Implementation of an Automated Pipeline for the Identification of Ground Glass Opacities on CT scans of Patient Affected by COVID-19

SUBMITTED BY
Riccardo Biondi

SUPERVISOR
Prof. Gastone Castellani

CO-SUPERVISOR
Dr. Nico Curti

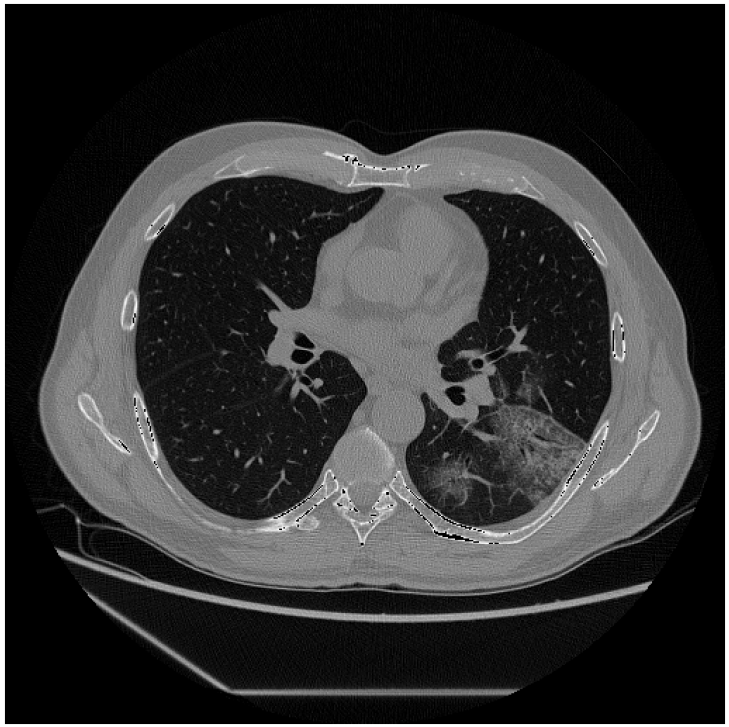
ALMA MATER STUDIORUM · UNIVERSITÁ DI BOLOGNA

11 December 2020

Ground Glass Opacities and Consolidation

What They Are and Why Identify Them

hazy opacities that does not obscure the underlying bronchial structures or pulmonary vessels found in CT images. Indicates a partial filling of air spaces in the lungs by exudate or transudate, as well as interstitial thickening or partial collapse of lung alveoli



COVID-19

- Viral(SARS-CoV-2)
- Acute infectious disease
- Peculiar GGO and CS patterns

Why Identify Them?

- **To Help** diagnosis
- **To Monitor**:
  - the course of the disease
  - the recovery of healed patients

State of the Art

Current Methods, Problems and Solution

Current Segmentation Methods

Manual or Semi-automatic:

- Time Consuming
- Requires Trained Personnel
- Subjected to Operator Expertise

Characteristics of the Pipeline Implemented

- Fully Automated: *remove subjectivity and dependency of external operator*
- Fast: *obtain results in a small amount of time*

Dataset

- 83 CT scans with annotation provided by *Department of Experimental, Diagnostic and Specialty Medicine*
- 2 Public Dataset

