Problem 6.12

Libraries

```
import tensorflow as tf
import numpy as np
import PIL
import cv2
import os
import sklearn
import pandas as pd
import pickle
import platform
from tqdm.notebook import tqdm
from sklearn.multiclass import OneVsOneClassifier
from sklearn import preprocessing
from sklearn import svm
from sklearn.pipeline import make_pipeline
from sklearn.preprocessing import StandardScaler
from scipy import stats as st
```

Computational Environment

```
physical_devices = tf.config.list_physical_devices('GPU')
my_system = platform.uname()
print(physical_devices)
print(f"System: {my_system.system}")
print(f"Node Name: {my_system.node}")
print(f"Release: {my_system.release}")
print(f"Version: {my_system.version}")
print(f"Machine: {my_system.machine}")
print(f"Processor: {my_system.processor}")
```

```
[PhysicalDevice(name='/physical_device:GPU:0', device_type='GPU')]
System: Darwin
Node Name: client-10-229-179-166.tamulink.tamu.edu
Release: 21.5.0
Version: Darwin Kernel Version 21.5.0: Tue Apr 26 21:08:29 PDT 2022; root:xnu-8020.121.3~4/RE
Machine: arm64
Processor: i386
```

Helper function

```
def load_image(path, width=484, preprocess_input=tf.keras.applications.vgg16.preprocess_in
    """
    Load and Preprocessing image
    """
    img = tf.keras.utils.load_img(path)
    x = tf.keras.utils.img_to_array(img)
    x = x[0:width,:,:]
    x = np.expand_dims(x, axis=0)
    return tf.keras.applications.vgg16.preprocess_input(x)
```

Data inspectation

```
dpath = os.path.join("data", "CMU-UHCS_Dataset")
pic_path = os.path.join(dpath, "images")
df_micro = pd.read_csv( os.path.join(dpath, "micrograph.csv"))
df_micro = df_micro[["path", "primary_microconstituent"]]

for i in range(0, len(df_micro)):
    img_ph = os.path.join(pic_path,df_micro.iloc[i][0])
    assert os.path.exists(img_ph)
    df_micro.iloc[i][0] = img_ph
df_micro2 = df_micro.copy()
CLS_rm = ["pearlite+widmanstatten", "martensite", "pearlite+spheroidite"] #(type, sample s
```

```
for c in CLS_rm:
    df_micro.drop(df_micro[df_micro["primary_microconstituent"] == c].index, inplace=True)
```

```
# labels
name_lbs = df_micro["primary_microconstituent"].unique()
le = preprocessing.LabelEncoder()
le.fit(name_lbs)
list(le.classes_)
```

```
['network', 'pearlite', 'spheroidite', 'spheroidite+widmanstatten']
```

```
dlabel = le.transform(df_micro["primary_microconstituent"])
df_micro.insert(2, "label", dlabel)
df_micro
```

	path	primary_microconstituent	label
0	data/CMU-UHCS_Dataset/images/micrograph1.tif	pearlite	1
1	data/CMU-UHCS_Dataset/images/micrograph2.tif	spheroidite	2
3	data/CMU-UHCS_Dataset/images/micrograph5.tif	pearlite	1
4	data/CMU-UHCS_Dataset/images/micrograph6.tif	spheroidite	2
5	data/CMU-UHCS_Dataset/images/micrograph7.tif	spheroidite+widmanstatten	3
...	...	...	...
955	data/CMU-UHCS_Dataset/images/micrograph1722.tif	spheroidite	2
957	data/CMU-UHCS_Dataset/images/micrograph1726.tif	spheroidite+widmanstatten	3
958	data/CMU-UHCS_Dataset/images/micrograph1730.png	spheroidite	2
959	data/CMU-UHCS_Dataset/images/micrograph1731.tif	pearlite	1
960	data/CMU-UHCS_Dataset/images/micrograph1732.tif	pearlite	1

Data Processing

```
# Train-test split
df_test = df_micro.copy()
df_train = pd.DataFrame(columns = df_micro.keys())

split_info = [("spheroidite", 100),\
              ("network", 100),\
              ("pearlite", 100),\
              ("spheroidite+widmanstatten", 60)] #(type, sample size)



for ln in split_info:
    label, n = ln
    id_train = df_micro[df_micro["primary_microconstituent"] == label][0:n].index
    df_test.drop(id_train, axis=0, inplace=True)
    df_train = pd.concat([df_train, df_micro.loc[id_train]])
```

```
df_train
```

	path	primary_microconstituent	label
1	data/CMU-UHCS_Dataset/images/micrograph2.tif	spheroidite	2
4	data/CMU-UHCS_Dataset/images/micrograph6.tif	spheroidite	2
8	data/CMU-UHCS_Dataset/images/micrograph10.png	spheroidite	2
9	data/CMU-UHCS_Dataset/images/micrograph11.tif	spheroidite	2
20	data/CMU-UHCS_Dataset/images/micrograph29.tif	spheroidite	2
...	...	...	...
596	data/CMU-UHCS_Dataset/images/micrograph1093.tif	spheroidite+widmanstatten	3
618	data/CMU-UHCS_Dataset/images/micrograph1129.tif	spheroidite+widmanstatten	3
631	data/CMU-UHCS_Dataset/images/micrograph1156.tif	spheroidite+widmanstatten	3
672	data/CMU-UHCS_Dataset/images/micrograph1218.tif	spheroidite+widmanstatten	3
673	data/CMU-UHCS_Dataset/images/micrograph1219.tif	spheroidite+widmanstatten	3

```
df_test
```

