Image segmentation techniques for biomedical modeling

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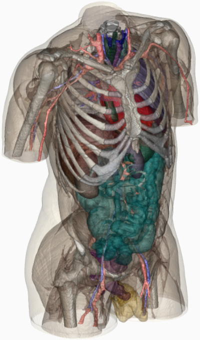
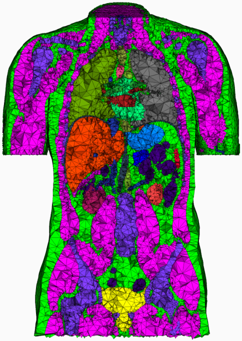
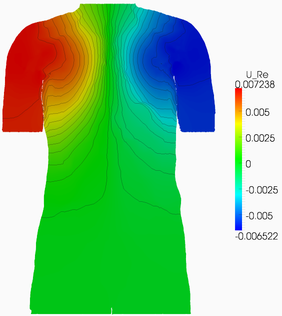
Bioimpedance and ECG modeling technology

Segmentation | Meshing | FEM







ITK-SNAP | CGAL Mesh | Ani3D | ParaView

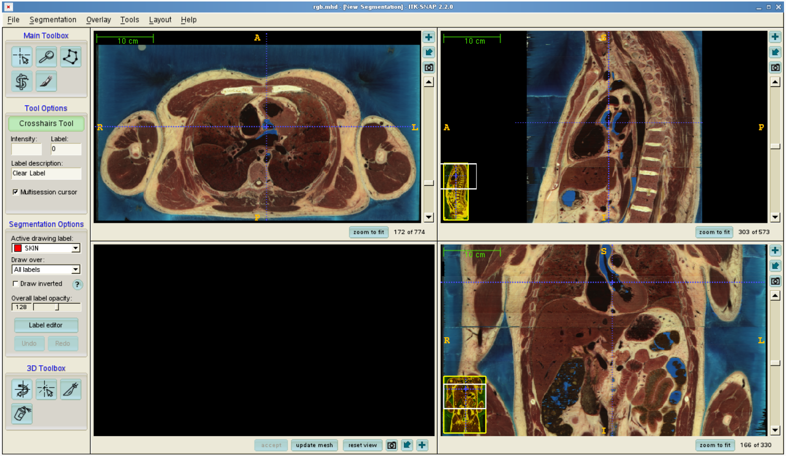
A. A. Danilov, et al. Modelling of bioimpedance measurements: unstructured mesh application to real human anatomy. RJNAMM, 2012.

Image segmentation

User-guided segmentation

ITK-SNAP – free software for Visualization and Segmentation

`www.itksnap.org`



User-guided segmentation

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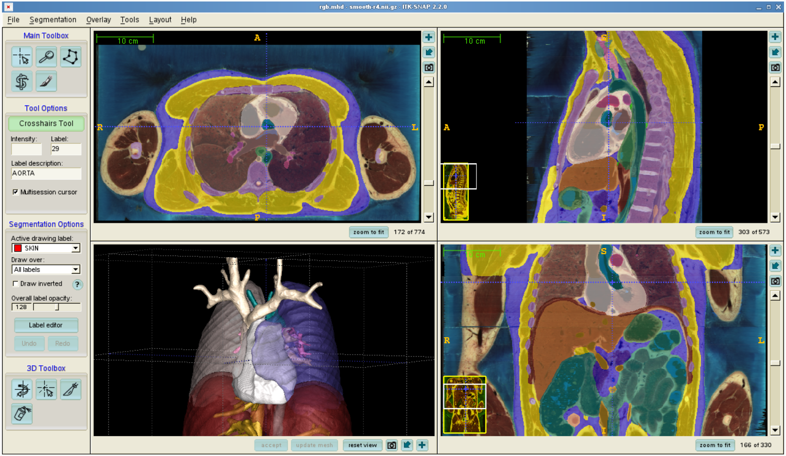
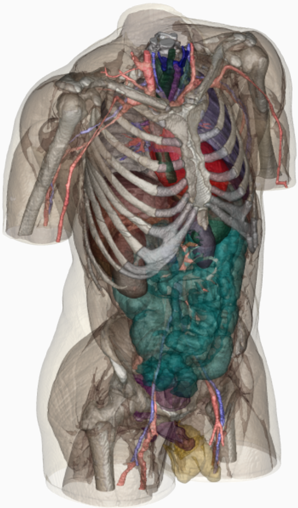


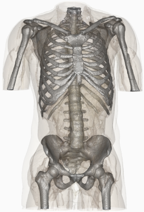
High resolution segmented model of VHP torso

