Integrated System for Planning Peripheral Bronchoscopic Procedures

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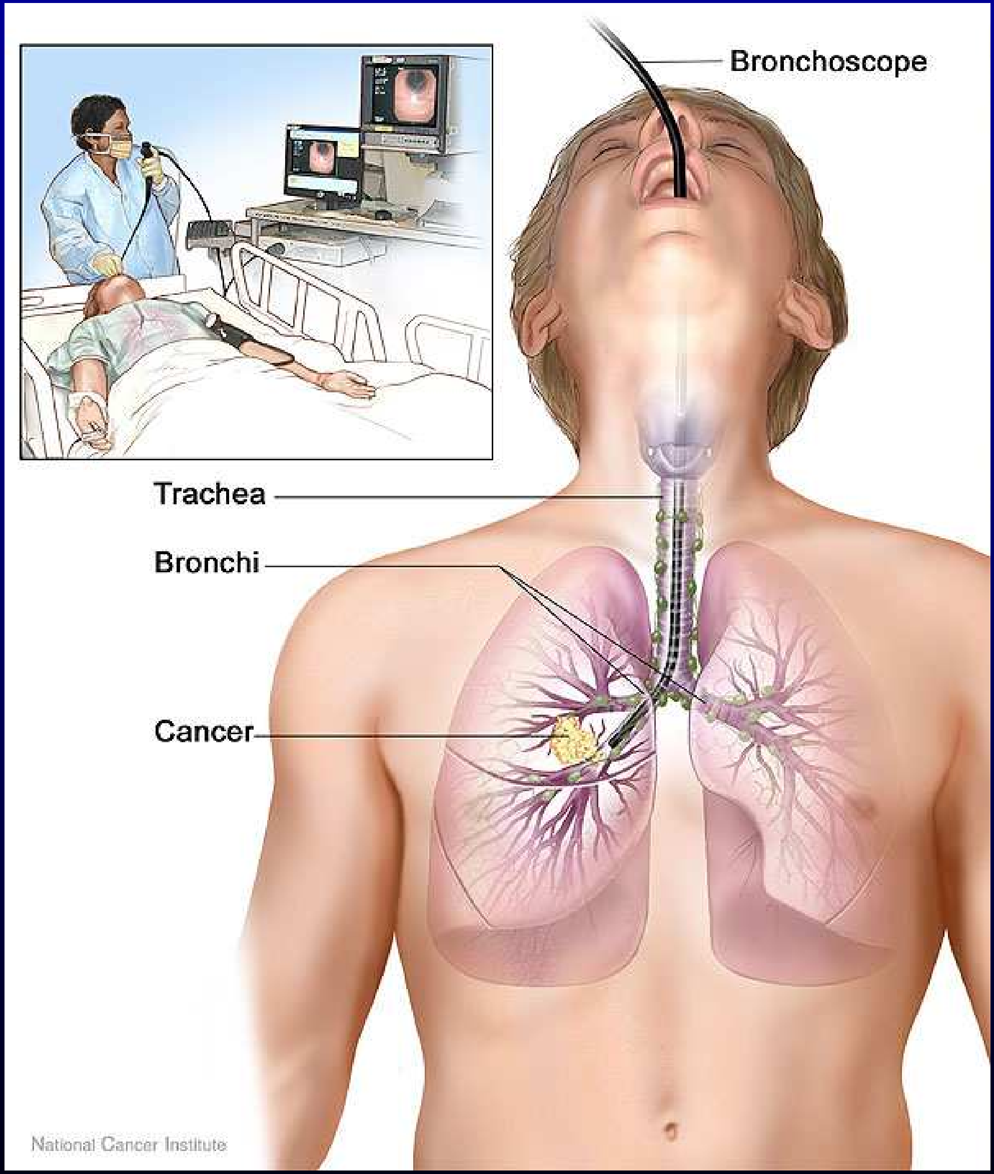
SPIE Medical Imaging: Physiology, Function, and Structure from Medical Images

San Diego, CA, 17 Feb. 2008.

Early Lung Cancer Diagnosis

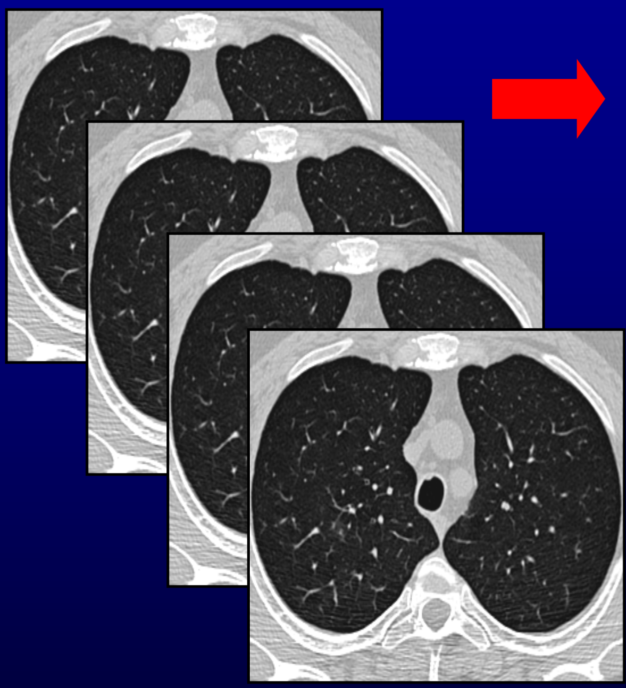
1. 3D MDCT image assessment

2. Follow-on diagnostic bronchoscopy



Drawing by Terese Winslow, "Bronchoscopy," *NCI Visuals Online*, National Cancer Institute

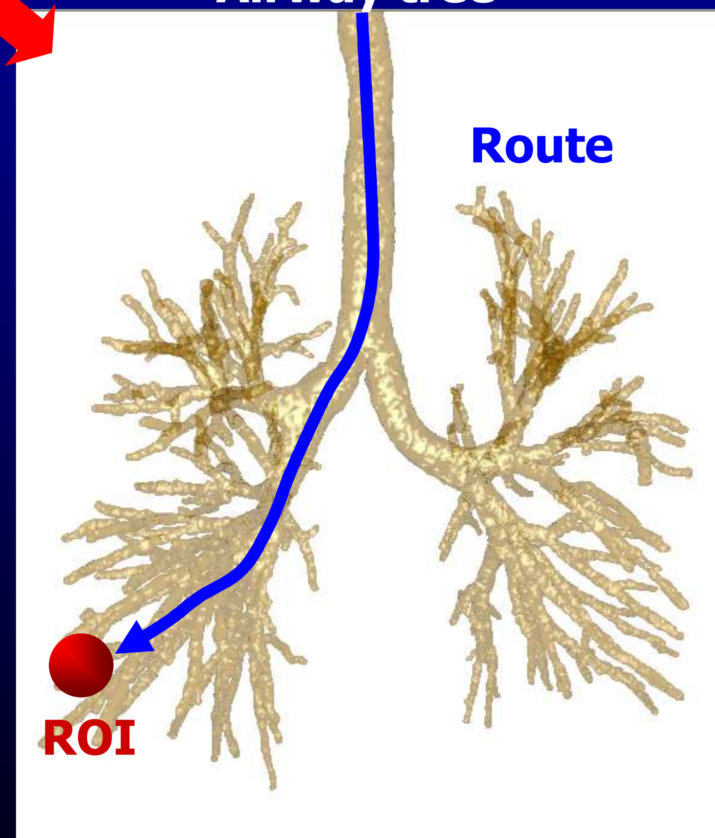
Current Planning Practice



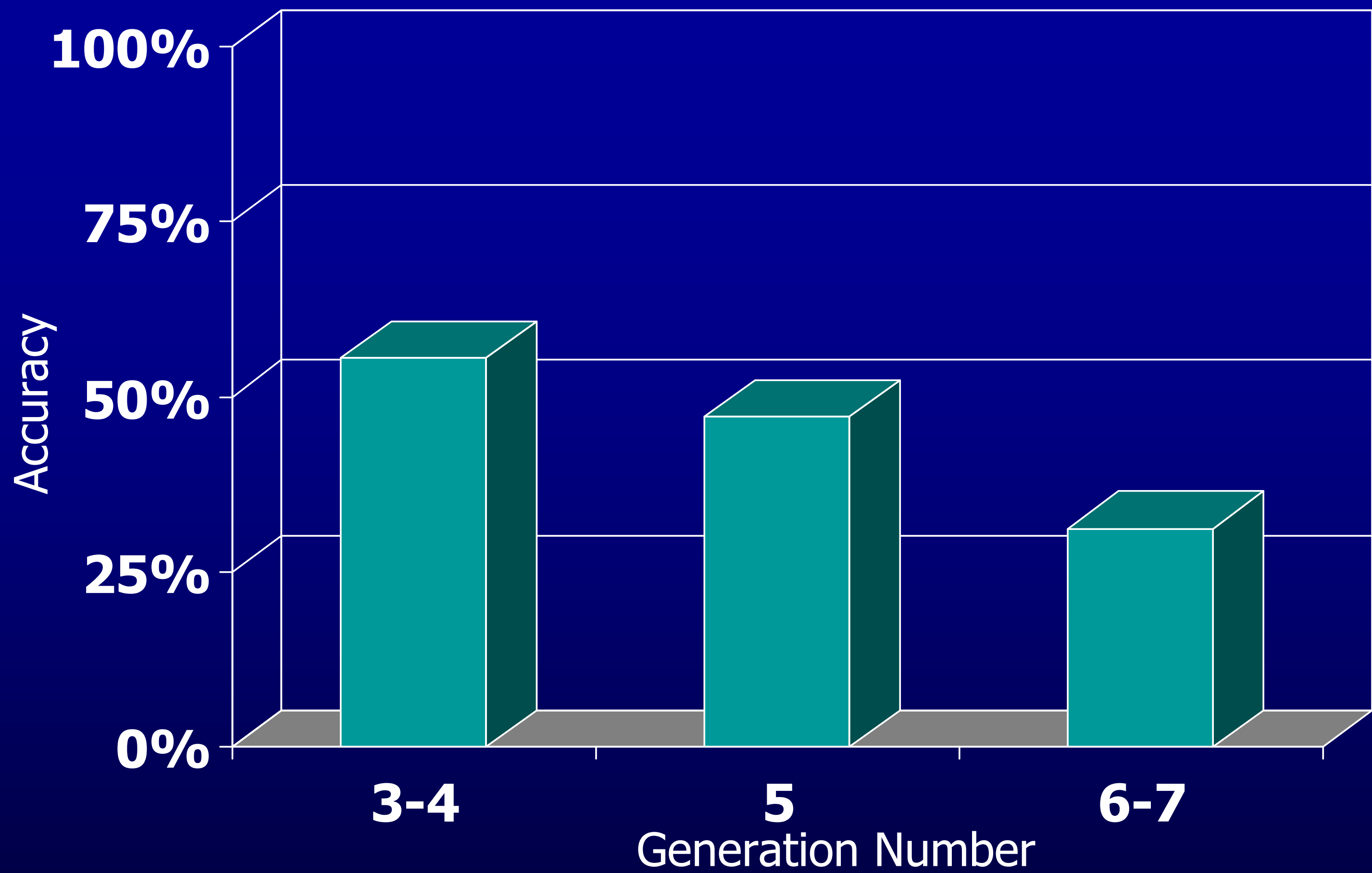
3D MDCT image

Mental Analysis

Airway tree



Current Planning Efficacy



Peripheral planning is very hard!

