ECG numerical modelling for patients with pathologies

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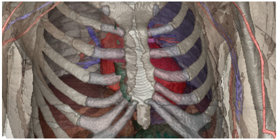
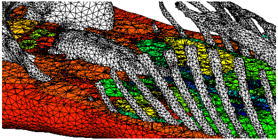
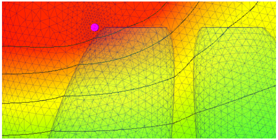
6th Russian workshop on mathematical models and numerical methods in biomathematics

Bioimpedance measurements

- Impedance is measured
- Several electric frequencies
- Local and segmental electrode schemes
- Hydration estimation, fat-free mass, muscle mass, etc.

Noninvasive, efficient, portable, simple and convenient

Research project at INM RAS, Moscow, Russia 2010 – present

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Victoria Salamatova, MIPT
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Bioimpedance measurements

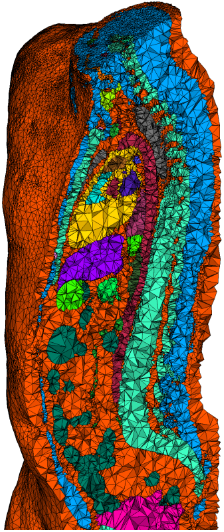
- Impedance is measured
- Several electric frequencies
- Local and segmental electrode schemes
- Hydration estimation, fat-free mass, muscle mass, etc.

Noninvasive, efficient, portable, simple and convenient

- Finite element method and adaptive tetrahedral grids for bioimpedance measurements modelling
- High-resolution multimaterial 3D models based on real human anatomy
- Sensitivity analysis for tetrapolar electrode schemes

S.Grimnes, O.G.Martinsen. Bioimpedance and Bioelectricity Basics. Elsevier, Amsterdam, 2008.

Mathematical model



$$\begin{aligned} \operatorname{div}(\mathbf{C}\nabla U) &= 0 && \text{in} \quad \Omega \\ \mathbf{J}_n &= \pm I_0/S_\pm && \text{on} \quad \Gamma_\pm \\ \mathbf{J}_n &= 0 && \text{on} \quad \partial\Omega \setminus \Gamma_\pm \end{aligned}$$

U – potential field
$\mathbf{C}$ – conductivity tensor
$\mathbf{E} = \nabla U$ – intensity field
$\mathbf{J} = \mathbf{C}\ \mathbf{E}$ – current density field
I_0 – current injection
$S_\pm$ – contact surface of electrodes

Bioelectrical conductivity

Typical conductivity parameters @ 50kHz (S/m)

Blood	0.7	+	0.02·*j*
Muscles	0.36	+	0.035·*j*
Fat	0.0435	+	0.001·*j*
Bones	0.021	+	0.001·*j*
Skin	0.03	+	0.06·*j*
Heart	0.19	+	0.045·*j*
Lungs	0.27	+	0.025·*j*

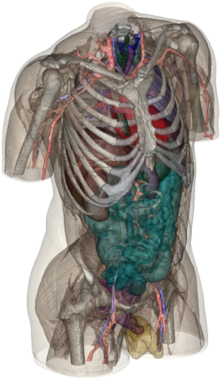
Gabriel S., Lau R.W., Gabriel C. The dielectric properties of biological tissue: III. Parametric models for the dielectric spectrum of tissues. // Phys.Med.Biol. 1996. V.41(11). P.2271-2293.

