3D Human Airway Segmentation for Virtual Bronchoscopy

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Outline

1. Introduction
2. Method
3. Segmentation Results
4. Virtual Bronchoscopy Applications

Introduction

- New 3D CT Images can be large: 512 X 512 X 400
  - Partial volume effects
  - Reconstruction artifacts
  - Patient breathing artifacts
- Airway segmentation necessary for Virtual Bronchoscopy
  - Path planning, rendering, quantitative analysis

  * Manual segmentation not an option

Previous Research

1. Knowledge-based
   - *W. Park et al., IEEE Trans. Med. Imaging,* Aug. 1998

2. Central-axis analysis
   - R. Swift et al., *Comp. Med. Imag. Graph*., Feb. 2002

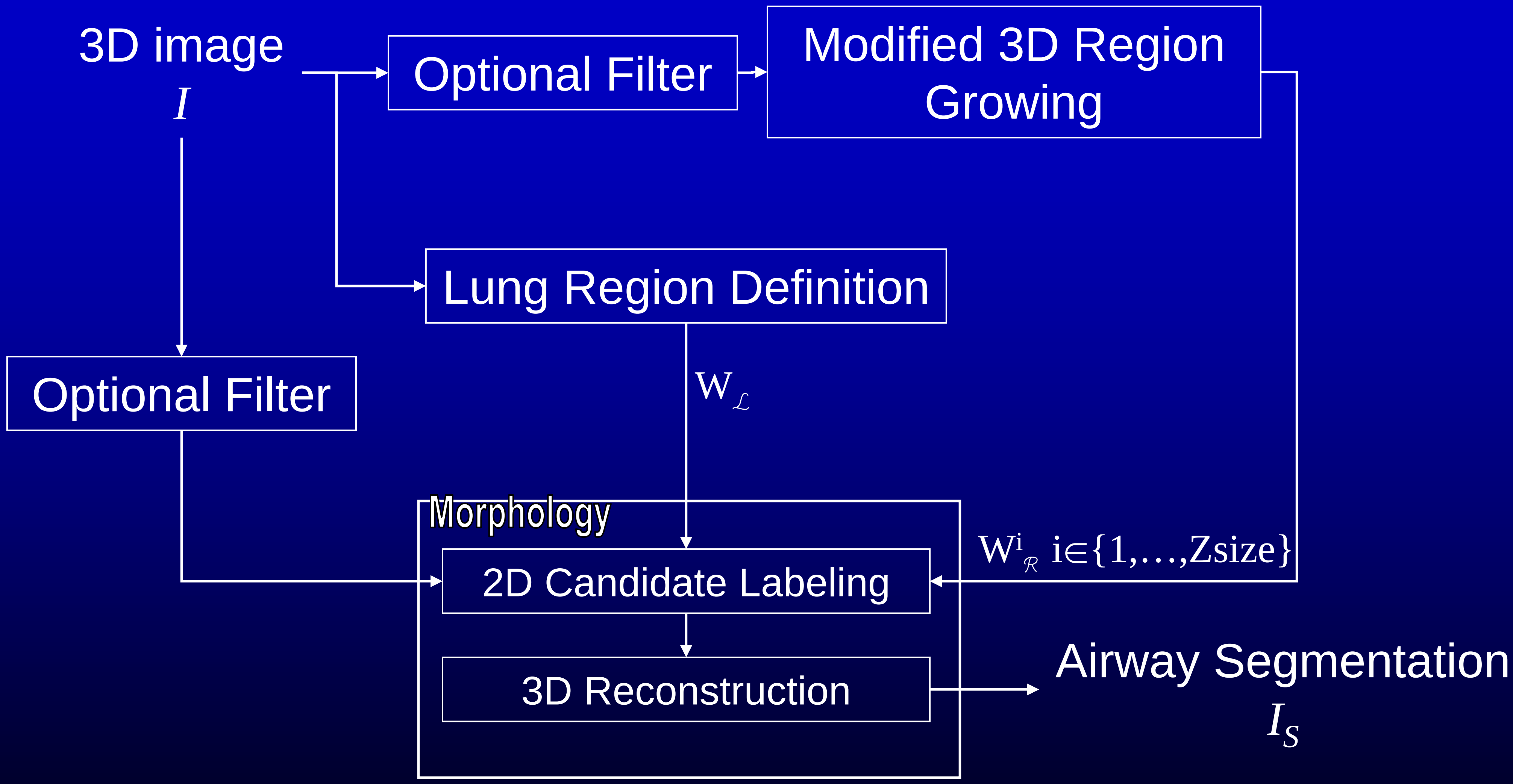
3. 3D Region growing (RG) → not robust
   - R. M. Summers *et al., Radiology,* Sept. 1996
   - K. Mori *et al.*, *13th ICPR,* 1996

4. Mathematical morphology → too slow
   - F. Preteux *et al.*, *J. Elect. Imaging*, Jan. 1999
   - D. Bilgen *et al., IEEE Trans. Med. Imaging*, submitted 2001

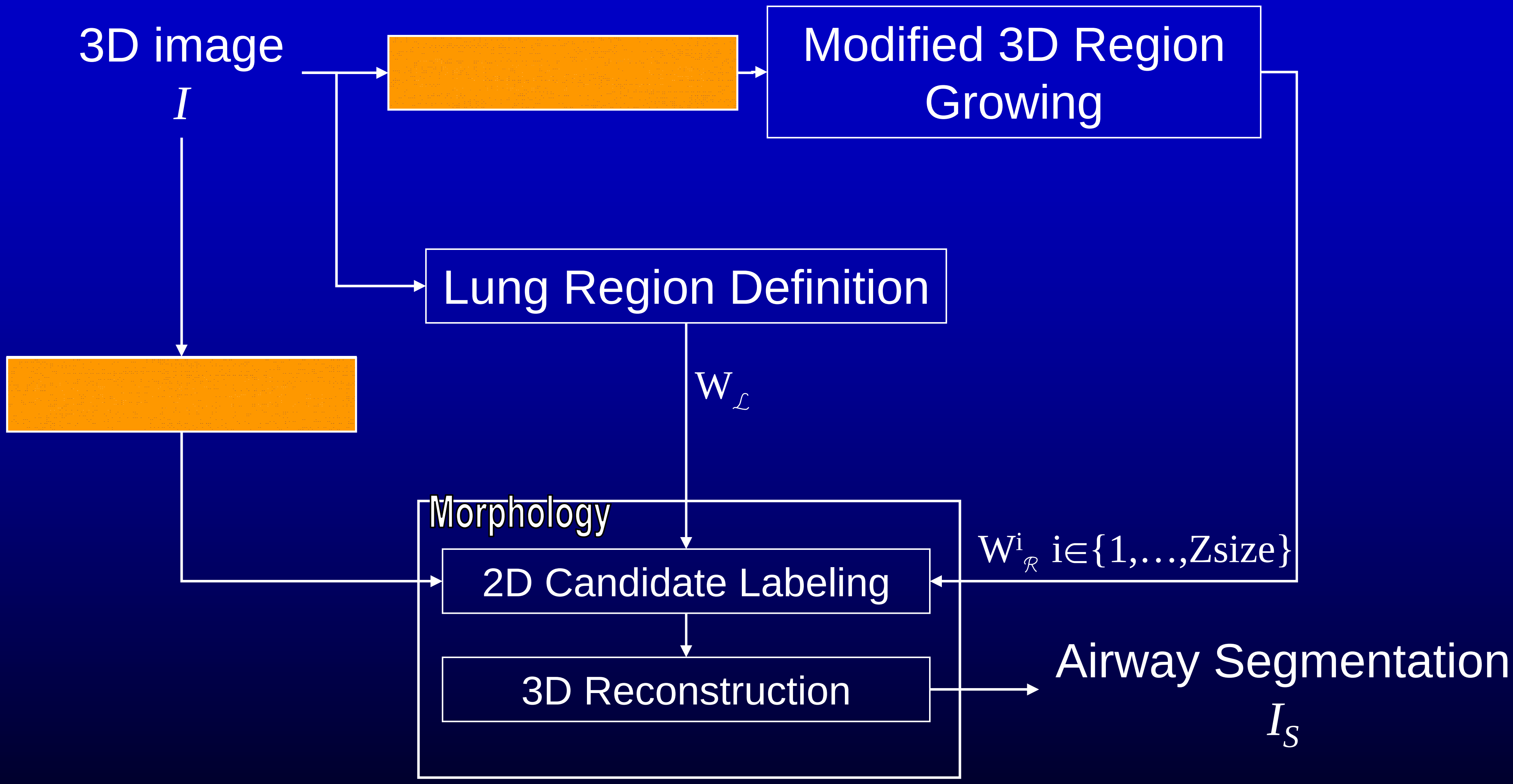
Proposed Hybrid Approach

- Combines 3D RG and Morphology based methods
- Use filtering to improve robustness of both methods
- Use results of 3D RG to reduce application area of the larger operators in the Morphology method
- Order of magnitude improvement in execution time

3D Airway Segmentation Overview



3D Airway Segmentation Overview



Optional Pre-Filtering of the Data

PURPOSE:

1. 3D RG can successfully complete without parenchymal leakage
2. Can help reduce false candidates in morphology method