Basic Idea

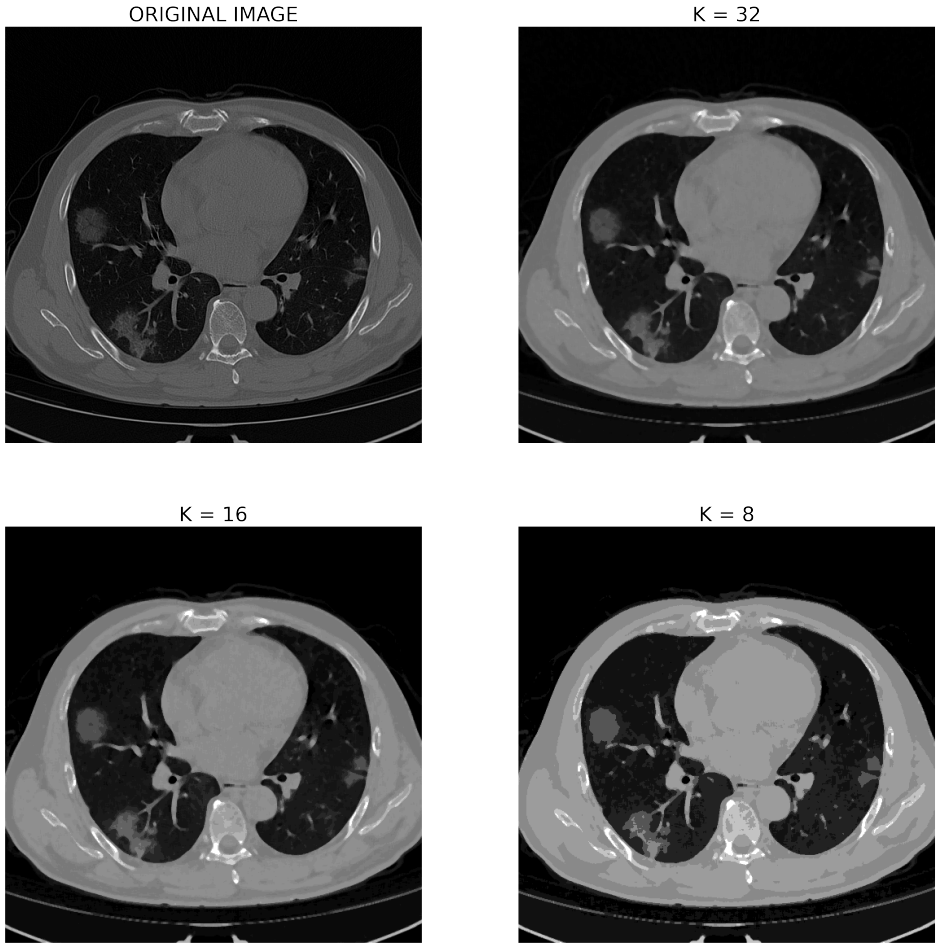
Colour Quantization for Medical Image Segmentation

GGO areas on CT Images

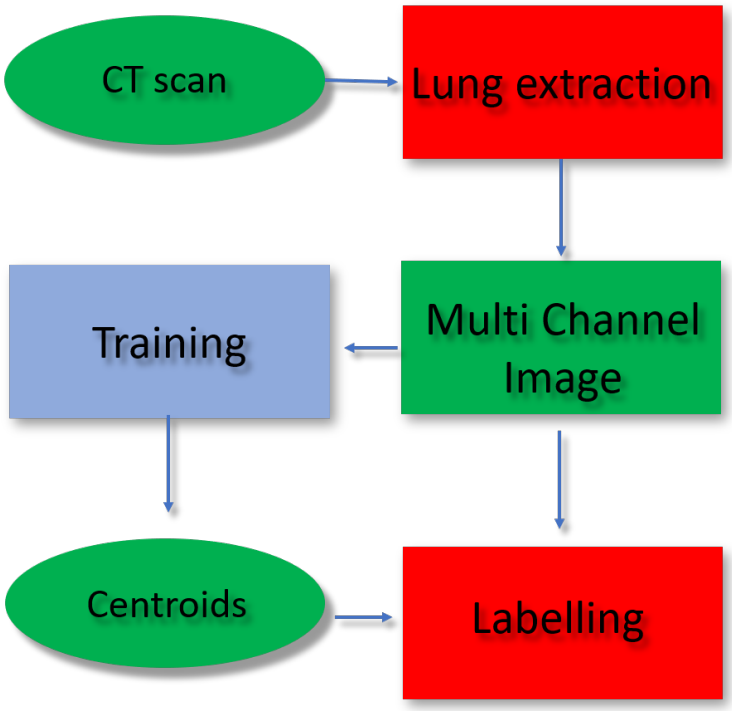
- Similar Gray Level
- Spatially Displaced

Basic Idea

- **Colour Quantization**: Group Pixel Based on colour similarity
- **Colour Space**: Constructed by taking into accounts different information



Implementation



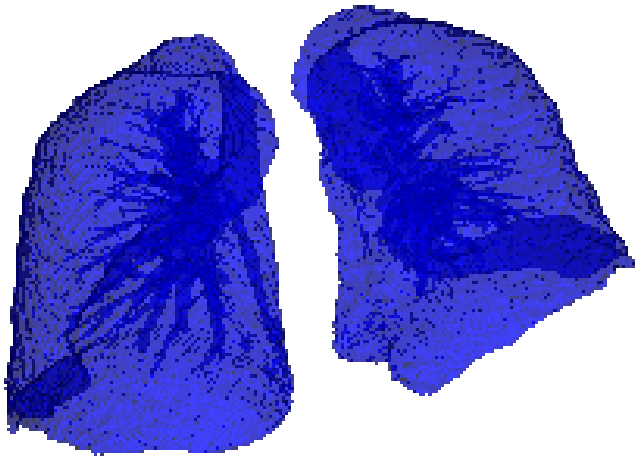
- **LANGUAGE:** Python
- **INSTALLATION:** Setup
- **OS:** Linux & Windows
- **DOCUMENTATION:** Generated with Sphinx
- **CI:** Travis & Appveyor
- **URL:** `https://github.com/RiccardoBiondi/segmentation`
- **DEPENDENCIES:** OpenCV & SimpleITK & Numpy

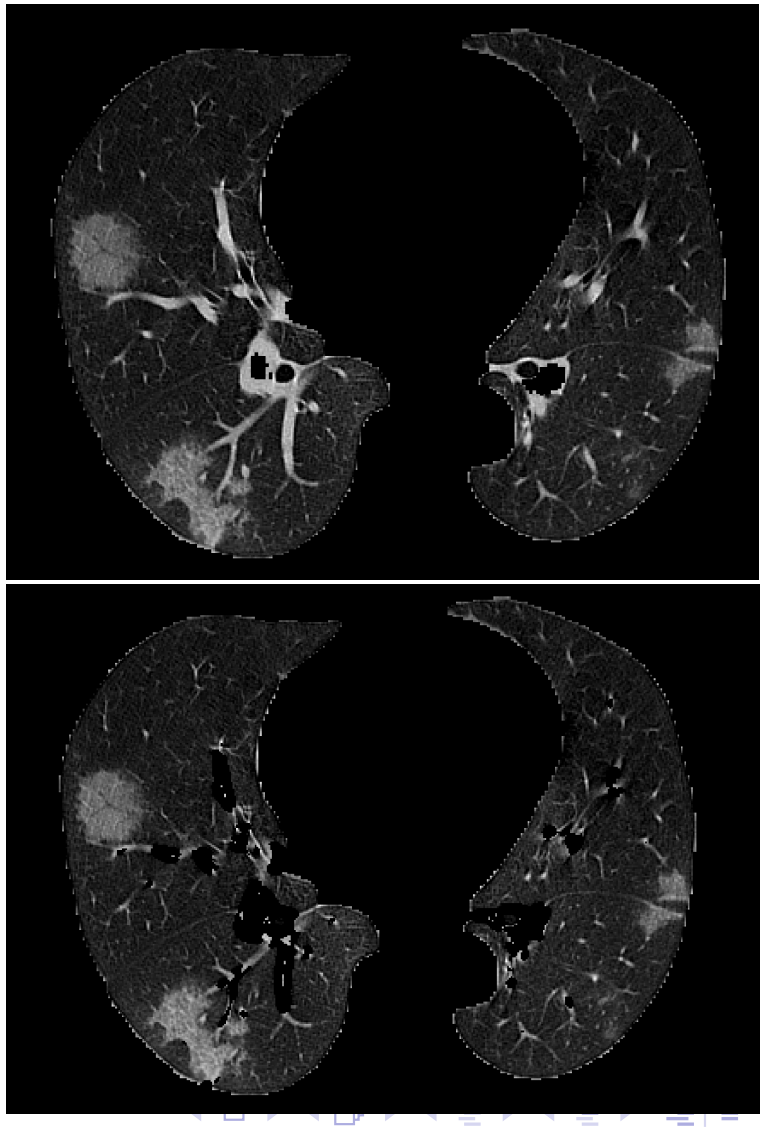
Lung Extraction

Focusing on the Region of Interest

Lung Extraction

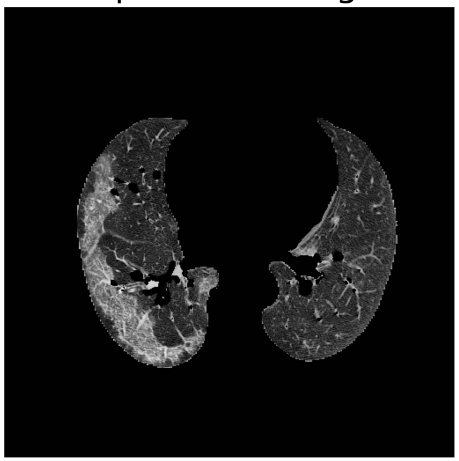
- Remove extra-lung regions
  - Pre-Trained U-Net: $DSC = 0.98 \pm 0.03$
- Remove Bronchial Structures
  - Maximum Eigenvalues Map
- $449.94 \pm 0.03\ ms$ per slice



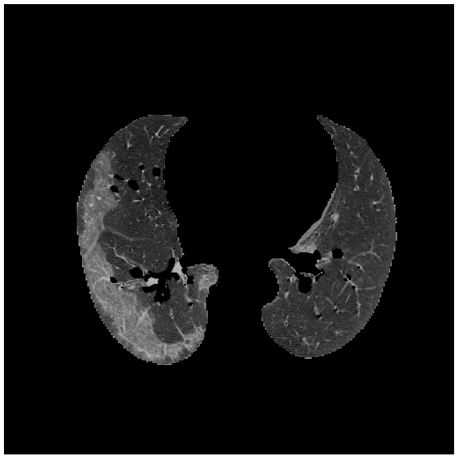


Multi Channel Image

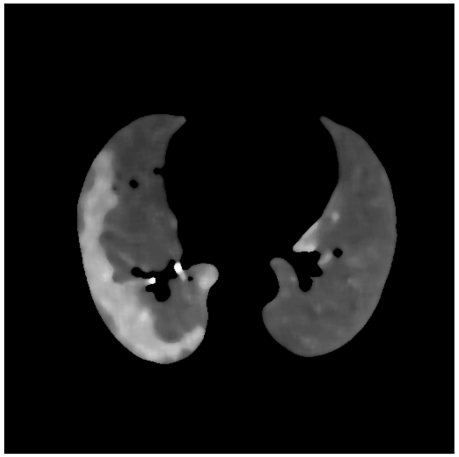
Equalized Image



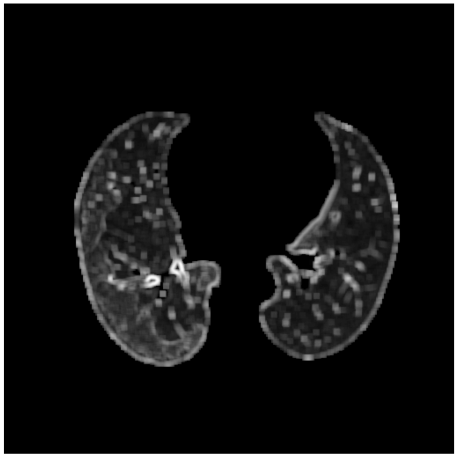
Gamma Corrected



Median Blurred



Standard Filtered



Single Voxel

- Histogram Equalized
- Gamma Corrected ($\gamma = 1.5$)

Neighbouring Voxels

- Median Blurred (*kernel size* $= 11$)
- Standard Deviation Map (*kernel size* $= 3$)

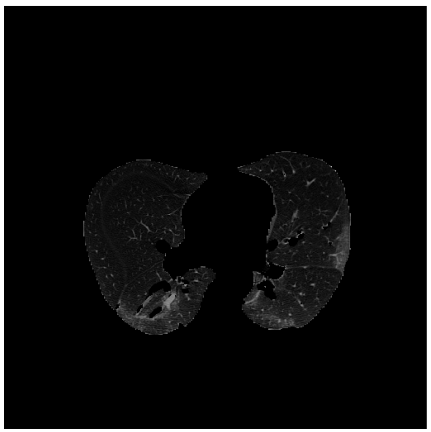
Training

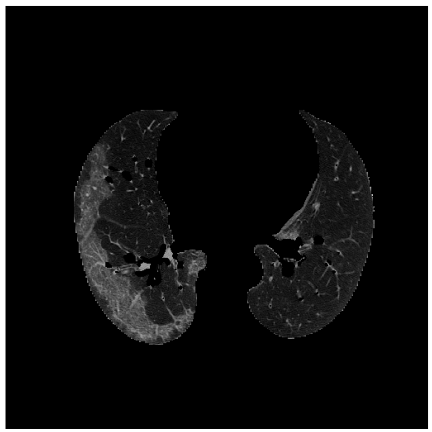
Centroid Estimation

k-means clustering to find the centroids in the color space

Clusters

- Healthy Lung
- Edges
- Bronchi
- Noise
- GGO and CS





Problem

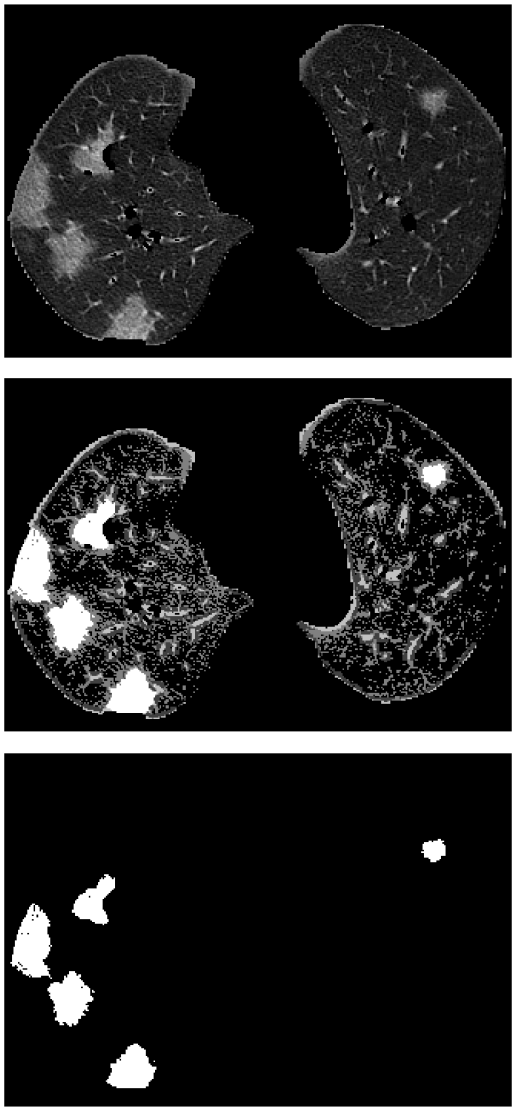
Non balanced cluster representation :

- Background : Overrepresented
- GGO and CS: Can be under represented

Solution

- Remove Background
- Careful Selection of the Scans

Labelling



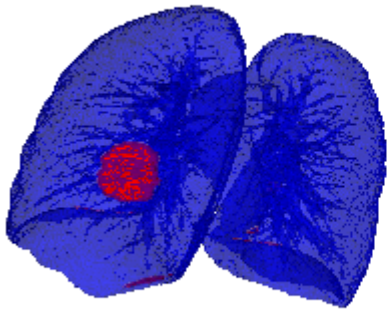
Input

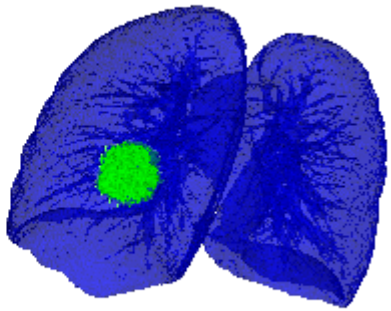
- Lung Extracted CT scan
- Centroids Set

- Build Multi Channel Image
- Labelling by minimizing : $\sum_{i=1}^{k} \sum_{S} \|x - \mu_i\|$
- Select the labels corresponding to GGO as CS
- $45.65 \pm 0.05\, ms$ per slice
- $DSC = 0.63 \pm 0.12$

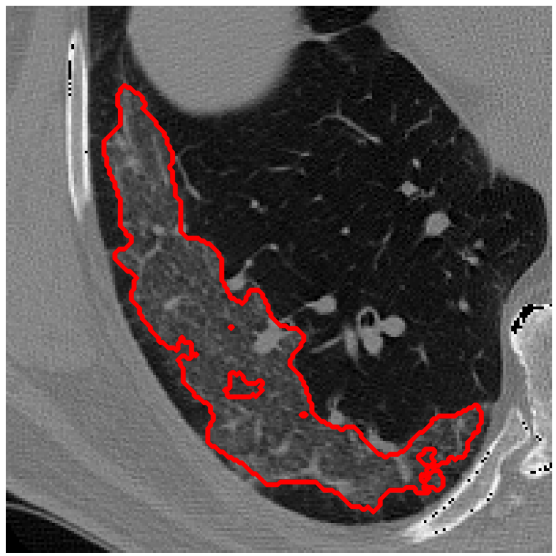
Results

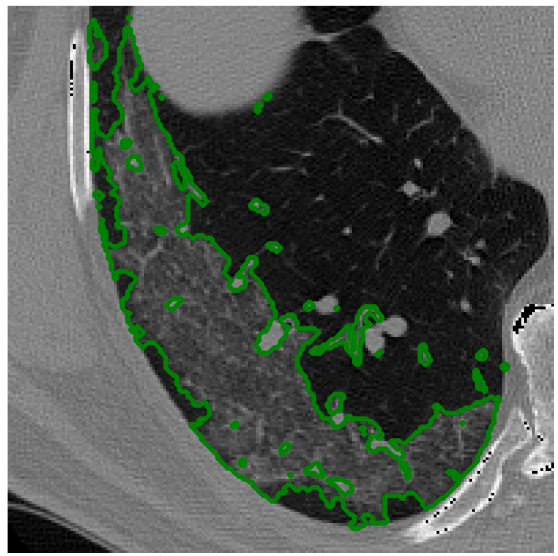
Visual Comparison





- green: semi-automated segmentation made by experts (some hours)
- red: automated pipeline results (less than *3 min*)



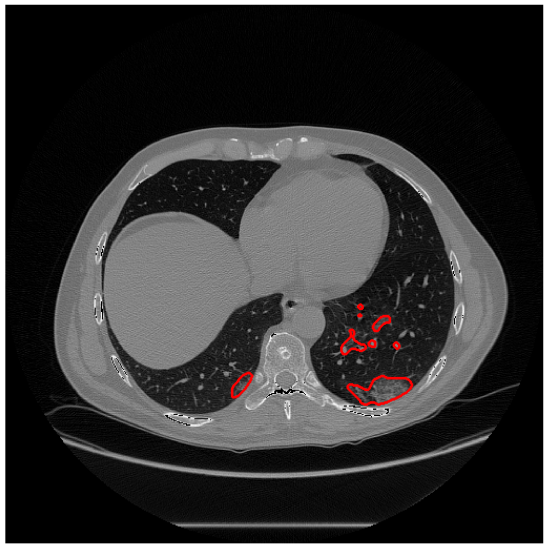


Results

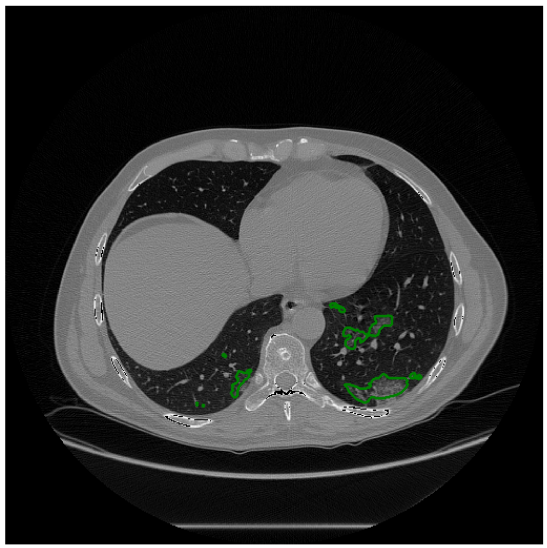
Experts Blind Evaluation

- 7 segmentations submitted to 3 experts (*with at least* 2 *years of experience*)
- 3 independent evaluations for each scans
- Internal accordance lower than 50%

ROSSO



VERDE



Percentage of positive assessments

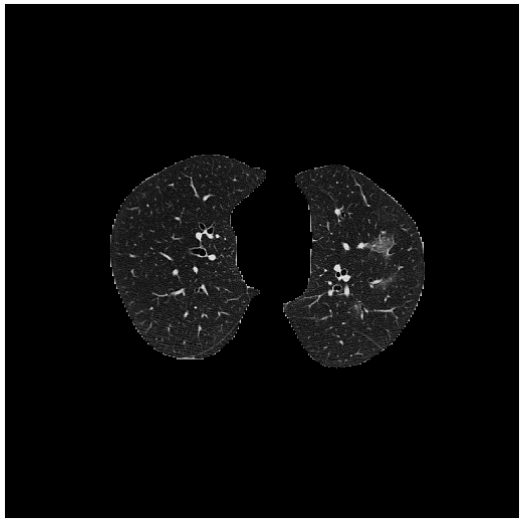
pipeline	32%
annotation	33%
none	35%

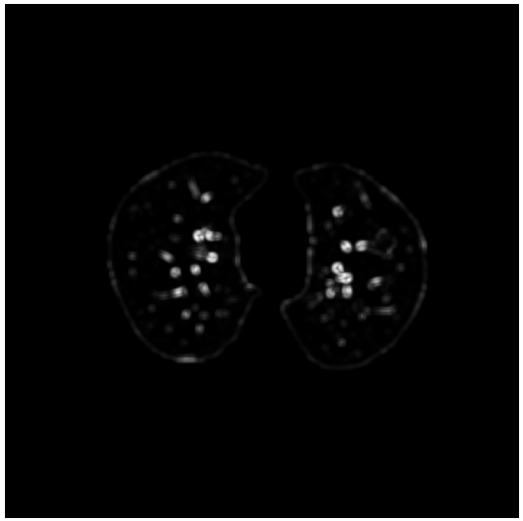
Conclusion

- **Achieved a segmentation in less than** $3\,min$
- **Fully automated**
- **Colour quantization has shown to be a suitable approach to face this kind of problems**
- **Interaction with specialised personnel needed to improve results**

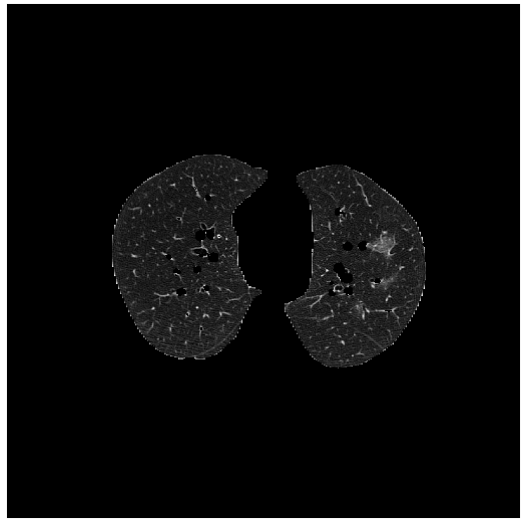
Max Eigenvalues Map

Bronchial Structure Removal



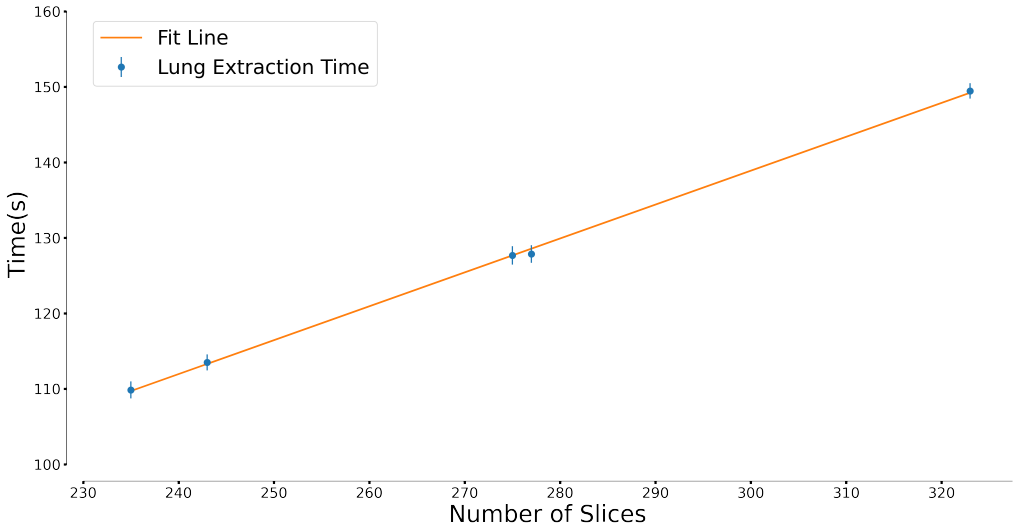


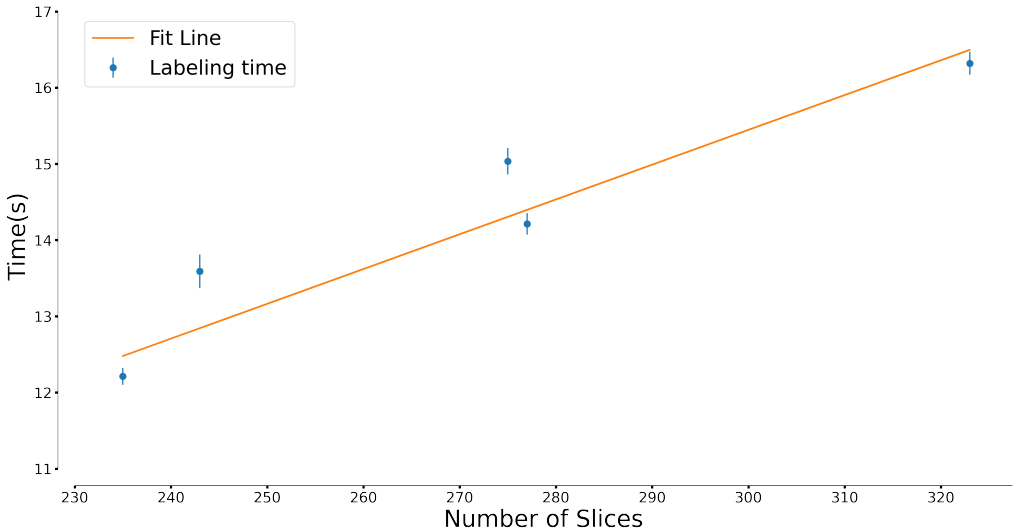
$$M = \begin{bmatrix} \sum_{S(p)} \left(\frac{dI}{dx}\right)^2 & \sum_{S(p)} \frac{dI}{dx}\frac{dI}{dy} \\ \sum_{S(p)} \frac{dI}{dx}\frac{dI}{dx} & \sum_{S(p)} \left(\frac{dI}{dy}\right)^2 \end{bmatrix}$$



Timing

Measuring the time performances





Time per slice

- **Lung Extraction:** 449.94 ± 0.03 *ms*
- **Labelling:** 45.65 ± 0.05 *ms*

Results

Sensitivity and Specificity

	Predicted		Annotation	
	Sensitivity	Specificity	Sensitivity	Specificity
Patient 1	0.412	~ 1.00	0.676	0.999
Patient 2	0.399	~ 1.00	0.698	0.995
Patient 3	0.570	~ 1.00	0.653	0.999
Patient 4	0.512	~ 1.00	0.325	0.999
Patient 5	0.628	~ 1.00	0.974	0.999