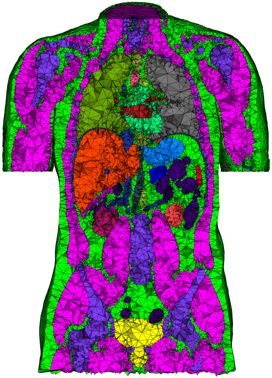
Modeling technology

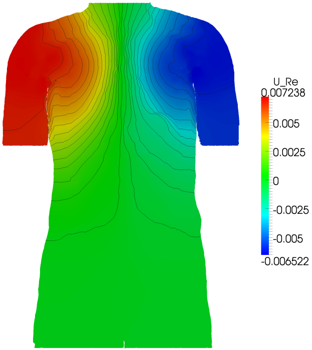
Segmentation

Meshing

FEM







ITK-SNAP

CGAL Mesh

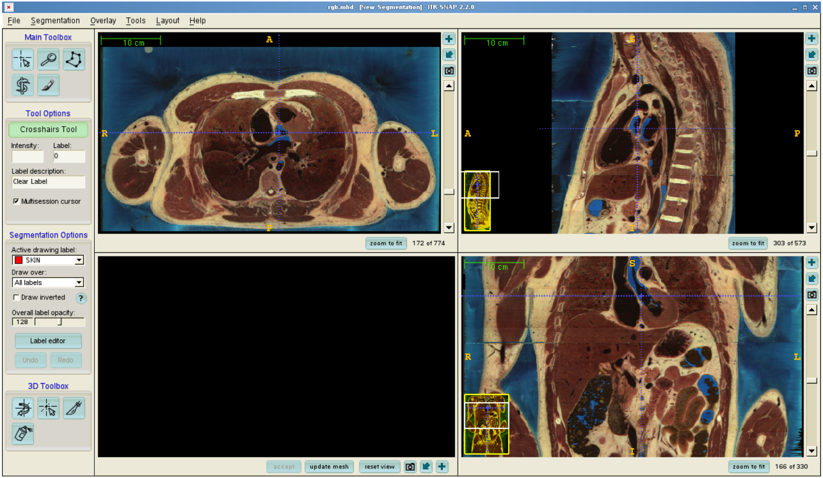
Ani3D

ParaView

A. A. Danilov, D. V. Nikolaev, S. G. Rudnev, V. Yu. Salamatova and Yu. V. Vassilevski, Modelling of bioimpedance measurements: unstructured mesh application to real human anatomy. *Russ. J. Numer. Anal. Math. Modelling* (2012) **27**, No 5, 431–440

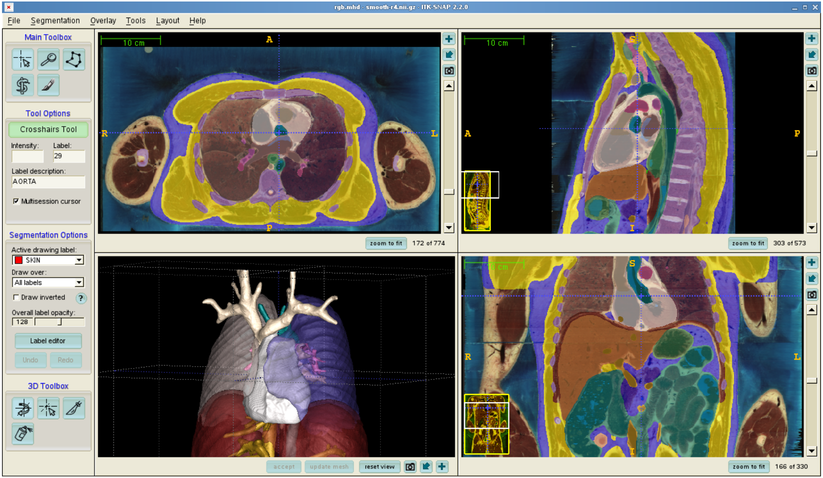
Visible Human Project

Visible Human Project U.S. National Library of Medicine
`www.nlm.nih.gov/research/visible`

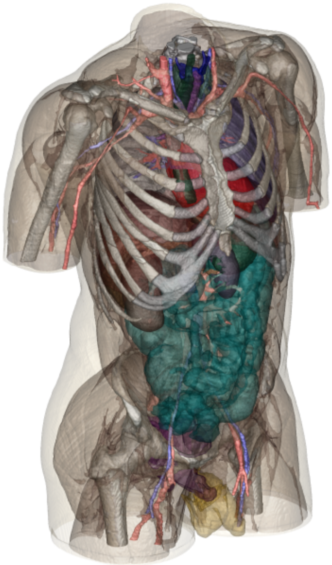


ITK-SNAP software

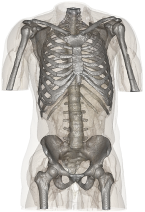
ITK-SNAP (`www.itksnap.org`)
Free software for Visualization and Segmentation

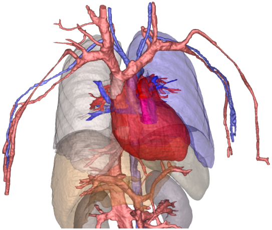


High resolution segmented model of VHP torso



$567 \times 305 \times 843$ voxels
$1 \times 1 \times 1$ mm
26 organs and tissues

