Recent Developments in
Ultrasound Visualization

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Basic Ultrasound Imaging
Ultrasound Characteristics

- Non-invasive
- Cheap
- High resolution
  - Spatially
  - Temporally
- Noise
  - Random
  - Speckle
Common Ultrasound Modes

- **2D Ultrasound**
  - B-Mode
- **3D Ultrasound**
  - Static 3D imaging
- **4D Ultrasound**
  - Dynamic 3D imaging
- **Doppler Ultrasound**
  - Color Doppler: directional
  - Power Doppler: non-directional
- **Contrast Ultrasound**
  - Microbubbles-based contrast agents
• Visualization of 3D/4D ultrasound data
• Recent advances in
  – Filtering
  – Classification
  – Illumination
  – Fusion and Guidance
Recent Developments in Ultrasound Visualization
Filtering

- Noisy character of ultrasound imaging makes filtering particularly important for 3D visualization
Lowest Variance Filtering

• Remove speckle and random noise
• Structure-preserving filtering
  – Determine local structure orientation
  – Filter along direction of lowest variance

Solteszova et al. 2012: Lowest-Variance Streamlines for Filtering of 3D Ultrasound
Local Structure Orientation

- Sample local voxel neighborhood on a sphere

**Solteszova et al. 2012**: Lowest-Variance Streamlines for Filtering of 3D Ultrasound
Directional Filtering

- Streamline integration along direction of lowest variance

*Solteszova et al. 2012: Lowest-Variance Streamlines for Filtering of 3D Ultrasound*
Results

Solteszova et al. 2012: Lowest-Variance Streamlines for Filtering of 3D Ultrasound
4D Filtering (1)

• Acceptable complexity of filtering method is limited by the target frame rate
  – **Idea:** only filter voxels that contribute to the final rendered image
  – **Problem:** filtering changes data values and hence can affect visibility globally
  – **Solution:** conservatively estimate a voxel’s visibility after filtering

*Solteszova et al. 2014: Visibility-Driven Processing of Streaming Volume Data*
4D Filtering (2)

- Only a fraction of voxels actually influence the final image due to transparency and occlusion

_Solteszova el al. 2014: Visibility-Driven Processing of Streaming Volume Data_
Visibility-Driven Filtering

**Solteszova el al. 2014: Visibility-Driven Processing of Streaming Volume Data**
Prediction of Filter Behavior

- Opacity of a filtered value of minimum and maximum of a neighborhood
- Possible for all convolution-based filters with normalized non-negative weights
- Lookup tables for conservative visibility mask calculation

Solteszova et al. 2014: Visibility-Driven Processing of Streaming Volume Data
Results (1)

unfiltered

regular filtering
5 fps

visibility optimized
10 fps

Solteszova et al. 2014: Visibility-Driven Processing of Streaming Volume Data
Results (2)

Solteszova et al. 2014: Visibility-Driven Processing of Streaming Volume Data
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CLASSIFICATION
Classification

• Mapping of data values to optical properties (usually color and opacity)

• Several challenges
  – Low dynamic range
  – Significant amount of noise and speckle
  – Varying intensities for the same tissue
  – Fuzzy boundaries
Variational Classification

- Simultaneous denoising and opacity assignment
- Variational approach based on isovalue and gradient

*Fattal and Lischinski 2001: Variational Classification for Visualization of 3D Ultrasound Data*
Scale Space Filtering

- Automatic adjustment of the global opacity transfer function based on scale-space filtering

Hönigmann et al. 2003: Adaptive Design of a Global Opacity Transfer Function for Direct Volume Rendering of Ultrasound Data
Predicate-based Classification

• **Problem:** classification of 3D ultrasound data for volume visualization
  – Standard 1D transfer functions don’t work well for ultrasound
  – Additional attribute dimensions can help, but classification space becomes difficult to navigate

• **Approach:** define a set of point predicates which can be combined via logical operations

