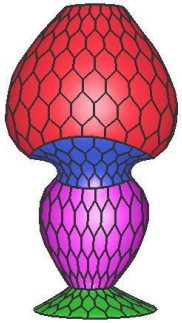
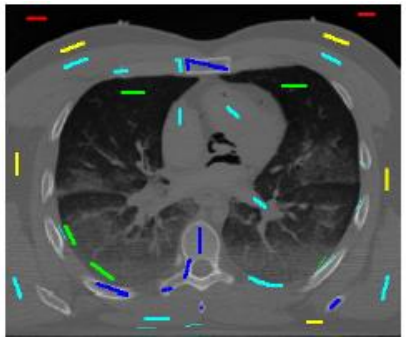
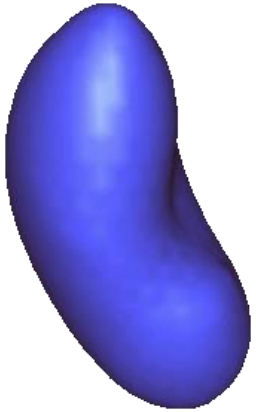


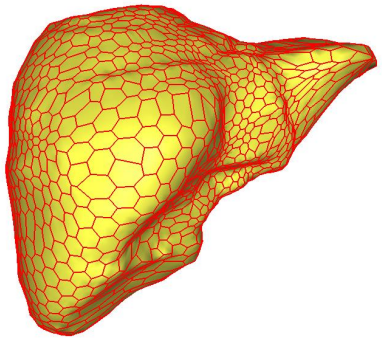


Reconstruction d'organes dans les formes

Hervé DELINGETTE

INRIA Sophia Antipolis



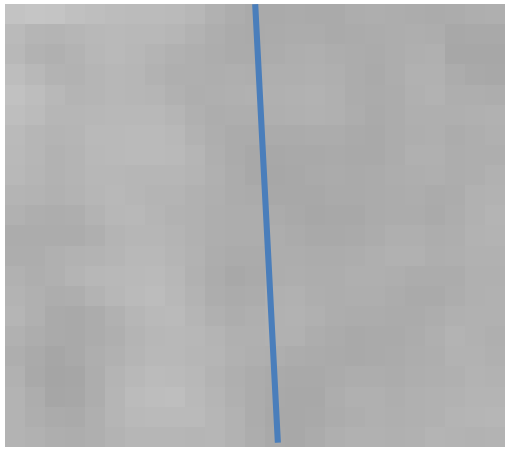


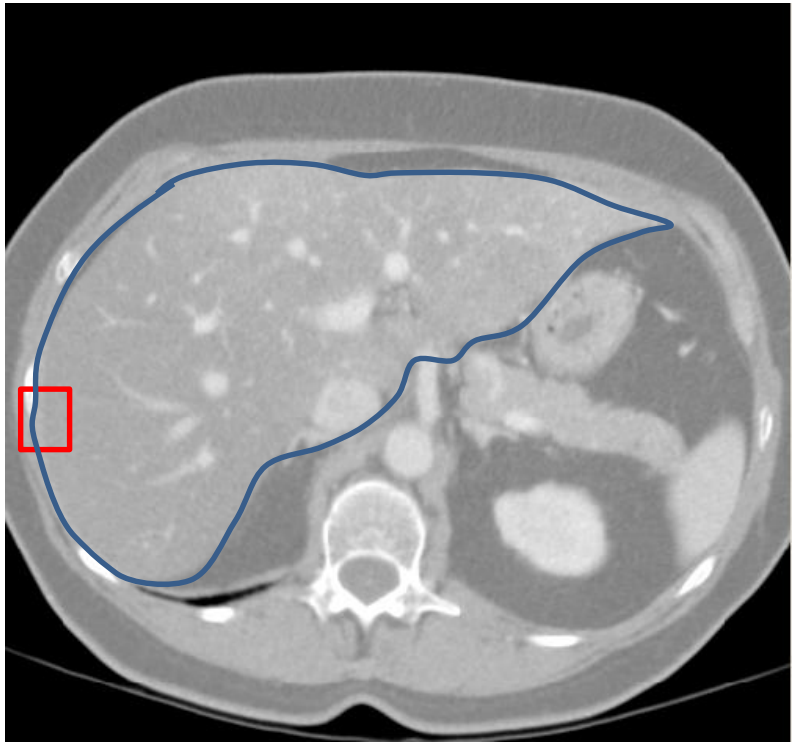
Segmentation d'images Computationnelle

Segmentation d'images Computationnelle

Segmentation d'images Computationnelle

Segmentation d'images Computationnelle





- Délinéation d'une structure requiert une connaissance de son apparence et de sa forme

Segmentation d'images Computationnelle

Intensité Uniquement

Classification d'Intensité

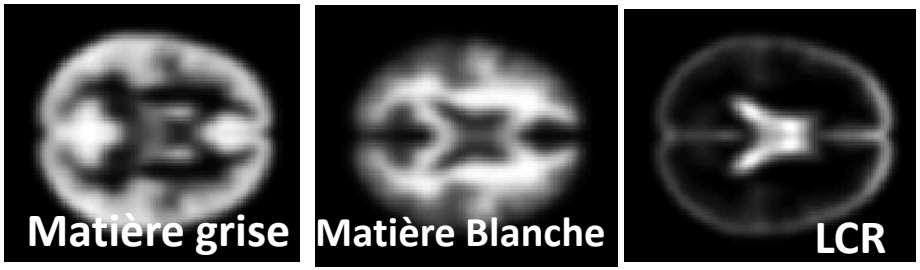
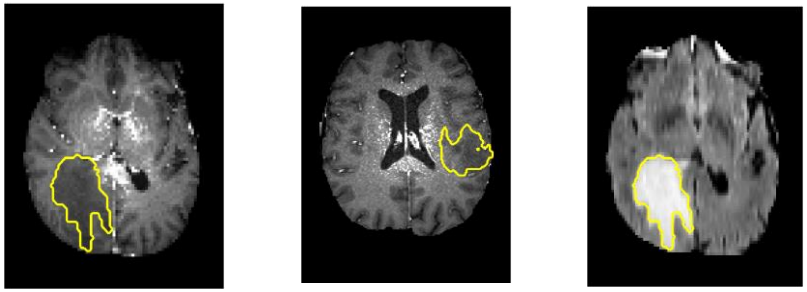


Image réhaussée
avec produit de contraste

Apprentissage (RF, SVM, Boost,ML)

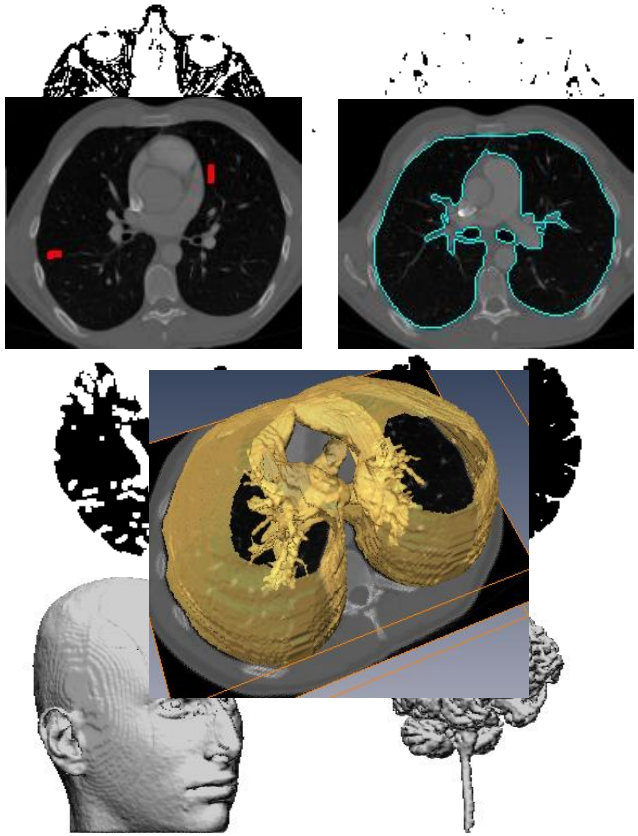


Imagerie cérébrale

Aucune forme Caractéristique

Forme Caractéristique

Segmentation d'images Computationnelle



Intensité et Connexité / Régularité

Morphologie Mathématique

Champs de Markov (coupure de graphes, RW)

Poumon

Vaisseaux

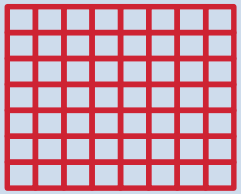
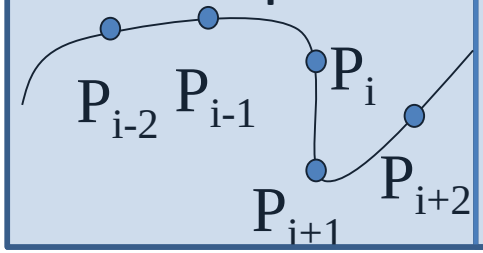
Os

Lésions

Aucune forme Caractéristique

Forme Caractéristique

Contrainte de Connexité / Régularité

	Formulation Continue / Variationnelle	**Formulation Discrète / Combinatoire**
Représentation Image 	Lignes de niveau	Coupure de Graphes
Représentation Frontière Explicite 	Contour / Surface active	Ciseaux Intelligents