Higgins *et al*., "Image-Guided Bronchoscopy for Peripheral Nodule Biopsy: A Phantom Study," ATS 2007.

Dolina *et al*., "Interbronchoscopist Variability in Endobronchial Path Selection: A Simulation Study," Chest, in press 2008.

Related Work

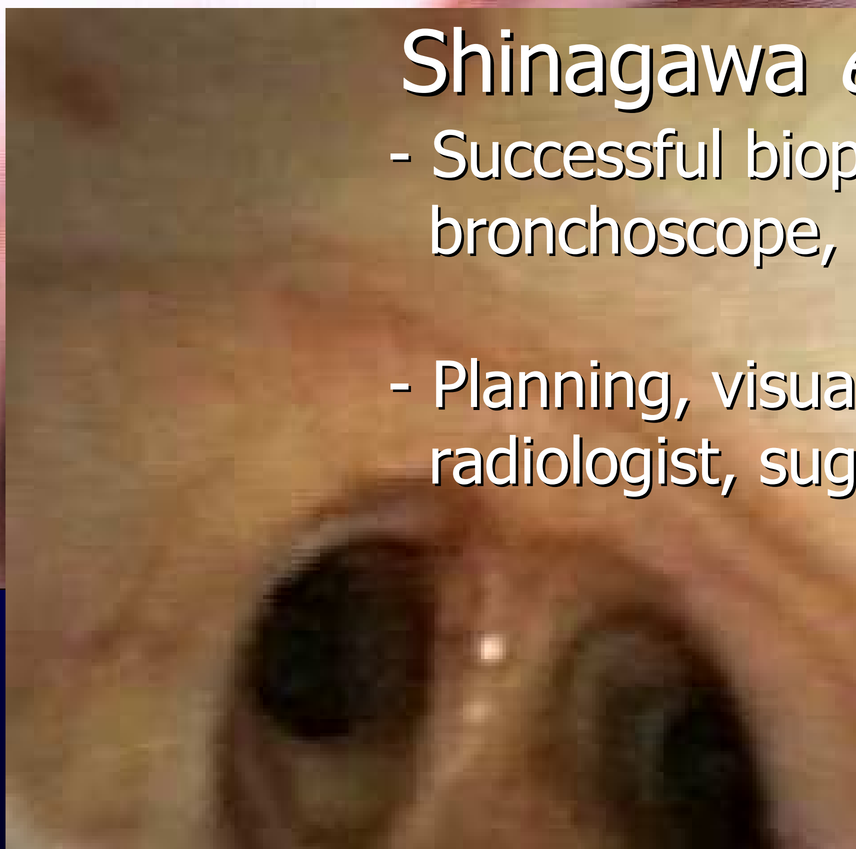
Image-guided live bronchoscopy

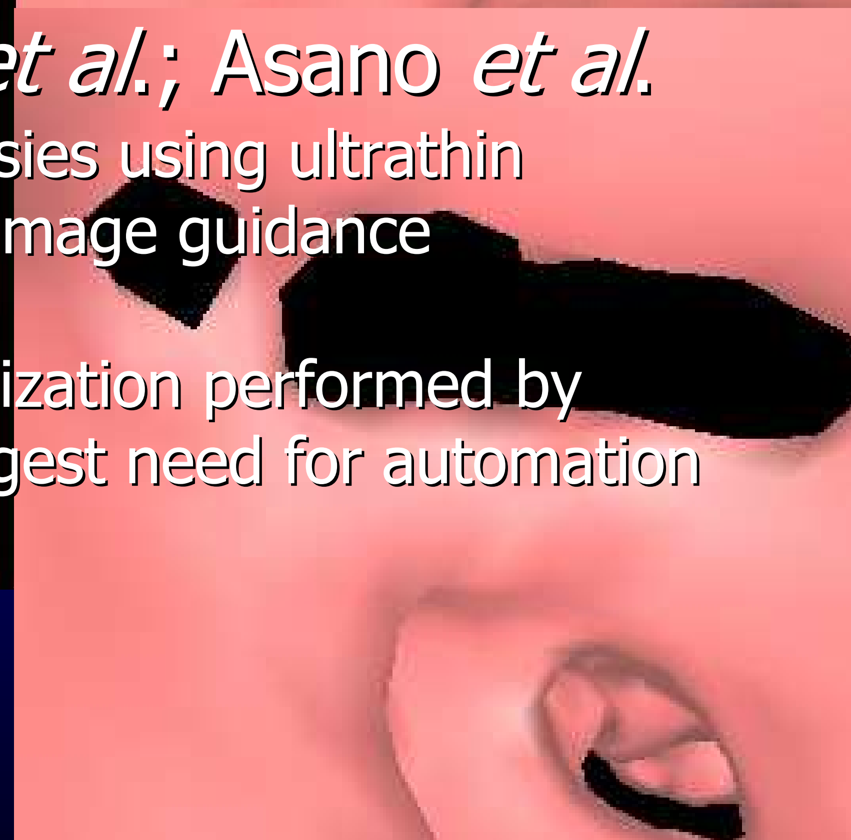
Live peripheral bronchoscopy

Shinagawa *et al.*; Asano *et al.*

- Successful biopsies using ultrathin bronchoscope, image guidance

- Planning, visualization performed by radiologist, suggest need for automation





Planning Overview

MDCT image acquisition

1. Define ROI
2. Segment airway tree
3. Define interior surfaces of airway tree
4. Extract airway centerlines
5. Determine appropriate route to ROI
6. Generate reports depicting route to ROI

Bronchoscopy

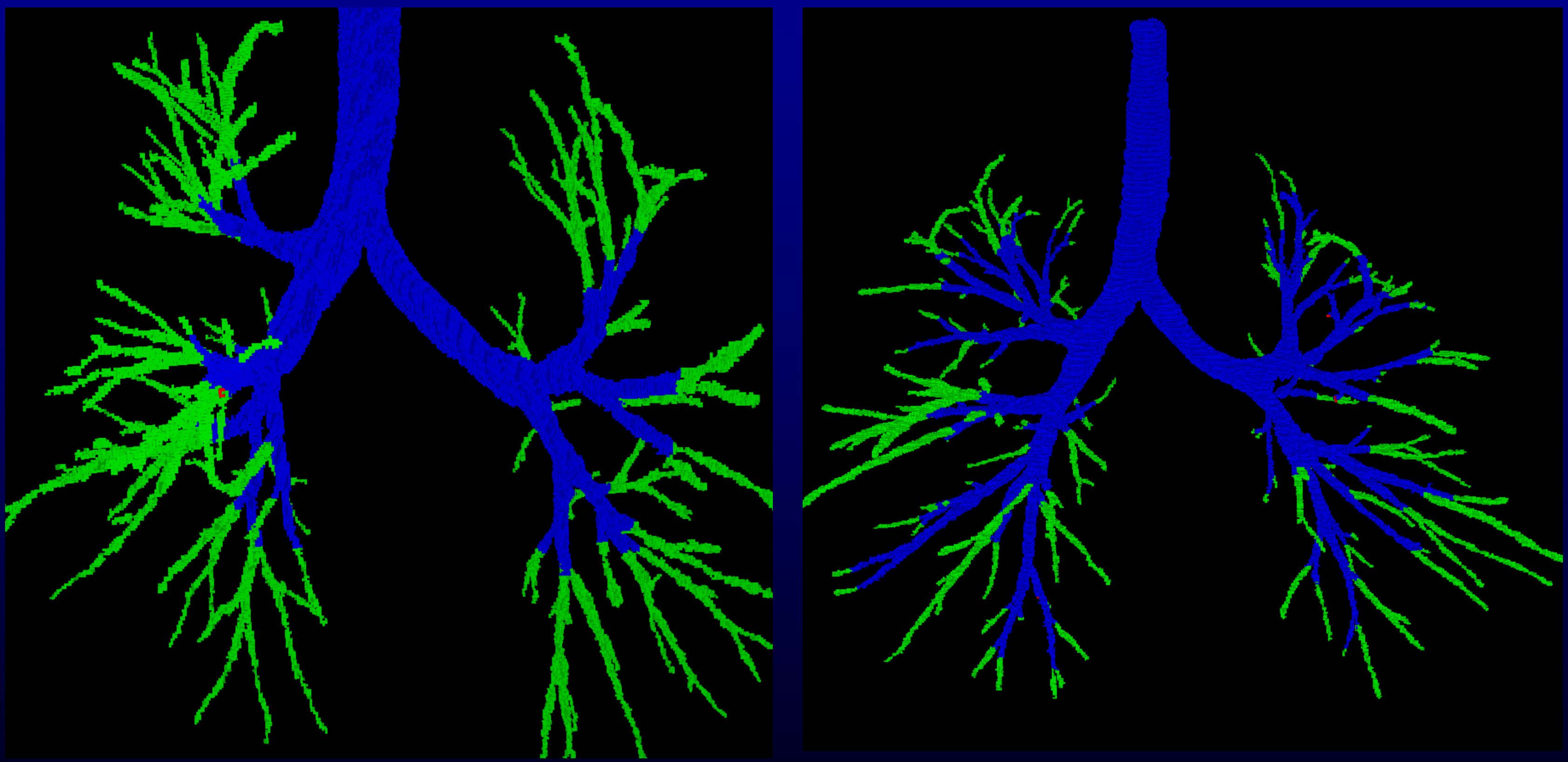
Step 1: ROI Definition

Lu/Higgins Live-Wire approach: Int. J. Comp. Asst. Rad. & Surg., Dec. 2007.

