Filtering, reconstruction and registration of 3D Ultrasound Images

Hervé Delingette

Projet Epidaure

Herve.Delingette@inria.fr

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Alexis Roche

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Hervé Delingette

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Overview

- Three Topics for 3D US imaging
  - Filtering
  - 3D Reconstruction
  - Registration

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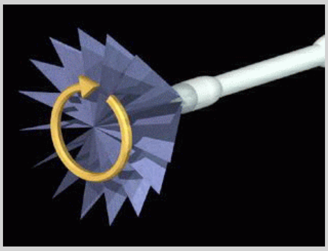
3D Ultrasound Images

- 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)

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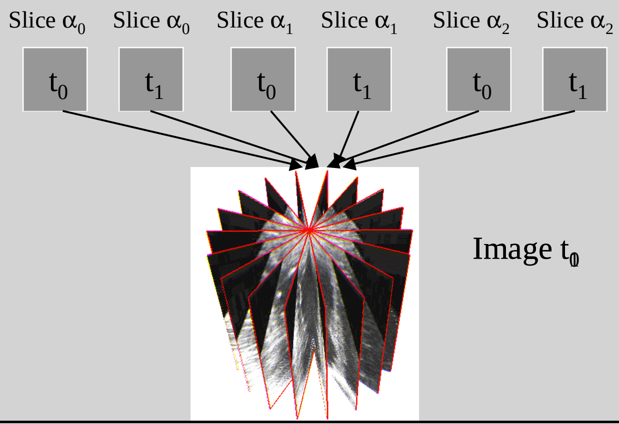
4D Ultrasound images

- Time serie of images gated on ECG signal



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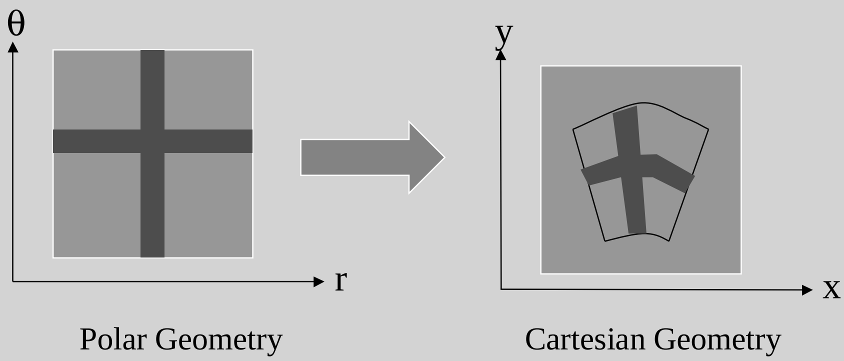
2D Image Storage Format

- Acquisition in polar geometry



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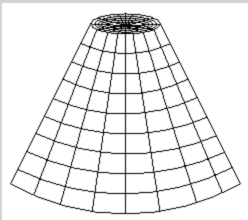
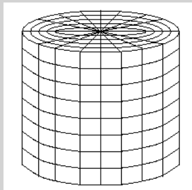
3D Image Storage Format

- Spherical Image Acquisition

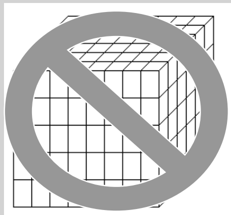


Spherical Geometry

Cylindrical Geometry



Cartesian Geometry



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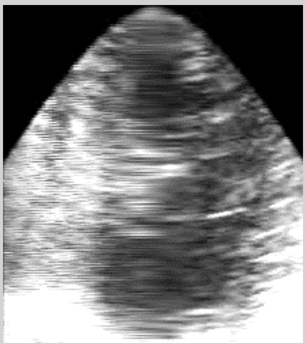
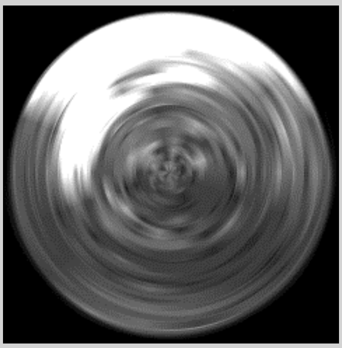
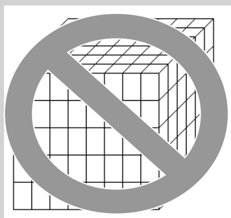
3D Image Storage Format

