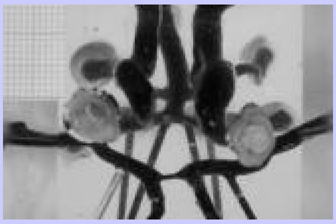
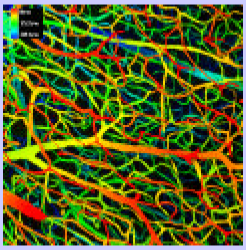
Medical Image Analysis





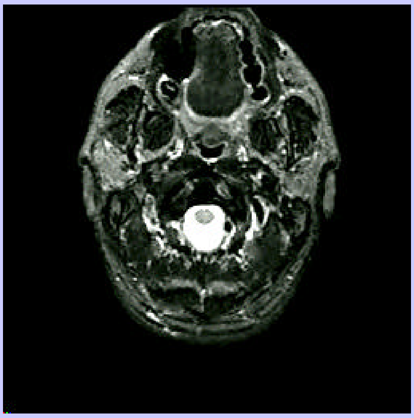
Application to 3D angiography

Grégoire Malandain

INRIA

2D Visualisation

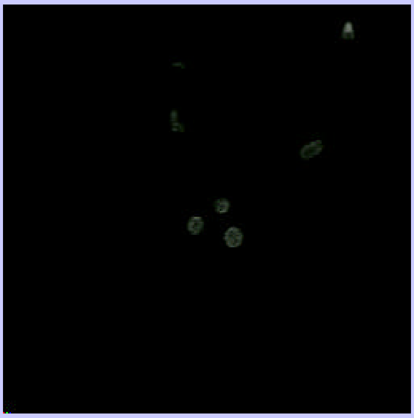
Adapted to large *volumes*



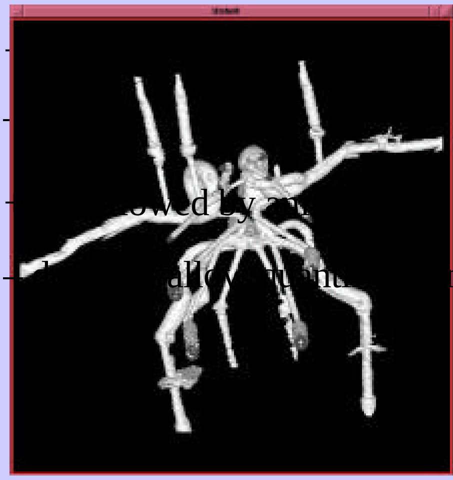
2D Visualisation

Adapted to large *volumes*

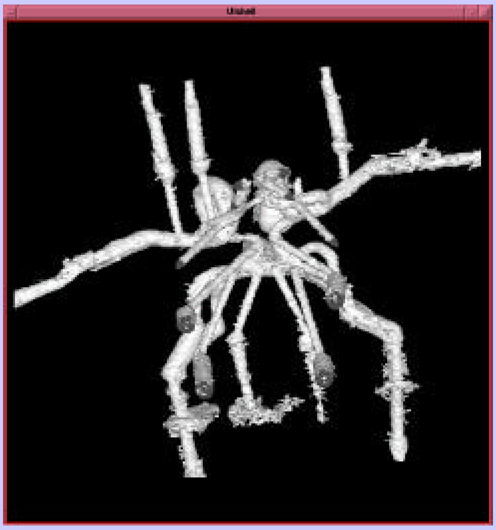
… but not to vessels



Maximum Intensity Projection



Isosurfaces

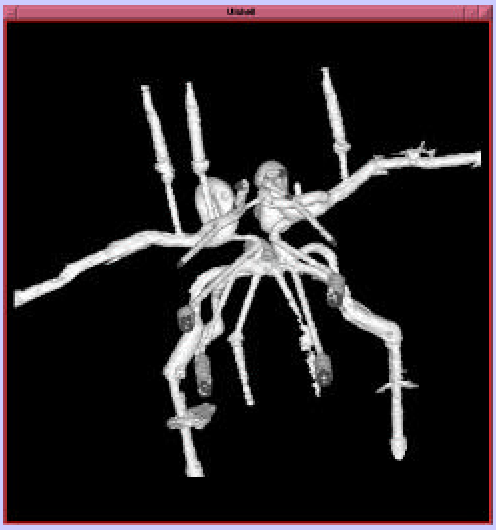


+ It's a segmentation
+ Allows quantification
– Effectiveness?

Threshold = 14

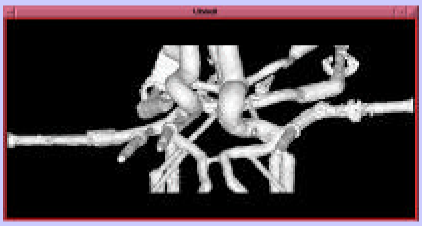
16/01/2003 Grégoire Malandain INRIA 5

Isosurfaces



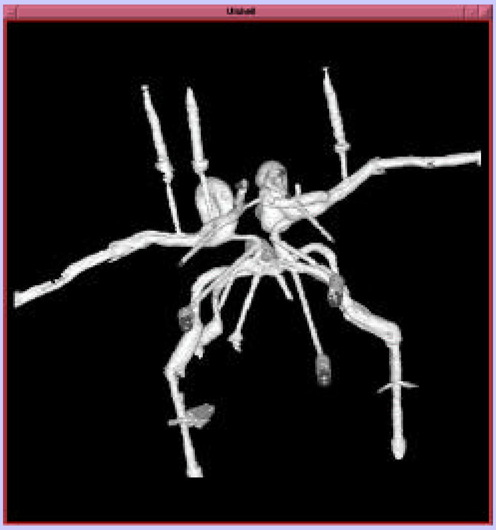
+ It's a segmentation
+ Allows quantification
– Effectiveness?

Threshold = 29



16/01/2003 Grégoire Malandain INRIA 6

Isosurfaces

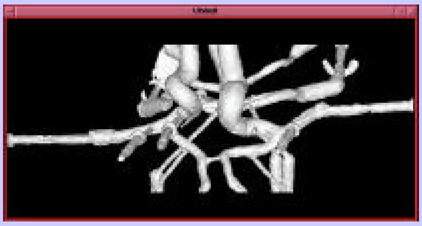


+ It's a segmentation

+ Allows quantification

– Effectiveness?

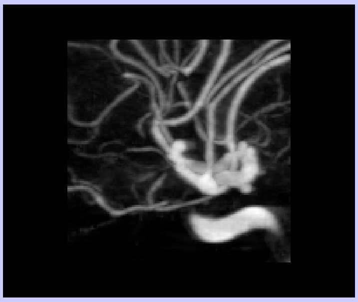
Threshold = 44

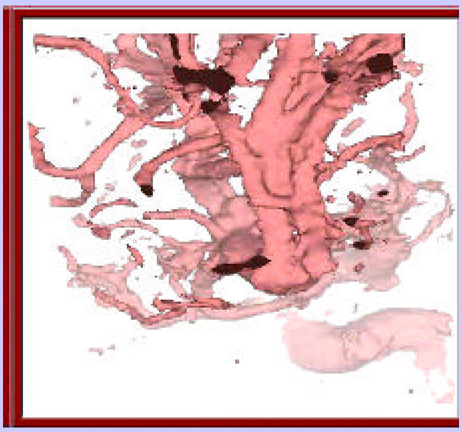


Isosurfaces

– Effectiveness of segmentation?

Topology changes





Segmentation issues

- Topological correctness

  Extraction of the central line

  Separation of adjacent structures

  Retrieval of junctions

- Geometrical correctness

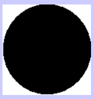
  Measure of length, diameter, area, ...

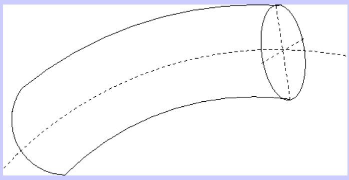
Principles

- Vessel modelling
- Vessel characterisation
- Central line extraction
- Radius estimation

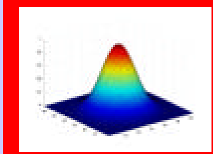
3D vessels modelling

- Tubular-like structures
  - Shape of the section?

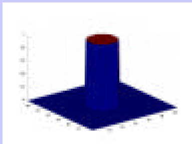




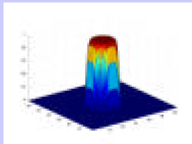
  - Intensity distribution inside the section?



Gaussian

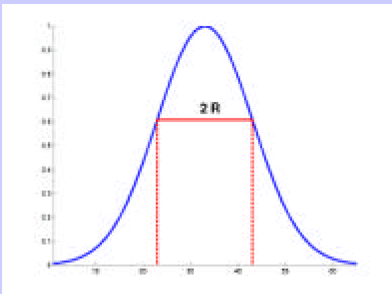


Constant



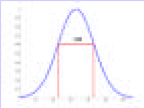
Gaussian * Constant

Intensity profile: 1D derivatives

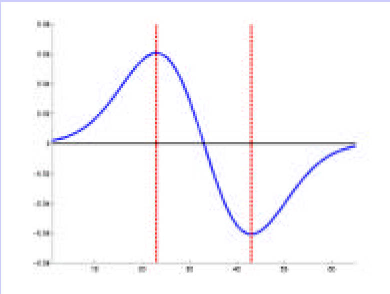


$$I(M) = Ce^{-(OM^2/2R^2)}$$

Intensity profile: 1D derivatives



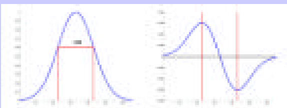
$$I(M) = Ce^{-(OM^2/2R^2)}$$



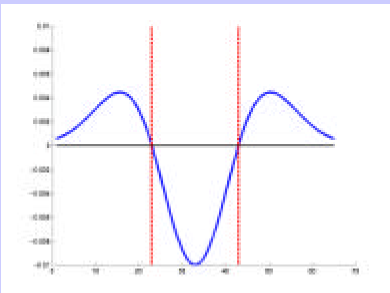
$$\frac{\partial I}{\partial x}$$

16/01/2003  Grégoire Malandain INRIA 13

Intensity profile: 1D derivatives



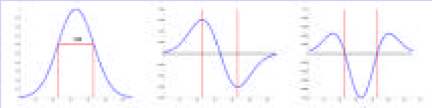
$$I(M) = Ce^{-(OM^2/2R^2)}$$



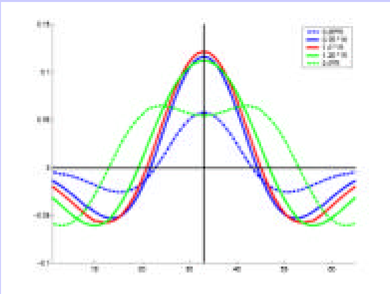
$$\frac{\partial^2 I}{\partial x^2}$$

16/01/2003  Grégoire Malandain INRIA 14

Intensity profile: 1D derivatives



$$I(M) = Ce^{-(OM^2/2R^2)}$$



Maximal response

$$\Leftrightarrow Resp(M) > Resp(M \pm e)$$

$$Resp(M) = \frac{\partial I}{\partial x}(M-r) - \frac{\partial I}{\partial x}(M+r)$$

Intensity profile: 3D derivatives

- Matrix of second derivatives: Hessian

$$H\,I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & I_{yz} \\ I_{xz} & I_{yz} & I_{zz} \end{bmatrix} = [V_1 \ V_2 \ V_3] \begin{bmatrix} l_1 & & \\ & l_2 & \\ & & l_3 \end{bmatrix} \begin{bmatrix} {}^T V_1 \\ {}^T V_2 \\ {}^T V_3 \end{bmatrix} \qquad l_i = I_{v_i v_i}$$

- Shape characterisation (white structure on dark background):

Sheet-like structure: $|l_1| >> |l_2|, |l_3| \quad l_1 < 0 \quad l_2, l_3 \approx 0$

Tubular structure: $|l_1|, |l_2| >> |l_3| \quad l_1, l_2 < 0 \quad l_3 \approx 0$

Cylinder direction: $\vec{V}_3$

Intensity profile: 3D response

- Vector of first derivatives: gradient $\nabla I = \begin{bmatrix} I_x \\ I_y \\ I_z \end{bmatrix}$

Cylinder direction: $\vec{\mathrm{v}}_3$

Directions in the orthogonal section: $\vec{\mathrm{v}} = \cos(a)\,\vec{\mathrm{v}}_1 + \sin(a)\,\vec{\mathrm{v}}_2$

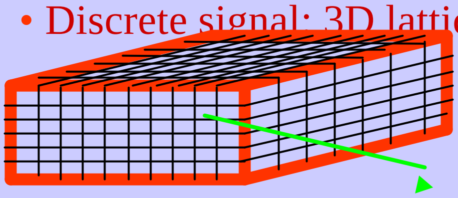
- 3D response

$$R(M) = \int_0^{2p} -\left(\vec{\nabla} I(M + r\,\vec{\mathrm{v}}).\vec{\mathrm{v}}\right) da$$

Maximal response $\Leftrightarrow R(M) > R(M \pm e\,\vec{\mathrm{v}}_{\mathrm{i}}), \quad \mathrm{i} = 1,2$

Derivatives computation

- Discrete signal: 3D lattice of voxels



M(i,j,k)=I(x,y,z)

$\frac{\partial}{\partial x} I(x, y, z)$?

- Convolution with a low-pass filter

$$\frac{\partial}{\partial x} I(x, y, z) \approx \frac{\partial}{\partial x}\left(G(x, y, z) * I(x, y, z)\right) = \left(\frac{\partial G}{\partial x}\right) * I$$

Practical issues

- Vessel of unknown radius σ_0

  Gaussian intensity profiles

- Derivatives computed with a Gaussian σ

  Response computed at a distance $\theta\sigma$

- Multi-scale extraction: several σ's

  How to compare scales?