Step 2: Airway-Tree Segmentation

Graham *et al.*, "Robust system for human airway-tree segmentation," SPIE 2008, Image Processing Conference, Tuesday Feb. 19, 1:40PM

Automatic segmentation:



Step 2: Airway-Tree Segmentation

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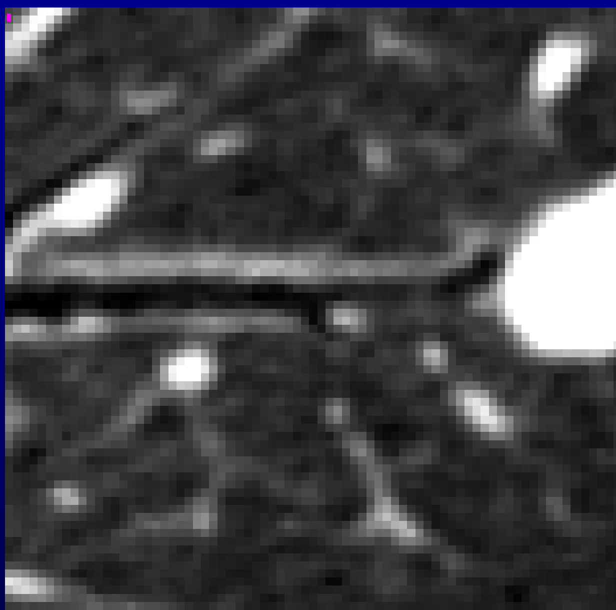
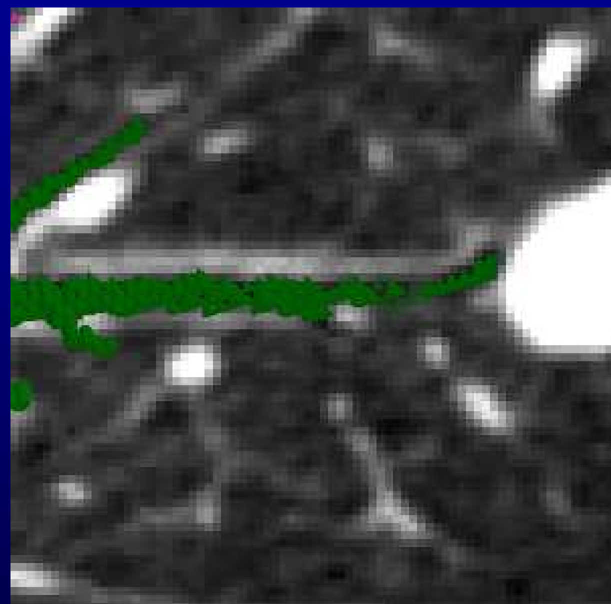
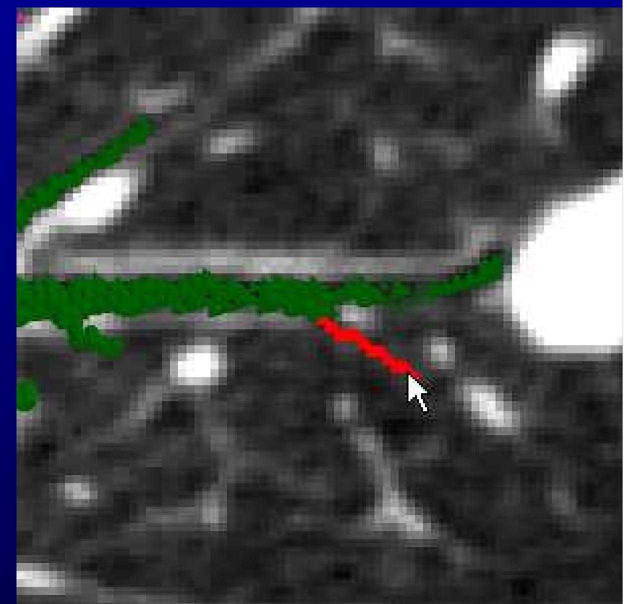
Interactive segmentation:



Airway, Lesion



Automatic Segmentation



Manual Extension

Planning Overview

MDCT image acquisition

1. Define ROI
2. Segment airway tree
3. *Define interior surfaces of airway tree*
4. Extract airway centerlines
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Bronchoscopy

Step 3: Airway-Tree Surfaces

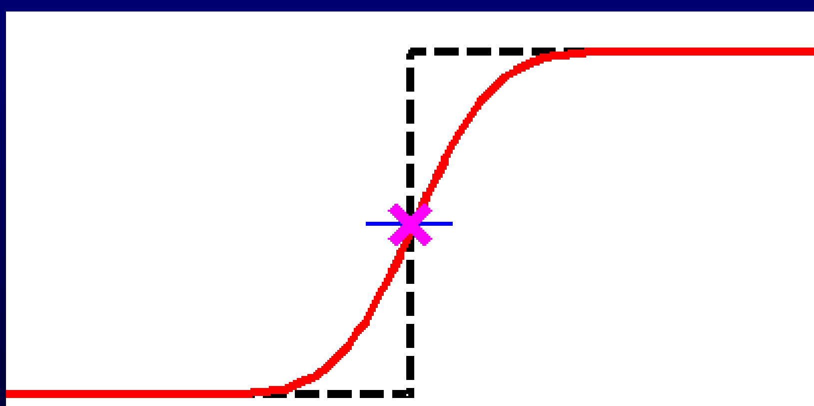
Objectives:

1. Sub-voxel accuracy in large airways
2. Topologically appropriate in poorly-defined airways

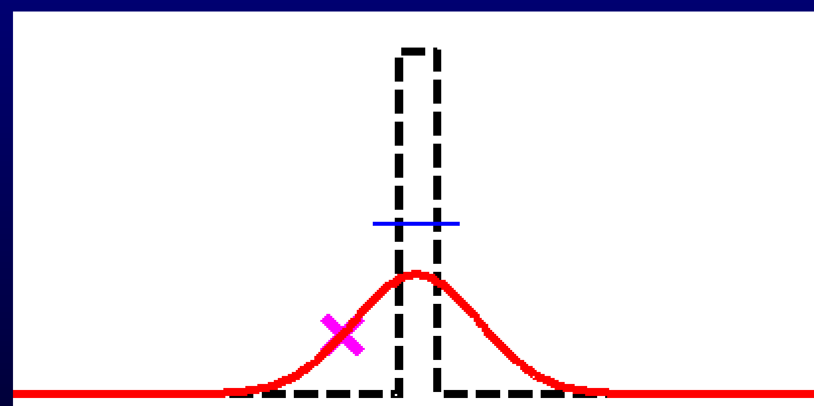
Old Approach[1]:

Constant-HU isosurface via Marching Cubes

- well-defines large airways, poor for smaller ones



thick wall

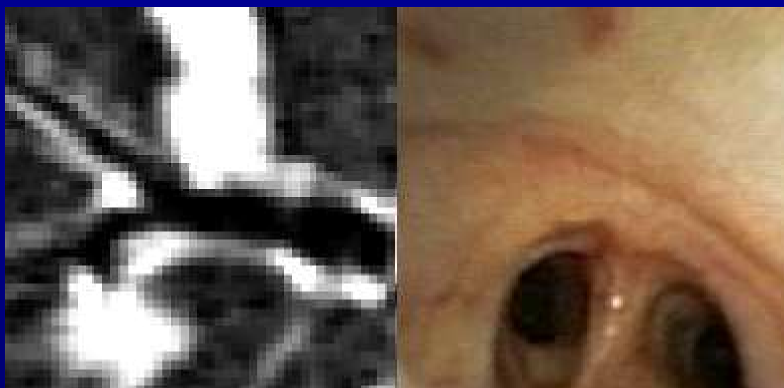


thin wall

[1]Helferty *et al.*, "Computer-based System for the Virtual-Endoscopic Guidance of Bronchoscopy," Computer Vision and Image Understanding, 2007.