- Spherical Image Acquisition





Cartesian Geometry



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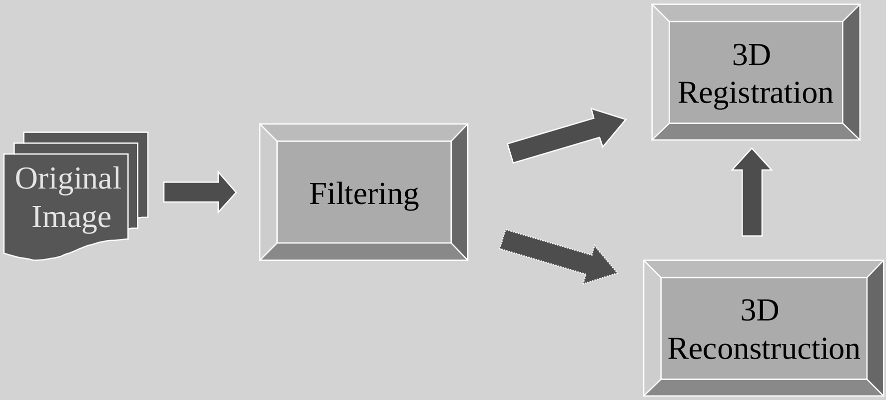
Global Scheme



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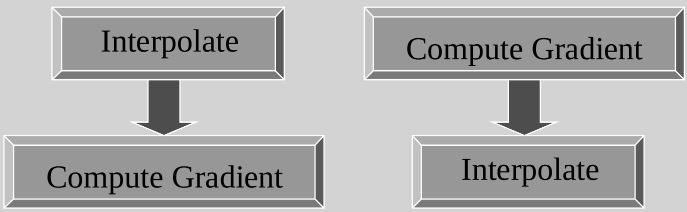
Gradient Computation

- 2D and 3D gradient information:
  - Used for 2D, 3D and 4D Anisotropic Diffusion
  - Used for segmentation based on deformable contours/surfaces
- Two options:



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Gradient Computation (2)

- Previous Work : (Herlin and Ayache 92)
- Cylindrical Filtering

$$(I \otimes f)(v) = \iiint f(v_x - r\cos\theta, v_y - r\sin\theta, v_z - z)\, I(r,\theta,z)\, r\,dr\,d\theta\,dz$$

- Implementation
  - convolution with local masks that depend on the distance to the axis

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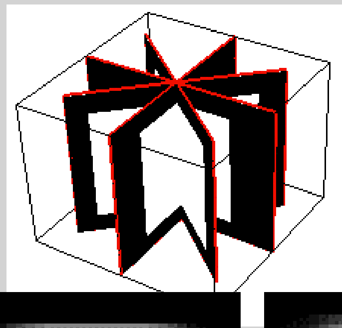
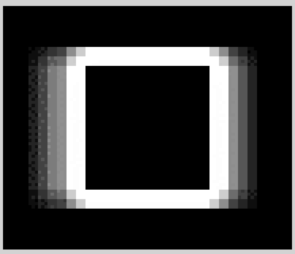
Gradient Computation (3)

- Example





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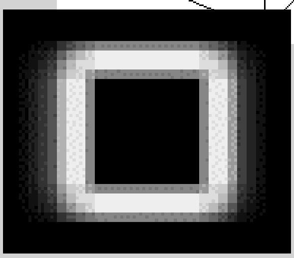

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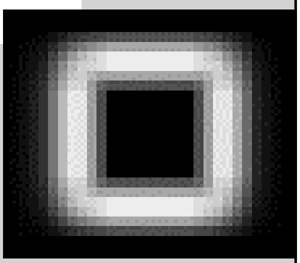

Window=7

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Gradient Computation (4)

Original Image it ? 2D Cartesian Cylindrical

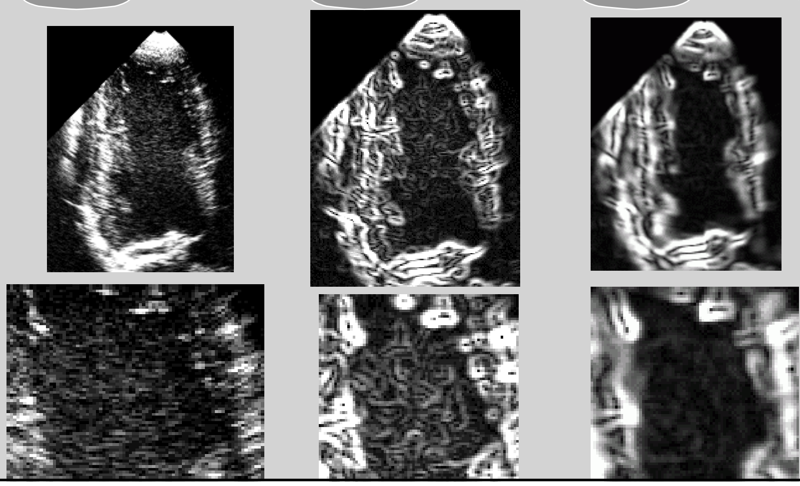

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Image Enhancement

- Improve detection of boundary
- Previous Work:
  – Diffusion Tensor : (Cottet et al. 95)
  – AOS Scheme for diffusion (Weickert et al. 98)
  – 4D Anisotropic Diffusion (Jacob et al. 99)