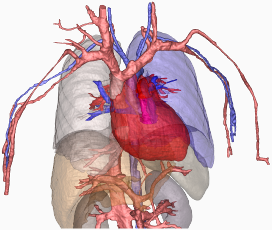


567 × 305 × 843 voxels

1 × 1 × 1 mm

26 organs and tissues

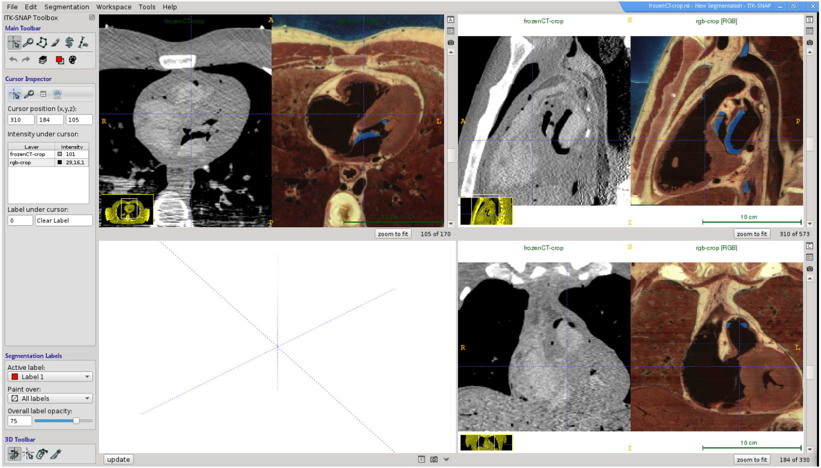




Total 146m voxels, 68m material voxels

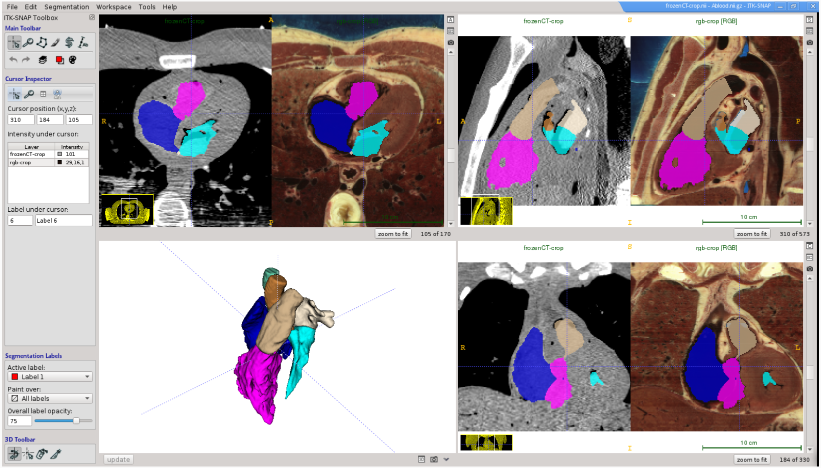
Heart segmentation

ITK-SNAP: levelset segmentation with random forest classifier



Heart segmentation

ITK-SNAP: levelset segmentation with random forest classifier



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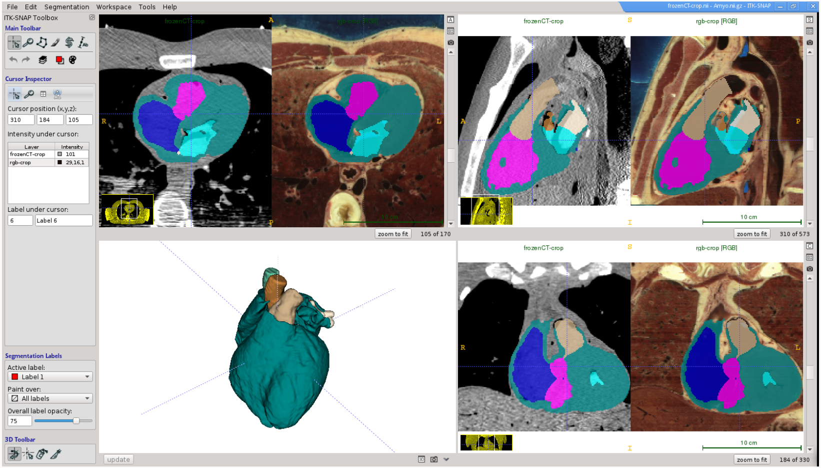
ITK-SNAP: levelset segmentation with random forest classifier