Contrainte de Connexité

- Image = Graphe de voxels

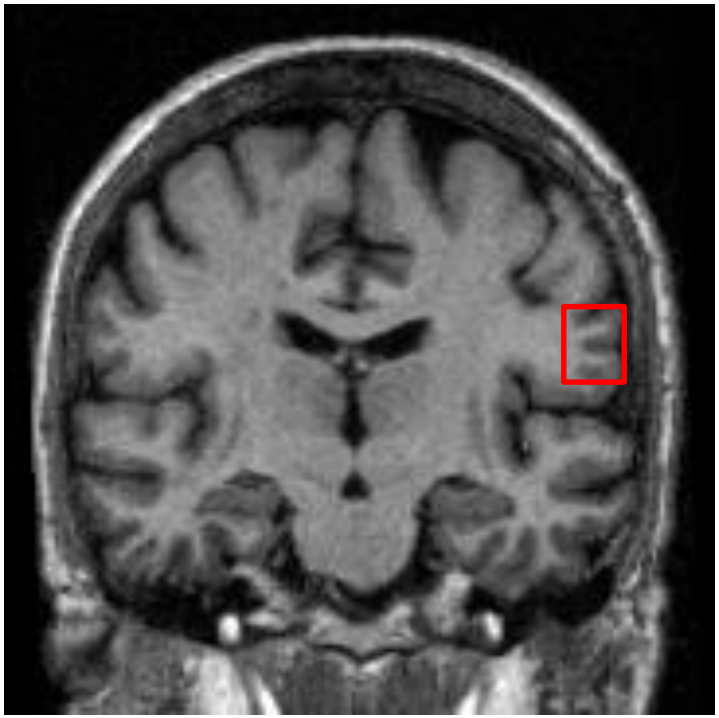
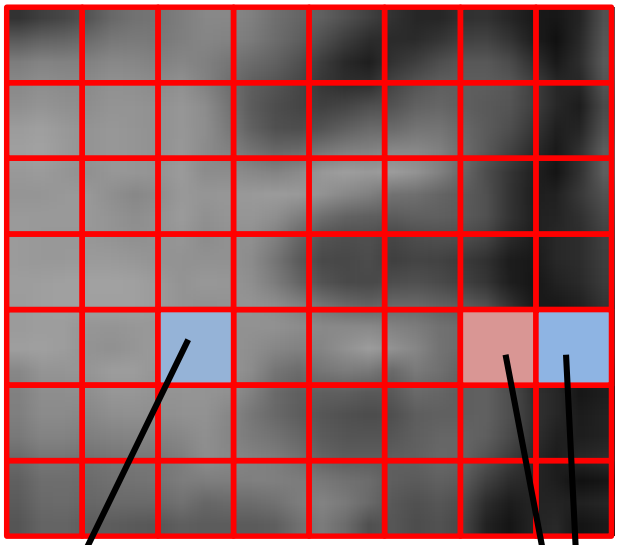


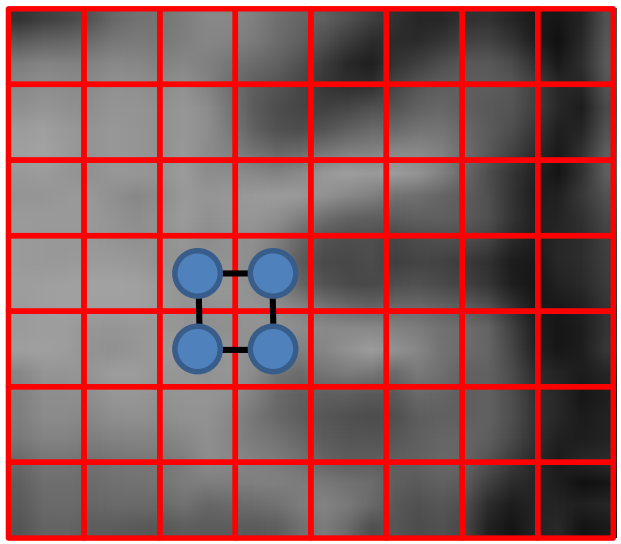
Image IRM cérébrale

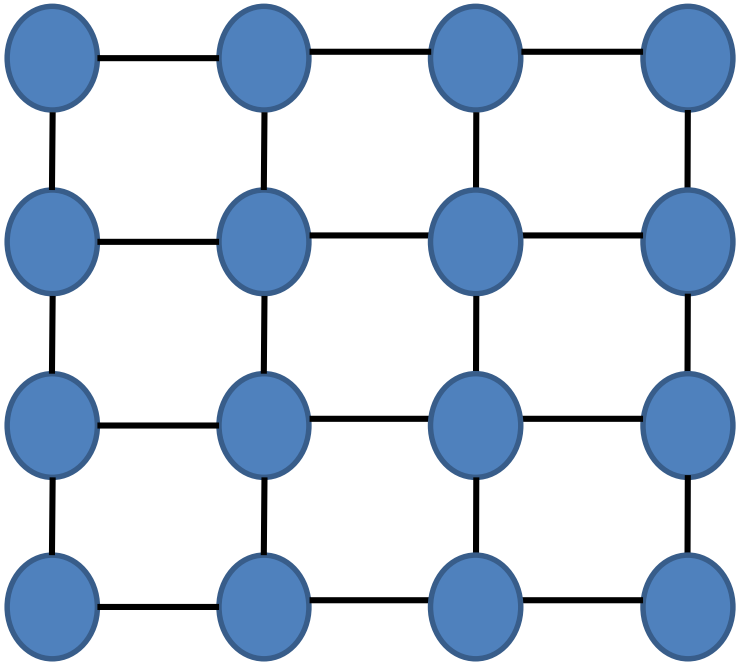


$P(y_i = l)$

$P((y_{i,} y_j) = (l, m))$

Champs de Markov



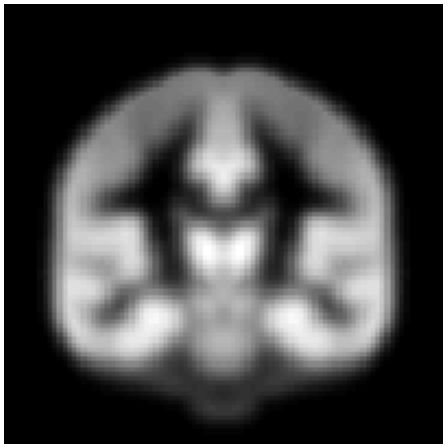


Segmentation d'image

Minimiser

$$Energie(\mathbf{y};\theta,\text{image}) = \sum_{i} \psi_1(y_i;\theta,\text{image}) + \sum_{i,j \in arêtes} \psi_2(y_i, y_j;\theta,\text{image})$$

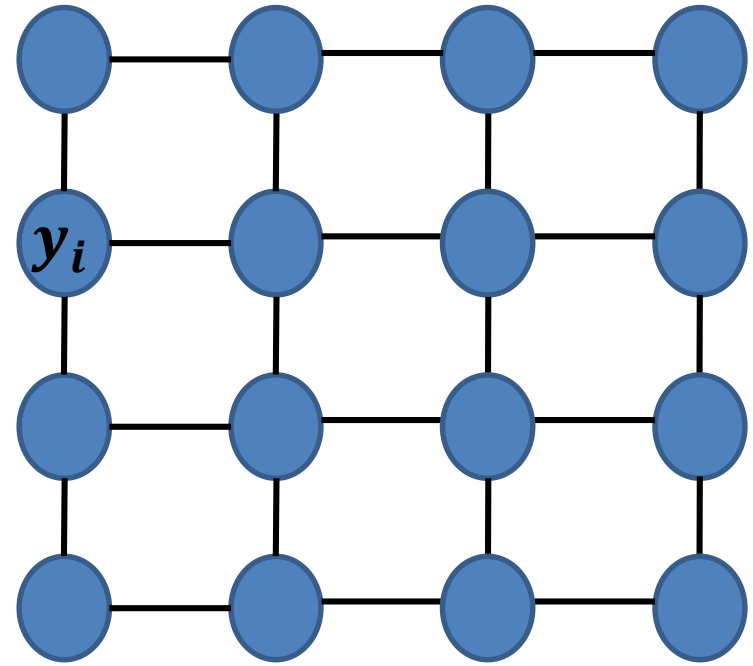
Champs de Markov



$\psi_1(y_i;\theta,\text{image})$

Coût voxel

$y_i = l \in \{0,1,..L-1\}$



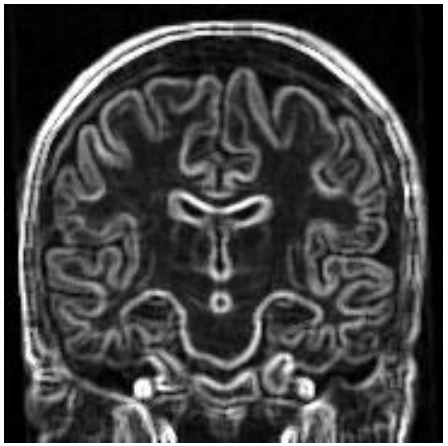
Sombre = faible probabilité
Clair = forte probabilité