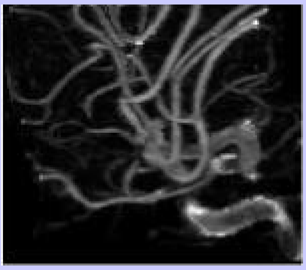
Multiscale issues

- Comparing scales

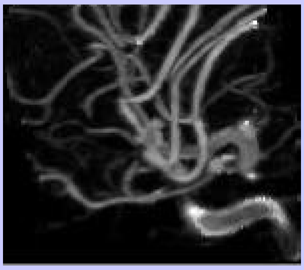
  γ-derivatives: $\partial_{x,g} = s^{g}\partial_{x}$

  invariance w.r.t. scaling: γ=1

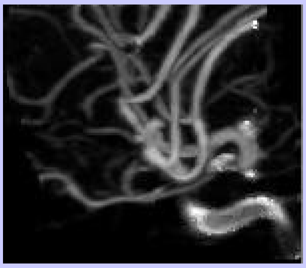
- Response extrema in space and in scale
- The profile modelling by a Gaussian
  - Optimal value of θ
  - Estimation of σ_0



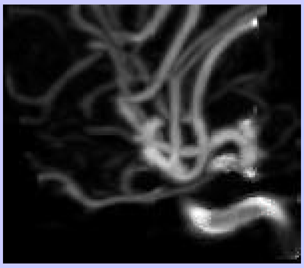
σ=1.0



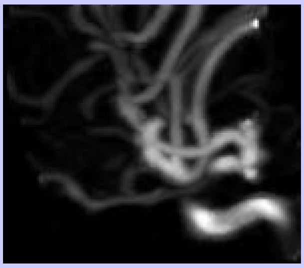
σ=1.28



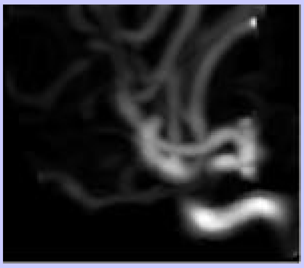
σ=1.65



σ=2.12

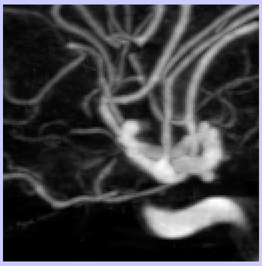


σ=2.72

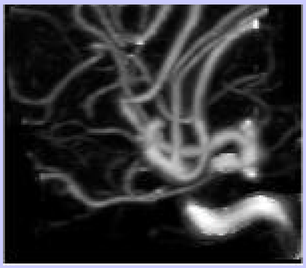


σ=3.5

Segmentation issues



Original image

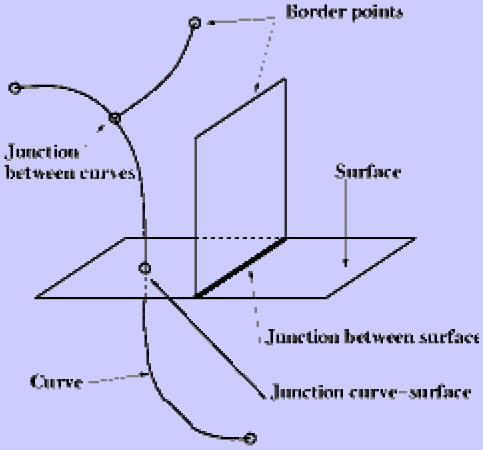


Multi-scale response

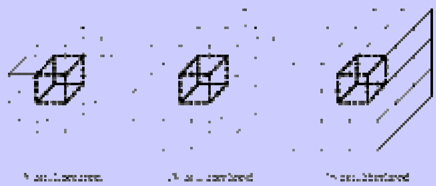
Multi-scale extrema

- How to recognise curves in the extrema?

3-D Digital Topology



3-D Digital Topology



C^* Number of (26-)connected components of the foreground in the (26-)neighborhood

$\overline{C}$ Number of (6-)connected components of the background in the (18-)neighborhood, (6-adjacent to the centre)

3-D Digital Topology

- Thinning the extrema

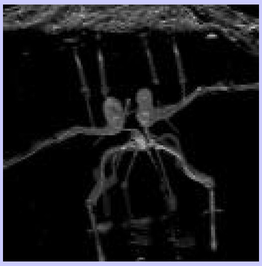
  Iterative removal of simple points $\left(C^{*} = \overline{C} = 1\right)$

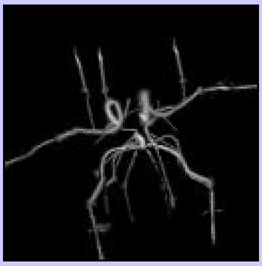
- Removing small pieces of curve

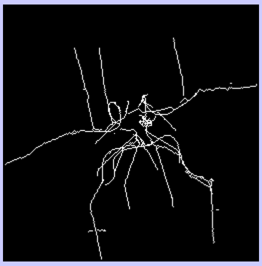
  Simple curves $\left(C^{*} = 2\,,\overline{C} = 1\right)$

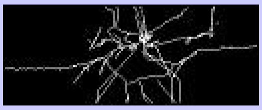
  are ended either by curves junctions $\left(C^{*} > 2\,,\overline{C} = 1\right)$

  or borders (i.e. simple points)

