CS534 Computer Vision
Assignment 1

Submitted by: st976
Sanchit Thakur

CODE

The code written for the assignment has been shown below. An ipynb file has also been submitted along with this document. In the ipynb file, there are several cells, with specific variables for file path and file name.

In [1]:

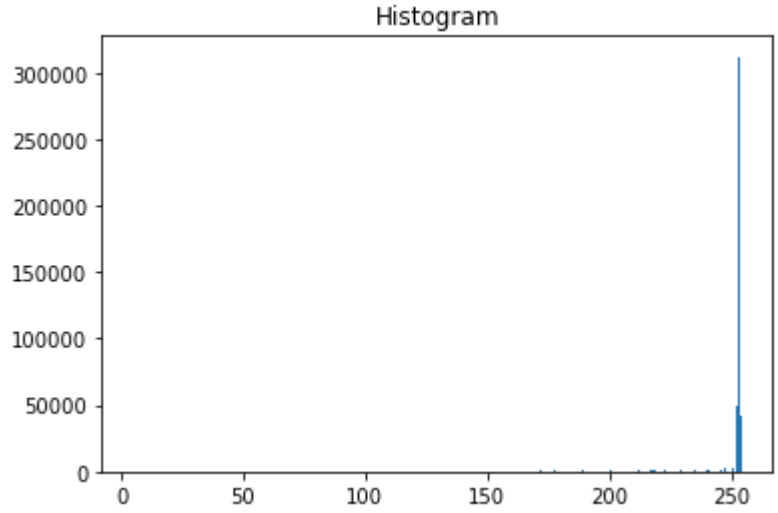
```
import numpy as np
import pandas as pd
from sklearn.metrics import confusion_matrix
from scipy.spatial.distance import cdist
from skimage.measure import label, regionprops, moments, moments_central, moments_norma
lized, moments_hu
from skimage import io, exposure
import matplotlib.pyplot as plt
from matplotlib.patches import Rectangle
import pickle
import os
from os import listdir
from pathlib import Path
```

TRAINING

In [2]:

```
folder_directory = '/Users/sanchitthakur/training_images'          #directory containin
g images

Features = []
char_ranges=[]
images = Path(folder_directory).glob('*.bmp')
for image in images:
    img=io.imread(image)
    hist = exposure.histogram(img)
    plt.bar(hist[1], hist[0])
    plt.title('Histogram')
    plt.show()
    th = 200
    img_binary = (img < th).astype(np.double)
    img_label = label(img_binary, background=0)
    print(np.amax(img_label))
    regions = regionprops(img_label)
    io.imshow(img_binary)
    ax = plt.gca()
    for props in regions:
        minr, minc, maxr, maxc = props.bbox
        if ((maxc-minc)<18 or (maxr-minr)<18):                #setting threshold for b
ounding boxes
            continue
        ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill = False, e
dgecolor = 'red', linewidth = 1))
        roi = img_binary[minr:maxr, minc:maxc]
        m = moments(roi)
        cr = m[0, 1] / m[0, 0]
        cc = m[1, 0] / m[0, 0]
        center = (cr, cc)
        mu = moments_central(roi, center)
        nu = moments_normalized(mu)
        hu = moments_hu(nu)
        Features.append(hu)
    char_ranges.append(len(Features))
    ax.set_title('Bounding Boxes')
print(char_ranges)
io.show()
```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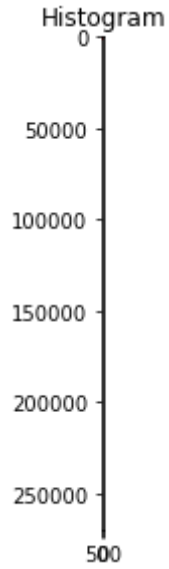
200
250

83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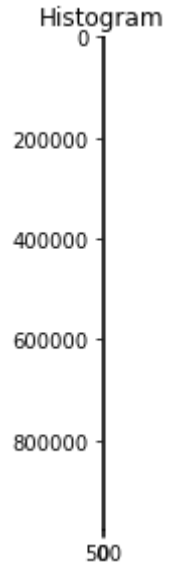
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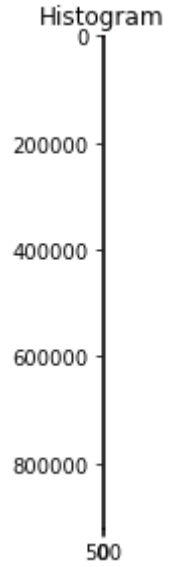
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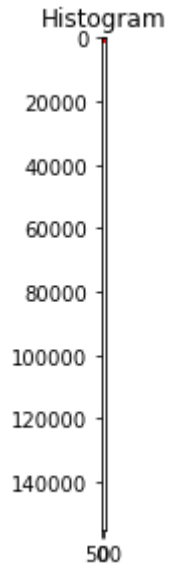
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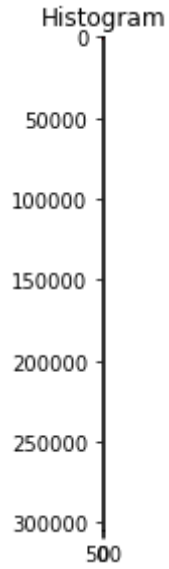
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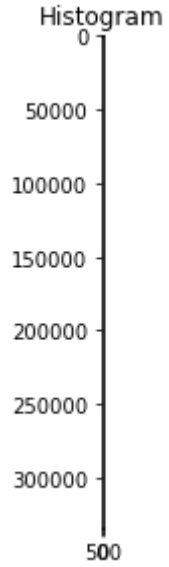
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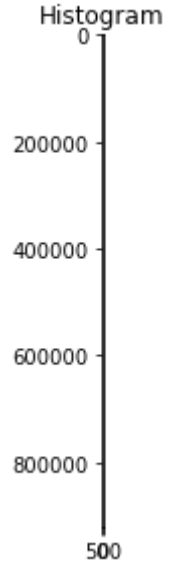
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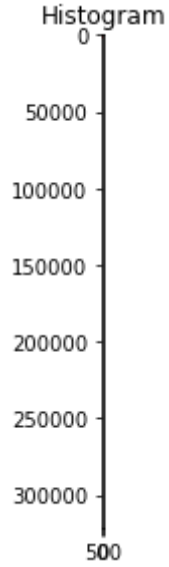
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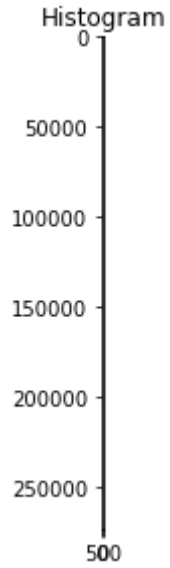
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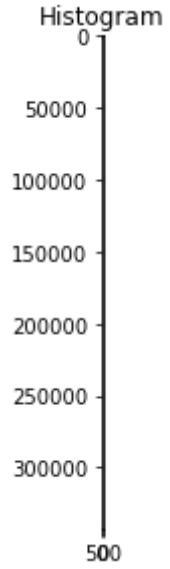
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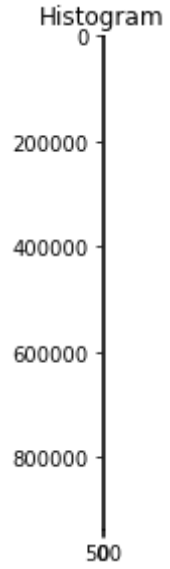
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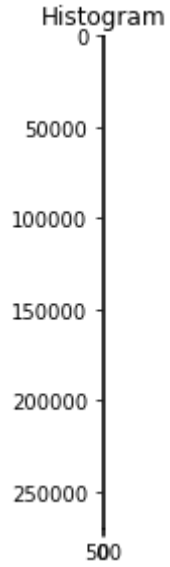
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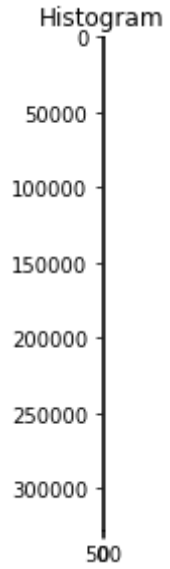
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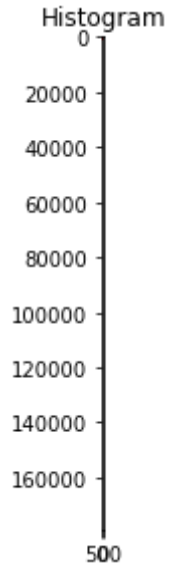
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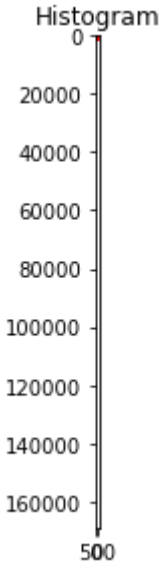


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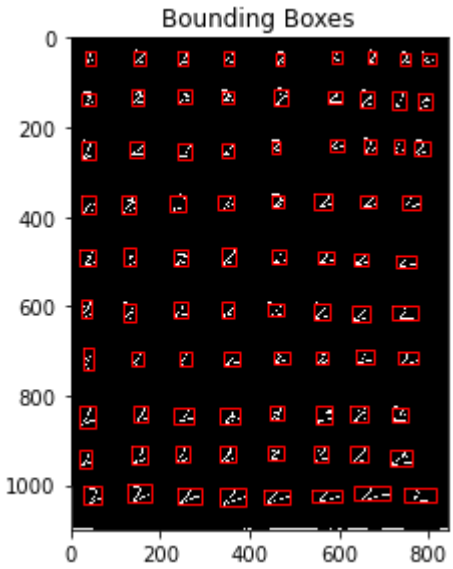

In [3]:

```
print(len(Features))
print(Features)
```

```
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```

```
10983538,  0.64825898,  1.73882193, -0.19399296,
        0.55694646, -1.83588638])]
```

In [4]:

```
characters =['a','d','f','h','k','m','n','o','p','q','r','s','u','w','x','z']
```

In [5]:

```
flat_features = np.array(Features)
flat_features=flat_features.flatten()
print(flat_features)
print(len(flat_features))

average=np.average(flat_features)
std_deviation=np.std(flat_features)
print(average)
print(std_deviation)
```

```
[ 0.41978144  0.00334312  0.00777133 ... -0.19399296  0.55694646
 -1.83588638]
8113
73726910.48480421
6668620926.293209
```

In [6]:

```
for i in range(len(flat_features)):
    flat_features[i] = (flat_features[i] - average)
    flat_features[i] = flat_features[i] / std_deviation

print(flat_features)
```

```
[-0.0110558 -0.0110558 -0.0110558 ... -0.0110558 -0.0110558 -0.0110558]
```

In [7]:

```
new_average = np.average(flat_features)
new_std_deviation = np.std(flat_features)
print(new_average)
print(new_std_deviation)
```

```
-2.6274229104897087e-18
1.0
```

In [ ]:

```
D = cdist(Features, Features)
```

In [9]:

```
D
```

Out[9]:

```
array([[ 0.        ,  0.19239384,  0.11554729, ...,  1.15500942,
        36.95903684,  2.78715464],
       [ 0.19239384,  0.        ,  0.07805201, ...,  1.05049527,
        36.94721035,  2.72555292],
       [ 0.11554729,  0.07805201,  0.        , ...,  1.08687799,
        36.95051384,  2.74546496],
       ...,
       [ 1.15500942,  1.05049527,  1.08687799, ...,  0.        ,
        36.51402916,  1.89202274],
       [36.95903684, 36.94721035, 36.95051384, ..., 36.51402916,
         0.        , 34.78710619],
       [ 2.78715464,  2.72555292,  2.74546496, ...,  1.89202274,
        34.78710619,  0.        ]])
```

In [10]:

```
D_index = np.argsort(D, axis=1)

print(D_index.shape)

print(D_index)
```

```
(1159, 1159)
[[   0  467    4 ...  575  190 1067]
 [   1 1130 1090 ...  575  190 1067]
 [   2   17   16 ...  575  190 1067]
 ...
 [1156 1154  311 ...  575  190 1067]
 [1157  304  370 ...  575  190 1067]
 [1158  371 1118 ...  575  190 1067]]
```

In [11]:

```
true_index=[]
predict_index=[]
for i in range(D_index.shape[0]):
    true_index.append(D_index[i,0])
    predict_index.append(D_index[i,1])
```

In [12]:

```
y_true=[]
# for calculating true labels
for i in true_index:
    k=0
    for j in char_ranges:
        if i >= j:
            k+=1
            continue
        y_true.append(characters[k])
        break
print(y_true)

y_pred=[]
#for calculating predicted labels
for i in predict_index:
    k=0
    for j in char_ranges:
        if i >= j:
            k+=1
            continue
        y_pred.append(characters[k])
        break
print(y_pred)
```

```
['a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a',
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'z', 'z', 'z', 'k', 'k']
```

In [13]:

```
confusion_matrix(y_true,y_pred)
```

Out[13]:

```
array([[24,  0,  0,  0,  0,  8, 15,  0,  2,  3,  0,  0,  9,  2,  1,  1],
       [ 1, 51,  1,  0,  1,  3,  1,  1,  1,  2,  3,  0,  1,  2,  1,  0],
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       [14,  2,  0,  0,  0,  6, 34,  0,  2,  3,  0,  0, 11,  1,  2,  1],
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       [ 2,  2,  0,  0,  0,  4,  2,  2, 36,  6,  9,  0,  0,  2,  0,  0],
       [ 4,  0,  0,  0,  0,  3,  3,  1,  8, 23,  6,  0,  2, 13,  0,  3],
       [ 1,  4,  0,  0,  0,  0,  1,  0, 12,  3, 48,  0,  0,  6,  0,  1],
       [ 0,  1, 10,  6,  0,  0,  0,  6,  0,  0,  0, 32,  0,  0,  1,  4],
       [10,  1,  0,  0,  0,  7,  5,  0,  2,  3,  0,  0, 20,  5,  1,  1],
       [ 1,  0,  0,  0,  1, 10,  2,  0,  4,  5, 10,  0,  6, 34,  0,  0],
       [ 1,  2,  4,  0,  1,  0,  1, 11,  1,  1,  0,  1,  0,  0, 45, 13],
       [ 3,  0,  0,  0,  2,  0,  2,  7,  0,  4,  0,  3,  2,  3, 11, 46]],
      dtype=int64)
```

In [14]:

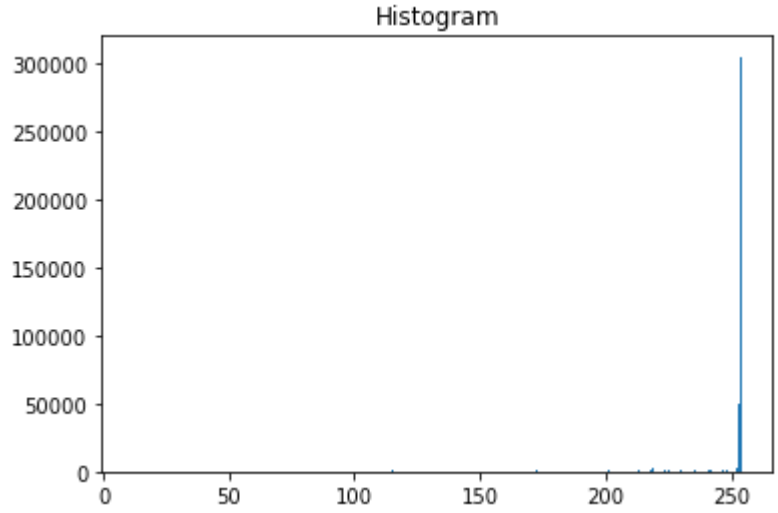
```
from sklearn.metrics import accuracy_score

print(accuracy_score(y_true, y_pred))
```

```
0.5383951682484901
```

FOR TEST IMAGE 1

In [15]:

```
folder_directory = '/Users/sanchitthakur/test_images'
Features_new = []
char_ranges_test = []
imgs = Path(folder_directory).glob('test1.bmp')
for img in imgs:
    im=io.imread(img)
    hist = exposure.histogram(im)
    plt.bar(hist[1], hist[0])
    plt.title('Histogram')
    plt.show()
    th = 200
    img_binary = (im < th).astype(np.double)
    img_label = label(img_binary, background=0)
    print(np.amax(img_label))
    regions = regionprops(img_label)
    io.imshow(img_binary)
    ax = plt.gca()
    for props in regions:
        minr, minc, maxr, maxc = props.bbox
        if ((maxc-minc)<18 or (maxr-minr)<18):
            continue
        ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill = False, e
dgecolor = 'red', linewidth = 1))
        roi = img_binary[minr:maxr, minc:maxc]
        m = moments(roi)
        cr = m[0, 1] / m[0, 0]
        cc = m[1, 0] / m[0, 0]
        center = (cr, cc)
        mu = moments_central(roi, center)
        nu = moments_normalized(mu)
        hu = moments_hu(nu)
        Features_new.append(hu)
    char_ranges_test.append(len(Features_new))
    print(len(Features_new))
    ax.set_title('Bounding Boxes')
    io.show()
print(char_ranges_test)
```


Histogram
300000
250000
200000
150000
100000
50000
0
0
50
100
150
200
250

```
80
67
```


Bounding Boxes
0
100
200
300
400
500
600
700
0
200
400

```
[67]
```

In [16]:

```
print(Features_new)
```

```
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       0.29742133, 0.05944898]), array([ 0.55650132,  0.05845873,  0.13680
943,  0.08850995,  0.00961401,
        0.01630939, -0.00155976]), array([ 0.49464649,  0.04337246,  0.090
30947,  0.06455179,  0.00484012,
        0.01046286, -0.00093005]), array([0.92603766, 0.54314464, 0.820629
37, 0.87826776, 0.74326544,
       0.63704062, 0.05913067]), array([0.69437758, 0.1601434 , 0.2876237
, 0.29517802, 0.08553358,
       0.10891186, 0.00902028]), array([0.82766714, 0.18721879, 0.6417306
2, 0.76416878, 0.52572071,
       0.3290165 , 0.09991597]), array([0.79455658, 0.25470718, 0.5547921
2, 0.66373961, 0.39386944,
       0.33375839, 0.08422588]), array([ 0.64734521,  0.00843148,  0.03145
098,  0.06942903, -0.00220364,
        0.00591253, -0.00238114]), array([ 6.91246497e-01,  3.63244510e-0
2,  5.70431700e-02,  2.01330478e-02,
        5.58867263e-04, -6.85103466e-05,  3.91383222e-04]), array([7.33835
098e-01, 4.22043158e-02, 5.74421006e-02, 1.11463438e-02,
       2.47461902e-04, 3.98879253e-04, 1.35315576e-04]), array([ 0.6817216
3,  0.01277674,  0.01827799,  0.06717652, -0.00222456,
        0.00714658, -0.00076956]), array([ 5.81527285e-01,  5.22653888e-0
3,  2.62114179e-02,  1.63223055e-02,
       -1.26790187e-04,  1.06372581e-03, -3.12899218e-04]), array([ 5.8659
8216e-01,  2.24114684e-02,  5.12896829e-03,  1.42308656e-02,
       -4.75435291e-05,  2.09420627e-03, -1.11898609e-04]), array([ 6.7687
1840e-01,  8.08773333e-02,  3.18351067e-02,  2.29140941e-02,
```

```
        4.73738706e-04,  6.23135518e-03, -3.98227836e-04]), array([ 0.7188
0718,  0.1575696 ,  0.18713999,  0.10267622,  0.00265572,
       -0.00313446, -0.01398276]), array([ 0.89500914,  0.18296843,  0.565
56977,  0.81530885,  0.38256169,
        0.29772307, -0.40020271]), array([4.69089447e-01, 1.25264262e-02,
3.44672380e-02, 5.32734517e-03,
       5.96749444e-05, 1.07623874e-04, 4.06216201e-05]), array([ 0.6931151
1,  0.12391085,  0.26464394,  0.35846821,  0.08290796,
        0.10758898, -0.07291472]), array([ 4.29289163e-01,  3.47950483e-0
2,  3.60904163e-02,  2.61640943e-02,
        1.17111257e-04, -1.84621704e-04, -7.95422123e-04]), array([ 6.7481
3765e-01,  9.12455613e-02,  1.23449851e-01,  8.42340271e-02,
       -6.46460019e-04, -5.86648648e-03, -8.56531213e-03])]
```

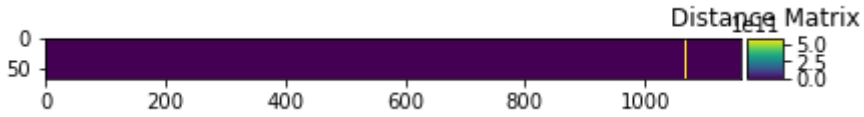
In [17]:

```
print(len(Features_new))
```

```
67
```

In [18]:

```
D_new = cdist(Features_new,Features)
io.imshow(D_new)
plt.title('Distance Matrix')
io.show()
```



In [19]:

```
print(D_new)
```

```
[[3.30731494e-02 1.62110586e-01 8.48026598e-02 ... 1.13367871e+00
  3.69559143e+01 2.77355247e+00]
 [7.31325238e-02 2.63966607e-01 1.86224201e-01 ... 1.19708705e+00
  3.69623183e+01 2.80908640e+00]
 [6.47857881e-02 1.33569305e-01 6.25989730e-02 ... 1.11756467e+00
  3.69552358e+01 2.76725771e+00]
 ...
 [5.54106178e-01 4.54303654e-01 4.81615936e-01 ... 7.23285568e-01
  3.67430023e+01 2.38647736e+00]
 [5.03274639e-02 1.76446738e-01 9.97325192e-02 ... 1.12473640e+00
  3.69499262e+01 2.76072385e+00]
 [3.05356585e-01 1.38859301e-01 1.96280474e-01 ... 9.47387340e-01
  3.69155931e+01 2.64223368e+00]]
```

In [20]:

```
D_index_new = np.argsort(D_new, axis=1)
```

In [21]:

```
print(D_index_new.shape)

print(D_index_new)
```

```
(67, 1159)
[[   3  917   15 ...  575  190 1067]
 [ 472   88   27 ...  575  190 1067]
 [ 462  882  918 ...  575  190 1067]
 ...
 [ 968  943  731 ...  575  190 1067]
 [ 710  679  672 ...  575  190 1067]
 [1095 1148  884 ...  575  190 1067]]
```

In [22]:

```
predict_index_new=[]
for i in range(D_index_new.shape[0]):
    predict_index_new.append(D_index_new[i,0])
#print(y_true_index)
print(predict_index_new)
```

```
[3, 472, 462, 3, 464, 11, 35, 115, 127, 95, 74, 67, 103, 132, 10, 910, 38
5, 439, 377, 62, 409, 26, 51, 482, 13, 462, 62, 50, 1066, 1028, 1028, 103
6, 1065, 463, 586, 511, 676, 676, 745, 746, 67, 1079, 610, 708, 1062, 978,
656, 662, 705, 966, 524, 731, 637, 749, 52, 1063, 1022, 52, 463, 463, 101
0, 1085, 883, 15, 968, 710, 1095]
```

In [23]:

```
y_pred_new=[]
for i in predict_index_new:
    k=0
    for j in char_ranges:
        if i >= j:
            k+=1
            continue
        y_pred_new.append(characters[k])
        break
print(y_pred_new)
```

```
['a', 'n', 'n', 'a', 'n', 'a', 'a', 'd', 'd', 'd', 'd', 'd', 'd', 'd',
'a', 'u', 'm', 'm', 'm', 'a', 'm', 'a', 'a', 'n', 'a', 'n', 'a', 'a', 'x',
'x', 'x', 'x', 'x', 'n', 'o', 'n', 'q', 'q', 'r', 'r', 'd', 'z', 'p', 'q',
'x', 'w', 'p', 'p', 'q', 'w', 'o', 'r', 'p', 'r', 'a', 'x', 'x', 'a', 'n',
'n', 'x', 'z', 'u', 'a', 'w', 'q', 'z']
```

In [24]:

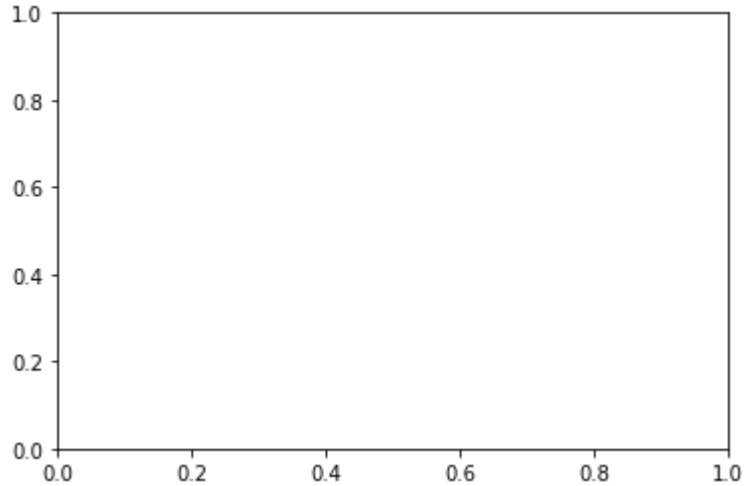
```
with open('/Users/sanchitthakur/pickle_files/test1_gt.pkl', 'rb') as file:
    my_dict = pickle.load(file)
classes = my_dict['classes']
locations = my_dict['locations']

print(classes)

print(locations)
```

```
['a' 'a' 'a' 'a' 'a' 'a' 'a' 'd' 'd' 'd' 'd' 'd' 'd' 'd' 'm' 'm' 'm' 'm'
 'm' 'm' 'm' 'n' 'n' 'n' 'n' 'n' 'n' 'n' 'o' 'o' 'o' 'o' 'o' 'o' 'o' 'p'
 'p' 'p' 'p' 'p' 'p' 'p' 'q' 'q' 'q' 'q' 'q' 'q' 'q' 'r' 'r' 'r' 'r' 'r'
 'r' 'r' 'u' 'u' 'u' 'u' 'u' 'u' 'u' 'w' 'w' 'w' 'w' 'w' 'w' 'w']
[[ 30  32]
 [108  30]
 [187  34]
 [262  36]
 [333  34]
 [485  32]
 [408  31]
 [ 26 108]
 [111 107]
 [185 107]
 [263 110]
 [338 111]
 [410 107]
 [486 110]
 [ 35 179]
 [117 185]
 [187 185]
 [261 181]
 [336 182]
 [413 182]
 [483 184]
 [ 34 255]
 [116 254]
 [186 259]
 [258 255]
 [330 259]
 [406 256]
 [484 250]
 [ 34 341]
 [118 331]
 [196 335]
 [272 335]
 [337 328]
 [411 331]
 [483 331]
 [ 33 402]
 [115 405]
 [194 399]
 [266 400]
 [340 397]
 [415 401]
 [488 404]
 [ 32 479]
 [116 475]
 [188 474]
 [257 473]
 [334 475]
 [408 476]
 [485 477]
 [ 32 561]
 [117 563]
 [195 561]
 [268 562]
 [336 559]
 [407 558]
 [487 553]
 [ 33 630]
```

```
[114 628]
[190 628]
[268 632]
[335 630]
[407 632]
[496 629]
[ 37 703]
[109 707]
[191 706]
[256 703]
[338 701]
[410 708]
[487 708]]
```

In [25]:

```
folder_directory = '/Users/sanchitthakur/test_images'
y_true_new=[]
imgs = Path(folder_directory).glob('test1.bmp')
for img in imgs:
    im=io.imread(img)
    th = 200
    img_binary = (im < th).astype(np.double)
    img_label = label(img_binary, background=0)
    regions = regionprops(img_label)
    ax = plt.gca()
    for props in regions:
        minr, minc, maxr, maxc = props.bbox
        if ((maxc-minc)<18 or (maxr-minr)<18):
            continue
        ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill = False, e
dgecolor = 'red', linewidth = 1))
        for i in range(len(locations)):
            if locations[i][0] > minc and locations[i][0] < maxc and locations[i][1] >
minr and locations[i][1] < maxr:
                y_true_new.append(classes[i])
```



In [26]:

```
print(y_true_new)
```

```
['a', 'a', 'a', 'a', 'a', 'a', 'a', 'd', 'd', 'd', 'd', 'd', 'd', 'd',
'm', 'm', 'm', 'm', 'm', 'm', 'm', 'n', 'n', 'n', 'n', 'n', 'n', 'n', 'o',
'o', 'o', 'o', 'o', 'o', 'o', 'p', 'p', 'p', 'p', 'p', 'p', 'q', 'q', 'q',
'q', 'q', 'q', 'r', 'r', 'r', 'r', 'r', 'r', 'r', 'u', 'u', 'u', 'u', 'u',
'u', 'w', 'w', 'w', 'w', 'w', 'w', 'w']
```

In [27]:

```
regions = regionprops(img_label)
io.imshow(img_binary)
ax = plt.gca()
bound_count = 0
for props in regions:
    minr, minc, maxr, maxc = props.bbox
    if ((maxc-minc) < 19 or (maxr-minr) < 19):
      continue
    ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill =
False, edgecolor = 'red', linewidth = 1))
    ax.text(maxc, maxr, y_pred_new[bound_count], color="white")
    bound_count += 1
ax.set_title('Bounding Boxes')
io.show()
```

In [28]:

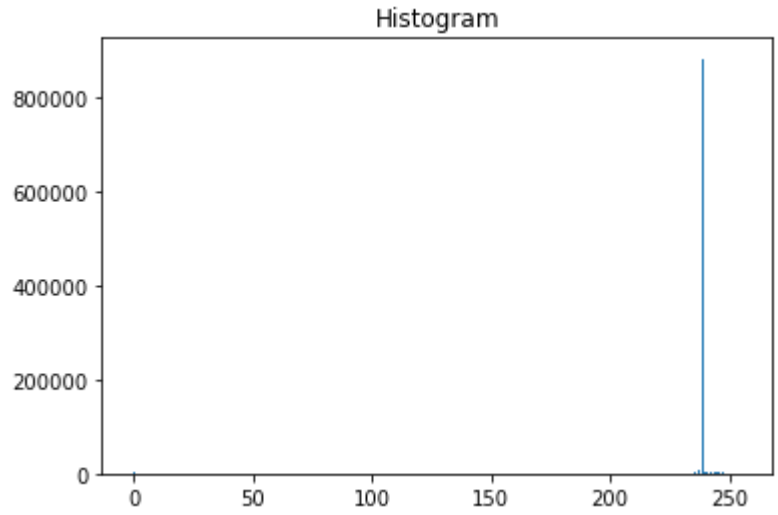
```
from sklearn.metrics import accuracy_score

print(accuracy_score(y_true_new, y_pred_new))
```

```
0.3283582089552239
```

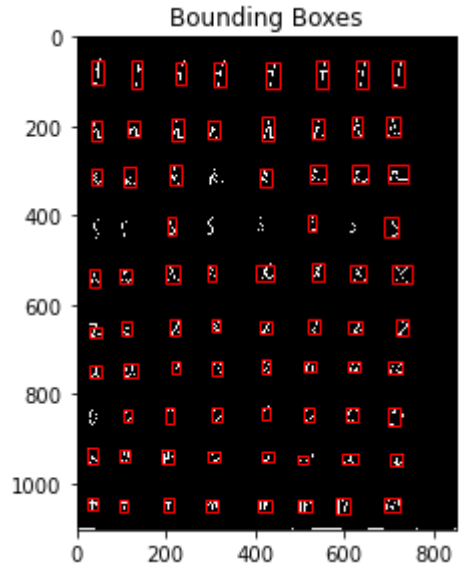
FOR TEST IMAGE 2

In [29]:

```
folder_directory = '/Users/sanchitthakur/test_images'
Features_last = []
char_ranges_test = []
imgs = Path(folder_directory).glob('test2.bmp')
for img in imgs:
    im=io.imread(img)
    hist = exposure.histogram(im)
    plt.bar(hist[1], hist[0])
    plt.title('Histogram')
    plt.show()
    th = 200
    img_binary = (im < th).astype(np.double)
    img_label = label(img_binary, background=0)
    print(np.amax(img_label))
    regions = regionprops(img_label)
    io.imshow(img_binary)
    ax = plt.gca()
    for props in regions:
        minr, minc, maxr, maxc = props.bbox
        if ((maxc-minc)<18 or (maxr-minr)<18):
            continue
        ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill = False, e
dgecolor = 'red', linewidth = 1))
        roi = img_binary[minr:maxr, minc:maxc]
        m = moments(roi)
        cr = m[0, 1] / m[0, 0]
        cc = m[1, 0] / m[0, 0]
        center = (cr, cc)
        mu = moments_central(roi, center)
        nu = moments_normalized(mu)
        hu = moments_hu(nu)
        Features_last.append(hu)
    char_ranges_test.append(len(Features_last))
    print(len(Features_last))
    ax.set_title('Bounding Boxes')
    io.show()
print(char_ranges_test)
```


Histogram
800000
600000
400000
200000
0
0
50
100
150
200
250

112
73


Bounding Boxes
0
200
400
600
800
1000
0
200
400
600
800

[73]

In [30]:

```
print(len(Features_last))

print(Features_last)
```

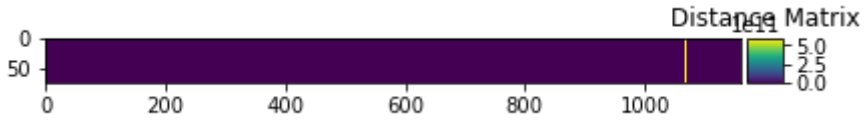
```
73
[array([3.65672859e+00, 8.15093998e+00, 4.95701500e+01, 6.98825102e+01,
       4.04161452e+03, 1.99329833e+02, 7.63180513e+02]), array([4.80152898
e+00, 1.58669537e+01, 1.16769303e+02, 1.61132320e+02,
       2.19440246e+04, 6.39413980e+02, 2.64072012e+03]), array([4.02815136
e+00, 1.11689783e+01, 7.65364182e+01, 1.01183475e+02,
       8.83896923e+03, 3.37653680e+02, 1.07642753e+03]), array([4.65175042
e+00, 1.62405188e+01, 1.17137025e+02, 1.48244447e+02,
       1.94704975e+04, 5.96444079e+02, 1.58691019e+03]), array([4.25942017
e+00, 1.28764698e+01, 9.18421661e+01, 1.18280918e+02,
       1.22600277e+04, 4.23595420e+02, 1.29291524e+03]), array([   3.01428
38 ,    6.00912577,   28.21044245,   38.37851938,
       1252.5327477 ,   94.06956162,  160.76498587]), array([  2.78570064,
5.05059084,  24.23370169,  33.223894  ,
       934.61445165,  74.66067027, 123.40553503]), array([  2.65073466,
4.70826326,  25.30040509,  33.1351733 ,
       951.81701383,  71.87221299, 120.34865978]), array([   3.64177504,
7.79532808,   25.14053347,   52.03971322,
       1873.782939  ,  145.1891661 ,  178.89362707]), array([3.88342089e+0
0, 1.03175788e+01, 4.67854334e+01, 7.04716757e+01,
       4.03354847e+03, 2.26250390e+02, 3.23224719e+02]), array([  3.247604
15,   5.89394954,  18.40054727,  37.7900909 ,
       994.18344819,  91.71760657,  68.07538238]), array([  2.75751346,
4.30434899,  13.11468038,  24.8179756 ,
       446.96205   ,  51.48781106,  26.42598054]), array([   3.60281761,
7.54793128,   24.82410413,   49.76663788,
       1739.95009342,  136.70093074,  179.83774091]), array([  2.5177553 ,
2.97136773,   5.47935507,  16.11912085,
       150.89122064,  27.78558141,  13.42747164]), array([   4.03958569,
9.39257492,   32.96099841,   68.54965924,
       3231.24352518,  210.04754061,  420.02183136]), array([  2.72408328,
3.7750806 ,   8.73418716,  21.18344785,
       287.43507794,  41.15763153,  20.168176  ]), array([ 1.72550969,  0.
30381578,  1.28307884,  3.48338709,  4.34083913,
        1.70466887, -5.94890597]), array([ 1.99662736,  1.56480245,  2.554
66091,  7.90788636, 35.36270919,
        9.8815295 , -3.57800876]), array([  2.62381077,   3.10966875,   5.
80429926,  17.77768714,
       180.58031408,  31.32595463,  -1.61567109]), array([   3.33663344,
6.50720279,   20.12274851,   39.40356671,
       1108.13373089,  100.48631371,   56.04692513]), array([   4.0053851
4,   10.16364903,   38.44057359,   67.85060274,
       3450.26486516,  216.25243361,  321.13542278]), array([  2.29122655,
2.93385975,   6.89416606,  13.66479513,
       132.55392048,  23.39117329,   4.52569584]), array([ 2.24037142,  2.
42932154,  4.44242411, 11.66443072, 83.49165244,
       18.17318394,  8.91592553]), array([   3.46094944,    6.23214155,
32.25647013,   49.21136297,
       1895.80462365,  122.64653276,  500.18716701]), array([  2.23247694,
2.56445185,   9.64383103,  10.41692316,
       102.28316848,  14.53800255,  20.95696705]), array([4.05011698e+00,
8.99049348e+00, 5.64043835e+01, 8.15506664e+01,
       5.38304572e+03, 2.44231559e+02, 1.27040951e+03]), array([ 1.8320321
2,  1.05512158,  2.33518354,  6.67723451, 23.40645185,
        6.83876467, 12.13836246]), array([ 7.95679752e-01,  7.20463103e-0
2,  5.69092785e-04,  5.15860104e-03,
       -6.30123215e-06, -6.51220015e-04,  6.19818293e-06]), array([1.51593
755, 0.42467048, 0.65905157, 3.31331499, 4.28434196,
       2.08705291, 2.36993594]), array([1.24808163, 0.58054587, 1.1846624
5, 2.58472998, 4.48783688,
       1.94555805, 0.56234891]), array([ 9.37314169e-01,  1.77109411e-01,
```

```
5.80265867e-02,  2.46887429e-02,
        8.77078110e-04,  4.79243937e-03, -3.22419843e-04]), array([1.10688
381, 0.11665568, 0.07992584, 0.05559412, 0.00113152,
       0.01812587, 0.00352887]), array([ 2.1447427 ,  1.21173701,  2.39595
261, 10.14701612, 42.94994798,
       11.15997119, 25.66103761]), array([0.85824908, 0.13876003, 0.071583
64, 0.240786  , 0.02210445,
       0.03377165, 0.02259911]), array([0.94668392, 0.29011814, 0.6805209
, 0.96836481, 0.7183823 ,
       0.48395955, 0.31919298]), array([ 1.79903768,  1.49381709,  5.15101
487,  7.13061094, 41.75566107,
        8.54295755, 11.1363442 ]), array([ 1.61574415,  1.03316419,  3.306
0547 ,  4.81441876, 18.95996771,
        4.73852056,  3.0736994 ]), array([ 1.66908701,  0.64997462,  2.804
20401,  4.37632892, 12.68415394,
        3.0566842 ,  8.61109697]), array([ 9.09174718e-01,  1.61093167e-0
1,  2.88260547e-01,  5.52210137e-02,
       -2.38975174e-04,  2.42306814e-03, -6.96295410e-03]), array([0.90364
609, 0.12671391, 0.44650066, 0.66695915, 0.27285739,
       0.19350036, 0.24087245]), array([ 1.49754837,  1.12461114,  3.54902
683,  4.68058218, 18.68264496,
        4.92277235,  3.85762595]), array([ 0.81408882,  0.12424397,  0.504
10081,  0.31623952,  0.1200423 ,
        0.11112182, -0.03914959]), array([0.90839257, 0.23420517, 0.193244
06, 0.7754386 , 0.28910265,
       0.3669587 , 0.08077475]), array([ 0.62473406,  0.01386874,  0.03312
886,  0.11004079,  0.00513925,
        0.01161544, -0.0042109 ]), array([0.84066563, 0.17275923, 0.156128
71, 0.5987949 , 0.18167126,
       0.24049986, 0.02272796]), array([ 6.04963497e-01,  4.07884774e-04,
4.18314887e-02,  9.49344462e-03,
        1.15636071e-04,  1.88456300e-04, -1.49731017e-04]), array([0.62117
859, 0.03440393, 0.019934  , 0.16304041, 0.00913659,
       0.02612947, 0.00170768]), array([ 6.95151480e-01,  1.06483157e-02,
5.18726005e-02,  1.65504147e-02,
        2.38651305e-04,  1.70537368e-03, -4.22144772e-04]), array([0.98532
405, 0.17831426, 0.21465032, 0.90746707, 0.39726316,
       0.37147757, 0.05088509]), array([0.79418636, 0.03729911, 0.0164631
9, 0.355025  , 0.0249007 ,
       0.05955859, 0.01080072]), array([1.17143482, 0.39459397, 0.6937429
7, 1.82129312, 1.96760892,
       1.12557839, 0.5654315 ]), array([ 1.52948846,  0.73482837,  1.83752
836,  4.40504502, 12.02089598,
        3.75812682,  3.54473083]), array([1.19309948, 0.33678552, 0.649880
99, 1.71038191, 1.72632348,
       0.9737686 , 0.5210826 ]), array([1.14415026, 0.14116691, 0.2439783
7, 0.83348962, 0.3647371 ,
       0.3045344 , 0.09076059]), array([ 1.64630129,  0.97247101,  2.40084
427,  5.54193532, 19.26892827,
        5.44107544,  6.11190938]), array([ 1.38176415,  0.37124499,  0.465
06703,  1.55366157,  1.31732281,
        0.94487452, -0.09388593]), array([1.23759704, 0.44590182, 0.915586
83, 2.25480228, 3.03503909,
       1.4918888 , 1.13338628]), array([0.8388265 , 0.10712253, 0.1690403
7, 0.52175602, 0.08621677,
       0.15991913, 0.12875056]), array([ 0.64231926,  0.02216101,  0.04844
878,  0.07213828, -0.00108495,
        0.01045392,  0.0041244 ]), array([0.77688718, 0.08970001, 0.016811
, 0.36799311, 0.0228849 ,
       0.10808167, 0.01772082]), array([ 6.15645173e-01,  5.37695203e-02,
2.92372285e-02,  1.41207773e-03,
```

```
        7.26564960e-06,  1.22118759e-04, -5.43429812e-06]), array([ 6.9352
5644e-01,  4.80221078e-02,  1.39273690e-02,  2.86586733e-02,
       -5.49030494e-04,  5.55402745e-03, -1.62440559e-04]), array([ 1.0947
2881,  0.5625529 ,  1.07084351,  1.02749695,  0.99521211,
        0.62072191, -0.41374189]), array([0.73306757, 0.1031975 , 0.009657
83, 0.25486733, 0.0123004 ,
       0.08186977, 0.00293097]), array([ 6.11901701e-01,  5.66736461e-02,
9.72512498e-04,  9.13575690e-03,
       -8.14068261e-06, -2.00323896e-03,  2.59857539e-05]), array([ 0.7240
6007,  0.05899957,  0.04531007,  0.3641518 ,  0.0452626 ,
        0.08714887, -0.0118013 ]), array([ 5.24735675e-01,  1.17338443e-0
2,  2.06812210e-02,  4.45957763e-02,
       -3.83208927e-04,  2.36988798e-03, -1.29899807e-03]), array([ 0.7355
3043,  0.06516343,  0.01019196,  0.20376289,  0.00548497,
        0.05081569, -0.00749266]), array([ 5.94301937e-01,  2.76058359e-0
2,  8.72395304e-03,  2.68392660e-03,
       -4.19448518e-06, -4.12128397e-04,  1.22911103e-05]), array([ 0.6295
2558,  0.05818703,  0.0203652 ,  0.07566831,  0.00155007,
        0.01743284, -0.00253388]), array([ 4.34798258e-01,  1.38868712e-0
2,  1.48487372e-03,  8.36500850e-03,
       -1.15843592e-06,  9.53952639e-04, -2.94583759e-05]), array([ 5.4110
1278e-01,  2.32673608e-02,  1.01705852e-02,  1.18216603e-02,
        1.23611561e-04,  1.72349005e-03, -3.90252610e-05]), array([ 4.2817
8056e-01,  5.08235744e-05,  7.88564570e-03,  2.41601849e-02,
       -3.22191944e-04, -1.55313776e-04, -8.60282592e-05])]
```

In [31]:

```
D_last = cdist(Features_last,Features)

io.imshow(D_last)
plt.title('Distance Matrix')
io.show()
```



In [32]:

```
print(D_last)
```

```
[[4.11876700e+03 4.11876606e+03 4.11876626e+03 ... 4.11903700e+03
  4.11542617e+03 4.11923347e+03]
 [2.21124927e+04 2.21124924e+04 2.21124924e+04 ... 2.21127614e+04
  2.21069215e+04 2.21128723e+04]
 [8.91158323e+03 8.91158259e+03 8.91158273e+03 ... 8.91184605e+03
  8.90600170e+03 8.91195104e+03]
 ...
 [2.08947017e-02 1.79287517e-01 1.03081015e-01 ... 1.14184505e+00
  3.69565098e+01 2.77904129e+00]
 [1.23486827e-01 8.23747334e-02 4.27632585e-02 ... 1.08271287e+00
  3.69505044e+01 2.74704230e+00]
 [2.51767035e-02 1.85883579e-01 1.09812886e-01 ... 1.13358120e+00
  3.69532843e+01 2.77025742e+00]]
```

In [33]:

```
D_index_last = np.argsort(D_last, axis=1)
```

In [34]:

```
print(D_index_last.shape)

print(D_index_last)
```

```
(73, 1159)
[[ 185  231  240 ...  575  190 1067]
 [ 143  194  865 ...  575  190 1067]
 [ 144  273  140 ...  575  190 1067]
 ...
 [ 919  917  915 ...  575  190 1067]
 [ 468  460  876 ...  575  190 1067]
 [  33  509    4 ...  575  190 1067]]
```

In [35]:

```
predict_index_last=[]
for i in range(D_index_last.shape[0]):
    predict_index_last.append(D_index_last[i,0])
#print(y_true_index)
print(predict_index_last)
```

```
[185, 143, 144, 194, 233, 264, 349, 349, 365, 255, 349, 295, 252, 229, 15
0, 226, 367, 228, 336, 344, 135, 299, 111, 268, 816, 157, 566, 1033, 565,
1072, 1100, 573, 234, 1000, 1124, 838, 1024, 597, 1128, 670, 197, 1138, 7
6, 451, 908, 455, 50, 1063, 1006, 45, 533, 599, 585, 593, 847, 545, 729, 9
08, 52, 45, 881, 1011, 941, 518, 1137, 45, 466, 51, 463, 1092, 919, 468, 3
3]
```

In [36]:

```
y_pred_last=[]
for i in predict_index_last:
    k=0
    for j in char_ranges:
        if i >= j:
            k+=1
            continue
        y_pred_last.append(characters[k])
        break
print(y_pred_last)
```

```
['f', 'f', 'f', 'f', 'h', 'h', 'k', 'k', 'k', 'h', 'k', 'k', 'h', 'h',
'f', 'h', 'k', 'h', 'k', 'k', 'f', 'k', 'd', 'h', 's', 'f', 'o', 'x', 'o',
'x', 'z', 'o', 'h', 'x', 'z', 's', 'x', 'o', 'z', 'q', 'f', 'z', 'd', 'n',
'u', 'n', 'a', 'x', 'x', 'a', 'o', 'o', 'o', 'o', 's', 'o', 'q', 'u', 'a',
'a', 'u', 'x', 'w', 'n', 'z', 'a', 'n', 'a', 'n', 'z', 'u', 'n', 'a']
```

In [37]:

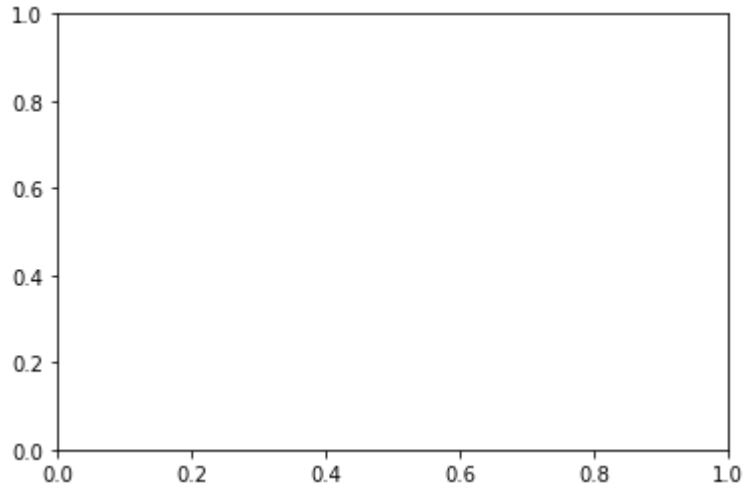
```
with open('/Users/sanchitthakur/pickle_files/test2_gt.pkl', 'rb') as file:
    my_dict = pickle.load(file)
classes = my_dict['classes']
locations = my_dict['locations']

print(classes)

print(locations)
```

```
['w' 'm' 'z' 'o' 'x' 'a' 'k' 'f' 'h' 's' 's' 'x' 'w' 'm' 'z' 'k' 'o' 'a'
 'h' 'f' 'w' 'm' 'o' 'x' 's' 'k' 'z' 'a' 'h' 'f' 'm' 's' 'w' 'x' 'h' 'k'
 'z' 'a' 'o' 'f' 'x' 's' 'm' 'k' 'z' 'a' 'o' 'w' 'h' 'f' 'w' 'm' 'o' 'a'
 'z' 's' 'k' 'h' 'x' 'f' 'm' 'w' 'o' 's' 'z' 'a' 'x' 'h' 'k' 'f' 's' 'm'
 'h' 'o' 'k' 'a' 'w' 'f' 'x' 'z']
[[  36.   938.5]
 [  35.  1046.5]
 [  41.   662. ]
 [  36.   853. ]
 [  40.5  540.5]
 [  42.5  749.5]
 [  44.5  313.5]
 [  46.    79.5]
 [  45.   210.5]
 [  42.5  432. ]
 [ 101.   433.5]
 [ 108.5  537. ]
 [ 106.   939. ]
 [ 105.5 1052. ]
 [ 111.   655. ]
 [ 118.5  315. ]
 [ 114.5  848.5]
 [ 120.5  747.5]
 [ 129.   206.5]
 [ 135.    83. ]
 [ 204.   939. ]
 [ 206.  1048. ]
 [ 208.   850. ]
 [ 215.5  530.5]
 [ 211.   425. ]
 [ 221.5  310.5]
 [ 221.   651. ]
 [ 221.   741. ]
 [ 225.5  207.5]
 [ 232.5   80.5]
 [ 301.5 1050. ]
 [ 297.5  426. ]
 [ 306.   940.5]
 [ 302.   530.5]
 [ 308.5  208.5]
 [ 310.5  313.5]
 [ 310.5  647.5]
 [ 312.   742. ]
 [ 313.5  846. ]
 [ 320.    84.5]
 [ 422.5  529.5]
 [ 411.5  419.5]
 [ 423.5 1049.5]
 [ 423.5  315. ]
 [ 424.5  650.5]
 [ 424.   738. ]
 [ 424.5  844. ]
 [ 429.   941. ]
 [ 428.   207. ]
 [ 439.    85.5]
 [ 507.   945.5]
 [ 512.5 1051. ]
 [ 519.5  845. ]
 [ 525.   738. ]
 [ 532.5  650. ]
 [ 529.   417.5]
```

```
    [ 540.   308. ]
    [ 542.5  206. ]
    [ 540.5  526.5]
    [ 550.    84. ]
    [ 598.  1051.5]
    [ 612.   945.5]
    [ 617.   847. ]
    [ 615.   421. ]
    [ 625.5  649.5]
    [ 623.   739. ]
    [ 632.   531. ]
    [ 628.5  201. ]
    [ 635.5  308. ]
    [ 638.5   83.5]
    [ 705.   426.5]
    [ 706.5 1048.5]
    [ 709.5  203. ]
    [ 712.   851.5]
    [ 720.5  306.5]
    [ 715.5  741. ]
    [ 715.   948.5]
    [ 719.5   83. ]
    [ 729.   533.5]
    [ 730.   651.5]]
```

In [38]:

```
folder_directory = '/Users/sanchitthakur/test_images'
y_true_last=[]
imgs = Path(folder_directory).glob('test2.bmp')
for img in imgs:
    im=io.imread(img)
    th = 200
    img_binary = (im < th).astype(np.double)
    img_label = label(img_binary, background=0)
    regions = regionprops(img_label)
    ax = plt.gca()
    for props in regions:
        minr, minc, maxr, maxc = props.bbox
        if ((maxc-minc)<18 or (maxr-minr)<18):
            continue
        ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill = False, e
dgecolor = 'red', linewidth = 1))
        for i in range(len(locations)):
            if locations[i][0] > minc and locations[i][0] < maxc and locations[i][1] >
minr and locations[i][1] < maxr:
                y_true_last.append(classes[i])
```



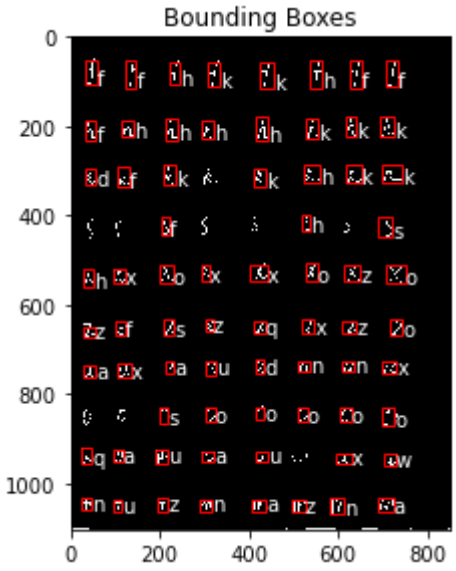
In [39]:

```
print(y_true_last)
```

```
['f', 'f', 'f', 'f', 'f', 'f', 'f', 'f', 'h', 'h', 'h', 'h', 'h', 'h',
'h', 'h', 'k', 'k', 'k', 'k', 'k', 'k', 'k', 's', 's', 's', 'x', 'x', 'x',
'x', 'x', 'x', 'x', 'x', 'z', 'z', 'z', 'z', 'z', 'z', 'z', 'z', 'a', 'a',
'a', 'a', 'a', 'a', 'a', 'a', 'o', 'o', 'o', 'o', 'o', 'o', 'o', 'w', 'w',
'w', 'w', 'w', 'w', 'w', 'w', 'm', 'm', 'm', 'm', 'm', 'm', 'm', 'm']
```

In [40]:

```
regions = regionprops(img_label)
io.imshow(img_binary)
ax = plt.gca()
bound_count = 0
for props in regions:
    minr, minc, maxr, maxc = props.bbox
    if ((maxc-minc) < 19 or (maxr-minr) < 19):
      continue
    ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill =
False, edgecolor = 'red', linewidth = 1))
    ax.text(maxc, maxr, y_pred_last[bound_count], color="white")
    bound_count += 1
ax.set_title('Bounding Boxes')
io.show()
```



In [41]:

```
from sklearn.metrics import accuracy_score

print(accuracy_score(y_true_last, y_pred_last))
```

```
0.3698630136986301
```

ENHANCEMENTS USING K NEAREST NEIGHBORS

FOR TRAINING DATA

In [42]:

```
training_dataframe = pd.DataFrame(Features, columns = ['Hu-1', 'Hu-2', 'Hu-3', 'Hu-4',
'Hu-5', 'Hu-6', 'Hu-7'])
print(training_dataframe)
```

```
         Hu-1      Hu-2      Hu-3       Hu-4          Hu-5      Hu-6  \
0     0.419781  0.003343  0.007771   0.000657  2.316787e-07 -0.000038
1     0.601798  0.027185  0.065230   0.004568 -5.744776e-06  0.000321
2     0.525447  0.023402  0.049593   0.006494 -1.540421e-06  0.000664
3     0.445520  0.009613  0.015942   0.001639 -1.739101e-07  0.000067
4     0.423849  0.007237  0.016761   0.004551 -2.070988e-05 -0.000314
...        ...       ...       ...        ...           ...       ...
1154  1.062887  0.026557  0.407546   0.784883 -2.905597e-01  0.121548
1155  2.378466  0.393376  6.468446  11.908190 -1.145468e+01  6.770693
1156  1.056021  0.060424  0.238214   0.833582 -2.511888e-01  0.202795
1157  2.013307  0.692937  1.925795   8.620815  9.433453e+00  7.151232
1158  1.198955  0.109835  0.648259   1.738822 -1.939930e-01  0.556946

           Hu-7
0     -0.000001
1     -0.000079
2     -0.000117
3     -0.000008
4     -0.000034
...         ...
1154  -0.335607
1155 -103.882978
1156  -0.273648
1157 -33.835470
1158  -1.835886

[1159 rows x 7 columns]
```

In [43]:

```
training_output = pd.DataFrame(y_pred, columns = ['Output'])
print(training_output)
```

```
     Output
0         n
1         z
2         a
3         u
4         a
...     ...
1154      z
1155      z
1156      z
1157      k
1158      k

[1159 rows x 1 columns]
```

In [44]:

```
training_dataframe['Output'] = y_pred
print(training_dataframe)
```

```
          Hu-1      Hu-2      Hu-3       Hu-4          Hu-5      Hu-6  \
0     0.419781  0.003343  0.007771   0.000657  2.316787e-07 -0.000038
1     0.601798  0.027185  0.065230   0.004568 -5.744776e-06  0.000321
2     0.525447  0.023402  0.049593   0.006494 -1.540421e-06  0.000664
3     0.445520  0.009613  0.015942   0.001639 -1.739101e-07  0.000067
4     0.423849  0.007237  0.016761   0.004551 -2.070988e-05 -0.000314
...        ...       ...       ...        ...           ...       ...
1154  1.062887  0.026557  0.407546   0.784883 -2.905597e-01  0.121548
1155  2.378466  0.393376  6.468446  11.908190 -1.145468e+01  6.770693
1156  1.056021  0.060424  0.238214   0.833582 -2.511888e-01  0.202795
1157  2.013307  0.692937  1.925795   8.620815  9.433453e+00  7.151232
1158  1.198955  0.109835  0.648259   1.738822 -1.939930e-01  0.556946

            Hu-7 Output
0      -0.000001      n
1      -0.000079      z
2      -0.000117      a
3      -0.000008      u
4      -0.000034      a
...          ...    ...
1154   -0.335607      z
1155 -103.882978      z
1156   -0.273648      z
1157  -33.835470      k
1158   -1.835886      k

[1159 rows x 8 columns]
```

In [45]:

```
X = training_dataframe.iloc[:, :-1]
y = training_dataframe.iloc[:,-1]
print(X)
print(y)
```

```
          Hu-1      Hu-2      Hu-3       Hu-4          Hu-5      Hu-6  \
0     0.419781  0.003343  0.007771   0.000657  2.316787e-07 -0.000038
1     0.601798  0.027185  0.065230   0.004568 -5.744776e-06  0.000321
2     0.525447  0.023402  0.049593   0.006494 -1.540421e-06  0.000664
3     0.445520  0.009613  0.015942   0.001639 -1.739101e-07  0.000067
4     0.423849  0.007237  0.016761   0.004551 -2.070988e-05 -0.000314
...        ...       ...       ...        ...           ...       ...
1154  1.062887  0.026557  0.407546   0.784883 -2.905597e-01  0.121548
1155  2.378466  0.393376  6.468446  11.908190 -1.145468e+01  6.770693
1156  1.056021  0.060424  0.238214   0.833582 -2.511888e-01  0.202795
1157  2.013307  0.692937  1.925795   8.620815  9.433453e+00  7.151232
1158  1.198955  0.109835  0.648259   1.738822 -1.939930e-01  0.556946

           Hu-7
0     -0.000001
1     -0.000079
2     -0.000117
3     -0.000008
4     -0.000034
...         ...
1154   -0.335607
1155 -103.882978
1156   -0.273648
1157  -33.835470
1158   -1.835886

[1159 rows x 7 columns]
0       n
1       z
2       a
3       u
4       a
       ..
1154    z
1155    z
1156    z
1157    k
1158    k
Name: Output, Length: 1159, dtype: object
```

In [46]:

```
from sklearn.neighbors import KNeighborsClassifier
knn = KNeighborsClassifier(n_neighbors = 6)
knn.fit(X,y)
```

Out[46]:

```
KNeighborsClassifier(n_neighbors=6)
```

In [47]:

```
knn.score(X,y)
```

Out[47]:

```
0.6945642795513374
```

FOR TEST IMAGE 1

In [48]:

```
testing_dataframe1 = pd.DataFrame(Features_new, columns = ['Hu-1', 'Hu-2', 'Hu-3', 'Hu-4', 'Hu-5', 'Hu-6', 'Hu-7'])
print(testing_dataframe1)
```

```
        Hu-1      Hu-2      Hu-3      Hu-4          Hu-5      Hu-6  \
0   0.447171  0.018152  0.017429  0.006175 -2.873476e-05 -0.000822
1   0.346953  0.001043  0.001654  0.001945  5.080003e-07 -0.000063
2   0.484009  0.009541  0.004782  0.005617 -2.910776e-05 -0.000140
3   0.444772  0.003923  0.021837  0.004754  8.222812e-08 -0.000298
4   0.495842  0.020451  0.024614  0.034905 -5.593822e-04  0.002273
..       ...       ...       ...       ...           ...       ...
62  0.895009  0.182968  0.565570  0.815309  3.825617e-01  0.297723
63  0.469089  0.012526  0.034467  0.005327  5.967494e-05  0.000108
64  0.693115  0.123911  0.264644  0.358468  8.290796e-02  0.107589
65  0.429289  0.034795  0.036090  0.026164  1.171113e-04 -0.000185
66  0.674814  0.091246  0.123450  0.084234 -6.464600e-04 -0.005866

           Hu-7
0  -5.725445e-05
1   3.451333e-06
2   4.310866e-07
3  -4.843126e-05
4  -8.566334e-04
..           ...
62 -4.002027e-01
63  4.062162e-05
64 -7.291472e-02
65 -7.954221e-04
66 -8.565312e-03

[67 rows x 7 columns]
```

In [49]:

```
knn_predict_test1 = knn.predict(testing_dataframe1)
knn_predict_test1
```

Out[49]:

```
array(['u', 'a', 'u', 'a', 'n', 'n', 'a', 'd', 'd', 'd', 'd', 'd', 'd',
       'd', 'n', 'a', 'm', 'm', 'm', 'a', 'm', 'n', 'u', 'a', 'a', 'n',
       'a', 'u', 'a', 'x', 'x', 'x', 'x', 'n', 'x', 'n', 'm', 'm', 'r',
       'p', 'd', 'o', 'p', 'q', 'q', 'w', 'd', 'p', 'w', 'r', 'd', 'r',
       'r', 'r', 'n', 'x', 'x', 'x', 'n', 'n', 'x', 'w', 'r', 'a', 'r',
       'm', 'a'], dtype=object)
```

In [50]:

```
y_test = pd.DataFrame(y_true_new)
print(y_test)
```

```
    0
0   a
1   a
2   a
3   a
4   a
.. ..
62  w
63  w
64  w
65  w
66  w

[67 rows x 1 columns]
```

In [51]:

```
folder_directory = '/Users/sanchitthakur/test_images'
imgs = Path(folder_directory).glob('test1.bmp')
for img in imgs:
  im=io.imread(img)
  img_binary = (im < th).astype(np.double)
  img_label = label(img_binary, background=0)
  regions = regionprops(img_label)
  io.imshow(img_binary)
  ax = plt.gca()
  bound_count = 0
  for props in regions:
      minr, minc, maxr, maxc = props.bbox
      if ((maxc-minc) < 19 or (maxr-minr) < 19):
        continue
      ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill =
  False, edgecolor = 'red', linewidth = 1))
      ax.text(maxc, maxr, knn_predict_test1[bound_count], color="white")
      bound_count += 1
  ax.set_title('Bounding Boxes')
io.show()
```

In [52]:

```
knn.score(testing_dataframe1,y_test)
```

Out[52]:

```
0.3582089552238806
```

FOR TEST IMAGE 2

In [53]:

```
testing_dataframe2 = pd.DataFrame(Features_last, columns = ['Hu-1', 'Hu-2', 'Hu-3', 'Hu
-4', 'Hu-5', 'Hu-6', 'Hu-7'])
print(testing_dataframe2)
```

```
       Hu-1       Hu-2        Hu-3        Hu-4          Hu-5        Hu-
6  \
0   3.656729   8.150940   49.570150   69.882510   4041.614518  199.32983
3
1   4.801529  15.866954  116.769303  161.132320  21944.024570  639.41398
0
2   4.028151  11.168978   76.536418  101.183475   8838.969233  337.65368
0
3   4.651750  16.240519  117.137025  148.244447  19470.497549  596.44407
9
4   4.259420  12.876470   91.842166  118.280918  12260.027672  423.59542
0
..       ...        ...         ...         ...           ...
...
68  0.594302   0.027606    0.008724    0.002684     -0.000004   -0.00041
2
69  0.629526   0.058187    0.020365    0.075668      0.001550    0.01743
3
70  0.434798   0.013887    0.001485    0.008365     -0.000001    0.00095
4
71  0.541101   0.023267    0.010171    0.011822      0.000124    0.00172
3
72  0.428178   0.000051    0.007886    0.024160     -0.000322   -0.00015
5

          Hu-7
0    763.180513
1   2640.720123
2   1076.427532
3   1586.910194
4   1292.915241
..          ...
68     0.000012
69    -0.002534
70    -0.000029
71    -0.000039
72    -0.000086

[73 rows x 7 columns]
```

In [54]:

```
y_test_2 = pd.DataFrame(y_true_last)
print(y_test_2)
```

```
    0
0   f
1   f
2   f
3   f
4   f
.. ..
68  m
69  m
70  m
71  m
72  m

[73 rows x 1 columns]
```

In [55]:

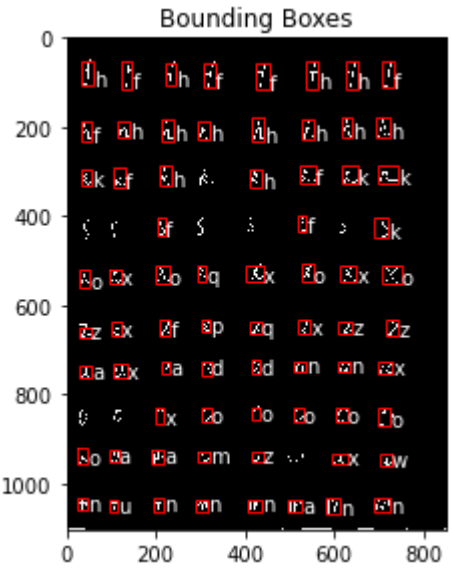
```
knn_predict_test2 = knn.predict(testing_dataframe2)
knn_predict_test2
```

Out[55]:

```
array(['h', 'f', 'h', 'f', 'h', 'h', 'f', 'f', 'h', 'h', 'h', 'h', 'h',
       'h', 'f', 'h', 'k', 'f', 'k', 'h', 'f', 'h', 'k', 'f', 'k', 'f',
       'o', 'x', 'o', 'q', 'x', 'o', 'o', 'x', 'p', 'f', 'x', 'z', 'z',
       'q', 'x', 'z', 'd', 'n', 'd', 'n', 'a', 'x', 'x', 'a', 'o', 'o',
       'o', 'o', 'x', 'o', 'o', 'a', 'a', 'm', 'z', 'x', 'w', 'n', 'n',
       'n', 'n', 'n', 'n', 'a', 'u', 'n', 'a'], dtype=object)
```

In [56]:

```
folder_directory = '/Users/sanchitthakur/test_images'
imgs = Path(folder_directory).glob('test2.bmp')
for img in imgs:
  im=io.imread(img)
  img_binary = (im < th).astype(np.double)
  img_label = label(img_binary, background=0)
  regions = regionprops(img_label)
  io.imshow(img_binary)
  ax = plt.gca()
  bound_count = 0
  for props in regions:
      minr, minc, maxr, maxc = props.bbox
      if ((maxc-minc) < 19 or (maxr-minr) < 19):
        continue
      ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill =
  False, edgecolor = 'red', linewidth = 1))
      ax.text(maxc, maxr, knn_predict_test2[bound_count], color="white")
      bound_count += 1
  ax.set_title('Bounding Boxes')
io.show()
```



In [57]:

```
knn.score(testing_dataframe2,y_test_2)
```

Out[57]:

```
0.3972602739726027
```

RESULTS:

(i). For all training images: For the training images provided, the code was run, and a training accuracy of 53.8% was observed. Each training image was binarized, all features from it were extracted, it was normalized and then recognition was run on the training data. Also, the recognized character classes were added to each image. The results thus are as follows:

In [1]:

```
import numpy as np
from sklearn.metrics import confusion_matrix
from sklearn.metrics import classification_report
from scipy.spatial.distance import cdist
from skimage.measure import (label, regionprops, moments, moments_central,
moments_normalized, moments_hu)
from skimage import io, exposure
import matplotlib.pyplot as plt
from matplotlib.patches import Rectangle
import pickle
import glob
```

In [2]:

```
img = io.imread('a.bmp')
```

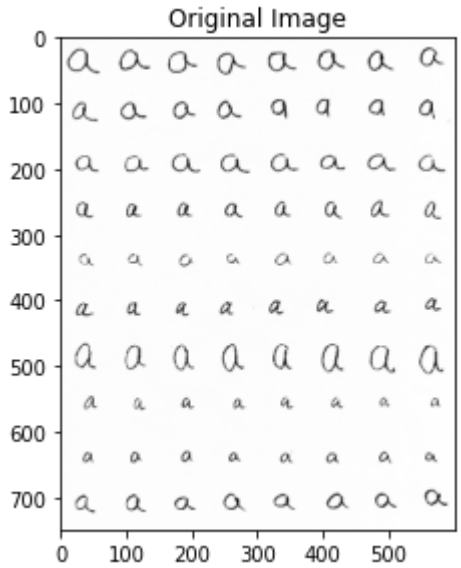
In [3]:

```
print(img.shape)
```

```
(750, 600)
```

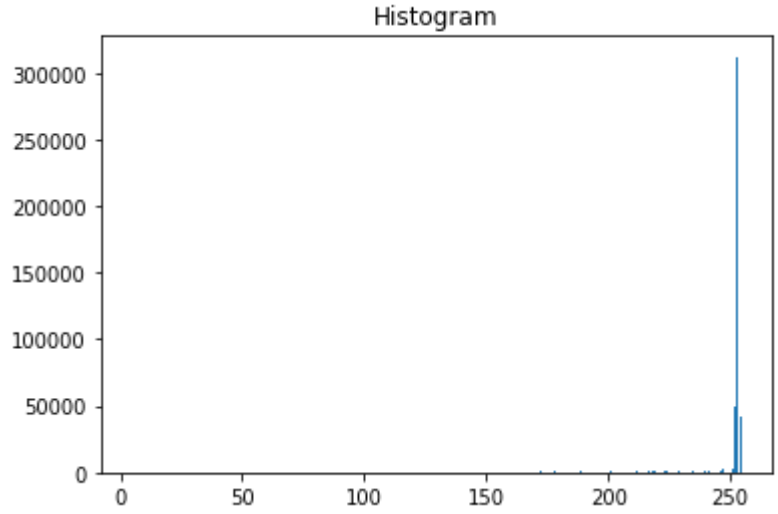
In [4]:

```
io.imshow(img)
plt.title('Original Image')
io.show()
```



In [5]:

```
hist = exposure.histogram(img)
plt.bar(hist[1], hist[0])
plt.title('Histogram')
plt.show()
```

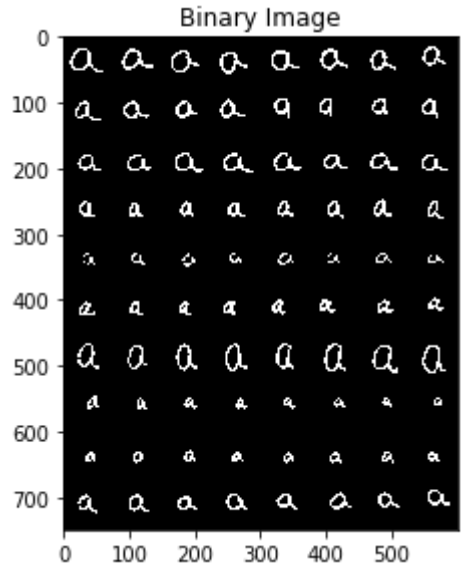


In [6]:

```
th = 200
img_binary = (img < th).astype(np.double)
```

In [7]:

```
io.imshow(img_binary)
plt.title('Binary Image')
io.show()
```



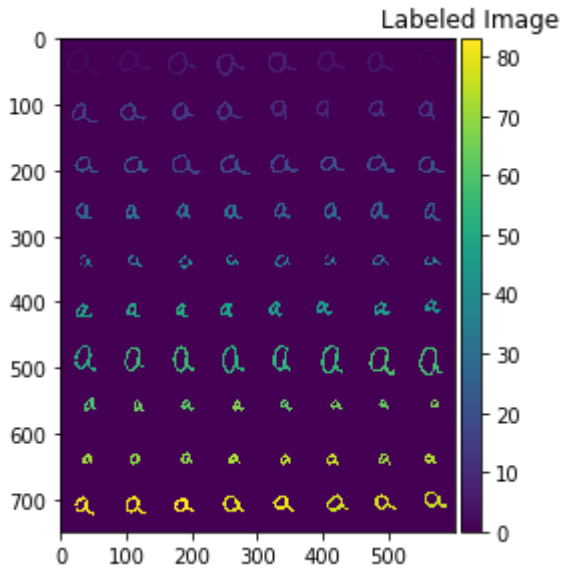
In [8]:

```
img_label = label(img_binary, background=0)
```

In [9]:

```
io.imshow(img_label)
plt.title('Labeled Image')
io.show()
```

```
/usr/local/lib/python3.7/dist-packages/skimage/io/_plugins/matplotlib_plug
in.py:150: UserWarning: Low image data range; displaying image with stretc
hed contrast.
  lo, hi, cmap = _get_display_range(image)
```



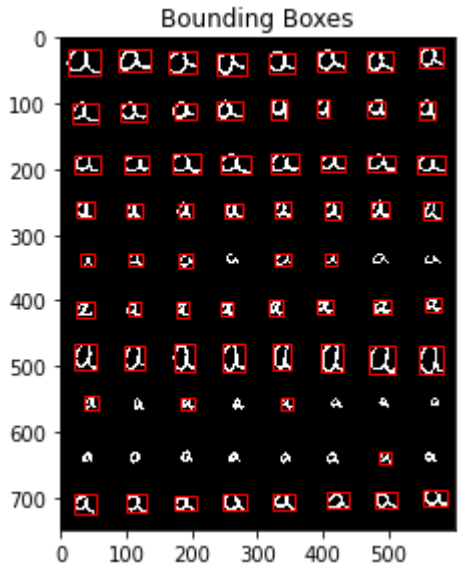
In [10]:

```
print(np.amax(img_label))
```

```
83
```

In [11]:

```
regions = regionprops(img_label)
io.imshow(img_binary)
ax = plt.gca()
Features=[]
for props in regions:
    minr, minc, maxr, maxc = props.bbox
    if ((maxc-minc) < 18 or (maxr-minr) < 18):
      continue
    ax. add_patch(Rectangle((minc, minr), maxc - minc, maxr - minr, fill =
False, edgecolor = 'red', linewidth = 1))
    roi = img_binary[minr:maxr, minc:maxc]
    m = moments(roi)
    cr = m[0, 1] / m[0, 0]
    cc = m[1, 0] / m[0, 0]
    center = (cr, cc)
    mu = moments_central(roi, center)
    nu = moments_normalized(mu)
    hu = moments_hu(nu)
    Features.append(hu)
ax.set_title('Bounding Boxes')
io.show()
```



In [12]:

```
Features
```

Out[12]:

```
[array([ 4.19781444e-01,  3.34312047e-03,  7.77133313e-03,  6.57288450e-0
4,
         2.31678734e-07, -3.79573946e-05, -1.46735401e-06]),
 array([ 6.01797836e-01,  2.71854852e-02,  6.52303270e-02,  4.56815900e-0
3,
        -5.74477635e-06,  3.21301838e-04, -7.86468011e-05]),
 array([ 5.25447113e-01,  2.34016383e-02,  4.95926512e-02,  6.49411569e-0
3,
        -1.54042128e-06,  6.64395707e-04, -1.16533491e-04]),
 array([ 4.45519984e-01,  9.61300674e-03,  1.59416217e-02,  1.63948182e-0
3,
        -1.73910076e-07,  6.74964178e-05, -8.37978064e-06]),
 array([ 4.23848858e-01,  7.23733290e-03,  1.67607430e-02,  4.55127240e-0
3,
        -2.07098781e-05, -3.13635682e-04, -3.39297373e-05]),
 array([ 5.22063820e-01,  8.57068778e-03,  1.24625007e-02,  6.80725070e-0
3,
        -6.11769890e-05,  1.27405685e-04, -1.37307467e-05]),
 array([ 4.63296703e-01,  9.54162245e-03,  1.42696703e-02,  8.46275098e-0
3,
        -8.16706087e-05, -3.32480048e-04, -4.44810933e-05]),
 array([ 4.73359378e-01,  4.38706903e-03,  1.50218485e-02,  5.85752759e-0
4,
         9.06083867e-07, -3.75968463e-05, -1.48257712e-06]),
 array([ 3.50176310e-01,  6.70622461e-03,  7.96321222e-04,  1.27586695e-0
2,
        -4.00023654e-05,  4.91526904e-04, -7.32751779e-06]),
 array([3.23299738e-01, 5.45130917e-03, 2.24569880e-03, 1.06094299e-04,
        2.56814052e-08, 1.69904273e-07, 4.49696925e-08]),
 array([ 3.36861739e-01,  1.08269017e-04,  3.85994660e-03,  3.42917317e-0
3,
         4.68758168e-06, -2.94923554e-05,  1.15618653e-05]),
 array([ 3.28273409e-01,  1.77314789e-03,  4.22404418e-03,  3.99744817e-0
3,
        -3.11118892e-06, -1.31260831e-04, -1.61289264e-05]),
 array([ 4.15603966e-01,  1.05791750e-02,  1.82936156e-02,  6.22358950e-0
3,
        -1.89106647e-05, -6.30561801e-04, -6.36570659e-05]),
 array([ 3.77501520e-01,  3.18519001e-03,  7.22226100e-03,  4.77522619e-0
4,
         6.34957082e-07, -2.12853527e-05, -6.19072175e-07]),
 array([4.68663678e-01, 2.88586914e-02, 5.92385453e-02, 7.33545252e-03,
        1.24331571e-04, 1.17333077e-03, 8.90159909e-05]),
 array([ 4.59484475e-01,  1.84670861e-02,  2.59034877e-02,  1.45896607e-0
2,
        -2.00541664e-04,  6.75709288e-05, -2.00566874e-04]),
 array([ 5.26567032e-01,  5.09655792e-02,  3.74029408e-02,  3.49235984e-0
3,
        -1.76313328e-05,  1.78381468e-04, -3.58093320e-05]),
 array([ 5.14523036e-01,  3.97752461e-02,  3.56587445e-02,  5.08870161e-0
3,
        -2.41975639e-05,  2.94087502e-04, -6.41348454e-05]),
 array([ 5.36084062e-01,  5.26178685e-02,  5.35196911e-02,  1.96203105e-0
2,
        -2.98823133e-04,  4.97854342e-04, -5.61192687e-04]),
 array([ 0.58137433,  0.04339864,  0.06650893,  0.08502284, -0.00164144,
         0.00724383, -0.00617927]),
 array([ 0.51548659,  0.02948318,  0.03754555,  0.06043118, -0.00093973,
         0.00433056, -0.00272082]),
```

```
 array([ 5.46468355e-01,  6.87297808e-02,  6.30939103e-02,  2.30863921e-0
2,
        -3.44547597e-04,  7.12200946e-04, -8.10946077e-04]),
 array([ 5.25470881e-01,  3.04138882e-02,  2.77444114e-02,  3.31925403e-0
2,
        -8.74103548e-04, -3.95502644e-04, -5.00547670e-04]),
 array([ 4.77406343e-01,  2.35794972e-02,  1.67654177e-02,  3.78880922e-0
3,
        -2.96248518e-05, -8.38563530e-05, -5.84948312e-06]),
 array([ 3.98564972e-01,  1.84006466e-03,  1.23512404e-02,  2.94175439e-0
2,
         9.71493929e-05,  1.23126784e-03, -5.52264626e-04]),
 array([ 4.06258002e-01,  5.04200957e-03,  2.42518085e-03,  4.16873520e-0
2,
         1.66793102e-04,  2.67929063e-03, -3.84544032e-04]),
 array([ 4.61740804e-01,  9.56883799e-03,  2.57289756e-03,  6.39812480e-0
2,
        -4.06926136e-04,  5.71683871e-03, -7.12943260e-04]),
 array([ 3.51057942e-01,  4.10906701e-03,  4.22115197e-03,  8.37216381e-0
3,
        -3.45943596e-05, -4.11272302e-04, -3.57817510e-05]),
 array([ 3.97821592e-01,  3.51314518e-03,  4.10799852e-03,  2.16495840e-0
2,
        -1.55909232e-04, -6.24485629e-04, -1.31822717e-04]),
 array([ 3.01159150e-01,  1.46316258e-03,  1.94595567e-03,  1.26254571e-0
2,
         2.27316125e-05,  4.10276518e-04, -5.83057344e-05]),
 array([ 3.08670209e-01,  4.23874936e-03,  9.14385273e-03,  6.54275367e-0
4,
        -1.10115169e-06, -9.21543639e-07,  1.16123767e-06]),
 array([ 2.75176128e-01,  4.35185812e-04,  2.54891710e-03,  4.83104885e-0
3,
         3.39996676e-06,  3.02617839e-05, -1.66083036e-05]),
 array([ 3.96336748e-01,  1.03001138e-02,  1.73903341e-03,  6.24543312e-0
3,
        -2.04536047e-05,  3.11889679e-04, -2.29972653e-06]),
 array([4.41257323e-01, 3.14237898e-03, 9.82286768e-03, 2.21395633e-02,
        2.58324239e-04, 4.89437715e-04, 1.99663969e-04]),
 array([ 4.59844825e-01,  5.87806672e-02,  4.43857723e-03,  1.19759578e-0
3,
        -1.13456735e-06,  2.82763890e-04, -2.51726252e-06]),
 array([ 3.53761185e-01,  1.72906996e-02,  4.06160185e-03,  2.52366637e-0
4,
        -1.73679260e-07, -3.13832826e-05, -1.87396564e-07]),
 array([4.02808107e-01, 7.67223079e-06, 3.68007419e-03, 8.94953772e-03,
        3.19176872e-05, 2.42614990e-05, 4.02388067e-05]),
 array([ 2.64517854e-01,  1.12893222e-03,  6.67305080e-03,  3.44451525e-0
4,
        -1.42908542e-07,  2.39539503e-06,  5.02286757e-07]),
 array([ 2.89665770e-01,  1.21741175e-03,  3.54510504e-03,  6.90375730e-0
3,
        -1.60945664e-05, -2.20375455e-04, -3.01241993e-05]),
 array([ 2.93086775e-01,  3.51534737e-03,  1.48419147e-03,  1.15795585e-0
2,
        -1.74300025e-05,  5.92573572e-04, -4.47284904e-05]),
 array([ 2.78128259e-01,  9.43213266e-04,  7.65522919e-03,  4.62234780e-0
4,
        -8.57362258e-07, -1.13182347e-05, -1.44817805e-07]),
 array([ 2.52393390e-01,  4.09460919e-03,  2.22535170e-03,  3.43946986e-0
3,
        -1.10300306e-06,  2.08901997e-04, -9.45146548e-06]),
```

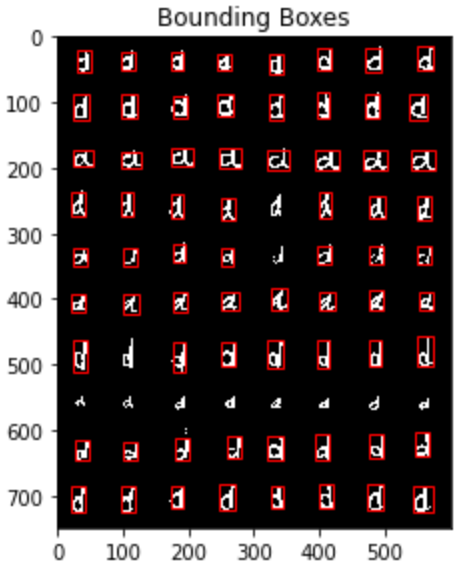
```
 array([ 3.02341685e-01,  6.40767808e-04,  8.53821763e-03,  2.17770233e-0
3,
        -4.49391916e-06, -5.44993845e-05, -8.24519269e-06]),
 array([ 2.89211063e-01,  3.07177206e-03,  1.30836608e-03,  8.40182610e-0
3,
        -1.79375635e-05,  2.56580074e-04, -2.13125194e-05]),
 array([ 2.82425687e-01,  4.89558433e-03,  1.08877173e-03,  1.13117560e-0
2,
        -3.88666335e-05,  6.92507282e-04, -8.07951275e-06]),
 array([0.76881243, 0.0601288 , 0.01555196, 0.33937966, 0.02147262,
        0.0716402 , 0.01211781]),
 array([0.8179576 , 0.09544629, 0.06128115, 0.4858258 , 0.06748552,
        0.1405165 , 0.04972608]),
 array([0.80409942, 0.13153018, 0.07475196, 0.48224163, 0.07340402,
        0.16823275, 0.05472826]),
 array([0.79030172, 0.09018153, 0.05293846, 0.42651463, 0.05022398,
        0.11691369, 0.03981218]),
 array([0.81858445, 0.0861075 , 0.0594244 , 0.47874807, 0.05585444,
        0.1299366 , 0.05831686]),
 array([0.6324188 , 0.0455754 , 0.02616502, 0.19995824, 0.01361261,
        0.03770398, 0.00488731]),
 array([0.70229876, 0.02299172, 0.00463728, 0.19938707, 0.00237937,
        0.01556347, 0.00557645]),
 array([ 0.6633233 ,  0.01228027,  0.0271892 ,  0.07838221, -0.00264133,
        -0.00562538, -0.00247319]),
 array([ 2.88929833e-01,  4.92568831e-03,  7.75144467e-03,  6.48047207e-0
3,
         3.11684275e-05,  4.31317450e-04, -3.37363468e-05]),
 array([ 2.78027570e-01,  4.70913705e-04,  3.99824700e-03,  7.40416298e-0
3,
        -8.96494058e-06, -1.59500056e-04, -3.92753281e-05]),
 array([ 2.80666310e-01,  6.93316740e-03,  4.83886858e-03,  4.65398971e-0
3,
        -2.09727670e-05, -3.34766546e-04, -6.92233025e-06]),
 array([ 2.70418300e-01,  4.00129225e-03,  5.74357585e-03,  1.12755383e-0
3,
        -1.92825116e-06, -7.06590266e-05, -2.12497808e-06]),
 array([ 4.15601540e-01,  2.34885864e-02,  1.91157097e-02,  1.19725754e-0
2,
        -1.23168650e-04, -6.31299847e-04, -1.32798626e-04]),
 array([ 3.84493391e-01,  5.04502606e-03,  5.45867547e-03,  8.06300898e-0
3,
        -5.26341642e-05,  2.70146354e-04, -9.54178310e-06]),
 array([ 3.79145939e-01,  1.99763322e-02,  1.44637742e-02,  5.53991826e-0
3,
        -1.43217216e-05,  5.56699130e-05, -4.74771117e-05]),
 array([ 3.94760424e-01,  1.36941292e-02,  8.16444494e-03,  3.83740966e-0
4,
        -4.32829128e-07, -6.24770873e-06, -5.23469427e-07]),
 array([ 3.91488129e-01,  8.61170266e-03,  1.02686769e-02,  1.37211443e-0
2,
        -1.59223130e-04, -1.35330435e-04, -3.42758331e-05]),
 array([ 3.74688395e-01,  6.95965748e-03,  7.52045193e-03,  4.84781114e-0
3,
        -1.60118885e-05, -3.38250897e-04, -2.45035202e-05]),
 array([ 4.32333452e-01,  2.63230247e-02,  2.58901895e-02,  4.15830803e-0
3,
        -2.99718443e-05,  1.06281418e-04,  3.10368095e-05]),
 array([ 3.90038821e-01,  1.00811432e-02,  1.33248680e-02,  1.78524302e-0
2,
        -1.79245585e-04,  2.58373678e-04, -2.09011928e-04])]
```

In [13]:

```
len(Features)
```

Out[13]:

65


Bounding Boxes
0
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400
500
600
700
0
100
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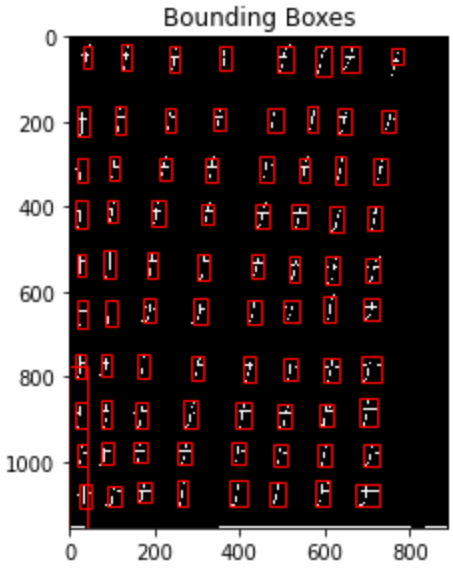
400
500


Bounding Boxes
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800
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200
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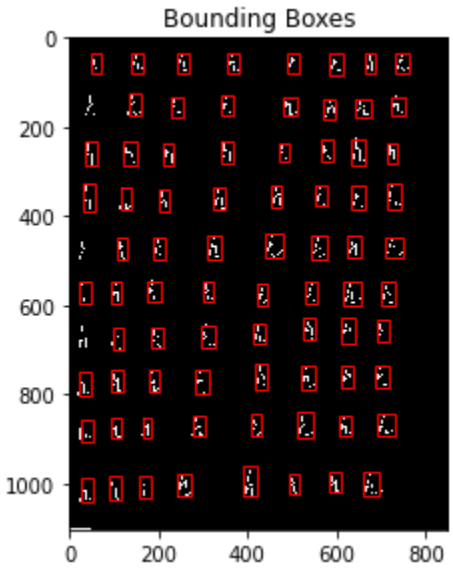
Bounding Boxes
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800
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0
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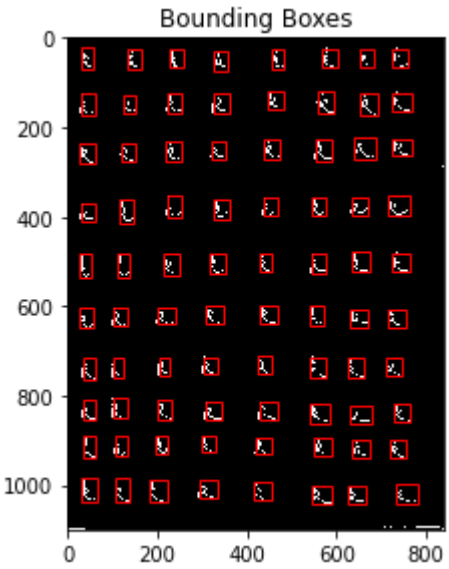
Bounding Boxes
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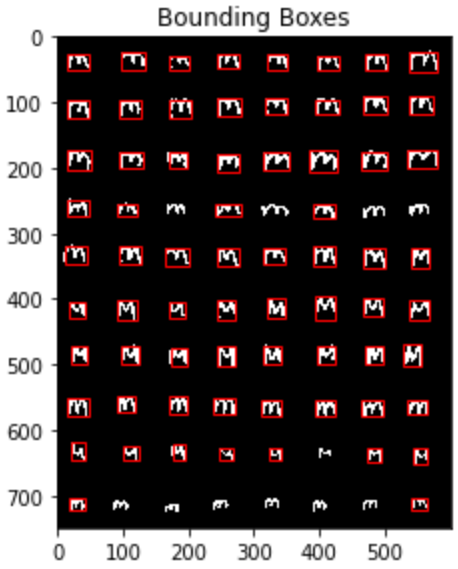
Bounding Boxes
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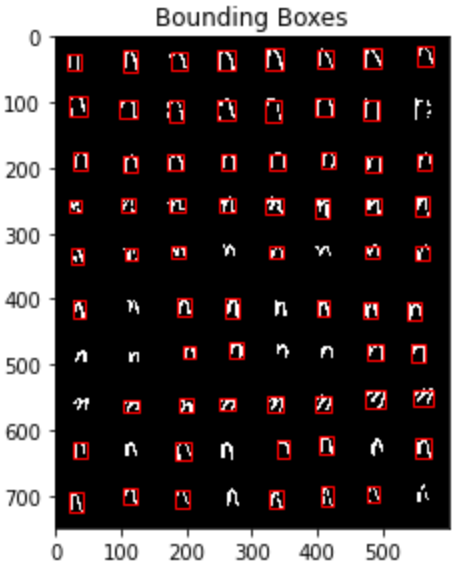
Bounding Boxes
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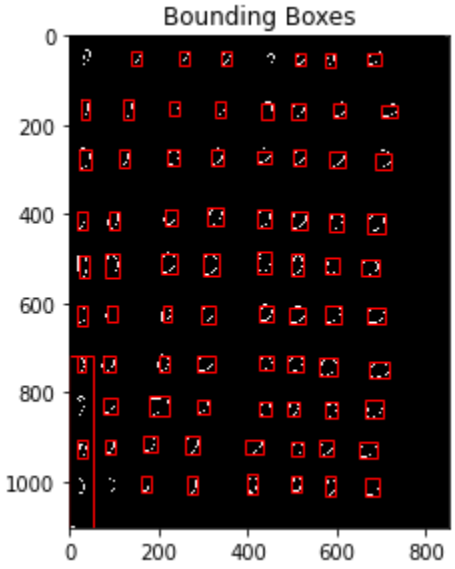
Bounding Boxes
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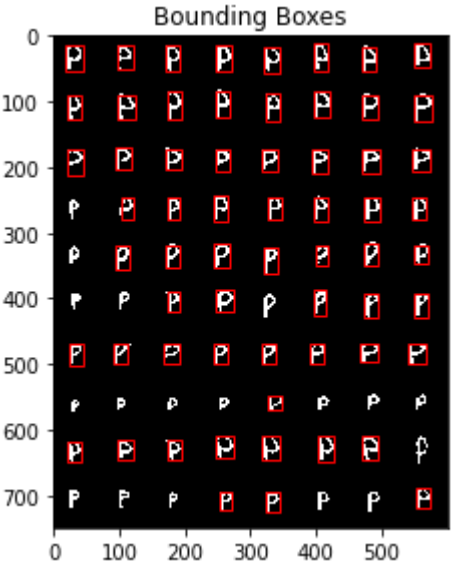
Bounding Boxes
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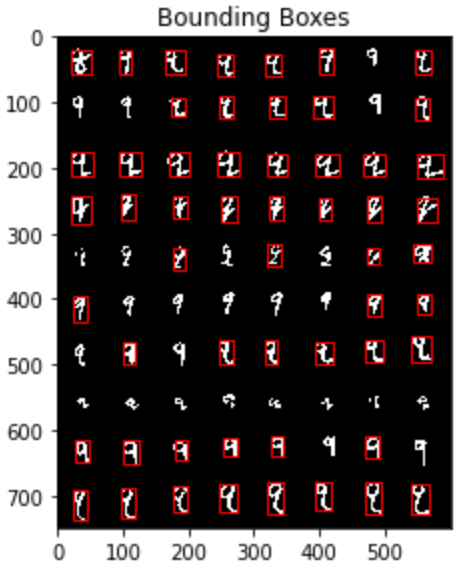
Bounding Boxes
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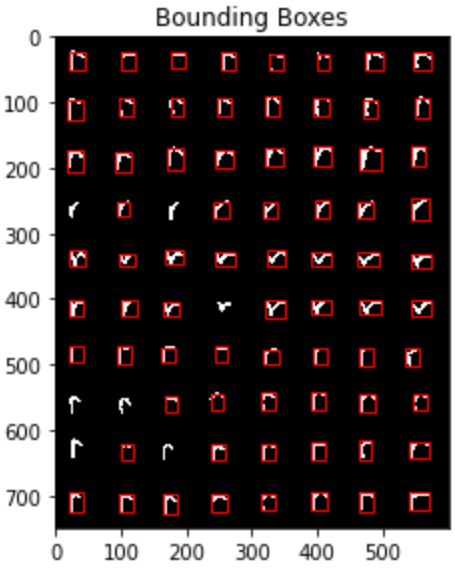
Bounding Boxes
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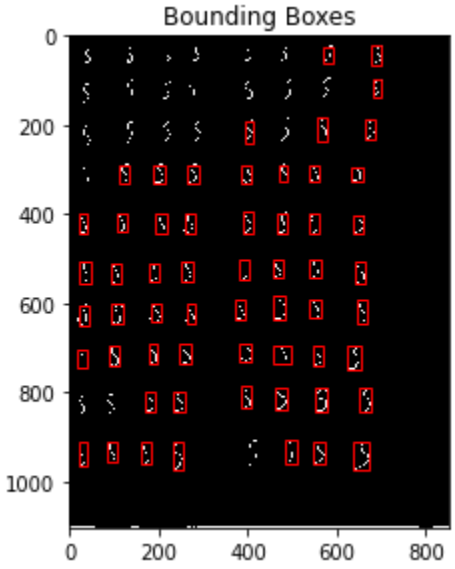
Bounding Boxes
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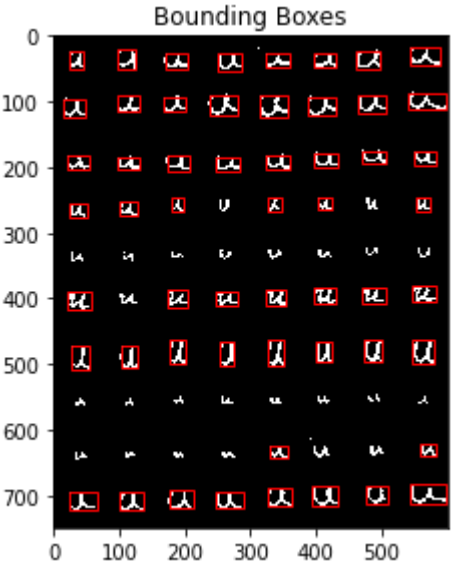
Bounding Boxes
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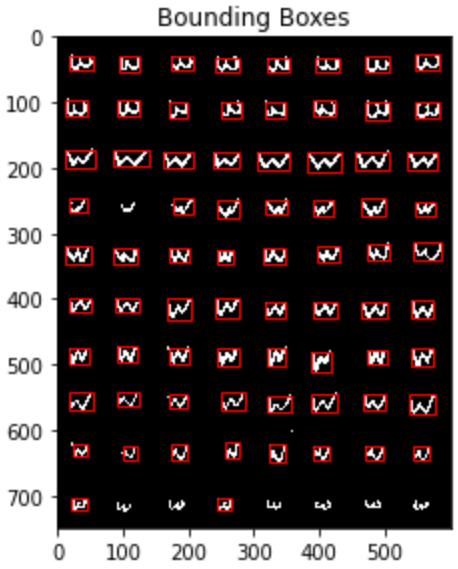
Bounding Boxes
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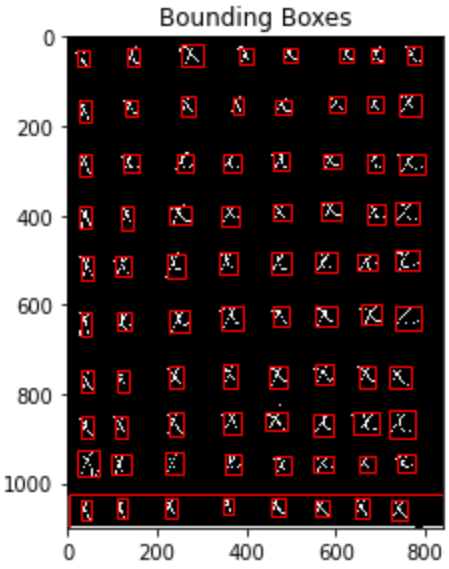
Bounding Boxes
0
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0
200
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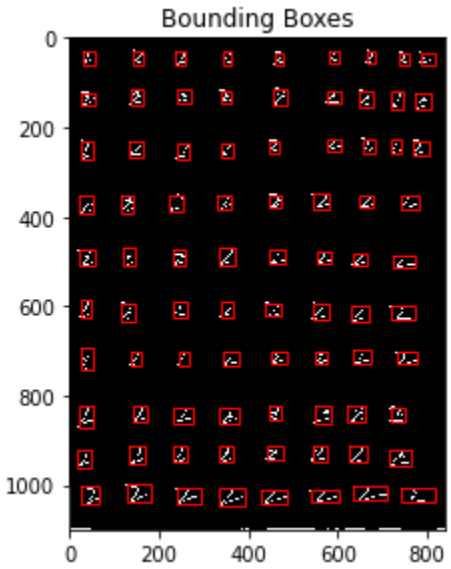
Bounding Boxes
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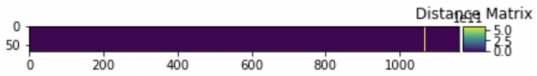
(ii). For the recognition phase: In this phase, the same process (as described above) was used on the test images provided. The distance matrix obtained for the two test images is shown below:

- Test image 1

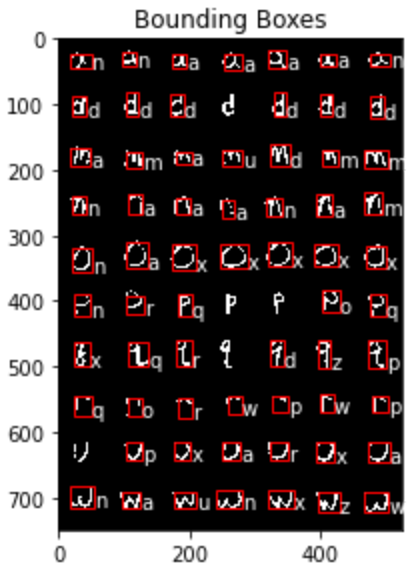
```
D_new = cdist(Features_new,Features)
io.imshow(D_new)
plt.title('Distance Matrix')
io.show()
```




```
[ ] print(D_new)
```

```
[[3.30731494e-02 1.62110586e-01 8.48026598e-02 ... 1.13367871e+00
  3.69559143e+01 2.77355247e+00]
 [7.31325238e-02 2.63966607e-01 1.86224201e-01 ... 1.19708705e+00
  3.69623183e+01 2.80908640e+00]
 [6.47857881e-02 1.33569305e-01 6.25989730e-02 ... 1.11756467e+00
  3.69552358e+01 2.76725771e+00]
 ...
 [5.54106178e-01 4.54303654e-01 4.81615936e-01 ... 7.23285568e-01
  3.67430023e+01 2.38647736e+00]
 [5.03274639e-02 1.76446738e-01 9.97325192e-02 ... 1.12473640e+00
  3.69499262e+01 2.76072385e+00]
 [3.05356585e-01 1.38859301e-01 1.96280474e-01 ... 9.47387340e-01
  3.69155931e+01 2.64223368e+00]]
```

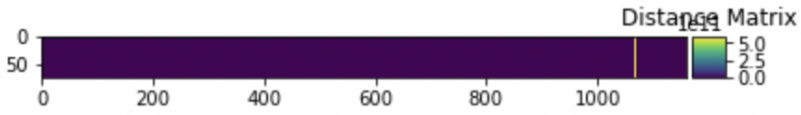
Test image connected components with bounding boxes and recognition results:



- Test image 2

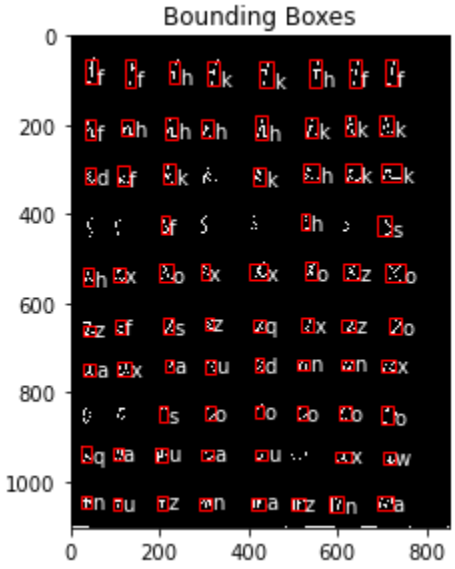
```
[ ]  D_last = cdist(Features_last,Features)

     io.imshow(D_last)
     plt.title('Distance Matrix')
     io.show()
```



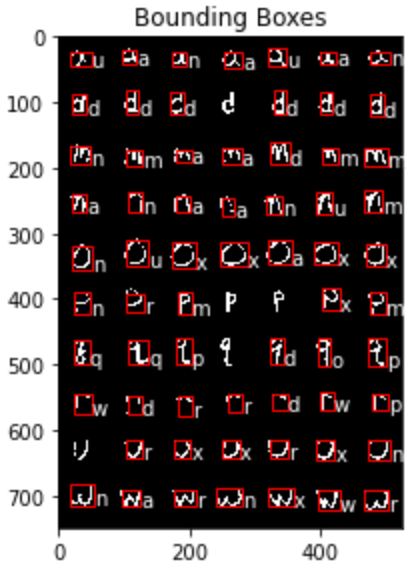
```
print(D_last)
```

```
[[4.11876700e+03 4.11876606e+03 4.11876626e+03 ... 4.11903700e+03
  4.11542617e+03 4.11923347e+03]
 [2.21124927e+04 2.21124924e+04 2.21124924e+04 ... 2.21127614e+04
  2.21069215e+04 2.21128723e+04]
 [8.91158323e+03 8.91158259e+03 8.91158273e+03 ... 8.91184605e+03
  8.90600170e+03 8.91195104e+03]
 ...
 [2.08947017e-02 1.79287517e-01 1.03081015e-01 ... 1.14184505e+00
  3.69565098e+01 2.77904129e+00]
 [1.23486827e-01 8.23747334e-02 4.27632585e-02 ... 1.08271287e+00
  3.69505044e+01 2.74704230e+00]
 [2.51767035e-02 1.85883579e-01 1.09812886e-01 ... 1.13358120e+00
  3.69532843e+01 2.77025742e+00]]
```

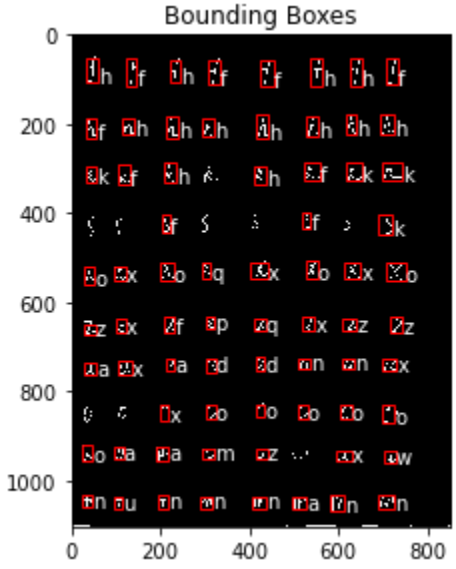


(iii). <u>Post enhancement (KNN):</u>

- Test image 1 connected components with bounding boxes and recognition results after enhancement:



- Test image 2 connected components with bounding boxes and recognition results:



(iv). <u>Recognition rates and other values:</u> All values used and calculated are stated below:

- Threshold value: After experimenting with multiple values, ultimately the threshold value of 18 was determined for the bounding boxes in order to ignore the components that are too small. Hence, the height and width of

each bounding box is compared to the threshold value of 18, and any boxes that are less than this are discarded.

- Components: For test image 1, 67 components were obtained, and for test image 2, 73 components were obtained. Both these values can be found in the code attached.
- Recognition rates:
  - ☐ Training accuracy: 53.8%
  - ☐ Testing accuracy for test image 1: 32.8%
  - ☐ Test accuracy for test image 2: 36.9%
  - ☐ Training accuracy after enhancement: 69.4%
  - ☐ Testing accuracy for test image 1 after enhancement: 35.8%
  - ☐ Testing accuracy for test image 2 after enhancement: 39.7%

ENHANCEMENTS

As is evident from the results, described above, both the training accuracy and the testing accuracy for both test images were not very satisfactory. It was also observed that the accuracy for both training and testing were degraded on normalization of features list. Hence, a small enhancement here itself is that though normalization was performed, non-normalized data was used in further steps, since upon repeated experimentation it was found to provide better accuracy rates.

For further enhancement, a better classifier was used. The idea of using KNN classifier was picked up from the suggestions provided. As we know, the K Nearest Neighbors algorithm is one of the simplest Machine Learning algorithms used for classification problems. It is a supervised algorithm which uses data and classifies new data points based on similarity measures (e.g. distance function). Classification is done by a majority vote to its neighbors.

Firstly, the features list was converted into a pandas dataframe. This dataframe contains 7 columns, corresponding to the 7 Hu moments. Each row in this dataframe corresponds to one character instance. An additional column called Output was added to this dataframe, containing the true labels for each feature. Next, from the sklearn.neighbors library, KNeighborsClassifier was imported.

After repeated experimentation with number of neighbors (3,4,5,6,7,etc.), the optimal result was obtained at 6 neighbors. Finally, the score was calculated.

As per my expectations, the accuracy rate increased upon using the KNN classifier. In my opinion, this is because in the case of closest neighbor, we only consider the class label of one neighbor. However, with KNN, we consider the K nearest neighbors, and this factors into our decision making. Hence, a better performance is observed.

As we can see, the suggested enhancement produced significant increase in the accuracy rates, as shown below:

	train	test1	test2
Without enhancement	0.53	0.32	0.36
with enhancement	0.69	0.35	0.39