Segmentation d'image

Minimiser

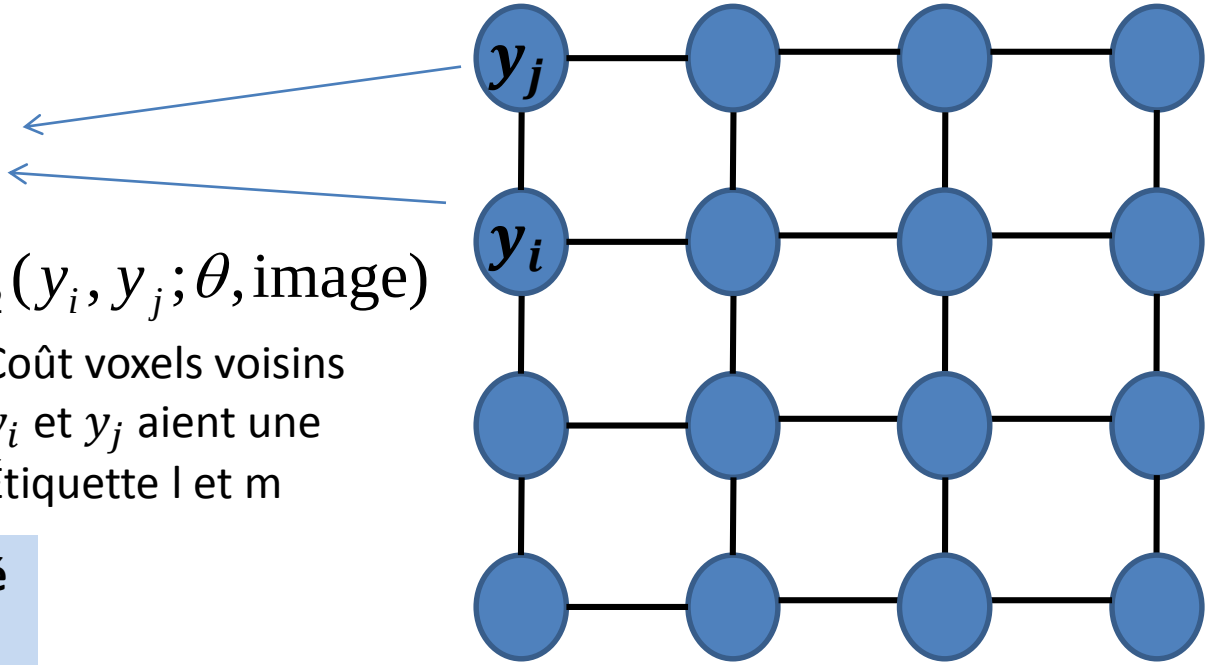
$$Energie(\mathbf{y};\theta,\text{image}) = \sum_i \psi_1(y_i;\theta,\text{image}) + \sum_{i,j\in arêtes} \psi_2(y_i,y_j;\theta,\text{image})$$

Champs de Markov



$$\psi_2(y_i, y_j; \theta, \text{image})$$

Coût voxels voisins y_i et y_j aient une Étiquette l et m



Sombre = faible probabilité
Clair = forte probabilité

Segmentation d'image

⟺

Minimiser

$$Energie(\mathbf{y}; \theta, \text{image}) = \sum_i \psi_1(y_i; \theta, \text{image}) + \sum_{i,j \in arêtes} \psi_2(y_i, y_j; \theta, \text{image})$$

Coupure de Graphe

- Cas particulier :
  - 2 étiquettes possibles : $y_i \in \{0,1\}$
  - Terme unaire positif $\psi_1(y_i;\theta,\text{image}) = c_i \cdot y_i \geq 0$
  - Interaction quadratique : $\psi_2(y_i, y_j;\theta,\text{image}) = c_{ij} y_i (1 - y_j)$
  - Contrainte métrique / submodulaire

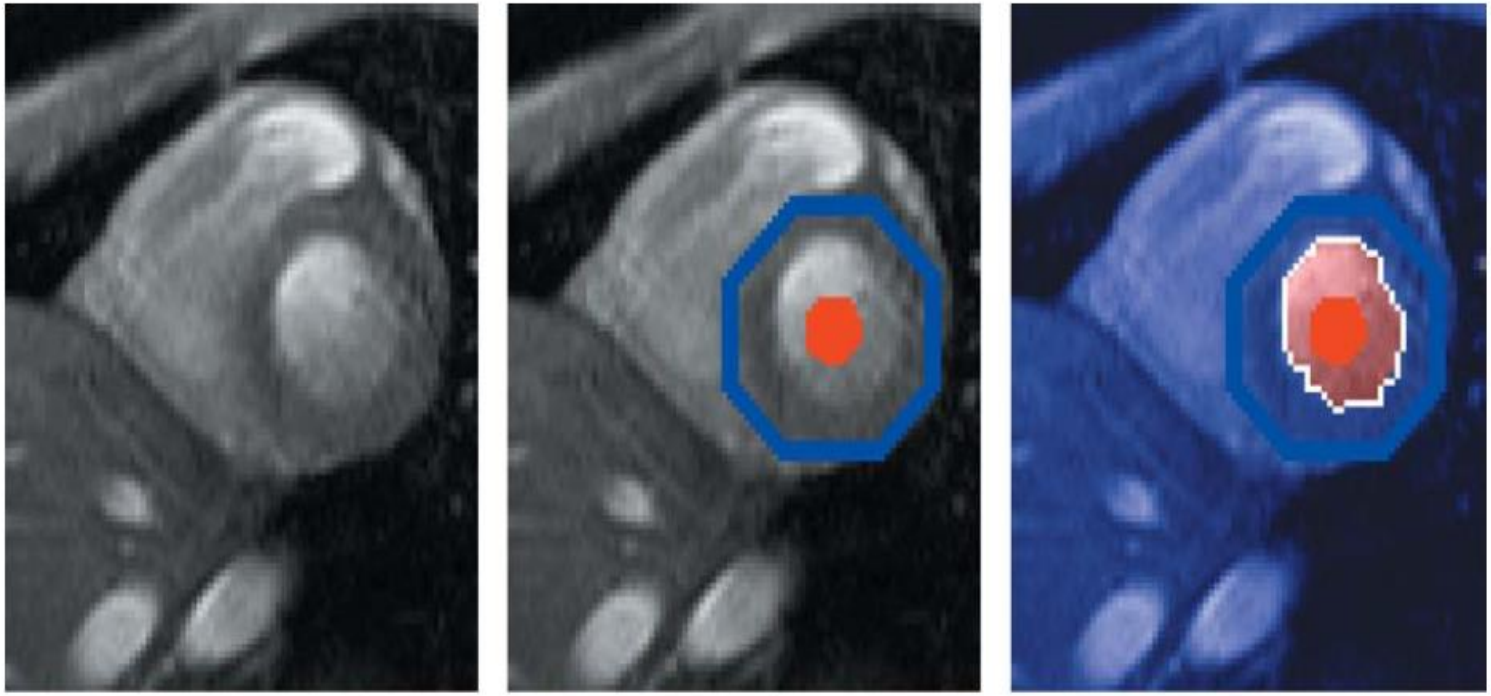
$$\psi_2(0,0;\theta,\mathrm{I}) + \psi_2(1,1;\theta,I) \leq \psi_2(0,1;\theta,\mathrm{I}) + \psi_2(1,0;\theta,\mathrm{I})$$

- Minimiser $\mathit{Energie}\ (\mathbf{y};\theta,\text{image})$ ⟺

Minimiser une coupure de graphe App. Combinatoire

D.M. Greig, B.T. Porteous and A.H. Seheult (1989), *Exact maximum a posteriori estimation for binary images*, Journal of the Royal Statistical Society Series B, **51**, 271–279.

Coupure de Graphe



Source : Boykov & Gareth Funka-Lea Graph Cuts and Efficient N-D Image Segmentation

pixels similaires dans un même segment

Segmentation par Coupure de graphe

- Algorithme de coupure de graphe :

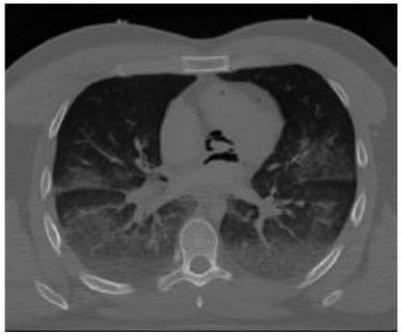
  Algorithme de Ford & Fulkerson (1951)

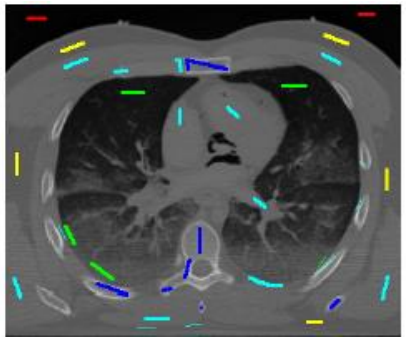
  Algorithme de BoyKov & Kolmogorov (2004)

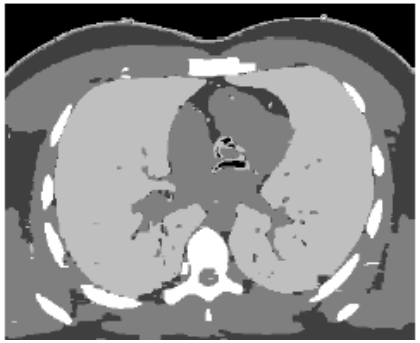
  Y. Boykov and V. Kolmogorov. An experimental comparison of min-cut/max-flow algorithms for energy minimization in vision. IEEE Transactions on Pattern Analysis and Machine Intelligence, 26(9):1124–1137, September 2004.