Step 3: Airway-Tree Surfaces

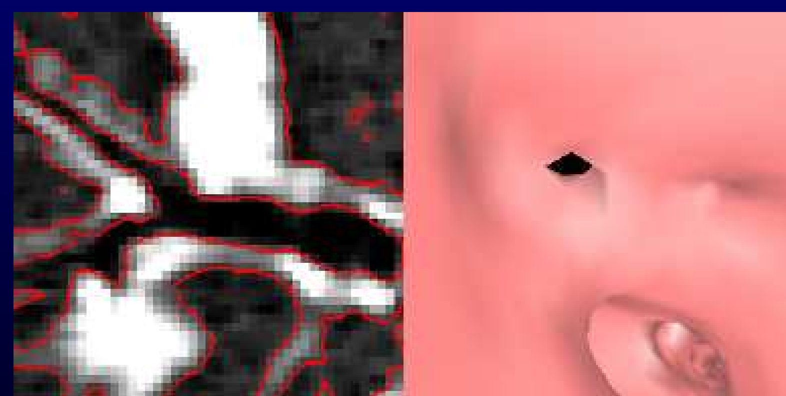
Appropriate isosurface may not exist



Original CT, Observed Video

Previous Approach: -600 HU isosurface

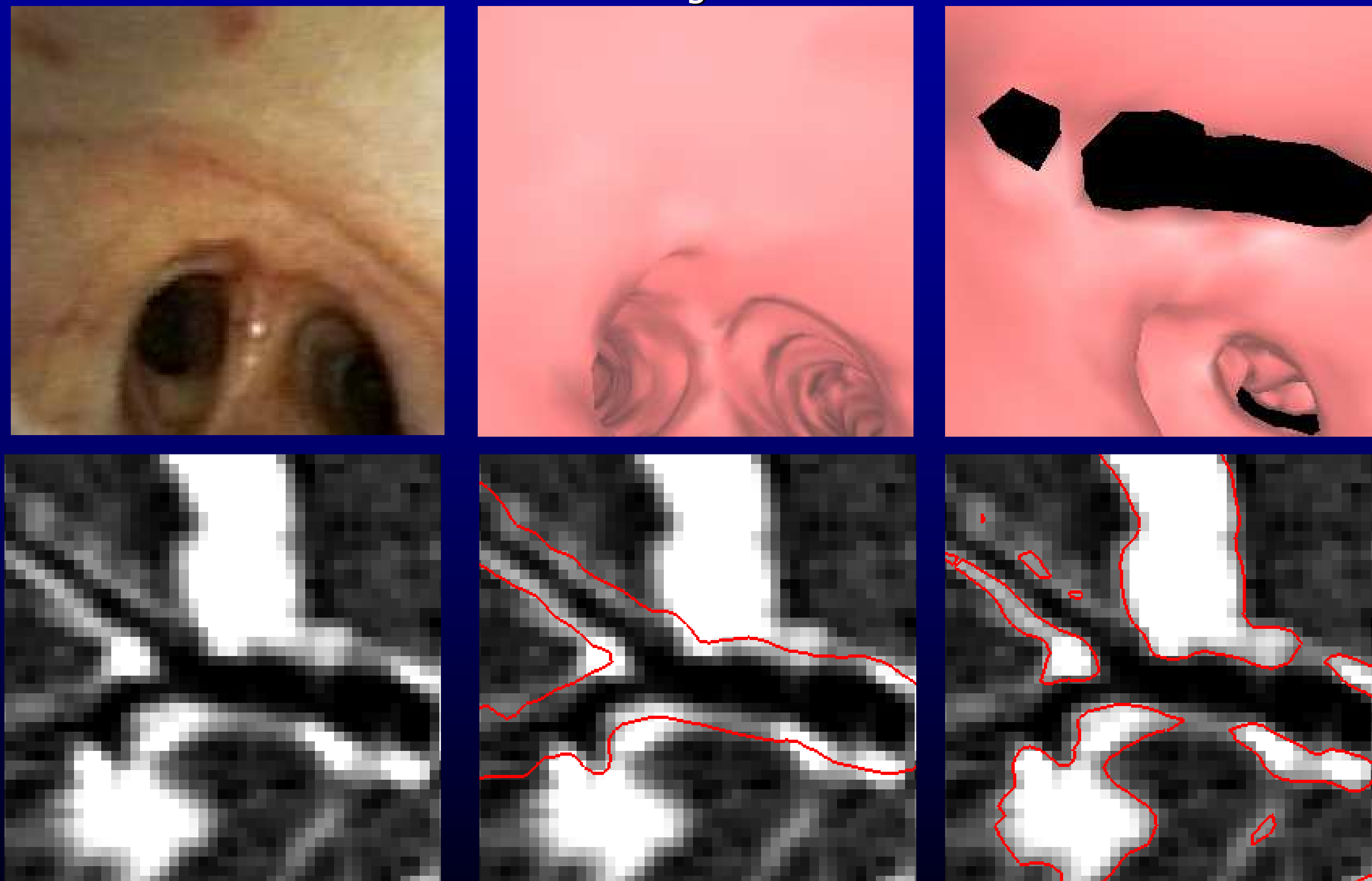
-700 HU isosurface



-800 HU isosurface

Step 3: Airway-Tree Surfaces

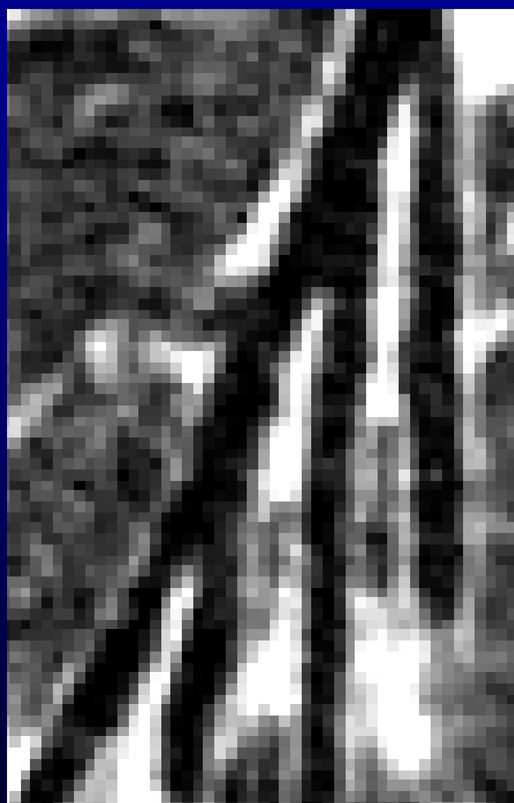
Raw Data | Our Method: Dilated Segmentation | Previous Approach



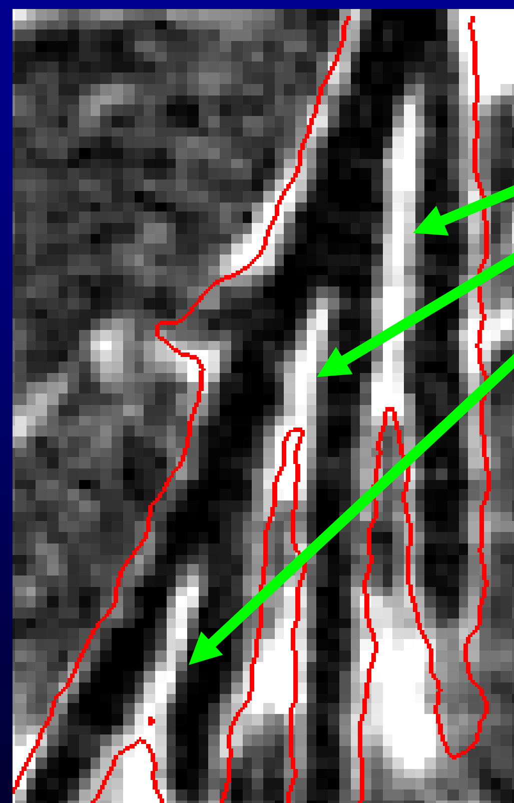
Step 3: Airway-Tree Surfaces

Uniform dilation can cause problems

Parallel peripheral airways

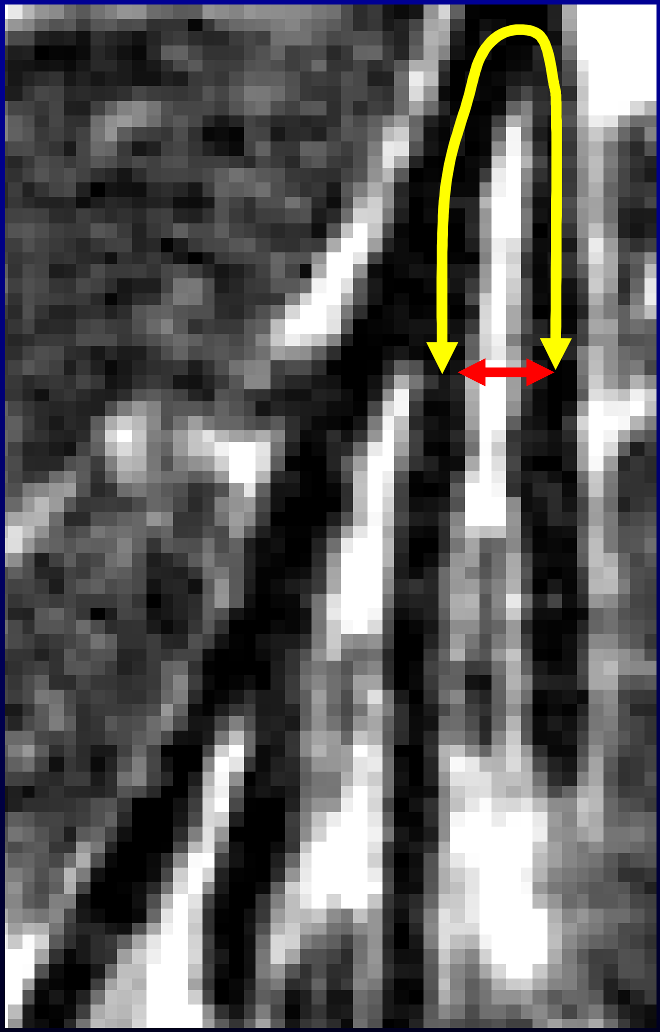


Uniform 1.0mm dilation



Multiple airways combined

Step 3: Airway-Tree Surfaces



Large Topological Distance

Small Geometric Distance

Prevent such self-intersections

Step 3: Airway-Tree Surfaces

Topological Dilation

LP Constraints:

Identify problematic components $d_S = 2d_D + \left|\left|[\Delta x, \Delta y, \Delta z]^T\right|\right|$

Each component's dilation distance f_j constrained by: $0 \leq f_j \leq d_D$

If component C_j close to C_k: $f_j + f_k \leq d_{jk} - \left(\left|\left|[\Delta x, \Delta y, \Delta z]^T\right|\right| + \epsilon\right)$

If C_i Is the ancestor of C_j then: $|f_i - f_j| \leq d_{smooth}$

LP Objective Function: $\max \sum_{i=0}^{N} f_i$

Modify grayscale image: $\mathbf{I}_T(\mathbf{x}) = H_\Delta \cdot \min_{i=0}^{N} [D(\mathbf{x}, C_i) - f_i]$

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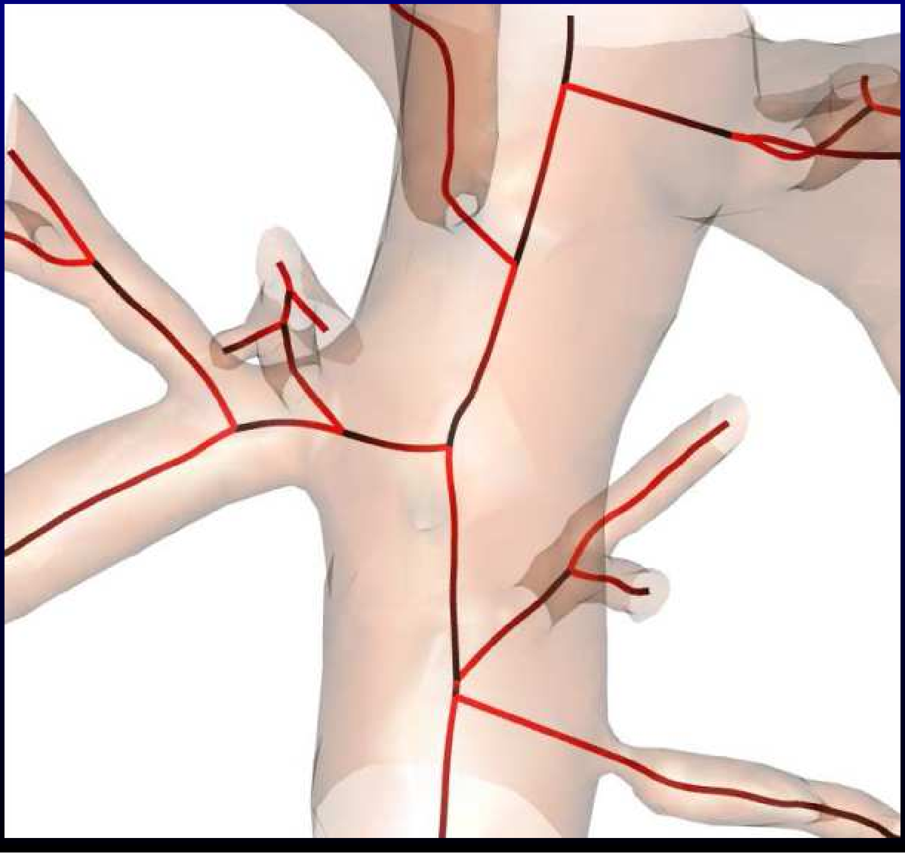
Bronchoscopy

Step 4: Airway-Tree Centerlines

Derived from airway surfaces,

Yu et al., “"System for the Analysis and Visualization of Large 3D Anatomical Trees,“ Computers in Biology and Medicine, Dec. 2007.

