Example-Guided Volume Segmentation

P. Brunet, A. Chica, E. Monclús, I. Navazo, A. Vinacua
UPC, Barcelona
Volume Segmentation
Volume Segmentation: a difficult problem

Noise
Acquisition artifacts
Unclear boundaries
Non-uniform densities
Complex anatomic structures
Volume Segmentation: a difficult problem

- Noise
- Acquisition artifacts
- Unclear boundaries
- Non-uniform densities
- Complex anatomic structures
Active Contours

Threshold-Based Approaches

(From Anna Vilanova)
Example-Guided Volume Segmentation
Example-Guided Volume Segmentation

Segmented Example ➔ Volume Model ➔ Triangular Mesh
Example-Guided Volume Segmentation

- Segmented Example
- Volume Model
- Attracted to
- Segmented Mesh
- Deformation
- Similar to
- Triangular Mesh
Example-Guided Volume Segmentation

- Volume Model
- Attracted to
- Segmented Mesh
- Deformation
- Similar to
- Triangular Mesh
- Segmented Example
  - Energy minimization
  - Adaptive
  - DB of Examples
“Watershed segmentation using prior shape and appearance knowledge”, Ghassan Hamarneh & Xiaoxing Li, 2009

"Deformable Models in Medical Image Analysis: A Survey," T. McInerney, D. Terzopoulos, Medical Image Analysis, 1996

“Globally constrained deformable models for 3D object reconstruction”, Montagnat, J., Delingette, H., Signal Proc. 1998

The Segmentation Algorithm

V: Volume Model

M: Example Mesh
The Segmentation Algorithm

V: Volume Model

M: Example Mesh

Interactive Registration (4 points)
The Segmentation Algorithm

V: Volume Model

M: Deforming Mesh

M: Example Mesh

Interactive Registration (4 points)

Affine Transformation
The Segmentation Algorithm

- **V**: Volume Model
- **M**: Deforming Mesh
- **Distance Field**
- Volume features (Edge detection + cleaning)
The Segmentation Algorithm

- **V**: Volume Model
- **M**: Example Mesh

- Energy minimization
- Adaptive

**Volume features**

**Distance Field**
The Segmentation Algorithm

V: Volume Model

M: Example Mesh

- Energy minimization
- Adaptive

Volume features

Distance Field
The Segmentation Algorithm

V: Volume Model

M: Example Mesh

- Energy minimization
- Adaptive

Volume features

Distance Field
The Segmentation Algorithm

\( \mathcal{V} \): Volume Model

\( \mathcal{M} \): Deforming Mesh

\( \mathcal{M} \): Example Mesh

Volume features \( B_v \)

Distance Field \( \mathcal{E}_{v,\partial} \)

\[
\mathcal{E}_\partial = \int_{\mathcal{M}} \text{dist}(x, B_V)^2 dS
\]

\[
\mathcal{E}_\partial = \sum_{v \in \mathcal{M}} \text{dist}(v, B_V)^2 = \sum_{v \in \mathcal{M}} \mathcal{E}_{v,\partial}
\]
The Segmentation Algorithm

V: Volume Model

M: Deforming Mesh

M: Example Mesh

Volume features $B_v$

$$\mathcal{E}_\partial = \int_{\mathcal{M}} \text{dist}(x, B_V)^2 dS$$

$$\mathcal{E}_\partial = \sum_{v \in \mathcal{M}} \text{dist}(v, B_V)^2 = \sum_{v \in \mathcal{M}} \mathcal{E}_{v, \partial}$$

$$\mathcal{E}_S = \sum_{v \in \mathcal{M}} d^2 \left( v, \sum_{v_i \in \text{ring}(v)} \lambda_{v_i} v_i \right) = \sum_{v \in \mathcal{M}} \mathcal{E}_{v, S}$$
The Segmentation Algorithm

\( V: \) Volume Model

\( M: \) Deforming Mesh

\( \mathcal{M}: \) Example Mesh

\[ \mathcal{E}_\partial = \sum_{v \in \mathcal{M}} \text{dist}(v, B_V)^2 = \sum_{v \in \mathcal{M}} \mathcal{E}_{v,\partial} \]

\[ \mathcal{E}_S = \sum_{v \in \mathcal{M}} d^2 \left( v, \sum_{v_i \in \text{ring}(v)} \lambda_{v_i} v_i \right) = \sum_{v \in \mathcal{M}} \mathcal{E}_{v,S} \]

\[ \mathcal{E} = \sum_{v \in \mathcal{M}} \sqrt{\mathcal{E}_{v,\partial} \cdot \mathcal{E}_{v,S}} \]

Min \( \mathcal{E}_\partial \)  Min \( \mathcal{E}_S \)
Implementation

For every mesh vertex \( v \)

\[
\begin{align*}
g &= \text{Gradient} \left( \text{DF}, v \right) \\
L &= \text{Laplacian} \left( v \right) \\
Ef &= \text{NormalizedFeatureEnergy} \left( v \right) \\
EL &= \text{NormalizedLaplacianEnergy} \left( v \right)
\end{align*}
\]

\[
v = v + \lambda \cdot g + \mu \cdot L
\]

EndFor

For every mesh vertex \( v \)

\[
\begin{align*}
g &= \text{Gradient} \left( \text{DF}, v \right) \\
L &= \text{Laplacian} \left( v \right) \\
Ef &= \text{NormalizedFeatureEnergy} \left( v \right) \\
EL &= \text{NormalizedLaplacianEnergy} \left( v \right)
\end{align*}
\]

if \( Ef < EL \) then  \( v = v + \lambda \cdot g + \mu \cdot L \)  else  \( v = v + \mu \cdot L \)  Endif

EndFor

\[
\lambda = \mu = 0.5
\]
Results: Metatarsal bone

Volume model: 256 x 256 x 272
Triangles: 18216
Iterations: 10+34
Results: Phalanx-2 and Calcaneus
Conclusions and Future Work

Deformation of an example mesh
   (From a Database of Segmented cases)
Interactive initial registration
Energy minimization
   • Attracting distance field
   • Copying local shape: laplacian coordinates
Adaptive scheme: Using the example shape in regions with poor volume features

Future:
Automatic initial registration
Filtering and cleaning unwanted volume features