Recognizing Spoken Digits

December 13, 2021

1 Recognizing Spoken Digits: Luis Pereda Amaya

[439]:
```
import pandas as pd
import numpy as np
import seaborn as sns
import matplotlib.pyplot as plt

from sklearn.cluster import KMeans
from sklearn.decomposition import PCA
from sklearn.mixture import GaussianMixture
from sklearn.metrics import confusion_matrix
```

[329]:
```
train_file = open("Train_Arabic_Digit.txt")
test_file = open("Test_Arabic_Digit.txt")
train_lines = train_file.readlines()
test_lines = test_file.readlines()
```

[672]:
```
# Parsing Training Data

count = -1
blocks = []
# Added spaces to the end of my code for this to work
for line in train_lines:
    if(len(line) == 13):
        if(count >= 0):
            blocks.append(block)
        count += 1
        block = []
    else:
        block.append(line.strip())
blocks.append(block[0 : len(block) - 1])

digits = []

for i in range(1, 11):
    digits.append(blocks[((i-1) * 660) : (i * 660)])
```

```
for i in range(10):
    for j in range(len(digits[i])):
        for k in range(len(digits[i][j])):
            digits[i][j][k] = digits[i][j][k].split(" ")
            digits[i][j][k] = [float(num) for num in digits[i][j][k]]


menDigits = []
womenDigits = []
for i in range(10):
    menDigits.append(digits[i][0:330])
    womenDigits.append(digits[i][330:660])

Digits = []
for i in range(10):
    frames = []
    for j in range(len(digits[i])):
        frames = frames + digits[i][j]
    Digits.append(frames)
digits = Digits

MenDigits = []
for i in range(10):
    men_frames = []
    for j in range(len(menDigits[i])):
        men_frames = men_frames + menDigits[i][j]
    MenDigits.append(men_frames)

WomenDigits = []
for i in range(10):
    women_frames = []
    for j in range(len(womenDigits[i])):
        women_frames = women_frames + womenDigits[i][j]
    WomenDigits.append(women_frames)
```

[677]:
```
len(blocks[0])
time = np.linspace(-1, 2, 38)

plt.figure(figsize=[20,20])
plt.xlabel("Time")
plt.ylabel("Frequency")
plt.xlim([])
plt.title("Plot of Mel-Frequency Cepstral Coefficient")
plt.plot(time, blocks[0])
```

[677]: [<matplotlib.lines.Line2D at 0x7fe61d53d5e0>,
<matplotlib.lines.Line2D at 0x7fe61d53d760>,
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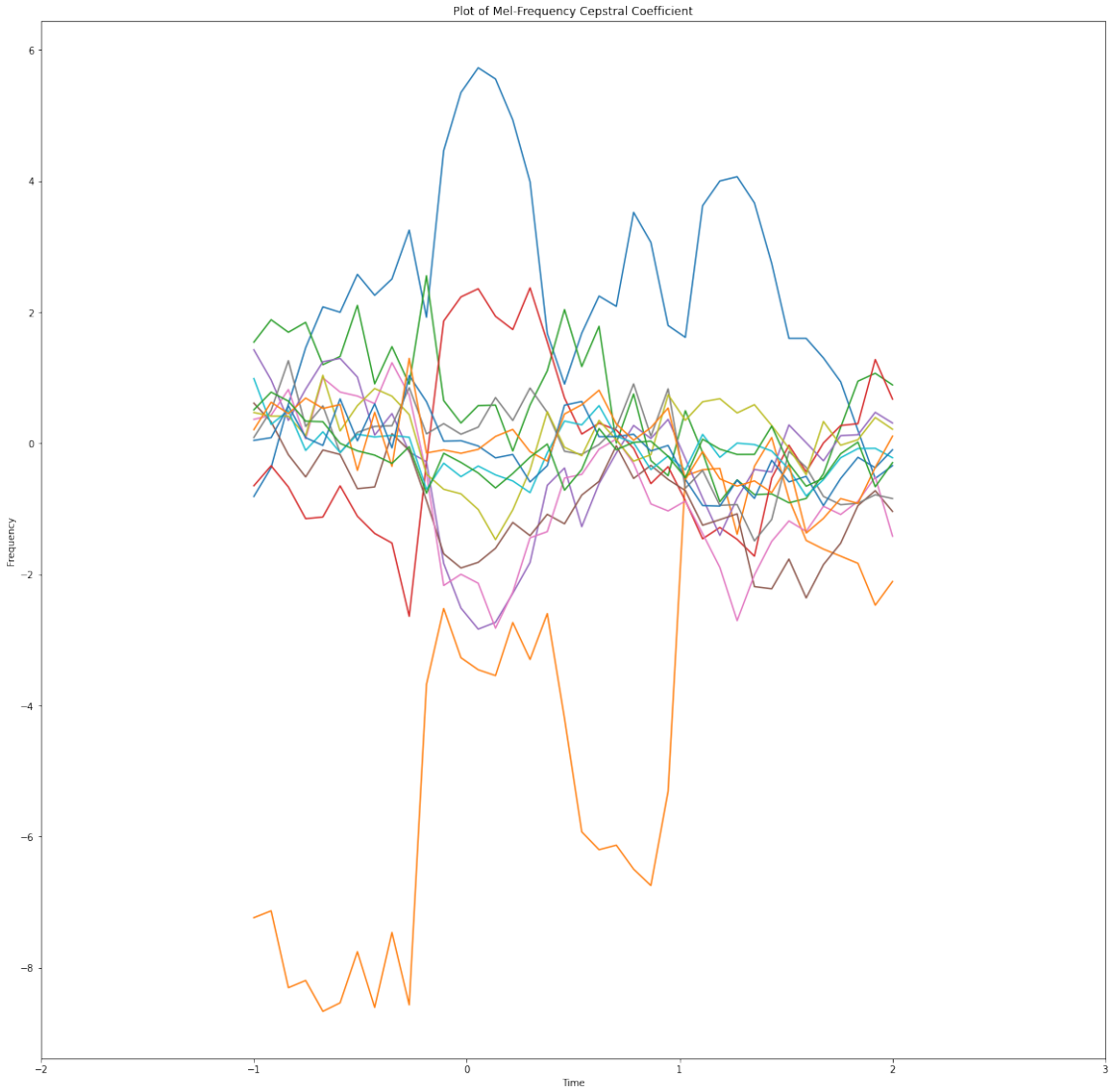
<matplotlib.lines.Line2D at 0x7fe61d53d640>,
<matplotlib.lines.Line2D at 0x7fe6311fe0a0>,
<matplotlib.lines.Line2D at 0x7fe61d52afa0>,
<matplotlib.lines.Line2D at 0x7fe6311fe280>,
<matplotlib.lines.Line2D at 0x7fe6311fe340>]