- Segmentation multi-étiquette:

  Algorithme α-expansion [Veksler 99] [Boykov 99]







R. Kéchichian, S. Valette, M. Desvignes, R. Prost: **Efficient multi-object segmentation of 3D medical images using clustering and graph cuts.** ICIP 2011

Utilisation de Graphes pour la segmentation

- Méthodes d'optimisation alternatives :
  - Loopy Belief Propagation [Felzenszwalb 2004]
  - Message passing [Komokadis 2011]

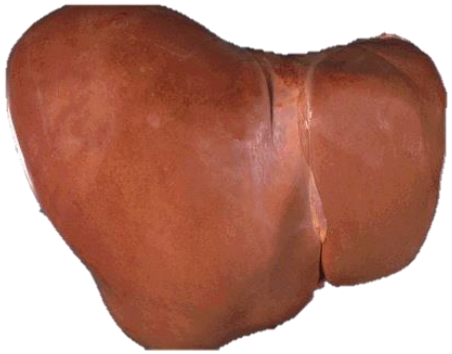
- Variables continues:
  - Coupure de Graphes Normalisée [Shi & Malik 2000]
  - Geos [Criminisi 2008]
  - Random Walker [Grady 2006]
  - Power Watershed [Couprie 2010]

Contrainte de Régularité

Contrainte de Connexité

Cerveau

Contrainte de Régularité

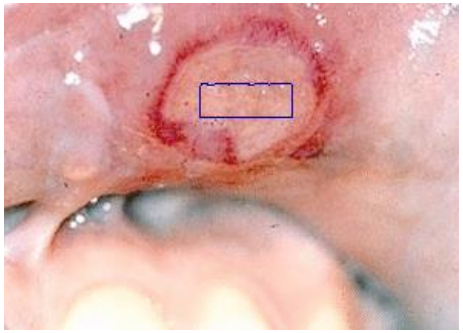


Foie

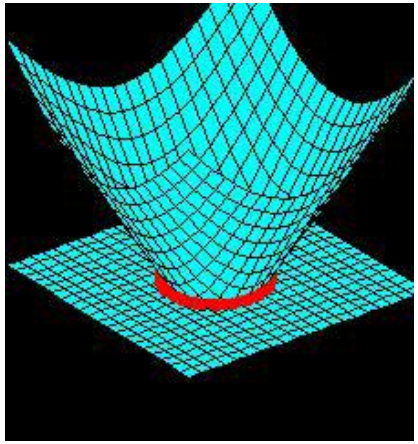
Source : Wikipedia

- Minimiser la longueur / surface de la frontière:
  - [Mumford & Shah 1989]
  - Geodesic Active Contours [Caselles 1997]

RAGS: Region-Aided Geometric Snake,
IEEE Transactions on Image Processing, volume 13, issue 5, pages 640 -- 652, May 2004

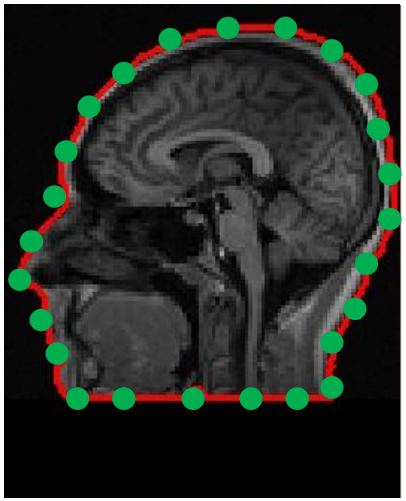


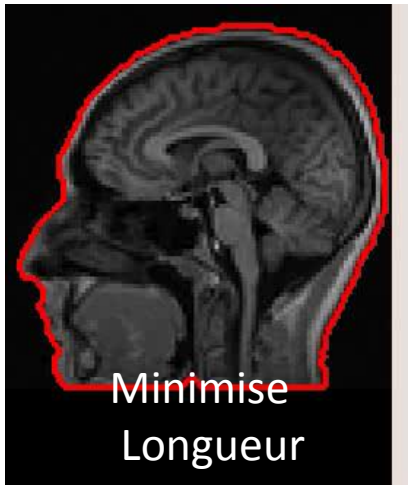
Contrainte de Régularité



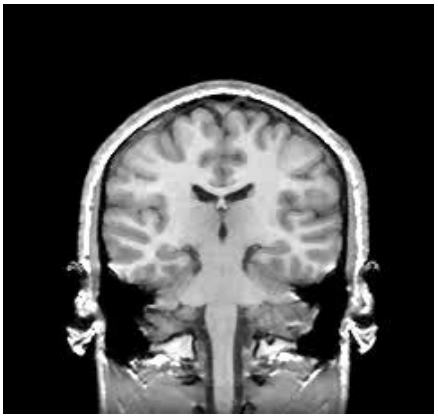
Source J. Sethian

- Représentation par courbes de niveau : $\psi(x,t) = 0$
  - Evolution $\frac{\partial \psi}{\partial t} = F|\nabla \psi|$
- Contrainte de Régularité plus forte :
  - Minimiser la courbure de la surface / contour



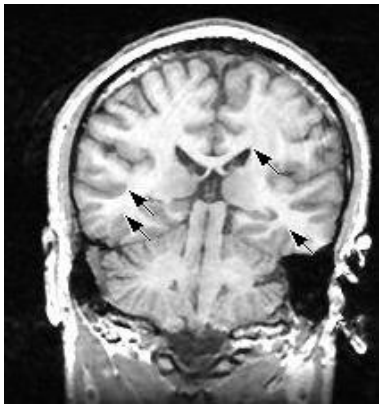


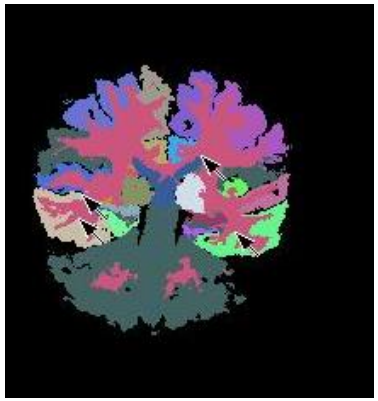
Segmentation d'images Computationnelle



Segmentation basée Atlas

Intensité et forme





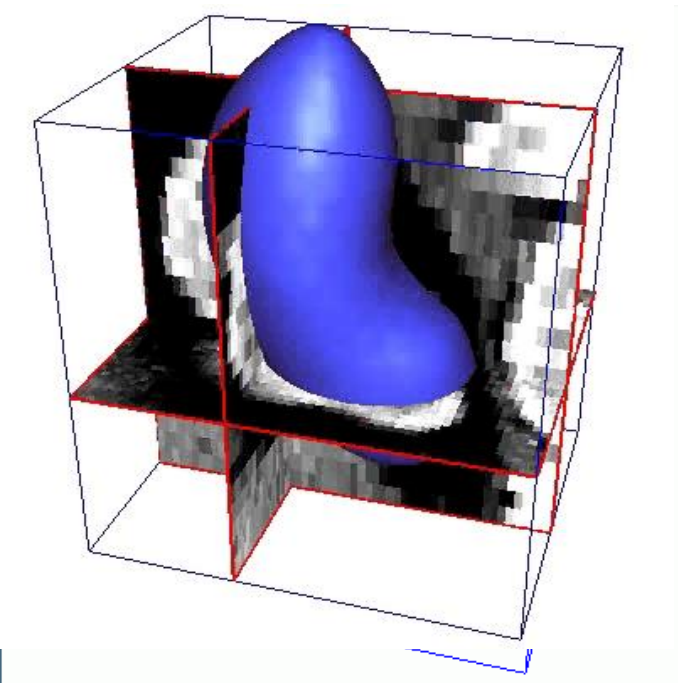
Coeur

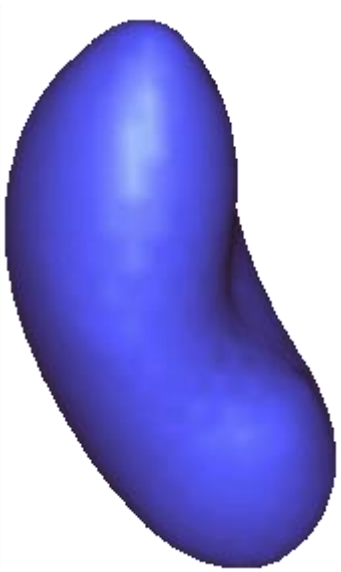
Foie Os

Aucune forme Caractéristique

Forme Caractéristique

Segmentation d'images Computationnelle





Segmentation basée Atlas

Modèles deformables

Intensité et forme

Coeur

Foie Os

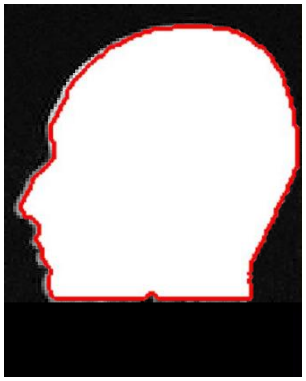
Aucune forme Caractéristique

Forme Caractéristique

Représentation de Forme

- Représentation extrinsèque / intégrale :

Instance d'une forme + groupe de transformation

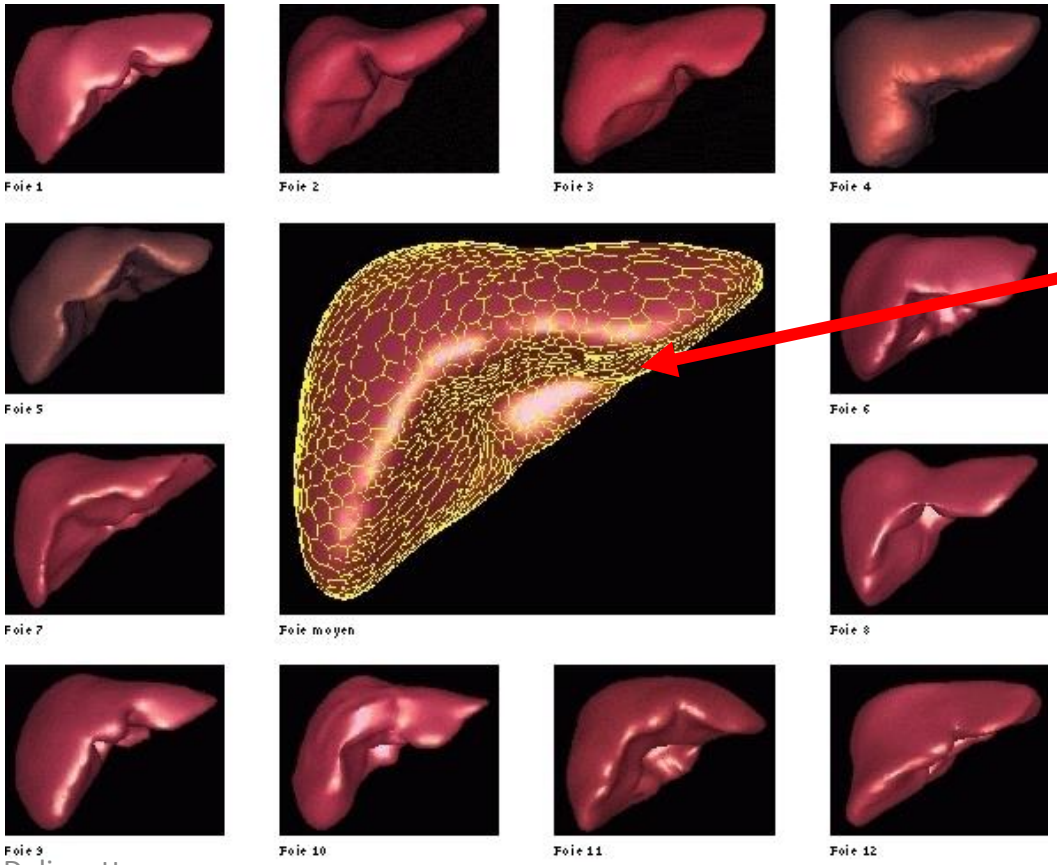


+ Transformations Rigides =

Représentation de Forme

- Représentation extrinsèque / intégrale :

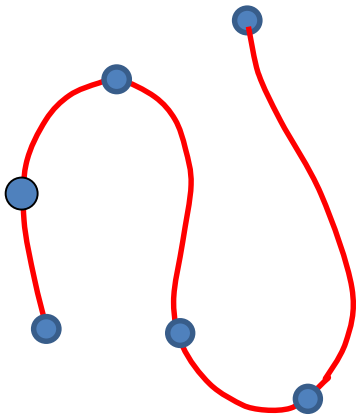
Variabilité d'une forme + groupe de transformation rigide

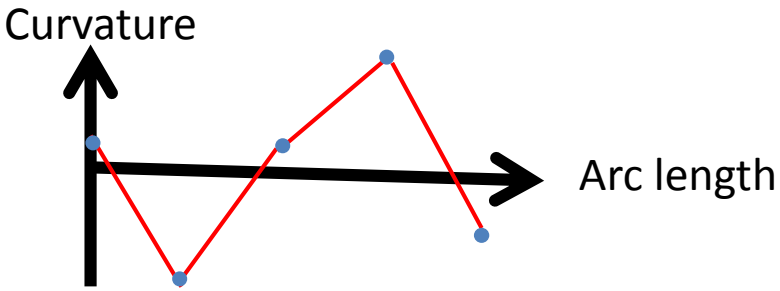


Modèle moyen du foie

Représentation de Forme

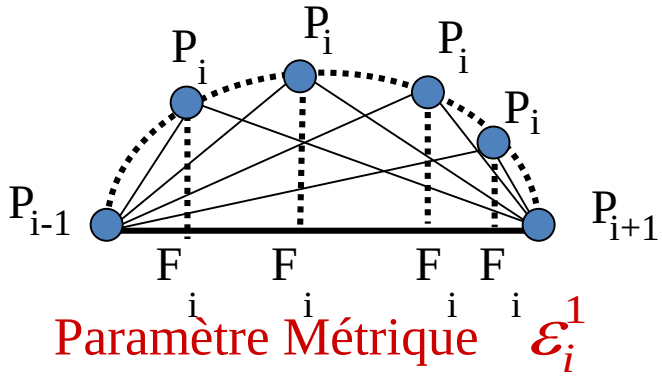
- Représentation intrinsèque / différentielle:
  - Connaissance des éléments différentiels d'ordre 1 (**métrique**) et 2 (**courbure**)
  - Cas Continu :
    - courbes planes : abcisse curviligne s et courbure $k(s)$

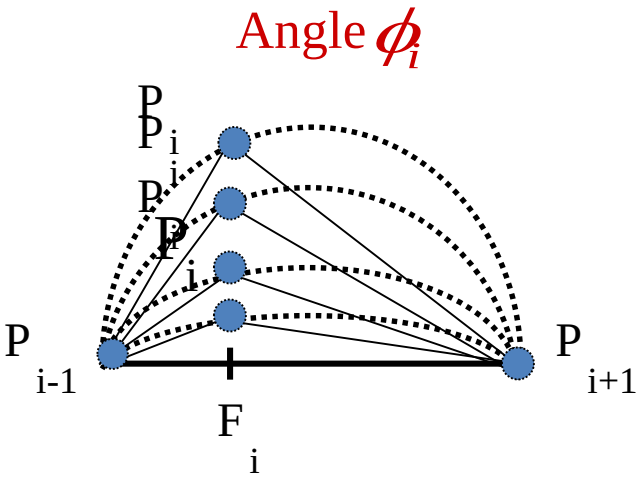




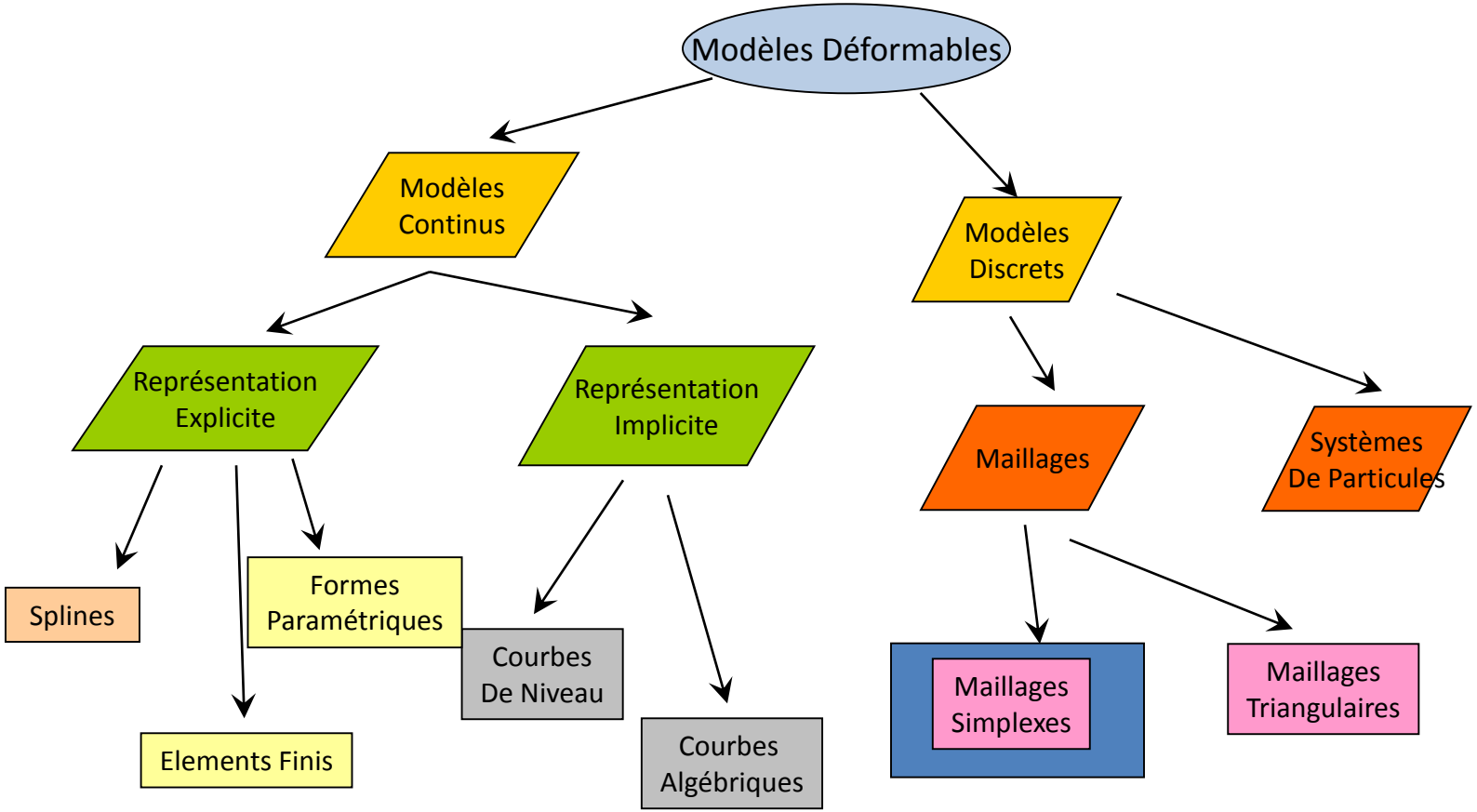
Représentation de Forme

- Représentation intrinsèque / différentielle:
  - Connaissance des éléments différentiels d'ordre 1 (**métrique**) et 2 (**courbure**)
  - Cas Continu :
    - courbes planes : abcisse curviligne s et courbure $k(s)$
    - Surface 3D : première et seconde forme fondamentale
  - Cas Discret :
    - Courbes polygonales





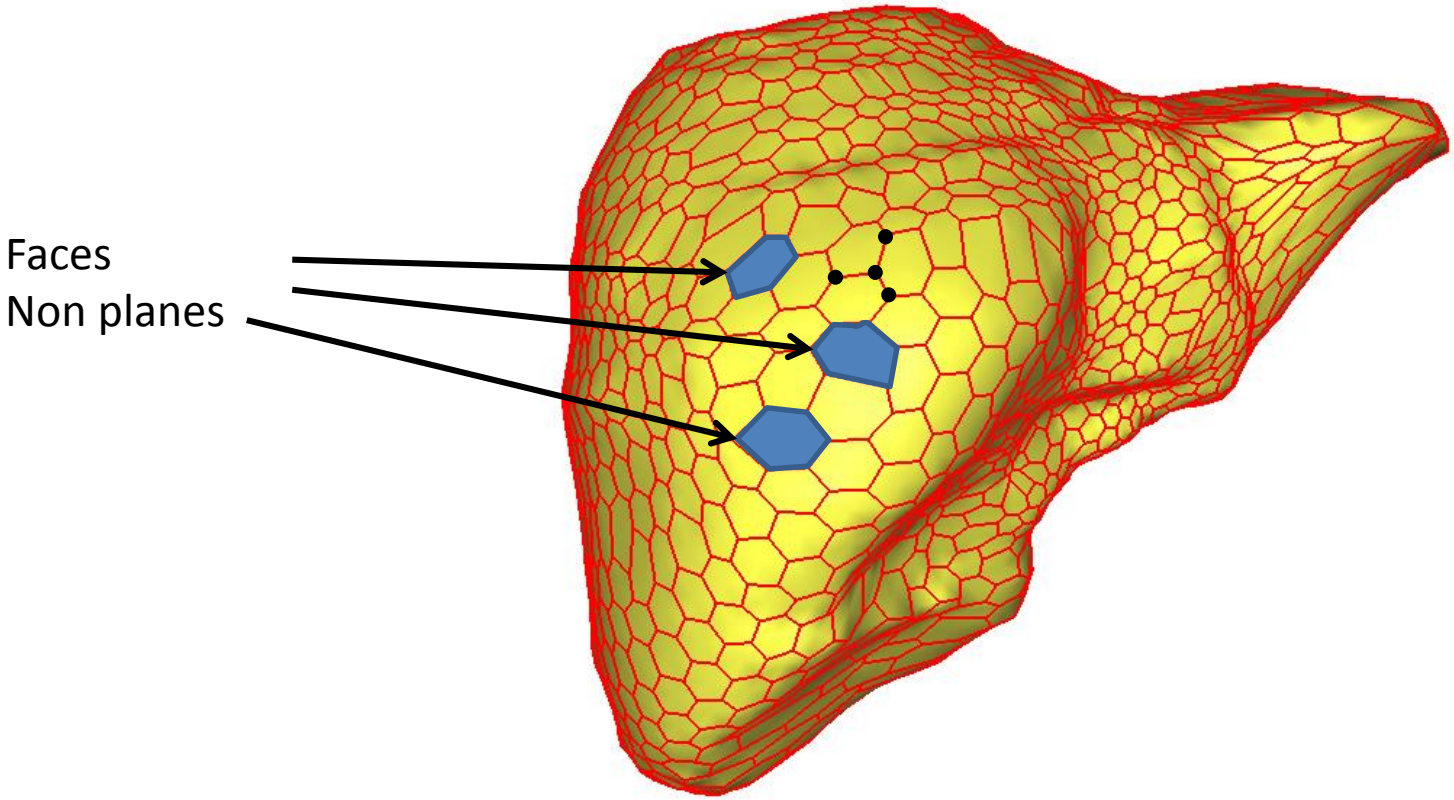
Représentation Géométrique des Modèles déformables



J. Montagnat, H. Delingette, and N. Ayache. **A review of deformable surfaces: topology, geometry and deformation**. *Image and Vision Computing*, 19(14):1023-1040, December 2001

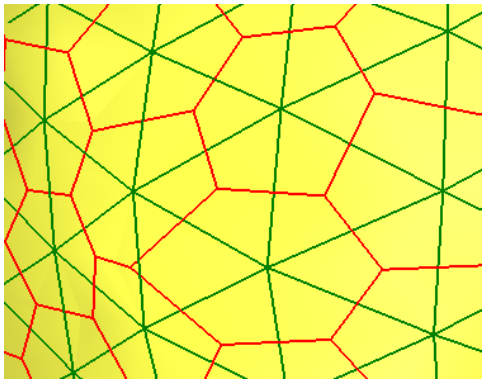
Maillage Simplexe

- Nombre de voisins constant (3 pour surface)

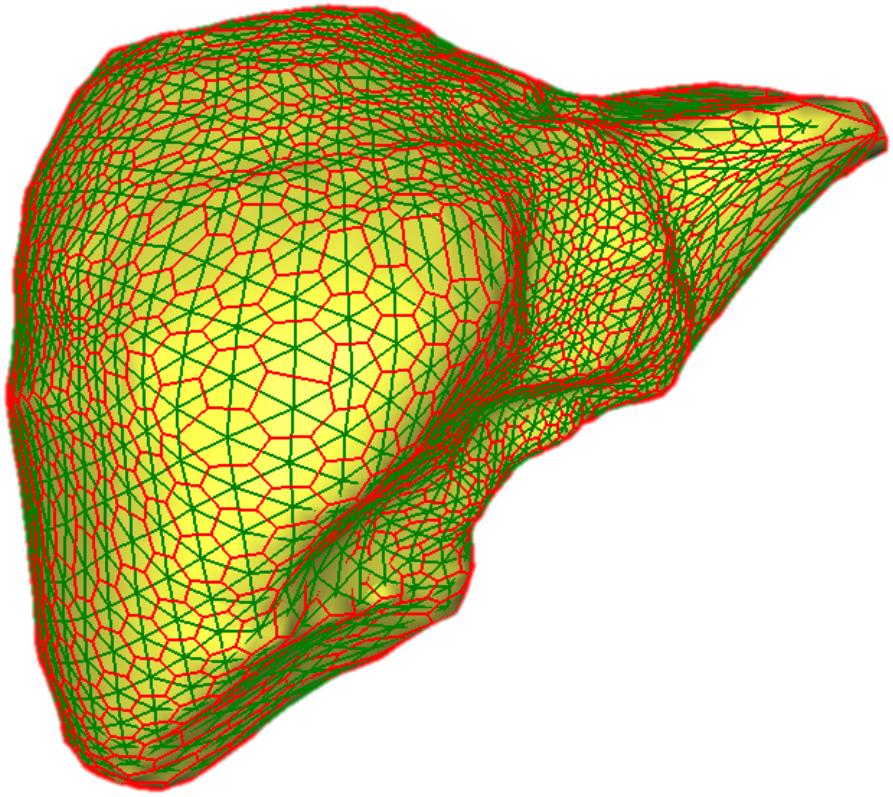


Maillage Simplexe

- Nombre de voisins constant (3 pour surface)
- Dualité avec les triangulations

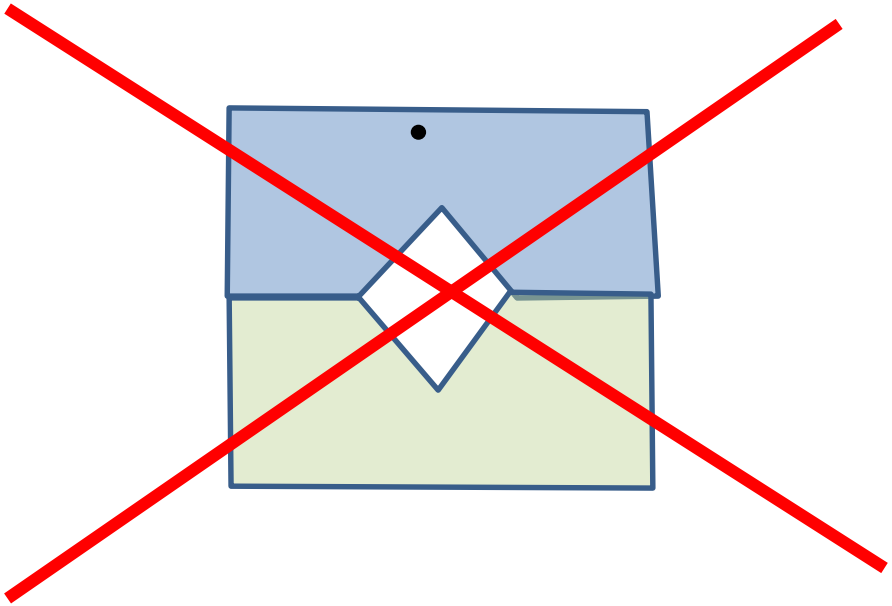


Dualité Topologique

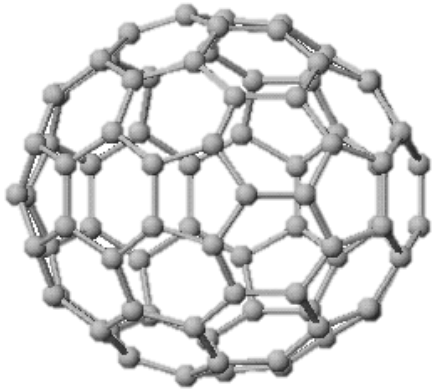


Maillage Simplexe

- Nombre de voisins constant (3 pour surface)
- Dualité avec les triangulations
- Représente des variétés topologiques



Maillages Simplexes



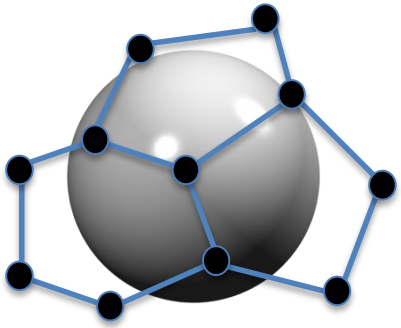
Fullrène

Statues de Rabarama

Source : Mario Nocentini

Source : Rabarama

Maillages Simplexes et Triangulations



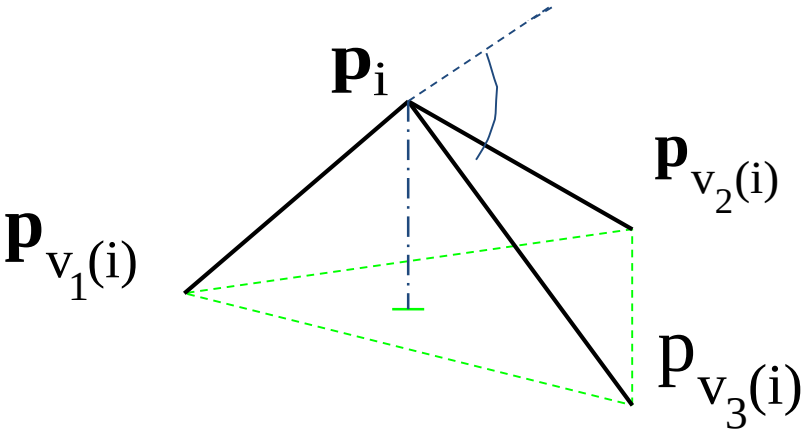
$$H_i = \frac{1}{R_i} = \frac{\sin \phi_i}{r_i}$$

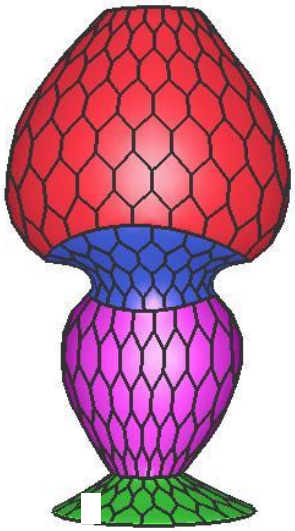
ϕ_i Angle simplexe

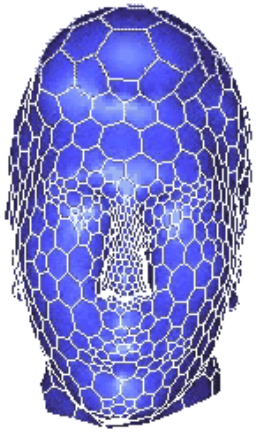
2-Maillage Simplexe	2-Triangulation
-Connexité fixe des sommets	-Nombre fixe de sommets par face
-Nombre variable de sommets par face	-Connexité variable des sommets
-Face non Plane (surface minimale)	-Face Plane
-Toujours variété topologique	-Peut ne pas être variété topologique
-Courbure moyenne au sommet	-Courbure gaussienne au sommet
- Angle Simplexe au sommet	- Angle Solide au sommet

Description locale de la forme

- Paramétrisation locale de la forme
- Contrôle de la forme







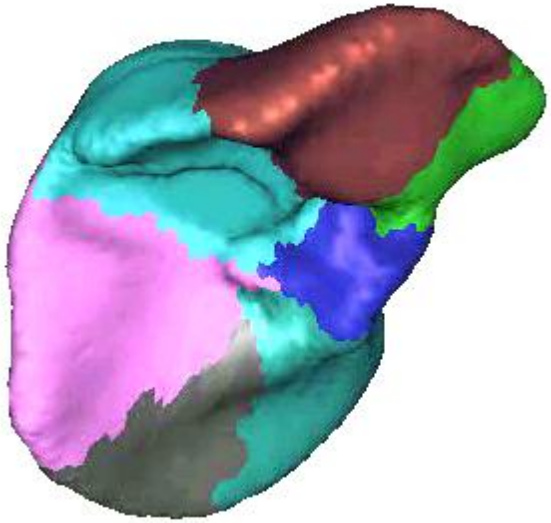
Influence des paramètres métriques $\varepsilon_i^1, \varepsilon_i^2$

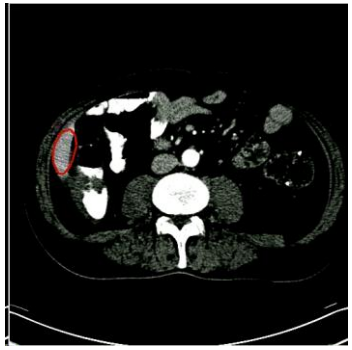
Influence de l'angle simplexe ϕ_i

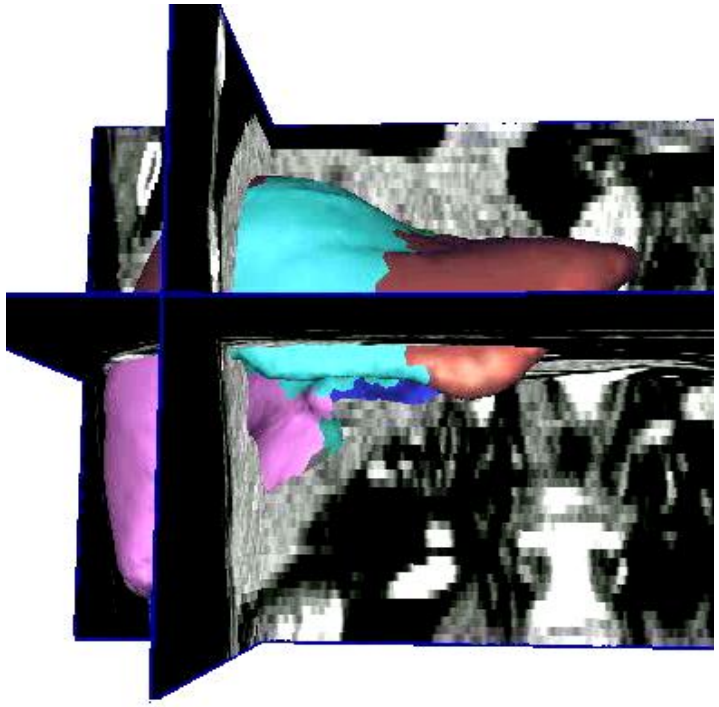
H. Delingette. General Object Reconstruction based on Simplex Meshes. International Journal of Computer Vision, 32(2):111-146, September 1999.

Modèles Déformables Simplexes

- Segmentation d'images médicales 3D



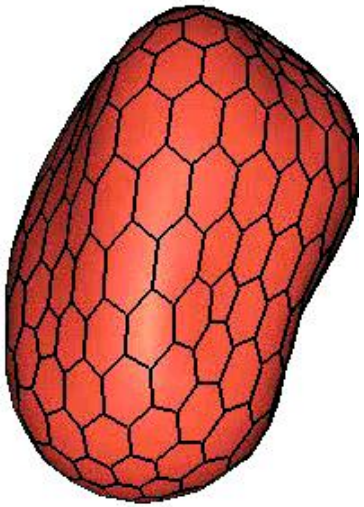


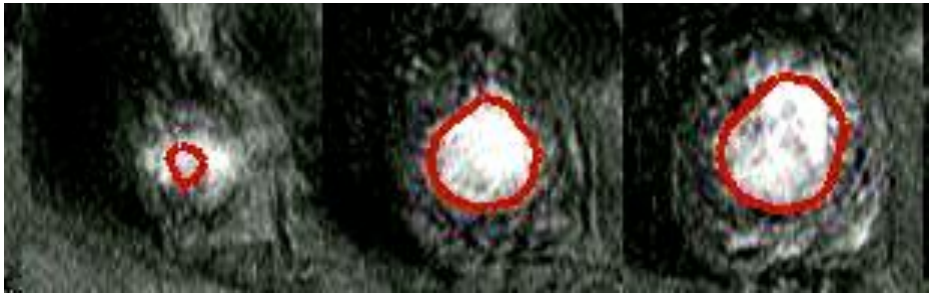


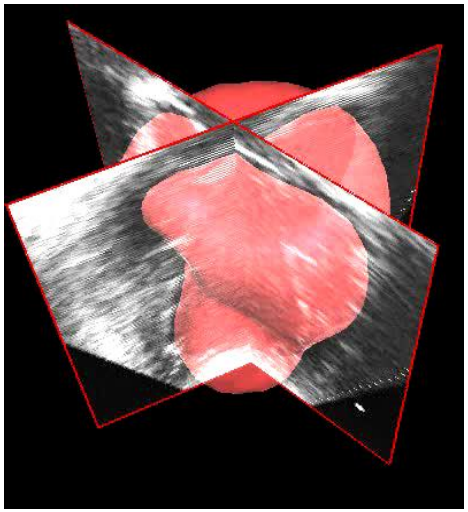
J. Montagnat and H. Delingette. Globally constrained deformable models for 3D object reconstruction. Signal Processing, 71(2):173-186, 1998.

Modèles Déformables Simplexes

- Segmentation d'images médicales 3D+T



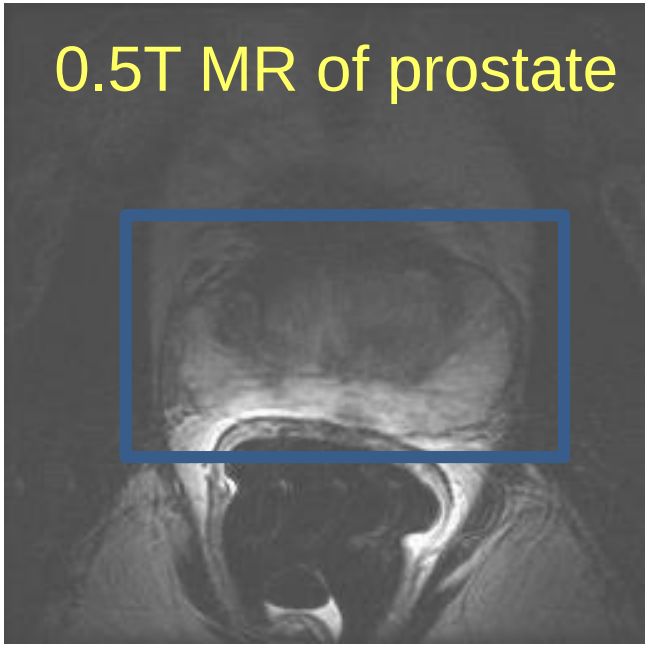


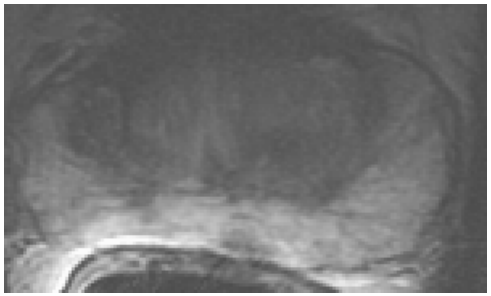


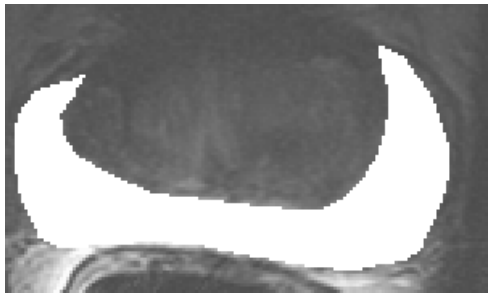
J. Montagnat and H. Delingette. 4D Deformable Models with temporal constraints : application to 4D cardiac image segmentation. Medical Image Analysis, 9(1):87-100, February 2005

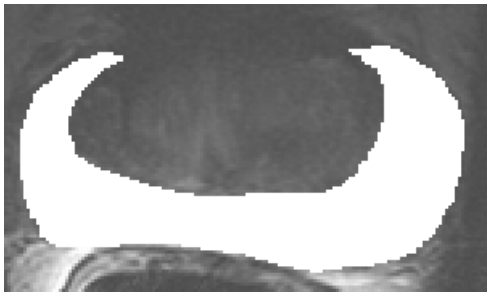
Perspectives

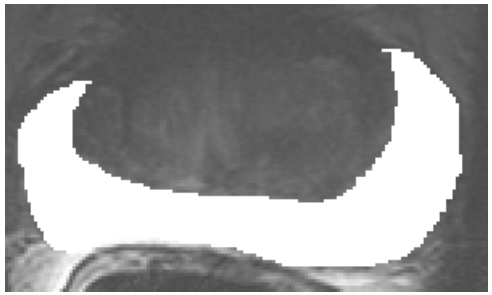
- Segmentation interactive
  - en temps-réel
  - “dans les formes”
- Approche non déterministe de la segmentation

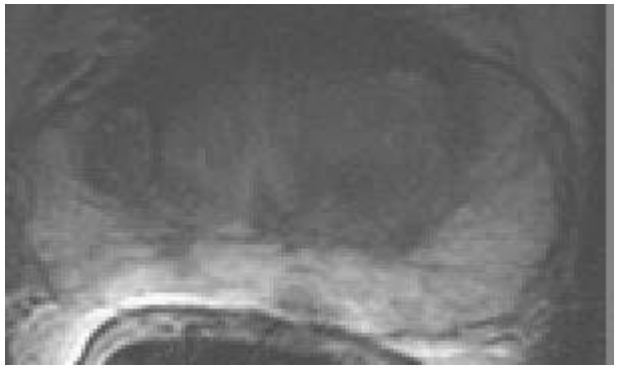


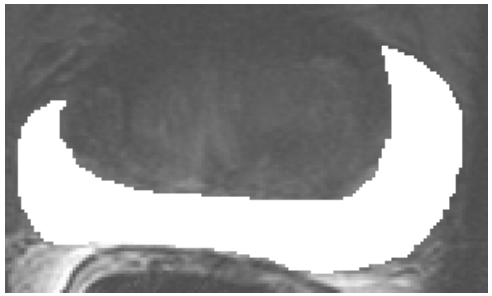


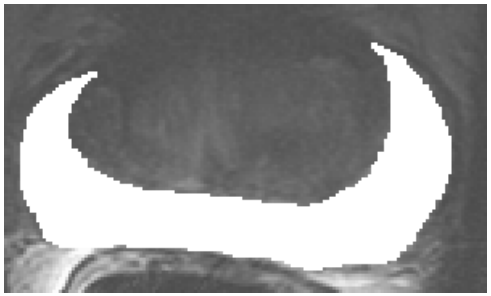












Source : S. Warfield Children Hospital, Boston

Perspectives

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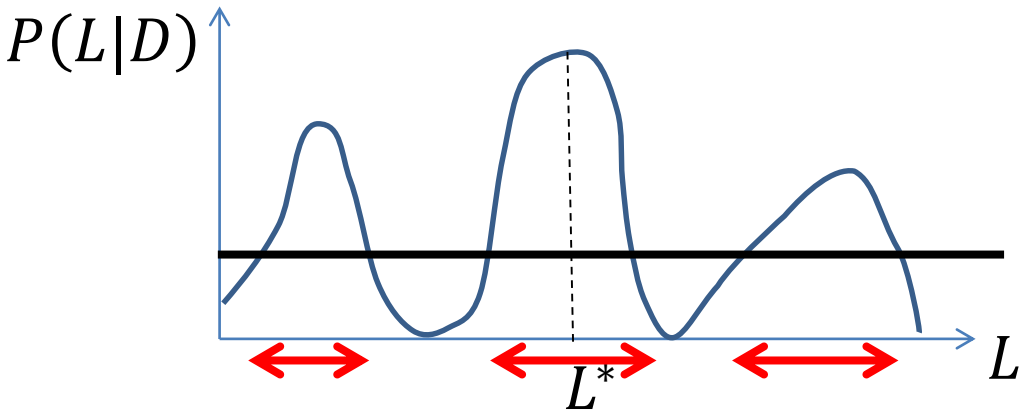

Perspectives

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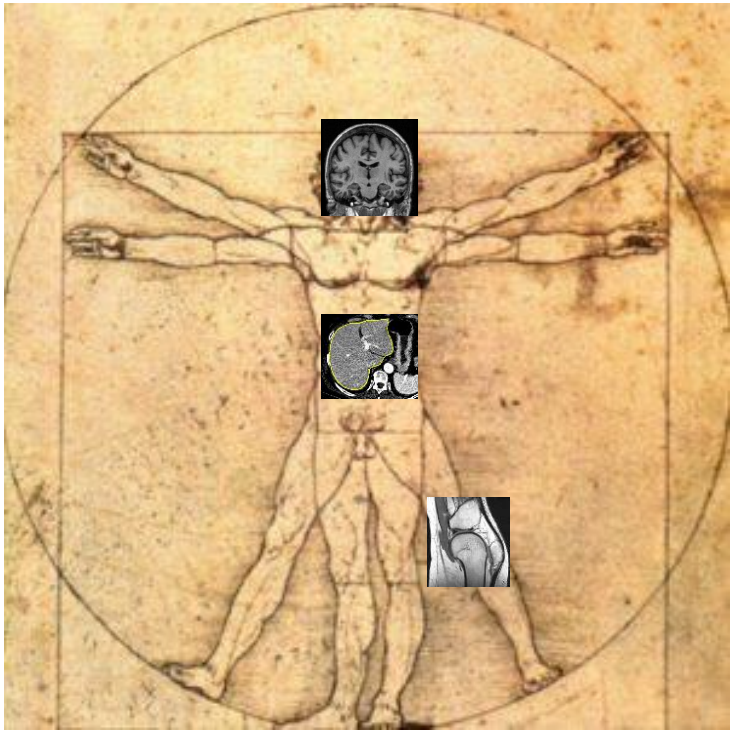
Perspectives

- Données Massives :
  - Explorer et cartographier l'espace des formes et de l'apparence des structures existant dans les images médicales