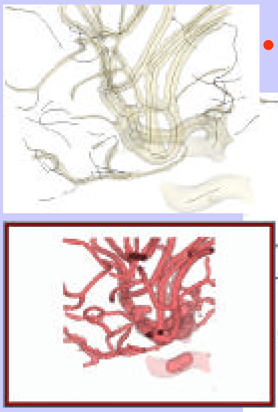

Original image


Multiscale response


Multiscale extrema / Pruned extrema



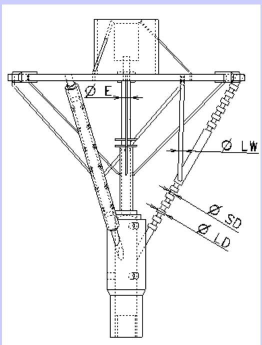
Reconstructions

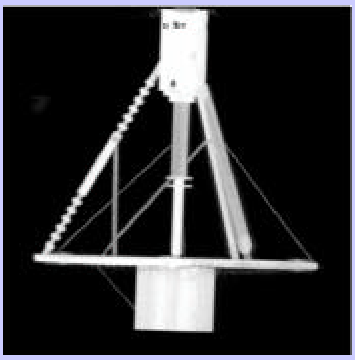


- Simple curves smoothing

Advantages of both MIP and isosurfaces

About radius estimation





LW = 2 mm E = 4 mm

SD = 2 mm LD = 4 mm

Voxel = 0.267 mm^3

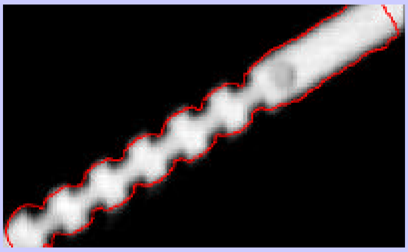
About radius estimation

- Estimation

  LW: 2.018 mm   E: 3.884-3.968 mm

  SD: 2.14 mm   LD: 3.6 mm

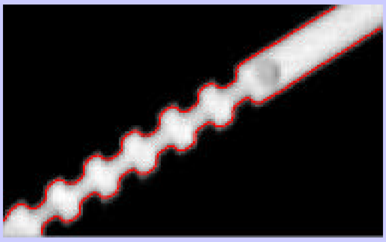
- is disturbed by 3-D computation



16/01/2003   Grégoire Malandain   INRIA   29

About radius estimation

- Estimation in 2D resampled sections

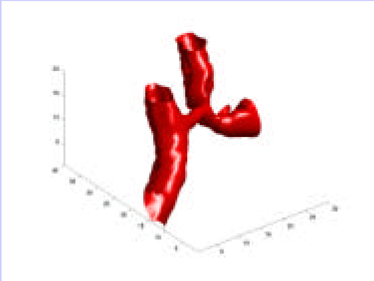


- Better but computationally more expensive

16/01/2003   Grégoire Malandain   INRIA   30

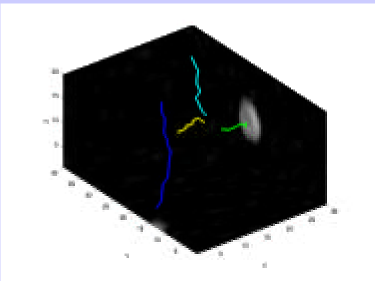
2D orthogonal sections resampling

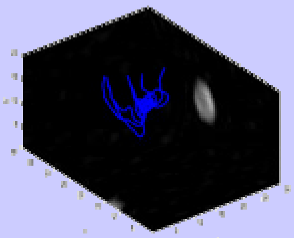
- Subvolume

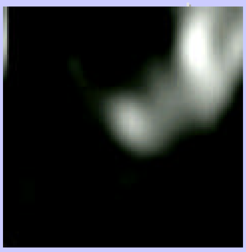


2D orthogonal sections resampling

- Subvolume (scanner)

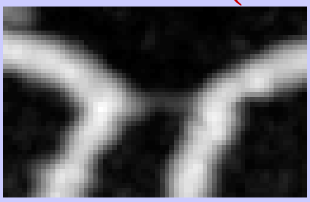


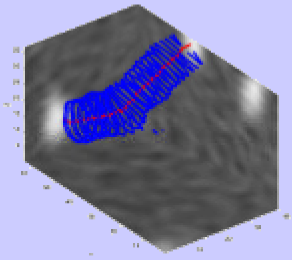


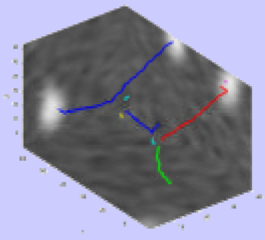


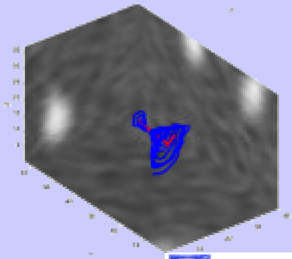
2D orthogonal sections resampling

- Subvolume (MRA)



