Surgery Simulation

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INRIA
Epidaure

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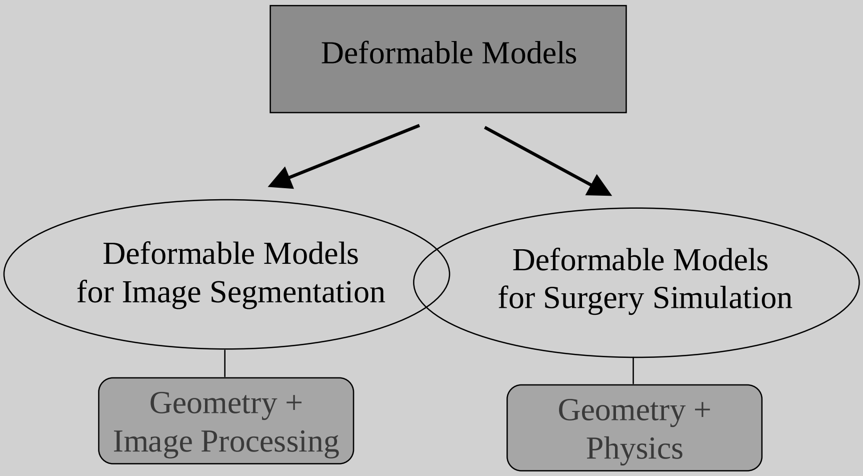
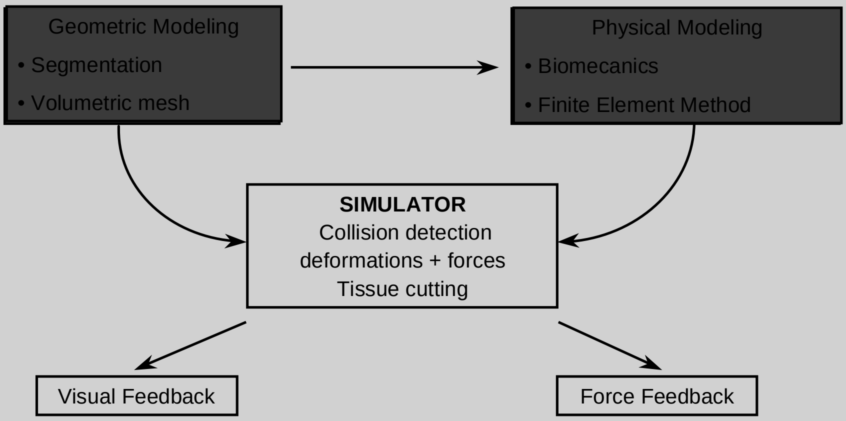
  - X. Pennec
- PhD Students :
  - J. Montagnat
  - G. Picinbonno
  - C. Forest

Lecture Structure (2)



Lecture Structure



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 :

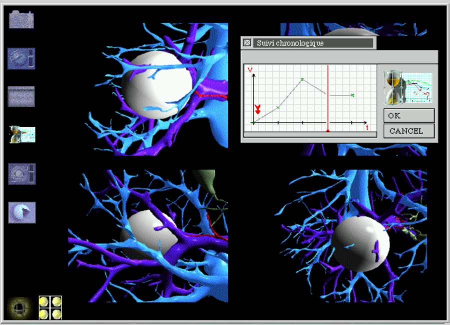
- 2D and partial Visualization
- Few or no quantitative evaluations
- Important expertise for interpreting images

Medical Imagery (3)

- The trends in medical imagery :
  - Better image quality
    - → Less artefacts, better contrast
  - Better acquisition speed
    - → 4D Imagery and less arterfacts 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

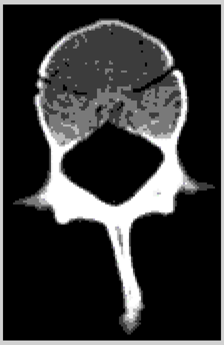
Classes of *Generic* Problems

1. Enhancement
2. Visualization
3. Segmentation
4. Compression
5. Registration
6. Statistics
7. Motion
8. Simulation

...

Medical Image Segmentation

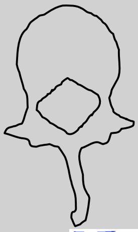
Necessary stage for a quantitative evaluation of medical images.



Input Image

Segmentation

Region Representation



Boundary Representation

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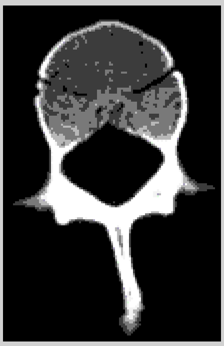
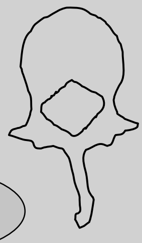
Medical Image Segmentation (2)



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



Extract

Combine

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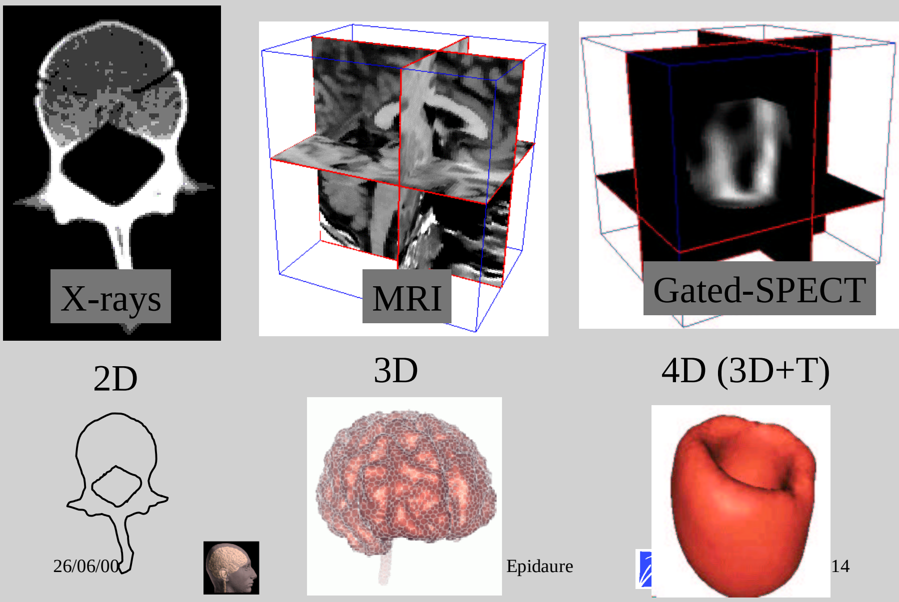
Comparison between segmentation methods

	Thresholding /Classification	Deformable Models	Markov Random Field
Shape Information	None	Important	local
Intensity Information	Essential	Important	Important
Boundary / Region	Region	Boundary	Region

Deformable Model Image Segmentation:

•Framework for combining “a priori” information of different nature with a strong shape information.

Deformable model segmentation



Medical Image Segmentation (1)

- Previous Approach

Highly contrasted Images	Less contrasted Images
Thresholding + Mathematical Morphology	Manual Delineation

1) Slice by slice approaches
2) Tedious work

Medical Image Segmentation (1)

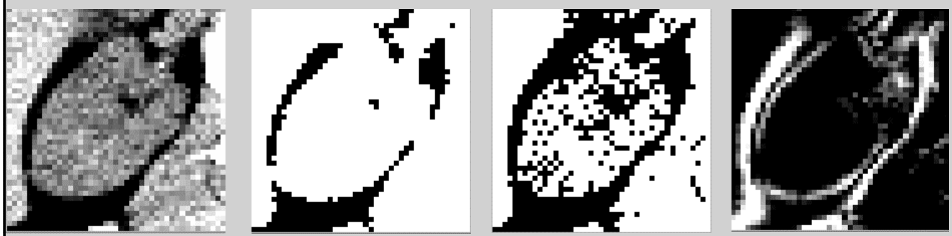
- Current Approach

Highly contrasted Images	Less contrasted Images
Thresholding + Morphology+Isosurfaces + Mesh Decimation	Deformable Models

1) Volumetric Approach
2) Interactive Work

Less Contrasted Images (1)