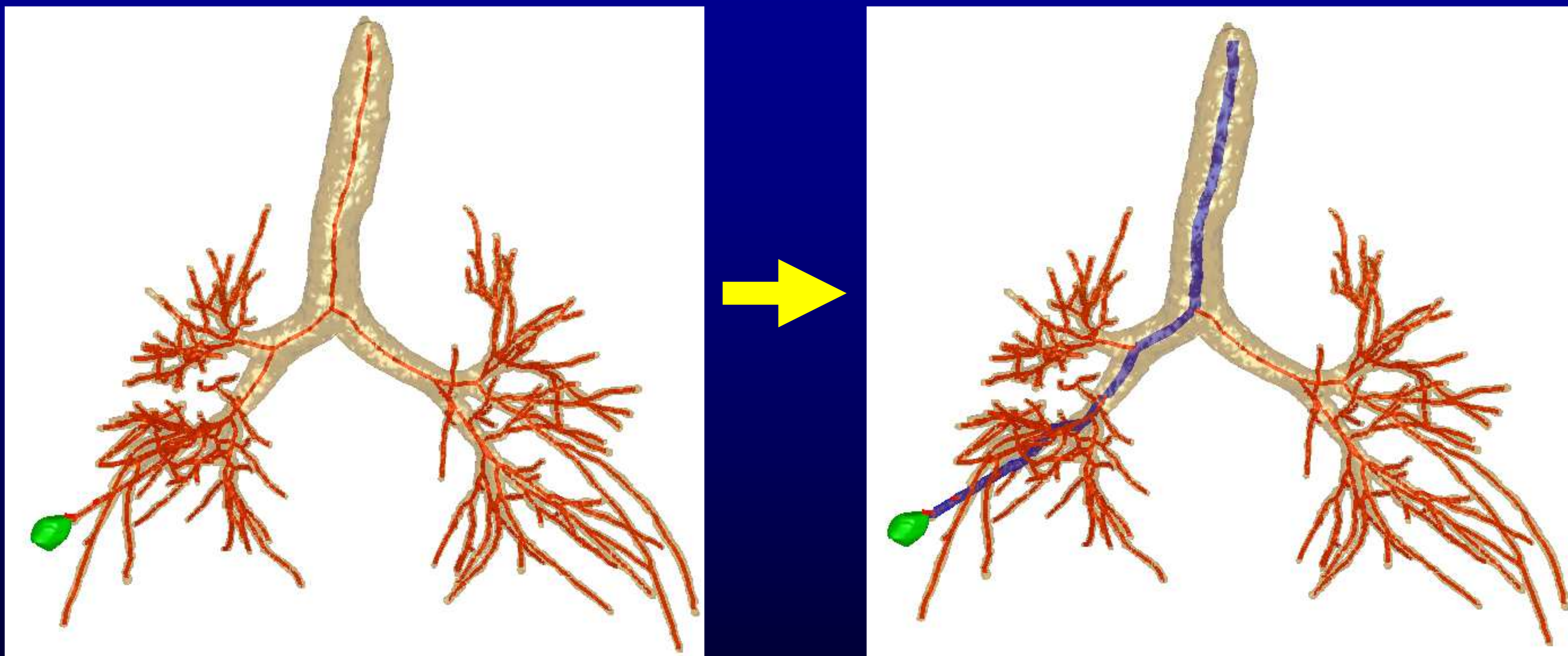
Used for: virtual bronchoscopic navigation, route planning



Step 5: Route Planning

Automatically determine route to ROI

J.D. Gibbs and W.E. Higgins, "3D Path Planning and Extension for Endoscopic Guidance," SPIE Medical Imaging 2008



Planning Overview

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MDCT image acquisition

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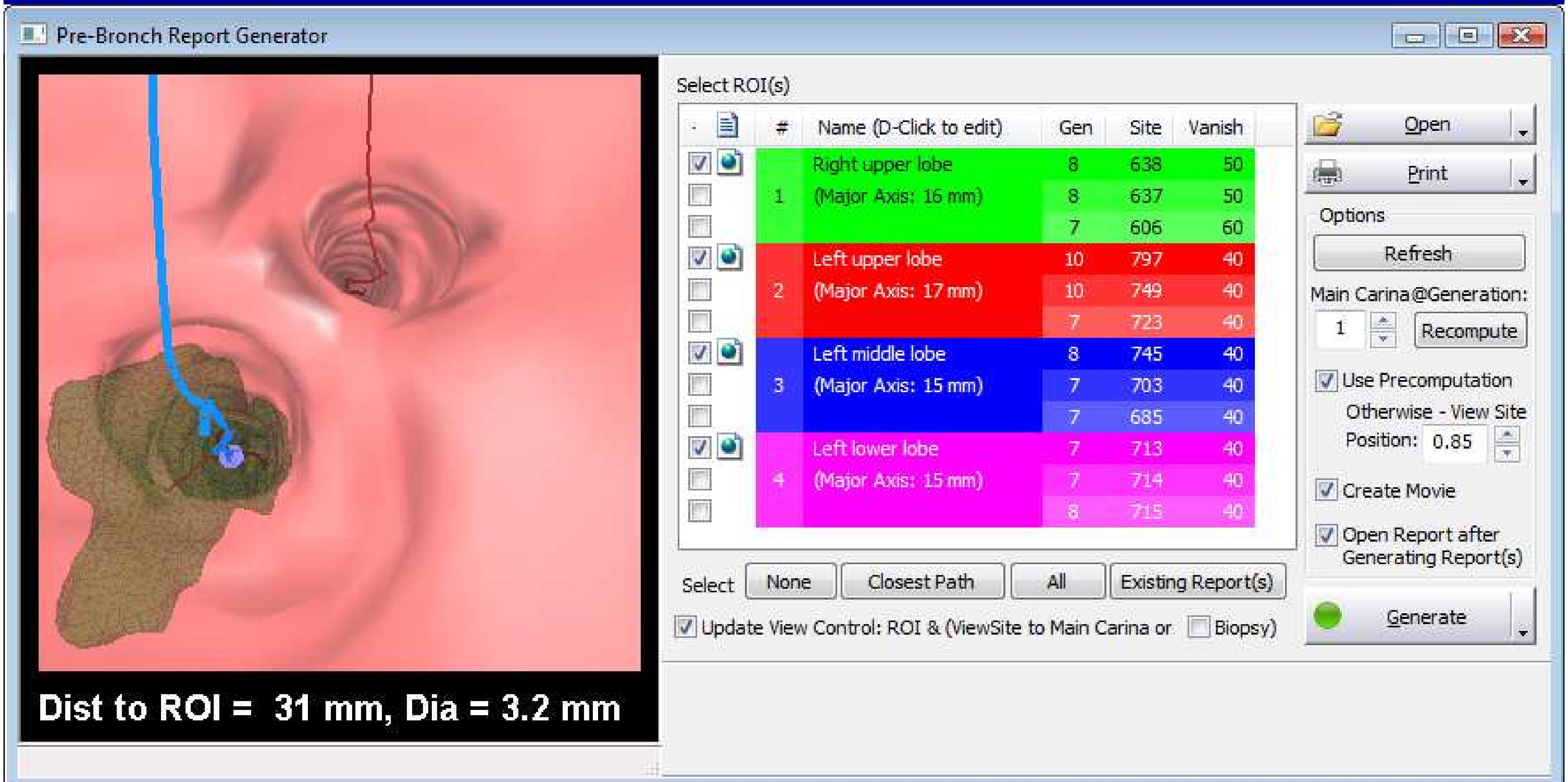
5. Determine appropriate route to ROI
6. *Generate reports depicting route to ROI*

Bronchoscopy

Step 6: Report Generation

Automatically create static and dynamic reports for each ROI



Results: Timing

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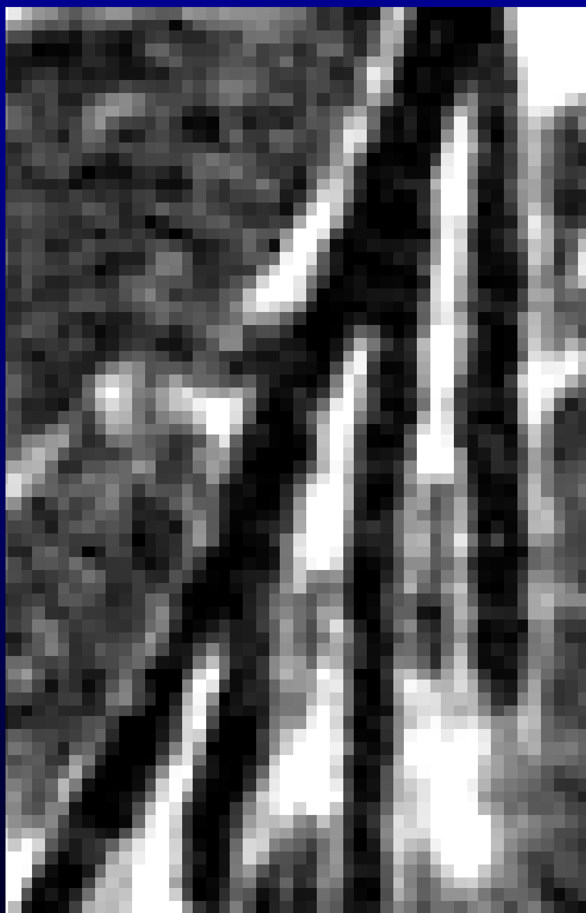
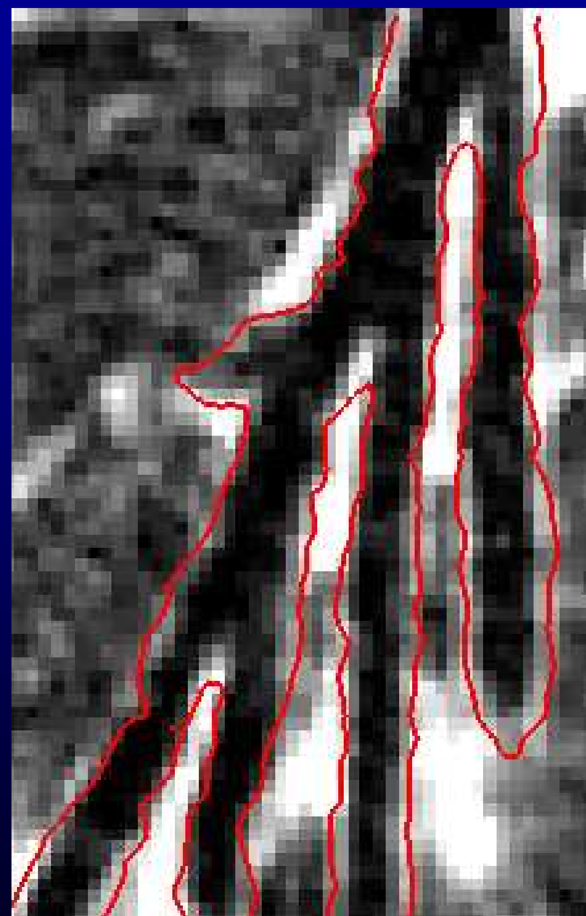
Patient	23	24	25	29	30	Average
ROI definition (sec/ROI)	122	67	76	284	114	140.8
Airway segmentation (sec)	407	672	508	870	570	605.3
Airway surfaces (sec)	76	73	67	71	106	78.6
Airway centerlines (sec)	93	63	56	89	116	55.8
Route planning (sec)	2	1	1	3	1	1.8
Report generation (sec)	15	29	16	17	14	16.3
Total (min:sec)	11:55	15:05	12:04	22:14	15:20	14:10

Results: Surfaces

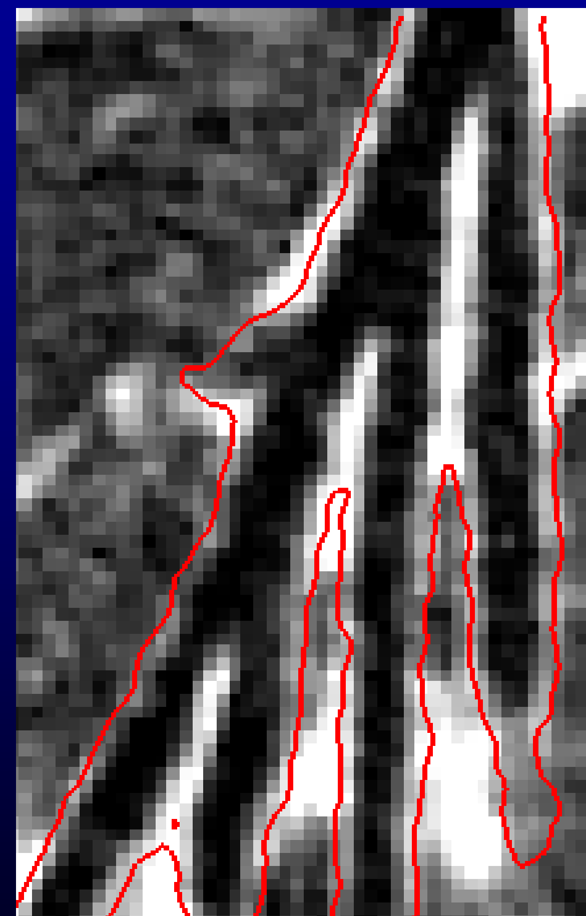
Topological Dilation



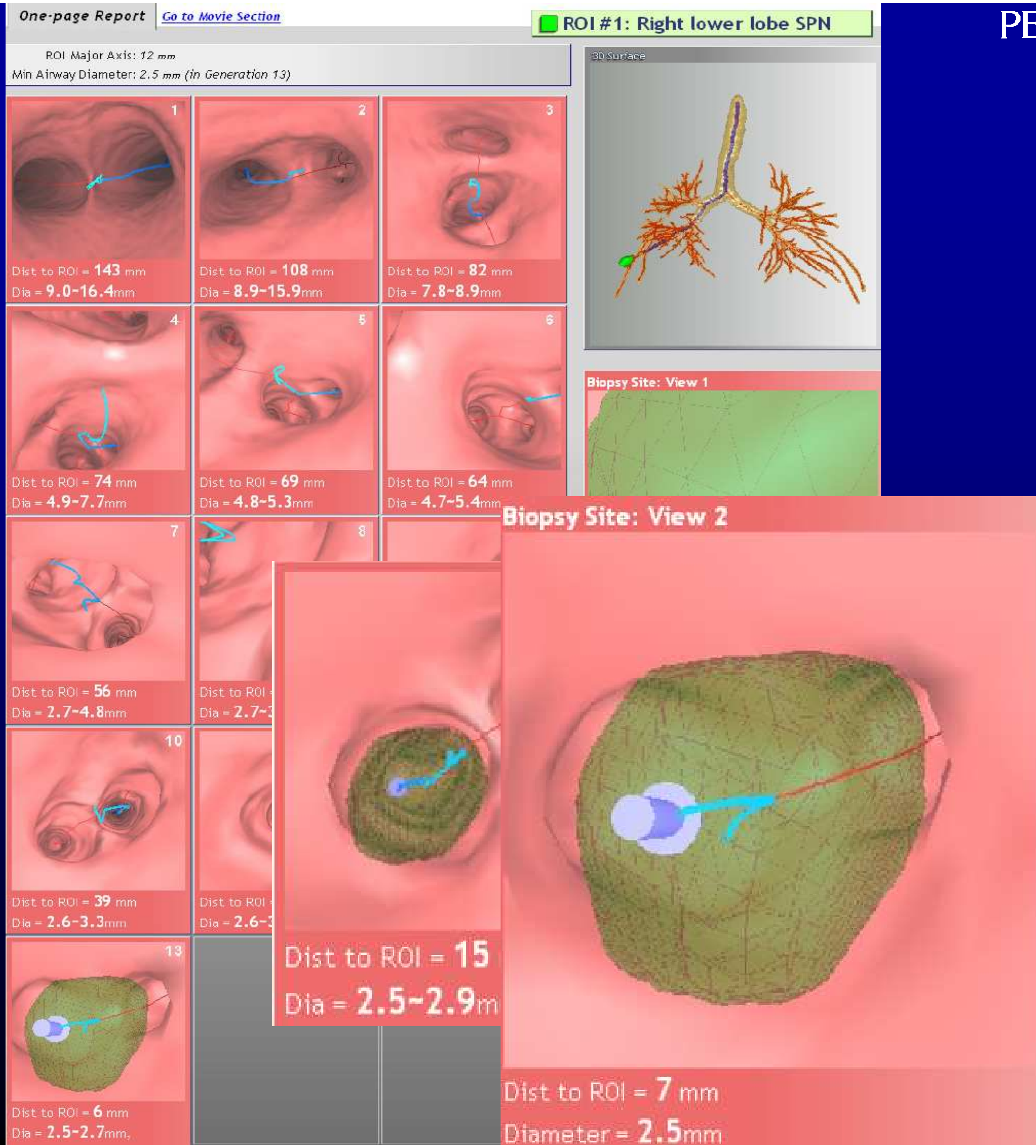
Raw CT Image



Resulting Surfaces



Uniform Dilation



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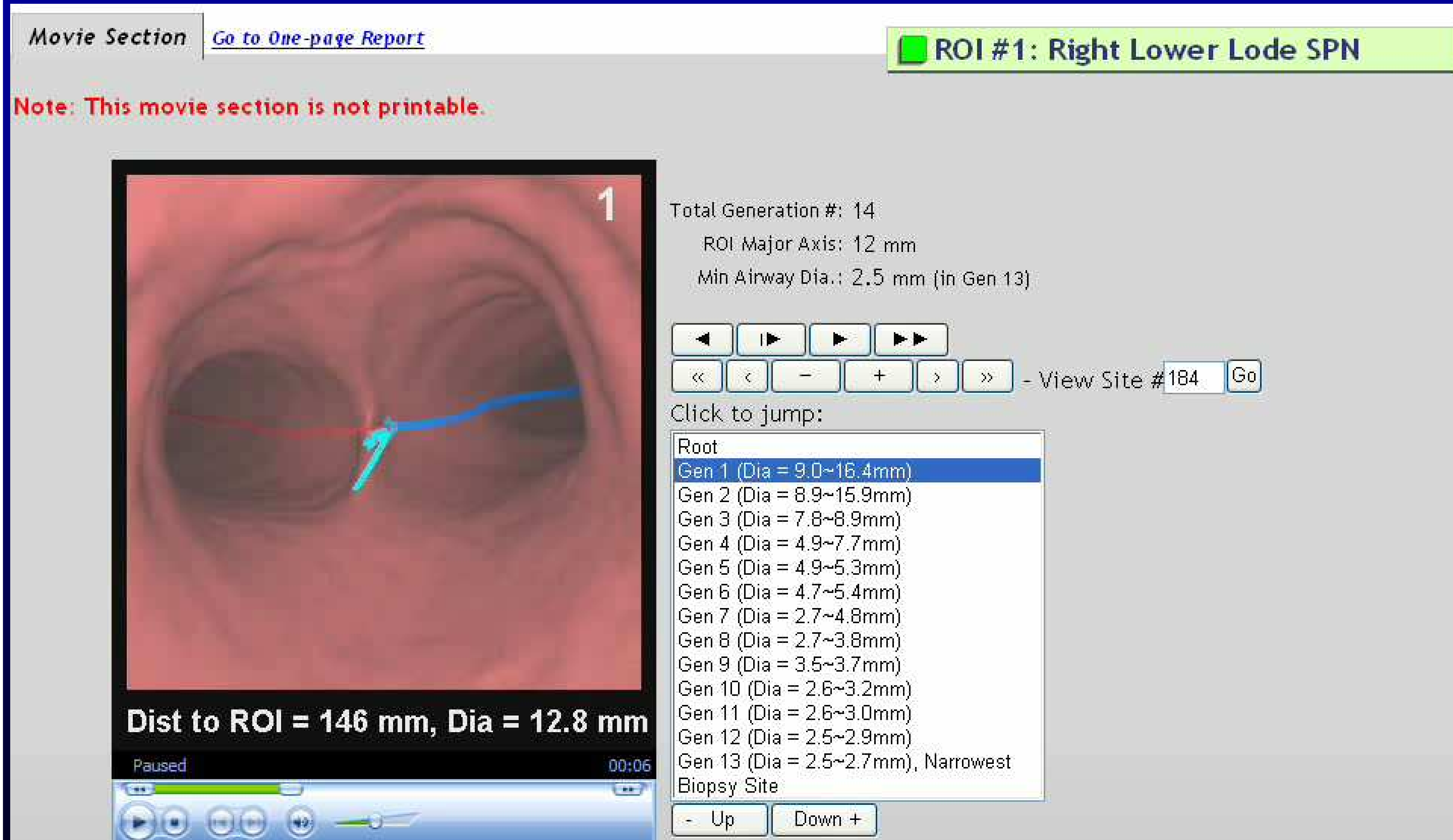
Results: Reporting



