# MSEN660 Final Project

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# 1 Part A

- We use the intermediate layers to featurize images.
- We create six pairwise classifiers, each trained on featurized image training sets for each of the 5 intermediate layers.
- Here is the convolution layer used and the cross-validated error estimate for each of the six pairwise two-label classifiers.

```
Pairwise Classifier 1 - spheroidite vs network
Layer 1 10 Fold CV Score: 0.395
Layer 2 10 Fold CV Score: 0.39
Layer 3 10 Fold CV Score: 0.395
Layer 4 10 Fold CV Score: 0.40000000000000001
Layer 5 10 Fold CV Score: 0.9650000000000001
Pairwise Classifier 2 - spheroidite vs pearlite
Layer 1 10 Fold CV Score: 0.420000000000000004
Layer 2 10 Fold CV Score: 0.420000000000000004
Laver 3 10 Fold CV Score: 0.42000000000000004
Layer 4 10 Fold CV Score: 0.425
Layer 5 10 Fold CV Score: 0.9550000000000001
Pairwise Classifier 3 - spheroidite vs spheroidite+widmanstatten
Layer 1 10 Fold CV Score: 0.625
Layer 2 10 Fold CV Score: 0.625
Layer 3 10 Fold CV Score: 0.625
Layer 4 10 Fold CV Score: 0.625
Layer 5 10 Fold CV Score: 0.74375
Pairwise Classifier 4 - network vs pearlite
Layer 1 10 Fold CV Score: 0.43500000000000005
Layer 2 10 Fold CV Score: 0.4450000000000001
Layer 3 10 Fold CV Score: 0.43000000000000005
Layer 4 10 Fold CV Score: 0.440000000000000006
Layer 5 10 Fold CV Score: 0.975
Pairwise Classifier 5 - network vs spheroidite+widmanstatten
Layer 1 10 Fold CV Score: 0.625
Laver 2 10 Fold CV Score: 0.625
Layer 3 10 Fold CV Score: 0.625
Layer 4 10 Fold CV Score: 0.625
Layer 5 10 Fold CV Score: 0.9875
Pairwise Classifier 6 - pearlite vs spheroidite+widmanstatten
Layer 1 10 Fold CV Score: 0.625
Layer 2 10 Fold CV Score: 0.625
Layer 3 10 Fold CV Score: 0.625
Layer 4 10 Fold CV Score: 0.625
Layer 5 10 Fold CV Score: 0.8875
```

Figure 1: Cross Validated Error Estimates for Each Pairwise Classifier for Each of the 5 Layers

- We observe that the last layer provides the lowest error for all of the pairwise classifiers. In fact we see that the error for a given pair wise classifier decreases as we use intermediate layers from deeper in the VGG 16 neural network.
- This could be partially because as we go deeper into the network, the features are more refined. Parts of the image like lines, edges, points etc are more apparent.

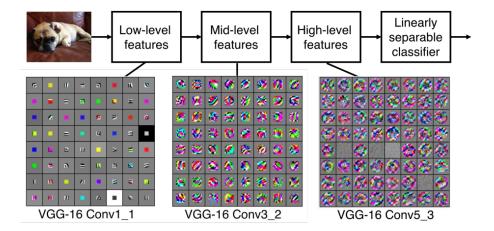


Figure 2: Illustration of increasing complexity of features for deeper layers-'From Stanford Course CS 231n'

#### 2 Part B

- Here we have the separate test error rates on the unused micrographs of each of the four categories, for the pairwise two-label classifiers and the multilabel one-vs-one voting classifier.
- For the pairwise classifiers we use the test micrographs with one of the two labels used to train the classifier.
- For the multilabel classifier, we use the test micrographs with one of the four labels in the training data.

```
Pair wise Classifier spheroidite vs network for spheroidite :
Score 0.9927007299270073
Pair wise Classifier spheroidite vs pearlite for spheroidite :
Score 1.0
Pair wise Classifier spheroidite vs spheroidite+widman statten for spheroidite :
Score 0.9671532846715328
Pair wise Classifiers Average score for spheroidite :
0.98661800486618
Pair wise Classifier spheroidite vs network for network :
Score 0.9017857142857143
Pair wise Classifier network vs pearlite for network :
Score 0.9107142857142857
Pair wise Classifier network vs spheroidite+widmanstatten for network :
Score 0.9285714285714286
Pair wise Classifiers Average score for network :
0.9136904761904763
Pair wise Classifier spheroidite vs pearlite for pearlite :
Score 1.0
Pair wise Classifier network vs pearlite for pearlite :
Score 1.0
Pair wise Classifier pearlite vs spheroidite+widmanstatten for pearlite :
Score 1.0
Pair wise Classifiers Average score for pearlite :
1.0
Pair wise Classifier spheroidite vs spheroidite+widmanstatten for spheroidite+widmanstatten :
Score 0.5714285714285714
{\tt Pair\ wise\ Classifier\ network\ vs\ spheroidite+widmanstatten\ for\ spheroidite+widmanstatten\ :}
Score 1.0
{\tt Pair\ wise\ Classifier\ pearlite\ vs\ spheroidite+widmanstatten\ for\ spheroidite+widmanstatten\ :}
Score 0.8095238095238095
Pair wise Classifiers Average score for spheroidite+widmanstatten :
0.7936507936507936
```

Figure 3: Test Error Rates for the Pairwise Two Label Classifiers

For Micrograph Type spheroidite
OnevsOne has Test score: 0.9679144385026738
For Micrograph Type network
OnevsOne has Test score: 0.9481132075471698
For Micrograph Type pearlite
OnevsOne has Test score: 1.0
For Micrograph Type spheroidite+widmanstatten
OnevsOne has Test score: 0.8765432098765432

Figure 4: Test Error Rates for the Multilabel OnevsOne Classifier

#### 3 Part C

• For the mixed pearlite + spheroidite and pearlite + widmanstatten micrographs, which were not used in training, we apply the trained one-vs-one multilabel voting classifier.

```
Micrograph Type: pearlite+spheroidite
Micrograph Image 0
One vs One Predicted: spheroidite
Micrograph Image 1
One vs One Predicted: spheroidite
Micrograph Image 2
One vs One Predicted: spheroidite
Micrograph Image 3
One vs One Predicted: pearlite
Micrograph Image 4
One vs One Predicted: spheroidite
Micrograph Image 5
One vs One Predicted: spheroidite
Micrograph Image 6
One vs One Predicted: spheroidite
Micrograph Image 7
One vs One Predicted: spheroidite
Micrograph Image 8
One vs One Predicted: spheroidite
Micrograph Image 9
One vs One Predicted: pearlite
Micrograph Image 10
One vs One Predicted: spheroidite
Micrograph Image 11
One vs One Predicted: spheroidite
Micrograph Image 12
One vs One Predicted: spheroidite
Micrograph Image 13
One vs One Predicted: spheroidite
Micrograph Image 14
One vs One Predicted: spheroidite
Micrograph Image 15
One vs One Predicted: spheroidite
Micrograph Image 16
One vs One Predicted: spheroidite
```

Figure 5: Snippet of Predictions for mixed pearlite + spheroidite

```
Micrograph Type: pearlite+widmanstatten
Micrograph Image 0
One vs One Predicted: pearlite
Micrograph Image 1
One vs One Predicted: pearlite
Micrograph Image 2
One vs One Predicted: pearlite
Micrograph Image 3
One vs One Predicted: spheroidite
Micrograph Image 4
One vs One Predicted: spheroidite+widmanstatten
Micrograph Image 5
One vs One Predicted: pearlite
Micrograph Image 6
One vs One Predicted: spheroidite
Micrograph Image 7
One vs One Predicted: pearlite
Micrograph Image 8
One vs One Predicted: spheroidite
Micrograph Image 9
One vs One Predicted: spheroidite
Micrograph Image 10
One vs One Predicted: pearlite
Micrograph Image 11
One vs One Predicted: pearlite
Micrograph Image 12
One vs One Predicted: pearlite
Micrograph Image 13
One vs One Predicted: spheroidite
Micrograph Image 14
One vs One Predicted: spheroidite
Micrograph Image 15
One vs One Predicted: pearlite
```