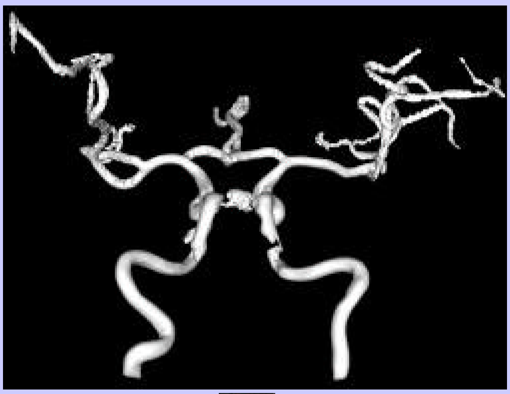


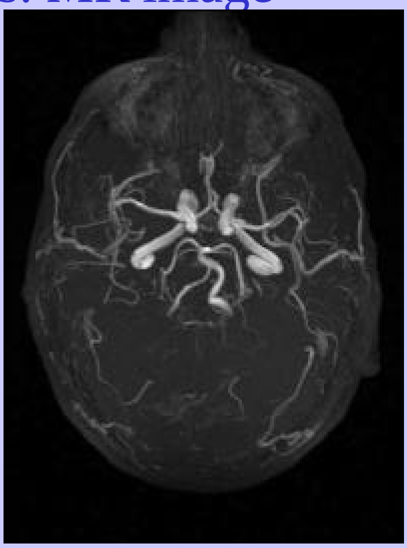




16/01/2003 Grégoire Malandain 33

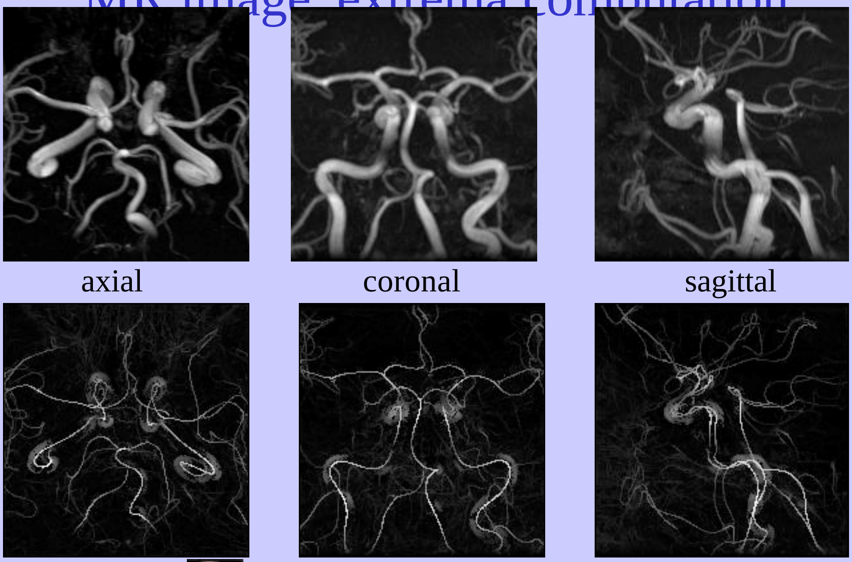
2-D cross-sections: MR image



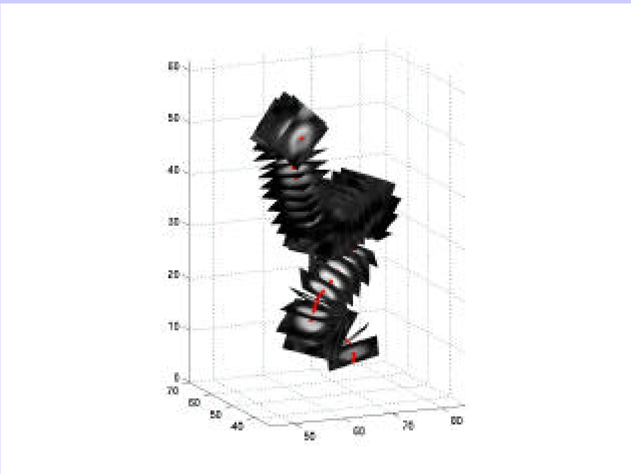


16/01/2003 Grégoire Malandain 34

MR image: extrema computation



MR image: 2-D cross-sections



Resampling with cubic splines

Travelling inside the vessel

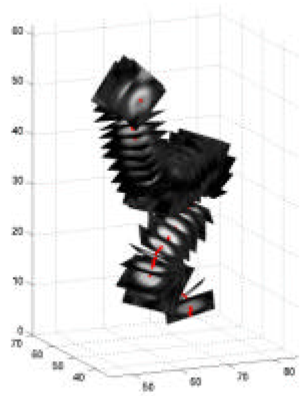
2-D cross-sections: segmentation

- ✓ Thresholding: iso-contours
- ✓ Edges detection
  - ↪ zero-crossings

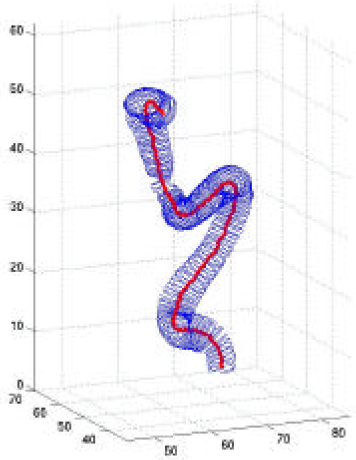
$$\Delta I = 0$$

$$\overrightarrow{\nabla I}.HI.\overrightarrow{\nabla I} = 0$$

- ✓ Sub-pixel accuracy



2-D cross-sections: segmentation

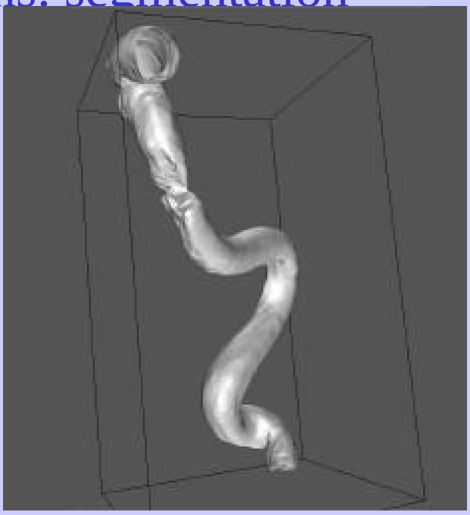


2-D cross-sections: segmentation

- ✓ allows to build a 3-D mesh

(computational geometry, Prisme team)

- ✓ numerical simulation



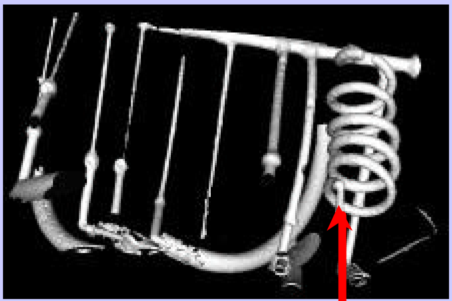
16/01/2003 Grégoire Malandain INRIA 39

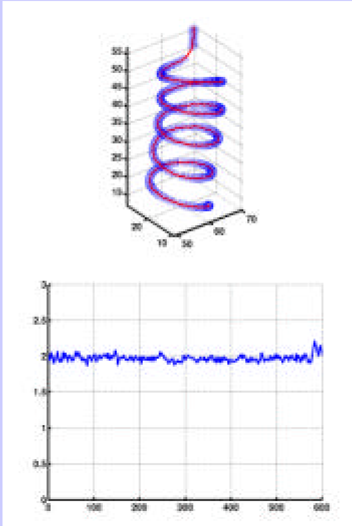
Synthetical model

Known vessels radii

16/01/2003 Grégoire Malandain INRIA 40

2-D cross-sections: segmentation





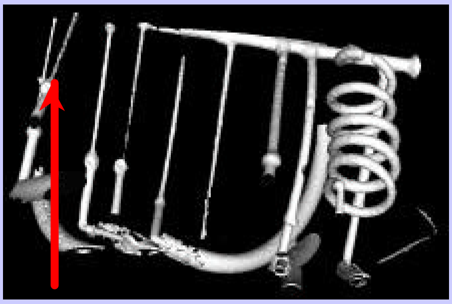
Diameter = 2.0 mm

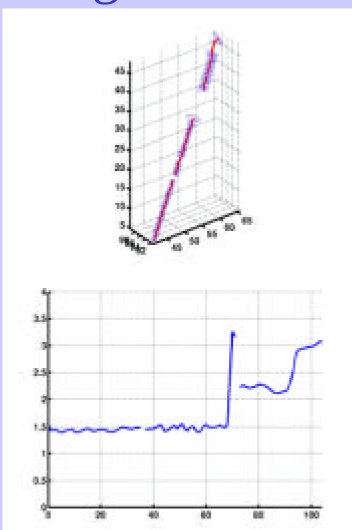
$$\overrightarrow{\nabla I}.HI.\overrightarrow{\nabla I} = 0$$

derivatives with gaussian of σ = 0.5 voxel

16/01/2003 Grégoire Malandain INRIA 41

2-D cross-sections: segmentation





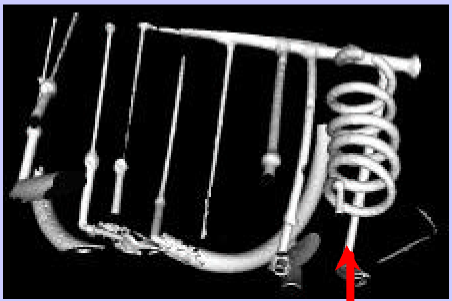
Diameter < 1.0 mm

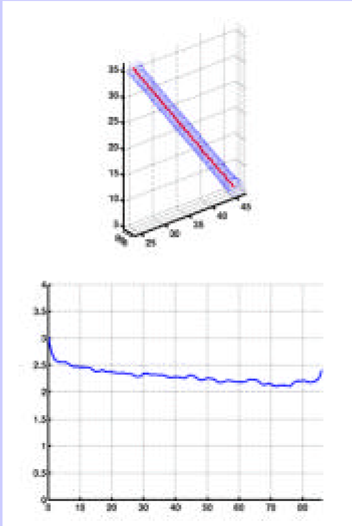
$$\overrightarrow{\nabla I}.HI.\overrightarrow{\nabla I} = 0$$