Heart segmentation

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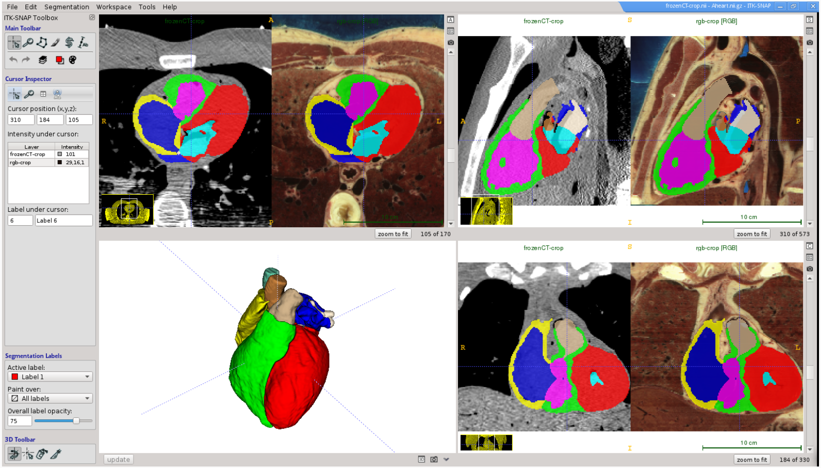
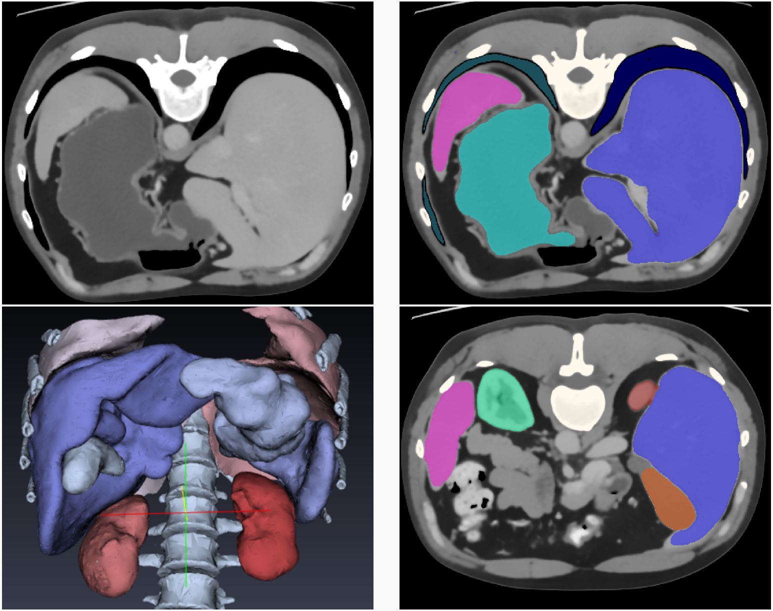


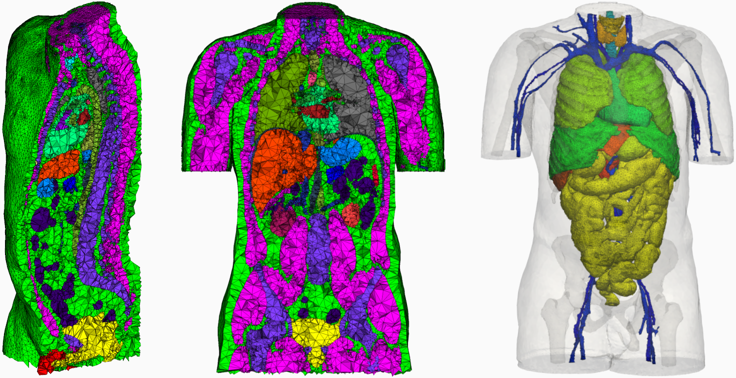
Personalized segmentation



Mesh generation

Unstructured tetrahedral meshes

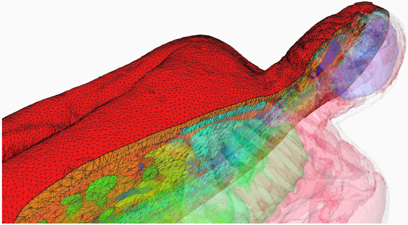
CGAL Mesh (`www.cgal.org`) – Delaunay mesh generation
Ani3D (`sf.net/p/ani3d`) – mesh cosmetics



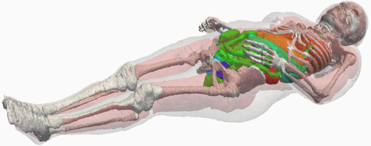
413 508 vertices, 2 315 329 tetrahedra, 84 430 boundary faces

