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# **The Gardens2 algorithm**

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## 1 Introduction

The Gardens2 algorithm [Grande-Barreto and Gómez-Gil, 2020] was developed to improve the co-registration output of a generic brain atlas tissue templates to a specific brain target. As a secondary task, the Gardens2 algorithm also can perform hard segmentation. The Gardens2 algorithm was implemented on MATLAB, and all the MRI (brain and atlas) inputs are in NII format. Make sure that the proper packaging for handling NII files is in your MATLAB software. Here<sup>1</sup> is the link to download a package to manipulate NII files. The brain atlases were downloaded from the McConnell Brain Imaging Center [Fonov et al., 2009, Fonov et al., 2011]. The link is here<sup>2</sup>. The 3D slicer software [Fedorov et al., 2012] required to perform the initial co-registration process. Here is the link<sup>3</sup>. It is recommended to use a field bias correction on MRI volume to improve subsequent algorithms’ output. For the implementation described in this document, the N4ITK MRI Bias correction algorithm was used (included in the 3D slicer software). For the algorithm parameters, it is recommended to use a full width at half maximum of 0.20.

## 2 The Gardens2 algorithm

The Gardens2 algorithm requires five NII and one MAT input files. The NII files consist in the brain MRI, brain mask, and three brain tissue templates named cerebrospinal fluid (csf), gray matter (gm), and white matter (wm). The MAT file contains the feature representation of the brain MRI volume. The brain MRI volume used for the implementation was taken from the Internet Brain Segmentation Repository (IBSR) [IBSR, 2007]. The implementation of the Gardens2 algorithm is divided into two parts, hard segmentation and partial maps. But first, it is necessary to perform co-registration and feature extraction.

### 2.1 Atlas co-registration

It is necessary to carry out an initial co-registration process to align the scans of each of the tissue templates with the brain MRI volume. The BRAINS algorithm [Johnson et al., 2007], included in the 3D Slicer platform, was used to perform the initial co-registration process. This procedure requires three inputs (tissue templates). For the implementation described by this manuscript the files used were *mni\_icbm152\_csf\_tal\_nlin\_asym\_09a*, *mni\_icbm152\_gm\_tal\_nlin\_asym\_09a*, and *mni\_icbm152\_wm\_tal\_nlin\_asym\_09a*. The outputs are *csf\_template*, *gm\_template*, and *wm\_template*. the co-registration process is also required to generate the brain mask. For the implementation described here, the file *IBSR\_01\_ana\_brainmask* (provided by the dataset) was co-registered to generate the brain mask. Look the Figure 1 to learn the proper parameter settings.

### 2.2 Feature extraction

The feature representation procedure is composed by two functions *cooc3d* [Carl, 2021] and *GLCMFeatures* [Brynnolfsson, 2021]. Execute the script *Feat\_represent.mat* to compute feature representation. This process requires the use of parallel computing, make sure you have this package installed. For the implementation described by this manuscript the files required are brain mask and *IBSR\_01\_ana\_strip* (mri volume).

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<sup>1</sup><https://la.mathworks.com/matlabcentral/fileexchange/8797-tools-for-nifti-and-analyze-image>

<sup>2</sup><http://www.bic.mni.mcgill.ca/ServicesAtlases/ICBM152Nlin2009>

<sup>3</sup><https://download.slicer.org/>

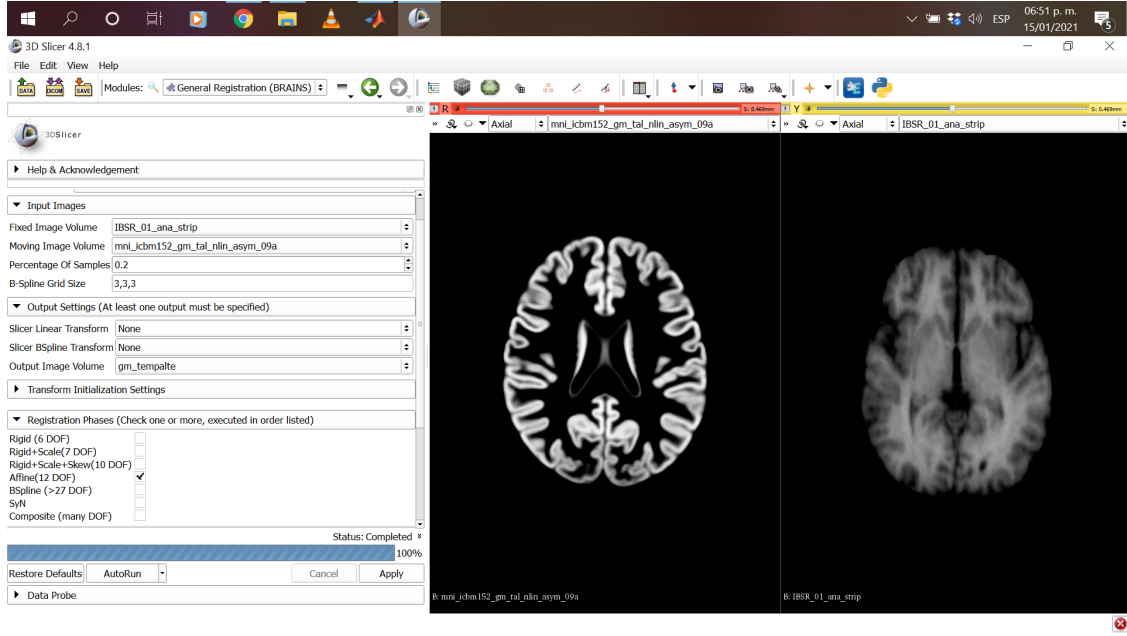


Figure 1. Brain MRI scan.

## 2.3 Hard segmentation

This implementation performs a hard partition of the voxels for each scan of the brain MRI volume. Open the *Gardens2\_hard\_seg.mat* script and execute lines 1 to 57 to initialize the internal parameters of the Gardens2 algorithm. Load the required input files using the following lines

```
atlas_csf = load_nii('Gardens2 pro\csf_template.nii');
atlas_gm = load_nii('Gardens2 pro\gm_template.nii');
atlas_wm = load_nii('Gardens2 pro\wm_template.nii');
GT = load_nii('Gardens2 pro\brain_gt.nii');
brain_msk = load_nii('Gardens2 pro\brainmask.nii');
load('Gardens2 pro\feats_Subject_x.mat','feat_all_ibsr')
```

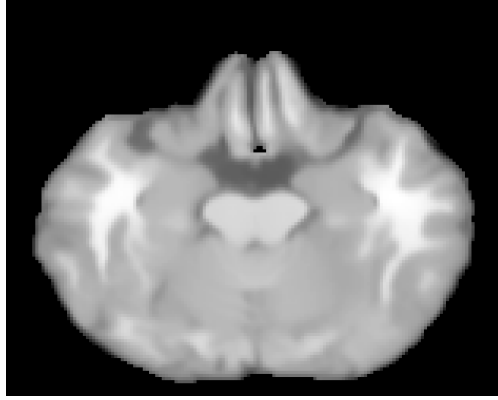
Transform the fuzzy labels of the brain tissue templates to a hard label format

```
[Atlas_parcial, Atlas_crisp] = Atlas_ref(mri, atlas_csf, atlas_gm, atlas_wm);
```

Next, it is necessary to calculate some indices to match the tissue templates' information with the feature representation

```
[col, row, dip] = size(mri.img);
midd = round((rt(2)-rt(1))/2)+rt(1);
slix = midd- 20 : midd + 29;
point = rt(1) : rt(2);
scan_length = length(slix);
```

Inside the main for loop (for  $scan = 1 : scan\_length$ ), the tissue templates' information and the feature representation are matched. The images are oriented in the axial plane. If the matching is correct, for the first iteration, the image depicted in Figure 2 will show up.



**Figure 2. Brain MRI scan.**

```
data = zeros(row*col,35);
slice = slic(scan);
xslice = find(point == slice);
Atlas_crisp_n = imrotate(Atlas_crisp(:,:,slice),90);
Atlas_parcial_n = imrotate(Atlas_parcial(:,:,slice),90);
mask = double(imrotate(round(abs(brain_msk.img(:,:,slice))),90));
xs = find(mask);
data(xs,:) = feat_all_ibs(1:length(xs),:,xslice);
l1nan = isnan(data);
data(l1nan) = eps;
ld = 16:35;
data(:,ld) = [];
BI = reshape(data(:,13),row,col);
aux = normalize(data(xs,:));
data(xs,:) = aux;
imshow(BI,[],'InitialMagnification','fit')
```

In digital image processing, the over-segmentation is an undesired result. However, in the Gardens2 pipeline, the over-segmentation is an intermediate output used to identify homogeneous regions in the image. The following lines perform the over-segmentation using the watershed transformation. The image depicted in Figure 3 will show up if the over-segmentation was successfully executed.

```
[J3,~] = imgradient(BI,'sobel');
L=watershed(J3); % Watershed transformation
LI0=logical(L); %
subregion=max(L(:)); % # de subregiones
subRs=zeros(subregion,size(data,2));
for k=1:subregion
    index=find(L==k);
    subRs(k,:)=mean(data(index,:),1);
end
subRs(1,:) = [];
subregion = size(subRs,1);
La= double(L);
La = La - 1;
l1nan = L == 1;
ln0 = L == 0;
La(l1nan) = 0;
```

```

La(ln0) = 0;
g0 = LI0==0;
AA = BI; AA(g0) = 0;
imshow(AA,[],'InitialMagnification','fit')

```

The Gardens2 algorithm is machine learning-based; therefore, it requires the computation of centroids for each tissue class to later perform the voxel clustering. The following lines execute these procedures. If the code compiles correctly, the image depicted in Figure 4(a) will show.

```

%% Centroid computation
[idx, Ci, tsamp] = refsubRs(subRs,LI0,La,data,Atlas_crisp_n,...
    subreg_cent,tissues);
[suger,Sub_inx,Cin_o,Gardened] = suggestedsubregion(subRs,percent_inclu,Ci,...
    Atlas_parcial_n,La,tissues,data);

%% Clustering subregions
Dis_n = zeros(subregion,tissues+2);
RN = 1 : subregion;
Cin_old = Cin_o;
for k = 1: subregion
    while true
        r = randi([min(RN),max(RN)]);
        ri = find(RN==r);
        if ~isempty(ri)
            RN(ri) = [];
            break
        end
    end
    B = subRs(r,:);
    l2 = find(La == r);
    A = Cin_old;
    Dis_n(r,1:tissues) = sum(A.^2 - 2*A.*B,2)';
    [~,lr] = min(Dis_n(r,1:tissues));
    Dis_n(r,end) = lr;
    Sub_inx(r) = lr;
    Gardened(l2) = lr;
    imshow(Gardened,[],'InitialMagnification','fit')
end

```

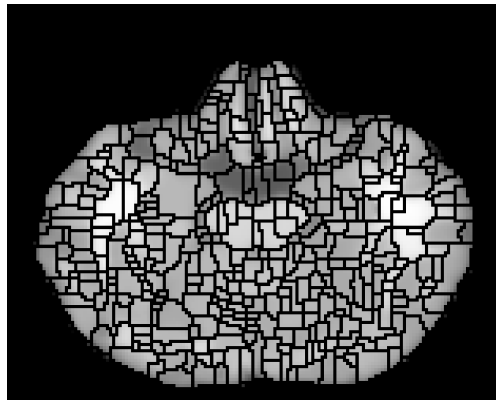
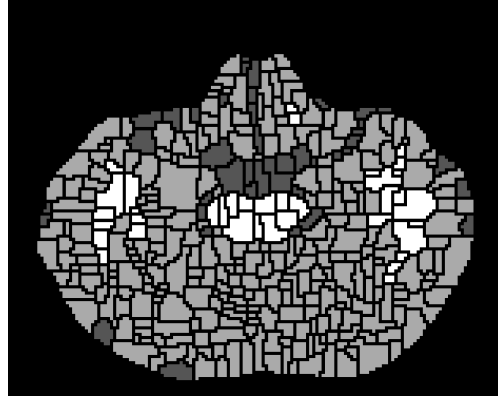
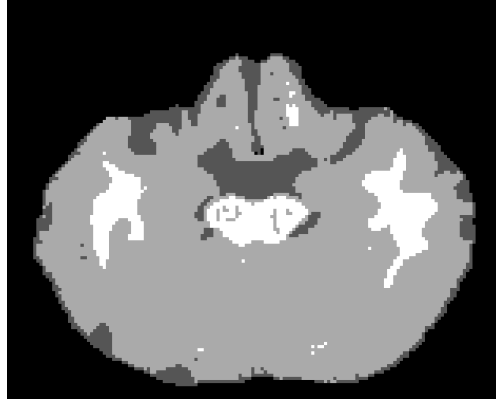


Figure 3. Result of the watershed transformation for the Brain MRI scan.



(a)



(b)

**Figure 4. Hard segmentation result of the Gardens2 algorithm.**

The watershed borders voxels are clustered using euclidean distance. The final result for the first scan of the brain MRI volume is depicted in Figure 4(b). Repeat the process for the remaining images of the volume.

```
%% Clustering of isolated voxels (Watershed borders voxels)
isolated_vox = mask & ~La;
lf = find(isolated_vox);
A = Cin_o;
for q = 1 : length(lf)
    B = data(lf(q),:);
    srd = sum(A.^2 - 2*A.*B,2);
    [~,srm] = min(srd);
    Gardened(lf(q)) = srm;
end
imshow(Gardened,[], 'InitialMagnification','fit')
```

## 2.4 Partial tissue maps

This implementation performs an atlas adjustment for the tissue templates. Before starting, it is necessary to execute the *Gardens2\_hard\_seg.mat* script; some parameters computed in that script

are required for this part of the code. Open the *Gardens2\_partial\_maps.mat* script and execute the lines 1 to 45 to load the required input scripts and set internal parameters of the algorithm. Partial tissue maps are calculated using a novel fuzzy function composed by the Euclidean distance and a regularization term. The centroids for each class are calculated with the following lines

```
%% Compute general centroids for the whole MRI volume
for qp = 1 : zli
    c1(qp,:) = CI(1, :, qp);
    c2(qp,:) = CI(2, :, qp);
    c3(qp,:) = CI(3, :, qp);
end

K(1,:) = mean(c1,1,'omitnan');
K(2,:) = mean(c2,1,'omitnan');
K(3,:) = mean(c3,1,'omitnan');
```

The core of the code is the function *stepfcm2*, which computes the tissue maps adjustment. This function first computes the euclidean distance for the analyzed voxels

```
%% Euclidean distance
% Voxels to analyze
xs = find(IM);
dist = zeros(size(Ci1, 1), size(aux, 1));
for k = 1:size(Ci1, 1)
    dist(k, :) = sqrt(sum(((aux-ones(size(aux,1),1)*Ci1(k,:)).^2),2));
end
```

The regularization process consists of adding a compensation factor, taken from the neighbor voxels on the partial maps, to the estimated euclidean distance. The regularization factor is large when the membership degree of neighboring voxels is large to tissue classes different from the analyzed. Therefore, a voxel's membership degree to a particular tissue class is large when the euclidean distance and the membership degree of neighboring voxels to other tissue classes are low. The following lines execute the outlined process

```
%% Regularization
dist3 = zeros(size(Ci1, 1), size(aux, 1));
for k = 1 : size(aux, 1)
    [xa,ya] = ind2sub([row+(2*d3),col+(2*d3)],xs(k));
    x3 = xa;
    y3 = ya;
    Ia = (tempA(x3-d3:x3+d3,y3-d3:y3+d3,:));
    for q = 1 : tissues
        g = ones(1,3);
        g(q) = 0;
        p2 = gamma*sum(sum((Ia.*w).^expo));
        p2 = p2(:);
        p2 = g*p2;
        dist3(q,k) = dist(q,k) + p2;
    end
end
tmp3 = dist3.^(-2/(expo-1));
U_new3 = tmp3./(ones(tissues, 1)*sum(tmp3)); %
U_new3 = round(U_new3,2);
```

Finally, the adjusted membership degrees of each tissue class are sorted to be displayed in image format. If the code compiles correctly, the image depicted in Figure 5 will show.

```
%% Sorting and visualization
for qp = 1 : 3
    temp4 = zeros(row,col);
    temp4(xs) = U_new3(qp,:);
    tempa(:,:,qp) = temp4;
end

csf_u(:,:,scan) = tempa(:,:,1);
gm_u(:,:,scan) = tempa(:,:,2);
wm_u(:,:,scan) = tempa(:,:,3);

subplot(2,2,1)
imshow(BI,[],'InitialMagnification','fit')
title ('MRI')
subplot(2,2,2)
imshow(tempa(:,:,1),[],'InitialMagnification','fit')
title ('CSF partial map')
subplot(2,2,3)
imshow(tempa(:,:,2),[],'InitialMagnification','fit')
title ('GM partial map')
subplot(2,2,4)
imshow(tempa(:,:,3),[],'InitialMagnification','fit')
title ('WM partial map')
```

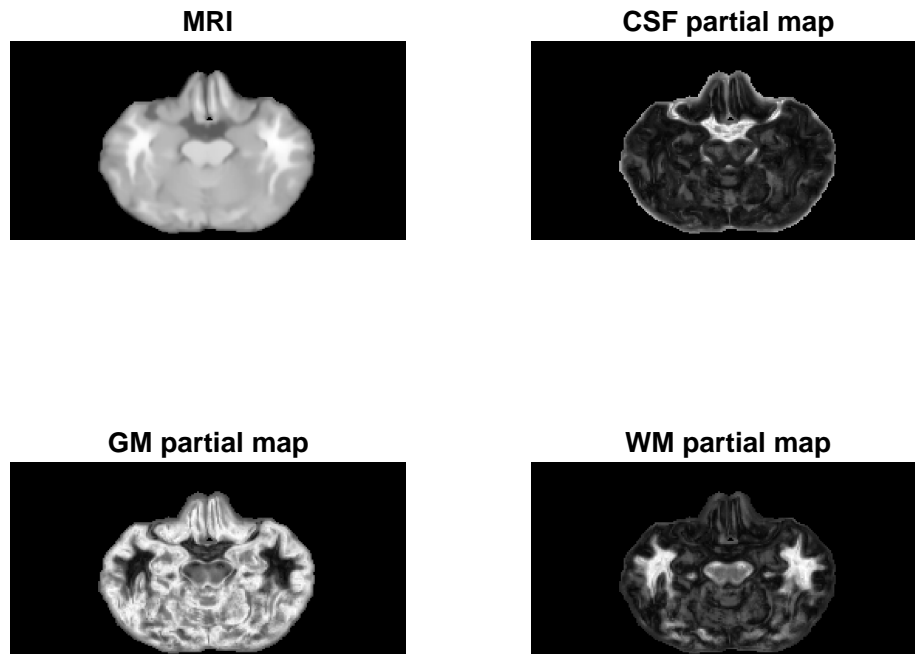


Figure 5. Partial maps for the brain MRI scan.



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