- Thresholding approaches cannot be used
- Example : kidney images

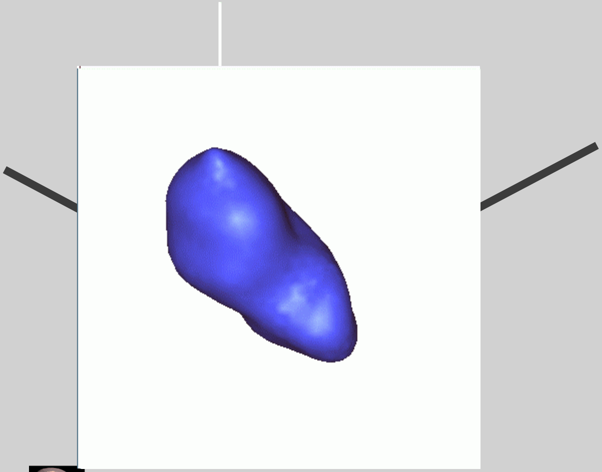


Original Slice Low Threshold High Threshold Gradient

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

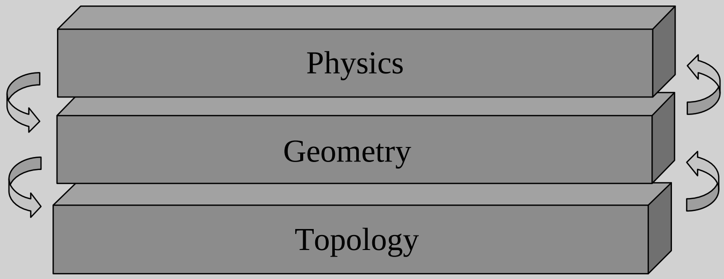


Deformable Models

- 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



- 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

$$E_{\text{total}} = E_{\text{internal}} + E_{\text{external}}$$

  - Bayesian Framework

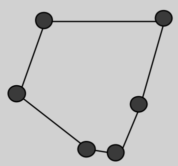
$$P(S \mid I) = \frac{P(I \mid S)\, P(S)}{P(I)}$$

Surface Deformation (2)

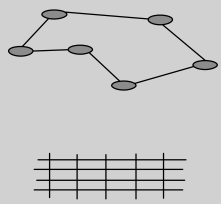
- The internal term $E_{internal}$ is either linked to :
  - “intrinsic” surface geometry to enforce different levels of smoothness (not linked to parametrization)
  - a given a priori “ shape” geometry
- $E_{internal}$ must be invariant to rotation, translation and scale

Deformable Model Geometry

- Two ways of deforming a shape :



Deformation in object space

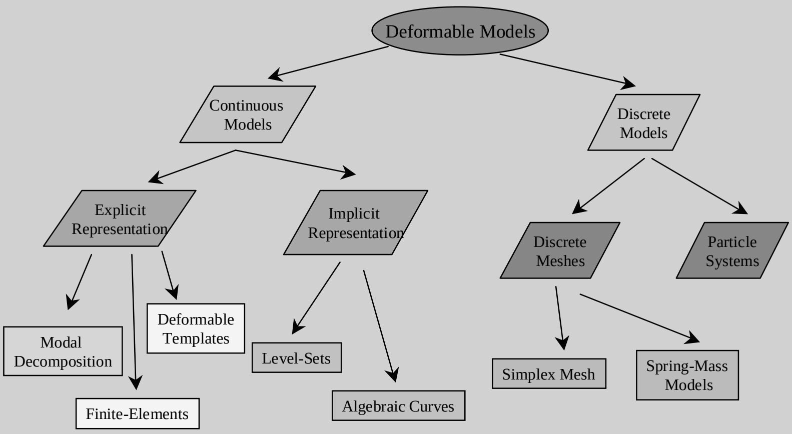


Deformation in Euclidean space

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

	Explicit Representation	Implicit Representation
Framework	Lagrangian	Eulerian
Efficiency	good	Poor
Ease of implementation	good	good
Topology Change	No	Yes
Include Borders	Yes	No
Interactivity	Good	Poor

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

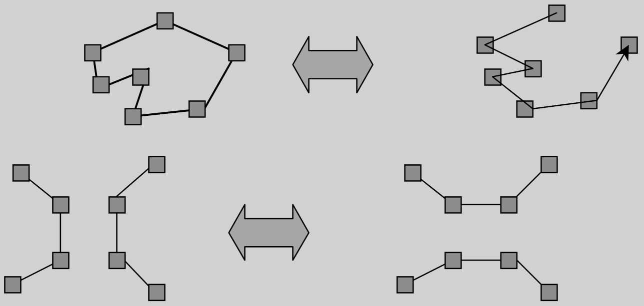
- Avantages :
  - Avoid the parametrisation problem
  - No restriction on topology
  - Limits the number of parameters -> increased efficiency
  - Leads to “intrinsic”deformation
- Limits :
  - Geometric information not available everywhere

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

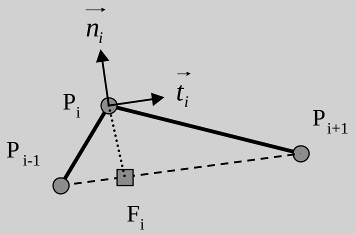
Discrete contours (1)

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



Discrete Contours (2)

- Geometry of planar contours
  - Tangent and normal vectors



Tangent

$$\vec{t}_i = \frac{P_{i-1}P_{i+1}}{\left\| P_{i-1}P_{i+1} \right\|}$$

Normal

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

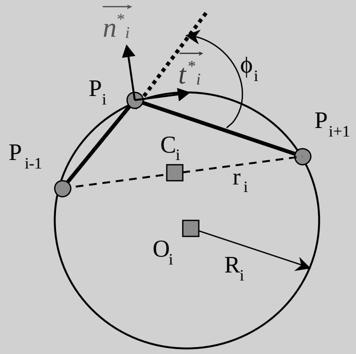
Metrics Parameters

$$F_i = \varepsilon_i^1 P_{i-1} + \varepsilon_i^2 P_{i+1}$$

$$\varepsilon_i^1 + \varepsilon_i^2 = 1$$

Discrete Contours (3)

- Geometry of planar contours



Conjugated Tangent and Normal

$$\vec{t}^{\,*}_{i} \qquad \vec{n}^{\,*}_{i}$$

Definition of discrete curvature

$$k_i = \frac{1}{R_i} = \frac{\sin \phi_i}{r_i}$$

Discrete Contours (4)

- Local shape description :
  - Metrics parameters : ε_i
  - Angle : ϕ_i
- Fundamental relation

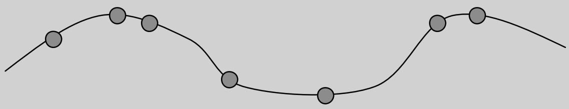
$$F_i = \varepsilon_i^1 P_{i-1} + \varepsilon_i^2 P_{i+1} + L\left(r_i, \left|2\varepsilon_i^1 - 1\right| r_i, \phi_i\right)\vec{n_i}$$

with

$$r_i = \frac{\left\|P_{i-1}P_{i+1}\right\|}{2} \qquad L(r_i, d_i, \phi_i) = \frac{(r_i^2 - d_i^2)\tan \phi_i}{\sqrt{r_i^2 + (r_i^2 - d_i^2)\tan^2 \phi} + r_i}$$

Discrete Contours (5)

- Links with differential geometry



When $\eta = \arg_i \| P_i P_{i+1} \| \to 0$

Then : $s_i \to s$ $\quad k_i \to k(s)$ $\quad \overrightarrow{t^*_i} \to \overrightarrow{t(s)}$ $\quad \overrightarrow{n^*_i} \to \overrightarrow{n(s)}$

But : $\overrightarrow{t_i}$ and $\overrightarrow{n_i}$ do not converge

Triangulation(1)