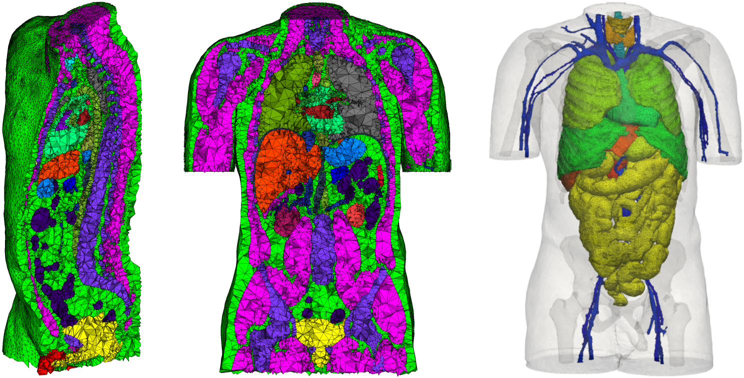




Total 146m voxels, 68m material voxels

Unstructured tetrahedral meshes

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

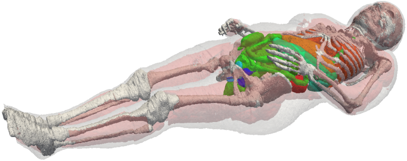


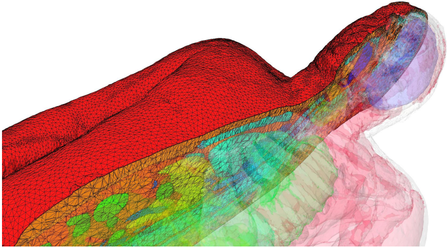
413 508 vertices, 2 315 329 tetraedra, 84 430 boundary faces

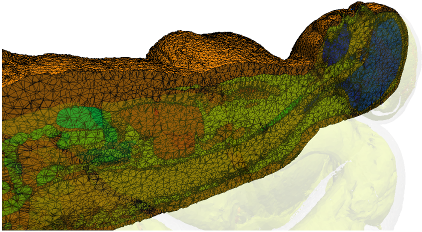
Full body male and female models

VHP-Man

VHP-Woman



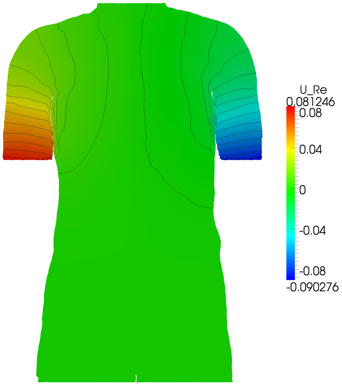




3m tetrahedra effective resolution: $1 \times 1 \times 1$ mm 30 tissues

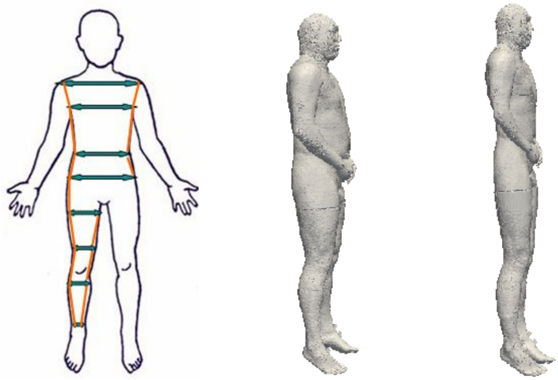
Numerical solution

P1 FEM by Ani3D package (GMRes + ILU2 solver)



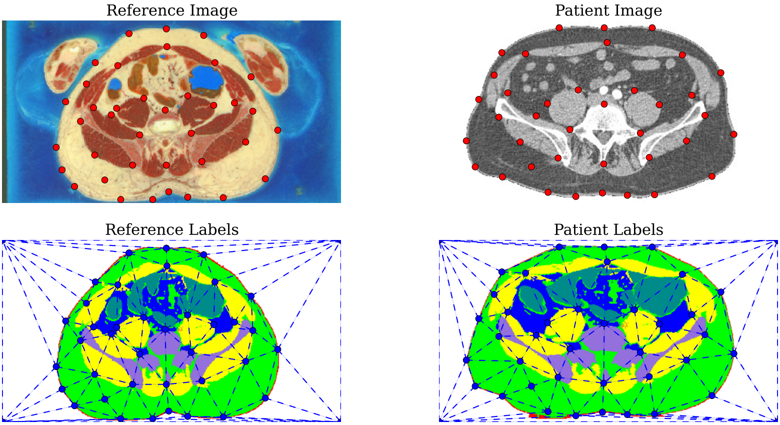
Patient specific models

First step – anthropometric adaptation



Simple fitting of the model

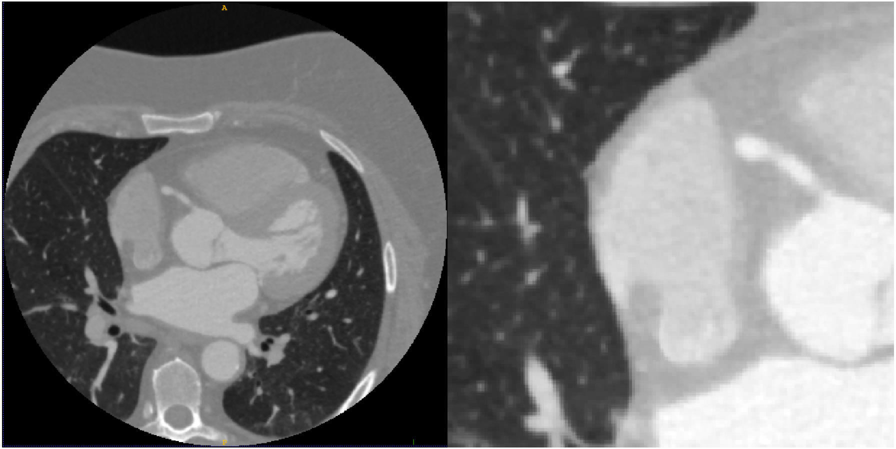
Control points adaptation



Piecewise affine mapping on control plane

MRI/CT data segmentation

DICOM image filter: Amira – Non-local means filter



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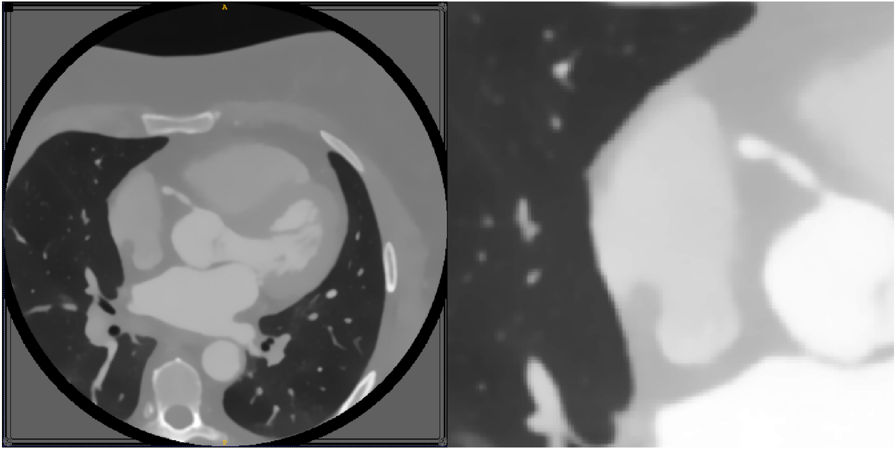
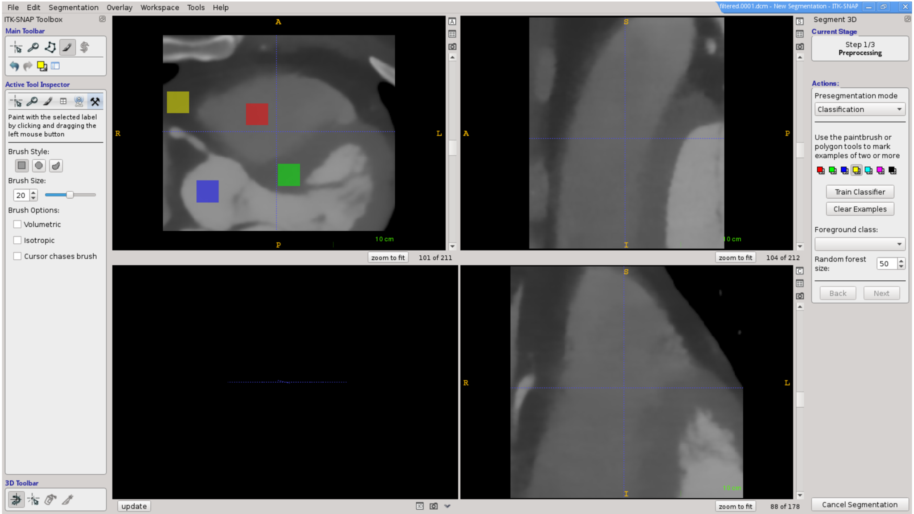


ITK-SNAP 3.2: supervised classification using random forest



MRI/CT data segmentation

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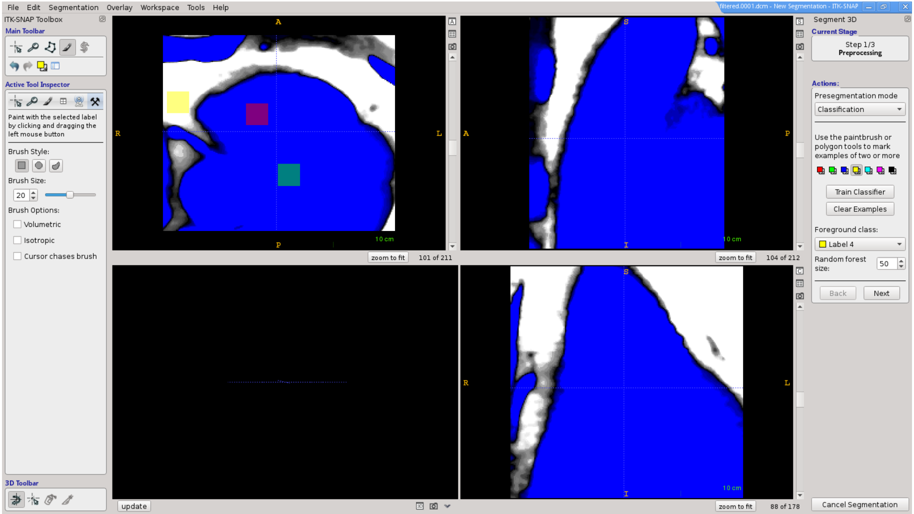

MRI/CT data segmentation

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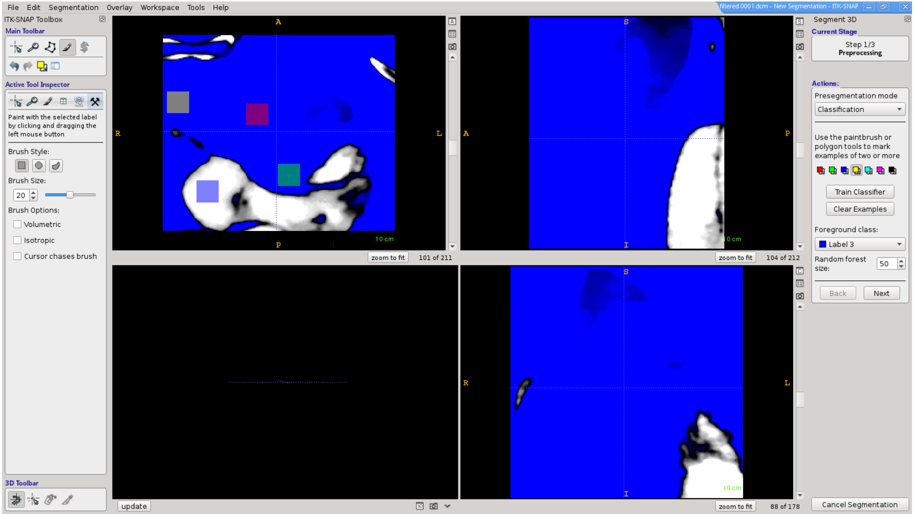

MRI/CT data segmentation

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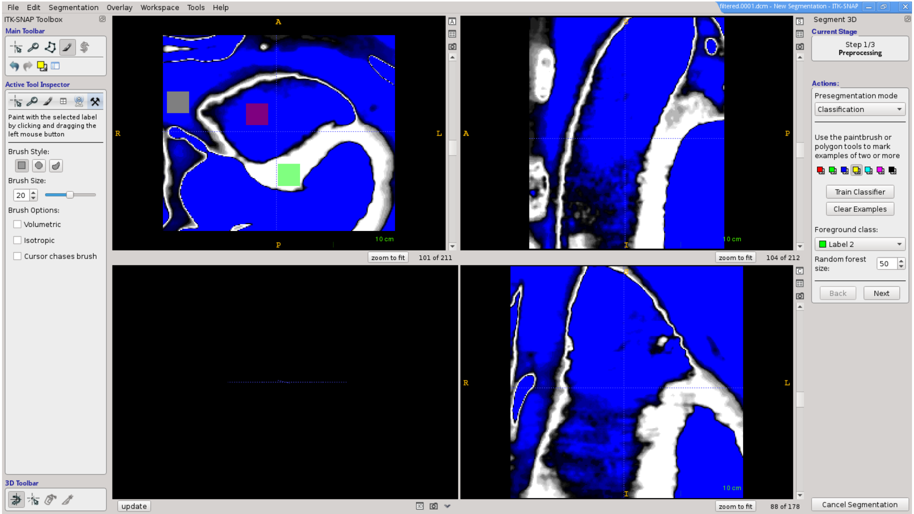

MRI/CT data segmentation

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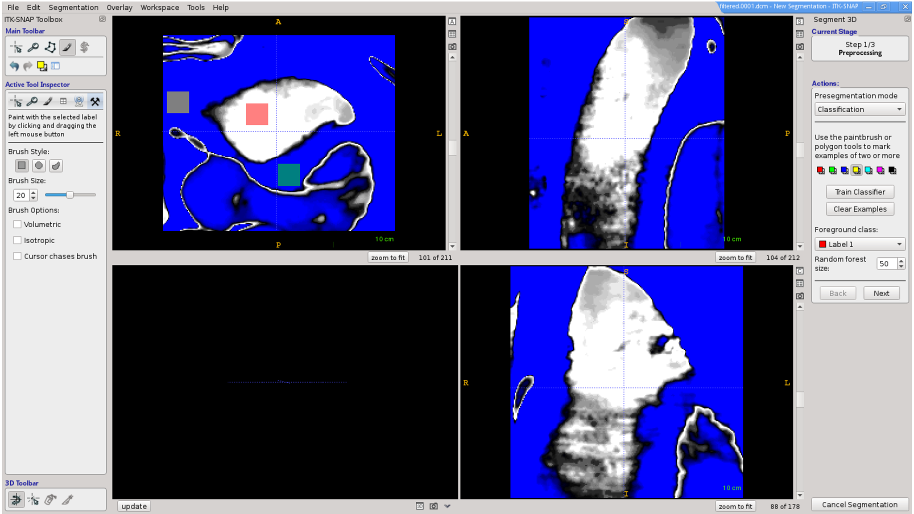
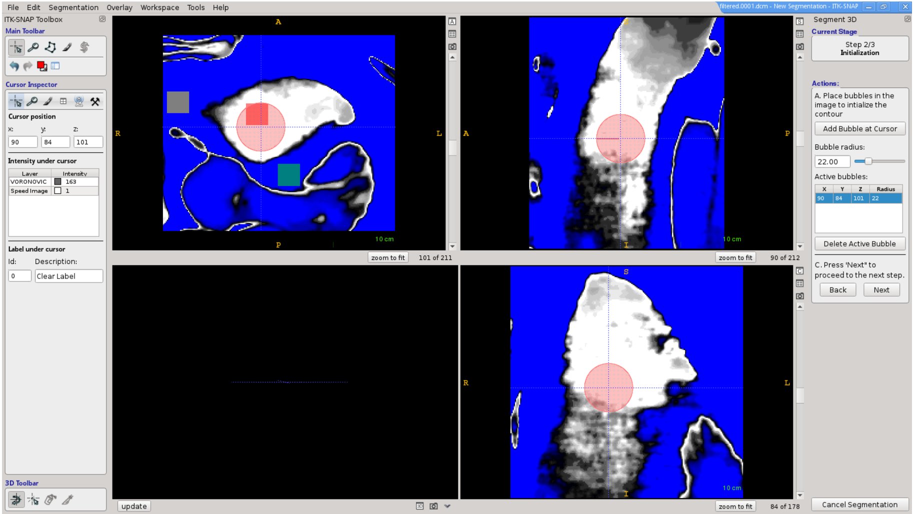


MRI/CT data segmentation

ITK-SNAP 3.2: active contour propogation



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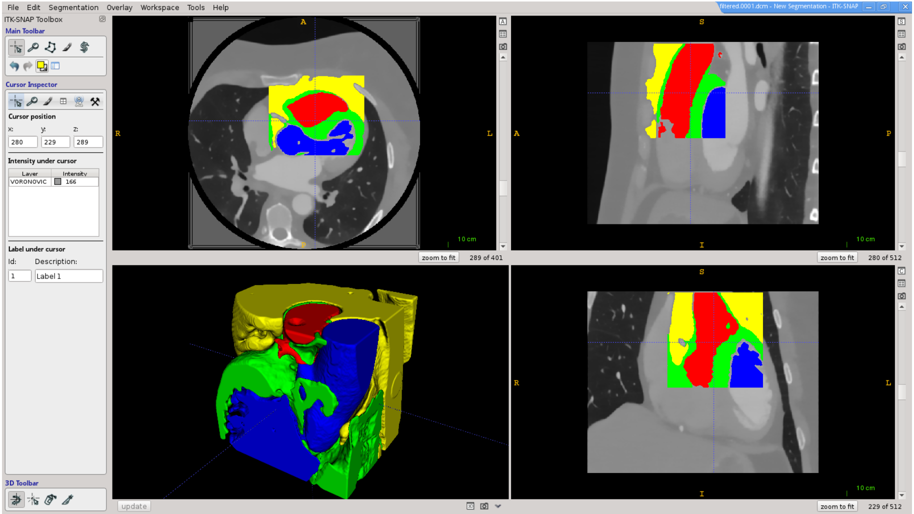
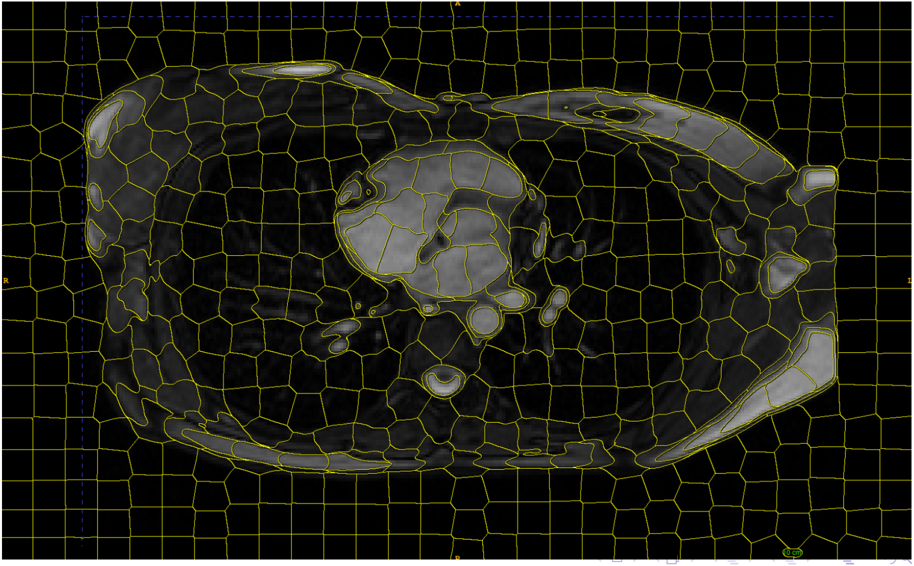


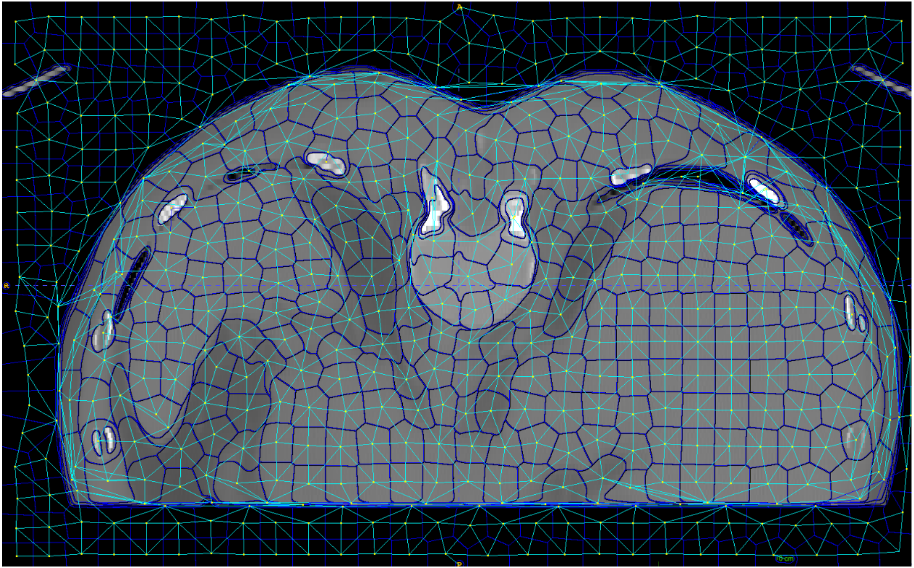
Clusters and Graph Cuts

SLIC Superpixels method

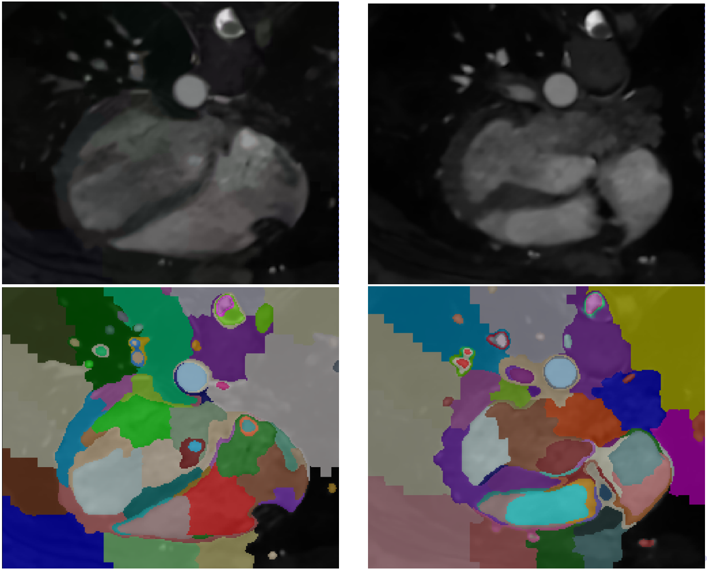


Clusters and Graph Cuts

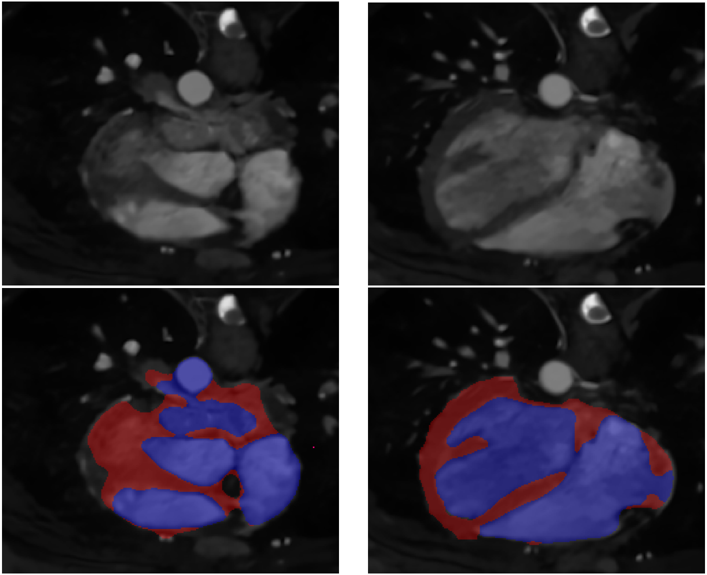
Region Adjacency Graphs



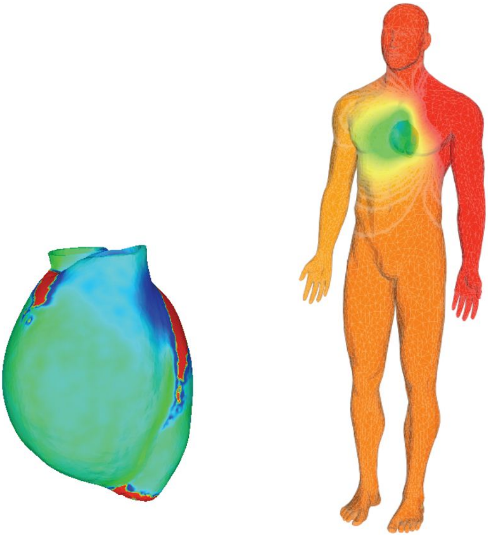
Clusters and Graph Cuts
Normalized Cuts



Clusters and Graph Cuts



ECG modelling



- Patient specific 3D models (heart + torso)
- Automatic and supervised segmentation
- Unstructured meshing
- Coupling of two models
- Cardiac Chaste (Oxford U) or similar
- Bioimpedance model
- Direct modelling of ECG
- Inverse problems

Thank you for your attention!

- Amira – http://www.fei.com/software/amira-3d-for-life-sciences/
- ITK-SNAP – http://www.itksnap.org/
- Convert3D – http://www.itksnap.org/c3d
- Cardiac Chaste – http://www.cs.ox.ac.uk/chaste/
- Bioimpedance – http://www.inm.ras.ru/research/bioimpedance