derivatives with gaussian of σ = 0.5 voxel

16/01/2003 Grégoire Malandain INRIA 42

2-D cross-sections: segmentation



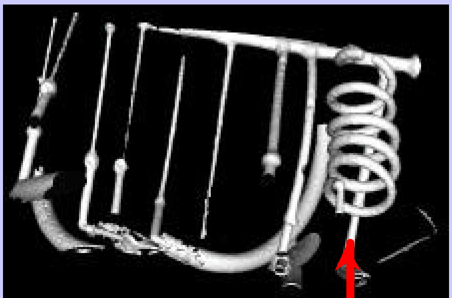


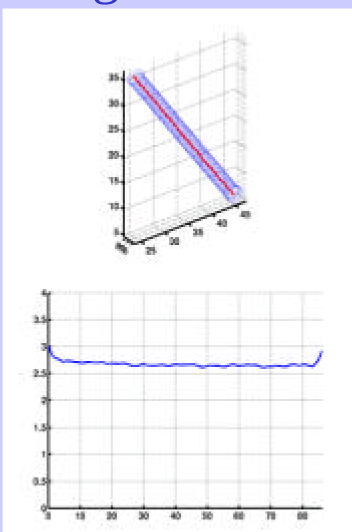
Diameter = 2.7 mm

$$\overrightarrow{\nabla I}.HI.\overrightarrow{\nabla I} = 0$$

derivatives with gaussian of σ = 0.5 voxel

2-D cross-sections: segmentation



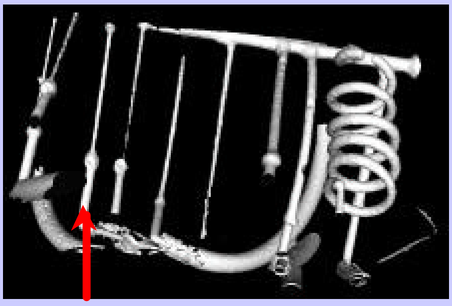


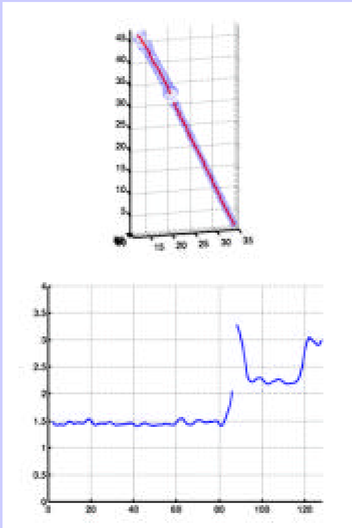
Diameter = 2.7 mm

$$\overrightarrow{\nabla I}.HI.\overrightarrow{\nabla I} = 0$$

derivatives with gaussian of σ = 1.0 voxel

2-D cross-sections: segmentation



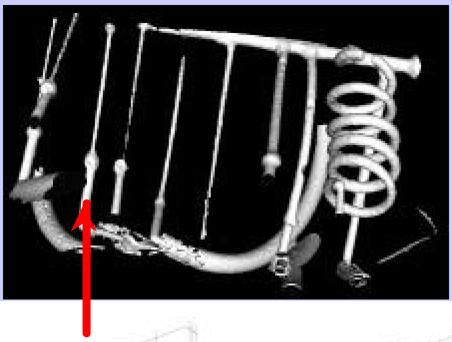


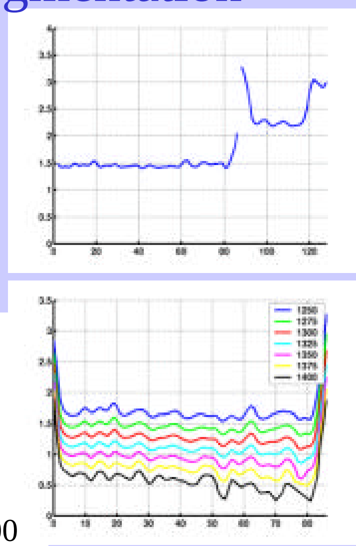
Diameter < 1.0 mm

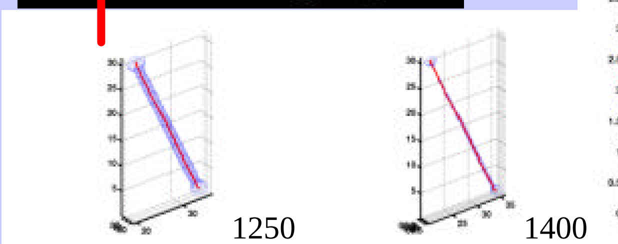
$$\overrightarrow{\nabla I}.HI.\overrightarrow{\nabla I} = 0$$

derivatives with gaussian of
σ = 0.5 voxel

2-D cross-sections: segmentation







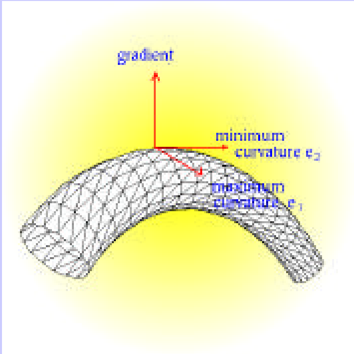
Pre-processing?

- Isotropic diffusion

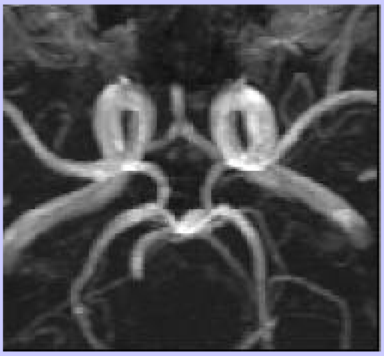
$$\frac{\partial I}{\partial t} = \Delta I = div(\nabla I) \quad \Rightarrow \quad I(t) = G_t * I(0)$$

- Anisotropic diffusion

$$\frac{\partial I}{\partial t} = div\left(g(|\nabla I|)\nabla I\right) = f_1 I_{\nabla I \nabla I} + f_2\left(\Delta I - I_{\nabla I \nabla I}\right)$$



Pre-processing?

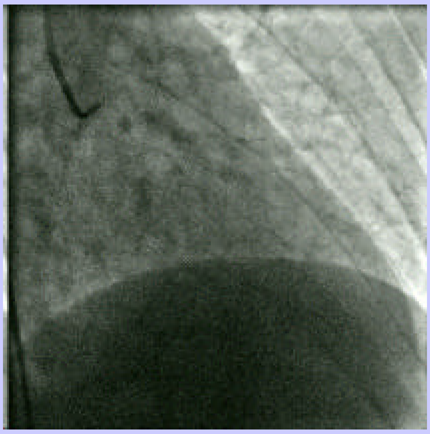


Tomographie à transmission et mouvement :
application à l'angiographie rayon X cardiaque

Motivations

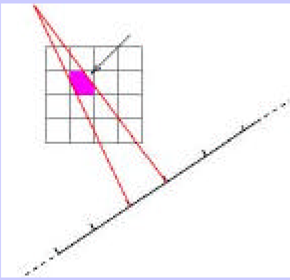
- Contexte diagnostique et interventionnel léger :
  détection / quantification 3D de sténoses
- Contexte interventionnel lourd :
  modèle patient pour la chirurgie mini-invasive robotisée

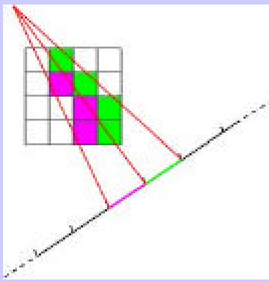
Angiographie cardiaque rotationnelle



Problème

- Voxels v_i
- Pixels p_j
- R_j vecteur des contributions des voxels au pixel p_j





$$R_j.v = p_j$$
$$R.v = p$$

Résolution

- Système linéaire de grande taille, sous-déterminé (+bruit de mesure)
- Méthodes (R, p) $\rightarrow$ v :
  - analytiques (FBP)
  - algébriques (ART, SIRT)
  - stochastiques (EM)
  - optimisation (CG)

Tomographie statique

- Observation en transparence (rayons-X)
- Plusieurs angles de vues
- ~~Objet statique~~

La matrice des contributions des voxels aux pixels est *modifiée par le mouvement* de l'objet observé

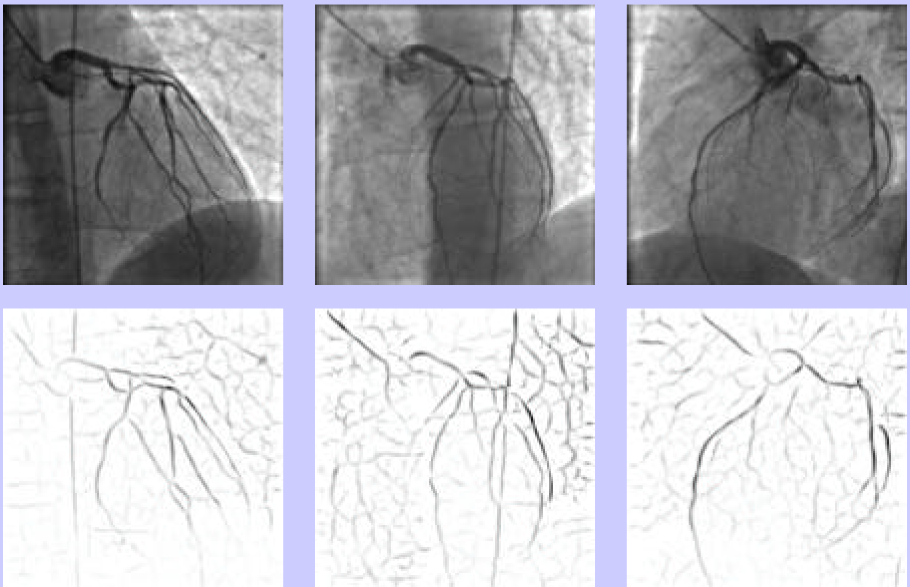
Tomographie dynamique

- Pour chaque vue :
  - Pour chaque voxel :
    - *on déforme son centre*
    - on projette le centre déformé
    - on l'attribue au pixel dans lequel la projection arrive

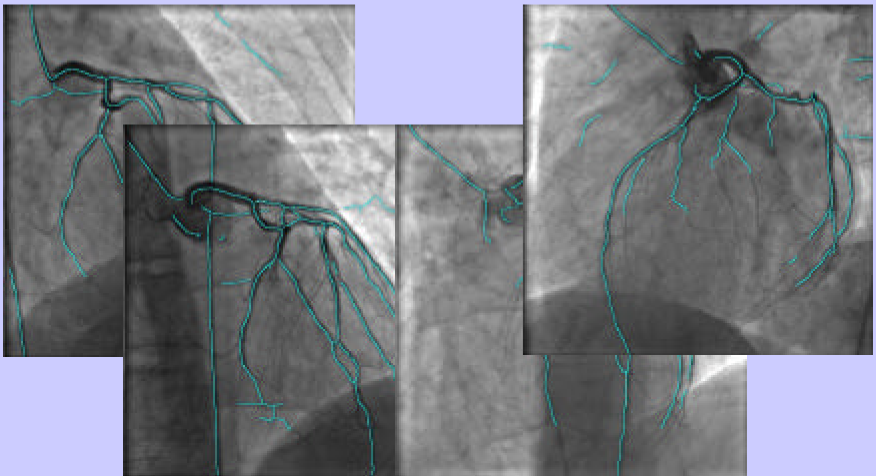
Tomographie dynamique

- Calcul de la déformation :
  - segmentation (analyse multi-échelle, intensité)
  - appariement
  - ajustement de faisceau
  - calcul de déformation 4D paramétrique

