# Brain Tissue Segmentation & ART Laboratory

Diagnostic Imaging Lab 3

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June 2, 2017

# 1 Task 1. Segmentation of Brain Tissue

## 1.1 Compulsory Task

### 1.1.1 Dice Index Table & Segmentation Results

Dice index values of various lab conditions are shown in Table 1. The slice used to test is the centre slice of the sample volume created by BrainWeb simulator. Apply k-means method to classify slice's points into three groups, which are white matter (WM), gray matter (GW) and cerebrospinal fluid (CSF). There are three experimental scenarios to test classification that can be observed in Table 1. The classification results of three scenarios are displayed in Figure 1, in which errors have been marked.

Volume/slice : central axial slice created by BrainWeb simulator
Segmentation method : k-means

| No. | Modality | Noise | Intensity Non-uniformity | Errors | Dice Index WM | Dice Index GM | Dice Index CSF |
|---|---|---|---|---|---|---|---|
| 1 | T1 & T2 | 0% | 0% | 385 | 98.68% | 97.25% | 97.74% |
| 2 | T1 & T2 | 5% | 20% | 871 | 96.50% | 93.78% | 96.58% |
| 3 | T1 & T2 & PD | 0% | 0% | 354 | 98.99% | 97.49% | 97.26% |

*Table 1: Dice index values for WM, GM and CSF under different lab conditions.*

### 1.1.2 Answers of Questions

**(Q1)** *What kind of signal do the voxel values (grayscale) in each volume represent?*
**A1:** The voxel values in each volume are represented by the magnitude of Fourier transformed k-space data. Assume that $F_r$ is the real part of Fourier transformed signal and $F_i$ is the imaginary part, thus, the magnitude $m$ can be computed as $m = \sqrt{{F_r}^2 + {F_i}^2}$.

**(Q2)** *What kind of noise (what distribution, Gaussian? other?) is present in the BrainWeb volume voxels?*
**A2:** The simulated images have two kinds of noise. Noise in Rayleigh distribution is added to the image background, and the noise in signal regions is consistent with Rician distribution.

**(Q3)** *What is meant by intensity non-uniformity (INU) in these images?*
**A3:** INU is an artifact that is caused by several issues, such as the uneven magnetic field, in-homogeneous body components, eddy currents and so on. In this case, the volume has 20% INU, which indicates that

the multiplicative INU magnetic field has a range of coefficients from 0.90 to 1.10 to generate the simulation volume of brain area.

**(Q4)** *What is Dice index and what does it represent? What is confusion matrix?*

**A4:** Dice index is a statistic that is usually used to quantify the similarity of two samples, especially evaluating the performance of the image segmentation problem. Computation of Dice index is shown as Equation 1 as well as in Figure 2. In this case, we can assume that $X$ is one ground truth slice, $Y$ is the segmentation result generated by k-means method. The larger the Dice index is, the better segmentation result we obtain.

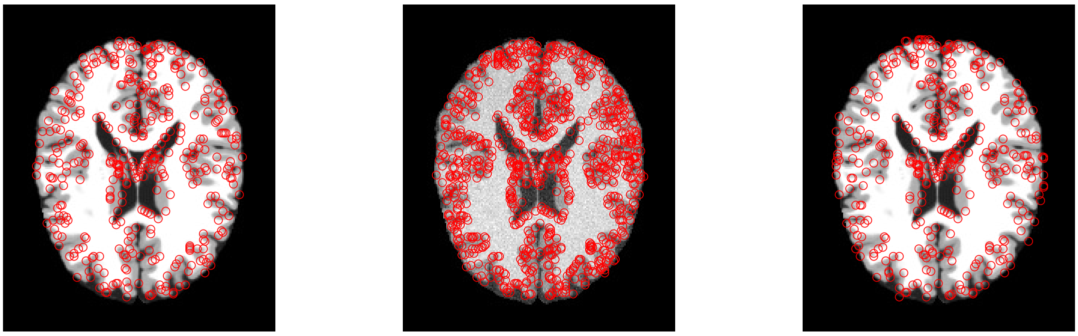
$$DI = \frac{2 \times |X \cap Y|}{|X| + |Y|} \tag{1}$$

**(Q5)** *Will segmentation results (Dice index) be improved when using more signal-modalities?*

**A5:** It can be observed from Table 1 that the segmentation result is improved when the PD volume is used. Since PD data provides more information of image pixels, enlarging the divergence of three groups which contributes to a better dataset for clustering method.

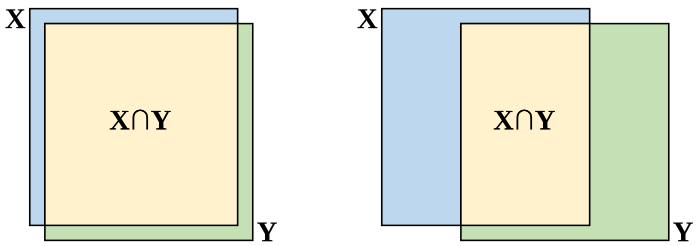
**(Q6)** *How will the noise/intensity non-uniformity affect the segmentation results?*

**A6:** Noise and INU in the volume can decay the performance of segmentation. Commonly, errors are located at the boundary between different brain tissues. Noise and INU is able to blur the boundary further, resulting in more errors.



(a) (b) (c)

*Figure 1: Errors of segmentation results under different conditions as shown in Table 1. (a) T1 & T2, 0% noise, 0% INU. (b) T1 & T2, 5% noise, 20% INU. (c) T1 & T2 & PD, 0% noise, 0% INU.*




(a) (b)

*Figure 2: Illustration of calculating dice index. (a) High similarity. (b) Low similarity.*

## 1.2 Optional Task

### 1.2.1 Jaccard Index & Segmentation on Whole Volume

Jaccard index is an another quantification to measure similarity of two samples. As shown in Equation 2, Jaccard index can be computed as intersection part of two samples over their union. Jaccard index of the segmentation on one brain slice is calculated as displayed in Table 2, where it can be found that the evaluation of segmentation on whole volume is also presented.

$$JI = \frac{|X \cap Y|}{|X| + |Y| - |X \cap Y|} \tag{2}$$

Volume/slice : central axial slice & whole volume created by BrainWeb simulator
Segmentation method : k-means

| | **One Slice** | | | **Whole Volume** | | |
|---|---|---|---|---|---|---|
| | WM | GM | CSF | WM | GM | CSF |
| **Dice Index** | 98.99% | 97.49% | 97.26% | 97.88% | 97.03% | 96.82% |
| **Jaccard Index** | 97.99% | 95.10% | 94.67% | 95.84% | 94.23% | 93.84% |

*Table 2: Similar coefficients for WM, GM and CSF segmentation of both one slice and whole volume.*

### 1.2.2 A Python Implementation Applying Simple Neural Network

A simple neural network is implemented to classify brain tissues into three groups, which are WM, GM and CSF. The simulation of brain volume (T1, T2 and PD) with 0% noise and 0% INU is the sample to be segmented. The volume has 181 slices in total, in which 60% of them are used to train the network, 20% slices are validation samples, the other 20% slices are test set to evaluate the performance of the network.

A two-hidden-layer network is applied to learn the pattern of different tissues. The structure of the network is presented as Figure 3. Three features are contained in each input sample. Both two hidden layers have 256 neurons. Three neurons are placed in output layer, since three possible groups are candidates. Softmax operation generates the probability of the sample belonging to each group. The segmentation result of one test slice is shown in Figure 4, and Table 3 indicates similarity coefficients of this test case.

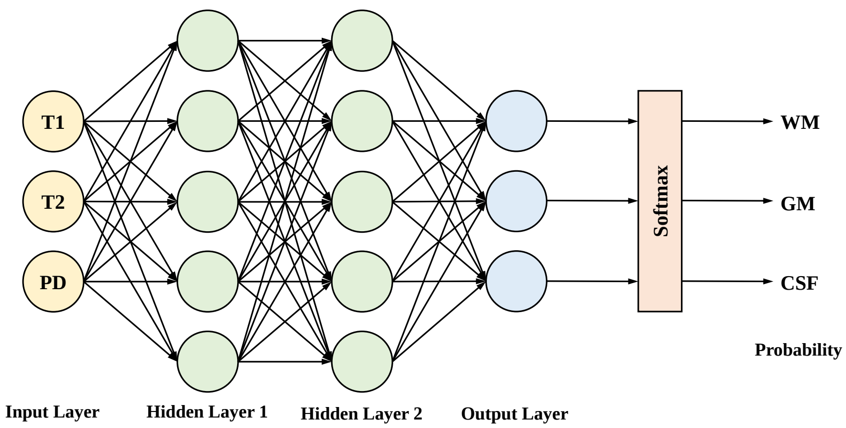



*Figure 3: The structure of the two-hidden-layer neural network.*

It can be observed from figure and table that the result generated by neural network is a bit better than k-means gives. However, unlike k-means, neural network is a kind of supervise learning method which needs true data to train the model. By contrast, k-means is able to cluster data according to different distributions of target groups.

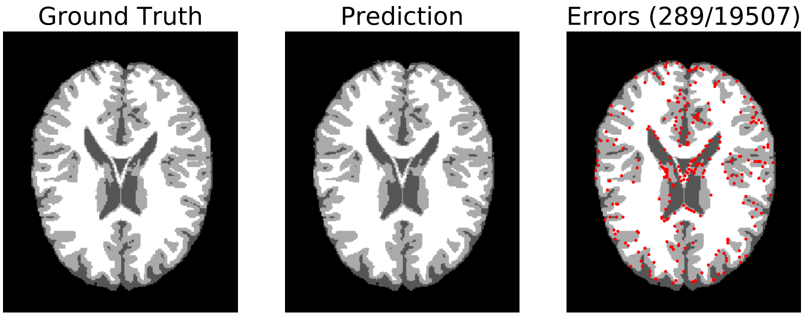



*Figure 4: Errors of segmentation result of one brain slice by a simple neural network.*

| Volume/slice : central axial slice created by BrainWeb simulator | | | |
|---|---|---|---|
| Segmentation method : two-hidden-layer neural network | | | |
| | **WM** | **GM** | **CSF** |
| **Dice Index** | 99.16% | 97.97% | 97.79% |
| **Jaccard Index** | 98.33% | 96.01% | 95.67% |

*Table 3: Similar coefficients for WM, GM and CSF of one slice segmented by neural network.*

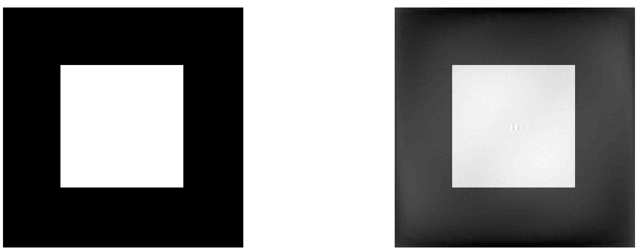
# 2 Task 2. Image Reconstruction by AIR-tools

## 2.1 Compulsory Task

This task is to study AIR-tools, no deliverables in this section.

## 2.2 Optional Task

A square is reconstructed by AIR-tools after 20 iterations of ART-Kaczmarz method without additional noise, which can be observed in Figure 5.



(a) (b)

*Figure 5: Reconstruction of a simple case by applying AIR-tools. (a) A simple case, a square, to be reconstructed. (b) Result of reconstruction after 20 iterations of ART-Kaczmarz method.*