

Modèles pour la reconnaissance de structures normales et pathologiques dans des images médicales

Isabelle Bloch

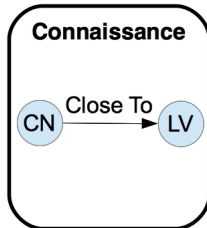
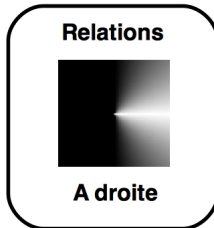
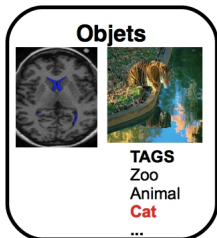
Telecom ParisTech - CNRS LTCI



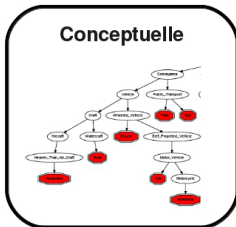
isabelle.bloch@telecom-paristech.fr

2015

Information imparfaite et de nature multiple



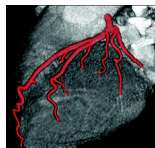
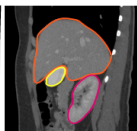
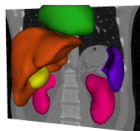
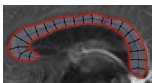
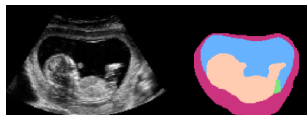
Voiture



Importance des modèles

Modèles pour guider la segmentation, la reconnaissance, l'interprétation :

- propriétés des images et des signaux (géométrie, statistiques...),
- forme et apparence,
- modèles iconiques (atlas),
- organisation spatiale (relations spatiales),
- physiologie,
- modèles symboliques,
- imprécision et incertitude.



Des images aux modèles :

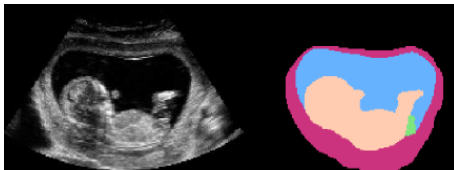
- exemple : construction de modèles anatomiques.

Modèles pour l'interprétation d'images

- Développer des modèles mathématiques pour représenter
 - les connaissances,
 - les informations contenues dans les images,conduisant à des algorithmes opérationnels pour l'interprétation d'images.
- Question du fossé sémantique.
- Cas pathologiques.
- Adéquation aux applications et aux besoins du monde médical.

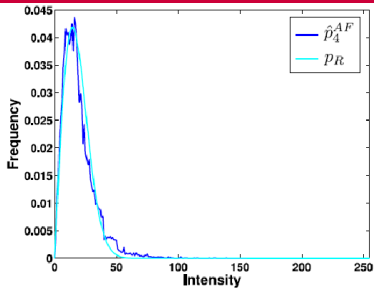
Segmentation du fœtus en imagerie ultrasonore 3D

(Jérémie Anquez)

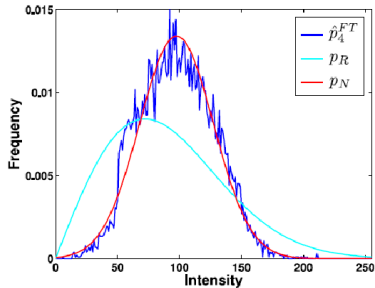


Statistiques de l'intensité des niveaux de gris :

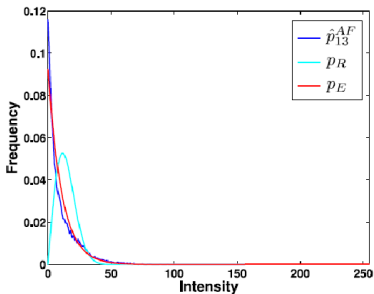
- Hypothèse habituelle : Rayleigh mais pas toujours adaptée...
- Loi exponentielle.
- Loi normale.
- Loi Gamma (forme plus générale).



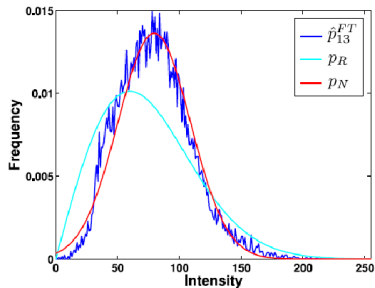
(a)



(b)



(c)



(d)

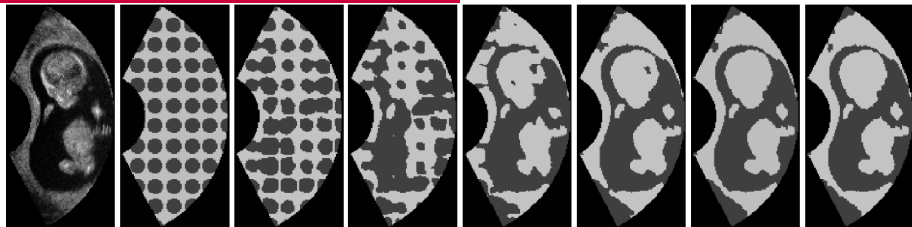
- Formulation probabiliste : partition $\mathcal{P}(\Omega) = \{\Omega_e, \Omega_i\}$ maximisant $p(I|\mathcal{P}(\Omega))p(\mathcal{P}(\Omega))$.

$$p(\mathcal{P}(\Omega)) \propto \nu \exp(-\nu|C|), \quad \nu > 0$$

$$p(I|\mathcal{P}(\Omega)) = p(I|\Omega_e)p(I|\Omega_i) = \prod_{x \in \Omega_e} p_e(I(x), \theta_e) \prod_{x \in \Omega_i} p_i(I(x), \theta_i)$$

$$p(\mathcal{P}(\Omega)|I) = \nu \exp(-\nu|C|) \prod_{x \in \Omega_e} p_e(I(x), \theta_e) \prod_{x \in \Omega_i} p_i(I(x), \theta_i)$$

- Formulation sous forme de minimisation d'énergie.
- Mise en œuvre avec des ensembles de niveau.
- Estimation directe ou approximation numérique des paramètres des lois.



I_5

Init.

30 it.

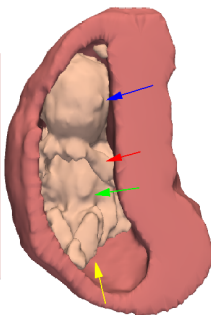
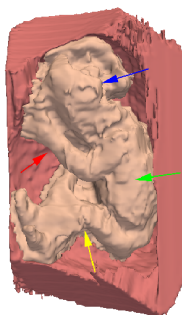
60 it.

90 it.

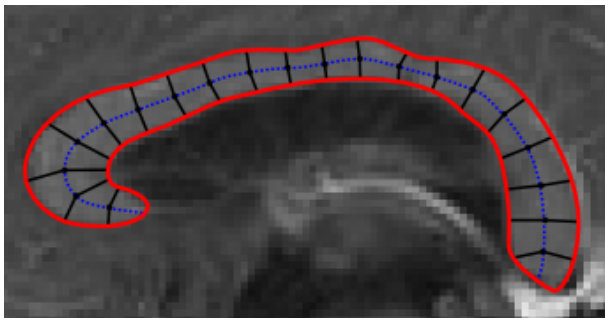
120 it.

220 it.

390 it.

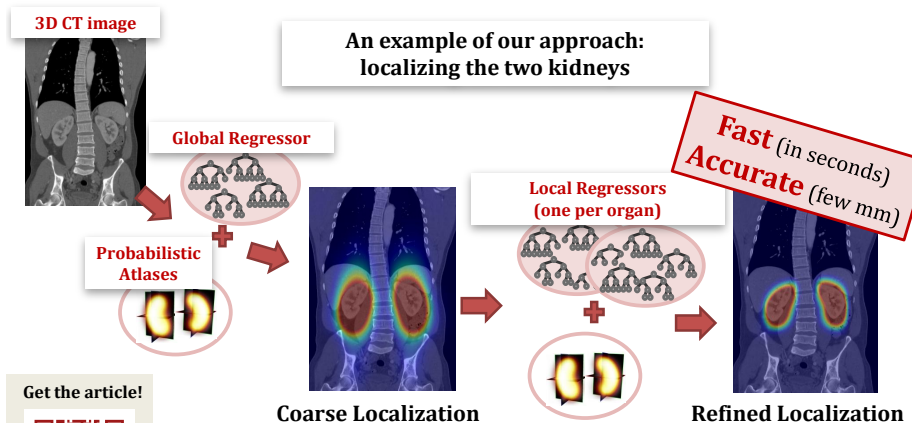


Segmentation du corps calleux en IRM (Romane Gauriau, avec CHU Bicêtre)



MULTI-ORGAN LOCALIZATION COMBINING GLOBAL-TO-LOCAL REGRESSION AND CONFIDENCE MAPS

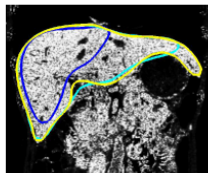
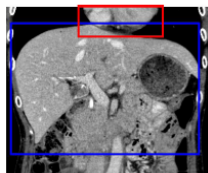
Romane Gauriau, Rémi Cuingnet, David Lesage, Isabelle Bloch



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Segmentation du foie et extension au multi-organes en CT (Romane Gauriau, avec Philips)



Liver and Heart
localization with
regression forest



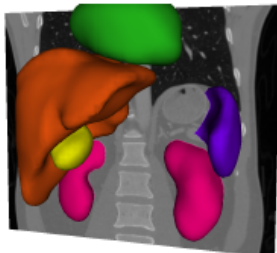
Liver probability
map
computation



Global-to-local
segmentation

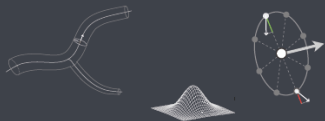


Refinement on
original image



Segmentation des coronaires en CT de haute résolution (David Lesage, avec Siemens)

Outline



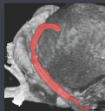
Core components

Geometric model

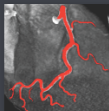
Bayesian model

Image feature

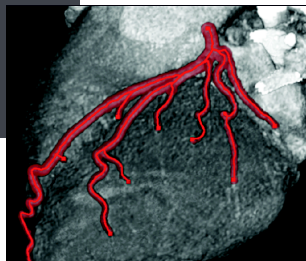
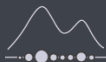
$$p(x_{0:t}|z_{1:t}) = \frac{p(x_t|x_{t-1})p(z_t|x_t)}{p(z_t|z_{1:t-1})}p(x_{0:t-1}|z_{1:t-1})$$



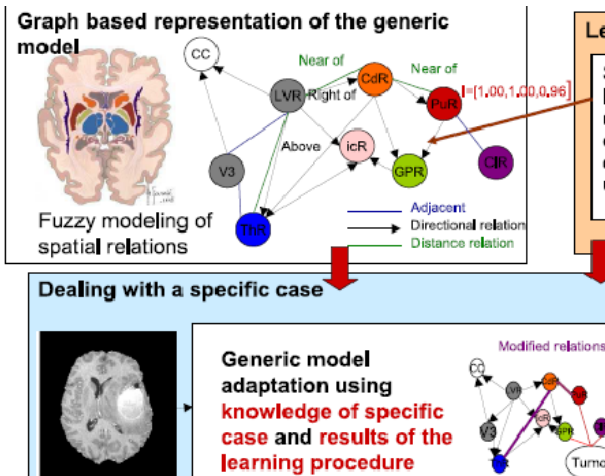
Minimal path optimization



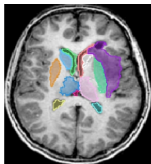
Particle filter tracking



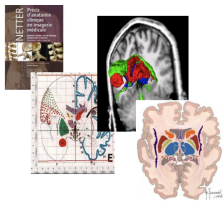
Modèles structurels



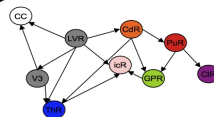
Représentation



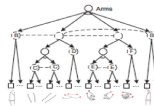
Connaissances



Représentation formelle



Graphes
[COLLIOT, DERUYVER, ...]

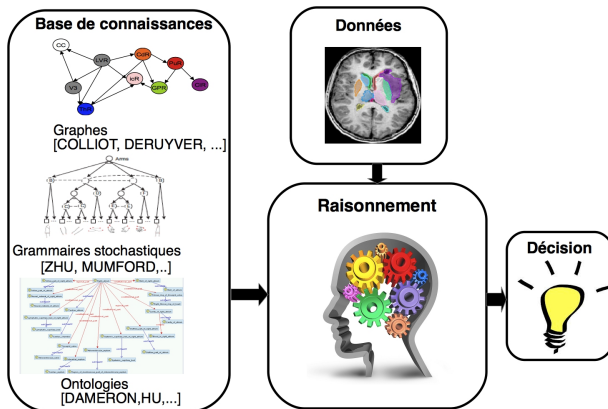


Grammaires stochastiques
[ZHU, MUMFORD, ...]



Ontologies
[DAMERON, HU, ...]

Raisonnement

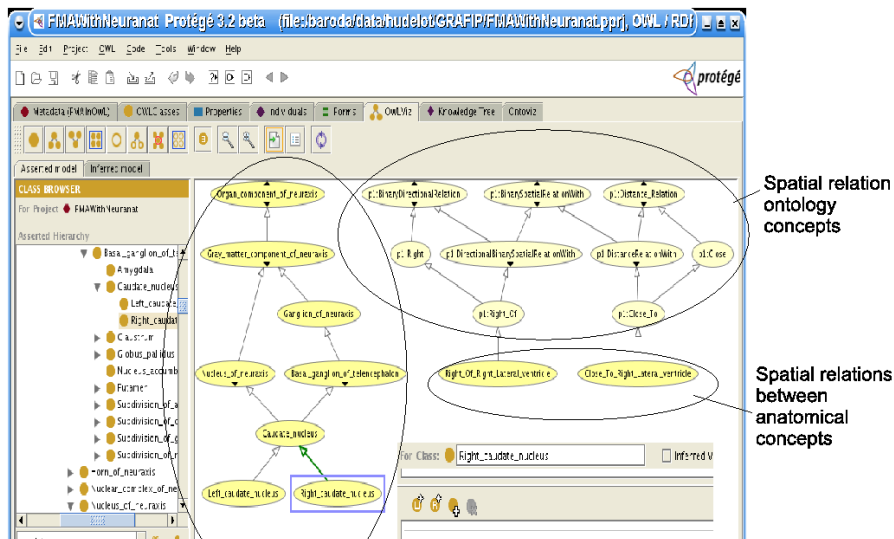


Mise en correspondance de graphes (inexacte), recalage et instanciation de modèles (ontologies, graphes conceptuels...), problèmes de satisfaction de contraintes...

Représentation de connaissances et raisonnement sur des entités spatiales et des relations spatiales

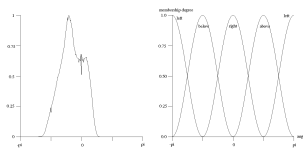
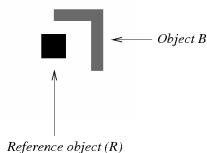
- Logiques spatiales.
- Cadre semi-quantitatif : représentations floues.
- Imprécision
 - sur les objets (absence de contours nets, segmentation grossière...),
 - sur les relations (ex : *à gauche de, assez proche de*),
 - sur le type de connaissance (ex : *le noyau caudé est proche du ventricule latéral*),
 - sur les questions posées (ex : *aller vers cet objet en restant à une certaine distance de sécurité*).

Ontologie de relations spatiales et FMA (Céline Hudelot, Jamal Atif)

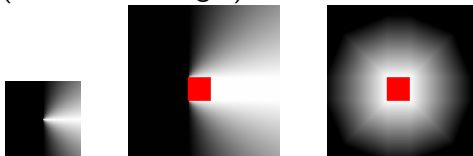


Représentations floues dans des domaines concrets

- Degré avec lequel une relation est satisfaite entre deux objets.



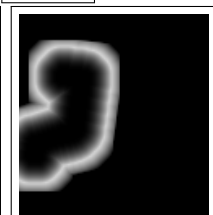
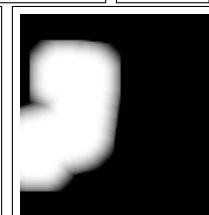
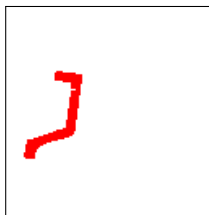
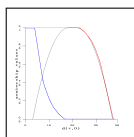
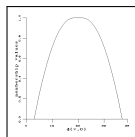
- Région de l'espace dans laquelle une relation à un objet de référence est satisfaite (à un certain degré).



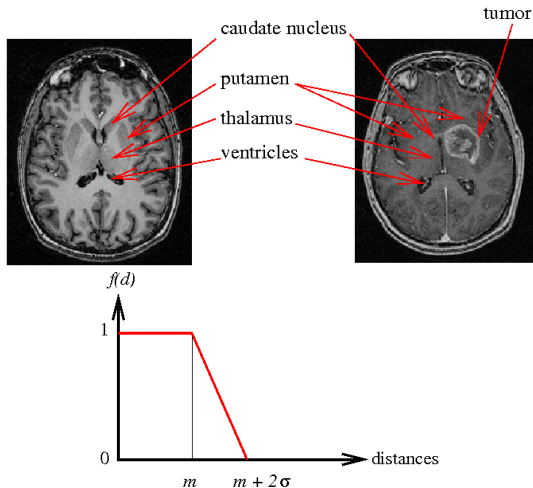
Formalisme mathématique : morphologie mathématique floue

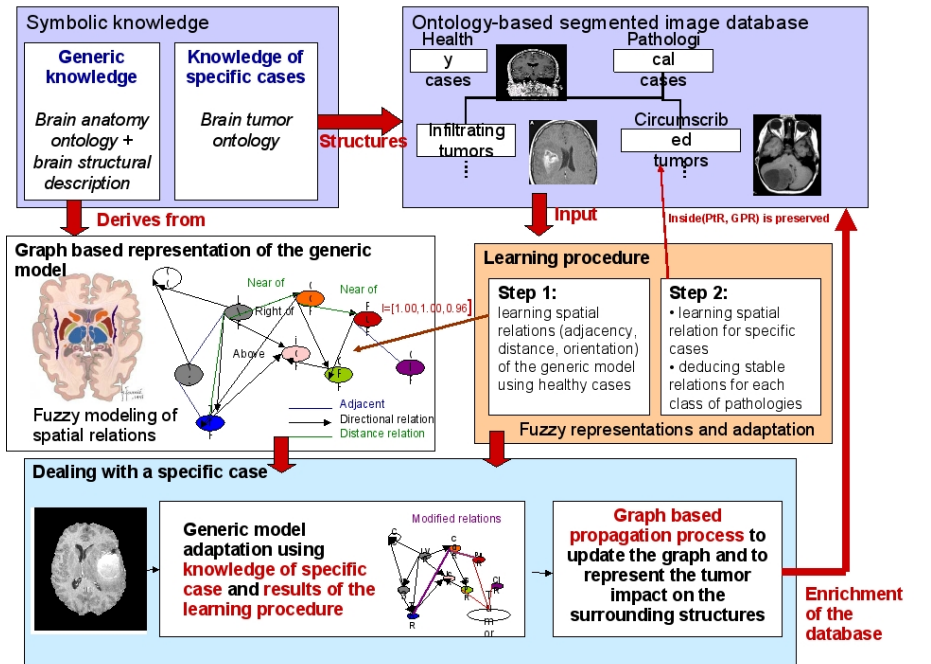
- Cadre algébrique (treillis complets).
- Equivalents flous de notions ensemblistes et algébriques, avec de bonnes propriétés.
- Relations spatiales modélisées comme une dilatation avec un élément structurant donnant la sémantique de la relation.

Exemple :



Apprentissage de relations spatiales





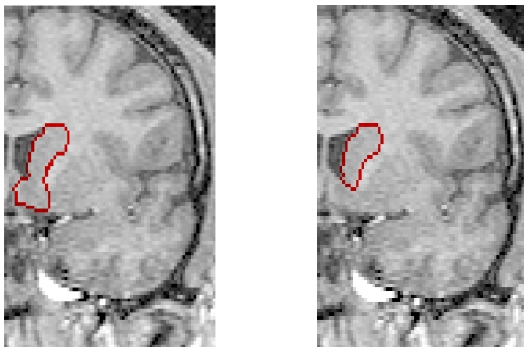
Modèles déformables avec contraintes structurelles (Olivier Colliot)

Evolution selon : $\gamma \frac{\partial \mathbf{X}}{\partial t} = \mathbf{F}_{int}(\mathbf{X}) + \mathbf{F}_{ext}(\mathbf{X})$.

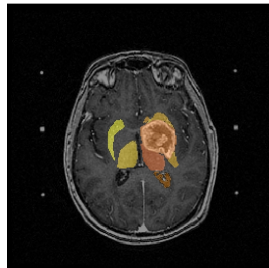
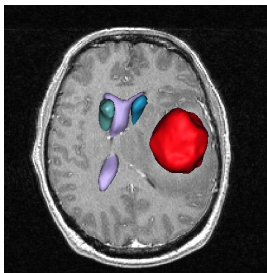
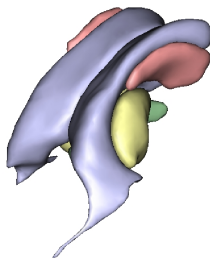
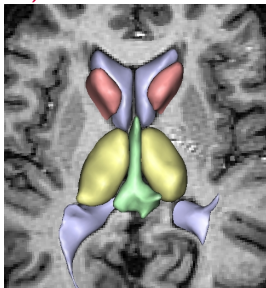
Forces internes : $\mathbf{F}_{int} = \alpha \nabla^2 \mathbf{X} - \beta \nabla^2 (\nabla^2 \mathbf{X})$ (régularisation).

Forces externes : $\mathbf{F}_{ext} = \lambda \mathbf{v} + \nu \mathbf{F}_R$

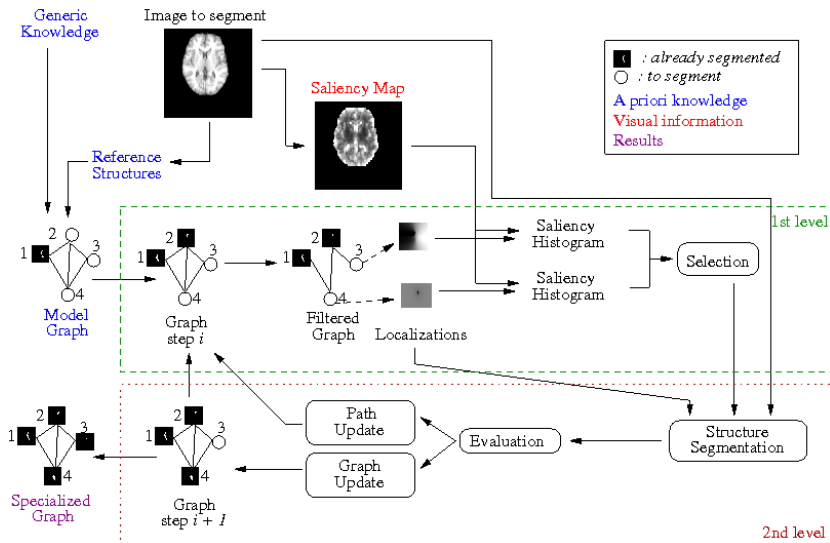
- $\mathbf{v}$: attraction vers les contours (par GVF),
- $\mathbf{F}_R$: force associée aux relations spatiales.

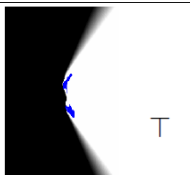
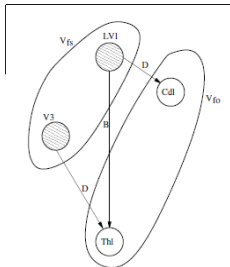
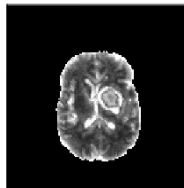
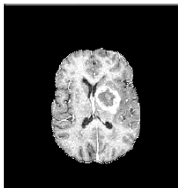
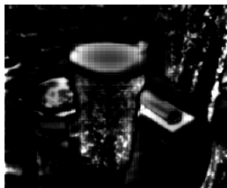
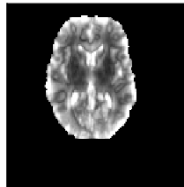
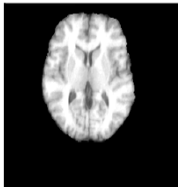
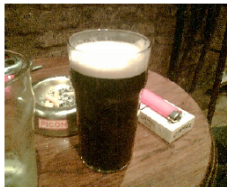


Quelques résultats de segmentation et reconnaissance (Olivier Colliot, Hassan Khotanlou)



Meilleur chemin de segmentation (Geoffroy Fouquier)

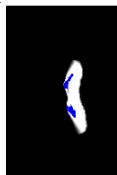




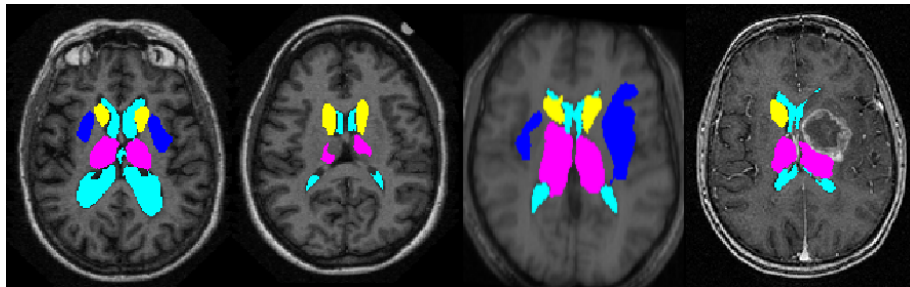
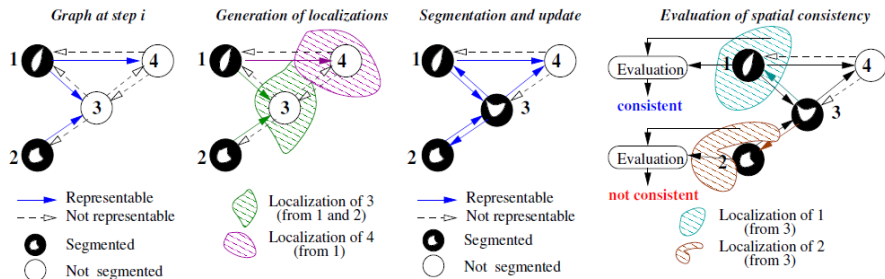
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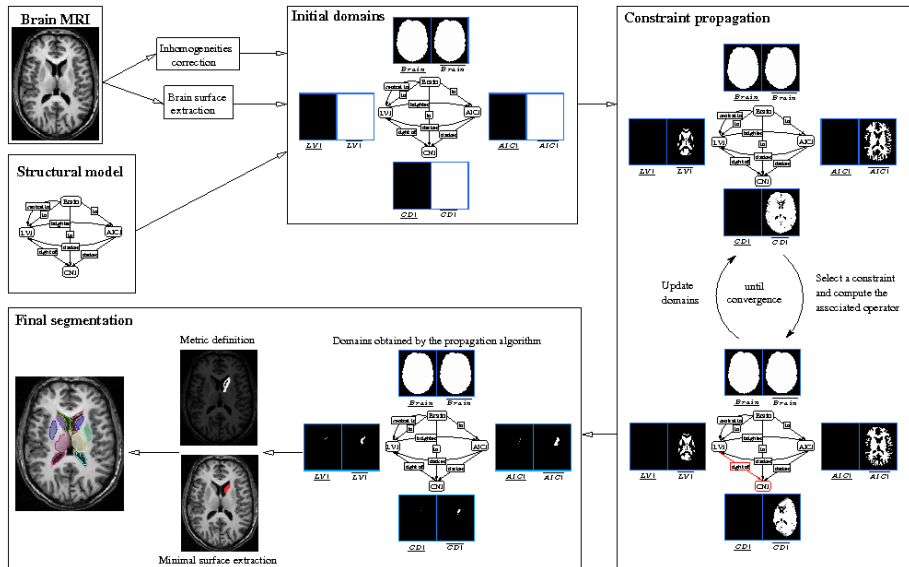
=



Evaluation et backtracking



Approche globale par CSP (Olivier Nempont)



- Variables = structures anatomiques.
- Domaine d'une variable = intervalle d'ensembles flous $[\underline{A}, \overline{A}]$.
- Exemple de contrainte : inclusion

$$C_{A,B}^{in} : \mathcal{D}(A) \times \mathcal{D}(B) \rightarrow \{0, 1\}$$

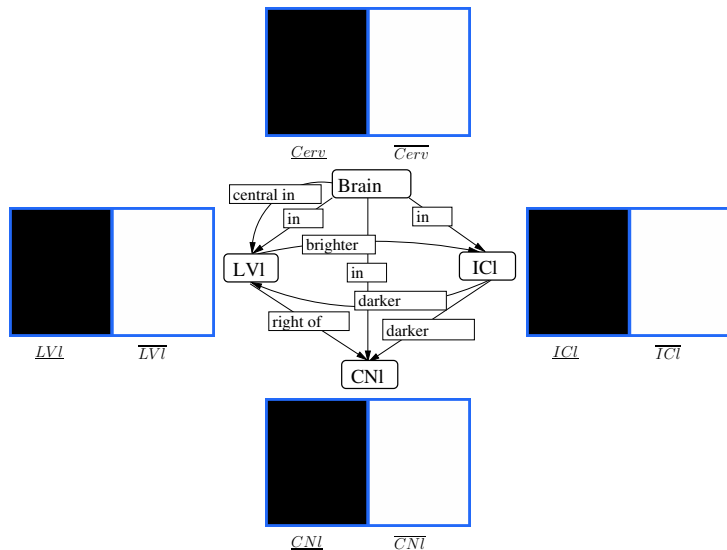
$$(\mu_1, \mu_2) \mapsto \begin{cases} 1 & \text{si } \mu_1 \leq \mu_2, \\ 0 & \text{sinon.} \end{cases}$$

- Propagateur correspondant :

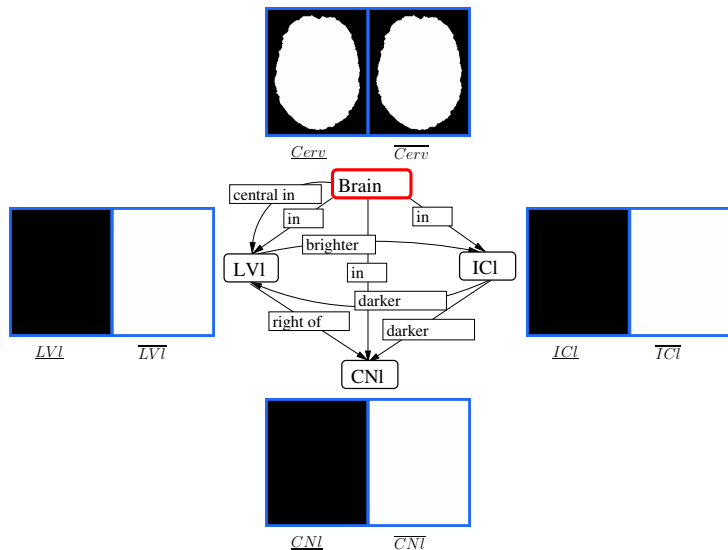
$$\frac{\langle A, B; (\underline{A}, \overline{A}), (\underline{B}, \overline{B}); C_{A,B}^{in} \rangle}{\langle A, B; (\underline{A}, \overline{A} \wedge \overline{B}), (\underline{B} \vee \underline{A}, \overline{B}); C_{A,B}^{in} \rangle}$$

- Ordonnancement des propagateurs et application itérative.

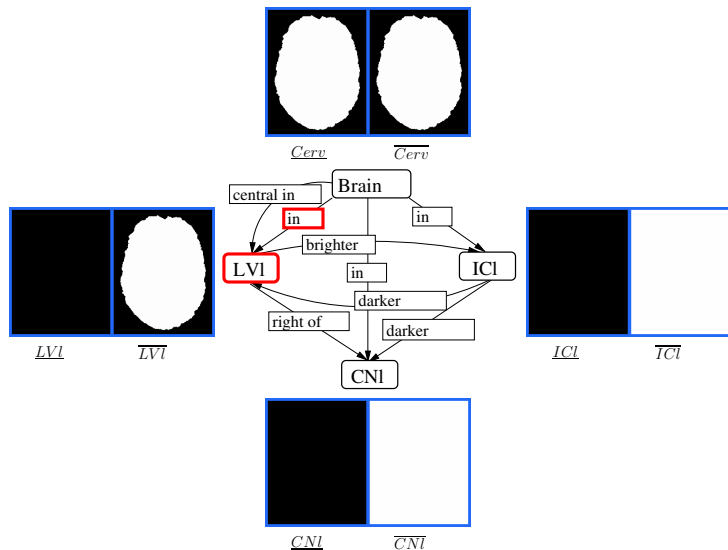
Propagation de contraintes



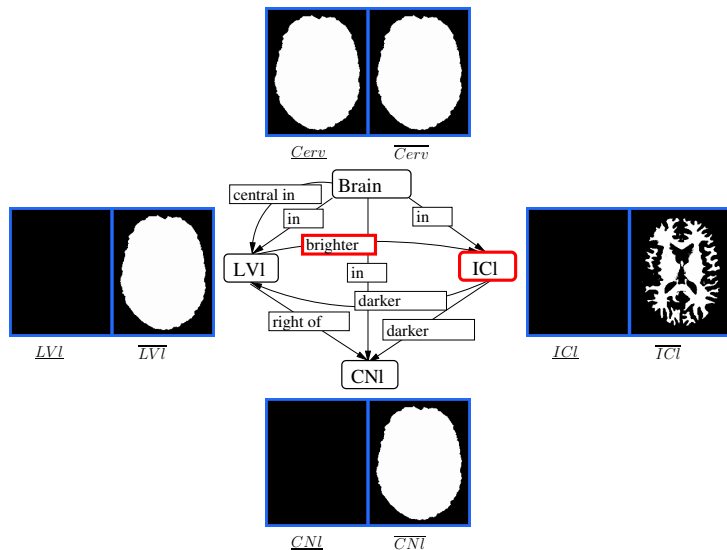
Propagation de contraintes



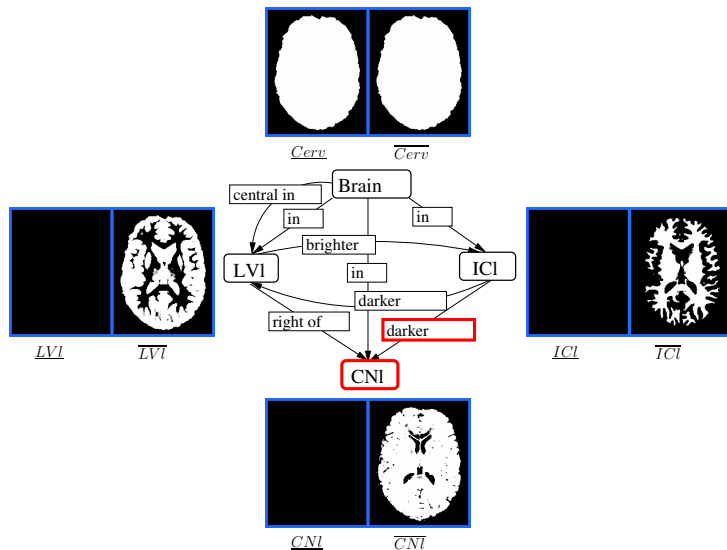
Propagation de contraintes



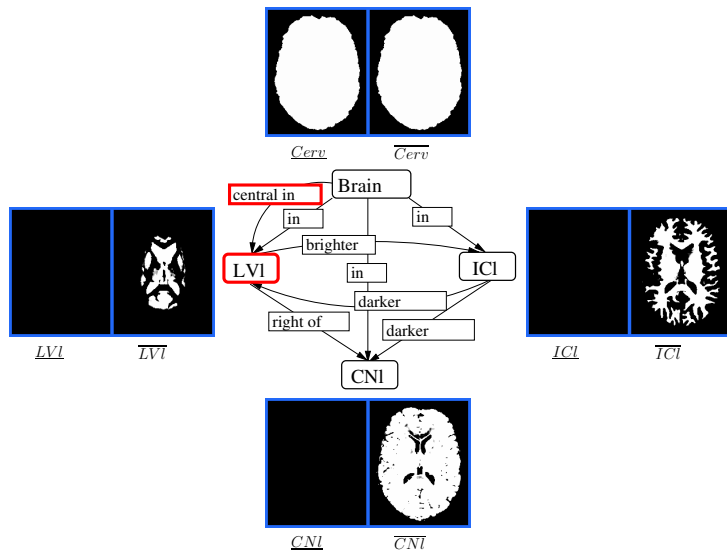
Propagation de contraintes



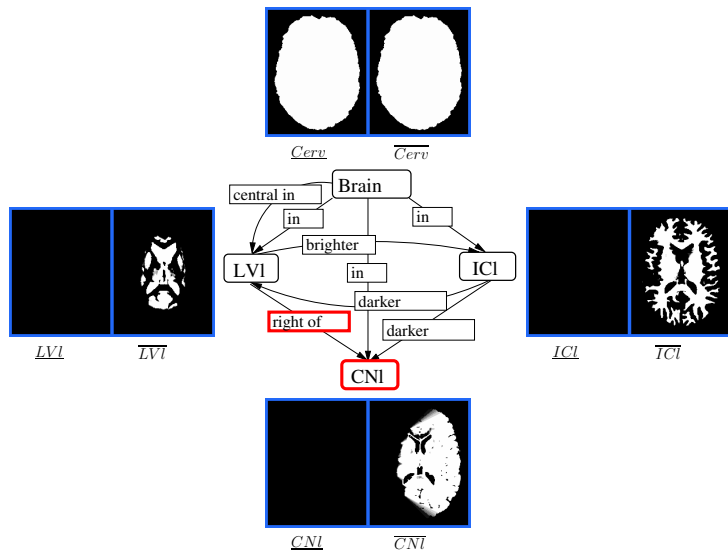
Propagation de contraintes

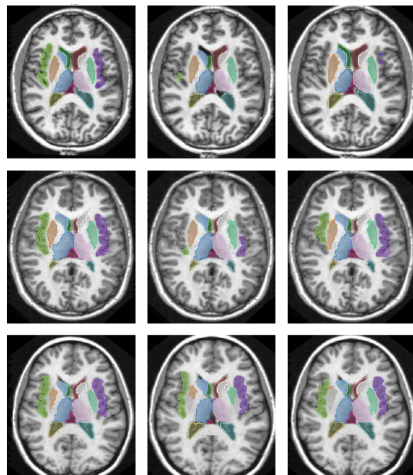
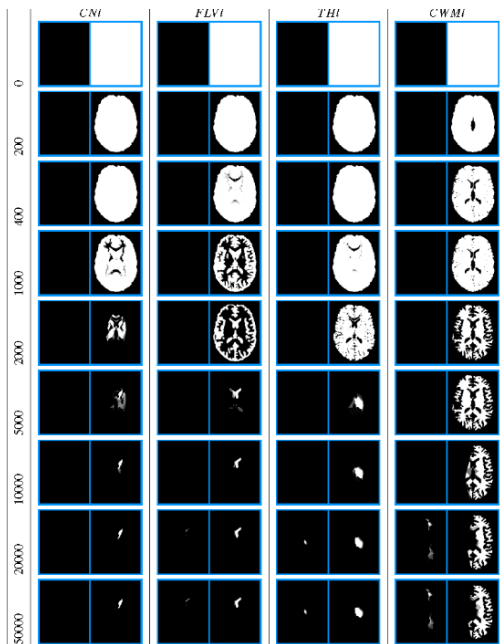


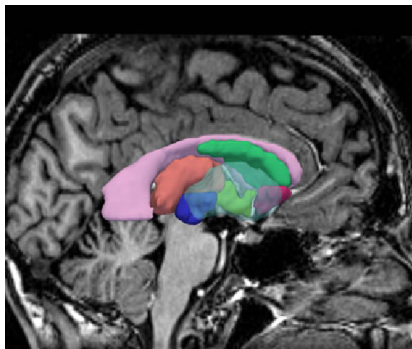
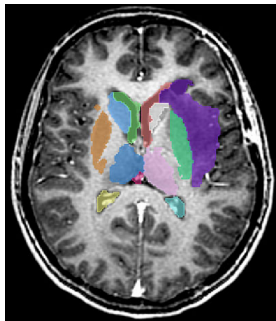
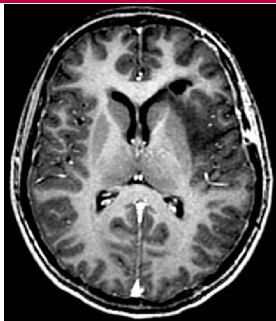
Propagation de contraintes



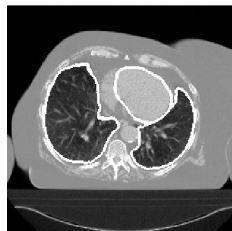
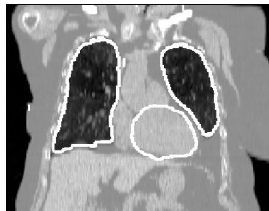
Propagation de contraintes







Modèles de structure + physiologie (S. Chambon, A. Moreno)



- Breathing model

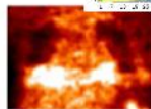
- Image data



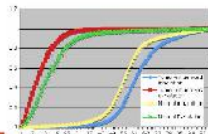
CT at end-expiration

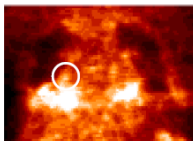


CT at end-inspiration



PET

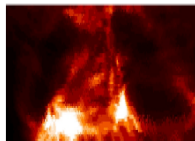




(a)



(b)



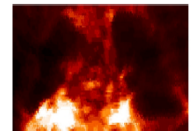
(c)



(d)



(e)



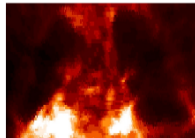
(f)



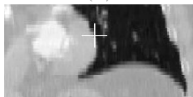
(g)



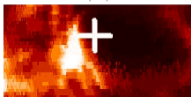
(h)



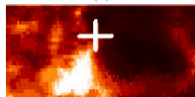
(i)



(j)



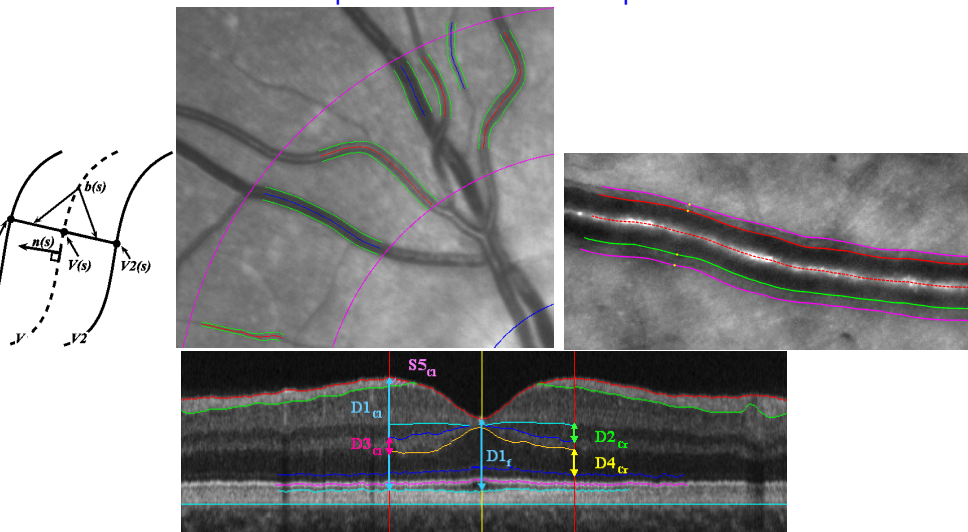
(k)



(l)

Imagerie de la rétine (avec l'ISEP et les XV-XX)

Modèles déformables couplés avec contrainte de parallélisme



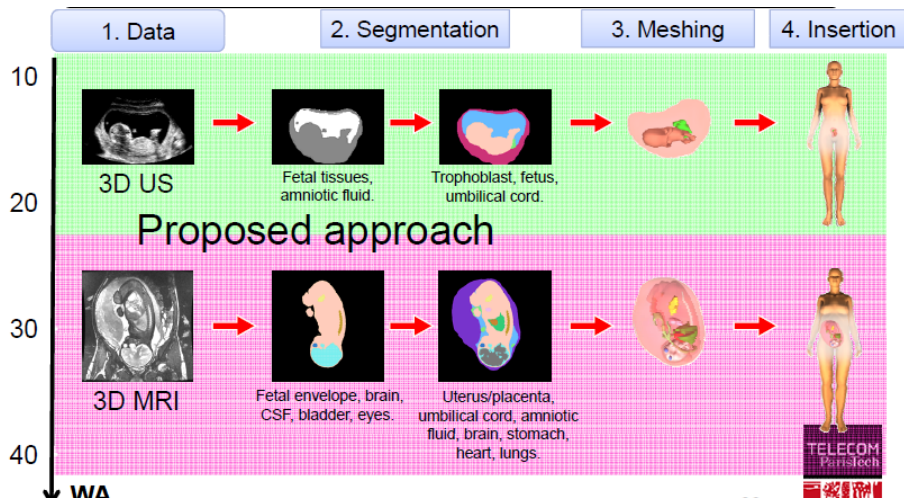
Modèles à partir d'images

Exemple : modélisation réaliste du corps humain (WHIST Lab, CHU Bicêtre...)

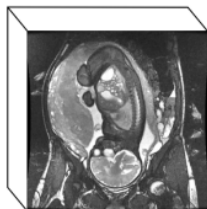
Schéma typique :

- 1 Modèles (signal, image, connaissances, domaine...).
- 2 Segmentation et reconnaissance des structures anatomiques.
- 3 Construction de modèles numériques réalistes (voxels étiquetés, maillages).
- 4 Déformations (position, âge, corpulence).
- 5 Simulations (ex : dosimétrie numérique).

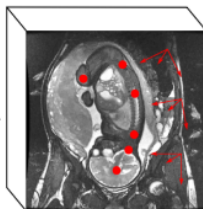
Fœtus et femme enceinte (J. Anquez, L. Bibin, S. Dahdouh, J. P. de la Plata)



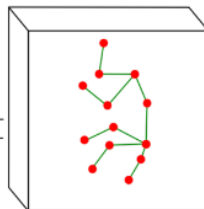
1. Caractérisation de la position fœtale



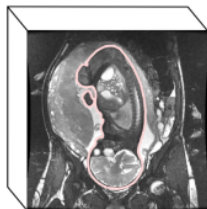
Détection des P_i



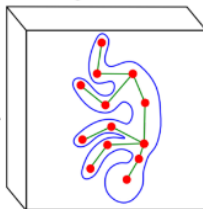
Instanciation de $\mathcal{O}$



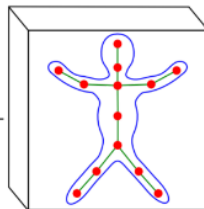
2. Segmentation du fœtus



Recalage du modèle



Modèle articulé





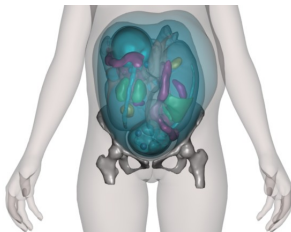
13 SA (US3D)



23 SA (IRM)

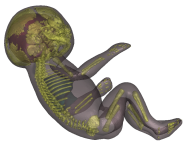
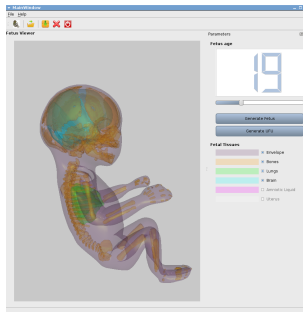
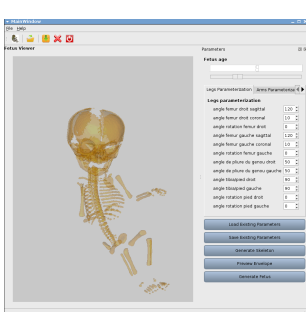


31 SA (IRM)

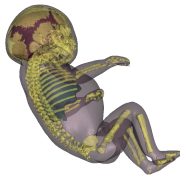


Modèles disponibles (pour la recherche) sur
<http://femonum.telecom-paristech.fr/>

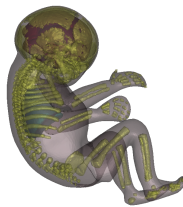
Modèle de croissance du fœtus (S. Dahdouh, A. Serrurier)



18 SA

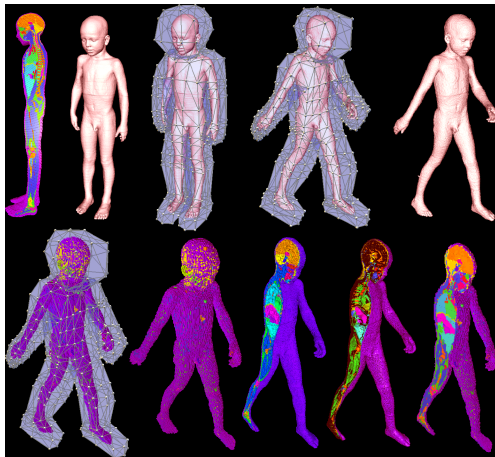
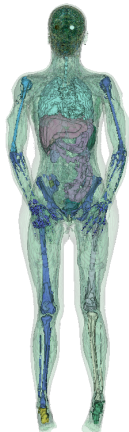
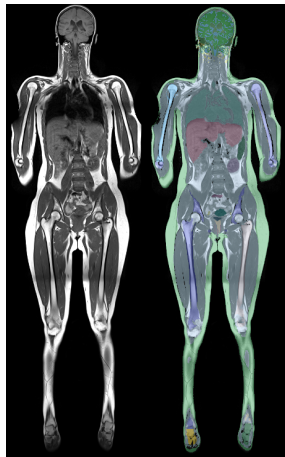


26 SA

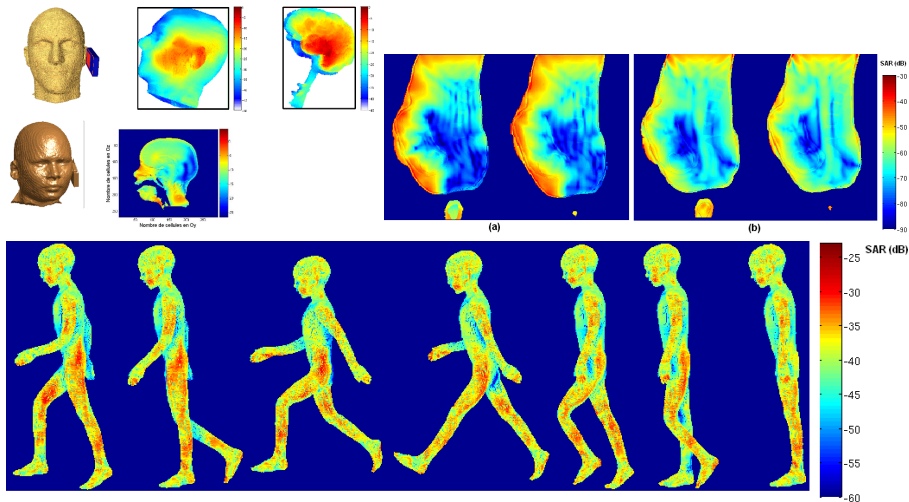


32 SA

Modèles d'enfants (G. Fouquier, S. Dahdouh, N. Faraj)



Application à la dosimétrie numérique (avec Orange Labs)



Quelques autres modèles et problèmes ouverts

- Modélisation de l'information bipolaire :
 - positive : observations, préférences,
 - négative : contraintes.
- Modélisation structurelle spatio-temporelle.
- Logiques (de description, floues, morphologiques...) $\Rightarrow$ raisonnement plus symbolique, abduction, révision...
- Apprentissage : données et connaissances expertes ?
- Fossé sémantique et ancrage de symboles.
- Annotation sémantique.
- Description verbale du contenu d'images.
- ...

Remerciements

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