Human Peripheral Feasibility Study: ATS 2008

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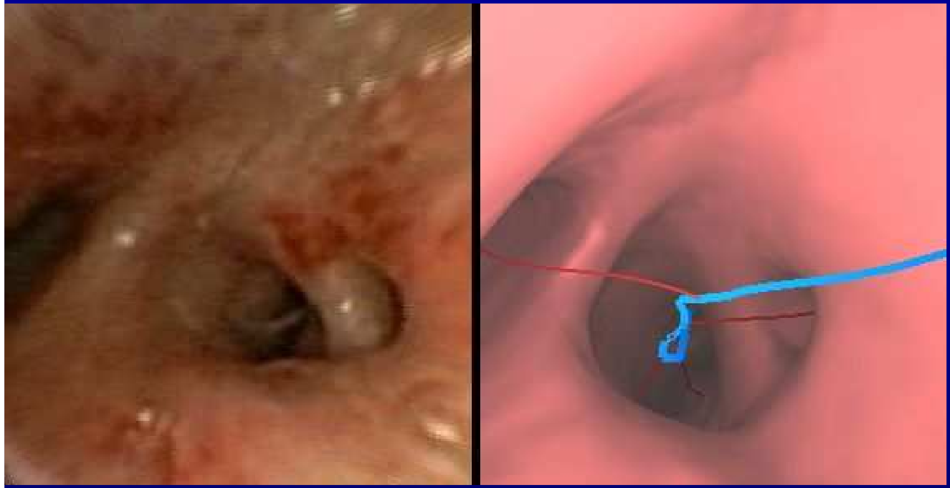
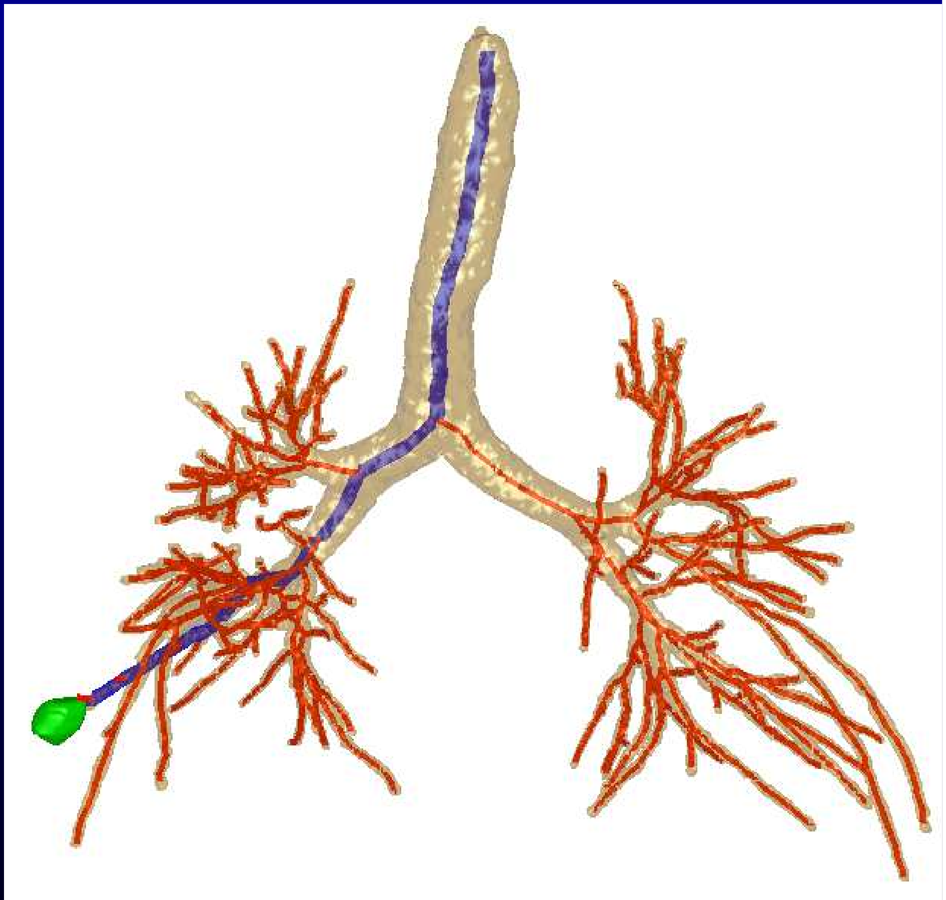
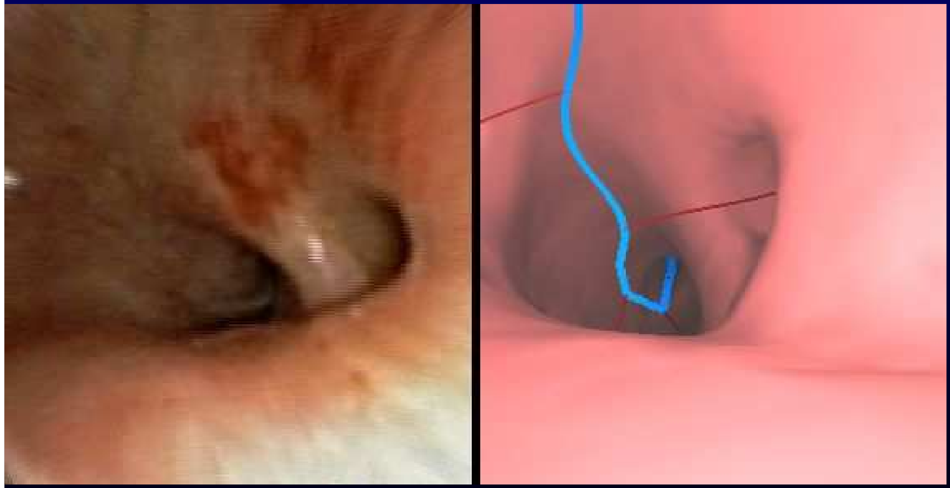
Generation 3: (RML takeoff)



- 2.8mm Olympus ultrathin bronchoscope
- 13 airway generations traversed

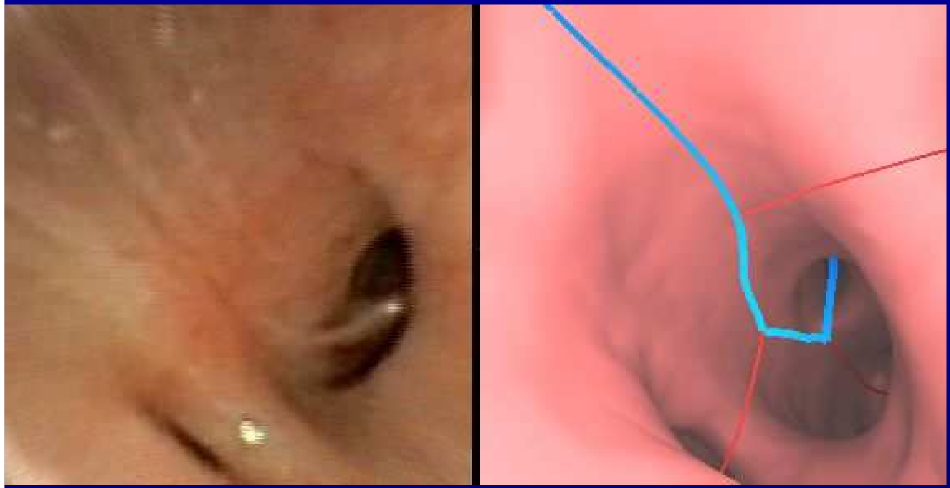


Generation 4



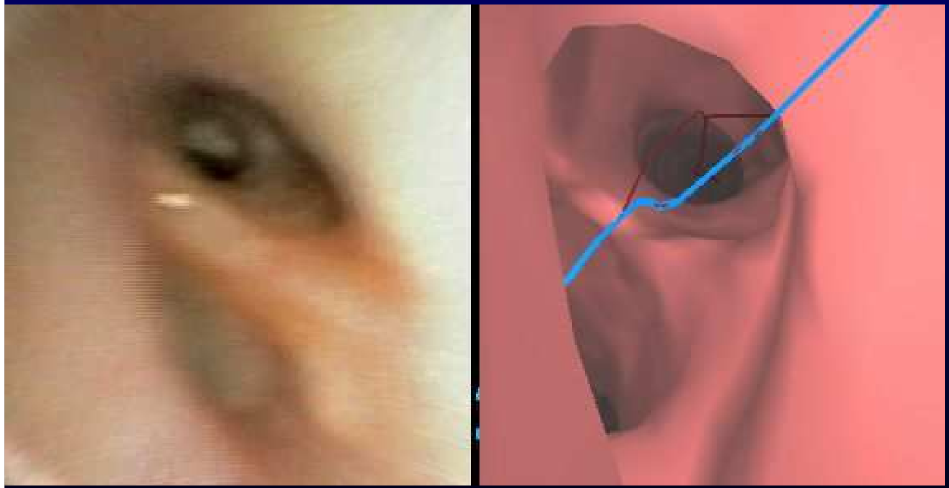
Human Peripheral Feasibility Study: ATS 2008

