ultrasound probe to help guide needle
  - Doctor views CT scan at time of procedure
Visualization Scenario

CT Scan Data

Ultrasound Data
Visualization Scenario

Ultrasound embedded in dense volume
Visualization Scenario

Ultrasound embedded in sparse volume
Visualization Scenario

Ultrasound with contextual cutaway
Key Requirements

- Volumetric data
  - Tissue types differentiated and ranked
    - Important materials most visible
    - Unimportant materials provide context

- Ultrasound image
  - Captured with 3D position and orientation of probe
  - Registration between coordinate frames [Wein05]
Volumetric Data (e.g. CT Scan)

Importance in the Transfer Function

Importance-Driven Shading

Viewpoint Information

Contextual Cutaway Views

Object of Interest (e.g. Ultrasound Plane)

Integrating Occlusion with Importance

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Visualization Pipeline

Volumetric Data (e.g. CT Scan)
- Importance in the Transfer Function
  - Importance-Driven Shading

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Defining Importance

Rank materials by relevance

1. Definition in volumetric space
   - Uses auxiliary volume
   - Requires preprocessing per dataset

2. Definition in transfer function space
   - Extra value in transfer function
   - Shared among datasets
Defining Importance

\[ |\n\text{VF}(x, y, z)\| \]

Component 1

\[ c_1, \alpha_1, I_1 \]

Material boundaries

F(x, y, z)

Component 2

\[ c_2, \alpha_2, I_2 \]
Visualization Pipeline

- **Volumetric Data (e.g. CT Scan)**
- **Viewpoint Information**
- **Object of Interest (e.g. Ultrasound Plane)**
  - Importance in the Transfer Function
  - Importance-Driven Shading
  - Integrating Occlusion with Importance
  - Contextual Cutaway Views
Feature Emphasis

- Visual distinction between materials
  - Emphasis of important materials

- Material properties
  - Color
  - Opacity

- Lighting properties
  - Shading conveys detail
Feature Emphasis

Full Shading

No Shading
Feature Emphasis

Full Shading

Importance Shading
Feature Emphasis

- Emphasis: $E$
- Shaded color: $C_{shaded}$
- Subdued color:
  $$C_{subdued} = E \times C_{unshaded} + (1 - E) \times C_{shaded}$$
- Final color:
  $$C_{final} = I \times C_{shaded} + (1 - I) \times C_{subdued}$$

Important Shading
Feature Emphasis
Visualization Pipeline

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Contextual Cutaways

- Object of interest obscured by volume
  - High importance
    - Should be visible
    - May obscure object
  - Low importance
    - Not necessarily visible
    - May not obscure object

- View-dependent cutaway structure

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Traditional Cutaways

\[ \theta \]

Clear

Base

Object of Interest

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Traditional Cutaways

Small $\theta$

Large $\theta$
Contextual Cutaways

\[ \theta_1 \]

\[ \theta_2 \]

\[ d \]

\[ v \]

Clear

Overlay

Transition

Base

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Layered Visualization

Base

Transition
Layered Visualization

Base, Transition

Overlay
Layered Visualization

Base, Transition, Overlay

Base
Visualization Pipeline

Volumetric Data (e.g. CT Scan)

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Contextual Cutaway Views

Integrating Occlusion with Importance
Occlusion

\[ \Omega = 1 \]

\[ \Omega = 0 \]
Occlusion Compensation

- Fade material based on occlusion value between two occlusion thresholds
  - Thresholds based on importance

- Modify opacity:
  - $\tau_u = I$
  - $\tau_l = \max(2 \cdot I - 1, 0)$
  - $\alpha' = \alpha \cdot (1 - \text{ramp}(\tau_u, \tau_l, \Omega))$
Occlusion Compensation

\[ \tau_u = I \]
\[ \tau_l = \max(2 \times I - 1, 0) \]

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Results

No cutaway
(over draw)
Results

Simple cutaway

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Results

Simple cutaway with interior
Results

Interior becomes overlay region
Results

Transition area added
Results
Implementation

- GPU Raycaster in GLSL
- Cutaway represented as height field
  - Created by rendering extruded geometry
  - Requires only 1 lookup per ray

- Performance
  - Interactive frame rates
  - 10-15 fps on high-end hardware
  - Dependent on sample rate, volume size, empty space skipping, etc.
Conclusions

- **Visualization**
  - Material importance defined within transfer function
  - Important materials emphasized through shading
  - View-dependent cutaway structure determines occlusion of object-of-interest
  - Materials removed in occluding areas, according to their importance

- **Application**
  - Visualize ultrasound data within CT scan for needle driven operations
  - Initial feedback has been positive
  - Currently being evaluated for clinical use
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