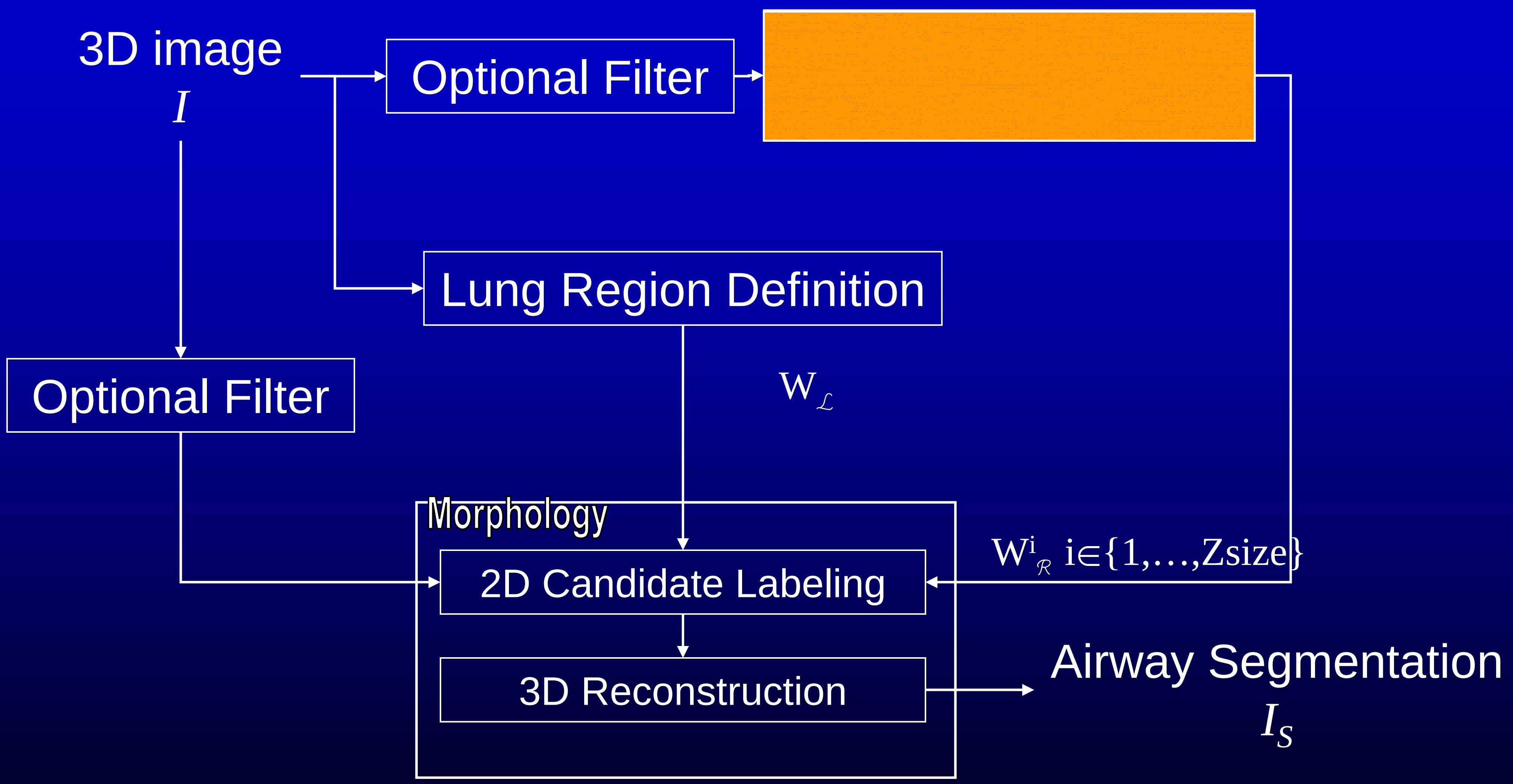
COST:

Lose some peripheral branches

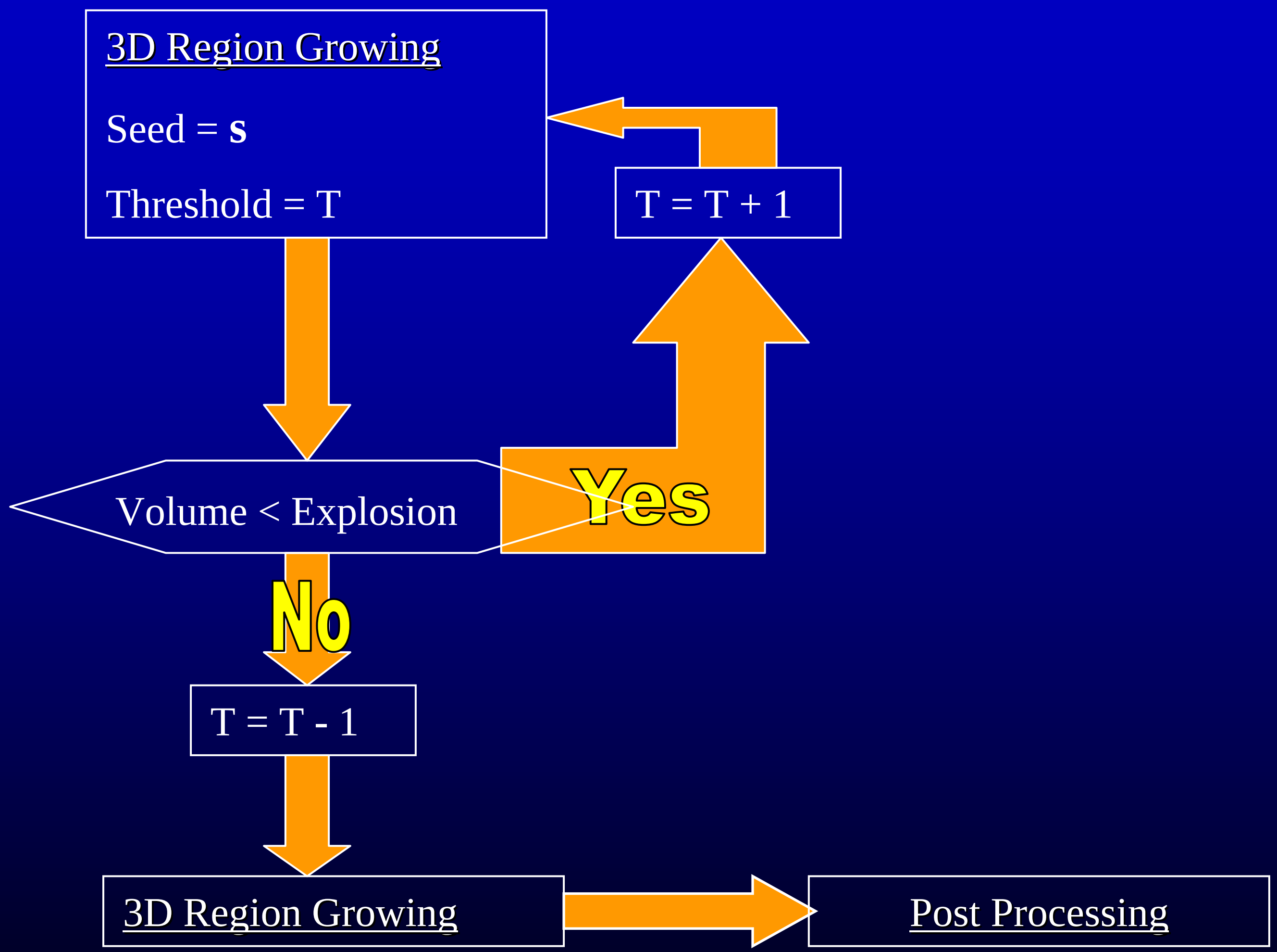
METHODS:

4-connected or 3 X 3 Median filter applied to each slice on 2D basis

3D Airway Segmentation Overview



Modified Adaptive 3D Region Growing



Post Processing

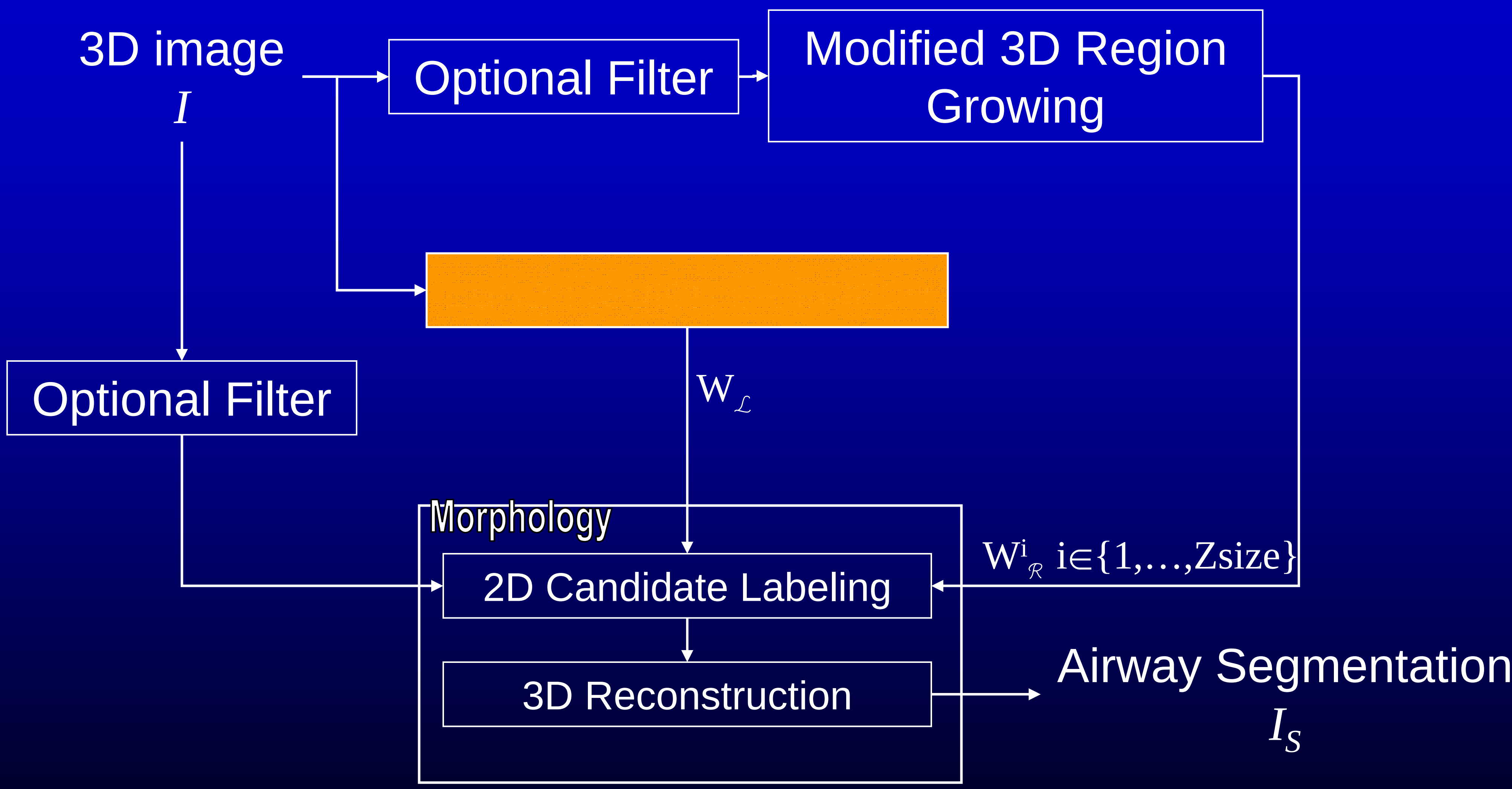
PURPOSE:

1. RG result contains cavities due to noisy data
2. Edges of segmentation can be very rough

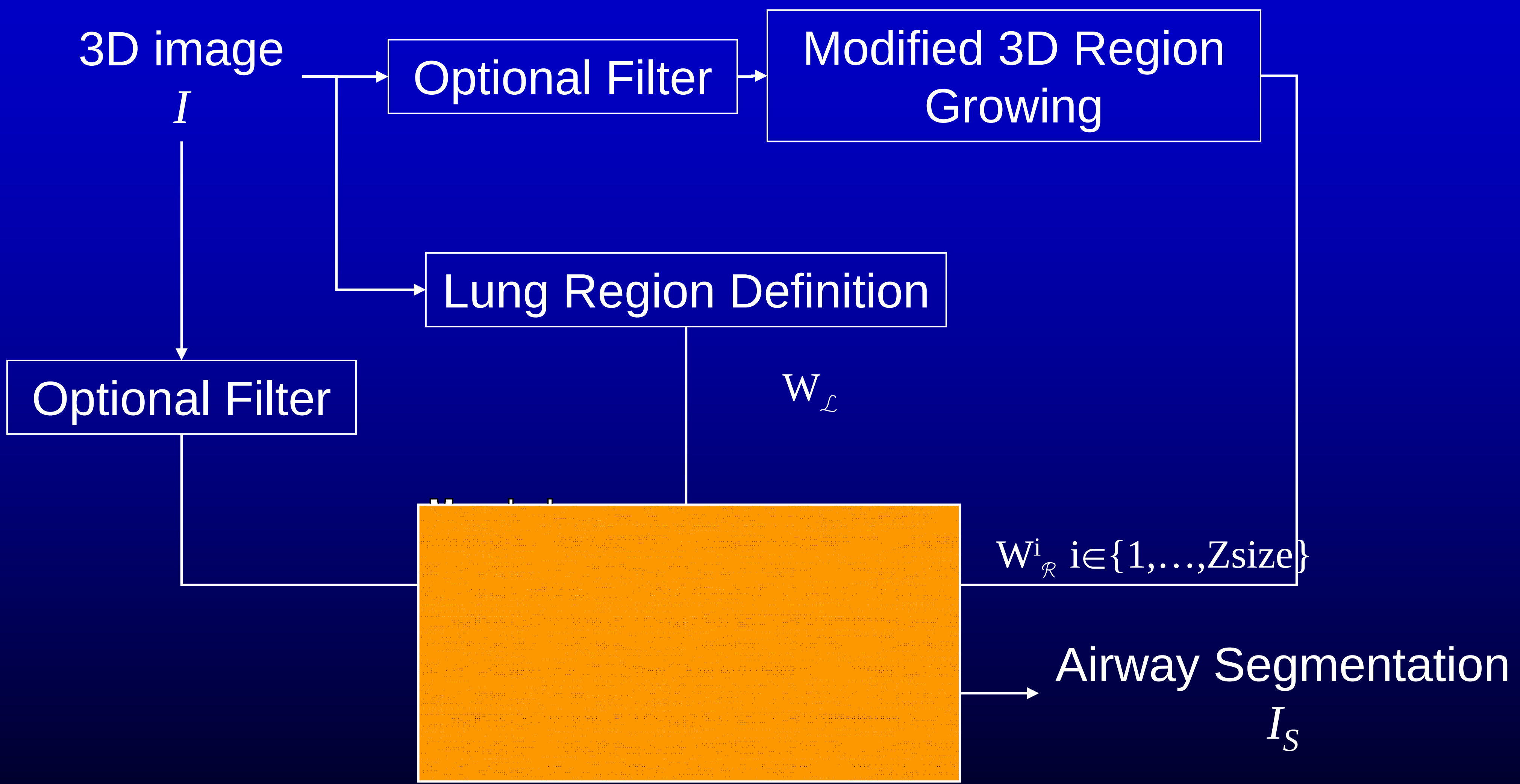
METHOD:

Cavity deletion and binary closing of RG segmentation

3D Airway Segmentation Overview



3D Airway Segmentation Overview



Morphology-Based Segmentation

Two-Step Process

1. 2D Candidate Labeling
    - Identify potential airways on a 2D basis
    - Uses gray-scale reconstruction with different operators

2. 3D Reconstruction

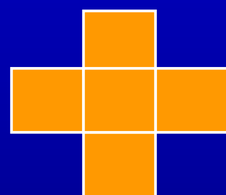
HYBRID:

Use results of 3D RG and Lung Region Definition to limit application area of step 1

2D Candidate Labeling

Basis Operator

$$B_4^1$$

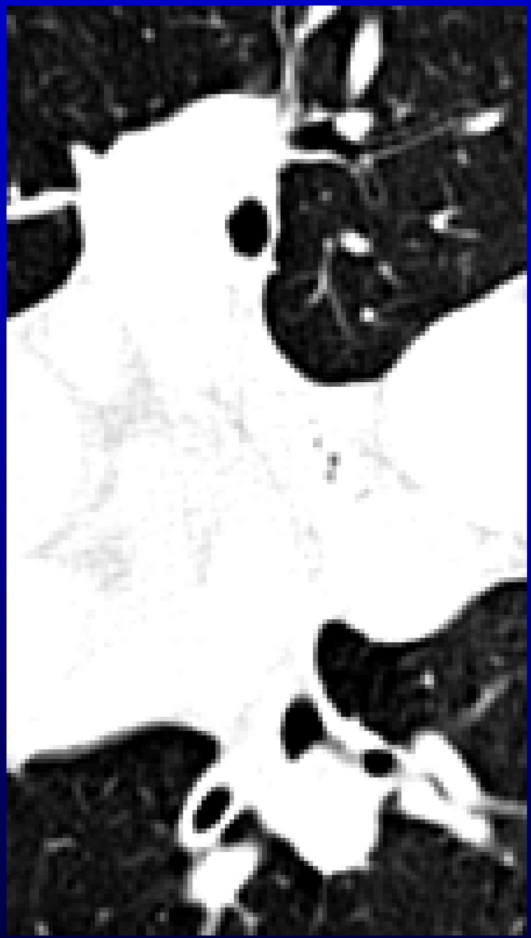


b[th] order homothetic operators

$$B_4^b = bB_4 = \underbrace{B_4 \oplus B_4 \oplus \cdots \oplus B_4}_{(b-1)\ \text{dilations}}$$

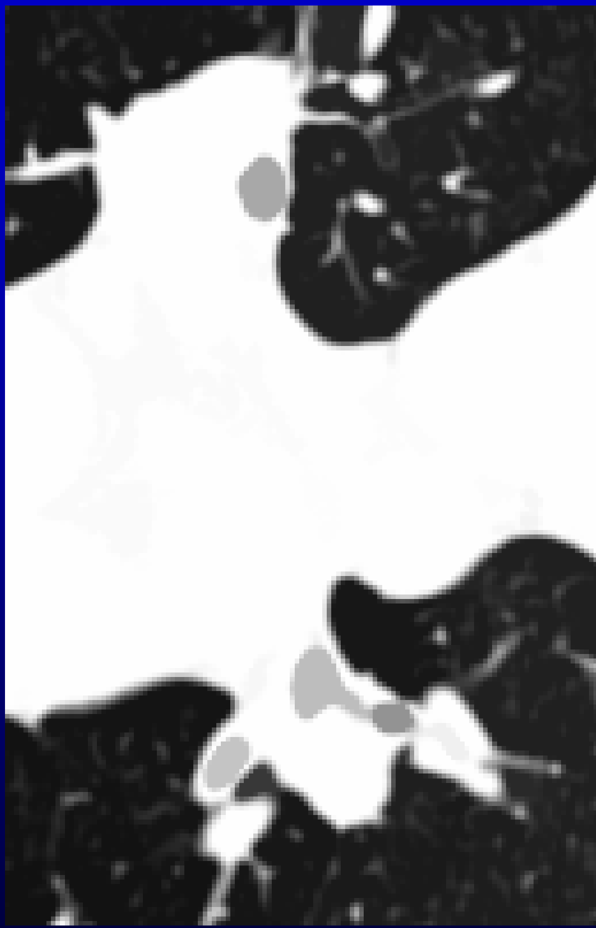
2D Candidate Labeling

1 Sample and threshold slice z from Image I



$$S(x, y) = I(x, y, z) \text{ if } I(x, y, z) \leq 0 \quad \text{else } 0$$

2D Candidate Labeling



2 Perform gray-scale closing with operator of size b

$$J_1^b = S \bullet B_4^b = (S \oplus B_4^b) \ominus B_4^b$$

3 Erode image and take maximum with original

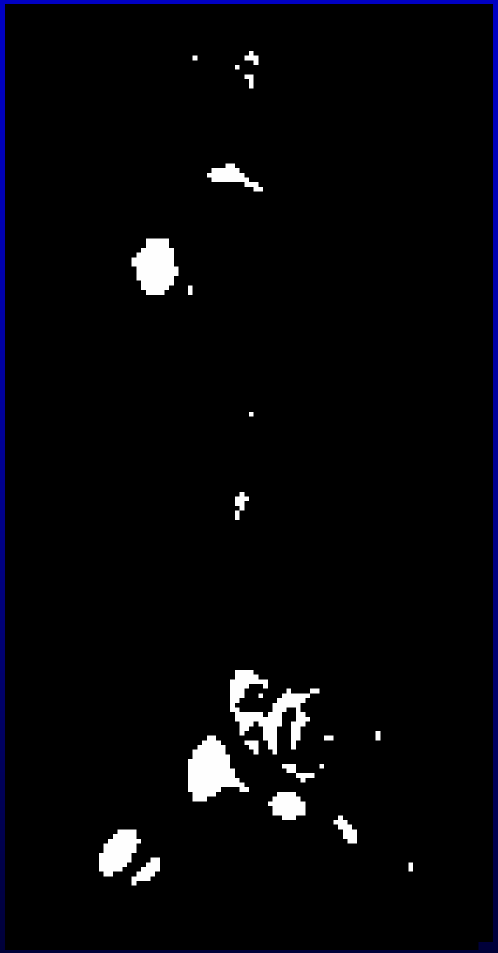
$$J_{k+1}^b = \max(J_k^b \ominus B_4^1, S)$$

4 Repeat above step until max no longer involves S

2D Candidate Labeling

5 Threshold result into binary image C

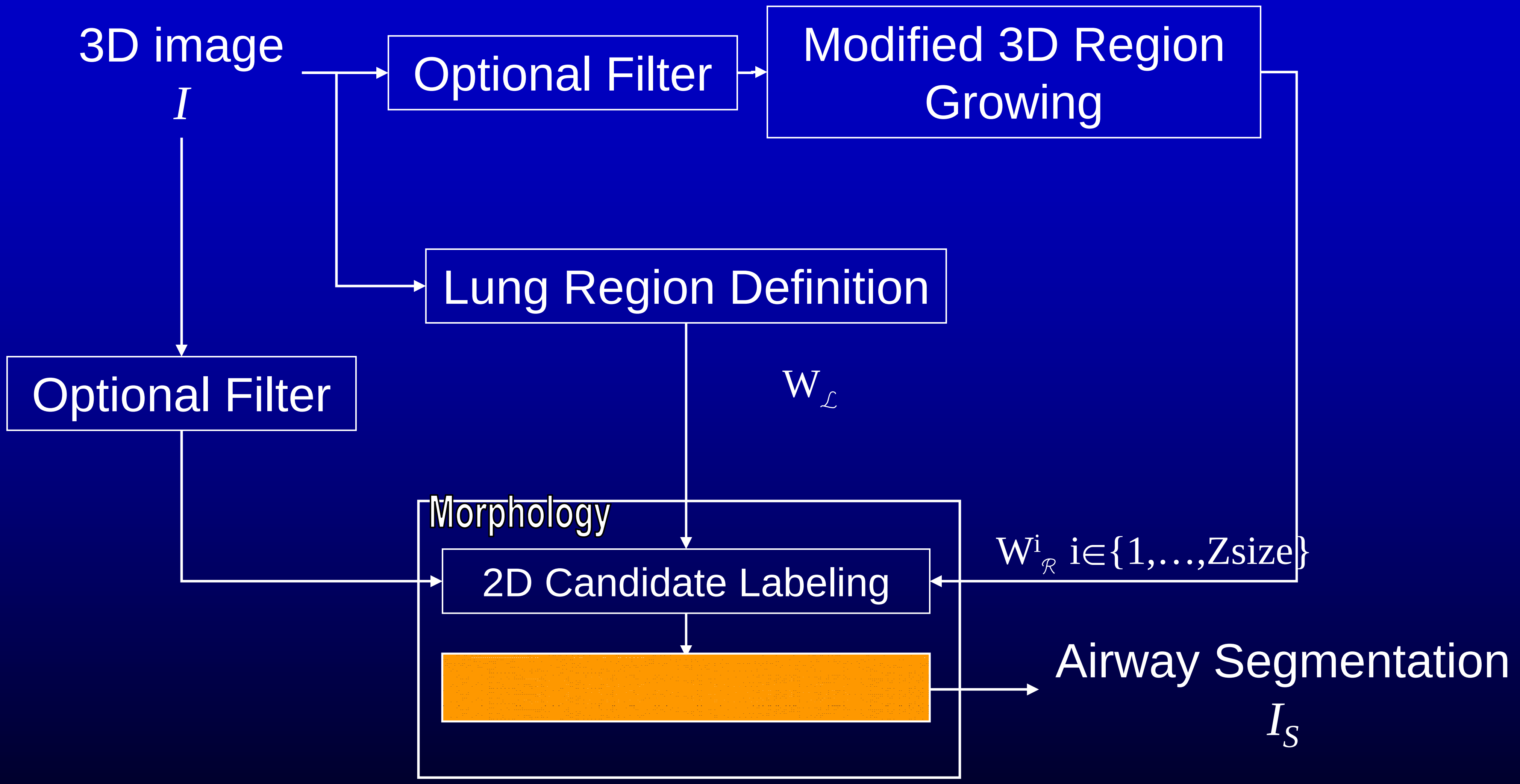
$$C^{b}(x,y) = 1 \text{ if } J_{\infty}^{b}(x,y) - S \geq \mathit{Threshold} \quad , 0 \text{ otherwise}$$



6 Union of results for all b determines candidate locations

$$C(x,y) = \bigcup_{b=1}^{M} C^{b}(x,y)$$

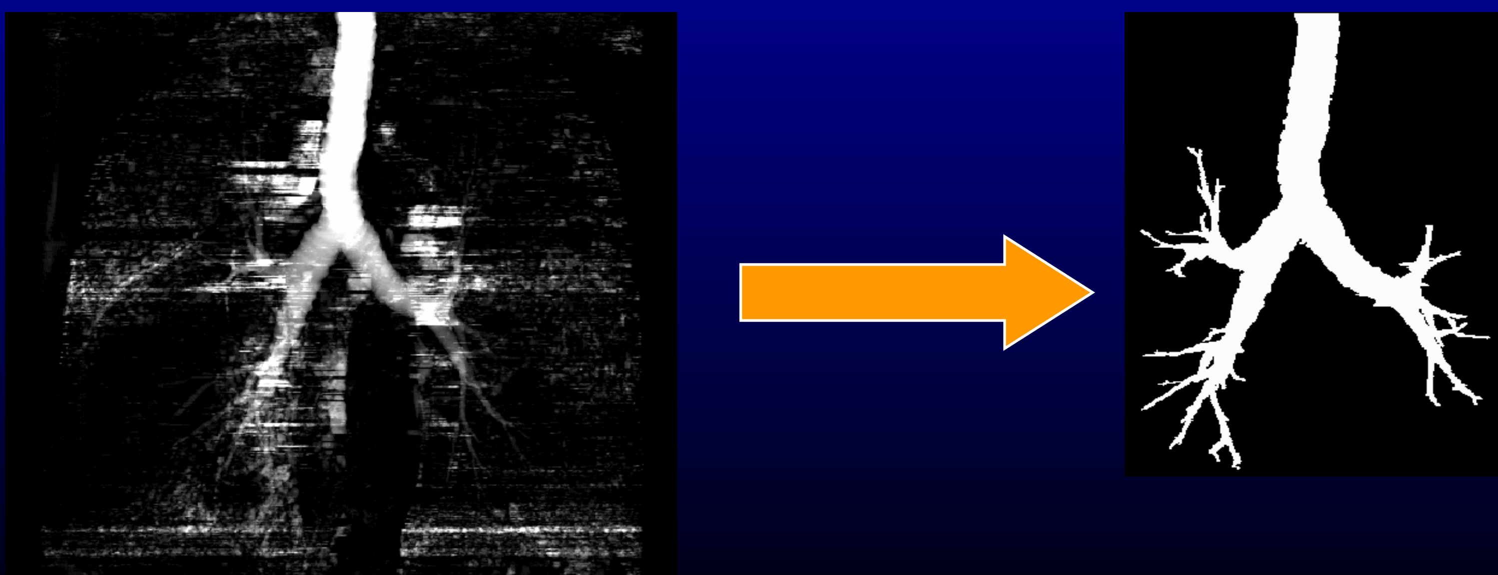
3D Airway Segmentation Overview



3D Reconstruction

- PURPOSE: Determine valid candidates to form final result

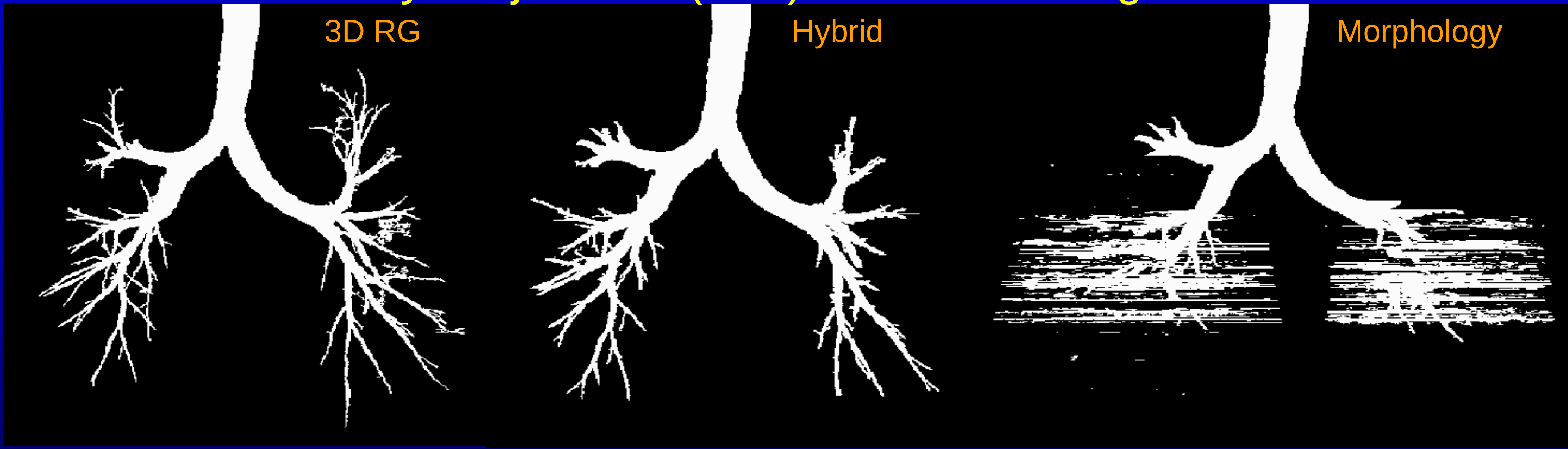
- METHOD:
  - Closed space dilation with unit kernel radius
  - 3D 6-connected region growing



I_S

Results: case h006

Maximum Intensity Projections (MIP) of resultant segmentations



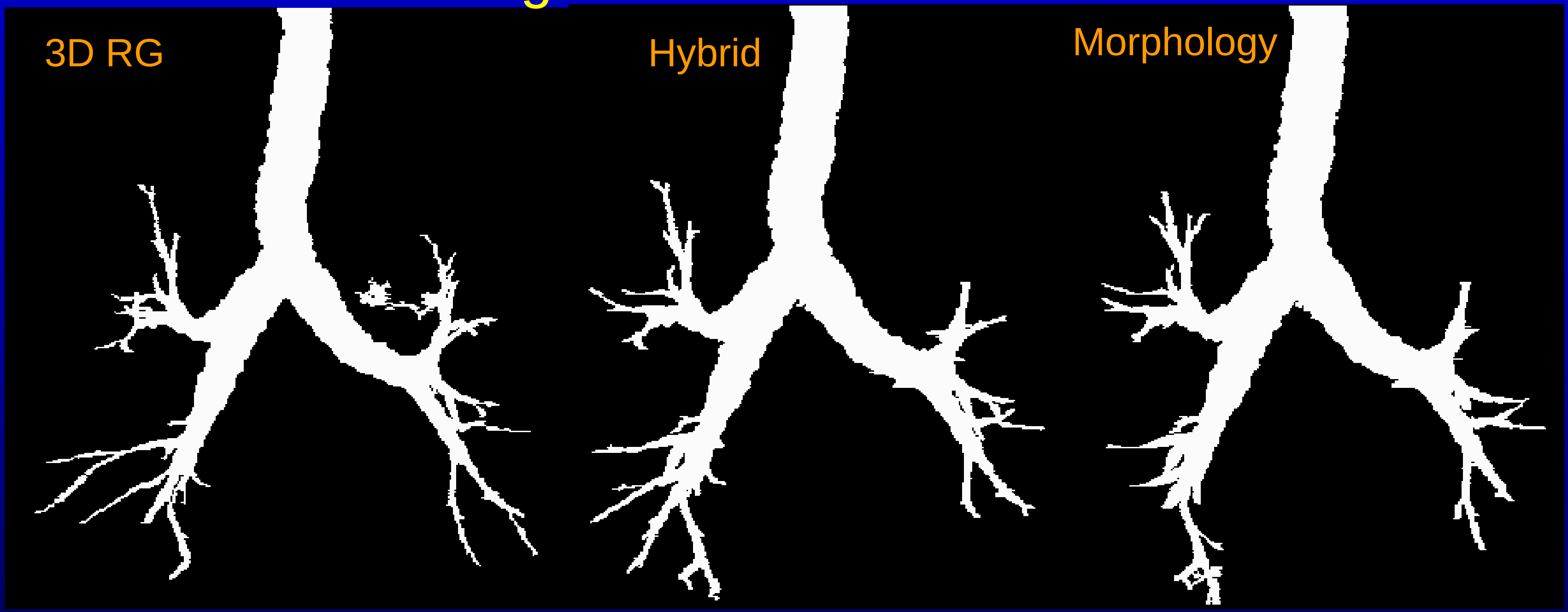
- Morphology method failed
- Different branches segmented
- No filtering used

Case h006: 512X512X574 287MB (0. 72mm X 0.72mm X 0.60mm)

Case h006_512_85, root site=(273,248,0), seger=(RegGrow,no filter,explode at T=50000)

Results: case h007

MIP of resultant segmentations



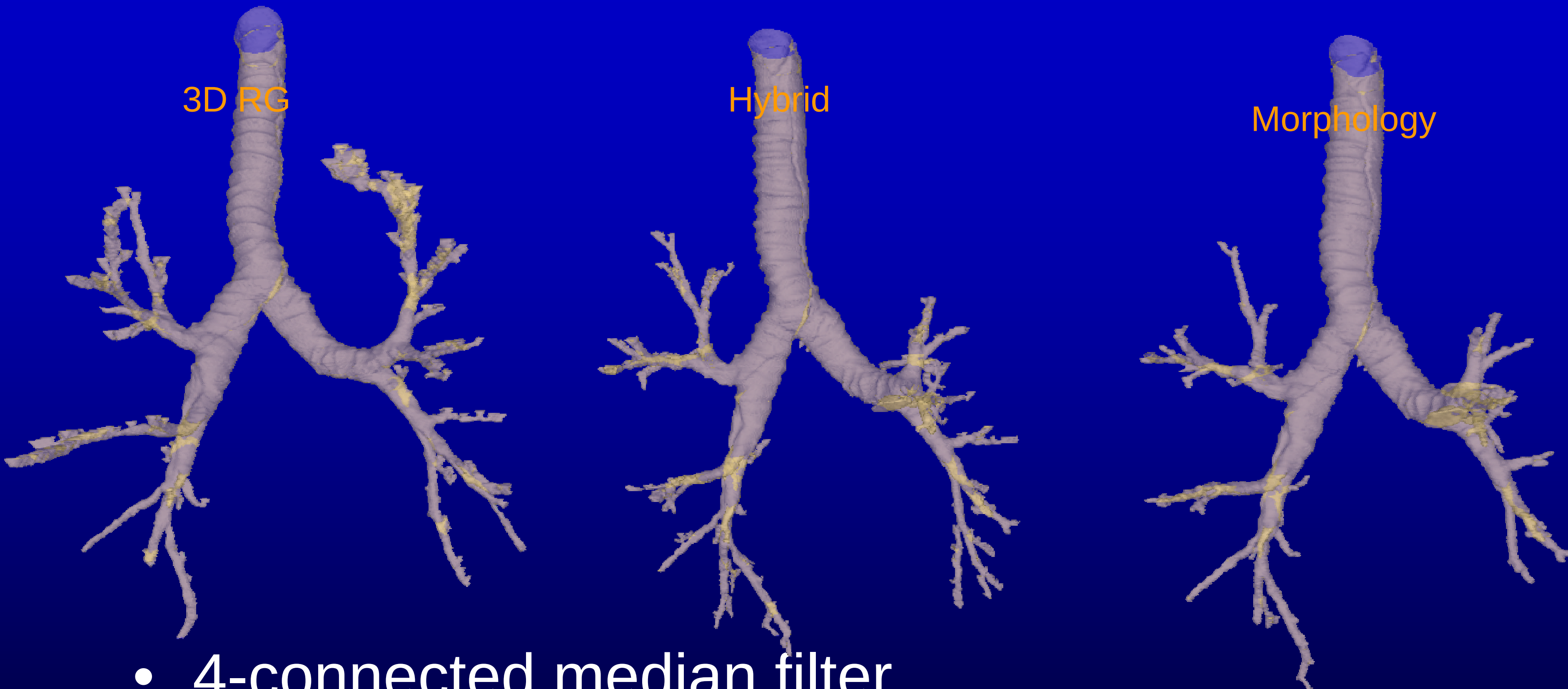
- 4-connected median filter
- 3D RG and Morphology methods show leakage

Case h007: 512X512X488 244MB (0.65mm X 0. 65mm X 0.60mm)

Case h007_512_85, root site=(266,221,0), seger=(RegGrow,star median,explode at T=50000)

Results: case h007

Tree Renderings



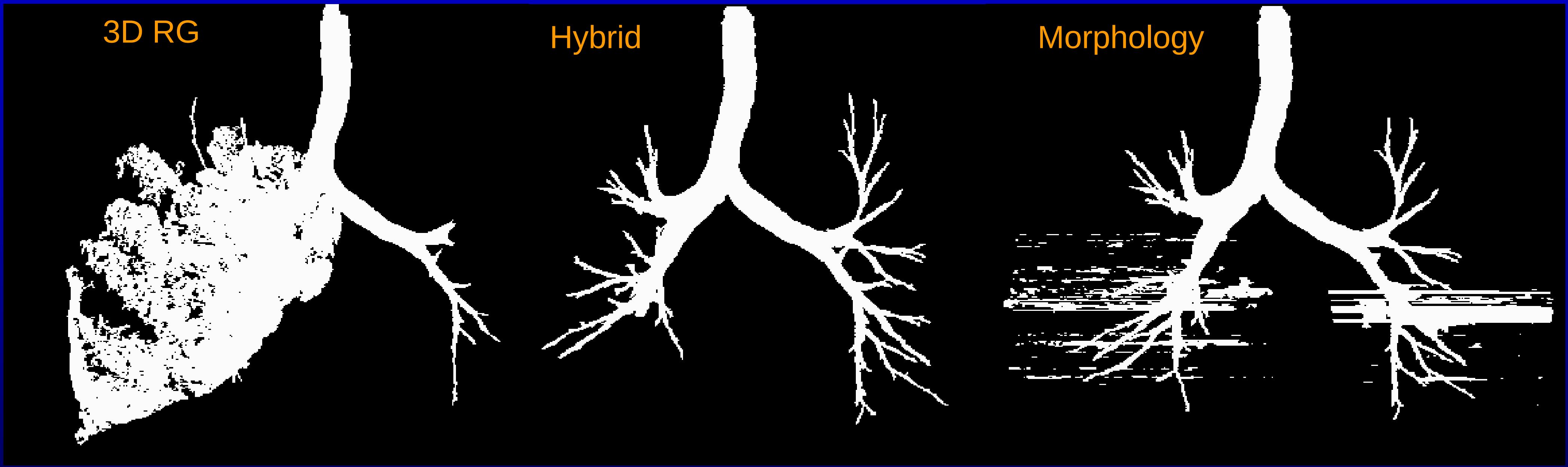
- 4-connected median filter
- 3D RG and Morphology methods show leakage

Case h007: 512X512X488 244MB (0.65mm X 0. 65mm X 0.60mm)

Case h007_512_85, root site=(266,221,0), seger=(RegGrow,star median,explode at T=50000)

Results: case h008

MIP of resultant segmentations



- Only hybrid method succeeded
- No filtering used

Case h008: 512X512X389 194MB (0.59mm X 0.59mm X 0.06mm)

Case h008_512_85, root site=(242,211,0), seger=(RegGrow,no filter,explode at T=50000)

Segmentation Time Results

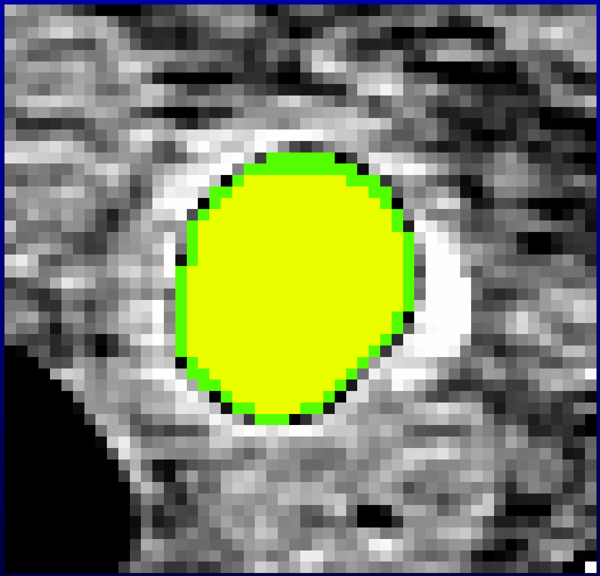
Method	Labeling seconds	Reconstruction seconds	Total seconds
3D RG	N.A.	N.A.	64
Hybrid	1700	1580	3280
Morphology	15380	3200	18580

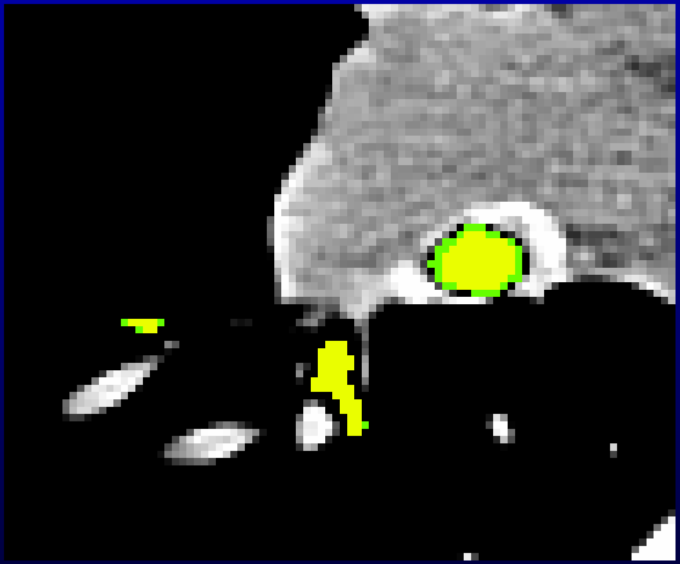
Hybrid demonstrates 10X improvement in labeling time