Generation 5

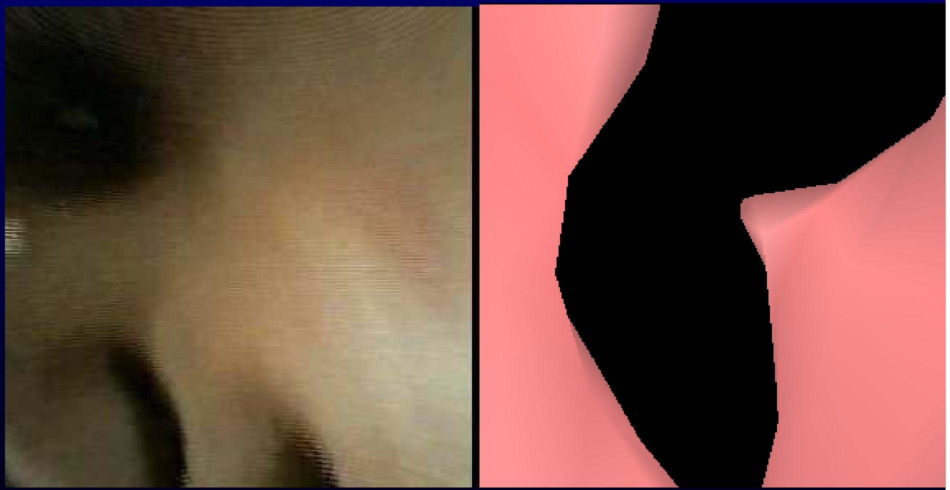


Generation 6

Generation 7



Generation 8



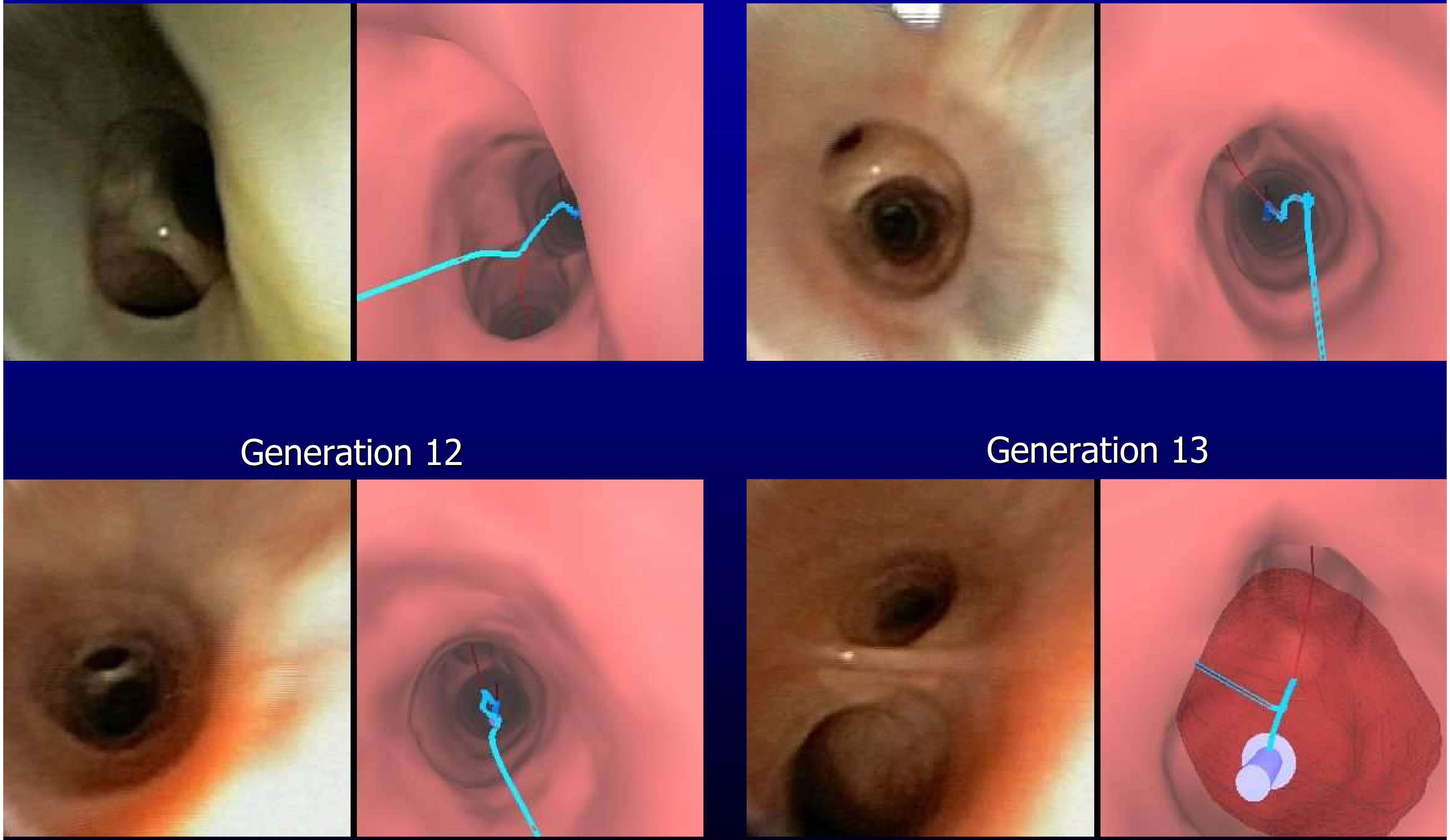
Human Peripheral Feasibility Study: ATS 2008

Generation 10

Generation 11

Generation 12

Generation 13



Conclusion

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- Automated planning system for peripheral bronchoscopy, fits within clinical workflow
- Improved airway-tree segmentation, surfaces enable peripheral bronchoscopy
  - Graham *et al.*, "Robust system for human airway-tree segmentation," SPIE 2008, Image Processing Conference, Tuesday Feb. 19, 1:40PM
- Used with guidance system in ongoing live human study
  - Graham *et al.*, "Image-Guided Bronchoscopy for Peripheral Nodule Biopsy: A Human Feasibility Study," ATS 2008.

Acknowledgements

National Cancer Institute of the NIH

- Grants #CA074325 and #CA091534

The Multidimensional Image Processing Lab at Penn State

Current Planning Practice

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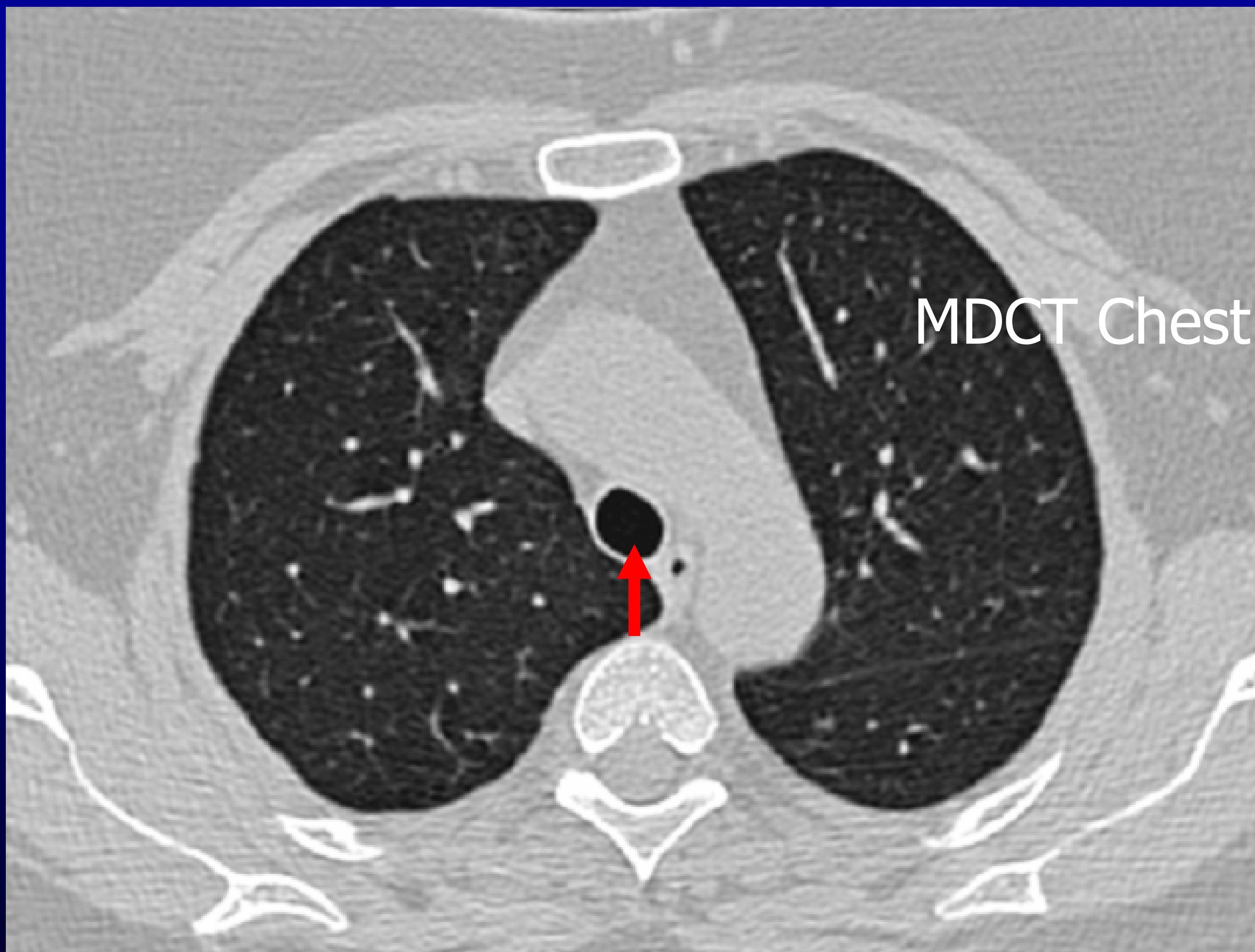
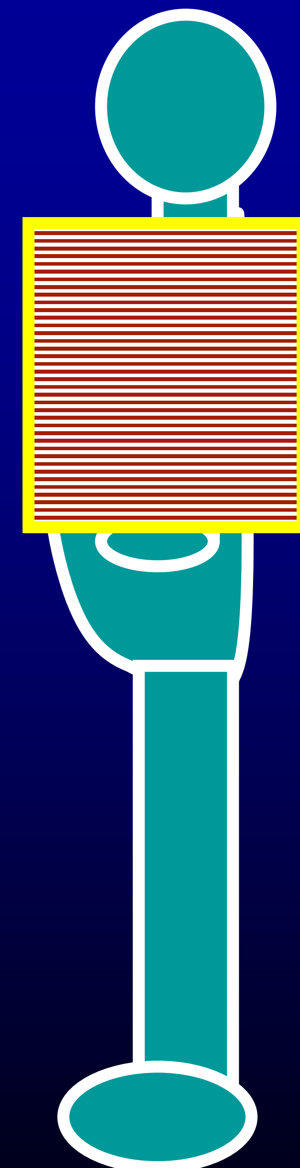


MDCT Chest Scan



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Step 3: Airway-Tree Surfaces

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In the periphery:

Non-uniformly dilate segmentation to preserve topology

Objective: Dilate by d_D without introducing self-intersections, preserve smoothness

1. Extract graph-theoretic topology of segmentation
2. Define dilation constraints
3. Embed dilation constraints into linear programming problem
4. Aggregate locally-dilated components