Schulte zu Berge et al. 2014: Predicate-based Focus-and-Context Visualization for 3D Ultrasound
Predicate Library

- Set of different local and non-local predicates
  \[ P = (f_P : X \rightarrow \{true, false\}, \kappa_P, \delta_P) \]
  - \( \kappa_P \) is an importance factor
  - \( \delta_P \) is the color modulation

- Examples of possible predicates
  - Range-based predicates
  - Direction-based predicates
  - Signal-to-Noise ratio predicate
  - Vesselsness predicate
  - Confidence predicate
  - Label predicate
Predicate Setup

- Simple widget to assign importances and colors
- Combination of predicates with Boolean operations (and, or, not)
Visual Mapping

• Importance-driven layered compositing, cf. [Viola et al. 2004, Rautek et al. 2007]

• High-importance layers receive higher visibility (depth relationships can be overridden)

• Predicates only affect hue and opacity, luminance comes from data values

Schulte zu Berge et al. 2014: Predicate-based Focus-and-Context Visualization for 3D Ultrasound
Predicate Histogram

- Sketch-based interface for predicate setup
- User draws *positive* and *negative* sketch
- Importance of each predicate is modulated accordingly

Schulte zu Berge et al. 2014: Predicate-based Focus-and-Context Visualization for 3D Ultrasound
Results (1)

- Shoulder dataset: combines visualization of **bone** and **muscle** tissue

Schulte zu Berge et al. 2014: Predicate-based Focus-and-Context Visualization for 3D Ultrasound
Results (2)

- Path of the **carotid artery** is shown in red
• **Achilles tendon** is shown in red

Schulte zu Berge et al. 2014: Predicate-based Focus-and-Context Visualization for 3D Ultrasound
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Volume Rendering (1)
Volume Rendering (2)

- emission
- absorption

usually ignored

out-scattering
Local Volume Illumination

- Only a function of gradient direction and light source parameters
  - Volumetric absorption between light source and sample point is ignored → no shadows
  - Multiple scattering is ignored → no color bleeding effects

![conventional rendering](image1.png)  ![fetoscopic image](image2.png)
Light Propagation in Tissue

• Human skin (and tissue in general) is translucent
  – Red penetrates deeper than blue and green light
  – Light scatters predominantly in forward direction
  – Light propagation tends to become isotropic after multiple scattering events
Fetoscopic Illumination Model

Volume data → Indirect light → Scattering → Shadows → Tone mapping → Final image

Volume data → Direct light → Ambient light → Specular

Varchola 2012: Live Fetoscopic Visualization of 4D Ultrasound Data
Fetoscopic Illumination Model

Varchola 2012: Live Fetoscopic Visualization of 4D Ultrasound Data
Light is attenuated along its way through the volume
Kniss et al. 2003: A Model for Volume Lighting and Modeling
Light Source Extent (1)

hard shadows

soft shadows
Light Source Extent (2)
Kernel Size (1)

shadow softness - low
shadow softness - medium
shadow softness - high
Kernel Size (2)

shadow softness - low
shadow softness - medium
shadow softness - high
Fetoscopic Illumination Model

- Volume data
- Indirect light
- Direct light
- Scattering
- Ambient light
- Shadows
- Specular
- Tone mapping
- Final image

Varchola 2012: Live Fetoscopic Visualization of 4D Ultrasound Data
Light is scattered multiple times before it reaches the eye
Indirect Lighting (2)

Kniss et al. 2003: A Model for Volume Lighting and Modeling
Chromatic Light Attenuation

- Color intensity (RGB)
- Position along diffusion profile
- Light orientation
Forward Scattering (1)

rendering without scattering

rendering with scattering
Forward Scattering (2)
Fetoscopic Illumination Model

- Volume data
- Indirect light
- Direct light
- Scattering
- Ambient
- Shadows
- Specular
- Tone mapping
- Final image

Varchola 2012: Live Fetoscopic Visualization of 4D Ultrasound Data
Front and Back Lighting

Light positioned in front

Light positioned behind the scene
Local Ambient Occlusion (1)

- Evaluate the average visibility of each point
  - Perform sampling in a small spherical neighborhood
  - Modulate ambient illumination intensity by the result
Local Ambient Occlusion (2)

without ambient term

with ambient term
Fetoscopic Illumination Model

volume data

indirect light

direct light

scattering

ambient

tone mapping

shadows

specular

final image

Varchola 2012: Live Fetoscopic Visualization of 4D Ultrasound Data
Specular Highlights
Fetoscopic Illumination Model

- Indirect light
- Direct light
- Volume data
- Scattering
- Ambient
- Shadows
- Specular
- Tone mapping
- Final image

Varchola 2012: Live Fetoscopic Visualization of 4D Ultrasound Data
Implementation

- GPU-based implementation using DirectX
  - Available as *HDlive* in GE’s latest generation of ultrasound machines (Voluson E8 / Expert)
  - Interactive performance of 15-20 fps limited by data acquisition
Results (1)

conventional rendering

fetoscopic rendering
Results (2)

conventional rendering

fetoscopic rendering
Results (3)
Results (4)

conventional rendering

fetoscopic rendering
Results (5)

photograph acquired with fetoscope
[A Child is Born, Nilson and Hamberger]

fetoscopic rendering
[Picture of the Month, Ultrasound in Obstetrics & Gynecology 38(5)]
Benefits

- Approximates realistic illumination in real-time
- Robust against noise and artifacts
- Better 3D perception may have diagnostic benefits
- Currently investigating other application scenarios (e.g., cardiac)

*Images and text*:
- **cleft lip**: better visibility of border and separation
- **down syndrome**: inclination of palpebral fissures
Cardiac Ultrasound
Chromatic Shadows

• Comparison between black and illustration-inspired blue shadows

*Solteszova el al. 2014: Chromatic Shadows for Improved Perception*
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FUSION AND GUIDANCE
Fusion and Guidance

• **Fusion:** combine multiple modalities to improve diagnostic value
  – Registered CT/MRI scans, blood flow, etc.

• **Guidance:** augment images with additional information
  – Orientation and navigation aids, etc.
B-Mode/Doppler Fusion

- Integrated visualization of B-Mode and Doppler data
- Non-photorealistic silhouette rendering for reduced visual clutter

Petersch et al. 2007: Blood flow in its context: Combining 3D B-Mode and Color doppler Ultrasonic Data
Vector Flow Imaging provides 3D velocity information

- Pathlets-based visualization
- Pathline integration on the GPU

Angelelli et al. 2014: Live ultrasound-based particle visualization of blood flow in the heart
Guidance in Liver Examinations

- **Couinaud segmentation**: divides the liver into different sections dependent on the blood vessels.
- **Registration** to a liver model for real-time Couinaud overlays during the scan.

*Viola et al. 2008: Illustrated Ultrasound for Multimodal Data Interpretation of Liver Examinations*
Cardiac Ultrasound Guidance

- Real-time augmentation of the ultrasound slice using an animated heart model

*Ford et al. 2012: HeartPad: Real-Time Visual Guidance for Cardiac Ultrasound*
Recent Developments in Ultrasound Visualization

CONCLUSIONS
Conclusions

• Selection of recent approaches for improved visualization of ultrasound data
• Importance of 4D ultrasound as a cheap and effective imaging modality is ever-increasing
• Technological advances (e.g. beamforming) offer continuous improvements in frame rate and image resolution
• Live 4D data is still very challenging and many problems remain unsolved
Thank you for your attention!

Acknowledgements
Veronika Solteszova, Åsmund Birkeland, Paolo Angelelli, Ivan Viola, Alexey Karimov, Andrej Varchola, M. Eduard Gröller, Erik Steen, Gerald Schröcker, Daniel Buckton