Rigid Lung Surface Registration using Distance Transform

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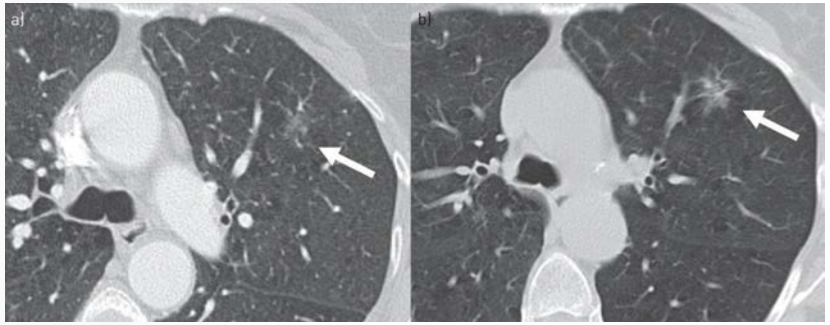
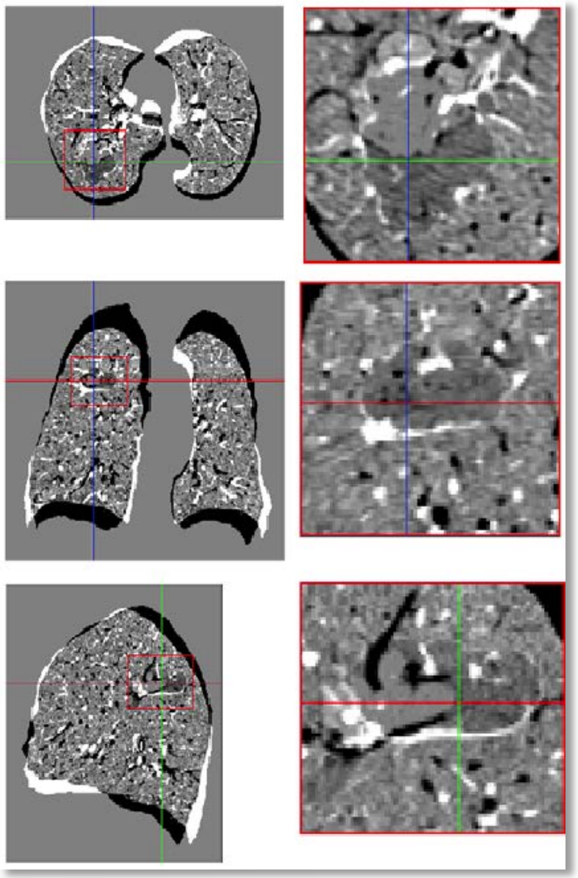
Contents

Introduction to Lung CT Registration



http://erj.ersjournals.com/content/42/6/1706

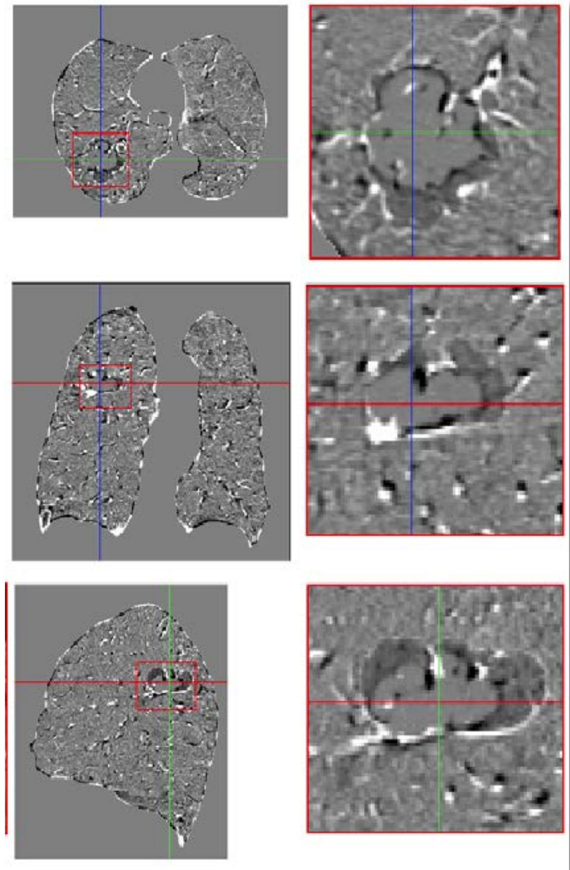
- Lung nodule follow up study.
- Misalignment of Z-axis (slice #). $\xrightarrow{\text{Registration}}$ Align corresponding nodules at same Z-axis.
- Registration accuracy of nodule region is important.
  - Align corresponding nodule area.
  - Preserve volume of nodule area (if non-rigid deformation applied).
  - Clinical diagnosis requires fast speed.



Subtraction w/o Registration

V.S.

Once the two images are properly aligned, the subtraction image reveal **substantial increase of the bulla size**.



Subtraction after Registration

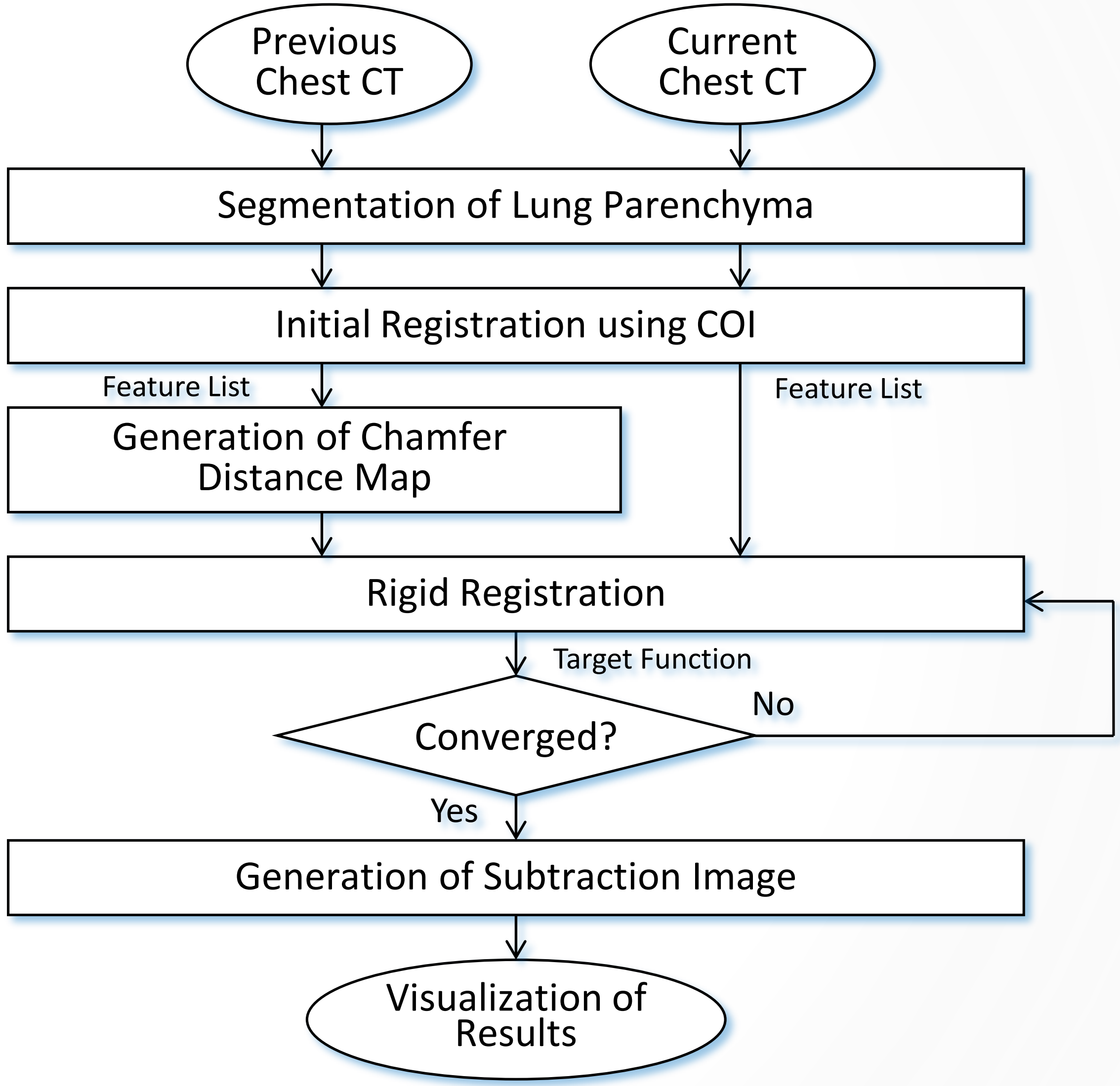
V. Gorbunova, "Image registration of lung CT scans for monitoring disease progression," Ph.D. Thesis, 2010.

Methods

- Segmentation of Lung Parenchyma
- Initial Registration
- Edge Detection
- Distance Transformation
- Similarity Metric
- Transform Parameter Optimization (Registration Process)
- Slice Interpolation
- Hierarchical Multi-Resolution Approach

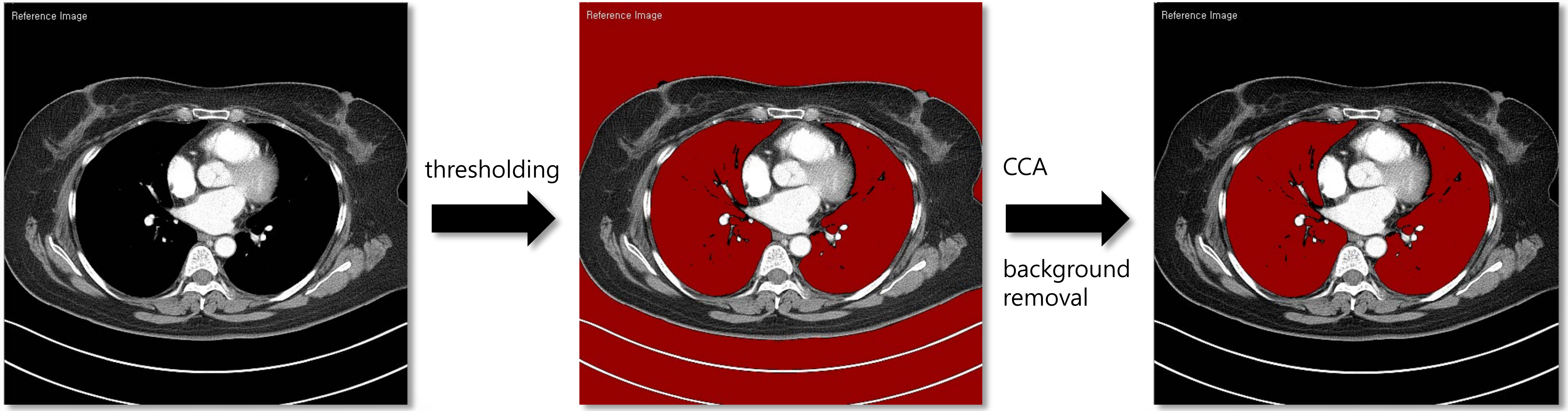
Methods - workflow

- **Prerequisites**:
  - Threshold.
  - Connected Component Analysis (CCA).
  - Edge Detection (? Extraction).
  - Implicit & Explicit Edge Representation.
  - Distance Transform.
  - 3D Transformation Matrix.
  - Multi-resolution Technique.