[333]:
```
# Parsing Test Data
count = -1
blocks = []
# Added spaces to the end of my code for this to work
for line in test_lines:
    if(len(line) == 13):
        if(count >= 0):
            blocks.append(block)
        count += 1
        block = []
    else:
        block.append(line.strip())
blocks.append(block[0:len(block) - 1])


test_digits = []
for i in range(1,11):
    test_digits.append(blocks[((i-1) * 220) : (i * 220)])

for i in range(10):
    for j in range(len(test_digits[i])):
        for k in range(len(test_digits[i][j])):
            test_digits[i][j][k] = test_digits[i][j][k].split(" ")
            test_digits[i][j][k] = [float(num) for num in test_digits[i][j][k]]
menTestDigits = []
womenTestDigits = []
for i in range(10):
    menTestDigits.append(test_digits[i][0:110])
    womenTestDigits.append(test_digits[i][110:220])

test_Digits = []
for i in range(10):
    frames = []
    for j in range(len(test_digits[i])):
        frames = frames + test_digits[i][j]
    test_Digits.append(frames)
# Will use test_blocks to iterate through blocks in test
test_blocks = test_digits

test_digits = test_Digits
```

[413]:
```
digits_subset = []

for i in range(len(Digits)):
    dig = []
    for line in Digits[i]:
        dig.append(line[0:12])
```

```
    digits_subset.append(dig)

test_blocks_subset = []

for i in range(len(test_blocks)):
    luis = []
    for block in test_blocks[i]:
        blo = []
        for line in block:
            blo.append(line[0:12])
        luis.append(blo)
    test_blocks_subset.append(luis)
```

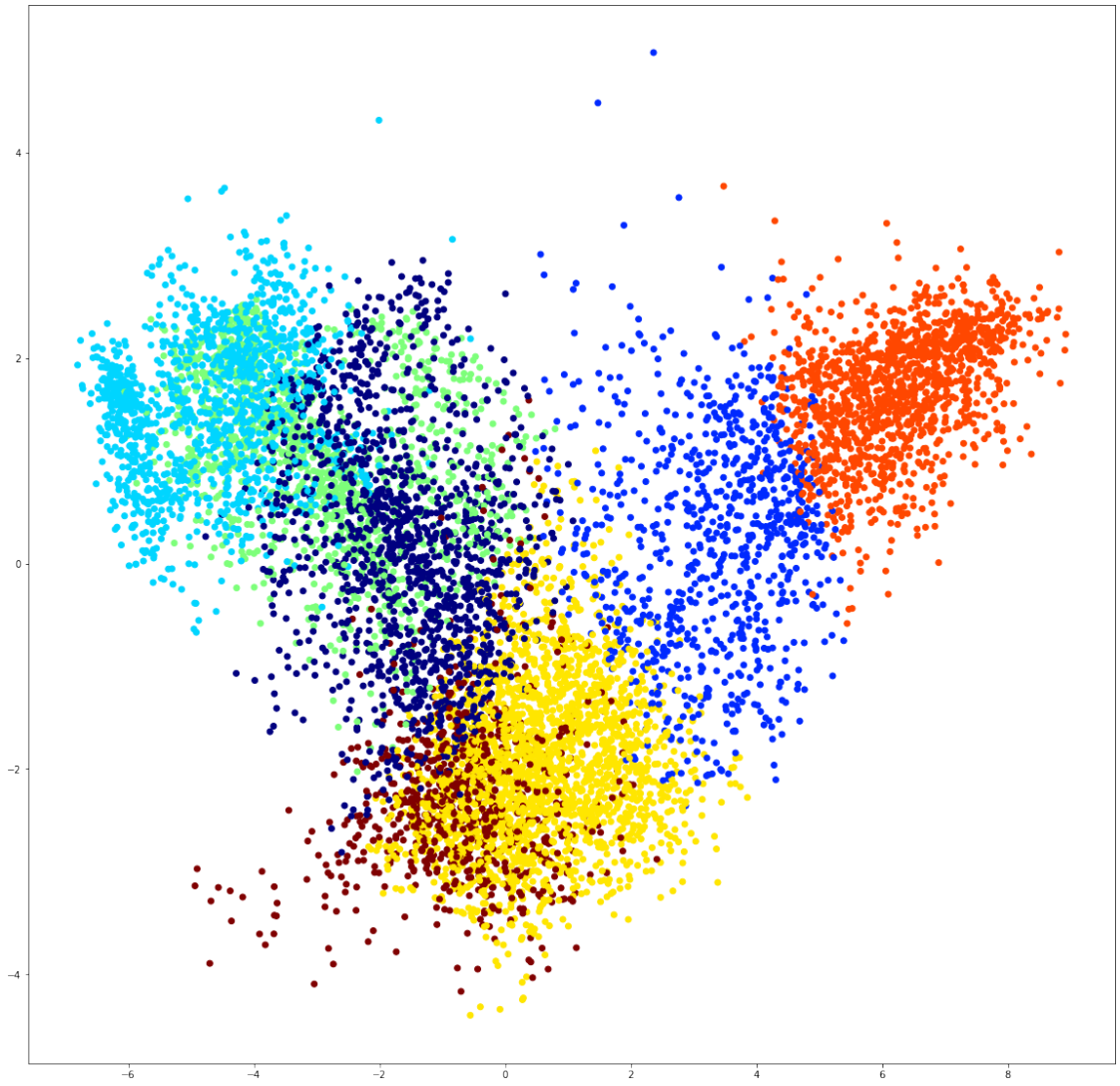
[416]:
```
print(len(test_blocks[0][0][0]))
print(len(test_blocks_subset[0][0][0]))
```

```
13
12
```

1.1 K-means

[338]:
```
def findKmeans(arr, digit, clusters):
    kmeans = KMeans(n_clusters=clusters).fit(arr[digit])
#     labels = kmeans.predict(arr[digit])
    labels = kmeans.labels_
    return kmeans, labels

def findAndPlotKmeans(arr, digit, clusters):
    plt.figure(figsize=[20,20])

    kmeans = KMeans(n_clusters=clusters).fit(arr[digit])
    cluster_centers = kmeans.cluster_centers_
    labels = kmeans.predict(test_Digits[digit])

    pca = PCA(n_components=2)
    pca_data = pca.fit_transform(test_Digits[digit])

    plt.scatter(pca_data[:, 0], pca_data[:, 1], c = labels, cmap='jet')
    return kmeans
```

[739]:
```
kmeans = findAndPlotKmeans(Digits, 2, 7)
```



1.1.1 GMM from KMeans

[604]:
```
digit_clusters = [6, 5, 5, 6, 7, 6, 5, 5, 9, 4]
digit_components = [6, 5, 5, 6, 7, 6, 5, 5, 9, 4]
kmeans_arr = []
kmeans_labels = []
for i in range(10):
    kmeans_arr.append(findKmeans(Digits, i, digit_clusters[i])[0])
    kmeans_labels.append(findKmeans(Digits, i, digit_clusters[i])[1])
```

[605]:
```
kmeans_arr_men = []
kmeans_arr_women = []
kmeans_labels_men = []
```

```
kmeans_labels_women = []

for i in range(10):
    kmeans_arr_men.append(findKmeans(MenDigits, i, digit_clusters[i])[0])
    kmeans_labels_men.append(findKmeans(MenDigits, i, digit_clusters[i])[1])

    kmeans_arr_women.append(findKmeans(WomenDigits, i, digit_clusters[i])[0])
    kmeans_labels_women.append(findKmeans(WomenDigits, i, digit_clusters[i])[1])
```

[606]:
```
kmeans_arr_subset = []
kmeans_labels_subset = []

for i in range(10):
    kmeans_arr_subset.append(findKmeans(digits_subset, i, digit_clusters[i])[0])
    kmeans_labels_subset.append(findKmeans(digits_subset, i,␣
 ↪digit_clusters[i])[1])
```

[607]:
```
kmeans_centers = []
for digit_model in kmeans_arr:
    kmeans_centers.append(digit_model.cluster_centers_)
```

[608]:
```
kmeans_centers_men = []
for digit_model in kmeans_arr_men:
    kmeans_centers_men.append(digit_model.cluster_centers_)
kmeans_centers_women = []
for digit_model in kmeans_arr_women:
    kmeans_centers_women.append(digit_model.cluster_centers_)
```

[609]:
```
kmeans_centers_subset = []
for digit_model in kmeans_arr_subset:
    kmeans_centers_subset.append(digit_model.cluster_centers_)
```

[610]:
```
df_arr = []
for i in range(10):
    cluster_df = pd.DataFrame()
    cluster_df['cluster'] = kmeans_labels[i]
    cluster_df['data'] = Digits[i]
    df_arr.append(cluster_df)
```

[611]:
```
df_arr_men = []
df_arr_women = []
for i in range(10):
    cluster_df_men = pd.DataFrame()
    cluster_df_men['cluster'] = kmeans_labels_men[i]
    cluster_df_men['data'] = MenDigits[i]
    df_arr_men.append(cluster_df_men)
```

```
    cluster_df_women = pd.DataFrame()
    cluster_df_women['cluster'] = kmeans_labels_women[i]
    cluster_df_women['data'] = WomenDigits[i]
    df_arr_women.append(cluster_df_women)
```

[612]:
```
df_arr_subset = []
for i in range(10):
    cluster_df_subset = pd.DataFrame()
    cluster_df_subset['cluster'] = kmeans_labels_subset[i]
    cluster_df_subset['data'] = digits_subset[i]
    df_arr_subset.append(cluster_df_subset)
```

[613]:
```
print(len(df_arr[0]))
print(len(df_arr_men[0]))
print(len(df_arr_women[0]))
print(len(df_arr_subset[0]))
```

```
23344
11588
11756
23344
```

[614]:
```
def findFullCov(data):
    arr = []
    for i in range(10):
        digit_covariances = []
        for j in range(digit_clusters[i]):
            np_arr = np.array(data[i][data[i].cluster == j])
            samples = np.array([x[1] for x in np_arr])
            cov = np.cov(samples.T)
            digit_covariances.append(cov)
        arr.append(digit_covariances)
    return arr
```

[615]:
```
full_covariances = findFullCov(df_arr)
full_covariances_men = findFullCov(df_arr_men)
full_covariances_women = findFullCov(df_arr_women)
full_covariances_subset = findFullCov(df_arr_subset)
```

[616]:
```
print(len(full_covariances[0]))
print(len(full_covariances[0][0]))
print(len(full_covariances[0][0][0]))
```

```
6
13
13
```

[617]:
```
def findDiagCov(fullCov):
    arr = []
    for i in range(10):
        cluster_diag_covs = []
        for cluster_cov in fullCov[i]:
            diag = np.diag(np.diag(cluster_cov))
            cluster_diag_covs.append(diag)
        arr.append(cluster_diag_covs)
    return arr
```

[618]:
```
diag_covariances = findDiagCov(full_covariances)
diag_covariances_men = findDiagCov(full_covariances_men)
diag_covariances_women = findDiagCov(full_covariances_women)
diag_covariances_subset = findDiagCov(full_covariances_subset)
```

[619]:
```
print(len((diag_covariances)))
print(len(diag_covariances[0]))
print(len((diag_covariances[0][0])))
```

```
10
6
13
```

[620]:
```
def findSphericalCov(data):
    arr = []
    for i in range(10):
        demeaned_arr = []
        demeaned_data = np.array([])
        for j in range(digit_clusters[i]):
            np_arr = np.array(data[i][data[i].cluster == j])
            samples = np.array([x[1] for x in np_arr])
            mean = samples.mean(axis = 0)
            demeaned = samples - mean
            demeaned_arr.append(demeaned)
        demeaned_data = np.concatenate(demeaned_arr)
        digit_var = np.var(demeaned_data)
        var_mat = np.identity(13) * digit_var
        arr.append(var_mat)
    return arr
```

[621]:
```
sphere_covariances = findSphericalCov(df_arr)
sphere_covariances_men = findSphericalCov(df_arr_men)
sphere_covariances_women = findSphericalCov(df_arr_women)
sphere_covariances_subset = findSphericalCov(df_arr_subset)
```

[622]:
```
print(len(sphere_covariances[0][0]))
```

```
13
```

[623]:
```
def findTiedCov(data):
    arr = []
    for i in range(10):
        demeaned_arr = []
        demeaned_data = np.array([])
        for j in range(digit_clusters[i]):
            np_arr = np.array(data[i][data[i].cluster == j])
            samples = np.array([x[1] for x in np_arr])
            mean = samples.mean(axis = 0)
            demeaned = samples - mean
            demeaned_arr.append(demeaned)
        demeaned_data = np.concatenate(demeaned_arr)
        demeaned_cov = np.cov(demeaned_data.T)
        arr.append(demeaned_cov)
    return arr
```

[624]:
```
tied_covariances = findTiedCov(df_arr)
tied_covariances_men = findTiedCov(df_arr_men)
tied_covariances_women = findTiedCov(df_arr_women)
tied_covariances_subset = findTiedCov(df_arr_subset)
```

[625]:
```
print(len(tied_covariances[0]))
print(len(tied_covariances[0][0]))
```

```
13
13
```

[626]:
```
def findWeights(data):
    arr = []
    for i in range(10):
        weights = []
        for j in range(digit_clusters[i]):
            np_arr = np.array(data[i][data[i].cluster == j])
            samples = np.array([x[1] for x in np_arr])
            weight = len(samples) / len(data[i])
            weights.append(weight)
        arr.append(weights)
    return arr
```

[627]:
```
digit_weights = findWeights(df_arr)
digit_weights_men = findWeights(df_arr_men)
digit_weights_women = findWeights(df_arr_women)
digit_weights_subset = findWeights(df_arr_subset)
```

[628]:
```
def setFullCovModel(centers, covs, weights):
    arr = []
    for i in range(10):
```

```
        gmm = GaussianMixture(n_components=digit_components[i],␣
↪covariance_type='full')
        gmm.means_ = centers[i]
        gmm.covariances_ = covs[i]
        gmm.weights_ = weights[i]
        gmm.precisions_ = np.linalg.inv(covs[i])
        gmm.precisions_cholesky_ = np.linalg.cholesky(gmm.precisions_)
        arr.append(gmm)
    return arr
```

[629]:
```
KMeans_GMM_full_cov = setFullCovModel(kmeans_centers, full_covariances,␣
↪digit_weights)
KMeans_GMM_full_cov_men = setFullCovModel(kmeans_centers_men,␣
↪full_covariances_men, digit_weights_men)
KMeans_GMM_full_cov_women = setFullCovModel(kmeans_centers_women,␣
↪full_covariances_women, digit_weights_women)
KMeans_GMM_full_cov_subset = setFullCovModel(kmeans_centers_subset,␣
↪full_covariances_subset, digit_weights_subset)
```

[630]:
```
def setTiedCovModel(centers, covs, weights):
    arr = []
    for i in range(10):
        gmm = GaussianMixture(n_components=digit_components[i],␣
↪covariance_type='tied')
        gmm.means_ = centers[i]
        gmm.covariances_ = covs[i]
        gmm.weights_ = weights[i]
        gmm.precisions_ = np.linalg.inv(covs[i])
        gmm.precisions_cholesky_ = np.linalg.cholesky(gmm.precisions_)
        arr.append(gmm)
    return arr
```

[631]:
```
KMeans_GMM_tied_cov = setTiedCovModel(kmeans_centers, tied_covariances,␣
↪digit_weights)
KMeans_GMM_tied_cov_men = setTiedCovModel(kmeans_centers_men,␣
↪tied_covariances_men, digit_weights_men)
KMeans_GMM_tied_cov_women = setTiedCovModel(kmeans_centers_women,␣
↪tied_covariances_women, digit_weights_women)
KMeans_GMM_tied_cov_subset = setTiedCovModel(kmeans_centers_subset,␣
↪tied_covariances_subset, digit_weights_subset)
```

[632]:
```
def setDiagCovModel(centers, covs, weights):
    arr = []
    for i in range(10):
        gmm = GaussianMixture(n_components=digit_components[i],␣
↪covariance_type='diag')
```

```
        gmm.means_ = centers[i]
        gmm.covariances_ = [np.diag(cluster) for cluster in covs[i]]
        gmm.weights_ = weights[i]
        diag_precisions_matrix = np.linalg.inv(covs[i])
        gmm.precisions_ = [np.diag(item) for item in diag_precisions_matrix]
        gmm.precisions_cholesky_ = np.array([np.diag(item) for item in np.
 ↪linalg.cholesky(diag_precisions_matrix)])
        arr.append(gmm)
    return arr
```

[633]:
```
KMeans_GMM_diag_cov = setDiagCovModel(kmeans_centers, diag_covariances,␣
 ↪digit_weights)
KMeans_GMM_diag_cov_men = setDiagCovModel(kmeans_centers_men,␣
 ↪diag_covariances_men, digit_weights_men)
KMeans_GMM_diag_cov_women = setDiagCovModel(kmeans_centers_women,␣
 ↪diag_covariances_women, digit_weights_women)
KMeans_GMM_diag_cov_subset = setDiagCovModel(kmeans_centers_subset,␣
 ↪diag_covariances_subset, digit_weights_subset)
```

[634]:
```
def setSphericalCovModel(centers, covs, weights):
    arr = []
    for i in range(10):
        gmm = GaussianMixture(n_components=digit_components[i],␣
 ↪covariance_type='spherical')
        gmm.means_ = centers[i]
        gmm.covariances_ = covs[i][0][0]
        gmm.weights_ = weights[i]
        sphere_precisions_matrix = np.linalg.inv(covs[i])
        gmm.precisions_ = sphere_precisions_matrix[0][0]
        gmm.precisions_cholesky_ = np.linalg.
 ↪cholesky(sphere_precisions_matrix)[0][0]
        arr.append(gmm)
    return arr
```

[635]:
```
KMeans_GMM_spherical_cov = setSphericalCovModel(kmeans_centers,␣
 ↪sphere_covariances, digit_weights)
KMeans_GMM_spherical_cov_men = setSphericalCovModel(kmeans_centers_men,␣
 ↪sphere_covariances_men, digit_weights_men)
KMeans_GMM_spherical_cov_women = setSphericalCovModel(kmeans_centers_women,␣
 ↪sphere_covariances_women, digit_weights_women)
KMeans_GMM_spherical_cov_subset = setSphericalCovModel(kmeans_centers_subset,␣
 ↪sphere_covariances_subset, digit_weights_subset)
```

1.1.2 ML Classification

[636]:
```
def findAccuracyNonGendered(covs):
    correct = 0
    total = 0
    for i in range(10):
        for block in test_blocks[i]:
            maxScore = covs[0].score(block)
            maxIndex = 0
            total += 1
            for digit in range(10):
                score = covs[digit].score(block)
                if(score > maxScore):
                    maxScore = score
                    maxIndex = digit
            if(maxIndex == i):
                correct += 1
    print(correct / total)
```

[637]:
```
def findAccuracyGendered(covs_men, covs_women):
    correct = 0
    total = 0
    for i in range(10):
        for block in menTestDigits[i]:
            maxScore = covs_men[0].score(block)
            maxIndex = 0
            total += 1
            for digit in range(10):
                score = covs_men[digit].score(block)
                if(score > maxScore):
                    maxScore = score
                    maxIndex = digit
            if(maxIndex == i):
                correct += 1
    for i in range(10):
        for block in womenTestDigits[i]:
            maxScore = covs_women[0].score(block)
            maxIndex = 0
            total += 1
            for digit in range(10):
                score = covs_women[digit].score(block)
                if(score > maxScore):
                    maxScore = score
                    maxIndex = digit
            if(maxIndex == i):
                correct += 1
    print(correct/total)
```

[638]:
```
def findAccuracySubset(covs):
    correct = 0
    total = 0
    for i in range(10):
        for block in test_blocks_subset[i]:
            maxScore = covs[0].score(block)
            maxIndex = 0
            total += 1
            for digit in range(10):
                score = covs[digit].score(block)
                if(score > maxScore):
                    maxScore = score
                    maxIndex = digit
            if(maxIndex == i):
                correct += 1
    print(correct / total)
```

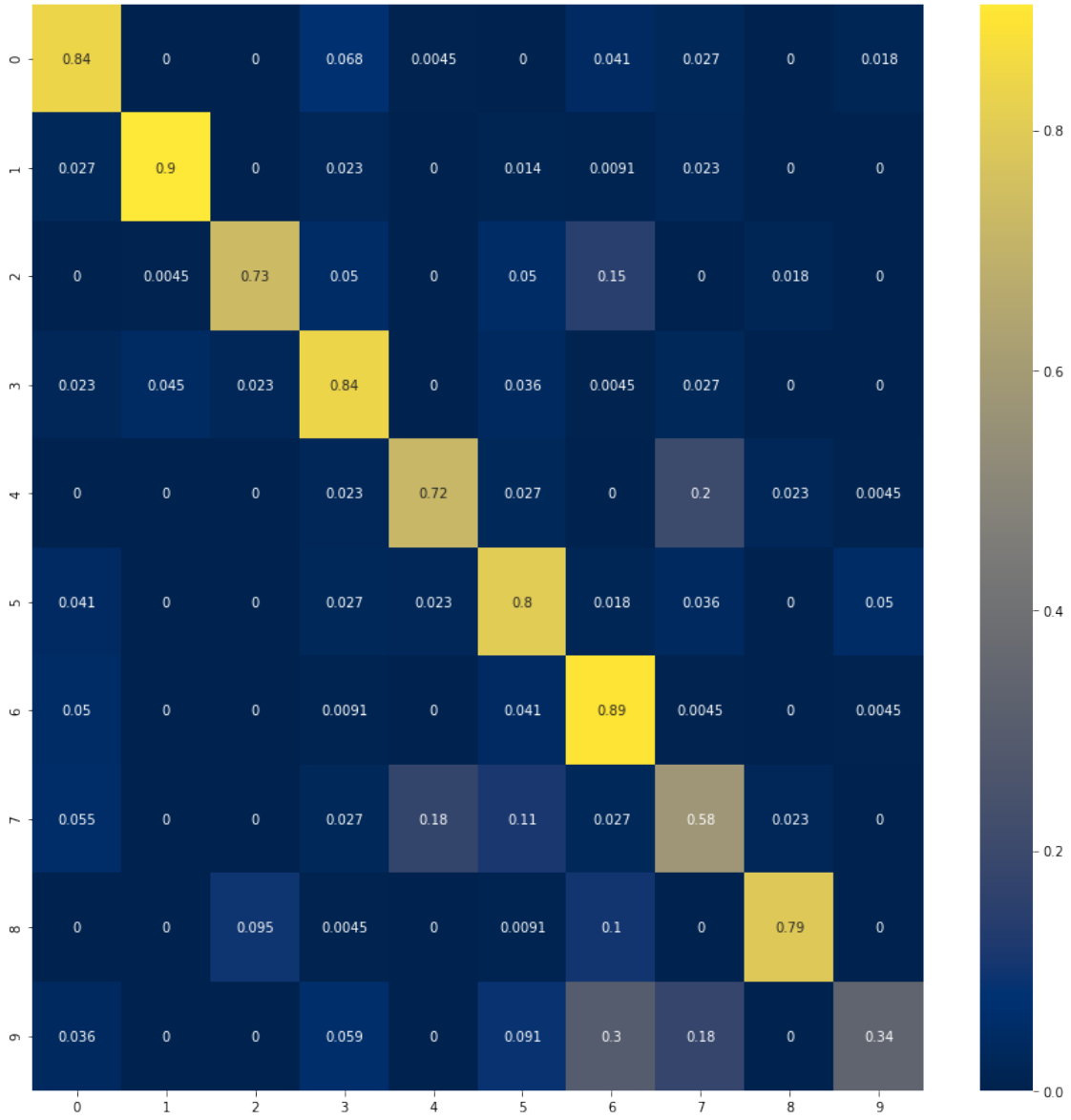
[639]:
```
def findConfusionMatrix(model, blocksForTest):
    true_values = []
    predicted_values = []

    for i in range(2200):
        true_values.append(i // 220)

    for i in range(10):
        for block in blocksForTest[i]:
            maxScore = model[0].score(block)
            maxIndex = 0
            for digit in range(10):
                score = model[digit].score(block)
                if(score > maxScore):
                    maxScore = score
                    maxIndex = digit
            predicted_values.append(maxIndex)
    cmat = confusion_matrix(true_values, predicted_values, normalize='true')
    return cmat
```

[722]:
```
def findConfusionMatrixGendered(covs_men, covs_women):
    true_values_men = []
    true_values_women = []
    predicted_values = []

    for i in range(1100):
        true_values_men.append(i // 110)
        true_values_women.append(i // 110)

    for i in range(10):
```

```
        for block in menTestDigits[i]:
            maxScore = covs_men[0].score(block)
            maxIndex = 0
            for digit in range(10):
                score = covs_men[digit].score(block)
                if(score > maxScore):
                    maxScore = score
                    maxIndex = digit
            predicted_values.append(maxIndex)
    for i in range(10):
        for block in womenTestDigits[i]:
            maxScore = covs_women[0].score(block)
            maxIndex = 0
            for digit in range(10):
                score = covs_women[digit].score(block)
                if(score > maxScore):
                    maxScore = score
                    maxIndex = digit
            predicted_values.append(maxIndex)
    true_values = true_values_men + true_values_women
    cmat = confusion_matrix(true_values, predicted_values, normalize='true')
    return cmat
```

[736]:
```
cmap = findConfusionMatrix(KMeans_GMM_spherical_cov_subset, test_blocks_subset)
plt.figure(figsize=[15,15])
sns.heatmap(cmap, annot=True, cmap = 'cividis')
```

[736]: <AxesSubplot:>



Non-Gendered

[641]:
```
# Spherical
findAccuracyNonGendered(KMeans_GMM_spherical_cov)
```

0.7454545454545455

[642]:
```
# Diagonal
findAccuracyNonGendered(KMeans_GMM_diag_cov)
```

0.7363636363636363

[643]:
```
# Tied
findAccuracyNonGendered(KMeans_GMM_tied_cov)
```

0.8440909090909091

[644]:
```
# Full
findAccuracyNonGendered(KMeans_GMM_full_cov)
```

0.6372727272727273

Gendered

[645]:
```
# Spherical
findAccuracyGendered(KMeans_GMM_spherical_cov_men,␣
↪KMeans_GMM_spherical_cov_women)
```

0.8045454545454546

[646]:
```
# Diagonal
findAccuracyGendered(KMeans_GMM_diag_cov_men, KMeans_GMM_diag_cov_women)
```

0.8013636363636364

[647]:
```
# Tied
findAccuracyGendered(KMeans_GMM_tied_cov_men, KMeans_GMM_tied_cov_women)
```

0.8731818181818182

[648]:
```
# Full
findAccuracyGendered(KMeans_GMM_full_cov_men, KMeans_GMM_full_cov_women)
```

0.6940909090909091

Subset

[733]:
```
# Spherical
findAccuracySubset(KMeans_GMM_spherical_cov_subset)
```

0.7436363636363637

[650]:
```
# Diagonal
findAccuracySubset(KMeans_GMM_diag_cov_subset)
```

0.7204545454545455

[651]:
```
# Tied
findAccuracySubset(KMeans_GMM_tied_cov_subset)
```

0.8472727272727273

[652]:
```
# Full
findAccuracySubset(KMeans_GMM_full_cov_subset)
```

0.5159090909090909

1.2 Expectation-Maximization

[653]:
```
# Seaborn stuff
    # pca_df = pd.DataFrame(data = pca_data, columns = ['1', '2'])
    # pca_df['color'] = pd.DataFrame(labels)
    # ax = sns.scatterplot(x = '1', y = '2', data = pca_df, hue = 'color',␣
↪legend = 'full', palette = 'husl')
```

[654]:
```
def findAndPlotEM(digit, components, covar_type):
#     plt.figure(figsize=[20,20])

    em_model = GaussianMixture(n_components=components, covariance_type=␣
↪covar_type).fit(Digits[digit])
    return em_model

#     pca = PCA(n_components=2)
#     pca_data = pca.fit_transform(test_Digits[digit])
#     plt.scatter(pca_data[:, 0], pca_data[:, 1], c = labels, cmap='jet')
```

[655]:
```
def findAndPlotEMGendered(digit, components, covar_type, genderBoolean):
    # Let true be male and false female (F for female)
    if (genderBoolean):
        em_model = GaussianMixture(n_components=components, covariance_type=␣
↪covar_type).fit(MenDigits[digit])
    else:
        em_model = GaussianMixture(n_components=components, covariance_type=␣
↪covar_type).fit(WomenDigits[digit])

    return em_model
```

[656]:
```
em_models_full = []
em_male_models_full = []
em_female_models_full = []

em_models_tied = []
em_male_models_tied = []
em_female_models_tied = []

em_models_diag = []
em_male_models_diag = []
em_female_models_diag = []

em_models_sphere = []
em_male_models_sphere = []
em_female_models_sphere = []
```

```
# Components defined empirically by looking for well defined clusters near 2n -␣
 ↪1 where n is phonemes
digit_components = [6, 7, 7, 6, 7, 6, 5, 5, 9, 4]
for i in range(10):
    em_models_full.append(findAndPlotEM(i, digit_components[i], 'full'))
    em_male_models_full.append(findAndPlotEMGendered(i, digit_components[i],␣
 ↪'full', True))
    em_female_models_full.append(findAndPlotEMGendered(i, digit_components[i],␣
 ↪'full', False))

    em_models_tied.append(findAndPlotEM(i, digit_components[i], 'tied'))
    em_male_models_tied.append(findAndPlotEMGendered(i, digit_components[i],␣
 ↪'tied', True))
    em_female_models_tied.append(findAndPlotEMGendered(i, digit_components[i],␣
 ↪'tied', False))

    em_models_diag.append(findAndPlotEM(i, digit_components[i], 'diag'))
    em_male_models_diag.append(findAndPlotEMGendered(i, digit_components[i],␣
 ↪'diag', True))
    em_female_models_diag.append(findAndPlotEMGendered(i, digit_components[i],␣
 ↪'diag', False))

    em_models_sphere.append(findAndPlotEM(i, digit_components[i], 'spherical'))
    em_male_models_sphere.append(findAndPlotEMGendered(i, digit_components[i],␣
 ↪'spherical', True))
    em_female_models_sphere.append(findAndPlotEMGendered(i,␣
 ↪digit_components[i], 'spherical', False))
```

[657]:
```
print(em_models_full[1].weights_)
```

```
[0.13623235 0.14152037 0.13250311 0.1778419  0.14170137 0.12950699
 0.14069391]
```

1.2.1 ML Classification

Can use same functions defined for KMeans

Non-gendered

[658]:
```
# Non-gendered Full
findAccuracyNonGendered(em_models_full)
```

```
0.8795454545454545
```

[659]:
```
# Non-gendered Tied
findAccuracyNonGendered(em_models_tied)
```

```
0.8859090909090909
```

[660]:
```
# Non-gendered Diag
findAccuracyNonGendered(em_models_diag)
```

```
0.8718181818181818
```

[661]:
```
# Non-gendered Spherical
findAccuracyNonGendered(em_models_sphere)
```

```
0.7613636363636364
```

Gendered

[662]:
```
# Gendered full
findAccuracyGendered(em_male_models_full, em_female_models_full)
```

```
0.8618181818181818
```

[663]:
```
# Gendered tied
findAccuracyGendered(em_male_models_tied, em_female_models_tied)
```

```
0.8877272727272727
```

[664]:
```
# Gendered diag
findAccuracyGendered(em_male_models_diag, em_female_models_diag)
```

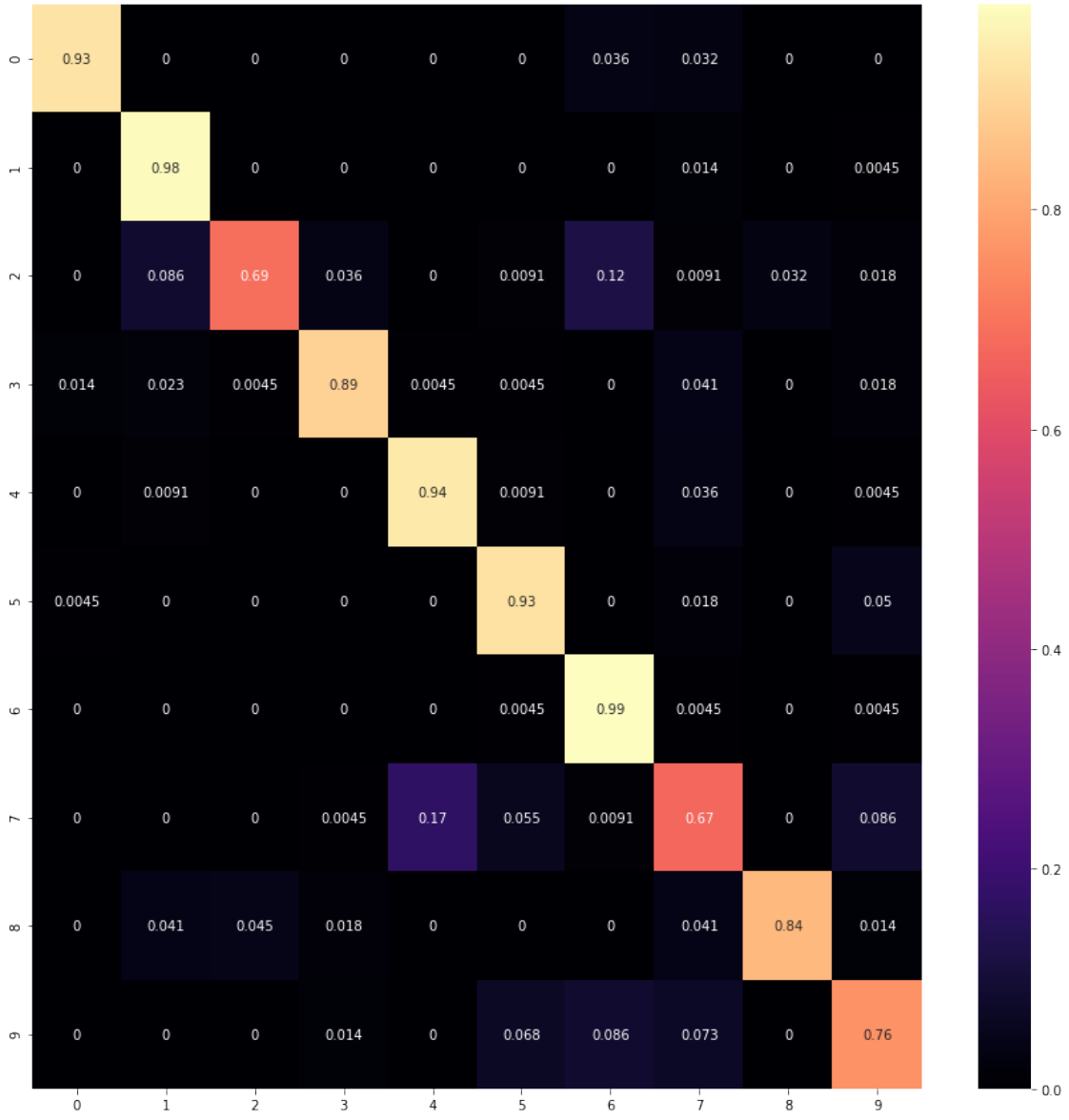
```
0.9027272727272727
```

[665]:
```
# Gendered spherical

findAccuracyGendered(em_male_models_sphere, em_female_models_sphere)
```

```
0.8327272727272728
```

[730]:
```
plt.figure(figsize = [15,15])
sns.heatmap(findConfusionMatrixGendered(em_male_models_full,␣
↪em_female_models_full), annot=True, cmap = 'magma')
```

[730]:
```
<AxesSubplot:>
```


0 0.93 0 0 0 0 0 0.036 0.032 0 0
1 0 0.98 0 0 0 0 0 0.014 0 0.0045
2 0 0.086 0.69 0.036 0 0.0091 0.12 0.0091 0.032 0.018
3 0.014 0.023 0.0045 0.89 0.0045 0.0045 0 0.041 0 0.018
4 0 0.0091 0 0 0.94 0.0091 0 0.036 0 0.0045
5 0.0045 0 0 0 0 0.93 0 0.018 0 0.05
6 0 0 0 0 0 0.0045 0.99 0.0045 0 0.0045
7 0 0 0 0.0045 0.17 0.055 0.0091 0.67 0 0.086
8 0 0.041 0.045 0.018 0 0 0 0.041 0.84 0.014
9 0 0 0 0.014 0 0.068 0.086 0.073 0 0.76
0 1 2 3 4 5 6 7 8 9
0.8
0.6
0.4
0.2
0.0

[ ]: