Medical Image Analysis KU, WS24
Assignment 3
3D Registration

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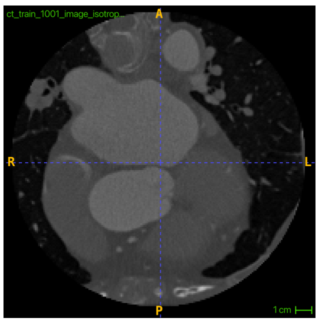
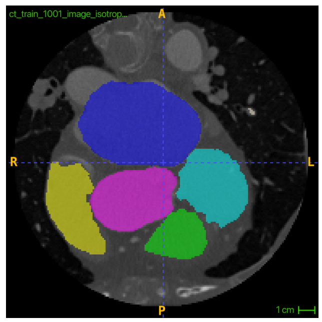
1 Task Description:

The main task of this assignment is to perform a 3D registration and an averaging of 20 provided cardiac volumes:

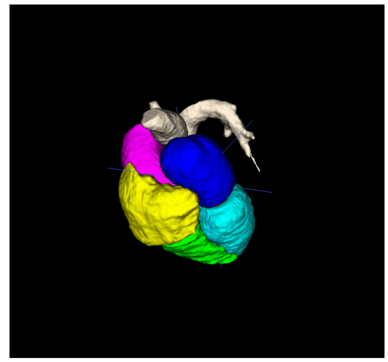
Provided data: For the assignment 20 cardiac CT volumes as well as the corresponding segmentation labels were provided (see Figure 1)



(a) CT cardiac volume w/o segmentation



(b) CT cardiac volume with segmentation



(c) CT cardiac volume in 3D

Figure 1: Provided data

The labels file provided segmentation labels for 7 parts of the heart indicated by different colors as shown in figure 1c:

- Left Ventricle
- Right Ventricle
- Left Atrium
- Right Atrium
- Myocardium
- Pulmonary Artery
- Aorta

all indicated with different number from 1-7 where 0 represented the background.

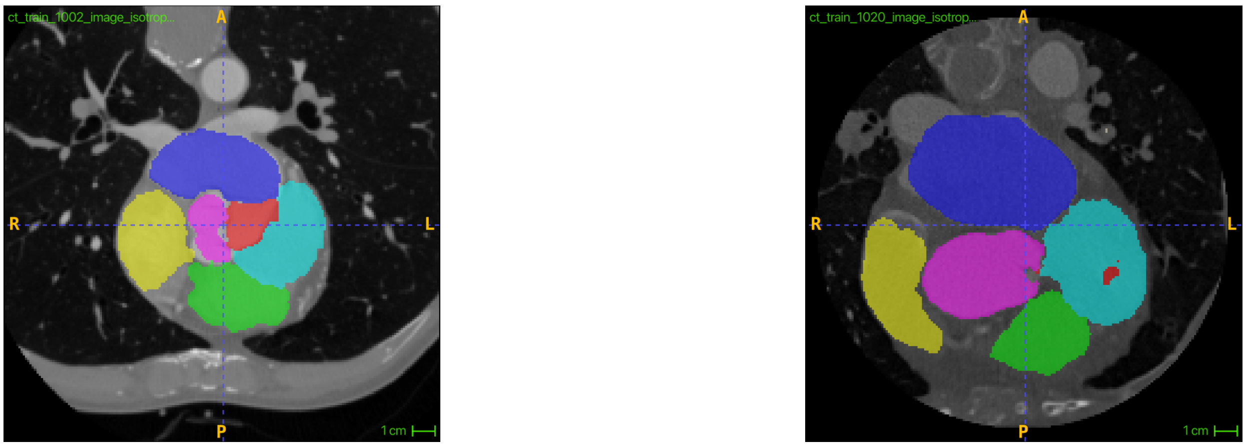
Additional task: Furthermore the instruction asked for a cropping to 128x128x128 of the registered images and perform a Principal Component Analysis on the registered images.

2 Steps for 3D Registration

To perform a 3D registration with the volumes, several tasks needed to be performed prior, to finally be able to compute an average 192x192x192 volume of all 20 volumes:

2.1 Center of gravity of segmentation labels

The first task was to compute the center of gravity of all segmentation labels (ventricles, atria, myocardium,...) of all 20 volumes as we knew that the volumes were not aligned overall. In figure 2 you can see section cuts of two different volumes with their respective segmentations.



(a) CT cardiac section volume 1

(b) CT cardiac section volume 2

Figure 2: Differences in providede data

In figure 3 you can see an example scatter plot of the chosen reference volume (1001) and a volume that should be rotated, translated and scaled to it. The plot includes the different centers of gravity (COGs) for all 7 labels as well as the overall center of gravity for all segmentation labels of the two volumes (indicated by *center of rotation*).

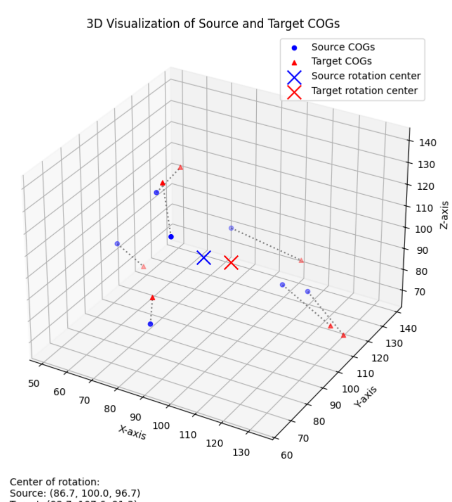


Figure 3: Centers of gravity

2.2 Calculate rotation, translation and scaling parameters

To be able to perform the 3D registration of the volumes the next steps was to compute all necessary parameters of the volumes that needed adjustment. These parameters were always calculated in relationship to the chosen reference volume. (in this case the first volume *1001* was selected as reference)

The parameters needed for the alignment of the volumes where the *rotation matrix*, the *translation vector* and the *scale factor* and these had to be calculated for each volume separately.

Steps for the Procrustes Alignment:

- The fist step is to determine the global center for all the COGs of the labels of one volume as shown in figure 3
- The next step is the centering of these points. In this step all the COGs get "centered" in one global center. Resulting in two matrices P and Q
- Compute Cross-Covariance Matrix H:
$$H = Q^T \cdot P$$
Where P is rotated onto Q
- Compute Rotation Matrix R: For computing the matrix a Singular Value Decomposition (SVD) on H is performed
$$R = USV^T$$
to then determine R by computing:
$$R = VU^T$$
- The next step is to calculate the translation.
$$t = \overline{q} - \overline{p}$$
- As a last step the scaling factor was calculated:
$$s = \frac{||Q||}{||P||}$$

These parameters were then used to translate, rotate and scale all volumes separately to the align best with the reference volume.

2.3 Apply transformation

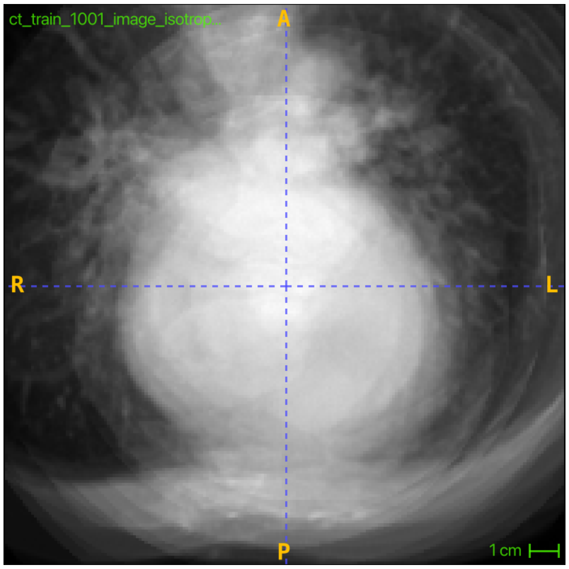
To perform the transformation of the volumes the *Similarity3DTransform()* from the *SimpleITK* package was used. To preserve the structure of the image the best while doing the transformation also the scaling was include.

So before starting with the transformation the before calculated parameters had to be adjusted so that they complied with the *SimpleITK* requirements.
Firstly the rotation matrix was scaled by transposing it and multiplying it with the scaling factor. This added isotropic scaling to the transformation.
Further more the center of the rotation was defined as the global center of all the COGs of the labels of the volume that needed adjustment. The final change was to input the negative translation vector so that the volume moves into the target coordinate space.

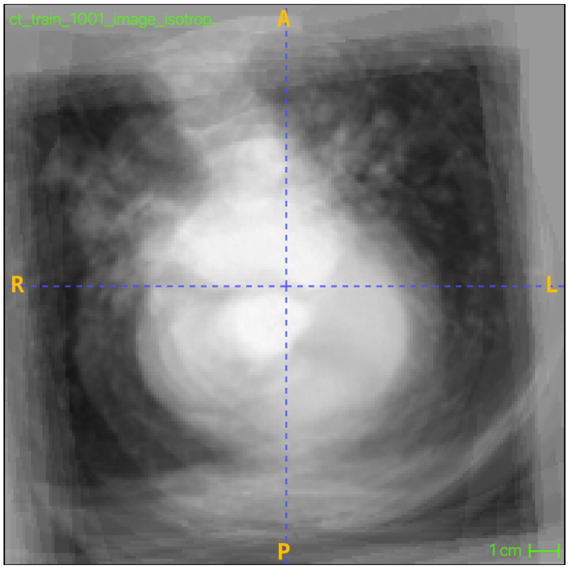
2.4 Averaging of images

The final step was to average all registered images so that they could be visualized in *ITK-Snap*.

In figure 4 you can see the the difference of the average before registration (figure 4a) and the average after registration (figure 4b.



(a) Average before registration



(b) Average after registration

Figure 4: Comparison of averages of volumes

3 Additional tasks

3.1 Similarity transform

To perform a similarity transform instead of a rigid transformation in 3D the isotropic scaling factor s needs to be introduced. This results in a 7 degrees of freedom (7-DOF) transformation, which allows for better alignment in scenarios where images may have been captured at different scales. When introducing the scaling factor, it ensures that the shape of the volume remains unchanged while allowing uniform expansion or contraction.

Meaning an rigid transformation in 3D is defined as:

$$x' = Rx + T$$

whereas the similarity transformation can be writen as:

$$x' = sRx + T$$

After testing both of the transformations, it was clearly visibly that an similarity transformation gave the better results and that's why it was implemented in the code.

3.2 Cropping the registered images

The task was to crop all registered images to an 128x128x128 portion and to ensure that no image parts that had segmentation labels were removed. This was realized by firstly registering all labels similar as for the volumes. The only difference was that here an Nearest Neighbour interpolation was chosen. After the registration the center of the labels was calculated finally determine the start and end of the crop. In figure 5 you can see the final croped image.

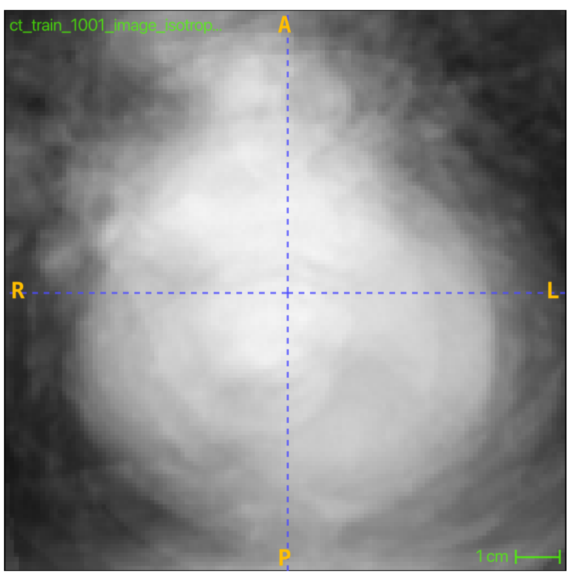


Figure 5: Cropped average