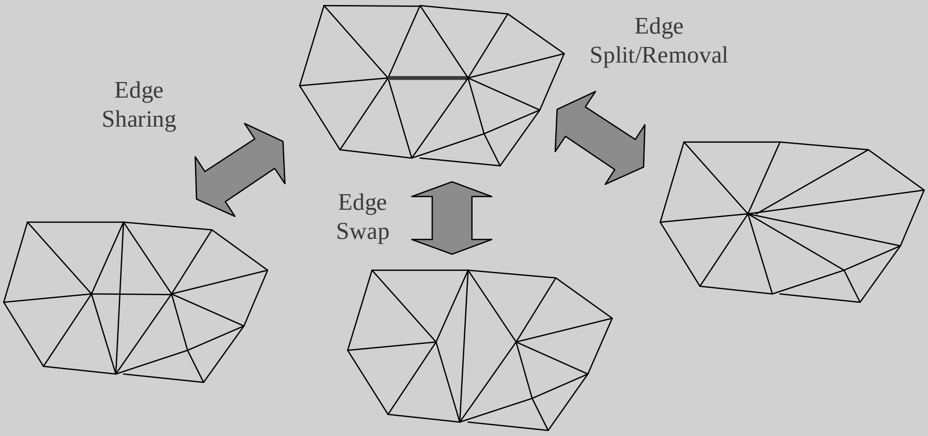
- Topology :
  - Triangulation must be a manifold
  - Follow Euler Relation :

  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

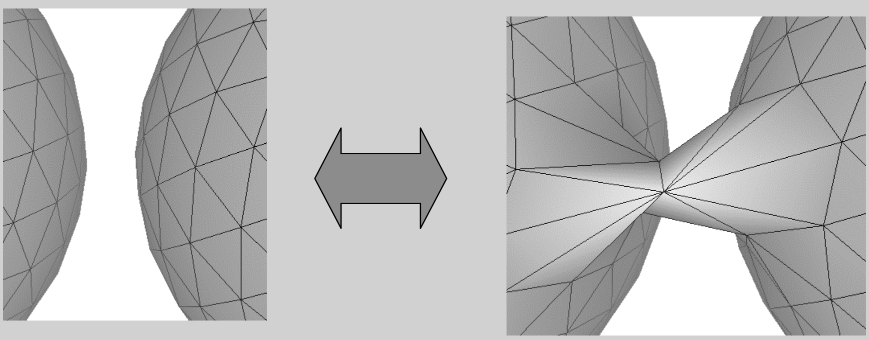
Triangulation(2)

- Topological Operators



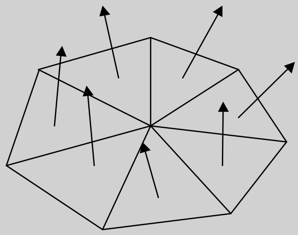
Triangulation (3)

- Non-Eulerian Operator



Triangulation (4)

- Geometric Definitions :
  - Normal at triangles
  - Normal at vertices (several definitions)
  - Spherical Excess at vertices : $e = 2\pi - \sum_i \psi_i$
  - Local Gaussian curvature : $K_i = \frac{e}{\sum_i A_i}$
  - Mean curvature on a triangle :



$$\iint_{Tr} H dA = l_1\theta_1 + l_2\theta_2 + l_3\theta_3$$

Triangulation (5)

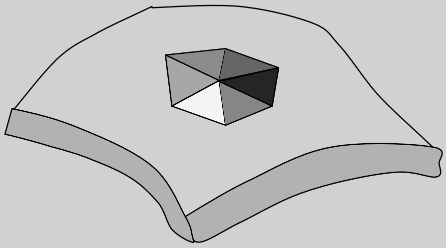
- Mean Curvature at vertex :
  - Definition through the relationship :

$$\delta(Area) = H\,\vec{n}$$

$$H_i\,\vec{n}_i = \frac{1}{4A} \sum_{j \in N(i)} (\cot\alpha_j + \cot\beta_j)(P_i - P_j)$$

Triangulation (6)

- Links with differential geometry



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

Triangulation (7)

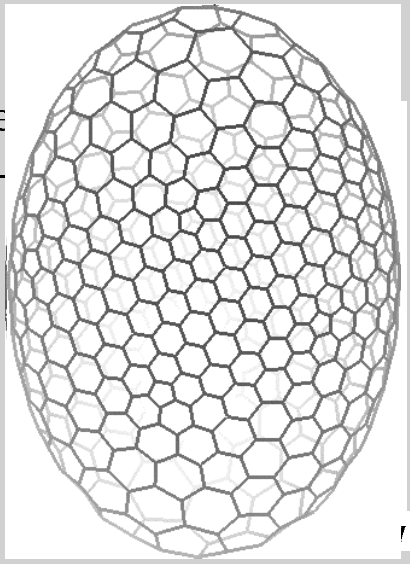
- In general, no convergence theorem except for the enclosed volume
  - Exemple : even the surface may diverge or converge towards the wrong value
- However the work of Morvan et al. Has proved that if the triangles do not degenerate

$$\sum_i A_i \to A \qquad K_i \to K \qquad \sum l_i \theta_i \to \iint_S H \, dA$$

Simplex Meshes (1)

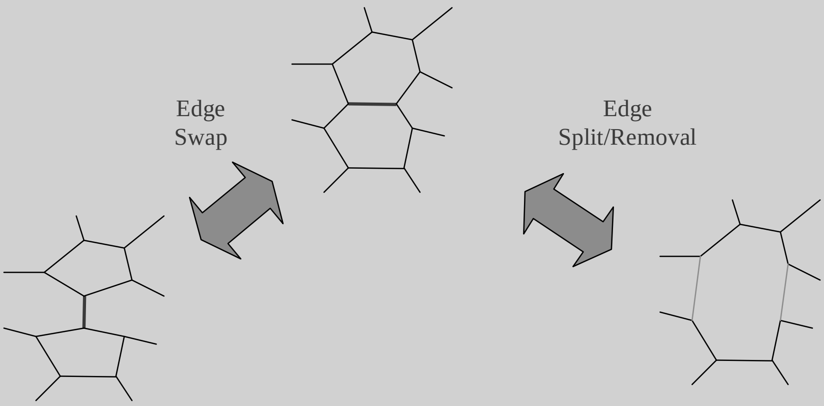
- Topology
- Follow Eule

V-E+F= 2(1-



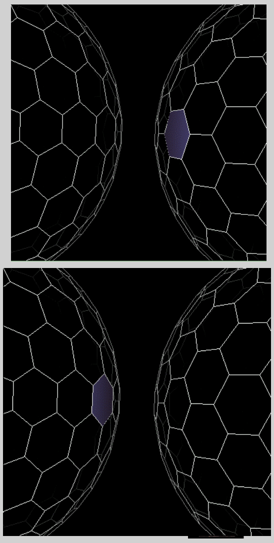
Simplex Meshes (2)

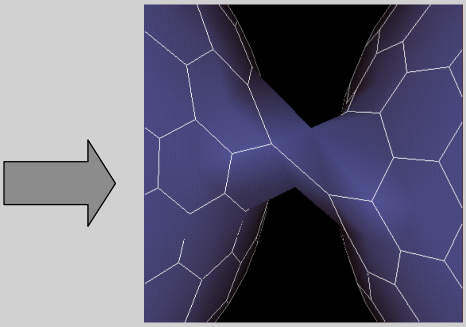
- Topological Operators



Simplex Meshes (3)

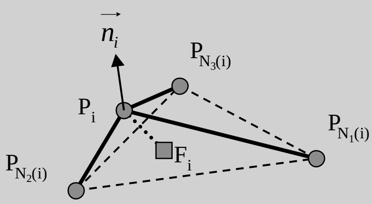
- Non-Eulerian Operator





Simplex Meshes (4)

- Geometric Definitions :
  - Normal at vertices



Normal

$$\vec{n_i} = (P_{N_1(i)}, P_{N_2(i)}, P_{N_3(i)})^{\perp}$$

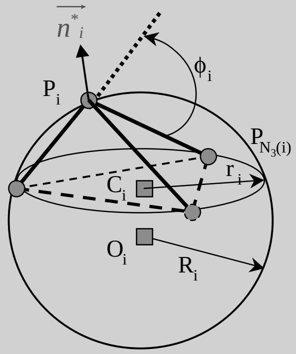
Metrics Parameters

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

$$\varepsilon_i^1 + \varepsilon_i^2 + \varepsilon_i^3 = 1$$

Simplex Meshes (5)

- Definition of curvature



Conjugated Normal — $\overrightarrow{n^*_i}$

Simplex Angle — ϕ_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

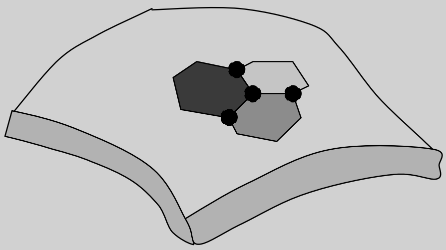
Simplex Meshes (7)

- Local shape description :
  - Metrics parameters : ε_i
  - Angle : ϕ_i
- Fundamental relation :

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

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:

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

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

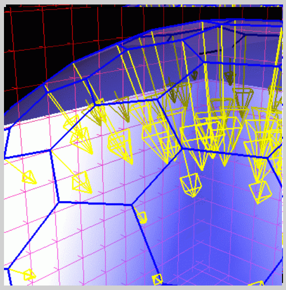
Deformable Models

- 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_{int}
- external (data) f_{ext}



Newtonian motion law

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

Discretization :

•Explicit

•Semi-Implicit

Regularisation of Simplex Meshes (2)

- Full Explicit Scheme :

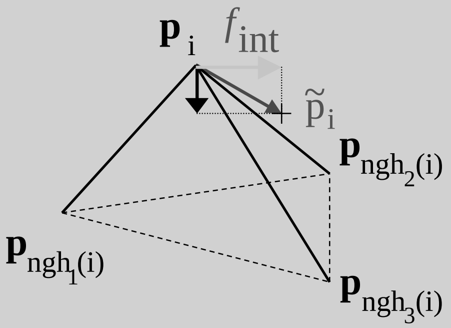
$$\mathbf{p}_i^{t+1} = \mathbf{p}_i^t + (1-\gamma)(\mathbf{p}_i^t - \mathbf{p}_i^{t-1}) + \alpha_i f_{int}(\mathbf{p}_i^t) + \beta_i f_{ext}(\mathbf{p}_i^t)$$

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

- Explicit Scheme :

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

Internal force f_{int}



Decouple :

- Shape Regularisation
- Vertex Spacing Control

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

f_{tg}

f_{nr} regularization

Internal force f_{int}

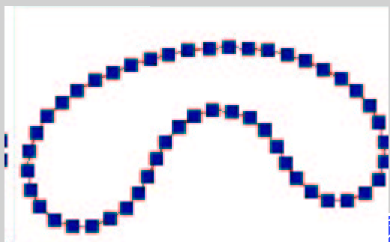
Vertex spacing control based on metric parameters :

- Make vertices evenly spaced

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

- Make vertices concentrate at curved parts

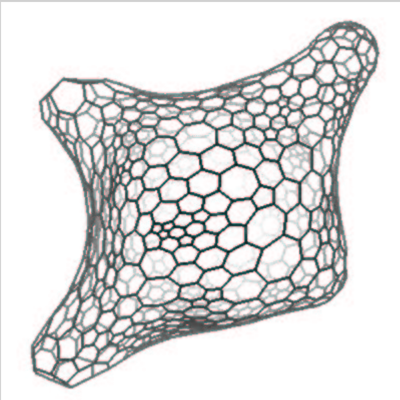
$$\tilde{\varepsilon}_i = \frac{1}{2} - 0.4\,\Delta\,\kappa_i$$ Metric depending on curvature



Surface regularization f_{nr}

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

f_{tg}



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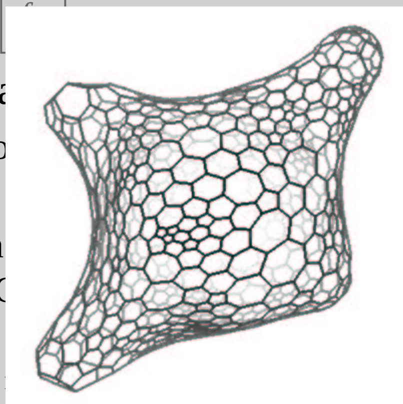

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Surface regularization (2) f_{nr}

$$\overrightarrow{f_{nr}} = \left(L(r_i, d_i, \phi_i^*) - L(r_i, d_i, \phi_i)\right)\vec{n}_i$$

- Choice of ϕ_i^* depends on the type of regularity :
  - Shape : $\phi_i^* = \phi_i^0$
  - C^0 : $\overrightarrow{f_{nr}} = \vec{0}$
  - C^1 : $\phi_i^* = 0$
  - C^2 : $\phi_i^* = \sum_{j \in Ngh(i)} \phi_j / Size(Ngh(i))$
  - G^2 : $\phi_i^* = \arcsin \sum_{j \in Ngh(i)} H_j r_i / Size(Ngh(i))$

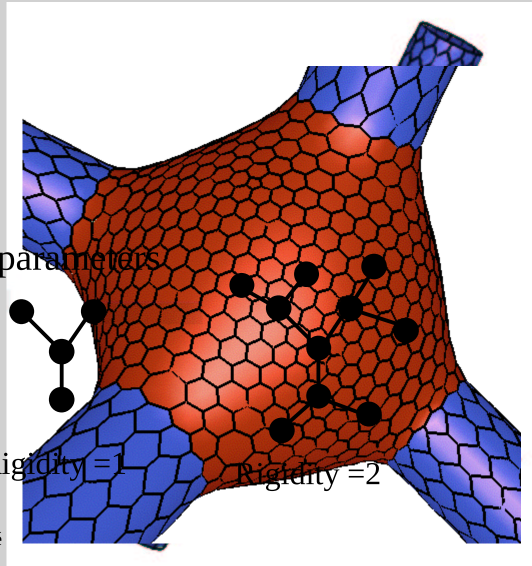
Surface regularization (3)

1) Position Continuity

2) Orientation Continuity

3) Curvature Continuity

- Choice of rigidity parameters



Rigidity =0 Rigidity =1 Rigidity =2

Surface regularization (4)

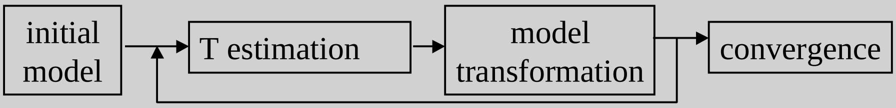
- Typical problem : lack of robustness due to local minima :

⇨ Use a "Coarse To Fine" approach

- Two concerns :
  - efficiency
  - simplicity of implementation

Registration

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



Transformation estimation

$$T = \arg\min_{T \in T_{reg}} \sum_i \left\| T(\mathbf{p}_i) - \text{Closest}(\mathbf{p}_i) \right\|^2$$

Registration (2)

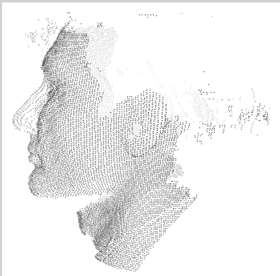
T_{reg}	resolution method	degree of freedom
rigid	explicit	6
similarity	explicit	7
affine	explicit	12
B-spline	Gradient descent	3n
PCA	Projection	3mN
Axial Symmetry	Projection	3v

Model registration

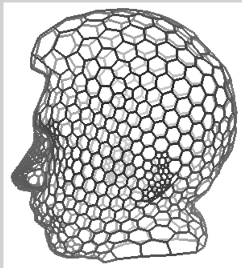
Closest point computation

$$\text{Closest}\ (\mathbf{p}_i) = \mathbf{p}_i + \beta_i f_{ext}(\mathbf{p}_i)$$

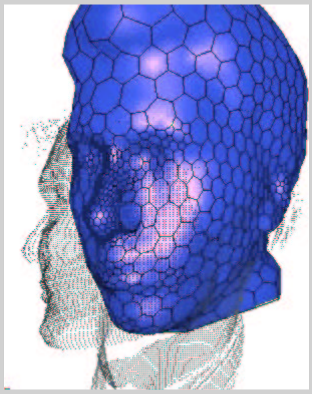
Example :



data



model



affine registration

Global constraint

Local forces : $m_i \dfrac{d^2\mathbf{p}_i}{dt^2} = -\gamma_i \dfrac{d\mathbf{p}_i}{dt} + f_{int}(\mathbf{p}_i) + f_{ext}(\mathbf{p}_i)$