Edge Localization

Segmented by both RG and Hybrid methods

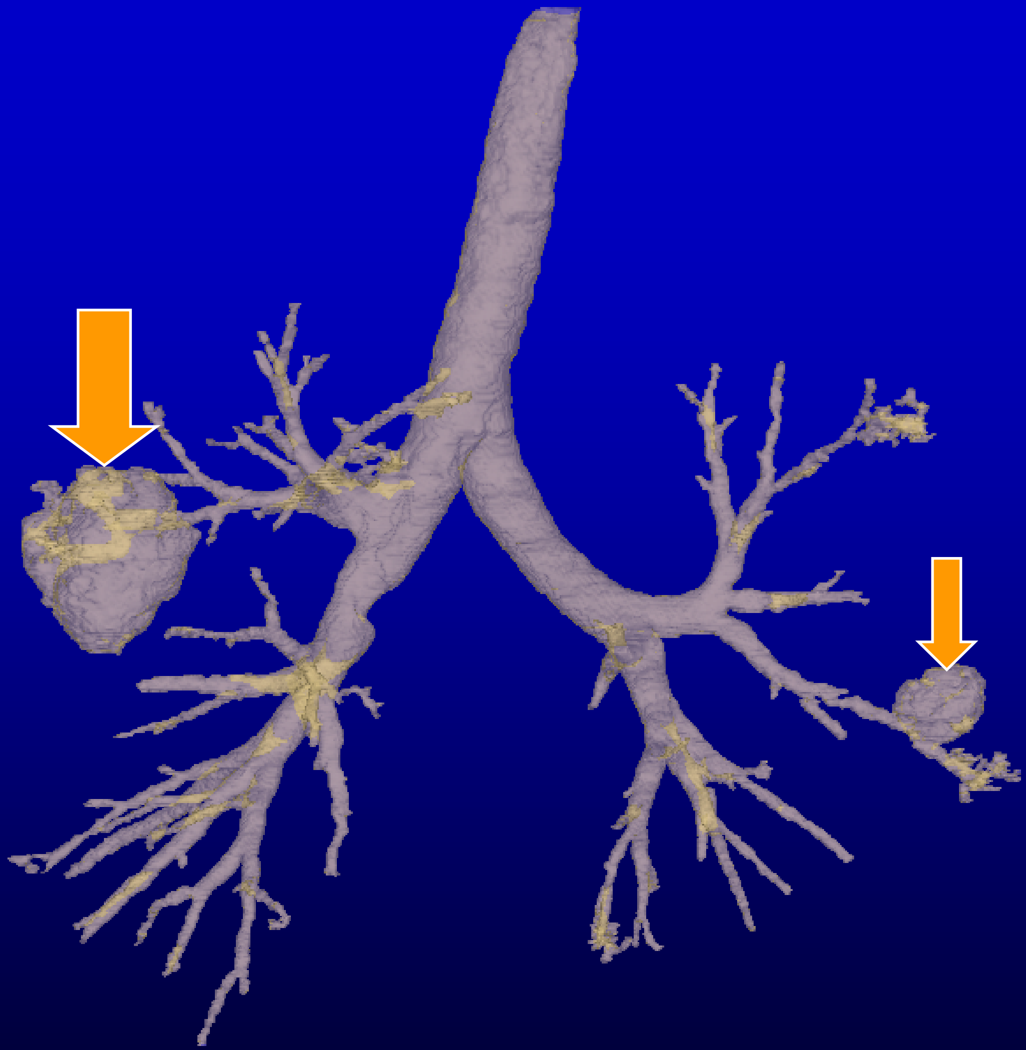
Segmented by Hybrid method only

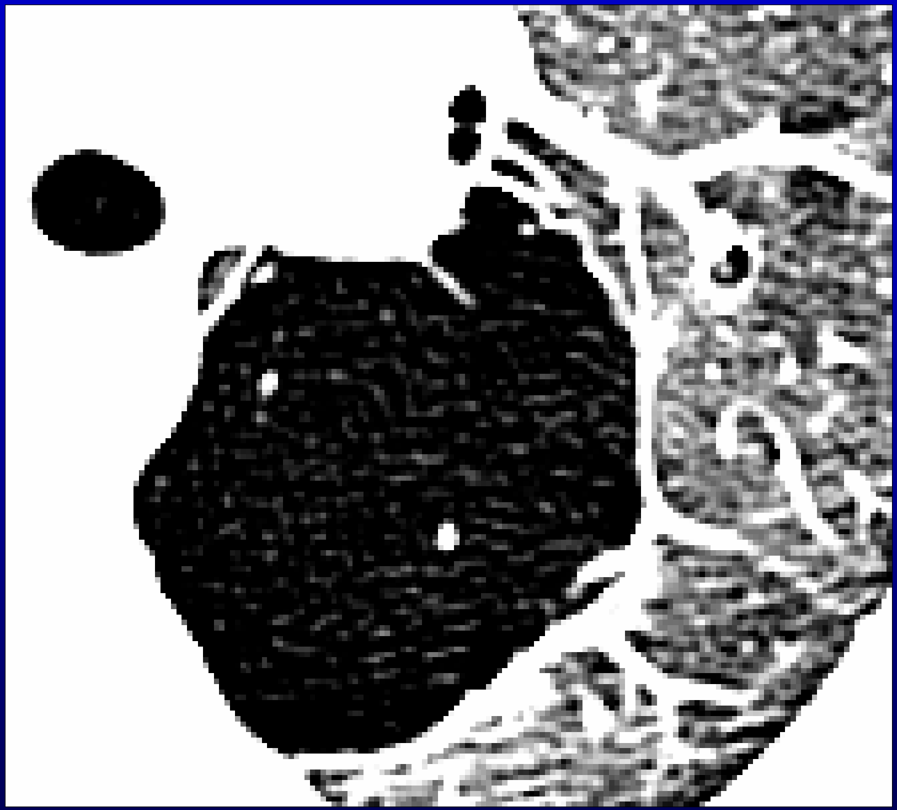




Hybrid method demonstrates better edge localization

H012 case: papilloma





(-1000,-800) WINDOWING

Hybrid and Morphology method fail in capturing **papilloma**

Virtual Bronchoscopy Applications

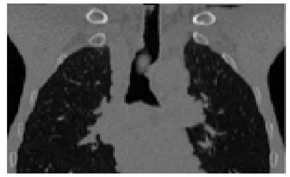
1. Airway Analysis
2. Peripheral Nodule Biopsy
3. Mediastinal Lymph-Node Biopsy

→ Use the *Virtual Navigator*.

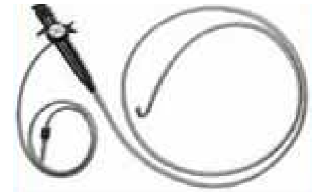
- Sherbondy *et al., SPIE Medical Imaging 2000*, vol. 3978
- Helferty *et al., SPIE Medical Imaging 2001*, vol. 4321
- Helferty *et al., ICIP 2002*

Virtual Navigator: architecture

Data Sources



CT Scan



Bronchoscope

Image Processing Analysis

Stage 1: 3D CT Assessment

- Identify Target ROI Sites
- Segment Airway Tree
- Calculate Centerline Paths
- Virtual Endoluminal Movies
- Cross-Section Area Calculations
- Volume Slices, Slabs, Projections

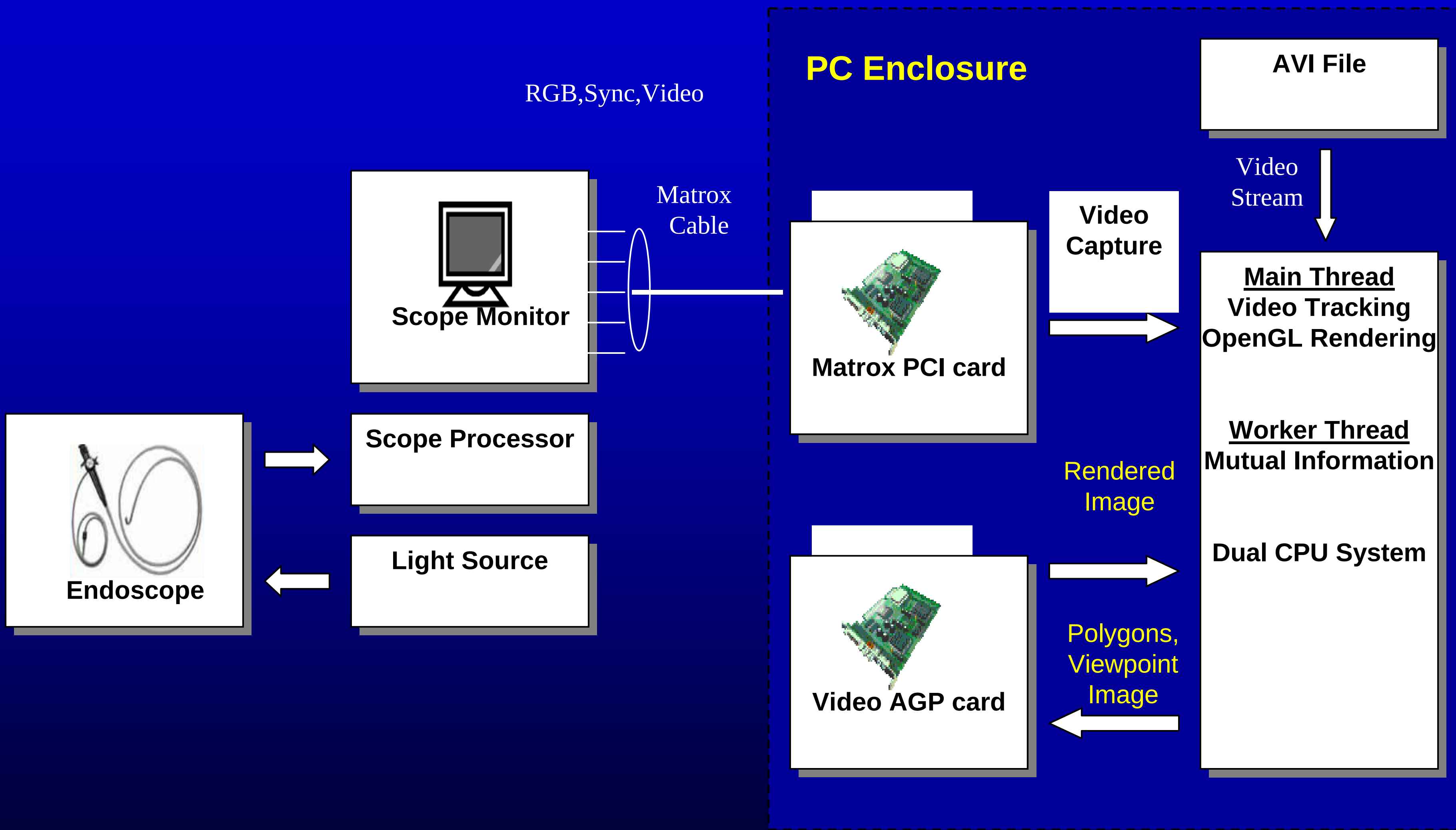
Stage 2: Live Bronchoscopy

- Capture Endoscope Video
- Correct Barrel Distortion
- Interactive Virtual Views
- Register Virtual CT to Video
- Draw Target Regions on Video

HTML Multimedia Case Report

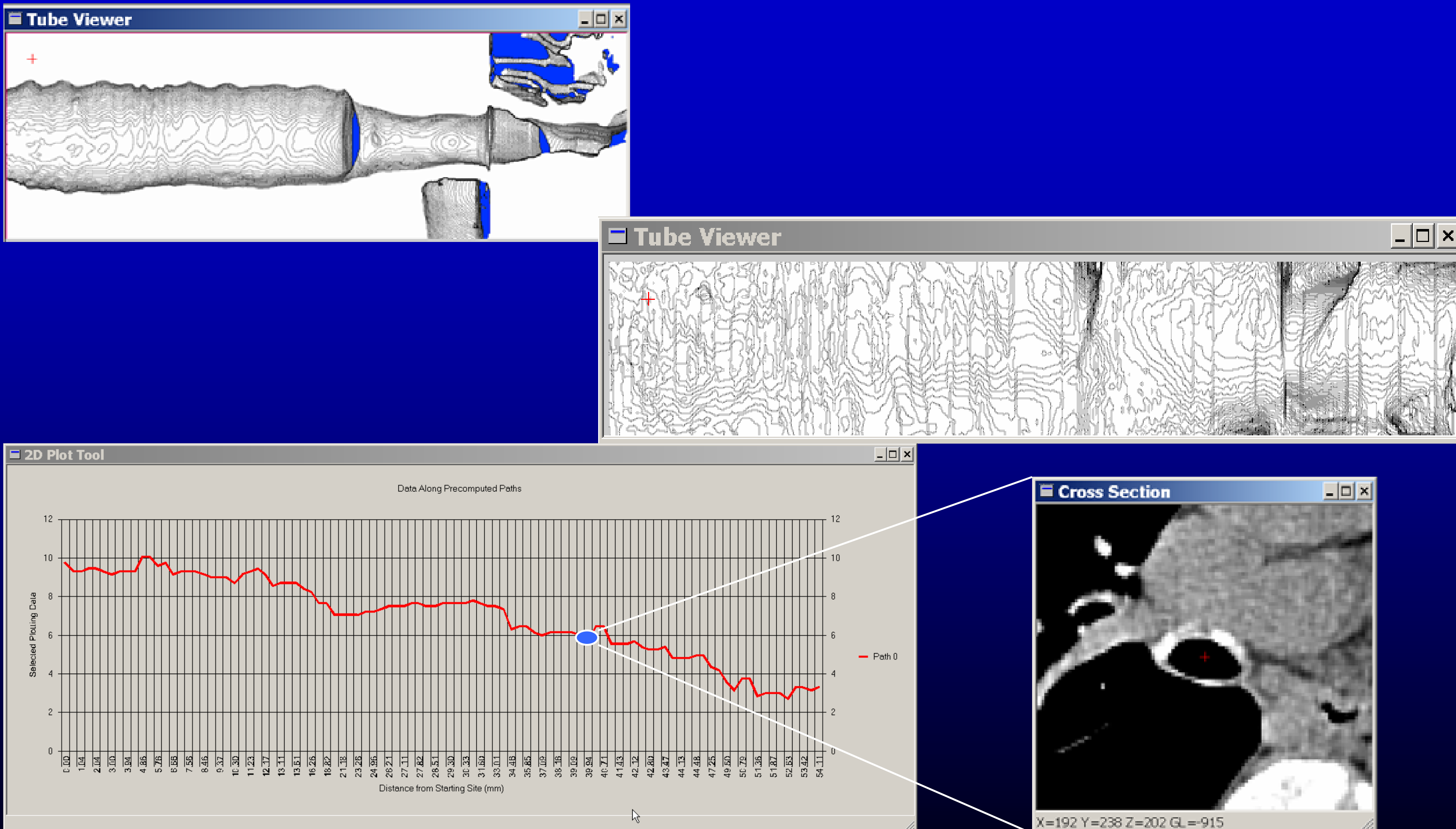
ROI List	Segmented Airway Tree	Centerline Paths	Screen Snapshots	Recorded Movies	Physician Notes

Virtual Navigator: Hardware



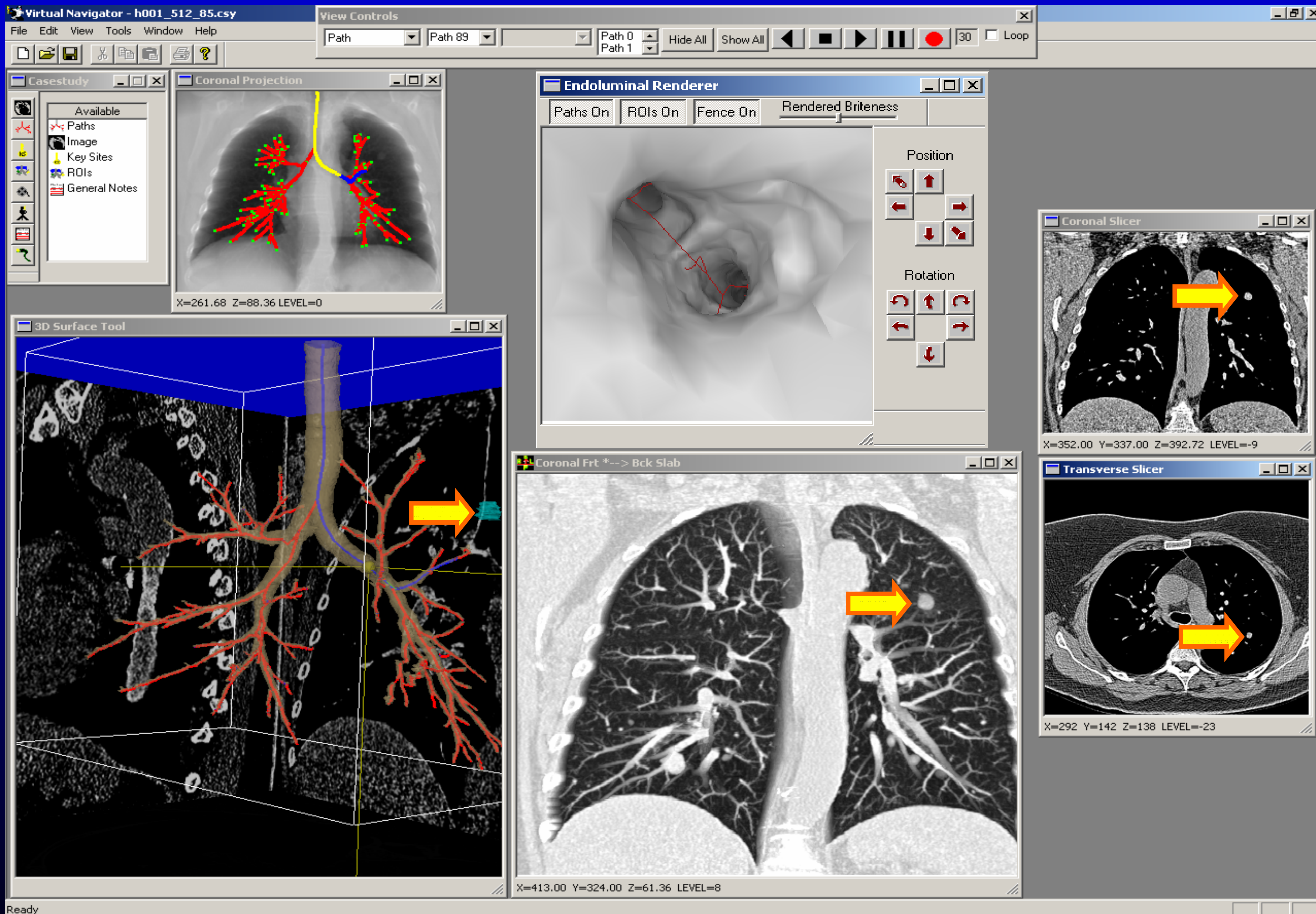
The system resides on a standard Windows-based PC. A Matrox video card serves as the interface between the PC and the videobronchoscope. The main software system,written in Visual C++, can run on an inexpensive laptop computer.

Airway Analysis (work in progress)



Case h16_512_85, root site=(263,233,45), seger=(RegGrow,star median,explode at T=50000)

Peripheral Nodule Biopsy (work in progress)



Case h001_512_85, root site=(273,292,0), seger=(RegGrow,star median,explode at T=-948),slab=(focus=20,vision=30,maxwin=400)

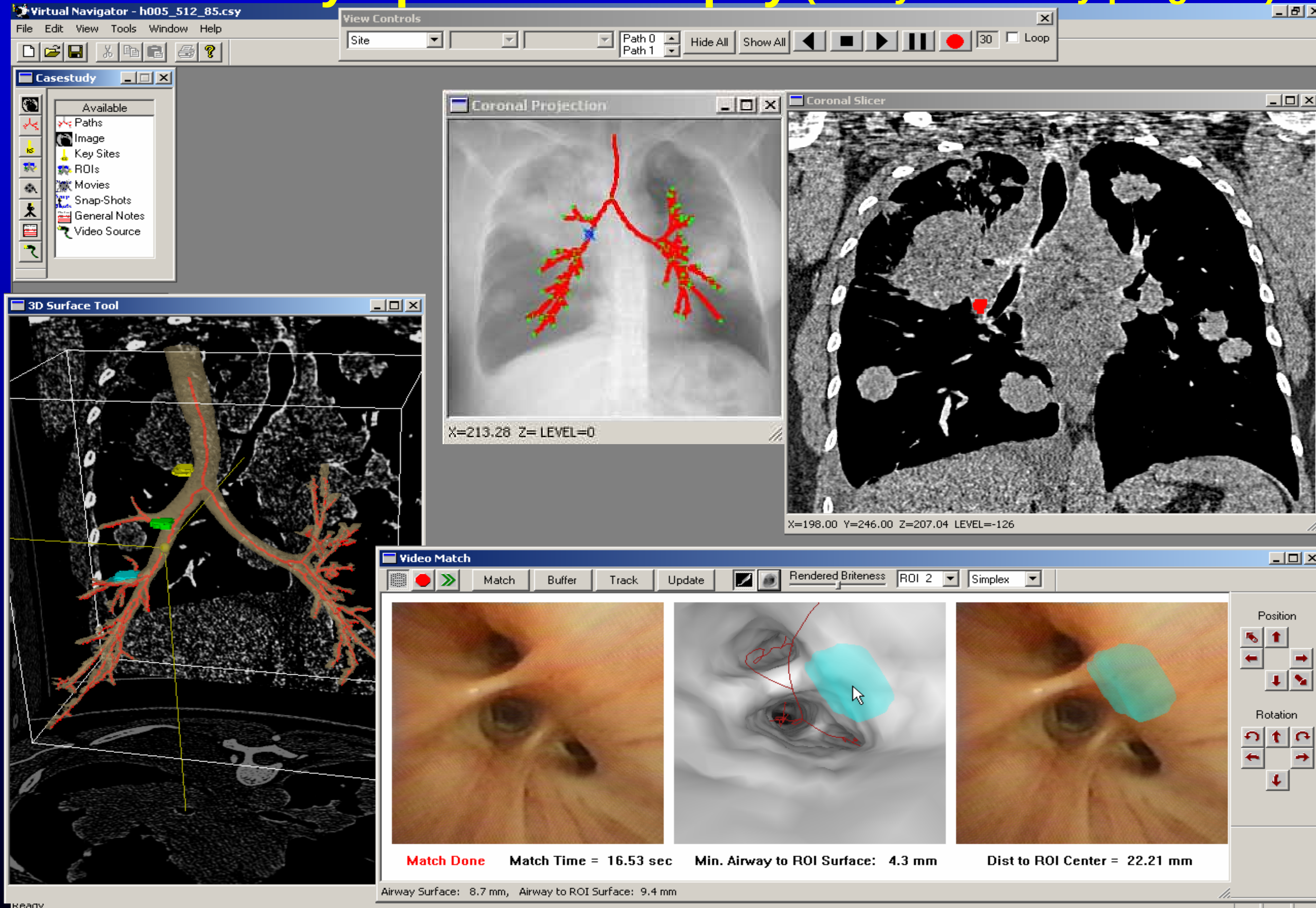
VB-Guided Mediastinal Lymph-Node Biopsy

1. Human Study underway

2. 29 cases to date (2/2002)

3. VB-Guided approach being compared to standard approach which uses CT film.

Mediastinal Lymph-Node Biopsy (study underway progress)



Case h005_512_85. Root site = (253,217,0), seger = (RegGrow, no filter), ROI #2 considered (Blue)

Conclusion

- Hybrid method
  - Clinically feasible
  - Similar results to Morphology

- No method superior
  - No method consistently recovered more airways
  - Hybrid and Morphology methods localize edges better
  - Only Region Growing succeeded in papilloma case

- Integrated segmentation tool-kit used for VB