Surgery Simulation

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INRIA Sophia-Antipolis

- INRIA : 5 research units in France
- 700 researchers and 500 Phd students
- Projet Epidaure dedicated to the processing of medical images.
Acknowledgment

- Colleagues:
  - N. Ayache
  - G. Malandain
  - X. Pennec

- PhD Students:
  - J. Montagnat
  - G. Picinbonno
  - C. Forest

Lecture Structure (2)

- Deformable Models
  - Deformable Models for Image Segmentation
    - Geometry + Image Processing
  - Deformable Models for Surgery Simulation
    - Geometry + Physics
Medical Imagery

- Medical Imaging is being used in all stages of medical practice:
  - Diagnosis
  - Therapy planning
  - Therapy control
Medical Imagery (2)

- Medical images are not optimally used:
  - 2D and partial Visualization
  - Few or no quantitative evaluations
  - Important expertise for interpreting images

Medical Imagery (3)

- The trends in medical imagery:
  - Better image quality
    - Less artefacts, better contrast
  - Better acquisition speed
    - 4D Imagery and less artefacts in 3D images
  - Better image resolution
    - More detailed and larger images
Medical Imagery (4)

- Require computerised tools

But... Take into account possible software failure
- Medical expert supervision

Classes of Generic Problems

1. Enhancement 2. Visualization
5. Registration 6. Statistics
7. Motion 8. Simulation
...

260600  Hervé Delingette  -  Epidaure
Medical Image Segmentation

Necessary stage for a quantitative evaluation of medical images.

- Input Image
- Segmentation
- Boundary Representation
- Region Representation

Medical Image Segmentation (2)

- Intensity Information
- Position Information
- Shape Information
- Motion Information

Extract
Combine
Comparison between segmentation methods

<table>
<thead>
<tr>
<th></th>
<th>Thresholding/Classification</th>
<th>Deformable Models</th>
<th>Markov Random Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape Information</td>
<td>None</td>
<td>Important</td>
<td>local</td>
</tr>
<tr>
<td>Intensity Information</td>
<td>Essential</td>
<td>Important</td>
<td>Important</td>
</tr>
<tr>
<td>Boundary/Region</td>
<td>Region</td>
<td>Boundary</td>
<td>Region</td>
</tr>
</tbody>
</table>

Deformable Model Image Segmentation:

• Framework for combining “a priori” information of different nature with a strong shape information.
### Medical Image Segmentation (1)

**• Previous Approach**

<table>
<thead>
<tr>
<th>Highly contrasted Images</th>
<th>Less contrasted Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thresholding + Mathematical Morphology</td>
<td>Manual Delineation</td>
</tr>
</tbody>
</table>

1) Slice by slice approaches
2) Tedious work

**• Current Approach**

<table>
<thead>
<tr>
<th>Highly contrasted Images</th>
<th>Less contrasted Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thresholding + Morphology + Isosurfaces + Mesh Decimation</td>
<td>Deformable Models</td>
</tr>
</tbody>
</table>

1) Volumetric Approach
2) Interactive work
Less Contrasted Images (1)

- Thresholding approaches cannot be used
- Example: kidney images

<table>
<thead>
<tr>
<th>Original Slice</th>
<th>Low Threshold</th>
<th>High Threshold</th>
<th>Gradient</th>
</tr>
</thead>
</table>

Deformable Models

- 2 main ideas:
  - Use of a priori information about the geometric nature of anatomical structures to delineate
  - Definition of structure boundaries based on intensity and intensity variation information
Deformable model based segmentation

Deformable Models

• Nature of geometrical models

• A priori Information:
  1) Geometric Information
     Weak Hypothesys: surface smoothness
     Strong Hypothesys: surface shape
  2) Grey-level intensity around the object boundary

• 4D Deformable Models
Deformable Models

• 3 different aspects of deformable models

- Physics
- Geometry
- Topology

• Each aspect should be as independent as possible

Surface Deformation (1)

• In general controlled the minimization of an energy term $E_{total}$

• Two “almost” equivalent framework
  • Mechanical Framework
    $$E_{total} = E_{internal} + E_{external}$$
  • Bayesian Framework
    $$P(S | I) = \frac{P(I | S) P(S)}{P(I)}$$
Surface Deformation (2)

- The internal term $E_{\text{internal}}$ is either linked to:
  - “intrinsic” surface geometry to enforce different levels of smoothness (not linked to parametrization)
  - a given a priori “shape” geometry
  - $E_{\text{internal}}$ must be invariant to rotation, translation and scale

Deformable Model Geometry

- Two ways of deforming a shape:
  - Deformation in object space
  - Deformation in Euclidean space
Deformable Model Geometry

- A deformable model can be described by:
  - Shape parameters for instance the axis of a deformable ellipsoid.
  - Deformation parameters for instance the 12 parameters of an affine transformation.
- Two extreme cases:
  - No shape parameters: registration framework
  - No deformation parameters: deformable model framework.

Deformable Model Geometry (3)
Deformable Model Geometry (2)

- Discrete versus Continuous representation
  - Discrete representation when at most a C0 continuity is available
  - Continuous representation where it is possible to estimate differential parameters (normal, curvature,...) almost everywhere on the model.

Deformable Model Geometry (3)

- Explicit vs Implicit Representations

<table>
<thead>
<tr>
<th></th>
<th>Explicit Representation</th>
<th>Implicit Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framework</td>
<td>Lagrangian</td>
<td>Eulerian</td>
</tr>
<tr>
<td>Efficiency</td>
<td>good</td>
<td>Poor</td>
</tr>
<tr>
<td>Ease of implementation</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Topology Change</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Include Borders</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Interactivity</td>
<td>Good</td>
<td>Poor</td>
</tr>
</tbody>
</table>
Deformable Model Geometry (4)

- Explicit Representations
  - *Polynomial finite support representations*: B-splines, Finite Elements, Finite Differences
    - Local Support of shape functions
  - *Modal decomposition*: Fourier parameters, modal analysis,..
    - Independence of shape parameters

Deformable Model Geometry (5)

- Implicit Representations
  - *Level-set Method*: surface is defined as the zero-crossing of a scalar function \( \psi(x) = 0 \)
    The surface evolves through a reaction-diffusion PDE
  - *Algebraic Surfaces*: surface is defined as \( P(x, y, z) = 0 \) where \( P() \) is a polynomial function.
Discrete Meshes

- **Avantages:**
  - Avoid the parametrisation problem
  - No restriction on topology
  - Limits the number of parameters -> increased efficiency
  - Leads to “intrinsic” deformation

- **Limits:**
  - Geometric information not available everywhere

Discrete Meshes (2)

- **Examples:**
  - Spring-mass models (not necessarily a manifold)
  - Simplex Mesh, Triangulation,...
  - Links with Finite Differences methods on regular lattices
  - Links with Finite element method with C0 shape functions
Discrete contours (1)

- **Topology**
  - A contour is closed or opened
- **Two topological operators**

![Topology Diagram]

Discrete Contours (2)

- **Geometry of planar contours**
  - Tangent and normal vectors

![Tangent and Normal Vector Diagram]

**Tangent**

$$\vec{t}_i = \frac{P_{i+1}P_{i+2}}{|P_{i+1}P_{i+2}|}$$

**Normal**

$$\vec{n}_i = \vec{t}_i$$

**Metrics Parameters**

$$F_j = \varepsilon_j^1 P_{i-1} + \varepsilon_j^2 P_{i+1}$$

$$\varepsilon_j^1 + \varepsilon_j^2 = 1$$
Discrete Contours (3)

- Geometry of planar contours

Conjugated Tangent and Normal

\[ t_i^* \quad n_i^* \]

Definition of discrete curvature

\[ k_i = \frac{1}{R_i} = \frac{\sin \phi_i}{r_i} \]

Discrete Contours (4)

- Local shape description:
  - Metrics parameters: \( \varepsilon_i \)
  - Angle: \( \phi_i \)
  - Fundamental relation

\[ F_i = \varepsilon_i^1 P_{i-1} + \varepsilon_i^2 P_{i+1} + L\left(r_i, |2\varepsilon_i^1 - 1| r_i, \phi_i \right)n_i \]

with

\[ r_i = \frac{||P_{i-1} P_{i+1}||}{2} \]

\[ L(r_i, d_i, \phi_i) = \frac{(r_i^2 - d_i^2) \tan \phi_i}{\sqrt{r_i^2 + (r_i^2 - d_i^2) \tan^2 \phi_i + r_i}} \]
Discrete Contours (5)

- Links with differential geometry

\[ \eta = \arg \left\| P_i P_{i+1} \right\| \rightarrow 0 \]

When \( \eta = \arg \left\| P_i P_{i+1} \right\| \rightarrow 0 \)

Then:
\[ s_i \rightarrow s, \quad k_i \rightarrow k(s), \quad t_i \rightarrow t(s), \quad n_i \rightarrow n(s) \]

But:
\[ t_i \text{ and } n_i \text{ do not converge} \]

Triangulation (1)

- Topology:
  - Triangulation must be a manifold
  - Follow Euler Relation:
    \[ V - E + T = 2(1 - g) - H \]
    where:
    - \( V \) = nb vertices \( E \) = nb edges and \( T \) = nb triangles
    - \( g \) is the genus of the manifold
    - \( H \) is the number of holes
Triangulation (2)

- Topological Operators

- Edge Sharing
- Edge Swap
- Edge Split/Removal

Triangulation (3)

- Non-Eulerian Operator
Triangulation (4)

- Geometric Definitions:
  - Normal at triangles
  - Normal at vertices (several definitions)
  - Spherical Excess at vertices: \( e = 2\pi - \sum \psi_i \)
  - Local Gaussian curvature: \( K_i = \frac{e_i}{A_i} \)
  - Mean curvature on a triangle:
    \[
    \int_{\mathcal{T}} HdA = l_1\theta_1 + l_2\theta_2 + l_3\theta_3
    \]

Triangulation (5)

- Mean Curvature at vertex:
  - Definition through the relationship:
    \[
    \delta(\text{Area}) = H \text{ } \vec{n}
    \]
    \[
    H_i \text{ } \vec{n}_i = \frac{1}{4A} \sum_{j \in N(i)} (\cot \alpha_j + \cot \beta_j)(P_j - P_i)
    \]
Triangulation (6)

- Links with differential geometry

What happens when the maximum size $\eta \to 0$ ?

Triangulation (7)

- In general, no convergence theorem except for the enclosed volume
  - Exemple: even the surface may diverge or converge towards the wrong value
  - However the work of Morvan et al. Has proved that if the triangles do not degenerate

$$\sum_i A_i \to A \quad K_i \to K \quad \sum_i \theta_i \to \int H \, dA$$
Simplex Meshes (1)

- Topology
- Follow Euler Relation:
  \[ V - E + F = 2(1 - \gamma) \]

Simplex Meshes (2)

- Topological Operators
  - Edge Swap
  - Edge Split/Removal
Simplex Meshes (3)

• Non-Eulerian Operator

Simplex Meshes (4)

• Geometric Definitions:
  • Normal at vertices

  Normal

\[ \vec{n}_1 = (P_{N_1(i)}, P_{N_2(i)}, P_{N_3(i)})^\perp \]

Metrics Parameters

\[ F_i = \varepsilon_i^1 P_{N_1(i)} + \varepsilon_i^2 P_{N_2(i)} + \varepsilon_i^3 P_{N_3(i)} \]

\[ \varepsilon_i^1 + \varepsilon_i^2 + \varepsilon_i^3 = 1 \]
Simplex Meshes (5)

• Definition of curvature

\[ \mathbf{n}_i \]

Conjugated Normal

Simplex Angle

\[ \phi_i \]

Definition of discrete curvature

\[ H_i = \frac{1}{R_i} = \frac{\sin \phi_i}{r_i} \]

Simplex Meshes (6)

• Property of the simplex mesh :
  • Sine Theorem
  • Half-angle property
  • Criterion for Delaunay Tetrahedrisation
Simplex Meshes (7)

• Local shape description:
  • Metrics parameters: $\varepsilon_i$
  • Angle: $\phi_i$

• Fundamental relation:

$$F_i = \varepsilon_i^1 P_{N_1(i)} + \varepsilon_i^2 P_{N_2(i)} + \varepsilon_i^3 P_{N_3(i)} + L(r_i, |2\varepsilon_i^1 - 1|r_i, \phi_i)\overrightarrow{n_i}$$

Simplex Meshes (8)

• Links with differential geometry

What happens when the maximum size $\eta \rightarrow 0$?
Simplex Meshes (9)

- Result concerning $H_i$
  - Property of the minimal sphere
  - Convergence theorem:

$$H_i \rightarrow H + (k_1 - k_2) \frac{a}{b}$$

$$a = \begin{vmatrix} \cos \theta_1 & \sin \theta_1 & v_1 \cos \theta_1 \\ \cos \theta_2 & \sin \theta_2 & v_2 \cos \theta_2 \\ \cos \theta_3 & \sin \theta_3 & v_3 \cos \theta_3 \end{vmatrix} = \begin{vmatrix} \cos \theta_1 & \sin \theta_1 & v_1 \\ \cos \theta_2 & \sin \theta_2 & v_2 \\ \cos \theta_3 & \sin \theta_3 & v_3 \end{vmatrix}$$

Deformable Models

- Nature of geometrical models
  1) Deformable Contours
  2) Deformable Surfaces

- A priori Information:
  1) Information géométrique de la surface
     Hypothèse faible : régularité de la surface
     Hypothèse forte : forme a priori de la surface
  2) Niveau de gris de la région dans l’image

- Modèles déformables 4D
Regularisation of Simplex Meshes

Local forces
- internal (regularization) \( f_{\text{int}} \)
- external (data) \( f_{\text{ext}} \)

Newtonian motion law

\[
m \frac{d^2 \mathbf{p}_i}{dt^2} = -\gamma \frac{d \mathbf{p}_i}{dt} + f_{\text{int}} (\mathbf{p}_i) + f_{\text{ext}} (\mathbf{p}_i)
\]

Discretization:
- Explicit
- Semi-Implicit

Discretization:
- Full Explicit Scheme:

\[
\mathbf{p}_i^{t+1} = \mathbf{p}_i^t + (1 - \gamma)(\mathbf{p}_i^t - \mathbf{p}_i^{t-1}) + \alpha_i f_{\text{int}} (\mathbf{p}_i^t) + \beta_i f_{\text{ext}} (\mathbf{p}_i^t)
\]

\[
\alpha_i \in \left[0, \frac{1}{2}\right] \quad \beta_i \in [0,1]
\]

- Explicit Scheme:

\[
\mathbf{p}_i^{t+1} = \frac{(3 - \gamma) \mathbf{p}_i^t - \mathbf{p}_i^{t-1} + \alpha_i f_{\text{int}} (\mathbf{p}_i^t) + \beta_i f_{\text{ext}} (\mathbf{p}_i^t)}{2 - \gamma}
\]
Internal force $f_{\text{int}}$

Decouple:
- Shape Regularisation
- Vertex Spacing Control

$2\frac{d^2\mathbf{p}_i}{dt^2} = -\gamma_i \frac{d\mathbf{p}_i}{dt} + f_{\text{int}}(\mathbf{p}_i) + f_{\text{ext}}(\mathbf{p}_i)$

$\tilde{\varepsilon}_i = \frac{1}{2}$  \hspace{1cm} Metric diffusion

$\tilde{\varepsilon}_i = \frac{1}{2} - 0.4 \Delta \kappa_i$  \hspace{1cm} Metric depending on curvature

Vertex spacing control based on metric parameters:
- Make vertices evenly spaced
- Make vertices concentrate at curved parts
Surface regularization \( f_{nr} \)

\[
m_i \frac{d^2 \mathbf{p}_i}{dt^2} = -\gamma_i \frac{d \mathbf{p}_i}{dt} + f_{int}(\mathbf{p}_i) + f_{ext}(\mathbf{p}_i)
\]

- Two main ideas for surface smoothing:
  - A priori shape information: "smooth around the shape"
  - Geometric regularity constraint with different level of continuity: \( C^0, C^1, C^2, \ldots \)

- Choice of \( \phi_i^* \) depends on the type of regularity:
  - Shape: \( \phi_i^* = \phi_i^0 \)
  - \( C^0: \ f_{nr} = 0 \)
  - \( C^1: \ \phi_i^* = 0 \)
  - \( C^2: \ \phi_i^* = \sum_{j \in \text{Ngh}(i)} \phi_j / \text{Size}(\text{Ngh}(i)) \)
  - \( G^2: \ \phi_i^* = \arcsin \left( \sum_{j \in \text{Ngh}(i)} H_{ij} \frac{1}{\text{Size}(\text{Ngh}(i))} \right) \)
Surface regularization (3)

1) Position Continuity
2) Orientation Continuity
3) Curvature Continuity

- Choice of rigidity parameters
  - Rigidity = 0
  - Rigidity = 1
  - Rigidity = 2

Surface regularization (4)

- Typical problem: lack of robustness due to local minima:
  Use a “Coarse To Fine” approach

- Two concerns:
  - efficiency
  - simplicity of implementation
Registration

Iterative Closest Point (ICP) [Besl, McKay 92]

\[ T = \arg \min_{T \in T_{\text{reg}}} \sum \| T(p_i) - \text{Closest}(p_i) \|^2 \]

Registration (2)

<table>
<thead>
<tr>
<th>( T_{\text{reg}} )</th>
<th>resolution method</th>
<th>degree of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>rigid</td>
<td>explicit</td>
<td>6</td>
</tr>
<tr>
<td>similarity</td>
<td>explicit</td>
<td>7</td>
</tr>
<tr>
<td>affine</td>
<td>explicit</td>
<td>12</td>
</tr>
<tr>
<td>B-spline</td>
<td>Gradient descent</td>
<td>3n</td>
</tr>
<tr>
<td>PCA</td>
<td>Projection</td>
<td>3mN</td>
</tr>
<tr>
<td>Axial Symmetry</td>
<td>Projection</td>
<td>3v</td>
</tr>
</tbody>
</table>
Model registration

Closest point computation

Closest \( (p_i) = p_i + \beta_i f_{\text{ext}}(p_i) \)

Example:

![Data](image1)

![Model](image2)

affine registration

Global constraint

Local forces:

\[
m_i \frac{d^2 p_i}{dt^2} = -\gamma_i \frac{dp_i}{dt} + f_{\text{int}}(p_i) + f_{\text{ext}}(p_i)
\]

Global force:

\[
f_{\text{global}}(p_i) = T(p_i) - p_i
\]

Globally constrained deformation

\[
m_i \frac{d^2 p_i}{dt^2} = -\gamma_i \frac{dp_i}{dt} + \lambda \left( f_{\text{int}}(p_i) + f_{\text{ext}}(p_i) \right) + (1-\lambda) f_{\text{global}}(p_i^t)
\]

locality
Local perturbation response

\[ \lambda = 100\% \quad \lambda = 50\% \quad \lambda = 0\% \]

With an affine constraint

Iterative convergence

[Blake et Zisserman 87], [Vemuri et Radislavljevic 94], [Cohen et Gorre 95]

\[ \lambda = 0 \quad 0 < \lambda < 1 \quad \lambda = 1 \]

global \quad global \quad local
rigid \rightarrow \text{similarity} \rightarrow \text{affine} \rightarrow \text{contraint}
**Local to global scheme**

- **rigid** → **similarity** → **affine** → **local**

**Deformable Surfaces**

- Possibility to refine and decimate simplex meshes based on curvature, face area, face elongation
- Possibility of global refinement

Leads to multi-resolution similarly to subdivision surfaces
Topology

Intersection detection (in 2D)

Grid approximation

Cell by cell detection

Examples

Two components splitting

Opened and closed contours
Comparison with level-sets [Sethian 96]

Level sets

\[ v(p) = \beta(p)(\kappa(p) + c) \]

Discrete contour

\[ f_{\text{int}}(p) \quad f_{\text{ext}}(p) = \beta(p)c n \]

Real time: 3.3 s

Real time: 0.42 s

External forces \( f_{\text{ext}} \)

\[ m_i \frac{d^2 p_i}{dt^2} = -\gamma_i \frac{dp_i}{dt} + f_{\text{int}}(p_i) + f_{\text{ext}}(p_i) \]

Force computation as a function of the distance to the closest boundary points:

- No oscillations
- Speed-up convergence
**External forces** $f_{\text{ext}}$

Deformation oriented along the vertex normal direction

- Geometry conservation
- Independent from vertex spacing

$$f_{\text{ext}}(p_i) = \left( \left( \text{Closest}(p_i) - p_i \right) \cdot n_i \right) n_i$$

---

**Line scanning algorithm**

Boundary search points on the model normal line

- Normal discretization
- Low cost

Image geometry
Gradient criterion

[Cohen et al 92], [McInerney et Terzopoulos 93], [Lötjönen et al 99]

Image gradient \( \| \nabla I \| \)
Low contrasted images (CT, MRI)

- range of the line scanning
- variation of the intensity
\[ \| \nabla I \| > s \]
- direction of the gradient consistent with normal direction
\[ \nabla I(\text{Closest}(p_i)) \cdot n_i > 0 \]

Segmentation: endocrane

Image scanner, structures osseuses

Temps de convergence: 13.8 s
modèle: \( 1169 \text{ cm}^3 \)
moulage: \( 1150 \text{ cm}^3 \)
Segmentation: foie

Image scanner de l'IRCAD, extraction du foie

Temps de convergence: 2 mn 12 s
Extraction des segments de Couinaud
Region criterion

[Ronfard 94], [zhu 94]

Noisy images: weak gradient response

Differential signal (US)

Gradient filtering by region information

\[ \nabla \text{gradient normal direction} + \text{anisotropic filtering of intensity} \]

Segmentation: heart

US image
Small bright regions

Convergence time: 28 s
Iconic approach
[Maes et al 97, Roche et al 98, Penney et al 98]

Reference intensity profile

Recalage multimodal CT-IRM T1
Modèles déformables

• Nature des modèles géométriques
  1) Contours déformables
  2) Surfaces déformables

• Informations a priori :
  1) Information géométrique de la surface
     Hypothèse faible : régularité de la surface
     Hypothèse forte : forme a priori de la surface
  2) Niveau de gris de la région dans l’image

• Modèles déformables 4D
4D simplex mesh

Trajectory of each vertex

Time regularization

Time force

Global constraint

\[ T = \arg \min_{T_{\text{reg}}} \sum_{i,t} ||T(p_{i,t}) - \text{Closest}(p_{i,t})||^2 \]

\[ m_i \frac{d^2 p_{i,t}}{dt^2} = -\gamma_i \frac{dp_{i,t}}{dt} + f_{\text{int}}(p_{i,t}) + f_{\text{ext}}(p_{i,t}) + f_{\text{time}}(p_{i,t}) \]

\[ m_i \frac{d^2 p_{i,t}}{dt^2} = -\gamma_i \frac{dp_{i,t}}{dt} + \lambda (f_{\text{int}}(p_{i,t}) + f_{\text{ext}}(p_{i,t}) + f_{\text{time}}(p_{i,t})) + (1 - \lambda) f_{\text{global}}(p_{i,t}) \]
Time smoothing

\[ \tilde{p}_{i,t} = \frac{p_{i,t+1} + p_{i,t-1}}{2} \]

Local perturbation

Trajectory memory

4D reference shape \( \{\varepsilon_{i,t}, \varphi_{i,t}, \psi_{i,t}\}_{i,t} \)
Segmentation 4D: SPECT
8 instant sequences
Reference model built by 3D image segmentation

End of diastole  End of systole

Convergence time: 56 seconds

Deformed model
Pathological case
Segmentation: MRI

Deformed 4D model

Model intersection with image

3D Ultrasound Images

- Cylindrical geometry of image acquisition

- 3D+T Imaging Systems
  - ATL Corporation (courtesy of G. Schwartz)
  - Echocardi3D (courtesy of M-O. Berger)
  - HP Corporation (courtesy of A. Noble)
Segmentation: US

4D sequence with a cylindrical geometry

9 planes per 3D image, 8 instants

Result

Deformed model intersection with image
3D Reconstruction (2)

• Synthetic Example:

Reconstruction 3D

• Exemple:
Reconstruction 4-D Ultrasound

Collaboration ATL

2D+T Reconstruction

2D+T Image Formation → 2D+T Surface Fitting → 3D Surface Fitting
2D+T Reconstruction (2)

- Example: Ventriculography (courtesy of CCM)

2D+T Reconstruction (3)
Conclusion

• Promising approach since:
  • Fairly fast
  • Suited for user interaction
  • Suited for incorporating various a priori information about shape, grey-level intensity, topology,..
  • Can be used for various image modalities, with various image resolution, geometry.

Conclusion (2)

• Future developments:
  • Improved robustness for initialization:
    • Use of complementary approaches (registration of atlases,...) for finding an initial estimate
  • Incorporate more a priori knowledge:
    • Use of statistical methods for acquiring relevant a priori information
  • Improved user interface suited for each segmentation tasks:
    • Use of complex software development for combining interface and computational procedures.