Results - Matched views

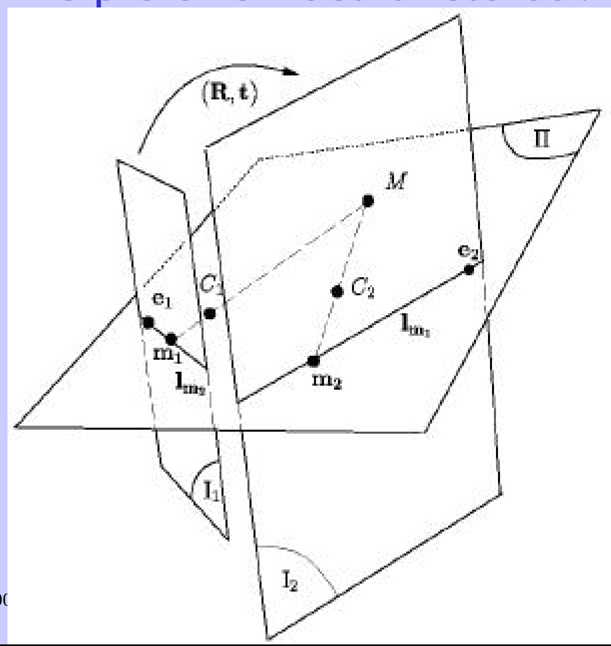


Segmentation

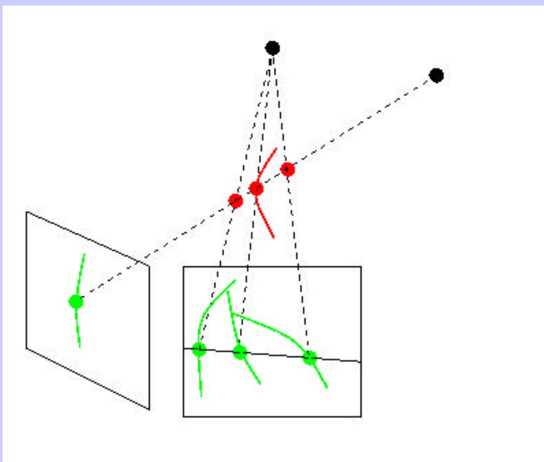


16/01/2003 Grégoire Malandain 58

Principle of binocular stereovision

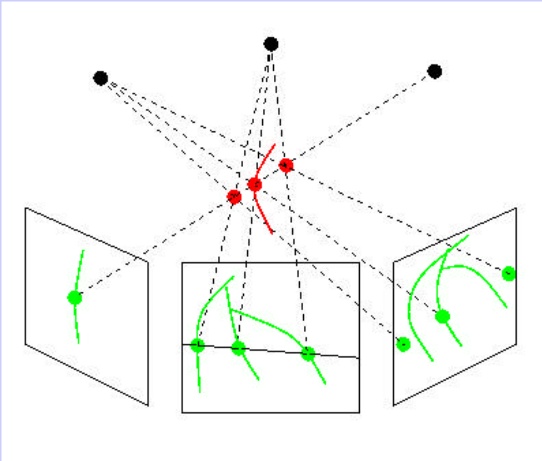


Principle of binocular stereovision



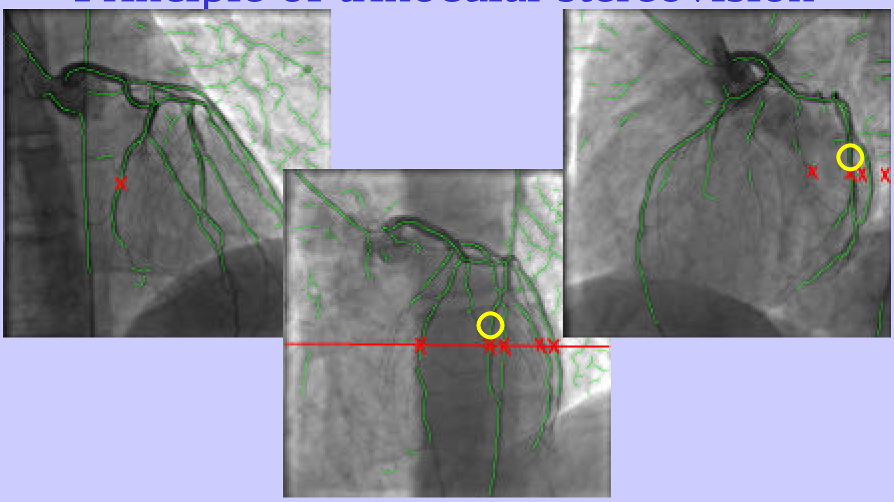
Binocular matching may be ambiguous

Principle of trinocular stereovision



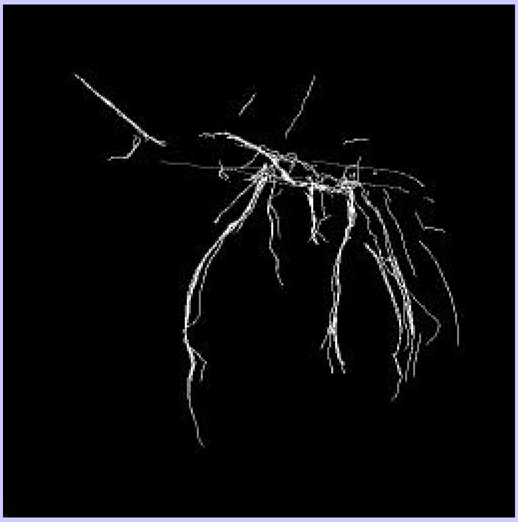
The third view often desambiguates the matching

Principle of trinocular stereovision



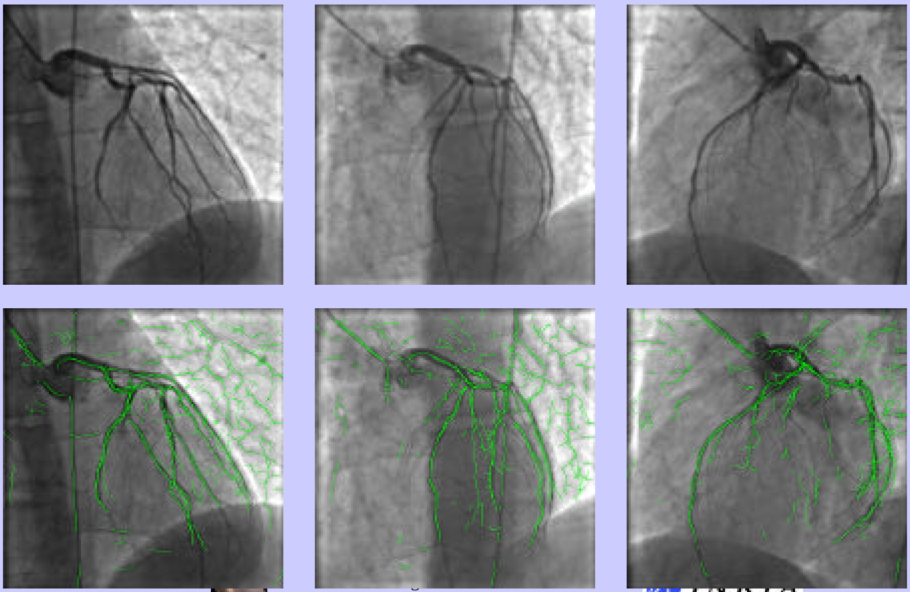
The third view often desambiguates the matching

Appariement / Ajustement

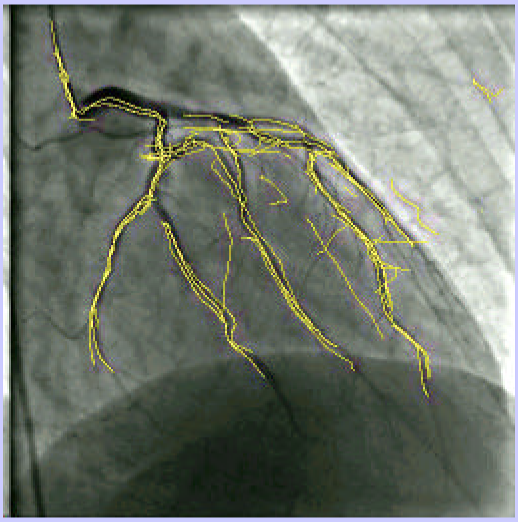


16/01/2003 Grégoire Malandain 63

Results - 3D Model Reprojection



Déformation 4D



16/01/2003 Grégoire Malandain 65

Formation de l'image

- Intégrales des atténuations le long des rayons : I'(x) = -µ I(x)

$$I(x) = I(0)\, e^{-\int_R m} \qquad \int_R m = \log(I(x)) - \log(I(0))$$

- On néglige :
  - l’incohérence du faisceau
  - le rayonnement diffusé primaire (collimation)
  - le rayonnement diffusé secondaire (détecteur)
  - le post-traitement sur les images

16/01/2003 Grégoire Malandain 66

Résultats : séquence 4D (3D+t)