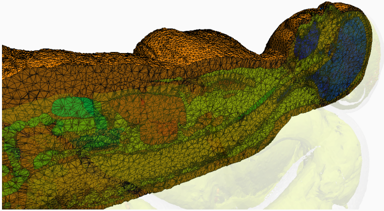
Full body male and female models

VHP-Man



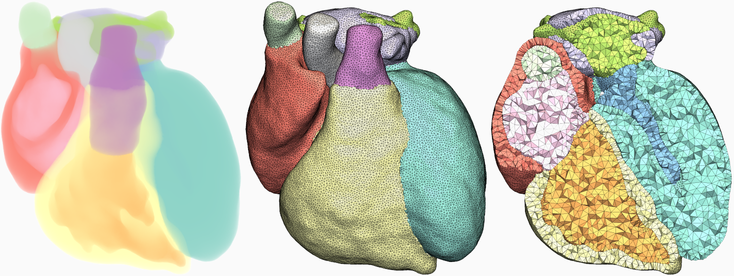
VHP-Woman





3m tetrahedra   effective resolution: $1 \times 1 \times 1$ mm   30 tissues

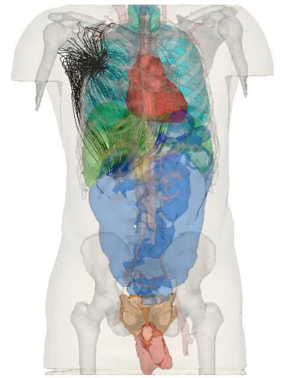
Heart models



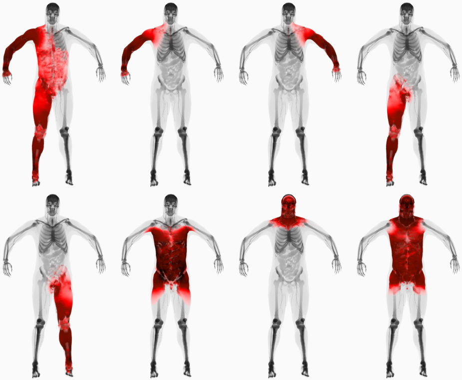
3D model of heart, atria and ventricles

Biomedical applications

Bioimpedance measurements model

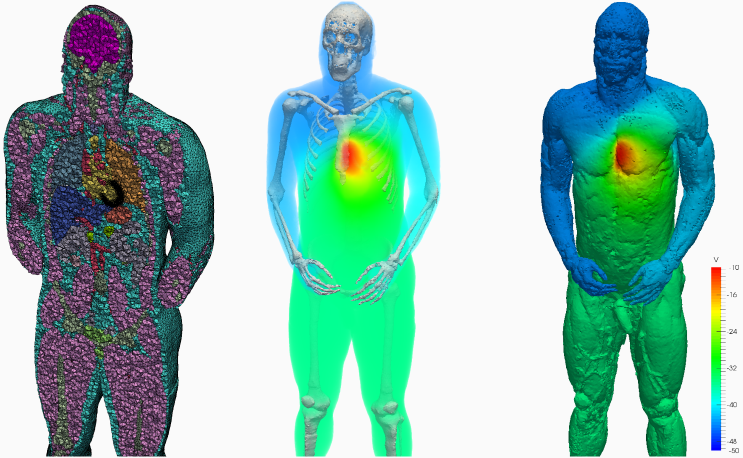


lung hydration



sensitivity areas of segmental scheme

Forward ECG calculation



VHP model, CGAL Mesh + Ani3D/AniMBA, Ani3D/AniFEM + Chaste

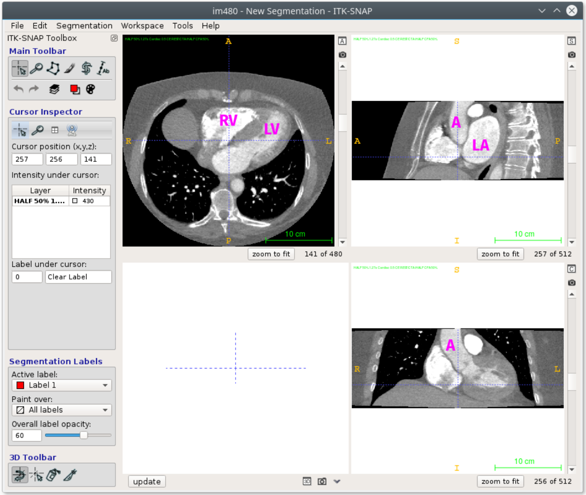
Leads $s = \phi_h \cdot \mathbf{p}_h$, $\quad \phi_h$ – cardiac potential, $\mathbf{p}_h$ – precalculated

Dynamic left ventricle model

Problem

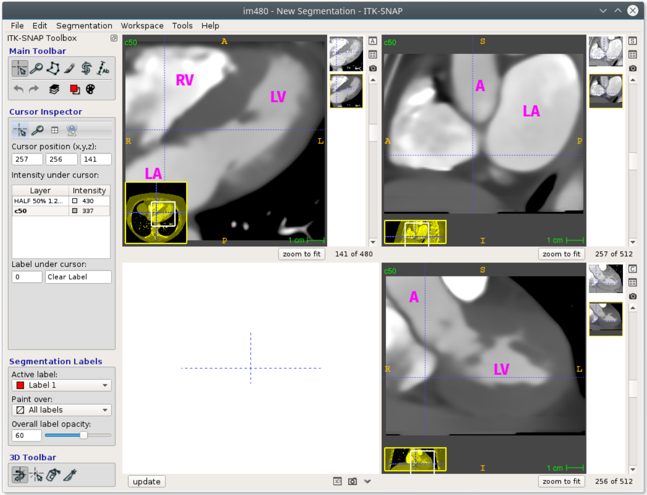
- Aim: hemodynamics modeling in heart ventricles
- Equations: 3D Navier-Stokes, Arbitrary Lagrange-Euler
- Domain: left ventricle, valves – boundary conditions
- Dynamics: ventricle walls reconstructed from ceCT images
- Data: ceCT, 100 images, 1.27 seconds
- Resolution: $512 \times 512 \times 480$, raw data – 24 Gb
- Patient: anonymized, female, 50 years old
- Problem: generation of dynamic mesh from ceCT images

