UNIVERSITY OF COPENHAGEN

MULTIPLE HYPOTHESIS TRACKING BASED EXTRACTION OF AIRWAY TREES FROM CT DATA

Using statistical ranking of template-matched hypotheses

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Abstract

Segmentation of airway trees from CT scans of lungs has important clinical applications, in relation to the diagnosis of chronic obstructive pulmonary disease (COPD). Here we present a method based on multiple hypothesis tracking (MHT) and template matching, originally devised for vessel segmentation, to extract airway trees. Idealized tubular templates are constructed and ranked using scores assigned based on the image data. Several such regularly spaced hypotheses are used in constructing a hypothesis tree, which is then traversed to obtain improved segmentation results.

Introduction

COPD is a leading cause of mortality worldwide, characterised by:

- Destruction of the lung tissue (emphysema)
- Morphological changes to the airways

Objective: Develop segmentation methods, with improved specificity and sensitivity, to study morphological changes of airway trees from CT.

Existing methods:

- Airway tree segmentation is a challenging problem
- Most methods try to strike a balance between *specificity* and *sensitivity*.
- Room for improvement on both fronts
- **Single hypothesis / greedy algorithms**
  - Instantaneous decisions
  - Only the best hypothesis is propagated
  - Sensitive to noise
  - Highly local solutions

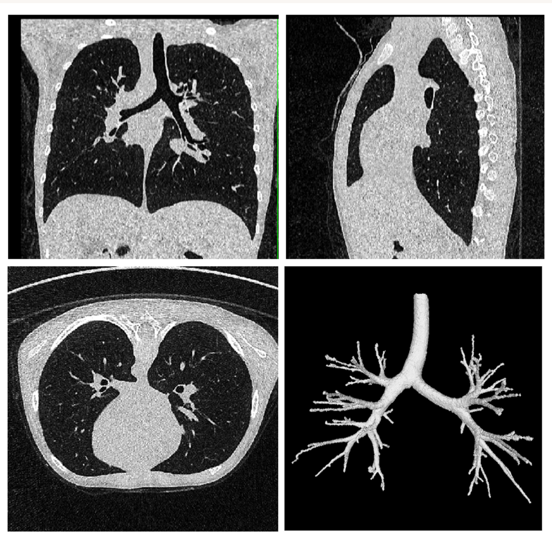


Figure 1: Coronal, sagittal and axial views from a CT, along with a reference segmentation.

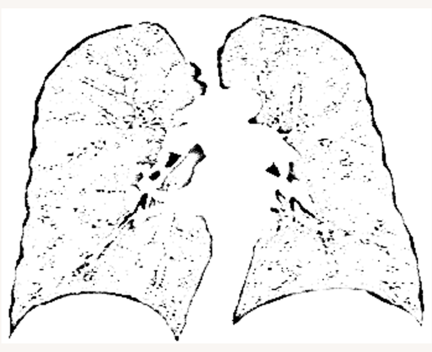


Figure 2: Coronal view of the probability image after classification. Darker regions correspond to high probability, and hence likely airway regions.

MHT-based methods

Idea: Defer decision at current step to a future step. Meanwhile, maintain all hypotheses.

Multiple hypothesis tracking (MHT)

Philosophy: Delay decisions. Use more data. Benefit from hindsight.

- Widely used in multi-target tracking [3]
- Deferred decision based on more data
- Several hypotheses are maintained
- Search depth controls the size of tree
- Trade-off between optimality, tractability

A tracking perspective to segmentation

- Prediction by regularly spaced guesses
- Image data is used to update the guesses

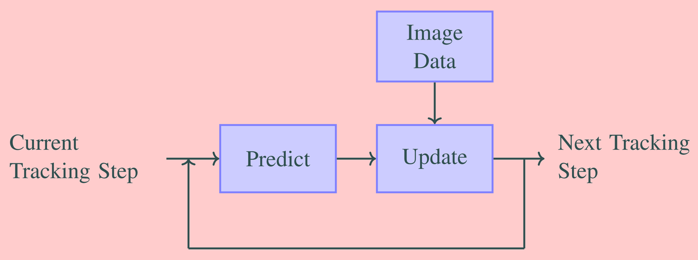


Figure 3: Overview of tracking between two steps

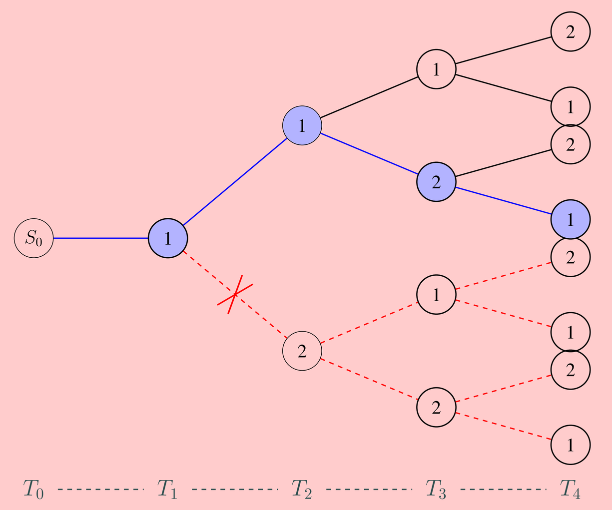


Figure 4: MHT tree, of search depth = 2. The decision at T_2 is made based on all the data upto T_4, tracing back the best global hypothesis depicted in blue.

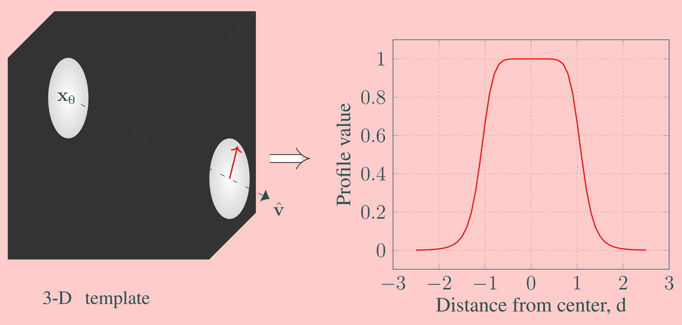


Figure 5: 3D tubular template of radius r, with center at $\mathbf{x}_0$ along the direction $\hat{\mathbf{v}}$. Intensity profile (p) at a crossection is shown on right.

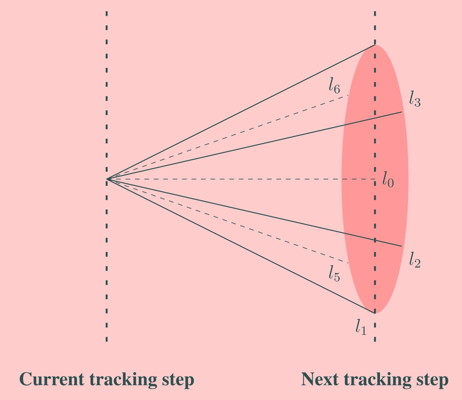
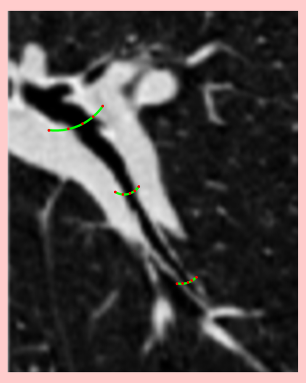


Figure 6: Generation of local hypotheses, l_i. Each hypothesis inherits paramters from previous step, uses a predetermined increment in direction and position to progress to the next step.



Org. MHT	Mod. MHT
(0.7, 2, **9**, 4, 0.5)	(0.1, 0.2, **1**, 0.4, 0.3)
(0.1, 2, **5**, 3, 0.3)	(0.2, 0.3, **1**, 0.4, 0.2)
(0.2, 1, **2**, 0.4, 0)	(0.1, 0.4, **1**, 0.3, 0.1)

Figure 7: Illustration of scores and thresholds in org. and ranking based MHT methods

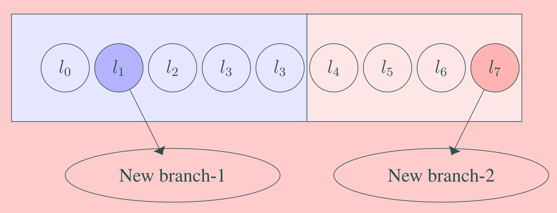


Figure 8: Each step, all hypotheses are considered for clustering. As an example here, two clusters are formed and the best hypothesis within each is propagated as a new branch.

Template matching-based MHT

Method based on [1], proposed for tracking small vessels:

- Designed to track small tubular structures
- Uses a scale-dependent score threshold
- Semi-automatic

Model

- Probability images obtained from trained KNN classifier ($K = 21$); airways ($p = 1$)
- Method in [1] is modified, while retaining the image model:

image = contrast*template + mean + noise, or

$$I(x) = k * T(\mathbf{x}; \mathbf{x}_0, r, \hat{\mathbf{v}}) + m + \epsilon \quad (1)$$

- Template function (T) used to map probability variations to a profile function (p)

$$T(\mathbf{x}; \mathbf{x}_0, \hat{\mathbf{v}}, r) = \frac{r^\gamma}{(d^2(\mathbf{x}; \mathbf{x}_0, \hat{\mathbf{v}}))^{\gamma/2} + r^\gamma} \quad (2)$$

d^2 is minimum squared distance between $\mathbf{x}$ and line along $\hat{\mathbf{v}}$ through $\mathbf{x}_0$ with $\gamma = 8$

Constructing the hypothesis tree

- Fixed number of guesses are generated
- Guesses are 3D templates based on parameters from previous step
- Corresponds to the "prediction" step.
- Predictions are "updated" by solving the weighted minimization problem:

$$\min_{\mathbf{x}_0, \hat{\mathbf{v}}, r, k, m} ||\mathbf{W}(\mathbf{x}_0, \hat{\mathbf{v}}, r)[k * T(\mathbf{x}; \mathbf{x}_0, r, \hat{\mathbf{v}}) + m\mathbf{1} - \mathbf{I}]||^2 \quad (3)$$

W is the weighting matrix.

- Guesses are ranked based on prominence of score, *removing the dependence on scale*

Idea: Quantify bright, tubular structures in dark background and rank them.

- Score from the estimated contrast:

$$\text{score} = \frac{\text{contrast}}{\text{std(contrast)}} \quad (4)$$

- Hypothesis tree is constructed to search for the best global hypothesis
- Each path through the hypothesis tree has an average global score

Handling branching

- Spectral clustering is performed
- If two clear clusters are observed, best hypothesis in each is tracked as new branch

Results

Data & Experiments

- Single seed point automatically placed at the origin of trachea; thus fully automatic
- Set of 32 images split into training, test sets
- Danish Lung Cancer Screening Trial data used [2]
- Probability images from KNN classifier
- Centerlines of segmentation results are compared with reference segmentations, to quantify estimation error:

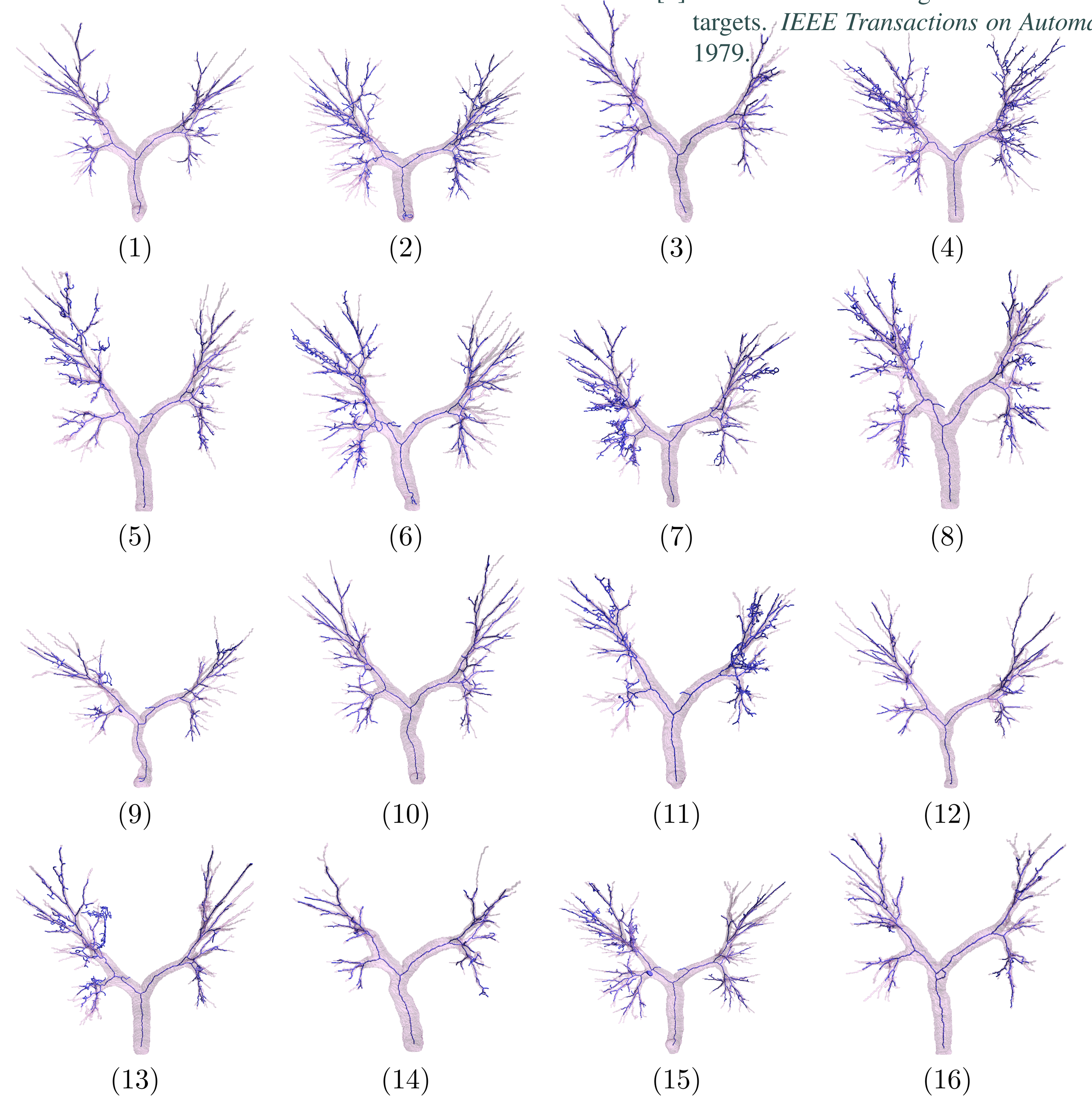


Figure 9: Centerlines of test set results overlaid with reference

Error distance:

$$d_{err} = \frac{\sum_{i=1}^{n_{op}} \min d_E(c_i - C_{ref})}{n_{op}} + \frac{\sum_{j=1}^{n_{ref}} \min d_E(c_j - C_{op})}{n_{ref}} \quad (5)$$

C_{ref}, C_{op} are centerlines of reference, output segmentations, with n_{ref}, n_{op} points respectively, d_E is Euclidean distance

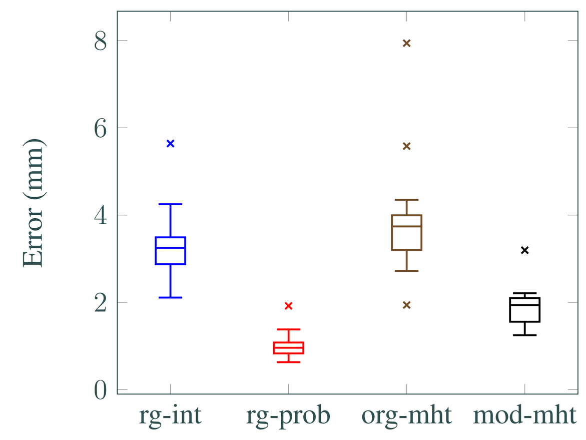


Figure 10: Performance comparison of the modified MHT (mod-MHT) method with the original MHT (org-MHT), region growing on intensity (rg-int) and region growing on probability (rg-prob)

Discussion

- Ranking based MHT method shows an improvement in performance.
- Fully automatic tree extraction method
- It does not outperform region-growing on probability images

Conclusions

- MHT allows for improved tracking decisions, as tracking solutions are not local.
- Method in [1] has been modified to extract airway trees.
- Ranking based scheme is more suitable for extracting airways, where structures of varying dimensions are observed.

Acknowledgements

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References

[1] Friman et.al. Multiple hypothesis template tracking of small 3d vessel structures. *Medical image analysis*, 2010.

[2] Jesper H Pedersen et.al. The danish randomized lung cancer ct screening trial-overall design and results of the prevalence round. *Journal of Thoracic Oncology*, 2009.

[3] Donald B Reid. An algorithm for tracking multiple targets. *IEEE Transactions on Automatic Control*, 1979.