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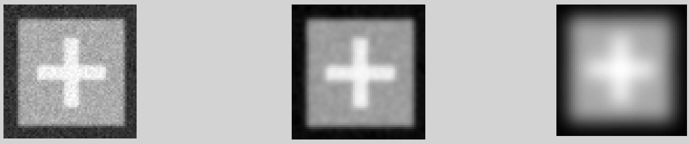
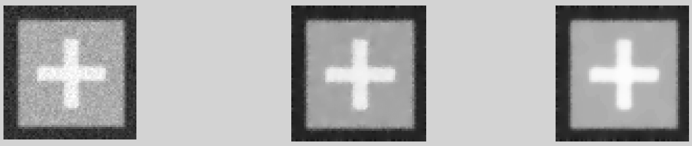
Anisotropic Diffusion

- Isotropic Diffusion $\frac{\partial I}{\partial t} = \Delta I = div(\vec{\nabla} I)$



- Anisotropic Diffusion $\frac{\partial I}{\partial t} = div(g(\|\vec{\nabla} I\|)\,\vec{\nabla} I)$



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Time-dependent Anisotropic Diffusion

- Time information helps removing speckle/noise
- Two approaches :
  - Perform 2D+T diffusion
  - Perform 3D+T diffusion

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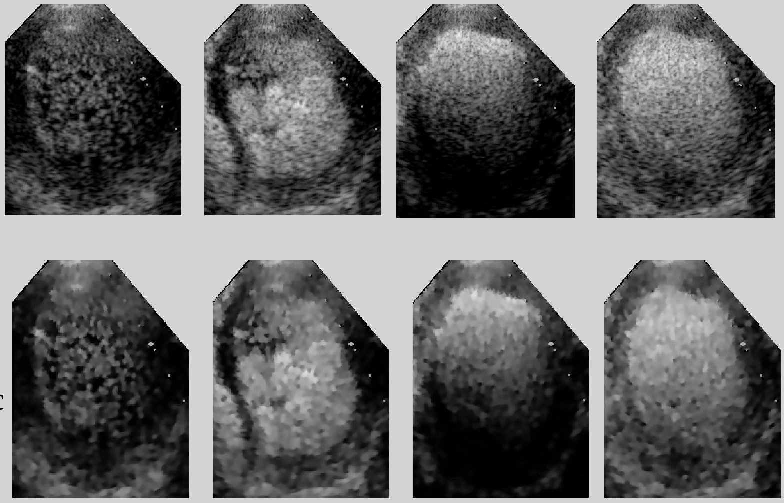
2D Diffusion

Original Images

2D Anisotropic Diffusion



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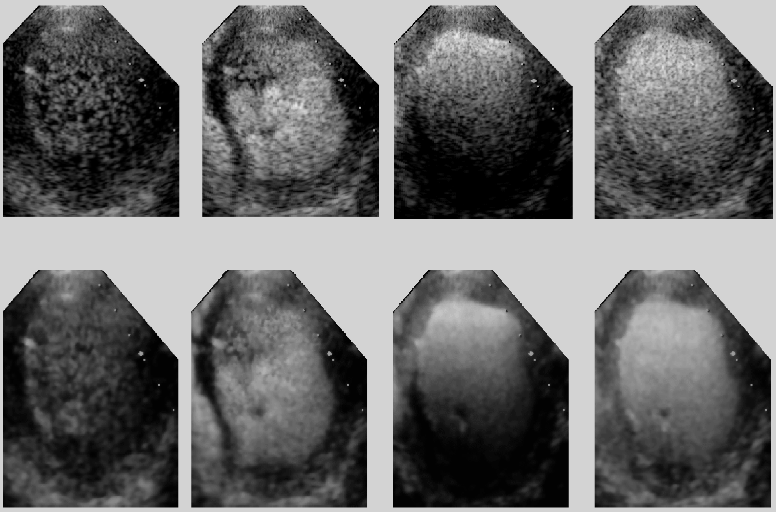
2D+T Diffusion

Original Images

2D+T Anisotropic Diffusion



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3D+T Diffusion

- Use Diffusion Tensor :

$$\frac{\partial I}{\partial t} = div\left(D(\| \vec{\nabla}^t I_\sigma \|)\, \vec{\nabla}^t I\right)$$

With :

$$\vec{\nabla}^t I = \begin{pmatrix} I_x \\ I_y \\ I_z \\ I_t \end{pmatrix}$$

$$D(\vec{\nabla}^t I) = \begin{pmatrix} \frac{1}{\sqrt{1+\left(\frac{I_x}{\lambda_x}\right)^2}} & 0 & 0 & 0 \\ 0 & \frac{1}{\sqrt{1+\left(\frac{I_y}{\lambda_y}\right)^2}} & 0 & 0 \\ 0 & 0 & \frac{1}{\sqrt{1+\left(\frac{I_z}{\lambda_z}\right)^2}} & 0 \\ 0 & 0 & 0 & \frac{1}{\sqrt{1+\left(\frac{I_t}{\lambda_t}\right)^2}} \end{pmatrix}$$