	path	primary_microconstituent	label
237	data/CMU-UHCS_Dataset/images/micrograph436.png	spheroidite	2
238	data/CMU-UHCS_Dataset/images/micrograph437.tif	spheroidite	2
239	data/CMU-UHCS_Dataset/images/micrograph440.png	spheroidite	2
241	data/CMU-UHCS_Dataset/images/micrograph442.tif	spheroidite	2
242	data/CMU-UHCS_Dataset/images/micrograph443.tif	spheroidite	2
...	...	...	...
955	data/CMU-UHCS_Dataset/images/micrograph1722.tif	spheroidite	2
957	data/CMU-UHCS_Dataset/images/micrograph1726.tif	spheroidite+widmanstatten	3
958	data/CMU-UHCS_Dataset/images/micrograph1730.png	spheroidite	2
959	data/CMU-UHCS_Dataset/images/micrograph1731.tif	pearlite	1
960	data/CMU-UHCS_Dataset/images/micrograph1732.tif	pearlite	1

Feature Extraction

```
# VGG16

base_model = tf.keras.applications.vgg16.VGG16(
    include_top=False,
    weights='imagenet',
    input_tensor=None,
    input_shape=None,
    pooling=None,
```

```
    classes=1000,
    classifier_activation='softmax'
)

base_model.summary()
```

```
Model: "vgg16"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_1 (InputLayer)        [(None, None, None, 3)]   0

 block1_conv1 (Conv2D)       (None, None, None, 64)    1792

 block1_conv2 (Conv2D)       (None, None, None, 64)    36928

 block1_pool (MaxPooling2D)  (None, None, None, 64)    0

 block2_conv1 (Conv2D)       (None, None, None, 128)   73856

 block2_conv2 (Conv2D)       (None, None, None, 128)   147584

 block2_pool (MaxPooling2D)  (None, None, None, 128)   0

 block3_conv1 (Conv2D)       (None, None, None, 256)   295168

 block3_conv2 (Conv2D)       (None, None, None, 256)   590080

 block3_conv3 (Conv2D)       (None, None, None, 256)   590080

 block3_pool (MaxPooling2D)  (None, None, None, 256)   0

 block4_conv1 (Conv2D)       (None, None, None, 512)   1180160

 block4_conv2 (Conv2D)       (None, None, None, 512)   2359808

 block4_conv3 (Conv2D)       (None, None, None, 512)   2359808

 block4_pool (MaxPooling2D)  (None, None, None, 512)   0

 block5_conv1 (Conv2D)       (None, None, None, 512)   2359808
```

```
 block5_conv2 (Conv2D)       (None, None, None, 512)   2359808

 block5_conv3 (Conv2D)       (None, None, None, 512)   2359808

 block5_pool (MaxPooling2D)  (None, None, None, 512)   0

=================================================================
Total params: 14,714,688
Trainable params: 14,714,688
Non-trainable params: 0
_________________________________________________________________
```

Use five layers

```
out_layer_ns = ["block{}_pool".format(i) for i in range(1,6)]
out_layer_ns
```

```
['block1_pool', 'block2_pool', 'block3_pool', 'block4_pool', 'block5_pool']
```

```
# Construct 5 models for feature extraction
extmodel = dict(zip(out_layer_ns, [tf.keras.Model(
    inputs= base_model.input,
    outputs=base_model.get_layer(bk_name).output
) for bk_name in out_layer_ns]))

extmodel
```

```
{'block1_pool': <keras.engine.functional.Functional at 0x2a7861070>,
 'block2_pool': <keras.engine.functional.Functional at 0x16f7c2070>,
 'block3_pool': <keras.engine.functional.Functional at 0x2a785cd90>,
 'block4_pool': <keras.engine.functional.Functional at 0x2a7855280>,
 'block5_pool': <keras.engine.functional.Functional at 0x2a7847190>}
```

```
# Display output dimensions
out_shapes = [extmodel[m].output_shape[-1] for m in extmodel.keys()]
out_shapes
```

```
[64, 128, 256, 512, 512]
```

```
# Initiate feature maps for testing and training
fs_train = [np.zeros((df_train.shape[0], n_f)) for n_f in out_shapes]
fs_test = [np.zeros((df_test.shape[0], n_f)) for n_f in out_shapes]

features_train = dict(zip(out_layer_ns, fs_train))
features_test = dict(zip(out_layer_ns, fs_test))

features_train
```

```
{'block1_pool': array([[0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        ...,
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.]]),
 'block2_pool': array([[0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        ...,
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.]]),
 'block3_pool': array([[0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        ...,
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.]]),
 'block4_pool': array([[0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        ...,
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.]]),
 'block5_pool': array([[0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        [0., 0., 0., ..., 0., 0., 0.],
        ...,
```

```
       [0., 0., 0., ..., 0., 0., 0.],
       [0., 0., 0., ..., 0., 0., 0.],
       [0., 0., 0., ..., 0., 0., 0.]])}
```

```
# Feature extraction with VGG16
#save file
paths =  dict(zip(["train", "test"],\
    [os.path.join(dpath, "feature_{}.pkl".format(n))\
     for n in ["train", "test"]]))
#if os.path.exists(os.path.join(dpath, "feature_train.pkl")) == False:
for m in tqdm(extmodel.keys()):
    for i, df in enumerate([df_train, df_test]):
        for j, ph in tqdm(enumerate(df["path"])):
            x = load_image(ph)
            xb = extmodel[m].predict(x, verbose = 0) # silence output
            F = np.mean(xb,axis=(0,1,2))
            # Save features
            if i ==0:
                features_train[m][j, :] = F
            else:
                features_test[m][j, :] = F
## Create new files
f_train = open(paths["train"], "wb")
f_test = open(paths["test"], "wb")
## Write
pickle.dump(features_train, f_train)
pickle.dump(features_test, f_test)
## Close files
f_train.close()
f_test.close()
```

```
  0%|          | 0/5 [00:00<?, ?it/s]

0it [00:00, ?it/s]

0it [00:00, ?it/s]

0it [00:00, ?it/s]

0it [00:00, ?it/s]
```

```
0it [00:00, ?it/s]

0it [00:00, ?it/s]

0it [00:00, ?it/s]

0it [00:00, ?it/s]

0it [00:00, ?it/s]

0it [00:00, ?it/s]
```

SVM

```
# load data
ftn = open(paths["train"], "rb")
ftt = open(paths["test"], "rb")
featn = pickle.load(ftn) # train feature
featt = pickle.load(ftt) # test feature
ftn.close()
ftt.close()

# label
ltrain = df_train[["primary_microconstituent", "label"]].reset_index()
ltest = df_test[["primary_microconstituent", "label"]].reset_index()
```

```
ltrain
```

	index	primary_microconstituent	label
0	1	spheroidite	2
1	4	spheroidite	2
2	8	spheroidite	2
3	9	spheroidite	2
4	20	spheroidite	2
...	...	...	...
355	596	spheroidite+widmanstatten	3
356	618	spheroidite+widmanstatten	3
357	631	spheroidite+widmanstatten	3
358	672	spheroidite+widmanstatten	3
359	673	spheroidite+widmanstatten	3

One-to-One SVM

```
class One2OneSVM:
    def __init__(self, n_class=4):
        self.n_class = n_class
        self.clfs_list = [svm.SVC(kernel="rbf", C=1., gamma="auto")\
                          for i in range(0,self.n_class*self.n_class)]

        self.clfs = [[self.clfs_list[self.n_class*i + j]\
                     for i in range(0,self.n_class)]\
                     for j in range(0,self.n_class)]
        self.cv = np.zeros((self.n_class,self.n_class))
    def train(self, ltrain, feature, fold=10):
        # traversal all features
        for i in range(0, self.n_class-1):
            lis = ltrain[ltrain["label"] == i].index.to_numpy()
            for j in range(i+1, self.n_class):
                ljs = ltrain[ltrain["label"] == j].index.to_numpy()
                # Data
                X = np.concatenate(\
                  (feature[lis,:],\
                   feature[ljs,:]), axis=0)
                Y = np.concatenate((np.ones(len(lis))*i,np.ones(len(ljs))*j))
                # Train SVM
                scores = sklearn.model_selection.cross_val_score\
                        (self.clfs[i][j], X, Y, cv=fold)
                self.clfs[i][j].fit(X,Y)
                self.cv[i][j] = 1 - np.max(scores)

    def test_1v1_error(self, ltest, feature):
        # traversal all features
        errM = np.zeros((self.n_class, self.n_class))
        for i in range(0, self.n_class-1):
            lis = ltest[ltest["label"] == i].index.to_numpy()
            for j in range(i+1, self.n_class):
                ljs = ltest[ltest["label"] == j].index.to_numpy()
                # Data
                X = np.concatenate(\
                  (feature[lis,:],\
                   feature[ljs,:]), axis=0)
                Y = np.concatenate((np.ones(len(lis))*i,np.ones(len(ljs))*j))
                # Train SVM
```

```
                y_pred = self.clfs[i][j].predict(X)
                errM[i,j] = error(Y, y_pred)
        return errM

    def predict(self, feature):
        predM = np.zeros(( int(self.n_class * (self.n_class -1)/2) , feature.shape[0]))
        c = 0
        for i in range(0, self.n_class-1):
            for j in range(i+1, self.n_class):
                predM[c,:] = self.clfs[i][j].predict(feature)
                c += 1
        return st.mode(predM, axis=0, keepdims=True).mode[0,:] #majority voting

def error(ans, pred):
    assert len(ans) == len(pred)
    return (ans != pred).sum()/float(ans.size)
```

(a)

> The convolution layer used and the cross-validated error estimate for each of the six pairwise two-label classifiers

The cross-validation error of pairwise two-label classifiers given convolution layer is shown in the following table.

(b)

> 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 described previously. For the pairwise classifiers use only the test micrographs with the two labels used to train the classifier. For the multilabel classifier, use the test micrographs with the corresponding four labels.

The empirical test error with unseen dataset is shown in the following table. The pairwise classifier was tested by the labels same as their training set. On the other hand, the multilable classifier is tested with fully four corresonding four labels.

```
def df_cv(m, clf, info=""):
    var1 = []
    var2 = []
```

```
    cvs = []
    errs = []
    for i in range(0, m.shape[0]-1):
        for j in range(i+1, m.shape[0]):
            var1.append(i)
            var2.append(j)
            cvs.append(clf.cv[i,j])
            errs.append(m[i,j])
    infos = [info] * len(errs)
    return pd.DataFrame({"Info": infos, "Label 1": var1, "Label 2": var2, "Test error": er
```

Pair-wise classifier

The final block performs best in cross validatoin score.

```
df_errors = []
for b in out_layer_ns:
    clf1 = One2OneSVM()
    clf1.train(ltrain, features_train[b])
    errs = clf1.test_1v1_error(ltest, features_test[b])
    df_errors.append(df_cv(errs, clf1, b))

res_error = pd.concat(df_errors)
res_error
```

	Info	Label 1	Label 2	Test error	Cross Validation Error
0	block1_pool	0	1	0.823529	0.500
1	block1_pool	0	2	0.290155	0.450
2	block1_pool	0	3	0.157895	0.375
3	block1_pool	1	2	0.906040	0.500
4	block1_pool	1	3	0.466667	0.375
5	block1_pool	2	3	0.071186	0.375
0	block2_pool	0	1	0.823529	0.350
1	block2_pool	0	2	0.709845	0.350
2	block2_pool	0	3	0.157895	0.375
3	block2_pool	1	2	0.919463	0.500
4	block2_pool	1	3	0.466667	0.375
5	block2_pool	2	3	0.071186	0.375
0	block3_pool	0	1	0.823529	0.400
1	block3_pool	0	2	0.290155	0.400

	Info	Label 1	Label 2	Test error	Cross Validation Error
2	block3_pool	0	3	0.157895	0.375
3	block3_pool	1	2	0.080537	0.450
4	block3_pool	1	3	0.466667	0.375
5	block3_pool	2	3	0.071186	0.375
0	block4_pool	0	1	0.823529	0.500
1	block4_pool	0	2	0.290155	0.450
2	block4_pool	0	3	0.157895	0.375
3	block4_pool	1	2	0.080537	0.500
4	block4_pool	1	3	0.466667	0.375
5	block4_pool	2	3	0.071186	0.375
0	block5_pool	0	1	0.073529	0.000
1	block5_pool	0	2	0.033679	0.000
2	block5_pool	0	3	0.060150	0.000
3	block5_pool	1	2	0.000000	0.000
4	block5_pool	1	3	0.088889	0.000
5	block5_pool	2	3	0.061017	0.125

Multiple one-vs-one classifier

```
# Multiclass one-vs-one
dfm_errors = []
for b in out_layer_ns:
    clf = OneVsOneClassifier(svm.SVC(kernel="rbf", C=1., gamma="auto").fit(features_train[
          ltrain["label"].to_numpy(int)))
    clf.fit(features_train[b],\
          ltrain["label"].to_numpy(int))
    y_predm = clf.predict(features_test[b])
    dfm_errors.append(error(y_predm, ltest["label"].to_numpy()))

# Display result
res_multi1v1 = pd.DataFrame({"Multiple One-Vs-One Classifier": out_layer_ns, "Test Error":
res_multi1v1
```

	Multiple One-Vs-One Classifier	Test Error
0	block1_pool	0.935035
1	block2_pool	0.944316
2	block3_pool	0.364269
3	block4_pool	0.364269
4	block5_pool	0.071926

(c)

For the mixed pearlite + spheroidite test micrographs, apply the trained pairwise classifier for pearlite vs. spheroidite and the multilabel voting classifier. Print the predicted labels by these two classifiers side by side (one row for each test micrograph). Comment your results

The pairwise SVM classifier performs better than Multiclass one-to-one classifier. Because the pairwise SVM is specialized for the binary problem and not be interfered with other classification setting.

```
ltestm = ltest[(ltest["primary_microconstituent"] == "pearlite") |\
      (ltest["primary_microconstituent"] == "spheroidite")]
feature_m = features_test["block5_pool"][ltestm.index.to_numpy(), :]
l = le.transform(["pearlite", "spheroidite"])

pred_pairs = clf1.clfs[l[0]][l[1]].predict(feature_m)
pred_multi = clf.predict(feature_m)

res_ps = pd.DataFrame({"Test Label": le.inverse_transform(ltestm["label"]),\
              "Pairwise (pearlite vs. spheroidite)": le.inverse_transform(pred_pairs.astyp
              "Multi-OnevsOne": le.inverse_transform(pred_multi)})

print(res_ps.to_string())
```

```
     Test Label Pairwise (pearlite vs. spheroidite)            Multi-OnevsOne
0    spheroidite                          spheroidite               spheroidite
1    spheroidite                          spheroidite               spheroidite
2    spheroidite                          spheroidite               spheroidite
3    spheroidite                          spheroidite               spheroidite
4    spheroidite                          spheroidite               spheroidite
5    spheroidite                          spheroidite               spheroidite
6    spheroidite                          spheroidite               spheroidite
7    spheroidite                          spheroidite               spheroidite
8    spheroidite                          spheroidite               spheroidite
9    spheroidite                          spheroidite               spheroidite
10   spheroidite                          spheroidite               spheroidite
11   spheroidite                          spheroidite               spheroidite
12   spheroidite                          spheroidite               spheroidite
13   spheroidite                          spheroidite               spheroidite
14   spheroidite                          spheroidite               spheroidite
15   spheroidite                          spheroidite               spheroidite
```

16	spheroidite	spheroidite	spheroidite
17	spheroidite	spheroidite	spheroidite
18	spheroidite	spheroidite	spheroidite
19	spheroidite	spheroidite	spheroidite
20	spheroidite	spheroidite	spheroidite
21	spheroidite	spheroidite	spheroidite
22	spheroidite	spheroidite	spheroidite
23	spheroidite	spheroidite	spheroidite+widmanstatten
24	spheroidite	spheroidite	spheroidite
25	spheroidite	spheroidite	spheroidite
26	spheroidite	spheroidite	spheroidite
27	spheroidite	spheroidite	spheroidite+widmanstatten
28	spheroidite	spheroidite	spheroidite
29	spheroidite	spheroidite	spheroidite
30	spheroidite	spheroidite	spheroidite
31	spheroidite	spheroidite	spheroidite
32	spheroidite	spheroidite	spheroidite
33	spheroidite	spheroidite	spheroidite
34	spheroidite	spheroidite	spheroidite
35	spheroidite	spheroidite	spheroidite
36	spheroidite	spheroidite	spheroidite
37	spheroidite	spheroidite	spheroidite
38	spheroidite	spheroidite	spheroidite
39	spheroidite	spheroidite	spheroidite
40	spheroidite	spheroidite	spheroidite+widmanstatten
41	spheroidite	spheroidite	spheroidite
42	spheroidite	spheroidite	spheroidite
43	spheroidite	spheroidite	spheroidite
44	spheroidite	spheroidite	spheroidite
45	spheroidite	spheroidite	spheroidite
46	spheroidite	spheroidite	spheroidite
47	spheroidite	spheroidite	spheroidite
48	spheroidite	spheroidite	spheroidite
49	spheroidite	spheroidite	spheroidite
50	spheroidite	spheroidite	spheroidite
51	spheroidite	spheroidite	spheroidite
52	spheroidite	spheroidite	spheroidite
53	spheroidite	spheroidite	spheroidite
54	spheroidite	spheroidite	spheroidite
55	spheroidite	spheroidite	spheroidite
56	spheroidite	spheroidite	spheroidite
57	spheroidite	spheroidite	spheroidite
58	spheroidite	spheroidite	spheroidite

59	spheroidite	spheroidite	spheroidite
60	spheroidite	spheroidite	spheroidite
61	spheroidite	spheroidite	spheroidite
62	spheroidite	spheroidite	spheroidite
63	spheroidite	spheroidite	spheroidite
64	spheroidite	spheroidite	spheroidite
65	spheroidite	spheroidite	spheroidite
66	spheroidite	spheroidite	spheroidite
67	spheroidite	spheroidite	spheroidite
68	spheroidite	spheroidite	spheroidite
69	spheroidite	spheroidite	spheroidite
70	spheroidite	spheroidite	spheroidite
71	spheroidite	spheroidite	spheroidite
72	spheroidite	spheroidite	spheroidite
73	spheroidite	spheroidite	spheroidite
74	spheroidite	spheroidite	spheroidite
75	spheroidite	spheroidite	spheroidite
76	spheroidite	spheroidite	spheroidite
77	spheroidite	spheroidite	spheroidite
78	spheroidite	spheroidite	spheroidite
79	spheroidite	spheroidite	spheroidite
80	spheroidite	spheroidite	spheroidite
81	spheroidite	spheroidite	spheroidite
82	spheroidite	spheroidite	spheroidite
83	spheroidite	spheroidite	spheroidite
84	spheroidite	spheroidite	spheroidite
85	spheroidite	spheroidite	spheroidite
86	spheroidite	spheroidite	spheroidite
87	spheroidite	spheroidite	spheroidite
88	spheroidite	spheroidite	spheroidite
89	spheroidite	spheroidite	spheroidite
90	spheroidite	spheroidite	spheroidite+widmanstatten
91	spheroidite	spheroidite	spheroidite
92	spheroidite	spheroidite	spheroidite
93	spheroidite	spheroidite	spheroidite
94	spheroidite	spheroidite	spheroidite
95	spheroidite	spheroidite	spheroidite
96	spheroidite	spheroidite	spheroidite
97	spheroidite	spheroidite	spheroidite
98	spheroidite	spheroidite	spheroidite
99	spheroidite	spheroidite	spheroidite
100	spheroidite	spheroidite	spheroidite
101	spheroidite	spheroidite	spheroidite

102	spheroidite	spheroidite	spheroidite
103	spheroidite	spheroidite	spheroidite
104	spheroidite	spheroidite	spheroidite
105	spheroidite	spheroidite	spheroidite
106	spheroidite	spheroidite	spheroidite
107	spheroidite	spheroidite	spheroidite
108	spheroidite	spheroidite	spheroidite
109	spheroidite	spheroidite	spheroidite
110	spheroidite	spheroidite	spheroidite
111	spheroidite	spheroidite	spheroidite
112	spheroidite	spheroidite	spheroidite+widmanstatten
113	spheroidite	spheroidite	spheroidite
114	spheroidite	spheroidite	spheroidite
115	spheroidite	spheroidite	spheroidite
116	spheroidite	spheroidite	spheroidite
117	spheroidite	spheroidite	spheroidite
118	spheroidite	spheroidite	spheroidite
119	spheroidite	spheroidite	spheroidite
120	spheroidite	spheroidite	spheroidite
121	spheroidite	spheroidite	spheroidite
122	spheroidite	spheroidite	spheroidite
123	spheroidite	spheroidite	spheroidite
124	spheroidite	spheroidite	spheroidite
125	spheroidite	spheroidite	spheroidite
126	spheroidite	spheroidite	spheroidite
127	spheroidite	spheroidite	spheroidite
128	spheroidite	spheroidite	spheroidite
129	spheroidite	spheroidite	spheroidite
130	spheroidite	spheroidite	spheroidite
131	spheroidite	spheroidite	spheroidite
132	spheroidite	spheroidite	spheroidite
133	spheroidite	spheroidite	spheroidite
134	spheroidite	spheroidite	spheroidite
135	spheroidite	spheroidite	spheroidite
136	spheroidite	spheroidite	spheroidite
137	spheroidite	spheroidite	spheroidite
138	spheroidite	spheroidite	spheroidite
139	spheroidite	spheroidite	spheroidite
140	spheroidite	spheroidite	spheroidite
141	spheroidite	spheroidite	spheroidite
142	spheroidite	spheroidite	spheroidite
143	spheroidite	spheroidite	spheroidite
144	spheroidite	spheroidite	spheroidite

145	spheroidite	spheroidite	spheroidite
146	spheroidite	spheroidite	spheroidite
147	spheroidite	spheroidite	spheroidite
148	spheroidite	spheroidite	spheroidite
149	spheroidite	spheroidite	spheroidite
150	spheroidite	spheroidite	spheroidite
151	spheroidite	spheroidite	spheroidite
152	spheroidite	spheroidite	spheroidite
153	spheroidite	spheroidite	spheroidite
154	spheroidite	spheroidite	spheroidite
155	spheroidite	spheroidite	spheroidite
156	spheroidite	spheroidite	spheroidite
157	spheroidite	spheroidite	spheroidite
158	spheroidite	spheroidite	spheroidite
159	spheroidite	spheroidite	spheroidite
160	spheroidite	spheroidite	spheroidite
161	spheroidite	spheroidite	spheroidite
162	spheroidite	spheroidite	spheroidite
163	spheroidite	spheroidite	spheroidite
164	spheroidite	spheroidite	spheroidite
165	spheroidite	spheroidite	spheroidite
166	spheroidite	spheroidite	network
167	spheroidite	spheroidite	spheroidite
168	spheroidite	spheroidite	spheroidite
169	spheroidite	spheroidite	spheroidite
170	spheroidite	spheroidite	spheroidite
171	spheroidite	spheroidite	spheroidite
172	spheroidite	spheroidite	spheroidite
173	spheroidite	spheroidite	spheroidite
174	spheroidite	spheroidite	spheroidite
175	spheroidite	spheroidite	spheroidite
176	spheroidite	spheroidite	spheroidite
177	spheroidite	spheroidite	spheroidite
178	spheroidite	spheroidite	spheroidite+widmanstatten
179	spheroidite	spheroidite	spheroidite
180	spheroidite	spheroidite	spheroidite
181	spheroidite	spheroidite	spheroidite
182	spheroidite	spheroidite	spheroidite
183	spheroidite	spheroidite	spheroidite
184	spheroidite	spheroidite	spheroidite
185	spheroidite	spheroidite	spheroidite
186	spheroidite	spheroidite	spheroidite
187	spheroidite	spheroidite	spheroidite

188	spheroidite	spheroidite	spheroidite
189	spheroidite	spheroidite	spheroidite
190	spheroidite	spheroidite	spheroidite+widmanstatten
191	spheroidite	spheroidite	spheroidite
192	spheroidite	spheroidite	spheroidite
193	spheroidite	spheroidite	spheroidite
194	spheroidite	spheroidite	spheroidite
195	spheroidite	spheroidite	spheroidite
196	spheroidite	spheroidite	spheroidite
197	spheroidite	spheroidite	spheroidite
198	spheroidite	spheroidite	spheroidite
199	spheroidite	spheroidite	spheroidite
200	spheroidite	spheroidite	spheroidite
201	spheroidite	spheroidite	spheroidite
202	spheroidite	spheroidite	spheroidite
203	spheroidite	spheroidite	spheroidite
204	spheroidite	spheroidite	spheroidite
205	spheroidite	spheroidite	spheroidite
206	spheroidite	spheroidite	spheroidite
207	spheroidite	spheroidite	spheroidite
208	spheroidite	spheroidite	spheroidite
209	spheroidite	spheroidite	spheroidite
210	spheroidite	spheroidite	spheroidite
211	spheroidite	spheroidite	spheroidite
212	spheroidite	spheroidite	spheroidite
213	spheroidite	spheroidite	spheroidite
214	spheroidite	spheroidite	spheroidite
215	spheroidite	spheroidite	spheroidite
216	spheroidite	spheroidite	spheroidite
217	spheroidite	spheroidite	spheroidite
218	spheroidite	spheroidite	spheroidite+widmanstatten
219	pearlite	pearlite	pearlite
220	spheroidite	spheroidite	spheroidite
221	spheroidite	spheroidite	spheroidite
222	spheroidite	spheroidite	spheroidite
223	pearlite	pearlite	pearlite
224	pearlite	pearlite	pearlite
225	spheroidite	spheroidite	spheroidite
226	spheroidite	spheroidite	spheroidite
227	pearlite	pearlite	pearlite
228	spheroidite	spheroidite	spheroidite
229	spheroidite	spheroidite	spheroidite
230	spheroidite	spheroidite	spheroidite

231	spheroidite	spheroidite	spheroidite
232	spheroidite	spheroidite	spheroidite
233	spheroidite	spheroidite	network
234	spheroidite	spheroidite	spheroidite
235	spheroidite	spheroidite	spheroidite+widmanstatten
236	spheroidite	spheroidite	spheroidite
237	spheroidite	spheroidite	spheroidite
238	pearlite	pearlite	pearlite
239	pearlite	pearlite	pearlite
240	spheroidite	spheroidite	spheroidite
241	pearlite	pearlite	pearlite
242	pearlite	pearlite	pearlite
243	spheroidite	spheroidite	spheroidite
244	spheroidite	spheroidite	spheroidite
245	spheroidite	spheroidite	spheroidite
246	spheroidite	spheroidite	spheroidite
247	spheroidite	spheroidite	spheroidite
248	spheroidite	spheroidite	spheroidite
249	spheroidite	spheroidite	spheroidite
250	spheroidite	spheroidite	spheroidite
251	spheroidite	spheroidite	spheroidite
252	pearlite	pearlite	pearlite
253	pearlite	pearlite	pearlite
254	pearlite	pearlite	pearlite
255	pearlite	pearlite	pearlite
256	pearlite	pearlite	pearlite
257	spheroidite	spheroidite	spheroidite
258	spheroidite	spheroidite	spheroidite
259	spheroidite	spheroidite	spheroidite
260	spheroidite	spheroidite	spheroidite
261	spheroidite	spheroidite	spheroidite
262	spheroidite	spheroidite	spheroidite
263	spheroidite	spheroidite	spheroidite
264	spheroidite	spheroidite	spheroidite
265	spheroidite	spheroidite	spheroidite
266	spheroidite	spheroidite	spheroidite
267	pearlite	pearlite	pearlite
268	pearlite	pearlite	pearlite
269	spheroidite	spheroidite	spheroidite
270	pearlite	pearlite	pearlite
271	spheroidite	spheroidite	spheroidite
272	spheroidite	spheroidite	spheroidite
273	spheroidite	spheroidite	spheroidite

274	pearlite	pearlite	pearlite
275	pearlite	pearlite	pearlite
276	spheroidite	spheroidite	spheroidite
277	pearlite	pearlite	pearlite
278	spheroidite	spheroidite	spheroidite
279	spheroidite	spheroidite	spheroidite
280	spheroidite	spheroidite	spheroidite
281	spheroidite	spheroidite	spheroidite
282	spheroidite	spheroidite	spheroidite
283	spheroidite	spheroidite	spheroidite
284	spheroidite	spheroidite	spheroidite
285	spheroidite	spheroidite	spheroidite
286	pearlite	pearlite	pearlite
287	pearlite	pearlite	pearlite
288	spheroidite	spheroidite	spheroidite
289	spheroidite	spheroidite	spheroidite
290	spheroidite	spheroidite	spheroidite
291	spheroidite	spheroidite	spheroidite
292	spheroidite	spheroidite	spheroidite
293	pearlite	pearlite	pearlite
294	spheroidite	spheroidite	spheroidite
295	spheroidite	spheroidite	spheroidite
296	pearlite	pearlite	pearlite
297	pearlite	pearlite	pearlite

(d)

> Now apply the multilabel classifier on the pearlite + Widmanst¨atten and martensite micrographs and print the predicted labels. Compare to the results in part (c)

There is no specific relation for these unseen datasets. The prediction can not extrapolate, and (c) has preferred prediction accuracy and consistency.

```
df_micro2 = df_micro2[(df_micro2["primary_microconstituent"] == "pearlite+widmanstatten")
(df_micro2["primary_microconstituent"] == "martensite")]

# Encode labels
le2 = preprocessing.LabelEncoder()
le2.fit(df_micro2["primary_microconstituent"].unique())
list(le2.classes_)
```

```
['martensite', 'pearlite+widmanstatten']
```

```
dlabel2 = le2.transform(df_micro2["primary_microconstituent"])
df_micro2.insert(2, "label", dlabel2)
```

```
df_micro2
```

	path	primary_microconstituent	label
15	data/CMU-UHCS_Dataset/images/micrograph20.tif	martensite	0
29	data/CMU-UHCS_Dataset/images/micrograph41.tif	martensite	0
31	data/CMU-UHCS_Dataset/images/micrograph44.tif	martensite	0
63	data/CMU-UHCS_Dataset/images/micrograph99.tif	martensite	0
71	data/CMU-UHCS_Dataset/images/micrograph114.tif	martensite	0
...	...	...	...
892	data/CMU-UHCS_Dataset/images/micrograph1599.tif	martensite	0
936	data/CMU-UHCS_Dataset/images/micrograph1684.tif	pearlite+widmanstatten	1
942	data/CMU-UHCS_Dataset/images/micrograph1697.tif	martensite	0
944	data/CMU-UHCS_Dataset/images/micrograph1700.tif	martensite	0
956	data/CMU-UHCS_Dataset/images/micrograph1723.tif	martensite	0

```
# Feature extraction with VGG16
if os.path.exists(os.path.join(dpath, "feature_test2.pkl")) == False:
    fs_test2 = np.zeros((df_micro2.shape[0], out_shapes[-1]))
    m = "block5_pool"
    for j, ph in tqdm(enumerate(df_micro2["path"])):
        x = load_image(ph)
        xb = extmodel[m].predict(x, verbose = 0) # silence output
        F = np.mean(xb,axis=(0,1,2))
        # Save features
        fs_test2[j, :] = F

    # Save data
    ## Create new files
    fs_test2_p = open(os.path.join(dpath, "feature_test2.pkl"), "wb")
    ## Write
    pickle.dump(fs_test2, fs_test2_p)
    ## Close files
    fs_test2_p.close()
```

```
#load data
fs_test2_p  = open(os.path.join(dpath, "feature_test2.pkl"), "rb")
fs_test2 = pickle.load(fs_test2_p) # train feature
fs_test2_p .close()
```

```
pred_multi2 = clf.predict(fs_test2)

res_ps2 = pd.DataFrame({"Test Label": le2.inverse_transform(df_micro2["label"]),\
              "Multi-OnevsOne": le.inverse_transform(pred_multi2)})

print(res_ps2.to_string())
```

```
                Test Label             Multi-OnevsOne
0               martensite                spheroidite
1               martensite                    network
2               martensite                   pearlite
3               martensite                spheroidite
4               martensite                spheroidite
5               martensite                    network
6               martensite                spheroidite
7   pearlite+widmanstatten                   pearlite
8               martensite                   pearlite
9               martensite                spheroidite
10              martensite                spheroidite
11  pearlite+widmanstatten                   pearlite
12              martensite                   pearlite
13  pearlite+widmanstatten                   pearlite
14              martensite                   pearlite
15  pearlite+widmanstatten                spheroidite
16  pearlite+widmanstatten  spheroidite+widmanstatten
17  pearlite+widmanstatten                   pearlite
18              martensite                   pearlite
19  pearlite+widmanstatten                spheroidite
20  pearlite+widmanstatten                   pearlite
21  pearlite+widmanstatten                spheroidite
22  pearlite+widmanstatten                spheroidite
23  pearlite+widmanstatten                   pearlite
24  pearlite+widmanstatten                   pearlite
25              martensite                   pearlite
26              martensite                spheroidite
27              martensite                   pearlite
```

28	martensite	spheroidite
29	martensite	pearlite
30	martensite	spheroidite
31	martensite	pearlite
32	pearlite+widmanstatten	pearlite
33	martensite	pearlite
34	martensite	spheroidite
35	pearlite+widmanstatten	spheroidite
36	martensite	spheroidite
37	pearlite+widmanstatten	spheroidite
38	pearlite+widmanstatten	pearlite
39	pearlite+widmanstatten	pearlite
40	martensite	pearlite
41	martensite	spheroidite
42	pearlite+widmanstatten	pearlite
43	pearlite+widmanstatten	spheroidite
44	pearlite+widmanstatten	spheroidite+widmanstatten
45	pearlite+widmanstatten	pearlite
46	pearlite+widmanstatten	pearlite
47	martensite	pearlite
48	pearlite+widmanstatten	pearlite
49	martensite	pearlite
50	pearlite+widmanstatten	spheroidite+widmanstatten
51	pearlite+widmanstatten	pearlite
52	martensite	pearlite
53	pearlite+widmanstatten	spheroidite
54	martensite	spheroidite
55	martensite	spheroidite
56	martensite	pearlite
57	martensite	network
58	martensite	spheroidite
59	pearlite+widmanstatten	pearlite
60	martensite	spheroidite
61	martensite	pearlite
62	martensite	spheroidite