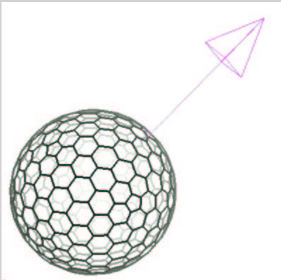
Global force : $f_{global}(\mathbf{p}_i) = \mathrm{T}(\mathbf{p}_i) - \mathbf{p}_i$

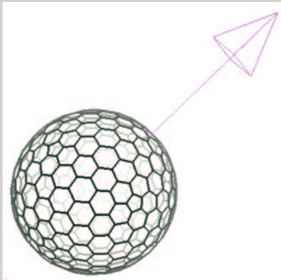
Globally constrained deformation

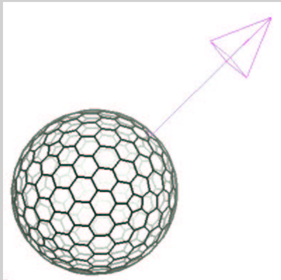
$$m_i \frac{d^2\mathbf{p}_i}{dt^2} = -\gamma_i \frac{d\mathbf{p}_i}{dt} + \lambda\left(f_{int}(\mathbf{p}_i) + f_{ext}(\mathbf{p}_i)\right) + (1-\lambda)\ f_{global}(\mathbf{p}_i^t)$$

locality

Local perturbation response







$\lambda = 100\%$ $\lambda = 50\%$ $\lambda = 0\%$

With an affine constraint

Iterative convergence

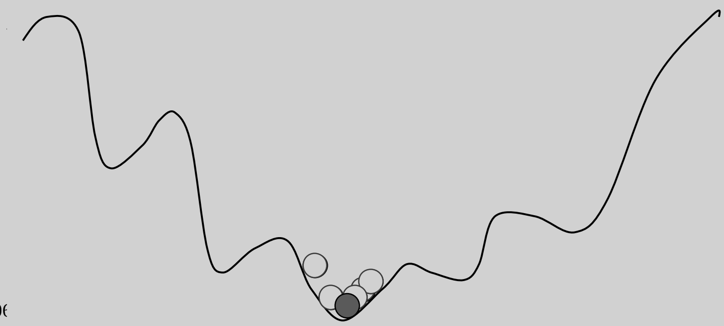
[Blake et Zisserman 87], [Vemuri et Radislavljevic 94], [Cohen et Gorre 95]

$\lambda=0$ ⟶ $0<\lambda<1$ ⟶ $\lambda=1$

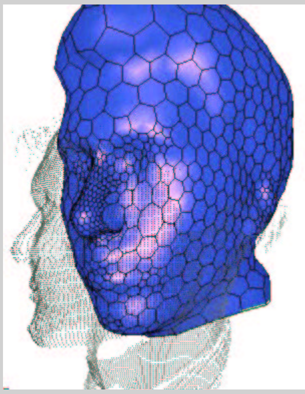
global: rigid → similarity → affine

global contraint

local



Local to global scheme

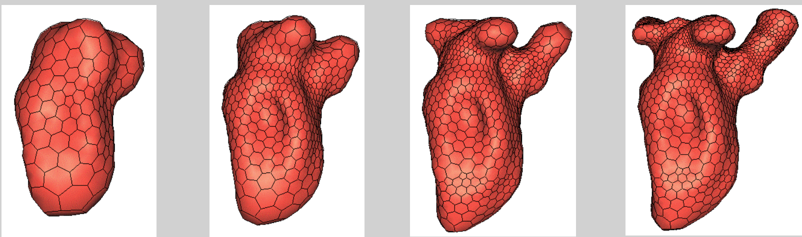


rigid → similarity → affine → local

Deformable Surfaces

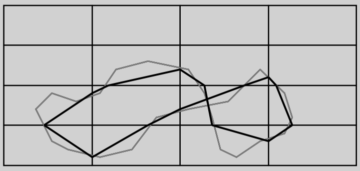
- Possibility to refine and decimate simplex meshes based on curvature, face area, face elongation
- Possibility of global refinement

⇒ Leads to multi-resolution similarly to subdivision surfaces

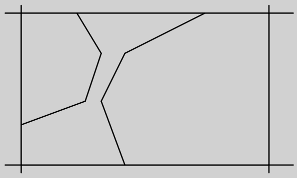


Topology

Intersection detection (in 2D)



Grid approximation



Cell by cell detection

Examples

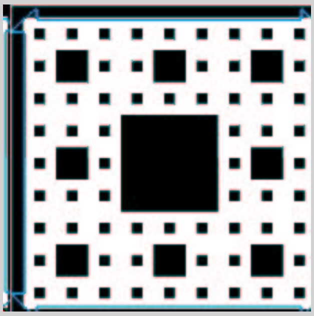
Two components splitting

Opened and closed contours

Comparison with level-sets [Sethian 96]

Level sets

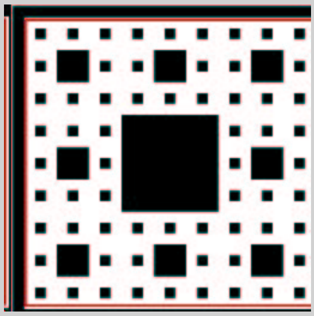
$\upsilon(\mathbf{p}) = \beta(\mathbf{p})(\kappa(\mathbf{p}) + c)$



Real time: 3,3 s

Discrete contour

$f_{\text{int}}(\mathbf{p}) \qquad f_{\text{ext}}(\mathbf{p}) = \beta(\mathbf{p}) c \mathbf{n}$



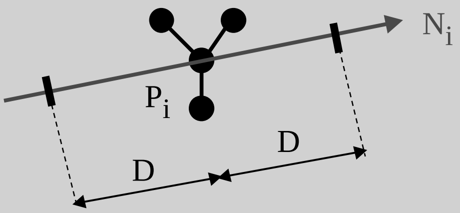
Real time: 0,42 s

External forces f_{ext}

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

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

➔ No oscillations
Speed-up convergence



External forces f_{ext}

Deformation oriented along the vertex normal direction

➔ Geometry conservation

Independent from vertex spacing

$$f_{ext}(\mathbf{p}_i) = \left(\left(\text{Closest}(\mathbf{p}_i) - \mathbf{p}_i\right) \cdot \mathbf{n}_i\right) \mathbf{n}_i$$

Line scanning algorithm

Boundary search points on the model normal line

Normal discretization

Low cost

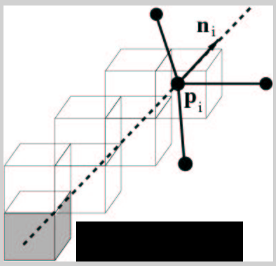
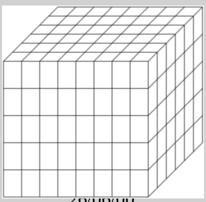
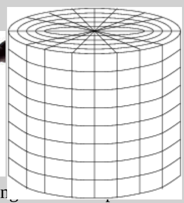
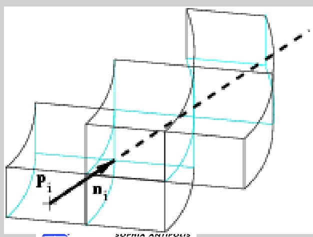


Image geometry







Gradient criterion

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

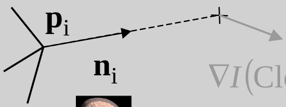
Image gradient $\|\nabla I\|$

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

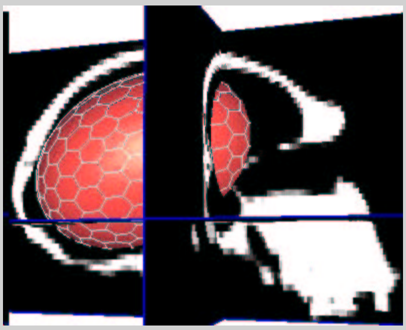


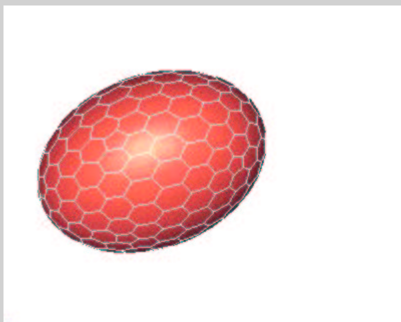
$\nabla I(\text{Closest}(\mathbf{p}_i))\cdot\mathbf{n}_i > 0$

$\nabla I(\text{Closest}(\mathbf{p}_i))$

Segmentation: endocrane

Image scanner, structures osseuses



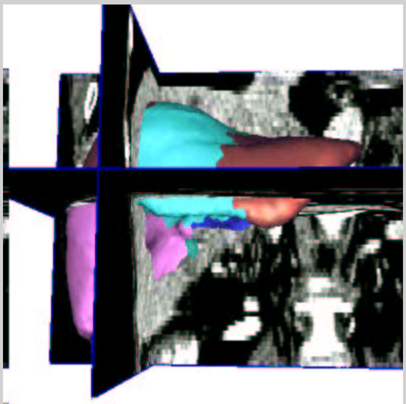


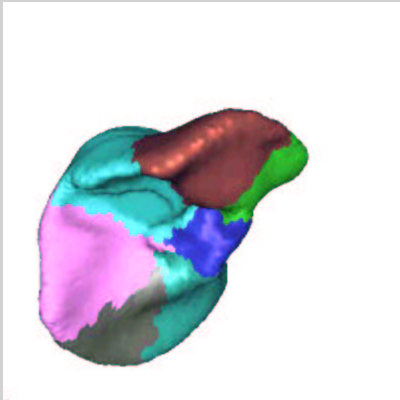
Temps de convergence: 13,8 s

modèle: 1169 cm^3
moulage: 1150 cm^3

Segmentation: foie

Image scanner de l'IRCAD, extraction du foie

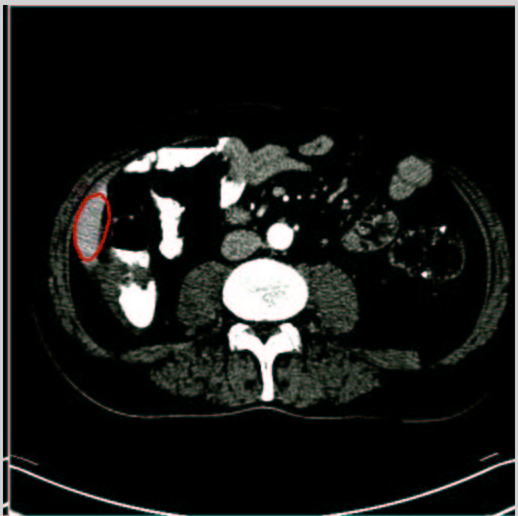




Temps de convergence: 2 mn 12 s

Extraction des segments de Couinaud

Segmentation: foie



Trace du modèle déformé

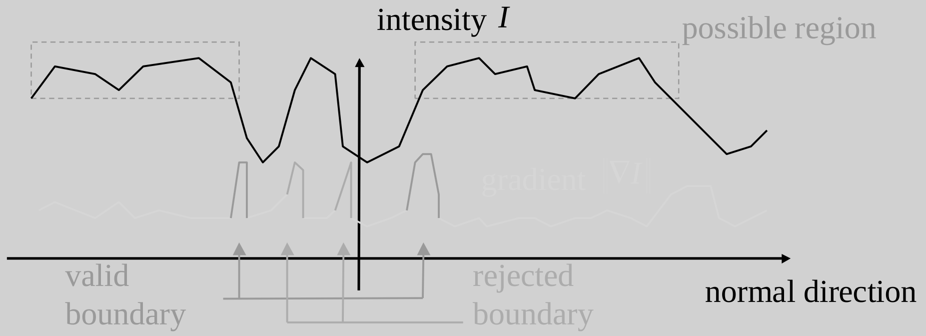
Region criterion

[Ronfard 94], [zhu 94]

Noisy images: weak gradient response

Differential signal (US)

Gradient filtering by region information



+ anisotropic filtering of intensity

Segmentation: heart

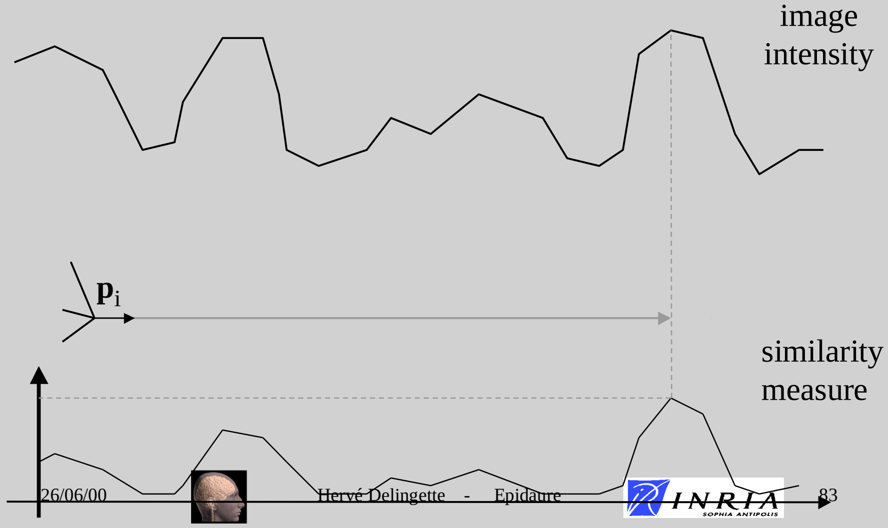
US image
Small bright regions

Convergence time: 28 s

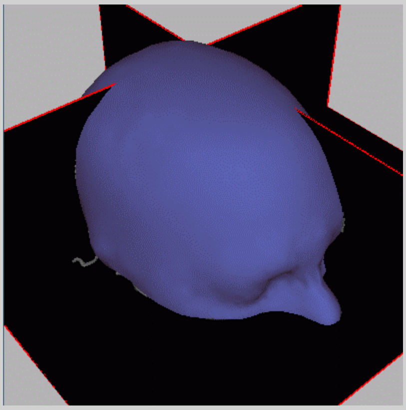
Iconic approach

[Maes *et al* 97, Roche *et al* 98, Penney *et al* 98]

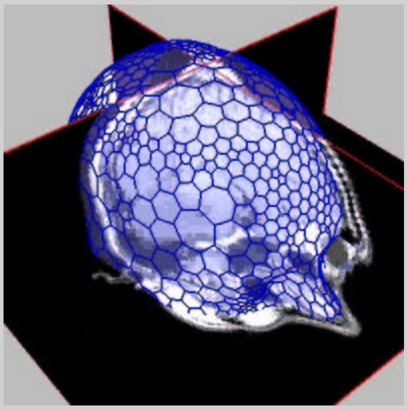
Reference intensity profile



Recalage multimodal CT-IRM T1

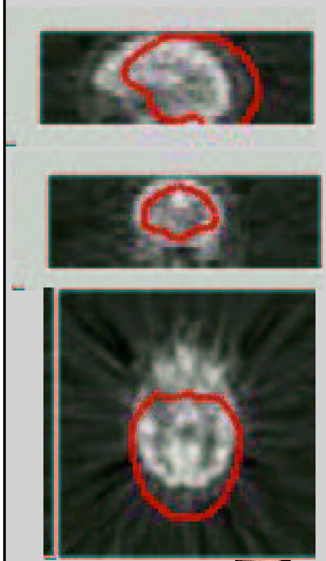


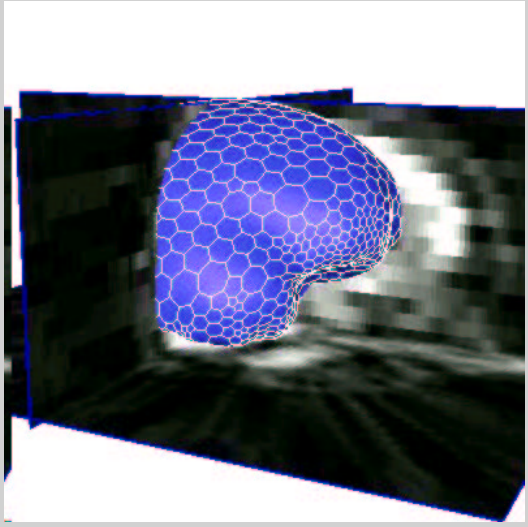
CT



IRM - T1

Multi-modal registration: IRM-PET



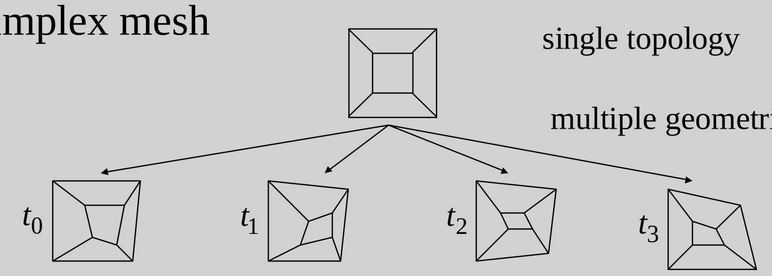


Modèles déformables

- 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

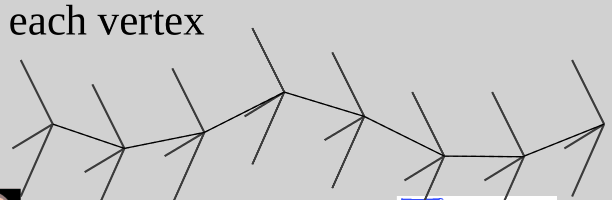
4D simplex mesh

4D simplex mesh



Trajectory of each vertex

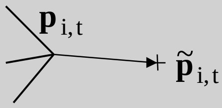
$\left\{ p_{i, t_j} \right\}_j$



Time regularization

Time force

$$f_{\text{time}}(\mathbf{p}_{i,t}) = \tilde{\mathbf{p}}_{i,t} - \mathbf{p}_{i,t}$$



$$m_i \frac{d^2 \mathbf{p}_{i,t}}{dt^2} = -\gamma_i \frac{d\mathbf{p}_{i,t}}{dt} + f_{\text{int}}(\mathbf{p}_{i,t}) + f_{\text{ext}}(\mathbf{p}_{i,t}) + f_{\text{time}}(\mathbf{p}_{i,t})$$

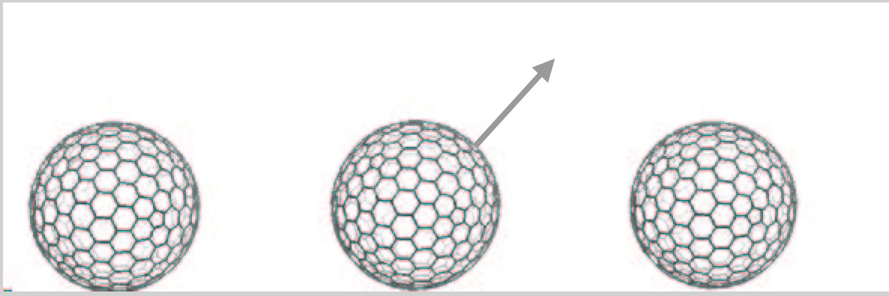
Global constraint

$$T = \arg\min_{T \in T_{\text{reg}}} \sum_{i,t} \left\| T(\mathbf{p}_{i,t}) - \text{Closest}(\mathbf{p}_{i,t}) \right\|^2$$

$$m_i \frac{d^2 \mathbf{p}_{i,t}}{dt^2} = -\gamma_i \frac{d\mathbf{p}_{i,t}}{dt} + \lambda \left(f_{\text{int}}(\mathbf{p}_{i,t}) + f_{\text{ext}}(\mathbf{p}_{i,t}) + f_{\text{time}}(\mathbf{p}_{i,t}) \right) + (1 - \lambda) f_{\text{global}}(\mathbf{p}_{i,t})$$

Time smoothing

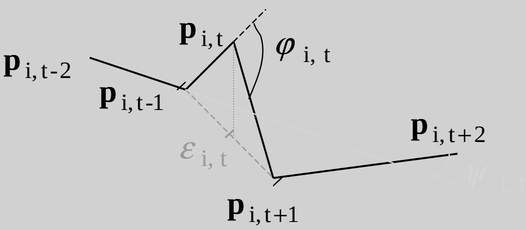
$$\tilde{\mathbf{p}}_{i,t} = \frac{\mathbf{p}_{i,t+1} + \mathbf{p}_{i,t-1}}{2}$$



t_{n-1} t_n t_{n+1}

Local perturbation

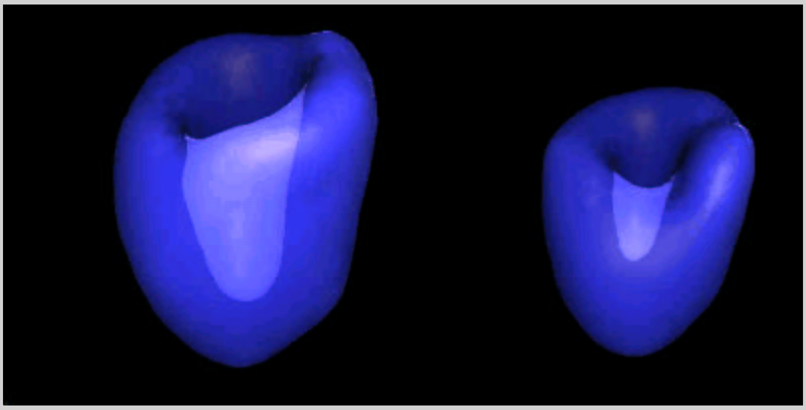
Trajectory memory



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

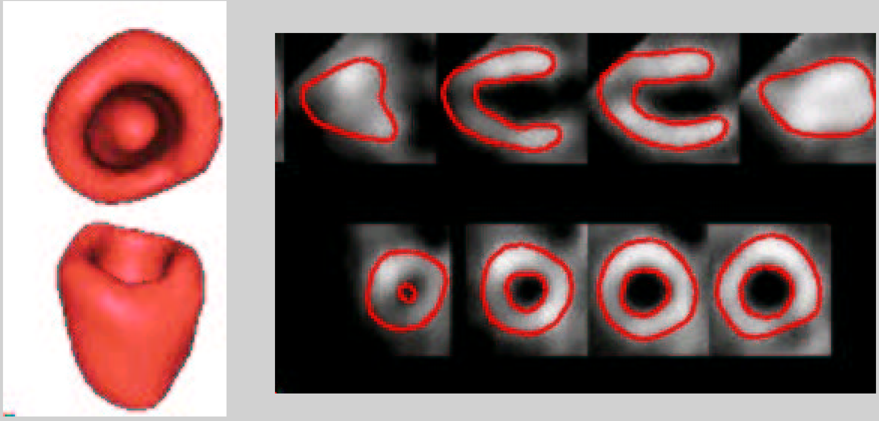


End of diastole   End of systole

Convergence time: 56 seconds

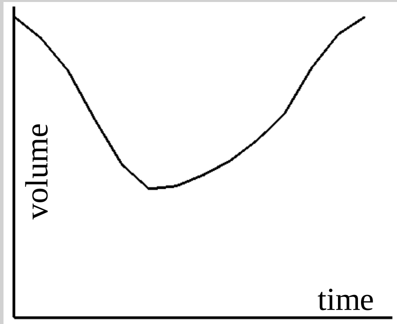
Deformed model

Pathological case

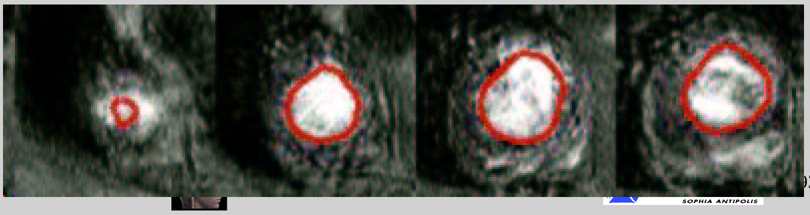


Segmentation: MRI

Deformed 4D model

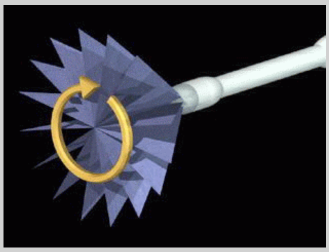


Model intersection with image



3D Ultrasound Images

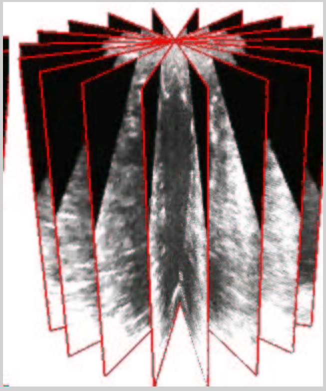
- Cylindical geometry of image acquisition



- 3D+T Imaging Systems
  - ATL Corporation (courtesy of G. Schwartz)
  - Echocard3D (courtesy of M-O. Berger)
  - HP Corporation (courtesy of A. Noble)

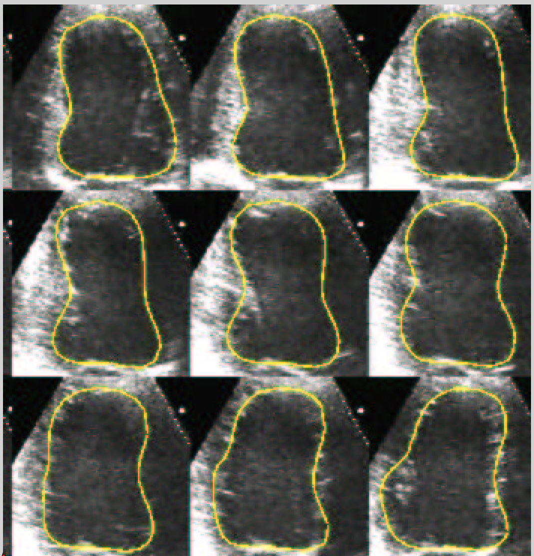
Segmentation: US

4D sequence with a cylindrical geometry



9 planes per 3D image, 8 instants

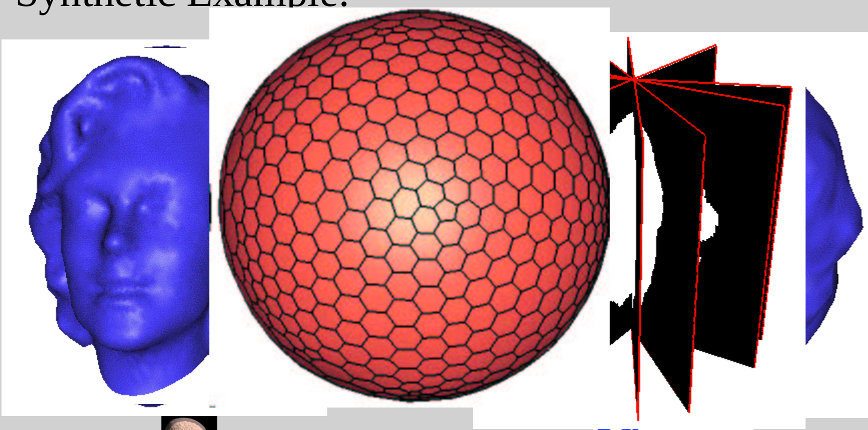
Result



Deformed
model
intersection
with image

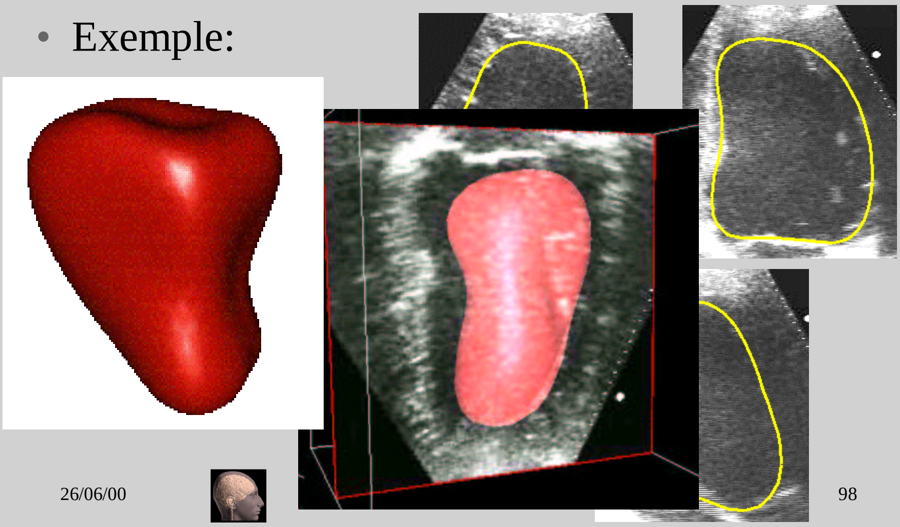
3D Reconstruction (2)

- Synthetic Example:

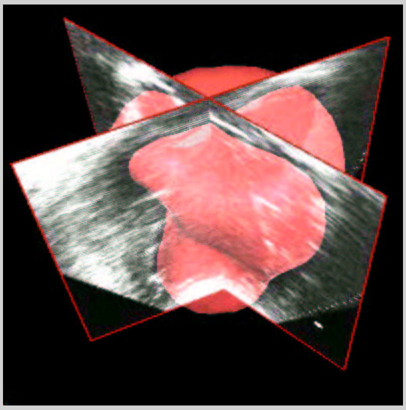


Reconstruction 3D

- Exemple:



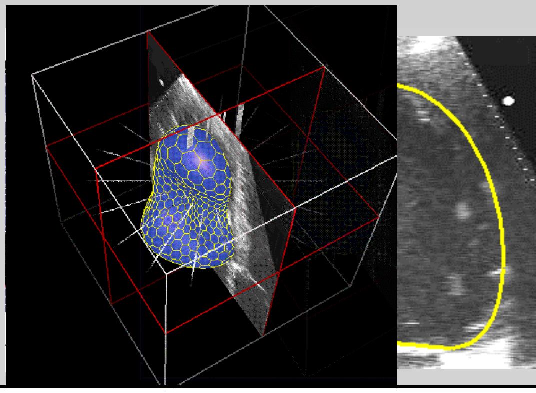
Reconstruction 4-D Ultrasound



Collaboration ATL

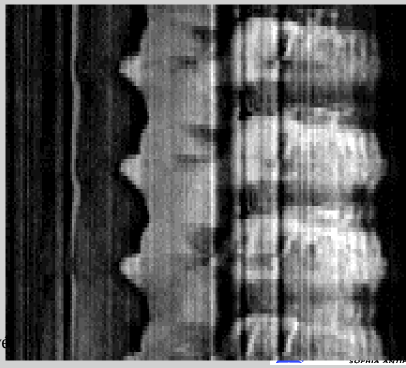
2D+T Reconstruction

2D+T Image Formation → 2D+T Surface Fitting → 3D Surface Fitting



2D+T Reconstruction (2)

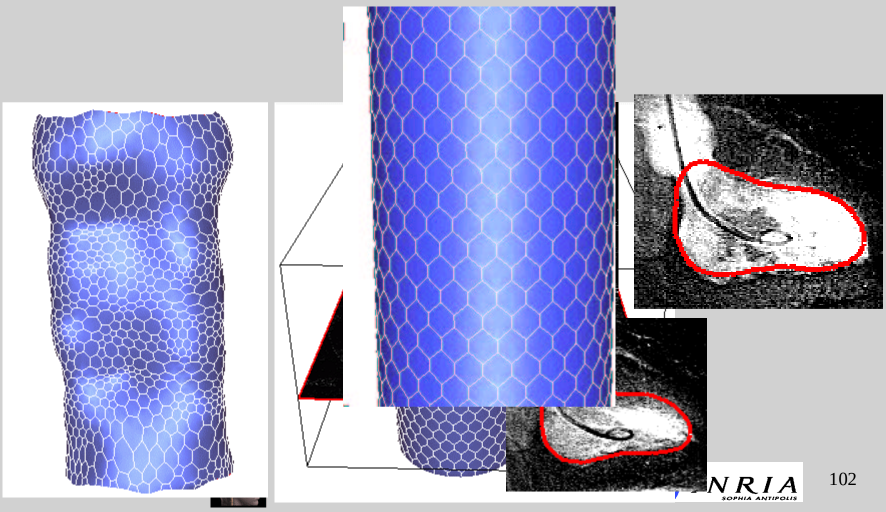
- Example : Ventriculography (courtesy of CCM)



Herve

101

2D+T Reconstruction (3)



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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.