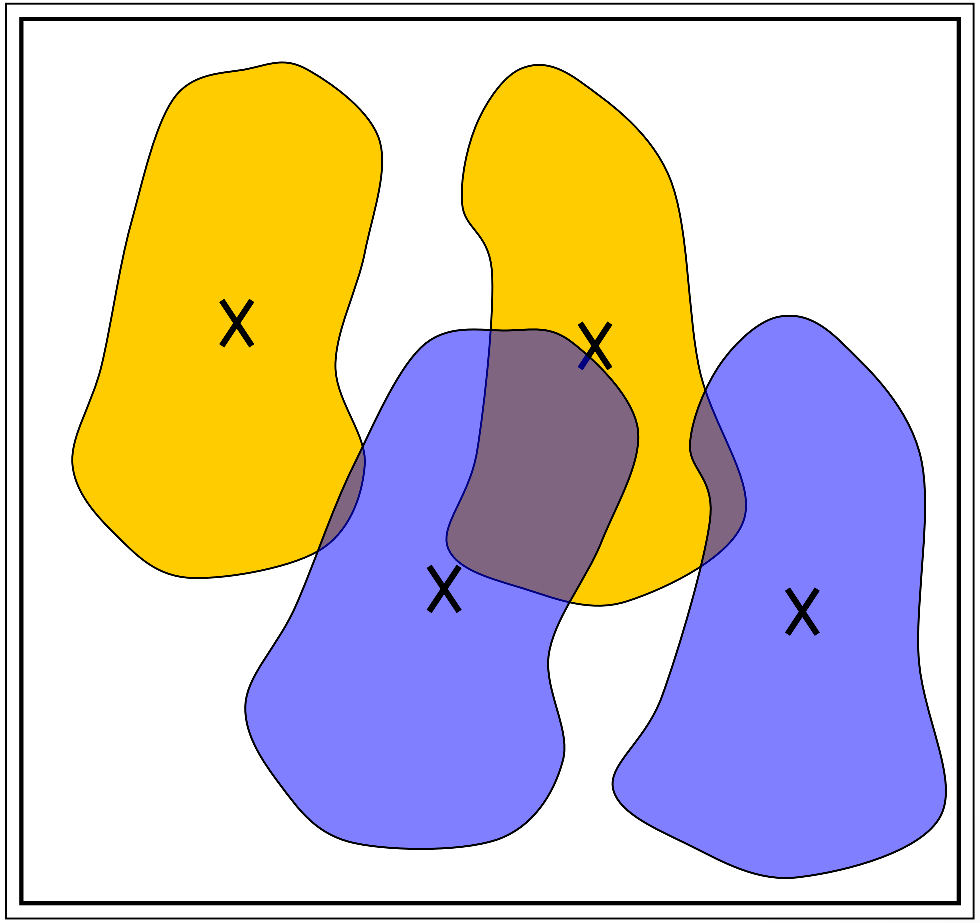
Methods – Segmentation of Lung Parenchyma

- Thresholding
  - -1024HU to -400HU
- Background removal
  - Inverse seed region growing with boundary points
- Connected component analysis (CCA)
  - Find largest connected component



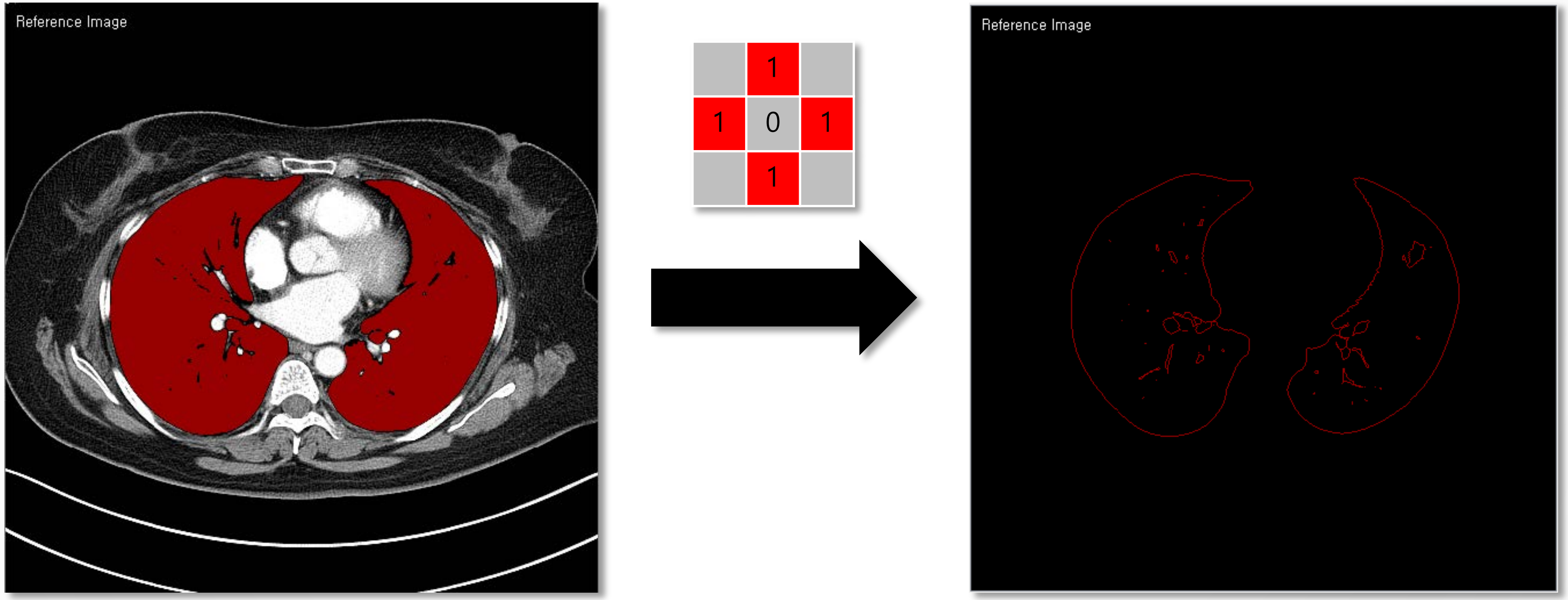
Methods – Initial Registration using COI

- Calculate center of inertia of lung mask
- Align the center of lung mask



Methods – Edge Detection

- Edge feature detection.
  - Sequence of 2D-based edge detection.



Methods – Generation of Chamfer Distance Map

- Chamfer distance
  - Approximation version of Euclidean distance.
  - Two pass algorithm.
  - Various windows can be used by Chamfer distance algorithm.

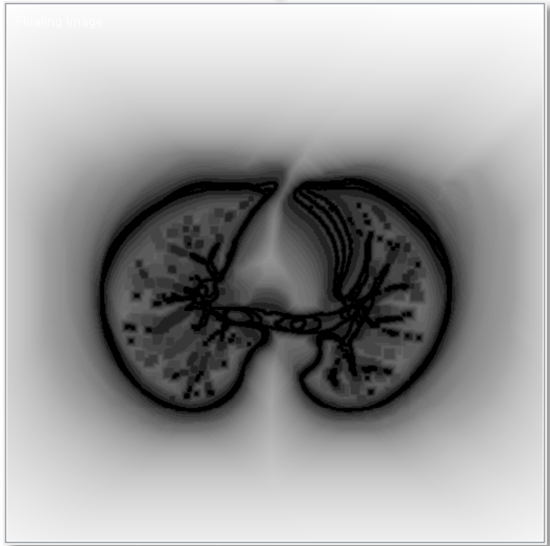
- We consider the boundary of a lung as an implicit surface.
- Perform distance transform from extracted boundary.

Forward Chamfer-mask

$$f_1(p) = \begin{cases} 0 & p \in surface \\ min\{f_1(q) + 1 : q \in F(p)\} & p \notin surface \end{cases}$$

$$f_2(p) = min\{f_1(p),\ f_2(q) + 1 : q \in B(p)\}$$

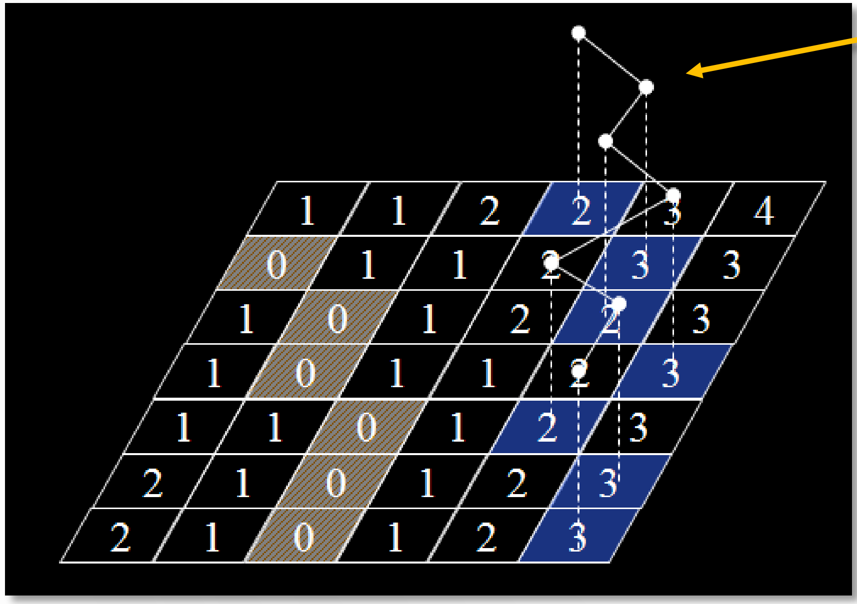
Backward Chamfer-mask



Methods – Registration between Distance Map & Explicit Surface

- Similarity metric
  - Average distance of two surfaces
  - Find transform that minimizes,

$$\frac{1}{N}\sum_{x \in Image_1} DistanceMap_{Image_2}(Transform(x))$$



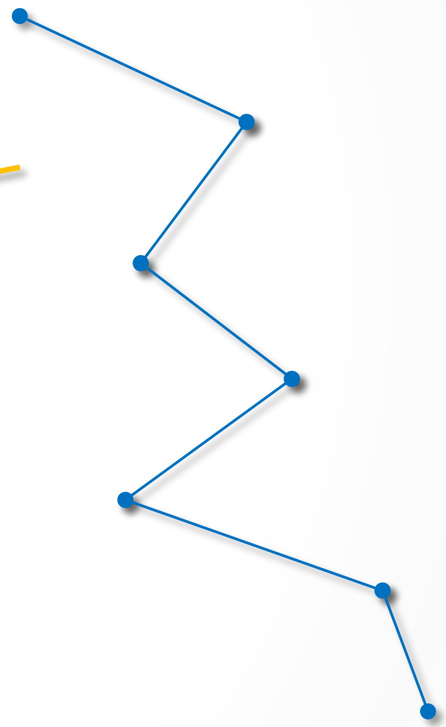
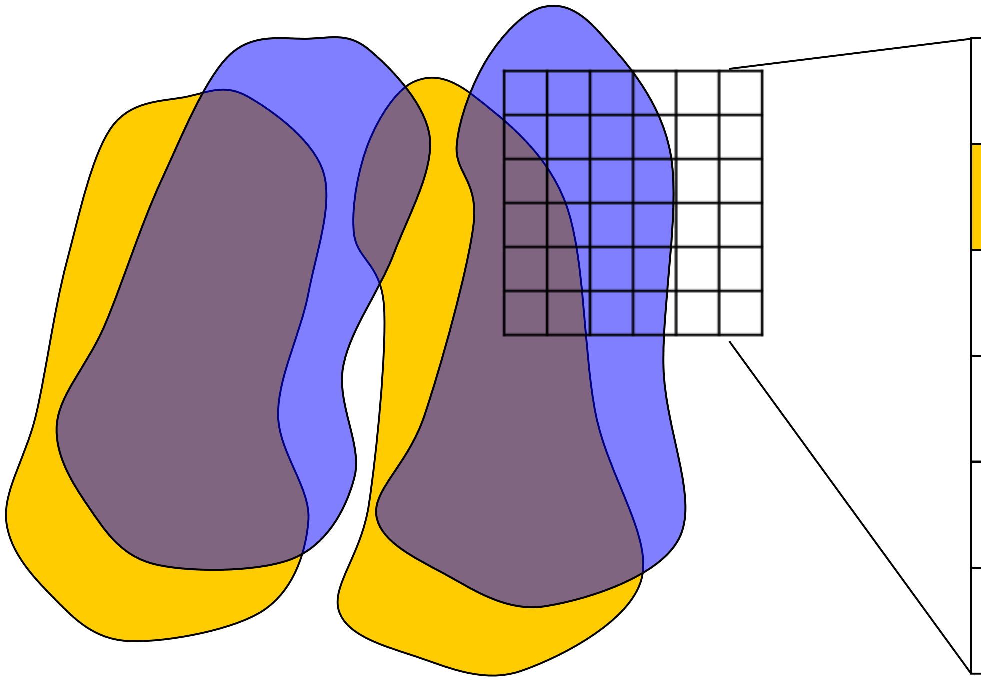


Image1 == explicit edge list

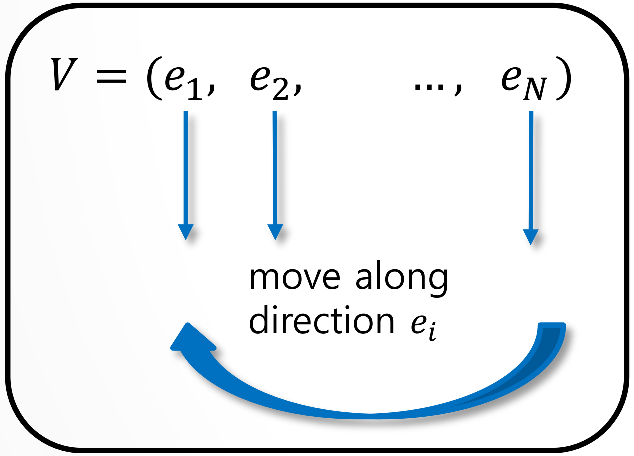
Methods – Registration between Distance Map & Explicit Surface

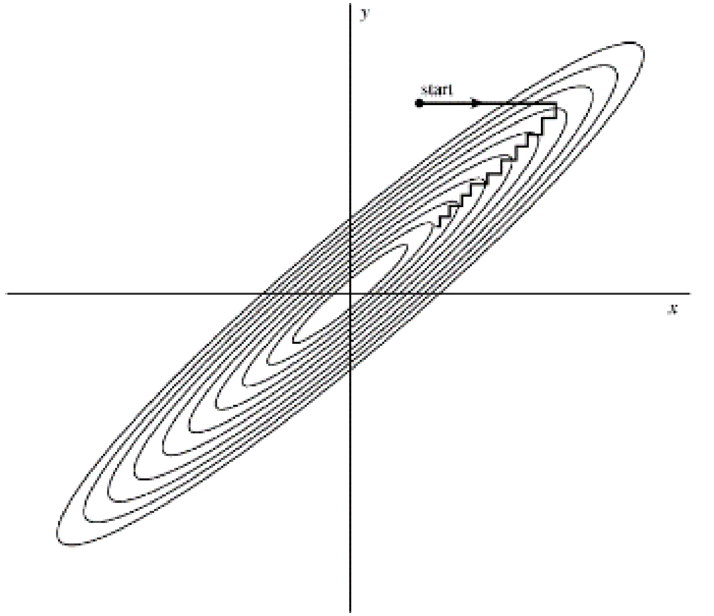


1	1	2	2	3	4
0	1	1	2	3	3
1	0	1	2	2	3
1	0	1	1	2	3
1	1	0	1	2	3
2	1	0	1	2	3

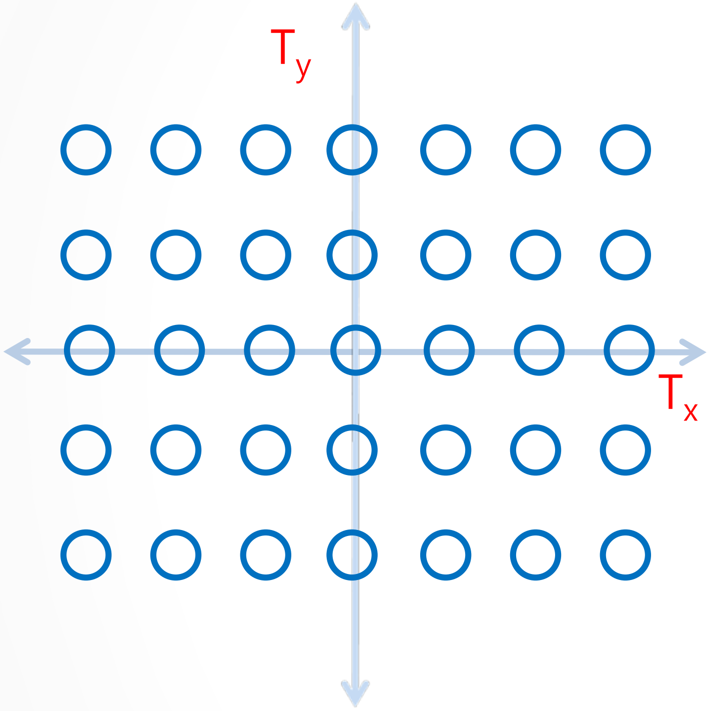
Methods – Coordinate Descent Method for Transform Parameter Optimization

- Multi-dimensional minimization method → sequences of *line minimizations*.
  - Different methods possibly differ only by how, at each stage.
- Choice of successive directions does not involve explicit computation of gradient.

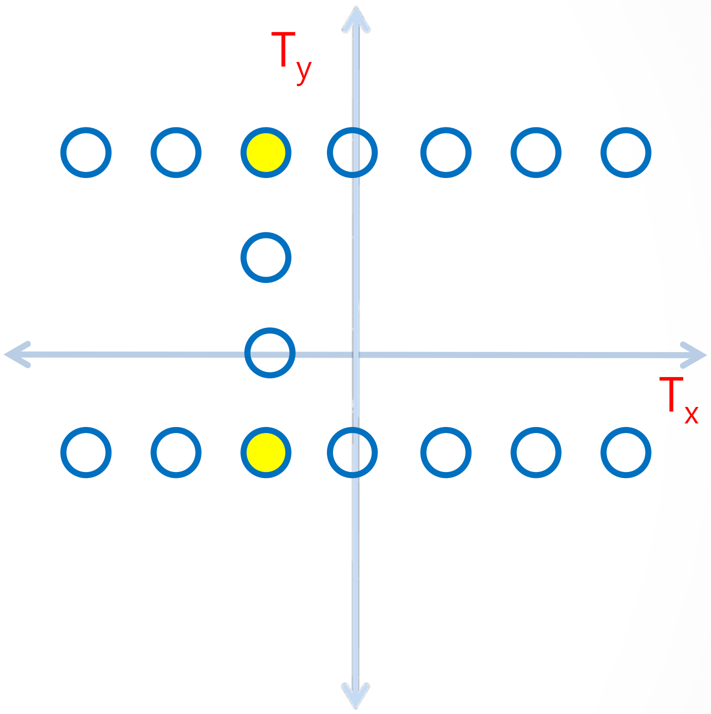




Methods – Coordinate Descent Method for Transform Parameter Optimization



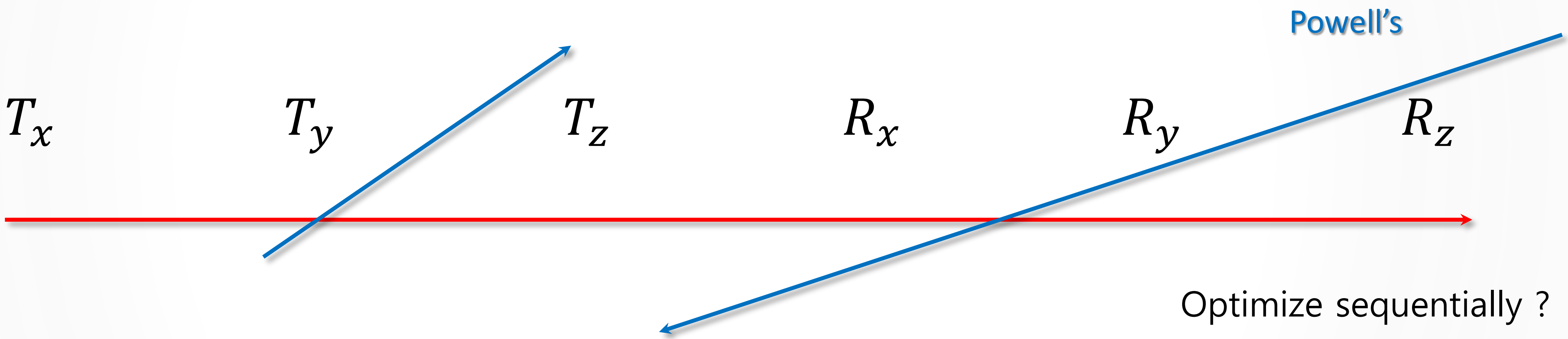
Global Search



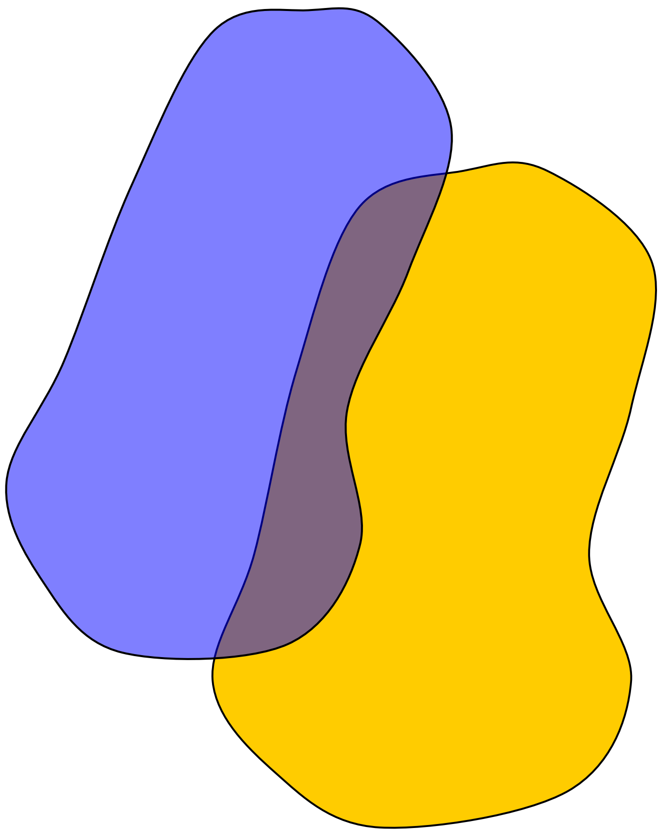
Coordinate Directional Search Method

Methods – Coordinate Descent Method for Transform Parameter Optimization

- Transformation Parameters.
  - 3 translations + 3 rotations.

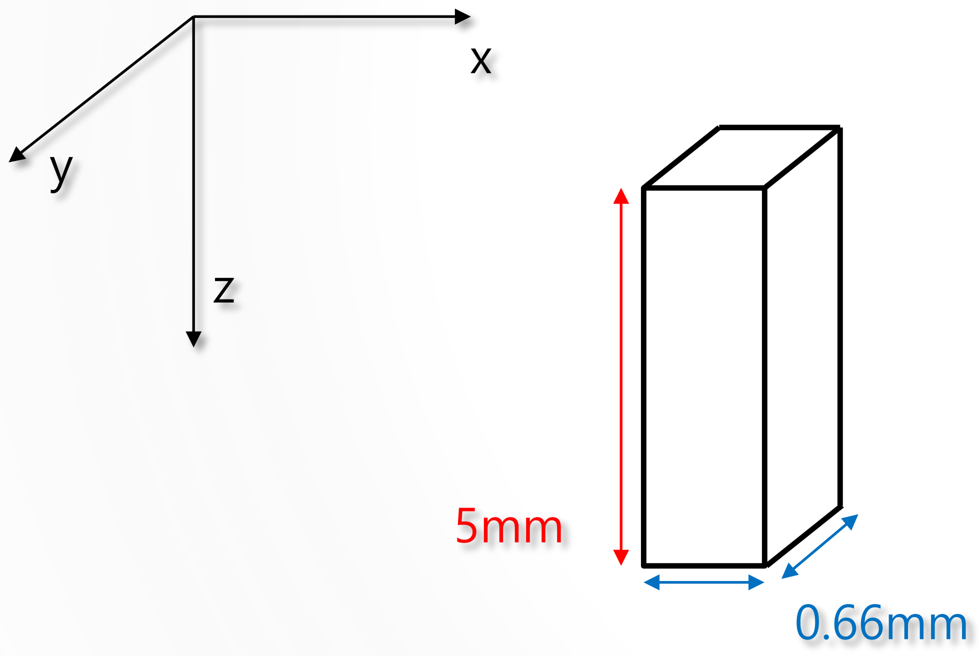


Methods – Coordinate Descent Method for Transform Parameter Optimization



Methods – Slice Interpolation

- Anisotropic characteristics of CT volume data.
  - Pixel spacing & slice spacing.
  - Cuboid voxel.

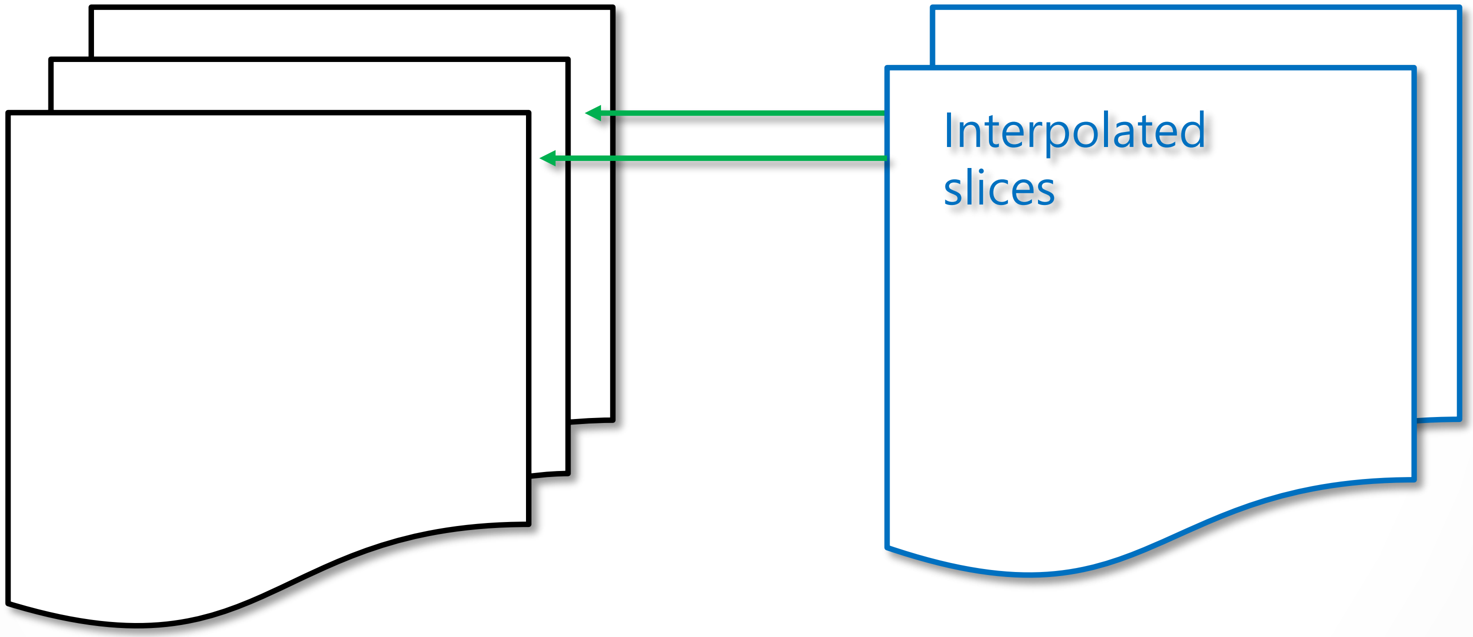


1 voxel translation (in image domain) for z-axis direction

Inaccurate results

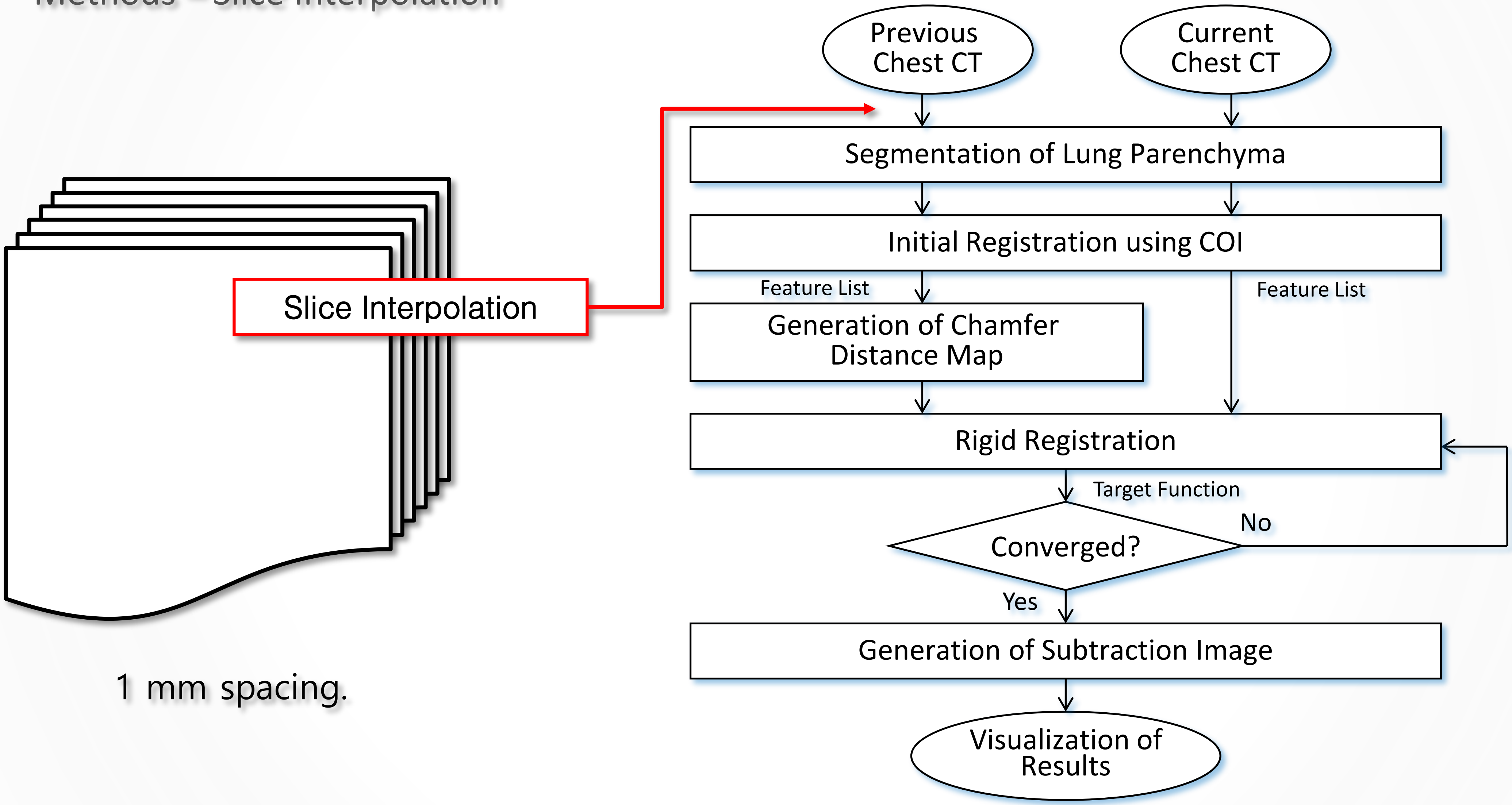
Methods – Slice Interpolation

Semi-isotropic volume construction



5 mm spacing.

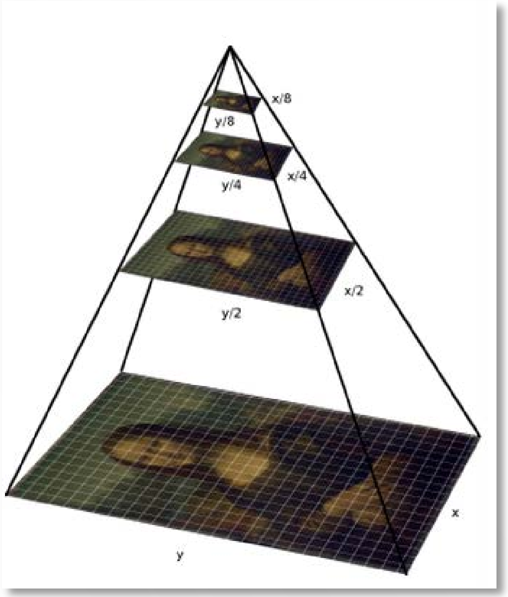
Methods – Slice Interpolation



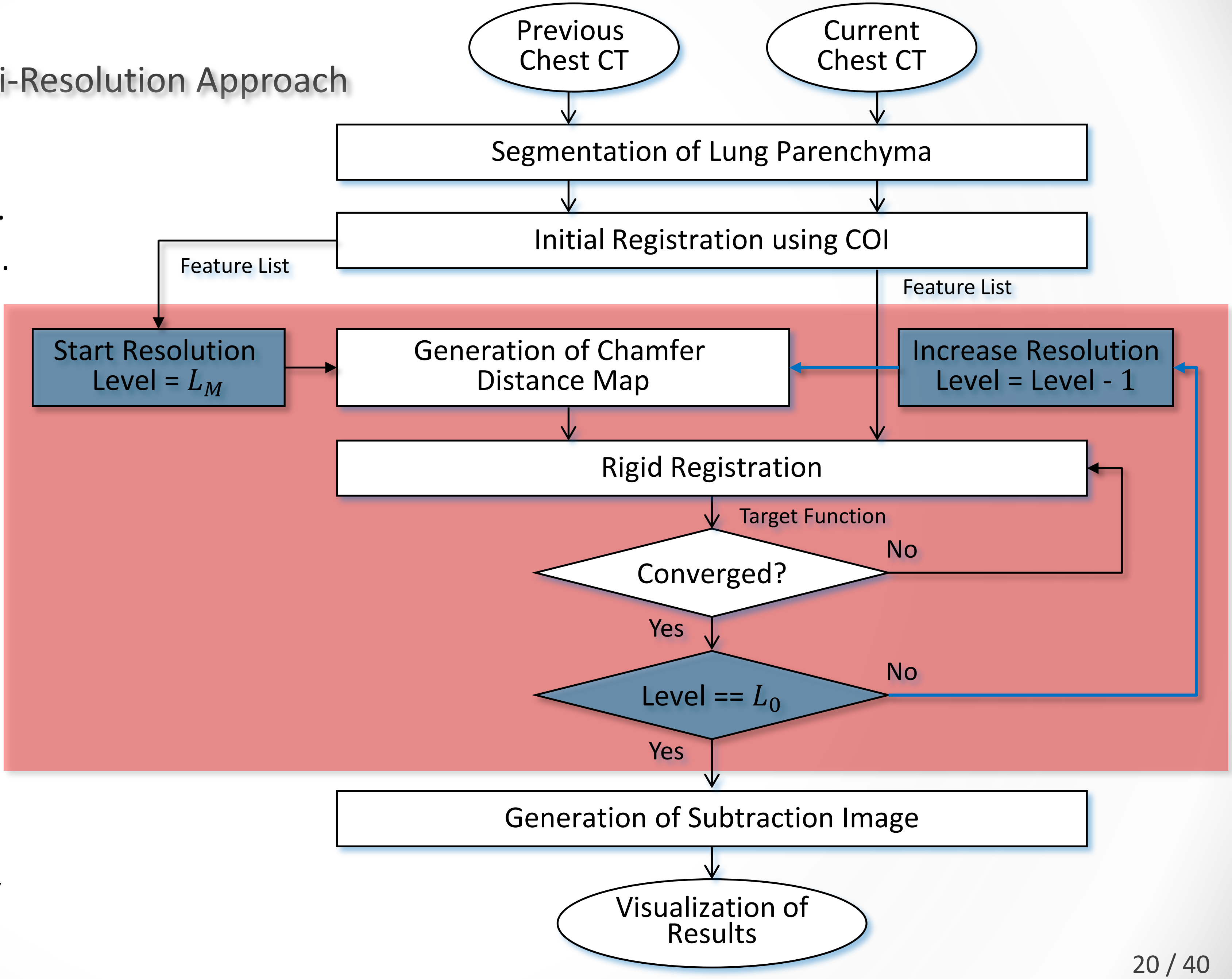
1 mm spacing.

Methods - Hierarchical Multi-Resolution Approach

- Fast convergence in higher levels.
- Robust to noise and local minima.

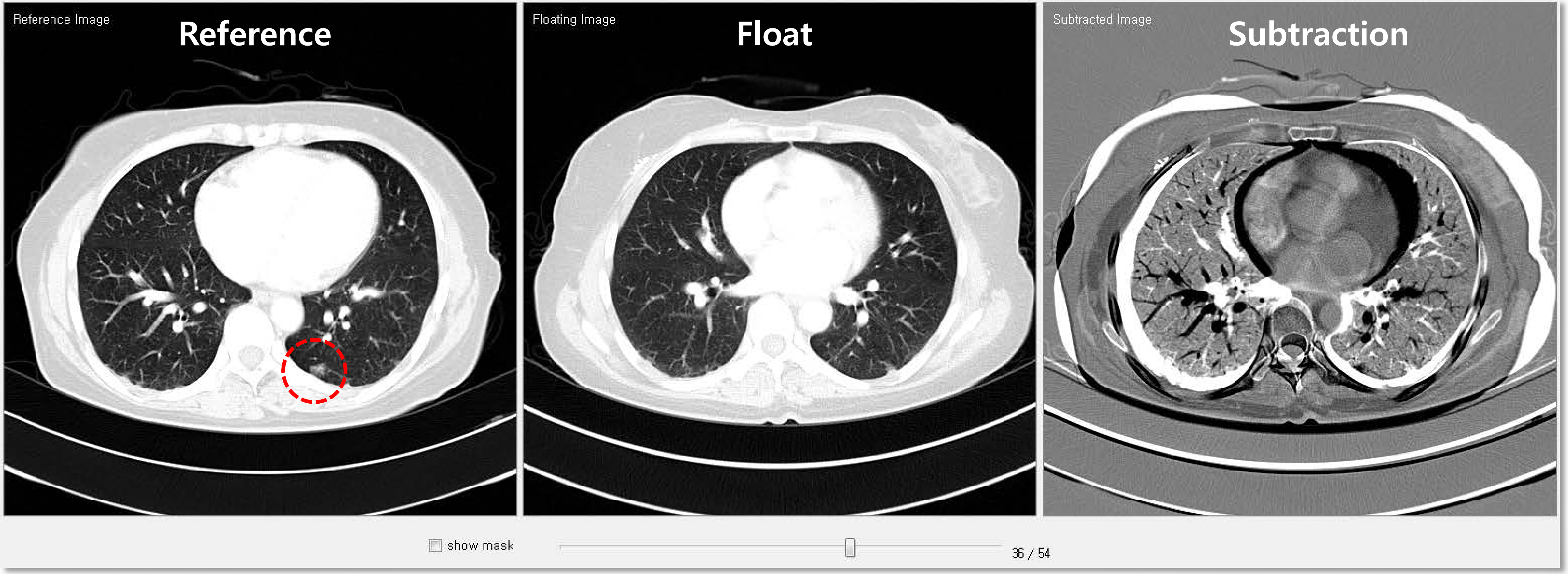


"Process from down-sampled image"



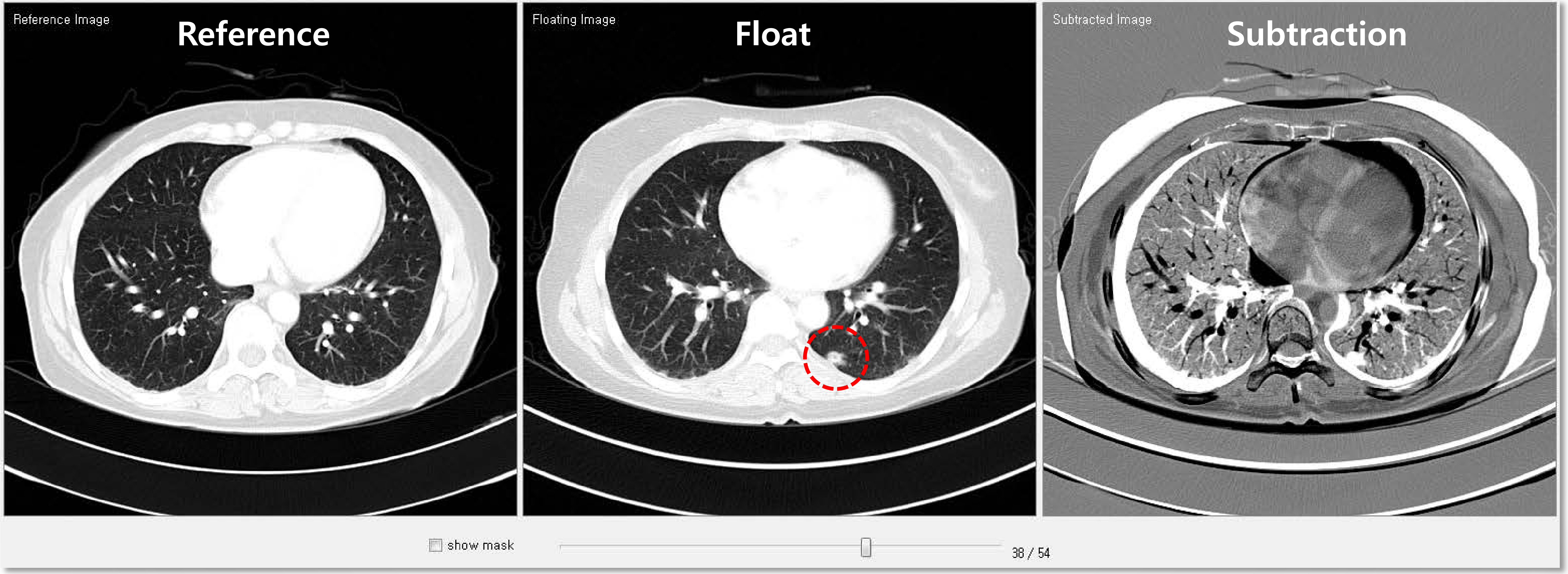
Experimental Results – Registration

- Before Registration (slice # : 36)



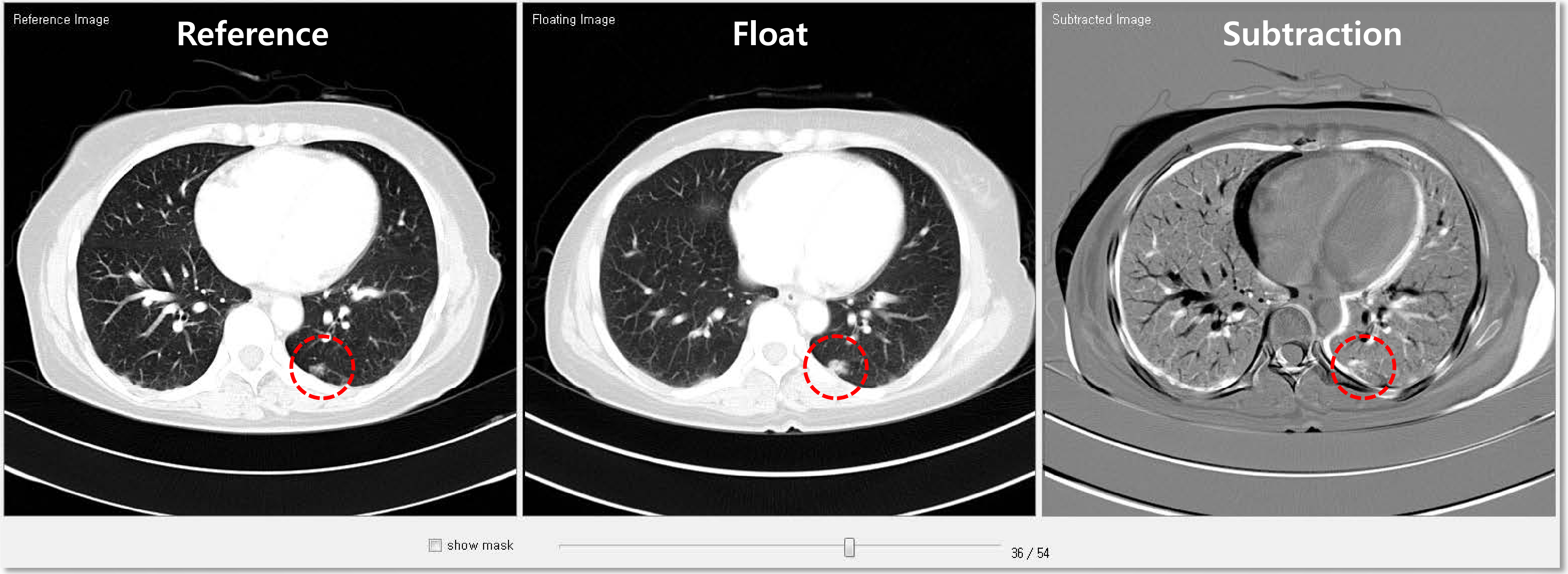
Experimental Results – Registration

- Before Registration (slice # : 38)

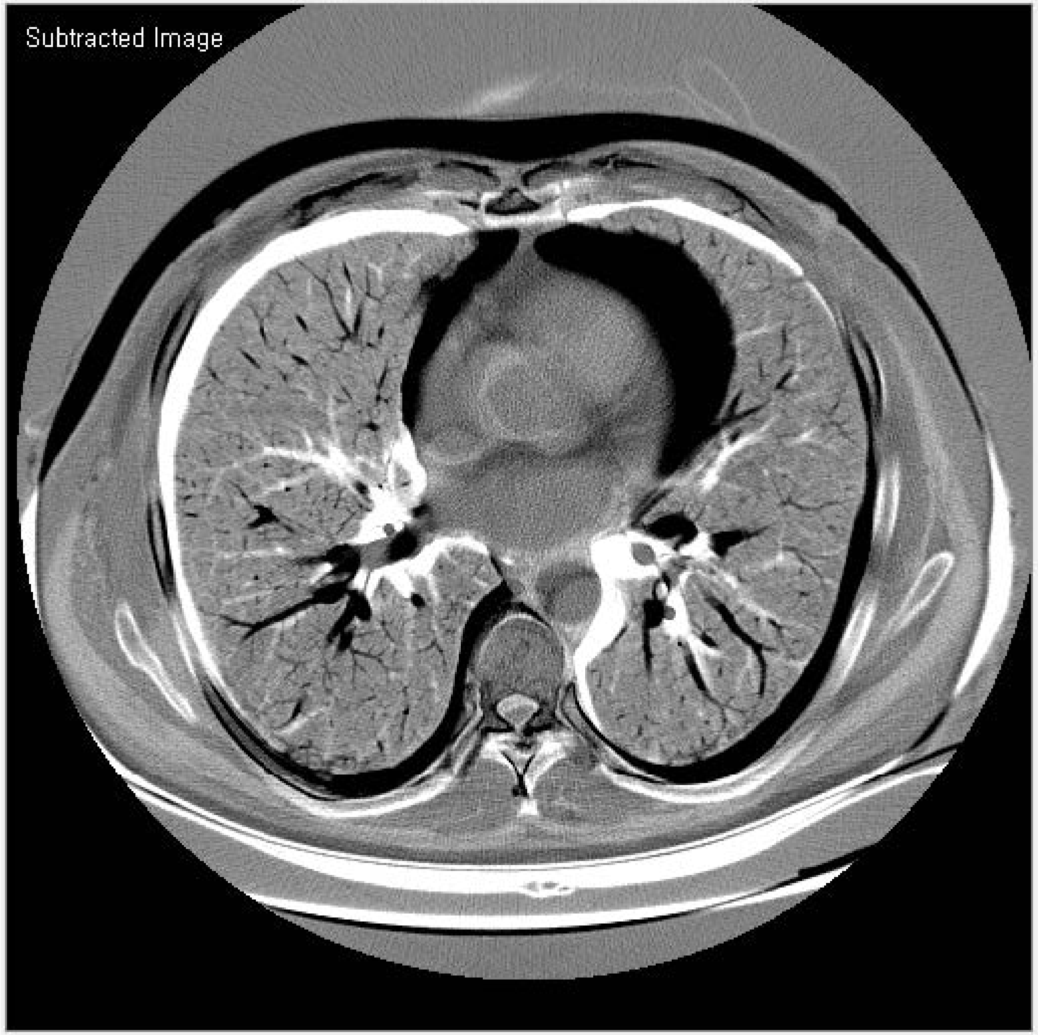


Experimental Results – Registration

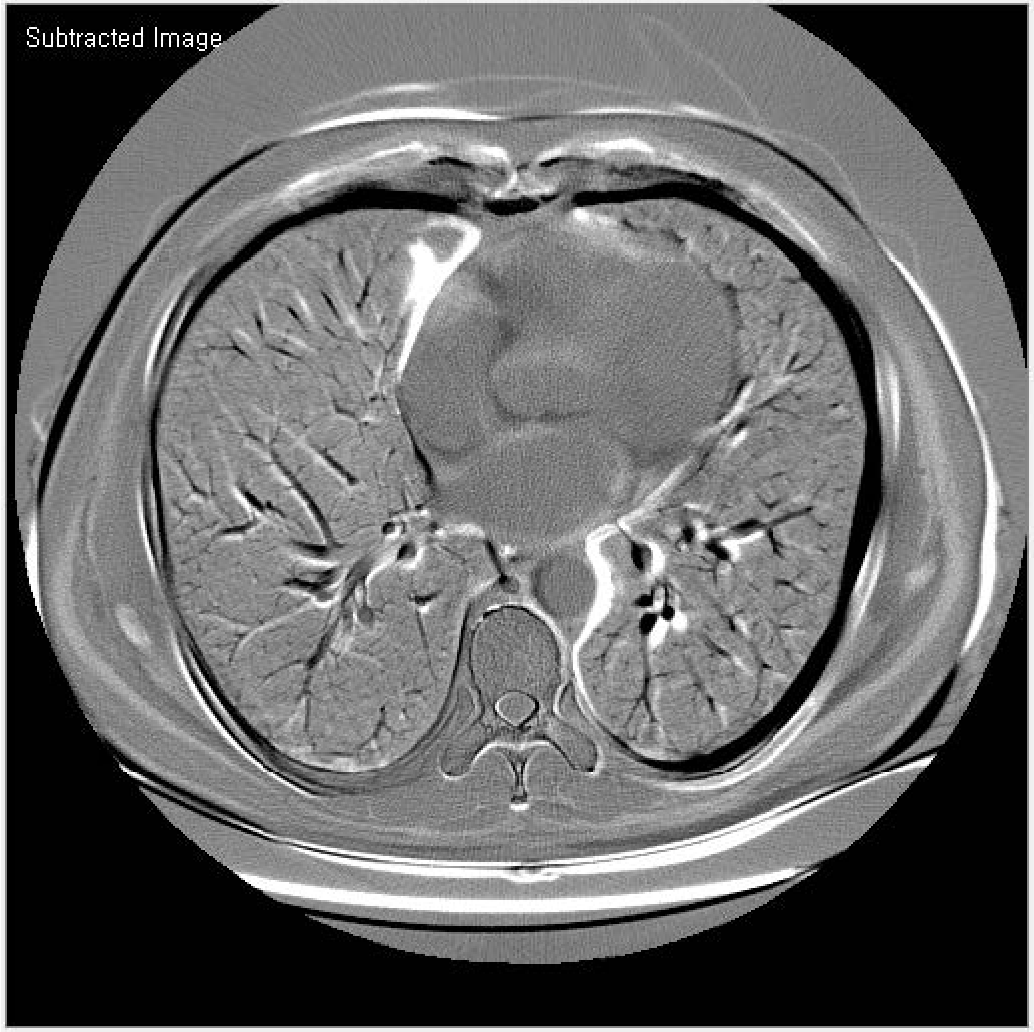
- After Registration (slice # : 36)



Experimental Results – Slice Interpolation



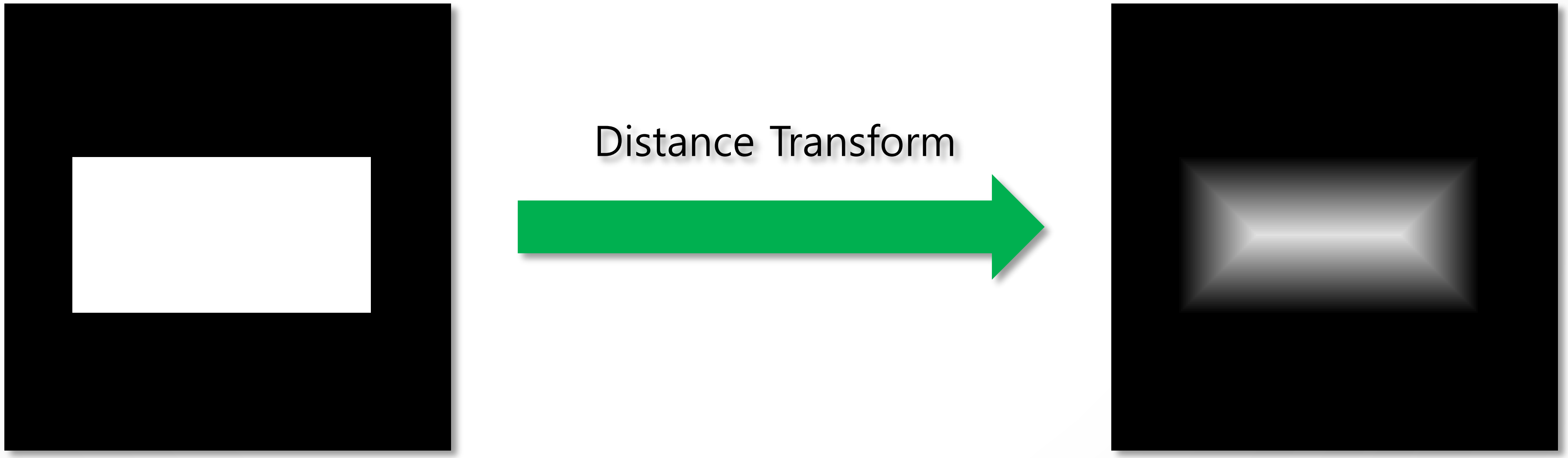
w/ 5mm



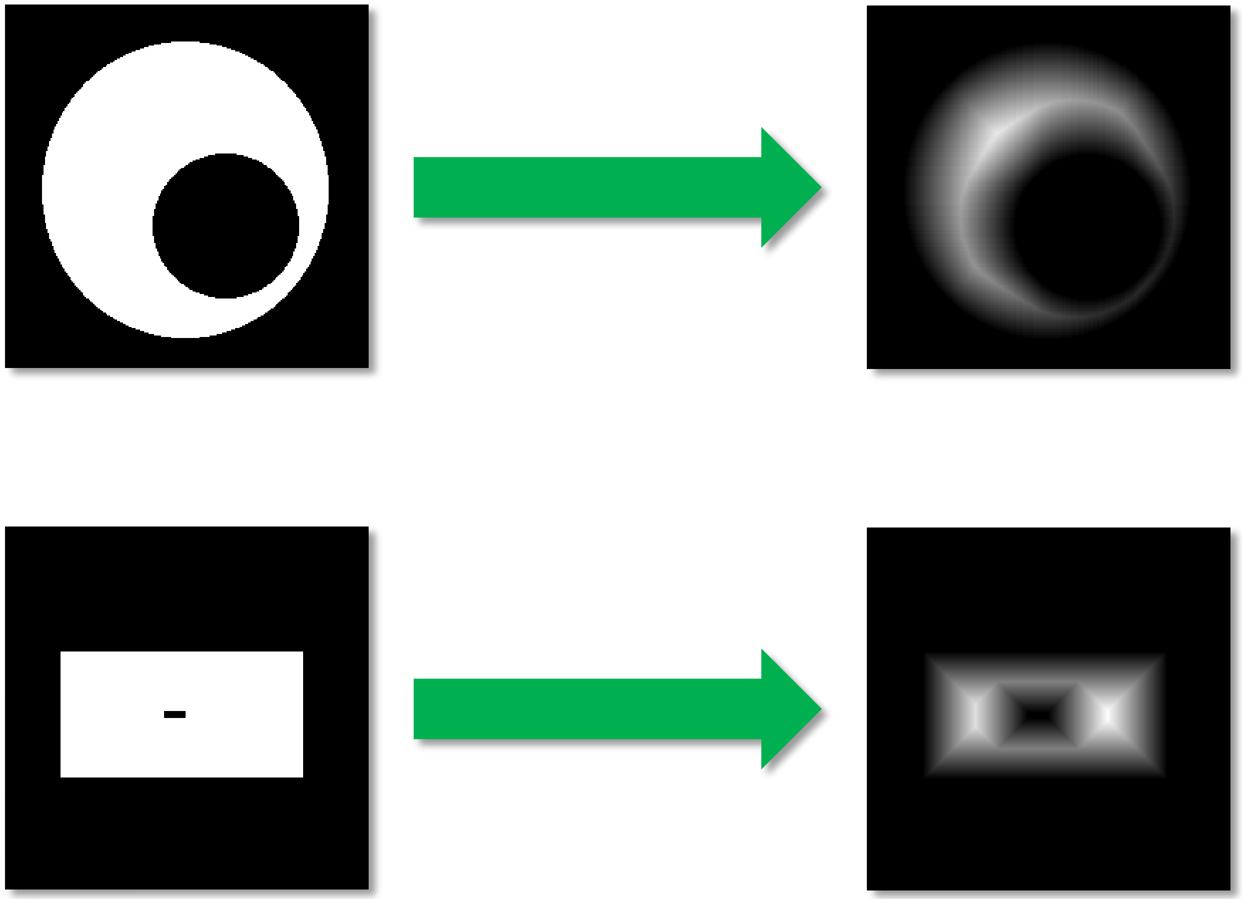
w/ 1mm

Appendix – What is Distance Transform ?

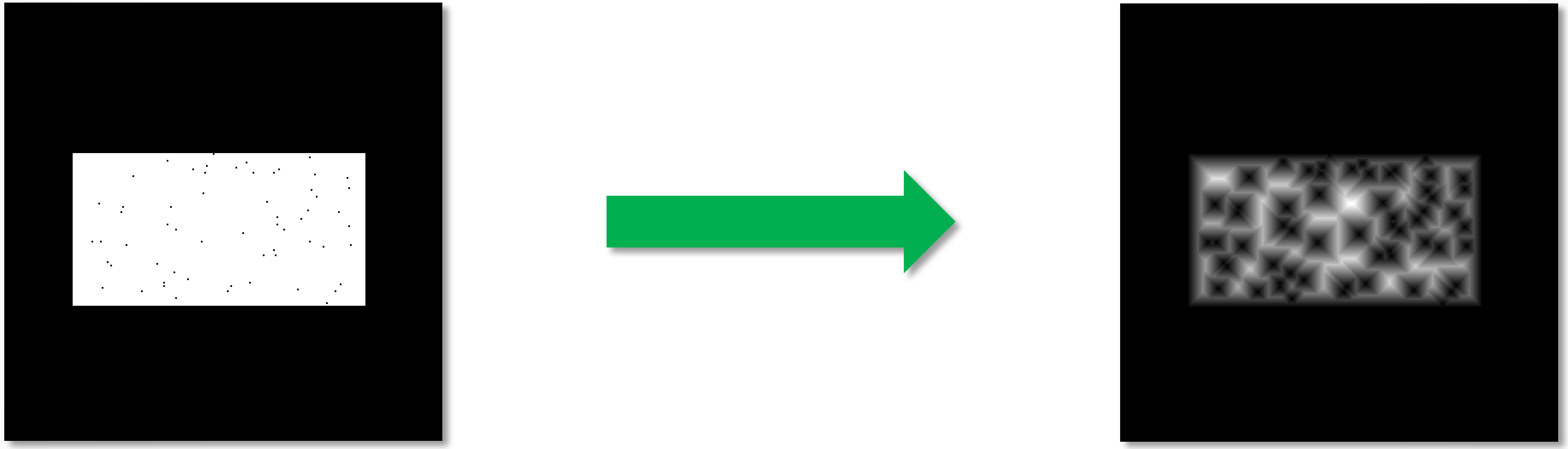
- Labeling of each pixel ***x*** by the distance to the closest point ***y*** in the background.
- $DT(P)[\boldsymbol{x}] = min_{y \in P} \mathbf{dist}(\boldsymbol{x}, y)$
  - P : point set of background
  - ***x*** : vector of image position
  - DT(P) : distance map



Appendix – What is Distance Transform ?



Appendix – What is Distance Transform ?



Appendix – Distance Transform Methods

- Euclidean distance ($L_2 - norm$)
  - $dist(x, y) = sqrt((x_1 - y_1)^2 + (x_2 - y_2)^2 + \cdots)$

- City-bock distance ($L_1 - norm$)
  - $dist(x, y) = |x_1 - y_1| + |x_2 - y_2| + \cdots$

- Chessboard distance ($L_\infty - norm$)
  - $dist(x, y) = \max(|x_1 - y_1|, |x_2 - y_2|, \ldots)$

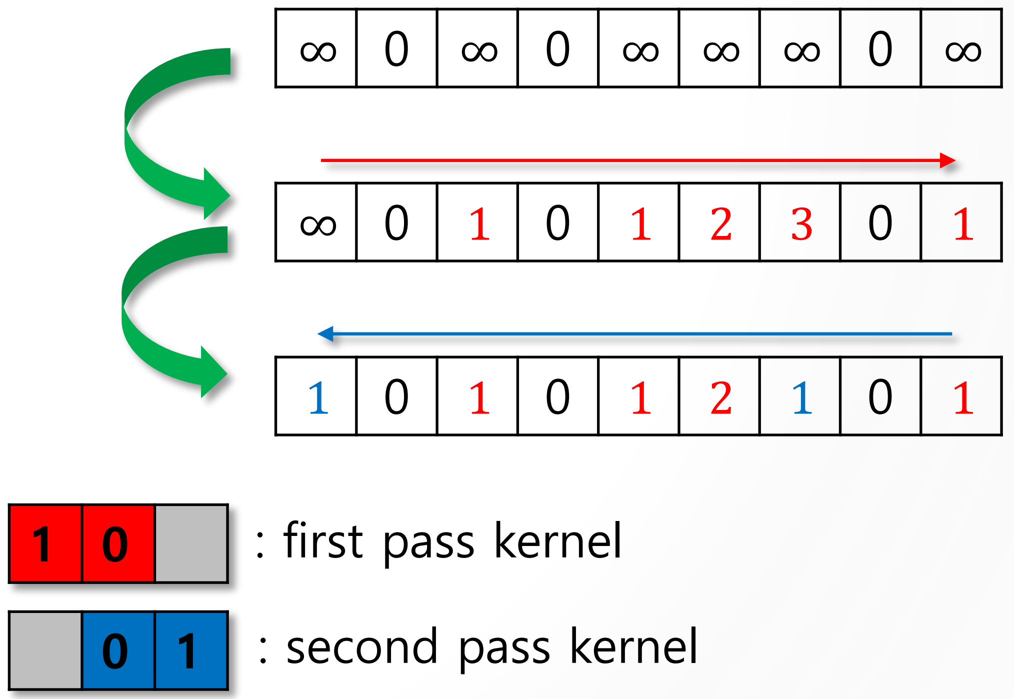
- *Chamfer distance*
  - Approximation version of Euclidean distance.
  - Design-dependent algorithms.

- *Distance propagation*
  - Narrow band distance transform.

Appendix – Distance Transform Computation

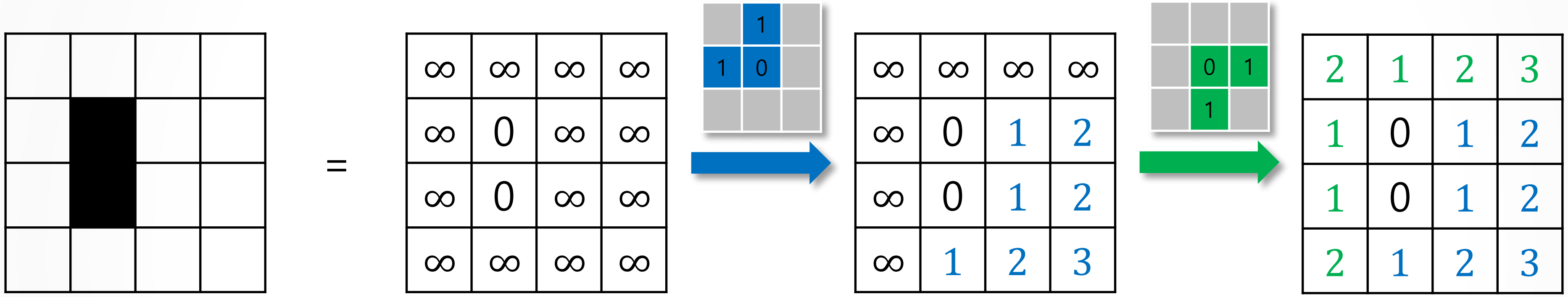
- Naïve approach
  - For each point on the grid, explicitly consider each point of P and minimize.
  - $O(n^2)$ *time complexity*.

- Better methods
  - Simple idea from 1D-case.
  - Two passes :
    - Find closest point on the left
    - Find closest point on the right if closer than one on left
  - Incremental :
    - Moving left-to-right, update distance
    - Analogous for moving right-to-left
  - $O(n)$ *time complexity*.

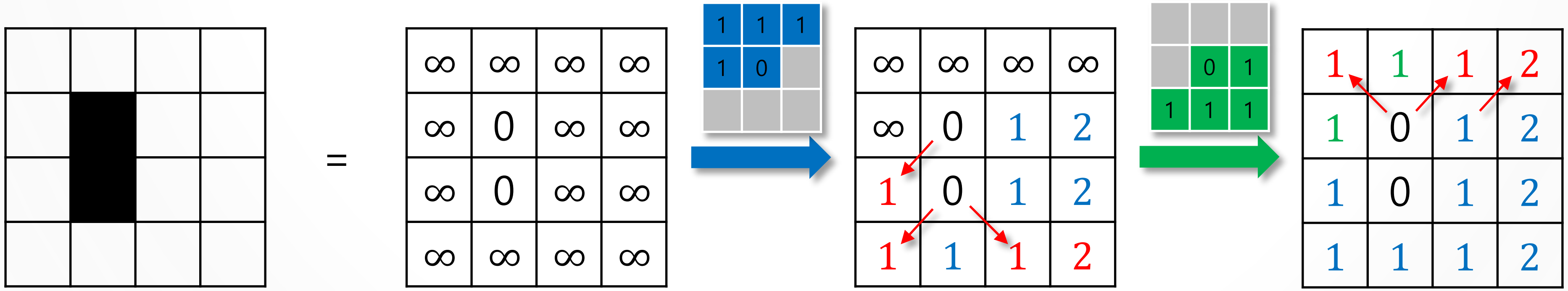


Appendix – Distance Transform Computation

- City block distance computation ($L_1 - norm$)



- Chessboard distance computation ($L_\infty - norm$)



Appendix – Distance Transform Computation

- Euclidean distance computation ($L_2 - norm$)
  - Simple local propagation methods are not correct.
  - Introduces considerable error, particularly at larger distances.
  - Approximation : *Chamfer distance*

$\sqrt{2}$	1	$\sqrt{2}$
1	0	

?

Appendix – Chamfer Distance Map

- Chamfer distance
  - Approximation version of Euclidean distance.
  - Two pass algorithm.
  - Various windows can be used by Chamfer distance algorithm.

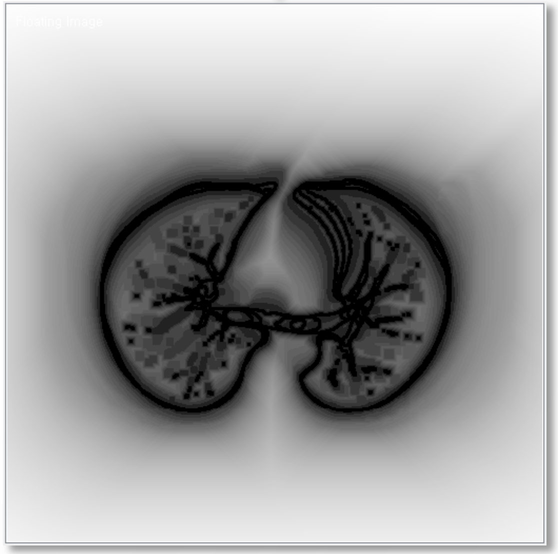
- We consider the boundary of a lung as an implicit surface.
- Perform distance transform from extracted boundary.

Forward Chamfer-mask

$$f_1(p) = \begin{cases} 0 & p \in surface \\ min\{f_1(q) + 1 : q \in F(p)\} & p \notin surface \end{cases}$$

$$f_2(p) = min\{f_1(p),\ f_2(q) + 1 : q \in B(p)\}$$

Backward Chamfer-mask



Appendix – Distance Propagation

- Distance propagation
  - Chamfer distance computation (two pass algorithm) is relatively too expensive for some applications.
  - Propagate distance from edge list
    - Use explicit edge representation

	0					
		0				
		0				
		0	0			
				0		

→

	1					
1	0	1				
	1	0	1			
	1	0	1			
	1	0	0	1		
		1	1	0	1	
				1		

Thank you!