Figure 6: Snippet of Predictions for mixed pearlite + widman statten

#### 4 Part D

- Now we apply the pairwise classifier pearlite vs. spheroidite to the mixed pearlite + spheroidite
- We can see that in almost all cases the two classifiers predict the same outcome for the micrograph images.

```
pearlite+spheroidite
Micrograph Image 0
Pairwise Classifier Predicted: spheroidite
OnevsOne Classifier Predicted: spheroidite
Micrograph Image 1
Pairwise Classifier Predicted: spheroidite
OnevsOne Classifier Predicted: spheroidite
Micrograph Image 2
Pairwise Classifier Predicted: spheroidite
OnevsOne Classifier Predicted: spheroidite
Micrograph Image 3
Pairwise Classifier Predicted: pearlite
OnevsOne Classifier Predicted: pearlite
Micrograph Image 4
Pairwise Classifier Predicted: spheroidite
OnevsOne Classifier Predicted: spheroidite
Micrograph Image 5
Pairwise Classifier Predicted: spheroidite
OnevsOne Classifier Predicted: spheroidite
Micrograph Image 6
Pairwise Classifier Predicted: spheroidite
OnevsOne Classifier Predicted: spheroidite
Micrograph Image 7
Pairwise Classifier Predicted: spheroidite
OnevsOne Classifier Predicted: spheroidite
Micrograph Image 8
Pairwise Classifier Predicted: spheroidite
OnevsOne Classifier Predicted: spheroidite
Micrograph Image 9
Pairwise Classifier Predicted: pearlite
OnevsOne Classifier Predicted: pearlite
Micrograph Image 10
Pairwise Classifier Predicted: spheroidite
OnevsOne Classifier Predicted: spheroidite
```

Figure 7: OnevsOne compared with Pairwise Classifier for Predicting the mixed pearlite + spheroidite micrographs.

### 5 Part E

• For the untrained martensite microstructure we apply the trained one-vsone multilabel voting classifier.

```
Micrograph Image 0 Predicted: spheroidite
Micrograph Image 1 Predicted: network
Micrograph Image 2 Predicted: pearlite
Micrograph Image 3 Predicted: spheroidite
Micrograph Image 4 Predicted: spheroidite
Micrograph Image 5 Predicted: network
Micrograph Image 6 Predicted: spheroidite
Micrograph Image 7 Predicted: pearlite
Micrograph Image 8 Predicted: spheroidite
Micrograph Image 9 Predicted: spheroidite
Micrograph Image 10 Predicted: pearlite
Micrograph Image 11 Predicted: pearlite
Micrograph Image 12 Predicted: pearlite
Micrograph Image 13 Predicted: pearlite
Micrograph Image 14 Predicted: spheroidite
Micrograph Image 15 Predicted: pearlite
Micrograph Image 16 Predicted: spheroidite
Micrograph Image 17 Predicted: pearlite
Micrograph Image 18 Predicted: spheroidite
Micrograph Image 19 Predicted: pearlite
Micrograph Image 20 Predicted: pearlite
Micrograph Image 21 Predicted: spheroidite
Micrograph Image 22 Predicted: spheroidite
Micrograph Image 23 Predicted: pearlite
Micrograph Image 24 Predicted: spheroidite
Micrograph Image 25 Predicted: pearlite
Micrograph Image 26 Predicted: pearlite
Micrograph Image 27 Predicted: pearlite
Micrograph Image 28 Predicted: spheroidite
Micrograph Image 29 Predicted: spheroidite
Micrograph Image 30 Predicted: pearlite
Micrograph Image 31 Predicted: network
Micrograph Image 32 Predicted: spheroidite
Micrograph Image 33 Predicted: spheroidite
Micrograph Image 34 Predicted: pearlite
Micrograph Image 35 Predicted: spheroidite
```

Figure 8: Predictions for multilabel OnevsOne Classifier on Martensite

#### 6 Part C Full Predictions

Micrograph Type: pearlite+spheroidite Micrograph Image 0 One vs One Predicted: spheroidite Micrograph Image 1 One vs One Predicted: spheroidite Micrograph Image 2 One vs One Predicted: spheroidite Micrograph Image 3 One vs One Predicted: pearlite Micrograph Image 4 One vs One Predicted: spheroidite Micrograph Image 5 One vs One Predicted: spheroidite Micrograph Image 6 One vs One Predicted: spheroidite Micrograph Image 7 One vs One Predicted: spheroidite Micrograph Image 8 One vs One Predicted: spheroidite Micrograph Image 10 One vs One Predicted: spheroidite Micrograph Image 11 One vs One Predicted: spheroidite Micrograph Image 12 One vs One Predicted: spheroidite Micrograph Image 14 One vs One Predicted: spheroidite Micrograph Image 15 One vs One Predicted: spheroidite Micrograph Image 16 One vs One Predicted: spheroidite Micrograph Image 17 One vs One Predicted: spheroidite Micrograph Image 18 One vs One Predicted: spheroidite Micrograph Image 18 One vs One Predicted: spheroidite Micrograph Image 18 One vs One Predicted: spheroidite Micrograph Image 19 One vs One Predicted:

spheroidite Micrograph Image 20 One vs One Predicted: spheroidite Micrograph Image 21 One vs One Predicted: spheroidite Micrograph Image 22 One vs One Predicted: spheroidite Micrograph Image 23 One vs One Predicted: pearlite Micrograph Image 24 One vs One Predicted: spheroidite Micrograph Image 25 One vs One Predicted: spheroidite Micrograph Image 26 One vs One Predicted: spheroidite Micrograph Image 27 One vs One Predicted: spheroidite Micrograph Image 28 One vs One Predicted: spheroidite Micrograph Image 29 One vs One Predicted: spheroidite Micrograph Image 30 One vs One Predicted: spheroidite Micrograph Image 31 One vs One Predicted: spheroidite Micrograph Image 32 One vs One Predicted: spheroidite Micrograph Image 33 One vs One Predicted: spheroidite Micrograph Image 34 One vs One Predicted: spheroidite Micrograph Image 35 One vs One Predicted: spheroidite Micrograph Image 36 One vs One Predicted: spheroidite+widmanstatten Micrograph Image 37 One vs One Predicted: spheroidite Micrograph Image 38 One vs One Predicted: pearlite Micrograph Image 39 One vs One Predicted: spheroidite Micrograph Image 40 One vs One Predicted: pearlite Micrograph Image 41 One vs One Predicted: spheroidite Micrograph Image 42 One vs One Predicted: pearlite Micrograph Image 43 One vs One Predicted: pearlite Micrograph graph Image 44 One vs One Predicted: spheroidite Micrograph Image 45 One vs One Predicted: spheroidite Micrograph Image 46 One vs One Predicted: spheroidite Micrograph Image 47 One vs One Predicted: spheroidite Micrograph Image 48 One vs One Predicted: spheroidite Micrograph Image 49 One vs One Predicted: spheroidite+widmanstatten Micrograph Image 50 One vs One Predicted: spheroidite Micrograph Image 51 One vs One Predicted: pearlite Micrograph Image 52 One vs One Predicted: spheroidite Micrograph Image 53 One vs One Predicted: spheroidite Micrograph Image 54 One vs One Predicted: pearlite Micrograph Image 55 One vs One Predicted: spheroidite Micrograph Image 56 One vs One Predicted: pearlite Micrograph Image 57 One vs One Predicted: spheroidite Micrograph Image 58 One vs One Predicted: pearlite Micrograph Image 59 One vs One Predicted: pearlite Micrograph Image 60 One vs One Predicted: spheroidite Micrograph Image 61 One vs One Predicted: spheroidite Micrograph Image 62 One vs One Predicted: pearlite Micrograph Image 63 One vs One Predicted: spheroidite Micrograph Image 64 One vs One Predicted: spheroidite Micrograph Image 65 One vs One Predicted: spheroidite Micrograph Image 66 One vs One Predicted: spheroidite Micrograph Image 67 One vs One Predicted: spheroidite Micrograph Image 68 One vs One Predicted: spheroidite Micrograph Image 69 One vs One Predicted: spheroidite Micrograph Image 70 One vs One Predicted: spheroidite Micrograph Image 71 One vs One Predicted: spheroidite Micrograph Image 72 One vs One Predicted: spheroidite Micrograph Image 73 One vs One Predicted: spheroidite Micrograph Image 74 One vs One Predicted: spheroidite Micrograph Image 75 One vs One Predicted: spheroidite Micrograph Image 76 One vs One Predicted: spheroidite Micrograph Image 77 One vs One Predicted: spheroidite Micrograph Image 78 One vs One Predicted: pearlite Micrograph Image 79 One vs One Predicted: pearlite Micrograph Image 80 One vs One Predicted: spheroidite Micrograph Image 81 One vs One Predicted: pearlite Micrograph Image 82 One vs One Predicted: spheroidite Micrograph Image 83 One vs One Predicted: spheroidite Micrograph Image 84 One vs One Predicted: spheroidite Micrograph Image 85 One vs One Predicted: spheroidite Micrograph Image 86 One vs One Predicted: spheroidite Micrograph Image 87 One vs One Predicted: pearlite Micrograph Image 88 One vs One Predicted: pearlite Micrograph Image 89 One vs One Predicted: spheroidite Micrograph Image 90 One vs One Predicted: spheroidite Micrograph Image 91 One vs One Predicted: pearlite Micrograph Image 92 One vs One Predicted: spheroidite Micrograph Image 93 One vs One Predicted: pearlite Micrograph Image 94 One vs One Predicted: spheroidite Micrograph Image 95 One vs One Predicted: spheroidite Micrograph Image 96 One vs One Predicted: pearlite Micrograph Image 97 One vs One Predicted: spheroidite Micrograph Image 98 One vs One Predicted: spheroidite Micrograph Image 99 One vs One Predicted: pearlite Micrograph Image 100 One vs One Predicted: spheroidite Micrograph Image 101 One vs One Predicted: spheroidite Micrograph Image 102 One vs One Predicted: spheroidite Micrograph Image 103 One vs One Predicted: pearlite Micrograph Image 104 One vs One Predicted: spheroidite Micrograph Image 105 One vs One Predicted: spheroidite Micrograph Image 106 One vs One Predicted: network Micrograph Type: pearlite+widmanstatten Micrograph Image 0 One vs One Predicted: pearlite Micrograph Image 1 One vs One Predicted: pearlite Micrograph Image 2 One vs One Predicted: pearlite Micrograph Image 3 One vs One Predicted: spheroidite Micrograph Image 4 One vs One Predicted: spheroidite+widmanstatten Micrograph Image 5 One vs One Predicted: pearlite Micrograph Image 6 One vs One Predicted: spheroidite Micrograph Image 7 One vs One Predicted: pearlite Micrograph Image 8 One vs One Predicted: spheroidite Micrograph Image 9 One vs One Predicted: spheroidite Micrograph Image 10 One vs One Predicted: pearlite Micrograph Image 11 One vs One Predicted: pearlite Micrograph Image 12 One vs One Predicted: pearlite Micrograph Image 13 One vs One Predicted: spheroidite Micrograph Image 14 One vs One Predicted: spheroidite Micrograph Image 15 One vs One Predicted: pearlite Micrograph Image 16 One vs One Predicted: pearlite Micrograph Image 17 One vs One Predicted: pearlite Micrograph Image 18 One vs One Predicted: spheroidite Micrograph Image 19 One vs One Predicted: spheroidite+widmanstatten Micrograph Image 20 One vs One Predicted: pearlite Micrograph Image 21 One vs One Predicted: pearlite Micrograph Image 22 One vs One Predicted: pearlite Micrograph Image 23 One vs One Predicted: spheroidite+widmanstatten Micrograph Image 24 One vs One Predicted: pearlite Micrograph Image 25 One vs One Predicted: spheroidite Micrograph Image 26 One vs One Predicted: pearlite

## 7 Part D Pearlite Spherodite Full Predictions

pearlite+spheroidite Micrograph Image 0 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 1 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 2 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: sp

fier Predicted: spheroidite Micrograph Image 3 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 4 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 5 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 6 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 7 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 8 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 9 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 10 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 11 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 12 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 13 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 14 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 15 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 16 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 17 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 18 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 19 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 20 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 21 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 22 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 23 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 24 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 25 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 26 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 27 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 28 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 29 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 30 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 31 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 32 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 33 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 34 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 35 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 36 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite+widmanstatten Micro-

graph Image 37 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 38 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 39 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 40 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 41 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 42 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 43 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 44 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 45 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 46 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 47 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 48 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 49 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite+widmanstatten Micrograph Image 50 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 51 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 52 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 53 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 54 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 55 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 56 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 57 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 58 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 59 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 60 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 61 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 62 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 63 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 64 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 65 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 66 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 67 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 68 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 69 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 70 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 71

Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 72 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 73 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 74 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 75 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 76 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 77 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 78 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 79 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 80 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 81 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 82 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 83 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 84 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 85 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 86 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 87 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 88 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 89 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 90 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 91 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 92 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 93 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 94 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 95 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 96 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 97 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 98 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 99 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 100 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 101 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 102 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 103 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 104 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 105 Pairwise Classifier Predicted: spheroidite OnevsOne Classi-

```
fier Predicted: spheroidite Micrograph Image 106 Pairwise Classifier Predicted:
spheroidite OnevsOne Classifier Predicted: network
   [11pt]article
   [T1]fontenc mathpazo
   graphicx caption no label label format = no label
   adjustbox xcolor enumerate geometry amsmath amssymb textcomp upquote
eurosym [mathletters]ucs [utf8x]inputenc fancyvrb grffile hyperref longtable book-
tabs [inline]enumitem [normalem]ulem mathrsfs
   Highlighting Verbatim command chars=
{}
   HW4_trial5
   breaklinks=true, colorlinks=true, urlcolor=urlcolor, linkcolor=linkcolor,
citecolor=citecolor,
   verbose,tmargin=1in,bmargin=1in,lmargin=1in,rmargin=1in
   [commandchars=
{}] In [3]:
                from keras.preprocessing import image from PIL
import Image from keras.applications.vgg16 import VGG16 from
keras.applications.vgg16 import preprocess input from keras.models im-
port Model
   import numpy as np
   [commandchars=
{}] In [4]: import pandas as pd df=pd.read'csv("/home/akshay/Documents/TAMU/Fall
18/660/MSEN660/Programming/Project 4/micrograph.csv")
   [commandchars=
      In
            [5]:
                     df.head()
                                 cols=df.columns
                                                    print(cols)
                                                                  print(cols)
print('size', df.size, 'length', len(df)) df[cols[1]][0]
   [commandchars=
{}] Index(['micrograph_id', 'path', 'micron_bar', 'micron_bar_units',
cron_bar_px', 'magnification', 'detector', 'sample_key', 'contributor_key', 'pri-
mary_microconstituent'], dtype='object') Index(['micrograph_id', 'path', 'mi-
cron_bar', 'micron_bar_units', 'micron_bar_px', 'magnification', 'detector', 'sam-
ple_key', 'contributor_key', 'primary_microconstituent'], dtype='object') size
9610 length 961
   [commandchars=
{}] Out[5]: 'micrograph1.tif'
   [commandchars=
{}] In [7]:
                 base model=VGG16(weights='imagenet',include top=False)
model=Model(input=base model.input,output=[base model.get layer('block1'pool').output,base model.get layer('block1'pool').
   feat=[] for i in range(0,len(df[cols[1]])): feat.append([])
           extracting
                        features
                                   from
                                               single
                                                                  for
                                                         image
                                                                         im-
                range(0, len(df[cols[1]])):
                                                img path=df[cols[1]][image i]
img=image.load img(img path)
                                x=image.img to array(img)
                                                             x=x[0:484,:,:]
#crop the bottom subtitles x=np.expand'dims(x,axis=0) x=preprocess'input(x)
print('image',image'i)
   block poolfeat=model.predict(x)
```

 $\label{eq:print} \begin{tabular}{ll} \#print('elements\ in\ feature\ list',len(block'poolfeat))\ \#for\ i\ in\ range(0,5): \\ \#print(block'poolfeat[i][0][0][0][0])\ \#print(block'poolfeat[i].shape)\ \#find\ mean\ across\ channels\ {\bf for\ block\ in\ range}(0,5):\ s=block'poolfeat[block].shape\ tot=0\ {\bf for\ i\ in\ range}(0,s[0]):\ {\bf for\ j\ in\ range}(0,s[1]):\ {\bf for\ k\ in\ range}(0,s[2]):\ tot+=block'poolfeat[block][i][j][k]\ feat[image'i].append(tot/(s[0]*s[1]*s[2]))\ \#print(feat[block].shape,'block',block'+1,'feature\ vector\ shape') \end{tabular}$ 

[commandchars=

 $\label{lem:py:2:by:def} \begin{tabular}{ll} $\{\}$] $$/home/akshay/.local/lib/python3.6/site-packages/ipykernel_launcher.py:2: UserWarning: Update your 'Model' call to the Keras 2 API: 'Model(inputs=Tensor("in..., outputs=[jtf.Tenso...)' \end{tabular}$ 

[commandchars=

{}] image 0 image 1 image 2 image 3 image 4 image 5 image 6 image 7 image 8 image 9 image 10 image 11 image 12 image 13 image 14 image 15 image 16 image 17 image 18 image 19 image 20 image 21 image 22 image 23 image 24 image 25 image 26 image 27 image 28 image 29 image 30 image 31 image 32 image 33 image 34 image 35 image 36 image 37 image 38 image 39 image 40 image 41 image 42 image 43 image 44 image 45 image 46 image 47 image 48 image 49 image 50 image 51 image 52 image 53 image 54 image 55 image 56 image 57 image 58 image 59 image 60 image 61 image 62 image 63 image 64 image 65 image 66 image 67 image 68 image 69 image 70 image 71 image 72 image 73 image 74 image 75 image 76 image 77 image 78 image 79 image 80 image 81 image 82 image 83 image 84 image 85 image 86 image 87 image 88 image 89 image 90 image 91 image 92 image 93 image 94 image 95 image 96 image 97 image 98 image 99 image 100 image 101 image 102 image 103 image 104 image 105 image 106 image 107 image 108 image 109 image 110 image 111 image 112 image 113 image 114 image 115 image 116 image 117 image 118 image 119 image 120 image 121 image 122 image 123 image 124 image 125 image 126 image 127 image 128 image 129 image 130 image 131 image 132 image 133 image 134 image 135 image 136 image 137 image 138 image 139 image 140 image 141 image 142 image 143 image 144 image 145 image 146 image 147 image 148 image 149 image 150 image 151 image 152 image 153 image 154 image 155 image 156 image 157 image 158 image 159 image 160 image 161 image 162 image 163 image 164 image 165 image 166 image 167 image 168 image 169 image 170 image 171 image 172 image 173 image 174 image 175 image 176 image 177 image 178 image 179 image 180 image 181 image 182 image 183 image 184 image 185 image 186 image 187 image 188 image 189 image 190 image 191 image 192 image 193 image 194 image 195 image 196 image 197 image 198 image 199 image 200 image 201 image 202 image 203 image 204 image 205 image 206 image 207 image 208 image 209 image 210 image 211 image 212 image 213 image 214 image 215 image 216 image 217 image 218 image 219 image 220 image 221 image 222 image 223 image 224 image 225 image 226 image 227 image 228 image 229 image 230 image 231 image 232 image 233 image 234 image 235 image 236 image 236 image 238 image 239 image 240 image 241 image 242 image 243 image 244 image 245 image 246 image 247 image 248 image 249 image 250 image 251 image 252 image 253 image 254 image 255 image 256 image 257 image 258 image 259 image 260 image 261 image 262 image 263 image 264 image 265 image 266 image 267 image 268 image 269 image 270 image 271 image 272 image 273 image 274 image 275 image 276 image 277 image 278 image 279 image 280 image 281 image 282 image 283 image 284 image 285 image 286 image 287 image 288 image 289 image 290 image 291 image 292 image 293 image 294 image 295 image 296 image 297 image 298 image 299 image 300 image 301 image 302 image 303 image 304 image 305 image 306 image 307 image 308 image 309 image 310 image 311 image 312 image 313 image 314 image 315 image 316 image 317 image 318 image 319 image 320 image 321 image 322 image 323 image 324 image 325 image 326 image 327 image 328 image 329 image 330 image 331 image 332 image 333 image 334 image 335 image 336 image 337 image 338 image 339 image 340 image 341 image 342 image 343 image 344 image 345 image 346 image 347 image 348 image 349 image 350 image 351 image 352 image 353 image 354 image 355 image 356 image 357 image 358 image 359 image 360 image 361 image 362 image 363 image 364 image 365 image 366 image 367 image 368 image 369 image 370 image 371 image 372 image 373 image 374 image 375 image 376 image 377 image 378 image 379 image 380 image 381 image 382 image 383 image 384 image 385 image 386 image 387 image 388 image 389 image 390 image 391 image 392 image 393 image 394 image 395 image 396 image 397 image 398 image 399 image 400 image 401 image 402 image 403 image 404 image 405 image 406 image 407 image 408 image 409 image 410 image 411 image 412 image 413 image 414 image 415 image 416 image 417 image 418 image 419 image 420 image 421 image 422 image 423 image 424 image 425 image 426 image 427 image 428 image 429 image 430 image 431 image 432 image 433 image 434 image 435 image 436 image 437 image 438 image 439 image 440 image 441 image 442 image 443 image 444 image 445 image 446 image 447 image 448 image 449 image 450 image 451 image 452 image 453 image 454 image 455 image 456 image 457 image 458 image 459 image 460 image 461 image 462 image 463 image 464 image 465 image 466 image 467 image 468 image 469 image 470 image 471 image 472 image 473 image 474 image 475 image 476 image 477 image 478 image 479 image 480 image 481 image 482 image 483 image 484 image 485 image 486 image 487 image 488 image 489 image 490 image 491 image 492 image 493 image 494 image 495 image 496 image 497 image 498 image 499 image 500 image 501 image 502 image 503 image 504 image 505 image 506 image 507 image 508 image 509 image 510 image 511 image 512 image 513 image 514 image 515 image 516 image 517 image 518 image 519 image 520 image 521 image 522 image 523 image 524 image 525 image 526 image 527 image 528 image 529 image 530 image 531 image 532 image 533 image 534 image 535 image 536 image 537 image 538 image 539 image 540 image 541 image 542 image 543 image 544 image 545 image 546 image 547 image 548 image 549 image 550 image 551 image 552 image 553 image 554 image 555 image 556 image 557 image 558 image 559 image 560 image 561 image 562 image 563 image 564 image 565 image 566 image 567 image 568 image 569 image 570 image 571 image 572 image 573 image 574 image 575 image 576 image 577 image 578 image 579 image 580 image 581 image 582 image 583 image 584 image 585 image 586 image 587 image 588 image 589 image 590 image 591 image 592 image 593 image 594 image 595 image 596 image 597 image 598 image 599 image 600 image 601 image 602 image 603 image 604 image 605 image 606 image 607 image 608 image 609 image 610 image 611 image 612 image 613 image 614 image 615 image 616 image 617 image 618 image 619 image 620 image 621 image 622 image 623 image 624 image 625 image 626 image 627 image 628 image 629 image 630 image 631 image 632 image 633 image 634 image 635 image 636 image 637 image 638 image 639 image 640 image 641 image 642 image 643 image 644 image 645 image 646 image 647 image 648 image 649 image 650 image 651 image 652 image 653 image 654 image 655 image 656 image 657 image 658 image 659 image 660 image 661 image 662 image 663 image 664 image 665 image 666 image 667 image 668 image 669 image 670 image 671 image 672 image 673 image 674 image 675 image 676 image 677 image 678 image 679 image 680 image 681 image 682 image 683 image 684 image 685 image 686 image 687 image 688 image 689 image 690 image 691 image 692 image 693 image 694 image 695 image 696 image 697 image 698 image 699 image 700 image 701 image 702 image 703 image 704 image 705 image 706 image 707 image 708 image 709 image 710 image 711 image 712 image 713 image 714 image 715 image 716 image 717 image 718 image 719 image 720 image 721 image 722 image 723 image 724 image 725 image 726 image 727 image 728 image 729 image 730 image 731 image 732 image 733 image 734 image 735 image 736 image 737 image 738 image 739 image 740 image 741 image 742 image 743 image 744 image 745 image 746 image 747 image 748 image 749 image 750 image 751 image 752 image 753 image 754 image 755 image 756 image 757 image 758 image 759 image 760 image 761 image 762 image 763 image 764 image 765 image 766 image 767 image 768 image 769 image 770 image 771 image 772 image 773 image 774 image 775 image 776 image 777 image 778 image 779 image 780 image 781 image 782 image 783 image 784 image 785 image 786 image 787 image 788 image 789 image 790 image 791 image 792 image 793 image 794 image 795 image 796 image 797 image 798 image 799 image 800 image 801 image 802 image 803 image 804 image 805 image 806 image 807 image 808 image 809 image 810 image 811 image 812 image 813 image 814 image 815 image 816 image 817 image 818 image 819 image 820 image 821 image 822 image 823 image 824 image 825 image 826 image 827 image 828 image 829 image 830 image 831 image 832 image 833 image 834 image 835 image 836 image 837 image 838 image 839 image 840 image 841 image 842 image 843 image 844 image 845 image 846 image 847 image 848 image 849 image 850 image 851 image 852 image 853 image 854 image 855 image 856 image 857 image 858 image 859 image 860 image 861 image 862 image 863 image 864 image 865 image 866 image 867 image 868 image 869 image 870 image 871 image 872 image 873 image 874 image 875 image 876 image 877 image 878 image 879 image 880 image 881 image 882 image 883 image 884 image 885 image 886 image 887 image 888 image 889 image 890 image 891 image 892 image 893 image 894 image 895 image 896 image 897 image 898 image 899 image 900 image 901 image 902 image 903 image 904 image 905 image 906 image 907 image 908 image 909 image 910 image 911 image 912 image 913 image 914 image 915 image 916 image 917 image 918 image 919 image 920 image 921 image 922 image 923 image 924 image 925 image 926 image 927 image 928 image 929 image 930 image 931 image 932 image 933 image 934 image 935 image 936 image 937 image 938 image 939 image 940 image 941 image 942 image 943 image 944 image 945 image 946 image 947 image 948 image 949 image 950 image 951 image 952 image 953 image 954 image 955 image 956 image 957 image 958 image

```
959 image 960
   [commandchars=
{}] In [8]: len(feat)
   [commandchars=
{}] Out[8]: 961
   [commandchars=
{}] In [73]: df[cols[9]][0]
   [commandchars=
{}] Out[73]: 'pearlite'
   [commandchars=
{}] In [17]: # Store the features #/media/akshay/OS/Users/aksha/OneDrive
                           A \& M
                                           University/Documents/TAMU/Fall
18/660/MSEN660/Programming/Project 4/ feat backup=feat import pickle
filename="feat.pickle" with open (filename, 'wb') as f: pickle.dump(feat,f)
   [commandchars=
{}] In [18]: with open(filename, 'rb') as f: feat = pickle.load(f) len(feat)
   [commandchars=
{}] Out[18]: 961
   [commandchars=
\{\}
           [240]:
                      y=[]
                             x'i=[]
                                       for
                                                in
                                                      range(0, len(df[cols[9]])):
if
        df[cols[9]][i] =='spheroidite':
                                               y.append(0)
                                                                 x i.append(i)
                                               y.append(1)
elif
          df[cols[9]][i] == 'network':
                                                                 x'i.append(i)
elif
        df[cols[9]][i] == 'pearlite':
                                         y.append(2)
                                                         x'i.append(i)
                                                                           elif
df[cols[9]][i]=='spheroidite+widmanstatten':
                                                  y.append(3)
                                                                 x i.append(i)
elif
       df[cols[9]][i]=='pearlite+spheroidite':
                                                  y.append(4)
                                                                 x i.append(i)
      df[cols[9]][i]=='pearlite+widmanstatten':
                                                   y.append(5)
                                                                 x i.append(i)
     df[cols[9]][i] == 'martensite':
                                    y.append(6) x'i.append(i)
                                                                 else:
                                                                         pass
print(len(y),y[0:10],len(x'i),x'i[0:10])
   [commandchars=
{}] 961 [2, 0, 4, 2, 0, 3, 1, 1, 0, 0] 961 [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
   [commandchars=
{}] In []: #training data
   [commandchars=
{}] In [260]:
                #pairwise combinations of labelled data from itertools
import combinations combs=list(combinations([0,1,2,3],2)) print(combs)
enc=-0:'spheroidite',1:'network',2:'pearlite',3:'spheroidite+widmanstatten',4:'pearlite+spheroidite',5:'pearlite-
   from sklearn.sym import SVC model1=SVC(gamma='auto',kernel='rbf')
   layers=np.zeros(len(combs))
                                          layer score=np.zeros([len(combs),5])
layer testscore=np.zeros([len(combs),5]) com count=0 import pdb
   test score=np.zeros(len(combs)) models=[]
   for com in combs:
   #training set X train=[] Y train=[] X test=[] Y test=[] print (com) for lab-
data in com: if labdata==0: count=0 i=0
   while(count;100):
                                 \mathbf{y}[\mathbf{i}] = 0
                           if
                                                    X'train.append(feat[x'i[i]])
                                i+=1 while(i;761):
Y'train.append(0)
                    count+=1
                                                             if
                                                                  y[i] = 0 :
```

X'test.append(feat[x'i[i]]) Y'test.append(0) i+=1 if labdata==1: count=0 i=0

```
while(count;100):
                                 y[i] = 1
                                                    X'train.append(feat[x'i[i]])
Y'train.append(1)
                    count+=1
                                 i+=1
                                          \mathbf{while}(i;761):
                                                                 y[i] = 1
                                                             if
X'test.append(feat[x'i[i]]) Y'test.append(1) i+=1 if labdata==2: count=0 i=0
   while(count;100):
                           if
                                 y[i] = 2
                                                    X'train.append(feat[x'i[i]])
Y'train.append(2)
                    count+=1
                                 i+=1
                                          while(i;761):
                                                             if
                                                                  v[i] = 2
X'test.append(feat[x'i[i]]) Y'test.append(2) i+=1 if labdata==3: count=0 i=0
   while(count;60): if y[i]==3: X'train.append(feat[x'i[i]]) Y'train.append(3)
count+=1 i+=1 while(i;761):
                                   if y[i]==3:
                                                    X'test.append(feat[x'i[i]])
                           \#pdb.set[trace() \#for layer in range(0,5):
Y'test.append(3)
                  i+=1
model=SVC(gamma='auto',kernel='rbf')
   #kfolds for each layer from sklearn.model'selection import KFold
   kf=KFold(n'splits=10,shuffle=True)
                                                        avgscore=np.zeros(5)
testscore=np.zeros(5) #cross validation 10 fold for train index, test index in
kf.split(X'train): x'train=[] x'test=[] y'train=[] y'test=[]
   for i in train index: x train.append(X train[i]) y train.append(Y train[i]) for
j in test index: x test.append(X train[j]) y test.append(Y train[j])
   for layer in range (0,5): x'train1=[] x'test1=[] for i in range (0, len(x'train)):
x train1.append(x train[i][layer])
                                    for
                                            i
                                                  in
                                                          range(0, len(x test)):
x test1.append(x test[i][layer])
   model.fit(x train1,y train)
                                               sco=model.score(x test1, y test)
avgscore[layer]+=sco
   #layer 5 performs best for all pairs of labels
                                                           #first train the
  pairwise models based on best layer y train=[]
                                                           for i
                                                                   in
                                                                        range
(0,len(Y'train)):
                   y train append(Y train[i])
                                              x'train=[]
                                                           for
                                                                        range
(0,len(X'train)): x'train.append(X'train[i][4])
   models.append(model.fit(x'train,y'train))
   avgscore=avgscore/10 layer'score[com'count,:]=avgscore #pdb.set'trace()
com count += 1
   [commandchars=
\{\}\][(0, 1), (0, 2), (0, 3), (1, 2), (1, 3), (2, 3)](0, 1)(0, 2)(0, 3)(1, 2)(1, 3)(2, 3)
3)
   [commandchars=
{}] In [259]: layer score[0]
   [commandchars=
{}] Out[259]: array([0.445, 0.445, 0.44, 0.44, 0.96])
   [commandchars=
{}] In [265]:
                 for i in range (0,6): print ('Pairwise Classifier', i+1,'-
',enc[combs[i][0]],'vs',enc[combs[i][1]]) for j in range(0,5): print('Layer',j+1,'10
Fold CV Score:',layer'score[i][j])
   [commandchars=
{}] Pairwise Classifier 1 - spheroidite vs network Layer 1 10 Fold CV Score: 0.395
Layer 2 10 Fold CV Score: 0.39 Layer 3 10 Fold CV Score: 0.395 Layer 4 10 Fold
CV Score: 0.4000000000000001 Layer 5 10 Fold CV Score: 0.9650000000000001
Pairwise Classifier 2 - spheroidite vs pearlite Layer 1 10 Fold CV Score:
0.42000000000000004 Layer 2 10 Fold CV Score: 0.42000000000000004 Layer 3
10 Fold CV Score: 0.42000000000000004 Layer 4 10 Fold CV Score: 0.425 Layer
```

```
spheroidite+widmanstatten Layer 1 10 Fold CV Score: 0.625 Layer 2 10 Fold
CV Score: 0.625 Layer 3 10 Fold CV Score: 0.625 Layer 4 10 Fold CV Score:
0.625 Layer 5 10 Fold CV Score: 0.74375 Pairwise Classifier 4 - network vs
pearlite Layer 1 10 Fold CV Score: 0.435000000000005 Layer 2 10 Fold CV
Score: 0.4450000000000001 Layer 3 10 Fold CV Score: 0.43000000000000005
Layer 4 10 Fold CV Score: 0.440000000000000 Layer 5 10 Fold CV Score:
0.975 Pairwise Classifier 5 - network vs spheroidite+widmanstatten Layer 1 10
Fold CV Score: 0.625 Layer 2 10 Fold CV Score: 0.625 Layer 3 10 Fold CV
Score: 0.625 Layer 4 10 Fold CV Score: 0.625 Layer 5 10 Fold CV Score: 0.9875
Pairwise Classifier 6 - pearlite vs spheroidite+widmanstatten Layer 1 10 Fold
CV Score: 0.625 Layer 2 10 Fold CV Score: 0.625 Layer 3 10 Fold CV Score:
0.625 Layer 4 10 Fold CV Score: 0.625 Layer 5 10 Fold CV Score: 0.8875
   [commandchars=
{}] In [258]: #now obtain test errors for pairwise classifiers
                                                                    #pairwise
combinations of labelled data test err=np.zeros(4) from sklearn.svm im-
port SVC com count=0 x train1v1=[] x test1v1=[] y train1v1=[] y test1v1=[]
enc=-0:'spheroidite',1:'network',2:'pearlite',3:'spheroidite+widmanstatten',4:'pearlite+spheroidite',5:'pearlite-
   for label in range(4):
   #training set X'train=[] Y'train=[] X'test=[] Y'test=[]
   if label == 0: count = 0 i = 0
   while(count;100):
                                 \mathbf{y}[\mathbf{i}] = 0
                                                   X'train.append(feat[x'i[i]])
x train1v1.append(feat[x i[i]])
                                 y'train1v1.append(0)
                                                           Y'train.append(0)
count+=1 i+=1 while (i_i len(y)): if y[i]==0: X'test.append (feat[x'i[i]])
Y''test.append(0) x''test1v1.append(feat[x'i[i]]) y'test1v1.append(0) i+=1 if
label==1: count=0 i=0
   while(count;100):
                           if
                                 \mathbf{v}[\mathbf{i}] = =1
                                                   X'train.append(feat[x'i[i]])
                                 Y'train.append(1)
x train1v1.append(feat[x i[i]])
                                                        vtrain1v1.append(1)
count+=1 i+=1 while(i_i len(y)): if y[i]==1: X'test.append(feat[x'i[i]])
Y''test.append(1) x''test1v1.append(feat[x''i[i]]) y''test1v1.append(1) i+=1 if
label==2: count=0 i=0
   while(count;100):
                           if
                                 y[i] = 2
                                                   X'train.append(feat[x'i[i]])
                                          :
x train1v1.append(feat[x i[i]])
                                 Y'train.append(2)
                                                        vtrain1v1.append(2)
count+=1 i+=1 while (i_i len(y)): if y[i]==2: X test.append (feat[x i[i]])
Y'test.append(2) x'test1v1.append(feat[x'i[i]]) y'test1v1.append(2) i+=1 if
label==3: count=0 i=0
   while(count;60):
                           if
                                y[i] = 3
                                                   X'train.append(feat[x'i[i]])
                                 Y'train.append(3)
x train1v1.append(feat[x i[i]])
                                                        y train1v1.append(3)
count+=1 i+=1 while(i_i len(y)): if y[i]==3 :
                                                    X'test.append(feat[x'i[i]])
Y''test.append(3) x''test1v1.append(feat[x''i[i]]) y'test1v1.append(3) i+=1
\#pdb.set[trace() \#for layer in range(0,5): y[test=[] for i in range(0,5)]
(0,len(Y'test)): y'test.append(Y'test[i]) x'test=[] for i in range (0,len(X'test)):
x'test.append(X'test[i][4])
   model=SVC(gamma='auto',kernel='rbf')
                                                                     count=0
                                                     sco=||
                  range(0, len(combs)):
for
                                               if
                                                     label
                                                              in
                                                                     combs[i]:
```

5 10 Fold CV Score: 0.95500000000000001 Pairwise Classifier 3 - spheroidite vs

sco.append(models[i].score(x'test,y'test)) pair1=combs[i][0] pair2=combs[i][1]

```
print('Score',sco[count]) count+=1 #pdb.set'trace()
   test \cdot err[label] = ((sco[0] + sco[1] + sco[2])/3) \#pdb.set \cdot trace()
   com count += 1
   print
           ('Pair
                    wise
                           Classifiers
                                        Average
                                                   score
                                                            for',enc[label],':')
print(test'err[label])
   [commandchars=
{}] Pair wise Classifier spheroidite vs network for spheroidite :
0.9927007299270073 Pair wise Classifier spheroidite vs pearlite for spheroidite
: Score 1.0 Pair wise Classifier spheroidite vs spheroidite+widmanstatten
for spheroidite: Score 0.9671532846715328 Pair wise Classifiers Average
score for spheroidite: 0.98661800486618 Pair wise Classifier spheroidite
vs network for network: Score 0.9017857142857143 Pair wise Classi-
fier network vs pearlite for network:
                                            Score 0.9107142857142857 Pair
wise Classifier network vs spheroidite+widmanstatten for network: Score
0.9285714285714286 Pair wise Classifiers Average score for network:
0.9136904761904763 Pair wise Classifier spheroidite vs pearlite for pearlite
    Score 1.0 Pair wise Classifier network vs pearlite for pearlite
Score 1.0 Pair wise Classifier pearlite vs spheroidite+widmanstatten for
             Score 1.0 Pair wise Classifiers Average score for pearlite
: 1.0 Pair wise Classifier spheroidite vs spheroidite+widmanstatten for
spheroidite+widmanstatten: Score 0.5714285714285714 Pair wise Classi-
fier network vs spheroidite+widmanstatten for spheroidite+widmanstatten
: Score 1.0 Pair wise Classifier pearlite vs spheroidite+widmanstatten for
spheroidite+widmanstatten: Score 0.8095238095238095 Pair wise Classifiers
Average score for spheroidite+widmanstatten: 0.7936507936507936
   [commandchars=
\{\}\] In [245]: len(y)
   [commandchars=
{}] Out[245]: 961
   [commandchars=
{}] In [267]: #one vs one classifier print(len(x train1v1),len(y train1v1),len(x test1v1),len(y test1v1))
from
              sklearn.multiclass
                                           import
                                                             OneVsOneClas-
sifier
            x train1v1p=[]
                                  x'test1v1p=[]
                                                      for
                                                                          in
range(0,len(x train1v1)):
                                 x train1v1p.append(x train1v1[i][4])
                                                                         for
            range(0, len(x test1v1)):
                                           x'test1v1p.append(x'test1v1[i][4])
ovc=OneVsOneClassifier(SVC(gamma='auto',kernel='rbf'))
abel testerr=ovc.fit(x train1v1p,y train1v1).score(x test1v1p,y test1v1)
print ('One vs One Multilabel Classifier Score:', multilabel testerr)
   [commandchars=
\{\}\} 360 360 431 431 One vs One Multilabel Classifier Score : 0.9280742459396751
   [commandchars=
{}] In [276]: #One vs One for each Label
   score=[] enc=-0:'spheroidite',1:'network',2:'pearlite',3:'spheroidite+widmanstatten',4:'pearlite+spheroidite
   x \cdot test = []
                v test=[]
                                     i
                                           in
                                                  range(len(x'i)):
y[i] = 0:
                         x'test.append(feat[x'i[i]][4])
                                                            y'test.append(0)
```

Classifier',enc[pair1],'vs',enc[pair2],'for',enc[label],':')

print

```
score.append(ovc.fit(x'train1v1p,y'train1v1).score(x'test,y'test))
print('For
             Micrograph
                            Type',enc[0]
                                             print('OnevsOne
                                                                 has
                                                                         Test
score:',score[0])
                   x \cdot test = []
                               v'test=[]
                                            for
                                                        in
                                                              range(len(x i)):
        y[i] = 1:
if
                            x test.append(feat[x i[i]][4])
                                                             y test.append(1)
score.append(ovc.fit(x'train1v1p,y'train1v1).score(x'test,y'test))
                                             print('OnevsOne
print('For
             Micrograph
                             Type',enc[1])
                                                                         Test
                                                                 has
score:',score[1])
                   x \cdot test = []
                               y test=[]
                                            for
                                                        in
                                                              range(len(x'i)):
if
        y[i] = 2:
                            x'test.append(feat[x'i[i]][4])
                                                             y test.append(2)
score.append(ovc.fit(x'train1v1p,y'train1v1).score(x'test,y'test))
print('For
             Micrograph
                            Type',enc[2])
                                             print('OnevsOne
                                                                         Test
                                                                 has
score:',score[2])
                  x \cdot test = []
                               v'test=[]
                                            for
                                                              range(len(x'i)):
        v[i] = 3:
if
                            x'test.append(feat[x'i[i]][4])
                                                             y test.append(3)
score.append(ovc.fit(x train1v1p,y train1v1).score(x test,y test))
                                                                   print('For
Micrograph Type',enc[3]) print('OnevsOne has Test score:',score[3])
   [commandchars=
     For Micrograph Type spheroidite
                                              OnevsOne has
0.9679144385026738 For Micrograph Type network OnevsOne has Test
score: 0.9481132075471698 For Micrograph Type pearlite OnevsOne has Test
score: 1.0 For Micrograph Type spheroidite+widmanstatten OnevsOne has
Test score: 0.8765432098765432
   [commandchars=
     In
         [268]:
                    #apply multilabel classifier for pearlite and wid-
manstatten and pearlite and widmanstatten samples x test=[] y test=[]
enc=-0:'spheroidite',1:'network',2:'pearlite',3:'spheroidite+widmanstatten',4:'pearlite+spheroidite',5:'pearlite-
                                  if y[i] = 4:
   for i in range(len(x'i)):
                                                  x'test.append(feat[x'i[i]][4])
y'test.append(4)
                     pred1=[]
                                    for
                                            i
                                                   in
                                                           range(len(x test)):
pred1.append(ovc.fit(x train1v1p, y train1v1).predict(x test)) print('Micrograph
Type:',enc[4]) for i in range(0,len(pred1[0])):
                                                    print ('Micrograph Im-
age',i) print ('One vs One Predicted:',enc[pred1[0][i]]) x'test=[] y'test=[]
for i in range(len(x'i)):
                                 if y[i]==5:
                                                  x test.append(feat[x i[i]][4])
y test.append(5)
                     pred2=[]
                                    for
                                                   in
                                                           range(len(x test)):
pred2.append(ovc.fit(x train1v1p,y train1v1).predict(x test)) print('Micrograph
Type:',enc[5]) for i in range(0,len(pred2[0])): print ('Micrograph Image',i)
print ('One vs One Predicted:',enc[pred2[0][i]])
   [commandchars=
{}] Micrograph Type: pearlite+spheroidite Micrograph Image 0 One vs One
Predicted: spheroidite Micrograph Image 1 One vs One Predicted: spheroidite
Micrograph Image 2 One vs One Predicted: spheroidite Micrograph Image 3
One vs One Predicted: pearlite Micrograph Image 4 One vs One Predicted:
spheroidite Micrograph Image 5 One vs One Predicted: spheroidite Micrograph
Image 6 One vs One Predicted: spheroidite Micrograph Image 7 One vs One
Predicted: spheroidite Micrograph Image 8 One vs One Predicted: spheroidite
Micrograph Image 9 One vs One Predicted: pearlite Micrograph Image 10 One
vs One Predicted: spheroidite Micrograph Image 11 One vs One Predicted:
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spheroidite Micrograph Image 12 One vs One Predicted: spheroidite Micrograph Image 13 One vs One Predicted: spheroidite Micrograph Image 14 One

vs One Predicted: spheroidite Micrograph Image 15 One vs One Predicted: spheroidite Micrograph Image 16 One vs One Predicted: spheroidite Micrograph Image 17 One vs One Predicted: spheroidite Micrograph Image 18 One vs One Predicted: spheroidite Micrograph Image 19 One vs One Predicted: spheroidite Micrograph Image 20 One vs One Predicted: spheroidite Micrograph Image 21 One vs One Predicted: spheroidite Micrograph Image 22 One vs One Predicted: spheroidite Micrograph Image 23 One vs One Predicted: pearlite Micrograph Image 24 One vs One Predicted: spheroidite Micrograph Image 25 One vs One Predicted: spheroidite Micrograph Image 26 One vs One Predicted: spheroidite Micrograph Image 27 One vs One Predicted: spheroidite Micrograph Image 28 One vs One Predicted: spheroidite Micrograph Image 29 One vs One Predicted: spheroidite Micrograph Image 30 One vs One Predicted: spheroidite Micrograph Image 31 One vs One Predicted: spheroidite Micrograph Image 32 One vs One Predicted: spheroidite Micrograph Image 33 One vs One Predicted: spheroidite Micrograph Image 34 One vs One Predicted: spheroidite Micrograph Image 35 One vs One Predicted: spheroidite Micrograph Image 36 One vs One Predicted: spheroidite+widmanstatten Micrograph Image 37 One vs One Predicted: spheroidite Micrograph Image 38 One vs One Predicted: pearlite Micrograph Image 39 One vs One Predicted: spheroidite Micrograph Image 40 One vs One Predicted: pearlite Micrograph Image 41 One vs One Predicted: spheroidite Micrograph Image 42 One vs One Predicted: pearlite Micrograph Image 43 One vs One Predicted: pearlite Micrograph Image 44 One vs One Predicted: spheroidite Micrograph Image 45 One vs One Predicted: spheroidite Micrograph Image 46 One vs One Predicted: spheroidite Micrograph Image 47 One vs One Predicted: spheroidite Micrograph Image 48 One vs One Predicted: spheroidite Micrograph Image 49 One vs One Predicted: spheroidite+widmanstatten Micrograph Image 50 One vs One Predicted: spheroidite Micrograph 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pearlite+widmanstatten Micrograph Image 0 One vs One Predicted: pearlite Micrograph Image 1 One vs One Predicted: pearlite Micrograph Image 2 One vs One Predicted: pearlite Micrograph Image 3 One vs One Predicted: spheroidite Micrograph Image 4 One vs One Predicted: spheroidite+widmanstatten Micrograph Image 5 One vs One Predicted: pearlite Micrograph Image 6 One vs One Predicted: spheroidite Micrograph Image 7 One vs One Predicted: pearlite Micrograph Image 8 One vs One Predicted: spheroidite Micrograph Image 9 One vs One Predicted: spheroidite Micrograph Image 10 One vs One Predicted: pearlite Micrograph Image 11 One vs One Predicted: pearlite Micrograph Image 12 One vs One Predicted: pearlite Micrograph Image 13 One vs One Predicted: spheroidite Micrograph Image 14 One vs One Predicted: spheroidite Micrograph Image 15 One vs One Predicted: pearlite Micrograph Image 16 One vs One Predicted: pearlite Micrograph Image 17 One vs One Predicted: pearlite Micrograph Image 18 One vs One 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<sup>{}]</sup> In [217]: print(pred2[0]) print(pred1[0]) [commandchars=

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{}] In [231]:  $\#Part\ D\ \#\ Now\ we\ want\ to\ apply\ the\ pairwise\ classifier\ pearlite\ vs\ spheroidite\ to\ the\ mixed\ pearlite\ vs\ spheroidite\ micrographs\ x'test=[]\ y'test=[]\ print\ (combs)\ for\ i\ in\ range(len(x'i)):\ if\ y[i]==4:\ x'test.append(feat[x'i[i]][4])\ y'test.append(4)\ pred3=[]\ for\ i\ in\ range(len(x'test)):\ pred3.append(models[1].predict(x'test))\ print(enc[4])\ for\ i\ in\ range(0,len(pred3[0])):\ print\ ('Micrograph\ Image',i)\ print\ ('Pairwise\ Classifier\ Predicted:',enc[pred3[0][i]])\ print\ ('OnevsOne\ Classifier\ Predicted:',enc[pred1[0][i]])$ 

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 $\{\}\}$  [(0, 1), (0, 2), (0, 3), (1, 2), (1, 3), (2, 3)] pearlite+spheroidite Micrograph Image 0 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 1 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 2 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 3 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 4 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 5 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 6 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 7 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 8 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 9 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 10 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 11 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 12 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 13 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 14 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 15 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 16 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 17 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 18 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 19 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 20 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 21 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 22 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 23 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 24 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 25 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 26 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 27 Pairwise Classifier Predicted: spheroidite OnevsOne 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spheroidite+widmanstatten Micrograph Image 37 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 38 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 39 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 40 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 41 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 42 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 43 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 44 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 45 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 46 Pairwise Classifier 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Predicted: spheroidite Micrograph Image 56 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 57 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 58 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 59 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 60 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 61 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 62 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 63 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 64 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 65 Pairwise Classifier 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Predicted: spheroidite Micrograph Image 75 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 76 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 77 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 78 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 79 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 80 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 81 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 82 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 83 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 84 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 85 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 86 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 87 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 88 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 89 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 90 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 91 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 92 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 93 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 94 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 95 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 96 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 97 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 98 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 99 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 100 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 101 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 102 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 103 Pairwise Classifier Predicted: pearlite OnevsOne Classifier Predicted: pearlite Micrograph Image 104 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 105 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: spheroidite Micrograph Image 106 Pairwise Classifier Predicted: spheroidite OnevsOne Classifier Predicted: network

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{}] [228]: In $\#Part \ E \ predict \ on \ martensite \ x.test=[] \ y.test=[]$ y[i] = 6:in range(len(x'i)):if x test.append(feat[x i[i]][4]) pred4=[] v test.append(6) for i inrange(len(x test)):pred4.append(ovc.fit(x'train1v1p,y'train1v1).predict(x'test)) print(enc[6]) in range(0, len(pred4[0])): print ('Micrograph Image',i,'Predicted:',enc[pred4[0][i]])

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{}}] martensite Micrograph Image 0 Predicted: spheroidite Micrograph Image 1 Predicted: network Micrograph Image 2 Predicted: pearlite Micrograph Image 3 Predicted: spheroidite Micrograph Image 4 Predicted: spheroidite Micrograph Image 5 Predicted: network Micrograph Image 6 Predicted: spheroidite Micrograph Image 7 Predicted: pearlite Micrograph Image 8 Predicted: spheroidite Micrograph Image 9 Predicted: spheroidite Micrograph Image 10 Predicted: pearlite Micrograph Image 11 Predicted: pearlite Micrograph Image 12 Predicted: pearlite Micrograph Image 13 Predicted: pearlite Micrograph Image 14 Predicted: spheroidite Micrograph Image 15 Predicted: pearlite Micrograph Image 16 Predicted: spheroidite Micrograph Image 17 Predicted: pearlite Micrograph Image 18 Predicted: spheroidite Micrograph Image 19 Predicted: spheroidite Micrograph Image 20 Predicted: spheroidite Micrograph Image 21 Predicted: spheroidite Micrograph Image 22 Predicted: spheroidite Micrograph Image 23 Predicted: pearlite Micrograph Image 24 Predicted: spheroidite Micrograph Image 25 Predicted: pearlite Micrograph Image 26 Predicted: pearlite Micrograph Image 27 Predicted: pearlite Micrograph Image 28 Predicted: pearlite Micrograph Image 26 Predicted: pearlite Micrograph Image 26 Predicted: pearlite Micrograph Image 27 Predicted: pearlite Micrograph Image 28 Predicted: pearlite Micrograph Image 26 Predicted: pearlite Micrograph Image 26 Predicted: pearlite Micrograph Image 27 Predicted: pearlite Micrograph Image 28 Predicted: pearlite Micrograph Image 29 Predicted: pearlite Micrograph Image 26 Predicted: pearlite Micrograph Image 26 Predicted: pearlite Micrograph Image 26 Predicted: pearlite Micrograph Image 27 Predicted: pearlite Micrograph Image 28 Predicted: pearlite Micrograph Image 29 Predicted: pearlite

graph Image 27 Predicted: pearlite Micrograph Image 28 Predicted: spheroidite Micrograph Image 29 Predicted: spheroidite Micrograph Image 30 Predicted: pearlite Micrograph Image 31 Predicted: network Micrograph Image 32 Predicted: spheroidite Micrograph Image 33 Predicted: spheroidite Micrograph Image 34 Predicted: pearlite Micrograph Image 35 Predicted: spheroidite [commandchars=

{}] In [220]: print(pred4[0]) [commandchars=

- $\{\}]$  In []: