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About my last master semester…

- In October 2013 I moved to **Rotterdam**, the Netherlands
- Erasmus University Medical Center (Erasmus MC)
- Biomedical Imaging Group Rotterdam (BIGR)
  Head: Prof. Wiro Niessen
- Supervisors FAU: Stefan Steidl, Andreas Maier
- Supervisors BIGR: Adria Perez-Rovira, Marleen de Bruijne

Erasmus MC
Universitair Medisch Centrum Rotterdam

Characterization of Lung Motion in Pompe Patients using 3D+t MRI Data

Thesis presentation

Katja Mogalle
June 30, 2014
Computer Science Dept. 5 (Pattern Recognition)
Friedrich-Alexander-Universität Erlangen-Nürnberg

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Outline

- Introduction
- The Big Picture
- Bias Field Correction
- Respiratory Motion Estimation
- Lung Surface Partitioning
- Motion Feature Extraction
- Conclusion and Outlook

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Pompe Disease

Rare inherited metabolic disorder

- 1 in 40.000 affected
- reduced activity of enzyme α-glucosidase
- glycogen accumulates and damages muscles

Symptoms

- slowly progressive myopathy
- wheelchair and/or ventilator dependency
- high variety in age of onset and course of disease

Treatment (Enzyme Replacement Therapy)

- very expensive
- highest success rate for patients at **early** disease stage

Motivation

Respiratory failure is major cause of death (monitored with spirometry)

Involvement of diaphragm must be detected early

Magnetic Resonance Imaging

- non-invasive
- advanced protocols allow for **dynamic 3D imaging** of thorax during breathing

Goal

- analyze breathing mechanics
- assess functioning of diaphragm

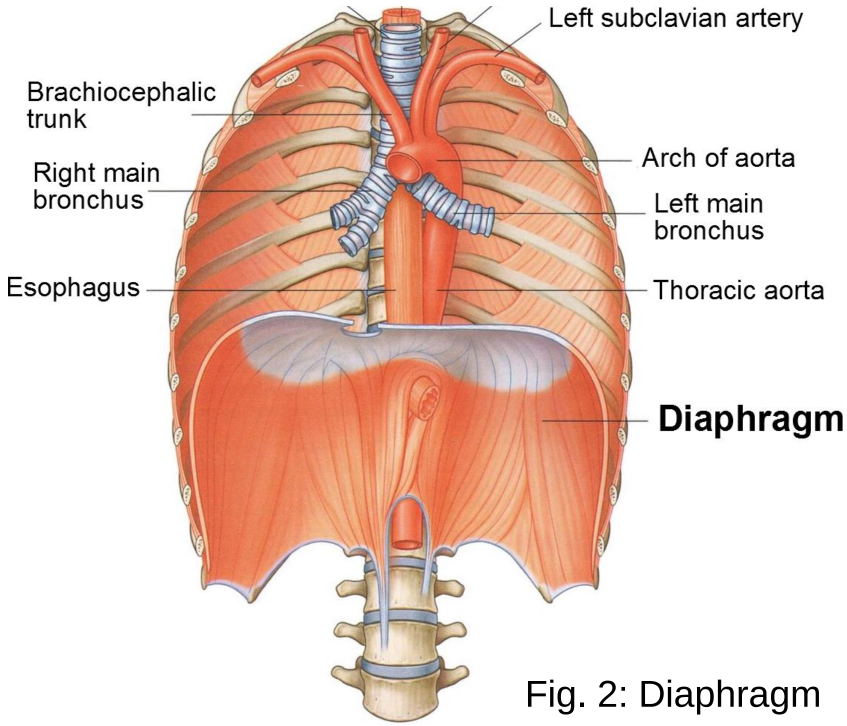
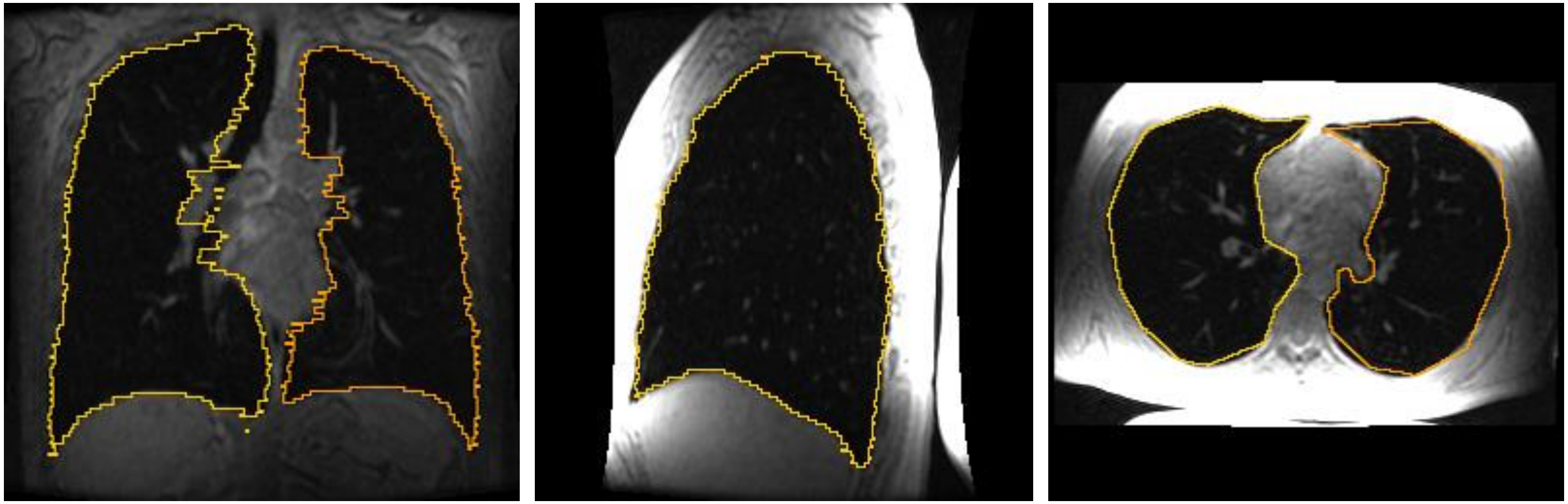


Fig. 2: Diaphragm

Data

MRI images for 10 Pompe patients and 6 healthy volunteers

- 3D **static scan** at end inspiration and manual **lung segmentation**



Volunteer 04, dimensions: 256 x 256 x 248, voxel size 1.46 x 1.46 x 1.5 mm

Data

MRI images for 10 Pompe patients and 6 healthy volunteers

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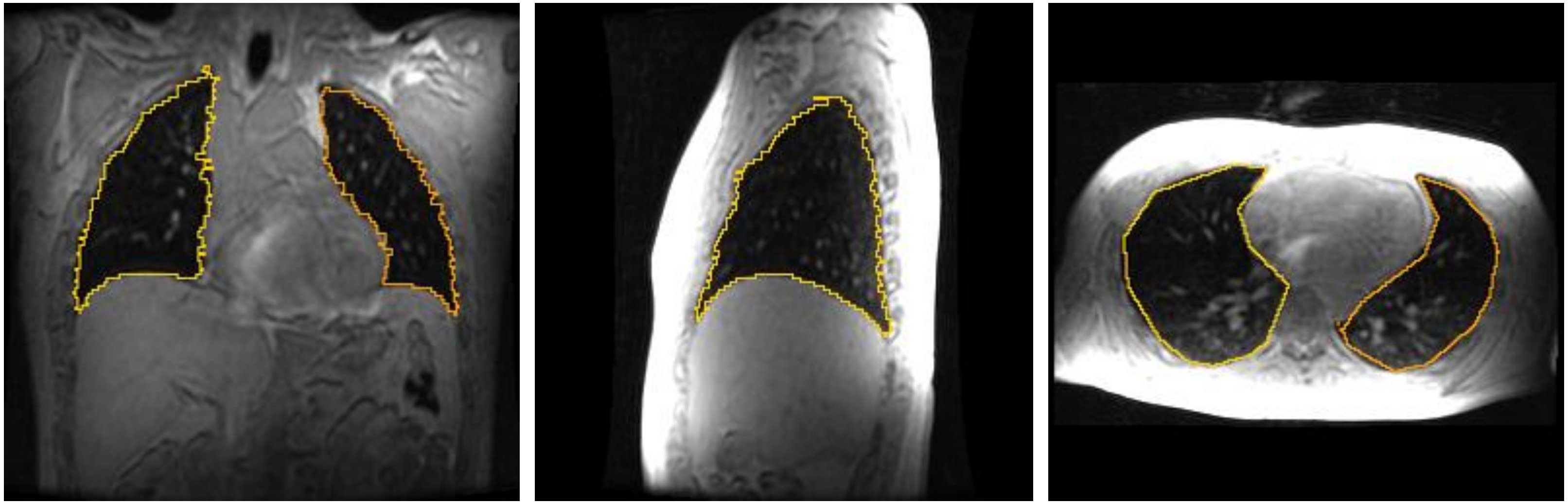
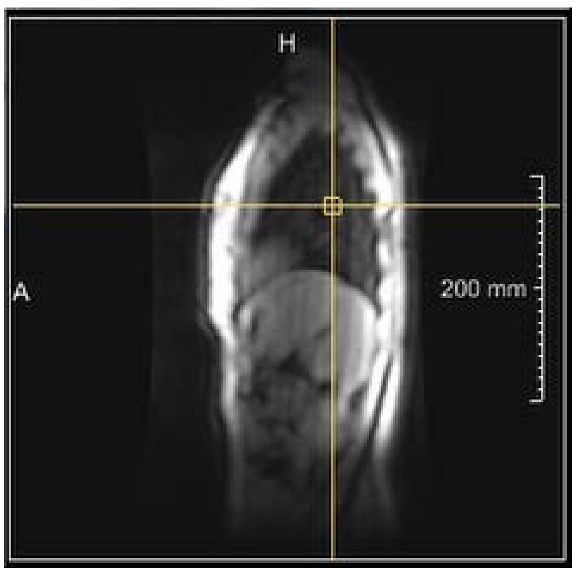


Volunteer 04, dimensions: 256 x 256 x 248, voxel size 1.46 x 1.46 x 1.5 mm

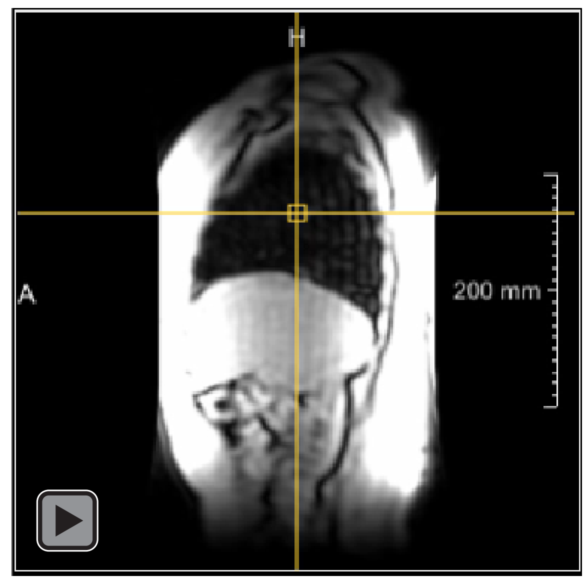
Data

MRI images for 10 Pompe patients and 6 healthy volunteers

- 3D+t **dynamic scan** (256x256x60x48 voxels, voxel size 1.875x1.875x6 mm)



Volunteer 03



Patient 07

State of the Art

- 62.5% [Kondo 2000] – 75% [Naish 2009] of the **lung volume change** is induced by **diaphragmatic movement**

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- lung volume measurements in MRI data correlate well with spirometry data, further analysis on normal diaphragm shape and movement [Gauthier 1994]

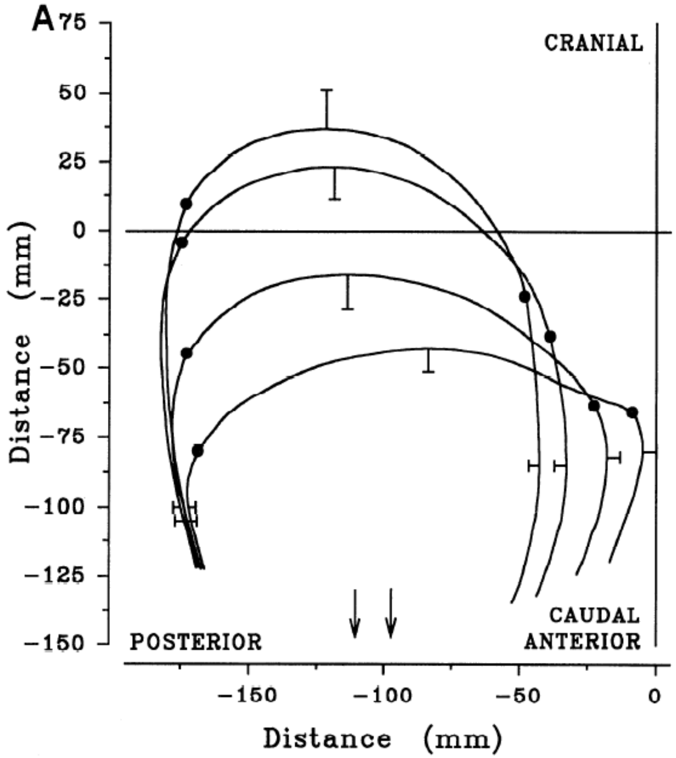


Fig. 4: Diaphragm movement

State of the Art

- 62.5% [Kondo 2000] – 75% [Naish 2009] of the **lung volume change** is induced by **diaphragmatic movement**
- lung volume measurements in MRI data correlate well with spirometry data, further analysis on normal diaphragm shape and movement [Gauthier 1994]
- lung motion estimation in 3D+t MRI data [Plathow 2009] via statistical shape models and active shape mechanism [Heimann 2007], to analyze impact of lung tumors

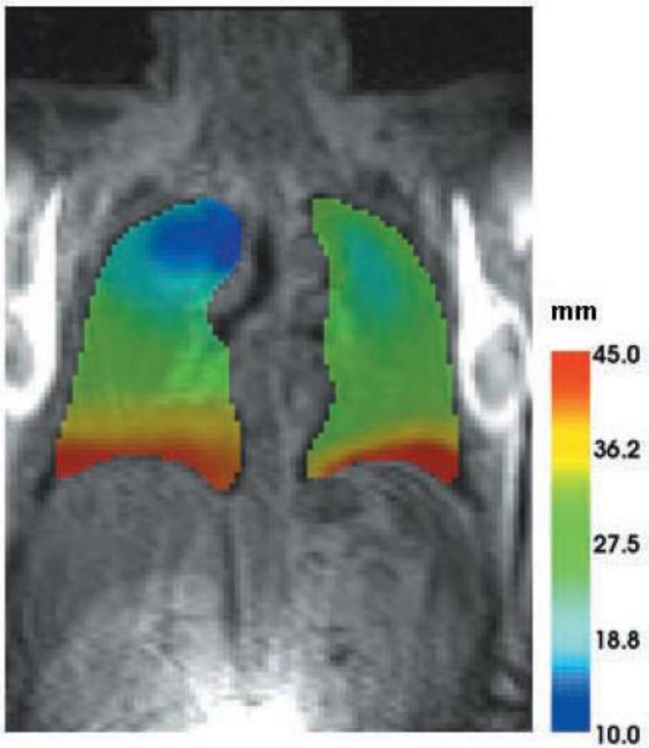
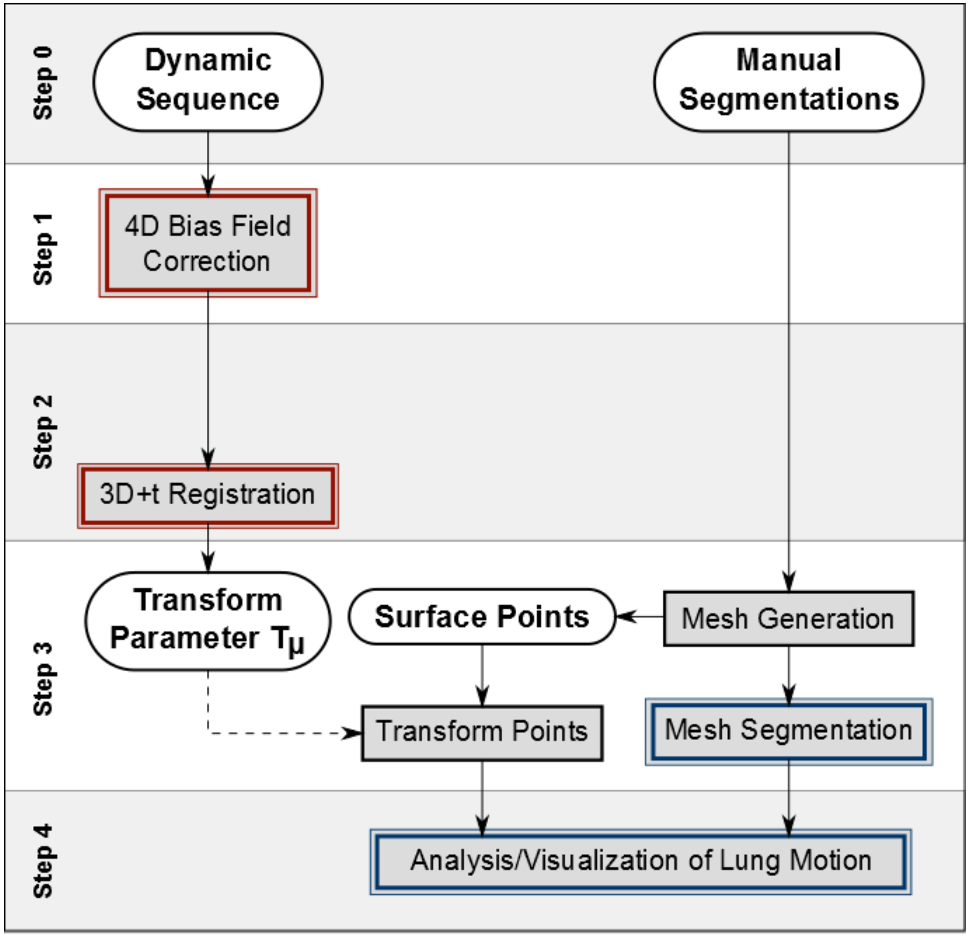
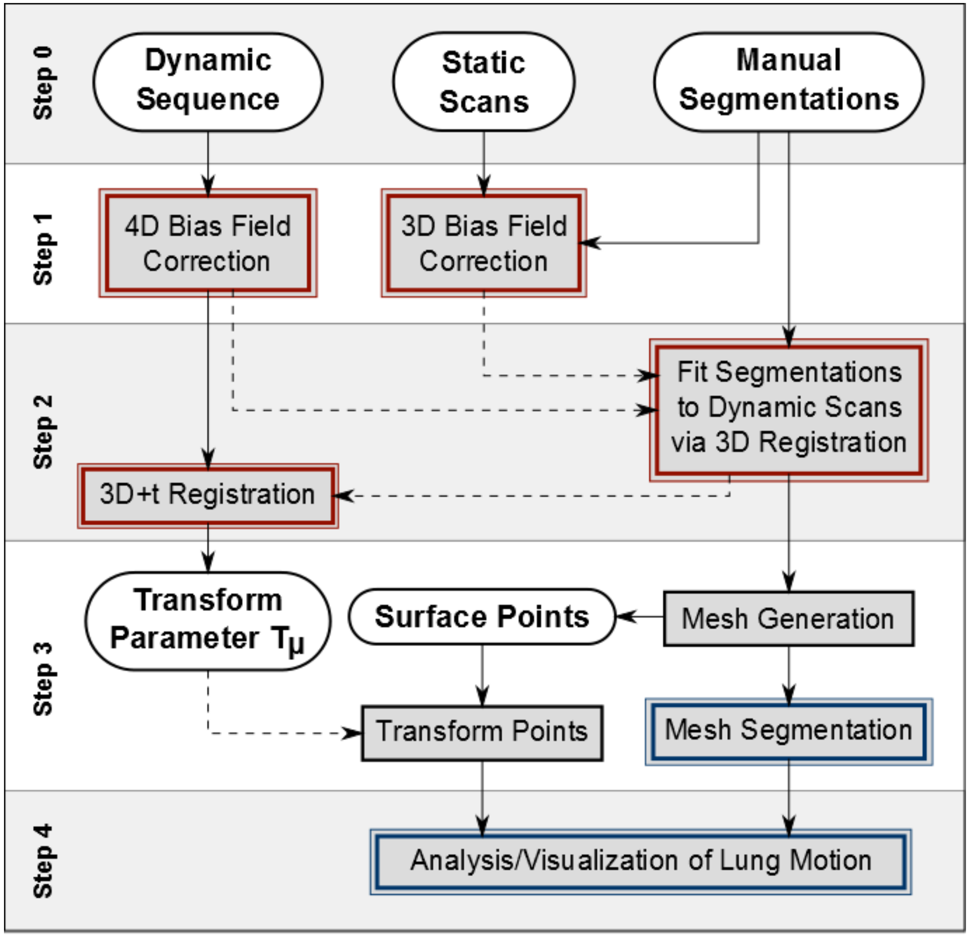


Fig. 5: Lung deformation

Pipeline


Step 0
Dynamic Sequence
Manual Segmentations
Step 1
4D Bias Field Correction
Step 2
3D+t Registration
Step 3
Transform Parameter Tμ
Surface Points
Mesh Generation
Transform Points
Mesh Segmentation
Step 4
Analysis/Visualization of Lung Motion

Pipeline


Step 0
Dynamic Sequence
Static Scans
Manual Segmentations
Step 1
4D Bias Field Correction
3D Bias Field Correction
Step 2
Fit Segmentations to Dynamic Scans via 3D Registration
3D+t Registration
Step 3
Transform Parameter Tμ
Surface Points
Mesh Generation
Transform Points
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Step 4
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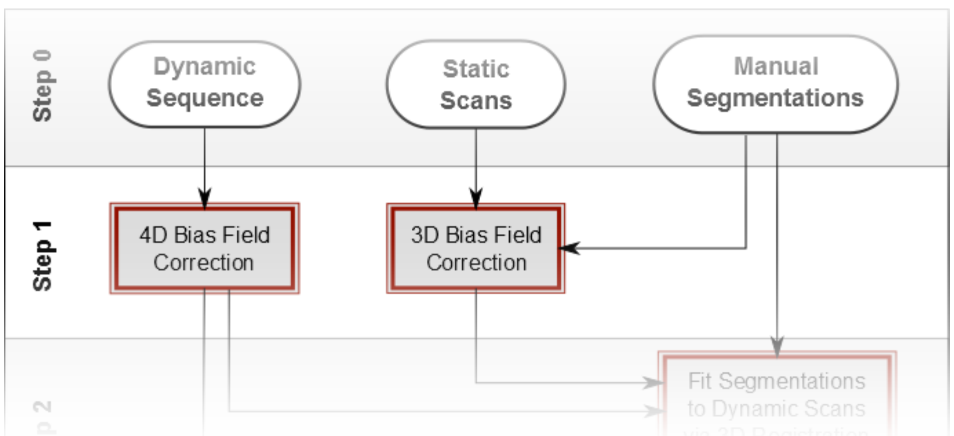
Bias Field Correction



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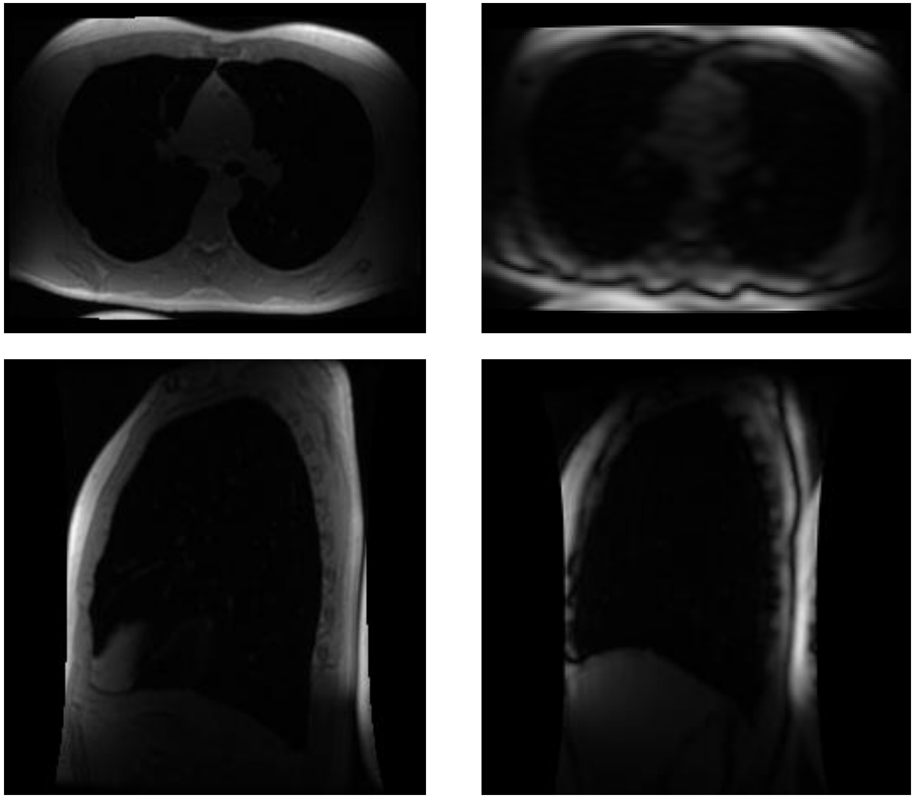
Intensity Inhomogeneity

Possible reasons for intensity inhomogeneity

- surface coil sensitivity
- fat/water contrast



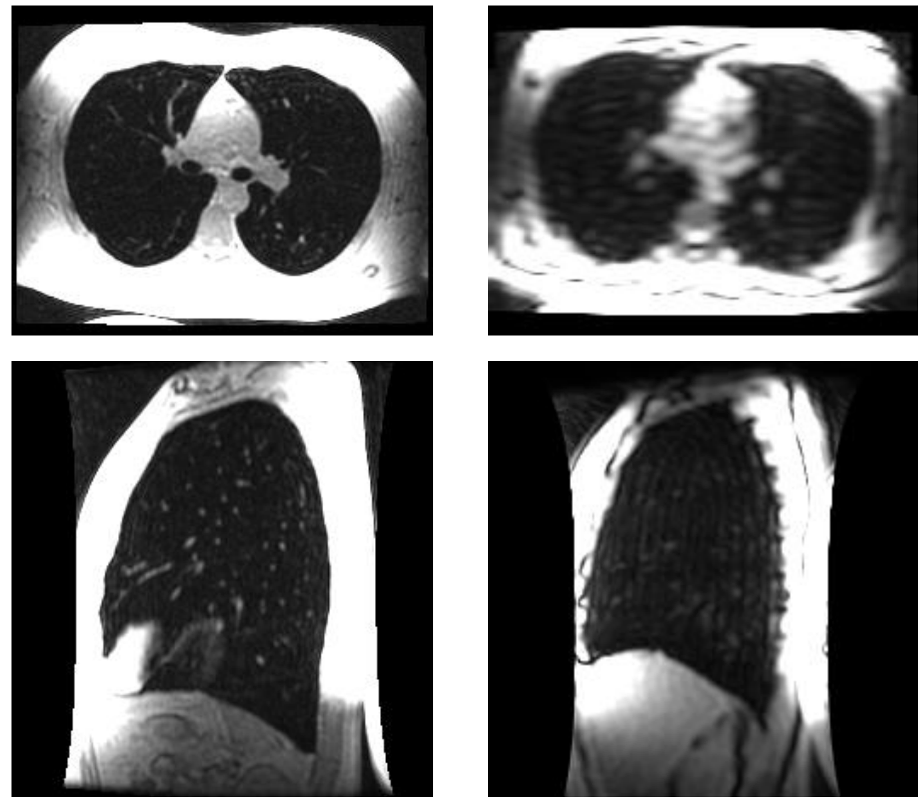
Intensity Inhomogeneity

Possible reasons for intensity inhomogeneity

- surface coil sensitivity
- fat/water contrast

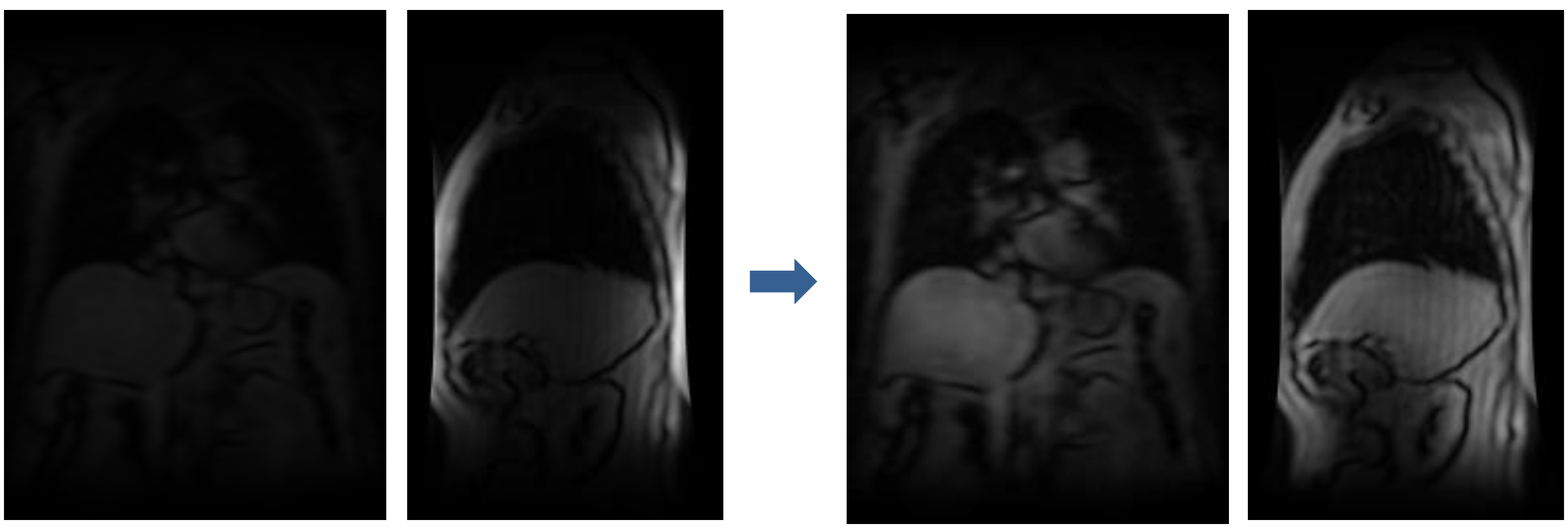
→ manual contrast adjustment shows inner structures