CeCT image segmentation



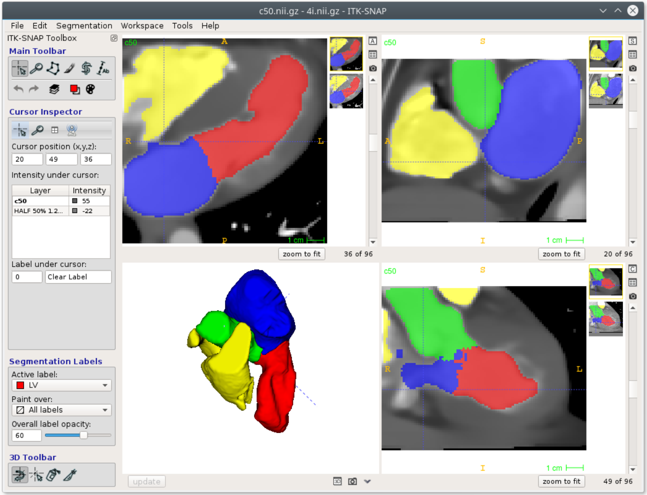
Initial ceCT image №50

CeCT image segmentation



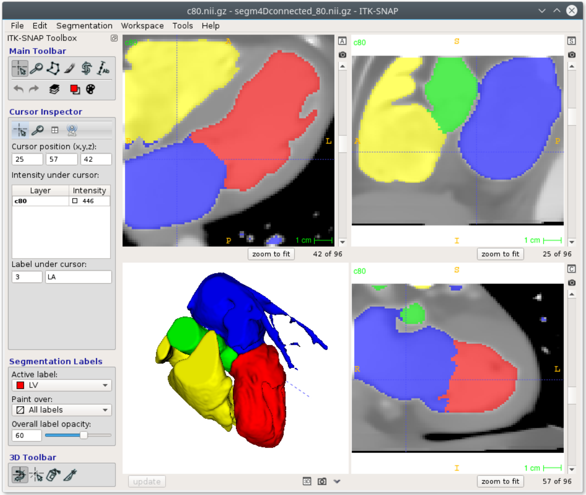
Smoothed ceCT image №50

CeCT image segmentation



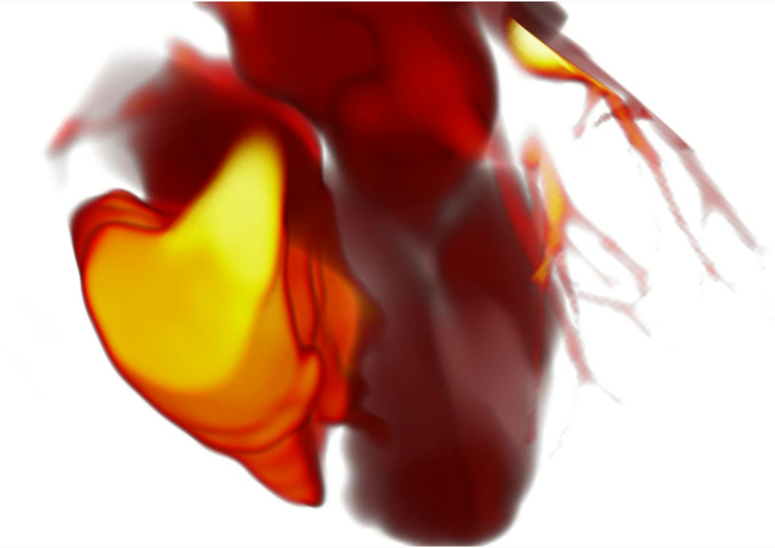
Manual segmentation №50

CeCT image segmentation



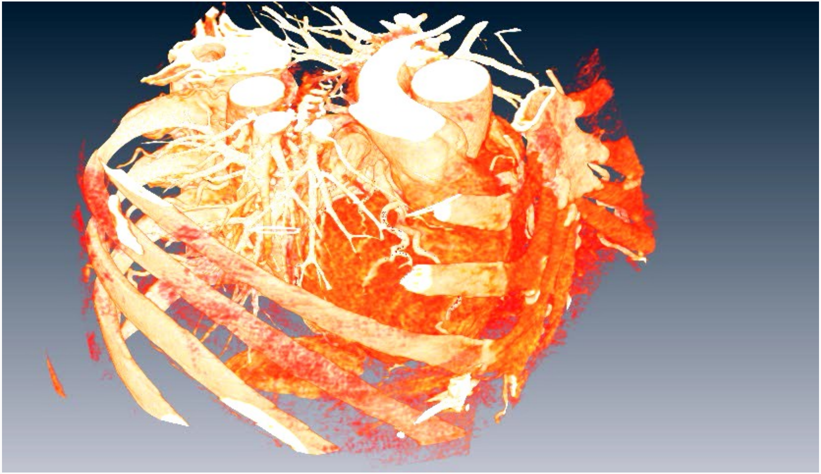
Automatic segmentation №80

Dynamic left ventricle model



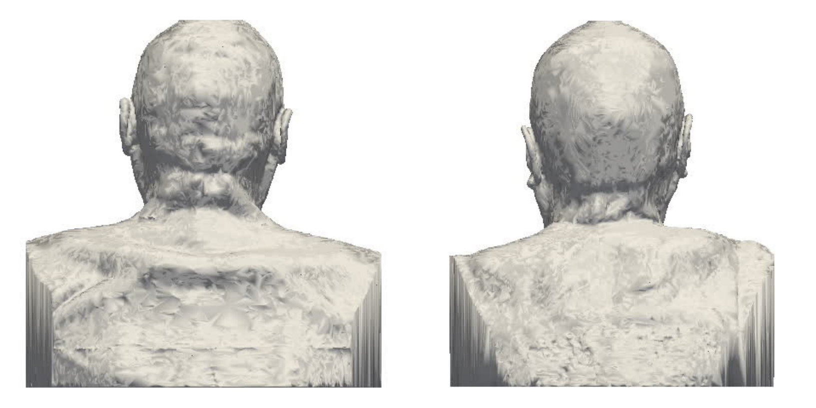
Blood vessels segmentation

Automatic patient-specific segmentation



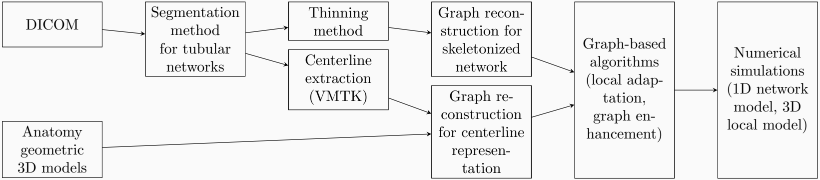
Coronary arteries segmentation

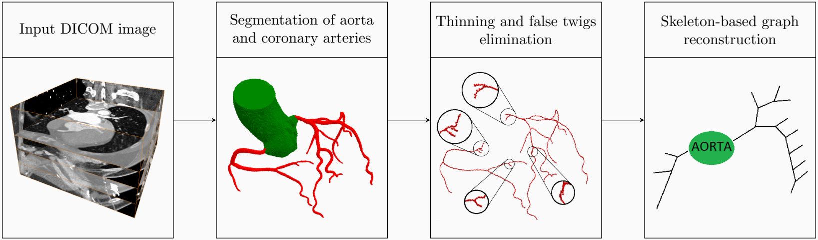
Automatic patient-specific segmentation



Cerebral arteries segmentation

Automatic patient-specific segmentation



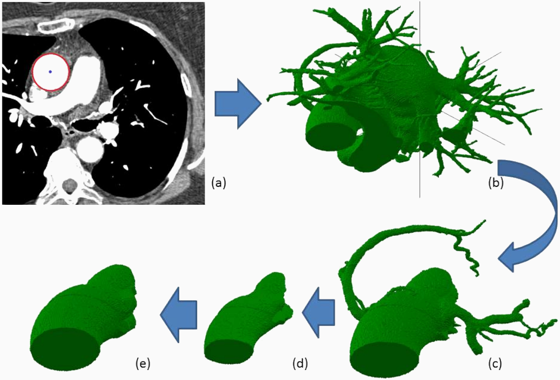


Overview of pipeline

A. Danilov, et al. Methods of graph network reconstruction in personalized medicine. IJNMBE, 2015.

Aorta segmentation

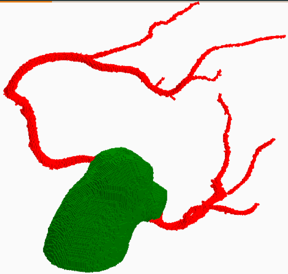
1. Hough circleness transform
2. Thresholding
3. Fast isoperimetric distance trees
4. Mathematical morphology operations

