EECE 8395 - Medical Image Segmentation

Project 3

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All local functions are attached at the end of the script.

```
clear all
close all
clc
```

Task 1

1a) First we load in our ground truth mandible and mandible segmentations from 3 raters

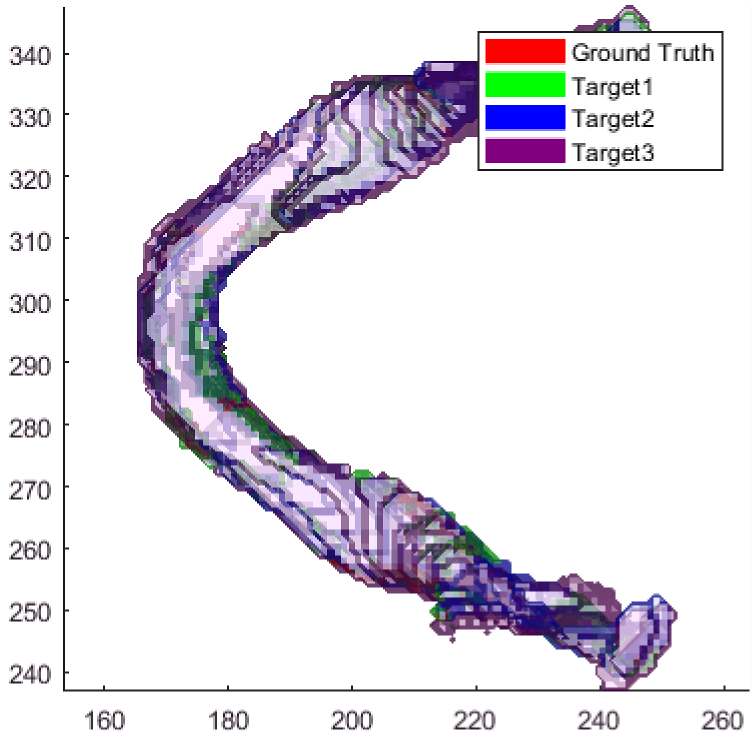
```
data_dir='C:\Users\reasatt\Data\EECE_395\';
gt = ReadNrrd([data_dir '0522c0001\structures\mandible.nrrd']);
t1 = ReadNrrd([data_dir '\0522c0001\structures\target1.nrrd']);
t2 = ReadNrrd([data_dir '\0522c0001\structures\target2.nrrd']);
t3 = ReadNrrd([data_dir '\0522c0001\structures\target3.nrrd']);
```

1b) Now we create surfaces for all of the volumetric segmentations.

```
gts = isosurface(gt.data,0.5);
gts.vertices = gts.vertices.*repmat(gt.voxsz,[length(gts.vertices),1]);
t1s = isosurface(t1.data,0.5);
t1s.vertices = t1s.vertices.*repmat(t1.voxsz,[length(t1s.vertices),1]);
t2s = isosurface(t2.data,0.5);
t2s.vertices = t2s.vertices.*repmat(t2.voxsz,[length(t2s.vertices),1]);
t3s = isosurface(t3.data,0.5);
t3s.vertices = t3s.vertices.*repmat(t3.voxsz,[length(t3s.vertices),1]);
```

1c) Display the surfaces in one figure

```
figure(1);clf
DisplayMesh(gts,[1,0,0],0.5);...
DisplayMesh(t1s,[0,1,0],0.5);...
DisplayMesh(t2s,[0,0,1],0.5);...
DisplayMesh(t3s,[0.5,0,0.5],0.5);...
legend('Ground Truth', 'Target1','Target2','Target3')
```



1d) Calculate volume

```
volume_gts=VolumeofMesh(gts);
volume_t1s=VolumeofMesh(t1s);
volume_t2s=VolumeofMesh(t2s);
volume_t3s=VolumeofMesh(t3s);
```

1e) Measure Dice similarity, mean symmetric absolute surface, Hausdorff distance between the ground truth and each of the three raters

Dice

```
dice_t1=dice(t1.data,gt.data);
dice_t2=dice(t2.data,gt.data);
dice_t3=dice(t3.data,gt.data);
```

Mean symmetric absolute surface, and Hausdorff distance

```
[mn1,mn2,mx1,mx2]=SurfaceDistance(gts,t1s);
meandist1=mean([mn1,mn2])
```

```
meandist1 = 0.1150
```

```
hausdorff1=max([mx1,mx2])
```

```
hausdorff1 = 1.1200
```

```

[mn1,mn2,mx1,mx2]=SurfaceDistance(gts,t2s);
meandist2=mean([mn1,mn2])
```

```
meandist2 = 0.1267
```

```
hausdorff2=max([mx1,mx2])
```

```
hausdorff2 = 2.3787
```

```

[mn1,mn2,mx1,mx2]=SurfaceDistance(gts,t3s);
meandist3=mean([mn1,mn2])
```

```
meandist3 = 0.8586
```

```
hausdorff3=max([mx1,mx2])
```

```
hausdorff3 = 5.2463
```

1g) Create a majority vote segmentation from the three rater segmentations, measure its volume, and measure Dice similarity, Mean surface, and Hausdorff distances to the ground truth

```
mv = t1;
mv.data = t1.data + t2.data + t3.data > 1.5;
mvs = isosurface(mv.data,0.5);
mvs.vertices = mvs.vertices.*repmat(mv.voxsz,[length(mvs.vertices),1]);
[mn1,mn2,mx1,mx2]=SurfaceDistance(gts,mvs);
meandistmv=mean([mn1,mn2])
```

```
meandistmv = 0.0860
```

```
hausdorffmv=max([mx1,mx2])
```

```
hausdorffmv = 1.1200
```

Task 2

Define filepaths

```
data_dir='C:\Users\reasatt\Data\EECE_395';
filepaths_gt=glob([data_dir '\*\structures\mandible.nrrd']);
% glob performs pattern matching of file and directory names based on
% wildcard characters. Downloaded from mathworks file exchange section.
filepaths_t1=glob([data_dir '\*\structures\target1.nrrd']);
filepaths_t2=glob([data_dir '\*\structures\target2.nrrd']);
filepaths_t3=glob([data_dir '\*\structures\target3.nrrd']);
```

Initialize variables to store data

```
n_sample=10;
volume_gts_vec=zeros(1,n_sample);
volume_t1s_vec=zeros(1,n_sample);
volume_t2s_vec=zeros(1,n_sample);
volume_t3s_vec=zeros(1,n_sample);

tp1_vec=zeros(1,n_sample);
tn1_vec=zeros(1,n_sample);
fp1_vec=zeros(1,n_sample);
fn1_vec=zeros(1,n_sample);
tp2_vec=zeros(1,n_sample);
tn2_vec=zeros(1,n_sample);
fp2_vec=zeros(1,n_sample);
fn2_vec=zeros(1,n_sample);
tp3_vec=zeros(1,n_sample);
tn3_vec=zeros(1,n_sample);
fp3_vec=zeros(1,n_sample);
fn3_vec=zeros(1,n_sample);

dice_t1_vec=zeros(1,n_sample);
dice_t2_vec=zeros(1,n_sample);
dice_t3_vec=zeros(1,n_sample);
dice_mv_vec=zeros(1,n_sample);
hausdorff1_vec=zeros(1,n_sample);
hausdorff2_vec=zeros(1,n_sample);
hausdorff3_vec=zeros(1,n_sample);
hausdorffmv_vec=zeros(1,n_sample);
meandist1_vec=zeros(1,n_sample);
meandist2_vec=zeros(1,n_sample);
meandist3_vec=zeros(1,n_sample);
meandistmv_vec=zeros(1,n_sample);
```

Compute data for the first 10 samples

```
for i= 1:n_sample
    tic
    gt = ReadNrrd(filepaths_gt{i});
    t1 = ReadNrrd(filepaths_t1{i});
    t2 = ReadNrrd(filepaths_t2{i});
    t3 = ReadNrrd(filepaths_t3{i});
    gts = isosurface(gt.data,0.5);
    gts.vertices = gts.vertices.*repmat(gt.voxsz,[length(gts.vertices),1]);
    t1s = isosurface(t1.data,0.5);
    t1s.vertices = t1s.vertices.*repmat(t1.voxsz,[length(t1s.vertices),1]);
    t2s = isosurface(t2.data,0.5);
    t2s.vertices = t2s.vertices.*repmat(t2.voxsz,[length(t2s.vertices),1]);
    t3s = isosurface(t3.data,0.5);
    t3s.vertices = t3s.vertices.*repmat(t3.voxsz,[length(t3s.vertices),1]);

    mv = t1;
    mv.data =double(t1.data + t2.data + t3.data > 1.5);
    mvs = isosurface(mv.data,0.5);
    mvs.vertices = mvs.vertices.*repmat(mv.voxsz,[length(mvs.vertices),1]);

    %% Calculate volume
    volume_gts=VolumeofMesh(gts);
    volume_t1s=VolumeofMesh(t1s);
    volume_t2s=VolumeofMesh(t2s);
    volume_t3s=VolumeofMesh(t3s);

    %% Calculate tp,tn,fp,fn
    [tp1,fp1,tn1,fn1]=class_perf(gt.data,t1.data);
    [tp2,fp2,tn2,fn2]=class_perf(gt.data,t2.data);
    [tp3,fp3,tn3,fn3]=class_perf(gt.data,t3.data);

    %% Dice coefficient
    dice_t1=dice(t1.data,gt.data);
    dice_t2=dice(t2.data,gt.data);
    dice_t3=dice(t3.data,gt.data);
    dice_mv=dice(mv.data,gt.data);

    %% Mean symmetric absolute surface, and Hausdorff distance
    [mn1,mn2,mx1,mx2]=SurfaceDistance(gts,t1s);
    meandist1=mean([mn1,mn2]);
    hausdorff1=max([mx1,mx2]);

    [mn1,mn2,mx1,mx2]=SurfaceDistance(gts,t2s);
    meandist2=mean([mn1,mn2]);
    hausdorff2=max([mx1,mx2]);

    [mn1,mn2,mx1,mx2]=SurfaceDistance(gts,t3s);
    meandist3=mean([mn1,mn2]);
    hausdorff3=max([mx1,mx2]);

    [mn1,mn2,mx1,mx2]=SurfaceDistance(gts,mvs);
    meandistmv=mean([mn1,mn2]);
    hausdorffmv=max([mx1,mx2]);

    %% Store all data
    volume_gts_vec(i)=volume_gts;
    volume_t1s_vec(i)=volume_t1s;
    volume_t2s_vec(i)=volume_t2s;
    volume_t3s_vec(i)=volume_t3s;

    tp1_vec(i)=tp1; tn1_vec(i)=tn1;fp1_vec(i)=fp1;fn1_vec(i)=fn1;
    tp2_vec(i)=tp2; tn2_vec(i)=tn2;fp2_vec(i)=fp2;fn2_vec(i)=fn2;
    tp3_vec(i)=tp3; tn3_vec(i)=tn3;fp3_vec(i)=fp3;fn3_vec(i)=fn3;

    dice_t1_vec(i)=dice_t1;
    dice_t2_vec(i)=dice_t2;
    dice_t3_vec(i)=dice_t3;
    dice_mv_vec(i)=dice_mv;

    hausdorff1_vec(i)=hausdorff1;
    hausdorff2_vec(i)=hausdorff2;
    hausdorff3_vec(i)=hausdorff3;
    hausdorffmv_vec(i)=hausdorffmv;

    meandist1_vec(i)=meandist1;
    meandist2_vec(i)=meandist2;
    meandist3_vec(i)=meandist3;
    meandistmv_vec(i)=meandistmv;

    time_elapsed=toc;
    split_path=strsplit(filepaths_gt{i},'\');
    fprintf('%d. computation done for patient %s, time taken: %.2f minutes\n',...
        i,split_path{6}, time_elapsed/60)
end
```

```
1. computation done for patient 0522c0001, time taken: 6.87 minutes
2. computation done for patient 0522c0002, time taken: 14.19 minutes
3. computation done for patient 0522c0003, time taken: 8.23 minutes
4. computation done for patient 0522c0009, time taken: 13.49 minutes
5. computation done for patient 0522c0013, time taken: 9.86 minutes
6. computation done for patient 0522c0014, time taken: 20.48 minutes
7. computation done for patient 0522c0017, time taken: 11.66 minutes
8. computation done for patient 0522c0057, time taken: 19.55 minutes
9. computation done for patient 0522c0070, time taken: 11.86 minutes
10. computation done for patient 0522c0077, time taken: 14.93 minutes
```

```
%save('project_3.mat')
```

```
%load('project_3.mat')
```

2a) Overall confusion matrix

```
tp1_all=sum(tp1_vec);
tn1_all=sum(tn1_vec);
fp1_all=sum(fp1_vec);
fn1_all=sum(fn1_vec);
T_cf1=table([tp1_all; fn1_all],[fp1_all; tn1_all],...
'VariableNames',{'gt_negative','gt_positive'},...
'RowNames',{'t1_negative';'t1_positive'});
fprintf('Confusion matrix between ground truth and target1\n\n'); disp(T_cf1)
```

```
Confusion matrix between ground truth and target1

                   gt_negative    gt_positive
                   ___________    ___________

    t1_negative    1.6507e+05            4190
    t1_positive          3817      3.5923e+08
```

```
tp2_all=sum(tp2_vec);
tn2_all=sum(tn2_vec);
fp2_all=sum(fp2_vec);
fn2_all=sum(fn2_vec);
T_cf2=table([tp2_all; fn2_all],[fp2_all; tn2_all],...
'VariableNames',{'gt_negative','gt_positive'},...
'RowNames',{'t2_negative';'t2_positive'});
fprintf('Confusion matrix between ground truth and target2\n\n'); disp(T_cf2)
```

```
Confusion matrix between ground truth and target2

                   gt_negative    gt_positive
                   ___________    ___________

    t2_negative    1.6597e+05            3654
    t2_positive          2913      3.5923e+08
```

```
tp3_all=sum(tp3_vec);
tn3_all=sum(tn3_vec);
fp3_all=sum(fp3_vec);
fn3_all=sum(fn3_vec);
T_cf3=table([tp3_all; fn3_all],[fp3_all; tn3_all],...
'VariableNames',{'gt_negative','gt_positive'},...
'RowNames',{'t3_negative';'t3_positive'});
fprintf('Confusion matrix between ground truth and target3\n\n'); disp(T_cf3)
```

```
Confusion matrix between ground truth and target3

                   gt_negative    gt_positive
                   ___________    ___________

    t3_negative    1.4798e+05         35285
    t3_positive         20903     3.592e+08
```

2b) Sensitivity and Specificity of the targets

```
Se1=tp1_all/(tp1_all+fn1_all);
Sp1=tn1_all/(tn1_all+fp1_all);
Se2=tp2_all/(tp2_all+fn2_all);
Sp2=tn2_all/(tn2_all+fp2_all);
Se3=tp3_all/(tp3_all+fn3_all);
Sp3=tn3_all/(tn3_all+fp3_all);
T_sen_sp=table([Se1;Se2;Se3],[Sp1; Sp2; Sp3],...
'VariableNames',{'Sensitivity','Specificity'},...
'RowNames',{'t1';'t2';'t3'});
disp(T_sen_sp)
```

```
          Sensitivity    Specificity
          ___________    ___________

    t1       0.9774        0.99999
    t2      0.98275        0.99999
    t3      0.87623         0.9999
```

Task 3

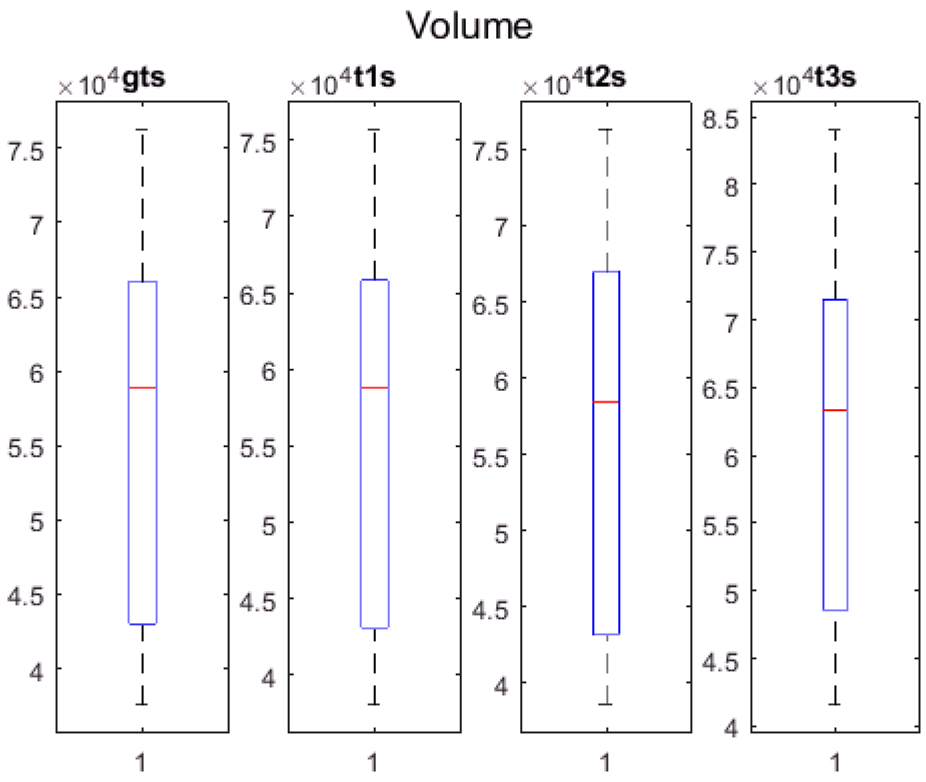
3a) Code is in the livescript.

3b) The segmentations are shown in Task 1c

3c) Boxplot of overall results of Task 1d to 1g

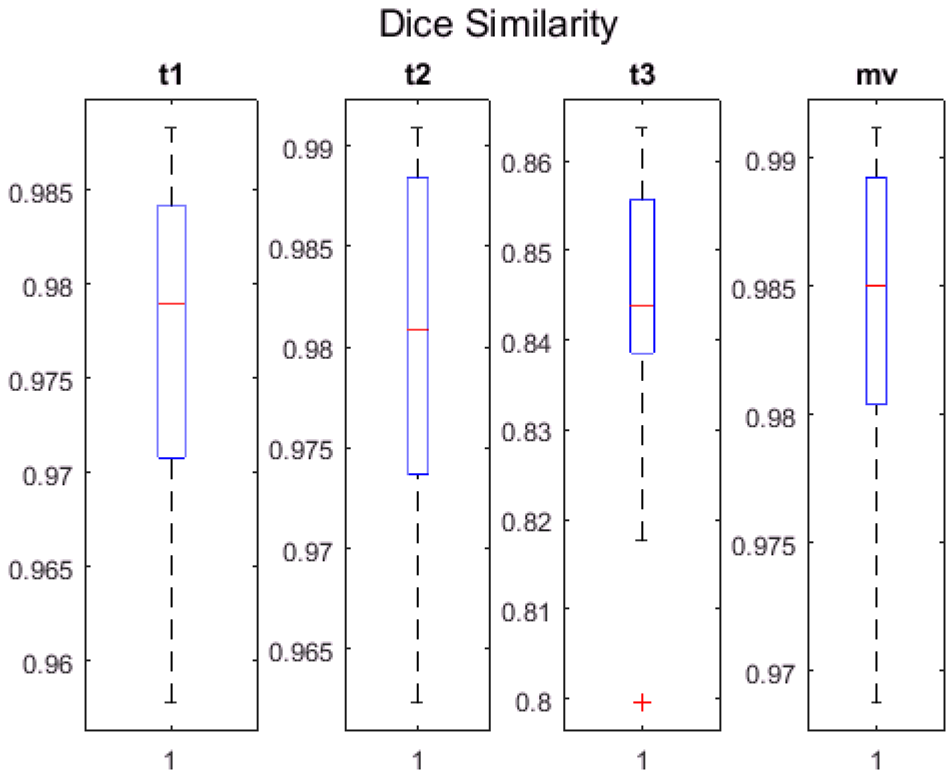
Volume

```
subplot(1,4,1); boxplot(volume_gts_vec);title('gts');...
subplot(1,4,2); boxplot(volume_t1s_vec);title('t1s');...
subplot(1,4,3); boxplot(volume_t2s_vec);title('t2s');...
subplot(1,4,4);boxplot(volume_t3s_vec);title('t3s');...
suptitle('Volume')
```



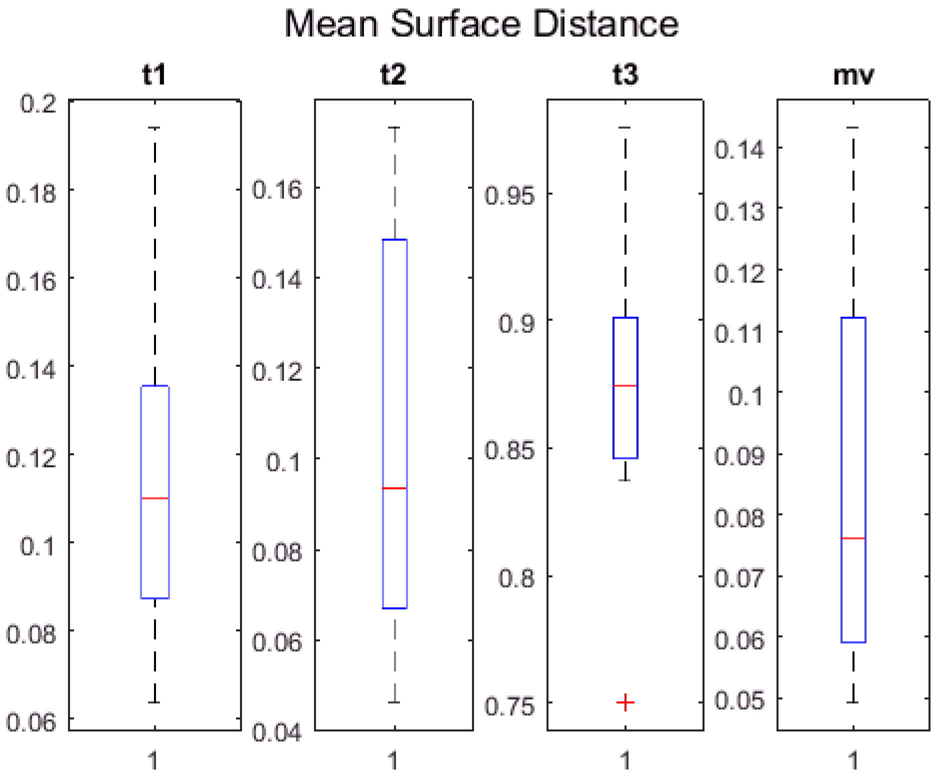
Dice

```
subplot(1,4,1);boxplot(dice_t1_vec); title('t1');...
subplot(1,4,2);boxplot(dice_t2_vec);title('t2');...
subplot(1,4,3); boxplot(dice_t3_vec);title('t3');...
subplot(1,4,4);boxplot(dice_mv_vec);title('mv');
suptitle('Dice Similarity')
```



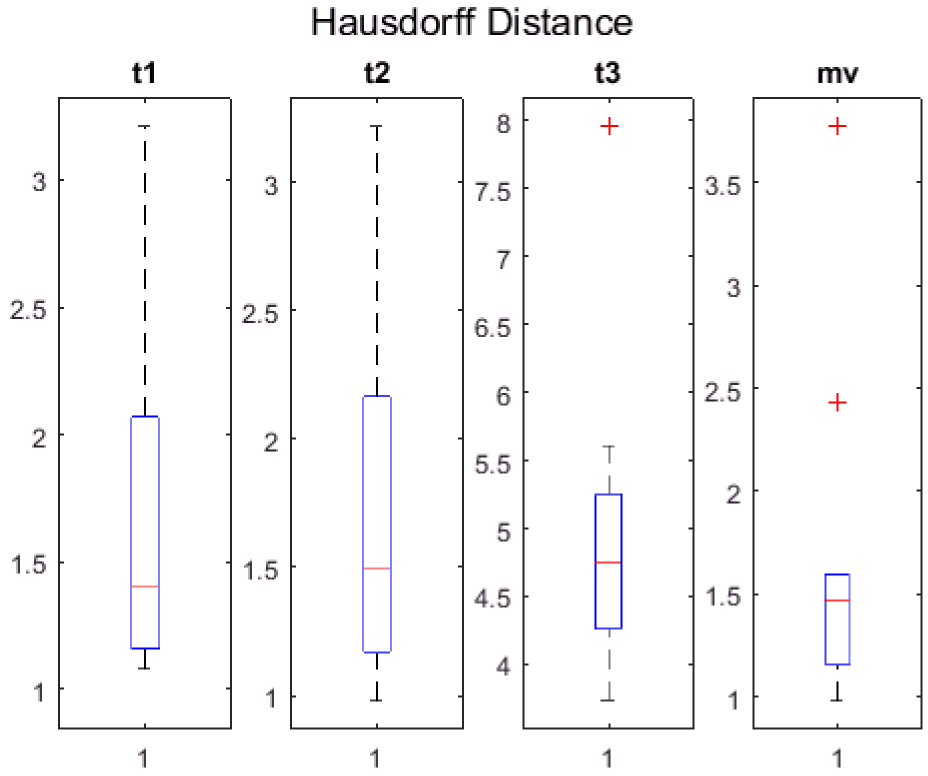
Mean surface distance

```
subplot(1,4,1);boxplot(meandist1_vec);title('t1');...
subplot(1,4,2);boxplot(meandist2_vec);title('t2');...
subplot(1,4,3);boxplot(meandist3_vec);title('t3');...
subplot(1,4,4);boxplot(meandistmv_vec);title('mv');...
suptitle('Mean Surface Distance')
```



Hausdorff distance

```
subplot(1,4,1);boxplot(hausdorff1_vec);title('t1');...
subplot(1,4,2);boxplot(hausdorff2_vec);title('t2');...
subplot(1,4,3);boxplot(hausdorff3_vec);title('t3');...
subplot(1,4,4);boxplot(hausdorffmv_vec);title('mv');...
suptitle('Hausdorff Distance')
```



3d) Wilcoxon signed-rank test

```
[p_volume_1,h_volume_1] = signrank(volume_gts_vec,volume_t1s_vec);
[p_volume_2,h_volume_2] = signrank(volume_gts_vec,volume_t2s_vec);
[p_volume_3,h_volume_3] = signrank(volume_gts_vec,volume_t3s_vec);
[p_volume_12,h_volume_12] = signrank(volume_t1s_vec,volume_t2s_vec);
[p_volume_23,h_volume_23] = signrank(volume_t2s_vec,volume_t3s_vec);
[p_volume_13,h_volume_13] = signrank(volume_t1s_vec,volume_t3s_vec);

[p_dice_12,h_dice_12] = signrank(dice_t1_vec,dice_t2_vec);
[p_dice_23,h_dice_23] = signrank(dice_t2_vec,dice_t3_vec);
[p_dice_13,h_dice_13] = signrank(dice_t1_vec,dice_t3_vec);

[p_meandist_12,h_meandist_12] = signrank(meandist1_vec,meandist2_vec);
[p_meandist_23,h_meandist_23] = signrank(meandist2_vec,meandist3_vec);
[p_meandist_13,h_meandist_13] = signrank(meandist1_vec,meandist3_vec);

[p_hausdorff_12,h_hausdorff_12] = signrank(hausdorff1_vec,hausdorff2_vec);
[p_hausdorff_23,h_hausdorff_23] = signrank(hausdorff2_vec,hausdorff3_vec);
[p_hausdorff_13,h_hausdorff_13] = signrank(hausdorff1_vec,hausdorff3_vec);

T_wil_volume=table([p_volume_1;p_volume_2;p_volume_3;p_volume_12;p_volume_23;p_volume_13],...
    [h_volume_1;h_volume_2;h_volume_3;h_volume_12;h_volume_23;h_volume_13],...
    'VariableNames',{'p_value','test_decision'},...
    'RowNames',{'gt and t1';'gt and t2';'gt and t3';'t1 and t2';'t2 and t3';'t1 and t3';});

T_wil_dice=table([p_dice_12;p_dice_23;p_dice_13],...
    [h_dice_12;h_dice_23;h_dice_13],...
    'VariableNames',{'p_value','test_decision'},...
    'RowNames',{'t1 and t2';'t2 and t3';'t1 and t3';});
```

```
T_wil_meandist=table([p_meandist_12;p_meandist_23;p_meandist_13],...
    [h_meandist_12;h_meandist_23;h_meandist_13],...
    'VariableNames',{'p_value','test_decision'},...
    'RowNames',{'t1 and t2';'t2 and t3';'t1 and t3';});

T_wil_hausdorff=table([p_hausdorff_12;p_hausdorff_23;p_hausdorff_13],...
    [h_hausdorff_12;h_hausdorff_23;h_hausdorff_13],...
    'VariableNames',{'p_value','test_decision'},...
    'RowNames',{'t1 and t2';'t2 and t3';'t1 and t3';});

fprintf('Wilcoxon signed-rank test for volume\n\n');disp(T_wil_volume)
```

```
Wilcoxon signed-rank test for volume

                  p_value     test_decision
                 _________    _____________

    gt and t1       0.8457    false        
    gt and t2      0.69531    false        
    gt and t3    0.0019531    true         
    t1 and t2      0.76953    false        
    t2 and t3    0.0019531    true         
    t1 and t3    0.0019531    true         
```

```
fprintf('Wilcoxon signed-rank test for dice similarity\n\n'); disp(T_wil_dice)
```

```
Wilcoxon signed-rank test for dice similarity

                  p_value     test_decision
                 _________    _____________

    t1 and t2      0.23242    false        
    t2 and t3    0.0019531    true         
    t1 and t3    0.0019531    true         
```

```
fprintf('Wilcoxon signed-rank test for mean surface distance\n\n'); disp(T_wil_meandist)
```

```
Wilcoxon signed-rank test for mean surface distance

                  p_value     test_decision
                 _________    _____________

    t1 and t2      0.32227    false        
    t2 and t3    0.0019531    true         
    t1 and t3    0.0019531    true         
```

```
fprintf('Wilcoxon signed-rank test for Hausdorff distance\n\n'); disp(T_wil_hausdorff)
```

```
Wilcoxon signed-rank test for Hausdorff distance

                  p_value     test_decision
                 _________    _____________

    t1 and t2            1    false        
    t2 and t3    0.0019531    true         
    t1 and t3    0.0019531    true         
```

In the cases that involve target 3, null hypothesis is rejected. Which means that the distribution of the target 3 segmentation is not similar to ground truth, target 1 and target 2 segmentations.

3e) The confusion matrix, sensitivity and specificity is shown in Task 2a and 2b

Used Functions

```
function dc=dice(data1,data2)
% calculate dice
tp=sum(sum(sum((data1 & data2))));
fp=sum(sum(sum((~data1 & data2))));
%tn=sum(sum(sum((~data1 & ~data2))));
fn=sum(sum(sum((data1 & ~data2))));
dc=2*tp/(2*tp+fp+fn);
end

function [mn1,mn2,mx1,mx2]=SurfaceDistance(gts,t1s)
% calculates mean surface distance
points=gts.vertices;
dist_gt2t1_min=1000*ones(1,length(points));
% tic
for i=1:length(t1s.faces)
    dist=Points2TriangleDistance(t1s.vertices,t1s.faces(i,:),points);
%     elapsed=toc;
    dist_gt2t1_min(dist_gt2t1_min>dist)=dist(dist_gt2t1_min>dist);
%     if mod(i,500)==0
%         disp(['forward pass eta: ',num2str(elapsed/i*(length(t1s.faces)-i)/60) ' minutes'])
%     end
end

points=t1s.vertices;
dist_t12gt_min=1000*ones(1,length(points));
% tic
for i=1:length(gts.faces)
    dist=Points2TriangleDistance(gts.vertices,gts.faces(i,:),points);
%     elapsed=toc;
    dist_t12gt_min(dist_t12gt_min>dist)=dist(dist_t12gt_min>dist);
%     if mod(i,500)==0
%         disp(['backward pass eta: ',num2str(elapsed/i*(length(gts.faces)-i)/60) ' minutes'])
%     end
end
mn1=mean(dist_gt2t1_min);
mn2=mean(dist_t12gt_min);
mx1=max(dist_gt2t1_min);
mx2=max(dist_t12gt_min);
end

function dist=Points2TriangleDistance(vertices, face,points)
% calculates minimum distance of all points from a single triangular surface
q1=vertices(face(1),:)';
q2=vertices(face(2),:)';
q3=vertices(face(3),:)';
v1=q2-q1; v2=q3-q1;
V=[v1 v2];
coeff=V\(points'-q1);
dist_vect=points'-(q1+V*coeff);
```

```
dist=vecnorm(dist_vect);
ind_rem=~(coeff(1,:)>=0 & coeff(2,:)>=0 & sum(coeff)<=1);
points_rem=points(ind_rem,:);
v3=q3-q2;

d=v1'*(points_rem'-q1)/vecnorm(v1)^2;
d(d>1)=1; d(d<0)=0;
e=v2'*(points_rem'-q1)/vecnorm(v2)^2;
e(e>1)=1; e(e<0)=0;
f=v3'*(points_rem'-q2)/vecnorm(v3)^2;
f(f>1)=1; f(f<0)=0;

d1=vecnorm(points_rem'-(q1+v1*d));
d2=vecnorm(points_rem'-(q1+v2*e));
d3=vecnorm(points_rem'-(q2+v3*f));
d_vect=[d1;d2;d3];
dist(ind_rem)=min(d_vect);
end

function d=vecnorm(v)
% calculates euclidean norm
d=sqrt(sum(v.^2));
end

function [tp,fp,tn,fn]=class_perf(data1,data2)
% calculates tp, fp, tn, fn from ground truth and target
tp=sum(sum(sum((data1 & data2))));
fp=sum(sum(sum((~data1 & data2))));
tn=sum(sum(sum((~data1 & ~data2))));
fn=sum(sum(sum((data1 & ~data2))));
end

function V=VolumeofMesh(O)
% calculates volume of a mesh
V=0;
for i=1:length(O.faces)
    v1=O.vertices(O.faces(i,1),:);
    v2=O.vertices(O.faces(i,2),:);
    v3=O.vertices(O.faces(i,3),:);
    V=V+...
    (-v3(1)*v2(2)*v1(3)...
    +v2(1)*v3(2)*v1(3)...
    +v3(1)*v1(2)*v2(3)...
    -v1(1)*v3(2)*v2(3)...
    -v2(1)*v1(2)*v3(3)...
    +v1(1)*v2(2)*v3(3))/6;
end
V=abs(V);
end
```