Bias field correction necessary for succeeding registration



Bias Field Correction with N4ITK [Tustison 2010]

- extension of popular N3 algorithm [Sled 1998]
- iterative method for bias field estimation using:
  - B-spline approximation
  - multi-resolution
  - masks, weight image



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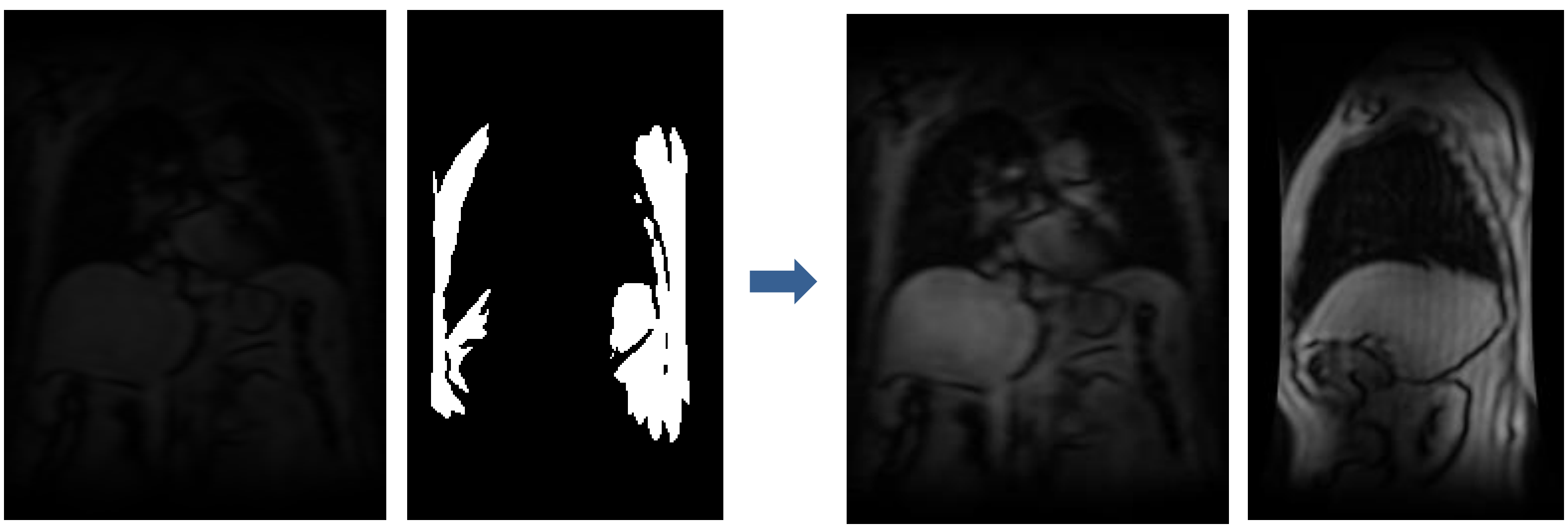


Improved Bias Field Correction using N4ITK

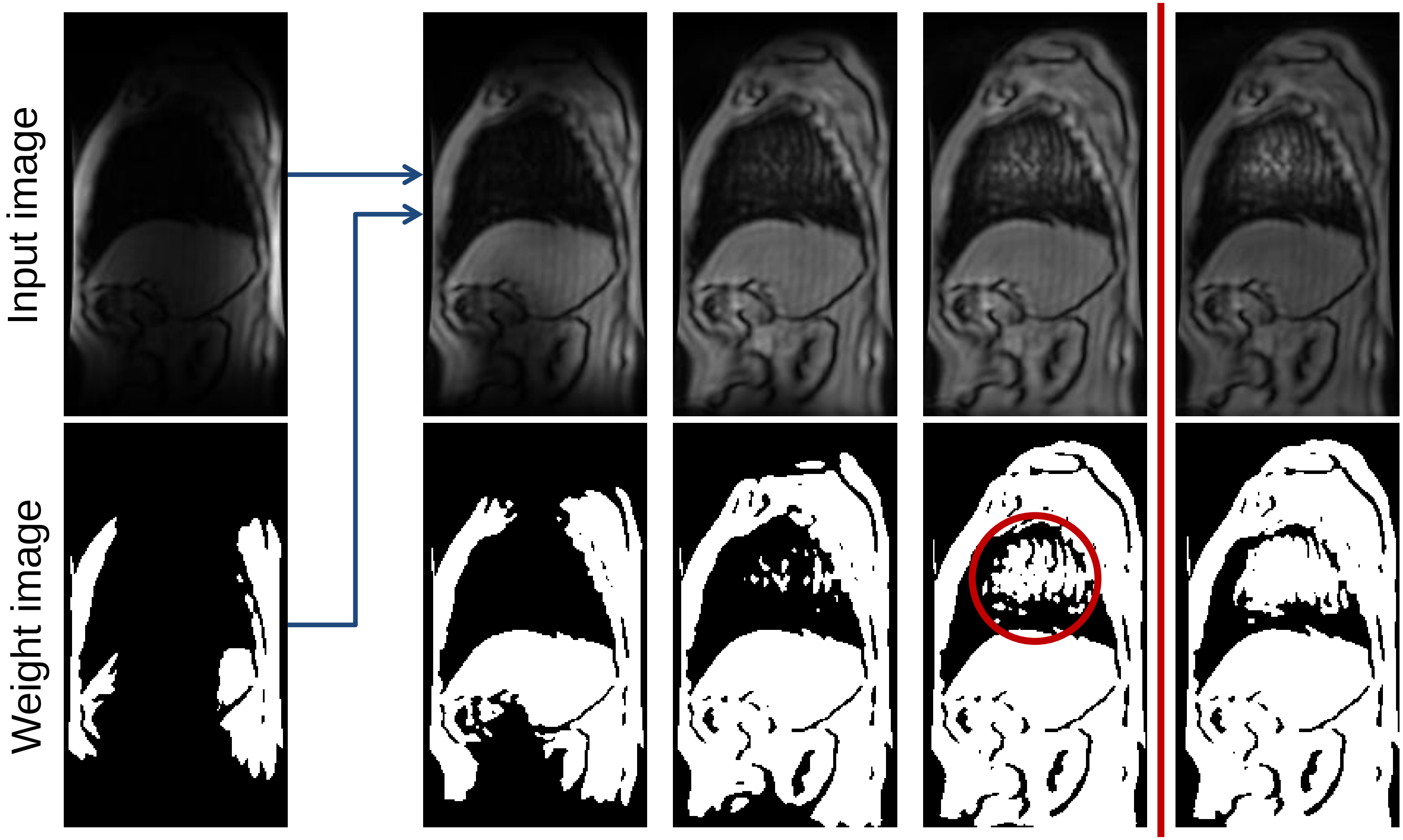
Parameter optimization

- spline distance
- number of resolutions
- number of iterations per resolution
- weight image

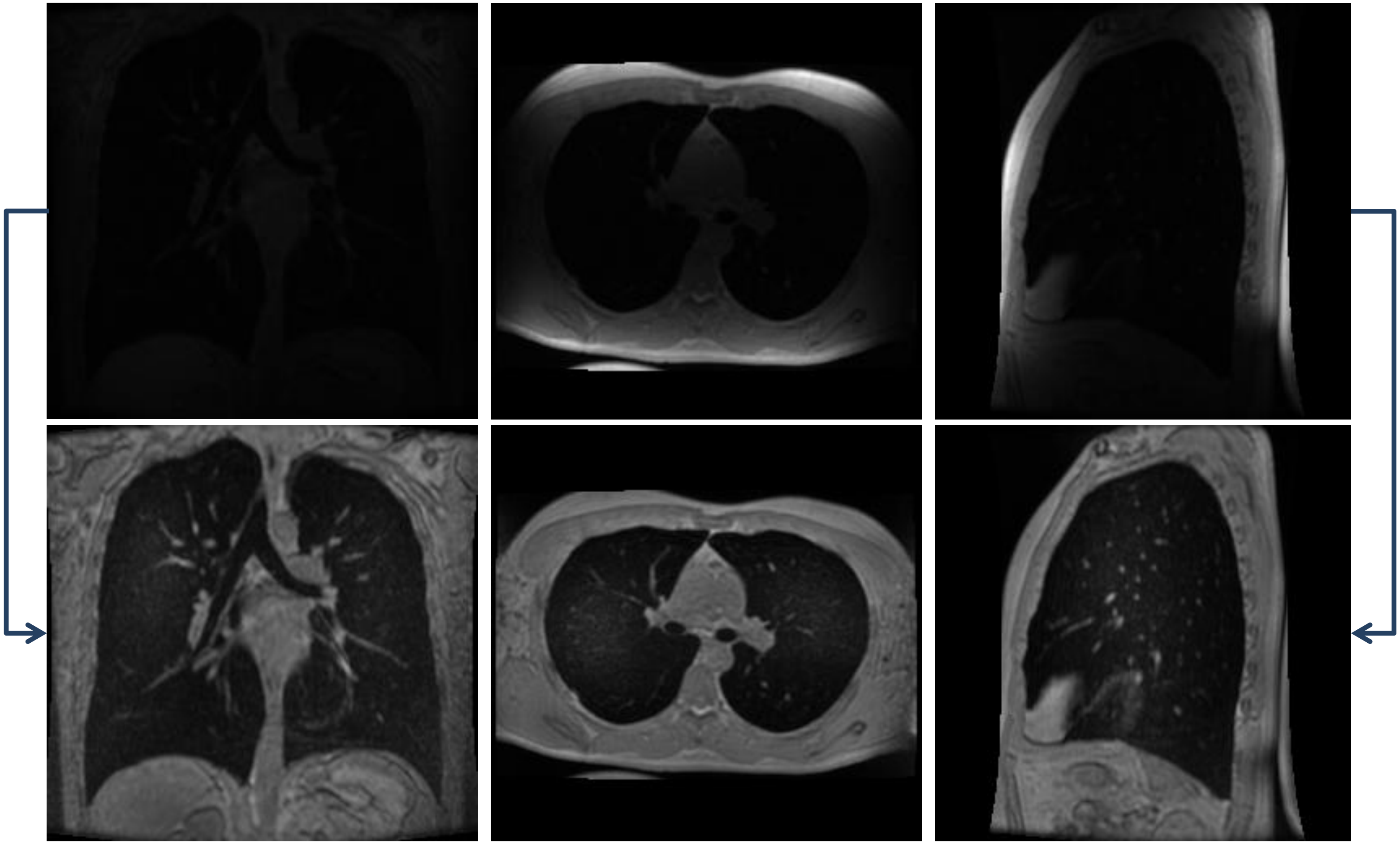
Iterative procedure:

- multiple runs of N4ITK on original image
- create mask from previous run via Otsu thresholding of the result

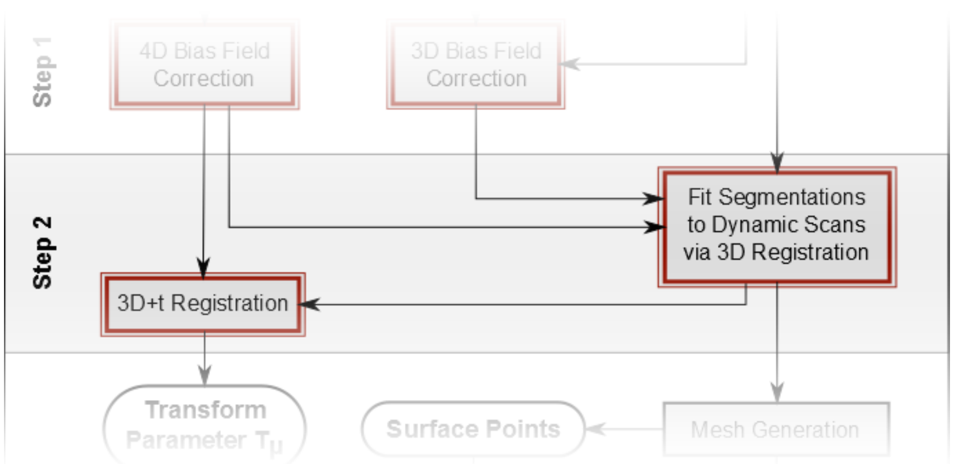
Improved Bias Field Correction using N4ITK



Improved Bias Field Correction using N4ITK



Respiratory Motion Estimation



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Non-rigid Registration of 3D+t Images

Main components [Metz 2011]

- transformation: free-form B-spline deformation model
- metric: variance of intensity values over time
- multi-resolution strategy

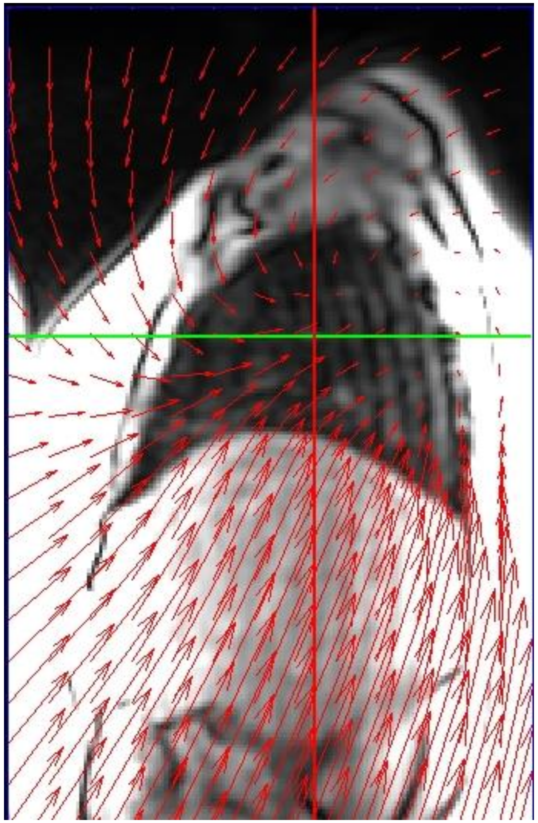
elastix

Parameter optimization

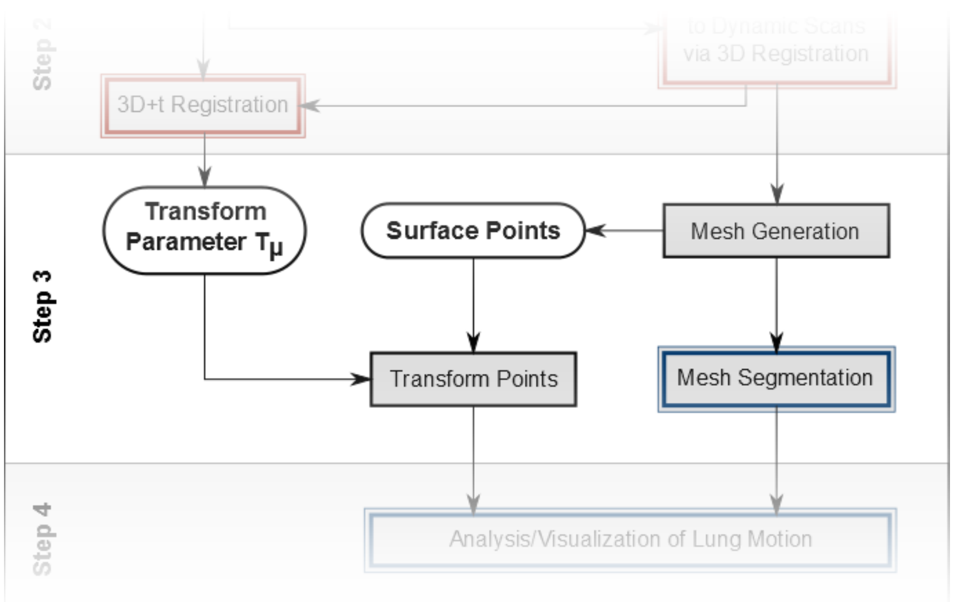
- spline distance forward transformation
- spline distance inverse transformation

Non-rigid Registration of 3D+t Images

Dense deformation field calculated from transformation parameters



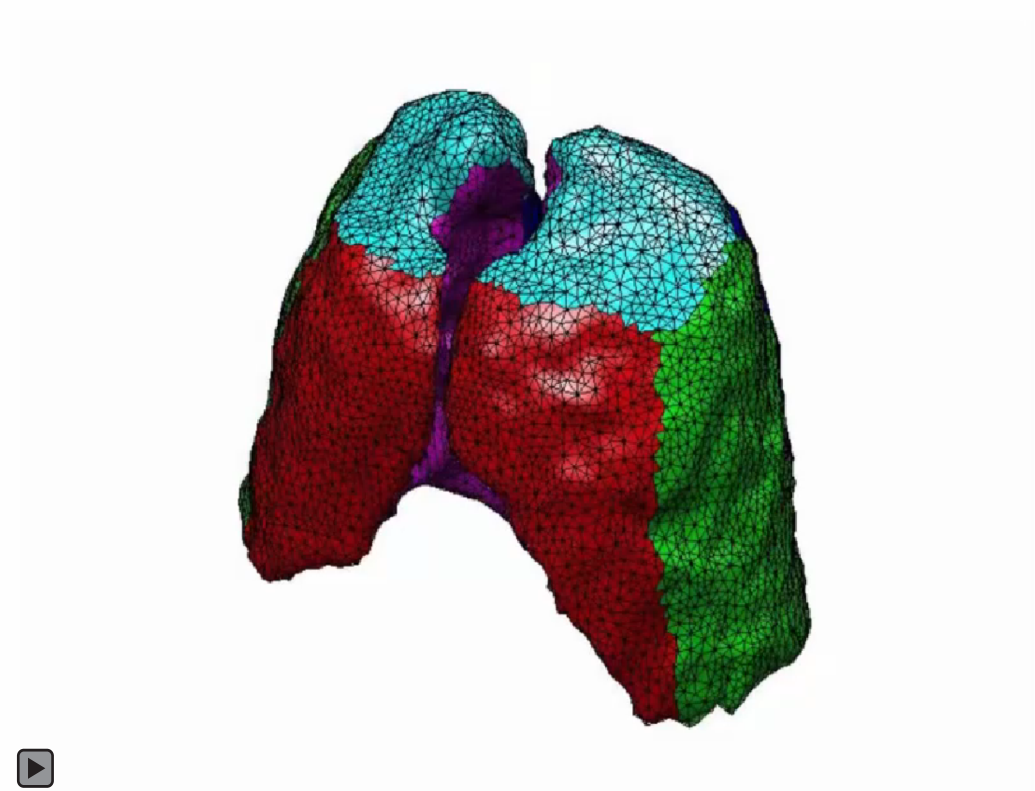
Lung Partitioning



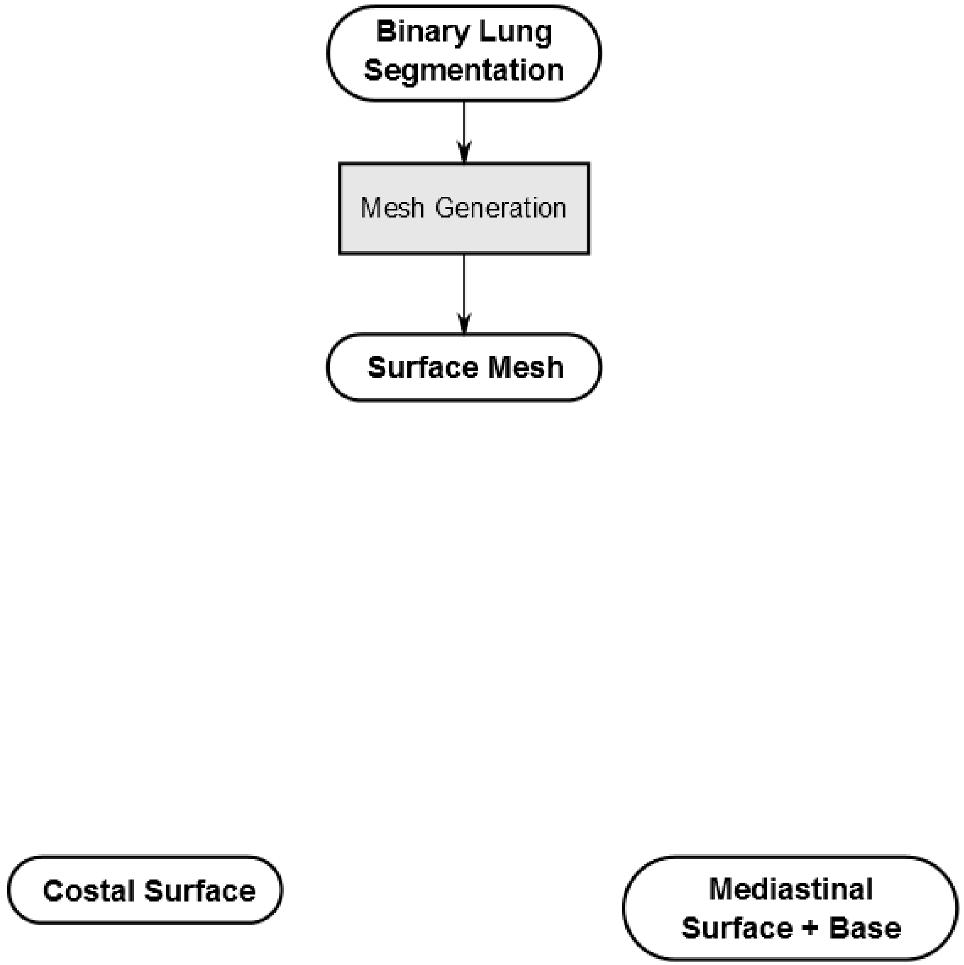
Lung Surfaces

Partitions of the lung surface

- base (diaphragmatic surface)
- mediastinal surface
- costal surface
  - anterior
  - posterior
  - lateral
  - apex



Mesh Segmentation Pipeline



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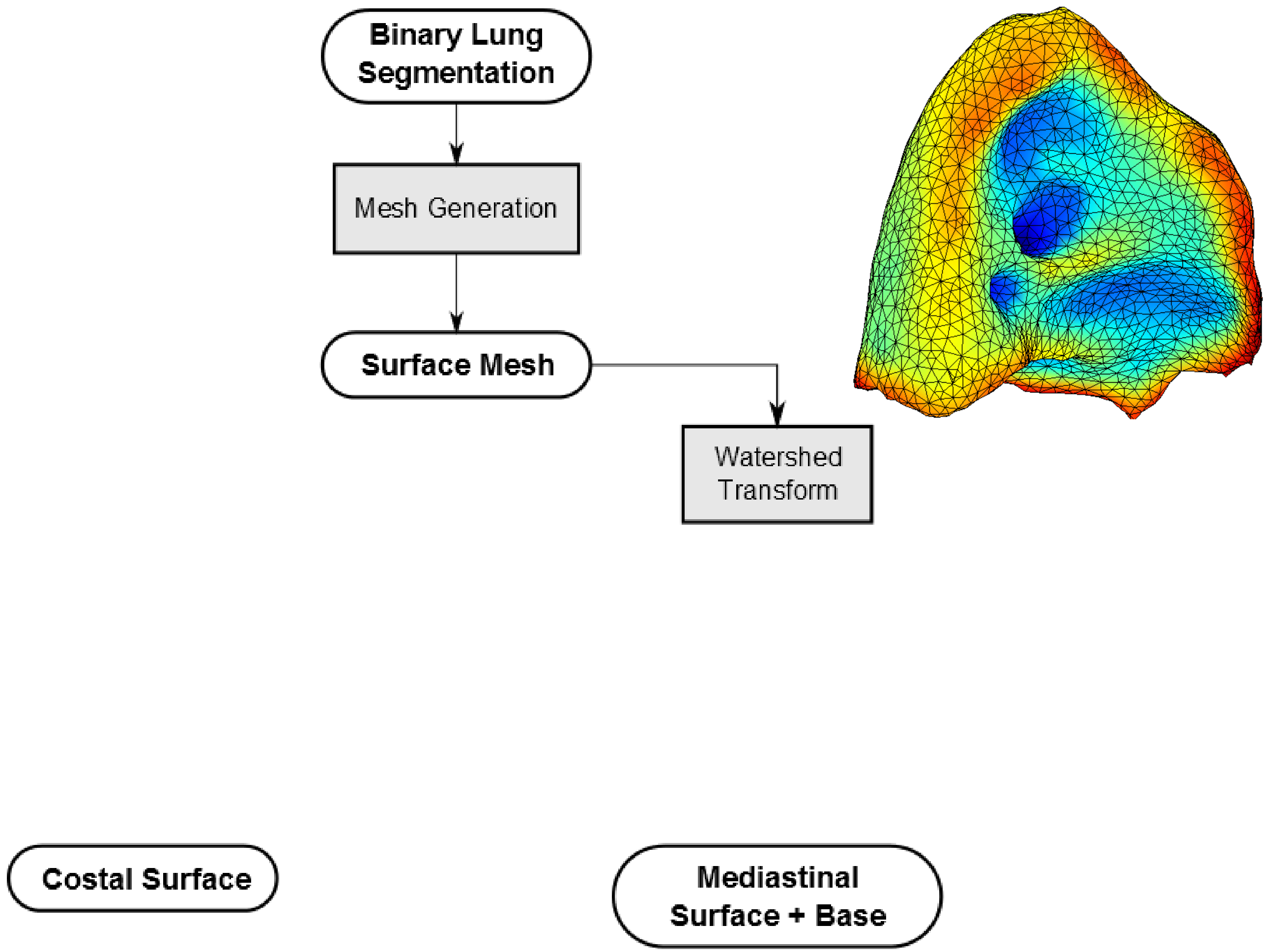

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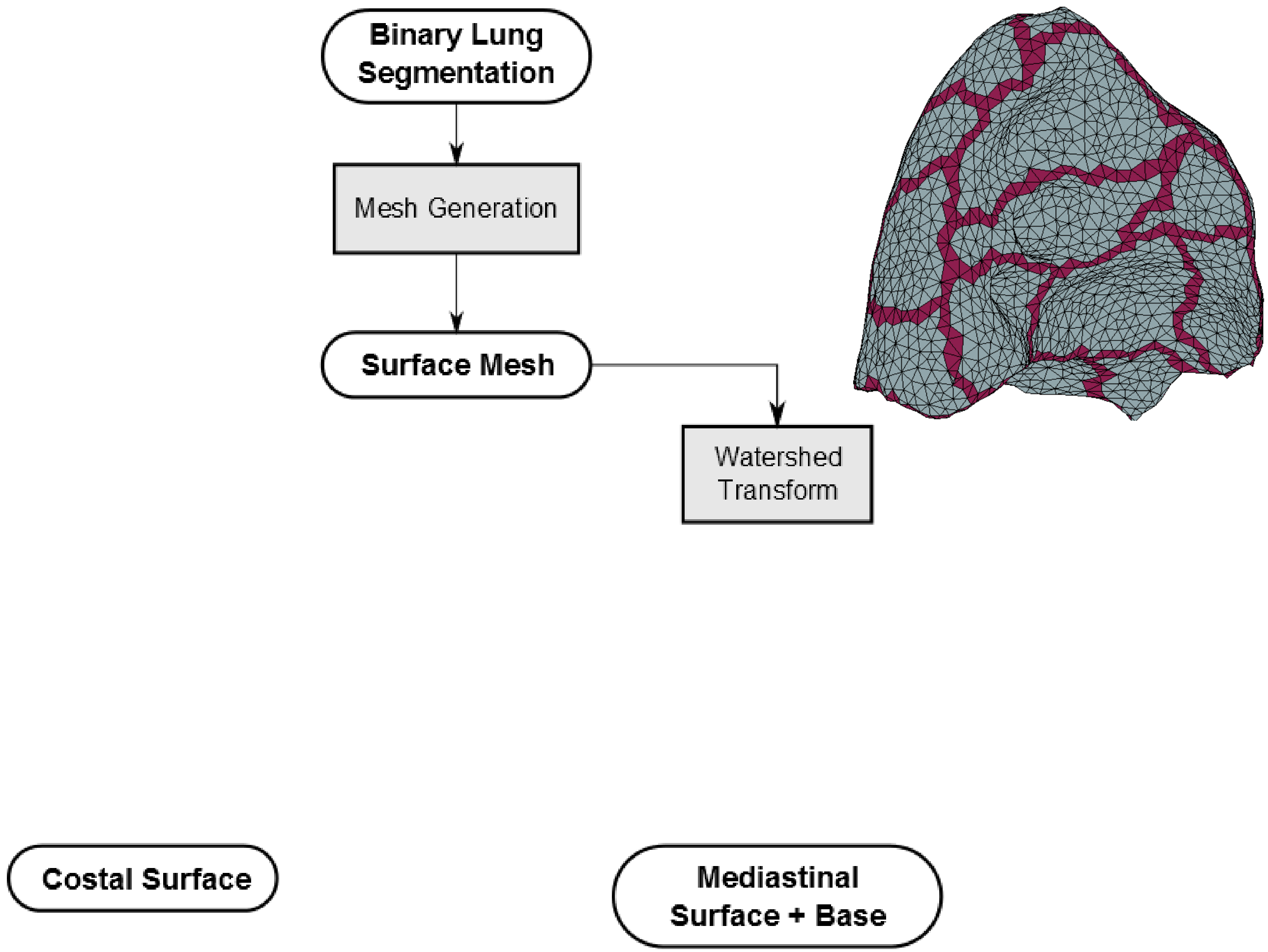

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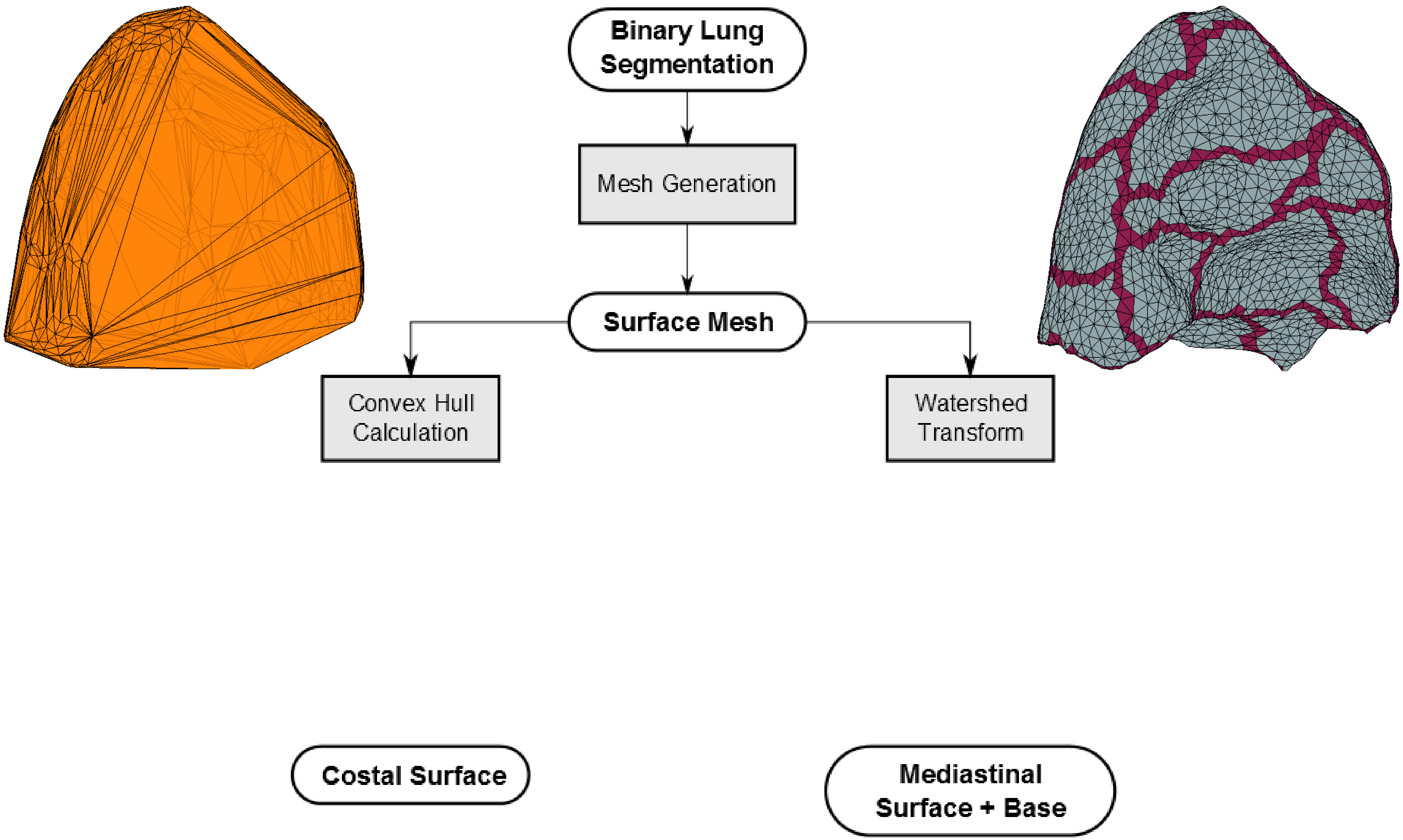

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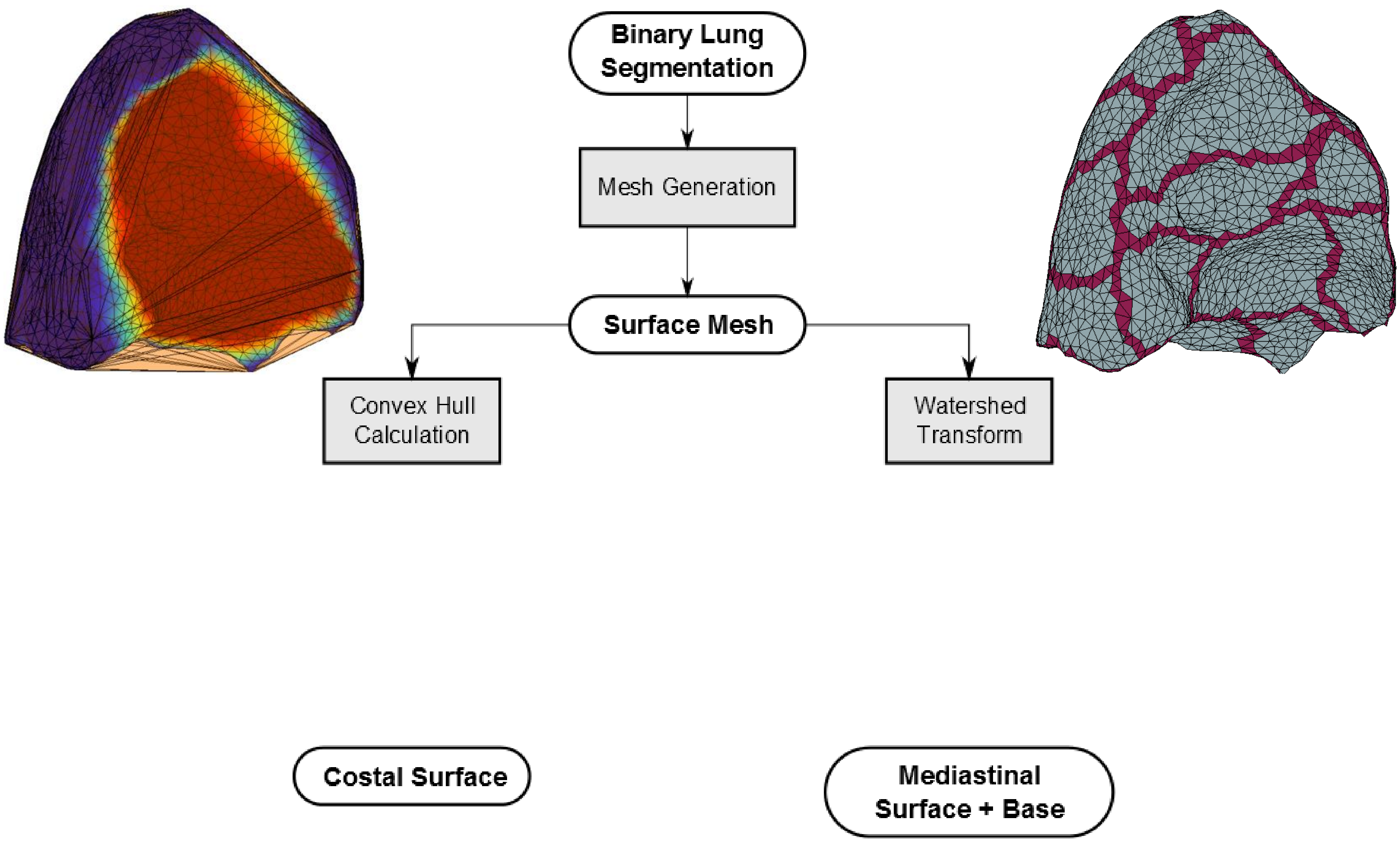

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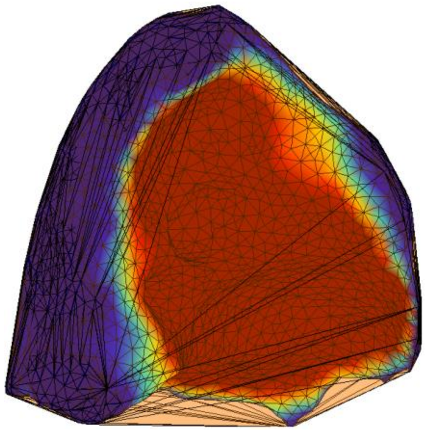

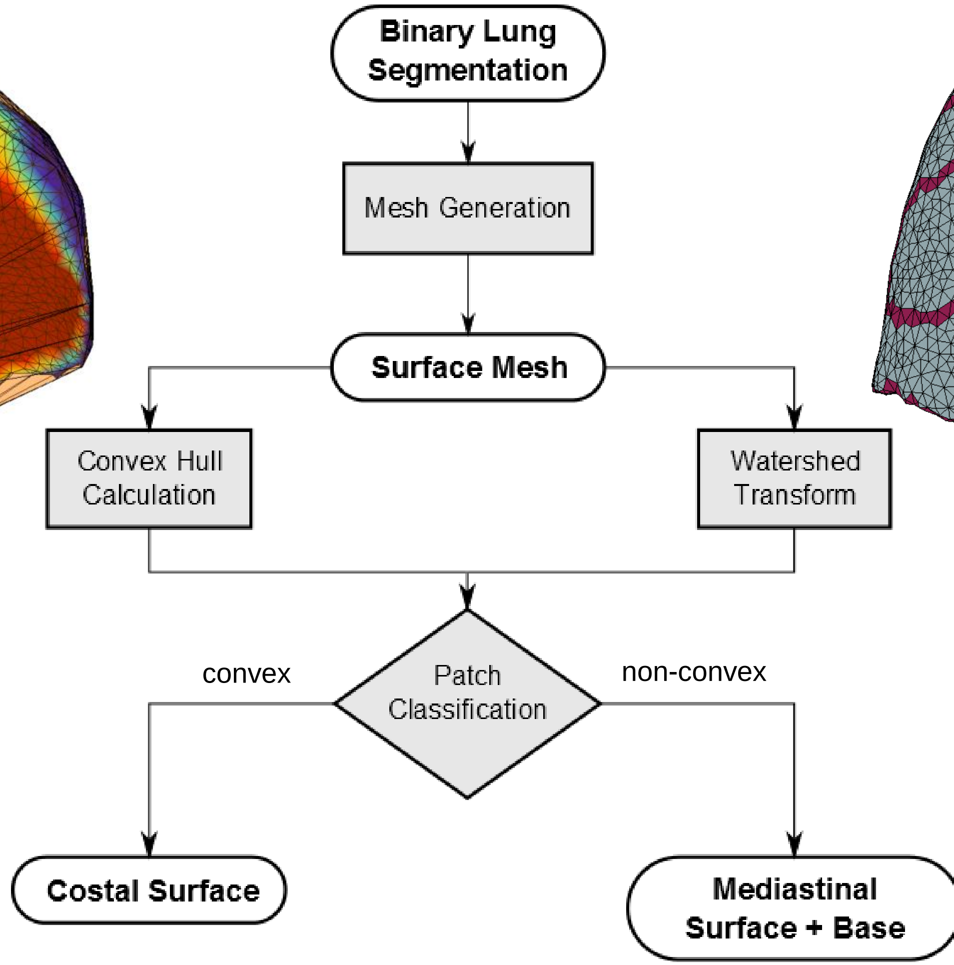

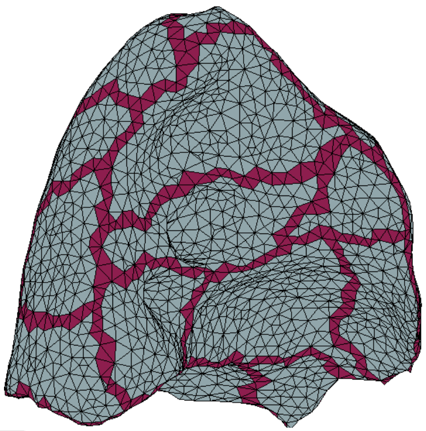

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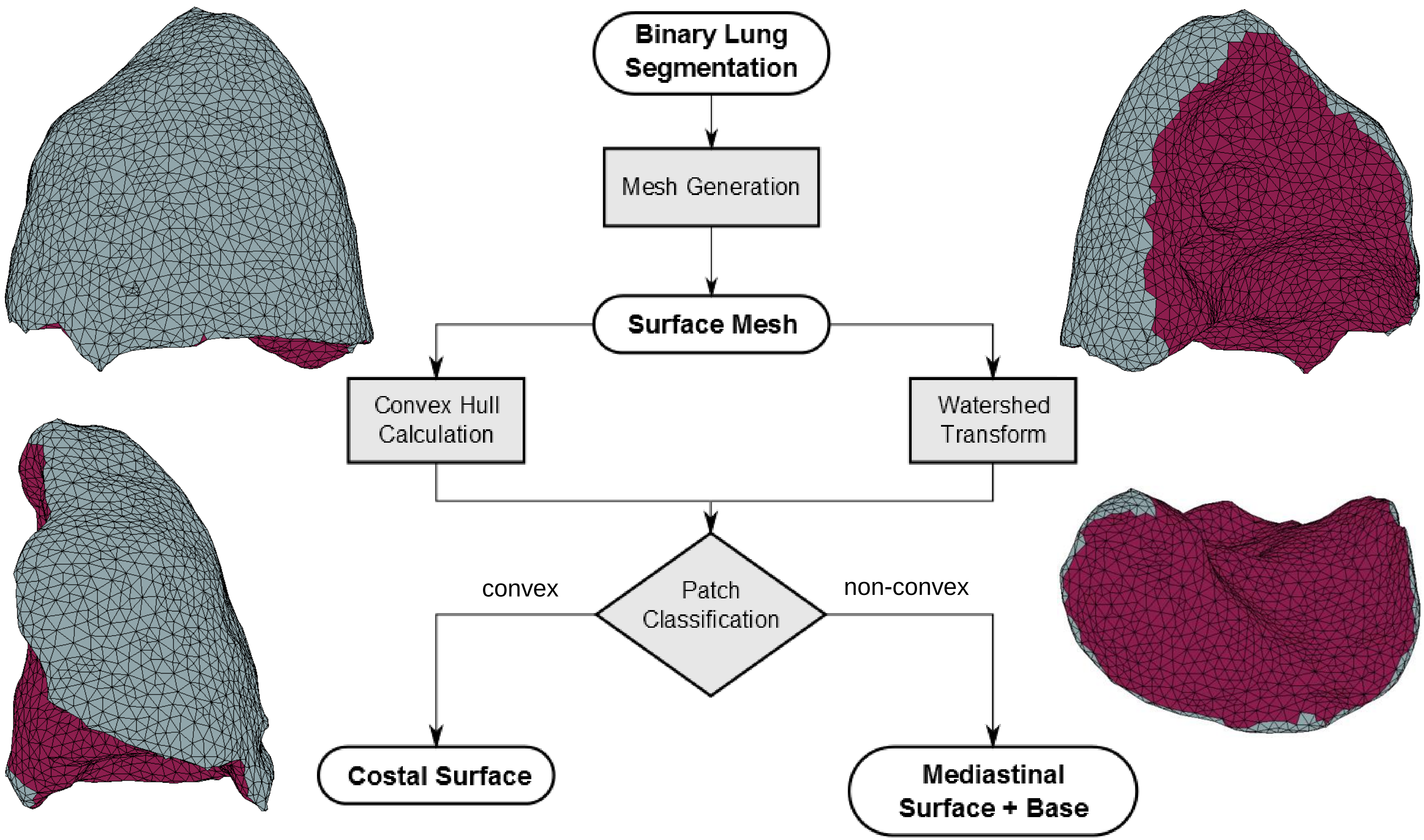

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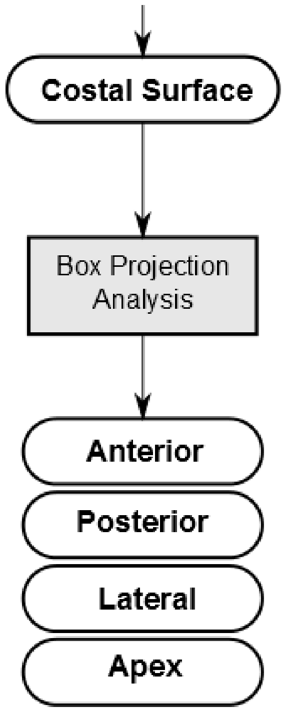

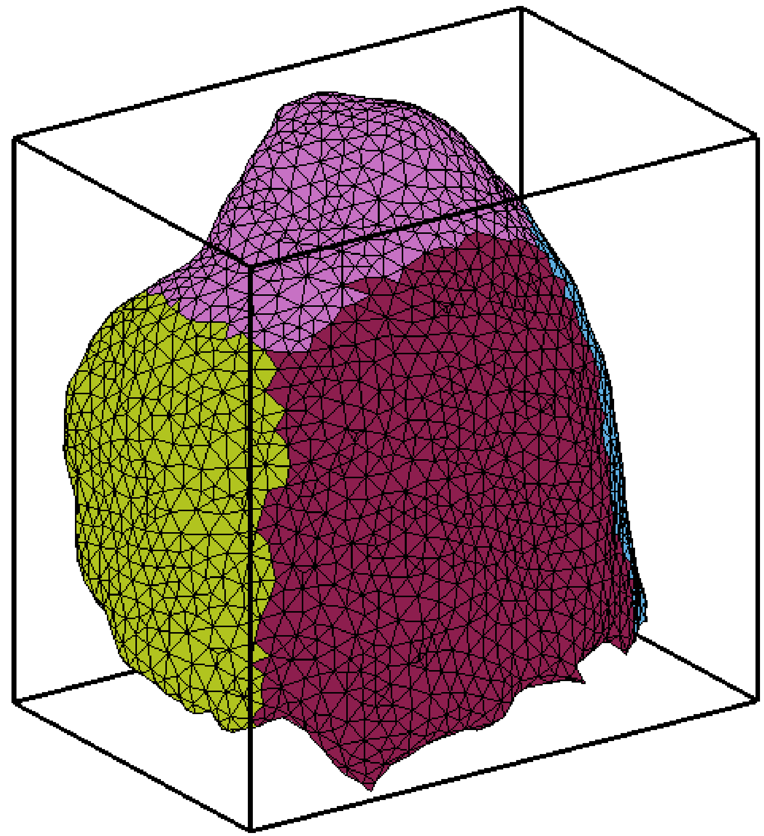

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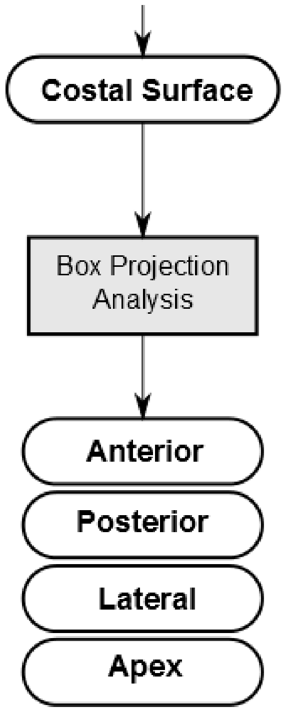

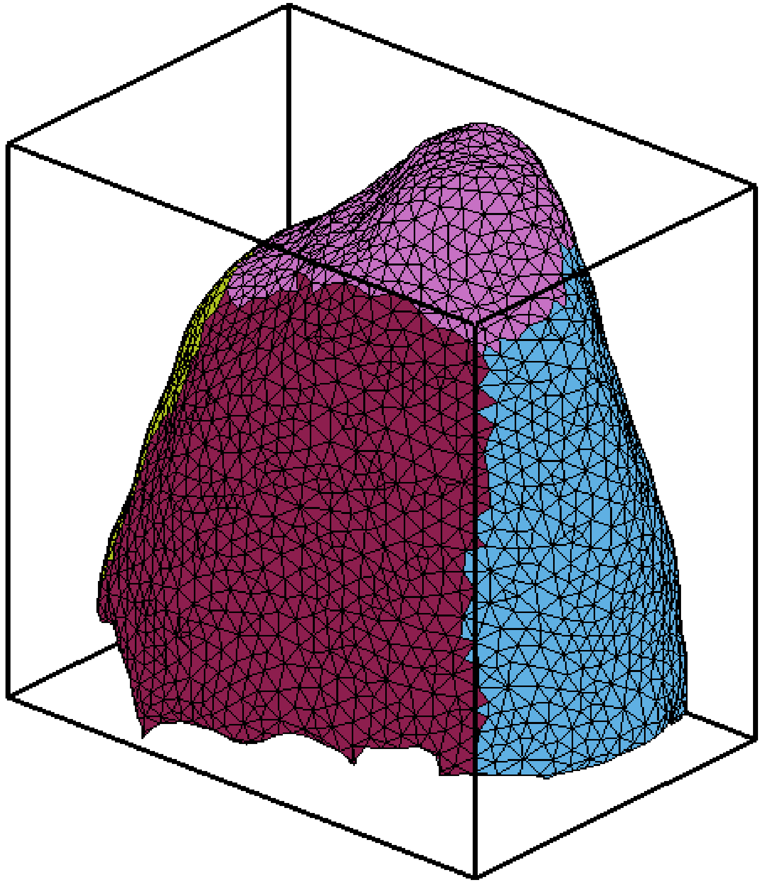

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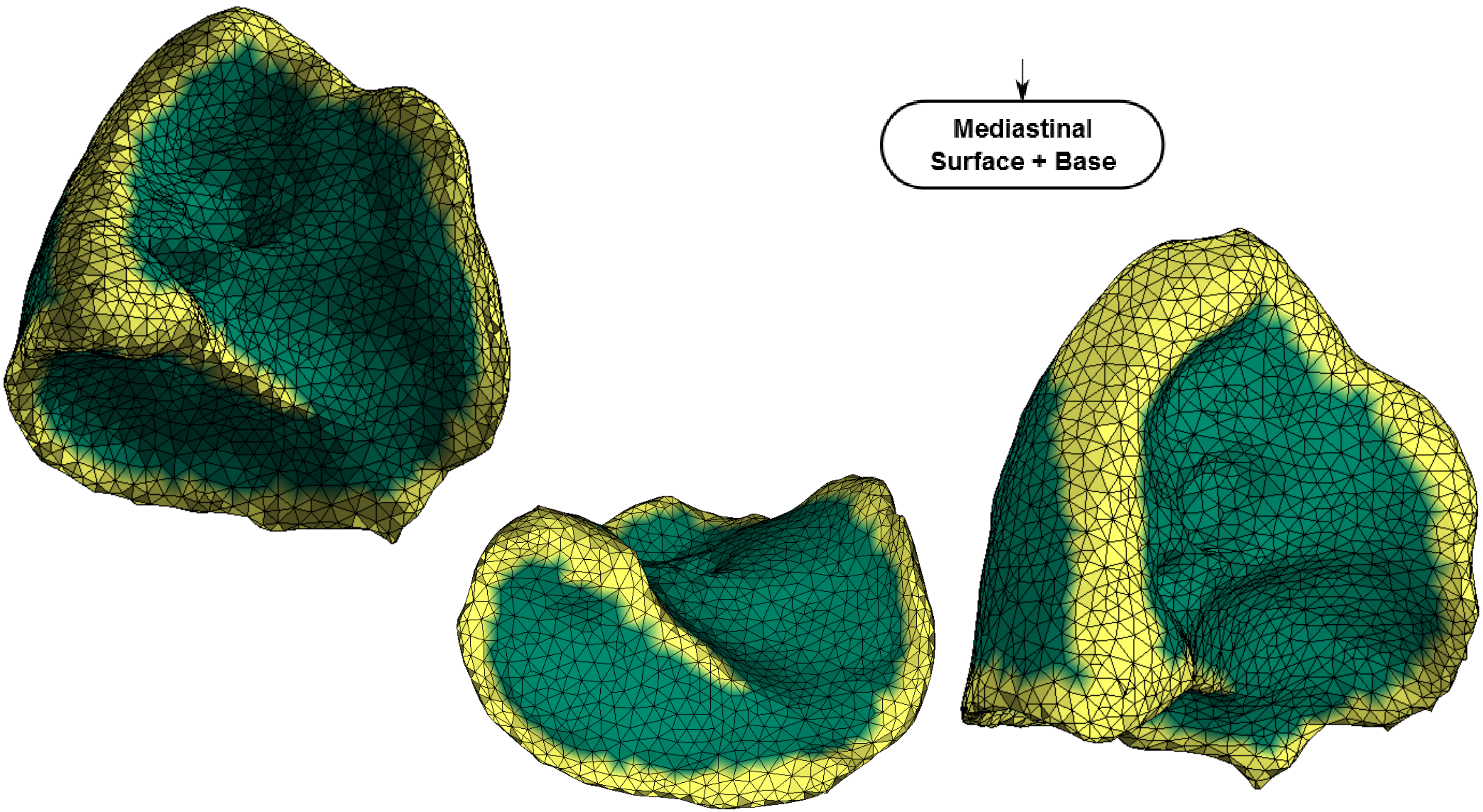

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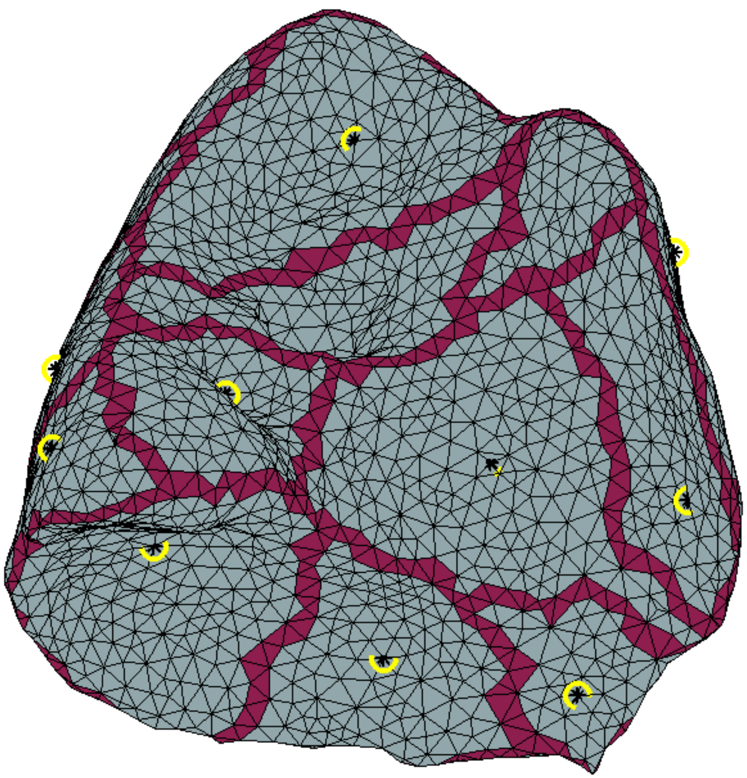

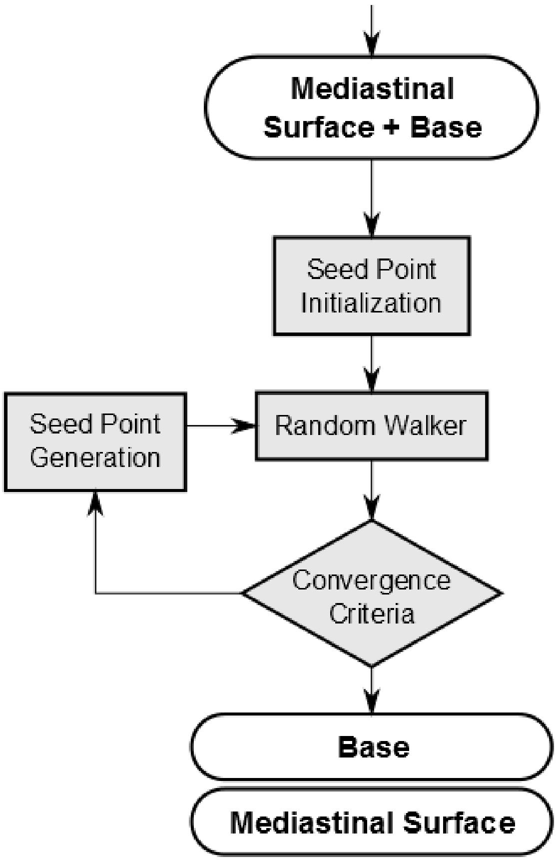

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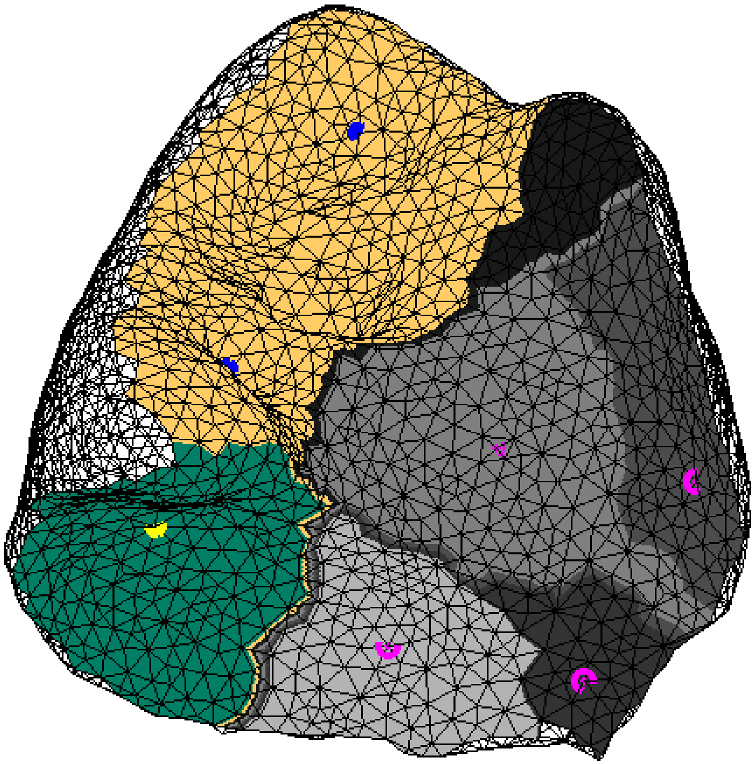

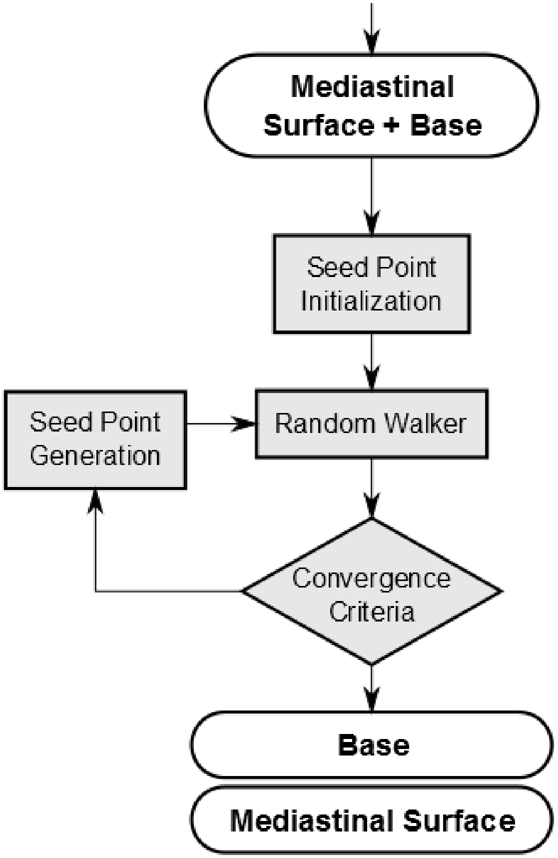

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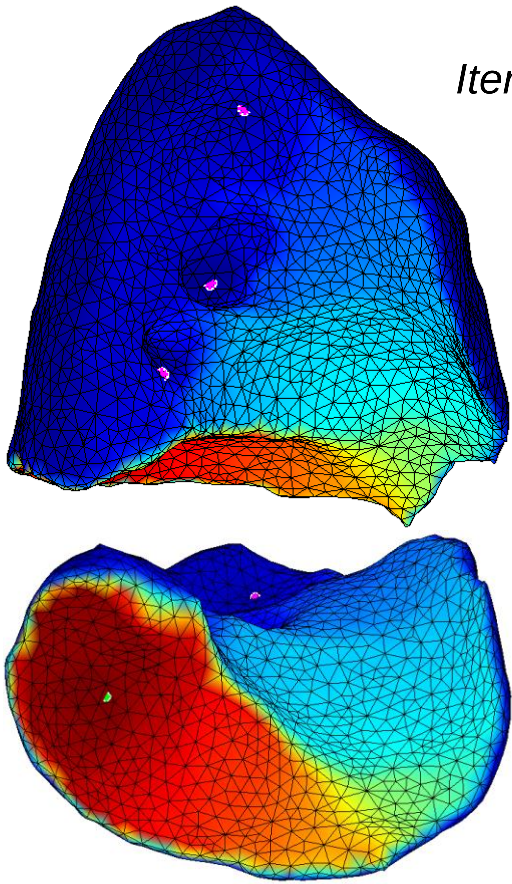
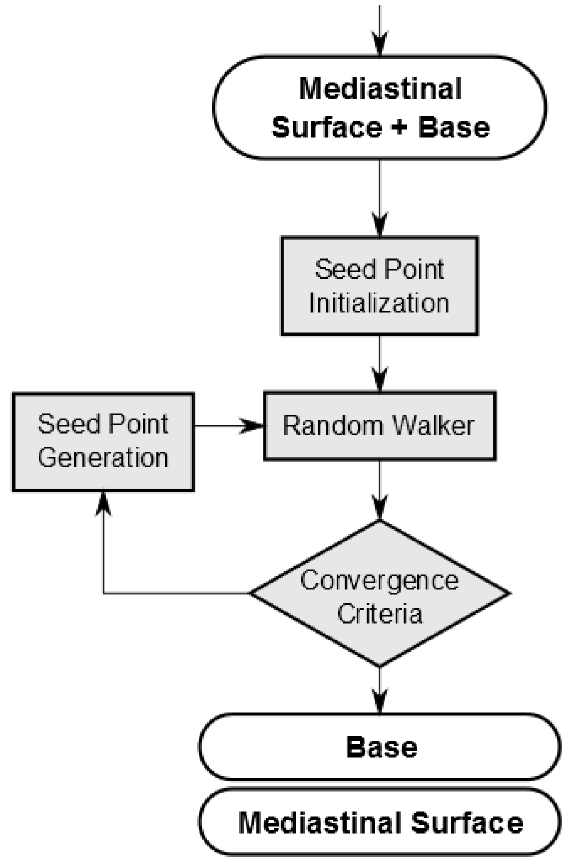
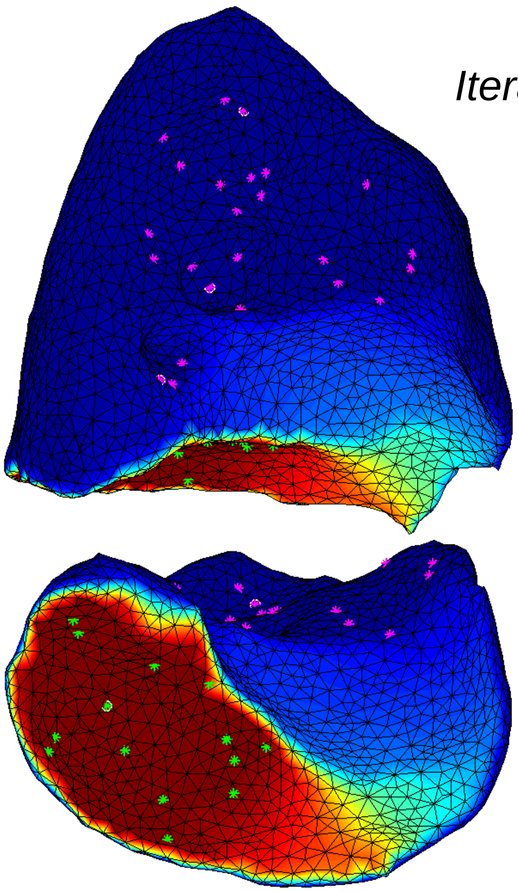


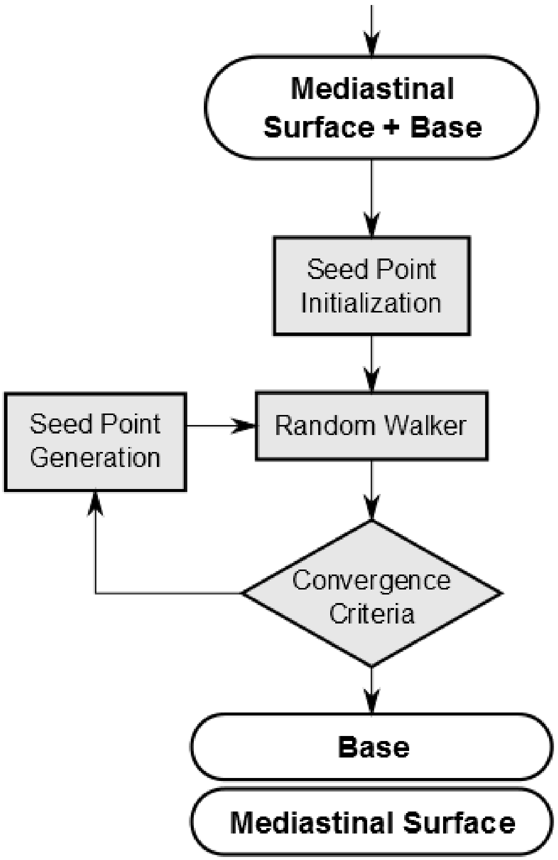
Iteration 1



Mesh Segmentation Pipeline

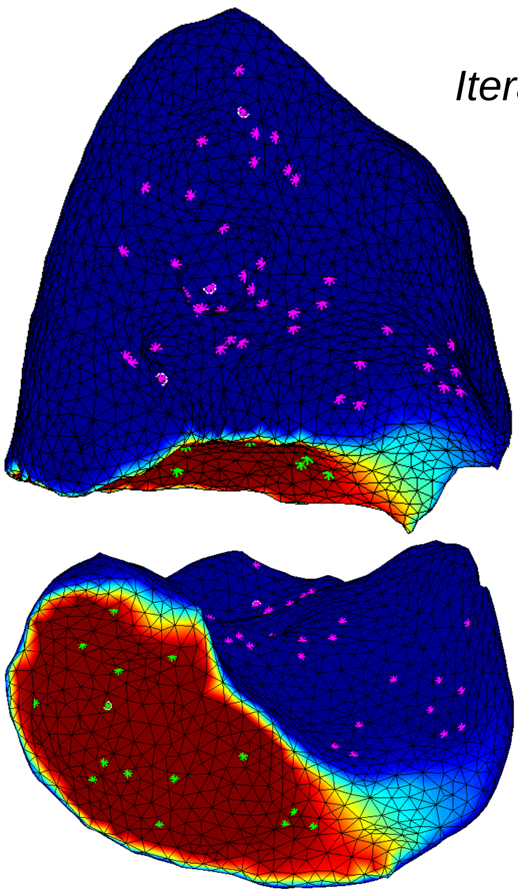


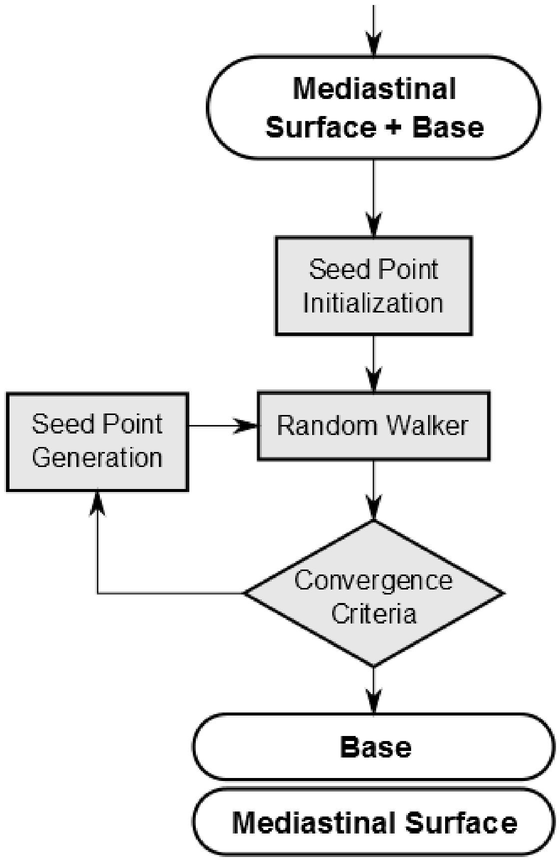
Iteration 2



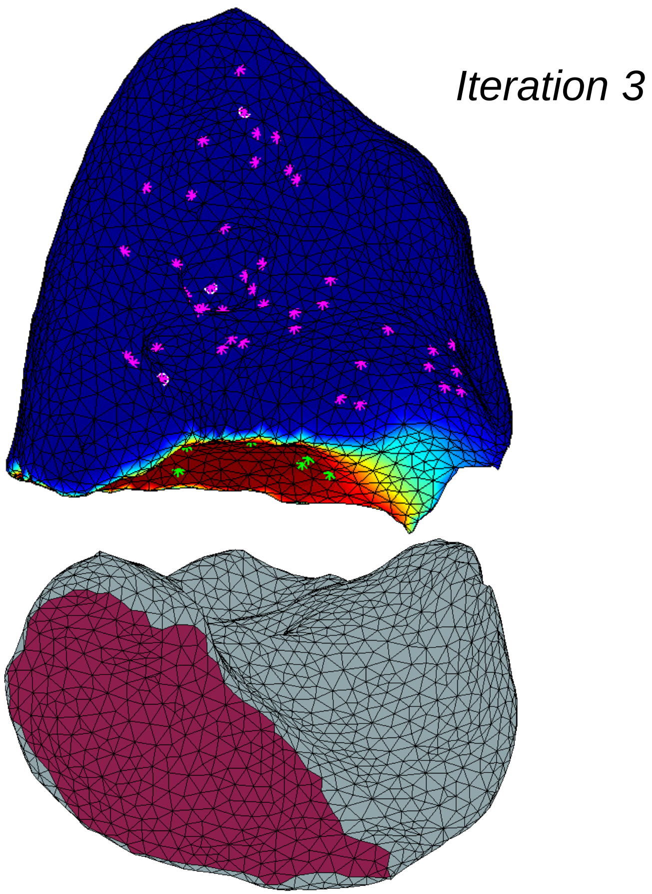
Mesh Segmentation Pipeline

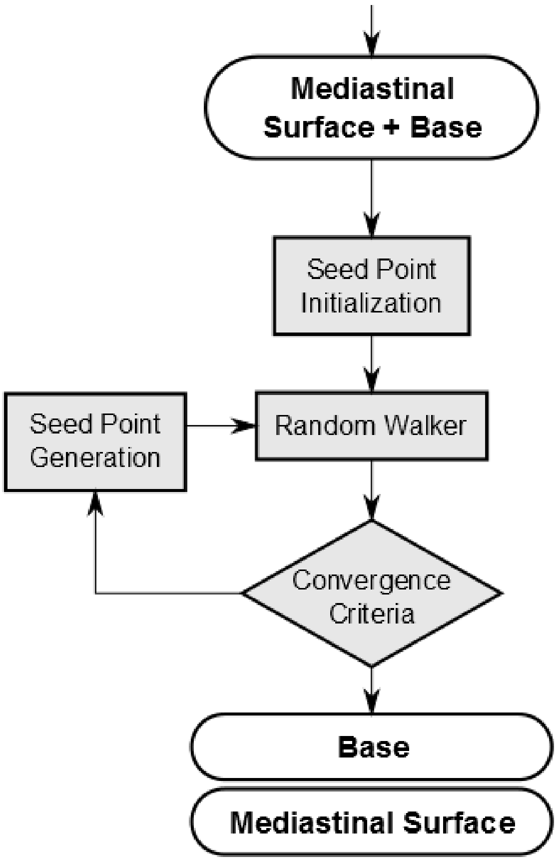
Iteration 3



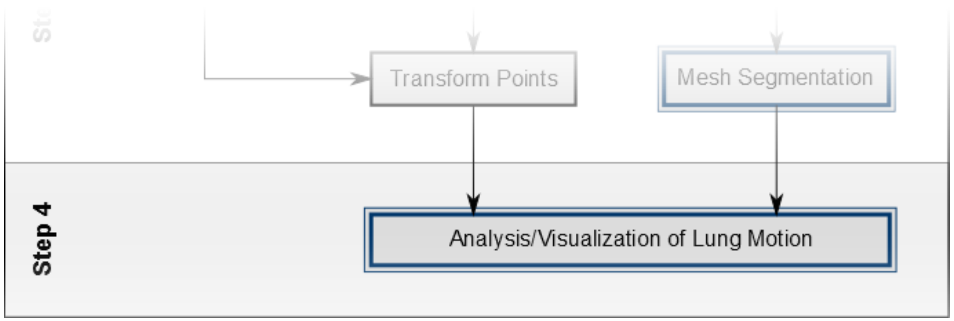


Mesh Segmentation Pipeline





Motion Feature Extraction



Global Motion Features

Lung **volume** calculated from mesh

Lung **size** in sagittal plane

- anteroposterior size: front most to back most point
- craniocaudal size: highest point of base to highest point apex

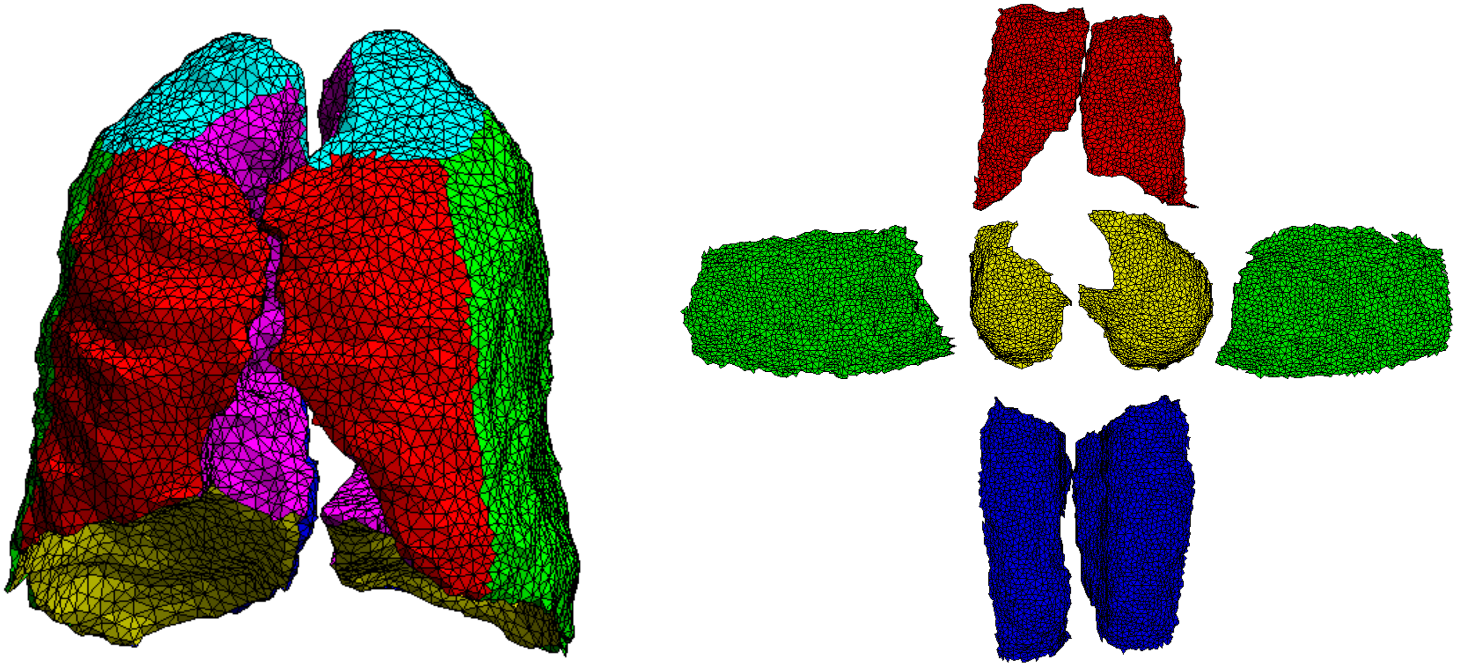
(Optional) differentiation between left and right lung

→ **expected behavior is not present in all cases**

→ **local analysis necessary**

Local Motion Features

- extract feature per vertex
- for easy visualization unfold lung based on segmentation



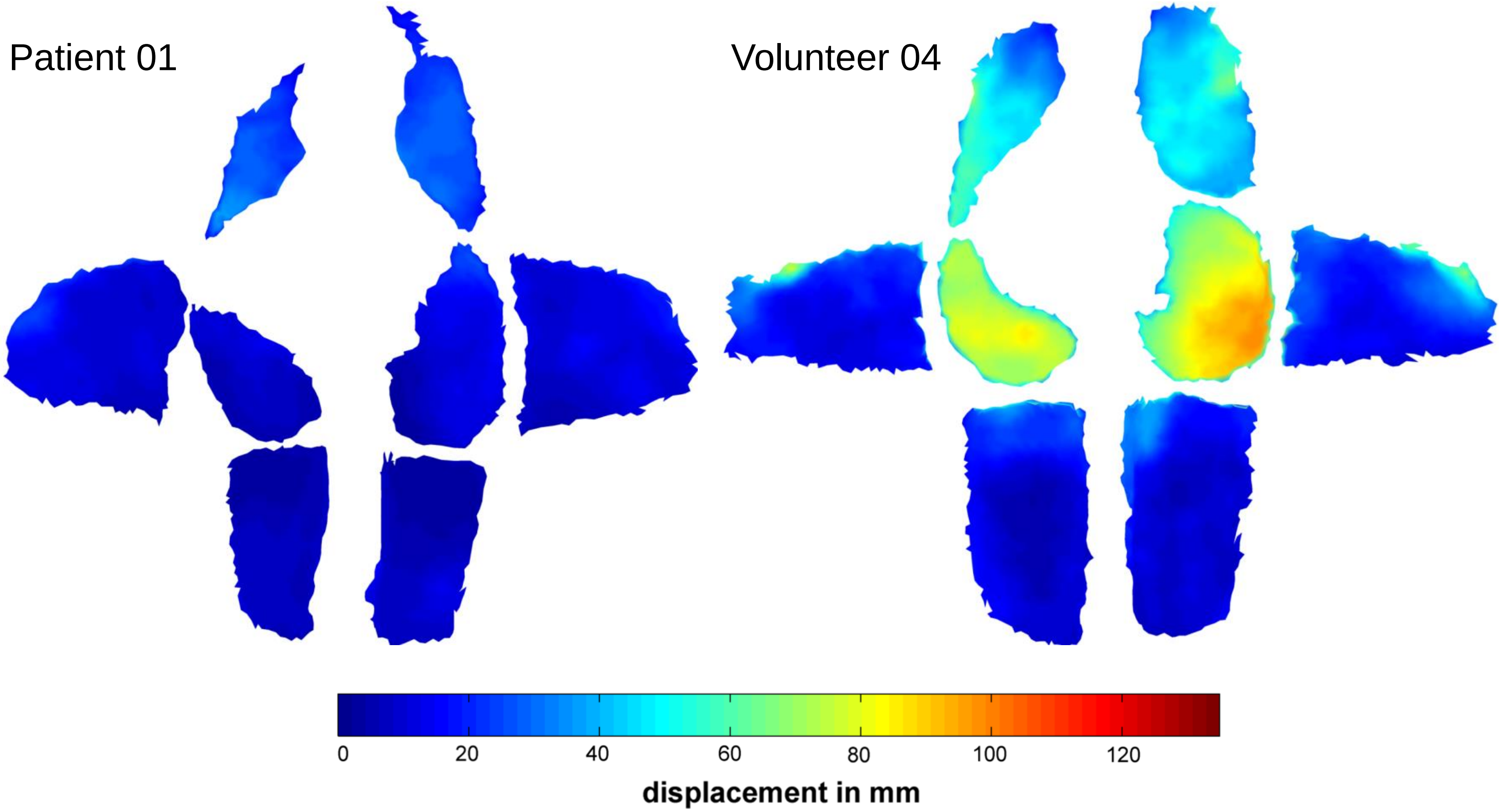
Local Motion Features

Total path length

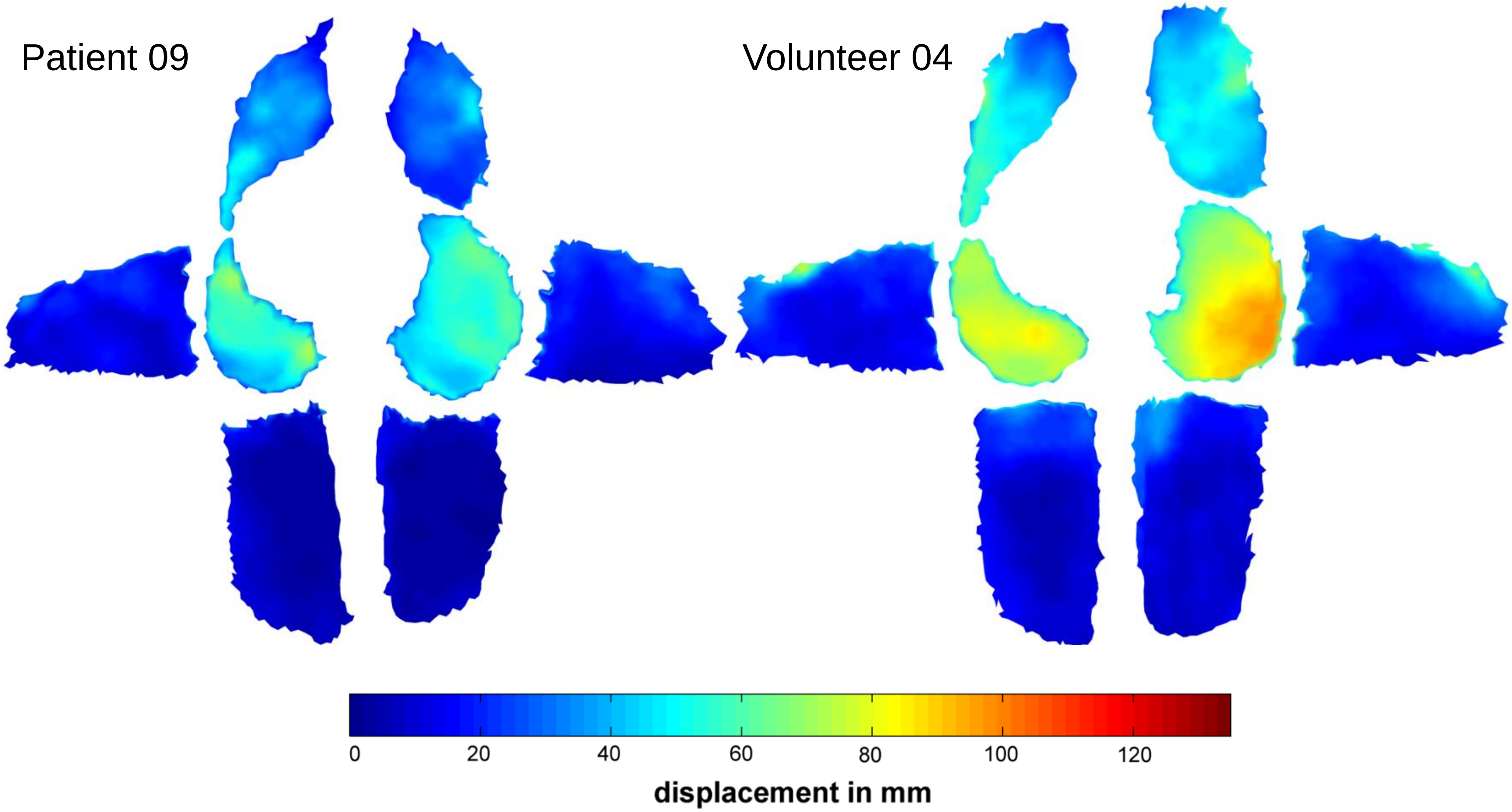
Total displacement

- **in direction related to segment**
- in axial plane
- in craniocaudal direction

Local Motion Features



Local Motion Features



Conclusion and Outlook

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Conclusion

Main steps have been taken towards a full automatic framework for lung motion characterization

- image preprocessing via bias field correction
- registration of dynamic sequence for estimation of lung deformation
- lung surface partitioning
- global and local motion analysis related to respiratory muscles

Results have high relevance for clinicians

Personal conclusion: in practice it is a very long way from the medical images provided by a radiologist to the aimed final quantitative analysis

Outlook

- automatic lung segmentation
- improvement of registration to handle ghosting
- analysis of other breathing maneuvers
- analysis of more patients and volunteers to build reference standard
- build ground truth for better optimization and evaluation

References

- Kondo, T., et al. (2000). A dynamic analysis of chest wall motions with MRI in healthy young subjects. *Respirology*, *5*(1), 19–25.
- Naish, J., Revest, P., & Court, D. S. (2009). *Medical Sciences* (1st ed., pp. 702–704). Edinburgh, UK: Saunders/Elsevier.
- Gauthier, A., et al. (1994). Three-dimensional reconstruction of the in vivo human diaphragm shape at different lung volumes. *Journal of Applied Physiology*, *76*(2), 495–506.
- Plathow, C., et al (2009). Estimation of pulmonary motion in healthy subjects and patients with intrathoracic tumors using 3D-dynamic MRI: initial results. *Korean Journal of Radiology*, *10*(6), 559–567.
- Heimann, T., et al. (2007). A shape-guided deformable model with evolutionary algorithm initialization for 3D soft tissue segmentation. *Information Processing in Medical Imaging*, *20*, 1–12.

References

- Sled, J. G., et al. (1998). A Nonparametric Method for Automatic Correction of Intensity Nonuniformity in MRI Data. *IEEE Transactions on Medical Imaging*, *17*(1), 87–97.
- Tustison, N. J., Avants, B. B., Cook, P. A., Zheng, Y., Egan, A., Yushkevich, P. A., & Gee, J. C. (2010). N4ITK: Improved N3 Bias Correction. *IEEE Transactions on Medical Imaging*, *29*(6), 1310–1320.
- Metz, C. T., et al. (2011). Nonrigid registration of dynamic medical imaging data using nD + t B-splines and a groupwise optimization approach. *Medical Image Analysis*, *15*(2), 238–249.
- Grady, L. (2006). Random walks for image segmentation. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *28*, 1768–1783.

Figures

- Fig. 1: MasterScreen Pneumo Spirometer (http://www.carefusion.com)
- Fig. 2: Diaphragm (Gray's Anatomy for Students)
- Fig. 3: Breathing mechanics (OpenStax College. The Process of Breathing, OpenStax-CNX Web site. http://cnx.org/content/m46549/1.6/, Jun 28, 2013.)
- Fig. 4: Diaphragm movement (Gauthier et al. 1994)
- Fig. 5: Lung deformation (Plathow et al. 2009)

Thank you for your attention!

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Universitair Medisch Centrum Rotterdam

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