Applications of Computer Vision in Medical Imaging

Preliminary Steps in Quantifying Pulmonary Emphysema

Lung Segmentation Algorithm for Low-Dose Radiation CT Scans

What is Pulmonary Emphysema?

- A **degenerative disease** that develops after many years of assault on lung tissues from cigarette smoke or other toxins that pollute the air.
- Emphysema causes **irreversible lung damage**.
- Currently, there is NO CURE.

What is Pulmonary Emphysema?

- Nearly three million Americans over the age of 18 have been diagnosed with Pulmonary Emphysema.

- The key to managing emphysema is to **identify the disease as early as possible so that preventive and therapeutic measures can be instituted.**

Preliminary Steps

- Years of research have shown me the importance of the integrity of starting data.
- Input data: segmented lung images.
- Accuracy of data greatly affects the quality of the final analysis.

Lung Segmentation

- *Segmentation* is the process by which structures of interest are separated from the rest of the image.
- Considerable challenge to make fully-automated.
- Difficulty inversely proportional to radiation exposure, due to increased noise presence. (Prevalent in low-dose CT Scans.)

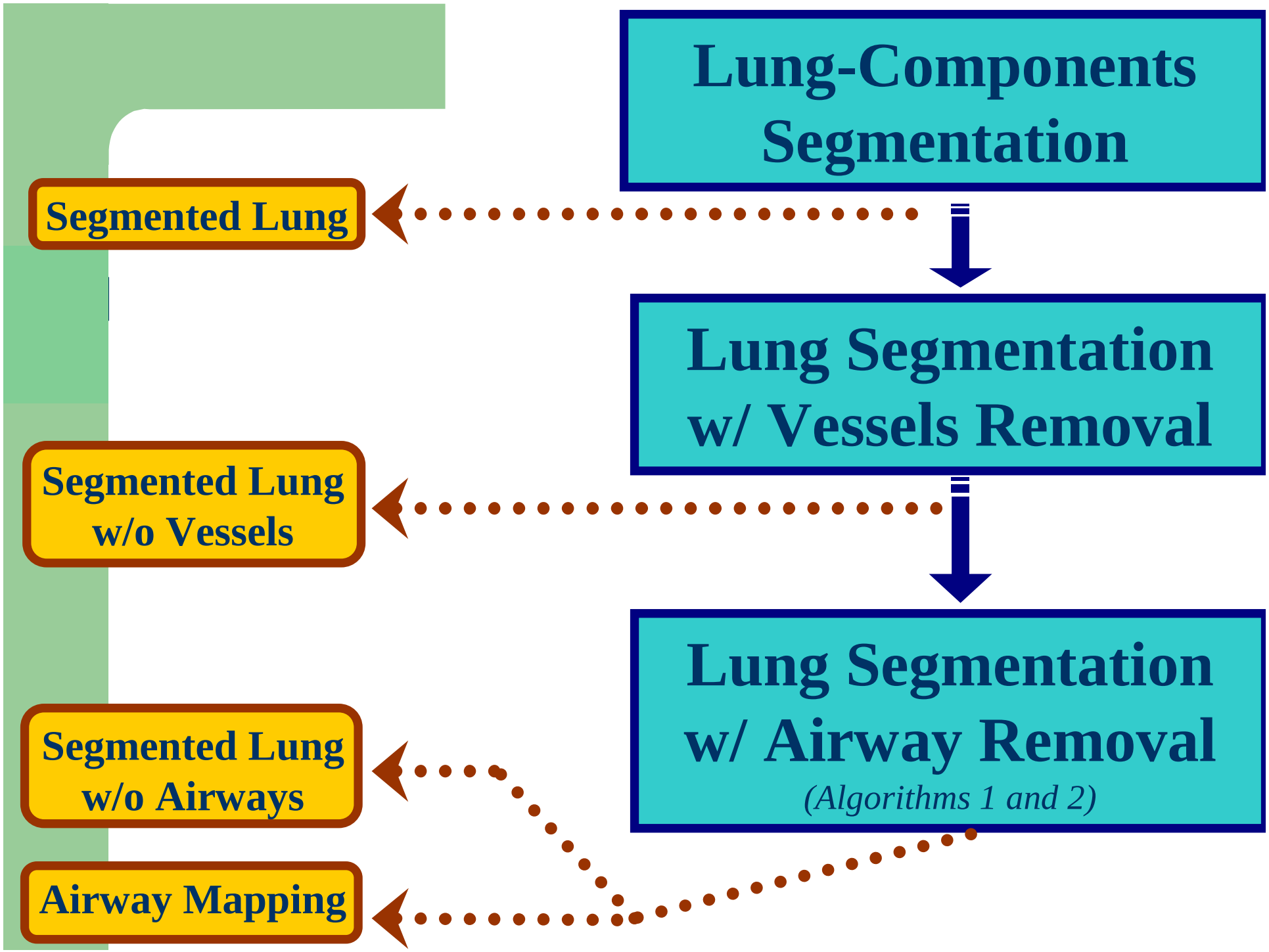
Lung Picture

- Low-dose lung CT scan image

Img1.vr

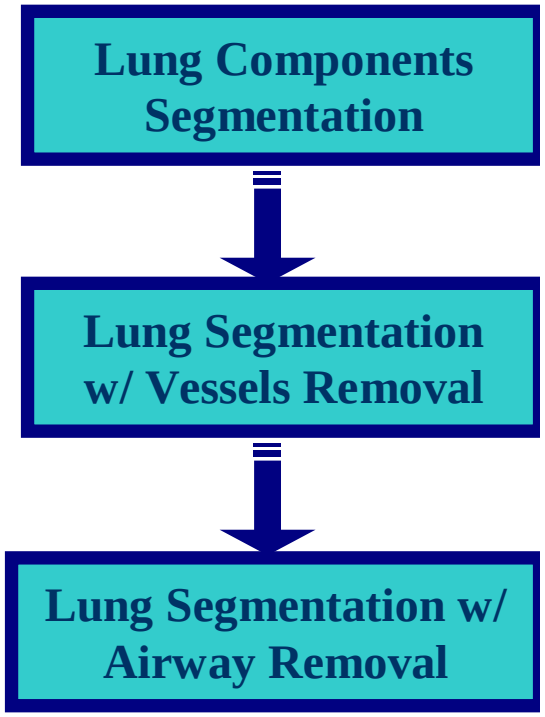
Lung Segmentation Algorithm for Low-dose CT scans

- Developed in a modular way
- Fully automated


Lung-Components Segmentation
Segmented Lung
Lung Segmentation w/ Vessels Removal
Segmented Lung w/o Vessels
Lung Segmentation w/ Airway Removal
(Algorithms 1 and 2)
Segmented Lung w/o Airways
Airway Mapping

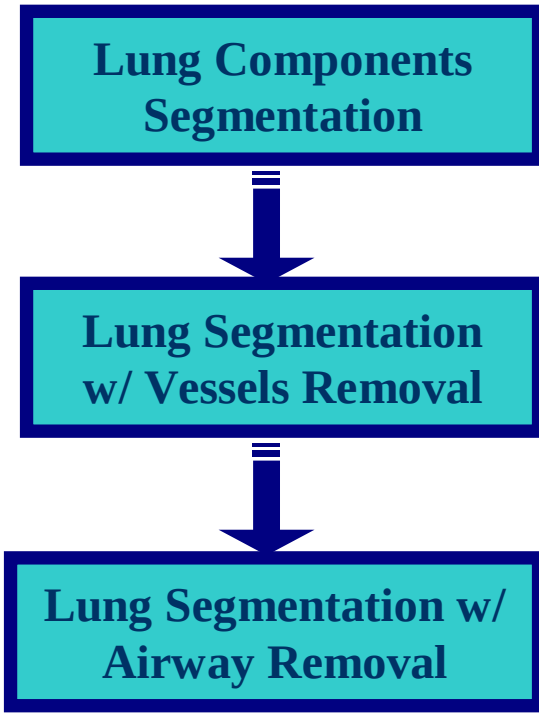
Lung Components Segmentation

- Areas of the body's tissue irrelevant to the lungs are removed (ribcage, mediastinum).
- Issues:
  - Increased noise levels
- Techniques:
  - Thresholding
  - Connected-Component Analysis
  - Image Masking
  - Background Labeling



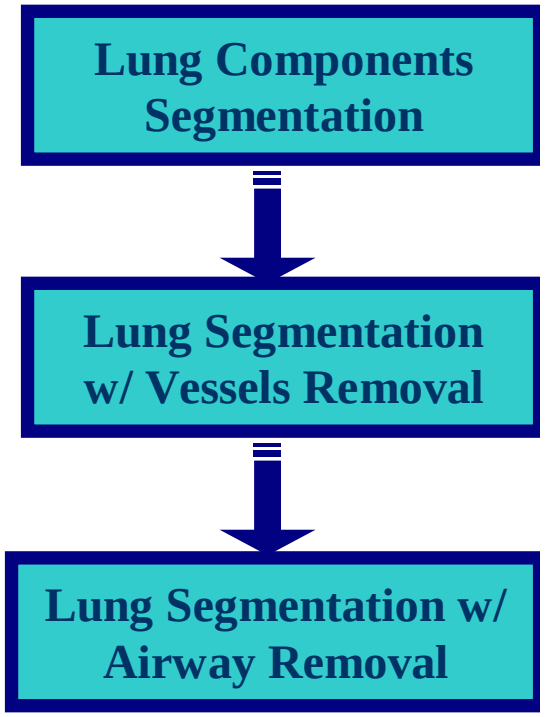
Vessels Removal

- Removal of blood vessels embedded in the parenchyma.
- Issues:
  - Close contact with parenchyma
  - Vasculature size minute in some areas
  - Partial volume errors
- Techniques:
  - Median Filtering, Thresholding, CCA
  - Morphological Operations
  - Image Masking, Background Labeling



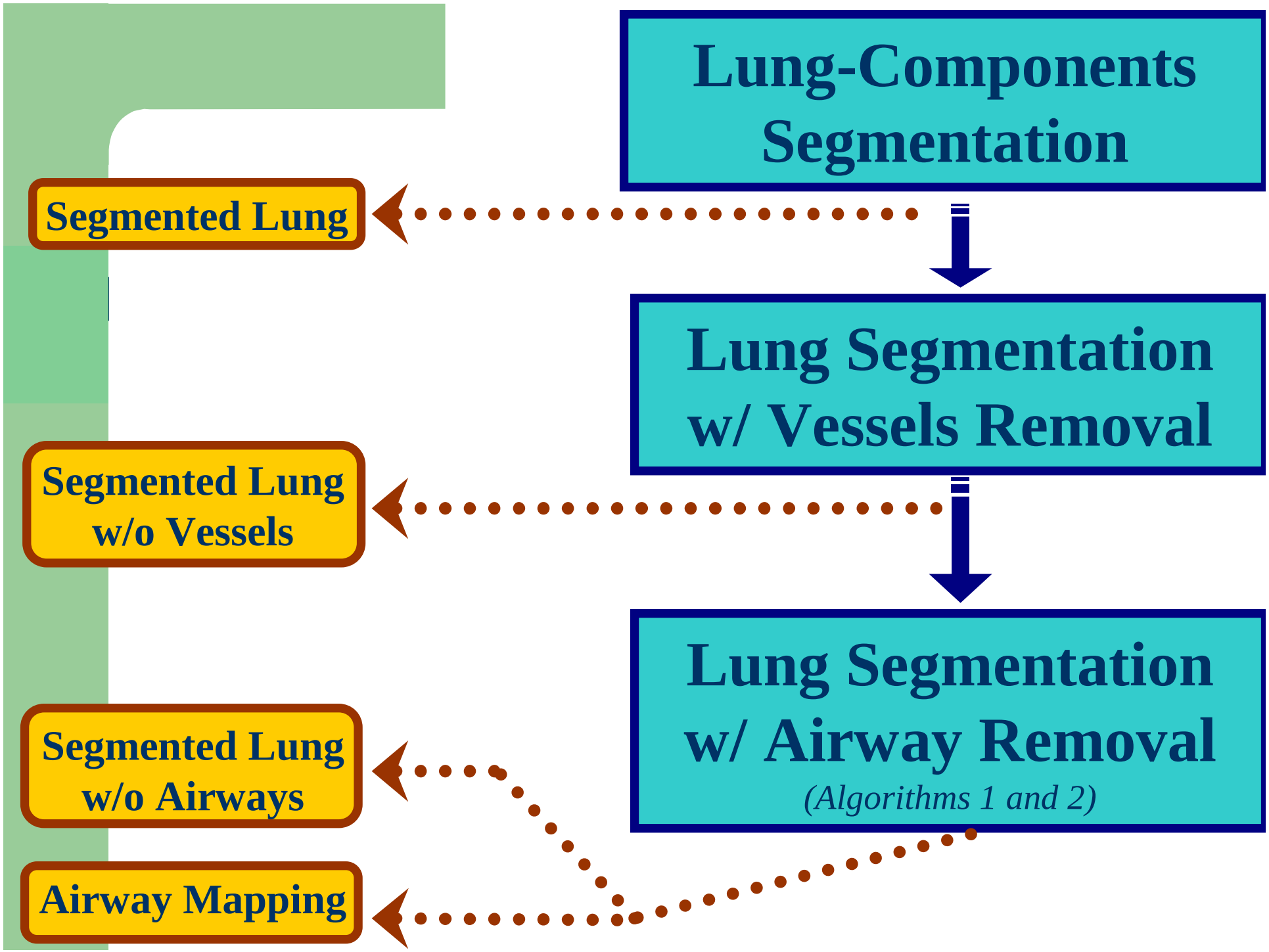
Airway Removal

- Segments out the lung airways from trachea to small bronchioles merging into parenchyma.



Airway Removal (continued)

- Issues:
  - Determining initial seed of trachea
  - False-positives in trachea split detection
  - Varying sizes of airways
  - Branching occurs at different angles
  - Frequent contact with parenchyma
  - Bronchi size extremely minute in some areas
- Techniques:
  - Connected Component Analysis
  - 2D/3D Region Growing
  - 2D “Explosion” Detection
  - 3D Component Tracing
  - Split Detection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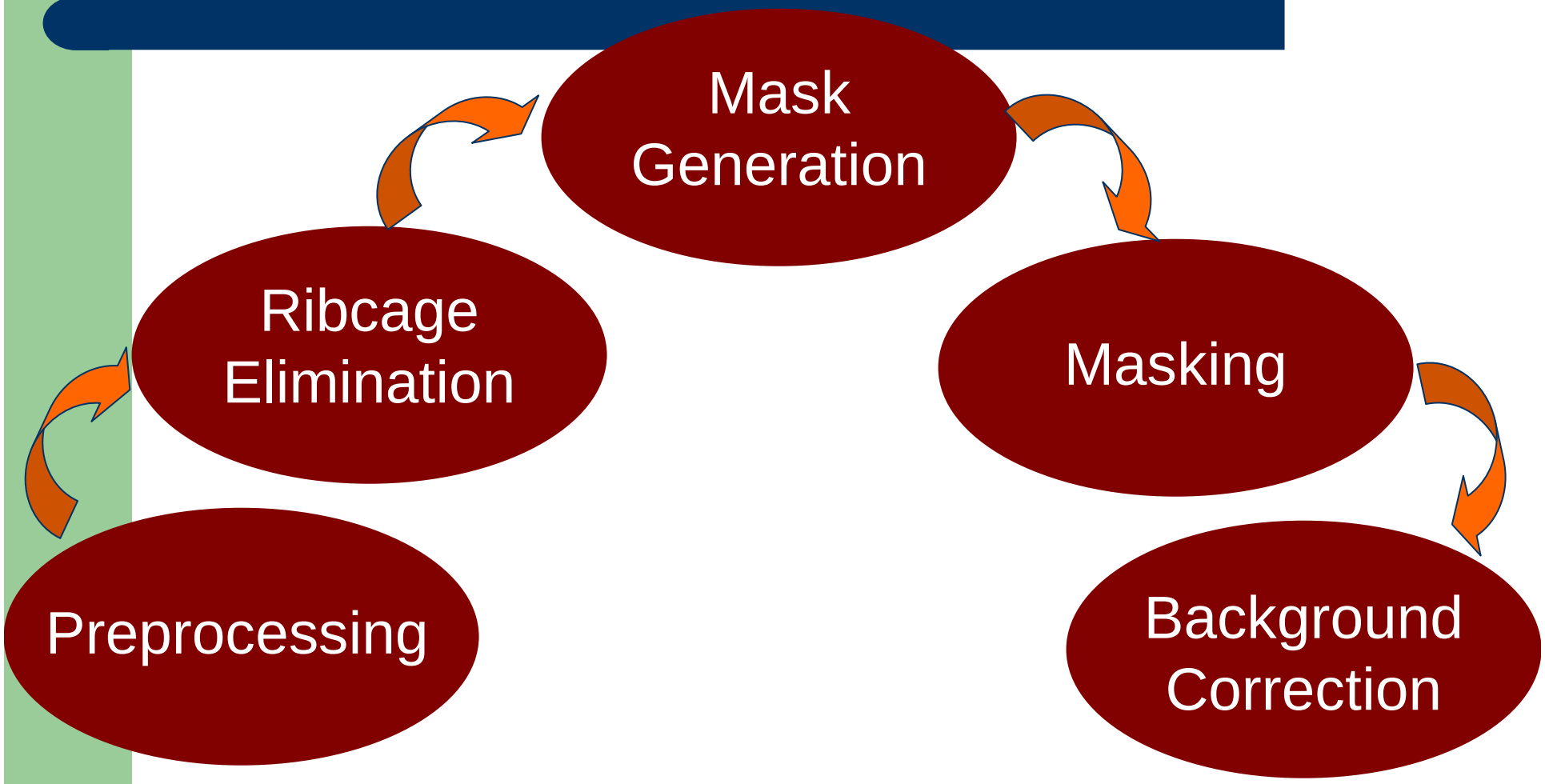
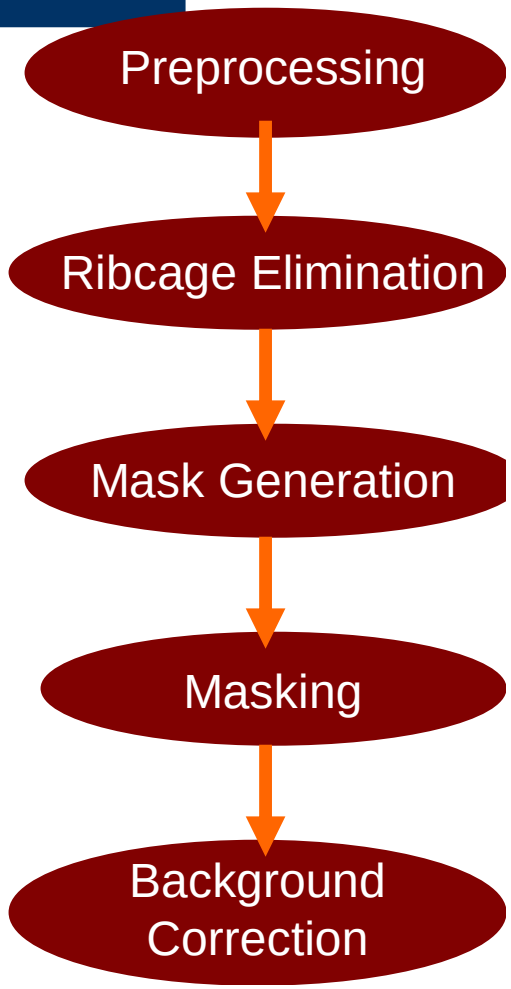
Lung Component Segmentation



Lung Component Segmentation

- Preprocessing
  - Noise filtering (median, mean)
  - Applied only to images generating a lung mask
- Ribcage Elimination
  - Recursive 3D filling algorithm
  - Region-growing



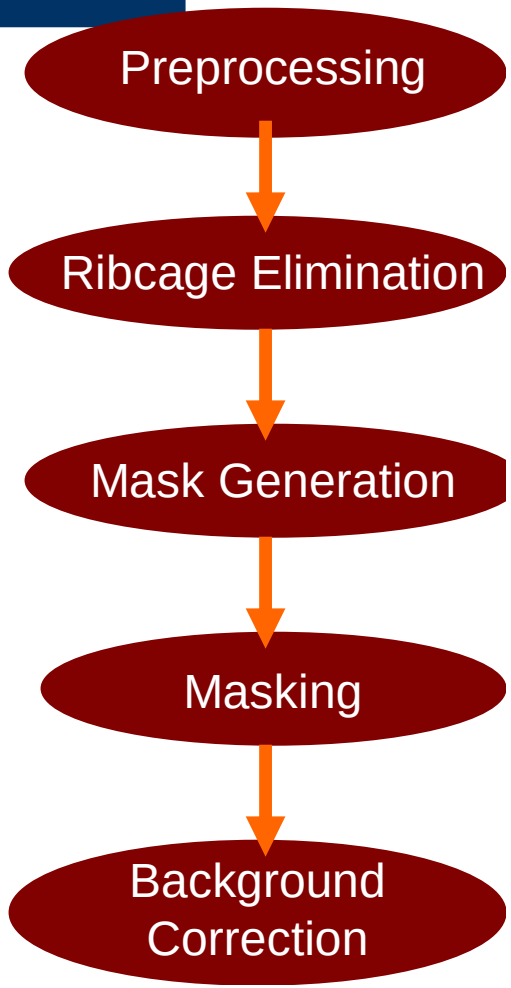
Ribcage Removal

- Intermediary images in the process of mediastinum and ribcage removal

Img2.vr

Lung Component Segmentation

- Lung Mask Generation
  - Thresholding combined with shape and connectivity constraints
  - CCA for detecting largest 3D component not at boundary of image
  - Closing operation (de)



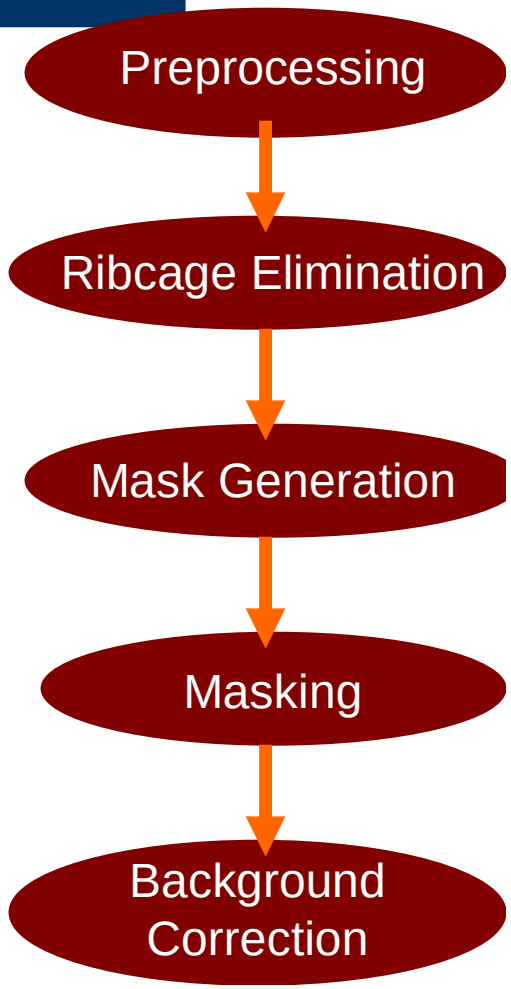
Lung Mask Generation Picture

- Intermediary image: mask of the lung

Img3.xv

Lung Component Segmentation

- Masking
  - Original Image && Mask
    - → Segmented Lung Image
- Background Correction
  - Background relabelling with values outside the range of the lung data
  - Needed for later quantification of COPDs



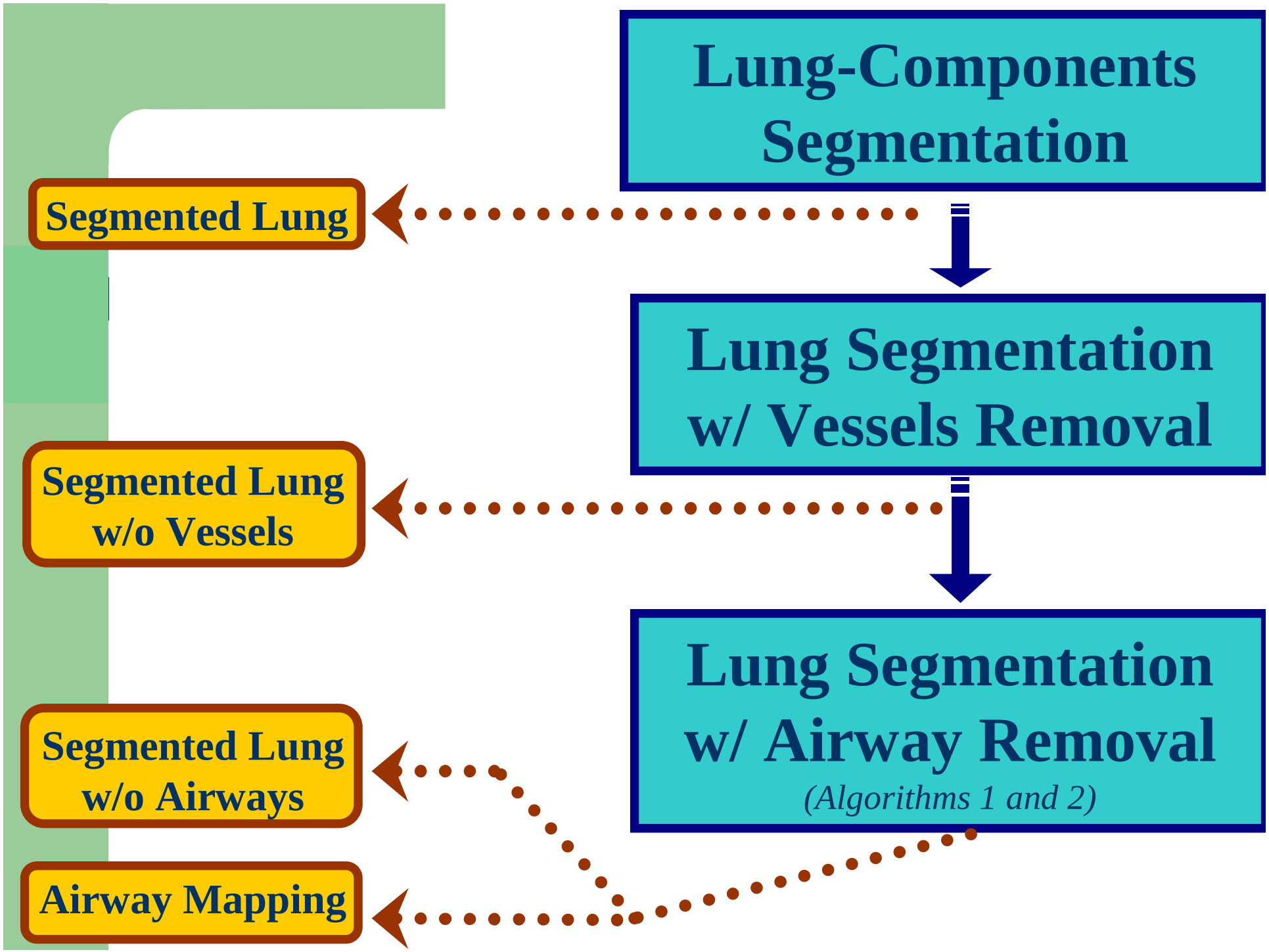
Lung Segmentation Pseudo-code

```
Lung-Segmentation ( image ) {
// Initially the main structures appearing are:
// ribcage (white), lung with vessels and airways (grey),
// air outside the human body (grey).

    preprocessed-image ← Preprocessing( image );
    lungs-outsideair   ← Ribcage-Elimination( preprocessed-image );
    mask               ← Lung-Mask-Generation( lungs-outsideair );
    segmented-lung     ← Masking( image, mask, "*" );

    return Background-Correction( segmented-lung );

}
```

Segmented Lung Components

CT-Scan of the segmented lung components

Img4.vr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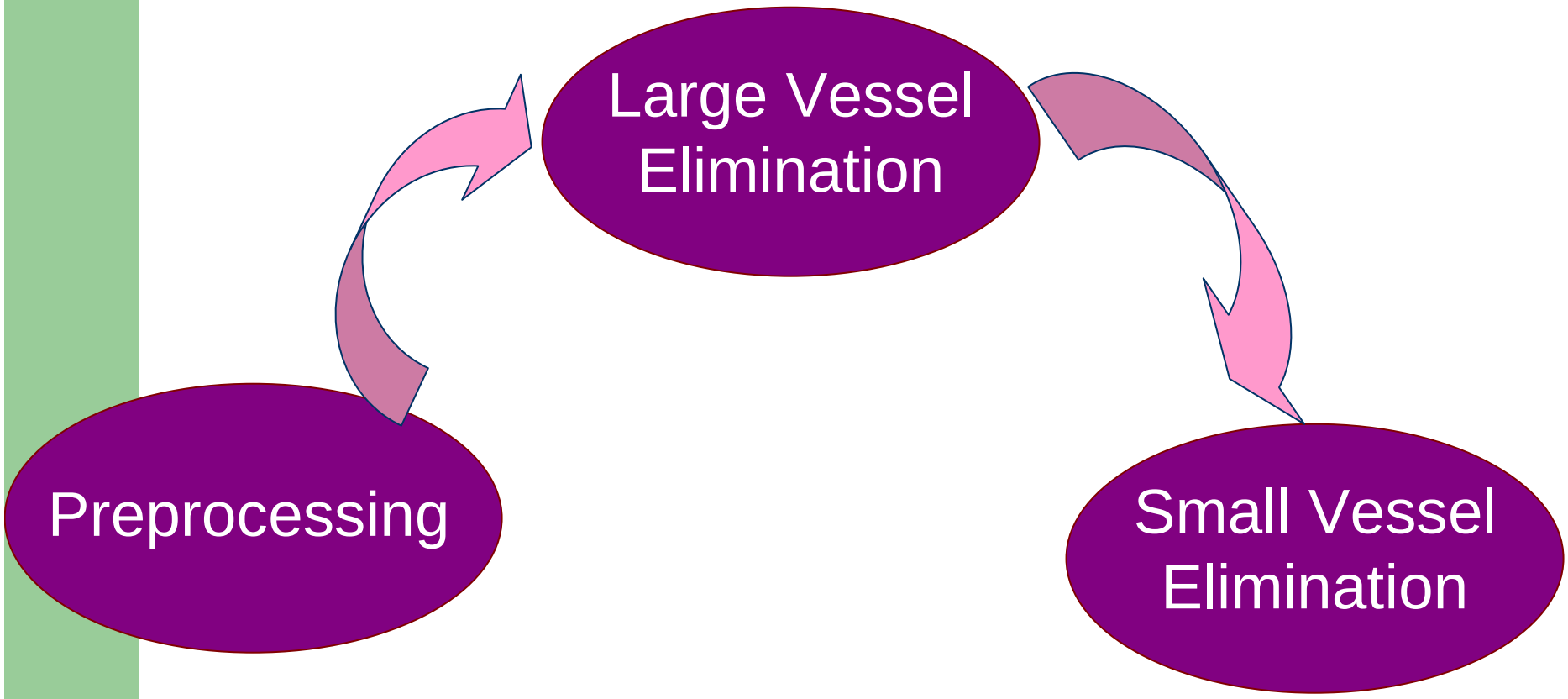
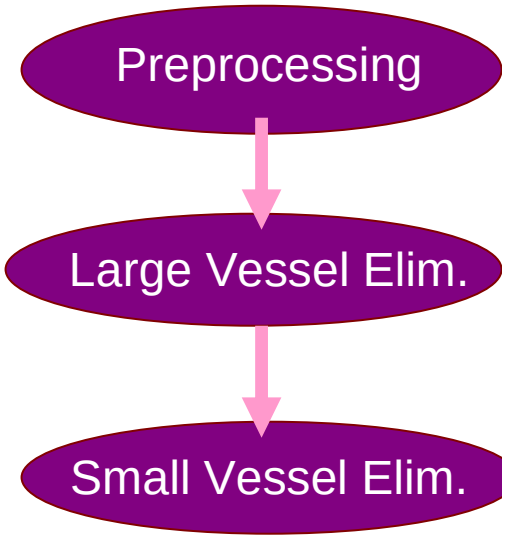
Vessels Removal



Vessels Removal

- Preprocessing
  - Median Filter (2x2) for smoothing the image and eliminating noise
- (Large/Small) Vessels Removal
  - Mask Generation
    - Threshold (TH1 / TH2)
    - CCA (SIZE1 / SIZE2)
  - Masking (&&)
  - Background Re-labeling



Intermediary images

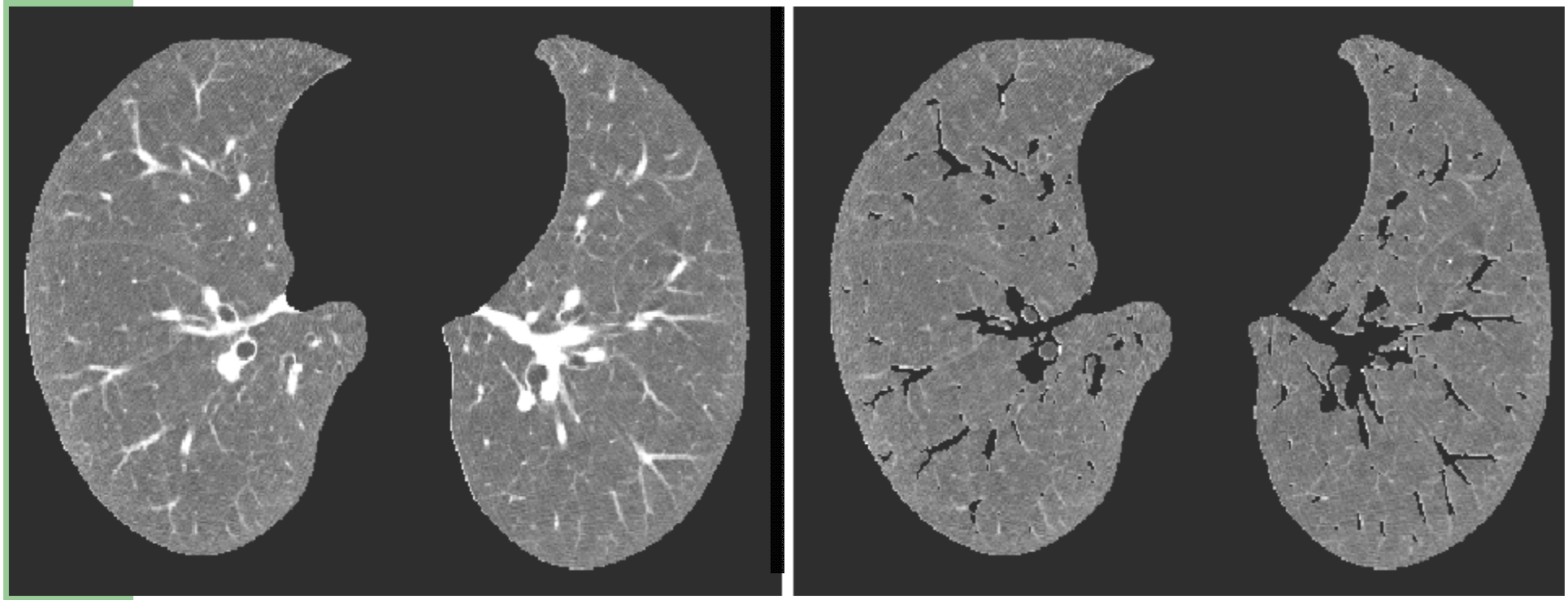
- Image of the vessels

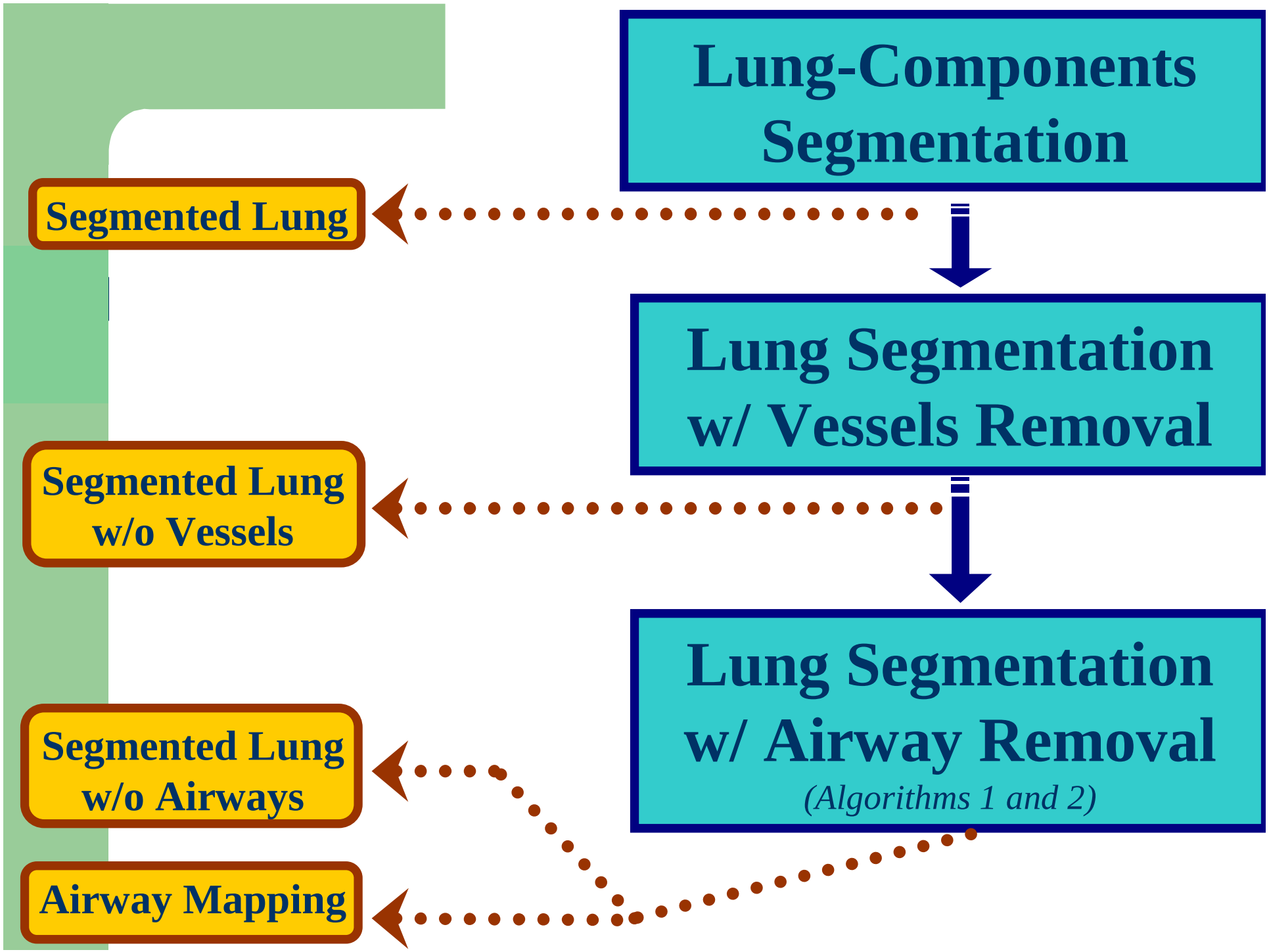
Img5.vr

Vessels Removal Pseudo-code

```
Vascular-Segmentation ( image ) {
    Preprocessing();

    // Process large vessels
    mask1 ← Vasculature-Mask-Generation( th1, size1, image );
    lung-without-vessels1 ← Masking( image, mask, "&" );
    processed1 ← Background-Correction( lung-without-vessels1 );

    // Process small vessels
    mask2  ← Vasculature-Mask-Generation( th2, size2, processed1 );
    lung-without-vessels2 ← Masking( processed1, mask2, "&" );
    processed2 ← Background-Correction( lung-without-vessels2 );

    return processed2;
}
```

Vessels Removal Results

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Airways Removal

- Most lung segmentation algorithms in the literature do not remove airways.
- Removal is necessary in later steps of our research.
- The algorithm also generates a map of the airways, useful in quantification of other COPDs.

Airways Removal

- First Algorithm, based on Burrowing and Split Detection
- Second Algorithm, redesigned, adding Dynamic Component Tracking
- Our discussion focuses on the second

Airways Removal Algorithm Outline

- Seed Selection acquires the trachea
- Airways followed from trachea to bronchioles
  - Adaptive morphological considerations
  - Novel changes to traditional 3D region growing
- Possible outputs
  - Airway Map
  - Segmented Lung without Airways

Morphological Properties

- Large database of CT images allows for an extensive study of the growth and properties of airways and lungs.

Morphological Properties

- Lungs located inside ribcage

  Streaking artifacts and increased noise in the upper and lower area of the lungs
- Relative 2D transversal position of lungs and trachea
- Trachea in the center of the image
- Apices of the lungs in the lower right & left region
- Right lung is larger and taller than the left lung

Morphological Properties

Algorithmic Approach

- Seed selection using redundant seeds in an adaptive neighborhood
- Scan for seeds is vertically, starting from the top ($y_{hi} \rightarrow y_{lo}$), working right to left ($x_{hi} \rightarrow x_{lo}$)
- Size checks to disregard seed set inside parenchyma

Morphological Properties

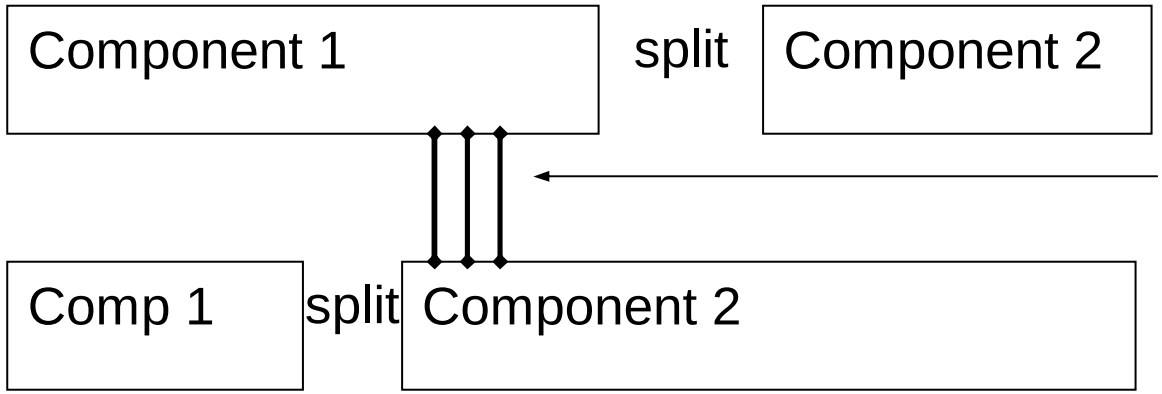
- Trachea doesn’t always split evenly into two main bronchi

  - Simple detection of a split can be done by comparing the size of the region obtained through 3D growth with the size of any chosen 2D component within the same slice

- A region split on a single slice does not imply that the main trachea bifurcates
- After the split, main bronchi split into secondary and tertiary bronchi at different angles

Algorithmic Approach

- Split-detection



Split is discontinuous because of overlap of component 1 and 2.

- Upwards and downwards tracing

Morphological Properties

- Lung airways have a tree-like structure
- Each branching decreases the size of airway
- Branching stops after several levels

Algorithmic Approach

- Area “explosion” detection for collisions with parenchyma
- Setting an adaptive growth factor as a function of branching level

Morphological Properties

- Both airways and emphysematous regions contain air, overlap in intensity range
- Further exacerbated by partial volume errors

Algorithmic Approach

- As the tracing descends into the lung, the acceptable threshold range for what is considered airway is narrowed.

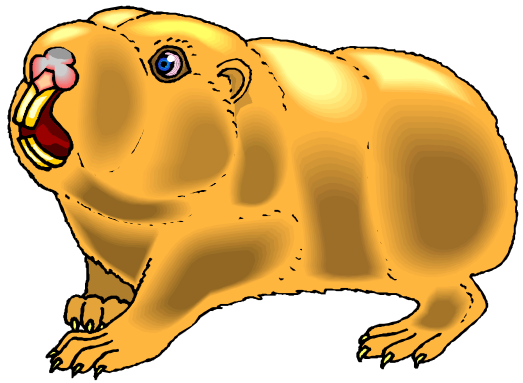
Morphological Properties

- Leaves of airway tree do not merge into lung parenchyma simultaneously.
- Airways may touch the parenchyma at some point, but continue expanding before a final merge.

Algorithmic Approach

- Burrowing technique
- Dynamic component labeling and tracking

Burrowing



- Novel replacement for traditional 3D growth, replacing it with copying and 2D expansion, backing up and correcting itself with limited growth when parenchyma is encountered

- Think of a gopher digging a long hole downwards

Burrowing

- Prevent the “cascading” of errors
  - Undesirable components are eliminated long before they are transferred to the next slice.
- Tracing of airways that contact with parenchyma
  - At the level of bronchioles, instead of eliminating components that have grown to encapsulate lung mass, these components were burrowed w/o 2D growth.

Burrowing Pseudo-code

```
for each slice > split-slice
    for  component-set
      eliminateUndesired( region-label, slice );
      burrowDown( region-label, slice, slice + 1, allowGrowth );

    // Detect region merging into lung parenchyma caused
    // by burrow & growth
    if          Region-Size-2D( region-label, slice + 1) >
                growthFactor * Region-Size-2D( region-label, slice )
    then        clear pixels created by burrowing
                burrowDown( region-label, slice, slice + 1, noGrowth );
```

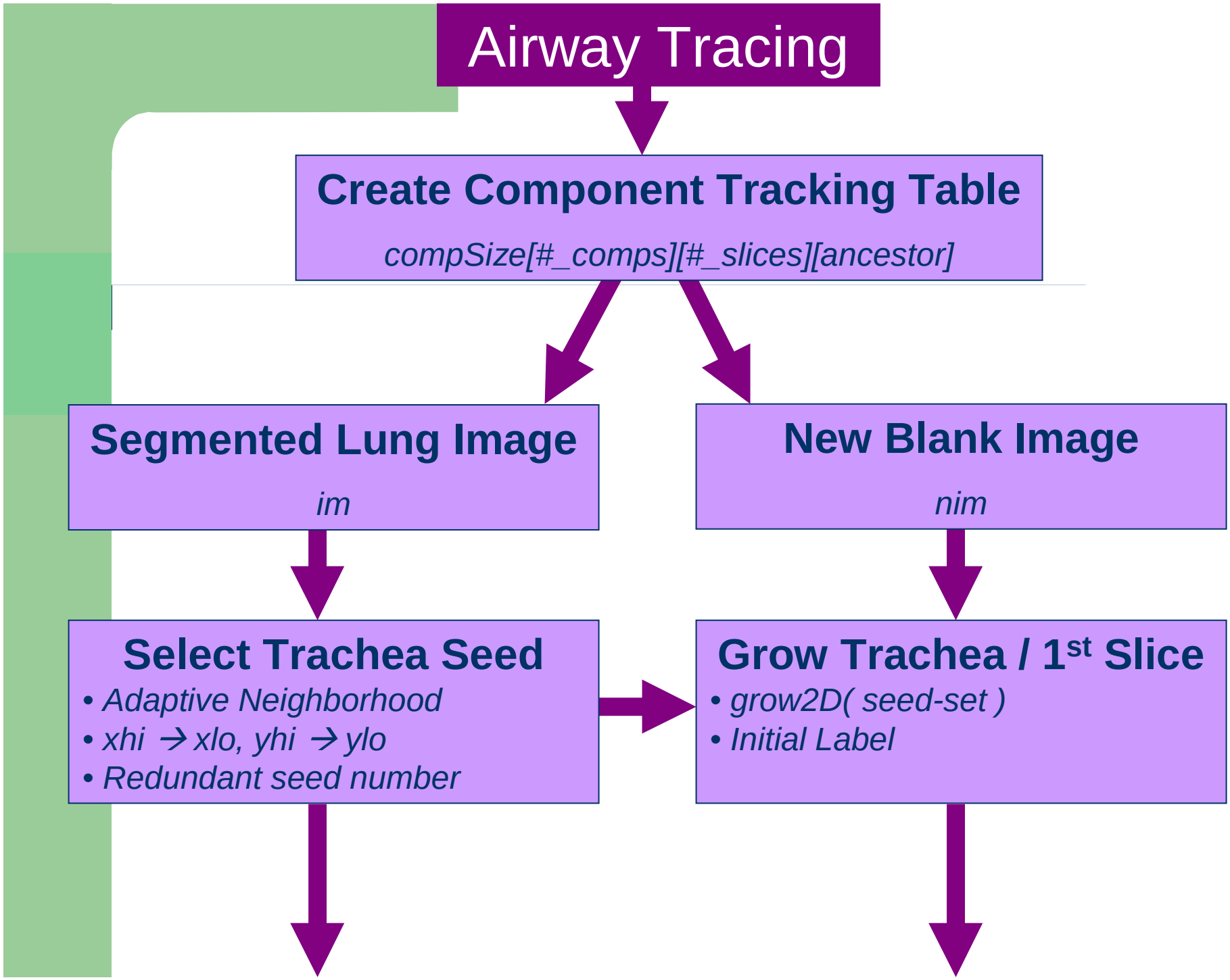
Dynamic Component Tracking

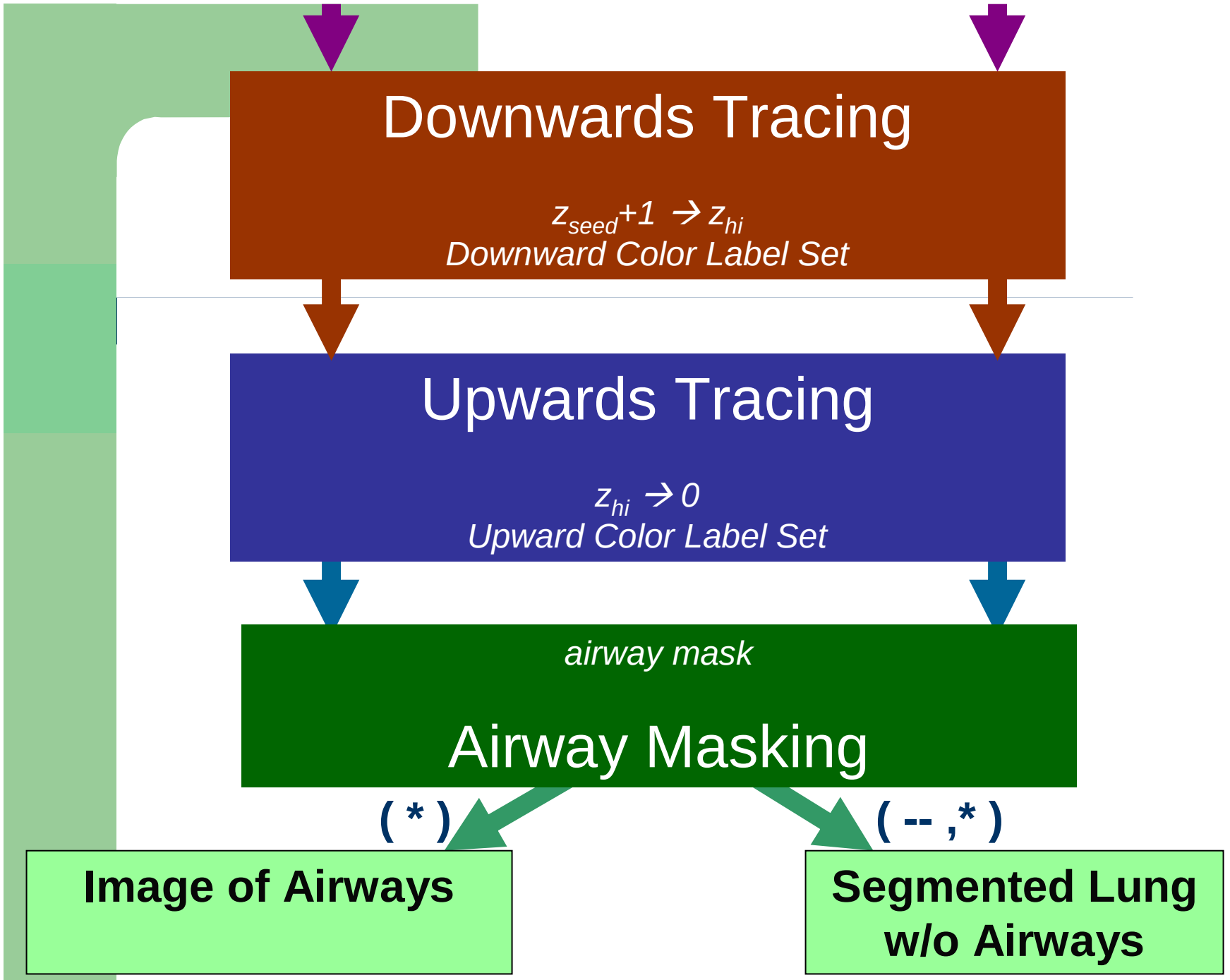
- Components on a slice are labeled throughout the tracing.
- Each component is associated with an ancestor and children for upwards and downwards tracing.
- Growth and shrinkage of airways is recorded through merging and splitting components.

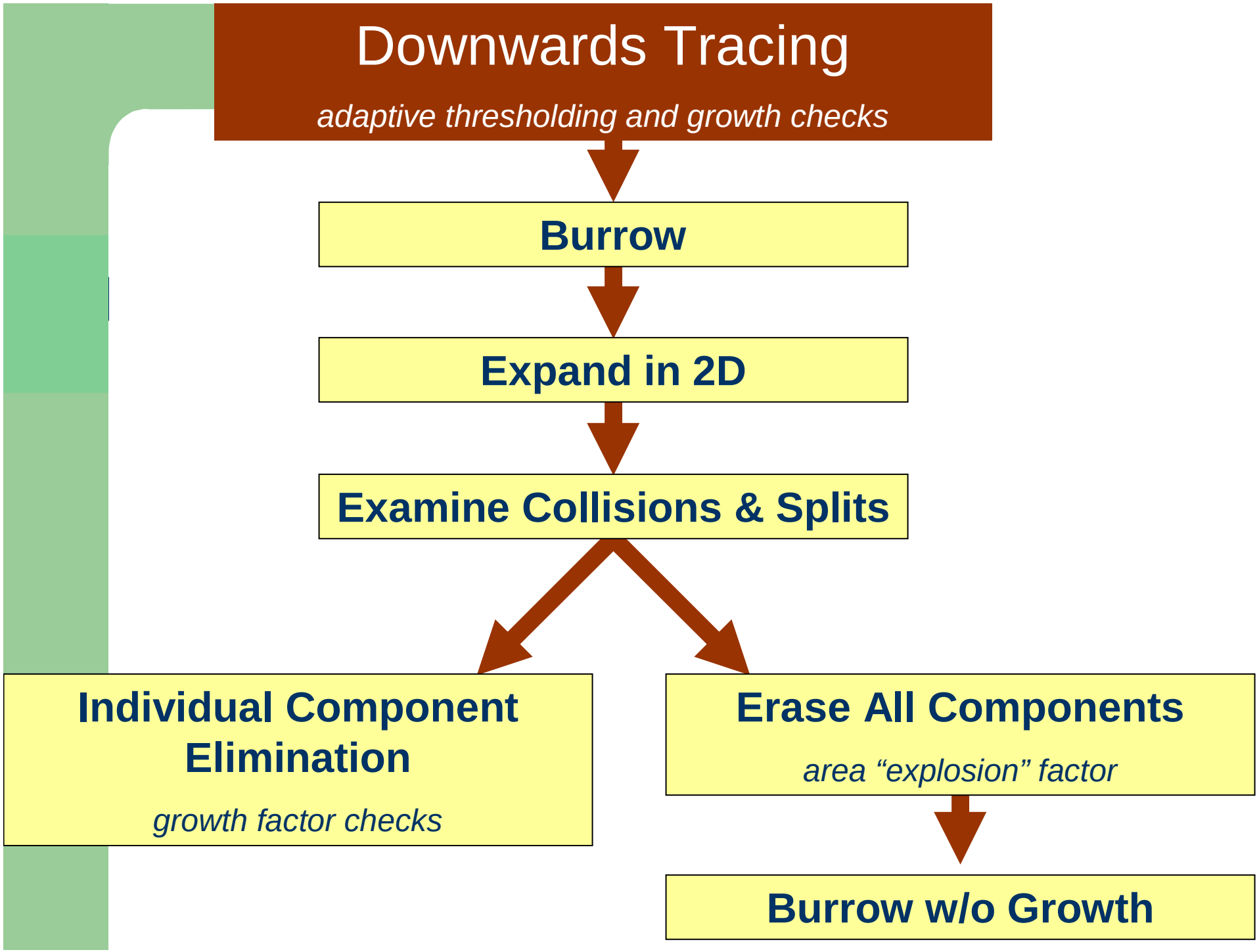
Airways Tracing

The airways mask

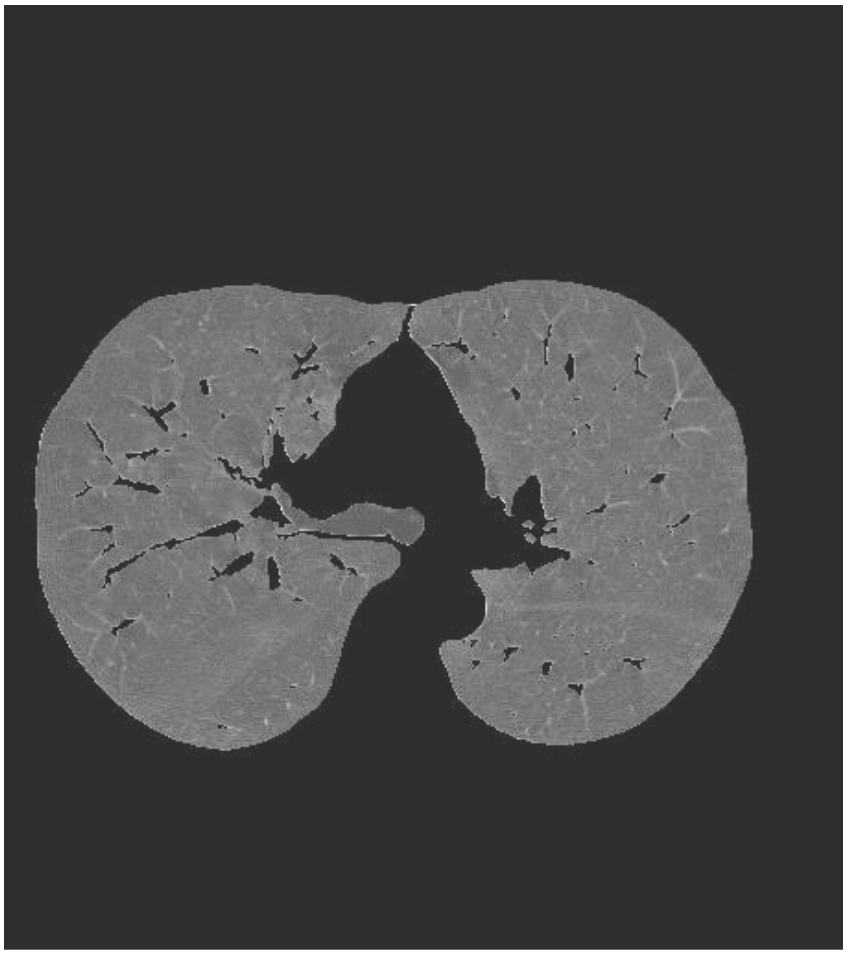
Img6.vr


Airway Tracing
Create Component Tracking Table
compSize[#_comps][#_slices][ancestor]
Segmented Lung Image
im
New Blank Image
nim
Select Trachea Seed
• Adaptive Neighborhood
• xhi → xlo, yhi → ylo
• Redundant seed number
Grow Trachea / 1st Slice
• grow2D(seed-set)
• Initial Label


Downwards Tracing
$z_{seed}+1 \rightarrow z_{hi}$
Downward Color Label Set
Upwards Tracing
$z_{hi} \rightarrow 0$
Upward Color Label Set
airway mask
Airway Masking
(*)
(-- ,*)
Image of Airways
Segmented Lung w/o Airways


Downwards Tracing
adaptive thresholding and growth checks
Burrow
Expand in 2D
Examine Collisions & Splits
Individual Component Elimination
growth factor checks
Erase All Components
area “explosion” factor
Burrow w/o Growth

Airway Removal Results



Lung (w/airways) and Airways Mask

Image clip: **Img7.vr**
Image clip: **Img8.vr**

Segmented lung with vessels and airways removal

Img9.vr

Conclusion

- A good lung segmentation program would allow for the concurrent evaluation of emphysema in the context of screening for other diseases.