Dynamic Cone Beam Reconstruction Using a New Level Set Formulation

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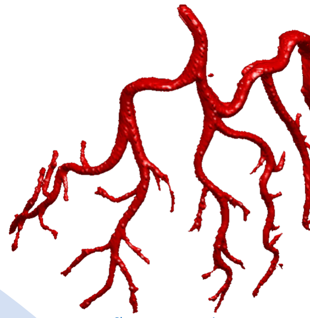
Introduction

- *Clinical Motivation:*
  Bringing together **pre-operative 3D** imaging and **intra-interventional 2D** angiography by enabling **4D reconstruction** from cone-beam projections.
- *Mathematical Assumption 1:*
  Direct tomographic reconstruction not feasible
  → Perform **symbolic reconstruction** as first step.
- *Mathematical Assumption 2:*
  Separation of shape and motion reconstruction not feasible
  → **Simultaneously** estimate **shape and motion**.

Image courtesy of Siemens Healthcare



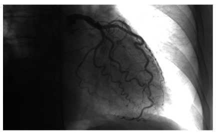
Shape reconstruction

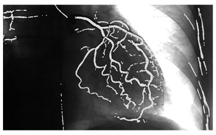
Methods

Preprocessing

Angio sequence
+
Vessel filters
(like Frangi or Koller)
=
Enhanced vessels

→ Input for shape reconstruction





Static Shape Model

$$\Phi_0(\boldsymbol{x}_0)\begin{cases} <0 & \Leftrightarrow \quad \boldsymbol{x}_0 \text{ inside vessel} \\ =0 & \Leftrightarrow \quad \boldsymbol{x}_0 \text{ on interface} \\ >0 & \Leftrightarrow \quad \boldsymbol{x}_0 \text{ outside vessel} \end{cases}$$

Motion Model

reference coordinate — temporal spline parameters

$$\boldsymbol{x}_0 = \boldsymbol{\varphi}(\boldsymbol{x}, t, \boldsymbol{\alpha}) = \underbrace{\boldsymbol{R}(t,\boldsymbol{\alpha})\,\boldsymbol{x} + \boldsymbol{T}(t,\boldsymbol{\alpha})}_{\text{rigid dynamic motion}}$$

Dynamic Shape Model

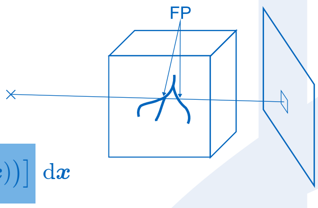
Dynamic shape = static shape & motion model

$$\Phi(\boldsymbol{x}, t) = \Phi_0\big(\boldsymbol{\varphi}(\boldsymbol{x}, t, \boldsymbol{\alpha})\big)$$

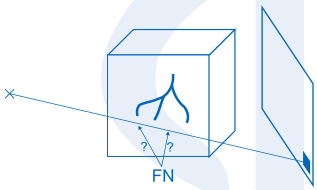
shape regul. — motion regul.

Penalties for false positives (FP) and false negatives (FN)

$$E_{\mathrm{FP}}(\Phi) = \sum_{l=1}^{L} \int_V \big[1 - H(\Phi(\boldsymbol{x}, t_l))\big] \times S_{\mathrm{FP}}\Big(I_l(\boldsymbol{P}_l(\boldsymbol{x}))\Big) \times \big[1 - I_l(\boldsymbol{P}_l(\boldsymbol{x}))\big]\,\mathrm{d}\boldsymbol{x}$$



$$E_{\mathrm{FN}}(\Phi) = \sum_{l=1}^{L} \int_A H\Big(\min_{\boldsymbol{x}\in X_l(\boldsymbol{p})} \Phi(\boldsymbol{x}, t_l)\Big) \times S_{\mathrm{FN}}\big(I_l(\boldsymbol{p})\big) \times I_l(\boldsymbol{p})\,\mathrm{d}\boldsymbol{p}$$



Final Data Terms

$$E_{\mathrm{FP}}(\Phi_0, \boldsymbol{\alpha}) = \sum_{l=1}^{L} \int_V \big[1 - H\big(\Phi_0(\boldsymbol{\varphi}(\boldsymbol{x}, t_l, \boldsymbol{\alpha}))\big)\big] \times S_{\mathrm{FP}}\Big(I_l(\boldsymbol{P}_l(\boldsymbol{x}))\Big) \times \big[1 - I_l(\boldsymbol{P}_l(\boldsymbol{x}))\big]\,\mathrm{d}\boldsymbol{x}$$

$$E_{\mathrm{FN}}(\Phi_0, \boldsymbol{\alpha}) = \sum_{l=1}^{L} \int_A H\Big(\min_{\boldsymbol{x}\in X_l(\boldsymbol{p})} \Phi_0(\boldsymbol{\varphi}(\boldsymbol{x}, t_l, \boldsymbol{\alpha}))\Big) \times S_{\mathrm{FN}}\big(I_l(\boldsymbol{p})\big) \times I_l(\boldsymbol{p})\,\mathrm{d}\boldsymbol{p}$$

Optimization

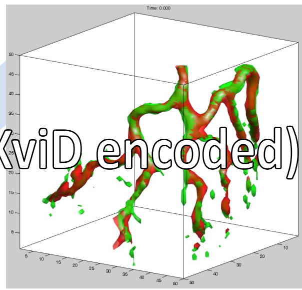
Gradient descent on 24-core machine (using OpenMP): ≈ 1h

Results & Discussion

- *Positional errors* (for rigid motions, Gaussian noise of 25%, 3mm voxel spacing):
  $\mu \pm \sigma$ = 0.88mm ± 0.46mm (sub-voxel accuracy!)
- *Shape errors* (for deformable motions, Gaussian noise of 30%, 3mm voxel spacing):
  Sensitivity: 74.2% Specificity: 99.6%
- *Contributions*: Dynamic level sets and level set reconstruction
- *Future work*: Phantom and real data; refined motion models; combination with tomographic methods and closing loop from reconstruction to segmentation

Click to play videos (XviD encoded)

gray levels = input projections, red = projected reconstruction



green = ground truth, red = reconstruction

Acknowledgements:

The authors thank Moritz Blume, Jan Boese, and Martin Brokate for valuable discussions. Credits also go to Tobias Klug and the Chair "LRR" at TUM for providing the high performance hardware and to Christopher Rohkohl for the phantom data.

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References:

- Chan, Vese: *Active contours without edges*. IEEE TIP 10(2) 2001 (on level set methods)
- Blume, Keil, Navab, Rafecas: *Blind motion compensation for positron-emission-tomography*. In: SPIE Med. Imag. 2009 (also doing joint image and motion estimation)
- Keil, Vogel, Lauritsch, Navab: *Dynamic cone beam reconstruction using a variational level set formulation*. In: Fully3D 2009 (extended version of this work)