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3D+T Diffusion (2)

- Implementation Issues :
  – Iteratively estimate gradient thresholds

$$\lambda_x, \lambda_y, \lambda_z, \lambda_t$$

  – Computationally expensive

Use of AOS discretization scheme

- Can use large time steps

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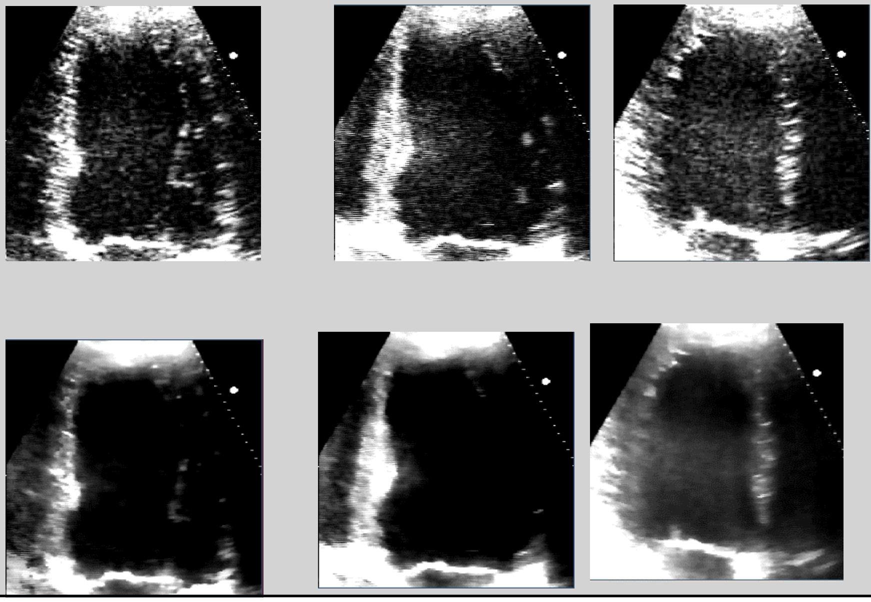
3D+T Diffusion (3)



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3D Reconstruction

- 2 Key Ideas:
  - – Find boundary points
  - – Perform 3D Regularization
- 2 Different Strategies
  - – Extract 2D contours and fit a 3D surface
  - – Extract a 3D surface directly

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First Strategy

3D US Images → 2D Gradient Computation → Contour Extraction → Surface Fitting

- Direct Contour extraction (Roux et al. 98)
- Use Deformable Contours (Noble et al. 98, Berger et al. 97)

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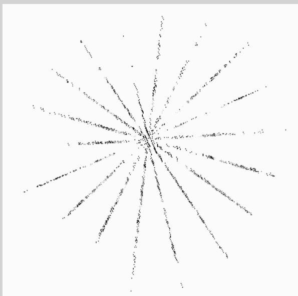
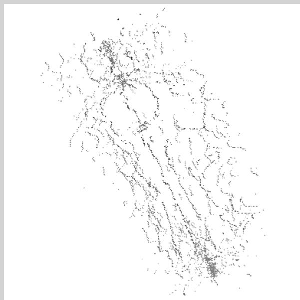
First Strategy (2)

- Example:

Feature Point Extraction





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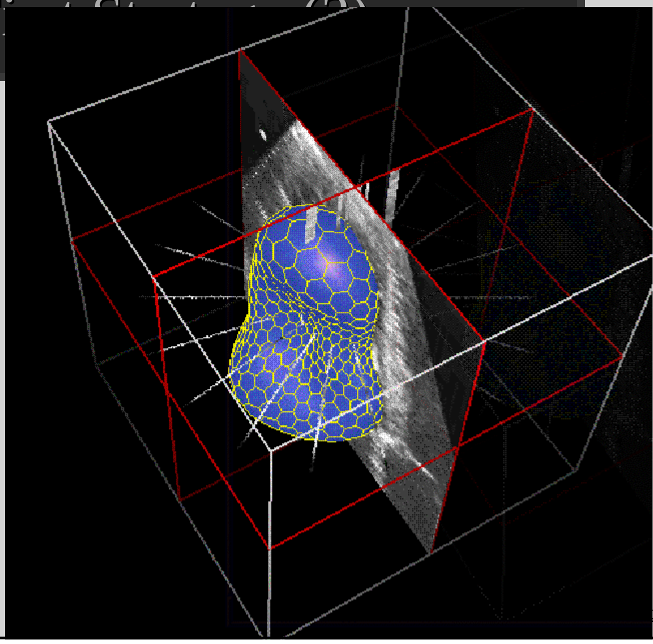
- Example:

Feature Point Extraction

↓

Surface Fitting



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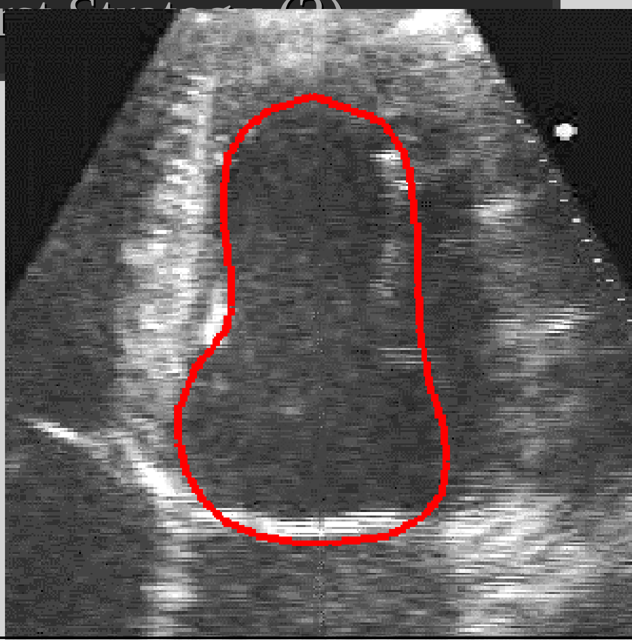
- Example:

Feature Point Extraction

↓

Surface Fitting



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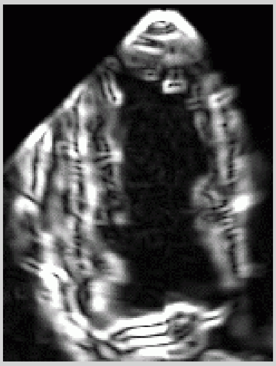
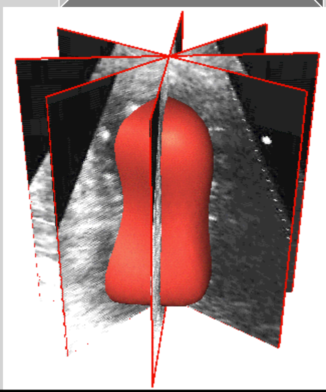
Second Strategy

3D US Images → 3D Gradient Computation → Surface Fitting





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3D Surface Fitting

- Use simplex meshes as the surface representation
- Use scan-line algorithm for external force computation in cylindrical images
- Use “region” (intensity+gradient) to detect boundaries

→ See J. Montagnat’s poster

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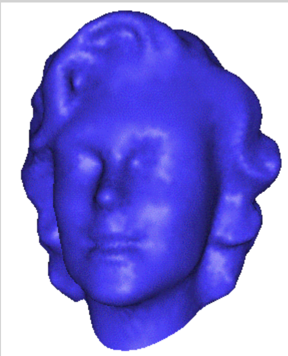
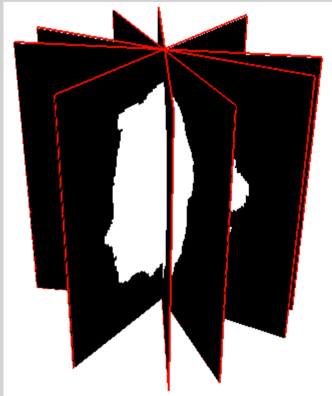
3D Surface Fitting (2)

- Synthetic Example:





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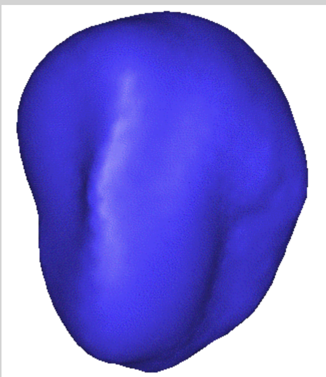
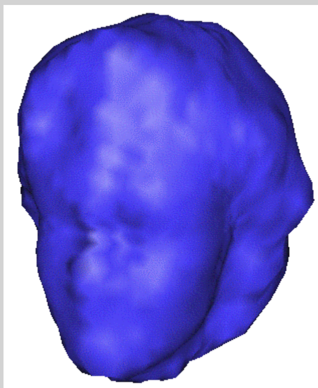
3D Surface Fitting (2)

- Synthetic Example:





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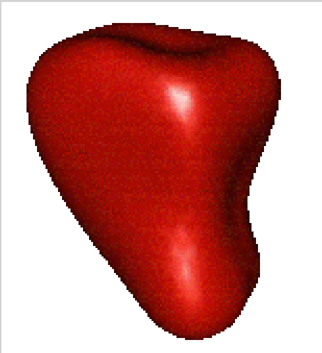
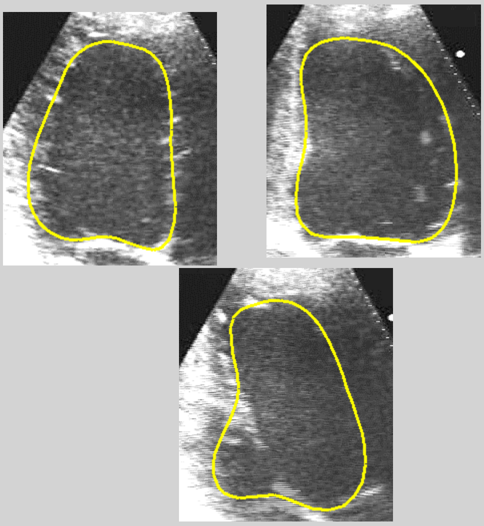
3D Surface Fitting (3)

- Example:





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4D Image Reconstruction

- 1 key idea
  - Use temporal information for shape regularization
- 3 different approaches
  - Weak temporal constraint
  - Strong temporal constraint for 2D+T
  - Strong temporal constraint for 3D+T

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Weak Temporal Constraint

- Use 3D model at time t as the initial model at time t+1
  - Straightforward generalization
  - Weak enforcement of time continuity
  - No periodicity of motion

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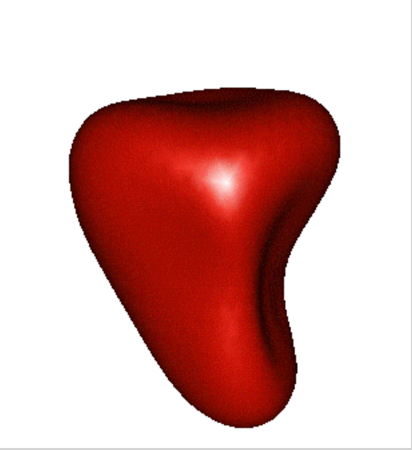
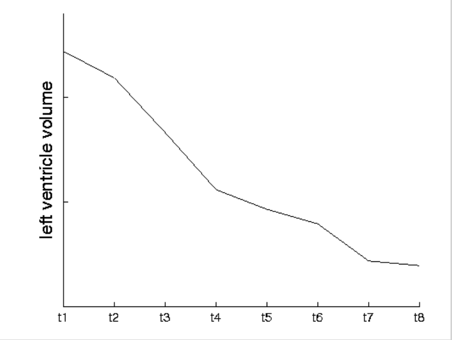
Weak Temporal Constraint (2)





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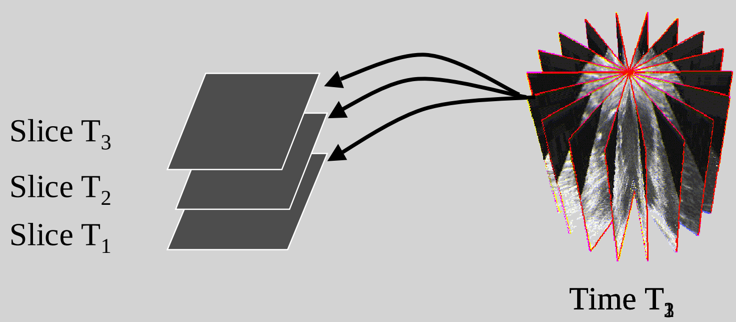
2D+T Reconstruction

2D+T Image Formation



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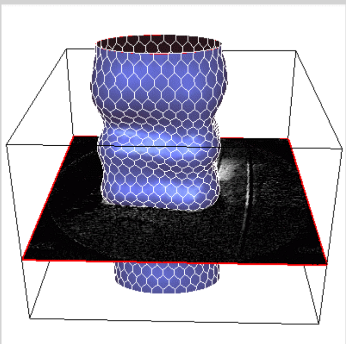
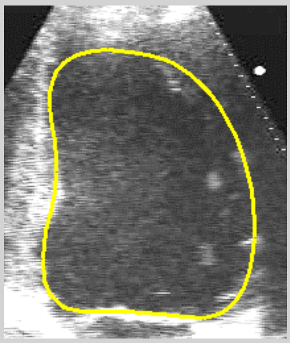
2D+T Reconstruction

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





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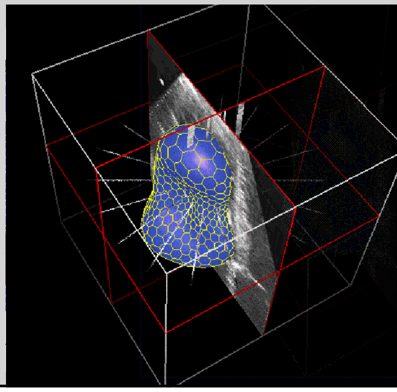
2D+T Reconstruction

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



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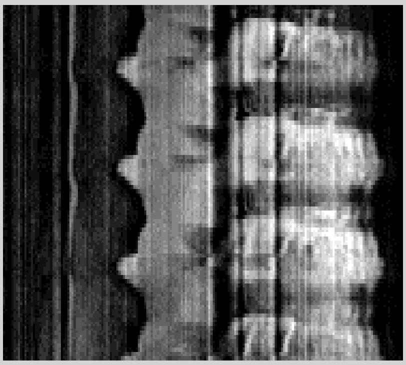
2D+T Reconstruction (2)

- Example : Ventriculography (courtesy of CCM)



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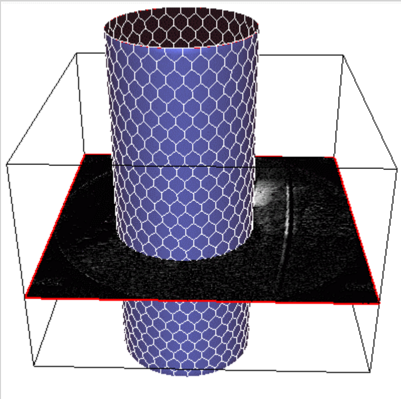
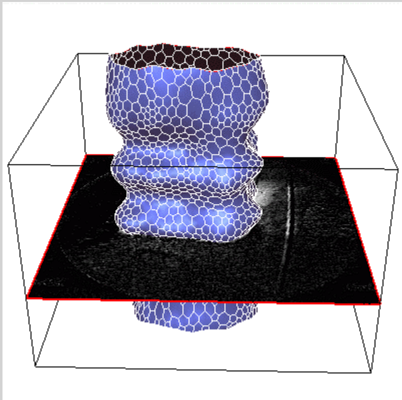
2D+T Reconstruction (3)





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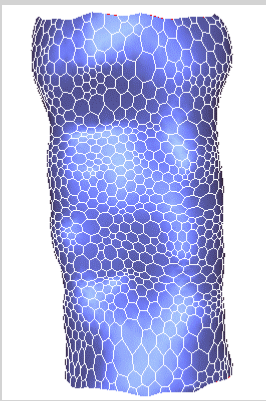
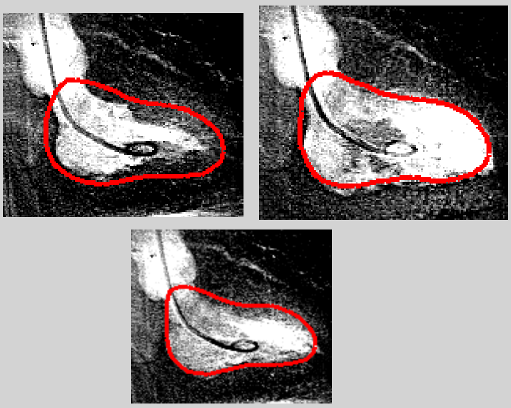
2D+T Reconstruction (3)





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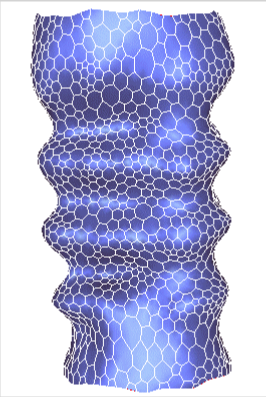
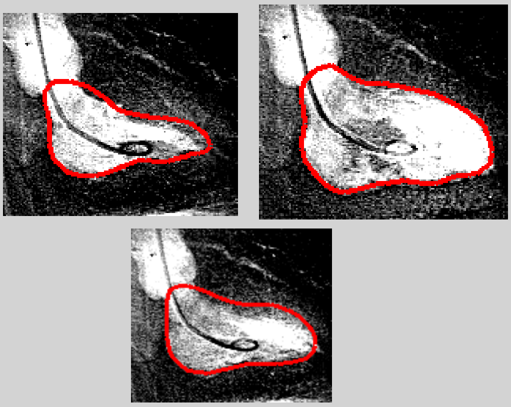
2D+T Reconstruction (3)





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3D+T Reconstruction

- Reconstruct simultaneously all 3D models with temporal constraints acting as regularizing forces
  - Enforce periodicity
  - Nicely differentiate between time/shape constraints
  - High memory+CPU requirements

• Previous work : (Declerck et al 98)

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Ultrasound image segmentation

- 4D image sequence
- 4D model deformation
- Resulting beating heart

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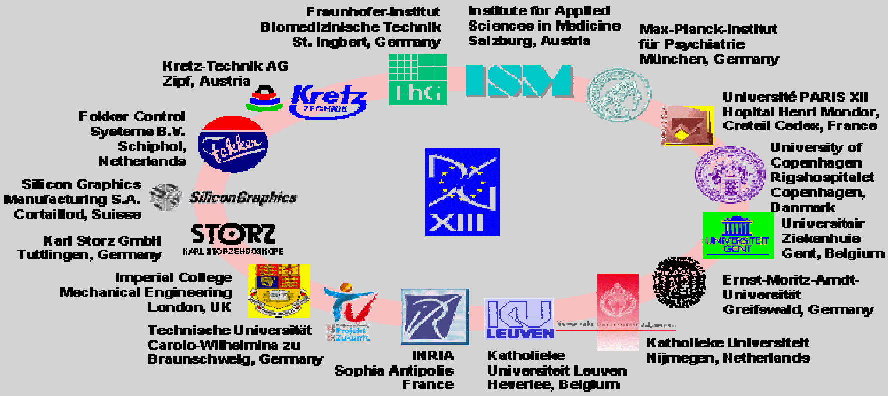
MR/US Registration

- updating pre-operative MR planning with intra-operative 3D US (Roboscope Project)



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MR/US Registration (2)

- Multi-modal image registration
- Related Work : (Hata et al. 94), (Erbe et al. 96), (Bucholz et al. 96) (Roche et al. 98)
- Iconic-based image registration

Hypothesis : Functional + Gaussian Noise

Criterion : Correlation Ratio

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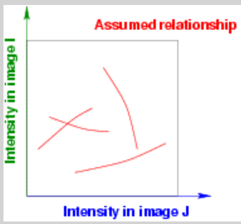
MR/US Registration (2)

- Multi-modal image registration
- Related Work : (Hata et al. 94), (Erbe et al. 96), (Bucholz et al. 96) (Roche et al. 98)
- Iconic-based image registration

Hypothesis : Unconstrained Transition Probabilities

Criterion : Mutual Information



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MR/US Registration (3)

- Results :
  - Satisfactory Accuracy : 2mm, 1Degree of rotation
  - Not robust : require close initialization

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MR/US Registration (4)

Original MR Image

Similarity measure	Failures
Correlation ratio	14%
Mutual information	51%

Anisotropic Diffused MR Image

Similarity measure	Failures
Correlation ratio	12,5%
Mutual information	28%

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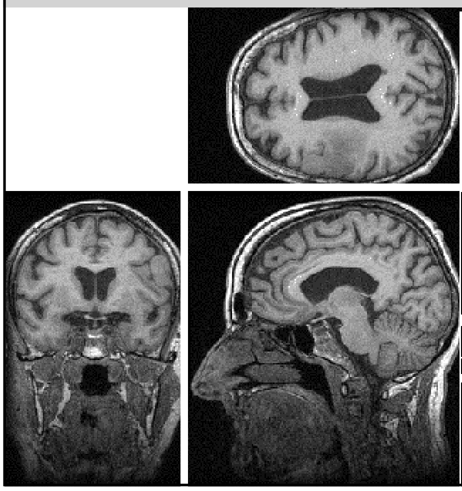
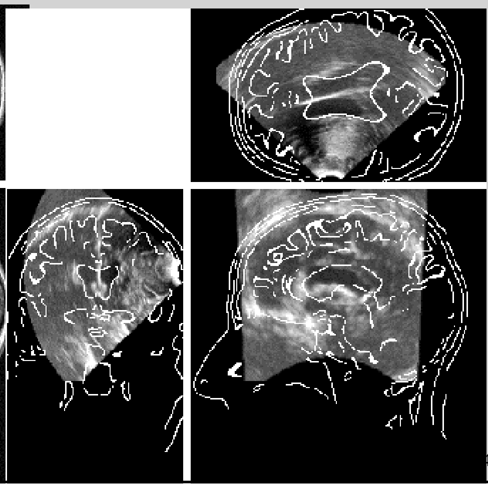
MR/US Registration (5)

MR image

Original MR+US





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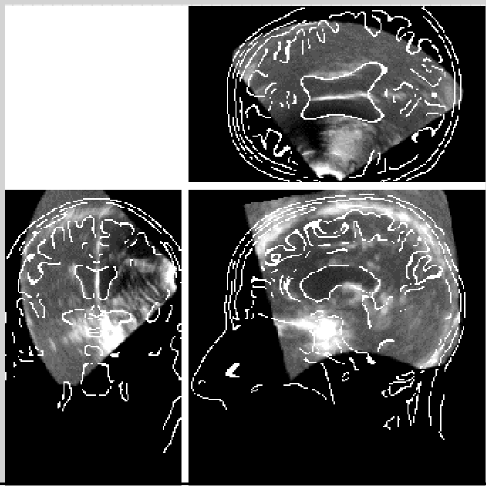
MR/US Registration (5)

US/MR Registration



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Conclusion

- Needs Validation
- Using geometry knowledge of 3D US images
  - Computation of 3D Gradient
  - 3D and 4D deformable models
- Perspectives:
  - add physical and anatomical knowledge

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