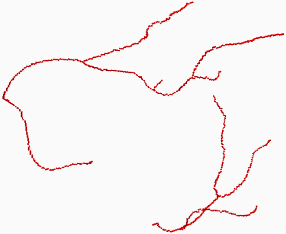


L. Grady. Fast, quality, segmentation of large volumes – isoperimetric distance trees. Computer Vision – ECCV 2006.

Coronary vessels extraction

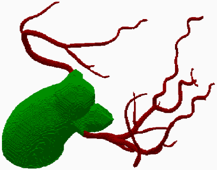
1. Ostia points detection
2. Frangi vesselness filter
3. Distance ordered homotopic thinning
4. Skeleton cleaning

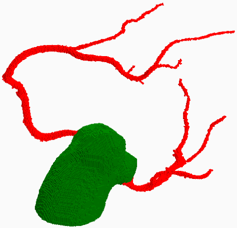




A.F. Frangi et al. Multiscale vessel enhancement filtering. MICCAI'98, 1998.

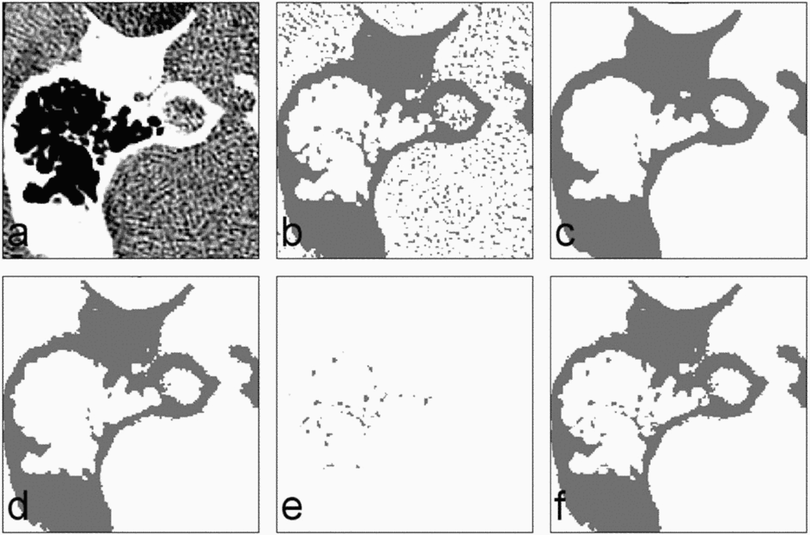
Coronary vessels segmentation





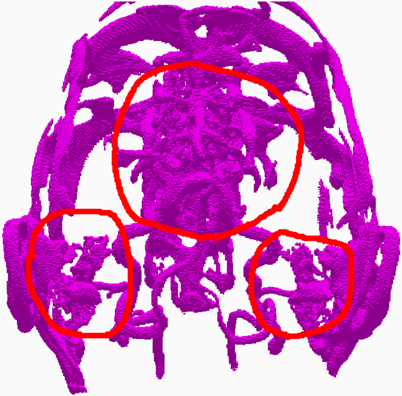
	Case 1	Case 2
Resolution	$512 \times 512 \times 248$	$512 \times 512 \times 211$
Spacing	$0.37 \times 0.37 \times 0.40$	$0.46 \times 0.46 \times 0.48$
Aorta segmentation	5.80 sec	5.19 sec
Frangi Filter	91.76 sec	73.94 sec

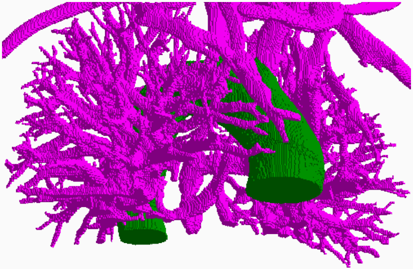
Bone elimination



H.A. Gratama van Andel. Removal of bone in CT angiography by multiscale matched mask bone elimination. Medical Physics, 2007.

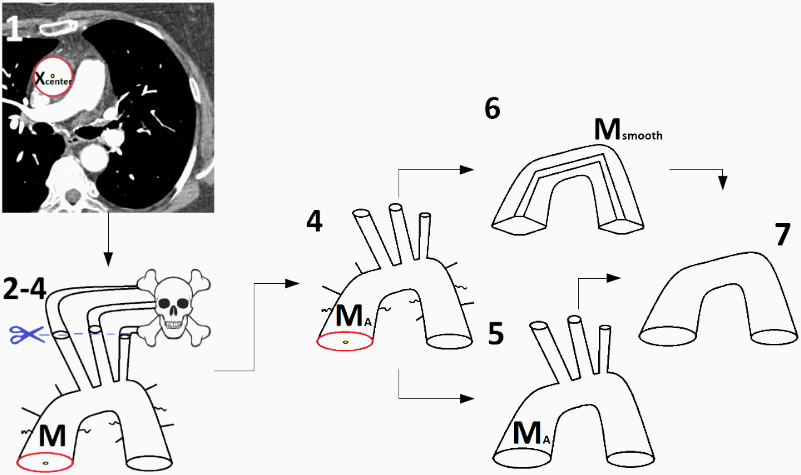
Frangi filter – naive approach





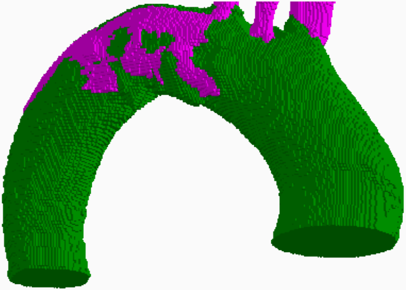
Additional preprocessing is essential!
Cavities and pulmonary vessels elimination

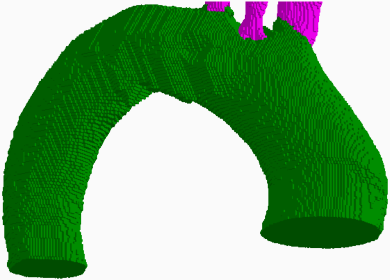
Aorta segmentation



Aorta automatic segmentation

Frangi filter – final steps





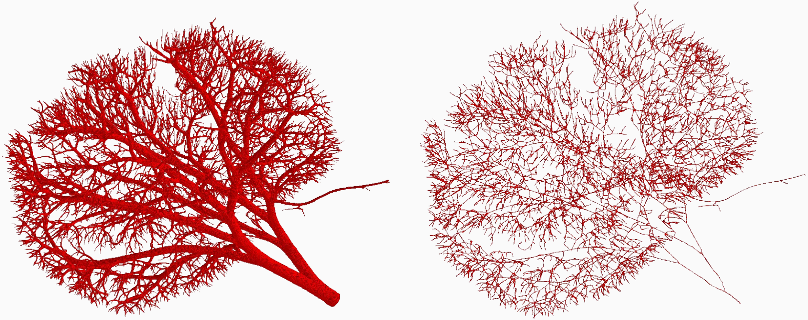
Arteries correction post-processing

Distance map is used for correct order of leaks elimination

Cerebral vessels segmentation

	Case 1	Case 2
Resolution	$512 \times 512 \times 501$	$512 \times 512 \times 451$
Spacing	$0.76 \times 0.76 \times 0.80$	$0.62 \times 0.62 \times 0.80$
Multiscale MMBE	11.20 sec	10.10 sec
Cavities elimination	7.76 sec	7.04 sec
Aorta segmentation	16.61 sec	15.33 sec
Frangi Filter	196.40 sec	184.91 sec
Bifurcation detection	7.61 sec	6.67 sec
Leak elimination	7.39 sec	6.76 sec

Vessels sceletonization

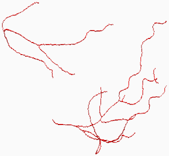


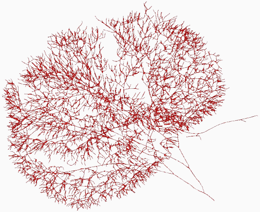
Micro-CT of vascular corrosion cast of rabbit kidney provided by J. Alastruey,
Department of Bioengineering, Imperial College London, UK.

Fast and robust centerline extraction

C. Pudney. Distance-ordered homotopic thinning: A skeletonization algorithm for 3D digital images. Computer Vision and Image Understanding 1998.

Skeletonization





	Case 1	Rabbit kidney
Resolution	$512 \times 512 \times 248$	$2000 \times 1989 \times 910$
Distance map	0.20 sec	58.12 sec
Thinning	0.79 sec	526.98 sec
False twigs cleaning	0.15 sec	16.61 sec
Graph construction	0.13 sec	12.27 sec
Skeleton segments	22 + 6	4302 + 2142

Conclusions

- Developed high-resolution 3D segmented and FEM models of male and female bodies
- Proposed methods for patient-specific segmentation
- Developed numerical methods for bioimpedance and ECG modelling
- Automatic coronary and cerebral arteries segmentation
- Robust skeletonization and graph reconstruction